Perspectives on Uncertainty in Climate Science

Text Companion to PowerPoint Presentation

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Introduction:

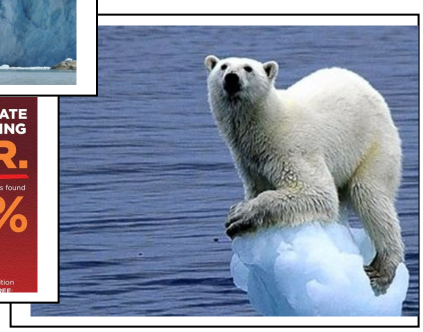
Word "around town" is that science is truth. Sorry to damp the zeal, but science is NOT truth. By definition, science equates to varying degrees of uncertainty, with hypotheses and theories bookending the uncertainty spectrum – to some, a rather boring outlook. Hypotheses – suggested explanations for how things work, and based upon observed evidence, offering potential prediction of phenomena whose correlative relationships may be causal – must be both testable and falsifiable. A hypothesis cannot be proven to be true; it can only be proven false. For a hypothesis to be elevated to theory – a rare and significant promotion – the hypothesis must survive multiple replications of results with a wide set of data, and it must be tested under a variety of circumstances. Even then, while uncertainty of a theory is minimized; it is never zero. Hence, science is the constant process of trying to figure out how things *might* work. To a scientist, this is exhilarating. To the non-scientist wanting a solid answer, not so much!

Well, this is all relatively bad news for those of us who study climate. Climate, by nature, does not lend itself well to being tested. We can't isolate its parts and study them in a lab. We can't condense decades and millennia into hours and days in order to extract multiple data points and long records. Intertwined and multiple "parts" of the climate system render its evaluation stymied by the endless unknown unknowns! So what do we do? We seek out proxy data – riddled with caveats. We invoke computer climate models – riddled with caveats. No matter which way we turn, we are faced with caveats, but it's the best we've got. Sometimes "we" get so used to working within these constraints imposed upon us, we begin to lose sight of our assumptions, and the attendant biases, caveats, and uncertainties laced throughout our research format. In time, it is not difficult to see how we come to believe the little fantasy world we have made for ourselves in attempt to make sense of nature's vast stomping grounds. And when it is demanded of us to stop equivocating, to make the discussion short and sweet, packaging into sound bites the complexities of 4.6 billion years' perspective on climate and how its changing character of today differs from any time past and how we humans and other earthly creatures will survive an onslaught that, by human perception, appears unprecedented and unendurable; "What can we do"!!!! Politics enters the stage, followed closely by celebrities and media. Messages are surgically edited to be woven into stories far more captivating than those told by the equivocating egg-heads; and photographers, accompanied by narrators with scholarly accents and compelling rhetoric, come in to educate the public. And the public find no choice but to believe. Uncertainty is forgotten, actually no, it is abandoned. Uncertainty is not for the impatient. Good intentions pave the path forward. So where does that leave us? How does one make policy decisions based on science, with uncertainty's role demoted to nuisance status?

It might be of interest to know that historically, skepticism has fueled forward movement of scientific discovery. Uncertainty has always motivated inquiry. Conversely, certainty has squelched it. Certainty entrenches paradigms. Examples dot history of paradigms kept on life support with increasingly complicated constructs to explain phenomena or occurrences inconsistent with hypothesized dynamics and behavior – the 1600-year-long geocentric model being a most vivid example. Upending of faulty paradigms often relies on evolution of technology. New evidence reveals surprises – those “unknown unknowns”. Ironically, those most educated in a field often are not the ones in history to have revolutionized thought. Lay persons and scientists of different specialties often were the ones who “saw” what was hidden from the hardened mental filters of those overly invested in a paradigm’s survival. Skepticism has gotten a bad rap in recent years. Instead, it should be embraced. It is skepticism - not conformity - that provides the checks and balances to humans’ tendency to see the expected.

How does one make good decisions in context of uncertainty? One must gather good evidence – not hearsay, not sound bites, nor “consensus”. Good evidence can be garnered only through understanding how conclusions are reached - the methodology and data used to construct them. This is not easy, but just accepting what others say – their filtered conclusions, even those of “respected” scientists or trusted dignitaries - not investigating the scientific process employed in generating a conclusion, and not exploring alternate possible explanations for observed phenomena, destines its victims to the unintended consequences.

