



# Anticipating Global Change Surprises

A Report of the Aspen Global Change Institute
Elements of Change Series

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ASPEN GLOBAL CHANGE INSTITUTE

# Anticipating Global Change Surprises

A report on the Aspen Global Change Workshop
July 31- August 13, 1994
Aspen, Colorado USA


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*Furthering the understanding of Earth Systems and global environmental change*

FUNDING
*The Aspen Global Change Institute gratefully acknowledges support for its 1994 summer science sessions*
PROVIDED BY THE
*National Aeronautics and Space Administration*
*Grant Number NAGW-3538,*
*National Science Foundation*
*Grant Number OCE-9417138,*
*Environmental Protection Agency, and interagency support of the Subcommittee on Global Change Research of the U.S. Global Change Research Program*

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*Archival videos of the presentations from this session are available through Aspen Global Change Institute's website, www.agci.org. Hardcopy versions of the report are also available on a cost of reproduction basis. Contact AGCI for more information.*



THE RECOMMENDED CITATION:
Hassol, S.J., J. Kasperson, and J. Katzenberger, eds. 1995, electronic edition 2008. Anticipating Global Change Surpirses. Proc. of an Aspen Global Change Institute Workshop 31 July-13 August 1994, Elements of Change series, AGCI.

DESIGN AND PRODUCTION:
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*Electronic edition: Susannah Barr*

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# Summary:
# *Anticipating Global Change Surprise*

Co Chairs: Stephen Schneider and B. L. Turner II

The possibility of unexpected physical, biological and social impacts of global scale environmental change is a principal uncertainty in estimating the urgency of implementing policy responses to the advent or prospect of global change.

Senator Bill Bradley once asked a panel of atmospheric scientists at a hearing on issues of global climate change, "just what kind of surprises did you have in mind?" After the obligatory, "We canÕt know a surprise in advance," those attending admitted that they did have some inklings: radical ocean current flip-flops, permafrost melting (and possible methane release), synergisms between habitat fragmentation and species migration in response to global changes, super hurricanes, environmental refugees and attendant political instability, breakthroughs in alternative energy system prices, unexpected disease vectors, and strongly stabilizing cloud feedback effects, were some of the examples mentioned. The list is highly speculative, formidably non-linear and very interdisciplinary. Yet, such possibilities can be uttered -- and other possible candidates for global change surprises were uncovered when people of achievement and insight, ranging across physical, biological, and social scientific disciplines were brought together in the congenial atmosphere of an Aspen Global Change Institute summer session.

The topic of anticipating global change surprises is highly relevant as we consider how to respond to global change in the face of uncertainty. The possibility of unexpected physical, biological and social impacts of global scale environmental change is a principal uncertainty in estimating the urgency of implementing policy responses to the advent or prospect of global change.

In addition to identifying and discussing a variety of candidates for global change surprises, the participants in this session worked through defining and clarifying relevant terms, and developed a typology of surprise that recognizes risk, uncertainty and ignorance. These clarifications and the typology are summarized in the following pages, as are selected candidates for global change surprises that emerged from the session.

*Clarifying Terms*

Surprise and uncertainty are often confused in the literature and in public discourse; various meanings are used within different communities and cultures.

*Definitions*

**Risk** The condition in which the event, process, or outcomes and the probability that each will occur is known.

*Issue* In reality, complete knowledge of probabilities and range of potential outcomes or consequences is not usually known and is sometimes unknowable.

**Uncertainty** The condition in which the event, process, or outcome is known (factually or hypothetically) but the probabilities that it will occur are not known.
*Issue* The probabilities assigned, if any, are subjective, and ways to establish reliability for different subjective probability estimates are debatable.

**Surprise** The condition in which the event, process, or outcome is not known or expected.
*Issue* How can we anticipate the unknown, improve the chances of anticipating, and, therefore, improve the chances of reducing societal vulnerability?

*Working definition*

Use of a strict definition of surprise logically entails that we cannot anticipate the event, process, or outcome, because the very act of anticipation implies some level of knowledge. Assessments designated as "surprises," however, indicate that the events, processes, and outcomes so registered were, in fact, knowable in one manner or another. This second type of "surprise" -- a broad use of the term -- is that from which the global-change community may learn much.

Following Holling (1986: 294), the AGCI group adopts the following working definition of this second type --

1. Surprise is a condition in which perceived reality departs qualitatively from expectations.

Use of this working definition does not deny the existence of surprise of the first type (narrow definition). *Unless otherwise designated, however, the remainder of this report deals with surprise of the second type.*

Suprise is a condition in which perceived reality departs qualitatively from expectations.

*Logic of Anticipating Surprise*

1. Given the second meaning, it is possible to anticipate a subset of surprises.

2. For example, complex systems, chaos, and other such theories provide a conceptual and analytical basis for understanding that surprises will occur, and a variety of methods (e.g., simulations, backcasting) and assessments that facilitate seeking and finding surprises.

3. Coupled with experience, this understanding permits the identification of potential arenas wherein surprise may take place.

4. This identification may (should) inform the public and policymakers of the issues, and thus potentially allow reduced vulnerability and enhanced environmental and societal resilience to surprise.

5. The probabilities that suspected "surprises" will take place within a specified arena are generated on a subjective basis (or by objective methods or models that rest on subjective assumptions), and vary significantly by individual, community and culture.

*Who is Surprised and Why?*

1. Surprise is dependent on expectations, and thus we must analyze how expectations are formed by individuals and groups.

2. This view implies that the degree of surprise depends on the extent to which reality departs from expectations and on the salience of the problem (e.g., hazards).

3. Expectations reside not only in the individual, but with groups, communities, or cultures, such as experts, policymakers, managers, and educators, who can share common ranges of expectations that are generated by group dynamics, leaders, and signal processors.

4. In many cases, surprise lies in the policy/managerial mindset and response to an unexpected or improbable (lowly anticipated: e.g., Three Mile Island) event.

5. A variety of factors contribute to this subcategory of surprise (#4), including: differences of opinions among the expert community; fit with broader policy agendas; and vested interests of agencies or groups to maintain a particular view.

6. Factors that may contribute to surprise (of our second type) among the science and policy communities are those involved under conditions of systems complexity and connectedness. Integrated systems modeling, for example, informs that (i) one surprise may lead to another because of sub-system coupling and other such issues and (ii) cascading surprises may emerge.

*Typological Map (Figure ii.1)*

There are many possible typologies of surprise (and uncertainty) (e.g., Brooks 1986; Timmerman 1986). Focusing on surprise of our second type and its subcategories (e.g., #4 above), we have been informed by one that may be particularly useful in distinguishing the sources of surprise and the difficulty in identifying and anticipating some types of surprise. Adapting from Faber, Manstetten, and Proops (1992), the AGCI meeting produced a typology, Figure ii.1, that recognizes risk, uncertainty, and ignorance. Here, risks are possible (usually undesirable) outcomes whose probability and existence are known. Uncertainty characterizes outcomes that are known to be possible but whose probabilities are not known. Ignorance, the main subject of the typology, is the most intractable: we are ignorant when we cannot or do not know a possible outcome. Following this typology and definition, ignorance may be where the most significant surprises lie. (It should be noted, however, that some do not make such strong distinctions among these three sources of surprise but see each as a variant on the same basic insight that outcomes are indeterminate.)

Ignorance, the main subject of the typology, is the most intractable: we are ignorant when we cannot or do not know a possible outcome. Following this typology and definition, ignorance may be where the most significant surprises lie.

Ignorance comes in two varieties. Closed ignorance is the unwillingness or inability to consider or recognize that some outcomes are not known but are perhaps possible. Open ignorance is the opposite and much more complicated. The willingness to acknowledge ignorance is a start to the identification of possible outcomes and anticipating surprises, but some forms of ignorance are easier to reduce than others. Ignorance that is relatively easy to reduce comes in two forms, depending on whether an individual or the group is ignorant. Personal or individual ignorance can be reduced by education, after which “surprises” may become “risks” on some typologies. On the other hand, communal ignorance requires creation of new knowledge through research, broadly within existing scientific concepts, ideas, and disciplines (what some call “normal” science -- science within an existing paradigm but not necessarily science that causes a revolution to a new paradigm).

The other type of open ignorance is more complex and less tractable. Ultimately all ignorance might be reducible, but much of it is very hard to overcome. Part of this hard-to-reduce ignorance stems from epistemology -- the rules that we think govern how the world works and the language and symbols we use to describe what we think and observe. Some people use the term “paradigm” to describe those rules, relationships, symbols, and language. (Some point out that “epistemological ignorance” can be a form of “closed ignorance” because epistemological blinders lead to an unwillingness or unwitting inability to consider alternatives.) The other part of this “hard”-to-reduce ignorance is intrinsic to the phenomenon at hand. Some phenomena may simply be unpredictable, at least from the technologies and analytical perspective now in existence. Notably, systems characterized by chaos are currently thought to be unpredictable in detail -- for example, detailed weather forecasts six months in advance are not possible, no matter how accurate the initial state of the weather condition is known because of chaotic dynamics of the atmosphere. And yet, the general character of some chaotic-like systems can be better understood, permitting models of them and, hence, forecasts of their impacts (e.g., El Ni ño or ENSO events). A further example of phenomenological ignorance is a change in the underlying forces of a system, producing markedly different observed outcomes.

This typology is helpful because:

- it makes a distinction among risk, uncertainty, and surprise;
- it also makes clear that phenomenological surprise is only one category of ignorance; and,
- it suggests that many surprises are easily reducible,
- whereas others are blocked by epistemological blinders that create expectations that exclude some categories of outcomes and, hence, surprise.

*Fitting the Map From the Bottom Up*

Tables ii.1 and ii.2 present a series of surprises pertinent to global environmental change presented at the AGCI summer session on “Anticipating Global Change Surprises.” To each candidate surprise (and in some cases highly uncertain outcomes that were perceived by many as surprises) in Table ii.1 is attached to the sources attributed to them as understood by our group. Without reviewing each table entry here, it is possible to fit these sources within the typology presented above. A few cases of phenomenological ignorance were presented, particularly those in which the technology of data retrieval outpaced the analysis of data (e.g., misreading remotely sensed imagery led to exaggerated estimates about the spatial scale of land-cover changes; or erroneous assumptions about outlier values of stratospheric ozone delayed detection of the Antarctic ozone hole). Most of the cases, however, suggested sources of surprise in global environmental change may be closely aligned with the following:

- narrowness of “paradigm” (epistemological ignorance)
- organizational goals and structure of organizational decisionmaking not consistent with the problem (closed ignorance; epistemological ignorance)
- organizational goals in conflict with the outcome (closed ignorance)
- purposeful obfuscation and blocking (closed ignorance)

Many surprises are easily reducible whereas others are blocked by epistemological blinders that create expectations that exclude some categories of outcomes and, hence, surprise.

- rigid common frameworks (epistemological ignorance -- frameworks/mindsets that impede effective use of normal science and learning)

There are, of course, many ways to typologize surprise. Our method focuses on the nature and source of surprise within individuals, communities, or cultures which largely involves different sources of ignorance.

*Scientific Versus Societal Surprise*

Outcomes are frequently a surprise to some individual, group, institution, community, and culture, or to society as a whole. Many of the surprises noted in the literature on the subject are scientific surprises -- surprises to the community of experts of a phenomenon or area. In contradistinction to these are societal surprises -- surprises involving events, new discoveries, or assessments that are processed by social institutions and agents in ways that focus social attention on the surprise and place it on societyÕs agenda for debate and possible action.

Figure ii.2 illustrates this process. At any time, a number of new events or surprises vie for the attention of society as a whole. They enter a process that Kasperson and colleagues (1988) describe as social amplification and attenuation, whereby the processing of the event or discovery by information and response systems either strengthens or weakens the signal value to managers, policymakers, and publics. Thus, some genuine scientific surprises fail to be taken up by the mass media, watchdog groups, or policymakers and fail to make it onto the societal agenda. Other surprises, perhaps less salient to scientists, undergo substantial amplification in signal value due to intense coverage in the mass media, lobbying by critics or environmental groups, connection to social movements, or concern on the part of policymakers or regulators. Thus, it is important to distinguish between scientific and social surprise and to evaluate how events interact with societal processes to amplify or attenuate the perceived significance of the surprise to managers, social institutions, and publics.

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*Improving the Anticipation of Scientific Surprise*

The sources of global-change surprise noted above point to several ways of improving the anticipation of the arenas or domains of surprise.

1. Encourage and integrate the role of synthesis and synthesizers -- appreciating "putting the puzzle together" and searching for connections across problem domains, disciplines, and perspectives.

2. Focus a larger fraction of the research effort on "outlier" outcomes (e.g., applying methods to sample the opinions of a broad range of knowledgeable experts as to the likelihood of a wide range of imaginable outcomes).

3. Support work at the edges (and across edges) of conceptual and problem areas.

4, Promote process- as well as product-oriented research and encourage multiple disciplines and communities to communicate and integrate their knowledge about global-change problems.

5. Insure the following attributes of research discourse and funding that have been insufficiently appreciated to date:

- skeptical welcoming of advocacy science/scientists and of the airing and professional evaluation of unconventional views; and

- multiplicity and constructive duplication of research domains among approaches and institutions.

6. Work backwards from posited future states to identify events or processes that might happen along the way: backcasting scenarios or reconstruct past scenarios in alternative ways to examine what might have happened (e.g., Brooks 1986).

7. Encourage the "strategic paradigm" as well as the "efficiency paradigm" to build resilience into social and environmental systems.

*Preparing for Surprise: Beyond the Science*

Many potential surprises can be anticipated as noted above. It is clear, however, that many hazard or problem arenas are intrinsically subject to surprise due to system complexity, lack of experience, or poor theoretical understanding. The scientific and managerial community and society as a whole should expect and prepare for the reality that, whatever anticipatory measures are undertaken, some surprises will inevitably occur. Put somewhat differently, the hubris that science and social science can predict the future sufficiently to anticipate the full range of both positive and negative surprises should be constrained. (For example, the recent Kobe earthquake has put to rest the notion that Japanese cities are adequately prepared to withstand major earthquakes.)

It is, of course, the negative and potentially catastrophic surprises that are of particular concern. Managers and social institutions are not helpless to these surprises simply because specific events and outcomes cannot be predicted reliably or even (perhaps) anticipated. What can be done is to increase the resilience and adaptability of receptors (human and ecological) that are at risk, thereby decreasing the sensitivity to the impacts of the unexpected or uncertain perturbations. Actions aimed at increasing the resilience and adaptability of potentially affected systems are noted below. They do not represent recommendations of AGCI but are provided as examples of the broader ranging amplifications of surprise and global change.

What can be done is to increase the resilience and adaptability of receptors (human and ecological) that are at risk, thereby decreasing the sensitivity to the imapcts of the unexpected or uncertain perturbations.

1. Diversifying economic productive systems: the tendency towards increased economic specialization carries the risk of vulnerability to controls (e.g., markets or absentee landlords) well beyond the local area which can have both positive and negative impacts on local resilience to environmental perturbations.

2. Avoidance of technological monocultures: reliance on a single technology, such as nuclear power, may be vulnerable to environmental or other perturbations with negative impacts on the economy.

3. Strengthening the broader entitlement structures: providing robust safety nets to respond to unforeseen events is a critical part of resilience.

4. Adaptive management systems: organizational theory suggests that different management systems have different capacities for dealing with surprise; those doing better are characterized by openness, participation of all parties, and flexibility, while those faring less well are characterized by command-and-control systems.

5. Disaster coping systems: improving designs of early-warning, monitoring, and alerting systems, and strengthening the capability of private and public sectors to respond rapidly to potential disasters should be encouraged.

6. Organizational memory and social learning: measures that improve memory and the ability to learn from surprises improve overall resilience to vulnerability to surprise.

*Concluding Comments*

Over a decade ago, Kates (1985:50) noted that "one of the distinguishing features of the past 15 years is that surprise persists and, paradoxically, grows." Looking to the next 15 years, he concludes: "Finally, there will be surprises -- surprises that in turn will generate new concerns and activities. There will also be other concerns and surprises unrelated to technological hazards, international tensions, social change, and resource needs" (p. 57). The professional community recognized global environmental change as a new source of surprise and concern more than a decade ago. The international community, including the public and policymakers, now have the same recognition.

