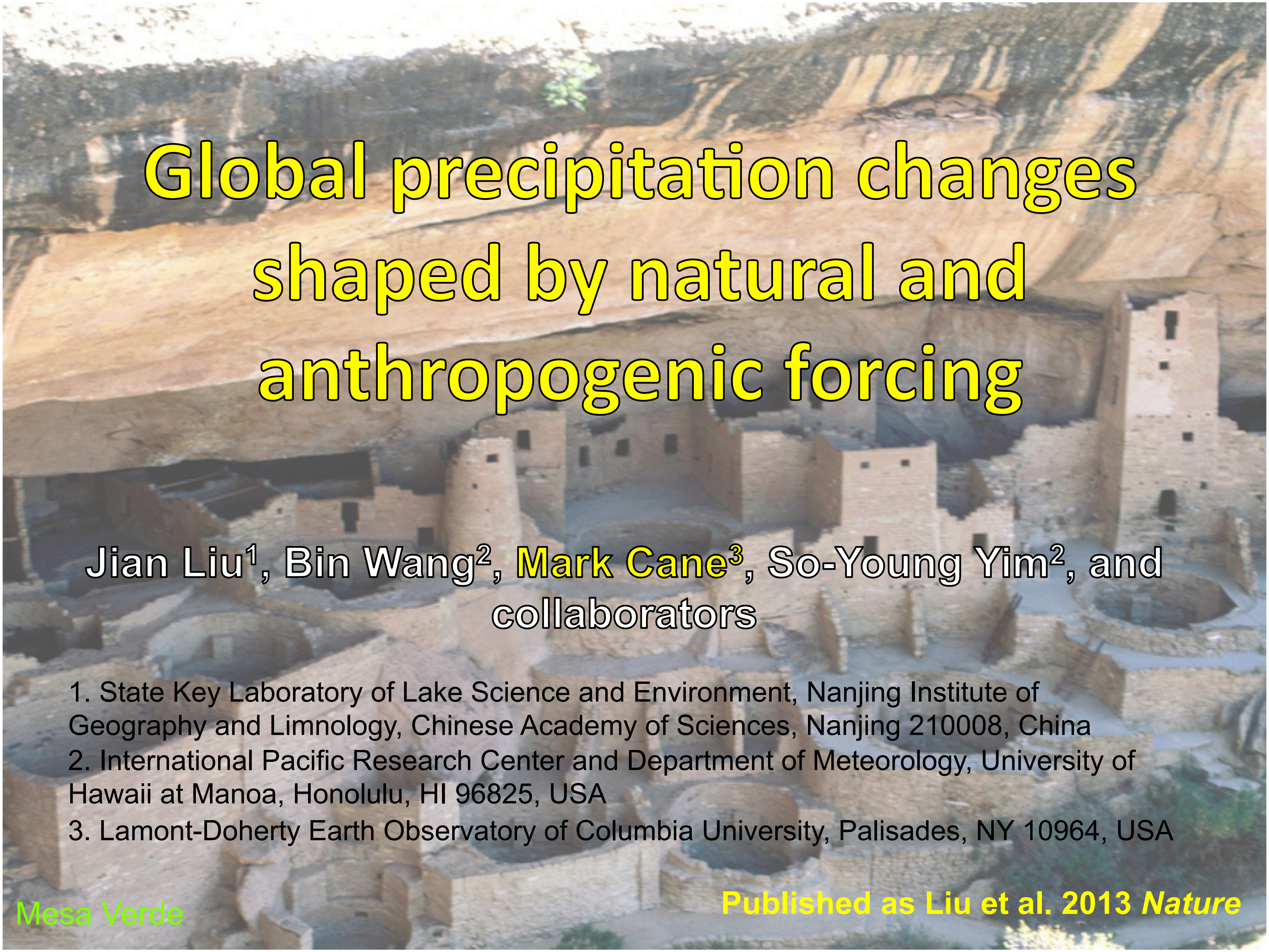

Global precipitation changes shaped by natural and anthropogenic forcing

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2. International Pacific Research Center and Department of Meteorology, University of Hawaii at Manoa, Honolulu, HI 96825, USA
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Mesa Verde

Published as Liu et al. 2013 *Nature*

In response to warming:

How much will it rain?

Theory and Models vs. Observations (at least, Wentz et al)

Where will it rain?

Which is related in part to the SST pattern in the tropical Pacific.

"El Niño like" vs. "La Niña like"

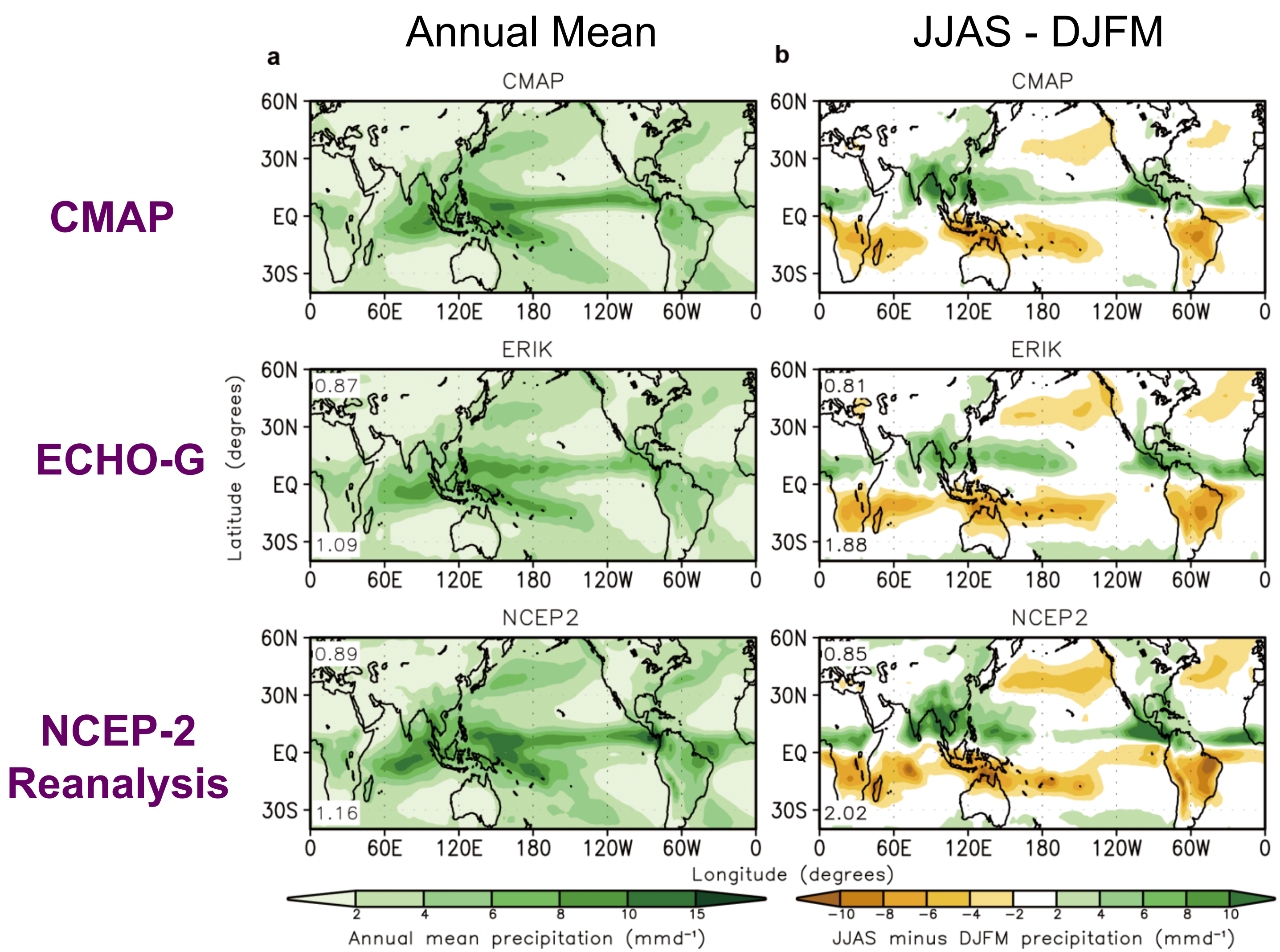
"Weaker Walker" vs. "Ocean Thermostat"

Some lessons from the last millennium -- primarily from a model (ECHO-G) simulation (ERIK) of the last millennium

