Cloud feedback during ENSO

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Outline

- Energetics of ENSO
  – How important is radiation?
- Feedback
  – Kernel method
- GCM vs. OBS
  – OBS: CERES + ERA-interim
  – GCM: CMIP5 models

Importance of radiation

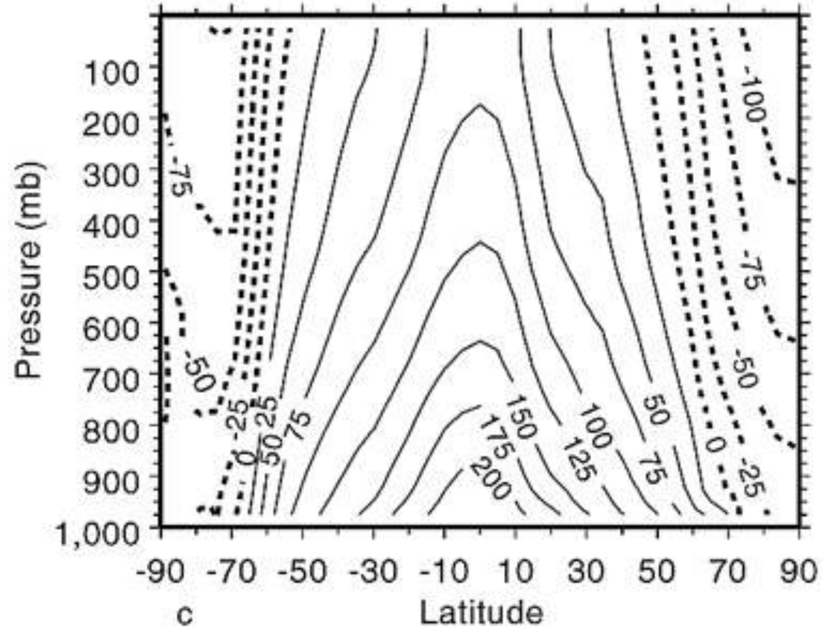
- Simple back-of-envelope calculation shows radiative heating is important for atmosphere but less for ocean.

  $1 W m^{-2}$ radiation anomaly translates to 3K/yr heating rate for whole atmosphere or 0.03K/yr for 250-meter ocean.

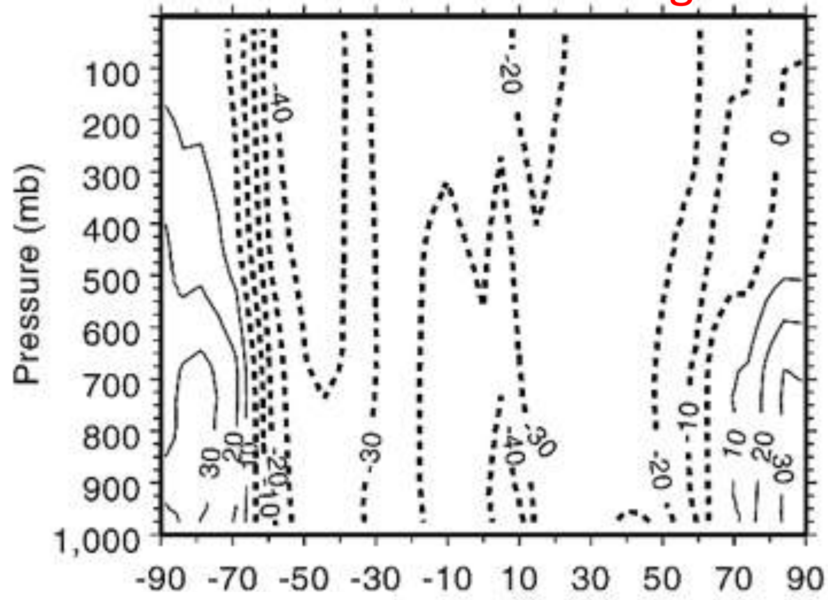
- Need for diagnosing how atmospheric radiation (TOA minus SFC) varies and influenced by different factors.

  e.g., Zhang et al. 2004.

ISCCP atmos radiation flux

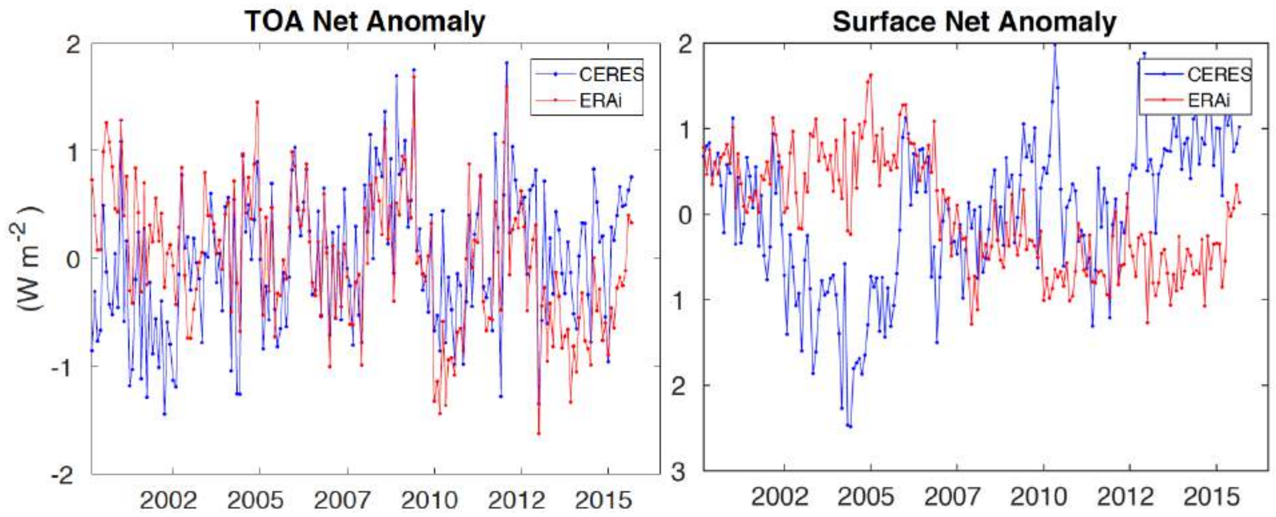


Cloud radiative forcing



Zhang, Rossow, Lacis, et al. 2004

Data and Method



- Radiation data
  - CERES (TOA)
  - ERAi (SFC)
- Atmospheric data
  - ERAi Temperature (T) and humidity (q)
- Radiation budget decomposition
  - Kernel method [Shell et al. 2008; Soden et al. 2008]

  $\Delta R_{cloud} = \Delta R_{total} - \sum K_X \Delta X$

  ΔR_{total}: CERES or ERAi radiation flux; K_X: radiative sensitivity kernel
  - A new set of ERAi atmosphere-based kernels
- "Feedback"
  - $\lambda_X = regr(\Delta R_X, SST)$: monthly radiation anomaly regressed to Nino3.4 SST

