Overview of the CCSM Program

"Cross-cutting Science using CCSM"

Bill Collins

http://www.cgd.ucar.edu/~wcollins

National Center for Atmospheric Research

Boulder, Colorado

- Brief history of the CCSM program
- Evolution of the model from CSM1 to CCSM3
- Challenges in simulating physical climate
- Creation of a 1st generation Earth system model

Thanks to the organizers of the workshop

- Financial resources:
  - Jay Fein (NSF)
  - Annick Pouquet (NCAR)
- Administrative support:
  - Barbara Ballard, Lisa Butler, & Carol Wimert (NCAR)
- Technical support:
  - Nick Wehrheim (NCAR)
- CCSM administrator and workshop coordinator:
  - Lydia Shiver (NCAR)

Thanks to new CCSM management

- Incoming:
  - CCSM Advisory Board:
    - Ricky Rood
  - Working Group co-chairs:
    - Peter Hess (Chem.)
    - David Lawrence (Land)
    - Zhengyu Liu (Paleo.)
    - Sumant Nigam (Variab.)
    - Michael Prather (Chem.)
- Outgoing:
  - CCSM Advisory Board:
    - Max Suarez
  - Working Group co-chairs:
    - Mike Alexander (Variab.)
    - Bette Otto-Bliesner (Paleo.)

Welcome to the International Postdoctoral Network for Earth System Science

http://www.asp.ucar.edu/ess/

International Global Biosphere Project (IGBP)

Analysis Integration Modeling of the Earth System (AIMES)

Organizers:
- Natalie Mahowald (NCAR)
- Peter Rayner (CNRS)
- Rik Leemans (UWag.)
- Marko Schulze (Bristol)
- Kathy Hibbard (NCAR)
- Paula Fisher (NCAR)

The ESS Workshop (June 23-25)

Goals of the workshop:

- Discuss Earth system science modeling/integration
- Develop a network of postdocs working on ESS

Participants in the ESS workshop:

- About 53 postdocs representing 17 countries
- 32 postdocs are also attending this meeting.

Selected highlights of the meeting

- Three plenary sessions:
  - IPCC (Tue.)
  - Paleoclimate and abrupt climate change (Wed.)
  - Challenges of building an Earth System Model (Wed.)

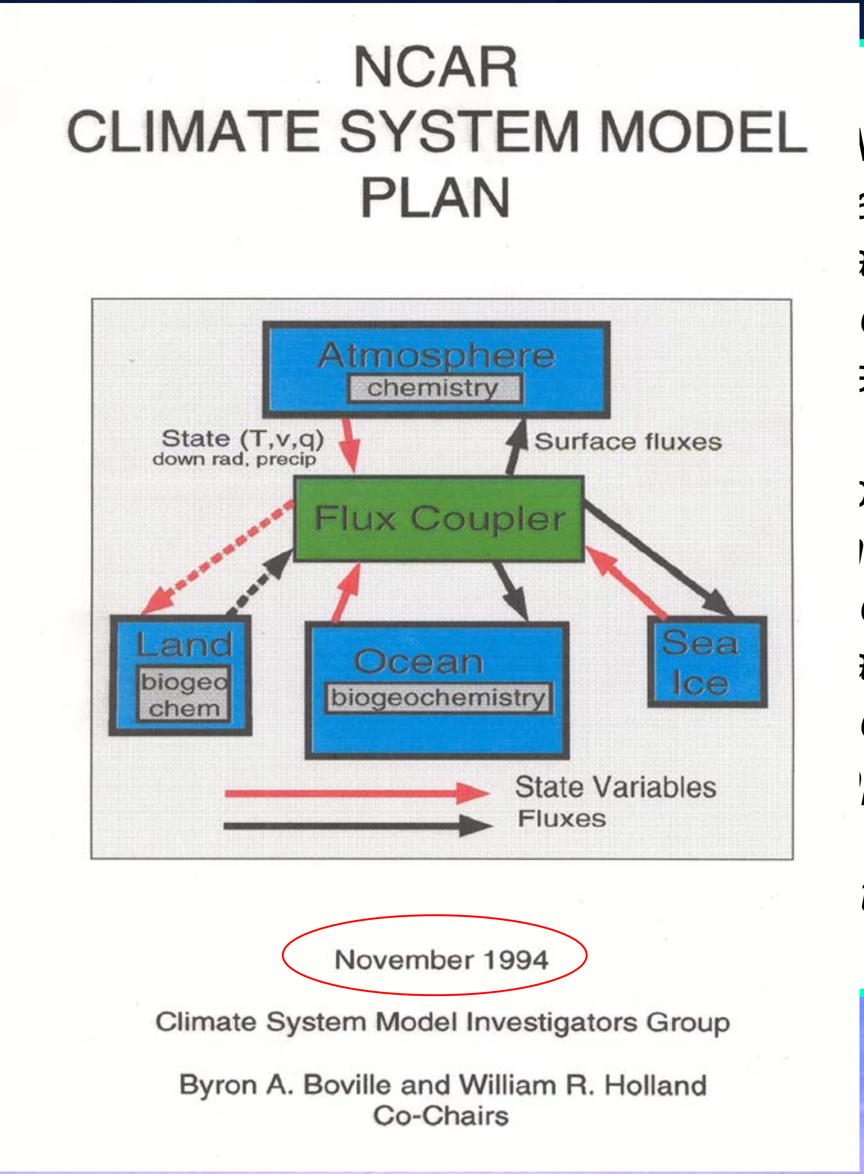
- Poster session (Tue.)

- 10th anniversary celebration cookout (Tue. evening)

Side meetings at the CCSM Workshop

- Mon., June 20:
  - 1st meeting of the Chemistry-Climate WG
  - SciDAC investigators' meeting
- Wed., June 22:
  - Earth system grid meeting
  - Isotope meeting
  - Abrupt Climate Change task group business meeting
- Thu., June 23:
  - Load balancing workshop
- June 23-25:
  - International postdoctoral scientist network for Earth systems' science

Initial planning for the CCSM program



basic schema for
M program:
a coupled model
ate; and
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e interactions

ongoing
ncluding:
of land surfaces;
anic and
chemistry;
per atmospheric

tive atmospheric

Evolution of CCSM

J. Climate, 1998 — **CSM 1.0** — June 1996

New ocean, land, sea-ice models
New physics in atmosphere

Kiehl & Gent, 2004 — **CCSM 2.0** — May 2002

New physics in all models

J. Climate, 2006
IJHPCA, 2005 — **CCSM 3.0** — June 2004

Journal of Climate CCSM3 Special Issue

http://www.ccsm.ucar.edu/publications

Group	Authors	Title
SSC	Collins et al	The Community Climate System Model: CCSM3
AMWG	Collins et al	The Formulation and Atmospheric Simulation of the Community Atmosphere Model: CAM3
AMWG	Boville et al	Representation of Clouds and Precipitation Processes in the Community Atmosphere Model (CA
AMWG	Hack et al	Simulation of the Global Hydrological Cycle in the CCSM Community Atmosphere Model (CAM3)
AMWG	Rasch et al	Characterization of Tropical Transient Activity in the CAM3 Atmospheric Hydrologic Cycle
AMWG	Rasch et al	Characteristics of Atmospheric Transport Using Three Numerical Formulations
AMWG	Hack et al	CCSM CAM3 Climate Simulation Sensitivity to Changes in Horizontal Resolution
CCWG	Meehl et al	Climate Change in the 20th and 21st Centuries and Climate Change Commitment in the CCSM3
CCWG	Kiehl et al	The Climate Sensitivity of the Community Climate System Model: CCSM3

Journal of Climate CCSM3 Special Issue

http://www.ccsm.ucar.edu/publications

Group	Authors	Title
LMWG	Dickinson et al	The Community Land Model and Its Climate Statistics as a Component of CCSM
LMWG	Bonan and Levis	Evaluating Aspects of the CAM and CLM Using a Dynamic Global Vegetation Model
OMWG	Large and Danabasoglu	Attribution and Impacts of Upper Ocean Biases in CCSM3
OMWG	Danabasoglu et al	Diurnal Ocean-Atmosphere Coupling
OMWG	Gent et al	Ocean Chlorofluorocarbon and Heat Uptake During the 20th Century in the CCSM3
OMWG	Bryan et al	Response of the North Atlantic Thermohaline Circulation and Ventilation to Increasing CO2
PaleoWG	Otto-Bliesner et al	Last Glacial Maximum and Holocene Climate in CCSM3
PaleoWG	Yeager et al	Low Resolution CCSM3
PaleoWG	Otto-Bliesner et al	Climate Sensitivity of Low Resolution Versions of CCSM3 to Preindustrial Forcings
PCWG	Holland et al	Influence of the Sea Ice Thickness Distribution on Polar Climate in CCSM3
PCWG	DeWeaver and Bitz	Atmospheric Circulation and Its Effect on Arctic Sea Ice in CCSM3 Simulations
PCWG	Bitz et al	The Influence of Sea Ice on Ocean Heat Uptake in Response to Increasing CO2
PCWG	Qu and Hall	Assessing Snow Albedo Feedback in Simulated Climate Change

Int. J. of High Performance Computing Applications

Special Issue, August, 2005 (Vol. 18, #3)

Author	Title
The Editors	Preface
Drake, John	Overview of the Software Design and Parallel Algorithms of the CCSM
Worley, Pat	Software Design for Performance Portability in the Community Atmosphere Model
Mirin, Art	A Scalable Implementation of a Finite-Volume Dynamical Core in the Community Atmosphere Model
Putman,Bill	Cross-platform performance of a Portable Communications Module the NASA Finite Volume General Circulation Model
Taylor, Mark	High Resolution Mesh Convergence Properties and Parallel Efficiency of a a Spectral Element Atmospheric Dynamical Core
Ghan, Steven	Load Balancing and Scalability of a Subgrid Orography Scheme in a Global Climate Model
Hoffman, Forrest	Vectorizing the Community Land Model (CLM)
Kerbyson, Darren	A Performance Model of the Parallel Ocean Program
Jacob, Rob	The Model Coupling Toolkit: A new Fortran90 toolkit for building multi-physics parallel coupled models.
Jacob, Rob	cpl6: The New Extensible, High-Performance Parallel Coupler for the Community Climate System Model.
Jacob, Rob	MxN communication and parallel interpolation in CCSM3 using the Model Coupling Toolkit.
Ding, Chris	Coupling multi-component models by MPH on distributed memory computer architectures
Deluca, Cecelia	Design and Implementation of Earth System Modeling Framework Components

Evolution of our climate simulations

CSM 1.0 — *June 1996*

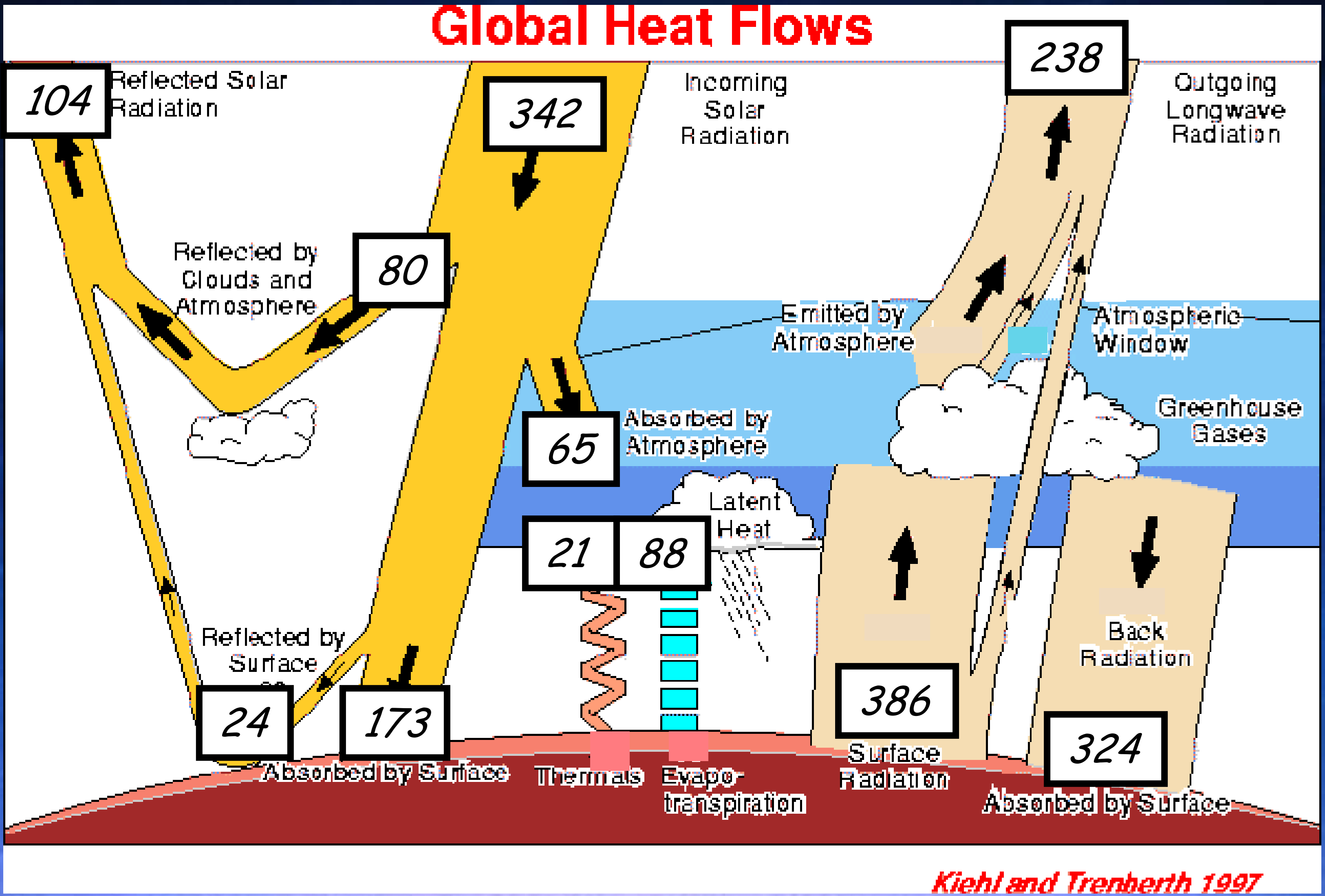
New ocean, land, sea-ice models
New physics in atmosphere