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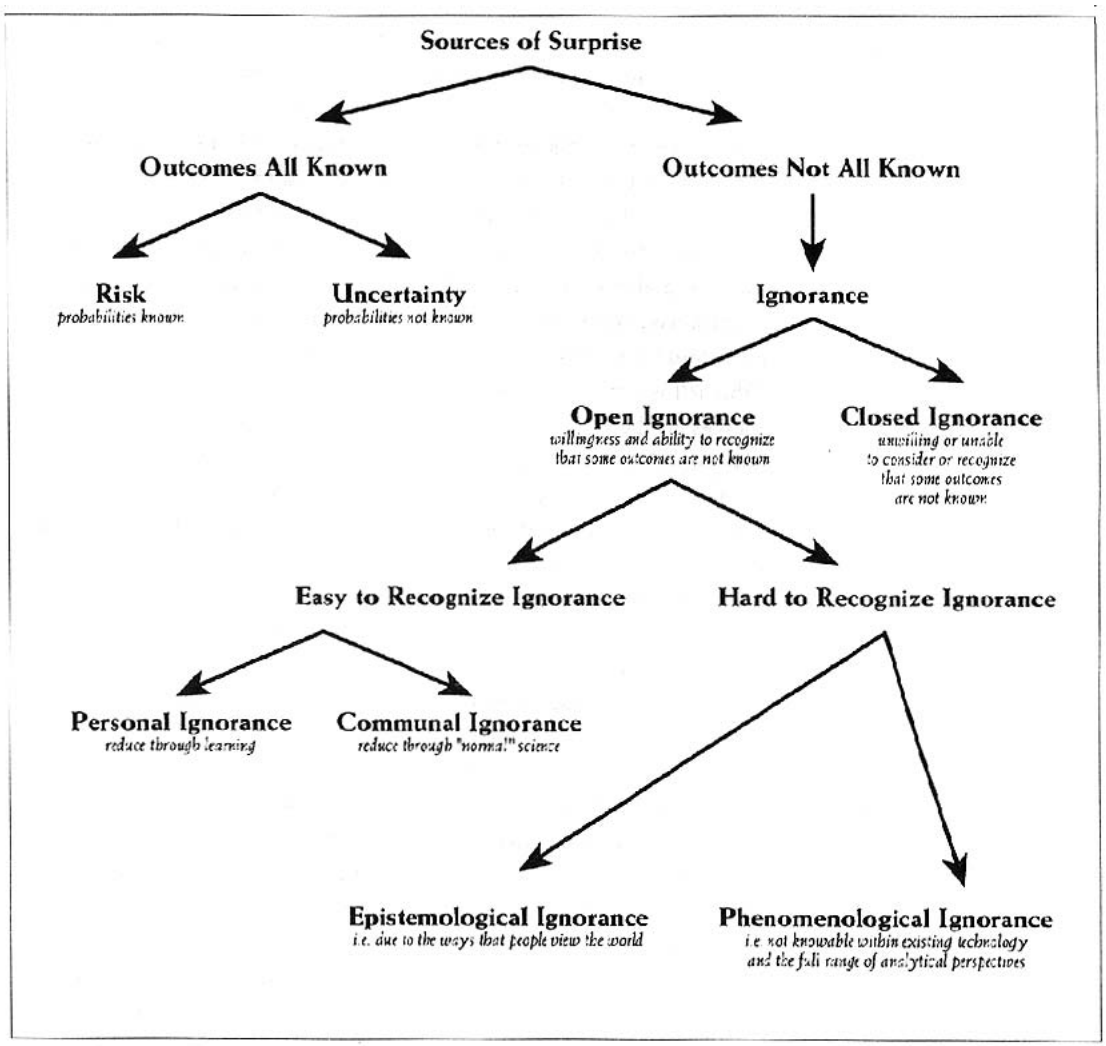


Figure ii.1
Typological Map of "Surprise"
(after Faber, Manstetten and Proops 1994)

Table ii.1

Candidates for Global Change “Surprise”
by Participants at the AGCI Summer Session on Anticipating Global Change Surprises

(entries not intended to be comprehensive or independent)

**A. Anthropogenic Forcing Functions**

- South remains proportionately behind the North in economic development.
- Transfer of wealth from South to North accelerates, widening the economic disparities between the two.
- The nation state demises, leading to conflict and collapse of economic growth.
- An underclass of nations is maintained owing to the diminished process of globalization.
- World mortality patterns are transformed by the emergence of a new, highly contagious virus.
- Medical technology increases life expectancy substantially.
- Human population growth rate does not decrease; the demographic transition does not happen globally.
- The smooth population trajectory foreseen in all standard projections of world population becomes woefully inaccurate in the face of sharp departures from them.
- Funding stops for technology development that would facilitate a low carbon future.
- Change takes place in the political consciousness of the value of nature and the will to act accordingly.
- The global market does not dominate (control) natural resource allocation locally, especially for land and water use; rather non- market institutions (e.g., control economies, quasi-market economies, local institutions) remain important.
- India matches China in CO2 emissions.
- Siberia incurs large-scale resource depletion/degradation and deforestation.

- Several catastrophic nuclear plant accidents lead to ban on nuclear power before inexpensive non-carbon backstop technology is available.
- A very inexpensive, noncarbon backstop technology is developed.
- China burns its coal without significant improvement in technology efficiency.
- China shifts to low-carbon alternative energy source (e.g., finds ample supply of natural gas or develops viable biomass industry).
- Energy use reverts to a parallel track with economic growth because (i) the cost of energy conservation proves too expensive and/or (ii) a switch from an industrial to a service economy proceeds slowly.
- CO2 emissions from developing countries do not increase.
- Land-cover change stabilizes in South America and South East Asia; deforestation slows dramatically.
- Synergism of habitat fragmentation, chemical assault, introduction of exotic species, and anthropogenic climate change affect biodiversity in unforeseen ways.
- Spatially varying (regional scale) competing forces create unforeseen regional climate anomalies (e.g., land-use changes, aerosols, or tropospheric ozone).
- Chemical pollution causes significant genetic change in humans and other species, possibly affecting fertility.

**B. Nonanthropogenic Forcing Functions**

- A gradual reduction in “conveyor belt” oceanic overturning leading to cooling at high latitudes occurs, despite general (but slower) global warming.
- Heat stored in the ocean at intermediate depths is released to the atmosphere, leading to rapid warming.
- Stratospheric cooling causes increased Polar Stratospheric Clouds and loss of ozone.
- Antarctic volcanoes lubricate ice-stream flow causing glacial surge and rapid sea level rise.
- The Greenland ice sheet surges.
- Changes in volcanism are induced by changes in climate.
- High latitude forests are not a CO2 sink.

- Dimethyl sulfide emissions decline with reduced sea ice.
- Dimethyl sulfide emissions change with sea-surface temperature change.
- Positive or negative biogeochemical feedbacks become climate forcing.

**C. Environmental Consequence**

- Regional climate anomalies lead to economic and political dislocations.
- Regional environmental degradation has global impacts on economic and political systems.
- Differential movement of species ranges in response to global environmental change causes irreversible or very long-term ecological damage (extinctions or cascading effects).
- Warmer climate could be more stable/less variable.
- Enhanced hydrological cycle leads to unanticipated extreme floods or droughts.
- Cloud liquid water increases causing increased cloud albedo and negative feedbacks on warming.
- Increased snow accumulation compensates faster outflow in West Antarctica when the Ross Ice Shelf disintegrates.
- Land-cover stabilizes in South America.
- Hurricane intensity changes with warming.

**D. Human Response to the Advent or Prospect of Global Change**

- Geoengineering is adopted.
- The climate convention increases funding for low-cost noncarbon backstop technologies.
- The creation of wildlife reserves and migration corridors lowers impact on biodiversity.
- Improved climate-change scenarios and better understanding of climate impacts identifies specific winners and losers and thereby destroys consensus in the international community for emissions reductions.
- CO2 build-up stalls for five years, derailing the current convention process.
- Society chooses to be relatively carbon free and resilient to climate change.

Table ii.2
Selected Candidates for Global Change Surprise Arranged According to "Surprise" Arenas

**Greenhouse gasses are less than 2 X CO2.**
T*he world emission rates peak and decline in the near future*.

√ Strong international agreements are implemented.
√ Rapid decarbonization of energy system takes place because
- low cost biomass alternatives are developed.
- artificial photosynthesis is mastered. inherently safe, inexpensive nuclear power is developed.
- large natural gas discoveries are made in China.
- China and Brazil develops a large biomass-energy industry.

√ Energy/GNP ratio declines sharply because
- low-energy technology is improved and adopted globally.
- development increases per capita GNP sharply

√ World economic growth rates decline sharply because
- of the demise of the nation state leading to conflict and collapse.
- of the emergence of a new, quick acting and highly contagious virus, reducing populations globally.

√ Minimal deforestation takes place because
- land-use cover stabilizes in South America and elsewhere in the tropics.

**Greenhouse gasses are far more than 2 X $CO_2$.**

*More than 50% of incremental CO2 remains in the atmosphere, sinks become saturated, and world emission rates grow sharply.*

√ No significant policies are adopted because

- improved understanding of climate impacts identifies winners and losers, thereby destroying consensus in the international community for emission reductions.
- people place low value on environmental impacts.
- of the demise of the nation state leading to conflict and collapse.

√ Decarbonization of the energy system stops because
- R&D on low-carbon sources halts.
- nuclear accidents cause a shutdown of all nuclear plants. China continues its commitment to coal use.
- India increases coal-based energy significantly.

√ Energy/GNP ratio stops declining because
- the Demographic Transition does not take place in developing world.
- energy prices remain low.

- cost of energy conservation proves too expensive to implement.
- a switch to a service economy in the Western or developed world proceeds slowly.

√ Increased deforestation takes place because

- Siberia incurs major deforestation and degradation.
- the developing world remains proportionately behind the economies of the developed world, leading to sustained land-cover changes.

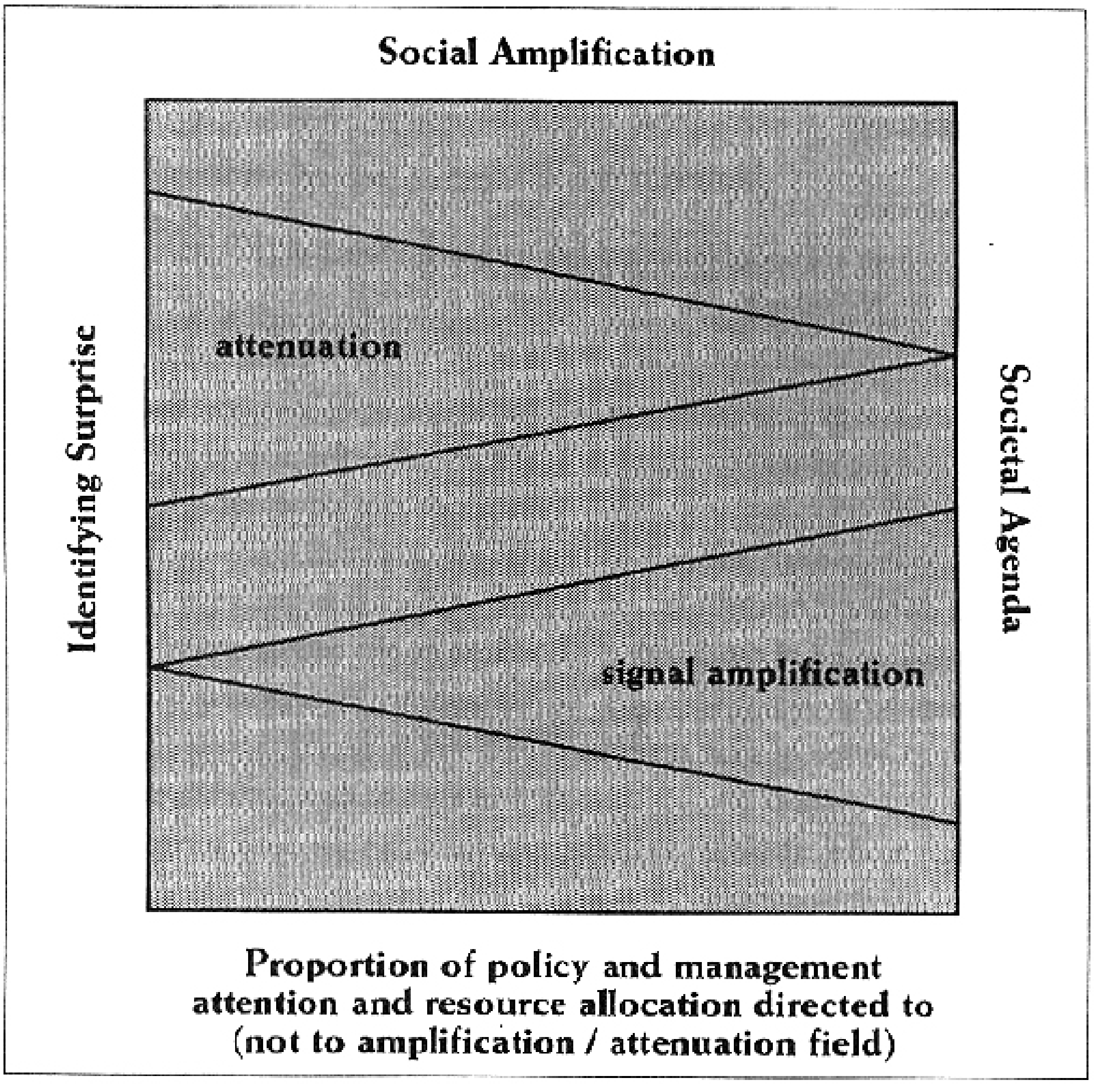


*Figure ii.2*

*Distinguishing Scientific verses Societal Surprise*

# Integrated Assessment Models as Tools to Study and Anticipate Global Change Surprises

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Integrated assessment models of climate change/global environment should:

- link science with policy
- link different disciplines
- cover a range of temporal scales
- cover a range of spatial scales

One such model, IMAGE 2.0, is a process-based, geographically explicit model of the global system which integrates society, biosphere and climate. Applications of the model include providing scenarios for the Intergovernmental Panel on Climate Change (IPCC) working groups, the Core Project of the International Geosphere-Biosphere Programme, and others contemplating the impacts of global climate change.

Image 2.0 is a process-based, geographically explicit model of the global system which integrates society, biosphere and climate.

The goal of the IMAGE 2.0 model is to present a balanced and integrated representation rather than to advance any of the particular areas of modeling. Economic calculations for driving forces are done on a regional basis; other calculations are done on a grid- cell basis. The size of a grid cell is half a degree latitude by half a degree longitude so cities do not show up. Even very large cities like Tokyo and New York do not cover more than 40% of any grid cell.

How might such a model be used to anticipate surprises? It can be helpful in seeing how nonlinear linkages of components of the system can produce surprises. Two potential surprises that emerge from the IMAGE 2.0 integrated assessment model are a change in the methane trend and a possible ocean circulation realignment.

*Methane Trend Potential Surprise*

Following water vapor and carbon dioxide, methane is the next most important gas contributing to radiative forcing. The counter- intuitive surprise scenario that emerges from the model is that even though methane emissions continue to increase, atmospheric concentrations of methane decrease after a peak in the year 2050 due to an increase in hydroxyl (OH) radical production and concentrations. This surprise scenario is a result of the coupled effects of land-cover changes, decreases in biomass burning, downward trends of carbon monoxide and methane emissions, and concentrations of hydroxyl radical and methane in the atmosphere.

*Ocean Realignment Potential Surprise*

This scenario assumes a slowing of the Gulf Stream and a 70% reduction of downwelling in the North Atlantic followed by stabilization. Thermohaline circulation is essentially switched off, resulting in reduced transport of heat from the tropics and a drop in surface air temperature of 2.5 degrees C in the Northern Hemisphere. Model runs indicate that this initial surprise then generates other surprises. The boreal forest is the major carbon sink in the year 2050, but ceases to be a carbon sink when the temperature cools by 2.5 degrees C, resulting in a net buildup of $CO_2$ with uncertain consequences.

Changes in ocean circulation can significantly affect the pattern and amplitude of climate change, the global carbon cycle, and the extent of agricultural areas. The strongest effect on the carbon cycle is the indirect effect of climate on the terrestrial carbon sink. Integrated modeling permits a more complete assessment of the potential impacts of such changes. In response to the question: "What happens if you turn the deep-water formation back on?" It appears that the rate of temperature rise concentrated in high latitudes where the downwelling occurs increases about threefold.

The counter-intuitive surprise scenario that emerges from the model is that even though methane emissions continue to increase, atmospheric concentrations of methane decrease after a peak in the year 2050 due to an increase in hydroxyl (OH) radical production and concentrations.

