Feedback Decomposition of the Global Surface Temperature Response to El Niño

Yi Deng and Taewon Park

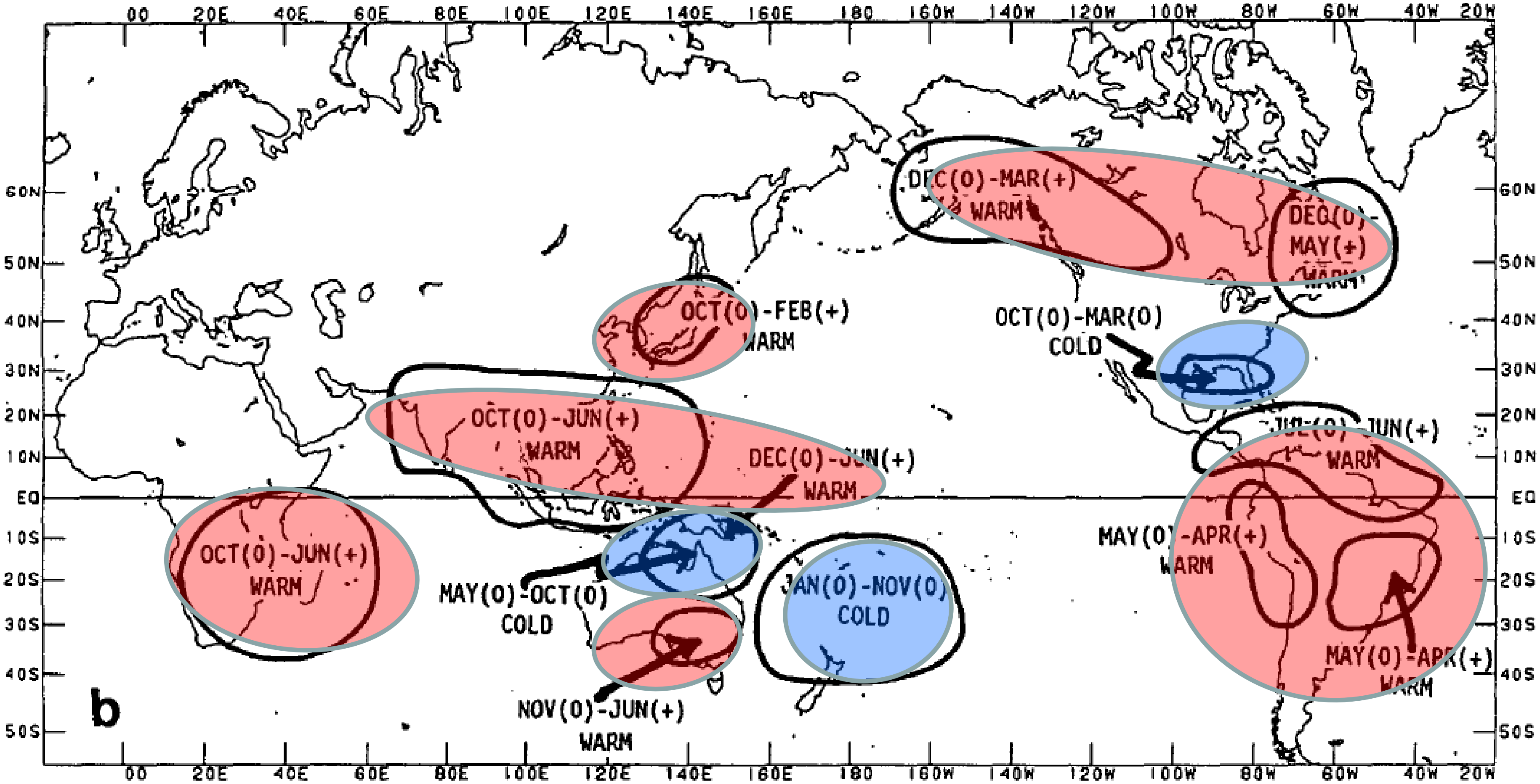
School of Earth and Atmospheric Sciences, Georgia Institute of Technology

Ming Cai
Department of Earth, Ocean and Atmospheric Science, Florida State University

September 20, 2011, DOE Climate and Earth System Modeling PI Meeting

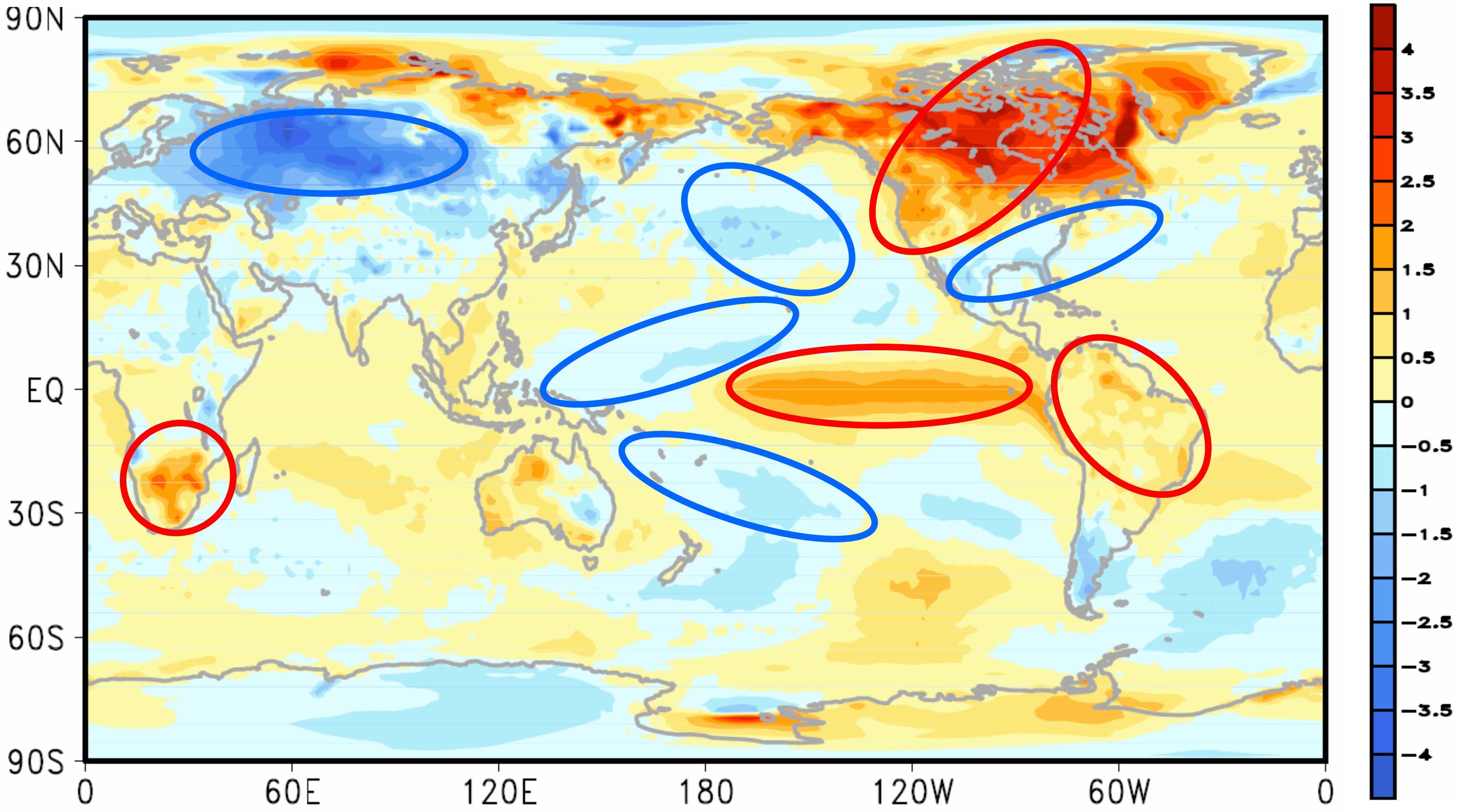
Funded by DOE Regional and Global Climate Modeling (RGCM) Program

