

# Climate feedbacks and relationships between TOA radiation and temperatures on Earth: CESM vs Observations

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## Why does the energy imbalance vary so much and so fast?

What does this imply

- For climate sensitivity analysis from data?
- For feedbacks?

**EARTH'S ENERGY BALANCE REVISITED**

# Fifty shades of feedbacks

$$R_T = F - \lambda \Delta T + \varepsilon$$



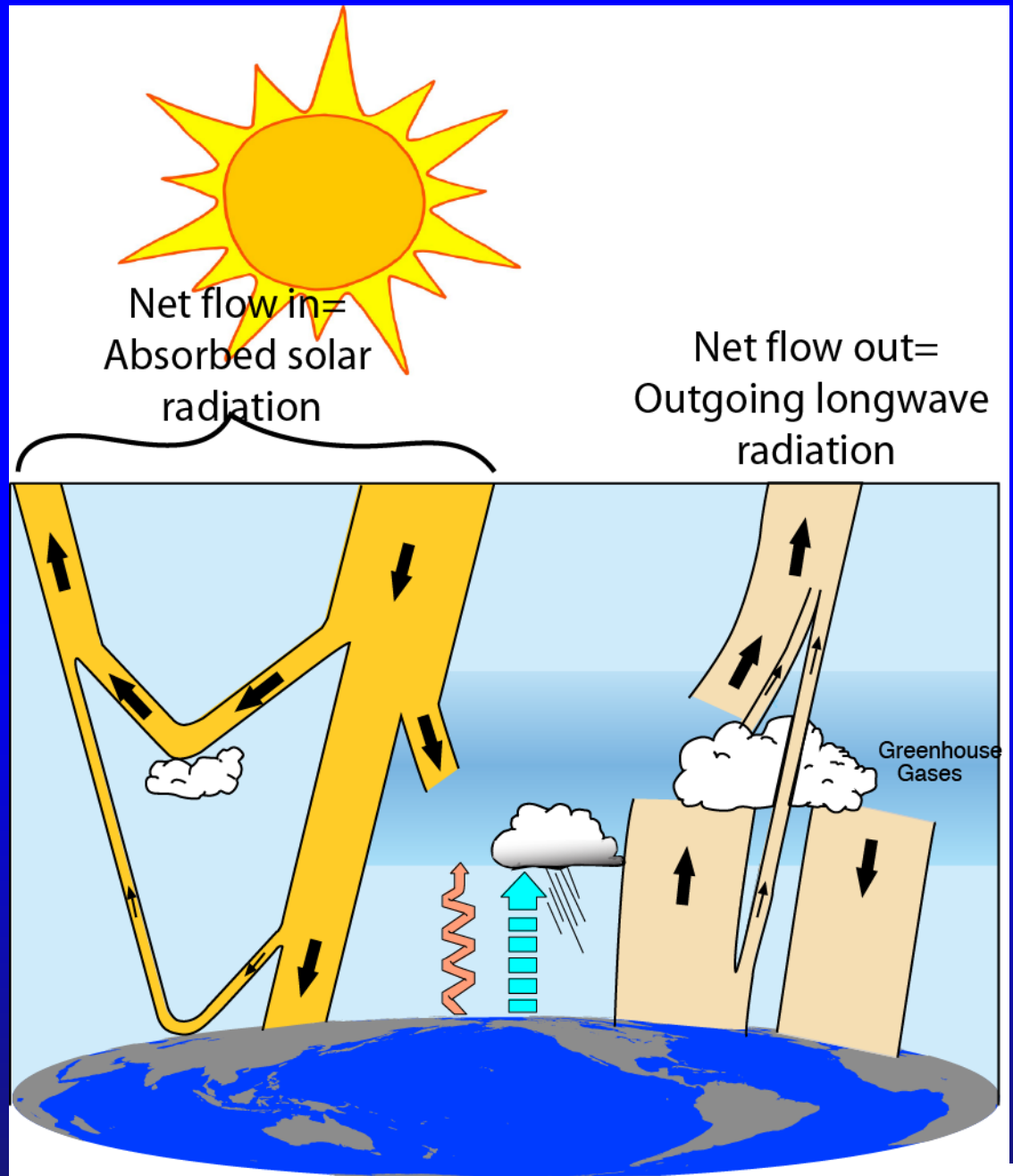
# Global warming:

Under no climate change, the net flow of energy in from the sun is balanced by the net radiation out to space.

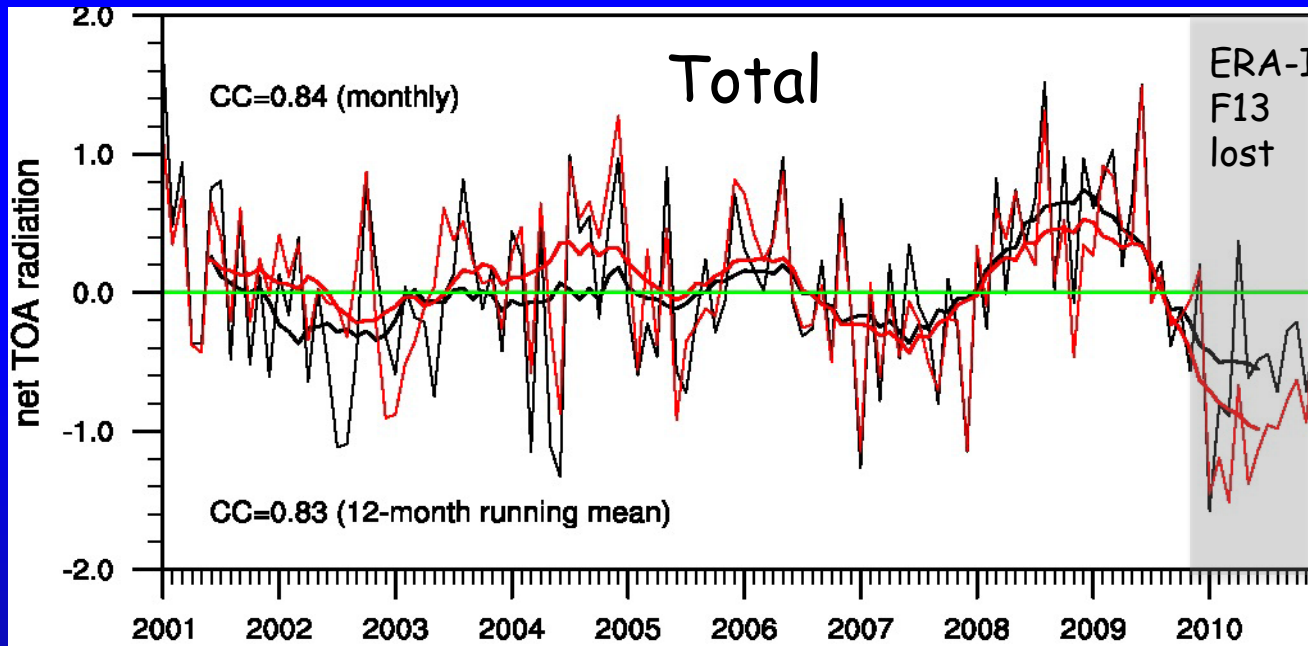
$$ASR = OLR$$

With global warming there is a net energy imbalance as heat trapping gases lower OLR:

$$\text{Net } R_T = ASR - OLR$$

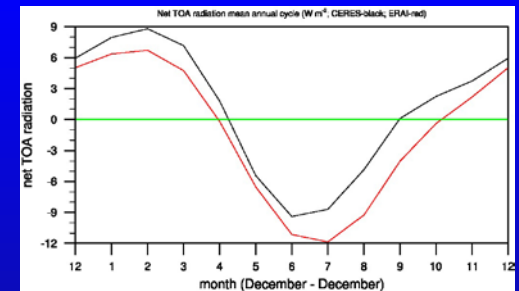


# Net TOA radiation anomalies



**CERES**  
ERA-Interim

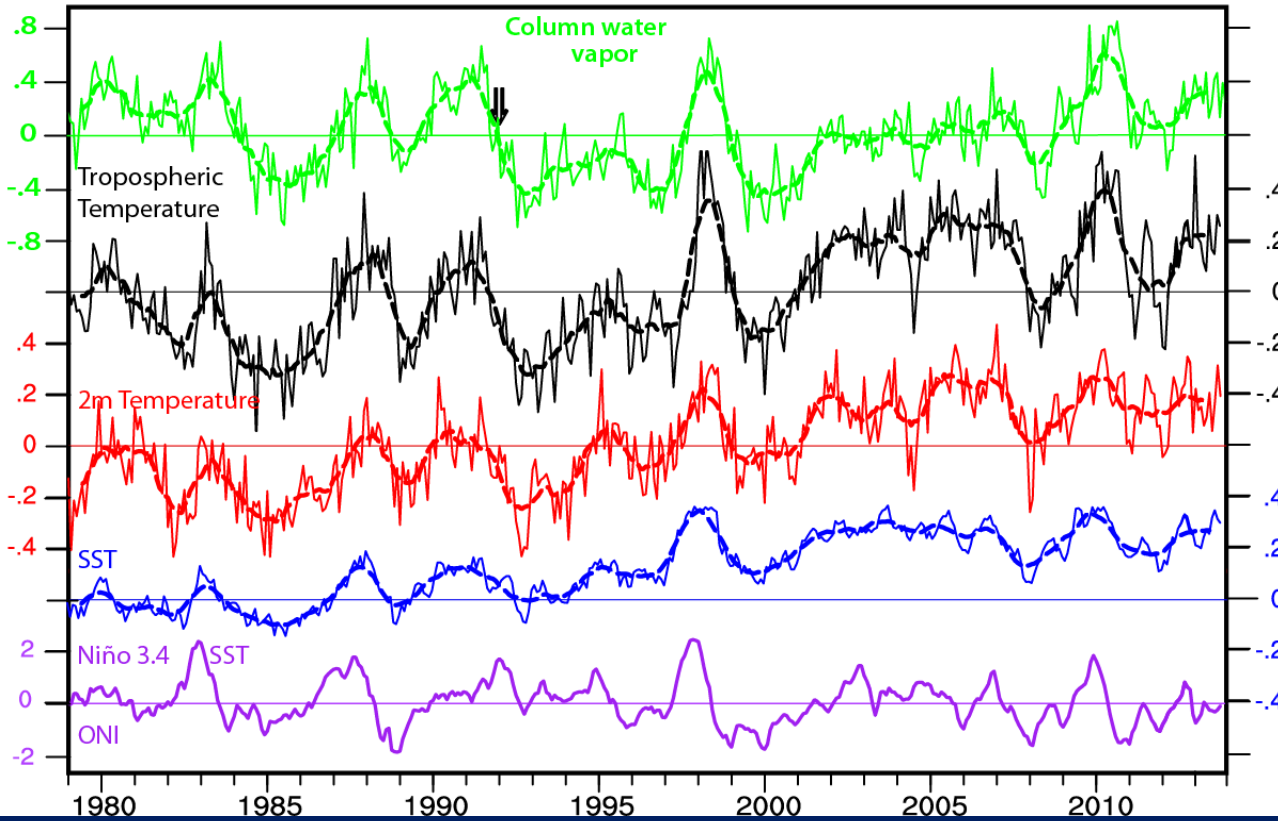
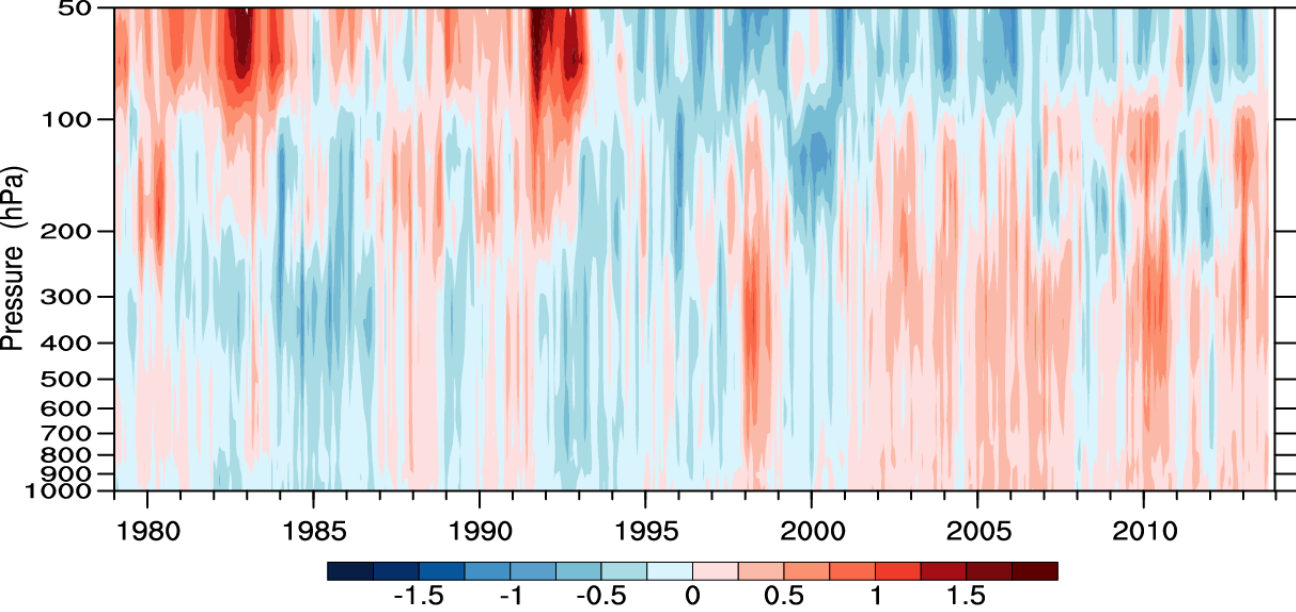
Mean annual cycle



Standard deviation  $0.64 W m^{-2}$ :  
Anomalies over  $1 W m^{-2}$  common.

Base period:  
Jan 2001-Dec 2010

# Global Temperatures Jan 1979 to Oct 2013



0.66

r=

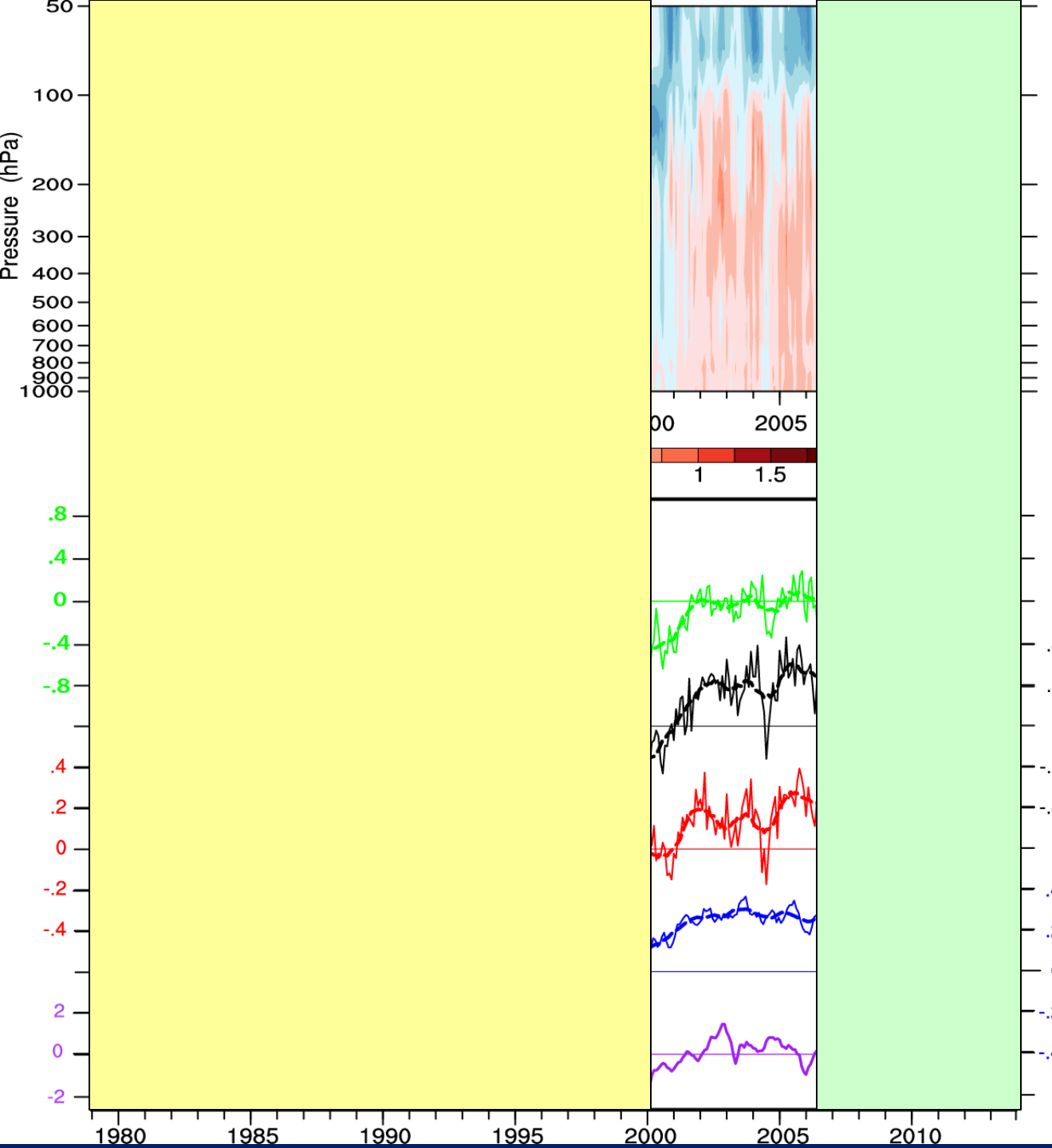
0.81

0.72 (0.77 2 mo)

0.37 (lag 4)

0.52 detrend (5)