Compelling, indeed.
But things are not always as they seem…



Scientists do agree: Temperatures have increased since 1850; CO_2 has too. CO_2 is an infrared warmer. With no positive or negative feedback responses, a doubling of it will lead to an approximate 1.1ºC temperature increase. Disagreement erupts over just how much temperature has risen; what part is due to CO_2; what part to land-use changes; what parts to natural or intrinsic influences. How well do models represent climate; what is climate’s sensitivity; are the data reliable? Is there really a problem? Is it a problem that can be solved with proposed solutions? And what are potential consequences of proposed solutions? It is said to be certain, to be “settled science”. *Really*!?!

The accompanying presentation (PowerPoint) compiles information the reader is less likely to know about – the uncertainties. This text provides a "reader's digest" version of that presentation (see link).

Seven points guide this inquiry into uncertainty:

1. Hypotheses
2. Models
3. Data
4. History
5. Consensus
6. Perceptions / Reality
7. Solutions

1. Hypotheses overview: *More than one hypothesis can explain observed behavior.*
Two general and contrasting views exist on climate behavior. One view is the "consensus" hypothesis, where external forcing – both natural and anthropogenic – dominates climate behavior ("climate change") -- a modification of the former anthropogenic global warming (AGW) hypothesis. The contrasting view allows a greater role for internally generated dynamics, especially on decadal-plus time scales.

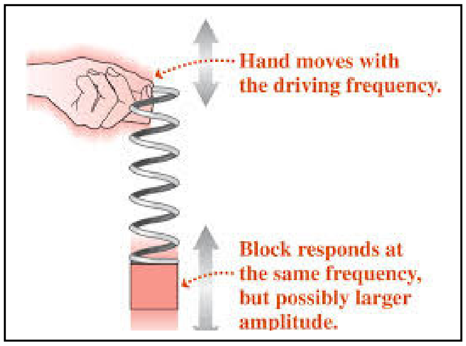
According to the external-forcing view, parts of a system operate relatively independently; the system is prone to instability, is not resilient, and, with continued anthropogenic greenhouse-gas-emission increases, is projected to result in catastrophic climatic changes.

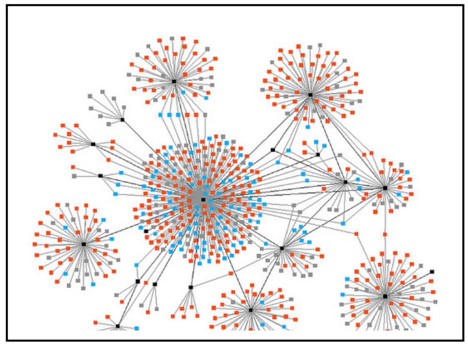
In contrast, the intrinsic-dynamics view envisions network-behavior dominating climate behavior, where parts of the ocean, ice, and atmosphere sub-systems self-organize over decadal-plus time scales, interacting with one another, and thereby initiating intra-network communication, conveying resilience and relative stability to the climate system.

The external forcing hypothesis is based on strong understanding of greenhouse-gas forcing, but low-to-very-low levels of understanding of other external forcings – clouds, aerosols, solar influence, for examples. Extreme increases in projected temperatures rely on incomplete understanding of reinforcing consequences of the original CO_2-induced warming, i.e. positive feedbacks. Little is understood about potential damping mechanisms – e.g. clouds, aerosols, atmospheric convection, and precipitation. Likewise, little is fully understood about, or attributed to, intrinsic dynamics. None of these weaknesses guarantees this hypothesis is wrong, but the uncertainties involved are striking. More striking is that the hypothesis is not testable. It cannot be falsified. The alternate hypothesis, the network hypothesis, is rooted in observation, among a variety of indices. Mechanisms have been elucidated as possible dynamics underlying climate-signal evolution. Uncertainties underlie this hypothesis, as well. Yet, its strength lies on observations. They are consistent with the hypothesis, and in time – years to decades - this hypothesis is testable and falsifiable.

How *Might* Climate Work?

Consensus Hypothesis:	Alternate Hypothesis:
Internal Dynamics: Minor Role	**Internal Dynamics: Major Role**



