

Climate Threat to the Planet:*

Implications for Energy Policy and Intergenerational Justice

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***Any Policy-Related Statements are Personal Opinion**

I changed the title of my talk. Global warming has implications for energy policy and intergenerational justice.

The propriety of a scientist discussing these implications is self evident.

Global Warming Story

1. Science Update

- Climate Sensitivity**
- Faustian Bargain**
- Missing Observations**

2. Energy Policy

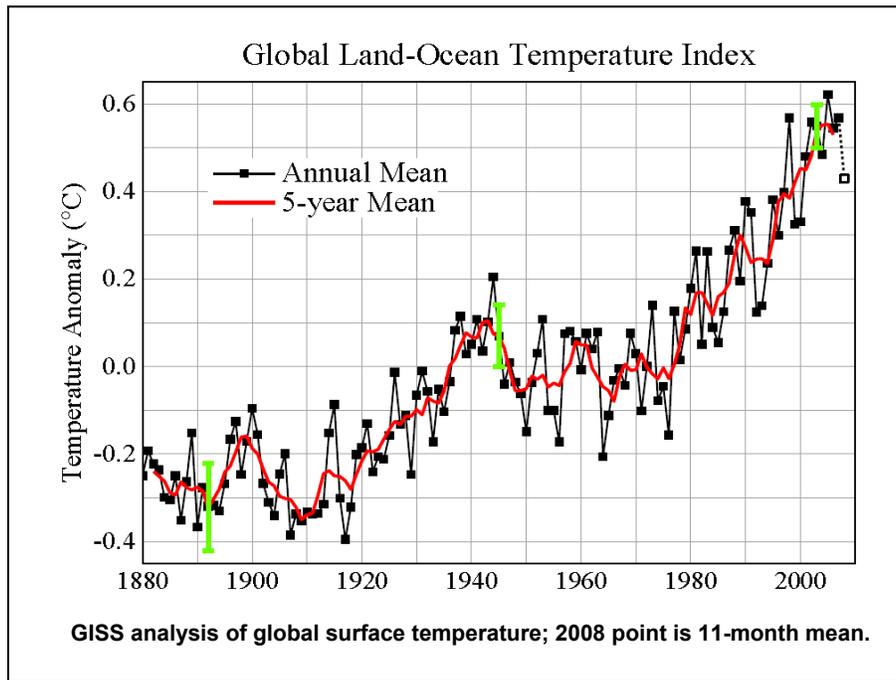
3. Intergenerational Justice

I will argue that we have a much sharper knowledge of global climate sensitivity than is usually stated.

Also the Faustian bargain that we have cut for ourselves is nastier than has been recognized.

And I will emphasize some important missing observations.

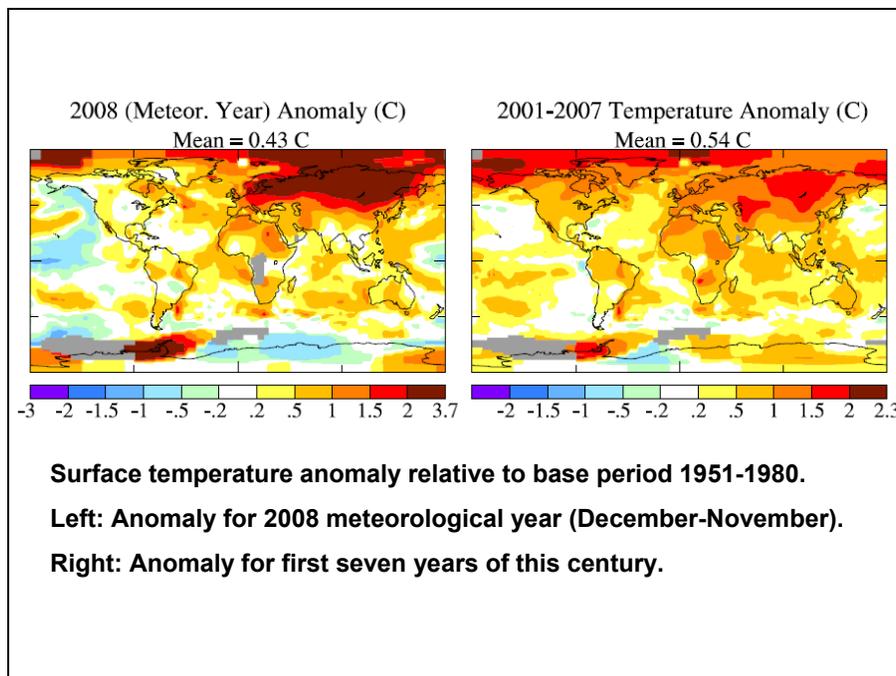
The scientific method and perspective have relevance that reaches beyond pure science. The urgency of implications for energy policy is not yet adequately recognized by governments, but it must be. The implications for intergenerational equity deserve greater attention.



2008 will probably be the ninth warmest year in the period of instrumental data.

Since 1998, which was anomalously warm due to the 'El Niño of the century', only 1999 and 2000 were cooler than 2008.

However, as I will show, the 2008 temperature is a fluctuation. It does not indicate a change in the long-term warming trend.

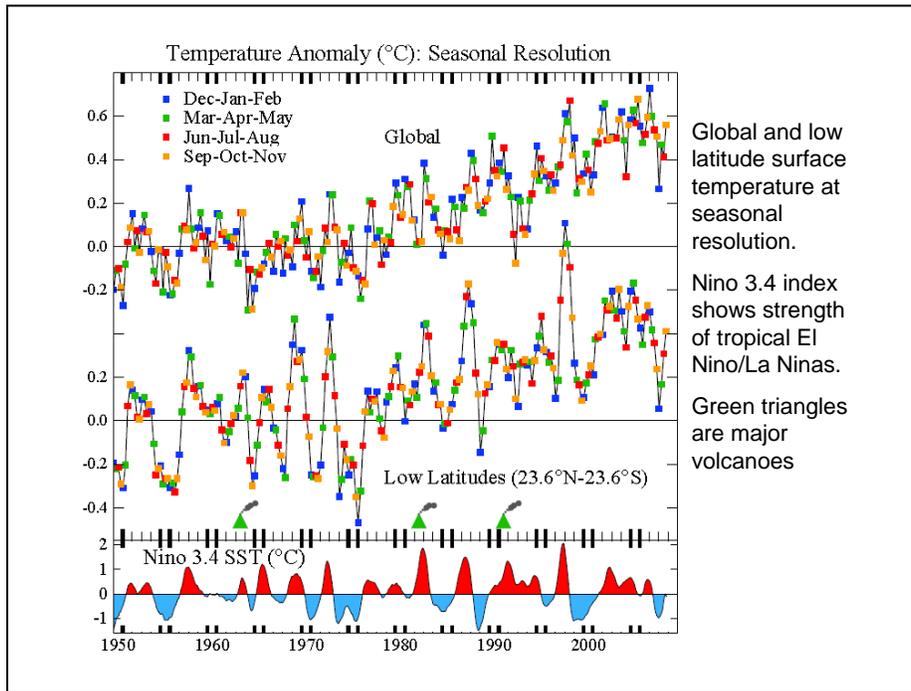


These maps compare the temperature anomalies of 2008 and the first seven years of this century.

The map on the left shows the temperature anomaly of the past 12 months relative to the base period 1951-1980.

It is unusually warm in most of Eurasia, the Arctic and the Antarctic Peninsula.

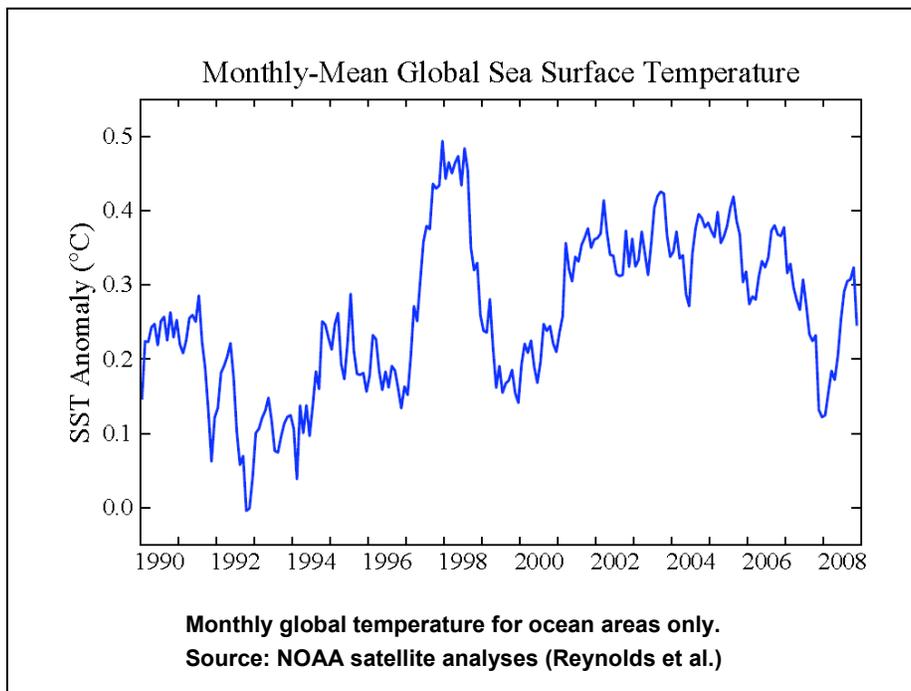
The Pacific Ocean is notably cool in 2008, as there was a strong La Niña early in the year, but, except for the Americas, the rest of the world was not cool compared to prior years.



Global temperature at seasonal resolution is shown by the top curve.

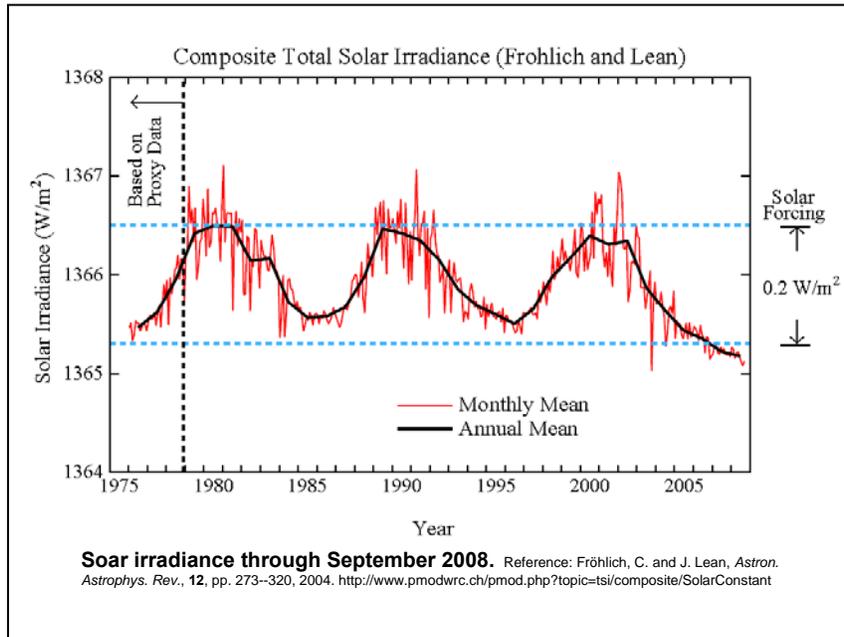
The greater variability of low latitude temperature, the second curve, is associated with the Southern Oscillation, as shown by the red-blue curve at the bottom, which is the Nino3.4 index for the Southern Oscillation.

Low latitude and global temperatures have largely recovered from the cool conditions of early 2008, which were associated with a moderately strong La Nina.



The effect of the Southern Oscillation on global temperature is easier to see if we get rid of noisy land data.

This is the monthly global ocean surface temperature. The El Nino of the century in 1997-8 is obvious, as is the recent La Nina. This La Nina is the main reason for the relative coolness of early 2008.



Let me make note of the assertion that the world could be headed into colder times because of changes on the sun, because that misconception has been spread widely.

Solar irradiance has been measured since the late 1970s, and the solar irradiance remains at or near a prolonged solar minimum, which is deeper than the prior measured minima. This is data of Frohlich and Lean through the end of September.

