Cybernetics of Climate

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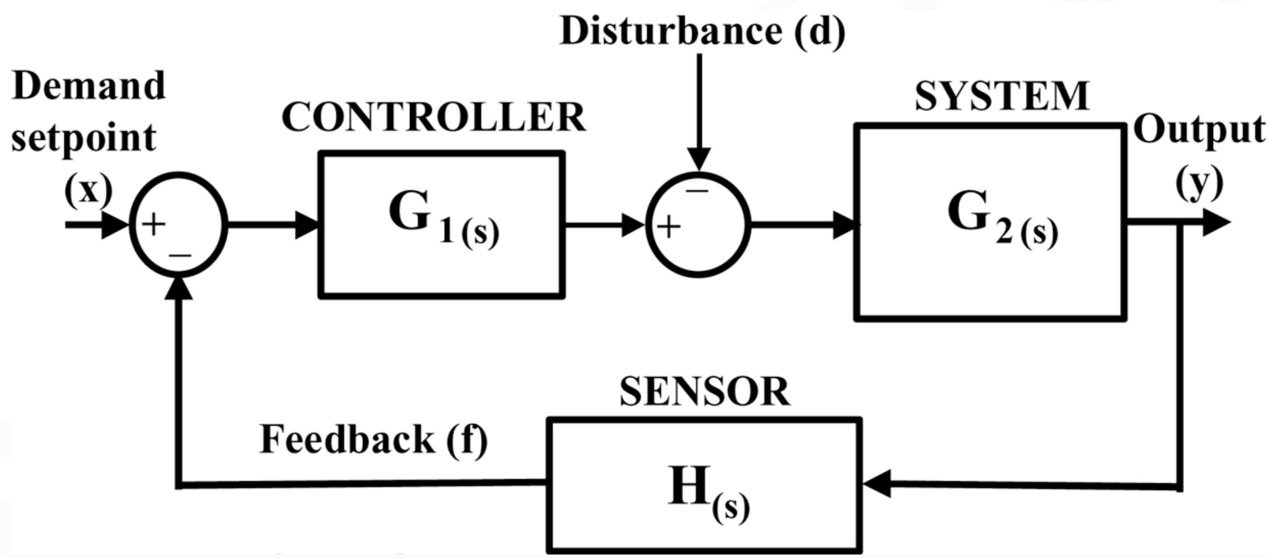
What is Cybernetics?

What Would Norbert Do?



To control a system:

- identify a target state
- model the system
- measure the system
- update the model
- modify the control points

Simple examples:

- home thermostat
- cruise control

What Makes it Cybernetics?

Original sense: stochastic (random models and channels with well-characterized statistics (Weiner)

i.e., formalized decision-making under uncertainty

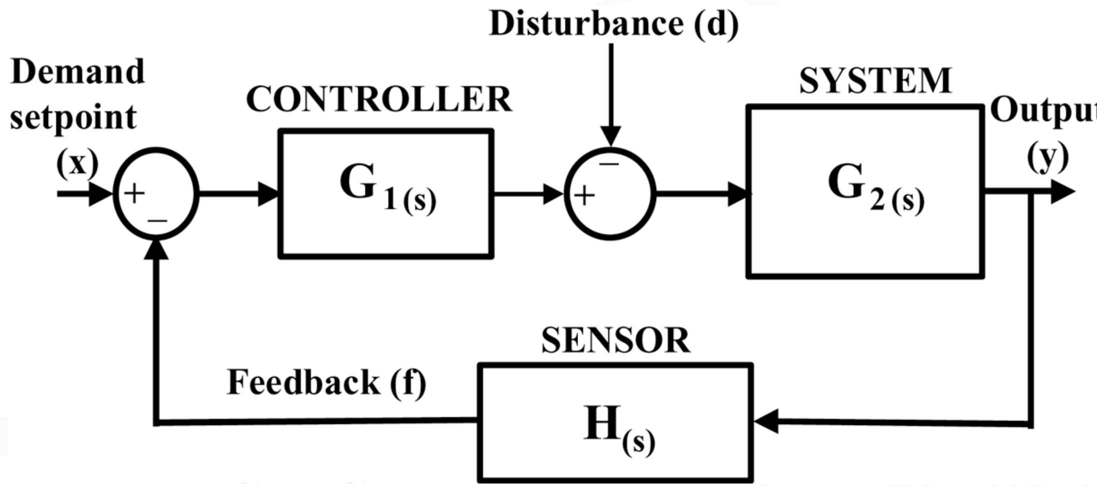
How it became associated with AI is a fascinating story which need not concern us here

Weiner became interested in informal decision-making under uncertainty. This is the case that interests us here.

Democracy as a Control System

The world is the system

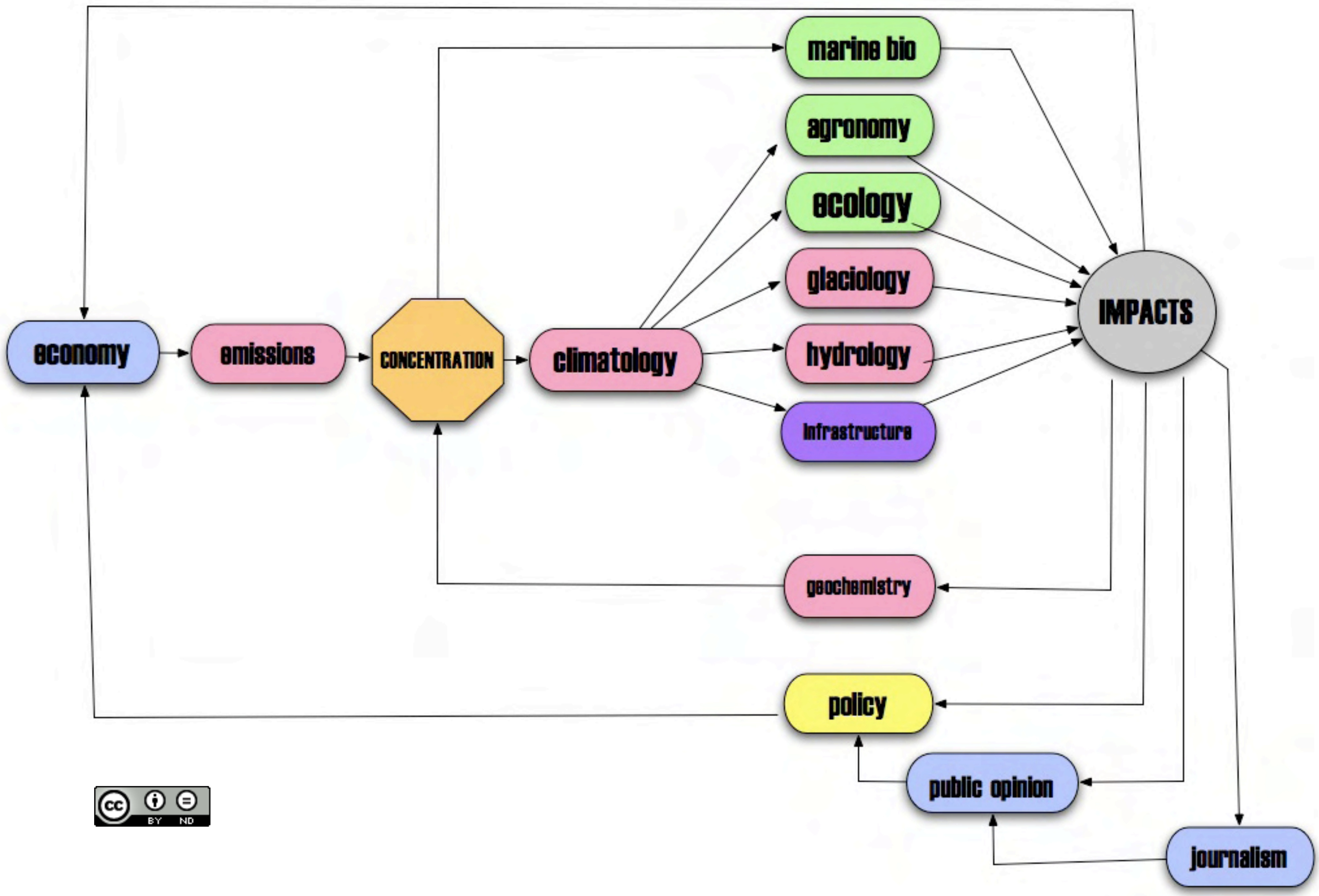
The sensors are:
- science,
- journalism
- politics



Not a bad analogy

Policy is the control

The performance of the system depends closely on the quality of the sensors as well as the design of the controller.


economy
emissions
CONCENTRATION
climatology
marine bio
agronomy
ecology
glaciology
hydrology
infrastructure
IMPACTS
geochemistry
policy
public opinion
journalism

You are here

What Does that Mean Really?