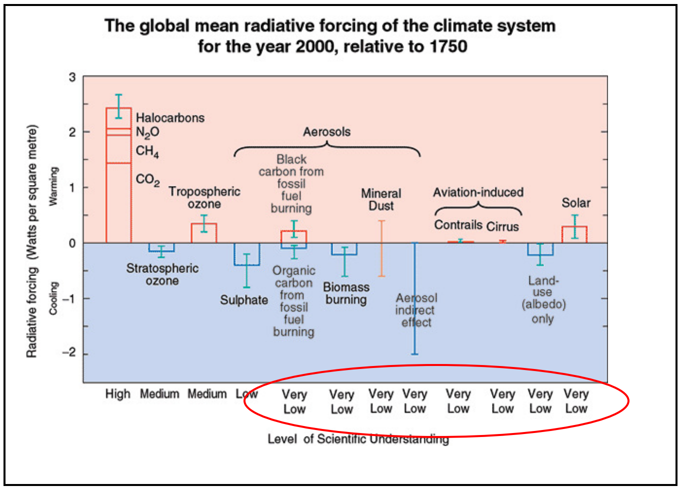


External Forcing Directly Controls	External Forcing Supplies Energy
System Passively Responds	Network "Parts" Couple: Communicate
"Parts" Behave Independently	Self-Organize Collective Behavior

2. Models: *Hypotheses, themselves, models are good tools, yet not "reality".*
Computer climate models – complex, incomplete, and flawed – have failed to capture the temporal and spatial signatures of observed climate behavior. Great tools, they are, but they, themselves, are hypotheses. Each one is an experiment, of sorts. A climate model can be thought of as a script, taking orders from computer programmers in the form of complex mathematical equations. Increased complexity of input is expensive and time-consuming. Hence, simplifying is required. Lost is the ability to capture details of climate phenomena too large or too complex for the model-grid's scale of resolution. To compensate, some "assumed-to-be unimportant" phenomena are omitted entirely; other phenomena are parameterized, meaning simple empirical formulas are used to represent the collection of phenomena as best as understood, with adjustable coefficients inserted – thermostats, of sorts, "tweakable" to fit observations. This does not mean output is necessarily wrong, but it does mean uncertainty looms in procedure and in results!!! A major problem arises when model outputs are considered to be "reality".

“Consensus” Hypothesis

External Forcing Dominates Climate Signature



Positive feedbacks *assumed* will occur create the projected extreme warming.

Adapted from IPCC AR4 2007

3. Data: *Ah yes, the data…*

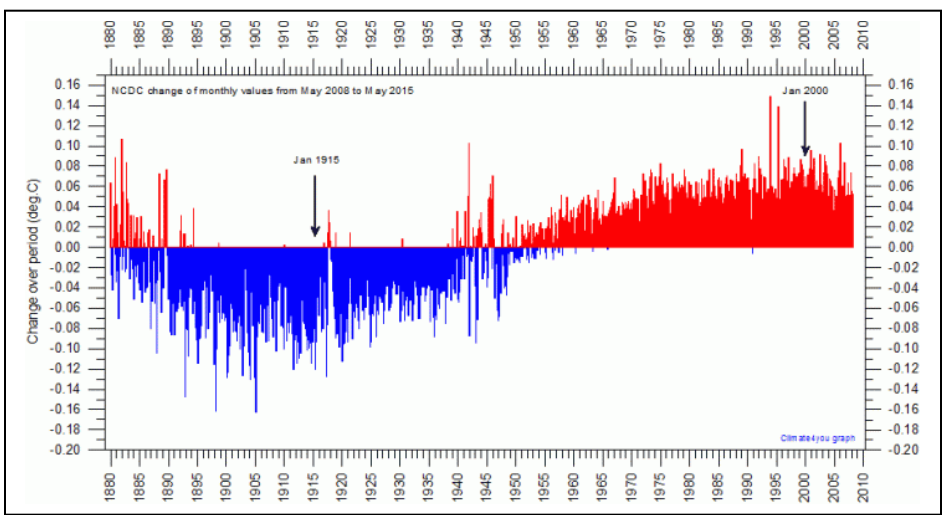
“But the data!!!” exclaimed the woman, hurriedly removing herself from my presence in undisguised disgust. All I said was, “climate is complex”.

This is an unfortunate tale. Few realize: Data records are a mess. That’s the short version. The long one is filled with justifications and fixes. In short, climate is long-term behavior and we don’t have long-term records. The longest instrument temperature records we have are patchwork compilations of temperature readings gathered from various and evolving technologies and varying degrees of instrumental precision. Confounding consistency are continual changes in measuring distributions; numbers of reporting stations; extent of coverage; and required conditions of the measuring stations; etc. Assumptions rule the temperature record. When we see data that make no sense, we speculate why. If the instrument, technology, conditions, and the like seem sketchy, we “document” such and “assume” what climate conditions likely existed and therefore what temperatures should have been recorded, based on a variety of guidelines, and we change the recorded temperatures to what we think it maybe really was….