Global

Jan 1979 to  
Oct 2013

We use

From models:  
1994-2005

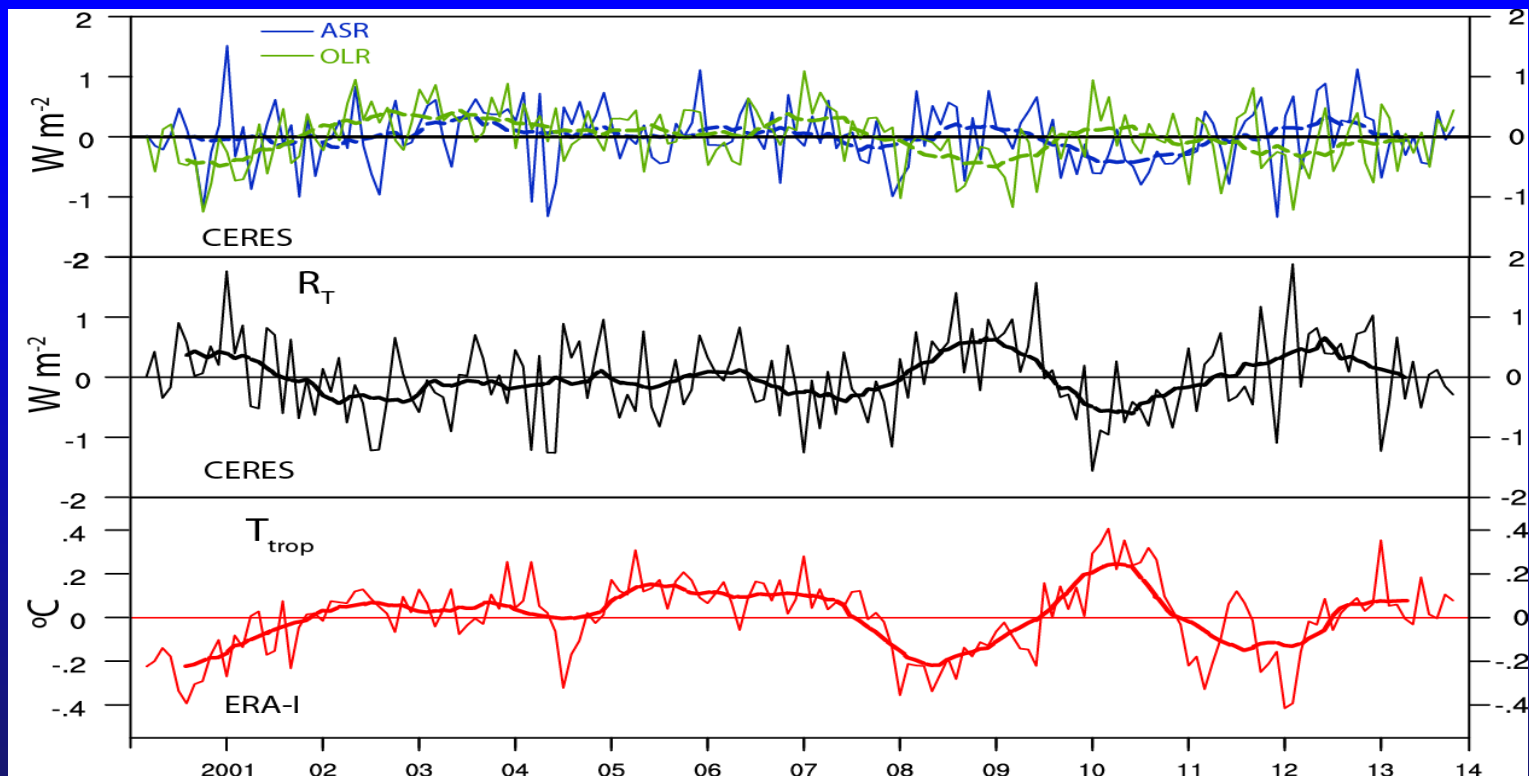
From obs:

3/2000-10/2013

# Correlation between tropospheric mean T and net TOA radiation

March 2000 through October 2013 (ERA-I w CERES) correlation = -0.57  
regression =  $-2.18 \text{ W m}^{-2}/\text{K}$

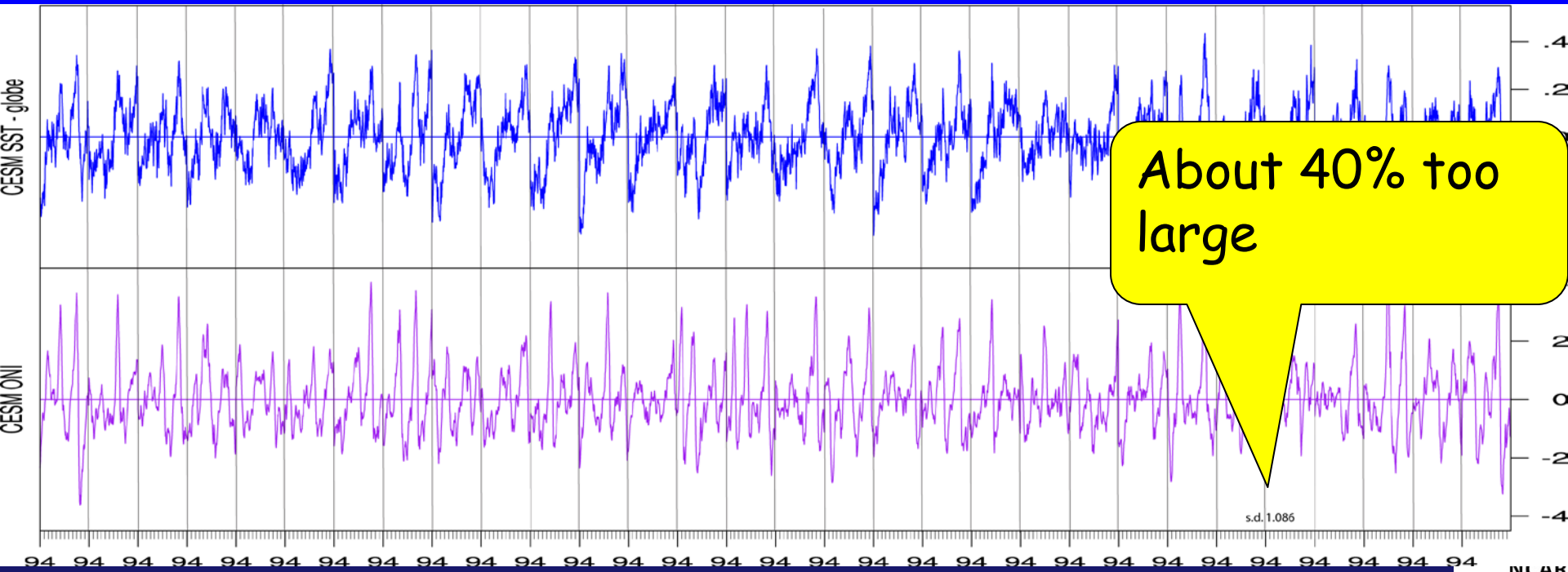
i.e. for a  $1^\circ \text{C}$  increase in T, there is  $2.18 \text{ W m}^{-2}$  extra radiation to space.