How should we think about that animation?

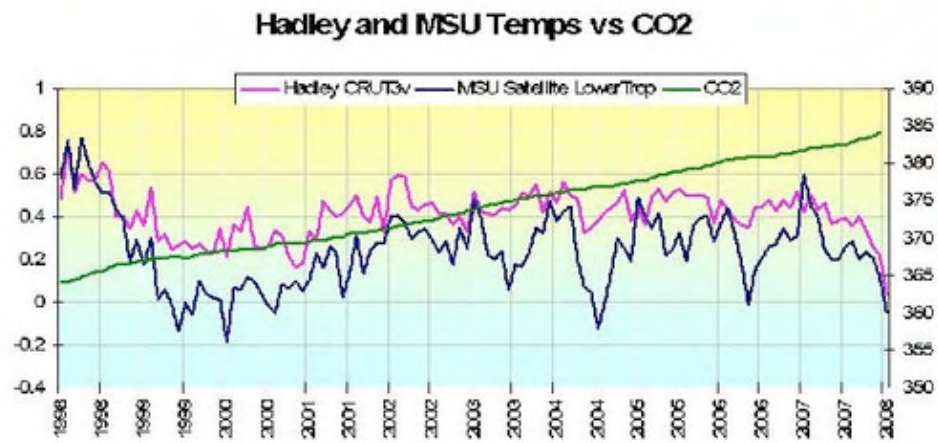
- Is it like a prediction of aerodynamics?
- Is it like a prediction of the stock market?
- Is it like a game, where the game designer wrote the desired answer into the system?
- How much do we care?
- What options are there for avoiding the outcome?

How NOT to Think About Climate Change

How Shouldn't We Think About CO_2?

People are drawn to say things
that one hopes they are smart enough
not to believe

Global Warming Stopped in 1998



R^2 HadCRUT3v and CO_2 = 0.001
R^2 UAH MSU LT and CO_2 = 0.005

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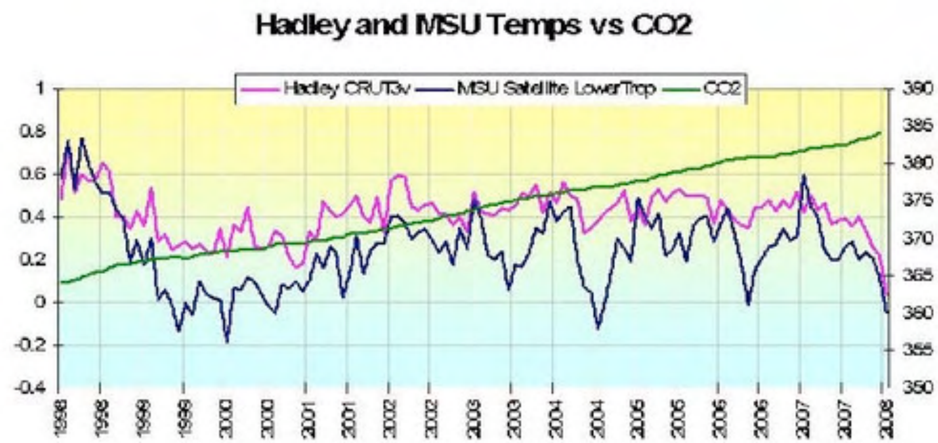
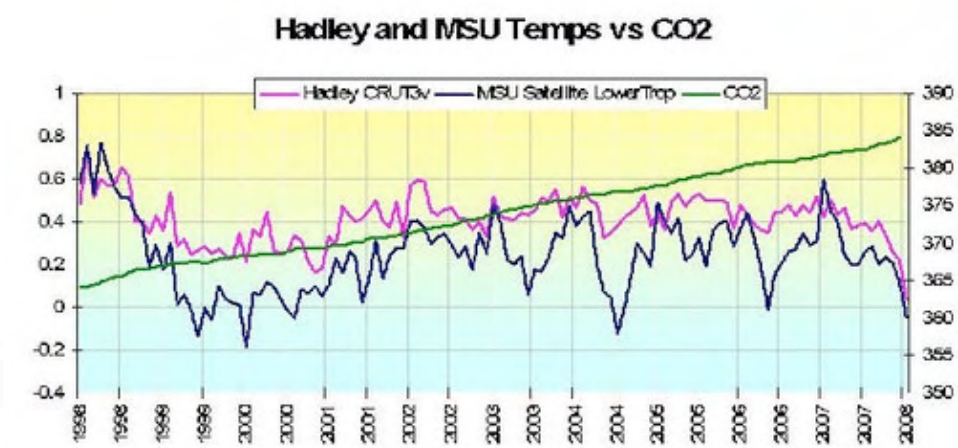


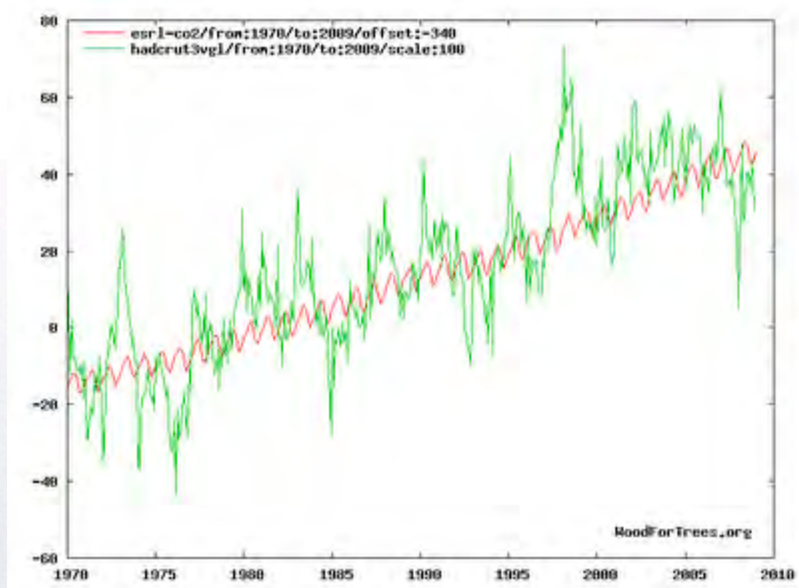
R^2 HadCRUT3v and CO_2 = 0.001
R^2 UAH MSU LT and CO_2 = 0.005

The facts are:

The sky is not falling; the Earth has been cooling for ten years, without help. The present cooling was NOT predicted by the alarmists' computer models, and has come as an embarrassment to them.

Global Warming Stopped in 1998





McCarthy and Moynihan

Noise injected into system is NOT random.

"Agnotology": cultivation of ignorance

Moynihan's rule:

You are entitled to your own opinion, but not to your own facts.

It's a slippery slope. Many professions designed around emphasizing convenient facts and de-emphasizing inconvenient ones. ("Lawyers' science" - McCarthy)

So:
What Are the Facts?

Please suspend skepticism.
I'm happy to debate offline.
I am delivering conventional wisdom here.

