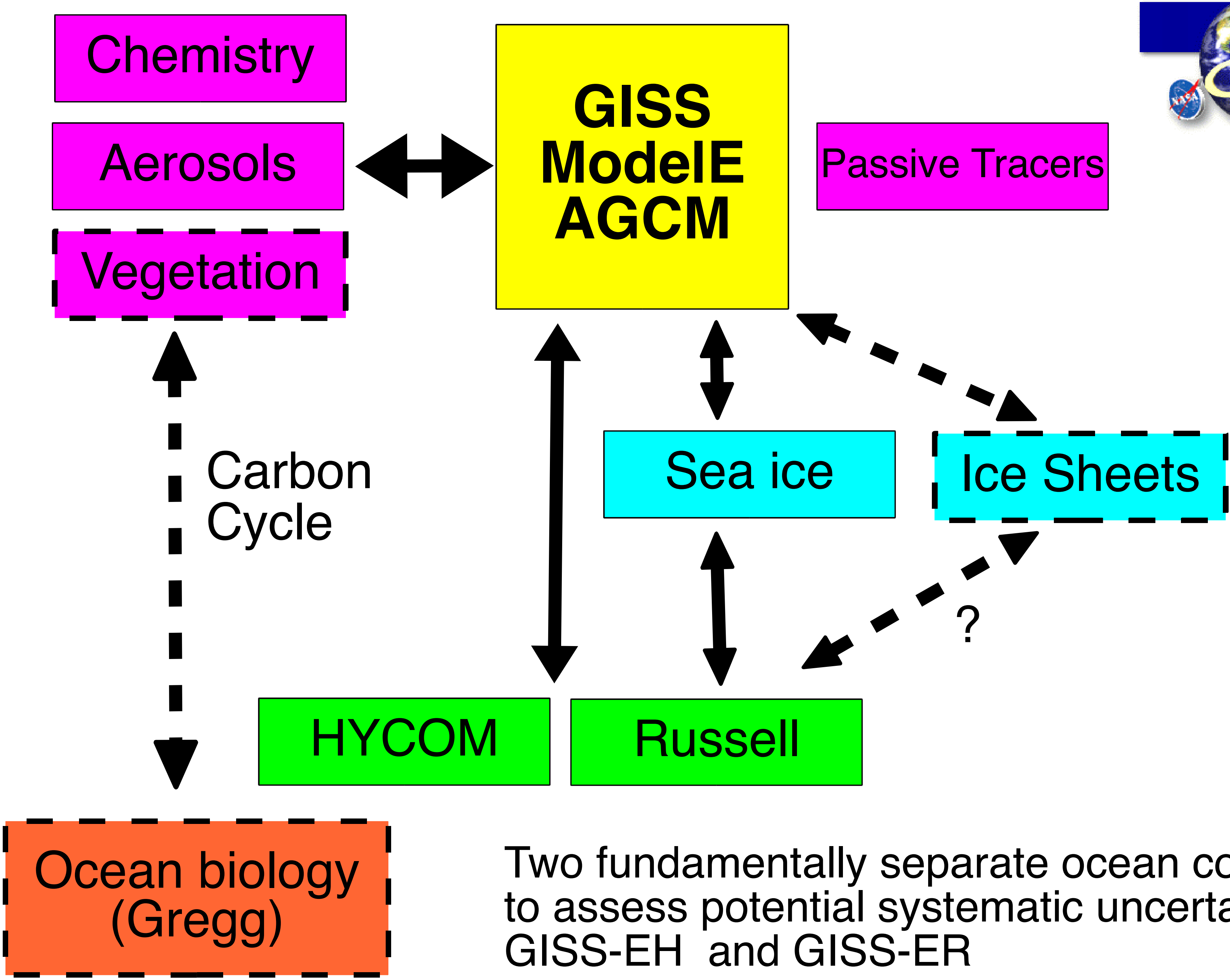
MAP meeting: Mar 7

GISS ModelE:
MAP Objectives and Results

1) IPCC AR4 devolpment/results
2) Earth System Science Components
    - Aerosols/Atmospheric Chemistry
    - Carbon Cycle (incl. Vegetation dynamics/ocean biology)
    - Ocean heat content/sea level rise
3) New developments/Future plans
    - Higher resolution (ocean/atm/ice)
    - Eta-coordinates/FV core/Cubed Sphere/ESMF
    - Ice sheet modelling
    - Climate@Home -Perturbed Physics Ensembles (PPE)



Two fundamentally separate ocean codes to assess potential systematic uncertainty GISS-EH and GISS-ER

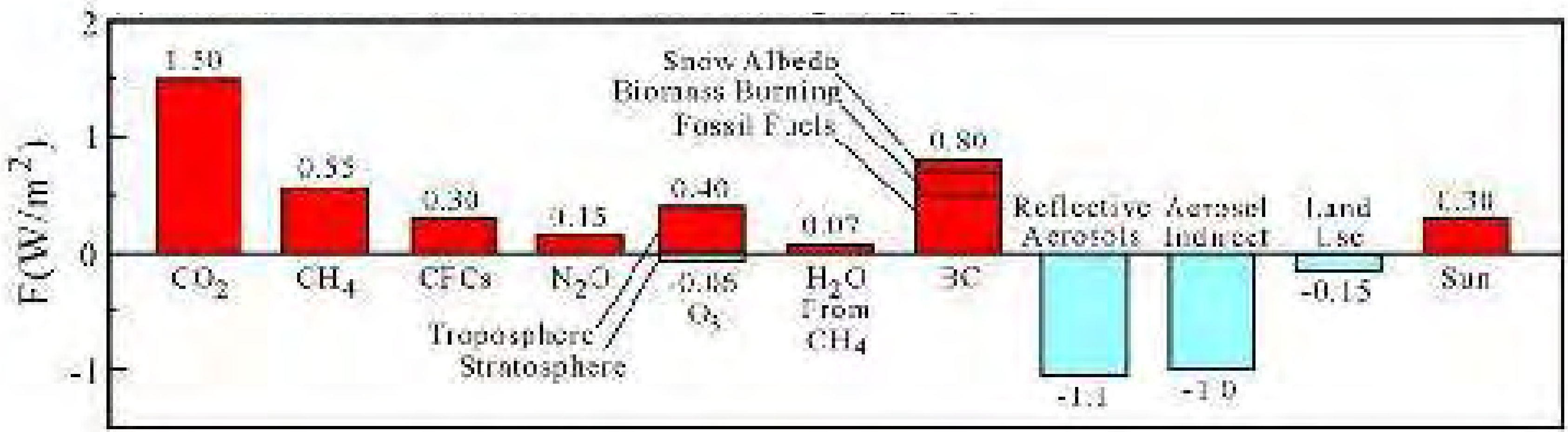
IPCC AR4 Configuration

- GISS ModelE AGCM
  - 4x5 resolution (effective ~1.3x1.7 tracer advection)

- HYCOM = Hybrid Miami Isopycnal Ocean Model
  - Isopycnic in interior, z-level at surface, Mass conserving, equivalent salt flux b.c.
  - AR4 Spec: 2 x 2 cos(lat) resolution, 16 layers Tri-polar grid, Kraus-Turner mixing, T/S advection
  - Testing: 1x1 (0.25 equator), 16 layers KPP mixing, density/spice advection

- Russell Ocean
  - z* coordinate, Mass conserving, KPP, GM, free surface, 'natural' b.c.'s
  - AR4 Spec: 4x5 (same grid as AGCM), 13 layers
  - Testing: 2x2.5 (same grid as next-gen AGCM)

Climate forcings 1750-2000



Greenhouse Gases

Aerosols

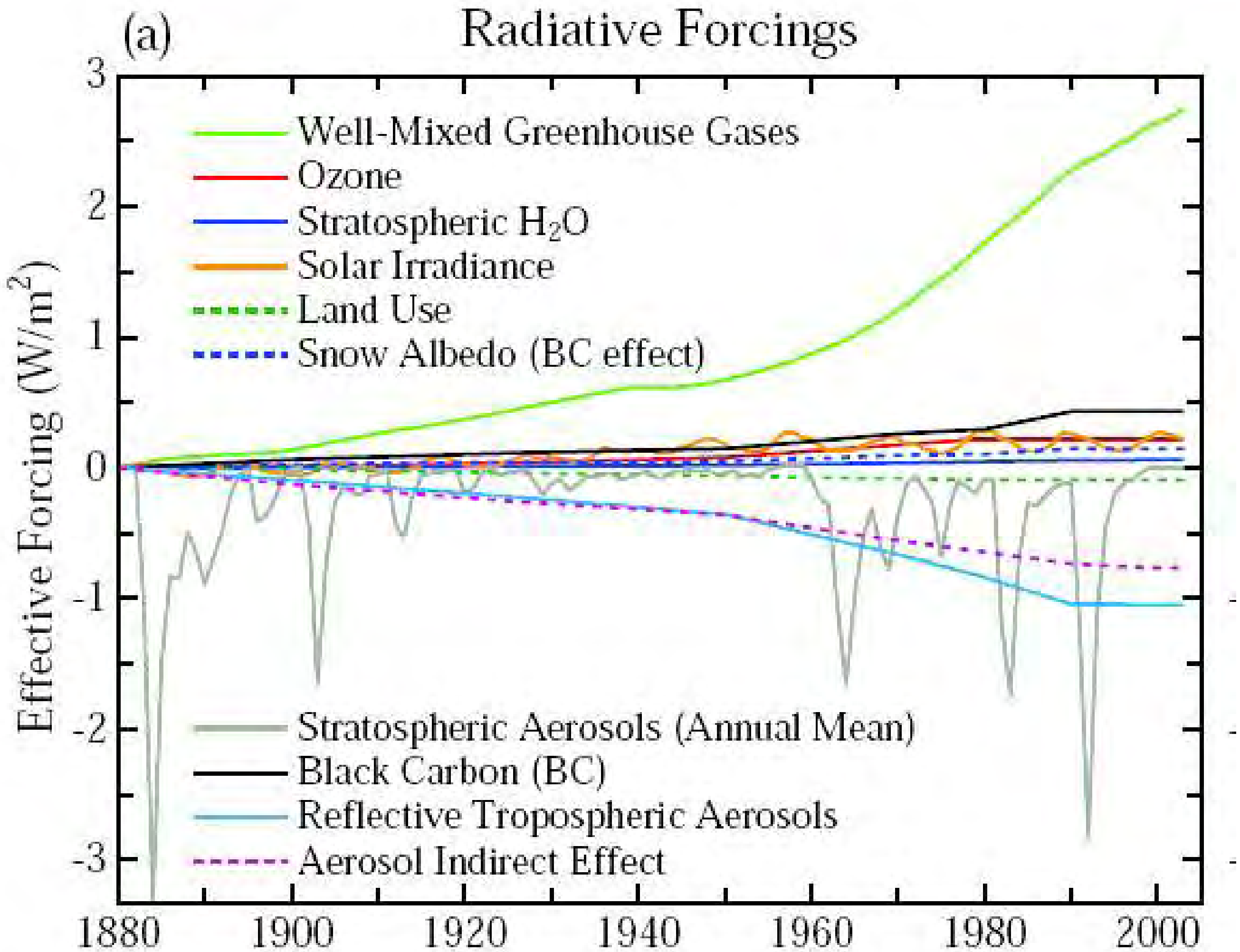
Land Use

Solar

Total Forcing: ~ 1.6 ± 1.0 W/m²

Hansen et al (2005)

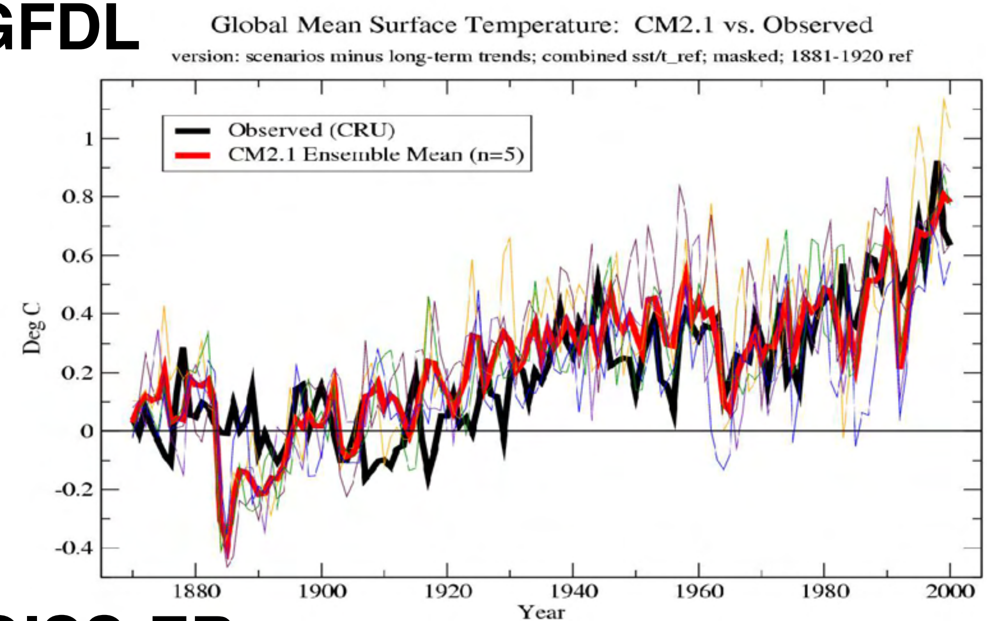
20th Century forcings...



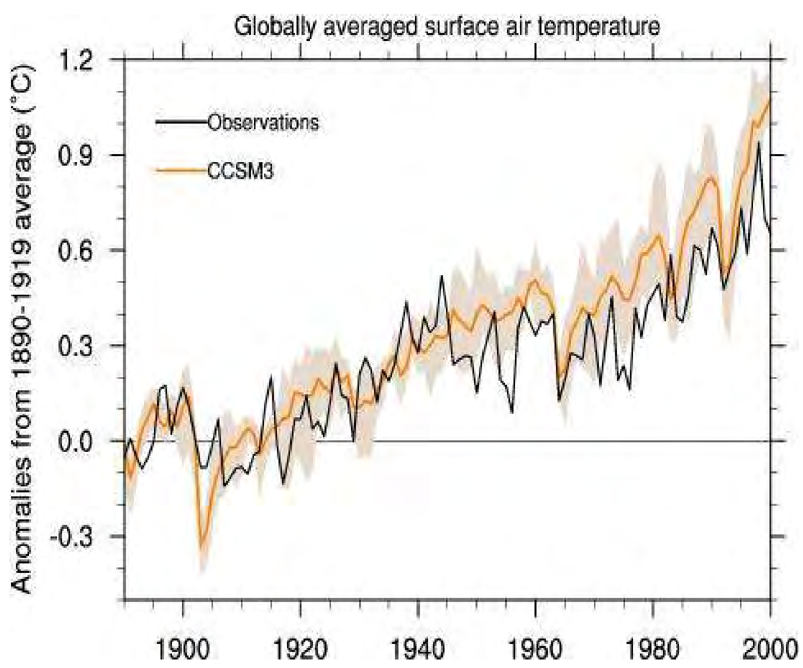
20^{th} Century response...

Three US models all show good match to global mean SAT....