CCSM 2.0 — *May 2002*

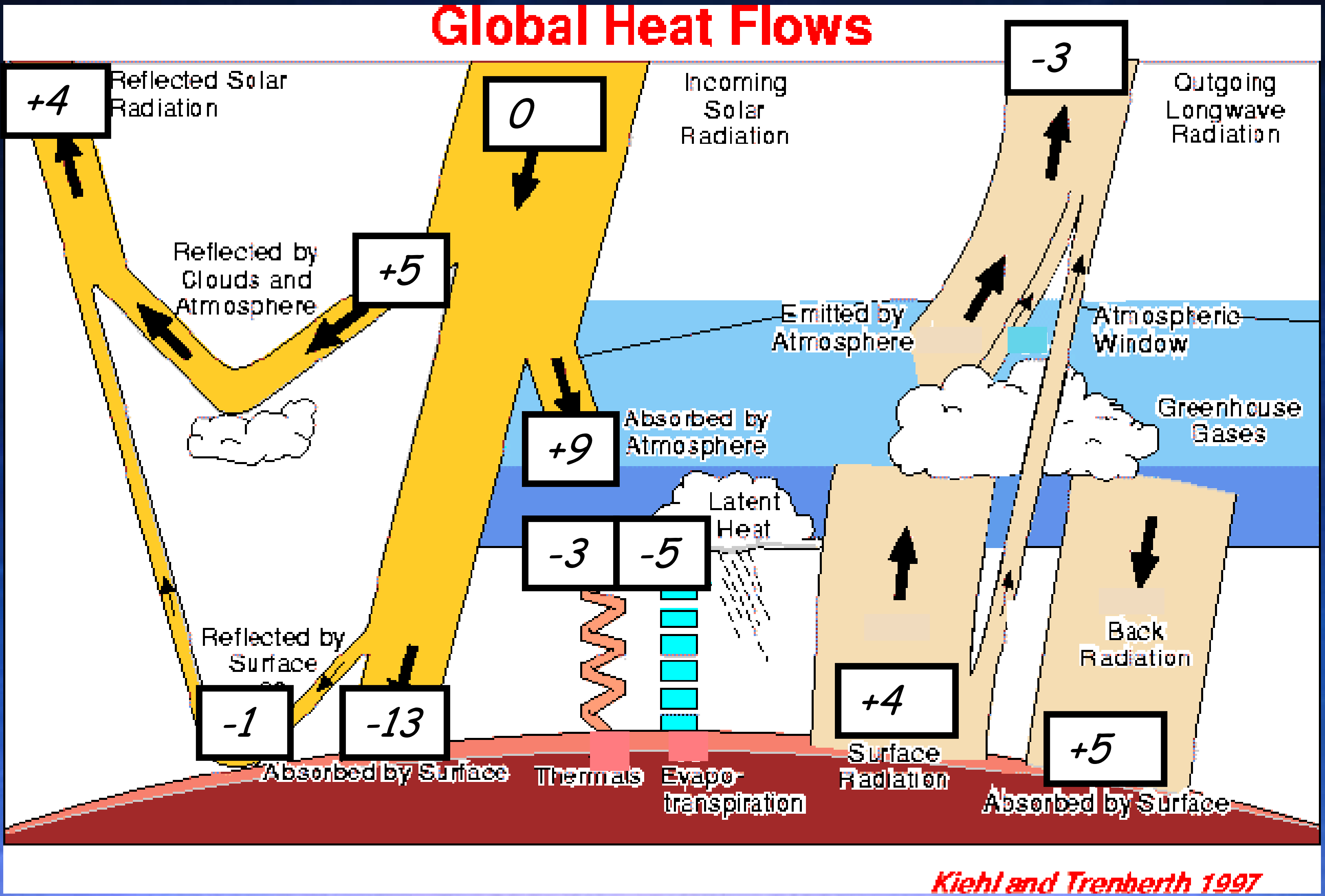
New physics in all models

CCSM 3.0 — *June 2004*

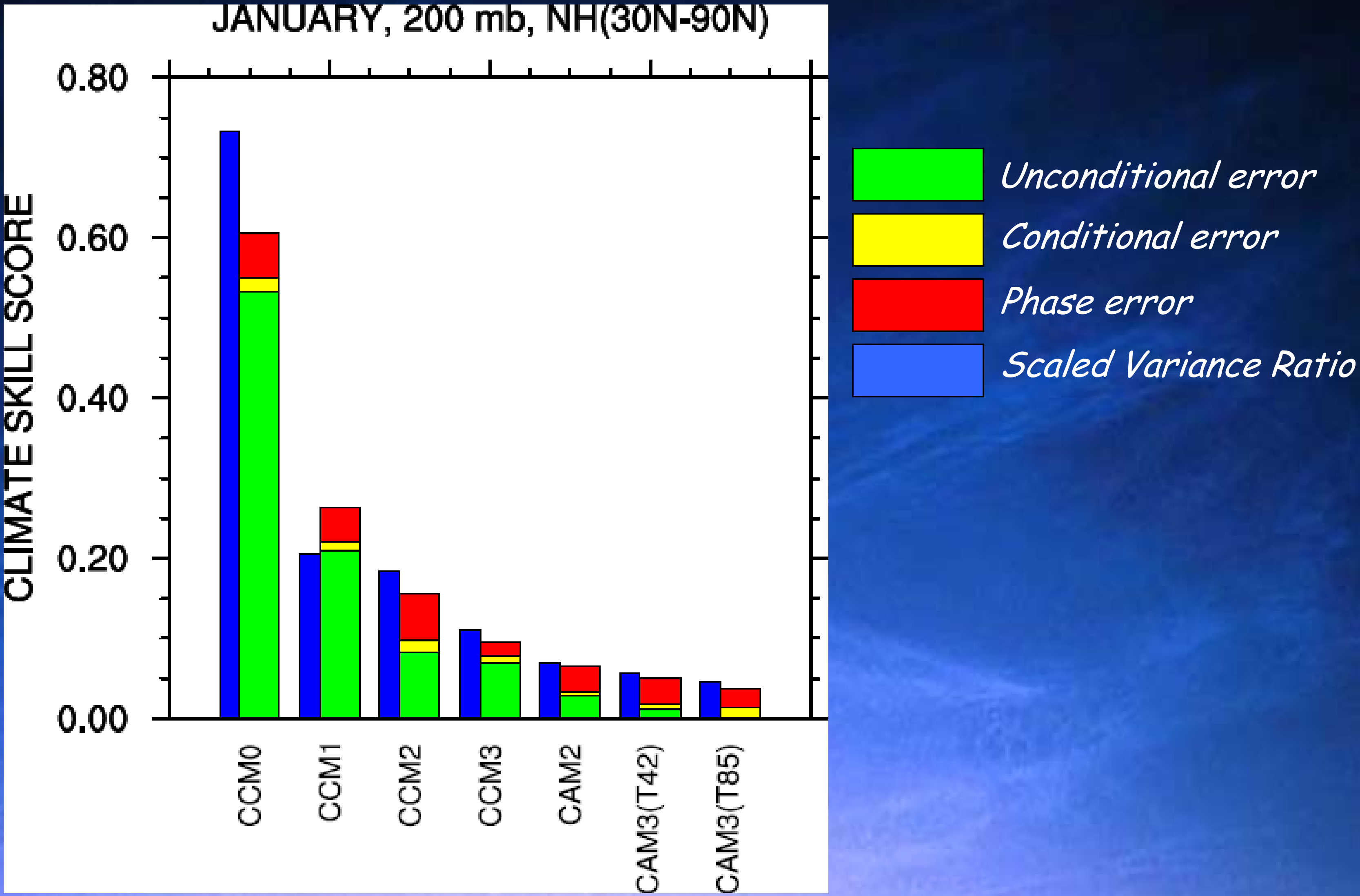
Energy balance of CSM1



Change in energy balance: CSM1→CCSM3

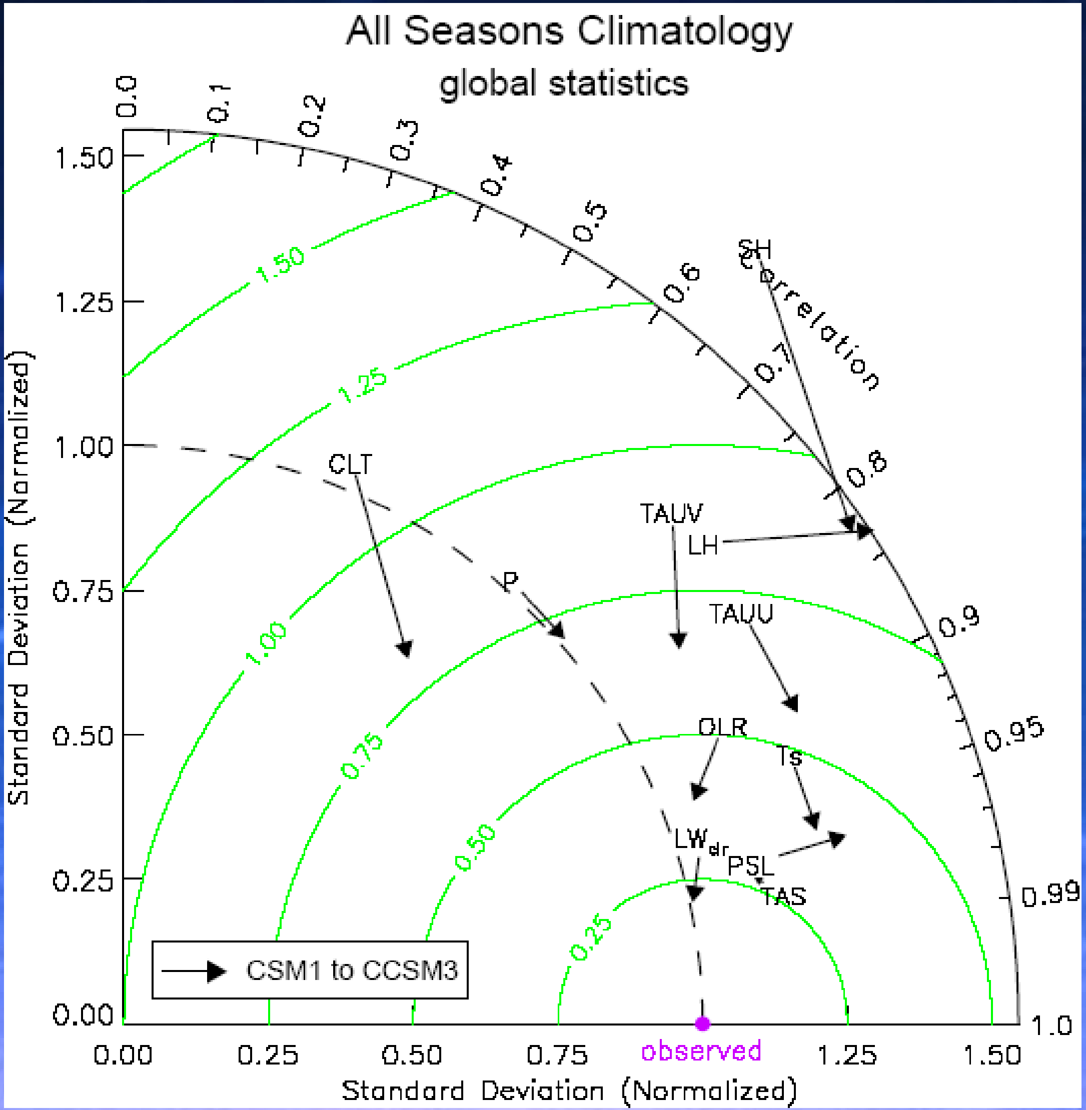


Improvements in Atmospheric Fidelity



D. Williamson, in Collins et al, 2005

Fidelity of Global Seasonal Patterns

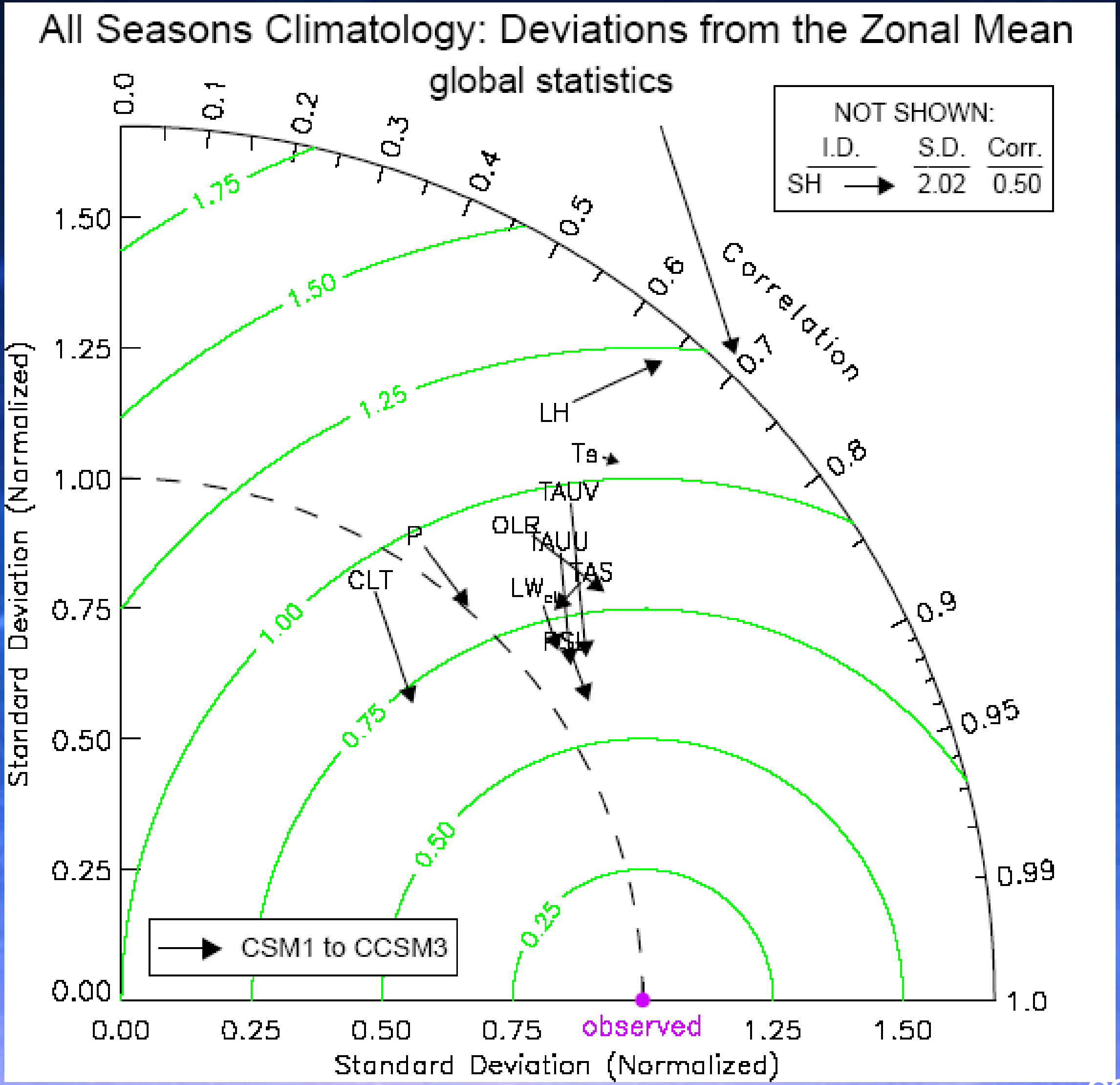


Taylor, Gleckler, and Wehner

CCSM Meeting
6/ 2005, Breckenridge

Fidelity of Global Seasonal Patterns

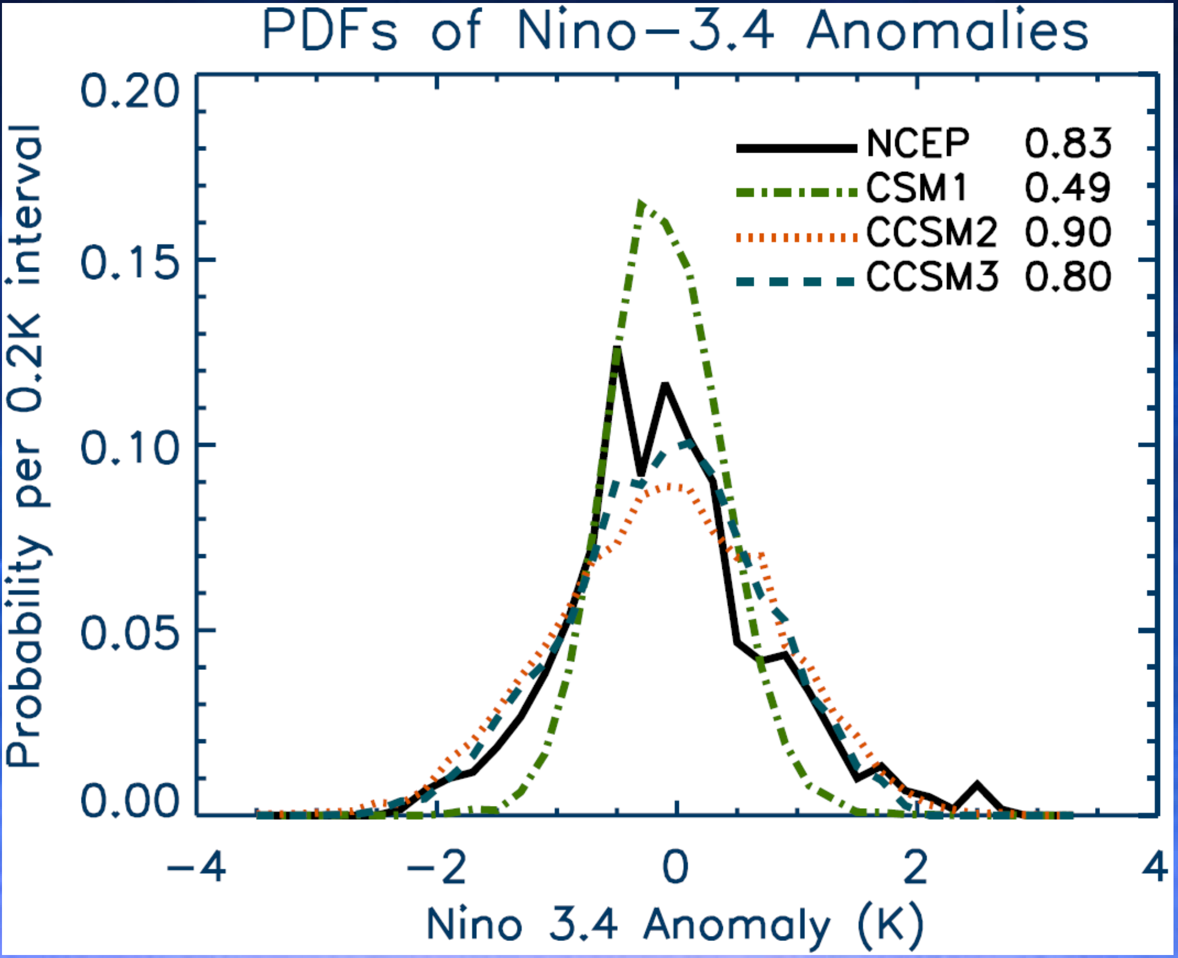
(zonal mean removed)