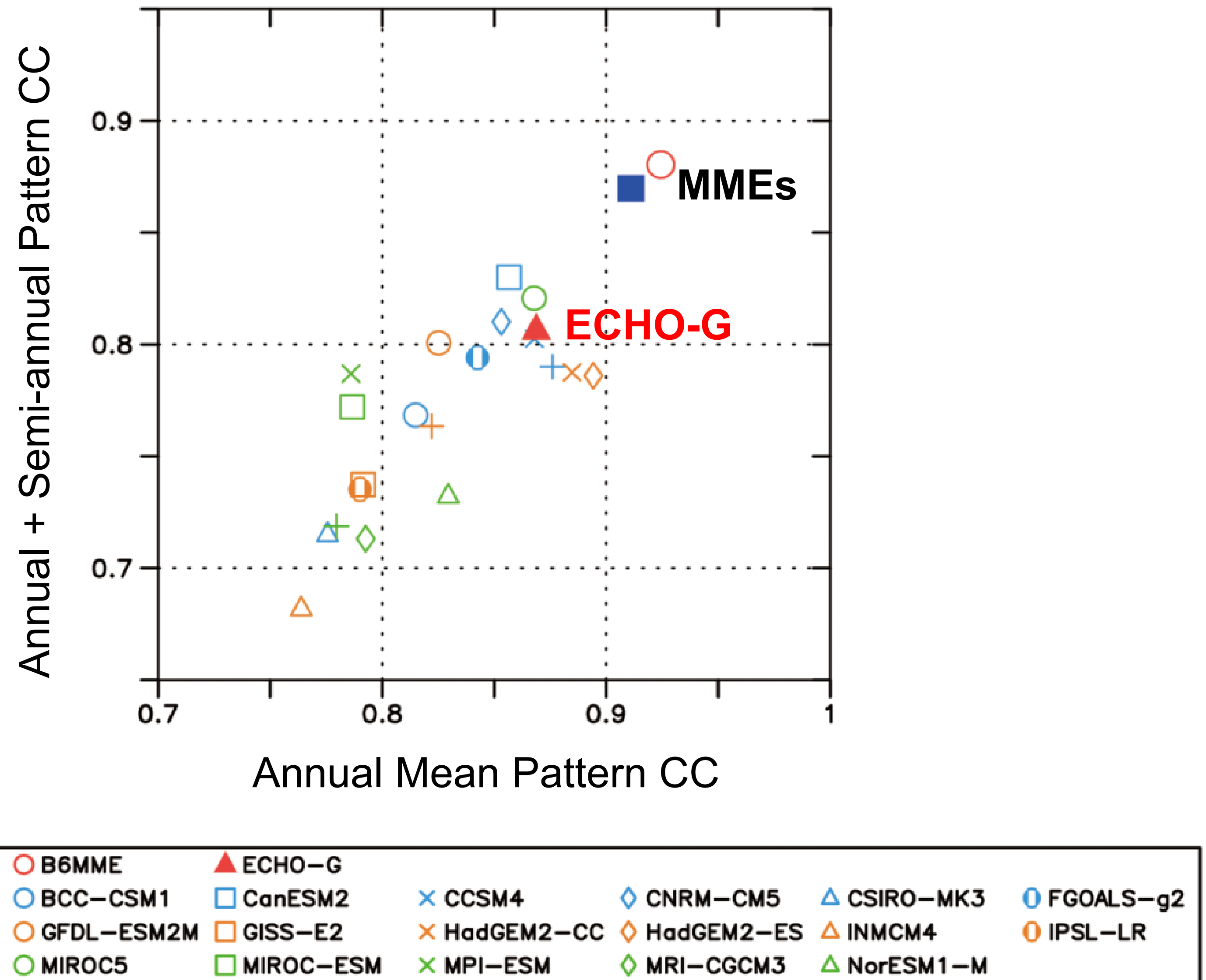
Greenhouse gases vs. Solar-Volcanic

Precipitation:

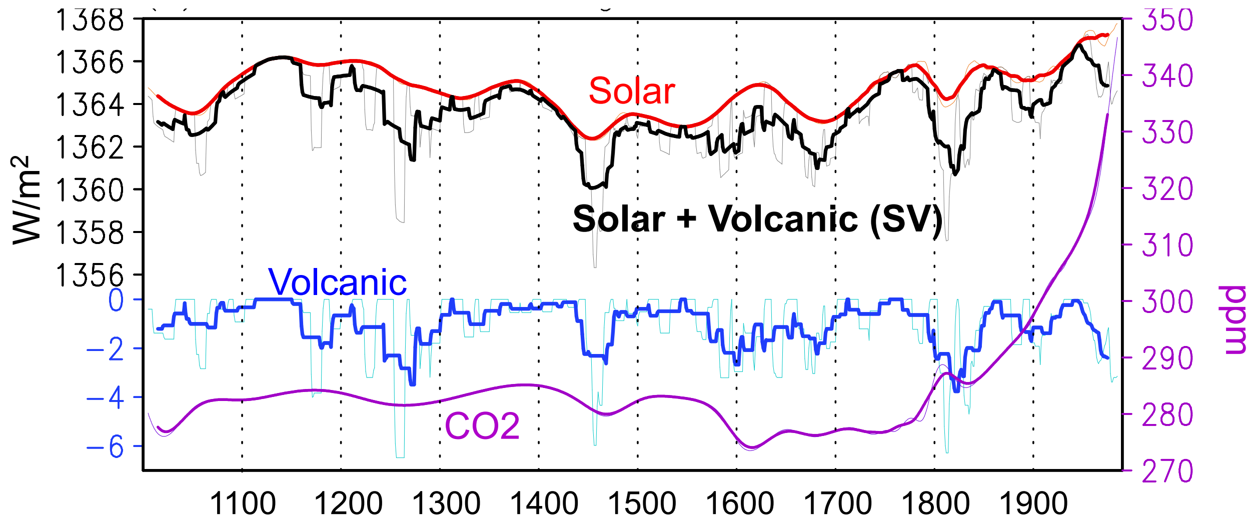
CMAP vs. ECHO-G vs. NCEP-2 Reanalysis



Precipitation (comparing to the obs. annual cycle): ECHO-G (ERIK) vs. 20 CMIP5 Models

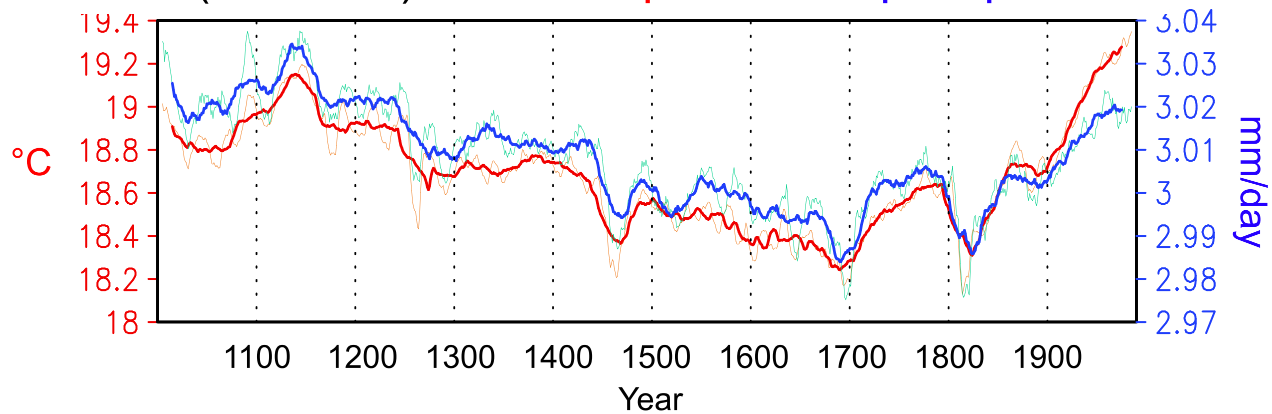


Solar-volcanic (SV) forcing & CO2 concentration (GHG)



FORCING

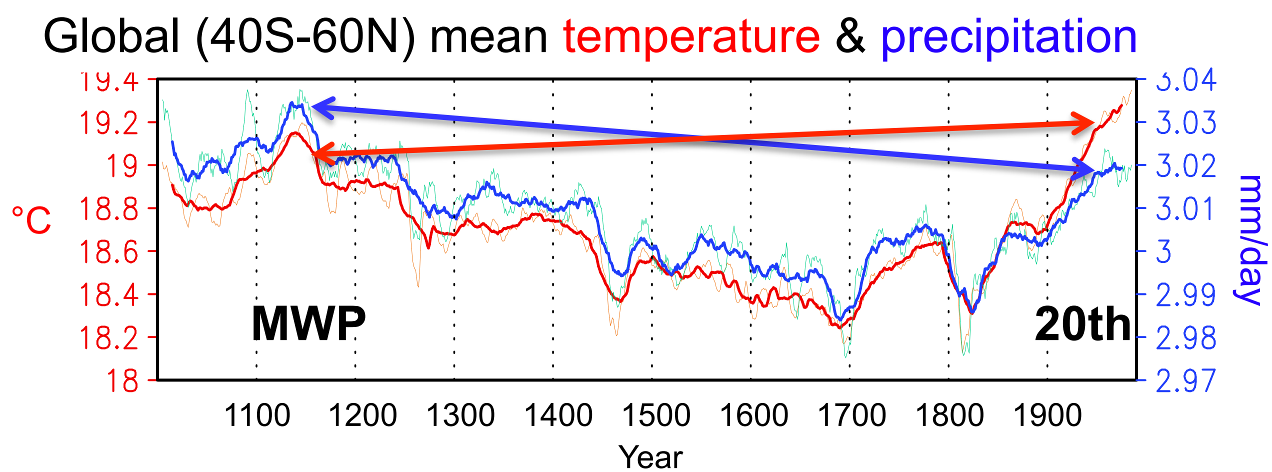
Global (40S-60N) mean temperature & precipitation



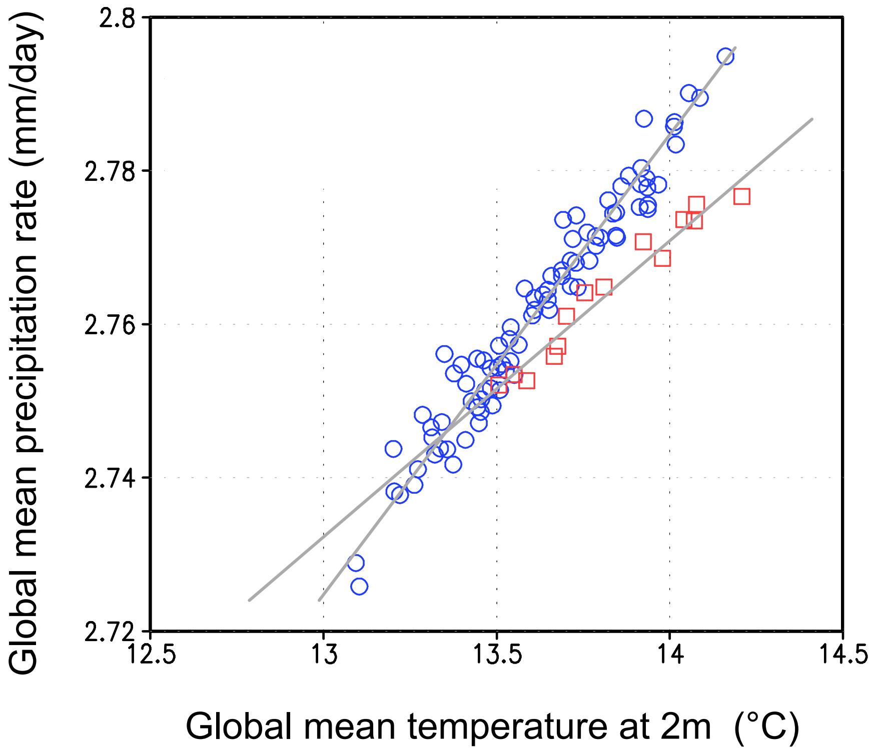
MODEL RESPONSE

From “ERIK”, an ECHO-G simulation of the last millennium
11-year running means

Global mean Temperature in the 20th Century is warmer than in the Medieval Warm Period (MWP) but the Precipitation rate is lower



