An Assessment of the *Strategic Plan* of the U.S. Climate Change Science Program

Key Uncertainties, Milestones and Issues in the CCSP

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Executive Summary

The development of the *Strategic Plan of the U.S. Climate Change Science Program* (CCSP) was a significant effort to identify key issues in understanding climate change, and to focus the US research effort and research dollars on those issues. As such, the *Plan* must identify the key uncertainties and develop a research program to address them. And given the complexity of climate science, some questions have to be answered before others.

This assessment of the key uncertainties, milestones and issues in the CCSP focuses on uncertainty due to natural variability and the CCSP's plans to address the issue. The importance of natural variability is clearly recognized by the Plan. For example, as stated in Chapter 5:

> "Because there is a substantial range of natural variability in the climate system due to internal processes alone, it is difficult to distinguish natural excursions from the 'norm' from changes that might be the result of forcing due to human activities, such as land-use change and aerosols." (5-101)

Until underlying natural variability is understood, it is impossible to separate the impact of human activity from natural variability when observed climate reflects both. This assessment focuses on the CCSP's plans to address natural variability, climate uncertainties, and the milestones for measuring progress in this effort.

Coverage of Key Uncertainties

The present study is an assessment of uncertainty in climate change science, especially uncertainty due to natural variability. Specifically, we examine how that uncertainty is expressed in the recently released Strategic Plan of the U.S. Climate Change Science Program.

Admiral Conrad Lautenbacher, U.S. Undersecretary of Commerce for Oceans and Atmosphere, summarizes the uncertainty this way – "Where we are today in climate change science is problematic. We need more fundamental understanding." (Reuters, December 1, 2003)

Our first conclusion is that, overall, the Strategic Plan does a good job of explicating many of the uncertainties, especially those related to natural variability. Among many examples, it concludes that:

> "Uncertainty about natural oscillations in climate on scales of several decades or longer and inconsistencies in the temperature profiles of different data sets are

> critical scientific questions that must be addressed to improve confidence in the understanding of how and why climate has changed." (Chapter 2 - page 22)
>
> "Improved data and information on the climate system's natural variability and recent changes are needed to increase confidence in studies that seek to detect and attribute changes in climate to particular causes." (2-23)
>
> "Understanding the magnitude of past climate variations is key to increasing confidence in how and why climate has changed and why it may change in the future." (2-23)

However, because our study is grounded in a prior study of six leading National Academy of Sciences reports, we are also in a position to assess the gaps in the CCSP Strategic Plan. (See Appendix A.) We find that while the Strategic Plan considers many key uncertainties in detail, it is virtually silent with regard to some other, equally central, questions.

For example, the Strategic Plan does not seem to regard the issue of solar influence on climate as important, for it is barely mentioned. Nor does it delve into the all important question of the global nature of the Little Ice Age (LIA) and Medieval Warm Period (MWP). In fact these terms never occur.

Yet the mechanism of solar forcing and the MWP - LIA cycle stand as competing theories of 20th Century warming, vis a vis human influence or, alternatively, a prime example of significant natural and human factors occurring simultaneously – factors that must be separated to understand human impact on climate. Evaluating these alternative theories is key to the central question of climate change science. Namely what role, if any, have humans had in observed climate change?

<u>Coverage of Milestones</u>

In addition to what key uncertainties are and are not covered, of special interest is the *Plan's* provision of numerous milestones, complete with time estimates, for resolving many important uncertainties. To our knowledge this is the first systematic attempt to develop a time-phased overview of climate science research. *It is highly commendable*.

It is also revealing that many of the key questions are not slated to be resolved until "beyond 4 years," the *Plan's* maximum time horizon. It is even more revealing that many of the "beyond 4 years" milestones deal with data development – data that is the starting point for evaluating possible human impact or natural variation mechanisms. These milestones confirm that the biggest uncertainties in climate science are not going to be resolved in the near future. *This is a very important finding for the Plan*.

<u>Critical Dependencies</u>

On the other hand, the *Plan* fails to take the obvious next step. That is to lay out the critical dependencies between these key research milestones, so as to find the critical path to resolution. This omission is puzzling because there is an explicit discussion of the importance of critical dependencies. Since these are nowhere specified, the *Plan* is seriously incomplete.

The CCSP *Strategic Plan* raises a basic timeframe question with regard to the fundamental climate change research issue. It raises the question of timeframe, but does not really address it, which is a serious deficiency.

The fundamental challenge facing climate change science is to determine the relative influence on climate of natural variability versus human activity. That is, given that climate is naturally variable, how much, if any, of the observed variation is due to human activities, and how much might be expected in the future?

This leads to the basic timeframe question. The Plan notes that resolving some research questions is critical to resolving others. It also lists a large number of research milestones that are central to the fundamental issue of possible human influence. Many of these milestones are estimated to be "beyond 4 years" in time to resolution.

The question is, does this mean that resolving the question of possible human influence on climate is beyond 4 years away? Whether this is so, or not, is an extremely important thing to know. Unfortunately, while the Plan lists many milestones and discusses the fact of criticality, it never assesses the specific criticalities of the milestones, one to another. Thus, the most important single piece of information that should flow from the Plan is missing.

For example, we have listed 34 of the many "beyond 4 years" research milestones that are particularly relevant to the issue of human influence. Three of the milestones listed are the following, from the chapter on climate variability and change.

> "Estimates of the spatial and temporal limits of predictability of climate variability and change forced by human activities [beyond 4 years]." (4-83)
>
> "An improved ability to separate the contributions of natural versus human-induced climate forcing to climate variations and change, resulting in more credible answers to 'If…, then…' policy-related questions [beyond 4 years]." (4-83)
>
> "Increased understanding of changes in natural variability and potential impacts on predictability that may result from anthropogenic forcing [beyond 4 years]." (4-83)

These three milestones clearly suggest that the time horizon for understanding the potential for climate change due to human activities is beyond four years. But that conclusion is nowhere drawn in the Plan. This is a very serious deficiency.

Many of the other research milestones have to do with specific aspects of climate and climate change. Their impact on the overall timeframe for resolving the fundamental questions is a matter for experts to determine, but it is likely to be significant. It is only when this complex set of criticality relations is unraveled that we will know when an answer to the question of possible human influence on climate may be forthcoming.

<u>A Systemic Confusion</u>

While the *Plan* offers definitions of "climate variability" and "climate change", there is no clear difference between the two definitions. Climate variability is "often due to internal processes," but this does not exclude human influence. In practice, "variability" is often used to mean natural variability and "change" to mean human induced change, but not always.

The resulting ambiguity is pervasive and in many places it is unclear whether natural variability or human induced change is being addressed. The regretful consequence is that what should be the focal point of research is in fact not well described at all.

<u>Overall Conclusion</u>.

Our final conclusion, therefore, is that overall the *Strategic Plan of the U.S. Climate Change Science Program* is a significant piece of work. The *Strategic Plan* successfully targets many of the key uncertainties in climate science, but with significant gaps in the *Plan* that still need to be filled. Consideration of certain mechanisms of natural variability needs to be expanded, and the network of critical dependencies needs to be defined.

