Testimony of Dr. Lisa J. Graumlich
Before The Select Committee on Energy Independence and Global Warming
U.S. House of Representatives
On The Foundation for Climate Science
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Chairman Markey, Ranking Member Sensenbrenner, Members of the Committee: I thank you for inviting me to testify today at this important and timely hearing. In what follows I will address the first of the questions posed in the Chairman's letter of invitation: "What are the observed changes to the climate system?" In my testimony, I will focus on the past 1000 years of climate history, drawing on my expertise in paleoecology, which includes reconstructing climate from tree ring and other proxy records. I will also comment on the report of the Scientific Assessment Panel, led by Lord Oxburgh, that provided an independent reappraisal of the science of the Climatic Research Unit (CRU), University of East Anglia as reflected in its key publications.

Executive Summary:
Climate has changed at various time scales throughout Earth's history, driven by a variety of factors such as continental drift, solar activity, and greenhouse gas concentration. Long-term records of "natural" climate variability offer a context to assess the significance of the current observed trends in global temperature. Many lines of evidence, including but not limited to tree rings, indicate that the Earth has experienced periods of relative warmth and cooling over the past 500-1000 years. In the Northern Hemisphere, there is <u>regional</u> evidence for relatively warm temperatures during medieval times and <u>regional</u> evidence for cooler temperatures during the 17th, 18th, and 19th centuries. Importantly, these records indicate that average Northern Hemisphere temperatures during the second half of the 20th century are likely warmer than any other 50-year period in the past 1000 years.

The key points of my testimony are the following:

- Estimates of global temperature trends on century time scales are non-trivial to calculate, requiring large-scale (e.g., hemispheric to global) data sets with sufficient coverage to average out local variation.
- Tree-ring data have been critical to the estimate of past climate variability because they resolve seasonal to annual climate conditions, and exist in spatially extensive networks with high replication.
- Independent research groups have combined tree-ring data with other annual- or decadal-resolution proxy climate records, such as annually laminated sediments, ice cores, coral growth bands, and historical documents to estimate Northern Hemisphere temperature trends. In all of these studies, there is a clear indication that the late 20th century is the warmest period in the past 500-1000 years.
- Recently, one of these research groups (the Climatic Research Unit at the University of East Anglia) was the subject of investigation requested by the House of Lords. An international panel headed by Lord Oxburgh found no

evidence that climatic data had been dishonestly selected, manipulated and/or presented to arrive at pre-determined conclusions that were not compatible with a fair interpretation of the original data.

1. Taking the Earth's temperature is a complex enterprise.

While we have an abundance of weather measurements, integrating these data into a single indicator of planetary warmth is not straightforward. The global and hemispheric temperature series, presented in the earlier testimony by Dr. Hurrell, incorporates land and marine station data. Over 3000 station records are used that have been corrected for non-climatic errors, such as station shifts and/or instrument changes. The geographic coverage of the station records is not uniform. Coverage is most dense in the most heavily populated parts of the world, particularly the United States, southern Canada, Europe and Japan. Further, the temporal coverage of the station data is not uniform. The number of available stations was small during the 1850s but increased to over 3000 stations after World War II. The marine data consist of sea surface temperatures (SSTs) that incorporate *in situ* measurements from ships and buoys. The SST record has been corrected for different types of buckets used in the ship-based measurement prior to 1942. Like the land data, coverage is not uniform and is most dense in the main shipping lanes in the Northern Hemisphere.

The irregular distribution of the available station data requires that some form of gridding is necessary in order for analyses (e.g., hemispheric averages) not to be biased. Typically, the land and marine data are combined by interpolating each to a uniform grid system over the surface of the earth (e.g., 5° latitude by 5° longitude). Several different methods have been used to interpolate station temperature data to a regular grid. Most often, researchers use a climate anomaly approach in which all station data are reduced to anomalies from a common 30-year period (e.g., 1961-1990). Gridbox anomaly values are the simple average of the station anomaly values within each grid box. Small differences arise in different analyses due to differences in gridding methods, such as treatment of spatial gaps in the data.