# CESM-LE and CAM-5.3 AMIP

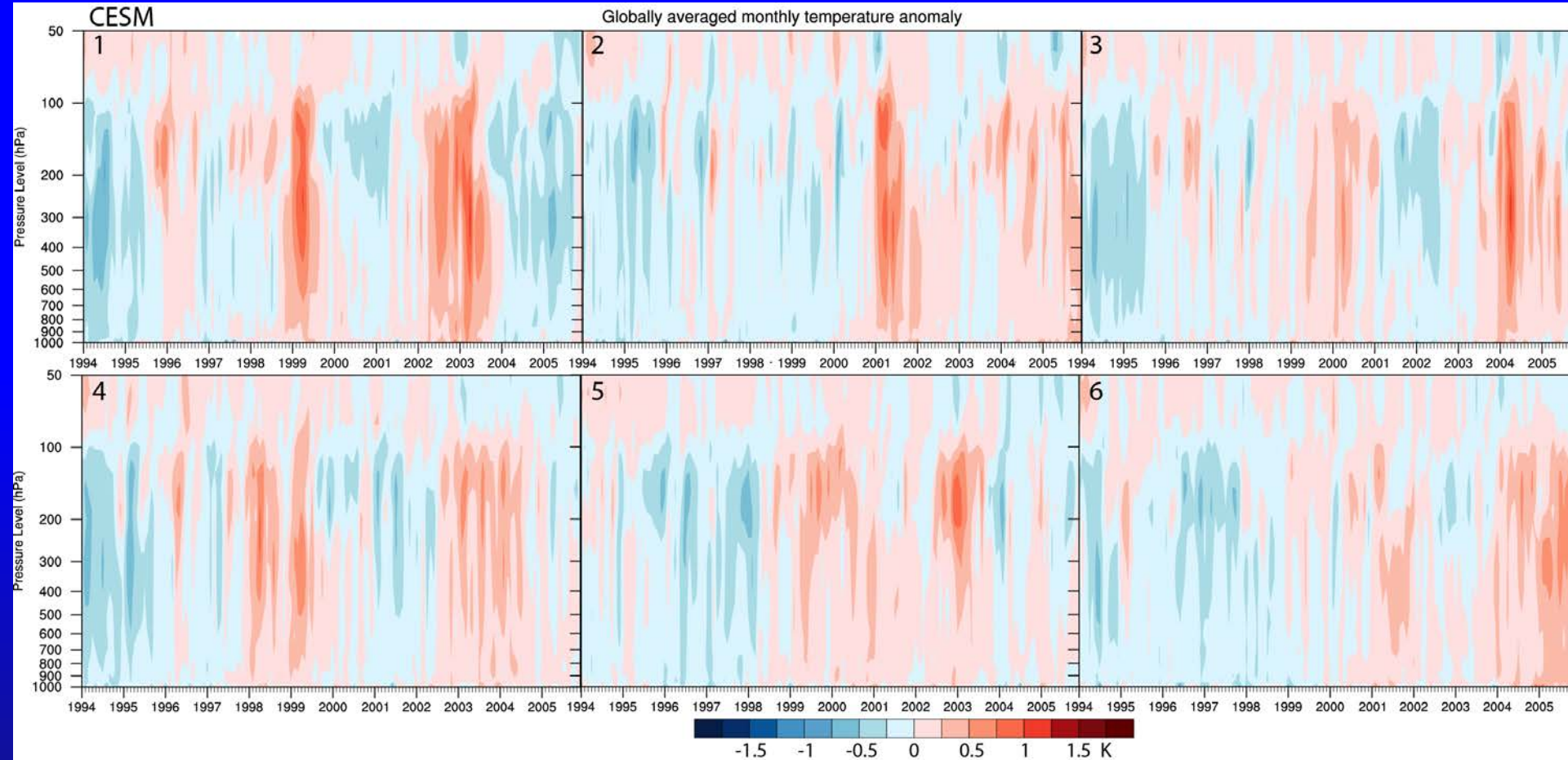
CAM 5.1

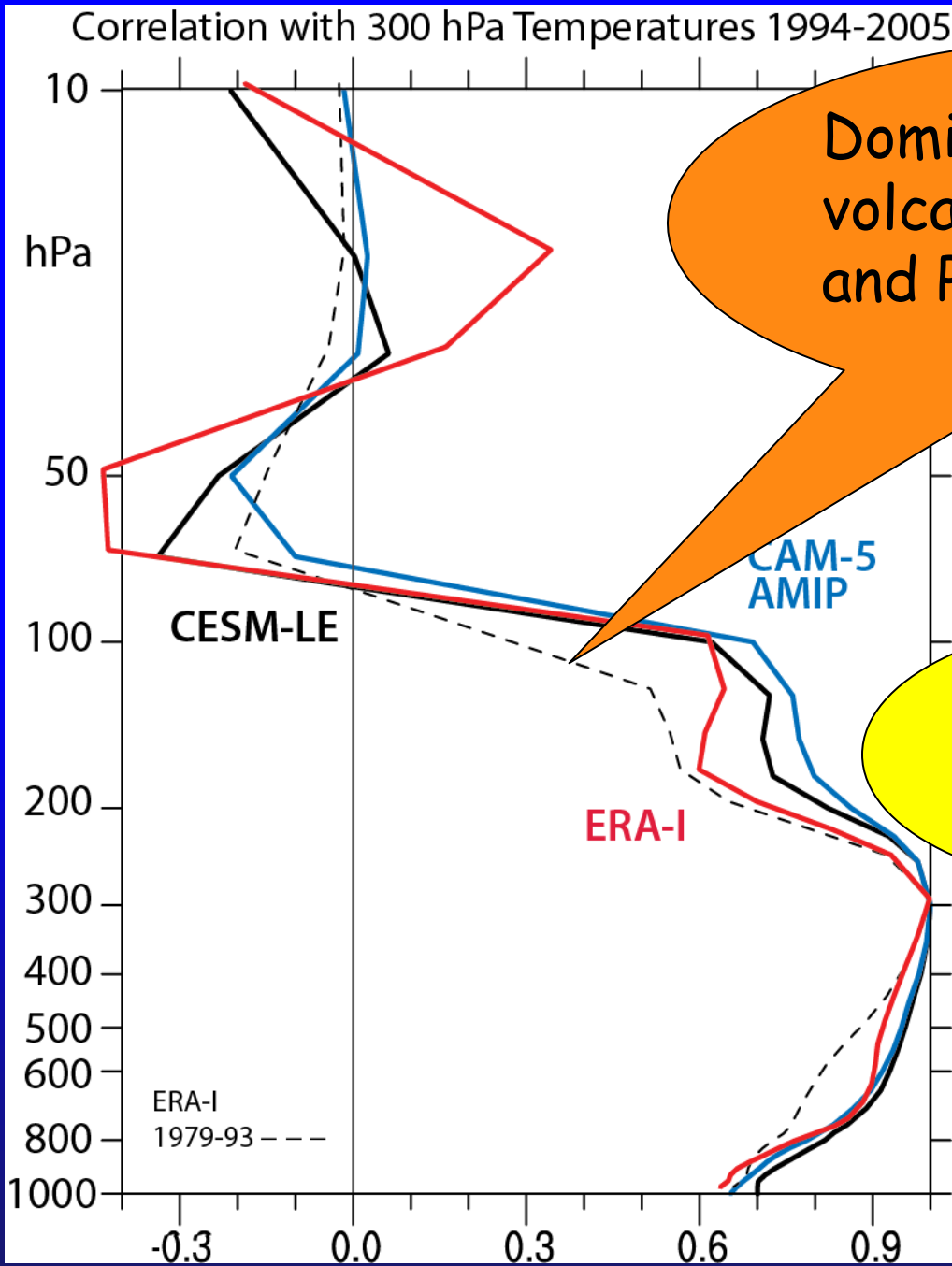
Focus on 1994-2005: post Pinatubo  
Large\_ensemble: 30 members  
AMIP: 1 member





