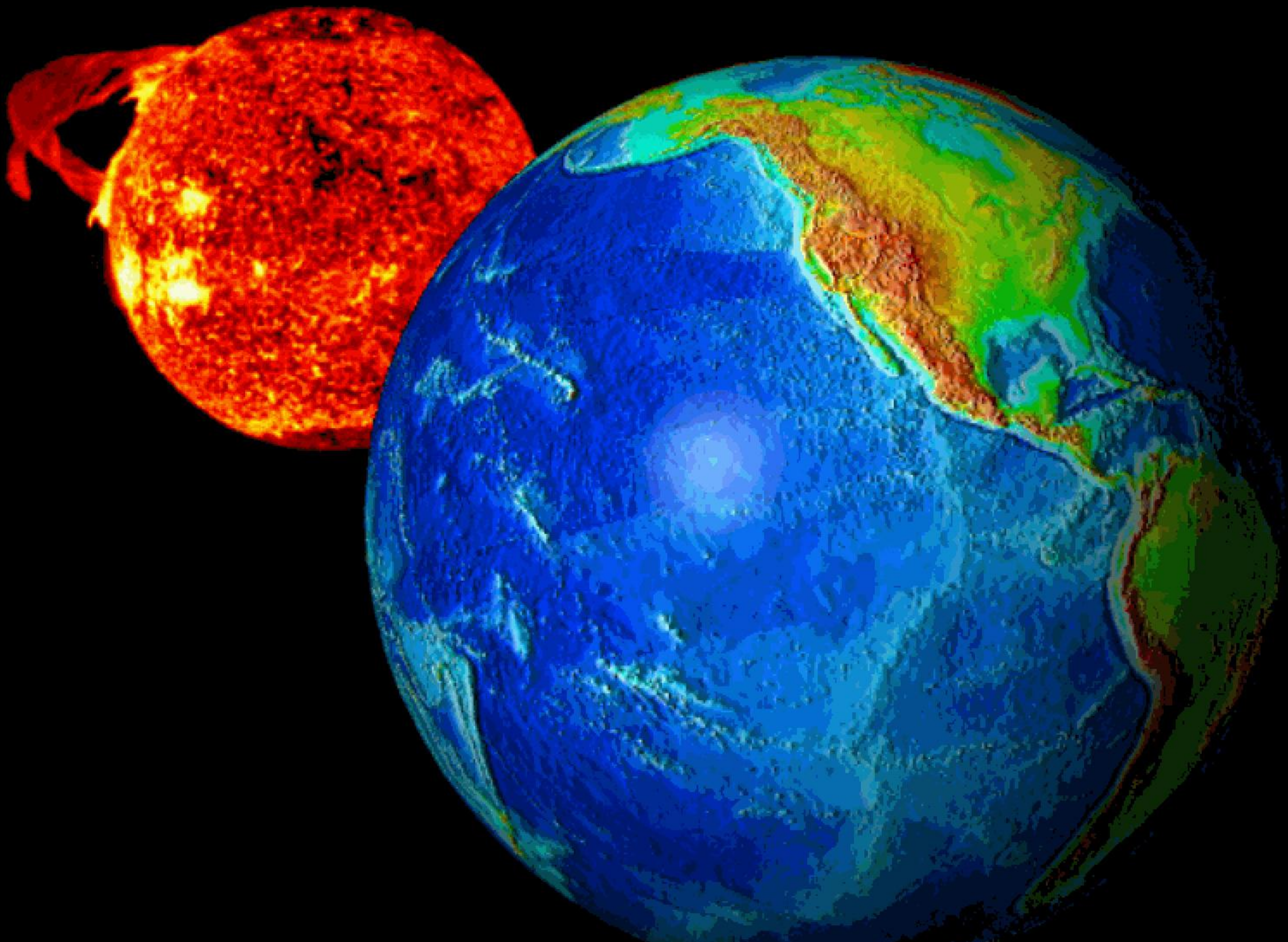
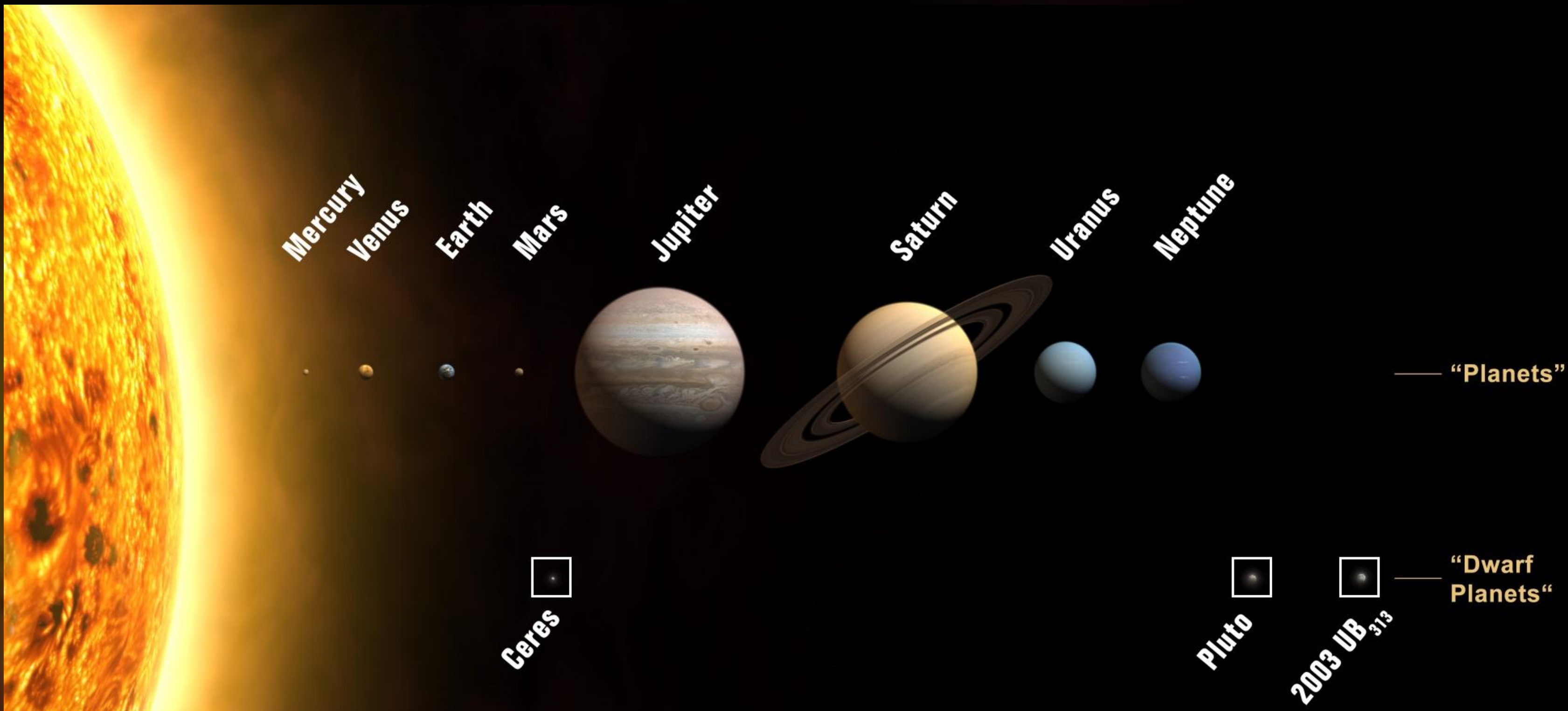


Climate Models of Earth and Planets



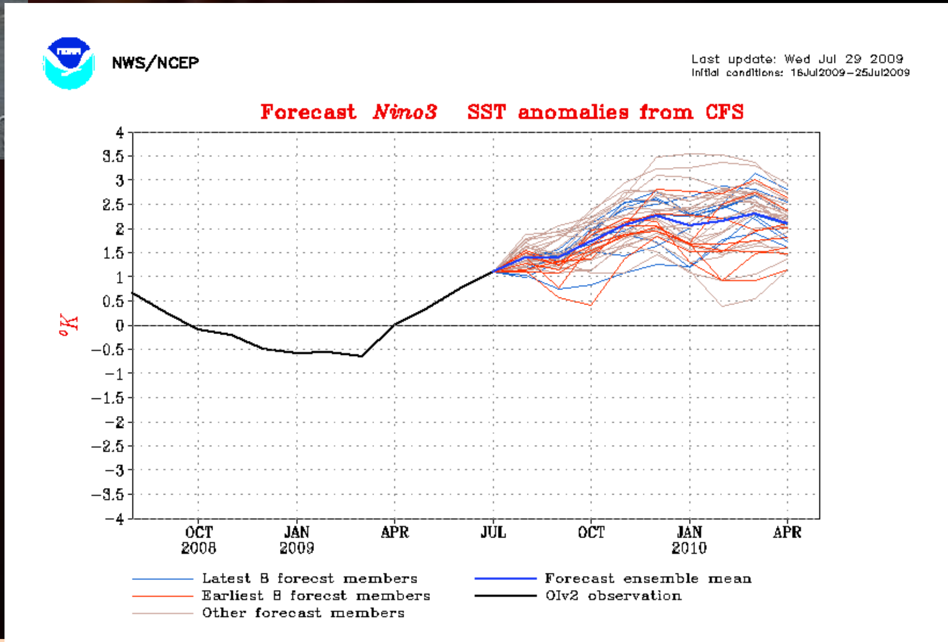
Caspar M. Ammann

National Center for Atmospheric Research, Climate and Global Dynamics Division

ammann@ucar.edu

“Climate Models” in the news this week:

First Cargo-ship scheduled to cross the Arctic Ocean to save 8000 miles…

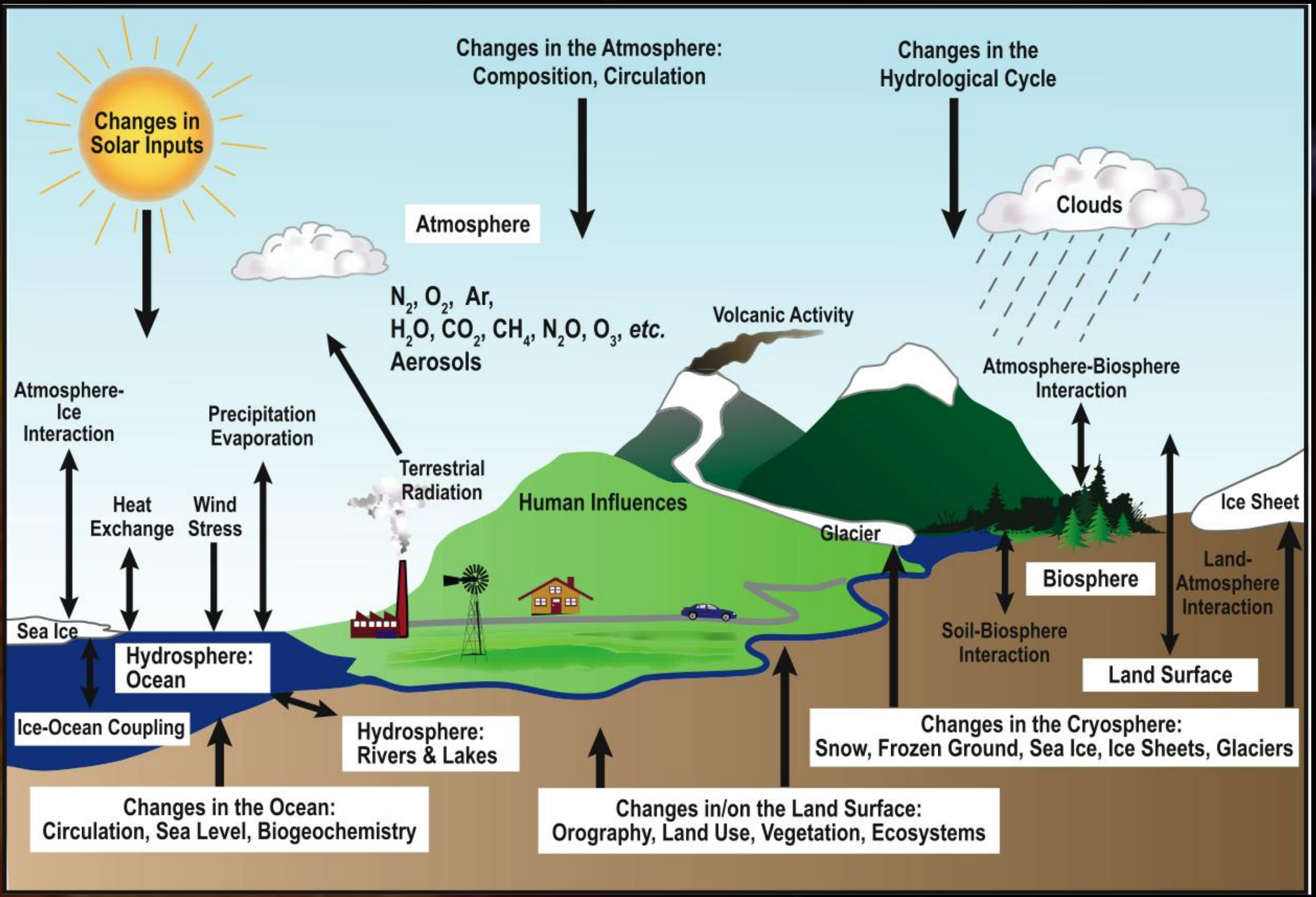


Forecast of development of El Nino by NHem Winter

Overview

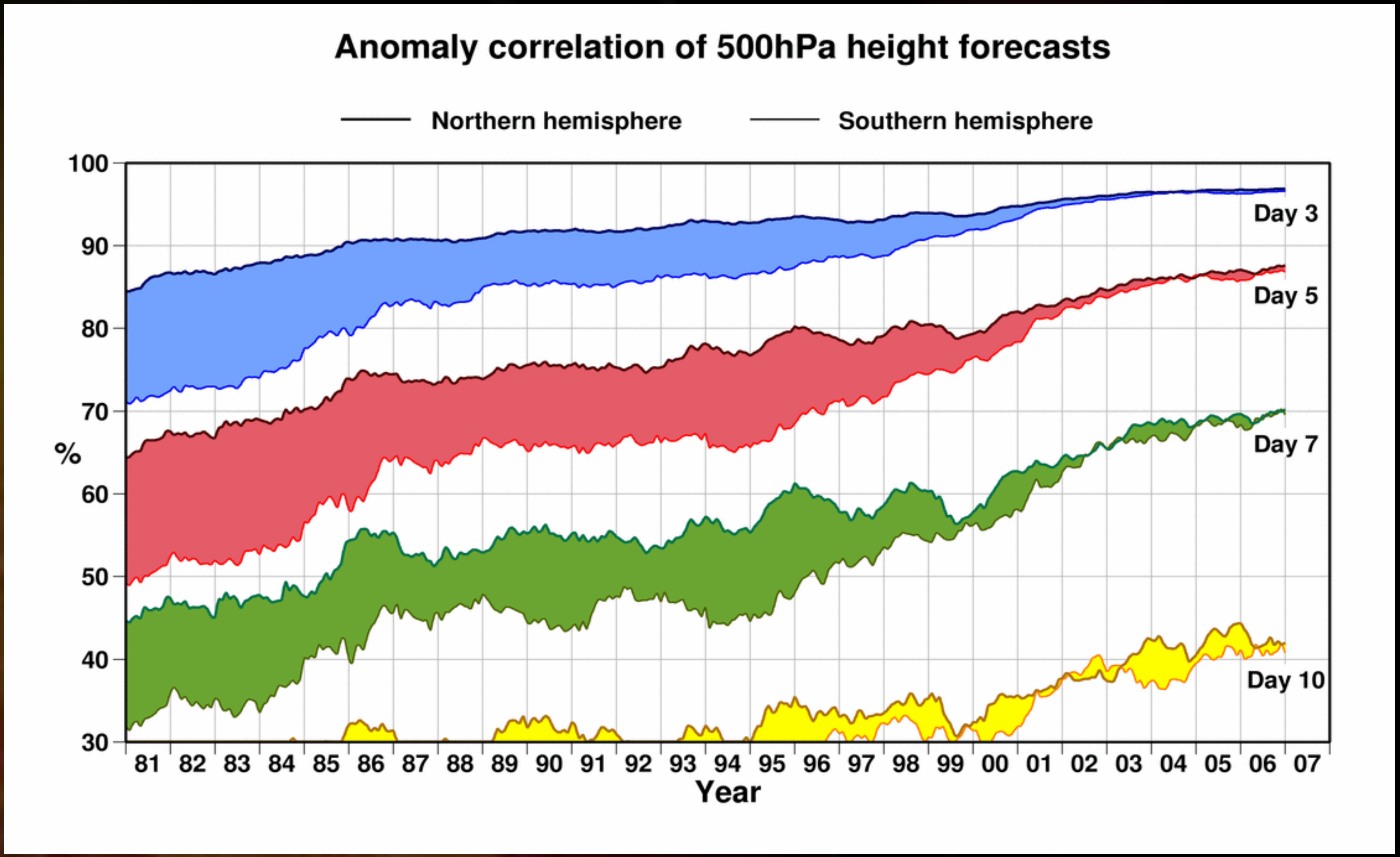
- Introduction Climate System
  - Climate : A forced, damped oscillator
- Range of Climate Models
  - Key physical laws that govern climate
  - Feedbacks
  - General Circulation Models, comprehensive Earth System Models
- Current State of the Art
  - Climate Change
  - Solar Variability and Climate Models
- Summary

Climate : a System with Processes



Source: IPCC

Limits to Weather / Storm forecast capability



Source: Anthes

Climate as a forced, damped oscillator system

Responds to external forcing, but has significant variability: therefore Chance for Predictability

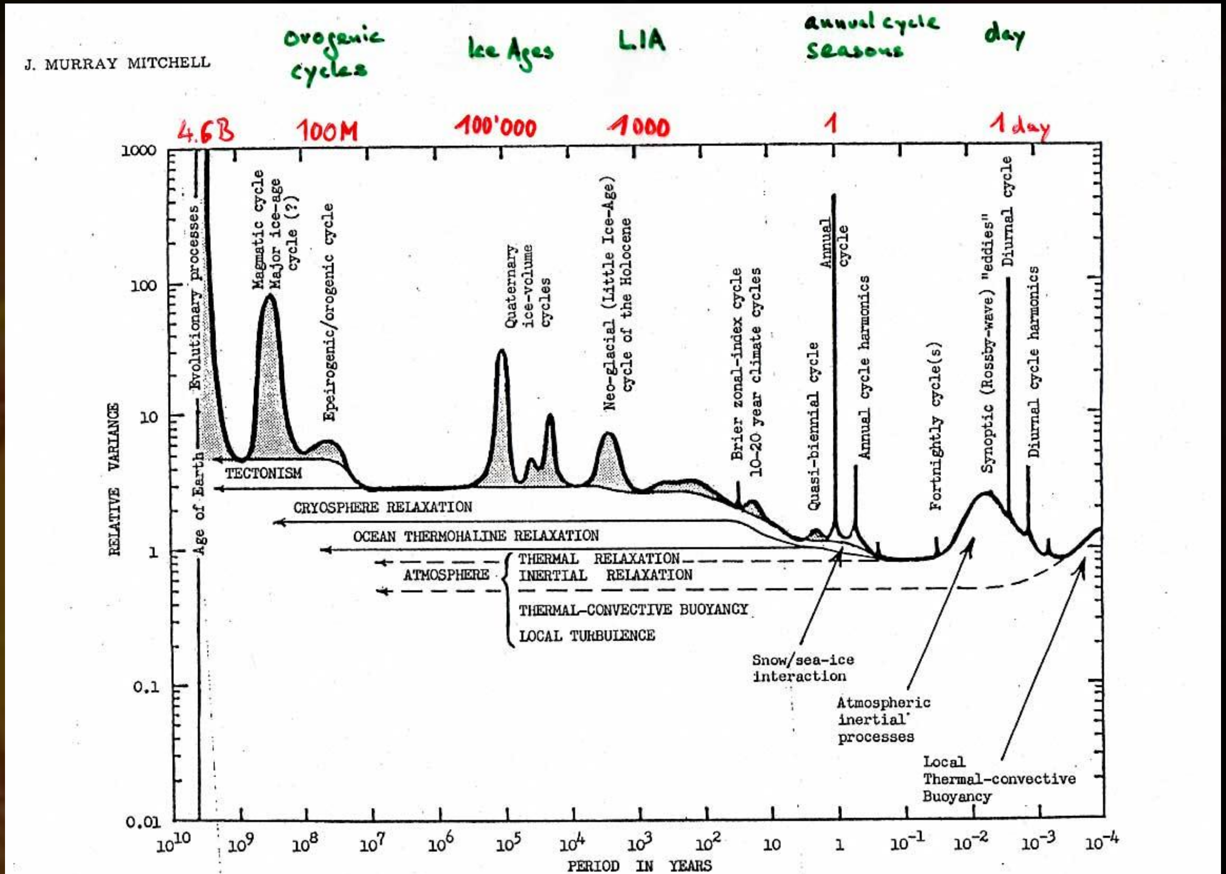


FIG. 2. The spectrum of Fig. 1 annotated to indicate the estimated contributions to total variance from various internal stochastic processes (below curve). Features of the spectrum which may or may not also be accounted for by internal stochastic processes are identified phenomenologically (above curve). The excess variance associated with each of these features is emphasized by stippling.

