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Top of the atmosphere (TOA) radiative flux anomalies due to temperature (T), water vapor (q) & surface albedo (α) variability

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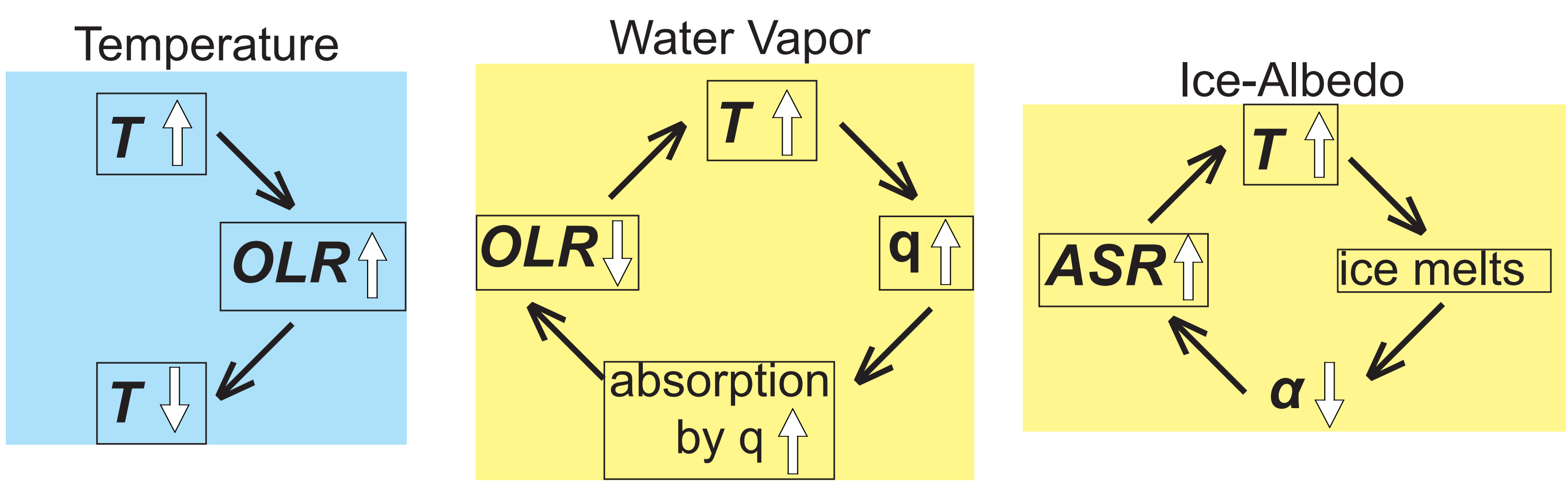
Introduction

The generation of climate models used for the IPCC 4th Assessment Report predict a range of climate sensitivity from 1.5 to 4.5 °C (Soloman et al, 2007). The key factor that contributes to spread is the strength of radiative feedbacks among models. *Radiative feedbacks* are physical processes that amplify or dampen the climate response to a given forcing. They are defined as the TOA flux change, dR, due to a change in feedback variable, dx, (x = temperature (T), water vapor (q), surface albedo (α), clouds), normalized by the global average surface temperature change, dT_s. The feedback strength (γ) is the sum of all radiative feedbacks:

$$\gamma = \frac{dR}{dT_s} = \gamma_T + \gamma_q + \gamma_\alpha + \gamma_{clouds} \quad \text{where,} \quad \gamma_x = \left(\frac{\partial R}{\partial x}\right)\frac{dx}{dT_s}$$

The radiative kernel technique (Soden et al, 2008) is used in this study to quantify TOA flux anomalies ($\gamma_x dT_s = K_x dx$) due to interannual variability in temperature, water vapor and surface albedo. The radiative kernel ($K_x = \left(\frac{\partial R}{\partial x}\right)$) is the TOA flux change due to a standard perturbation calculated at each grid point and level using the Community Atmospheric Model Version 3 (Shell et al, 2008). We use present day simulations of the NCAR Community Climate System Model Version 3 and GFDL Climate Model 2.1 to examine variability in TOA flux anomalies and compare results to "observed" variability over the 20-year period from 1989 to 2008 in the ECMWF ERA-Interim Reanalysis dataset .