Taylor, Gleckler, and Wehner

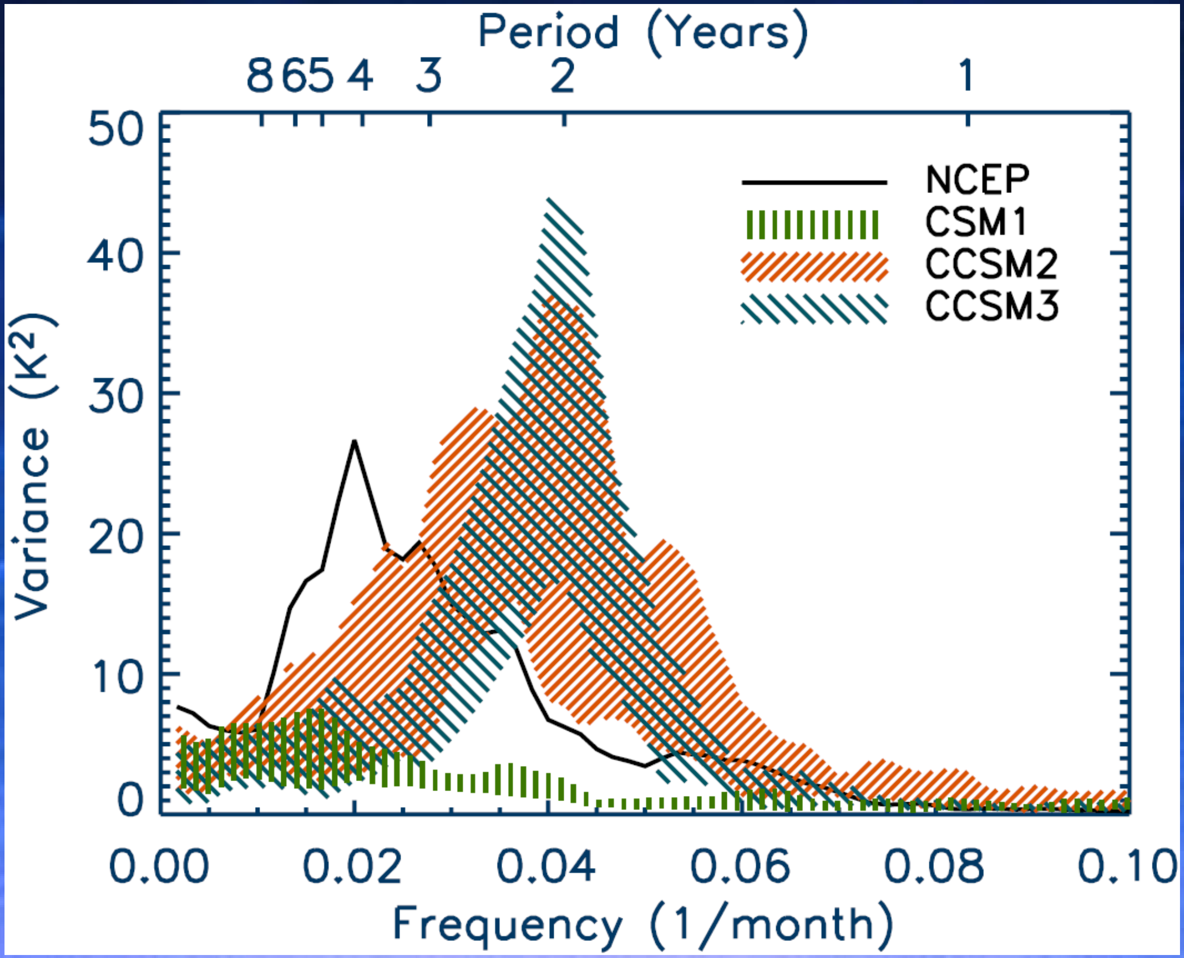
CCSM Meeting
6/ 2005, Breckenridge

ENSO Variance



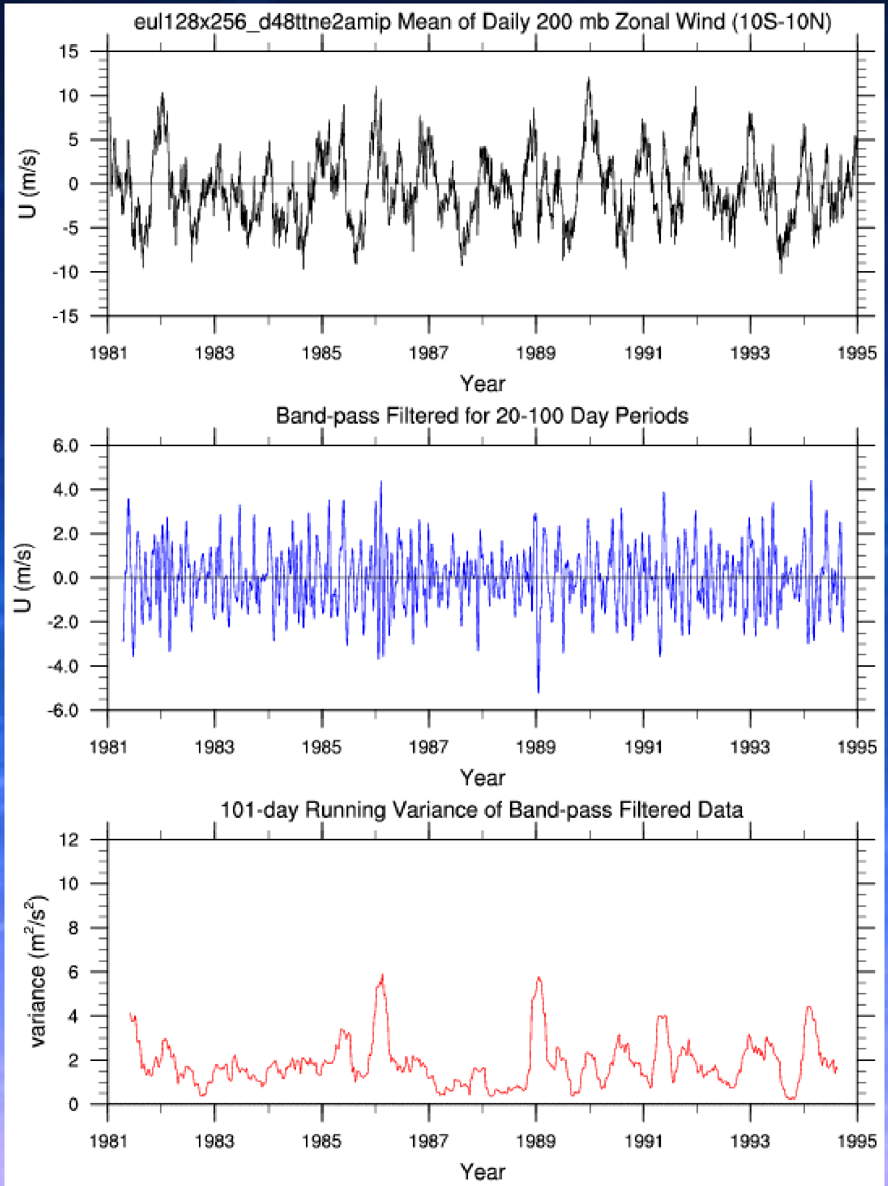
Collins et al, 2005

ENSO Power Spectra



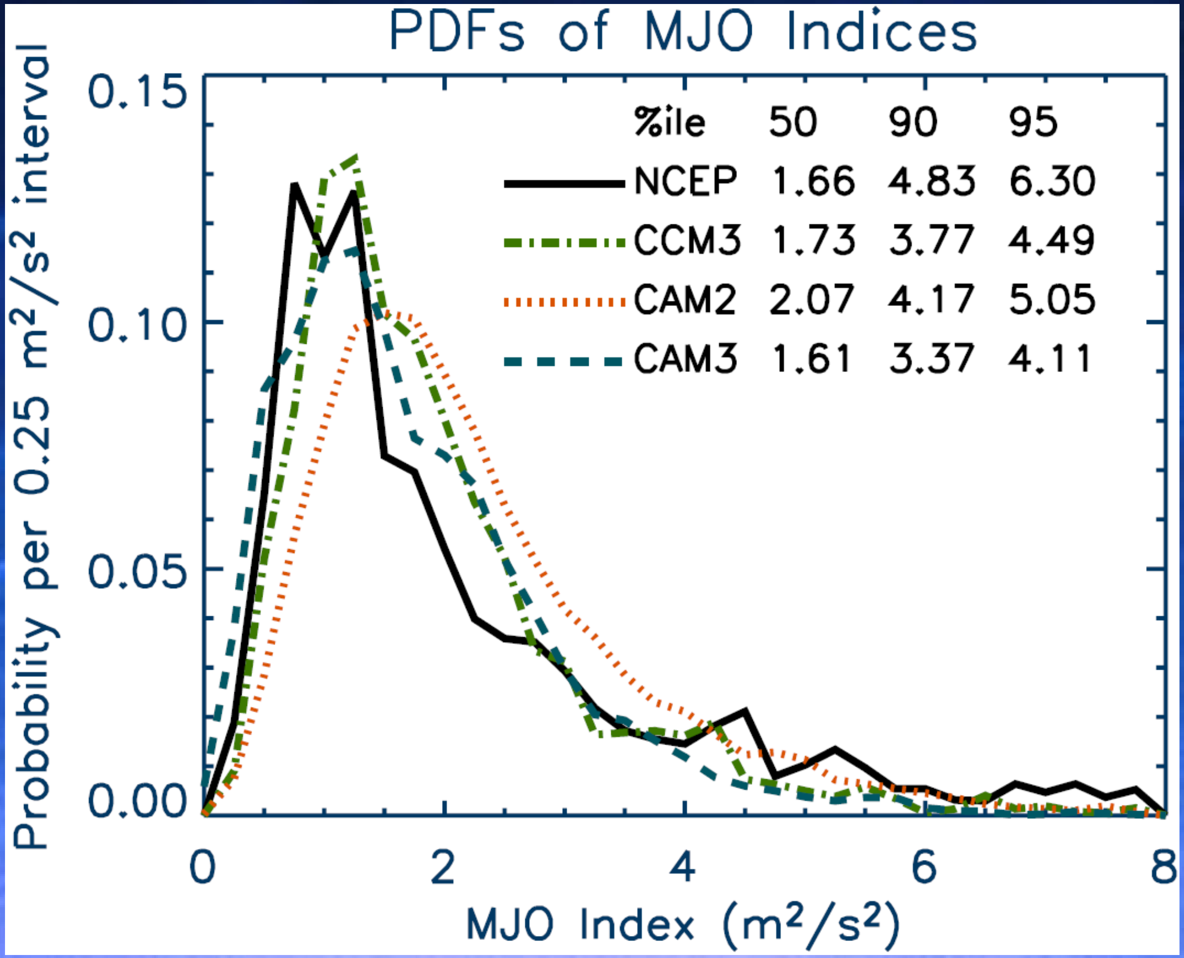
Gent and Kiehl, 2004; Collins et al, 2005

MJO Index



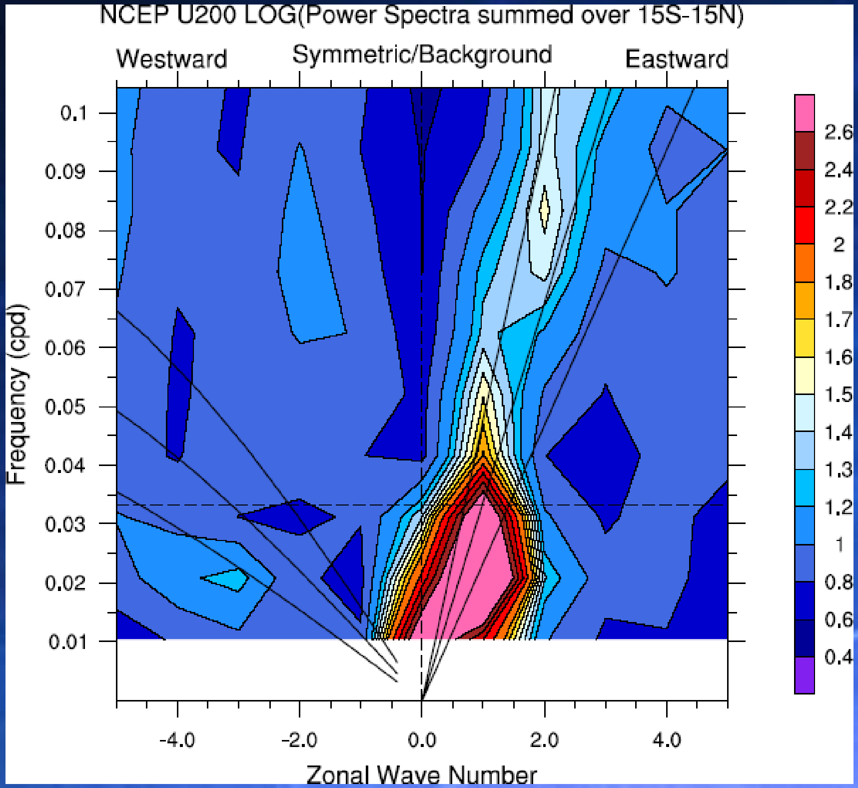
eul128x256_d48ttne2amip Mean of Daily 200 mb Zonal Wind (10S-10N)
U (m/s)
15
10
5
0
-5
-10
-15
1981
1983
1985
1987
1989
1991
1993
1995
Year
Band-pass Filtered for 20-100 Day Periods
U (m/s)
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
1981
1983
1985
1987
1989
1991
1993
1995
Year
101-day Running Variance of Band-pass Filtered Data
variance (m²/s²)
12
10
8
6
4
2
0
1981
1983
1985
1987
1989
1991
1993
1995
Year

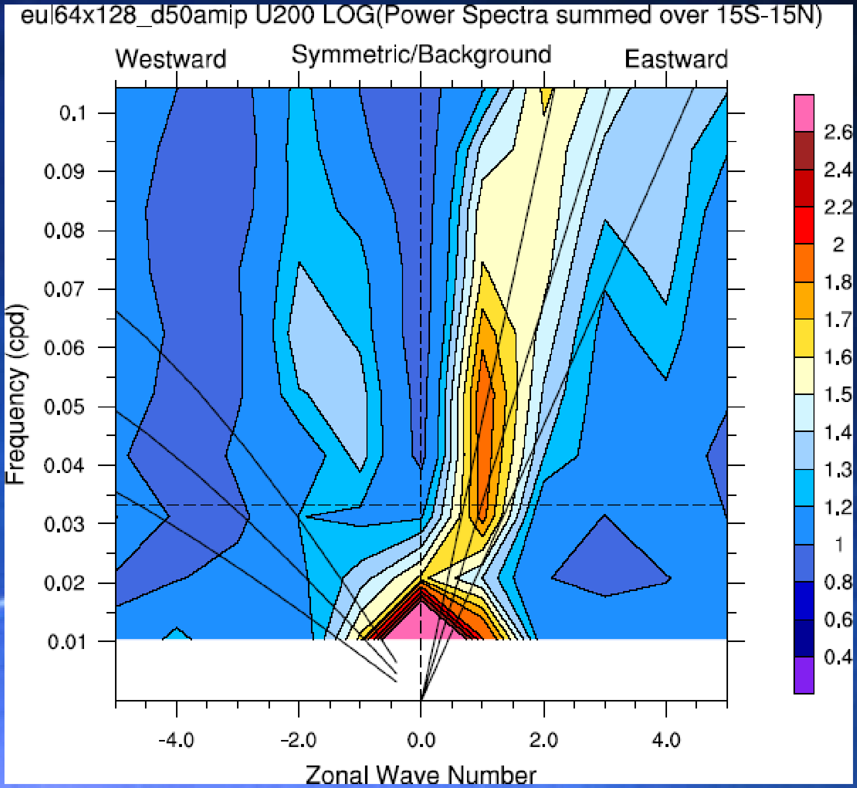
MJO Variance



Collins et al, 2005

MJO Propagation





Scientific objectives for the near future

- Major objective:
  Develop, characterize, and understand
  the most realistic and comprehensive model of the observed climate system possible.

- Subsidiary objectives:
  - Analyze and reduce the principal biases in our physical climate simulations using state-of-the-art theory and observations.
  - Simulate the observed climate record with as much fidelity as possible.
  - Simulate the interaction of chemistry, biogeochemistry, and climate with a focus on climate forcing and feedbacks.

Processes for chemistry-climate interactions

- The project has developed representations of:
  - Reactive chemistry in the troposphere
  - Detailed physics & chemistry of the upper atmosphere
  - Prognostic aerosols
  - Terrestrial biogeochemistry
  - Representations of land-use change & urbanization
  - Oceanic ecosystem dynamics & biogeochemistry
- These components are running now.
- Initial simulations are underway to study their stability, dynamics, and effects on climate.

