Originally Processed With FOIA(s):
2005-0336-F

FOIA Number:
2005-0336-F

FOIA MARKER

This is not a textual record. This is used as an administrative marker by the George Bush Presidential Library Staff.

Record Group/Collection:	George H.W. Bush Presidential Records
Collection/Office of Origin:	Science and Technology Policy, Office of (OSTP)
Series:	Bromley, D. Allan, Files
Subseries:	Global Climate Change Files

OA/ID Number:	62050
Folder ID Number:	62050-003

Folder Title:
Global Change: Articles/Papers [1 of 2] [1989-91]

Stack:	Row:	Section:	Shelf:	Position:
	0	0	0	0

1991

GC
WMO papers

CLIMATE CHANGE

World leaders' viewpoints

WORLD METEOROLOGICAL ORGANIZATION

WORLD METEOROLOGICAL ORGANIZATION

CLIMATE CHANGE

World leaders' viewpoints

WMO - No. 748

Secretariat of the World Meteorological Organization
Geneva, Switzerland
1991

ISBN 92-63-10748-3

NOTE

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Meteorological Organization concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Contents

Foreword
by Professor G. O. P. Obasi
Secretary-General
WMO

The study of climate and climatic change has always been one of the primary responsibilities of the World Meteorological Organization and of its predecessor, the International Meteorological Organization, founded over a century ago. Even in the late 1960s and early 1970s WMO was already particularly concerned about changes to the world's climate and to the composition of the atmosphere — now an issue of ever-increasing importance.

In February 1979, WMO convened the first World Climate Conference jointly with other organizations of the United Nations system. In the intervening years we have witnessed the growing concern about climate and environmental issues that has led to the establishment of special bodies such as the WMO/UNEP Intergovernmental Panel on Climate Change and also to a whole series of ministerial meetings culminating in the Second World Climate Conference (Geneva, 29 October – 7 November 1990). The Ministerial Declaration of the Conference, adopted by representatives of 137 countries, helps pave the way for the preparation of a Framework Convention on Climate Change.

The great interest of the nations of the world in issues related to environment in general and to the atmosphere and climate in particular is well demonstrated by the fact that many Heads of State and leading diplomats participated personally in those meetings. Their interventions were well-considered, clear and thought-provoking. To put on record some of their views, it was therefore decided to conduct interviews with some of these eminent personalities in connection with WMO World Meteorological Day, celebrated each year on 23 March.

The WMO Executive Council had already decided that the theme for World Meteorological Day 1991 should be 'The atmosphere of the living planet Earth' and this was most appropriate to the purpose of the interviews. This booklet contains the record of these interviews presented in alphabetical order of the names of the countries.

On behalf of the World Meteorological Organization, I wish to express my gratitude to President Fernando Collor de Mello of Brazil, President François Mitterrand of France, His Majesty King Hussein of Jordan, Prime Minister Edward Fenech-Adami of Malta, President Flavio Cotti of Switzerland and President Robert Mugabe of Zimbabwe for according the interviews contained in this booklet. WMO is indeed honoured by their participation.

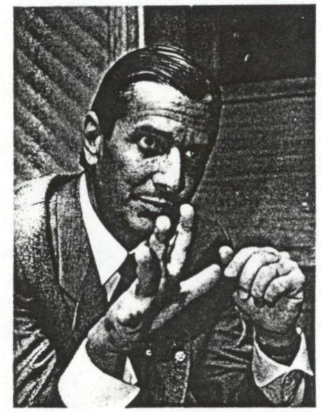
Thanks are also due to Dr Hessam Taba who, in his capacity as a consultant to the Secretary-General of WMO, assisted in the preparation of these interviews and edited this booklet.

G. O. P. Obasi
Secretary-General

His Excellency Fernando Collor de Mello

President of the Federative Republic of Brazil

According to environmentalists, Latin America is losing its forests and jungles at an alarming rate, some of the cities are among the most polluted, soil erosion affects the productive land, and regional seas are replete with sewage, chemical and other wastes. Is the situation indeed as ominous as it is presented?



Latin America nowadays faces a series of environmental problems. These are associated, on the one hand, with mounting pressures on natural resources, and, on the other, with rapid urbanization and the very growth of industrial activity. The serious economic crisis that has hit the region since the beginning of the past decade has had an adverse impact on the environment and on the quality of life of local populations.

One must bear in mind, however, that Latin America is not the sole region to suffer from environmental problems, which, being to a large extent a consequence of less than sustainable development models, manifest themselves in more serious forms in the developed world.

A problem of particular importance is the rapid decline of tropical forests as a result of increased demand for farmland, gathering of firewood, the commercial use of wood and inappropriate settlement policies. Deforestation affects tropospheric chemistry and hence the global climate. In your opinion, how serious are the consequences of deforestation today in Brazil and how much damage has been done?

The most up-to-date data available on the vegetation cover of the Amazonian Region, collected by the Brazilian *Instituto de Pesquisas Espaciais* (INPE) (Space Research Institute), São Paulo, show that the actual figures for deforestation areas or rates are much less alarming than those given in certain projections from abroad made available internationally. To begin with, deforestation has indeed occurred, but at constant rates, not at exponential ones as suggested by some scientists and experts. The total area where deforestation, both recent and traditional, has occurred approaches 394 000 square kilometres (around 7.8% of the total area of Legal Brazilian Amazonia). The average deforestation rate for the period 1978-1989 has been calculated as 21 776 square kilometres (2.2 million hectares) per year, i.e. approximately four times less than the 80 000 square kilometres per year estimated by the World Resources Institute. The data collected by the INPE indicates that total deforestation in Amazonia corresponds to 254 tons of CO_2 emissions into the atmosphere — or 3.7% of the total emissions throughout the world.

During the Bergen Ministerial Conference on Sustainable Development in the ECE Region (May 1990), the Secretary of the Environment of Brazil spoke on your behalf. He mentioned the importance of the rainforest and referred to the results of the study and research work conducted at the Institute of Research

for Amazonia (INPA) in Manaus. He gave an account of how the destruction of the tropical forest in Brazil would affect climate not only in the region, but all over the globe. Since this is an extremely important issue, would you like to offer your own personal view?

As I have been stressing since the time of the electoral campaign to the Presidency, one of my Administration's priorities is to tackle environmental problems by means of a positive approach. In this context, I do recognize the importance of protecting climate and the atmosphere. In so far as the protection of the great carbon reservoirs — such as forests and oceans — is a part of this problem, Brazil is ready to offer its contribution in a constructive manner, through incentives to programmes and projects for the protection of the Amazonian forest. We consider it absolutely indispensable, however, that other countries play their part in this process, e.g. by reducing emissions of greenhouse gases of fossil-fuel origin derived from their gigantic fleets of cars and from their industrial parks.

There is a new administration in Brazil and you yourself, as a young President, are seriously preoccupied with problems of atmospheric pollution, adverse climatic changes and deforestation. You have already taken some steps within the country to improve the situation. Could you please outline in some detail the measures you have taken?

With the aim of promoting the protection of the Amazonian forest, we in Brazil are finalizing the overall economic-ecological mapping of the region. This programme is based on the assumption that environmental protection cannot be dissociated from the promotion of social and economic development. It will allow the precise definition of potentials of the various areas in the region, which is necessary for the correct applicability of models of sustainable development in the forest. In that programme, it is expected that 20 new 'extractivist reserves' would be added to the five reserves already existing. Combating of illegal deforestation and burning in the critical period of June to September has been made possible by 'Operation Amazonia', an overall effort launched in April 1990 and combining sophisticated satellite surveys and monitoring with local checking and enforcement on the ground. Illegal, indiscriminate taking of lands in Amazonia is being forcefully opposed by all means permitted by law, including even the co-operation of the Armed Forces.

A comprehensive programme of environmental education is being launched at the same time, with a view to broadening and deepening perceptive motivation of the younger generation with respect to the importance of environmental protection in conjunction with the promotion of sustainable development.

Since you have already curbed some of the projects which were not environmentally sound, what sort of alternatives do you have in mind and what sort of assistance would you require?

It is not easy to implement development-project options that are clearly directed to a 'sustainable' dimension. These options often require considerably larger investments, longer planning, a solid effort towards motivating local communities, and onerous fiscal and supervisory operations. They also require special education and training of personnel, and access to technologies and equipment which are often too expensive and not available in the domestic market. It will be absolutely necessary to intensify international co-operation in the environmental area. Equally essential, steps

must be taken to promote more just and equitable world-wide economic relations, without which the reactivation of economic activity and economic growth in developing countries cannot take place. It is in this sense that we welcome with great interest the new language of co-operation reflected in the recent Declaration of Dublin (European Communities Council) and the Declaration of Houston (Summit of the Seven).

All activities necessary to maintain a clean atmosphere, to prevent adverse climatic change, to control deforestation, to avoid undesirable environmental impacts on agriculture, in brief to meet the very goal of sustainable development, require expenditure. In your opinion how can the necessary financial resources be made available to developing countries in order to broaden their access to environmentally clean technologies?

The channelling of additional financial resources, under concessional conditions, and the right of access, on preferential terms, to the new, 'clean' technologies, those that protect and help recover the environment, are two fundamental issues. They are intimately related to the promotion of sustainable development in developing countries.

New and additional credits and technologies are necessary not only for improving the quality of the environment in each country, but also in terms of providing the means of implementing whatever new international obligations are agreed upon through international negotiations. In fact, every agreement should include specific arrangements for the transfer of additional resources to developing countries.

Additional financing for domestic environmental planning could be channelled by means of more bilateral grants or concessions as well as by a new financing unit within the World Bank (we note that the proposed establishment of a

'Global Environmental Facility' within the purview of the IBRD is under consideration by its Development Committee). Additional resources are also needed if we are to face positively the environmental components embedded in most development and infrastructure projects.

There is little doubt that the reduction of the emission of greenhouse gases and the consequent adverse climate change require a new policy in the use of fossil fuels, wider use of alternative energy, an effective energy conservation programme, the curbing of deforestation in tropical regions and the exploitation of natural resources on a sustainable basis. In this context, you may wish to explain the present situation in Brazil as regards the use of gazohol and ethanol or any other energy alternatives you have developed.

Greenhouse gas emissions derived from fossil fuel combustion are relatively small in Brazil. The highly industrialized countries, being most responsible for that kind of emission, must take the lead in making commitments aiming at reducing these emissions. As for the specific question concerning the use of alcohol as an alternative to other fuels, let me stress that Brazil has developed an autonomous and quite efficient technology in this field. As you know, a substantial part of the Brazilian car fleet is alcohol-run, thus contributing significantly to the reduction of CO_2 emissions.

As pointed out by the Brazilian delegation to the White House Conference on Science and Economics Research Related to Global Change (April 1990), the following questions deserve particular attention: What activities, in the developing countries, have to be curtailed for environmental purposes that do not imply a serious social cost? Is it possible to allow a better

distribution of emissions within the national boundaries so that the most productive and desirable activities are favoured? Do you not agree that these problems require solutions prior to the setting up of regulations and legislation which would be difficult for developing nations to respect?

One should never separate the question of implementing environmental protection measures in developing countries from that of promoting social and economic development. The present situation in our countries requires a special and differential treatment, the mobilization of additional resources and access to new technologies. These are *sine qua non* conditions if we are able gradually to adapt productive activities to environmentally more demanding standards. The measures of control eventually to be adopted through new international agreements on the protection of the environment must not take the form of an inequitable freeze of present levels of quality of life in the various countries.

The setting of ceilings for greenhouse gas emissions and the identification of 'emitting' activities to be selectively controlled, under more or less comprehensive standards, in accordance with their positive impact on economic development, should be among those ideas to be contemplated in the forthcoming negotiating process that will lead to a framework convention on climate.

In your opinion, what are the most urgent measures required to prevent Latin America from becoming the victim of a profound socio-environmental crisis?

As already indicated, it seems to me that those elements absolutely necessary for a programme that would prevent the double crisis — socio-economic and environmental — in Latin America and the Caribbean must include the return of economic activity to the region; the re-negotiation, in more equitable terms, of the regional external debt; and the channelling of financial and technological resources on a preferential basis. Within the next year, the Regional Action Plan for the Environment in Latin America and the Caribbean, now under preparation, should be adopted. As an outcome of governmental negotiations, the Action Plan is expected to establish priorities for co-operative action within the regional context. It should *inter alia* also provide the basis for diversifying channels and mechanisms responsible for receiving foreign resources, originating from both multilateral and bilateral initiatives, for programmes directed to the protection of the environment in the area.

Brazil will host the 1992 United Nations Conference on Environment and Development (UNCED). What do you feel should be the main outcome of the Conference?

Owing to its dimension and importance, the United Nations Conference on Environment and Development, to be held in Brazil in 1992, will undoubtedly become one of the great diplomatic events in the history of the United Nations. The fundamental goal of the Conference will be to include, definitively, environmental considerations in the planning and promotion of social and economic development, emphasis being given to the importance of concepts of sustainable, environmentally rational development.

UNCED should play a fundamental role in the consolidation of principles which should guide economic activity of the different societies according to a revised model of development. For that reason, it should create mechanisms that permit the sharing, on a global scale, of the benefits of economic development — the assumption being that underdevelopment and poverty constitute, in

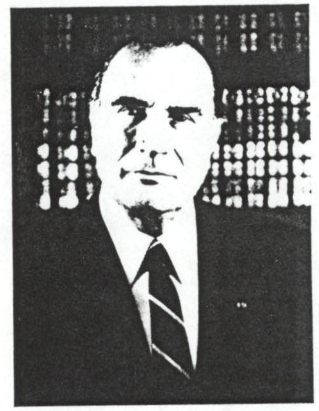
their own right, major causes for the degradation of the environment. UNCED should furthermore consolidate mechanisms to ensure differential and preferential treatment for developing countries in the field of legal obligations related to the environment, as well as to permit these countries, under more favourable conditions, access to financial resources and technologies indispensable for the implementation of sustainable development models.

In addition, the climax of the 1992 Conference should be the adoption of various international legal instruments for the protection of the environment. Finally, it should set an agenda for sustainable development in the next century.

* * *

His Excellency François M. Mitterrand

President of the French Republic



The heads of 24 governments from all the continents met on 10 and 11 March 1989 in The Hague (Netherlands) at the Summit on the Protection of the Global Atmosphere, convened by three countries, including France. The fact that you appeared personally demonstrates the importance you attach to this problem. Would you like to expand on this topic?

France attaches the highest importance to protection of the global atmosphere, whether in order to preserve the stratospheric ozone layer or to limit emissions of toxic as well as greenhouse gases. It was for this reason that my country took the initiative of making such an appeal, together with Norway and the Netherlands. Actually, I believe that a supra-national body must be created which will alone be able to monitor effectively compliance with the international regulations to be decreed for this purpose.

In your address at The Hague you inferred that, even if uncertainties still remained from the scientific point of view, the nature of the problem was such that it required immediate *international action. Many nations still believe that protection of the environment and ecosystem is an expensive undertaking. Do you believe that observational and research aspects of the monitoring and protection of the global atmosphere should receive priority?*

It was, of course, the scientists who first warned all the citizens and leaders of the various countries about the urgency of ensuring the global protection of the environment. France therefore attaches the highest importance to the development of research and to the proper dissemination of observations. It was, in fact, for this reason that, in June 1989, I requested the creation of a World Observatory of the Planet and that, at the last summit in Houston, I proposed, on behalf of France, the creation of a centre for disseminating satellite data concerning environmental protection. Nevertheless, I consider that our action should not be limited to research aspects and that it is a matter of urgency to act even if all of the scientific uncertainties have not yet been removed. If our countries do not adopt concrete measures to limit emissions of harmful gases, the resultant delay will have considerable economic repercussions in the future.

The signatories of the Hague Declaration acknowledged that the industrialized nations had a special responsibility to assist the developing countries, which might be the ones most seriously affected by changes in the Earth's climate and environment. What form do you think such assistance could take?

Clearly, the more prosperous nations have special obligations toward the developing countries, particularly since it is our countries which still pollute the atmosphere most. The assistance which we should give to the

developing countries can take several forms, such as the creation of international bodies devoted to the solution of problems specifically affecting the developing countries. France thus proposed the creation of the Sahara and Sahel Observatory, which has started its work to control desertification. We must also not forget the various economic forms of aid, including loans or gifts, to the developing countries which are the most affected by climate changes.

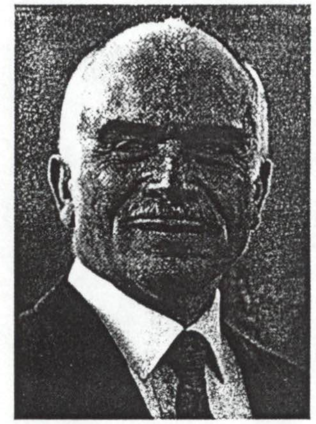
Do you feel that the nations of the world are ready to contemplate joint action to combat and mitigate the threat to the world from the greenhouse effect?

I note that all nations of the world have become aware of the threat of the greenhouse effect to climate evolution. Obviously, we are not yet all in agreement on how the necessary action is to be undertaken. However, I feel that an increasing number of countries are prepared to make appropriate efforts by making known the limits of carbon dioxide emissions which they intend to respect. This process will still take a long time, but I think that wisdom will prevail.

* * *

His Majesty
Hussein I

King of the
Hashemite Kingdom of Jordan



The fact that you personally attended the Hague Summit demonstrates your great interest in and profound concern regarding problems of climate change and preservation of the environment. You stated that the quality of life was being threatened by the growing dangers to the Earth's atmosphere. Do you wish to highlight some of these dangers?

The dangers to the Earth's atmosphere are manifold. Some of them may seem area-specific, such as deforestation, desertification, and depletion of freshwater resources, which afflict Jordan and the Middle East in general, or acid rain and pollution in more highly industrialized regions; but these phenomena are global in their effect, just as much as the greenhouse effect or the depletion of the ozone layer. This is because the ecosystem is so finely balanced that a disruption in any part of it would throw the system out of balance. Hence the importance of the Hague Summit of March 1989, because it highlighted the global nature of the challenge and the need for a co-ordinated and comprehensive world effort to overcome it.

Global climate change, air, sea- and freshwater pollution, acid rain, hazardous substances, deforestation and energy policies are among the most important problems facing mankind. During recent years, numerous international meetings at all scientific and political levels have been held to discuss these issues and preparations are in progress for holding the United Nations Conference on Environment in Brazil in 1992. Do you believe that, by 1992, political and financial means will be available to tackle these problems?

I believe that the financial and technological means to tackle these problems are available, but the measures necessary for protecting the environment have often come into conflict with the short-term needs of development, or with the profit motive, which also cannot be ignored. It is the duty of political decision-makers to draw up and implement policies that give incentives to the private as well as public sectors to pursue the dual objective of progress and preservation with equal emphasis.

On many occasions, it has been suggested that the implementation of an efficient environmental protection programme requires three quite distinct measures: (a) *establishment of an international authority or strengthening of existing authorities under the aegis of the United Nations to supervise the preservation of the environment;* (b) *establishment of an international funding source to assist developing nations in setting up environmental protection projects; and* (c) *setting up of a comprehensive environmental legal machinery with its own principles, rules, criteria and standards. You may wish to offer your own views on these.*

The global nature of the challenge requires a co-ordinated and comprehensive effort to tackle it, and I

believe that the United Nations is the body best qualified to deal with this momentous task since it already has a specialized agency for the purpose, and particularly in view of its revitalized role. However, there is certainly a need to strengthen the United Nations Environment Programme, as well as all other United Nations bodies, to enable them to cope better with the challenges that face humanity.

Concerning funds for the environment protection programmes, the challenge lies in interlinking the goals of progress and preservation. Therefore, serious consideration must be given to the means that would best achieve this end. It may be more efficient to increase co-operation between the United Nations Environment Programme and its sister programme, the UNDP.

The same applies to the legal machinery. However, on this topic, I would like to stress that the success of the global effort to protect the environment depends on international co-operation. Therefore, the principles, rules, criteria, and standards must be applicable and pertinent to both developing and developed nations, and not favour one group's interests over those of the other.

The greenhouse effect, attributed to man-made emissions of carbon dioxide, methane and chlorofluorocarbons, is a particularly world-wide problem as regards both cause and impact. The industrialized nations have begun the painful process of discovering past mistakes and the developing countries want compensation for reducing the emissions they produce. The WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) has suggested that there are sufficient grounds to act on global warming. Do you believe that a global agreement could be reached, in the next few years, to reduce the emission of the greenhouse gases?

I see no alternative to global co-operation to solve the problem. The technology exists to provide substitutes for activities causing harmful emissions and certainly the financial resources are there. The problem lies in assessing correctly each country's needs and capability, and in allocating each country's share of the effort. The developing countries are already overburdened by their development needs and they need assistance, both financially and technically, to contribute to such a programme.

Governments are deeply concerned over the condition of the world's ecosystem, food supply and human health. Developing nations, however, do not as yet have the means to integrate economic development and environmental preservation. Some donors, funding institutions and development banks have shown interest in providing financial assistance if the ethics of sustainable development are incorporated in the assistance programme. Do you believe that this approach will limit the flexibility of the developing countries in the trade-off between environment and development consideration?

Developing nations face a complexity of problems related to development. These include providing food, employment, housing, education, and health services to an ever-increasing population. In addition, some have to cope with a debilitating debt problem, which handicaps their growth. In certain regions, such as the Middle East, the absence of peace also hinders socio-economic progress. The preservation of the environment has to compete with the vital issues of survival for a place on any developing country's national agenda. Therefore, it becomes essential to provide developing countries with incentives and assistance to pursue

conservation programmes, but this should be done in a way that enhances their development programmes, not place an additional burden on their already stretched resources. This would make economic planning more difficult, but, in the long run, it is the only way.

The developing nations have an urgent need for access to, and actual transfer of, up-to-date environmental protection technology. In your view, how can this be achieved at little or no cost and without unduly impeding economic development?

It is important to stress that technology transfer, in this situation in particular, is not a hand-out from the more advanced countries, but an investment on their part in a better future for all mankind. It is a long-term investment whose rewards may not be appreciated fully for some years to come. However, if this principle were accepted, the mechanism of the transfer would not present an insurmountable obstacle.

Since all climate-related social issues are interrelated and call for international action, they require the participation of the developing nations. Unless developing countries have a pool of specialists trained in all aspects of climate change and environmental preservation, they cannot participate effectively in the implementation of such programmes. In your opinion, what action could be taken to speed up the process of training and to encourage participation at a national or international level?

The problem is a real one, and it is compounded by the fact that the resources of developing countries are overstretched to meet basic bread-and-butter issues. The realization that conservation of the environment is not an esoteric interest is comparatively new, even in developed nations. This is why conservation has not received the order of priority that it deserves. Hence, the training of specialists at higher levels of education, though an important step, would not be sufficient. It would not be sufficient to allocate a share of the scholarships and academic exchange programmes to conservation-related disciplines; equally important is the creation of awareness at grass-roots level of the importance of conservation, and to this end we also need help from countries with longer experience in the field.

Twenty years after the Stockholm Conference, the 1992 United Nations Conference to be held in Brazil will provide an important opportunity for the international community to take stock and assess the progress achieved in the field of protection of the atmosphere and environmental preservation. It is of utmost importance that developing nations make every effort to take part in this important gathering. What would be your personal wishes as regards the outcome of the Conference?

The purpose of this meeting is to confront a problem that faces all humanity, and it is of the utmost importance that all nations participate fully. I would like to see the conference address with equal emphasis the concerns of developed and developing countries, in a spirit of co-operation, which would be a very good precedent of joint world action against a common danger.

Could you please describe some of the climatic problems of particular concern to the Hashemite Kingdom of Jordan in the context of the scenario of a probable global warming?

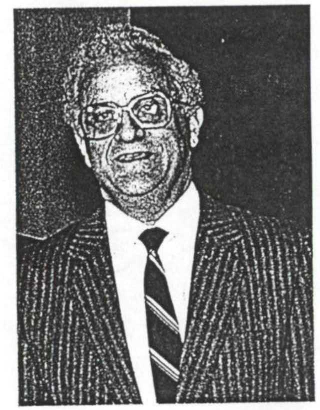
I have made reference to the problems of salination of the already scarce water resources, earth erosion and desertification. But these problems have to be taken in a regional context since their solution, which is crucial to our development and economic planning, is made more difficult by the political realities which make regional co-operation difficult in the absence of peace.

Of course all these problems would be accentuated all the more by global warming, which would add to the causes of instability in the region. The problem would thus feed on itself and snowball out of control.

* * *

The Honourable Edward Fenech-Adami

Prime Minister of the Republic of Malta



In 1988 the Government of Malta took the initiative to advance international action on the issue of global climate change when it prepared a resolution for consideration by the United Nations General Assembly entitled 'Protection of the global climate for present and future generations of mankind'. What prompted your Government to take such initiative?

In August 1988, Professor David Attard, who teaches international law at the University of Malta, asked to see me on a matter which he felt was of international importance. At the meeting, Professor Attard stressed the need for co-operation with respect to the protection of the global climate. He explained that the world's climate was being threatened by certain human activities. There was a great risk that these activities could lead to a global warming, the magnitude of which — over such a short time scale — had never been witnessed in the history of civilized man.

In his view, whilst serious work was being undertaken by a number of scientific organizations, there was little co-ordination of such effort. Given the magnitude of the problem and the limited resources available, it was important that there should be less overlapping and more co-ordination. Furthermore, Professor Attard stressed the need to have the problem considered at the highest political level — the United Nations General Assembly.

In view of the serious threat which climate change presented, I felt that my Government should take urgent action. I discussed the issue with the then Minister of Foreign Affairs, Dr V. Tabone, who immediately agreed on the necessity for action at the United Nations. On 9 September 1988, my Government requested that the issue of climate change be put on the agenda of the 43rd session of the General Assembly. Our request was accepted and furthermore a Plenary Meeting of the Assembly was convened to examine the question.

In short, Malta's initiative on climate was aimed at creating a global response to climate change. Clearly, whether developed or developing, each State has an interest in the global climate. Its protection is vital to life on Earth. We must strive to ensure that future generations do not inherit a planet which cannot sustain life.

I assume that before or when you submitted the draft resolution, you solicited support from some agencies or organizations. Which organizations did you contact and what were their reactions?

Yes, we did sound a number of organizations and personalities prior to raising the question of climate change at the United Nations. In fact, at the formative stages of our initiative, I instructed our Foreign Office to seek the advice of the relevant international organizations, in particular WMO and UNEP. I felt that the former could offer guidance on the scientific aspects of the

issue, whilst the latter had the policy-making expertise in dealing with global environmental problems. I was of the opinion that the support of WMO and UNEP was crucial if our initiative was to succeed. I shall never forget the vigorous support we received from Professor G. O. P. Obasi and Dr M. K. Tolba, both of whom visited us in Malta and assisted us in the formulation of our policy.

In fact, we feel that our initiative on climate should be considered as a tribute to all those persons, agencies and organizations that had undertaken the necessary work and research to ascertain that our fears were based on sound scientific evidence.

In my view, there can be no effective policy-making in the area of environmental pollution unless the decision-maker is presented with reliable scientific evidence. It is therefore vital in developing our response strategies to climate change that we continue to support and strengthen the research programmes on climate.

On the other hand, we must be careful not to allow any scientific uncertainty to hinder our responses in countering climate change. Given the seriousness and traumatic effects of climate change, mankind cannot and should not await absolute scientific consensus before taking action, for by then it may be too late. We simply cannot afford to procrastinate. The scientist and the policy-maker must work hand in hand to provide a survival strategy for our planet. In this respect the co-operation between UNEP and WMO provides an excellent example.

Do you believe that the resolution as adopted by the United Nations meets the expectations of the Government of Malta and others who supported it? What are the salient points of the resolution?

I believe that the resolution does meet to a very large extent the expectations of the Maltese Government and the 55 States that co-sponsored it. The fact that it was unanimously adopted by the United Nations General Assembly reflects the general support which our initiative enjoyed.

Briefly, the resolution sets out the constitutive elements of a global strategy to ensure the effective protection of our global climate. These elements can be divided into three broad categories: (*a*) institutional, (*b*) scientific, and (*c*) legal.

The UN resolution clearly identifies the Intergovernmental Panel on Climate Change as the body through which WMO and UNEP should ensure that the necessary action is taken. I am glad to note that the panel has already prepared an authoritative report on climate change. The scientific and socio-economic aspect of climate change is another area which the resolution required the panel to consider. The creation of a legal framework within which mankind's activities to protect the climate can be regulated was another goal set out by the resolution.

Clearly, we would have liked some of its provisions to be worded in a stronger tone. In fact, events over recent months — as I shall explain — have proved us right. Nevertheless, given the uniqueness of our initiative and its sensitive nature, we felt that prudence and caution in our demands were necessary to ensure consensus and success.

If you look at Resolution 43/53, paragraph 10 (*e*) reads 'Elements for inclusion in a possible future international convention on climate'. The original Maltese draft used the word 'possible' to qualify 'elements' and not 'convention'. In our negotiations in the Second Committee of the General Assembly, it became clear — at least in October/November 1988 — that there was no general agreement over whether there

was a need for a climate convention. We left the General Assembly determined to muster international support for the conclusion of a climate convention. In the months that followed, it became clear that Malta's position was receiving widespread support, as was confirmed in Resolution 44/207 on climate, which emerged from the 44th session of the United Nations General Assembly. In this resolution, the international community is urged to begin preparations for negotiations on a framework convention on climate, taking into account the work of the Intergovernmental Panel on Climate Change.

I would like to conclude my answer by raising what I consider to be a fundamental issue. If the international community is to succeed in coping with global environmental problems, new rules of international law have to be formulated. It is our belief that the current state of international law is not mature enough to enable us to tackle these problems effectively. We live today in a situation where a small group of States can tamper with the global environmental equilibrium at the expense of the international community. In this respect, I feel it is noteworthy that Malta has introduced the concept of the *common concern of mankind*. And climate change is a common concern of mankind.

This concept, which has been confirmed by the General Assembly in Resolution 43/53, should develop into a principle allowing the international community to act on matters which are of common interest. In the case of climate, the international community would be entitled to concern itself with activities which cause climate change, even when such activities occur within a State's boundaries. The principle of domestic jurisdiction can no longer be allowed to be used as a defence when global environmental well-being is at stake.

In conjunction with the draft resolution submitted by the Government of Malta, the Maltese Government had also proposed the need for an 'international convention on climate' which would provide a legal and institutional framework to deal with climate change and global warming. Could you please expand on this?

As I pointed out in my last answer, my Government feels that there should be an international convention on climate. We feel that the conclusion of such a treaty would signal to the world community the existence of a firm political will to counter the problem of climate change. It should provide a global framework within which national, regional and international measures to protect the climate can be developed, harmonized and co-ordinated.

The instrument should be primarily a framework convention enumerating the general principles and providing for the development of a number of protocols which could contain concrete measures. In this respect the Vienna Convention on the Ozone Layer is a useful model. It is a framework treaty which deals with a global environmental problem — the protection of the ozone layer.

One must however also realize that the question of climate change is a much more complicated and intricate issue. It is all-embracing, affecting every aspect of human life. Furthermore, those human activities which produce climate change are very numerous.

We also have to bear in mind that we have a temporal problem. Mankind simply does not have the time to await the negotiation and conclusion of a framework convention without any agreement on concrete measures. Malta is therefore proposing that, coupled with the conclusion of a climate convention, the international community should strive to adopt at least two protocols

which will require concrete measures to be taken in two particular areas:

- Rational forestry management;
  and
- Energy efficiency.

It is our view that there exists sufficient support for the adoption of these protocols. Clearly, their observance would produce results that are beneficial to the global climate. Furthermore, measures in the areas I have just mentioned would also produce other benefits such as economic savings.

In your address on the occasion of the Meeting of Resident Representatives of the United Nations Development Programme (Malta, March 1989) you said that the need to protect the global environment was not incompatible with the need to develop and improve the human condition. Could you please expand on this?

If an environmental protection strategy is to be effective and successful it has to take into account the economic needs and development realities of the international community. Increasingly, even in a very small State such as ours, decision-makers have to act bearing in mind the need to protect the environment and the urge to develop and grow. In my view one has to achieve a balance between these two goals. Clearly, there are cases where development causes environmental problems. On the other hand, we have to ask: Can there be 'true' development, if there is widespread degradation?

The solution to this dilemma is often a complicated, multidimensional and intricate one. Those countries which have grown and developed cannot expect others suddenly to stultify their development and growth. Clearly, all States must act responsibly. Underdevelopment is no excuse for a State to abuse the environment. Nevertheless, the developed States have a responsibility to ensure that the developing States are allowed to grow and at the same time meet their environmental obligations. This responsibility, it seems to me, stems from two factors:

- The developed States have in many cases grown at the expense of the environment. Their development has produced adverse environmental effects which the international community is still facing today. This degradation occurred when some members of the international community were not even States. It was not unknown for States to undertake their hazardous activities in distant colonial territories. The development of the nuclear States is littered with such occurrences;

- The developed States have the resources and the technological capabilities to develop environmentally benign technologies. There should be channels for the transfer of these technologies, and for the funding of the establishment and application of these technologies in developing States.

The results of the recent London Ozone Layer Conference demonstrate the need to recognize developmental concerns if global environmental strategies are to succeed. The ozone layer surrounds us all — developed, developing, rich, poor, small and great. It protects the some five billion inhabitants of the Earth from possible destruction. The need to phase out

chlorofluorocarbons (CFCs) has serious developmental consequences. CFCs play an important part in our economic growth. We cannot expect developing States — which are aspiring to the same development as industrialized States and which have for a number of years been gearing up to exploit CFCs — suddenly to abandon the economic interests of their peoples. I fully understand the position of China and India on this matter.

I feel that the solution of the London Conference attempts to create a reasonable and realistic balance between economic growth and environmental protection. It attempts to tighten controls on CFCs on a global basis. It envisages the developed States assisting developing States to adopt and adapt to the new technologies that provide CFC alternatives. This assistance is coupled with the setting up of a 240 million US dollar fund to finance this transfer of technology.

I believe that the London solution provides a unique model for balancing development and environmental protection. It will be useful in our fight to protect the global climate. It will demonstrate that it is possible to tackle global environmental problems even if there are developmental consequences.

Clearly, with respect to climate, the financial assistance will have to be of a greater magnitude. That is why Malta has advocated the establishment of a World Climate Fund. The London Conference demonstrates that such a fund is a realistic goal. It strengthens our resolve.

Finally, I should like to point out that Malta has prohibited the use in aerosol sprays of all ozone-damaging chemical compounds after 31 December 1990. After this date no aerosol spray product containing such compounds will be allowed to be manufactured, imported or exported.

On several occasions you have referred to the possible establishment of a 'Euro-Mediterranean Centre to deal with regional aspects of environmental problems. Would you give a few examples of problems which could be dealt with by such a centre?

Malta has proposed the establishment of a Euro-Mediterranean Centre to deal with the problems of climate change. The main goal of this centre would be to examine the ramifications of climate change on a regional basis. The Euro-Mediterranean region is particularly suited for such an exercise. It surrounds a semi-enclosed sea bordered by developed and developing littoral States facing each other. Climate change — with possible consequences such as atmospheric warming and sea-level rise — could have catastrophic effects on the region.

We hope that such a centre would provide solutions with applications not just in this one particular region but also in other parts of the globe. It is imperative, if it is to succeed, that a global approach to combat climate change should include the development of regional approaches to the problem.

Another area of global environmental concern to which you have been drawing attention recently relates to the environmental protection of 'extra-territorial space'. Could you please expand on this?

My Government is concerned that the current environmental debate centres mainly on controlling harmful activities occurring in areas that fall under national jurisdiction. This is understandable, as international control is largely based on the will of sovereign States.

Unfortunately, there are huge areas of our globe where not enough attention is given to their environmental protection. The high seas and superjacent airspace are two such areas. Because they are extra-territorial, their protection is left largely unregulated. The little regulation that exists is ineffective.

It is for these reasons that Malta has recommended to the General Assembly that a group of eminent persons should be established to examine the problem. Vast expanses of extra-territorial space belong to the 'common heritage of mankind'. No State or States should be allowed to abuse them.

We have been talking about global responses to climate-change issues as well as measures that might be undertaken to deal with environmental matters on a regional scale. Could you please enumerate some of the climatic and environmental issues of particular importance to Malta?

The very temperament of our people is a reflection of our climate, which has influenced our lives. Atmospheric warming, rainfall deficiency and sea-level rise will dramatically affect our small island and life thereon. Water resources and agriculture are two important resources that are already strained. We already spend 30 per cent of our energy bill transforming sea-water into drinking water. Tourism, which is one of the island's major foreign-currency earners employing thousands, would suffer if the heat became intolerable. Already we find that warm summers in the north of Europe (our main market) affect the number of incoming tourists.

Another major environmental problem is land use. Our small island has to cope with the development requirements of a dense population.

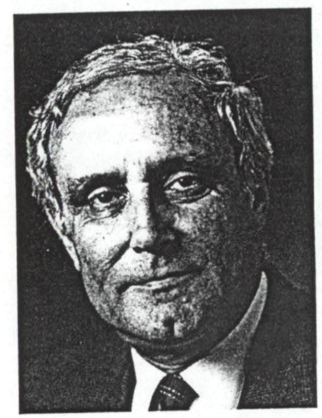
Would you like to send a message to the nations of the world on the occasion of the WMO World Meteorological Day 1991, the theme of which is 'The atmosphere of the living planet Earth'?

The changing composition of the atmosphere risks breaking irreparably the delicate and intricate elasticity of the Earth's environment. At this rate the very air our children will breathe will choke rather than replenish their lungs. Urgent action to protect the planet's atmosphere is needed. We procrastinate at our peril.

* * *

His Excellency Flavio Cotti

President of the Swiss Confederation



The Second World Climate Conference, which was held in Geneva from 29 October to 7 November 1990, was a resounding success. You chaired the Ministerial Session of the Conference and are therefore particularly well placed to comment on the deliberations and interventions of the participants. Could you please start by giving your personal impressions of the Session?

I believe the Ministerial Session was a landmark in many regards. First of all, it was the first time that so many nations of the world (137), some of which were represented at the highest political level, participated in a conference on climate. Second, the Ministerial Declaration issued at the close of the Session recognized the need to transfer to developing countries additional financial resources and environmentally sound technologies on a fair and most favourable basis. Third, it recognized precaution as the principle that should underlie any action dealing with climate change. Finally, it clearly showed the readiness of the most industrialized countries to take a first step in stabilizing or reducing their greenhouse-gas emissions.

I was extremely disappointed, however, at the failure of the industrialized world to reach a consensus on the stabilization of CO_2 emissions, which I consider to be an absolutely indispensable first step.

Many delegations from the developing countries attended the World Climate Conference and participated in the Ministerial Session. What comments can you make on the participation and the interventions of the developing nations on climate-change issues?

The fact that most of the developing countries were represented at the Conference is a very encouraging sign. The Intergovernmental Panel on Climate Change made considerable efforts in this direction and I am convinced that their large participation in the Ministerial Session was the fruit of these efforts.

I was most impressed with the determination with which delegations of low-lying coastal and island States voiced their deep concern and criticized the Ministerial Declaration for failing to take into account their special situation. Although most of these States produce hardly any greenhouse gases, they will probably be the first hit by any sea-level rise induced by global warming. Their position is to remind us that, while the global community may be facing a common threat, the political reality is that individual nations face threats of quite distinct scales and gravity.

In the Ministerial Declaration, it is mentioned that the potential impact of climate change could threaten the environment and consequently social and economic development in general, and even jeopardize survival in some island

States and low-lying coastal arid and semi-arid areas. Do you have the impression that the developing nations are very much concerned about these issues?

Developing nations are certainly aware that they will be particularly affected by global warming and the resulting changes in climate, although it is clear that the alleviation of poverty and economic development continue to be their primary and immediate concerns. As mentioned above, the less industrialized low-lying coastal States and islands, such as those found in the South Pacific and Indian Oceans, are expected to be among the most severely affected by the effects of global warming. This group expressed its special concerns very clearly and forcefully at the Second World Climate Conference, and will no doubt take a very active part in the negotiations of an international convention on climate change.

The Ministerial Declaration also makes reference to the need for co-operation between advanced and developing nations in order to address climate-change issues without hindering national development objectives of the latter. In your opinion, what should the main elements be for such co-operation?

An important area of co-operation is in the scientific domain, as was rightly emphasized in the scientific and technical deliberations at the Conference. At the moment, many developing countries must merely accept the verdict of a scientific community of which they do not form part. Besides, there is a need for financial and technical co-operation, in order to allow the developing countries to take measures to prevent climate change. It is also necessary to enhance co-operation aimed at controlling population growth in these countries.

In recognizing the need to intensify research on the social and economic implications of climate change, the Ministerial Declaration acknowledged the need for the full participation of the developing countries in these efforts. How, in your view, can the developing nations take part in such activities?

These activities should now be conducted within the framework of the negotiating process for an international convention on climate change, as well as in the context of the continuing work of the IPCC. Every effort, financial or otherwise, will be made to promote the widest possible participation by the developing countries in this process.

The Ministerial Session of the Conference noted the specific difficulties of some developing countries whose economies are highly dependent on fossil-fuel production and exportation. In order to meet the incremental costs of taking the necessary measures to address climate-change issues, these countries need external assistance. In what way do you think such assistance could be provided?

As has been pointed out in many conference statements and declarations to date, the consequences of a global warming will affect economies and every aspect of society. It is clear, therefore, that all nations will need increasingly to pursue their economic development on an ecologically sustainable basis. I am convinced that this can be achieved, in the interest of all nations, through large-scale international efforts and intensified international co-operation and solidarity.

One of the most effective ways of helping the developing countries to participate in the stabilization of greenhouse gas

concentrations is technology transfer. Could you please indicate some of the steps taken by the Swiss Government in this direction?

At the request of Parliament and in order to mark the 700th Anniversary of the Swiss Confederation, the Swiss Government has submitted to Parliament a credit proposal to the amount of 700 million Swiss Francs to assist developing countries in solving their external debt problem and in taking measures to protect their environment. This credit will also provide for technical assistance projects.

The Ministerial Declaration invites the Eleventh Congress of the World Meteorological Organization (Geneva, 1991) to formulate, in collaboration with other UN Agencies, plans for the effective co-ordination of climate-change, research and monitoring programme activities. Do you believe that the nations of the world, in particular the more developed countries, are willing to give their full support to the international agencies and provide them with adequate funds to pursue these aims?

A special fund has been created by the World Meteorological Organization for this very purpose. The United States and Canada have already pledged important contributions to this fund (US $500 000 and CAN $1 million respectively). Other countries, including Switzerland, are in the process of assessing their contributions to this fund.

Would you care to describe in a few words the position of the Swiss Government regarding the United Nations Conference *on Environment and Development (UNCED) scheduled to be held in 1992 in Brazil?*

Like other governments, the Swiss Government is now in the process of preparing its position in view of the 1992 Conference. What is already clear now is that one of its objectives, i.e. linking the questions of environment and of development, has already been achieved, as is illustrated in the Ministerial Declaration of the Second World Climate Conference. We expect the 1992 Conference, like its forerunner in 1972 at Stockholm, to be a milestone in the development of human societies, in their relationship both with nature and between north and south, east and west.

To this end, we expect the Conference to provide a major impulse for intensified co-operation and solidarity among all nations, in particular between north and south, and renewed solidarity between mankind and his environment. We expect, in particular, that concrete results will be achieved in 1992 in the areas of climate change, biodiversity, and protection of coastal waters, through the signing of legally binding instruments and through clear commitments from all nations.

* * *

His Excellency Robert Gabriel Mugabe

President of the Republic of Zimbabwe

In view of the current environmental problems facing developing countries, whose national product depends upon agriculture, forestry, mining and energy production, we are warned that continued exploitation of these resources will result in further degradation of the environment unless a policy of sustainable development is adopted. As Head of State of a developing country, how do you view this issue?

Naturally it is an issue that I regard as being of paramount importance. The problem is to achieve a balance between the socio-economic development and self-sufficiency that we in the developing world strive for but which depends largely upon our natural resources, and safeguarding these very resources from over-exploitation and exhaustion. Agriculture is, of course, the classic example. Unless precautions are taken, topsoil is removed by the wind in dry weather and by runoff in the rainy season and, in either case, finds its way into rivers — thousands of tons each year, I believe, and this does not augur well for the future. With the rivers becoming heavily silted up, the flood danger is increased as well. Farmers must learn and put into practice techniques that will protect the precious topsoil they cultivate, and they must not indiscriminately cut down forests in their quest for more arable land. In Zimbabwe we are grappling with this problem, but there is still a long way to go. We want to get across to the people the need to avoid overgrazing, and this is particularly difficult because a rural family's wealth and standing is judged by the number of cattle and goats it possesses; that has been their way of thinking from time immemorial. And if we want to stop people cutting down trees for fuel or for building themselves a home, we must be able to offer them some alternative.

Such environmental problems relate in the main to the developing countries. But in recent years it has been found that certain activities in the industrialized countries provoke environmental degradation that is no less dramatic and frightening; I refer in particular to the release of chlorofluorocarbons that attack the stratospheric ozone, and to the overloading of the planet's atmosphere with carbon dioxide and other so-called greenhouse gases, which scientists tell us will change the climate everywhere. There are other industrial effluents that cause toxic smogs and acid rain, and destroy life in lakes, rivers and even the sea.

The developed countries have now realized their mistakes and urge us in the developing world not to repeat them. Developing countries can be forgiven for wanting to raise their often desperately low standard of living by launching their own industrial revolution, but nevertheless we do heed the warnings. We have experienced for ourselves the terrible consequences of drought and desertification and, as I have said, we are doing what we can to teach farmers and planners to avoid the many pitfalls. We know that our few industrial plants

sometimes release harmful substances into the air or water, and we are anxious to clean them up if we possibly can. It is indeed a difficult balance to achieve — between economic progress and protecting the environment.

Starting with the United Nations Conference on the Human Environment, in 1972, quite a number of international gatherings at governmental level have reached agreement on certain action to limit further environmental deterioration; I am thinking for instance of the Plan of Action to Combat Desertification drawn up at Nairobi in 1977, the Vienna Convention on the Protection of the Ozone Layer in 1985, the Montreal Protocol in 1987 and the important meeting at The Hague in March 1989 which you attended. Now the UN General Assembly has called for a Conference on Environment and Development to be held in Brazil in 1992. Do you believe this conference will be able to lay down a coherent action programme? Which are the issues of greatest concern?

I think it is a good idea to hold this conference in Brazil and I hope that it will be really well attended. As I said, we in the developing world are well aware of the danger to our natural environment and of the need for concerted action to limit further degradation. The programme of action should, in my view, be more than a general exhortation. It should commit countries to action in each of the various specific problem areas. I imagine that Brazil was chosen as the venue of the conference partly to emphasize the deforestation issue, which I fully agree is of the utmost importance. But clear directives will need to be set down with regard to the ozone issue, greenhouse gases, acid rain, marine pollution, agricultural mismanagement, the ecological balance and so on. We shall also have to focus on action in the different regions of the world; obviously here in developing Africa we would need a different programme from that in Europe, for example. Here we must have a strategy for action that is realistic and practicable, commensurate with the financial resources and expertise available to us. Moreover, if we are to keep it up, we shall have to have support from the developed world; that is inescapable. I should like to see some form of regional organization charged with supervising the implementation of the action plan on behalf of the United Nations. For us, the Organization of African Unity (OAU) could do it. Summing up, therefore, I should like the Brazil Conference to size up the problem of the environment and then prescribe the necessary action by continent, region and even by nation.

The UN General Assembly has declared drought and desertification to be of special importance in the quest for environmentally sound and sustainable development. Speaking on behalf of African countries that already suffer from the scourge of desertification, what approach would you advocate to tackle the problem at both national and international levels?

The problem is an immense one. I remember visiting Somalia in 1978 and I could have wept to see beautiful fertile fields being smothered by tons and tons of sand. One feels so helpless witnessing trees being choked by the advancing desert, rather like people being drowned in a flood. But things can and must be done. Sand-dune stabilization programmes are in progress in several arid and semi-arid countries; suitable types of vegetation are planted to prevent the the sand being carried by the wind, and thereby arrest the advance of the dune. These

programmes could be internationally co-ordinated and extended so as to become regional in scope. Such an effort would surely merit support from developed nations. But in parallel with this action, we must put a stop to those agricultural practices that favour desertification, such as overgrazing, deforestation or ploughing up and down rather than along the hillsides.

As I am sure you are aware, the ECA Conference of Ministers decided in 1987 to create an African Centre of Meteorological Applications for Development (ACMAD) the principal object of which will be to foster projects aimed at monitoring, predicting and giving warning of impending drought or other potentially disastrous weather-related events. Once this centre is fully operational it will be an effective complement to existing Drought Monitoring Centres such as, for example, the one in Harare. With this in mind, do you agree that African countries should present their problems collectively to the Conference on Environment and Development in the hope of attracting more support for institutions such as these?

We are well placed to know the terrible ravages of drought. It is a natural factor that, together with the man-induced ones I already mentioned, is extremely propitious to desertification. It seems to me that we are getting droughts more and more frequently, and they affect huge areas, not just one country or part of a country. Therefore anything we can do to prepare for droughts or mitigate their effects needs to be considered in a regional framework. So yes, while we may talk about the consequences of droughts in our own lands, our perception of the problem needs to be holistic. Therefore, I agree that African countries should present their case collectively to the Conference. Incidentally, drought and desertification are not problems specific to Africa.

Concerning the accumulation of chlorofluorocarbons and other greenhouse gases in the atmosphere, the UN General Assembly has noted that these substances are emitted mostly by the developed countries, which must bear the main responsibility in taking remedial action. However, since the consequences will be world-wide, what do you think the developing countries can and should do?

I have to agree that responsibility for combating the problem lies first and foremost with the developed countries. I quite see the invidious position their governments are in: many have balance-of-payment deficits and want their industrial products to remain competitive in the world market, and closing down factories will create problems of unemployment. On the other hand, I feel that their efforts up to now to find cleaner substitutes and processes have been rather half-hearted. That is where research should primarily be directed. There is really little that the developing countries can do in this respect other than keep up the pressure on developed countries to behave responsibly. We shall certainly do this at the meeting of Heads of State of the Commonwealth countries next year.

At The Hague summit meeting last year you pointed out that developing countries could not afford to divert resources from their current development priorities, but you did pledge to take measures to combat desertification. What specifically has been done in Zimbabwe?

For one thing we are seeing to it that contour ridges are made on cultivated hillsides to arrest erosion by water runoff. Also we have launched a tree-planting campaign which seems to be popular, and we make a point of

planting indigenous trees which are deep-rooted and can survive droughts and hold the soil in place. These species have proved to be better adapted to our conditions than imported European trees or eucalyptus. What we must still do is persuade farmers to reduce their head of livestock to within the limits of sustainable grazing, get them to cultivate grass and build dams for irrigation. As for the implantation of new industries, we shall be very careful to see that proper environmental impact studies are carried out first, and only when we have complete assurance that any effects would be minimal will a permit be issued.

I think you would agree that environmental preservation is best achieved through educating the public. Are you in favour of the subject being included in the curricula of secondary and even primary schools?

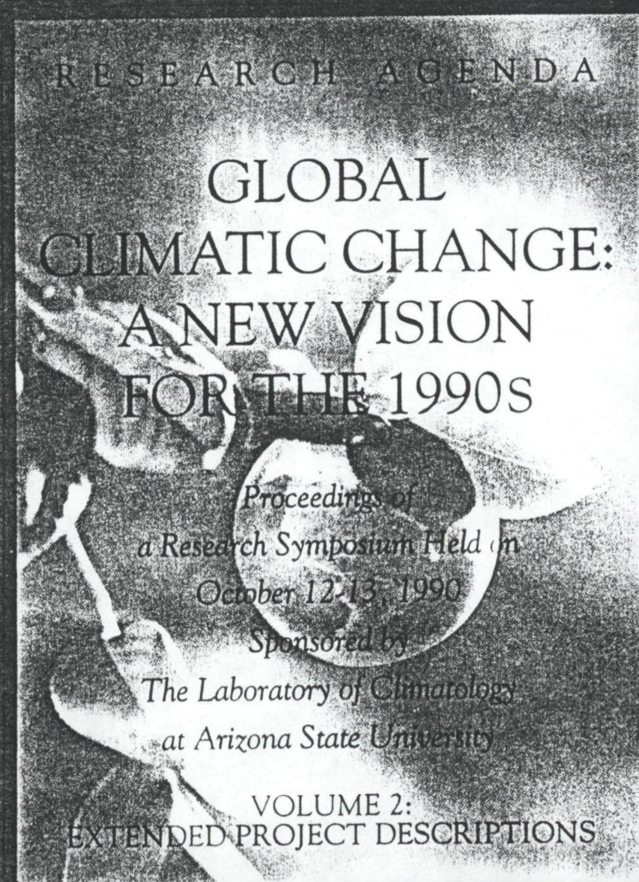
Most certainly. A lot is done in my country to ensure that children are made aware from an early age of the intrinsic value of an intact environment. For example, the Forestry Commission has sponsored competitions for essays or poems on the theme. Environmental protection may not yet be formally included in school curricula, but, once the syllabus has been properly formulated with the help of experts, it will be, and the sooner the better.

During the summit meeting in Toronto in 1988, Chancellor Helmuth Kohl suggested a bargain whereby the poorest of the developing countries could have some of their debts cancelled in exchange for taking environmental protection measures. What is your reaction to this proposition?

