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Global Warming: Sea Level Rising [1990]

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EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

December 21, 1990

MEMORANDUM TO D. ALLAN BROMLEY

FROM: NANCY G. MAYNARD

SUBJECT: Presidential Memos on Sea Level Rise, Climate Change and Framework Convention

Since there appears to be some confusion about the status of these memos, I thought it might be helpful to provide you for your reference the different drafts which I have submitted over the past month and a half. The following are attached:

(1) Sea Level Rise Memo

October early(?) . Memo requested

October 14 . Sea Level Rise Memo submitted by NM to Ken Yale as working draft (A)

. Edited by KY, passed back, and changes made - several times

November 15 . Completed Memo submitted to KY (B)

November 21 . Completed memo (with new changes) handed to DAB (in HI week of 11/15)

. NM faxed sanitized version of substance to DAB
for use in HI if desired

(2) Framework Convention Memo

October early . Memo requested (FC broken out into separate piece from global change memo during editing of global change memo)

November 15 . Framework Convention Memo submitted by NM/VS to KY as working draft (C)

. Edited by KY, passed back, and changes made - several times

December 8 . Text with changes by DAB passed to NM for incorporation

December 9 . Changes incorporated and returned to KY (D)

(3) Global Change Status Memo

- late Sept. . Memo requested
- Sept 29-Oct 9 . Maynard out of office - annual leave
- October 15 . Global Change Memo submitted by NM to KY as working draft (E)
 .A number of major changes/editing of this document by KY/DAB/NM
- November 15 . New Version with edits from above submitted by NM to KY (F)
- November 21 . This version also submitted to DAB
- December 8 . Text with changes by DAB passed to NM for incorporation
- December 8 . DAB requested a shorter memo to be crafted out of both Global Change Status Memo to cover all material in both
- December 9 . Changes by DAB in original memo incorporated by NM and returned to KY (G)
- December 9 . New, shorter memo written and submitted by NM to KY (H)
- December 21 . Resubmitting all of the above

10/14/90

NH
X

not final

MEMORANDUM ON SEA LEVEL RISE

I have been advised by the NSC that the issue of sea level rise was raised on your recent trip to the Pacific Islands. As this is likely to become an increasingly visible issue, I thought it might be useful to provide you with an up-to-date summary of the most recent published scientific information on sea level rise - the articles which are serving as the basis for present public discussions on this issue - as well as some possible constructive responses to inquiries regarding sea level rise, in case it should arise again.

The most recently published scientific conclusions on sea level rise which presently serve as the basis for public discussions on the issue:

- (1) National Academy of Sciences, National Research Council, Sea-Level Change, 1990

"...On the basis of estimates of global warming of the atmosphere and ocean resulting from increasing concentrations of carbon dioxide and other greenhouse gases, it is possible to make an approximate forecast of global rise in sea level during the next 100 years... One hundred years from now it is likely that sea level will be 0.5 to 1 meter higher than it is at present...."

- (2) Second World Climate Conference Scientific/Technical Statement, November 1990 (Endorsing the same conclusions of the IPCC Working Group I)

"...Without actions to reduce emissions, global warming is predicted to reach 2 to 5 degrees C over the next century..the warming is expected to be accompanied by a sea level rise of 65 cm +/- 35 cm by the end of the next century...."

- (3) IPCC Working Group III (Response Strategies Working Group) Report on Strategies for Adaptation to Sea Level Rise, November 1990. (Attachment A)

This report is the first survey on a global scale of adaptive options for coastal areas in response to a possible acceleration of sea level rise and the implications of these options.

"Global climate change may raise sea level as much as one metre over the next century and, in some areas, increase the frequency and severity of storms. Hundreds of thousands of square kilometers of coastal wetlands and other lowlands could be inundated..."

"...Some nations are particularly vulnerable. Eight to ten million people live within one metre of high tide in each of the unprotected river deltas of Bangladesh, Egypt, and Vietnam. Half a million people live in archipelagos and coral atoll nations that lie almost entirely within three metres of sea level, such as the Maldives, the Marshall Islands, Tuvalu, Kiribati, and Tokelau. Other archipelagos and island nations in the Pacific, Indian Ocean and Caribbean could lose much of their beaches and arable lands, which would cause severe economic and social disruption...."

Possible responses to future inquiries on the sea level issue:

The concern that you heard expressed on your trip to the Pacific Islands by some of the leaders of the small island nations stems from the increasing amount of scientific literature being published, such as those listed above, on sea level rise.

These leaders, many of whom live on small islands with less than three meters total elevation, clearly feel particularly vulnerable to this possible effect of global warming. This concern was reiterated in a speech by the Prime Minister of Tuvalu at the Second World Climate Conference two weeks ago. (Attachment B)

Because we here in the U.S. (1) have a solid history of high quality observation and research programs on sea level as well as activities which are currently underway and planned under your U.S. Global Change Research Program (USGCRP) for 1991 and beyond, and (2) have been active participants in many international programs such as the IPCC process, we can discuss a number of constructive actions we are already taking to deal with the issue of climate change and sea level rise. A summary of these actions follows:

(1) The issue of understanding and monitoring sea level is a high priority in your US Global Change Research Program. A few examples of specific USGCRP activities related to sea level rise are:

- . Increased deployment of the global sea level stations. (To measure absolute sea level. NASA, NOAA, DOD)
- . Global ice sheet observations. (To monitor changes in ice sheets and ice caps by remote sensing. DOI, NASA, NSF, NOAA)
- . Regional glacier monitoring. (DOI)
- . Studies of atmospheric and oceanic circulation based in part on coupled numerical models. (Estimate ocean temperature (thermal expansion) and air temperature (surface ice melting) DOE, NASA, NSF, NOAA)
- . Study the geologic record to reconstruct past sea level histories and causes. (NSF, DOI, NOAA)

(2) We in the U.S. have been full partners in the international process which has been examining this issue - for example, in the three IPCC working groups (science, impacts, and responses) In particular, we participated, as one of the 70 countries involved, in the production of the Report of the Coastal Zone Management Subgroup of the IPCC Working Group III called Strategies of Adaptation to Sea Level Rise, just published in November 1990. This document recommends:

"...for coastal nations to begin the process of adapting to sea level rise not because there is an impending catastrophe, but because there are opportunities to avoid adverse impacts by action now, opportunities that may be lost if the process is delayed..."

There are ten recommendations for more specific actions in the categories of (a) national coastal planning, (b) international cooperation, and (c) research, data and information.

Through these and other programs like these, the U.S. is continuing to work with colleagues in the international community to provide the best information for well-informed and thoughtful decision-making on this subject.

Comment on the recent NASA paper you referred to in the Pacific Islands trip

Finally, I thought it might be useful to comment on the article to which you referred during your trip to the islands, "Precise Monitoring of Global Temperature Trends from Satellites". This article is a perfect example of one of the most recent developments by our scientific community on the global change issue, which provides useful information to the global warming/sea level rise issue. As you know, the article's significant result was that they have developed a technique (passive microwave radiometry from satellites) which provides accurate estimates of global atmospheric temperatures needed for a better understanding of climate change and the climate system.

While their ten-year temperature record is too short for use at this time in any analysis of climate change, the use of this technique will provide relatively precise determination of the locations and magnitudes of temperature change events.

I hope this background information is useful to your discussions. If you have any questions, please do not hesitate to call.

3

November 15, 1990

MEMORANDUM FOR THE PRESIDENT

FROM: D. ALLAN BROMLEY

SUBJECT: Sea Level Rise

I have been advised by the NSC that the issue of sea level rise was raised on your recent trip to the Pacific Islands. As this is likely to become an increasingly visible issue, I thought it might be useful to provide you with an up-to-date summary of the most recent published scientific information on sea level rise - the articles which are serving as the basis for present public discussions on this issue - as well as some possible constructive responses to inquiries regarding sea level rise.

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"Global climate change may raise sea level as much as one metre over the next century and, in some areas, increase the frequency and severity of storms. Hundreds of thousands of square kilometers of coastal wetlands and other lowlands could be inundated..."

"...Some nations are particularly vulnerable. Eight to ten million people live within one metre of high tide in each of the unprotected river deltas of

Bangladesh, Egypt, and Vietnam. Half a million people live in archipelagos and coral atoll nations that lie almost entirely within three metres of sea level, such as the Maldives, the Marshall Islands, Tuvalu, Kiribati, and Tokelau. Other archipelagos and island nations in the Pacific, Indian Ocean and Caribbean could lose much of their beaches and arable lands, which would cause severe economic and social disruption...."

Possible responses to future inquiries on the sea level issue:

The concern that you heard expressed on your trip to the Pacific Islands by some of the leaders of the small island nations stems from the increasing amount of scientific literature being published, such as those listed above, on sea level rise.

These leaders, many of whom live on small islands with less than three meters total elevation, clearly feel particularly vulnerable to this possible effect of global warming. This concern was reiterated in a speech by the Prime Minister of Tuvalu at the Second World Climate Conference two weeks ago. (Attachment B)

Because we here in the U.S. (1) have a solid history of high quality observation and research programs on sea level as well as activities which are currently underway and planned under your U.S. Global Change Research Program (USGCRP) for 1991 and beyond, and (2) have been active participants in many international programs such as the IPCC process, we can discuss a number of constructive actions we are already taking to deal with the issue of climate change and sea level rise. A summary of these actions follows:

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- . Regional glacier monitoring. (DOI)
- . Studies of atmospheric and oceanic circulation based in part on coupled numerical models. (Estimate ocean temperature (thermal expansion) and air temperature (surface ice melting) DOE, NASA, NSF, NOAA)
- . Study the geologic record to reconstruct past sea level histories and causes. (NSF, DOI, NOAA)

(2) We in the U.S. have been full partners in the international process which has been examining this issue - for example, in the three IPCC working groups (science, impacts, and responses) In particular, we participated, as one of the 70 countries involved, in the production of the Report of the Coastal Zone Management Subgroup of the IPCC Working Group III called Strategies of Adaptation to Sea Level Rise,

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There are ten recommendations for more specific actions in the categories of (a) national coastal planning, (b) international cooperation, and (c) research, data and information.

Through these and other programs like these, the U.S. is continuing to work with colleagues in the international community to provide the best information for well-informed and thoughtful decision-making on this subject.

Comment on the recent NASA paper you referred to in the Pacific Islands trip

Finally, I thought it might be useful to comment on the article to which you referred during your trip to the islands, "Precise Monitoring of Global Temperature Trends from Satellites". This article is a perfect example of one of the most recent developments by our scientific community on the global change issue, which provides useful information to the global warming/sea level rise issue. As you know, the article's significant result was that they have developed a technique (passive microwave radiometry from satellites) which provides accurate estimates of global atmospheric temperatures needed for a better understanding of climate change and the climate system.

While their ten-year temperature record is too short for use at this time in any analysis of climate change, the use of this technique will provide relatively precise determination of the locations and magnitudes of temperature change events.

I hope this background information is useful to your discussions. If you have any questions, please do not hesitate to call.

C

D-12-1

NOVEMBER 14, 1990

MEMORANDUM FOR THE PRESIDENT

FROM: D. ALLAN BROMLEY

SUBJECT: FRAMEWORK CONVENTION NEGOTIATIONS IN FEBRUARY

A number of major tasks have been identified to be completed by the time of the first negotiating session of the Framework Convention on Climate Change in February to help develop a detailed strategy for the U.S. for dealing with greenhouse gases and to define a negotiating position for the Session. The Second World Climate Conference was clearly a success for the U.S. with regard to the final version of the Ministerial Declaration; however, we risk becoming isolated in February without the announcement of a U.S. strategy, which I believe will be possible by that date.

In order to be well-prepared for the negotiations, a large amount of research and analysis tasks are being carried out by a number of different agencies in order to provide the U.S. with the best information available for negotiating the convention from the U.S. point of view. They have been reporting results to and receiving policy guidance from the DPC Global Change Strategy Group, which I chair. The process has included a State Department Policy Coordinating Committee, the Task Force on a Comprehensive Approach, the Economics Task Force, a Task Force on the Private Sector and the FCCSET Committee on Earth and Environmental Sciences (CEES).

The following is a summary of some of the main tasks which are underway:

Some of Major Tasks Presently Underway in Preparation for the February Negotiations

- o "The Economics of Long-term Global Climate Change - A Preliminary Assessment", Report of an Interagency Task Force (Chaired by CEA) Published September 1990.
- o Preliminary assessments of best available information on effectiveness and economic consequences of various response strategies before negotiations begin.
- o Calculation of the impact on radiative forcing of emissions targets implemented by only a subset of countries (e.g., OECD members)
- o Detailed analysis of the comprehensive approach
- o Determine what could be listed under "no regrets" heading

- o Assessment of existing institutions and mechanisms related to financial assistance for climate change

Major policy issues to be Addressed before the Start of the Negotiations

In addition to the interagency activities which are being carried out in preparation for the negotiations, there are a number of major issues to be resolved by the White House prior to February:

1. Appointment of a head of delegation for the Framework Convention negotiations. This could be the same person as the "Special Ambassador", called for by the Carnegie Commission to be appointed to oversee the complex preparatory efforts leading up to the 1992 United Nations Conference on Environment and Development, to be held in Brazil (the "Brazil Conference). As part of the strategy determination, this will require the early appointment of a specific person to head our delegation, so he or she can get up to speed in a very short amount of time.
2. Further development of positions on major issues such as comprehensive approach, economic aspects of emissions reductions, targets and timetables, the precautionary principle, and financial assistance.
3. Beginning development or further development of any new policy initiatives that may be needed in conjunction with a framework convention. One initiative that may prove most useful is the National Energy Strategy.
4. Compilation of Administration accomplishments in the environmental area.
5. Timing of any new announcements on climate change policy. The beginning of the framework convention negotiating session may heighten public awareness of the issue. It coincides with the State of the Union address.

Timetable for Preparations for the First Negotiating Session

A timetable has been developed, which received Governor Sununu's approval during our November 8th meeting. It is an ambitious timetable and will take a considerable amount of effort to make sure this is kept on track, but it is essential to our preparation for February negotiations.