Recent evolution of climate forcing

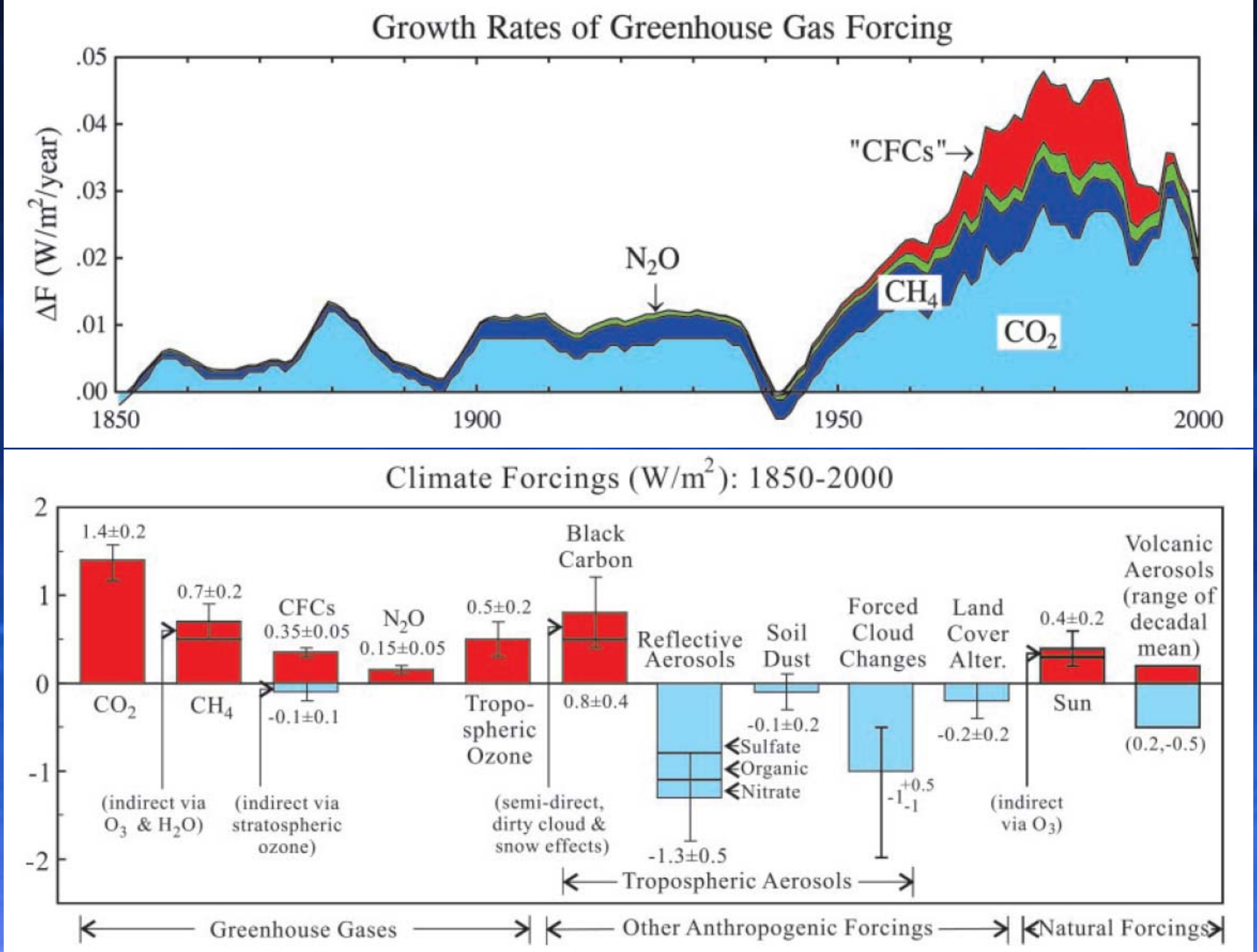
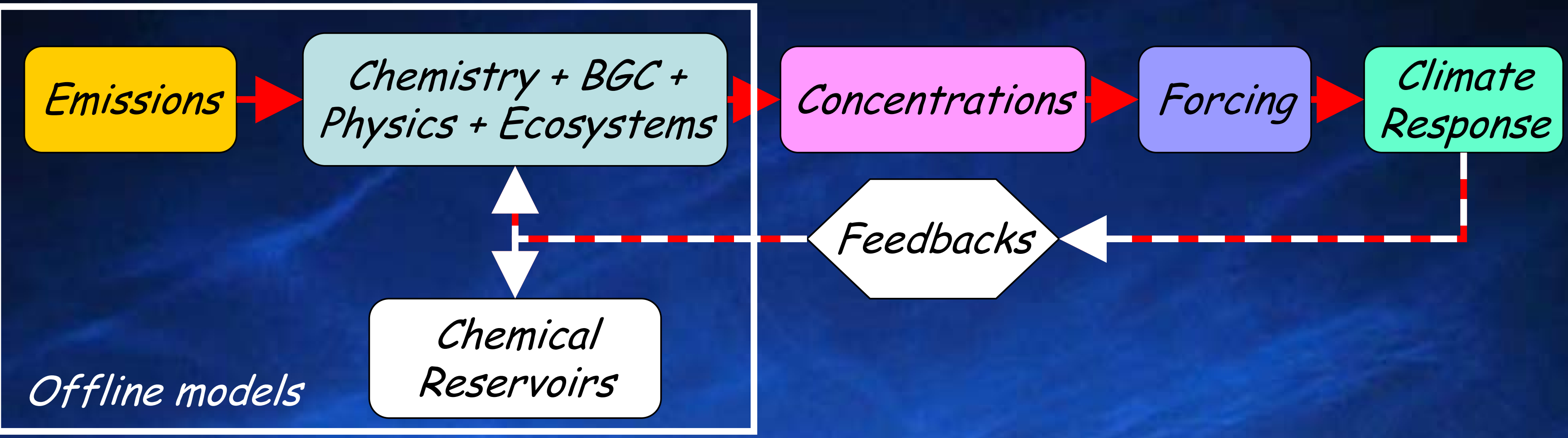


Fig. 1. Estimated climate forcings; error bars are partly subjective 1σ uncertainties.

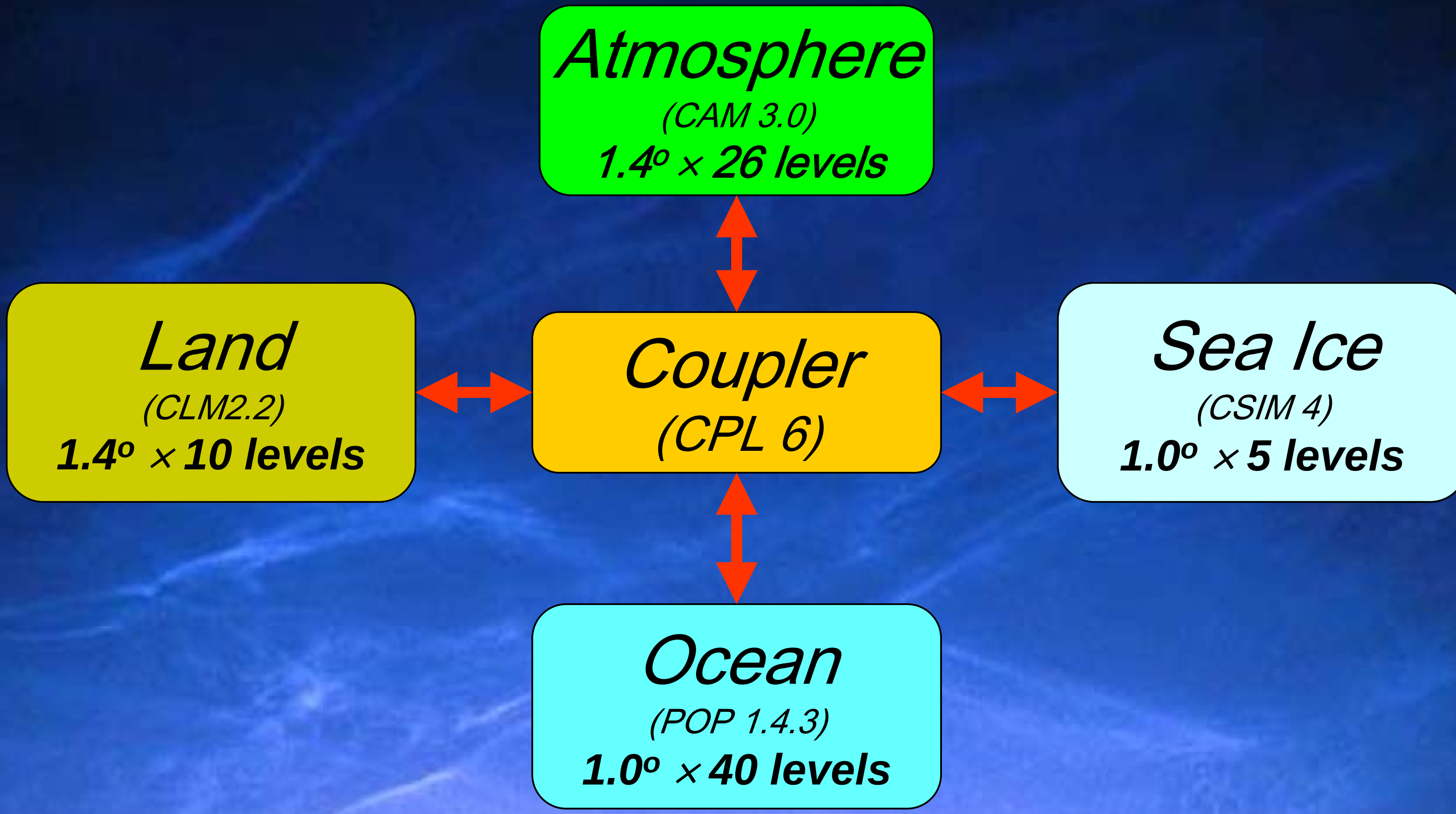
Hansen and Sato, 2001

Simulating the chemical state of the climate system



- In the past, we have generally used offline models to predict concentrations and read these into CCSM.
- This approach is simple to implement, but
  - It cuts the feedback loops.
  - It eliminates the chemical reservoirs.
- The next CCSM will include these interactions.

Configuration of NCAR CCSM3

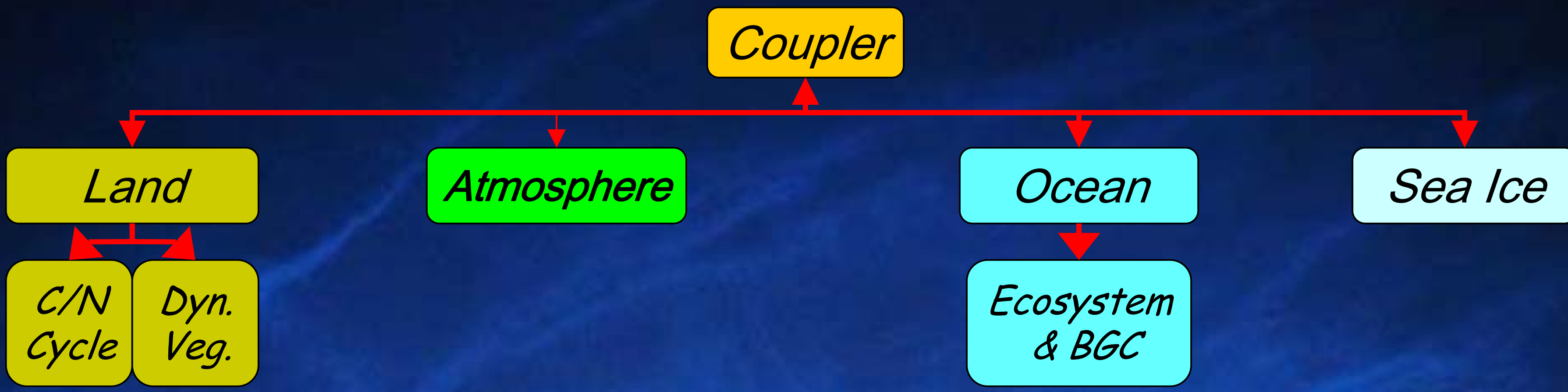


http://www.ccsm.ucar.edu

Collins et al, 2005

CCSM Meeting
6/ 2005, Breckenridge

Extension of CCSM3 to a 1st generation Earth system model



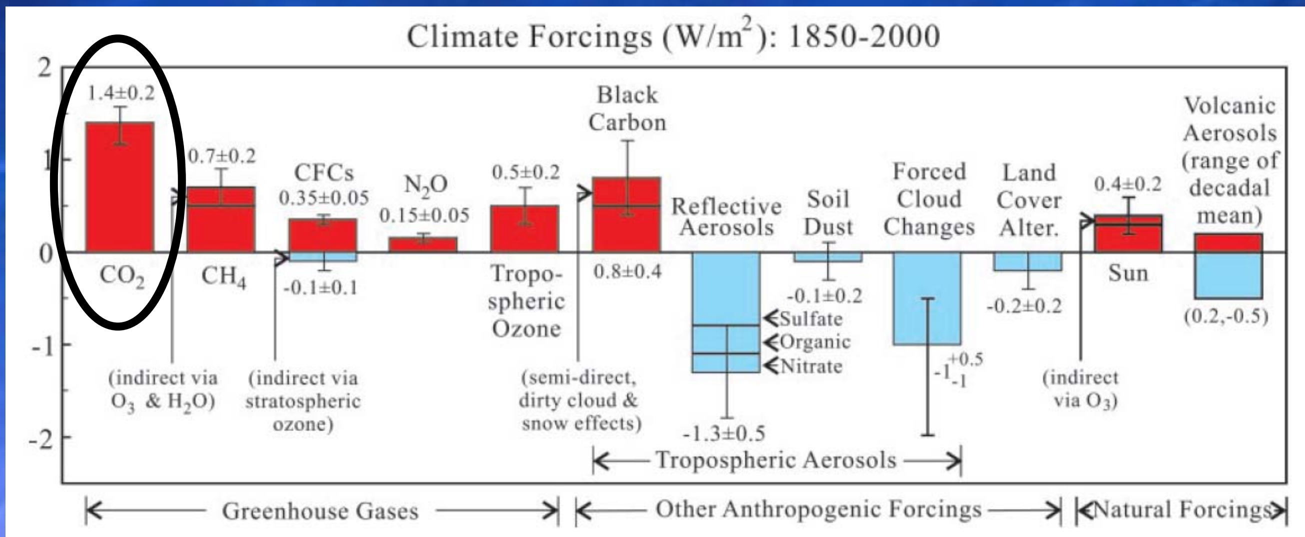
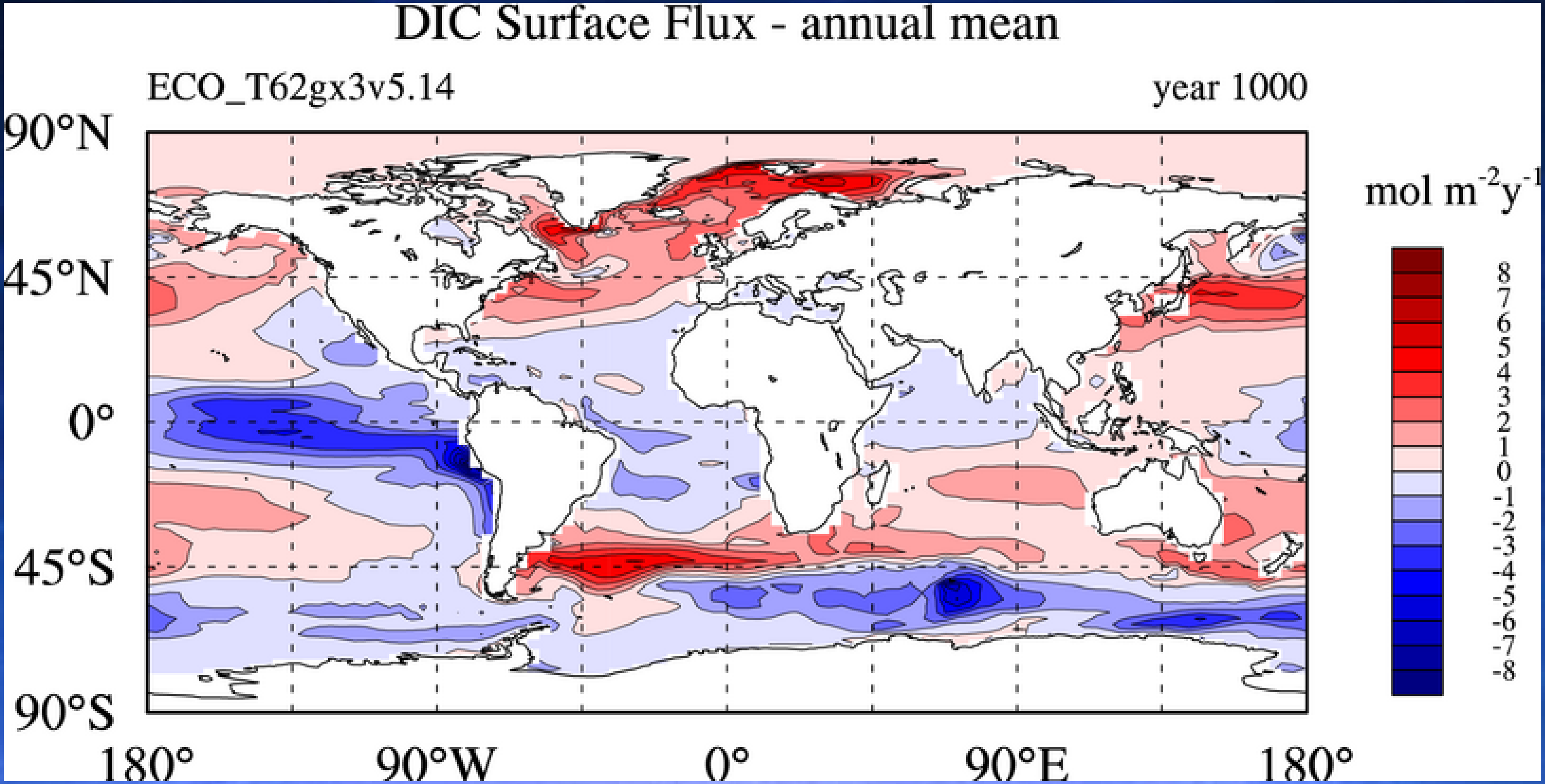


Fig. 1. Estimated climate forcings; error bars are partly subjective 1σ uncertainties.

