

Uncertainties: How Little Do We Really Understand?

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Introduction

Just after Neal Lane was confirmed as director of OSTP, I was asked to bring all the presentation materials that I had and meet with him for two hours to help him gain an understanding of the climate change issue. We ended up spending almost four hours as Neal asked many challenging questions and probed deeply to better understand what the issue was all about. Neal quickly developed an excellent sense of the issue as he prepared for an upcoming Congressional hearing on the subject. Neal does not want to learn just a little, he wants to learn a lot.

Like that occasion, my talks usually focus on what is known about the changing climate. For this talk, however, I was asked to talk about what we don't know, what the uncertainties are and the prospects for doing something about them.

Background

Since its assessment process began in 1990, each of the successive reports of the Intergovernmental Panel on Climate Change (IPCC) has summarized the rapidly improving understanding of the science and strengthened the findings that human activities are having an increasing effect on the global climate and that the future will bring even more rapid change. The IPCC is not some patched together international committee, but a means of bringing together hundreds of the world's best scientists as authors and thousands as reviewers to generate truly authoritative technical reviews of scientific understanding. Then, through an intense dialogue process that builds on the scientific review chapters, experts in interpreting technical matters for government leaders representing over 150 countries work with the leading authors to prepare an overview intended to carefully convey the meaning of the science to policymakers. In doing this, they translate the findings from the hypothesis-testing paradigm to the relative risk paradigm that decision-makers on public issues seem most interested in having provided (a process similar to a medical doctor and patient engaging in a dialogue about the significance of the latest medical advance for their particular situation). While exceedingly time-consuming and intense, the process has, in a very real sense, worked miracles, producing documents that have been unanimously agreed to without dissent by all of the countries and by all of the leading scientists serving as

lead authors—and the agreement is not just about the main points and overall thrust, but with every word and phrase.

This is not to say that some of the participants would not prefer a slight adjustment here or there—after all, understanding past behavior and projecting future behavior of the Earth system over time scales of centuries is arguably the most difficult of all the many grand challenges faced by the scientific community, both in terms of innate complexity and in terms of the matters at stake. Not surprisingly, therefore, formulation of the results in terms of likely, and even unlikely, but possible, ranges is the approach used to gain unanimous support—make the umbrella big enough so that the results of every well-qualified scientific result can fit under it, where well-qualified means that the result remains plausible after not only journal review but after intense interaction among authors and international scientific review. Every scientist in the world is given the opportunity through their work to try to enlarge the umbrella, or to punch a hole in the results—with so many scientists and countries being interested, every finding of possible relevance gets considered. This process assures that the consideration is thorough and that findings do not go beyond what is widely accepted. In no way can the IPCC's results be said to be over the edge environmental rhetoric—every IPCC participant is skeptically challenging everything that is said, making sure every statement can be strongly backed up. If ever there was a process that should be viewed as providing authoritative results, this is it.

For most of the nations and companies in the world, the IPCC results have been widely accepted—but not for a number of companies based in the US and now for members of the Administration and one side in the Congress. Funded by special interests, including a major corporation based here in Houston, a relatively small set of scientists and a larger set of lawyers and lobbyists has morphed the natural inclination of skepticism of all responsible scientists into a movement that they have named *The Skeptics*, transforming what would normally be a traditional discussion of how well established the ranges of estimates are into a polarized debate where evidence is selected and interpreted in highly one-sided and often unjustified ways. This past Halloween-week, when the Senate debated the climate change issue for the first time in 5 years, has seen a truly distressing manifestation of scientific findings being misinterpreted, brushing aside the careful laying out of scientific results and of how well the IPCC's findings can be justified. All of the careful efforts that were made as part of the IPCC process (and also the US National Assessment process) to create lexicons of levels of confidence so that words were carefully defined and thoughtfully used are being obliterated in fusillades of imprecise talk and objections to the science. Rather than accept the measured statements of a thoughtful process, individual Senators are pulling out results from this paper or that and suggesting that a single result, too often a result that has not even been thoroughly peer-reviewed, is shifting the proverbial pyramid of knowledge that the scientific community has carefully built through its traditions of review and the testing of statistical significance. As a result, the discussion of the science itself, not just questions of how one might respond to the science, has become polarized and partisan.