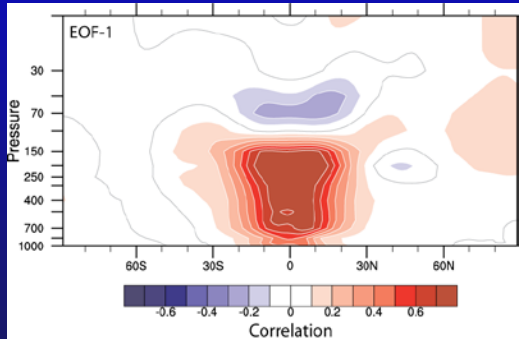
# 6 ensemble members



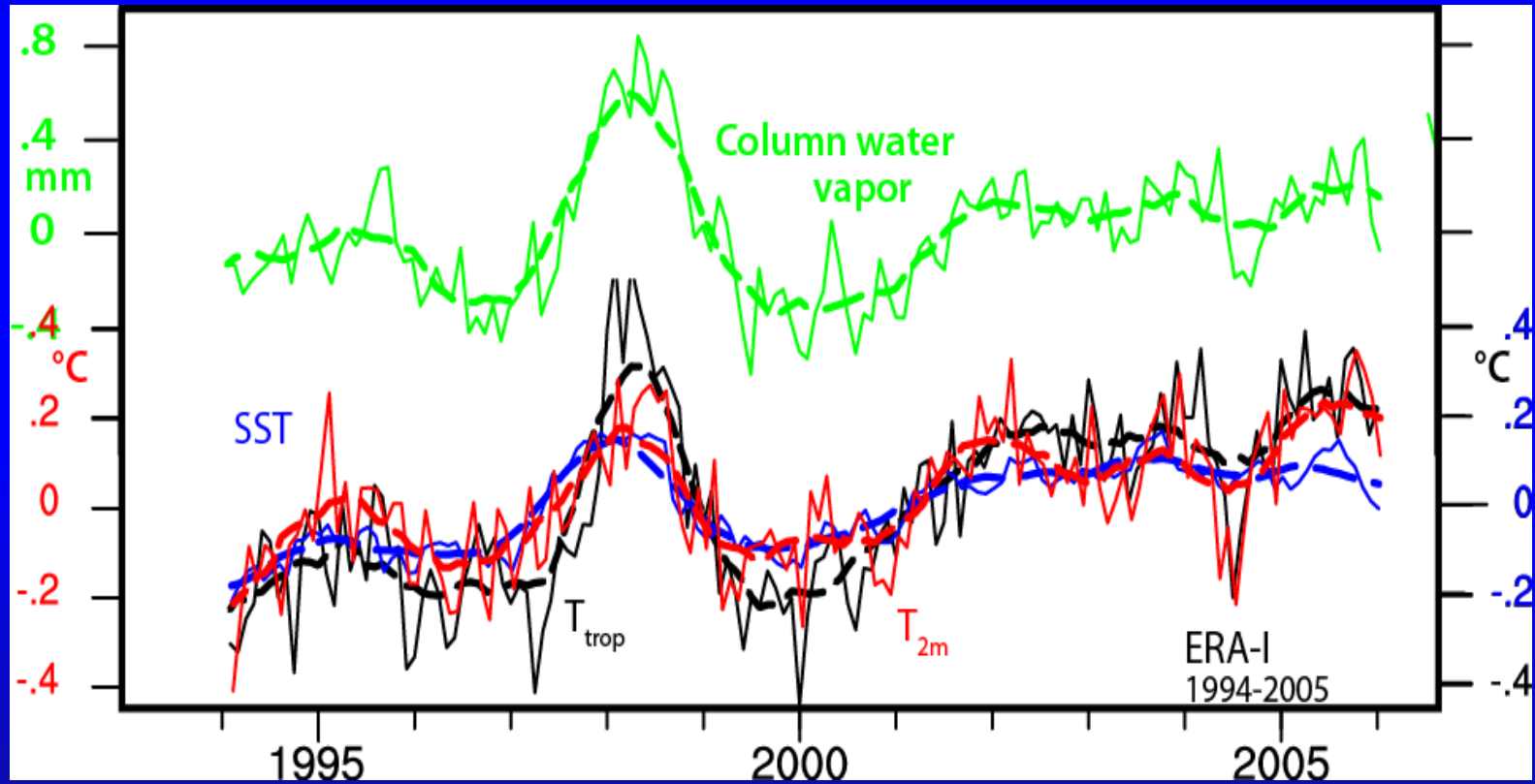


Dominated by 2 volcanoes: El Chichon and Pinatubo

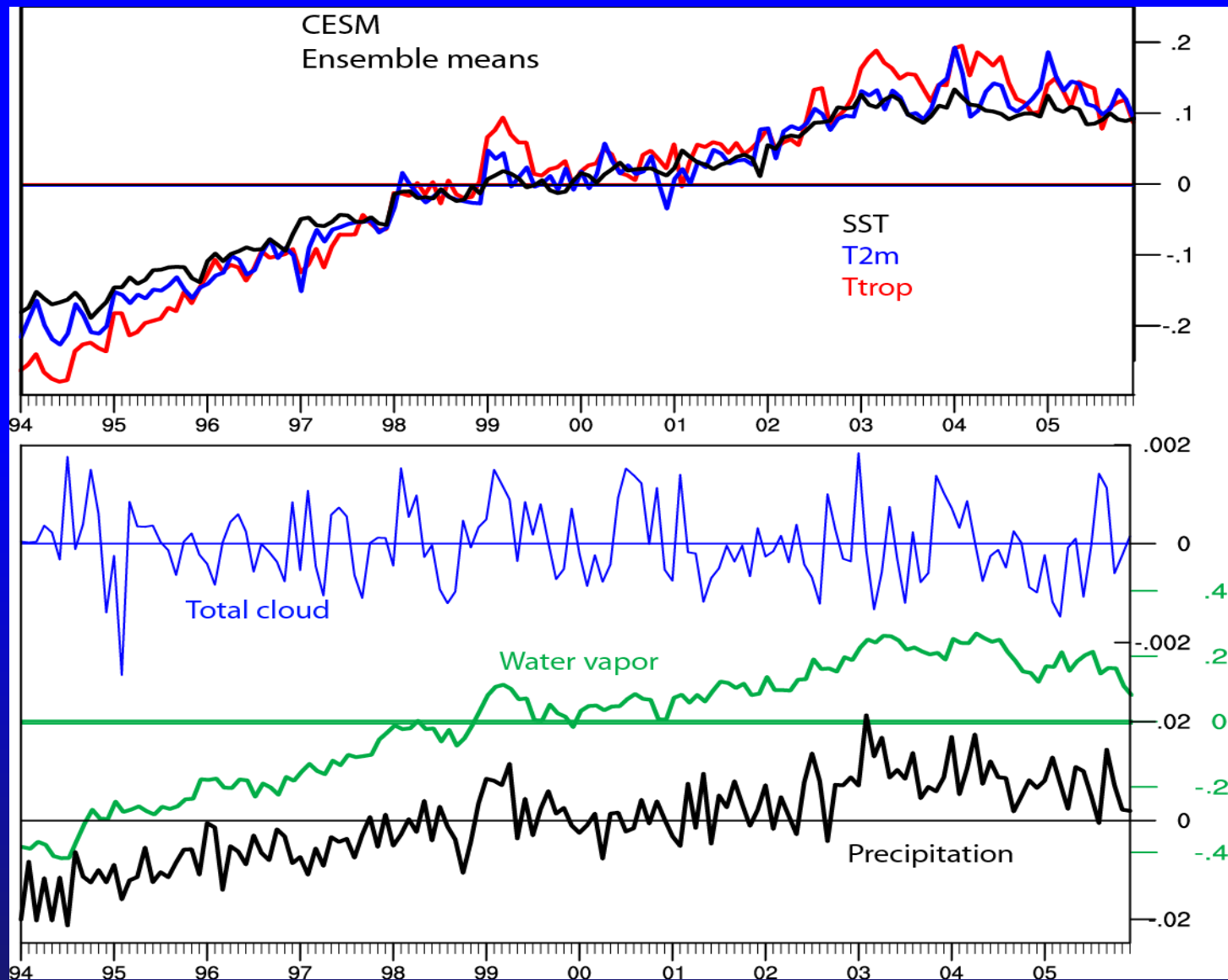
Model: "top heavy"



# CAM5-AMIP run: specified SSTs



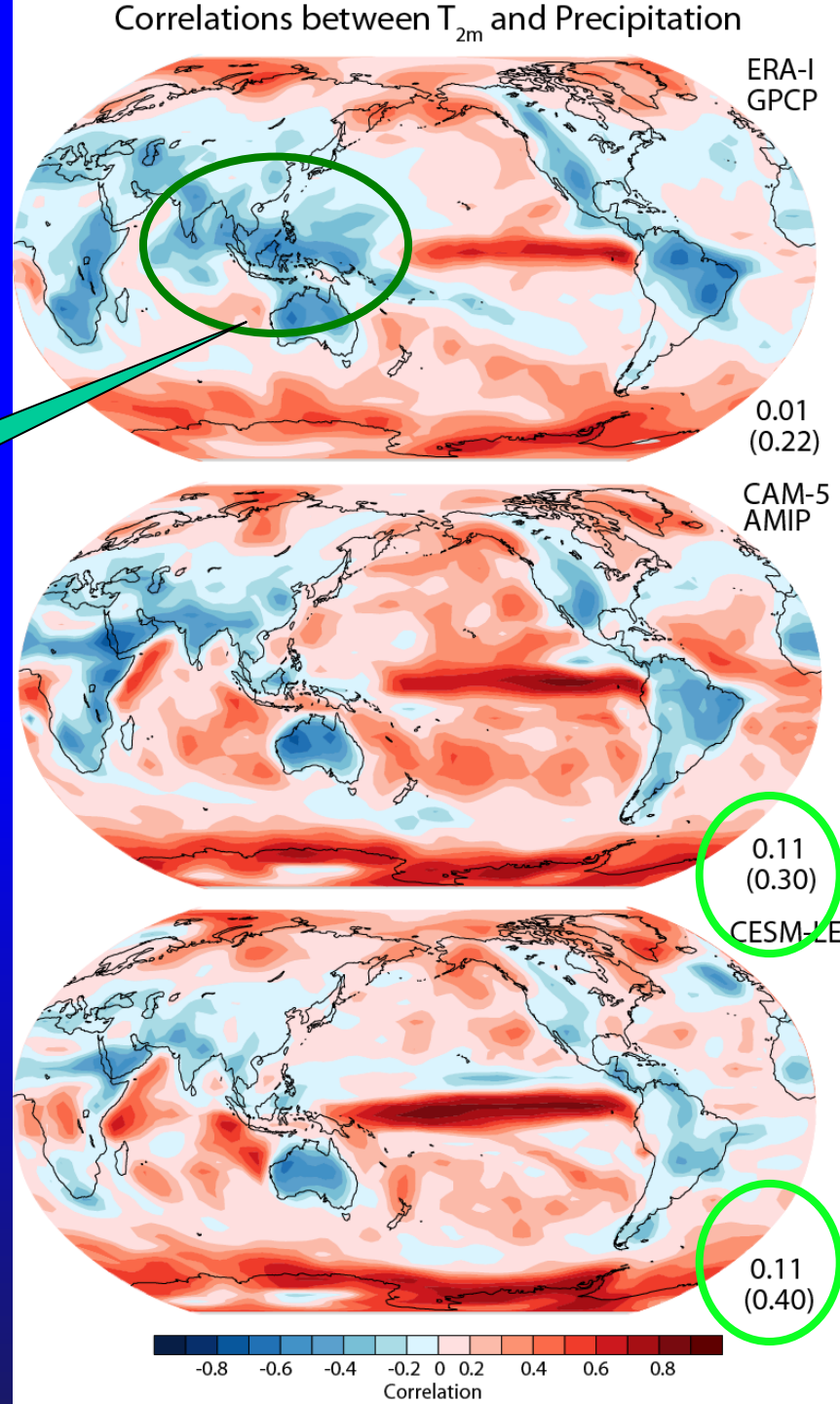
# CESM-LE ensemble mean 1994-2005



# Correlations between $T_{2m}$ and precipitation

Over ocean:  
observed -ve vs  
+ve in model

This is mostly ENSO:  
Walker circulation does  
not adequately suppress  
precipitation in W Pacific  
during El Niño in model.