These solar irradiance variations do not have any known relation with the shorter period oscillations of Pacific Ocean temperature. In a few moments I show quantitatively that the effect of the sun is not negligible on longer time scales (the time scale of the 10-12 year solar cycle and longer time scales), but it is much smaller than the climate forcing due to human-made greenhouse gases.

Basis of Understanding

1. Earth's Paleoclimate History

2. On-Going Global Changes

3. Climate Models

(note: modeling #3, but aids other two)

Our understanding of climate change, our expectation of human-made global warming comes principally from the history of the Earth, from increasingly detailed knowledge of how the Earth responded in the past to changes of boundary conditions, including atmospheric composition.

Our second most important source of understanding comes from global observations of what is happening now, in response to perturbations of the past century, especially the rapid warming of the past three decades.

Climate models, used with understanding of their limitations, are useful, especially for extrapolating into the future, but they are clearly number three on the list.

Climate Change Depends on

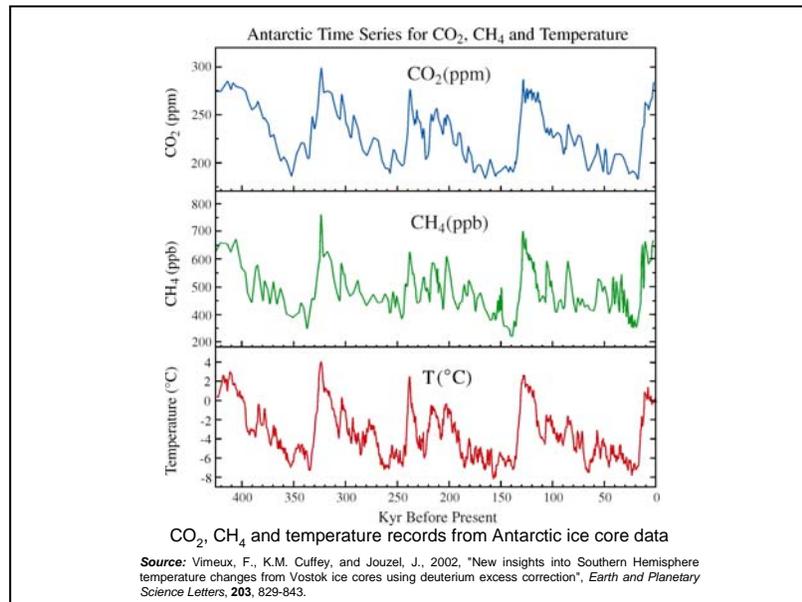
(global, averaged over chaos)

1. **Equilibrium Climate Sensitivity**
2. **Forcings: Human & Natural**
3. **Response Time (Ocean Inertia)**

Deterministic global temperature change depends mainly upon three things: (1) the equilibrium climate sensitivity, (2) the forcings that are applied to the system, and (3) the response time, which is primarily dependent on the ocean.

Recent research and data clarify the status of our understanding of these three characteristics, with important implications.

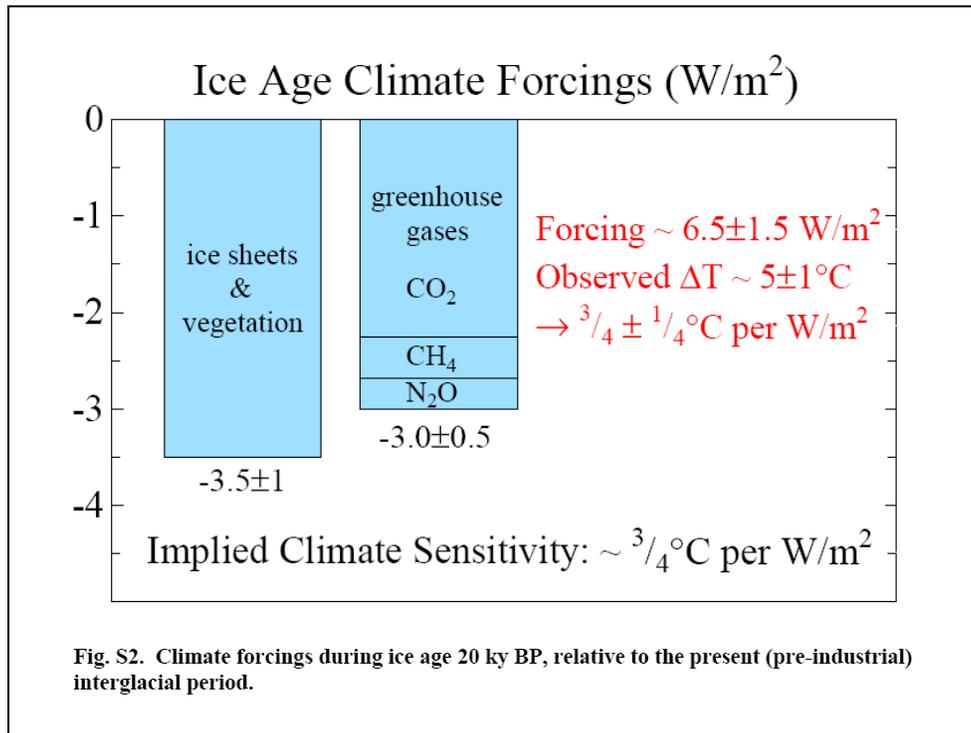
If all three of these were unknown, we would have a very difficult time understanding climate change and making predictions. Fortunately, if we are clever enough in how we define climate sensitivity, we can now specify it with great precision and accuracy.



We have good records of the long-lived atmospheric gases from ice cores, covering 400,000 thousand years, even 800,000 years.

And we have records of the temperature not only from the ice cores, but from ocean cores all around the world ocean.

We can compare the last ice age, 20 thousand years ago, with the current interglacial period, considering the surface conditions and the long-lived greenhouse gases as specified boundary conditions.



This yields an empirical climate sensitivity. It is $\frac{3}{4}$ C per W/m^2 or 3 C for doubled CO_2 .

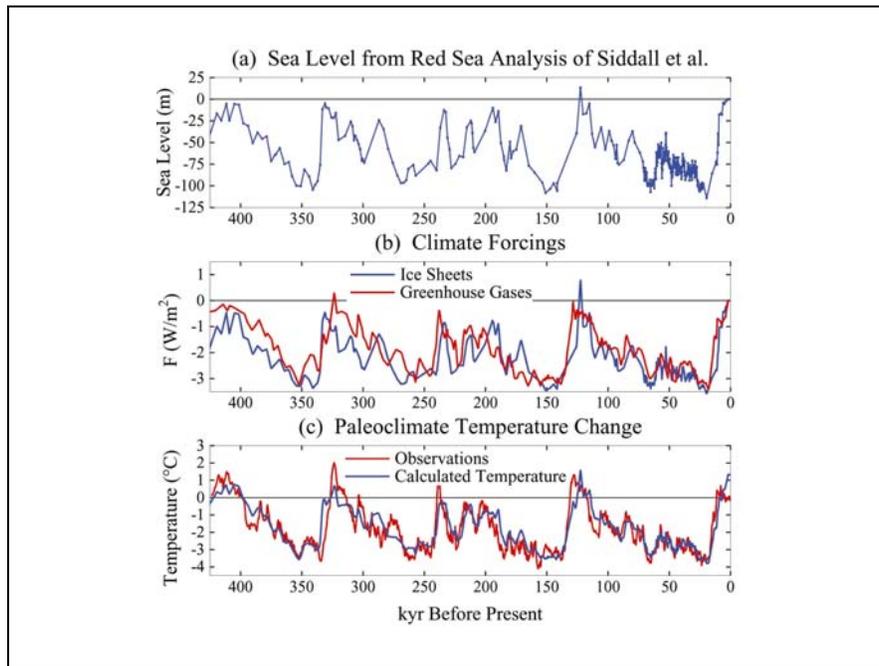
This climate sensitivity includes all fast feedback processes: water vapor, clouds, sea ice, snow, and aerosols.

The physics is exact, it is not modeled. All of the feedbacks operate correctly.

It is important to realize that aerosols should be included as a fast feedback.

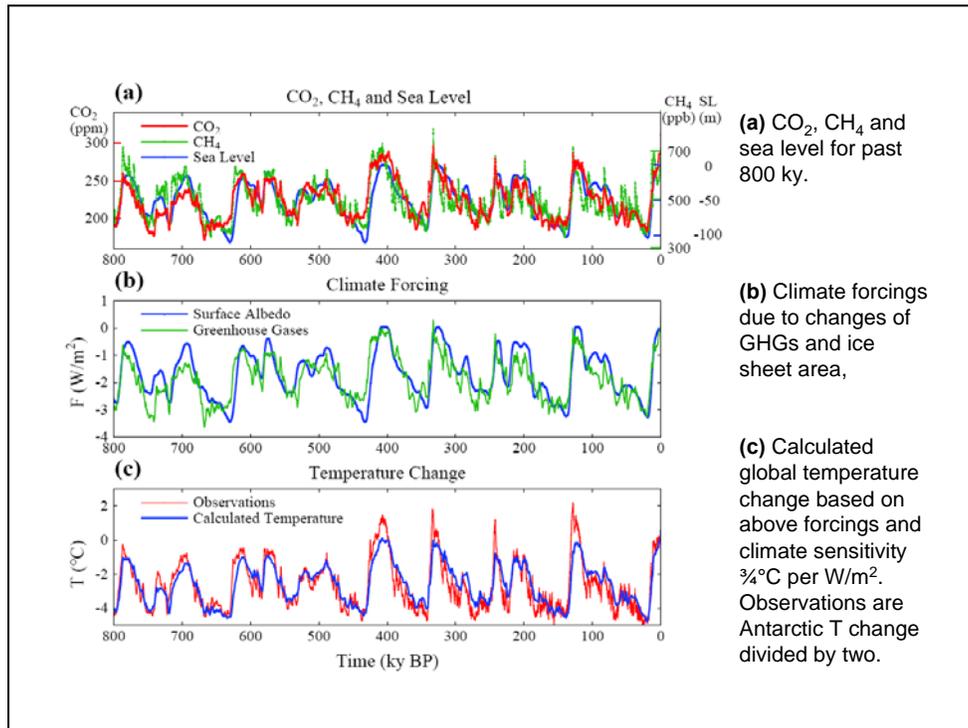
As the planet becomes warmer, the atmosphere is moister, and the aerosol load is reduced.

This is consistent with recent satellite observations, which show a decreasing background aerosol amount as the planet has become warmer, even though the global aerosol source strength did not decrease.



We know sea level for the full 400,000 years, which implies the ice sheet size and surface albedo. We also know the greenhouse gas amounts versus time.

Those two forcings, multiplied by $\frac{3}{4}$ degree per Watt, yield good agreement with observed temperature for the entire record.



Now we can look at 800,000 years. The same sensitivity fits for the earlier times, even better.

Bottom line: The fast feedback climate sensitivity is nailed. It is 3 C for doubled CO₂, plus or minus half a degree.

Empirical Climate Sensitivity

$3 \pm 0.5\text{C}$ for 2XCO_2

1. Includes all fast-feedbacks*

*water vapor, clouds, aerosols, surface albedo

(Note: aerosol feedback included)

2. Paleo yields precise result

3. Relevant to today's climate

sensitivity generally depends on climate state

Notes:

- (1) It is unwise to attempt to treat glacial-interglacial aerosol changes as a specified boundary condition (as per Hansen et al. 1984), because aerosols are inhomogeneously distributed, and their forcing depends strongly on aerosol altitude and aerosol absorptivity, all poorly known. But why even attempt that? Human-made aerosol changes are a forcing, but aerosol changes in response to climate change are a fast feedback.
- (2) The accuracy of our knowledge of climate sensitivity is set by our best source of information, not by bad sources. Estimates of climate sensitivity based on the last 100 years of climate change are practically worthless, because we do not know the net climate forcing. Also, transient change is much less sensitive than the equilibrium response and the transient response is affected by uncertainty in ocean mixing.
- (3) Although, in general, climate sensitivity is a function of the climate state, the fast feedback sensitivity is just as great going toward warmer climate as it is going toward colder climate. Slow feedbacks (ice sheet changes, greenhouse gas changes) are more sensitive to the climate state.

