Hydroclimate changes in the tropical Pacific over the last millennium:

data-model comparisons and possible mechanisms

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Thank you to: Ashley Maloney, Yen-Ting Hwang, Aaron Donohoe

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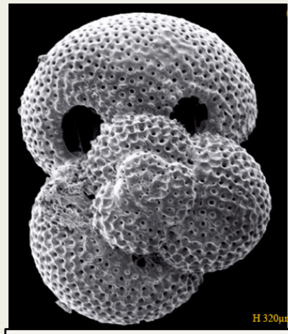
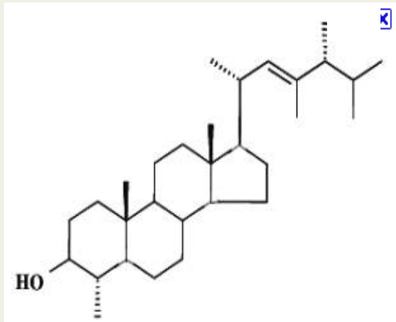
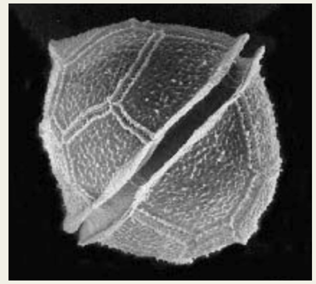
NCDC/NCEI paleoclimate datasets







<u>57 proxy records</u>

- Hydroclimate records from the tropical Pacific region
- Span 100-1000 yr BP with temporal resolution ≤ 100 yrs
- Dating error < 100 yrs

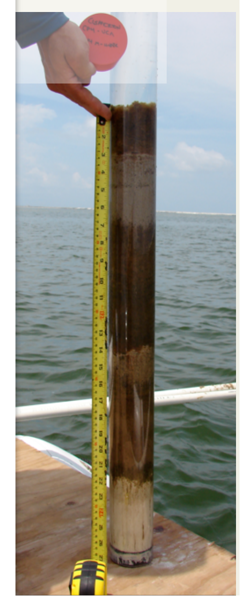
- Speleothems
- Lake and marine sediment
- Tropical glaciers

NCDC/NCEI paleoclimate datasets

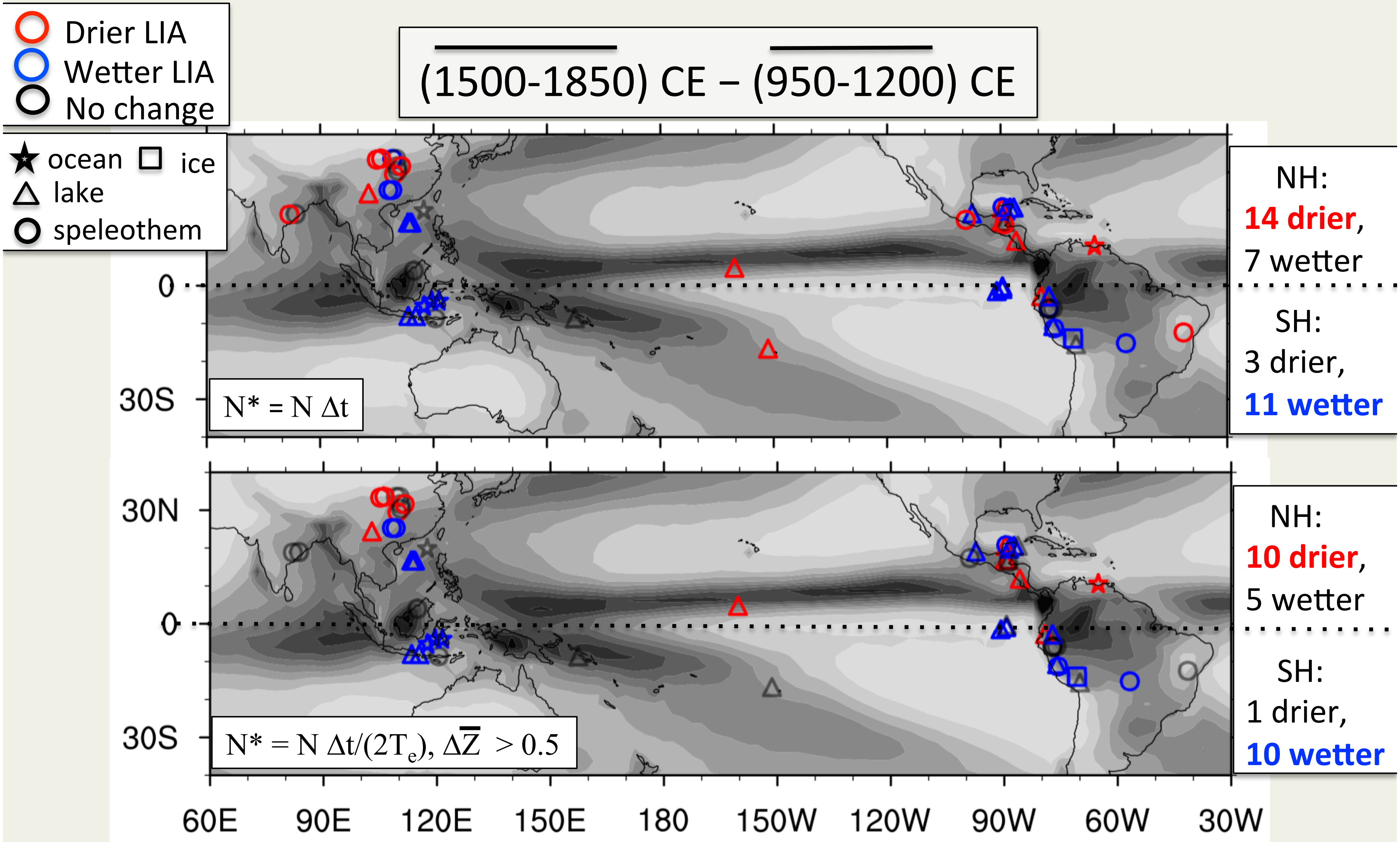
Author, Year	Proxy
Apaestegui, 2014	d18O speleo
Atwood, 2014	dinosterol dD
Baker, 2009	d18O diatom
Berkelhammer, 2010	d18O speleo
Bhattacharya, 2015	d18O authig carb
Bird, 2011	d18O authig calcite
Cai, 2010	d18O speleo
Cai, 2010	d18O speleo
Carolin, 2016	d18O speleo
Cheng, 2013	d18O speleo
Conroy, 2008	sediment grain size
Curtis, 1996	d18O gastrocod/ostrocods
Curtis, 1996	d18O gastrocod/ostrocods
Curtis, 1998	d18O gastrocod/ostrocods
Curtis, 1998	d18O gastrocod/ostrocods
Curtis, 1998	d18O gastrocod/ostrocods
Dong, 2010	d18O speleo
Dong, 2010	d18O speleo
Dykoski, 2006	d18O speleo
Griffiths, 2009	d18O speleo
Haug, 2001	Ti concentration
Hillman, 2014	d18O authig calcite
Hodell, 2005	d18O gastrocod/ostrocods
Hodell, 2008	lake sediment density
Hu, 2008	d18O speleo
Kanner, 2013	d18O speleo
Kennett, 2012	d18O speleo
Koneckey, 2013	dD n-alkanoic acid
Lachniet, 2012	d18O speleo

Author, Year	Proxy
Medina-Elizalde, 201(	d18O speleo
Moy, 2002	Red color intensity
Nelson, 2016	dD biomarkers
Newton, 2006	d18O, Mg/Ca forams
Novello, 2012	d18O speleo
Novello, 2016	d18O speleo
Oppo, 2009	d18O, Mg/Ca forams
Partin, 2007	d18O speleo
Reuter, 2009	d18O speleo
Rodbell, 1999	Greyscale
Rodysill, 2012	d13Corg
Sachs, 2009	dDTLE
Sinha, 2011	d18O speleo
Stansell, 2012	d18O ostrocod
Thompson, 2013	d18Oice
Tierney, 2010	dD C30 fatty acid
Toomey, 2016	Ti/Ca
van Breukelen, 2008	d18O speleo, d18O/dD fluid
Wang, 1999	d18O G. ruber (diatom)
Wang, 2005	d18O speleo
Yan, 2011	Sediment mean grain size
Yan, 2011	Sediment mean grain size
Yan, 2011	Sediment mean grain size
Zhang, 2008	d18O speleo
Zhao, 2015	d18O speleo
Cosford, 2009	d18O speleo
Tan, 2011	d18O speleo

