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HEARING ON
GLOBAL CHANGE RESEARCH
INDICATORS OF GLOBAL WARMING AND SOLAR VARIABILITY

Thursday, February 27, 1992

Washington, D.C.

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HEARING ON

GLOBAL CHANGE RESEARCH:

INDICATORS OF GLOBAL WARMING AND SOLAR VARIABILITY

Thursday, February 27, 1992

U.S. Senate

Committee on Commerce, Science

and Transportation

Washington, D.C.

The committee met, pursuant to notice, at 10:05 a.m, in Room SR-253, Russell Senate Office Building, Hon. Al Gore presiding.

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OPENING STATEMENT OF HON. AL GORE, U.S. SENATOR FROM TENNESSEE

Senator Gore: Ladies and gentlemen, we will get a round table discussion underway here this morning. I would like to thank everybody for coming. This is the third in a series of earth science roundtables to examine the latest findings of global change researchers, and today we are going to examine new evidence of past and present global climate change.

There has been so much emphasis on the temperature record as measured by thermometers that many researchers in other fields have been telling the rest of us for years that there is more than one way to take a measurement of what has been happening in the past and what is happening right now, so we are looking forward to hearing from them.

For the past several years Dr. Jim Hansen at the Goddard Institute of Space Studies and Dr. Tom Wigley at the University of East Anglia and others have compiled millions of individual air and ocean temperature readings in an effort to determine how mean global temperatures have changed over the last 100 years.

Their work indicates that the mean temperature has increased between 0.3 and 0.6 degrees Celsius since 1890. This increase, especially the rapid increase observed over the last 20 years, is consistent with the predictions of computer models of global warming and seems to validate computer

predictions of much larger increases in the future -- 1.5 to 4.5 degrees Celsius within the next 50 years.

The last 2 years have been the hottest 2 years in the recorded record, and that could be just the beginning. If the models are right, it is likely that the 1990's will replace the 1980's as the hottest decade in the recorded record. However, there are those who question the mean temperature data, sometimes for reasons that are understandable, more often, in my view, for political reasons, but in any event critics point out that the temperature record may contain errors due to changes over the years in the procedures and the equipment used to collect the data and due to a lack of data from certain parts of the globe.

In addition, they argue that the so-called heat island effect caused by the growth of cities in some of the places where these temperature readings have been taken may be causing erroneously high readings in recent decades. I believe that Jim Hansen, Tom Wigley, and their colleagues, have actually done a meticulous and very good job of accounting for these possible sources of error, and so do the world's most prominent climatologists.

The Intergovernmental Panel of Climate Change, a group of more than 300 leading earth scientists, has concluded that the signal is real. There is clear evidence of an increase in global mean temperature of 0.3 to 0.6 degrees Celsius over the

last 100 years.

Still, as I mentioned at the outset it is important to look for any other data that might corroborate the thermometer data, so today we have a number of prominent scientists who have devoted many, many years to finding other ways with which to determine past temperatures. They have studied glaciers, tree rings, and boreholes drilled in the earth to derive temperature records from sites all over the world.

By measuring these proxy indicators they have been able to construct annually averaged temperature data that is almost as good as direct temperature readings and in some cases actually better, and they have been able to extend the temperature record back hundreds and even thousands of years, allowing us to compare the climate changes we are seeing today with those of the past. Past climate changes in turn can give us some idea of what we might be facing in coming years.

In the last million years the earth's climate has very dramatically -- during the last Ice Age the earth's mean temperature was about 5 degrees Celsius cooler than it is today. To some people that does not sound like much, but the difference in places like New York City, Seattle, Boston, and Chicago, is the difference between a nice day like today and having 1 mile of ice over your head.

The models predict that by the year 2100 temperatures could increase another 5 degrees or more worldwide, very

rapidly reaching levels unmatched in more than 60 million years. When you look back in time, it is possible to get some idea of what that could mean.

One of the first things noticed is that a change in global mean temperature does not mean that temperatures change by the same amount everywhere. Indeed, a 5-degree increase in global temperature can translate into a 10-degree rise in one region and virtually no change at all in other regions, and even a decrease in still other regions, so even a small change in global mean temperature can have a major impact on the ecosystems that have adapted to the present temperature levels.

It can have a major impact on water supply and on human welfare and in certain vulnerable regions, particularly when we take into account the fact that human civilization has configured itself to the global climate balance which has within rough parameters persisted for the last 9,000 years since the first cities appeared.

The record of past climate change can also aid researchers seeking to understand the working of the earth's climate system and climate modelers trying to predict future manmade climate change. Past really is prologue, as the saying carved on stone not far from here tells us. We really need to feel confident in our past models of climate change if we're going to have faith in the computer model's predictions

of what is likely to happen in the future.

A number of today's witnesses will discuss exactly how data on past climate change can be used to test our computer models and expand our understanding of the earth's climate system. Some of what we will hear today will be very technical and there may be a tendency to get lost in the jargon. We cannot afford to do that, and in fact one of the reasons we have shifted to this roundtable format instead of the traditional hearing structure is to invite the various members of the roundtable to jump in to clarify any points that they think need clarification, even when others are presenting their views on the subject.

At least five of my colleagues on the subcommittee have indicated that they are going to do their best to break into other scheduling priorities and attend part of this session here today, and so please do not be disconcerted if we jump in at various times to try to clarify something because one of our motives is to try to break through any language that is quite comfortable within the scientific community but seems forbidding to those of us who are not scientists and so occasional interruptions will come just to try to clarify exactly what is being said.

But the underlying reason for all of this, of course, is that the research being presented here today has a real and direct connection to the policymaking process in Congress.

Without the hard work of researchers like the ones in this roundtable discussion we cannot hope to carry on a dialogue with the public and the administration about what many of us believe is the number 1 crisis facing global civilization today.

I for one believe we should move quickly to respond to it, but we will never have all the answers and I know that many of our witnesses will discuss the uncertainties in their data today, but we do have clear evidence that all is not well with the world. We are spilling billions of tons of greenhouse gases into the atmosphere every year, and we are beginning to see the effects right now.

I look forward to hearing from our witnesses and let me just briefly discuss the ground rules, and if anybody has a suggested change in the ground rules that is open too, but I want to suggest that we follow the rule that the Senate has found very useful for 200 years, and that is if you would direct your questions and comments -- if you direct your statements and comments through the Chair, that will minimize the direct conflict that can sometimes drown out the exchange of views.

Secondly, if we can start with brief opening statements that are relatively short, just to start of kind of a preview of what you think needs to be said, and then I have a road map that I am going to follow to try to direct the discussion in a

way that will make certain every one of you will have a full opportunity to say what you want to get across during the discussion itself, so do not feel like you have to get it all said in the opening statement.

[The prepared statement of Senator Gore follows:]

Senator Gore: Now, let us begin with some opening statements in this order. First of all, Dr. Gordon Jacoby -- excuse me. I have started off with a mistake right off the bat. Dr. Gordon Jacoby -- I knew better than to pronounce it wrong -- with the Tree Ring Lab at Lamont-Doherty Geological Observatory in Palisades, New York, who will be directly followed by Dr. Roseanne D'Arrigo -- I knew that one, but I wanted to check it -- also at Lamont-Doherty, and I appreciate the visit I had at Lamont-Doherty recently with a number of researchers up there, and if you could start off with your opening statement, Dr. Jacoby.

STATEMENT OF DR. ROSEANNE D'ARRIGO AND DR. GORDON JACOBY, TREE RING LAB, LAMONT-DOHERTY GEOLOGICAL OBSERVATORY, PALISADES, NEW YORK 10964

Dr. D'Arrigo: I am going to be discussing indicators of climactic and biospheric change evidence from tree rings and annual growth rings of old-age trees are used to develop high resolution, precisely dated time series of climactic and biospheric change over recent centuries to millennia. These records can help assess whether temperature increases over the past century exceed the natural variability of the climate system.

The quantitative tree growth information can also be used to determine if natural vegetation is being influenced by direct carbon dioxide fertilization or nutrient change along with climate-induced growth variation. We find a general tendency for tree rings from temperature-sensitive trees at high latitude and high elevation sites in both hemispheres to show enhanced growth over the recent period of increasing trace gases.

Although there are, of course, exceptions for individual time series the combined records for sub-arctic North America show a warming trend which exceeds growth of previous centuries. That is reflected in the following graph.

[Chart.]

Dr. D'Arrigo: This graph shows a reconstruction of

Northern Hemisphere annual temperatures. It is based on tree ring data from across the northern boreal tree line and is shown for the common period of 300 years from the 1670's through the 1970's. We have also shown the instrumental record for the more recent period indicated by the green dashed line. The main feature of this graph is that the recent warming of the past century appears to exceed the reconstructed temperatures back to the 1670's.

Now, I would like to show a more recently sampled site which we sampled just this past summer in the northern Brooks Range of Alaska.

Senator Gore: I am sorry that the audience -- we have got this turned in a way that makes it impossible for many of the audience to see it. If it will not disrupt things too much and --

Dr. D'Arrigo: This graph as I mentioned is a recently sampled site from the northern Brooks Range in Alaska which shows that the trees recover from a relative cooling in the Sixties and Seventies and show warming in the 1980's.

In Northwestern Alaska northern tree ring records and observations of tree line movements indicate that the present warming may exceed events for the last 1,000 years. Sub-Arctic records from the northern Ural Mountains of Russia, however, show equally warm precedents over the past millennia. High elevation mid-latitude record from the western U.S. show

enhanced growth which is at least partly attributable to warming.

One high elevation millennia-long record from the Southwestern U.S. shows only one positive growth period equal to that of the present at the beginning of the proposed Medieval warm epoch around the late 900's.

For the Southern Hemisphere, a 1,000-year tree ring record from Tasmania indicates anomalous warming since 1965. That is shown in the following graph.

[Chart.]

Dr. D'Arrigo: This indicates a recent growth increases. This is a tree ring chronology from Tasmania indicating a recent growth increase and inferred warming which is anomalous in relation to the entire 1,000-year record. A tree ring series from Southern Tierra del Fuego in Argentina, representing some of the southernmost forest in the world, indicates recent warming which does not, however, exceed previous warm periods in the last several centuries.

Whether or not these tree growth increases are representative of large components of the biosphere and of enhanced carbon sequestering is not known. Also presently uncertain is whether natural vegetation is responding directly to anthropogenic CO_2 or nutrient fertilization effects. Improved understanding would require additional tree ring and other records from both hemispheres.

The inherent value of forest as sinks for carbon, and hence as potential buffers for increasing greenhouse gases, cannot be overestimated. Although some trees are presently increasing in growth, it is misleading to conclude that the biosphere will benefit in part because forest may have insufficient time to adapt to the unprecedented rate and magnitude of projected anthropogenic climate change.

Warming over the past century in the Northern Hemisphere is less supported by the tree ring as well as other proxy and instrumental data. The relatively sparse records from the Southern Hemisphere, middle to higher latitudes, also indicate some unusual warming, particularly in recent decades. These warmer conditions are in many cases unusual in the context of the past 200 to 400 years, but may or may not have precedent during the past millennium, depending on the region or individual data set.

Overall and unusual warming appears certain. Whether it is unique in the context of the past 1,000 years is possible but presently uncertain, and will require more research.

Thank you.

[The prepared statement of Drs. Jacoby and D'Arrigo follows:]

Senator Gore: Let me just say by way of preview, that some of the anomalous readings in certain parts of the world will be addressed by the modelers on the panel later in the presentation.

Dr. Jacoby --

Dr. Jacoby: That was the statement --

Senator Gore: Was that the statement on behalf of both of you? Okay, I have it now.

Now an opening statement from Dr. Henry Pollack, Chairperson of the Department of Geological Sciences at the University of Michigan in Ann Arbor.