  X: T, q, C; units: W m^{-2} K^{-1}

Radiative kernels

- Computation of K_X

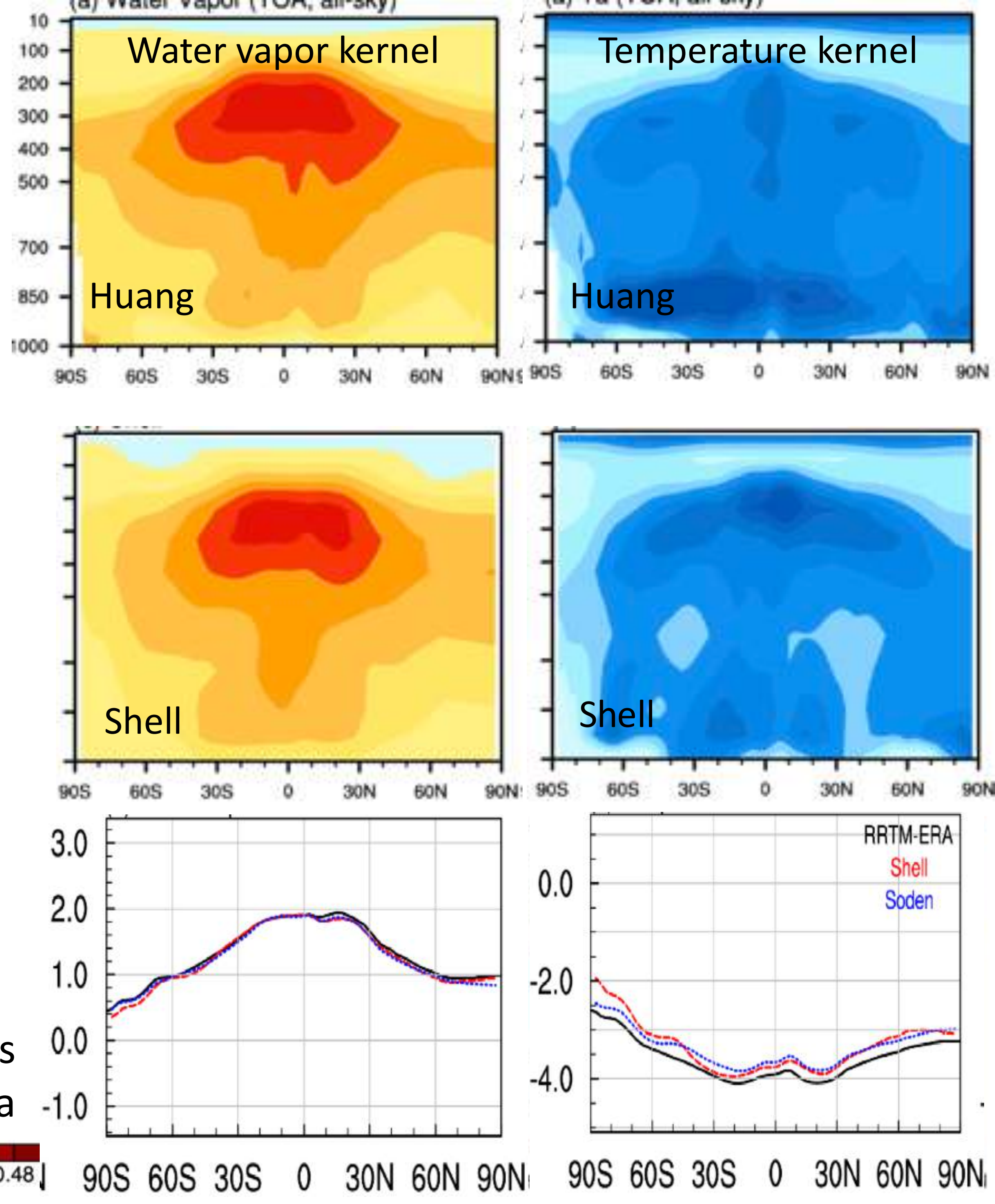
$K_X = [R(X+\Delta X) - R(X)]/\Delta X$

$R(X)$: RRTM

X: ERAi

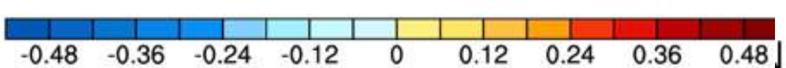
Global 2.5°x2.5°, 5 years' 6-hourly atmos profiles used to compute K_X, and then averaged at each grid point for every calendar month. [Huang et al. 2017]

- Agreement with other kernel sets



TOA radiative kernels

Units: W m^{-2} K^{-1} / 100 hPa



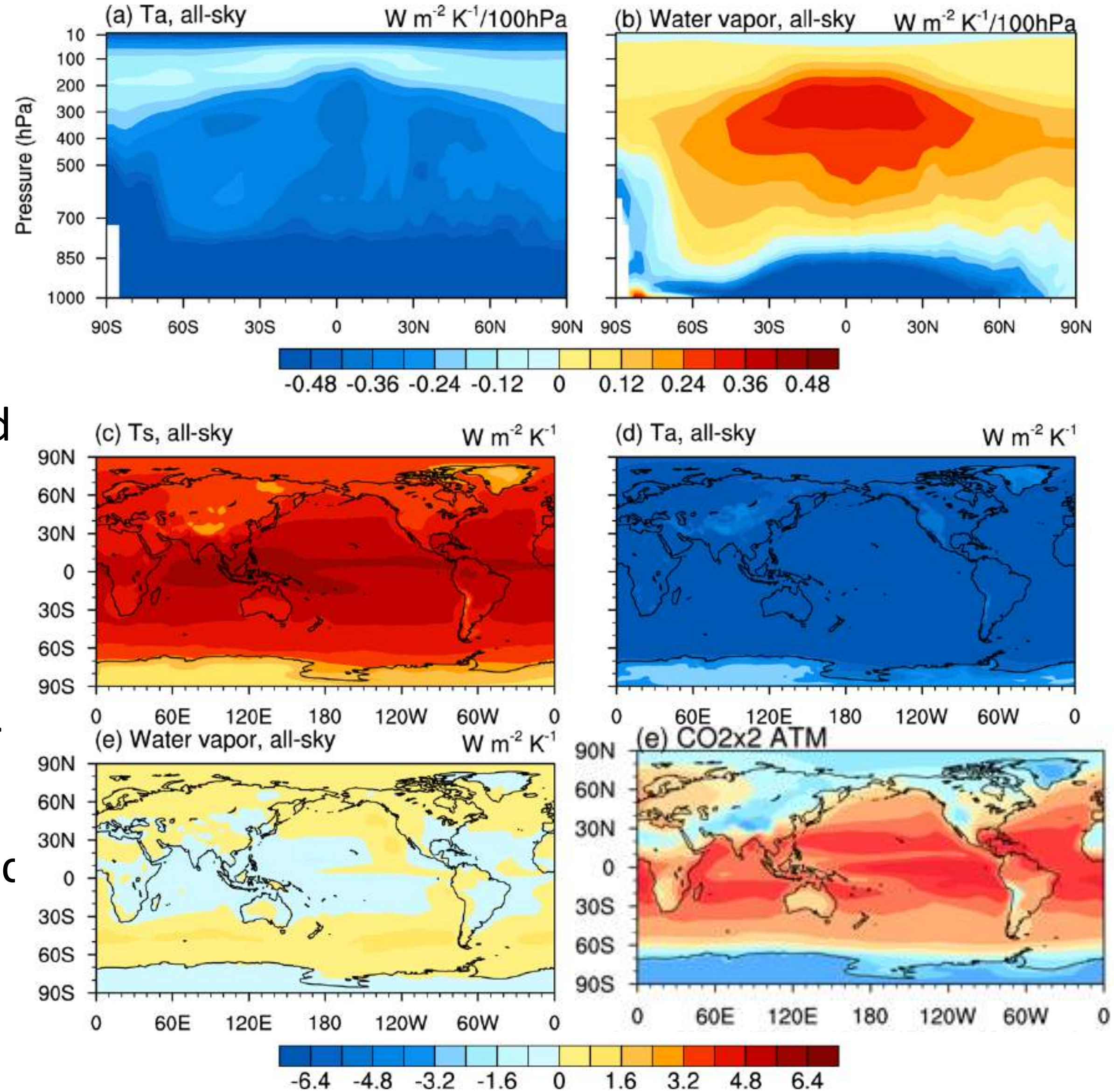
Atmospheric radiation kernel

- $R_{atm}=R_{toa}-R_{sfc}$: positive downward (warming)

a, b) **<u>Zonal and annual mean</u>** atmospheric temperature and water vapor kernel.

