Climate Observing System Requirements: How do we get there?

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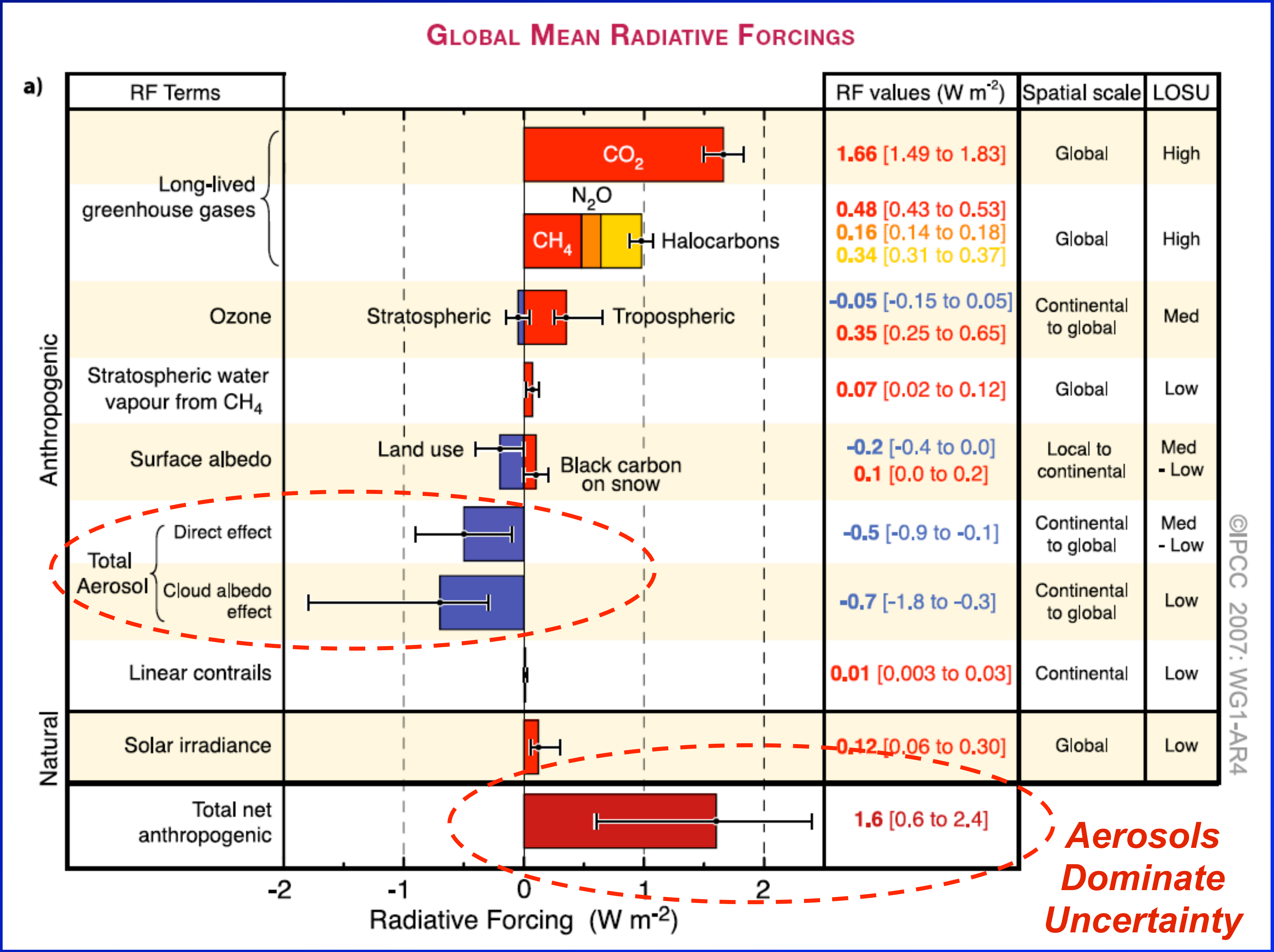
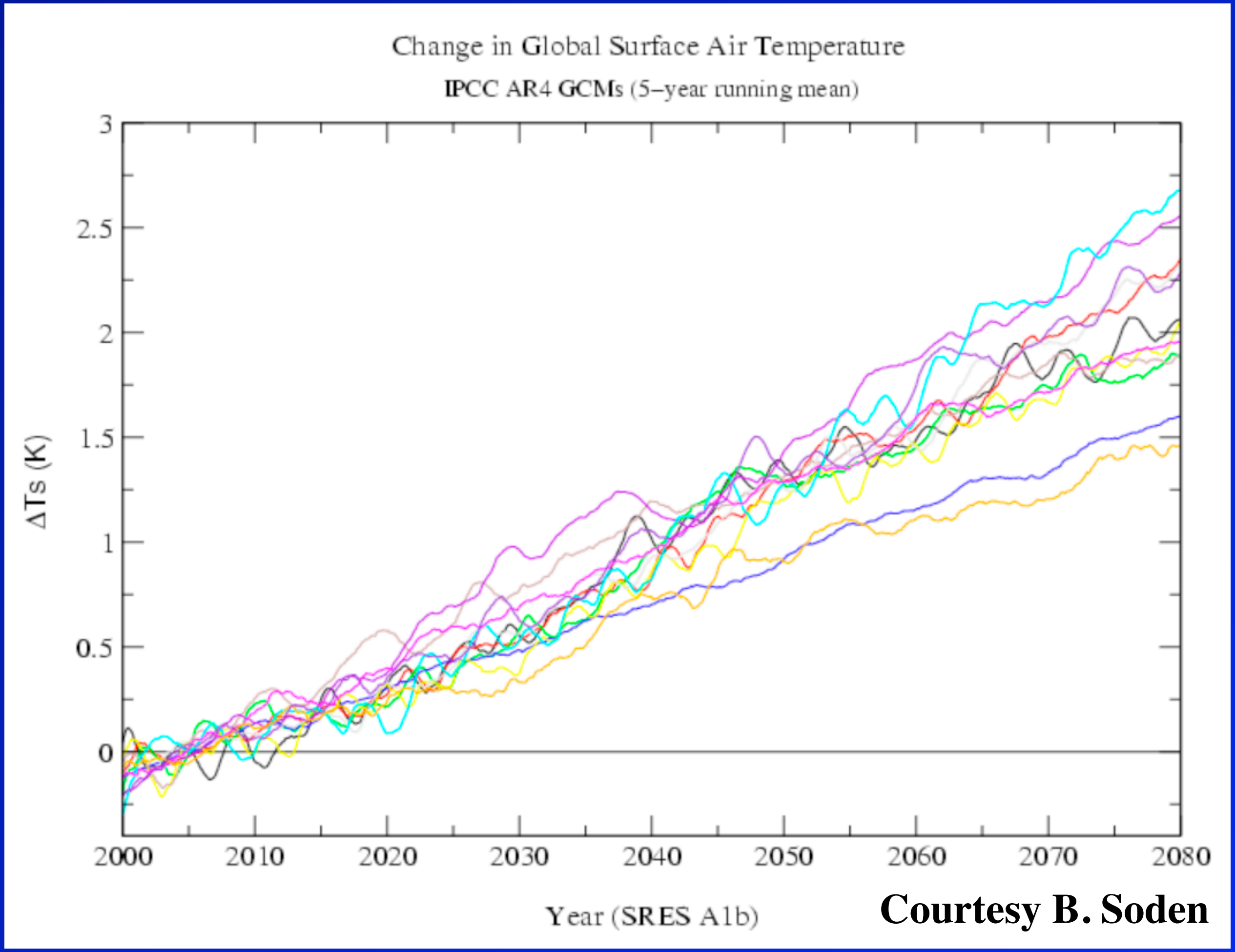
IPCC AR4 Radiative Forcing Chart