In the face of this externally generated disruption of the traditional interpretation and evaluation of the state of scientific understanding with carefully stated uncertainties, we

now seem to have two types of uncertainties—those that are being identified and emphasized by special interests, and those that are the really significant uncertainties in the scientific sense. A few comments about the most important of each type seem in order.

Uncertainties Emphasized by the Special Interests

There are quite a host of aspects of the issue that *The Skeptics* claim are so uncertain that the whole notion of global warming should be overturned, at least Senator Inhofe in his protestations seems to be giving this impression. Among the most frequently mentioned uncertainties are the following, for each of which I'll also offer a comment on its present status:

1. *Changes in tropospheric and surface temperatures do not match*: Although Christy and Spencer have yet to acknowledge the new findings, an independent attempt to use the satellite data to reproduce their results—a step called for by the NRC a few years ago—yields a trend line that quite closely matches the surface temperature record, while also matching an independent record of change in tropopause height. The difference in the trends of the satellite results occurs because of differences in the approach used to calibrate satellite sensors on different satellites. That the results are so sensitive to such calibrations makes clear that the uncertainty limits claimed by Christy and Spencer were really measures of precision, and not overall uncertainty.
2. *Temperatures 1000 years ago were as warm as current conditions—the warming of the 20th century is just a natural fluctuation*: This claim turns out to be based primarily on results from around the North Atlantic basin and results from around the globe do not show simultaneous changes in all regions. Indeed, there are times when limited regions may have undergone a fluctuation that made conditions for a decade or so as warm as at present, but not a time when virtually all regions were at or above their historic highs at the same time. Multiple reconstructions based on a wide range of proxy indicators, including tree rings, corals, etc., now convincingly indicate that the 20th century was, with very high confidence, the warmest period in the last 1000 years¹, and suggestive that this is the case throughout the Holocene (the last 10,000 years), meaning in the last 120,000 years since the last interglacial. Counting the number of papers is not an accepted way to estimate uncertainty, yet this is the approach of *The Skeptics*.

¹ The Skeptic community is currently abuzz over a paper by two Canadians, one a retired mining official and the other an economist, that purports to find serious errors in the seminal paper by Michael Mann and colleagues reporting on the temperature record of the past 1000 years. A rebuttal was issued October 31 by Mann and colleagues pointing out obvious and very serious flaws in the McIntyre and McKittrick critique, errors so egregious and timing so fortuitous that it makes one wonder if there has not been some skullduggery involved.

3. *Twentieth century warming is primarily a recovery from the Little Ice Age and results largely from natural changes in solar output* (or changes in cosmic rays, or solar field strength, or the lengths of sunspot cycles, or whatever curve one can construct) rather than the increase in greenhouse gas concentrations. Most of these claims are based on little more than correlations rather than on causal mechanisms supported by high quality, or even any quantitative, data. Some claims require small changes in a solar parameter to magically have large effects on the climate while insisting that much larger changes in energy due to the increasing concentrations of greenhouse gases will only cause small changes in temperature. A number of these results would require overturning all that science has learned about global and planetary energetics while failing to explain how the Sun possibly knows to initiate its unique changes at exactly the same time that human activities start having an influence. In these arguments, *The Skeptics* glory in reporting the uncertainties described by IPCC about greenhouse gases and climate sensitivity while the same uncertainty is waved away in presentations that would make a revivalist preacher proud.
4. *The time history of 20th century warming does not match the rise in the CO₂ concentration*: In such criticisms, *The Skeptics* compare results of idealized studies of the effects of CO₂ alone to observations that reflect the climatic response to all factors—natural and anthropogenic. Careful analyses including all of the recognized factors are showing that natural and anthropogenic influences considered together provide a quite reasonable and internally consistent match to the broad time history of changes during the 20th century².
5. *Model simulations generate results that match observations “no better than a set of random numbers”*: Faced with the model results matching the observed multi-decadal changes over the 20th century, the newest criticism, made in the recent lawsuit seeking to ban distribution of the US National Assessment, is to insist that model simulations reproduce the actual decadal variations of the climate. In that these variations are induced mainly by occasional volcanoes, possible solar variations, and natural air-sea oscillations such as the El Niño/Southern Oscillation, the test proposed for the models is to start in 1860 and make accurate forecasts of the effects of such chaotic and unspecified forcings out through the 20th century, that is for 140 years. Such an accomplishment would certainly be desirable, but would violate all we know about the chaotic behavior of the Earth system—that the models seem to generate random numbers is thus exactly what they should be doing given this expectation. Even though such a test has no real relevance to evaluating model capabilities for projecting century-long changes in the climate due to

² However, it is important to note that not all factors are yet being fully included. Among these are changes in land cover, all types of aerosols, and changes in the altitude of aerosol emissions and precursors over time (which may affect their lifetime in the atmosphere, and therefore the spatial extent of their influence.)

human activities, this criticism does make for a wonderful, if extremely misleading sound bite, and so represents a leading example of an instigated uncertainty.