Radiative Feedbacks



Clear Sky Test

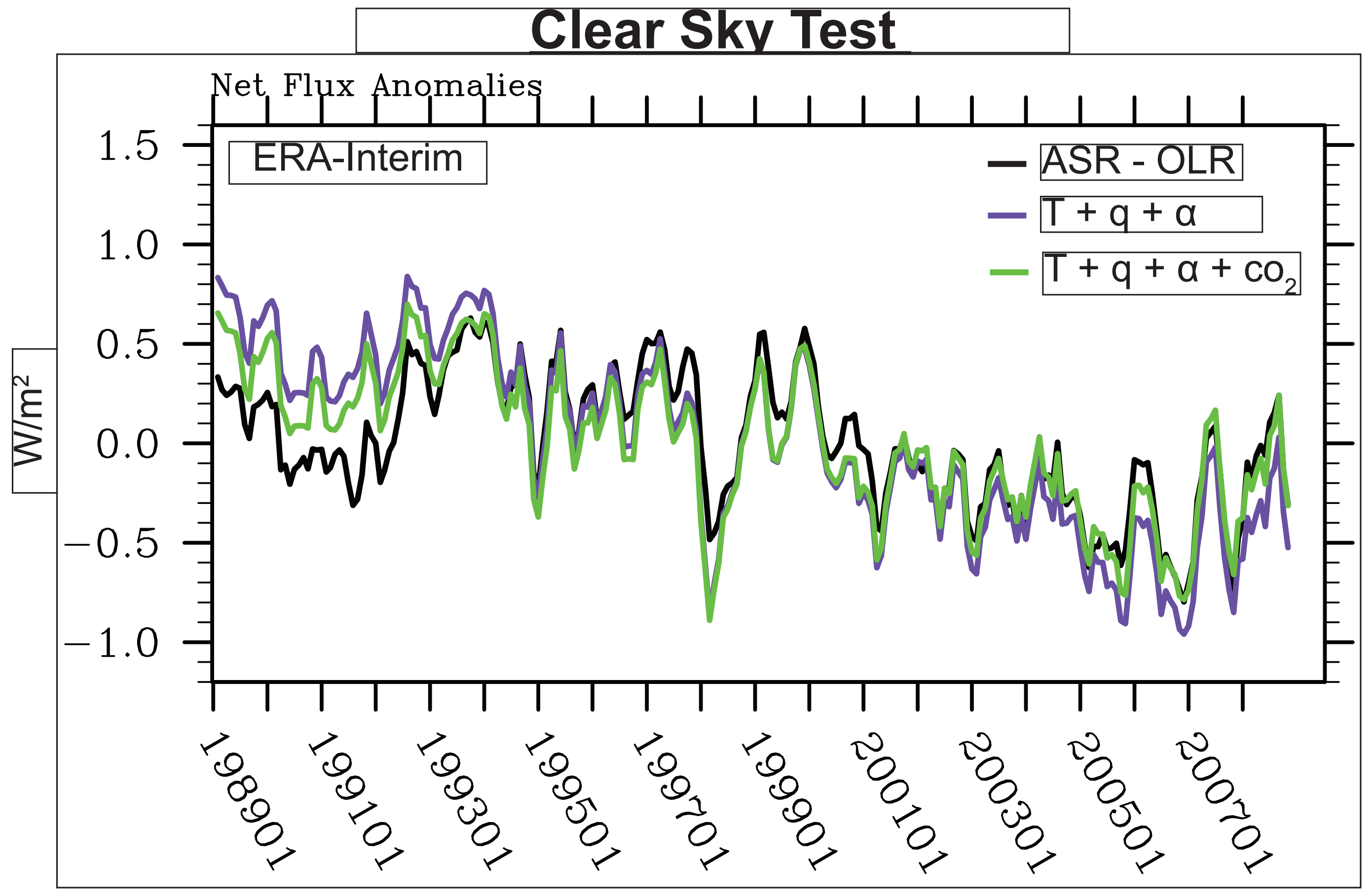