STATEMENT OF DR. HENRY N. POLLACK, CHAIRPERSON, DEPARTMENT OF GEOLOGICAL SCIENCES, UNIVERSITY OF MICHIGAN, ANN ARBOR, MICHIGAN

Dr. Pollack: Good morning, Senator. Thank you for the opportunity to testify at this committee hearing and to participate in this round table discussion.

My research focuses on the reconstruction of the Earth surface temperature history over the past five centuries, a period of time spent in both the pre-industrial and the industrial era, and a period of time in which the population of the Earth has increased tenfold.

I analyze present day sub-surface temperatures as measured in boreholes to recover information about past temperature variations at the Earth's surface.

The method is based on the fact that temperature changes at the surface propagate into the sub-surface, but are filtered in the process. The filter removes short-term variations at shallow depths, but allows longer term variations to propagate to greater depths, thus the geothermal record preserves information about long-term trends in the surface temperature history but does not record short-term fluctuations.

This method is complementary to other methods that we will be discussing today, such as tree rings, ice cores, lake settlements and historical records, each of which provides

information on some aspect of climate over the same time period. The borehole record provides a direct temperature record.

Preliminary analyses of the geothermal record from several regions in North America show that for the period of time, basically the 20th Century for which there are widespread meteorological records, that the boreholes tracked the atmosphere quite well, in particular the regional variability which you had mentioned earlier that shows that some areas are warming more than the global average and some less and some are actually cooling.

This also appears in the sub-surface record and indicates that this tracking is with some fidelity and gives us confidence that we can use this method to go backward in time into the period prior to the meteorological record.

Senator Gore: Now just to clarify that point, what you are saying there is that for the last 120 years or so, you can compare the readings you get from your borehole analysis with what was called a minute ago the instrumental record meaning the thermometer readings that Jim Hansen and Wigley and others have come up with and when you get an exact correlation, that gives you confidence that you can then project farther back into the past than the thermometer readings go and reconstruct an older temperature record?

Dr. Pollack: That is correct, sir. Borehole temperature

logs exist for many continental areas around the world and I should emphasize that this methodology works only on the continents and not in the ocean basins. The records that exist around the world have the potential to provide significant information about climate change in the centuries prior to the establishment of the instrumental meteorological observatories, and as well from areas where observatories have never been deployed, in particular, the criticism that is sometimes leveled at the meteorological record, that is it the urban heat island effect because most observatories are in urban areas.

That can be overcome with the borehole record because the Earth's crust is recording these temperatures everywhere and one can drill in remote areas quite removed from urban disturbances.

Thank you.

Senator Gore: Thank you very much. We will come back to that, and look forward to it.

Dr. Lonnie Thompson is with the Byrd Polar Research Center at Ohio State University in Columbus and we welcome you, Dr. Thompson.

STATEMENT OF DR. LONNIE G. THOMPSON, BYRD POLAR RESEARCH CENTER, OHIO STATEMENT UNIVERSITY, COLUMBUS, OHIO

Dr. Thompson: Thank you, Senator Gore, members of the committee.

My testimony today is going to concern evidence for recent and rapid warming in the tropics as derived from the analysis of ice cores and also by the changes in positions of the margins of these glaciers in recent past.

The ice sheets and ice caps of the Earth has long been recognized as excellent archives of the atmospheric history from which we can reconstruct the Earth's climate and the environmental changes of the past.

Much of the climate information which is important to man occurs at the lower latitudes, variations in El Nino, monsoons, so it is very important to have a global perspective in these ice core records.

So the records I am going to be concentrating on come from high elevation, low latitude areas on the Earth. I would also state that these programs were not undertaken to look for evidences for global warming. They were undertaken to create high resolution records of our past in these low latitude areas to compare with the records that we are creating for the polar regions.

Some of the evidence that we have found from three sites that we have studied in the Central Asian area in Tibet, in

one area in the tropical Andes of Peru are as follows: We find in the oxygen isotopes which is our paleoindicator of temperature there is a 1 to 2 part per million enrichment over the last 50 years. This would indicate a warming.

Meteorological observations, these are from meteorological stations and they are very rare in these very remote parts of the world, but they show in the areas of these ice caps a .5 to 1.2 degree C warming.

On the Gregoriev Ice Cap in the Soviet Union or the former Soviet Union, we did borehole temperature measurements in 1990. In 1962 a Soviet expedition to this ice cap also did borehole temperatures. In 1962 20 meter temperatures which are equivalent to mean annual temperatures in a glacier were -4.2 degrees C. In 1990 they were -2 degree C, indicating a significant warming in this area.

We have been working on a tropical ice cap down in the Andes of Peru since 1974 and so we have a very long database for that ice cap. We revisited this ice cap about 5 months ago in 1991 and we found that there had been very significant retreat on the margins of this ice cap and also the loss of the annual isotope signal which had been preserved up until 1983, and led to the drilling of this ice cap in 1983 which produced a record which is 1,500 years in length.

That record is no longer being preserved in the annual oscillations in those isotopes. Over the period of the study

of that ice cap we have monitored, actually measured the retreat of the margin of the ice cap and if we look at the rate of retreat, what we find is in the period from 1963 to 1978, the rate of retreat was 5 meters per year.

From 1978 to 1983 it was 8 meters per year. From 1983 to 1991 it was 14 meters per year, almost triple what it was in the initial measurement period.

Other researchers who are looking at tropical glaciers also find that those in the Ruwenzori in African, on Mt. Kenya -- I know of no tropical glacier that is advancing under present day climate conditions.

Thank you.

[The prepared statement of Dr. Thompson follows:]

Senator Gore: Thank you. We will be hearing more about that and look at some slides in a moment.

Now let me turn to Dr. Paul Damon, Professor Emeritus at the Department of Geosciences at the University of Arizona in Tucson and let me preface the introduction of our next couple of opening statements by saying that when one looks at temperature indicators that come not from thermometers but from parts of the natural system, one has to look at other factors that also have an effect on these natural indicators.

So we are very grateful for the fact that two of the leading experts in the world are able to join us to look at the solar variability role in interpreting a lot of this data, and we will get into it in more detail later, but for an opening statement, I want to recognize Dr. Paul Damon.

STATEMENT OF DR. PAUL E. DAMON, PROFESSOR EMERITUS, DEPARTMENT OF GEOSCIENCES, UNIVERSITY OF ARIZONA

Dr. Damon: Thank you, Senator Gore.

I am an isotope geochemist and we in particular have been studying cosmogenic isotopes. These are isotopes produced by cosmic rays, radioactive isotopes such as carbon 14 which you are all familiar with and beryllium 10. Well, it so happens that these isotopes, the production of these isotopes is modulated by solar activity, by the plasma from the sun, the magnetic field from that, also by the Earth's magnetic field, but we can de-convolute those two parameters.

So we have now a record of solar activity that goes back 800,700 years and just to take the last 1,000 years, for example, we have a clear signal for the Dalton Solar Minimum, and that would be a cosmogenic isotope maximum with a longer minimum, the Wolf Minimum, the Medieval Solar Maximum, I refer to it a the Medieval Solar Maximum. It is also referred to as the Medieval Ethic and the Oort Minimum, that carries you back 1,000 years.

So we have that complete record.

Senator Gore: Now just to interject briefly, what you are describing with all of those phrases are periods of unusual activity on the sun which has an effect on the radiation received by Earth from the sun and there are certain well-known periods that scientists have studied and named,

going way back and now by using your measurement techniques, you have been able to rather precisely map the contours of these periods going back a thousand years?

Dr. Damon: That is correct. And of course, we have quantitative data, the various astronomers that we refer to had more qualitative information, the sort of solar activity everybody agrees on.

For example, at the present time we have solar flares which disrupt communication networks, disrupted the Ontario electrical distribution system. I believe these isotopes demonstrate that for the first time in 700 years, we have now entered a period of solar activity like the Medieval Solar Maximum which if the Medieval Solar Maximum is a good indicator, a good analog, we will continue for 150 years, that is until the middle of the next century.

Now there is -- it has been my working hypothesis since the 1967, the last 25 years, has been that the sun is not a perfectly governed heat engine as far as solar radiance is concerned.

If it were, it would be surprising, even unnatural. We now know of course that during the last solar cycle, from the solar max experiment, that there has been a one-tenth percent change in the total solar irradiance and however, and my working hypothesis is that a long with this modern solar maximum there will be a change in solar irradiance. The past

record indicates that it would probably not exceed 8/10th degree centigrade, 1.4 degrees fahrenheit.

Now this can be misconstrued. It is in the same direction as the greenhouse effect, and will be until the middle of this century, and I personally have no doubt that there is -- a greenhouse effect is important. For example, the Earth would be about 34 degrees centigrade cooler, 61 degrees fahrenheit cooler if it were not for the greenhouse effect, and if the Earth had the very dense CO2 atmosphere of Venus, it would be 260 degrees centigrade which is 500 degrees fahrenheit.

So what I am saying is that the sun which has been ignored should not be ignored, that it is a factor, but it will -- if the past record is a guide to the future, it should not exceed about 8/10th degrees centigrade and will be in the same direction as the greenhouse effect.

This could mean however one of two things, that the present warming -- it would indicate if there is a solar component that the estimates at double of the C02 content of the atmosphere might be at the low end of the estimates or that there is a longer lag time between the greenhouse forcing and the atmospheric response which of course might be due to the role of the oceans producing a longer lag time than people have estimated. Thank you.

[The prepared statement of Dr. Damon follows:]

Senator Gore: Just to clarify one point. According to your calculations these natural periodic fluctuations in the amount of energy coming from the sun have entered a period, now, where we are at the beginning of a warming cycle where that particular phenomena is concerned, that you believe could last a century and a half.

Dr. Damon: Yes. I want to state that this is a working hypothesis, that the longer periods -- I have transparencies we could show later if it is pertinent -- would involve a change of about a half a percent in the solar constant. This is a matter of contention, of course.

It is a matter of contention whether or not the medieval warm epic was really such a warm epic. At a recent conference on the medieval warm epic, the only point of agreement was that it certainly was not a little ice age. And so I think I can say with some confidence that if my hypothesis is correct, that the maximum warming before it starts decreasing, the solar effect would not be above eight-tenths degree centigrade.

Senator Gore: And so one of the conclusions that you reach is that while these regular variations in solar intensity have been neglected and need to be studied more intensively in order to improve our understanding of some of these natural indicators and how the models are working, it is your opinion that the range of the effect to be expected there

would likely be swamped by the range of the effect due to the kind of forcing from greenhouse gases?

Dr. Damon: Eventually, yes. At the present time it would confuse matters, in that part of the six-tenths degree centigrade warming would be solar warming. Now for some reason, I think because of excesses during the 1920's and 1930's of the 11 year cycle, cycle freaks, et cetera, there has been great resistance in the scientific community to the concept of the sun, as I say, as an imperfectly governed heat engine as far as irradiance is concerned.

As a consequence the funding in global change for -- in seven categories, the solar category has been placed seventh of seven categories, at the bottom. I think that is a great mistake which should be remedied.

Senator Gore: At the end of our round table discussion today, after we look at these other questions we are going to look at the implications of what we have heard for the allocation of research funding in various areas. And we will come back to that point. Next, Dr. Judith Lean from the Naval Research Laboratory with the Department of the Navy here in Washington. Welcome.

STATEMENT OF DR. JUDITH LEAN, CODE 4165L, NAVAL RESEARCH LABORATORY, DEPARTMENT OF THE NAVY, WASHINGTON, D.C.

Dr. Lean: Thank you. I am working at the Naval Research Lab on two topics that are relevant to this, to the hearings of solar influences on climate change. Firstly, I am involved in making measurements of solar radiation. And currently we have an experiment on the Upper Atmosphere Research Satellite, which is right now looking at the sun.

