Radiative and Dynamical Forcing of El-Niño-Related Global Temperature Anomalies in the Observations and in CMIP5 Models

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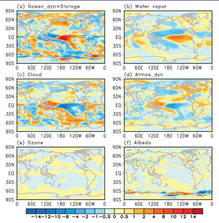
Introduction

Temperature response to ENSO
- Tropical Gill-type response
- PNA pattern
- Storm track change
- High-latitude stratospheric warming

ENSO-related Feedback
- Water vapor feedback
- Cloud feedback
- Albedo feedback
- Ozone feedback
- Ocean dynamics and sensible/latent heat flux
- Atmospheric dynamics - atmospheric bridge

Climate Feedback-Responses Analysis Method (CFRAM)
Cai an Lu (2009), Lu and Cai (2009)

Decomposition of temperature response to ENSO in observation



Deng et al. (2012), Park et al. (2012)

Suggested Question: How about ENSO-related temperature decomposition in the CGCMs?

Data

- **Observation: The ERA-interim**
  - Period: 1979~2010, Only DJF data are analyzed.
- **CMIP5 Models**
  - Historical run of 1861-2005. Only DJF data are analyzed
  - 15 Models: BCC-CSM1-1, BNU-ESM, CCSM4, CESM1-CAM5-1-FV2, GFDL-CM3, GFDL-ESM2G, GISS-E2-H, GISS-E2-R, IPSL-CM5A-LR, MIROC5, MIROC-ESM, MIROC-ESM-CHEM, MPI-ESM-LR, MPI-ESM-P, NorESM1-M

Methods

CFRAM Formulation

- The total energy balance at M atmospheric layers and one surface (M+1)th layer

$$\vec{\mathbf{R}} = \vec{\mathbf{S}} + \vec{\mathbf{Q}}^{non-radiative}$$

$\vec{\mathbf{R}}$: LW radiation flux; $\vec{\mathbf{S}}$: SW radiation flux; $\vec{\mathbf{Q}}^{non-radiative}$: Energy due to non-radiative dynamical processes

- The difference between two climate states

$$\Delta\vec{\mathbf{S}} - \Delta\vec{\mathbf{R}} + \Delta\vec{\mathbf{Q}}^{non-radiative} = \Delta\frac{\partial\vec{\mathbf{E}}}{\partial t} \approx \Delta\vec{\mathbf{Q}}^{(atmos_dyn)} + \Delta\vec{\mathbf{Q}}^{(sfc_dyn+storage)}$$

Change in energy storage

w : water vapor
c : cloud
α : albedo
atmos_dyn : Atmospheric dynamics
sfc_dyn : Surface dynamics
storage : heat storage

$$\Delta\vec{\mathbf{S}} \approx \Delta\vec{\mathbf{S}}^{(w)} + \Delta\vec{\mathbf{S}}^{(c)} + \Delta\vec{\mathbf{S}}^{(\alpha)}$$

$$\Delta\vec{\mathbf{R}} \approx \Delta\vec{\mathbf{R}}^{(w)} + \Delta\vec{\mathbf{R}}^{(c)} + \frac{\partial\vec{\mathbf{R}}}{\partial\vec{\mathbf{T}}}\Delta\vec{\mathbf{T}}$$

Planck feedback matrix $\left(\frac{\partial\vec{\mathbf{R}}}{\partial\vec{\mathbf{T}}}\right) = \begin{pmatrix} \frac{\partial R_1}{\partial T_1} & \cdots & \frac{\partial R_1}{\partial T_{M+1}} \\ \vdots & \ddots & \vdots \\ \frac{\partial R_{M+1}}{\partial T_1} & \cdots & \frac{\partial R_{M+1}}{\partial T_{M+1}} \end{pmatrix}$

- Rearranging the terms …

$$\Delta\vec{\mathbf{T}} = \left(\frac{\partial\vec{\mathbf{R}}}{\partial\vec{\mathbf{T}}}\right)^{-1}\left\{\Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(w)} + \Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(c)} + \Delta\vec{\mathbf{S}}^{(\alpha)} + \Delta\vec{\mathbf{Q}}^{(atmos_dyn)} + \Delta\vec{\mathbf{Q}}^{(sfc_dyn+storage)}\right\}$$