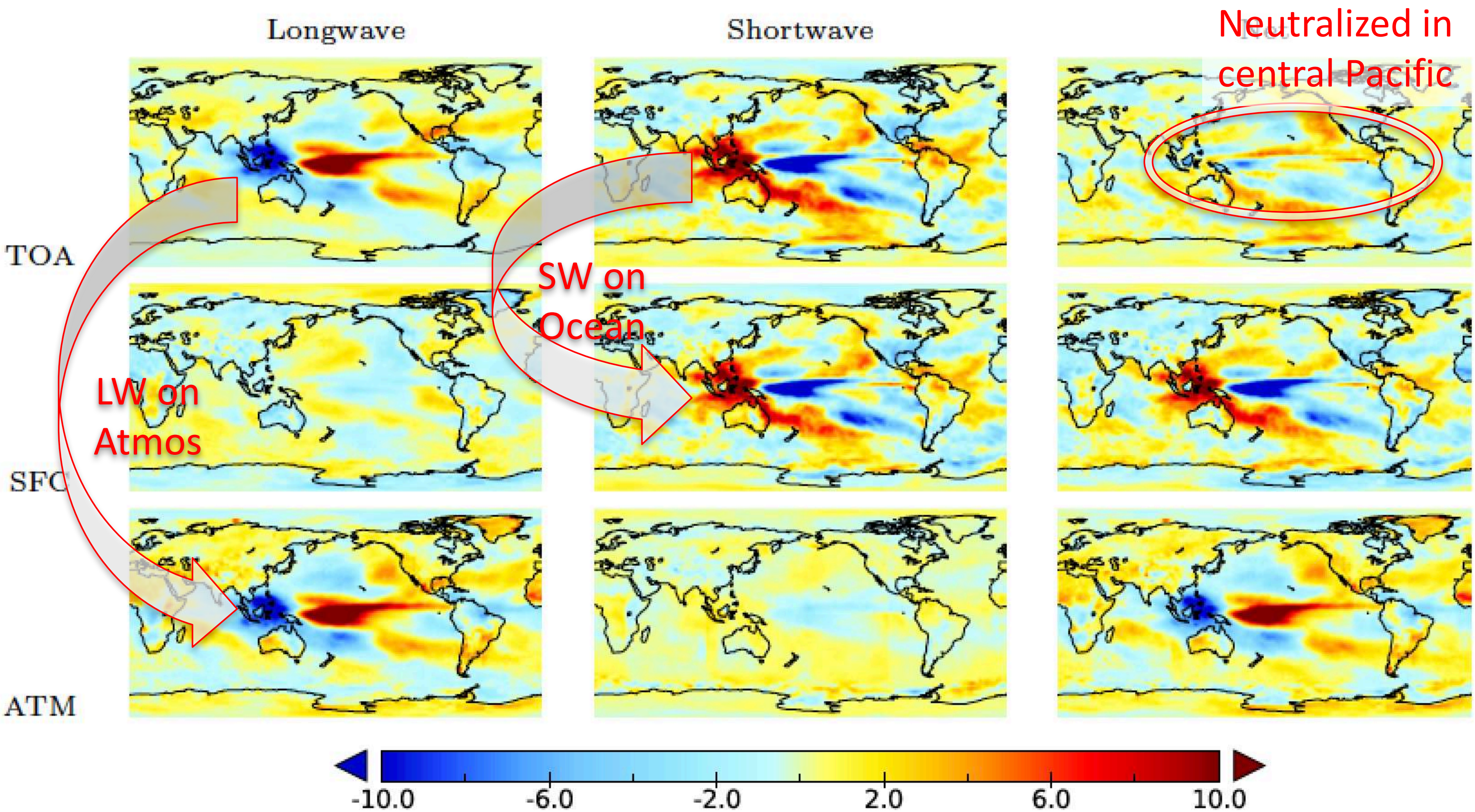
c, d, e) Annual mean surface temperature, **<u>vertically integrated</u>** atmospheric temperature and water vapor kernels.

f) The **<u>sum</u>** of c-e: atmospheric radiation change when the surface and atmosphere uniformly warm by 1K while conserving relative humidity.



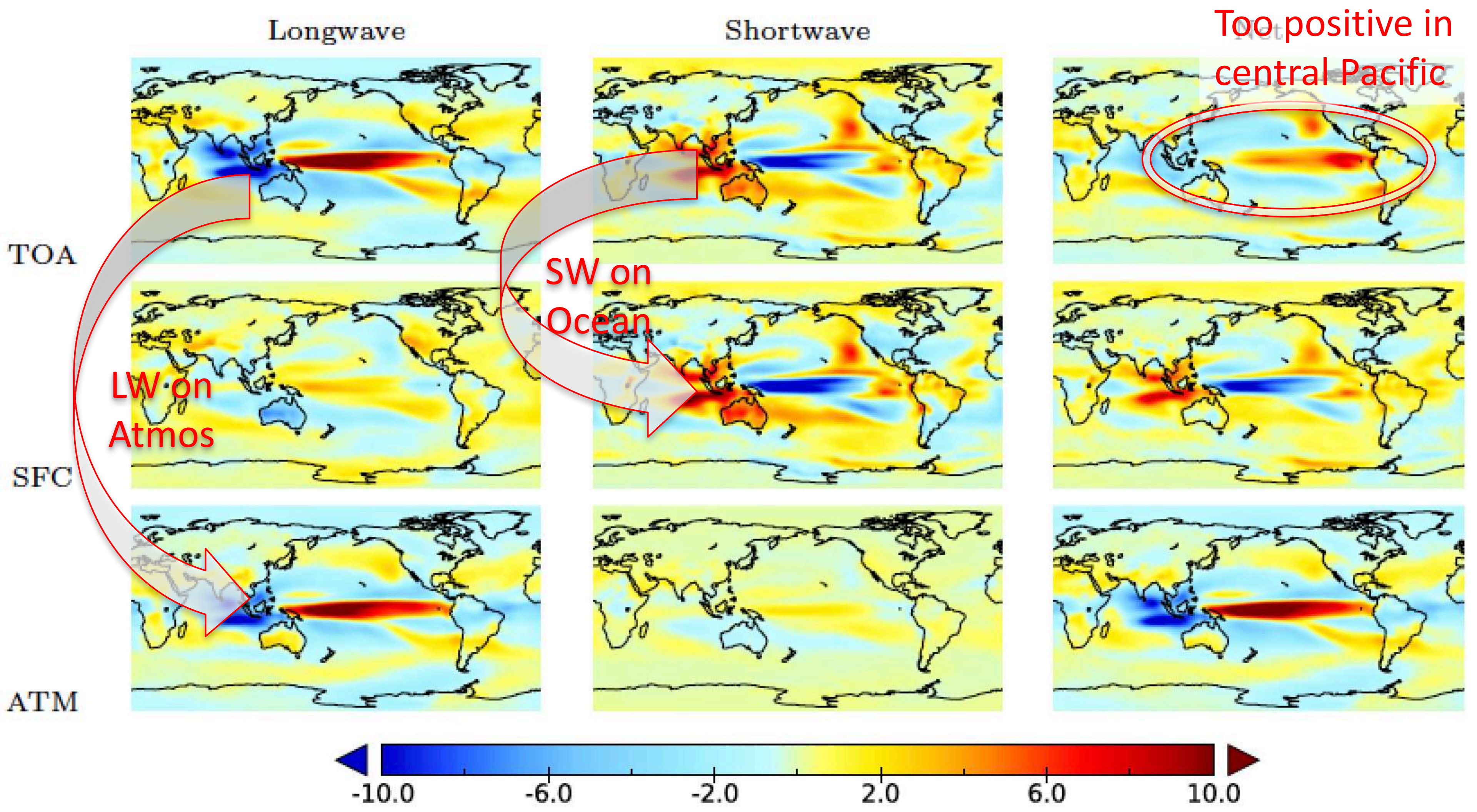
Contrasting patterns of H_2O and CO_2 forcing!

