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Feedback Attribution of the El Niño-Southern Oscillation-related Atmospheric and Surface Temperature Anomalies

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Introduction

The literatures have investigated …

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

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

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

The present study aims to …

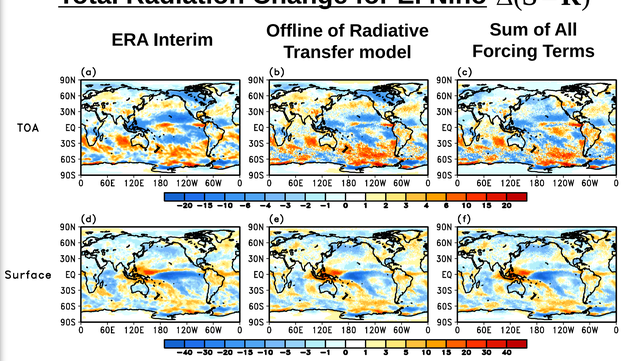
Quantifying the contributions of partial temperature changes to the ENSO-related temperature anomalies

Data

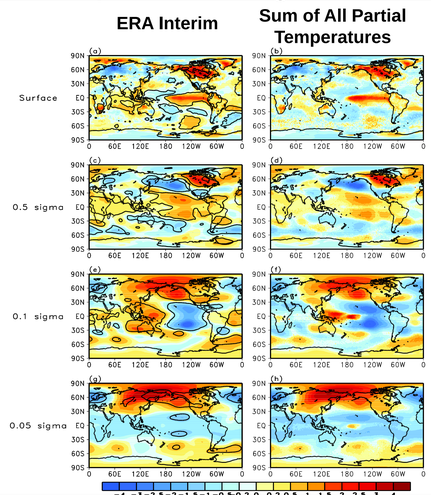
- **The ERA-interim**
  - Resolution: 1.5˚ ×1.5˚, 37 pressure levels from 1000 to 1 hPa
  - Period: 1979~2010, Only DJF data are analyzed.
  - Variables: Solar insolation, surface pressure, surface temperature, surface latent/sensible heat flux, surface downward/upward SW, ozone, air temperature, specific humidity, cloud amount, and cloud liquid/ice water
- **Nino index**
  - Monthly NINO 3.4 index downloaded from http://www.noaa.gov.data.indices

Validation of CFRAM

Total Radiation Change for El Niño $\Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})$



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



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

$$\Delta\frac{\partial\vec{\mathbf{E}}}{\partial t} = \Delta\vec{\mathbf{S}} - \Delta\vec{\mathbf{R}} + \Delta\vec{\mathbf{Q}}^{non-radiative}$$

Change in energy storage

$$\Delta\vec{\mathbf{Q}}^{non-radiative} - \Delta\frac{\partial\vec{\mathbf{E}}}{\partial t} \approx \Delta\vec{\mathbf{Q}}^{(atmos\_dyn)} + \Delta\vec{\mathbf{Q}}^{(ocean\_dyn+storage)}$$

w : water vapor
c : cloud
α : albedo
atmos_dyn : Atmospheric dynamics
ocean_dyn : Oceanic dynamics
storage : heat storage

$$\Delta\vec{\mathbf{S}} \approx \Delta\vec{\mathbf{S}}^{(w)} + \Delta\vec{\mathbf{S}}^{(c)} + \Delta\vec{\mathbf{S}}^{(\alpha)} + \Delta\vec{\mathbf{S}}^{(O_3)}$$

$$\Delta\vec{\mathbf{R}} \approx \Delta\vec{\mathbf{R}}^{(w)} + \Delta\vec{\mathbf{R}}^{(c)} + \Delta\vec{\mathbf{R}}^{(O_3)} + \frac{\partial\vec{\mathbf{R}}}{\partial\vec{\mathbf{T}}}\Delta\vec{\mathbf{T}}$$

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 …

$$\Delta\vec{\mathbf{T}} = \left(\frac{\partial\vec{\mathbf{R}}}{\partial\vec{\mathbf{T}}}\right)^{-1}\left\{\Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(w)} + \Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(c)} + \Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(O_3)} + \Delta\vec{\mathbf{S}}^{(\alpha)} + \Delta\vec{\mathbf{Q}}^{(atmos\_dyn)} + \Delta\vec{\mathbf{Q}}^{(ocean\_dyn+storage)}\right\}$$

Water vapor; Ozone; Atmospheric dynamics; Cloud; Albedo; Oceanic dynamics + heat storage

Decomposition Procedure

Define Neutral, El Niño, La Niña cases
- 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

Composite

Input for Radiative transfer model

Surface	Multi-layer
Solar insolation	Ozone
surface pressure	Air temperature
surface 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

$\Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(w)}$ $\Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(c)}$ $\Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(O_3)}$ $\Delta(\vec{\mathbf{S}}-\vec{\mathbf{R}})^{(\alpha)}$ $\Delta\vec{\mathbf{Q}}^{(atmos\_dyn)}$ $\Delta\vec{\mathbf{Q}}^{(ocean\_dyn+storage)}$