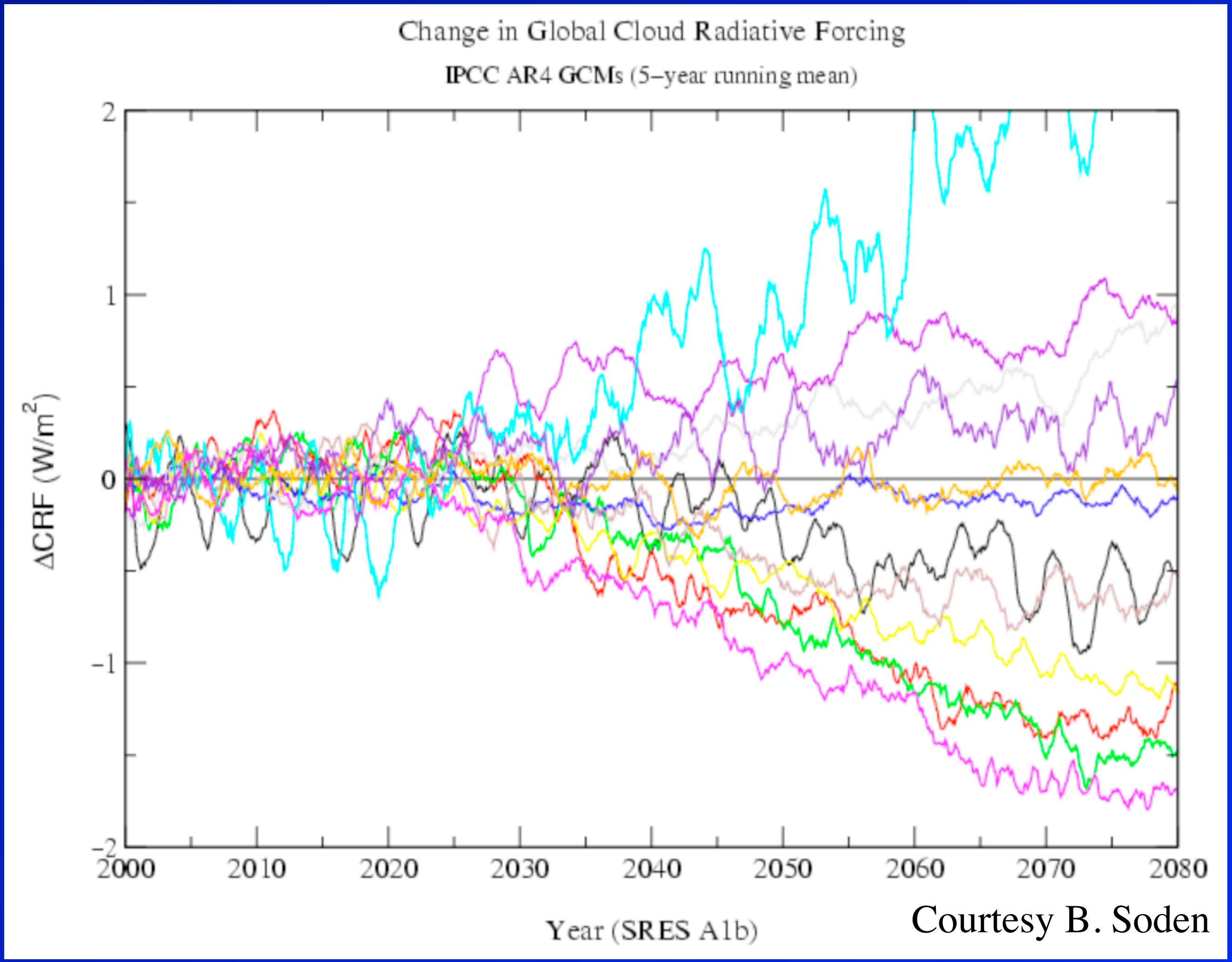


Why? IPCC Global Temperature Change



High sensitivity and low sensitivity climate models don't separate clearly in global temperature change until 2040: temperature trends along not enough. Why? High sensitivity models have more initial delay from large ocean heat capacity: so in early decades of change, warming ~ independent of sensitivity.

IPCC Sensitivity Variations Caused by Cloud Feedback
Cloud Feedback is Decadal Change in Cloud Radiative Forcing



Climate sensitivity change driven by cloud feedback: change in net cloud radiative forcing over decades. Largest single change is low cloud changing earth albedo and therefore fraction of solar irradiance absorbed.

What are key climate sensitivity metrics?

IPCC AR4 Summary:

The possibility of developing model capability measures ('metrics'), based on the above evaluation methods, that can be used to narrow uncertainty by providing quantitative constraints on model climate projections, has been explored for the first time using model ensembles. While these methods show promise, a proven set of measures has yet to be established

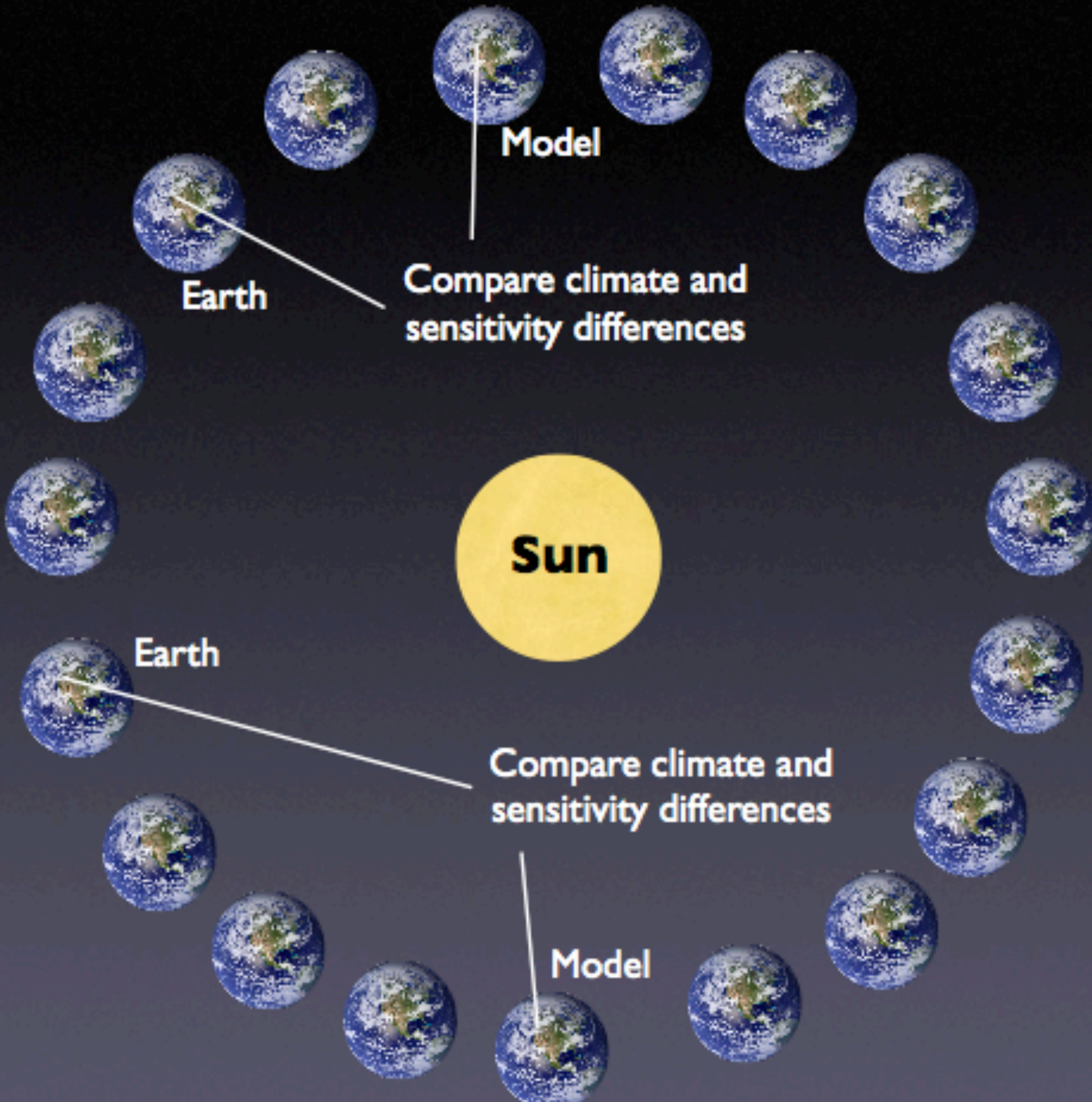
What can we do?

Perturbed Physics Ensembles

Where next?

