Cloud-convection feedbacks

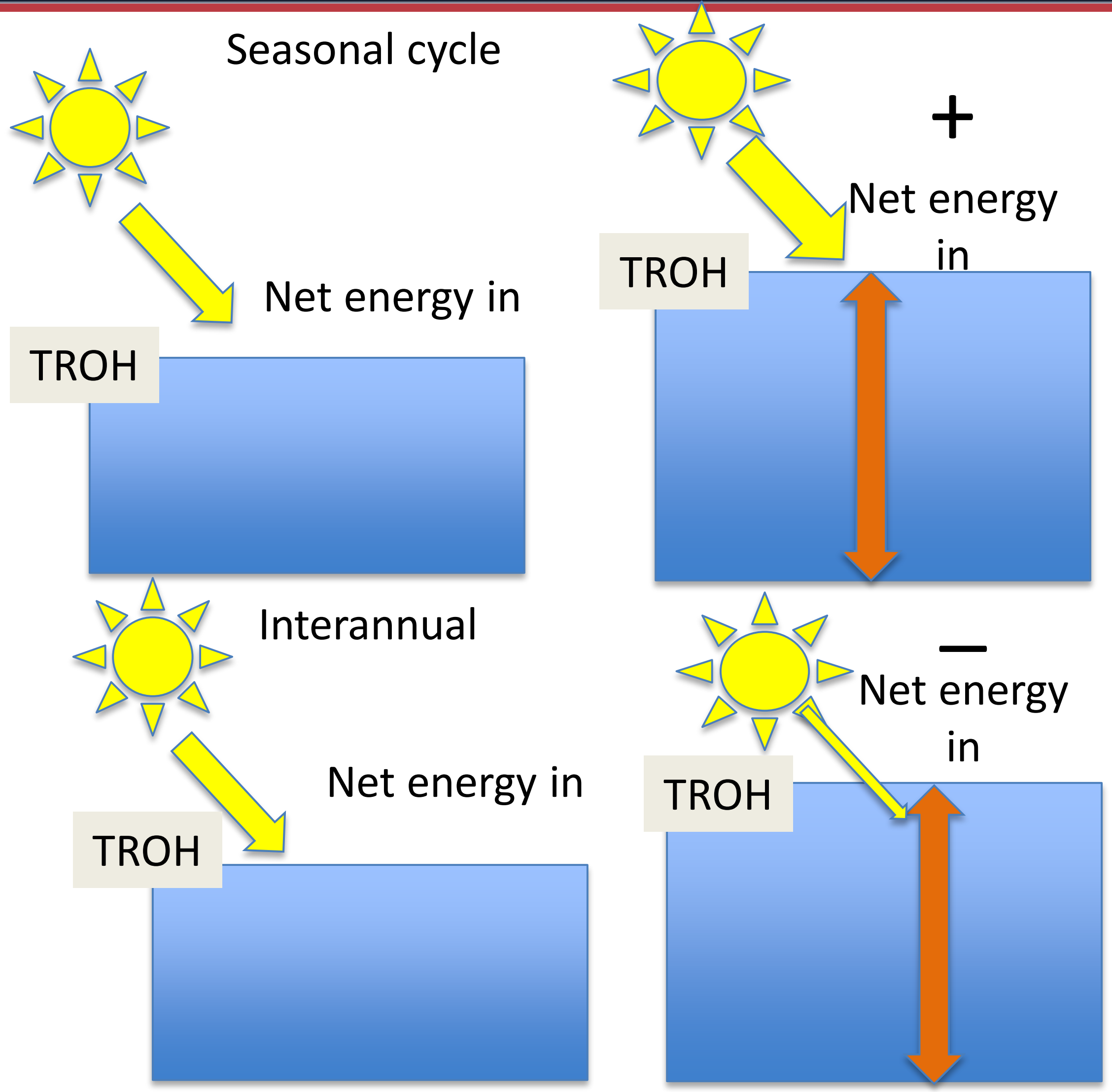
The 'breathing' of the tropical troposphere
(Hakuba et al., 2018 – in prep)

Amplification of the hydrological cycle under ENSO
(Stephens et al., 2018; GRL)