I: The Greenhouse Effect is Real

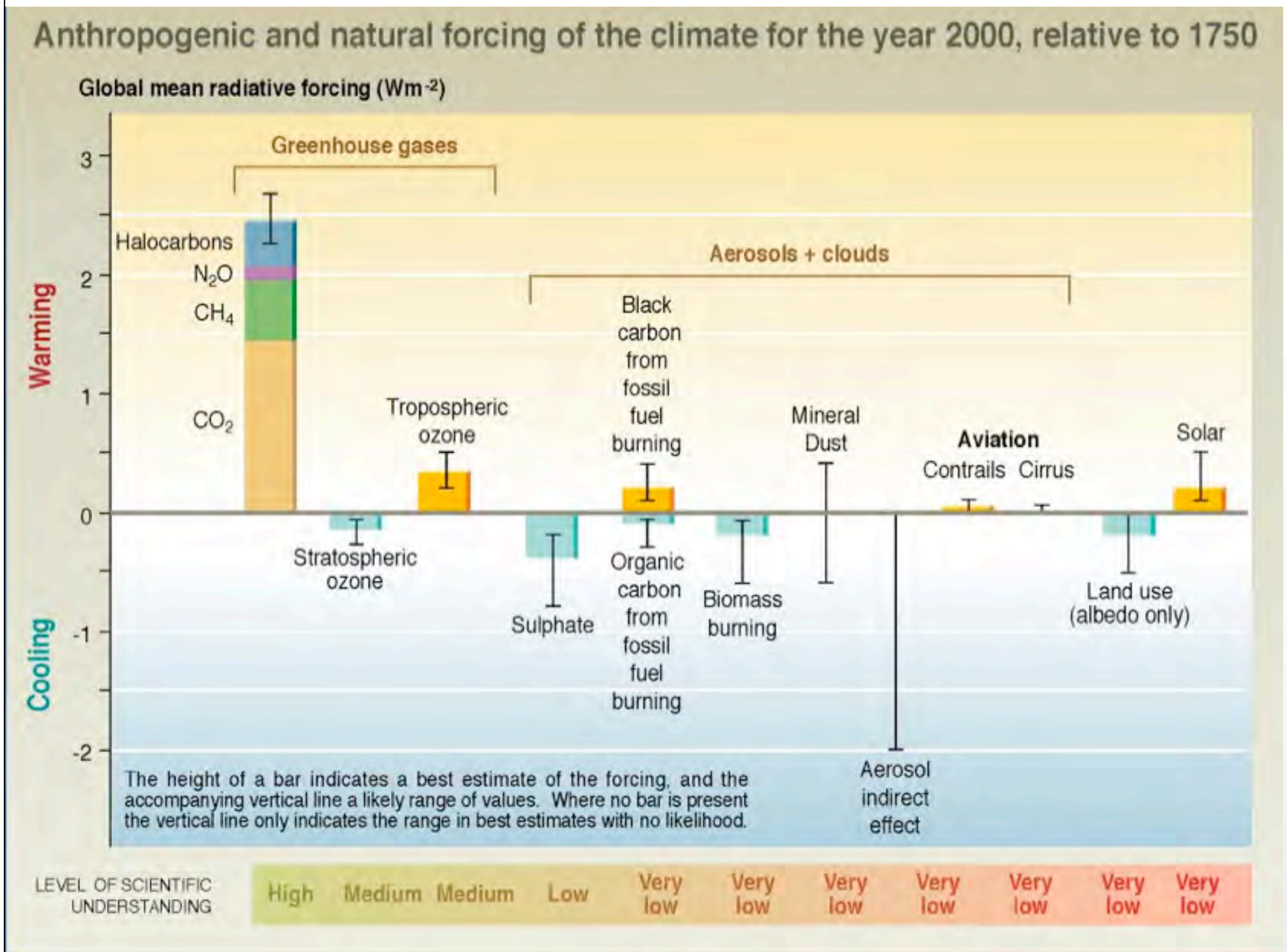
The surface temperature of Venus
cannot be accounted for otherwise.

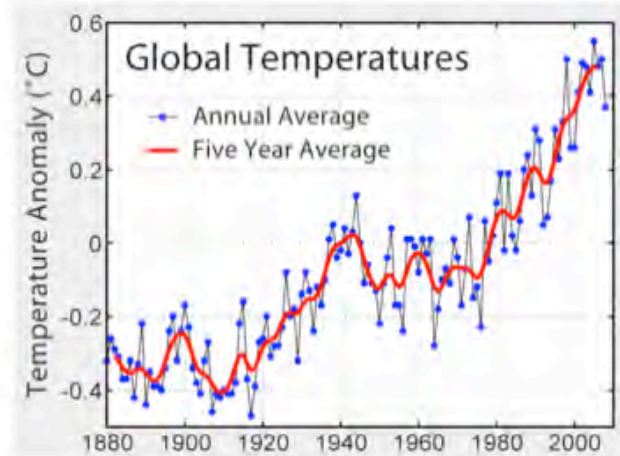
The effect is slower than linear but does not saturate.

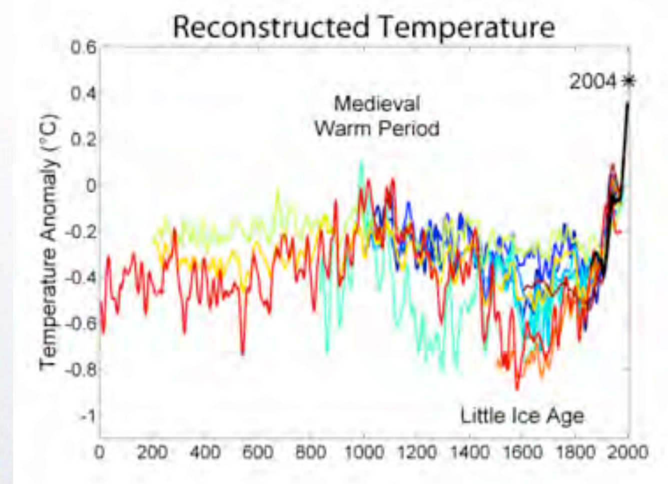
Under terrestrial conditions, CO_2 effect
is roughly logarithmic.

Sensitivity is therefore expressed "per doubling".