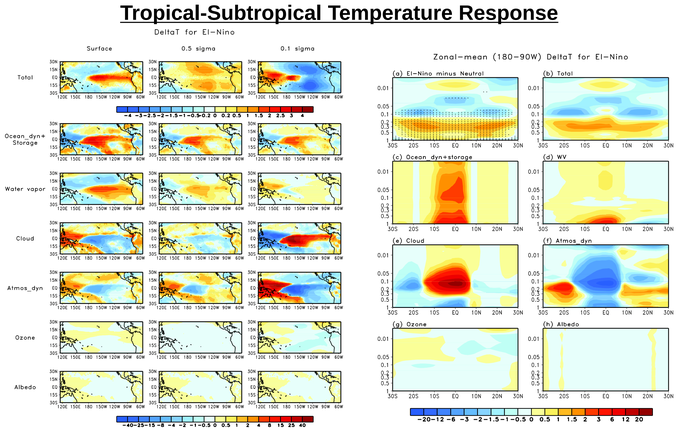
CFRAM (Lu and Cai, 2009)

Partial temperature changes

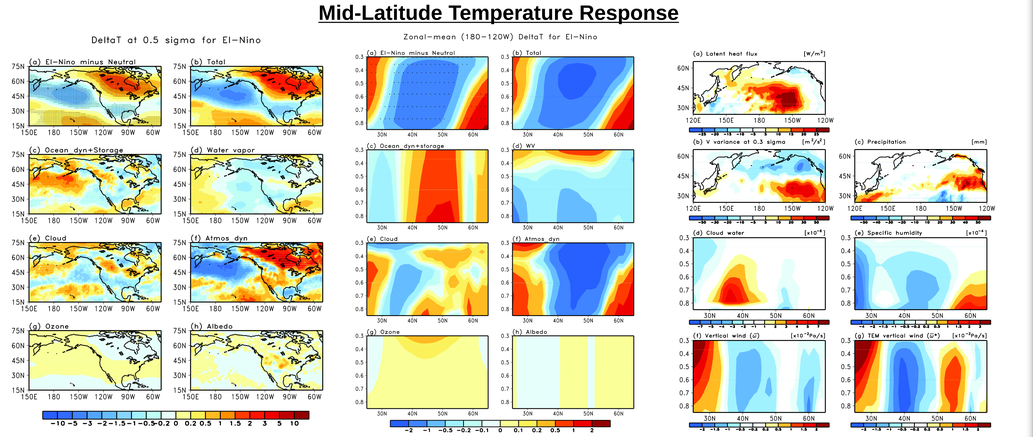
$\Delta\vec{\mathbf{T}}^{water\ vapor}$ $\Delta\vec{\mathbf{T}}^{cloud}$ $\Delta\vec{\mathbf{T}}^{ozone}$ $\Delta\vec{\mathbf{T}}^{albedo}$ $\Delta\vec{\mathbf{T}}^{atmos\_dyn}$ $\Delta\vec{\mathbf{T}}^{ocean\_dyn+storage}$

Decomposition Results

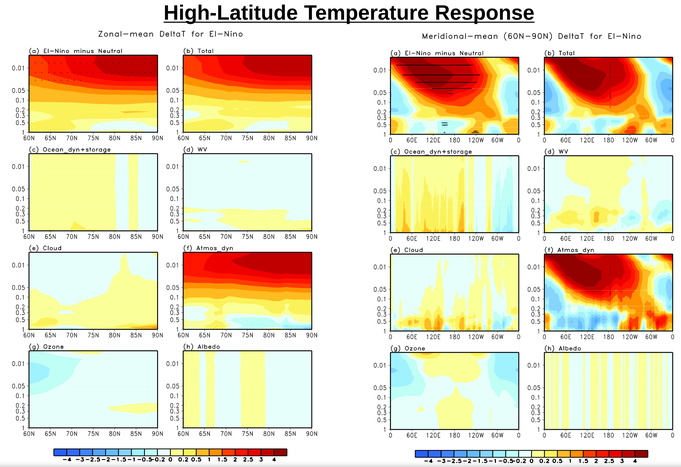
Tropical-Subtropical Temperature Response



Mid-Latitude Temperature Response



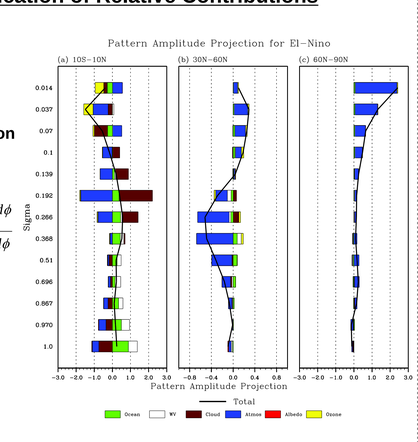
High-Latitude Temperature Response



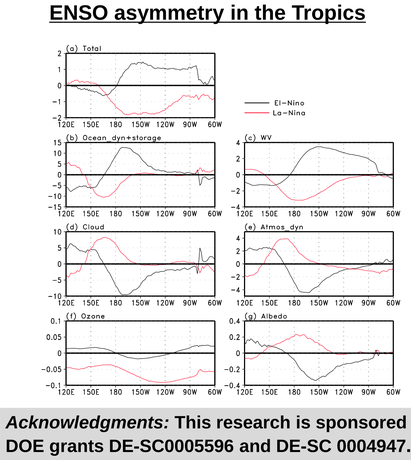
Quantification of Relative Contributions

Pattern Amplitude Projection

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



ENSO asymmetry in the Tropics



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