Cloud feedback: OBS



$\lambda_X = regr(\Delta R_X, SST)$: Radiation anomaly regressed to Nino3.4 SST units: W m^{-2} K^{-1}

Cloud feedback: GCM



NCAR CESM is shown here; similar bias in all CMIP5 models.

units: W m^{-2} K^{-1}

Cloud feedback: CMIP3 vs. OBS

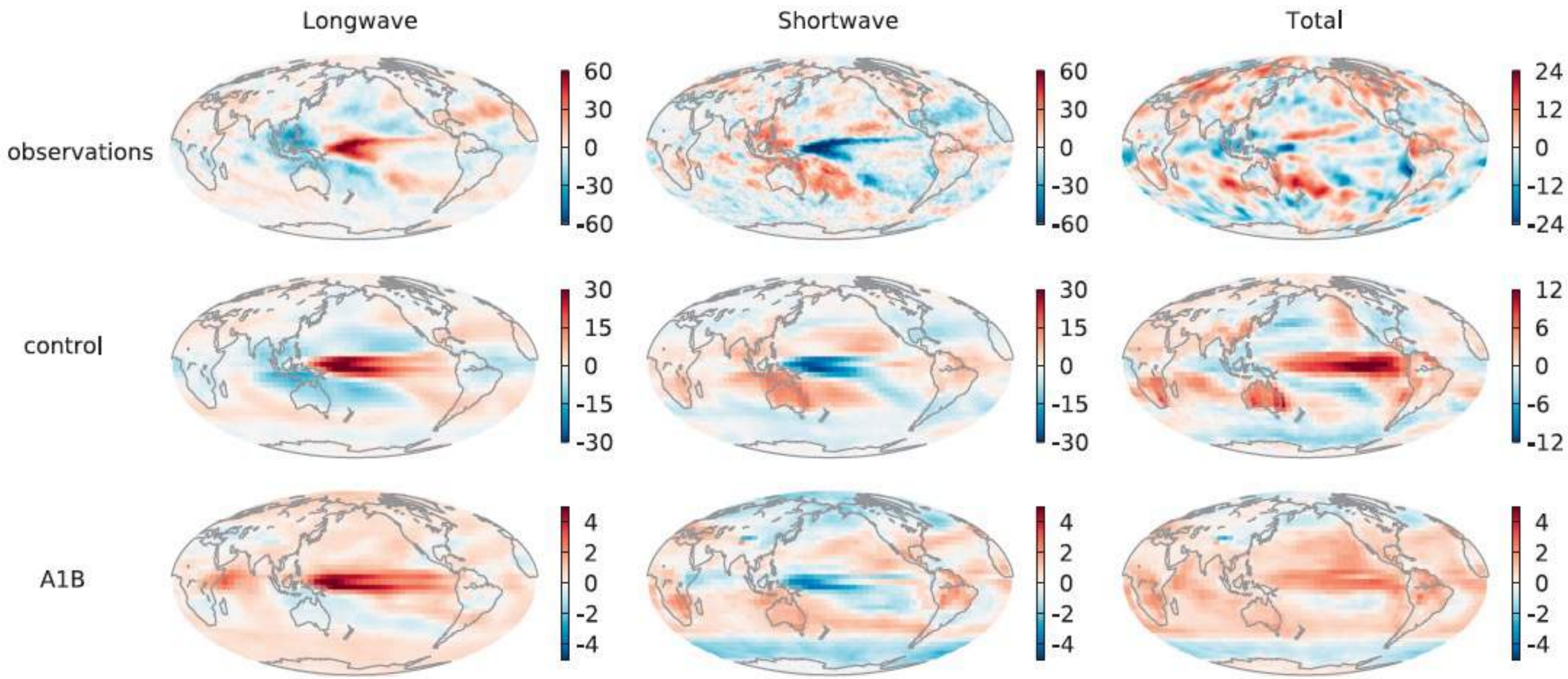
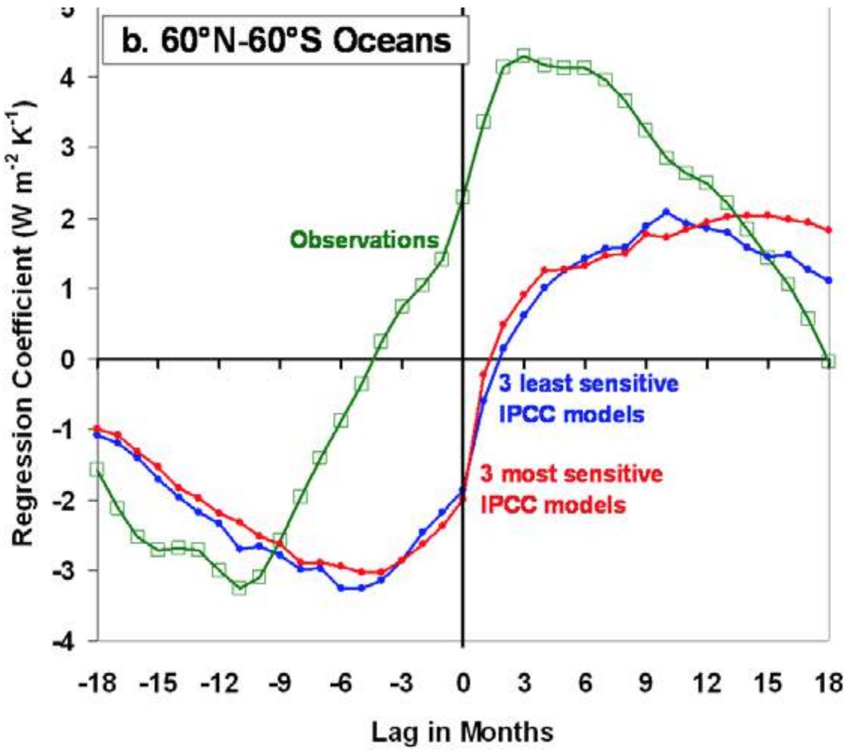


FIG. 5. (left) Longwave cloud feedback, (middle) shortwave cloud feedback, and (right) net cloud feedbacks, for (top) ERA-Interim reanalysis combined with CERES measurements of all-sky flux, (middle) the control ensemble, and (bottom) the A1B ensemble. In all panels, the units are W m^{-2} K^{-1}. Note that the color scale varies among the panels.

Similar model bias (too positive TOA cloud feedback) was reported earlier [Dessler 2013]

Is GCM cloud feedback too positive?