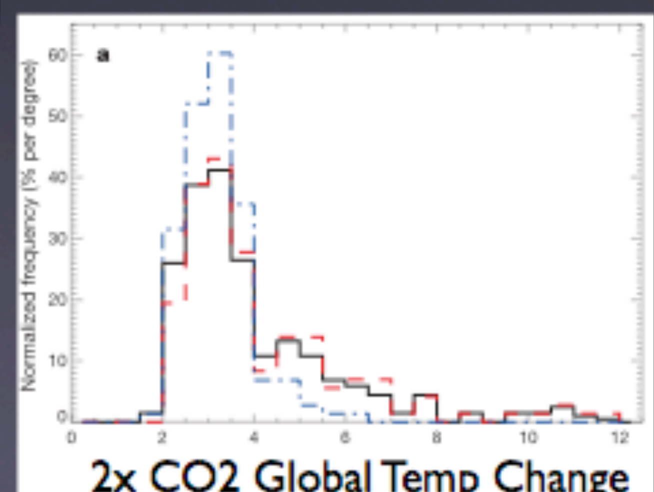
Coupled ocean atmosphere model runs, more complete output metrics, realistic 20th to 21st century forcing runs

60,000 Earth-Like Planets

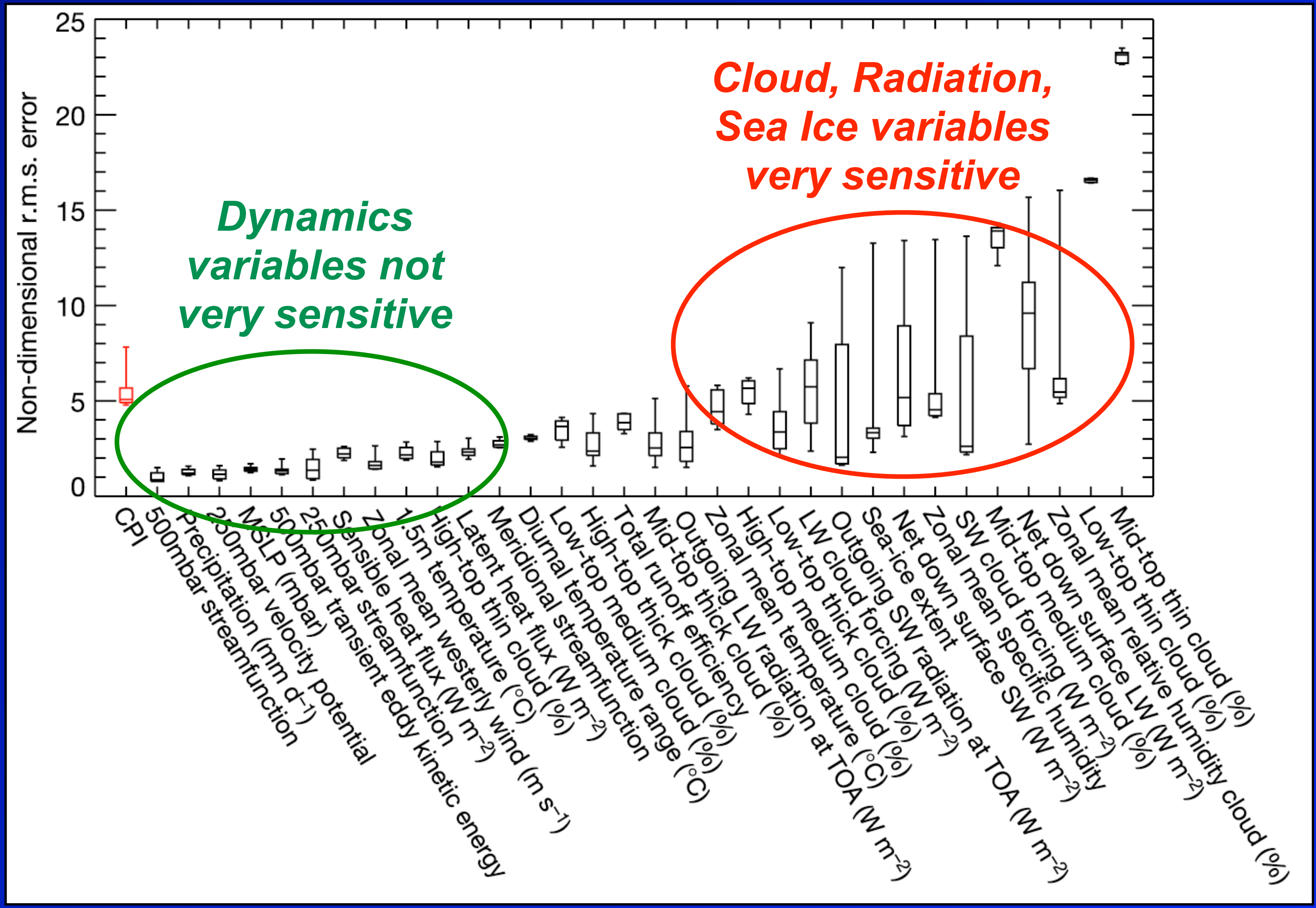


climateprediction.net:
constant known physics
vary uncertain physics
Run for normal CO_2
Run for doubled CO_2

Stainforth et al., 2005, Nature



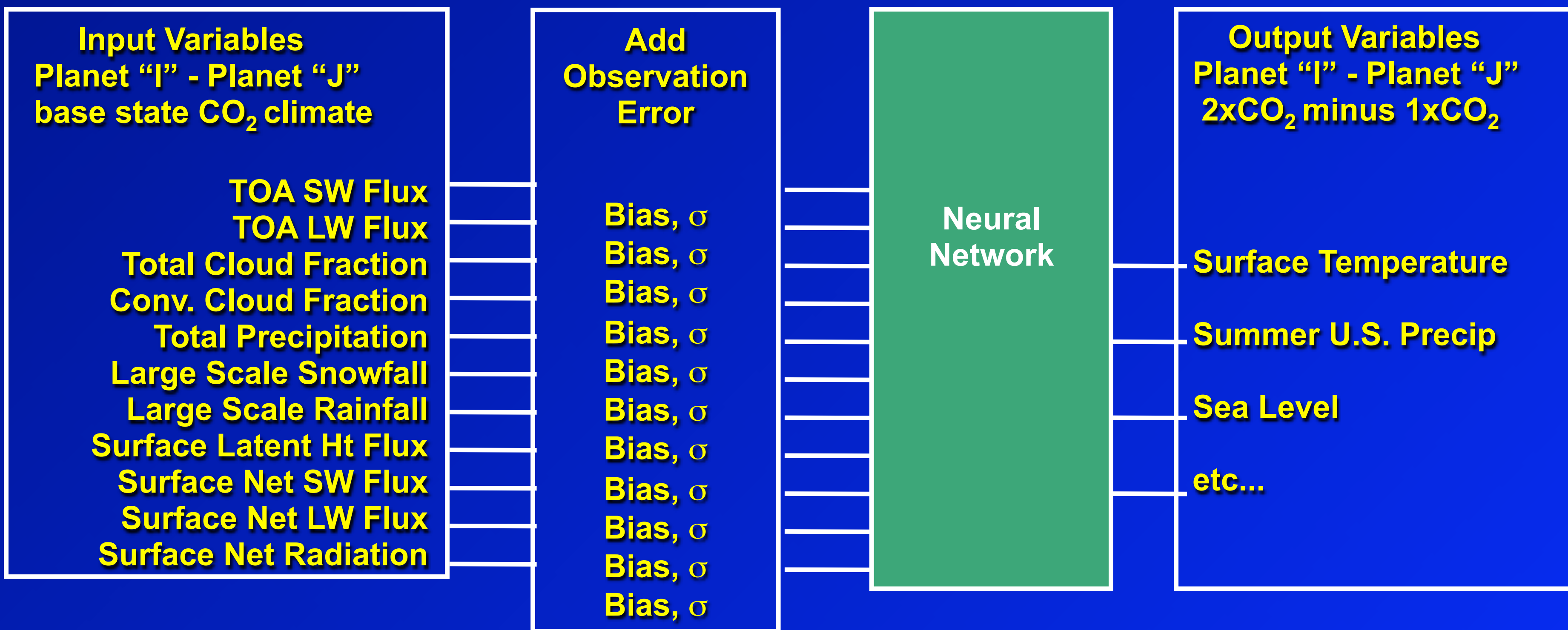
Amount of change for a factor of 6 in climate model sensitivity (2K to 12K for doubling CO_2)