Great care has been taken to assess the accuracy of the resulting global and Northern Hemisphere temperature anomaly series and, in most publications, accuracy estimates are included in time series graphs. In general, accuracy declines as one goes back in time. Error analyses indicate that values are about four times as uncertain during the 1850s with a steady increase in accuracy between 1860 and 1950.

The several research groups that have used available station data and independently calculated global and Northern Hemisphere temperature series come up with estimates that are largely coherent. All analyses indicate relatively stable temperatures from the beginning of the station records through 1910, relatively rapid warming through the 1940s, followed by relatively stable temperatures through the mid-1970s. From the mid-1970s onwards, temperatures rise rapidly. For example, the period 2001-2009 is 0.19°C warmer than the 1991-2000 decade and the 1990s were the warmest complete decade in the series.

The rise in temperatures since the 1970s, along with other evidence of warming (e.g., melting of snow and ice, sea level rise) support one of the key findings of Working Group I of the IPCC Fourth Assessment Report that the "warming of the climate system is unequivocal." Given that we know that climate has changed throughout the Earth's history, it is critical to put the recent warming trend into the context of the natural variability of the Earth's climate system. Paleoclimatic data provide such as context.

2. Past records of climate play a central role in climate change science because they define "natural variability" over decades to centuries.

On time scales of decades to centuries, global and regional temperatures vary due to changes in solar radiation, volcanic gases and ash, ocean-atmosphere interactions, and greenhouse gas concentrations. Detection of human impacts on the climate system requires an understanding of how recent changes fit into a larger pattern of natural variability. High-resolution paleoclimatology plays a key role in this enterprise, making use of natural archives such as tree rings, coral growth bands, laminated and high-accumulation freshwater and marine sediments, speleothems, and annual bands in polar and high-elevation ice caps to infer changes in climate at annual time steps. Decades of field and laboratory research developing these data sources has resulted in global networks of well-replicated data that rival the spatial coverage of the observational climate records. Tree-ring records are uniquely widespread relative to other natural archives of climate and thus figure prominently in regional to hemispheric scale analyses.

There are a number of critical issues that must be faced in using tree rings and other proxy records to infer climate variation. These include the precision and accuracy of the chronology; the degree to which the processes producing each archive are understood and may be compared with observed climate; the consistency or inconsistency of response to climate throughout the period of interest; and the extent to which each type of record can capture climate variability over a wide range of timescales, from interannual to millennial, as well as spatial scales. For tree-ring data, arguably the most critical questions have arisen regarding the best way to separate the inherent biological growth trends from the climatic signal. A large portion of the scientific literature in paleoclimatology focuses on addressing these issues and ongoing research seeks to fine-tune our understanding of the nature of the climate signal in proxy records.

3. Analyses of large-scale networks of high-resolution proxy climate data indicate that the medieval period experienced warmer temperatures in certain regions and at different time periods. There is also broad agreement that late 20th century is warmest period in past 500-1000 years.

Historical and paleoclimatic records in western Europe and the North Atlantic lend support to the concepts of a “Medieval Warm Period”. For example, Norse seafaring and colonization around the North Atlantic at the end of the 9th century indicated that regional North Atlantic climate was warmer than during the cooler "Little Ice Age" of the 15th - 19th centuries. While the logic underlying this argument is oversimplified, the notion that a “Medieval Warm Period” could occur in the absence of human-induced changes in greenhouse gas concentrations has captured public imagination.

Several peer-reviewed studies that have produced very large spatial-scale reconstructions have come to the same conclusion: medieval warmth varied widely in terms of its precise timing and regional expression. However, there is widespread agreement that the warmest period prior to the 20th century very likely occurred between AD 950 and 1100. The analysis of the spatial extent of the expression of warmth during the medieval is restricted to the availability of proxy records from this period, records that ultimately need to be more widespread to capture global patterns and forcing. However, in studies to date, there is a clear indication that the late 20th century is the warmest period in the past 500-1000 years. Global climate models with a variety of natural (volcanic and solar) and anthropogenic forcing (greenhouse gases) factors have been used to simulate changes in climate through the last 1000 years. Varying levels of natural forcings account for the observed response in proxy records pre-1765, but the addition of anthropogenic forcing is required to induce the response observed in recent centuries.