The motivation for adjusting data is honest; at least we hope it is. A recent increase in the frequency of data adjustments in temperature trends has raised red flags, with findings of undocumented changes, questionable extrapolation practices, and computer-initiated “homogenization” changes made according to assumptions. Some argue that where assumptions might have trumped accuracy, the number of errors is so small as to not present a problem. Yet, it seems yesterday’s data sets showed variability over the years. Now the warm 1930s and 1940s have been erased, relegated to mythology. We shiver as we are told of the “warmest years on record” by *hundredths* of a degree, and with minor data re-calculations, “pauses” in observed temperature trends disappear overnight, and we are told to accept this, and we do, in light of all the uncertainties. Can this be???

There is more than one way to evaluate temperature. Four categories commonly used include surface thermometers, satellite-retrieved measurements, balloon-mounted instrumentation, and proxy data. None of these temperature trends match the modeled trends. Quantitatively, among the four temperature records, while their trends are analogous to one another, the magnitudes of their trends are not. Surface temperature-trends are steeper than satellite-retrieved and balloon-based temperatures; while satellite and balloon temperatures are similar to one another. Tree-rings buck the trend further, with one of cooling since 1940, most strongly since the 1960s. Tree-rings, depending on tree species and location, capture a variety of climate details – e.g. moisture content, sun exposure, and also temperatures, generally maximum ones. On the other hand, much of the increase observed in surface instrumental land-temperature increases can be attributed mostly to increases in minimum temperatures, which, when averaged with their daily maximum counterparts, reflect increase. Satellite and balloon instrumentation infers temperature of the lower troposphere, where greenhouse-gas warming is supposed to be greater than surface warming. Thus, all methods differ in where and what they measure. All temperature data are further enhanced by extrapolations of “neighboring” stations, some up to 1200 km away, as in the Arctic – the region known to host the widest extremes in temperature on multidecadal timescales. Sea-surface-temperature measuring methods have their own story. And then we model data – or reanalysis products - to infill “missing” data points. And sometimes we mix modeled data with observational data, subtracting one from the other, in order to evaluate climate. But right or wrong, accurate or inaccurate, this is what we have. Judgment on such is not the point here. The point is uncertainty – bias is injected at every step of “settled science.

Changes made to Surface T Record <u>applied</u> between 2008 and 2015:
For record: 1880 to 2010

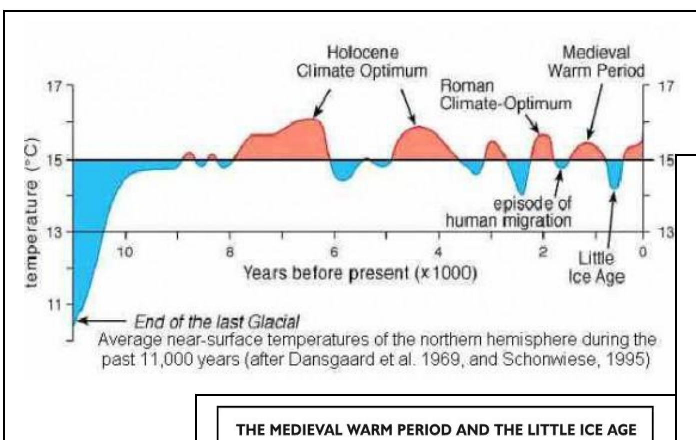


<1945 record was adjusted cooler; > 1950 record adjusted warmer
Bob Tisdale citing prof. Ole Humlum

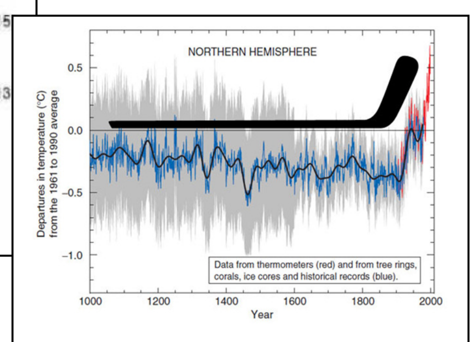
4. History: *In contrast with the data, history speaks of variability and precedent…*
Archival records speak to hot intervals – "The Arctic Ocean is warming up, icebergs are growing scarcer; in some places the seals are finding the water too hot…a radical change in climate conditions and hitherto unheard-of temperatures in the Arctic…well-known glaciers have entirely disappeared" (Washington Post: November 2, 1922). And in 1933, the New York Times: "America in longest warm spell since 1776…a 25-year rise." And again in 1947, the New York Times: "A mysterious warming of the climate is slowly manifesting itself in the Arctic, engendering a serious international problem…"

And history tells us of cold – July 18, 1970, New York Times: "The United States and the Soviet Union are mounting large-scale investigations to determine why the Arctic climate is becoming more frigid, why parts of the Arctic sea ice have recently become ominously thicker and whether the extent of that ice cover contributes to the onset of ice ages." Fortune Magazine in February of 1974 warns of a "…very important climate change going on right now… not merely something of academic interest….if it continues, will affect the whole human occupation of the earth…"

A longer view of climate, one supported by thousands of papers pre-dating the 1990s, showed pronounced variability and warm intervals equal to those of today, the most recent of which was about a thousand years ago. Studies in the late 1990s removed that variability. And while the science behind the historical climate revisions has been challenged and shown flawed, the public perception of past uniformity lingers.