Global mean precipitation rate versus global mean temperature

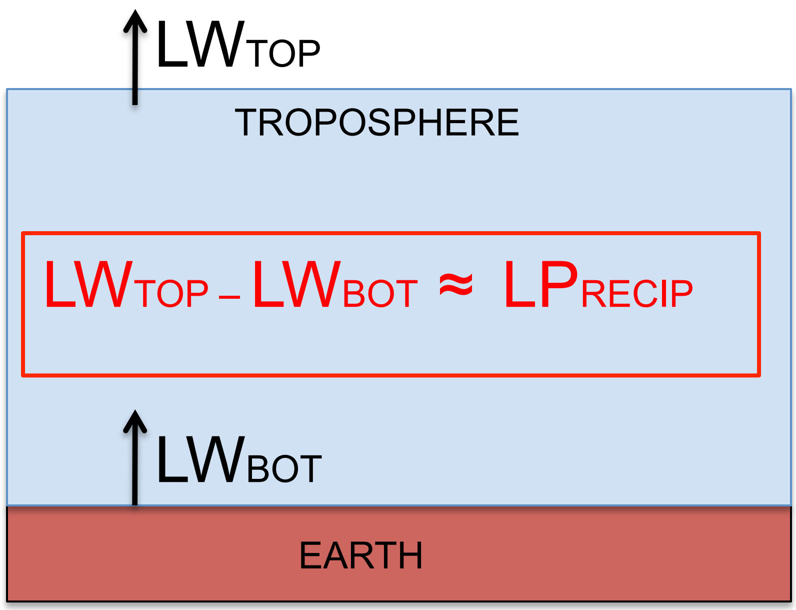


○ **Solar-Volcanic (SV)**
Pre-industrial era (1000-1850):
0.058 mm/day per °C = **2.1% /°C**

□ **GHG** + SV
Industrial era (1850-1990):
0.039 mm/day per °C = **1.4% /°C**

Data are decadal mean values from the ERIK forced millennial simulation.

The global tropospheric balance is
Longwave Flux Divergence ≈ Latent Heating



Since Δ LW is less for GHG warming than for Solar-volcanic warming, precipitation is less.

See Allan and Ingram 2002, *Nature*

In response to warming:

Where will it rain?

We look at the part related to the SST pattern in the tropical Pacific.

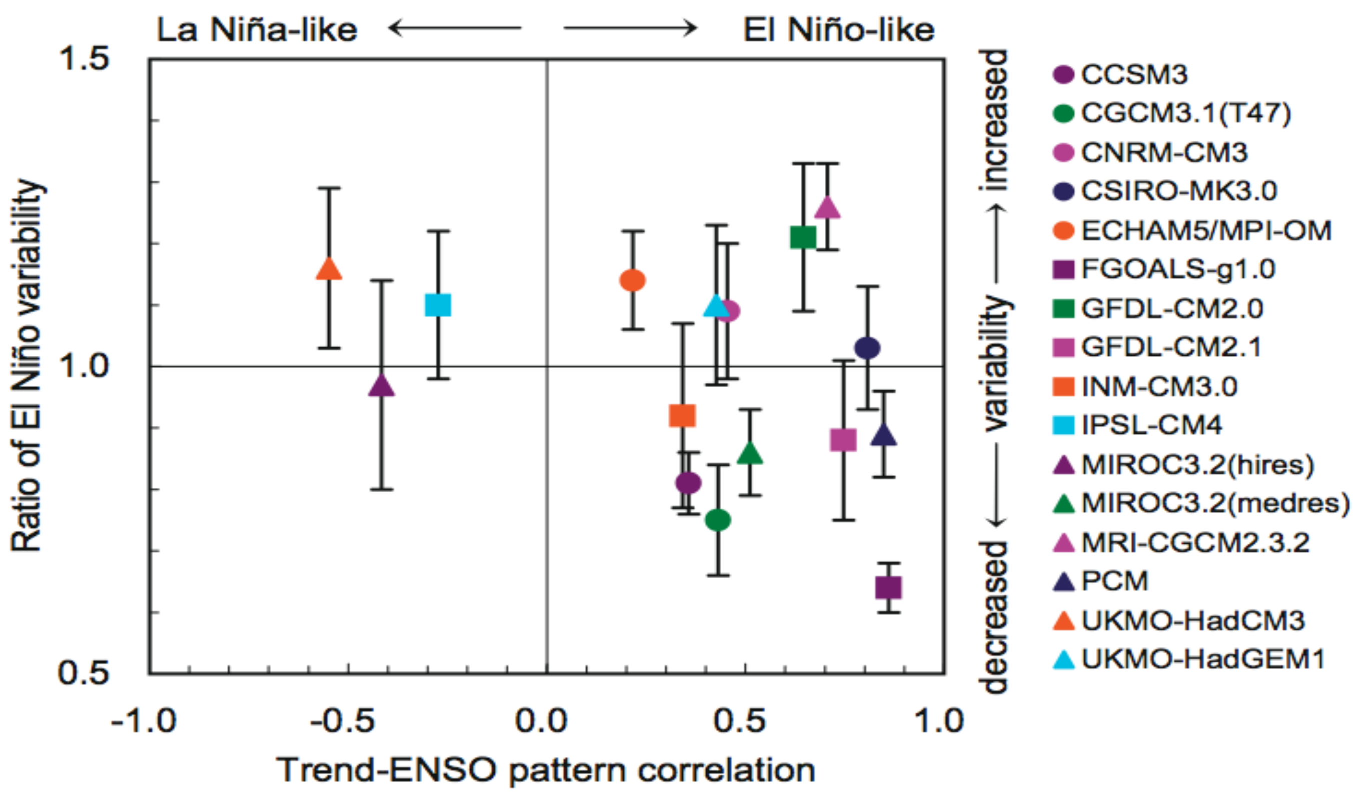
"El Niño like" vs. "La Niña like"

"Weaker Walker" vs. "Ocean Thermostat"

Which theory is right?
Both are sound physics.
Which is applicable?

The tropical Pacific in AR4

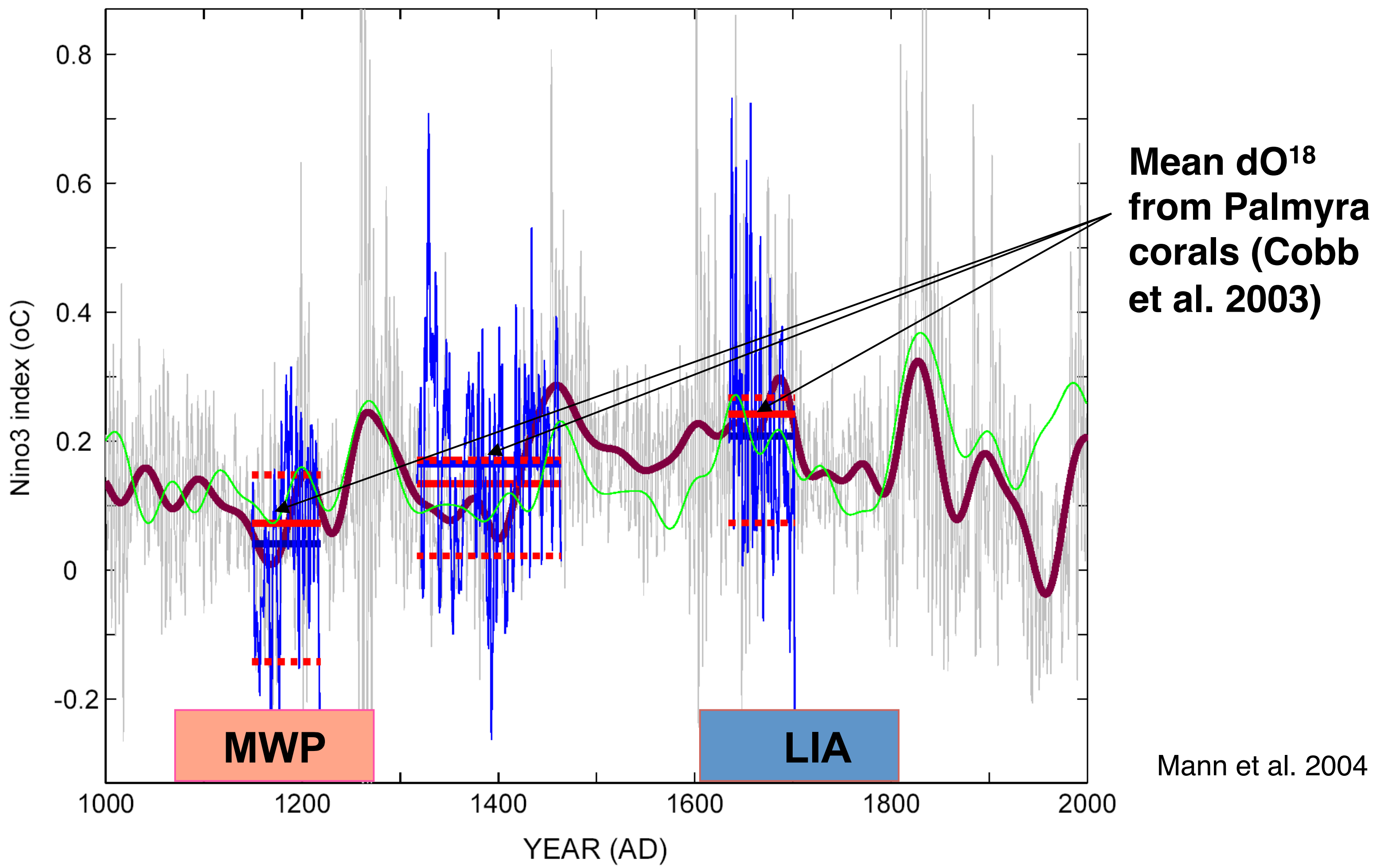
Weaker Walker → El Niño-like



Yamaguchi, K., and A. Noda, 2006: Global warming patterns over the North Pacific: ENSO versus AO. *J. Meteorol. Soc. Japan*, **84**, 221–241.