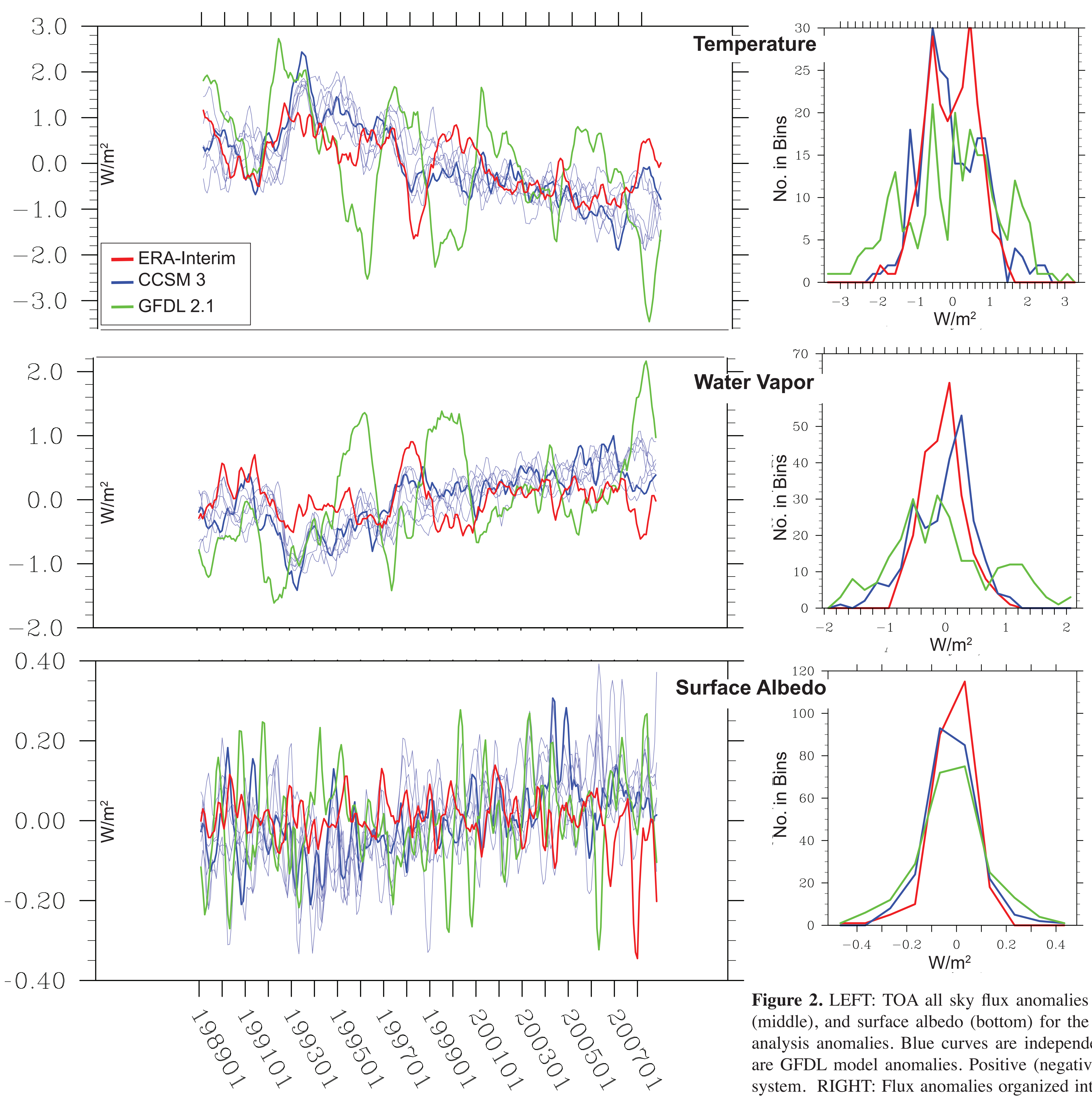