Conclusions regarding surprises:

- global surprises emerge from linkages among different components of the global system and different trends in different regions
- "cascading surprises" can be expected
- interdisciplinary, interregional approaches are needed

Conclusions regarding integrated models:

Integrated models can be tools to study and anticipate surprises:

- express linkages in global systems - energy, land cover, emissions, climate
- evaluate consequences of surprises
- produce nonlinear, unexpected results
- can help to identify policies that are robust to surprise

How can we design policies and research robust to surprise?

- global monitoring/data analysis with timely feedback to policy
- adaptive environmental management
- institutional learning
- multidisciplinary strategic analysis

In short, integrated assessment models are useful in that the couplings bring interesting nonlinearities (surprises) to the surface.

In the discussion which followed Alcamo's presentation, it was pointed out that the IMAGE 2.0 model, despite its Dutch lineage, fails to include sea level rise.

# IMAGE 2.0
# Framework and Models of Linkages

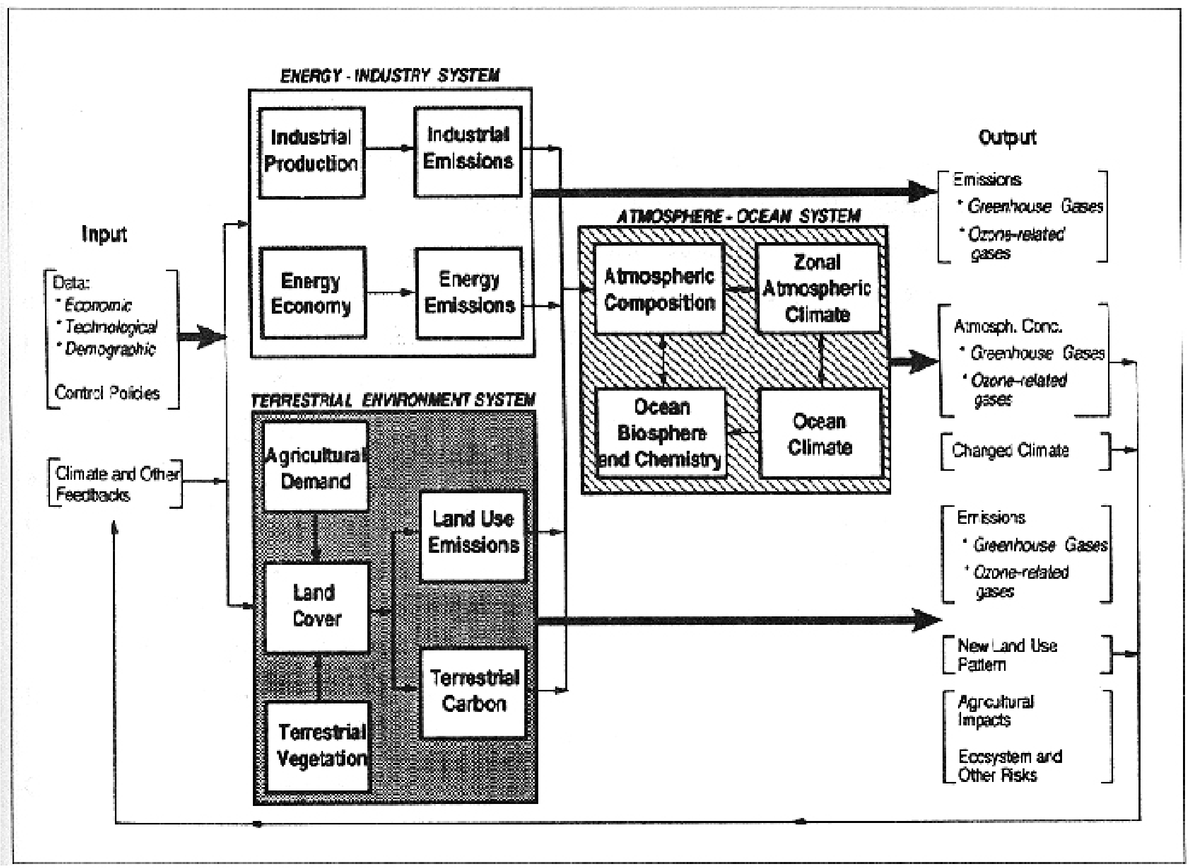


*Figure 1.1: Schematic diagram of IMAGE 2.0 showing its framework of models and linkages*

# Public Perceptions of Global Warming

Richard Berk
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*Los Angeles, California*

We can "simulate" possible future climates and ask what people would be willing to pay to avoid certain outcomes. The information we obtain from such surveys is important because eventually, we can feed survey data into climate models to simulate social feedbacks to climate.

What do people value about climate? How important is climate to things people value? There is use value as well as non-use value (i.e., for wildlife habitat, even if there is no personal contact or use, we feel better knowing it's there). Because there is no market for climate (not even a flawed one), we need to infer value. What is the best way to infer value? We can infer it from the behavior of individuals or we can set up a hypothetical market -- a game for people to play -- based on the concept of "contingent valuation" (CV) or "willingness to pay."

But what do people know about future climate? What can they know? We can "simulate" possible future climates and ask what people would be willing to pay to avoid certain outcomes. In framing the questions, we must be aware of social rhetoric (i.e., if we ask, "Is it a good idea to plant trees,?" everyone will say yes) and other response biases. How the questions are framed will, of course, affect the responses.

In order to begin to understand the value people place on climate, a survey was conducted in which the key question concerned contingent valuation. The survey asked, "Would you be willing to pay x dollars more a year for the things you normally buy in order to prevent this climate situation from occurring?" The amount of money, x, was varied randomly between $25 and $500 in $25 increments; temperature and precipitation outcomes were also varied, and the results were plotted. Four "parameters" of the resulting distributions were explored in detail:

- the mean
- the spread
- extreme values
- clustering of extreme values

The information we obtain from such surveys is important because eventually, we can feed survey data into climate models to simulate social feedbacks to climate. We can then feed climate model results back into more social surveys, and so on.

Not surprisingly, the higher the bid (x), the lower the probability that someone will accept it. Also not surprising, people regard big deviations from the climate they're accustomed to as unacceptable. In this survey, 600 interviewees evaluated 12 scenarios. Such a randomized experiment is the easiest way to get an unbiased result.

*Conclusions*

A general conclusion is that people act much as you would expect them to, but not nearly as fast. Another general conclusions is that there was complete disconnect between climate scenarios and policies. Other conclusions include:

A -- the public can consider complex issues -- they can “unpack” climate change
B -- surveys do not have to be written as sound bites
C -- responses to surveys on climate change depend on current climate conditions
D -- biography (gender, race, education level, etc.) does affect response
E -- temperature is more important to people than precipitation
F -- variability in weather does not seem to matter to people
G -- “small” changes in climate do not matter
H -- CV is not ready for prime time (not useful sensibly in policy arena)

In the group discussion, it was pointed out that response may vary depending on the weather at the time of the survey (i. e., like the 1988 summer heat wave) and media coverage. The effects shown in this survey are small compared to results of CV surveys dealing with other environmental disasters.

Some conference participants thought it was important to connect temperature scenarios to likely outcomes so people could make better decisions ( i.e., tell them how many elderly people would die as a result of the heat at a particular temperature, etc.). The participants advancing this viewpoint said that if people understood the dimensions, they could give us a better idea of what they really value. We need to present scenarios to people in terms they can relate to, these participants claimed, otherwise it is meaningless; we need to provide a frame of reference. Berk’s response to this was that if you load questions with emotional stimuli, you get too much bias; everyone responds to certain emotional stimuli, such as old people dying.

People act much as you would expect them to, but not mearly as fast.  It took big climate changes to budge people

What was the biggest surprise in this survey? It took big climate changes to budge people. And, it was pointed out, public perceptions are reality in social science. For example, one participant said, after the Valdez oil spill, the quality of the salmon was fine, but people wouldn’t buy or eat it, because of the perception that its quality was low. In economic terms, the *perceived* quality was what mattered.

# The Surprises in the Greenhouse May Be Chemical (and in Retrospect, Obvious)

William Chameides
Georgia Institute of Technology, School of Earth & Atmospheric Sciences
*Atlanta, Georgia*

98 U.S. cities are out of compliance with EPA limits on ozone, and 70 million Americans are exposed to unhealthy concentrations of ozone.

Global change is an observational fact, not a theoretical possibility. Humankind is a major factor in this change. Examples of human impacts include the increase in atmospheric carbon dioxide, stratospheric ozone depletion, and increases in tropospheric ozone.

The 1990s have already witnessed a significant global change surprise - the unexpected slowing in the upward trend in some greenhouse gases (GHGs), namely carbon dioxide, methane and nitrous oxide. Is this just a blip in the long-term upward trend or a new regime? What is the cause of this surprise? Mt. Pinatubo effects? Other ideas? Chameides points to a remote possibility (perhaps a 1 to 5% probability) that by some global process, the Earth system is accommodating anthropogenic emissions.

On the subject of atmospheric chemistry and global change, the public's concerns are centered on 1) personal health, 2) human welfare, and 3) ecological impacts. The subject of tropospheric ozone touches all of these concerns. There are different regimes of tropospheric ozone. Ozone in the upper free troposphere (some of which comes from the stratosphere) is an effective GHG and measures about 40-80 parts per billion by volume (ppbv). In the boundary layer, it occurs at high levels (80-200 ppbv) and is mainly a result of urban smog. In rural areas, the levels are relatively low and the concerns are related to production of food and human health. In remote areas, the concerns are mainly about ecosystem impacts. There are currently significant effects of ozone pollution.

In the area of human health:

- 98 U.S. cities are out of compliance with EPA limits on ozone, and
- 70 million Americans are exposed to unhealthy concentrations of ozone.

Agricultural impacts include:

- $3 to 5 billion lost annually in crop production, and
- significant losses in forest products.
-

Tropospheric ozone is also a significant GHG.

A clear upward trend in tropospheric ozone concentrations in the Northern Hemisphere is probably due to anthropogenic activities. A doubling or tripling of background levels of tropospheric ozone may have caused an increase in radiative forcing of some 0.2 to 0.5 watts per square meter ($W/m^2$) and could also be causing a decrease in net production in forest ecosystems of 1 to 3% per year. This represents a significant increase in radiative forcing and

a significant decrease in forest production. What is causing the ozone increase and what are its implications?

*VOC+ $NO_x$ + Sunlight = ozone*

*($O_3$)* Nitrogen oxides ($NO_x$) and volatile organic compounds (VOCs), the vast majority of which come from anthropogenic sources, are the precursors of tropospheric ozone. The amount of NOx most closely controls the amount of ozone. Lower VOC levels cause the system to react more slowly by lowering reactivity but will result in the same concentration in the end. Conversely, lowering $NO_x$ levels causes the reaction to build up more quickly but results in less ozone in the end. Therefore, Chameides believes that what we really must do is lower NOx emissions to control ozone pollution. Current policy, however, is mostly concerned with lowering VOC levels, which merely exports the ozone somewhere else and raises background levels of atmospheric ozone. Will urban ozone-reducing policies actually increase global levels of tropospheric ozone? We need to make connections between spatial scales and be concerned about regional and global impacts as well as local ones.

What we really must do is lower $NO_x$ emissions to control ozone pollution. Current policy, however, is mostly concerned with lowering VOC levels.

Empirical evidence indicates that ozone level is a function of $NO_x$ emitted. This relationship exists even in remote areas and the increase in ozone globally is a result of $NO_x$ emissions. Humans are changing the chemistry of the atmosphere; 75% of $NO_x$ comes from fossil fuel burning, biomass burning, fertilizer-induced soil emissions, and aircraft emissions. The observed increase in ozone levels highlights a series of specific concerns and suggests some potential surprises. In the area of climate, upper tropospheric ozone is an effective greenhouse gas, and aircraft $NO_x$ emissions could be enough to perturb upper tropospheric ozone. (Particularly in winter months, there is a significant contribution by aircraft to NOx in the upper troposphere.) New aircraft may be more fuel-efficient, but emit more $NO_x$. There is also evidence that ozone changes may be affecting hydroxyl (OH) levels and thus, the oxidative capacity of the troposphere.

*Increasing Tropospheric Ozone: Specific Concerns Climate*

- Upper tropospheric ozone ($O_3$) is an effective greenhouse gas.
- Are aircraft NOx emissions perturbing upper tropospheric $O_3$?
- Some greenhouse gases are affected by the oxidative capacity of the troposphere.
- Are $O_3$ changes affecting the oxidative capacity? How?

*Biospheric Effects*

- Increasing $O_3$ on regional and hemispheric scales may be suppressing net productivity and growth in ecosystems.
- Is there a significant perturbation of biospheric trace gas emissions?
- Is there a significant impact on carbon storage and ultimately on atmospheric $CO_2$?
- Is $O_3$ pollution affecting agriculture and world food production?

*Potential Surprise*

- Will urban ozone pollution mitigation policies that emphasize VOC reductions rather than $NO_x$ reductions implemented in the US and elsewhere accelerate the build-up of tropospheric ozone?

Ozone pollution also affects crops. Ozone gets into plants' stomata, penetrates cell walls, and makes membranes brittle. In some cases, the membrane breaks; in less severe cases, the membrane weakens and the plant must work hard to repair it, reducing productivity. Antioxidants, such as vitamin C, may help protect against oxidants like ozone. Irrigation opens plants' stomata, making them more susceptible to ozone effects. Changes in net production over a growing season varies a great deal depending on crop - those that breathe more (annual crops versus trees) suffer the greatest impacts. Crop yields vary as a function of ozone in the atmosphere - yield reductions of 5 to 10% are associated with ozone concentrations in the range of 50 to 75 parts per billion by volume). More sensitive crops are affected at 50 parts per billion; rice is less sensitive, and is affected at around 70 parts per billion.

Generally, we burn fossil fuels in the same places we produce food and use fertilizer. On 23% of the world's land mass we burn 74% of the fossil fuels and grow 62% of the food (using 77% of the nitrogenous fertilizer). These regions are the economic drivers of the globe. Globally, 10 to 30% of all cereals are produced in regions subject to ozone impacts. These ozone impacts could triple in the next 25 years. A back-of-the-envelope calculation supports a prediction that 3 to 5% of the world's food production could thus be eliminated through loss of plant productivity.

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Tropospheric ozone increases could result in total food crop losses similar in magnitude to estimates of those due to global warming. If a net global crop loss of 1 to 5% resulted from each of these factors, there could be more than a doubling effect since they may occur in opposite regions from each other.

# Regional Climate Studies and Tropical Cyclones

Jenni-Louise Evans
Pennsylvania State University
*University Park, Pennsylvania*

Tropical cyclones, storms characterized by winds of 17 meters per second or greater, occur at a frequency of 80 per year globally, plus or minus 7% (about 5 storms). There is very little variation in their annual occurrence. Globally, Evans believes this number is unlikely to change, though regionally, we do not understand enough to say.

If the wind speed of a cyclone is doubled, the destructive potential increases approximately four times. We currently have little skill at forecasting cyclone size, though we can forecast track. General circulation models (GCMs) don't include tropical cyclones because they are smaller in area than the grid scale.

Worldwide, cyclones cause about $10 billion in damage each year and are responsible for 10,000 human deaths on annual average. These numbers can be much higher in individual bad years; 300,000 Bangladeshis died in one year (1970) from storm surges.

Worldwide, cyclones cause about $10 billion in damage each year and are responsible for 10,000 human deaths on annual average.

Emphasizing the need to conduct regional climate studies, Evans summarized an array of techniques. Among these, listed in order from less useful to more useful, she discussed:

- extrapolation of recent observations
- direct inference from GCMs
- analogs of past climate
- nested climate modeling
- theoretical models
- inferring changes from indirect GCM diagnostics
- sensitivity studies using process models
- detailed data analysis, including interannual variability studies
- combination of (5), (7), and (8) with GCM information on foreshadowed large-scale changes

As many of these methods as possible should be used.

Current theoretical models generally only look at one variable, sea surface temperature (SST), even though we know that tropical cyclones are affected by other variables as well. Warm water is rare, and Evans' data show little correlation between storm intensity and warm water. Not enough people are working on the problem, and most people working on it are in the United States, focusing mainly on the Atlantic. Gray looks at other factors and has studied, for example, long-term cycling in western Sahel rain storms in Africa and their possible association with

hurricanes in Florida. SST may be too limiting as the focus of study, as opposed to atmospheric variables.