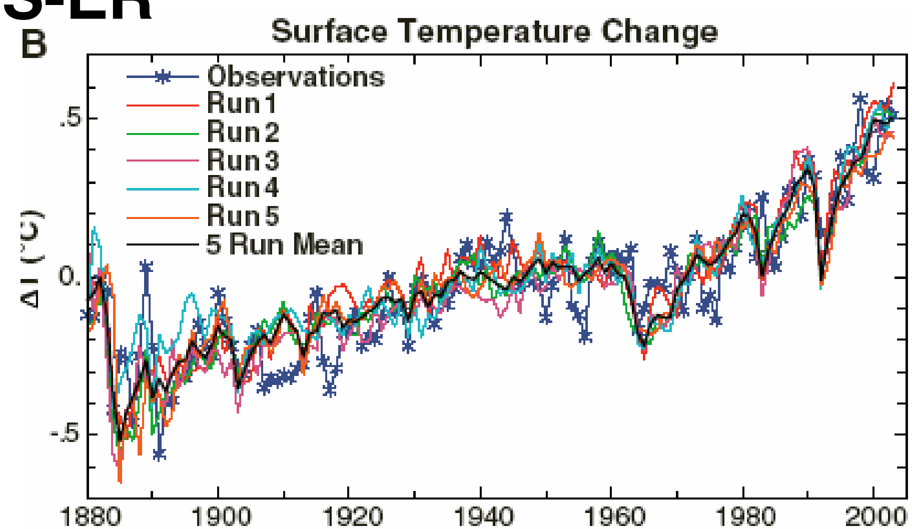
GFDL



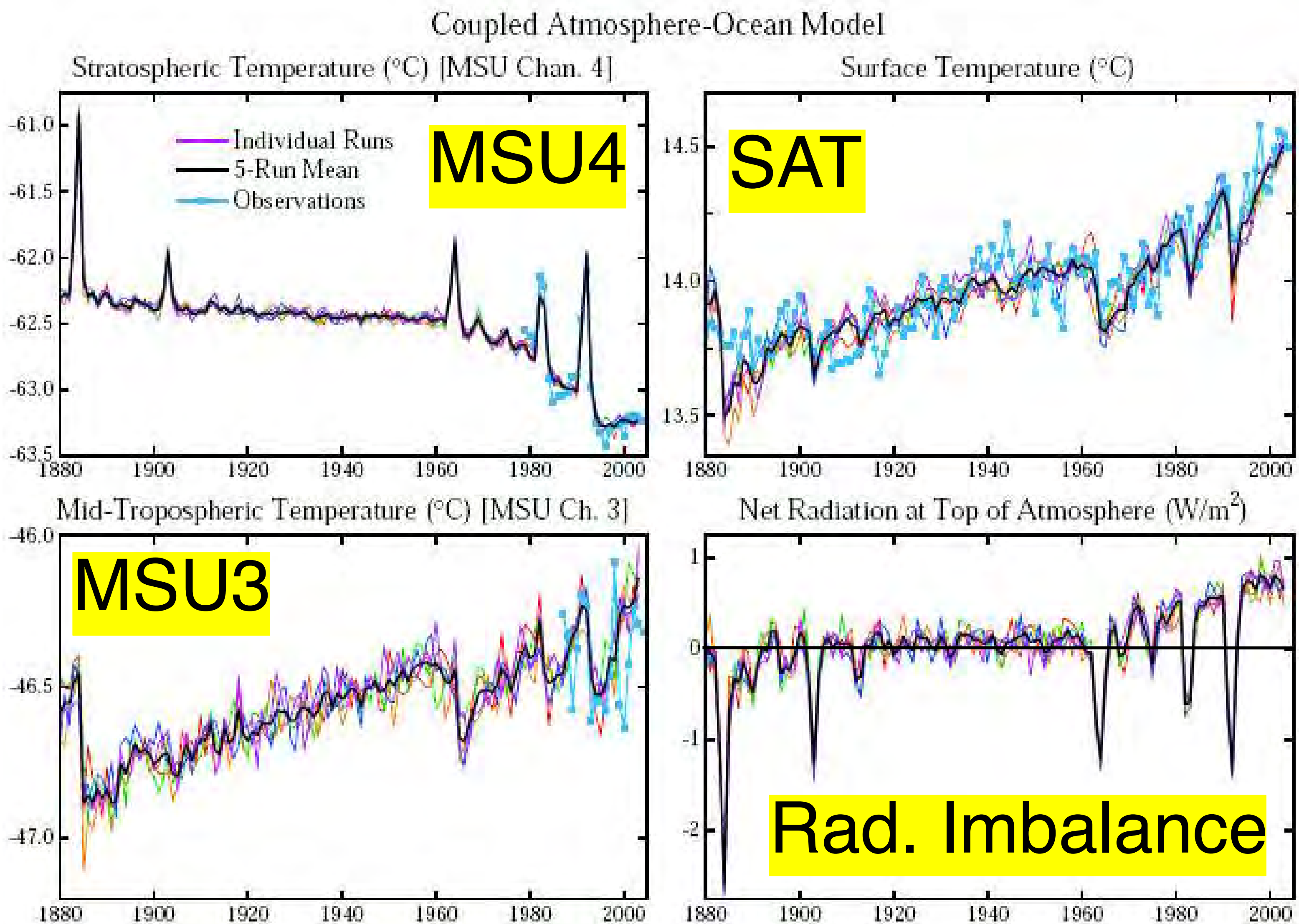
CCSM/NCAR



GISS-ER



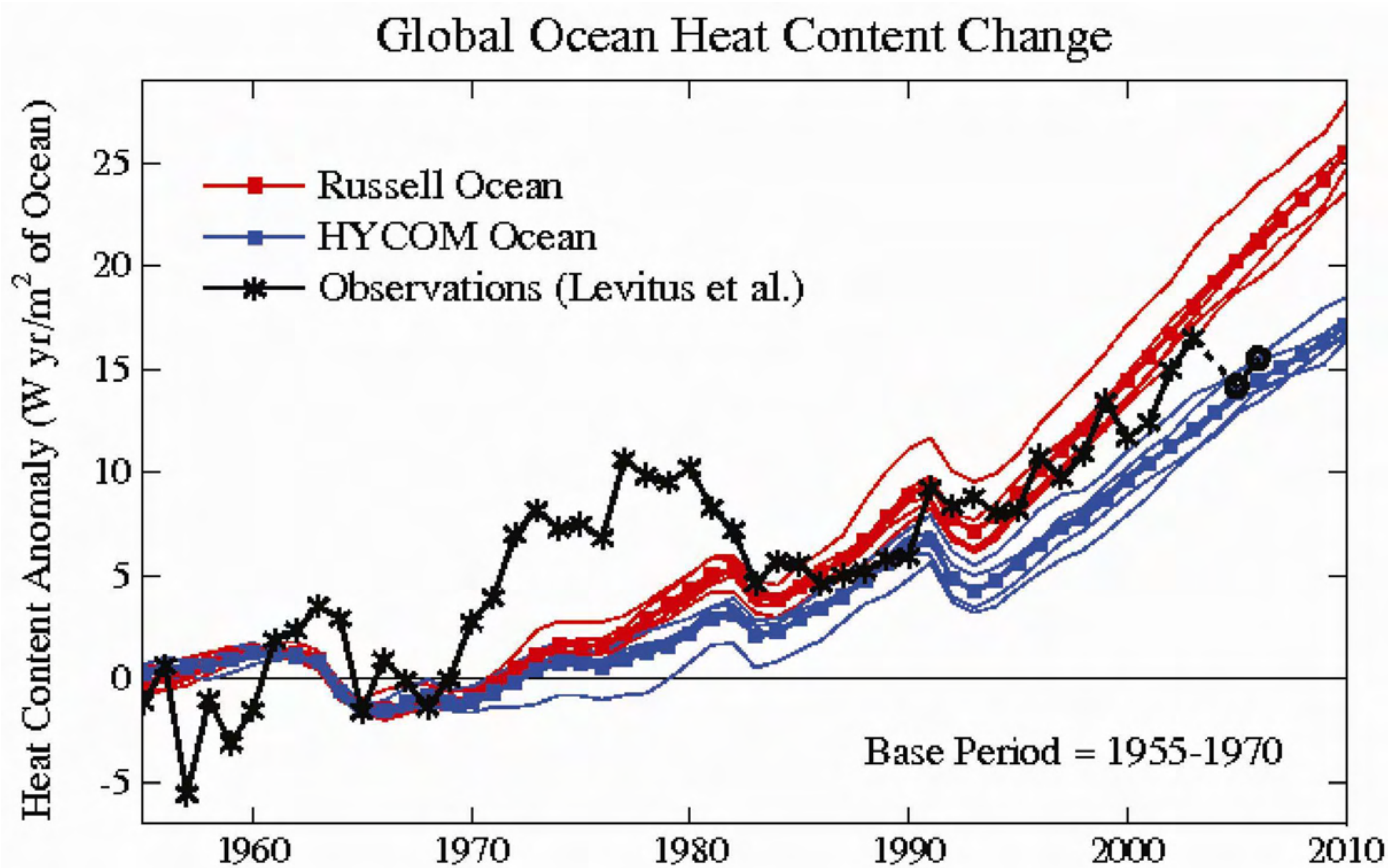
20th Century climate (IPCC AR4)



GISS-ER

Hansen et al (2007)

Ocean Heat Content change 1955-2006

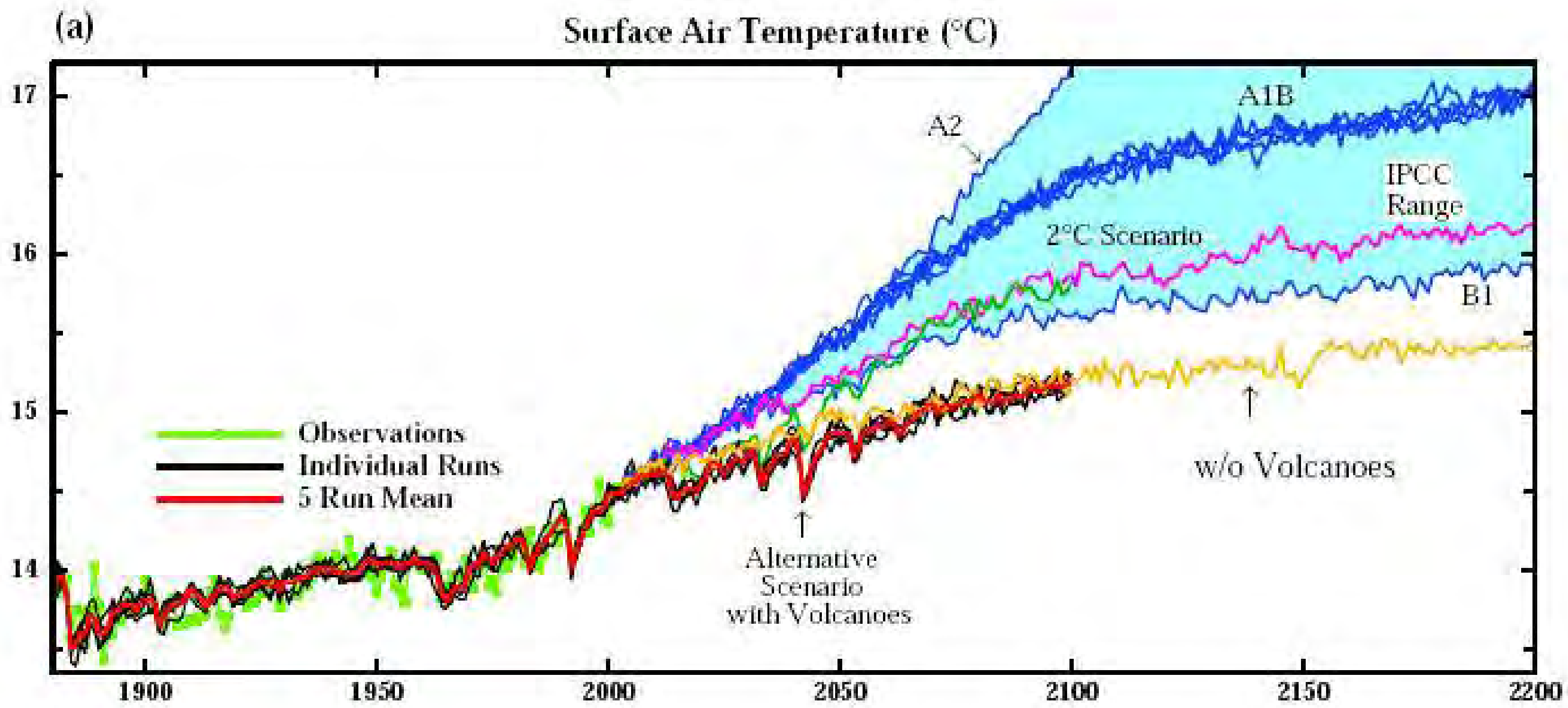


GISS-ER

GISS-EH

Ocean heat content rise ~ TOA imbalance/committed warming
GISS models bracket obs. => ~0.5 C "in the pipeline"

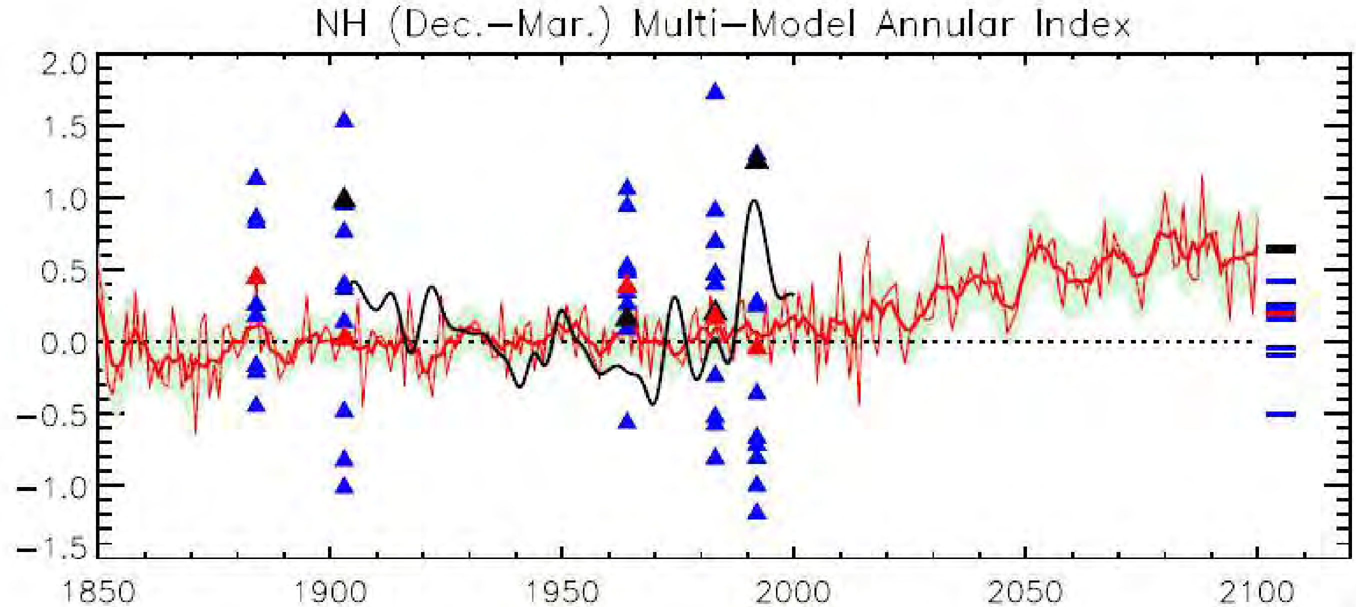
Future temperatures?

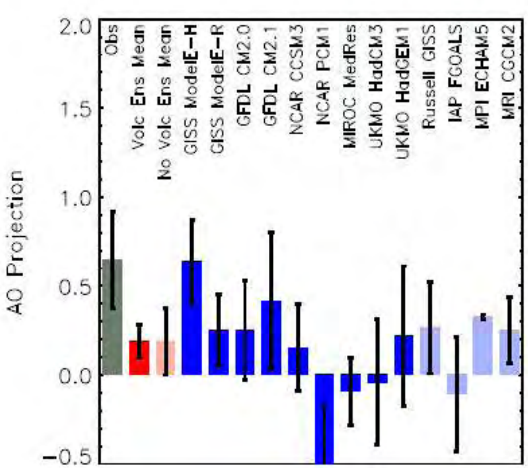


...according to the GISS Model

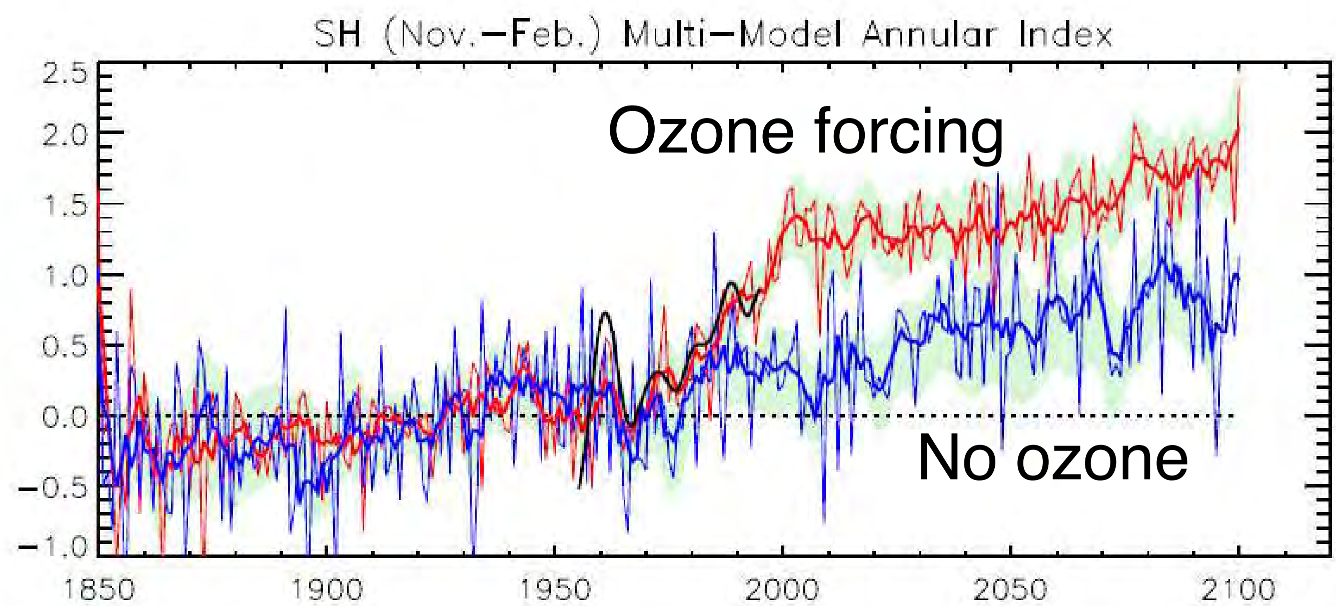
Forcing of Annular Modes

Annular modes respond to GHG, O_3, volcanoes, SST?
IPCC AR4 models



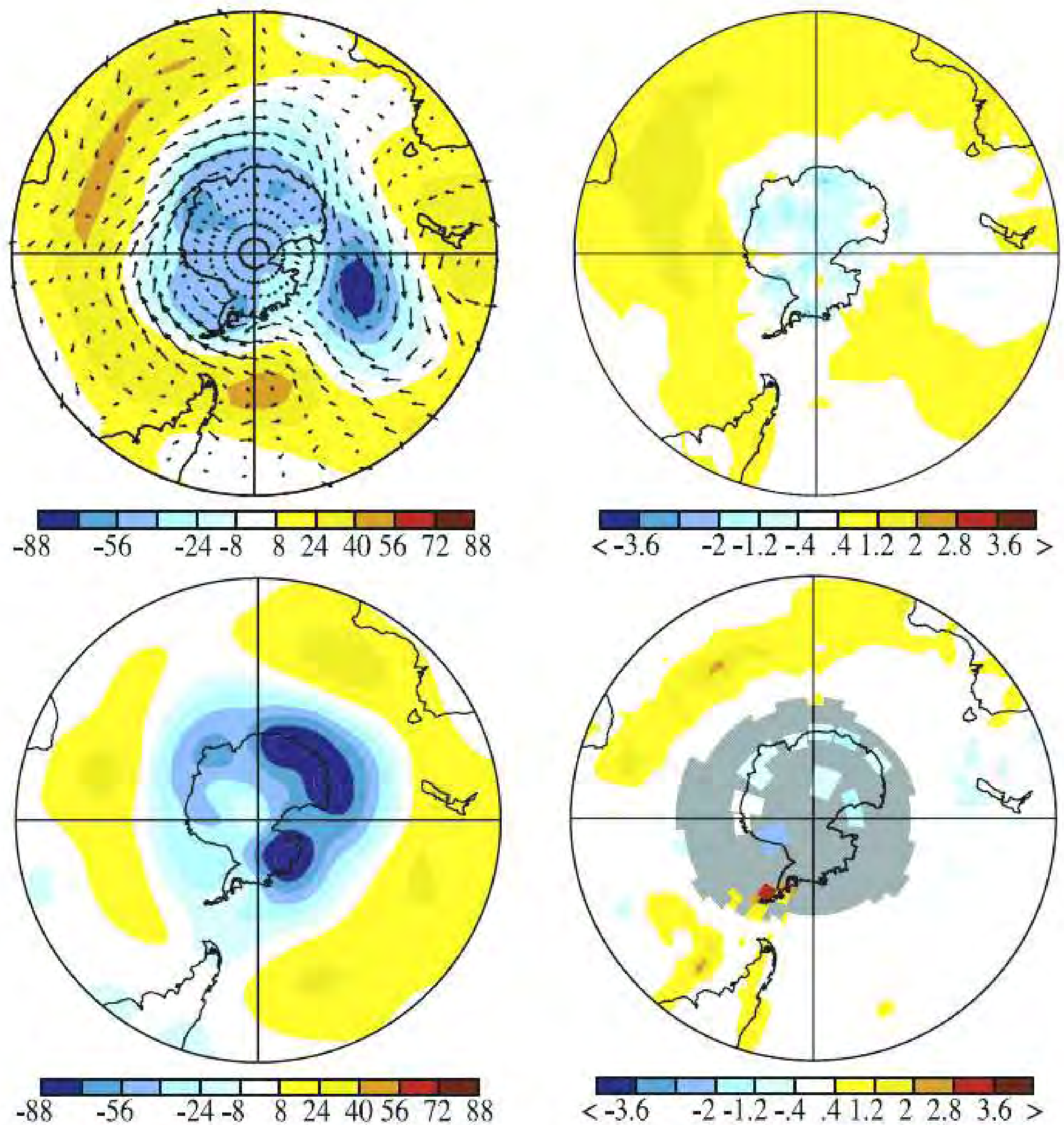


Miller et al (2007)



Global warming, Antarctic cooling?