The *Plan* also breaks new ground by defining milestones, with time estimates, for the research results. However, it fails to consider the critical dependencies between milestones. As a result it fails to say when the fundamental questions about possible human influence on climate might be answered. In this regard, the *Strategic Plan* is seriously incomplete.

David Wojick

I. Key Uncertainties Expressed in the Strategic Plan.

A. Statements on the uncertainty of climate variability in general.

Concern about climate science uncertainty is a common element throughout the *Strategic Plan* chapters. As seen in the following sampling of quotations from the *Plan*, this runs the spectrum from gathering basic data about past climate variations, to better understanding the mechanisms of decade and longer natural oscillations in climate, to serious weaknesses in assessing regional and local scale phenomena, to abrupt climate change and to separating natural and human induced climate change.

- *Data on Natural Climate Variability*
  "Uncertainty about natural oscillations in climate on scales of several decades or longer and inconsistencies in the temperature profiles of different data sets are critical scientific questions that must be addressed to improve confidence in the understanding of how and why climate has changed." (Chapter 2, Page 22)

  "Improved data and information on the climate system's natural variability and recent changes are needed to increase confidence in studies that seek to detect and attribute changes in climate to particular causes." (2-23)

  "Understanding the magnitude of past climate variations is key to increasing confidence in how and why climate has changed and why it may change in the future." (2-23)

  "Advances will require improvements in paleoclimatic data as well as modern observational data systems, because in general the latter have been present for too short a time to extract robust features of climate variability on decadal or longer time scales." (4-75)

- *Mechanisms and Modeling*
  "The overall scientific strategy described in this chapter includes: Process studies to elucidate critical processes that govern the climate system, but which in many cases are poorly understood and modeled." (4-75)

  "Focus 1.3: Sharpen understanding of climate extremes through improved observations, analysis, and modeling, and determine whether any changes in their frequency or intensity lie outside the range of natural variability." (2-24)

  "While there is a great deal known about the mechanisms that affect the response of the climate system to changes in natural and human influences, many basic questions remain to be addressed." (2-28)

"Modeling deficiencies are related both to limits in understanding the physics of the climate system and insufficient fine-scale treatment of the key processes." (4-76)

"CCSP-supported process research will address basic climate system properties and interactions, including improving characterization of the circulation and interaction of energy in the atmosphere and oceans. It will also seek to reduce uncertainties regarding a number of 'feedbacks' or secondary changes caused by the initial influence that can either reinforce or dampen the initial effect of greenhouse gases and aerosols. These feedbacks include changes in the amount and distribution of water vapor, changes in extent of ice and the Earth's reflectivity, changes in cloud properties, and changes in biological and ecological systems that could significantly change emissions or absorption of greenhouse gases." (2-29)

"Clarifying the uses and limitations of climate models at different spatial and temporal scales will contribute to appropriate application of these results." (2-29)

"Evaluation of the potential impacts associated with different atmospheric concentrations of greenhouse gases and aerosols is an important input to weighing the costs and benefits associated with different climate policies. Further research is required to integrate still limited understanding of effects of different concentration levels, and the influence of human activities on concentrations, and to develop methods for aggregating and comparing impacts across different sectors and settings." (2-32)

- *Regional and Local Scale Phenomena*
  "Research indicates that there are limits to the predictability of regional and local scale phenomena. At this point, modeled projections of the future regional impacts of global climate change are often contradictory and are not sufficiently reliable tools for planning." (2-29)

  "We are just beginning to understand how climate variability and change influence the local and regional occurrence and severity of extreme events such as hurricanes, floods, droughts, and wildfires." (4-73)

- *Rapid Climate Change*
  "A cause for concern about which there is considerable uncertainty is the potential for changes in extreme events, and rapid, discontinuous changes in climate. ... The historical record of past climates revealed through the study of ancient ice cores and other paleoclimate data indicates that the climate system can change relatively rapidly in response to internal processes or rapidly changing external forcing. Increasing our understanding of the conditions that could give rise to events such as rapid changes in ocean circulation is a key aspect of CCSP-supported research." (2-29)

"We have yet to obtain confident estimates of the likelihood of abrupt climate transitions, although such events have occurred in the past (NRC, 2002)." (4-74)

"The Climate Variability and Change element will play a central integrating role in the Climate Change Science Program (CCSP)." (4-75)

"Analyses of the paleoclimate record—the record of the Earth's environmental history derived from sources such as ice cores, tree rings, and lake and ocean sediments—provide compelling evidence for past abrupt climate changes. In some locations, changes of up to 16°C in temperature and a factor of two in precipitation have occurred within decades to years, yet lasted for centuries and longer (NRC, 2002). Paleoclimate data indicate that these changes have been manifested by significant shifts in the baseline climate and in the character and patterns of variations about average conditions." (4-83-84)

"Abrupt climate changes may be associated with the crossing of a climatic threshold, the onset of nonlinear responses, or feedbacks in the climate system. To date, however, the causes of past abrupt changes are not fully explained or understood. In addition, present climate models fail to adequately capture the magnitude, rapidity, and geographical extent of past abrupt changes." (4-84)

"Improved paleoclimatic data sets, expanded observing and monitoring systems and rigorous paleoclimate modeling studies will be required to identify the causes and mechanisms of past abrupt changes." (4-84)

- *Natural versus Human Induced Change*
  "Because there is a substantial range of natural variability in the climate system due to internal processes alone, it is difficult to distinguish natural excursions from the 'norm' from changes that might be the result of forcing due to human activities, such as land-use change and aerosols." (5-101)

  "Geological and paleoclimatic records indicate that major changes in carbon cycle dynamics have occurred in the past. These changes have been attributed to a variety of feedbacks, non-linear responses, threshold effects, or rare events. For example, there is evidence that huge, near-instantaneous releases of CH_4, very likely from clathrate (CH_4 hydrate) deposits, have affected the climate system in the past. Changes in the ocean's thermohaline circulation may have caused large changes in ocean CO_2 uptake. Failure to consider such possibilities in model projections could result in large over- or under-estimates of future atmospheric carbon concentrations, with consequent implications for policy scenarios." (7-147)

  "We now know that effects of environmental changes and variability may be manifested in complex, indirect, and conflicting ways." (8-161)

> "Improvements in how scientific uncertainty is evaluated and communicated can help reduce misuse of this information." (2-36)

B. Statements on Some of the Principle Natural Climate Variation Mechanisms

In many respect consistent with numerous National Academy of Science reports on climate change and the importance of, and lack of knowledge about, natural variation, the *Strategic Plan* addresses a substantial range of mechanisms that contribute to natural climate variability. In some instances, however, how the *Plan* addresses some of these mechanisms is cursory at best.