I should regret it very much if the alleviation of the developing countries' debts were made conditional on environmental protection. It is putting the cart before the horse. The whole problem of Third World debts has to be looked at as a separate issue. Certainly, if debts were to be written off or the interest rates lowered, developing countries would be better able to cater for environmental considerations in development planning. And I am sure they would too, because, as I said before, environmental deterioration is very real to us in Africa, threatened as we are by advancing deserts. So from our point of view, our creditors — the developed countries — should decide to write off the debts, saying as they do so that they hope the developing countries will give urgent attention to safeguarding the environment.

The theme of World Meteorological Day (23 March) in 1991 is 'The atmosphere of the living planet Earth'. Is there any message you would like to give to the nations of the world on that occasion?

My message would be a very simple one. The problem of managing the environment, be it the atmosphere, the sea or the land, must be taken seriously, and every national budget must make provision for protecting the environment in one way or another, depending upon the particular circumstances. Planet Earth is mother to all of us. If we upset the delicate balance of nature in one place, the effect is likely to spread far and wide, and may be irreversible. Mankind alone is responsible for the health of the planet Earth, and we must leave it as we would like to find it. That is the least we can do for our future generations.


RESEARCH AGENDA
GLOBAL
CLIMATIC CHANGE:
A NEW VISION
FOR THE 1990s
Proceedings of
a Research Symposium Held on
October 12-13, 1990
Sponsored by
The Laboratory of Climatology
at Arizona State University
VOLUME 2:
EXTENDED PROJECT DESCRIPTIONS

4-6-8

EXTENDED PROPOSALS & BUDGETS

THE PULSE OF SEA LEVEL DURING THE PAST CENTURY

David G. Aubrey
Woods Hole Oceanographic Institution

INTRODUCTION

Sea levels have fluctuated throughout the history of the earth, dropping some 200m in the last 50 million years. Sea level responds to changes in the volume of the world oceans due both to differences in basin geometry and to changes in density and total mass of water (glacial effects). Man's measurement of sea levels introduces yet another uncertainty: all measurements are made relative to the coast, so that the vertical motion of the coast itself introduces a bias into the data. In the past, these vertical movements have been ignored by many researchers, in spite of evidence that these movements can be orders of magnitude larger than putative rises in ocean level. In a book scheduled for publication in early 1991, Aubrey and Emery document these fluctuating land levels along the world's coasts, and show that they result in a bias of uncertain but large magnitude.

Sea levels are an important indicator of climatic change, because they integrate many effects that are normally associated with these types of change. Sea level integrates the combined effects of varying ocean density structure, whose detail it is impossible to measure accurately enough all over the globe for the purpose of assessing climatic change. Wunsch and Roemmich have demonstrated interdecadal fluctuations in ocean density and have discussed the non-uniqueness of any interpretation because of geographical fluctuations in density. Sea level also integrates the input of fresh water from glaciers. Rather than measuring glacial volume or mass balance of all of the continental and marine grounded glaciers, sea level integrates this input over the globe. While sea level might not be the ultimate diagnostic of climatic change, it is surely valuable as an early indicator.

But, can we measure sea level accurately? For more than a hundred years, sea level has been measure–that is to say the level of land relative to the sea. Measurements have been undertaken with a wide variety of mechanical systems on oceanic platforms. That such crude and varied instruments can measure changes averaging only a millimeter or two per year is astounding, but apparently true. What is left to measure is the influence of changing land surface on the relative sea-level measurements. Up until now this separation has not been possible. However, new technology now affords us the opportunity to make these measurements, using Very Long Baseline Interferometry (VLBI), Differential Global Positioning Systems (DGPS) and Absolute Gravity Meters (AGM). These permit measurements of vertical motion with accuracies of a centimeter or so with respect to the center of mass of the globe or some fixed reference frame. If we tie these geodetic measurements into our tide-gauge recordings, we can unambiguously separate land motion from true sea level rise.

We propose to perform such measurements of geodetic control at a network of about 25 tide-gauge stations throughout the globe, where long-term tide records exist, and positioned in areas sensitive to sea-level change. Our sites will be chosen to be less influenced by direct human activities, such as local compaction due to groundwater or hydrocarbon extraction, changes in river flow, or other disturbances. These measurements will be made at about 8 stations per year, and measured on a three-year repeat interval. As we progress through time, we will develop a long-term baseline of land-level changes at these sites, and at different time scales, so that we can remove the effects of land-level changes from tide-gauge records. We will therefore establish the true rate and probabilistic limits on the global sea level record. At present we cannot distinguish a change in sea-level of 3 mm/year, which is an unacceptable error if we want to use sea level as a diagnostic tool to study climatic change. This new program will remedy that problem.

Our budget will allow us to establish the permanent geodetic control sites in our first three years, and the monitor those positions thereafter. There may be additional costs associated with the purchase of an Absolute Gravity Meter. While this is an ongoing project, budget totals are only for a five-year period.

$500,000/year first three years
$300,000/year, years 4-5

Total (Five years) $2,100,000

Impact of Desertification on Regional and Global Warming

Robert C. Balling
Arizona State University

The present search for greenhouse-related temperature signals is complicated by a number of potential contaminants in long-term climatic records. Urban heat islands, station relocations, instrument changes, calibration errors, varying observation times, and microclimatic changes near the instruments are among the well-known problems in using existing temperature observations. Although these contaminants to the temperature records have received considerable attention within the past decade, the list is undoubtedly incomplete. Recently, evidence has surfaced that human-induced desertification is producing yet another statistically significant warming trend in the land-based temperature data; this temperature signal may be easily mistaken as a form of greenhouse warming. Accordingly, the purpose of the proposed research is to determine the physical causes, magnitude, and significance of the warming trend in the temperature record that is uniquely related to widespread human-induced desertification.

The role of desertification in altering the surface energy budget, and ultimately the near-surface air temperature, also has received considerable attention since the mid-1970s. Many investigators have concluded that desertification in arid and semi-arid lands leads to a reduction in vegetative cover, surface and near-surface moisture, and local evapotranspiration rates. With less radiant energy going to evapotranspiration, daytime surface temperatures increase and higher near-surface air temperatures result from the altered energy fluxes. Because the desertification processes occur over years or decades, it is reasonable to expect a relative warming trend for the areas of the earth that have experienced substantial desertification.

Results from a Preliminary Study

Recently, I completed a preliminary study showing the impact of human-induced desertification on temperature trends; the study will be published in the *Bulletin of the American Meteorological Society* early in 1991. In that study, I used a map of desertification produced for the United Nations by Howard Dregne of Texas Tech University. Using a 5° latitude by 10° longitude grid, I selected every pair of points around the globe where one grid point was within an area of *severe desertification* while an adjacent land-surface grid point (exactly 5° of latitude apart) was characterized by *no desertification*; eleven of these pairs were located in all. For each month from 1881 to 1987, the temperature anomalies (from the widely-used Jones et al. gridded temperature data base) of the two points were subtracted from one another, and a linear trend was determined for the array of differences. The results indicated a warming signal associated with desertification for all eleven pairs (seven of the trends were statistically significant at the 0.99 level of confidence); this warming signal in the temperature data averaged +0.50°C per century.

The pilot study probably produced a substantial *underestimation* of the impact of desertification on the temperature record given the limitations of the datasets. The map prepared by Dregne is highly generalized and was constructed with limited detailed information on the timing and degree of degradation caused by human activities. The interpolation schemes used by Jones et al. to generate the gridded temperature data from the widely-scattered stations in the semi-arid and arid regions of the world tend to smooth any high-resolution spatial differences in the temperature trends. Nonetheless, a statistically significant desertification-related warming signal was identified clearly in this pilot study.

Specific Objectives of the Proposed Research

The purpose of the proposed research is to determine the physical causes, magnitude, statistical significance, and the areal extent of a warming signal that may be associated with human-induced desertification of the past century. Specific objectives and goals of the study will include:

(a) determine the differential warming signal associated with various intensities of observed desertification and identify areal differences that exist in the differential warming signals (e.g., does the desertification in the Sonoran Desert produce a response that is different from a response in the Sahel),
(b) use satellite-derived vertical profiles of the atmosphere to determine the three-dimensional structure (e.g., latitudinal, longitudinal, and vertical) of the near-surface temperature responses to vegetation removal, and
(c) develop an improved analytical model for simulating the influence of vegetation removal on surface and near surface thermal and moisture regimes.

Research Design

In order to address these three objectives, three distinctly different, but highly interrelated, research activities will be pursued. To begin, all 5° latitude by 10°

longitude land-surface grid points will be located on the Dregne map, and each of the points will be classified as having (a) no, (b) slight, (c) moderate, (d) severe, or (e) very severe desertification at the time of map construction. Given the Jones et al. gridded temperature data and the Dregne classification for each point, a series of multivariate statistical techniques will be used to identify the annual and seasonal impact of the climatic response to the desertification intensities.

Scientists at the NASA Jet Propulsion Laboratory have access to the vertical-profile data collected by the TIROS polar-orbiting satellites from 1979-present. These vertical profiles of temperature, available for 64 levels of the atmosphere, are taken within seconds of one-another and are available for various times of the day. Given that the matched profiles are taken within seconds of one-another, potential problems regarding absolute calibration are minimized. By selecting matched profiles from carefully chosen areas where spatial discontinuities exist in desertification classes, we will determine the near-surface temperature differences and the vertical extent of the temperature alteration. These analyses will determine the value of the satellite sensor system in this type of research.

Michael Novak (University of British Columbia) has recently published a series of papers describing his newly developed analytical model for simulating micrometeorological changes associated with vegetation removal in semi-arid and arid lands. The equations governing the soil thermal and atmospheric thermal and moisture regimes (assuming both media to be one-dimensional semi-infinite slabs and "turbulent K-theory" for the atmosphere) are expanded and the results of his model appear to have remarkable accuracy in simulating known atmospheric changes associated with vegetation removal. In this proposed research, Novak will further test his model with data collected by our group for an extensive vegetation discontinuity along the U.S./Mexico border. His model will be "tuned" in these analyses, expanded t o simulate effects over larger areas, and compared to the results from analyses of satellite and historical climate data.

'TCOME OF THE PROPOSED STUDY

Results of the pilot study were extremely encouraging, and they strongly suggest that the impact of desertification on the temperature trends of the globe must be considered in future searches for greenhouse signals. Obviously, the differential warming associated with desertification can be confused easily with other signals in the data that may or may not be related to greenhouse effects. The proposed study should produce the results necessary to resolve the causes, magnitude, and significance of this feedback mechanism. Following completion of the six-month project, a full set of journal articles, conference presentations, and press releases will result from the effort.

PRELIMINARY BUDGET

Evaluation of the Historical Climate Records:	
ASU Salaries:	
Half-time support for Balling (12 months)	27,000
Benefits (@30%)	8,100
ASU Graduate Assistant (0.5 time for 9 months)	9,500
Benefits (@3%)	285
Computing (provided by ASU)	0
Travel (to conferences)	3,000
Publication Charges (page charges, report costs)	2,000
Subtotal	49,885
ASU On-Campus Indirect Costs (@51.0%)	25,441
Total Costs (Historical Climate Data Analysis)	$75,326
Analysis of Satellite-Derived Vertical Profile Data:	
Sub-Contract to Jet Propulsion Lab for Data Acquisition and Analysis	175,000
ASU Off-Campus Indirect Costs (@33.6%)	58,800
Total Costs (JPL's Vertical Profile Analysis)	$233,800
Development and Improvement of an Analytical Model:	
Sub-Contract to Novak for Model Development and Improvement (includes all computing, salary and miscellaneous expenses)	35,000
ASU Off-Campus Indirect Costs (@33.6%)	11,760
Total Costs (Modeling Research Component)	$46,760
Total Project Costs	**$355,886**

A Synoptic Climatological Analysis of Trends in Arctic Air Mass Characteristics in the Northern Hemisphere

Robert E. Davis
University of Virginia

CTION

In light of predictions of global warming based primarily upon general circulation model (GCM) output, many climatologists have undertaken a detailed analysis of recent climate trends based upon historical data. Undoubtedly, the most carefully scrutinized datasets have been global surface temperature records, which have been analyzed with regard to diurnal and seasonal variations, spatial changes over latitude bands, continental versus maritime readings, and urban versus rural records (e.g., Balling and Idso, 1989; Karl and Jones, 1989; Sansom, 1989; Hansen and Lebedeff, 1988; Karl et al., 1988; Wigley, 1987). However, if some warming does occur, changes will be evidenced not only in the temperature record, but in a broad array of atmospheric parameters which reflect the dynamics and thermodynamics of the atmosphere. For example, alterations would be expected in the general circulation, since disparate warming in the high latitudes should decrease the hemispheric temperature gradient and weaken the polar jet. Changes might also be anticipated in the characteristics or frequencies of air masses over the high and mid-latitudes. Because the basic nature of the atmospheric circulation could vary, it is important to investigate this change from a *multivariate* as well as a univariate perspective.

Background carbon dioxide concentrations from pre-industrial times have been estimated to be in the range of 260 to almost 300 ppm (e.g., Idso, 1989; Neftel et al., 1985; Raynaud and Barnola, 1985), and current concentrations are estimated at about 350 ppm (Wigley, 1987). Other radiatively significant trace gase–methane, nitrous oxides, and chlorofluorocarbon–have also been increasing dramatically in the atmosphere and *in toto* represent a radiative forcing of about 80 percent of the change in carbon dioxide from 270 to 350 ppm. Thus, when these trace gases are accounted for, the current atmosphere has an effective carbon dioxide concentration of about 410 ppm, or 150 percent of the pre-industrial background concentration (Michaels, 1990). One would therefore expect that some evidence of global warming currently exists, particularly in those regions of the globe most sensitive to warming, based upon GCM output.

General circulation models indicate that, under the influence of doubled carbon dioxide concentrations, surface air temperature will increase disparately over the high latitude land areas during the low sun season. Significant warming is "anticipated" over Alaska and northwestern Canada and in Scandinavia in the winter. Although forecasted summer increases are lower in magnitude than in winter, significant maxima are located over the north-central United States and south-central Canada, and western Europe.

The goal of this proposed research is determine if significant trends exist in the frequencies or characteristics of the air masses found in these regions, based upon the historical record. If variations are uncovered, and if their direction matches those forecast by GCMs, then an important confirmation of the climate models ability to predict temporal variation will be made. Conversely, if no signal is apparent in the historical data, then one must call into question the application of GCM output to regional-scale climate forecasting.

PROCEDURES

Synoptic climatological procedures allow for the multivariate analysis of daily historical weather data. Although a variety of classification techniques are appropriate in synoptic climatological analysis, only a few of the methods which are most pertinent to the proposed research are discussed here.

Of the wide variety of automated or computer-based synoptic typing techniques, those which utilize empirical orthogonal functions and/or cluster analysis to define recurring weather patterns have recently become quite common. Kalkstein and Corrigan (1986) developed a Temporal Synoptic Index which classifies each day's weather at an individual site into one of a discrete number of classes. The weather characteristics of each class, or synoptic type, are distinct and statistically different from the conditions in the other synoptic types. This approach has recently been applied to analyze arctic temperature trends (Kalkstein et al., 1990) and results indicate some evidence of arctic warming based upon increasing frequencies of the warmest air masses, decreasing frequencies of the coldest air masses, and warming of the coldest air masses over the available period of record. However, these results must be viewed with caution since the analysis was based primarily on *surface* weather records which are subject to urbanization effects which can be significant even for relatively small population changes (Balling and Idso, 1989). A second approach involves a spatial classification in which stations experiencing similar weather conditions over a 24-hour period are grouped (Davis, 1988; Davis and Kalkstein, 1990). The resulting weather types represent air masses or air mass boundaries (frontal systems) and closely correspond to surface weather map features.

The synoptic climatological technique proposed here is a combination of the temporal and spatial techniques described above. It involves utilizing a spatial network of rawinsonde stations and grouping days in which upper air dynamics and thermodynamics are similar at standard pressure levels. Thus, a four-dimensional analysis is possible, since the spatial, vertical, and temporal variations in atmospheric conditions can be analyzed using one method. This regional, upper-air analysis has been successfully utilized in current and ongoing research in characterizing atmospheric states over the western United States.

Specifically, rawinsonde data will be sampled for both Alaska and western and central Canada and Scandinavia and the western Soviet Union in December, January, and February. Additionally, data for June, July, and August will be compiled for the north-central United States and southern Canada, and western Europe. These general locations are the areas in which the global climate models predict maximum warming in a doubled carbon dioxide environment. The available record lengths will vary, but in some instances rawinsonde data are available from the mid 1950s, providing up to 35 years of data for analysis. The following variables will be sampled twice each day: air temperature, dew point temperature, geopotential height, and the east-west (u) and north-south (v) components of the wind vector. These variables represent a combination of dynamic (flow) and thermodynamic (thermal) variables which are commonly used to identify synoptic types. These variables will be sampled at the 850, 700, 500, and 250 mb standard pressure levels. If rawinsonde data are available over particularly mountainous areas, a pressure lower than 850 mb may be necessary to assure representative sampling over the region.

The synoptic types will be developed using a combination of multivariate statistical techniques. First, the large data array for each region will be input into a principal components analysis. This is used to eliminate the high degree of multicollinearity present in these data and to reduce the size of the data array to a more manageable number of principal components while still retaining a large portion of the variance in the data. Then, based on the resulting component scores, a two-stage clustering technique will be employed to identify the synoptic types. First, *average linkage* clustering is used to identify the number of synoptic types and to characterize the mean conditions of each type (Sokal and Michener, 1958). Then, using these cluster means as seeds, *convergent k-means* clustering is used to develop the final synoptic climatology (MacQueen, 1967). Various tests have indicated that this two-stage clustering procedure of applying hierarchical (average linkage) and then non-hierarchical (k-means) methods produces more distinct clusters than using either method alone (Milligan, 1980). As a result of these procedures, those days in which the regional, upper-air conditions are similar will be grouped into the same synoptic types.

Since each day will be classified into one of a finite number of synoptic situations, it is relatively simple to analyze the changes in monthly or yearly frequencies using a variety of statistical techniques. Some of the possible analytic methods include trend analysis, time series analysis, profile analysis, and regression analysis. Through these techniques it will be possible to determine if statistically significant trends exist in the character of the atmospheric circulation over the available period of record.

PRODUCTS

As a result of this research, several key questions regarding climatic change will be addressed:

1. Are there any statistically significant trends in the frequency of synoptic types in the "climatically sensitive" regions defined by the GCMs?
2. Are there any identifiable changes in the characteristics of the synoptic types?
3. If trends do indeed exist, are they compatible with the variation forecast by general circulation models in an enhanced CO_2 environment?

These questions are critical scientific issues in the climate change community and should add significant insight into both the extent to which atmospheric characteristics have varied in the recent past and the ability of climate models to predict future conditions in an atmosphere characterized by increased levels of greenhouse gases.

The total cost of this research project is $600,000 over two years. This includes summer salary for the principal investigator, year-round salary for two graduate students, purchase of rawinsonde data, computer time, some minor equipment purchases, administrative costs, travel and publication charges and overhead. A detailed budget for the two-year period will gladly be provided upon request.

REFERENCES

Balling, R.C. and S.B. Idso (1989) Historical temperature trends in the United States and the effect of urban population growth. *Journal of Geophysical Research* 84, 3359-3363.

Davis, R.E. (1988) *The Development of a Spatial Synoptic Climatological Index for Environmental Analysis*. Ph.D. dissertation, Dept. of Geography, Univ. of Delaware, Newark, Delaware, 210pp.

Davis, R.E. and Kalkstein, L.S. (1990) Development of an automated spatial synoptic climatological classification. *International Journal of Climatology*, 10, 769-794.

Hansen, J. and S.L. Lebedeff (1988) Global surface air temperatures: update through 1987. *Geophysical Research Letters* 15, 323-326.

Idso, S.B. (1989) *Carbon Dioxide and Global Change: Earth in Transition*. IBR Press, Tempe, Arizona, 292pp.

Kalkstein, L.S. and Corrigan, P. (1986) A synoptic climatological approach for environmental analysis: assessment of sulfur dioxide concentrations. *Annals of the Association of American Geographers* 76, 381-395.

Kalkstein, L.S., Dunne, P., and Vose, R. (1990) Detection of climatic change in the western North American arctic using a synoptic climatological approach, *Journal of Climate*, 3, 1153-1167.

Karl, T.R. and P.D. Jones (1989) Urban bias in area-averaged surface air temperature trends. *Bulletin of the American Meteorological Society* 70, 265-270.

Karl, T.R., Baldwin, R.G., and M.G. Burgin (1988) Time series of regional season averages of maximum, minimum, and average temperature, and diurnal temperature range across the United States, 1901-1984. U.S. Dept. of Commerce, Historical Climatology Series 4-5, National Climatic Data Center, Asheville, North Carolina. 108pp.

MacQueen, J. (1967) Some methods for classification and analysis of multivariate observations. *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability* 1, 281-297.

Michaels, P.J. (1990) The greenhouse effect and global change: review and reappraisal. *International Journal of Environmental Studies* 36, 55-71.

Milligan, G.W. (1980) An examination of the effect of six types of error perturbation on fifteen clustering algorithms. *Psychometrika* 45, 325-342.

Neftel, A., Moor, E., Oeschger, H., and B. Staugger (1985) Evidence from polar ice cores for the increase in atmospheric CO2 in the past two centuries. *Nature* 315, 45-47.

Raynaud, D. and J.M. Barnola (1985) An Antarctic ice core reveals atmospheric CO2 variations over the past few centuries. *Nature* 315, 309-311.

Sansom, J. (1989) Antarctic surface temperature time series. *Journal of Climate* 2, 1164-1172.

Sokal, R.R. and Michener, C.D. (1958) A statistical method for evaluating systematic relationships. *University of Kansas Science Bulletin*, 38, 1409-1438.

Wigley, T.M.L. (1987) Relative contributions of different trace gases to the greenhouse effect. *Climate Monitor* 16, 14-28.

The Effect of Rising Atmospheric CO_2 Concentration on Carbon Accumulation in a Deciduous Forest Ecostystem

Bert G. Drake
Smithsonian Environmental Research Center

The direct effects of rising CO_2 on vegetation may turn out to have impacts on ecosystem processes and the global carbon budget which are as important as the effects of climate change. More importantly, stimulation of carbon dioxide assimilation and growth of plants may mitigate the rate of the rise in atmospheric CO_2 concentration.

Biological processes exert a powerful impact on atmospheric CO_2 concentration. During summer, photosynthesis of green plants draws the concentration down and during fall when the decay of dead plant material is the dominant process, it rises again. At 60°N latitude this seasonal variation is approximately 15 ppm (Gammon, Sundquist, and Fraser, 1985). In the past 20 years, seasonal amplitude of the average CO_2 concentration at Mauna Loa has increased (Keeling, 1989), indicating that the biological activity has increased in this time.

This effect arises from one of the most well-known plant physiological processes: the increase of photosynthesis, growth and water use efficiency when CO_2 concentrations are increased above present normal ambient levels. Almost as important is the interaction between elevated CO_2 and temperature because the stimulation of photosynthesis by elevated CO_2 increases as temperature increases. At 15°C the effect of doubling the CO_2 concentration on photosynthesis is about 15% increase but at 35°C, this increase is near 100%. In other words, rising CO_2 could conceivably double photosynthesis in tropical and subtropical regions.

Would increased photosynthesis significantly effect the atmospheric pool of carbon? The annual injection of CO_2 from fossil fuels is about 5 Gt/y and about 1-2 Gt/y from deforestation which produces an annual increase in atmospheric CO_2 of approximately 3 Gt with the remainder going into the oceans (Tans, et al. 1990). The exchange of CO_2 between the atmosphere and the biosphere is roughly 100 Gt assimilated and about the same amount lost per year (Woodwell, 1989). These exchange rates are so large compared to the magnitude of the anthropogenic sources of CO_2 that small changes in either photosynthesis or respiration could drive the carbon dioxide content in the atmospheric pool up or down (Houghton,et al. 1985; Woodwell, 1989).

Thus, vegetation has a potentially significant role in mitigating the rise in atmospheric CO_2. I believe that this effect has been too lightly dismissed in the current flood of discussion of the effect of global climate change on ecosystems and redistribution of plant communities. Although the direct effect of rising CO_2 on vegetation is considered possible (e.g., Bacastow and Keeling, 1973;Emanuel, Shugart and Stevenson, 1985; Shands and Hoffman, 1987; Jarvis, 1989), current thinking is dominated by the view that terrestrial ecosystems are a source rather than a sink for CO_2, mainly because of deforestation (Houghton,et al.1985). Discussion of deforestation and the role of CO_2 in changing climate with the consequent possibilities for changes in distribution of ecosystems, seems to have eclipsed consideration of the direct effect of CO_2 on ecosystem carbon metabolism, the hydrologic budget, etc..

Which ecosystems should be studied? Approximately 65% of the terrestrial carbon accumulation occurs in forest ecosystems. However, our knowledge of the responses of forests to rising CO_2 is limited to about thirty studies with tree seedlings in controlled environments and generally under conditions in which the possible effects of CO_2 on growth and photosynthesis have been minimized Eamus and Jarvis, 1989; Jarvis, 1989).

The studies of wetland species we have carried out in the field for the past four years have shown that there is a very large stimulation of carbon accumulation in ecosystems by elevated CO_2 and that most of the additional carbon (by comparison with the same ecosystems growing in normal ambient CO_2 concentration) is stored in below ground roots and rhizomes (Curtis, et al., 1989 a,b; 1990). Our studies have also shown that plants grown in the field under natural conditions respond differently to elevated CO_2 than do those grown in controlled environments. We have found that elevated CO_2 increases photosynthetic capacity (Arp and Drake, in review; Ziska et al., 1990; Long and Drake, In press) rather than decreasing it as has been found in many laboratory studies, and that the rate of plant respiration is decreased (Drake, et al. in review). These two effects, if they occur in forest ecosystems, will mean that as the CO_2 rises, ecosystems will accumulate and store much more carbon than they do at present.

Studies of natural vegetation will obviate any possible artifacts which may complicate interpretation of results in the context of the impact of rising CO_2 on ecosystem processes. For this reason we propose to conduct a field study of the effects of elevated atmospheric CO_2 concentration on the deciduous forest ecosystem. We will use open top chambers on the forest floor to study the responses of shade tolerant tree species, we will use open top chambers in an old field in which juvenile tree species have been planted and follow the development of second growth forest, and we will attempt to use branch chambers on mature trees to determine whether the responses to elevated CO_2 observed in immature tress also occur in mature trees.

We propose to construct and operate a system of 30 chambers divided roughly equally between the forest canopy, the forest understory and second growth deciduous forest. This will allow five replicates of each treatment in each of the three components of the forest; second growth, understory and canopy. CO_2 will be increased in one-half of the chambers to twice the level occurring in those receiving normal ambient CO_2 concentration. We will study photosynthesis, evapotranspiration, respiration, growth of above and below ground plant structures, soil organic matter, nutrient cycling, canopy structure and the carbon budget. In order to determine the long-term effects of elevated CO_2 on this forest ecosystem will utilize a model of forest growth parameterized with the data obtained in the experimental work.

References

Bacastow, R. and C.D. Keeling. 1973. Atmospheric carbon dioxide and radiocarbon in the natural carbon cycle. II.Changes from A.D. 1700 to 2070 as deduced from a geochemical model. In: G.M.Woodwell and E. Pecan, eds. *Carbon and the Biosphere*. U.S.Atomic Energy Commission, Washington, D.C.

Curtis, P.S., Drake, B.G., Leadley, P.W., Arp, W.J. and D.F.Whigham. 1989a. Growth and senescence in plant communities exposed to elevated CO_2 concentrations on an estuarine marsh. *Oecologia* 78:20-26.

Curtis, P.S., Drake, B.G. and D.F. Whigham. 1989b. Nitrogen and carbon dynamics in C3 and C4 estuarine marsh plants grown under elevated CO_2 in situ. *Oecologia* 78:297-301.

Curtis, P.S., Balduman, L.M., Drake, B.G. and D.F. Whigham. 1990. The effect of elevated atmospheric CO_2 on belowground processes in C3 and C4 estuarine marsh communities. *Ecology*.

Drake, B.G., Leadley, P.W., Arp, W.J., Nassiry, D. and P.S. Curtis. 1989. An open top chamber for field studies of elevated atmospheric CO_2 concentration on salt-marsh vegetation. *Functional Ecology* 3:363-371.

Drake, B.G., Leadley, P.W., Arp, W., Curtis, P. and D F. Whigham. In press. The effect of elevated atmospheric CO_2 on C3 and C4 vegetation on Chesapeake Bay. *Proceedings, International Symposium on Physiological Ecology of Aquatic Plants, August 29-September 2, 1988*. Elsevier, Amsterdam.

Drake, B.G., Ziska, L.H., Bunce, J.A., Arp, W.J., Hogan, K. and A.P. Smith. In review. Dark respiration in plants grown in the field exposed to elevated atmospheric CO_2.

Eamus, D. and Jarvis, P. 1989. The direct effects of increase in the global atmospheric CO_2 concentration on natural and commercial temperate trees and forests. Advances in *Ecological Research*, 19:2- 56.

Emanuel, W.R, Shugart, H.H. ad M.P. Stevenson. 1985. Climatic change and the broad-scale distribution of terrestrial ecosystem complexes. *Climate Change* 7:29-43.

Gammon, R.H., Sundquist, E.T. and P.J. Fraser. 1985. History of carbon dioxide in the atmosphere. In: J.R. Trabalka, ed. *Atmospheric Carbon Dioxide and the Global Carbon Cycle*. US Department of Energy, DOE/ER-0239. pp.25-62.

Houghton, R.A.. 1987. Terrestrial metabolism and atmospheric CO_2 concentrations. *BioScience*. 37:672-678.

Jarvis, P.. (1989) Atmospheric carbon dioxide and forests. *Philosophical transactions of the Royal Society*, London. B. 324:369-392.

Keeling, C. 1989. *Overview of Scripps program to observe atmospheric carbon dioxide*. Scripps Institution of Oceanography preprint, 2 January, 1989.

Long, S.P. and Drake, B.G. In Press. The effect of long-term CO_2 fertilization in the field on the quantum yield of photosynthesis in the C3 sedge: Scirpus olneyi. *Plant Physiology*.

Shands, W.E. and Hoffman, J.S. 1987. *The Greenhouse Effect, Climate Change, and U.S. Forests*. The Conservation Foundation, 1250 Twenty-fourth Street, N.W., Washington D.C., 20037

Tans, P.R., Fung, I.Y., and Takahashi, T. 1990. Observational constraints on the global atmospheric carbon dioxide budget. *Science*.

Woodwell, G.M. Whittaker, R.H., Reiners, W.A., Likens, G.E., Delwiche, C.C., and D.T Botkin. 1978. The biota and the world carbon budget. *Science* 199:141-146.

Ziska, L., Drake, B.G. and S. Chamberlain. 1990. Long-term photosynthetic response in single leaves of a C3 and C4 salt marsh species grown in elevated atmospheric CO_2 in situ. *Oecologia* 83:469-472.

BUDGET

I. Site establishment	**$310,000**
30 Chambers at $2000 each	$60,000
CO_2 monitoring and control systems	$100,000
Data acquisition and management system	0
Capital construction and site preparation	$100,000
II. Annual Operating Costs	**$400,000**
A. Personnel	$210,000
1. Post doct. research associates (2 @35,000)	$70,000
2. Senior technicians (2 @40,000)	$80,000
3. Students (3 @20,000)	$60,000
B. Utilities	$80,000
1. Power	$15,000
2. CO_2	$75,000
C. Expendable supplies	$100,000
D. Travel	$10,000
III. Overhead (23% of direct costs)	**$530,000**
IV. Total costs for five years	**$2,830,000**

To Study the Hadley Zone as a Planetary Air Conditioner

Hugh W. Ellsaesser
Lawrence Livermore National Laboratory

PROPOSITION

It is proposed that in the Hadley Zone, or tropical band from roughly 30N to 30S latitude, the confinement of essentially all precipitation processes to deep convection with its compensating broadscale subsidence, means that any acceleration of the hydrological cycle will lead to a *negative* water vapor greenhouse feedback rather than *positive* feedback as presently predicted by most climate models.

The rationale for this proposition, is that any acceleration of the hydrological cycle not only accelerates the convective updrafts producing the precipitation but also accelerates the broadscale subsidence surrounding the convective updrafts. For the ITCZs and monsoons this means acceleration of the Hadley return flow downwelling over the subtropics of both hemispheres which is responsible for the broadscale aridity and deserts of the subtropics of today. For tropical cyclones and isolated thunderstorms of the tropics, it means acceleration of the broadscale subsidence known to surround these storms. In all cases it means an acceleration of the subsidence responsible for the confinement of trade cumulus to a vertically restricted moist layer capped by a temperature inversion and an abrupt drop in humidity.

The net result will be a thinner water vapor greenhouse blanket, permitting outgoing IR radiation to escape to space from a lower level and/or higher temperature than now, rather than a thicker one as predicted by current climate models.

OSAL

It it is proposed to document the above proposition and to draft parameterization schemes by which climate models can be constructed to more closely represent the physical effects resulting from convective processes within the tropics.

One of the principal unexpected results of the deep convection of the tropics is that the latent heat of condensation released in convective updrafts is not mixed with the surrounding atmosphere at the level at which condensation occurs. Rather this released heat merely supplies the buoyancy which keeps the updraft rising. The atmospheric heating that occurs as a result of deep convection, is the adiabatic warming which occurs as a result of the compensating subsidence which occurs over a broad area surrounding the convective updrafts. In the case of the ITCZs and monsoons, this subsidence and warming can occur far removed from the convective updrafts. In fact, the bulk of it occurs in the hemisphere opposite from that in which the convective updrafts occur.

)ACH

The initial step in this proposal will be a careful comparison of vertical profiles and fluxes of energy and moisture parameters from observational data and from various current climate models. This will be done over a latitude range extending from the ITCZ to the subtropical ridge.

It is anticipated that this will both confirm the proposition and provide information as to how convection parameterization needs to be modified for modeled convection to produce the same physical effects in the atmosphere as does actual convection.

CES

This is obviously an open ended project leading all the way from by a single investigator to construction and operational application of a full-scale three-dimensional GCM climate model. However, until the first step proposed above is successfully completed, launching of a larger project is unlikely to be possible in today's climate. Completion of the initial proposal is estimated to require approximately one calendar year of 50% of the time of the principal investigator, i.e., roughly $75,000 with overhead.

PHICAL SKETCH

Dr. Ellsaesser, an atmospheric scientist, retired from USAF Air Weather Service after 21 years as a weather officer and from the Lawrence Livermore National Laboratory after 24 years in climate research. He is continuing his studies at LLNL as a Participating Guest Scientist.

BASELINING THE ATMOSPHERIC STATE INCLUDING CLIMATE (BASIC)

Michael Garstang
University of Virginia

INTRODUCTION

The ongoing buildup in greenhouse gases has led to increasing speculation about their detrimental climatic and environmental impact. The more popular scenarios, which envision global warming and ecological disaster, descend from a deceptively simple positive feedback hypothesis: greater amounts of infrared-absorbing gases will increase atmospheric emissivity; therefore, globally averaged surface temperature will increase due to an increase in downward emitted longwave radiation originating at the earth's surface. However, the scientific debate over the global warming issue has definitely not ended. The global effects of negative cloud feedback upon surface temperature deserves far more attention (Lindzen, 1990).

Based upon observations from tropical field experiments of the past two decades (Massie, 1990; Chong and Hauser, 1990; Houze, 1982; Johnson and Young, 1983), new global cloud data (Warren, et at., 1988), and the historical temperature record (Karl, et at., 1988a, 1988b, 1989), we hypothesize that a greenhouse signal is appearing in global clouds trends and surface moisture rather than in global temperature trends. To test this hypothesis, we propose a strategy for measuring the effects of these trends on net radiation at two key action points in the tropics.

The planet has already gone half-way to an effective doubling of pre-industrial carbon dioxide, the most important greenhouse gas besides water vapor (Michaels, 1990). Yet, the historical temperature record, after corrections for the urban heat island effect and for long-term site bias, does not show any significant warming during this century (Karl, et al., 1988a, 1988b, 1989).

A recent General Circulation Model (GCM) experiment by Rind and Peteet (1989) attempted to simulate the Last Glacial Maximum corresponding to 116 to 106 kyr B. P. The results showed large discrepancies between the GCM response to Milankovitch orbital forcing and the geophysical evidence of ice sheet initiation. Specifically, the model failed to maintain snow cover through the summer locations of suspected initiation of the major ice sheets, despite the reduced summer and fall insolation. Moreover, when 10-m-thick ice was inserted in all locations where continental ice sheets existed during the Last Glacial Maximum, the model failed to maintain it as well, producing energy and mass imbalances which removed the ice within five years. Rind and Peteet concluded that there are three possibilities: (1) their GCM model is wrong, (2) the response is being misinterpreted, or (3) the forcing function is not properly specified. Is there warm bias in the current GCM's? Are the GCM's and the simple positive feedback hypothesis neglecting important negative feedback?

HYPOTHESIS AND OBJECTIVES

The main atmospheric response to greenhouse forcing may not be an increase in global surface temperature. The lack of an observed surface temperature trend implies that we should reject the simple positive feedback hypothesis and test alternative hypotheses which include both negative and positive feedback.

Oceanic cloud data for 1952 to 1981 (Warren et al., 1988) show global trends in amounts of cumulonimbus have increased at all latitudes, with a maximum increase in the Intertropical Convergence Zone (ITCZ). Additionally, the occurrence of completely clear sky has increased in the regions dominated by the Subtropical Anticyclones (STA's). These trends may reflect global change signals related to greenhouse forcing. What sort of feedback could explain these observed cloud trends and the absence of a surface warming trend?

Under clear sky conditions, increasing amounts of greenhouse gases will increase downward radiation emitted by the atmosphere. Therefore, a positive radiation-surface temperature signal should appear in large areas like the STA's, which are dominated by strong subsidence and tend to have few clouds. The increased downward longwave radiation due to greenhouse forcing should promote surface warming, higher sea surface temperatures, and more surface evaporation.

On their equatorward side, the STA's feed moisture to the ITCZ, the region of maximum thunderstorm activity on the planet. Results from ABLE-2B, GATE, MONEX, and COPT, show that tropical line disturbances, common in the ITCZ, exert negative feedback on surface temperature over large areas for periods of up to 12 hours (Fitzjarrald and Garstang, 1981). Large tropical thunderstorm complexes generate compensating mesoscale circulations in response to vertical eddy heat fluxes. These circulations warm and dry the middle and upper troposphere and cool and moisten the lower troposphere. The vertical eddy heat fluxes in tropical squall lines maintain the upper tropospheric geopotential gradient needed to drive the poleward directed upper limb of the Hadley Circulation.

In summary, the STA and ITCZ are important centers of action in the Hadley circulation. An ongoing increase in downward longwave radiation due to the buildup of greenhouse gases promotes surface warming and more evaporation in areas free of clouds. Trade winds on the equator side of the STA will thus carry more moisture into the ITCZ which should respond with an increase in thunderstorms. Observations show that low level drying and cooling in the wake of tropical squall lines exert negative feedback on surface temperature. At the global scale, this negative cloud feedback in the STA and could help explain the absence of a warming trend in the surface temperature record.

The objectives of the proposed study are thus to:

1. Seek differential response between two locations where a maximum but opposite signal is expected from any greenhouse warming of the atmosphere.
2. Identify the variables and/or parameters which are likely to contain the largest signal-to-noise ratio. It is postulated that this signal will be largest in such quantities as cloudiness, atmospheric moisture, and radiation heating and cooling.
3. Design an observing systems that can be established and maintained at the two key locations for a period as long as 10 years.
4. Archive and make available in real time the observations from the two BASIC stations to the community at large.
5. Carry out an analytical program on a continuous basis evaluating the signals of BASIC for evidence of climate response and change.

METHODS

The proposed work fall into five parts.

1. Identify BASIC Monitoring Sites.

Two basic monitoring sites are proposed. The strength of two sites is seen in terms of looking for predicted extremes in response. A large but opposite response to greenhouse loading in middle and high latitudes should be seen in the low level inflow to the Intertropical Convergence Zone (ITCZ) and upper level outflow and sinking in the Subtropical Anticyclones (STA). Differential response between the two locations in cloudiness, moisture, energy, and radiative quantities (net radiation) should be large. It is proposed that the first part of this study use GCM/climate models to:

(1) identify paired centers of action having an opposite response, and
(2) identify variables and/or calculated quantities which have a very high differential signal.

We will initially focus upon a location in one of the tropical centers of action (e.g. the Central Amazon Basin) and a location in one of the subtropical high pressure systems (e.g. the Cape Verde Islands).

2. Identify BASIC Observed Variables/Parameters.

In concert with 3.1 above we will test the expected response of variables and calculated quantities to greenhouse gas enhancement. We postulate that a crucial response is likely to be net radiation at the surface and in the upper troposphere. We will test this postulate and use the results to decide upon the variable to be measured and parameters to be calculated.

3. Instrumenting the BASIC Stations

Once locations and variables have been established in 1. and 2. above, we will design the instrument system to be employed. In principle, we expect to combine surface and surface based measurements with the satellite measurements. The objective would then be, for example, to produce at both locations, the best measurements of net radiation through the tropospheric column. To achieve this objective, we would design and produce net radiometers which are used in concert with rawind and profiler soundings from the ground. The final system designed would be capable of long term continuous measurements at each BASIC site.

4. Operation of the BASIC Stations.

We would undertake to establish the two BASIC stations and to operate these stations in cooperation with the local authorities. We would design the system to telemeter via satellite the observations in real time to a base station in the United States. We would set up procedures for ongoing quality control, archiving, and documentation. We would work in close cooperation with the National Center for Atmospheric Research (NCAR) and their efforts to develop equipment and sensors suited to our purposes.

5. Analysis.

We would mount an analytical program in part based upon the GCM/climate models to continually incorporate and evaluate the measurements and differential signal being obtained from the two BASIC stations. We would keep current with estimates of greenhouse gas chambers and find and explain lack of response in our measurements. We see BASIC as an absolute essential process if we are ever to establish links between the anthropogenic greenhouse gases and climate change.

ET

Stage I.	*Identify BASIC monitoring sites.* Year 1.	$150,000
Stage II.	*Identify BASIC variables.* Year 1.	$150,000
Stage III.	*Identify and acquire BASIC instrumentation systems.* Year 2-3.	$1,000,000
Stage IV.	*Operate BASIC stations and do analysis.* Year 4-10.	$2,450,000
	Total request over 10 years:	***$3,750,000***

:NCES

Chong, M. and D. Hauser, 1990: A tropical squall line observed during the COPT 81 experiment in West Africa. Part III. Heat and moisture budgets. *Mon. Wea. Rev.*, 118, 1696-1706.

Fitzjarrald, D. R. and M. Garstang, 1981: Boundary-layer growth over the tropical ocean. *Mon. Wea. Rev.*, 109, 1762-1772.

Houze, R. A., Jr., 1982: Cloud clusters and large-scale vertical motions in the tropics. *J. Meteor Soc. Japan*, 60, 396-410.

Johnson, R. H. and G. S. Young, 1983: Heat and moisture budgets of tropical mesoscale anvil clouds. *J. Atmos. Sci.*, 40, 2138-2147.

Karl, T. R., R. G. Baldwin, and M. G. Burgin, 1988a: *Time series of regional seasonal averages on maximum, minimum, and average temperature, and diurnal temperature range across the United States:* 1901-1984, 107 pp (Available from the National Climatic Data Center, Federal Building, Asheville, NC 28801).

Karl, T. R., H. F. Diaz, and G. Kukla, 1988b: Urbanization: Its detection and effects in the United States climate record. *J. Clim.*, 1, 1099-1123.

Karl, T. R., J. D. Trapley, R. G. Quayle, H. F. Diaz, D. A. Robinson, and R. S. Bradley, 1989: The recent climate record: what it can and cannot tell us. *Rev. Geophys.*, 27, 405-430.

Lindzen, R. S. 1990: Some coolness concerning global warming. *Bull. Amer. Meteor Soc.*, 71, 288-299.

Massie, H. L., Jr., 1990: Energy budget in tropical line disturbances during the 1987 Amazon wet season. Ph.D. dissertation, University of Virginia, under preparation.

Michaels, P. J. 1990: Greenhouse disaster? Submitted to *Science*.

Rind, D. and D. Peteet, 1989: Can Milankovitch orbital variations initiate growth of ice sheets in a general circulation model? *J. Geophys. Res.*, 94, 12.851-1287.

Warren, S. G., C. J. Hahn, J. London, R. M. Chervin, and R. L. Jenne, 1988: *Global Distribution of Total Cloud Cover and Cloud Type Amounts over the Ocean*. U.S. Dept. of Energy Publication DOE/ER - 0406, 42 pp + Maps.

Data Management to Reduce Uncertainties of Greenhouse Effect Prognostications and to Validate Climate Change Models

Nathaniel B. Guttman
National Climatic Data Center

Research designed to reduce the uncertainties of greenhouse effect prognostications as well as comparisons designed to validate climatic change models require data. These data, to be useful, must be archived, available, and accessible. Additionally, corollary information about how the data were collected, processed and stored must also be archived, available and accessible to avoid misuse of aggregations and summarizations of the data.

Although the detection and quantification of climate change on a global scale is a worthwhile scientific endeavor, policy is often set based on regional impacts of climate on economic considerations. Examples of economic considerations are agricultural production (plants and animals), maintenance of adequate water supplies, coastline development, and energy usage.

The proposed data management activity will aid researchers working on both global and regional climate change problems. The objective of the proposal is to compile and manage an accessible data base that is suitable for: 1) describing observed patterns in climate-sensitive regions such as the tropics and high altitude deserts, 2) using as a baseline for model and scenario tests and comparisons, and 3) furthering the understanding of currently poorly explained processes such as deep convection energy transport. The proposal consists of four parts geared to data requirements that are necessary for meeting the objective.

Data Base Development

Meteorological variables that will meet the objective are static quantities such as temperature and precipitation, and dynamic quantities such as momentum and energy fluxes. Satellite and in situ measured and derived quantities for both surface and upper air are candidates for inclusion in the data base. GCM model output data are also desirable for inclusion. The variables as well as locations of climate-sensitive regions will be determined in concert with the research community.

Recognizing that many data bases currently exist, especially of static surface variables, it is important to justify the need for development of a new data base. The proposed data base will consolidate and integrate existing data bases into one source; contain data for the *specific* purpose of describing patterns in climate-sensitive regions, testing models and scenarios, and furthering the understanding of dynamic processes; and allow for future inclusion of variables that are not presently available, such as high altitude specific humidity.

This first part of the proposal consists not only of selecting the variables and locations for inclusion in the data base, but also the building of the management framework for the data base. This latter effort involves the development of formats, file structures, integration with existing data bases, and inventories of data completeness.

UMENTATION OF DATA HISTORY

Identification of non-climatic changes in data observing, processing and storing is critical to properly aggregating and summarizing data. The second part of the proposal, determining the history of the data, is a labor intensive effort of searching for information from various sources, and compiling a comprehensive documentary.

Observing information will be compiled about site characteristics and changes; instrument type, calibration, maintenance, and response characteristics; and changes in observing methods and codes. Data processing information will include quality assurance procedures, data transfer/manipulation activities, and data adjustment techniques.

YSIS OF DATA PROBLEMS

Assessing the importance of the changes indicated in the data history is the third part of the proposal. Climate is generally described by measures of central tendency and variability. The impacts of the documented non-climatic changes on means and/or medians and on variances of data series will be statistically evaluated.

Some work has been accomplished on the effects of non-climatic changes. An example is the time of observation bias in maximum and minimum temperature records. Much more work, however, remains to be accomplished on, for example, the effects of disparate sensor responses, instrument maintenance schedules, data quality control procedures, and assumptions upon which derived data are based. Climatic homogeneity of combined data series as well as rationales for adjusting data depend on assumptions of randomness and/or systematic biases of non-climatic effects. Statistical analysis of these errors will be performed.

ACCESSIBILITY

To be useful, the compiled data and information about the data must be easily accessible. The last part of the proposal is the design and building of a proposal is the design and building of a personal computer workstation network. Efficiency and user friendliness of possible system configurations will be investigated. One possible design is a central station that would hold all the data, process all applications, and then transmit requested information to slave stations. Another possible design is a central data station with applications processed individually at surrounding stations after transmittal of the data.

Applications consist of geographic information system (raster and vector) and statistical software. Many software packages are commercially available. The design of the network will be based on integrating hardware and software so that researchers accessing the data will be able to efficiently perform spatial and temporal statistical analyses as well as display results both pictorially and topographically.

BUDGET

Part	*Cost*
Data Base Development	$500,000
2 Senior Systems Analyst-years	250,000
2 Senior Climatologist-years	250,000
Documentation of Data History	350,000
5 Climatologist clerk-years	250,000
1 Climatologist	100,000
Analysis of Data Problems	650,000
5 Senior Climatologist/Statistician-years	650,000
User Accessibility	500,000
Hardware/software purchase	100,000
2.5 Senior Systems Analyst-years	330,000
0.5 Senior Climatologist-years	70,000
Total	$2,000,000

STORMS, WAVES AND CLIMATE CHANGE IN A WARMING WORLD - A RESEARCH PROPOSAL

Bruce Hayden
University of Virginia

To date, evaluations of and the debate about the $2xCO_2$ General Circulation Model (GCM) global climate output statistics have been largely restricted aggregate global surface temperatures and global patterns of surface temperatures. Temperature is but one of dozens of estimates of climate attributes that are estimated in GCM experiments. Given that the effective trace gas (CO_2 plus others radiatively active gases) changes since 1850 amounts to going half way to a CO_2 doubling, we should already have experienced measurable changes in the general circulation of the atmosphere. Changes in the frequency and geography of surface cyclones and anticyclones and changes in the latitude and intensity of the jet stream aloft should already have taken place.

The proposed work will evaluate the historical changes that have taken place in the 1) climatology of surface cyclones and anticyclones of the Northern Hemisphere, 2) climatology of the jet stream, and 3) northward transport of eddy kinetic energy and compare them to the changes indicated by $2xCO_2$ GCM climate simulations.

STORM FREQUENCY, MAGNITUDE AND TRACK

Over the North American sector there have been large changes in the frequency of cyclones (Hayden 1975, 1981: Hayden and Smith 1982; Reitan 1974 & 1979; and Ziska and Smith 1980). Along the Atlantic Coast of North America the frequency of storms since 1885 have been of the same order as the seasonal frequency cycle. In general, storm frequency has historically increased during warming from 1900 to 1940 and has declined in the subsequent cooling. This is counter to the expectations from $2xCO_2$ GCM simulations. In addition, the track of cyclones over eastern North America has shifted south and eastward during this century. This also is counter to trace gas warming indications. Doubled atmospheric carbon dioxide GCM experiments project a northward displacement of locus of maximum eddy kinetic energy released by storms and a reduction in the amount of kinetic energy released. This would indicate a northward contraction of the polar vortex and with it the main storm tracks. The climate models also project warmer tropics and much warmer polar regions (Hansen 1981a, 1981b, 1989). A reduced temperature gradient would indicate a weakened and more northerly jet stream (Hayden 1977). Data exist to expand these studies of cyclone frequency to the rest of the Northern Hemisphere.

'SIS OF THE SUBTROPICAL ANTICYCLONES

The GCM 2xCO_2 experiments indicate that the subtropical anticyclones and the attendant Hadley circulations displaced northward in a trace gas warmed world (Mitchell, 1983 Manabe 1980). These anticyclones over the northern hemisphere oceans undergo a seasonal excursion of about 5 degree latitude during the last third of June (Bryson, 1958). While the record of the position and size of the subtropical anticyclones exist in synoptic map form and in electronic files from 1899 to the present, these data resources have not been studied to determine the secular variations over the past 90 years. From these existing records we can test the notion that greenhouse warming has begun by asking the question, "Has the mean latitude position of the subtropical anticyclones shifted northward during the period of trace gas increase?" From these records of the subtropical anticyclones, the GCM results can be compared to the historical record and evaluated. We propose to do this work for the subtropical anticyclones over the North Pacific and over the North Atlantic oceans.

'SIS OF THE SUBPOLAR ANTICYCLONES

Much of the warming indicated in 2xCO_2 GCM simulations is found in the Arctic and sub-Arctic. Mitchell (1983) indicates that the "polar cell" element of circumpolar circulations should be displaced northward in a trace gas warmed world. While Trenberth (1990) has studied the subpolar anticyclones over historical times and compared them to GCM results and found no correspondence, similar work on the subpolar anticyclones remains to be done. GCM simulations also indicate that winter season anticyclones over central Asia and over the north American arctic and subarctic are diminished in intensity while the cyclones are increased in intensity and the temperatures of the air masses produced in the anticyclones are said to more moderate in temperatures as a result of greenhouse warming (Kalkstein 1990). Pressure field records and surface synoptic charts are available from 1899 and the secular history of these major features of the general circulation of the atmosphere have not been studied to date.

ꞦCH SCHEDULE

Many of the records required to complete the proposed work exist in paper copy, synoptic weather chart form. The extraction of the needed data from 90 years of charts (32,850 maps) is a manpower intensive activity. Much of the first year's work will involve data extraction from maps and charts. In addition, existing electronic files of daily surface pressure data for the Northern Hemisphere will be used. However, care must be used with this data as the data extraction procedure for the period 1899-1940 is different from the period 1940-1990. Maximum and minimum pressure values for half of the Northern Hemisphere data points have small errors for the period before 1940. Multivariate analyses of the data fields will begin in the second year. Two years of analytical work will be required to complete the proposed work.

REFERENCES

Bryson, R.A. and Lahey, J.F. 1958. *The march of seasons*. Final Report, Dept. of Meteorology, U. of Wisconsin, 41pp.