Source: Mitchell 1976

Opportunities from using Models

- Study isolated processes
- Sensitivity of system to feedbacks (interactions)
- First principle basis allows for application independent of time: Past-present and future of conditions

  - Past configurations
  - Different “planets”, time, configuration, water planet, dry plant, synchronous rotation
  - Sources for Abrupt climate change

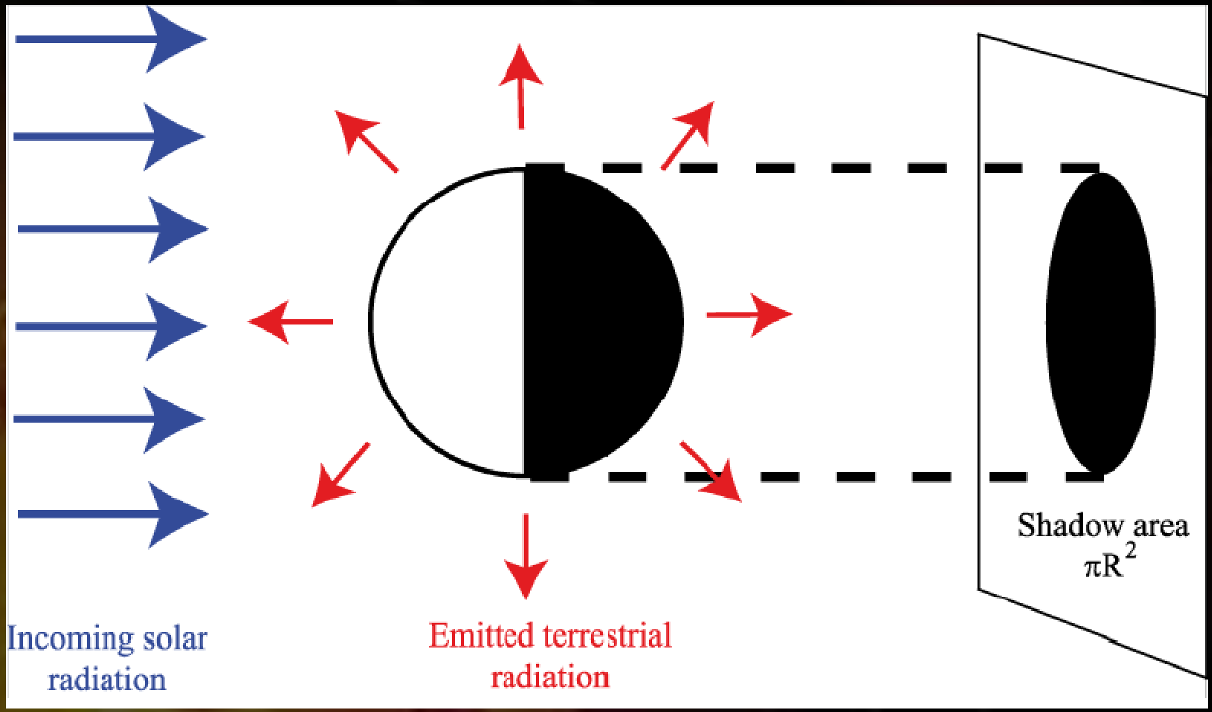
Range of Climate Models

selective, but detailed information can be found in (e.g.):

McGuffie K. and A. Henderson-Sellers:
A Climate Modelling Primer (3rd Edition)

Washington W. and C.L. Parkinson: An Introduction to Three-Dimensional Climate Modeling

Planetary Energy Balance



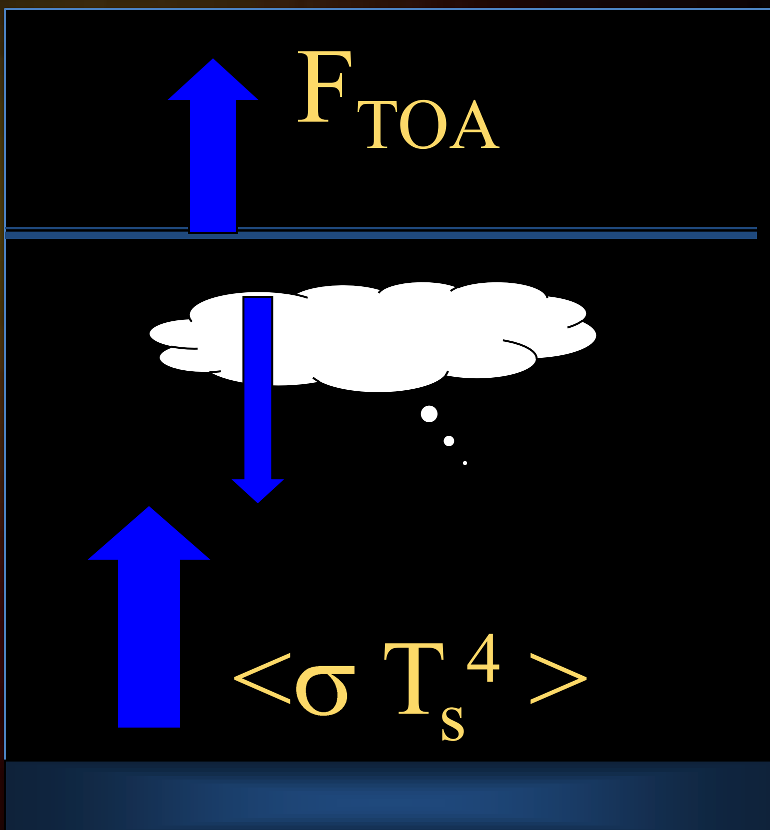
Balance of Incoming Solar vs Outgoing Longwave Radiation:

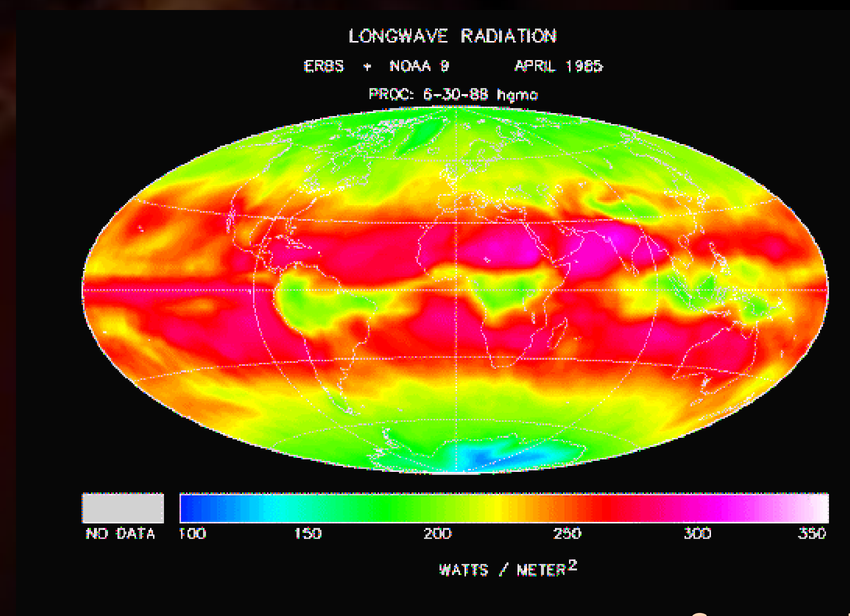
$\frac{1}{4}(1-\alpha) S = \sigma T^4$: T = 255K (-18C), but observed ~287K

The Greenhouse Effect

Greenhouse Effect (Energy)

$$G = \langle \sigma T_s^4 \rangle - F_{TOA} \ Wm^{-2}$$





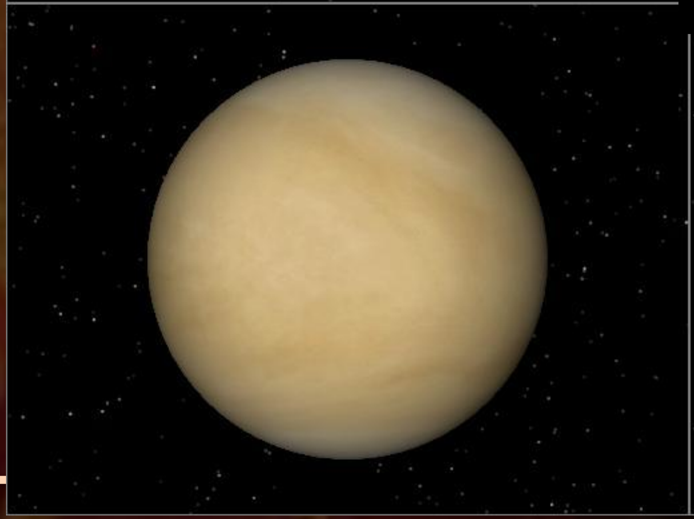
Source: Kiehl

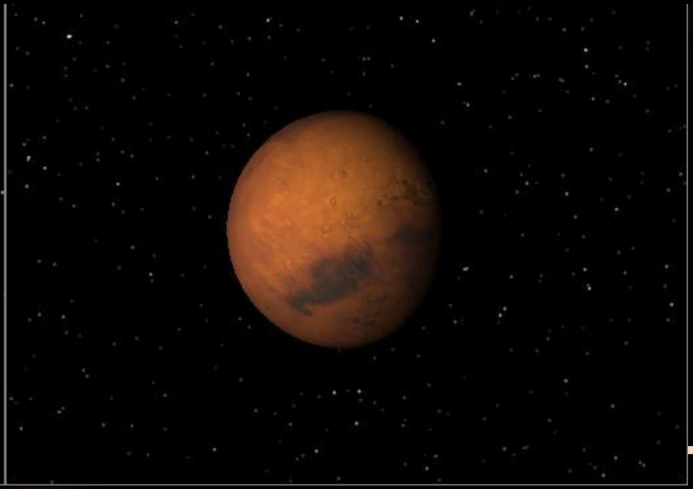
Energy Balance in Planetary Comparison

Venus Surface T= 735K
CO_2: 96.5%, WaterVapor: 0.002%

Earth Surface T= 287K
Co_2: 0.039%, WaterVapor ~1%

Mars Surface T= 227K
CO_2: 95.7%, WaterVapor: 0.03%



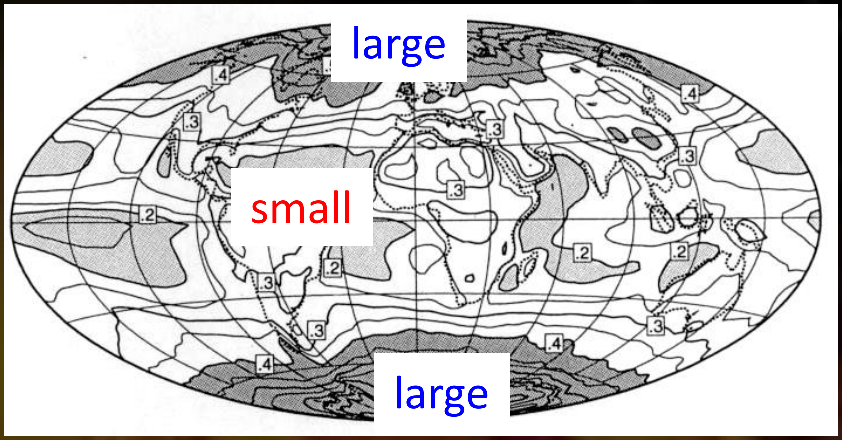


Energy Balance in Planetary Comparison

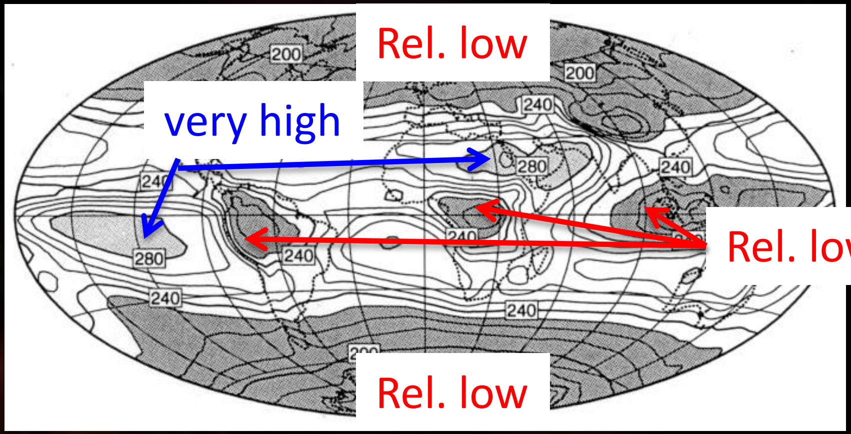
Venus	Surface T= 735K, albedo= 0.75
	CO_2: 96.5%, WaterVapor: 0.002%
	Atmosphere: 0.6-1 hPa
Earth	Surface T= 287K, albedo= 0.3
	Co_2: 0.039%, WaterVapor ~1%
	Atmosphere: 1013 hPa
Mars	Surface T= 227K, albedo= 0.25
	CO_2: 95.7%, WaterVapor: 0.03%
	Atmosphere: 93,000 hPa

Energy Balance Across Earth: Feedbacks!

