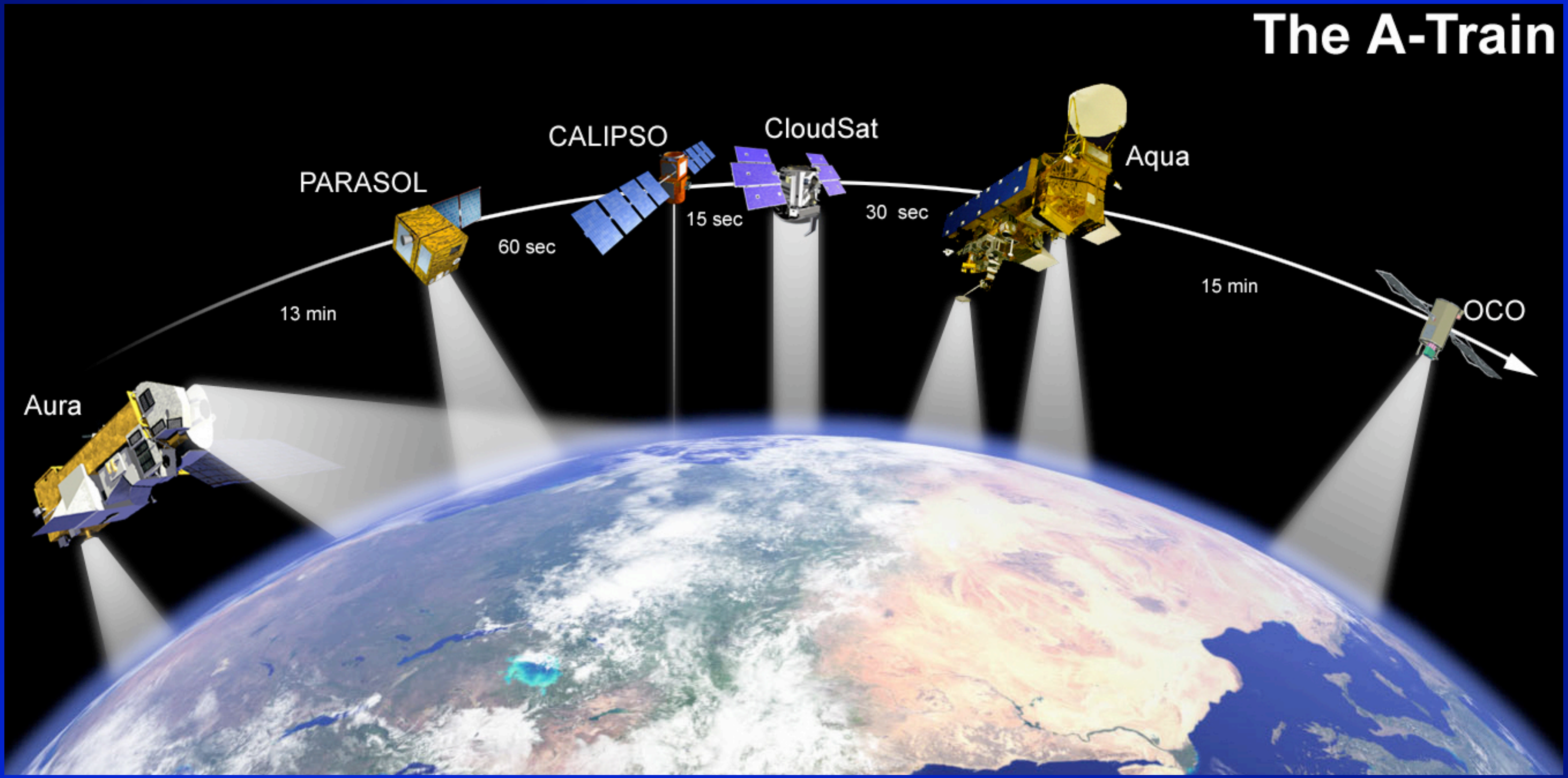
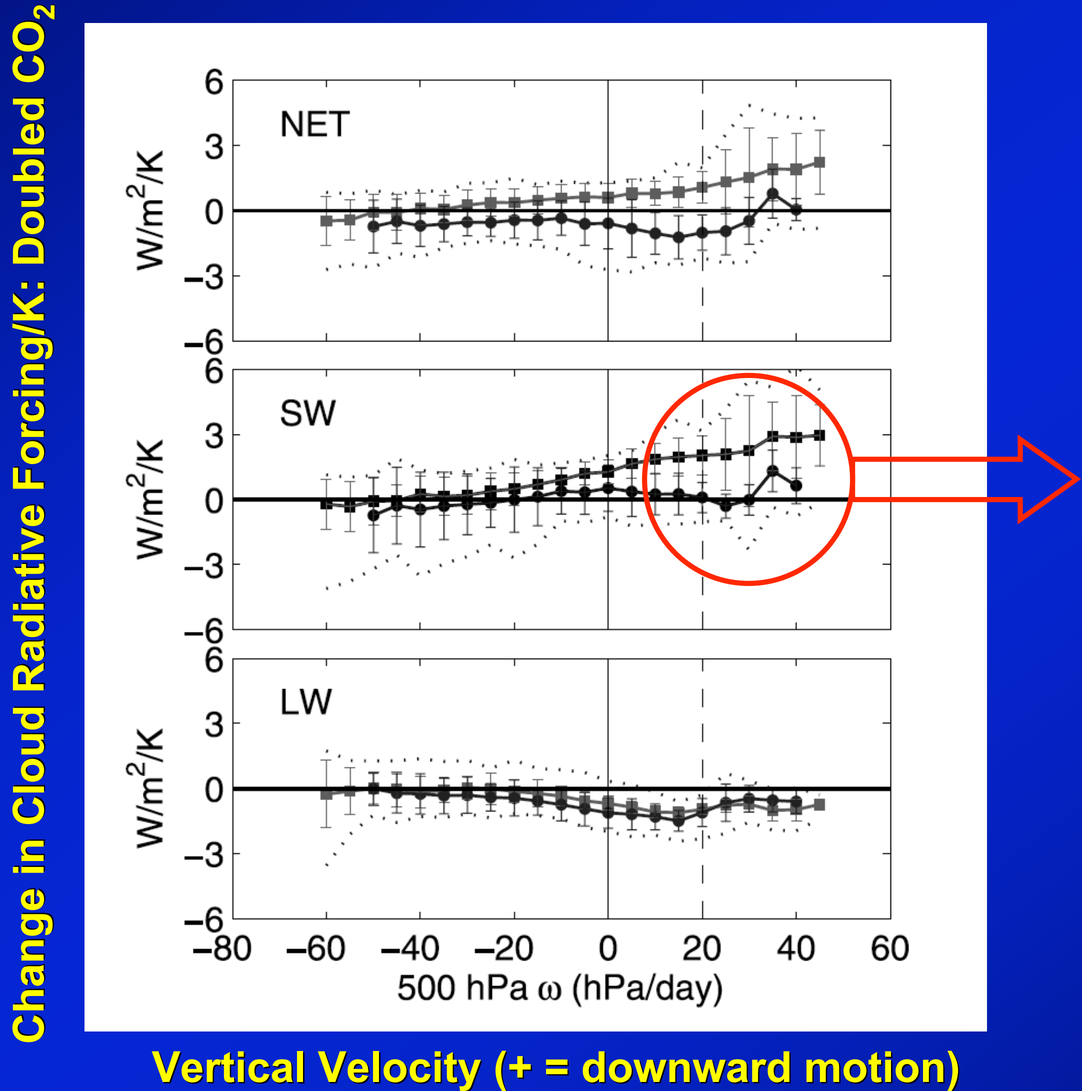
Climate, MMFs, & Satellite Observations



CMMAP Team Meeting
Ft. Collins, CO Aug 17, 2006

Changing Cloud Forcing vs Vertical Velocity

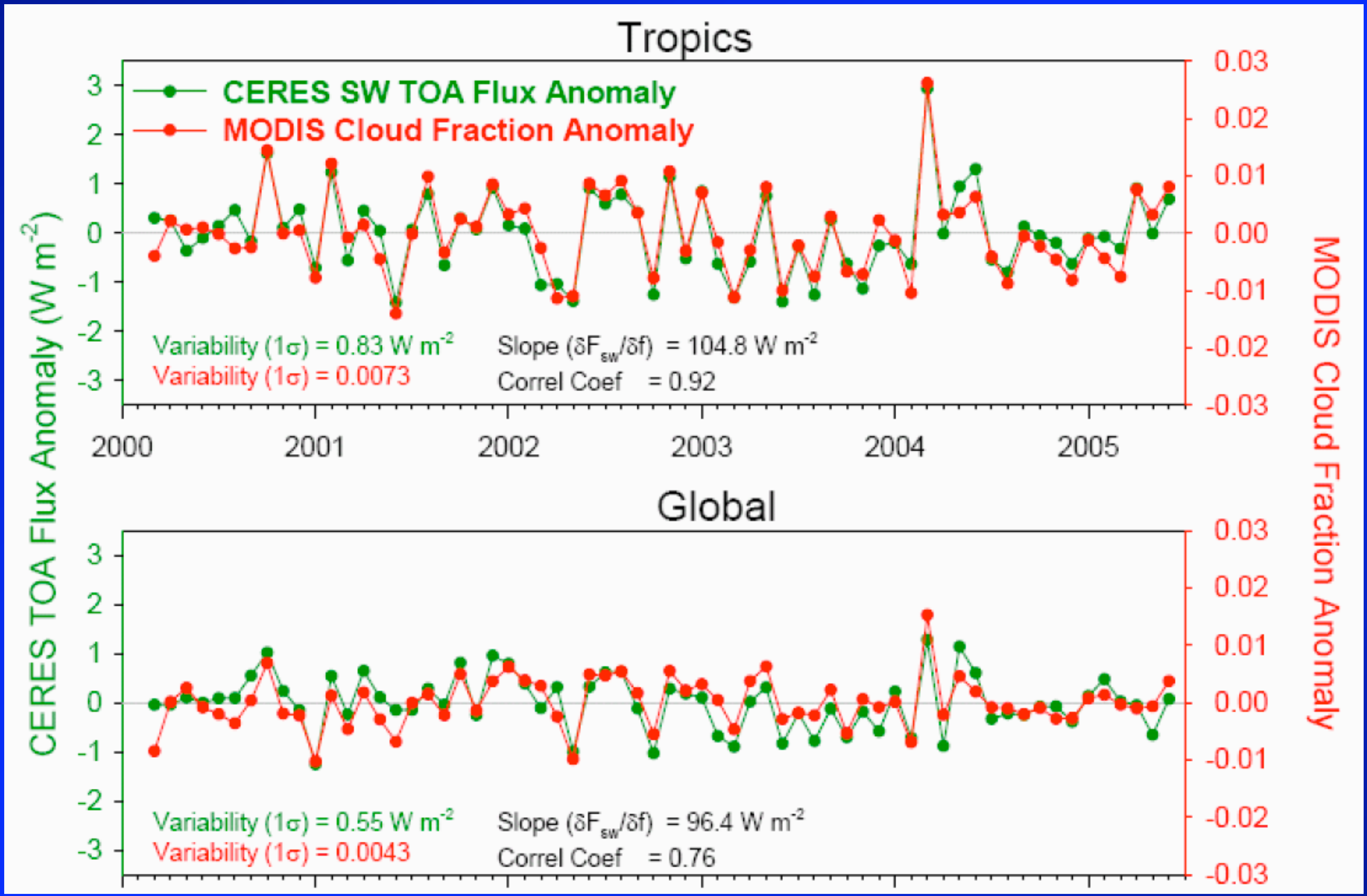
15 IPCC AR4 Climate Models: 30S to 30N Ocean



Low Clouds Dominate Cloud Radiative Forcing Changes (SW reflected flux) and Cloud Feedback uncertainty