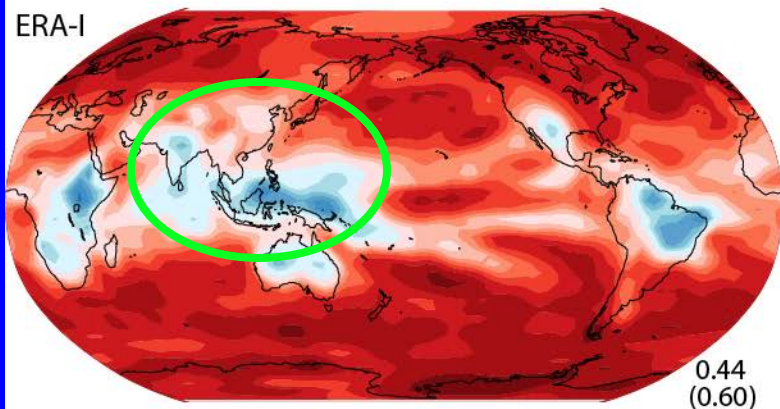


$T_{2m}$ -Wv

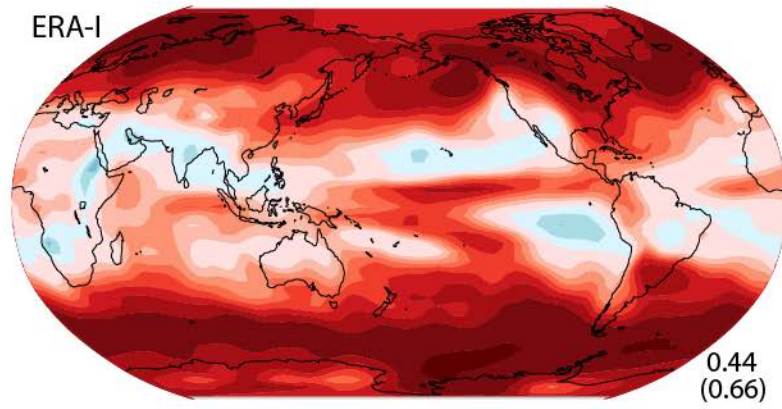
CORRELATIONS

$T_{trop}$ -Wv

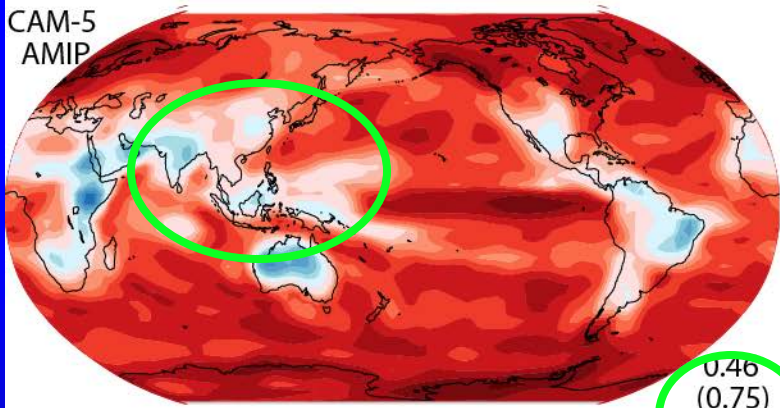
ERA-I



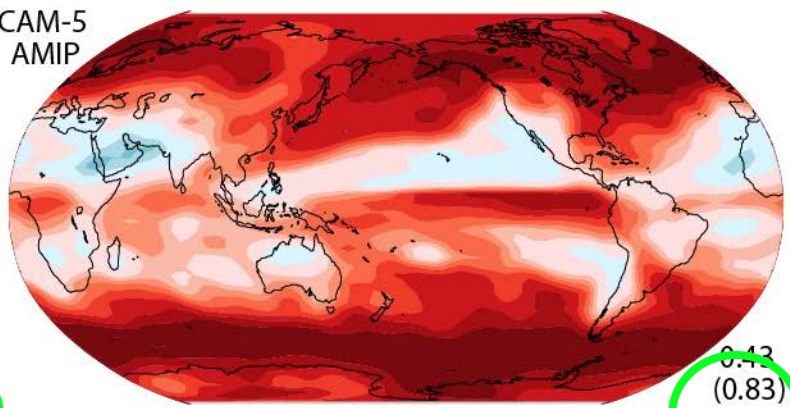
ERA-I



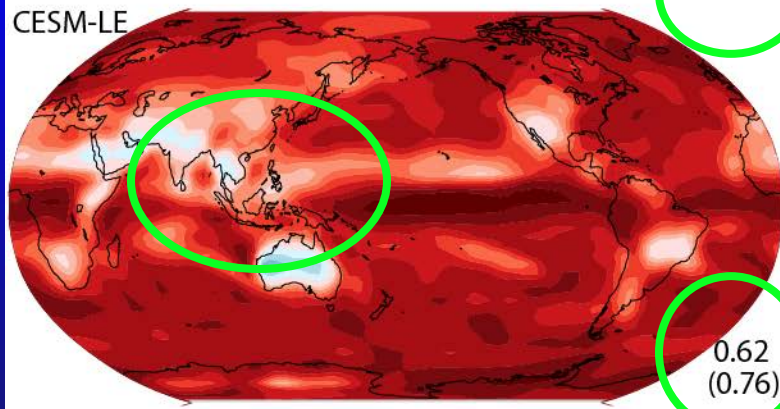
CAM-5  
AMIP



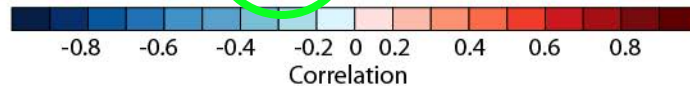
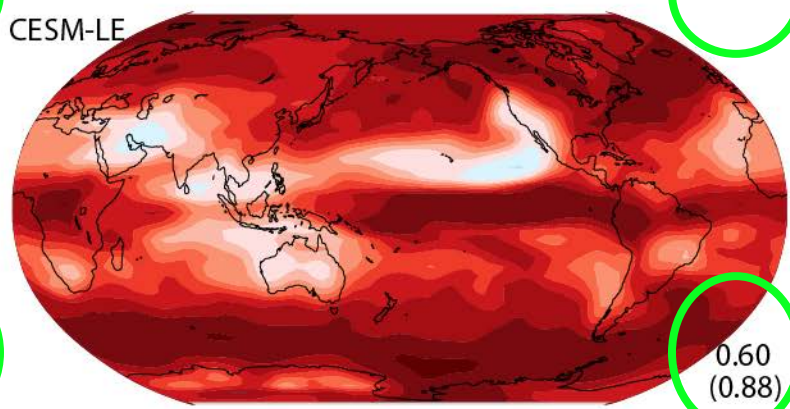
CAM-5  
AMIP



CESM-LE



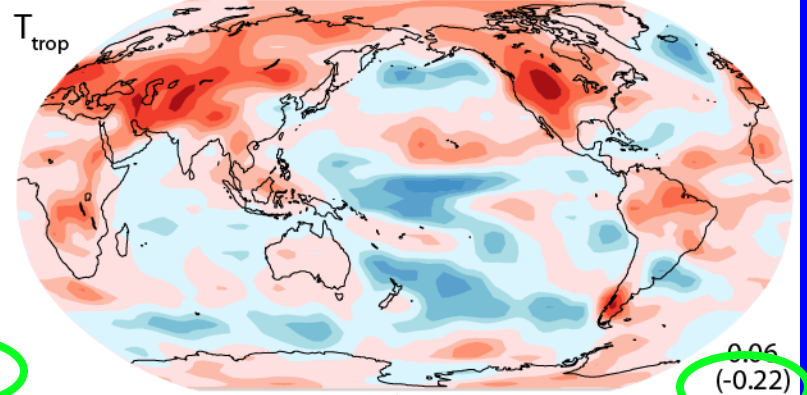
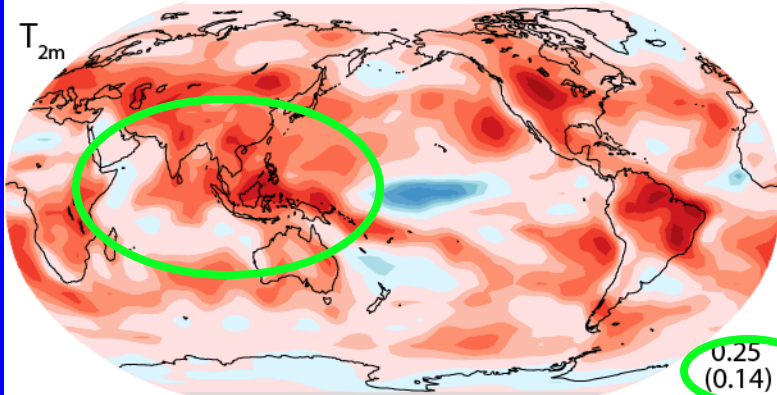
CESM-LE