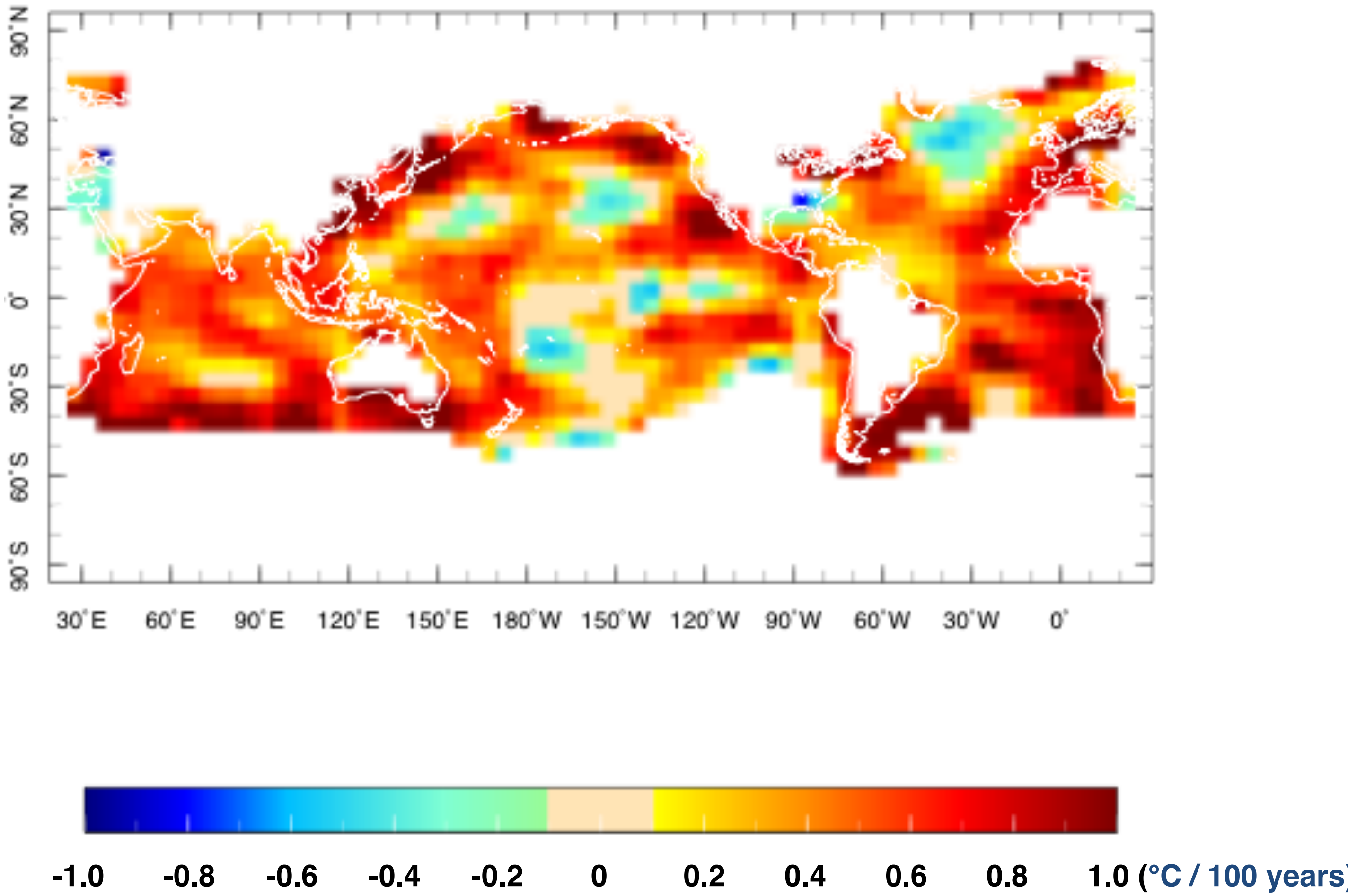
Zebiak-Cane Model Comparison with Fossil Corals from the Central Pacific