Global Surface Temperature Response to El Niño



(Halpert and Popelewski 1992)

Global Surface Temperature Response to El Niño (DJF)



Surface Temperature Anomaly (El Niño Composite - ENSO-Neutral Composite, ERA Interim)

Question

What are the relative contributions of the various radiative feedbacks and atmospheric/oceanic dynamical feedbacks to the global surface temperature anomaly associated with El Niño?

Coupled atmosphere-surface climate feedback-response analysis method (CFRAM) (Lu and Cai 2008; Cai and Lu 2008)

Energy balance of each layer within an atmospheric-surface column:

$$\vec{\mathbf{R}} = \vec{\mathbf{S}} + \vec{\mathbf{Q}}^{turb} + \vec{\mathbf{Q}}^{conv} + \vec{\mathbf{D}}^{v} + \vec{\mathbf{D}}^{h} + \vec{\mathbf{W}}^{fric} - \frac{\partial \vec{\mathbf{E}}}{\partial t}$$

Considering the differences between two climate states: El Niño versus ENSO-Neutral

$$\Delta\vec{\mathbf{R}} = \Delta\vec{\mathbf{S}} + \Delta\vec{\mathbf{Q}}^{turb} + \Delta\vec{\mathbf{Q}}^{conv} + \Delta\vec{\mathbf{D}}^{v} + \Delta\vec{\mathbf{D}}^{h} + \Delta\vec{\mathbf{W}}^{fric} - \Delta\frac{\partial \vec{\mathbf{E}}}{\partial t}$$

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

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

Feedback decomposition of El Niño temperature response:

$$\Delta\vec{\mathrm{T}} = \left(\frac{\partial \vec{\mathrm{R}}}{\partial \vec{\mathrm{T}}}\right)^{-1}\left\{\overset{\substack{\text{ozone}\\ \downarrow}}{\Delta^{(o)}(\vec{\mathrm{S}}-\vec{\mathrm{R}})} + \underset{\substack{\uparrow\\ \text{surface}\\ \text{albedo}}}{\Delta^{(\alpha)}\vec{\mathrm{S}}} + \overset{\substack{\text{cloud}\\ \downarrow}}{\Delta^{(c)}(\vec{\mathrm{S}}-\vec{\mathrm{R}})} + \underset{\substack{\uparrow\\ \text{water vapor}}}{\Delta^{(w)}(\vec{\mathrm{S}}-\vec{\mathrm{R}})} + \overset{\substack{\text{surface latent}\\ \text{heat flux}\\ \downarrow}}{\Delta\vec{\mathrm{Q}}^{LH}} + \underset{\substack{\uparrow\\ \text{surface sensible}\\ \text{heat flux}}}{\Delta\vec{\mathrm{Q}}^{SH}} + \overset{\substack{\text{surface}\\ \text{energy transport/storage}\\ \downarrow}}{\Delta\vec{\mathrm{Q}}^{sfc\_dyn}} + \underset{\substack{\uparrow\\ \text{atmospheric}\\ \text{energy transport/storage}}}{\Delta\vec{\mathrm{Q}}^{atmos\_dyn}}\right\}$$

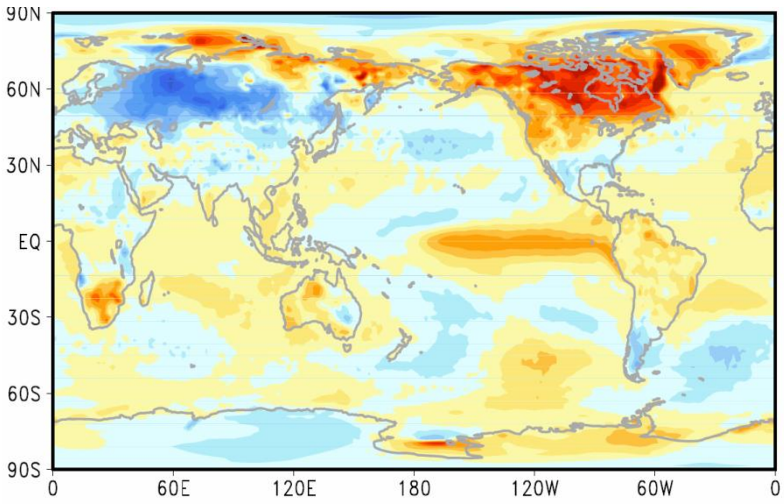
Data and calculation procedure

- ECMWF ERA Interim on a 1.5° X 1.5° grid, with 37 pressure levels, 1989 to present

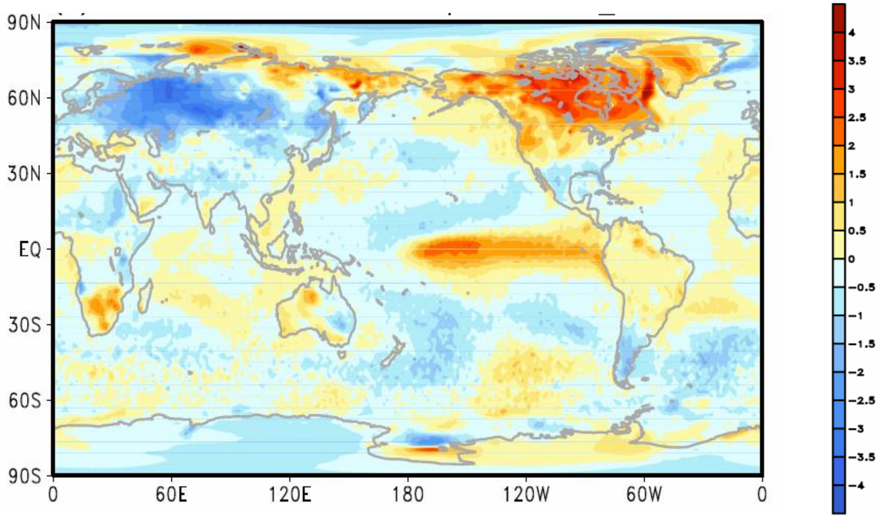
- Composite fields (downward solar radiation at the TOA, temperature, specific humidity, cloud liquid/ice water, etc) created for an El Niño winter (DJF) and an ENSO-Neutral winter (DJF)

- Planck feedback matrix $\dfrac{\partial \vec{\mathbf{R}}}{\partial \vec{\mathbf{T}}}$ and radiative energy perturbations calculated offline with Fu-Liou’s radiative transfer model