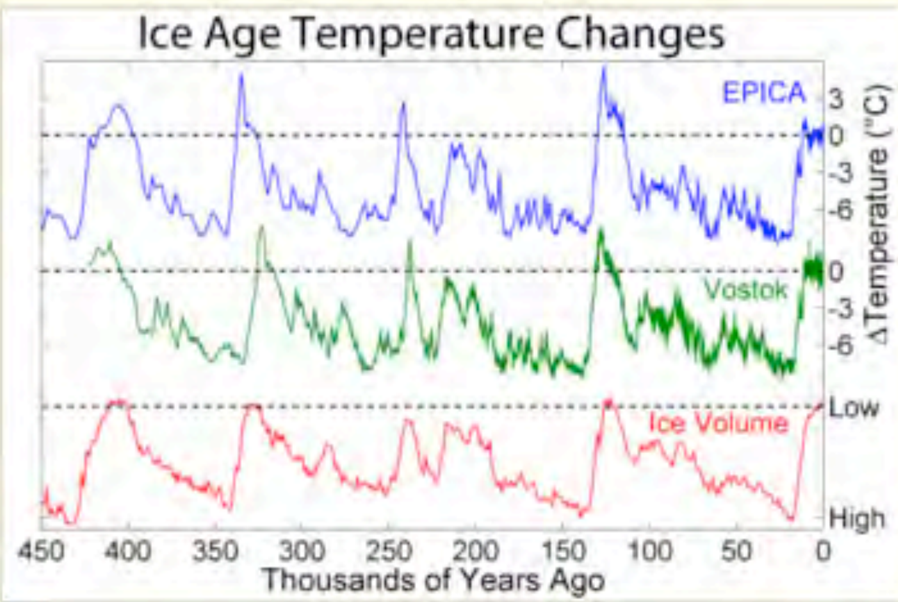
II: Greenhouse Forcing is Now Dominant



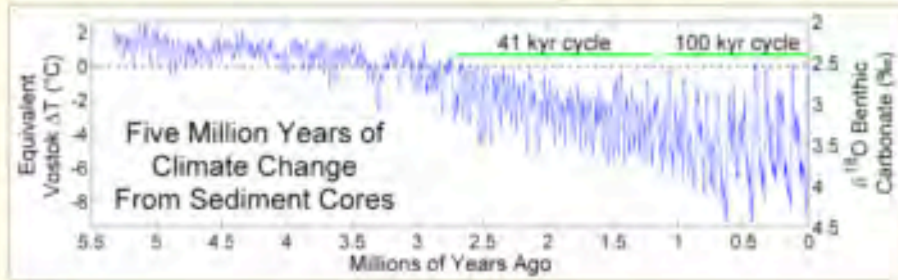




III: Recent Natural Climate is Unstable



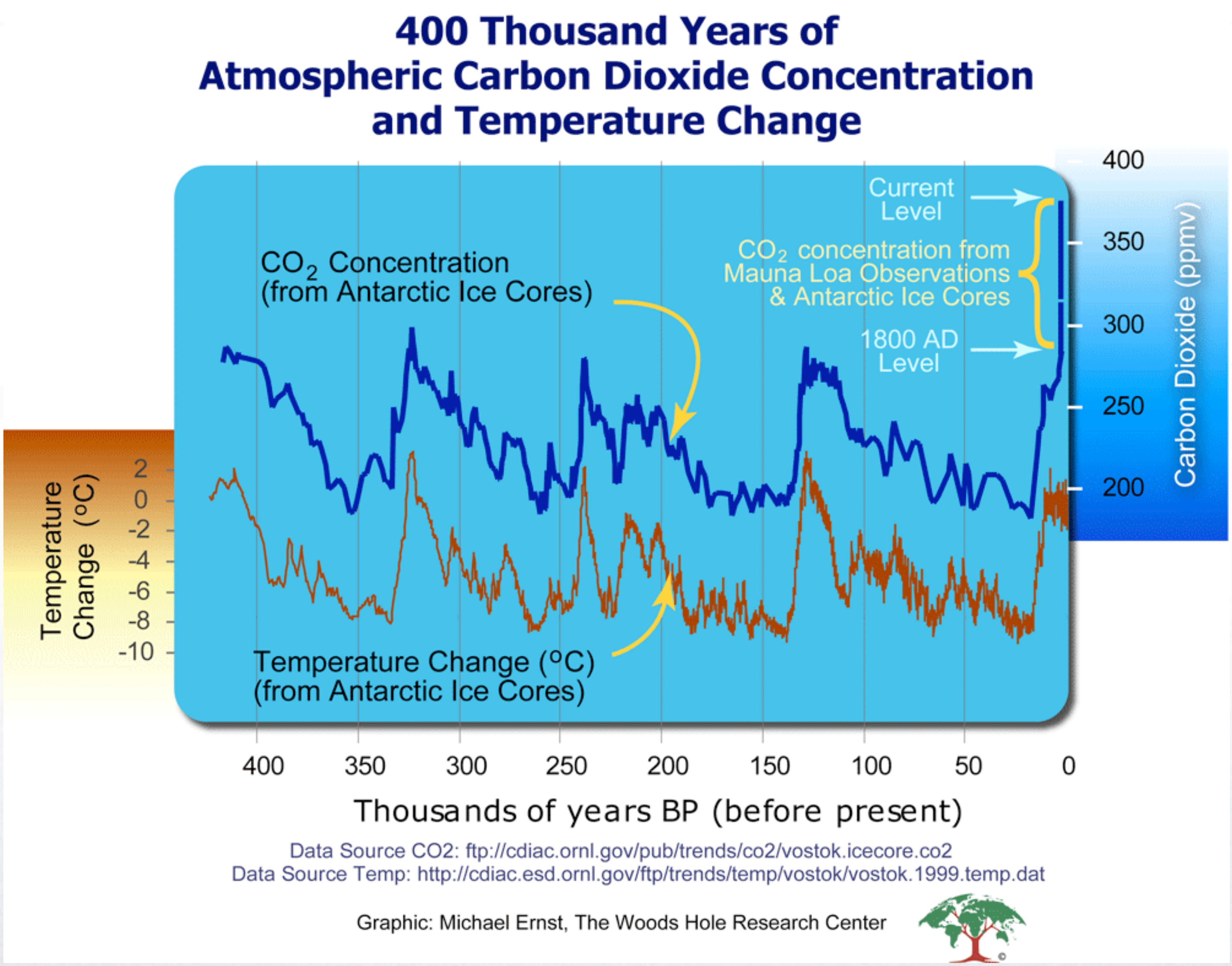
Changes in Antarctic temperature and ice volume during the last four glacial/interglacial cycles



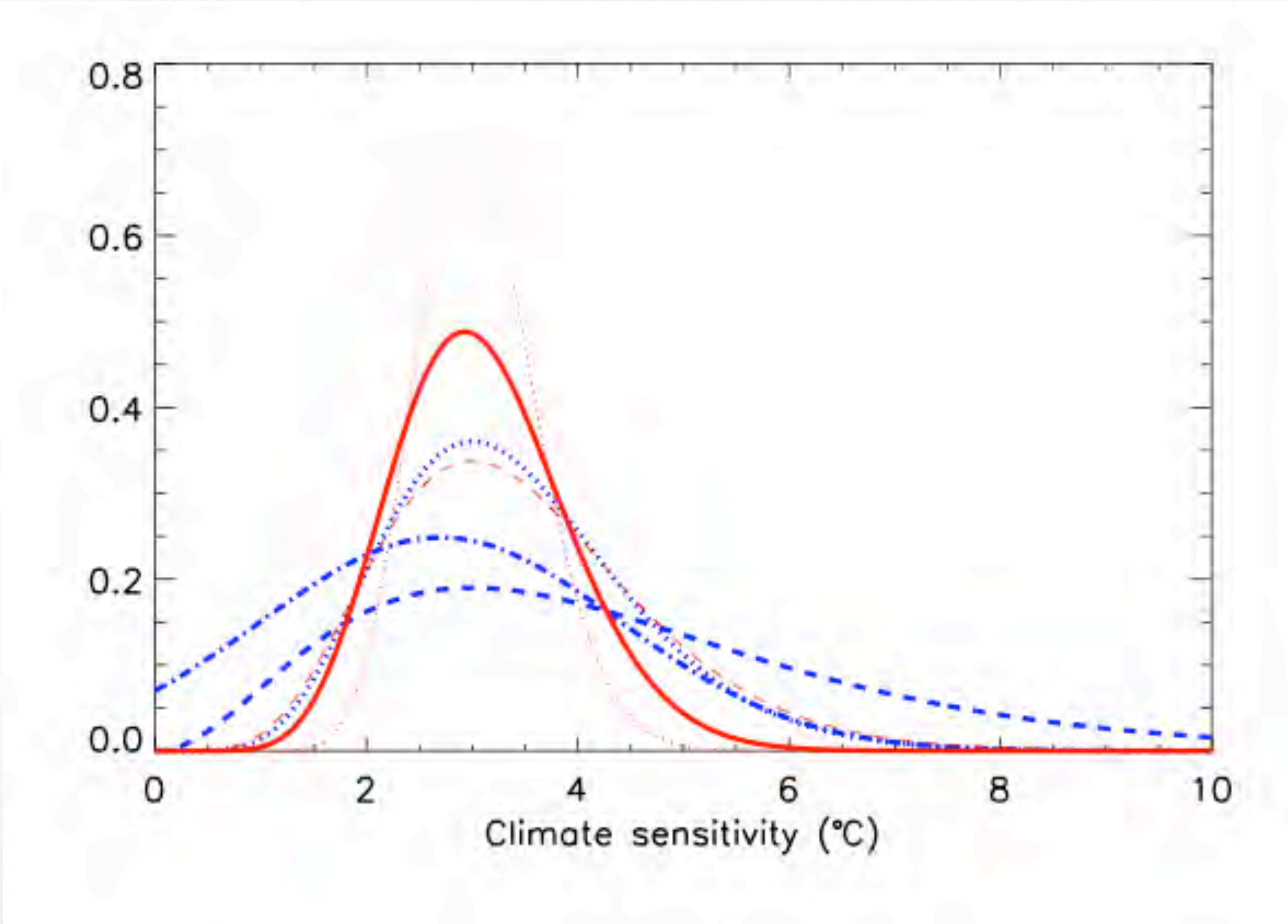
Long history of the ice age and changes in Antarctic climate over the last five million years.

Instability relates to advancing/retreating ice

IV: Tight Correlation; Lag/Lead Unclear



V: Sensitivity Is Well Constrained (*)