Graeme Stephens, *NASA JPL*

GEWEX UTCC PROES workshop,
Paris, France, 22-23 October 2018

The ‘breathing’ of the tropical troposphere



20N/S tropical averages

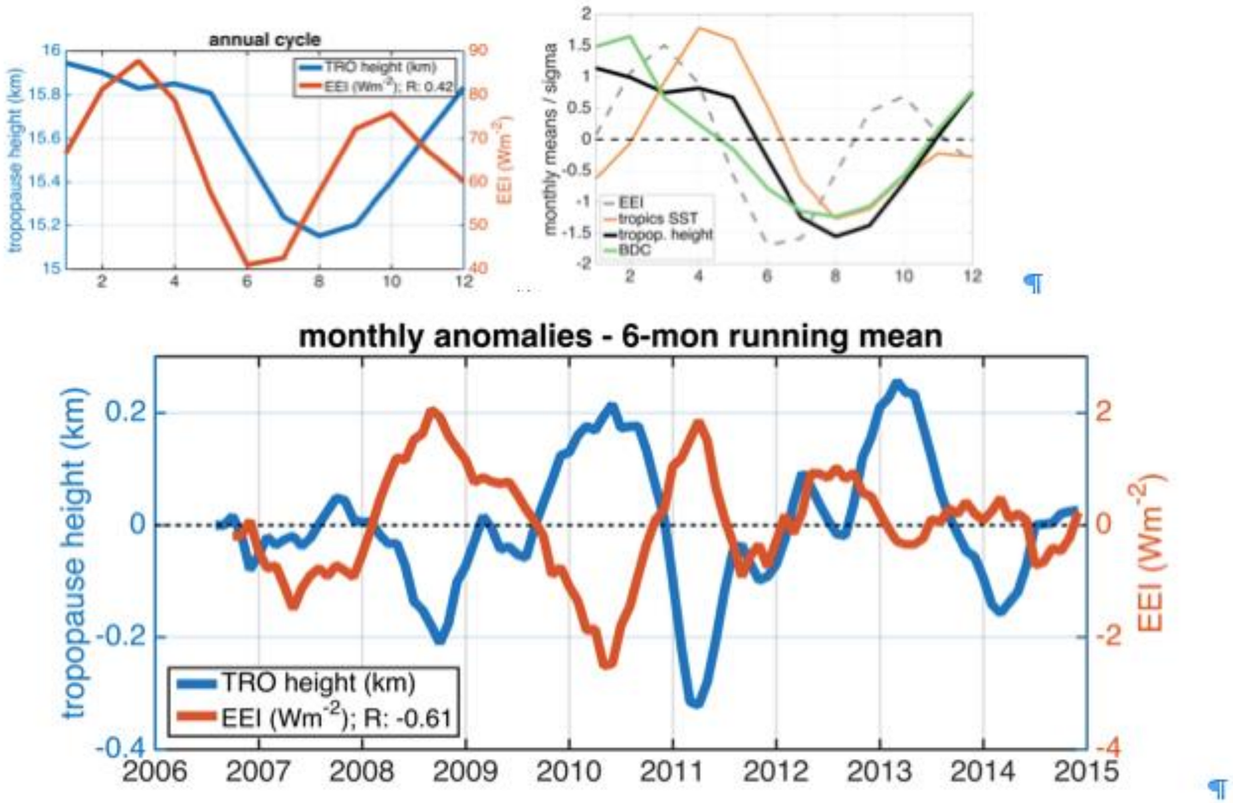
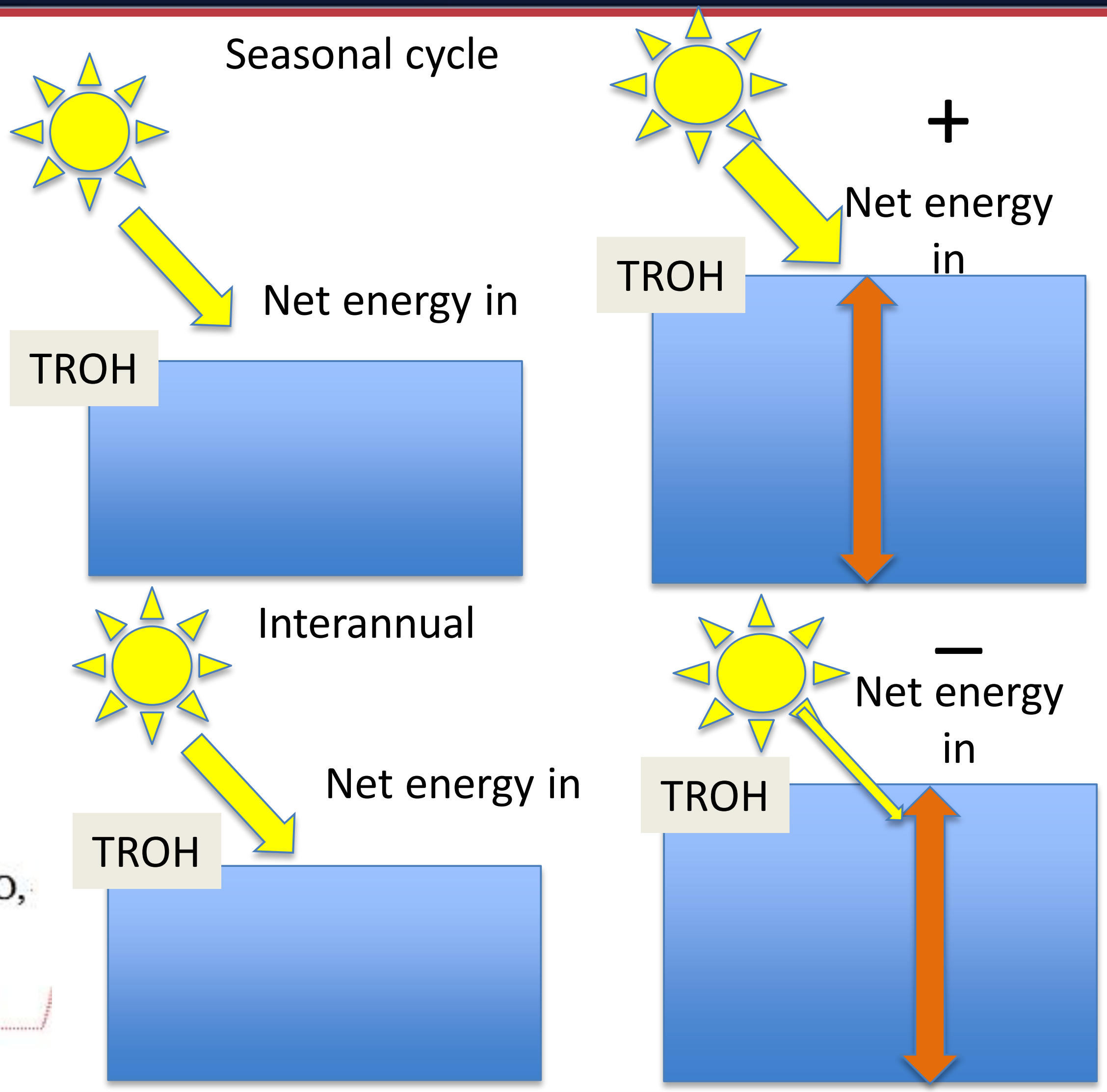
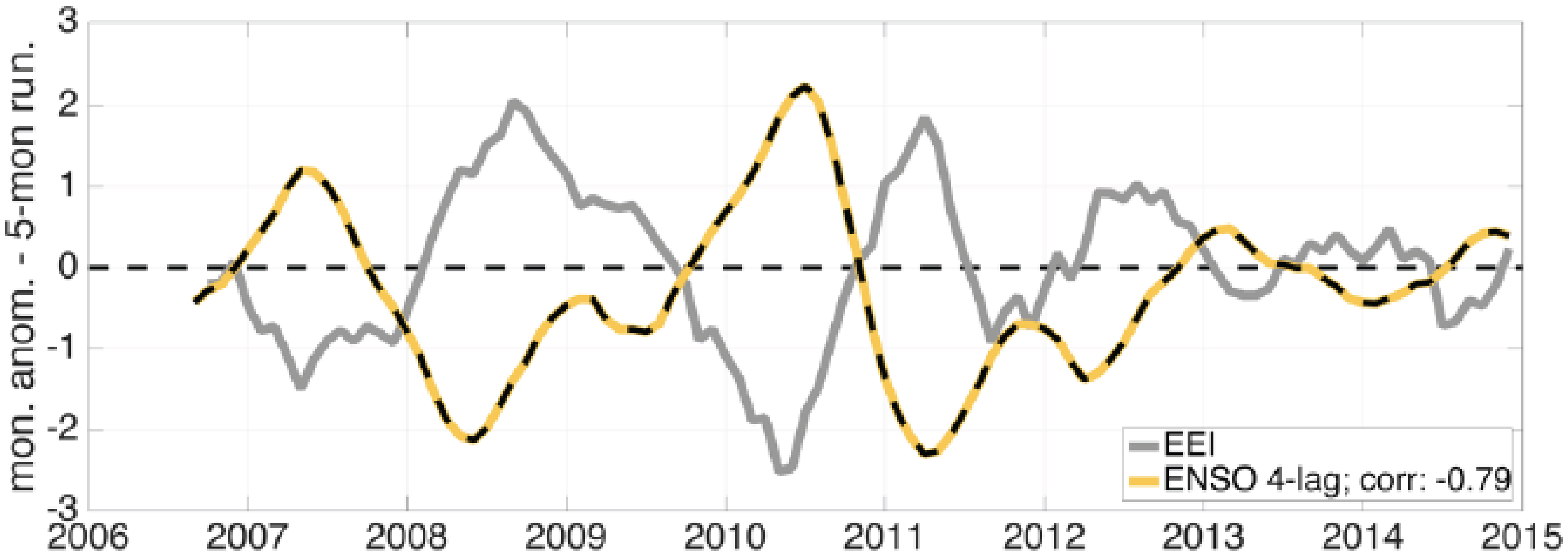


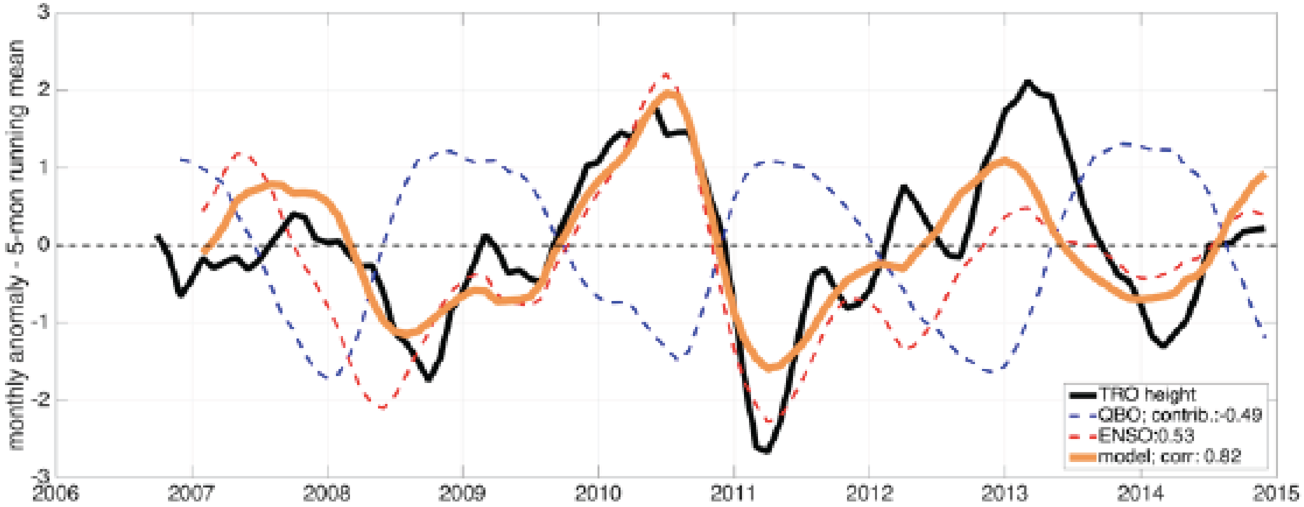
Figure 1: a) Annual cycle (2006-2015) of (top left) thermal tropopause height *'TROH'* (GPS-RO, JPL Genesis) & TOA net radiative flux (TEB, CERES EBAF) representative of deep tropics (10S-10N). b) Annual cycles of TROH, TEB, tropical SST and BDC index with annual means removed. (Bottom) c) Interannual variability in TROH and EEI based on six-months running means of monthly anomalies.