- Partial temperature changes associated with various feedbacks obtained

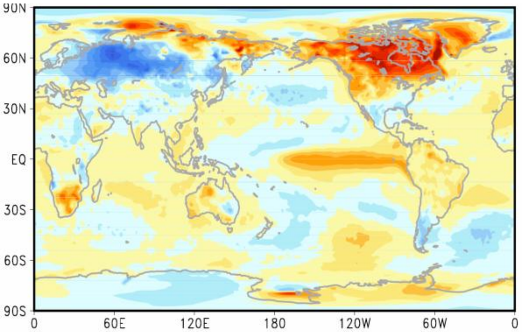


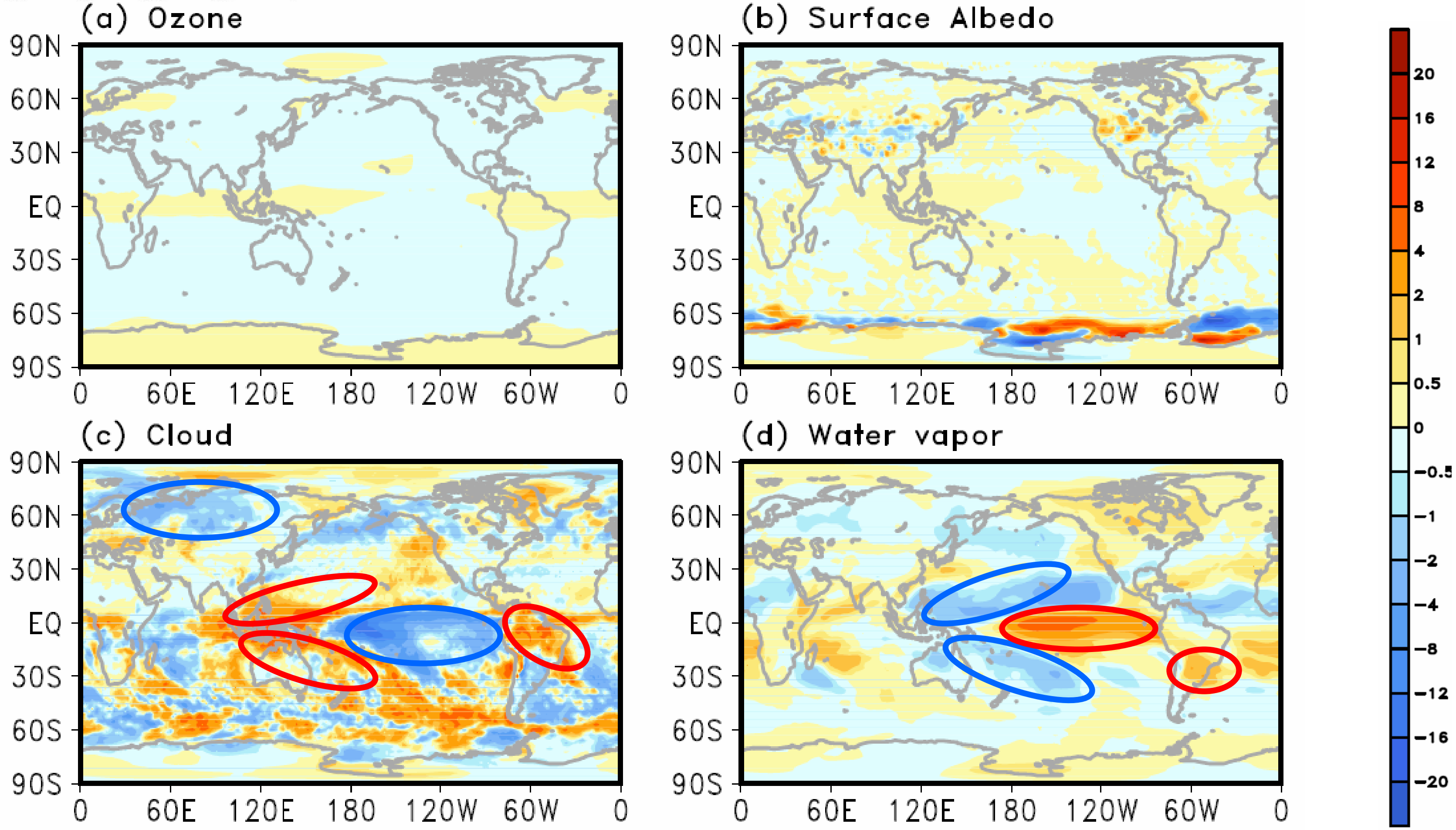
Composite El Niño Surface Temperature Anomaly



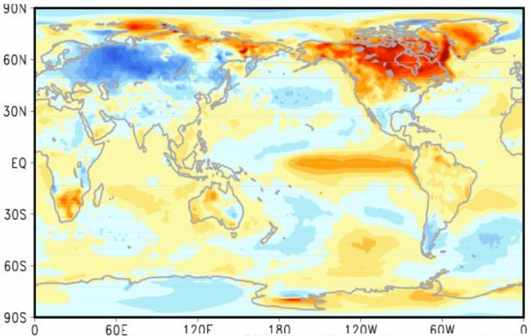
Sum of partial temperature changes derived with CFRAM