4. Recently, an international panel was given the charge to investigate the scientific integrity of the Climate Research Unit at the University of East Anglia, known for the development of observational and paleoclimate data products. The panel concluded that there was no evidence that climatic data had been dishonestly selected, manipulated and/or presented to arrive at pre-determined conclusions that were not compatible with a fair interpretation of the original data.

Earlier this year, I served as one of seven members of the Independent Panel, chaired by Lord Oxburgh, to assess the integrity of the research published by the Climatic Research Unit (CRU) in the light of various external assertions. The Panel worked by examining representative publications by members of the Unit and subsequently by making two visits to the University and interviewing members of the Unit. The CRU publications focus on estimating hemispheric and global temperatures from observational and paleoclimatic data networks. As indicated above, this line of research involves an iterative process of seeking new data sources, addressing data inconsistencies and errors, and, in the case of tree-ring data, separating climatic signals from biological growth trends.

The Independent Panel concluded that, "We saw no evidence of any deliberate scientific malpractice in any of the work of the Climatic Research Unit and had it been there we believe that it is likely that we would have detected it. Rather we found a small group of dedicated if slightly disorganized researchers who were ill-prepared for being the focus of public attention." The full report in appended to my testimony.

Beyond the specific findings of Lord Oxburgh's Independent Panel, I would like to suggest that the interest of the public in the data and methods used by paleoclimatologists has benefited the scientific community in several ways. There is new motivation and, to some degree greater resources for, archiving data and software products. There is more open access software for tree-ring analyses under development, which will increase the transparency of the analytic procedures. Yet more scientific attention is being devoted to the understanding of the biological processes of formation of tree-ring and other proxy data. Finally, within the university community, we see greater professional recognition for devoting efforts to communicate science to the general public. All of this bodes well for progress in linking our scientific understanding of climate change with sensible and robust strategies for mitigation and adaptation.

Report of the International Panel set up by the University of East Anglia to examine the research of the Climatic Research Unit.

Introduction

1. The Panel was set up by the University in consultation with the Royal Society to assess the integrity of the research published by the Climatic Research Unit in the light of various external assertions. The Unit is a very small academic entity within the School of Environmental Sciences. It has three full time and one part time academic staff members and about a dozen research associates, PhD students and support staff. The essence of the criticism that the Panel was asked to address was that climatic data had been dishonestly selected, manipulated and/or presented to arrive at pre-determined conclusions that were not compatible with a fair interpretation of the original data. The members of the Panel are listed in Appendix A at the end of this report.

2. The Panel was not concerned with the question of whether the conclusions of the published research were correct. Rather it was asked to come to a view on the integrity of the Unit's research and whether as far as could be determined the conclusions represented an honest and scientifically justified interpretation of the data. The Panel worked by examining representative publications by members of the Unit and subsequently by making two visits to the University and interviewing and questioning members of the Unit. Not all the panel were present on both occasions but two members were present on both occasions to maintain continuity. About fifteen person/days were spent at the University discussing the Unit's work.

3. The eleven representative publications that the Panel considered in detail are listed in Appendix B. The papers cover a period of more than twenty years and were selected on the advice of the Royal Society. All had been published in international scientific journals and had been through a process of peer review. CRU agreed that they were a fair sample of the work of the Unit. The Panel was also free to ask for any other material that it wished and did so. Individuals on the panel asked for and reviewed other CRU research materials.

4. The Panel's work began with a detailed reading of the published work. Every paper was read by a minimum of three Panel members at least one of whom was familiar with the general area to which the paper related. At least one of the other two was a generalist with no special climate science expertise but with experience of some of the general techniques and methods employed in the work. Most of the members of the Panel read all the publications. The publications provided a platform from which to gain a deeper understanding of the Unit's research and enabled the Panel to probe particular questions in more detail.

5. Broadly the work of the Unit falls into two parts:
    - Construction and interpretation of tree ring chronologies extending over some thousands of years with a view to gaining information about past climates:
    - Studies of temperatures over the last few hundred years from direct observations.