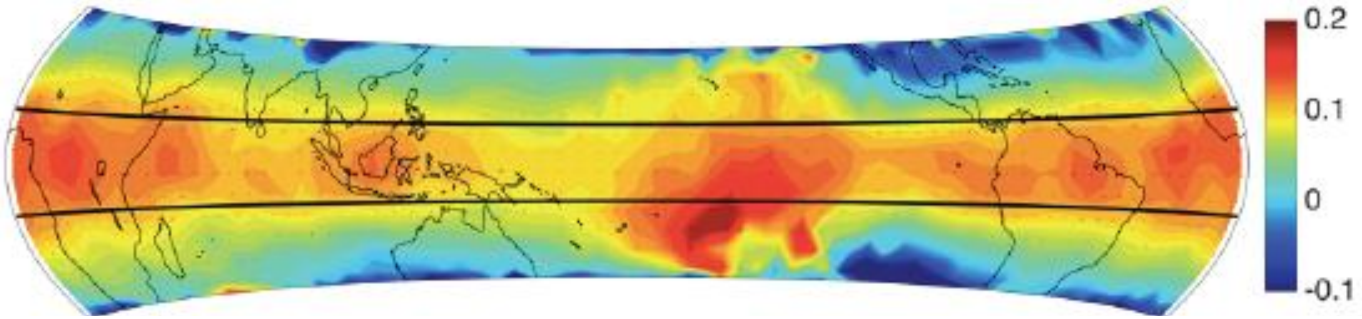


EEI variation largely driven by ENSO (4mnth lag) –TROH –ENSO?



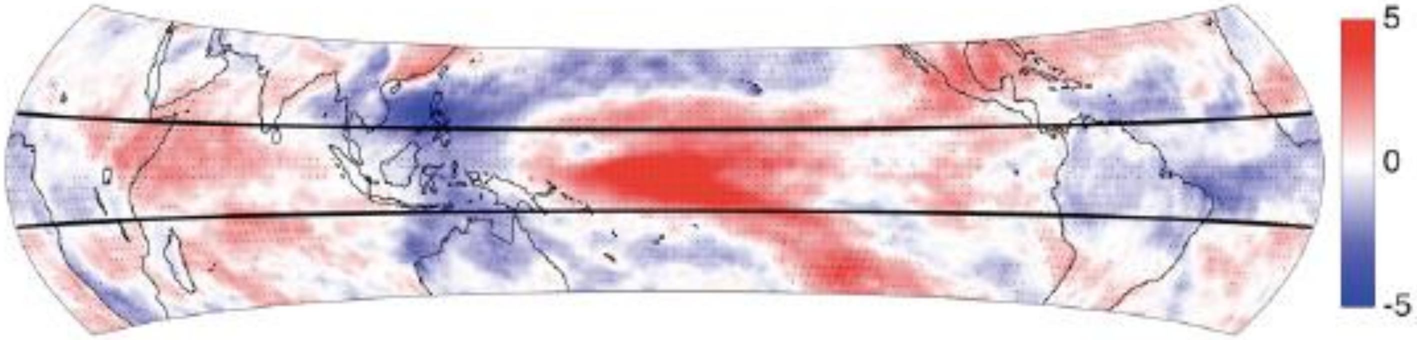
ENSO & QBO added lags



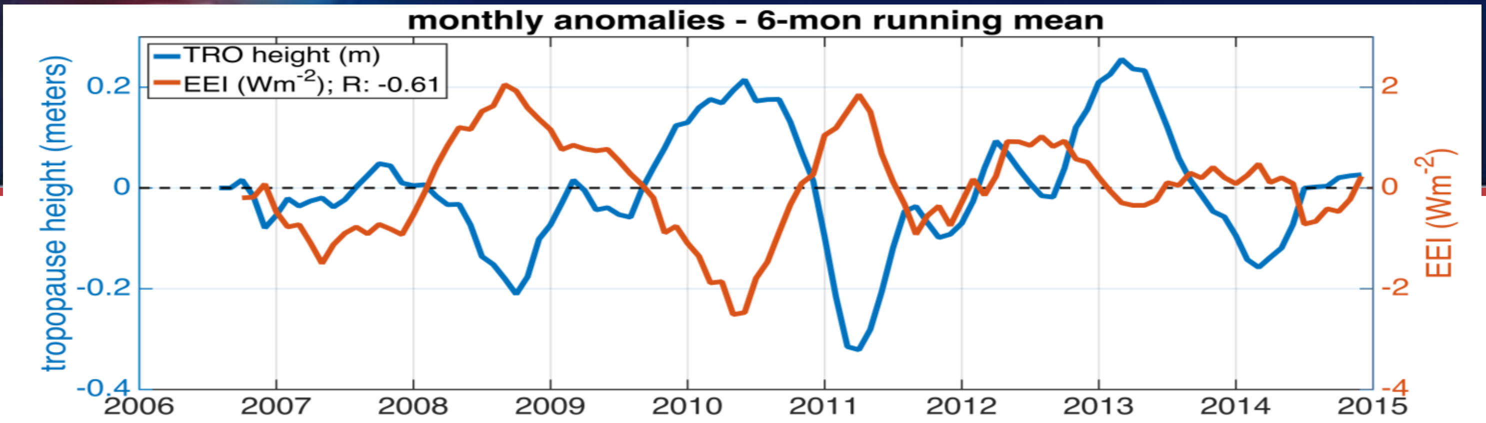


(km)

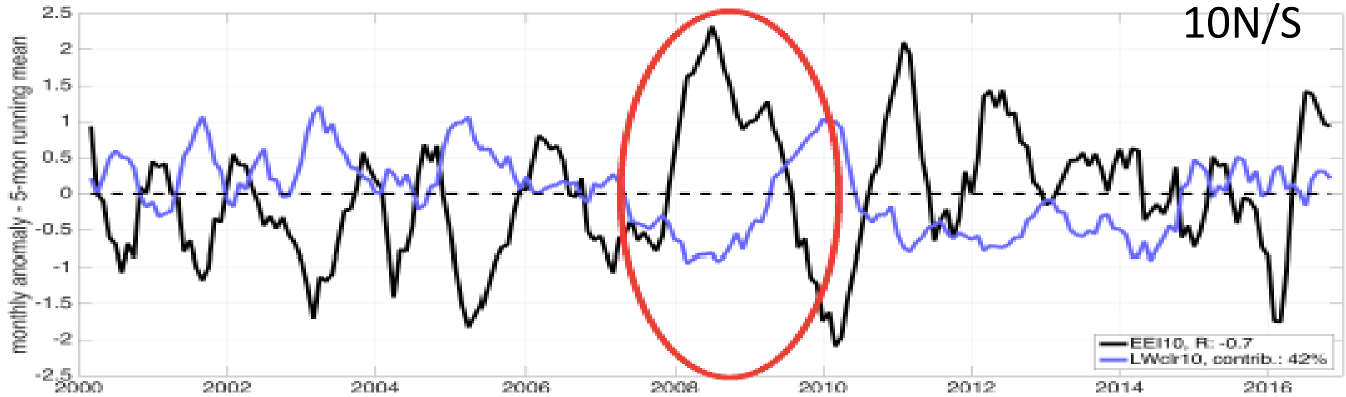
TRO breaths throughout tropics with some spatial variability