The timetable makes a number of assumptions. 1) That we will appoint a specific person to be head of delegation (a "Special Ambassador", perhaps), 2) That the staff-level group which plans each Task Force meeting convene more often and be expanded slightly, to include OMB and some other agencies. The timetable is as follows:

November 28	Global Change Strategy Task Force Meeting
	Agenda items: (1) Progress Report on Preparations for framework convention by PCC WGCC subgroups; (2) briefing on comprehensive approach EPA/DOJ; 3) Tasking out of additional information required and preparation of options paper on major, outstanding issues needing resolution.
November 30	Deadline for all PCC WGCC Workgroup reports. Tentative deadline for Comprehensive Approach Task Force materials and Economics Task Force report.
December 1-7	Staff meetings to develop final options papers for presentation to full Global Change Working Group for approval.
December 10	Full DPC GCWG to 1) review options paper, 2) review U.S. preparations for, and approaches to, negotiating a framework convention, 3) discussion of PCC WGCC Workgroup reports, and 4) tasking of additional work product.
December 11-19	Staff meeting as needed to compile and integrate additional information, put options paper into final draft form.
December 18	Strategy Task Force Meeting, if needed.
	Agenda items: (1) package options (based on all comments) for consideration by DPC GCWG.
December 20	Full DPC Global Change Working Group meeting.
	Agenda items: (1) Review Options Package to be presented to full DPC.
December 20- January 6	Staff meeting as needed to further refine options paper and compile additional information.
December 25	Christmas Day
January 7	Options package distributed to DPC members in preparation for meeting.
January 15	Full DPC meeting to consider Options package.
January 22	Full DPC meeting to consider Options package.

We will keep the Governor apprised of the development of strategic options.

CC: Governor Sununu

with JAMES D
D. B. 12/8/90
D. B. 12/8/90

December 8, 1990

MEMORANDUM FOR THE PRESIDENT

FROM: D. ALLAN BROMLEY

SUBJECT: FRAMEWORK CONVENTION NEGOTIATIONS IN FEBRUARY

A number of major tasks have been identified that must be completed by the time of the first negotiating session of the Framework Convention on Climate Change in February if we are to develop a detailed strategy for the U.S. for dealing with greenhouse gases and to define a negotiating position for the Session. The Second World Climate Conference was clearly a success for the U.S. with regard to the final version of the Ministerial Declaration as I outlined in my last memorandum to you; however, as I emphasized earlier, we risk becoming isolated in February without the announcement of a U.S. strategy, which I believe will be possible by that date.

In order to be well-prepared for the negotiations, a substantial amount of research and analysis is being carried out by a number of different agencies in order to provide the U.S. with the best information available for negotiating the Convention on the U.S. point of view. The groups involved have been reporting results to, and receiving policy guidance from, the DPC Global Change Strategy Group, which I chair. The process has included a State Department Policy Coordinating Committee, a Task Force on a Comprehensive Approach, an Economics Task Force, a Task Force on the Private Sector and, finally, the FCCSET Committee on Earth and Environmental Sciences (CEES).

The following is a summary of some of the main tasks now underway:

Some of Major Tasks Presently Underway in Preparation for the February Negotiations

- o Development of the report, "The Economics of Long-term Global Climate Change - A Preliminary Assessment", Report of an Interagency Task Force (Chaired by CEA) Published September 1990.
- o Preliminary assessments of best available information on effectiveness and economic consequences of various response strategies before negotiations begin.
- o Calculation of the impact on radiative forcing of emissions targets implemented by only a subset of countries (e.g., OECD members)
- o Detailed analysis of the comprehensive approach and the establishment of greenhouse potential indices

- o Determine what should be listed under our "insurance policy" actions
- o Assessment of existing institutions and mechanisms relating to possible future financial assistance for climate change activities internationally

Major policy issues to be Addressed before the Start of the Negotiations

In addition to the interagency activities which are being carried out in preparation for the negotiations, there are a number of major issues to be resolved by the White House prior to the start of the February discussions:

1. Appointment of a head of delegation for the Framework Convention negotiations. Although this could be the same person as the "Special Ambassador", called for by the Carnegie Commission (Please see Attachment A) to be appointed to oversee the complex preparatory efforts leading up to the 1992 United Nations Conference on Environment and Development, to be held in Brazil (the "Brazil Conference"). My recommendation is that reflecting the excellent done work in Geneva, Bob Reinstein, xxxxxxxx to "Buff" Bohlen, be asked to co-chair the February delegation. As part of the strategy determination, the early appointment of these or other persons to head our delegation is essential so they can get up to speed in the very short time available. This again argues for Reinstein or xxxxxx since they/he are fully experienced.

2. Further development of positions on major issues such as comprehensive approach, economic aspects of emissions reductions, targets and timetables, the precautionary principle, and financial assistance.

3. Beginning development or further development of any new policy initiatives that may be needed in conjunction with a framework convention. One initiative that may prove most useful is the National Energy Strategy.

4. Compilation of Administration accomplishments in the environmental area.

5. Timing of any new announcements on climate change policy. The beginning of the framework convention negotiating session may heighten public awareness of the issue. It coincides with the State of the Union address.

6. Appointment of the "Special Ambassador" or other appropriate person, with the requisite support staff to begin, as soon as possible, to prepare for US participation in the 1992 Brazil Conference on the Environment. This conference is in the same series as the 1972 Stockholm Conference on the Environment where Senator Howard Baker was the Special Ambassador. In the intervening years, Christian Herter and Jean Wildarsky have also served as Special Ambassadors, leading US participation on major international conferences

The Carnegie Commission (Attachment A) has set forth the arguments in favor of such an appointment. Howard Baker, I know, felt that he should have been appointed even more than two years prior to the 1982 conference in view of the very large amount of work and consultation required. It bears emphasis that the 1992 Conference will cover

a very broad range of environmental topics - including global climate change as a small part of the discussion.

I strongly support the idea of the "Special Ambassador" because I see the necessary workload as definitely precluding any of your present staff from doing an adequate job in addition to their other responsibilities. I have discussed this matter with John Sununu and he is giving thought to names that might be recommended to you for consideration for such an appointment.

I believe that it will be important to appoint someone who already commands widespread visibility and respect nationally because pulling together the very diverse communities and interests that will demand input to the formulation of the US position at this very important conference will require political and diplomatic skills of high order - in addition to a firm understanding of the environmental issues involved.

The mechanisms that you have already in place - specifically, the EPRG chaired by Roger Porter and the DPC GCWG that I chair - will be able to provide substantial support to the appointed individual but I very strongly recommend that he or she be provided with an adequate staff based on all experience with earlier conferences of this type.

Timetable for Preparations for the First Negotiating Session

A timetable has been developed, which I have discussed with John Sununu during our November 8th meeting. It is an ambitious timetable and it will take a considerable amount of effort to make sure that this is kept on track, but I consider that it is essential to our preparation for February negotiations.

The timetable makes a number of assumptions. 1) That you appoint the head of delegation, 2) That the staff-level group which plans each Task Force meeting convene more often and be expanded slightly, to include OMB and other relevant agencies. The timetable is as follows:

November 28	Global Change Strategy Task Force Meeting
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Global Change Working Group for approval.

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- December 11-19 Staff meeting as needed to compile and integrate additional information, put options paper into final draft form.
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- December 20-
January 6 Staff meeting as needed to further refine options paper and compile additional information.
- December 25 Christmas Day
- January 7 Options package distributed to DPC members in preparation for meeting.
- January 15 Full DPC meeting to consider Options package.
- January 22 Full DPC meeting to consider Options package.

We will keep John Sununur apprised of the development of strategic options and will look forward to your decisions regarding the options forwarded to you by the DPC.

not final

Global Change Status Report

This memo is to provide you with a status report on global change with regard to the most recent scientific conclusions as well as our current position in the world community on this issue.

The present status of knowledge on the science of global change.

Since the first part (scientific/technical session) of the Second World Climate Conference in Geneva 2 weeks ago (747 participants, 120 countries) was devoted to, among other things, producing the most current summary of the scientific results of the past decade of research on climate under the World Climate Programme and other climate-related programs, it may be useful to review the information presented at that Conference. It is the information upon which most countries are basing their discussions as well as their decisions regarding global change issues.

o The Conference agreed that the scientific conclusions set out by the IPCC reflect the international consensus of scientific understanding of climate change.

A few examples of their specific conclusions:

o "Emissions resulting from human activities are substantially increasing atmospheric concentrations of the greenhouse gases. These increases will enhance the natural greenhouse effect, resulting on average in an additional warming of the Earth's surface."

o "Without actions to reduce emissions, global warming is predicted to reach 2 to 5 degrees C over the next century, a rate of change unprecedented in the past 10,000 years."

o "The warming is expected to be accompanied by a sea level rise of 65 cm = - 35 cm by the end of the next century."

o "Global warming induced by increased greenhouse gas concentrations is delayed by the oceans; hence, much of the change is still to come. Inertia in the climate system due to the influence of the oceans, the biosphere and the long residence times of some greenhouse gases means that climate changes that occur may persist for centuries."

o Natural sources and sinks of greenhouse gases are sensitive to a change in climate. Although many of the response or feedback processes are poorly understood, it appears that, as climate warms, these feedbacks will lead to an overall increase rather than a decrease in greenhouse gas concentrations."

o The Conference noted that, as stated in the IPCC Report, there is substantial scientific uncertainty in the details of predictions of climate change... To narrow the uncertainties, the Conference recommended enhanced research and observational systems for a number of high priority research areas (e.g., oceans, clouds, carbon cycle, polar ice sheets and sea ice)

(2) The present position of the U.S. in the world community in the global change issues

The international political environment surrounding both the scientific and Ministerial portions of the Second World Climate Conference (SWCC), which ended last week in Geneva, provides a good barometer for where we are in the international arena of global change.

Background: The past year leading up to the SWCC:

- o The U.S. arrived in Geneva against the backdrop of our past year's cautious approach to the global change issue - in contrast to most other countries who have been publically willing to commit to specific targets and timetables for reducing greenhouse gas emissions, regardless of cost or economic uncertainties. Over the year, we have continued to insist that we should be taking actions that are justified for other reasons ("no regrets"). In addition, we also, for much of the year, publically reserved judgement on the science of global change, stating that we were waiting for the results of the IPPC Working Group I Report on the Scientific Assessment of Climate Change (now published - June 1990).

- o While our cautious approach toward any specific plans or strategies for stabilization of CO₂ and other greenhouse gases has been factually well-justified, it has, unfortunately, been poorly-understood and our motives have been badly misconstrued. In fact, we have not called for any specific targets to date because of the lack of sufficient economic information available to us to craft a realistic plan.

- o Over the past year, at several highly-visible, high-level meetings on climate change, such as Noordwijk, the U.S. along with other major powers have been party to statements, which agree that stabilization of CO₂ emissions should be achieved as soon as possible and that "such stabilisation should be achieved by..industrialized nations.. as soon as possible, at levels to be considered by the IPCC and the Second World Climate conference of November 1990"

The U.S. and The Second World climate conference

- o By the time of the SWCC two week ago, the U.S. had become even further isolated on the global change issue because just prior to the start of the Ministerial portion of the Conference, the EC reached an agreement which called for "...stabilization of CO₂ emissions ...by the year 2000 at 1990 levels, although noting that some countries are not in a position to commit themselves to this objective". (reference to UK whose target year for stabilization is 2005). In addition, several weeks prior to that, both Japan and Australia announced plans for stabilization or reduction of their carbon dioxide emissions.

- o At the conference itself, opening speeches by several heads of state, King Hussein of Jordan and Prime Minister Thatcher, in particular (the latter was a call

to arms for responding to climate change) set the stage for some difficult negotiations at the preparatory meetings and at the Ministerial Conference, where the U.S. was clearly viewed as the last hold-out among the industrialized countries not willing to propose a plan for the stabilization or reduction of its greenhouse emissions.

- o After a lot of skillful negotiating by the U.S. delegation at the preparatory meetings, and later, in the Ministerial meeting, all of the five major issues of concern to the U.S. (to which I referred in my memo to you of October 26), were negotiated in such a way as to favorably reflect our position on each issue. This was quite a feat given the political environment at the conference.

- o Our success in negotiating a Ministerial Declaration favorable to the U.S. positions, despite the rather wide-spread hostility regarding our refusal to offer a plan for stabilizing greenhouse gases, was probably due to the fact that all countries present genuinely wanted a declaration to be issued from the meeting and that such a declaration is meaningless without the U.S. Furthermore, most countries recognize that the upcoming negotiations on a Climate Change Framework Convention are the best vehicle for obtaining real commitments to such actions as stabilization of CO₂ and other greenhouse gases. In fact, at the Second World Climate conference, a number of countries, including the EC worked hard to help us to find compromise language so that we did not become completely isolated on the issue.

Where do we go from here?

- o It is clear that we must have a well-defined position for the U.S. to take to the table at the first negotiating session of the Climate Change Convention which will include a strategy or plan for stabilizing or reducing greenhouse gas emissions.

- o We can no longer state that we are waiting for the science; the IPCC science report is now out and it represents the consensus of the international scientific community. The report was endorsed by the Scientific/Technical Session of the SWCC who concluded that:

"...notwithstanding scientific and economic uncertainties, nations should now take steps towards reducing sources and increasing sinks of greenhouse gases through national actions and negotiations of a global convention on climate change, and related legal instruments, with the long-term goal of halting the build-up of greenhouse gases at a level that minimizes risks to society and natural ecosystems...."

The good news is that a number of recent interagency activities, many of which are being coordinated under my DPC Global Change Strategy Task Force, are in the process of developing and compiling important new information on this issue which, combined with results of analyses of benefits from actions we are already taking, such as the Clean Air Act, may soon make it possible to propose a strategy toward an economically-feasible, realistic plan regarding U.S. greenhouse gas emissions.

My next memo to you will provide you with a summary of some of the kinds of new

information which is becoming available on the issue as well as a summary of our preparations for the February negotiations, including a timetable for production of some of the most important materials.

We obviously have a great deal of hard work to do between now and the start of the negotiations, but it is an important issue to us both scientifically and politically. I firmly believe that we will be able to make some excellent progress on both fronts over the next few months.

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November 15, 1990

MEMORANDUM FOR THE PRESIDENT

FROM: D. ALLAN BROMLEY

SUBJECT: Global Change Status Report

This memo is to provide you with a status report on global change with regard to the most recent scientific conclusions as well as our current position in the world community on this issue.

The present status of knowledge on the science of global change.

Since the first part (scientific/technical session) of the Second World Climate Conference in Geneva 2 weeks ago (747 participants, 120 countries) was devoted to, among other things, producing the most current summary of the scientific results of the past decade of research on climate under the World Climate Programme and other climate-related programs, it may be useful to review the information presented at that Conference. It is the information upon which most countries are basing their discussions as well as their decisions regarding global change issues.

o The Conference agreed that the scientific conclusions set out by the IPCC reflect the international consensus of scientific understanding of climate change.

A few examples of their specific conclusions:

o "Emissions resulting from human activities are substantially increasing atmospheric concentrations of the greenhouse gases. These increases will enhance the natural greenhouse effect, resulting on average in an additional warming of the Earth's surface."

o "Without actions to reduce emissions, global warming is predicted to reach 2 to 5 degrees C over the next century, a rate of change unprecedented in the past 10,000 years."

o "The warming is expected to be accompanied by a sea level rise of 65 cm =- 35 cm by the end of the next century."

o "Global warming induced by increased greenhouse gas concentrations is delayed by the oceans; hence, much of the change is still to come. Inertia in the climate system due to the influence of the oceans, the biosphere and the long residence times of some greenhouse gases means that climate changes that occur may persist for centuries."

o Natural sources and sinks of greenhouse gases are sensitive to a change in climate. Although many of the response or feedback processes are poorly understood, it appears that, as climate warms, these feedbacks will lead to

an overall increase rather than a decrease in greenhouse gas concentrations."