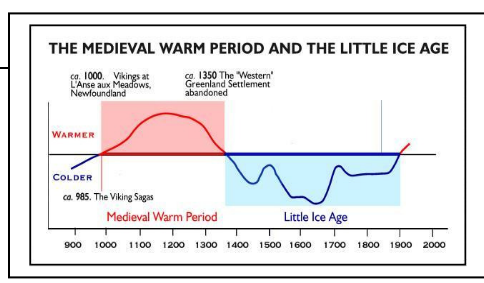


History Adjusted?



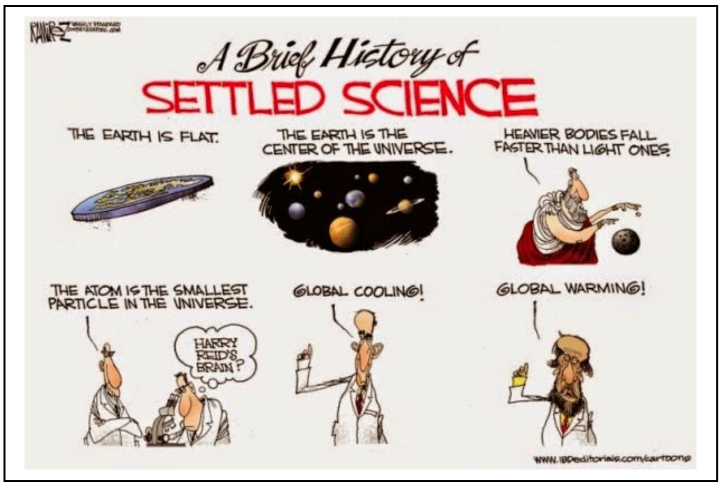
Mann, Bradley, Huges1999

History



IPCC FAR 1990

5. Consensus: *Not a measure of scientific validity.*
Science has always been a story of revision. Consensus-based paradigms come and go. The geocentric model endured for 1600 years. But consensus plays no role in scientific validity. Yet, one can understand their evolution. Limitations of technology, egos, hardened mental filters, and the like can contribute to a flawed paradigm's endurance. Typically paradigms are perpetuated by the best educated. Those not immersed in the field and not financially tied to the discipline were the ones who saw through a different filter and revolutionized a science that was not necessarily their area of expertise.



Sometimes scientists find themselves split between being scientists and being useful to society. Most have read the words of scientist Stephen Schneider, now deceased, but once a scientist at NCAR: "We are not just scientists, but human beings…We have to offer up scary scenarios, make simplified, dramatic statements, and make little mention of any doubts we might have…" And then that of an NCAR scientist (to remain unnamed) who spoke to a class of mine in 2007, "We should not talk to the politicians about our doubt or the uncertainties of our model output; we should keep that among ourselves, when we are talking to other scientists. It is our moral duty to express certainty." Yes, scientists are human…