A policy statement from a World Meteorological Organization/International Council of Scientific Unions (WMO/ICSU) panel on tropical cyclones and climate change says that first-order effects of SST on tropical cyclone frequency and intensity should not be expected. Second order effects are expected to be less significant than El Niñ o effects. We actually know very little about tropical cyclones and, in particular, how they interact with the climate system. This statement prompted group discussion with Evans saying that it is the most responsible statement that can be made at this time, whereas some maintained that in light of the uncertainty, it is irresponsible to say that increases in frequency and intensity should *not* be expected.

In conclusion, Evans believes that the earlier speculation of some experts that tropical storms could increase in frequency and intensity has become dogma in the media and policy arena, as well as with the general public, despite the fact that most experts on this issue feel that their data do not support this speculation, and that they are more uncertain now than before.

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# Potential Feedback Between Climate and Methane Clathrate

Danny Harvey
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*Toronto, Ontario, Canada*

Methane clathrate is an ice-like compound in which methane molecules are caged in cavities formed by water molecules. It looks like ice and it forms in the oceans in continental slope sediments. It is stable under certain temperature and depth combinations, and is not found shallower than 250 meters deep. Most of the methane clathrate is of biological origin and is concentrated at the base of the stable zone. In principle, there may be an enormous reserve of methane ($CH_4$) in clathrate but there is a several orders of magnitude uncertainty about how much is actually present. With warming, it could move from a stable to an unstable condition, resulting in the release of the enclosed $CH_4$, leading to a significant positive climate feedback (surprise).

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The potential marine release of methane is much more significant than that of terrestrial permafrost regions because the release from land would be greatly delayed whereas oceanic continental shelves might produce a quick, continuous release followed by pulse releases, or a delayed but sudden release.

In short, the destabilized methane could:

- migrate into the stable zone, release latent heat in sudden release
- accumulate beneath the stable zone with pressure build up and fracture release
- accumulate beneath the stable zone, release shear strength, thereby causing sediment slumping if on a slope
- 

What happens when methane bubbles reach the sediment-water interface?

- some bubble dissolution into ocean water
- some oxidation of dissolved methane before it reaches the atmosphere - variation by 7 orders of magnitude - so how much will reach atmosphere is a big question.

The model presented by Harvey represents an attempt to construct a plausible, reasonable worst-case scenario driven by anthropogenic emissions of $CO_2$ and methane. Assumptions are biased toward worst case; they neglect possible impact of lower sea level, the possible retention of methane in residual clathrate structure, etc. For these assumptions, climate-clathrate feedback enhances global warming by 6 to 7% for low climate sensitivity, and by 20% for high climate sensitivity. Harvey estimates that there is a 20 to 30% probability of a 20% feedback.

# Policy Tools to Limit Global Warming

Danny Harvey
University of Toronto
*Toronto, Ontario, Canada*

There are significant opportunities to reduce $CO_2$ at a net cost savings. Economists argue that if this potential really exists, why isn't it happening now? One key reason is transaction cost.

Harvey believes that a middle-of-the-road, surprise-free scenario is reason enough to do something about global warming. There are significant opportunities to reduce $CO_2$ at a net cost savings. Economists argue that if this potential really exists, why isn't it happening now? One key reason is transaction cost. Looking at technical potential and engineering analysis, the potential does exist, so we should look for ways to reduce transaction costs.

Harvey presented a proposal for saving electricity in Toronto with a goal of a 20% reduction in electricity use. Looking at a "frozen efficiency" projection and two other projections, he claims that in the study area, it is in society's interest to reduce electricity use by up to 50%. A program under consideration in Toronto will try to get as much of that identified efficiency potential as possible by overcoming the usual barriers: awareness and credibility problems; lack of coordination among key players, transaction costs, and up front financing.

If there is an economically desirable outcome, private sector money can be used; but financial institutions often lack awareness of energy efficiency potentials. Thus the financing scheme for this program includes a private sector pool and a government pool for loan securitization, up front payments to contractors, and the generating of positive cash flow for consumers by having the costs of financing the retrofits be lower than the savings in utility costs. In addition, by combining gas, water, electricity, and financing costs all into one bill, some administrative savings are realized. Loans are structured a with 20-30% margin of error so savings are generally greater than anticipated. The figure that follows illustrates a financial structure for funding a local plan to reduce greenhouse gas emissions (Figure 6.1).

The government's role in reducing overall risk is to cover defaults through property taxes; anything extra goes back into the pool. That is a significant difference between this program and conventional government subsidies. The system uses the leveraging of a larger pool of capital to reduce risk and obtain lower interest rates; this pooling of money reduces transaction costs to financial institutions The target is maximum energy and water savings. The methods are private sector financing, positive cash flow, and a decentralized structure.

In conclusion, the surprise may be that it is not so costly to reduce $CO_2$ emissions.

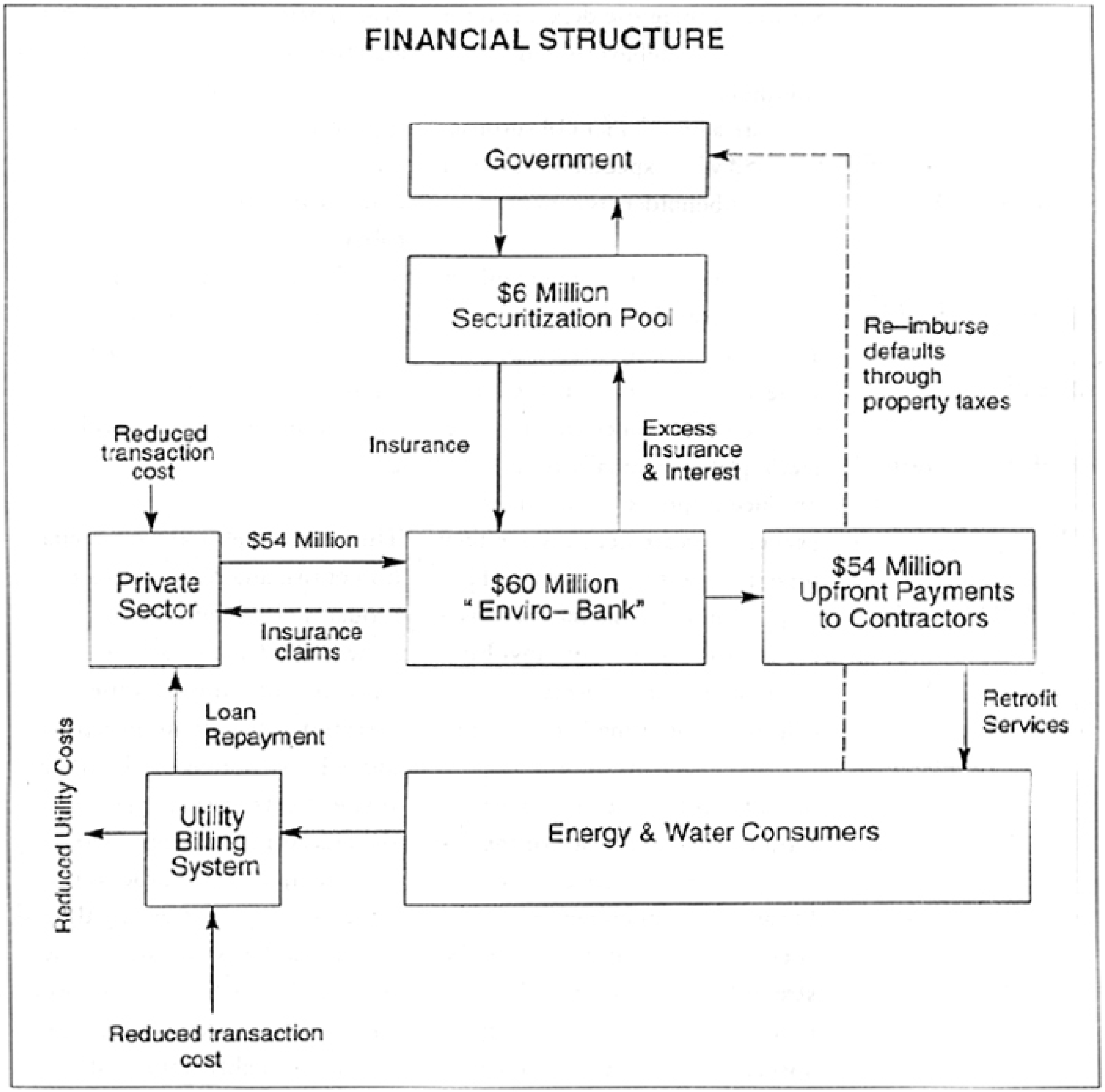

FINANCIAL STRUCTURE
Government
$6 Million Securitization Pool
Insurance
Excess Insurance & Interest
Re–imburse defaults through property taxes
Reduced transaction cost
Private Sector
$54 Million
$60 Million "Enviro– Bank"
Insurance claims
$54 Million Upfront Payments to Contractors
Retrofit Services
Loan Repayment
Reduced Utility Costs
Utility Billing System
Energy & Water Consumers
Reduced transaction cost

Figure 6.1

# Observations About Surprise from the Hazard and Risk Perspective

Roger Kasperson
Clark University
*Worcester, Massachusetts*

One hypothesis is that the degree of surprise is a function of the strength of expectations, the signal value of the event, and the salience of the hazard to the beholder.

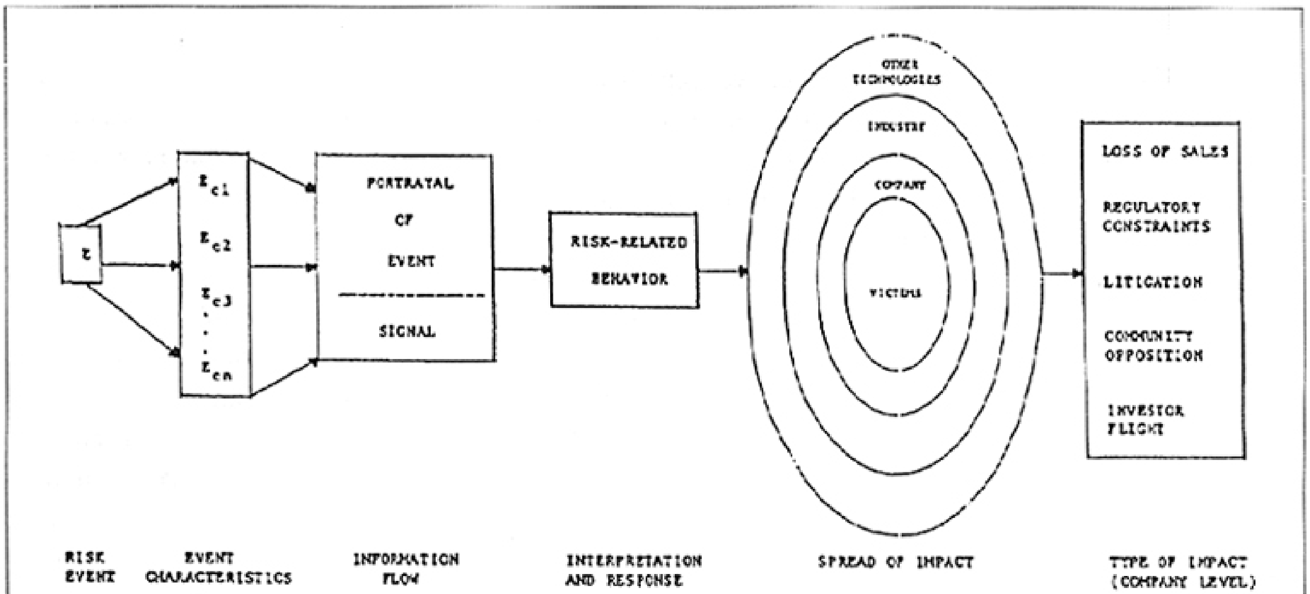
Surprise occurs when perceived reality departs qualitatively from expectations (Holling, 1986). Surprise is therefore dependent on expectations, behaviors and interpretations. Since expectations are a key element of surprise, how and why expectations arise in different beholders is central.

Expectations arise from metaphors and concepts that provide order and understanding to science and society. Concepts are rooted in experience and since concepts are incomplete, eventually they produce surprises. The longer expectations are held beyond their time, the greater the degree of surprise and adjustment. Surprises are of many types; some involve rareness and large uncertainties, others do not. One hypothesis is that the degree of surprise is a function of the strength of expectations, the signal value of the event, and the salience of the hazard to the beholder; each of these variables is important to the strength of the response. Surprises also depend on the “surprise specialists” (i.e., environmental groups, non-governmental organizations, etc.), who, Kasperson says, search for and sometimes manufacture surprises.

Risk signals are messages about a technology, activity, or event indicating that a new risk has appeared or that an existing risk is more or less serious or manageable than previously thought. Attributes that affect signal value include newness, catastrophic potential, involuntary exposure, blame, management of risk events distributional effects, and the societal processing of the risk or event.

The social amplification/attenuation of risk and risk events are products of the information system (media, interpersonal network, etc.), the response system (organizations, groups, individuals, attentive publics) and ripple effects (cascading effects, secondary and tertiary). The social-amplification process may either amplify or attenuate the risk event and the event’s signal value. Surprise is very much about how this process operates. The figure below is a highly simplified representation of the social amplification of risk and potential impacts on (in this example) a corporation.

Kasperson believes that society’s current management system keeps generating surprises; it is management system failure in many cases, i.e., we “couldn’t believe” the extreme measurements of the ozone hole or we would have known about it sooner; we could have prevented Three Mile Island and the Valdez oil spill, but the mind set that it could not happen kept us from doing so. This is management failure; we need to expand the uncertainty bounds. People systematically underestimate the potential for error and overestimate how much we know.




Highly simplified representation of the social amplification of risk and potential impacts on a corporation.

*Figure 7.1*

**Some examples of recent surprises and interpretations of what went wrong**

| Surprise | Signal |
|---|---|
| Ozone Hole | Scientific Ignorance/Uncertainty |
| Three Mile Island | “Mind Set” (Kemeny Commission) |
| Bhopal | Managers Not in Control |
| Love Canal | Intense Social Amplification |
| Somalia Famine | Managers and Alerters Fail |
| Hurricane Hugo | Vulnerability, Emergency Response Failure |
| Challenger Accident | NASA Suppression of Risk Information |
| World Trade Center Bombing | US Not Invulnerable to Terrorism/Rare Events |

# Eliciting Expert Judgments about Uncertainty in Climate Prediction

David Keith
Harvard University
*Cambridge, Massachusetts*

On the most basic questions, the experts agreed about the answers as well as the range of uncertainty.

David Keith and Granger Morgan (of the Carnegie-Mellon cross- disciplinary group) interviewed 16 climate experts in order to:

- better quantify existing uncertainty in climate prediction
- research resource allocation questions and cost of information
- seek support for other integrated assessment efforts
- improve techniques for eliciting expert judgments in technical domains
- improve communication of uncertainty between climate prediction community and impact assessment community - especially what things each wants and needs to know from the other.

They plan to elicit expert judgment on three climate change topics: climate prediction, ecosystem impacts and socioeconomic impacts. Keith reported on the first topic.

Face-to-face interviews consisted of an introduction, general discussion, uncertainty in prediction of policy-relevant variables, disaggregated sources of uncertainty in global change in temperature, research resource allocation, and surprise. On the most basic questions, the experts agreed about the answers as well as the range of uncertainty. On more difficult questions, such as how much will the gradient between the poles and the equator change or how will precipitation change, there is much less agreement.

Key issues in the general discussion section included mega-models (don't trust results but the process of constructing these things is useful and important; there's a failure to link disciplines); down scaling; modeling versus data collection; mission-oriented versus curiosity-driven research; linking focused studies to global models.

The budget allocation exercise, which asked each expert to make funding choices for the US Global Change Research Program, found general consensus that too much money goes into NASA's Earth Observing System (EOS); many thought we could have multiple, smaller, more flexible platforms that would be more effective than the large, expensive EOS we now fund. Another interesting outcome was that the experts believe there is a chance (~20%) that after a 15- year research program funded exactly as they wanted, there would be an increase in uncertainty about climate change.

There appeared to be evidence of a possible bandwagon effect: there was closer agreement on the temperature sensitivity issue than on other questions, perhaps because there has been more discussion of that question and people have been influenced by the opinions of others.

How to determine who is a credible expert is still a key question, and who you choose will always bias the results to some extent. This group used three criteria in choosing their experts: prominence, location (due to funding realities), and a matrix of subject areas to cover. When trying to assess questions of surprise and uncertainty, techniques such as this survey of experts can be a good way of trying to assign probabilities to events.