1. Solar energy variation - direct and indirect.

While support is growing for the view that solar activity may play a far more significant role in long term climate change than believed in the past, the Strategic Plan in fact contains relatively few references to this potentially significant phenomenon. Among the few references to solar variability is the following:

> "Although observed changes in incoming solar radiation, a natural climate forcing, are small relative to changes in net radiative forcing by greenhouse gases (IPCC, 2001a, b) there is some evidence that feedbacks within the climate system may magnify otherwise weak solar variability. In spite of many research efforts over the past several decades and longer, the physical processes responsible for such feedbacks remain uncertain." (4-76)

2. Internal oscillations - PDO, NAO, AO, ENSO, etc.

> "El Nino-Southern Oscillation (ENSO) is a widely-recognized, large-scale climate oscillation in the equatorial Pacific Ocean that changes phase every few years, with significant implications for resource and disaster management. There are other climate cycles that last decades, centuries, and even millennia, as revealed in studies of the Earth's climate history." (2-22)

> "We have identified several major recurrent natural patterns of climate variability other than ENSO, but do not yet know to what extent they are predictable." (4-73)

> "One of the major advances in climate science over the past decade has been the recognition that much of the climate variability is associated with a relatively small number of recurrent spatial patterns, or climate modes. These include, in addition to ENSO, the North Atlantic Oscillation (NAO), the northern and southern hemisphere annular modes (NAM, SAM), Pacific Decadal Variability (PDV), Tropical Atlantic Variability (TAV), the Tropical Intra-Seasonal Oscillation (TISO), and monsoon systems. At present, there is limited understanding of the physical mechanisms that produce and maintain natural climate modes..." (4-80)

"There is now compelling evidence that some natural climate variations, such as ENSO, PDV, and the NAO/NAM, can significantly alter the behavior of extreme events, including floods, droughts, hurricanes, and cold waves (IPCC, 2001a, b)." (4-86)

"A question central to both short-term climate predictions and longer-term climate change is how climate variability and change will alter the probability distributions of various quantities, such as of temperature and precipitation, as well as related temporal characteristics (e.g., persistence), and hence the likelihood of extreme events." (4-86)

"Understanding of the processes by which climate variability and change modulate extreme event behavior is incomplete." (4-86)

"It will be necessary to advance scientific understanding and quantitative estimates of how natural climate variations such as ENSO, NAO/NAM, SAM, or PDV alter the probabilities of extreme events (e.g., floods, droughts, hurricanes, or storm surges)." (4-87)

"Higher-resolution paleoclimatic data will be necessary to improve descriptions and understanding of how natural climate variations have in the past altered drought, mega-drought, flood, and tropical storm variability." (4-87)

"As climate knowledge improves, evaluation can be extended to multi-year and decadal time scales, which will provide an important bridge to policy and decision options related to longer-term changes." (4-90)

3. Ocean variation.

"Some critical ocean phenomena, including ocean mixing and large-scale circulation features that determine the rate of storage and transport, remain as key challenges to understand, assess, and model." (4-76)

"Significant research into how to numerically model the full three-dimensional circulation of the ocean will be required in order to accurately project impacts and time scales for abrupt changes, which range from interannual ENSO variability to centennial-millennial fluctuations in the ocean circulation." (4-84-85)

"The future behavior of the ocean carbon sink is most uncertain because of potentially large feedbacks among climate change, ocean circulation, marine ecosystems, and ocean carbon cycle processes." (7-141)

"Research will be required to integrate and reconcile oceanic and atmospheric carbon uptake estimates through enhanced data synthesis and numerical

> modeling approaches including both forward and inverse models as well as data assimilation. Data from the Climate Variability and Change research element will be needed to support the development and implementation of models linking climate, ocean circulation, ocean carbon biogeochemistry, and marine ecosystem dynamics to assess more accurately the relationship of carbon sources and sinks to global climate change." (7-142)

4. Biospheric variation.
Biosphere is another mechanism that receives relatively little attention in the Strategic Plan. Among the references are the following.

> "The interaction between land use and climate variability and change is poorly understood and will require the development of new models linking the geophysics of climate with the socioeconomic drivers of land use." (6-119)

> "An innovative approach is needed to quantify, understand, model, and project natural and human drivers of land-use and land-cover change." (6-123)

5. Surface versus satellite temperature variation.
Note: there are very few references to this mechanism in the Strategic Plan.

> "Uncertainty about natural oscillations in climate on scales of several decades or longer and inconsistencies in the temperature profiles of different data sets are critical scientific questions that must be addressed to improve confidence in the understanding of how and why climate has changed." (2-22)

> "Inconsistencies in the temperature profiles of different data sets reduce confidence in understanding of how and why climate has changed." (2-23)

6. Aerosol forcing mechanisms.

> "There is a high level of uncertainty about how climate may be affected by different types of aerosols, both warming and cooling, and thus how climate change might be affected by their control." (2-27)

> "One of the largest uncertainties about the net impact of aerosols on climate is the diverse warming and cooling influences of the very complex mixture of aerosol types and their spatial distributions. Further, the poorly understood impact of aerosols on the formation of both water droplets and ice crystals in clouds also results in large uncertainties in the ability to project climate changes." (3-55)

"The relationship of aerosols to climate change is complex because of the diverse formation and transformation processes involving aerosols. This complexity underlies many of the important research questions related to aerosols." (3-55)

"Significant research is required to complete our understanding of aerosols and their role in climate change processes. The representation of aerosol properties and their distribution in the atmosphere is highly complex." (3-56)

"Uncertainties related to the effects of aerosols on climate are large, with both warming and cooling effects possible depending on the nature and distribution of the aerosol." (3-57)

7. The hydrologic cycle.

"Critical processes that are inadequately represented in climate models include atmospheric convection, the hydrological cycle, and cloud radiative forcing processes." (4-76)

"Inadequate understanding of and limited ability to model and predict water cycle processes and their associated feedbacks account for many of the uncertainties associated with our understanding of long-term changes in the climate system and their potential impacts." (5-98)

"The distribution and nature of atmospheric aerosols have an effect on both cloud radiative properties and the generation of precipitation. Moreover, the impact of increased upper tropospheric/ lower stratospheric water vapor on the radiative balance and cloud structure is potentially quite large. These effects are not yet well enough understood to accurately project their impact on water and energy cycles or to predict the effects of climate change on regional water resources. Although significant advances have been made in modeling moderately sized watersheds, current global climate models cannot properly simulate many aspects of the global water cycle, such as precipitation amounts, frequency, and diurnal cycle, as well as cloud distribution and its influence on climate. Without appropriate models to conduct tests, it is difficult to attribute observed trends to human-induced climate changes or natural variability." (5-101)

"Appropriate paleoclimate data sets must be assembled to provide a long-term perspective on water cycle variability. New models are needed that can simulate critical water processes at resolutions that allow comparison with long-term data sets. Finally, a wide range of process studies must be conducted to provide understanding of the mechanisms that maintain the water cycle system." (5-102)