Dendroclimatology

1. Tree growth is sensitive to very many factors including climate. By piecing together growth records from different trees, living or dead, it is possible to determine the temporal variation of growth patterns going back many hundreds of years. The dendroclimatological work at CRU seeks to go beyond this and to extract from the dated growth patterns the local and regional history of temperature variations. The Unit does virtually no primary data acquisition but has used data from published archives and has collaborated with people who have collected data.

2. The main effort of the dendroclimalogists at CRU is in developing ways to extract climate information from networks of tree ring data. The data sets are large and are influenced by many factors of which temperature is only one. This means that the effects of long term temperature variations are masked by other more dominant short term influences and have to be extracted by statistical techniques. The Unit approaches this task with an independent mindset and awareness of the interplay of biological and physical processes underlying the signals that they are trying to detect.

3. Although inappropriate statistical tools with the potential for producing misleading results have been used by some other groups, presumably by accident rather than design, in the CRU papers that we examined we did not come across any inappropriate usage although the methods they used may not have been the best for the purpose. It is not clear, however, that better methods would have produced significantly different results. The published work also contains many cautions about the limitations of the data and their interpretation.

4. Chronologies (transposed composites of raw tree data) are always work in progress. They are subject to change when additional trees are added; new ways of data cleaning may arise (e.g. homogeneity adjustments), new measurement methods are used (e.g. of measuring ring density), new statistical methods for treating the data may be developed (e.g. new ways of allowing for biological growth trends).

5. This is illustrated by the way CRU check chronologies against each other; this has led to corrections in chronologies produced by others. CRU is to be commended for continuously updating and reinterpreting their earlier chronologies.

6. With very noisy data sets a great deal of judgement has to be used. Decisions have to be made on whether to omit pieces of data that appear to be aberrant. These are all matters of experience and judgement. The potential for misleading results arising from selection bias is very great in this area. It is regrettable that so few professional statisticians have been involved in this work because it is fundamentally statistical. Under such circumstances there must be an obligation on researchers to document the judgemental decisions they have made so that the work can in principle be replicated by others.

7. CRU accepts with hindsight that they should have devoted more attention in the past to archiving data and algorithms and recording exactly what they did. At the time the work was done, they had no idea that these data would assume the importance they have today and that the Unit would have to answer detailed inquiries on earlier work. CRU and, we are told, the tree ring community generally, are now adopting a much more rigorous approach to the archiving of chronologies and computer code. The difficulty in releasing program code is that to be understood by anyone else it needs time-consuming work on documentation, and this has not been a top priority.

8. After reading publications and interviewing the senior staff of CRU in depth, we are satisfied that the CRU tree-ring work has been carried out with integrity, and that allegations of deliberate misrepresentation and unjustified selection of data are not valid. In the event CRU scientists were able to give convincing answers to our detailed questions about data choice, data handling and statistical methodology. The Unit freely admits that many data analyses they made in the past are superseded and they would not do things that way today.

9. We have not exhaustively reviewed the external criticism of the dendroclimatological work, but it seems that some of these criticisms show a rather selective and uncharitable approach to information made available by CRU. They seem also to reflect a lack of awareness of the ongoing and dynamic nature of chronologies, and of the difficult circumstances under which university research is sometimes conducted. Funding and labour pressures and the need to publish have meant that pressing ahead with new work has been at the expense of what was regarded as non-essential record keeping. From our perspective it seems that the CRU sins were of omission rather than commission. Although we deplore the tone of much of the criticism that has been directed at CRU, we believe that this questioning of the methods and data used in dendroclimatology will ultimately have a beneficial effect and improve working practices

Temperatures from Historical Instrumental Records

1. The second main strand of work at CRU has been the collection and collation of instrumental land temperature records from all over the world and the construction of regional, hemispherical and global scale temperature records. These records are irregularly distributed in space and time. Modern records come largely from land-based meteorological stations but their geographical distribution is uneven and strongly biased in favour of the northern hemisphere

where most of the Earth's land masses are located. Oceans cover two thirds of the Earth's surface and away from the main shipping routes coverage is thin. For earlier centuries the record is much sparser. Deriving estimates of past temperatures on a global, hemispheric and regional scale from incomplete data sets is one of the problems faced by the Unit and in consequence an important current interest is the discovery of useable old temperature records from a variety of sources.