Bony and Dufresne GRL, 2005

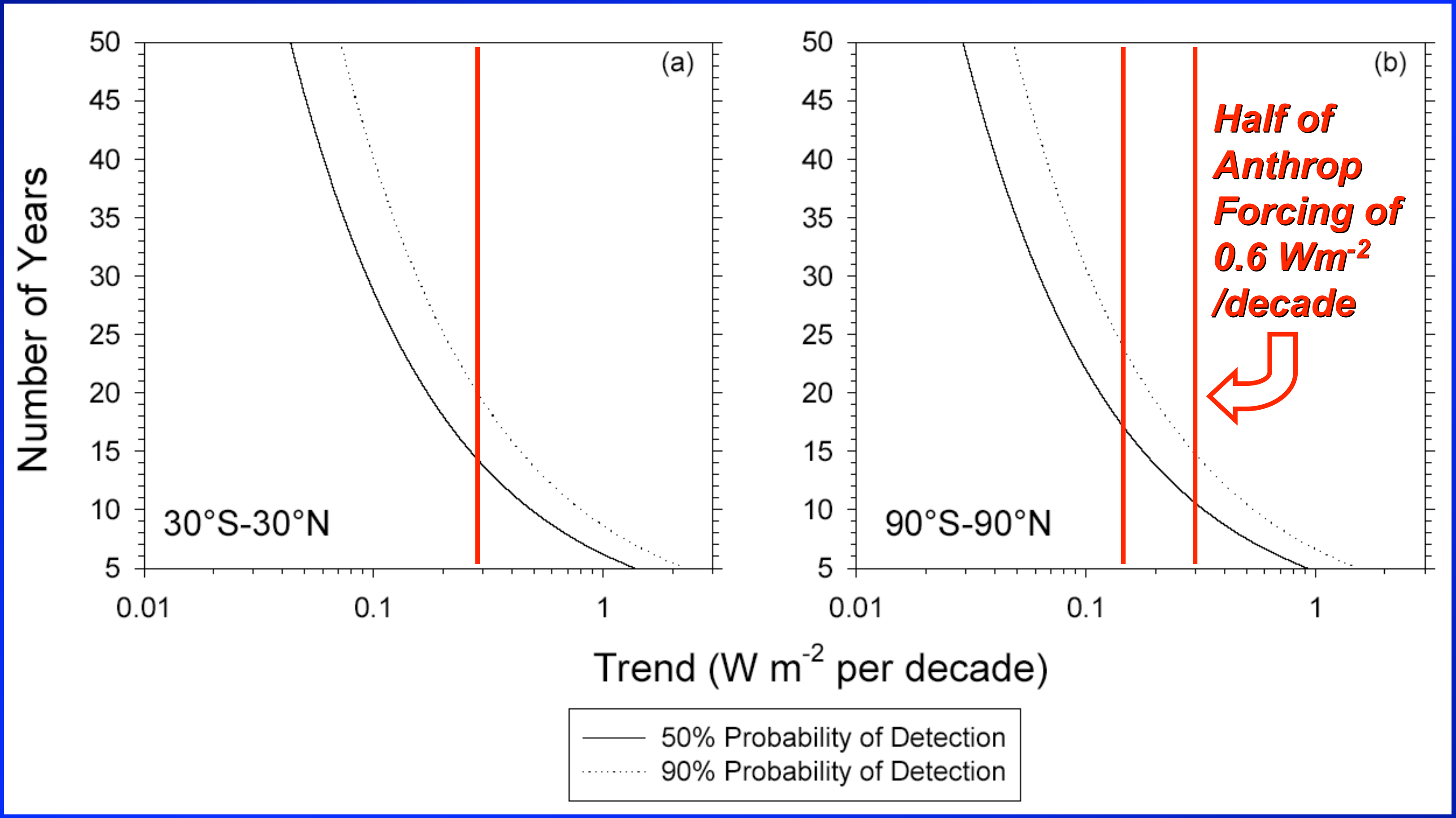
Reflected SW Flux and Cloud Fraction Anomalies



Cloud Fraction, not Optical Depth dominates interannual variations of reflected solar fluxes.

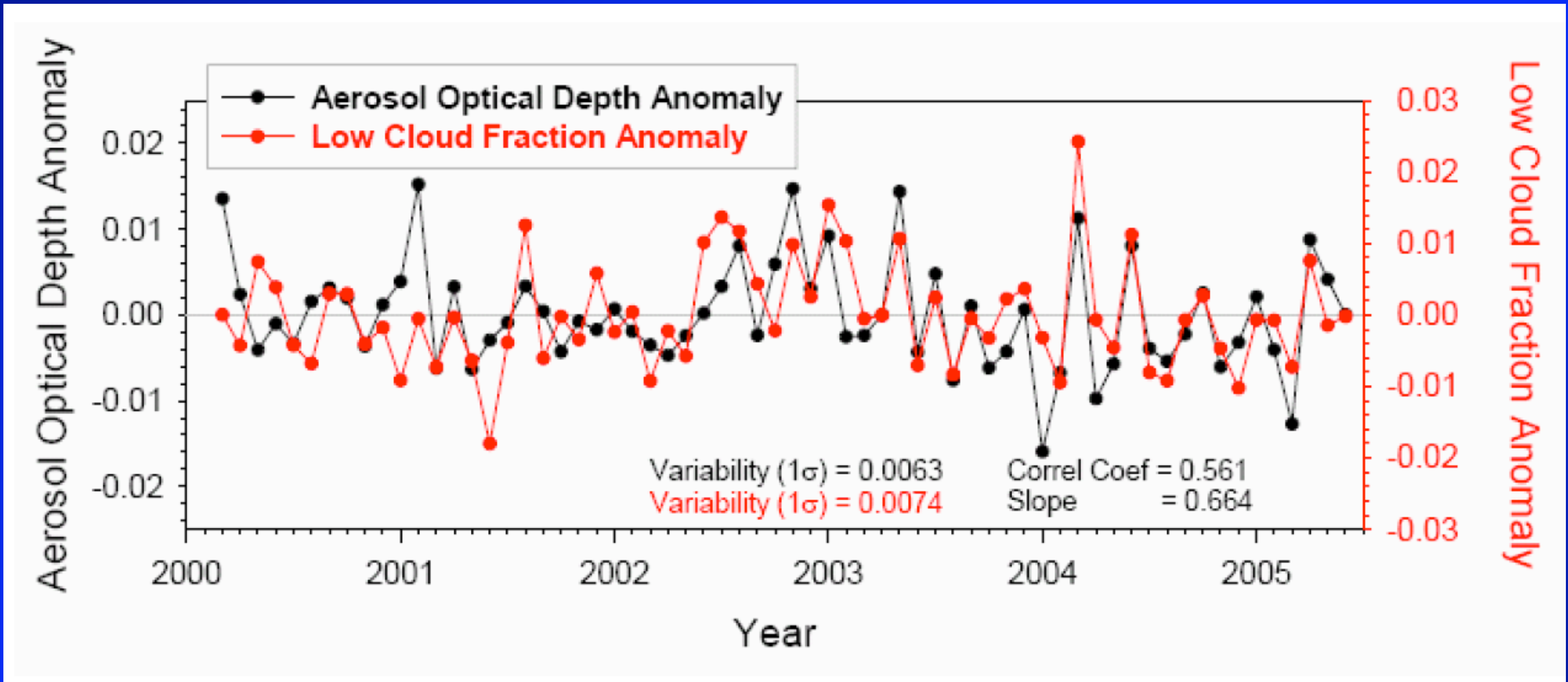
Loeb et al., AGU 2005

Using CERES to Determine Length of Climate Data Record Needed to Constrain Cloud Feedback



Given climate variability, 15 to 20 years is required to first detect climate trends at cloud feedback level with 90% confidence, and 18 to 25 years to constrain to +/- 25% in climate sensitivity

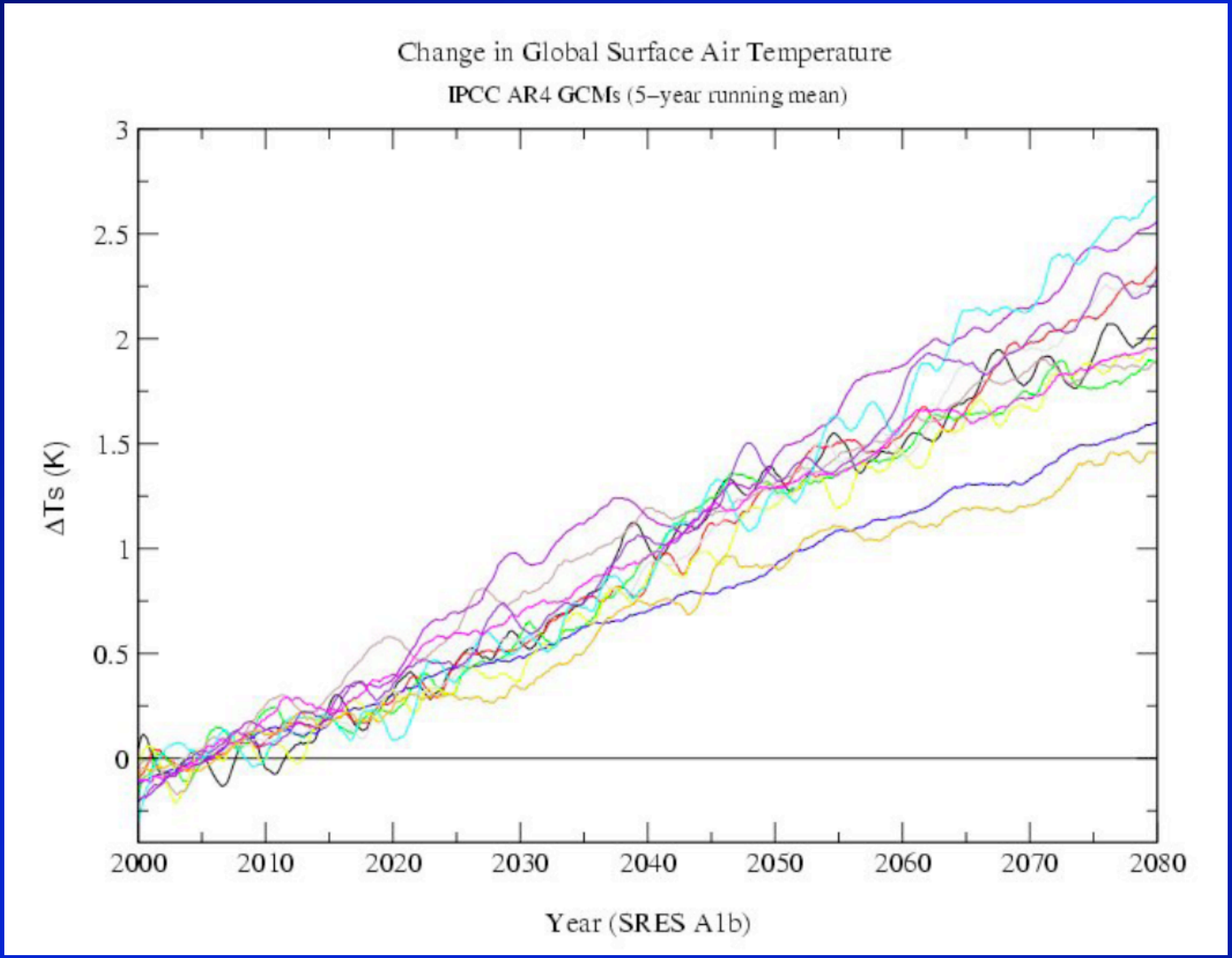
Aerosol and Low Cloud Changes: CERES/MODIS Tropical Oceans, 30S to 30N



Aerosol Optical Depth and Low Cloud Fraction are correlated but not locked together.