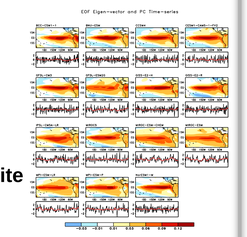
Water vapor · Cloud · Albedo · Atmospheric dynamics · Surface dynamics + heat storage

Decomposition Procedure

Define Neutral, El Niño, La Niña cases

ERAI
El Niño case: Nino 3.4 index > 1 σ → 7 El Niño cases
La Niña case: Nino 3.4 index < −1 σ → 5 La Niña cases
Neutral case: |Nino 3.4 index| ≤ 0.5 σ → 9 Neutral cases

CMIP5
ENSO index: PC time-series of EOF 1st mode for the Tropical Pacific surface temperature without long-term trend (detrended TS)



Composite

Input for Radiative transfer model

Surface	Multi-layer
Solar insolation	Air temperature
Surface pressure/ temperature	Specific humidity
surface latent/sensible heat flux	Cloud amount
surface downward/upward SW	Cloud liquid/ice water

Fu-Liou radiative transfer model
(Fu and Liou, 1992; 1993)

Energy perturbation terms

$\Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(w)}$ $\Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(\alpha)}$ $\Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(c)}$ $\Delta\vec{\mathbf{Q}}^{(atmos_dyn)}$ $\Delta\vec{\mathbf{Q}}^{(sfc_dyn+storage)}$

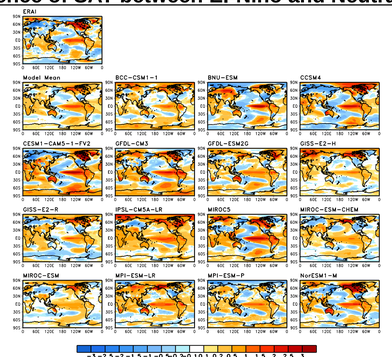
Partial temperature changes

$\Delta\vec{\mathbf{T}}^{water\ vapor}$ $\Delta\vec{\mathbf{T}}^{cloud}$ $\Delta\vec{\mathbf{T}}^{albedo}$ $\Delta\vec{\mathbf{T}}^{atmos_dyn}$ $\Delta\vec{\mathbf{T}}^{sfc_dyn+storage}$

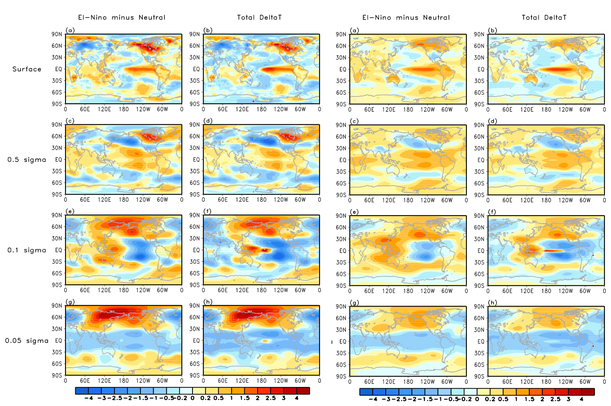
CFRAM
(Lu and Cai, 2009)

Validation of CFRAM

Difference of SAT between El-Nino and Neutral winters



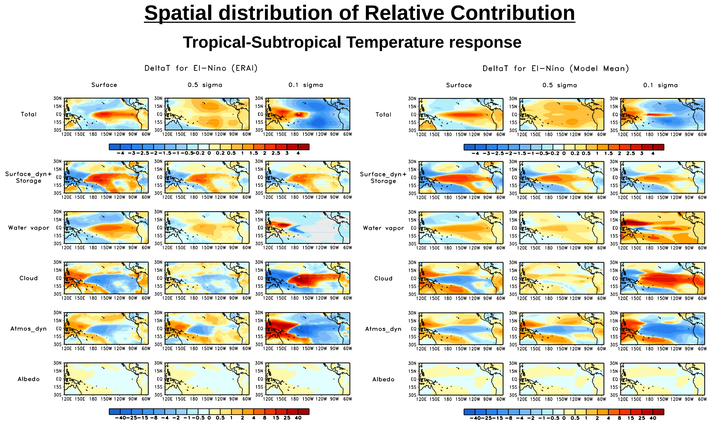
Total Temperature Change for El Niño $\Delta\vec{\mathbf{T}}_{Total}$