Figure 1. The clear sky test is a measure of how well the radiative kernel technique accounts for the net TOA flux anomalies (black); that is, absorbed solar radiation (ASR) minus outgoing longwave radiation (OLR). The sum of temperature, water vapor, albedo, and external forcing contributions (green) must balance the net TOA flux anomalies (black) within a small margin of error (ε) in order to validate the use of the radiative kernel technique in this analysis ($ASR - OLR = T + q + \alpha + CO_2 + \varepsilon$).

All Sky TOA Flux Anomalies



- GFDL model has greater extremes than CCSM and ERA
- Cross-Correlation with ERA
  - CCSM Run 2: r = .644
  - GFDL: r = .108

- GFDL model has greater extremes than CCSM and ERA
- Cross-Correlation with ERA
  - CCSM Run 2: r = .346
  - GFDL: r = -0.214
- CCSM appears to have a stronger trend than ERA

- CCSM, GFDL capable of capturing extreme values seen in ERA, but much more frequently.
- Cross-Correlation with ERA
  - CCSM Run 2: r = -0.085
  - GFDL: r = -0.70
- CCSM Run2 best correlates with ERA in T and q, but among the worst correlations in albedo.

Figure 2. LEFT: TOA all sky flux anomalies due to anomalies of temperature (top), water vapor (middle), and surface albedo (bottom) for the period 1989-2008. Red curves are ERA-Interim reanalysis anomalies. Blue curves are independent CCSM3 runs with Run 2 in bold. Green curves are GFDL model anomalies. Positive (negative) values indicate energy gained (lost) by the Earth system. RIGHT: Flux anomalies organized into 0.2 W/m² bins (0.1 W/m² bins for surface albedo).

Next Steps

- Compare with other 20th century reanalysis products (NCEP)
- Test robustness of radiative kernel technique applied to interannual variability by comparing results with other techniques
- Evaluate other CMIP3 models and compare with CMIP5 models
- Examine regional TOA flux anomalies (N. H., S. H., Tropics, Mid-Lats, High-Lats)
- Calculate metrics of variability (auto-correlation, probability distribution, spectra) for entire 20th century for model intercomparison

We plan to isolate those models and configurations that adequately capture the current "observed" variability in the TOA energy balance components. While insufficient by itself, ability to simulate observed climate variability is a necessary condition in order to constrain and gain confidence in future projections.

Shell, K. M., et al. (2008), *Using the radiative kernel technique to calculate climate feedbacks in NCAR's Community Atmospheric Model*, J. Clim.,21, 2269–2282, doi:10.1175/2007JCLI2044.1.
Solomon, S., D. Qin, M. Manning, M. Marquis, K. Averyt, M. M. B. Tignor, H. L. Miller Jr., and Z. Chen, Eds., 2007: *Climate Change 2007: The Physical Science Basis*. Cambridge University Press, 996 pp.
Soden, B. J., and I. M. Held, R. Colman, K. M. Shell, J. T. Kiehl, and C. A. Shields, 2008: *Quantifying climate feedbacks using radiative kernels*. J. Climate, 21, 3504–3520.