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

Murphy et al. Nature, 2004

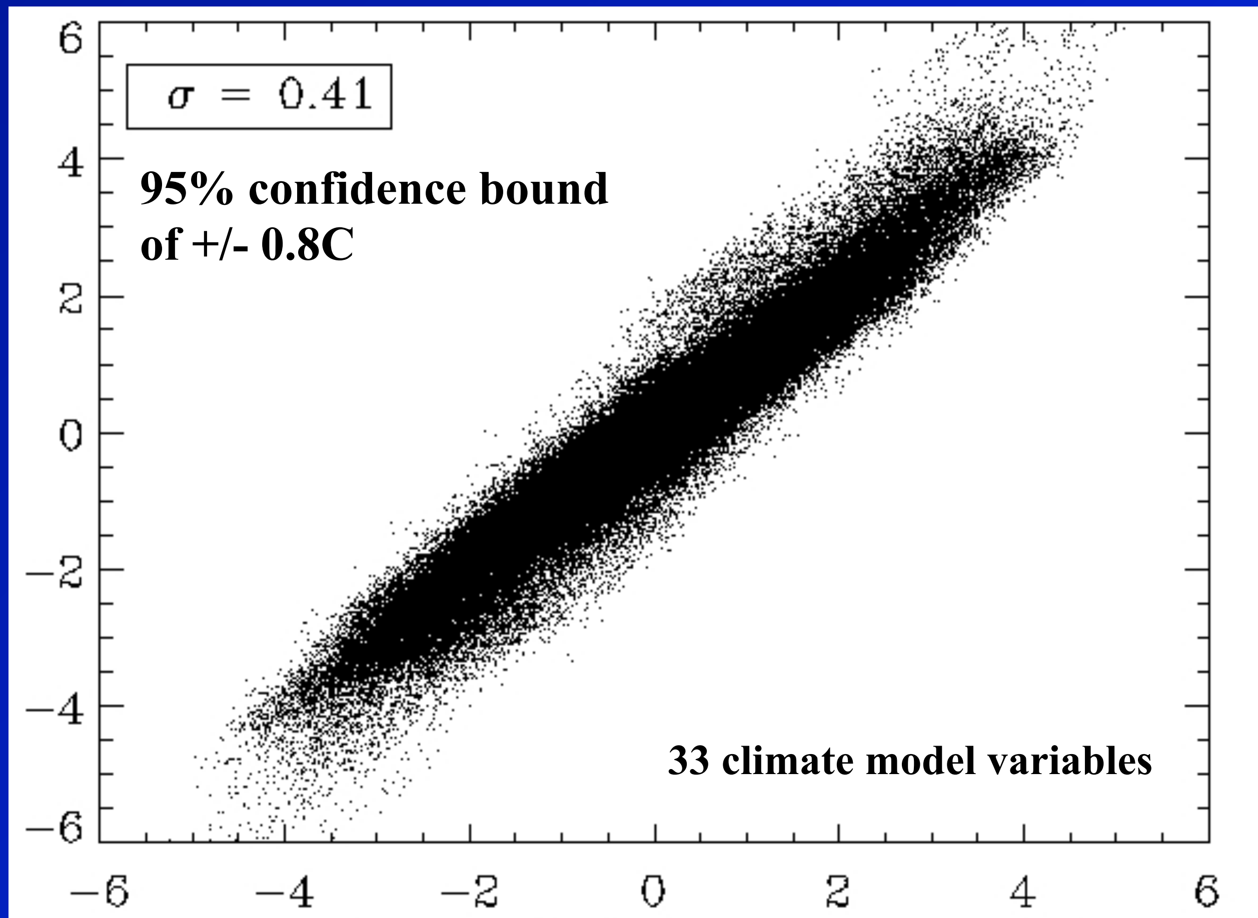
Neural Net Structure
Climate OSSEs



Difference in neural net performance with and without observation errors
Isolates effect of observation error on constraining climate uncertainty

Neural Net Prediction of Climate Sensitivity

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

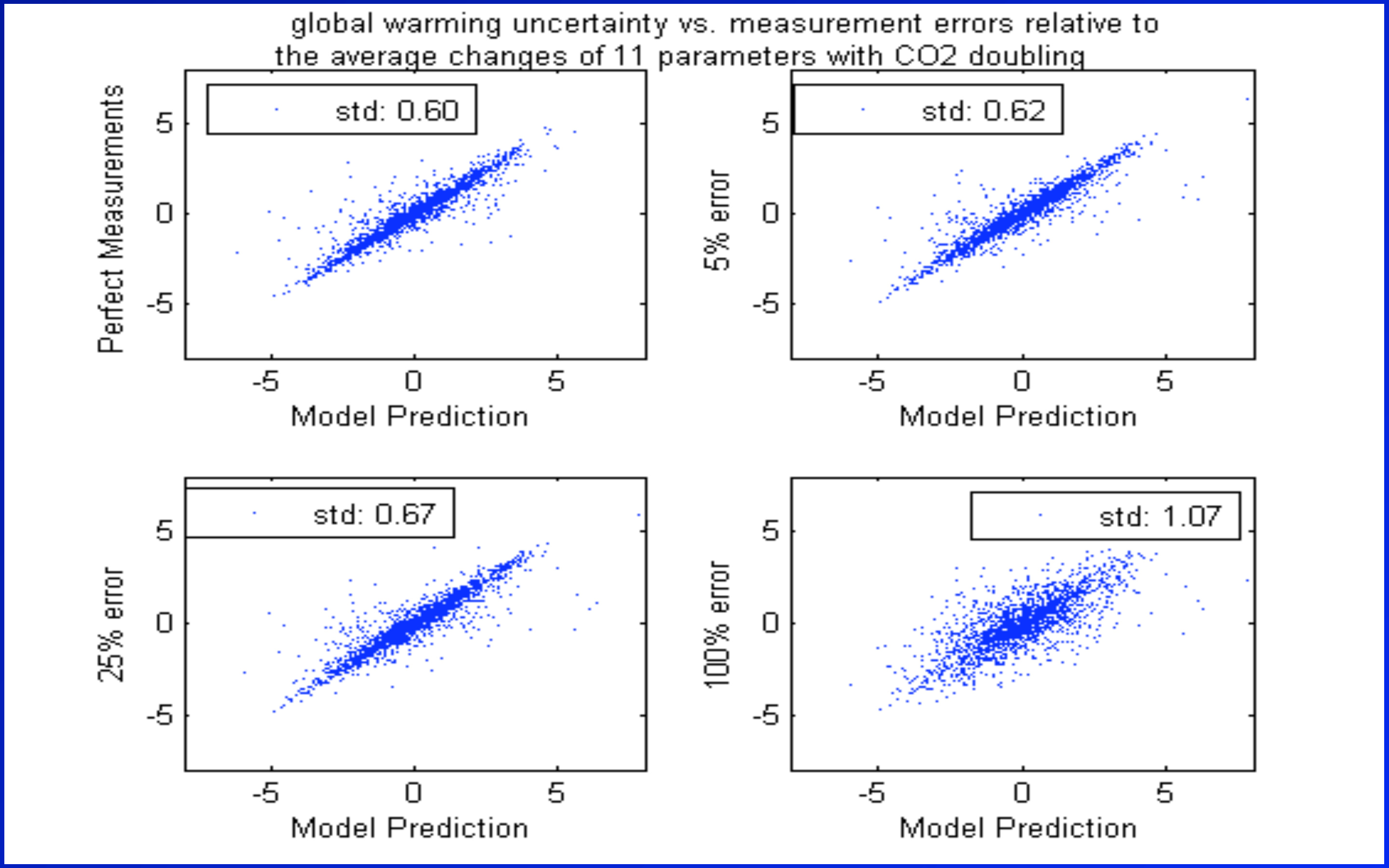


Neural Net Prediction: Doubled CO_2 Global Temp Change
(uses Planet I and J normal CO_2 climate only)

Y. Hu, B. Wielicki, M. Allen

Effect of Observation Error on Neural Net Prediction Accuracy (2xCO_2, Deg C)

(error specified as % of mean 2xCO_2 change for any variable)