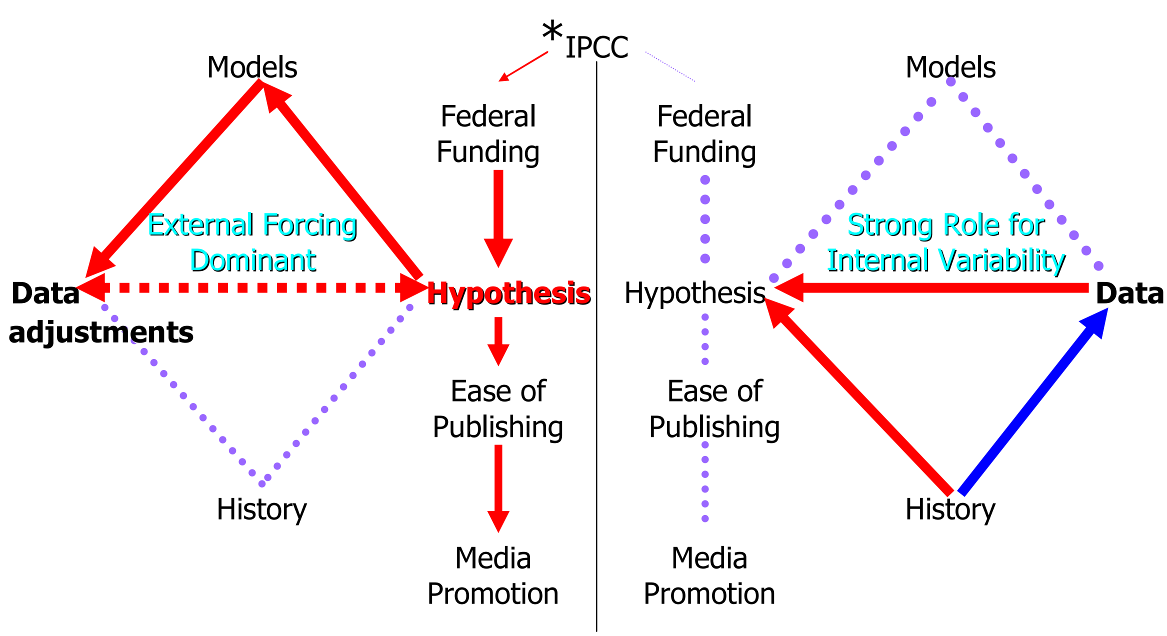
The diagram that follows traces my view of how today's consensus evolved.

The left side shows the IPCC* conclusions and goals feed the federal funding for grants given to scientists to study, specifically, the effect of anthropogenic CO_2 emissions on climate behavior (AGW: anthropogenic global warming). This is the "external-forcing-dominant" paradigm. Thus, the funding feeds the AGW hypothesis. In turn, the hypothesis inspires the computer-climate-model designs. The modeled output, in turn, has led slowly to the observed data being adjusted, as the observed data records tend to be inconsistent with "theory". The data, while fed by models and hypothesis, in turn, feed the hypothesis. Studies supporting the consensus hypothesis are easily published, review processes more streamlined and lenient than with studies whose conclusions do not support the hypothesis or are neutral. This all dove tails with media promotion, typically highlighting only AGW-supporting conclusions and not the methodology and data used to derive the conclusion, and not the author's noted limitations and weaknesses of the study and its conclusions.

The right side shows the fate of a non-AGW hypothesis: The IPCC does not fuel funding for the hypotheses that are not "AGW", those that tend to argue for a strong role for internally generated dynamics (intrinsic variability). In the case of an alternate hypothesis, the data inspire the hypotheses. The historical data feed the hypothesis. Modeling with the atmosphere–ocean coupled general circulation models (AOGCMs) used for IPCC-related research do not support these hypotheses; it is assumed that critical dynamics are either absent or poorly represented in the AOGCMs.

White asterisks: modified and modeled data. .Red dotted line: no correlation. Blue arrow: arrow points from end member that supports the other. .Red arrow: arrow points to end member being driven by other member. Red dashed double arrow means the two end members are consistent or supportive of one another.

How Today's Consensus Evolved:



*The Intergovernmental Panel on Climate Change (IPCC) assesses the scientific, technical and socio-economic information relevant for the understanding of the risk of ***human***-induced ***climate change***.

6. Perceptions/Reality: *Things aren't always as they seem.*
"Photo-journalism and social media have enhanced our understanding of the world. They bring to our eyes, and our hearts, the enormity of global changes that imperil our future." This eloquent statement, said to me recently by an acquaintance, was followed by an attempt to boost the credibility of her words – "And I'm a Republican"! Yes, I understand the political framing, much as I rebel against it - as it has no place in science – but that is today's reality. And she was on to something; indeed, photo-journalism and the power of social networking have scripted our perceptions and redesigned reality for our consumption. But, behind every photograph of a stranded polar bear, of mountain glaciers shrinking, of drought-ravaged landscapes, of tornado-inflicted devastation, of flooded neighborhoods, of pounding seas and calving glaciers, hurricane-pounded surfs and ice-locked shipping ports, our impulse to assign cause to effect confounds our ability to reason, to see the story behind the sensation.