Albedo

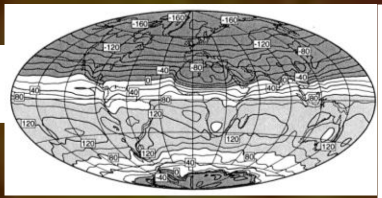


Outgoing LW

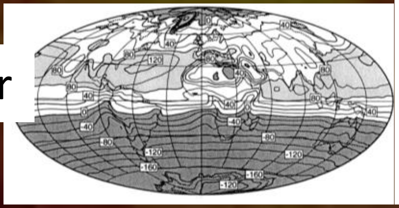


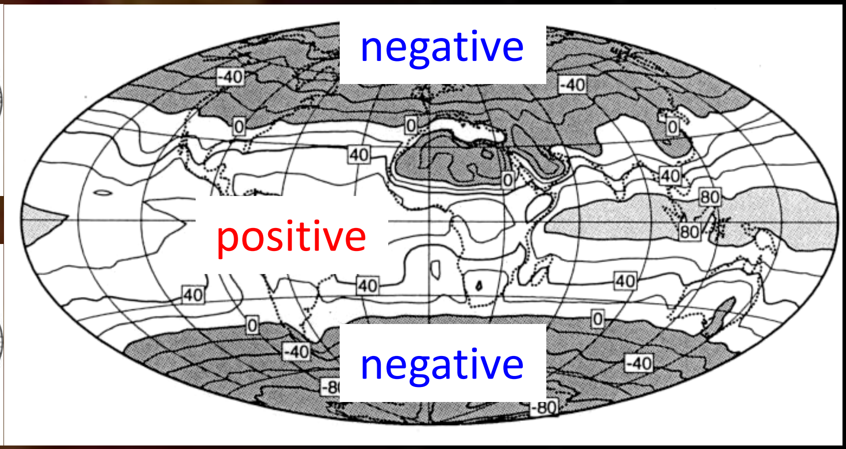
Net TOA

N-Winter

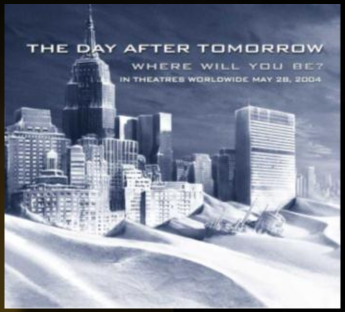


N-Summer

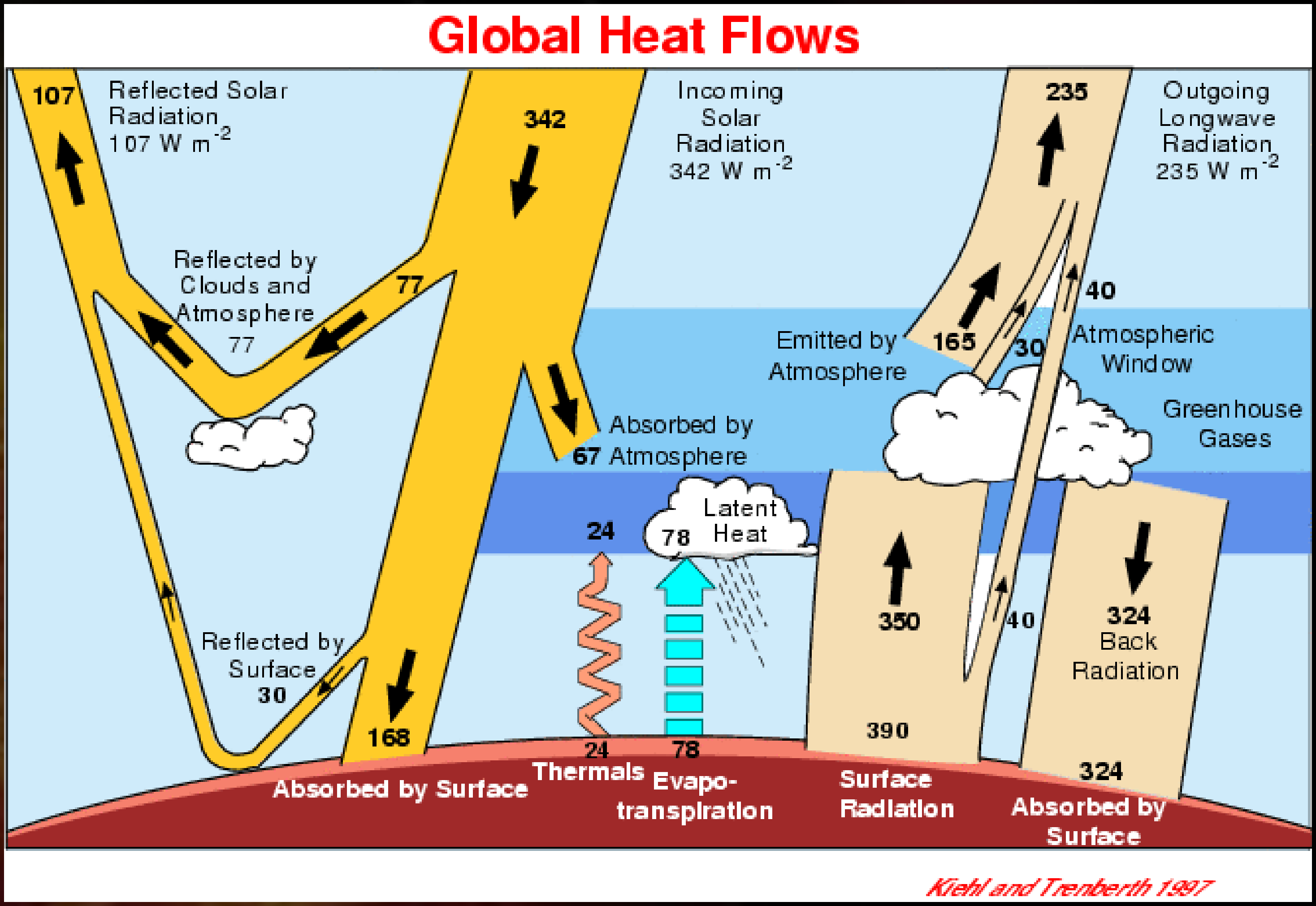




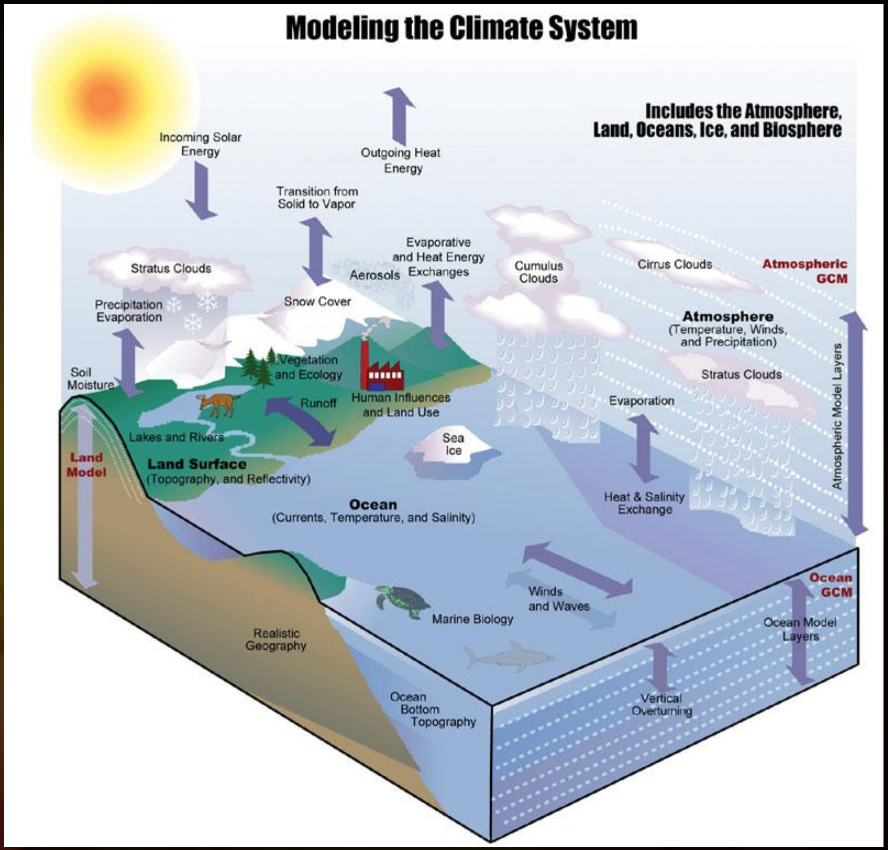
Arctic Today: Negative or Positive Feedback?

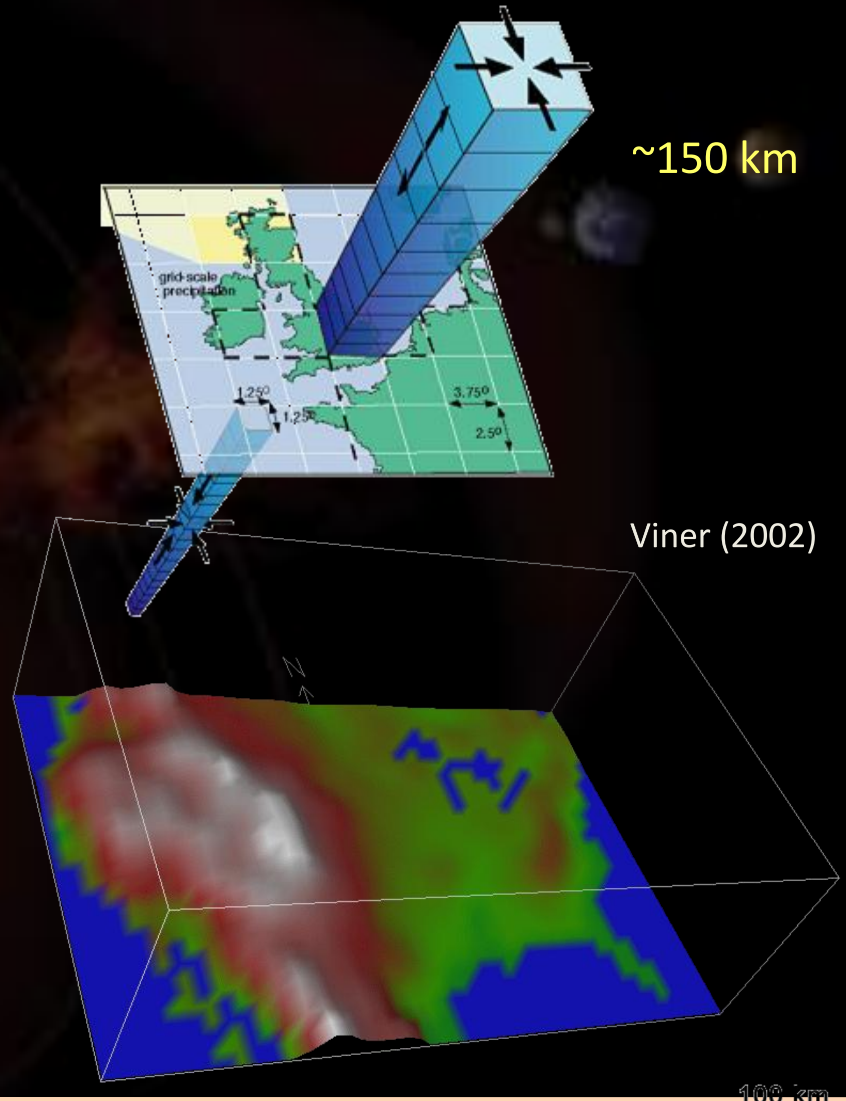


Dynamical Atmosphere with Complex Feedbacks



Climate and Earth System Models



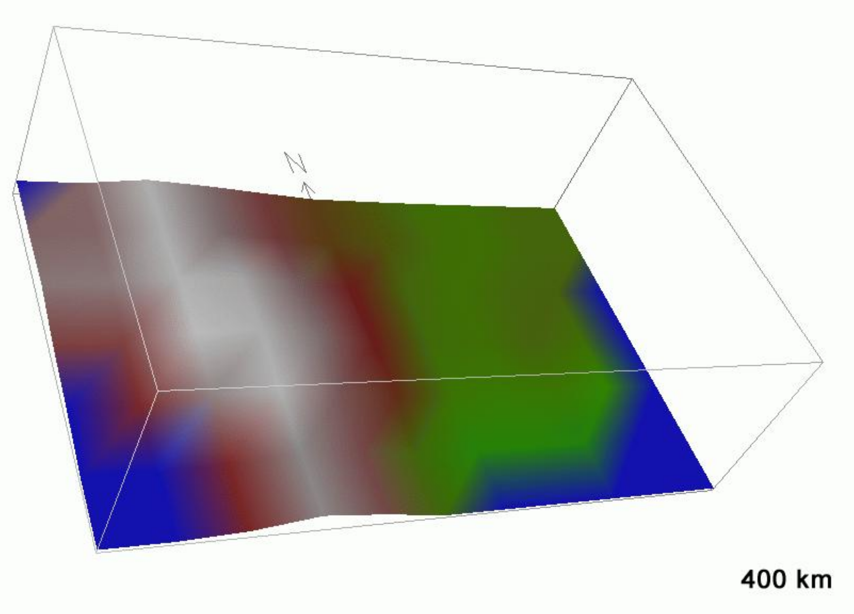


Viner (2002)

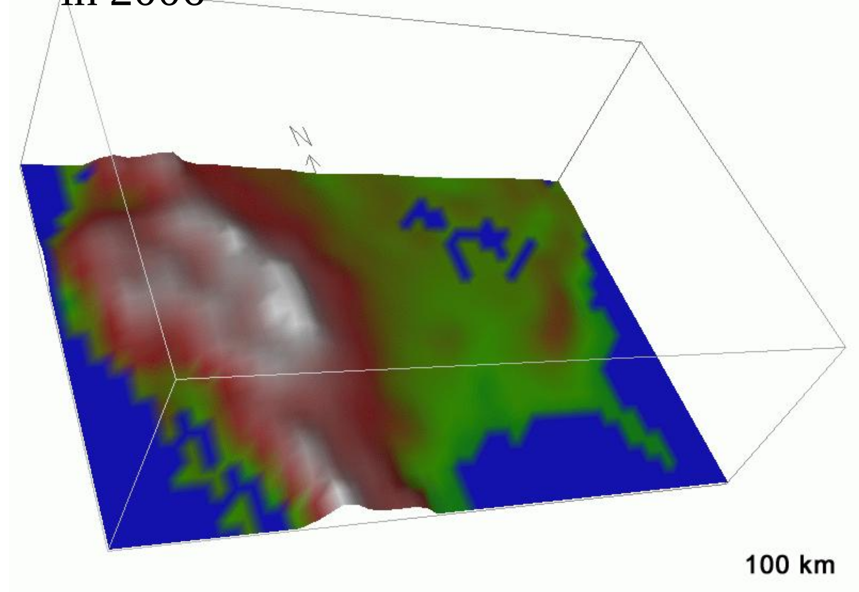
<u>Model Computation</u>:

- 15 minute time steps
- 1 quadrillion calculations /yr

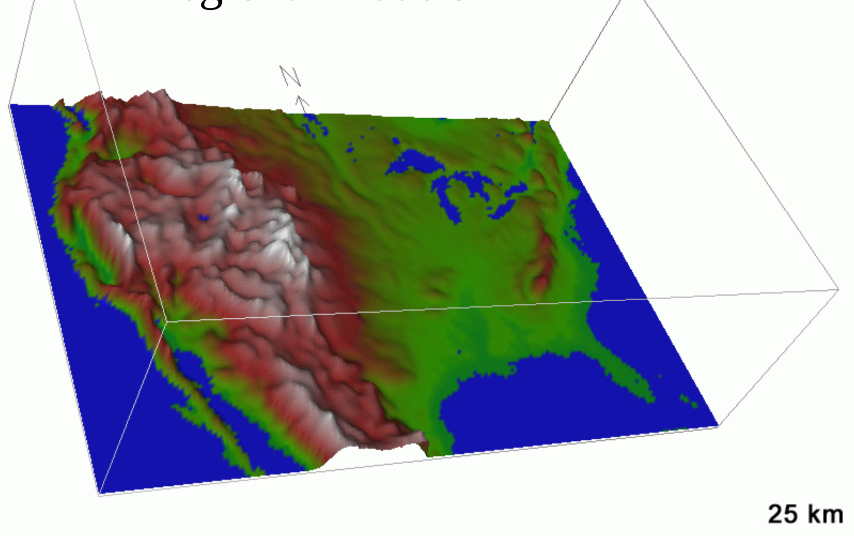
Climate Models circa early 1990s



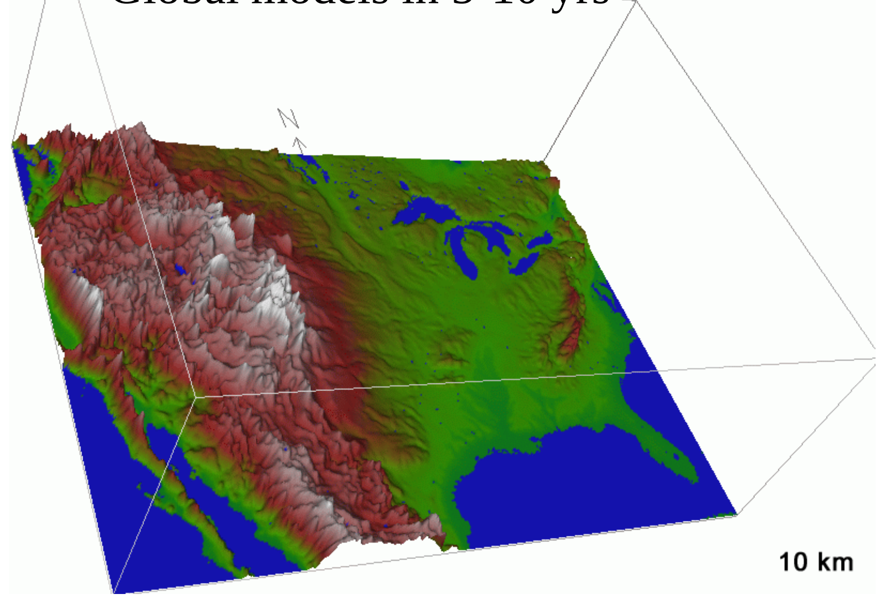
Global coupled climate models in 2006



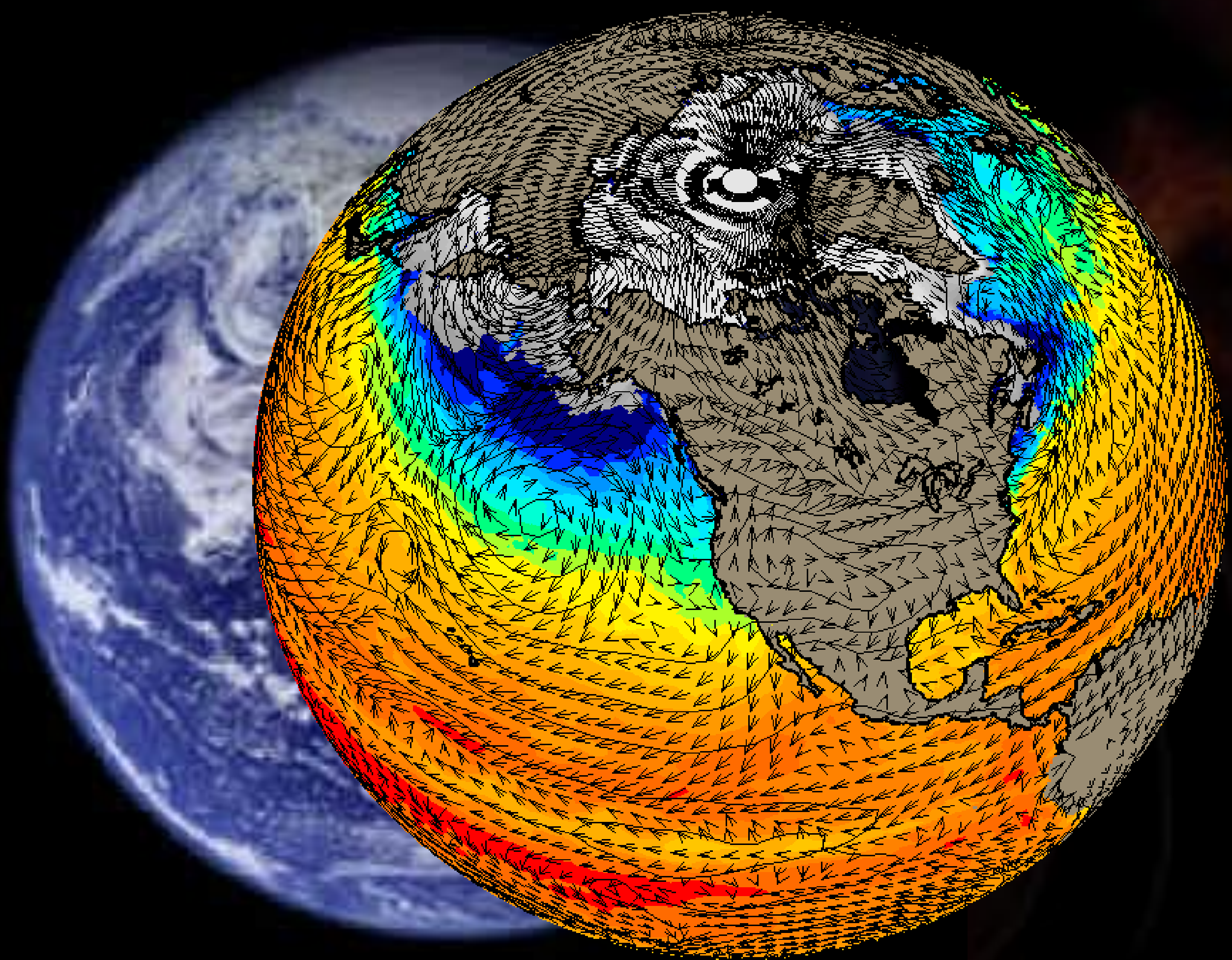
Regional models



Global models in 5-10 yrs



Inputs into a modern Climate Model

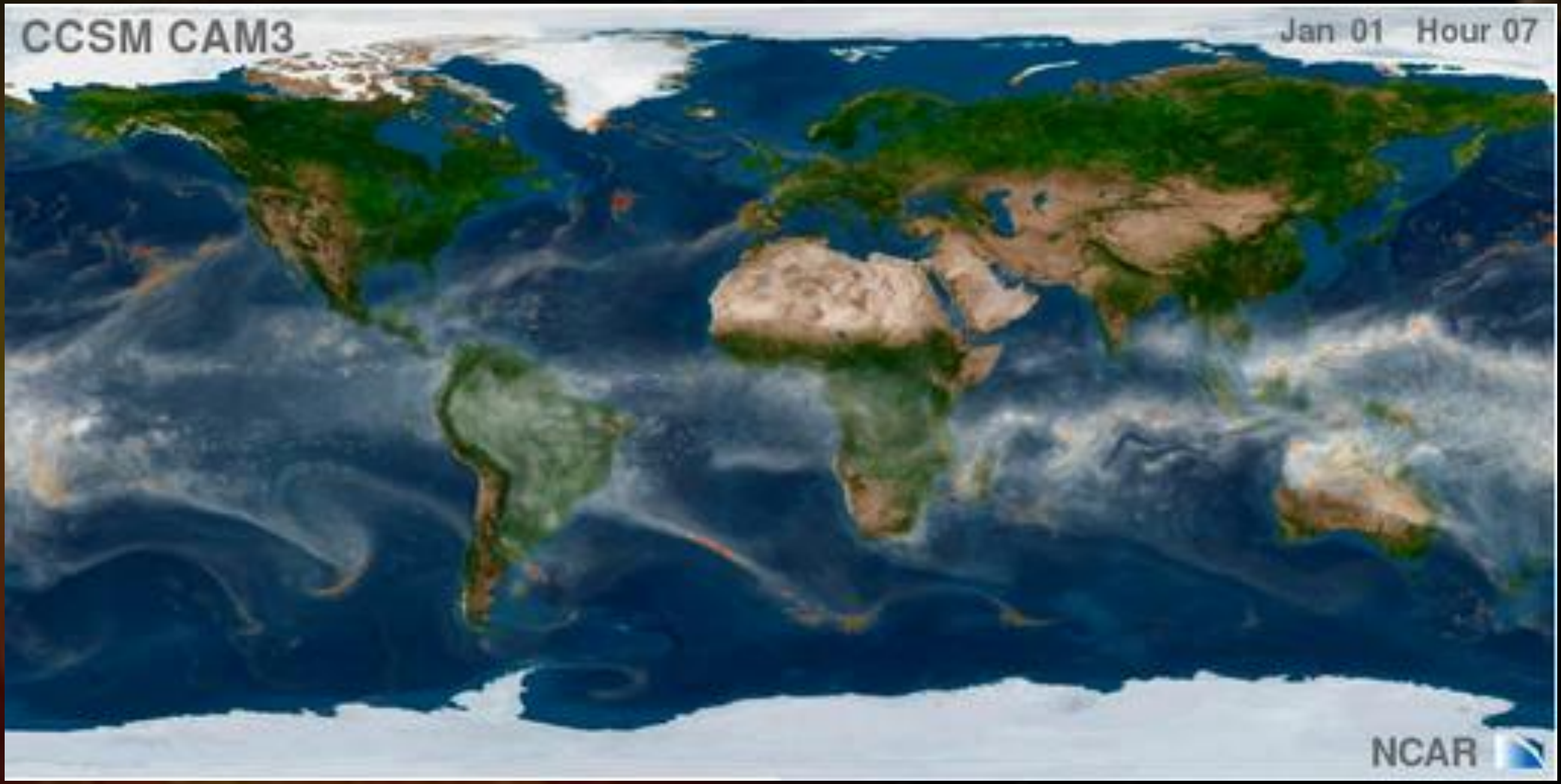


- Sunlight
- Earth rotation
- Continents
- Emissions

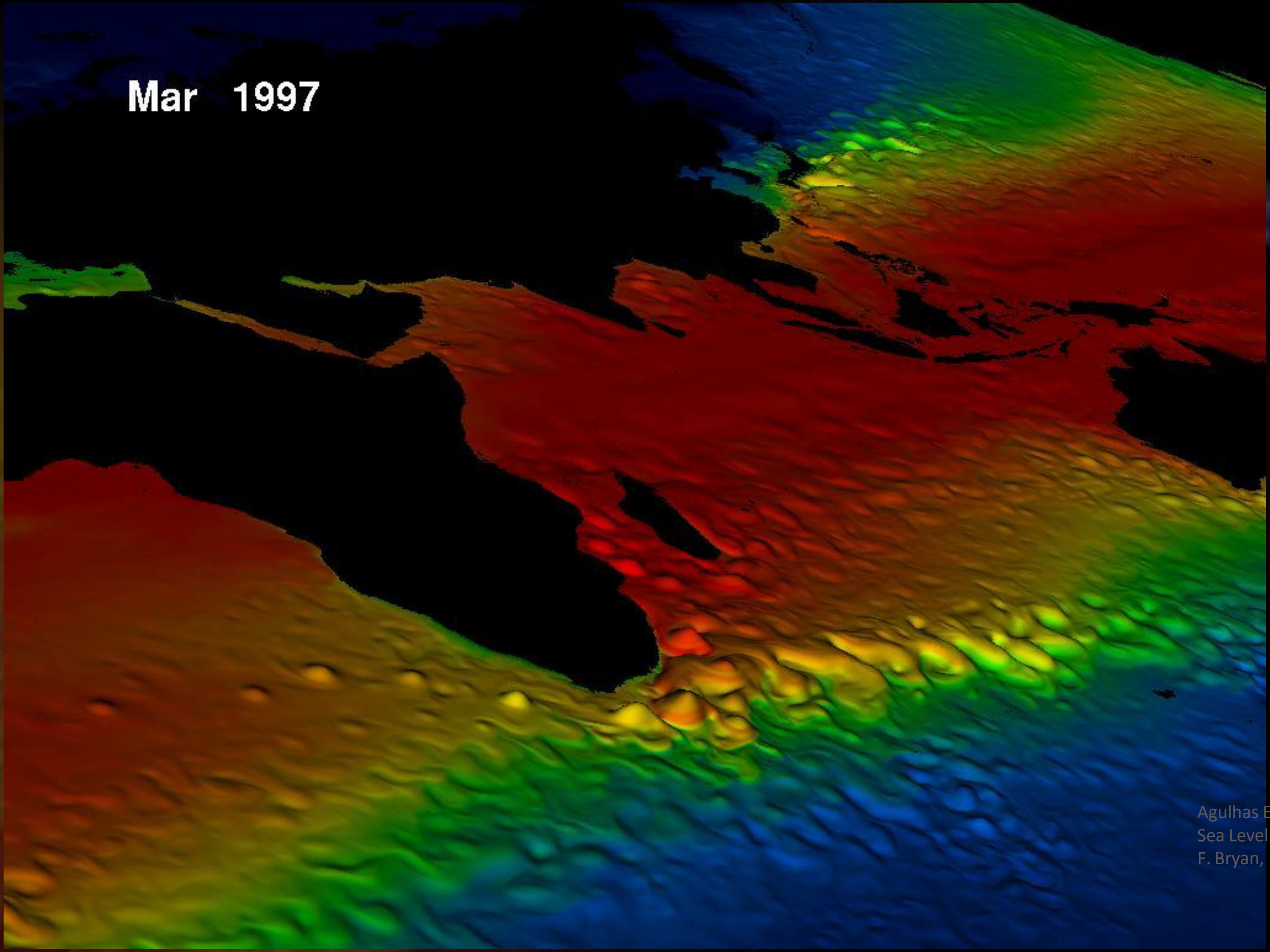
Model then predicts:

- Weather, clouds
- Ocean circulation
- Sea level
- Vegetation
- Aerosol
- Atm. Chemistry
- Carbon Cycle
- Ice sheets
- …

NCAR Community Climate System Model



Ocean Eddy Simulation at 0.1 degrees

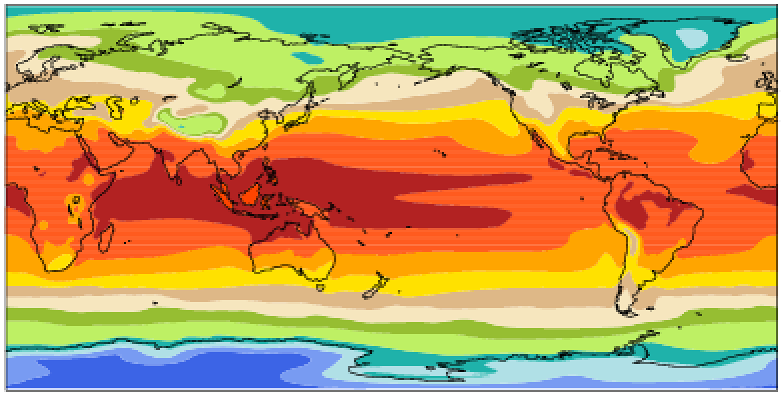


Agulhas Eddies
Sea Level
F. Bryan, NCAR

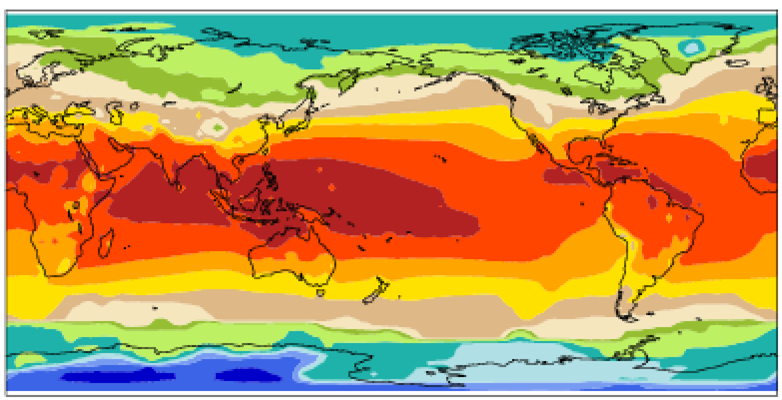
Mean and Variability of CCSM-3

Surface Air Temperature

Model

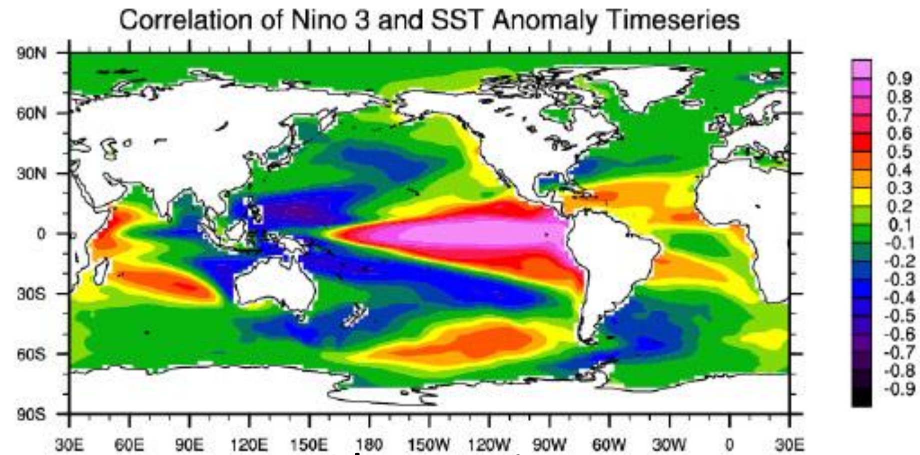


Observations

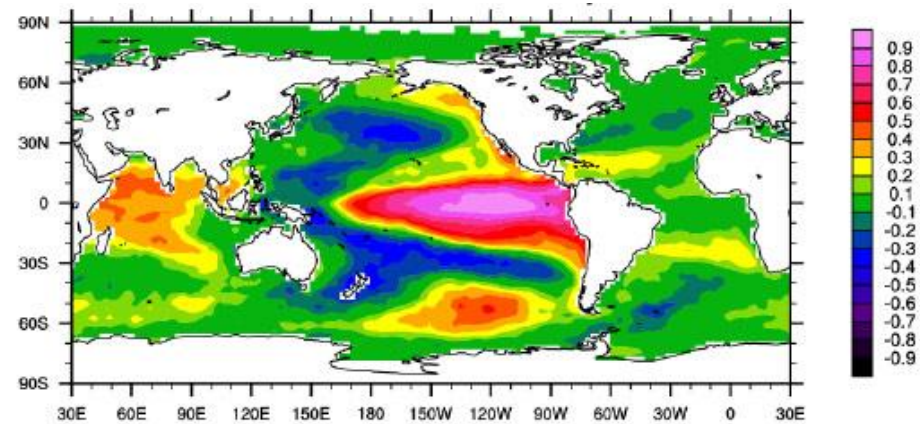


El Niño-Variability

Model



Observations



Climate Modeler's Commandments

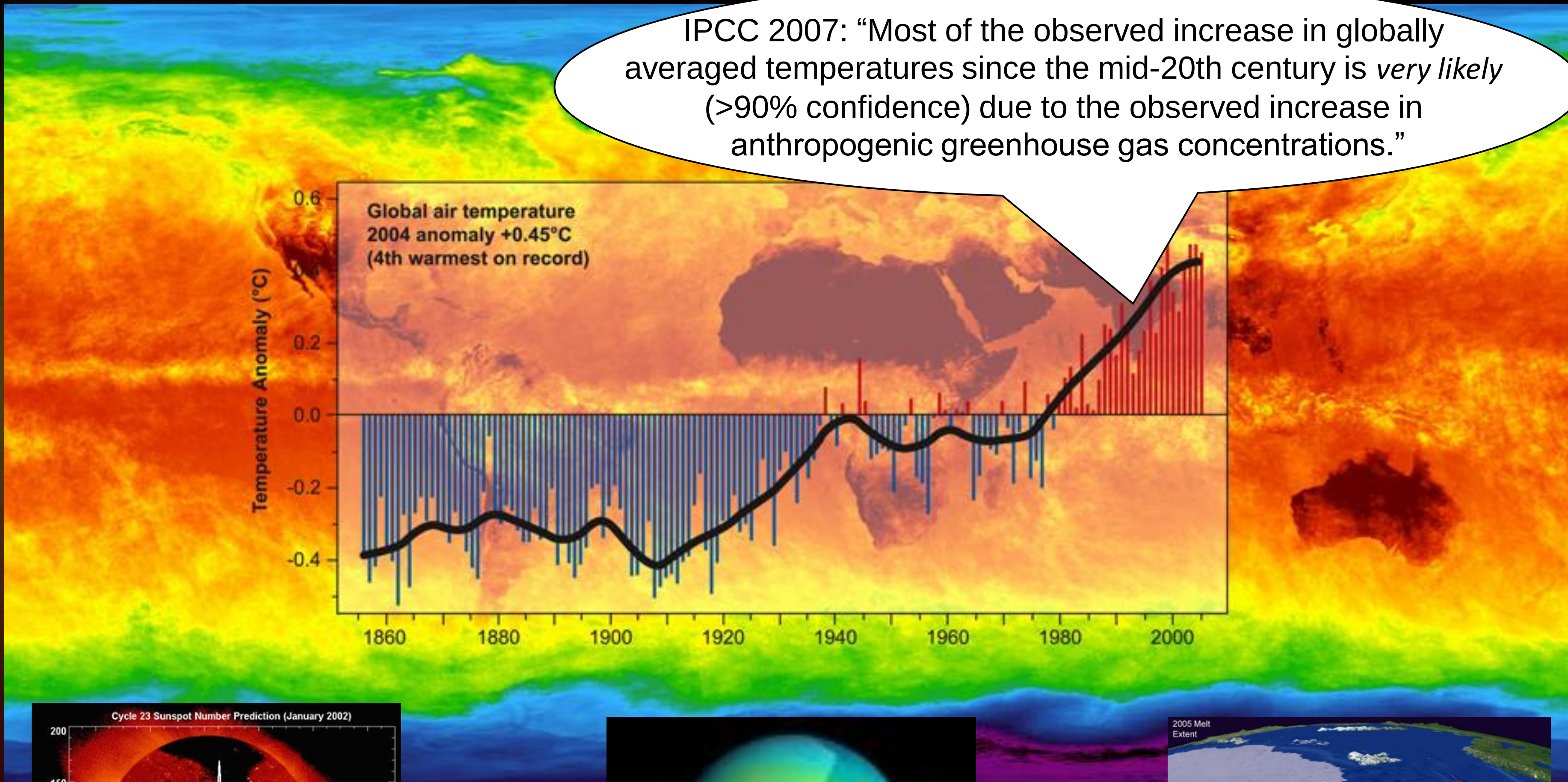
by John Kutzbach (Univ. of Wisconsin)

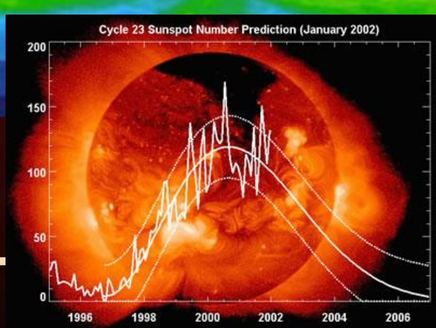
1. Thou shalt not worship the climate model.
2. Thou shalt not worship the climate model, but thou shalt honor the climate modeler, that it might be well with thee.
3. Thou shalt use the model that is most appropriate for the question at hand.
4. Thou shalt not change more than one thing at a time at first.
5. In making sensitivity experiments, thou shalt hit the model hard enough to make it notice you.
6. Thou shalt not covet fine-scale results with a coarse-scale model.
7. Thou shalt follow the rules for significance testing and remember the model's inherent variability.
8. Thou shalt know the model's biases and remember that model biases may lead to biased sensitivity estimates.
9. Thou shalt run the same experiment with different models and compare the results.
10. Thou shalt worship good observations of the spatial and temporal behavior of the earth system. Good models follow such observations. One golden observation is worth a thousand simulations.

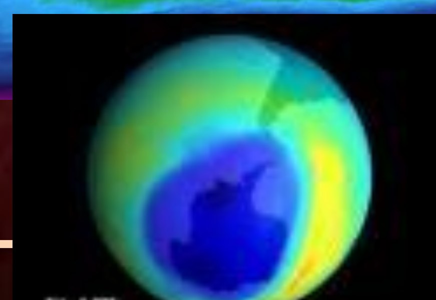
Comprehensive Climate Models and Climate Change

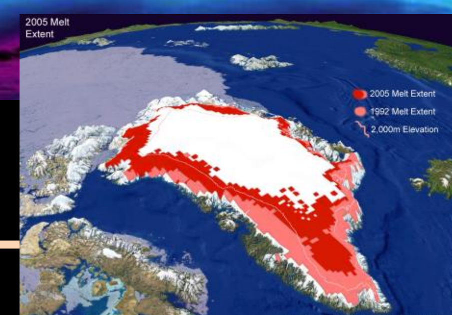
3 Decades in Earth Observations and Change

IPCC 2007: “Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* (>90% confidence) due to the observed increase in anthropogenic greenhouse gas concentrations.”





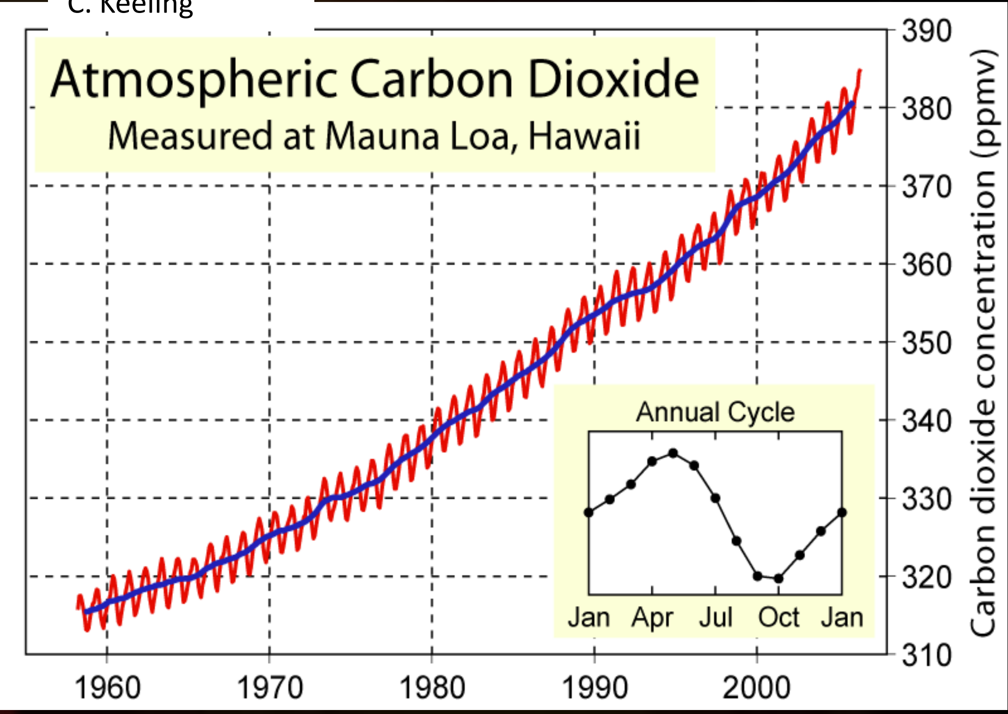




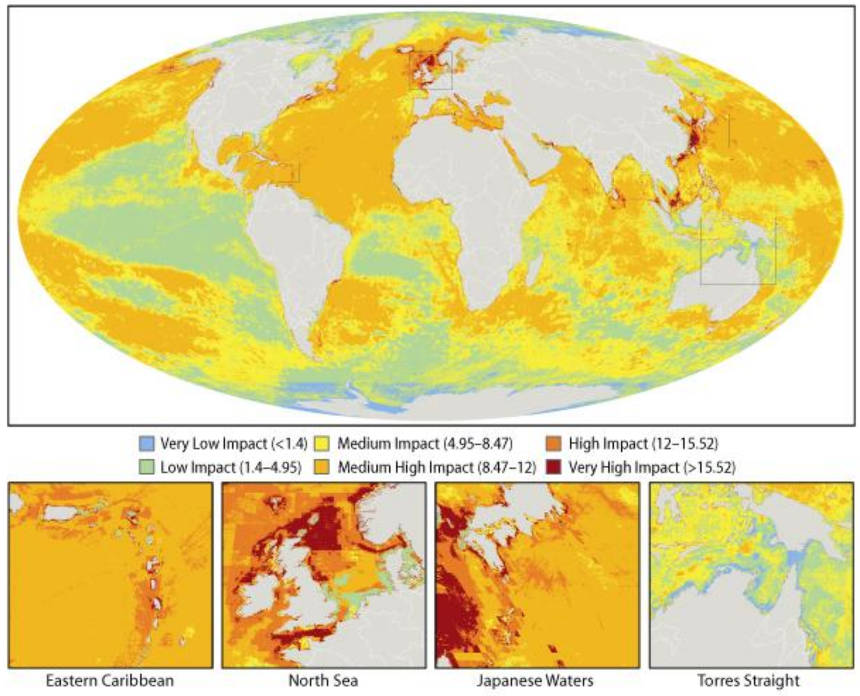
True Global Reach of Humans


C. Keeling

Atmosphere



Oceans

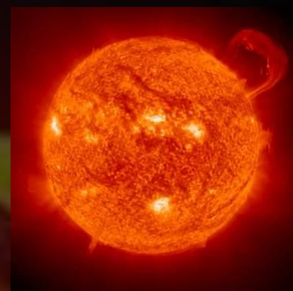


"Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future."