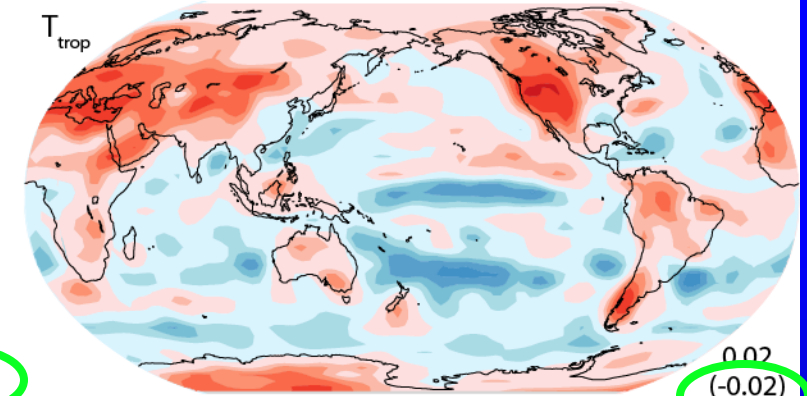
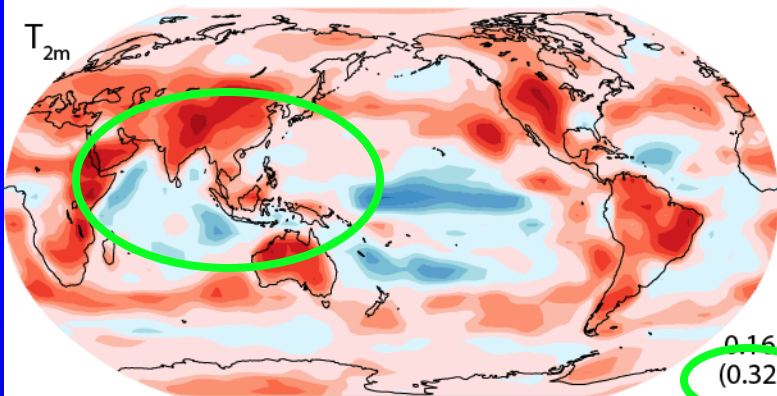


# Correlations: T - ASR

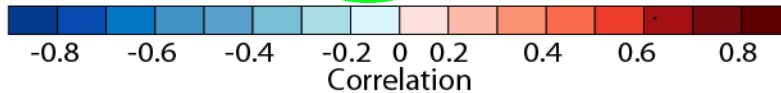
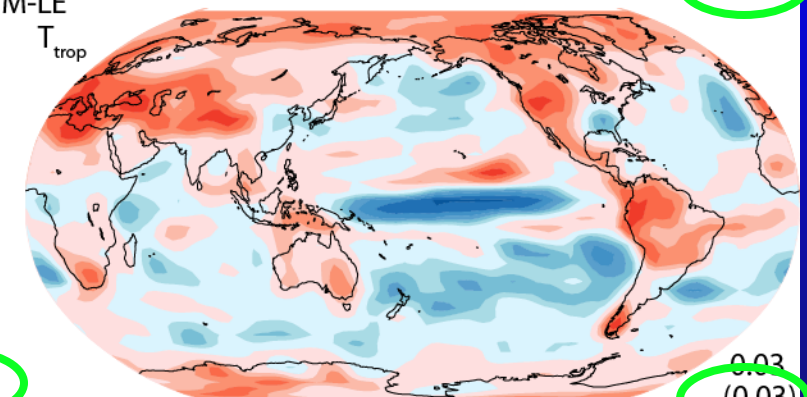
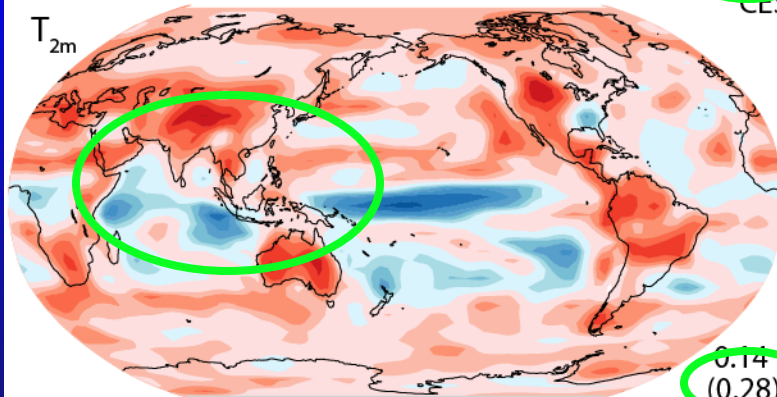
ERA-I - CERES



CAM5-AMIP

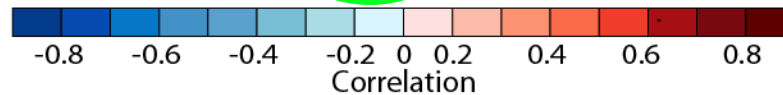
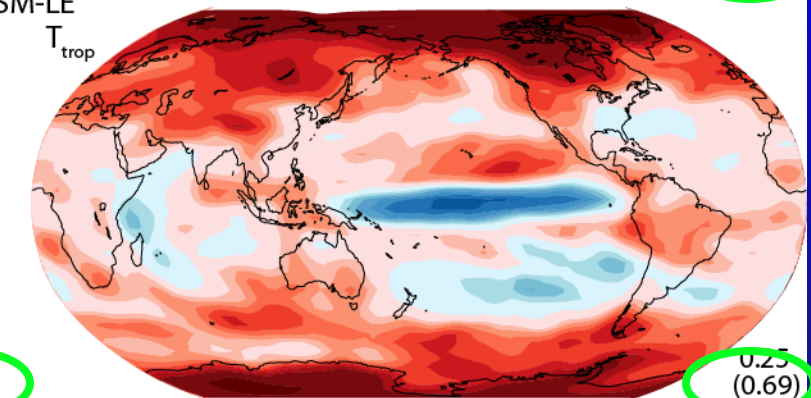
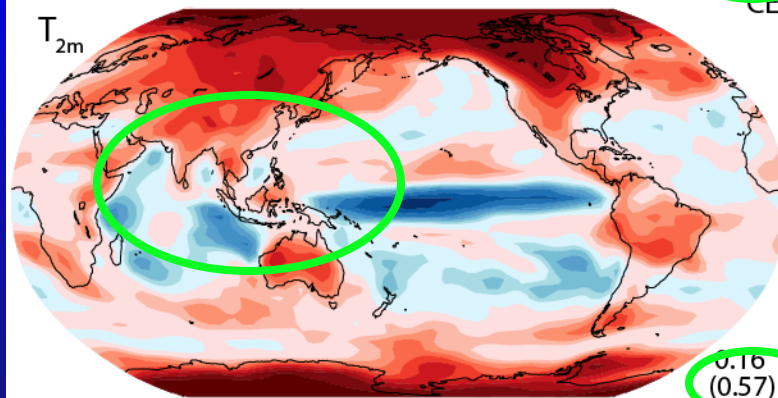
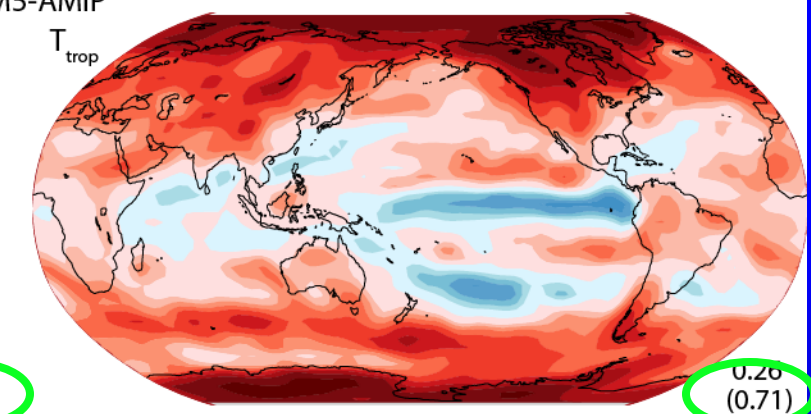
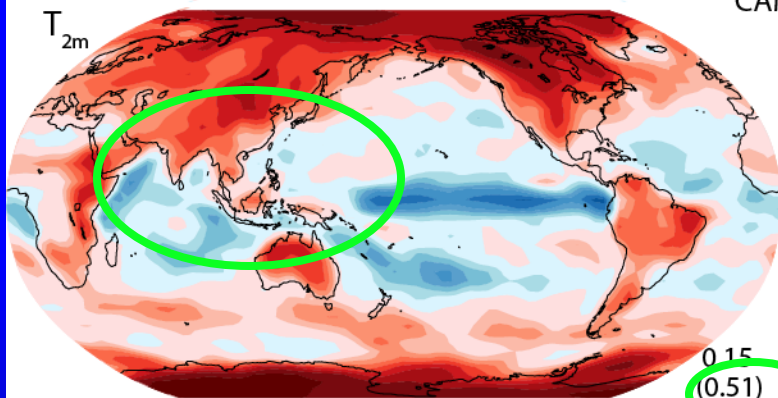
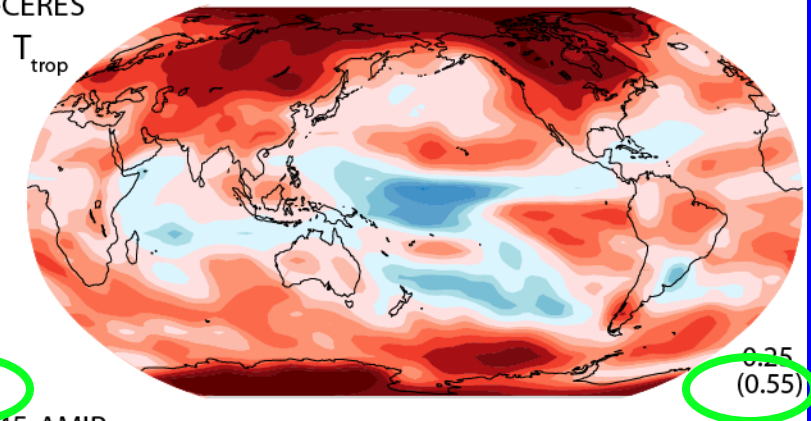
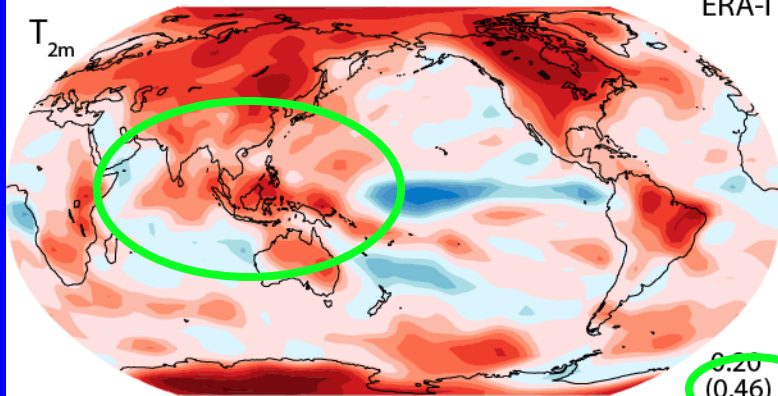