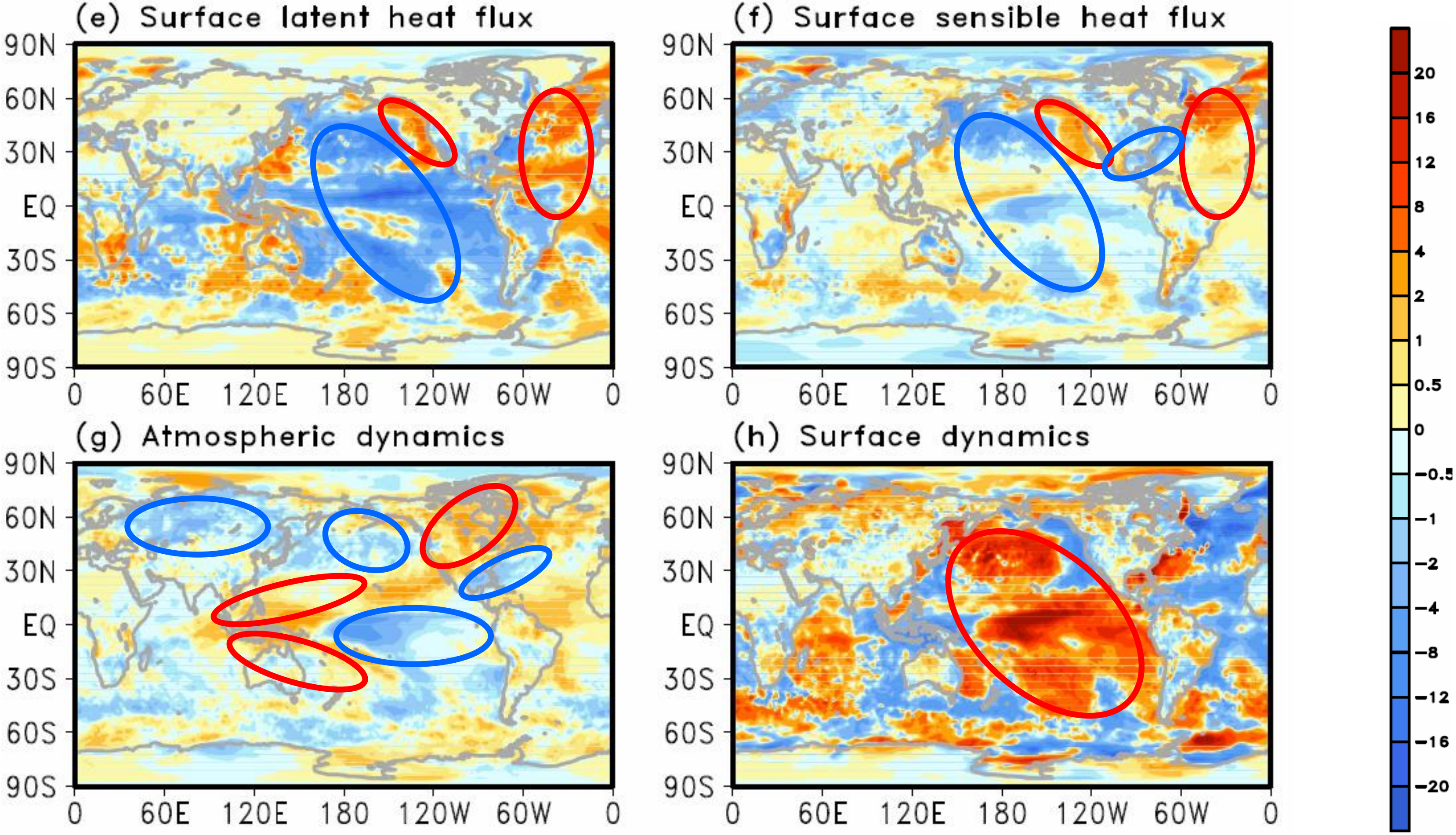
Feedback decomposition - Overview



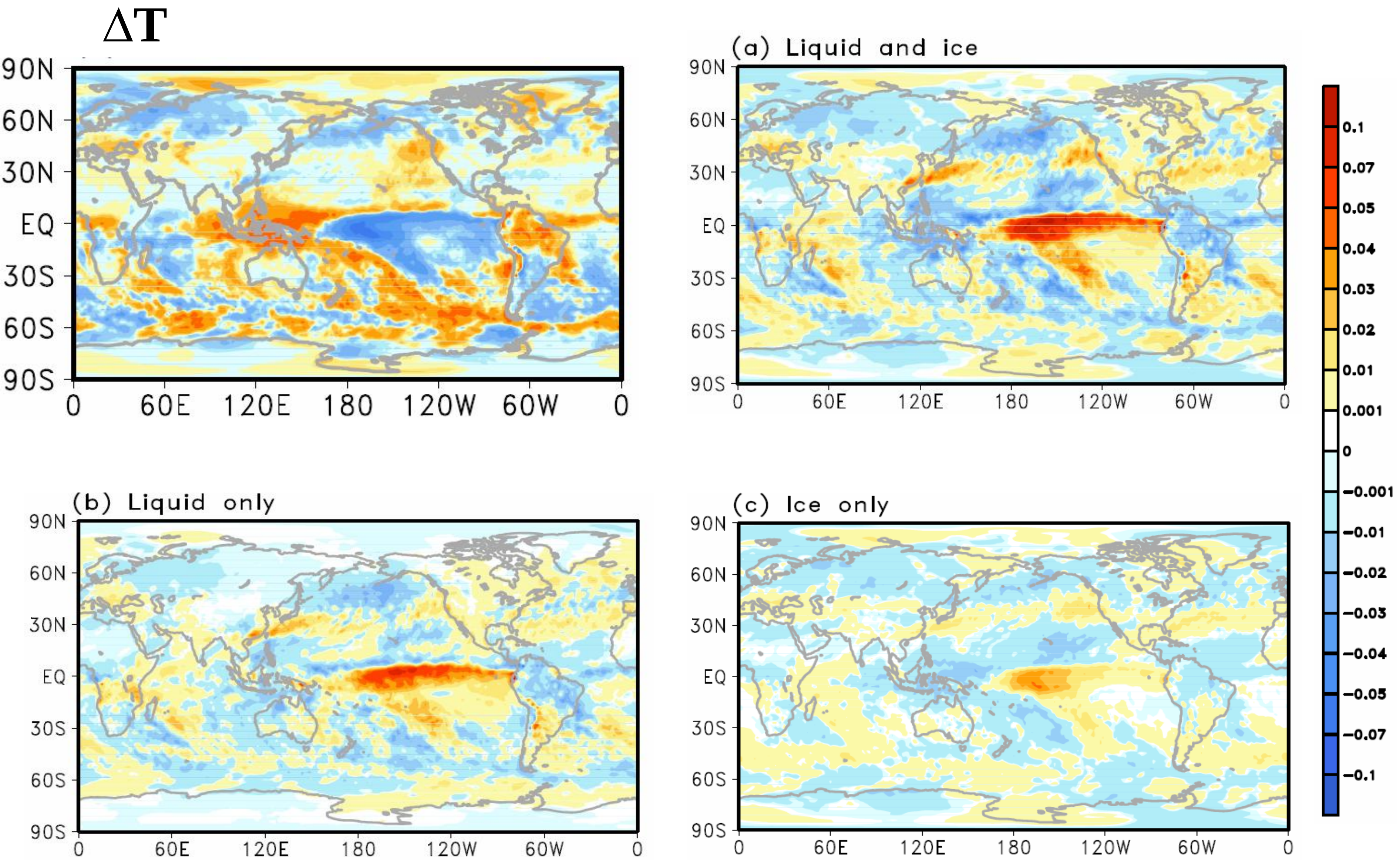


Feedback decomposition - Overview

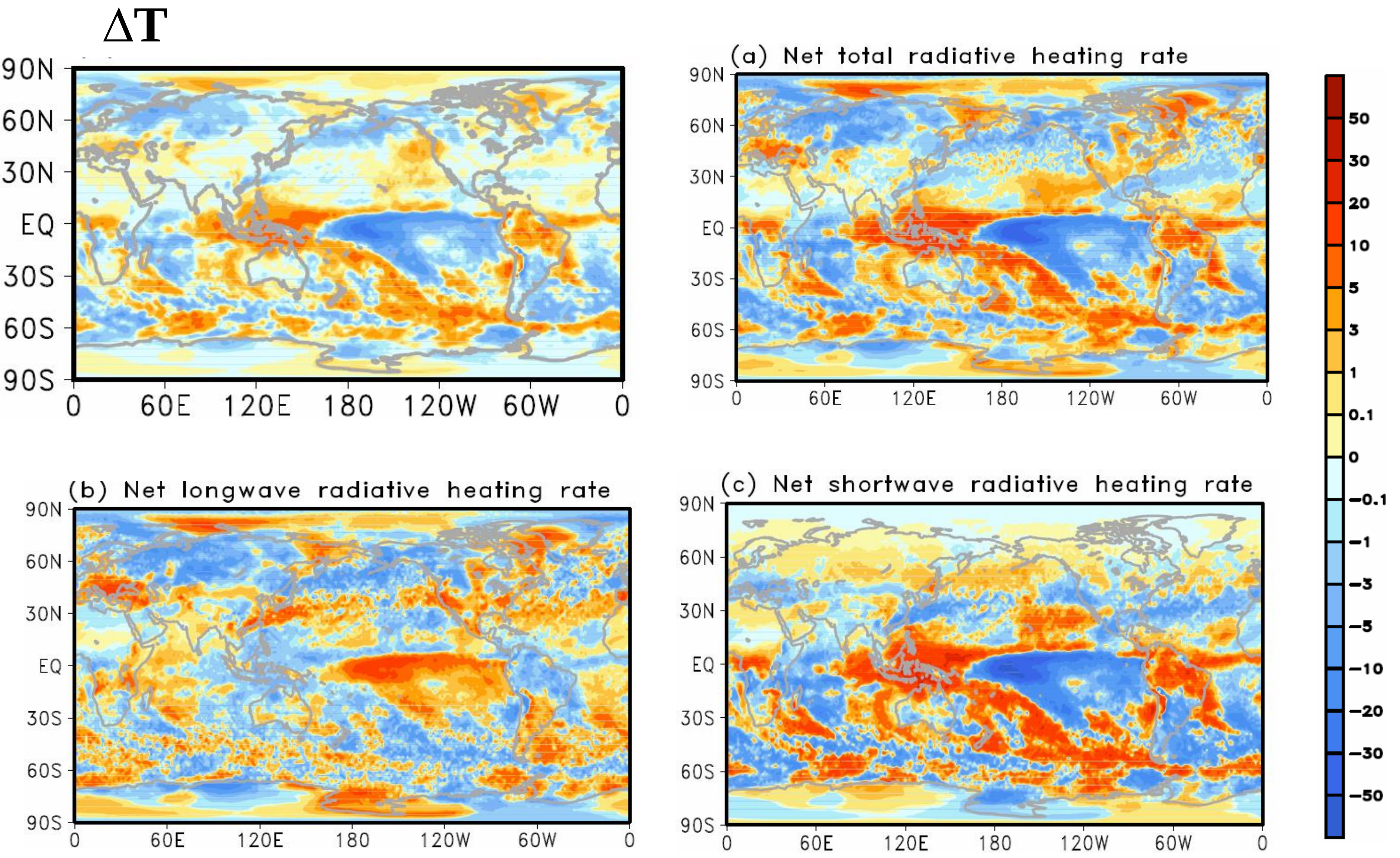




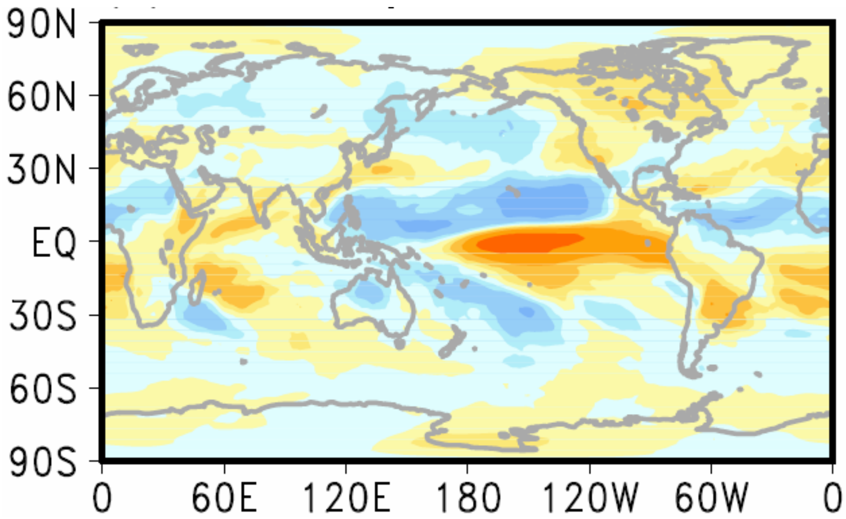
Feedback decomposition - Cloud



Feedback decomposition - Cloud

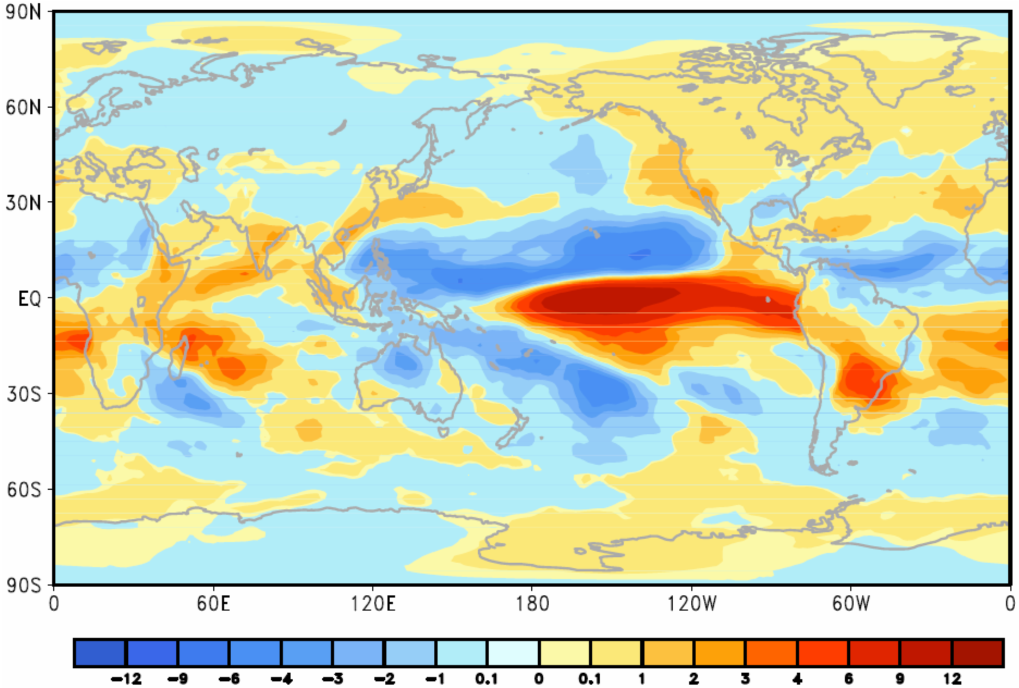


Feedback decomposition – Water vapor

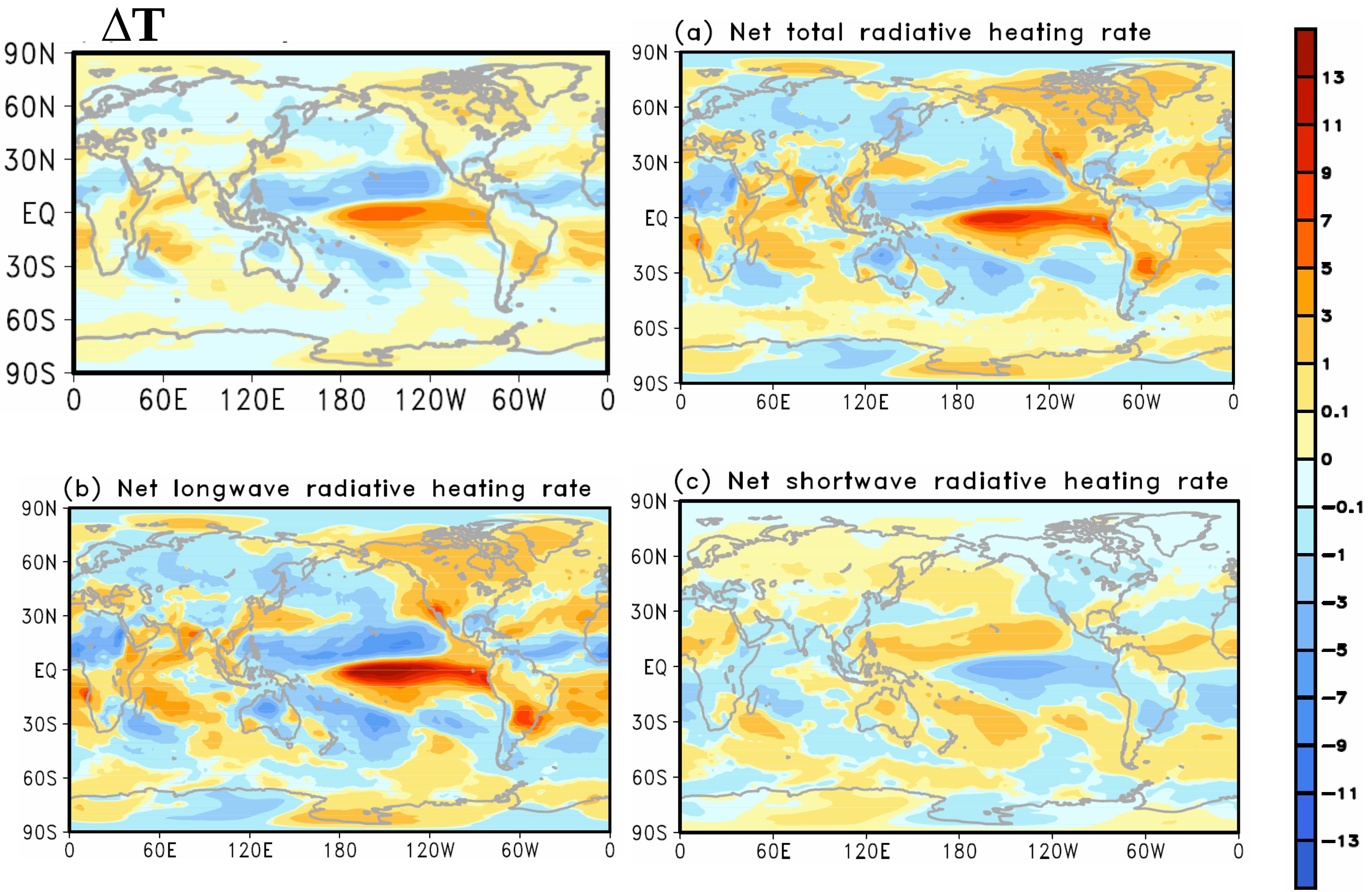


ΔT

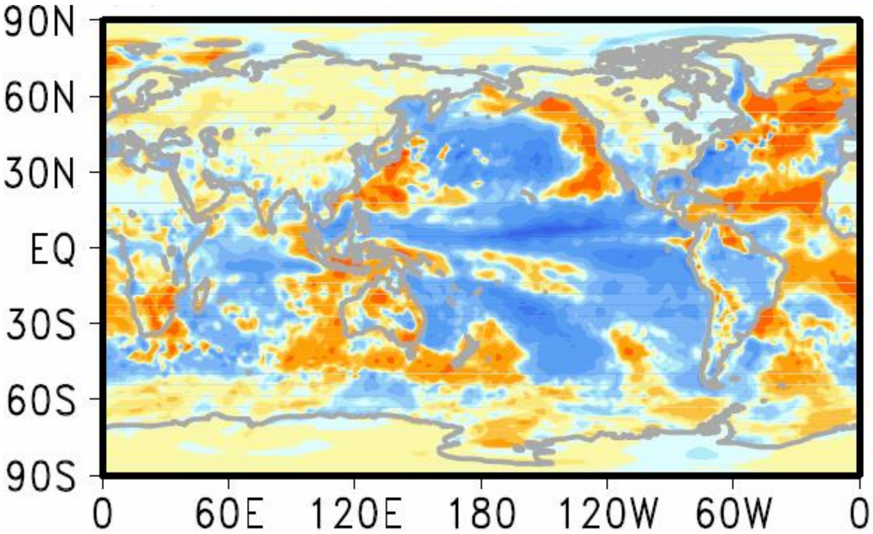