"Clouds strongly influence the energy budget because of their impact on the radiative balance, but the net cloud-radiation feedback is uncertain. Quantifying the water vapor-cloud-radiation feedback is key to understanding climate sensitivity and the factors governing climate change." (5-103)

"Given the same greenhouse gas increases, individual climate models produce different rates of warming and drastically different patterns of circulation, precipitation, and soil moisture depending on how feedback processes are represented in the models. Basic understanding of feedback processes must be improved and incorporated into models." (5-103)

"New parameterizations of water cycle/ climate feedbacks (e.g., cloud-aerosol and land-atmosphere) and sub-grid scale processes (e.g., clouds, precipitation, evaporation) will have to be developed and validated, and the sensitivity of global climate models to these new parameterizations will have to be evaluated." (5-104)

"While precipitation forecasts on “weather” time scales have improved, current global and regional models demonstrate limited skill in predicting precipitation, soil moisture, and runoff on seasonal and longer time scales." (5-105)

II. Milestones for Resolving Key Uncertainties.

The Strategic Plan's strategy for addressing key science uncertainties, including natural climate variability, is to establish specific research efforts along with goals or "milestones" for their completion. The Plan establishes milestone timelines ranging from "beyond 4 years" to shorter time horizons. This is an important effort, but a very difficult one.

This effort also provides a key to understanding what and when certain scientific uncertainties might be reduced. The long time horizon for addressing key scientific uncertainties implicit in the *Strategic Plan* can be seen by grouping the key milestones in the *Plan* into the following categories:

- Basic data and historic information for analysis;
- Understanding of physical/chemical processes;
- Climate modeling, assumptions, and testing;
- Quantification of potential changes;
- Assessment of potential predictability;
- Improved ability to separate human-induced from natural-induced climate forcing.

When these milestones are analyzed, they reveal a startling fact: many of the milestones focus on basic data development – data that is the starting point for evaluating and then modeling possible mechanisms. If basic data is not available for four or more years, the process for separating human-induced climate change from natural climate change or variability must necessarily be a long one.

A. Beyond Four Years Milestones

Basic Data and Historic Information For Analysis

- "Characterization of the impact of human activities and natural sources on global and regional aerosol distributions [beyond 4 years]." (3-58)
- "Quantitative estimates of carbon fluxes from managed and unmanaged ecosystems in North America and surrounding oceans, with regional specificity [beyond 4 years]." (7-140)
- "An evaluation of how North American emissions contribute to and influence global atmospheric composition [beyond 4 years]." (3-62)
- "Documentation of trends in key water cycle variables through data analysis, and comparisons with model simulations to assess the mechanisms responsible for these trends [beyond 4 years]." (5-102)

- "Improved regional water cycle process parameterizations based on process studies conducted over regional test beds to improve the reliability of climate change projections [beyond 4 years]." (5-102)
- "Development of analyses for a State of the Water Cycle evaluation [beyond 4 years]." (5-102)
- "New space-based systems for measuring global precipitation will be developed and implemented to support the needs of the Climate Variability and Change, Carbon Cycle, and Land-Use/ Land-Cover Change elements [beyond 4 years]." (5-107)
- "Report on past trends in land cover or land use that are attributable to changes in climate (e.g., changes in forest type, changes in specific agricultural crops, or changes in the presence or absence of agriculture) [beyond 4 years]." (6-127)
- "Reports on the effects of land use and land cover on the mitigation and management of greenhouse gases [beyond 4 years]." (6-127)
- "Landscape-scale estimates of carbon stocks in agricultural, forest, and range systems and unmanaged ecosystems from spatially-resolved carbon inventory and remote sensing data [beyond 4 years]." (7-140)
- "Prototype State of the Carbon Cycle Report focused on North America (2 years); more comprehensive report [beyond 4 years]." (7-140)
- "Observational and modeling constraints on ocean carbon dynamics, land-ocean exchange, and air-sea fluxes for the continental margin regions surrounding North America [beyond 4 years]." (7-143)
- "Quantification of global air-sea fluxes of CO_2, lateral ocean carbon transport, delivery of carbon from the land to the ocean, particle fluxes and export rates, and the spatial distribution of carbon in the ocean on seasonal to interannual time scales using remote and in situ measurements and data assimilation models [beyond 4 years]." (7-143)

Understanding of Physical/Chemical Processes

- "Better understanding and description of the physical and chemical processes (and their uncertainties) that form, transform, and remove aerosols during long-range atmospheric transport [beyond 4 years]." (3-58)
- "Estimates of the climate sensitivity and potential feedbacks to climate change of carbon cycling processes in the Southern Ocean [beyond 4 years]." (7-143)
- "Analysis of global CH_4 dynamics, with the potential for reduced uncertainties, based on a new synthesis of observational data and improved models that address radiative forcing and the potential for abrupt change [beyond 4 years]." (7-149)

Climate Modeling, Assumptions, and Testing

- "Estimates of atmospheric composition and related processes to be used in assessments of the vulnerability of ecosystems to urban growth and long-range chemical transport [beyond 4 years]." (3-62)

- "Diagnostic/prognostic models of the coupled climate, chemistry/transport, and ecological systems [beyond 4 years]." (3-65)
- "Improvements in the representation of major modes of climate variability in climate change projection models and predictions of regional patterns of different modes of climate variability [beyond 4 years]. (4-83)
- "In collaboration with Climate Variability and Change, sensitivity tests of global models to improve parameterizations of feedbacks and sub-grid scale processes (land-cover change, land surface processes, precipitation, clouds, etc.) [beyond 4 years]." (5-104)
- "Downscaling techniques, such as improved regional climate models, that bridge the disparate spatial and temporal scales between global model outputs and atmospheric, land surface, and river basin processes, for improved evaluation of potential water resource impacts arising from climate variability and change [beyond 4 years]." (5-107)
- "National and global models with a coupled climate-land use system [beyond 4 years]." (6-127)
- "Models of ocean uptake of carbon that integrate biogeochemistry, ocean circulation, and marine ecosystem responses [beyond 4 years]." (7-143)
- "Advanced carbon cycle models that incorporate improved parameterizations based on data from manipulative experiments, soil carbon transformation studies, and paleoclimatic and paleoecological studies [beyond 4 years]." (7-149)

Quantification of Potential Changes

- "Quantification of the potential changes in the cryosphere, including the effects of permafrost melting on regional hydrology and the carbon budget, and the consequences for mountain snowpacks, sea ice, and glaciers [beyond 4 years]." (5-104)
- "Report on projected trends in land cover or land uses that are attributable to changes in climate (e.g., changes in forest type, changes in specific agricultural crops, or changes in the presence or absence of agriculture) [beyond 4 years]." (6-127)
- "In collaboration with Climate Variability and Change, the capability for long-range prediction of drought and flood risks (seasonal to interannual time scales) [beyond 4 years]." (5-107)
- "Evaluation of the potential for dramatic changes in carbon storage and fluxes due to changes in climate, atmospheric composition, ecosystem disturbance, ocean circulation, and land-use change, and characterization of potential feedbacks to the climate system [beyond 4 years]." (7-149)
- "Quantification of important feedbacks from ecological systems to climate and atmospheric composition to improve the accuracy of climate projections [beyond 4 years]." (8-164)