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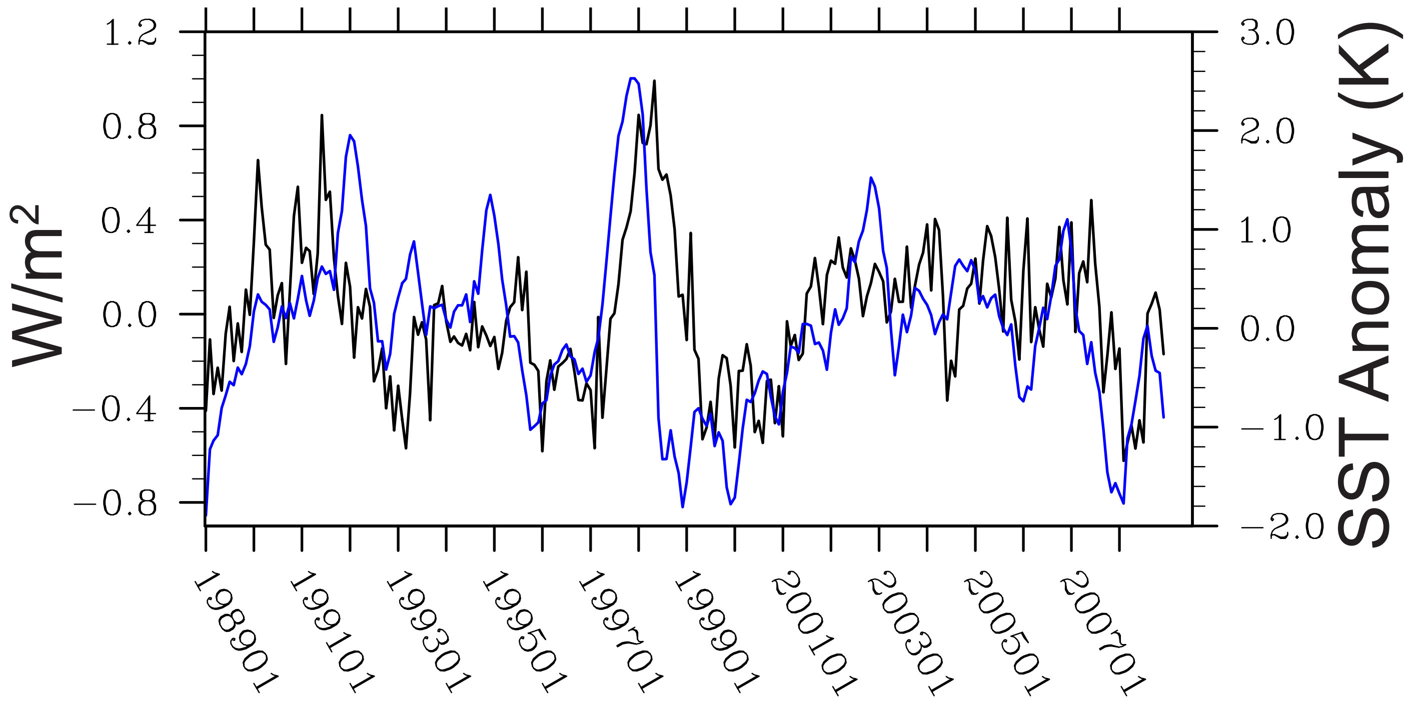
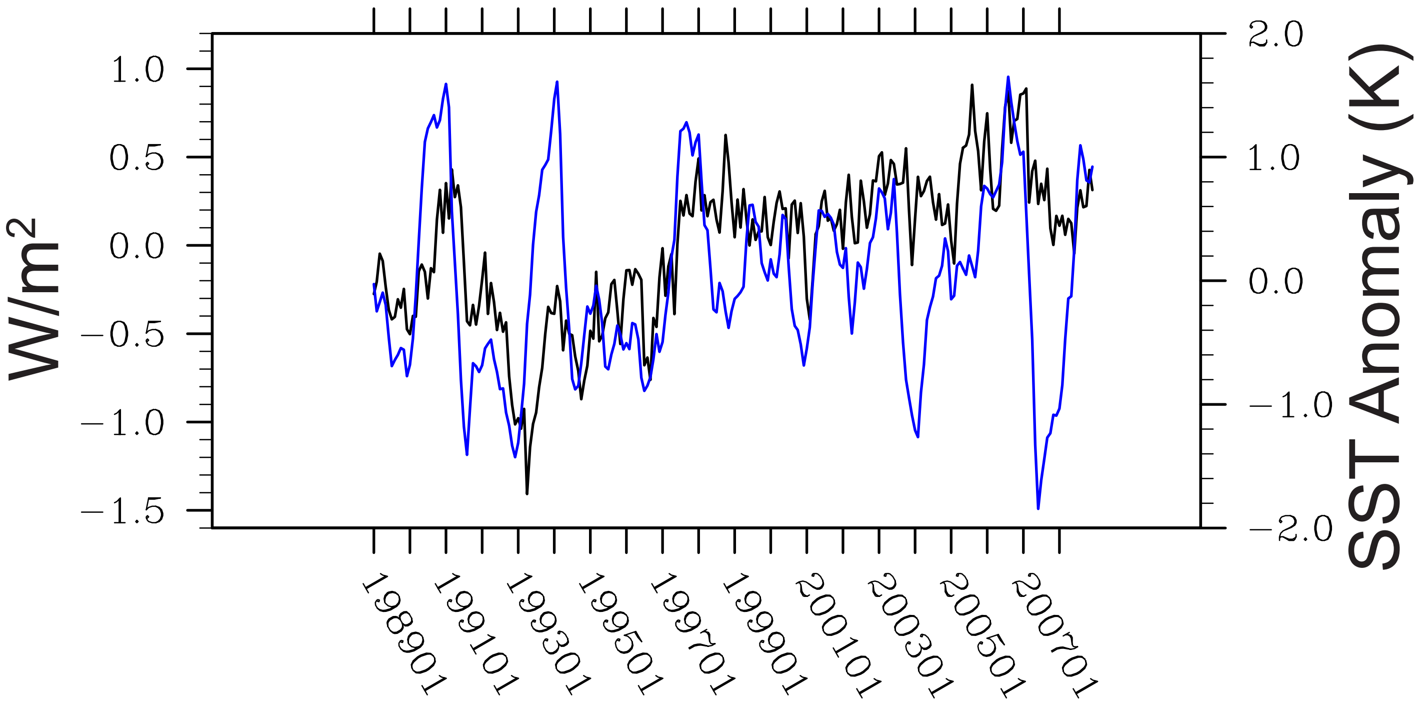
Is TOA flux variability related to ENSO?