There are additional examples—new ones are concocted every time that responsible scientists divert their efforts to address the boisterously presented claims of such misleading statements. That this is all mainly a diverting tactic was made clearest to me in the fall of 1997 when I ventured into what seemed like the lion's den to debate Pat Michaels before the Virginia Coal Council. My laying out of the science and Pat's critique were pretty routine. It was the other speakers, in this case, who really provided the insights about what uncertainties really meant to those opposed to accepting climate change. The president of the United Mine Workers of America was the most realistic in his views, indicating that scientific uncertainties did not matter at all—what really mattered was what the Administration believed. His talk was followed by two presentations on the estimated costs of reducing carbon emissions, one by the chairman of a major Midwestern utility that was planting trees in South America and sequestering carbon for \$2 per ton, and the other by an economic modeler employed by the utility industry who estimated the cost of reduced emissions at \$200 per ton. These results alone would suggest an uncertainty of about 10 around a geometric mean estimate of \$20 per ton. Such a large uncertainty, however, did not divert the meeting's attention from concerns over the ranges in climate model results, which can equivalently be expressed in terms of a climate sensitivity of 2.5 C per CO₂ doubling with a factor of only 1.8 uncertainty (so less than one-fifth as uncertain). Yet, in the debate this past week Senator Inhofe was reporting the number of job losses that the Kyoto Protocol would have caused in a particular state to 3-significant figures with no allowance for uncertainty at all, and President Bush cited the same results to two-significant figures when he rejected the Kyoto Protocol. Consistency in treating uncertainties is clearly not a requirement for the critics of climate change science³.

The Virginia Coal Council session concluded with a presentation by the public affairs official who developed the anti-Kyoto ads run just before the opening of the Kyoto conference—the one's where the map was cut up while the announcer said that the proposed protocol wasn't global and wouldn't work. This speaker's advice to the attendees regarding the science was to never, ever, no matter what, never ever concede the science, for once the science is conceded, the moral high-ground is lost and nothing could stop action being taken. Such a strategy surely seemed to be the basis of this week's debate in the Congress, with Senator Lieberman concluding the discussion with an exasperated statement about how unfortunate it was that the debate was still about the science and not about what actions might be taken.

How this divide, this disdain for expert scientific assessments, is ever to be overcome is not at all clear to me. Some say it will take a climate disaster, and indeed conditions such as those this past summer in Europe have certainly reinforced their acceptance of

³ Another example of this inconsistency is the Administration's unqualified claims of the safety of genetically modified seeds, plants, and foods, while claiming immobilizing uncertainties are associated with the issue of climate change.

the science and disdain for the US Administration's position. Unfortunately, however, such an occurrence does not seem imminent for the US because it is so large that it is unlikely that all the major regions will experience the same type of severe anomaly at the same time. This year, for example, the western US is unusually dry while the eastern US unusually wet. It is easy to say, therefore that this situation is just natural variability, with one change here and another there, forgetting that the atmosphere is interconnected and just such outcomes are to be expected as the world warms, regions experiencing first one anomaly then another (recall, for example that a bit over a year ago the eastern US was in severe drought and the west was generally cooler than normal). Demagoging the issue seems to be much easier than educating the public about the complexities of how the Earth will really warm. And The Skeptics lie in wait, jumping in to criticize when events are explained in simple terms to say the science is not certain and uncertainties are being ignored. And if uncertainties are responsibly presented along with a summary of the key findings, as in the NRC 2001 report prepared at the request of the Bush Administration, reports such as the Vision document just put out by the Administration's Climate Change Science Program become the result, in which only the sentences with the word uncertainty in them are included. It is no wonder that so many in the scientific community are withdrawing from public discussion in frustration, content just to do their own science rather than get pummeled in exchanges with *The Skeptics*, acting as mercenaries for special interests.