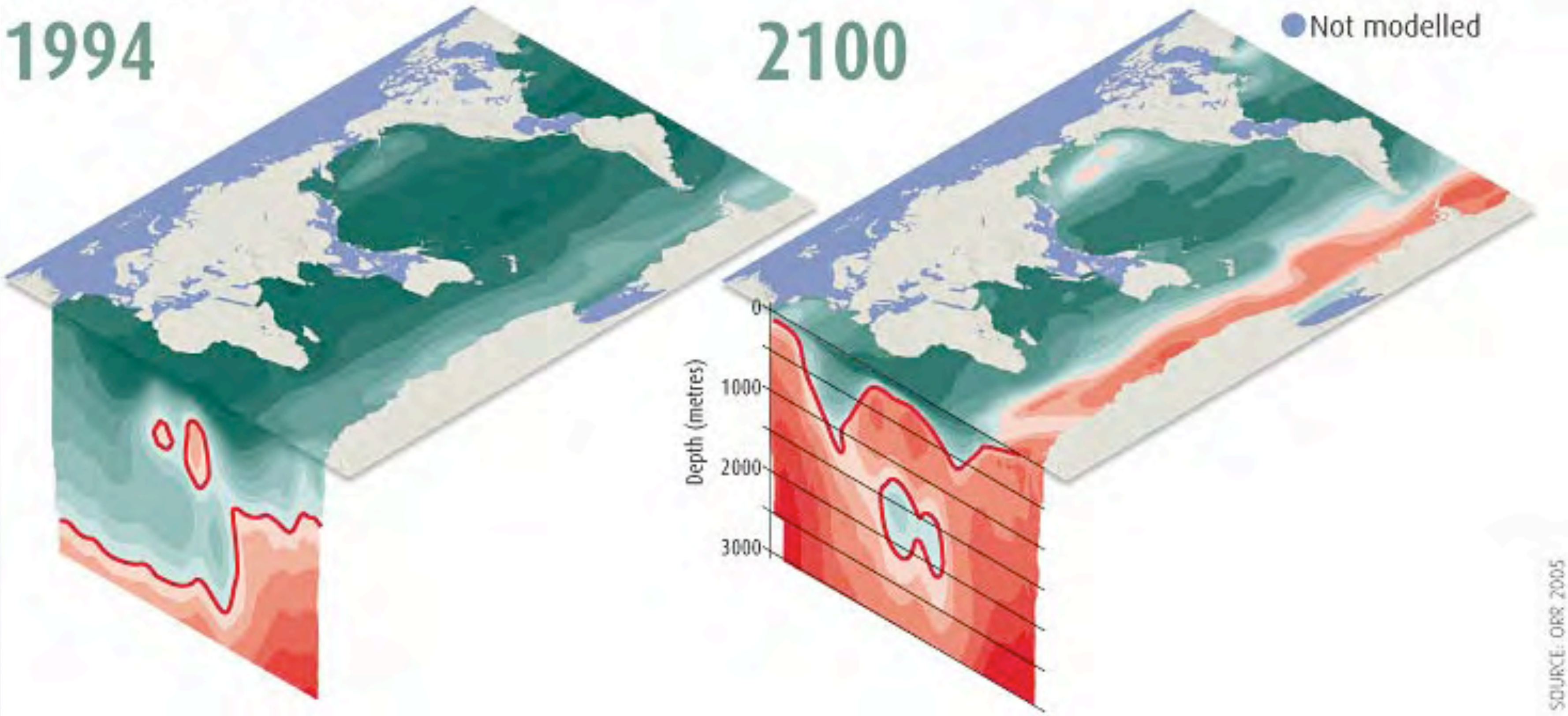


Bayesian analysis of observational data: Annan & Hargreaves

VI: Carbon Matters

SHELL HELL

Many creatures make their shells or skeletons from a form of calcium carbonate called aragonite. This is possible because, apart from the deepest waters, most seawater is supersaturated with carbonate ions (green areas). As CO_2 levels rise, the saturation horizon will move upwards and even some surface water will become undersaturated (red). Tropical corals thrive in water three or four times past *the saturation point (dark green)*



VII: Climate Matters

Civil Engineering
Agriculture
Hydrology
Ecosystems
Sea Level

VIII: Tipping Points

Ice Sheets
Arctic Sea Ice
Deforestation
Surface Ocean Dynamics
Deep Ocean Dynamics
Global Wind Patterns
Fossil Methane

mutually coupled
could make matters much worse
we don't know when

IX: Carbon is Forever

About 80% of C perturbation has 100 year half-life

Remaining 20% has 10K year half-life

Normal “pollutants” wash out or decay

Problem in this case, unlike most, is not emissions rates;
it’s ***cumulative*** emissions!

X: Our Intuitions Fail Us

We believe the problem is modest.

We believe we can wait for the problem to become more serious before acting.

We fail to understand that
the only sustainable emissions rate
is effectively zero.

We fail to understand that
our actions and inactions
only take effect decades in the future.

Political Style Thinking About Climate

Climate policy questions Type I:

- **is** inadvertent climate modification happening?
- if so, **is it severe enough** that we should intervene?
- are the models **right**?
- are the scientists influenced by money/fame?

Yes/no questions aimed at political goals.

Parallels political/legal debates, not scientific ones.
Seeks certainty where none may be available.
Promotes polemics, polarization.

Type I Approach is Indeterminate

Reasoning is connected to near-absolutist principles.

A) Precautionary principle: prove that you are doing no damage to the planet (emission presumed guilty)

B) Freedom principle: prove that the action is harmful (emission presumed innocent)

These are both plausible principles,
yet irreconcileable and impractical.

Battle of ideologies cannot be settled by reason.

Scientific Thinking About Climate

Climate policy questions Type II:

- **how sensitive** is the climate to human activity?
- **what level** of climate change is excessive?
- **what amount** of atmosphere change is tolerable?

Answers are quantitative and probabilistic.
Embraces and propagates uncertainties, rather than shutting conversation down.
Allows systematic investigation, compromise.
Cybernetic; integrates models with decisions.

The Climate Sciences

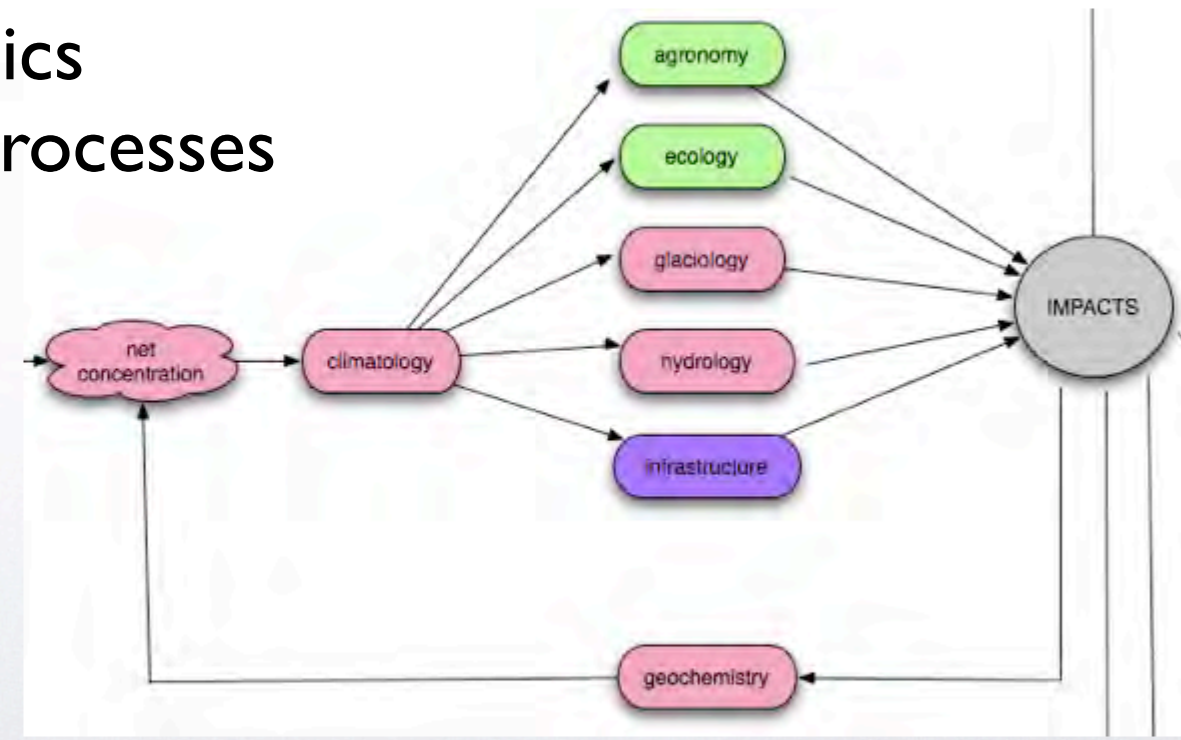
What are the climate sciences?
What is the role of computation?

The Climate Sciences

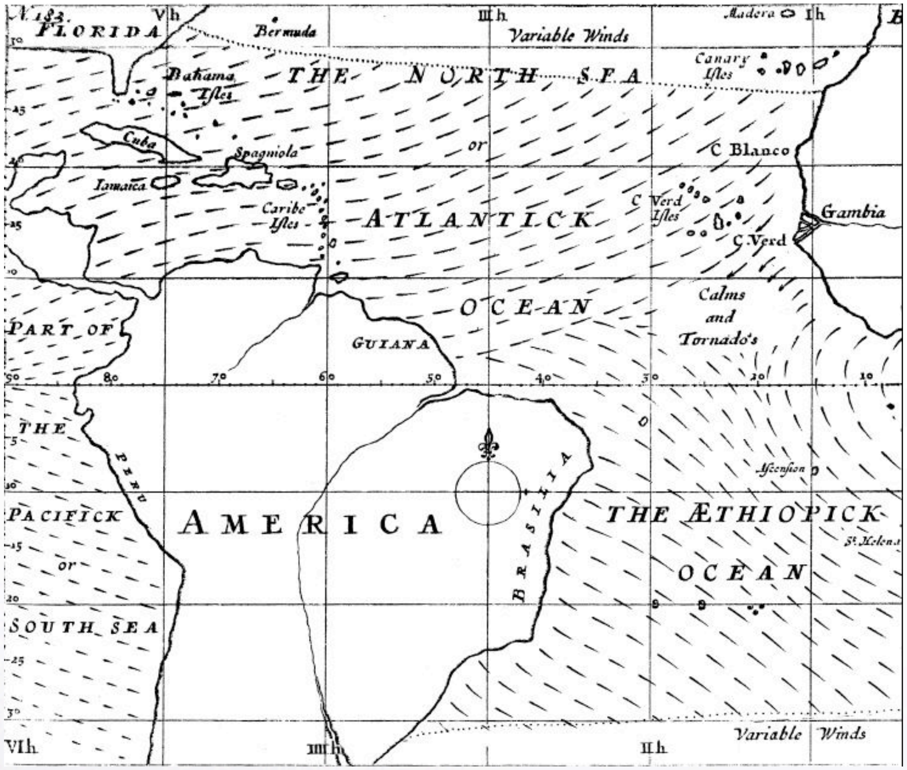
Climatology =

1) Meteorology
2) Oceanography
3) Sea Ice Dynamics
4) Land Surface Processes

Client Disciplines:



Roots of Meteorology



1725: E. Halley of comet fame maps the general circulation.