Δq



Feedback decomposition – Water vapor

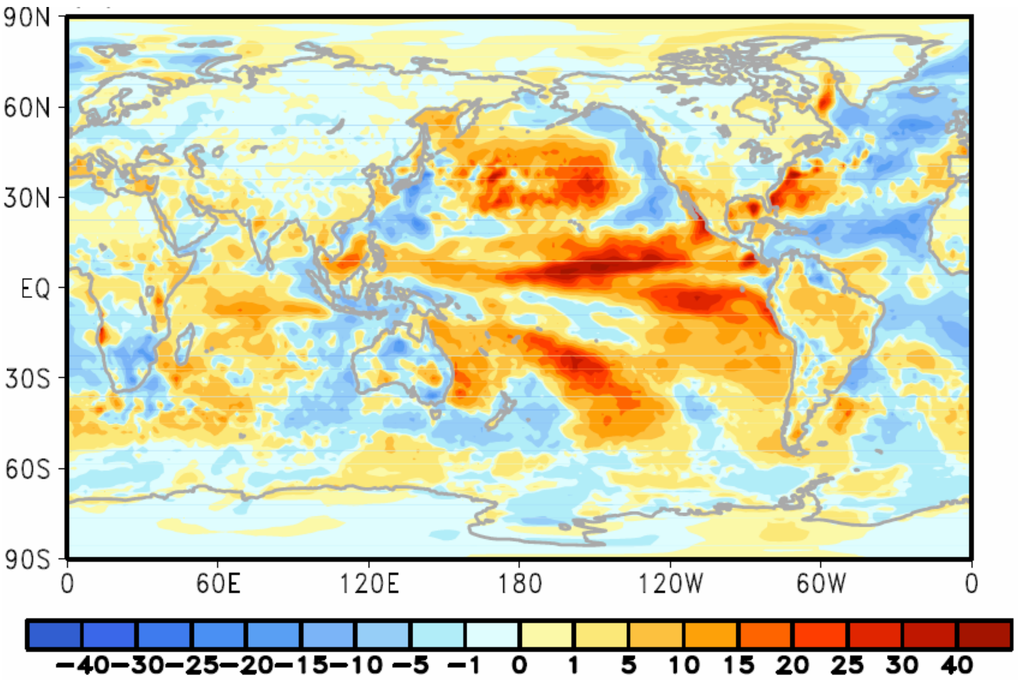


Feedback decomposition – Surface latent heat flux

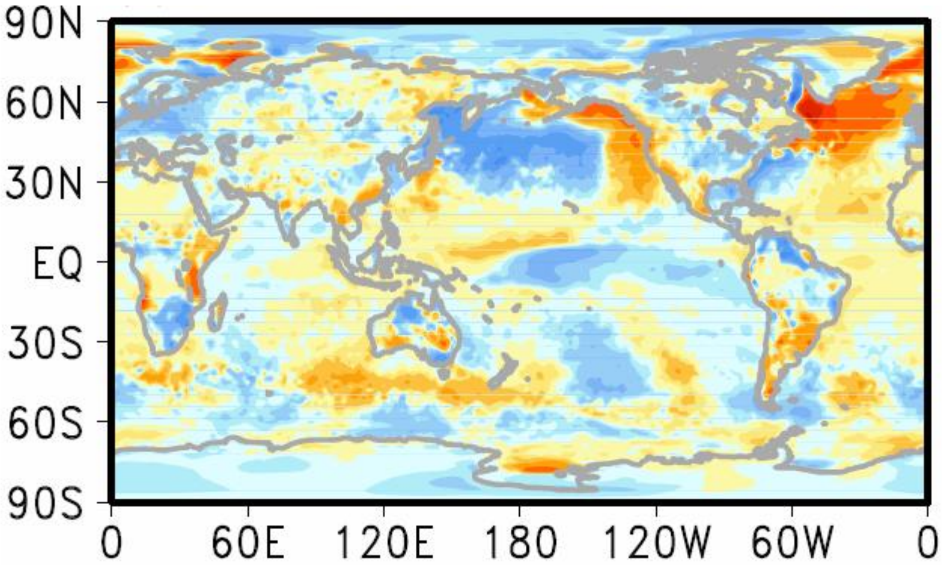


$\Delta \mathbf{T}$

$\Delta \mathbf{Q}^{LH}$

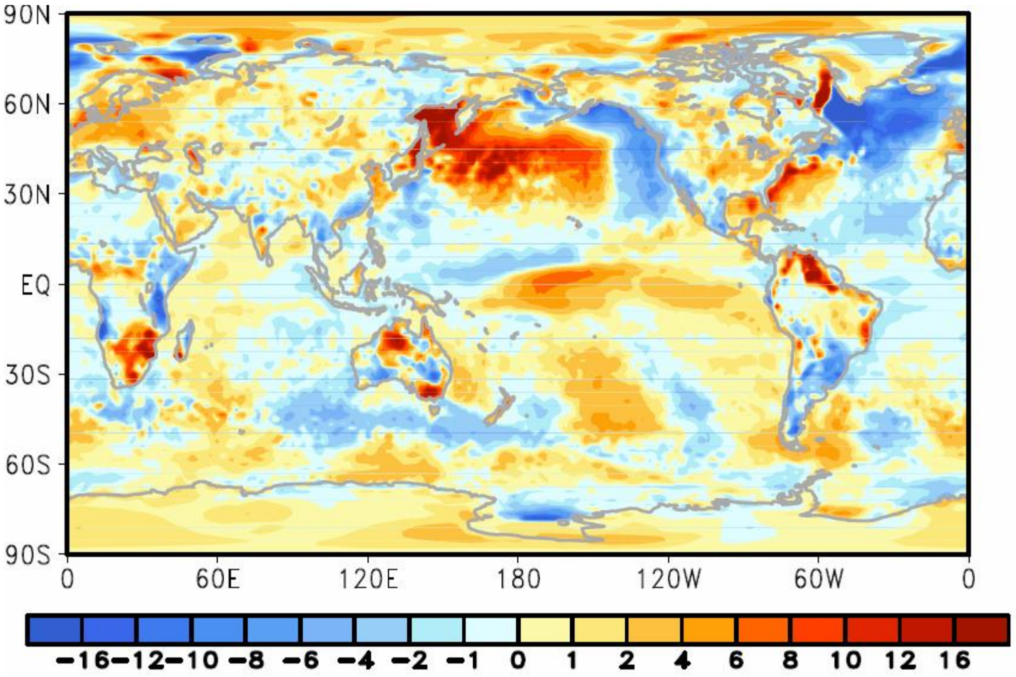


Feedback decomposition – Surface sensible heat flux



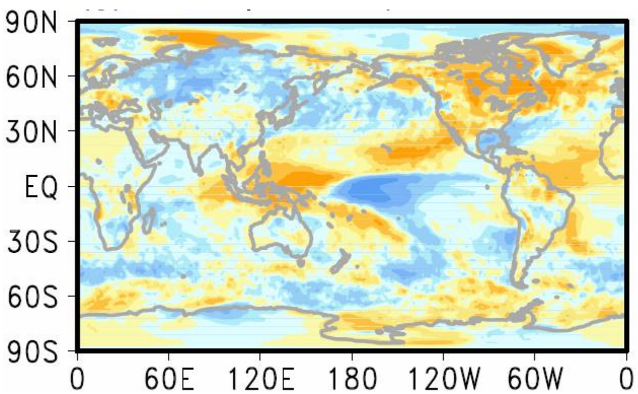
$\Delta \mathbf{T}$

$\Delta \mathbf{Q}^{SH}$

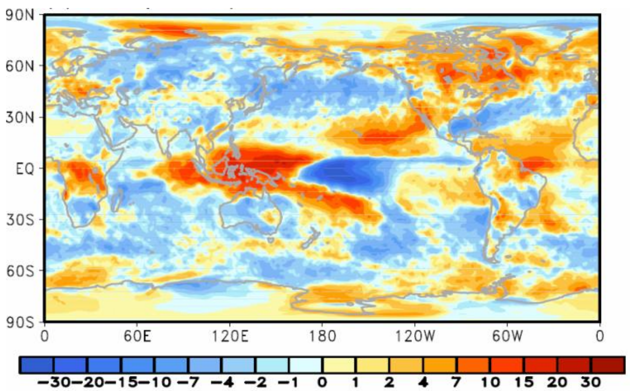