Ocean Thermostat ➔ La Niña-like



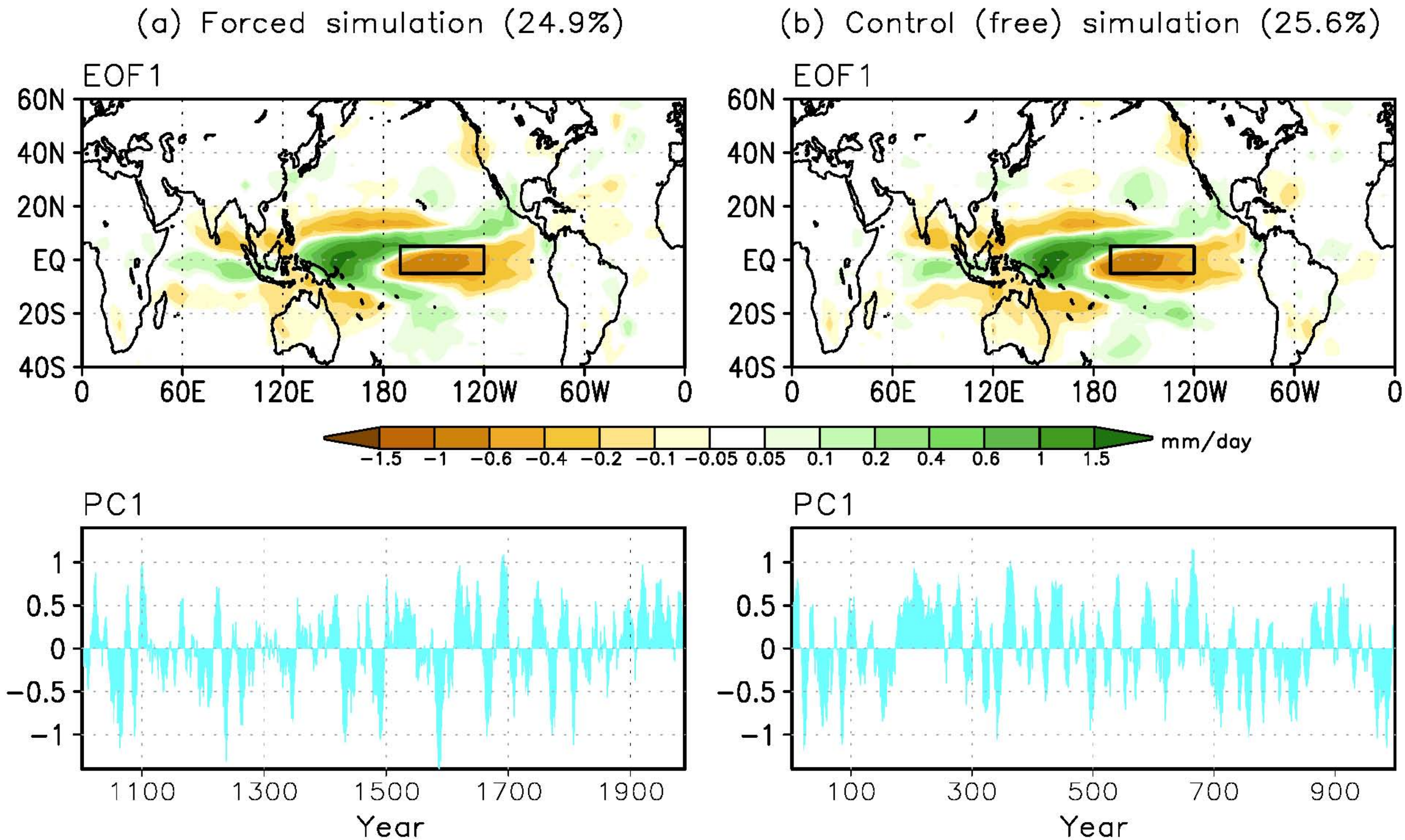
Mann et al. 2004

20th Century Temperature Trends

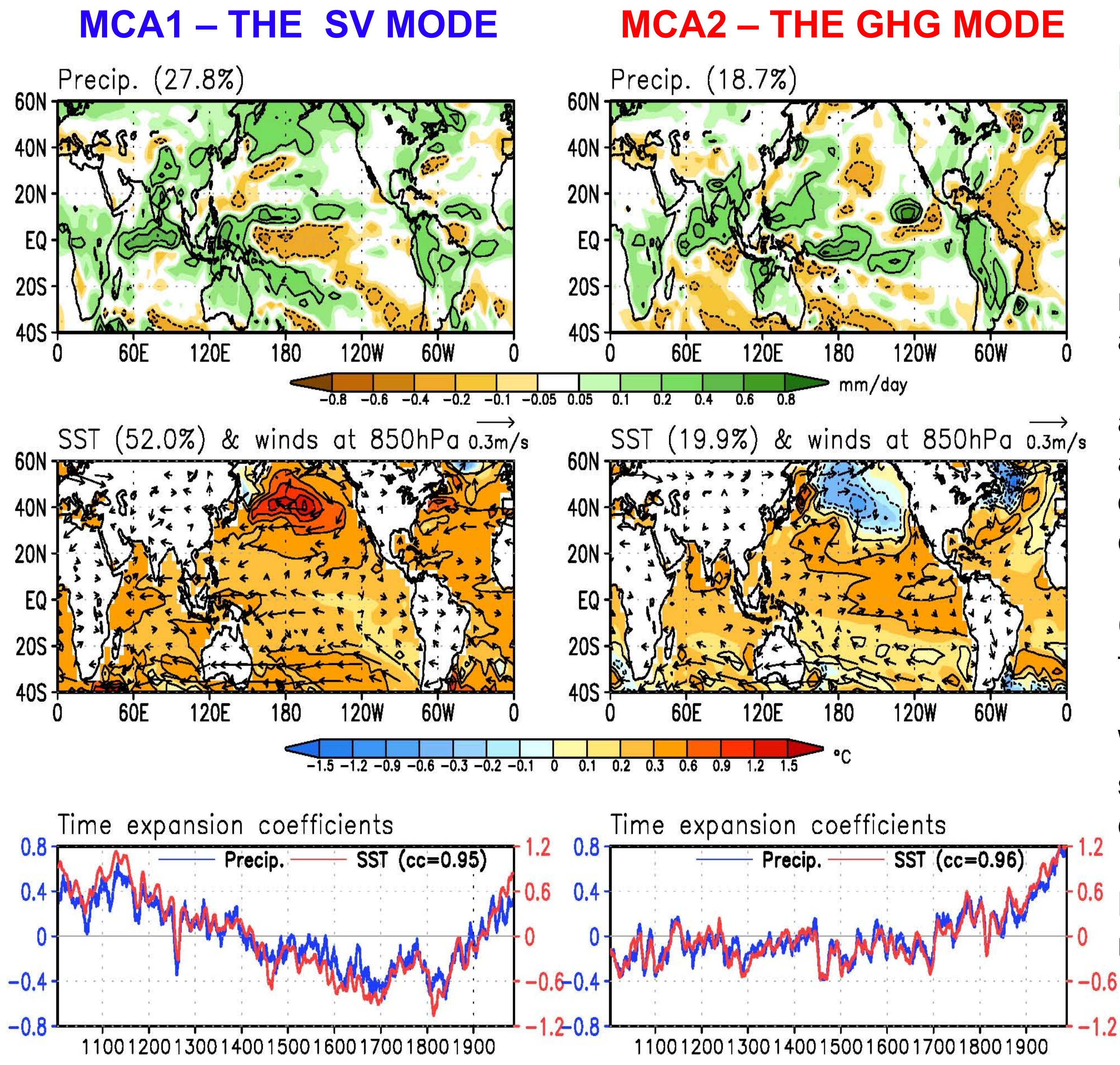


Updated from
Cane et al *Science* 1997

The internal mode of global precipitation



Spatial structure (upper) and principal component (lower) of the internal (unforced) mode. Based on 11-year running means. The box is the Nino3.4 region.



First remove PC1 of precipitation, the leading internal mode (IM).

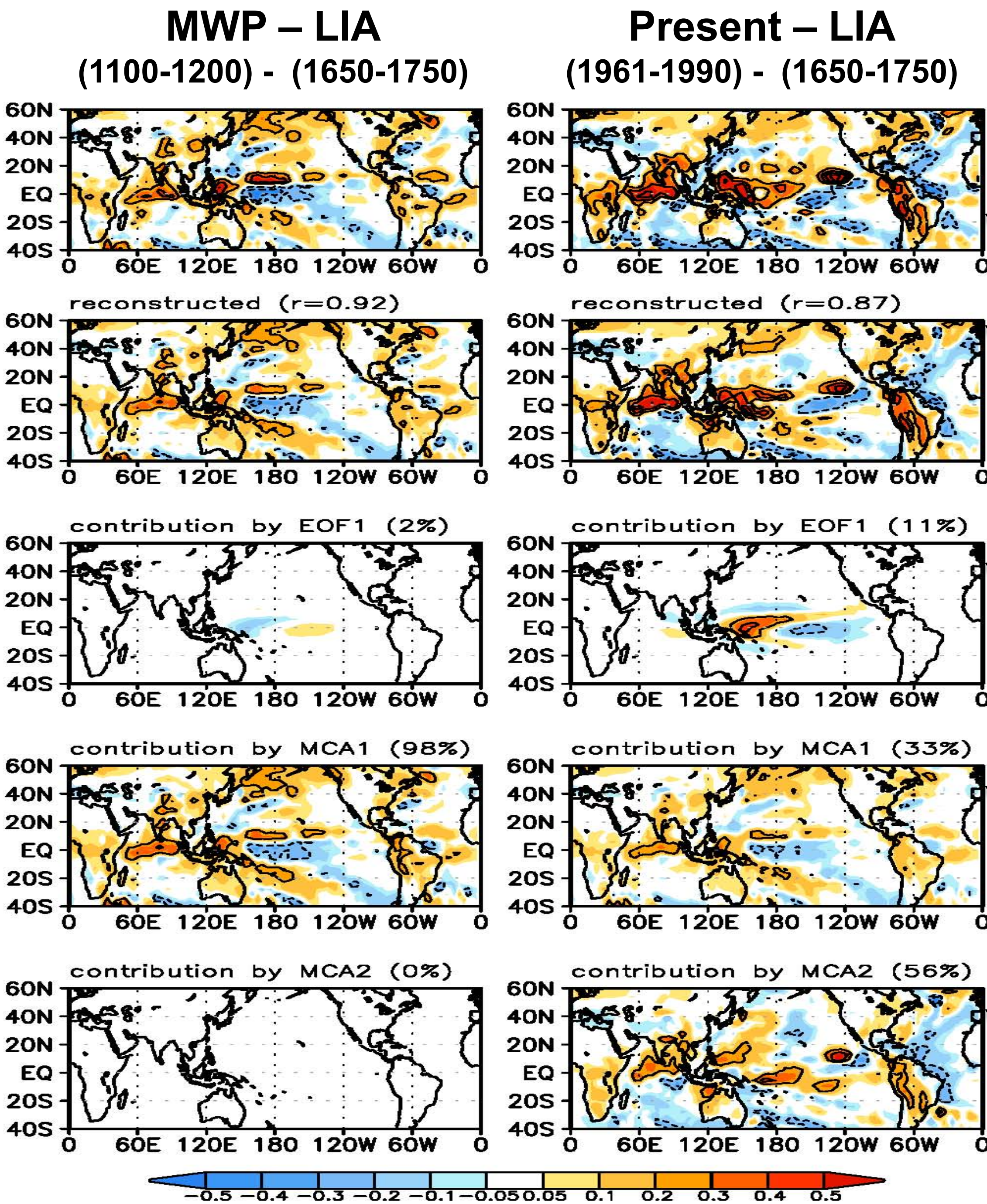
(left) The leading SVD mode of the precipitation and SST for the period 1000-1990. Also shown are the 850hPa wind anomalies regressed onto the time expansion coefficient of SST.

(right) As above but for the second SVD mode.

Wind vectors shown are significant above 95% confidence level.

Based on 11-year running means.

Reconstruction and attribution of the global precipitation changes



Total precipitation in the forced run.

Reconstructed precipitation = internal (IM) + SV + GHG modes.
The r values (.92, .87) are the correlation coefficients between the reconstructed and total fields.

IM contribution (2%, 11%)
The % values is the fractional variance explained by each mode in the reconstructed fields.

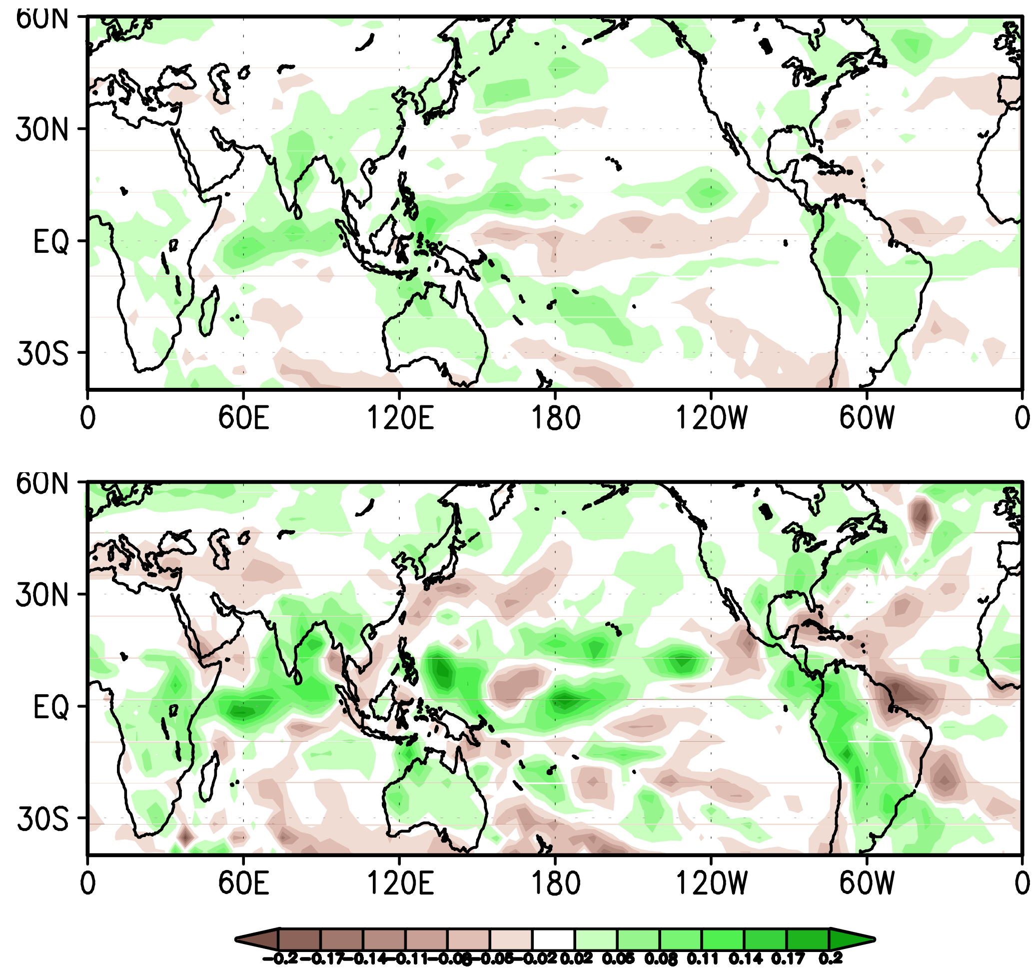
SV mode contribution (98%, 33%)