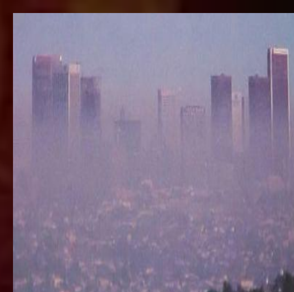
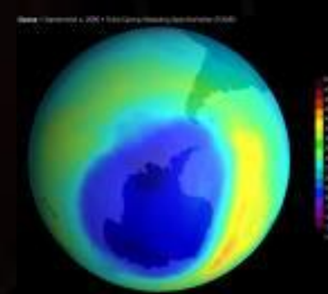
Roger Revelle, 1957

Factors that affect Climate

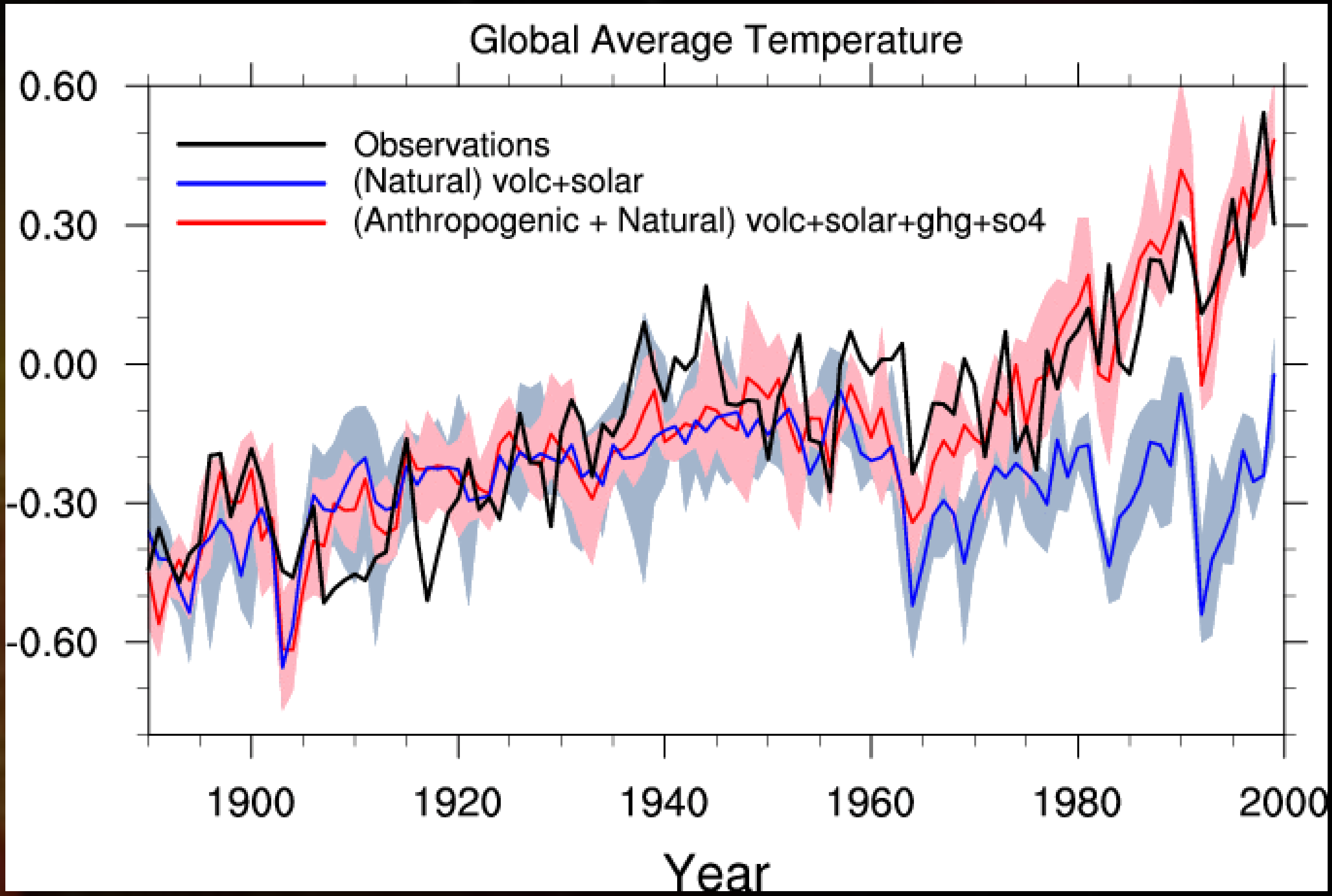
- Natural Factors: Sun and Volcanos




- Human emissions: Greenhouse gases, Aerosol, Ozone

Simulations of the 20th century: Time



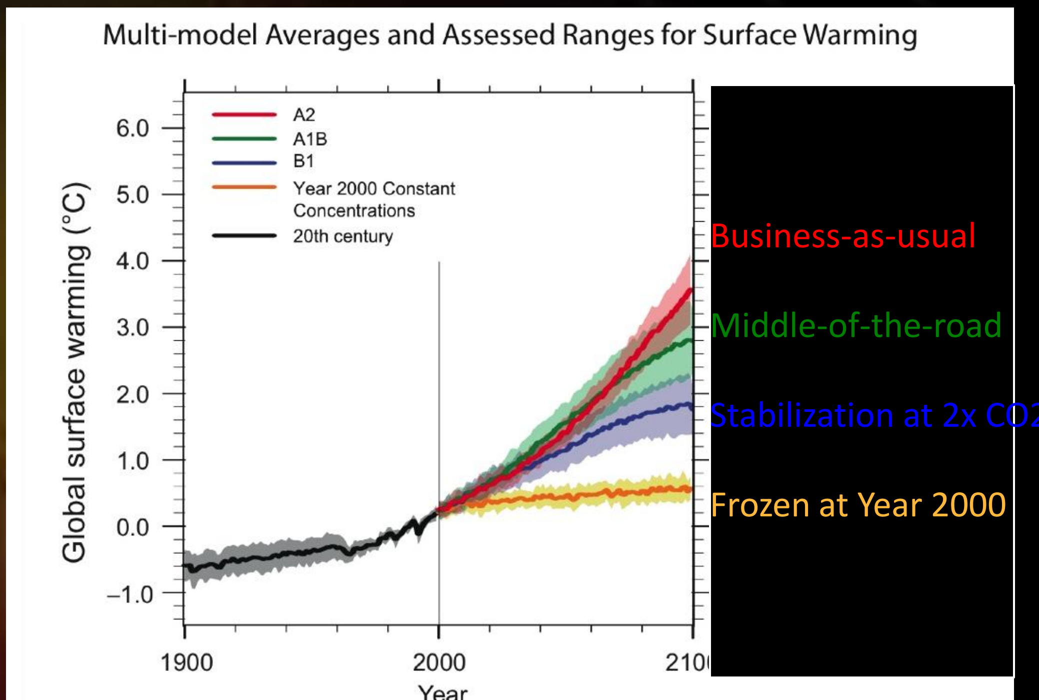
All forcings

Natural only

Meehl et al. 2004

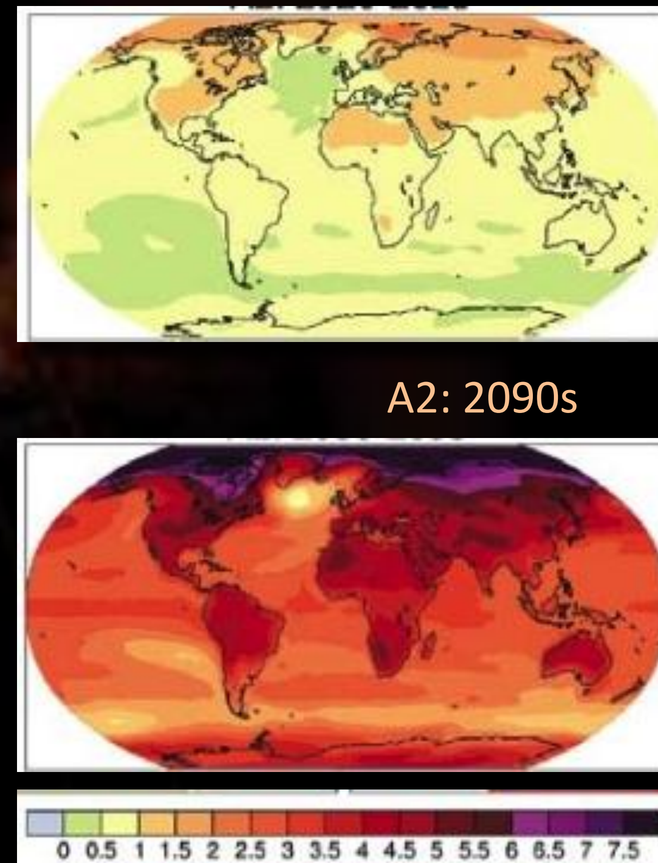
Future Climate Projections

Note: These are "What If" Scenarios, not predictions



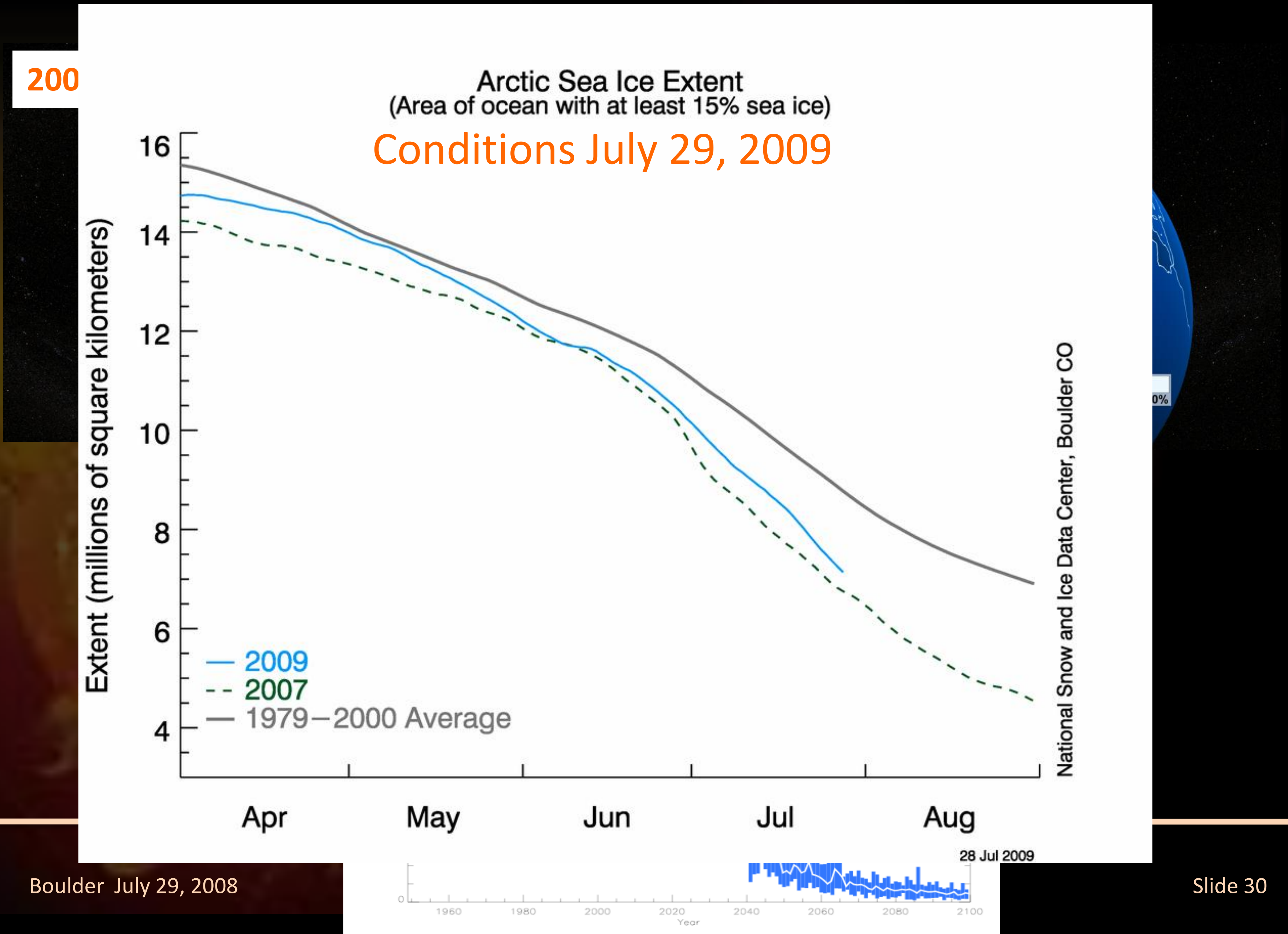
A2: 2020s

A2: 2090s

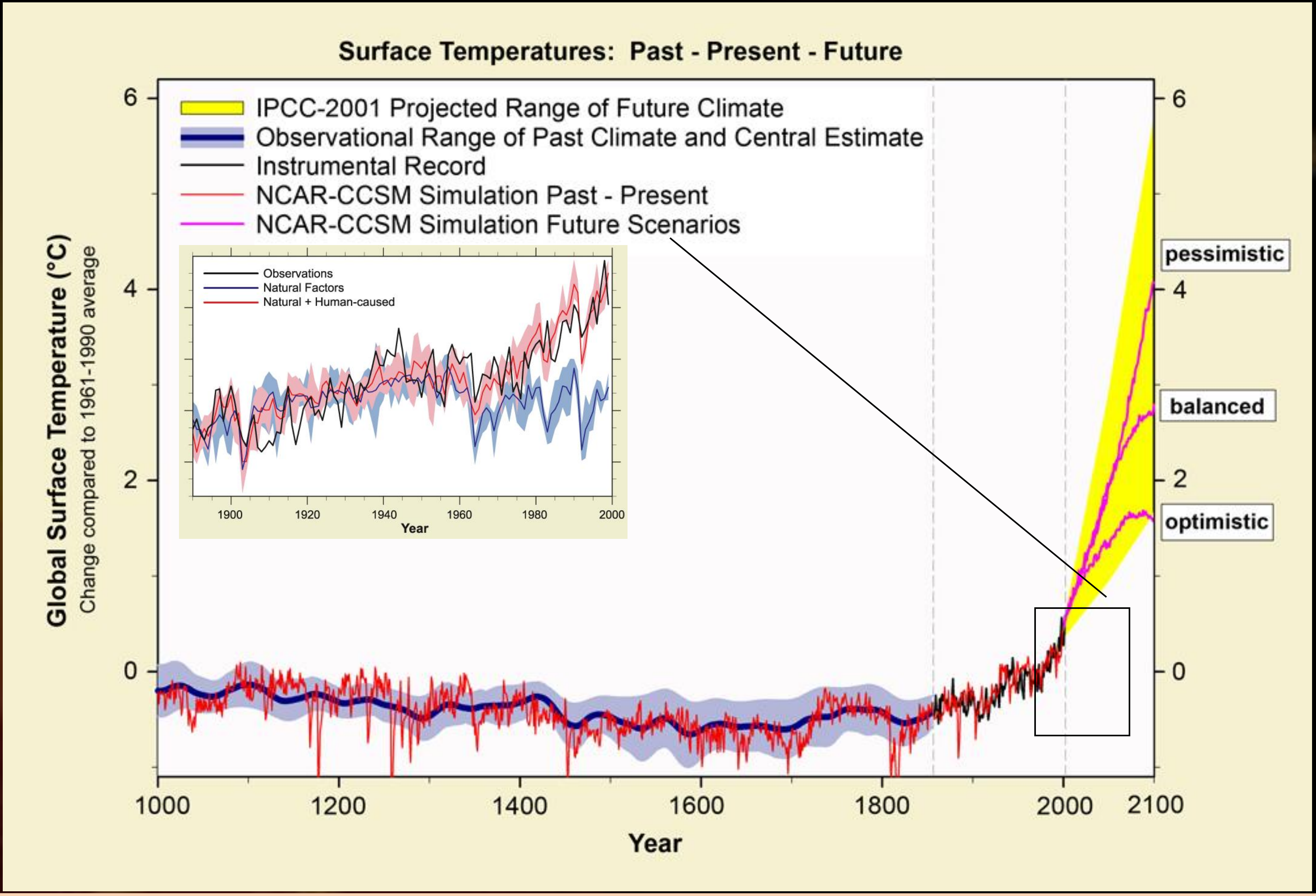


IPCC, 2007

Sea Ice : Observations and Model Projections



Past-Present-Future : The historic picture …



Ammann et al., 2007

Past-Present-Future : The geologic picture …

250 Million Years ago

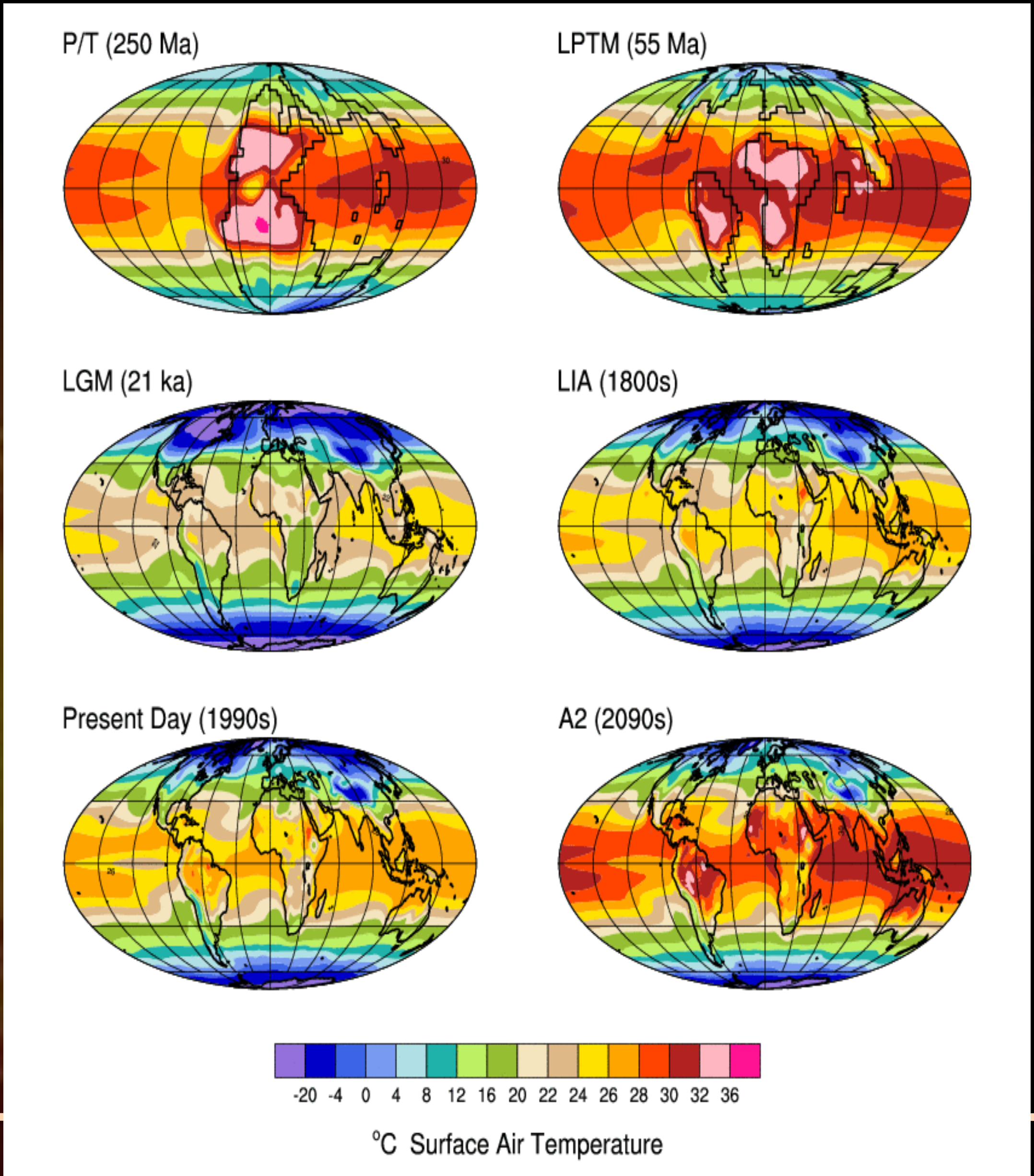
55 Million Years ago

21,000 Years ago

200 Years ago

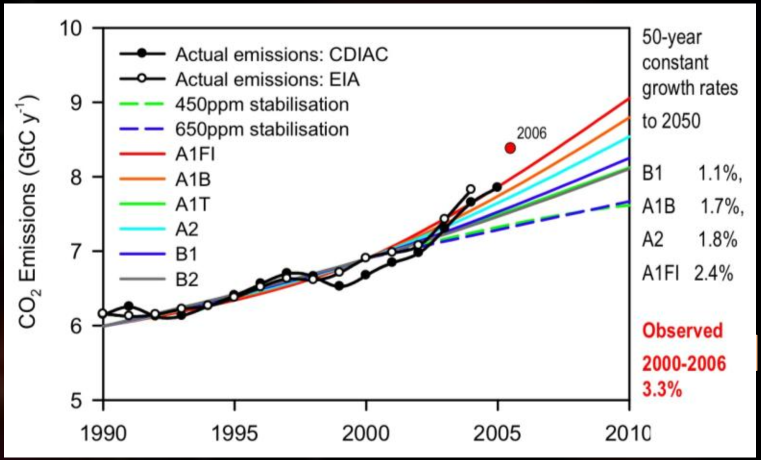
Today

100 Years From Today under Business as usual



Are we over-blowing the problem?