Loeb et al., AGU 2005

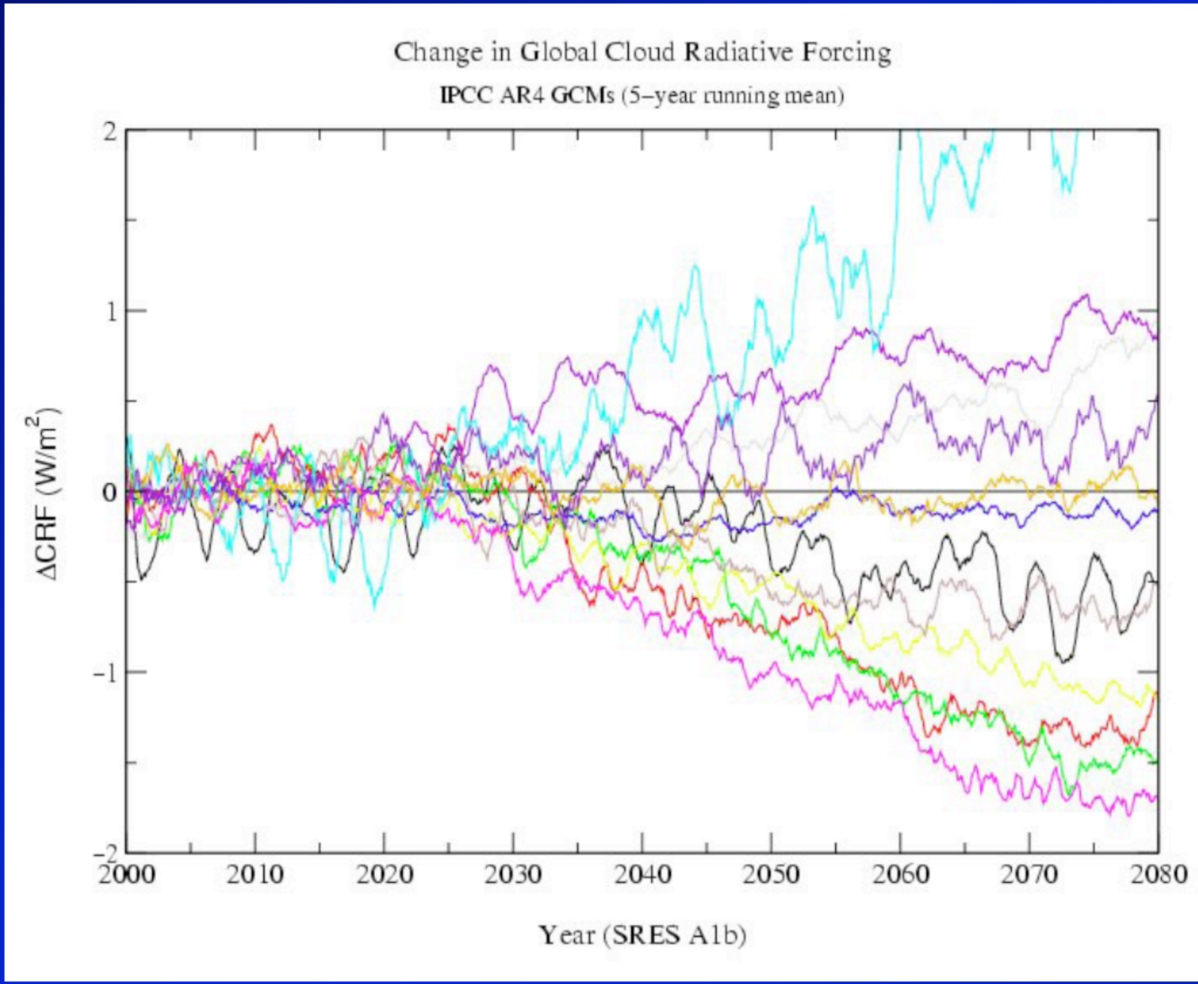
Global Surface Temperature Change
AR4 Climate Models



Must determine climate sensitivity and therefore cloud feedback well before temperature signals show sensitivity: can't wait to after 2030

- Weak ability to distinguish climate sensitivity until after 2030
- Early temperature response similar because more sensitive climate models have a stronger ocean response delay.

Cloud Radiative Forcing AR4 Climate Models



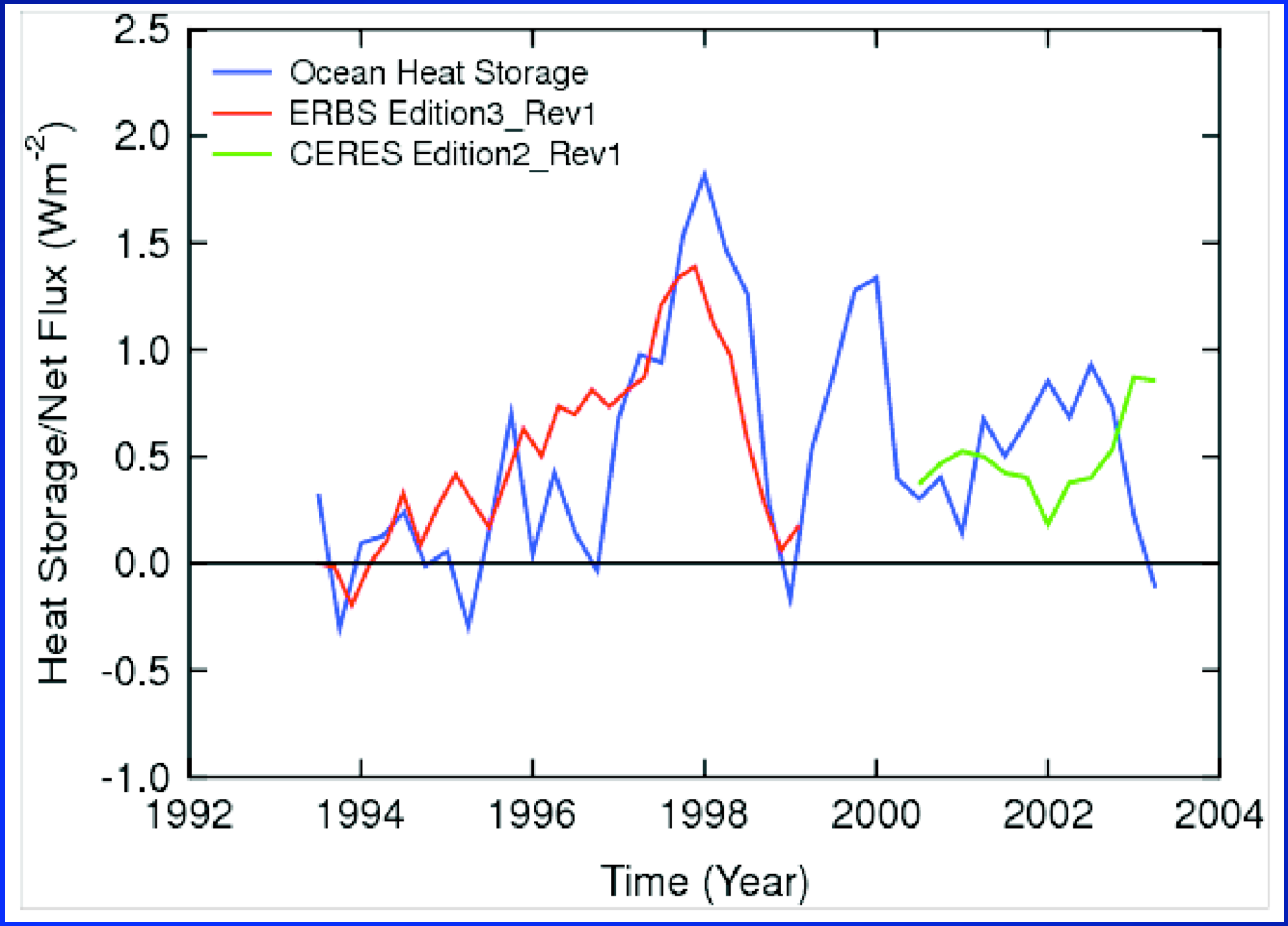
- *Strong Positive Cloud Feedback*

- *Weak Positive Cloud Feedback*

- Noise likely dominated by ocean heat storage variability
- Cloud Feedback linear in change of cloud radiative forcing but because of clear sky changes even negative CRF change is a slight positive feedback.

B. Soden, Pers. Comm. 7/06

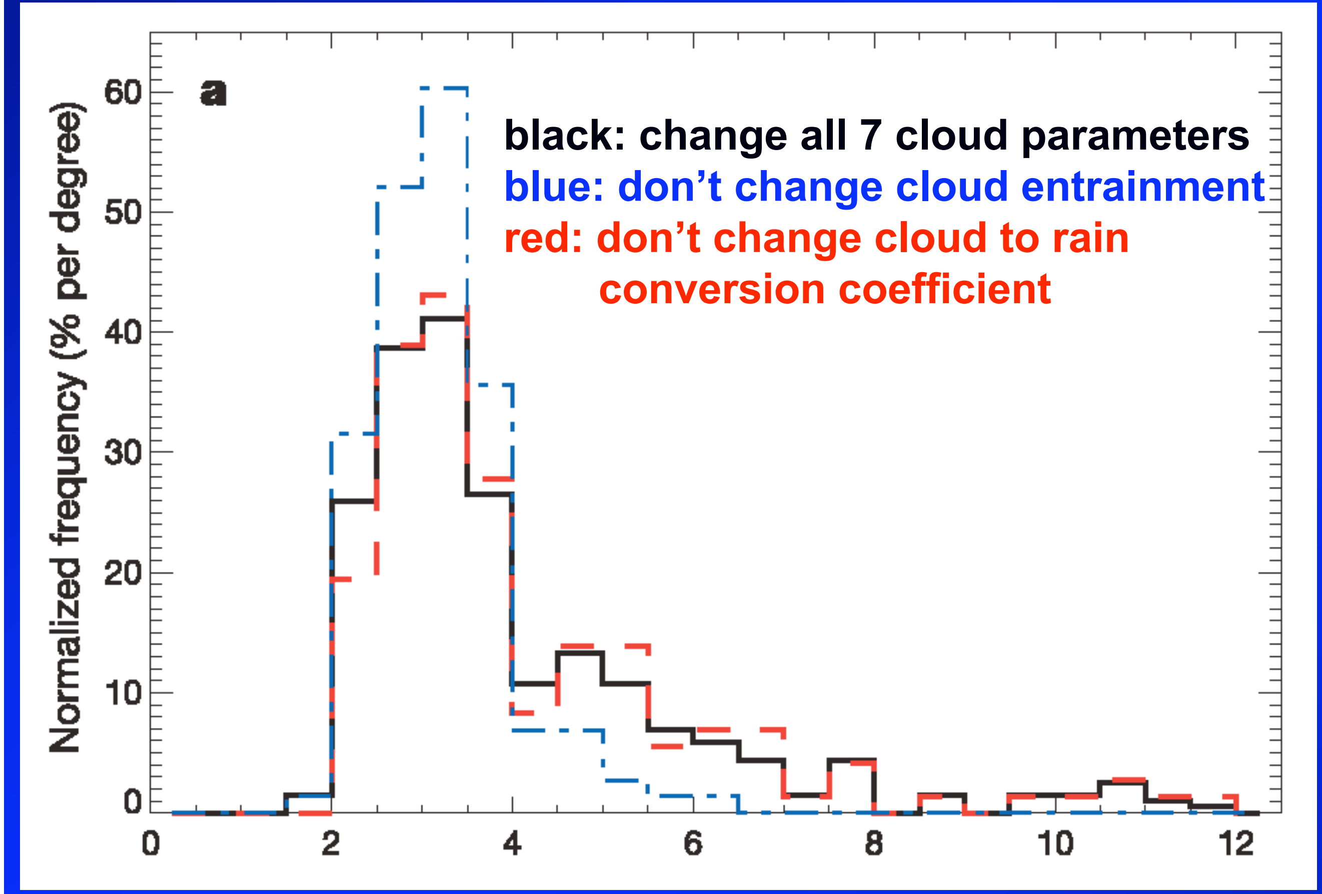
CERES Net Radiation vs Global Ocean Heat Storage