1735: G. Hadley presents mechanism for trade winds.

Meteorology becomes a branch of physics.

Slow progress in 18th c.

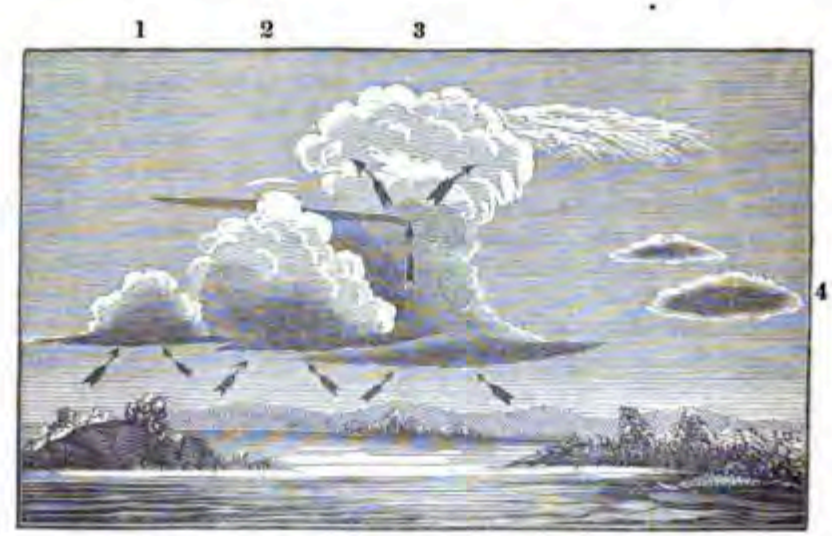
19th Century Yanks vs Brits

Energy of water phase changes discovered by Dalton, ca. 1800.

American James Espy figures out convective clouds.

British had noted large spiral structures.

Mutual mockery, but both were right!



at the top, assuming, successively, the appearances of 1, 2, 3, generally called cumuli : or, if the upmoving current should be driven out of its perpendicular motion by an upper current of air, the clouds which might then form would be ragged and irregular, called broken cumuli, as 4. These will always be higher than the base of cumuli, but much lower than cirrus. While the cloud continues to form and swell up above, its base will remain on the same level, for the air below the base has to rise to the same height before it becomes cold enough, by diminished pressure, to begin to condense its vapor into water ; this will cause the base to be flat, even after the cloud has acquired great perpendicular height, and assumed the form of a sugar loaf. Other clouds, also, for many miles around, formed by other ascending columns, will assume similar appearances, and will moreover have their bases

Meteorology as Physics

W. Bjerknes around 1900 set out to create a complete mathematical theory of meteorology.

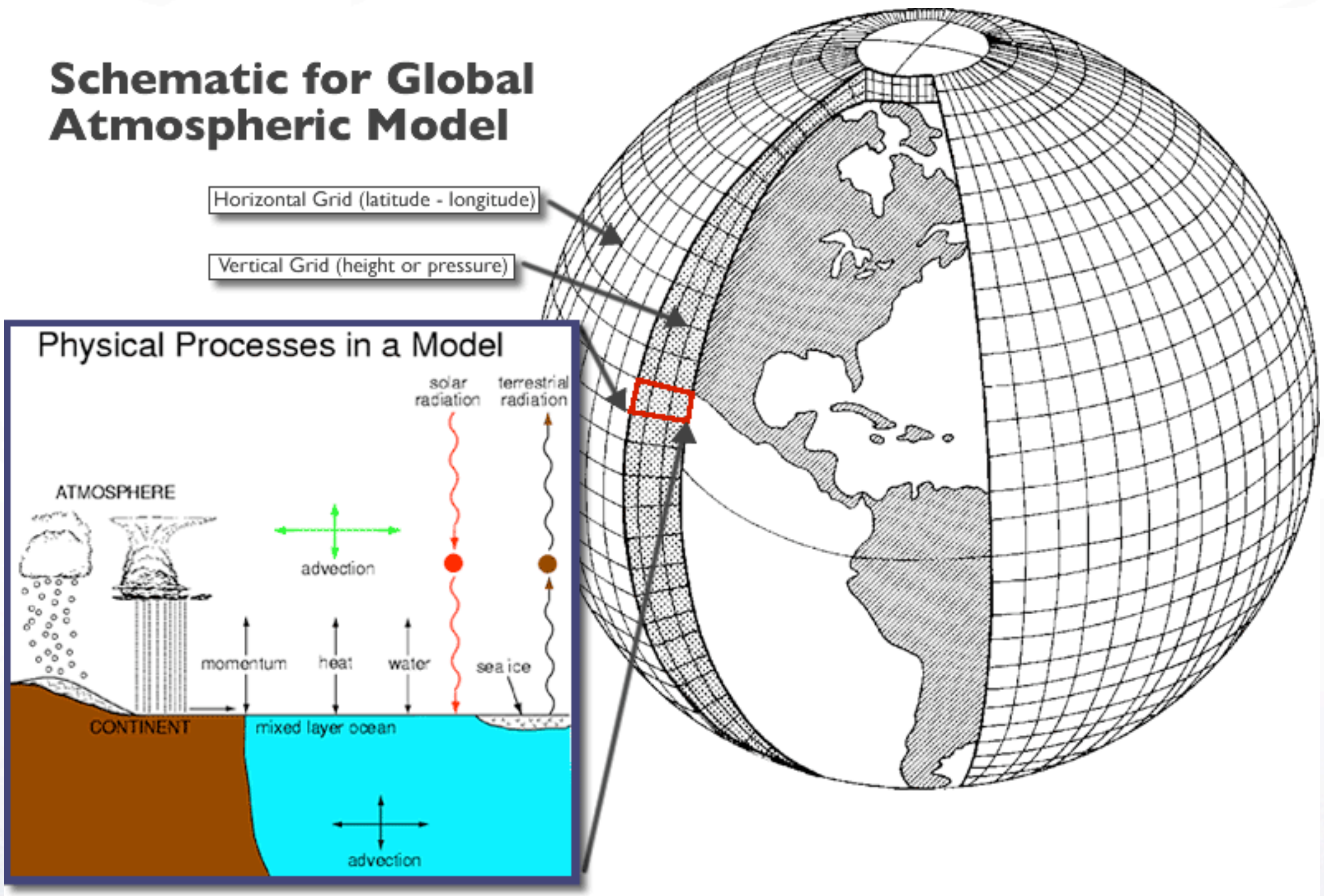
Developed a set of seven equations still used today.

Faced extreme difficulty with calculations, came up with mechanical contraptions to draw maps based on maps.

Practical calculations had to await the digital computer.

One of the first computer applications (von Neumann involved, published 1950) was a weather prediction.