All Sky Water Vapor LW Flux Anomaly with Nino 3.4 SST Anomaly

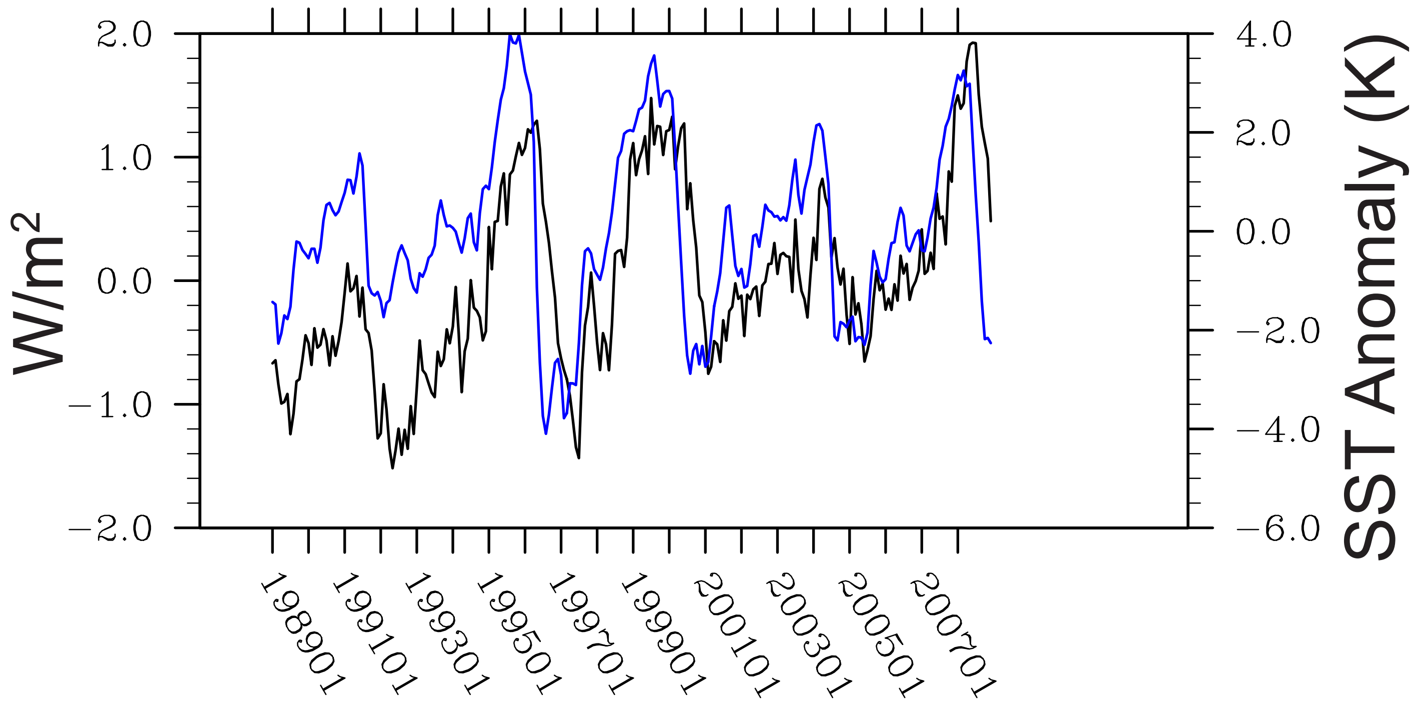
ERA-Interim, Correlation at Zero Lag: 0.424



CCSM3 Run2, Correlation at Zero Lag: 0.387



GFDL 2.1, Correlation at Zero Lag: 0.579



For each simulation, a measure of ENSO was calculated for the Nino 3.4 region by subtracting the area averaged monthly climatology (1989-2008) from the area average sea surface temperature (SST). The SST anomalies (blue) are plotted above with the corresponding TOA LW flux anomalies due to water vapor (black). It appears that global TOA flux variability is more strongly related to ENSO in the GFDL 2.1 model than in CCSM 3 and ERA-Interim reanalysis.