Climate Change Depends on

1. Equilibrium Climate Sensitivity

Nailed: it's 3°C for 2xCO₂

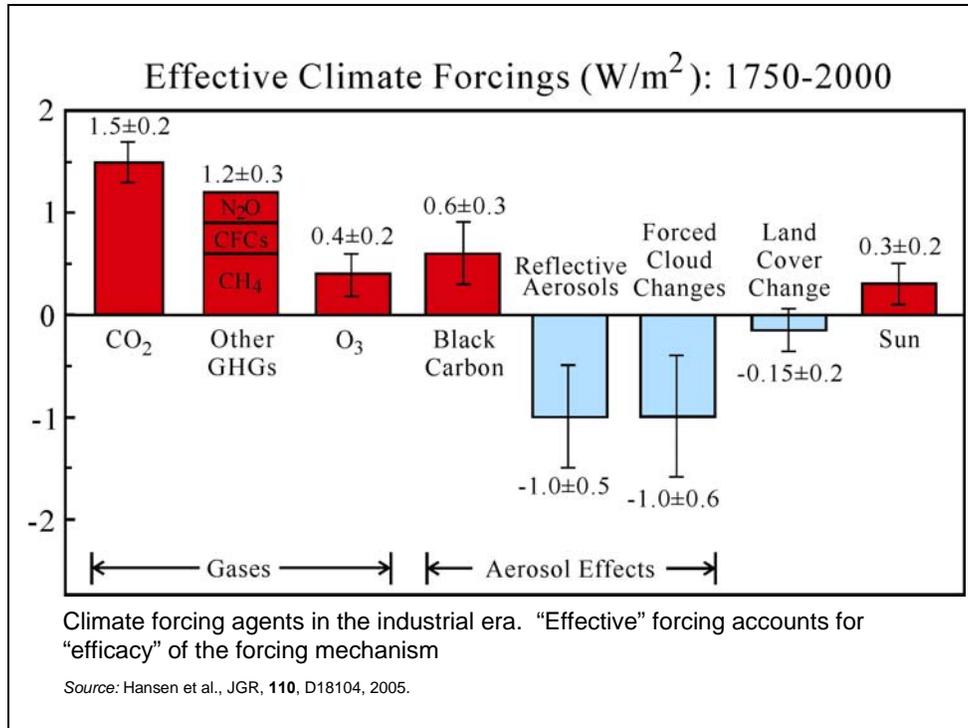
2. Forcings: Human & Natural

3. Response Time (Ocean Inertia)

So the equilibrium climate sensitivity is well established.

But that still leaves two uncertainties: the climate forcings and the climate response time.

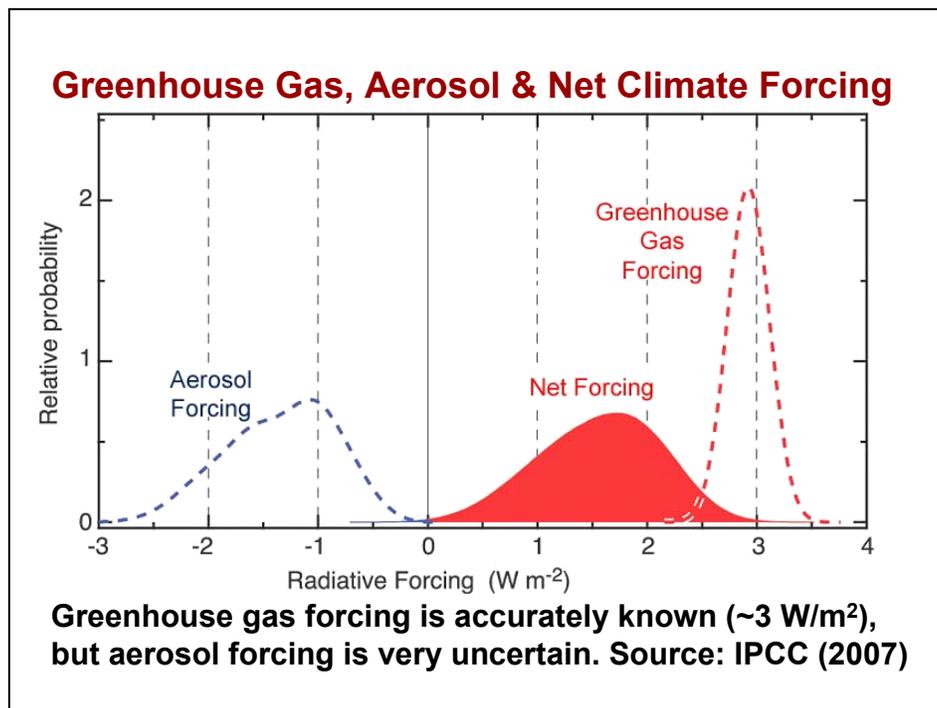
Everybody understands that the forcings are uncertain.



There are two major forcings in the industrial era, both human-made.

The greenhouse gas forcing is large and positive, causing warming. It is known very accurately.

Aerosols cause a net negative forcing, via their direct effect on sunlight and their effect on cloud properties, but the error bars are huge.



IPCC has a good way of showing this uncertainty.

The greenhouse gas forcing is a sharp function, well-known at about +3 W/m².

But the aerosol forcing might be anywhere between zero and -3 W/m².

So the net forcing, the red area, is anywhere between zero and +3 W/m², probably between about +1 and +2 Watts.



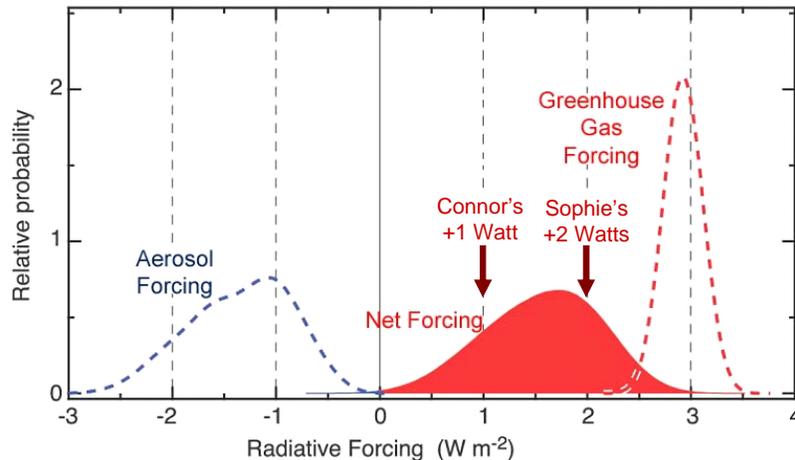
How do the different climate modeling groups decide upon the aerosol forcing?

I asked my granddaughter Sophie, and she said that it was about two Watts.

Her brother could only count 1 Watt.

But I took Sophie's advice, not Connor's.

Greenhouse Gas, Aerosol & Net Climate Forcing



Greenhouse gas forcing is accurately known ($\sim 3 \text{ W/m}^2$), but aerosol forcing is very uncertain. Source: IPCC (2007)

I'm just kidding, of course, we had a rationale for the aerosol forcing that we used, but my point is that there is a good deal of arbitrariness in the decision, and we must admit that the error bar is huge.

So keep in mind that it is almost as likely that the actual net forcing is close to Connor's +1 Watt as to Sophie's +2 Watts.



Figure 20. The Faustian bargain. Humans have enjoyed the fruits of the industrial revolution and avoided a large cost in climate change, as aerosol cooling has mitigated greenhouse warming. Payment comes due when humanity realizes that it cannot tolerate the further exponential growth of air pollution that would be needed for continued mitigation of global warming.

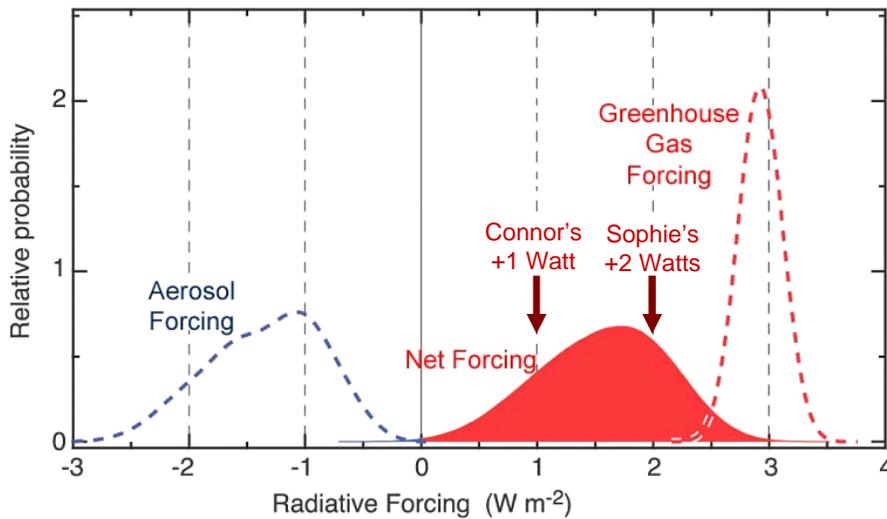
Why is this important, 1 Watt or 2 Watts? Because of the Faustian bargain that humanity has made.

If Sophie is right, aerosols have only reduced the greenhouse gas forcing from 3 W to 2 W.

But if Connor is right, the climate change we have already seen is a consequence of only about 1 W net forcing – implying that most of the greenhouse warming is still hidden by aerosols. In that event, just as Dr. Faustus, after enjoying the fruits of his dreams, was eventually dragged off to Hades with fearful shrieking, so to, humanity, after enjoying the economic fruits of fossil fuels, may be dragged to its doom.

Unfortunately, the people suffering such a fearful fate may be Sophie, Connor, and all of their cohorts, rather than the parties who made the bargain with the devil – but that is another part of my talk.

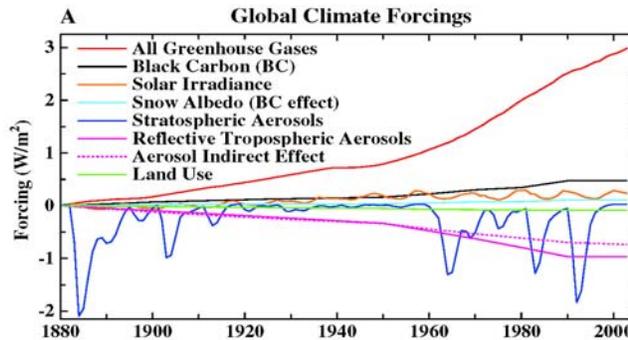
Greenhouse Gas, Aerosol & Net Climate Forcing



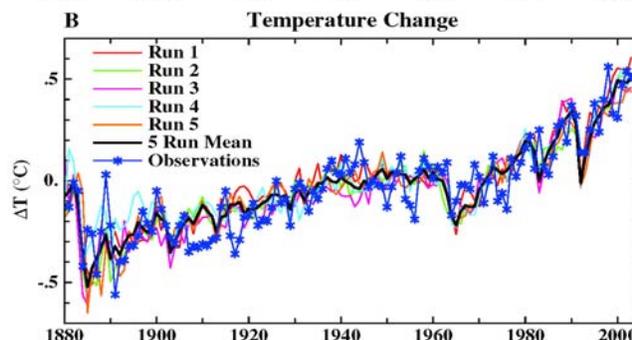
Greenhouse gas forcing is accurately known (~3 W/m²), but aerosol forcing is very uncertain. Source: IPCC (2007)

Back to 1 Watt, 2 Watts. Unfortunately, new information suggests that the truth is somewhere to the left of Sophie – but how close it is to Connor is unclear.

(A) Forcings used to drive climate simulations.



(B) Simulated and observed surface temperature change.



Source: Earth's energy imbalance: Confirmation and implications. *Science* 308, 1431, 2005.

When we use Sophie's 2 Watts net forcing, we get beautiful agreement with observed global temperature over the past century.