GHG mode contribution (0%, 56%)

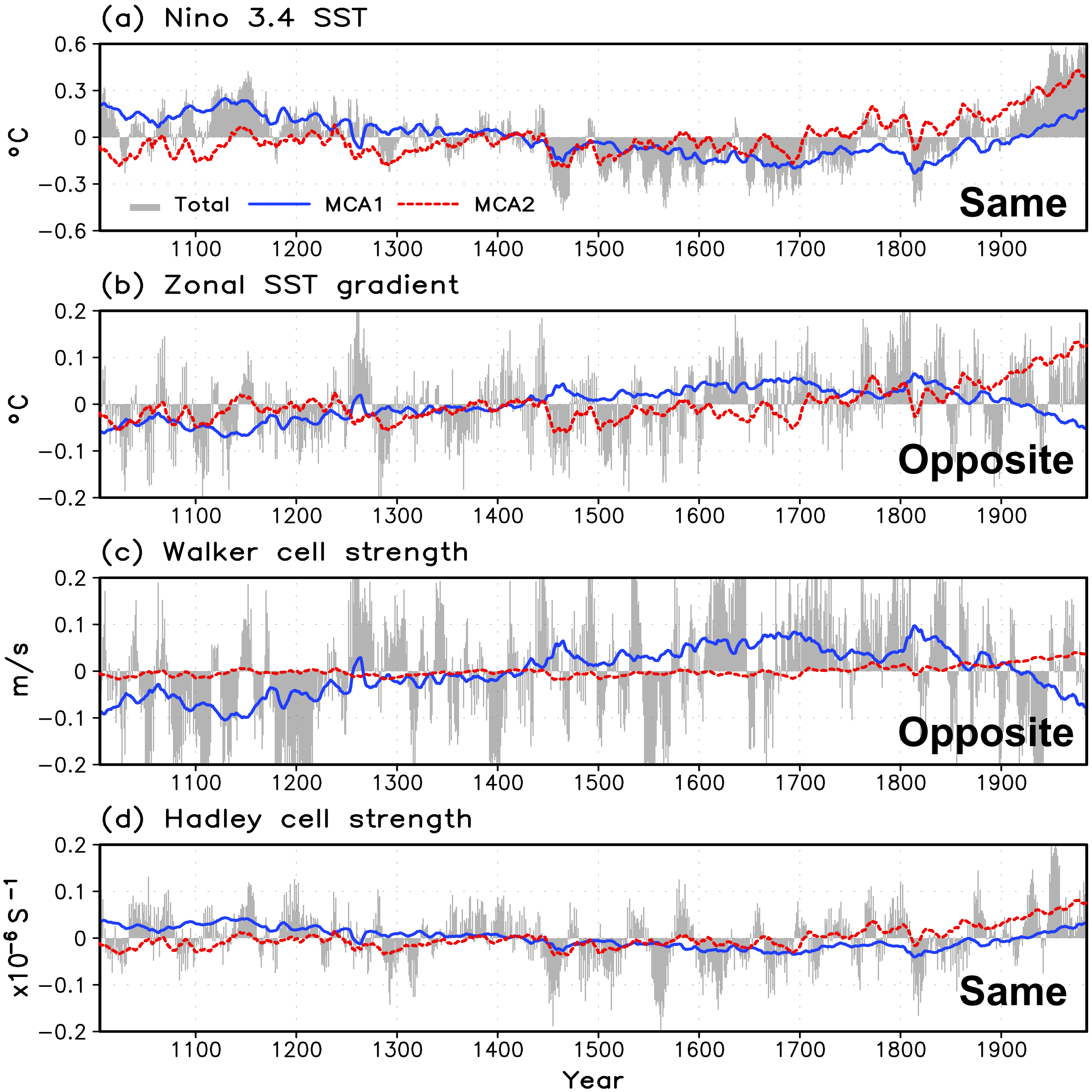
Precipitation regressed onto

Solar-volcanic (SV) forcing

Greenhouse Gas(GHG) forcing



SV MODE (MCA1) and GHG MODE (MCA2) Characteristics 1000-1990



The grey curve is the total anomaly.

(a)Nino 3.4 SST.

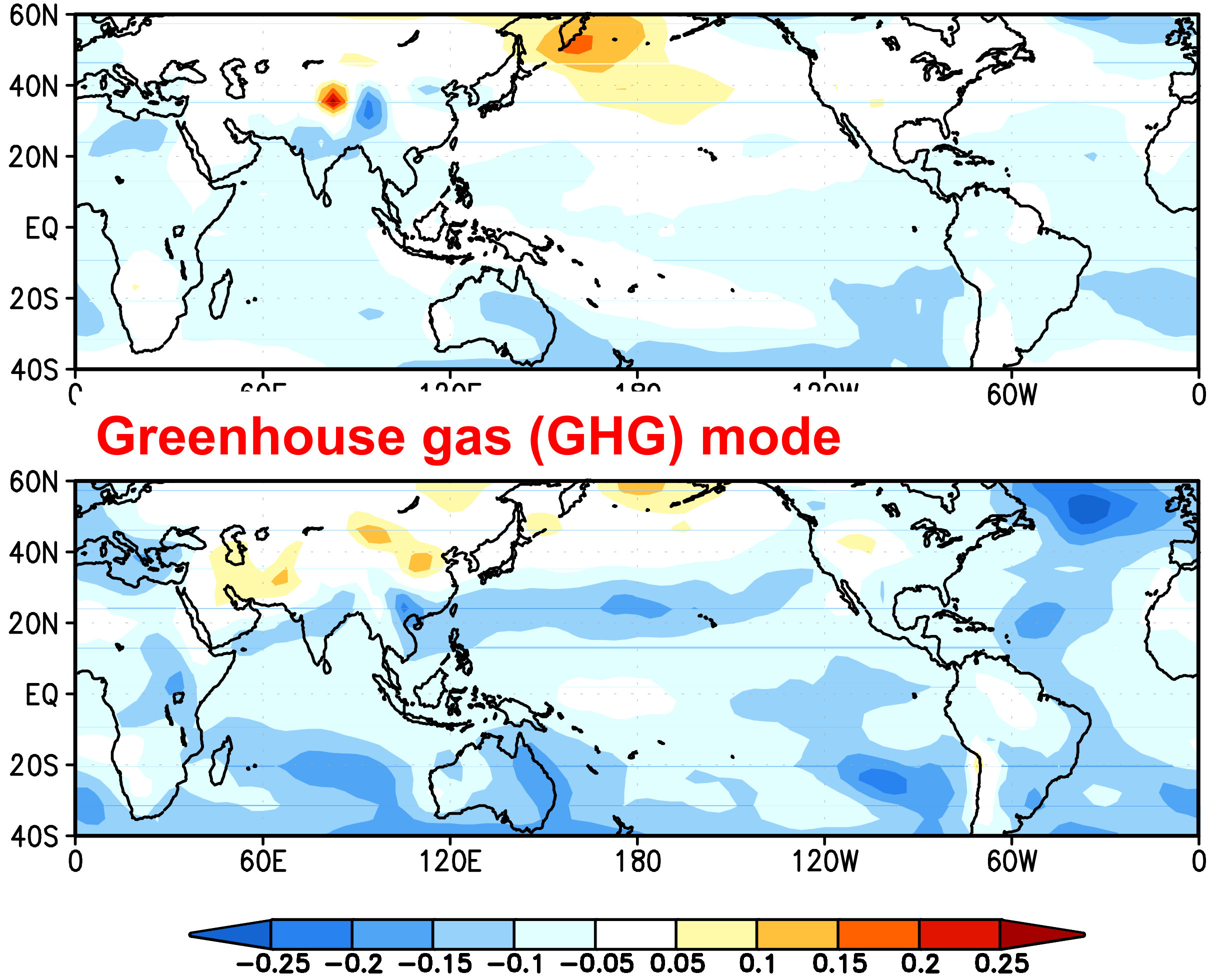
(b) Zonal SST gradient: the eastern Pacific (10°S-10°N, 160°-90°W) minus the western Pacific (10°S-10°N, 120°-160°E) SST.

(c) Walker Cell strength: the zonal wind at 850 hPa averaged in (10°S -10°N, 120°E-150°W).

(d) Hadley Cell strength: differential divergence between 200 hPa and 850 hPa, averaged over (0-360°E, 15°S-0°) for DJF.

Stability (T850- T500) regressed onto

Solar-Volcanic (SV) mode



Static s
forced r
Negativ
stabiliz

V

GHG response is more stable, favoring Weaker Walker mechanism

Summary

In many theories for the response to warming,
warming is warming, but
the type of forcing does matter.