# Demography and Global Change

Geoffrey McNicoll
Australian National University
*New York*

Major demographic fluctuations over large populations are historically rare. Changes that are locally drastic disappear in global aggregates. Even the greatest demographic catastrophe in modern history - the 1959-61 famine in China associated with the Great Leap Forward policy, which resulted in 30 million excess deaths and a 35 million deficit in births - had a barely perceptible impact on the curve of world population growth. Simulations of India's population trajectory show that introducing sharp mortality peaks at regular intervals has only a slight effect on the course of India's population growth. Thus it makes sense for demographers to work generally with "surprise-free" projections - making assumptions of smooth trends in mortality and fertility.

Over the long run, small differences in fertility are enourmously consequential.

Over the long run, small differences in fertility are enormously consequential. The United Nations (UN) long term population projections demonstrate this sensitivity.

As Figure 9.1 shows, a fertility rate that stabilizes at 2.06 children per woman ("replacement level") results in a world population of 11 billion in the year 2150 (UN medium projection); at the slightly higher level of 2.17 children per woman, the 2150 population reaches 21 billion (UN medium-high), and at the slightly lower level of 1.96 children per woman, the population reaches a peak of 8 billion in 2050, then falls back to 6 billion in 2150 (UN medium-low projection).

Commenting on the efforts to model population-environment interactions, McNicoll noted the estimate by Bongaarts that population growth accounts for one-third of the projected rise in CO2 emissions by 2100. However, since this calculation already assumes a falling rate of population growth (in line with the UN medium projection), it does not offer a new demographic route to lower emissions. McNicoll was skeptical of the feedbacks on mortality from population-caused pollution and soil degradation introduced in the models of Meadows and colleagues (*Limits to Growth*, 1972, *Beyond the Limits*, 1992). However, he did not rule out possibilities for demographic collapse in the future - not necessarily associated with feedbacks from population growth.

He offered a six-part categorization of "demographic surprise" scenarios that might lead to regional or global population collapse:

1. atmospheric dust/aerosols impede photosynthesis and cool Earth's surface, triggering crop failure and perhaps killing other vegetation; ex.: major volcanic eruptions; "nuclear winter"

2. disease: new or newly virulent pathogens affect humans or crops; ex. in the past: smallpox, measles; in the future: new viruses, perhaps some more infectious variant of HIV.
3. climate change, exceeding adaptive capacity of agricultural systems or supporting ecosystems; ex.: shift in ocean currents affecting coastal temperatures, new pest regimes, forest die-off.
4. environmental degradation from human impact, yielding population overshoot and collapse; local examples are common but global analog seems implausible (except through climate change).
5. breakdown of physical infrastructure, such as distribution systems supplying major cities, irrigation systems, etc., typically resulting from war.
6. institutional breakdown: erosion of legitimacy or performance of institutions of state and economy; ex.: "failed states" such as Liberia, Sierra Leone, Somalia.

McNicoll argued that the policies that have proven effective are: 1) rapid economic growth, leading to "demographic transition"; 2) authoritarian control by a government; 3) "fortuitous institutional inheritance" - situations where social or cultural pressures to curtail fertility emerge naturally as population increases.

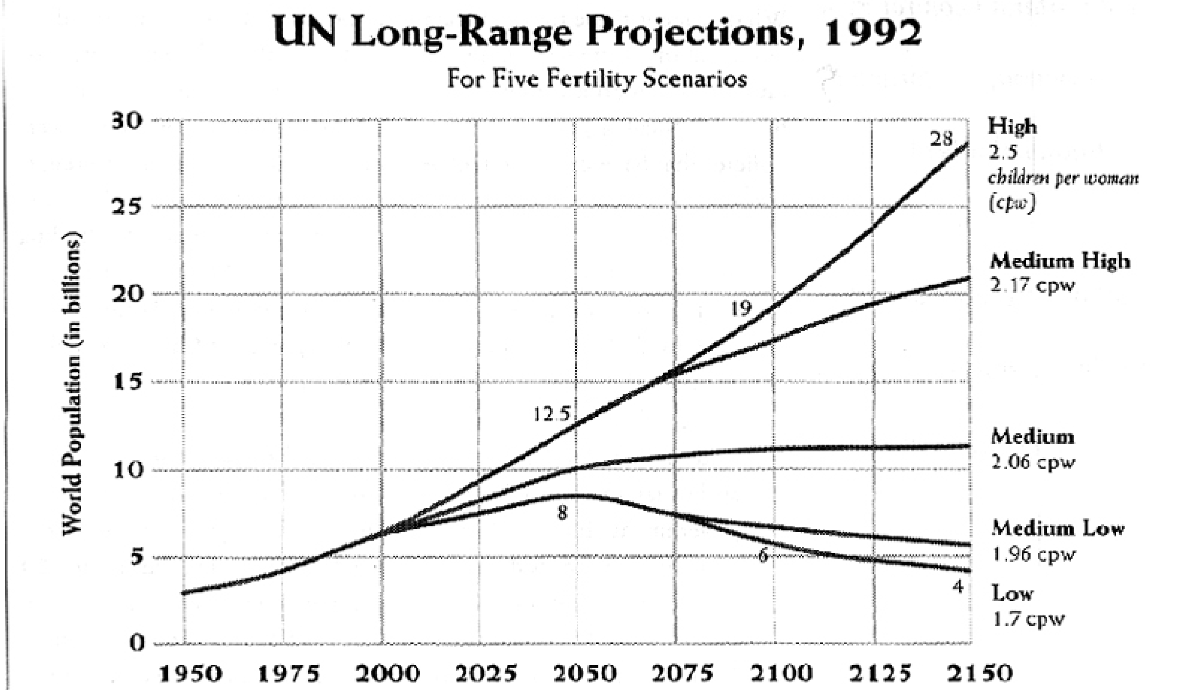
McNicoll viewed the first three as potentially global phenomena, the last three as more likely to be regionally confined.

What scope is there for deliberate modification of the demographic future through policy intervention? McNicoll argued that the policies that have proven effective are:

1. rapid economic growth, leading to "demographic transition" along the lines that occurred in the industrialized world; affluence and equity lead to lower fertility.
2. authoritarian control by a government able to enforce compliance with its demographic goals and not much concerned with human costs; China in 1970s is the principal example.
3. "fortuitous institutional inheritance" - situations where social or cultural pressures to curtail fertility emerge naturally as population increases, with minimal need for a government role; there is scope for policies that seek to create those situations through institutional reform (e.g., in land tenure, local finance, women's emancipation).

McNicoll was skeptical that distribution of contraceptives through family planning programs had a strong independent effect on fertility. (He judged the empirical evidence on the matter to be inconclusive.) He noted that current emphases in international population policy were on education and women's empowerment, which would tend to reduce fertility by affecting the demand for children. The debates leading up to the 1994 International Conference on Population and Development in Cairo stressed this direction.

During the discussion, some took exception to the notion that distributing contraceptives was ineffective, noting that if the 120 million couples who want but do not have access to contraceptives were given them, we could cut population in the year 2050 by 2 billion.




*The difference between a medium high scenario (where world population in 2150 would be ~ 21 billion) and a medium low scenario (where world population in 2150 would be ~6 billion) would only be 1/5 child per woman (2.17 - 1.96 = 0.2).*

*Figure 9.1*

# Environmental Refugees

Norman Myers
Independent Scientist
*Oxford, United Kingdom*

Environmental refugees can be defined as "persons obliged to leave their traditional or established homelands for reasons of environmental problems on a permanent basis with little or no hope of ever returning."

Norman Myers cites economist colleagues who estimate that in the United States, $227.4 billion, or 4% of the US gross national product, is lost due to environmental damage. Globally, Myers identifies 18 "hot spot areas for biodiversity" - areas defined by their high species concentration and their high chance of habitat loss. Some 20% of all plant species are on 0.5% of the land surface and they are at extreme risk. Sub-Saharan Africa can best meet its food needs, not only by planting more crops but by planting more trees. This is because 10-20% more soil moisture could be preserved if trees were planted near growing areas; there would also be more fuel wood, and better watershed services, such as regular water flows and cleaner water.

Environmental refugees can be defined as "persons obliged to leave their traditional or established homelands for reasons of environmental problems (deforestation, desertification, floods, nuclear plant accidents, etc.), on a permanent or semi-permanent basis with little or no hope of ever returning." Myers estimates that there are currently about 25 million of these environmental refugees in the world, compared to about 17 million traditional (political) refugees. No formal accounting is currently taken of these environmental refugees, though they are the fastest growing category of refugees, and their numbers could reach 50 million by the year 2010. There could be 200 million of them in a greenhouse- warmed world. Half of present environmental refugees are in Sub- Saharan Africa.

Global warming could produce four major impacts that would create more environmental refugees:

1. increased drought
2. disruption/intensification of monsoon systems
3. intensification of typhoon systems and destructive impacts of this intensification
4. sea-level rise and storm surges

These would particularly affect low-lying coastal areas with already- subsiding coasts such as Bangladesh, the Nile Delta and China's coastal zone. (Coastal subsidence is largely due to natural processes and humans pumping ground water.) The problems created in low- lying areas would be further exacerbated as cholera and other water-borne diseases proliferated.

# The United States Global Change Research Program: Priorities for Addressing Unmet Needs

Rick Piltz
Committee on Science, Space and Technology
US House of Representatives
Washington, DC

Rick Piltz offered an overview of the US Global Change Research Program (USGCRP). He provided a brief comparison of the program under the Bush and the Clinton administrations. Though he praised the reforms of the latter, he identified persistent unmet needs in the overall research agenda. Calling for that agenda to feed ongoing policy, Piltz proposed a series of priorities for scientists as well as decisionmakers.

Posing uncertainties in terms of decisionmakers' own uncertainties in ways that are relevant to those decisionmakers can go a long way towards building a bridge between the worlds of science and policy making.

The Bush administration's unwillingness to commit to a $CO_2$ policy produced, in effect, a mandate to focus on long-term scientific uncertainties such as those that preoccupy Working Group I of the Intergovernmental Panel on Climate Change (IPCC). Thus "policy-relevant" rhetoric (science before policy) heralded the need to postpone decisions pending a "comprehensive predictive understanding of the Earth system."

The Clinton administration's 50-point technocratic Climate Action Plan takes a proactive approach to the climate treaty. This proactive stance entails looking beyond the year 2000 in planning for the inevitable impacts attendant on future climate change as well as an acknowledgment of the need for linkages between assessment of global change and ongoing public policy. Thus the research agenda requires additional priorities that will meet a series of unmet needs.

In Piltz's view, the USGCRP agenda has not given enough attention to:

- research on impacts, both environmental and socioeconomic
- research on response strategies, such as mitigation and adaptation, and their implications
- integrated assessments

How should we make analyses of impacts and response strategies relevant to the policy arena? Piltz suggests tackling this problem by working to reduce the scientific illiteracy among decisionmakers. In addition, posing uncertainties in terms of decisionmakers' own uncertainties and illuminating those uncertainties in ways that are relevant to those decisionmakers can go a long way towards building a bridge between the worlds of science and policy making.

# Possible Surprises in Nonhuman Animals and How they Affect Humans

Terry Root
University of Michigan
*Ann Arbor, Michigan*

Ecosystems are being damaged by human-induced disruption of the dynamics between and among species. Such ecosystem impacts can have a domino or cascading effect within a system.

Ecosystems are being damaged by human-induced disruption of the dynamics between and among species. Such ecosystem impacts can have a domino or cascading effect within a system. In some cases, an extinction may not appear to be catastrophic and this gives the public a false sense of security, i.e. the passenger pigeon went extinct, and so far we have seen no apparent major ramifications for the human population. There are other examples that have had major impacts for humans.

An observed increase in Prairie Canid populations, attributable to humans drastically reducing wolf populations, provides a good example of unexpected cascading effects. In the natural system, wolves control coyotes, and coyotes control red foxes; so if you suppress wolf populations, coyote populations explode; if you suppress coyotes, populations of red foxes explode. So what have humans done by suppressing the wolf? We have caused a population explosion among red foxes. Why is this a problem? Down the food chain, red foxes hunt water fowl. Currently, water fowl abundance continues to fall; duck populations in red-fox areas have been decimated (Meanwhile, humans are spending lots of money to try to protect water fowl -- so humans can hunt them -- but the reintroduction of wolves or coyotes would probably be more effective). Also, skunk and raccoon populations are exploding because there are no wolves to control them. Rabies from raccoons is now a significant threat to humans in some parts of the country (e. g., U.S. east coast). So by eliminating wolves, we have altered the balance of an entire ecosystem. These are “surprises.”

Another example is a case involving the dodo bird, which was brought to extinction by humans hunting it as a food source. In that ecosystem, the seed husk of a predominant local tree is so tough that the seeds canÕt sprout. The dodo bird would eat the fruit of the tree, swallow the seed and use rocks in its gizzard to sand down the seed husk. In this way, the dodo bird ensured the propagation of the trees. So by killing off the bird, humans also killed off the tree. This is how effects can cascade through an ecosystem. A third example is the replacement of US grasslands with agricultural lands. This has caused a decline in grassland birds. The use of fertilizers, pesticides and herbicides on agricultural land further damages the bird populations.

Chemicals in the environment do affect human beings. Pesticides in ground water are now a fact of life, contrary to the long-held, popular myth that ground water could be entirely purified by filtering through soil. There is bird embryo deformation as a result of our use of agricultural chemicals. There is also increasing incidence of cancer in fish as a result of these chemicals. Birds and fish that are mainly bottom feeders are most affected by the build up of chemical residues. Theodora Colburn and others are investigating connections between environmental

chemicals (such as PCBs) that may mimic estrogens and the reductions in sperm count in human and other animals, as well as other dysfunctions of the reproductive system.

On the positive side, laws enacted to protect ptarmigan and other species have been largely successful and some species are making a comeback. In such cases, people foresaw potential extinctions, and intervened in time. Dead birds used to be fashionable on womenÕs clothing and hats but the publication of data on the tons of bird feathers used and the numbers of birds being devastated turned that fashion around and stopped the bird slaughter.

Terry Root is studying impacts of temperature changes from global warming (especially winter night impacts) on wintering birds in North America. Using National Audubon Society Christmas Bird Count data from 1900 to the present, she is examining the relationship of environmental factors (such as temperature, frost, vegetation, and humidity) to the distribution of birds. Bird ranges are strongly correlated with isotherms. A large percentage of species have their northern boundary affected by temperature, frost, and/or vegetation. Those species that are limited by temperature will move as the climate changes; those limited by vegetation will not be able to move so quickly. This will disrupt communities of birds, leading to potentially catastrophic results. The synergistic effects of a combination of these effects with habitat fragmentation caused by increased development and agriculture will likely exacerbate this problem. What will happen when land-use changes split up predators and prey? An additional factor is the introduction of non- native species and their impacts on native ones. Through the tearing apart of communities, land use changes, and introduction of alien species, many potential surprises may emerge.

Those species that are limited by temperature will move as the climate changes, those limited by vegetation will not be able to move so quickly. This will disrupt communities of birds, leading to potentially catastrophic results.

Root has also been studying the effect of climate on passerine birds. Her data show that the northern boundary metabolic rate is 2.5 times the basal metabolic rate for all passerine birds limited by temperature. A small scale study showed that temperature is the critical variable for passerines. Results from both 1990 and 1991 data show that birds limited by temperature do move with changes in temperature. In short, global warming will prompt the immediate migration of some types of birds. In effect, this is the beginning of an ecological climate model. Additional work is needed to incorporate birds limited by vegetation, land use patterns, community disruption, relations between species, human impacts, etc., to develop a more complete model.

On the subject of the appropriate scale for biological/global change research, Root believes that small scale experiments are needed to understand the internal dynamics of an ecosystem, but that one cannot necessarily extrapolate these results out to the large scale. Large scale research helps to pinpoint which species should be studied at the small scale. A good research plan therefore begins with large scale studies to find associations and define which species to study at the small scale; it will probably then be necessary to revisit the larger scale. Most biology experiments are conducted on areas smaller than a tennis court. Such work is important but inadequate for understanding regional- and global-scale processes.

The interactions between biotic and abiotic effects also merit study. The findings of small- and large-scale biological research must be studied and coupled with the research of climatologists working on larger scales. Impact assessment, policy assessment, and policy choice feed back into anthropogenic disturbances.

# Examples of Surprise from an Ongoing Global Warming Research Project

Scott Saleska
University of California
*Berkeley, California*

They are conducting a field experiment that applies suspended overhead heaters to a series of plots to discern effects of global warming on complex natural ecosystems.