How An Atmosphere Model Works



Repeatedly apply the 7 equations in each box

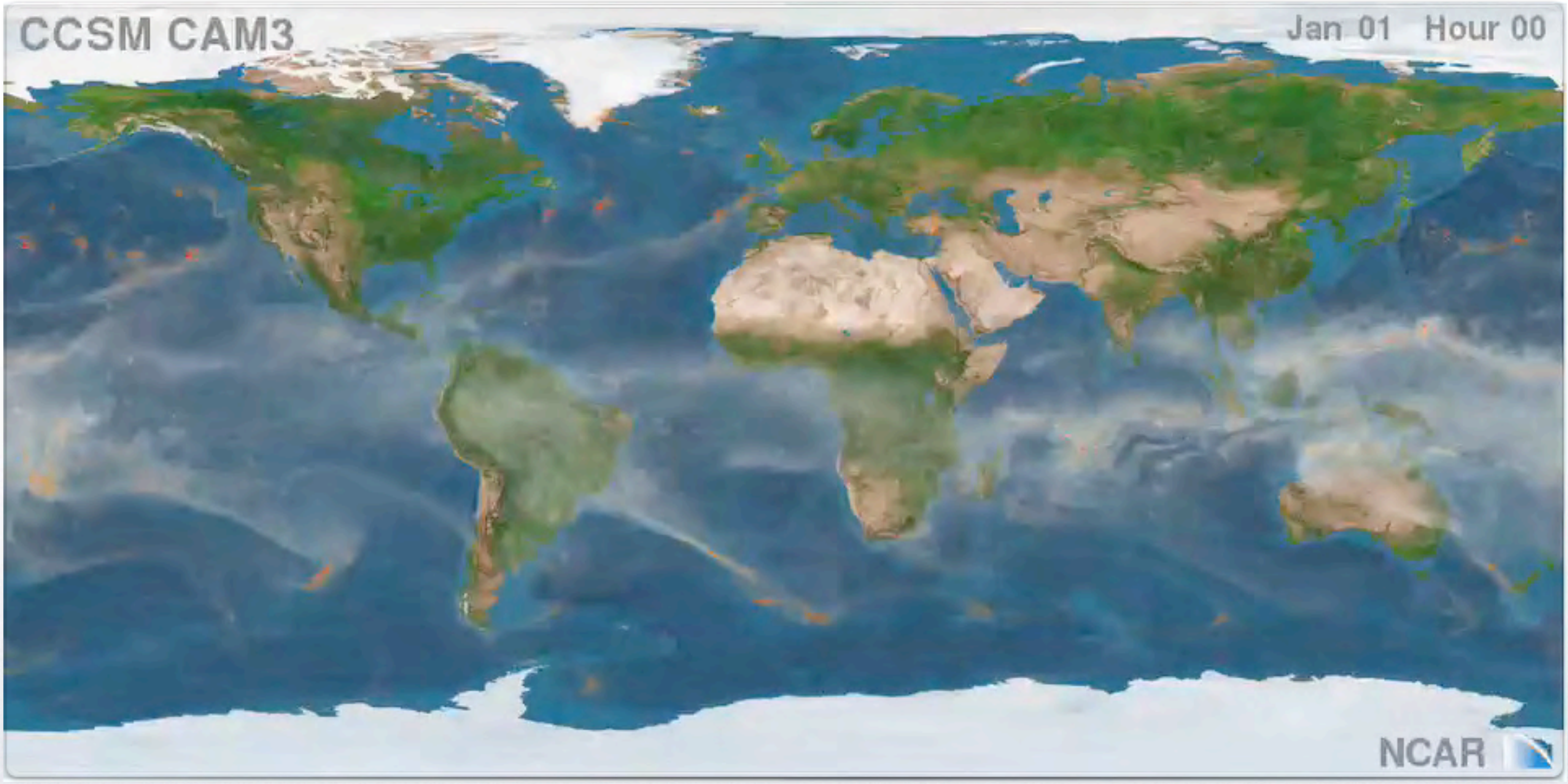
From Weather to Climate

Idea to run a weather model for a long time is natural.

Always drifts from reality eventually, but it is better if it has **stable statistics**, its own “climate”, and better still it its “climate” is realistic. Oceanography followed a similar trajectory.

Culminated in the early 1990s with the CGCM. Extremely many arithmetic operations: 10^18 FlOps.

A Modern Atmospheric Model



How Models are Used

Z. Liu of Wisconsin hypothesized that PDO was a result of baroclinic Rossby waves in N Pacific*
(* think A is caused by B)

Opposed to conventional wisdom (A caused by C)

In two coupled models with PDO signal (A), Liu suppressed baroclinic Rossby waves (B)

PDO signal (A) went away = support for hypothesis

Impact on policy: none

Not About "Global Warming"

Note that this science is not about anthropogenic climate change or "global warming".

Climatology has intrinsic intellectual interest, and as a prototype problem in multiphysics.

Concern about greenhouse gases emerged from a different branch of climate science, roots back to 1840s.

Climate models need to include that physics, and so serve both to corroborate it and examine impacts.

Climatology on Center Stage

Climatologists don't like center stage and aren't good at it.

Climatologists traditionally interact with agriculture, aviation and military sectors. Conservative inclinations. Had no choice but to report the greenhouse problem.

Was known since 1950s, warned about since 1970s.

Became controversial after J. Hansen told Congress in 1988 that anthropogenic greenhouse warming "had started".

Good News

Models are "tuned" to reproduce current conditions.

Do these methods apply outside modern experience?

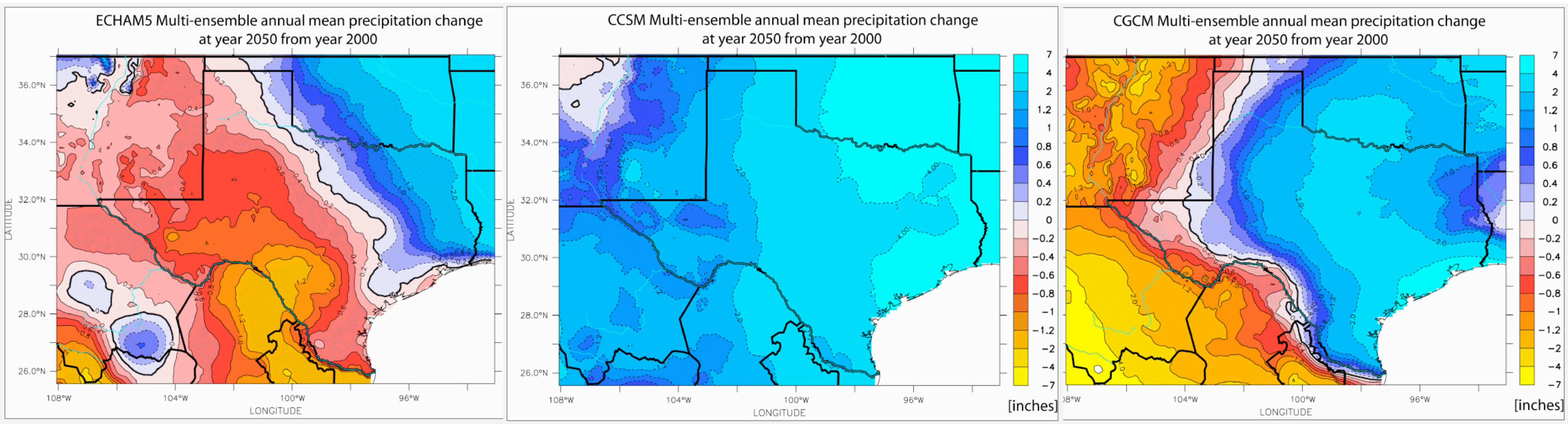
Yes, we can **test directly against the deep past.**

We can **apply the principles to other planets.**

Get reassuringly good match in most cases.

Bad News

Models disagree on smaller scales.
especially on precipitation.
Texas precipitation is especially uncertain!



Precipitation 2050 from three different model groups

Summary

Models disagree on smaller scales esp on precipitation.

Qualitatively a success but **intended use is within field**

Use informing policy, client disciplines should be considered qualitative at best and was not part of original design.

Can regional prognostics succeed? Unknown.
Have they? No. Very difficult (third order) problem.

Great resistance to new code base.
Codes are not huge but are very tightly coupled.

Other Climate-Related Sciences

Climate models, despite reputation, are successful
Rise to the level of **simulation**, like aeronautics
Can learn substantive things about real system
Can be and often are overused and misused

compare:

Geochemical models?
Ecological models?
Hydrological models? (note need for ontologies)

Economic models???

Obvious Roles for Computer Science

Ontologies (heterogeneous data)

Model description languages

Model transformation schemes:
- propagating uncertainties
- automatic sensitivities
- parameter inversions

Managing large ensembles (what I'd do with a petaflop)

Managing large datasets

Can CS Help with the Underlying Problem?