I also have been working for the past decade or so in developing models to explain why the sun's radiation varies. And I think the key is the sun is a great object of fascination, but it is really quite a common middle aged star. But it is a variable star, and that is the key. We have known for a long time that the sun varies. For example, if we look at measurements of sun spots over the past 300 years, there has been an overall increase in solar activity according to these indicators.

But what has happened in the last decade that has put this whole concept of solar activity on a new footing is that we have had measurements from satellites that have measured the radiation from the sun, spectrally integrated radiation from the sun comes down to earth. And so although this radiation was at one point called the solar constant, implying that it was constant, we know it is not constant.

And furthermore, it changes with the sun's 11 year

activity cycle. So, for example in 1980 the radiation from the sun was at a maximum, and now in 1991 it is at a maximum again, and it went through a minima. Now it changed by about a tenth of a percent, which is very small. But if you compare that solar forcing from 1980 to 1986 with the forcing of greenhouse gases, then it essentially compensated over that time period.

And so really on the short term, we really do need to see how the sun's radiation is modulating and climate forcing. But for the longer term issues, for example 50 to 100 year time scales, then we need to know what is the sun's radiation doing over those time scales. The measurements do not exist for that and so we have to look at proxies, and we can do that in a number of ways.

One of the things we can do is look at other stars like the sun. And as I said the sun is very garden variety. There are other stars like the sun. Observations have shown that these stars can vary more, a little bit more than the sun. And in particular the concept of the morning minimum when the sun goes into a period where its activity cycle goes away, it is not uncommon in stars like the sun. And at that time the radiation appears to be decreased below what it is in a regular cycle.

And so these observations that we have now, over the past decade, together with observations of stars like the sun, tell

us that, yes, the sun's radiation varies, and tells us that there is a very strong possibility that it has varied by more than we have observed it in the past decade. But we can take our understanding of the origin of the variations of the sun in terms of active region sunspots et cetera, and couple that into solar observations. And when we do that we come up with numbers like limits on the variability of maybe three-tenths of a percent.

And David Rind is probably going to talk more about this, but this will translate into a temperature change of maybe .47, .5 degrees. And so our current understanding is that the sun varies over the longer time scale, but the limits on that variability would imply these numbers like three-tenths of a percent, certainly not the 1 percent to 2 percent that is being suggested. You would need to have the sun varied to counter something like the greenhouse warming.

[The prepared statement of Dr. Lean follows:]

Senator Gore: Okay. Well we will come back to this, but if I can summarize.

Dr. Lean: I have some few graphs.

Senator Gore: Well we may have a chance to look at them, depending upon how this goes, but thank you very much. Both of you are making it clear that the range of temperature change associated with solar variability is significantly smaller than the range of temperature variability discussed in connection with the thickening of the greenhouse gas layer. And there is a very real possibility that if Dr. Damon's calculations are correct, this expected upcoming increase will exacerbate rather than mitigate the warming projected in the models from greenhouse gas increases.

Dr. Lean: I was just going to say that I agree with you saying that in the long term the solar changes are smaller than what is projected for greenhouse gases. But in the concept of early detection of global warming, it is very important to know what the sun is doing now.

Senator Gore: Absolutely. Because right now in the early stages of the increased temperatures associated with greenhouse gas thickening, the amount of forcing expected from greenhouse gases and the amount expected from solar variability are maybe running neck and neck. And in order to interpret the greenhouse gas effect at this stage, one has to have a more accurate understanding of the effect coming from

solar variability.

Dr. Lean: That is right, because you could make a measurement of temperature over the period 1980 to 1986 and see that it was flat, and you would think that there were no greenhouse gas effects. But that is because the radiation has been decreasing.

Senator Gore: So you have to be prepared to look at both causes during the range of variability that we are currently in. But as the greenhouse gas blanket gets much thicker, then it just overwhelms.

Dr. Lean: But that is projected to be in the next 50 to 100 years, so the question is do we have that long to wait.

Senator Gore: That is right. Well let me say we have two more opening statements, but I want to acknowledge the presence of our distinguished ranking Republican, Senator Larry Pressler, who has been my partner on this subcommittee and the work we have done. And if you have an opening statement of any kind, Senator Pressler, we would entertain it.

STATEMENT OF HON. LARRY PRESSLER, U.S. SENATOR FROM SOUTH DAKOTA

Senator Pressler: Mr. Chairman, I will place my opening statement in the records.

[The prepared statement of Senator Pressler follows:]

[COMMITTEE INSERT]

Senator Gore: Thank you very much. Two other opening statements. Dr. Jerry Mahlman is well known to the committee as director of the Geophysical Fluid Dynamics Laboratory at NOAA at Princeton. And we appreciate your help in the past, and thank you for helping us make sense of these disparate fields here today, Dr. Mahlman.

STATEMENT OF DR. JERRY D. MAHLMAN, DIRECTOR, GEOPHYSICAL FLUID DYNAMICS LABORATORY, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY

Dr. Mahlman: Thank you, Senator. I would like to point out that neither Dr. Rind nor myself will be speaking from prepared testimony, because of the clearance barrier. And so I will be speaking extemporaneously in response to some of the comments that have already been made.

First, I would like to congratulate you and the subcommittee for choosing this subject. I was involved in a climate model and climate research planning effort, and we were trying to identify those aspects of understanding climate that had the highest probability of producing a substantial improvement in our knowledge within the next couple of years. And the overwhelming winner was the attempt to provide increased synthesis of disparate data sets in the context of what theory and modeling are saying. And so I regard this as a first step toward that all important process where I think we really can make some contribution.

Senator Gore: Well I want you to know the staff has nothing to do with this, it is all me.

[Laughter.]

Dr. Mahlman: That is what they told me.

[Laughter.]

Dr. Mahlman: I would also like to make a comment or two

on the modeling perspective, about that we can except on the natural variability of the climate irrespective of external forcing of one kind or another. That thanks to the advent of class 7 computers for the first time, we have been able to use coupled atmosphere ocean mathematical models of the climate to look at the role on the natural variability of the unstable interactions between the ocean and the atmosphere.

And what we find is that the natural variability on the system on decade to centuries time scales can produce an envelope of temperature change for the global mean surface temperature on the order of half a degree Celsius. And, again, that is an number that is large enough to confound the record, but is very consistent with some of the bumps and wiggles we see in the ascending temperatures of the past century. But we see that it is not a simple monatomic increase. And so we now begin to realize that we, even irrespective of external solar and other types of climate forcing, that we have to interpret that in the context of natural variability.

The other thing I would like to add to the discussion about the natural record is that there is another very important temperature record that is often ignored in policy circles, and that is what is happening away from the surface of the atmosphere. From the so-called radio-sun record, that is careful worldwide effort mainly to improve weather

forecasts, and that record shows very interesting structure. That it shows over the past 25 years noticeable warming, and that warming over this interim period is higher in the tropics than at high latitudes.

Originally appearing to be contradictory to what the models were saying, but now that we have models that are not looking at equilibrium climate but transient climate change relative to gradual greenhouse forcing in the context of an active ocean, this is the signal we expect to see.

Senator Gore: Let me just clarify that point briefly, to make sure that I understand it. When you talk about equilibrium change and transient change, what you are saying is that -- well, it is kind of similar to what Dr. Pollock was saying earlier in connection with his borehole data, that is you can have short-term changes that have an effect that looks different in different parts of the world. But over time, as in the case of these boreholes, as it sinks lower into the earth, that short-term fluctuation is washed out and you get a longer term, steadier pattern of change. The equilibrium change is the stored up steady change, but the transient change is that short term.

Dr. Mahlman: Transient change in the context of climate modeling. We think of how the climate system will react to the changed greenhouse forcing over the next century, and so we are not talking about fluctuations over years, we are

talking about fluctuations over decades to a century.

And in this case what we are finding is that the climate sensitivity to change greenhouse forcing is highest in high latitudes, as we have all learned, but the response rate is faster in the low latitudes. So, again, theory is giving a different perspective as to how to interpret the signal, and so what we are finding is that is the case.

The other thing we are finding that is quite remarkable in the atmospheric record, is that the upper part of the troposphere and lower stratosphere are cooling, and cooling much more than the original theory would have predicted. And the reason that is so is because the ozone is decreasing there much faster than theory had predicted. And so that is a characteristic signal in the record that is already showing up, that is now consistent with what we will call more enlightened theoretical perspectives.

The other thing, I think, that is remarkable in the atmospheric record is that the water content of the atmosphere is increasing in a way that is quite consistent with the temperature increases, and are consistent with what climate models have predicted. And that has been a debate of considerable ferocity and amplitude lately.

Senator Gore: It even worked its way into one of these roundtables.

Dr. Mahlman: Indeed it has, and I think the

observational record is speaking fairly clearly on that subject.

Senator Gore: Just recently.

Dr. Mahlman: Yes.

Senator Gore: Okay, well may we will come back to that. Dr. David Rind is our final opening speaker here, from the NASA Goddard Institute for Space Studies in New York. Welcome.

STATEMENT OF DR. DAVID RIND, NASA GODDARD INSTITUTE FOR SPACE STUDIES, NEW YORK, NEW YORK

Dr. Rind: Thank you, Senator. I guess we have heard from some people who work with data and have indicated what the variability they see in their record is, and in particular the degree of warming they have noticed recently. We have also heard from people who have observed the sun, and noted that the sun is an inconstant star.

And obviously the question that everybody is interested in addressing, particularly in this particular setting, is how much of the variability that we have seen is due to the sun's variation. And what we have been doing is trying to model that. Because presumably if you can put in the forcing that the sun presumably has, or the change in that forcing, and get the records that people actually see in a model, you not only verify the concept you also verify the model. And these are the same models being used for climate change assessment.

So we have been looking at solar variability in the model on a wide range of time scales. And I will just briefly address some of the issues that have come up recently in the popular press.

One has to do with this question of whether warmer sea surface temperatures at high latitudes would actually lead to a new ice age. The sun is involved in this sort of picture because it is the variations in the orbit of the earth around

the sun that people believe lead to the initiation of ice ages. And I think it can be shown fairly clearly that the likelihood of warmer sea surface temperatures in conjunction with solar variations leading to a new ice age within the next 20,000 years is minuscule, if not nonexistent.

On a relatively shorter time scale, the question arises what about the little ice age, how much has the solar variation during that time period led -- what proportion of the cooling that was seen at that time is associated with solar variation. Some of us are part of a project that is trying to combine modeling of different forcing functions for the little ice age with data acquisition by a wide variety of techniques for the little ice age, and see if one can produce a match. Can you get the patterns of change from this particular type of forcing?

And Judith Lean has an estimate of about .25 percent to .3 percent variation in solar constant, which has been modeled and a pattern has been produced for the temperature changes that would result in the model from that variation. And that pattern can then be compared with data for the little ice age. At this point in time the jury is still out as to whether that is the likely forcing function, but it certainly is -- as Judith mentioned, it gives you about a half a degree Celsius change in the model, with our current sensitivity.

So at this point in time it is certainly not an

inconsequential forcing function. As you go further and closer in time to the present, what about the last century, how much has solar variability contributed to the warming that we have seen during the last century?

Well, it certainly is not impossible that warming such as the warm peak during the 1930's is associated with solar fluctuations. There are empirical techniques that people have, of trying to reproduce what the sun was doing at that time. None of these are known very well. Some of them correlate with the temperature changes, and in particular people have looked at things like the length of change of the solar cycle.

Do these things really work, or are they just correlation techniques? Well, we can get into that a little bit more, but one thing we know is, during the last solar cycle we know what the magnitude of the solar radiance variation was. And if the solar radiance variation is only of that magnitude, then probably a lot of the subsequent temperature changes we will see will not be affected by the sun. But as Judith emphasized, we do not know that for sure, and other stars give us .3 percent or .4 percent. And if that does happen in the foreseeable future, that could certainly confuse the record.