Hansen, J., Johnson, D., Lacis, A., Lebedeff, S., Lee, P., Rind, D., and Russell, G. 1981. Climate impact of increasing atmospheric carbon dioxide. *Science*, 213(4511):957-966.

Hansen, J. and Lacis, A.A. 1989. Sun and dust versus greenhouse gases: an assessment of their relative roles in global climate change. *Nature* 346:713-719.

Hayden, B.P. 1975. Storm wave climates at Cape Hatteras, North Carolina: recent secular variations. Science, 190:981-983.

Hayden, B.P. and Dolan, R. 1977. Seasonal changes in the planetary wind system and their relationship to the most severe coastal storms. *Geoscience and Man* XVIII:113-119.

Hayden, B.P. 1981. Secular variation in Atlantic coast extratropical cyclones. *Monthly Weather Review*, 109(1):159-167.

Hayden, B.P. and Smith, W. 1982. Season-to-season cyclone frequency prediction. *Monthly Weather Review*, 110(4):239-253.

Manabe, S., and Wetherald, R.T. 1980. On the distribution of climate change resulting from an increase in the co2 content of the atmosphere. *J. Atmos. Sci.*, 337:99-118.

Mitchell, J.F.B. 1983. The seasonal response of a general circulation model to changes in co2 and sea temperatures. *Quart. J. R. Met. Soc.*, 109:113-152.

Reitan, C.H. 1974. Frequencies of cyclones and cyclogenesis for North America, 1951-1970. *Monthly Weather Review*, 102(12):861-868.

Reitan, C.H. 1979. Trends in the frequencies of cyclone activity over North America. *Monthly Weather Review*, 107(12):1684-1688.

Tren berth, K.E. 1990. Recent observed interdecadal climate changes in the Norhtern Hemisphere. *Bul. Am. Met. Soc.*, 71:988-993.

Washington, W.M. and Meehl, G.A. 1989. Climate sensitivity due to increased CO_2: experiments with a coupled atmosphere and ocean general circulation model. *Climate Dynamics*, 1:1-38.

Zishka, K.M. and Smith, P.J. 1980. The climatology of cyclones and anticyclones over North America and surrounding ocean environs for January and July, 1950-1977. *Monthly Weather Review*, 108(4):387-401.

ARCH BUDGET*

	1991-92	1992-93	1993-94	Total
P.I. Summer Salary	23000	24000	25000	72000
2 Doctoral Students	25000	25000	25000	75000
Student assistants	4000	3000	3000	10000
Services	3000	3000	3000	9000
Equipment	20000	0	0	20000
Publication Costs	2000	3000	5000	10000
Travel	3000	4000	4000	11000
Subtotals	80000	62000	65000	227000
Overhead	48000	37200	39000	124200
Total Costs	*128000*	*99200*	*104000*	*351200*

**This budget is a draft budget and not an official budget of the University of Virginia*

ATMOSPHERIC CO_2 SEQUESTERING BY TREES: A LONG-TERM FIELD EXPERIMENT

Sherwood Idso
Agricultural Research Service, U.S. Department of Agriculture

ROUND

Earth's atmospheric CO_2 concentration has been rising steadily since the inception of the Industrial Revolution, due primarily, it is believed, to mankind's increasing numbers and their expanding usage of energy derived from coal, gas and oil. A major concern arising out of this phenomenon is the possibility of CO_2-induced greenhouse warming; while a major benefit could be a significant stimulation of the biosphere due to the aerial fertilization effect of atmospheric CO_2 enrichment (Idso, 1989).

Linking these two phenomena is the possibility that the latter effect may mitigate the former by removing CO_2 from the air at a rate that increases with atmospheric CO_2 concentration, such that the air's CO_2 content may ultimately be stabilized at a level that would not be too climatically disruptive. Hence, it is of paramount importance to obtain reliable information on the long-term response of trees to atmospheric CO_2 enrichment, as they represent the terrestrial biosphere's primary means of sequestering carbon (Sedjo, 1989).

In almost all tree experiments conducted to date, however, there have been a number of serious deficiencies. In the words of Jarvis (1989), "the experiments (have) virtually all(been) short term (less than twelve months) on very young trees that are often pot-bound, with growth restricted by the lack of active sinks in nutrient-deficient condition." Hence, as he continues, "there is considerable need for long-term experiments in which growth is not artificially restricted."

We are conducting one such experiment at Phoenix, Arizona. Since November of 1987, we have been continuously enriching two clear-plastic-wall open-top chambers enclosing four sour orange (*Citrus aurantium*) trees planted directly into the ground as small seedlings with an extra 300 parts per million (ppm) of CO_2, while four similar-aged trees have been grown in non-CO_2-enriched chambers. We have periodically assessed the growth rates of the trees via a number of different measures—trunk cross-sectional areas, leaf numbers, trunk and branch volumes, root density distributions, fruit numbers, leaf net photosynthesis and starch production rates—and in every category investigated, we have found the CO_2-enriched trees to be between two and three times as productive as the ambient-treatment trees (Idso and Kimball, 1991; Idso et al., 1991a,b).

The significance of this finding is illuminated by the study of Marland (1988), who concluded that a doubling of the mean annual volume increment of the world's existing closed forests would be sufficient to remove CO_2 from the atmosphere at a rate roughly equivalent to current fossil-fuel burning releases. Clearly, if the world's other tree species react to CO_2 enrichment as sour orange trees do, such a state of biospheric vigor will be achieved sometime in the coming century. And as Marland has further noted, maintaining such conditions for only 18-26 years would "return to the biosphere all of the carbon that has been released over the last 100 to 200 years." Hence, the problem of earth's rapidly rising atmospheric CO_2 concentration may hold within it the seeds of its own solution, if other trees behave similarly to the orange trees we have studied and if the tremendous CO_2-induced growth enhancement we have documented continues to be maintained over the life of the trees and is not reduced by environmental stresses related to rising temperatures, drought, and nutrient deficiencies.

EXPERIMENT

We propose to shed more light on the above issues by conducting a new long-term experiment on a different, but as yet unspecified, tree species at the Maricopa Agricultural Center (MAC) located 30 miles south of Phoenix. This facility is operated by the University of Arizona and has been suggested as a future site of the U.S. Water Conservation Laboratory and the Western Cotton Research Laboratory by the USDA's Agriculutural Research Service, which is determined to develop MAC into a world-class agricultural research center.

Whereas our on-going experiment is looking at CO_2 enrichment effects under conditions of adequate water and nutrients and current climate characteristics, the proposed experiment will add water, nutrients, and temperature as additional variables. Hence, where we are currently studying 8 trees (4 ambient and 4 CO_2-enriched), we will need to study 64 trees in the new experiment to adequately determine the effects of these other stresses (67% of adequate water, no addition of nutrients, and temperatures 3°C above ambient). The water treatments will be imposed by differential irrigation, the nutrient treatments by differential applications of fertilizers, and the temperature treatment by installing heaters in the air supply systems that service the chambers.

Each chamber will enclose a 5m x 5m area and have a variable height that will increase with tree growth. Initially, 5 trees will be planted in each chamber: a primary tree in the center and 4 secondary trees in each corner. The secondary trees will be destructively harvested at six-month intervals, following the start of CO_2 enrichment on either 1 April or 1 October. This will allow us to calibrate trunk cross-sectional areas with total biomass, so that subsequent biomass development can be estimated from the readily measured trunk diameter. It will also allow us to clearly define the effects of CO_2 enrichment throughout the cool and warm parts of the year and add to the richness of the temperature aspect of the study. Other measurements will be basically identical to those of our current experiment.

No new scientific staff is required for this experiment. However, there will probably be many cooperators. In the case of the free-air carbon dioxide enrichment study of cotton that is currently being conducted at MAC, for example, there are over two dozen cooperating scientists from four different USDA locations and five other institutions participating in the research. Our new study would probably attract even more collaborators. Each of them would cover their own costs, however, thereby greatly increasing the scientific return on each of the research dollars herein requested.

ERENCES

Idso, S.B. 1989. *Carbon Dioxide and Global Change: Earth in Transition*. IBR Press, Tempe, AZ. 292 p.

Idso, S.B. and B.A. Kimball. 1991. Effects of two and a half years of atmospheric CO_2 enrichment on the root density distribution of three-year-old sour orange trees. *Agric. For. Meteorol.*, in press.

Idso, S.B., B.A. Kimball, and S.G. Allen. 1991a. CO_2 enrichment of sour orange trees: two-and-a-half years into a long-term experiment. *Plant Cell Environ.*, in press.

Idso, S.B., B.A. Kimball, and S.G. Allen. 1991b. Net photosynthesis of sour orange trees maintained in atmospheres of ambient and elevated CO_2 concentration. *Agric. For. Meteorol.*, in press.

Jarvis, P.G. 1989. Atmospheric carbon dioxide and forests. *Phil. Trans. Roy. Soc. Lond.* 324B:369-392.

Marland, G. 1988. *The Prospect of Solving the CO_2 Problem through Global Reforestation*. U.S. Dept. Energy, Washington, DC. 66 p.

Sedjo, R.A. 1989. Forests to offset the greenhouse effect. *J. Forestry* 87(7):12-15.

ET

I. Initial Costs

Utilities	10,000
Trailer	30,000
CO_2 Analyzers	18,000
Valves, Flow Meters, Pumps, Chamber materials, Blowers	64,000
CO_2 Installation	20,000
Labor	200,000
Miscellaneous	50,000
Total	***$392,000***

II. Annual Operating Costs

Land	8,000
Laboratory	14,000
CO_2	560,000
Electricity for blowers	96,000
Heating	272,000
Labor to maintain enrichment apparatus	60,000
Supplies and maintenance	100,000
Total	***$1,110,000***

III. Technicians to collect plant response data

Ten at $25,000 per year	250,000

IV. Summary

Initial Costs	$392,000
5 years at $1,360,000 per year	$6,800,000
5-year total cost	$7,192,000

Personnel:
Sherwood B. Idso
Bruce A. Kimball

Institution:
U.S. Water Conservation Laboratory
4331 E. Broadway Road, Phoenix, AZ 85040
(602) 379-4356

IMPACT OF INDUSTRIAL AEROSOLS ON THE SURFACE RADIATION BUDGET

George Kukla
Lamont-Doherty Geological Observatory of Columbia University

David A. Robinson
Rutgers, The State University of New Jersey

Andrew A. Lacis
Goddard Institute for Space Studies

William Rossow
Goddard Institute for Space Studies

It is generally accepted that clouds are among the most influential variables in th climate system, despite remaining one of its least understood components. Spatia and temporal variations in cloud distribution and composition play a major role i global climate change. Because of limited knowledge on cloud behavior, differin parameterizations of cloud related feedbacks in general circulation models (GCM lead to major differences in the simulation of regional and global climate changes (e.g Gates, 1988; Schlesinger, 1985; Coakley et al., 1983; Gutowski et al., 1988). Al cloud-related processes remain in urgent need of further investigation and thei representation in GCMs needs substantial improvement.

It is known that the optical properties of clouds, as well as of the clear atmosphere, ar to a large degree modified by tropospheric aerosols. Over large areas of the Norther Hemisphere these aerosols are of man-made origin and significantly influence th radiative environment (Twomey, 1977). Industrial aerosols in the lower troposphe have a large areal extent, not only over land (Husar and Paterson, 1980; Alkezween and Busness, 1984), but also over parts of the ocean (Coakley et al., 1987). Although their largest concentration is in the lowest 3 kilometers of the atmosphere, where they are regularly washed out by rain (Henmi and Reiter, 1978), a sizeable-fraction reaches the tropopause (Lyons, 1980) and is transported to the Arctic, where they concentrate as Arctic haze (Chung, 1978; Rahn et al., 1977). The most effective way in which industrial aerosols may influence climate is in the form of cloud concentration nuclei. This results in increases in cloud optical thickness and albedo (Twomey et al., 1984). Aerosol impacts on surface temperature may vary in intensity and sign, although most evidence points toward cooling. Impacts vary as a function of the composition and size of the particles, atmospheric humidity, physical properties of the clouds, the radiative characteristics of the underlying surface and the height of any inversions (Bolin and Charlson, 1976).

There are strong indications that sulphate-based industrial aerosols are concentrated in areas of high SO_2 emissions (Environmental Research and Technology, 1983; Winchester, 1980) and that these are warming at a slower rate than the rest of the hemisphere (Cess, unpublished; Karl, et al., unpublished). Global SO_2 emissions have doubled every 20 years since the 1940's, a trend which is expected to continue (Hameed and Dignon, 1988; Dignon and Hameed, 1989).

Observational studies are needed ultimately understand aerosol interactions with clouds and with surface radiation fields, and to assess their combined impact on climate ant their potential role in global change. Satellite, aircraft, and surface observations will have to be linked to assess the impact on a global scale.

The DOE-sponsored study of Gutowski et al. (1988) found that large variations and deficiencies exist in parameterization of the meteorological physics of regional surface energy fluxes. These variations are strongly expressed in the presence of clouds. None of the models compared in the 1987 study took time-related variations of tropospheric aerosols into account. Had they done so, even large deferences in model simulations would likely have resulted.

It is clear that a reliable projection of future climate must take into account the potential mitigating influence of industrial aerosols on greenhouse warming. This will first require learning more about the impact industrial aerosols have on the surface radiation budget, defining the spatial coverage of industrial aerosols using ground and satellite data, and modelling the impact of industrial aerosols on global climate using GCMs, with input parameterized using field data.

We propose to address each of the tasks defined above in a cooperative effort amongst scientists at Lamont (L-DGO), Rutgers University (RU) and the Goddard Institute for Space Studies (GISS).

Local and regional field programs will take place in the New York Metropolitan area, utilizing solar and terrestrial data which has been gathered at Palisades, NY for the past 4 years and which will continue to be collected. In addition, during the project the video imagery of sky conditions will be made and measurements taken of SO_2 and other atmospheric constituents from Palisades and numerous other metropolitan sites (Fig. 1).

The metropolitan area, and Palisades in particular, is ideally suited for the project, being situated in a region subject to air masses varying from moist marine to dry arctic, and from pristine windy to highly-polluted stagnant. Each air mass has a unique aerosol signature which influences clouds and the surface radiative environment. The network will enable: (1) expansion of local radiation results to the size of a typical GCM grid, (2) incorporation of the regionally-representative measured parameters in a GCM, (3) comparison with information obtained from the relatively unpolluted ARM site, and other unpolluted locals, (4) comparison of the collected information with satellite measurements, and (5) assessments of the long-term radiative impact of the pollutants.

The satellite investigation will include validating the International Satellite Cloud Climatology Program (ISCCP) sky condition and surface radiation algorithyms for clear sky under a variety of aerosol loadings. This is an initial step in the eventual quantification of the global distribution of industrial aerosols using satellite data. Ground truth from the New York Metropolitan field work and satellite data from the ISCCP global archive at GISS will be employed in the validation effort. The climatic impact of industrial aerosols will be tested using the GISS GCM. Results of aerosol impacts on the surface radiation budget from the field program will be employed in model parameterization.

OBJECTIVES

1) Characterize the surface radiative environment with clear and cloudy skies over an industrialized region under a variety of aerosol loadings.

2) Validate the ISCCP sky condition and surface radiation algorithyms for clear skies under a variety of aerosol loadings.

3) Assess industrial aerosol impacts on global climate using the GISS GCM.

FIELD MEASUREMENTS

a) L-DGO Radiation Station

Downwelling shortwave (SW) and longwave (LW) irradiances have been continuously measured at Palisades, NY since 1987 as a part of the cirrus-oriented extended time observations in the First ISCCP Regional Experiment. This includes observations of hemispheric, spectral and diffuse broad band fluxes in the SW, visible (VIS) and near infrared (NIR) and hemispheric irradiance in the LW. Temperature, humidity, and wind data were simultaneously collected at an automated weather station. Upfacing radiometers at Palisades are mounted on a rooftop approximately 120 m above sea level and 15 m above the ground. The site is not shaded by topography and only a few groves of trees within 5° of the horizon obscure a full hemispheric view of the sky. More detail on the Palisades program is provided in Robinson et al. (1988 and 1989). The data analysis was in part done at Rutgers University.

A comparison of the surface radiative environment at Palisades in the presence of cirrus and clear skies showed cirrus to have a larger impact on the surface radiative environment in winter than in summer. The presence of cirrus clouds in both seasons resulted in a decrease in atmospheric transmissivity of approximately 0.03 compared with clear skies. This reduction was noted at solar zenith angles less than 80°. Midday transmissivities under cirrus and clear skies were almost identical in winter and summer, despite a 30° difference in zenith angle. Cirrus transmissivities were about 0.06 higher in winter than in summer at similar zenith angles (Fig. 2). The seasonal differences are primarily a result of variations in the tropospheric aerosols, ozone and water vapor. Downwelling longwave irradiances were about 30 W/m^2 higher for winter cirrus episodes and 15 W/m^2 higher in summer cases compared with clear-sky episodes. Cited results are based on one year of data and only for cases where horizontal visibility at the surface exceeded 16 km. The frequent cases where visibility was less than 16 km while skies remained clear have yet to be studied in detail. Preliminary results indicate large differences in the clear-sky radiative environment correlating with visibility and varying concentrations of tropospheric aerosols.

b) New York and New Jersey air pollution monitoring networks.

The New York State Department of Environment Protection Division of Environmental Quality (NJDEP, 1989) maintain dense networks which monitor air quality in the greater NY metropolitan area. Corresponding state offices have been contacted, and are willing to make network data available for the proposed project.

The sampling network in the metropolitan is shown in Figure 1. A few of the stations are equipped with broad band radiometers. The network is sufficiently dense to enable the computation of regional averages of the pollutants which in turn can be compared with the radiation time series from Palisades and additional radiation monitoring stations in the area.

The New Jersey program involves: 1) continuous air monitoring, 2) particulate sampling, and 3) precipitation sampling. The Continuous Air Monitoring network consists of 26 automated remote stations which transmit data around-the-clock to a centralized computer facility in Trenton. The computer interrogates the field monitors once each minute to retrieve the data. Pollutants monitored by this network include: sulfur dioxide, carbon monoxide, ozone, nitrogen oxides, smoke shade, and meteorological parameters such as wind speed/direction, temperature, relative humidity, solar radiation, and barometric pressure.

The Particulate Sampling Network consists of 32 remote sites. Each sampler collects a 24-hour sample at least once every six days. A total of 28 samplers were operated in 1988 for total suspended particulates, 23 samplers for inhalable particulates, and 2 dichotomous samplers to divide the inhalable particulates into fine and coarse fractions. Subsequent laboratory analyses include determinations of concentrations of lead, other trace metals, benzo(a)pyrene, sulfates, nitrates and extractable organic matter.

The Precipitation Sampling Network has three sites. Rain water samples are retrieved either on a weekly basis or after each storm event. Laboratory analyses provide information on the observed pH and conductivity along with the concentrations of sulfate, nitrate, chloride, calcium, magnesium, potassium, sodium and ammonium ions.

The New York State monitoring system is similar. Sulfur dioxide and sulfates are measured at 26 locations throughout the state. Particulates are sampled in six day intervals.

WORK PLAN

The proposed work plan is summarized in Figure 2 and discussed below.

A) Irradiance data will continue to be gathered at Palisades. Earlier activities associated with FIRE have resulted in the implementation of first-rate, well-calibrated radiation observation procedures and the development of software to standardize and reduce the raw data and calculate radiance-derived variables. Inter-calibrated observational data and derived products can thus become available for analysis and dissemination to other ARM participants within a relatively short time after collection.

The following irradiances will be observed:

1) full hemispheric downwelling SW (0.28-2.80 μm)
2) diffuse downwelling SW
3) full hemispheric downwelling near-infrared (NIR) (0.70-2.80 μm)
4) diffuse downwelling NIR
5) hemispheric downwelling LW (4.0-50.0 μm)
6) hemispheric upwelling LW
7) hemispheric SW

Measurements will be made using Epply Precision Spectral Pyranometers (measuring SW) and Epply Pyrgeomters (measuring LW). A Campbell CR-21 digital recorder will record data as one minute averages of ten second samples. These data subsequently will be transferred to cassette tape and later dumped to 45Mb removal disks or 9-track tape using a Campbell C-20 cassette interface. Analyses will be performed on Macintosh SE and II computers. The radiometers will be periodically calibrated at the Eppley Laboratory and with other ARM instruments.

A number of variables will be derived from the measured irradiances including: (1) visible irradiance, (2) visible diffuse irradiance, (3) atmospheric transmissivity, (4) optical depth in the SW, (5) surface albedo over representative surfaces, and (6) net radiation over representative surfaces. The latter two will require an expansion of the rooftop measurements to locations across the metropolitan area under a variety of atmospheric conditions.

B) Videotapes of sky hemisphere will be taken at selected intervals including the times of NOAA polar orbiter, Landsat and Spot overpasses. These will provide detailed documentation of clear skies, cloud type and percent cloud cover. We will use the system developed and pilot tested by Whitlock and Purgold (1989). The videotapes will be processed at the Rutgers remote sensing center using analytical techniques developed in the FIRE Project (Fig. 4).

In addition, horizontal visibility will be measured by taking photographs from the rooftop station. Visibility will be calculated by measuring the contrast between targets lying along a line from the station to hilltops over 20 km distant using computerized image processing techniques.

C) Sulphur dioxide concentrations in the lower troposphere will be continually measured at the Palisades station using a pulsed florescent analyser. This instrument is similar to those used by the NJ Department of Environmental Protection.
We also consider the acquisition of the Brown Automated Spectrophotometer, which measures the total concentration of SO_x and NO_x in the atmospheric column.

Industrial Aerosol Impacts on Global Climate: GCM studies

To address the potential impact industrial aerosols may be having or may in the future have on global and regional climate, three full-scale runs of the GISS GCM are planned. A critical component to all runs will be the improved parameterization of aerosol impacts on the surface radiative environment, provided it results from the NY

Metropolitan field studies. Model runs will include:

1) A clean air version (0 x SO_2), which will assume a zero loading of industrial tropospheric aerosols over the globe.

2) A realistic current tropospheric aerosol loading version (1 x SO_2, 1 x CO_2). Here, the concentration of tropospheric aerosols will be a function of the mean SO_2 per unit area loading derived from the compilation of Hameed and Dignon (1988).

3) A large-range model (8 x SO_2, 2 x CO_2) which will assess the expected climate impact of industrial aerosols by the middle of the 21st century. This is based on the assumption that SO_2 emissions will continue to double every 20 years, as they have since World War II, and the CO_2 will double by 2050.

NCES

Alkezweeney, A.J., and K.M. Busness, 1984. Observation of aerosol chemical composition and acidity in northwest and southeast regions of the United States. The Science of the Total Environment. 39: 125-133.

Bolin, B, and R. J. Charlson, 1976. On the role of the tropospheric sulfur cycle in the shortwave radiative climate of the earth. Ambio. 5: 47-54.

Chung, Y.S., 1978. The distribution of atmospheric sulfates in Canada and its relationship to long-range transport of air pollutants. Atmospheric Environment 12: 1471-1480.

Coakley, J.A., Cess, R.D., and F. B. Yurevich, 1983: The effect of tropospheric aerosols on the earth 's radiation budget: A parameterization for climate models. J. Atmospheric Sciences 40: 116-138.

Coakley, J.A., R. L. Bernstein, and P.A. Durkee, 1987. Effect of ship-stack effluents on cloud reflectivity. Science 237: 1020-1022.

Dignon, J., and S. Hameed, 1989. Global emissions of nitrogen and sulfur oxides from 1860 to 1980. APCA Journal 39: 180-186.

Environmental Research and Technology, 1983. Volumes 2 and 3. The Sulfate Regional Experiment: Report of Findings.

Gates, W.L., 1988. Status of global model simulation of climatic effects of increased atmospheric carbon dioxide. Report of the Fourth Session of the CAS/JSC Working Group on Numerical Experimentation, WMO/TD No. 278, Appendix B, 7pp.

Gutowski, W.J., D.S. Gutzler, D. Portman, and W.C. Wang, 1988. Surface Energy Balance of the Three General Circulation Models: Current Climate and Response to Increasing Atmospheric CO2. Technical Report DOE/ER/60422-H1, U.S. Dept. of Energy, Washington DC.

Hameed. S., and J. Dignon, 1988. Changes in the geographical distribution of global emissions of NO_x and SO_x from fossil fuel combustion between 1966 and 1980. Atmos. Environ. 22: 441.

Henmi, T., and E.R. Reiter, 1978. Regional residence time of sulfur dioxide over the eastern United States. Atmos. Environ. 12: 1489-1495.

Lyons, W.A., 1980. Evidence of transport of hazy air masses from satellite imagery. Annals New York Academy of Sciences, 400-417.

New Jersey Department of Environmental Protection, 1989. 1988 Air Quality Report.

New York State Department of Environmental Conservation, 1989. New York State Air Quality Report Ambient Air Monitoring System. DAR-89-1. 199pp.

Rahn, K.A., R. D. Borys, and G.E. Shaw, 1977. The Asian source of Arctic haze bands. Nature 268: 713-715.

Robinson, D.A., G. Kukla, and A. Frei, 1988. FIRE extended time/limited area observations at Palisades, New York. Proceedings of the FIRE Science Team Workshop, Vail CO, 367-372.

______, 1989. Impact of cirrus on the surface radiative environment at the FIRE ETLA Palisades, NY site. Proceedings of the FIRE Science Team Workshop, Monterey, CA.

Schlesinger, W.H., 1985. The formation of caliche in soils of the Mojave Desert, California. Geochim et Comoch. Acta, 49: 57-66.

Twomey, S.A., 1977. Atmospheric Aerosols. Developments in Atmospheric Science 7. Elsevier, The Netherlands.

Twomey, S.A., M. Pipegrass, and T.L. Wolfe, 1984. An assessment of the impact of pollution on global cloud albedo. Tellus 36B: 357-366.

Whitlock, C.H., and C.G. Purgold, 1989. A VCR imaging system for cloud experiments. Presented at the FIRE Science Team Meeting, Monterey, California, 1989.

Winchester, J.W., 1980. Sulfate formation in urban plumes. Annals New York Academy of Sciences, 297-308.

BUDGET

Estimated Cost for three year project: $422,834

RE 1:

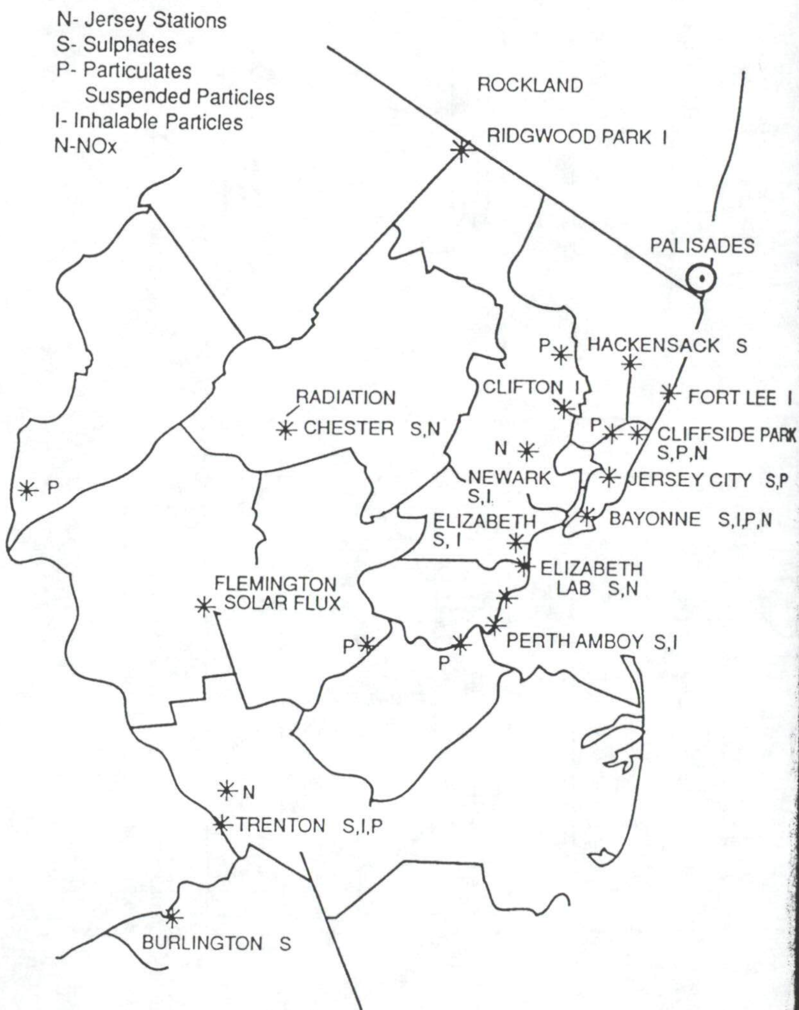
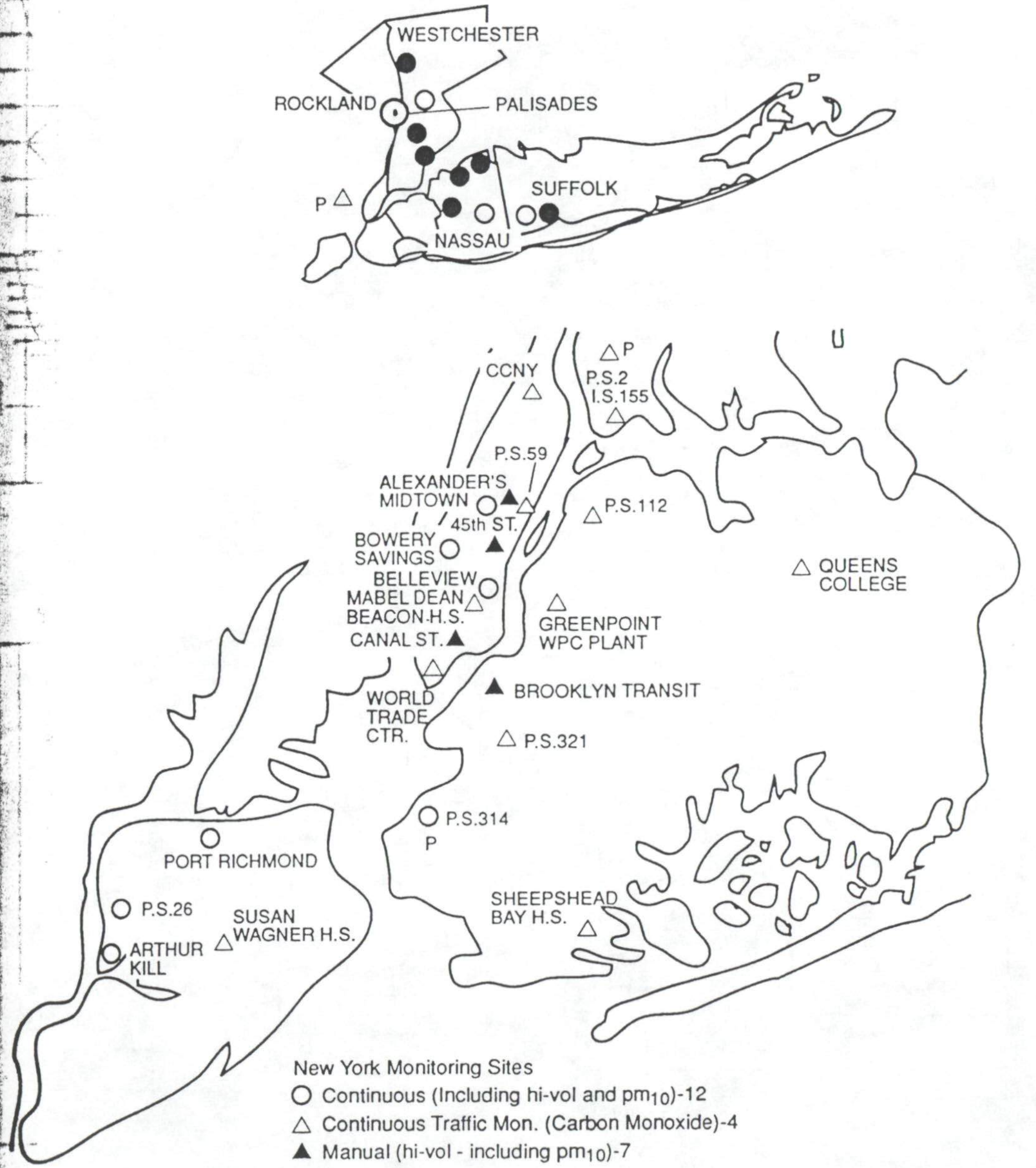
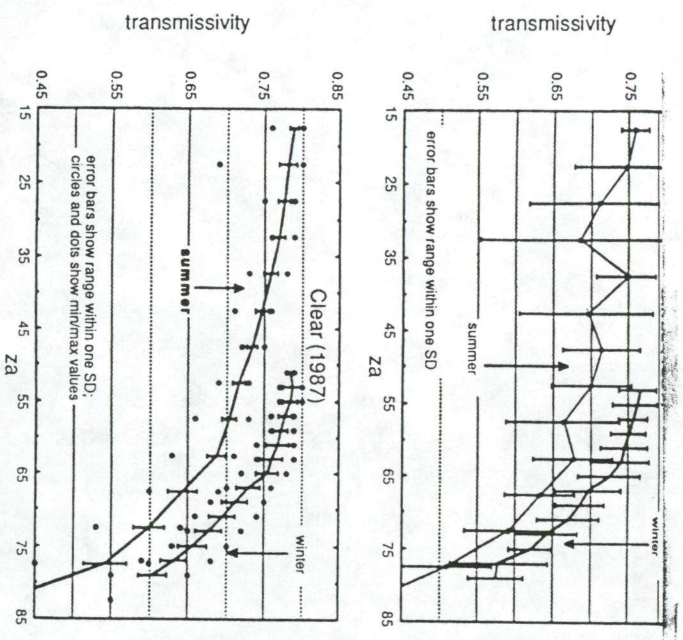


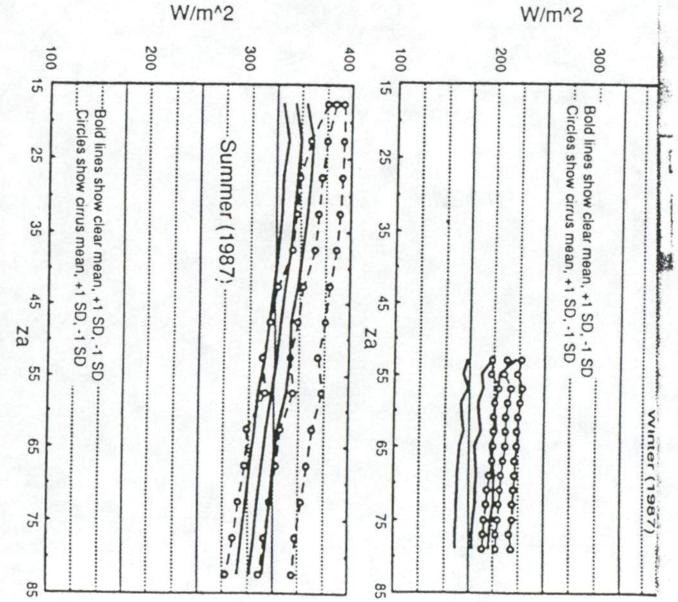
FIGURE 1 CONT'D.



GURE 2:

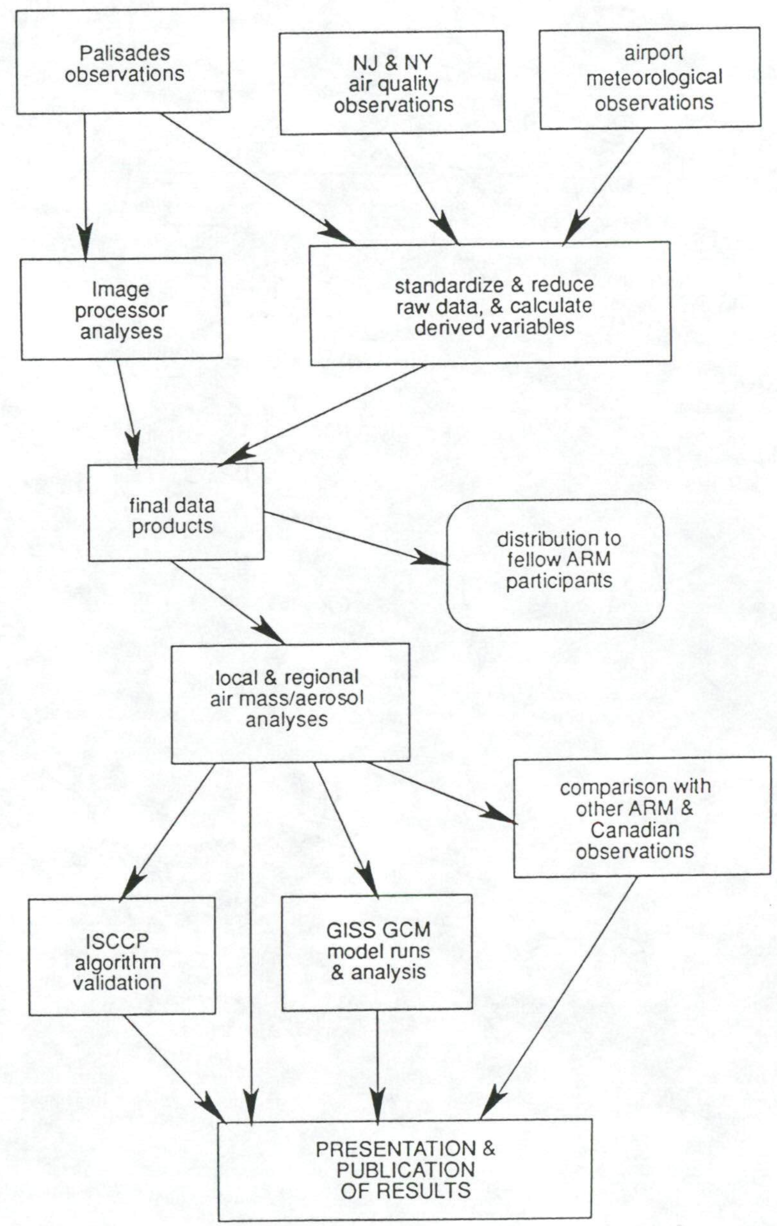


Summer versus winter transmissivities with cirrus (top) or clear (bottom) skies present. Data are plotted by solar zenith angle (za).



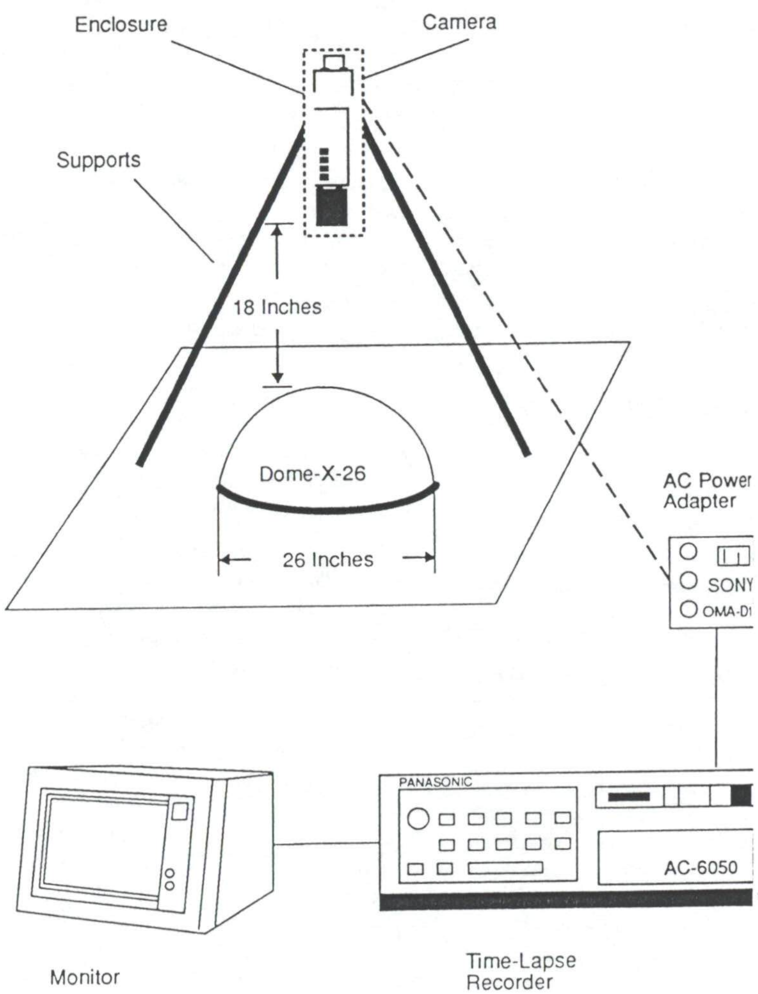
Downwelling longwave irradiance with cirrus and clear skies in winter (top) and summer (bottom). Data from 1987 daylight hours are plotted by solar zenith angle.

FIGURE 3:



Proposed work plan for the L-DGO/RU/GISS ARM Project

URE 4: TIME-LAPSE CLOUD CAMERA SETUP



Planned sky monitoring video system.

Mitigation of the CO_2 Warming by Natural Climate Changes in the Ending Interglacial

George Kukla
Columbia University

ABSTRACT

It is proposed to analyze in detail the paleoclimatic records of several past interglacial to glacial transitions and assess to what degree the periodic natural climate shifts in the declining phase of the current interglacial can mitigate the CO_2 warming.

The study will take advantage of the international workshop organized by the author of the proposal in Spain in April 1991, dealing with a similar subject.

We plan to assemble an international team of experts on past climates, critically analyze available evidence, and use it first for the validation of the new generation of coupled ocean-atmosphere circulation models and, second, for the prediction of the combined impact of natural variability and increased greenhouse gases on the near-future climates.

We expect to demonstrate the combined impact will be considerably different and of lesser magnitude than the predictions based on the 2 x CO_2 equilibrium climate models.

OBJECTIVE

To analyze paleoclimatic records and assess to what degree the climatic impact of rising carbon dioxide can be mitigated by natural climate shifts in the final phase of the current interglacial.

RATIONALE

The concentration of greenhouse gases is rapidly increasing. Future climates will differ from today as a result of combined man-made and natural forcing of the climate system.

Seasonal and geographic distribution of current temperature trends disagrees with the model predicted pattern of the warming impact (Plantico et al., 1990) of the increasing CO_2 (Fig. 1). In particular the North Atlantic and North Pacific cooled in the last 50 years while most models expected warming (Kukla et al., submitted). Most climatologists assume that this is due to the natural climate variability which is still higher than the CO_2 signal.

It is known that on the geologic time scales the planet is now approaching a transition into a glacial stage. Alternations between the interglacials and the glacials are the most prominent feature of past natural climate variability. During glacials the lands surrounding the North Atlantic cooled and became covered by ice. It has been convincingly demonstrated that the transitions from interglacials into glacials occurred repeatedly and in close correlation with the specific configuration of the earth orbit around the sun which matches the present one (Follieri et al., 1988; Kukla et al., 1981).

It is largely believed that the gross climate changes are progressing at such a slow rate that they are irrelevant on the time scale of centuries. This however, is a misconception. In the high and middle northern latitudes the shifts occurred in several steps, each marked by an accelerated environmental change lasting no more than a few centuries or possibly decades, and separated from the next step by two or more millenia of stable environments (de Beaulieu and Reille, 1989; Woillard, 1979; Kukla, 1980). It is this stepwise progression which is the most puzzling attribute of the past climate variations and which makes the natural climate variability a potentially important element in the prediction of the next century climates.

The mechanism of the glacial/interglacial changes remains unexplained. General circulation models, used for the prediction of the CO_2 impact, have been as of yet unable to simulate the transition when forced by the modified insolation. It is partly for that reason that some climatologists question whether the present generation of the general circulation models is sufficiently accurate to be trusted in the prediction of the next century CO_2 enriched climates (Rind et al., 1989). The trust in the predictions is being further undermined by the results of the first few coupled ocean-atmosphere circulation models which offer the most complete representations of climate systems developed to date. All of these models show potential CO_2 impact on the deep water formation and on the thermohaline oceanic circulation in general. According to the models, the deep water production rate decreases under increasing CO_2 concentrations (Stouffer et al., 1988; Washington and Meehl, 1989; Mikolajewicz et al., 1990). Such process, if real, would lead to considerable reduction of the CO_2 warming in the high latitudes. A similar mechanism is also the prime suspect in the search for the causes of the natural interglacial to glacial transitions (Rind et al., 1986; Broecker and Denton, in print).

Since directly obtained observations of deep water circulation are sporadic and inaccurate, it is highly advisable to expand them by paleoclimatic data, which cover both the land and the ocean during long intervals with variable environments at times grossly different from the present ones. Preliminary evaluation of these data indicates that the interglacials were characterized by vigorous deep water formation in the high latitudes, whereas the slowdown and/or cessation of the deep water formation was associated with the glacial periods.

A great wealth of information was obtained in recent decades from paleoclimatic records worldwide on the past natural climate variations. This includes both land and the oceans. This information is priceless for validation of numerical global climate models used for the prediction of CO_2 impacts. In addition, since the past climate changes were quasi-periodic, the information can be utilized independently in the probability forecast of the likely course of natural climates (Kukla, 1988).

The importance and timeliness of research oriented toward the prediction of future climate changes can not be overemphasized. In the last two years scientific gatherings at highest governmental levels of several countries underlined the urgent need of such research.

It is our intention to critically review and correlate existing paleoclimatic data from environments of continuous deposition. We want to focus on the interglacials and early glacials as the analogs of near future.

We also plan to investigate the relation of the past natural climate variability to orbital configuration and corresponding insolation distribution in order to detect those parts of the earth system which show the highest sensitivity to insolation forcing.

WORK PLAN

The bulk of the work will consist of the critical reanalyses of the already available data, assessment of their accuracy and limitations, reinterpretation of the records, and compilation of the results on a global scale.

Selected intervals in the key records will be sampled in more detail so as to obtain a decadal resolution where possible.

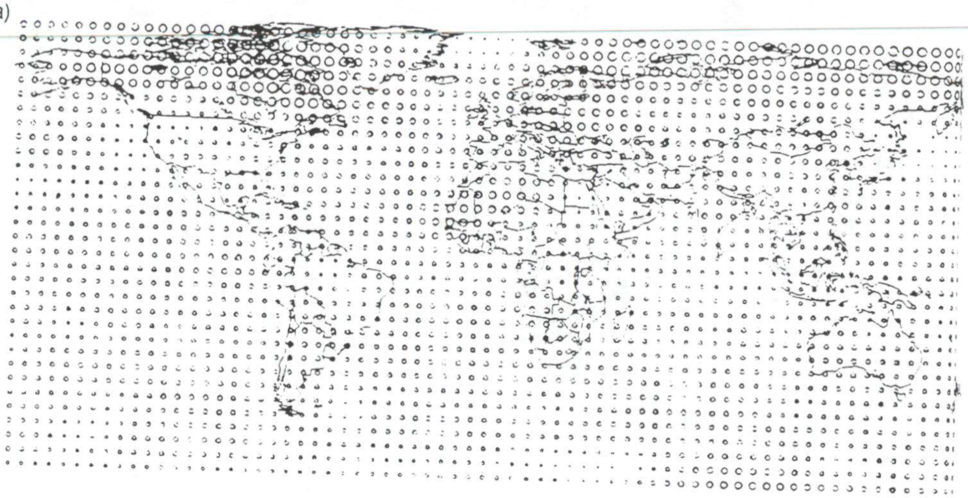
Since many of the best pollen cores were studied by foreign scientists, and the cores are located overseas, consulting arrangements will have to be made to secure the necessary cooperations.

Additional details from the deep sea sediments will be obtained either directly by the Lamont team from the cores stored at the Observatory or by the external researchers on a per sample charge basis.

Workshops of the team members are planned in the second and the third year of the project.

FIGURE 1:

a)



b)

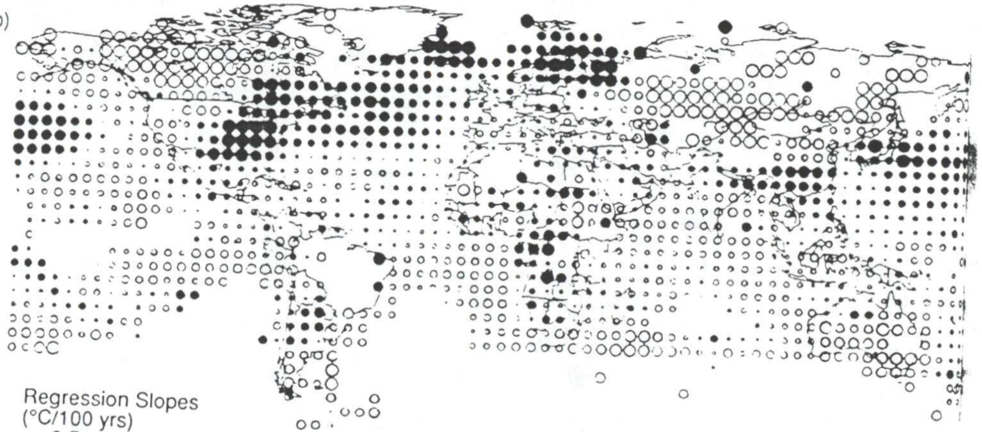
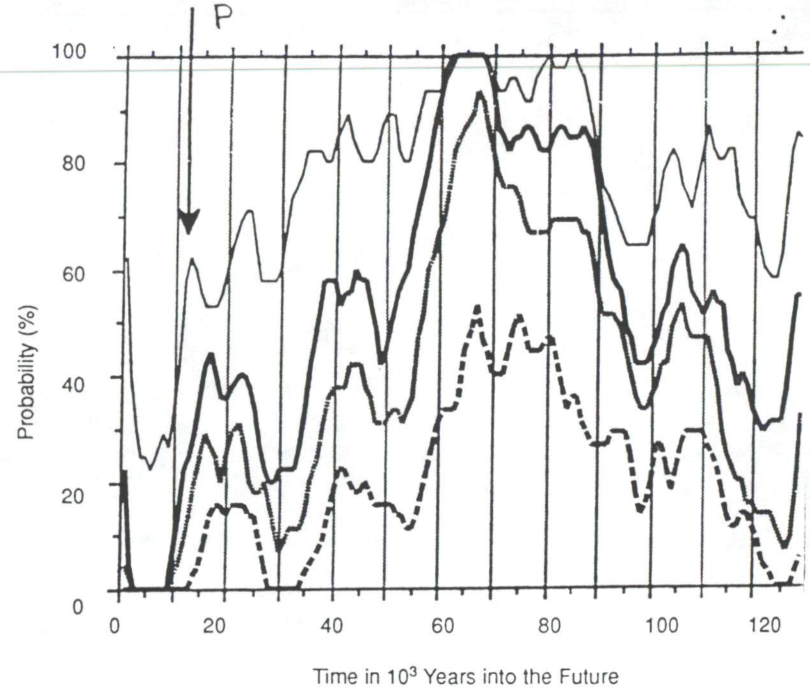


FIGURE 2:



The accumulated probability (in %) of the occurrence of the five climate states ranging from an interglacial to a full glacial plotted as a function of time elapsed from a termination. Present day position (P) marked with an arrow. Data smoothed by 1-2-1 weighting. Based on the Macedonian core, ODP 677, and the Xifeng I loess sequence. Interglacial in thin line, temperate interstadial in full, stadial dashed amd glacial in heavy dashed line.

The following is the list of researchers expected to take part in the project:

Pollen and other land data:

Maria Follieri, Dipartimento Di Biologia Vegetale, Universita Degli Studi "La Sapienza", P. le Aldo Moro, 5, 00185 Roma, Italy

T.A. Wijmstra, Hugo de Vries Laboratory, University of Amsterdam, Kruislaan 318, 1098 SM Amsterdam, The Netherlands

Jacques-Louis de Beaulieu, Laboratoire de Botanique Historique et Palynologie, UA 1152 du CNRS, Faculte des Sciences et Techniques, St-Jerome, 13397 Marseille Cedex 13, France

Helmutt Muller, BGR, Stilleveg 2, D3 Hannover-Bucholz, Germany

Henry Hooghiemstra, Hugo de Vries-Laboratory, Department of Palynology and Paleo/Actuo Ecology, University of Amsterdam, The Netherlands

Thomas Webb, III, Brown University, Providence, Rhode Island 02912

Ice records:

Jean Jouzel, Laboratory Glaciologie BP 96, 38402 St. Martin d'Meus, Cedex, France

Jean Robert Petit, Laboratory Glaciologie BP 96, 38402 St. Martin d'Meus, Cedex, France

Ocean paleocirculation:

Nick Shackleton, Godwin Laboratory, Free School Lane, Cambridge, CB2 3RS England

William Ruddiman, Lamont-Doherty Geological Observatory, Palisades, N.Y. 10964

Laurent Labeyrie, Centre des Faibles Radioactivities, Laboratoire mixte CNRS-CEA, P.C. 91190, Gif-sur-Yvette, France

Jean-Claude Duplessy, Centre des Faibles Radioctivities, Laboratoire mixte CNRS-CEA, 91198 GIF-Sur Yvette Cedex, France

Wallace Broecker, Lamont-Doherty Geological Observatory, Palisades, N.Y. 100964

Karen Luise Knudsen, Department of Micropaleontology, Institute of Georgia, University of Aarhus, DK-8000 Aarhus C, Denmark

Current oceanic and atmospheric circulation:

Kirk Bryan, GFDL, Princeton University, Princeton, New Jersey 08540

Knut Aagaard, NOAA/PMEL, 7600 Sand Point Way NE, Building 3, Seattle, Washington 98115-0070

Lawrence Mysak, University of McGill-Montreal, Centre for Climate and Global Change Research, 805 Sherbrooke Street, NW, Montreal, Quebec H3A 2K6

Thomas Karl, Applied Climatology Branch, NOAA-NESDIS National Climatic Data Center, Federal Building, Asheville, North Carolina 28801

Coupled ocean-atmosphere models:

Suki Manabe, GFDL, Princeton University, Princeton, New Jersey 08540

Gerald Meehl, National Center for Atmospheric Research, Boulder, CO 80307-3000

EXPECTED RESULTS

Expected results of the study are as follows:

1) Probability forecast of natural climate developments during the next century. Assessment of the degree to which these developments will mitigate the CO_2 impact.
2) A data base useful for the validation and improved parameterization of coupled ocean-atmosphere models. Model estimate of the next century climates as resulting from the combined impact of CO_2 and natural processes on the system.
3) Improved understanding of operational models of the climate system.