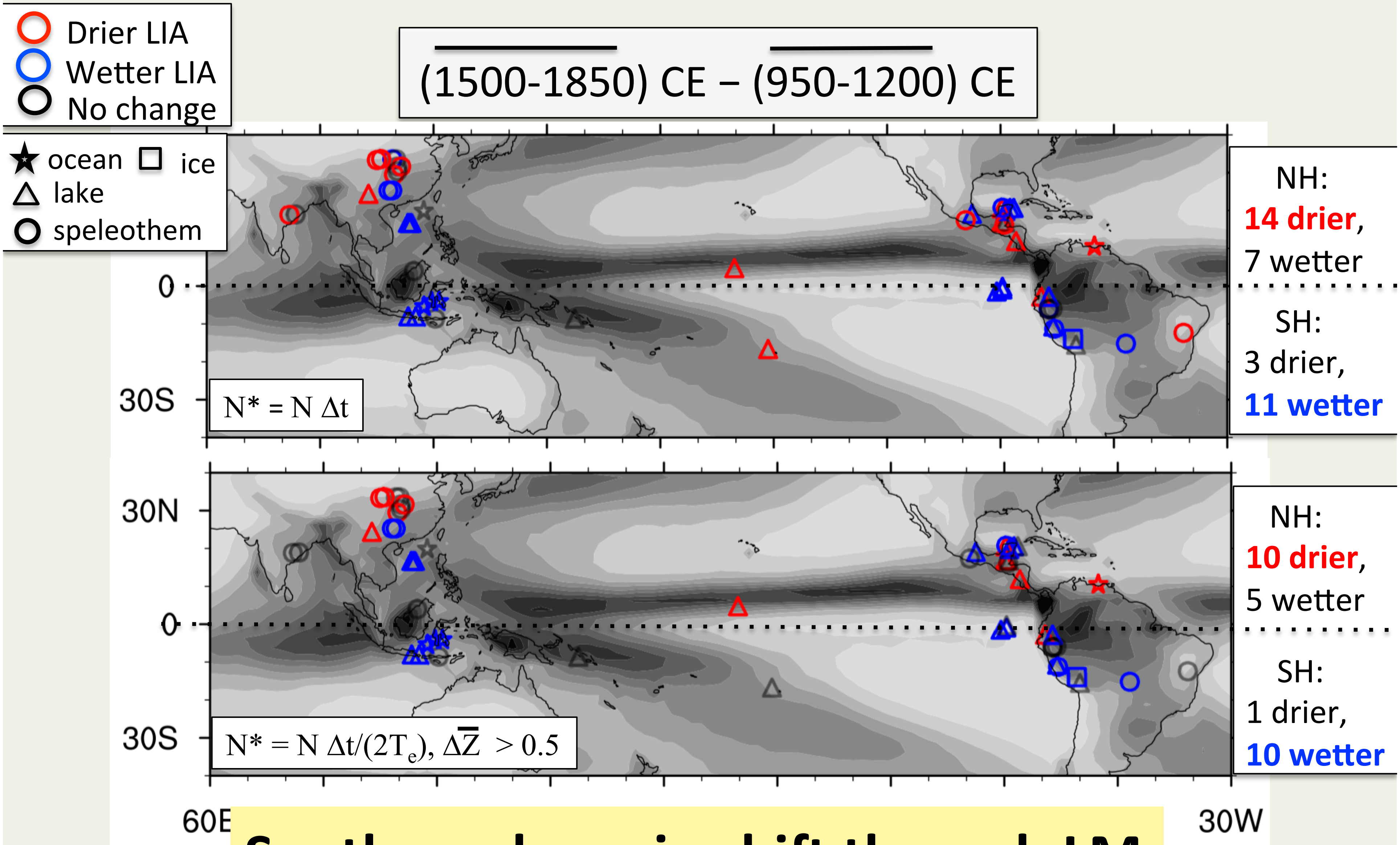
- Hydr… n
- Span… yrs
- Datin…



Longterm hydroclimate changes over LM

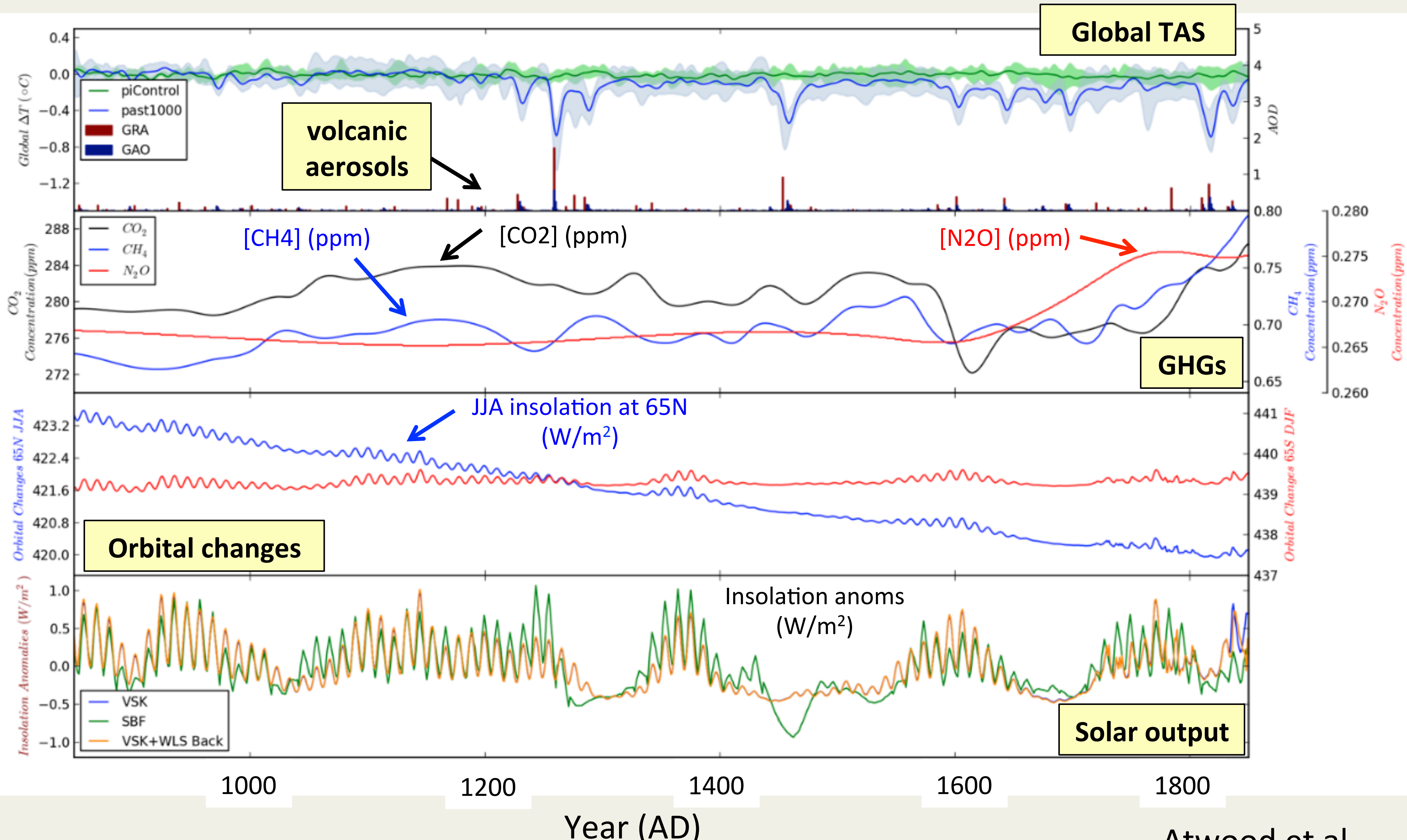


Longterm hydroclimate changes over LM



Southward precip shift through LM

PMIP3 last millennium simulations



Models:

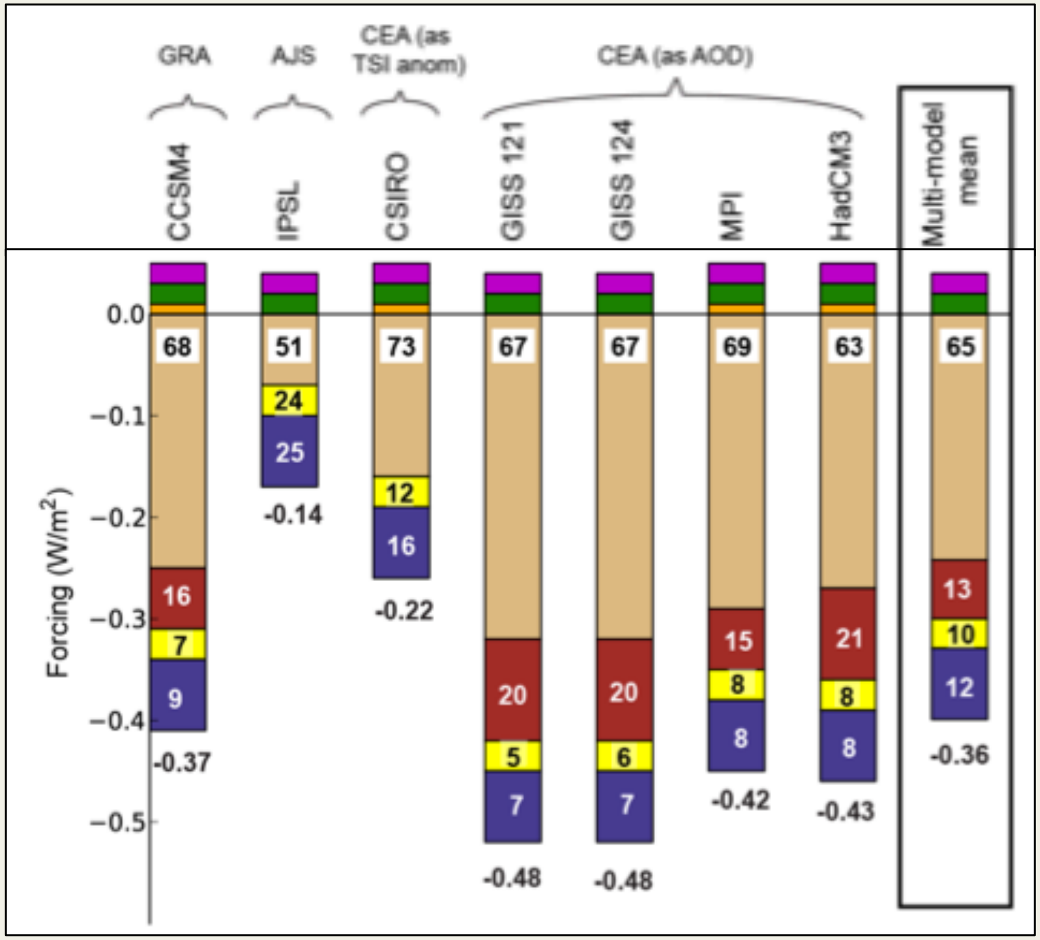
CCSM4	GISS-121	GISS-124	MPI	CSIRO	HadCM3	IPSL

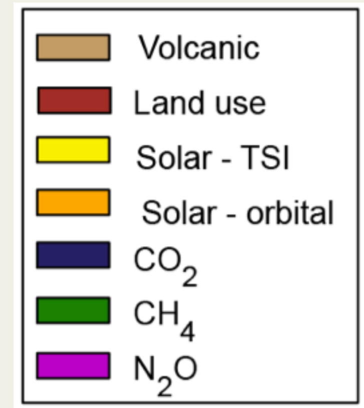
Atwood et al., J. Clim (2016)

Volcanic forcing drove global cooling during the LIA

Volcanic forc

Model

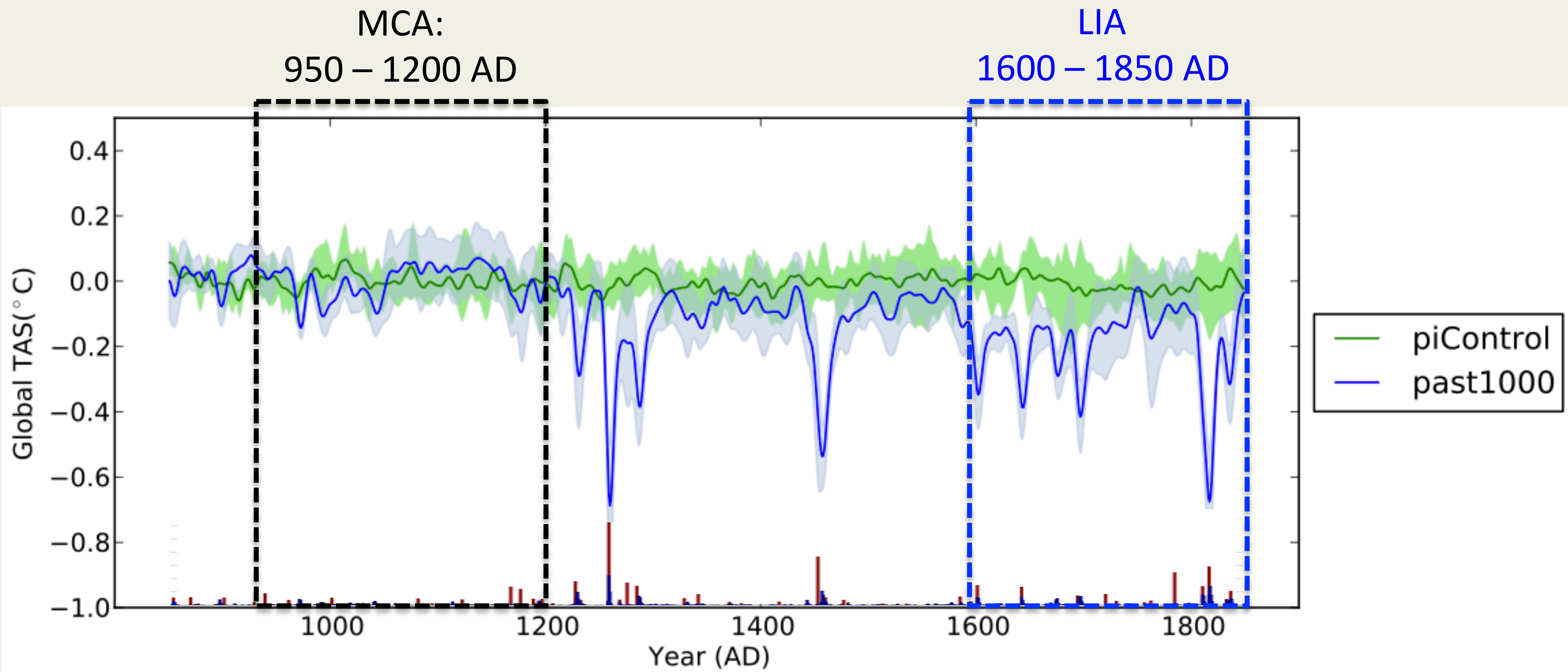




Atwood et al., J. Clim (2016)

- LIA forcing dominated by volcanic forcing (65%)
- Land use (13%), GHG (12%) and solar (10%) changes make up much smaller contributions

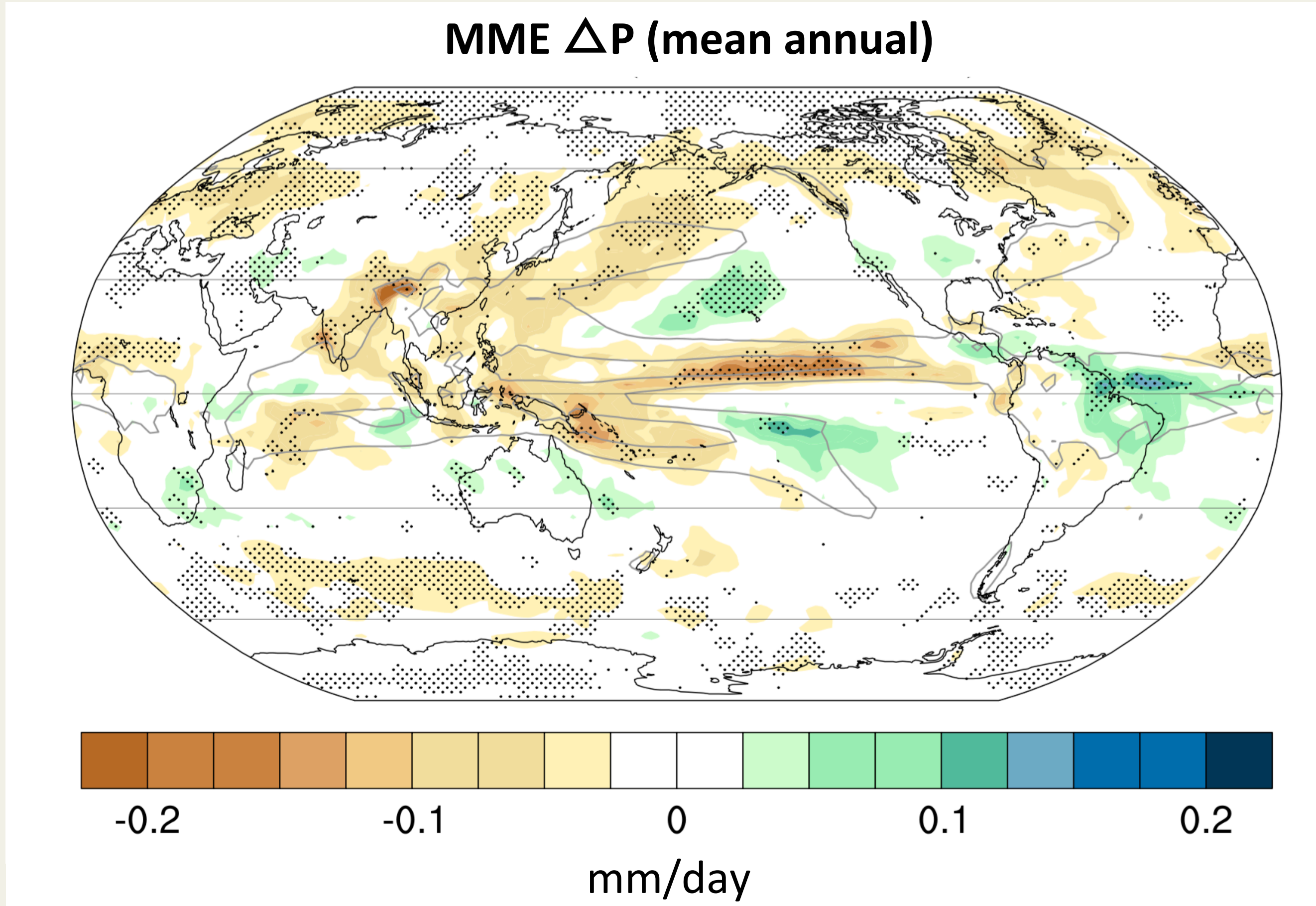
Global temp trends in PMIP3 models



Multi-model precip changes (LIA – MCA)