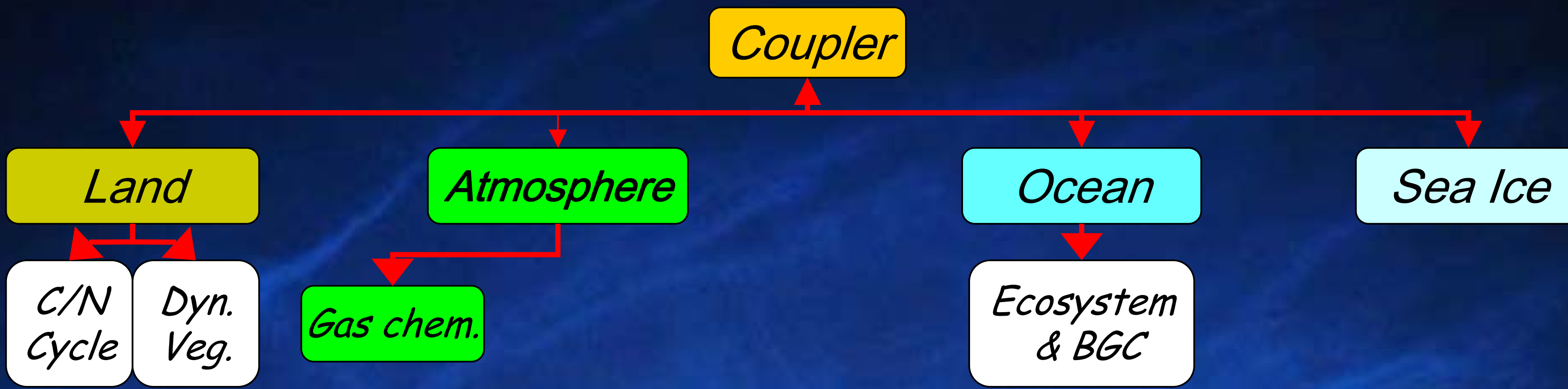
Flux of CO_2 into the world oceans

(Ocean ecosystem model)



Moore, Doney, and Lindsay

Tropospheric Ozone



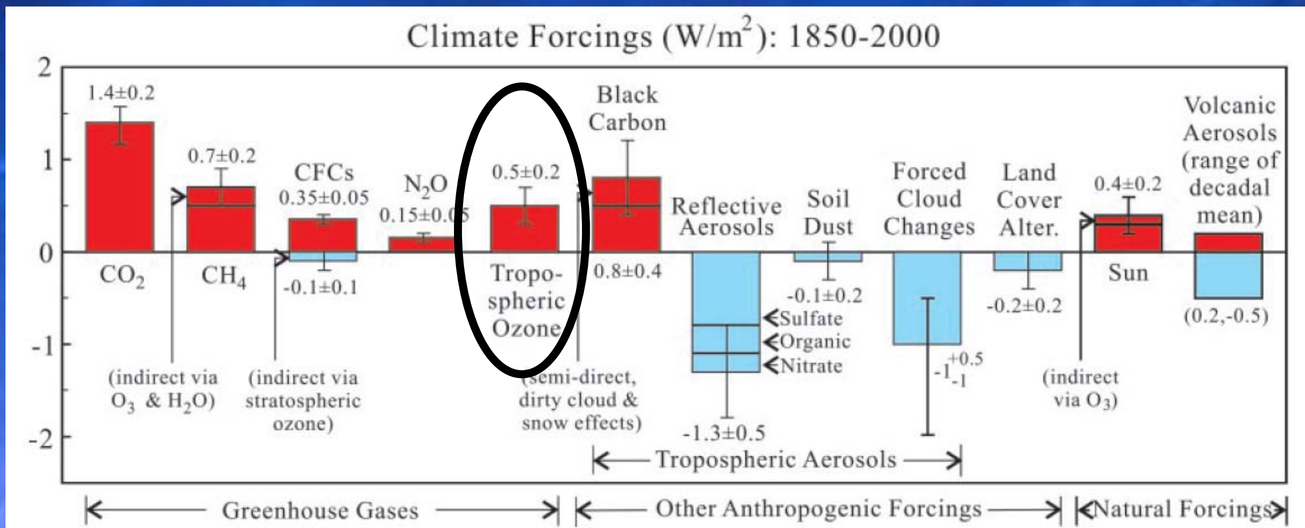
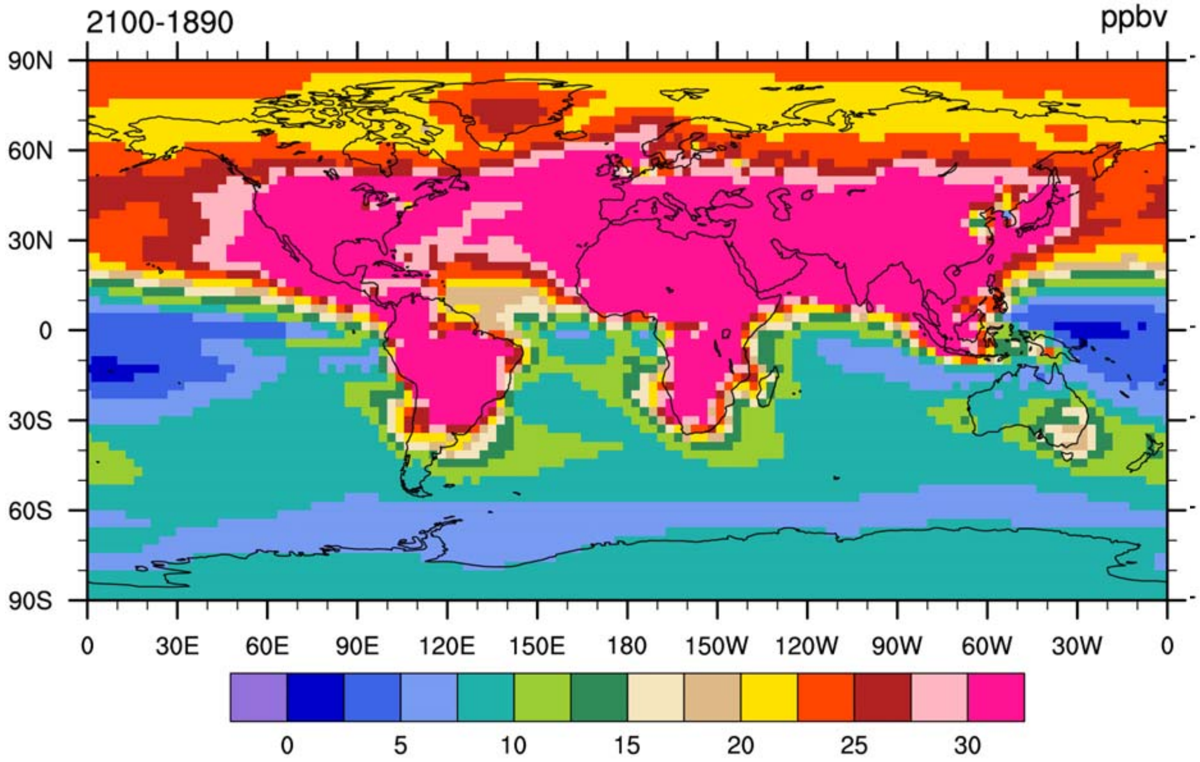


Fig. 1. Estimated climate forcings; error bars are partly subjective 1σ uncertainties.

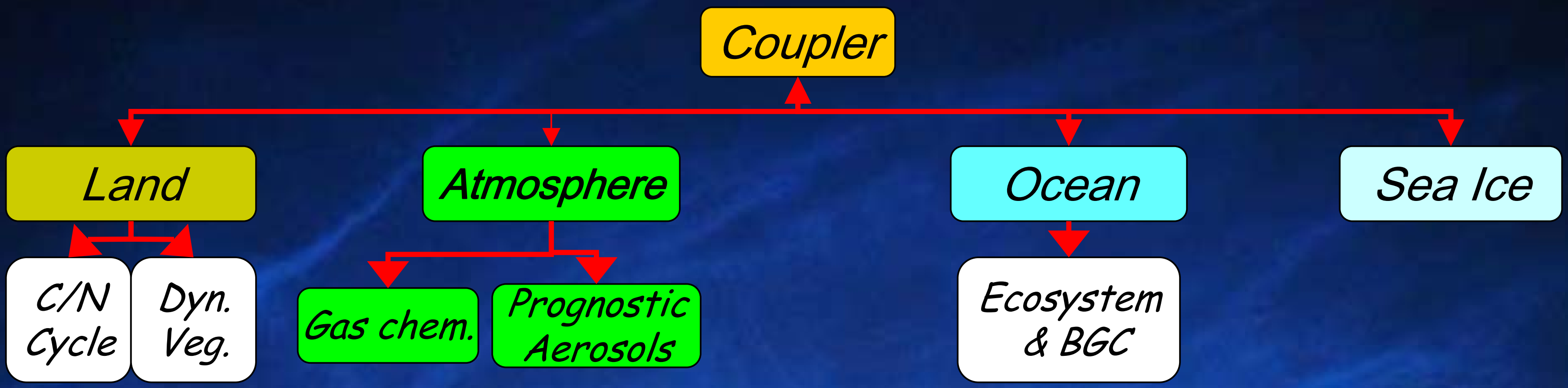
Evolution of tropospheric ozone

(1890-2100, following A2 scenario)



Lamarque et al, 2005

Tropospheric Aerosols



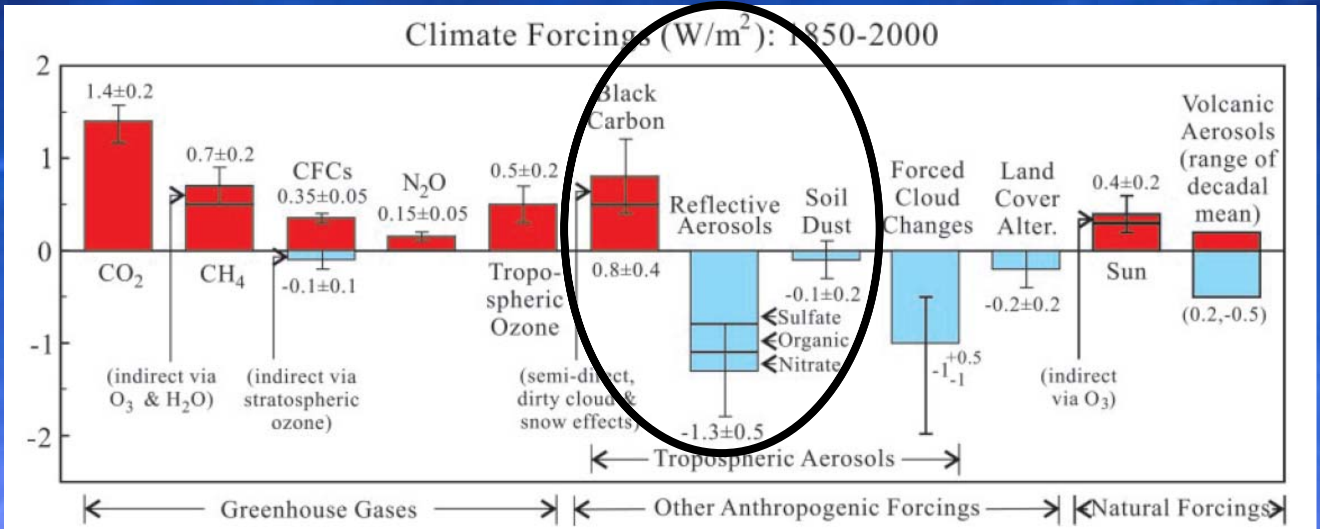
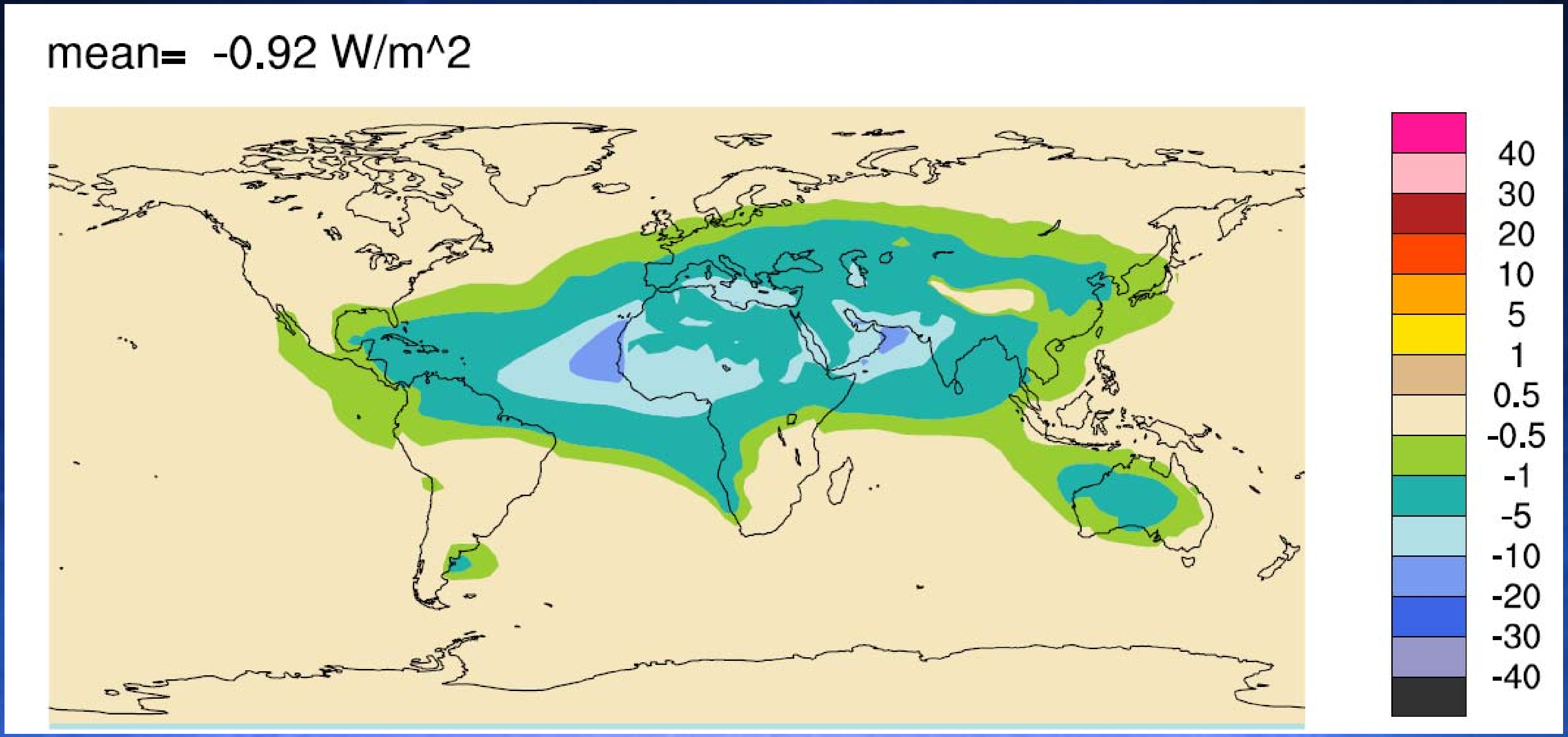


Fig. 1. Estimated climate forcings; error bars are partly subjective 1σ uncertainties.