Greenhouse gases vs. Solar-Volcanic

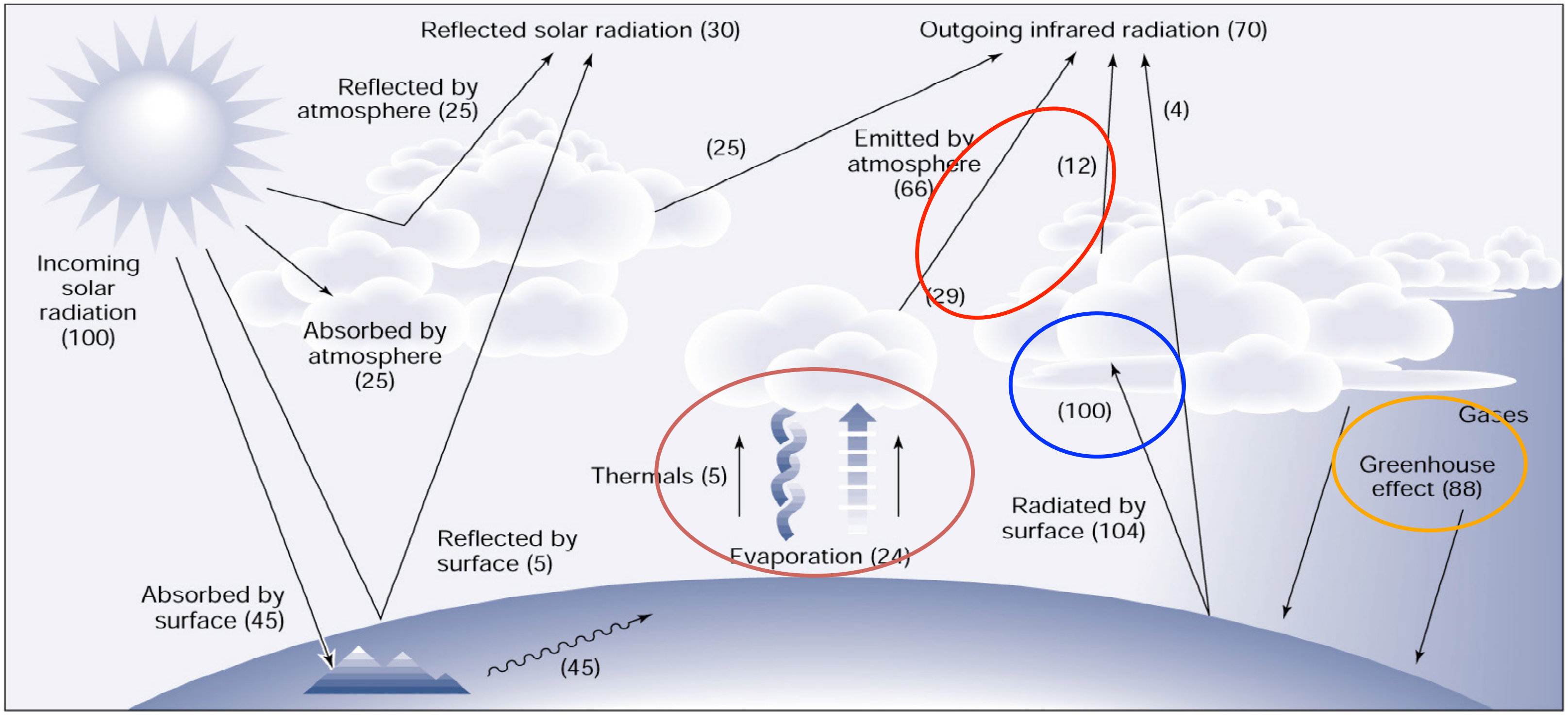
More precip than normal vs. Even more precip
A consequence of global tropospheric energy budget

"El Niño like" vs. "La Niña like"
"Weaker Walker" vs. "Ocean Thermostat"

Favored by static stability differences, but also see
DiNezio et al on changes in the thermocline,
Meehl et al (2003,…) on differences in N-S spatial heating,
***And best of all (?)* Tim Merlis' talk this afternoon (E-W)**

Thank you

Net Radiative Cooling Balances Latent Heating of Troposphere

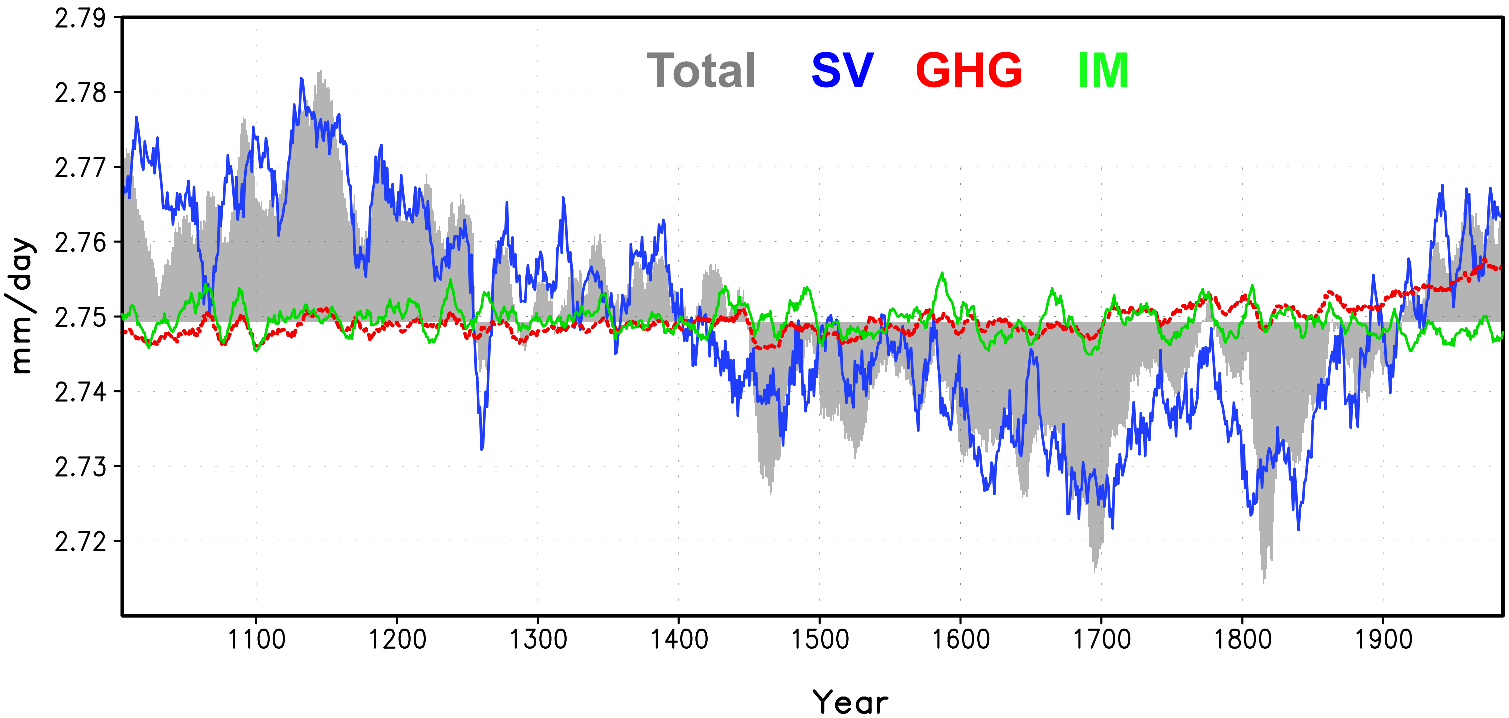


R = 29+12 + 88 – 100 = 29 = LP

IR emitted to space	IR emitted to surface	IR absorbed By atmos.	Latent Heat Flux

ΔR = LΔP

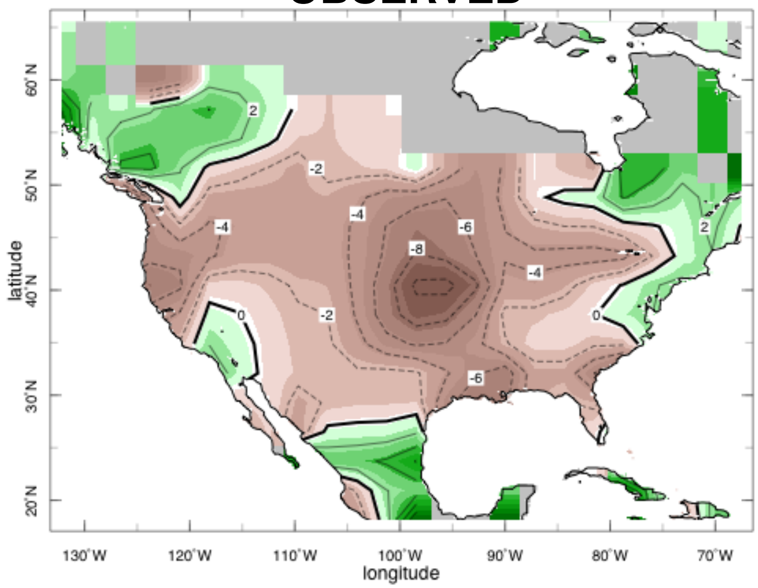
Total and Reconstructed Global Mean Precipitation



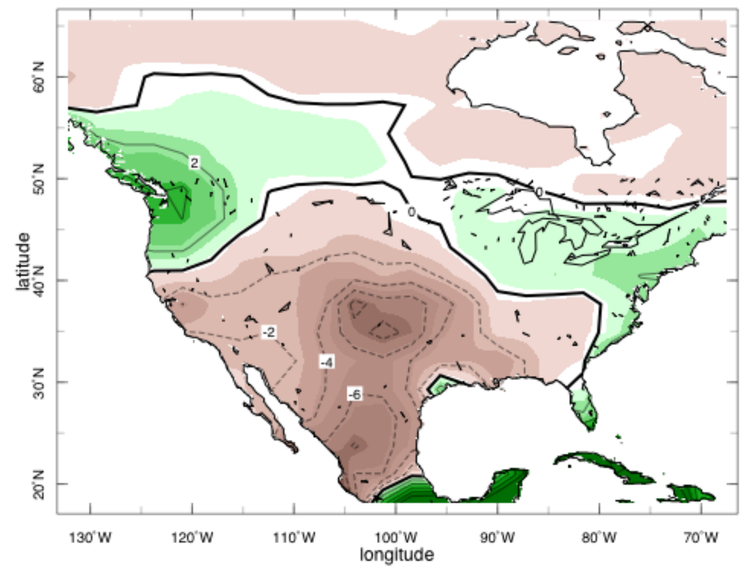
Entire period: SV (CC=0.90, FV=79.6%), GHG (CC=0.01, FV=1.0%), IM (CC=0.16, FV=2.4%)
Preindustrial: SV (CC=0.90, FV=79.8%), GHG (CC=-0.01, FV=-1.4%), IM (CC=0.21, FV= 3.7%)
Industrial: SV(CC=0.88, FV=75.1%) GHG (CC=0.62, FV=36.7%), IM (CC=-0.41, FV=-20.2%)