Response to ozone depletion and GHGs



Model

Observations

SLP **Temperature**

What was unsatisfying in AR4?

- Persistent climate simulation biases
- Insufficient ocean variability
- Fully interactive aerosols/chemistry not used
  - Parameterised indirect effects
- Unknown sensitivity to physics perturbations
- No ability to project non-thermal sea level rise
- Feedbacks on radiative comps. (GHGs, O3, aerosols)

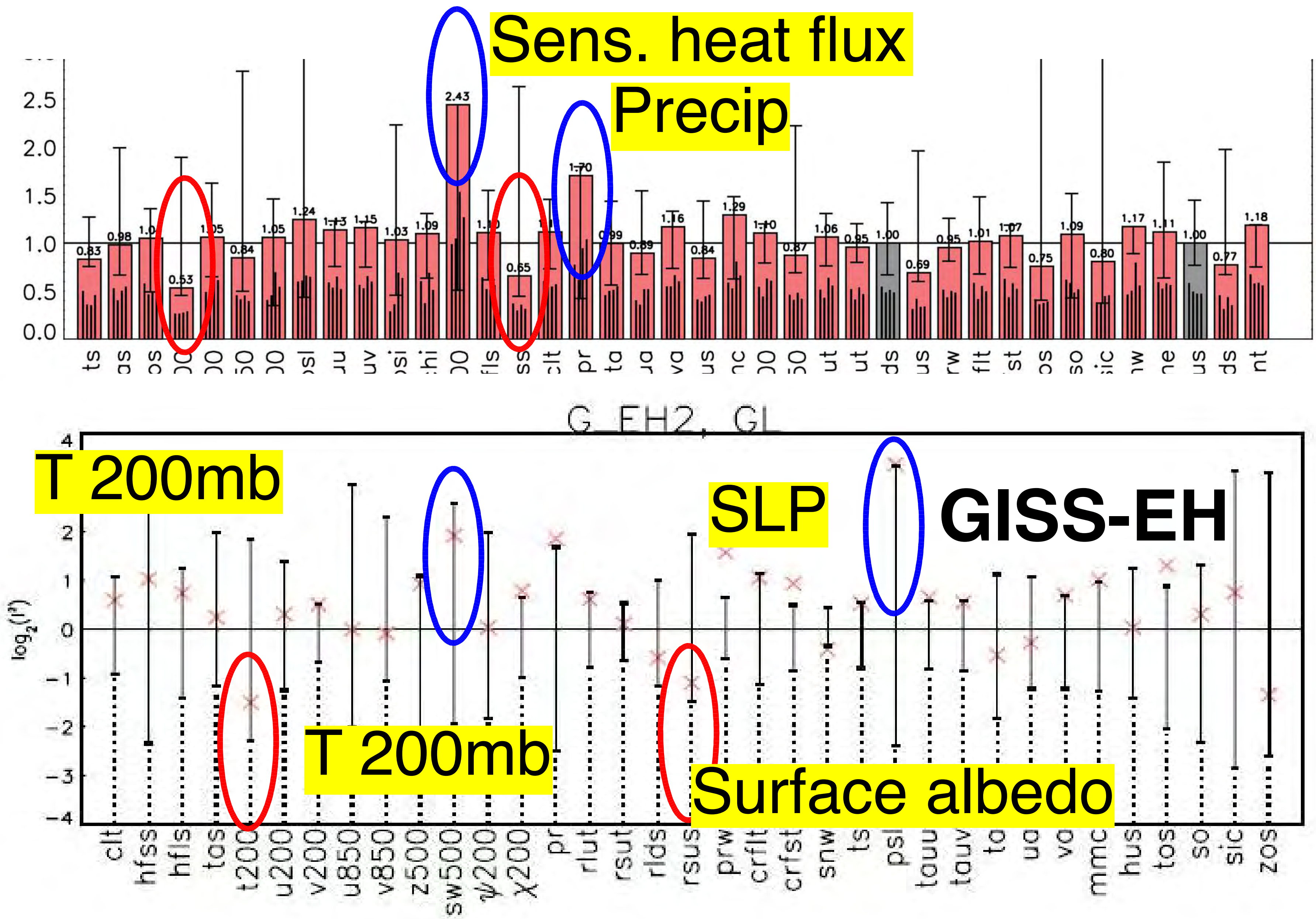
Solutions?

- Higher resolution (F40)? Yes, but not sufficient
- Improved physics (clouds/BL/dynamical core)
- More Earth System interaction. Evaluation?
- Carbon cycle, Ice sheets
- Perturbed Physics Ensembles?

AR4 Intercomparison

Stat Waves 500mb

GISS-ER

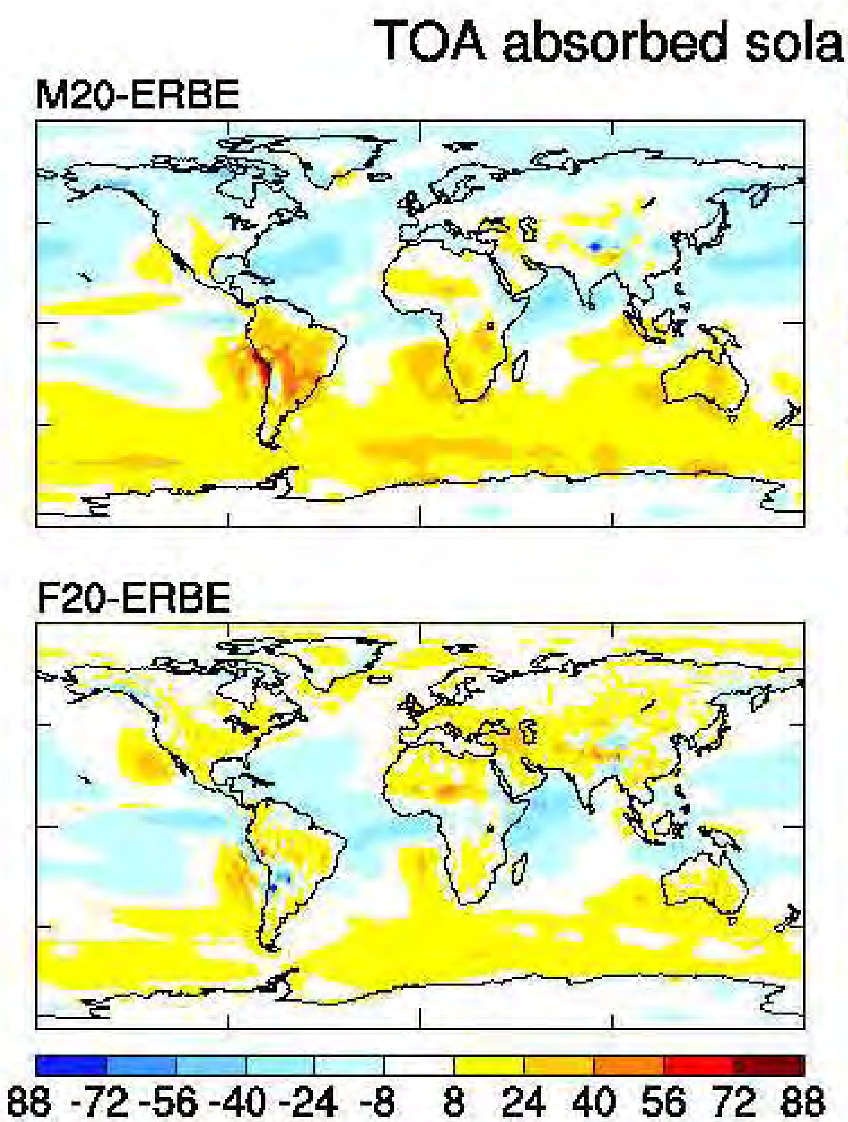


Worse

Better

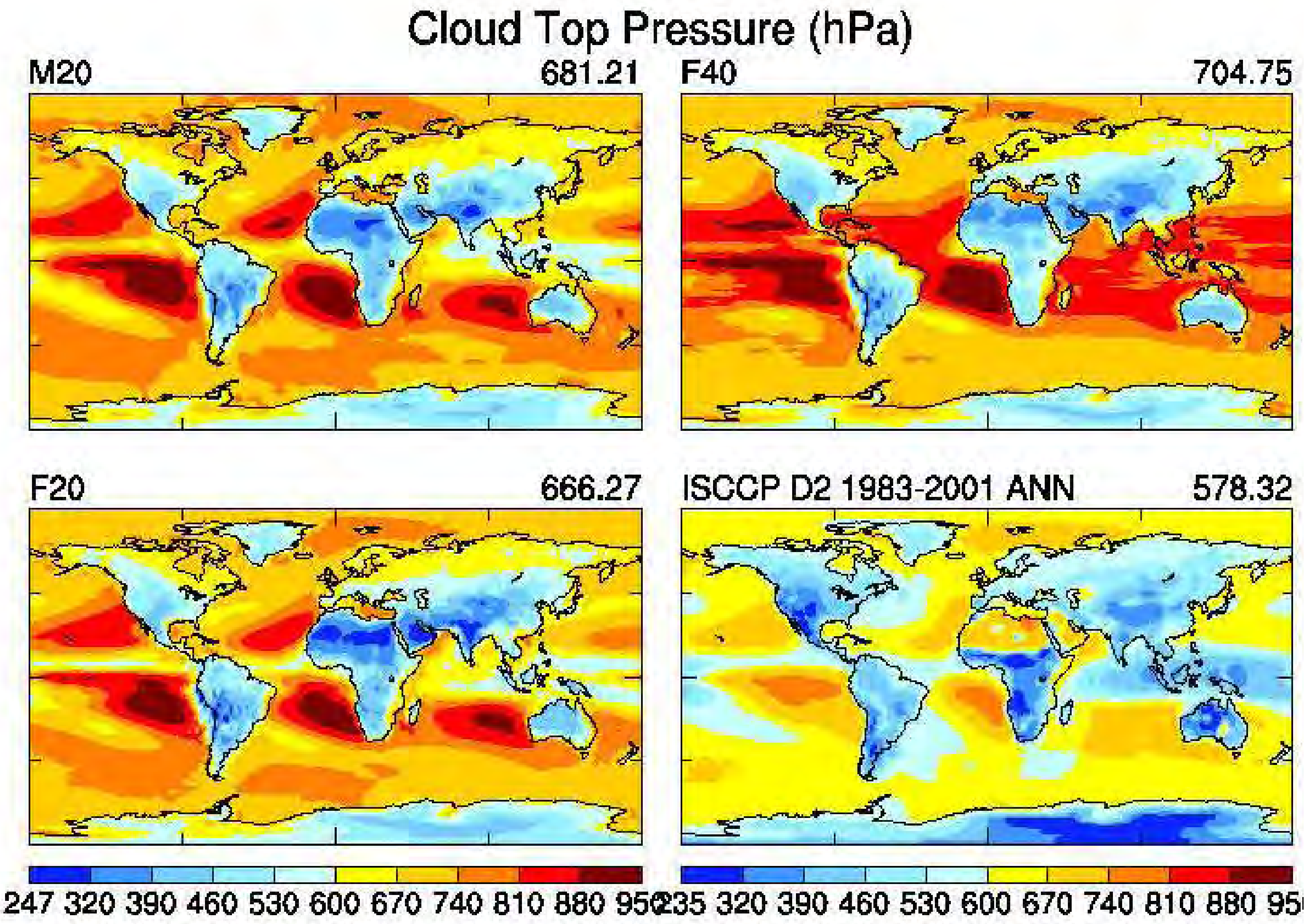
Reichel and Kim (2007)

New F40 results

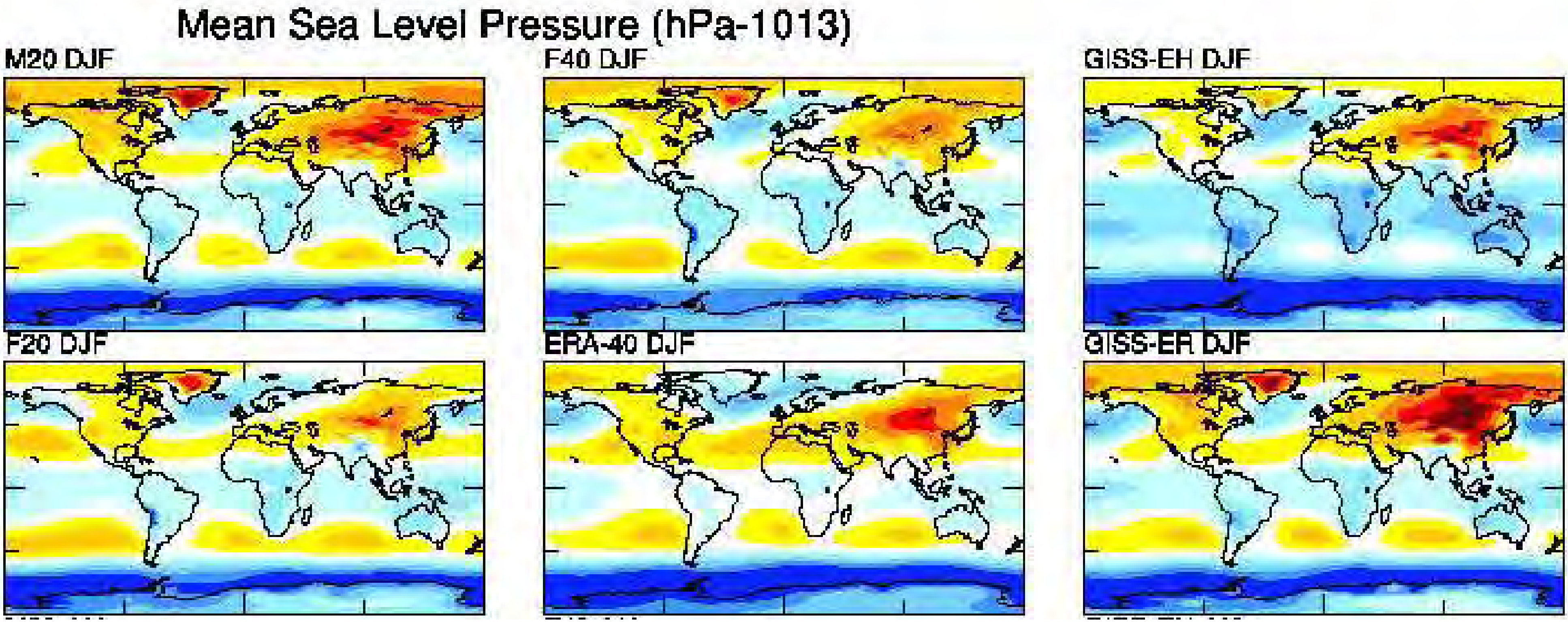


Convective region albedos too low
Mid lat improvements

F40 results (cont)



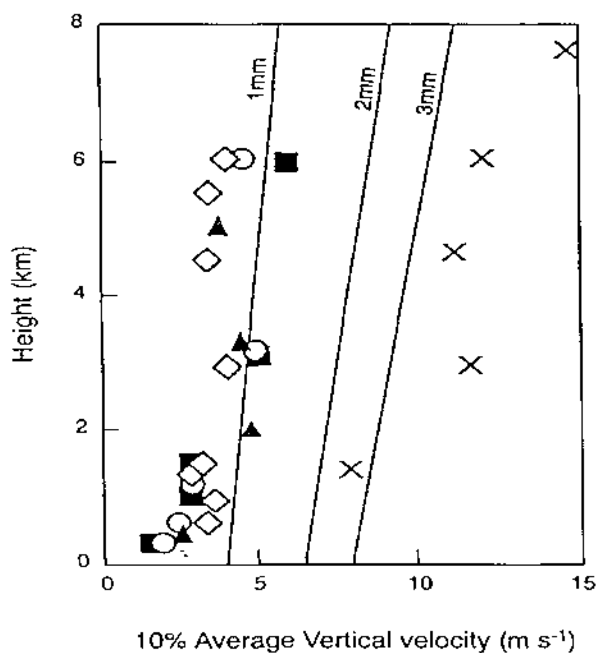
F40 results (cont)