- o The Conference noted that, as stated in the IPCC Report, there is substantial scientific uncertainty in the details of predictions of climate change... To narrow the uncertainties, the Conference recommended enhanced research and observational systems for a number of high priority research areas (e.g., oceans, clouds, carbon cycle, polar ice sheets and sea ice)

(2) The present position of the U.S. in the world community in the global change issues

The international political environment surrounding both the scientific and Ministerial portions of the Second World Climate Conference (SWCC), which ended last week in Geneva, provides a good barometer for where we are in the international arena of global change.

Background: The past year leading up to the SWCC:

- o The U.S. arrived in Geneva against the backdrop of our past year's cautious approach to the global change issue - in contrast to most other countries who have been publically willing to commit to specific targets and timetables for reducing greenhouse gas emissions, regardless of cost or economic uncertainties. Over the year, we have continued to insist that we should be taking actions that are justified for other reasons ("no regrets"). In addition, we also, for much of the year, publically reserved judgement on the science of global change, stating that we were waiting for the results of the IPCC Working Group I Report on the Scientific Assessment of Climate Change (now published - June 1990).

- o While our cautious approach toward any specific plans or strategies for stabilization of CO₂ and other greenhouse gases has been factually well-justified, it has, unfortunately, been poorly-understood and our motives have been badly misconstrued. In fact, we have not called for any specific targets to date because of the lack of sufficient economic information available to us to craft a realistic plan.

- o Over the past year, at several highly-visible, high-level meetings on climate change, such as Noordwijk, the U.S. along with other major powers have been party to statements, which agree that stabilization of CO₂ emissions should be achieved as soon as possible and that "such stabilisation should be achieved by..industrialized nations.. as soon as possible, at levels to be considered by the IPCC and the Second World Climate conference of November 1990"

The U.S. and The Second World climate conference

- o By the time of the SWCC two week ago, the U.S. had become even further isolated on the global change issue because just prior to the start of the Ministerial portion of the Conference, the EC reached an agreement which called for "...stabilization of CO₂ emissions ...by the year 2000 at 1990 levels, although noting

that some countries are not in a position to commit themselves to this objective". (reference to UK whose target year for stabilization is 2005). In addition, several weeks prior to that, both Japan and Australia announced plans for stabilization or reduction of their carbon dioxide emissions.

- o At the conference itself, opening speeches by several heads of state, King Hussein of Jordan and Prime Minister Thatcher, in particular (the latter was a call to arms for responding to climate change) set the stage for some difficult negotiations at the preparatory meetings and at the Ministerial Conference, where the U.S. was clearly viewed as the last hold-out among the industrialized countries not willing to propose a plan for the stabilization or reduction of its greenhouse emissions.

- o After a lot of skillful negotiating by the U.S. delegation at the preparatory meetings, and later, in the Ministerial meeting, all of the five major issues of concern to the U.S. (to which I referred in my memo to you of October 26), were negotiated in such a way as to favorably reflect our position on each issue. This was quite a feat given the political environment at the conference.

- o Our success in negotiating a Ministerial Declaration favorable to the U.S. positions, despite the rather wide-spread hostility regarding our refusal to offer a plan for stabilizing greenhouse gases, was probably due to the fact that all countries present genuinely wanted a declaration to be issued from the meeting and that such a declaration is meaningless without the U.S. Furthermore, most countries recognize that the upcoming negotiations on a Climate Change Framework Convention are the best vehicle for obtaining real commitments to such actions as stabilization of CO₂ and other greenhouse gases. In fact, at the Second World Climate conference, a number of countries, including the EC worked hard to help us to find compromise language so that we did not become completely isolated on the issue.

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"...notwithstanding scientific and economic uncertainties, nations should now take steps towards reducing sources and increasing sinks of greenhouse gases through national actions and negotiations of a global convention on climate change, and related legal instruments, with the long-term goal of halting the build-up of greenhouse gases at a level that minimizes risks to society and natural ecosystems...."

The good news is that a number of recent interagency activities, many of which are

being coordinated under my DPC Global Change Strategy Task Force, are in the process of developing and compiling important new information on this issue which, combined with results of analyses of benefits from actions we are already taking, such as the Clean Air Act, may soon make it possible to propose a strategy toward an economically-feasible, realistic plan regarding U.S. greenhouse gas emissions.

My next memo to you will provide you with a summary of some of the kinds of new information which is becoming available on the issue as well as a summary of our preparations for the February negotiations, including a timetable for production of some of the most important materials.

We obviously have a great deal of hard work to do between now and the start of the negotiations, but it is an important issue to us both scientifically and politically. I firmly believe that we will be able to make some excellent progress on both fronts over the next few months.

Smith LTB's Change 6
1/12/91

DRAFT

December 9, 1990

MEMORANDUM FOR THE PRESIDENT

FROM: D. ALLAN BROMLEY

SUBJECT: Global Climate Change Status Report

This memo is to provide you with a status report on global climate change with regard to the most recent scientific conclusions as well as my estimate of the U.S. position in the world community with respect to this issue.

The present status of knowledge concerning the science of global climate change.

Since the first part (scientific/technical session) of the Second World Climate Conference in Geneva (747 participants, 120 countries) was devoted to, among other things, producing the most current summary of the scientific results of the past decade of research on climate under the World Climate Programme and other international climate-related programs, it may be useful to review the information upon which most countries are basing their discussions as well as their policies and decisions regarding global climate change issues.

- o The Conference agreed that the scientific conclusions set out by the IPCC reflect the international consensus of scientific understanding of climate change.

A few examples of their specific conclusions:

- o "Emissions resulting from human activities are substantially increasing atmospheric concentrations of the greenhouse gases. These increases will enhance the natural greenhouse effect, resulting on average in an additional warming of the Earth's surface."

- o "Without actions to reduce emissions, global warming is predicted to reach 2 to 5 degrees C over the next century, a rate of change unprecedented in the past 10,000 years."

- o "The warming is expected to be accompanied by a sea level rise of 65 cm $\pm$ 35 cm by the end of the next century."

- o "Global warming induced by increased greenhouse gas concentrations is delayed by the oceans; hence, much of the change is still to come. Inertia in the climate system due to the influence of the oceans, the biosphere and the long residence times of some greenhouse gases means that climate changes that occur may persist for centuries."

- o Natural sources and sinks of greenhouse gases are sensitive to a change in climate. Although many of the response or feedback processes are poorly understood, it appears like that, as climate warms, these feedbacks will lead to an overall increase rather than a decrease in greenhouse gas concentrations."

- o The Conference noted that, as stated in the IPCC Report, there is substantial scientific uncertainty in the details of predictions of climate change... To narrow the uncertainties, the Conference recommended enhanced research and observational systems for a number of high priority research areas (e.g., oceans, clouds, carbon cycle, polar ice sheets and sea ice)

(2) The present position of the U.S. in the world community on global climate change issues

The international political environment surrounding both the scientific and Ministerial portions of the Second World Climate Conference (SWCC), which ended last week in Geneva, provides a good barometer as to where we are in the international arena with respect to global climate change issues.

Background: The past year leading up to the SWCC:

- o The U.S. arrived in Geneva against the backdrop of the last year of what many countries regard as our cautious approach to the global climate change issue - in contrast to most other countries who have been publicly willing to commit to specific targets and timetables for reducing greenhouse gas emissions, regardless of cost or lack of economic uncertainties. I remain convinced that many of these countries have no idea as to how they plan to achieve their commitments or what the cost might be. We have continued to insist that we should be taking actions that are justified for other reasons (an insurance policy, if you will). In addition, we also, for much of the year, publicly reserved judgement on the science of global change, stating that we were waiting for the results of the IPCC Working Group I Report on the Scientific Assessment of Climate Change (now published - June 1990).

- o While our approach toward any specific plans or strategies (timetables and percentages) for stabilization of CO₂ and other greenhouse gases has been factually well-justified, it has, unfortunately, been poorly-understood and our motives have been badly misconstrued. In fact, we have not called for any specific targets to date because of the lack of sufficient reliable economic information available to us to craft any realistic plan.

- o Over the past year, at several highly-visible, high-level meetings on climate change, such as that at Noordwijk last November, the U.S. - along with most other major powers - have signed statements, which, in principle, agree that stabilization of CO₂ emissions should be achieved as soon as possible and that "such stabilization should be achieved by..industrialized nations.. as soon as possible, at levels to be considered by the IPCC and the Second World Climate conference of November 1990"

- o We have been actively promoting a comprehensive approach to the greenhouse gas question wherein all gases would be treated on an equal footing based on a scientifically determined "greenhouse potential index" which takes into account not only their intrinsic molecular greenhouse efficiency but also their average residence time in the atmosphere and other considerations.

We urge this approach as being fair - in that it inherently recognizes that third World countries in with their methane and other emissions are also significant contributors to the greenhouse problem; in that it will make possible a market approach - both nationally and internationally - that can achieve the maximum improvement in the greenhouse situation at minimum cost; and in that it avoids the potential problems inherent in attempting to develop individual protocols for each greenhouse gas.

The U.S. and The Second World climate conference

- o By the time of the SWCC several weeks ago, the U.S. had become further isolated on the global climate change issue because just prior to the start of the Ministerial portion of the Conference, the EC reached an agreement which called for "...stabilization of CO₂ emissions ...by the year 2000 at 1990 levels, although noting that some countries are not in a position to commit themselves to this objective". (reference to UK whose target of stabilization by 2005). In addition, several weeks prior to that, both Japan and Australia announced plans for stabilization or reduction of their carbon dioxide emissions.

- o At the conference itself, opening speeches by two heads of state, King Hussein of Jordan and Prime Minister Thatcher, in particular (the latter was a call to arms for responding to climate change) set the stage for some difficult negotiations at the preparatory meetings and at the Ministerial Conference, where the U.S. was clearly viewed as the last hold-out among the industrialized countries not willing to propose a definite plan with timetables and percentages for the stabilization or reduction of its greenhouse emissions.

- o After much skillful negotiating by the U.S. delegation at the preparatory meetings, and later, in the Ministerial meeting, all of the five major issues of concern to the U.S. (to which I referred in my memo to you of October 26), were negotiated in such a way as to favorably reflect our position on each issue. This was quite a feat given the political environment at the conference. We give a great deal of credit to Robert Reinstein of State and John Knauss of NOAA for outstanding work here.

- o Our success in negotiating a Ministerial Declaration favorable to the U.S. positions, despite rather wide-spread hostility regarding our refusal to offer a plan for stabilizing greenhouse gases, was probably a reflection of the fact that all countries present genuinely wanted a declaration to be issued from the meeting and their recognition that such a declaration would be meaningless without the participation of

the U.S. Furthermore, most countries recognize that the upcoming negotiations toward a framework convention are the best vehicle for obtaining commitments to such actions as stabilization of CO₂ and other greenhouse gases. In fact, a number of countries, including even the EC worked hard to help find compromise language so that we did not become isolated on the issue.

Where do we go from here?

- o I am convinced that we must have a well-defined position for the U.S. to take to the table at the first negotiating session of the Climate Change Convention (which you will host here in Washington in early February 1991) which will include a strategy for stabilizing or reducing greenhouse gas emissions.

- o I do not believe that we can credibly state that we are waiting for the science; the IPCC science report is now out and represents the consensus of the international scientific community. The report was endorsed by the Scientific/Technical Session of the SWCC which concluded that:

"...notwithstanding scientific and economic uncertainties, nations should now take steps towards reducing sources and increasing sinks of greenhouse gases through national actions and negotiations of a global convention on climate change, and related legal instruments, with the long-term goal of halting the build-up of greenhouse gases at a level that minimizes risks to society and natural ecosystems...."

The good news is that a number of our recent US interagency activities, many of which are being coordinated under the DPC Global Change Strategy Task Force, are in the process of developing and compiling important new information on this issue which, combined with results of analyses of benefits from actions we are already taking, such as the Clean Air Act, may soon make it possible to propose a strategy toward an economically-feasible, realistic plan regarding U.S. greenhouse gas emissions.

The EPA, for example, has noted that the policies that you have already put in place will enable us to hold our US greenhouse gas emissions in the year 2000 to the value they had in 1987. All of these policies have other justification (as part of our insurance policy) but their net effect is, we believe, larger than can be claimed today by any other nation. While others have made more extensive promises for future action, we in the US, under your leadership, have been taking specific actions. But we have failed to get this across either to the international community or to our own environmental activists who keep insisting that we are "dragging our feet" or insisting on "research instead of action".

My next memo to you will provide a summary of some of the new information which is becoming available on the issue as well as a summary of our preparations for the February negotiations, including a timetable for production of some of the most important materials.

We obviously have much hard work to do between now and the start of the February negotiations, but it is an important issue to us both scientifically and politically. I firmly believe that we will be able to make excellent progress on both fronts over the next few months and that we will be in a position to present credible options to you for your decision prior to the February sessions.

THE WHITE HOUSE

WASHINGTON

December 9, 1990

MEMORANDUM FOR THE PRESIDENT

FROM: D. ALLAN BROMLEY

SUBJECT: Global Climate Change Status Report

This memo is to provide you with a status report on global climate change with regard to the most recent scientific conclusions as well as my estimate of the U.S. position in the world community with respect to this issue.

The present status of knowledge concerning the science of global climate change.

The report from the scientific session of the Second World Climate Conference in Geneva last month (747 participants, 120 countries) provides a good summary of the information upon which most countries are basing their discussions as well as their policies and decisions regarding global climate change issues.

- o The Conference agreed that the scientific conclusions set out by the IPCC reflect the international consensus of scientific understanding of climate change.

A few examples of their specific conclusions:

- o "Emissions resulting from human activities are substantially increasing atmospheric concentrations of the greenhouse gases. These increases will enhance the natural greenhouse effect, resulting on average in an additional warming of the Earth's surface."

- o "Without actions to reduce emissions, global warming is predicted to reach 2 to 5 degrees C over the next century, a rate of change unprecedented in the past 10,000 years."

- o "The warming is expected to be accompanied by a sea level rise of 65 cm $\pm$ 35 cm by the end of the next century."

- o The Conference noted that, as stated in the IPCC Report, there is substantial scientific uncertainty in the details of predictions of climate change. To narrow the uncertainties, the Conference recommended enhanced research and observational systems for a number of high priority research areas (e.g., oceans, clouds, carbon cycle, polar ice sheets and sea ice)

Your U.S. Global Change Research Program (including space observations of the Earth by EOS) is carrying out key research on these important topics.