PUBLICATION OF THE RESULTS

The dissemination of the results will be tightly controlled in order to maintain the current high credibility of the team members, to prevent unwarranted statements and avoid overreaction of the media. All team members will be requested to circulate their papers resulting from the project for internal review prior to publication. Such reports will describe in detail the work done on individual sites and will be submitted to corresponding specialized journals. Workshop proceedings will appear with executive summaries coedited by all participants and the brief summaries will be published in the leading scientific journals with wide international distribution (Nature, Science, etc.).

REFERENCES

Broecker, W. S. and G. Denton. (in print). What drives glacial cycles?:

De Beaulieu, J. L. and M. Reille. 1989. The transition from temperate phases to stadials in the long upper Pleistocene sequence from Les Echets (France). *Palaeogeo. Palaceoclim. Palaeocol.* 72: 147-159.

Follieri, M., D. Magri and L. Sadori. 1988. 250,000 year pollen record from Valle Di Castiglione (Roma). *Pollen et Spores*. XXX (3-4): 329-356.

Kukla, G. 1980. End of the last interglacieal: A predictive model of the future? Sr. E.M. Van Zinderen Bakker and J.A. Coetzee (Ed.), *Paleoecology of Africa and the Surrounding Islands*. A.A. Balkema, Rotterdam, 395-408.

Kukla, G., A. Berger, R. Lotti and J. Brown. 1981. Orbital signature of interglacials. *Nature*. 290: 295-300.

Kukla, G. 1990. Global climate change model. Natural climate variation: Data base and probabilities. Prepared for the Battelle Pacific Northwest Laboratory, Lamont, Palisades.

Kukla, G., T. Karl, R. Knight, G.A. Meehl, W.M. Washington, and J. Gavin. (submitted). Current temperature trends: Transient response to the CO_2 increase? *Nature*.

Mikolajewicz, U., B.D. Santer and E. Maier-Reimer. 1990. Ocean response to greenhouse warming. *Nature*. 345: 589-593.

Plantico, M.S., T.R. Karl, G. Kukla, and J. Gavin. 1990. Is recent climate change across the United States related to rising levels of anthropogenic greenhouse gase? *J. Geophys. Res*. 95: 16617-16637.

Rind, D., D. Peteet, W. Broecker, A. McIntyre and W. Ruddiman. 1989. The impact of cold North Atlantic sea surface temperatures on climate: implications for the Younger Dryas cooling (11-10K). *Clim. Dyn*. 1:3-33.

Rind, D., D. Peteet and G. Kukla. 1989. Can Milankovitch orbital variations initiate the growth of ice sheets in a general circulation model? *J. Geophys. Res*. 94 (D10): 12851-12871.

Stouffer, R.J., S. Manabe and K. Bryan. 1989. Interhemispheric asymmetry in climate response to a gradual increase of atmospheric CO_2. *Nature*. 342: 660-662.

Washington, W.M. and G.A. Meehl. 1989. Climate sensitivity due to increased CO_2: experiments with a coupled atmosphere and ocean general circulation model. *Clim. Dynamics*. 4: 1-38.

Woillard, G.M. 1979. Abrupt end of last interglacial s.s. in NE France. *Nature*. 281: 558-562.

Fig. 1.
a) The winter warming due to the 30% increase of CO_2 as expected from the equilibrium 2 x CO_2 coupled ocean-atmosphere model of Washington and Meehl (1989). Approximately comparable to the combined greenhouse forcing over the 1945-1986 period. Circles proportional to the magnitude of warming.

b) The current winter 1945-1986 linear surface temperature trends compared to the expect CO_2 warming impact over the same time period in the equilibrium climate model of Washington and Meehl, 1989. (From Kukla et al., submitted to Nature.) The full circles show cooling, the open circles show warming. Radius is proportional to the intensity of the trend. The largest circles show trends equal or greater than 2.5 °C/42 years.

Fig. 2.
Probability of the natural climate states during the next 130,000 years, (from Kukla, 1990). Explained on the figure.

BUDGET

Estimated cost for three year project: $497,499

PERSONNEL DEVELOPMENT IN CLIMATE-RELATED SCIENCES

Richard Lindzen
Massachusetts Institute of Technology

The most significant problem facing any proposed program to improve our understanding of climatic and other environmental issues is the shortage of well trained, talented personnel. The problem has several aspects.

1) Science and technology are generally less popular among the best students.
2) The problems involved in understanding the atmosphere and oceans are among the very hardest and most challenging problems in all of science.
3) Low status pertains to working in fields like meteorology and oceanography –relative to working in traditional areas like mathematics and physics. This situation is institutionalized in places like the People Republic of China where far higher exam scores are needed to enter physics and mathematics than to enter any of the Earth Sciences.

The graduate program in Meteorology and Physical Oceanography at the Massachusetts Institute of Technology have long been regarded as the pre-eminent program in this area. Nevertheless, we have only 8 first year graduate students — most of whom are from abroad. With rare exceptions, the students are not capable of dealing with the most challenging problems. The increasing number of large research programs in all aspects of the atmospheric and oceanic sciences is already suffering from personnel shortages, though this is sometimes disguised by the heavy emphasis on equipment over people. Indeed the job situation in the research sector is not impressive. If society is serious about improving our understanding of the climate system, then this personnel situation must be remedied.

An important step in remedying this situation involves recruiting the best available minds into climate sciences. Towards this end, we propose the establishment of fellowship programs which are sufficiently generous to be able to attract students who might not otherwise choose these fields. A similar program sponsored by the Ford Foundation in the late 40s and early 60s was remarkably successful.

The present proposal is for the establishment of three such fellowships each year at M.I.T. Assuming graduate studies to last four years (this is actually about a year less than is average), it will take four years for the cost of the program to plateau (apart from inflationary increases). The fellowships will pay the student 10% more than standard assistantships (M.I.T. sets this limit), and will provide each recipient with a fund of $7000 per year to support research and educational activities (books, supplies, personal computers, attendance at meetings and workshops, etc.).

It goes without saying, that the ultimate attractiveness of any field will depend on the employment opportunities for students completing their studies. There is little that individual universities can do in this regard; however, all research sponsors should be encouraged not to undertake large programs without provision for adequate personnel.

Salaries & Wages	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	10 Year Total
Yr 1:3 Fellows											
Tuition	$21,200	$22,854	$24,636	$26,558	$28,629	$30,862	$33,270	$35,865	$38,865	$41,678	
Stipend	$15,048	$15,840	$16,632	$17,464	$18,337	$19,254	$20,216	$21,227	$22,288	$23,403	
Research & Education Expense	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	
	$43,248	$45,694	$48,268	$51,021	$53,966	$57,116	$60,486	$64,092	$67,951	$72,081	$0
	$129,744										
Year 2: 6 Fellows		$274,162									
Year 3: 9 Fellows			$434,414								
Year 4+: 12 Fellows				$612,257	$647,593	$685,392	$725,832	$769,102	$815,407	$864,968	
Total Salary	$129,744	$274,162	$434,414	$612,257	$647,593	$685,392	$725,832	$769,102	$815,407	$864,968	$5,958,870
Employee Benefits*	$52,546	$111,035	$178,110	$254,087	$271,989	$291,292	$308,478	$326,868	$346,548	$367,612	$2,508,565
Total Salary & Benefits	$182,290	$385,197	$612,523	$866,343	$919,582	$976,684	$1,034,310	$1,095,970	$1,161,956	$1,232,580	$8,467,435
Indirect Costs**	$104,817	$221,488	$370,577	$528,469	$565,543	$605,544	$641,272	$679,501	$720,412	$764,199	$5,201,834
TOTAL Required	**$287,107**	**$606,685**	**$983,100**	**$1,394,813**	**$1,485,125**	**$1,582,228**	**$1,675,582**	**$1,775,471**	**$1,882,368**	**$1,996,779**	**$13,669,259**

1. Tuition increase @ rate of 7.8% per year.
2. After year 4 Stipend increases 1.05 per year.
3. Stipend includes 10% allowance over MIT standard annual amount

Employee Benefit Rates:		Overhead Rates
Yrs 1-2:	.405	0.575
Yr. 3:	.41	0.605
Yr.4:	.415	0.61
Yr.5:	.42	0.615
Yrs 6-10:	.425	0.62

WATER VAPOR BUDGET IN THE UPPER TROPOSPHERE

Richard Lindzen
Massachusetts Institute of Technology

Far and away the most important greenhouse gas in the Earth's atmosphere is water vapor. The downward flux of infrared radiation at the Earth's surface is about 340 Wm^{-2}. Of this amount, 290 Wm^{-2} is due to water vapor and about 40 Wm^{-2} is due to stratiform clouds; only about 10 Wm^{-2} is due to carbon dioxide. Moreover, the Earth's surface does not cool primarily by radiation; rather, it cools mostly by evaporation, and the heat is then carried to the upper troposphere by convection. As a result, it is water vapor in the upper troposphere (above 6 km) that is of primary radiative importance in determining the temperature of the Earth. According to Arking (1990), a molecule of water vapor at 8 km is about as important as 100 molecules near the ground. Unfortunately, current measurements of water vapor between 6 and 9 km are considered totally unreliable, while measurements above 9 km are essentially non-existent.

Vis a vis climate, the situation is even more serious. The direct response of most existing large scale climate models to a doubling of carbon dioxide is only about 1°C. Larger responses are due to positive feedbacks, and in all models predicting a large response (2-5°C) to carbon dioxide, the most important feedback is due to water vapor. The response amplification due to feedbacks is given by an expression

$$gain = \frac{1}{1-f}$$

where f is the sum of all contributions to the feedback. In the GISS and GFDL models, the contributions of feedbacks from water vapor, clouds, and snow/ice are about 0.4, 0.2, and 0.1 respectively. If one shows gain (or response) rather than feedback, and begins with the water vapor feedback –adding the others sequentially, one gets the impression that water vapor is not important. This, however, is an egregiously misleading way of presenting things. It is clear, from the above equation, that in the absence of the water vapor feedback, the remaining feedbacks cannot even amplify the direct response to 2°C. As Mitchell, et al (1989) has shown, the cloud feedback may be negative rather than positive. The response is then reduced rather than magnified. The question we wish to deal with is whether the water vapor feedback is real.

In present models, the positive water vapor feedback arises from the fact that these models use cumulus parameterizations which increase specific humidity at all levels as temperature increases. Observationally and theoretically, this is correct for the boundary layer; however, in the upper troposphere, we have no observations. We are, therefore, forced to examine the theoretical foundations of the parameterizations used by the models. These parameterizations are of two types: 1) convective adjustment, or 2) Kuo type schemes (Kuo, 1974). The latter is over 16 years old while the former is over twenty years old. Both have long been known to be grossly inaccurate portrayals of the behavior of cumulonimbus convection (Arakawa and Schubert, 1974, Emanuel, 1990, Geleyn, et al, 1982). Both markedly distort the contributions of deep cumulus convection to both the heat and moisture budgets. In the case of the moisture budget, convective adjustment acts to simply saturate the atmosphere; in order to avoid gross model misbehavior (such as a runaway green house), this is generally reduced arbitrarily to some fixed relative humidity less tha 100%. The Kuo parameterizations act to influence the environment by having dee clouds simply mix into the environment at all levels. As Ooyama (1971) an Arakawa and Schubert (1974) noted, this is not at all the way moist convectiv plumes behave. Rather, parcels rise rapidly through the convective towers, detraining where they reach neutral buoyancy. Their effects on the environment arise ultimatel from the subsidence required outside the clouds in order to balance the upward flo in the clouds. The moisture budget in the Arakawa-Schubert parameterization arise from the fact that the clouds detrain saturated air high in the troposphere wher temperatures are so cold that saturation involves minute specific humidities. Th subsidence of this air acts to make lower levels very dry. I have incorporated thi physics into my own cumulus parameterization (Lindzen, 1981, 1988) which has bee successfully tested at the European Centre for Medium Range Weather Forecastin (Geleyn, et al, 1982), and is the basis for their current parameterization.

We have been able to show that such a parameterization leads to a strong negativ water vapor feedback (viz Figure 1). The reason is simple: surface warming causes th cloud elements to rise to higher, colder levels where saturated air corresponds t smaller specific humidities, which in turn reduces the supply of moisture to lowe levels. Using Arking's (1990) calculations (viz Figure 2), one can show that th resulting radiative effects are capable of strongly counteracting the original warming There is, nonetheless, a significant source of uncertainty in our calculations: neithe we nor Arakawa and Schubert considered the contribution to the moisture budge from the reevaporation of precipitation (in the form of both ice and water) falling outside the cloud towers[1]. Current observations show this effect is certainly significant in the lower troposhere, and may also have effects in the upper troposhere. As far as we can tell this may, in fact, enhance the negative feedback, but the matter needs checking, which is one of the things we propose to do.

---

[1]We implicitly allow for this in the lowest 2-3 km of the atmosphere by considering this layer to be turbulently mixed, thus avoiding the unrealistic heating and drying that Arakawa and Schubert find at these levels—due to the fact that they do not even allow for the reevaporation from precipitation from shallow clouds.

The process depends in some measure on the microphysics of clouds which is very uncertain. As a result, we plan to conduct extensive parametric studies in order to determine the possible range of effects. In addition, we plan to introduce both our cloud parameterization for effects on both heat and moisture and an accurate radiative transfer scheme into a simplified global model similar to that developed by Lindzen et al (1982) in order to directly estimate effects on global temperature.

'PORT LEVEL

We seek support for hiring one postdoctoral research associate and one predoctoral research assistant to participate in this research.

REFERENCES

Arakawa, A. and W.H. Schubert (1974) A cumulus parameterization scheme utilizing a one-dimensional cloud model. *J. Atmos. Sci.*, 31, 270-286.

Arking, A. (1990) Feedback processes and climate response. To appear in *Proceedings of the Conference on Climate Impacts of Solar Variablity*, NASA Conference Publication CP-3086.

Emanuel, K. (1990) A Scheme for Representing Cumulus Convection in Large-Scale Models. *Report No.* 3, Center for Global Change, M.I.T., 50 pp.

Geleyn, J.-F., C. Girard, and J.-F Louis (1982) A simple parameterization of moist convection for large-scale atmospheric models. *Beitr. Phys. Atmosph.*, 55, 325-334.

Kuo, H.L. (1974) Further studies of the parameterization of the influence of cumulus convection on large-scale flow. *J. Atmos. Sci.*, 31, 1232-1240.

Lindzen, R.S. (1981) Some remarks on cumulus parameterization. *Proceedings of the NASA Clouds in Climate Conference*, NASA Report, available NASA/Goddard Institute of Space Studies.

Lindzen, R. S. (1988) Some remarks on cumulus parameterization. *PAGEOPH*, 16, 123-135.

Lindzen, R.S. A.Y. Hou and B.F. Farrell (1982) The role of convective model choice in calculating the climate impact of doubling CO_2. *J. Atmos. Sci.*, 39, 1189-1205.

Mitchell, J.F.B., C.A. Senior, and W.J. Ingram (1989) CO_2 and climate: a missing feedback? *Nature*, 341, 132-134.

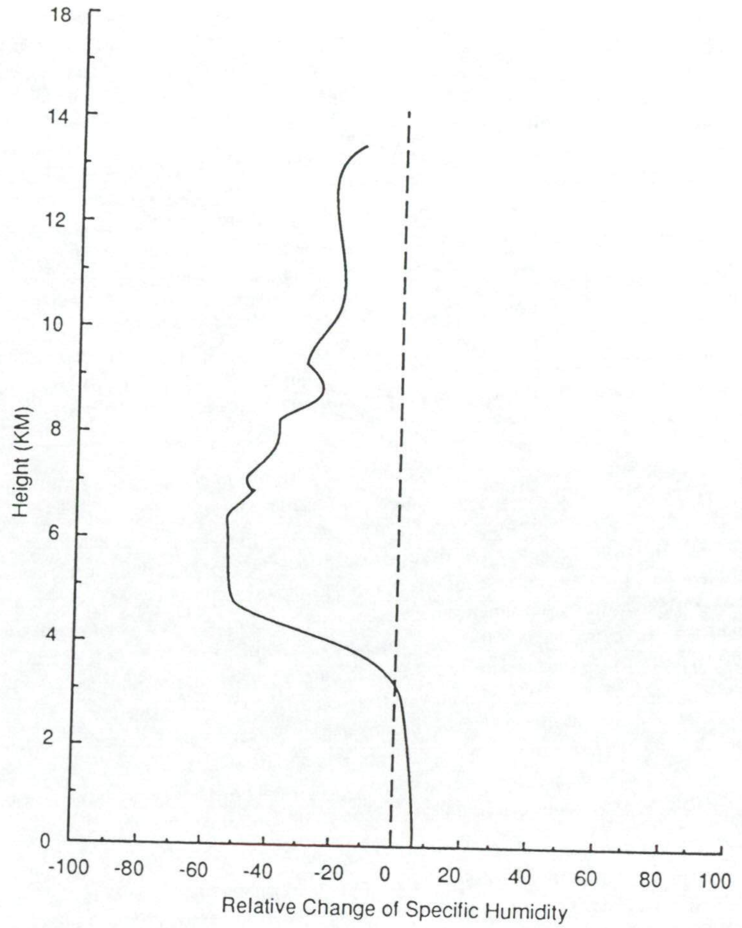
Ooyama, K. (1981) A theory on parameterization of cumulus convection. *J. Meteor. Soc. Japan*, 49, (special issue), 744-756.

PROPOSED BUDGET - WATER VAPOR PROPOSAL 1/1/91 - 12/31/91

Salaries & Wages	
Post-Doc - 12 months ($2100/month)	$25,200
GRA - 12 months	13,680
1/91 - 6/91:	1110
7/91 - 12/91:	1170
Admin. Asst. - 1 month	2,140
Total Salary	***$41,010***
Employee Benefits On campus rate: .045	16,613
Total Salary& Benefits	***$57,633***
Operating Expenses	
Materials & Services	2,000
Travel	2,000
Total Operating Expenses	4,000
Total Direct Cost	***$61,633***
Overhead: .575	35,439
Total Required	***$97,072***

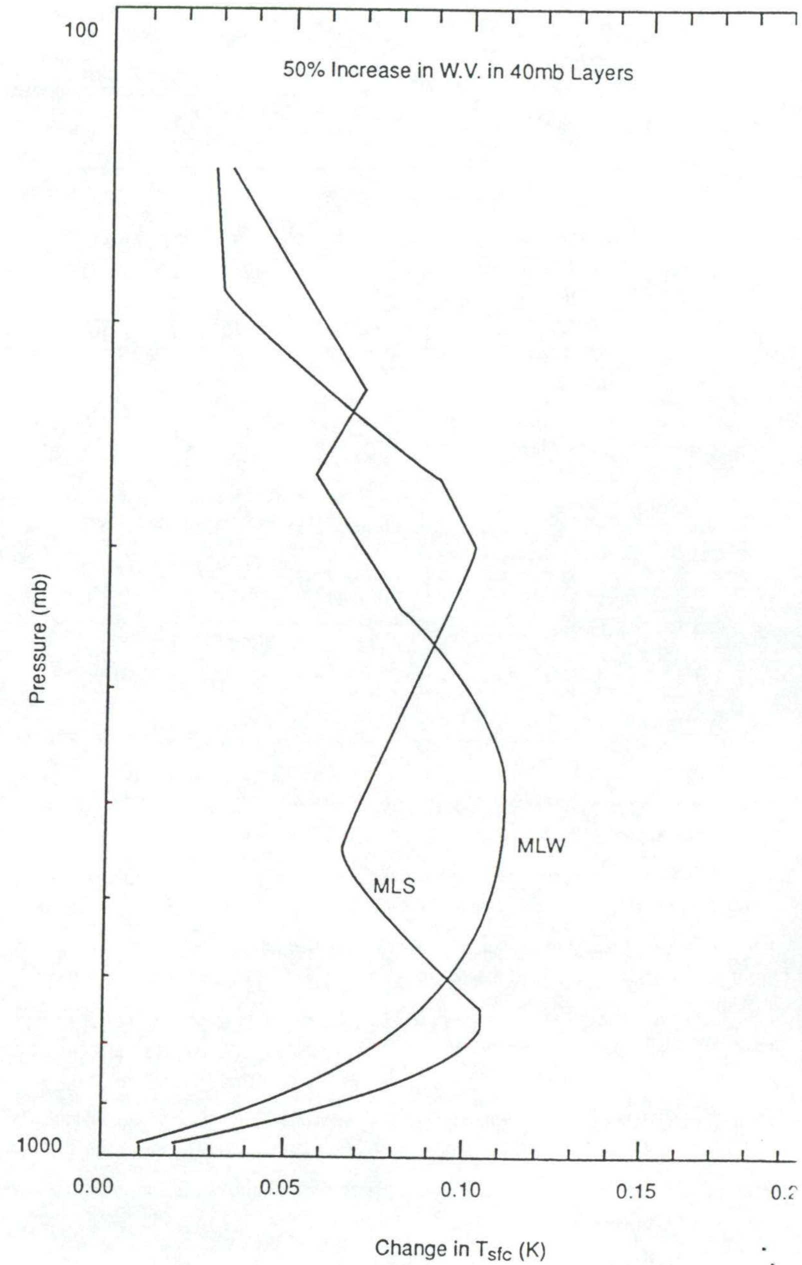
Funding at this level –subject to inflationary increases will be needed for three years

FIGURE 1:



Relative change of specific humidity when atmospheric temperature is increased by 1 K. (in percent) (The perturbation is constant with height).

FIGURE 2:



The change in surface temperature due to a 50% increase in water vapor in a 40mb layer, as a function of the height of the layer.

Transport and the Greenhouse Effect

Richard Lindzen
Massachusetts Institute of Technology

Central to the possibility of global warming is the greenhouse effect. This effect, which is due to the fact that the atmosphere is significantly transparent to visible radiation, but blocks cooling by infrared radiation, is responsible for the fact that the Earth is 33°C warmer than it would be in the complete absence of greenhouse gases. That said, it must be added that the usual depiction of the greenhouse effect is profoundly incomplete. A typical example of the usual depiction is shown in Figure 1, taken from the Policymakers Summary of the recent IPCC Working Group I Report (Houghton, et al, 1990). What this figure suggests, is that radiative processes are responsible for cooling the surface of the Earth. This is simply untrue; the surface cools mostly by evaporation, and heat is carried from the bottom of the atmosphere by mechanical transport which bodily carries the heat to higher altitudes and latitudes where the greenhouse potential is much less. This has been understood for almost a century. An example of the effect of this is seen in Figure 2 taken from Moller and Manabe (1960). Three curves are shown for the vertical profile of temperature (in °K, absolute Kelvin temperature; the temperature in °C is the Kelvin temperature minus 273°): two are based on the pure radiative picture (including and excluding the infrared properties of clouds); the third includes a crude parameterization of transport (i.e., convective adjustment.) What one sees from this figure is that with pure radiative cooling, the surface would have an average temperature of about 350°K; only with transport included is the temperature reduced to the observed 288°K. What happens more generally is illustrated in the accompanying schematic shown in Figure 3. Heat is carried from the tropical lower atmosphere to higher altitudes and latitudes where the infrared opacity is less. It is primarily from the regions above where the heat is deposited that the infrared opacity is important. Thus, without knowing exactly where the heat is deposited, it is impossible to calculate the temperature of the Earth. There are three major components of the transport for purposes of climate: 1) Cumulonimbus convection, 2) The Hadley circulation, and 3) Baroclinic eddy transport. It is well known that none of these processes is accurately simulated in existing large scale models. We propose to study each of these processes in order to determine whether there are any underlying physical principles that would permit improved modelling with both large and simpler climate models.

IMBUS CONVECTION

We have developed a parameterization for cumulonimbus convection (Lindzen, 1981, Lindzen, 1988) which has been shown by the European Centre for Medium Range Weather Forecasting to be the most accurate of the commonly available parameterizations (Geleyn, et al, 1982), and is the basis of their recently implemented standard parameterization. The parameterization, however, suffers from not taking account of the role of reevaporation of rain falling outside the cloud. This is currently believed to be important. However, we will not discuss this further here since the whole issue of cumulus parameterization is central to our proposal to study the moisture budget of the upper troposphere.

Hadley Circulation

The Hadley Circulation refers to the larger scale overturning of the atmosphere associated with rising motion near the equator, and sinking near 30° latitude. This circulation has been studied extensively (Schneider and Lindzen, 1977, Schneider, 1977, Held and Hou, 1980, Lindzen and Hou, 1988, Lindzen, 1990, Hou and Lindzen, 1990). We have discovered several important properties of this major motion system: 1) It is the major supplier of angular momentum to middle latitudes, and appears to play a major role in forcing the mid-latitude eddies which carry heat to higher latitudes; 2) The Hadley Circulation is sensitive to the displacement of the surface temperature maximum from the equator as well as to the zonally averaged concentration of precipitation; 3) When the surface temperature maximum is displaced from the equator (as it almost always is), the Hadley Circulation consists mainly in a single cell which rises primarily in the 'summer' hemisphere, and extends well into the 'winter' hemisphere –transport into the 'summer' hemisphere is minimal; and 4) The observed intensity of the Hadley Circulation is consistent with only modest zonally averaged concentration of rainfall –suggesting that the intensity of the Hadley Circulation does not depend on the local width of the Intertropical Convergence Zone, but rather on the displacement of this zone by longitudinal asymmetries arising from monsoons and easterly waves.

All the above studies have included the heating of the atmosphere in a very crude manner. What remains to be done is the incorporation of accurate parameterizations of both cumulus heating and of the trade wind boundary layer. We propose to carry out these extensions.

Baroclinic Eddy Transport

'Baroclinic eddies' refers primarily to those large scale transient eddies which carry heat from the subtropics to higher latitudes. They are largely responsible for maintaining the habitability of high latitudes in winter. The traditional theory of the process for maintaining these eddies (Charney, 1947, Eady, 1949) attributes their maintenance to hydrodynamic instabilities arising from surface temperature gradients. Subsequent studies attempted to relate the observed north-south temperature distribution to some critical value needed for instability (Pocinki, 1955, Stone, 1978, Lindzen and Farrell, 1981, Lindzen, et al, 1982, Cehelsky and Tung, 1990). These studies were moderately successful, but depended on semi-empirical adjustments. Moreover, recent studies (Farrell, 1987) suggest that upper level shears may play a role comparable to surface gradients in maintaining these eddies. We propose to undertake an extensive numerical study of what are the primary factors in generating baroclinic eddies, and of whether there is a nonlinear equilibrated state for these eddies which determines their quantitative role in climate.

Support Level

We seek support for hiring one postdoctoral research associate and one predoctoral research assistant to participate in this research.

ENCES

Cehelsky, P. and K.K. Tung (1990) Nonlinear baroclinic adjustment. *J. Atmos. Sc.* in press.

Charney, J.G. (1947) The dynamics of long waves in a baroclinic westerly current. *J. Meteor.*, 4, 135-163.

Eady, E.T. (1949) Long waves and cyclone waves. *Tellus*, 1, 33-52.

Farrell, B. (1987) On developing disturbances in shear. *J. Atmos. Sci.*, 42, 2191-2199.

Geleyn, J.-F., C. Cirard, and J.-F Louis (1982) A simple parameterization of moist convection for large-scale atmospheric models. *Beitr. Phys. Atmosph.*, 55, 325-334.

Held, I.M. and A.Y. Hou (1980) Nonlinear axially symmetric circulations in a nearly inviscid atmosphere. *J. Atmos. Sci.*, 37, 515-533.

Hou, A.Y. and R.S. Lindzen (1990) Intensification of the Hadley circulation due to concentrated heating.

Houghton, J.T., G.J. Jenkins, and J.J. Ephraums, editors (1990) *Climate Change, The IPCC Scientific Assessment*, Cambridge Univ. Press, Cambridge, 365 pp.

Lindzen, R.S. (1981) Some remarks on cumulus parameterization. *Proceedings of the NASA Clouds in Climate Conference*, NASA Report available NASA/Goddard Institute of Space Studies.

Lindzen, R.S. (1988) Some remarks on cumulus parameterization. *Pageoph*, 16, 123-135.

Lindzen, R.S. (1990) The Hadley circulation. *Proc. ECMWF Conf. on Tropical Meteorology*.

Lindzen, R.S. and B.F Farrell (1980) The role of polar regions in global climate, and the parameterization of global heat transport. *Mon. Wea. Rev.*, 108, 2064-2079.

Lindzen, R.S., A.Y. Hou and B.F. Farrell (1982). The role of convective model choice in calculating the climate impact of doubling CO_2. *J. Atmos. Sci.*, 39, 1189-1205.

Lindzen, R.S. and A.Y. Hou, (1988) Hadley circulations for zonally averaged heating centered off the equator. *J. Atmos. Sci.*, 45, 2416-2427.

Moller, F. and S. Manage (1961) Uber das Strahlungsgleichgiwicht der Atmosphare, *Z. fur Met.*, 15, 3-31.

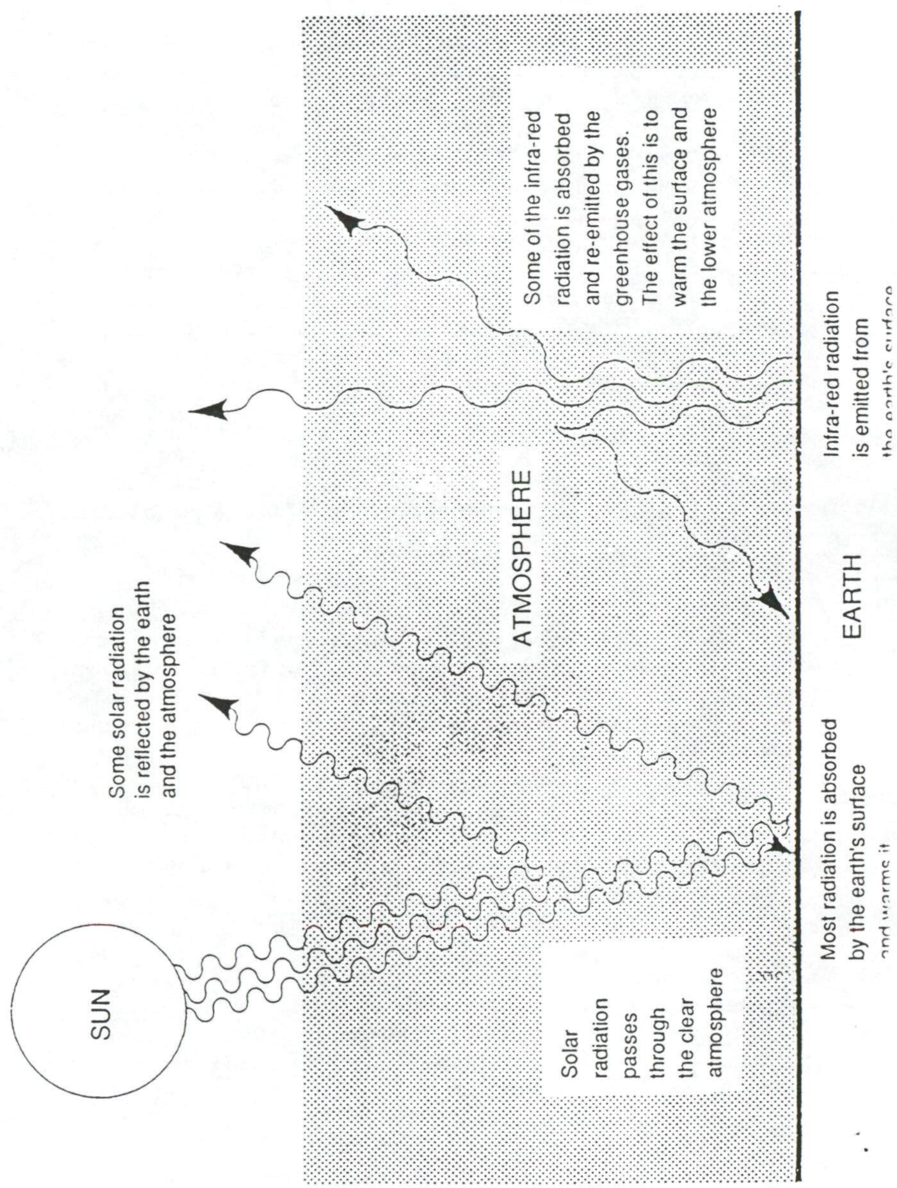
Pocinki, L. (1955) Stability of a simple baroclinic flow with horizontal shear, *AF Cambridge Research Center, Geophys. Research Paper*, 38, 78 pp.

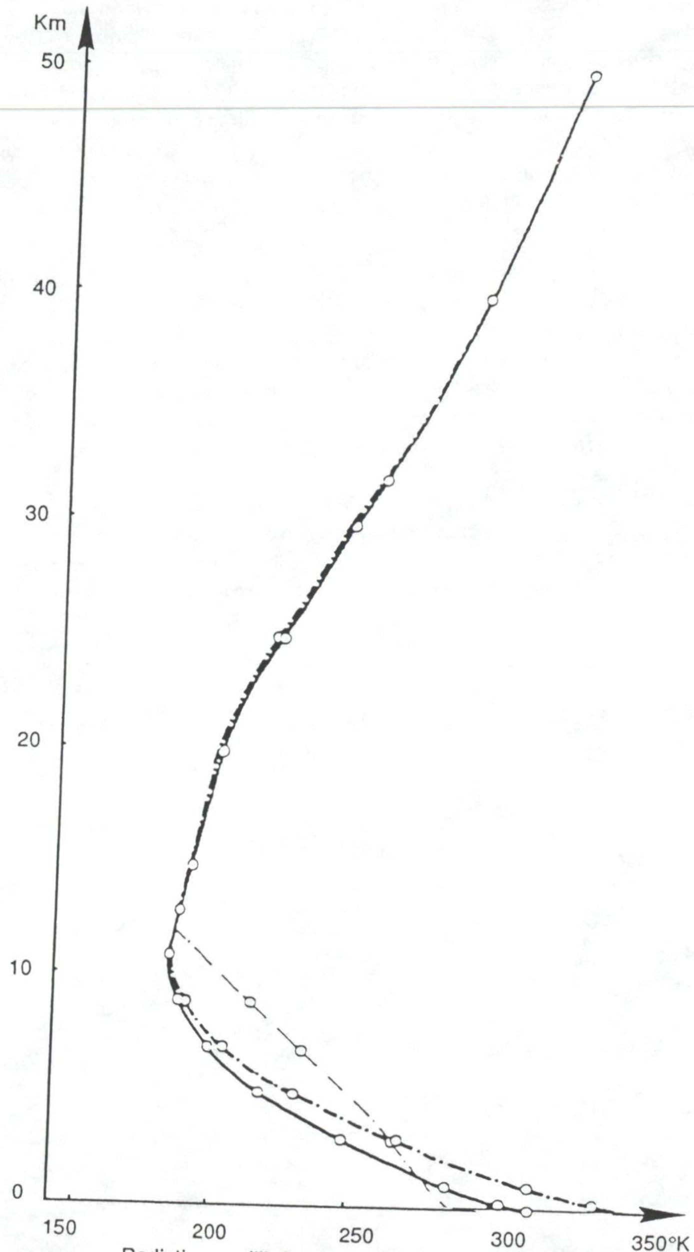
Schneider, E.S. (1977) Axially symmetric steady state models of the basic state of instability and climate studies. Part II: Nonlinear calculations. *J. Atmos. Sci.*, 34, 280-296.

Schneider, E.S. and R.S. Lindzen (1977) Axially symmetric steady state models of the basic state of instability and climate studies. Part I: Linearized calculations. *J. Atmos. Sci.*, 34, 253-279.

Stone, P.H. (1978) Baroclinic adjustment. *J. Atmos. Sci.*, 35, 561-571.

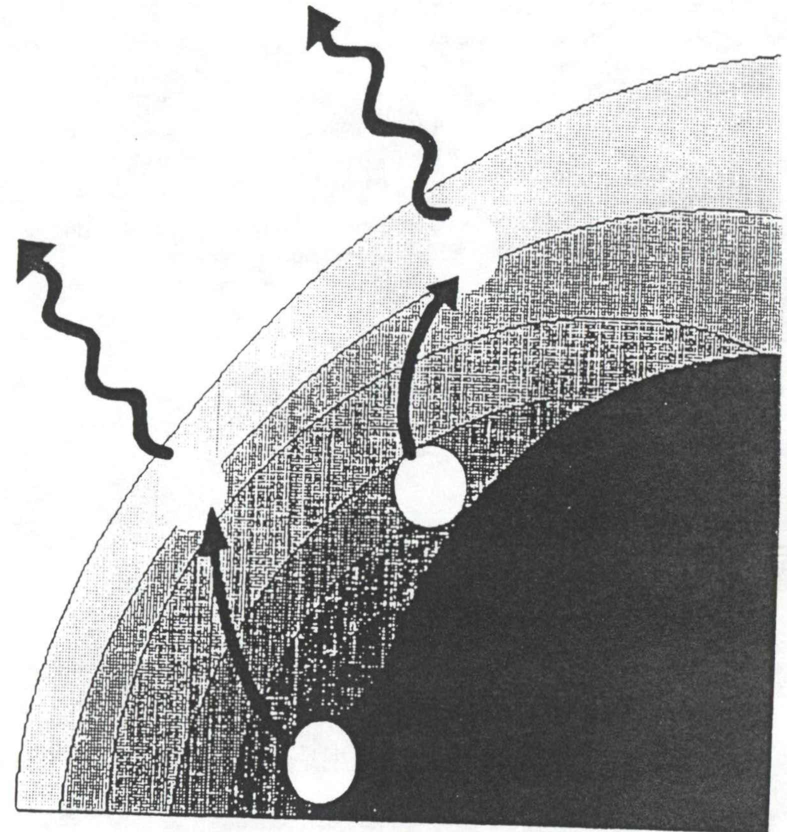
FIGURE 1: A SIMPLIFIED DIAGRAM ILLUSTRATING THE GREENHOUSE EFFECT





Radiative equilibrium in the earth's atmosphere.

After Moller and Manabe (1961). (a) —O— Calculations for clear skies.(b) -•—•— Calculations for 6/10 cloudiness. (c)-O—•- Moistadiabat with same heat content as (b). Conditions correspond to the yearly mean at latitude 40° and a mean $\xi_{\odot}$ = 0.5. Results were obtained by the matrix method.



Infrared opacity is greatest at the ground over the tropics, and diminishes as one goes poleward and upwards. Air currents bodily carry heat to regions of diminished infrared opacity where the heat is radiated to space.

) BUDGET - TRANSPORT PROPOSAL 1/1/91 - 12/31/91

Salaries & Wages	
Post-Doc - 12 months ($2100/month)	$25,200
GRA - 12 months	13,680
1/91 - 6/91:	1110
7/91 - 12/91:	1170
Admin. Asst. - 1 month	2,140
Total Salary	*$41,020*
Employee Benefits On campus rate: .045	16,613
Total Salary& Benefits	*$57,633*
Operating Expenses	
Materials & Services	2,000
Travel	2,000
Total Operating Expenses	4,000
Total Direct Cost	*$61,633*
Overhead: .575	35,439
Total Required	*$97,072*

Funding at this level –subject to inflationary increases will be needed for three years

LARGE SCALE CLIMATE MODELLING

Richard Lindzen
Massachusetts Institute of Technology

Large scale general circulation models are potentially useful tools to study the interactions of a wide variety of simultaneously acting processes. Unfortunately, if the underlying processes are not understood, these models have proven to be poor tools for improving our understanding because of the clumsiness of the models and the complexity of their output (among other problems). Moreover, although current large scale climate models extremely coarse versions of the models used for numerical weather forecasting (and the weather forecasting models have numerous shortcomings –though they have been improving). The reason for using coarse models for climate studies is economic: climate models must run for much longer periods than forecasting models. It is sometimes argued that climate models can deal with the atmosphere more coarsely because they are only concerned with long term averages. Unfortunately, the relevant atmospheric processes involved in climate are the same processes involved in weather; there is, therefore, no basis for this wishful thinking.

In view of the above, it is clear that climate models are not yet the tools we need. Nonetheless, it is generally believed that they will eventually be what we need for comprehensive studies of the full effects of climatic forcing. Given the effort that is needed to develop such models, it can be argued that they should be developed in anticipation of our improved understanding of the individual processes and selective interactions[1]. However, it is clear that any such development must involve the close and continuous interaction of theoreticians, observational analysts, experienced modelers, numerical analysts, and even computer designers. These interactions are not to be found in any existing climate modelling effort. M.I.T., in collaboration with the Lincoln Laboratories, is in a unique position to develop such a synergistic effort. It would, however, be expensive. I estimate the cost to be in the range of $5-20 million per year. We are already taking preliminary steps toward setting up such an effort. If there is interest in supporting an effort at this level, we would be glad to prepare a detailed proposal.

[1] It should be noted that only one of the models currently used for climate studies was developed from 'scratch'. This is the GFDL model which is almost twenty years old. All the other models were ported from other groups. Thus, The GISS model is an elaborated version of Arakawa's old 3-level model. Oregon uses the Arakawa-Mintz 2-level model. The NCAR Community Climate Model was imported from Australia, although it originated at GFDL.

GLOBAL CHANGE AND THE PRODUCTIVITY OF RANGELANDS

Herman Mayeux, Hyrum B. Johnson and H. Wayne Polley
U.S. Department of Agriculture
Agricultural Research Services
Temple, TX

The Earth's surface consists of 51% rangeland and permanent pasture (including grazed open forest), 21% closed forest, 11% cropland, and 17% barren and urban lands. Range and pasture cover 55% of the U.S. and 80% of the Western states. Almost 1 billion acres of rangeland and pastureland in the U.S. provide a variety of "goods and services," generating about 55% of total farm cash receipts, including almost $80 billion annually from livestock products alone. It is difficult to place a value on other products, like clean water and recreational opportunities from rangelands, but their value is considerable. Potential effects of global change on range and pasture are equally as important as those on agronomic crops and forests.

The CO_2 concentration of the atmosphere has increased by about 30% in the last two centuries and may increase to twice the current level sometime in the next century. Fixation of carbon from atmospheric CO_2 by plants through the process of photosynthesis is the basic source of energy and biomass accumulation, supporting all food chains on earth. Recent and on-going research at numerous locations indicates that several biological effects of continued increases in atmospheric CO_2 operate in concert to enhance the productivity of vegetation, even in the event of global warming (Cure and Acock, 1986). These physiological effects include increased photosynthetic rates (carbon assimilation) and quantum yield (the efficiency of light energy conversion by plants), reduced rates of respiration (metabolic carbon loss) and transpiration of water (Gates et al., 1983, Pearcy and Bjorkman, 1983), and amelioration of the limitations imposed upon growth by stress (Idso, 1989). Comparisons of plant growth in atmospheres with current and future CO_2 levels demonstrate that these physiological effects will be reflected in improved plant performance, including increased biomass and ultimate size of individual plants, numbers of leaves, stems, and branches, increased leaf area and leaf thickness, and delayed senescence. Timing and output of reproductive processes may also be accelerated at higher CO_2 levels.

Potential increases in the inherent productivity of crops (Kimball, 1983) and native vegetation (Oechel and Strain, 1985) have been predicted as a consequence of increasing CO_2. In natural ecosystems like rangelands, shifts in species composition have also been predicted (Bazzaz, 1990, Patterson and Flint, 1990). These effects have important implications concerning management and the use of vegetation resources.

Of critical importance to the understanding of the nature of the effects of global change on natural vegetation is the general finding that plants with the C3 photosynthetic pathway are relatively more favored by additional atmospheric CO_2 than are those with the C4 pathway (Pearcy and Bjorkman, 1983). The implications of this difference are of concern because vast areas of Western rangeland are dominated by C3 shrubs or C4 warm-season grasses. Either C3 or C4 grasses are grown in permanent perennial pastures, with C3 grasses predominating in the West and C4 grasses more common in the East. Plants seeded in annual grass and legume pastures are predominantly C3.

The response of C3 herbs to increasing CO_2 over ranges that are now subambient and representative of the recent past can be dramatic. In a recent experiment in our lab, oats (Avena sativa) and wild mustard (Brassica kaber) were grown in a continuous CO_2 gradient from 150 ppm to current ambient, about 350 ppm. Over the range of increasing CO_2 from 250 to 350 ppm, representative of the change in the last 150 years, net carbon assimilation of both species increased by over 50%. Leaf area and oven-dry weight of topgrowth increased by the same extent or more, indicating that historical changes in CO_2 may have had profound effects on the growth of C3 herbs.

At least four recent references suggest that increasing CO_2 has already begun to influence productivity of forests. For instance, after a thorough analysis of annual growth rings of two species of pine trees, LaMarche et al. (1984) concluded that "greatly increased tree growth rates observed since the mid 19th century exceed those expected from climatic trends but are consistent in magnitude with global trends in CO_2, especially in recent decades." Historic increases in wheat (Gifford, 1979) and soybean (Allen et al., 1987) yields may be partly due to CO_2 increases already experienced.

Clearly, research underway at several locations successfully addresses the effects of future increases in atmospheric CO_2 on plant physiology and performance, and largely positive effects have been documented. Limited experimental results suggest that the 30% increase in CO_2 may have already impacted plant productivity in positive ways, especially in forests, but the implications of this possibility have not ben considered on extensive agricultural lands not managed intensively, primarily grasslands. As several reviewers have pointed out (i.e. Bazzaz, 1990), our knowledge of plant response to rising CO_2 is limited to studies of crop species and, to a lesser extent, trees grown under highly artificial and controlled conditions. Little is known about the implications for extensively managed agricultural resources, as opposed to intensive agriculture. Similarly, little interest has been evident in the important question of whether the historical increase in CO_2 from about 270 to 350 ppm has influenced the characteristics of native vegetation, despite widespread acceptance of the higher relative sensitivity of plants to changes in CO_2 at levels below current ambient. The development of an understanding of how continued global change will influence the structure and function of natural ecosystems like rangelands is of special interest because of their economic importance. The likelihood that fundamental ecosystem processes will be affected in ways that cannot be predicted based upon curren[t] approaches is large, and the opportunity for identifying future effects by documentin[g] existing responses to the current increase in CO_2 must not be dismissed. Importan[t] native plant and ecosystem responses to increasing CO_2 include:

1. Increased primary productivity associated with higher carbon assimilatio[n] rates and lower respiration rates.
2. Lengthened growing seasons and higher productivity due to increased wate[r] use efficiency, and increased water yields from rangeland watersheds.
3. Amelioration of constraints imposed by stress.
4. Increased importance of mutualistic and symbiotic relationships which enhance productivity, such as rhizobial nitrogen fixation and mycorrhizal infection.
5. Shifts in species composition caused by variation among species in their abilities to respond to increasing CO_2 and resulting differences in competitiv[e] ability and fitness.
6. Increasing biotic carbon storage, with the overall effect of decreasing atmospheric CO_2 levels and ameliorating possible climatic effects, and more site-specific effects such as improvement of soil properties by increasing organi[c] matter content or replenishing soil carbon lost over decades of tillage.

The hypothesis we propose to test is that the productivity of rangelands is increasin[g] because of rising atmospheric CO_2 levels. The primary objective is to determine th[e] extent to which the 30% increase in CO_2 already experienced has had an effect o[n] physiology and performance of important rangeland plants and productivity of plan[t] communities, and has influenced fundamental ecosystem processes. Such information has inherent value and implications for management, but will also provide an additional approach to estimating future effects of rising CO_2, by extrapolation into the future.

Specific Objectives

1. Determine the extent of variation in response to CO_2 among individual species and between the major functional groups of plants represented on rangelands: C3 herbs, C4 herbs, C3 woody species, and succulent CAM species.
2. Quantify the effects of increasing CO_2 on the outcome of competition between species of the same and different functional groups.
3. Identify the physiological mechanisms by which increasing CO_2 increases plant performance and influences competitive ability, and document the manner in which these physiological responses are manifested in whole-plant performance.
4. Test the hypothesis that increasing CO_2 interacts strongly with the responses of plants and plant assemblages to changes in the availability of resources which often limit productivity of rangelands, especially water, nutrients, and light (amelioration of stress).
5. Assess the extent of the effect of increasing CO_2 on mutualistic processes such as symbiotic nitrogen fixation and mycorrhizal nutrient capture.
6. Assess the extent and implications of increased biotic carbon storage in biomass and soils associated with increasing carbon assimilation and root production and decreasing respiration.

Plants will be exposed to atmospheres of varying CO_2 concentration in two ways, each with distinct advantages and applications. In both, however, plants will be exposed to CO_2 levels which range from well below to above current ambient.

Plants will be grown in three air-conditioned glasshouses with daytime atmospheric CO_2 concentrations maintained near 200, 350, and 500 ppm. This will allow replicated experiments in large pots, mostly addressing objectives 1, 2, and 3. The sub-ambient treatment will be created by maintaining high leaf area of actively photo-synthesizing plants ("sinks") in addition to those included in experiments, as has been accomplished in a chamber at Temple, as described below.

The second approach is unique in that plants are grown along a continuous gradient of CO_2 concentration from below pre-industrial levels (200 ppm) through current ambient to that of the future, providing a CO_2 treatment series representative of the real world as opposed to the large, single-step incremental increases of the glasshouse approach. The gradient is established and maintained by photosynthetic depletion of CO_2 in air moved slowly through elongated growth chambers by a blower. CO_2 concentration at the high end is determined by that of the CO_2 enriched air provided to the entrance to the chamber, and at the lower end by varying the rate of air flow to increase or decrease the extent of photosynthetic CO_2 assimilation. Air flow rate is automatically varied by algorithms in microloggers, which alter the voltage applied to the DC fan motor, based upon the difference in observed and intended CO_2 concentration at the low end of the chamber gradient and instantaneous photon flux density. Temperature and humidity gradients are controlled by passing the chamber air through chilled-water cooling coils to set to the desired dew point and resistance heating coils at appropriate intervals. The feasibility of this approach has been demonstrated by operation of a 39-m long prototype within a glasshouse during the last two years. Placing such systems outdoors offers several advantages relative to those operated indoors, such as more representative light regimes, larger effective plot areas, and more realistic soil volumes for plant growth, perhaps eliminating the possibly spurious acclimation of plants to elevated CO_2 sometimes noted under less natural conditions.

Two such chambers, each almost 100 m long, will be constructed outdoors on ARS-owned land at the Temple Lab. Effective width of the soil surface beneath the chambers will be 1m and the chambers' height will be increased over time to accomodate increasing height of the enclosed vegetation. The site is a native tall-grass prairie with representative herbaceous vegetation. The chamber will be formed by polyethylene film secured along both edges to concrete runners set at ground level and supported by a rounded frame, with access clamps provided for sampling soil and plants. One chamber will be placed upon undisturbed soil and vegetation to monitor changes in net primary productivity by species, litter production, phenological development, soil respiration rates, and other gross parameters over time (years). The soil beneath the other chamber will be enriched in 15N and enclosed in successive 1-m^3 water-tight containers to facilitate control of resource availability in studies of competition and stress effects. Clear acrylic tubes 4 cm in diameter will be installed to a depth of 3m in the soil beneath the chamber on undisturbed soil and to 1 m beneath the other chamber for measurement of water content by neutron attenuation and for video monitoring of root growth.

Physiological plant responses will be monitored by porometric methods and wh plant performance by conventional methods such as non-destructive photoelect estimation of leaf area accumulation and destructive determination of end-of-seas standing crop. Water use efficiency will be calculated at both the leaf and pla assemblage level in the chamber placed on disturbed, containerized soils, and in bo chambers using recently developed stable isotope technology.

REFERENCES

Allen, L.H., Jr., K.J. Boote, J.W. Jones, P.H. Jones, R.R. Valle, B. Acock, H.H. Roge and R.C. Dahlman. 1987. Response of vegetation to rising carbon dioxid Photosynthesis, biomass, and seed yield of soybean. *Global Biogeochem. Cycles* 1:1-1

Bazzaz, F.A. 1990. The response of natural ecosystems to the rising global CO_2 level *Ann. Rev. Ecol. Syst.* 21:167-196.

Cure, J.D. and B. Acock. 1986. Crop responses to carbon dioxide doubling: literature survey. *Agric. For. Meteorol.* 38:127-145.

Gates, D.M., B.R. Strain, and J.A. Weber. 1983. Ecophysiological effects of changin atmospheric CO_2 concentration. Pages 503-526 in O.L. Lange, P.S. Nobel, C.I Osmond, and H. Ziegler, Eds. *Physiological Plant Ecology IV, Encyclopedia of Pla Physiology*. New Series, Vol. 12D., Springer-Verlag, Berlin.

Gifford, R.M. 1979. Growth and yield of CO_2-enriched wheat under water-limite conditions. *Aust. J. Plant Physiol.* 6:367-378.