... most likely not ...:

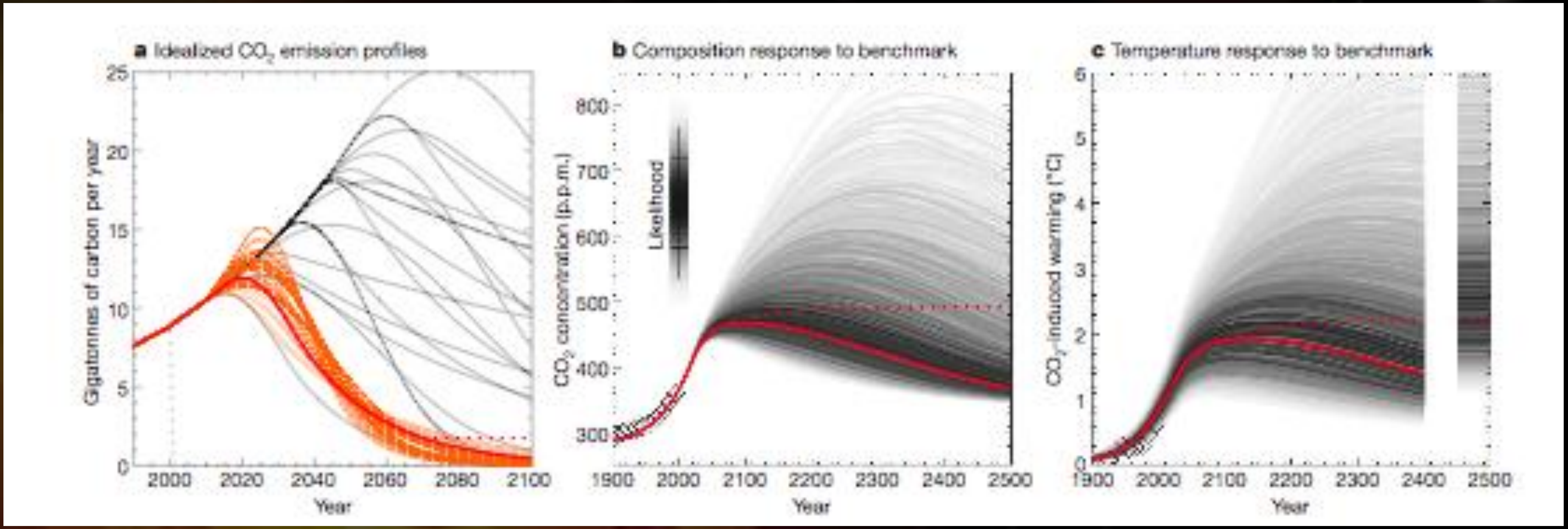


Canadel et al. 2007

- speed of sea ice retreat?
- melting on ice sheets?
- weaker trends in models in some responses (precip)?
- Vegetation feedback not as efficient
- models in paleo applications: never quite the amplitude …

Long Climate "Tail" of Reduction Scenarios for 2100

Emissions　　　Composition　　　Temperature

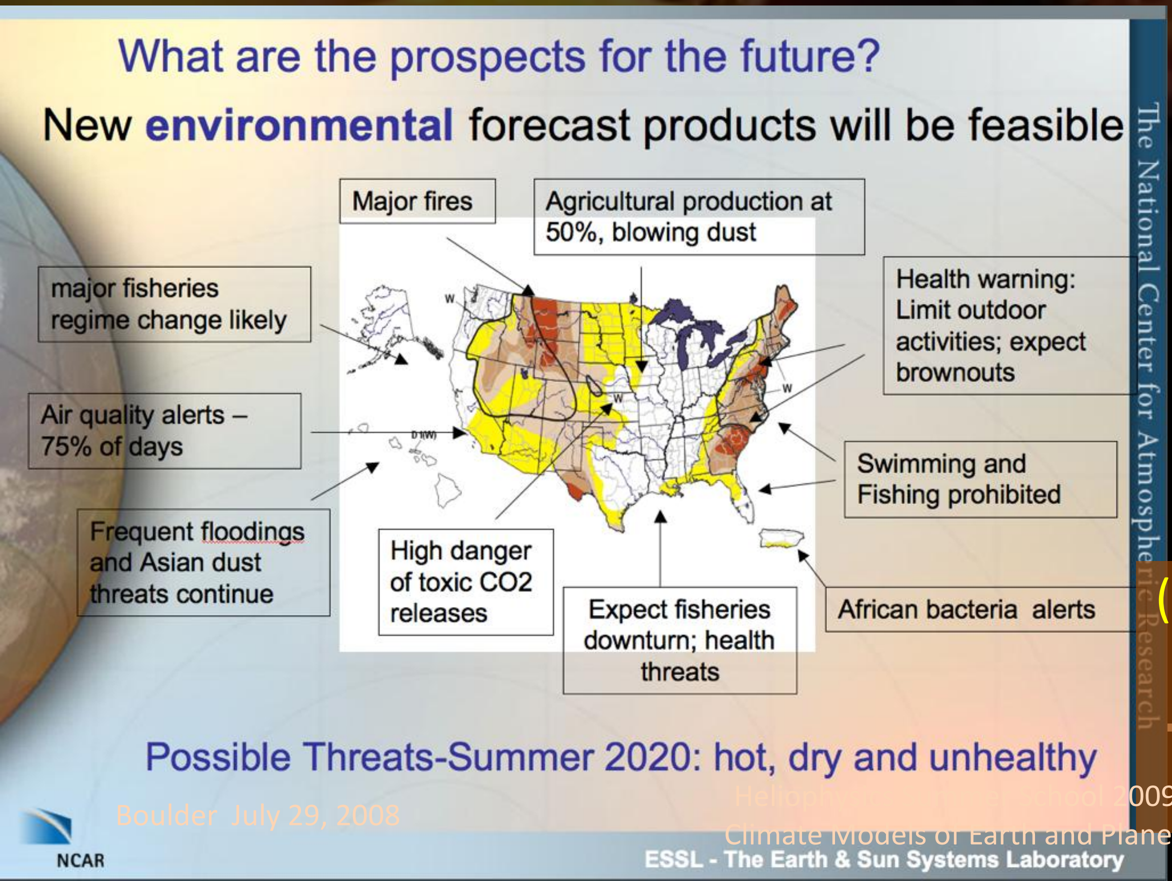


2000　　2100　　1900　　2500　　1900　　2500

Scientific Challenges: AR5

(1) CLIMATE SENSITIVITY:

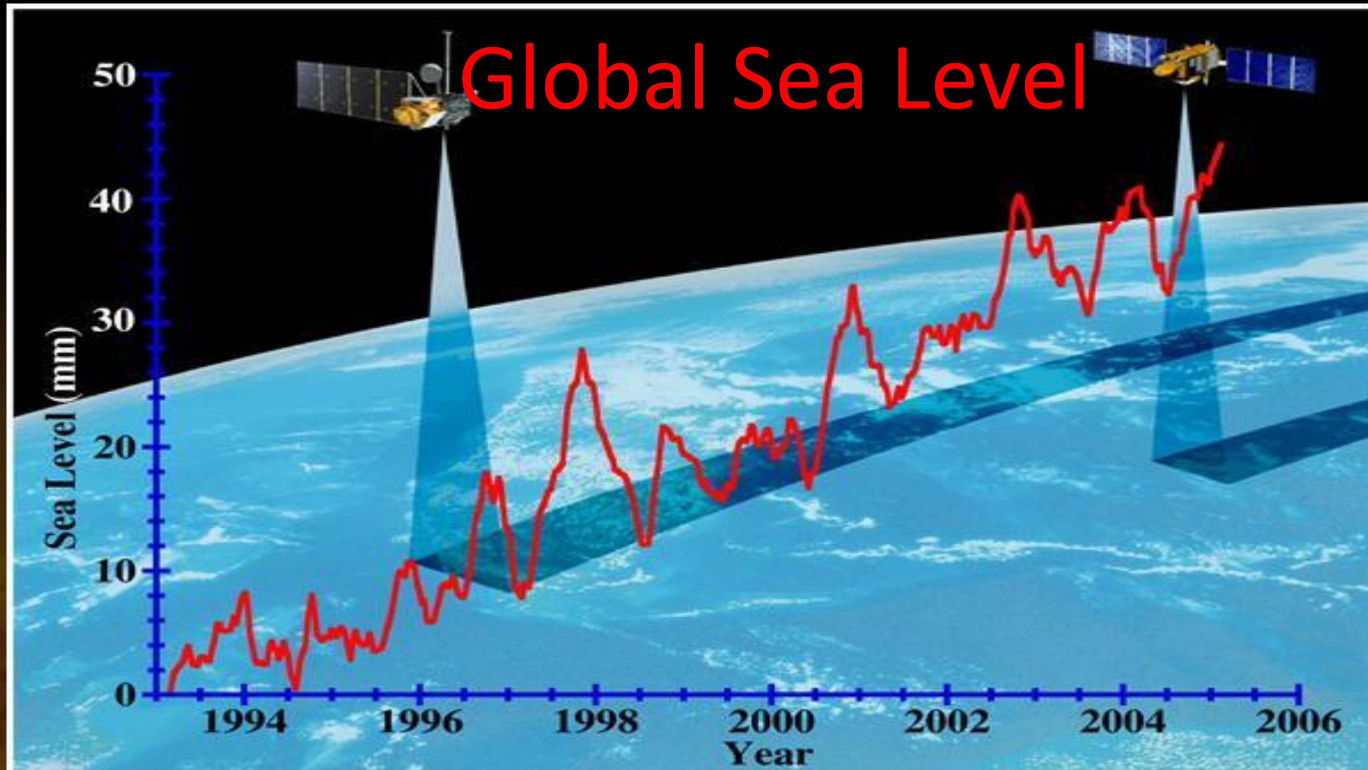
Long, multi-century projections to study Carbon Cycle Feedbacks, Sea Level Change



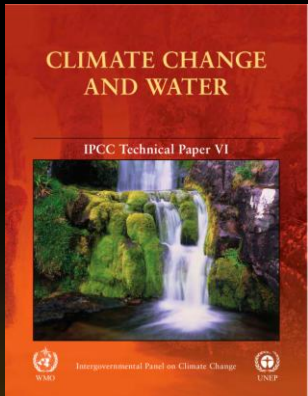
(2) REGIONAL DYNAMICS:

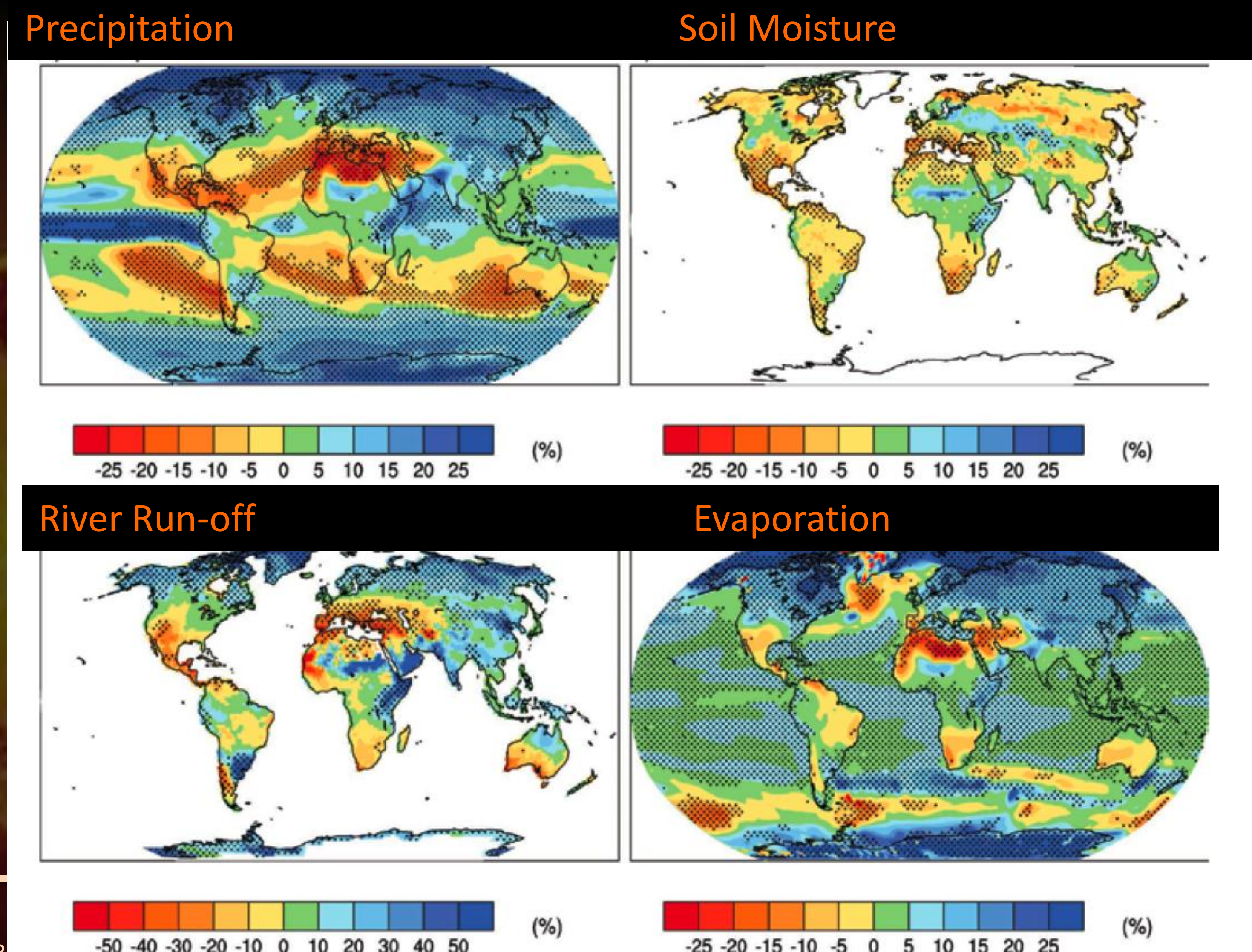
Very high-res simulations of the next 20-30 years for regional prediction