During LIA in tropical Pacific:

- Drier Pacific ITCZ
- Eastward shift of SPCZ
- Drier E. Asia/ India



*Stippling: 5/6 models agree on the sign of ∆P

Atwood et al., (in prep)

Precip changes (LIA – MCA)

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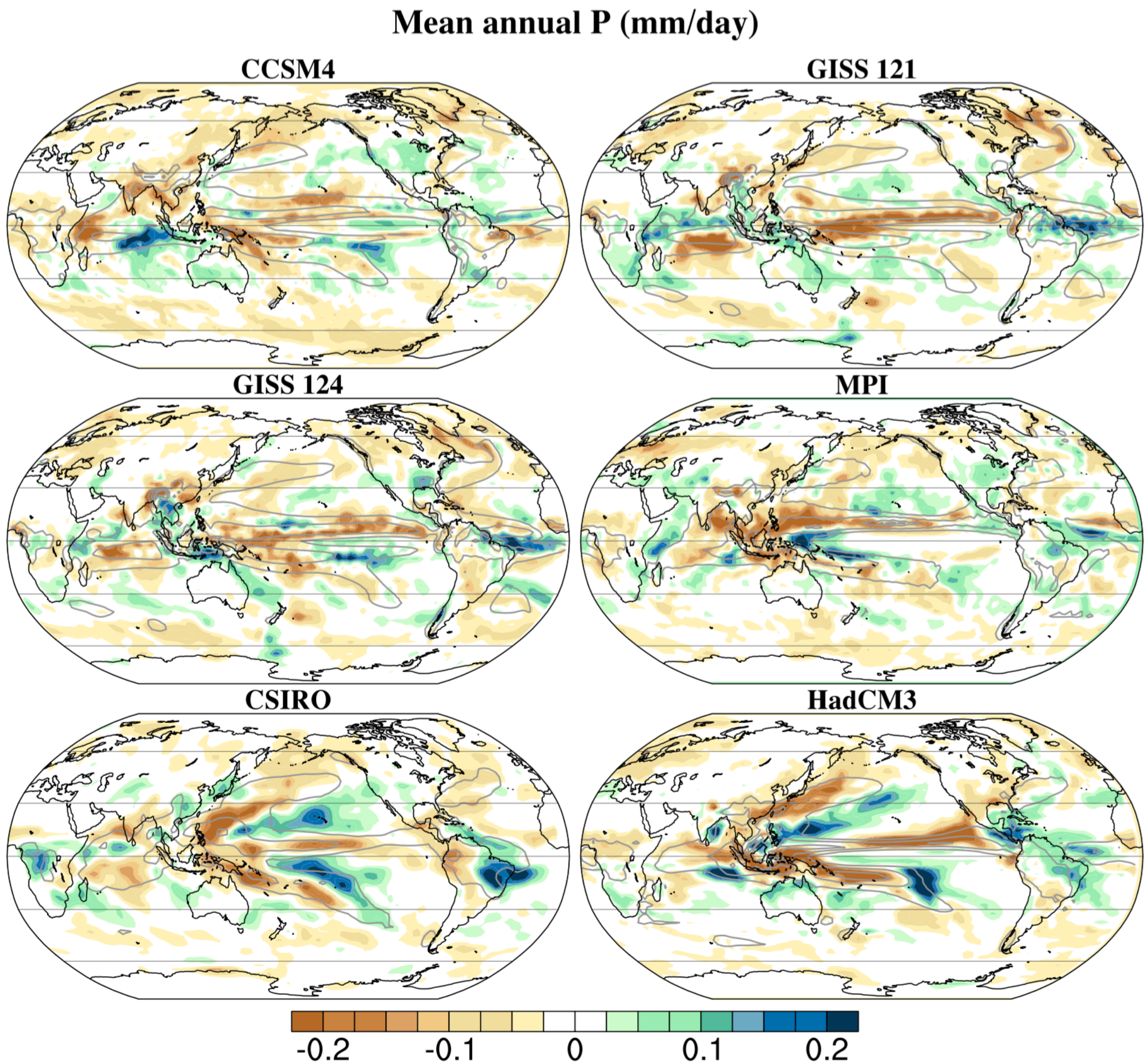

Atwood et al., (in prep)

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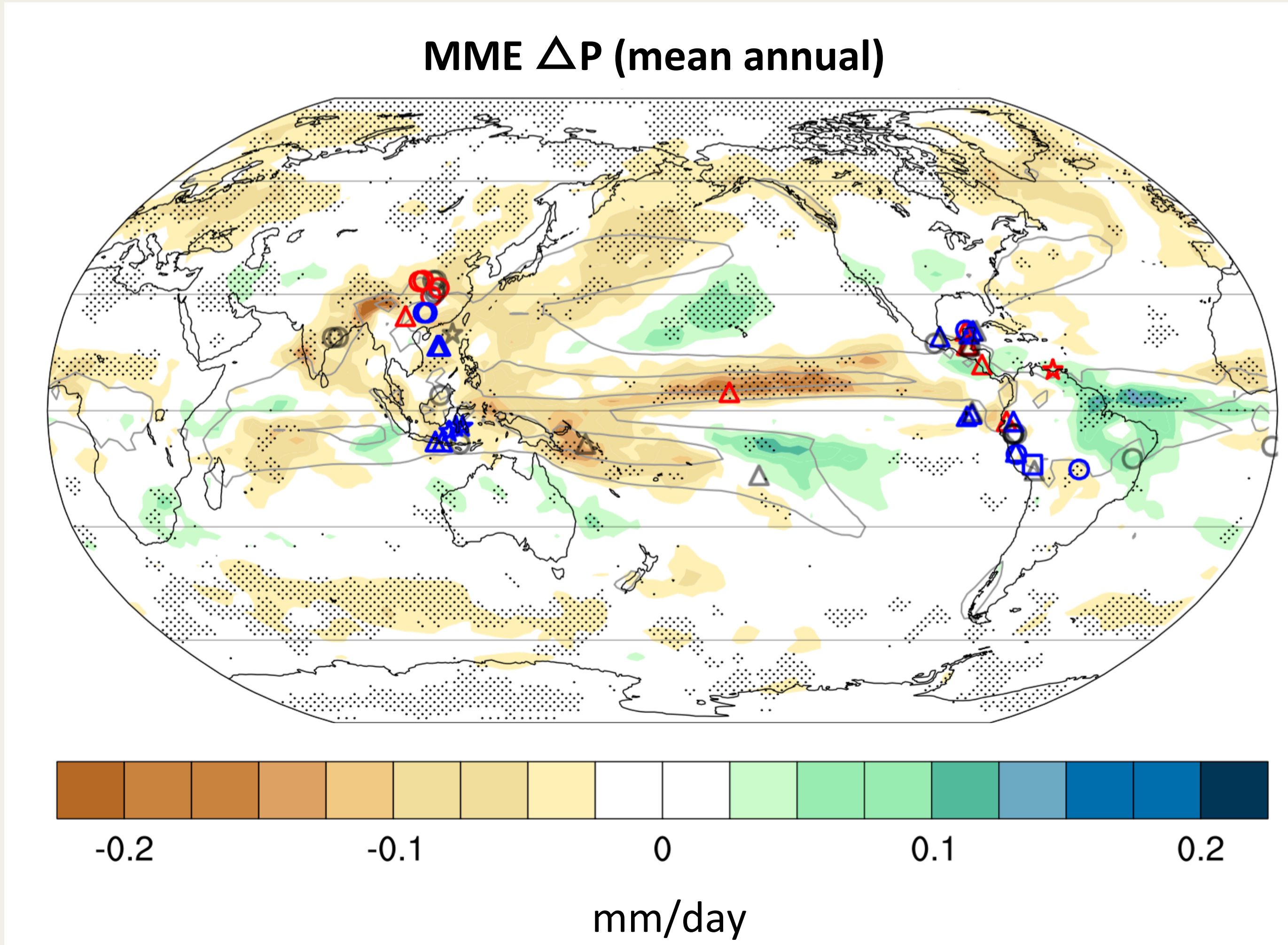
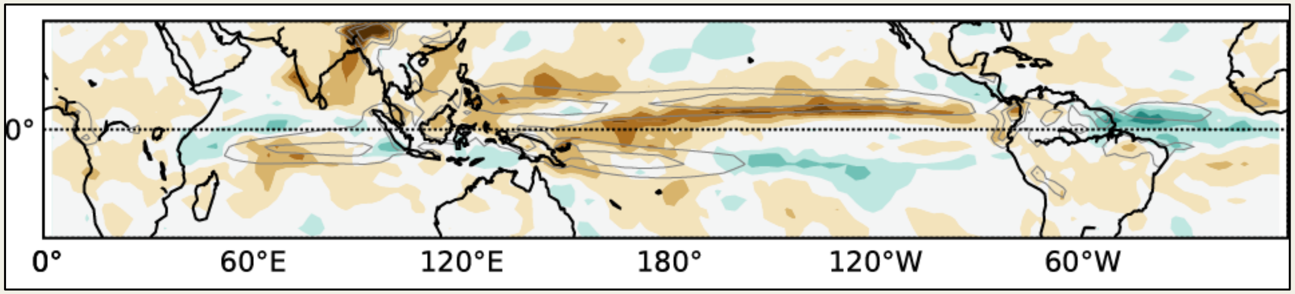


Atwood et al., (in prep)

*Stippling: 5/6 models agree on the sign of ΔP

Moisture budget decomposition

Δ(P-E)



Δu = dynamic contributors

Δq = **thermodyn contributors**

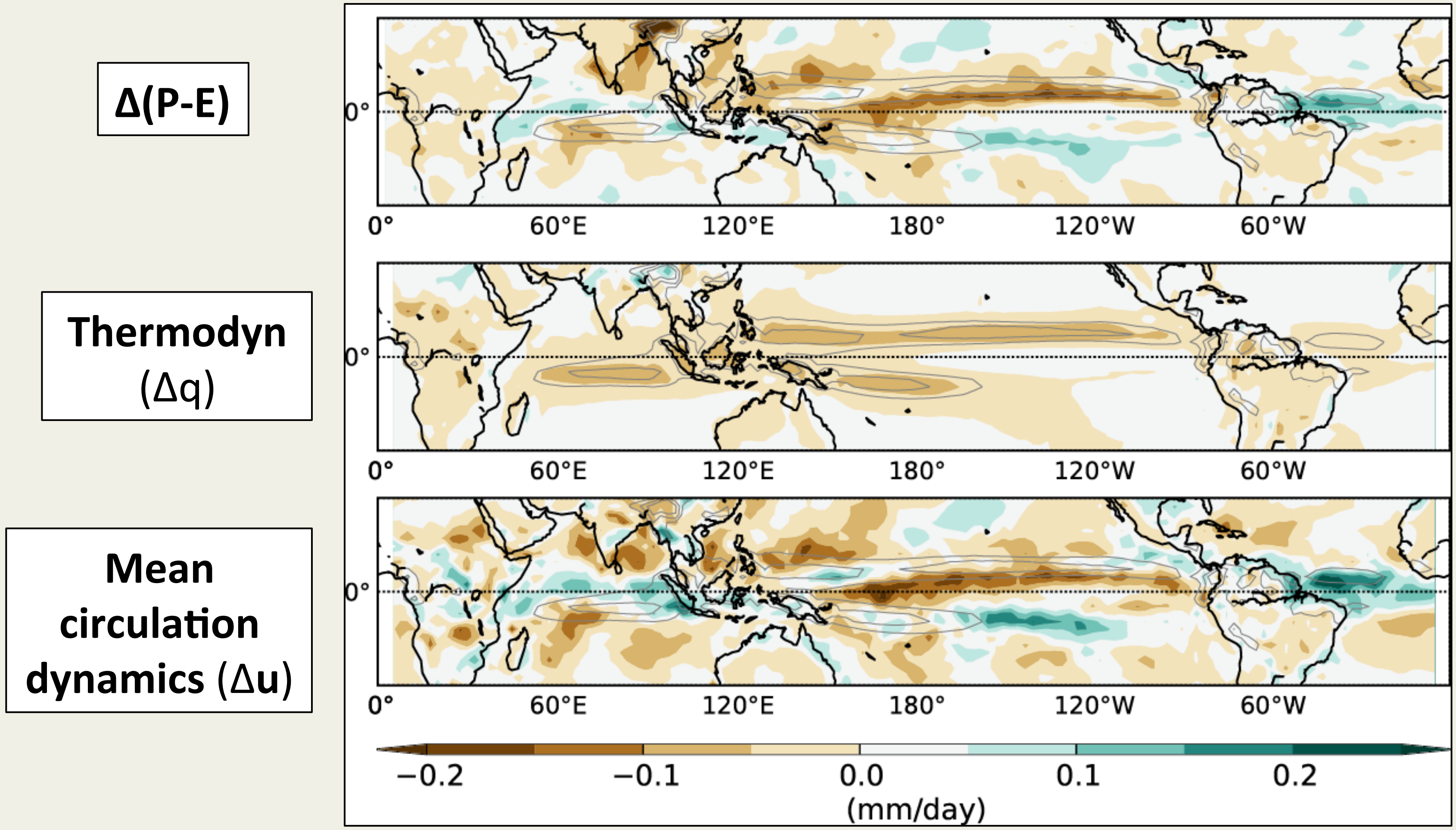
Moisture budget

$$\rho_w g\delta(P-E) \approx -\int_0^{p_s} (\delta\bar{\mathbf{u}}\cdot\nabla\bar{q}_{20} + \bar{\mathbf{u}}_{20}\cdot\nabla\delta\bar{q} + \delta\bar{q}\nabla\cdot\bar{\mathbf{u}}_{20} + \bar{q}_{20}\nabla\cdot\delta\bar{\mathbf{u}})\,dp - \int_0^{p_s}\nabla\cdot\delta(\overline{\mathbf{u}'q'})\,dp - \delta S.$$