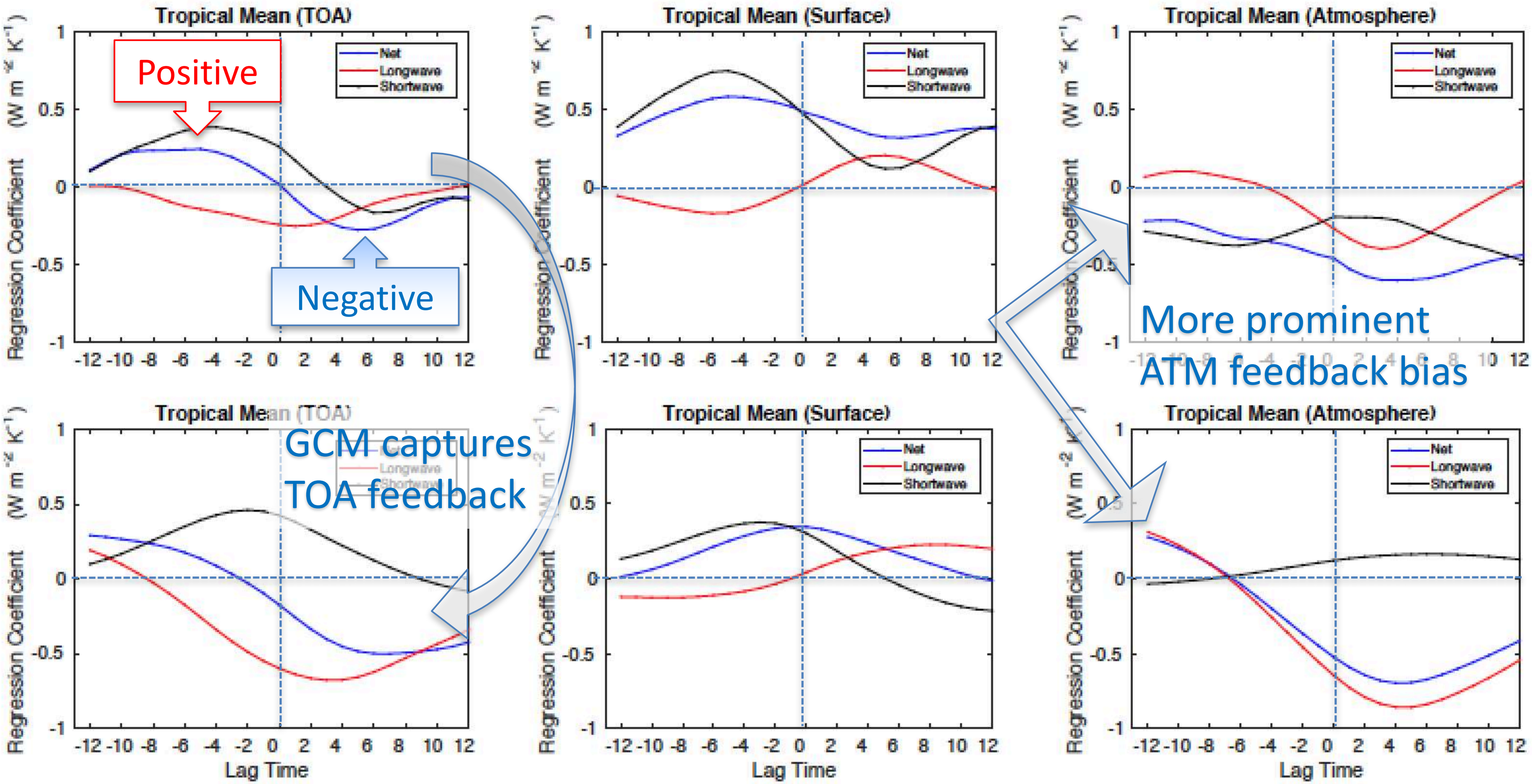
- Biased dR/dT_S in GCMs?
  - Comparison between CERES and some GCMs (CMIP3) showed seemingly too positive radiative feedback in GCMs [Spencer&Braswell 2011].
  - Debate between Lindzen&Choi 2009, 2011, Spencer&Braswell 2011; Murphy 2010, Trenberth 2010, Dessler 2011; Trenberth 2011, …



R-Ts lead/lag regression
R: CERES (upward positive);
Ts: HadCRUT3

Note the sign definition is opposite here.

Tropical mean cloud feedback during ENSO cycle



Upper: CERES; Lower: CESM

$\lambda_{X,t} = regr(\Delta R_X, SST; t)$: Lagged regression to Nino3.4 SST

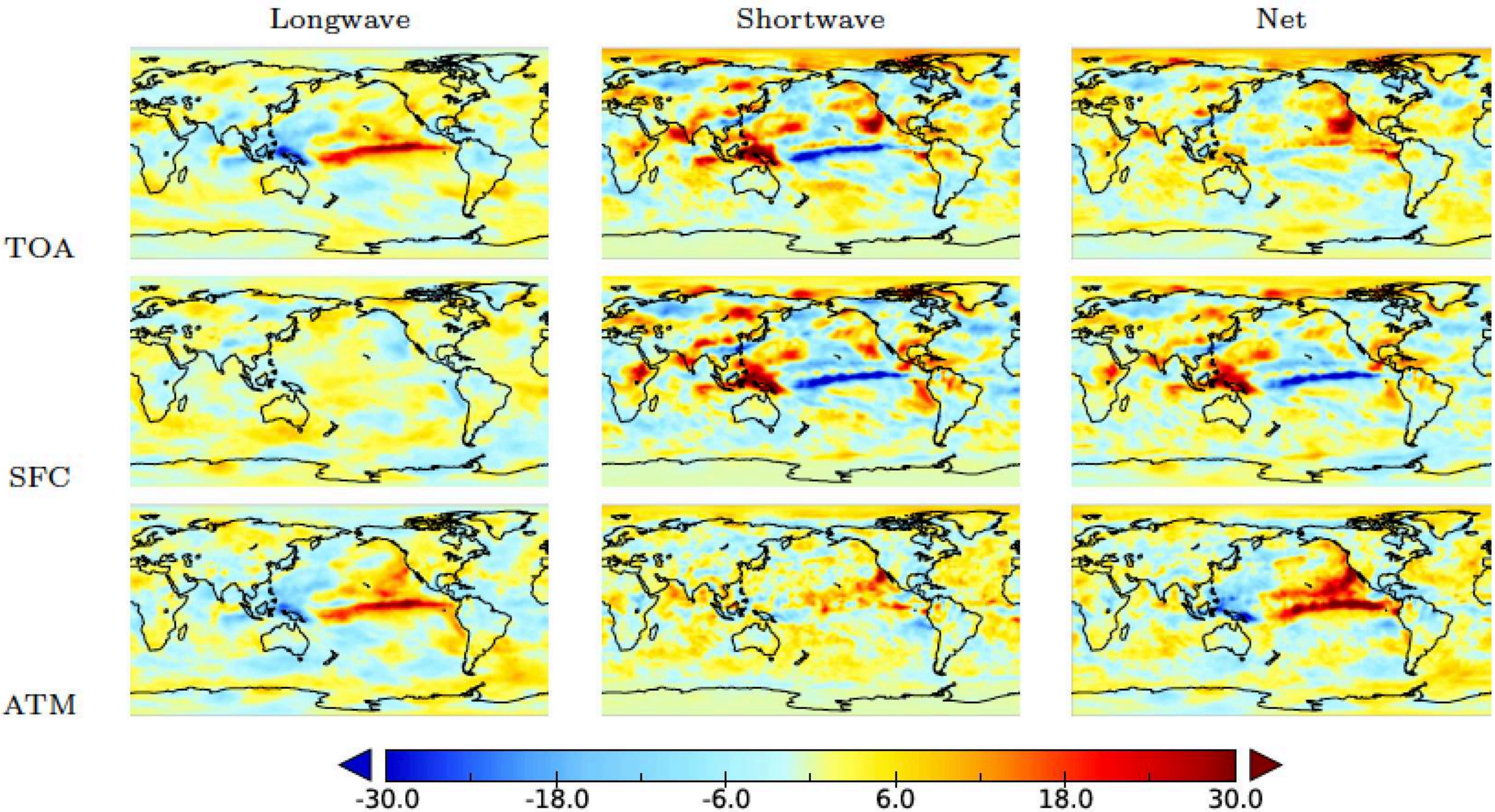
t: lag time; X: T, q, C; units: W m^{-2} K^{-1}

Conclusions

- Cloud TOA radiation feedback is a positive energetic feedback for the tropical atmos-ocean system during the developing phase of ENSO and a negative feedback during the dissipating phase. GCM can reproduce this basic dR/d(SST) relationship.
- GCM ATM feedback is noticeably more biased, especially when LW and SW components are separately examined.
- CMIP5 GCMs still show a noticeable too-positive cloud TOA feedback bias in the central and eastern Pacific regions. This is due to a too positive LW cloud ATM feedback in this region.