We will need to carefully unscramble cloud feedback and natural variability in ocean heat storage: a fusion of ocean/atmosphere data

Wong et al. 2006
J.Climate, in press

Perturbed Physics Ensemble: Pdf of Climate Sensitivity for Doubling CO_2

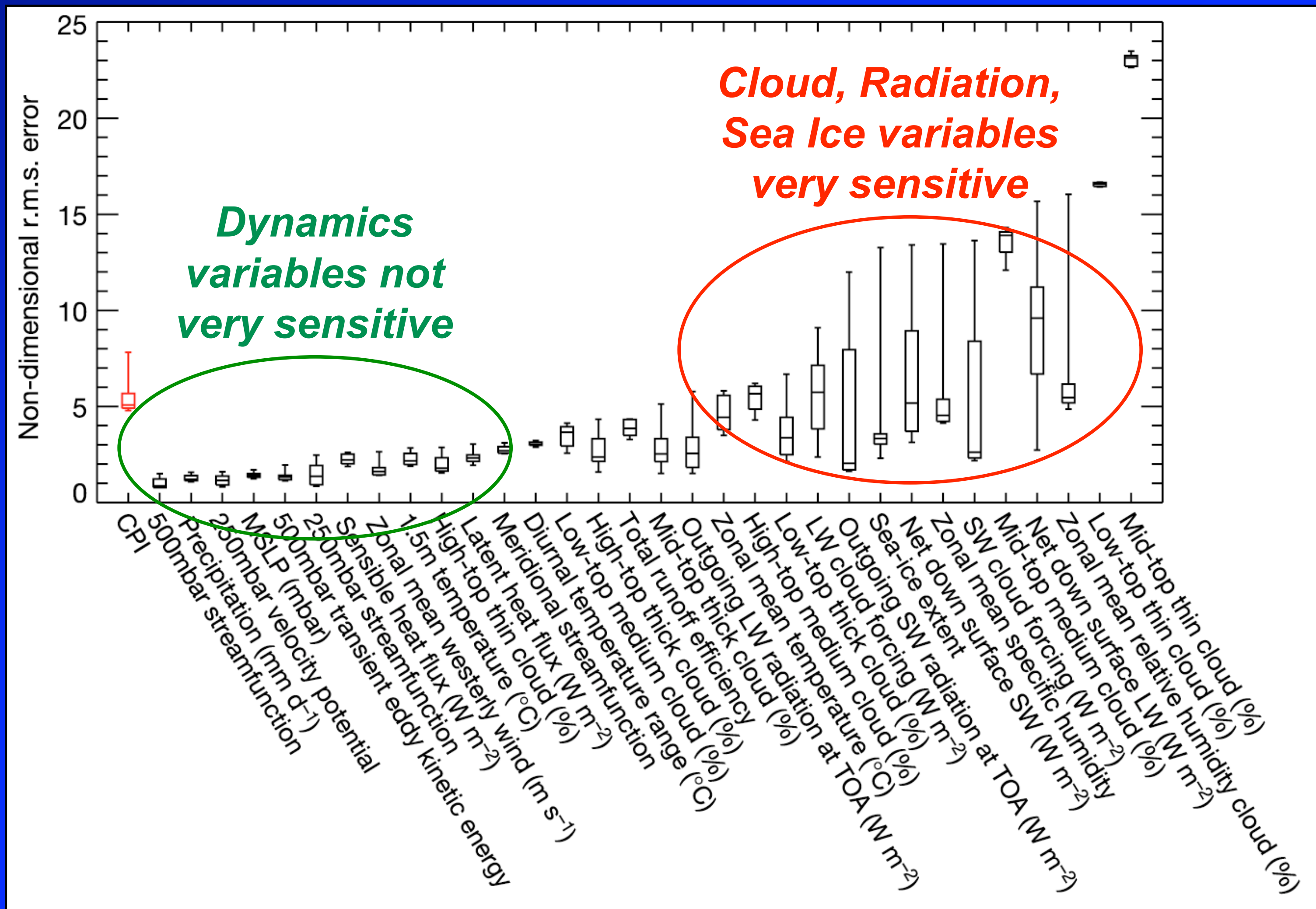


Doubled CO_2 Global Surface Temp Change (deg C)

Run Characteristics
- 2500 runs
- Global Sfc Temp
- Vary 7 cloud and precipitation parameterizations
- note $3^7 = 2187$
- HadAM3 atmosphere
- Mixed Layer Ocean
- Flux Adjust from initial SST run
- last 8 years of 15yr doubled CO_2 runs

Stainforth et al., Nature, 2005

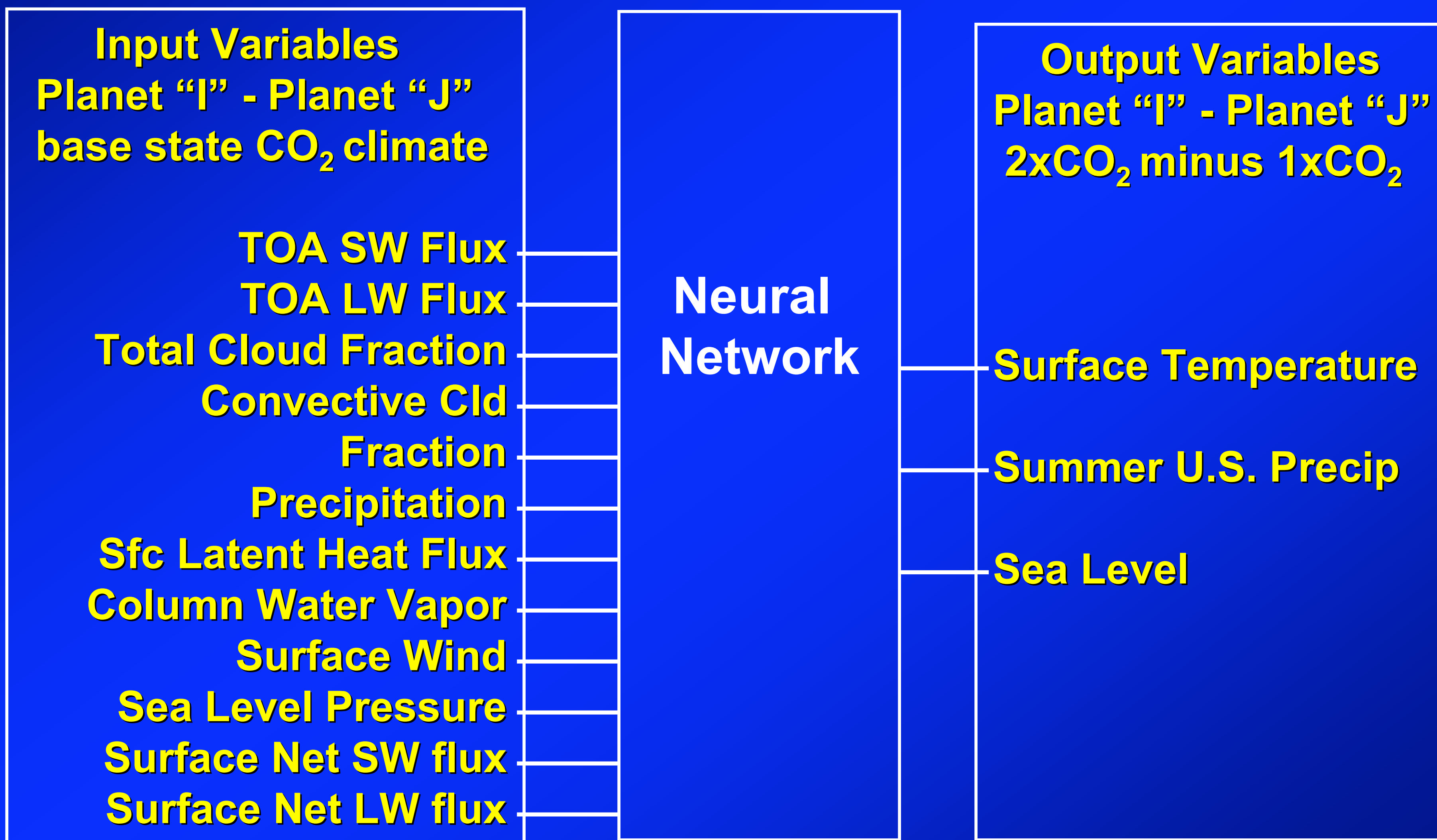
Amount of change for a factor of 6 in climate model sensitivity (2K to 12K for doubling CO_2)



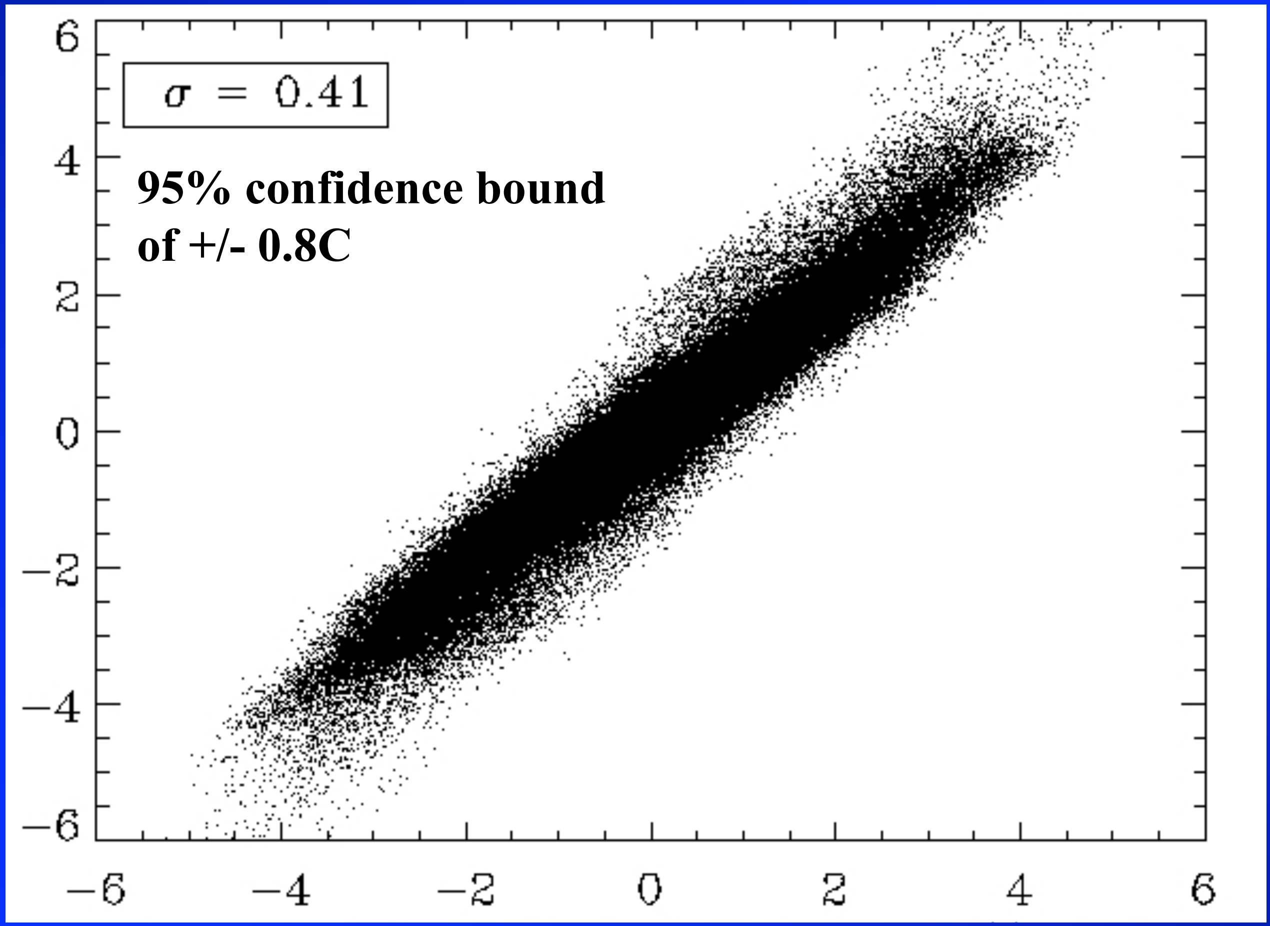
Weather = dynamics, Climate = energetics
Need Climate Change OSSEs, Climate Obs. Reqmts