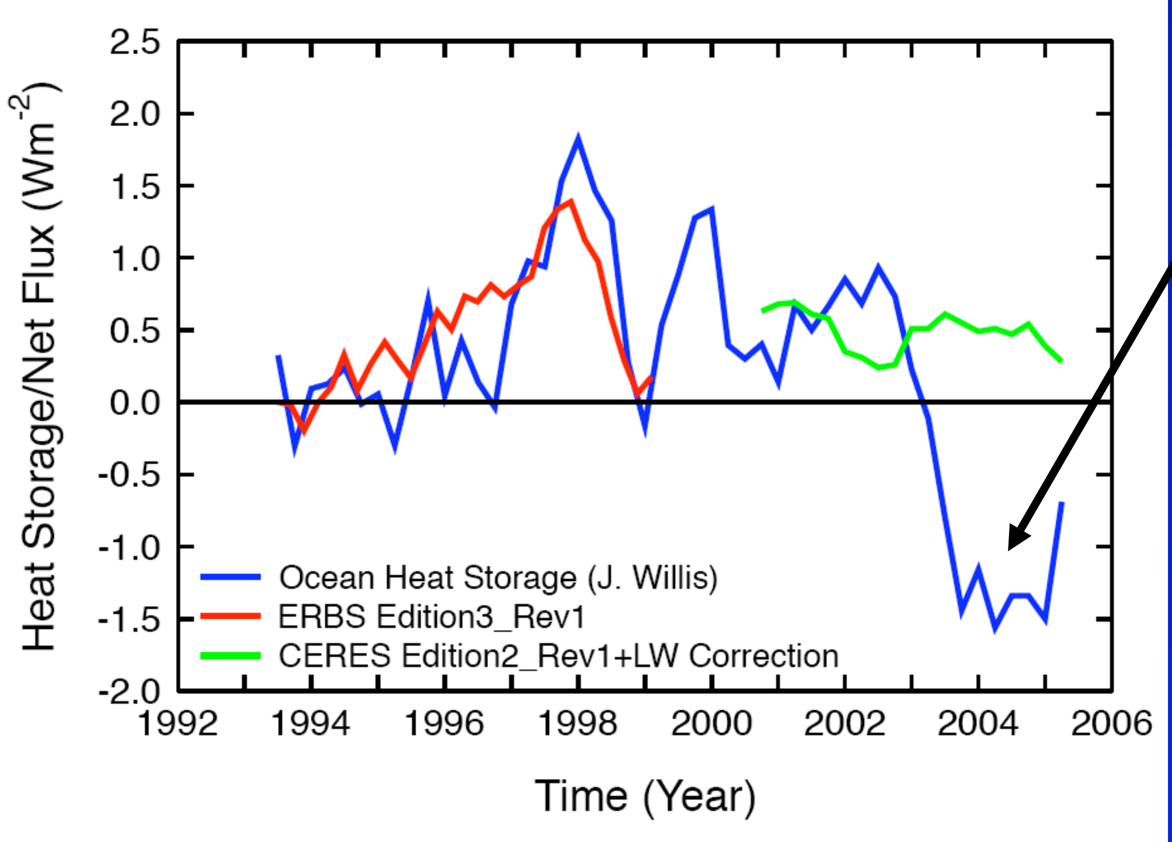
If no observation constraint: sigma 1.5 K

Early Conclusions Using 2500 Mixed Layer Models Doubled CO_2 Climate Sensitivity

- Climate change metrics (e.g. decadal change) are much more powerful constraints than base state (e.g. global maps)
- Neural net 2.5 times more accurate than linear regression for base state metrics: these are very nonlinear
- Cross model applicability (UKMO trained but test on IPCC) is not robust for base state metrics, but is robust for climate change metrics.
- At global scale, energetics variables are more powerful than dynamics
- At regional climate metrics will likely involve both energetics and dynamics
- Observation system error degrades ability to constrain climate sensitivity rapidly as errors exceed 25% of expected climate change

Recent Ocean Cooling? No Global Warming?

A case study in the need for independent observations & analysis



Recent Ocean Cooling?

Lyman et al., Science 2006

Net Radiation(CERES): No

Altimeter Sea Level: No

GRACE Ice Sheet: No

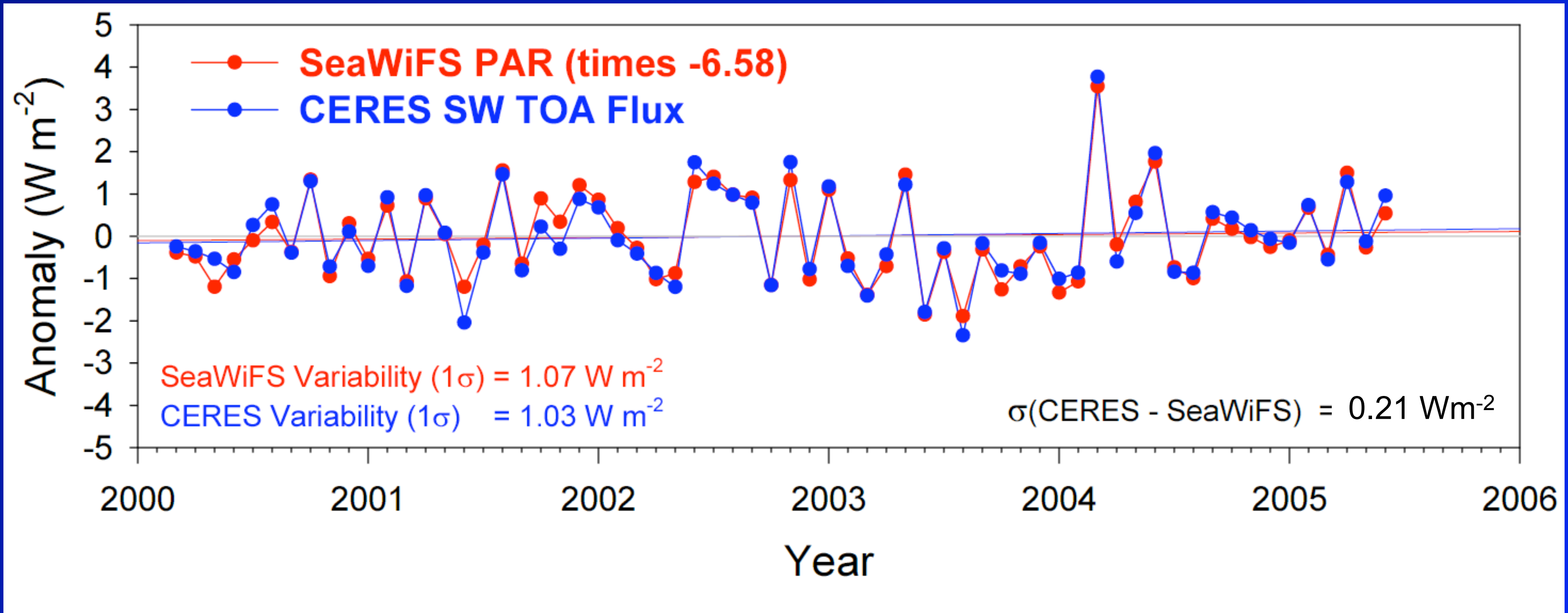
1992 to 2003 data from Wong et al. J. Climate 2006

The answer: warm bias in XBT in-situ data (dominate pre-2002) cold bias in ARGO in-situ data (dominate post 2002): cooling in 2004/5 vanishes when bias is corrected. mystery solved. Paper on in-situ biases submitted to GRL (Willis et al.)

Ocean Warming in 2003-2005 similar to average warming over 1993-2003. Remains consistent with ocean heating predicted by IPCC climate models

Independent Observations: Proving Key Climate Variations

Compare CERES broadband reflected solar flux (calibration, multiple instruments to detect change differences in orbit)
To independent SeaWiFS narrowband PAR (lunar stability, S/C pitchover)