Climatology is the merger of 2 disciplines with input from two others

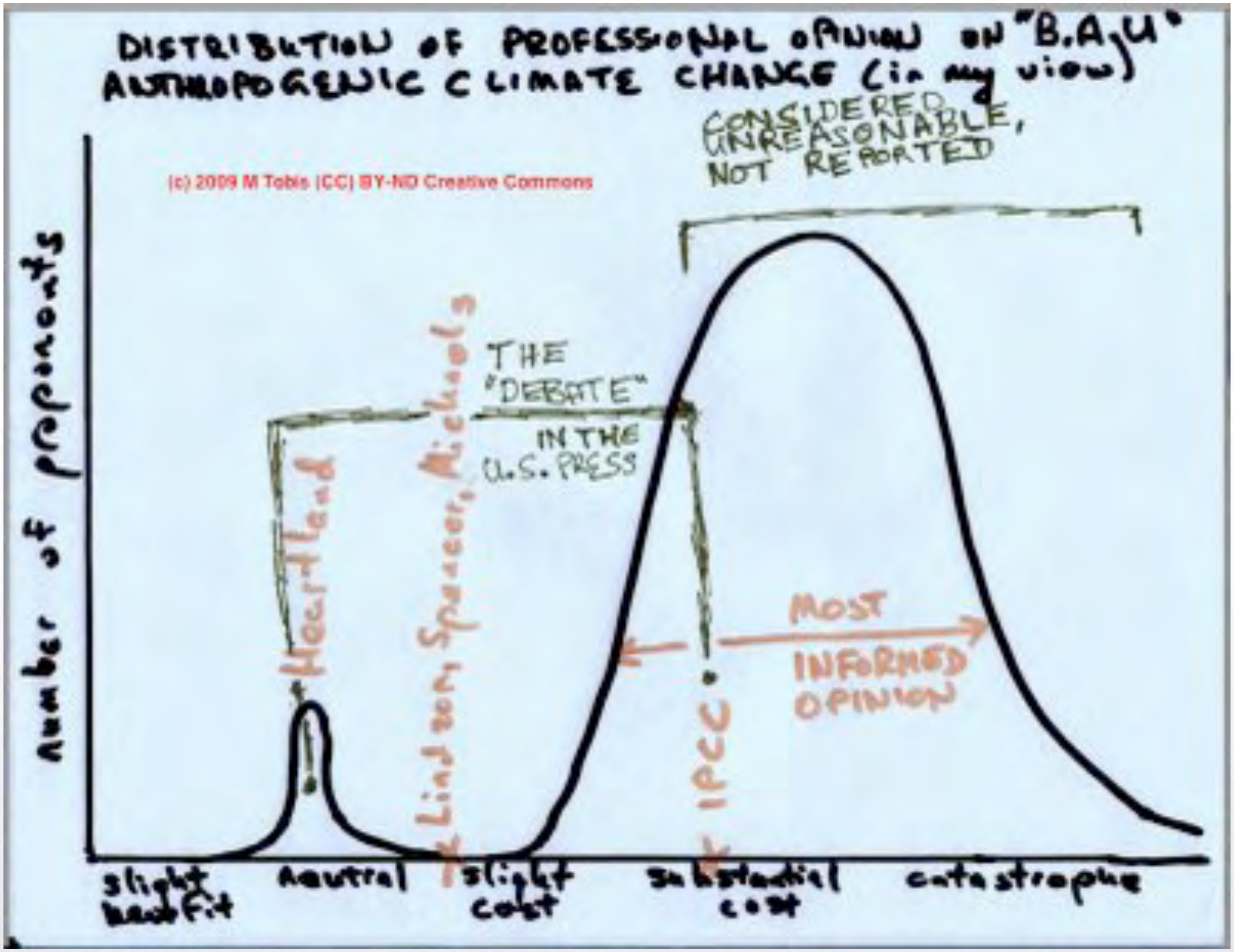
Much interest in adding three more: atmospheric chemistry, glaciology, geochemistry

The actual policy problem involves many other complex areas of human activity

Practical SWE problem with many stakeholders and views? Could modeling the problem space help?

How the Debate "Works"

The Debate is Badly Skewed



Pick a Number between 390 and 10000

Pick a global target maximum, then see if policy needed.

We are currently at 390. (Started at 280, going up 1%/yr.)

450? What activists are pulling for. Social, climate risks balanced?

600? Viability of ocean life threatened. (Yes, even though it has been over 600 in the past. Equilibration is slow.) Still start soon.

1000? "Dramatically different planet", huge climate impacts likely. Constitutes a very strong bet against climatology, marine biology.

10000? Direct physiological stress. Far off though.

How the Conversation Should Work

Climatology is not the weak link in climate policy.

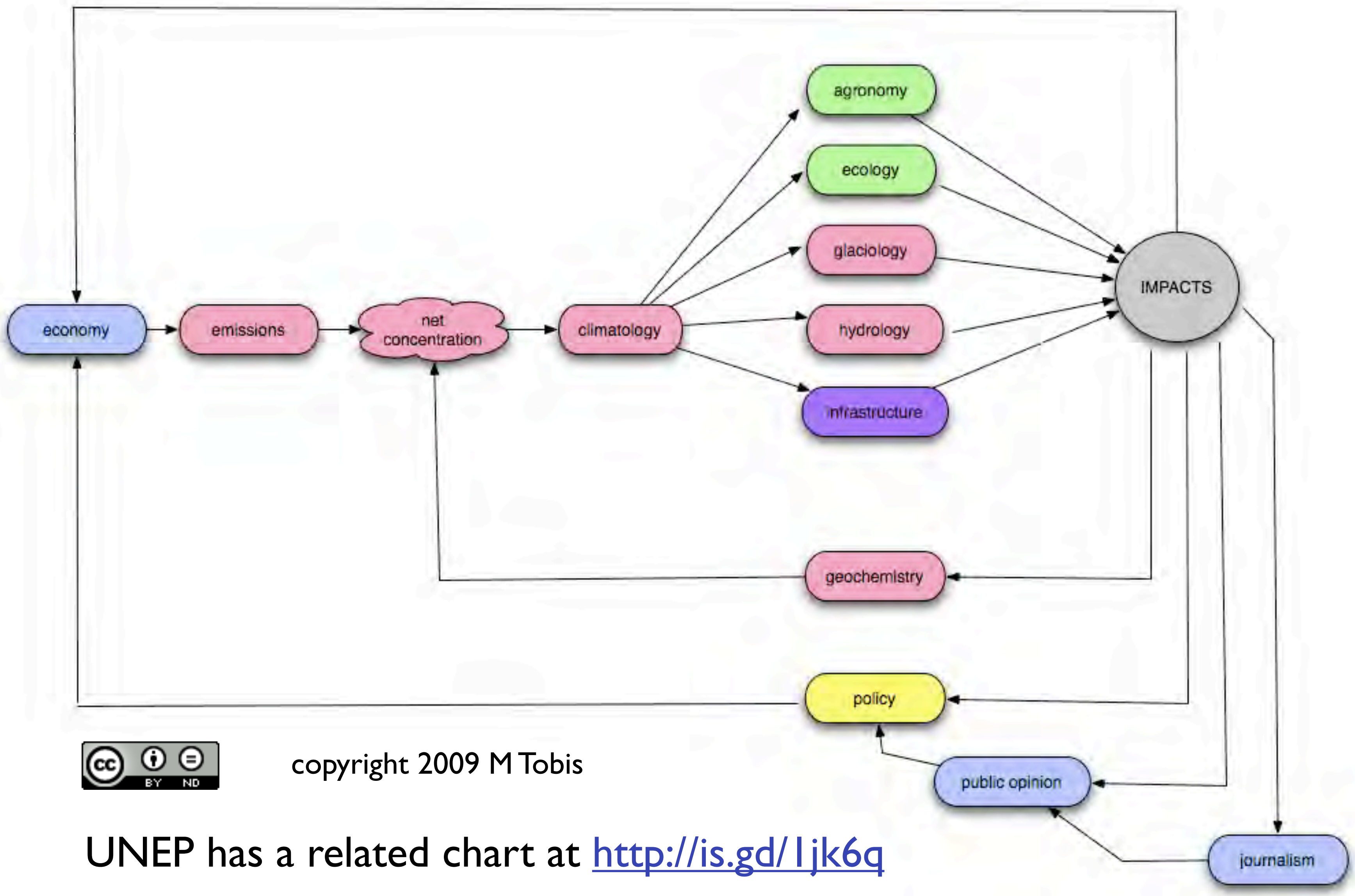
Sensible discussion should revolve around numerical targets not yes/no or "true/false" propositions.

450 appears to be the lowest economically feasible peak.

People for 350 need to specify removal mechanisms.
    Leading candidate "CCS" unpopular in some circles.

350 people are right about this: Drop the "yes"/"no".
Pick and defend a number.

The Situation is Very Complex



UNEP has a related chart at http://is.gd/1jk6q

That's only one slice of the problem!

Population
Energy
Food
Water
Peace and Security
Freedom and Dignity
Nature
Climate

These once were quite separate!
No choice but to manage all of them!

How to Cope?

Scientific input into decision-making needed.

Transparency and effective flow of information between science and society becomes crucial.

But there is deliberate obfuscation!

Can computer science help?

Computer Mediated Education

Both the CO_2 problem and the fossil fuel problem are stock-and-flow problems that can be animated. A huge class of earth science problems follows.

Build a construction toolkit for undergrad-level simulations that can be displayed and manipulated on the web. Attend to usability and design.

Tools to let people put rigorous thoughts online.

Distributed Reputation Systems

Web 2.0 to the rescue?

A fundamental challenge for social media:
reputation systems that actually work!

As scientists we believe in a real hierarchy of knowledge

The hierarchies are invisible across disciplinary boundaries

How can we know who is making sense?

Not just ontology but epistemology!

Science as MMPORPG

Combine reputation systems and educational tools.

Assign real prizes to solutions of real problems.

Build a community of reality rather than of fantasy.

Finale

CONCLUSIONS

Many roles for computation in sustainability science:

Numerical methods
Languages and compilers
Data ontologies
Ensemble controllers and inversion strategies

but also:

Social media
Reputation systems
Visualization systems

Exhortation

We are as gods, and we had damned well better get good at it.

-Stewart Brand