Idso, S.B. 1989. *Carbon Dioxide and Global Change: Earth in Transition*. Inst. fo Biospheric Res. Press, Tempe, AZ. 292pp.

Kimball, B.A. 1983. Carbon dioxide and agriculture - an analysis of 770 prio observations. U.S. Dept. Agric., Agric. Res. Serv., Water Conserv. Lab. Rep. 14. Phoenix, AZ.

LaMarche, V.C., D.A. Gray, H.C. Fritts, and M.R. Rose. 1984. Increasing atmospheric carbon dioxide: Tree ring evidence for growth enhancement in natural vegetation. *Science* 225:1019-1021.

Oechel, W.C., and B.R. Strain. 1985. Native species responses to increased atmospheric carbon dioxide concentration. Pages 118-154 in B.R. Strain and J.D. Cure, Eds. *Direct Effects of Increasing Carbon Dioxide on Vegetation*. U.S. Dept. of Energy, Washington, DC., DOE/OE-0238.

Patterson, D.T. and E.P. Flint. 1990. Implications of increasing carbon dioxide and climate change for plant communities and competition in natural and managed ecosystems. Pages 83-110 in B.A. Kimball, N.J. Rosenberg, and L.H. Allen, Jr., Eds. *Impact of Carbon Dioxide, Trace Gases, and Climate Change on Global Agriculture.* Amer. Soc. Agron. Special Pub. No. 53.

Pearcy, R.W. and O. Bjorkman. 1983. Physiological effects. Pages 65-105 in E.R. Lemon, Ed. *CO_2 and Plants: The Response of Plants to Rising Levels of Atmospheric Carbon Dioxide*. Amer. Assoc. Advan. Sci. Select. Symp. No. 84. Westview Press, Boulder, CO.

	Year 1	Year 2	Year 3	Year 4	Total
Equipment					
3 water chillers	$60,000	–	–	–	$60,000
Resistance heaters	6,400	–	–	–	6,400
Air handling system	2,500	–	–	–	2,500
3 PC's	13,200		–	–	13,200
4 microloggers	21,000			–	21,000
9 hygrometers	10,200				10,200
4 PAR sensors	900				900
3 IRGA's	19,000				19,000
CO_2 metering system	3,000				3,000
Ass't electronics	3,000				3,000
Air pumps	800				800
Circulating fans	1,800				1,800
Irrigation system	1,000				1,000
3 sequential samplers	5,000				5,000
Neutron meter	4,800				4,800
Heating, cooling coils	6,000				6,000
Construction					
Equipt. building	10,000	–	–	–	10,000
Soil compartments	4,500	–	–		4,500
Poly. Support	2,200	–			2,200
Expendable supplies					
CO_2	4,000	4,000	4,000	4,000	16,000
Polyethelene film	1,200	1,200	1,200	1,200	4,800
Misc.	3,000	3,000	3,000	3,000	12,000
Misc.					
Stable isotopes	20,000	–	–	–	20,000
Isotope analysis	–	10,000	10,000	10,000	30,000
Subtotals	**203,500**	**18,200**	**18,200**	**18,200**	**258,100**
Salaries (temp.)					
Electronics tech.	27,000	28,808	29,960	31,158	117,626
Biol. technicians	44,600	46,348	48,240	50,170	189,394
Post doc.	33,500	34,840	36,234	37,683	142,257
Total Salaries	105,800	110,032	114,434	119,011	449,277
Grand Totals	**309,300**	**128,232**	**132,634**	**137,211**	**707,377**

GLOBAL AND HEMISPHERIC VERIFICATION OF CURRENT GENERAL CIRCULATION MODELS

Patrick J. Michaels
University of Virginia

General Circulation Models (GCMs) have been used for approximately 15 years as tools to estimate the spatial and temporal changes in climate that might be expected to result from human alterations of the atmosphere. While it is generally acknowl- edged that they are currently inadequate for estimation of local climatic changes, it is thought that their global estimates should be given some credence. In fact, it those estimates that have served as the primary scientific basis for many of the draconian solutions now proposed to prevent global warming. I believe it is safe to say that if these models did not exist, we would not see the current level of political activity directed towards human greenhouse effect alterations.

The five popularly used models, in their mid-1980's iteration, produced a mean global warming for doubled CO_2 of 4.2°C. This seems not much different than the 19th century calculations of Arrhenius, which projected a net global warming of ap- proximately 5°, and this correspondence is often cited as an argument for the robustness of the projections.

CO_2 is not the only anthropogenerated emission that increases infrared absorption ir the lower atmosphere. Others include Methane, Nitrous Oxide, and the Chloroflou rocarbons. The effects of the non-CO_2 species can be expressed radiatively as if the were CO_2, and the resultant effective concentration in the atmosphre is nov approximately 420ppm. Measured background values (i.e. prior to industrialization are 260-279ppm. Thus *we have already gone half-way to an effective doubling of the pr industrial CO_2 concentration*.

While it is customary to present the history of global temperature in the last 100 yea as "at least not contradictory to" projections, those models produce an expecte equilibrium warming for this trace gas change of approximately 2.5°C, while a leas squares fit of the entire global data set of Jones and Wigley gives a rise of 0.45°C durir that period. Further, most of the warming has been in the southern hemisphere, whi virtually all of the warming of the northern hemisphere was prior to the major postw emission of the trace gases.

In fact, the southern hemisphere should warm up least and slowest, because its surfa is almost entirely water. Yet even using liberal estimates of the length of time that t oceans should retard the warming still sugests that the hemisphere should ha warmed up over a degree (primarily after 1950), and the observed net warming in tl period is 0.25°C.

One is then left with the proposition if in fact the models are correct, then measured temperature must be in error. While this logic seems preposterous or surface, there are in fact several problems associated with surface tempera measurement that make the global records somewhat dubious, although most of measurement biases would probably tend towards falsely warm records than fal cold ones.

The most reliable record is the U.S. Historical Climate Network record of Karl, which shows no net warming over the last 100 years. However, it does show that night temperatures are rising while day values are declining. This is consistent with a world in which the traces gases *and* clouds increase simultaneously.

Thus, if GCM's only account for increases in infrared absorbing trace gases and either inadequately calculate clouds, or do not include other emissions (such as SO_2) that can increase cloudiness, they may in fact be failing in their *global* projections; this proposal is designed to provide a simple test of that hypothesis.

One of the many output variables from GCM's are seasonal sea level pressure (SLP) anomalies that develop as the infrared forcing increases in transient models. It is the changes in the magnitude and the frequency these air masses that in fact creates the changes in day-to-day weather that drive some of the more apocalyptic notions of future climate.

SLP integrates most of the changes in other atmospheric state variables that occurs in these models. Statistical techniques of multivariate analysis—particularly certain types of factor analyses—can be used to define the eigenvectors of these changes, on both seasonal and hemispheric scales. These eigenvectors conveniently and economically represent the overall changes in the atmosphere that would be expected as a result of the trace gas alterations. A combination of the most important ones explains most of the expected changes in atmospheric behavior. The value of this combination changes as the modelled atmosphere changes.

Since 1950 there has been a considerable increase in the infrared forcing from the greenhouse gases—equivalent to a 70ppm increase in CO_2. This gives an effective rise of approximately 1% per year, similar to that modelled in GCMs of the National Center for Atmospheric Research and NASA. These models, called "transients" because the increase in trace gas forcing is realistic (rather than the "shock doublings") used in most other models) will show some systematic change in the major eigenvectors of SLP.

An excellent record of global SLP also exists, and pressure data suffers from very few of the confounding effects that may compromise temeperature records, such as the urban heat island effect. An analogous calculation of its eigenvectors and their behavior since 1950 can easily be made. We will then compare the temporal history of this record to that of the GCM sea level pressure eigenvectors.

It is our prior working hypothesis that the GCMs indicate that the SLP eigenvectors should now be signifcantly different than they were 40 years ago, and that the observed SLP eigenvectors in fact will not be different than they were in the 1950's, or that many of the changes may in fact be opposite in direction to those predicted by GCMs.

The implication is that the GCMs are not only failing locally (which is generally conceded), but that in fact they are failing globally. If this is true, then their use as one of the pillars supporting the policy edifice is inappropriate.

While we suspect that this objective quantitative analysis will in fact show that these models are inappropriate to support policy, our results can also be used to help improve the same models by specifying their areas of failure. It is our prior hypothesis that the major areas where improvement will be required will be in model calculated temperature changes at high latitudes in winter–precisely the temperatures expected to change the most by these models. In the Northern Hemisphere, this may be the warming that could be reduced by cloudiness. If cloudiness is the cause, then the daytime temperatures will warm very little. Daytime and summer temperatures, of course, are the primary driving variables for the apocalyptic greenhouse scenarios.

BUDGET

Length of Project:	Two Years
Cost (including overhead and fringe):	$100,000/year
Expenses:	1.0 FTE Professional Climatologist Computational Equipment and Time Data Acquisition
Total Expenses:	*$200,000*

PRE-PROPOSAL FOR ESTABLISHMENT OF GLOBAL DATA BASE AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Reginald E. Newell
Massachusetts Institute of Technology

INTRODUCTION

It is proposed to set up a Global Data Base (GDB) at MIT which will include parameters which are relevant to the global warming issue.

The data selected would be used to address the following main questions:

1) Has there been a global warming in the last 150 years or is the observed temperature record simply reflecting normal climatic fluctuations?
2) If global warming has occurred is it related in any way to the observed increase in atmospheric CO_2?
3) If there is no significant evidence for a global warming what are the physical factors controlling the observed fluctuations?
4) Have changes in the atmospheric water cycle, which dominates the atmospheric energy budget, occurred in this period? Have changes in other components of the energy budget occurred?
5) What are the mechanisms by which atmospheric CO_2 or H_2O, or both, influence the energy budget?
6) How are changes at the earth's surface, both land and ocean, related to free air circulation, temperature and moisture changes and to changes in the radiative fluxes both through and at the top of the atmosphere?
7) What are the best values for the meridional energy fluxes by the atmosphere and the ocean and what can be said about their variability?

The GDB would be open to international visitors. Data sets would be interchanged with those in other Data Centers either by CD-ROM or by direct computer linkages. The sets could be used by all modeling groups including one planned at MIT's Center for Global Change.

COMPONENTS BY QUESTION

1) There are presently four data sets being used to study this question: a collection of land data by Bradley et al. (1985); a collection of land data by Hansen and Lebedeff (1987); a collection of ship's reports which has been used to produce the Global Ocean Surface Temperature Atlas (GOSTA), a joint project of MIT and the UK Meteorological Office (Bottomley et al., 1990); and a set of marine data - the Comprehensive Ocean-Atmosphere Data Set (COADS) (Shultz et al., 1985; Oort et al., 1987). The first step here would be to combine the COADS and GOSTA data sets and to add all other available data, for example that from whaling ships. As is obvious from a video of GOSTA there are a significant number of gaps in the coverage. The second step would be to re-evaluate the corrections applied to buckets used for sea surface temperature measurements before 1920; experiments are now taking place with the Woods Hole Sea Educational Association students and ships. The third step would be to reconstruct a chronology of surface temperatures over the ocean from 1856 to the present, then develop various criteria to study the significance of the changes.

2) When atmospheric CO_2 is doubled, infrared radiation at the ground increases by about 2 Wm^{-2}. There is considerable uncertainty regarding the fate of this additional radiation: over the tropical ocean it has been suggested that much of this energy goes into evaporation so that essentially no temperature change occurs whereas over land, particularly dry land, a temperature increase would be expected (Newell and Dopplick, 1979). The sensitivities of these two regions are thought to be about 30 $Wm^{-2}K^{-1}$ and 1 $Wm^{-2}K^{-1}$ respectively so it is important to examine the geographical distribution of surface temperature and surface moisture changes (see also Idso, 1980). Moisture analyses must therefore be added to the data collected in item 1.

3) Some of the pertinent physical factors studies recently by Wu et al. (1990) are solar irradiance, atmospheric turbidity and the Southern Oscillation Index, a measure of pressure field perturbations in the tropical Pacific. Data on the first is now being accumulated from satellite observations and can be obtained. Turbidity has been deduced from sunshine records. A major effort is required to improve the data base before 1920 as only a few sunshine records have been converted to turbidity from that period. Other approaches need to be explored.

4) Probably the most reliable component of the water cycle that can be monitored for a long period is the surface specific humidity, measured using wet and dry bulb thermometers, and available for both land and sea. This would be a major new dataset compilation performed as part of the GDB. An attempt would also be made to collect and examine data for the computation of evaporation from both land and sea; interannual variations can be computed for the ocean back to 1940. Precipitation is difficult to estimate at sea and can only be deduced from satellite data for the past 20 years. Free air moisture values would also be collected. Any changes in these would influence infrared radiative fluxes, a point stressed by Doherty and Newell (1984), Ellsaesser (1984) and Lindzen (1990).

5) In order to calculate the terms in the atmospheric energy budget values of free air temperature, moisture, and wind velocity are required as a function of pressure. These are only available from about 1950 onwards. Values of radiative fluxes and cooling rates can be computed from observations of temperature, moisture and cloudiness. The top-of-the atmosphere fluxes can be checked with satellite observations. The generation of zonal and eddy available potential energy can be examined for variations of moisture, temperature and cloudiness such as those that occur during El Nino events. For these budget daily values are necessary; they can be obtained from NOAA from 1980 only.

6) Much of the data necessary to answer question 6 will have been collected for question 5. Satellite measurements of air temperature and cloudiness and detailed marine data to compute sea-air energy transfer will also be needed. An analyzed set of cloud data, the International Satellite Cloud Climatology Project (ISCCP), has been prepared under WMO auspices (Schiffer and Rossow, 1985) and we would obtain copies of this set.

7) An additional data set necessary to recompute the meridional oceanic energy flux is the Master Oceanic Observations Data Set (MOODS update 5) (see Hsiung et al., 1989). Atmospheric energy flux can be computed from data available under question 5. At present different techniques give oceanic fluxes which differ by a factor of two (Newell and Hsiung, 1990).

Once these data sets are collected they will be kept up-to-date in real time so that continuous assessments may be made of the mass, moisture, energy and momentum budgets.

PERSONNEL

PI for the GDB project would be Professor Reginald E. Newell. In addition to 130 publications concerned with the atmosphere and ocean he has compiled a set of general circulation statistics into a monograph on Tropical General Circulation (Newell et al. 1972, 1974), initiated the joint MIT-UK Met Office project that resulted GOSTA, and has supervised over 50 graduate theses. A Research Associate would be appointed to manage GDB and there would be a programmer, two graduate students and two undergraduates under MIT's Undergraduate Research Opportunities Program (UROP). In addition after the first year a Visiting Scientist program, limited to 9 month periods, would be instituted.

REFERENCES

Bottomley, M., C.K. Folland, J. Hsiung, R.E. Newell and D.E. Parker, Global Ocean Surface Temperature Atlas "GOSTA", U.K. Met. Office, 20 pp. and 313 plates, 1990.

Bradley, R.S., et al., A Climatic Data Bank for Northern Hemisphere Land Areas 1851-1980, TR017 U.S. Dept. of Energy, Washington, D.C., 335 pp., 1985.

Doherty, G.M. and R.E. Newell, Radiative effects of changing atmospheric water vapor, *Tellus*, 36B, 149-162, 1984.

Ellsaesser, H.W., The climatic effect of CO_2: a different view, *Atmospheric Environment*, 18, 431-434, 1984.

Hansen, J.E., and S. Lebedeff, Global trends of measured surface air temperatures, *J. Geophys. Res.*, 92, 13345-13372, 1987

Hsiung, J., R.E. Newell, and T. Houghtby, The annual cycle of oceanic heat storage and oceanic meridional heat transport, *Quart. J. R. Meteor. Soc.*, 115, 1-28, 1989.

Idso, S.B., The climatological significance of a doubling of earth's atmospheric carbon dioxide concentration, *Science*, 207, 1462-1463, 1980.

Lindzen, R.S., Some coolness concerning global warming, *Bulletin Amer. Meteor. Soc.*, 71, 288-299, 1990.

Newell, R.E. and T.G. Dopplick, Questions concerning the possible influence of anthropogenic CO_2 on atmospheric temperature, *J. Appl. Meteor.*, 18, 822-825, 1979.

Newell, R.E. and J. Hsiung, Recent oceanic meridional flux estimates and their relationship with temperature gradients, *J. Phys. Ocean.*, 20, 483-486, 1990.

Newell, R.E., J.W. Kidson, D.G. Vincent, and G.J. Boer, *The General Circulation of the Tropical Atmosphere and Interactions With Extratropical Latitudes*, Vol. I, 258 pp, and Vol. II, 371 pp., MIT Press, 1972 and 1974.

Oort, A.H., Y.H. Pan, R.W. Reynolds and C.F. Ropelewski, Historical trends in the surface temperature over the ocean based on COADS, *Clim. Dyn.*, 2, 29-39, 1987.

Schiffer, R.A. and W.B. Rossow, ISCCP Global Radiance Data Set: A new resource for climate research, *Bull. Amer. Meteor. Soc.*, 66, 1498-1505, 1985.

Slutz, R.J. and seven others, COADS Release 1, ERL, Boulder, Colorado, 1985.

Wu, Z-X., R.E. Newell, and J. Jsiung, Possible factors controlling global marine temperature variations over the past centruy, *J. Geophys. Res.*, 95, 11799-11810, 1990.

ET (IN K$)

Salaries and Wages	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Total*
Total Sal. & Wages plus Fringe Benefits	191	264	274	286	299	1,314
Total Operating Expenses	23	24	25	25	24	121
Equipment (Computers)	60					
Total Direct Costs	274	288	299	311	323	1,495
Overhead Minus Equip. and UROP Student	121	163	169	176	183	812
Total Expenses	395	451	469	487	505	2,307

Computer purchase. It is proposed to purchase two SUN SPARC stations, a CD-ROM optical disc reader, Pinnace-Microsystem optical disc read-write and peripherals which [illegible] $60,000.

Preproposal for a Center to Model Atmosphere-Ocean Ecosystem Interactions

Roger A. Pielke
Colorado State University

Introduction

Current GCM models have provided useful insight into the physical mechanisms associated with the general circulation of the earth. Unfortunately, several significant physical processes have not been adequately represented up to the present in using GCMs to investigate natural and potential man-caused climate change. These include the two way interaction between the biosphere and the atmosphere, the influence of anthropogenic aerosols on cloud radiative and dynamic processes, and the generation of atmospheric circulations due to spatial and temporal variations in landscape.

To properly represent these features, as well as other features of the general circulation (such as extratropical cyclone development, mesoscale atmospheric and oceanographic circulation) also requires better spatial resolution than achieved in current GCMs (Pielke et al., 1988; Pielke, 1990; and Pielke and Kittel, 1988). Existing evidence suggests that horizontal grid intervals on the order of 10-30 km (with sufficient vertical resolution –~50 levels in the lower troposphere) may be sufficient to explicitly spatially resolve the dominant energy containing motions in the atmosphere-biosphere-ocean interactions, with smaller spatial scales parameterized using one-dimensional model frameworks.

Coupled Model

Atmospheric Model

If horizontal grid intervals of 10 km with 50 vertical levels are assumed to be necessary in order to properly simulate the general circulation, approximately 5 x 108 grid points would be required to resolve the entire globe. Until recently, this computational requirement was not perceived to be possible in the near term (less than 10 years). Teraflop calculation speeds and gigabyte memory are required. Massively parallel supercomputer structure such as proposed in the IBM VULCAN could, however, provide these capabilities (e.g., see also Walatka, 1990).

Ocean Model

Oceanographic models have grid point data requirements on a global scale which are on the same order as the atmospheric models. Coupling with the atmosphere is achieved at the ocean surface through the turbulent heat, moisture, and momentum fluxes and from rain and snowfall.

Ecosystem model

The total number of grid points used to characterize the ecosystem using ecosystem species composition models is unclear (since we do not yet know the spatial structure of the current landscape), but is expected to be less than that of the atmospheric and ocean models. Ocean ecosystem models (to include phytoplankton effects) also need to be implemented. Coupling with the atmosphere would be achieved through the fluxes of heat, moisture, trace gases and momentum and from long-wave and short-wave radiative flux effects.

Coupling in time

Since the atmospheric time scales are typically much more rapid than for the ocean and ecosystem, we will explore efficient algorithms to update ocean and ecosystem conditions with time scales which are long compared with the atmosphere modeling.

Summary and Budget

This brief write-up is a preproposal and a more detailed write-up is necessary in order to elaborate on the broad general statements given above. We hope that the opportunity to create such an atmosphere-ocean-ecosystem coupled model using massively parallel supercomputers is recognized.

The cost to create this Center would be on the order of 3 million dollars per year for a ten year period plus the initial procurement of a massively parallel system (e.g. such as the IBM VULCAN and data storage devices). We would need about 5 investigators in each of the three descriptive areas plus several programmers and other support staff. The Center would be housed at Colorado State University, but would involve a range of investigators from other research groups.

Pielke, R.A., 1988: Evaluation of climate change using numerical models. In "Monitoring Climate for the Effects of Increasing Greenhouse Gas Concentrations. Proceedings of a Workshop". R.A. Pielke and T. Kittel, Eds., Cooperative Institute for Research inthe Atmosphere (CIRA), Fort Collins, Colorado, August 1987, 161-172.

Pielke, R.A.., 1990: Overlooked scientific issues in assessing hypothesized greenhouse gas warming. *Proceedings, 1990 Electric Utility Business Environment Conference and Exhibition*, Denver, Colorado. March 7-9, 1990, 199-208.

Pielke, R.A. and T. Kittel, Editors, 1988: *Monitoring climate for the effects of increasing greenhouse gas concentrations*. A Compendium of Papers Presented at a Workshop Sponsored by the Cooperative Institute for Research in the Atmosphere, Fort Collins, Colorado, August 26-28, 1987.

Walatka, P.P., 1990: Microprocessors compete with fastest supercomputers *U/NAS/ NEWS (The Numerical AerodynamicsSimulation Program Newsletter)*, NAS Systems Division of NASA Ames Research Center, 5 (9), September, 1990.

Direct Effects of an Increase in Atmospheric Carbon Dioxide

W.E. Reifsnyder
Yale University

)N

Atmospheric carbon dioxide concentrations have increased approximately 25% in the past century. Current estimates of CO_2 emissions in the future indicate that current concentrations may double by the year 2090 (Houghton et. al 1990). By that time, increase in other greenhouse gases may yield an equivalent greenhouse gas concentration about four times the present value.

Laboratory and field experiments indicate substantial increases in growth by plan exposed to elevated carbon dioxide concentrations. However, relatively litt information is available on the combined effects of carbon dioxide enrichment an concomitant changes in climate. Such information is necessary for realistic projectio of agricultural productivity and as input to models of natural systems.

Research projects designed to provide information on these direct and interacti responses of plants include the following:

OBJECTIVE

Expand the Free-Air Carbon dioxide Enrichment (FACE) project to include one more forest tree species and forest ecosystems.

One of the obvious difficulties in carrying out a long-term field project involvi forest trees is that they are perennial and they grow. In ten years time, a plantatio of fast-growing conifers may grow from foot-high seedlings to ten-meter tree Instrumentation to produce and monitor planned carbon dioxide concentratio must be designed to keep up with this growth. In addition, evergreen trees in warn moist regions grow during the entire year, with the requirement that the experime be continued through most if not all of the year. On the other hand, deciduous tre in temperate climates will grow only during that period of the year when they ha leaves.

Requirements for an initial expansion of the FACE project into forest ecosyste include the following: 1) selection of a relatively slow-growing species; 2) a lar mono-culture plantation, either recently established or about to be planted; 3) fl terrain, to minimize topographic effects; and 4) near a commercial source of carbo dioxide.

BUDGET

(Projected cost: $1,000,000 per year for ten years)

OBJECTIVE

Assemble data base of crop and forest yield data for past century (or longer, if possible in areas where "technology" (i.e., cultural practices such as fertilization, changes i irrigation practices, seed source, etc.) can be considered constant. Analyze these dat for changes in yield that can be appropriately associated with atmospheric carbo dioxide increases over the past century.

Interest in the effects of modern technology on the yield of grain crops was stimulate by pioneering work of Thompson (1972). He hypothesized that most of the effect of agriculture research (genetics, fertilization, irrigation, etc.) have been manifeste in farm practice in the United States since about the end of World War II. Prior t that, year-to-year fluctuation in crop yield was supposed to be due primarily to natura climatic fluctuation, with little or no secular change in yield. Since that time, yield have increased dramatically, with this trend superimposed by fluctuating climate.

It can be expected that there are areas of the world where technological change i agriculture practice has been minimal over the past two centuries. Rice culture prio to the "green revolution" may be one of these. a brief reanalysis of the Thompson dat referred to above indicates that prior to 1945 there was a significant linear increas in corn yield consistent with the measured increase in atmospheric carbon dioxid

The growth of unmanaged forest is the result of a large number of exogenous variable such as precipitation amount and distribution; variation in temperature regime; year to-year fluctuation in climate; the vagaries of insect pests, among many others. It is also, of course, dependent on the supply of solar radiation and atmospheric carbon dioxide. Unmanaged forests in any part of the world should show some increase in growth due to carbon dioxide increase, which can be determined through sophisticated ring-width analyses.

Two parallel projects are proposed: one to search for and analyze long-term agricultural yield databases that are relatively unaffected by technology change; and another to explore the possibilities of using dendrochronological data in a search for carbon dioxide effects.

(Projected cost: $100,000 per year for five years)

Expand existing growth-chamber and glasshouse studies on the interaction between carbon dioxide increase and temperature/moisture changes (both increases and decreases).

Estimates of growth enhancement range from 0.5 to 2.0% for each 10 ppm increase in atmospheric CO_2 (Strain and Cure, 1985). Little information is available on the combined effects of increasing carbon dioxide concentration and secular changes in climate on growth and phenology of terrestrial plants. Most speculation on the ecological effects of "greenhouse warming" (and, indeed, "glacial cooling") has ignored the synergistic effects of direct CO_2 increases and secular climate change. However, experiments in controlled environment chambers have generally indicated that concomitant increases in air temperature and CO_2 have enhanced biomass increases resulting from increased CO_2 concentrations alone (Allen 1988). Thus the need is great for information on plant response to various scenarios of CO_2 increase and climate change. Existing projects should be expanded and new projects supported.

(Projected cost: $1,000,000 per year for five years.)

Allen, Jr., L.H. 1988. Plant responses to rising CO_2. *Proceedings of the 79th Annual Meeting of the Air Pollution Control Association*, 22-27 June 1986.

Thompson, L. M., 1969. Weather and technology in the production of corn in the U.S. corn belt. *Agronomy Journal*.; 61. 453-456.

EFFECT OF RAPID CLIMATIC CHANGE ON ECOSYSTEM FUNCTION

W.E. Reifsnyder
Yale University

A major concern of the IPCC Working Group II (IPCC 1990) appears to be that "projected changes in climate will present...ecosystems with a climate warmer than that experienced during their recent evolution and there will be warming at a rate 15-40 times faster than past glacial-interglacial transitions"; and that these changes will cause disruption of ecosystems. (It should be noted that IPCC working groups do not agree on the magnitudes and rates of change. Working Group I indicates that the rate should be more like three times the maximum historical rate). However, these ecosystem response predictions assume that ecosystem change responds to global mean temperature, a patently false assumption: ecosystems respond to the changes that occur in the immediate environment to which they are subjected. Nevertheless, there have been ecosystems that have been subjected to large changes occurring over periods of time ranging from decades to millennia.

Information is potentially available from past records of climate changes and concomitant ecosystem changes that can be analyzed to provide answers to the effects of climate change on ecosystems, both natural and managed. Analyses of this sort are currently available in the published scientific literature. To utilize this information, the following projects are suggested:

OBJECTIVE

Perform microanalyses on climate change since the last glaciation in order to identify regions where climate change has been especially large and rapid.

Current interest in climate change has kindled interest in the historical climate record. Good instrumental records of surface temperature on a world-wide basis exist only from the middle of the last century. A recent compilation of existing data (Boden et al 1990) presents data for the globe from 1850 and for various regions in the United States from 1900. Earlier climates have been inferred using various methodologies.. (See Houghton et al 1990, Chapter 7, for a summary of current knowledge)

Preliminary analysis of data presented in Houghton et al (1990) indicate that there probably have been periods since the last ice age when global mean temperatures increased by approximately 0.1 C per decade for periods of at least a century and perhaps for several centuries. Further analysis of the raw data will refine these estimates.

BUDGET

(Projected cost: $100,000 per year for 5 years)

OBJECTIVE

Analyze existing climate/ecosystem data for information on ecosystem response to relatively rapid secular changes in the significant climatic parameters.

Various methods have been used by paleoecologists to determine ecosystems of the past. Among these are pollen analysis, glacial varve analysis and dendrochronology. These same methods have been used to infer past climates. Indeed, there is an implied circularity of reasoning here; the same data have been used to infer both ecosystem change and climate change. The state of the ecosystem (and its changes over time) is used to infer climate, which is then presumed to be the major cause of the changes in the ecosystem. However, careful and sophisticated analysis may be able to provide enough independent evidence to give confidence in interpreting climate change and ecosystem response in terms of future changes.

At any rate, ferreting out change/response information from the paleological and historical data will provide important clues to likely ecosystem response to possible climate warming. Further research and reinterpretation of existing data should be pursued vigorously.

BUDGET

(Projected cost: $75,000 per year for four years)

Boden, T. A., P. Kanciruk and M. P. Farrell. 1990. *Trends '90. A compendium of data on global change*. ORNL/CDIAC-36. Oak Ridge: Carbon Dioxide Information Analysis Center.

Houghton, J. T., G. T. Jenkins and J. J. Ephraums (editors). *Climate Change. The IPCC scientific assessment.* Cambridge: Cambridge University Press.

SOCIAL/POLITICAL RESPONSE TO PROJECTED THREATS OF "GREENHOUSE" WARMING

W.E. Reifsnyder
Yale University

The phenomenon of massive social and political response to dire–though unsubstantiated–predictions of apocalyptic climate change in unprecedented. In the recent past, society has responded to "real" threats, that is, to observations of happenings in the real world. For example, it was observed that certain forests were dying, apparently the result of an external threat. Research indicated a probable (but not certain) cause, atmospheric contaminants such as sulfur dioxide. Oil spills obviously created havoc, at least in the short term and in localized areas. Various chemicals used by agriculture and industry have been shown to have undesirable effects on animals and humans in certain concentrations. Society has responded to such perceived threats in a variety of ways, political, social, and economic.

In the global warming phenomenon, however, society is responding to a threat produced only in the world of mathematical models. No real world data have been adduced to demonstrate any human, animal or plant response to carbon-dioxide-produced warming. This is a situation that cries out for intensive sociological research: How has society responded to the perceived threat of global warming? What have been societal responses to actual changes in local and regional and global climate? What are the causes of the observed societal responses to the perceived threats? Whether or not the threats materialize, what can we learn from our current responses that will be of value in responding to future real or perceived threats? These are areas ripe for social science research, little of which has been done to the present time.

In addition, society has responded to past climate changes in ways that are still a matter of scientific speculation and controversy. Although it seems obvious that the evolution and development of mankind has been profoundly influenced by the earth's climates and their evolution, it has been difficult to establish specific cause-and-effect relationships.

A number of research projects are suggested to answer some of these questions.

Evaluate societal response to periods of rapid climatic change, based on historical data.

Societies have responded to climate change in a wide variety of ways. Individuals or groups can migrate to escape undesirable or untenable climatic conditions. They can adapt to changing conditions through a variety of mechanisms. For example, they can erect buildings to insulate themselves from an unfavorable conditions; they can invent, develop and install a technology to enable them to survive in a hostile environment. They can develop crops that will thrive under the changed conditions or they can erect glasshouses to permit establishment of a favorable microclimate. Many other strategies exist.

It has been suggested (Calvin, 1990) that the human brain evolved dramatically in response to the need for man to survive the climatic changes implicit in the ice ages and interglacial periods. Calvin suggests that a brain that can function effectively in widely different climates has an adaptive superiority to one that can function effectively in only one climate.

OBJECTIVE

Investigate the response of the world's agricultural system to past climatic change, both short- and long-term.

Modern temperate-zone agriculture has demonstrated a remarkable resiliency and adaptability to rapidly changing social, economic and environmental conditions (NAS 1976). Farmers employ a wide variety of techniques in the attempt to insulate themselves from the vagaries of climate: they switch to plant varieties better adapted to the changing conditions; they plant different crops entirely; they fertilize, irrigate and husband their crops in ways calculated to improve plant response to the changing conditions. In this context, it should be noted that the year-to-year fluctuations in climate are several orders of magnitude greater than the slow secular change of climate proposed in the various climate-warming scenarios.

In order to put the adaptability of agriculture into the context of a potential greenhouse warming, retrospective studies should be made of the responses of the agricultural system to past climatic change and fluctuation, on regional and global scales.

BUDGET

(Projected cost: $100,000 per year for 6 years)

REFERENCES

Calvin, W. H. 1990. *The ascent of mind. Ice ages and the evolutional intelligence*. New York: Bantam Books.

Griffiths, C., G. W. Sheldon and W.J. McG. Tegart (editors). 1990. Potential impacts of climate change. *Report from Working Group II to IPCC*. Intergovernmental Panel of Climate Change.

NAS 1976. *Climate and food. Climatic fluctuation and U.S. agricultural production.* A report of the Committee on Climate and Weather Fluctuations and Agricultural Production, National Research Council. Washington, DC: National Academy of Sciences.

GLOBAL CLIMATE CHANGE-RESEARCH PROPOSAL

S. Fred Singer
Visiting Scholar
National Air and Space Museum

RATURE VARIATION

In the past 100 years the content of greenhouse gases in the atmosphere has been increasing as a result of human activities. Yet there appears to be no discernible warming in the global climate record which could be directly attributed to greenhouse warming. Not only is the temperature increase too small (and at times even negative, for example between 1940 and 1975), but the details of the small general increase do not match what is predicted by model calculations.

This is a puzzling result, since no one doubts that the natural greenhouse exists and has been keeping the earth warm and habitable for billions of years. Three types of explanations are generally put forward to explain the discrepancy — the absence of an observed enhanced greenhouse effect resulting from the enhancement of greenhouse gases:

1. Negative feedbacks from clouds, ocean currents, or water vapor convection not taken into account in the models) are diminishing the greenhouse effect.
2. Natural climate fluctuations are offsetting the expected greenhouse warm ing.
3. The ocean with its large heat capacity is delaying the enhanced warming.

It is important therefore to find and measure specific "fingerprints" of greenhouse warming that would distinguish it from other kinds of warming, say an increase in solar insolation. One place to look for it is in the noctural cooling of a surface with very little overlying water vapor–a high-altitude desert, like the Gobi or Tibet, the Bolivian altiplano, or Mauna Loa, Hawaii. One would expect to find a trend in the nocturnal cooling that could be compared with the simple one-dimensional theory. (See Appendix)

My approach to the project is both experimental and theoretical. Through Nathaniel Guttman (NOAA), I hope to find the existence of records and then, working with appropriate collaborators, analyze them. At the same time, with the collaboration of Michael Schlesinger, I will analyze the results of his model calculations to look for the evidence of increasing nocturnal temperatures.

FECTS OF AEROSOLS (PARTICULATES FROM HUMAN ACTIVITIES

Everyone is familiar with the possibility of enhanced greenhouse effects from fossil fuel burning. But it is important to investigate all possible human activities to determine if they could have long-term consequences on climate change or on stratospheric ozone (See e.g. the stratospheric effects of human-produced methane; S.F. Singer, 1971).

a) Increased SO_2 emissions (Pat Michaels) and increased biomass burning (Joyce Pennen, Paul Crutzen) can increase the number of cloud nuclei, cloudiness, optical albedo — and thereby offset enhanced greenhouse warming.
b) Exhausts of high-altitude aircraft can create a cirrus veil that has a very small optical albedo but a large infrared opacity (See calculations by S.F. Singer 1988). Its net effect could be a substantial greenhouse warming.

Three experimental approaches are contemplated in order to determine the importance of this effect.

1. In situ observations of aircraft exhausts –to be done in collaboration with NASA-Langley.
2. Observation from a surface station with LIDAR –to be done in collaboration with University of Hawaii.
3. Passive observations of infrared sky emissions (from Hawaii) using an IR interferometer.

APPENDIX
GLOBAL WARMING: DIFFERENT CAUSES, DIFFERENT CONSEQUENCES

Global warming –and more generally, global climate change –can be caused by many quite different mechanisms. Currently, greenhouse effects due to CO_2 command the greatest public attention, and are at the heart of international efforts to "stabilize" the climate of the earth. But there are other physical mechanisms that can act in addition– or in opposition to CO_2: Other greenhouse gases, like methane, that would be more difficult to control; changes in the albedo of the earth's surface or atmosphere; long-term changes in ocean circulation or other ocean properties; changes in solar emissions or in the solar "constant".

How can we tell from the climate record which of the many causes have been responsible for the observed changes: And would the effects of a climate change be different for different causes?

The first question is quite controversial, scientifically and otherwise. In examining the global temperature record since 1880 many focus on a reported overall warming of about 0.5°C as evidence for a greenhouse effect (Jim Hansen). Others, focusing instead on the 25-year cooling period from 1940 to 1965, conclude that the greenhouse effect must be small (Hugh Ellsaesser, Patrick Michaels), with other influences on climate predominating: aerosols from volcanism or other sources (Reid Bryson, Paul Handler); astronomical variations (Wally Broecker, P.R. Bell); solar changes (Marshall Institute).

The second question is seldom asked; but there is no reason *a priori* why the same *average* change in global temperature should have the same kinds of consequences. The key point of this discussion is that the usual presentation of the data– as a global, yearly average –hides important information. This point is pretty well accepted when we discuss spatial averaging, as discussed originally by Will Kellogg (1989). After all, it is the regional not the global effects of temperature and precipitation that matter to people, through agriculture and other important human activities.

But temporal averaging also hides important information. For example, super-hot summers, coupled with super-cold winters, produce the same annual average as would a small seasonal variation – but with obviously quite different impacts on ecology and human activities (Michaels, 1990).

Here, however, I want to focus on the diurnal temperature variation and compare two specific mechanisms: 1) greenhouse effects and 2) solar change. I want to show that the consequences can be quite different, and use the result to counteract the glib comparison, and equivalence, often made between a projected greenhouse warming and historic temperature increases that may not be due to greenhouse gases.

1) In previous work on the nuclear winter phenomenon, I have analyzed the warming produced by several greenhouse effects that were ignored in the original publications, including the effects of stratospheric cirrus created by the initial nuclear bursts themselves (preceding the fires that lead to the smoke cloud). One simple test of this hypothesis is to look for a lessened nocturnal cooling of a high-altitude desert surface (Singer, 1988; p. 237) where cooling proceeds mainly by infrared radiation into space. Tom Karl has recently published temperature trends, separating yearly averages for day and night; the data show no daytime trend but a slight nocturnal increase (1989). While this result is not any confirmation of the hypothesis, it does suggest the presence of an enhanced greenhouse effect.

2) On the other hand, if the global warming were produced by an increase in solar radiation, then simple radiation theory would lead one to expect an increase in daytime temperatures, but no increasing trend in nocturnal temperatures for surfaces where energy loss takes place by radiation.

The consequences would be very different too — reducing the diurnal temperature swing in one case, increasing it in the other. In addition:

1) Warmer nights would lengthen the growing season for crops. Coupled with higher than average precipitation and higher CO_2 concentrations, this would benefit agriculture greatly.

2) On the other hand, higher daytime temperatures may damage crops directly, or by reducing soil moisture.

Before proceeding further it is important to test these ideas.

a) We need nocturnal cooling curves for high-altitude deserts, like Tibet or the U.S. southwest, and study their trends as a function of time.

b) We need to extract a diurnal temperature variation from global circulation models. In both spectral and finite-difference models the computational time-steps are quite short, less than an hour; but the diurnal cycle of radiation is averaged over a much longer time, 24 or 12 hours. The surface temperature is averaged over a month, season, or year, although a program could be developed that performs a different averaging. It is important to see, whether a diurnal temperature variation can be extracted from the present GCM runs.

Kellog, W.W. 1989. "Carbon Dioxide and Climate Changes" in *Global Climate Change; Human and Natural Influences* (S.F. Singer, ed.), Paragon House, New York.

Michaels, P. J. 1990: Greenhouse disaster? Submitted to *Science*.

Singer, S.F. 1988. Re-Analysis of the Nuclear Winter Phenomenon. *Meteorol. Atmos. Phys.*, 38, 228-239.

Singer, S. F. 1971. Stratospheric Water Vapor Increase due to Human Activities. *Nature*. 233, 543.

CLIMATIC CHANGES AND WATER RESOURCES

Vujica Yevjevich
Colorado State University

PROJECT NO. 1: Identification of Eventual Climatic Changes by Using River Runoff

The current claims on climatic changes refer to temperature and precipitation. Outputs of climatic models predict the arid areas to become drier (greater temperature and smaller precipitation). Also, the general warming due to the greenhouse effect will melt some permanent snow and ice and raise the ocean level. As the river runoff integrates precipitation and evaporation, it may serve as the monitoring variable on whether the effect of warming increases or decreases the net water budget of a river basin. That is the reason for WMO to attempt to use river flows as an eventual control variable of climatic change. At present, the German Hydrological Service gathers and stores for WMO data on selected river gauging stations from all around the world.

The use of runoff as the monitoring variable faces the basic problem of errors in data: sampling, random, systematic errors, and particularly non-homogeneity caused by versatile human activities and natural disruptions. Monthly values seem to be less reliable than annual runoff. The crucial aspects for the accuracy of eventual corrections for identified non-homogeneity, and selection of most change-discriminating statistical techniques. Figure 1 shows annual runoff series of the Rhine River at Basle, Switzerland, 177 years of data (1808 - 1984), with mean annual values of various periods. It does not show a significant change. Similar results are obtained for annual runoff series of the Gota River in Sweden (with a period as long as the Rhine River) and other rivers in Europe and the USA for periods of instrumentally obtained data of 100 years or more.

Very careful selection of stations, rigorous analysis and correction of data, and the best statistical discrimination of change should be always used in research to substantiate any reliable climatic change.

PROJECT NO. 2: Effects of Eventual Climatic Changes on Water Resources Systems

The world has invested tremendous capital into agriculture productivity, industrial infrastructure and various water resources systems. The economic infrastructure maintains standards of living and supports the modern civilization. The basic question here is how the claimed ongoing of forthcoming climatic changes would affect these systems and infrastructure in general, and water resources in particular?

The arid areas (such as the Great Plains of the United States and the Prairies of Canada) have attained a high level of agriculture productivity. If it comes out to be true that these areas with the climatic change would become much warmer and drier than at present, the agriculture will suffer enormously. The basic question becomes should all nations with arid areas of significant ongoing agriculture production start immediately to plan and implement massive irrigation projects, even with diversion of water from large rivers hundreds and thousands of miles away? The dilemma then becomes, either to completely stop further increase in greenhouse warming, with immense investment, or to divert only a small portion of these investments into large irrigation projects, to stabilize agriculture production at a still higher level than at present (case of Great Plain)?

Furthermore, should outputs of existing water resources systems be revised according to predicted climate changes, and decrease or increase of future average production, with economic aspects completely revised?

Prediction of forthcoming rise of sea level due to greenhouse warming poses a fundamental question, namely whether defenses of coastal areas should be now planned and implemented, with the coastal water resources systems adjusted to this change? Or, should one trust the claims that investment into a decrease of warming should be proportionally much smaller than the cost of those adjustments?

Relationship of Sea Level and Continental Water Resources Developments

The budget of water retained on continents and islands is related to the budget of water in the atmosphere and oceans. Reservoirs, ponds, increase of lake and aquifer levels, irrigation and other water supplies, represent an increase in the continental water budget and a decrease in ocean level. Overpumping of aquifers and drainage of swamps have an opposite effect. The first developments seem of much larger effect. This change in water budget due to human activities have received relatively little attention. it should be investigated carefully because the necessary data for it are available. Future activities, such as building of reservoirs, increase of aquifer levels, irrigation and other water supplies, will represent a decrease of sea level. Apart from the current needs for water storage, special research projects on this topic may become attractive due to significant transfer of ocean water to continents: 1. Use of large depression for reservoirs (such as Qattara Depression, Dead Sea, etc.), with production of power and sea water minerals, change in the arid microclimate, and sea level decrease; 2. Building of very large reservoirs in distant cold regions for hydropower and then production of hydrogen as the clean energy source; 3. Creation of large reservoirs in desertic regions wherever feasible; 4. Increase of irrigation area from present 300 million to future 750 million hectares, as was doubled from 150 million to 300 million after the second world war, for feeding of the world population; 5. Planned recharge of large aquifers (such as the potential artificial water recharge of the Ogallala aquifer in the Great Plains of the USA).

With the eventual warming of the lower atmosphere and large transfer of ocean water to continents through beneficial developments, the increased capacity of the air for moisture will also represent a corresponding decrease in ocean level. All the above strategic approaches should be investigated with their physical and economic consequences.

ES FOR TESTING, AND CONCLUSIONS ON MERIT OF RESEARCH ON THE OJECTS

The above three projects are based on the following hypotheses to be tested and on the following conclusions to be verified:

1. River runoff may represent the best variable to be used in detecting the eventual changes, because of integration eventual changes in precipitation and evaporation, and integrated areal (regional, basin-wide) effect of eventual changes, provided research data sets are rigorously selected, corrected for an evident non-homogeneity, and the best statistical methods used in discrimination of eventual changes.

2. There is a widely recognized, high uncertainty on whether and how much the climatic changes due to the eventual warming of the atmosphere have already occurred or would occur in the future. Proposals, advanced in the public media by some scientists, to start immediately with the reduction, and in the final phase with the elimination, of emissions of carbon-based gases into the atmosphere, should be very carefully investigated and even challenged. Simply, these gases may be more beneficial than detrimental to the humanity and the Earth in the long run, because when most of the carbon, at present locked in the upper crust of the Earth as fuels, was in the atmosphere, the Earth had the lushest biological cover which ever existed.

3. Instead of investing billions of dollars to reduce the emission of carbon-based gases into the atmosphere, it looks much more attractive to use that capital for the three basic activities, each with multiple benefits, namely: (i) reduction of chemicals emitted into the air by industrial and energy productions, which create the acid rain, with all its consequences; (ii) increase of irrigation and other water supplies; and (iii) significant increase of water stored in various unproductive spaces at the continental surfaces and underground.

4. Elimination of noxious gases from the the air would protect the ozone layer, eliminate destruction of forests, other biological cover, buildings, monuments, lakes, etc., while the carbon-based gases, especially carbon dioxide, would increase forest and agriculture productivity worldwide.

5. By increasing irrigation areas in the world, say from the present 300 million to the future 750 or more million hectares, not only would this be easier and safer to sufficiently feed all the world population, but also water will be transferred from oceans to continents and atmosphere, and thus would decrease or maintain the ocean level, with the resulting increase in the average continental precipitation and river runoff.

6. By building many new large, medium, and small reservoirs on unproductive lands of the world, and by increasing lake levels and levels of aquifers, not only the production of clean energy would increase (hydroelectric power, associated clean hydrogen energy production for industry and cars), but also many water resources and industrial problems could be solved, while at the same time decreasing or maintaining the ocean level.

7. Instead of fighting only the uncertainly in model predictions of an important new phenomenon, namely of eventual human-generated climatic change, with large investment to only avoid something with no other benefits, the basic approach should be to use all the benefits of likely unavoidable emissions of carbon-based gases into the atmosphere and oceans, while fighting the negative aspects of eventual climatic changes with these investments, and at the same time benefitting humanity in multiple ways.

8. The above three projects of the relationship between the eventual climatic changes and water resources, with critical research approaches and results, should be considered to be successful, if they only demonstrate that investment into the large-

scale elimination of emissions of carbon dioxide and the other carbon-based gases, in order to fight uncertainty in predictions from climate models, would be a tremendous potential waste in resources, as well as, if they prove that the alternative are better solutions than reducing these emissions. With it, the cost of these three research projects will be much more productive than only paid off.

RATIONS AND BUDGETS FOR THE THREE PROPOSED TS

Project no. 1:
Identification of Eventual Climatic Changes by Using River Runoff

Duration of the project: four years, with the selected monitoring stations and the expected methodology for continual upgrading of results.
Cost of the four year investigations: $400,000

Project no. 2:
Effects of Eventual Climatic Changes on Water Resources Systems

Duration of the project: three years, with the basic assessments that would be the physical and economic consequences of eventual climatic changes on the existing systems under various regional climatic conditions.
Cost of the three year investigations: $300,000

Project no. 3:
Relationship of the Sea Level and the Continental Water Resources Developments

Duration of the project: three years, with the basic information how the needed and vast water resources developments would affect the sea level, and the solution of uncertainties in the prediction of the eventual climatic changes.
Cost of the three year investigations: $300,000

Total cost of the investigations: $1,000,000

REGIONAL VARIATIONS AND REGIONAL INTERRELATIONS OF TROPOSPHERIC TEMPERATURES SINCE 1950

Gerd R. Weber
Coal Research Institute
deral Republic of Germany

nerally conceded that there is a lack of correspondence between model- nd observed temperatures in the troposphere. In addition, temperature itself is difficult. For example, presently derived tropospheric temperatures ds data rich continental areas. There are substantial indications that erature trends over data poor regions (such as the oceans) may in e over data rich regions.

sently derived tropospheric temperature trends may slow a larger recent decades than has actually occurred. Consequently, an elucidation eal magnitude of warming may in fact counter some claims of disastrous ning.

ses ntual umanity entual climatic results, should be nent into the large- 85

We will determine tropospheric temperatures by calculating the 300-1000mb thickness. This is done for the Northern Hemisphere on a monthly and yearly basis. We have already reanalyzed seasonal means for 1966-1989, and have gained considerable experience with in dealing with this data stream.

Specifically, using the annual averages of the 1966-89 analyses, the work by Weber (1990) for 1977-1986 will be extended to the longer time frame. Appropriate statistical techniques will be applied to search for teleconnection patterns in the 300-1000mb thickness field since 1966.

The analysis will then be extended to individual seasons. Particular emphasis will be placed on the question of what impacts a warming originating in the tropics might have on circulation and temperature patterns in mid-latitudes. This analysis will include time-lagged correlations in order to determine how regional temperature anomalies evolve and progress from one season to the next, and in which way that influences temperature and circulation patterns in different areas of the Northern Hemisphere.

We will then apply our methodology to the Southern Hemisphere in order to derive regionalized tropospheric temperatures. Severe problems are expected because of the paucity of data; but we expect that the pattern that will emerge will be more reliable than the one used presently, which is clearly biased towards the continents—even to a larger extent than the Northern Hemisphere. We will also search this pattern for teleconnections similar to those sought in the Northern Hemisphere. There is also the distinct possibility that temperature anomalies over the Southern Hemisphere continents may be reflections of ENSO events via a standing wave amplification in the mid-latitudes over the Southern Hemisphere oceans. Inter-hemispheric comparisons will be made as to the regions affected by warming or cooling.

(Estimated cost $200,000)

file 4-6-8

CFC ALLIANCE
SPECIAL BULLETIN

2011 Eye Street, N.W., Fifth Floor, Washington, D.C. 20006

December, 1989

THE NEW CFC TAX

The Omnibus Budget Reconciliation Act of 1989 imposes a new excise tax on certain ozone-depleting chemicals and on imports of products made with or containing such chemicals. The Treasury Department and the IRS have begun the process of implementing the new tax and expect to publish guidance for taxpayers on a variety of issues relating to the tax before the end of 1989.

The following is an explanation of the new tax. The explanation is based on the best information currently available. Until the IRS publishes guidance on the tax, however, a number of the issues discussed in this paper will remain uncertain. Before making business decisions that could be affected by the resolution of these issues, taxpayers should seek independent professional advice.

Taxable Chemicals

The bill defines eight chemicals as ozone-depleting chemicals and applies the new tax to them. The eight chemicals are those subject to production limitations under the Montreal Protocol and the implementing EPA regulations. The chemicals are the following:

CFC-11	**(trichlorofluoromethane)**
CFC-12	**(dichlorodifluoromethane)**
CFC-113	**(trichlorotrifluoroethane)**
CFC-114	**(1, 2-dichloro-1, 1, 2, 2-tetrafluoroethane)**
CFC-115	**(chloropentafluoroethane)**
Halon-1211	**(bromochlorodifluoromethane)**
Halon-1301	**(bromotrifluoromethane)**
Halon-2402	**(dibromotetrafluoroethane)**

*Methyl chloroform & carbon tet were added in 1991.

Additions to this list of taxable chemicals can be made only by Congress. Therefore if other chemicals become subject to the Montreal Protocol or to other production limitations, those chemicals would not be subject to the tax unless Congress takes legislative action.

The bill excludes from the definition of ozone-depleting chemicals those chemicals produced outside the United States and not imported into the United States. Thus, ozone-depleting chemicals produced outside the United States by a U.S. taxpayer are not subject to the tax unless imported into the United States.

Taxable Events

The tax is imposed in three instances:

- Sale or use by manufacturer, producer, or importer. The principal taxable event is the sale of ozone-depleting chemicals after December 31, 1989, by the manufacturer, producer, or importer of the chemicals. The tax also will apply where the manufacturer, producer, or importer of ozone-depleting chemicals uses the chemicals after December 31, 1989, instead of selling them.
- Sale or use of imported products for which ozone-depleting chemicals are production material. In order to reach indirect imports of ozone-depleting chemicals, the tax applies to the sale or use by an importer, after December 31, 1989, of imported products for which any ozone-depleting chemical is used as material in the manufacture or production process.
- Ownership of floor stocks. The tax is imposed on stocks of ozone-depleting chemicals owned by any person (other than the manufacturer, producer or importer of the chemicals) on January 1, 1990 if the chemicals are held for sale or for use in further manufacture. The tax also is imposed on stocks of taxable chemicals held for the same purposes on January 1 of each year 1991 through 1994 if the tax rate for such chemicals increases on that date.