This climate model, the GISS climate model, has sensitivity 3C for doubled CO₂, which is realistic (by the way, the realistic fast-feedback climate sensitivity of the model does not mean that the individual fast feedbacks are accurately modeled, only that their net effect is approximately correct).

So does this result confirm that the net climate forcing really is about +2 Watts?

Climate Change Depends on

1. Equilibrium Climate Sensitivity

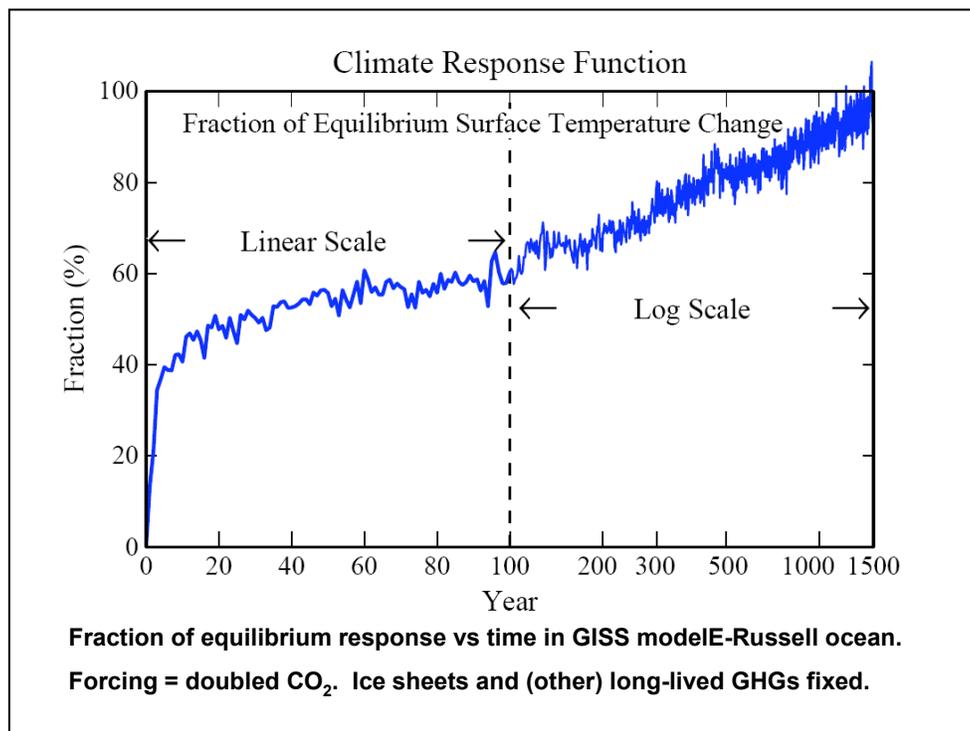
Nailed: it's 3°C for 2xCO₂

2. Forcings: Human & Natural

3. Response Time (Ocean Inertia)

No – because there is another important variable, the climate response time.

And we now have several reasons to believe that the climate response time of the GISS ocean model, and most ocean models, is probably too long. Most of the IPCC ocean models seem to mix too rapidly.

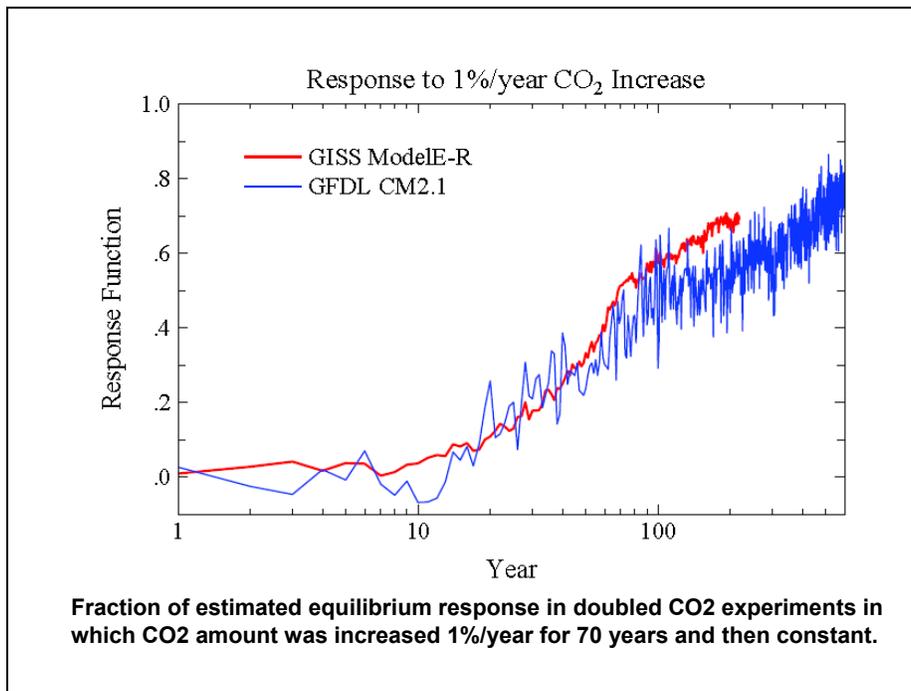


This is the climate response function for the GISS model with the Russell ocean. The response function is the fraction of the equilibrium response (versus time) to an instantaneous forcing, in this case a doubling of atmospheric CO₂.

Only 60 percent is achieved after a century and 90 percent after a millennium.

IPCC did not ask modelers to supply their climate response function, which is the most important characterization of the ocean model.

But fortunately Tom Delworth at GFDL, Gokhan Danabasoglu at NCAR, and Jonathan Gregory in the UK for the Hadley model, kindly provided me with long runs of their models.

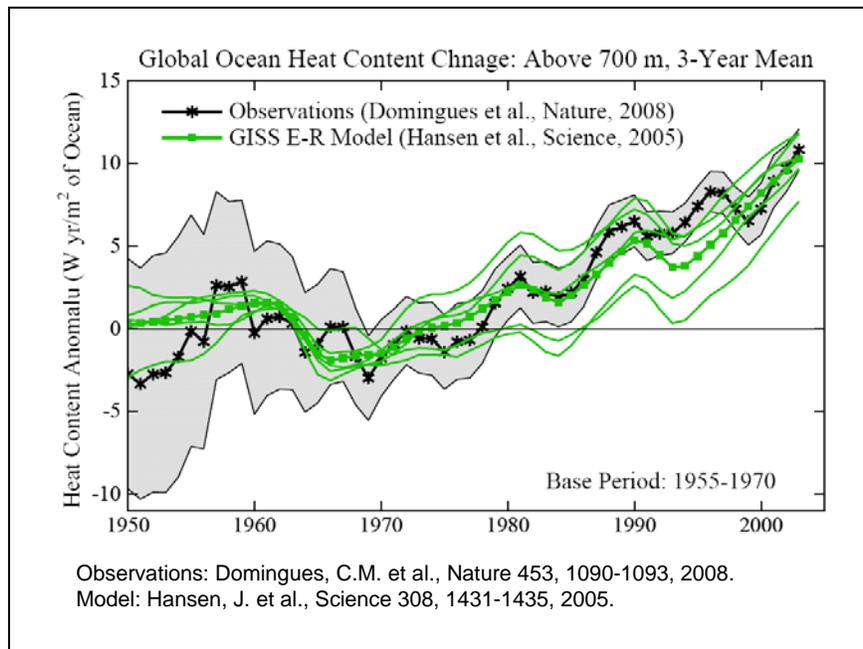


Comparisons show that all four models have similarly long surface temperature response times. Unfortunately, this does not indicate that the models are right.

On the contrary, there are numerous indications that they have a common problem.

First, overall, they tend to mix transient tracers more than observed.

Second, theoretical work at GiSS, by Vittorio Canuto's group, shows that mixing parameterizations, such as the common KPP approximation, cause too much mixing in the upper ocean.

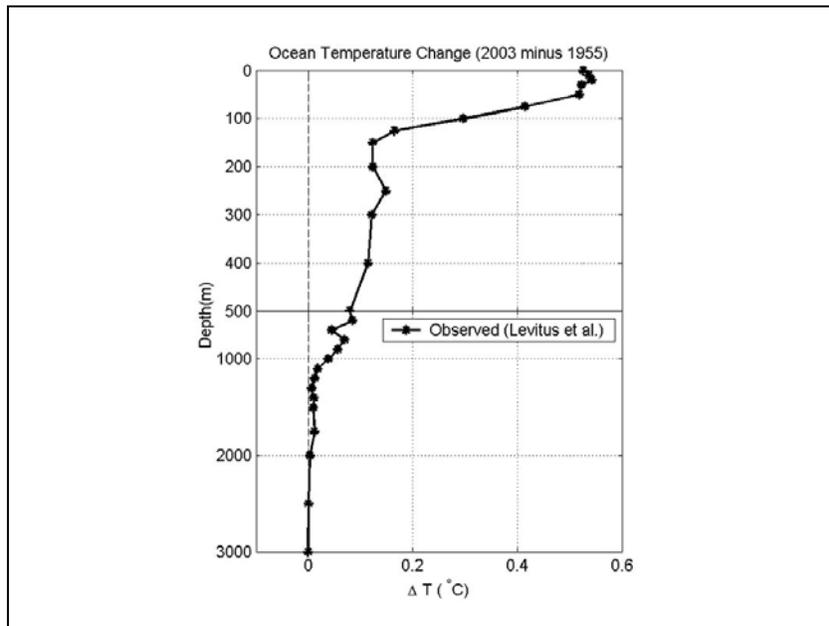


Third, there is the most important measurement – the change of ocean heat content.

Twenty years ago, when I was asked 'what is the most important measurement for global climate change', I said 'ocean heat storage, because that defines the planet's energy imbalance.

Measurements are getting better, but most measurements are mainly in the upper ocean.

Reanalyses of old data, such as this analysis for the upper 700 m, are doing a better job of correcting for instrumental changes, but there are still big uncertainties and disagreements between the researchers.

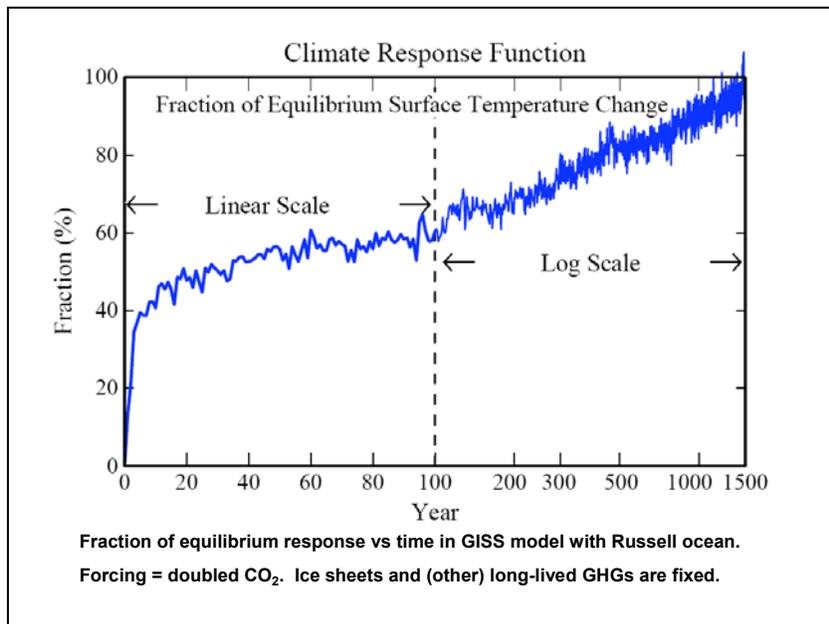


The situation in the deep ocean is worse. There is not enough good data.

Levitus' analysis yields very little heat gain in the deep ocean.

I think that he may underestimate heat storage because of an assumption of no change where no observations exist.