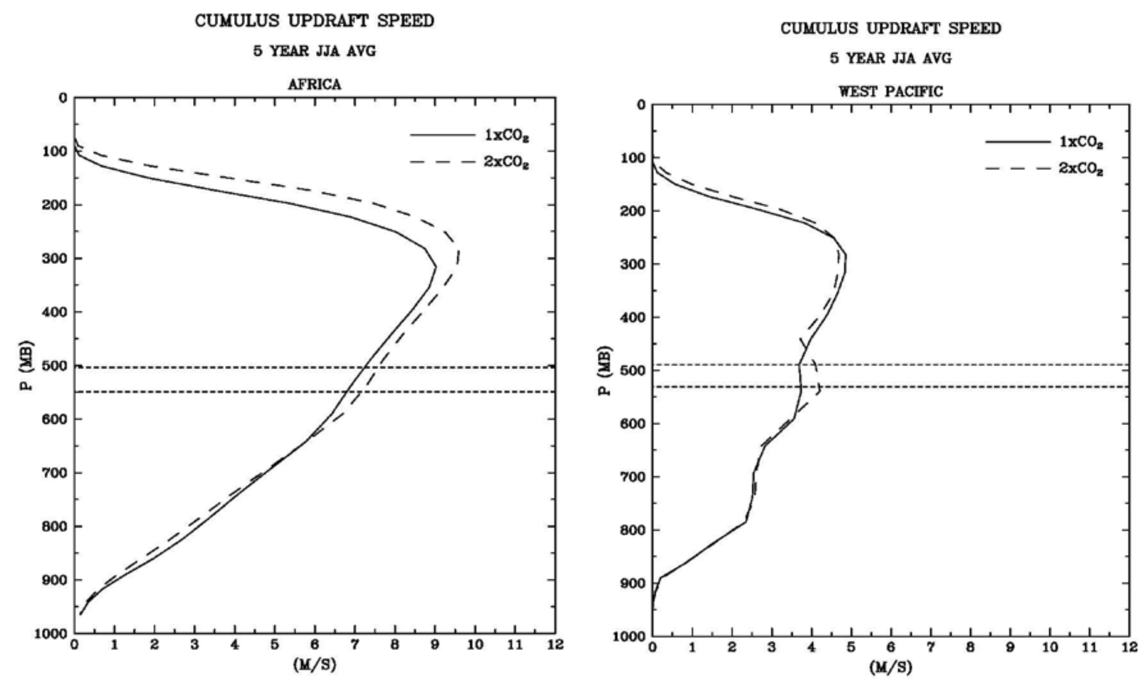
Improvements in storm tracks/SLP mid latitudes
Deep convection worse (incomplete development)

Diagnostic GCM cumulus updraft speed

$$\frac{1}{2}\frac{\partial \overline{w}^{c2}}{\partial z} = ag\overline{\left(\frac{T_v{}'}{T_v} - l\right)}^{c} - b\delta\overline{w}^{c2} - \overline{w}^{c2}\epsilon$$



Observed (Zipser and Lutz 1994)

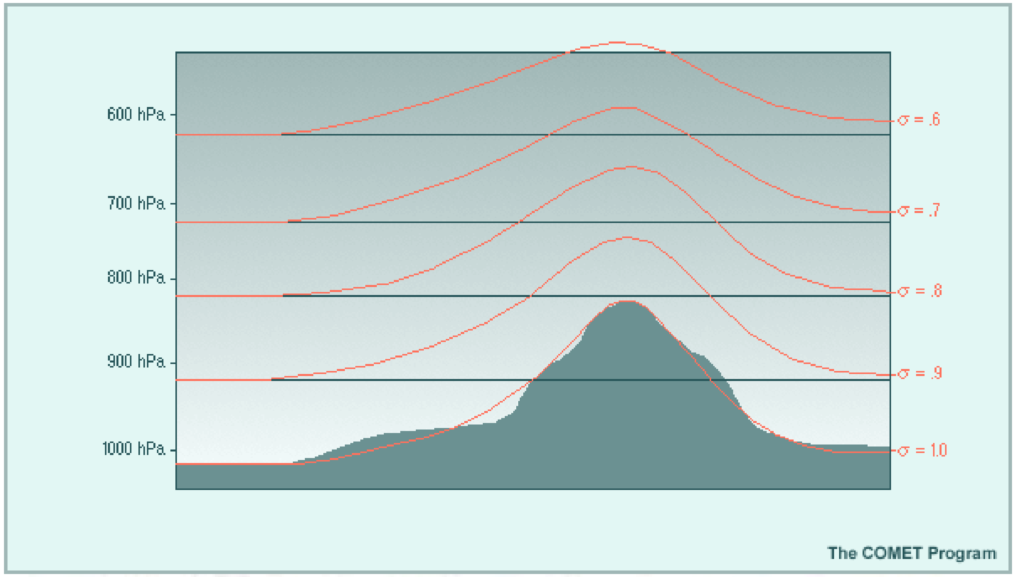


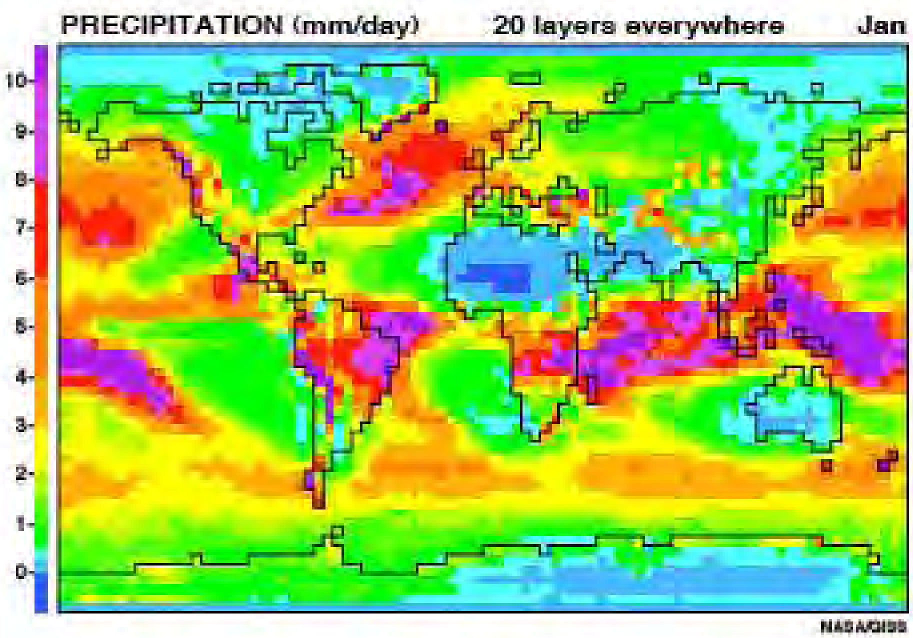
GCM

Gregory (2001) combined with Marshall-Palmer DSD and empirical size-fallspeed relations for liquid/graupel/ice, allows for interactive estimates of convective precipitation efficiency and effect on anvil cloud feedback

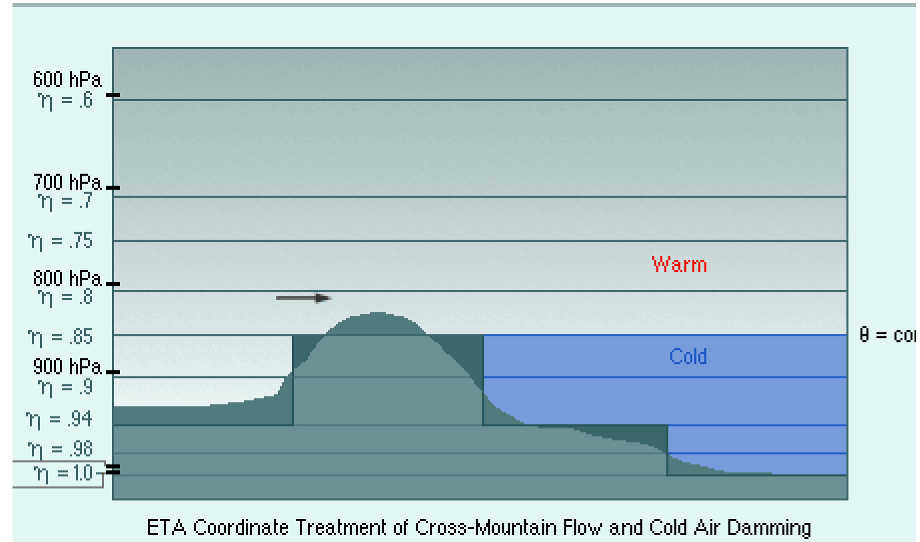
Eta-Coordinate: Precipitation

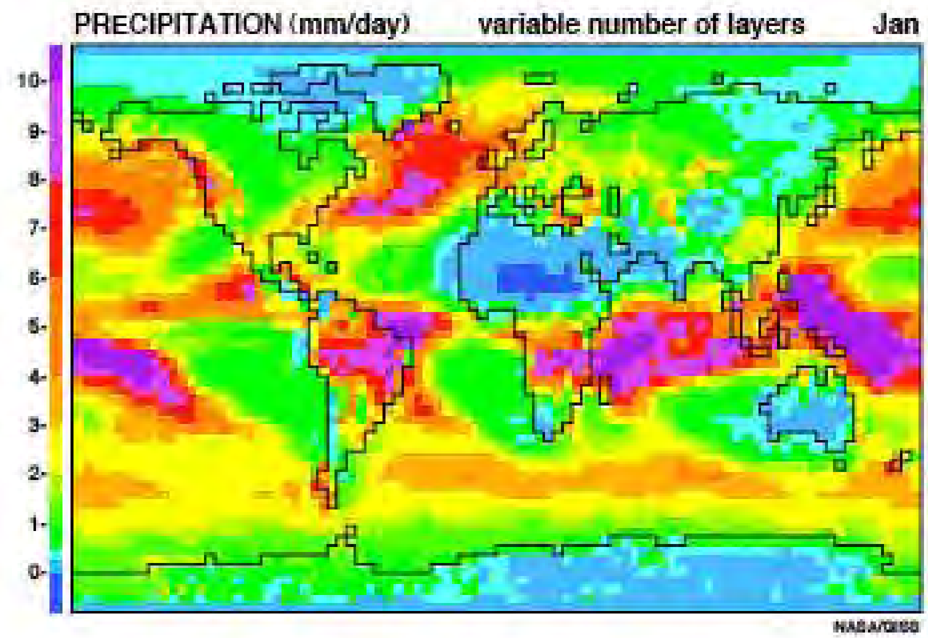
Near surface σ-coordinate





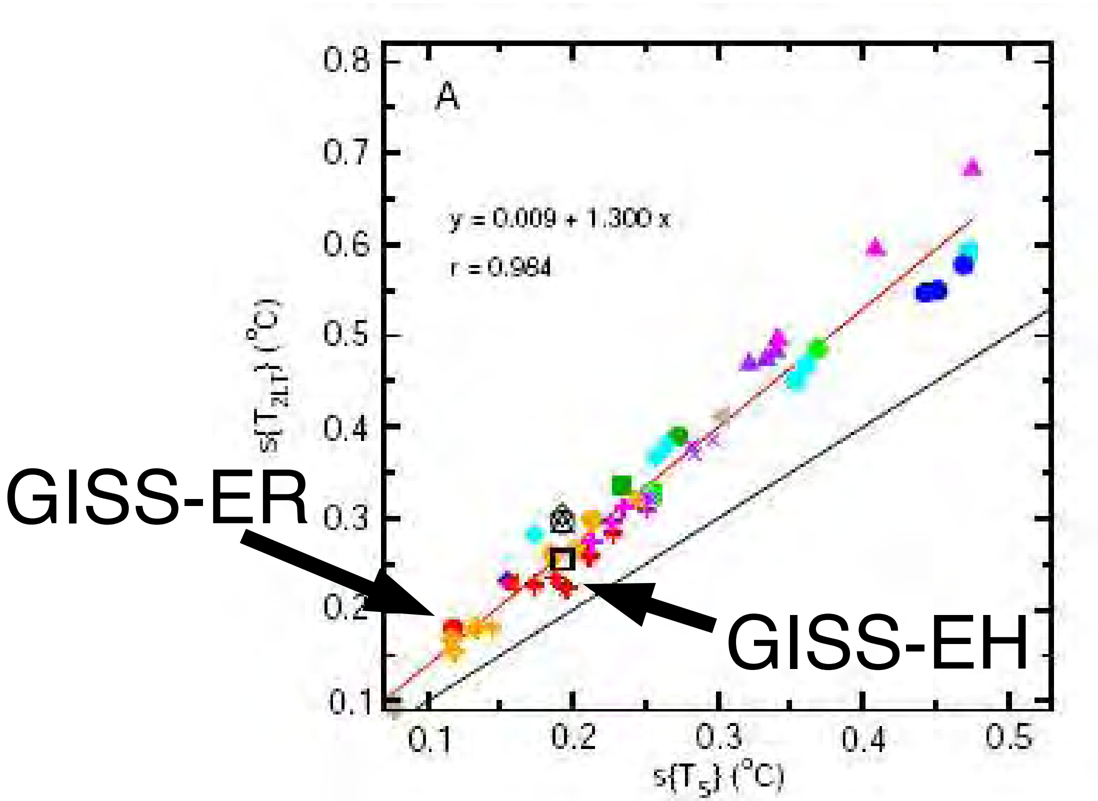
Near surface eta-coordinate





Tropical Ocean variability?

Higher resolution – particularly in tropics is essential for better tropical/global variability:

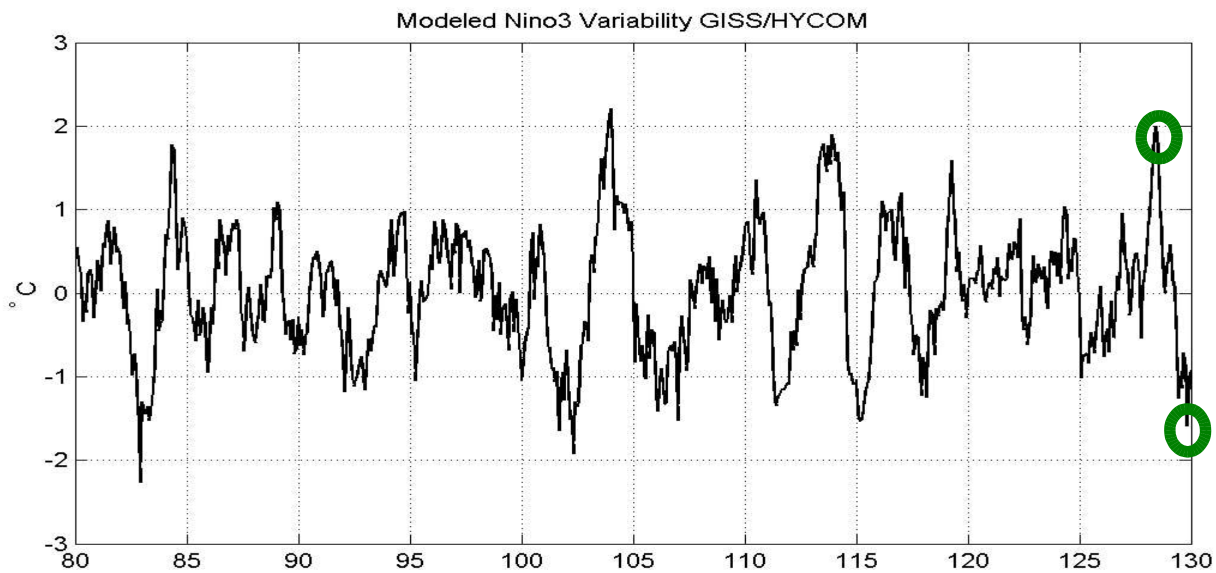


GISS-ER factor of 5 too small Nino-3.4

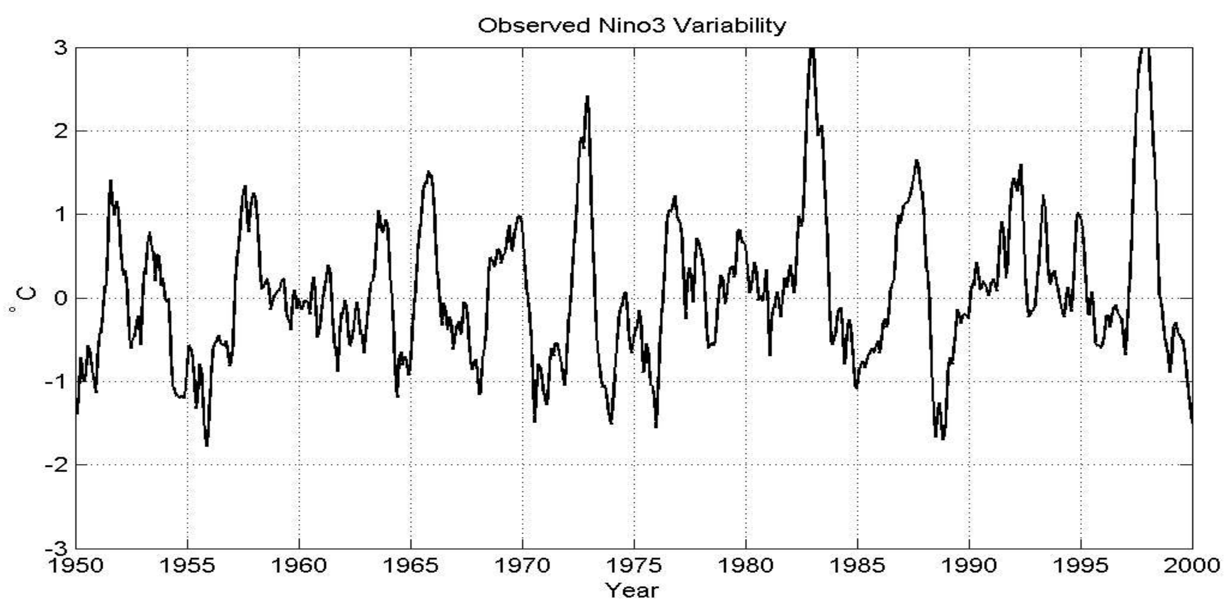
Needs: 1x1 globally ¼ in tropics?