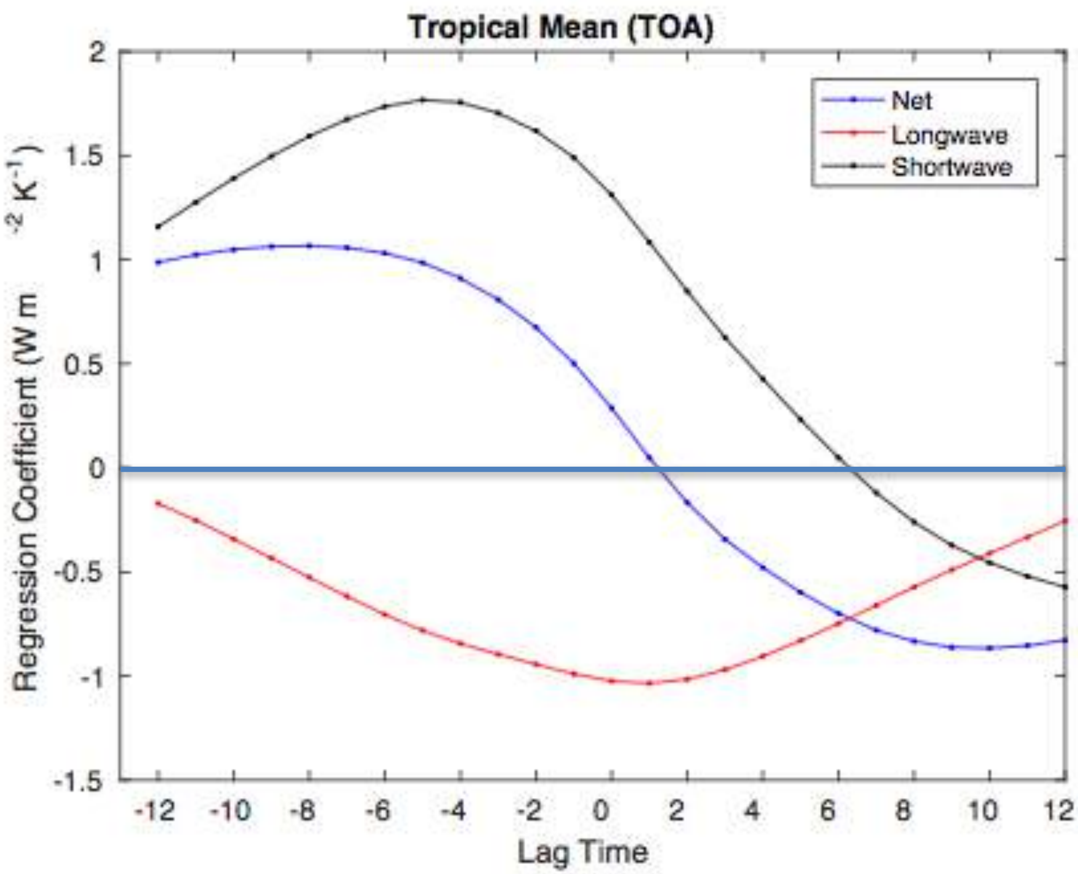
Additional slides

Regr(dR$_{total}$,SST)

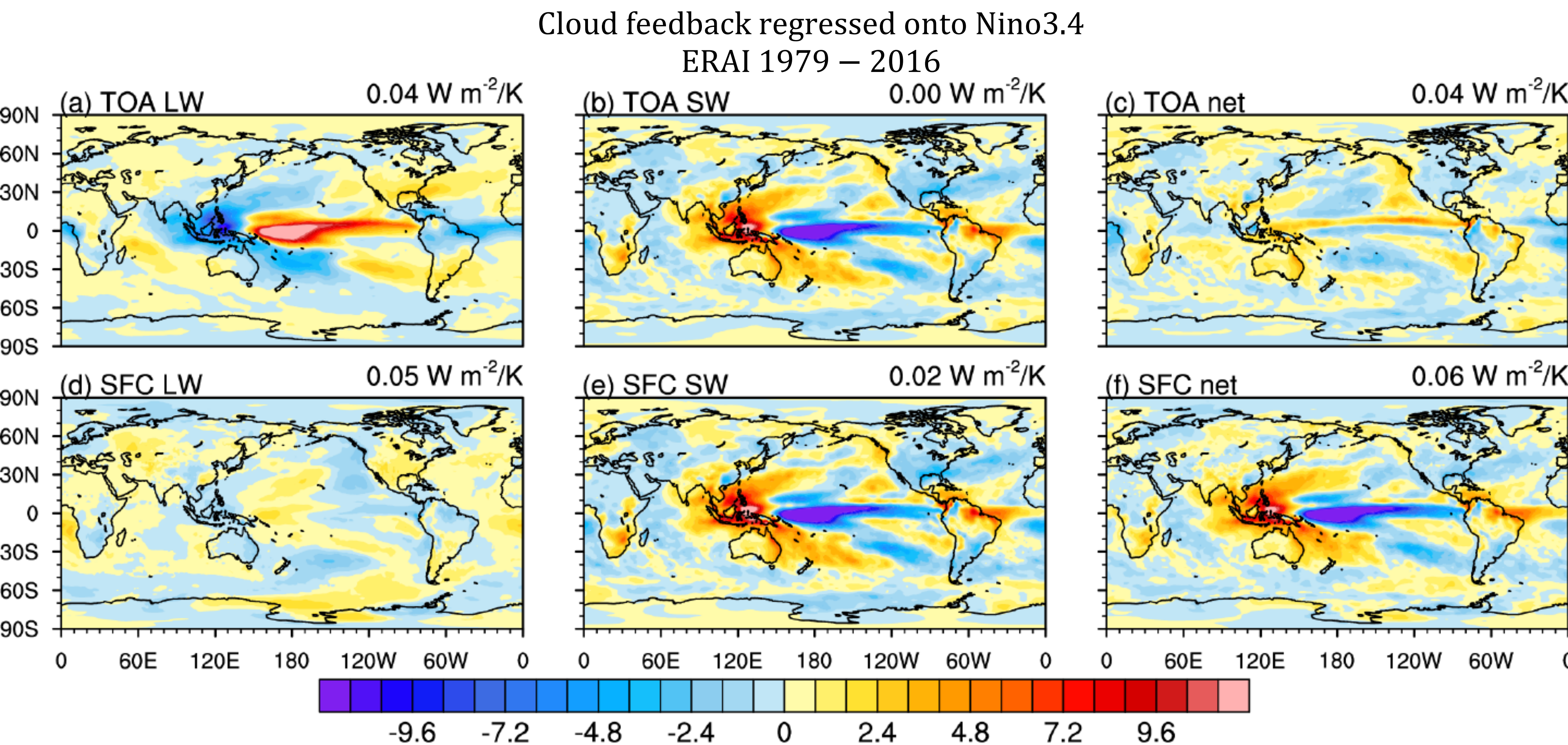


units: W m^{-2} K^{-1}

Feedback during ENSO



- The lead-lag regression analysis verifies that dR/dTs transits from positive to negative during the ENSO cycle;
- This transition is mainly caused by the cloud feedback.