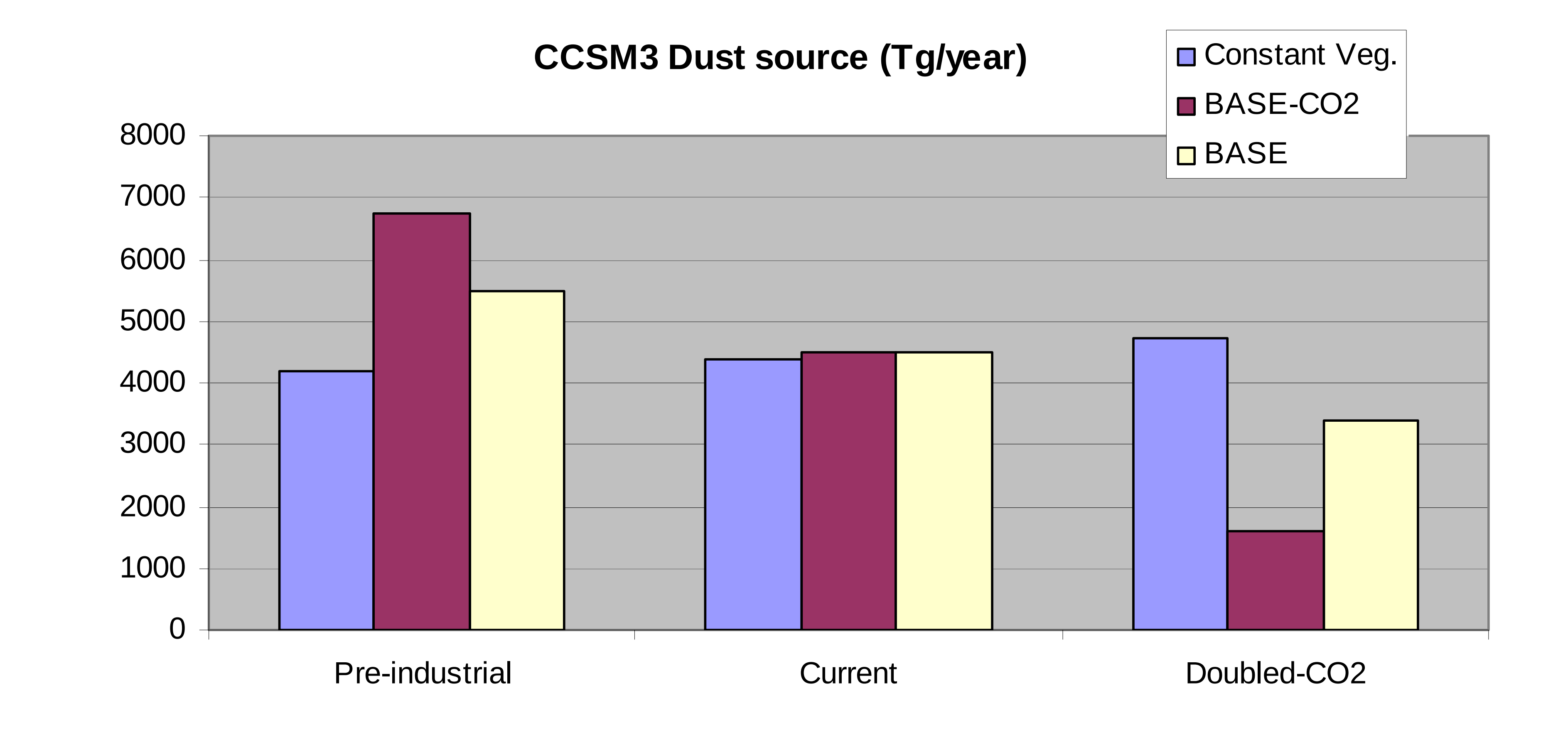
TOA Shortwave Forcing by Dust

(1995-2000)



Mineral aerosol source sensitivity to anthropogenic climate change

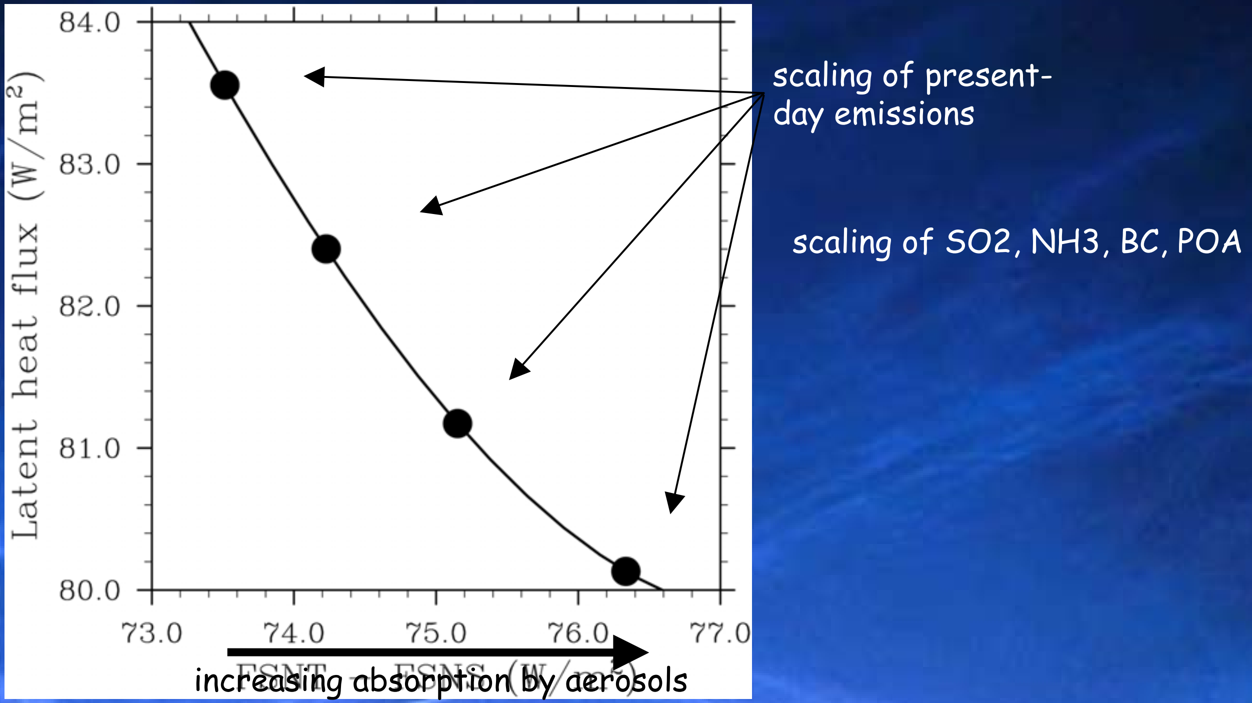
(no land use, water use changes included)



- **Large sensitivity due to changes in source areas**
- **If include impacts of carbon dioxide fertilization of vegetation, source 50% larger in pre-industrial and 60% lower in future compared with today.**
- **If only include impacts of precipitation and surface wind changes source 20% larger in preindustrial, and 25% smaller in future compared with today.**

Mahowald et al. in prep

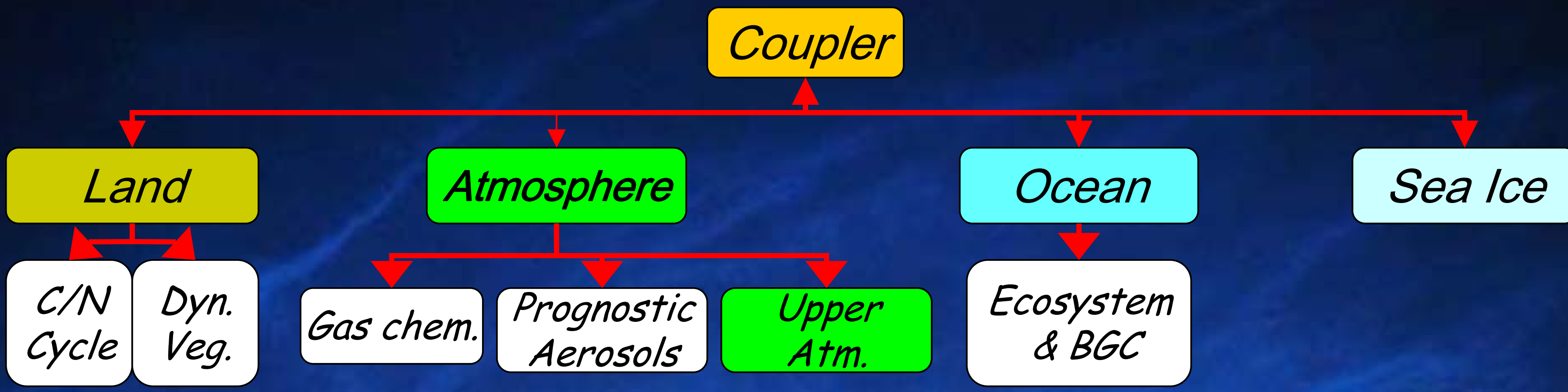
Response of the chemistry-climate system to changes in aerosols emissions.



The hydrological cycle (measured by the global integral of the latent heat flux) slows down with increasing aerosol loading

Lamarque and Kiehl

Solar Forcing



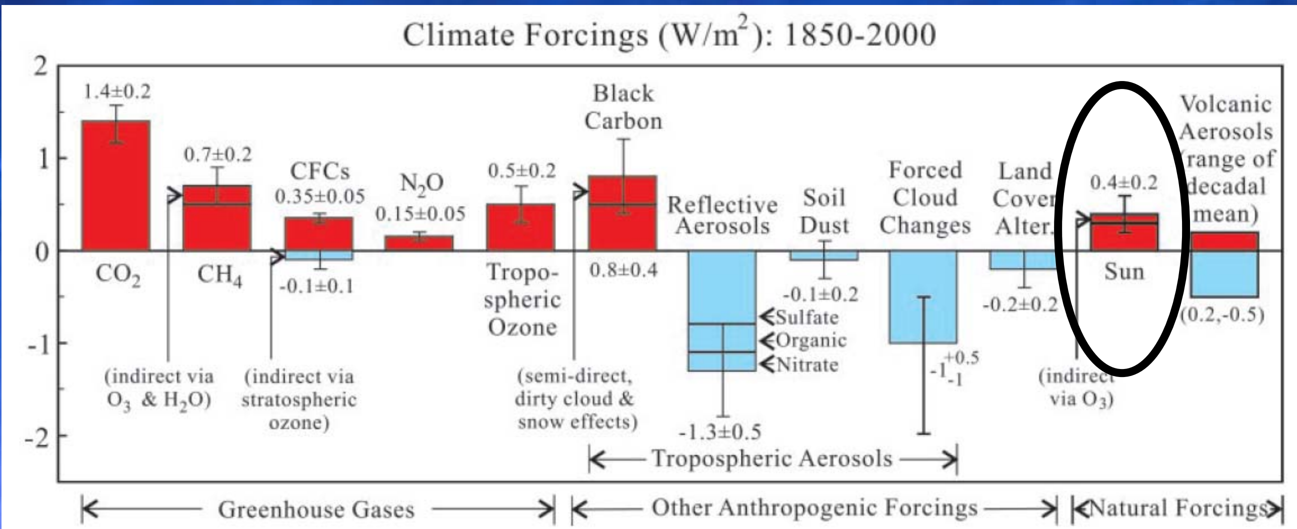
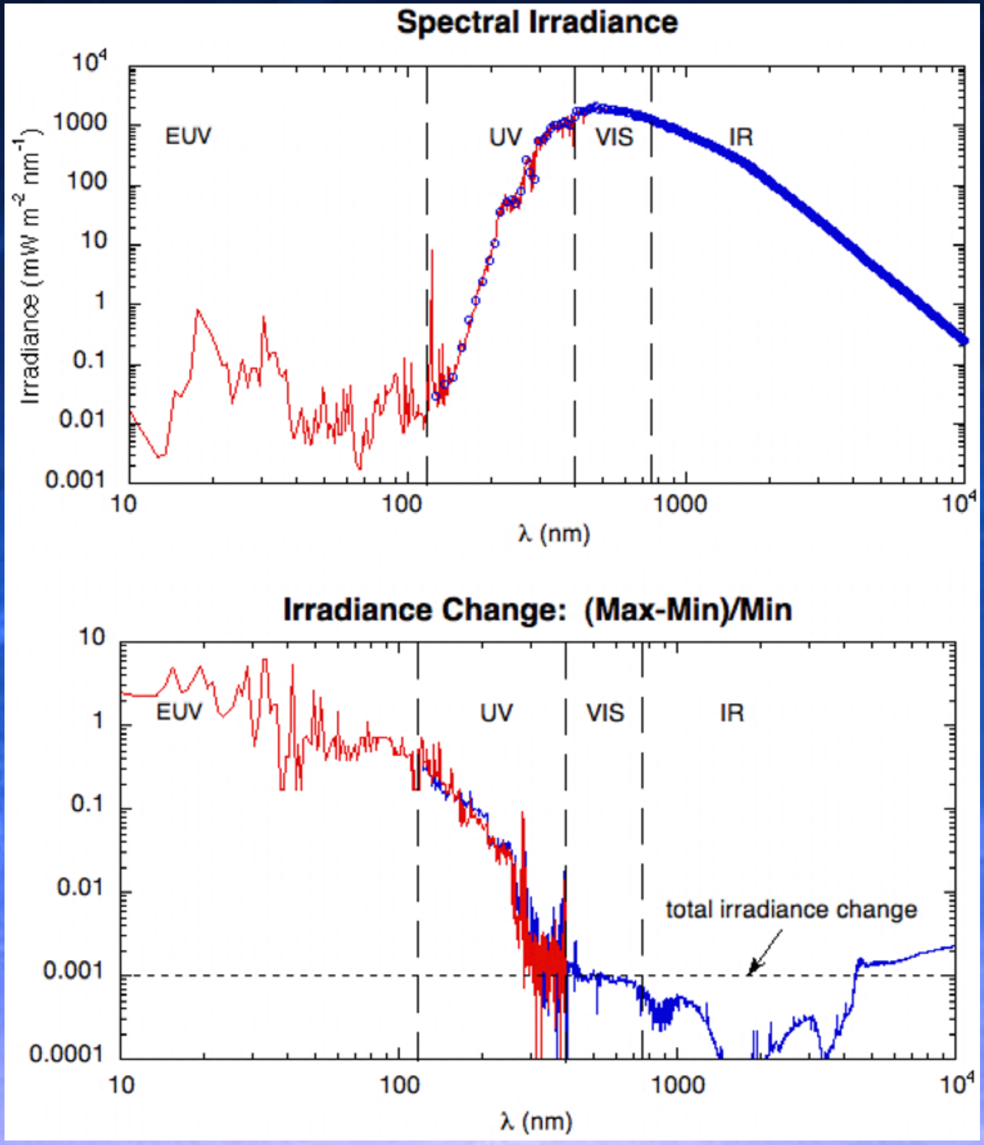


Fig. 1. Estimated climate forcings; error bars are partly subjective 1σ uncertainties.

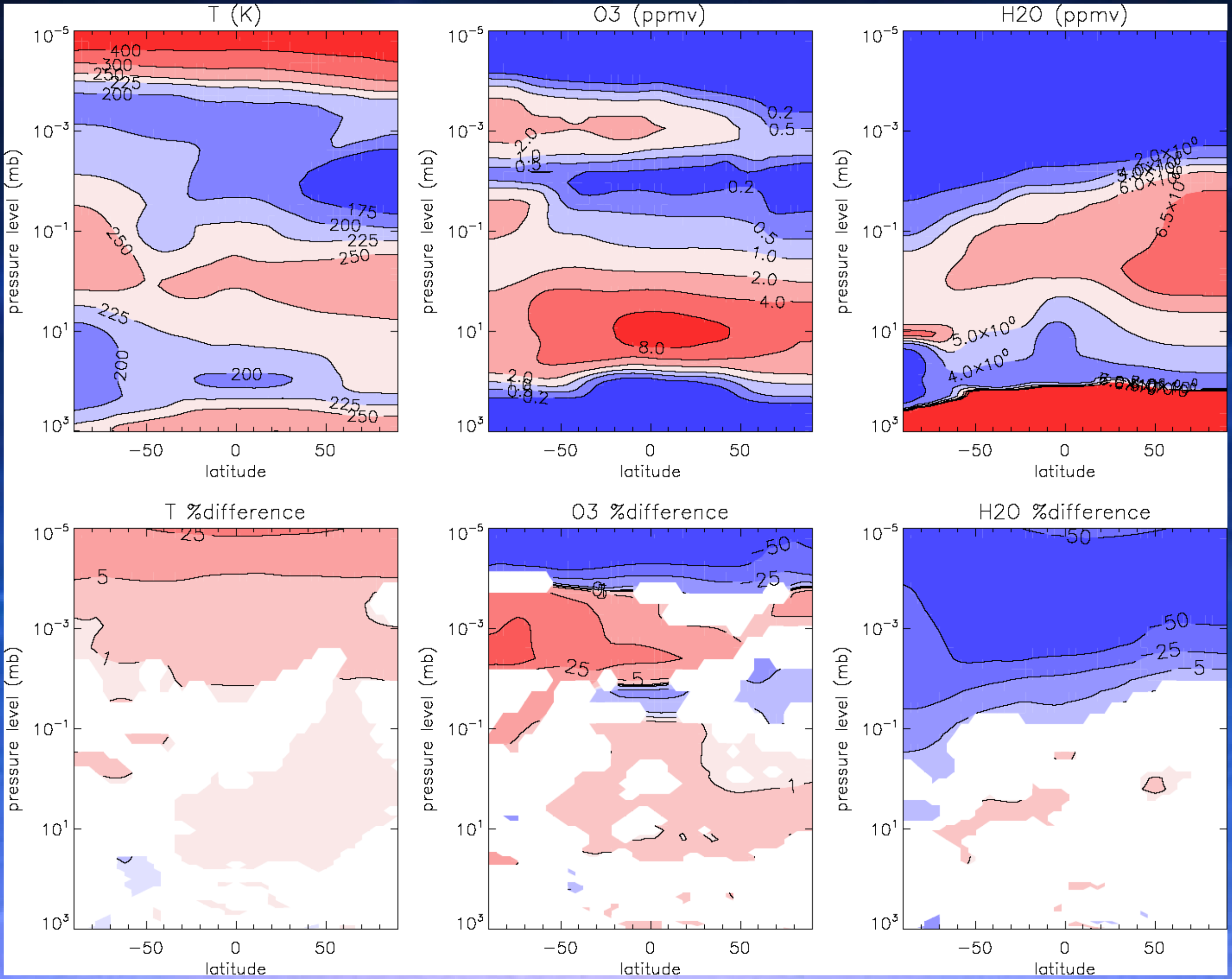
Solar Cycle Studies: Model Input



Spectral composite courtesy of:

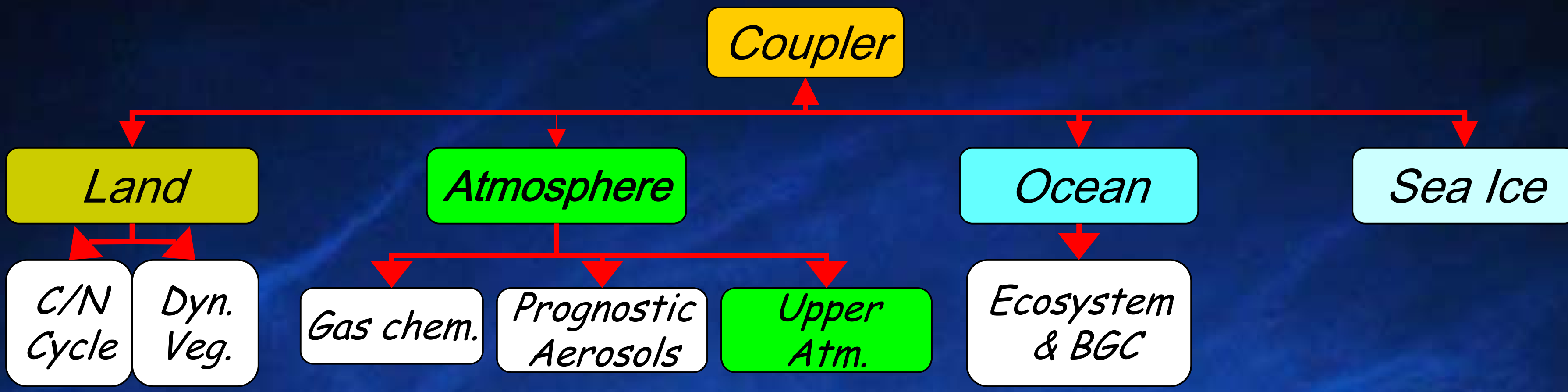
Judith Lean (NRL)
and
Tom Woods (CU/LASP)

Response of the upper atmosphere to solar variability



March and Matthes

Historical Forcings, including CFCs and volcanic aerosols



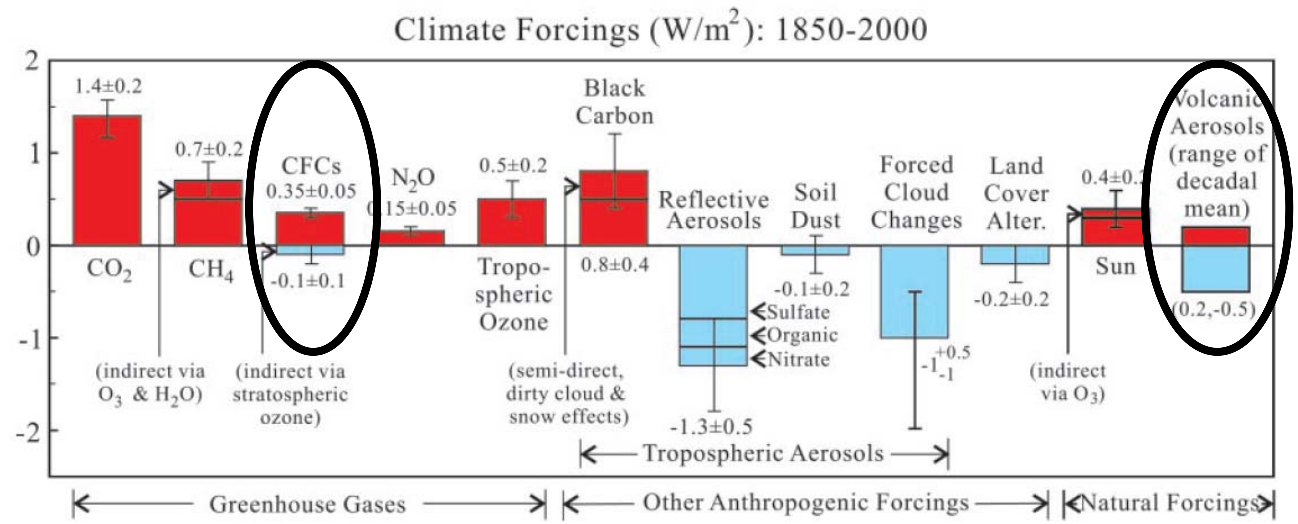
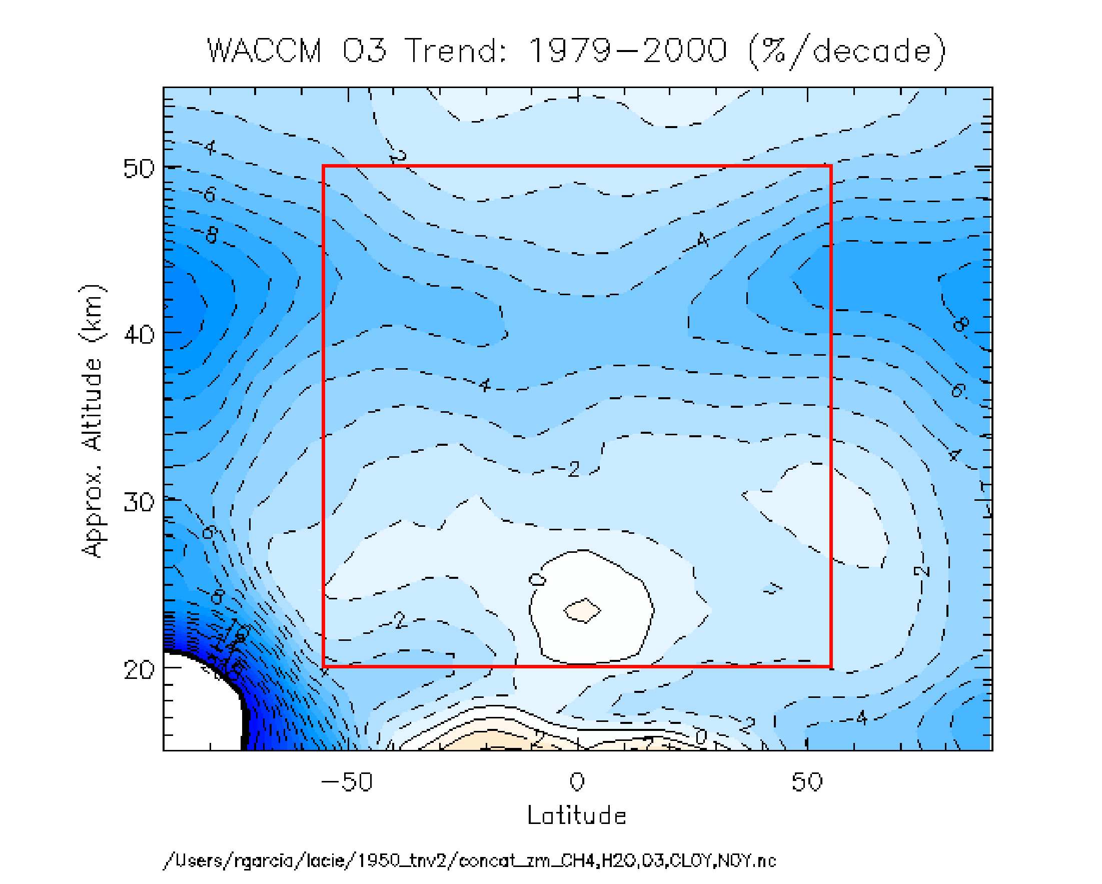
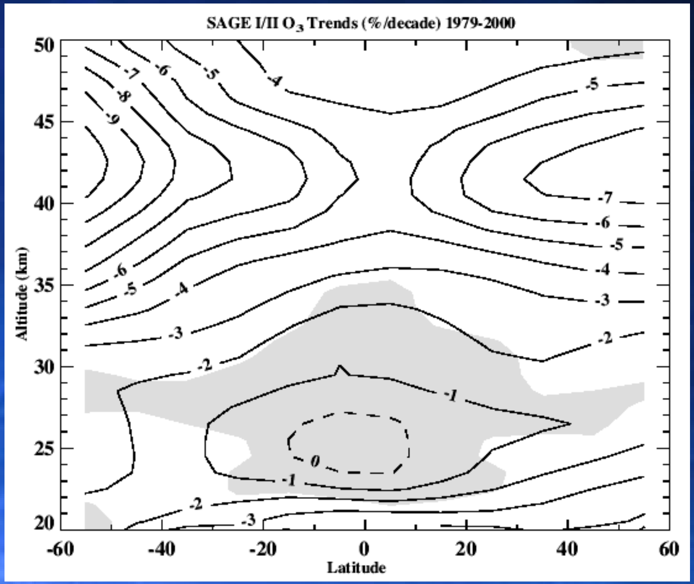


Fig. 1. Estimated climate forcings; error bars are partly subjective 1σ uncertainties.

Calculated and Observed Ozone Trends



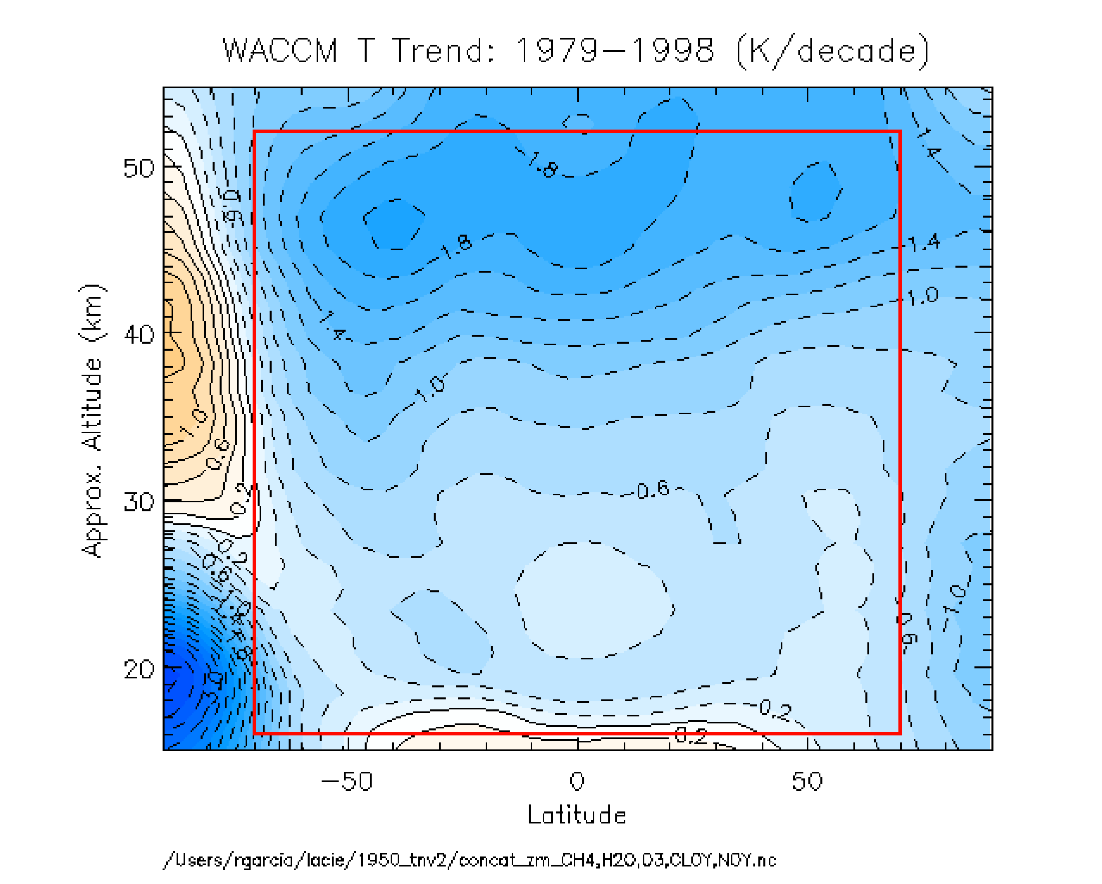
SAGE-I 1979-1981 and
SAGE-II 1984-2000



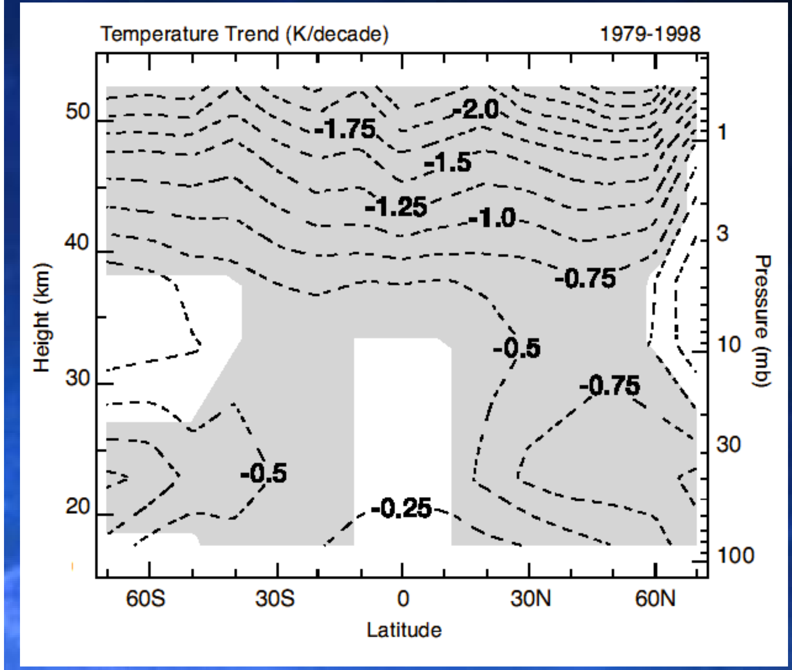
Rolando Garcia

- Red inset on left covers approximately same region as observations on right
- Agreement is quite good, including region of apparent "self-healing" in lower tropical stratosphere

Calculated and Observed Temperature Trends



SSU + MSU 1979-1998

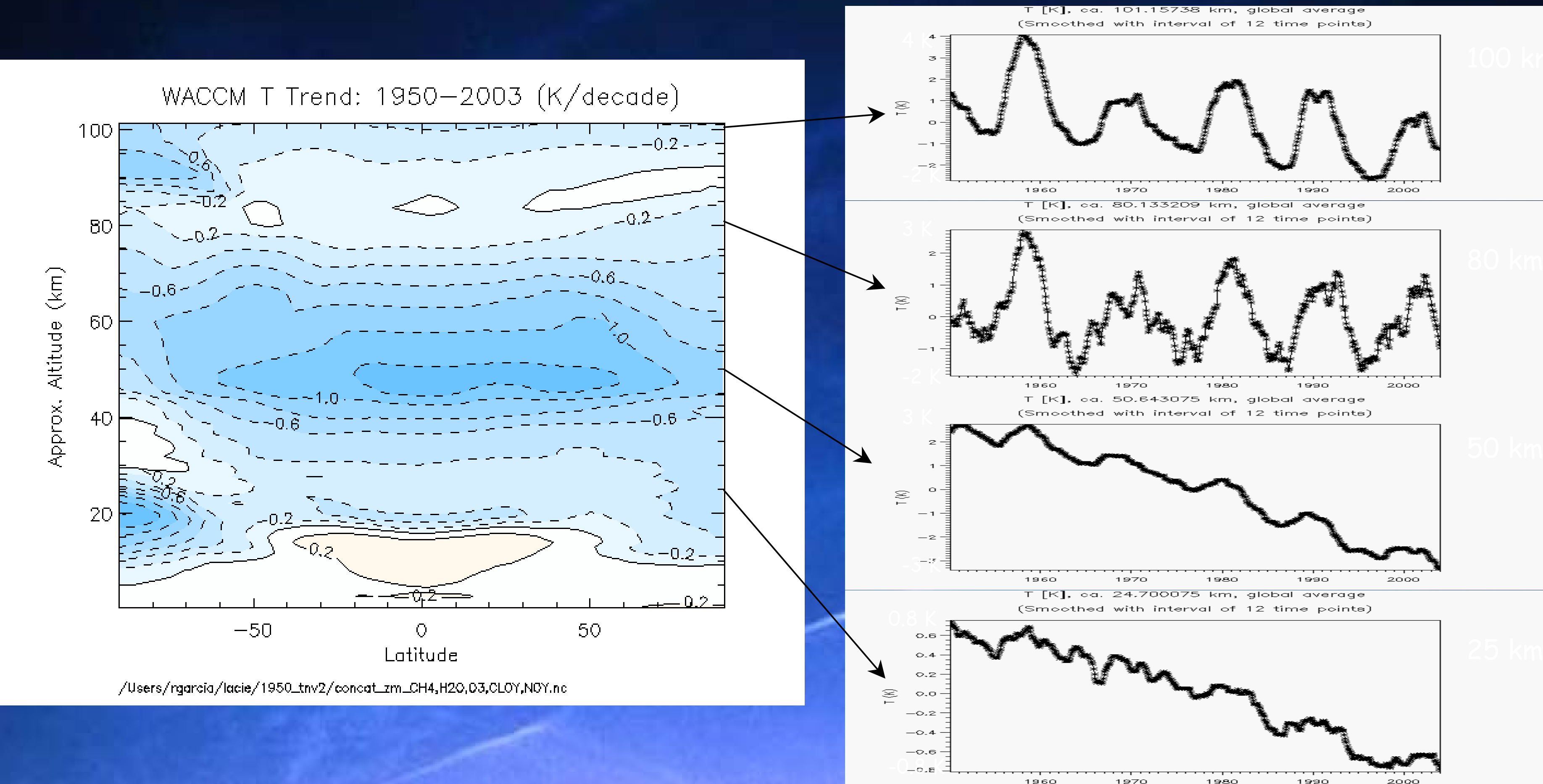


Rolando Garcia

- Red inset on left covers approximately same region as observations on right
- Note comparable modeled vs. observed trend in upper stratosphere, although model trend is somewhat smaller