CESM-LE



# Correlations: T - OLR

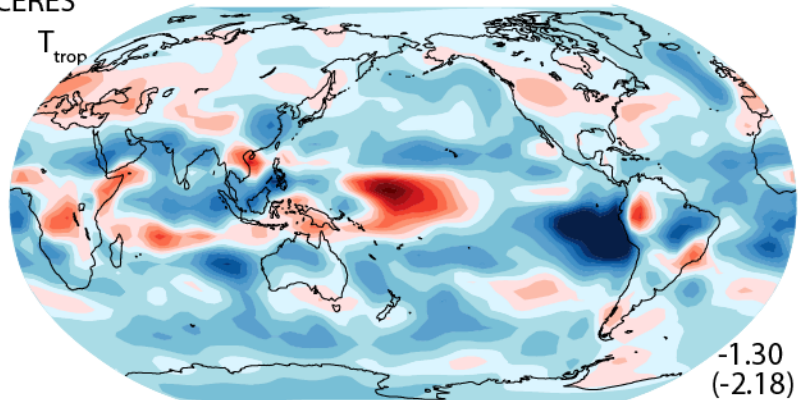
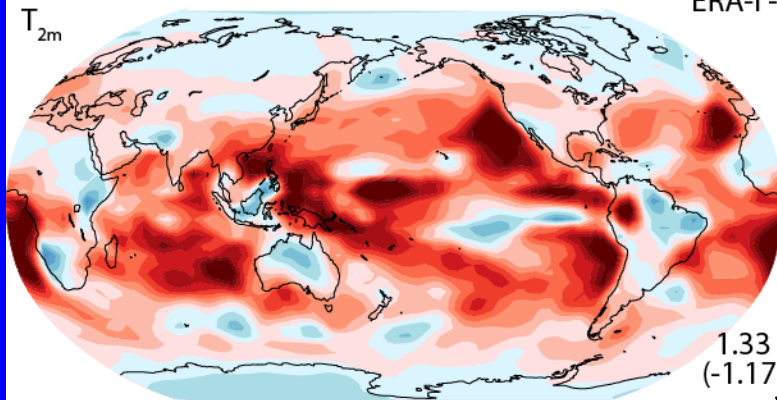
ERA-I - CERES





# Regressions: $T - R_T$

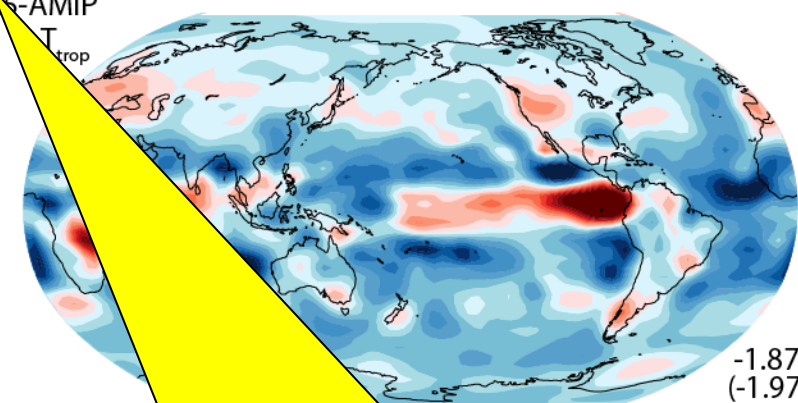
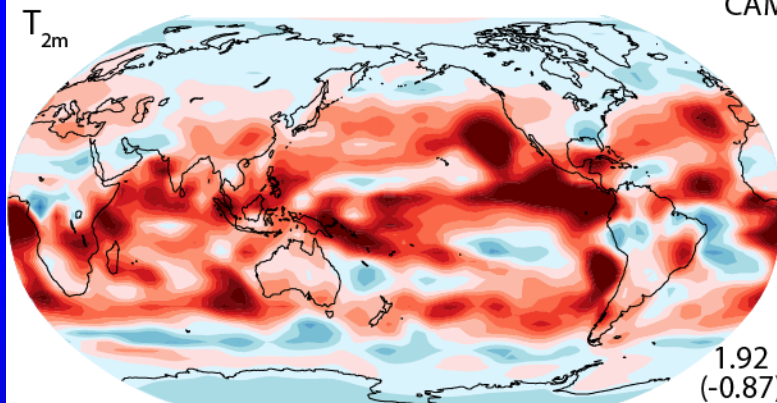
ERA-I - CERES



1.33  
(-1.17)

-1.30  
(-2.18)

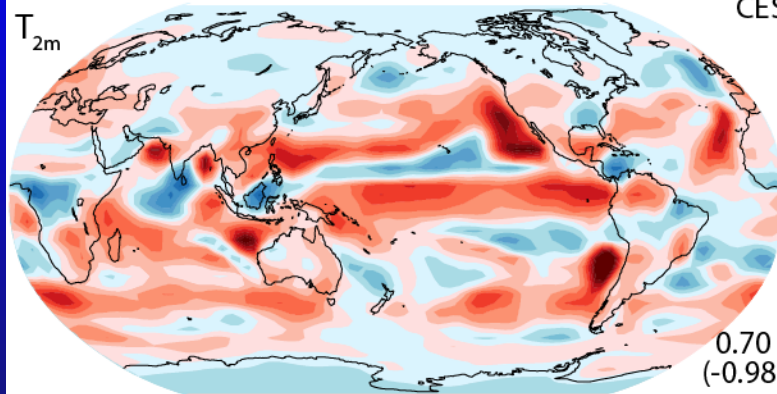
CAM5-AMIP



1.92  
(-0.87)

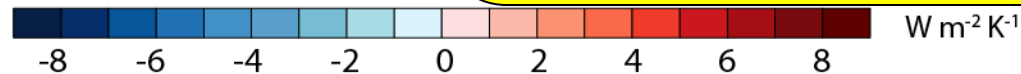
-1.87  
(-1.97)

CESM-LE



0.70  
(-0.98)

These change from strong +ve for global mean of local relationships to strong -ve for the global means.



# Feedbacks

$$R_T = F - \lambda \Delta T + \varepsilon$$

1994-2005

For  $T_{\text{trop}}$  (1000-150 hPa) regression in  $W m^{-2} K^{-1}$

	RT=	ASR-	OLR	
Observed:	-2.18	-0.68	1.49	$\pm 0.1$
AMIP	-1.96	-0.05	1.91	
CESM-LE	-1.71	0.08	1.79	

For  $T_{2m}$

	RT=	ASR-	OLR	
Observed:	-1.17	0.58	1.76	
AMIP	-0.87	0.92	1.78	
CESM-LE	-0.98	0.81	1.78	$W m^{-2} K^{-1}$

Negative feedback in model not as strong as observed, mainly because of ASR (cloud).

# Biases in model

The model does very well in many respects, but...

- ENSO too large, different.
- Vertical profile of temperature in CESM top heavy: is this because of enhanced ENSO or more generically related to deep convection?
- The dry zone in tropics is under represented.

# Biases over warm pool

- Walker circulation plays a key role (non-local links between E and W Pacific)
- Over oceans, high SST  $\rightarrow$  more precip & more water vapor and cloud  $\rightarrow$  ASR, and OLR less. In model extends to warm pool (not in obs).



# Biases in model

- Generally, Cloud  $\uparrow \rightarrow$  ASR  $\downarrow \rightarrow$   $T_{2m} \downarrow$
- Hence ASR and  $T_{2m}$  are +ve correlated over land and some places over ocean; **lot less in model**
- In model, over oceans,  $T_{2m} \uparrow \rightarrow$  cloud and convection  $\uparrow \rightarrow$  ASR  $\downarrow$  and -ve correlation
- Too much ASR as temperatures rise means total radiation feedbacks with temperatures are not negative enough.
- **Does this mean that climate sensitivity is too large in model?**