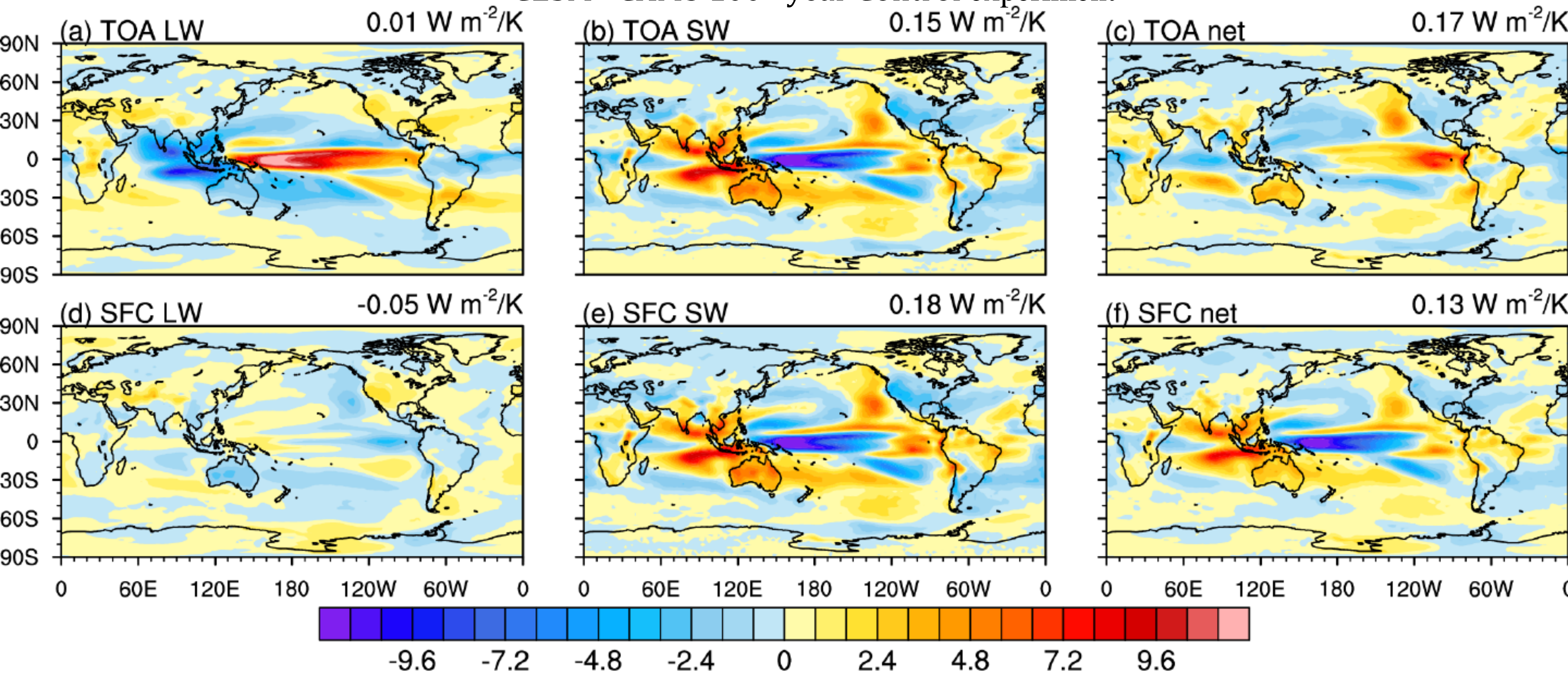


Changes to make:

First row: Show TOA only here, highlight non-positive feedback from obs;

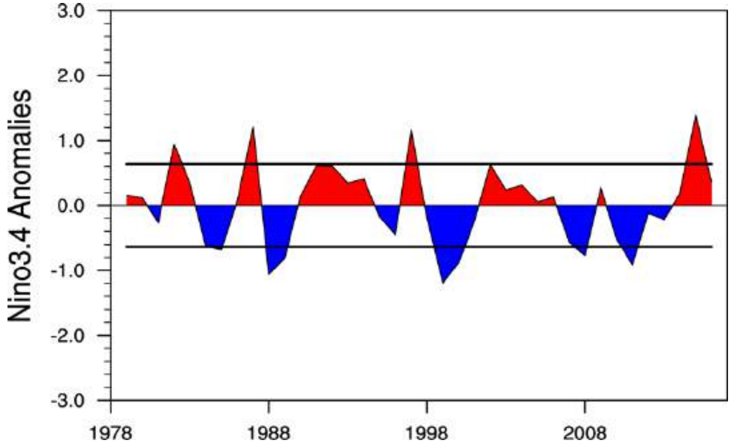
Second row: multi-GCM mean

Cloud feedback regressed onto Nino3.4
CESM–CAM5 100–year Control experiment

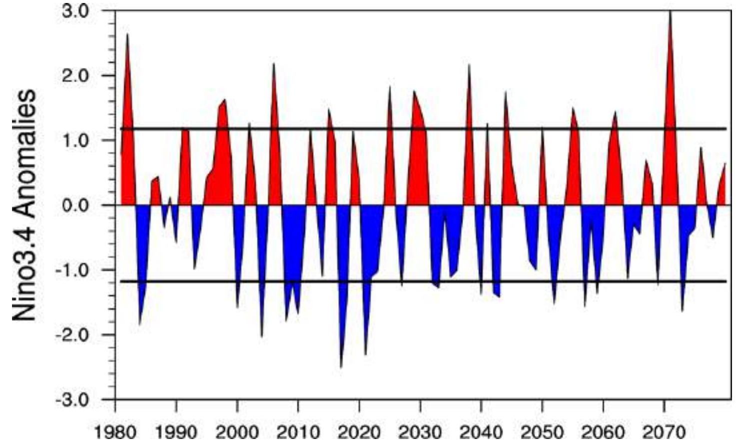


Show Net for each GCM – highlight the too-positive feedback. multi-GCM mean LW/SW/Net

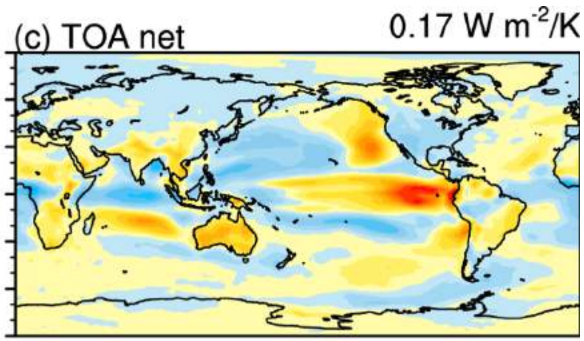
$Nino3.4\ for\ ERA\ from\ 1979\ to\ 2016$