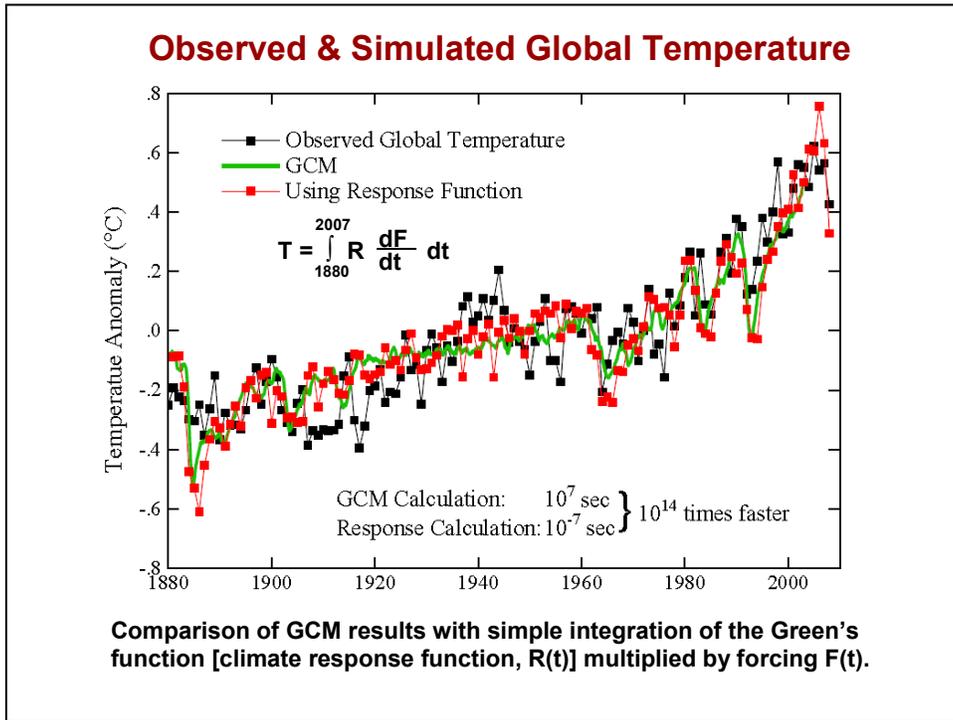
Nevertheless, the ocean data show very little increase of ocean heat in the past few years. Overall, it has become clear that there is a discrepancy between observations and the heat gain calculated in most models, if the models use a net human-made forcing of +2 W/m² and if the oceans mix as deeply as most ocean models do.



Most of the IPCC models that had a realistic sensitivity of 3C for doubled CO₂ used a net forcing of about 2 W/m². Conceivably there is a sub-conscious preference for a forcing that yields a surface warming similar to that observed.

Now, if the climate model response function is too slow, what does that imply? It means that the net forcing must be less than 2 W/m², if we want to retain good agreement with observed global warming.

Can we say something quantitatively without waiting for the next generation of ocean models? Maybe, because this climate response function is the simple Green's function for this climate model.

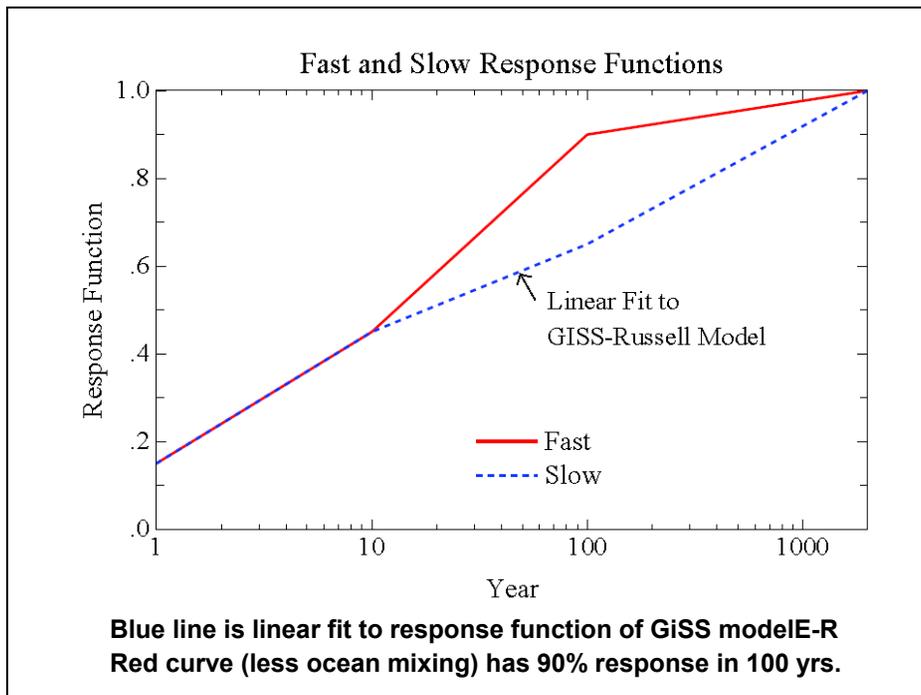


All we must do is multiply the response function by the annual change of forcing and integrate over time.

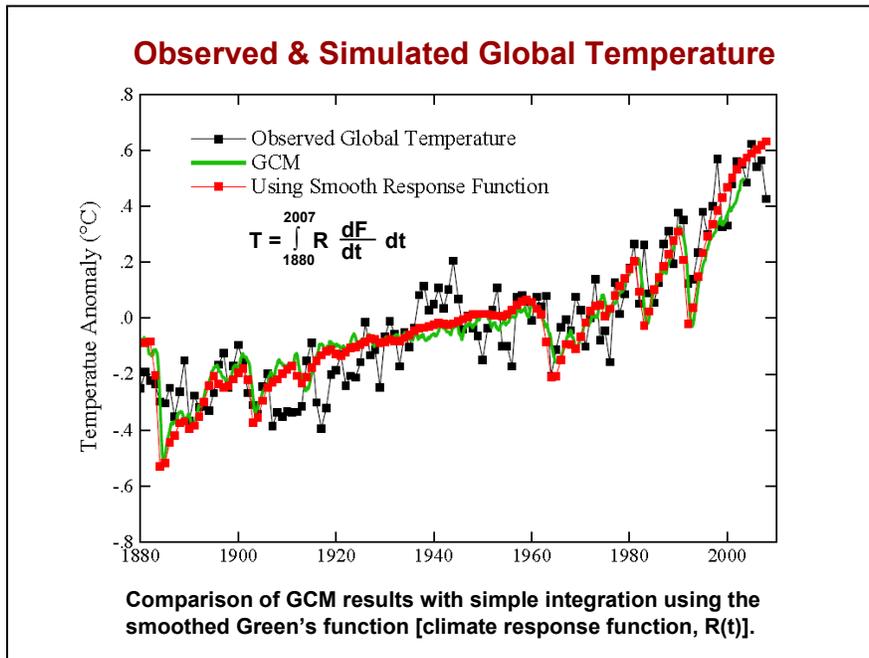
In ten to the minus seven seconds, we obtain a predicted global temperature change.

The result, the red curve, agrees very well with the GCM result, which required 10 to the plus seven seconds, or four months.

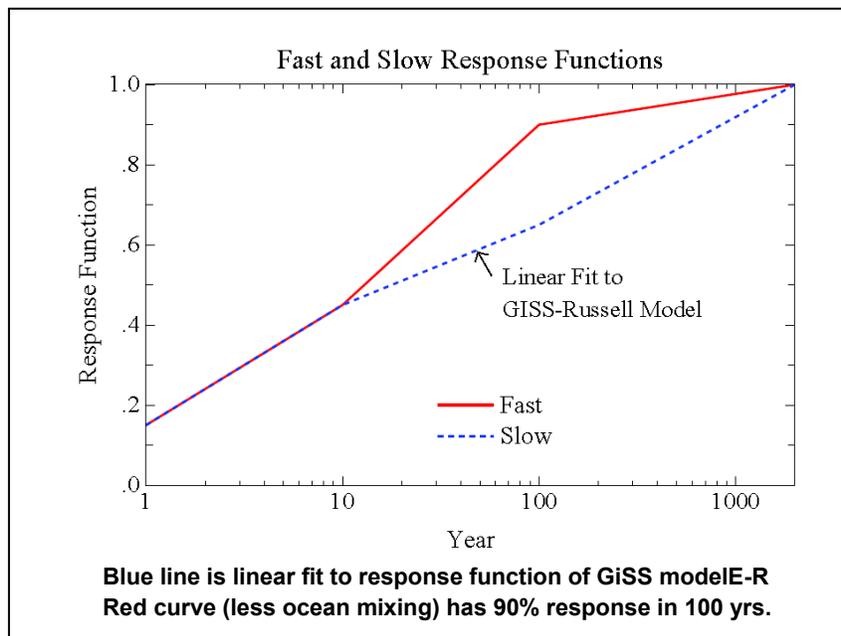
So we saved a factor of ten to the fourteenth power.



The bumps and valleys in the response function are chaos. So if we want to see the effect of forcings clearly, it may be better to take a linear fit to the response function, shown by the blue line.



By using the linearly smoothed response function we lose the realistic-looking interannual variability, but we can see the calculated response to forcings such as volcanoes more easily.



Now, we would like to know: what are the consequences if the real-world ocean mixes less rapidly than in GCMs?

The response in the first 10 years depends mainly on the ocean mixed layer, but on longer time scales the surface response is faster if mixing into the deep ocean is slower.

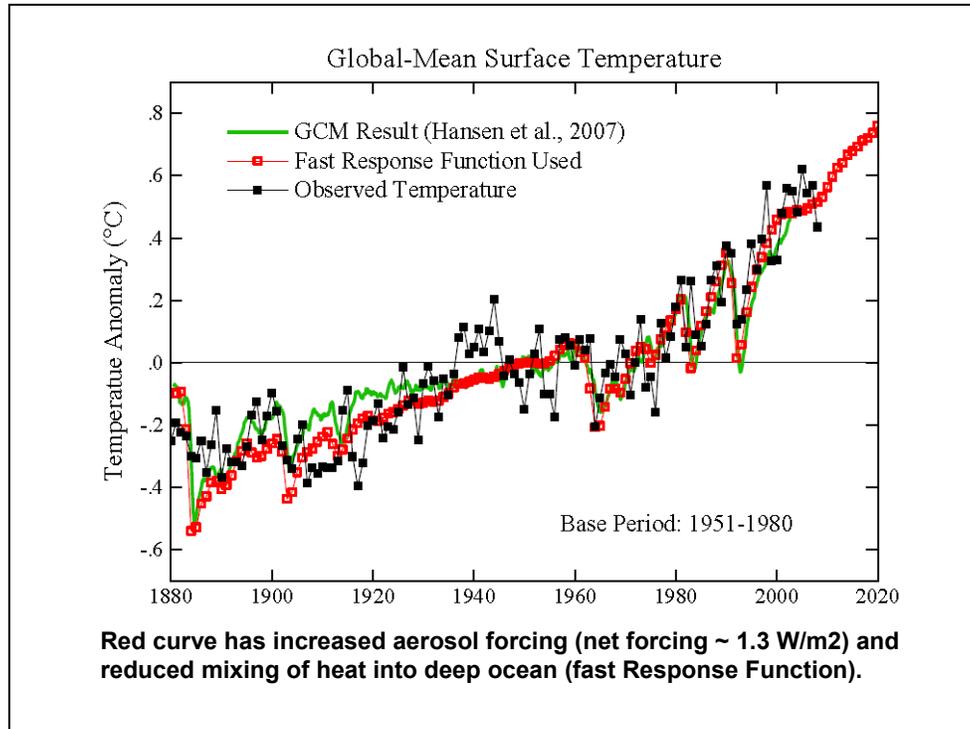
The real world probably falls between the blue and red curves, but we know not where.

The faster climate forcing, the red curve, would require a net forcing closer to Connor's 1 Watt.

Are there any testable consequences of these two alternatives?

Well, if Connor is right, if the net forcing is closer to 1 Watt, then the portion of the forcing that the planet has not yet responded to is much smaller than in the case of net 2 W/m² forcing, i.e., the planet is closer to energy balance.

That means that global temperature will be more responsive to ongoing changes of global climate forcing, even moderate changes such as solar irradiance changes of 0.2 W/m².



An example is shown in this calculation using the fast Response Function and increased aerosol forcing, so that the net forcing is only 1.3 W/m² rather than 2 Watts.