Assessment of Potential Predictability

- "An assessment of potential predictability beyond ENSO, e.g., associated with PDV, NAO, annular modes, tropical Atlantic and Indian Ocean variability and trends, and the monsoons [beyond 4 years]." (4-83)
- "Estimates of the spatial and temporal limits of predictability of climate variability and change forced by human activities [beyond 4 years]." (4-83)
- "Improved projections of climate change forcings (i.e., atmospheric CO2 and CH4 concentrations) and quantification of dynamic feedbacks among the carbon cycle, human actions, and the climate system, with better estimates of errors and sources of uncertainty, from prognostic models [beyond 4 years]." (7-150)
- "Increased understanding of changes in natural variability and potential impacts on predictability that may result from anthropogenic forcing [beyond 4 years]." (4-83)

Improved Ability to Separate Human-Induced from Natural-Induced Climate Forcing

- "An improved ability to separate the contributions of natural versus human-induced climate forcing to climate variations and change, resulting in more credible answers to “If…, then…” policy-related questions [beyond 4 years]." (4-83)

B. 2 - 4 Years and Beyond Milestones

Basic Data and Historic Information for Analysis

- "New and improved climate data products, including: assimilated data from satellite retrievals and other remotely sensed and in situ data for model development and testing; consistent and regularly updated reanalysis data sets suitable for climate studies; centuries-long retrospective and projected climate system model data sets; high-resolution data sets for regional studies (e.g., Atmospheric Radiation Measurement site data to initialize and evaluate cloud resolving models); and assimilated aerosol, radiation, and cloud microphysical data for areas with high air pollution, such as urban centers throughout the world [2-4 years and beyond]." (4-78)
- "Targeted paleoclimatic time series as needed, for example, to establish key time series of observations and natural forcing mechanisms as benchmarks of climate variability and change [2-4 years and beyond]." (4-78)
- "Improved effectiveness of global and regional observing systems, including deployment of new systems and re-deployment of existing systems, based on guidance provided by modeled climate sensitivities and feedbacks [2-4 years and beyond]." (4-78)
- "Development and extension of critical data sets to improve analyses of climate variability and attribution of causes of climate change [2-4 years and beyond]." (4-82)

- "Improved observational databases, including paleoclimate and historical data records, and model simulations of past climate to detect and analyze regional trends in extreme events and to assess whether changes in the frequencies of extreme events lie within or outside the range of natural variability [2-4 years and beyond]." (4-88)

Understanding of Physical/Chemical Processes

- "Improved estimates of the climate response to different emissions (e.g., carbon dioxide (CO2), aerosols, black soot) and land-use scenarios [2-4 years and beyond]." (4-78)
- "Improved understanding and parameterizations of key mechanisms for seasonal-to-decadal variability, based on process studies together with modeling research and analyses [2-4 years and beyond]." (4-83)

Climate Modeling, Assumptions, and Testing

- "Refined estimates of the role of climate feedback processes in affecting climate sensitivity and improvements in their representation in climate models, leading to a narrowing of the range of climate model projections [2-4 years and beyond]." (4-78)
- "Increased understanding and confidence in attribution of the causes of recent and historical changes in the climate [2-4 years and beyond]." (4-78)
- "Improved high-resolution, three-dimensional ocean circulation models [2-4 years and beyond]." (4-82)
- "Improved representation of processes (e.g., thermal expansion, ice sheets, water storage, coastal subsidence) in climate models that are required for simulating and projecting sea level changes [2-4 years and beyond]." (4-83)
- "Improved diagnostic capabilities to better interpret the causes of high-impact climate events, such as droughts or unusually cold or warm seasons [2-4 years and beyond]." (4-88)

Quantification of Potential Changes

- "Policy-relevant information on climate sensitivities and the uncertainties in climate model projections due to climate system feedbacks, in support of the IPCC and other national and international assessments [2-4 years and beyond]." (4-78)

Assessment of Potential Predictability

- "Extended model-based data sets to assess predictability and develop new approaches to improving seasonal to interannual climate predictions [2-4 years and beyond]." (4-82)
- "Improved predictions of El Niño-LaNiña, particularly the onset and decay phases [2-4 years and beyond]." (4-82)
- "Assessments of potential predictability and forecasts of probabilities of extreme events associated with natural climate variations [2-4 years and beyond]." (4-88)

Improved Ability to Separate Human-Induced from Natural-Induced Climate Forcing

- "Improved probability forecasts of regional manifestations of seasonal climate anomalies resulting from ENSO [less than 2 years and beyond]." (4-82)
- "Policy-relevant information on natural climate variability and the potential predictability of climate variability and change in support of national and international science assessments [2-4 years and beyond]." (4-83)
- "Policy-relevant information on past variability and trends in extreme events, and probabilistic estimates of possible future changes in frequencies, intensities, and geographical distributions of extreme events in support of national and international assessments [2-4 years and beyond]." (4-88)

C. 2 – 4 Year Milestones

Basic Data and Historic Information for Analysis

- "Improved description of the global distributions of aerosols and their properties [2-4 years]." (3-57)
- "A 21st century chemical baseline for the Pacific region against which future changes can be assessed [2-4 years]." (3-62)
- "In 2006, the U.S. atmospheric research community will produce the first State of the Atmosphere report that describes and interprets the status of the characteristics and trends associated with atmospheric composition, ozone layer depletion, temperature, rainfall, and ecosystem exposure [2-4 years]." (3-65)
- "Dynamically consistent global time series of observations, e.g., regularly updated and extended global climate reanalyses; 50-year long, 1° ocean data assimilation products [2-4 years]." (4-82)
- "A paleoclimatic database designed to evaluate the ability of state-of-the-art climate models to simulate observed decadal- to century-scale climate change, responses to large changes in climate forcing, and abrupt climate change [2-4 years]." (4-82)
- "Improved estimates of global air-sea-land fluxes of heat, moisture, and momentum needed to discern characteristics of ocean-atmosphere-land coupling and to assess the global energy balance [2-4 years]." (4-82)
- "Planned satellite measurements and focused field studies to better characterize water vapor in the climate-critical area of the tropical tropopause (the boundary between the troposphere and the stratosphere) [2-4 years]." (5-102)
- "Regional and global precipitation products that merge measurements from different satellite and other remote sensing data streams to support joint Water Cycle/Climate Variability and Change studies of ocean- and land-atmosphere coupling and the global energy balance [2-4 years]." (5-102)
- "Integrated long-term global and regional data sets of critical water cycle variables such as evapotranspiration, soil moisture, groundwater, clouds, etc. from satellite and in situ observations for monitoring climate trends and early detection of potential climate change [2-4 years]." (5-102)
- "Enhanced data sets for feedback studies, including water cycle variables, aerosols, vegetation, and other related feedback variables, generated from a

combination of satellite and ground-based data [2-4 years]. These data sets will be critical for most CCSP elements." (5-104)
- "Quantitative measures of atmospheric CO_2 and CH_4 concentrations and related tracers in under-sampled locations [2-4 years]." (7-140)
- "Quantification of temporal changes in the global ocean inventories of anthropogenic carbon and related biogeochemical constituents [2-4 years]." (7-143)
- "Estimates of the interannual variability in the regional and basin-scale air-sea CO_2 fluxes for the North Atlantic and North Pacific based on in situ measurements, remote sensing, and data assimilation [2-4 years]." (7-143)
- "Definition of the initial requirements for ecosystem observations to quantify feedbacks to climate and atmospheric composition, to enhance existing observing systems, and to guide development of new observing capabilities [2-4 years]." (8-164)