Finally, going out to the latter part of the next century when you are into a doubled carbon dioxide world, models generally show that the double carbon dioxide warming is

equivalent to an impact of about 2 percent solar constant change. 2 percent is very large and it is beyond our expectations. And therefore under those circumstances I think the first order assumption would be that solar -- as you get farther out during the next century the solar impact will not be significant enough to offset greenhouse gas warming.

Senator Gore: Are you familiar with the information Dr. Mahlman referred to about water vapor occurring in the atmosphere in conjunction with temperature increases?

Dr. Rind: Actually I do have a couple of vugraphs to show you.

Senator Gore: Well, maybe we had better halt that if it is not right on point, but since we had a round table discussion that got into that earlier I think it is significant and because what I hear you saying is that -- and this comes from the SAGE II satellite, correct?

Dr. Rind: SAGE II, and even the radiosonde data, maligned as it is, actually shows somewhat of an agreement with it.

Senator Gore: And again what it shows is that water vapor at high altitudes actually does, as predicted, increase with warmer temperatures. Some have speculated that water vapor at those altitudes might decrease with warmer temperatures, but the observational evidence now indicates that is wrong.

Dr. Rind: Yes, and this is, when you get right down to it, this is if not the most important point, one of the top two important points in terms of understanding climate sensitivity, because if water vapor truly increases throughout the atmosphere as climate warms, then you have really amplified the greenhouse effect to magnitudes that are considerable.

Senator Gore: Well, I do not think we will spend a lot of time on it because I think with maybe one or two important exceptions, nobody else is really surprised by that finding. I am going to suggest now that we go back through roughly according to the order that we started the opening statements with, and I want to encourage a dialogue, but the subjects that I am going to suggest we deal with will follow this road map.

I am going to suggest we talk in a little bit more detail now about the implications of these tree ring findings and then building upon that and in the effort to make the synthesis that Dr. Mahlman referred to, talk a little bit more about Dr. Pollack's borehole data and then talk a little bit more about Dr. Lonnie Thompson's mid latitude glacier data -- or low latitude glacier data, excuse me. And then try to relate that to the solar variability and the models in the overall effort to get the sort of synthesis that will give us another way of looking at the temperature record and its

relationship to man-made changes.

I invite any of my colleagues to jump in whenever they want.

Dr. Jacoby, and Dr. D'Arrigo, you referred to temperature sensitive trees. Now, let me just clarify this in my mind. Tree rings vary according to the availability of moisture, the prevailing temperature, the availability of nutrients, et cetera, but what I guess you are saying is that you carefully selected the trees that you studied from those areas of the world where the main factor which causes variation in the growth rate of trees is temperature.

Areas where there is almost always enough water, and nutrients do not play the role enforcing variable growth that they might in some places, but you have looked at areas where the factor which really causes a change in the growth rate and in the density of cells, and in the width of the trees rings, is the temperature, have I got that right?

Dr. D'Arrigo: That is right.

Dr. Jacoby: That is correct, Senator. We deliberately go to the extreme northern tree line in North America. We have gone down to Tierra Del Fuego, in Tasmania, areas where you are at the very limits of tree survival. In those areas there actually is, especially in the North Hemisphere, nitrate limitation because of cold soils and poor nutrient turnover. However, that is a constant limitation throughout time. The

varying limitation is the year to year temperature changes that the trees are very sensitive to.

Senator Gore: Put that microphone a little bit closer to you.

Dr. Jacoby: We deliberately select these sites to find areas where this sensitivity is magnified so the trees are very closely tuned to temperature for their very survival. And these trees, contrary to some opinions, are actually dependent upon year round temperatures, not just temperature during the growing season, because photosynthesis can take place anytime say above around 4 degrees centigrade. And so they are integrating long, seasonal effects and not just the actual growing season.

Senator Gore: All right now, do your overall results, and you are familiar with other researchers in your field, correct?

Dr. Jacoby: Yes.

Senator Gore: Do your results, and those of the others with whom you are familiar, create a pattern that is consistent with general global warming over the last century and especially during the last 20 years?

Dr. Jacoby: Yes they do. They match that very well. The general tendency is for tree-growth increase say since around the late 1800's, increased rapidly earlier this century. There is a decrease in recorded temperatures in the

sixties and seventies. The tree ring data matches that. A recurving upwards of the temperature and the tree ring data coinciding during the last decade and a half.

And breaking away from sort of a scientific mumbo jumbo and jargon, I have actual physical specimens here that one can readily look at and see wider rings responding to the temperature.

Senator Gore: Can we see them?

Dr. Jacoby: Yes. I also have a section here a bit more dramatic. This is from a tree that died in 1931 and so the outer rings are narrower because the tree is dying, but you can see a 300 year old tree suddenly growing wider rings over the last century.

Senator Gore: Now, wait a minute, before you get to that, tell Senator Pressler and me what we are looking at.

Dr. Jacoby: Each one of those lineations that you see, the darker lines, are the wood formed at the end of the growing season. The lighter portion is, it is called early wood, the wood growing in the early portion of the growing season and the ring width, that is our fundamental measured unit that we measure to detect what the tree's health and growth rate was for that year.

Senator Gore: And we are looking at 1800 to 1990?

Dr. Jacoby: That is correct.

Senator Pressler: And the assumption is that if the tree

grows more that year the temperatures are what?

Dr. Jacoby: That is warmer, wider ring means warmer temperature.

Senator Pressler: But as the tree gets older, it slows in its growth?

Dr. Jacoby: That is true in these particular trees. Usually a younger tree will grow wider rings and grow and the rings will more or less be constant in thickness so it is very unusual to see trees 300 and 400 years old suddenly growing wider rings.

Senator Gore: Now you take these 400 year old trees and you bore into them to get the sample, right?

Dr. Jacoby: That is correct. It is not a destructive sampling.

Senator Gore: How long does it take them to die after you do this procedure?

[Laughter.]

Dr. Jacoby: I have revisited sites that I cored 15 years ago.

Senator Gore: I am just kidding, Doctor.

[Laughter.]

Dr. Jacoby: You struck a nerve with that one.

[Laughter.]

Dr. Jacoby: But as a followup there also are long time series of moisture sensitive trees where people including

ourselves have deliberately looked for trees that are sensitive to moisture stress, and from trees in those locations we can get long term records of precipitation variation.

Senator Gore: What are we seeing here?

Dr. Jacoby: The same thing. You can see the rings are very, very narrow in the center of that piece and in about 40 or 50 rings they started growing wider rings. That is from the northern Alaska.

Senator Gore: Okay, now that is very interesting. Is there a lot of disagreement in your field of specialty about this?

Dr. Jacoby: Within the field of people studying temperature sensitive trees, some of the publications we cited are from other researchers, like within the contiguous U.S., the western U.S., those are other people's data. I do not have a vugraph, but there are data from another researcher in Canada again showing this warming, so there is a general consensus that the growth is increasing in these areas.

One thing I would like to add, that these are not representative forest growth in general. These are trees deliberately sought out for particular locations as being temperature sensitive so these should not be used for carbon budget modeling. These are separate special trees.

Senator Gore: Okay. That is why I wanted to establish

that early on these are trees that are especially selected as ones of a kind and in locations where you can accurately identify the sensitivity to temperature change. Now, what does your tree ring data tell us about regional climate change when there have been changes in the global mean temperature in the past?

We heard earlier from Dr. Mahlman and Dr. Rind that the models predict a change in global mean temperature, will be accompanied by a different pattern in some regions than others. Does your tree ring data tell us anything about that?

Dr. Jacoby: Yes it does. As Dr. D'Arrigo mentioned in her presentation, in Scandinavia, and also in northern Russia, it appears that there were equally warm periods within the last 1,000 years. It appears tentatively in the Alaska record that we are possibly warmer.

Senator Gore: Equally warm periods just in those regions?

Dr. Jacoby: In those regions. Those are single time series for those regions. In Alaska, in that particular region, the Brooks Range of Alaska it appears that it may be warmer than it has been before for the past 1,000 years. Also, as Dr. D'Arrigo mentioned, the tree line is evidently moving to higher latitudes and farther north in Alaska, and so you can key out these regional differences. And one thing you may have seen in the curve, there was a warming in the middle

to late 1700's, that is very regional.

Overall it is somewhat muted when you put all of them together. The present warming is more ubiquitous across all of these regions in the northern hemisphere and so there is a difference in the regional variations versus a consensus assembling all of these data into one unified temperature trend.

Senator Gore: Dr. Mahlman, are you familiar with the regional results they are talking about here?

Dr. Mahlman: I am not familiar with the regional patterns.

Senator Gore: We will invite you to comment for the record, if you will, on whether or not that is in fact precisely consistent with the effect in the models you talked about, but I want you to have a chance to look at it in more detail.

Senator Pressler: Let me just ask if I could a question. Does the mountain glacier activity, and the bore hole temperatures, parallel this information? I mean, is this a way of checking one temperature during a period against another? For example, I do not know how much deeper drilling we are doing now. I know the Russians have done some, maybe they have stopped. I note in this material I have that there has been mountain glacier activity in Kenya checked. Does that corroborate with the tree data?

Dr. Jacoby: I cannot address Kenya because tropical trees are a very difficult, very separate thing. We do look at ice core information from, say, Devon, Ireland, north of where our trees are in northern Canada and that corroborates our tree ring data. We look at borehole measurements by Lockenbrook and Marshall in the U.S. Geological Survey in Alaska. The tree ring data matched their records.

In eastern Canada the tree ring data and the bore hole temperatures also corroborate and so it is not just one particular data set uniquely standing alone. It is corroborated by other information, from other types of proxy records.

Senator Gore: Well, let us invite Dr. Pollack and Dr. Thompson to respond to Senator Pressler also. We will give you a chance in a moment to show your slides and what-not. But what about his question?

Dr. Pollack: I certainly would agree with the response from Dr. Jacoby. The borehole temperature records from arctic Alaska, on the north slope, show a pronounced warming of 2 to 4 degrees over the past century, and that is consistent with the glacier warming effect taking place in the polar regions. Further south in Canada, the effect is diminished and in parts of the great plains of the U.S.A., there is almost no change at all.

So we are seeing regional variability that is consistent

with, at least in broad pattern, with regional variability described by the tree rings.

Dr. Thompson: The glacier evidence from Mount Kenya and also from the Ruwenzoris in central or equatorial Africa, in those areas where observations have been made, Hastenrath and Kruss have shown that on Mount Kenya since 1963, between 1963 and 1987, the total area of ice on Mount Kenya have decreased by 40 percent. A recent work by Kruss on the Speke glacier in the Ruwenzoris, it has been extensively studied, and that glacier shows that the retreat from 1958 to 1977 was 35 to 40 meters, but from 1977 to 1990 that retreat has been 150 meters.

Senator Gore: Can you show us some of that? Why do we not go straight to that, because Senator Pressler has honed in on this. Can you show us some of that? I know you brought some slides. And we will come back to you, Dr. Pollack.

Senator Pressler: Anything you can tell us about Kenya, I am going there in a month or so. I want to impress them with my knowledge.

Dr. Thompson: What I have prepared is kind of an overview of the tropical records that are on slides.

Senator Gore: Why do we not look at that if you can do that relatively briefly, and we will see some pictures of these glaciers you are talking about.

[Pause.]

Dr. Thompson: What I would like to do is to give a very rapid global view of what we know about --

Senator Gore: And make sure Senator Pressler can see what you are doing there. Why do you not stand on the far corner there?

Dr. Thompson: If you look at the global map here, we are looking at sites. Most of the ice core work has been done in Greenland and down in Antarctica, but at the high elevations are the mountains of the Andes and Peru and over in central Asia, there are a number of sites that do contain high resolution climate records.

[Slide.]