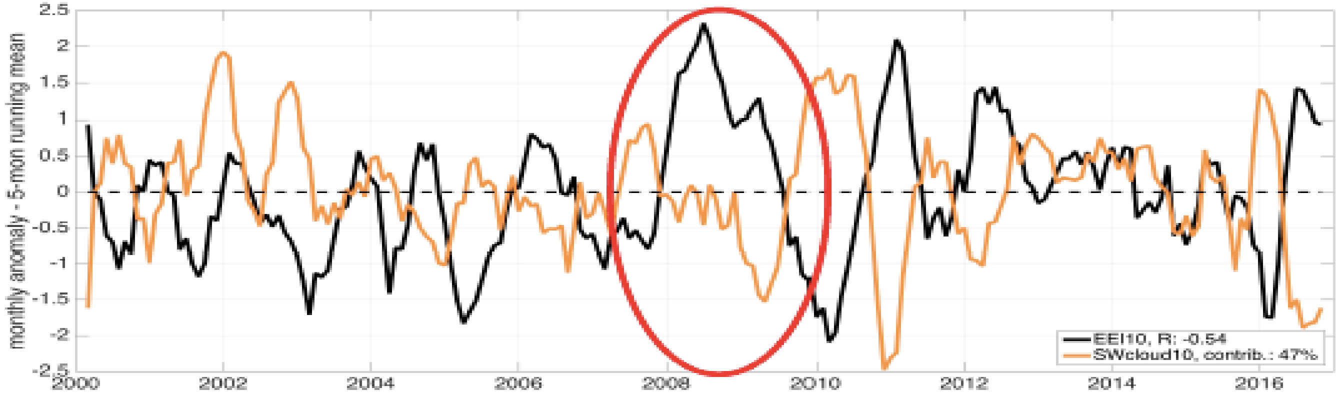
CF pattern due to TRO breathing



LW clear 42%



SW cloudy 47%



1) We observe a strong anti- correlation between interannual variations of energy into the tropics and the height of the tropopause - ie less energy in, the deeper the atmosphere

2) The interannual variation of EEI arises from variations in clear sky LW emission and cloudy sky shortwave reflection

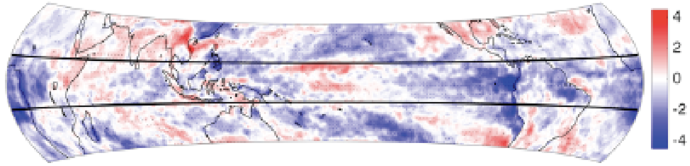
Does this correlation between EEI and tropopause height expose feedbacks between clouds & their SW radiation properties and the depth of the troposphere and the subsequent ability of the tropics to remove heat build up by emission?

Breathing of EEI?

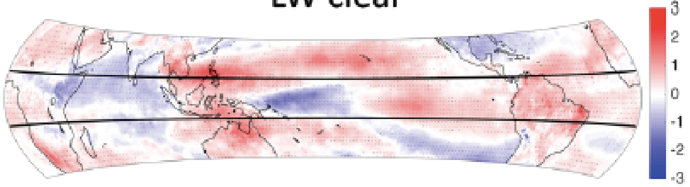
Regression against bulk change in tropopause height (quite similar to ENSO regression)

Blue (negative) in LW and SW fluxes yields red (positive) in EEI

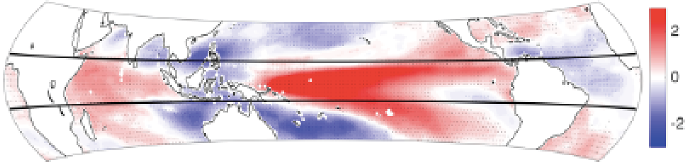
EEI



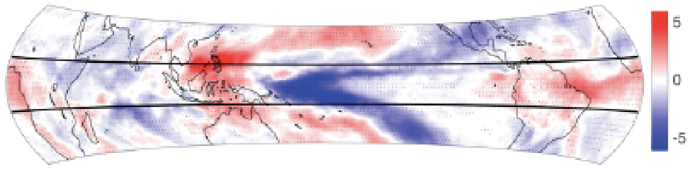
LW clear



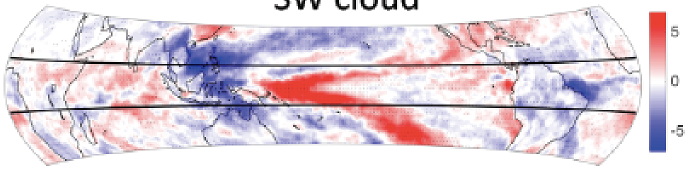
Water vapor (WV)



LW cloud



SW cloud

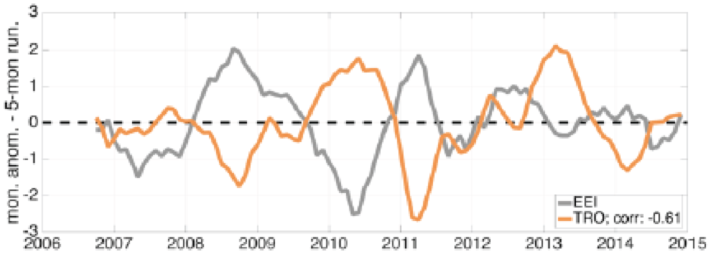


Although LW cloud was masked and did not correlate well with EEI changes in bulk, pattern is very distinct and opposite of SW cloud. It appears responsible for positive EEI near deep convective region. Looking at maps, the LW fluxes seem to govern the EEI change!

In contrast to bulk regression, LW clear decreases slightly where strongest increase in WV, and enhanced in drying region. Averaged, LW clear increases while WV increases in deep tropics.

We don’t yet know the consequence of this finding on the larger aspects of the Earth system