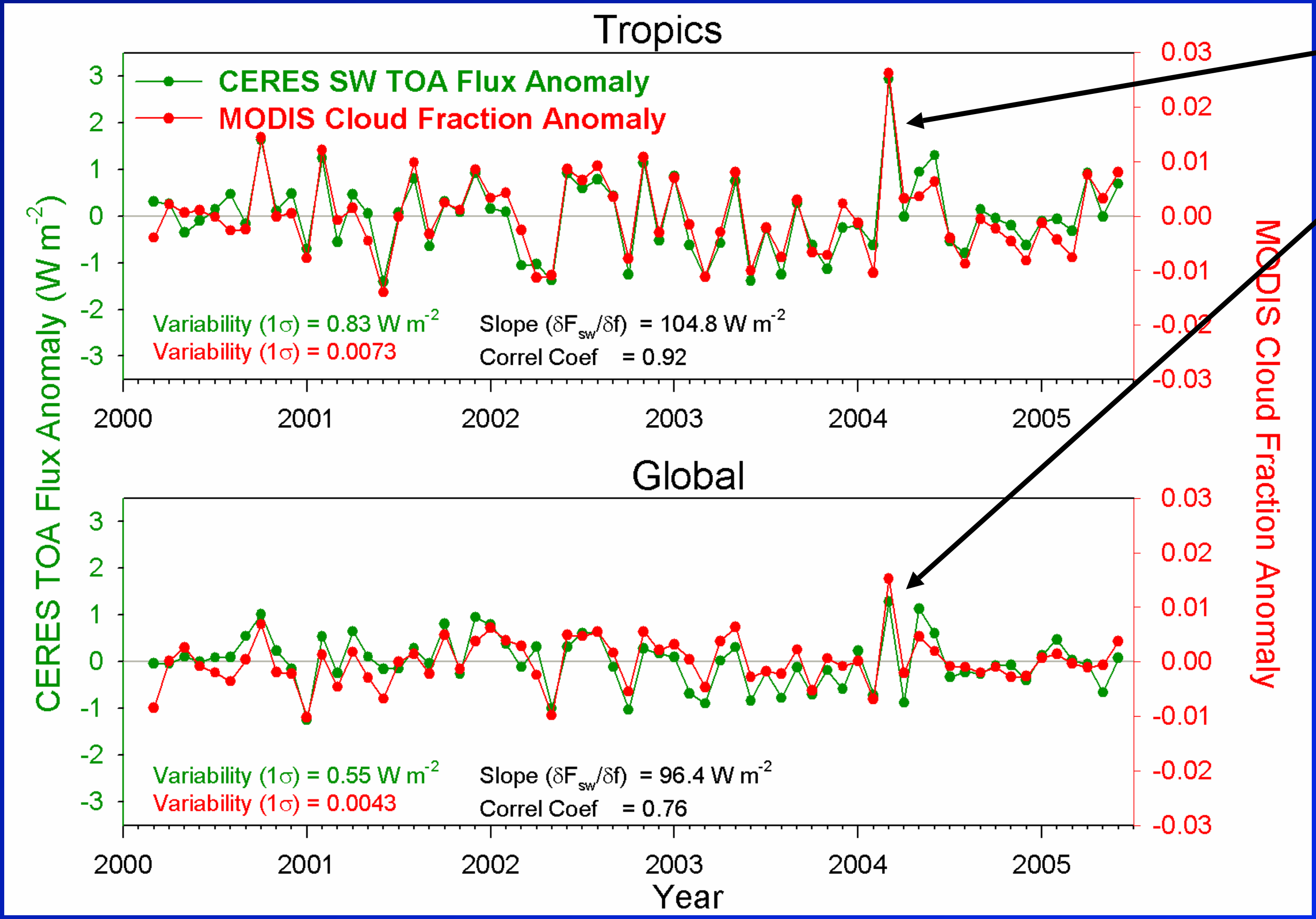


Shows consistent calibration stability at < 0.3 Wm^{-2} per decade (95% conf) climate decadal change accuracy requirements

Comparison is only valid for tropical ocean and simple cloud fraction changes. Aerosol, land, desert, snow, and vegetation all cause 10 times larger narrowband to broadband inconsistencies)

Loeb et al. 2007 J. Climate

What drives changes in global albedo?
How large are they? *The first rigorous determination*



Tropics drives global albedo variations. Global is in phase with tropics and 1/2 the magnitude (CERES flux data)

Cloud fraction variations are the driver. Not optical thickness or cloud particle size. Low cloud changes dominate. (MODIS cloud data)

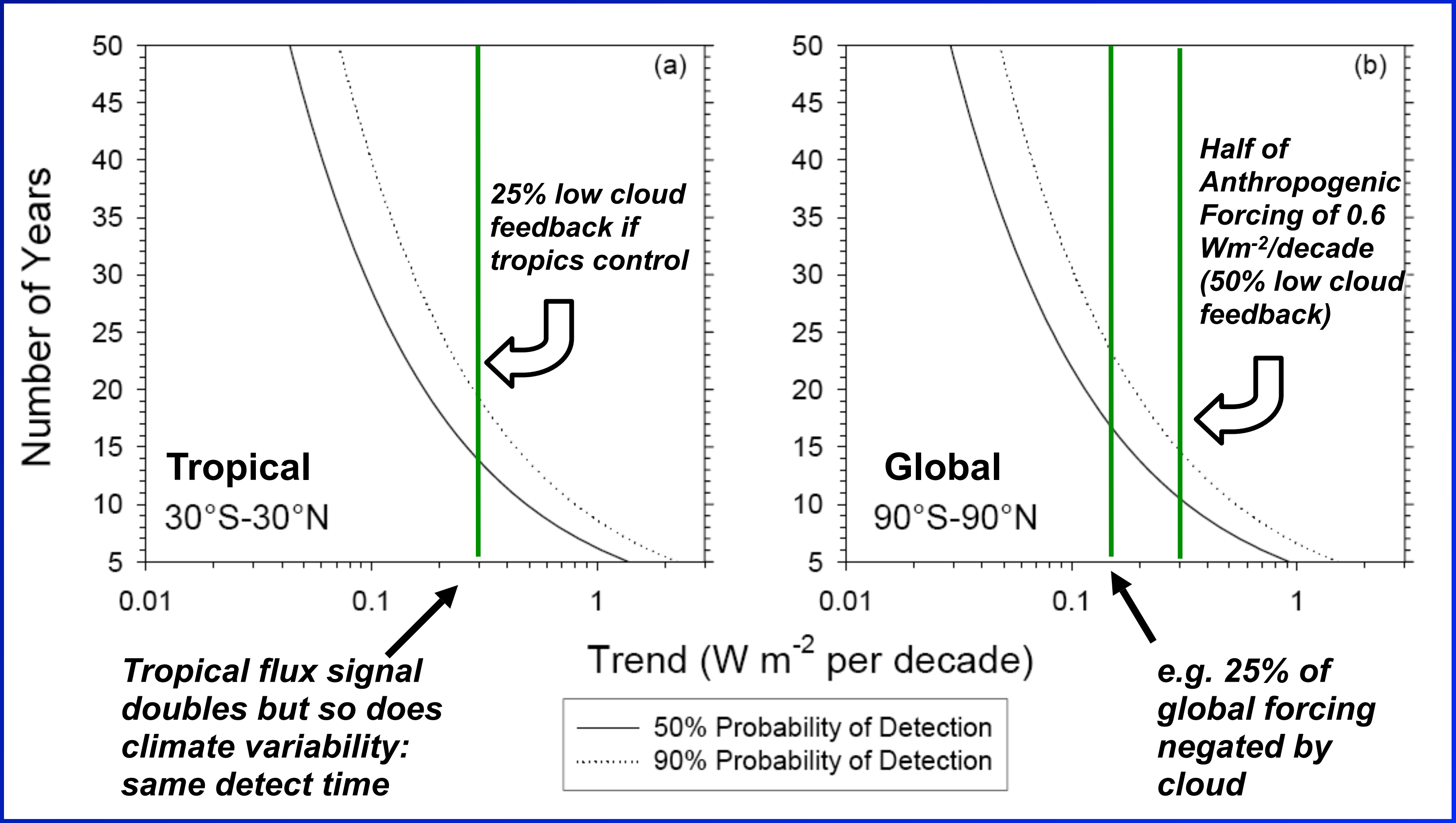
Results are based on combined climate analysis of Terra's CERES radiation budget instruments (2), MODIS cloud and aerosol analysis, snow & ice maps, GEOS 4.0.3 weather assimilation for temperature/humidity for climate applications. Note: 0.3 albedo ~ 100 Wm^{-2} reflected shortwave flux

Loeb et al., GRL (2007)

IPCC AR4 Report: Low Cloud Feedback Largest Uncertainty

How long to observe a 25% low cloud feedback?