This smaller net forcing makes the effect of the solar cycle only a bit more apparent, in the waviness of computed temperature, which rises to a new record level within the next few years. The calculation assumes that the coming solar cycle will be similar to the last one. (A few small volcanoes in the past few years also contribute slightly to the waviness; stratospheric aerosol data was kindly provided by Larry Thomason).

So I expect to see new global temperature records within several years. But when you add in chaotic variability, short-term change of global temperature does not provide a very strong discriminate for the forcing.

[A comment from the audience: K.K. Tung recently published a paper (GRL 35, L17707, doi:10.1029/2008GL034240, 2008) with an insightful analysis of the solar cycle influence on temperature, yielding a conclusion consistent with that discussed here. Another audience member asked whether I would make a specific prediction – my response was that I would expect an unambiguous new global temperature record during the first term of the Obama administration, because four years is long enough to get us out of the current solar minimum.]



Sophie and Connor 3 years later – this year (2008)

So I went back to Sophie and Connor, who 3 years later should be older and wiser, and asked ‘what is it 1 Watt or 2 Watts?’ They said that they don’t know.

Missing Observations

- 1. Ocean Heat Content**
→ Planetary Energy Imbalance
- 2. Stratospheric Aerosols**
SAGE III sitting on shelf!!
- 3. Tropospheric Aerosols**
Same Magnitude as GHGs

Climate is a Research Problem

The only way we are going to be able to figure this out is to get the right observations.

First of all that means better observations of ocean heat content, including the deep ocean.

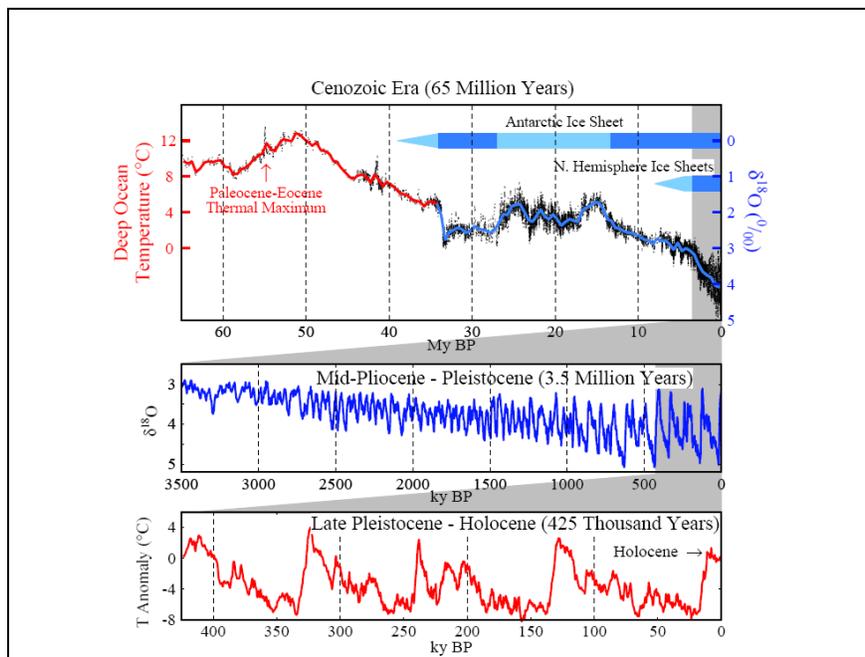
Second we must measure aerosols with the required accuracy, which none of the current satellite instruments have.

The instrument that can measure stratospheric aerosol properties with great accuracy is sitting on a shelf at Langley Research Center.

When the NASA Administrator and the White House eliminated the first line of the NASA Mission Statement, “to understand and protect the home planet”, and slashed the Earth Science budget, there are consequences.

There are plans to measure tropospheric aerosols with the needed accuracy for the first time with the Glory mission in 2009, but no follow on measurements are on the books.

Climate change is a research problem, it requires decadal measurements, and it is not a problem that can be handed over to an operational agency.



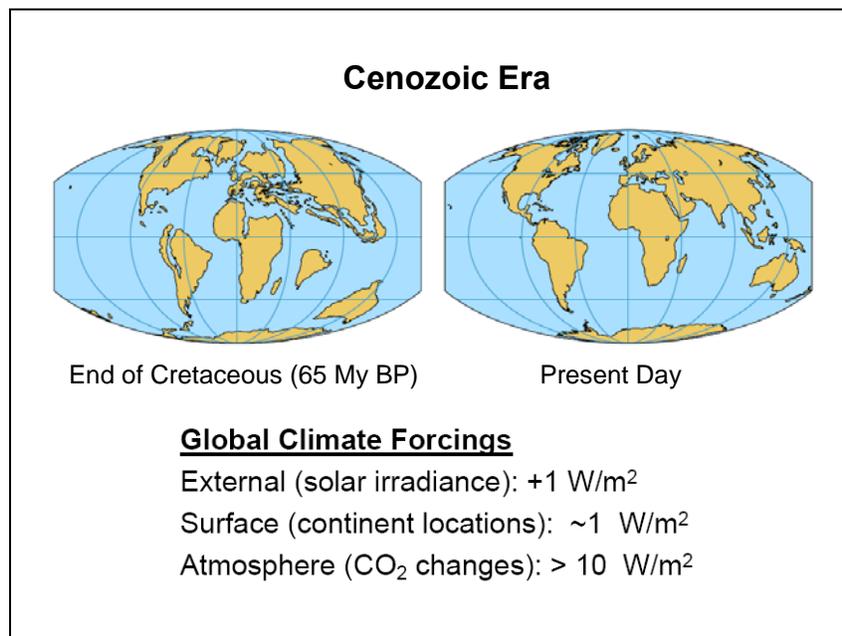
Back to paleoclimate. It is useful to look at longer time scales.

Pleistocene climate oscillations are complex, including dynamics and interactions.

But the detailed information that we have on Pleistocene oscillations should not cause us to lose sight of the forest for the trees.

The surface albedo change in going from the ice-free state, such as existed 50 million years ago, to the depths of the ice age, or even snowball Earth conditions is entirely a feedback, which makes climate more sensitive.

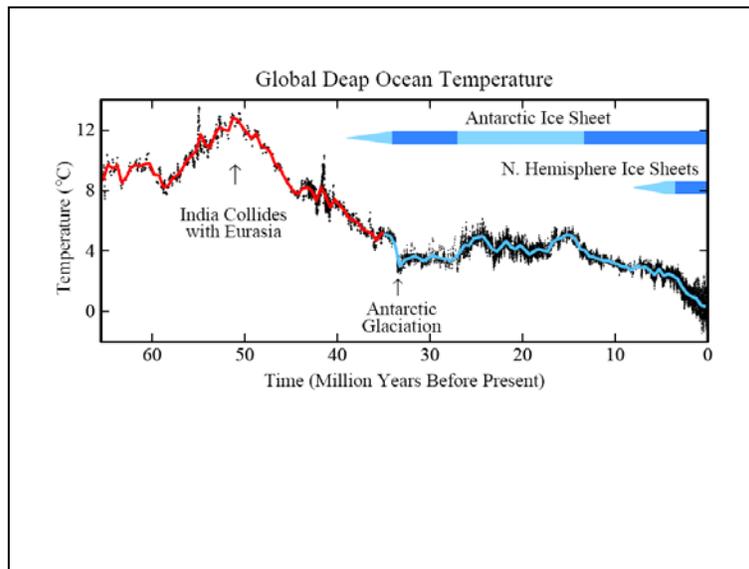
Between the depths of the last ice age and deglaciation of Antarctica climate sensitivity to a specified greenhouse gas change is doubled to about 6 C for doubled CO₂ because of the surface albedo feedback.



The dominant climate forcing over at least the first half of the Cenozoic must have been CO₂, because CO₂ was as much as 1000 ppm, causing a forcing of more than 10 W/m² relative to glacial periods. Other candidate forcings are an order of magnitude smaller.

The large CO₂ changes are no surprise as the volcanic source and weathering sink of CO₂ are not in general balanced.

At the beginning of the Cenozoic India was still south of the equator, moving north rapidly at 20 cm per year, plowing through the Tethys Ocean that had long been the depocenter for carbon-rich sediments from major rivers of the world.



The subduction and metamorphosis of ocean crust, with resulting volcanic emissions of CO₂, caused the planet to warm until India collided with Asia about 50 million years ago.

As the source of CO₂ decreased and the sink due to weathering of the Himalayas and Tibetan Plateau increased, the planet cooled until, we estimate in a recent paper*, CO₂ had declined to about 450 ppm, at which point Antarctica glaciated quite rapidly.

*Hansen, J., Mki. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D.L. Royer, and J.C. Zachos, 2008: Target atmospheric CO₂: Where should humanity aim? *Open Atmos. Sci. J.*, **2**, 217-231, doi:10.2174/1874282300802010217, http://pubs.giss.nasa.gov/docs/2008/2008_Hansen_etal.pdf

Summary: Cenozoic Era

1. Dominant Forcing: Natural ΔCO_2

- Rate ~100 ppm/My (0.0001 ppm/year)
- Human-made rate today: ~2 ppm/year

Humans Overwhelm Slow Geologic Changes

2. Climate Sensitivity High

- Antarctic ice forms if CO₂ < ~450 ppm
- Ice sheet formation reversible

Humans Could Produce "A Different Planet"

Two conclusions should be emphasized. First the natural imbalance between geologic sources and sinks of CO₂ is of the order of one ten-thousands of a ppm per year. In a million years that can cause a change of 100 ppm.

But the human-made rate of change is today about 2 ppm per year, about ten thousand times greater than the natural rate.

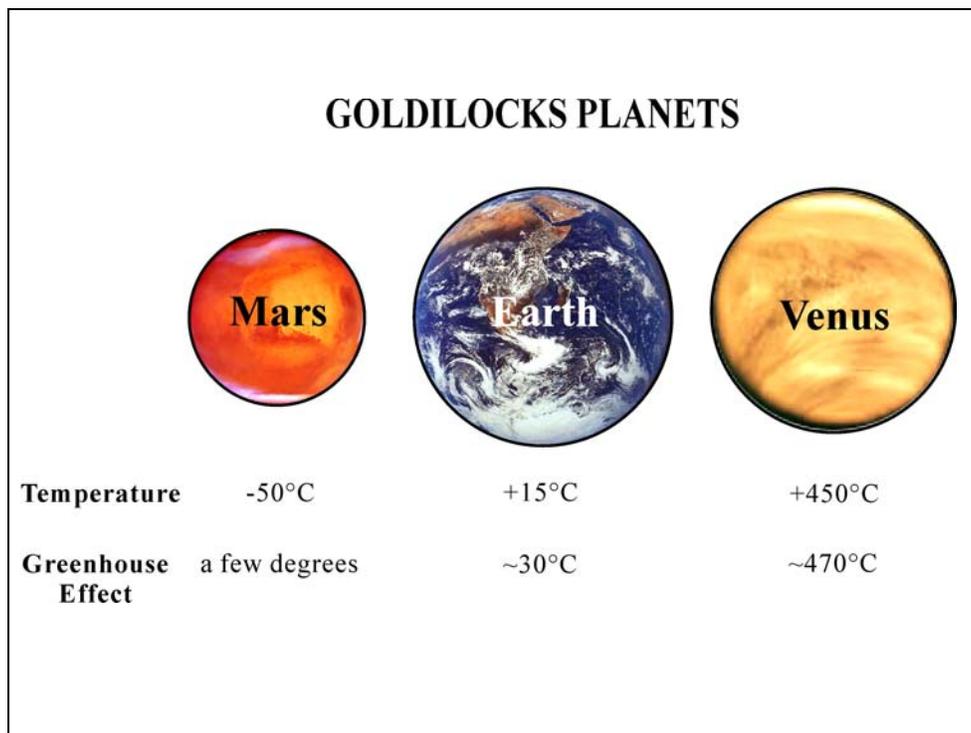
So the assertion that we should not be concerned about human-made climate change, because there have been much larger natural climate changes is nonsense. There have been larger changes, but on very long time scales. On any time scale of interest to humanity, humans will be in charge of the climate change.