Dr. Thompson: In these low latitude sites because the climate is monsoon there is a very distinct annual variation and you can see this on the margin of Quelccaya ice cap. The snow falls about 10 feet per year and there is a very marked dry season so it is very easy to date these cores.

Senator Gore: So each one of those layers is another year's worth of ice?

Dr. Thompson: That is right. And by taking the drilling system, and to get into some of these remote aread we need special --

Senator Gore: It looks sort of like tree rings.

Dr. Thompson: Exactly like tree rings.

[Slide.]

Dr. Thompson: To get into these very remote areas we cannot use the general drilling technology. For this ice cap we use solar power. These cores --

[Slide.]

Senator Gore: That is ecologically responsible, Dr. Thompson.

[Laughter.]

[Slide.]

Dr. Thompson: The cores are then brought back to a cold room where they are stored and can be processed in a clean room, and the ice cores arc out many different parameters in the environment.

[Slide.]

Dr. Thompson: This gives a list of some of those parameters. One of the very important ones is a record of the atmospheric variations of CO_2 and methane trapped within the bubbles. This allows us to look at the long term variations in these gases long before the anthroprogenic impact. We can look at those layer thicknesses and tell something about how precip has changed through time. We can look at atmospheric temperatures through stable isotopes, either hydrogen or oxygen.

We can also look at the chemistry of the atmosphere. We can look at the solubles and the insolubles. We look at past volcanic activity, we can look at cosmogenic nucleons such as

Beryllium tin, look at how the isotopes or approximate temperature responds to variations in these types of isotopes.

[Slide.]

Dr. Thompson: This is a record from Siple Station in Antarctica which really gives you the perspective of CO_2 increase. The triangles in the squares are based on the gas bubbles in the ice, in the overlap of the actual observations in Mauna Loa. So you can see the impact of the industrial revolution on these CO_2 concentrations in the earth's atmosphere.

Now, of course, when we look at the projections into the future of increases in these gases, CO_2, methane, chlorofluorocarbons, nitrous oxides, then we get this picture of the earth warming as we go from -- this is from the NASA.

Senator Gore: That is from a computer model?

Dr. Thompson: This is a computer model projections into the future 1980's, 1990's, 2010. But as you look at these what you will see is that the warming is not uniform, and that there are as Senator Gore said areas where there is actually cooling taking place in this transition period.

But I want to point out these two sites. This is central Asia, central Asia where these ice core records are coming from is the center of the largest land mass on earth and therefore these models would suggest that these should be sensitive areas to look for change.

[Slide.]

Dr. Thompson: If we look at the sites in western China and the Soviet Union, the Dunde ice cap is in the northeastern part of the Tibetan plateau. The Gulea ice cap is in the western part of the Tibetan plateau, and the Gregoriev ice cap is up in the Tien Shan with the Soviet Union. These records are coming from between the 600 and the 340 millibar level in the earth's atmosphere.

[Slide.]

Dr. Thompson: This is the Dunde ice cap in the northern part of the Tibetan plateau. We see some horses up here for scale.

[Slide.]

Dr. Thompson: The summit of this ice cap is 5,325 meters. Again, we are at the 500 millibar level in the earth's atmosphere.

[Slide.]

Dr. Thompson: If we look at the glacier, the length of record that we can get depends upon three basic things, how thick the glacier is -- this ice cap is 140 meters, what the annual accumulation rate is, which is 400 millimeters of water per year, and most importantly about the ice, temperature at the ice bedrock contact, if it is below freezing. The temperature here is -4.7 degrees centigrade, and theoretically, you can get a record of the very first snow

fall in the formation of this ice cap.

[Slide.]

Dr. Thompson: Now the records that we are talking about here today is one part of the items we measure and that is the isotopes, and the first thing we have to do is determine whether the isotopes in the region are giving a proxy of the temperature, and the only way we can do that is to compare it to temperature records that exist in these regions. And the records we are looking at here is the winter temperatures from Shanghai, China. China has very long historical records. From about 1800 to the present, it is based on instrument. From here back it is phenological data.

Senator Gore: What is that?

Dr. Thompson: Historical documents, freezings of lakes, freezings of rivers. And then this is the isotope curve over this period. Now, if you assume these relationships hold back in time, then the ice cores can give you a very long-time perspective.

[Slide.]

Dr. Thompson: Here we are looking at 50-year averages for the last 12,000 years for this part of the world. The reds are isotopically enriched, warmer. The blues are isotopically cooler periods. And if you look at these variations you will see the warm and the cool, but if you look at the most recent period, that is 1937 to 1987, isotopically

it is more enriched than the other period in this 12,000 year record.

Senator Gore: Now, wait a minute. The last 50 years according to this record is the warmest 50-year period in the entire 12,000 years you have studied?

Dr. Thompson: That is correct. And we always take two cores. Now, when you look at it like this, you have to be aware of the fact that when you look back in time where time is being compressed and, therefore, on this profile we are looking at the analysis of 3,250 samples.

Senator Gore: Now, wait just a second. One other interruption, forgive me. 12,000 years ago, we were just at the end of the last ice age, correct?

Dr. Thompson: This is coming out of the last ice age in this part of the world.

Senator Gore: And so is it unreasonable to extend your analysis to say that probably that means it is the warmest 50-year period in the last 120,000 years at least?

Dr. Thompson: Well, I think --

Senator Gore: You do not have the evidence, but since the last ice age ended at the time your record begins and extended back beyond that for another, what -- I am taking you farther than you are comfortable in going, so you just keep saying what you --

Dr. Thompson: I am looking at the record for which we

have the most confidence in the time scale, and we always take two records, because we want to look at the reproducibility. This was based upon water samples brought from the field. The second core was brought back frozen, and because it was brought back frozen, we could sample it in more detail, and there were 7,045 analyses done on that core.

[Slide.]

Dr. Thompson: This is the record from that core, and again, it tells us the same thing, that the last 50 years, 1937 to 1987, is the warmest period of record. Now, if you want to get the best record from this core, it is better to combine these.

[Slide.]

Dr. Thompson: Where we now have a record based upon 10,000 analyses. And if we do this we still see the same relationship, and that is that this last 50-year period has been the warmest period in this part of the earth. This is the northern part of Tibet.

Now, in order to find out whether this is unique, we have to look at some other areas.

[Slide.]

Dr. Thompson: And we have done that in a preliminary way. One of these is to look at the Gregoriev ice cap in the Tien Shan, where we are 42 degrees north. The Dunde ice cap was 38 degrees north. This ice cap is at about the 600

millibar level in the earth's atmosphere.

[Slide.]

Dr. Thompson: We had Soviet support to get the drilling equipment in here.

[Slide.]

Dr. Thompson: And we have, from this site, three lines of evidence of recent warming. One is based on borehole temperatures, which I mentioned. This is the curve from 1962. The Soviets work on the glacier. This is the 1990 curve that we produced, showing a 2 degree C. warming, and this is in actual measured temperatures.

These are meteorological stations -- the temperatures from the Tien Shan stations, which starts in 1930 and goes up to the present, and you can see again about a .5 degree warming.

The nearest Met station to the Dunde ice cap in China is Dellingha, and that record goes from 1956 up to the present. You will see a very sharp increase, about 1 degree C in instrumental data for that site. And if you look at the isotopic record from these two cores from the Gregoriev and the Dunde core, you see about a 1 part per mil enrichment over this period of time.

[Slide.]

Dr. Thompson: Now, we are in the process of looking at what is the largest glacier ice cap in China. It is the Gulea

ice cap located in the western Qualoong. This ice cap covers over 200 square kilometers. It is part of an ice mass that covers 8,000 square kilometers. The ice cap is at an elevation of 6,707 meters, 22,000 feet.

[Slide.]

Dr. Thompson: So it puts you at the 350 millibar level in the earth's atmosphere.

[Slide.]

Dr. Thompson: Right now, we only have shallow records coming from this glacier. The core was drilled in 1990, and in 1991. And what these cores show is a very striking increase in delta values, shown by the reds, around 1985, and so very recent change there. Now we can look at --

Senator Gore: Wait a minute. When you say delta values, what you are saying is that since in this glacier, consistent with the others, but with a more detailed record, you see a striking increase in warming during the period since 1985?

Dr. Thompson: A 1.2 part per mil increase in delta values, but very abrupt, and this is unusual and we do not know why this is, but if we look at a Met station on the plateau, on the north side of the plateau, just down wind, the same latitude --

[Slide.]

Dr. Thompson: -- and compare the mean delta values for Gulea, which you see here, to the actual temperature

measurements at that station, you will see that there is a very sharp increase in 1985, in the observed temperatures here. We do not understand why it is so abrupt, and why it is just very recent in this part of the world.

[Slide.]

Dr. Thompson: Probably the most convincing record of change comes from the Quelccaya ice cap in the Andes of southern Peru. This was the subject of very intense investigation for 10 years.

[Slide.]

Dr. Thompson: And it led to the drilling in 1983, of two cores through this ice cap, and in these cores, you can actually see the annual layers, and the annual dust layers. So we had very accurate dating of the cores, and these go back to 470 A.D.

[Slide.]

Dr. Thompson: And when you look at the analysis of the samples from these cores, this is the visible stratigraphy, these are the annual variations in dust. You can see the dry season dust layers giving very distinct layers, and I want to point out these. These are annual oscillations in isotopes. They are annual, they allow for very precise dating of the sequence, but notice how distinct they are in this record.

[Slide.]

Dr. Thompson: We were able to reconstruct a very good

record. These are the decato-values of particles, both insoluble, accumulation of those layer of thicknesses, and the delta, the oxygen isotopes, and these are for the last 1,000 years for this part of the world. You see the little ice age stands out here, a period of lower isotope values, cooling, and increases in dust occurring during this period of time.

The event here is the eruption of Winapatina. This eruption occurred over a period of 2 weeks, it is in the church records in southern Peru, and it gives us a very precise dating, and confirmation of the dates on this core.

[Slide.]

Dr. Thompson: This is the way we relate these isotope records to temperature records. This is from Lansburg's reconstruction of temperatures for the Northern Hemisphere. These are based on instrumental records from about 1740 to the present, and this is based again, on phenological data in the earlier part.

If we look at the two isotope curves from Qori Kalis, you will see the very high reproducabilities in these, and also, there is very high correlation between what we see in the isotope and what we think we know about the Northern Hemisphere temperature over this period.

This is from the Dunde ice cap over in China, and we see again the little ice age period here, but a much stronger warming taking place in that record.

[Slide.]

Dr. Thompson: Now, because we do have annual values, we can actually look at the year-by-year changes in these parameters. And I am not going to dwell on this except to say that if you look at the year-to-year variations, we look at the onset of the Little Ice Age, you will see that it abruptly starts in 1490 A.D. in the dust record, and abruptly ends in 1880, within only a few years, when you go from conditions that characterize the Little Ice Age, to the conditions that characterize the 20th century.

[Slide.]

Dr. Thompson: Now we went back to this ice cap 5 months ago. What we wanted to do was bring the record up to the present. In 1970 -- and let me focus this -- in 1976, when we were doing the survey for this glacier, we took cores across from this ice cap, and in 1976, the three profiles here, you can see that the lower elevation sites, the annual signal was lost at depth, and the reason it was lost is because we had the movement of water through the snow pack.

At the summit, we have these annual oscillations being preserved, and based on this, we chose to drill this ice cap in 1983. In 1991, we took another core from the summit, the same place that this core came from, and you can see that now that annual signal is lost, because there is now movement of water vertically at the summit of this ice cap.

You can see the mean isotope values went from -19.4 in 1976, and now they are -17.4, indicating an enrichment which is our indicator of warming. But what happened to the ice cap?

[Slide.]

Dr. Thompson: This is a margin of this ice cap as viewed, a boulder about the size of the middle of this circle here, being pushed by the glacier in 1977.

[Slide.]