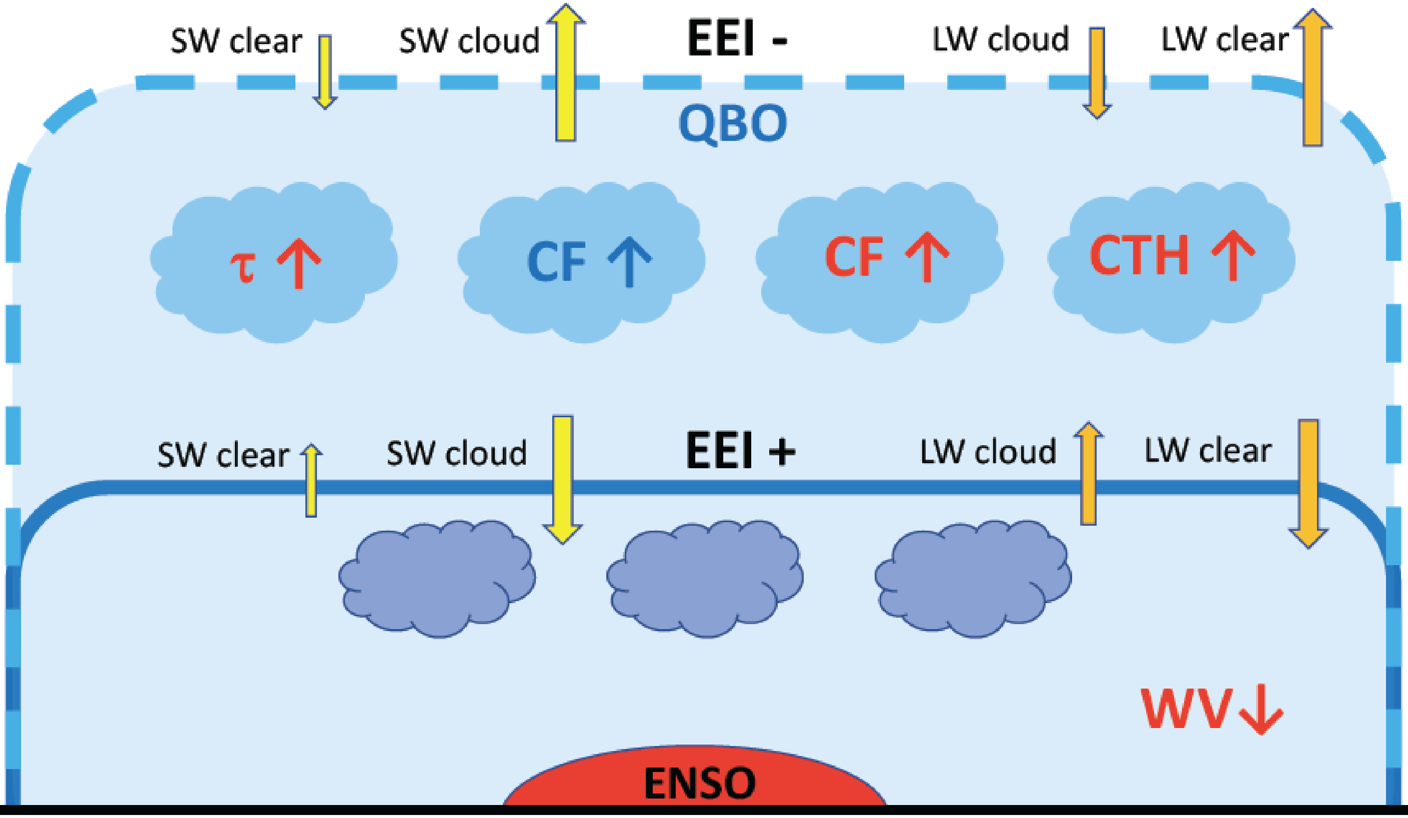
”Simple” feedbacks for deep tropics bulk inter-annual variations in EEI



Tropopause height (thermal, but cold point similar)and EEI are anti-correlated

Higher tropopause

Lower tropopause



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Key Points:
- Satellite data demonstrate regional super C-C intensification of hydrological cycle in response to warm phase of ENSO
- Observations and global climate models show similar responses and evidence for large-scale dynamical response to ENSO
- Atmospheric feedbacks involve shifts in patterns of latent and radiative heating acting on dynamics that enhance hydrological cycle response

Supporting Information:
- Supporting Information S1

Regional Intensification of the Tropical Hydrological Cycle During ENSO

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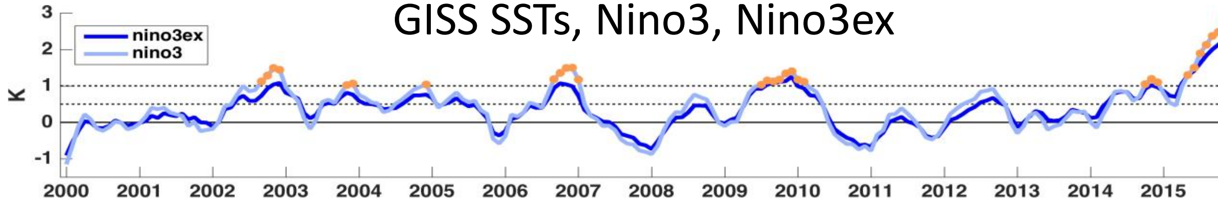
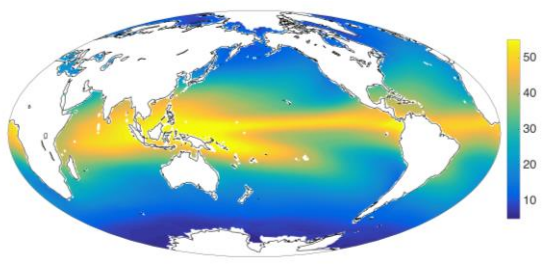
Abstract This study provides observational evidence for feedbacks that amplify the short-term hydrological response associated with the warm phase of the El Niño-Southern Oscillation. Our analyses

- GISS SST
- CERES EBAF 2000-2015
  - TOA, surface radiative fluxes
- Scatterometer 2000-2009
  - Surface winds, convergence/divergence
- Aqua – AIRS,MODIS 2003-2015
  - clouds, humidity
- CloudSat-CALIPSO 2006-2011
  - vertical cloud profiles, radiative heating rate profiles heating
- GPCP – 1978-2015
  - Precipitation, with ECMWF divergence defines ITCZ location & extent
- DMSP-based microwave 1984-2015 climatology (NASA measures)
  - cloud liquid water, water vapor
- OA Woods Hole turbulent fluxes (OAflux)
- MERRA & ERA reanalysis

GISS SSTs, Nino3, Nino3ex

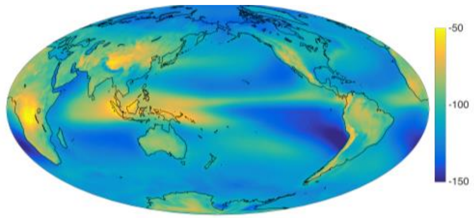


1984-2015 mean CWV



kgm^{-2}

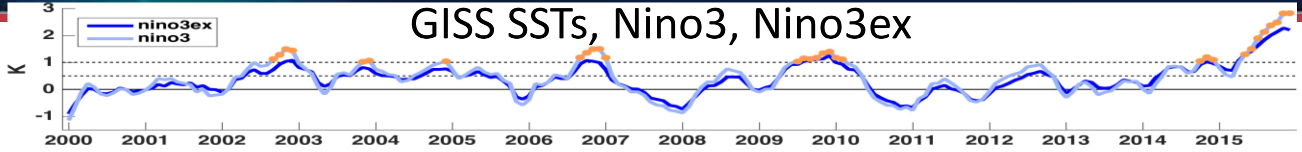
2000-2015 CERES
Atmospheric radiative Heating

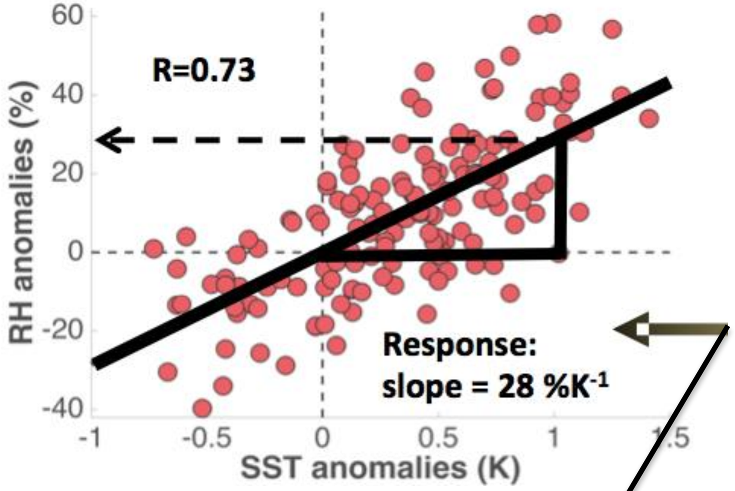


Wm^{-2}

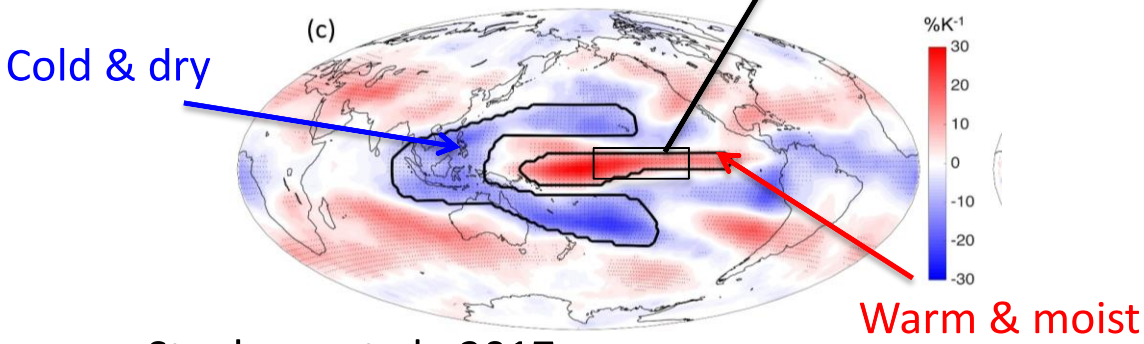
Convection related feedbacks within ENSO