Seager et al., 2010

Atwood et al.,
(in prep)

Moisture budget decomposition



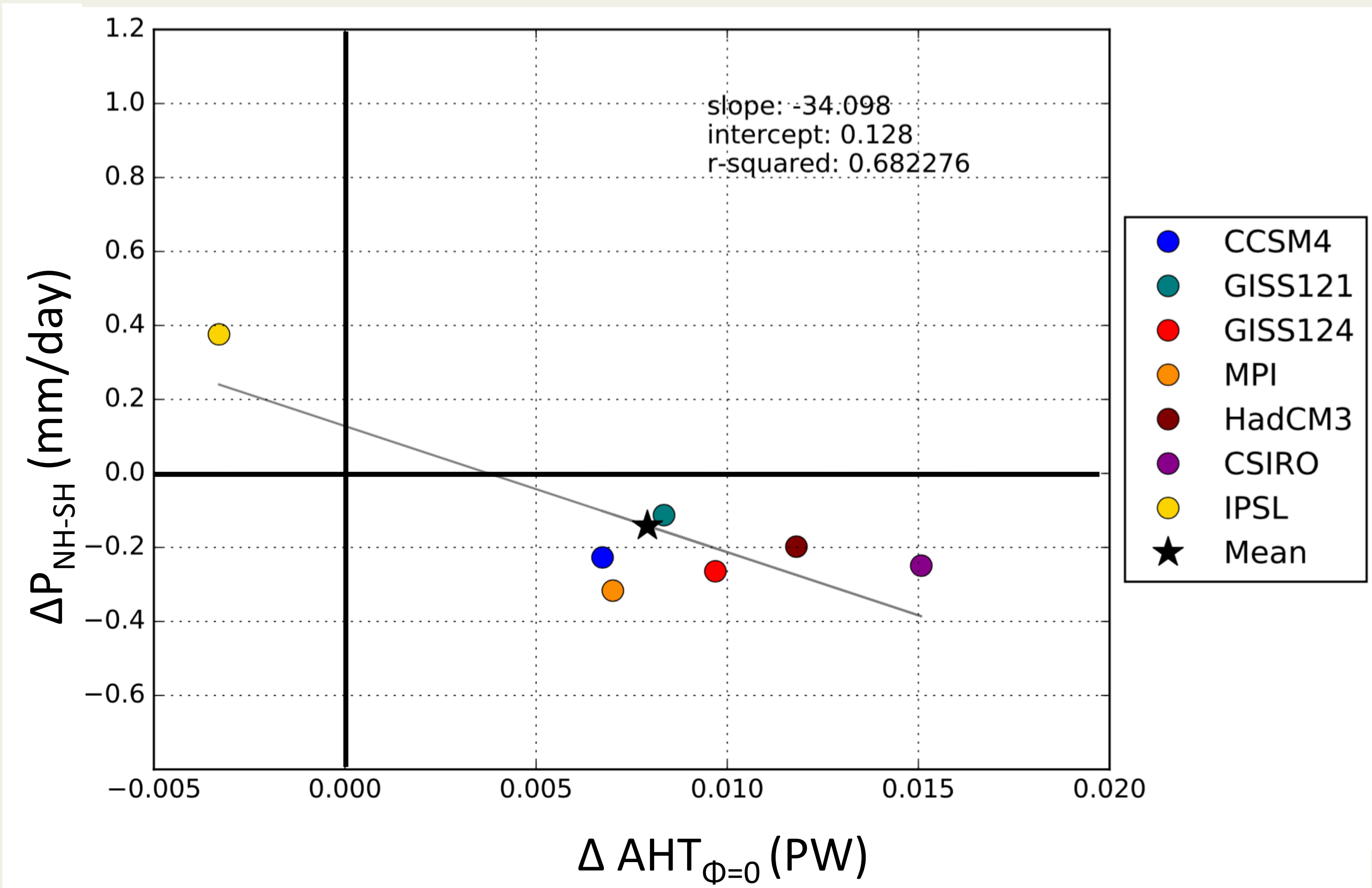
P-E changes:

- Global cooling drives drying in rainy regions
- Positive dynamical feedback in Pacific ITCZ

Atwood et al., (in prep)

In 6/7 PMIP3 models, tropical precipitation shifts south during LIA

northward ITCZ shift



southward ITCZ shift

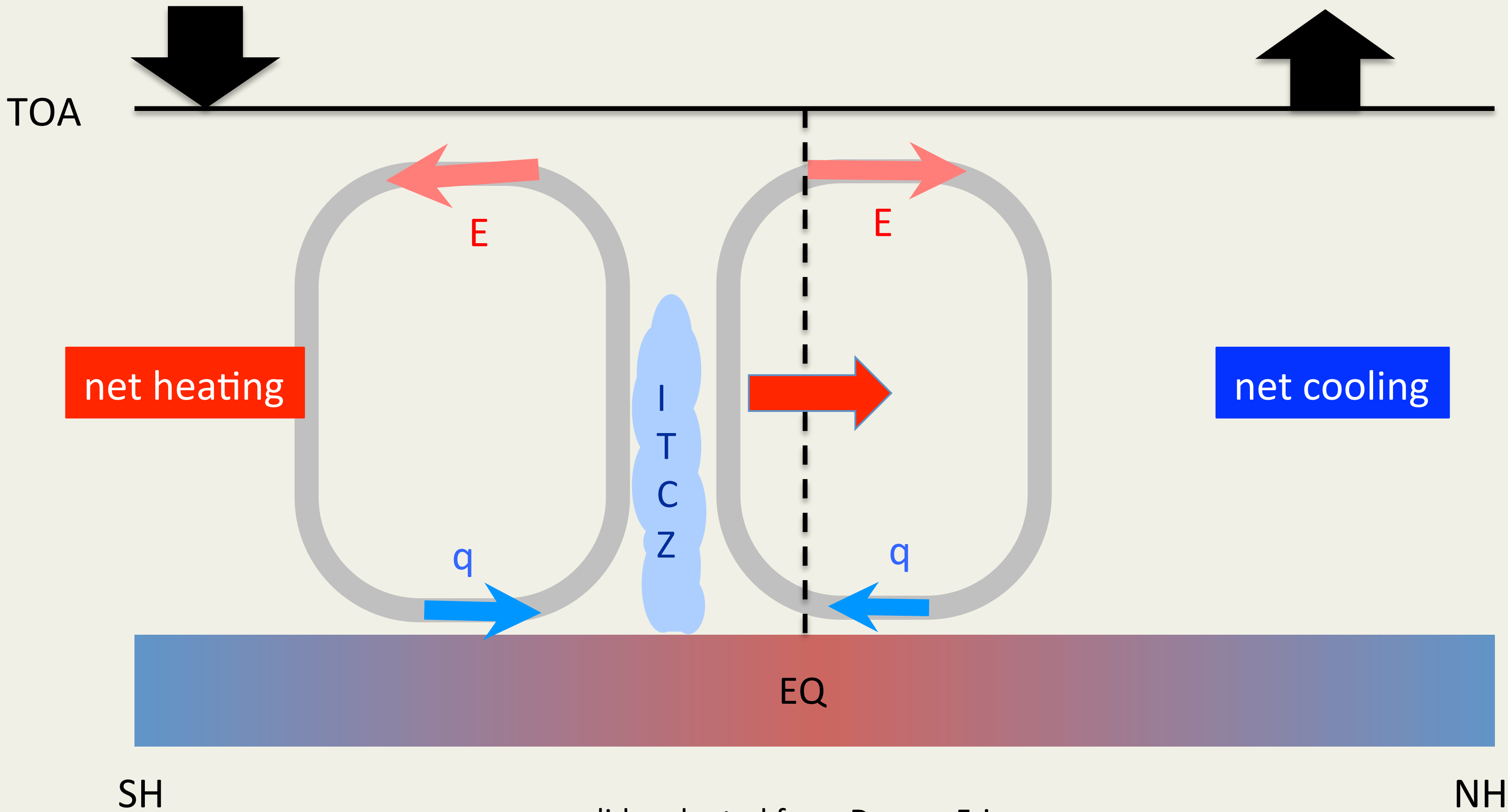
anom. **southward AHT**

anom. **northward AHT**

Why might tropical precip shift south during the LIA?

<u>Energetic constraints:</u>

Greater cooling of NH than SH causes southward shift of ITCZ during LIA



slide adapted from Dargan Frierson

Why might tropical precip shift south during the LIA?

<u>Theory:</u>
Greater cooling of NH than SH causes southward shift of ITCZ during LIA

<u>Possible mechanisms:</u>

1. Hemispheric asymmetry in climate *forcings*
   - **Volcanic, land use**, solar, orbital forcing

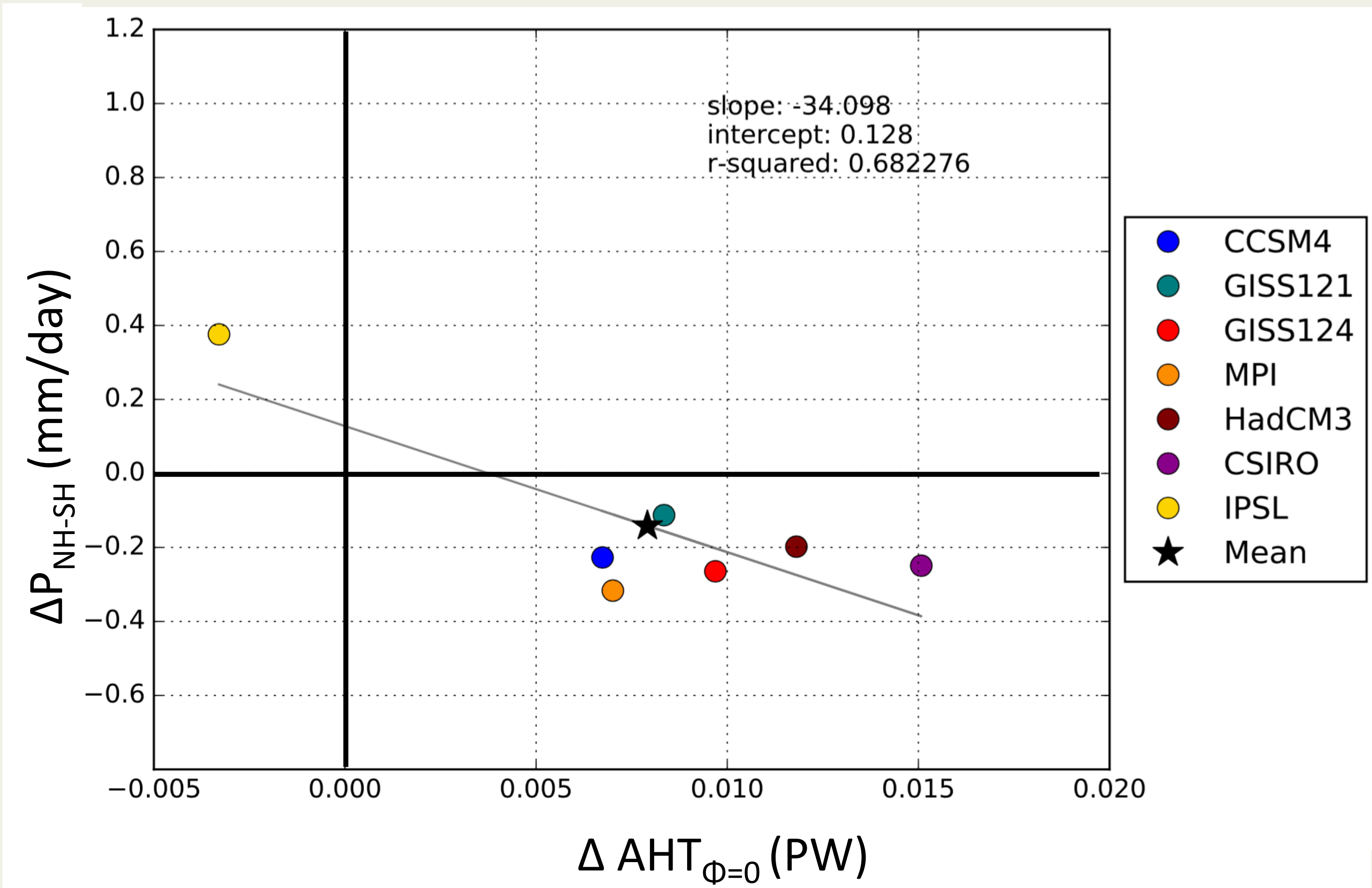
2. Hemispheric asymmetry in *feedbacks*
   - Snow/sea ice extent
   - Clouds