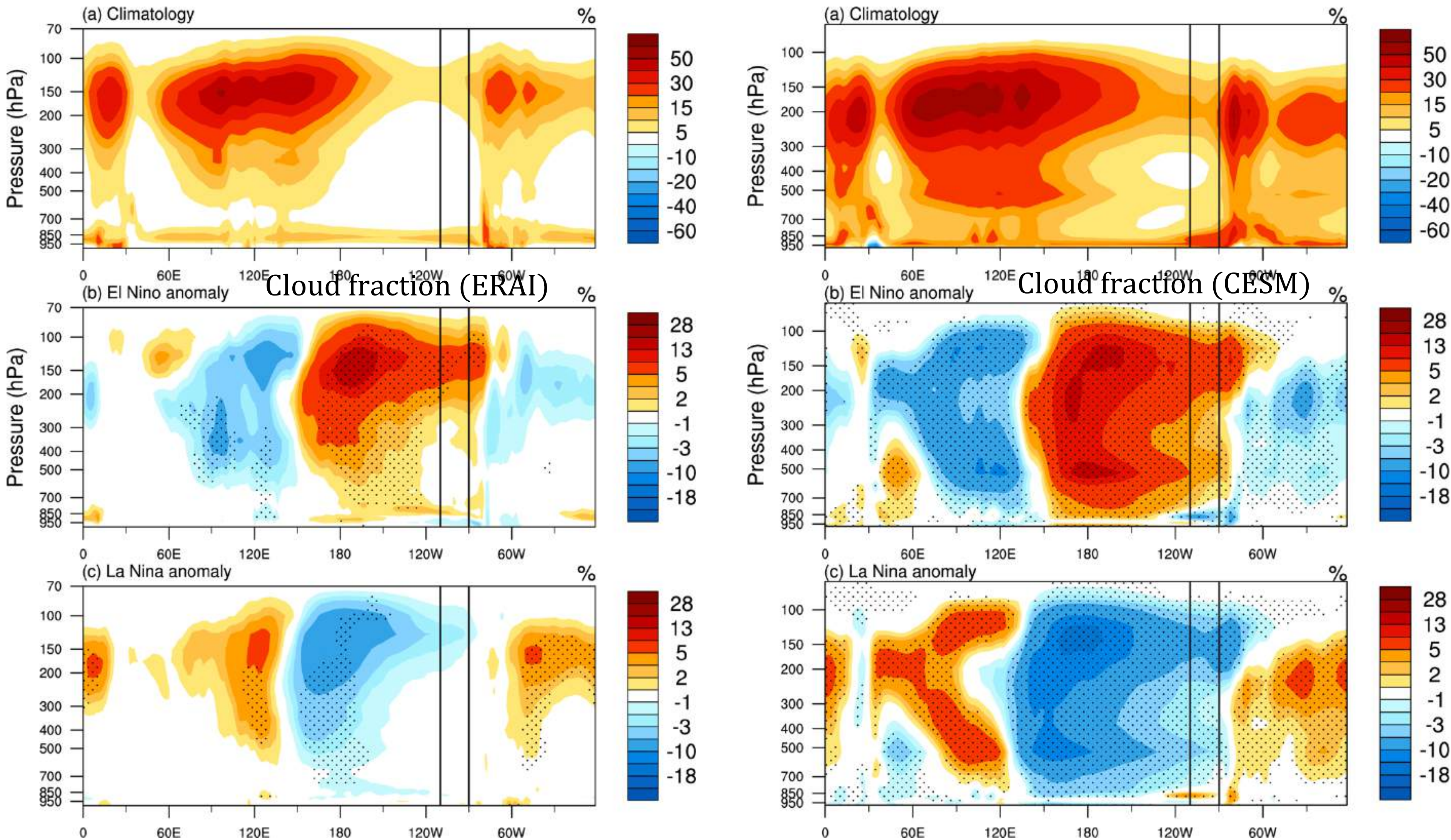


$Nino3.4\ for\ CESM\ from\ 1981\ to\ 2080$



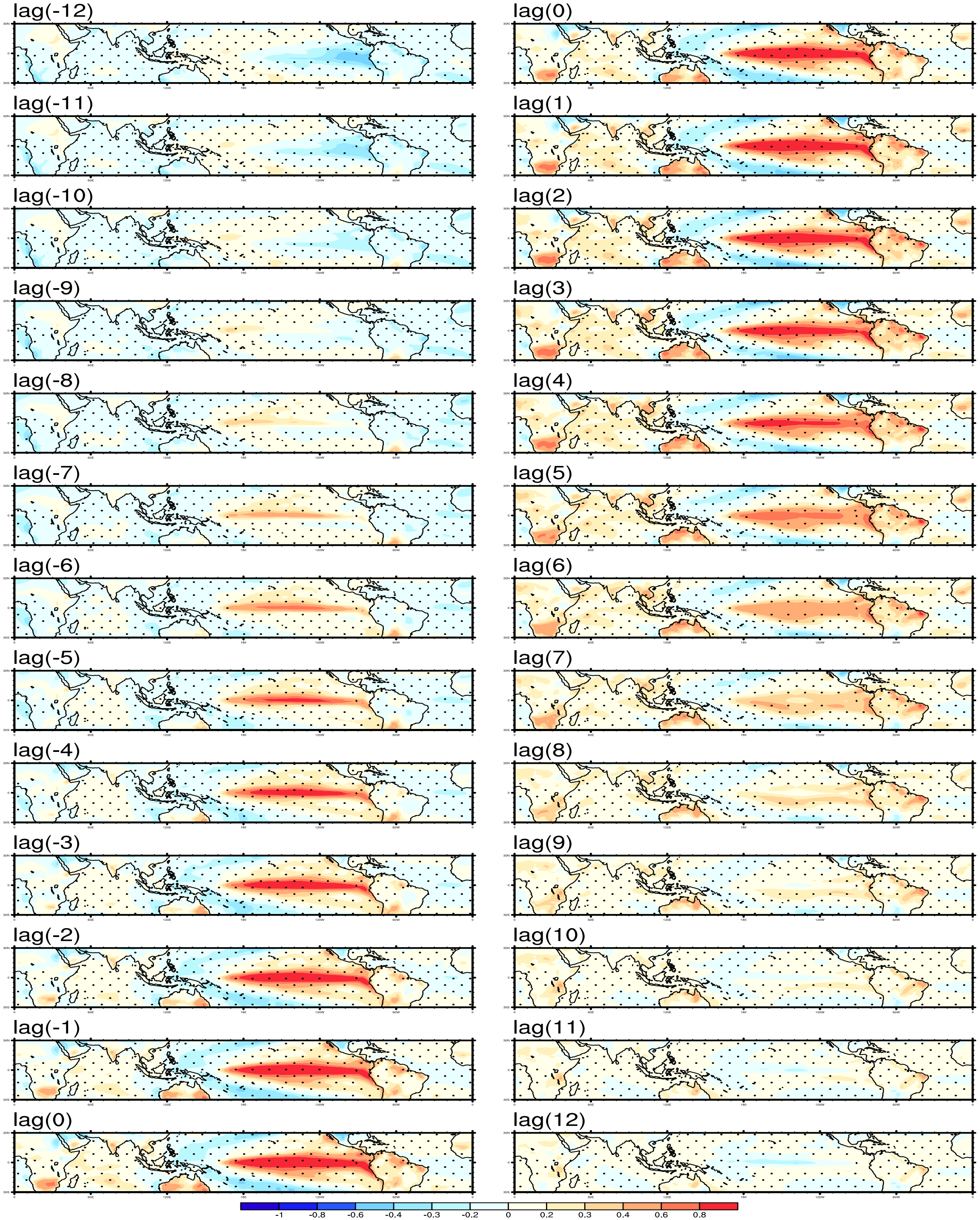
$Composite\ analysis$
$5S-5N$




Cloud fraction (ERAI)
Cloud fraction (CESM)
(a) Climatology
(b) El Nino anomaly
(c) La Nina anomaly
%
Pressure (hPa)
70
100
150
200
300
400
500
700
850
950
0
60E
120E
180
120W
60W
50
30
15
5
-10
-20
-40
-60
28
13
5
2
-1
-3
-10
-18

ENSO development

- Tropical temp. regressed to Nino3.4 index
- Average dTs > 0 beginning from lag=-6 mon.
- Data: ERA-Interim



ENSO development

- Tropical SW radiation regressed to Nino3.4 index
- Average dTs > 0 beginning from lag=-6 mon.
- Data: ERA-Interim