Global Sea Level

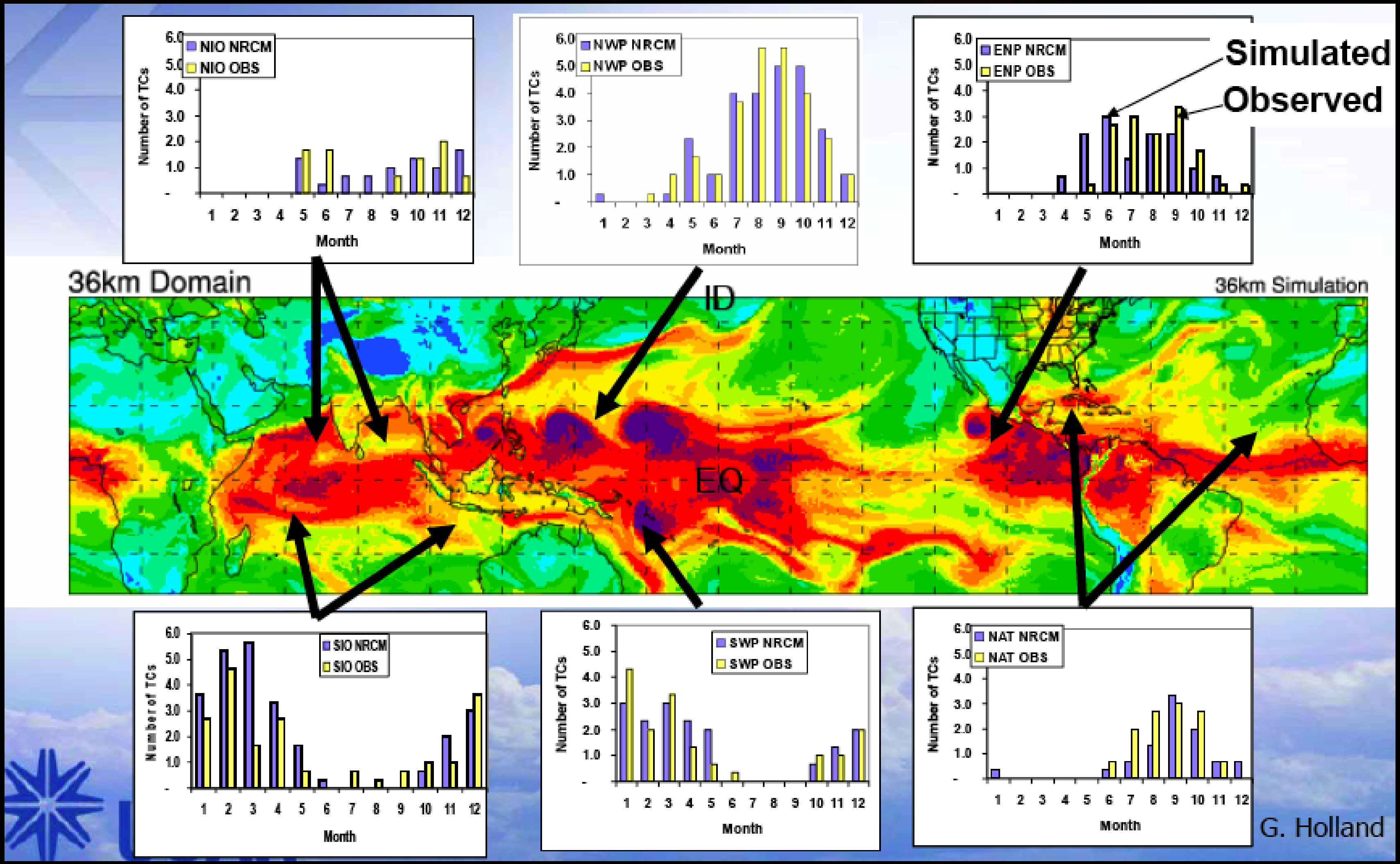


New Focus on Regional Water

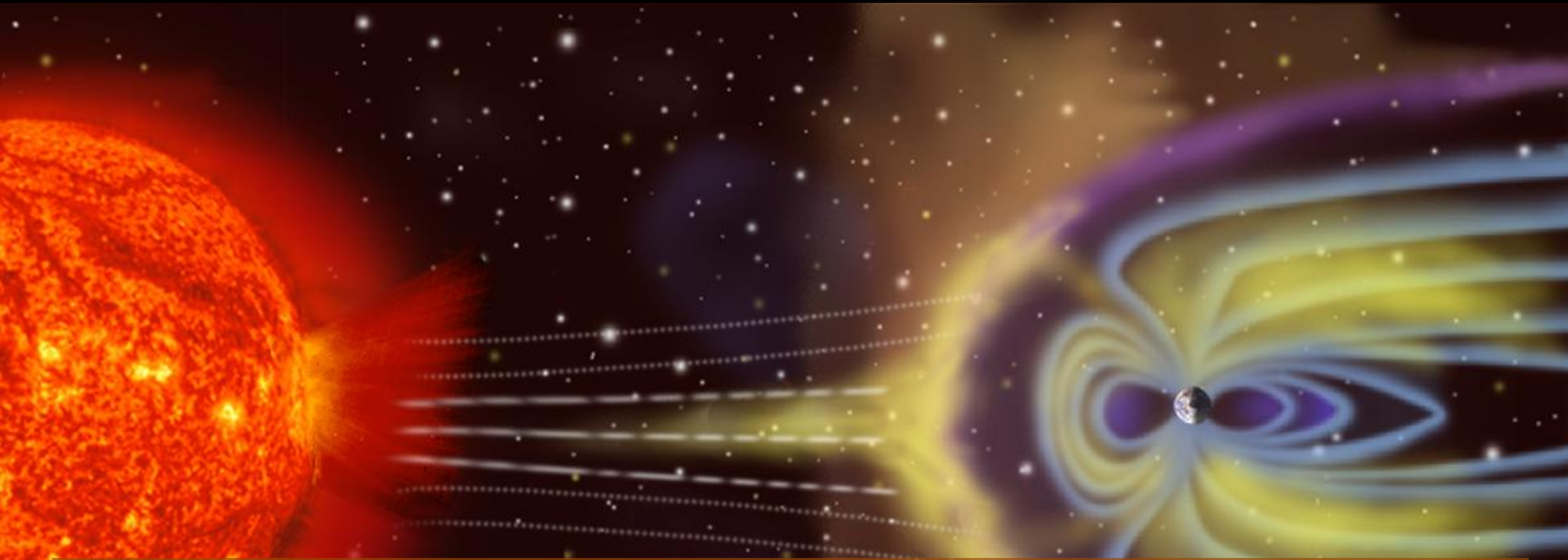




Nested Regional Model In Global GCM



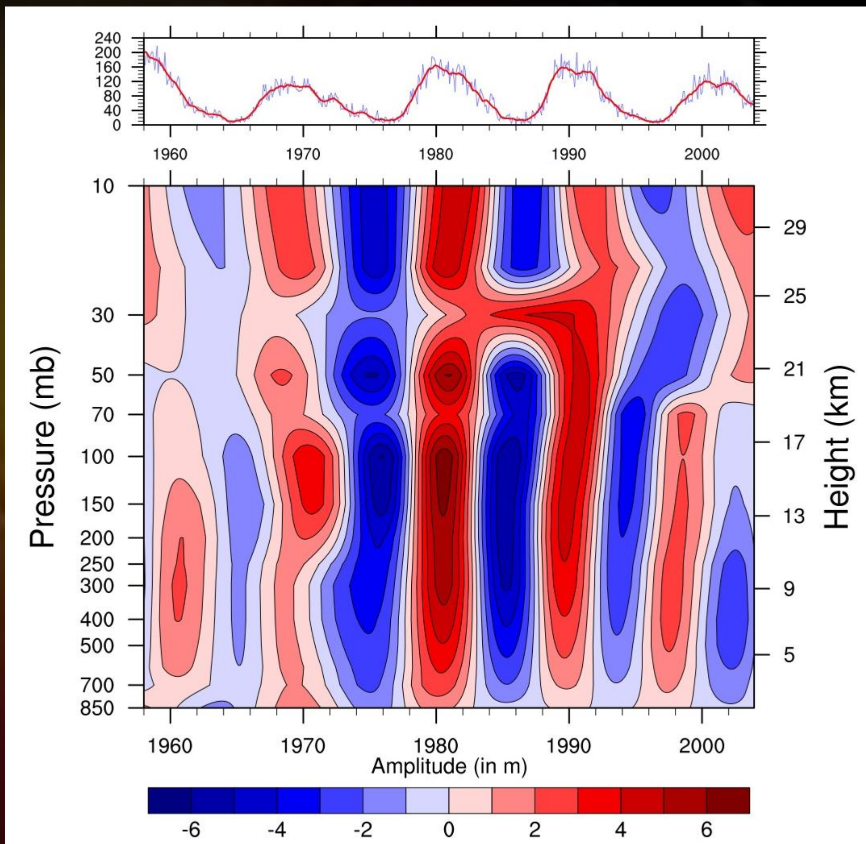
Pathways of solar impact on Climate



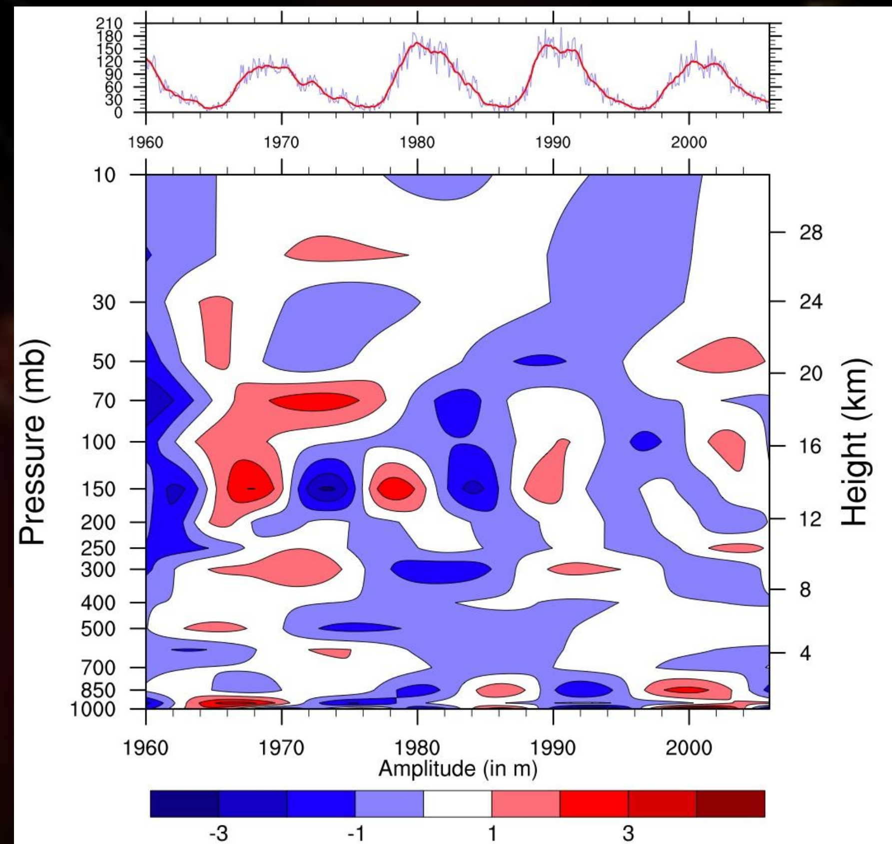
- Direct radiative influence of total energy change
- Indirect radiative effects through spectral variations
- Indirect effects through Atmospheric Dynamics and possibly change in coupled variability

Solar Cycle Example

Need for Improved top-down coupling for Regional Change



EMD: Obs (NCEP)

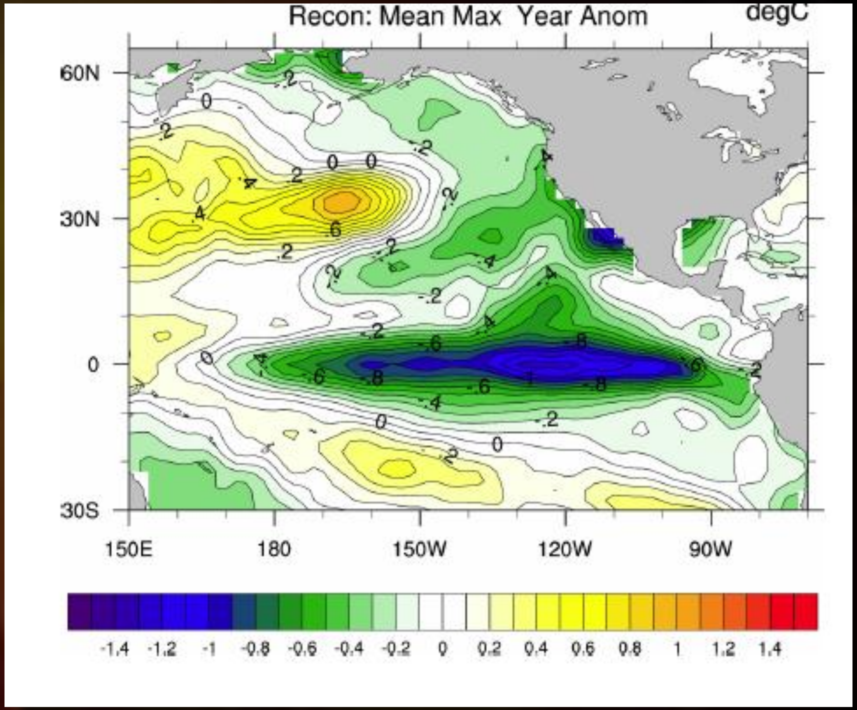


EMD: WACCM (incl ozone)

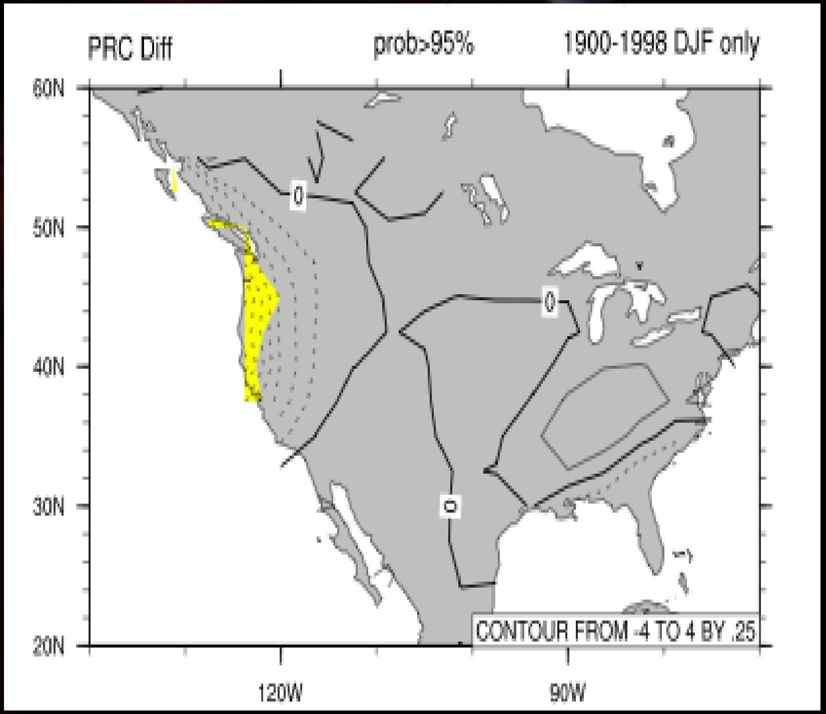
Effect of High Solar Activity on the Pacific

Predictability of an 11-yr Cycle Signal? (only solar max)

SST anomalies
(1856-2004)



Precip. anomalies

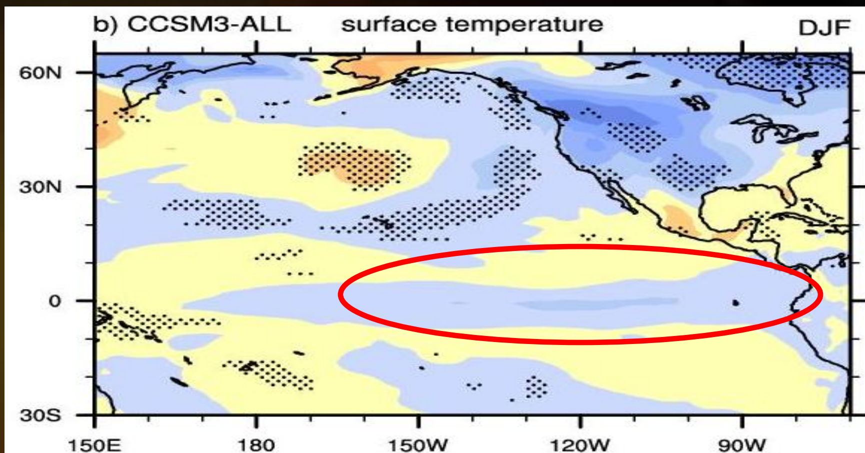


Van Loon et al. 2007

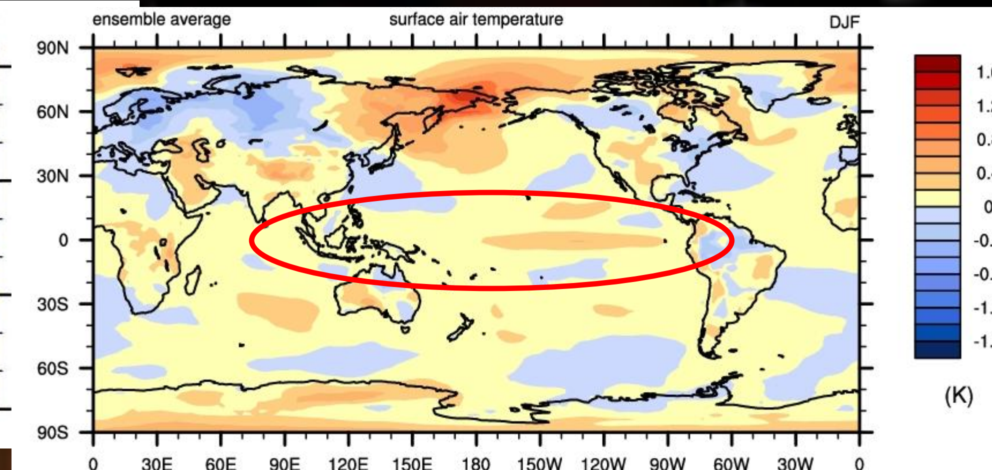
IPCC AR4 Models: Surface Temperatures

Solar 11-year Cycle: Max - Climatology

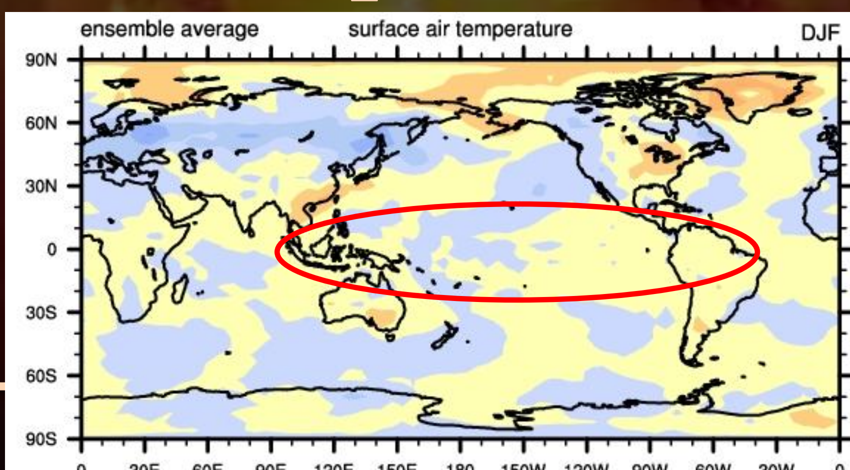
NCAR CCSM 3.0



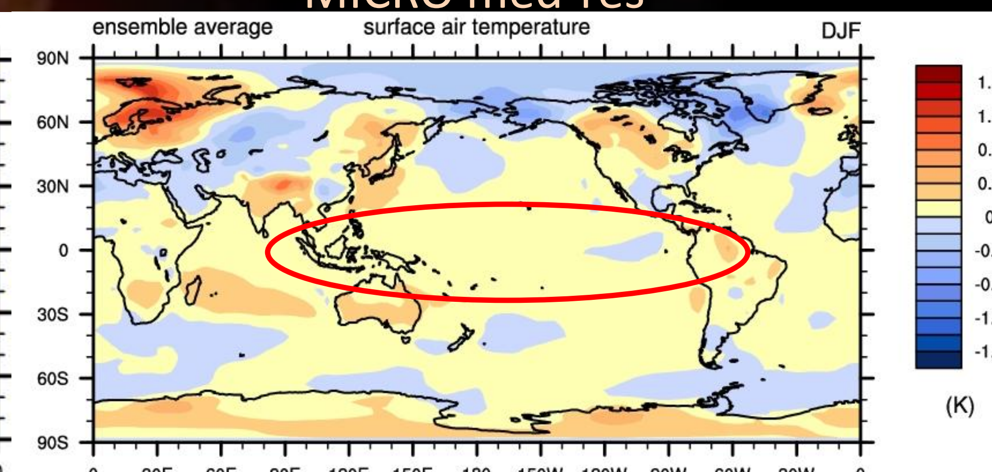
GFDL 2.1



GISS e_h

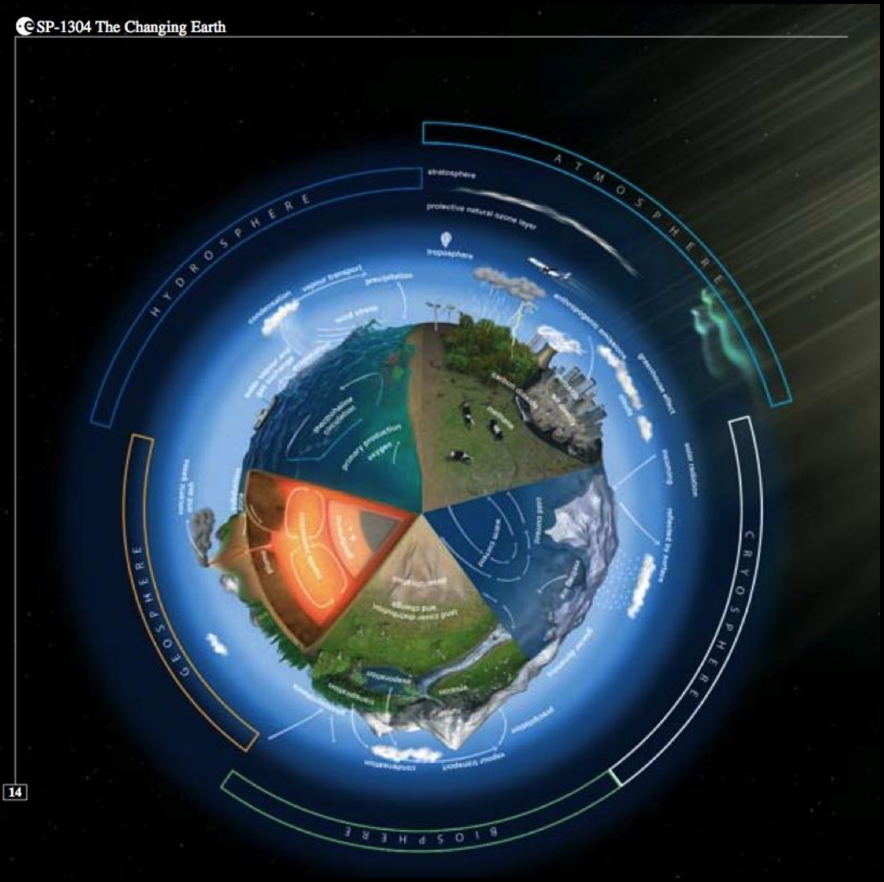


MICRO med-res



Source: Van Loon, Meehl, Arblaster

Towards a more complete Earth System Perspective



Climate Models are an integral part of Climate and Climate Change research.