Understanding of Physical/Chemical Processes
- "Empirically tested evaluation of the capabilities of current models to link emissions to (i) global aerosol distributions and (ii) the chemical and radiative properties (and their uncertainties) of aerosols [2-4 years]." (3-57)
- "An estimate of the indirect climate effects of aerosols (e.g., on clouds) that is improved beyond the estimate in the last Intergovernmental Panel on Climate Change report [2-4 years]." (3-58)
- "Observationally-assessed and improved uncertainty ranges of the radiative forcing of the chemically-active greenhouse gases [2-4 years]." (3-60)
- "Strengthened processes within the national and international scientific communities providing for integrated evaluations of the impacts on human health and ecosystems caused by the intercontinental transport of pollutants, the impact of air pollutants on climate, and the impact of climate change on air pollutants. The evaluations will be useful in developing integrated control strategies to benefit both regional air quality and global climate change, and the local attainment of air quality standards [2-4 years]." (3-65)
- "Results from process studies related to the indirect effects of aerosols on clouds will be available for future assessments of climate sensitivity to aerosols [2-4 years]." (5-102)
- "Results from field and modeling experiments to study the role of mountain environments on precipitation and runoff production [2-4 years]." (5-107)
- "Sensitivity studies addressing how land use and land cover related changes in surface albedo, greenhouse gas fluxes, and particulates affect climate [2-4 years]." (6-127)
- "Report on the effects of land-use and land-cover changes on local carbon dynamics. The report will discuss implications for sources and sinks of terrestrial carbon and the overall carbon budget and will be developed in collaboration with the Carbon Cycle and the Climate Variability and Change research elements [2-4 years]." (6-127)

- "Greater understanding of the role of nutrients and trace metals, phytoplankton functional groups, primary productivity, and subsurface transport and dynamics in carbon export to the deep sea [2-4 years]." (7-143)
- "Improved models of ocean biogeochemical processes based on linkages with ocean observations from repeat transects and time-series measurements [2-4 years]." (7-143)

Climate Modeling, Assumptions, and Testing

- "A simulation of the changes in the impacts of global tropospheric ozone on radiative forcing over the past decade brought about by clean air regulations [2-4 years]." (3-61)
- "New observationally tested parameterizations for clouds and precipitation processes for use in climate models based on cloud-resolving models developed in part through field process studies [2-4 years]." (5-104)
- "Incorporation of water cycle processes, interactions, and feedbacks into an integrated Earth system modeling framework [2-4 years]." (5-104)
- "Carbon cycle models: customized for North America; with improved physical controls and characterization of respiration; and employing the first carbon data assimilation approaches [2-4 years]." (7-140)
- "Carbon models that include the long-term effects of land use [2-4 years]." (7-149)
- "Advanced carbon models able to simulate interannual variability at ecosystem, landscape, and ocean basin scales for selected areas [2-4 years]." (7-149)
- "Reports presenting a synthesis of current knowledge of observed and potential (modeled) feedbacks between ecosystems and climatic change to aid understanding of such feedbacks and identify knowledge gaps for research planning [2-4 years]." (8-164)

Quantification of Potential Changes

- "New drought monitoring and early warning products based on improved measurements of precipitation, soil moisture, and runoff, and data assimilation techniques to inform drought mitigation planning [2-4 years]." (5-107)
- "Metrics for representing the uncertainty in predictions of water cycle variables and measurably improved forecast products for water resource managers [2-4 years]." (5-107)

Assessment of Potential Predictability

- No key milestones.

Improved Ability to Separate Human-Induced from Natural-Induced Climate Forcing

- No key milestones.

D. Milestones for Less than 2 Years and Beyond, 2 Years, and Less than 2 Years

Basic Data and Historic Information for Analysis

- "Improved methodologies for carbon source and sink accounting in agriculture and forestry [2 years]." (7-140)
- "In collaboration with the Observing and Monitoring element, development of an integrated global observing strategy for water cycle variables, employing Observational System Simulation Experiments as appropriate [less than 2 years]" (5-102)
- "Regional reanalysis providing a wide range of high resolution, daily water cycle analysis products for a 25-year period, for use in analyzing features absent in global climate data assimilation products [less than 2 years]." (5-107)

Understanding of Physical/Chemical Processes

- "Analysis of existing databases and theories about climate-related processes that affect land-use change, including uncertainty analysis [less than 2 years]." (6-127)
- "Evaluation of how the type and distribution of land cover affects regional weather and climate patterns [less than 2 years]." (6-127)

Climate Modeling, Assumptions, and Testing

- No key milestones.

Quantification of Potential Changes

- No key milestones.

Assessment of Potential Predictability

- "Improved probability forecasts of regional manifestations of seasonal climate anomalies resulting from ENSO [less than 2 years and beyond]." (4-82)

Improved Ability to Separate Human-Induced from Natural-Induced Climate Forcing

- No key milestones.

III. Critical Dependencies -- the Missing Part of the *Plan*

The *Plan* defines "critical dependencies" as follows.

> "Critical dependencies -- Topics within the *Strategic Plan* for which progress in one research element is only possible if related research is first completed in other areas." (D-3)

'First completed' is the key concept here. If a milestone N is critically dependent on milestone M, then N cannot proceed until N is first completed. The *Plan* goes on to explain the nature and importance of critical dependencies in climate change research. For example:

> "The interdisciplinary research elements of the CCSP partition the overall Earth system and the issue of climate change into discrete and manageable sets of research problems. While partitioning the problem is necessary for both research and program management purposes, it carries with it the potential to divert attention from critical questions that are beyond the scope of the individual research elements, instead emphasizing lower priority issues that reside completely within a single research area." (2-37)

> "Thus, a key challenge facing the CCSP is engaging in integrated planning that 'puts back together' the pieces of the Earth system and fosters problem-driven interdisciplinary research. This is especially true for 'critical dependencies,' topics for which progress in one research element is only possible if related research is first completed in other areas. The CCSP will need to foster integration across research elements and disciplines; among basic research and supporting activities such as observations, modeling, and data management; in the development of comprehensive climate models; and between participating departments and agencies if it is to achieve its objectives." (2-37)

> "Because the components of the Earth system interact continuously, research in one program element often has a critical dependency with work in other elements. Critical dependencies can involve insights from process studies, data flows, model components, and other research and operational activities." (2-38)

> "The most obvious set of critical dependencies is in the area of observational data. In many cases, observations of the underlying physical state of the Earth system (e.g., temperature, precipitation history) are required before questions about climate or global change can be addressed." (2-39)

> "A challenge for the CCSP will be to coordinate production of information required to satisfy these critical dependencies so that they meet requirements and are sequenced properly. The CCSP will coordinate development of implementation plans for the research elements to meet this challenge." (2-39)

Of particular interest is the idea of the so-called "critical path." This is a common concept in project management. Given that some tasks have to be done before others, there is a network of precedence relations. If one maps these for a given project you get a network diagram. In this network there are various paths from the first tasks to the last ones. Different paths pass through different subsets of tasks, like A-->D-->R-->End. If you add the times to do each task, then each path has a time length. Typically there is one path that is longest, and that is the critical path. Slipping any task on that path will slip the entire project.