In the previous Administration, its science advisers understood what uncertainty meant, both in the scientific and in the public policy realms, and they articulately defended the science and explained the significance of uncertainties. With the current Administration, everything (except the likely economic impacts) is said to be uncertain, with no differentiation of which uncertainties are important to the bottom line and which are not, with no metric to try to interrelate them⁴. With the US hosting the chair of IPCC Working Group I on climate change science, continuation of the present attitude about uncertainties is going to run into very different attitudes and approaches in other countries. We will get an early inkling of this in 2004 as the 8-nation Arctic Climate Impact Assessment emerges from scientific review and is presented for acceptance by the various governments, including the US. With Alaska experiencing among the world's most rapid warming, Washington seems frozen in polarized gridlock over relatively small uncertainties that continue to be touted mainly to prevent thoughtful discussion.

The Serious Scientific Uncertainties

While the public debate seems dominated by the instigated uncertainties, there are indeed some true scientific uncertainties that limit how precisely projections for a hundred years ahead can be made. They are fundamentally of two types:

⁴ When the NRC's *Pathways* report came out almost 5 years ago, the response of a prominent Congressman was to count the number of questions in the report and then say that clearly nothing could be done until all of the questions were answered, with no understanding that science generally builds knowledge over time and there is no time when there is no answer and then with one more bit of information there suddenly is an answer.

- (a) Those that result from a shortage of computing power that does not allow the Earth system to be represented in models to the extent of our scientific understanding. This type of uncertainty could be largely overcome if the US would invest in computer resources for study of climate change of a magnitude comparable to what Japan and the UK are investing. Simulations with higher resolution models show much more realistic representations of many features of the weather, from typhoons to fronts. The US really must invest more resources in such central computing efforts (to increase both computer power and the staff to thoroughly analyze the improved results)—this will provide better representations of current understanding, giving better regional resolution while also providing a higher level of confidence in the results.
- (b) Those uncertainties that arise because of a shortcoming in our understanding of physical mechanisms or because the future of society and the Earth system cannot be projected in sufficient detail and accuracy as a result of unknowable social and technological trends and because of the inherently chaotic behavior of the atmosphere, which makes details about future weather unknowable. While chaotic behavior also occurs on the decadal and longer scales, it appears unlikely that the changing climate will be so overwhelmingly affected by unknowable variations that the change in the baseline climate due to changing concentrations of greenhouse gases will not be the predominant effect.

The uncertainties that really do affect projections of future conditions include the following, to name a few (and provide a few comments on their status):

1. *Climate forcings*: Climate change is driven by forcings. Reconstruction of past forcings is uncertain because of inadequate observations and projection of future forcings is uncertain due to dependence on demographic, technological, economic, and social projections as well as on whatever policies of various types might be agreed to. In addition, various types of other influences can have an effect, such as decisions about air pollution that can affect the chemical reactivity of the atmosphere. Forcings are also of multiple types, including changes in greenhouse gas composition, changes in aerosol loading (both scattering and absorbing aerosols), changes in land cover, changes in water management, and so on. To provide plausible estimates of what might happen if various assumptions are made, sets of scenarios have been developed. To avoid being disproved by future events, experts developing the most recent set of IPCC scenarios allowed for a very wide range of possibilities, creating a wide range of ultimate impacts, with the worst possible case often being reported. While this has created a backlash of criticism about scare-mongering because of the use of very low probability cases, the previous set of IPCC scenarios was focused around a central, business-as-usual case that was criticized for not representing a wide enough set of possibilities. Recent approaches are proposing to associate probabilities with the various scenarios, but this will surely generate a wide range of perspectives about possibilities and likelihood. While all of this discussion generates a lot of noise, the rate of warming over the next several decades will hardly be affected by the scenario chosen because the Earth system is still

adjusting to past changes in forcing. However, for the more distant future, actual emissions will matter somewhat more, although on that time scale, uncertainties about the sensitivity of the climate would seem to matter more.