(2) The present position of the U.S. in the world community on global climate change issues

Background: The past year:

o Over the past year, our approach to the global climate change issue has been viewed as cautious in contrast to most other countries who have been publicly willing to commit to specific targets and timetables for reducing greenhouse gas emissions, regardless of cost or lack of economic uncertainties. I remain convinced that many of these countries have no idea as to how they plan to achieve their commitments or what the cost might be. We have continued to insist that we should be taking actions that are justified for other reasons (an insurance policy, if you will).

o While our approach toward any specific plans or strategies (timetables and percentages) for stabilization of CO₂ and other greenhouse gases has been factually well-justified, it has, unfortunately, been poorly-understood and our motives have been badly misconstrued. In fact, we have not called for any specific targets to date because of the lack of sufficient reliable economic information available to us to craft any realistic plan.

o This past year, at several highly-visible, high-level meetings on climate change, such as that at Noordwijk last November, the U.S. - along with most other major powers - have signed statements, which, in principle, agree that stabilization of CO₂ emissions should be achieved as soon as possible and that "such stabilization should be achieved by..industrialized nations.. as soon as possible, at levels to be considered by the IPCC and the Second World Climate conference of November 1990"

o By the time of the SWCC last month, the U.S. had become further isolated on the global climate change issue because just prior to the start of the Ministerial portion of the Conference, Japan, Australia and even the EC announced plans for stabilization of CO₂ emissions. The U.S. was viewed as the last hold-out among the industrialized countries not willing to propose a definite plan with timetables and percentages for the stabilization or reduction of its greenhouse emissions.

o After much skillful negotiating by the U.S. delegation at the preparatory meetings, and later, in the Ministerial meeting, all of the five major issues of concern to the U.S. (to which I referred in my memo to you of October 26), were negotiated in such a way as to favorably reflect our position on each issue. This was quite a feat given the political environment at the conference. We give a great deal of credit to Robert Reinstein of State and John Knauss of NOAA for outstanding work here.

(3) Where do we go from here?

o I am convinced that we must have a well-defined position for the U.S. to take to the table at the first negotiating session of the Climate Change Convention (which you will host here in Washington in early February 1991) which will include a strategy for stabilizing or reducing greenhouse gas emissions.

o I do not believe that we can credibly state that we are waiting for the science; the IPCC science report is now out and represents the consensus of the international scientific community.

o The good news is that a number of our recent US interagency activities, many of which are being coordinated under the DPC Global Change Strategy Task Force, are in the process of developing and compiling important new information on this issue which, combined with results of analyses of benefits from actions we are already taking, such as the Clean Air Act, may soon make it possible to propose a strategy toward an economically-feasible, realistic plan regarding U.S. greenhouse gas emissions.

The EPA and DOE, for example, have calculated that the policies that you have already put in place will enable us to hold our US greenhouse gas emissions in the year 2000 to the value they had in 1987. While others have made more extensive promises for future action, we in the US, under your leadership, have been taking specific actions. But we have failed to get this across either to the international community or to our own environmental activists who keep insisting that we are "dragging our feet" or insisting on "research instead of action".

o To correct this notion and to help put the U.S. squarely back in a strong leadership position in the international global change arena, the members of my Global Change Strategy Task Force under the DPC are presently putting together a plan outlining how we in the U.S. will address the issue of greenhouse gas emission reduction - based upon emissions reductions achieved by present and planned Administration policies.

o We obviously have much hard work to do between now and the start of the February negotiations, but it is an important issue to us both scientifically and politically. I firmly believe that we will be able to make excellent progress on both fronts over the next few months and that we will be in a position to present credible options to you for your decision prior to the February sessions.

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8 **SECTION 9**

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10 **SEA LEVEL RISE**
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19 **Peer Reviewed Assessment**
20 **for WG1 Plenary**
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EXECUTIVE SUMMARY

This chapter addressed three questions:

- Has global-mean sea level been rising during the last 100 years?
- What are the causal factors that could explain a past rise in sea level?
- And what increases in sea level can be expected in the future?

Despite numerous problems associated with estimates of globally-coherent, secular changes in sea level based on tide gauge records, we conclude that it is highly likely that sea level has been rising over the last 100 years. There is no new evidence that would alter substantially the conclusions of earlier assessments regarding the rate of change. Our judgement is that:

- the average rate of rise over the last 100 years has been 1.0 - 2.0mm/yr.
- there is no firm evidence of accelerations in sea level rise during this century (although there is some evidence that sea level rose faster in this century compared to the previous two centuries).

As to the possible causes and their specific contributions to past sea level rise, the uncertainties are very large, particularly for Antarctica. However, in general it appears that the observed rise can be explained by thermal expansion of the oceans, and by the increased melting of mountain glaciers and the margin of the Greenland ice sheet. From present data it is impossible to judge whether the Antarctic ice sheet as a whole is currently out of balance and is contributing, either positively or negatively, to changes in sea level.

Future changes in sea level were estimated for each of the IPCC forcing scenarios (using the same simple box model as in Section 6). For each scenario, three projections - best estimate, high and low - were made corresponding to the estimated range of uncertainty in each of the potential contributing factors. It is found that:

- for the IPCC Business-as-Usual Scenario at year 2030, global-mean sea level is 8 - 29cm higher than today, with a best-estimate of 18cm. At the year 2070, the rise is 21 - 71cm, with a best-estimate of 44cm.
- most of the contribution is estimated to derive from thermal expansion of the oceans and the increased melting of mountain glaciers and small ice caps.
- on the decadal time scale, the role of the polar ice sheets is expected to be minor, but they contribute substantially to the total uncertainty. Antarctica is expected to contribute negatively to sea level due to increased snow accumulation associated with warming. A rapid disintegration of the West Antarctic Ice Sheet is unlikely within the next century.
- for the lower forcing scenarios (B,C and D), the sets of sea level rise projections are similar, at least until the mid-21st century. On average these projections are approximately one-third lower than those of the Business-as-Usual Scenario.

Even with substantial decreases in the emissions of the major greenhouse gases, future increases in temperature and, consequently, sea level are unavoidable - a sea level rise "commitment" - due to lags in the climate system.

This present assessment does not foresee a sea level rise of ≥ 1 metre during the next century. Nonetheless, the implied rate of rise for the best-estimate projection corresponding to the IPCC Business-as-Usual Scenario is about 3-6 times faster than over the last 100 years.

9.1 SEA LEVEL RISE

This section is primarily concerned with decade-century changes in global-mean sea level, particularly as related to climatic change. First, the evidence for sea level rise during the last 100 years is reviewed as a basis for looking for climate-sea level connections on a decade-to-century timescale. Next, the possible contributing factors - thermal expansion of the oceans and the melting of land ice - to both past and future sea level change are examined. Finally, the issue of future sea level due to "greenhouse" warming is addressed.

9.2 FACTORS AFFECTING SEA LEVEL

Changes in sea level occur for many reasons on different time and space scales. Tide gauges measure sea level variations in relation to a fixed benchmark and thus record "relative sea level" change due both to vertical land movements and to real (eustatic) changes in the ocean level. Vertical land movements result from various natural isostatic movements, sedimentation, tectonic processes and even anthropogenic activities (e.g., groundwater and oil extraction). In parts of Scandinavia, for instance, relative sea level is decreasing by as much as 1m per century due to isostatic "rebound" following the last major glaciation. In attempting to identify a globally-coherent, secular trend in MSL, the vertical land movements "contaminate" tide gauge records and have to be removed.

Eustatic sea level is also affected by many factors. Differences in atmospheric pressure, winds, ocean currents and density of seawater all cause spatial and temporal variations in sea level in relation to the geoid (the surface of constant gravitational potential corresponding to the surface which the ocean would assume if ocean temperature and salinity were everywhere 0°C and 35 o/oo, respectively, and surface air pressure was everywhere constant). Changes in the geoid itself, due to re-distribution of mass within the Earth, are irrelevant on the decadal-century timescales under consideration. Over these timescales, the most important climate-related factors are likely to be thermal expansion of the oceans and melting of land ice (but not floating ice shelves or sea ice).

9.3 HAS SEA LEVEL BEEN RISING OVER THE LAST 100 YEARS ?

It is highly likely that global-mean sea level (MSL) has been rising. This is the general conclusion of no fewer than 13 studies of MSL change over various periods during the last 100 years (Table 9.1). The estimates range from about 0.5mm/yr to 3.0mm/yr, with most lying in the range 1.0-2.0mm/yr.

In addition, several assessments of the likely rate of past sea level rise have been made which include detailed reviews of the literature: 12±5cm since 1900 (SCOPE 29; sea-level review by Robin, 1986); 10-25cm since 1900 (US.DoE; review by Barnett, 1985); and 10-20cm over last 100 years (PRB; review by Aubrey, 1985). Rather than repeat those reviews, we shall focus on the three most recent studies and ask whether they provide any new information that would substantially alter previous assessments.

9.3.1 Comparison of Recent Estimates

The analyses by Gornitz and Lebedeff (1987; also see Gornitz, 1990) used tide-gauge data from 130 stations with minimum record length of 20 years to estimate the average rate of sea level change over the period 1880-1982. This analysis differed from previous analyses (Gornitz et al. 1982) by including a more careful correction for vertical land movements using extensive data from ¹⁴C dated Holocene sea level indicators (see below). This correction significantly reduced the spread of the trend estimates from the individual stations (Figure 9.1).

Using two different averaging techniques to produce composite global MSL curves (averaging individual stations versus regional trends), the study obtained estimates of $1.2 \pm 0.3\text{mm/yr}$ and $1.0 \pm 0.1\text{mm/yr}$ respectively. These results do not differ significantly from their previous findings.

The study by Barnett (1988) is an update of previous work (Barnett, 1983, 1984) in which 155 stations are analysed over the period 1880-1986. A rate of 1.15mm/yr is obtained, in close agreement with the rates noted above. However, from a comparison of the composite global sea level curves (Figure 9.2), it is apparent that while Gornitz and Lebedeff's curve appears linear over the entire time period, Barnett's curve suggests a steeper rate of rise over about 1910-1980 - approximately 1.7mm/yr . This is more nearly in line with estimates of Peltier and Tushingham (1990) for the same time period (see Table 9.2).

Peltier and Tushingham (1989;1990) select a minimum record length of 51 years, correct the data for ongoing glacial isostatic adjustments using a geophysical model, and analyse the corrected data using both linear regression (LR) techniques and empirical orthogonal function (EOF) analyses. From a final total of 40 stations over the time period 1920-1970, they conclude that the global rate of sea level rise is $2.4 \pm 0.9\text{mm/yr}$. This rate is considerably higher than most other estimates noted in Table 9.1. However, the authors caution that the results are sensitive to variations in the analysis procedure. As shown in Table 9.2, variations in either the record length or period of record have large effects on the estimated rate of rise. In fact, for all combinations other than their preferred period 1920-1970 (chosen to maximize the number of stations with a minimum 50-year record length), the estimated rates are lower and, in a number of cases, compare favourably with those of Gornitz and Lebedeff (1987), Barnett (1988) and Trupin and Wahr (1990).

Why the differences? Possible reasons have to do with choice of minimum record length, period of record, number of stations, geographical representation, correction procedures for vertical land movements, and methods of data aggregation and analysis. Unfortunately, these factors are interrelated and not easily isolated from published studies. Nevertheless, it is significant that, despite the differences, both the recent and earlier studies all find a positive trend in global MSL. This seems to be a rather robust finding. There is, however, the possibility that all the studies could be systematically biased.

9.3.2 Possible Sources of Error

There are several potential sources of systematic bias common to all such studies. First, they make use of the same global MSL dataset, that of the Permanent Service for Mean Sea Level (PSMSL), an International Council of Scientific Unions databank located at the Bidston Observatory, U.K. (Pugh et al., 1987). The PSMSL collects data from approximately 1300 stations worldwide. However, only 850 of these are suitable for time series work (the PSMSL "Revised Local Reference" (RLR) dataset, and 420 of these are 20 years or more in length. Tide gauge records contain many signals other than a secular trend. These stem primarily from large interannual meteorological and oceanographic forcings on sea level and, in principle, can be modelled and thereby removed from the record. In practice, the variability is such that accurate trends can be computed only given 15-20 years of data, which significantly reduces the size of the dataset available for analysis.

Second, there is an historical geographical bias in the dataset in favour of Northern Europe, North America and Japan. Areas of Africa, Asia, ocean islands and polar regions are sparsely represented. The geographical bias inherent in any global dataset will propagate into all studies. This bias can be reduced (but not eliminated) by treating regional subsets of the dataset as independent information, as has been done in the recent studies described above.

The problem of geographical bias is now being addressed with the establishment of the Global Level of the Sea Surface (GLOSS) global tide gauge network coordinated by the Intergovernmental Oceanographic Commission (IOC) (Pugh, 1990). Most islands involved

now have tide gauges and most continental GLOSS stations (other than polar sites) are now operational, but much work remains to improve standards and the reliability of observations.

Finally, perhaps the most important source of error stems from the difficulties involved in removing vertical land movements from the dataset. In addition to the effects noted above, most mid-latitude stations located on continental margins are especially susceptible to effects from sedimentation, groundwater and oil extraction, and tectonic influences and could be undergoing general submergence, which, unless accounted for, could introduce a positive bias into any global MSL secular trend (Pirazzoli et al., 1987). In order to identify a globally-coherent trend that can be linked to changes in global climate, such effects have to be removed. The issue is how to do so.

In the future, the inherent ambiguity between land and ocean level changes in a tide gauge record will be solved by the use of advanced geodetic methods, but such data are not available for present analysis (Carter et al., 1989). In lieu of new geodetic data, one approach adopted by recent analyses has been to model explicitly the expected geology-induced MSL changes at each tide gauge site by the use of ancillary Holocene data (e.g., molluscs, corals, peats. Gornitz et al., 1982; Gornitz and Lebedeff, 1987) or by the use of geodynamic models of the Earth (Peltier and Tushingham, 1989; 1990). The other approach is simply to assemble a sufficiently broad geographical spread of records such that (it is hoped) the net contribution of land movements reduces to zero (Barnett, 1983; 1984; 1988).

These differences in approach probably account substantially for the different results noted in Table 9.1. But it cannot be said with confidence that vertical land movements (or, that is, the failure to account adequately for them), along with reliance on a single dataset and problems of geographical bias, have not systematically biased all studies in the same direction.

9.3.3 Accelerations in Sea Level Rise

Is there evidence of any "accelerations" (or departures from long-term linear trends) in the rate of sea level rise? From examinations of both composite regional and global curves and individual tide-gauge records, there is no convincing evidence of an acceleration in global sea level rise during the twentieth century. For longer periods, however, there is weak evidence for an acceleration over the last 2-3 centuries

Long-term analyses are hindered by the scarcity of tide-gauge records longer than 100-120 years. Data are limited to a few stations in Europe and North America. Woodworth (1990) inspected individual tide gauge records in Europe and found that although there is no general evidence for an increasing (or decreasing) rate of MSL change during the past century, a regionally-coherent acceleration of the order of 0.4mm/year per century is apparent over the last 2-3 centuries. This finding is supported by Gornitz and Solow (1989) who find weak evidence for an increase in the trend around 1895. Similar conclusions were reached by Ekman (1988) from an examination of one of the longest tide-gauge records, at Stockholm. Extension of such findings to the global scale, however, should be carried out with caution.