2. In the latter part of the 20th century CRU pioneered the methods for taking into account a wide range of local influences that can make instrumental records from different locations hard to compare. These methods were very labour intensive and were somewhat subjective. Much of this work was supported by the US Department of Energy and was published with the details of station corrections several times a year. Since the 1980s the Unit has done no more of this work and have concentrated on the merging and interpretation of data series corrected by others. There have been various analyses of similar publicly available data sets by different international groups. Although there are some differences in fine detail that reflect the differences in the analytical methods used, the results are very similar.

3. The Unit has devoted a great deal of effort to understanding how instrumental observations are best combined to derive the surface temperature on a variety of time and space scales. It has become apparent from a number of studies that there is elevation of the surface temperature in and around large cities and work is continuing to understand this fully.

4. Like the work on tree rings this work is strongly dependent on statistical analysis and our comments are essentially the same. Although there are certainly different ways of handling the data, some of which might be superior, as far as we can judge the methods which CRU has employed are fair and satisfactory. Particular attention was given to records that seemed anomalous and to establishing whether the anomaly was an artefact or the result of some natural process. There was also the challenge of dealing with gaps in otherwise high quality data series. In detailed discussion with the researchers we found them to be objective and dispassionate in their view of the data and their results, and there was no hint of tailoring results to a particular agenda. Their sole aim was to establish as robust a record of temperatures in recent centuries as possible. All of the published work was accompanied by detailed descriptions of uncertainties and accompanied by appropriate caveats. The same was true in face to face discussions.

5. We believe that CRU did a public service of great value by carrying out much time-consuming meticulous work on temperature records at a time when it was unfashionable and attracted the interest of a rather small section of the scientific community. CRU has been among the leaders in international efforts to determining the overall uncertainty in the derived temperature records and where work is best focussed to improve them.

6. The Unit has demonstrated that at a global and hemispheric scale temperature results are surprisingly insensitive to adjustments made to the data and the number of series included.

7. Recent public discussion of climate change and summaries and popularizations of the work of CRU and others often contain over-simplifications that omit serious discussion of uncertainties emphasized by the original authors. For example, CRU publications repeatedly emphasize the discrepancy between instrumental and tree-based proxy reconstructions of temperature during the late 20th century, but presentations of this work by the IPCC and others have sometimes neglected to highlight this issue. While we find this regrettable, we could find no such fault with the peer-reviewed papers we examined

Conclusions

1. We saw no evidence of any deliberate scientific malpractice in any of the work of the Climatic Research Unit and had it been there we believe that it is likely that we would have detected it. Rather we found a small group of dedicated if slightly disorganised researchers who were ill-prepared for being the focus of public attention. As with many small research groups their internal procedures were rather informal.

2. We cannot help remarking that it is very surprising that research in an area that depends so heavily on statistical methods has not been carried out in close collaboration with professional statisticians. Indeed there would be mutual benefit if there were closer collaboration and interaction between CRU and a much wider scientific group outside the relatively small international circle of temperature specialists.

3. It was not the immediate concern of the Panel, but we observed that there were important and unresolved questions that related to the availability of environmental data sets. It was pointed out that since UK government adopted a policy that resulted in charging for access to data sets collected by government agencies, other countries have followed suit impeding the flow of processed and raw data to and between researchers. This is unfortunate and seems inconsistent with policies of open access to data promoted elsewhere in government.

4. A host of important unresolved questions also arises from the application of Freedom of Information legislation in an academic context. We agree with the CRU view that the authority for releasing unpublished raw data to third parties should stay with those who collected it.

Submitted to the University 12 April 2010

Addendum to report, 19 April 2010

For the avoidance of misunderstanding in the light of various press stories, it is important to be clear that the neither the panel report nor the press briefing intended to imply that any research group in the field of climate change had been deliberately misleading in any of their analyses or intentionally exaggerated their findings. Rather, the aim was to draw attention to the complexity of statistics in this field, and the need to use the best possible methods.