2. *Climate feedbacks*: The atmosphere-ocean-land-ice-biology system is so complex that there will always be shortcomings in its representation in climate models. However, the past behavior of the climate suggests a likely range for the climate sensitivity—that is, a normalized measure of the responsiveness of the climate. The present range, most often expressed as the change in temperature resulting from a doubling of the CO₂ concentration, is 1.5 to 4.5°C. The feedback mechanism contributing the largest share to this range is how cloud cover will respond and add to or moderate the changing climatic conditions: will there be more low-level clouds that will moderate the warming by reflecting more solar radiation, as the most recent NCAR model suggests; or will there be fewer low clouds and more high-level clouds that create an amplifying influence, as a number of other models suggest; or will there be little net effect from changes in cloud cover as other models suggest. This has been a dominating uncertainty for roughly 25 years with little progress being made; this may change, however, over the next few years because there are indications that the newer generations of models with much finer-resolution are doing a much better job of representing present cloud fields, and so will hopefully be better in representing changes. The other approach to narrowing the range is to use past behavior of the Earth system to try to deduce what the climate sensitivity is. This has turned out to be difficult for many reasons, including lack of information about past forcings, about the rate of heat uptake of the ocean (variations of which can accommodate a wide range of climate sensitivities), and about the climatic response itself. At present, these types of analyses do suggest that the sensitivity is unlikely to be lower than the present lower bound, but the studies have been unable to constrain the upper bound below about twice the accepted value. Over the next few decades, this uncertainty actually has relatively little influence on the rate of warming, but this uncertainty is very important for projecting long-term changes and impacts.
3. *Changes in the likelihood, frequency, location and/or intensity of unusual events*: Because the climate system varies naturally, the environment and society have largely adapted to a reasonable range of conditions. Climate change, however, will be adding significant amounts of energy to the system, and theoretical analyses, model simulations, and recent climatic trends all suggest that there will be changes in the occurrence of extreme and unusual events. Already, the intensity of heavy rains is increasing; at the same time, warming increases the rate of evaporation, leading to more rapid loss of soil moisture and therefore more frequent water stress conditions and more intense and longer droughts. As the natural oscillations occur, new extremes will be reached, perhaps passing thresholds for various plants and animals. While such changes seems very plausible, accurately projecting what will occur will be very challenging, yet uncertainties about such extremes are considered the most important priority for many in industry so that an appropriate level of resilience can be built in. For the US, the types of changes in extremes that could occur, yet for which we have

only very limited information, include changes in hurricane intensity⁵ and location (e.g., tracking up the East Coast with high winds and high storm surges pitted against low-lying communities and infrastructure); unusually wet winter and then dry summer conditions in the western US; multiyear droughts in the Great Plains and Midwest, dramatically lowering levels in the Mississippi River and Great Lakes; and warm, dry winters in the western mountain states that lead to dramatic reductions in snowpack and greatly reduced water availability for agriculture, energy generation, and communities.

4. *Sea level rise*: Archeological and paleoclimatic evidence indicates that sea level had not varied much during historical times until starting to rise during the 19th century. During the 20th century, the rise was roughly 15-20 cm, with some indications that the rate of rise was accelerating during the 1990s. Obvious contributions to the rise are coming from thermal expansion of the oceans (which is clear from observations of rising ocean temperatures) and melting of mountain glaciers. However, these contributions do not fully explain the observed rise. Changes in water storage on land (in reservoirs and in vegetated lands) and in underground aquifers seem to be one likely contributor, and changes in Greenland and Antarctica may have occurred, although data are sparse. For the future, the effects of thermal expansion and mountain glaciers can be reasonably estimated—the real question is what will happen with respect to Greenland and West Antarctica, the melting of each of which over perhaps a 1000 years would raise global sea level by of order 6 m—most of Houston will either be under water or behind huge levees. For the 21st century, the IPCC projects that the contribution of the two ice sheets to sea level rise will be quite small (also seeming confident that snow will build up on East Antarctica). While what the public discussion is mainly about has been whether the upper bound of IPCC-projected warming of over 5°C during the 21st century is plausible, yet what a number of US glaciologists wrote in objecting to the IPCC conclusions about the sea level estimates was that Greenland and West Antarctica may be much more vulnerable to warming than was estimated and so IPCC may be underestimating the amount of sea level rise. Given how much low-lying land there is in the US, this is a critical uncertainty, yet one that will be very hard to resolve because the freezing point is basically a threshold—below it and the snow builds up, above it and a process of inevitable collapse is initiated. To ensure ice sheet collapse does not begin, conditions favoring accumulation must be ensured, but with such conditions, there will be no observational evidence about where the threshold will be. Will society accept a purely theoretical calculation of the threshold, or will the world wait for evidence until melting has begun, at which time it will be too late to go back?
5. *Impacts on the environment*: Projections indicate that the rate of climate change will be much more rapid than any during the period of the development of