Let us assume that a desired end point of the Climate Change Science Program is when we can make a considered policy decision on human induced warming. The Strategic Plan describes many milestones, over 100, that must be met to achieve this goal. We can ask what the network looks like? We can also ask what the critical path is and how long it is?

Reading the Strategic Plan, we conjecture that many of the various milestone time estimates simply ignore these critical dependency network aspects. That is, there are milestones that say "we will do N in 2 years" and "we will do R" in 2 years", but R is critically dependent on N. If N and R each take 2 years, then R takes 4 years to complete, not 2 years.

In particular, many of the time estimates for climate forecasts, especially regional forecasts, seem to be unrealistically near. Given that many of the fundamental climate research issues have time estimates of "beyond 4 years," it is unrealistic to envision any form of climate forecasting in a shorter time frame.

We must ask what the critical path is, and how long it is?

IV. Natural versus Human Induced Change-- a Systemic Confusion

The concepts of natural climate variability and human induced climate change are often conflated. In the *Plan*, "climate variability" means natural change. "Climate change" sometimes refers to human induced change, but sometimes it refers to change in general, regardless of cause.

These are very different research issues, in fact the distinction goes to the heart of the climate change policy debate. The effect of human activities on climate -- past, present, or future -- cannot be determined if we do not first understand natural variation. So natural variation should be a major focus of research. It is therefore unfortunate that much of the *Plan*'s discussion of climate change is couched in terms that combine these two concepts, and so confuses them. For example, regarding extreme events, the *Plan* says the following.

> "A question central to both short-term climate predictions and longer-term climate change is how climate variability and change will alter the probability distributions of various quantities, such as of temperature and precipitation, as well as related temporal characteristics (e.g., persistence), and hence the likelihood of extreme events." (4-86)

The term "change" is used twice in rapid succession. First to refer to general change and second to refer to human induced change. But there is no indication that this is so. Then too, the concepts of natural variability and human induced change are combined in such a way that an important point is missed. Namely, that the effect of natural variability on the probability of extreme events must be determined before the effect of human activity can be begun to be estimated.

Much of the discussion of climate variability and change in the *Plan* follows this conflating format. Indeed, it flows from the *Plan*'s own definitions, which are given as follows.

> "Climate variability -- Variations in the mean state and other statistics of climatic features on temporal and spatial scales beyond those of individual weather events. These often are due to internal processes within the climate system. Examples of cyclical forms of climate variability include El Niño Southern Oscillation, the North Atlantic Oscillation (NAO), and Pacific Decadal Variability (PDV). See also climate change." (D-3)

> "Climate change -- A statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or to external forcing, including changes in solar radiation and volcanic eruptions, or to persistent human-induced changes in atmospheric composition or in land use. See also climate variability." (D-2)

Technically, there is no clear difference between these two definitions. Climate change may be natural or human induced. Climate variability is "often due to internal processes," but this does not exclude human influence. In practice, however, "variability" is often used to mean natural variability and "change" to mean human induced change, but not always.

The resulting ambiguity is pervasive. In many places it is impossible to tell whether the research issue in question has to do with natural variability, or human induced change. The unfortunate consequence is that what should be the focal point of research is in fact not well described at all.

Appendix A:
Executive Summary of Our Previous Report on Natural Variability.

The New View of Natural Climate Variation
Fundamental Climate Science Issues
Raised In 6 Major National Academy of Science Studies
January, 2003.

EXECUTIVE SUMMARY

Six different National Academy of Science [NAS] reports since 1998 have identified very fundamental questions that have to be faced when making a credible assessment of climate change – and our current ability to understand and project possible change in the future. In many instances new scientific research is beginning to address some of these key issues, but just beginning.

When viewed in their entirety, these NAS reports go to the very core of the question of "uncertainty" in climate modeling. Traditionally, "uncertainty" has been interpreted as an "error bar" --- for a given increase in Greenhouse Gas (GHG) emissions, what is the range of likely and/or potential increases in global temperature?

The issues in the NAS reports and recent research are far more fundamental and clash with an underlying premise of much climate modeling over the past decade – that climate over the past century and a half has been effectively constant and any changes are primarily because of man's activity. As stated by the National Academy of Sciences:

"The evidence of natural variations in the climate system -- which was once assumed to be relatively stable -- clearly reveals that climate has changed, is changing, and will continue to do so with or without anthropogenic influences." (*Dec-Cen Variability*, Summary)

If climate has been as volatile on decade to century or longer scales as is now become apparent, due to multiple mechanisms, then the following deep questions arise:

-- Do we have an accurate understanding of past climate changes?
-- Do we know what has caused past changes in climate?
-- Do we know why climate is changing today?
-- Do we know how to model these mechanisms?
-- Can we separate the impact of these new factors from the potential influence of greenhouse gas emissions or other potential anthropogenic impacts?

What is so important is that this understanding - of what we do not understand - is a recent development.

The difference our new found lack of understanding makes is also simple. In a naturally changing climate rather than a stable climate, it is far more difficult to tell if and how human activities have had a discernible influence on climate, or how human activities may influence the future. Since we do not yet know why climate changes, we do not yet know why it has changed in the last century, or even how it has changed. We also cannot yet say how it is likely to change in the future.

The conclusion is obvious. We must now direct our climate change research effort to confront our newly found lack of understanding. A decade of research has taught us what we don't know. It has taught us important questions. Now we must seek the answers.

This report has a single goal. That goal is to catalog key uncertainties in a naturally varying climate system -- uncertainties that range from observation to explanation to modeling -- that have been clearly documented in at least six major studies by the U.S. National Academy of Sciences.

These studies were:
-- *Abrupt Climate Change: Inevitable Surprises* (2001);
-- *Climate Change Science: An Analysis of Some Key Questions* (2001);
-- *Decade-to-Century-Scale Climate Variability and Change: A Science Strategy* (1998);
-- *Global Environmental Change: Research Pathways for the Next Decade* (1999);
-- *Issues in the Integration of Research and Operational Satellite Systems for Climate Research: Part I. Science and Design* (2000); and
-- *The Atmospheric Sciences: Entering the Twenty-First Century* (1998).