Dr. Thompson: This is the same boulder in 1978. You can see the wall pulling back from the ice cap.

[Slide.]

Dr. Thompson: This is in 1979. This wall is about 15 --

Senator Gore: Is that the same boulder?

Dr. Thompson: That is the same boulder. This wall was about 15 to 20 meters high.

[Slide.]

Dr. Thompson: This is 1983.

[Slide.]

Dr. Thompson: And this is 1991. It is very difficult to get the boulder and the ice into the same frame.

[Slide.]

Dr. Thompson: And if you look at the wall, if you go down to where the wall is, this is the boulder back here. You can see it is only about 2 feet thick under present

conditions.

[Slide.]

Dr. Thompson: Now we have surveyed the Qori Kalis glacier. This is the largest outlet glacier coming off of this ice cap. This is what it looked like in 1983. It is a convex glacier. There is no lake in the front of it. In 1991, 5 months ago, you can see that it has retreated. There is a vertical wall here. There is now a lake in front of this glacier, and it is now a concave glacier.

Senator Gore: Now, wait a minute. That is just in 8 years?

Dr. Thompson: That is 8 years, and if we look at the actual record --

Senator Gore: That is not complicated to interpret that.

Dr. Thompson: It is very obvious the change that is taking place on this ice cap. This was the position of the glacier in 1963, based upon aerial photographs. This is the position in 1978. We set up a survey line, took terrestrial photographs so that we could actually map that position. This was the position in 1983. This was the position in 1991, and you can see this lake has formed.

If you look at the rate of change, we see that in this period from 1963 to 1978, it is 5 meters per year. 1978 to 1983, it is 8 meters per year. 1983 to 1991, it is 14, almost triple what it was in the earlier part.

Now glaciers change for many reasons. One is temperature and the other is precip, but because we have annual layers on this -- in this ice cap, we can look at the long-term precip variations.

[Slide.]

Dr. Thompson: We can do that here. These are the averages of precip for the entire -- going back to 470 A.D. And if you look at these long-term variations, you can see there are natural dry periods, wet periods, dry periods, wet, dry. But within the last century, the precip has been normal or slightly above normal, so given study state conditions, no change in temperatures, this glacier should have stayed or maybe slightly advanced under these conditions. So I think it is very clear evidence that it is temperature.

[Slide.]

Dr. Thompson: Now how do these records in the tropics compare to the records coming from the polar regions? I am going to show that the last 1,000 years from Greenland, and from the Dunde ice cap in Central China, from Qori Kalis, and compare it to two records in Antarctica.

[Slide.]

Dr. Thompson: And if we do that, these are decato averages of isotopes. Again, reds are warmer and blues are colder. As you can see, the little ice age period running through these four records -- this is a period that when

temperatures were colder, glaciers advanced in Europe and China, and North America. In the Antarctic peninsula, we find that the isotope record says it was warmer in that part of the world.

If we come into the 20th century, we see warming taking place, except in the Antarctic peninsula, where there is an apparent cooling. But if we look at all of these records, we will see the highest correlations coming between the two northern hemisphere sites, and between the Quelccaya and the South Pole site, as far as the warm periods and the cold periods. But the maximum change is taking place in Central Asia, as far as the warming taking place there.

Senator Pressler: Why do you not have Africa or Kenya up there?

Dr. Thompson: We went to Lewis glacier on Mount Kenya in 1978 to see if we could get annual records from that glacier, and the problem is in 1978, there was already melting taking place on Lewis glacier, so that you got this smooth profile, because water was already moving vertically through that glacier. Only if the glacier is cold do you get the annual layers preserved.

Senator Pressler: I would like you to send me personally anything you have on Kenya and the studies there. You mentioned that there was this 40 percent melt in what, a year. I do not want to throw this off as you are presenting here,

but you can send that to me later.

Senator Gore: Let me say that I will ask the subcommittee staff to collect that information and make sure that it is done thoroughly.

Dr. Thompson: I have two reprints with me, one for Kenya, and one for the Ruwenzori glacier, which show, in these two tropical locations -- there is a paper by Hastenrath and Kruss, 1992, last month in Nature, which documents the retreat that has taken place on the glaciers on Mount Kenya, and one in 1991, by the German group, showing the retreat of the Speke glacier in Ruwenzori. We are getting a consistent story on these tropical glaciers.

Senator Gore: Is that pretty much it? This is so thorough and well documented. Just to clarify this, you have a paper that is now in press, correct? This has not been printed yet, but it is in the process of coming out?

Dr. Thompson: It is under review, yes, on this most recent work.

Senator Gore: Well, we are very grateful to your willingness to come and present it today. I do not know of a more thorough study on these ice cores. It is absolutely fantastic. I want to come back to Dr. Pollack, but just because you raised this question on the regional effects, I wanted to ask Dr. Mahlman and Dr. Rind whether or not the kinds of temperature changes we have heard about in the low

latitudes and at the poles -- he combined the poles with the low latitudes, whether those changes are consistent with what the models would lead us to look for?

And we are going to have to move quickly through this material, just because of time constraints.

Dr. Mahlman: The question that Senator Gore asked is to what degree can mathematical modeling provide perspective to this kind of data.

[Vugraph.]

Dr. Mahlman: This is a tutorial example taken from an actual model calculation just recently completed for more than the 200 years that I show here, but this is a couple atmosphere ocean calculation with a full dynamical ocean below, and this is the natural variation of the global average surface temperature in the model that has no solar forcing changes, no greenhouse forcing changes, no nothing changes other than the natural interactive character of the climate.

And the thing that makes this such a vexing problem is that the ocean has incredible memory in it and the skinny little atmosphere that interacts with the ocean can produce changes in the ocean that feed back to the atmosphere.

And for this model time period we are getting sort of peak to trough variations naturally, about a half degree, and that is for the global average.

I do the same thing for the Northern Hemisphere, mean,

for exactly the same model calculation.

[Vugraph.]

Dr. Mahlman: You see the splatter is larger already than what you saw in the previous graph and that it is now peak to peak, almost .6 degrees and if you take that, I do not have a graph to show that, but if you take it for say the continental United States, then the amplitude of natural variation would be larger and if you take -- here is the catch that you have to be concerned with with this kind of uninterpretation of the data -- is that the shorter the period of record you look at, or the smaller the region you look at, the more you are confounded by the natural variability in the system.

We call this a signal-to-noise problem, and this is one of the reasons why we scientists have a fondness for looking at the global average surface temperature because the people who do policy get very frustrated because they say, I do not live in the global average. I live in South Dakota or wherever. My wife is South Dakota, so she made me say that.

[Laughter.]

Dr. Mahlman: The simple point is that if you are looking at a particular place and you have to either argue that this is an integrator of the climate system or that you average over long periods of time, so for example, the question of interpreting the glacial data from 1983 to 1991 is fundamentally a tricky one as I think all of us would agree.

And so, the challenge to us is how do we integrate all of this disparate information to begin to have more confidence about whether or not what we see is due to the greenhouse. As many of us suspected, it is indeed the case, but because of the complexity and the natural variation of the system, it is very difficult to point to. Yes, this is the smoking gun, and this is unambiguously due to the greenhouse effect. We think so, but the case is still being assembled.

Senator Gore: Now one of the other indicators, just briefly, Dr. Rind, we talked about and we are going to talk some more about the borehole data and we talked about glaciers and we talked about tree rings, and solar variability and we just talked about what the models show.

Another indicator is the way the atmosphere reacts to warming, and you indicated earlier than these recent findings show that the stratosphere is cooling and the degree of moisture at high altitudes is increasing in proportion to the warming that has taken place.

Could you briefly tell us about that or do you have those --

Dr. Muhlman: I have a picture that acts as a leading -- to what David Rind would say and I think together we add up to something coherent here.

[Vugraph.]

Dr. Muhlman: This is a lousy slide, but I just took it

off yesterday and this is a picture of the atmosphere from the South Pole to the North Pole and from the ground to about 20 kilometers in the lower stratosphere, and this is a difference map between the average of the 1978 to 1988 temperature from the 1963 to 1973 temperature and the dotted lines are those regions for which we are statistically confident that these are actual changes and not just random variations.

And what we see is that in the warming in the order of .4 degrees in the lower troposphere, with centering around the tropics, and very substantial cooling in the lower stratosphere and this cooling is much larger than you can ascribe to carbon dioxide only --

Senator Gore: Now that is complicated of course, I do not want to complicate it further, but it is complicated by the destruction of ozone, is it not?

Dr. Mahlman: It is dominated by the destruction of ozone because the destruction of ozone has been quite large, particularly here in the southern hemisphere.

Senator Gore: And that is because the ozone layer normally absorbs heat and when it is thinned out it cannot absorb as much heat.

Dr. Mahlman: That is correct, and so it absorbs less irradiation and so we see the transition between heating and cooling having a more complicated pattern than we originally thought.

The other point that I wanted to make that David Rind that can amplify on is this warming region here in the lower troposphere in the balloon record shows that the increase in water vapor is consistent with the simplest equilibrium thermal dynamics arguments and that also is consistent with what the models are saying.

In my view, the radiosonde record is not quite good enough to describe what is happening in the upper troposphere which is a large point of contention and that is why this SAGE satellite is there to bail us out and that is what David could speak to.

Senator Gore: Okay, Dr. Rind, we will hold the record open on this particular point for other views to be expressed to the subcommittee, and there is at least one other view. I did not know when this hearing was put together that this new data was going to show up at this point.

And out of fairness I do want to give an opportunity to respond to these one scientist who has disagreed with this, but just to set the context the question of whether warming will lead to more moisture in higher altitudes or less moisture is significant really only because one of the few critics of the theory of global warming has based his criticism on the assertion that when warming occurs it will lead to or it is likely to lead to less moisture in higher altitudes.

This is Dr. Richard Lindsen and we had an earlier round table on this point, and without going back into that, he still believes that it is likely warming will lead to less moisture in the upper altitudes, but in putting together this hearing we discovered that all of a sudden, with these new satellite measures we have the data now to look at whether that is right or wrong.

So, Dr. Rind.

[Vugraph.]

Dr. Rind: What I am showing here first is reconstruction that I just got from Jim Hansen of the surface air temperature change from 1880 through 1991, and you can see as Senator Gore said previously, 1990 was the warmest year in this particular data set. 1991 was second, and obviously the slope here is a very strong slope.

There was warming here and one of the questions that presumably we could address is how much this had to do with solar variability and how much of this has to do with solar variability. Nevertheless, this is a very distinctive feature of all sorts of temperature reconstructions, very extensive warming from the late 1970s on.

As a brief aside, before getting into the question of water vapor, I thought you might like to see the monthly pictures.

[Vugraph.]

Dr. Rind: In particular, in 1991 you will notice that 1991 was pretty warm up until the middle of year and then there has been cooling, very strongly centered in the tropics subsequent to that, and of course, Mt. Pinatubo went off in June and it is expected that Mt. Pinatubo could bring the temperature down temporarily for up to about a centigrade, although that is somewhat uncertain at this point.

Senator Gore: Occurring at the time of El Nino also, so that is also complicating it.

Dr. Rind: Yes. What we did was take out of the last 4 years the years actually, 1986 through 1989.

[Vugraph.]

Dr. Rind: We looked at in both the radiosonde data and the SAGE 2, water vapor data, what the difference in water vapor was at various levels of the atmosphere. This is near the surface of the atmosphere. This is upper levels in the troposphere and this is the difference in the humidity in the atmosphere between the warm years and the cold years.

So if these numbers are positive it implies that the humidity has increased in the atmosphere and basically in both the SAGE data and the radiosonde data, you see increases in water vapor up through the troposphere basically.

Senator Gore: Okay. Is that it?

Dr. Rind: As far as that point goes, yes.

Senator Gore: Well, we need to move on so if you can get

to your other points in time for me to get to the other witnesses.