For low clouds: Earth reflected solar flux dominates the feedback

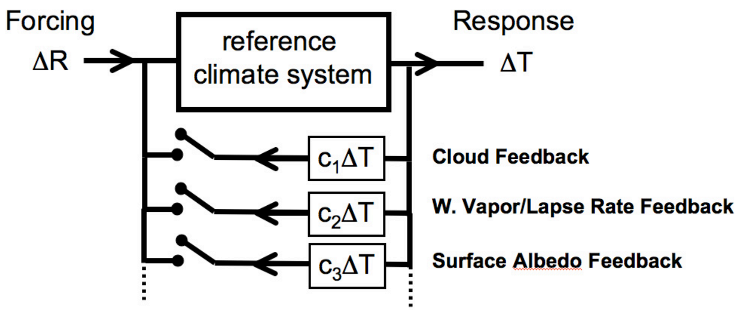


Given climate variability, 15 to 20 years is required to detect cloud feedback trends with 90% confidence. Loeb et al. J. Climate, 2007

Requires cloud radiative forcing calibration stability of 0.3% per decade

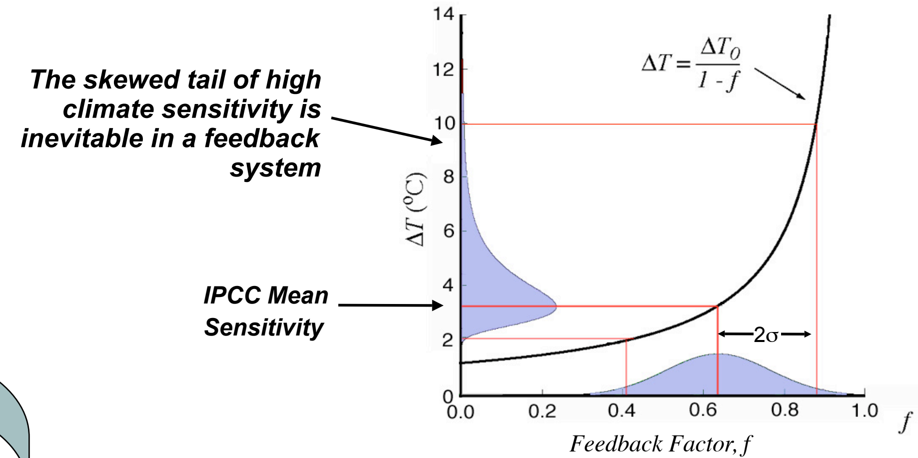
Climate Sensitivity Uncertainty

The Climate Feedback System

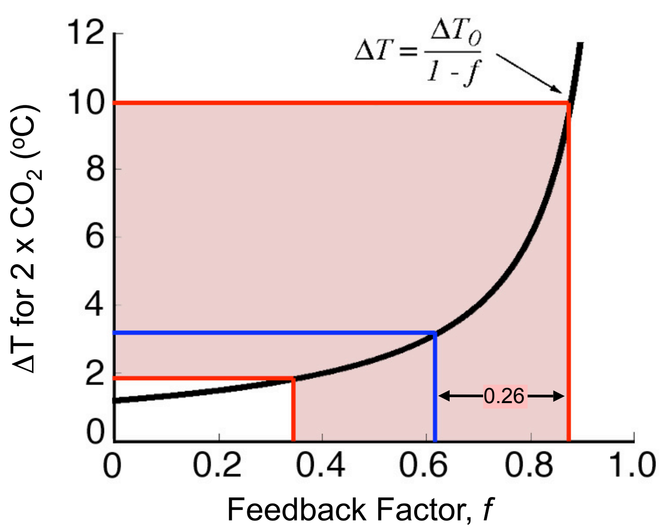


Reducing uncertainty in predictions of ΔT is critical for public policy since changes in global surface temperature drive changes in sea level and precipitation

Uncertainty in Feedback Defines Climate Sensitivity Uncertainty

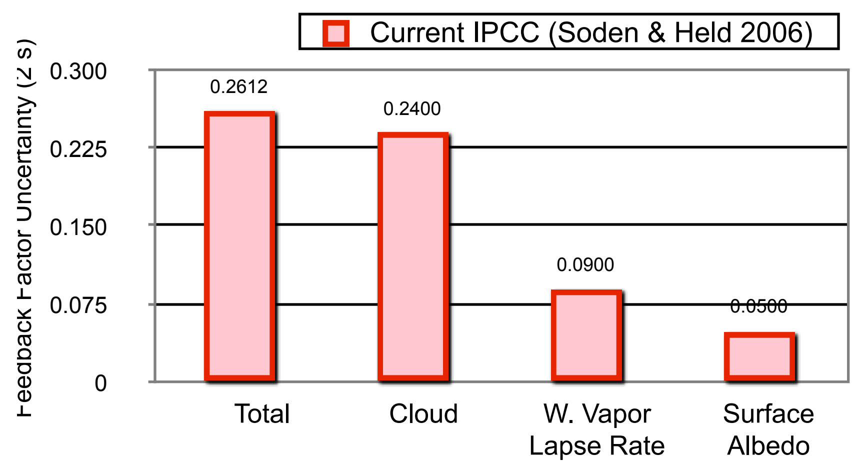


Current Climate Uncertainty



Current measured feedback uncertainties result in large uncertainties in predicted ΔT (Roe and Baker, 2007). ΔTo = the Earth's temperature as a simple blackbody

IPCC Climate Feedback Uncertainty

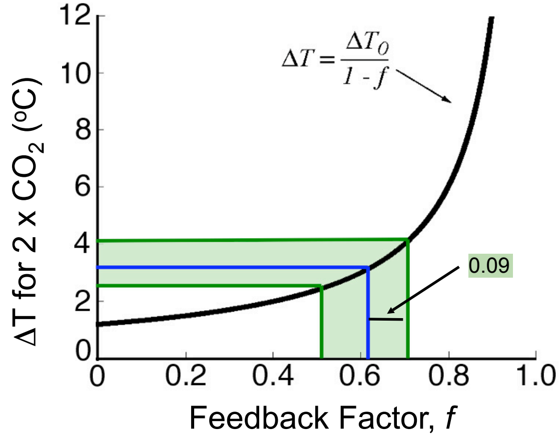


The uncertainty in climate feedback is driven by these three components. The feedback for the climate system is

$f = 0.62 \pm 0.26$ (2σ)

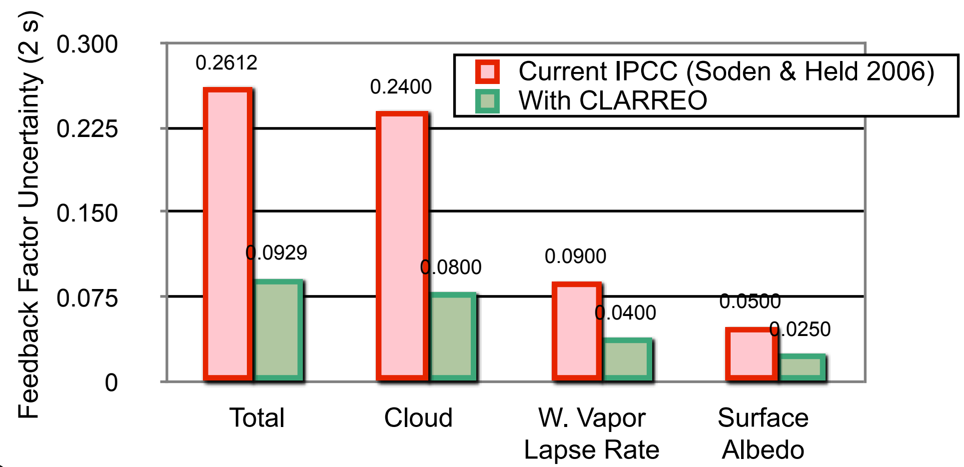
CERES/CLARREO Requirements Based on Reducing Feedback Uncertainty: Cloud Feedback Example

Reducing Climate Uncertainty Requires a More Accurate Measurement of Feedback



The high accuracy measurements from CLARREO can constrain predictions of ΔT through improved estimates of the feedback. The accuracy requirement is driven by the goal for climate uncertainty reducton.

CLARREO Reduces Climate Uncertainty



These feedback uncertainty goals define the CLARREO observation requirements

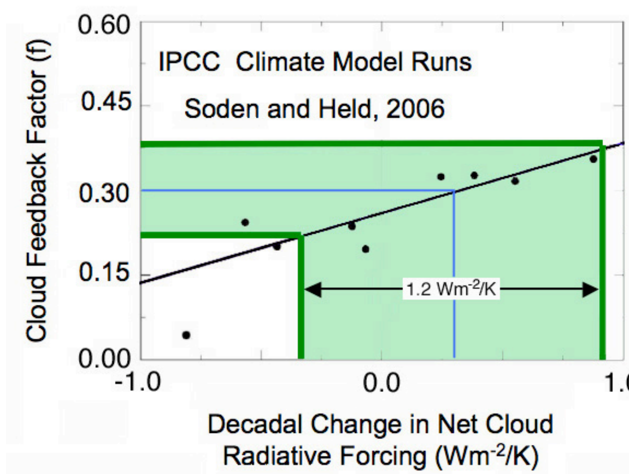
Decadal Trend Observation Requirement

The uncertainty goal for feedback factor *f* sets the observation goal for Net Cloud Radiative Forcing (CRF) at 1.2 Wm^{-2}/K

IPCC models predict a 0.2 K / decade warming in the next few decades independent of sensitivity. (because the warming is controlled by the slow ocean response time)

Therefore, the Net CRF observation goal is:
(1.2 Wm^{-2}/K) * (0.2K/decade) = 0.24 Wm^{-2}/decade