3. Changes in ocean heat transport (e.g. change in AMOC)

In 6/7 PMIP3 models, tropical precipitation shifts south during LIA

northward ITCZ shift

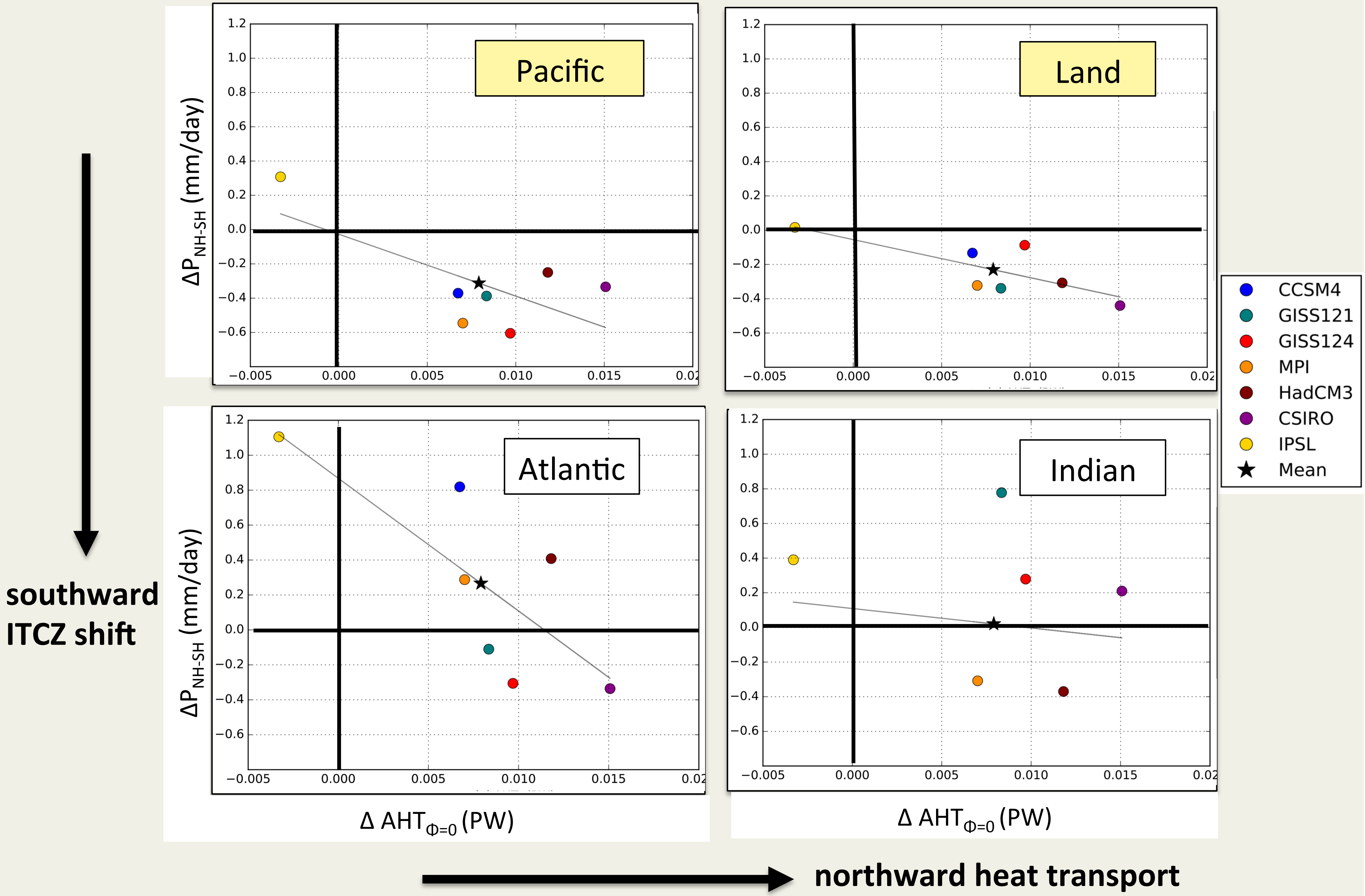
southward ITCZ shift



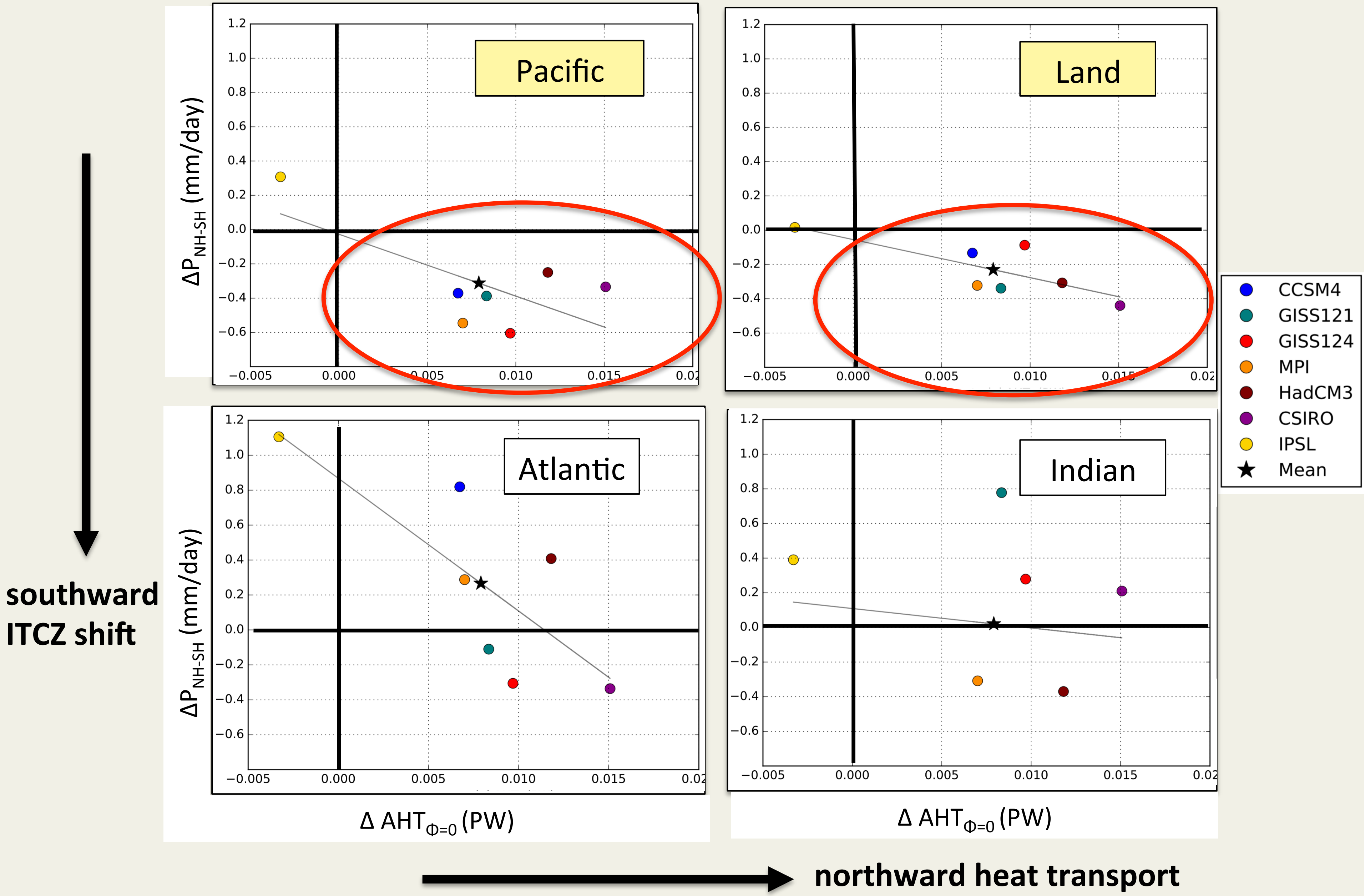
anom. **southward AHT**

anom. **northward AHT**

Southward shift occurs in Pacific and over land



Southward shift occurs in Pacific and over land



What led to the southward shift in tropical precip?

Forcing mechanisms

1. Volcanic forcing
2. Land use forcing
3. Solar/orbital forcing

Climate feedbacks

1. Ice albedo feedback
2. Cloud feedback
3. Water vapor feedback

Ocean heat transport

APRP Method (Taylor et al., 2007)

Decompose changes in TOA SW flux into changes in sfc albedo, clouds, and non-cloud scattering and absorption

$\Delta Q_S = \Delta S(1\text{-}A) - S\Delta A$ (change in shortwave flux at TOA)

$\Delta A = \Delta A_\mu + \Delta A_\gamma + \Delta a_\alpha$

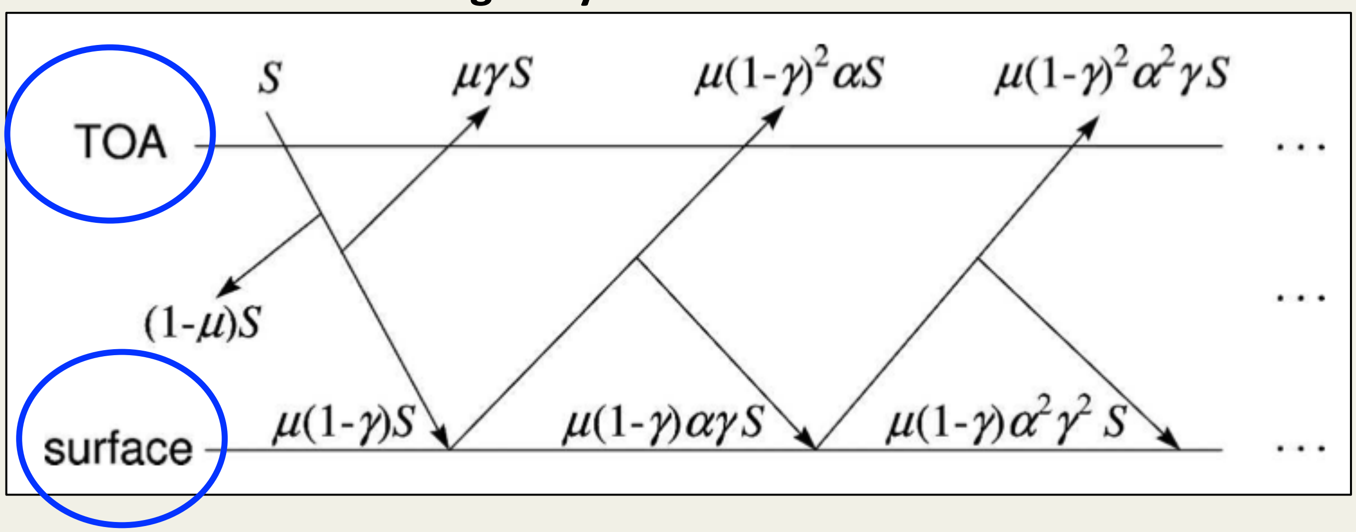
$\Delta A_\alpha = A(\mu, \gamma, \alpha_2) - A(\mu, \gamma, \alpha_1)$