For examples: Polar-bear populations have rebounded, especially since the hunting rules were changed in the 1950s. The bears have redistributed their populations within the Arctic, and for those in regions of greater ice loss, the white giants have been found to exhibit "foraging plasticity" – i.e. they are changing their diets[1]. In the cases of droughts, hurricanes, weather events, etc - many exhibit decadal to multidecadal cyclical behavior, with human population shifts further modifying the trends – not shown to be due to global warming, but through land-use changes, through changes in perception about the events due to where population centers have migrated, and to greater exposure due to 24/7 news and a camera phone in every pocket. Calving glaciers are calving because they are growing; retreating glaciers, especially mountain glaciers, are retreating for a variety of reasons – while rising temperatures certainly play a role in some cases, little evidence supports global warming as the main culprit. In fact, mountain glaciers are really bad thermometers – adjacent glaciers may exhibit opposing trends, with one advancing and the other retreating. Much of the retreat witnessed in glaciers occurred long before carbon-dioxide emissions were prominent. And precipitation patterns, winds, solar-insolation patterns are among factors dominating the behavior of these alpine features. Sea-level-rise is occurring at a rate about 2mm/year, depending on the study cited. A cyclical component underlies a linear one. Complications in measuring and comparing current to historical measurements confound clear assessments. Greenland and Antarctic ice sheets, if melted, would contribute the most severe consequences to rising water, but dynamics are complex and our understanding of them not at all imbued with certainty.

Scientists compound the misperceptions at times. The famous study by Parmesan et al (1999)[2], associating warming with the poleward-migration patterns of butterflies in northern Europe is one such example. A shift has been documented, but a conclusive reason was far from established, a direct link to temperature not forthcoming. But the "conclusion" was promoted anyway. The uncertainties lay in the inconvenient – about

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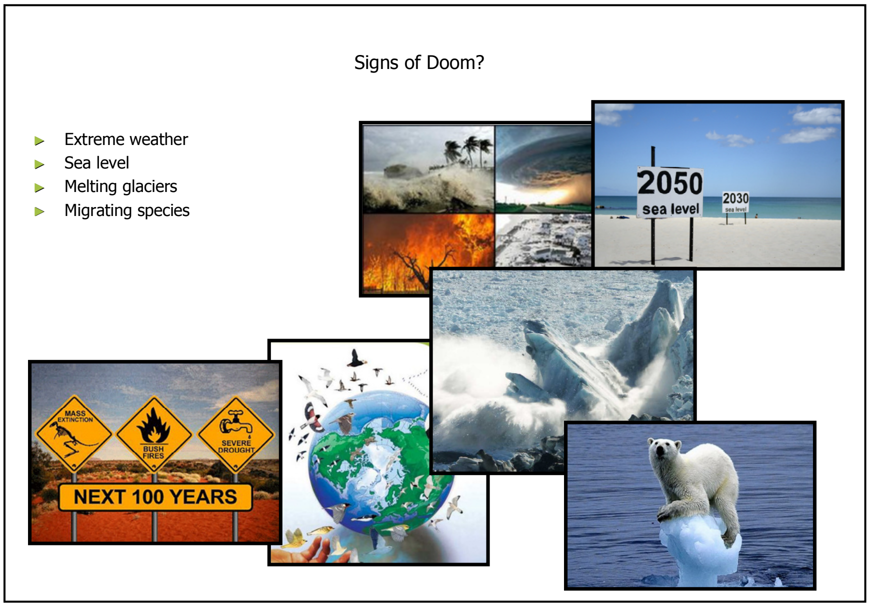
[1] Gormezano and Rockwell (2013): What to eat now? Shifts in polar bear diet during the ice-free season in western Hudson Bay; Ecology and Evolution 3(10):3509-3523; doi:10.1002/ece3.740
[2] Parmesan et al. (1999): Poleward shifts in geographical ranges of butterfly species associated with regional warming; Nature 399, 579-583; doi:10.1038/21181

third of the 35 species studied moved north with warming temperatures; approximately two-thirds expanded north, not abandoning their southern bounds. A small percentage actually shifted southward with increasing temperatures. The list is long of these ambiguities in study results – none pliable within sound bites, herein muting the message of uncertainty!