The second conclusion is that we cannot burn all the fossil fuels, which would double or triple the amount of CO₂ in the air, without setting the planet on a course to the ice free state. It would be a rocky trip, and it would take some time, as the ice sheets collapsed and sea level rose 250 feet. But it should not be doubted – feedbacks work in both directions – ice sheet formation is reversible.

Climate Threat to the Planet

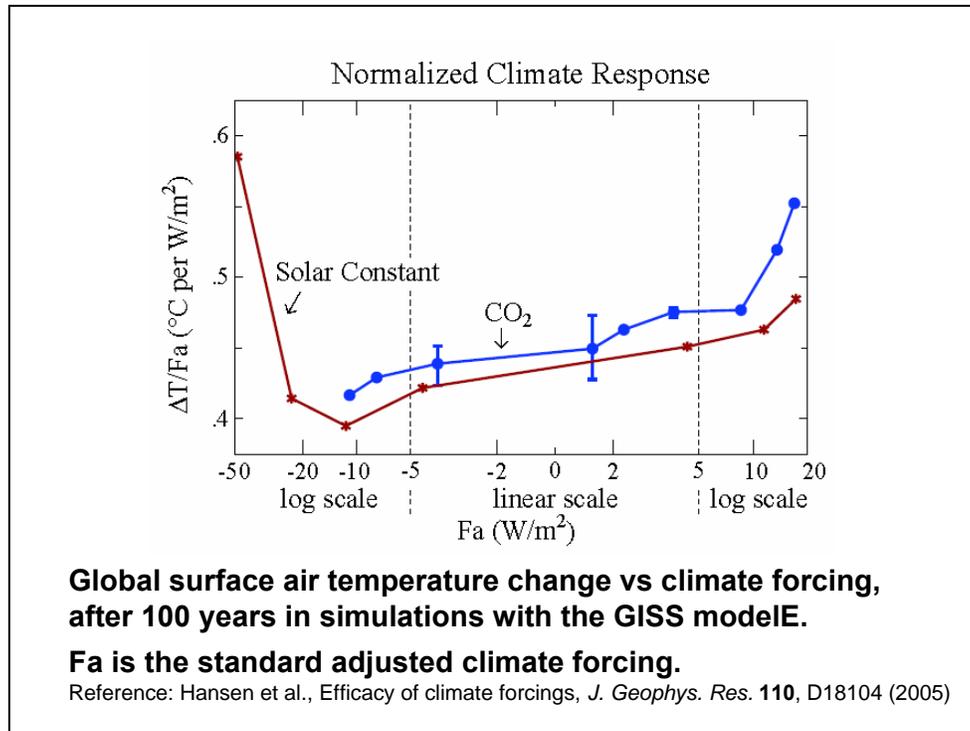
The Venus Syndrome

The Venus syndrome is the greatest threat to the planet, to humanity's continued existence.



Earth is Goldilock's choice among the planets, the one that is just right for life to exist. Not too hot. Not too cold.

How does the Earth manage to stay in this habitable range? Is there a Gaia phenomenon keeping the climate in bounds? A nice idea, but it doesn't work.



The Earth's climate becomes more sensitive as it becomes very cold, when an amplifying feedback, the surface albedo, can cause a runaway snowball Earth, with ice and snow forming all the way to the equator.

If the planet gets too warm, the water vapor feedback can cause a runaway greenhouse effect. The ocean boils into the atmosphere and life is extinguished.

The Earth has fell off the wagon several times in the cold direction, ice and snow reaching all the way to the equator. Earth can escape from snowball conditions because weathering slows down, and CO₂ accumulates in the air until there is enough to melt the ice and snow rapidly, as the feedbacks work in the opposite direction. The last snowball Earth occurred about 640 million years ago.

Now the danger that we face is the Venus syndrome. There is no escape from the Venus Syndrome. Venus will never have oceans again.

Given the solar constant that we have today, how large a forcing must be maintained to cause runaway global warming? Our model blows up before the oceans boil, but it suggests that perhaps runaway conditions could occur with added forcing as small as 10-20 W/m².

Runaway Greenhouse Effect?

1. Unprecedented Speed of +Forcing
2. Negative Feedbacks (e.g. Increased Weathering Rate) of Little Help
3. Solar Irradiance has Increased

My Opinion:

All Coal → ?? (Runaway Possible)

Coal + Tars → !! (Dead Certainty)

There may have been times in the Earth's history when CO₂ was as high as 4000 ppm without causing a runaway greenhouse effect. But the solar irradiance was less at that time.

What is different about the human-made forcing is the rapidity at which we are increasing it, on the time scale of a century or a few centuries. It does not provide enough time for negative feedbacks, such as changes in the weathering rate, to be a major factor.

There is also a danger that humans could cause the release of methane hydrates, perhaps more rapidly than in some of the cases in the geologic record.

In my opinion, if we burn all the coal, there is a good chance that we will initiate the runaway greenhouse effect. If we also burn the tar sands and tar shale (a.k.a. oil shale), I think it is a dead certainty.



Figure 20. The Faustian bargain. Humans have enjoyed the fruits of the industrial revolution and avoided a large cost in climate change, as aerosol cooling has mitigated greenhouse warming. Payment comes due when humanity realizes that it cannot tolerate the further exponential growth of air pollution that would be needed for continued mitigation of global warming.

That would be the ultimate Faustian bargain. Mephistopheles would carry off shrieking not only the robber barons, but, unfortunately and permanently, all life on the planet.

United Nations Framework Convention on Climate Change

Aim is to stabilize greenhouse gas emissions...

*“...at a level that would prevent
dangerous anthropogenic interference
with the climate system.”*

Metrics for “Dangerous” Change

Extermination of Animal & Plant Species

1. Extinction of Polar and Alpine Species
2. Unsustainable Migration Rates

Ice Sheet Disintegration: Global Sea Level

1. Long-Term Change from Paleoclimate Data
2. Ice Sheet Response Time

Regional Climate Disruptions

1. Increase of Extreme Events
2. Shifting Zones/Freshwater Shortages

Tipping Point Definitions

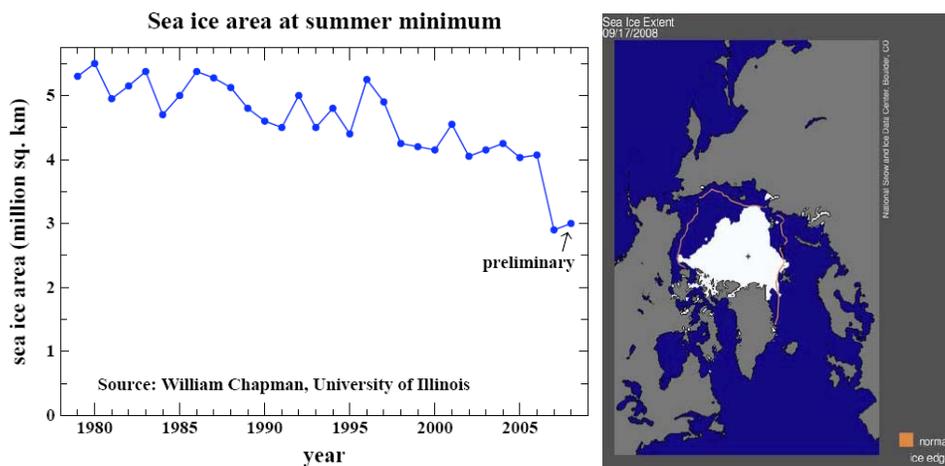
1. Tipping Level

- Climate forcing (greenhouse gas amount) reaches a point such that no additional forcing is required for large climate change and impacts

2. Point of No Return

- Climate system reaches a point with unstoppable irreversible climate impacts (irreversible on a practical time scale)
Example: disintegration of large ice sheet

Arctic sea ice area at summer minimum.



Arctic Sea Ice Criterion*

1. Restore Planetary Energy Balance

→ CO₂: 385 ppm → 325-355 ppm

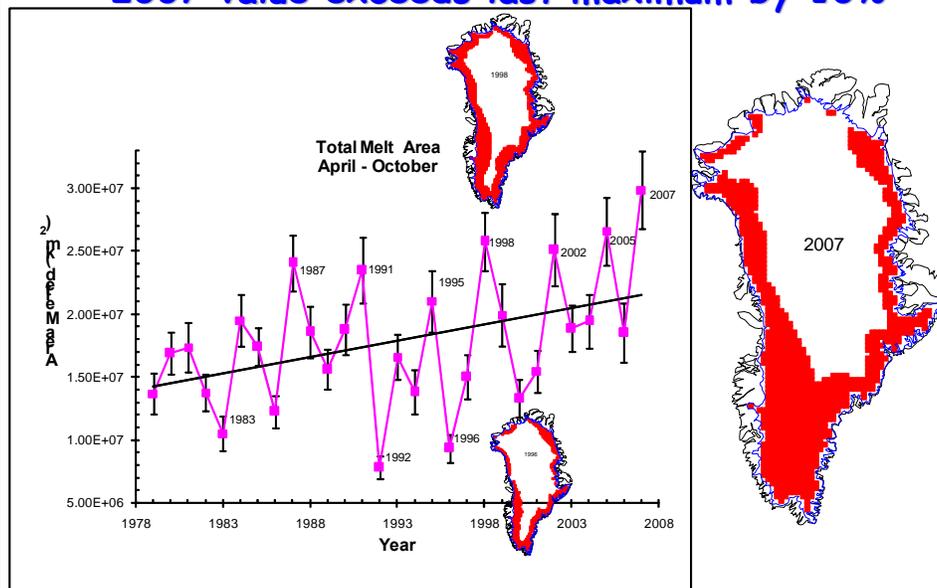
2. Restore Sea Ice: Aim for -0.5 W/m²

CO₂: 385 ppm → 300-325 ppm

Range based on uncertainty in present planetary energy imbalance (between 0.5 and 1 W/m²)

* Assuming near-balance among non-CO₂ forcings

Greenland Total Melt Area - 2007 value exceeds last maximum by 10%



Surface Melt on Greenland

Melt descending into a moulin, a vertical shaft carrying water to ice sheet base.



*Source: Roger Braithwaite,
University of Manchester (UK)*

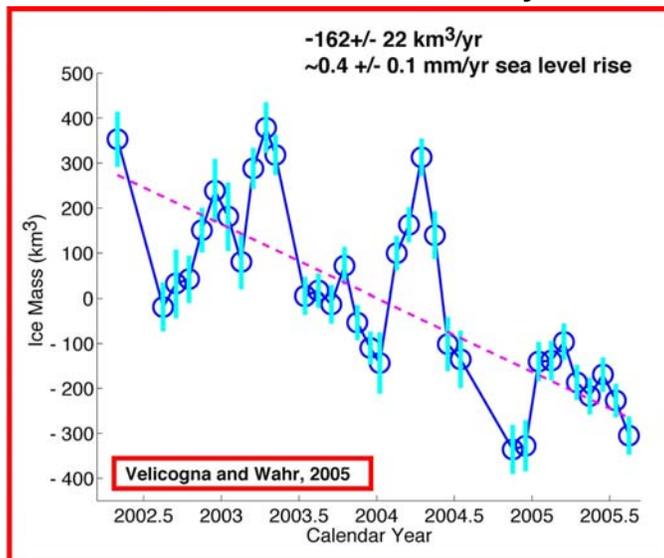
Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.

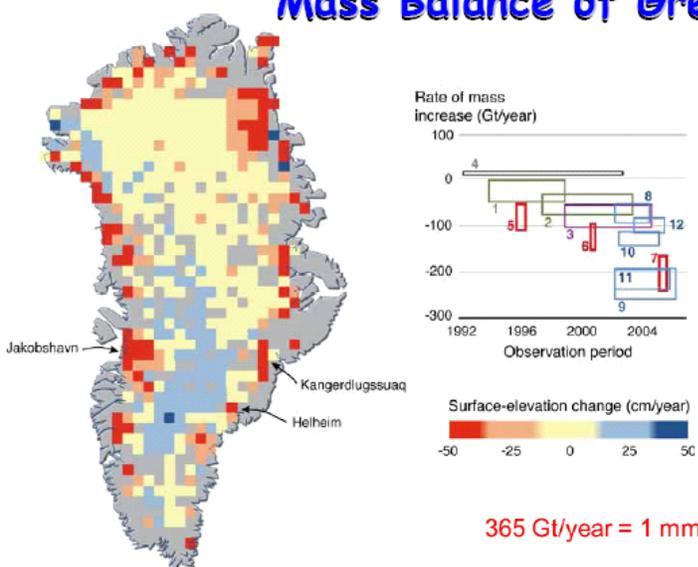


*Source: Prof. Konrad Steffen,
Univ. of Colorado*

Greenland Mass Loss – From Gravity Satellite



Mass Balance of Greenland



Greenland ice-sheet: rate of change from airborne laser-altimeter surveys (green), airborne/satellite laser-altimeter surveys (purple), mass-budget calculations (red), temporal changes in gravity (blue).