We now turn to the possible contributing factors to see if we can explain the past rise.

9.4 POSSIBLE CONTRIBUTING FACTORS TO PAST AND FUTURE SEA LEVEL RISE

There are four major climate-related factors that could possibly explain a rise in global MSL on the 100-year time scale. These are:

- (1) thermal expansion of the oceans;
- (2) glaciers and small ice caps;
- (3) the Greenland ice sheet; and
- (4) the Antarctic ice sheet (including the special case of the West Antarctic ice sheet).

In this section, we examine the sensitivity of each factor to changes in climate (particularly temperature), and estimate its possible contribution to past sea level change. In the subsequent section, attention is then turned to future sea level change.

9.4.1 Thermal Expansion of the Oceans.

At constant mass, the volume of the oceans, and thus sea level, will vary with changes in the density of sea-water. Density is inversely related to temperature. Thus, as the oceans warm, density decreases and the oceans expand - a "steric" rise in sea level. Marked regional variations in sea-water density and volume can also result from changes in salinity, but this effect is relatively minor at the global scale.

In order to estimate oceanic expansion (past or future), changes in the interior temperature, salinity and density of the oceans have to be considered, either empirically or by models. Unfortunately, observational data are scant, both in time and space (Barnett, 1985). A few recent analyses have been carried out on the limited time-series data. For instance, Roemmich (1985) examined the 1955-1981 Panuliris series of deep hydrographic stations off Bermuda, and Thomson and Tabata (1987) examined the Station PAPA (northeast Pacific Ocean) steric height anomalies for a similar 27-year record. The latter study found that open ocean steric heights are increasing linearly at 0.93mm/year. However, in this and other studies, the large interannual variability creates too much "noise" to be confident of the estimate derived from such a short time-series. Moreover, the limited geographical coverage makes inference to the global scale problematic. In a few decades, current efforts such as the World Ocean Circulation Experiment (WOCE) will begin to fill the data gaps and overcome these problems.

An alternative approach could be based on numerical models of the ocean's circulation (Barnett, 1985). Ideally, detailed three-dimensional models could describe the various oceanic mixing processes and could simulate heat transfer and expansion effects throughout the oceans. However, such models are in the early stages of development and applications to problems of global warming and thermal expansion are few in number. A drawback of this sort of model is that the computing time required precludes numerous runs for sensitivity analyses.

Instead, for the present assessment a simple upwelling-diffusion energy-balance climate model is used. Typically, this type of model represents the world's land and oceans by a few "boxes", and complicated processes of oceanic mixing are simplified in one or more parameters (for review see Hoffert and Flannery, 1985). The same model was used to estimate the transient global warming (see Sections 6 and 8 for other results, and Section 8 for the justification for using this type of model). The inclusion of expansion coefficients in the model (varying with depth and, possibly, latitude) allows the sea level changes to be estimated as well. In order to maintain consistency throughout this assessment, both past and future (see below) thermal expansion effects are also estimated with this modelling technique, bearing in mind that full understanding of the dynamic processes and their effects on the depths and timing of ocean warming will eventually require more physically realistic models.

The simple model is forced by past changes in radiative forcing due to increasing atmospheric concentrations of greenhouse gases (see Section 2). The internal model parameters that most affect the output are the diffusivity (K), the sinking water to global mean temperature change ratio (π) and the climate sensitivity (ΔT_{2x} , the global-mean equilibrium temperature change for a CO_2 doubling): see Section 6). In order to estimate past thermal expansion effects, the parameter values were constrained to maintain consistency with observed global warming over the same time period (i.e., 0.3 - 0.6°C; see Section 7). For the period 1880-1985, the resultant range of sea level rise due to thermal expansion is about 2-6cm (also see Wigley and Raper, 1987; 1990).

9.4.2 Land Ice

A distinction is made between glaciers and small ice caps, the Greenland ice sheet and the Antarctic ice sheet, since different climatic characteristics and different response times are involved. Table 9.3 lists some of their physical properties.

A large uncertainty exists regarding the volume of glaciers and small ice caps. Although the total area is relatively well-known (Haeberli et al., 1988), the mean thickness is not. Here a value of 200m is adopted, which really is a first-order estimate. Fortunately, on small time scales, (up to several decades), it is really the surface area that determines the changes in runoff.

Although the positive and negative contributions to the mass budget of the Greenland and Antarctic ice sheets noted in Table 9.3 sum up to zero, it is actually unknown how close the ice sheets are to equilibrium (a more detailed discussion is given below). This introduces the problem of choosing an initial state for model integrations to estimate future sea level. In a previous assessment (Oerlemans, 1989), the year AD 1850 was taken as a starting point, and it was suggested to simply add the "unexplained part" of past sea level rise to the calculated future contributions from thermal expansion and land ice. The unexplained trend can also be associated with long-term changes of the ice sheets, but also to unknown tectonic effects. We return to this particular problem later.

From Table 9.3 a notable difference between the Greenland and Antarctic ice is evident. On Greenland there is significant ablation (melting and runoff, evaporation); on Antarctica ablation is a negligible component in the total mass budget. This is also reflected in the altitude of the equilibrium line (= zero annual mass gain). It is instructive to consider this in the light of a generalised mass-balance curve, where mass gain and loss are plotted as a function of annual surface air temperature (Figure 9.3). The resulting mass balance is in metres of water equivalent per year. Depending on the annual temperature range, ablation occurs for annual temperatures higher than -15 to -10°C. At the lower reaches, accumulation increases with temperature, reaches a maximum in the vicinity of the freezing point and then decreases.

The net specific balance thus shows two ranges with different behaviour. In range (a) mass balance increases with temperature, in range (b) it decreases with temperature. This makes the response of ice masses to climatic change complicated. Most glaciers and the Greenland ice sheet are mainly, but not entirely, in region (b). The Antarctic ice sheet with its much colder climate is situated in region (a). In case of a climatic warming, one expects an increasing surface mass balance for the Antarctic ice sheet (contributing to a sea level lowering) and a decreasing mass balance for the other ice bodies (contributing to sea level rise).

9.4.3 Glaciers and Small Ice Caps

The majority of valley glaciers has been retreating over the last hundred years. Although long records of glacier length are only available for some glaciers in the European-North Atlantic region (Figure 9.4), geomorphological investigations have made it clear that the trend of glacier retreat has generally been world-wide since the Little Ice Age (Grove, 1988). Wastage was most pronounced in the middle of the 20th century. Around 1960, many glaciers started to advance. In the 1980s this advance slowed down or stopped in several glacier basins (e.g., Haeberli et al., 1989), but not everywhere. In Scandinavia, for instance, mass balance remained positive on the maritime glaciers and close to zero on the others.

The main published estimate of the contribution of retreating glaciers to past sea level rise is that of Meier (1984). In his analysis, Meier assumed that the magnitude of the long-term changes, for which data are sparse, are proportional to the difference between summer and winter balance, for which data are more abundant. This allowed extrapolation of measurements on a few glaciers to a world-wide scale. Meier estimated that during the period 1900-1961, glacier retreat contributed 2.8cm, or 0.46 ± 0.26 mm/yr, to global sea level rise. By using data

from three well-documented glaciers in temperate climate regions, Meier also extrapolated the record to encompass 1885-1974. This gives an average rate of sea level rise which is somewhat less than 0.46mm/yr.

During the period 1900-1961, global mean temperature rose by approximately 0.35 K (see Section 7, this volume), yielding a sensitivity in terms of sea level rise of 1.3 mm/yr per degree (with the ocean area equal to 361 million km²).

This sensitivity value is broadly supported by mass balance studies. In the study noted above Meier found a net glacier *mass balance* of -0.38 ± 0.2 m/yr for 25 well studied glaciers, converting to a sensitivity of -1 m/yr per degree temperature rise. This can be compared to other, more direct estimates. For example, based on an analysis of 29 years of climatological and mass balance data from the Hintereisferner (a well-studied glacier in the Austrian Alps), Greuell (1989) finds a sensitivity of -0.41 m/yr per degree warming. Kuhn (1990) suggest a global value of the order of -0.5 m/yr per degree. Sensitivity tests with an energy balance model for a glacier surface, including albedo feedback, yields values ranging from -0.45 m/yr per degree warming for drier climates to -0.7 m/yr per degree warming for moist climates (Oerlemans, 1990). Altogether, these studies come up with smaller values than the -1m/yr per degree derived from Meier's estimate of change in glacier mass balance combined with a figure for the global temperature change. Its probably the use of this *global* temperature change from which the discrepancy arises. It is known that summer temperature is the important parameter, and it also seems unlikely that the mean change over the glacierized regions can be represented by the global mean temperature. The global sensitivity value inferred by these studies is 1.2 ± 0.6 mm/yr per degree warming. In our judgement glacier shrinkage will continue and accelerate in a warmer climate.

9.4.4 The Greenland Ice Sheet.

Estimates of the mass budget of the Greenland ice sheet have been hampered by a pronounced lack of data. Accumulation measurements have been done on a few traverses only (see Radok et al., 1982). Systematic ablation measurements in the marginal zone have been carried out in several places, but all located in the southwestern part of Greenland (Braithwaite and Oleson, 1985, 1989). The only profile from the ice margins to the region well above equilibrium line is the EGIG profile (Expedition Glaciologique Internationale au Groenland, West Greenland, at about 70°N latitude). Here mass balance and meteorological measurements have been carried out in the summer seasons of 1959 and 1967 (Ambach, 1963, 1979).

Table 9.4 lists estimates of the total mass budget of the Greenland ice sheet as compiled by Robin (1986). The differences appear quite large. The zeros in the column "balance" should not be interpreted as an indication for a balanced state - equilibrium has only been assumed. When going through the original papers it becomes clear that, on the basis of currently available data, there is considerable uncertainty regarding the current state of balance of the ice sheet. An imbalance of up to 30% of the annual mass turnover cannot be excluded.

A few studies have also been undertaken to detect changes in some selected area. Along the EGIG line in central West Greenland, there is some indication of slight thickening in the interior part of the ice sheet. A study along the "Oregon State University line" in South Greenland suggested a close balance between accumulation and ice discharge, at least in the interior part (Kostecka and Whillans, 1988).

On the basis of satellite altimetry, Zwally (1989) found that the mass balance of the southern part of the ice sheet has been positive in the period 1978-1986. He reports that thickening of the ice sheet occurred in both the ablation and accumulation zone (order of magnitude 0.2m/yr). Although there are doubts regarding the accuracy of the results (Douglas et al., 1990), this work shows the enormous potential of radar altimetry to monitor changes on the large ice sheets.

Most outlet glaciers for which observations exist (this is mainly in central and southern part of the west coast of Greenland) have retreated strongly over the last century (Weidick, 1984). As the retreat occurred in many regions, on a relatively short time scale (100 years), and in a period of significant warming in Greenland, increased ablation rates must be responsible for this. However, the large ablation zones of the inland ice must have suffered from this too. The implications for past sea level rise will be discussed shortly.

A few estimates have been made of the sensitivity of Greenland mass balance to climatic change. They are listed in Table 9.5. The method of Ambach and Kuhn (1989) is based on a new analysis of the EGIG data. In their approach, the mass and energy budget at the equilibrium line is expanded with a linear perturbation technique, allowing the calculation of the change in the equilibrium-line altitude (dELA) associated with small changes in temperature, precipitation and radiation. By extrapolating dELA to the entire ice sheet, an estimate can then be made of the change in ablation and accumulation area, and, by assigning mass-balance values, of the total ice mass budget. Bindschadler's (1985) calculation is based on the same mass-balance measurements, but a (minor) correction is made for a retreating ice margin. The value listed as Oerlemans et al. (1990) results from a straightforward sensitivity test with an energy balance model applied to four regions of the ice sheet. Braithwaite and Olesen (1990) have used an energy balance model to study their ablation measurements in southwest Greenland, and attempted to extrapolate the result to the entire ablation zone. There is a reasonable agreement between all those studies, but this is partly due to dependence of the input.

Above, only temperature has been considered as a climatic input parameter. In fact, changes in the seasonal cycle, in precipitation and cloud patterns have occurred and will occur in the future. The potential importance of such factors can be studied by sensitivity tests, and some results have been listed in Table 9.5. It has been suggested that even in the relatively warm climate of Greenland, snow accumulation may increase when temperature goes up (e.g., Reeh and Gundestrup, 1985). If annual precipitation would increase uniformly by 5% per degree warming, the "precipitation effect" can offset about 30% of the "temperature effect". Setting the annual precipitation proportional to the amount of precipitable water in a saturated atmospheric column [see Oerlemans and Van der Veen, 1984, p. 140] would imply, for mean conditions over the Greenland ice sheet, a 4% increase in precipitation for a 1 K warming. This leads to a best estimate of the sensitivity of 0.3 ± 0.2 mm/yr per degree K. The error bar is large because:

- (i) There is considerable uncertainty on how precipitation patterns over Greenland will change in a warmer climate.
- (ii) It is unknown whether iceberg calving from the outlet glaciers will increase due to increased basal water flow (Bindschadler, 1985). However, the ice possibly involved in rapid retreat of calving fronts is almost afloat, so the contribution to sea-level rise will be negligible. Consequent thinning of grounded ice further upstream is not likely to affect sea level within the next 100 years.
- (iii) It is unknown how factors like surface albedo and cloudiness will change.

With a record of mean summer temperatures, the sensitivity can be used to produce an estimate of Greenland's contribution to past sea level rise. As shown in Figure 9.5, the 1866-1980 summer temperature departures (relative to the 20-year average for the reference period 1866-1885) shows an overall warming of about 0.5°C . However, the decadal changes are pronounced, with a large warming of about 2°C occurring up to 1930-35 and a cooling trend thereafter. By summing the product between the sensitivity value and the temperature departure for each year from 1880-1980, the 100-year contribution to sea level is estimated. Assuming initial conditions in equilibrium and a sensitivity of 0.3 ± 0.2 mm/yr per degree, the summation yields 23 ± 16 mm (or 0.23 ± 0.16 mm/yr). So the contribution from Greenland to past sea level rise appears to be somewhat less than that from glaciers and thermal expansion.