At a research site in Gothic, Colorado, Saleska and colleagues are heating a meadow. They are conducting a field experiment that applies suspended overhead heaters to a series of plots to discern effects of global warming on complex natural ecosystems. The site - a high-altitude, alpine meadow on the western slope of the Rocky Mountains - is expected to be especially responsive to global warming due to snow-melt response, albedo feedbacks, and soil that has 20 kilograms of carbon per square meter (about twice the US average).

Electric resistance heaters apply twenty watts per square meter of infrared heat to ten heated plots alternated with unheated plots. Probes in the soil at depths of 5, 10, and 25 centimeters log temperature and moisture every two hours. The researchers also measure whole system carbon dioxide flux.

Among the not-surprising micro climate results were 2° C higher daily average soil temperature in the heated plots relative to the control plots.

Surprises include:

1. *Micro climate results* The soil temperature difference between heated and control plots contains a mid-day spike of almost 6° - more than expected - probably because the heaters dried out the soil, so more of the sun's energy striking the heated plots went into warming the soil rather than evaporating water from it.
2. *Ecosystem carbon storage* The researchers used a special chamber to measure carbon flux in all plots every four hours, six times a day. Results revealed that from June to September, there is consistently less carbon storage in the heated plots than in the control plots. Though it is early to draw clear conclusions, extrapolating these results to the global scale would yield a significant impact. Globally, there are 10 million square kilometers of meadow; if the effect on carbon storage measured here were global, (everything else being equal) there would be an extra gigaton of carbon per year in the atmosphere of a greenhouse-warmed world. Some sort of carbon-flux feedback from warming should not be surprising but is currently not included in the general circulation models. There is a high correlation between carbon dioxide concentration and temperature for the past 160,000 years as evidenced in the ice-core record. Could this be due to release of carbon from tundra during warming periods?
3. *Shifts in albedo* In the heated plots of the upper zone, which is more representative of the area as a whole, sagebrush (which is drought tolerant) is doing better than forb and grasses (there is a higher rate of sagebrush recruitment and growth). The albedo

(reflectivity) of sagebrush is less than forb by ~3% (~12% for sagebrush compared to ~15% for forb), resulting in a net increase in absorption to the system on the order of $10 W/m^2$. So if the system converts from forb and grasses to sagebrush, there will be more solar absorption. The affects of warming on species composition go beyond changes in albedo, and eventually may result in a less diverse ecosystem.

Designing research policies to anticipate surprise:

- encourage innovation and unconventionality in scientific research
- encourage interdisciplinary approaches to research

Scott Saleska believes that the institutions of science resist innovation, reward the conventional, resist surprise, and resist and fail to reward interdisciplinary approaches, where "institutions" include funding sources, refereeing practices for scientific publications, hiring, promotion, and tenure decisionmaking. The ensuing discussion about these ideas found some arguing that this is either not true or is exaggerated. The question remains: what are the problems impeding the development of the state of art?

Saleska would like to see the establishment of programs explicitly designed to fund and otherwise support innovative, unconventional and interdisciplinary global change research, i.e., NASA global change fellowships, Pew Scholars Programs, and Aspen Global Change Institute programs.

To know one's ignorance is the best part of knowledge. To work to reduce ignorance, we should make public policy that is flexible and takes ignorance (uncertainty and surprise) into account. Since surprise is inevitable, we should strive to make policy that accounts for it.

If the system converts from forb and grasses to sagebrush, there will be more solar absorption. The affects of warming on species composition go beyond changes in albedo, and eventually may result in a less diverse ecosystem.

# Education and Global Change

Bob Samples
Sol y Sambra
*Santa Fe, New Mexico*

Colin Turnbull says the soul is "that which opens the mind." Bob Samples calls science a ballet of the mind. To create children who are scientifically literate, we must give up the protection of the illusion of certainty and be open to risk and authenticity. Surprise is the birthplace of learning. Surprise is a disruption in one's belief system, or an admission of ignorance. A real question in education is, "How can we manage surprise so as to learn from it?"

To create children who are scientifically literate, we must give up the protection of the illusion of certainty and be open to risk and authenticity. Surprise is a disruption in one's belief system, or an admission of ignorance. A real question in education is, "How can we manage surprise so as to learn from it?"

There are access routes to multiple intelligences. Since children tend to act the way they are expected to act, they often substitute conformity for learning. How often they're exposed to learning experiences is key. Ambiguity is the heart of real learning, but our traditional educational system stresses exactness and specificity. We should allow children to be free to discover discrepant events. At the beginning of true learning, children go to the playful domain (right brain) when left to discover on their own; then they'll go over to left brain for validation, then back to the right, and so on. This is the map of learning - back and forth until so much order persists that playfulness is terminated and proposition yields to fact. We need to educate so as to keep this cycle churning.

How can we encourage creativity so children can imagine surprises? How can we help keep children open minded all the way through the educational experience so they won't simply reach conventional conclusions and can instead discover "surprise"?

It is important not to discount the personal experiences of each child. Children can call upon widespread experiences and vast knowledge.

A surprise with implications for education is that stroke victims can be helped by ignoring the disability and focusing instead on calling out qualities of information that were stored in other, non-injured parts of the brain. Samples believes that every part of the brain knows everything any other part of the brain knows, so we can teach people to distribute experience rather than to isolate it. When people believe they haven't lost their mental capacity, they recover faster. They tap into learning that existed before, and create access routes into different realms. This can be applied to children's learning too. In a way, stroke victims are analogous to disenfranchised children in schools.

A vital first thing to do is to construct experiences that will get students into nature. People are designed to learn in a variety of ways, and nature is a perfect source.

The authoritarian model of education seeks to create people who have a high capacity to reason and can control their unconscious. A reliance on Newtonian order says "this is the body of knowledge you must know." Authoritarians want to require everyone else to have same experience base as they did - a rational neurosis.

"Consciousness is what you pay attention to. If you want to change your consciousness, just pay attention to different things."

*Learning is evolution*

One model of learning styles is based on personal preference for these different qualities:

- subjective must affect the person personally
- reflective sit and be quiet
- active activity based
- objective global uniformity

Explorations into areas that are not their dominant mode of learning help children become courageous in exploring. We must let children know their choices are valid and also offer them forays into other ways of learning. We need to prepare materials that have a wide array of success for children with different learning styles. Don't provide rewards for inauthentic performance; it's a deceit and a poor way of trying to boost self esteem and shows how willingly children submit to coercion.

We should get biological metaphors into the education system to balance the effect of over indulgence in Newtonian metaphors.

An evolutionary model of a value prejudice field:

- Authoritarian - believe they represent a higher level or system
- Dependency/manipulative - try to change people they come into immediate contact with through coercion and emotional manipulation
- Intrinsic - know that the source of stress comes only from inside; the only system one truly has control over is oneself; any energy expended is expended authentically
- Trans intrinsic - authentic and allows for everyone else's authenticity
- Pan intrinsic - makes changes in the way the world sees itself

In education as well as in natural systems Samples believes:

*Diversity* -- nurtures survival whereas specialization nurtures extinction
*Optimization* -- rather than maximization; reserve to fall back on
*Cooperation* - rather than competition
*Self-Regulation* -- natural systems are self-regulating
*Change* -- is continuous in evolving systems
*Connectedness* -- all parts of system connected to other parts
*Equivalence of niche* -- all roles are equivalent

We should get biological metaphors into the education system to balance the effect of over indulgence in Newtonian metaphors.

# Anticipating Global Change Surprises

Stephen Schneider
Stanford University
*Stanford, California*

Global change can be defined as change to the Earth system that either occurs globally or occurs regionally and sufficiently often to be of global significance. Schneider focused his comments on the component of global change attributable to human activity.

From medical care to insurance, nearly every aspect of human life depends on speculation by experts; why do we demand from global change science a far higher level of objectivity and certainty than we demand in other areas of our lives?

Probability estimates of particular events' occurring do not come from objective methods but rather depend on assumptions that are themselves subjective (i.e., physical, biological or social assumptions underlying "objective" methods used to calculate probabilities are usually intuitive). In the final analysis, probability estimates are the subjective judgments of experts. From medical care to insurance, nearly every aspect of human life depends on speculation by experts; why do we demand from global change science a far higher level of objectivity and certainty than we demand in other areas of our lives? Once we accept that probability estimates are subjective judgments and intuitions of experts, key issues then become: 1) what is the credibility of the sources for scenarios and their probabilities and 2) how do we establish methods to sample reliable intuitions?

The definition of what constitutes a high or low probability is also important. Clear delineation of the numbers that go with terms such as "very probable," "not enough evidence," etc., is critical. The recent attachment of ranges of numbers to such terms by the Intergovernmental Panel on Climate Change (IPCC) is a welcome improvement.

Referring, by way of example, to a model of predicted changes in precipitation patterns that might result from global warming, Schneider stressed the importance of taking model results "seriously, but not literally."

The process of multidisciplinary exchange will lead us to the discovery of surprises at the interfaces of subjects - to ideas unlikely to be uncovered within a single discipline. This discovery marks the transition from a *multi*- to an *inter*disciplinary perspective.

Schneider used various examples to demonstrate a large degree of consensus among the accepted experts - indeed the big global change questions spark far less controversy than is portrayed in the media. Although everyone admits a large degree of uncertainty, several surveys of experts judgments reveal fairly widespread agreement on major global change issues, except in the case of budget allocation for the US Global Change Research Program.

The synergism of fragmentation of habitat and climate change will cause already stressed creatures and systems to be further stressed and this is one of the greatest environmental threats we face. Other points Schneider discussed include the importance of scale, the need to look at things at the "tails" of distributions, and how to identify potential issues that aren't even on our "radar screen" yet.

# Economics and Global Change Surprises

James Sweeney
Stanford University
*Stanford, California*

When discussing anthropogenic impacts on global climate change, the focus must be on the energy sector. Gross domestic product (GDP), energy consumption, and carbon emissions are all coupled to some extent. The United States is using less energy for each unit of GDP than before, and producing less carbon for each unit of energy than before, but the growth trends in all three factors still go up together. In other countries, this varies. For developing countries, a shift toward commercial fossil fuels from biomass burning is causing carbon emissions to grow as fast as the economies.

Fifty to sixty years from now, the carbon emissions from China alone will be greater than the total world's current emissions.

Sweeney says that some of the things called renewable or biomass fuels are frauds because they don't really decarbonize the energy sector. One example is the use of so-called "biofuel" in gasoline, when the fuel is made from corn grown and distilled using fossil fuels.

Long-term projections of energy use are difficult to make because there are many things we don't know about energy technology development, social changes, etc. Nevertheless, various modelers have generated business-as-usual scenarios for future world carbon emissions, and the long range projections are clearly cause for concern. Figure 16.1 shows 6 to 7 fold increases in emissions by the year 2100 in a business-as-usual scenario! Figure 16.2shows regional projections of carbon emissions. The implications up to about 2020 don't look so bad, but several decades later, it looks like real trouble. Based on very common assumptions, the possibility of very large carbon emissions in the future is very likely.

The dominant economic growth is projected to be in China, which expects to use its large and dirty coal reserves to fuel this development. We must take a world view when looking at carbon emissions. Cutting US emissions by some small percentage is equivalent to rearranging deck chairs on the Titanic. Fifty to sixty years from now, the carbon emissions from China alone will be greater than the total world's current emissions. You can't fix this problem thinking short term and thinking about the US alone - it is a world problem. In all the models of future regional carbon emissions, China accounts for the most significant growth. There are large variations among the models' predictions about emissions from the former Soviet Union. In the US, some significant increases are expected if we do nothing, but Sweeney thinks it is unlikely that this will come to pass because the US will probably do something.

Who will pay for China to solve the problem? We must begin to think about the environment as an internationally tradable commodity. There are already some examples of multilateral deals in which one country protects its forests or makes some effort to reforest with other countries paying for it -- the so-called debt-for- nature swaps.

Policy responses to climate change include both mitigation and adaptation strategies. What will the physical environmental effects be, and what is the value of these effects? What will be the cost of adaptation to these physical effects? One policy mindset suggests that we can mitigate climate change in a costless way -- a no-regrets strategy -- by doing things it makes sense to do anyway, i.e., increasing energy efficiency.

Regarding how much emissions can be reduced and at what cost, one study concluded that 25% of carbon emissions could be cut while saving money, and that two-thirds could be cut at zero cost by paying for costly ones with ones that pay you back. But Sweeney, skeptical of this notion, calls the "technology view" a static view. In reality, he says, technology changes happen over time; there is a process by which the turnover takes place, and therefore a time trend is involved in economic models.

We must begin to think about the environment as an internationally tradable commodity.

Before the energy crisis, labor hours per unit GDP fell faster than energy per unit GDP as society began using energy and capital in place of human labor; this was "technology advance" (shifting from a labor-based economy to an industrial economy does this). Following this general trend of declining labor, we are now headed the other way, mainly due to the prevalence of the two-worker family. Accompanying our attempts to move away from energy intensity; there is a shift in technology focus. There is a reduction in both labor and energy and the expectation is that we will become more energy efficient over time because it will be in people's best interests. They will choose to do what is good for them and thus adopt the "best" technologies.

In order to get the market to work efficiently, we must get the prices right, which means, among other things, including environmental externalities. Are there free energy savings available, above and beyond what would be adopted by the market? Do people apply too high a discount rate? Sweeney thinks not. There is a high implicit discount rate; people have credit limitations. There is undiversifiable risk, and options value. Are people rejecting investments with a high rate of return? Is this irrational ? Sweeney thinks not. If technology is changing rapidly there is good reason not to buy first generation products. An example is the early compact fluorescent lamp (CFL). Since the technology improved so rapidly, the original CFL may not have paid for itself as promised because you'd want to get rid of the obsolete technology before you had exhausted its useful life and the financial commitment is irreversible.

Technology-driven estimates suggest that there is significant carbon reduction available for free and that people are not currently adopting technologies that they should be adopting due to lack of knowledge and/or failures of the marketplace. Sweeney disagrees with this notion. He believes most decisions are being made rationally, and in accordance with market principles.

Significant economic growth is projected over time so we need to bring down the energy intensity per unit of GDP (a demand side issue) and also decarbonize energy sector (a supply side issue).

How will the demand side respond to economic forces? Evidence that it will respond is that long-run aggregate price elasticity is in the -0.3 to -0.7 range, meaning that a 10% increase in energy prices leads to a 3-7% reduction in energy demand with GDP growth held constant. There is a slow adjustment process; in one year, the elasticity is an order of magnitude lower.

Usage elasticities are much smaller than those associated with equipment characteristics. For example, there is more significance in the heating system than in the thermostat setting, and in the car, rather than in how much it is driven. Modelers tend to underestimate the long run elasticities because they take into account only the modelers' concept of technology; they underestimate or ignore substitution possibilities. During the oil price shocks, the elasticity was at the upper end of the response range, around 7%.

Sweeney believes that most of the action is not on the demand side, but rather in decarbonization through technologies that use less fossil fuels. He believes that we will use up all the oil that exists and most of the natural gas (unless there are vast amounts as yet undiscovered). The issue is how much of the coal we will use and with what technologies. How do we ensure that fundamental research goes into making appropriate, low-carbon technologies available? It would be a mistake to force premature technologies on the system through government intervention.

There is a hysteresis effect: when energy prices go up, and people insulate their homes or create new technologies, even if prices go back down, the insulation will still be there and the new technology will still be there. So we don't lose all gains as prices fall back down. But when they do, some of the choices made when they were higher may look like bad choices. Smooth price rises are better than shocks.

Sweeney thinks that unless something changes, the most likely scenario is that we could have dramatic increases in carbon emissions, about 7 times current levels, and possibly even more. But that is the business-as-usual scenario and many think it unlikely that it will happen that way.

How hard do we have to push the system with price rises to see significant carbon reductions? Very hard, Sweeney says. It would take a tax of $20-$150 per ton just to stabilize emissions. To get 20% reduction, $100-$400 tax per ton would be needed, and this would require a real political commitment.

Do the prices of non-fossil "backstop" technologies vary with fossil prices? A potential area of surprise lies here; what will be the costs of these future technologies? Will we pursue policy options to bring down the costs of these non-fossil technologies?

The models, which are only looking at the cost of mitigation options, include no externalities. The environmental effects of carbon emissions are very long term. What happens to the ecosystem and biodiversity, and what are the socioeconomic impacts? What is the value we place on these things?

What is the cost of avoiding carbon emissions increasing by a factor of 7? If one becomes 12 times as wealthy as now, the value of nonmaterial things rises relative to the value of the dollar. As people get wealthier, the value of environmental amenities grows relative to material things. The small reduction in GDP necessary to avoid major environmental disruption seems worth it. Throughout this discussion, fairness issues were raised. Who pays for the commons, *i.e.* clean air? The developed countries must be willing to pay for reducing emissions by China; they should be compensated for not using their coal to fuel their development.