They are now capable of representing most of the key processes of the coupled Earth System

A suite of open questions remain (including solar influence): Need for cross-disciplinary approaches

Long-term projection challenges:

Carbon Cycle Feedbacks, Polar amplification, ice sheet stability and sea level, Rate of Change

Regional predictions:

Modes of variability and radiative forcing

Climate Change Summary

Climate has always been changing, and we generally know why.

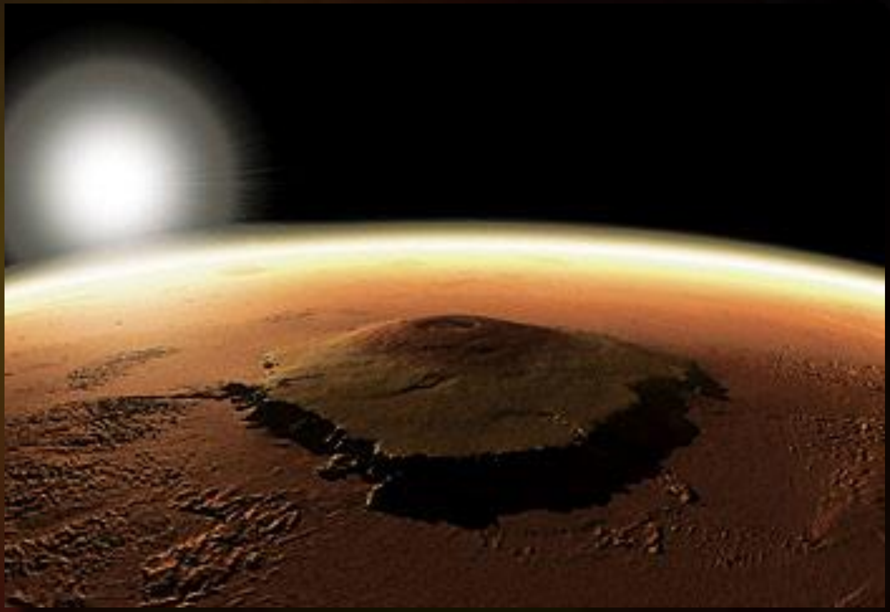
Climate Change is happening; Human carbon emissions are the cause.

Models are capable of reproducing the key processes on the global scale, but regional details remain to be resolved.

We are more likely underestimating the future changes than overestimating them.

Future climate changes could quickly reach the magnitude of a Glacial - Interglacial Transition. Greenhouse conditions could resemble Eocene climates…

Planetary Lessons - Conclusions



- Interpretation requires long, reliable data from many locations
- Multiple processes with typical time scales affect the system
- Coupling of “traditional” systems reveals the actual level of under-standing of mechanisms
- Data assimilation (s.l.) and new statistical tools offers ways of constraining uncertainties and to integrate diverse data and theories

The Great Challenge:

Balancing Climate and Energy Needs

Problem is that Climate has very long time scales involved – hard or impossible to turn back the wheel

Time scales

- Stellar / Planetary Evolution (10^6-10^9 years)
  (Faint early Sun, early Mars, volcanic activity on Mars and Venus,..)
- Planetary Orbital Configuration (10^4-10^5 years)
  (ice ages on Earth, Mars?…)
- Solar Variability (hours - 10^3 years)
  (11-yr cycle, centennial sunspot minima,…)

nature
Vol 446 | 5 April 2007 | doi:10.1038/nature05718

LETTERS

Global warming and climate forcing by recent albedo changes on Mars

Lori K. Fenton[1], Paul E. Geissler[3] & Robert M. Haberle[2]

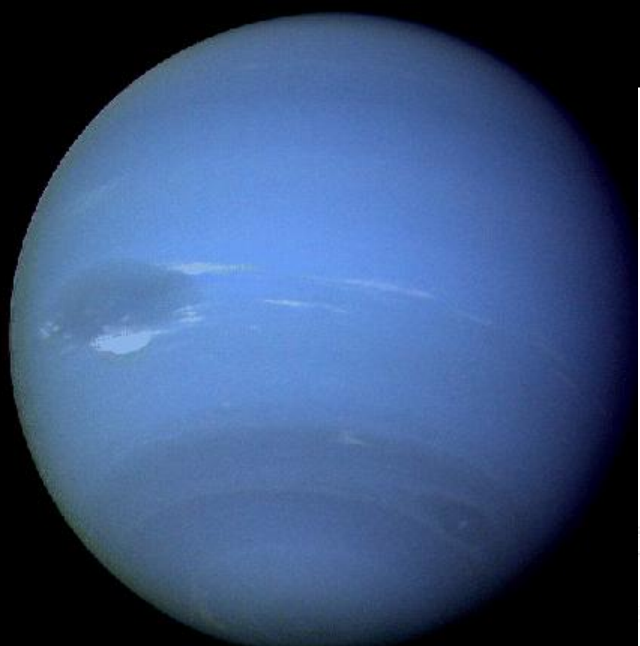
Simulated Temperature increase betwe
and Mars Global Surveyer: 0.65K (70s vs 90s)

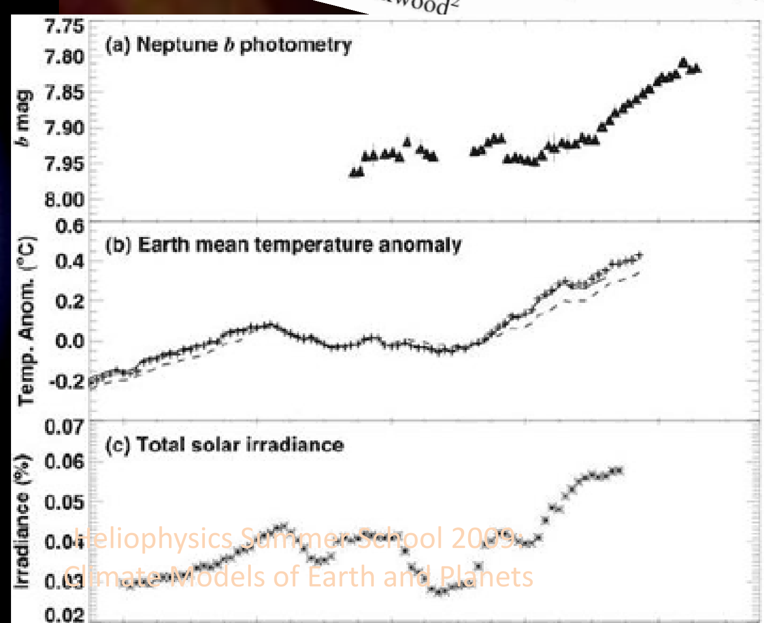
Click Here for Full Article

GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L08203, doi:10.1029/2006GL028764, 2007

Suggestive correlations between the brightness of Neptune, solar variability, and Earth's temperature

H. B. Hammel[1] and G. W. Lockwood[2]

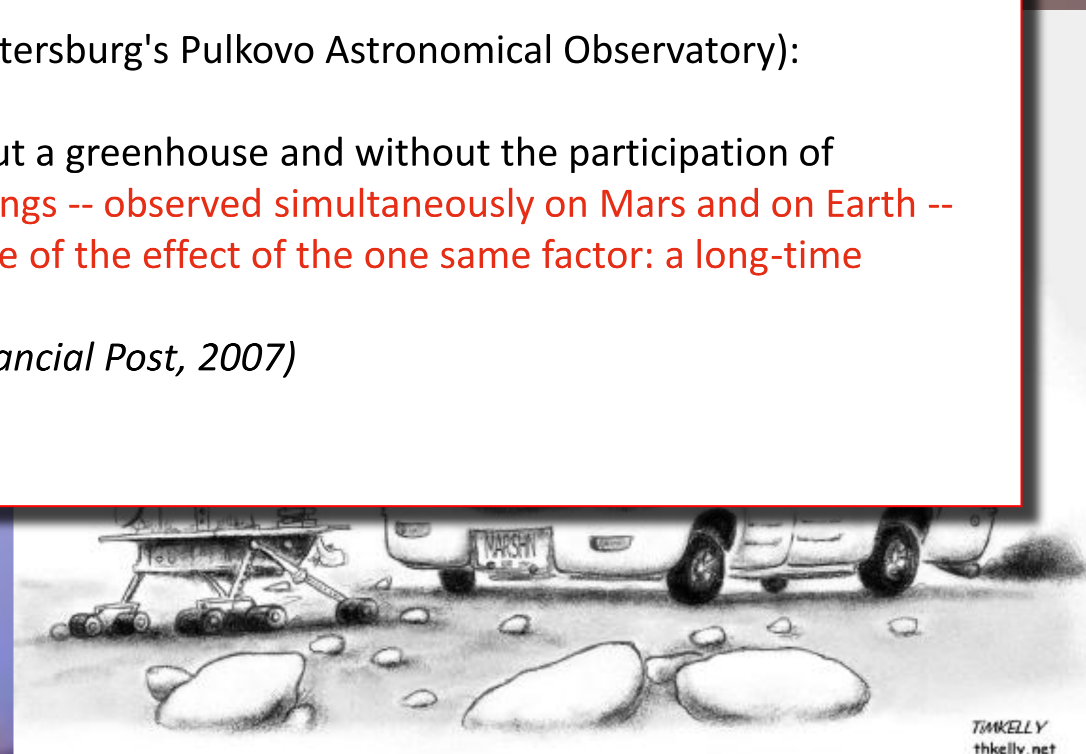




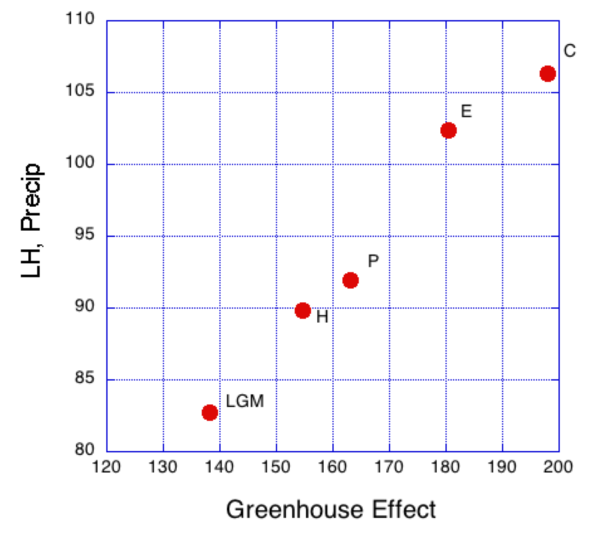
Dr. Habibullo Abdussamatov (Saint Petersburg's Pulkovo Astronomical Observatory):

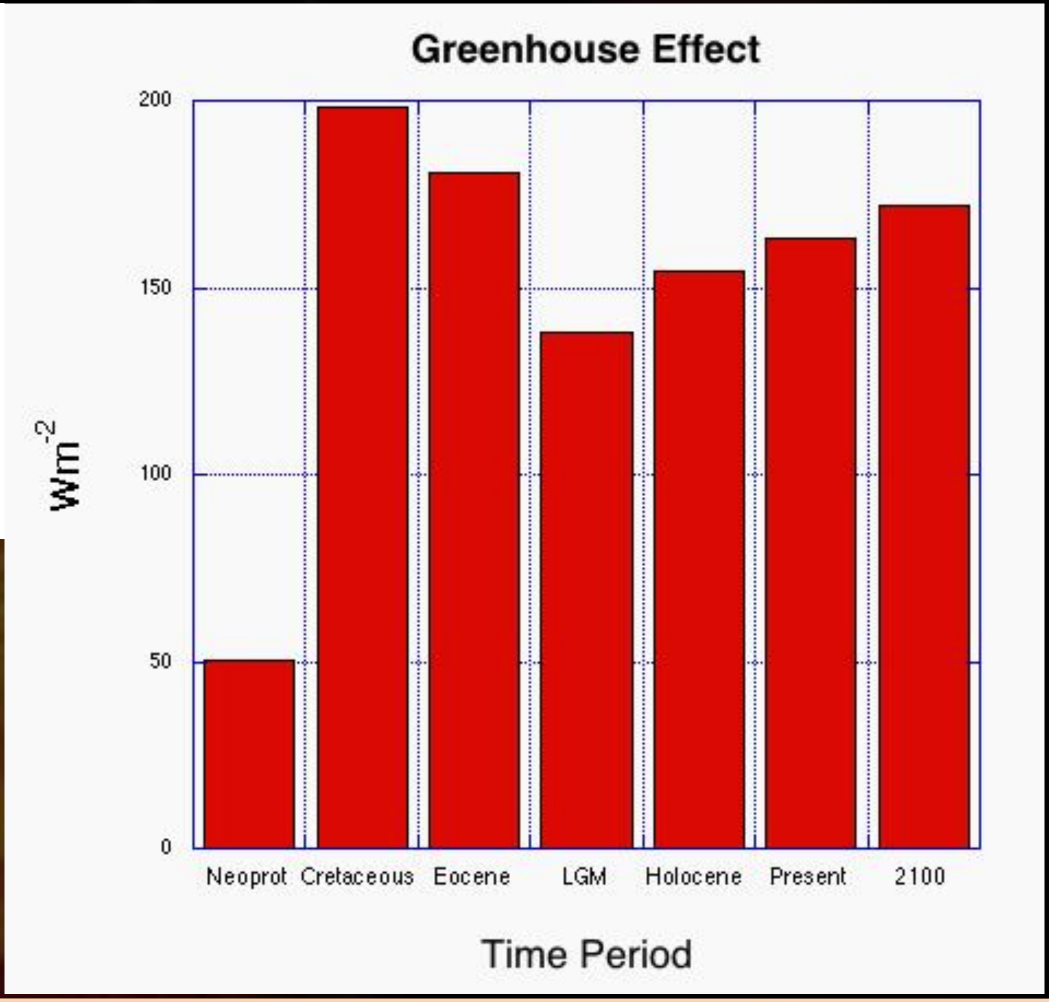
"Mars has global warming, but without a greenhouse and without the participation of Martians. These parallel global warmings -- observed simultaneously on Mars and on Earth -- can only be a straightline consequence of the effect of the one same factor: a long-time change in solar irradiance."

(Financial Post, 2007)

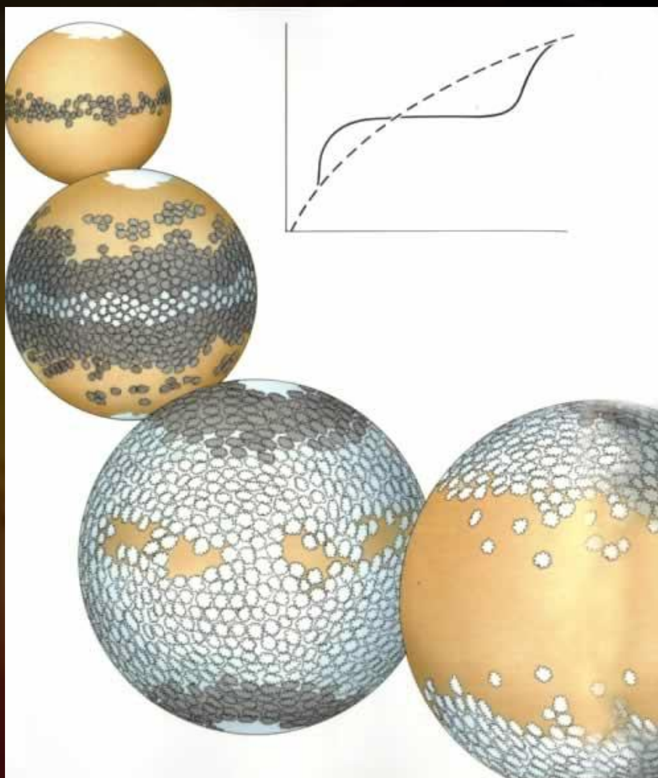


The Greenhouse Effect





Feedback Processes: "Daisyworld"



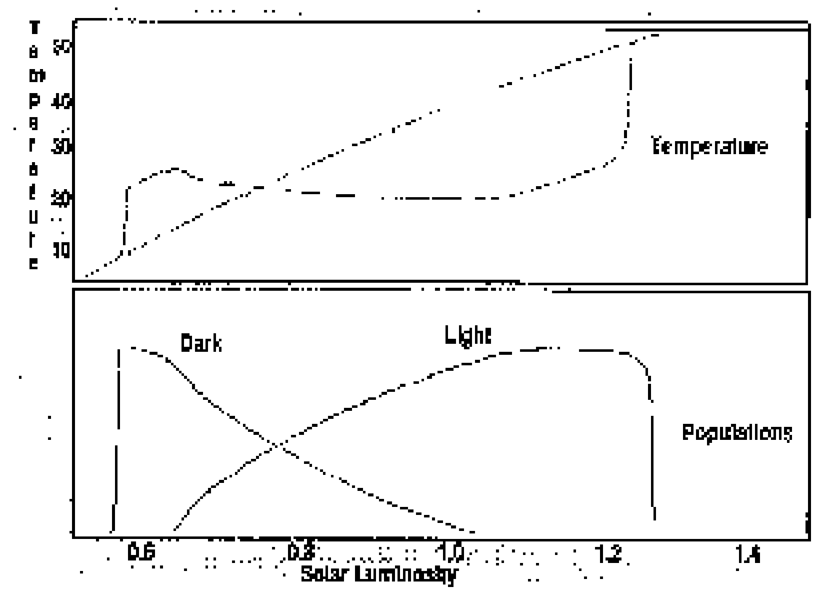


Figure 3. Daisyworld. Dark and light daisy species compete and have a temperature controlling effect in a world where the sun's intensity is increasing.

Overview

- Introduction Climate System (10m)
  - Intro examples: Models all around us (..2)
    - (…overview)
  - What are models for: different objectives but key: process analysis, prediction
    - (…2 : Clim sys slide, text sum)
  - System is an externally forced damped oscillator
    - (… 1 : Mitchell Powerspectrum)
- Range of Climate Models I (5)
  - Key physical laws that govern climate encapsulated by equations depending on perspective: …1
  - 0-D: Planetary Energy Balance (…1)
  - 1-D: Convective, diffusive Model (…1)
- Role of Feedback Mechanisms (5)
  - Daisyworld (…1)
  - Examples real world: Water vapor, Clouds, vegetation, methane (…1)
- Range of Climate Models II (10)
  - 2-D: Meridional transport, or global EBM (…1)
  - Non-Earth: 1 or 2D models quite well adapted: some exception Clouds, Dust on Mars: (…1)
  - EMICs: Intermediate Complexity Models (…1)
  - 3-D: General Circulation Models, comprehensive Earth System Models (…2 movies, 2 slides)
- Current state of the art (15)
  - Climate System representation (…5)
  - Climate Change (…3)
  - Solar Variability and Climate Models (5 minutes …2)
  - Upcoming new components (5 minutes …3)
- Summary (5 …2)