9.4.5 The Antarctic Ice Sheet.

The question of balance of the Antarctic ice sheet proves to be a very difficult one. From a physical point of view, regarding the very long time scale introduced by geodynamics and thermomechanical coupling in the ice sheet, it seems unlikely that the present ice sheet has adjusted completely to the last glacial-interglacial transition. A detailed modelling study by Huybrechts (1990), in which a glacial cycle of the Antarctic ice sheet is simulated on a 40km grid, suggests that the large-scale imbalance will not be more than a few percent of the annual mass turnover (corresponding to a rate of sea level change of less than 0.1 mm/yr). This does not exclude the possibility, however, that climate fluctuations with a shorter time scale have pushed the ice sheet out of balance. Also, there is increasing evidence that marine ice sheets, like the West Antarctic, could exhibit pulsating mass discharge which is not climate-related, but may have important consequences for sea level.

Budd and Smith (1985) made an assessment of the net balance by compiling a set of accumulation and ice velocity measurements (Table 9.6). The latter allow to make a rough estimate of the ice discharge from the main ice sheet across the grounding line, viz. 1879×10^{12} kg/yr. They find a number of about 2088×10^{12} kg/yr for the accumulation and estimate the net balance to be positive by 209×10^{12} kg/yr. This would correspond to a rate of sea level change of about -0.6mm/yr. Subsequent estimates of the total accumulation have produced lower values. Giovinetto and Bentley (1985) state that accumulation over the grounded part of the ice sheet is only 1468×10^{12} kg/yr. With the mean value for discharge from above, this yields a net balance of -411×10^{12} kg/yr. Fortuin and Oerlemans (1990) find, on the basis of a data set independently compiled from the archives of the Scott Polar Research Institute (SPRI), a mass gain at the surface of 1817×10^{12} kg/yr. With the discharge number from Budd and Smith, this then implies a net balance of -62×10^{12} kg/yr.

It must be stressed that the inference of ice mass discharge from a limited number of *surface* velocity measurements involves many uncertainties. The ratio of surface velocity to vertical mean velocity is such an uncertain factor. More seriously, outflow velocities vary dramatically from point to point, so lateral extrapolation and interpolation around the coast introduces very large errors. A comprehensive comparison of earlier estimates of the surface mass balance was given by Giovinetto and Bull (1987). Their discussion suggests that the total surface accumulation over grounded ice is not known to an accuracy better than 10%. When considering the net balance, this figure will be worse.

In conclusion, it is unknown whether the Antarctic ice sheet is currently in balance and whether it has been contributing to sea level rise over the last 100 years or not. A 20% imbalance of mass turnover cannot be detected in a definite way from present data.

Several methods exist to investigate how accumulation on the Antarctic ice sheet may change when temperature changes. Analysis of the gas content in the deep Antarctic ice cores gives an indication of how accumulation varied between glacial and interglacial conditions (Lorius et al., 1984; Jouzel et al., 1989). In fact, it gives support to the view that accumulation on the interior is roughly proportional to the saturation mixing ratio of water vapour in the air above the inversion, as first suggested by Robin (1977). Another method involves regression analysis on measured temperatures and accumulation rates (Muszinsky, 1985; Fortuin and Oerlemans, 1990). However, it is not so clear that a relation between accumulation and temperature based on spatial variation can be applied to climatic change. It is also possible to use precipitation rates as predicted by general circulation models of the atmosphere. Although the quality of these models has increased gradually, simulation of the climate of the polar regions still shows serious shortcomings (Schlesinger, 1990), and the results concerning glacier mass balance must be considered with much caution. So far, a systematic comparison between observed accumulation on the ice sheets and output from such models has not yet been published.

Table 9.7 lists a number of estimates of the change in Antarctic mass balance for a uniform warming of 1 degree K. Muszinsky's estimate is the highest: a decrease of 0.38 mm/yr in sea level. The multiple regression analysis reported in Fortuin and Oerlemans (1990) yields a

substantially lower value. In this analysis, which was based on a much larger newly compiled data set, a distinction was made between ice shelves, escarpment region and interior. Accumulation is strongly related to both temperature and latitude, parameters which also have a high mutual correlation. Taking this correlation out leads to a significantly weaker temperature dependence of the accumulation, but it can be argued that this approach is preferable when considering climate sensitivity. The value listed under "proportional to water vapour mixing ratio" was calculated by integrating over a 20km grid covering the entire ice sheet, with temperatures extrapolated from the data set used in the multiple regression mentioned above. The values thus obtained are rather close to the one suggested by Muszinsky's work.

Support for the idea that higher temperatures will lead to significantly larger accumulation also comes from observations on the Antarctic Peninsula. Over the past 30 years temperature has gone up here by almost 2K, whereas accumulation increased by as much as 25% in parallel with this (Peel and Mulvaney, 1988). Although this cannot be taken as proof of a causal relationship, it is in line with the sensitivity estimates listed in Table 9.7, which span a factor of two.

In summary, all quoted studies show an increase in accumulation with warming and thus a decrease in sea level. An ablation zone does not effectively exist in Antarctica, and a large warming would be required in order for ablation to influence mass balance.

9.4.6 Possible Instability of The West Antarctic Ice Sheet.

Most of the early attention to the issue of sea level rise and greenhouse warming was related to the stability of the West Antarctic ice sheet. Parts of this ice sheet are grounded far below sea level and may be very sensitive to small changes in sea level or melting rates at the base of adjacent ice shelves (e.g., Mercer, 1978; Thomas et al., 1979; Lingle, 1985; Van der Veen, 1986). In case of a climatic warming, such melting rates could increase and lead to disappearance of ice rises (places where the floating ice shelf runs aground). Reduced back stress on the main ice sheet and larger ice velocities may result, with subsequent thinning of the grounded ice and grounding-line retreat.

It is hard to make quantitative statements about this mechanism. Several attempts have been made to model this ice sheet-shelf system and to study its sensitivity (Thomas et al., 1979; Lingle, 1985; Van der Veen, 1986, 1987; Budd et al., 1987). Van der Veen (1986), in a rather extensive study, concludes that the earlier estimates of the sensitivity of West Antarctica were too large. Budd et al. (1987) also give an extensive discussion on the response of the West Antarctic Ice Sheet to a climatic warming. Their considerations are based on a large number of numerical experiments with flow-band models. According to these experiments, very large ice-shelf thinning rates (10 to 100 times present values) would be required to cause rapid disintegration of the West Antarctic Ice Sheet. For a probably more realistic situation of a 50% increase in ice-shelf thinning rate for a one-degree warming (order of magnitude), the associated sea level rise would be about 0.1mm/yr for the coming decades.

Much of the drainage of the West Antarctic ice sheet goes through a number of fast flowing ice streams, the dynamics of which were not properly included in the modelling studies mentioned above. In recent years it has become clear from new observational studies (e.g., Bentley, 1987; Alley et al., 1987; MacAyeal, 1989) that those ice streams show much variability on a century and may be even decadal time scale. Although much of this variability is probably not related directly to climate change, it demonstrates the potential of this part of the ice sheet to react quickly to any change in boundary conditions. A comprehensive model of the ice streams and their interaction with the main ice body does not yet exist, unfortunately. Still, as argued by D.R. MacAyeal (abstract to the 1989-American Geophysical Union meeting on sea level change, unpublished), an extreme limit of the response of the West Antarctic ice sheet to greenhouse warming can be estimated. In his view the accelerated discharge of ice only occurs in the regions where sufficient subglacial sediments (the lubricant for the ice streams) is

present. For a typical greenhouse warming scenario, the bulk of the increased mass outflow would occur between 100 and 200 years from now, and the actual projected West Antarctic contribution to sea level rise would be -10 cm after 100 yrs (increase in surface accumulation still dominating), +40 cm after 200 yrs, +30 cm after 300 yrs (ice stream discharge stopped).

In summary, there is no firm evidence to suggest that the Antarctic ice sheet in general, or the West Antarctic ice sheet in particular, have contributed either positively or negatively to past sea level rise. On the whole, the sensitivity of Antarctica to climatic change is such that a future warming should lead to increased accumulation and thus a negative contribution to sea level change.

9.4.7 Other Possible Contributions

Sea level could also have been affected by net increases or decreases in surface and groundwater storage. In particular, groundwater depletion (through pumping) and drainage of swamps, soils and wetlands would contribute to a MSL rise. On the other hand, increases in surface storage capacity - especially large dams but also the combined effects of many small reservoirs and farm ponds - would detract from sea level.

Decreases in groundwater levels are commonly reported from all over the world from many different environments. This suggests that total groundwater storage volumes have been diminishing, particularly during the last 50 years. Data are meagre, however. One rough estimate (Meier, 1983; also see Robin, 1986) is that, globally, net depletion has amounted to about 2000km³ (equivalent to 0.55cm in sea level) during this century. Land drainage, particularly in Northwest Europe and North America over the last 100 years, has reduced soil and shallow groundwater storage over wide areas, but the actual amounts of water are difficult to estimate.

Substantial increases in surface storage have occurred since the 1930s. Newman and Fairbridge (1986) estimated that this has amounted to about 18750km³ (-5.2cm in sea level, using 362 x 10⁶km² for ocean area) over the period 1932-1982. Golubev (1983; Also see Robin, 1986), however, makes a much lower estimate, 5500km³ (-1.5cm in sea level).

Overall, the estimates appear too imprecise and the data insufficient, especially for groundwater changes, to be able to conclude much about the possible net effects on past sea level rise.

9.4.8 Synthesis

The estimated contributions to past sea level rise can now be summarised (Table 9.8). Assuming the contribution from Antarctica has been zero, the combined contributions from thermal expansion, mountain glaciers and the Greenland ice sheet over the last 100 years total about 11cm. This is within the range of observed sea level rise (10 - 20cm), albeit at the lower end. The range of uncertainty is large: -1.5cm to 24cm.

9.5 HOW MIGHT SEA LEVEL CHANGE IN THE FUTURE?

Various estimates of future sea level rise are noted in Table 9.9. Such estimates are very difficult to compare because different time periods are chosen, and because assumptions regarding future greenhouse gas concentrations, changes in climate, response times, etc., are either different or not clearly stated. In general, most of the studies in Table 9.9 foresee a sea level rise of somewhere between 10cm and 30cm over the next four decades. This represents a rate of rise that is significantly faster than that experienced, on average, over the last 100 years.

Projections for the present assessment are made using the standard IPCC greenhouse gas forcing scenarios. These consist of a "business-as-usual" scenario, and three lower scenarios (B-D) in which greenhouse gas emissions are substantially reduced. Three projections are made for each scenario (12 projections in total) reflecting the high, low and best-estimate assumptions for each of the contributing factors, as described below.

9.5.1 Methods and Assumptions

Estimates of the thermal expansion effects are obtained using the upwelling-diffusion model of Wigley and Raper (1987) described in 9.4.1 and in Section 6. For each scenario, the model is run using a climate sensitivity (ΔT_{2x}) of 1.5°C, 2.5°C and 4.5°C for the low, best-estimate and high projections, respectively, with the diffusivity set to 0.63cm²sec⁻¹ and π set to 1 (see Section 6 for the justification of the choice of diffusivity and π values).

Concerning glaciers and small ice caps, significant warming may decrease the ice-covered area within a hundred years. Thus, in order to make realistic estimates of the glacier contribution, the changes in glacier area have to be taken into account. This is accomplished using a simple, global glacier melt model (Raper et al., 1990). The model contains three parameters that have to be prescribed: initial ice volume, a global-mean glacier response time and a representative glacier temperature sensitivity parameter. The parameter values were chosen to match estimated rates of glacier volume loss over the last 100 years. The model was run from 1861 to 2100 (implying that, at present, glaciers are in disequilibrium).

With respect to the Greenland and Antarctic ice sheets (including West Antarctic Ice Sheet and the Antarctic Peninsula), the dynamic response can effectively be ignored for the time scales considered here. The static changes in the surface mass balance can thus be represented by the sensitivity values discussed above, that is:

- $\Delta h = 0.3 \pm 0.2$ mm/yr per degree for the Greenland ice sheet
- $\Delta h = -0.3 \pm 0.3$ mm/yr per degree for the Antarctic ice sheet

Based on the latest results from transient runs of fully-coupled ocean-atmosphere GCM's (Stouffer et al., 1989), it was assumed that temperature changes were equivalent to the global mean, except in Greenland where temperature changes were enhanced by a factor of 1.5.

9.5.2 Discussion

The resultant projections of global sea level rise to the year 2100 are shown in Figures 9.6 and 9.7. Under the "Business-as-Usual" scenario, the best estimate is that, for the year 2030, global sea level would be 18cm higher than today. Given the stated range of uncertainty in the contributing factors, the rise could be as little as 8cm or as high as 29cm. By the year 2070, the projected range is 21-71cm with a best-estimate of 44cm, although it should be cautioned that projections this far into the future are fraught with many uncertainties, many of which are external to thermal expansion and land ice melting.

The major contributing factors to the sea level rise are thermal expansion of the oceans and glaciers and small ice caps. The minor contributions to sea level from the Greenland and Antarctic ice sheets are positive and negative, respectively (Table 9.10).

For scenarios B,C and D (Figure 9.7), the sets of projections are similar. This is because with low forcing scenarios, the temperature and sea level effects are more sensitive to ΔT_{2x} and the history of forcing change up to 1990 than to forcing change post-1990. The best-estimates for the year 2070 fall in the range 27-33cm, about one-fifth less than in the "Business-as-Usual" case.

The fact that sea level continues to rise throughout the 21st century - even under the forcing scenarios that imply very strict emission reductions demonstrates the strong effect of past

changes in greenhouse gas concentrations on future climate and sea level. This is because of the lag effects introduced by the thermal inertia of the oceans and the response times of land ice to climate changes. In effect, this creates a very substantial sea level rise "commitment". This is illustrated in Figure 9.8. Here, the IPCC "Business-as-Usual" Scenario of greenhouse forcing is imposed to the year 2030 with no further changes in forcing thereafter. Sea level, however, continues to rise at almost the same rate for the remainder of the century.

This section has been concerned primarily with *global* mean sea level rise. It should be borne in mind that sea level will not rise uniformly around the world. First, at any given coastal location sea level will be influenced by local and regional vertical land movements. In some circumstances, these are large and will mask climate related changes in ocean volume. Second, dynamic processes in the ocean and atmospheric circulation will also cause sea level to change regionally. For example, a sensitivity study with a dynamic ocean model showed regional differences of up to a factor of two relative to the global-mean value (Mikolajewicz et al., 1990). Finally, changes in the frequency of extreme sea level events may be most important in their impact on coastal zones, but are currently difficult to quantify because of the uncertainties in regional predictions of climatic change.

In general, for the coming decades, the present best-estimate projection of sea level rise for the business-as-usual case does not represent a major departure from those found in the recent literature (Table 9.9).

9.6 SUMMARY AND CONCLUSION

This chapter has addressed three questions:

- Has global-mean sea level been rising over the last 100 years?
- What are the causal factors that could explain a past rise in sea level? and,
- What increases in sea level can be expected in the future?