The descriptions of these key uncertainties have been scattered within these reports, numbering thousands of pages, and thus are not clearly or widely recognized.

So, in keeping with the rest of this report, we here present a set of quotes from these major NAS studies that clearly state what we have just said - we do not know the extent of climate change in the past, we do not know why climate changes, and we must focus our research on this issue. Only then can we integrate the potential role of past increases in GHG emissions into recent climate history, and only then can we begin to assess the outlook for future climate.

<u>Sample quotations from the NAS reports</u>.

> "Climate research on decade to century ("dec-cen") timescales is relatively new. Only recently have we obtained sufficient high-resolution paleoclimate records, and acquired faster computers and improved models allowing long-term simulations, to examine past change on these timescales. This research has led to genuinely novel insights, most notably that **the past assumption of a relatively stable climate state on dec-cen timescales since the last**

glaciation is no longer a viable tenet. The paleorecords reveal considerable variability occurring over all timescales, while modeling and theoretical studies indicate modes of internal and coupled variability driving variations over dec-cen timescales as well." (*Pathways*, p. 129, Changes in the Climate System on Decadal to Century timescales, Introduction. Emphasis added.)

"Thus, **dec-cen climate research is only at the beginning of its learning curve**, with dramatic findings appearing at an impressive rate. In this area **even the most fundamental scientific issues are evolving rapidly**. Adaptability to new directions and opportunities is therefore imperative to advance understanding of climate variability and change on these timescales." (*Pathways*, p. 129, Changes in the Climate System on Decadal to Century timescales, Introduction. Emphasis added.)

"To date, **we do not have a comprehensive inventory of global patterns, nor do we understand their mechanisms**, couplings, longevity, or full implications for climate predictions." (*Pathways*, p. 140. Emphasis added.)

"The new paradigm of an abruptly changing climatic system has been well established by research over the last decade, **but this new thinking is little known and scarcely appreciated in the wider community of natural and social scientists and policy-makers**." (*Abrupt Climate Change*, p. 1. Emphasis added.)

"The climate change and variability that we experience will be a commingling of the ever changing natural climate state with any anthropogenic change. While we are ultimately interested in understanding and predicting how climate will change, regardless of the cause, an ability to differentiate anthropogenic change from natural variability is fundamental to help guide policy decisions, treaty negotiations, and adaptation versus mitigation strategies**. Without a clear understanding of how climate has changed naturally in the past, and the mechanisms involved, our ability to interpret any future change will be significantly confounded and our ability to predict future change severely curtailed."** (*Dec-Cen Variability*, Preface, Emphasis added.)

"Large gaps in our knowledge of interannual and decade-to-century natural variability hinder our ability to provide credible predictive skill or to distinguish the role of human activities from natural variability. Narrowing these uncertainties and applying our understanding define the mission of climate and climate change research and education for the twenty-first century." (*Atmospheric Sciences*, p. 278. Emphasis added.)

"For example, **is the accelerated warming the result of natural variability caused by an unusually persistent coincidence of the NAO [North Atlantic Oscillation] and PNA [Pacific-North American teleconnection], or the result of the modification of natural modes (patterns) by anthropogenic changes**

in radiative forcing that alter the phasing, or some combination of both of these? Likewise, there appears to have been a distinct change in the character (frequency and severity) of El Nino and La Nina events during this period of accelerated warming. Is this a consequence of the influence of anthropogenic change on the dominant natural modes of climate variability, or is it a natural, low-frequency (dec-cen) modulation of a high-frequency (interannual) mode?" (*Dec-Cen Variability*, Summary. Emphasis added.)

"The characteristic scales of climate variability demand long time series in order to determine the critical processes as well as to separate natural variability from anthropogenic influences. **Unlike weather forecasting, the interval between stimulus and response can be years to centuries.** With a high level of background variability, subtle changes in Earth's climate system can be difficult to detect." (*Integration of Research and* Satellites, p. 8. Emphasis added.)

"A satisfactory demonstration of secular trends in the Earth's climate system ... requires analysis at the forefront of science and statistical analysis. **Model predictions have been available for decades, but a clear demonstration of their validity, a demonstration that will convince a reasoned critic on cross examination, is not yet available.** This is not in itself either a statement of failure or a significant surprise. Rather, it is a measure of the intellectual depth of the problem and the need for carefully orchestrated, long term observations." (*Pathways*, p. 522, Research Imperatives, Crosscutting Themes. Emphasis added.)

"**Climate variability and change on decade to century timescales involves all of the elements of the U.S. Global Change Research Program**: natural and anthropogenic variability and change; past, present, and future observational networks and databases; modeling requirements; and physical, chemical, biological, and social sciences, with considerable attention to the human dimensions of climate change." (*Pathways*, pp. 129-130, Changes in the Climate System on Decadal to Century timescales, Introduction. Emphasis added.)

"Recommendation 1: **Research priorities and resource allocations must be reassessed, with the objective of tying available resources directly to the major unanswered Scientific Questions** identified in this report. The USGCRP's research strategy should be centered on sharply defined and effectively executed programs and should recognize the essential need for focused observations, both space-based and in situ, to test scientific hypotheses and document change." (*Pathways*, p. 521, Research Imperatives. Emphasis added.)

"Recommendation 2: Following on Recommendation 1, **the national strategy of the USGCRP for Earth observations must be restructured and must be**

> **driven by the key unanswered Scientific Questions**." (*Pathways*, p. 523, Research Imperatives. Emphasis added.)

Natural climate variability is a key element in the "major unanswered Scientific Questions" referred to above and is the topic of this report. Taken together, they present a new view of climate change, a view dominated by natural variation, in ways we do not yet understand.

The implications of this new view of natural variability and the NAS studies is clear and stated succinctly in *Climate Change Science: An Analysis of Some Key Questions:*

> "**Predictions of global climate change will require major advances in understanding and modeling**..." (*Climate Change Science*, p 23, Research Priorities. Emphasis added.)

The complete earlier study of climate science uncertainties presented in 6 major National Academy of Sciences (National Research Council) reports is available at: <http://www.nam.org/wojick>.

Appendix B:
CCSP Strategic Plan Chapters Cited in this Study.

The Strategic Plan of the U.S. Climate Change Science Program is available at <http://www.climatescience.gov./Library/stratplan2003/>.

The Chapters addressed in this assessment are:

CHAPTER 2. INTEGRATING CLIMATE AND GLOBAL CHANGE RESEARCH.

CHAPTER 3. ATMOSPHERIC COMPOSITION.

CHAPTER 4. CLIMATE VARIABILITY AND CHANGE.

CHAPTER 5. WATER CYCLE.

CHAPTER 6. LAND-USE/LAND-COVER CHANGE.

CHAPTER 7. CARBON CYCLE.

CHAPTER 8. ECOSYSTEMS.