Murphy et al. Nature, 2004

Neural Net Structure



Neural Net Prediction of Climate Sensitivity



Planet "I" minus Planet "J"
Doubled CO_2 Global Temp Change

Neural Net Prediction: Doubled CO_2 Global Temp Change
(uses Planet I and J normal CO_2 climate only)

Y. Hu, B. Wielicki, M. Allen

Major Challenges

- MMF is a BIG step in scale from normal climate model: 200km to 4km
- LES boundary layer global modeling is still a long way away
- Climate records typically suffer from one or more problems:
  - Data record too short (e.g. satellites)
  - Data record not very accurate (e.g. some paleo, radiosondes, satellites)
  - Data record poorly sampled (e.g. tree rings, coral, bore holes)
  - Critical variables are missing (clouds for glacial/interglacial cycles)
- Field experiments have more complete variables, but few samples and limited climate states (e.g. ARM, FIRE)
- Definitive climate metrics for prediction accuracy don't yet exist
- No climate OSSE (Observing System Simulation Experiments) exist to design rigorous observing system requirements
- We are currently flying blind with 1000s of possible climate metrics (variable, time scale, space scale, statistic)

New Tools To Attack the Challenges

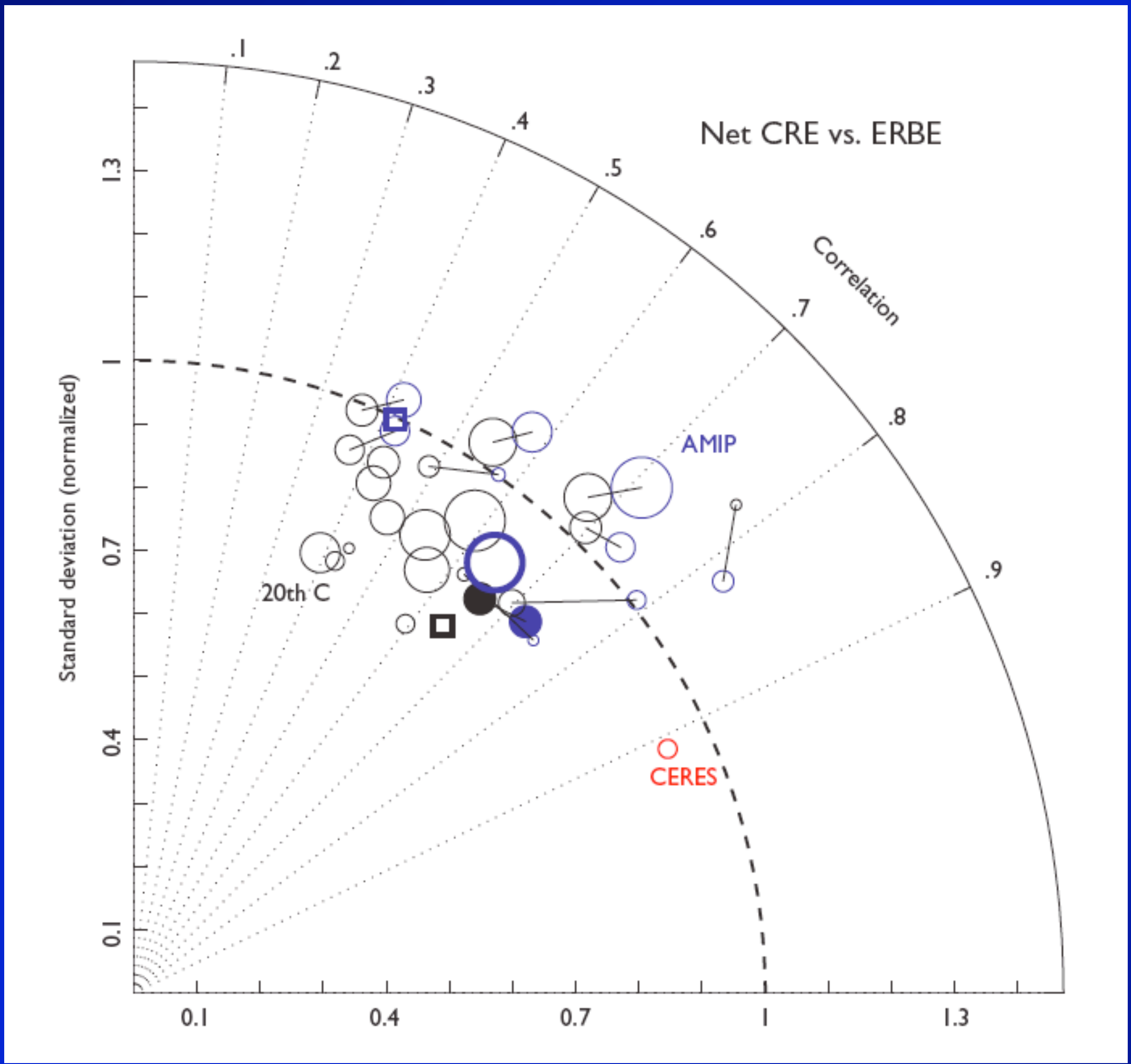
- MODELING TOOLS

- Climateprediction.net: 1000s of earth like climate systems
- MMF Multi-scale Modeling Framework: process to global annual scales
- DARE: global 3-D CRM using navier stokes scaling
- New CRM microphysics and boundary layer parameterizations
- New Aerosol chemical transport and assimilation systems
- Improved 4-D atmospheric state using AIRS

New Tools To Attack the Challenges

- OBSERVATION TOOLS
- EOS Global Aerosol/Cloud/Radiation/Precip data: 1998-present (e.g. TRMM, Terra, Aqua)
- GEWEX Satellite data: ISCCP, SRB, NVAP, GPCP: 1983-present
- A-train: CALIPSO, CloudSat, Aqua
- ARM surface site time series: mid 90s to present
- Ocean scatterometer surface wind vectors and divergence
- Improved surface networks: Aeronet and BSRN
- New types of cloud and radiation data analysis:
  - ISCCP cloud type principle components (Jacob & Rossow)
  - Cloud system objects (Xu)
  - Dynamic State (Bony)
  - Partial derivatives of dCloud / dAtmosphere, dCloud / dAerosol
  - Decadal and Interannual variations of cloud, aerosol, radiation
  - GEWEX assessments for radiation, cloud, precip, aerosol underway

Taylor Diagrams: Radiation/Cloud/Precip
MMF not yet demonstrated better

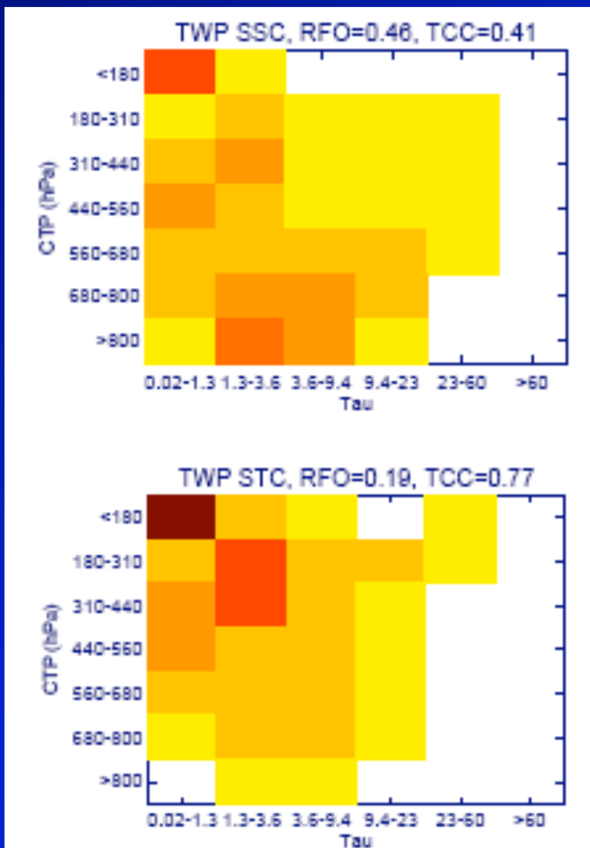


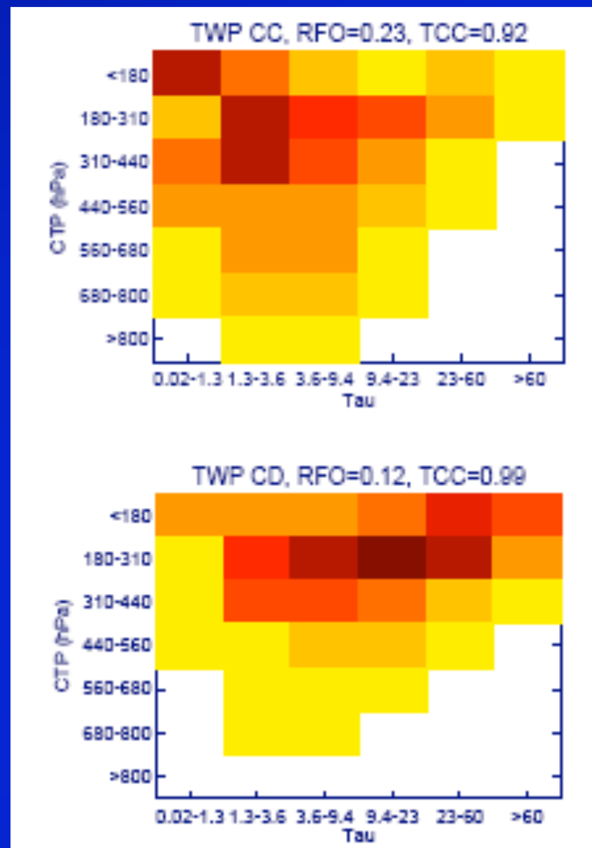
The good news: MMF is as good as climate models tuned to ERBE already

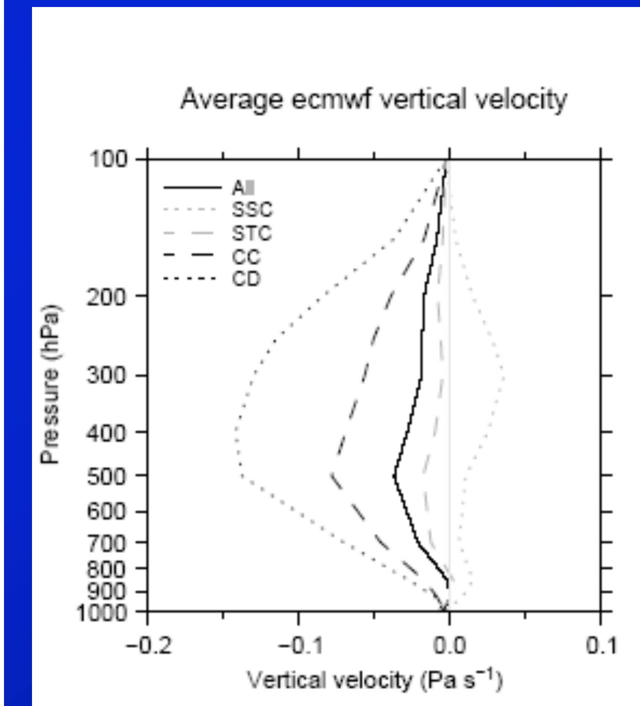
The bad news: Not yet better

Pincus, CMMAP Meeting, 8/06

Cluster analysis of satellite data: Cloud Regimes (Jakob et al. 2005)