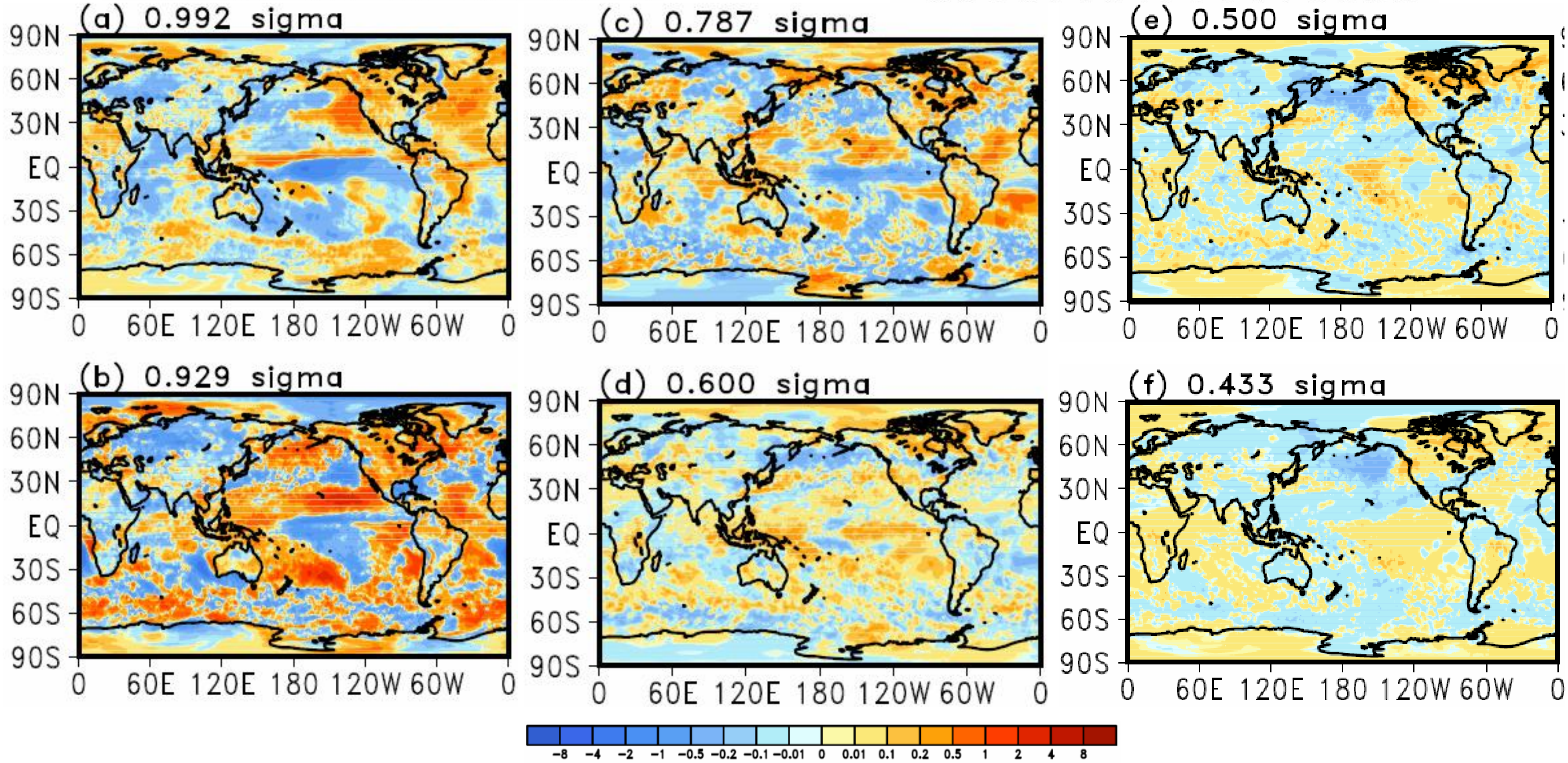
Feedback decomposition – Atmospheric energy transport/storage

ΔT

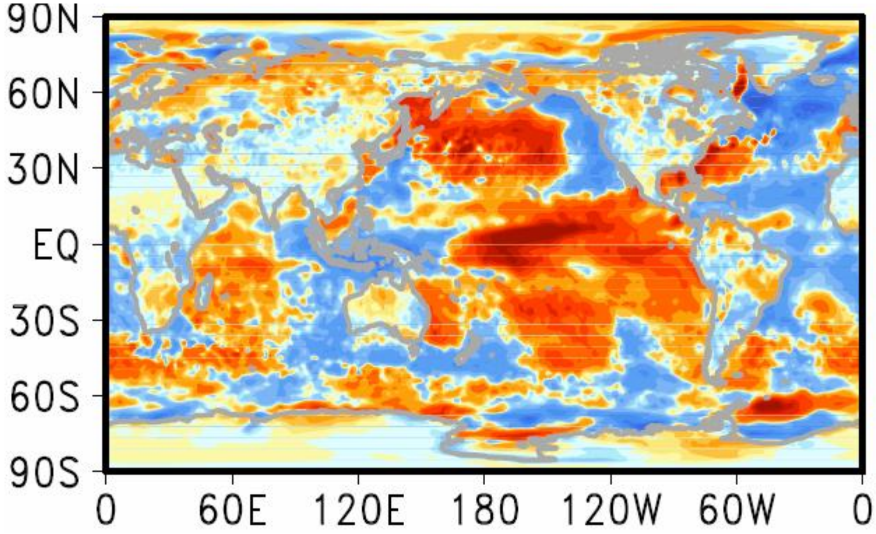


ΔQ^{atmos_dyn}



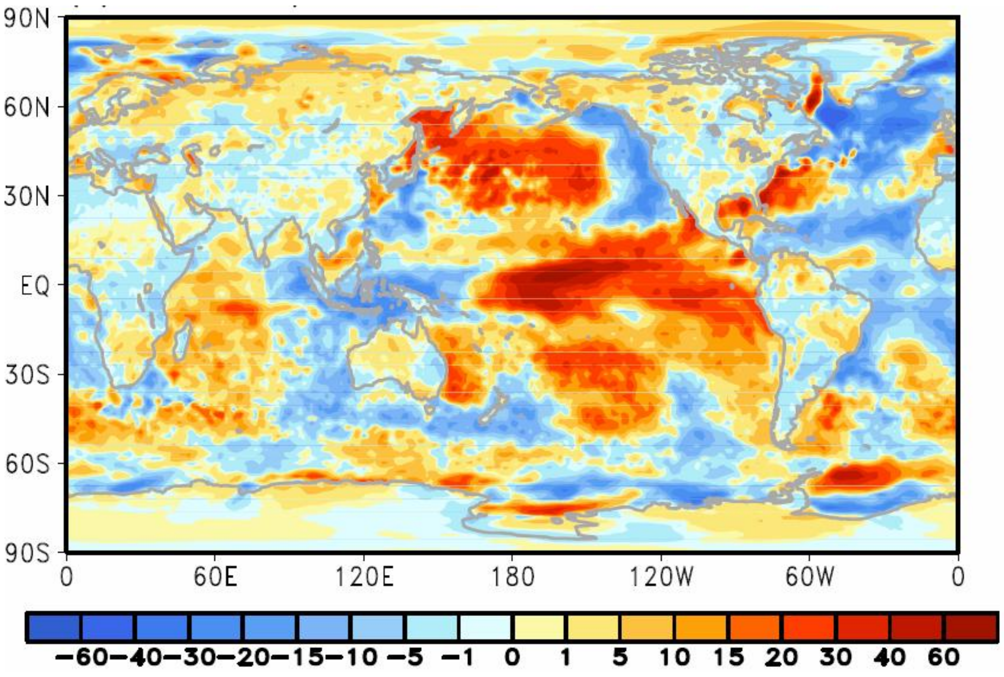


Feedback decomposition – Surface (oceanic) energy transport/storage



$\Delta \mathbf{T}$

$\Delta \mathbf{Q}^{sfc\_dyn}$



Conclusion

- Except for ozone and surface albedo, radiative feedbacks related to clouds and water vapor are mainly confined to the tropical and subtropical regions, and non-radiative feedbacks are globally important in setting up the surface temperature response.

- Positive (negative) SST anomaly over the eastern (western) equatorial Pacific are largely contributed by ocean dynamics in an El Niño winter, and water vapor feedback acts to reinforce this anomalous SST pattern while cloud feedback and atmospheric dynamics work to destroy it.

- Changes in surface latent heat flux (i.e., evaporation feedback) and surface sensible heat flux lead to negative (positive) partial temperature changes over a large portion of the Pacific (Atlantic) .

- Atmospheric dynamics is the primary driver of an extratropical surface temperature anomaly characteristic of PNA, and this temperature anomaly is partly reinforced by surface latent and sensible heat flux near the west coast of North America and by sensible heat flux over the southeast U.S.