Dr. Rind: Do you want the other points now?

Senator Gore: If you can do them quickly.

[Vugraph.]

Dr. Rind: Another point that people have asked is about the impact of solar variability and Gerry Muhlman brought up the point that when you run these coupled ocean atmosphere models you get variability throughout the record, and we saw in that temperature reconstruction that you did get warming in the 1930s and then it cooled off and now you are getting substantial warming in the 1980s, is this real? Is this a greenhouse effect? Is this natural variability? What is it associated with?

If you plot the temperature changes in the 1930, this brown line as a function of latitude, from the equator to high latitudes, notice that high latitudes warmed tremendously in the 1930s where the tropics actually had very little warming.

In comparison, the 1980s show warming across the whole wide range of latitudes. The 1980s look like a very different signal from the 1930s, at least at far as this latitudinal changes goes, and one of the estimates we had done was that actually if you increase the ocean circulation a little bit, you can get a temperature change that looks a lot more like the 1930s, whereas, the double C02 temperature change looks a

lot more like the 1980s.

So just from the standpoint of the latitudinal signature of the response, there is a chance we may be able to separate the different types of forcing.

Finally, in terms of this question of what is happening in the record, Dave Robinson at Rutgers has produced a reconstruction of snow cover which is the top picture here.

[Vugraph.]

Dr. Rind: For the Northern Hemisphere from mid-1970 up through 1990, snow cover increases this way and temperature increases that way. As temperature has been increasing in the Northern Hemisphere the hemisphere-wide snow cover has been decreasing, very correlation and therefore any significant effort that people are making to try to imply that as you warm the sea surface temperatures, you may actually cause new glaciers to grow on land and snow to stay on land.

At least up to this point in time, the data is very counter to that, and this actually goes hand in hand with borehole records and glacial records. The snow cover record also seems to verify that snow cover has actually been strongly decreasing as the climate warms.

Senator Gore: Well, the point of all of this, as I understand what Dr. Mahlman and Dr. Rind are saying is that these other indicators greatly buttress the confidence we can have in the computer models and strongly imply that a policy

of business as usual will in fact likely lead to increasing temperatures of 1.5 to 4.5 degrees centigrade with C02 doubling or a rate of increase 10 times faster than anything we have seen in these climate records for the last 10,000 to 12,000 years, and perhaps longer.

Dr. Rind: Finally, the last point I would like to make which would be a lead in actually what Judith Lean could discuss is the solar impact on all of this and the impact of solar variability.

[Vugraph.]

Dr. Rind: Jim Hansen and Any Lasis produced an estimate of what the solar change, the solar radiance change in the 1980s was relative to the greenhouse gas change during the 1980s. And you can see that if you add the solar decrease that occurred in the mid-1980s to the greenhouse forcing in the mid-1980s you get essentially a flat forcing.

Then when the solar went up, they added together and you got a positive impact.

Senator Gore: This is the point you were getting to earlier, why do you not lead that up and Dr. Lean, do you want to comment on that?

Dr. Lean: Sure, I can comment on that, in a broader context or just on that specifically?

Senator Gore: Well, he showed an earlier graph also, the implication of what these modelers are telling us is that your

warmer temperatures associated with variations in the solar output have to be included in our analysis of the temperature record because as this graph shows, the temperature record, and you actually indicated this early, the temperature record can appear to be a flat at a time when solar radiation is declining.

And even though the temperature record is flat, that would mean that the greenhouse effect is pushing temperatures up compared to what they would be if solar radiation was not going down, and then the further implication is that when the natural variation in solar output turns back up again, it will exacerbate the warming due to increases in greenhouse gas concentrations, correct?

Dr. Lean: Yes. Actually, I have an extension of that where I have extrapolated for the next few solar cycles that I could show you so that you would see how the sun might modulate the greenhouse gases.

Dr. Damon: They can extrapolate for centuries using other cycles.

Senator Gore: Well, we are running out of time and I want to get to Dr. Pollack, so you all decide what the most relevant of those presentations might be. Do you each want to present one to two?

Senator Pressler: Mr. Chairman, while they are walking up, I am going to have to depart, but I would also request

some information on the Ruwenzori Range in Uganda, some of the information if anybody has that, just to send to me personally.

Thank you very much.

Senator Gore: We will make absolutely certain that you get that, Senator Pressler, and thank you very much for your work in this area.

I want to acknowledge the presence of my colleague, Senator John Kerry who has been one of the most active members of the Senate in this issue and invite you to jump in at any point you want, Senator Kerry.

Senator Kerry: Appreciate it, Mr. Chairman. I am, unfortunately, one of those who has a schedule conflict, but I did want to get a sense of the texture of this, and I am impressed the manner in which you are proceeding.

Senator Gore: Well, thank you very much, Senator Kerry.

We have a specialist on tree ring data and borehole data in the tundra and ice core work in the tropical glaciers at high altitudes, all of which validate the thermometer temperature record which has been attacked as possibly having some weaknesses in it. Now we see exactly the same pattern from all of these other indicators and a synthesis of information from a whole different group of scientific fields that all produce exactly the same results, a result which importantly corresponds also what the computer models show

which like the thermometer record have been subject to some attack, and so this synthesis is one that I think is extremely important.

And what we are looking at again here now is information on solar variability and Dr. Judith Lean and Dr. Damon in just a moment, have told us that this is a complex field and in order to really interpret it responsibly, we have to take into account that these indicators from natural systems like the ones I mentioned are affected by variations in what the sun has been doing.

But we are delving into this complex area and what we are finding is that it presents us with the same overall message.

Dr. Lean: This is an extension of what David's shown where you project future solar cycles, and remember I said the sun has an 11-year cycle, and this is based upon observations we have now.

The point that I would like to make is we have observations over one solar cycle only, and that is what this is referring to.

[Vugraph.]

Dr. Lean: The sun has an activity, as indicated by this long-term record. These are sunspots. It is not irradiance that has been continually increasing over the past 300 years, so you have seen in some of the climate records the existence of the Maunder Minimum. This is a period when the 11-year

cycle died away, and so things like this complicate the record and just -- this is sort of playing Devil's Advocate a little bit.

[Vugraph.]

Dr. Lean: You can take things like global sea surface temperature records and you can correlate them with the sunspot number so again you have correlations that perhaps suggest the sun is playing more of a role than the measurements would indicate. We do not know the answer to this, but nor can we dispense with it entirely and in part on the longer-term scale we really need to be careful of that as well.

[Vugraph.]

Dr. Lean: Historical solar activity records such as Dr. Damon can talk about indicate that the sun has a series of minima and maxima, so that the 11-year cycle as we know it is something that is a contemporary thing and in fact historically we believe that in terms of these minima the 11-year cycle goes away and the irradiance decreases, and you can see here the correlation between the Maunder Minima and the lowest temperatures of the Little Ice Age, which you can see in the ice core records and the winter severity indices.

Now, if the sun -- these are some calculations from Tom Wigley who is going to come here. If the sun went into a Maunder Minima period starting in the year 2000, went down

into a minimum, what could we expect to happen in terms of greenhouse forcing?

[Vugraph.]

Dr. Lean: These are the results of that. This is the greenhouse gas and this is different sensitivities, and so even taking the historical record and combing it of what we know now of the sun we can say yes, there is an effect, but presumably according to these calculations it is not going to moderate the greenhouse effects, but there is a possibility that it is going to be significant.

Senator Gore: Thank you very much. Dr. Damon.

STATEMENT OF DR. PAUL E. DAMON, PROFESSOR EMERITUS, DEPARTMENT OF GEOSCIENCES, UNIVERSITY OF ARIZONA, TUCSON, AZ 85721

Dr. Damon: I will make it brief.

Senator Gore: Yes, please do, and while you are walking up there we had a report from a group called the Marshall Institute some time ago -- and I was not going to get into this because they are not here, and I will consult with the Republicans on the committee because we may want to have a follow-up hearing to give them a chance to say whatever they wish on this and maybe look at this a little more closely.

But you are an expert in this field and you are familiar, I am sure, with the conclusion reached by the Marshall Institute that the sun is likely to cool off and it is actually lucky, according to them, that we are putting all these greenhouse gases up there, because it will negate a period of cooling that we are entering into. Did you find their report persuasive?

Dr. Damon: No. They make two errors in their calculations?

Senator Gore: Errors? I made one of those once and I was very disconcerted.

[Laughter.]

Senator Gore: You reported their errors to them?

Dr. Damon: Yes. They put in a lag time where it should

not have been and made an error in calculation.

Senator Gore: It was a simple mathematical mistake?

Dr. Damon: Yes, and also a conceptual mistake, and I think what I show here will demonstrate that.

Senator Gore: But the effect is that it led them to predict cooling when actually they should have predicted warming?

Dr. Damon: That is right.

Senator Gore: That is rather significant.

Dr. Damon: I will do what they did but do it correctly.

Senator Gore: But do it briefly, too, and I want to emphasize that we will hold the record open, without objection, for any comment or response from them, because again if I had known that we were going to get into this I would have invited them. I will invite them to a subsequent session and give them a chance to respond if they wish to do so.

Go ahead.

Dr. Damon: Here you have the record of both carbon 14 -- and I will not go through the means of removing the geomagnetic field data from this, and also beryllium 10. The C14 is from the cellulose tree rings measurement and the beryllium 10 data is from the South Pole. This is data of Dr. Stiver from the University of Washington and Risenbeck, et al., from France.

The South Pole is an ideal place to get this data, and you can see starting from over here you have this minimum that occurred at the end of the 19th Century. You have the Dalton Minimum, the Maunder Minimum, the Storey Minimum, the Wolf Minimum, and what I call the Medieval Solar Maximum, where historical records show that aurora were seen at very low latitudes, such as in recent time there were two sightings of aurora in Tucson, and people called the police or the fire department because they thought there was a huge fire and the aurora had been seen as far south as Central Mexico, and then this is the Oort Minimum, known from historical data.

Well, you will notice that this Medieval Solar Maximum, which is also referred to as the Medieval Warm Epic -- although the agreement is not really very good as to just exactly how warm it was. It certainly was warmer than the Little Ice Age -- lasted for about 150 years.

Now, this is the result of the combustion of fossil fuels, and so we cannot see the effect of the sun in the carbon 14 because of industrial activity, but beryllium 10 is not affected by industrial activity and so you can see that solar activity which is the inverse of the -- the isotopes are the inverse of the solar activity, has now returned after 700 years to the level of the Medieval Solar Maximum.

Well now, these variations are not random. There is a complicated periodicity related to them.

[Vugraph.]

Dr. Damon: This is particularly important for long-term changes and most of these are due to the shape of that signal, but the two that I want to point out which are most important is this which we have defined better at 212 years and we call this the Seuss period, this frequency of 212. It is well-known from the sunspot cycle. It is the Gleisberg period, and that shows up in the data that Dalton Minimum is the effect of the Gleisberg.

[Vugraph.]

Dr. Damon: Now we have done sort of an experiment, a thought experiment here. We have taken the past climactic record as a boundary condition and we have assumed that the temperature change from the Medieval Solar Maximum to the Little Ice Age is only about 8/10ths of a degree centigrade. Looking at all of the climactic indicators of the past it cannot be much more than that, and so we have assigned to the Gleisberg a change in the solar constant of 0.23 percent, and to the Seuss 0.23 percent, or about 6/10ths maximum change in the solar constant.

Here you see Reid's smoothing of the sunspot cycle, which you can see has been increasing as mentioned by Judith Lean. Here are the two sets of data, Jones et al. and Hansen and Lebedeff, and here is our simulated model here, and you see that it increases rapidly and you have to put a lag time in

here for mixing with the surface of the ocean. It flattens off and then it starts up again, and if this is correct then you will see what will happen in the future.

[Vugraph.]