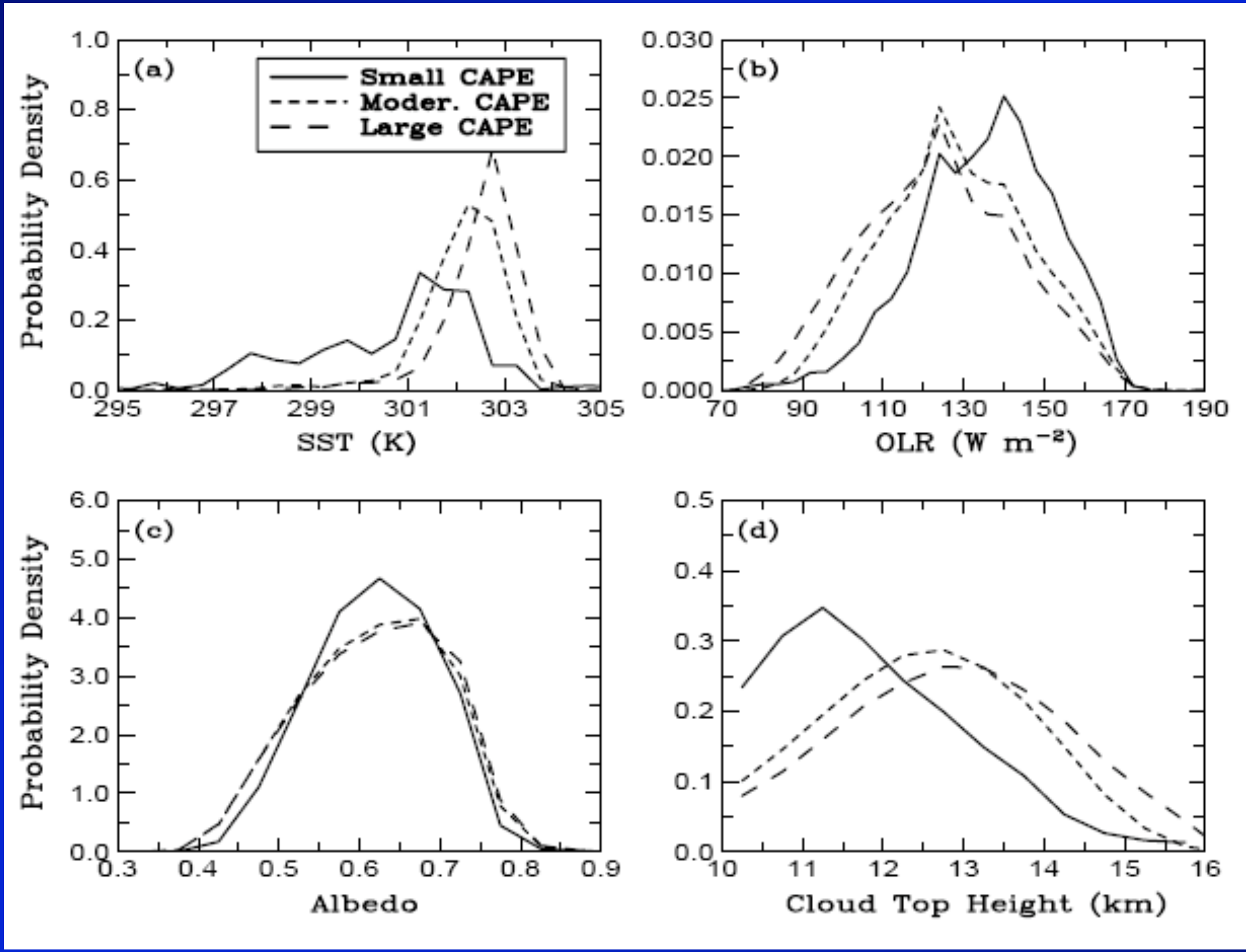




SSC: Suppressed shallow clouds;
STC: Suppressed thin cirrus;

CC: Convectively active cirrus
DC: Deep convection

Comparison of CAPE of Large-size Tropical Convective Cloud Objects, March 1998 TRMM



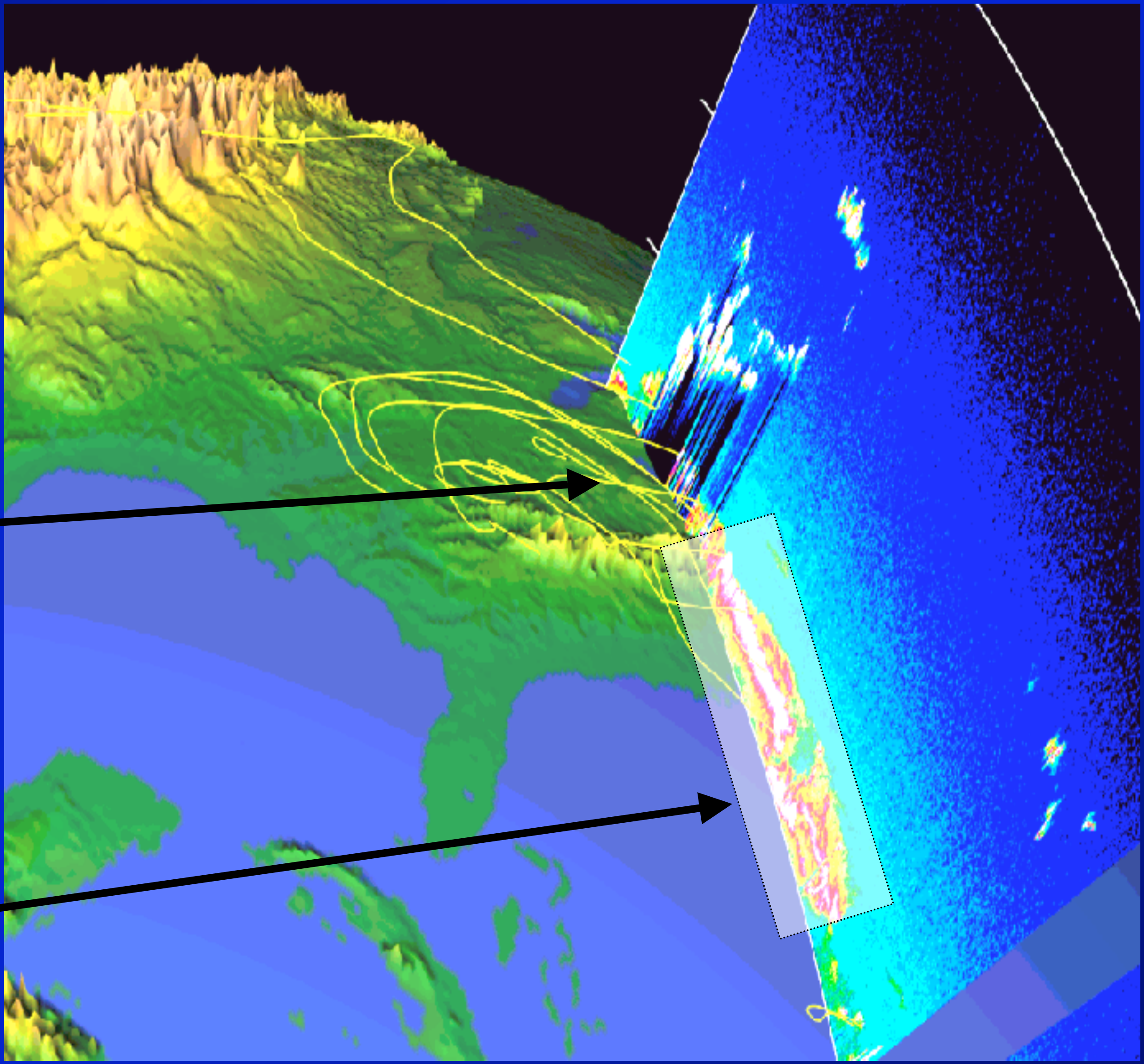
Contiguous Cloud Objects pdfs of 20km CERES fovs: Overcast Zcld > 10 km Tauvis > 10

System Diameter > 300 km

Xu et al. Cloud object Data online

Cloud Objects and CALIPSO/CloudSat

Vertical levels improve back-trajectories for aerosol source regions



Cloud object

How can CMAPP take advantage of these new capabilities?

- MMF sampling is sufficient to do climate accuracy cloud tests
  - MMF may be challenged, however, to directly do climate sensitivity
- MMF is well suited to comparisons with new global satellite data from 1km to global scales, days to years
- MMF well suited to do direct comparisons to new cloud analysis methods such as cloud types, objects, dynamic state
- MMF is well suited to eventually target aerosol indirect effect and try to unscramble cloud dynamics and aerosol effects.
- Given difficulty of getting accurate boundary layer T(z), q(z), vertical velocity from current 4-D assimilation, can MMF improve this situation in an NWP mode?

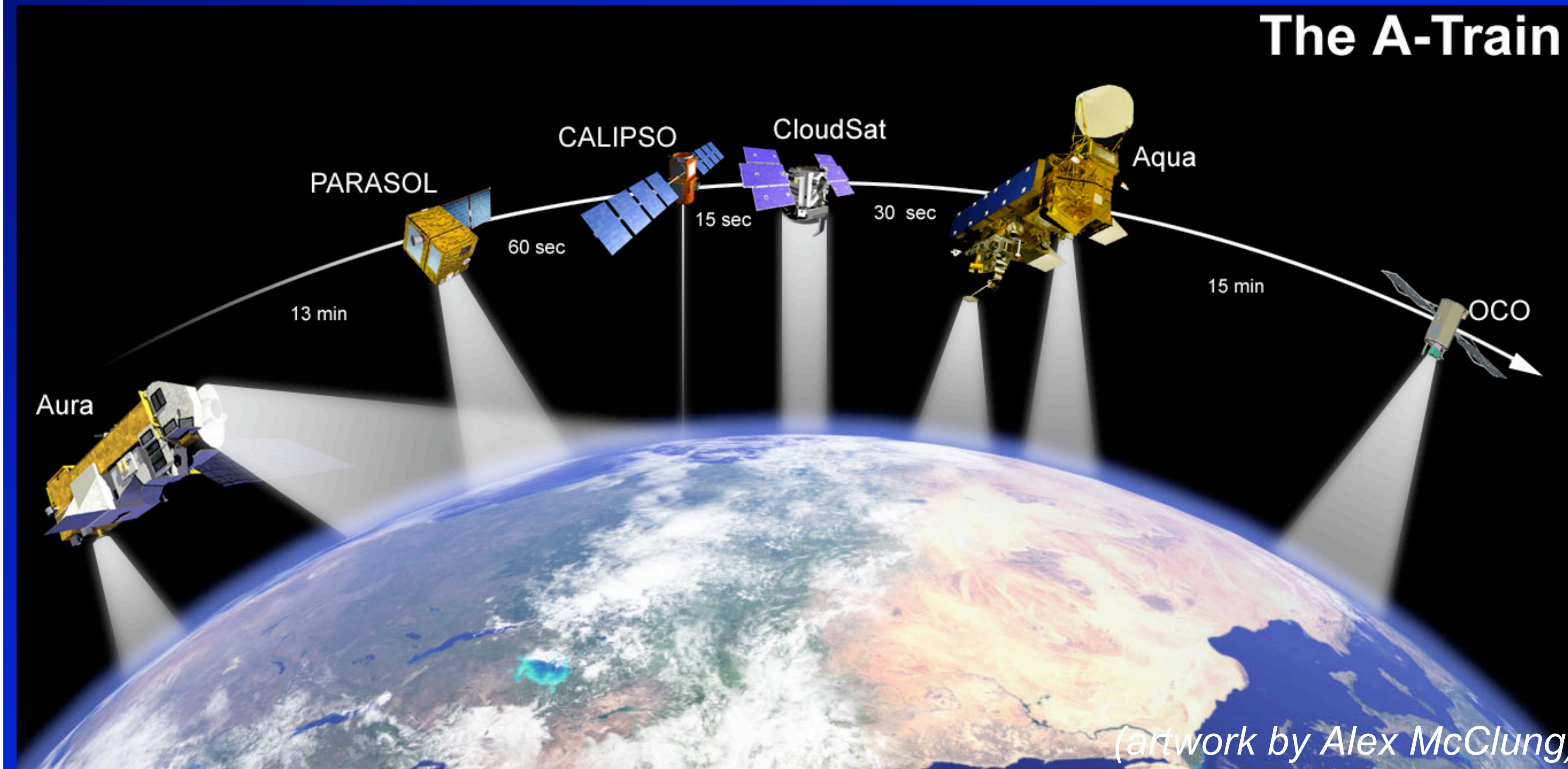
How can we focus CMAPP Model vs Observation Activities?