These three taxable events are explained in more detail below.

Persons Required To Remit the Tax to the IRS

- Regular tax on sale or use. The producer, manufacturer or importer of the chemicals is liable to the IRS for the regular tax upon the sale or use of the chemicals by such person.

- Imported products. The importer of taxable imported products is liable to the IRS for the tax upon the sale or use of such products by the importer.
- Floor stocks. The owner of the chemicals on January 1 of each applicable year is liable to the IRS for the floor stocks tax.

Calculation of Amount of Tax

The amount of the tax is determined under the following formula:

	Base Tax		Ozone-Depletion		Pounds of
Tax =	Amount	X	Factor	X	Chemicals

This formula applies in all instances and to all ozone-depleting chemicals except, as described in more detail below, halons and chemicals used in the manufacture of rigid foam insulation. Thus, the formula applies in the normal case of the sale or use of chemicals by the producer, in the case of the floor stocks tax, and in the case of imported products. In the latter case, the formula applies to the quantities of ozone-depleting chemicals used as material in the manufacture or production of the imported products.

Base Tax Amount

The bill designates a specific base tax amount for the years 1990-1994 and provides for an increase of 45 cents for each year beyond 1994. The base amounts through 1999 are as follows:

1990	$ 1.37	1995	$ 3.10
1991	1.37	1996	3.55
1992	1.67	1997	4.00
1993	2.65	1998	4.45
1994	2.65	1999	4.90

Ozone-Depletion Factors

Each ozone-depletion factor represents the comparative potential ozone-depletion resulting from the same weight of a given chemical. The factors are as follows:

CFC-11	1.0	Halon 1211	3.0
CFC-12	1.0	Halon 1301	10.0
CFC-113	0.8	Halon 2402	6.0
CFC-114	1.0		
CFC-115	0.6		

The ozone-depletion factors designated in the statute are those specified in the Montreal Protocol. Like the list of chemicals subject to the tax, changes in the ozone-depletion factors can result only from Congressional action.

Application of the Tax on Sales by the Producer

- In the case of the regular tax on sales of ozone-depleting chemicals by the producer, the bill applies the tax to the quantity actually "sold." Thus, for example, under the plain meaning of the bill, tank truck heels and other similar quantities are not taxable until and unless they are sold.
- Although the bill is silent on the precise calculation of a producer's taxable sales volume, the normal procedure in the case of other federal excise taxes is to calculate the volume on a net basis -- that is, gross sales volume less returns and adjustments. An IRS official has indicated informally that this normal calculation should apply.
- In calculating the tax, fractions of pounds of chemicals are not rounded. The partial pounds are multiplied by the same ozone-depletion factor and base tax amount as whole pounds.
- The bill is silent on the issue of when a sale is deemed to occur for purposes of the tax. In the absence of specific rules, general tax rules probably would apply. Under the general rules, the IRS examines the substance, not the form, of a transaction to determine whether a sale has occurred. In such an examination, a sale generally is deemed to occur when the benefits and burdens of ownership are transferred, not merely when paper evidence of the sale is executed. This standard also would be relevant for determining ownership of taxable chemicals for purposes of the floor stocks tax.

Application of the Tax on Imported Products

- For imported products, the bill provides that the tax is equal to the amount of tax which would be imposed if the chemicals that were used as material in the manufacture or production of the products had been sold in the United States.
- To calculate the quantity of chemicals used as material in the manufacture or production of imported products, the Secretary of the Treasury is directed in the bill to choose one of three methods:

A. Data Provided by Importer. The Secretary can accept data the importer supplies showing the volume of chemicals used as material in the production process.

B. Domestic Industry Norms. If the importer fails to provide sufficient data, the Secretary can calculate the chemical amounts based on standards of use in the equivalent domestic industry.

C. **Five Percent of Appraised Value.** The bill also provides that, if necessary, the Secretary can bypass the foregoing procedures and impose a tax equal to five percent of the value of the imported product. This provision is intended to serve primarily as an incentive for importers to come forward with evidence as to the amount of ozone-depleting chemicals in their products.

- Treasury Department economists have begun work to compile a list of imported products for which ozone-depleting chemicals are used in the production process, and to determine the average quantity of the chemicals so used in each product.

- The Secretary of the Treasury also is authorized to prescribe regulations exempting products that use de minimis amounts of ozone-depleting chemicals as material in the production process. However, no such de minimis exception applies if the ozone-depleting chemicals are used for purposes of refrigeration or air conditioning, creating an aerosol or foam, or manufacturing electronic components.

Application of the Floor Stocks Tax

- As stated previously, the floor stocks tax is imposed on January 1 of each year 1990 through 1994 on any ozone-depleting chemical owned by any person (other than the manufacturer, producer, or importer) on such date and held for sale or for use in further manufacture. The amount of the floor stocks tax is as follows:

  1990: The amount of tax that would have been imposed if the chemical had been sold during 1990.

  1991-1994: The excess of the tax that would have been imposed on the sale of the chemical by the manufacturer, producer or importer on January 1 of that year, over the tax, if any, previously imposed on the chemical.

- The floor stocks tax is applicable to wholesalers, retailers, distributors, contractors, and any other type of business that holds stocks of ozone-depleting chemicals for sale or for use in further manufacture.

- The bill contains no exemption from the floor stocks tax for small businesses or for businesses that hold de minimis quantities of chemicals. The IRS is considering the possibility of instituting exemptions administra-tively.

- The tax applies only to stocks of chemicals held for sale or for use in further manufacture. However, the bill does not contain a definition of the term "use in further manufacture." The term probably is best read as denoting direct, proximate use in an actual manufacturing process. (If the bill had been intended to have a broader meaning, it probably would have been drafted to apply to stocks held "by" a manufacturer or simply "by" any business.) An IRS official has informally agreed with this conclusion; it is unclear, however, as to whether the IRS will publish any detailed guidance on this issue in the near future.

- Assuming the above interpretation of the term "use in further manufacture" is correct, then, as an example, stocks of chemicals held for use as a solvent in a manufacturing process probably would be taxable, as would stocks of chemicals held by a manufacturer of refrigeration equipment for use as a refrigerant in equipment made by the company. However, stocks of chemicals held for use other than a direct use in a manufacturing process -- for example, stocks of chemicals held for use in cooling systems for a factory -- probably would not be taxable. Stocks of chemicals held for use in routine factory maintenance also might not be taxable.

- The bill is drafted to apply the floor stocks tax only to ozone-depleting chemicals themselves and not to products that contain ozone-depleting chemicals (in contrast with the treatment of imports). Thus, generally speaking, the IRS probably does not have the power to apply the tax to such products. In administering the tax, however, the IRS probably does have the power to prevent taxpayers from abusing the purpose of the floor stocks tax through abnormal business practices.

- The bill is silent as to the tax treatment of chemical blends consisting partly of taxable chemicals and partly of non-taxable chemicals. The IRS also has not indicated any position on this issue.

- The IRS is expected to publish guidance on the payment procedures for the floor stocks tax by the end of the year. As in virtually all other federal taxes, it is expected that the responsibility for reporting and paying the tax will be the taxpayer's. In other words, the taxpayer's legal liability to pay the tax arises under the legislation and will not depend on identification or contact of the taxpayer by the IRS. According to an IRS official, the floor stocks tax probably will be payable on IRS form 720, which is the excise tax return. The IRS will revise the form to accommodate the floor stocks tax.

- The following are examples of the computation of the floor stocks tax:

  A. A dealer holds 200 pounds of CFC-115 for sale on January 1, 1990. The floor stocks tax will equal \$164.40 (\$1.37 x 0.6 x 200).

  B. ABC Company holds 300 pounds of CFC-12 on January 1, 1993 for use in further manufacture. ABC Company purchased the chemical in June 1992. The floor stocks tax will equal \$294. That amount is the difference between the tax that would be imposed if the initial sale of the chemical had occurred on January 1, 1993, \$795 (\$2.65 x 1.0 x 300) and the tax previously imposed in 1992, \$501 (\$1.67 x 1.0 x 300).

  C. A dealer holds 400 pounds of halon 1211 for sale on January 1, 1990. No floor stocks tax is imposed because, under the bill, halon 1211 is not treated as an ozone-depleting chemical until January 1, 1991.

  D. A dealer holds 400 pounds of halon 1211 for sale on January 1, 1991. The floor stocks tax will equal \$100. That amount is the difference between the tax that would be imposed if the initial sale of the halon had occurred on January 1, 1991, $100 (25 cents/lb. x 400 lbs.) and the tax already imposed, $0.

E. XYZ Company holds 500 pounds of halon 2402 on January 1, 1994. XYZ Company purchased the chemical in 1992. The floor stocks tax will equal $7,825. That amount represents the difference between the tax that would be imposed if the initial sale of the chemical had occurred on January 1, 1994, $7,950 ($2.65 x 6.0 x 500) and the tax previously imposed on the sale of the halon 2402 to XYZ Company in 1992, $125 (25 cents/lb. x 500 lbs.) Note: No floor stocks tax was imposed in January 1, 1993 because the tax rate for halons, 25 cents/lb., remained the same.

Exemptions from the Tax

The bill provides five full or partial exemptions from the tax, as follows:

- Chemicals produced from recycling.
- Chemicals used as feedstocks.
- Exports.
- Halons.
- Chemicals used in the manufacture of rigid foam insulation.

These exemptions apply in all instances where the tax applies (i.e., the regular tax on sale or use, the tax on imported products, and the floor stocks tax). The exemptions are explained below. Note that no exemption exists for sales of chemicals to a federal, state, or local governmental agency.

Recycling exemption

- The bill fully and permanently exempts from the tax chemicals diverted or recovered in the United States as part of a recycling process. In effect, this exemption simply treats a recycling operation as not production or manufacture of ozone-depleting chemicals for purposes of the tax.
- Chemicals recovered by the original producer of the chemicals from loading operations, tank truck heels, and similar sources probably do not qualify for the recycling exemption (assuming such chemicals had not previously been taxed). Such chemicals probably would be treated as normal taxable chemicals when sold by the producer thereof.

Feedstock Exemption

- The bill also fully and permanently exempts from the tax any ozone-depleting chemical used and entirely consumed in the manufacture or production of any other chemical.
- The bill implements the feedstock exemption by permitting sales of chemicals for feedstock use to be made tax-free. The exemption applies both on direct sales from the producer to the exempt user and on sales to a wholesaler or distributor who intends to resell to the exempt user.
- The exemption for sales of ozone-depleting chemicals for feedstock use applies only if the parties to the transactions meet registration requirements to be prescribed by the Secretary of the Treasury. See the separate discussion of the registration requirements below.
- If tax is actually paid on chemicals used as a feedstock, the user is permitted to obtain a refund of the tax from the IRS.

Export Exemption

- The bill provides producers of ozone-depleting chemicals with a partial exemption for exports. The exemption consists of a base portion and an additional portion.
- The base portion of the export exemption is the percentage of the producer's yearly production equal to the percentage of production the producer exported in 1986.
- The percentage calculation of the base portion is made using ozone-depletion factor adjusted pounds, as follows:

  Percentage Allowed =

$$\frac{\text{1986 Ozone-depletion factor adjusted pounds exported}}{\text{1986 Ozone-depletion factor adjusted pounds produced}}$$

- Ozone-depletion factor adjusted pounds (ODFAPs) are calculated by multiplying the number of pounds of each chemical (pounds exported if calculating the numerator; pounds produced if calculating the denominator) by the chemical's ozone-depletion factor. The ODFAPs for each of the eight chemicals are then added together to determine the total ozone-depletion factor adjusted pounds.
- The bill provides that the determination of the level of exports of each producer for 1986 is to be determined based on data published by the EPA.
- The second part of the export exemption relates to production increases destined for export. Under the Montreal Protocol and implementing rules, the EPA is authorized to grant additional production allowances to U.S. producers for the explicit purpose of export. Those exports are exempt from the tax.
- The bill indicates in a cross reference that producers of ozone-depleting chemicals have the discretion to transfer part of their export exemptions to third parties.
- Ozone-depleting chemicals used as a material in the manufacture of products that are exported are not exempt from tax under the bill.

Halon Exemption

- Halons receive favorable treatment through 1993. After 1993, they are treated the same as all other ozone-depleting chemicals. The treatment for 1990-1993 is as follows:

1990: All sales and uses of halons are exempt from tax. The term "ozone-depleting chemical" does not include halon-1211, halon-1301 or halon-2402 for the year 1990.

1991-93: Taxed at a rate of 25 cents per pound, without adjustment for ozone-depletion factor. (Note: the bill actually expresses this preferential rate in terms of varying percentages of each year's regular tax rate, rather than as a 25-cent-per-pound rate.)

Rigid Foam Insulation Exemption

Chemicals used or sold for use in the manufacture of rigid foam insulation receive preferential treatment through 1993.

Procedurally, this preferential treatment is structured in precisely the same manner as the feedstock exemption, so that producers are permitted to sell chemicals at the preferential rate for use in making rigid foam insulation. Such sales can be made both to direct users and to wholesalers and distributors who intend to resell to rigid foam makers. As in the feedstock exemption, the IRS will impose registration requirements that must be followed in order for sales to be permissible at the preferential rate. (See the discussion below.) In cases where sales are not made at the preferential rate, purchasers of chemicals who use the chemicals in the making of rigid foam insulation are permitted to obtain a refund of the excess tax paid.

The preferential treatment for chemicals used in the manufacture of rigid foam insulation is as follows:

1990: Complete exemption.

1991-93: Taxed at a rate of 25 cents per pound, without adjustment for ozone-depletion factor. (Note, as in the case of the halon exemption, the bill actually expresses this preferential rate in terms of varying percentages of each year's regular tax rate, rather than as a 25-cent-per-pound rate).

The bill does not define the term "rigid foam insulation." According to an IRS official, the IRS is aware of several issues that have arisen in interpreting the term, but has not yet resolved the issues.

Registration Requirement for Feedstock and Rigid Foam Exemptions

The IRS is expected to provide guidance by the end of the year as to the registration requirement for the feedstock and rigid foam exemptions.

According to an IRS official, it is likely that, at least for the short-term, the IRS will prescribe a system of exemption certificates in lieu of a comprehensive system for actually registering producers and purchasers with the IRS.

An exemption certificate would be, essentially, a declaration by the purchaser of chemicals that such chemicals will be put to a tax-preferred use. The IRS would prescribe the form and content of the certificate and would require that the certificate be signed under penalty of perjury. The purchaser would prepare and sign the certificate and deliver it to the producer.

- Once received by the producer in proper form, the certificate would entitle the producer to sell chemicals to the purchaser at the preferential tax rate applicable to the use declared in the certificate. The producer would not need to exercise judgment as to whether the purchaser was legally entitled to the preferential rate and would not be subject to an IRS challenge for having relied upon the certificate in failing to collect the full tax from the purchaser.
- The purchaser would be fully subject to IRS audit to determine the validity of its claim for a preferential tax rate, and IRS penalties would apply in the case of improper claims.

Payment Schedules

- The initial payment for taxes on the sale or use of ozone-depleting chemicals and imported products is due April 1, 1990.
- The IRS will issue guidance mandating a payment schedule beyond April 1, 1990. The likely period will be semi-monthly with the taxes required to be deposited within nine days after the end of each semi-monthly period.
- The floor stocks tax is due April 1 of each year.

IRS Enforcement

- The normal IRS tools for enforcing other taxes apply to the new CFC tax. For example, the IRS will have the authority to impose penalties ranging from five percent of underpayments for negligence, to 75 percent of underpayments for civil fraud, and to fines or imprisonment for criminal fraud.
- The IRS probably will pay particular attention to policing the exemptions from the tax. In other words, the IRS will seek to ensure that chemicals purchased tax-free for an exempt purpose are so used.

* * *

This document was prepared by James C. Gould, a partner in the Washington, D.C. law firm of Vinson & Elkins.

This Week in SCIENCE

Origins of agriculture

As humans progress from foragers to farmers, three important transitions occur in their relations with plant foods: once wild plants are domesticated, a food-producing economy comes into being, and production focuses on a small number of crops. In eastern North America, these milestones in human-plant relations were reached centuries apart (page 1566). The first indications that humans were intervening in plant life cycles appear between 2000 and 1000 B.C.: morphologic signs in seed specimens suggest that a form of squash, a sunflower, and two other plant crops had been domesticated. Later, between 250 B.C. and A.D. 200, the trend toward food-producing economies became widespread. And, between A.D. 800 and 1100, when complex sociopolitical changes were taking place, maize was introduced from tropical regions and became the major crop and food. This history, presented by Smith, represents a synthesis of information from the archeologic record and from measurements (with new techniques) of ages and characteristics of seed samples, human bones, artifacts, and other relevant materials. The work firmly establishes eastern North America as an independent center of plant domestication.

Thickening Greenland ice sheet

CHANGES in the volume of ice stored on continental ice sheets greatly affect global sea level because the sheets are so massive. Satellite radar measurements now indicate that the Greenland ice sheet south of 72°N has been thickening by about 0.23 meter/year since 1975 (pages 1587 and 1589). The measurements of ice surface elevation were made with altimeters on three satellites; elevation changes were calculated from comparisons of data obtained during different orbits. Depending on whether the ice sheet north of 72°N is also thickening and whether thickening is a recent or long-term phenomenon, the mass increase could correspond to falls in global sea level of 0.2 to 0.7 millimeter/year. Zwally discusses how ice sheet mass, sea level, and climate are related: over the short term, global warming could produce more precipitation and greater ice accumulations at Greenland and Antarctica and thus a drop in sea level; over longer periods, however, the dynamic response of the glaciers to warmer temperatures and increased precipitation is less clear, and sea-level rises could occur if the glaciers start flowing faster.

Recoil aspiration

AMPHIBIANS and air-breathing nonpolypterid fishes breathe by pulse pumping: the buccal cavity of the mouth fills with air, and when the mouth is closed air is forced into the lungs. In contrast, birds, mammals, and reptiles breathe by aspiration: their lungs expand first and air is then sucked in. Although primitive air-breathing polypterid fishes lack the structures thought to be essential for aspiration (diaphragms and movable ribs), they too have been found to breathe by a form of aspiration (page 1593). High-speed x-ray pictures of mouths and lungs and measurements of air pressure in the fishes' pleuroperitoneal cavities show that air is exhaled when the bony-scaled "jacket" or integument actively deforms and is inhaled as the integument passively recoils. Brainerd *et al.* note that recoil aspiration may have been used by the earliest amphibians, who, like their air-breathing fish ancestors and the polypterid fishes, had ventral bony scales.

SCID mice and childhood leukemia

A system for evaluating the progression of acute lymphoblastic leukemia, the most prevalent form of leukemia in children, has been devised by Kamel-Reid *et al.* (page 1597). When cultured cells derived from a leukemic child were injected into SCID mice (mice with severe combined immune-deficiency disease), the cells first grew in the bone marrow and later spread to the spleen, liver, and kidneys, just as they do in diseased children. As disease advanced, and again in keeping with the human pattern, the leukemic cells metastasized to the mouse's brain, lungs, intestines, and pancreas. If indeed the pattern of tumor cell differentiation and metastasis in mice is faithful to that in children, the SCID mice could become valuable adjuncts in the management of individual cases of leukemia. The course of disease in a child might be predicted from its course in the mice, treatment protocols could be evaluated in mice, and the success of chemotherapies could be determined by injecting patient's cells into mice and searching for growth of tumor cells.

RNA editing

Is the evening primrose using a nonstandard genetic code or is it doing some unusual editing of its RNA? The question arose as a result of observations by Hiesel *et al.* that there was not exact correspondence between the sequences of nucleotides in certain mitochondrial genes and in the complementary DNA molecules patterned on messenger RNA molecules made from those genes (page 1632). Specifically, the nucleotide cytosine (C) in the genes was frequently represented by thymidine (T) in complementary DNA molecules; had editing not occurred, the sequences of the complementary DNA and the DNA of the gene should have been identical. The replacements of some (but not all) of the Cs by Ts were found not only in the coding regions of the genes but also in those parts of the genes that do not get translated; the rate of such exchanges was about 1 in 58 nucleotides. The changes in the coding region were not silent but led to the insertion of different amino acids in the protein products; interestingly, the affected amino acids were ones that proved to be highly conserved in evolution. How the editing occurs (perhaps through some chemical modification) and whether it is a common or an unusual phenomenon remain to be determined. ■ RUTH LEVY GUYER

4. K. Tanaka *et al.*, *Rapid Commun. Mass Spectrom.* **2**, 151 (1988).
5. M. Karas, D. Bachman, U. Bahr, F. Hillenkamp, *Int. J. Mass Spectrom. Ion Processes* **78**, 53 (1987).
6. M. Karas and F. Hillenkamp, *Anal. Chem.* **60**, 2299 (1988).
7. P. Williams and B. U. R. Sundqvist, *Phys. Rev. Lett.* **58**, 1031 (1987).
8. D. Fenyo *et al.*, *J. Phys. (Paris) C* **2**, 33 (1989).
9. J. B. Fenn, in *Applied Atomic Collision Physics*, H. S. W. Massey, E. W. McDaniel, B. Bederson, Eds. (Academic Press, New York, 1982), vol. 5, pp. 349–378.
10. R. Kelly and R. W. Dreyfus, *Nucl. Instrum. Methods Phys. Res. B* **32**, 341 (1988).
11. L. Q. Huang, R. J. Conzemius, G. A. Junk, R. S. Houk, *Anal. Chem.* **60**, 1490 (1988).
12. M. Karas, A. Ingendoh, U. Bahr, F. Hillenkamp, *Biomed. Environ. Mass Spectrom.* **18**, 841 (1989).
13. J. L. Wiebers, in *High Performance Mass Spectrometry: Chemical Applications*, M. L. Gross, Ed. (ACS Symposium Series 70, American Chemical Society, Washington, DC, 1978), p. 248.
14. The work of D.E.L. was supported under NIH grants RCDA CA 00911 and GM 37788. R.W.N. was partly supported by personal funds (P.W.). We are deeply indebted to J. D. Gust for allowing us free access to the laser system.

21 July 1989; accepted 18 October 1989

Growth of Greenland Ice Sheet: Measurement

H. JAY ZWALLY, ANITA C. BRENNER, JUDY A. MAJOR, ROBERT A. BINDSCHADLER, JAMES G. MARSH

Measurements of ice-sheet elevation change by satellite altimetry show that the Greenland surface elevation south of 72° north latitude is increasing. The vertical velocity of the surface is 0.20 ± 0.06 meters per year from measured changes in surface elevations at 5906 intersections between Geosat paths in 1985 and Seasat in 1978, and 0.28 ± 0.02 meters per year from 256,694 intersections of Geosat paths during a 548-day period of 1985 to 1986.

DETERMINATION OF THE BALANCE between mass input and outflow of the polar ice sheets is needed for understanding of the ice-sheet response to climate change and the contributions to sea-level rise or fall. Measurement of elevation change by satellite altimetry offers a method of determining changes in ice volume and therefore mass balance (*1*). The 3-year operation of GEOS-3 radar altimeter from April 1975 to June 1978 (*2*), followed by the 3-month operation of the Seasat radar altimeter from July to September 1978, provided a time series of ice elevations, but the precision and spatial coverage of GEOS-3 was limited. The U.S. Navy Geosat radar altimeter (*3*), which was launched in March 1985, has provided a large number of recent repetitive measurements. We have determined changes in ice-surface elevations using data from GEOS-3, Seasat, and the first 18 months of Geosat. The estimated change in ice volume and its significance is discussed in a companion paper (*4*).

Changes in surface elevation were determined where successive sub-satellite paths intersect (Fig. 1). The measured elevation difference at a crossover point is $dH = H_2 - H_1 + E$, where H_2 and H_1 are the surface elevations during successive orbits at times t_2 and t_1, respectively, and E is the random measurement error from a distribution with a SD. The error for each elevation measurement is $E/\sqrt{2}$, which includes errors in the altimeter-range measurement and in determination of the vertical position of the orbit. The magnitude of E is determined from analysis for which $(H_2 - H_1)$ are small. Although E is usually larger than actual elevation changes, average changes can be obtained over areas of the ice sheet for time periods in which there are a sufficiently large number of measurements.

The range measured (Fig. 1) is to the average surface elevation in the "pulse-limited" footprint [maximum circular area from which radar reflection is simultaneously received by the altimeter (*2, 5*)]. The minimum pulse-limited footprint is 3.6 km in diameter for the GEOS-3 altimeter and 1.6 km for both the Seasat and Geosat altimeters, over smooth surfaces and larger over rough surfaces. Ranges are obtained at 0.66-km intervals along the satellite tracks; therefore, successive footprints overlap by 40% or more. Surface elevations at the crossover point are obtained by interpolation. Determination of the absolute surface elevation at satellite nadir would require correction for the slope-induced offset of the pulse-limited footprint from nadir (*6*), which is caused by the tendency of the pulse-limited footprint to be located at the closest surface lying within the larger "beam-limited" footprint, which is ten times the size of the pulse-limited footprint (*5*). However, for the purpose of studying elevation changes, correction for slope-induced errors is not necessary because the pulse-limited footprint is usually located at the same place on the surface during successive transits.

We corrected surface elevations for variations in the effective atmospheric path length, earth tides, and lags in the automatic radar-pulse tracking circuitry of the altimeter (*3, 4*). For GEOS-3 and Seasat, residual errors in the radial position of the satellite with respect to the center of the earth are reduced by reference of the orbital positions to a common ocean surface derived from the Seasat and GEOS-3 altimeter data. After orbit adjustment, the SD of the elevation differences is 4.7 m for GEOS-3–GEOS-3 crossovers and 1.0 m for Seasat-Seasat crossovers. The standard errors for single measurements are 3.3 m for GEOS-3 and 0.70 m for Seasat. The calculated SD for GEOS-3–Seasat differences is 3.4 m. Precise orbit information over ice-covered areas is included with the Geosat data (*7*). The SD of the elevation differences at 16,250 Geosat-Geosat crossovers for which the time difference between measurements is <15 days is 1.49 m. The Geosat single-measurement error is therefore 1.05 m. In these analyses, crossover differences greater than 10 m were discarded (15 m for GEOS-3) (*8*). The relative SD for Geosat-Seasat differences is therefore 1.26 m. The remaining errors are mainly a combination of altimeter measurement error over irregular surfaces and residual orbit errors.

Two methods were used to obtain the rate of change of surface elevation from a set of

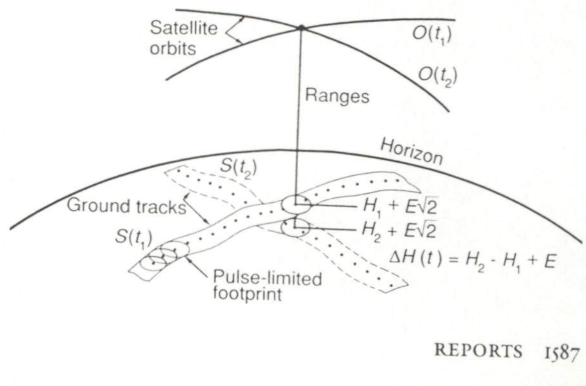


Fig. 1. Crossover method for measuring changes in surface elevation, $S(t)$, from radar-altimeter measured elevations, $H(t)$, on successive orbital paths (O) of the satellite. Horizontal location of the crossover point is determined within a few meters. The relative error, E, for measurement of elevation change, dH, at a single crossover is about 1.4 m.

H. J. Zwally and R. A. Bindschadler, Oceans and Ice Branch, Code 671, National Aeronautics and Space Administration (NASA), Goddard Space Flight Center, Greenbelt, MD 20771.
A. C. Brenner and J. A. Major, ST Systems Corporation, 4400 Forbes Way, Lanham, MD 20706.
J. G. Marsh, Space Geodesy Branch, Code 626, NASA, Goddard Space Flight Center, Greenbelt, MD 20771.

Table 1. Average rates of change in ice-sheet elevation and relative error at a single crossover of the satellite radar altimeters. N, number of crossovers.

Satellite	N	dH/dt (m/year)	Maximum dt (years)	Interval	Relative error (m)
GEOS-3–Seasat	657	0.11 ± 0.14	3.2	April 1975 to June 1978	3.4
Geosat-Seasat	5,906	0.20 ± 0.06	7.0	July 1978 to October 1985	1.26
Geosat-Geosat	256,694	0.28 ± 0.02	1.5	April 1985 to September 1986	1.49

crossover measurements. If a sufficient number of measurements were made during two distinct periods separated by a relatively large time interval (dt), then the surface velocity is the average crossover height difference divided by the time interval $[\Sigma(H_2 - H_1)_i/N)/dt$, where $(H_2 - H_1)_i$ is the elevation difference at the ith crossover and N is the number of crossovers]. This method is appropriate for comparing the 3 months of Seasat measurements with Geosat measurements made 7 years later.

The second method, the dH/dt method, is appropriate for a set of crossovers that tend to have randomly distributed time intervals. The slope of a linear fit to the crossover differences, $dH_i = (H_2 - H_1)_i$, versus their time intervals, $dt_i = (t_2 - t_1)_i$, gives the thickening ($dH/dt > 0$) or thinning rate ($dH/dt < 0$). In this method, we implicitly assume that dH/dt is a linear function of time and that the data are randomly distributed about a linear trend. The SE of the slope and the SD of the points about the linear fit can only be used to assess the statistical significance of a linear trend if cyclical components in the data are small.

The dH/dt method has several advantages. All crossovers created by a series of altimeter measurements can be used. The effect of possible seasonal changes in either the surface elevation or radar back-scattering properties is reduced, because a specific dt_i, for example, might have summer-to-winter and winter-to-summer measurements. Also, the value of the dH intercept at $dt = 0$ can indicate measurement biases.

We first applied the dH/dt method to GEOS-3 and Seasat data, which extended to 65.1°N and 72.07°N, respectively. The average rate of increase in surface elevation south of 65.1°N obtained from 525 crossover differences was 0.35 ± 0.17 m/year (*9*). Subsequent analysis with 127 more crossovers gave a dH/dt of 0.11 ± 0.14 m/year (Table 1). The SD of the 657 dH_i values with respect to the linear fit is 3.48 m, consistent with the 3.40-m estimated relative error (Table 1). A similar analysis of 626 GEOS-3–GEOS-3 crossovers gave a dH/dt of 0.07 ± 0.23 m/year. Although these three values of dH/dt are positive and overlap within 1 SD, the confidence regarding ice-sheet thickening based on these data alone is not high.

The dH/dt analysis for 548 days of Geosat measurements between 1 April 1985 and 30 September 1986 (Fig. 2) gives 0.284 ± 0.004 m/year for 256,694 crossover differences. The ice sheet area covered is from the southern tip of Greenland to 72°N. The SD of the points about the line is 1.14 m, for an iterative 3 SD editing with SD convergent to 2%. In the calculation of SE of the slope, we assume that errors among the dH_i are independent, even though some correlation may be expected among the crossovers along a given orbit. Depending upon the magnitude of the residual orbit error compared to the altimeter measurement error, the number of crossovers per orbit, and the degree of correlation from one crossover to another, the true error on the slope for this case could be as much ± 0.02 m/year.

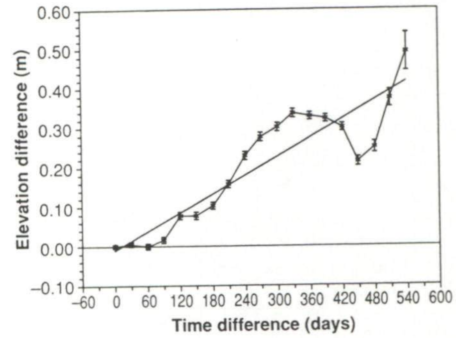


Fig. 3. Average dH_i of Fig. 2 in 30-day intervals versus dt (see text). Nonlinear components caused by seasonal effects are smaller than the linear trend of 0.28 m/year.

In our analysis, $dH = H_a - H_d$, where H_a is the elevation obtained on the orbit path ascending in latitude and H_d is the elevation on the path descending in latitude, regardless of whether $t_a > t_d$ or $t_a < t_d$. The dH intercept at $dt = 0$, obtained by averaging all dH_i for which $|dt_i| < 15$ days, gives an ascending-descending orbit bias equal to −0.48 ± 0.01 m. This bias indicates that Geosat descending orbit calculations are systematically too high relative to ascending orbits in the vicinity of Greenland.

Although the dH/dt method reduces the effect of possible seasonal variations in the measured elevation, a seasonal modulation in the deviation of the dH_i values about the linear fit is evident in Fig. 2. Minimal deviations appear at about 0, 6, and 12 months, and maximal deviations at about 3 and 9 months. To examine the effect of this semiannual variation on the linear trend analysis, we averaged the dH_i in 30-day intervals [$dH_m = \Sigma(H_2 - H_1)_i/n$, where n is the number of measurements in the interval]. The dH_m for $dt < 0$ were then averaged with the corresponding values for $dt > 0$ (Fig. 3). Although there are obvious nonlinear components, the variations about the linear fit are not large and are nearly symmetrical. Linear fits to the mean values give 0.289 ± 0.032 m/year and 0.279 ± 0.020 m/year, before and after averaging the mean values for $dt < 0$ and $dt > 0$, which are consistent with the slope in Fig. 2.

Elevation changes between Geosat and Seasat measurements are more meaningful for mass balance studies because of the 7-year interval between the two satellites; however, comparisons may be influenced by differences in the orbit calculations, or their relative ocean-geoid levels. Coarse-grid information received from the Navy on their altimeter measurements of the ocean surface in the vicinity of Greenland with Geosat is sufficient, however, to estimate the possible bias with respect to the Seasat measurements. The estimated Geosat-Seasat eleva-

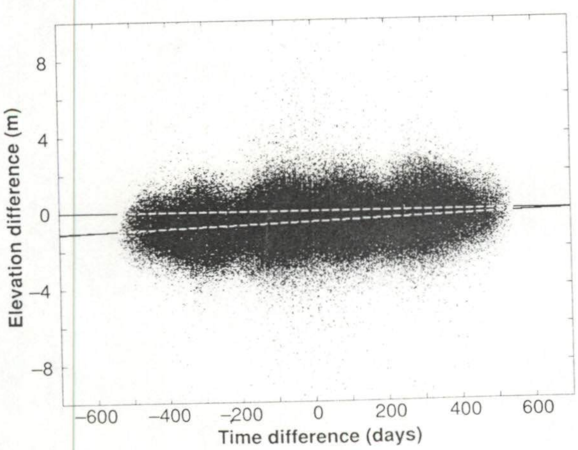


Fig. 2. Elevation differences dH_i at 256,694 Geosat-Geosat crossovers versus dt_i. Negative dt_i indicate that the elevation measurement, H_2, on an orbit ascending in latitude preceded the elevation measurement, H_1, on an orbit descending in latitude. Intercept at $dt = 0$ shows an ascending-descending orbit bias of −0.48 m. The rate of increase in surface elevation is 0.28 ± 0.02 m/year.

tion bias over Greenland is 0.4 ± 0.4 m, which we treat as a correction with a systematic error. In other respects, the Geosat and Seasat altimeters are similar in design, and the same range-correction retracking algorithm was used over ice. We accounted for the ascending-descending orbit bias by analyzing the crossovers of ascending Geosat orbits with Seasat separately from those with descending Geosat orbits, and then averaging the two results. We avoided seasonal biases by comparing the Seasat data for 15 July to 10 October 1978 with Geosat data for the same period of 1985. The resulting Geosat-Seasat average elevation difference for 5906 crossovers is 1.785 ± 0.014 m. After correction for the Geosat-Seasat orbit bias, it is 1.385 ± 0.414 m. The average rate of change over the 7-year interval at these crossover locations is thus 0.20 ± 0.06 m/year. The altimeter measurements (Table I) thus show that the southern Greenland ice sheet has been thickening since the mid-1970s.

REFERENCES AND NOTES

1. H. J. Zwally, *J. Glaciol.* **15**, 444 (1975).
2. R. L. Brooks, W. J. Campbell, R. O. Ramseier, H. R. Stanley, H. J. Zwally, *Nature* **274**, 539 (1978).
3. J. L. MacArthur, P. C. Marth, Jr., J. G. Wall, *Johns Hopkins Appl. Phys. Lab. Dig.* **8** (no. 2), 176 (1987). The first 18 months of the Geosat mission (D. R. McConathy and C. C. Kilgus, *ibid.*, p. 170) are classified for geodetic purposes, but the data over ice was released as unclassified data for ice studies (H. J. Zwally, J. A. Major, A. C. Brenner, R. A. Bindschadler, *ibid.*, p. 251). The geodetic mission has been followed by an unclassified exact-repeat mission (G. H. Born, J. L. Mitchell, G. A. Heyler, *ibid.*, p. 260), but the orbit determinations currently available are much less precise.
4. H. J. Zwally, *Science* **246**, 1589 (1989).
5. T. V. Martin, H. J. Zwally, A. C. Brenner, R. A. Bindschadler, *J. Geophys. Res.* **88**, 1608 (1983).
6. A. C. Brenner, R. A. Bindschadler, R. H. Thomas, H. J. Zwally, *ibid.*, p. 1617 (1983).
7. S. L. Smith III, G. B. West, C. W. Malyevac, *Johns Hopkins App. Phys. Lab. Dig.* **8** (no. 2), 197 (1987).
8. The distribution of most of the crossover elevation differences is Gaussian; however, some differences greater than 3 SD of the Gaussian distribution are believed to be caused by measurement of ranges to different locations on the surface on successive orbits. In some cases along a single orbit, two ranges to different places on the surface, differing in elevation by as much as 20 m, are indicated by simultaneous, double-peaked radar returns (*5*). To eliminate such cases, crossover elevation differences greater than 3 SD of the primary Gaussian distribution were discarded in the analysis of elevation changes.
9. H. J. Zwally, *Ann. Glaciol.* **8**, 200 (1985).

10. This work is supported by NASA's Ocean Processes Program. We thank R. Thomas in particular for support and discussions and his help in arranging to obtain the Geosat data. T. Davis, C. Kilgus, J. MacArthur, S. Smith, and others in the U.S. Navy and Johns Hopkins Applied Physics Laboratory provided the Geosat data and associated information that made this research possible. We also thank C. Lingle, S. Stephenson, T. Seiss, S. Fiegles, and others for assistance with computer programming and data processing.

29 June 1989; accepted 13 October 1989

Growth of Greenland Ice Sheet: Interpretation

H. Jay Zwally

An observed 0.23 m/year thickening of the Greenland ice sheet indicates a 25% to 45% excess ice accumulation over the amount required to balance the outward ice flow. The implied global sea-level depletion is 0.2 to 0.4 mm/year, depending on whether the thickening is only recent (5 to 10 years) or longer term (<100 years). If there is a similar imbalance in the northern 60% of the ice-sheet area, the depletion is 0.35 to 0.7 mm/year. Increasing ice thickness suggests that the precipitation is higher than the long-term average; higher precipitation may be a characteristic of warmer climates in polar regions.

The mass balance of the Greenland and Antarctic ice sheets is of current interest, largely because of its direct relation to global sea level, which appears to be rising by 2.4 ± 0.9 mm/year (*1*). Although both thermal expansion of the ocean (*2*) and melting of small glaciers (*3*) contribute to sea-level rise, the major source of water is undetermined. Also, the possibility of enhanced ice-sheet melting in a warmer climate (*4*) is of concern. Glaciers respond to both precipitation and temperature in such a manner, however, that enhanced precipitation may offset increases in surface melting (*5*).

Each year, approximately 3000 km^3 of water is exchanged between the ocean and the ice sheets of Greenland and Antarctica, a volume equivalent to 8 mm of water from the entire surface of the world's oceans. The uncertainty in ice-sheet mass balance has been at least ±30% of the annual mass exchange (*6*); this uncertainty is equivalent to ±2.4 mm/year of sea-level change. Recently, Meier *et al.* (*7*) estimated that there has been a small positive balance for both Greenland (−0.1 ± 0.4 mm/year of sea-level change) and Antarctica (−0.6 ± 0.6 mm/year). In contrast, recent total flux estimates (*8*) of annual snow accumulation, iceberg discharge, and peripheral melting of the Antarctic ice sheet indicate that the net ice loss has been 750 km^3/year, which is 35% of the mass input and equivalent to 1.9 mm/year of sea-level rise.

Satellite radar altimetry measurements show that the surface elevation of the Greenland ice sheet south of 72°N (Fig. 1) increased from 1978 to 1986 (*9*). The measured elevation change varies with latitude (Fig. 2), and the errors are larger at lower latitudes and lower ice-sheet elevations mainly because of the smaller number of crossovers (*10*). The largest elevation increases were over the southern dome around 63.5°N and in the central region near 72°N during 1985 to 1986.

The spatially averaged elevation changes, obtained by analyzing the crossover differences in ice-sheet elevation bands (Fig. 3) and weighting those values by the fractional area in each band (0.12, 0.14, 0.20, 0.31, and 0.23 for lower to higher elevations), are 0.233 ± 0.041 m/year for 1978–1985 Geosat-Seasat measurements and 0.239 ± 0.030 m/year for 1985–1986 Geosat-Geosat measurements. In southern Greenland, the equilibrium line (boundary between net ablation and net accumulation) is at ~1200 to 1500

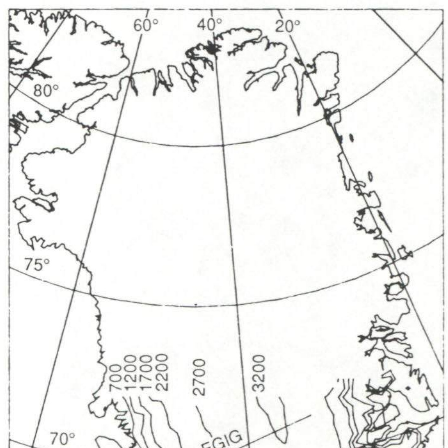


Fig. 1. Map of Greenland showing surface elevations in region covered by satellite radar altimetry and locations of surface measurements (EGIG, D3, and OSU) of elevation change.

Oceans and Ice Branch, Code 671, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, MD 20771.

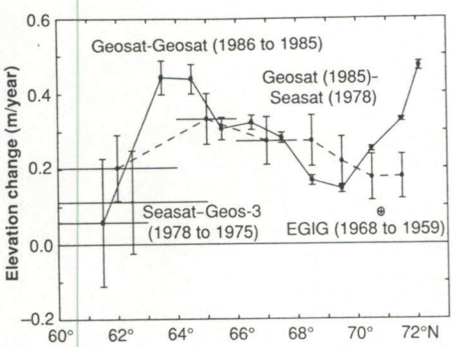


Fig. 2. Average changes in ice-sheet surface elevation in latitude bands. The 1985–1978 Geosat-Seasat values are from the difference between elevations in late summer 1985 and late summer 1978. The 1986–1985 Geosat-Geosat values are from the *dH/dt* method of analysis. The respective 1985–1978 and 1986–1985 average values for all crossovers are 0.20 m/year and 0.28 m/year (*9*). Earlier values are from EGIG traverse near 70.5°N (Fig. 1) and GEOS-3–Seasat analysis.

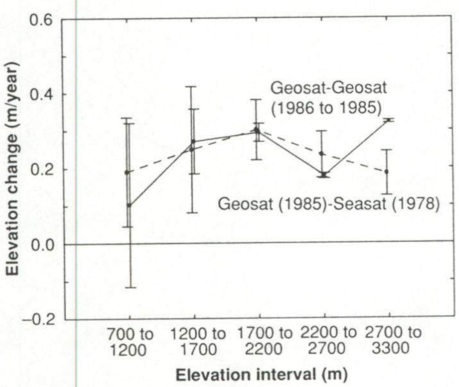


Fig. 3. Average ice-sheet surface elevation changes by elevation bands. Thickening is indicated for both time periods in both the accumulation and ablation zones (above and below ~1200 to 1500 m). Spatially averaged elevation change is 0.23 ± 0.04 m/year.

m. Therefore, thickening is indicated for both time periods in both the accumulation and ablation zones, although the errors are large for the ablation zone.

Repeat long-line leveling on traverses in 1959 and 1968 (EGIG, Fig. 1) (*11*) showed that the ice sheet was thickening by 0.09 m/year at least locally (*12*). Within the ablation zone near the western margin, the ice sheet thinned at ~0.30 m/year between 1948 and 1959 (*13*) and 0.24 m/year between 1959 and 1968 (*12*). Reeh and Gundestrup (*14*) concluded that the ice sheet was thickening at Dye 3 (D3, Fig. 1) by 0.03 ± 0.06 m/year. Kostecka and Whillans (*15*) derived a thickening rate of 0.06 ± 0.08 m/year along a transect (OSU, Fig. 1) west of Dye 3. These results consistently indicate that the accumulation zone was thickening, but the magnitudes are smaller than the spatially averaged altimeter results. In the ablation zone, the results are of opposite sign.

In general, changes in ice-sheet elevation may be caused by variations in surface balance (accumulation minus ablation), firn compression, ice flow, or crustal deformation

$$dH/dt = [A(t) - B(t)]/R_s - V_{cp} - V_i + V_b = dH'/dt + V_b \qquad (1)$$

and the (net) mass balance is

$$dM/dt = A(t) - B(t) - V_i R_i \qquad (2)$$

where H is surface elevation; dM/dt, A, and B are the mass-change rate, the surface-accumulation rate, and the surface-ablation rate in meters of water equivalent per year; R_s is the (relative) density of snow being added; R_i is the density of solid ice (0.92); V_{cp} is the velocity of firn compression; V_i is the downward subsurface velocity of the firn-ice transition (*16*); H' is ice-sheet thickness; and V_b is the vertical velocity of the ice base due to crustal deformation. If the surface integral of $dM/dt = 0$, over either a local area or the entire area of an ice sheet, the area is in balance.

Whereas changes in precipitation and surface ablation have immediate effects on surface elevation, changes in ice flow in response to changes in ice-sheet boundary conditions have much slower effects (*17*). Therefore, elevation changes measured over a decade could indicate either a recent change in accumulation or long-term changes in ice velocity or accumulation. Reeh and Gundestrup (*14*) suggested that the 0.03 ± 0.06 m/year thickening at Dye 3 may be caused by a slowing of the ice flow because of the downward propagation of stiffer post-Wisconsin ice. In regard to precipitation changes, accumulation time series have been obtained at only a few locations. Ice cores from the central region of the ice sheet near 71°N show that accumulation rates increased about 3.3% per 100 years over the last 300 years (*18*), and a similar change has been observed at Dye 3 (*19*). However, accumulation rates in the central region decreased about 10% from peak values between 1940 and 1985 (*18*), and the rates near Dye 3 decreased about 40% from 1935 to 1970 (*20*), while precipitation at land stations in northern mid-latitudes appeared to increase (*21*). Therefore, the specific cause of ice-sheet thickening cannot be deduced, but it is likely that the present ice velocities have been determined by the long-term (>100 years) surface conditions and that the observed ice thickening indicates that present accumulation rates are larger than the long-term average.

The rate of mass change and implied sea-level depletion can be estimated from the spatially averaged dH/dt values. In southern Greenland, the value of V_b due to post-glacial isostatic adjustment is between 0 and 0.009 m/year (*22*). Therefore, the average change in ice-sheet thickness, dH'/dt, is 0.23 ± 0.04 m/year. Changes in the ice velocity and the average V_{cp} over 8 years are likely to be small. The ice-sheet area south of 72°N is 0.70×10^6 km^2 (1/517 of global ocean area), and the measured change in volume is therefore 160 km^3/year. A lower end estimate of mass change is obtained for the situation where the elevation change is a short-term (5- to 10-year) increase in precipitation, in which case the average density of the snow being added is about 0.5 R_i. An upper-end estimate is obtained for a change from either a long-term (>100 years) increase in precipitation or a decrease in ice flow, for which the appropriate density is 0.92 R_i. The calculated global sea-level depletion thus ranges from 0.20 to 0.41 mm/year.

The average accumulation rate on the ice sheet south of 72°N is about 0.5 m/year water equivalent (*23*). Therefore, the 0.23 m/year thickness change represents a mass imbalance ranging from about 25 to 45%, depending on whether the change is short or long term. About 60% of the area of the Greenland ice sheet lies north of the radar altimeter coverage, and the average accumulation rate there is roughly half of the southern value. If the northern region has a similar positive mass balance, even though the meteorological and glaciological situation may be quite different, the northern thickening rate would be half of the southern value. In this case, the total sea-level depletion would be 0.35 to 0.7 mm/year.

A 2.4 mm/year sea-level rise (*1*) with contributions of 0.4 mm/year from small glaciers (*3*), 0.4 mm/year from ocean thermal expansion (*2*), and a −0.5 mm/year from Greenland, implies that the contribution to sea-level rise from Antarctica is 2.1 mm/year. The agreement of this value, however, with the 1.9 mm/year estimate for Antarctica based on net mass fluxes, may be fortuitous, in consideration of the large uncertainty in the flux estimates.

The relation between precipitation changes and temperature changes in polar regions is of central importance to understanding current and future behavior of the ice sheets. In polar regions, enhanced precipitation is associated with warmer temperatures because of the greater transport of moisture in warmer air (*24, 25*). Various results (*26*) suggest that the increase in precipitation is 5 to 20% per Kelvin. The effects of enhanced precipitation and warmer temperatures on ice-sheet mass balance differ in the ablation and accumulation zones. Above the equilibrium line, most surface melt water is refrozen and retained locally. Therefore, increased precipitation increases the mass input, and melting has little effect. Below the equilibrium line, increases in precipitation reduce the net summer ablation and partially offset increases in melting. Although the altitude of the equilibrium line increases with increased temperature, it decreases with increased precipitation and with increased cloudiness (*27*). Therefore, changes in position of the equilibrium line might be small as temperature and precipitation increase together. Because nearly 100% of the Antarctic ice sheet and 85% of the Greenland ice sheet are above the present equilibrium line, the dominant short-term effect is likely to be ice-sheet growth. An increase in precipitation and temperature should cause an immediate positive change in the mass balance and a gradual steepening of an ice sheet, which would continue for many years as the ice flow responded to the driving stresses.

In conclusion, Greenland ice-sheet growth is consistent with the generally warmer temperatures (*28*) experienced in this century. If climate continues to warm, enhanced precipitation in polar regions may offset increases in melting. Although the Antarctic ice sheet is a likely source of water for current sea-level rise, its mass balance is uncertain. Over much of Antarctica, which contains 91% of the earth's ice, the annual mass input is only 10% of the Greenland values, so that significant elevation changes may be ten times as small. Laser altimetry measurements (*29*) are needed there, because of its better range precision and ability to cover the critical ablation zones where radar altimeters do not adequately follow the more irregular ice surfaces.