GISS SSTs, Nino3, Nino3ex

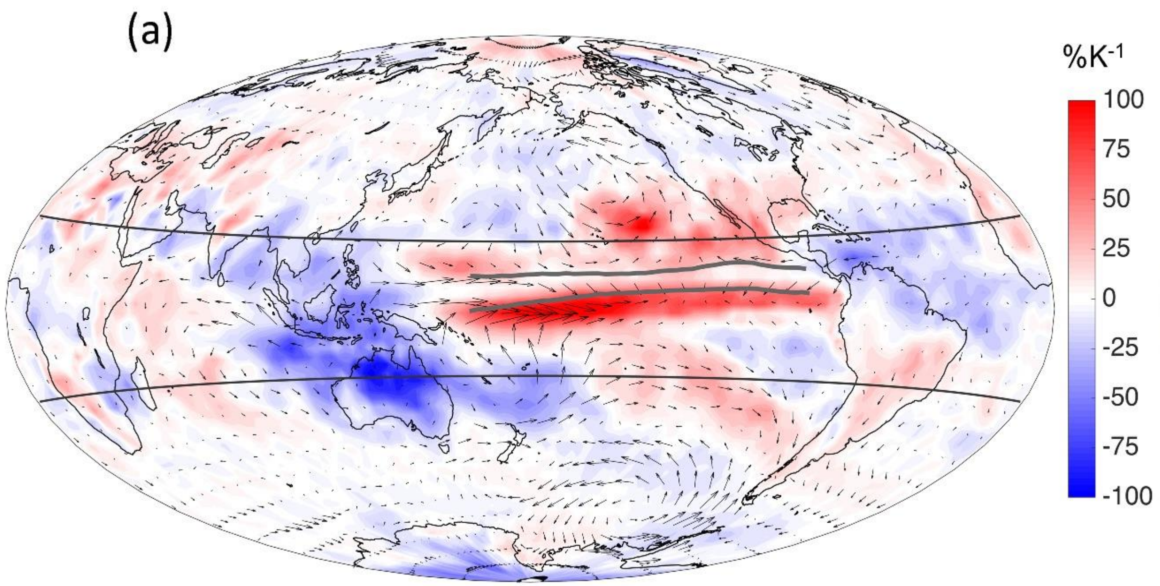




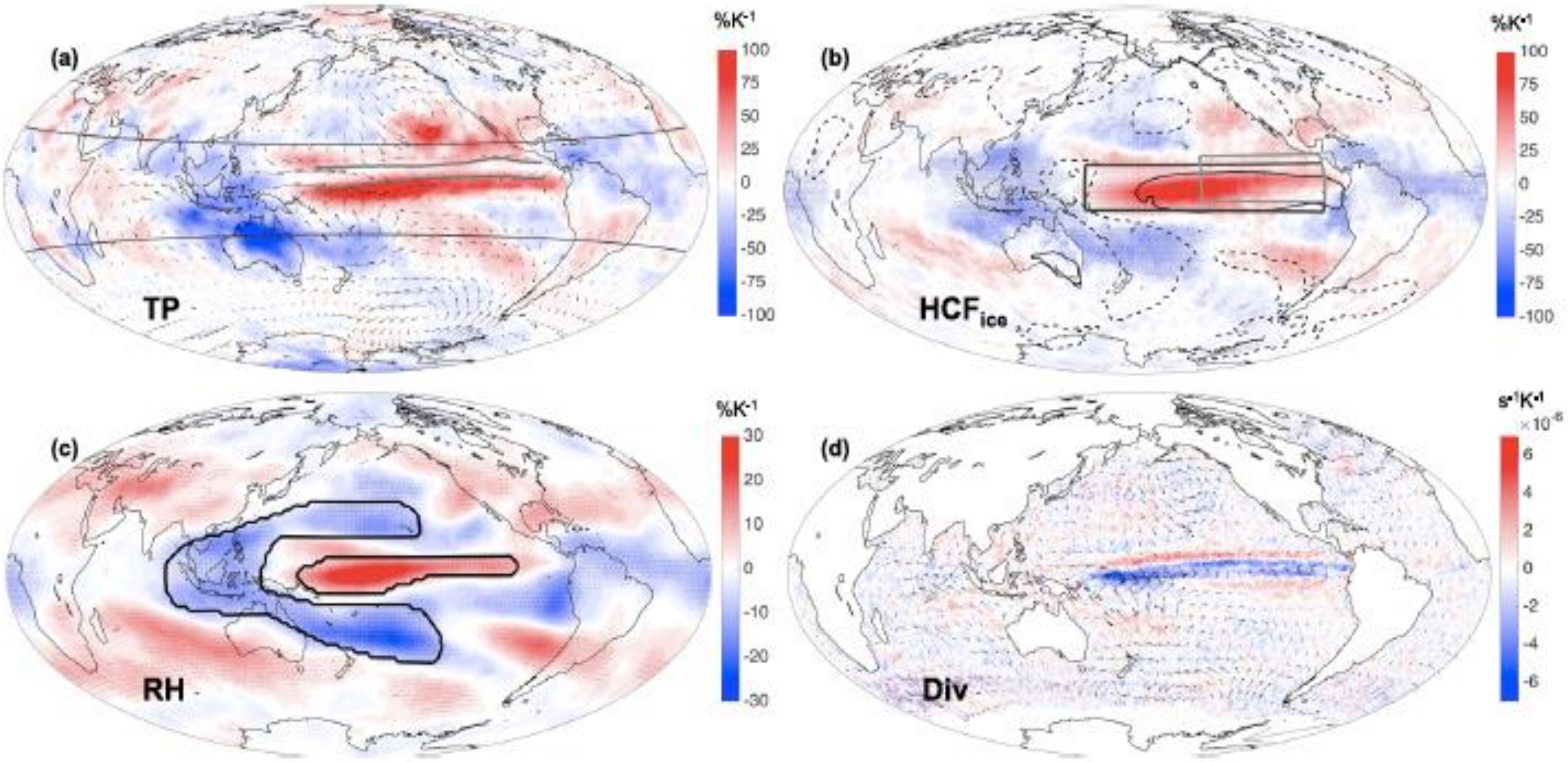
The global UTH response to Nino3 warming



Stephens et al., 2017



GPCP precipitation response (relative)
Surface wind response (MERRA)
Mean location of ITCZ