Sources (corresponding to numbers on rectangles): 1 and 2 Krabill and others 2000; 3 Thomas and others 2006; 4 Zwally and others 2005; 5 to 7 Rignot and Kanagaratnam 2008; 8 and 9 Velicogna and Wahr 2005 and 2008; 10 Ramillien and others 2006; 11 Chen and others 2008; 12 Luthke and others 2008.

Sea Level Criterion*

1. Prior Interglacial Periods

→ CO₂ <~ 300 ppm

2. Cenozoic Era

→ CO₂ <~ 300 ppm

3. Ice Sheet Observations

→ CO₂ < 385 ppm

* Assuming near-balance among non-CO₂ forcings

Pier on Lake Mead

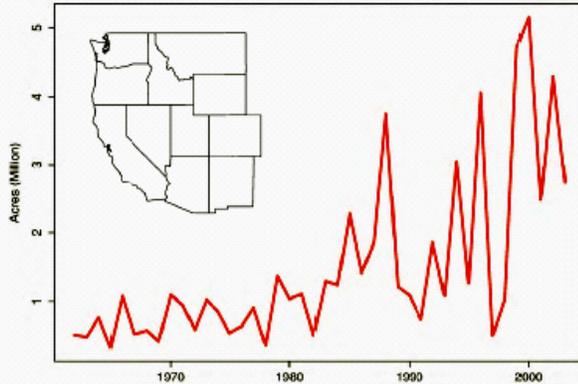


Subtropics expected to expand with global warming.
Observations show 4 degrees of latitude expansion.

Fires Are Increasing World-Wide

Wildfires in Western US have increased 4 fold in 30 years.

Western US area burned

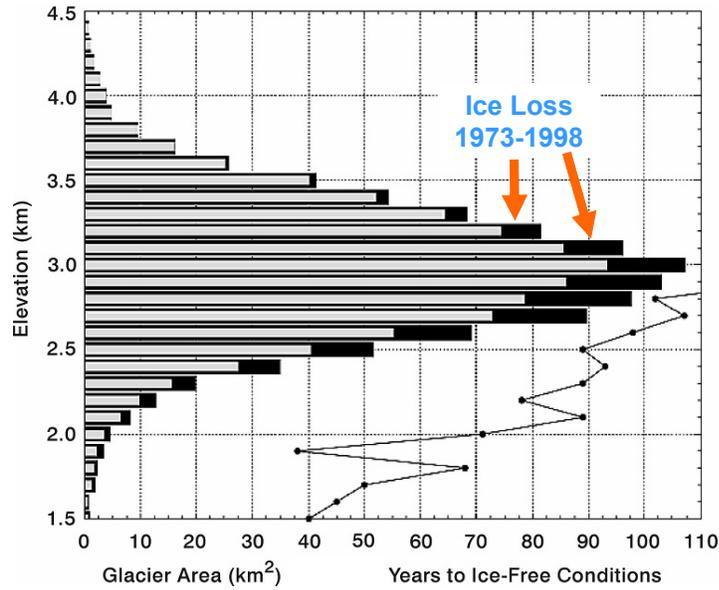


Source: Westerling et al. 2006

Rongbuk Glacier



Rongbuk glacier in 1968 (top) and 2007. The largest glacier on Mount Everest's northern slopes feeds Rongbuk River.



Black bar: ice loss in 1973-1998. Curve: years until ice gone, at that loss rate.
 Paul, F. et al., Geophys. Res. Lett. 31, L21402, 2004.

Stresses on Coral Reefs



Coral Reef off Fiji (Photo: Kevin Roland)

Assessment of Target CO₂

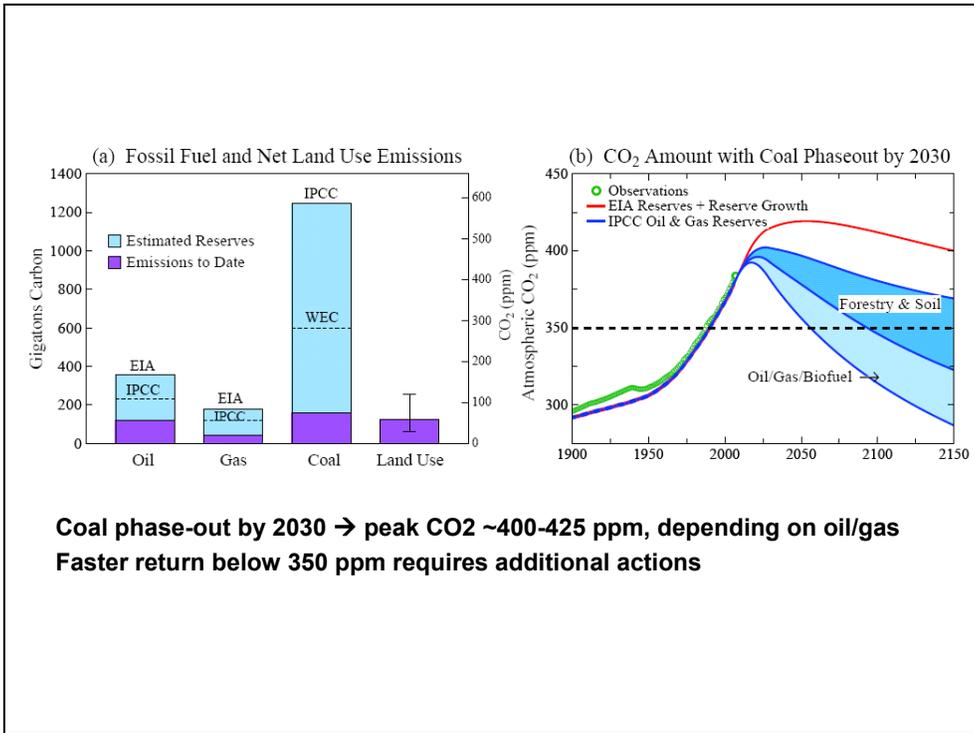
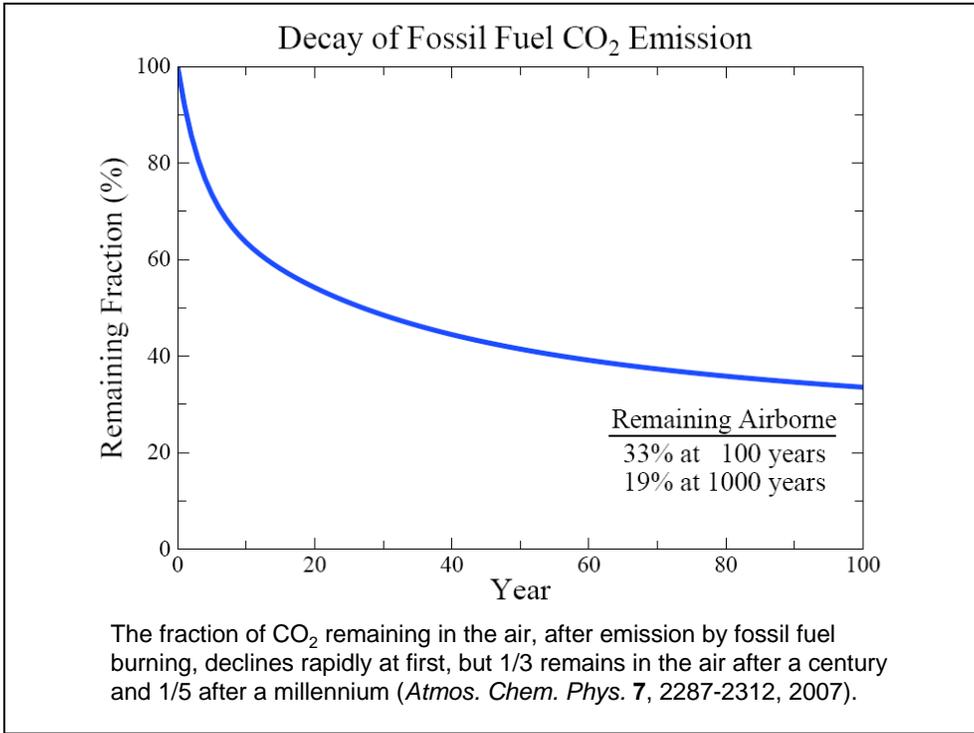
<u>Phenomenon</u>	<u>Target CO₂ (ppm)</u>
1. Arctic Sea Ice	300-325
2. Ice Sheets/Sea Level	300-350
3. Shifting Climatic Zones	300-350
4. Alpine Water Supplies	300-350
5. Avoid Ocean Acidification	300-350

→ Initial Target CO₂ = 350* ppm
*assumes CH₄, O₃, Black Soot decrease

Target CO₂:

< 350 ppm

To preserve creation, the planet
on which civilization developed



Initial Target CO₂: 350 ppm

Technically Feasible

(but not if business-as-usual continues)

Quick Coal Phase-Out Critical

(long lifetime of atmospheric CO₂)

(must halt construction of any new coal plants that do not capture & store CO₂)

“Free Will” Alternative

1. Phase Out Coal CO₂ Emissions

- by 2025/2030 developed/developing countries

2. Rising Carbon Price

- discourages unconventional fossil fuels & extraction of every last drop of oil (Arctic, etc.)

3. Soil & Biosphere CO₂ Sequestration

- improved farming & forestry practices

4. Reduce non-CO₂ Forcings

- reduce CH₄, O₃, trace gases, black soot

The Challenge

**We can avoid destroying creation!
(+cleaner planet, + good jobs!)**

**We have to figure out how to live
without fossil fuels someday...**

Why not now?

What's the Solution?*

(Not Carbon Cap or % Target!!!)

- 1. Coal Emissions Phase-Out**
UK, US, Germany Should Lead
- 2. Carbon Price & 100% Dividend**
For Transformations, Avoid UFF

*** Just my opinions, of course**

Carbon Tax & 100% Dividend

- 1. Tax Large & Growing (but get it in place!)**
 - tap efficiency potential & life style choices
- 2. Entire Tax Returned**
 - equal monthly deposits in bank accounts
- 3. Limited Government Role**
 - keep hands off money!
 - eliminate fossil subsidies
 - let marketplace choose winners
 - change profit motivation of utilities
 - watch U.S. modernize & emissions fall!

Jake - 11 months



Jake is our newest grandchild, my son's first child. Jake has not done much of anything to cause global warming. He doesn't even walk yet. He crawls fast. I interrupted one of his crawls when I called him to look up so I could snap this picture. My parents lived about 90 years, so Jake will probably be around most of this century. He will live in the greenhouse world that we choose to create.

Intergenerational Conflict

Intergenerational inequity and injustice is the result, affecting the young and unborn.

'Did not know' defense of prior generations no longer viable.

Ethical and legal liability questions raised by actions that deceived the public.

Continued failure of political process (not even available to young and unborn) may cause increasing public protests.

Climate Change Protest at Kingsnorth Power Station



Greenpeace activists on the painted chimney
October 8 2008. Photograph: Will Rose/Greenpeace

Kingsnorth Six: Not Guilty



Huw Williams, Kevin Drake, Ben Stewart, Tim Hewke, Emily Hall and Will Rose outside Maidstone Crown Court.

Photograph: Jiri Rezac/Greenpeace

Web Site

www.columbia.edu/~jeh1

includes

**Target Atmospheric CO₂: Where Should
Humanity Aim?**

**Global Warming Twenty Years Later:
Tipping Points Near**

In Defence of Kingsnorth Six