Precipitation Anomaly 1932-1939

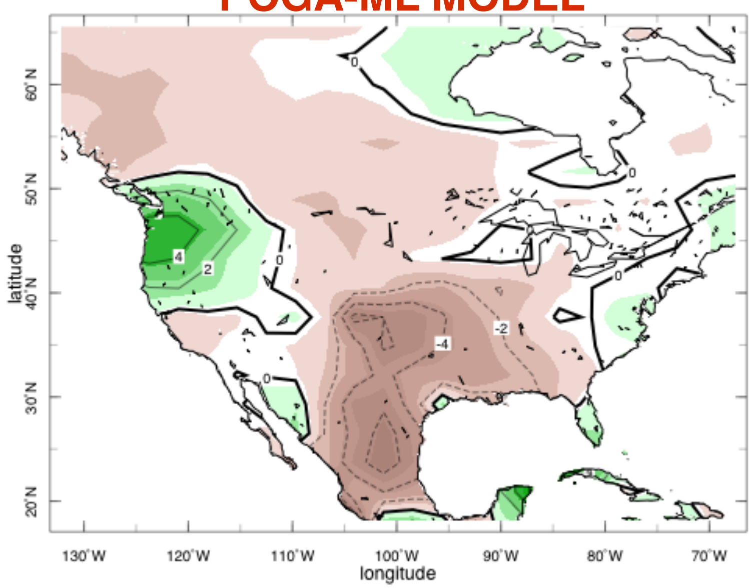
OBSERVED



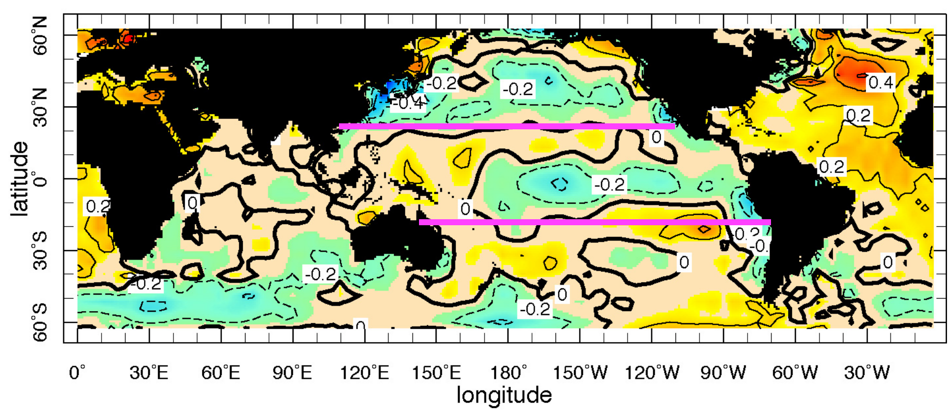
GOGA MODEL



POGA-ML MODEL



OBSERVED
SEA SURFACE TEMPERATURE



Courtesy of Richard Seager

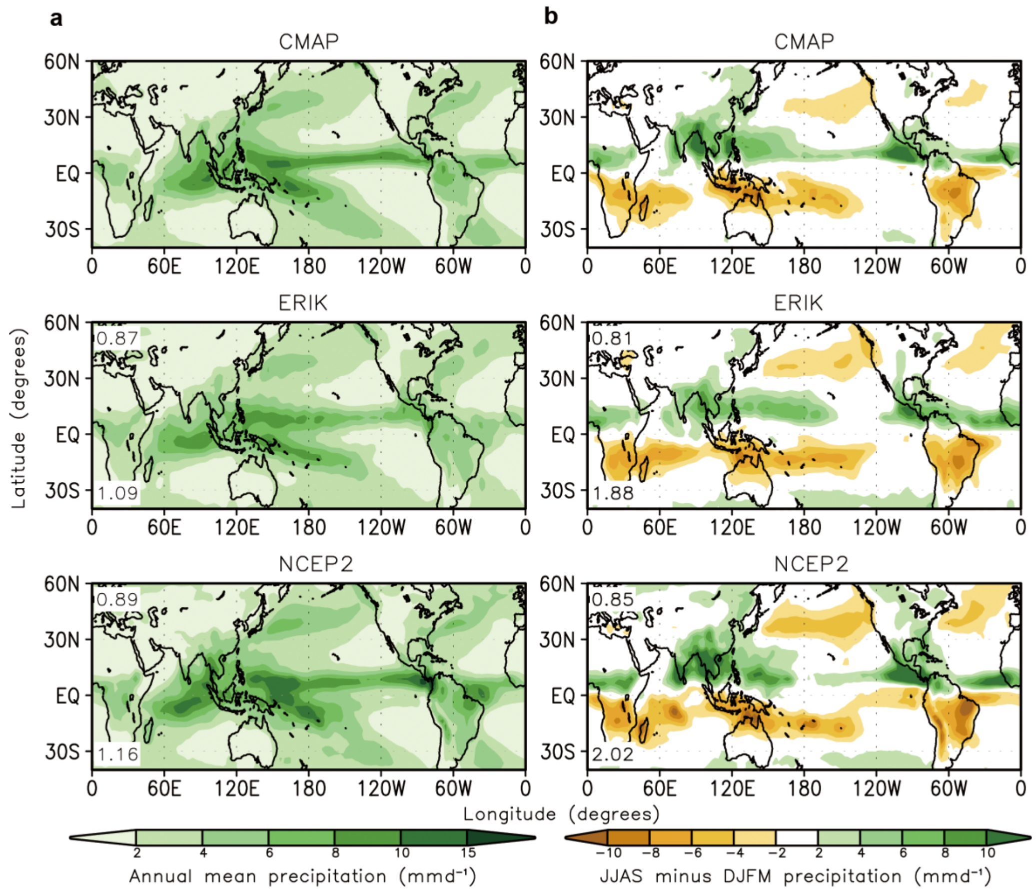


Figure S1 | Validation of the model precipitation climatology by comparison of the observed and simulated climatology of global precipitation rate (mm d^{-1}). a, annual mean and **b,** the leading mode of the annual cycle measured by JJAS (June through September) minus DJFM (December through following March) derived from CMAP (top), ECHO-G ERIK forced run (middle), and NCEP-2 reanalysis (bottom). CMAP and NCEP-2 reanalysis climatological data were derived for the period 1979–2004. The 25-year climatology simulated in the ECHO-G ERIK forced run was derived for the period AD 1965–1990. The numbers shown in the upper-left corners and the lower-left corners indicate the pattern correlation coefficients with the CMAP observational analysis and root mean square errors (adopted from Liu et al. 2009).

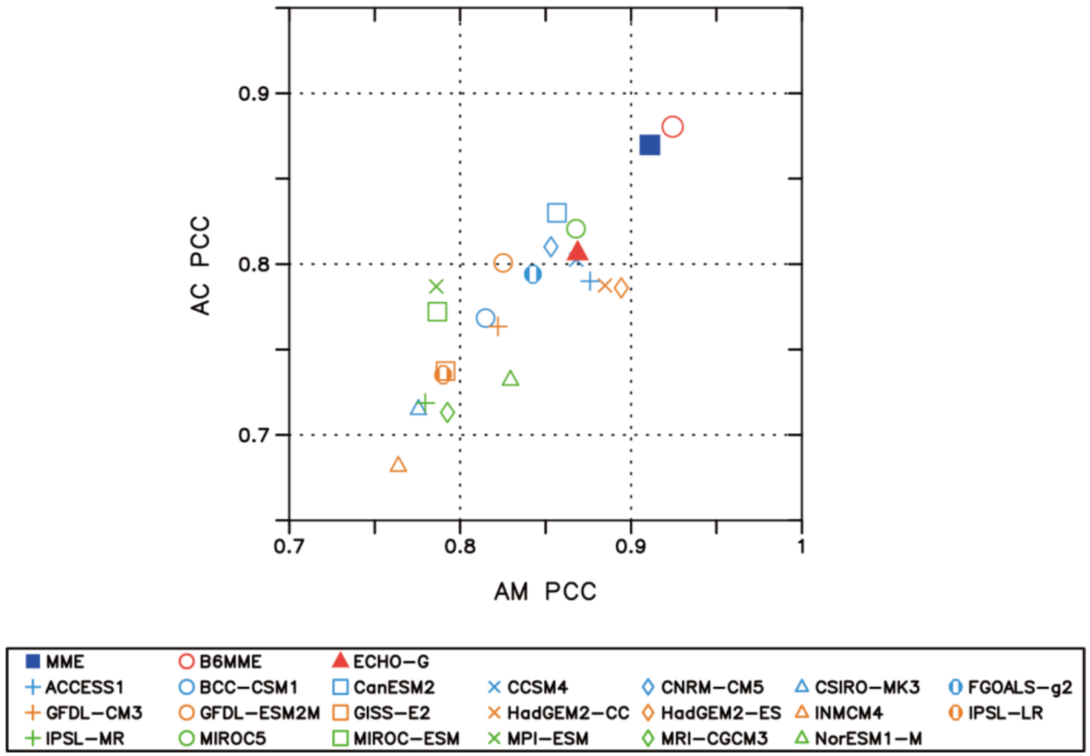


Figure S2 | The precipitation climatology of the ECHO-G model in comparison with 20 CMIP5 CGCMs. The abscissa is the pattern correlation coefficient (PCC) for the annual mean and the ordinate is the PCC of the combined first and second annual cycle of precipitation. The CMIP 5 model climatology is for the 26 years 1980-2005 and for ECHO-G it is the 30-year mean from 1961-1990. The spatial domain is 0^{o}-360^{o}E, 60^{o}S-60^{o}N. The observed precipitation data were obtained from combining CMAP and GPCP data. The ECHO-G model performance is comparable to the best CMIP5 models. All models are outperformed by multi-model ensemble means: MME denotes the mean of all 20 CMIP5 models and B6MME denotes the mean of the 6 best models.