Santer et al 2005

Nino3 index

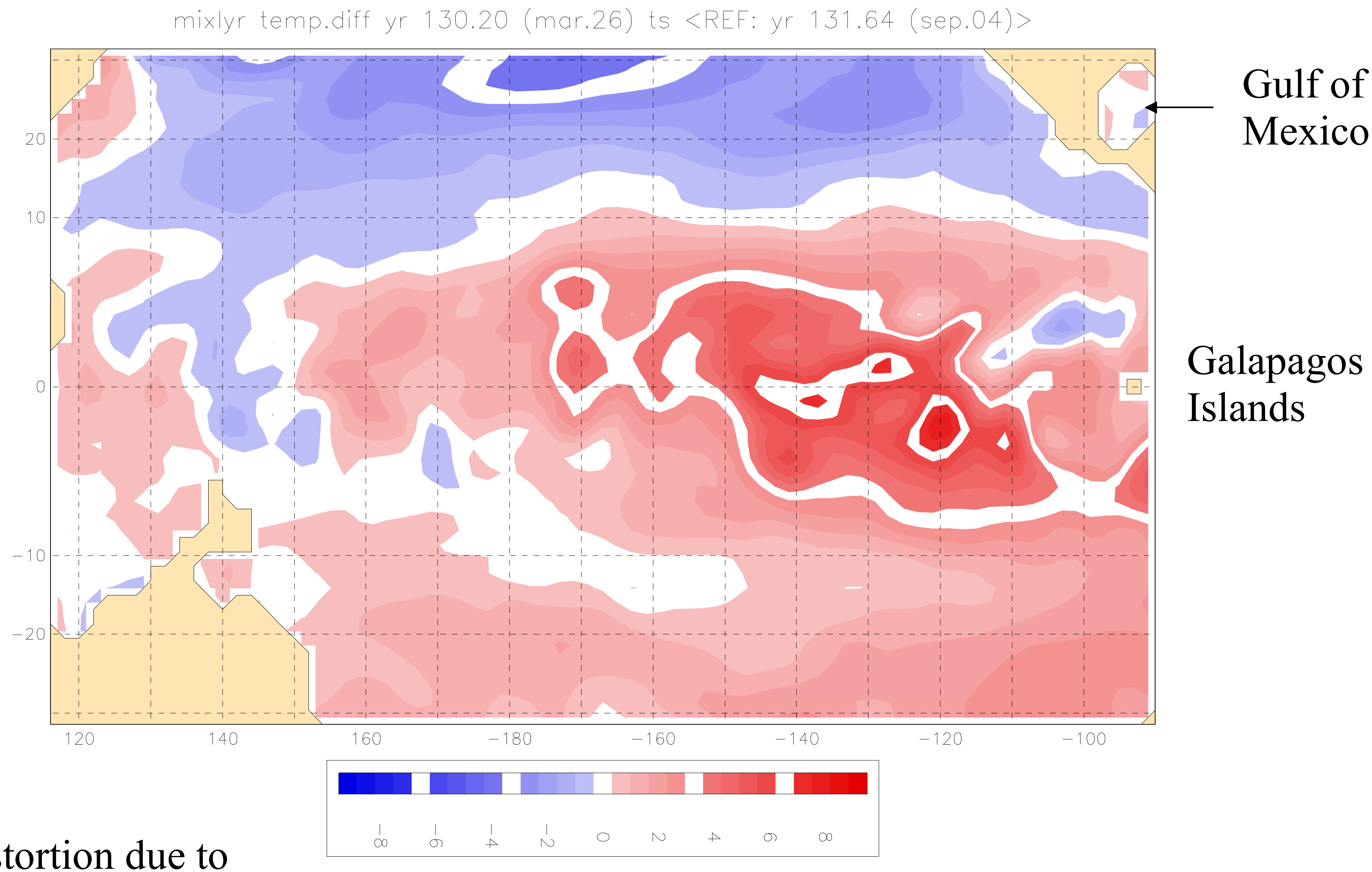


GISS-EH
New version
50 year period
(control run)



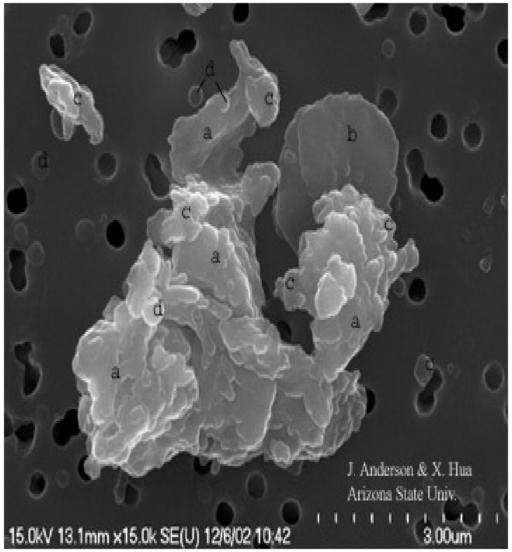
Observations
1950-2000

Sea surface temperature difference
El Nino minus La Nina (GISS-EH)

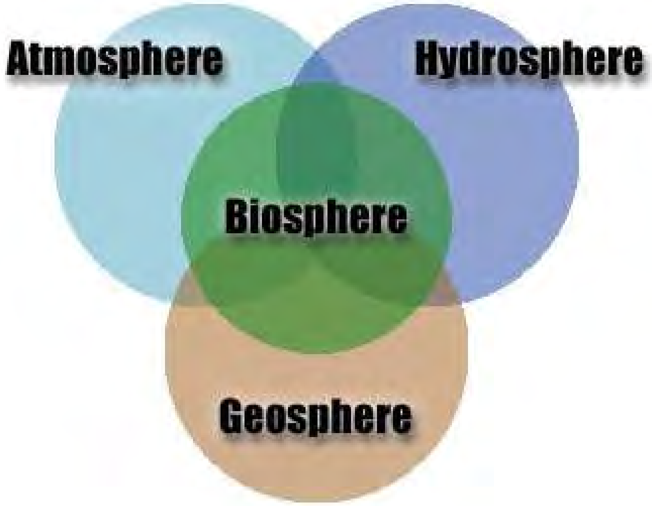


(Note distortion due to meridional grid refinement)

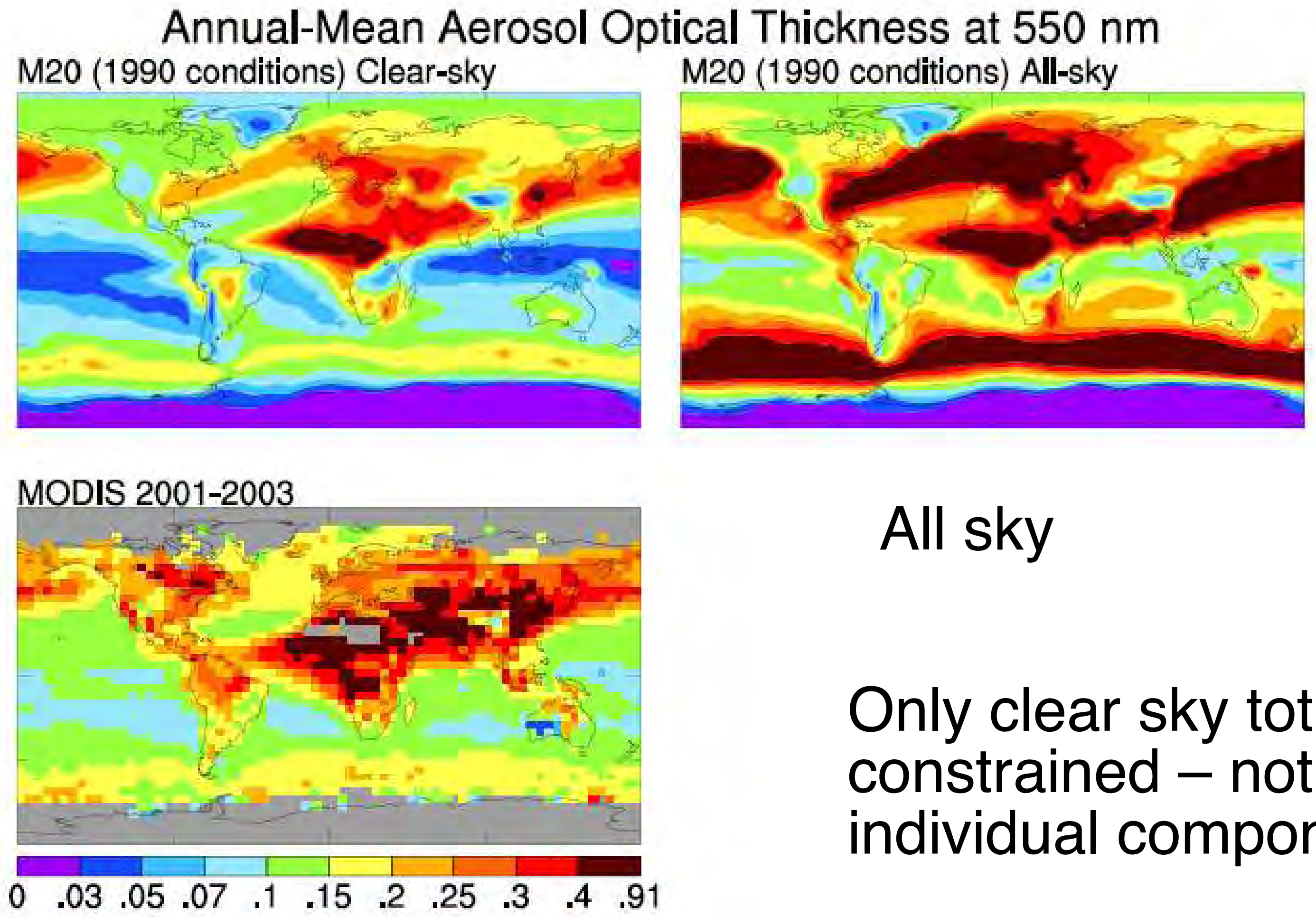
Towards fully interactive ESMs...



- Aerosols <=> Chemistry <=> Radiation
  - Dust/Sea salt, heterogenous chemistry
  - Cloud-aerosol indirect effects
  - RH-aerosol effects
  - Moments-based bin microphysics (GISS-MATRIX)
- Dynamic vegetation => Emissions
  - ENT model (Nancy Kiang)
  - Ozone, secondary organic aerosols, isoprene
  - Ecosystems <=> temperature, precipitation
  - Methane
- Chemical deposition <=> Vegetation
  - Nitrogen/Surface ozone impact veg.
  - Other nutrients to plankton
- Ocean biology => Albedo/Emissions
  - Ocean plankton/ecosystem model (Gregg)
  - Carbon cycle



Aerosol optical thickness

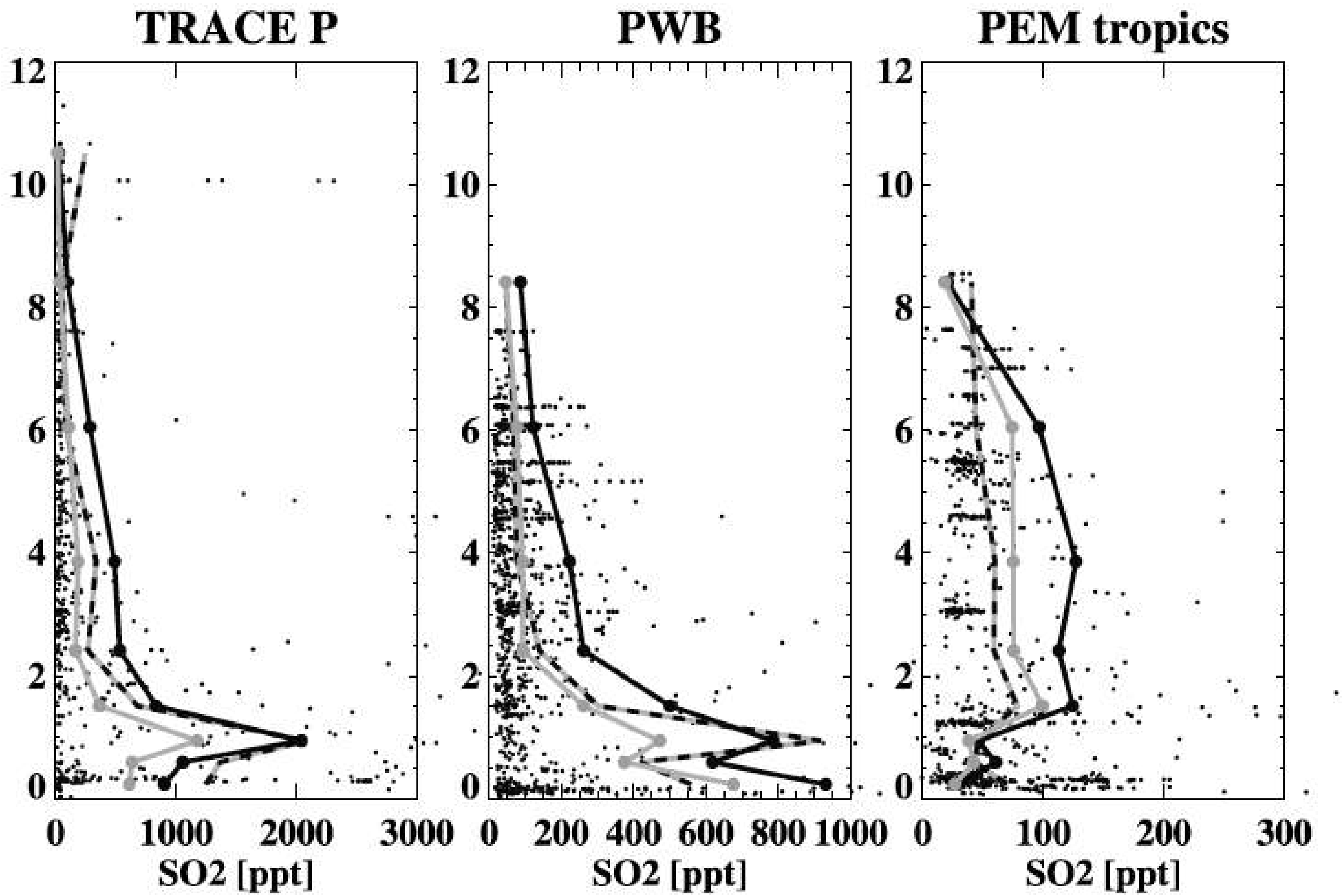


All sky

Only clear sky total is constrained – not individual components

Clear Sky

Impact of heterogenous chemistry

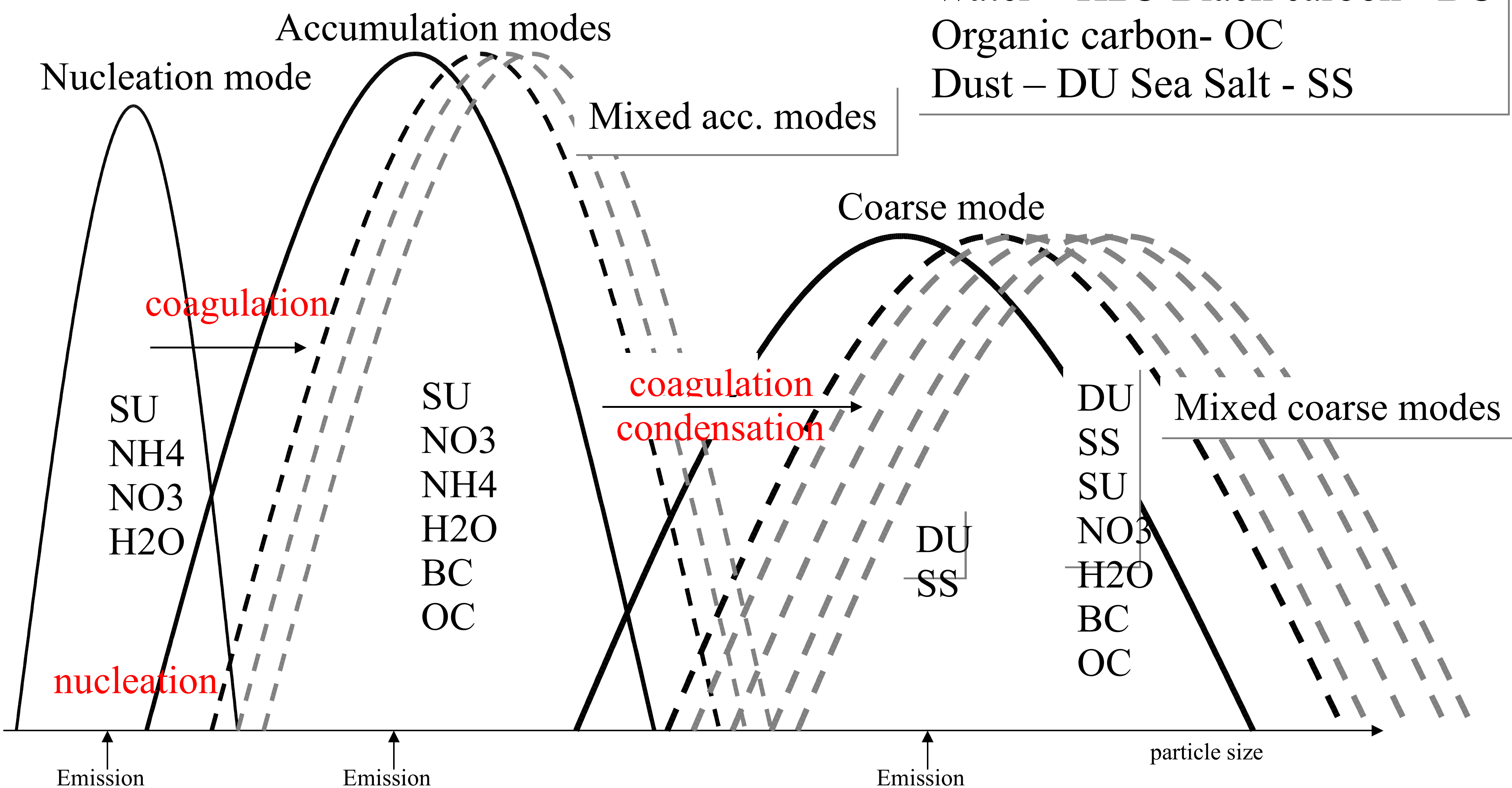


32% reduction in SO_2 when oxidation on dust is included
Big impact on dust load as well...