α = sfc albedo

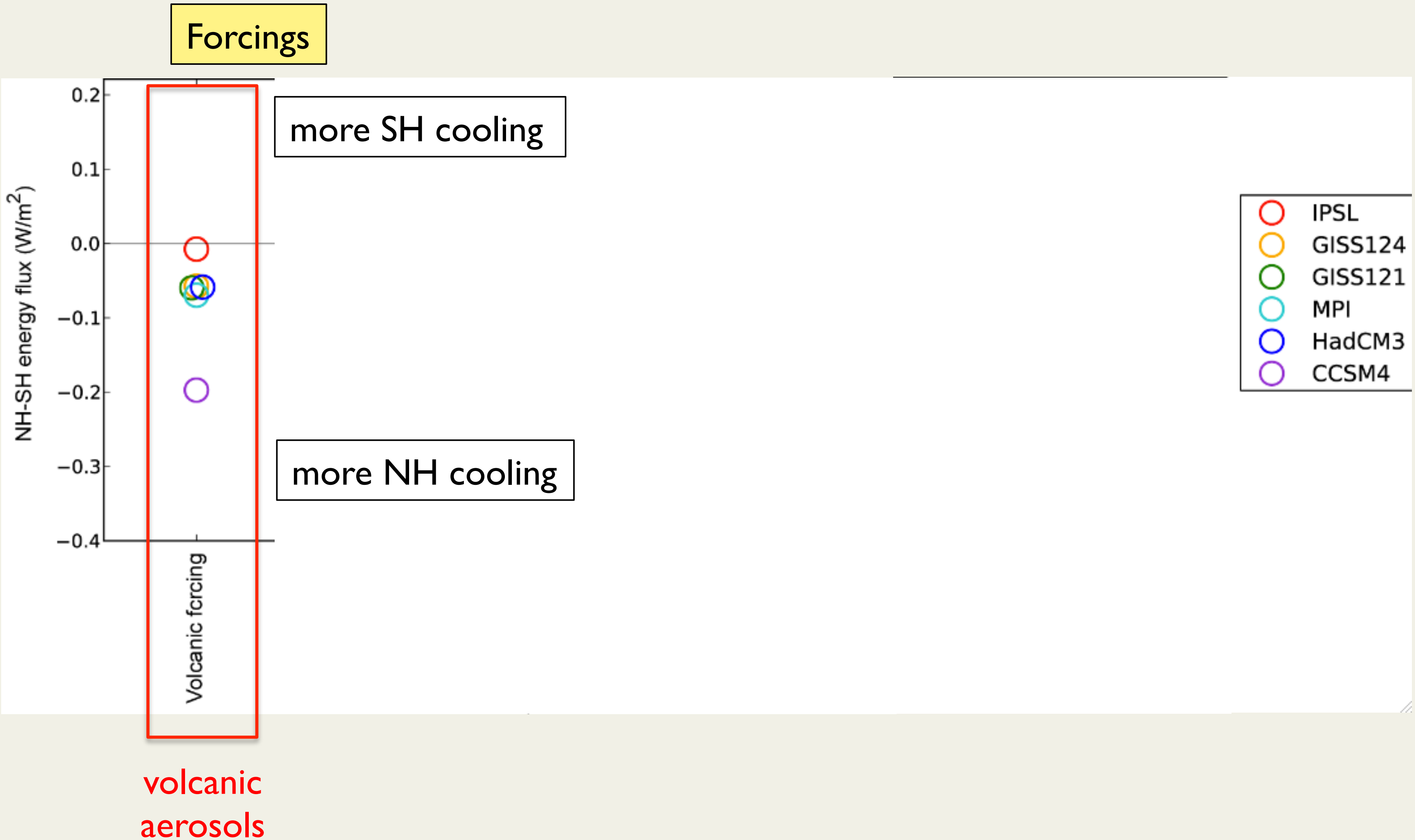
$1 - \mu$ = fraction of incident rad absorbed by atm