The array of data and methodological problems inherent in estimating the rate of past sea level change is large. The selection of data and its manipulation can make a difference of more than a factor of two in the global trend estimate. While recent analyses of MSL trends involve more refined means of data correction and analysis, they generally support, not alter, the broad conclusions of previous assessments. It is our judgement that:

- global sea level has been rising.
- the average rate of rise over the last 100 years has been 1.0 - 2.0mm/yr.
- there is no firm evidence of an acceleration in global MSL rise over this century (although there is some evidence that sea level rose faster in this century compared to the previous two centuries).

It appears that the past rise in sea level is due largely to thermal expansion of the oceans and increased melting of glaciers and the margins of the Greenland ice sheet. There is no firm basis for supposing that the Antarctic ice sheet has contributed either positively or negatively to past sea level change. In general, these findings support the conclusion, based on analyses of tide gauge records, that there has been a globally-coherent, secular rise in sea level, and that the causes are most likely related to climatic change.

Future changes in sea level were estimated for each of the IPCC forcing scenarios. For each scenario, three projections - best estimate, "Business-as-Usual" and low - were made corresponding to the estimated range of uncertainty in each of the potential contributing factors.

It is found that:

9 Sea Level Rise

- for the "Business-as-Usual" Scenario at year 2030, global-mean sea level is 8-29cm higher than today, with a best-estimate of 18cm. At the year 2070, the rise is 21-71cm, with a best-estimate of 44cm.
- most of the contribution is estimated to derive from thermal expansion of the oceans and the increased melting of mountain glaciers.
- the Antarctic ice sheet contributes negatively to sea level due to increased accumulation associated with warming. Increased outflow of ice from the West Antarctic ice sheet is likely to be limited, but the uncertainty is large.
- the Greenland ice sheet contributes positively to sea level rise, but part of the enhanced melting and runoff may be offset by increased snowfall in the higher parts, so the uncertainties are very large.
- For the lower forcing scenarios (B,C and D), the sea level rise projections are similar, at least until the mid-21st century. On average these projections are approximately one-third lower than those of the "Business-as-Usual" Scenario.

Even with substantial decreases in the emissions of the major greenhouse gases, future increases in temperature and, consequently, sea level are unavoidable - a sea level rise "commitment" - due to lags in the climate system.

In general, this review concludes that a rise of >1 metre over the next century is unlikely. Even so, the rate of rise implied by the business-as-usual best-estimate is 3-6 times faster than that experienced over the last 100 years. The prospect of such an increase in the rate of sea level rise should be of major concern to many low-lying coasts subject to permanent and temporary inundation, salt intrusion, cliff and beach erosion, and other deleterious effects.

TABLES

Table 9.1: Estimate of Global Sea-Level Change
(updated from Barnett, 1985; Robin, 1986).

Rate (mm/yr)	Comments	References
>0.5	Cryologic estimate	Thorarinsson (1940) †
1.1 ± 0.8	Many stations, 1807-1939	Gutenberg (1941)
1.2 - 1.4	Combined methods	Kuenen (1950)
1.1 ± 0.4	Six stations, 1807-1943	Lisitzin (1958, in Lisitzin 1974)
1.2	Selected stations, 1900-1950	Fairbridge & Krebs (1962)
3.0	Many stations, 1935-1975	Emery et al. (1980)
1.2	Many stations -> regions, 1880-1980	Gornitz et al. (1982)
1.5	Many stations, 1900-1975	Klige (1982)
1.5 ± 0.15 †	Selected stations, 1903-1969	Barnett (1983)
1.4 ± 0.14 †	Many stations -> regions, 1881-1980	Barnett (1984)
2.3 ± 0.23 †	Many stations -> regions, 1930-1980	Barnett (1984)
1.2 ± 0.3 †	130 stations, 1880-1982	Gornitz & Lebedeff (1987)
1.0 ± 0.1 †	130 stations >11 regions, 1880-1982	Gornitz & Lebedeff (1987)
1.15	155 stations, 1880-1986	Barnett (1988)
2.4 ± 0.9 §	40 stations, 1920-1970	Peltier & Tushingham (1989; 1990)
1.7 ± 0.13 §	84 stations, 1900-1980	Trupin and Wahr (1990)

† = Value plus 95% confidence interval

§ = Mean and standard deviation

Table 9.2: Time-dependency of the Tide Gauge Records (Modified from Peltier & Tushingham, 1990)

Window Width (y)	Start Year	End Year	No. of Records Avail.	LR Est. of SL Rise (mm/yr)	SD of LR Est. (mm/yr)	EOF Est. of SL Rise (mm/yr)	SD of EOF Est. (mm/yr)
Fixed Window Width							
51	1890	1940	11	1.6	1.5	0.7	0.7
51	1900	1950	20	1.6	0.9	1.2	0.6
51	1910	1960	27	1.8	0.8	1.4	0.6
51	1920	1970	40	2.3	0.8	2.4	0.9
51	1930	1980	33	2.0	1.1	1.5	0.6
Variable Window Width							
71	1900	1970	13	1.9	0.8	1.2	0.5
66	1905	1970	17	1.9	0.8	1.2	0.5
61	1910	1970	24	1.9	0.8	1.5	0.6
56	1915	1970	29	2.1	0.8	1.7	0.7
51	1920	1970	40	2.3	0.8	2.4	0.9
46	1925	1970	52	2.2	1.0	2.3	1.1
41	1930	1970	66	1.9	1.1	1.9	1.1
36	1935	1970	82	1.6	1.5	1.4	1.0

All tide gauge records have been reduced using the standard model.

Table 9.3: Some physical characteristics of glacier ice on earth.
 Sources: Flint (1971), Ambach (1980), Radok (1982), Drewry (1983),
 Haeberli et al. (1988), Ohmura and Reeh (1990).
 Estimated accuracy: † = 15%, †† = 30%, otherwise better than 10%.

	Antarctica (grounded ice)	Greenland	Glaciers & small ice caps
Area (10^6 km^2)	11.97	1.68	0.55
Volume (10^6 km^3 ice)	29.33	2.95	0.11 ††
Mean thickness (m)	2,488	1,575	200 ††
Mean elevation (m)	2,000	2,080	-
Equivalent sea level (m)	65	7	0.35 ††
Accumulation (10^{12} kg/yr)	2200 ††	535 †	-
Ablation (10^{12} kg/yr)	< 10 ††	280 ††	-
Calving (10^{12} kg/yr)	2200 ††	255 ††	-
Mean equilibrium - line altitude (m)	-	950 †	0 - 6,300
Mass turnover time (yr)	~15,000	~5,000	50 - 1,000

Table 9.4: Mass budget of the Greenland ice sheet in 10^{12} kg/yr , as suggested by various authors.

Source	Accumulation	Ablation	Calving	Balance
Bader (1961)	+630	-120 to -270	-240	+270 to +120
Benson (1962)	+500	-272	-215	+13
Bauer (1967)	+500	-330	-280	-110
Weidick (1984)	+500	-295	-205	0
Reeh (1985)	+487	-169	-318	0
Ohmura & Reeh (1990)	+535			

9 Sea Level Rise

Table 9.5: Sensitivity of Greenland mass balance in 10^{12} kg/yr, as obtained by various authors. T = temperature, P = precipitation, C = cloudiness. Expressed in rate of change of global mean sea level (mm/yr).

Source	T (+1°C)	P (+5%)	C (+5%)	Remarks
Ambach & Kuhn (1989)	+0.31	-0.13		Analysis of EGIG data
Bindschadler (1985)	+0.45			EGIG data/retreating margin
Braithwaite and Olesen (1990)	+0.36 to +0.48			Energy balance calculation
Oerlemans (1990)	+0.37	-0.11	-0.06	Energy balance Model

Table 9.6: Antarctic mass balance (10^{12} kg/yr), † = without Antarctic Peninsula. Proper reference for SPRI (Scott Polar Research Institute) *map* and *data*: Drewry (1983).

	Flux at grounding line	Surface balance (<i>grounded</i> ice)	Net
Budd and Smith (1985)	~1879	2088	0 to +418
Digitization SPRI <i>map</i> Huybrechts (1990)		2363	
Radok et al. (1986)		2158 1765 †	
Giovinetto and Bentley (1985)		1468 †	
Fortuin and Oerlemans (1990) [based on SPRI <i>data</i>]		1817	

Table 9.7: Estimates of the change in Antarctic mass balance for a 1 K warming. $\Delta q_s/\Delta T$ represents change of saturation water vapour mixing ratio of air above the inversion.

Source	Change in sea level (mm/yr)	Remarks
Muszynski (1985)	-0.38	Regression on 208 data points
Fortuin and Oerlemans (1990)	-0.139 (interior) <u>-0.061</u> (escarpment) -0.200 (total)	Regression on 486 data points (only grounded ice)
Proportional to $\Delta q_s/\Delta T$	-0.34	20 km grid over grounded ice

Table 9.8: Estimated contributions to past sea-level rise (in cm).

	LOW	BEST ESTIMATE	HIGH
Thermal expansion	2	4	6
Glaciers/small ice caps	1.5	4	7
Greenland Ice Sheet	1	2.5	4
Antarctic Ice Sheet	-5	0	5
TOTAL	-0.5	10.5	22
OBSERVED	10	15	20

Table 9.9: Estimates of future global sea level rise (cm)
(Modified from Raper et al., 1990)

	CONTRIBUTING FACTORS				TOTAL RISE ^a		
	Thermal Expansion	Alpine	Greenland	Antarctica	Best Estimate	Range ^f	To (Year)
Gornitz (1982)	20	20 (Combined)			40		2050
Revelle (1983)	30	12	13		71 ^b		2080
Hoffman (1983)	28 to 115	28 to 230 (Combined)				56 to 345 26 to 39	2100 2025
PRB (1985)	c	10 to 30	10 to 30	-10 to 100		10 to 160	2100
Hoffman (1986)	28 to 83	12 to 37	6 to 27	12 to 220		58 to 367 10 to 21	2100 2025
Robin (1986) ^d	30 to 60 ^d	20±12 ^d	to +10 ^d	to -10 ^d	80 ⁱ	25 - 165 ⁱ	2080
Thomas (1986)	28 to 83	14 to 35	9 to 45	13 to 80	100	60 to 230	2100
Villach (1987) (Jaeger, 1988) ^d					30	-2 to 51	2025
Raper et al. (in press)	4 to 18	2 to 19	1 to 4	-2 to 3	21 ^g	5 to 44 ^g	2030
Oerlemans (1989)					20	0 to 40	2025
Van der Veen (1988) ^h	8 to 16	10 to 25	0 to 10	-5 to 0		28 to 66	2085

^a - from the 1980s

^b - total includes additional 17cm for trend extrapolation

^c - not considered

^d - for global warming of 3.5°C

^f - extreme ranges, not always directly comparable

^g - internally consistent synthesis of components

^h - for a global warming of 2-4°C

ⁱ - estimated from global sea level and temperature change from 1880-1980 and global warming of 3.5±2.0°C for 1980-2080.

Table 9.10: Factors contributing to sea level rise (cm), 1985 - 2030.
"Business-as-Usual" Scenario - Best Estimate for 2030.

	Thermal Expansion	Mountain Glaciers	Greenland	Antarctica	TOTAL
HIGH	14.9	10.3	3.7	0.0	28.9
BEST ESTIMATE	10.1	7.0	1.8	-0.6	18.3
LOW	6.8	2.3	0.5	-0.8	8.7

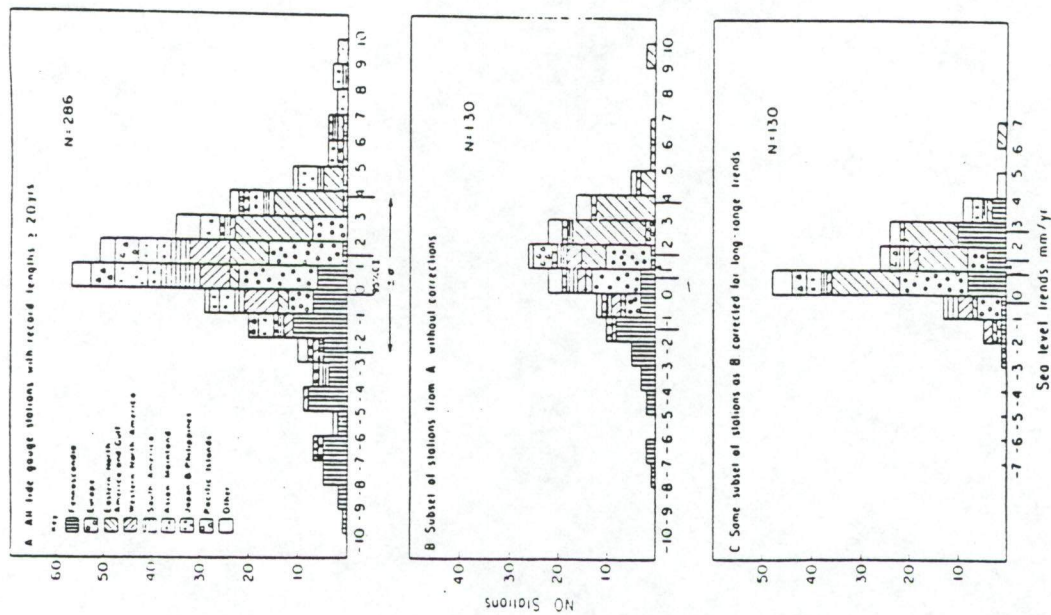


Figure 9.1: Histogram of number of tide-gauge stations vs sea-level trends. Triangle indicates mean rate of sea-level rise; lines indicate the bounds of the 95% C.I. and $\pm$ sigma respectively. (A) All tide-gauge stations with record length > 20 years; raw data. (B) Subset of tide-gauge stations; long-range trends included. (C) Same subset of stations as (A); long range trends subtracted. (from Gornitz, 1990)

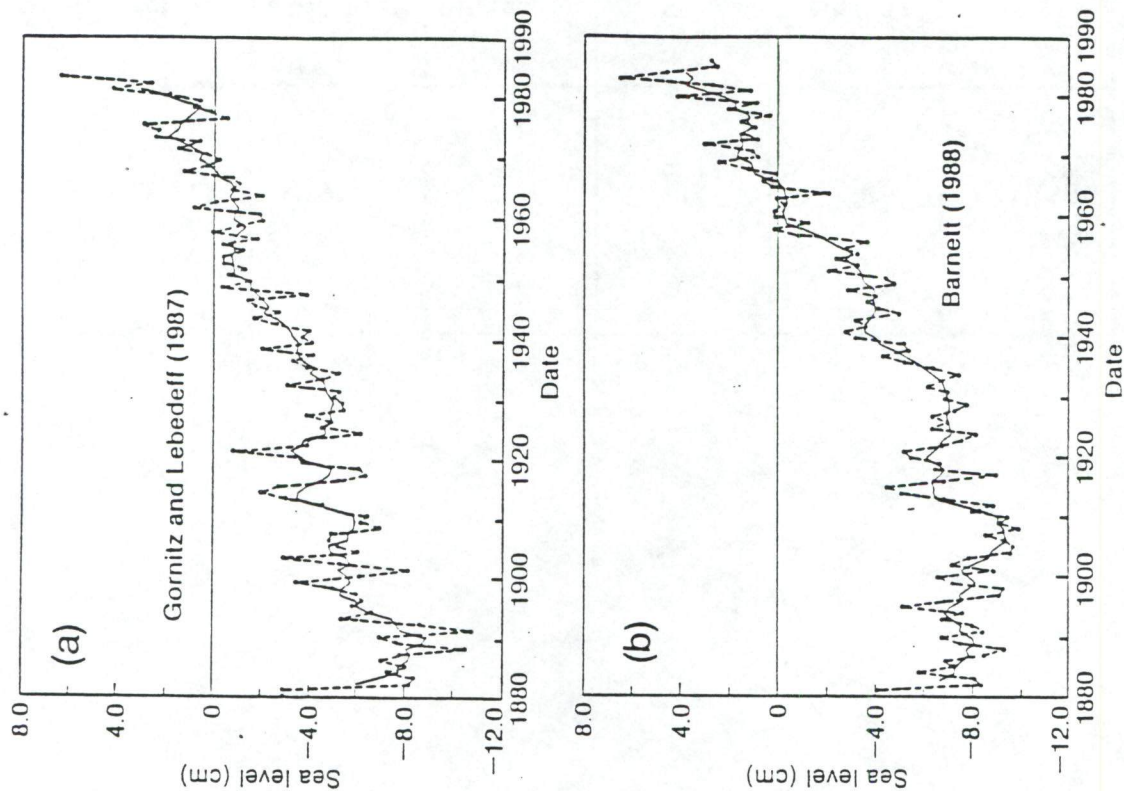


Figure 9.2: Global mean sea level rise over the last century. The baseline is obtained by setting the average for the period 1951-1970 to zero. The dashed line represents the annual mean, and the solid line the 5-year running mean. (a) Gornitz and Lebedeff (1987), (b) Barnett (1988).