⁵ Simulations using the national hurricane model indicated that a warming of 2 C increased the maximum 6-hour rainfall amount by over 25%, so imagine Houston experiencing a rain amount of near 40 inches instead of the 30 inches or so experienced in the recent inundation.

existing ecosystems. Already, IPCC's assembly of results indicates that the ranges of many types of species are changing in response to the very limited amount of change that has already occurred. Because each species will have its own sensitivity to the changes, rapid change has the strong potential for disrupting the complex interactions among various species that have developed over time. If there are keystone species, the potential exists that many species could be affected if only one cannot keep up, whether due to an inability to seed and regrow in time or a lack of suitable habitat or soils, etc. Uncertainties will continue to be quite significant, and may not even be able to be estimated at all, due to the many possibilities and situations. Yet, it is clear there will be changes even if we do not know precisely what they will be. With so many services being provided by the ecosystems, it is not even clear how to try to express the risk and uncertainty involved.

For each of these areas, and more, there are indeed many aspects that it will be virtually impossible to pin down in advance of the changes, but there are real possibilities to make some progress. What is most frustrating about all the attention being given to the instigated uncertainties is that it is drawing resources away from getting at the real uncertainties that society faces—at the very least trying to get a better sense of the risks lying ahead.

Discussion

In considering the importance of all of these uncertainties for policy-making, there are several factors to keep in mind. In particular, it is important to remember that uncertainties can cut both ways—the situation could be worse than is being estimated. In addition to the issue of the potential for initiating the collapse of the great ice sheets, there is the potential for the melting of the permafrost and methane clathrates leading to a sharp increase in the atmosphere's methane concentration, for locking into unusual atmospheric circulation patterns as systems strike major mountain chains in new and unusual ways, in disrupting the overturning circulation of the world's oceans (which would also accelerate the rise in sea level and reduce the availability of nutrients in surface waters), and many more, including others that may truly come as surprises, as did the Antarctic ozone hole.

In addition, while there are a great many certainties, they cannot simply be combined in the cascading manner that is traditionally carried out in engineering analyses. For several reasons it is unproductive to think about uncertainties in this way. First, not all of these uncertainties are related in a linear way; they are instead interlinked and coupled. Second, there are integral constraints arising from relationships such as the conservation of energy that limit rates of change. Third, we have a long climatic record that provides strong indications of what the range of possibilities can be. Fourth, although there are many possible combinations of emissions scenarios and climate sensitivities, when considered together they yield a relatively narrow spread of possible outcomes. When the next step is taken, namely, investigating the potential impacts of the changes in climate on natural ecosystems, it does not matter what combination of factors caused the climate change to occur—what is clear is that if there is a climatic change, there will be an ecological response. Cascading uncertainties in the traditional

manner results in a significant over-estimate of uncertainties and under-estimate of how much that we do know.

Conclusion

In my view, a major cause of the contention over uncertainties is a lack of clarity on the definition of uncertainty itself and how it is applied. For *The Skeptics*, it appears that they consider any understanding uncertain unless there is perfect knowledge, which is a very high bar indeed. While the importance of fossil fuel sources of energy to the economy provides justification for a reasonably high bar, expecting, in essence, to gain a criminal conviction of all aspects of this issue with evidence that is beyond all reasonable doubt is a behavior more akin to a defense lawyer than to thoughtful public decision-making.

In virtually all business, government, and personal decisions, uncertainties are present and options must be weighed in terms of the relative likelihood or risk of something occurring, taking into account the balance between what is well and poorly understood. Taking into account potential risks, addressing issues in an adaptive manner that can be adjusted with new knowledge, aiming for win-win options, enhancing research to build resilience to a range of possible outcomes; all of these and other approaches are often used in many different fields, yet are being obstructed by the instigators of *The Skeptics*. There is no shortage of uncertainties to be considering, each however being accompanied by understanding to some degree. The climate change issue, like so many others, will require that decision-making be carried out in the face of uncertainties. While the previous Administration was embarked on this path, how to return to it now remains a major challenge for the scientific and political communities.

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