Bauer and Koch (2005)

Aerosol Microphysics: GISS-MATRIX

Sulfate – SU Nitrate - NO3
Ammonium - NH4
Water – H2O Black carbon - BC
Organic carbon- OC
Dust – DU Sea Salt - SS



Preliminary Model Results:

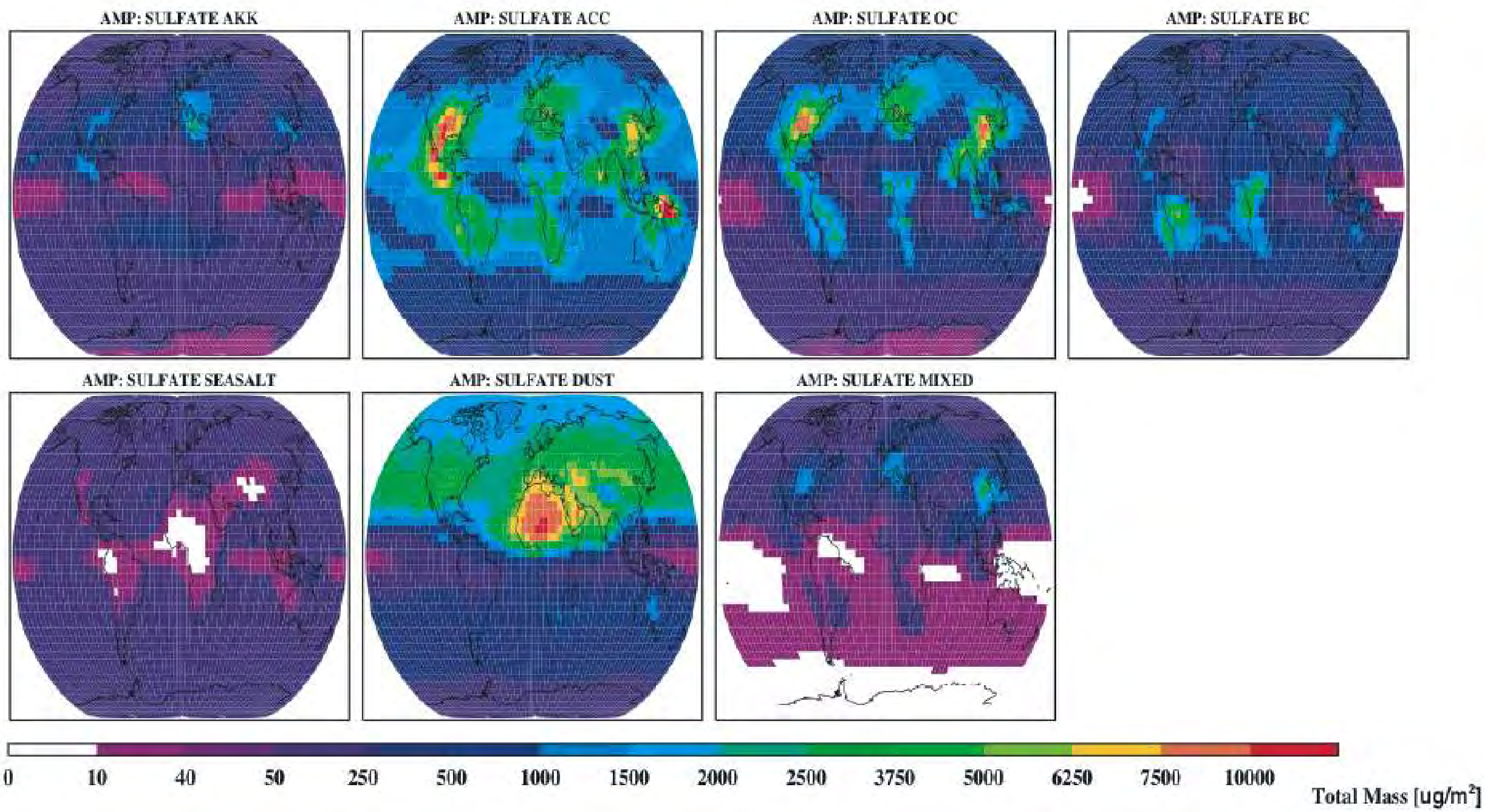
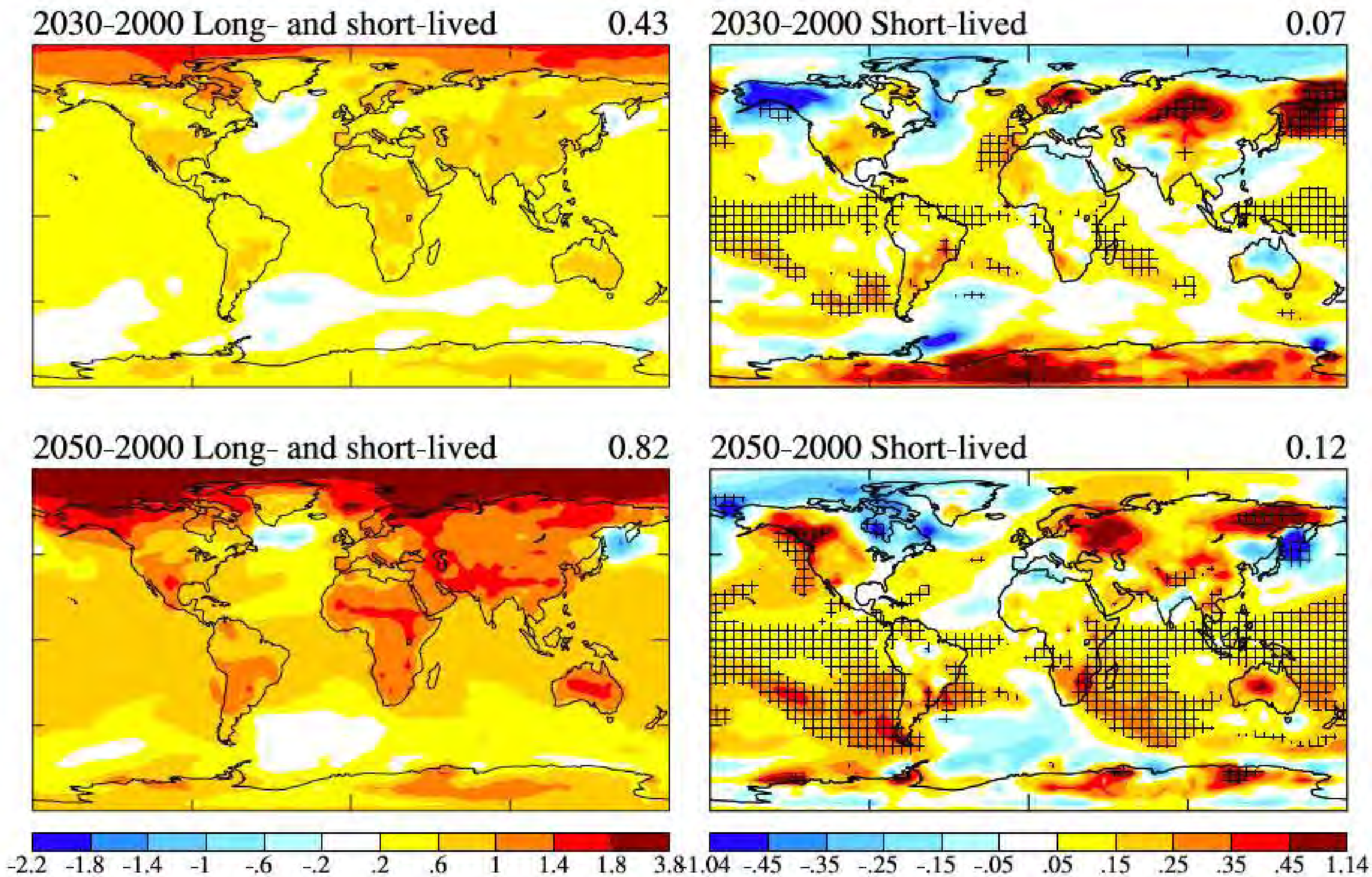


Figure 1:Column mean mass concentrations of sulfate material, as present in the aitken mode (AKK), accumulation mode (ACC), attached to organic carbon, black carbon, sea-salt, mineral dust and tertiar mixtures. Units are in [mg/m^2]

See S. Bauer (poster)

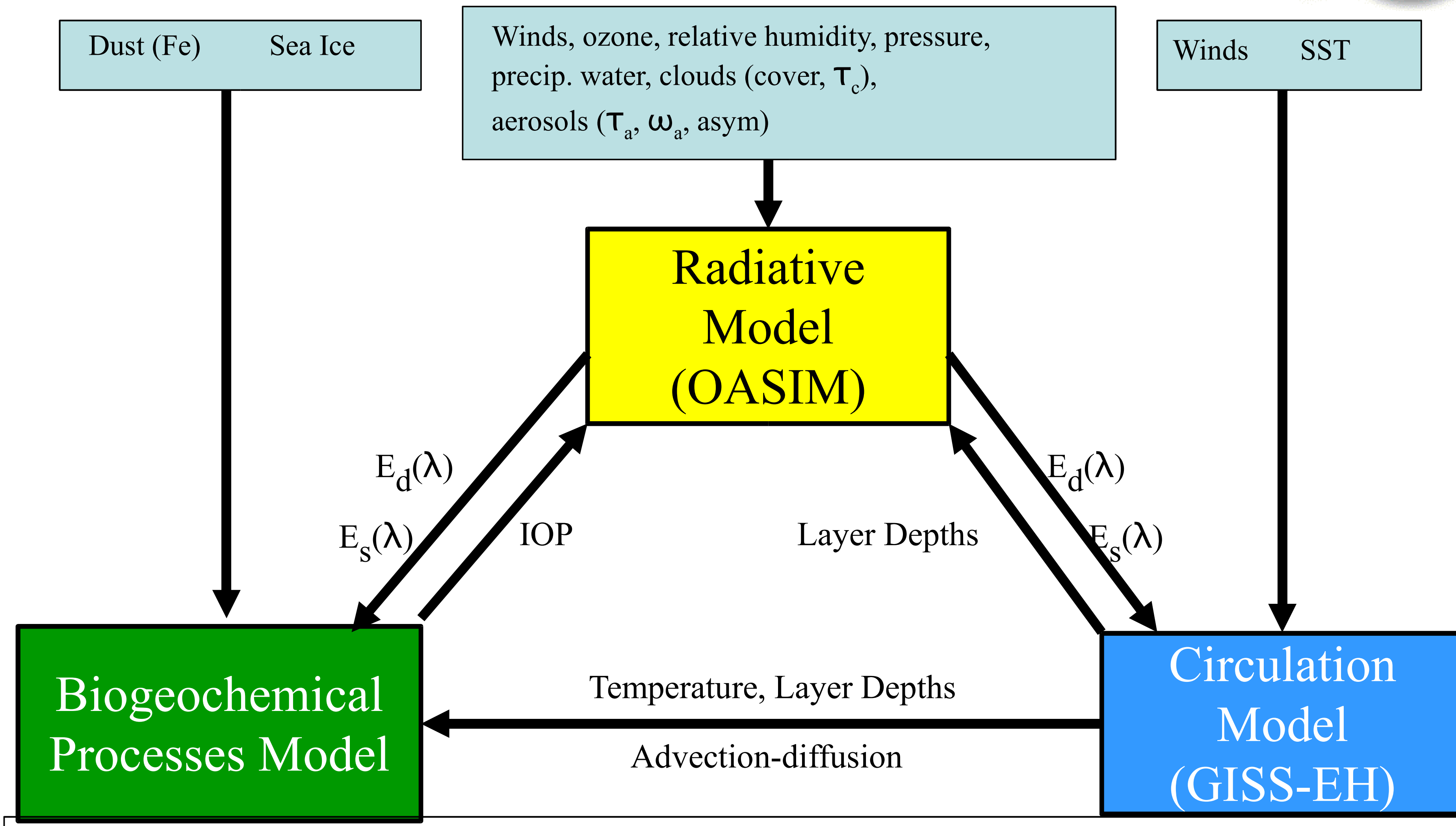
Climate forcing: short-lived gases

$CO_2+CH_4+O_3$ O_3



Very senstive to highly uncertainozone precursor emissions

Ocean Biology Linkage (NOBM)



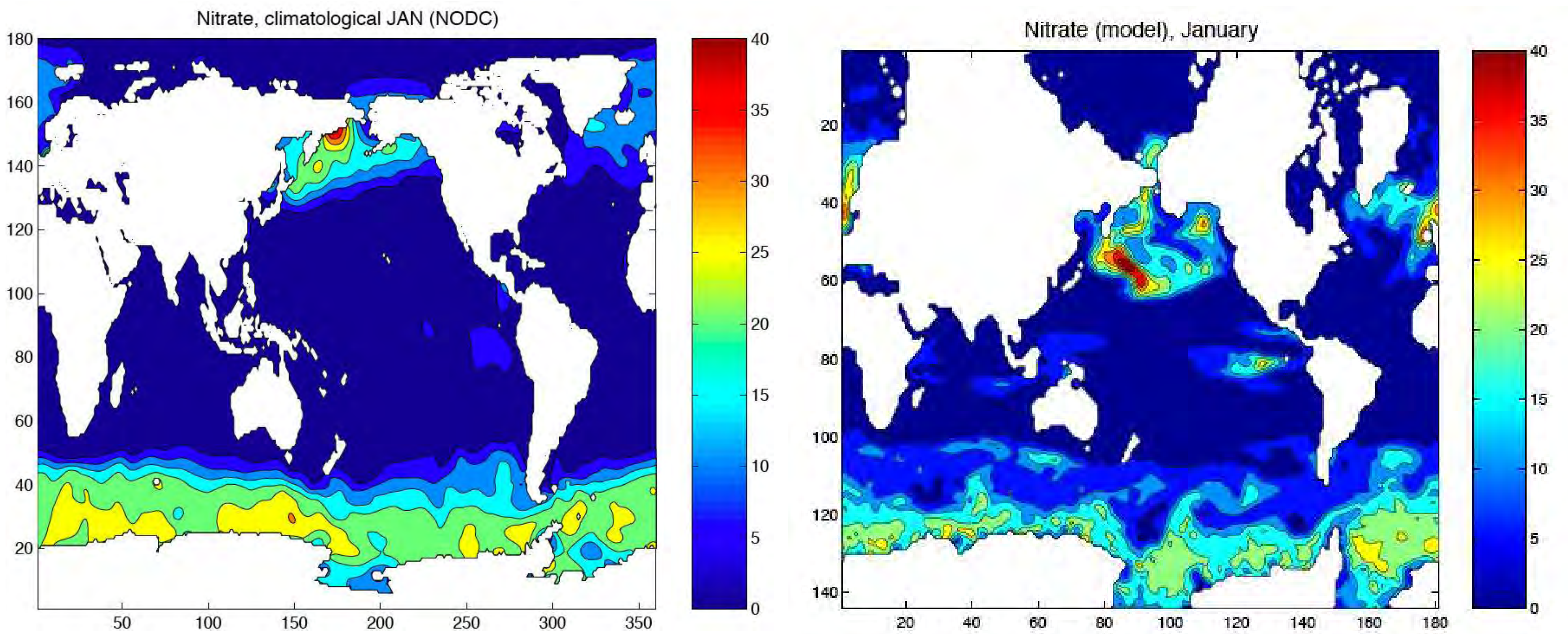
Outputs:

Chlorophyll, Phytoplankton Groups

Primary Production, Nutrients, DOC, DIC, pCO_2

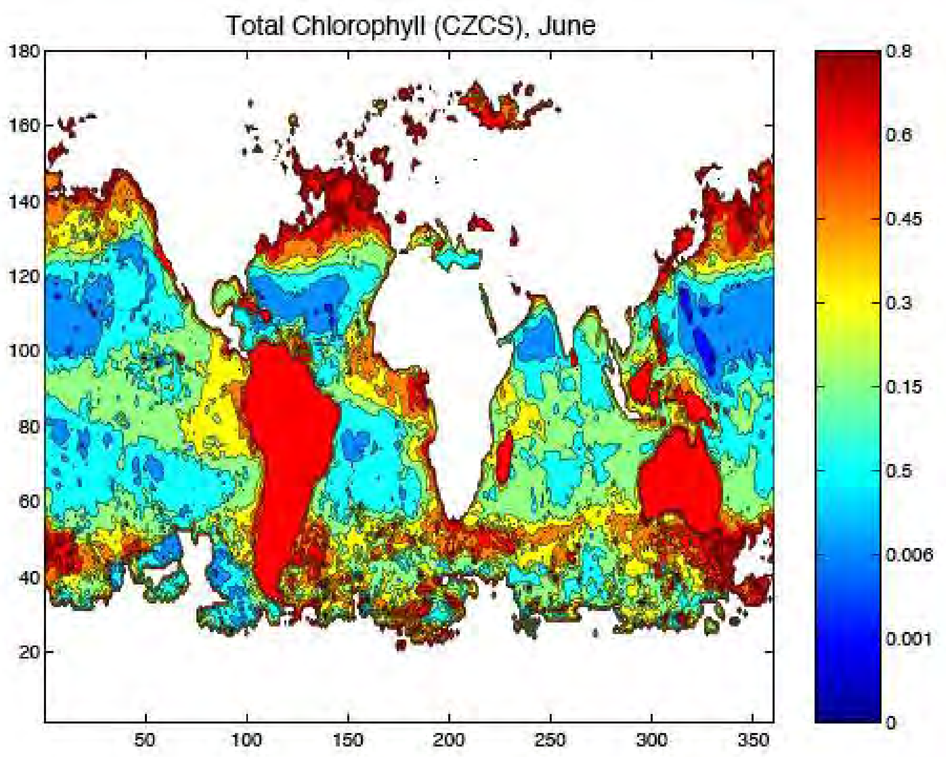
Spectral Irradiance/Radiance

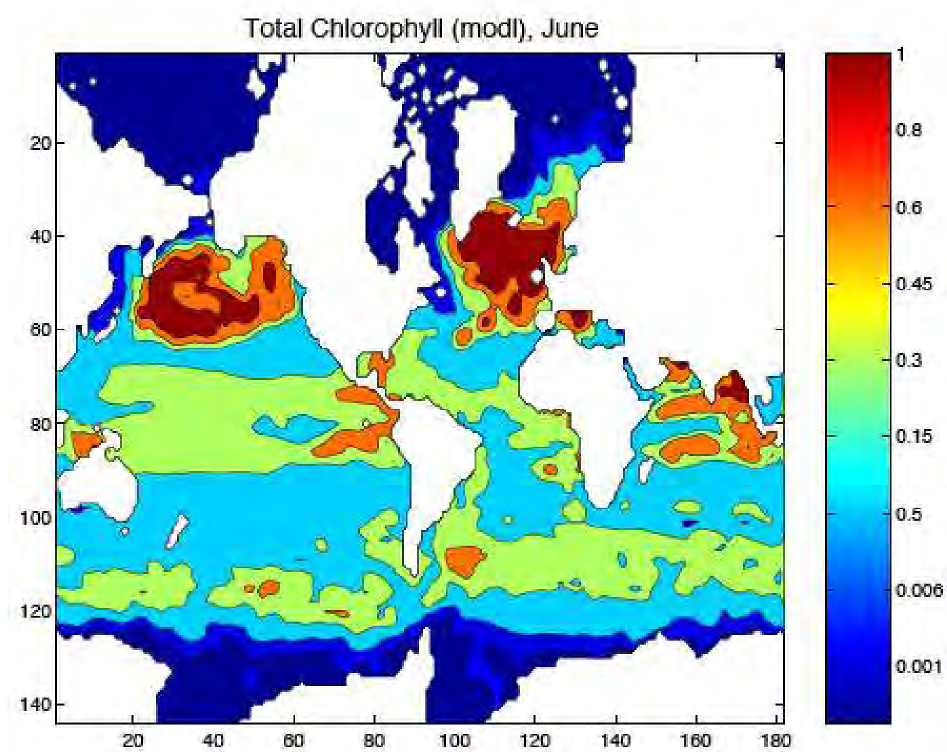
Ocean Carbon Cycle: Nitrate



Preliminary results: GISS-EH (note different projections)

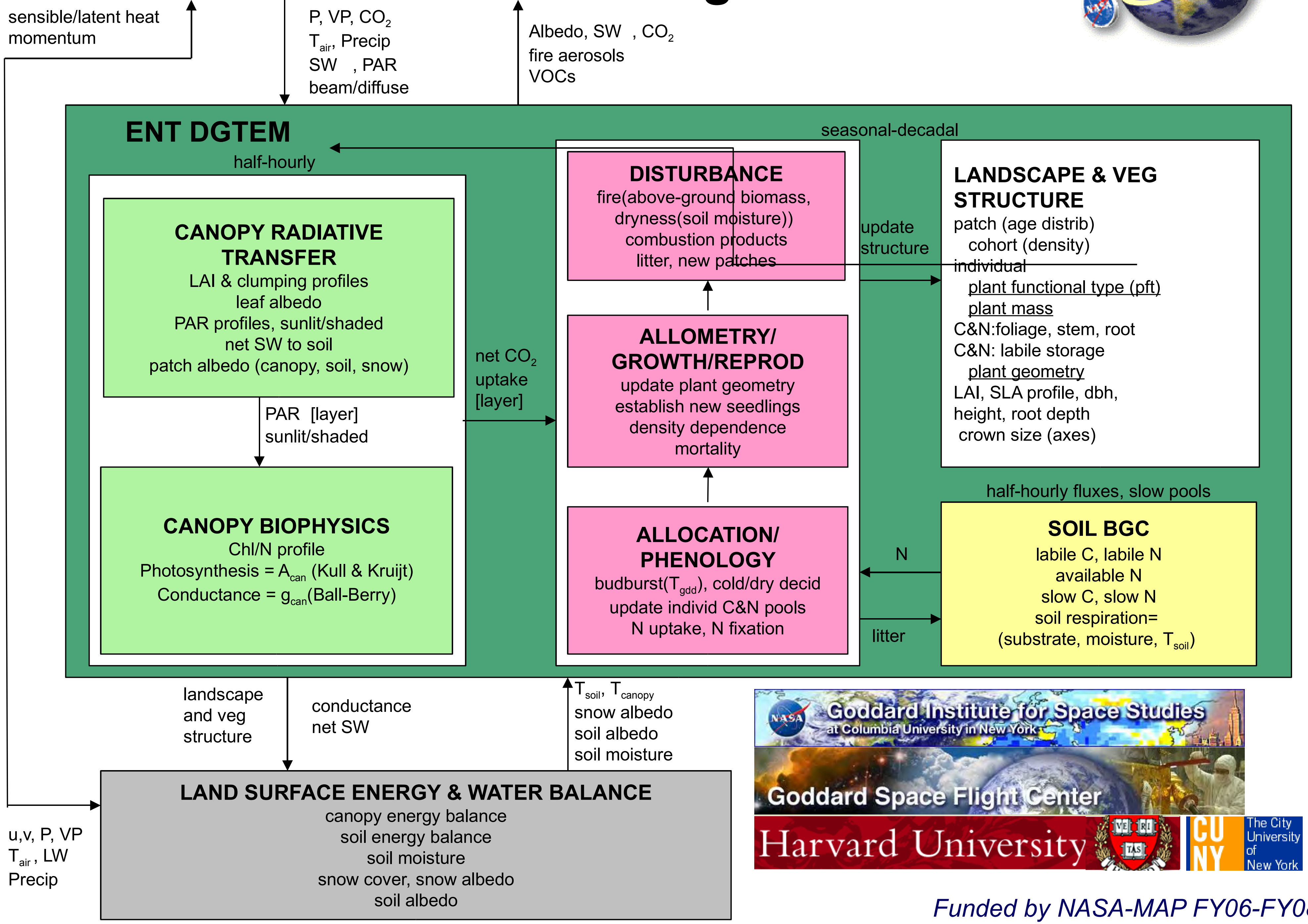
Ocean Carbon Cycle: Total Chlorophyll





Preliminary results: GISS-EH (note different projections)

ENT – Dynamic Vegetation

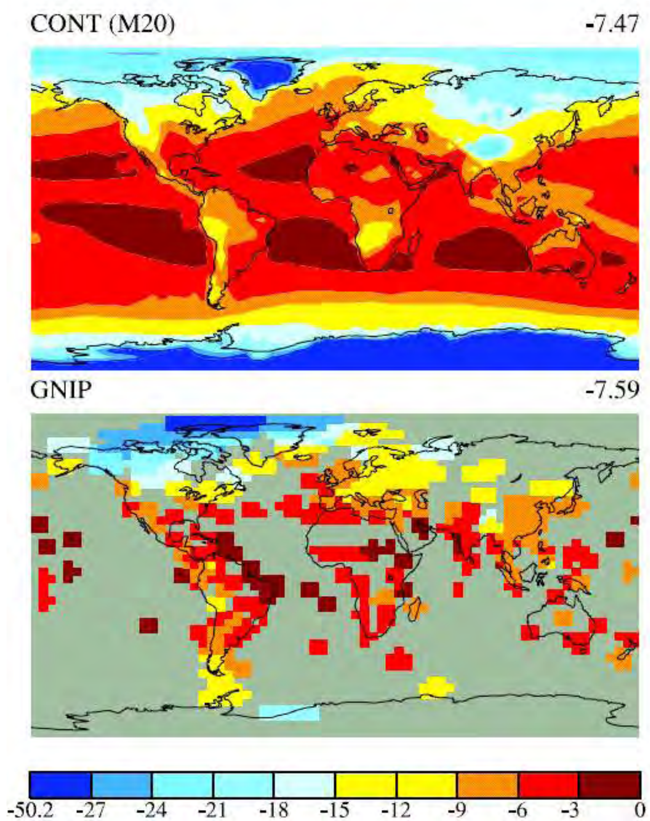


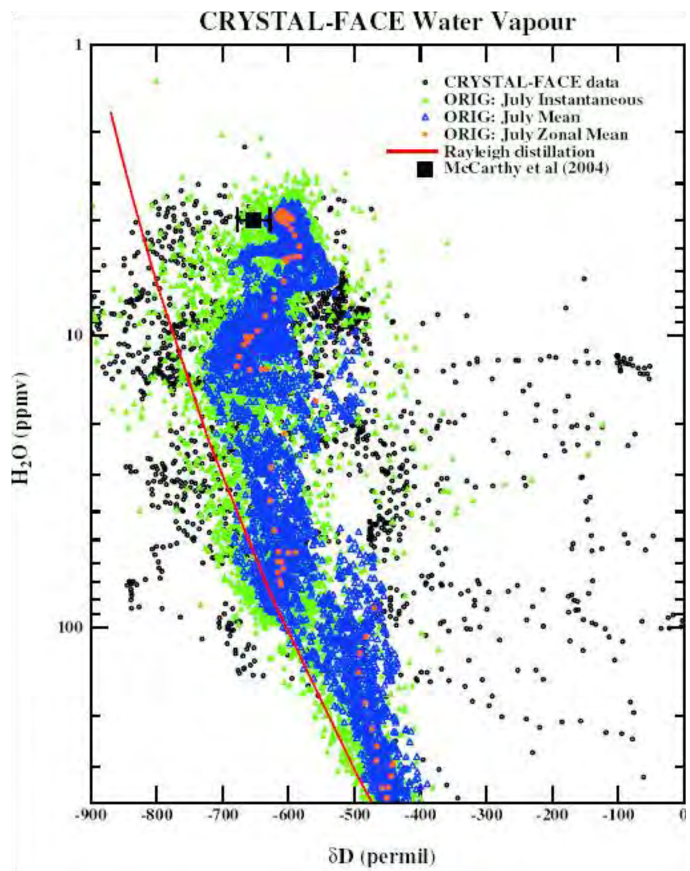
Funded by NASA-MAP FY06-FY08.

Modeling of atmospheric water isotopes

Water isotopes were included as tracers in GISS ModelE and compared to surface observations (GNIP, IAEA) and atmospheric profiles. Potentially, isotopes will be able to distinguish between cloud paramterisations in models and trace water through the hydrological system (TES).

$\delta^{18}O$ in precipitation



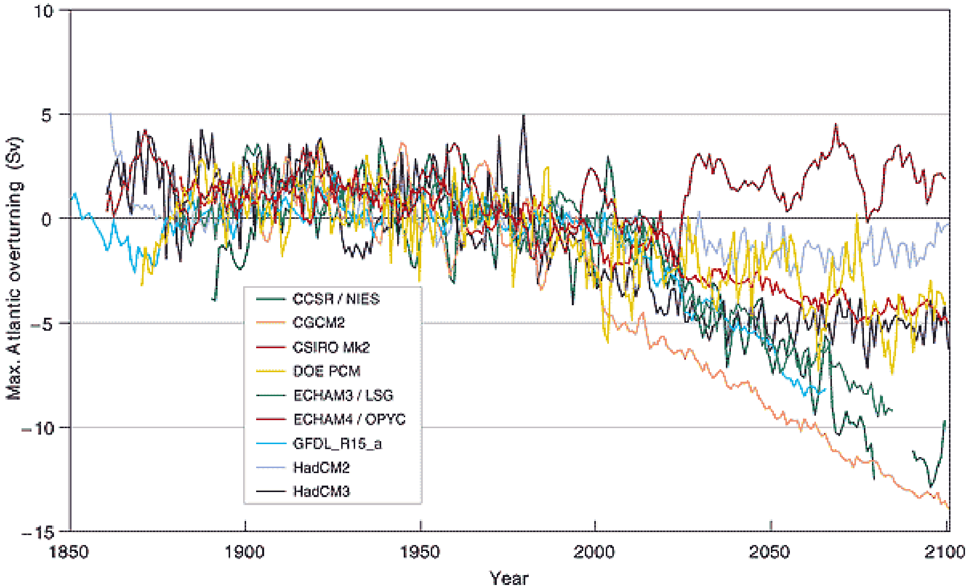


δD in water vapour compared to CRYSTAL-FACE observations

Schmidt et al, 2005

Putting it together: ESMs connect past change with future projections

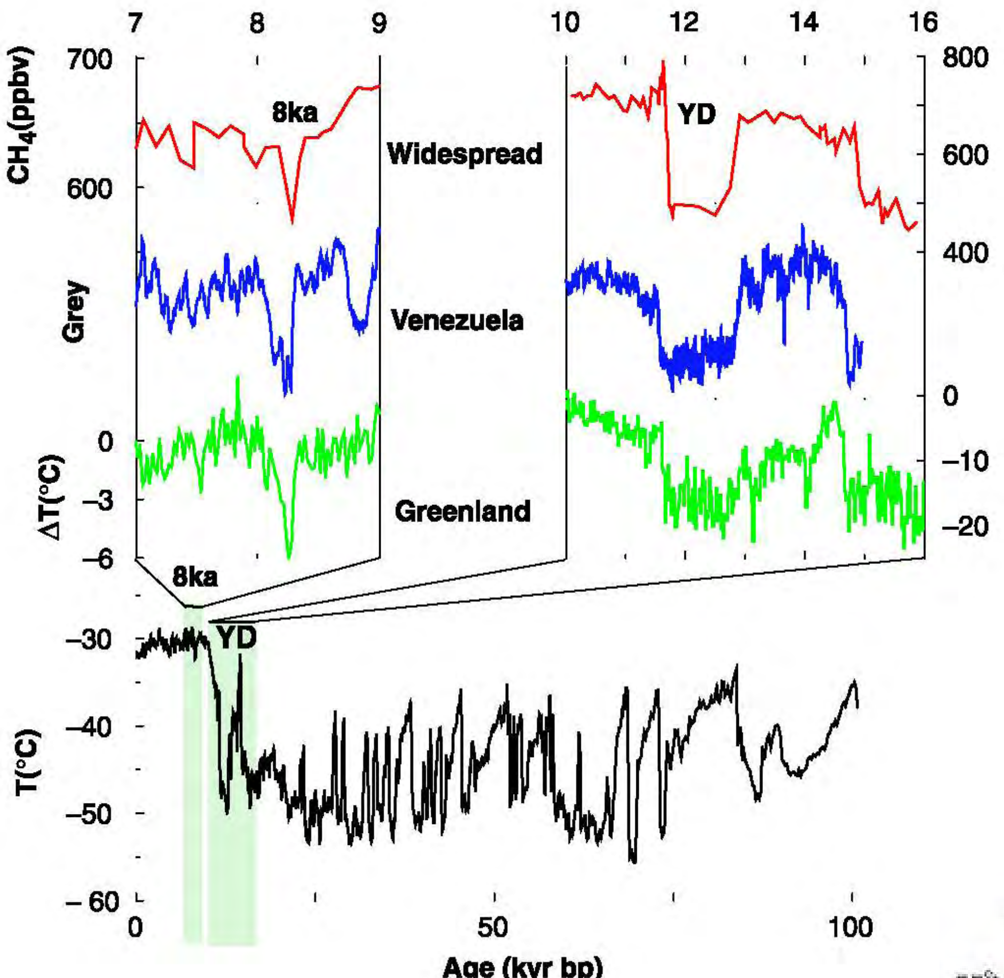
- Large uncertainty in projections of North Atlantic MOC in IPCC
  - Only examples of MOC variability are in paleo record
  - Records are proxies: ice cores, ocean sediment, cave + lake records
- ESMs now contain this physics
- Take quantified forcing from past change
  - => Forward model proxy response
  - Isotopes, dust, aerosols, methane



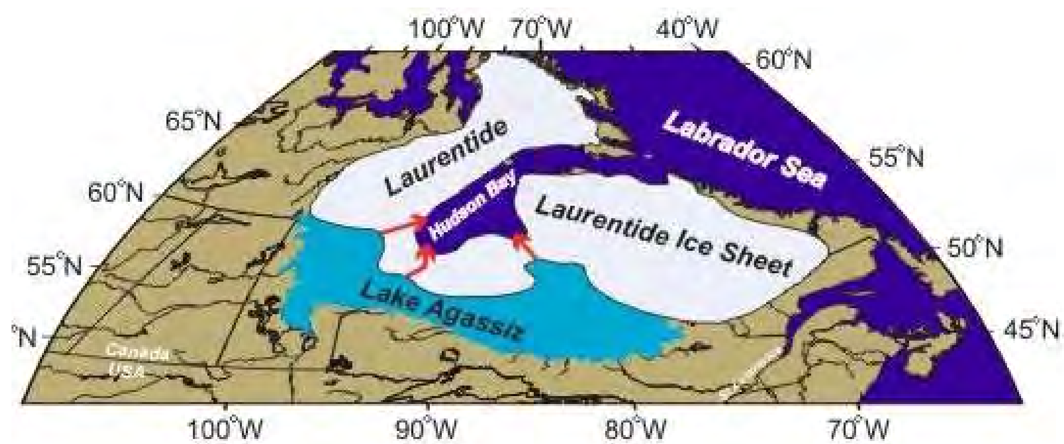
Enter the 8.2 kyr event...

Biggest abrupt climate change event in Holocene seen in Greenland ice cores

Coincident with final draining of Lake Agassiz?