As people get wealthier, the value of environmental amenities grows relative to material things. The small reduction in GDP necessary to avoid major environmental disruption seems worth it.

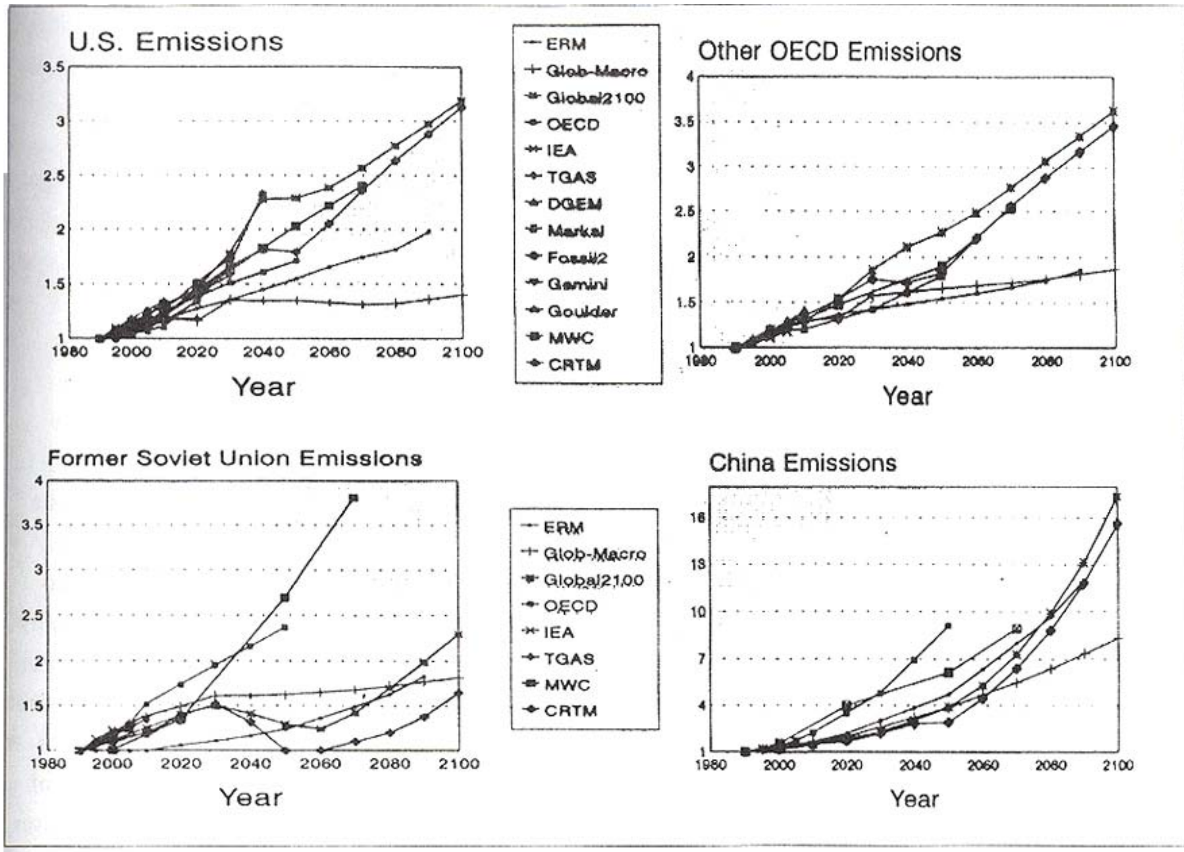



*Figure 16.1*
*Regional Carbon Emissions*
*Indexed to 1990 = 1.0*

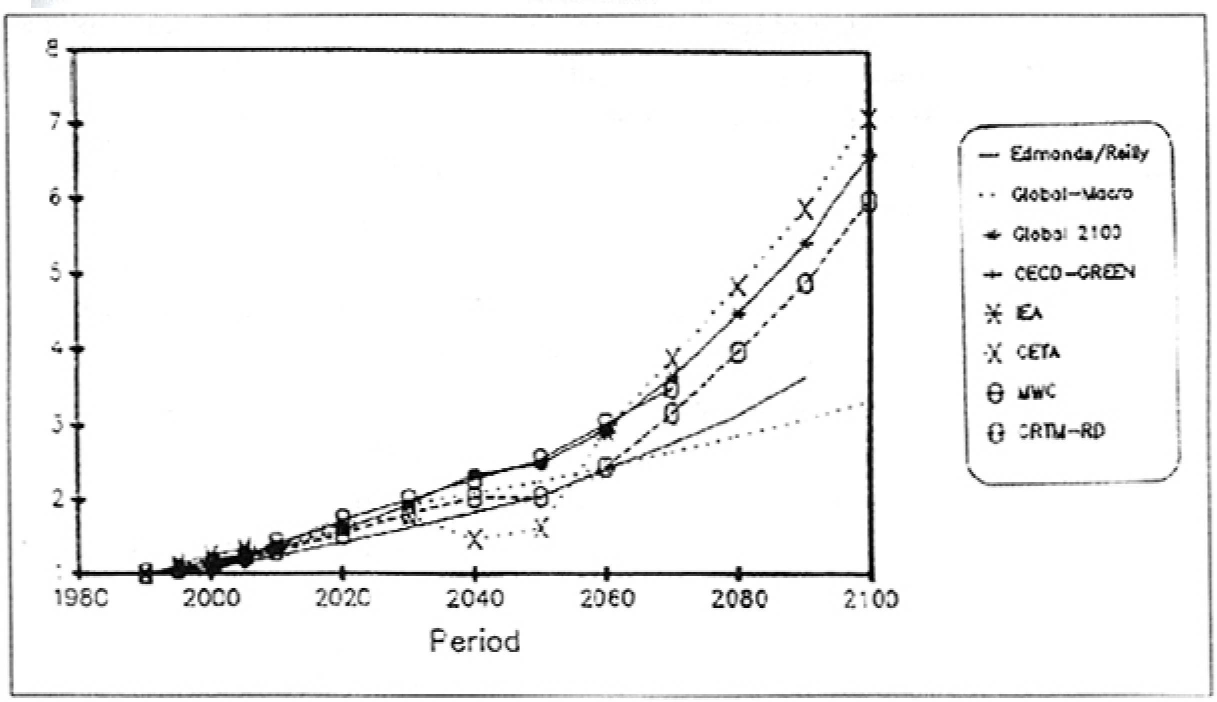



*Figure 16.2*
*Reference World Total / Total Carbon Emissions*
*Indexed to 1990*

# Social Science and Global Change Surprises

B. L. Turner
Clark University
*Worcester, Massachusetts*

Drawing upon his recent review of the social science literature on the topic of global-change surprises, Turner summarized the findings of several major studies by social scientists. Although researchers are well aware of the existence of surprises, they continue to base social science models on aggregated averages and pay scant attention to surprise-rich scenarios. As Harvey Brooks (1986, 326) observes

"The focus on surprise-free models and projections is not the result of ignorance or reductionism so much as of the lack of practically usable methodologies to deal with discontinuities and random events. The multiplicity of conceivable surprises is so large and heterogeneous that the analyst despairs of deciding where to begin, and instead proceeds in the hope that in the longer sweep of history, surprises and discontinuities will average out, leaving smoother long-term trends that can be identified in retrospect and can provide a basis for reasonable approximations to the future."

It is important to recognize that a very large literature exists on the typologies of surprise and uncertainty as well as on the philosophy or perspectives with which to deal with the phenomena in the abstract. The majority of this work comes from the interdisciplinary field of risk-hazard studies. Turner focuses here not on that literature, but on the efforts that actually forecast or provide scenarios of surprise. This literature is far smaller, indeed sparse in specifics from the expert community. There are two classes of work: big picture scenarios and specific surprises. The studies rarely distinguish uncertainty from surprise.

Brooks (1986) identifies three general types of surprises:

- unexpected discrete event (e.g., Three Mile Island)
- discontinuities in long-term trends (e.g., stagflation in OECD in 1970s)
- the sudden emergence into political consciousness of new information (e.g., ozone hole and CFCs)

*Surprising Futures* (Svedin and Aniannsm, 1987) the report of a meeting convened by the Swedish Council for Planning and Coordination of Research in 1987, outlines four potentially surprising future scenarios:

- *The Big Shift* The center of the world economy moves to the Orient and South Asia. The Western World stagnates in population and economic activity.
- *The Big Load* A world of 20 billion people emerges at relatively high standards of living in terms of energy use and agricultural production.
- *History Lost* Science loses its dominance and stagnates. Data, etc. are lost as well as lessons from the past. World becomes fragmented and localized.

Turner's work with agricultural experts leads to a more pessimistic view about the promise of technological breakthroughs having a large impact on increasing global food supplies.

- *Hope Regained* - World population is far less than expected. Current developed world moves to environmentally sensitive behavior. Much of the South increases significantly in economic development by focusing on the small scale.

A report (Toth *et al*. 1989) from a meeting at the International Institute for Applied Systems Analysis (IIASA) details the following potential sources of surprise:

*Population*

- Sources of surprise likely to be in the key determinants of population growth (e.g., fertility) as well as the consequences of such growth.

*Energy*

- important countries move to “soft” energy sources (Lovins)
- the impact of urbanization on LDC energy use
- increase in primary energy use due to electrification
- decision not to use nuclear power
- decision of producers not to meet demand
- frequent TMI-type incidents
- price shocks

*General*

- North-South economic distinctions remain
- technology does not allow a three- to four-fold increase in energy use
- unknown environmental feedbacks

Turner also alluded to C.S. Holling’s observation (1986) that “surprises occur when causes turn out to be sharply different than was conceived, when behaviors are sharply unexpected, and when action produces a result opposite to that intended - in short, when perceived reality departs *qualitatively* from expectation.” Turner also noted how quickly the critical issues change: only 3-4 of the 31 problems identified in the Study of Critical Enrvironmental Problems (SCEP 1977) are still on the agenda. (Surprise!)

Key for future work, other than improved methods of dealing with surprise and uncertainty, is to provide a more rigorously devised and expansive list of surprises for the expert community. Turner’s work with agricultural experts leads to a more pessimistic view about the promise of technological breakthroughs having a large impact on increasing global food supplies.

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# Potential Roles of Climatic Surprise in the Evolution of International Law on Climate Change, Beginning with the Current Framework Convention on Climate Change

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Surprises can be positive or negative, actual, theoretical, or artificial, i.e., generated by models, journalists or pundits. Focusing here on negative, actual surprises, Victor predicts a vast oversupply of surprises that will find scientists spending their time in attribution, e.g., is an event (surprise) caused by global warming?

The conventional wisdom is that negative surprises will provide pressure for more stringent action to slow global warming and that will make the Climate Convention more effective. Most policy advocates assume that environmental policy evolves in ratchets, pushed along in brief windows of opportunity. Fears and evidence of surprises are key elements of climate politics because they can provide both a window for political actions by focusing on the costs of unchecked global warming and thus help marshal public support in favor of costly anti-greenhouse actions. Law and policy could move very quickly in an atmosphere marked by many surprises and with less attention to nuances of science and expert advice.

But the conventional wisdom may be wrong. We don't know where the climate convention is going. Trying to manage the economy and its greenhouse gas emissions requires an international legal framework, and if this is not done well, it could be extremely costly. When attempting to develop such a framework, it helps to have a smoking gun, such as a dead forest or an ozone hole to spur international action, but this is not always possible. It may be politically expedient to develop law (rapidly) in the context of climate surprises, but could easily lead the policy responses down the wrong track, and that is a problem if only because whatever institutions are created to manage the climate problem will be durable and difficult to change, and the climate problem itself will require long term (many decades, perhaps centuries) policy responses.

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*Where the convention stands*

The Framework Convention on Climate Change is a legal text in international law, meaning that it will be ratified and binding on the parties. Is there connection between such "hard law" and what actually happens at the domestic level? The basic goal of the Climate Convention is that countries should try to bring levels of greenhouse gas (GHG) emissions to 1990 levels by the year 2000 -- a "soft target" that probably will not be met by many. A recent report from OECD shows that several countries are really trying. Most countries really do obey international law, but no one can predict what levels will really be in the year 2000. The convention further requires developed countries to help developing countries pay for these changes. All parties to the convention are required to submit reports detailing their emissions and their policies to control these emissions. What happens to the reports is key. Other systems of reports -- notably

those managed by the OECD and the International Monetary Fund (IMF), do seem to work because the reporting obligations are taken seriously, and the reports are subjected to serious reviews. Virtually every international environmental agreement requires reports but they are often late, of poor quality, and include questionable data. In the climate convention the reports will be publicly available and nongovernmental organizations (NGOs) will have at least informal roles in double-checking that governments actually do what they claim in their reports and that governments live up to their international commitments. Getting the reporting system to be effective is much more important than the actual goals and timetables in the convention.

The Global Environment Facility (GEF) will be the interim financial mechanism. GEF is a $2 billion pot of money to be spent on global problems. GEF, which has operated for three years, will be the financial mechanism for implementing the climate and biodiversity treaties.

Developing countries have been dragged into the issue and have not set the agenda. The developed world (led by the "green groups") has set the environmental agenda.

The Intergovernmental Panel on Climate Change (IPCC) is becoming less and less relevant to the Convention, i.e., all issues of legal organization and content are untouched by the IPCC. They could help with global warming potentials (GWP), an important policy-relevant concept, but the method chosen by IPCC simply lumps everything into one number. Victor prefers allowing countries to set their own targets expressed in terms of greenhouse (radiative) forcing,thus avoiding the use of a GWP, but he acknowledges that this is not the way it will probably go. Indeed, the ongoing process is based more on the Montreal Protocol model , where emissions targets were set, and different gases were weighed according to their ozone depletion potential (ODP).

The Secretariat for the Framework Convention on Climate Change (FCCC) has been extremely busy since Rio. By late August 1994, 93 countries had ratified the convention; 110 may sign on before the Conference of Parties (COP) convenes in Berlin on March 28, 1995.

*Issues relevant to how the Convention has evolved*

1. Among the symbols that drive politics are the fear of surprise and catastrophe. Symbols are central because the stakes are high and facts are soft. Many scientists are in frustrating, decidedly "unscientific" roles -- such as commenting on whether symbols such as "playing dice with the planet," are accurate descriptions of the climate dangers.
2. The anti-symbols that industry and some scientists are producing in response to green symbols frequently amount to symbol debunking and character assassination of proponents (i.e., saying scientists are crying wolf to get funding for their research). Alternative symbols -- those that don't focus on looming catastrophe -- have been in short supply.
3. This issue has been put on the agenda by the environmental movement in industrialized countries. Because symbols play such a prominent role, it may turn out that agendas will be set by those countries -- primarily the rich democracies -- that can use symbols effectively.
4. Developing countries have been dragged into the issue and have not set the agenda. The developed world (led by the "green groups") has set the environmental agenda. The developing countries have focused on other issues like financial resources, technology transfer, and equity. The exception to this is the Low-lying Countries Coalition, which, for obvious reasons, is concerned about rising sea levels; but they have not been successful in anything they have fought for.

*Is surprise relevant for the future of the convention?*

If surprise occurs, it will affect the symbols. Many surprises will occur, and scientists will spend more time debunking the link between global warming and unsurprising events than actually identifying real surprises. The focus will be on negative surprises e.g. catastrophic extreme weather events, because of the politics and symbols -- negative surprises are crucial to those who favor strong controls on greenhouse gas emissions because they underscore the potentially catastrophic effects of climate change.

Because virtually all ideas and pressure for greenhouse policy come from the domestic level, the international policy level is probably not very relevant. Similarly, the existence and salience of surprises at the domestic level matters most. This contradicts the romantic notion of a unified world response.

*The Vision Thing: Where is the Convention Headed?*

The logical next step is a protocol, but on what? Transportation, energy efficiency standards, transfer of energy-efficient technologies?

Parts of conventional wisdom worth rethinking:

- targets and timetables
- convention/protocol model
- hard law versus soft law
- how to make package deals (stakes are high)
- how to deal with cross-cutting issues
- how to deal with non-compliance generally and in specific cases
- liability, cause and effect problem in a noisy system
-

For amplification of some of these ideas, see “Keeping the Climate Treaty Relevant,” by David Victor and Julian Salt, *Nature*, 26 January 1995, pp 280-282.