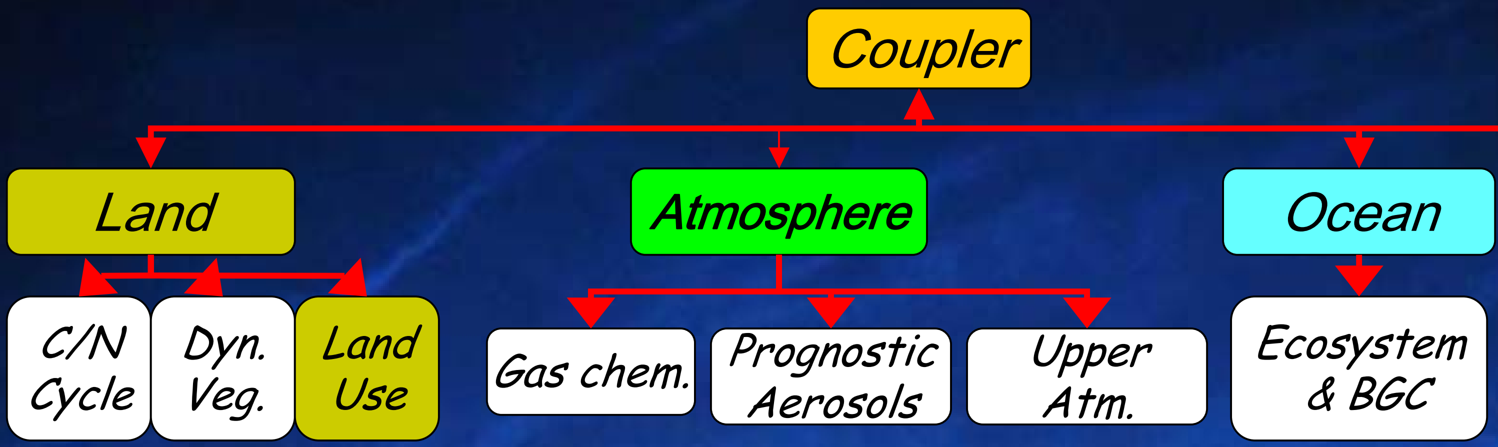
Calculated Temperature Trends, 1950-2003

Global-means, deseasonalized



Caution: 11-year solar signal not removed in trend calculations;
this is large above 50 km, as shown on right

Agricultural land use



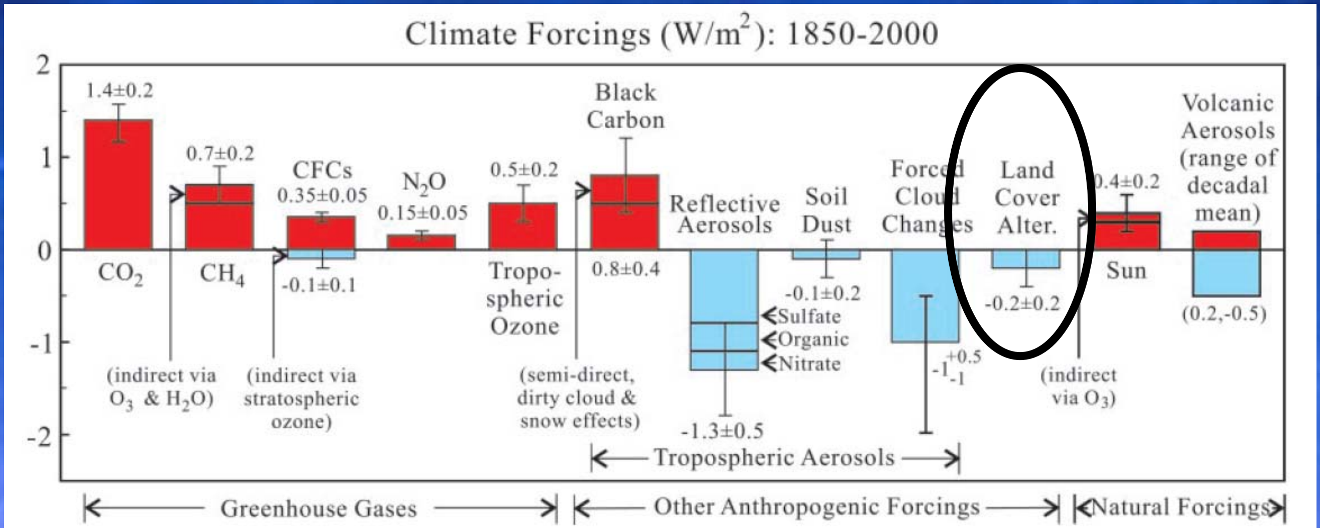
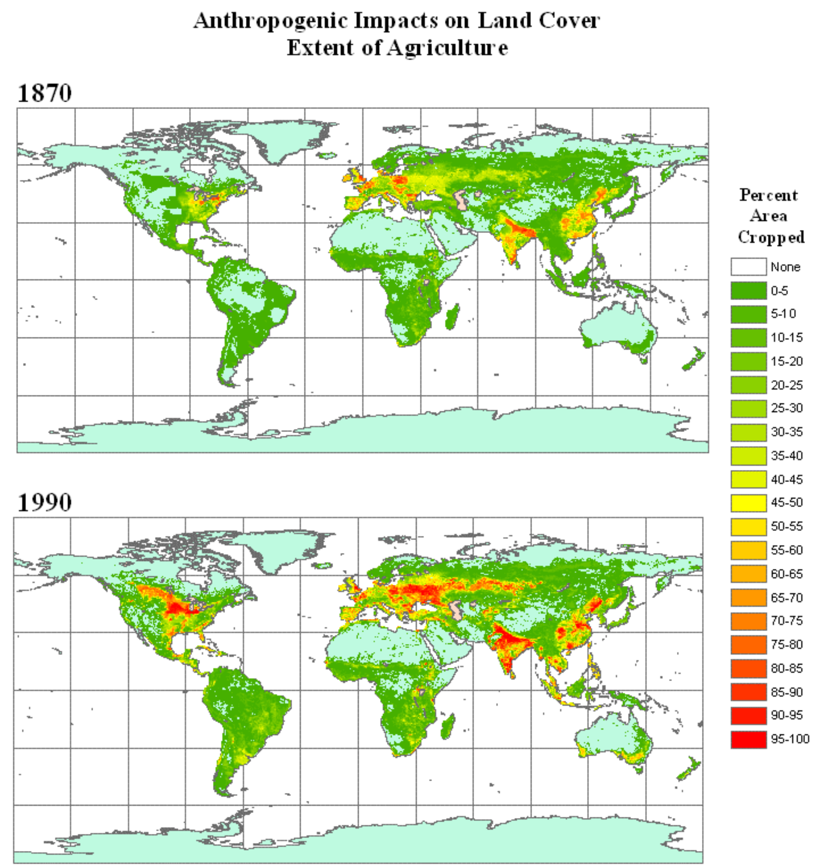


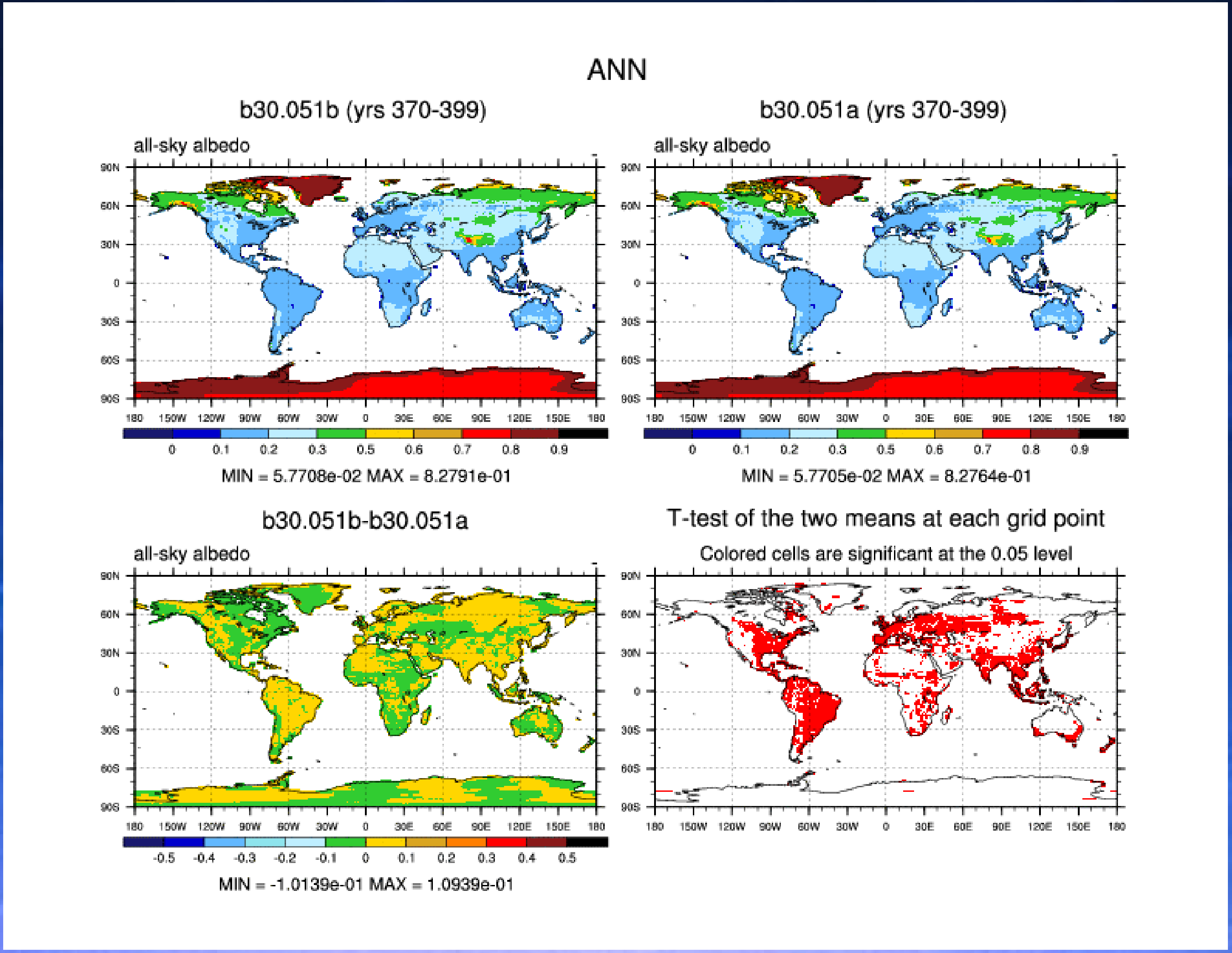
Fig. 1. Estimated climate forcings; error bars are partly subjective 1σ uncertainties.

Historical changes in agricultural land use



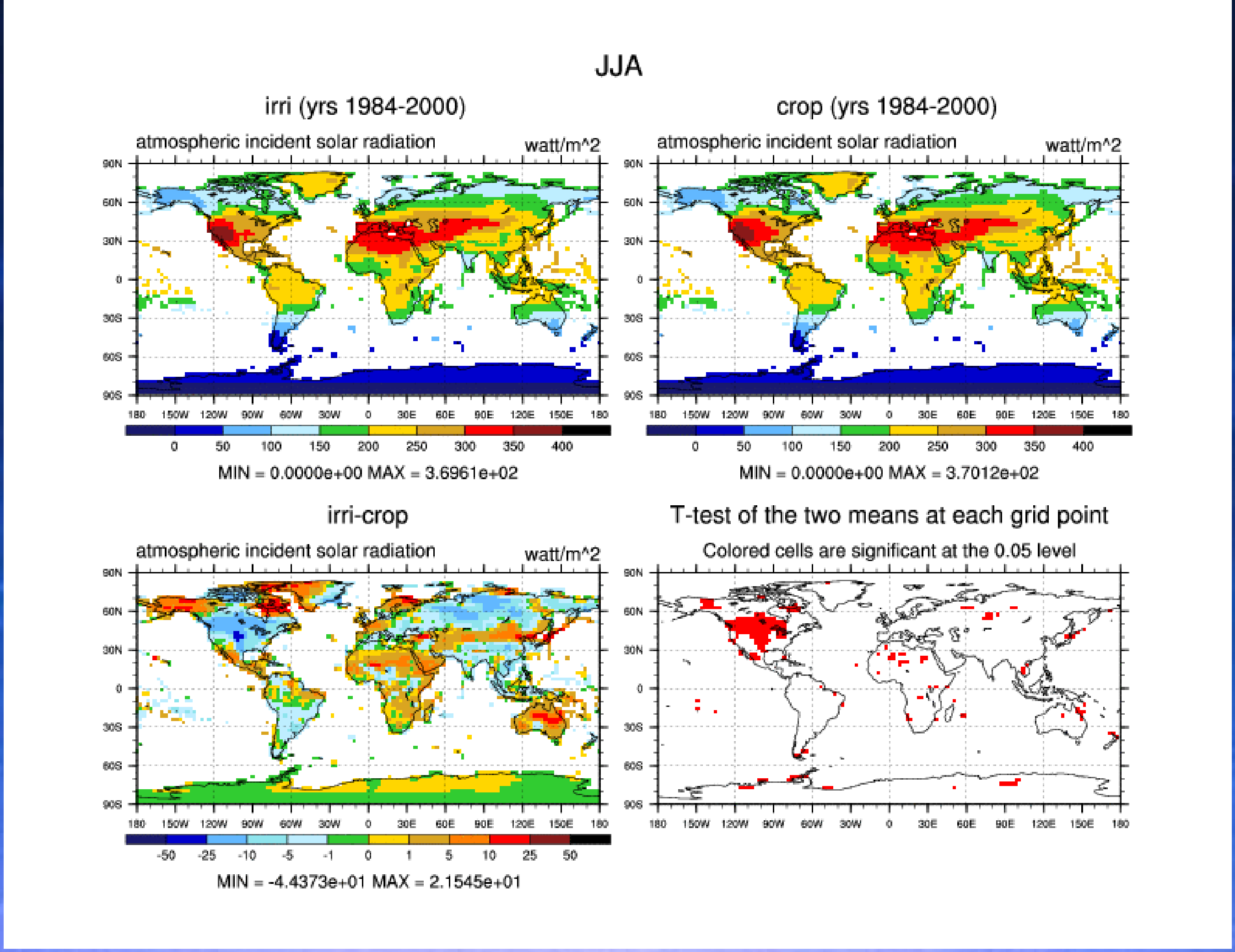
Johan Feddema

Changes in surface albedo by land use



Johan Feddema

Changes in surface insolation by irrigation



Sam Levis

New chair of the CCSM SSC:
Peter Gent begins 7/1/05

Conclusions

- The CCSM project has succeeded in building and applying three generations of AOGCMs.
- Many aspects of the mean state and variability have improved from CSM1 to CCSM3.
- However, major challenges in simulating the physical climate remain, especially tropical variability.
- The project is now experimenting with the elements of a 1st generation Earth system model.
- A major challenge for that model is how to represent cloud-aerosol interactions, including indirect effects.