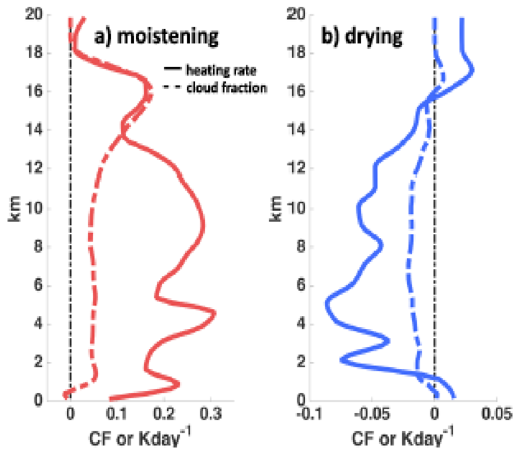
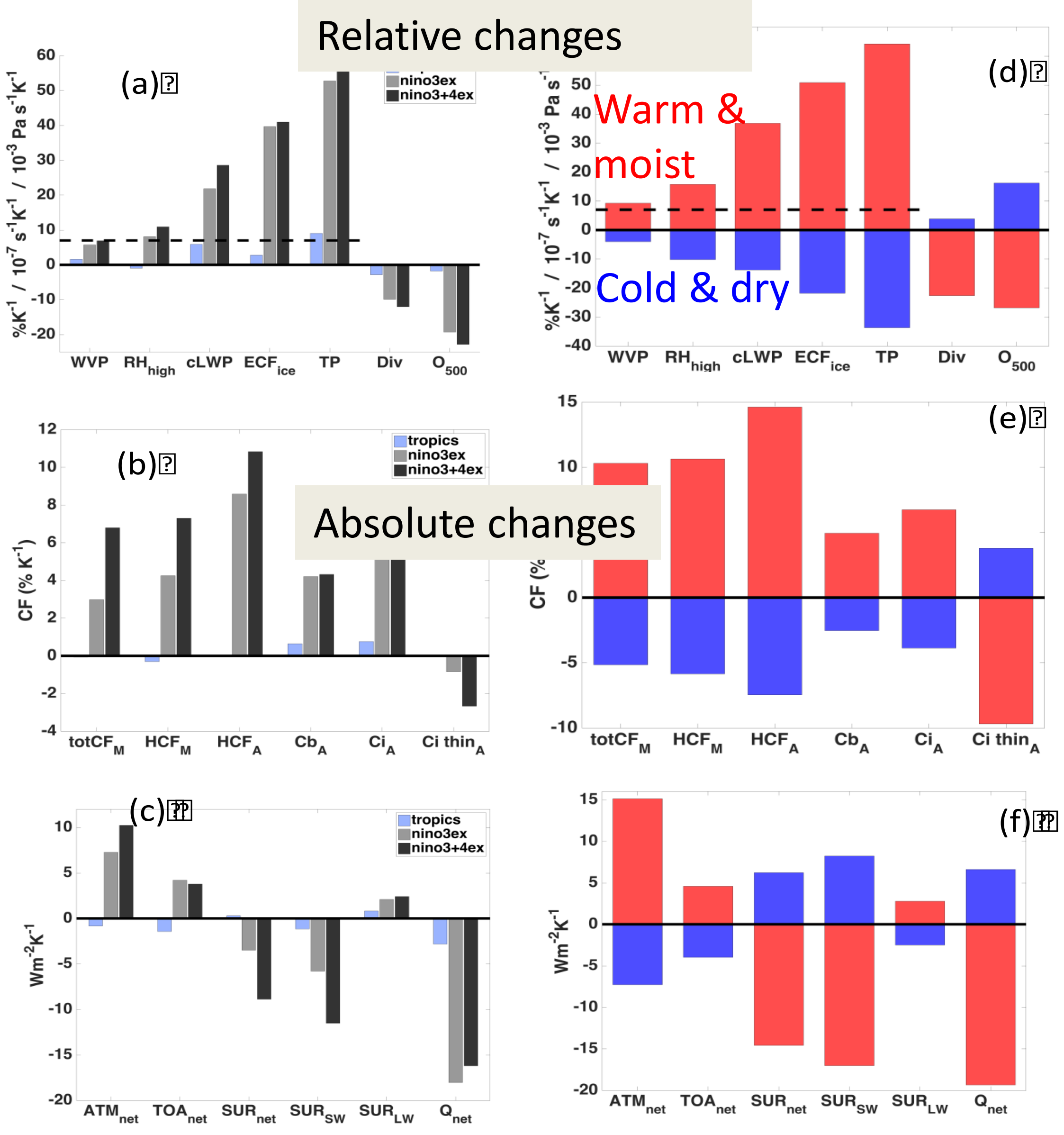


Figure 2. Anomalous CloudSat radiative heating rate (Kday^{-1}, solid) and cloud fraction profiles (dashed, cloud amount is between 0 and 1) in the (a) moistening and (b) drying regions. The anomalies are constructed from the averages of the 2006 and 2009 El Niños with respect to the climatological mean of that data record (2006–2011).

Figure 1. (a) The global distribution of the linear regression slope representing the response of GPCP precipitation (TP) to SST variability in the Niño3ex region identified in panel b (gray box). Superimposed is the MERRA-2 surface wind response and the mean northern and southern boundaries of the ITCZ for the 2000–2015 period and the 20°N and 20°S boundaries defining the tropics. (b) The response of AIRS ice cloud cover (HCF$_{ice}$) together with the Niño3ex region (grey box) and a larger Niño3 + 4ex region (black box), which captures most of the positive responses of convection. The Niño3ex region is a latitudinally extended version of the Niño3 region and was determined by the extent of the mean location of the ITCZ boundaries in (a). Contours represent El Niño SST anomaly composites (winters of 2006, 2009, and 2015) at −0.25 K (dashed) and at +1 K (solid). (c) Response of AIRS 200–500 hPa layer mean relative humidity (RH). This response is used to identify the regions of responses that are warming and moistening (referred to as "moistening region") and cooling and drying ("drying region") (d) Scatterometer surface wind and divergence responses (div) to the Niño3ex warming. Stippling in (b) and (c) indicates where the regressions correlate at |0.2| or higher.

Synthesis of aggregated responses



Regional responses in condensed water is super CC

- high clouds (ECF_{ice}) ~41%K^{-1}
- cloud liquid water content (cLWP) ~28%K^{-1}
- precipitation (TP) ~55%K^{-1}

Regional water vapor response ~ CC

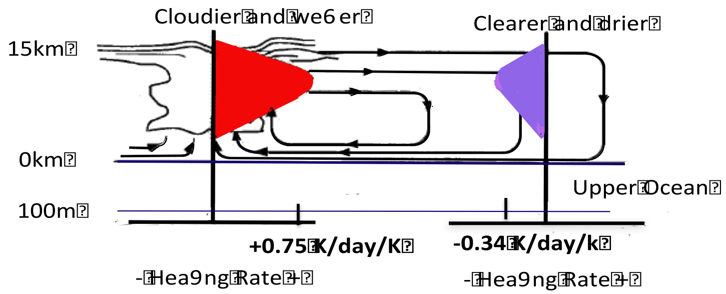
Regional surface flux responses dominated by cloud effects on solar flux changes (~17 $Wm^{-2}K^{-1}$)

Tropical cloud changes are dominated by high clouds changes

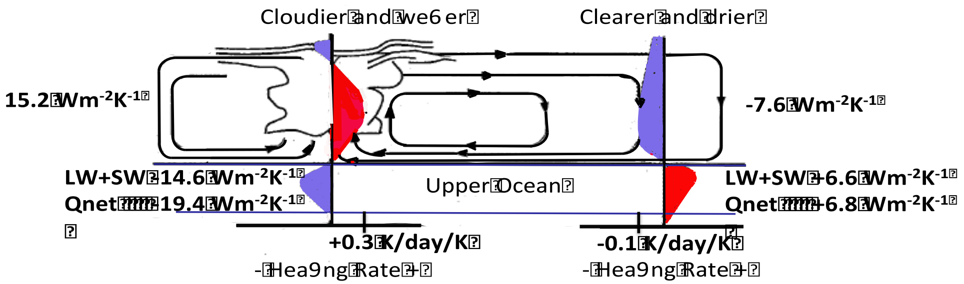
Radiative heating gradients (+15 $Wm^{-2}K^{-1}$ to -7$Wm^{-2}K^{-1}$) **reinforce LH gradients & circulation**