- Define some key initial cloud/radiation metrics to show improvements over current climate and NWP models
  - Traditional monthly gridded climate statistics (e.g. AMIP, Taylor Diagram). Some already done on 19-yr AMIP run
  - Bony diagram for cloud versus vertical velocity
  - Jacob/Rossow cloud type diagrams
  - Xu cloud objects
  - Select a few key weeks or months to start with
- Evolve metrics as other efforts improve relationships of climate prediction to model/observation differences (climateprediction.net)
- Make model output easily available. Will some effort be available to manage and modify model output statistics, data formats, documentation, distribution?
- Start with some highly subsetted data sets and evolve from there.

Should we be focusing more on low cloud MMF improvements?

- IPCC Cloud Feedback uncertainty dominated by low cloud
- Weakest MMF physics currently boundary layer cloud
- Aerosol indirect effect largest IPCC radiative forcing uncertainty, and also is dominated by low cloud changes
- Aerosol indirect effect is a long term direction and requires progress on cloud feedback of low cloud first.
- Biases in low cloud show up quickly in NWP mode: one week MMF runs might be enough to show dramatic improvements.
- Mini-LES Big Brother SAM and MMF tests for boundary layer cloud
- Current traditional climate model metrics including Taylor diagrams look like small improvements for early MMF
- Diurnal cycles, ENSO, and MJO improved, but not clear these relate strongly to uncertainties in climate sensitivity

The EOS Afternoon Satellite Constellation



CMMAP Backup Slides

CERES: Integrated Data for Radiation/Cloud/Aerosol

- 2 to 10 times ERBE accuracy: moving from 5 W/m^2 toward 1 W/m^2

- TOA, surface and atmosphere fluxes

- A radiative 4-D assimilation: integration of surface/ cloud/aerosol/atmosphere constrained to TOA flux

Input Data

- CERES Crosstrack Broadband
- CERES Hemispheric Scan ADMs
- MODIS Cloud/Aerosol/Snow&Ice
- Microwave Sea-Ice
- MATCH Aerosol Assimilation
- GEOS 4-D Assimilation Weather (fixed climate assimilation system)
- Geostationary 3-hourly Cloud
- Consistent Intercalibration

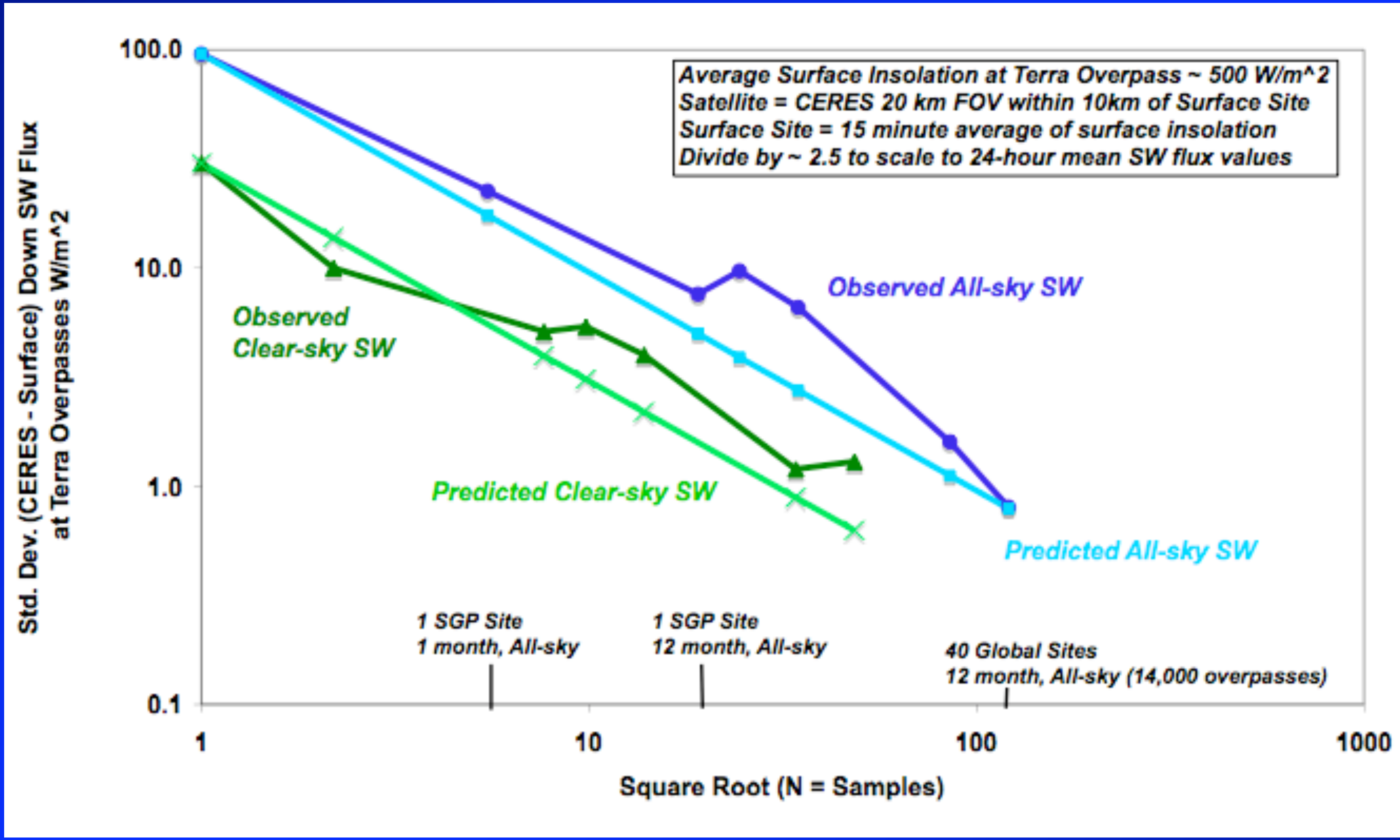
Output Data

ERBE-Like TOA Fluxes (20km fov, 2.5 deg grid)

CERES Instantaneous TOA/Sfc/Atmosphere Flux
- 20km field of view (SSF, CRS products)
- 1 degree grid (SFC, FSW products)
- Fluxes, cloud & aerosol properties

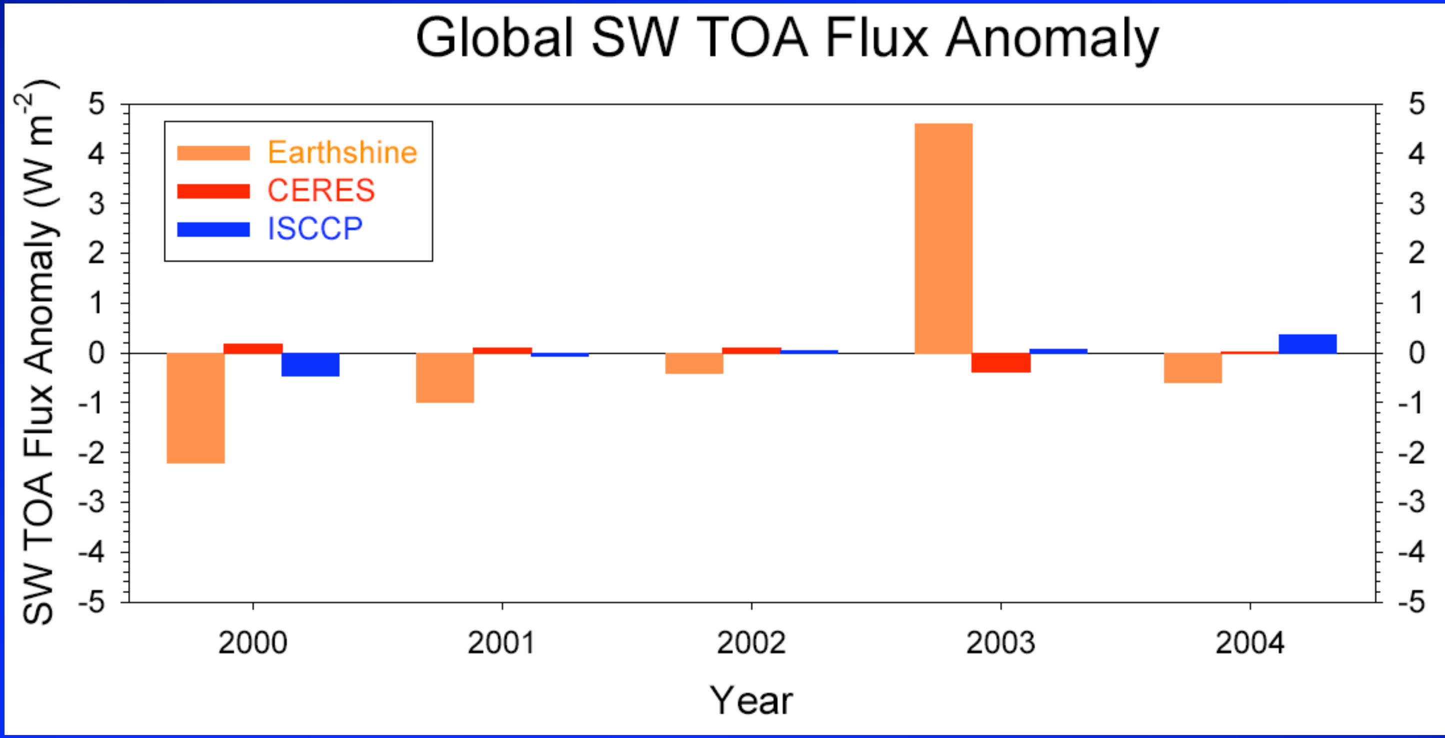
CERES Time Averaged TOA/Sfc/Atmosphere
- 3-hourly, daily, monthly
- 1 degree grid (SRBAVG, AVG, ZAVG products)
- Fluxes, cloud and aerosol properties