REFERENCES AND NOTES

1. W. R. Peltier and A. M. Tushingham, *Science* **244**, 806 (1989).
2. R. Etkins and E. Epstein, *ibid.* **215**, 287 (1982); V. Gornitz, S. Lebedeff, J. Hansen, *ibid.*, p. 1611.
3. M. F. Meier, *ibid.* **226**, 1420 (1984).
4. J. Hansen *et al.*, *J. Geophys. Res.* **93**, 9341 (1988).
5. For example, a detailed study of an Alaskan glacier at 60.4°N shows that there has been significant growth since 1976 as both temperature and precipitation increased (L. R. Mayo and D. C. Trabant, in *The Potential Effects of Carbon Dioxide-Induced Changes in Alaska*, J. H. McBeath, Ed. (*Misc. Publ. 83-1*, Univ. of Alaska, Fairbanks, AK, 1984).
6. R. H. Thomas *et al.*, *NASA Tech. Memo. 86233* (1985).
7. M. F. Meier *et al.*, *Glaciers, Ice Sheets, and Sea Level: Effect of a CO_2-Induced Climatic Change* (National Academy of Sciences, Washington, DC, 1985).
8. Estimates of Antarctic accumulation, iceberg discharge, and basal melting made since 1955 showed a positive mass balance before about 1974, but improved recent values show that an increase in the estimate of accumulation [M. B. Giovinetto and C. R. Bentley, *Antarctic J. U.S.* **20**, 6 (1985)] is more than offset by larger increases in the estimates of iceberg discharge [O. Orheim, p. 210 in (*7*)] and basal melting [S. S. Jacobs, R. G. Fairbanks, Y. Horibe, in *Oceanology of the Antarctic Continental Shelf*, S. Jacobs, Ed. (*Antarct. Res. Ser. 43*, American Geophysical Union, Washington, DC, 1985), pp. 59–85.
9. H. J. Zwally, A. C. Brenner, J. A. Major, R. A. Bindschadler, J. G. Marsh, *Science* **246**, 1587 (1989).
10. Errors are 1 SD of *dH/dt* slope for Geosat-Geosat measurements, and SD of the mean crossover difference plus error in relative geoid correction for Geosat-Seasat measurements. The density of orbital crossovers is largest at the maximum latitude of 72°N and decreases significantly to the south, because of the geometry of the ground tracks. Seasat data coverage is shown in H. J. Zwally, R. A. Bindschadler, A. C. Brenner, T. V. Martin, and R. H. Thomas [*J. Geophys. Res.* **88**, 1589 (1983)] and typical Geosat coverage in H. J. Zwally, A. C. Brenner, J. A. Major, and R. A. Bindschadler [*Johns Hopkins Appl. Phys. Lab. Dig.* **8**, 251 (1987)]. The density of elevation differences is also smaller at lower elevations, because the altimeter measurements are less continuous over the steeper and more irregular surface near the ice-sheet margins and the altimeter measurement errors are also larger. The SD (with 3 SD editing) for Geosat-Geosat crossovers increases from 1.06 m at 72°N to 2.93 m between 60°N and 63°N. Similarly, SD is 1.06 m in the elevation band between 2700 and 3300 m and 4.79 m in the band between 700 and 1200 m.
11. By the Expedition Glaciologique Internationale au Groenland (EGIG).
12. H. Seckel, *Medd. Groenl.* **187**, no. 4 (1977).
13. A. Bauer, A. Ambach, O. Schimpp, *ibid.*, **174**, no. 1 (1968).
14. N. Reeh and N. S. Gundestrup, *J. Glaciol.* **31**, 108, 198 (1985).
15. J. M. Kostecka and I. M. Whillans, *ibid.* **34**, 31 (1988).
16. In a continuity equation, V_i equals the downward ice velocity plus the vertical ice motion due to horizontal advection.
17. Also, changes in V_{cp} are a secondary effect primarily determined by changes in $A(t)$ and $B(t)$, and changes in V_b are negligible.
18. H. B. Clausen, N. S. Gundestrup, S. J. Johnsen, R. Bindschadler, J. Zwally, *Ann. Glaciol.* **10**, 10 (1988).
19. N. Reeh *et al.*, *J. Glaciol.* **20**, 27 (1978).
20. N. Reeh, H. B. Clausen, N. Gundestrup, S. J. Johnsen, B. Staufer, *Int. Assoc. Hydrol. Sci. Publ. No.* **118**, 177 (1977).
21. R. S. Bradley *et al.*, *Science* **237**, 171 (1987).
22. Glacio-isostatic uplift ended 4000 to 5000 years ago (A. Weidick, in *Geology of Greenland*, A. Escher and W. S. Watt, Eds. (The Geological Survey of Greenland, Denmark, 1976), p. 450. Figure 3 in (*1*) shows that the rise is 3 mm/year near the coast and 9 mm/year in the central area.
23. Accumulation data are summarized in U. Radok *et al.*, *Climatic and Physical Characteristics of the Greenland Ice Sheet: Parts I and II* (Univ. of Colorado, Boulder, 1982).
24. G. de Q. Robin, *Philos. Trans. R. Soc. London Ser. B* **280**, 143 (1977).
25. D. H. Bromwich, *Rev. Geophys.* **26**, 149 (1988).
26. Antarctic data in (*24*) suggest 6% per Kelvin at the surface and 11% per Kelvin above the surface inversion layer for the equation of M. Mellor [*Polarforschung* **5**, 179 (1963)]. Temperature and accumulation records since 1965 at an Antarctic coastal station give 18% per Kelvin [D. W. S. Limbert, in *Environment of West Antarctica: Potential CO_2-Induced Changes*, M. F. Meier and C. R. Bentley, Eds. (National Academy of Sciences, Washington, DC, 1984), pp. 116–139]. The positive linear relation between Greenland accumulation and $\delta^{18}O$ values (*18*) and, therefore, temperature give 5% per Kelvin; modeling experiments [M. E. Schlesinger and J. F. B. Mitchell, *Rev. Geophys.* **25**, 760 (1987)] show precipitation increases of about 0.2 m/year in polar regions for greenhouse warming associated with a doubling of CO_2 concentration, which is a change of about 5 to 20% per Kelvin at the latitudes of Greenland.
27. W. Ambach and M. Kuhn, pp. 255–257 in (*7*), show equilibrium rise of 77 m per Kelvin increase in surface air temperature, a fall of 73 m per 0.1-m increase in snowfall, and a fall of 4 m per 10% increase in cloudiness.
28. J. Hansen and S. Lebedeff, *Geophys. Res. Lett.* **15**, 323 (1988).
29. J. L. Bufton, J. E. Robinson, M. D. Femiano, F. S. Flatow, *IEEE Trans. Geosci. Remote Sensing* **GE-20**, 544 (1982).

30. This work is supported by NASA's Ocean Processes Program. I thank S. Jacobs for his compilation of estimates of Antarctic mass fluxes and D. Bromwich for pointing me to literature on polar precipitation. I appreciate the useful discussions with R. Alley, R. Bindschadler, C. Lingle, S. Stephenson, and R. Thomas.

29 June 1989, accepted 13 October 1989

Thermomolecular Pressure in Surface Melting: Motivation for Frost Heave

J. G. Dash

A thermomolecular pressure is associated with surface melting, and it can drive mass flow along an interface under a lateral temperature gradient. The pressure is a universal thermodynamic function in the limit of thick films. It may be responsible for frost heave in frozen ground.

Surface melting continues to attract considerable experimental and theoretical interest, as it involves fundamental questions in surface science and condensed matter physics and practical applications in materials processing (*1–5*). Although the phenomenon has been explored in a limited number of materials, it is believed to be a general characteristic of most classes of solid materials. The motivating force for the effect is the lowering of the interfacial free energy of a solid surface by a layer of the melted material, which occurs for all solid interfaces that are wetted by the melt liquid. Such a reduction of the free energy allows a macroscopically thick film of the liquid to be stabilized at a temperature below the normal melting point. The surface free energy of the film varies with its thickness and asymptotically approaches the value for semi-infinite liquid. This variation

Department of Physics, FM-15, University of Washington, Seattle, WA 98195.

1986

Global temperature variations between 1861 and 1984

P. D. Jones, T. M. L. Wigley & P. B. Wright*

Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

Recent homogenized near-surface temperature data over the land and oceans of both hemispheres during the past 1 years are combined to produce the first comprehensive estimates of global mean temperature. The results show little tre in the nineteenth century, marked warming to 1940, relatively steady conditions to the mid-1970s and a subsequent rap warming. The warmest 3 years have all occurred in the 1980s.

GLOBAL mean surface air temperature is the most commonly used measure of the state of the climate system. When general issues of climatic change are addressed, global mean temperature change is often used as a yardstick; the age of the dinosaurs was warmer than today, the ice ages were colder, and so on. Paradoxically, in the present era of instrumental meteorology, with data coverage far better than at any earlier time, our knowledge of global mean temperature changes is still uncertain. Variations in global mean air temperature are of considerable importance, as they are a measure of the sensitivity of the climate system to external forcing factors such as changes in carbon dioxide concentration, solar output and the frequency of explosive volcanic eruptions. Quantifying the response of the climate to external forcing changes is a major goal of climatology and a prerequisite for predicting future climatic change. As a step towards this goal, we present here the first global synthesis of near-surface temperature measurements over the land and oceans.

Most earlier estimates of global and hemispheric mean temperature (see refs 1, 2) were based solely on data from land-based meteorological stations. Since >70% of the globe is ocean, one might suspect the global representativeness of such estimates, although on long timescales (≥decades) the thermal coupling between land and ocean should ensure that the land data largely mirror changes occurring over the oceans[1]. Recently, data from ships at sea collected for routine weather forecasting purposes, have been compiled by groups in the United Kingdom[3,4] and the United States[5,6], and these data give us the potential to calculate improved estimates of global mean temperature. Apart from our own work[7], the only previous attempt to analyse both land and marine data is that of Paltridge and Woodruff[8,9]. These authors, however, failed to account for inhomogeneities in the marine data, which are substantial (see below and also refs 4 and 10). The quality and coverage of the land data they used was also less than adequate, but this is understandable because they were primarily interested in sea-surface temperature variations.

The land data we use are those from refs 11, 12. These have been carefully examined to detect and correct for non-climatic errors that may result from station shifts or instrument changes, changes in the methods used for calculating means, urban warming, and so on. Although problems still exist[13,14], the quality of these data is much better than that of material used in earlier studies. Area averages based on these data show medium to long timescale trends (≥10 yr) whose spatial consistency provides a strong pointer to the data's overall reliability[1,11,12]. The marine data we employ are those in the COADS (Comprehensive Ocean Atmosphere Data Set) compilation[6] which extends to 1979, and data from the Climate Analysis Center, NOAA, for 1980-84. We use both sea surface temperatures (SST) a marine air temperatures (MAT).

Marine data problems

Both SST and MAT data contain 'inhomogeneities', variati resulting from non-climatic factors[4,10,15]. For example, ea SSTs were measured using water collected in uninsulated, can buckets, while more recent data come either from insula bucket or cooling water intake measurements, with the la considered to be 0.3-0.7 °C warmer than uninsulated buc measurements[10]. For marine air temperatures, changes in t size and speed of ships, especially those increases associa with the sail to steam transition, are both thought to h influenced data homogeneity. In addition, many early air te perature observations were not taken in screened locatio Because of these non-climatic factors, both SST and MAT d must be corrected (or 'homogenized') to remove their effec

Folland *et al.*[4,16] and Folland and Kates[17], using the U Meteorological Office (UKMO) data bank[3], attempted to ov come these problems by identifying specific sources of er attempting to quantify these and using this information to ma corrections to the raw gridded data. Such corrections ha inherent uncertainties because of difficulties in their *a pri* quantification and a lack of knowledge of how most measur ments were taken. Information on whether bucket or inta measurements were made has, in most cases, apparently be lost or never recorded. It has also been shown[18] that supposed homogeneous (that is bucket-only or intake-only) SST da series appear to have non-climatic changes that are similar those found in mixed data series, suggesting that all histori data sets contain a mix of measurement types. Since 19 however, it is generally assumed that available SST data conta a reasonably consistent mix of intake and bucket measur ments[18].

The Folland *et al.*[4] corrected MAT and SST series have be compared with averages of land-based data by Jones *et al.*[11 Agreement is reasonable since the start of the twentieth centu although MAT values for the years 1942-45 appear to be t warm in both hemispheres. Before 1900, the marine and la series diverge markedly, with both marine series being abo 0.3 °C warmer than the land data.

Correcting the COADS data

The COADS compilation contains some 63.25 million no duplicated SST observations, of which 0.96 million have be 'trimmed' to remove extreme outliers[5]. While these are mo data than in the UKMO SST set (which has about 46 milli non-duplicated observations[4]), the effective area and density coverage is very similar in both data sets. However, unlike t UKMO data set used by Folland *et al.*[4], none of the data i COADS have been corrected for non-climatic effects. Our fi task, therefore, was to homogenize the COADS data. We

* Present address: Max-Planck-Institut für Meteorologie, Bundesstrasse 55, 2000 Hamburg 13, FRG.

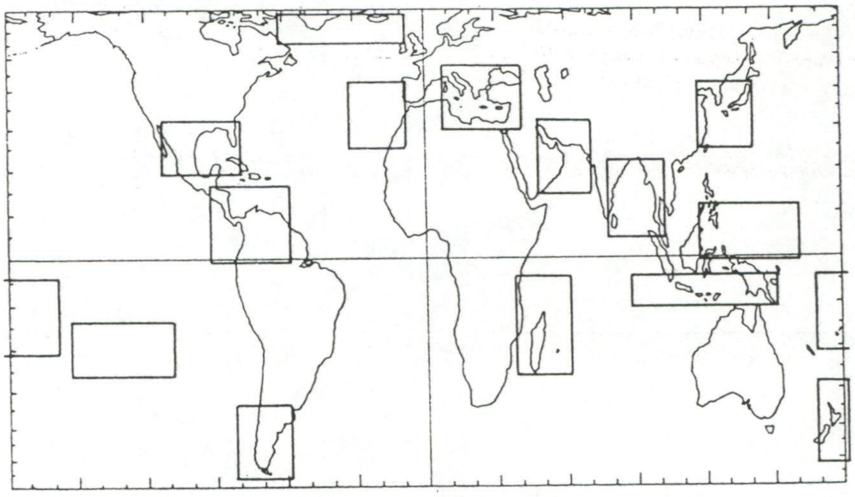


Fig. 1 Map showing the 15 regions where marine air temperatures and land-based temperatures were compared (Peters equal-area rectangular projection).

is by comparing marine and land data in areas where the two abut or overlap (coastal areas and around ocean islands).

The trimmed COADS data include monthly means and medians on a 2°×2° grid, together with the number of observations in a month and the mean observation date. We compressed the data onto a more manageable grid (5°×5° for MAT, 4°×10° for SST) after first eliminating values where the number and distribution of observations was likely to have produced unrepresentative monthly means, and expressed the values as anomalies from a 1950–79 reference period. As a test of data quality at this stage we calculated hemispheric mean values by appropriately weighting the gridded MAT and SST data (NH, Northern Hemisphere; SH, Southern Hemisphere). Year-to-year fluctuations for these uncorrected data were found to be in excellent agreement with the UKMO corrected data (NHSST, $r=0.86$; NHMAT, $r=0.87$; SHSST, $r=0.88$; SHMAT, $r=0.75$ over 1856–1979: correlation coefficients calculated using residuals from a 10-yr gaussian filter), but, as expected, the long-term (>10 yr) fluctuations showed marked differences. Similar high frequency correlations between SST and MAT for the uncorrected COADS data (NH, $r=0.91$; SH, $r=0.89$) were higher than for the corrected UKMO data (NH, $r=0.81$; SH, $r=0.80$).

Because of the high SST–MAT correlation (see also ref. 19), SST data can be corrected by comparison with MAT data, once the latter have been corrected. For the MAT data, any attempt to assess, *a priori*, the magnitudes of errors arising from instrumental changes, changes in observation methods, and the effects of changes in ships' thermal inertia, speed and size (the latter determines the height at which observations were taken), must be fraught with uncertainty. Data reliability and long-term homogeneity can be far more convincingly demonstrated for the gridded land data than for the marine data because land station data homogeneities can be more easily identified, explained and corrected[11,12]. We therefore use these data directly to correct the marine data. Fifteen regions (see Fig. 1) were chosen in which land and marine data are in close proximity. Area averages of annual mean MAT and land air temperature were calculated for each region using the uncorrected COADS data and the homogenized land data produced by Jones *et al.*[11,12]. No attempt was made to consider night-time observations only, as used by Folland *et al.*[4]. In addition to the 15 pairs of area averages, annual mean coastal land time series were produced for both hemispheres and compared with the uncorrected hemispheric-mean MAT series.

The 17 land minus MAT time series were then examined for systematic differences between the land and marine data. For the period 1861–1979 (both marine and Southern Hemisphere land data are unrepresentative before 1861 because of poor data coverage), five distinct periods could be discerned in all 15 regional land minus MAT time series and in the two hemispheric land minus MAT time series. The latter are shown in Fig. 2. The three main periods are: the period up to the 1880s when the MAT data appear to be too warm by 0.4–0.5 °C; the period from the 1900s to 1941 when the MAT data are too cold by 0.1–0.2 °C; and 1946–79 when there is no obvious bias. There is a strong upward trend in the land-minus-MAT difference between the mid 1880s and the late 1900s, and the war years, 1942–45, are marked by anomalously warm MAT values. The consistency between the hemispheres is clear from Fig. 2, and the land minus MAT data for the individual smaller regions, although showing greater inter-annual variability, all show the same features.

The nineteenth century land minus MAT data also show differences between the values before and after about 1873 (see Fig. 2). By examining land, MAT and SST data it can be shown that this difference is also likely to reflect a non-climatic

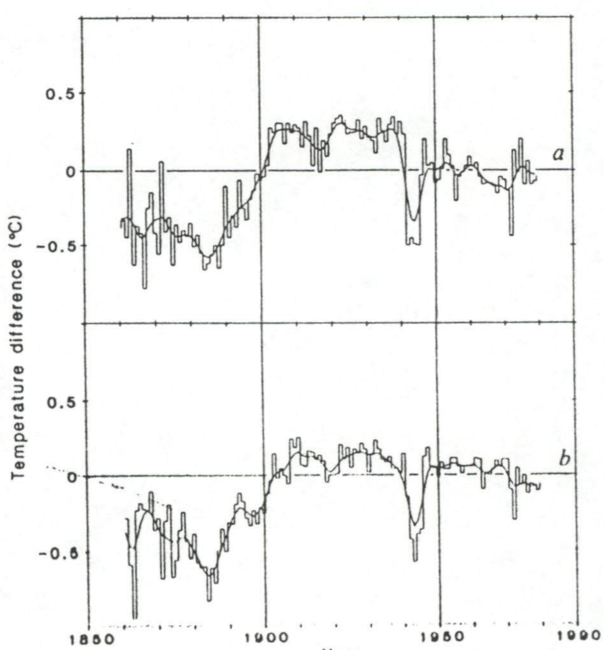


Fig. 2 Temperature differences: coastal land values minus uncorrected COADS marine air temperature values for the Northern (*a*) and Southern (*b*) Hemispheres. Smooth curves show 10-yr gaussian filtered values, padded at each end as described in ref. 11.

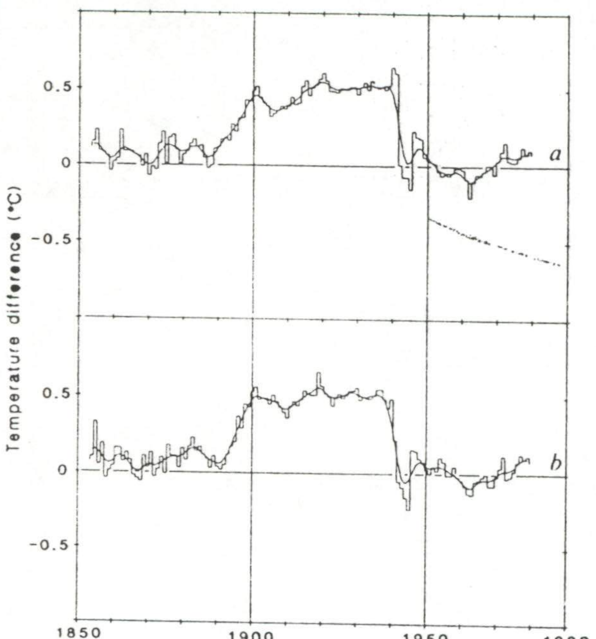


Fig. 3 Temperature differences: corrected marine air temperatures minus uncorrected sea surface temperatures for the Northern (a) and Southern (b) Hemispheres. Smooth curves show 10-yr gaussian filtered values.

inhomogeneity in either the MAT data or the land data, probably the former.

The means and standard deviations of the land minus MAT values are shown in Table 1. The consistency of these values strongly suggests that these land/MAT discrepancies are not climatic in origin. They may, therefore, be used to estimate annual correction factors for the MAT data in order to make these data compatible with the existing homogenized land data. Except for the 1942-45 period, when war conditions apparently prompted observers to measure temperature in unconventional locations[4], the specific reasons for these non-climatic MAT fluctuations are not known. Although their reality cannot be questioned, there is clearly some uncertainty in the magnitude of the implied corrections.

The correction values we have used (added to the raw MAT data) are (°C): 1861-73, −0.40; 1874-89, −0.48; 1903-41, 0.17; 1942-45, −0.54; 1946-79, 0.0; with linear interpolation between 1889 and 1903. Slightly different corrections were judg[ed] necessary for Southern Hemisphere data between 1941 and 19[45]: 1941, −0.14; 1942-45, −0.44. Most of the transition dates f[or] these correction factors, which are based on a number of co[n]siderations, could be altered slightly with no appreciable eff[ect] on the resulting corrected MAT values. Although the 0.08 difference in the MAT corrections before and after 1873 ma[y] be inappropriate if it arises from a land data inhomogenei[ty] we judge this to be unlikely. It has the effect of slightly reduci[ng] the magnitude of the long-term MAT warming between t[he] period before 1873 and today. The corrections generally refle[ct] the mean land minus MAT values shown in Table 1, but t[he] precise values used and the transition dates also take MAT-SS[T] comparisons into account. Our corrections differ markedly fro[m] those applied by Folland *et al.*[4] to their night-time MAT da[ta]. This is a clear indication of incompatibilities between the corre[c]ted UKMO MAT data and the homogenized land data (see al[so] refs 11 and 12).

Having corrected the MAT data, we can now estimate t[he] SST corrections required to ensure overall compatibility betwe[en] the land, MAT and SST data by comparing the corrected MA[T] and raw SST values. Table 2 and Fig. 3 show the hemispher[ic] mean differences between the corrected MAT data and the r[aw] SST data. As with the MAT analysis, three distinct periods c[an] be discerned: pre-1890 when the SST data are slightly b[ut] consistently cooler than the MAT data; 1903-41 when SSTs a[re] markedly cooler than MATs; and post-1945 when there is n[o] consistent difference. Rather complex transitions exist betwe[en] these three phases. The MAT-SST difference curves are esse[n]tially the same in both hemispheres. This is a strong indicati[on] that the differences reflect non-climatic effects, and it provid[es] a valuable consistency check on the MAT corrections.

The implied SST corrections are (°C): 1861-89, 0.08; 1903-4[1], 0.49; 1942-45, −0.10; 1946-79, 0.0; with linear interpolatio[n] between 1889 and 1903. For 1941 we applied a slightly differe[nt] correction in the Southern Hemisphere, 0.19 °C. As for MA[T], these corrections also differ somewhat from those used by Fo[l]land *et al.*[4]. In their analysis, SST values were adjusted to ensu[re] compatibility with corrected MAT values, just as we have do[ne]. However, since their corrected MAT values must differ notic[e]ably from those produced here, differences in the SST corre[c]tions will, in part, reflect these MAT differences.

In our analysis, the difference between the twentieth centu[ry] SST correction factor before 1941 and after 1946 is 0.49 °C. Th[is] difference is in the range (0.3-0.7 °C) generally accepted for t[he] difference between uninsulated bucket and intake SS[T] measurements[18,20,21]. The precise reasons for the differences th[at] we obtain between the nineteenth century and early twenti[eth] century MAT and SST corrections are uncertain. For MAT, t[he] change is likely to be related to the transition from sail to stea[m]. Between 1880 and 1910, the percentage of steamship tonna[ge] as a fraction of total shipping tonnage rose from ~25 to 75[%] (ref. 22). Noticeable increases in ship speed occurred over t[he] period 1880-1900, and in ship size over the period 1890-19[..]

Table 1 Comparison between coastal land and MAT data

		1861-73	1874-89	1903-41	1942-45	1946-79
NH	$\bar{X}$	−0.35	−0.50	0.23	−0.49	−0.02
	s	0.26	0.11	0.09	0.02	0.12
SH	$\bar{X}$	−0.36	−0.53	0.10	−0.44	0.03
	s	0.23	0.14	0.09	0.09	0.10
NH (9 region	$\bar{X}$	−0.36	−0.42	0.17	−0.54	−0.03
average	$s(\bar{X})$	0.40	0.21	0.10	0.10	0.05
SH (6 region	$\bar{X}$	−0.61	−0.52	0.17	−0.44	0.05
average	$s(\bar{X})$	0.57	0.36	0.22	0.15	0.08
Correction		−0.40	−0.48	0.17	−0.54	0.00

$\bar{X}$ = mean land minus MAT value; s = corresponding standard deviation defined by $s^2=(Y-1)^{-1}\Sigma(X_j=\bar{X})^2$ where X_j is the value in year j, and Y is the number of years; $s(\bar{X})$ = standard deviation of the means defined by $(s(\bar{X}))^2=(n-1)^{-1}\Sigma(\bar{X}_i-\bar{X})^2$ where n is the number of regions (6 or 9), $\bar{X}_i$ is the mean for region i and $\bar{X}$ is the average value of $\bar{X}_i$. The last line shows the inferred correction which was added to the uncorrected annual MAT data.

Table 2 Comparison between corrected MAT data and uncorrec[ted] SST data

		1861-89	1903-41	1942-45	1946-7[9]
NH	$\bar{X}$	0.08	0.49	−0.07	0.02
	s	0.08	0.08	0.07	0.09
SH	$\bar{X}$	0.07	0.50	−0.14	0.02
	s	0.04	0.05	0.08	0.08
Correction		0.08	0.49	−0.10	0.00

$\bar{X}$ = mean MAT minus SST value; s = corresponding standard de[vi]ation. The correction is the number added to the uncorrected ann[ual] SST data.

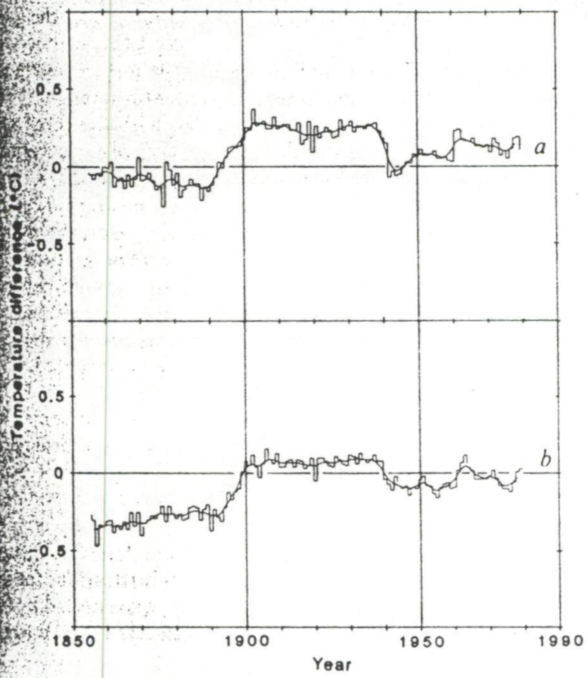


Fig. 4 Differences between the hemispheric-mean sea surface temperature values produced in the present work and those of Folland *et al.*[4]; Northern Hemisphere (*a*), Southern Hemisphere (*b*). Smooth curves show 10-yr gaussian filtered values. The implied warmth of the Folland *et al.* SH data relative to the NH (by ~0.2 °C), is due to their use of 1951–60 as a reference period. Conditions during this decade differed noticeably from the mean conditions during the reference period, 1950–79, used here (see Fig. 5).

(ref. 22). These dates should be compared with the duration of the rising trends in land minus uncorrected-MAT data in both hemispheres shown in Fig. 2. Changes in MAT may be related to exposure changes attendant on the above, and to other changes in instrument exposure procedure which occurred over the same period. For SST, the main reasons for the change may be the standardization of the measuring technique and the introduction of more reliable instruments[23]. It is also possible that, in the mid to late nineteenth century, many bucket temperatures were not taken in the shade[24]. In addition, some of the earlier measurements may have been made with wooden rather than canvas buckets. The latter, being uninsulated and subject to evaporative cooling, produce lower temperature readings.

The overall differences between the hemispheric mean SST values produced here and those of Folland *et al.*[4] are shown in Fig. 4. The results for an MAT comparison are similar. The discrepancies are large and comparable in magnitude to either set of corrections. The reasons for these differences stem mainly from the different correction factors applied to what are essentially similar raw data. Because there are several sources of data inhomogeneity, we have not attempted to correct for these individually. The result should be more complete than Folland *et al.*[4] who attempted to make specific corrections for identified sources of inhomogeneity based on physical arguments. Our corrections synthesize the effects of several different factors. However, while they ensure compatibility between the marine and land data, the fact that the reasons for these corrections are uncertain must point towards some remaining uncertainty in our corrected marine data, especially in the nineteenth century.

Global mean temperatures

It is a relatively simple matter to produce estimates of annual global mean surface air temperature using the available (corrected) marine data and the most recent compilations of land data[11,12]. There are three different ways in which global or hemispheric (land plus marine) averages can be calculated. The first method is to average only those grid point values (with appropriate cosine weighting) for which data exist. This is the way hemispheric means have been produced for the land data[11,12]. The second and third methods assume that each of the four independent time series (NH and SH land and NH and SH marine, either SST or MAT) are, at all times, representative either of their maximum coverage or of the total areas of the four domains. The results obtained differ but little, and the use of either SST or MAT to represent the marine domains produces only minor differences. We therefore show only results using the second method based on SST data, obtained using

$$T\,\text{global} = 0.25\text{NH land} + 0.25\text{NH SST} + 0.2\text{SH land} + 0.3\text{SH SST}$$

(Fig. 5) where, after 1957, SH land includes Antarctic data from

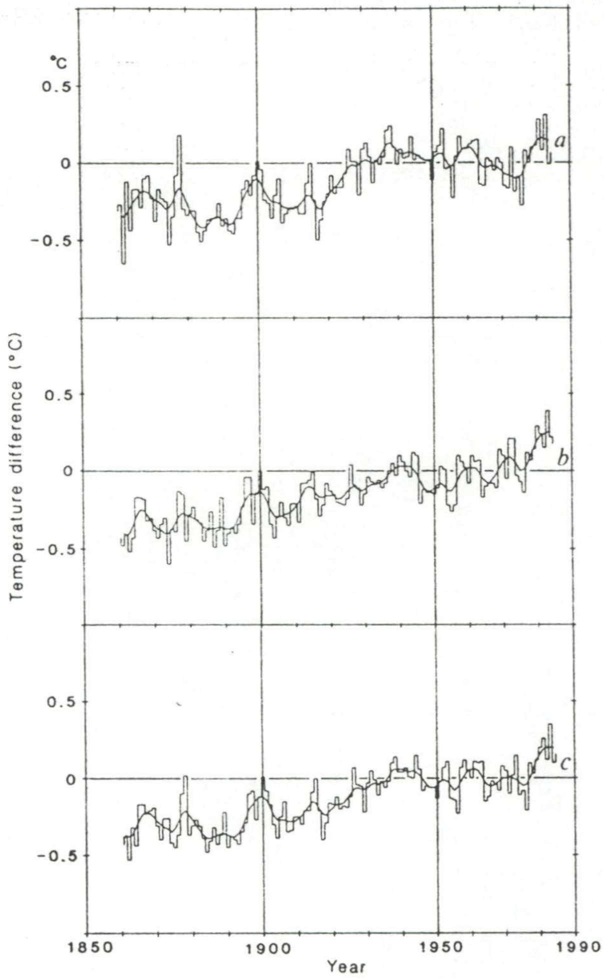


Fig. 5 Global (*c*) and hemispheric (Northern, *a*; Southern, b) annual mean temperature variations since 1861, based on sea-surface temperature data to represent the marine domain and using weights corresponding approximately to the maximum coverage for the four domains (method two in the text). Smooth curves show 10-yr gaussian filtered values. 1980–84 values are based on SST data obtained from the Climate Analysis Center, U.S. National Oceanic and Atmospheric Administration (see ref. 29 for information about this data source). These data were adjusted to be compatible with the values in earlier years by comparing values in both hemispheres over the overlap period, 1970–79. The CAC data correlate highly with the COADS data ($r = 0.984$ for the Northern Hemisphere mean and $r = 0.991$ for the Southern Hemisphere mean).

Raper *et al.*[25], updated. The insensitivity to the precise method of weighting arises because all time series are quite strongly correlated.

The reliability of the time series given in Fig. 5 as true hemispheric and global averages can be questioned because the spatial coverage, even at best, is less than 75% and because the coverage changes with time. Coverage is always much better in the Northern Hemisphere. Coverage before 1900 is generally less than one third of the globe, down to <20% in the 1860s. The question of representativeness of the land data has been considered in detail in refs 1, 11 and 12. Although marine coverage before 1900 is sparse, the spatial correlation length over the oceans is large and limited coverage should still give results representative of a much larger area. Nevertheless, there are large parts of the Southern Hemisphere that nearly always lack data, especially the southern oceans south of 45 °S and the whole of the southeastern Pacific (except near the South American coast). Before 1957, when most Antarctic data first became available, there are essentially no data at all for the globe south of 45 °S (refs 25, 26). Although this represents only ~15% of the area of the globe, temperature fluctuations at high latitudes are known to be larger than at lower latitudes and so can have a disproportionate effect on the global average[12,27]. Any interpretation of Fig. 5 must bear in mind both these basic data deficiencies and the marine data uncertainties implied by Fig. 4. We note, however, that the latter do not affect the gro features of the global mean changes observed this century.

The global curve is extremely interesting when viewed in th light of recent ideas of the causes of climatic change[1,2]. Th data show a long timescale warming trend, with the three wa mest years being 1980, 1981 and 1983, and five of nine warme years in the entire 134-yr record occurring after 1978. Wi regard to the hypothesized warming due to increasing concentr tions of carbon dioxide and other greenhouse gases, the over change is in the right direction and of the correct magnitude[1,7]. However, the relatively steady conditions maintained betwe the late 1930s and mid 1970s requires either the existence some compensating forcing factor or, possibly, a lower sensiti ity to greenhouse gas changes than is generally accepted.

We thank particularly C. K. Folland, D. E. Parker, P. Kelly, T. P. Barnett and D. J. Shea for useful comments. W thank D. E. Parker and C. K. Folland (UK Meteorologic Office) for access to unpublished data used in Fig. 4 Sc Woodruff (Environmental Research Laboratories, US Nation Oceanic and Atmospheric Administration) for an early copy the trimmed COADS data set, and the Climate Analysis Cent US National Oceanic and Atmospheric Administration, for th recent marine data used in Fig. 5. This work was funded by th Carbon Dioxide Research Division, US Department of Energ grant no. DE-FGO2-86-ER60397.

Received 10 February; accepted 28 May 1986.

1. Wigley, T. M. L., Angell, J. K. & Jones, P. D. in *Detecting the Climatic Effects of Increasing Carbon Dioxide* (eds MacCracken, M. C. & Luther, F. M.) 55-90 (U.S. Dept of Energy, 1985).
2. Hansen, J. *et al. Science* 213, 957-966 (1981).
3. Shearman, R. J. *Met. Mag.* 112, 1-10 (1983).
4. Folland, C. K., Parker, D. E. & Kates, F. E. *Nature* 310, 670-673 (1984).
5. Woodruff, S. D. in *Proc. 3rd Conf. on Climate Variations and Symp. on Contemporary Climate: 1850-2100*, 14-15 (American Meteorological Society, Boston, 1985).
6. Slutz, R. J. *et al. Comprehensive Ocean-Atmosphere Data Set Release 1* (NOAA Environmental Research Laboratories, Boulder, 1985).
7. Wigley, T. M. L., Jones, P. D. & Kelly, P. M. in *The Greenhouse Effect, Climatic Change, and Ecosystems* (eds Bolin, B., Döös, B. R., Jäger, J. & Warrick, R. A.) (SCOPE series, Wiley, in the press).
8. Paltridge, G. W. & Woodruff, S. *Mon. Weath. Rev.* 109, 2427-2434 (1981).
9. Paltridge, G. W. *Mon. Weath. Rev.* 112, 1093-1095 (1984).
10. Barnett, T. P. in *Detecting the Climatic Effects of Increasing Carbon Dioxide* (eds MacCracken, M. C. & Luther, F. M.) 91-107 (U.S. Dept of Energy, 1985).
11. Jones, P. D. *et al. J. Clim. appl. Met.* 25, 161-179 (1986).
12. Jones, P. D., Raper, S. C. B. & Wigley, T. M. L. *J. Clim. appl. Met.* 25 (in the press).
13. Bradley, R. S., Kelly, P. M., Jones, P. D., Diaz, H. F. & Goodess, C. *A Climatic Data Bank for the Northern Hemisphere Land Areas, 1851-1980, DoE Tech. Rep. No. TR017* (U.S. Dept of Energy, 1985).
14. Bradley, R. S. & Jones, P. D. in *Detecting the Climatic Effects of Increasing Carbon Diox* (eds MacCracken, M. C. & Luther, F. M.) 29-53 (U.S. Dept of Energy, 1985).
15. Wright, P. B. *Mon. Weath. Rev.* 114 (in the press).
16. Folland, C. K., Parker, D. E. & Newman, M. in *Proc. 9th Annual Climate Diagnos Workshop*, 70-85 (U.S. Dept. of Commerce, NOAA, Washington DC, 1984).
17. Folland, C. K. & Kates, F. E. in *Milankovitch and Climate* (eds Berger, A., Imbrie, Hays, J., Kukla, G. & Saltzman, B.) 721-727 (Reidel, Dordrecht, 1984).
18. Barnett, T. P. *Mon. Weath. Rev.* 112, 303-312 (1984).
19. Cayan, D. R. *Mon. Weath. Rev.* 108, 1293-1301 (1980).
20. Saur, J. F. T. *J. appl. Met.* 2, 417-425 (1963).
21. James, R. W. & Fox, P, T. *Comparative sea-surface temperature measurements, Mar Science Affairs Rep. No. 5*, WMO Publ. No. 336 (Geneva, 1972).
22. Kirkaldy, A. W. *British Shipping, Its History, Organization and Importance* (Kegan Pa Trench, Trubner, London, 1919).
23. Krümmel, O. *Handbuch der Ozeanographie*, Vol. 1 (Engelhorn, Stuttgart, 1907).
24. Brooks, C. F. *Mon. Weath. Rev.* 54, 241-253 (1926).
25. Raper, S. C. B., Wigley, T. M. L., Mayes, P. R., Jones, P. D. & Salinger, M. J. *Mon. Wea Rev.* 112, 1341-1353 (1984).
26. Raper, S. C. B., Wigley, T. M. L., Jones, P. D., Kelly, P. M., Mayes, P. R. & Limbert, W. S. *Nature* 306, 458-459 (1984).
27. Kelly, P. M., Jones, P. D., Sear, C. B., Cherry, B. S. G. & Tavakol, R. K. *Mon. Weath. Re* 110, 71-83 (1982).
28. Wigley, T. M. L. & Schlesinger, M. E. *Nature* 315, 649-652 (1985).
29. Reynolds, R. W. & Gemmill, W. H. *Trop. Ocean-Atmos. Newslett.* No. 23, 4-5 (1984).

LETTERS TO NATURE

Observation of terrestrial orbital motion using the cosmic-ray Compton–Getting effect

D. J. Cutler* & D. E. Groom*

Department of Physics, University of Utah, Salt Lake City, Utah 84112, USA

* Present addresses: Instrumentation Laboratory, North 3939 Freya, Spokane Washington 99207, USA (D.J.C.); Supercollider Central Design Group, LBL 90-4040, Berkeley, California 94720, USA (D.E.G.)

Using underground observations, we have found a small diurnal amplitude modulation of the cosmic-ray muon intensity which agrees in amplitude and phase with a first-order relativistic effect due to the Earth's motion, as discussed by Compton and Getting more than fifty years ago. The parent particles are sufficiently rigid (~1.5 TeV/c) that solar and geomagnetic effects should be minor. The muon flux deep underground is relatively insensitive to near-surface meteorological effects, and temperature effects production height would produce intensity variations nearly of phase with the observed effect. Analysis of the arrival times 5×10[8] muons during a period of 5.4 yr yields a fractional amp tude variation of $2.5^{+0.7}_{-0.6}\times10^{-4}$, with a maximum near dawn, 08:18±1.0 h local mean solar time (LT). The expected amplit is 3.40×10^{-4}, with the maximum at 06:00 LT.

Compton and Getting[1] showed that a cosmic-ray detec with an energy threshold would observe an enhanced inten when it moved along its direction of maximum sensitivity w respect to the rest frame of the cosmic-ray plasma. If the cosm ray energy distribution were a power law of the form $E^{-\gamma}$, th the fractional intensity enhancement above a fixed energy thre old should be

$$\frac{\Delta I(\theta)}{\langle I\rangle}=(2+\gamma)\frac{v}{c}\cos\theta$$

where θ is the angle between the direction of detector sensitiv and its velocity vector. A term v/c arises because the detec sweeps out a column of the cosmic-ray plasma, another te $2v/c$ because the solid angle transformation increases t intensity in the direction of motion, and a term $(\gamma-1)$

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 92, NO. D11, PAGES 13,345–13,372, NOVEMBER 20, 1987

Global Trends of Measured Surface Air Temperature

JAMES HANSEN

NASA Goddard Space Flight Center, Institute for Space Studies, New York

SERGEJ LEBEDEFF

Sigma Data Services Corporation, New York

We analyze surface air temperature data from available meteorological stations with principal focus on the period 1880–1985. The temperature changes at mid- and high latitude stations separated by less than 1000 km are shown to be highly correlated; at low latitudes the correlation falls off more rapidly with distance for nearby stations. We combine the station data in a way which is designed to provide accurate long-term variations. Error estimates are based in part on studies of how accurately the actual station distributions are able to reproduce temperature change in a global data set produced by a three-dimensional general circulation model with realistic variability. We find that meaningful global temperature change can be obtained for the past century, despite the fact that the meteorological stations are confined mainly to continental and island locations. The results indicate a global warming of about 0.5°–0.7°C in the past century, with warming of similar magnitude in both hemispheres; the northern hemisphere result is similar to that found by several other investigators. A strong warming trend between 1965 and 1980 raised the global mean temperature in 1980 and 1981 to the highest level in the period of instrumental records. The warm period in recent years differs qualitatively from the earlier warm period centered about 1940; the earlier warming was focused at high northern latitudes, while the recent warming is more global. We present selected graphs and maps of the temperature change in each of the eight latitude zones. A computer tape of the derived regional and global temperature changes is available from the authors.

1. INTRODUCTION

Surface air temperature has been measured at a large number of meteorological stations for the past century, mainly at northern hemisphere land locations. These station data have been used by a number of investigators [e.g., *Willett,* 1950; *Mitchell,* 1961; *Budyko,* 1969; *Vinnikov et al.,* 1980; *Yamamoto and Hoshiai,* 1980; *Jones et al.,* 1982, 1986*a*; *Jones and Kelly,* 1983; *Bradley et al.,* 1985] to estimate temperature change, with appropriate caveats concerning restrictions of spatial coverage (cf. review by *Wigley et al.* [1986]). Analysis of ocean surface temperature change has also been made [*Paltridge and Woodruff,* 1981; *Barnett,* 1984; *Folland et al.,* 1984] on the basis of ship data. Because the land and ocean data sets each have their own problems concerning data quality and uniformity over long periods (see previously cited references above, especially *Barnett* [1984] and *Jones et al.* [1986*a*]), it seems better to analyze the two data sets separately, rather than lumping them together prior to analysis. Another valuable source of global temperature data is provided by the radiosonde stations (*Angell and Korshover,* 1983]. This source includes data through the troposphere and lower stratosphere but is restricted to the period from 1958 to the present.

Although it is safer to restrict temperature analyses to regions with dense station coverage, there is a great incentive for trying to obtain estimates of long term global temperature change. Such global data would provide the most appropriate comparisons for global climate models and would enhance our ability to detect possible effects of global climate forcings, such as increasing atmospheric CO_2. In this paper we use the temperature records of meteorological stations to obtain an estimate of global surface air temperature change, and we estimate the errors due to incomplete spatial coverage.

Jones et al. [1986*c*] recently published an estimate of global near-surface temperature change obtained by combining the surface air temperature measurements of meteorological stations with marine surface air and surface water temperature measurements. We compare their results with ours at the end of this paper; our global mean and hemispheric mean results are generally in good agreement with theirs.

In section 2 we define the surface air temperature data set we employ, including illustration of the global distribution of stations, and we estimate the area over which the temperature change obtained from a given station is meaningful. In section 3 we describe the method we use to combine the records of different stations, which is designed to retain temperature change information while minimizing effects of incomplete spatial and temporal coverage. In section 4 we present detailed graphs of our results for global, hemispheric, zonal and regional temperature change. In section 5 we make several checks of the significance of the inferred trends, for example, by using an artificial global temperature history generated by a three-dimensional general circulation model to obtain a measure of the error due to incomplete spatial coverage, by reanalyzing the northern hemisphere temperature trend using a station distribution comparable to that available in the southern hemisphere, and by omitting urban stations to test for possible anthropogenic heat island effects. In section 6 we compare the derived hemispheric and global temperature change with the recent results of *Jones et al.* [1986*c*] and *Angell and Korshover* [1983; private communication, 1987].

Paper number 7D0578.
0148-0227/87/007D-0578$05.00

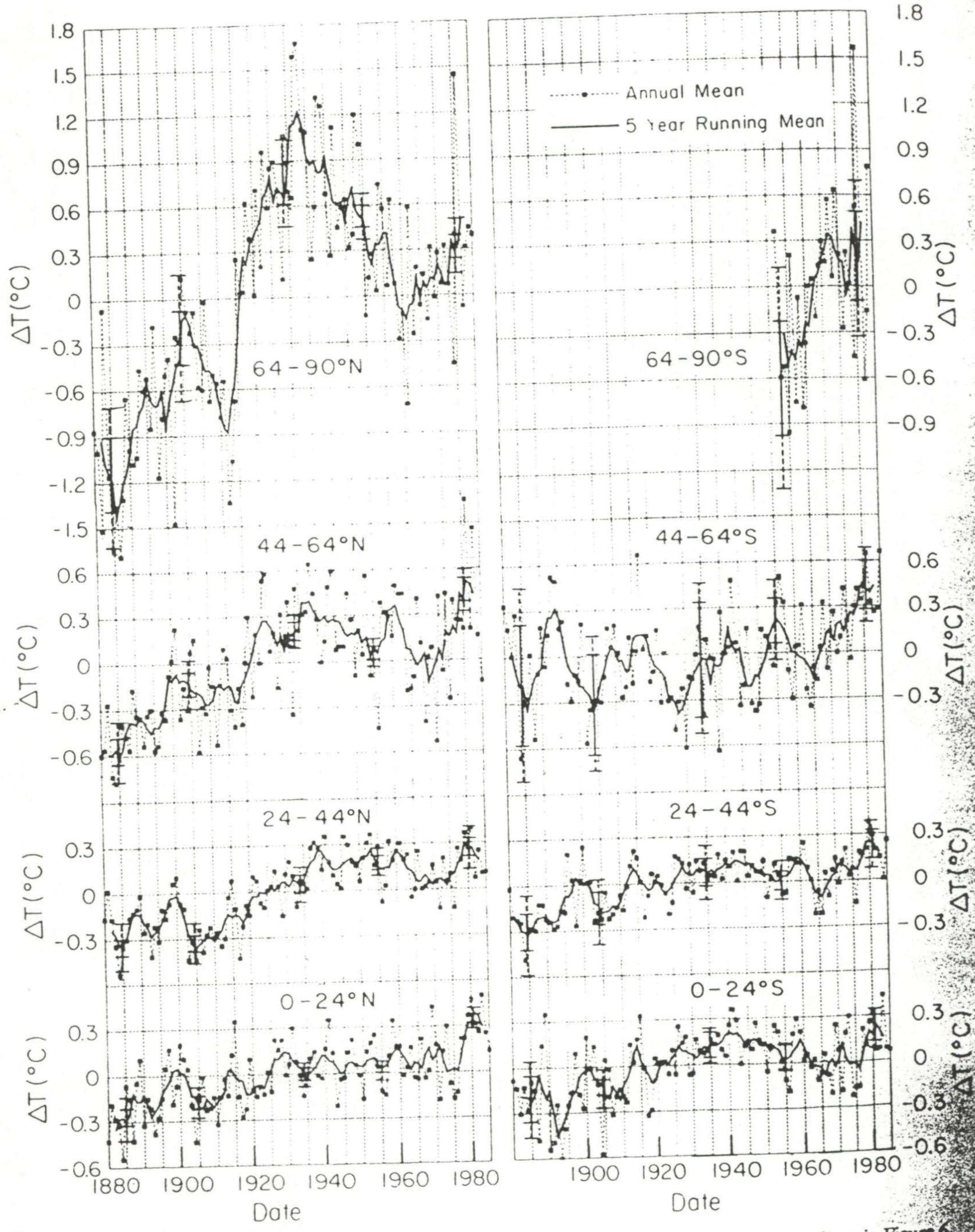


Fig. 7. Surface air temperature change for the eight latitude zones of Figure 2. Graphical details as in Figure 6.

data-free areas with the oceans. However, based on the

the high northern latitude zones. For most zones it is now

GW

"CORRESPONDENCE TRACKING"

TYPE: INFORMATION DOCUMENT NUMBER: 9121356

****

FROM: WOODROW WILSON INTERNATIONAL CENTER FOR SCHOLARS

TO: DR. BROMLEY

DATE OF CORRESPONDENCE: 04/27/91

SUBJECT: RE: THE LACK OF A CONSENSUS WITHIN THE SCIENTIFIC COMMUNITY ON THE EXISTENCE OF SIGNIFICANT GREENHOUSE WARMING FROM RISING LEVELS OF CARBON DIOXIDE.

****

ASSIGNED TO:

ACTION REQUIRED:

****

SENDER'S DUE DATE: OSTP DUE DATE:

DATE COMPLETED:

****

COPIES TO: ENVIRONMENT

****

WHITE HOUSE TRACKING #: CONTACT PERSON: DR. SINGER

REMARKS:

DATE RECEIVED: 05/07/91 FILE: ENVIRONMENT

THE WOODROW WILSON CENTER

91213526

RECEIVED

91 MAY 7 P 5: 14

OFFICE OF THE DIRECTOR

April 27, 1991

O. Allen Bromley
White House Sciene Advisor
1600 Pennsylvania Avenue, N.W.
Washington, DC 20500

Dear Mr. Bromley:

Contrary to conventional wisdom, there does not exist today a consensus within the scientific community on the existence of significant greenhouse warming from rising levels of carbon dioxide.

More and more prominent atmospheric scientists are calling into question the validity of current climate models, and consider control efforts--lacking credible support from science and cost-benefit analysis--to be ill-advised, premature and, worse, likely counterproductive.

Underscoring that point is the enclosed article, just published in the journal Cosmos. Its authors are among the most renown names in energy and atmospheric research:

Dr. Roger Revelle, winner of the 1990 National Medal of Science, initiated the program of global CO_2 measurements that is widely credited with focusing world attention on the greenhouse effect.

Dr. S. Fred Singer was the first scientist to predict the increase in atmospheric methane--an important greenhouse gas--from human activities.

Dr. Chauncey Starr, winner of the 1990 National Medal of Technology and a widely recognized expert on nuclear energy, is the author of seminal papers on technical and societal risk analysis.

You will note that the National Academy of Sciences report, "Policy Implications of Greenhouse Warming," released this month, supports the thesis of the Cosmos article recommending energy conservation and efficiency increases that make economic sense. These should be done--regardless of whether there is greenhouse warming or not.

You should also note the research paper by climate modeler Prof. Michael Schlesinger of the University of Illinois, published last month in the scientific journal Nature. His calculations clearly show that there is no need for immediate action. A delay for even a decade would have little impact on future climate.

If you would like additional comments on this important environmental issue, Dr. Singer can be reached at his Washington office at 202-357-2879 or at home at 703-503-5064.

WOODROW WILSON INTERNATIONAL CENTER FOR SCHOLARS
1000 JEFFERSON DRIVE, S.W. WASHINGTON, D.C. 20560
202-357-2429 TELEX 264729 FAX 202-357-4439

"What to Do About Greenhouse Warming: Look Before You Leap," <u>Cosmos</u>, Vol. 1, No. 1. pp. 28-33

ABOUT THE AUTHORS:

As director of the Scripps Institution of Oceanography, **DR. ROGER REVELLE** initiated the program of global CO_2 measurements that is widely credited with focusing world attention on the greenhouse effect. Dr. Revelle has served as science advisor to the U.S. Department of the Interior and as director of the Harvard Center for Population Studies, and is now a professor of science and public policy at the University of California at San Diego. A member of the National Academy of Science, Revelle was awarded the National Medal of Science in 1990.

DR. S. FRED SINGER was the first scientist to predict the increase in atmospheric methane--an important greenhouse gas--from human activities. Dr. Singer has served as chief scientist at the U.S. Department of Transportation and as deputy assistant administrator of the Environmental Protection Agency. He was the first director of the U.S. weather satellite program and developed the currently used satellite technology for measuring ozone in the upper atmosphere. A professor of environmental sciences at the University of Virginia, Singer is currently a guest scholar at the Woodrow Wilson International Center for Scholars. His most recent book is <u>Global Climate Change</u> (Paragon House, 1990).

Winner of the 1990 National Medal of Technology, **DR. CHAUNCEY STARR** is the founding president of the Electric Power Research Institute in Palo Alto, California, former president of Atomics International, and former dean of engineering at the University of California at Los Angeles. A widely respected expert on nuclear energy and a member of the National Academy of Engineering, Starr has designed nuclear reactors and fuel cycles and has published seminal papers on technical and societal risk analysis.

WHAT TO DO ABOUT GREENHOUSE WARMING: LOOK BEFORE YOU LEAP

S. Fred Singer
Roger Revelle
Chauncey Starr

Greenhouse warming has emerged as one of the most complex and controversial environmental and foreign-policy issues of the 1990s.

It is an environmental issue because carbon dioxide (CO_2), generated from the prolific burning of oil, gas and coal, is thought to enhance, by trapping heat in the atmosphere, the natural greenhouse effect that has kept the planet warm for billions of years. Some scientists predict drastic climatic changes in the 21st century.

The scientific base for a greenhouse warming is too uncertain to justify drastic action at this time.

It is a foreign-policy issue because, for a number of reasons, the United States has taken a more cautious approach to dealing with CO_2 emissions than have many industrialized nations. Wide acceptance of the Montreal Protocol, which limits and rolls back the manufacture of chlorofluorocarbons (CFCs) to protect the ozone layer, has encouraged environmental activists at international conferences the past three years to call for similar controls on CO_2 from fossil-fuel burning.

These activists have expressed disappointment with the White House for not supporting immediate action. But should the United States assume "leadership" in a hastily-conceived campaign that could cripple the global economy, or would it be more prudent to assure first, through scientific research, that the problem is both real and urgent?

We can sum up our conclusions in a simple message: *The scientific base for a greenhouse warming is too uncertain to justify drastic action at this time.*

There is little risk in delaying policy responses to this century-old problem since there is every expectation that scientific understanding will be substantially improved within the next decade. Instead of premature and likely ineffective controls on fuel use that would only slow down but not stop the further growth of CO_2, we may prefer to use the same resources—trillions of dollars, by some estimates—to increase our economic and technological resilience so that we can then apply specific remedies as necessary to reduce climate change or to adapt to it.

That is not to say that prudent steps cannot be taken now; indeed, many kinds of energy conservation and efficiency increases make economic sense even without the threat of greenhouse warming.