Dr. Damon: Now we are simply projecting those cycles into the future, and you see here is the 88 Gleisberg here, and here you have the 212 and the 208 here, the Seuss cycle, and here is the combined effect. The temperature would reach a maximum somewhere just before the middle of the next century. The total change would be about 8/10ths of a degree centigrade. We have put that in as a boundary condition. Then the temperature would decrease, but would not reach the level of the modern solar minimum here.

Now, notice that we have done this in two different ways. We can take that period 1100 to 1250 and say that the modern maximum, if that is a good analogue, would last for 150 years, and here it is 150 years, but independently we have taken the two cycles and projected them into the future, and you see we get the same effect, which I think gives some credence to what I call a Gadonkin experiment, a thought experiment, on the effect of solar energy in the future.

Notice, however, that we do not get a cooling, we get a warming in the middle of the century, and even when the cooling occurs it does not become as cold as the beginning or the end of the 19th Century. I called Jastrow immediately and

told him about that and he has seen this data. I think he must by now have changed his mind.

Senator Gore: Do you think so? Well, we will ask him.

Dr. Damon: Well, if he has not, he will have to argue with the facts.

Senator Gore: Well, I draw three conclusions from what you are saying: first, we have to get more information about the work that the field that you and Dr. Lean are specializing in in order to improve our ability to decipher the signals we are seeing in these temperature records, but secondly the total magnitude of the temperature change associated with these cycles is far less than the magnitude of the changes predicted in the models on global warming.

Third, the cycles that you study show that the smaller magnitude temperature changes will actually for the next 60 years or so exacerbate the warming that is predicted as a result of extra greenhouse gases in the atmosphere and then after the middle of the next century the anticipated decline in the amount of temperature due to this solar variability will by that time be completely swamped by the magnitude of change associated with the greenhouse gases.

Dr. Damon: That is right, but it does complicate matters.

Senator Gore: It complicates the interpretation of it, and in order to improve our understanding of it we need to

have a better data record and more extensive research in the field that you all specialize in.

Dr. Rind: I think the distinction you drew between your points two and three is just the right one, that for the next several decades we are talking about a potential solar influence that may be comparable to greenhouse gas influence in one sense or another, but on the longer term doubled CO_2 two times the CO_2 in the atmosphere's equivalent in models to a 2 percent solar constant change, and that is way outside the range of the variables that Judith referred to, or the estimates that people are making from solar models.

Senator Gore: Not just the sun, but other stars in the same category as the sun.

Dr. Damon: It would be four times.

Senator Gore: Dr. Mahlman.

Dr. Mahlman: A follow-up point to that that some have argued, as was even implied in Reid and Gage's research, is that the current observational temperature record over the last century can be possibly explained by solar cycle arguments.

The problem with that assertion is that it is an implicit or tacit claim that the system is extraordinarily sensitive to small variations in solar constant, and equally extraordinarily sensitive to equivalent greenhouse forcing, and anyone who makes that argument must come up with a

mechanism as to how to get around that logical fact.

Senator Gore: Well, if in fact we do have another roundtable on this particular point of solar variability perhaps we could get into that as well, and we will certainly consult with Dr. Damon and Dr. Lean and your colleagues on that. We have a number of other earth science roundtables that we want to get to, but perhaps in the future we can look at this in more detail.

Dr. Pollack, your work is just as impressive and detailed as what we have been looking at. Because of the time constraints I fear that we have not done justice to it, but let me ask you a few questions.

Your borehole data is best gathered on continents, obviously, because water interferes with the heat transport mechanism that you rely upon for your temperature record, and as a result you, just as Dr. D'Arrigo and Dr. Jacoby, have found it sensible to look at trees that are especially sensitive to temperature.

You found it sensible to concentrate your borehole work in tundra and permafrost regions, among others, because that gives you the ability to get more accurate measurements of this heat transport down into the earth, is that correct?

Dr. Pollack: Your comments are correct, but I would like to add, the initial success of the methods in the permafrost regions of Alaska because of the freezing of the water and not

having that perturbation, that success has now been achieved in other settings in temperate and tropical areas, obviously not due to permafrost. But there are other geological settings where ground water perturbation is insignificant.

Senator Gore: So you began in the permafrost and the tundra, but now you have got it elsewhere as well

Dr. Pollack: That is right. And it has the potential for application in all continental settings.

Senator Gore: Is there a lot of controversy about the measurements you have made? It seems pretty straightforward.

Dr. Pollack: I do not think there is controversy. The initial feeling was that perhaps the success in the Arctic might not be achieved in temperate and tropical areas. But since that time of that puzzling or wondering, we have now made measurements in the other settings and find that technique is quite robust.

Senator Gore: So you have a pretty high degree of confidence that you can measure warming of the earth in the last century. Is that correct?

Dr. Pollack: Well that is right. Beyond the last century, in fact, we think we have signal that takes us back two or three centuries.

Senator Gore: So you have got a record that goes back prior to the thermometer records. And when you look at the temperature change over that entire period of time, does the

pattern correspond with -- you answered Senator Pressler's question earlier briefly, but does the pattern correspond with that predicted by the models, by that found in the tree ring data, and that analyzed by Dr. Thompson in the glacial record?

Dr. Pollack: I know that we are pressed for time, but if I could show a few illustrations.

Senator Gore: We are pressed for time, but I want to see it. If you could run through it relatively quickly.

Dr. Jacoby: One brief comment, while he is going over there, relevant to Dr. Damon's presentation. In one location in Alaska we have a 1,000 year tree ring record, and the maxima in growth and minima in growth generally tend to coincide with his solar variations.

Senator Gore: Is that right? Well that is very interesting, and I want it to add to the list of those measurements that all correspond with each other, the thermometer record complied by Hansen and Wigley et cetera. It seems to me that any controversy about Hansen and Wigley's record has been pretty much demolished by the synthesis of all of these other records here. It is just such an overwhelming set of conclusions that all correspond with each other. Go ahead, Dr. Pollock.

[Vugraph.]

Dr. Pollack: Thank you. First, I just want to quickly show what this can and cannot do. What we have here is in the

strong Wigley line record. That is the tree ring record for the northern hemisphere that Dr. Jacoby and D'Arrigo presented. And if we let that drive as a temperature driving function at the earth's surface, then it would imprint the temperature record in the subsurface, and we could recover from that this bold line. And you can see that is what the borehole would reconstruct as a surface temperature history, as compared to what the tree rings would suggest from the surface.

But the main point I want to make is that it is really quite good back to a century, and if there is any doubt that the Hansen and Wigley analyses are somehow contaminated by urbanization and the like, one could take borehole records from non-urbanized areas and analyze them. And I think this will give you confidence that we would be able to recover that last century quite well.

For earlier times, one can see that you get a smooth record of what has taken place at the surface.

[Vugraph.]

Dr. Pollack: Let me just show some results quickly. Here is a series of boreholes from Southern Canada, of which the clusters shown with stars down here were inverted for a temperature history.

[Vugraph.]

Dr. Pollack: And this is the temperature history, shown

also with a carbon dioxide record, but I am not going to discuss that. The temperature history shows a strong warming from about the early part of the nineteenth century. That is shown here, and it includes, of course, the twentieth century warming that we are aware of. But this shows that the twentieth century warming is actually a continuation of a longer term trend there.

And about half of this, roughly 2 degrees of warming -- in the past, oh, 180 years, about half of it seems to be a recovery from an earlier cold spell, probably associated with the little ice age, and half is an overshoot from a longer term average that existed in the past. So the borehole record does confirm the twentieth century warming that we see in the meteorological record, as well as giving us some insight into the past history of the surface temperature in that area.

The borehole studies are relatively new compared to many of these other investigations. Most of the work has taken place in North America, and I will give you just a quick summary of the types of results that are occurring. The Lockenbrook and Marshall record from Arctic Alaska shows about a 2 to 4 degree warming over the past century.

The Southern Canada region which I just discussed shows a similar warming trend, but of lesser amplitude, only 1 to 2 degrees. And this seems to have started over -- the warming has been occurring over a longer interval, about half of which

is due to the twentieth century warming and half in nineteenth century.

The New England area and Eastern Canada likewise shows a similar rise in temperature, but confined to essentially the past century. And I am sorry that Senator Pressler is not here to see South Dakota, but it has not had too much of a change in the last century. Some work in the great basin of Utah shows very modest warming in this century. The main of this is that the regional variability that we see in the atmospheric record is also tracked well in the subsurface record.

Senator Gore: And corresponds with that predicted in the models.

[Vugraph.]

Dr. Pollack: This is the Hansen and Lebedeff summary for the 1980 to 1985 period, and while it does not reproduce real well on this screen, we all know and recognize that the polar regions have shown the greatest change in the meteorological record. And, of course, the Arctic Alaska borehole work confirms that, and some of the regional variation that one sees here.

Although I have shown you mainly North America, this region of Eastern Canada and New England is what has a signal well above average and it has tracked well. And the boreholes work in Africa, in some of these areas that actually show

cooling, are also verified by the subsurface temperatures. And so I have a great deal of confidence in the Hansen and Lebedeff meteorological record.

And in areas that are far from urbanization and far from the effects of heat islands and the like, the subsurface record tracks this quite nicely. And so I think it adds confidence to it, and offers a methodology that could extend the record into areas that have not been monitored by weather stations.

[Vugraph.]

Dr. Pollack: Lastly, I just would point out the density of borehole records that exist because of other geophysical studies that have gathered temperature profiles over the last 2 decades. And it is not surprising, of course, that the density in North America and Europe and in the Unified Team and Japan and Australia and in parts of the Southern Hemisphere, one can see that the potential for apply this method in already existing records is high. And, of course, if one wants to find particular areas or identify particularly sensitive spots in model calculations, one can drill holes and examine its past history over the past few centuries.

Senator Gore: That is really an extremely impressive presentation, and I want to thank you. And I would like to say that I draw some lessons from this roundtable about our research priorities. Just as ecology involves the study of

the whole and not just a few parts, and even where the parts are studied, they are studied in relation to the whole, it seems to me that when we go about the task of research, we might make more progress by looking at the kind of synthesis that this roundtable has hinted at.

And the implication for research funding, it seems to me, is that we must pay more attention to the work of scientists in fields as disparate as borehole analysis, tree ring analysis, glacier analysis, and solar variability and computer modeling. Because when we bring the evidence from different fields together in a careful way, the synthesis which results can save us an enormous amount of time as we seek firmer conclusions about what in fact is the likely consequence of the anthropogenic or manmade changes to the global environment.

And so I will be recommending, as chairman of this subcommittee, in consultation with my colleagues, that we insist that the agencies pay adequate attention to the importance of the work in these fields we have heard about here today. And finally, in conclusion -- well on that point, may I just ask each of our participants here today to respond for the record, and not orally but for the record, on what you believe the priorities in research activity and funding ought to be in the coming several years. Because I would like to be able to understand your conclusions with respect to that, and

use them in my dialogue with the executive branch as well.

In conclusion on the substance we have discussed here today, the record complied from this widely disparate fields all correspond. The measurements from tree rings, from boreholes, and from ice cores, present exactly the same pattern which, when understood with the sophistication that we are given from the solar variability specialist, enabled us to compare them to what the computer models predict and in the process validate the thermometer record, increase the confidence we have in the computer modeling, and increase the confidence we have in what those computer models tell us about the likely consequence of a so-called business as usual approach to the relationship between human civilization and the global environment.

I would like to thank the staff of the subcommittee on both sides of the aisle and my personal staff, for the enormous amount of work that has gone into pulling these various fields together. And in conclusion I would like to again thank each of our participants for sharing their enormous expertise in a kind of unusual format which I hope has been as interesting as productive for you as it has been for the subcommittee. And with that we will stand adjourned. Thank you.

[Whereupon, at 12:30 p.m., the hearing was adjourned.]