Surface SW Flux Validation Noise



Remarkable consistency for interannual anomalies 0.5 to 1 Wm^{-2}

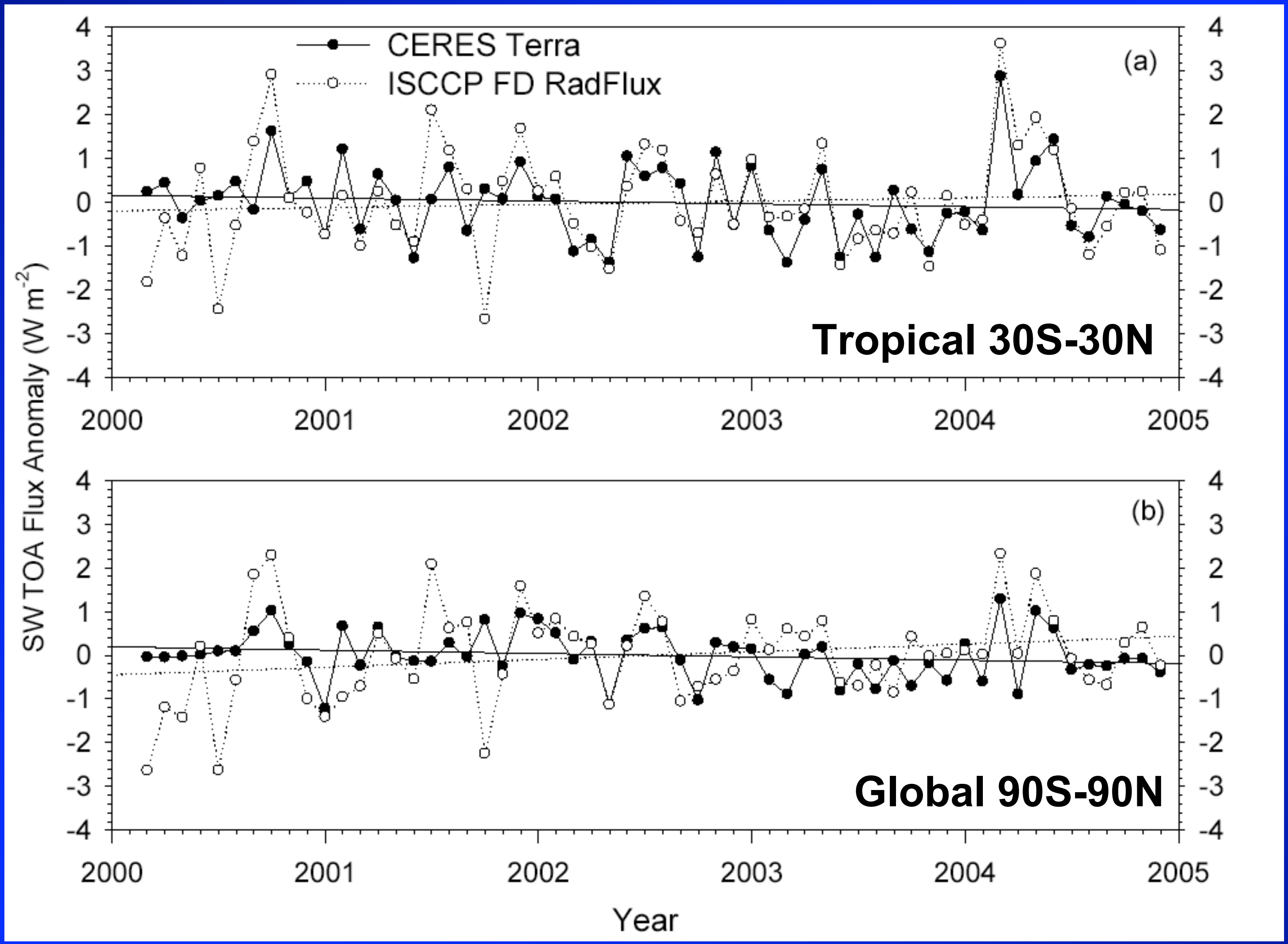
Earthshine, ISCCP, CERES: 2000 to 2004



Climate accuracy requirements are poorly understood by the community: recent Earthshine 6% changes were published in Science, causing much confusion

Loeb et al., AGU 2005

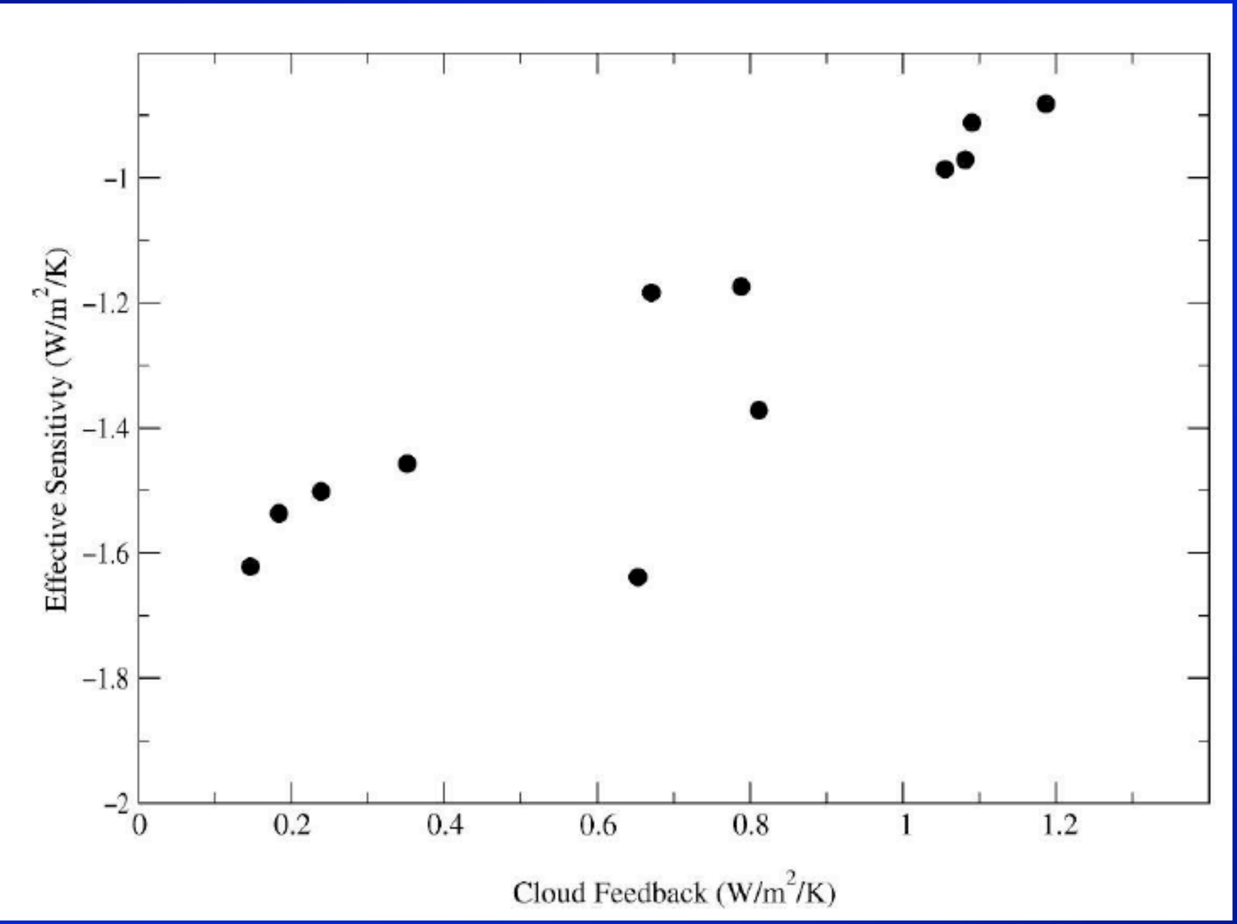
ISCCP FD versus CERES: 2000 to 2004



Meteorological satellite climate data is not accurate or stable enough to determine decadal trends, but very useful for regional studies.

Loeb et al., AGU 2005

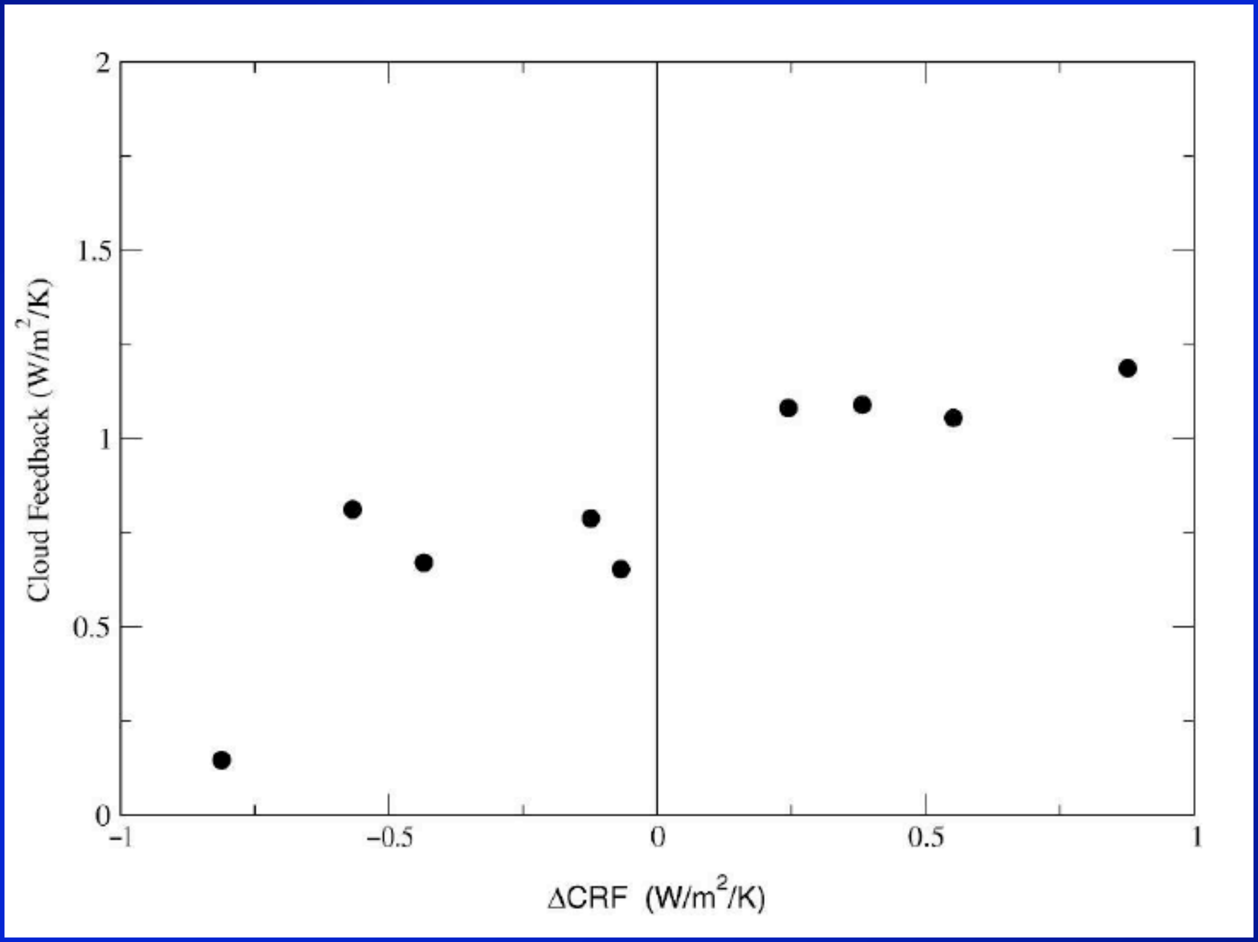
Climate Sensitivity vs Cloud Feedback IPCC AR4 Models



Climate sensitivity is essentially linear in cloud feedback

Soden et al. 2006
J.Climate

Cloud Feedback vs Cloud Radiative Forcing
IPCC AR4 Models



Cloud Feedback is essentially linear in cloud radiative forcing change

Soden et al. 2006
J.Climate