γ= scattering coeff

Single layer atm model

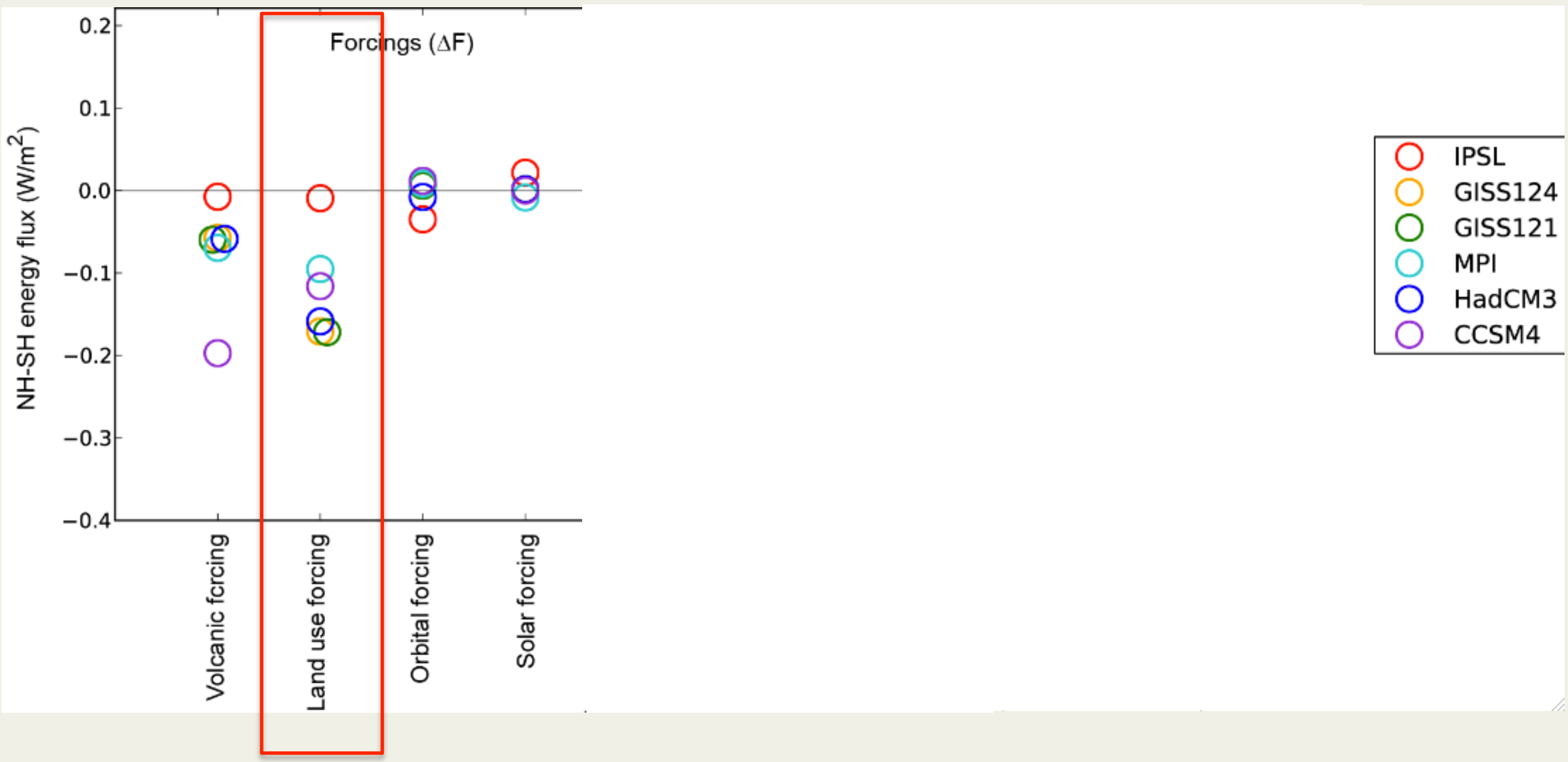


Changes in hemispheric energy budget during Little Ice Age



Changes in hemispheric energy budget during Little Ice Age

Forcings



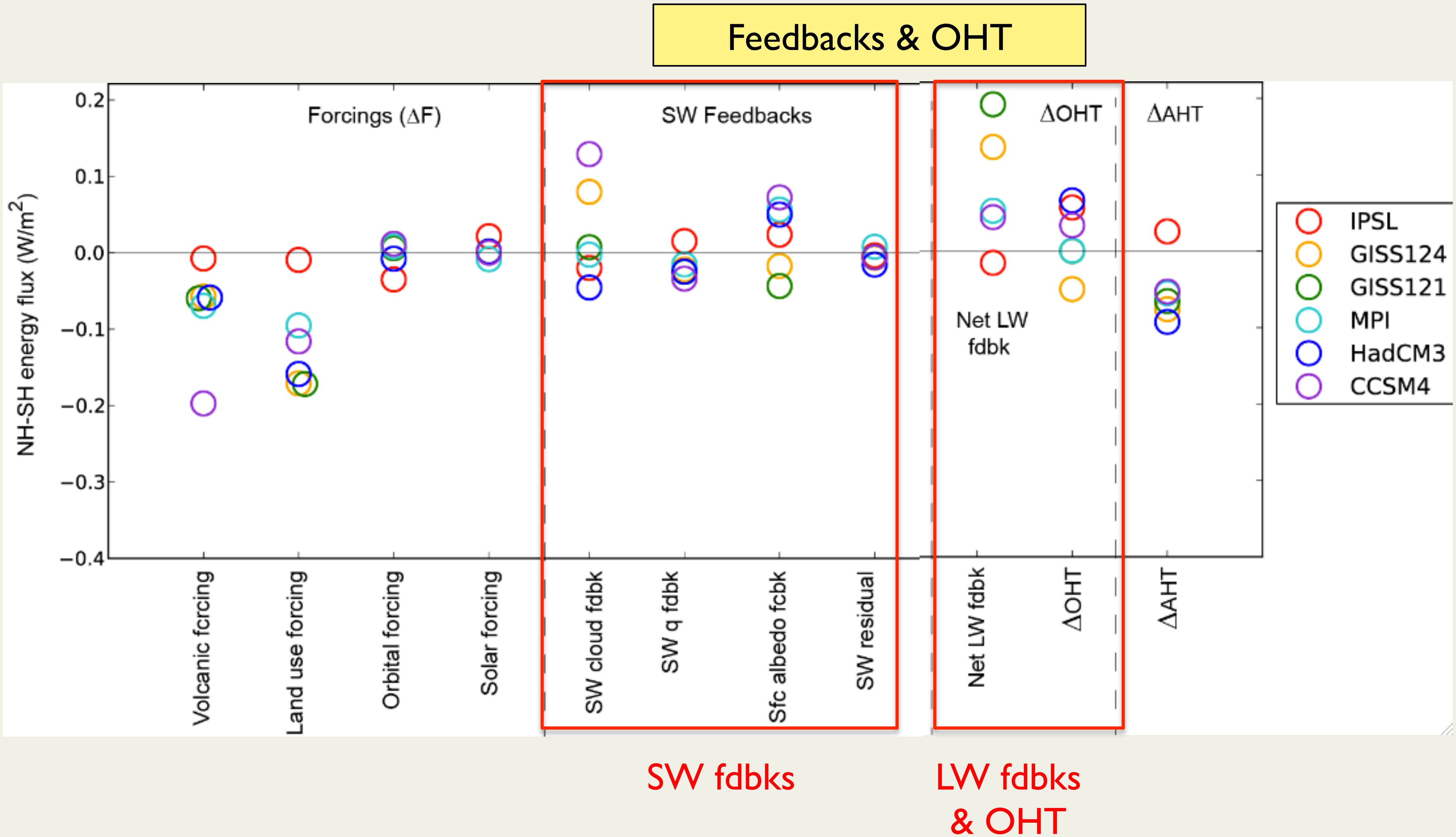
land use changes

Changes in hemispheric energy budget during Little Ice Age

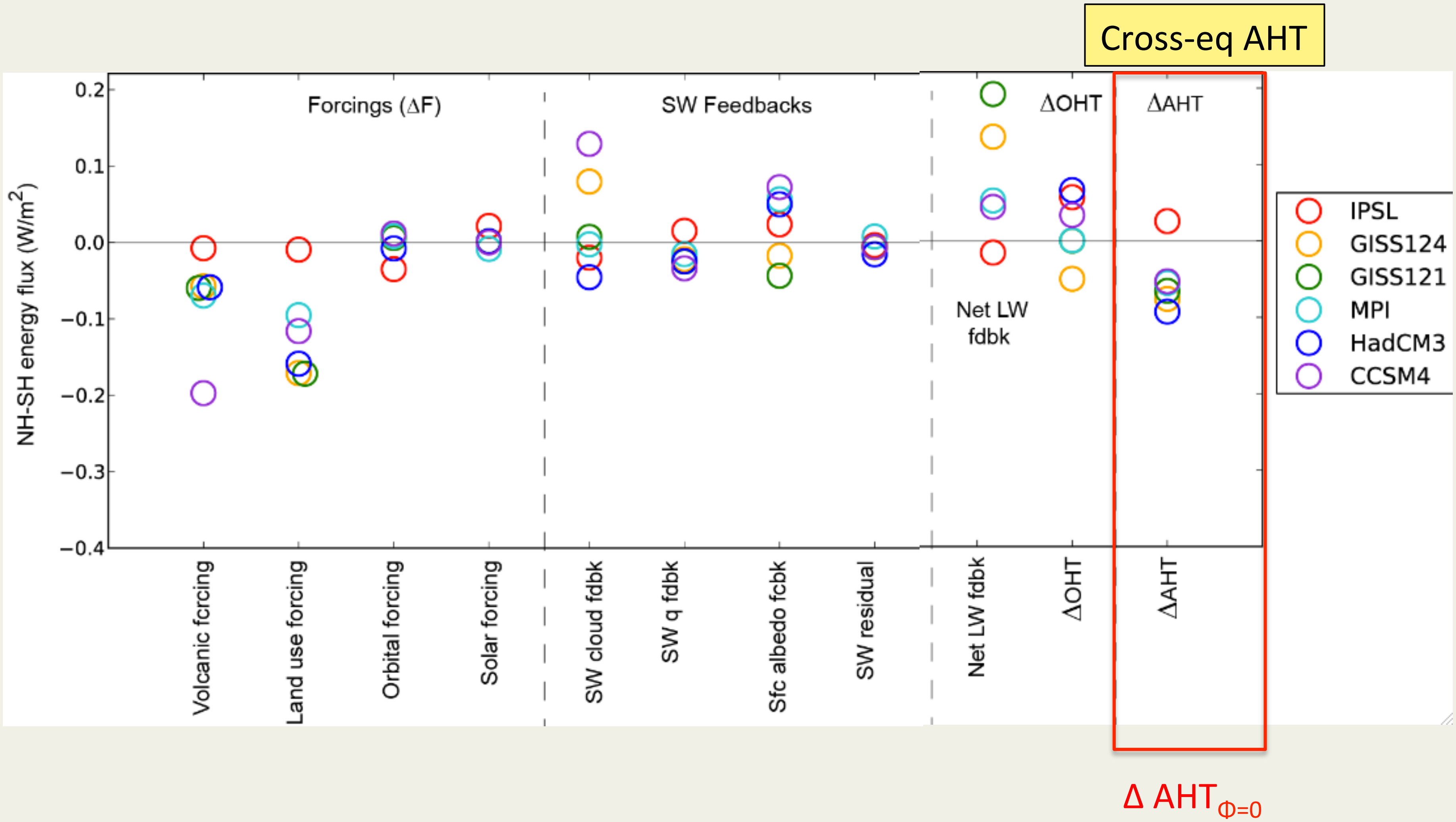
Forcings

Orbital and solar forcing

Changes in hemispheric energy budget during Little Ice Age

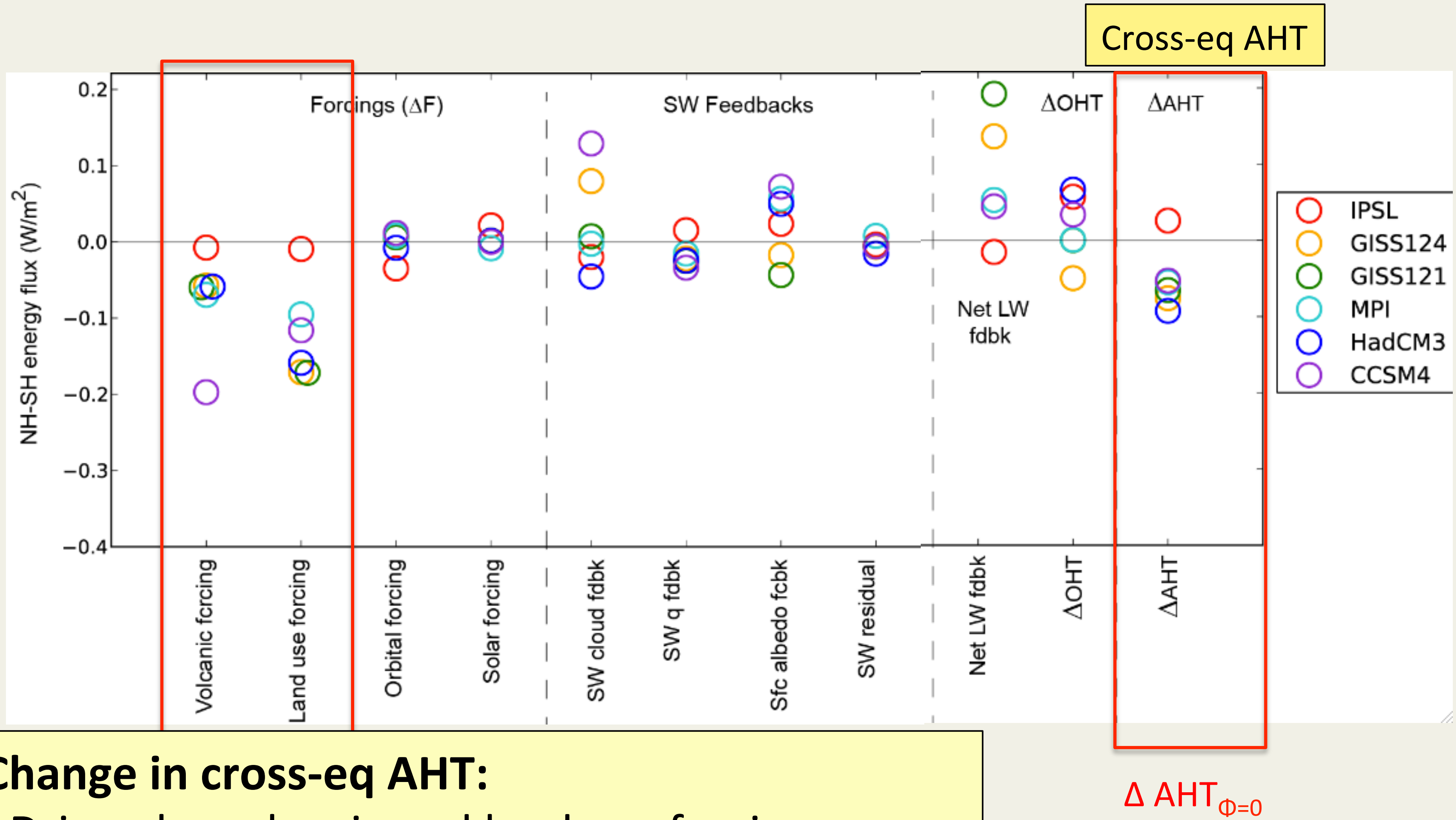


Changes in hemispheric energy budget during Little Ice Age



Atwood et al., (in prep)

Changes in hemispheric energy budget during Little Ice Age



Change in cross-eq AHT:

- Driven by volcanic and land use forcing
- Opposed by LW feedbacks

Atwood et al., (in prep)

What led to the southward shift in tropical precip?

Forcing mechanisms:

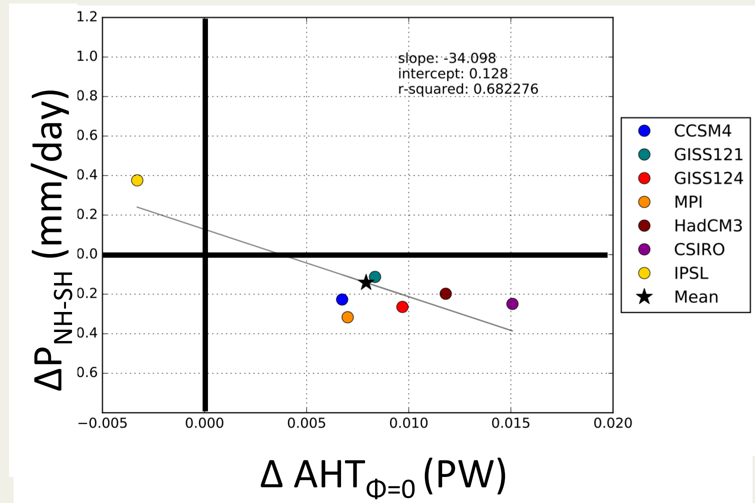
1. Volcanic forcing (✓)

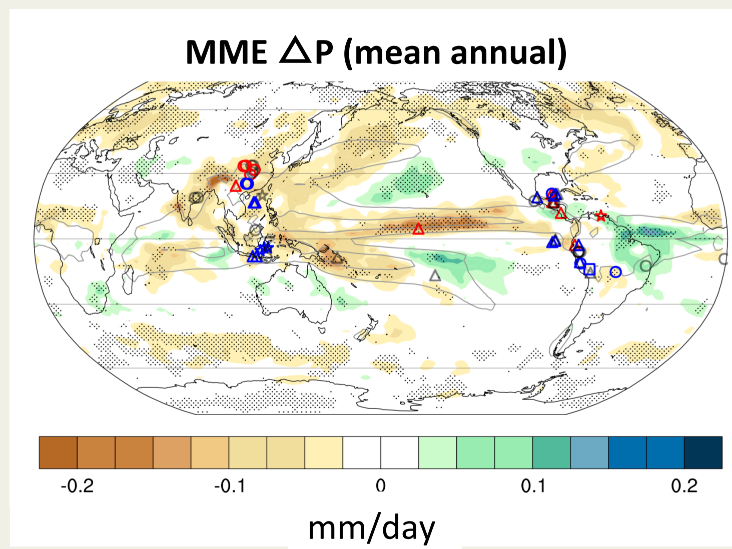
2. Land use forcing (✓)

3. Solar/orbital forcing

Climate feedbacks

1. Ice albedo feedback
2. Cloud feedback
3. Water vapor feedback





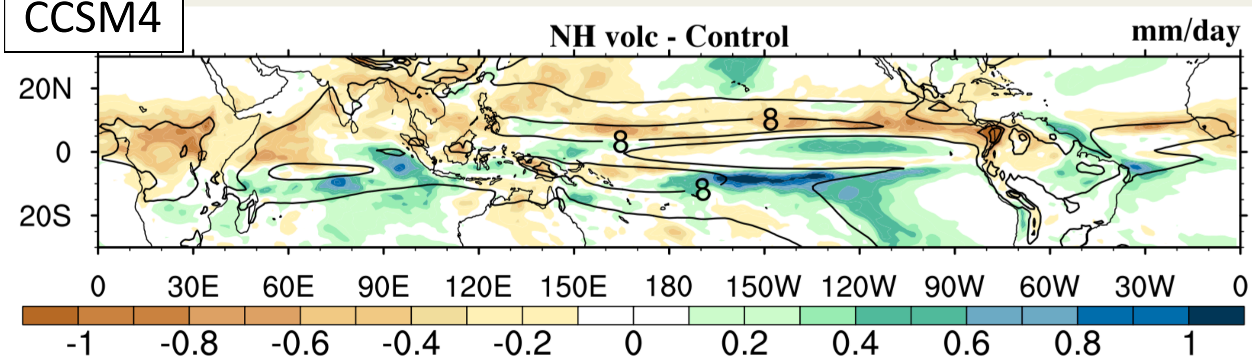
Conclusions

- **Southward shift in tropical Pacific LIA precip occurs in models and proxies**
- In models, southward shift is accompanied by **anomalous northward cross-eq. AHT driven by volcanic forcing and land use changes**
- Regional precip changes during LIA:
  - **Drying in N. Pacific ITCZ** and SE Asia (eastward shift of SPCZ, moistening in eq. Atlantic)
  - Driven by **thermodynamic changes** and enhanced by **strong positive dynamical feedback**.