Cloud Feedback Uncertainty Goal Defines the Observation Requirement



CERES/CLARREO Requirements for Cloud Feedback

CERES/CLARREO Calibration Requirement For Measuring Cloud Feedback

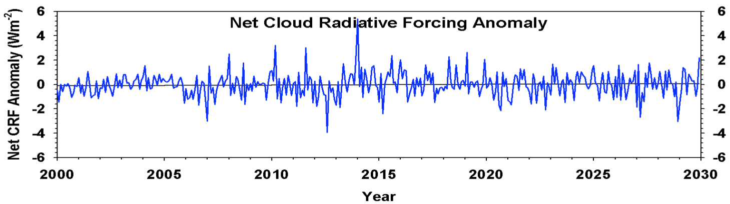
The Net CRF observation goal sets the decadal calibration goal:

Net CRF = SW CRF + LW CRF
CRF = Clear minus All-Sky TOA Flux

Shortwave (SW): 0.24/50 = 0.5% (2σ)
Longwave (LW): 0.24/30 = 0.8% (2σ)

This requirement is four times more accurate than the current SW broadband channel absolute accuracy:
Requires overlap for current observations (no gap)
and/or
Requires CLARREO for future observations (gap OK)

CERES/CLARREO Sampling Requirement



The Net CRF observation goal also sets the sampling requirements

- 20+ year record for trend to exceed natural variability
- Full swath sampling for low observation sampling noise
- 20km FOV or smaller to separate clear and cloud scenes

Solution: CLARREO required to calibrate broadband observations to needed absolute accuracy. CERES provides sampling of the Net CRF decadal change.

The Quest Has Just Begun

A new era of climate Observing System Simulation Experiments (OSSEs), a new era of calibration.

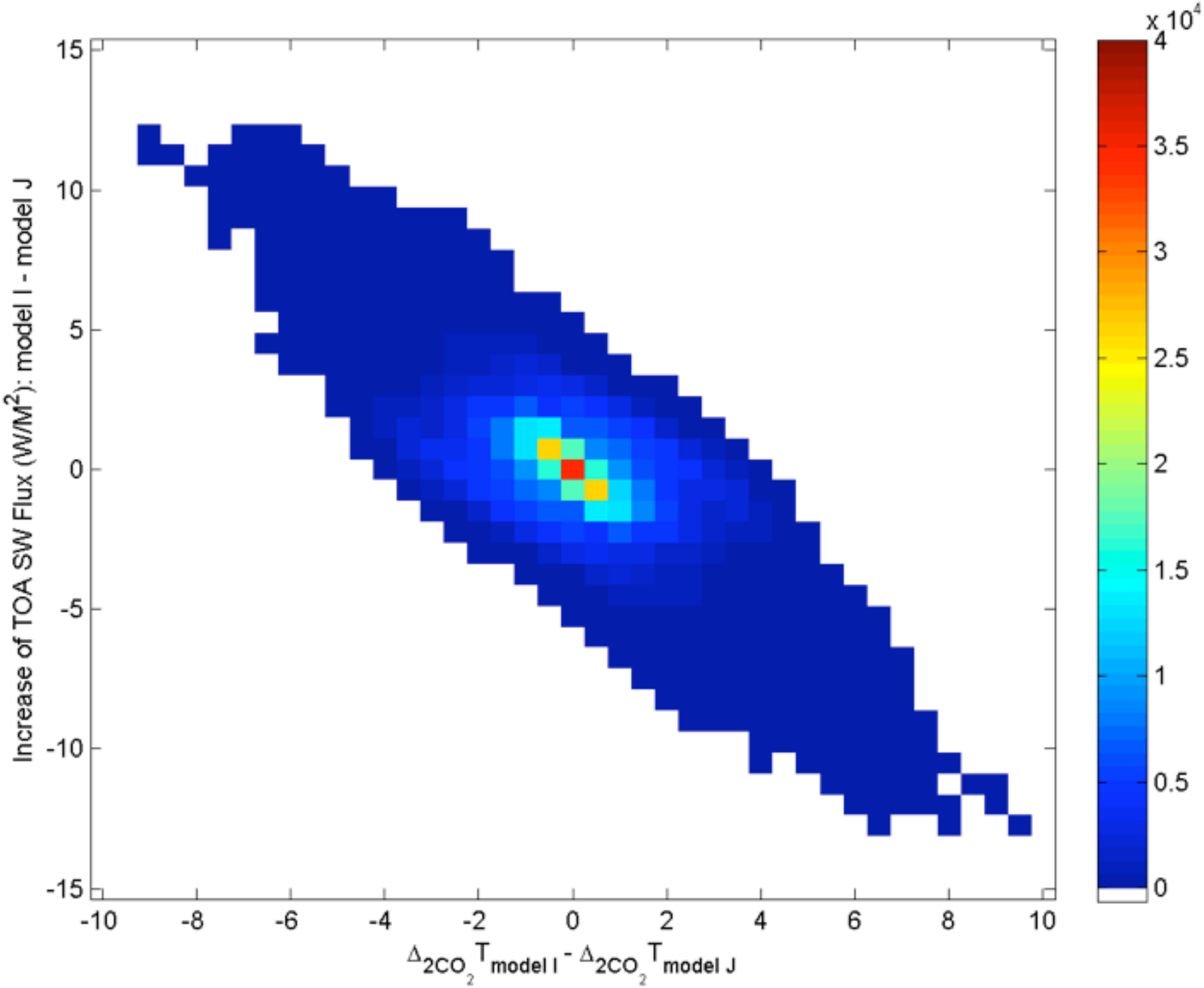
- A new methodology for linking climate model uncertainties to observation requirements has been highlighted.
- The current large uncertainties in climate feedbacks are not inevitable, nor is large uncertainty in climate sensitivity. CLARREO will likely play a key role.
- The example of cloud feedback linked to Net CRF does NOT eliminate the need to separately determine aerosol indirect effect. This remains the largest radiative forcing uncertainty and must be subtracted from the observed decadal change in SW CRF.

Additional Climate Feedbacks:

Similar climate model and data sampling analyses could be performed for other climate feedbacks

- water vapor/lapse rate feedback will require latitude profile and height profile requirements for temperature and humidity. Can be extended to spectral fingerprinting.
- surface albedo (e.g. snow/ice) will require latitude dependent requirements
- other feedbacks could also be considered in this framework.
- climateprediction.net perturbed physics modeling provides an ideal framework to explore the relationships.

Climate Sensitivity Vs Decadal Change



CPDN runs: 2500 perturbed cloud physics mixed layer 2X CO2 vs 1X CO2

Sensitivity versus change in global reflected solar flux (low cloud feedback)

Model i vs j is Analog for Model vs Earth

Hu and Wielicki

TOA Flux Decadal Variations

- Years N to detect trend ω with noise σ (natural variability plus observation uncertainty) scales as:

  $N \sim (\sigma/\omega)^{2/3}$ (B. Weatherhead, 1998)

  - *3 times larger noise leads to 2 times longer detection time ($\sim \sigma^{2/3}$)*
  - *3 times larger trend leads to 1/2 the detection time ($\sim \omega_o^{-2/3}$)*
  - *If noise and trend increase by the same ratio: same detection time.*
- At large time/space scales (e.g. global annual) climate variability "noise" is minimum, but issues with instrument calibration and consistent space/time sampling are significant. At smaller time/space scales climate variability is much larger, but so might be signals. We currently cannot evaluate an advantage at regional/zonal/global scales. Need further analysis to quantify σ and N versus time/space. Use climate model ensembles for ω hypothesis to "test"?
- Need improved studies of climate change metrics and their ability to constrain prediction accuracy using large ensembles of climate models with varying climate physics, sensitivity, climate change.

Recent New Wrinkles on Feedbacks/Sensitivity

- Tropospheric Adjustment and Cloud Feedback
  - Gregory and Webb, J. Climate 2008
  - Is most cloud feedback like an indirect forcing acting at time scales less than a year? appears to in GCMs
  - Good news: suggests can observe now
  - Bad news: like aerosol indirect effect its a cause and effect challenge to unscramble
- Radiative Perturbation analysis of feedbacks (water vapor, surface, lapse rate, cloud)
  - Soden & Held (2006) and others: surface albedo, lapse rate, w. vapor feedbacks
  - Soden et al J. Climate July 2008: radiative perturbation method for cloud radiative forcing: corrects issues with mixing clear atmosphere and cloud effects.
  - Suggests global/zonal/vertical decadal change is key.