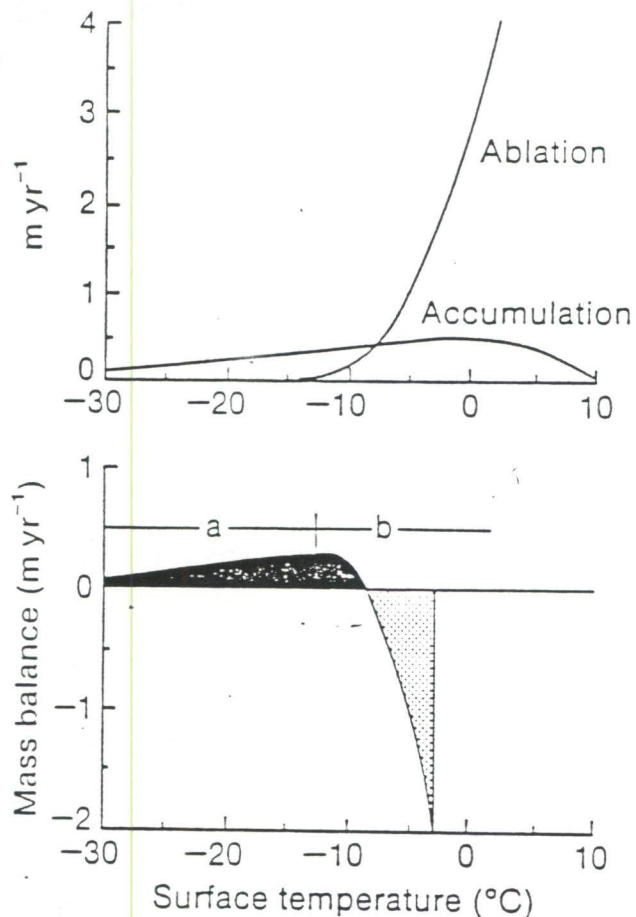


Figure 9.3: Dependence of ablation (evaporation and runoff) and accumulation on annual surface temperature (upper panel). The dependence of net annual balance (lower panel) on temperature changes sign, which complicates the response of glaciers to climate change. The picture is schematic and will change from place to place. In regions with excessive precipitation, the mean temperature at equilibrium is higher.

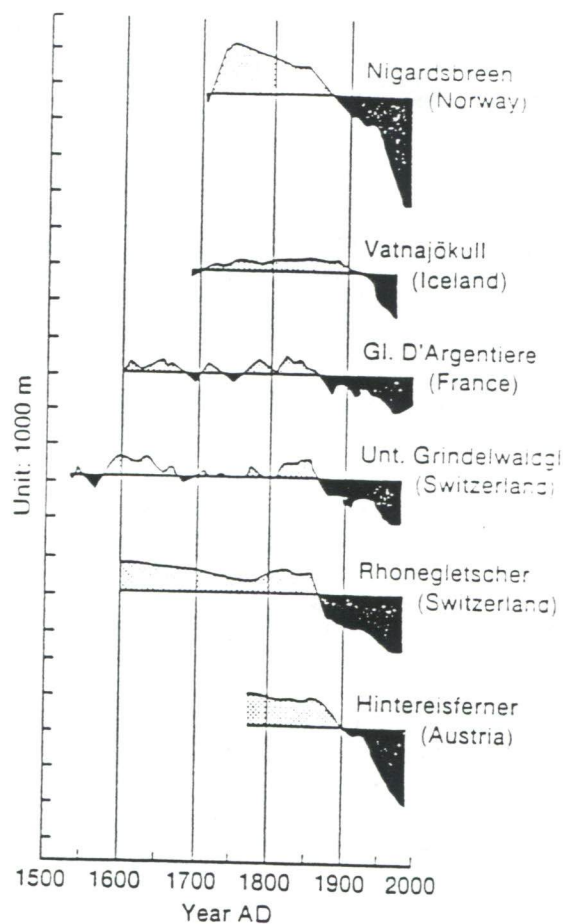


Figure 9.4: Variations of some selected glaciers as measured by their length. Data from Bjornsson (1979); Ostrem et al. (1977); Kasser (1967, 1973); Kasser and Haeberli (1979); Muller (1977); Vivian (1975); Haeberli (1985)

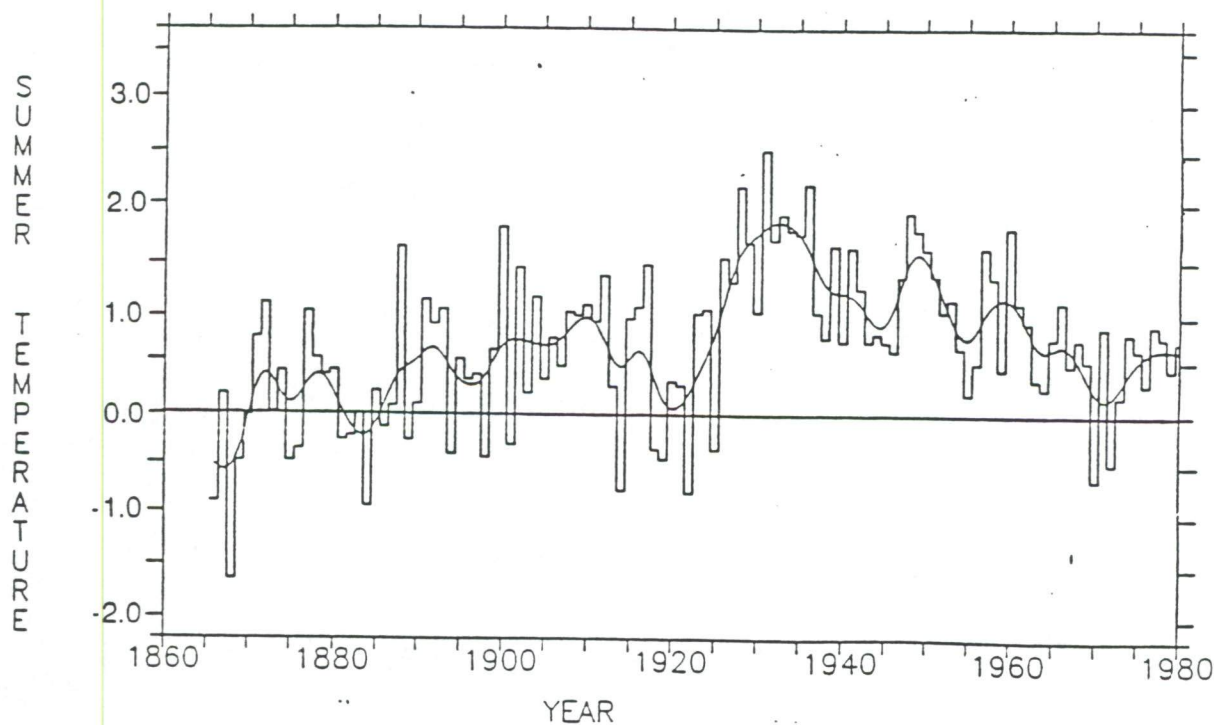


Figure 9.5: Summer (JJA) temperature (deg C) as departures from reference period 1866-1885 averaged over Greenland. The smoothed curve is a moving 10-year filter.

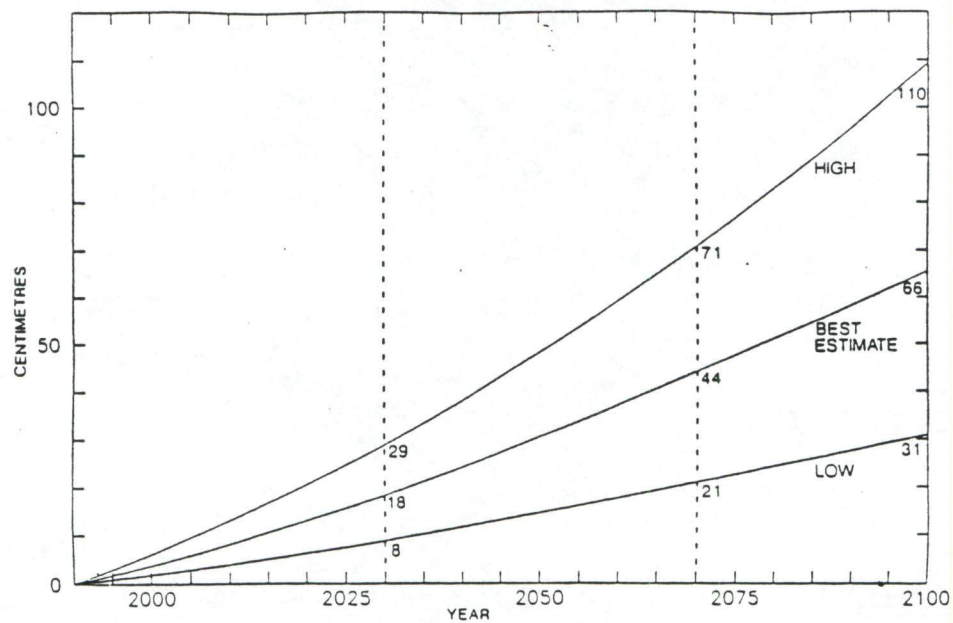


Figure 9.6: Global sea-level rise, 1985-2100, for Policy Scenario Business-as-Usual.

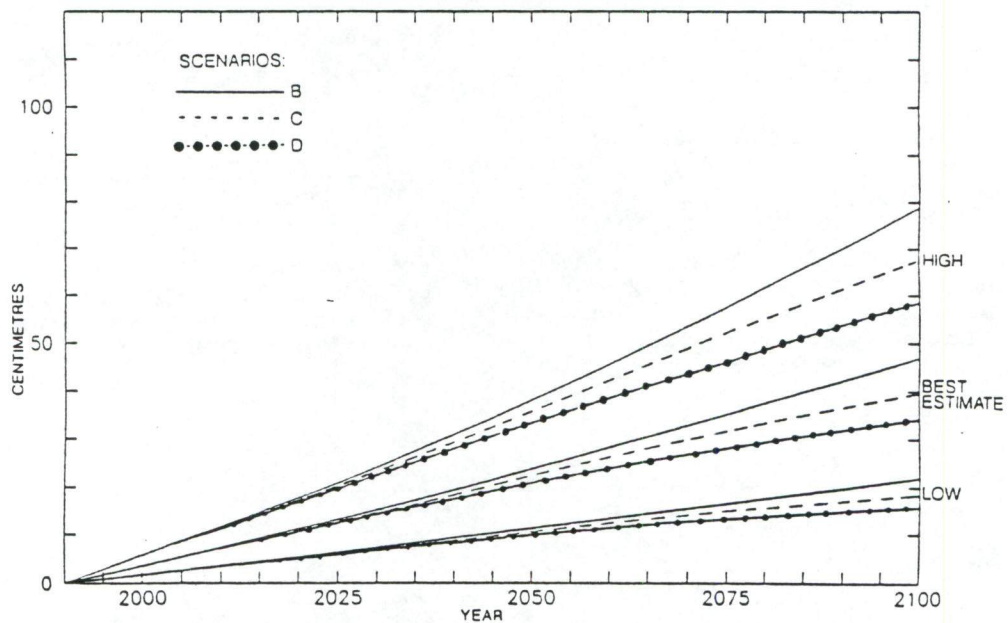


Figure 9.7: Global sea-level rise, 1985-2100, for Policy Scenarios B, C, D.

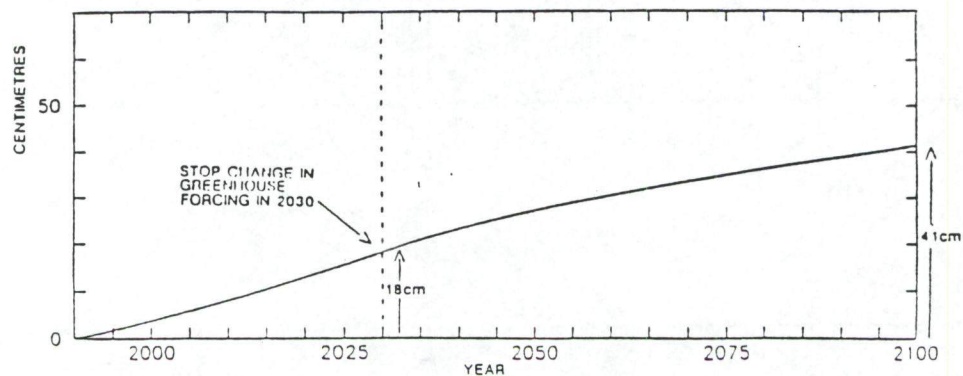


Figure 9.8: Global Sea-level commitment to the year 2100. Scenario Business-as-Usual forcing applies to year 2030 and is held constant thereafter. Scenario Business-as-Usual best estimates apply.

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