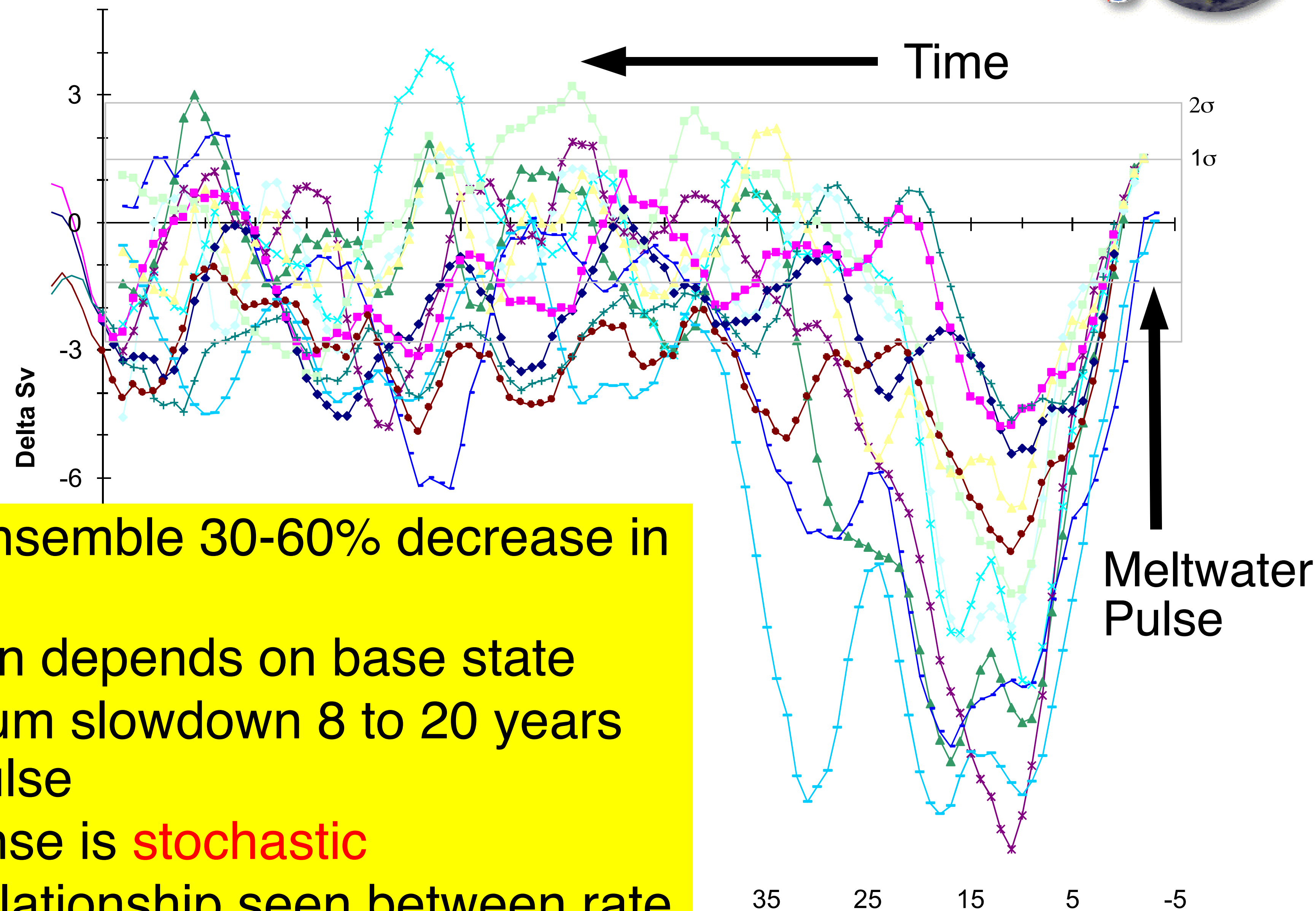


Richard Alley



Peter Clarke

The 8.2 kyr simulations...



Over ensemble 30-60% decrease in NADW

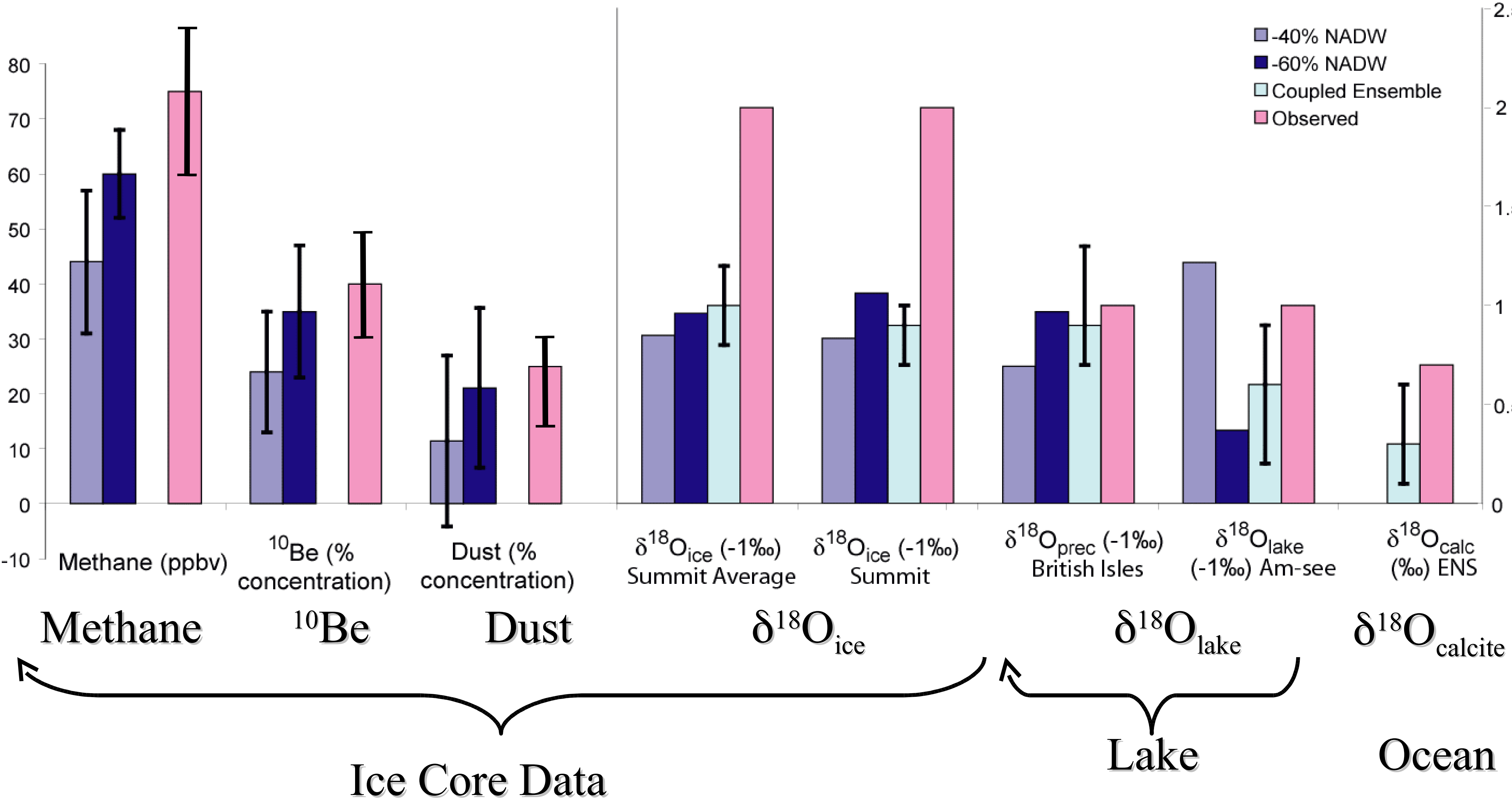
Duration depends on base state

Maximum slowdown 8 to 20 years after pulse

Response is stochastic

Little relationship seen between rate or volume of flux and response.

Multi-proxy comparisons...



Use ensemble mean to drive CH_4 wetland emissions, + dust, ^{10}Be (aerosol) concentrations at Summit (Includes snow acc. decrease (15-20%). Methane change assuming no change in N-S gradient, but with feedback on its own lifetime

Implications for future projections

8.2 kyr event **NOT** an analog for future change

- Instead, test of key physics that may be important
- Potential screen for outlier models

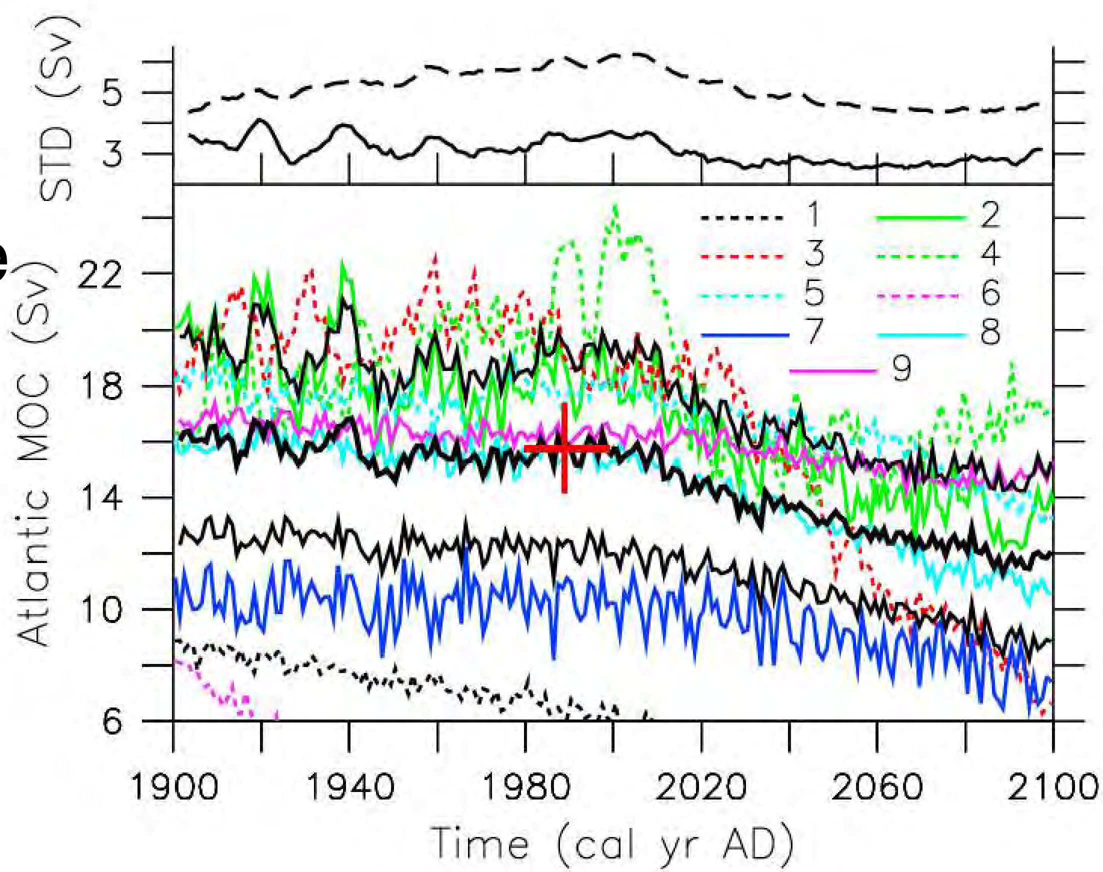
AR4: 2100 A1B scenario?

GISS models:

- ~20% NADW decrease
- No abrupt change
- No actual cooling

Schmittner et al (2006):

- Weighted: -25%
- Unweighted: -27%



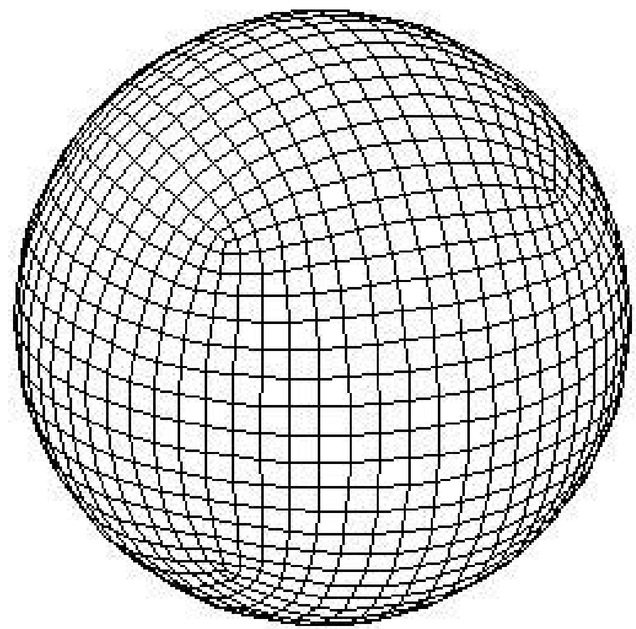
Ice Sheet Modeling

- Current ISMs are 'woefully' inadequate
  - Shallow ice approximation doesn't capture full rheology
  - Dynamic changes in ice flow not simulated
  - Surface energy balance/hydrology primitive
  - Unable to match GRACE/IceSat changes
- GCMs need credible ISM to reduce uncertainty in sea level projections
- US Common Architecture based on GLIMMER interface?
  - Bill Lipscomb
- Multi-agency suppport? (NASA, NOAA, DOE?)
- Requires ISM development + support for coupling efforts

New ideas

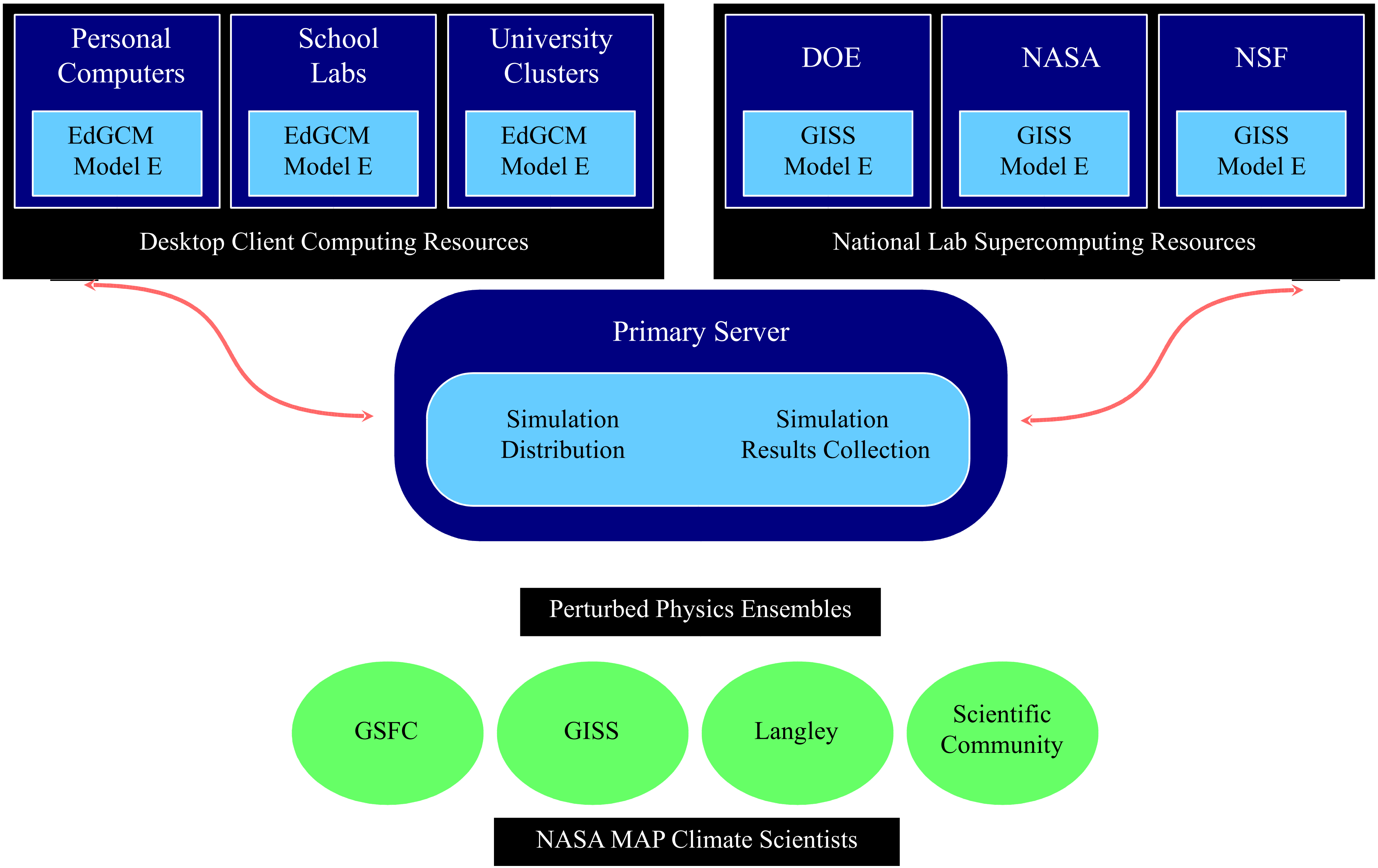
Climate@Home:
    Perturbed Physics Ensembles

Cubic-sphere grid:
    logically rectangular
    8 mild singularities
    GSFC support using FvCore



Cloud Super-parameterisations
    Interest from Comp. Sci. at CU

Climate@Home: Multiple ways to do PPE



GISS ModelE Summary

- AR4 results good background for future MAP progess
- Ocean models weak point
  - Will require more resources for AR5
  - Two ocean models bracket obs. Oc.Ht.Cont. changes
  - Similar reduction in NADW by 2100
  - Similar reasons to that seen in other models
- Improvements to ENSO simulation important for future runs
- Earth System components (chemistry, aerosols, isotopes)
  - Applications to paleo/modern/future projections
- Testing aerosol microphysics, carbon cycle (ocean + ENT)
- FVcore incorporation (coded but not working)
- ESMF infrastructure/libraries used
- New projects?
  - Ice sheet modelling, Climate@Home, cubed sphere