APPENDIX A
PANEL MEMBERSHIP

Chair: Prof Ron Oxburgh FRS (Lord Oxburgh of Liverpool)

Prof Huw Davies, ETH Zürich
Prof Kerry Emanuel, Massachusetts Institute of Technology
Prof Lisa Graumlich, University of Arizona.
Prof David Hand FBA, Imperial College, London.
Prof Herbert Huppert FRS, University of Cambridge
Prof Michael Kelly FRS, University of Cambridge

APPENDIX B

Peer-reviewed publications for assessment.

1. Brohan, P., Kennedy, J., Harris, I., Tett, S.F.B. and Jones, P.D., 2006: Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. *J. Geophys. Res.* **111**, D12106.

2. Briffa, K. R., F. H. Schweingruber, P. D. Jones, T. J. Osborn, S. G. Shiyatov, and E. A. Vaganov. 1998a. Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. *Nature* **391**:678-682.

3. Briffa, K. R., F. H. Schweingruber, P. D. Jones, T. J. Osborn, I. C. Harris, S. G. Shiyatov, E. A. Vaganov, and H. Grudd, 1998b. Trees tell of past climates: but are they speaking less clearly today? *Philosophical Transactions of the Royal Society of London Series B – Biological Sciences* 353, 65-73.

4. Briffa, K. R. 2000. Annual climate variability in the Holocene: interpreting the message of ancient trees. *Quaternary Science Reviews* **19**, 87-105.

5. Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Harris, I.C., Jones, P.D., Shiyatov, S.G. and Vaganov, E.A., 2001: Low-frequency temperature variations from a northern tree-ring density network. *J. Geophys. Res.* **106**, 2929-2941.

6. Briffa, K. R., V. V. Shishov, T. M. Melvin, E. A. Vaganov, H. Grudd, R. M. Hantemirov, M. Eronen, and M. M. Naurzbaev. 2008. Trends in recent temperature and radial tree growth spanning 2000 years across northwest Eurasia. *Philosophical Transactions of the Royal Society B-Biological Sciences* **363**, 2271-2284.

7. Jones, P.D. and Moberg, A., 2003: Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. *J. Climate* **16**, 206-223.

8. Jones, P.D., Raper, S.C.B., Bradley, R.S., Diaz, H.F., Kelly, P.M. and Wigley, T.M.L., 1986a: Northern Hemisphere surface air temperature variations: 1851-1984. *Journal of Climate and Applied Meteorology* **25**, 161-179.

9. Jones, P.D., Raper, S.C.B. and Wigley, T.M.L., 1986b: Southern Hemisphere surface air temperature variations: 1851-1984. *Journal of Climate and Applied Meteorology* **25**, 1213-1230.

10. Jones, P.D., Groisman, P.Ya., Coughlan, M., Plummer, N., Wang, W-C. and Karl, T.R., 1990: Assessment of urbanization effects in time series of surface air temperature over land. Nature 347, 169-172.

11. Jones, P.D., Lister, D.H. and Li, Q., 2008: Urbanization effects in large-scale temperature records, with an emphasis on China. Journal of Geophysical Research, 113, D16122.

Supporting documentation

Briffa and Melvin (2009) which is online at
http://www.cru.uea.ac.uk/cru/people/briffa/yamal2009/

TR017 – Bradley, R.S., Kelly, P.M., Jones, P.D., Goodess, C.M. and Diaz, H.F., 1985: A Climatic Data Bank for Northern Hemisphere Land Areas, 1851-1980, U.S. Dept. of Energy, Carbon Dioxide Research Division, *Technical Report TRO17*, 335 pp.

TR022 – Jones, P.D., Raper, S.C.B., Santer, B.D., Cherry, B.S.G., Goodess, C.M., Kelly, P.M., Wigley, T.M.L., Bradley, R.S. and Diaz, H.F., 1985: A Grid Point Surface Air Temperature Data Set for the Northern Hemisphere, U.S. Dept. of Energy, Carbon Dioxide Research Division, *Technical Report TRO22*, 251 pp.

TR027 – Jones, P.D., Raper, S.C.B., Cherry, B.S.G., Goodess, C.M. and Wigley, T.M.L., 1986: A Grid Point Surface Air Temperature Data Set for the Southern Hemisphere, 1851-1984, U.S. Dept. of Energy, Carbon Dioxide Research Division, *Technical Report TR027*, 73 pp.