Tropics wide responses are small underscoring the point that opposing responses occur

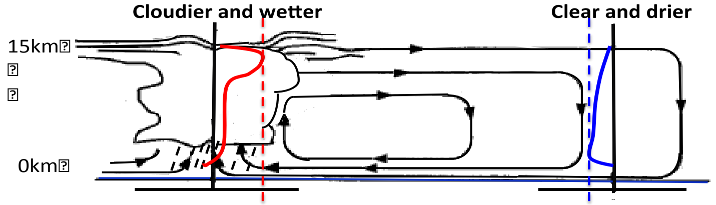
a) Latent heaAng gradients



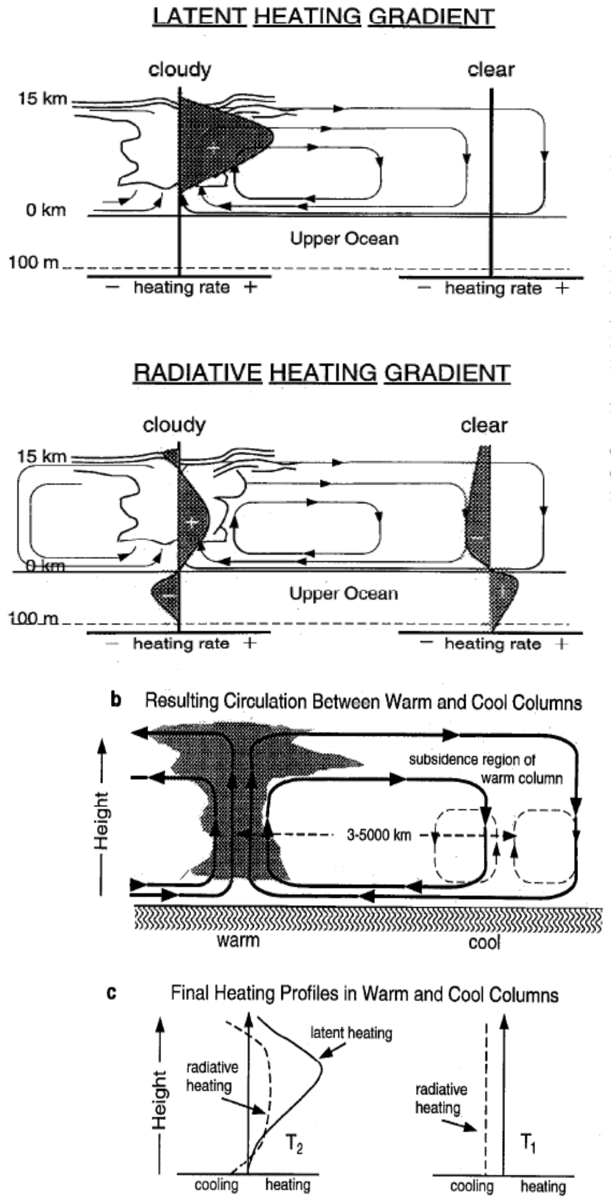
b) RadiaAon Gradients



c) Hydrological parameters



	Cloudier and wetter	Clear and drier
Cloud amount	18%/K	-2%/K
High Cloud amount	15%/K	-8%/K
Cb/CA	5 %/K	-3 %/K
Ci/CA	7 %/K	-4 %/K
thinCi/CA	-10 %/K	4 %/K
Cloud LWP	37.1 gm^{-2}/K	-10.3 gm^{-2}/K
Precipitation	2.9 mm.day^{-1}/K	-1.3 mm.day^{-1}/K
Column WV	9%/K	-5%/K
RH 200-500 hPa	16%/K	-10%/K



Summary

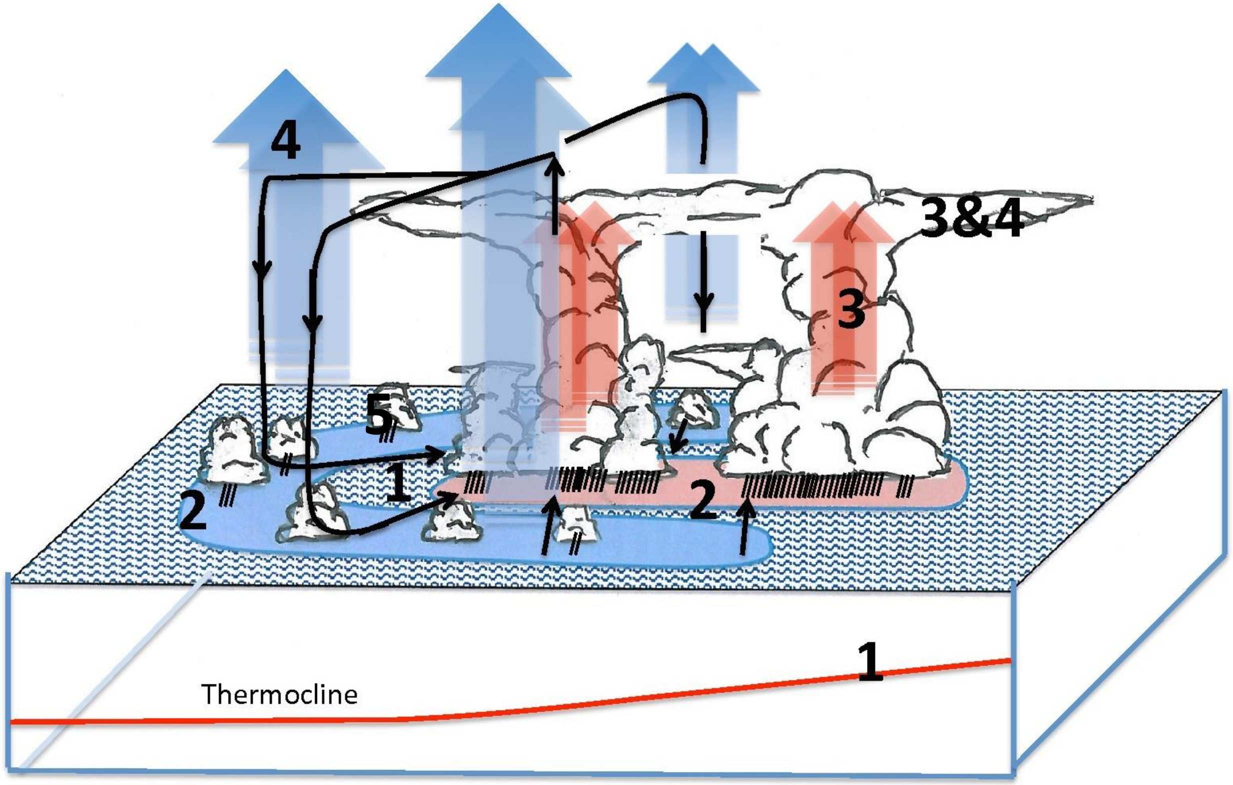
ENSO is an example of a coupled dynamical-radiative-convective system – its all about heating coupled to dynamics

Atmosphere produces reinforcing (+ve) feedbacks and the surface opposing (-ve) feedbacks as envisaged in Webster 1994

Regional responses of the condensed water properties (clouds and precipitation) are far from linear and do not follow the responses expected from simple CC thermodynamic arguments.

4 Reduced high clouds, drier troposphere and enhanced radiative cooling to space and increased subsidence

4 Enhanced surface heat flux



1 Weakened easterlies, weakened ocean mixing and increases SST

+ve Bjerknes feedback

2 Warmer SSTs & reduced surface heat fluxes

-ve heat flux feedback

3 Enhanced precipitation, latent & radiative heating

3 & 4 Increased high clouds

5 Enhanced low-level convergence