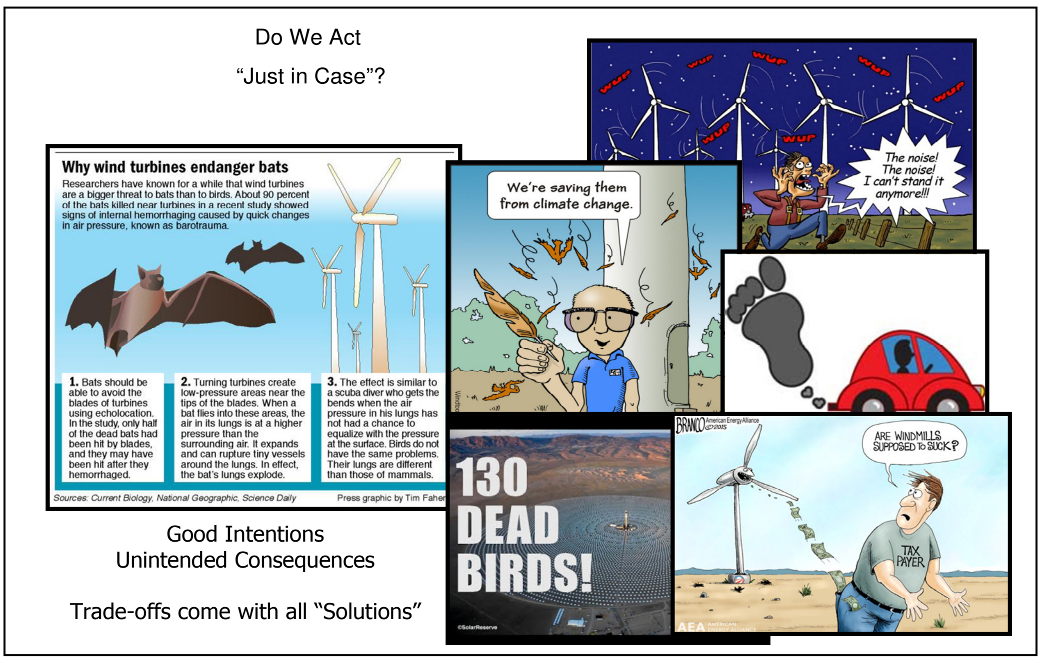
7. Solutions: *Everything is a tradeoff. Beware the fix being worse than the problem.* There is the view point that we should just 'do something', just in case… And argument can be made for this opinion. But arguments can be made against too, many laid out in this text and its accompanying Power Point presentation.

Regulation is one approach toward a solution. Will there be unintended impacts? Economic? Environmental? What countries will comply? CO_2 knows no boundaries. And most importantly, what "correction' in the climate-change trend can be effected? Will our best intentions curtail warming significantly? By some estimates, a 40% decrease of CO_2 emissions in the United States, alone, will avert a scant 0.016ºC of projected warming by 2050, assuming a climate sensitivity of 2ºC.[3] And if climate sensitivity is assumed larger, at the high end of estimates, say 4.5ºC, then the temperature-increase averted by 2050 will be 0.025ºC, and by 2100, 0.056ºC. Bring all industrialized nations under regulatory control, and if the collective reduction of emissions is 20%, with an assumed climate sensitivity mid-range, at 3ºC, the temperature-increase thwarted is estimated at 0.025ºC; by 2100, 0.045ºC. Is the science settled enough to justify the drastic economic adjustments required for the projected solution realized? What level of uncertainty is acceptable?

And seeking energy resources that provide beneficial alternates is not at all a bad thing, for a variety of reasons, not just environmental. But caution is warranted, as with good

[3] meaning that climate is assumed to behave in such a way, that for a doubling of CO2, temperatures will increase 2ºC

intentions, there is always a trade-off, usually hidden behind the good feeling of "doing something". For example, wind turbines: Just a few months ago, the German medical community requested a halt to further turbine installation until the health impacts of turbine-associated low-frequency noise can be further studied. Perhaps stories of dying sheep and goats due to sleep deprivation and reported human problems of headaches, dizziness, nausea and insomnia associated with noise from the whapping blades hold merit. Birds and bats are casualties - hundreds of thousands each year, with trickle-down consequences on insect populations (increasing mosquitoes, for one). Costs and pollution of associated fossil-fuel use are a dirty secret, a consequence of "on-demand" backup requirements, consequent of wind's inconsistent presence. Local weather changes result from turbine-altered wind patterns. And solar solutions are not without issue. Manufacturing-related leakage of SF_6 and NF_3 – greenhouse gases 23,000 and 17,000 times as potent as CO_2; reduced albedo (reflectivity) in desert areas due to acreage covered in black panels; and birds vaporizing in flight over hot panels. "Clean" trucks, newer than five-years-old, in Europe, are associated with unexpected increases (34%) in black carbon emissions – soot – a warming agent.



These points are a small sampling of the many documented issues of re-designing our energy use. Not that re-structuring would not be worthwhile to strive toward, but we have talked about this goal for at least forty years and little progress has been made. It must be realized that every source of generating and transmitting energy comes with trade-offs. None are without flaws and detriments.

Deciding on action is difficult, a personal opinion. Understanding the level of scientific certainty of the proposed problem is one step toward that decision. How settled is the science? How much uncertainty hides behind the loud voices and compelling photographs?