THE SCIENTIFIC BASE

The scientific base for greenhouse warming (GHW) includes some facts, lots of uncertainty and just plain lack of knowledge—requiring more observations, better theories and more extensive calculations. Specifically, there are reliable measurements of the increase in so-called greenhouse gases in the earth's atmosphere, presumably as a result of human activities. There is uncertainty about the strength of sources and sinks for these gases, i.e., their rates of generation and removal. There is major uncertainty and disagreement about whether this increase has caused a change in the climate during the last century. There is also disagreement in the scientific community about predicted future changes as a result of further increases in greenhouse gases. The models used to calculate future climate are not yet good enough because the climate-balancing processes are not sufficiently understood, nor are they likely to be good enough until we gain more understanding through observations and experiments.

As a consequence, we cannot be sure whether the

S. Fred Singer ('57) is professor of environmental sciences at the University of Virginia and served as the first director of the U.S. weather satellite program, among several government positions.

Roger Revelle ('43), professor of science and public policy at the University of California at San Diego, is former director of the Scripps Institution of Oceanography. He is a member of the National Academy of Sciences and last year received the National Medal of Science.

Chauncey Starr ('68) is the president emeritus of the Electric Power Research Institute and former dean of engineering at the University of California at Los Angeles. He is a member of the National Academy of Engineering. Last year he received the National Medal of Technology.

conditioning and industrial processes are making an important contribution but will soon be replaced by less-polluting substitutes.

Water vapor (H_2O) turns out to be the most effective greenhouse gas by far. It is not manmade, but is assumed to amplify the warming effects of the gases produced by human activities. We don't really know whether H_2O has increased in the atmosphere or whether it will increase in the future—although that's what all the model calculations assume. Indeed, predictions of future warming depend not only on the amount but also on the horizontal and especially the vertical distribution of H_2O, and on whether it will be in the atmosphere in the form of a gas or as liquid cloud droplets or as ice particles. The current computer models are not complete enough to test these crucial points.

THE CLIMATE RECORD

The issue now is whether the 25 percent increase of CO_2 in the atmosphere, mainly since World War II, calls for immediate and drastic action to limit and roll back global energy use. Taking account of increases in the other trace gases that produce greenhouse effects, we have already gone halfway to an effective GHG doubling—something that cannot be reversed in our lifetime—and, according to the prevailing theory, locked in a temperature increase of about 1.6 degrees Celsius.

But has there been a climate effect caused by the increase of greenhouse gases in the last decades? The data are ambiguous to say the least. Advocates for immediate action profess to see a global warming of about 0.5 degrees C since 1880, and point to record global temperatures in the 1980s and the warmest year on record in 1990. Most atmospheric scientists tend to be cautious, however; they call attention to the fact that the greatest temperature increase occurred *before* the major rise in greenhouse gas concentration. It was followed by a quarter-century decrease between 1940 and 1965 when concern arose about an approaching ice age! Following a sharp increase during 1975-80, there has been no clear upward trend during the 80s despite some very warm individual years and record GHG increases. Similarly, global atmospheric (rather than surface) temperatures measured by Tiros weather satellites show no trend in the last decade.

Scientists Kirby Hanson, Thomas Karl and George Maul of the National Oceanic and Atmospheric Administration (NOAA) find no overall warming in the U.S. temperature record, contrary to the global record assembled by James Hansen of the National Aeronautics and Space Administration (NASA). Using a technique that eliminates urban "heat islands" and other local distorting effects, they confirm the temperature rise before 1940, followed, however, by a general decline. Reginald Newell and colleagues at the Massachusetts Institute of Technology (MIT) report no substantial change in the global sea-surface temperature in the past century; yet the ocean, because of its much greater heat inertia, should control any atmospheric climate change.

Perhaps most interesting are the NOAA studies that document a relative rise in night temperatures in the U.S. in the last 60 years, while daytime values stayed the same or declined. This is just what one would expect from the increase in atmospheric greenhouse gas concentration. But its consequences, as University of Virginia climatologist Patrick Michaels and others have pointed out, are benign: A longer growing season, fewer frosts, no increase in soil evaporation.

It is therefore fair to say that we haven't seen the huge greenhouse warming, of between 0.7 and 2.5 degrees C, expected from the conventional theories. Why not? This scientific puzzle has many suggested solutions:

- The warming has been "soaked up" by the ocean and will appear after a delay of some decades. Plausible—but there is no evidence to support this theory until deep-ocean temperatures are measured on a routine basis, as suggested by Scripps Institution oceanographer Walter Munk. Feasibility tests are currently underway, using a sound source at Heard Island in the South Indian Ocean and a global network

ANOTHER ICE AGE COMING?

Global temperatures have been declining since the dinosaurs roamed the earth some 70 million years ago. About 2 million years ago, a new "ice age" began—most probably as a result of the drift of the continents and the buildup of mountains. Since that time, the earth has seen 17 or more cycles of glaciation, interrupted by short (10,000 to 12,000 years) interglacial or warm periods. We are now in such an interglacial interval, the Holocene, that started 10,800 years ago. The onset of the next glacial cycle cannot be very far away.

It is believed that the length of a glaciation cycle, about 100,000 to 120,000 years, is controlled by small changes in the seasonal and latitudinal distribution of solar energy received as a result of changes in the earth's orbit and spin axis. While the theory can explain the timing, the detailed mechanism is not well understood—especially the sudden transition from full glacial to interglacial warming. Very likely an ocean-atmosphere interaction is triggered and becomes the direct cause of the transition in climate.

The climate record also reveals evidence for major climatic changes on time scales shorter than those for astronomical cycles. During the past millennium, the earth experienced a "climate optimum" around 1100 A.D., when Vikings found Greenland to be green and Vinland (Labrador?) able to support grape growing. The "Little Ice Age" found European glaciers advancing well before 1600 and suddenly retreating starting in 1860. The warming reported in the global temperature record since 1880 may thus simply be the escape from this Little Ice Age rather than our entrance into the human greenhouse.

translate to longer growing seasons and fewer frosts. Increased global precipitation should also be beneficial to plant growth.

Keep in mind also that year-to-year changes at any location are far greater and more rapid than what might be expected from greenhouse warming; and nature, crops and people are already adapted to such changes. It is the extreme climate events that cause the great ecological and economic problems: Crippling winters, persistent droughts, extreme heat spells, killer hurricanes and the like. But there is no indication from modeling or from actual experience that such extreme events *would* become more frequent if greenhouse warming becomes appreciable. The exception might be tropical cyclones, which—Balling and Randall Cerveney argue—would be more frequent but weaker, would cool vast areas of the ocean surface and increase annual rainfall. In sum, climate models predict that global precipitation should increase by 10 to 15 percent, and polar temperatures should warm the most, thus reducing the driving force for severe winter-weather events.

We can be putting into effect policies and pursue approaches that make sense even if the greenhouse effect did not exist.

There is finally the question of sea-level rise as glaciers melt—and fear of catastrophic flooding. The cryosphere certainly contains enough ice to raise sea level by 100 meters; and, conversely, during recent ice ages, enough ice accumulated to drop sea level 100 meters below the present value. But these are extreme possibilities; tidal-gauge records of the past century suggest that sea level has risen modestly, about 0.3 meters. But the gauges measure only *relative* sea level, and many of the gauge locations have dropped because of land subsidence. Besides, the test locations are too highly concentrated geographically, mostly on the U.S. East Coast, to permit global conclusions. The situation will improve greatly, however, in the next few years as precise absolute global data become available from a variety of satellite systems.

In the meantime, satellite radar-altimeters have already given a surprising result. As reported by NASA scientist Jay Zwally in *Science*, Greenland ice-sheets are gaining in thickness—a net increase in the ice stored in the cryosphere and an inferred *drop* in sea level—leading to somewhat uncertain predictions about future sea level. Modeling results suggest little warming of the Antarctic Ocean because the heat is convected to deeper levels. It is clearly important to verify these results by other techniques and also get more direct data on current sea-level changes.

Summarizing the available evidence, we conclude that even if significant warming were to occur in the next century, the net impact to the entire planet may well be beneficial—with some regions enjoying improved climate, some encountering worse. This would be even more true if the long-anticipated ice age were on its way.

In view of the uncertainties about the degree of warming, and the even greater uncertainty about its possible impact—what should we do? During the time that an expanded research program reduces or eliminates these uncertainties, we can be putting into effect policies and pursue approaches that make sense even if the greenhouse effect did not exist.

ENERGY POLICIES

Conserve energy by discouraging wasteful use globally. Conservation can best be achieved by pricing rather than by command-and-control methods. If the price can include the external costs that are avoided by the user and loaded onto someone else, this strengthens the argument for proper pricing. The idea is to have the polluter or the beneficiary pay the cost. An example would be peak-pricing for electric power. Yet another example, appropriate to the greenhouse discussion, is to increase the tax on gasoline to make it a true highway-user fee—instead of having most capital and maintenance costs paid by various state taxes, as is done now. Congress has lacked the courage for such a direct approach, preferring instead regulation that is mostly ineffective and produces large indirect costs for the consumer.

Improve efficiency in energy use. Energy efficiency should be attainable without much intervention, provided it pays for itself. A good rule of thumb: If it isn't economic, then it probably wastes energy in the process and we shouldn't be doing it. Over-conservation can waste as much energy as under-conservation. (For example, destroying all older cars would certainly raise the fuel efficiency of the fleet, but replacing these cars would consume more energy in their manufacture.) If energy is properly priced, i.e., not subsidized, the job for government is to remove the institutional and other road blocks:

- Provide information to consumers, especially on life-cycle costs for home heating, lighting, refrigerators and other appliances.
- Encourage—but not force—the turnover and replacement of older, less efficient (and often more polluting) capital equipment: Cars, machinery, power plants. Some existing policies that make new equipment too costly go counter to this goal.
- Stimulate the development of more efficient systems, such as a combined-cycle power plant or a more efficient internal-combustion engine.

Use non-fossil-fuel energy sources wherever this makes economic sense. Nuclear power is competitive now, and in many countries is cheaper than fossil-fuel power—yet it is often opposed on environmental

April 1991, Nature

Does climate still matter?

Jesse H. Ausubel

We may be discovering climate as it becomes less important to well-being. A range of technologies appears to have lessened the vulnerability of human societies to climate variation.

AMIDST widespread agreement that the planet is committed to at least some climatic change induced by human activity, there is growing pressure to "slow the greenhouse express" (ref. 1). Here I examine climate through the lens of technology and innovation, to clarify what adaptations have succeeded and the trends in vulnerability to climate. I also examine whether the greenhouse effect by itself will call into play new technologies, or whether the evolution of technology will largely be 'business as usual' regardless of climate change. Finally, I identify some ways that government may assist adaptation.

My focus is on adaptability of human systems, including agriculture. Adaptability of ecosystems and the ethics of human behaviour that brings about large-scale transformations of the Earth must also be considered in balancing responses to the greenhouse issue.

What are often labelled adaptive measures are themselves the impacts of climatic change. Innumerable adaptations in food, clothing and shelter are responses to the spatial and temporal variability of climate. Humans do not wait guilelessly to receive an impact, bear the loss, then respond with an adaptation. Rather they attempt to anticipate and forstall problems.

Innovations

Technical innovations relevant to climate and their diffusion occur in all societies and sectors and in many forms. Technology includes both hardware (for example, materials, physical structures, devices and machines) and software (rules and recipes for behaviour).

Illustrative innovations of hardware are cisterns and dams to store water, tractors to speed rapid harvests, and new crop cultivars to reduce susceptibility to drought. Perhaps less obvious, but of great importance for adaptation to climate, are information technologies. In the United States, during several years in the 1980s sales of information technologies to the agricultural sector were comparable to sales of farm equipment. The long history of software innovations includes tide tables, irrigation scheduling, and weather forecasts. Along with the readily classified hardware and software are climate-related behavioural, social and institutional innovations, such as agricultural credit banks, national parks, green political parties and flood insurance.

Software and social innovations are almost always indispensable for the technology of new hardware. Major innovations, in transportation for example, are in fact clusters of innovations involving not only new materials and physical processes but also new forms of social organization, including financing and management. Transportation systems exemplify technology that has been important in adaptation to climate through expanding the availability of food from a local to a global scale. Reliance on food from afar not only diversifies diet, but also spreads production risks across more climatic zones.

Early communities drew the bulk of their food from small areas. One of the earliest city states, Uruk in Mesopotamia, probably grew most of its sustenance except for animals within 20 kilometres of the city walls[2]. Two millennia later, Greece and Rome obtained most of their food from overseas colonies across the Aegean and Mediterranean seas[3]. At its height, Rome acquired 200,000 tons of grain annually for its one million inhabitants, most of it shipped from Africa, Sardinia and Sicily. What marine transportation did in the classical world, the steam locomotive did in the nineteenth century, halving the cost of land transport. The railroads penetrated the great land masses of North America and Australasia. Their operations were little affected by climate, topography or other local conditions. Great parts of the new worlds were dedicated to cultivation of single crops to supply world markets and to smooth availability through the year.

Technological inventions and innovations that have had roles in human ability to adapt to climate over the last 100 years or so range widely[4]: food preservatives (1873) to overcome problems of seasonal food production; light bulbs (1879) to make work safe and effective indoors; aluminum (1887) and other structural materials to resist environmental deterioration; refrigeration (1895) and air-conditioning (1902, 1906) to facilitate activity in hot seasons and locations; automobiles (1890s) to provide personal transportation that is much less sensitive to climate than horses or pedal bicycles; mechanical windshield wipers (1916) to see in the rain; antifreeze (ethylene glycol) (1929) to safeguard motors in winter; frozen food (first sales, 1930) to diversify diet among regions and seasons; radio-beam navigation (1934) to fly in poor visibility; and weather (1960) and Earth resources (1972) satellites for analysis and forecasts of weather and climate.

In many respects we seem to be 'climate-proofing' society, making ourselves less subject to natural phenomena. For centuries and millennia we relied mainly on behavioural and social adaptation. We took siestas when the sun was high and sought refuge in hill stations in the monsoon season. Large pastoral and nomadic populations followed the seasonal availability of resources and avoided climatic stresses. Much of the planet remained seasonally or entirely uninhabitable for climatic reasons. With current technology many people can live in virtually any climate that now exists. Modern water supply and heating and ventilation systems, along with medicines (for example, quinine and vaccines) and public health measures, have enabled large populations to inhabit formerly uninhabitable regions. By 1980 the population in semiarid, desert and mountain regions had passed 35 million or 15 per cent of the US population[5]. Lacking modern technology, these zones accomodated less than one per cent of the population in 1860 and six per cent in 1920.

Preferences

The ability to colonize almost the entire planet is due to the human ability to carry with us that particular range of environment in which we can survive and prosper[6]. In wealthier societies, preferences are shifting toward hot and dry climates that were forbidding a century ago. Evidence of lessening human vulnerability is also found in health. For example, a flattening of monthly rates of total mortality in Japan between 1899 and 1973 is explained partly by diminution of the previous, climatically driven seasonal peaks[7].

Production can now proceed more or less continuously in severe environments. For example, North Sea offshore oil platforms operate 24 hours per day, 365 days per year. At a price, services, such as aviation, are now available at almost all times and places. Aviation began as a system that was extremely sensitive to weather and is increasingly less so, due to expanded range; avionics, radar and guidance systems; understanding of thunderstorms, wind shear, and other weather phenomena; and changes in construction materials. Crops and livestock can now be produced 'indoors' protected from the elements. In some cases, alternatives to outdoor production are so advantageous that a crop is displaced. Originally spurred by the need for supplies in wartime, synthetic rubber from petrochemical feedstocks, which is not subject to the vagaries of pests, droughts and floods, and other risks outdoors, has overwhelmed natural rubber from trees. In 1990, ten per cent of US fish production was in the controlled environment of fish farms[8], up from one per cent in 1980 and projected to reach 20 per cent in 2000.

Consumption is also insulating itself from environment. Inside most shopping malls, for example, only fashions or decorations signal the season. Sports are increasingly played in domed stadiums isolated from the weather. In affluent societies, winter vacations in warm climates have become a popular adaptation to escape climatic impacts.

Forecasting is itself a key technology that reduces vulnerability to weather and hence climate. Forecasts can help accommodate peak loads in electric power systems during heat waves. Improved forecasting, in conjunction with increased incomes and better transportation, has also enabled more people to enjoy recreation in all seasons.

Synchronicity

The decline of 'synchronicity', the naturally enforced time regimen of social groups, is a feature of life in advanced societies. In agricultural societies, the rhythm of life is strongly determined and coordinated for almost all by the seasons and the associated demands for labour in the field. In advanced economies, where both production and consumption may proceed almost continously and only about five per cent of the population farms, weather and climate no longer control schedules. The fact that the peak season for holidays in advanced societies is the late summer, a peak season for labour in agricultural societies, indicates the transformation that has taken place.

In the late 1970s and early 1980s a group of US researchers explored the 'lessening' hypothesis of climate impacts[9], which states that persistent and adaptive societies, through their technological and social organization, lessen the impacts of recurrent climatic fluctuations of similar magnitude upon the directly susceptible population and indirectly lessen the impacts on the entire society. In the cases studied, substantial evidence was found to support the hypothesis of lessening impacts. For example, in the US Great Plains, the most severe disruptions to livelihood and health occurred during the earliest periods, when incidences of malnutrition and starvation were recorded. Investigation of the more recent periods showed much smaller impacts for comparable drought stress, because of a variety of adjustments and strategies, including more extensive and effective anticipatory action.

An alternative to the lessening hypothesis is that increasingly elaborate technical and social systems insulate us from the adverse effects of recurrent climatic fluctuation at the cost of increased vulnerability to catastrophe from less frequent natural and social perturbations. In a global economy, such vulnerability might be devolved or shared ever more widely. Presumably this vulnerability to catastrophe, surprise or nonlinear effects is what worries many about the greenhouse effect. But the evidence seems to weigh against the suggestion that technology, lifestyles and other forces are creating a more 'brittle' system in the face of climate change.

Society appears to proceed along 'technological trajectories' that enable, for example, more travel, more financial transactions, and more messages. The succession of technologies that make possible this increased activity appears to diminish in sensitivity to climate. Although it was usually true that neither rain nor sleet stayed the American postman from his rounds, no system of postmen could be as faithful as the modern telecommunications system that now carries a much larger share of messages than the old system of letters. Similarly, a system of energy from wood and hay was more climatically sensitive than one reliant on oil and natural gas. Water and wind power are, of course, more sensitive to climate. In the late eleventh century, the areas under Norman rule in England had about one water mill for every 50 households[10], providing power to grind grains, work metal, weave textiles and cut wood. In 1694 France had 80,000 flour mills, 15,000 industrial mills, and 500 iron and metallurgical works, altogether almost 100,000 facilities powered by wind and water. Although such an industrial infrastructure is tightly adapted using climatic resources, it is also vulnerable to climate variability and change.

The trend toward less climatic vulnerability also exists in transportation. Well into the nineteenth century, sailing vessels were the preferred long-distance transport and frequently becalmed. World steamship tonnage exceeded sailing tonnage only in 1893. Although coal cost more than wind, steamships rapidly became cheaper as well as faster than sailing ships, because their schedules were more regular and avoided the circuitous routes required by sailing vessels. Transport underground through tunnels by high-speed magnetically levitated trains is already on the drawing boards in Japan; such systems would be less sensitive to climate than the surface and air systems now in use.

Climate is only one of several factors that have driven the evolution of systems of communications, transport and energy. It is probably secondary. But vulnerability to climate and other environmental forces may be a good proxy for quality and reliability of service. To the extent that the systems evolve in the direction of higher quality and reliability, these trajectories of development may also decrease vulnerability of major systems to climatic change. It would be useful to identify exceptions to this pattern, should they exist.

As incomes depend less on activities out of doors, societies become less vulnerable to climate. The trend in all developed countries since the industrial revolution began is away from employment outdoors (Fig. 1) and toward employment in the service sector, most of which is in climate-controlled office buildings and shops. With a lag of 50–100 years the same trend is found in less developed countries, where 40–50 per cent of the population is now engaged in agriculture. If the current trend continues, this fraction should diminish to 20–25 per cent by 2050.

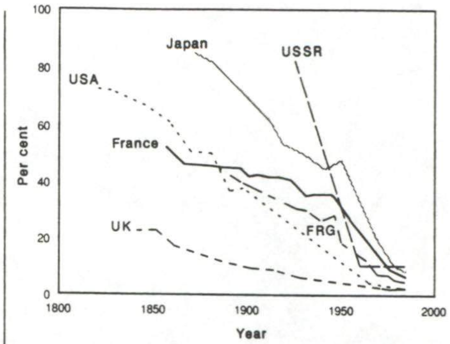


FIG. 1 Share of the workforce employed in agriculture[21].

What are the times characteristic of technical innovation and diffusion of technologies in relation to the time of human-induced climatic change? Taking account of both CO_2 and non-CO_2 greenhouse gases, major climatic shifts are expected during 40–50 years (ref. 11). A retrospect on technology during the past century suggests the extent of change during the decades to come: in 1890 there was little farming in California and Australia, and key technologies did not yet exist or were not widely applied to impound and transport water, or to transport and store agricultural products promptly; in 1903 the Wright Brothers flew 59 seconds at Kitty Hawk, North Carolina, whereas in 1990 in the United States, over 500 million air passengers flew around 450 × 10^9 miles[12]; commercial transatlantic aviation, relying on the jet engine, superseded travel by ocean liners about 1960; tourism has been extended to Antarctica, and scientific bases there are occupied year round, despite the fact that it was only in 1911–1912 that Roald Amundsen reached the South Pole and Robert Scott died there; penicillin, the first important antibiotic, was discovered by Alexander Fleming in 1928, and large-scale production began only as recently as 1943; nuclear power for electricity generation first came into use in the late 1950s, but within about 30 years it was able to provide over 70 per cent of France's electric power; until 1965 no satellites were used for any routine application, whereas satellite systems now girdle the Earth, watching for storms, relaying communications, and helping ships and planes navigate anywhere on the globe; and finally, although the microprocessor was only introduced in 1971 and the personal computer appeared about 1977, Americans are now using over 50 million personal computers.

During the period in question and with or without climatic change, technology will transform the way people live. Food, energy, transportation and all the other systems that support human life and the economy will be changed by technologies that can be glimpsed now, such as genetic engineering, fusion, superconductivity and desalination, as well as by technologies yet to be easily pictured. Fifty to a hundred years will allow the replacement of most major technolgical systems. Indeed, 50 years are enough time to turnover almost the entire capital stock of the society. About two-thirds of capital stock is usually in machines and equipment and about one-third in buildings and other structures. In Japan, the average renewal period for capital stock in business, the time it takes for machinery and equipment in an industry to be almost completely replaced, ranges from about 22 years in the textile industry down to ten years or less in such fast-moving industries as telecommunications and electrical machinery (see Table). In agriculture the estimated life span of cultivars in the United States is seven years for maize, eight for sorghum and cotton, and nine for wheat and soybeans[13], and most experts believe the life span of cultivars will grow shorter. Relative to greenhouse warming, turnover is also fast for nonmachinery capital stock, which includes buildings, pipelines, and so forth. According to recent surveys, in the Federal Republic of Germany in 1985 some 60 per cent of the stock is less than 20 years old and in the Soviet Union some 80 per cent is less than 20 years old (Fig. 2).

At first such figures may surprise us. But some reflection about the built environment relieves the surprise. Consider the office space in a modern city. Most of the space is in buildings completed in the last 20–30 years. These new buildings are filled with new equipment, for example, new telephone systems. Indeed, even older buildings are filled with modern equipment that did not exist 15 or 20 years ago. The same is true for supermarkets, restaurants and other stores. A large fraction of residential housing is similarly young and, in turn, filled largely with new domestic appliances of all kinds. If societies grow at a rate of 2–3 per cent per year, as the industrialized societies have for the past 150 years, then half of all capital stock will always be younger than 30 years old.

Probably the systems that take longest to build are infrastructures. Even these are constructed in less than a century[14]. Many infrastructure systems are (or should be) continuously reconstructed. For example, roads are repaved every 5–15 years, depending on use. The 7,000-kilometre canal system of the United States was almost entirely built in the 30 years between 1820 and 1850. More than 90 per cent of the 300,000-mile US railway network was laid in the 65 years between 1855 and 1920. The paving of virtually the entire six million-kilometre surface road system of the United States was accomplished between 1920 and 1985. The US interstate highway system was completed in about 30 years from the time that it was announced by President Eisenhower. It is interesting to consider whether climatic change could require any public works on this scale; coastal protection and interbasin water transfer would seem the most likely candidates.

Because capital stock continuously turns over on a time scale of a few decades, it will be possible to put in place much technology that is adjusted to a changing climate. This can be done without extraordinary measures given reasonably accurate information about the future. For the shortest lifetimes, even accurate information about the present climate will do.

CAPITAL STOCK RENEWAL

Industry	Renewal period
All industries	13.4
Manufacturing (all)	15.8
Electrical machinery	9.8
Transport machinery	13.2
Pulp and paper	13.7
General machinery	14.2
Chemicals	16.6
Food stuff	16.7
Steel and non-ferrous metals	21.1
Textiles	22.5
Non-manufacturing (all)	11.8
Service	8.1
Transport and telecommunications	10.7
Construction	11.9
Finance and insurance	12.8
Distribution	15.6
Real estate	15.8
Electricity, gas and water supply	15.8

Average renewal period for capital stock of business corporations in Japan by industrial sector, 1986-87 (ref. 22).

That perhaps 90 per cent of the global capital stock in the year 2040 will be built after 1990 does not diminish the significance of some long-lived structures. Action may be necessary to protect cities such as Venice, where preservation of historic buildings is the goal. In such cases, the process of replacement is not relevant.

The adaptations for long-term climatic change will probably mostly be the same as for other climate variation. The technologies, small and large, that buffer human activity over the long-term will be the same ones that mollify the difference between daytime and nighttime temperatures, protect against normal variability between days, shield from storms and hail, adjust to the seasons, and adapt to the wide range of climates where people already live.

No one has yet presented a radical innovation uniquely adaptive for the greenhouse effect. The main innovations directed at the greenhouse effect are so far organizational, in particular research groups in universities and government and assessment groups, such as the Intergovernmental Panel on Climate Change (IPCC). If the future greenhouse climate in any place will consist of climates that already exist somewhere on Earth, then many of the adaptations may look familiar.

Because the population of the world is imploding into cities, it seems logical that technologies that make cities habitable in unwelcoming climates will be among the technologies that are most important. Houston, Phoenix and Toronto may offer lessons. The trend in such places is toward ever larger enclosures of space and passageways connecting them, where workers and shoppers are not subject to the elements. Already during much of the year in such cities few people are seen outside on the streets. Technologies for 'smarter' buildings and for more efficient building materials should be adaptive. Cities in developing countries, which are often in difficult climates to begin with and face worsening problems of urban pollution, may well lack the resources to apply such technologies to raise or maintain the quality of life in the face of changing climate.

Until this century much of the human struggle with climate was to keep warm. Because the struggle succeeded, in 1850 the population in Europe, a land of well-chronicled and damaging winters, was three times as large as that of Africa and nine times as large as that of Latin America[15]. Now a main change in adaptation will be emphasis on technologies to stay cool. There is already pressure and success in this direction, population grows in tropical regions and people migrate south in temperate zones. Chemicals for refrigeration that do not exacerbate the greenhouse effect may thus earn a premium, and, of course, low greenhouse gas emission technologies to produce electricity and energy in general.

For water resources, larger-scale control of flows may be the trend. The Thames Barrage and the Netherlands Rhine Delta scheme may exemplify massive hydraulic systems that will be imitated in areas of major coastal populations. Fresh-water systems in some regions would also be made more robust by extending networks of supply over wider spaces through interbasin transfer and other strategies. In practical terms, many of the technologies needed may be well-established, for example, tunnelling, pumps and other technologies traditional to civil and mechanical engineering, updated with electronic sensors and other devices for management and control. Technologies for management of water demand will be equally or more attractive in many regions; these would include not only hardware technologies for minimizing leaks, but also software technologies from operations research, as well as economic and other incentives.

In agriculture, with a few notable exceptions, most emerging technologies are expected to reduce substantially the land and water required[16]. At least in the United States the trends in agricultural technology are in the direction that should be sought in view of climatic change. Almost all technologies that are attractive for agriculture are only more attractive in light of the possibility of climatic change. Specifically, appealing directions for agricultural innovation might include diversification of crop production by varying maturity, heat and drought tolerance, input needs, and end uses; innovation in planting and spacing; collecting and recycling irrigation run-off; soil moisture conser-

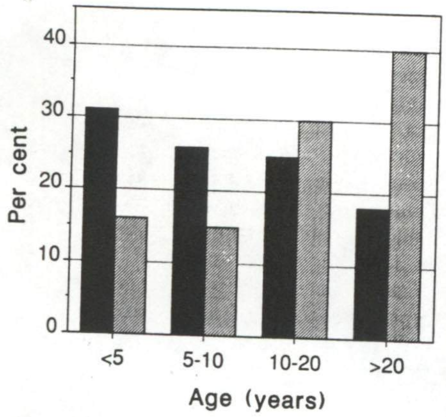


FIG. 2 Age distribution of nonmachinery capital stock in the FRG, data for 1985 (ref. 23) (hatched bars), and in the Soviet Union (solid bars), data as of 1986 (USSR State Committee on Statistics, Statistics on social indicators and capital vintage structure in industry, undated memo, Institute for Social and Economic Statistics, Moscow; courtesy of A. Grübler, Laxenburg, Austria).

vation; better moisture-use efficiency and improved use of plastics and other new materials; resistance to pests and insects; management practices; institutional measures; programmes and facilities to support extreme contingencies; and infrastructure. Many of these are applications of information technologies, as well as biotechnologies and more traditional agricultural and mechanical technologies. It may be possible to design and select plants adapted to higher concentrations of CO_2 and other changes in the atmosphere.

Though many innovations helpful in a rapidly changing climate are more likely to come from private enterprise than government, governments can help in two ways.

One way governments can aid adaptation is through timely information. One variety is assessments of the issues relating to climatic change. A second important and more operational variety of information is improved weather and climate forecasts. Eventually the climate of the far future will become tomorrow's weather. Information about it is likely to improve the possibility that it will be more resource than hazard.

There has been a gradual, measured improvement in weather forecasting during the past 20 years (ref. 17). In the greenhouse issue, all nations should find strong motivation to improve forecasts and the data and research underlying them. The quality of weather analyses and forecasts in many developing countries, especially in the tropics, is markedly lower than those in developed countries, particularly in the northern hemisphere. Advances in numerical modeling and extension of technology for monitoring in tropical regions can cause substantial improvements.

A third innovation in information relates to markets. The needs are for facilitation of information flows and improvements in rules for markets, in particular, markets for water. In many nations, water is allocated largely through administrative means based on water rights. Water transfers accommodate new patterns of climate, as well as changing farming and urban and industrial growth. They allow water to be used where it is most valuable[18]. Flexibility of water transfer is important, because the life of water projects is often 50–100 years or more[19].

Substantial subsidies for water for irrigation, in particular, lead to prices that encourage inefficiency. There is little incentive to conserve. Higher cost of constructing water projects and more demand and competition for water for such uses as preservation of wildlife, recreation, and cities make the issue serious. Several long-term contracts in the Central Valley of California provide water for only $3.50 per acre-foot, whereas new sources of supply would cost the federal government or the state $200–300 per acre-foot per year for construction alone[18]. Allowing and encouraging voluntary marketing of the resource among users could help adapt to climate changes and produce economic benefits. Voluntary water transfers could take several forms, including permanent sales, long-term leases, short-term leases, and leases contingent on drought.

Although markets may require innovation by government in providing information and rules, there are also traditional 'hardware' opportunities for innovation in public works. Government is the primary purchaser, financier and manager of systems of water supply and waste disposal, as well as coastal facilities. These take decades to site and construct and then can last generations. There may be opportunities for government to enhance innovation in infrastructure in light of the possibility of a changing environment.

Conclusion

Technologies are available for adaptation to climate on a spectrum of space, time and cost. Within minutes and for a few dollars one can buy an umbrella for local protection against a shower. Such technologies diffus[e] rapidly into the society, in a matter of month[s] or years. Larger and more costly innova[tions], like electric refrigerators, may take 2[0] or 30 years to become pervasive. At the othe[r] end of the spectrum, large systems, like thos[e] for water and transportation take several decades or generations to extend themselve[s] fully and may cost tens or hundreds of billions of dollars.

Technological performance has improve[d] throughout human history, and in this century waves of innovation have come eve[r] more rapidly[20]. In many systems, there have been steady improvements in efficiency of about two per cent per year, so that systems built today, for instance in energy, are about twice as efficient as those built 30 years ago[21]. Today generating a kilowatt of electricity in a steam plant takes only 15 per cent as much fossil fuel as at the turn of the century. A doubling of overall efficiency of several major systems should be possible just by replacing existing systems with best technologies and practices available today. This, of course, takes capital, and it is not clear that the expected rate of climatic change warrants an acceleration over the rate of change in physical capital stock that is already occurring, as long as the new stock is acquired with the best information about future climate in mind.

The general direction of change in technology and civilization is heartening for those anxious about climatic change. The trend is toward systems that are less vulnerable to climate. It would seem to be sensible to maintain this course and not to revert to reliance on such technologies as sailing ships and water mills that are more sensitive to climate. The highest need is probably to assure the inventive genius, economic power, and administrative competence that make the many technologies useful in adapting to climate available to the most people. □

Jesse H. Ausubel is at The Rockefeller University, New York, New York 10021-6399, USA.

1. Nordhaus, W. D. *Setting National Priorities: Policy for the Nineties* (ed. Aaron, H.) 185-211 (Brookings, Washington, 1990).
2. Adams, R. McC. & Nissen, H. *The Uruk Countryside: The Natural Setting of Urban Societies* (University of Chicago Press, Chicago, 1972).
3. Newman, L. F. (ed.) *Hunger in History: Food Shortage, Poverty, and Deprivation* (Blackwell, Oxford, 1990).
4. Desmond, K. *Harwin Chronology of Inventions, Innovations, and Discoveries from Pre-History to the Present Day* (Constable, London, 1986).
5. Schelling, T. C. in *Changing Climate* (National Research Council) 449-482 (National Academy Press, Washington, 1983).
6. Escudero, J. C. *Climate Impact Assessment* (eds Kates, R. W., Ausubel, J. H. & Berberian M.) 251-272 (Wiley, Chichester, 1985).
7. Weihe, W. H. *Proceedings of the World Climate Conference* 313-368 (World Meteorological Organization, Geneva, 1979).
8. *New York Times*, 1 August 1990, p. C1.
9. Warrick, R. A. *Climatic Constraints and Human Activities* (eds Ausubel, J. & Biswas, A. K.) 93-123 (Pergamon, Oxford, 1980).
10. Reynolds, T. S. *Sci. Am.* **251**(1) 122-130 (1984).
11. Intergovernmental Panel on Climate Change *Scientific Assessment of Climate Change, Report to IPCC from Working Group 1* (World Meteorological Organization, Geneva, 1990).
12. US Bureau of the Census *Statistical Abstract of the United States: 1990* 110th edition (US Government Printing Office, Washington, 1990).
13. Duvick, D. N. *Econ. Botan.* **38**, 161-178 (1984).
14. Grübler, A. *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport* (Physica, Heidelberg, 1990).
15 McEvedy, C. & Jones, R. *Atlas of World Population History* (Penguin, New York, 1978).
16. Office of Technology Assessment, *Technology, Public Policy, and the Changing Structure of American Agriculture* (US Government Printing Office, Washington, 1986).
17. World Meteorological Organization (WMO) *The World Weather Watch: 25th Anniversary 1963-1988* (WMO No. 709, Geneva, 1988).
18. Wahl, R. W. *Markets for Federal Water: Subsidies, Property Rights, and the Bureau of Reclamation* (Resources for the Future, Washington, 1989).
19. Waggoner, P. E. (ed.) *Climatic Change and US Water Resources* (Wiley, New York, 1989).
20. Mensch, G. *Stalemate in Technology* (Ballinger, Cambridge, 1979).
21. Nakicenovic, N. & Grübler, A., *Technological Progress, Structural Change and Efficient Energy Use: Trends worldwide and in Austria, International Part* (International Institute for Applied Systems Analysis, Laxenburg, 1989).
22. Economic Planning Agency *Economic Survey of Japan, 1987-1988* (Tokyo, 1989).
23. Statistiches Bundesamt *Wirtschaft und Statistik* 4/89 (Metzler-Poeschl, Stuttgart, 1989).

SCIENCE & GOVERNMENT REPORT

22nd Year of Publication

The Independent Bulletin of Science Policy

Volume XXII, No. 11 P. O. Box 6226A, Washington, D. C. 20015 © June 15, 1992

Prelude to Rio

How Bush's Science Aide Got Gored on Capitol Hill

The worst that can be said about a Presidential Science Adviser is that he misinforms the President and misrepresents scientific and technical issues to the public. The commission of both sins was charged to D. Allan Bromley, the President's Assistant for Science and Technology, by Senator Al Gore (D-Tenn.) in an abrasive two-hour encounter on environmental issues on May 21.

Lectured, assailed, and admonished by Gore, Bromley strongly denied the allegations and accused the Senator of blaming him for environmental nonsense uttered by senior Administration officials. But Bromley was extremely vague about what he has contributed to the environmental education of George Bush. And he finally conceded that, as White House Science Adviser, he has retreated from the strong environmental stance that he took as Professor of physics at Yale.

Gore, who has staked out the environment as his chief Senatorial concern, afforded Bromley only a few of the rhetorical courtesies that legislators customarily bestow upon senior scientists in the witness chair. Obviously well briefed for Bromley, who apparently did not anticipate an inquisition, Gore brought the hearing to an end by declaring that on environmental matters, Bromley "has not well served the country, the President, or future generations."

The hearing drew virtually no press attendance because the only announced topic was the routine confirmation of a noncontroversial nominee, Karl Erb, for an inconspicuous position, Associate Director of the White House Office of Science and Technology Policy (OSTP), of which Bromley is Director. The proceedings in such cases are usually ceremonial, congratulatory, and brief. But with the approach of the Rio Earth Summit, Gore had an additional item on the agenda: The origin of President Bush's insistence that too many important scientific "uncertainties" exist to justify rapid reductions in the emission of greenhouse gases.

After Bromley introduced Erb to the Commerce, Science, and Transportation Committee, the nominee was dispensed with in a friendly few minutes. Gore then said he wanted "to take a little time here to look at the larger picture and examine the role of OSTP within the policymaking process." The organization has undergone a revival from the neglect of the later Reagan years, Gore said, "But how effective has OSTP been? Is science really informing the policy process at the White House? I am not sure that it is, at least not when it comes to global warming," Gore said.

(Continued on Page 2)

Slogging on in Bethesda

NIH Still Deep in Swamps Of Strategic Planning

"Constitutions should be short and obscure," said Napoleon.

This gift of wisdom has regrettably not been adapted to the task of writing a Strategic Plan for the National Institutes of Health, a chore on which innumerable mandarins and foot soldiers of biomedical research have been laboring for over a year. So far, they have produced a 500-page draft that, by many accounts, is considered to require a good deal of work.

Last week, some 35 of them, eminences of academe, science, and medicine, were at it again, ringed around a table in Bethesda, quibbling inconclusively over the pro-

(Continued on Page 5)

In Brief

Margot O'Toole will receive a $10,000 award June 25 for sounding the alarm in what has come to be known as the Baltimore Case. The award, established by Michael Cavallo, a Cambridge, Mass., businessman, recognizes people who risk their necks in the public interest, which O'Toole did in 1986 when, as a postdoc, she questioned a paper co-authored and stoutly defended by Nobelist David Baltimore. NIH later concluded that Baltimore's co-author had faked data for the paper, as O'Toole had charged. Scheduled to speak at the award ceremony: Rep. John Dingell (D-Michigan), who has savaged NIH for initially bungling the inquiry.

University of Michigan President James Duderstadt, Chairman of the National Science Board, came out looking foolish in a newspaper exchange with a Congressman who has criticized NSF for its past insistence that the US faces a massive "shortfall" of scientists. Writing June 2 in the Washington Post, *Duderstadt said NSF was being criticized for "a single preliminary research study performed five years ago." Rep. Howard Wolpe (D-Michigan) replied on June 13 that the study was repeatedly revised between 1987 and 1991, widely distributed to the press and Congress, and cited more than 50 times in public by former NSF Director Erich Bloch.*

Engineering salaries have failed to match inflation for the fifth straight year, and unemployment among engineers is at 4 percent, a record for recent years, according to a nationwide survey by the American Association of Engineering Societies. On the bright side, the survey found that beginning salaries have perked up, with the median this year at $34,600.

. . . Has Bush Ever Had a Briefing on Global Change?

(Continued from Page 1)

The Senator then proceeded into a lengthy monologue largely directed at the Administration's claims of scientific uncertainties on global warming. "It often seems that the Administration is ignoring the scientific data when it comes to global climate change," Gore declared. "And if that is the case, part of the responsibility is yours," he told Bromley, "because it is your job to bring to the President's attention, in clear terms, the scientific advice which should inform his decisions."

Gore asked Bromley whether he was familiar with the research of Sherwood Idso, a Phoenix-based US Department of Agriculture scientist who has found favor in White House political circles because of his cheerful findings on the greenhouse effect. According to Idso, higher agricultural productivity will be the principal result of a CO2 buildup. The Idso thesis is embodied in a film, *The Greening of Planet Earth*, which is distributed by the National Coal Association and Western Fuels. Asked by Gore if he had seen the film, Bromley said he had not, "but I know about it." Gore asked for Bromley's "appraisal of the scientific merits of this film."

Bromley sidestepped the role of scientific film reviewer, and asserted that he has never had "any difficulty communicating with the President." As for Idso's research, Bromley said it "shows that enhanced concentrations of carbon dioxide can, in fact, under laboratory conditions, cause enhanced growth rates in certain plants ... a species of orange plant, orange trees. But I would have to say that this is only the beginning of a research program that is very important," Bromley added.

Gore responded that Idso's film "has had a big influence on views within the Administration," and asked Bromley to grade the film for scientific accuracy.

"I am afraid, sir," Bromley replied, "that I would have to say that it oversells and overgeneralizes."

"Well, the Administration has sponsored showings of this film," Gore said. "The Department of Energy and Commerce sponsored a debut of *The Greening of Planet Earth*. The Secretary of Energy spoke at the event. And again, individuals in the Administration have repeatedly cited this film as a reference point for their understanding of the science. Have you done anything to correct the misimpression within the Administration and potentially within the President's mind?" Gore asked.

Bromley said the cited cabinet secretaries, and other department heads, have been "exposed to what I felt was the most up-to-date scientific summaries that I could find, given by people like Bob Watson from NASA, Dan Albritton from NOAA, people from the general scientific community." The Science Adviser added that "this particular movie is something you will, of course, recognize, as totally out of my control."

Gore. Now, has the President himself been briefed by these individuals, Watson and Albritton? Recent news accounts state that the President has never had a scientific briefing on this subject.

Bromley. That, of course, is not true. But he has not been briefed, to the best of my knowledge, by either Watson or Albritton.

Gore. Why not? If they are leading the scientific assessment for the government, and this is such an important question, why would they not brief him?

Bromley. Well, I think the answer to that, sir, is the President's time is extraordinarily valuable and he does not want lengthy, detailed scientific briefings because he does not have a scientific background himself. And what he wants is the kind of concentrated overview that he gets from me and the members of his [President's] Council of Advisors for Science and Technology [PCAST].

Gore. Who has briefed the President on global climate change? Who has given the scientific briefing to him?

Bromley. The members, for example, of PCAST who have expertise in this area. Tom Lovejoy, whom I think you know from the Smithsonian.... Norman Borlaug, the father of the Green Revolution ... Dan Nathans, of course, who has [the] Nobel Prize for his work in the stages of recombinant DNA technology, is well aware of a lot of this.

Gore. They have given the President a briefing on global climate change?

Bromley. We have discussed with the President matters of global climate change, yes.

Gore. Has the President ever had a specific scientific briefing on global climate change?

Bromley. I have not given him a specific one that was on that subject alone. That has certainly been part of our discussion on many occasions. And I am quite confident that Bill Reilly [Administrator of the Environmental Protection Agency] has talked with him on a number of occasions where this has been a significant part of the discussion. But we have never scheduled specifically—today we are going to meet with the President to talk about the science of global climate change—no.

(Continued on Page 3)

Editor and Publisher
Daniel S. Greenberg

Associate Publisher
Wanda J. Reif

Circulation Manager
Glen D. Grant

Independently published by Science & Government Report, Inc., twice monthly, except once each in January, July, August, and September. Annual subscriptions: Institutions, $358.00 (two years, $610.00). Bulk and individual rates upon request. Editorial offices at 3736 Kanawha St. NW, Washington, DC 20015. Tel. (202) 244-4135. For subscription service: PO Box 6226A, Washington, DC 20015. Tel. 1-800-522-1970; in Washington, DC 785-5054. Reproduction without permission is prohibited. SGR is available on University Microfilms International. Claims for missing back issues will be filled without charge if made within six weeks of publication date. ISSN 0048-9581.

. . . Senator Challenges Bromley on Scientific Data

(Continued from Page 2)

Returning to the Idso film, Gore asked Bromley whether he knew that the "coal industry financed it, and gave $250,000 to a company that Dr. Idso set up, and a company of which his wife is President."

Bromley repeated he had "never seen the film" and added, "nor do I intend to."

Gore questioned whether it was desirable to have cabinet officers sponsoring the film and "individuals within the Administration citing it as a reason why we do not really have to worry much about global warming." Charging that Idso, a government employe, "is promoting uncertainty in the minds of policymakers so as to allow the continued belching of greenhouse gases at undiminished rates," Gore said: "That is a little bizarre, is it not?"

Bromley agreed that "it does sound somewhat bizarre," but insisted that "I do not have any personal information on this." [Concerning Idso, Bromley notified Gore on June 4 that "My understanding is that USDA is conducting an official inquiry into the circumstances you raised during the hearing."]

Gore asked Bromley whether he was familiar with a report, *Global Warming Update*, published recently by the George C. Marshall Institute, a conservative think tank in Washington, DC, discounting the dangers of global warming. Bromley replied that the report "has never been peer-reviewed," and added that "in this particular case, the data may have been used selectively."

Then why, Gore asked, is the Marshall report "repeatedly referred to by important members of the Administration as a source for their belief that uncertainty predominates, and that we do not yet know enough to take the kind of action that was urged upon us in the recent negotiations on a climate-change treaty?"

Bromley responded that it "is unfair to claim that the Administration is using this Marshall report. Members may. I cannot control that."

Gore referred to a speech Bromley gave last December in Baltimore to an international meeting of chemists, in which, the Senator charged, Bromley exaggerated the uncertainties of global-change research. In the speech, Gore continued, "you stated that 'preliminary work suggests that the second- and third-order processes involving methane as a greenhouse gas may be of substantial importance and of opposite sign to the first-order processes.' "

Gore asked, "Now what evidence did you have at the time to support that statement?"

Bromley replied that in preparing the speech he was briefed by Watson of NASA and Albritton of NOAA, but "subsequently, it has turned out that the statements that were made during that briefing were more precise than they perhaps should have been. And that there is more uncertainty, in fact, than was indicated." Bromley added that the subject is under study with greater computational power, which indicates that "the results from the first runs would have to be modified.... And so that is the uncertainty that I refer to." He assured Gore that when he gave the speech, he used the "best information available."

Gore. Well, the only person in the scientific community that my staff and I have been able to find, in the literature or on the public record, who has ever indicated that the indirect effect of methane on global warming is negative is you....

Bromley. Senator, I would be incredibly insulted if you were, in fact, suggesting that I made up this—

Gore. No, of course not.

Bromley. —for the purposes of the Baltimore meeting.... I told you where I got these numbers.

Gore. Of course I am not suggesting, in any way, that you made it up. And please, let me correct your impression that might even be a possibility. Not at all. But you may also—you may take offense at what I am really suggesting, and that is that your inclination to emphasize uncertainties in the science of global warming may be leading you into errors, and may be resulting in advice to the President of the United States on the most important scientific question he faces, that leads him to believe that the science of global warming is fraught with considerably more uncertainty than the scientific community believes it is.

Referring to the Baltimore speech, Gore asked Bromley to explain his assertion that sulfur dioxide reductions mandated in 1990 by amendments to the Clear Air Act would help reduce CO_2 emissions. How? the Senator asked.

Bromley. By requiring more efficient operation of the plant.

Gore. Such as—by what technique?

Bromley. I do not know the details, sir. I would be happy to get them for you.

Gore. Well, you made an assertion in a public-policy forum....as the President's Science Adviser, in a highly charged context, where decisions are going [to be made] about proposed actions to combat global warming. And you are making the assertion that the Clean Air Act amendments have already done something about global warming. And I now ask you exactly how does that work and you say you do not know.

Bromley. I am not prepared to detail the exact mechanisms done on the utility plant. But I will get them for you.

Gore. Well, what makes you think there are some?

Bromley. Because people I trust tell me.

Gore. Who?

Bromley. The people who brief me on the specific activities in the Clean Air legislation.

Gore. Are you familiar that scrubbers, the technology of choice to limit sulfur dioxide, typically result in a 4-percent increase in CO_2 for each BTU of energy produced?

Bromley. No, I was not aware of that.

Gore. That is a fact. If you wish to check it and correct

(Continued on Page 4)

. . . Life Was Much Simpler in Academe, Bromley Says

(Continued from Page 3)
the statement for the record, you are certainly welcome to do so.... [Bromley subsequently sent a memo to Gore citing various provisions of the Clean Air Act that he said would reduce CO2 emissions.]

Noting that the White House had opposed a Clean Air amendment concerning CO2 that he had offered, Gore said: "So, when I hear statements by the President's Science Adviser and others prominent in the Administration that the Clean Air Act constitutes a response to global warming, I am puzzled."

Gore then brought up the name of F. Sherwood Rowland, Professor of Chemistry, UC Irvine. "He is a scientist of some renown in the field of global climate change research. Would you agree?" the Senator asked.

Bromley. To some degree.

Gore. Do you wish to elaborate?

Bromley. No.

Gore. He was among those who heard your speech in Baltimore and was quoted in the *Baltimore Sun* as saying that he did not "recall in 17 years of science hearing a talk with so many errors." He said that it was his opinion that you, Dr. Bromley, were "out of touch with the scientific community" and that "President Bush is receiving abysmal scientific advice." Do you question Dr. Rowland's expertise on the science of global climate change?

Bromley. He is entitled to his opinion. But I think I should also tell you that following that statement by Dr. Rowland at Baltimore, he was taken aside by a number of senior people there. And I think perhaps he would, at this point, say that he regretted his statements.

Gore. That is not the impression I have received.

Gore next brought up the Intergovernmental Panel on Climate Change (IPCC), noting that it had reported an increase in greenhouse-gas emissions and that "These increases will enhance the greenhouse effect, resulting, on average, in an additional warming of the earth's surface."

Asked whether he agrees, Bromley replied, "It is not a question of agreeing or disagreeing.... The context is that we have not seen any unambiguous signal for greenhouse warming that we can attribute to carbon dioxide in the atmosphere.... Eventually we will see one if we keep putting carbon dioxide into the atmosphere."

Noting that the IPCC report was produced over three years by "300 of the leading climate-change researchers in the world," Gore asserted that Bromley's skepticism "may be a possible explanation for why the position of the President of the United States is at odds with the position of every other leader of every other industrial country in the world. He may not be getting the same advice that the world scientific community is managing to filter through to all of the other leaders of the world. You are in charge of that filter," the Senator told Bromley.

Referring to a speech on global warming that Bromley gave in 1988, a year before his White House appointment, Gore noted that "you said the consequences for our descendants may well be catastrophic. We have no time to waste." Asked whether he still held those views, Bromley replied that his 1988 expressions "are perhaps a little more extreme than they are now."

Gore noted that in the same speech, Bromley stated that "it is essential for us to realize that we who use a disproportionate share of the planet's energy must take the lead in reducing utilization of fossil fuels."

Gore. Do you still believe that is the appropriate response?

Bromley. Life is much simpler when viewed from an academic environment than when one recognizes all the aspects of the situation....

As the hearing approached a conclusion, Gore spoke a few words of praise for Bromley, telling him that "I know of so many instances where you have done wonderful and valuable work on behalf of this country and generations to come."

But he capped the proceedings with a bitter assessment of the performance of a man who holds a noble conception of the role of Presidential science advice. Telling Bromley that his environmental advice "has not well served the country, the President, or future generations," Gore added:

"I think it has served the President's short-term political needs by providing him some comfort that there is so much uncertainty surrounding the science of global warming that he need not feel the same sense of urgency that every other leader of an industrial nation seems to feel...."—DSG

New Stirrings in Gallo Case

The investigation of Robert Gallo has started to sizzle following SGR's publication June 1 of a devastating rebuttal of an NIH report that exonerated the renowned researcher of scientific misconduct associated with identification of the AIDS virus.

SGR was bound by a vow of silence as to the origin of the rebuttal, but the *Chicago Tribune* reported on June 14 that it was prepared "with the assistance of Suzanne Hadley," who was the chief investigator of the case at NIH. Hadley resigned from the investigation last year after NIH Director Bernadine Healy demanded that she soften some of her comments about Gallo.

Hadley has since been on detail to the House subcommittee chaired by Rep. John Dingell (D-Michigan), a longtime critic of NIH's handling of misconduct charges. Following publication of the SGR report, the Department of Health and Human Services sent Dingell's staff 32 detailed questions concerning the doubts raised about the exoneration of Gallo.

Last week, NIH announced that Gallo would meet with the press on June 24 to answer written questions submitted in advance.