Many surprises will occur, and scientists will spend more time debunking the link between global warming and unsurprising events than actually identifying real surprises.

# Potential Surprises in Clouds and Aerosols and their Effect on the Earth's Radiation Budget

Stephen G. Warren
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If phytoplankton are responsible for keeping cloud droplets small, we'd better leave them alone and let them do their job. If we perturb or destroy phytoplankton, the Earth may overheat, there is potential for suprise.

**Clouds and the Earth's radiation budget**

The Earth's climate is determined by the amount of solar energy intercepted by the planet and the fraction of that energy that is absorbed. One quarter of the solar constant, or 343 watts per square meter ($W/m^2$), is intercepted, and approximately 30% of this (the planetary albedo) is reflected back to space, leaving 70% or 240 $W/m^2$ to be absorbed. Earth emits the same amount, 240 $W/m^2$, to space as terrestrial radiation. About half the Earth's albedo is due to reflection of sunlight by clouds. If Earth's albedo changed from 30% to 29%, a 2° warming at the surface would occur (ice age was 6° colder). The global average cloud cover is ~60%. We get about half a degree of warming for every 1 $W/m^2$ increase so 4 $W/m^2$ increase yields 2° of warming.

The radiative properties of clouds are dependent on quite different variables in the two wavelength regimes. Short-wave albedo of clouds is controlled by cloud thickness, droplet sizes, and sun angle. Long wave emission, in contrast, is essentially controlled just by the cloud-top temperature. The relative importance of the two competing effects of clouds depends on the circumstances. The short-wave cooling effect is dominant for clouds over the ocean (and over other dark surfaces), in daytime, in summer, and for low clouds. The long-wave warming effect is dominant for clouds over snow (and over other bright surfaces), at night, in winter, and for high clouds.

*Dimethyl Sulfide (DMS) as a source of cloud condensation nuclei (CCN): DMS-climate interactions, direct and indirect climatic effects of anthropogenic sulfate aerosols, and changes in cloud cover amounts*

Clouds form on CCN, and the albedo of clouds is determined by the number and size of cloud droplets, so there is an effect on albedo if we change the number and/or size of CCN. Such a change could have climatic significance. What are the CCN and what could change the number of aerosol particles? They are mostly sulfates. Over the oceans, most of the sulfate particles (~80%) result from oxidation of dimethyl sulfide (DMS) of biological origin, so changes in biological productivity or changes in species abundance (diatoms, coccolithophorids, phaeocystis) could change the number of CCN and therefore cause changes in the size distribution of cloud droplets, affecting the albedo and lifetimes of clouds. There is a correlation between CCN and DMS in the remote ocean -- low in winter and high in summer during periods of high productivity up to a saturation point of 300 CCN per cubic meter. In unpolluted regions, there are more CCN when there are higher levels of DMS.

Because the albedo of clouds (and thus the Earth's radiation budget) is sensitive to CCN density, biological regulation of the climate is possible through the effects of temperature and sunlight on phytoplankton population and DMS production. To counteract the warming due to doubling of carbon dioxide, an approximate doubling of CCN would be needed. On the other hand, a reduction in DMS production might well exacerbate climate warming.

There are important implications of this hypothesis. If phytoplankton are responsible for keeping cloud droplets small, we'd better leave them alone and let them do their job. If we perturb or destroy phytoplankton, the Earth may overheat; there is potential for surprise. Are variations in DMS production responsible for part of seasonal and interannual variations of planetary albedo? Are phytoplankton involved in a climatic feedback? The scenario is as follows: sea surface temperature (SST) drops, DMS production drops, cloud droplet size increases, albedo falls, transmittance goes up, solar radiation at the sea surface and SST rise, resulting in a negative feedback.

To counteract the warming due to doubling of carbon dioxide, an approximate doubling of CCN would be needed. On the other hand, a reduction in DMS production might well exacerbate climate warning.

Both the sign and the magnitude of this feedback are unknown. It would have to be negative to be consistent with the "Gaia Hypothesis." On the other hand, if it is positive, it could help explain the ice ages. It could be positive if a warmer ocean means less biological productivity. But even if all species increase DMS production when temperature or sunlight increases, the total production of DMS might still decrease if warmer SST and more sunlight favored diatoms over coccolithophorids and phaeocystis in species competition, because diatoms produce less DMS per capita.

The highest concentrations of DMS anywhere in the world are near the coast of Antarctica. Why do *Phaeocystis pouchetii* produce so much DMS? Their habitat is the sea-ice zone in both the Arctic and Antarctic. Perhaps they produce so much DMS to shield themselves from the high salinity of the brine pockets in sea ice, where they spend the winter. Colder temperatures and higher salinity could select for species that produce the most DMS. If sea ice declines due to global warming so that the habitat for these organisms shrinks, we could drastically reduce DMS production and ... surprise, a positive climate feedback!

Regarding the sensitivity of DMS production to climatic change: (1) Seasonal cycle at Cape Grim (Tasmania) shows more DMS production in summer (negative feedback?) and (2) Ice-age cycle at Vostok (Antarctica) shows more sulfate and MSA deposited during glacial period; this suggests that more DMS is produced in a colder climate (positive feedback?) Different answers result on different time scales.

There is now evidence that anthropogenic sulfate aerosols (from burning of sulfur-containing fossil fuels) can contribute significantly to the Earth's albedo even without nucleating cloud droplets.

How can aerosols compete with clouds for reflection of sunlight?

- aerosols affect short-wave much more than long-wave
- aerosols are in the linear region of radiative transfer
- aerosol has increased over large areas; cloud area hasn't changed much
- we are looking at changes in albedo, not absolute amounts of albedo

Sulfate aerosols can thus affect climate directly, by increasing the backscattering of solar radiation in cloud-free air and indirectly, by providing additional CCN. But at most 6% of the anthropogenic aerosol appears to be available for forming new aerosol particles. Warren says we were lucky to avoid a surprise here, lucky that clouds are so insensitive to increases in sulfur.

Uncertainties and Surprises Dr. Warren brought to AGCI Summer Session II from AGCI Summer Session I on *Cloud Radiation Feedbacks and the Credibility of Atmospheric Models*.

*Uncertainties*

- enhanced hydrological cycles
- cloud liquid water path increases with climate warming
- stratospheric cooling, driven by increasing emissions of greenhouse gases, causes increased polar stratospheric clouds and hence, decreased stratospheric ozone
- warming causes less stratocumulus, more cumulus, less cloud cover, more UV radiation reaching Earth

If we clean the sulfur out of the fuels, we might have no compensating effect and we might get major warming.

*Surprises*

- DMS emissions affected by SST (threshold) or UV changes?
- reduced sea ice area, decline of *Phaeocystis*, decreased DMS?
- super greenhouse effect occurs when the sulfate haze clears?

Regarding this last potential surprise, the scenario goes as follows: Anthropogenic sulfate and $CO_2$ both come from fossil fuels and have a compensating effect in the Northern Hemisphere. Sulfate is removed from the atmosphere by rain before reaching the Southern Hemisphere, but carbon dioxide is not; this may be why the Southern Hemisphere is warming more than the Northern. So if we clean the sulfur out of the fuels, we might have no compensating effect and we might get major warming.

SURPRISE.

# Global Change Surprises: Examples from the Past and Possibilities for the Future

Robert Watts
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Have we really already detected a global warming signal in the temperature record? Is there a deep ocean surprise in the future? Watts defined climatic surprise as a relatively dramatic and unexpected change, perhaps rapid, at least in geological terms. He then offered what he called plausible and interesting explanations for three past climatic surprises which occurred on short geologic time scales:

1. Roughly 100 million years ago in the Cretaceous period it was warmer and the temperature difference between the poles and the equator was smaller. Antarctica was a polar desert, with no ice cap, and then it cooled quickly and the ice cap formed, some 60 to 80 million years ago. That was a surprise.
2. From 2 million years ago to about 1 million years ago, as ice sheets were formed periodically on the North American continent, an abrupt change brought glacial cycles with periods of 30,000 to 40,000 years, and another abrupt change brought glacial cycles with longer periods of 100,000 to 120,000 years.
3. Ice core data show that at the end of the last glacial cycle, at the start of the present warm period, extreme events, such as the Younger-Dryas cooling in midst of warming, could have occurred on time scales as short as 20 years.

Ice core data show that at the end of the last glacial cycle, extreme events, such as the Younger-Dryas cooling in the midst of warming, could have occured on time scales as short as 20 years.

The ocean contains a mixed layer 50 to 100 meters deep. The more ocean and less land there is, the smaller the variability from summer to winter (land has only a small heat capacity compared to ocean).

Watts posed one plausible explanation of why the seasonality, the difference between peak summer and winter temperatures, is larger for larger continents than for smaller continents. When Australia was joined to Antarctica, 100 million years ago, the polar land mass was so large that mid-summer temperatures were higher than freezing, preventing the formation and growth of a permanent ice sheet. When Australia “drifted” away, the polar continent became small enough that mid-summer temperatures remained below freezing so that an ice cap could form.

A similar event might explain the transition in North America from small 30,000 to 40,000 year glacial advances to large advances with 100,000 to 200,000 year periods. As long as the northernmost points on the continent are far enough from the poles, the continental ice sheet will grow and recede in response to variations in the EarthÕs orbital cycles of the obliquity and the latitude of the perihelion, which affect the distribution and seasonality of the received solar radiation. The summers are warm enough for all of the glacial ice to melt during high

latitude warm periods. As the continent "drifts" closer to the pole, some ice remains at the end of the polar warm periods, and glaciers continue to grow until some other mechanism, yet to be explained, causes them to retreat after about 100,000 years.

The Younger Dryas cooling event may have been caused by a temporary change in the formation of North Atlantic deep water. Upwelling of deep water in the mid-latitudes traps heat in the upper part of the ocean. If the rate of deep water formation (and consequently the upwelling speed) decreases, heat can diffuse downward, cooling the surface and warming the water at intermediate depths.

Watts modeled temperature change due to a 50% reduction in Atlantic thermohaline strength after 5, 10, 15, 20, and 25 years. A series of isotherm plots shows a rapid decrease in temperature in the North Atlantic (3° in 5 years). A maximum decrease is reached in about ten years (very rapid), then recovers very slowly.

The recent detection of a warming of water at intermediate depths in the North Atlantic lends credence to this hypothesis. Watts emphasizes that detection of global warming is a three dimensional problem.

What might be the effect of variations in the thermohaline circulation on recent climate? A variety of global surface temperature data sets shows an apparent 0.5° C warming over the past 100 years. However, the Northern Hemisphere actually experienced a cooling trend from the 1940s to the 1970s. Moreover, singular spectrum analysis of these data, as well as longer, local data sets, identifies consistent periodic temperature variations with periods ranging from a decade to more than a century. Watts speculates that these variations may be responsible for the absence of a surface warming from the 1940s to the 1970s. A decrease in upwelling in the North Atlantic ocean of just 10% could easily lead to a cooling of the upper ocean large enough to temporarily cancel the effects of greenhouse warming. The recent detection of a warming of water at intermediate depths in the North Atlantic lends credence to this hypothesis. Watts emphasizes that detection of global warming is a three dimensional problem.

# Response of Terrestrial Ecosystems to Carbon Dioxide Fertilization

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Forests represent 65% of the net primary productivity/carbon fixing on the Earth's land surface and so have enormous implications for carbon dioxide ($CO_2$) concentrations. To understand forests, we need to know how both plants and soil microorganisms react to $CO_2$, how plants affect microbes, and how microbes affect plants. Soil microorganisms contain 1.5% of the carbon (C) and 3% of the nitrogen (N), but microbial activity of the soil decomposes organic matter, which releases $CO_2$, so there's a large potential to have an impact on carbon and nitrogen cycles.

The greatest potential for change comes through the indirect effects of plant production and changes in microbial activity in the soil.

The greatest potential for change comes through the indirect effects of plant production and changes in microbial activity in the soil. Plant production is an important driver of microbial activity. Elevated $CO_2$ has the potential to affect these processes, both directly and indirectly, but direct effects are likely to be very few. The concentration of $CO_2$ in the soil is 8-100 times that in the current atmosphere, so the relatively small increase from 350 to 700 parts per million of atmospheric concentration is likely to have only a minor effect. Many soil microorganisms are very tolerant to changes in $CO_2$.

There is a link between plant productivity and soil microbial activity. Plant productivity is limited by the rate at which N is released by microbial activity. In turn, plants need N. When rates of N release outstrip rates of availability, then availability begins to control the balance between release and uptake. The amount of C allows for net growth of microbial populations. Elevated $CO_2$ levels have the potential to increase soil C availability, causing potential fertilization effects.

Zak's research addressed the relationship between net primary productivity (NPP), soil C availability, and microbial biomass at study sites throughout the United States, in a wide range of biomes with a wide range of NPP and soil characteristics. A significant relationship between NPP and soil texture accounts for two-thirds of the variation in US sites. There is also a significant relationship between NPP and microbial biomass (amount of C in the microbes).

Zak says plant production is significantly related to microbial biomass which accounts for 41% of the variation. In ecology, a 41% regression is quite large, relatively. Zak's results show that elevated $CO_2$ will increase plant photosynthesis and so the soil availability of labile carbon. Moreover, an attendant increase in protozoan activity will increase N availability. This demonstrates the "priming" effect of elevated $CO_2$ - increased N, C, microbial biomass, etc., initiate a positive feedback loop.

Is there a possible negative feedback? A research group from the United Kingdom (Diaz and Grime) says it could happen that nitrogen could decrease in availability with elevated $CO_2$, and plant production could grind to a halt - surprise!

$CO_2$ and N variations occur naturally on a seasonal course in ecological systems; both elevated $CO_2$ and elevated nitrogen availability are potent determinants of plant photosynthesis.

This observed increase in photosynthesis increased total biomass of plants by 50% at high N availability and by 25% in low N availability. It also revealed that plants are taking most of the productivity increase and putting it into the roots to forage for more water and N. The increase in root biomass seems to come from increased production and mortality of roots, with the rate of increase outstripping rate of mortality. At elevated $CO_2$ and high N availability, plants allocate most C below ground to obtain nutrients. They become more efficient in their use of N to form plant tissue.

At elevated $CO_2$ and high N availability, plants allocate most carbon below ground to obtain nutrients. Elevated $CO_2$ caused no significant increase in soil carbon availability and a negative feedback in plant-soil systems

Elevated $CO_2$ caused no significant increase in soil C availability and no difference in the metabolic rate of C. We need to understand throughput; how is it turning over? There is no negative feedback in litter chemistry in field experiments; this only occurs in pots where root bound plants lose fine root carbon.

*Conclusions*

Elevated $CO_2$ caused no significant increase in soil C availability and a negative feedback in plant-soil systems unlikely. If plants forage by increasing productivity and mortality of roots, it doesn't make sense that they would turn off the resource for which they are foraging.

How common is it to observe below ground biomass increase? Out of 28 studies of 17 tree species in an environment with elevated levels of $CO_2$, 27 report a below ground biomass increase, 0 report a decrease and 1 reports no change. So we know that increased $CO_2$ in the atmosphere will cause an increase in below ground biomass (roots). see (Rogers et al.)

How does that root increase translate into changes in microbial activity? It is the fuel that drives microbial activity. The mean response is a 24% increase of microbial activity in soil. So increased C availability increases both microbial activity and biomass. How does it affect community? There is no change in composition of the community of soil microbes (based on lipid analysis). Are there changes in N availability? Yes, with a mean response of 76%, a small net increase or no net change seems likely. There is no evidence of decline - no negative feedback.

Temporary increases in NPP are likely to occur in increased $CO_2$. What does this mean for ecosystem carbon storage? The initial slope of the growth curve is more steep but we don't know what will happen out into the future. Short term studies with short-lived plants gives us little insight into what will happen down the road. In particular, questions in temporal scale could hold surprises. Will we get to the same place more rapidly or will we get to a different place?

One important difference between experiments and reality is that in reality, $CO_2$ is increasing gradually in the environment compared to experiments that go from ambient levels to doubled

levels immediately. Growth is a multivariant response and therefore it is difficult to sort out. We could also use paleodata on trees, to see how changes in $CO_2$ that have already occurred have affected growth.

Zak disputes the claim that there could be a negative feedback on vegetation growth in the short term due to nutrient availability. The majority of evidence suggests a positive feedback on photosynthesis and a negative feedback on ambient $CO_2$. We do not have enough information to discern long-term impacts.

The mean response is a 24% increase of microbial activity in soil. So increased C availability increases both microbial activity and biomass.

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Furthering the understanding of Earth Systems and Global Environmental Change