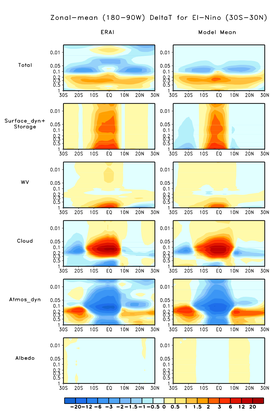
Decomposition Results

Spatial distribution of Relative Contribution

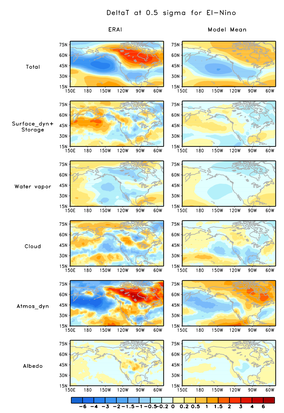
Tropical-Subtropical Temperature response



Zonal-mean feature over 30S~30N



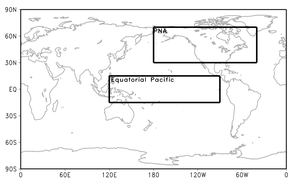
Temperature response over PNA region



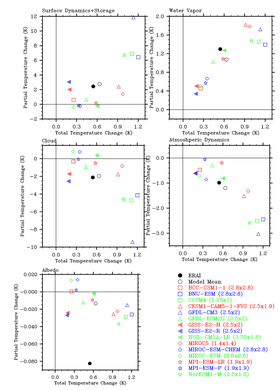
Quantification of Relative Contributions

Pattern Amplitude Projection

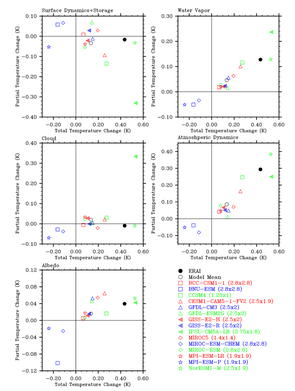
$$\overrightarrow{\mathbf{PAP}}_i = A^{-1}\int_A a^2\Delta\vec{\mathbf{T}}\cos\phi\,d\lambda\,d\phi \Big/ A^{-1}\int_A a^2\Delta\vec{\mathbf{T}}_i\Delta\vec{\mathbf{T}}\cos\phi\,d\lambda\,d\phi \cdot A^{-1}\int_A a^2(\Delta\vec{\mathbf{T}})^2\cos\phi\,d\lambda\,d\phi$$



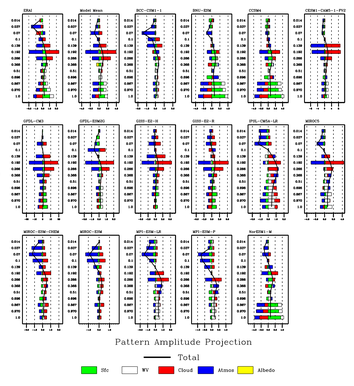
PAP over Equatorial Pacific



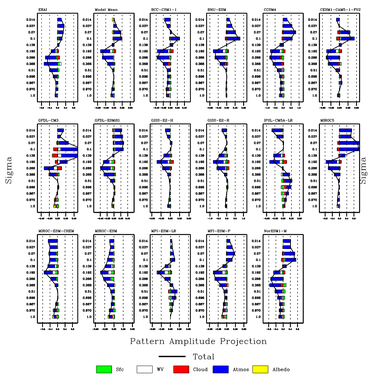
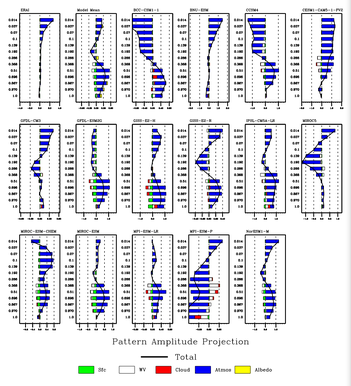
PAP over PNA region



Vertical Distribution of PAP over 10S~10N



Vertical Distribution of PAP over 30N~60N



Vertical Distribution of PAP over 60N~90N