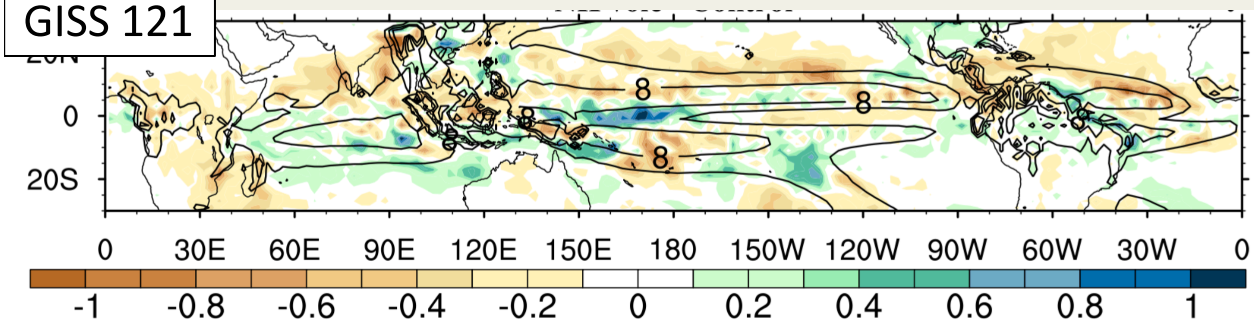
Extras

Precip response to NH volcanos

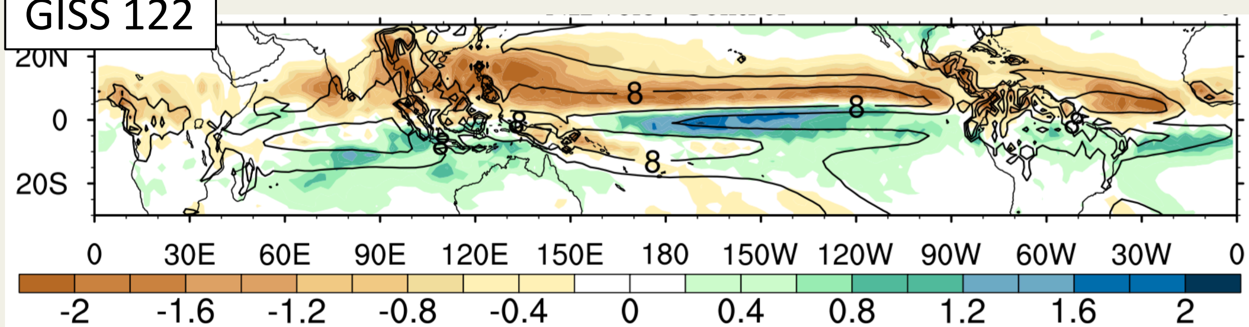
CCSM4



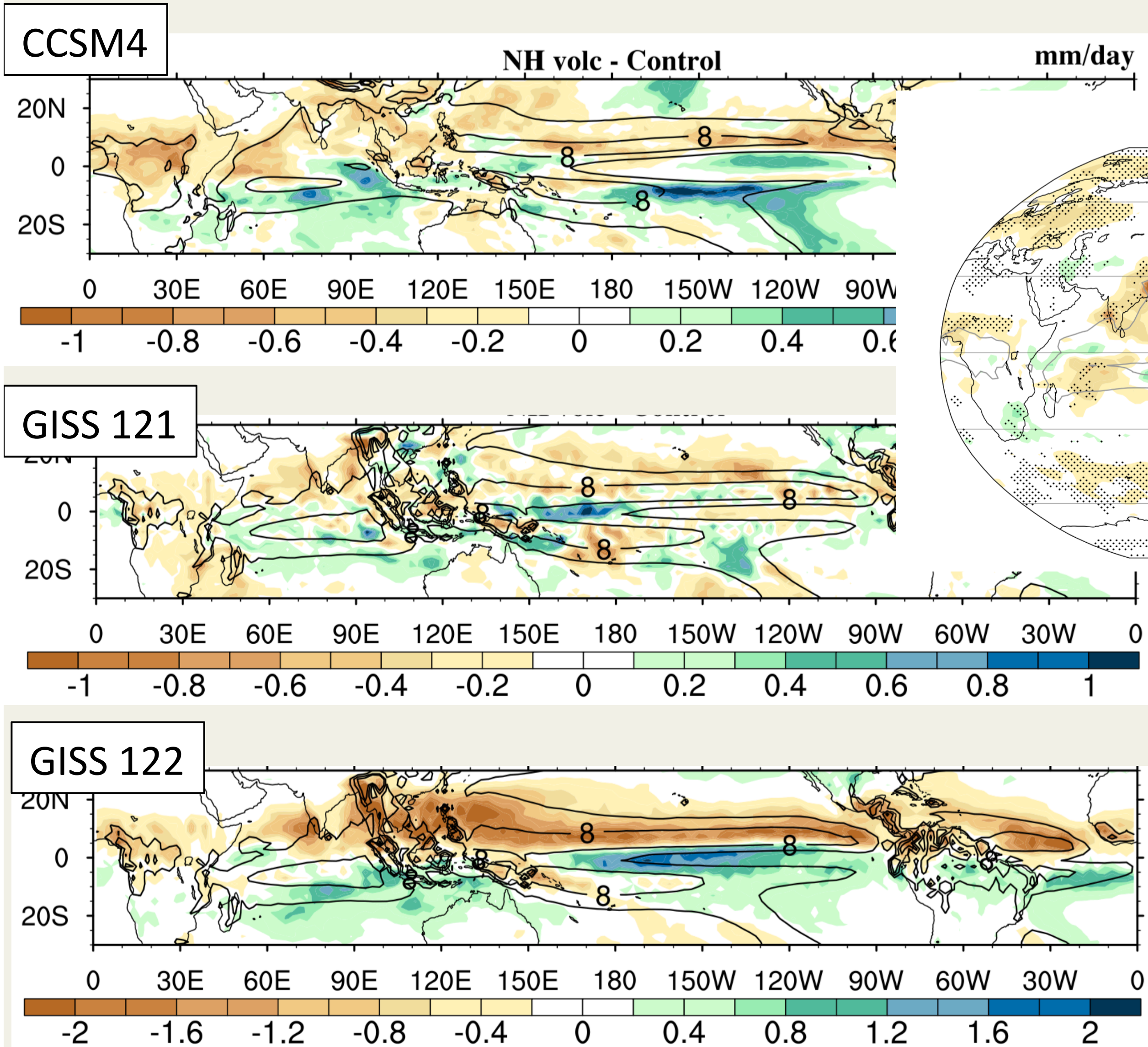
GISS 121

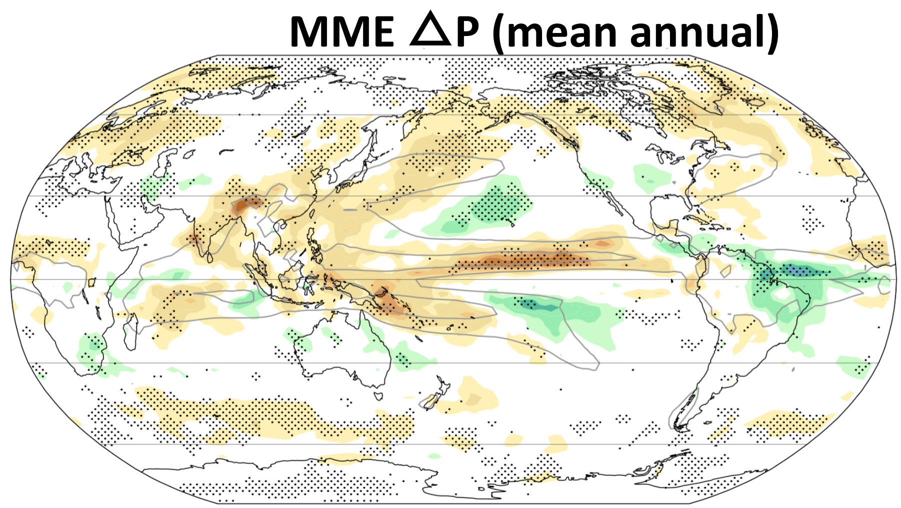


GISS 122



Precip response to NH volcanos





- **Drying over land and Pacific ITCZ**
- **Zonally-uniform southward precip shift**

LIA global cooling contributions

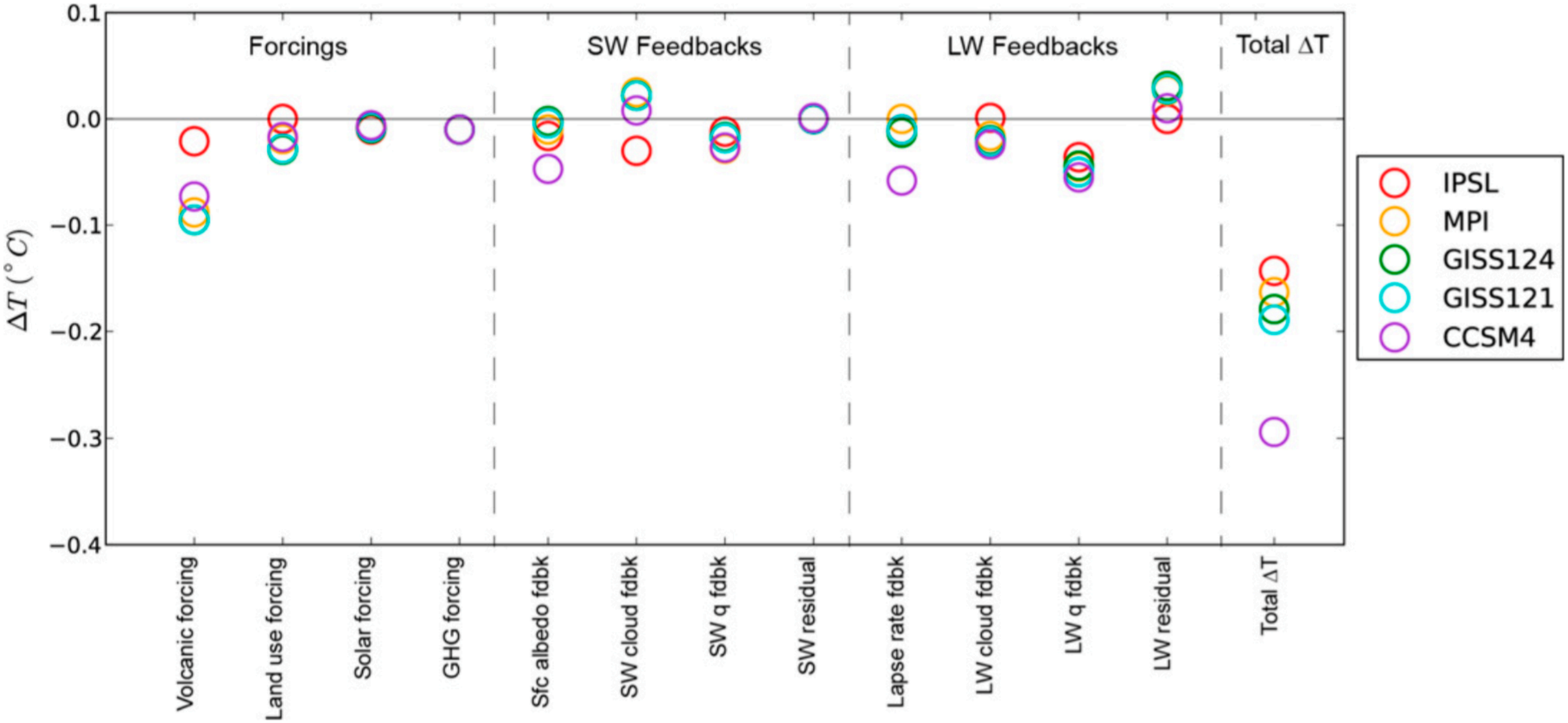


FIG. 7. Global cooling contributions from Eq. (18) due to volcanic, land use, solar, and GHG forcings and the SW and LW feedbacks compared to the total globally averaged temperature change between the LIA (1600–1850 CE) and MCA (950–1200 CE). The difference between the total cooling and the sum of the forcings and feedbacks is the Planck response. Global cooling contributions were not calculated for HadCM3 and CSIRO because of data unavailability (see text for details).

Atwood et al.,
J. Clim (2016)

LIA global cooling contributions

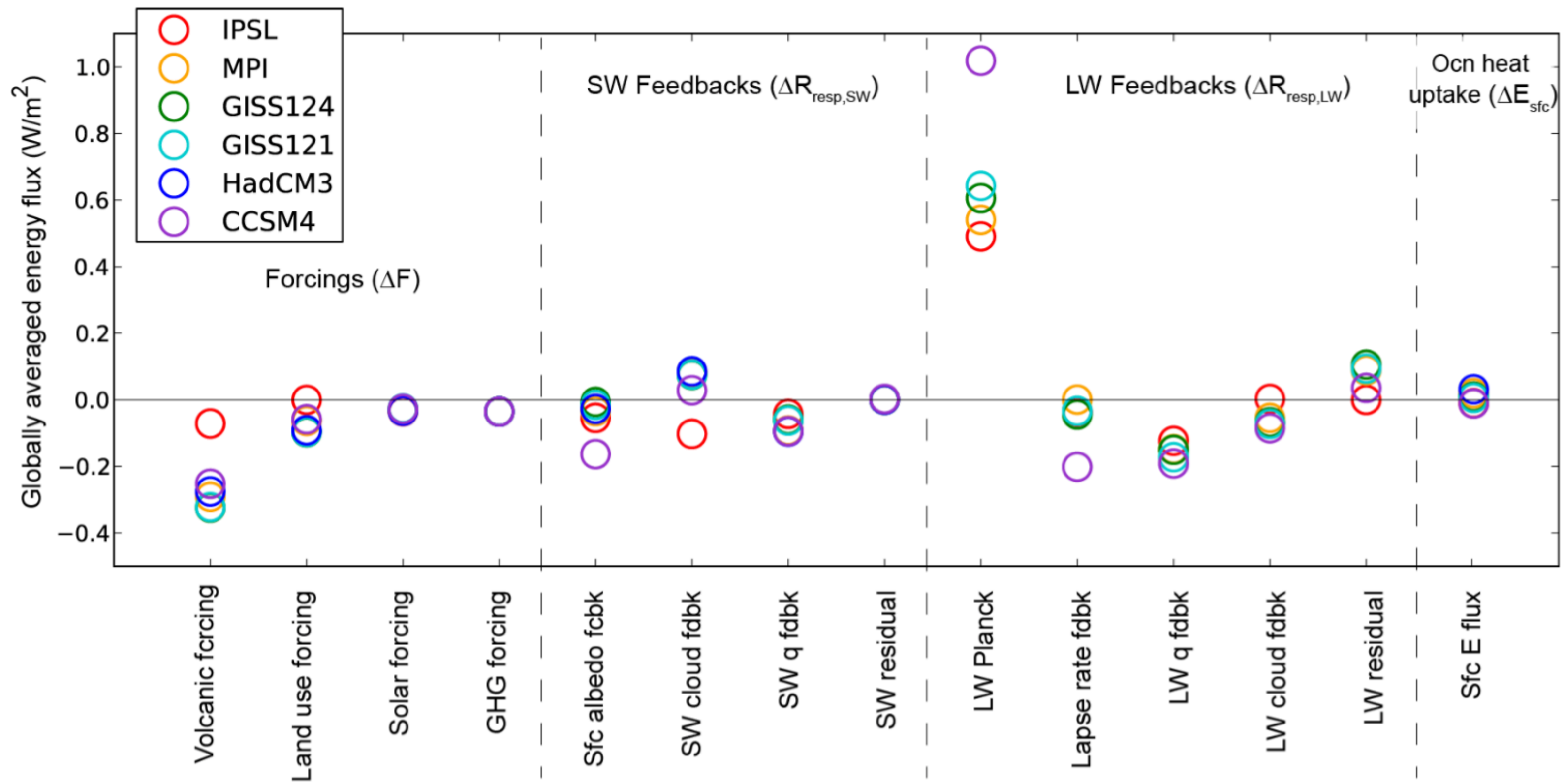
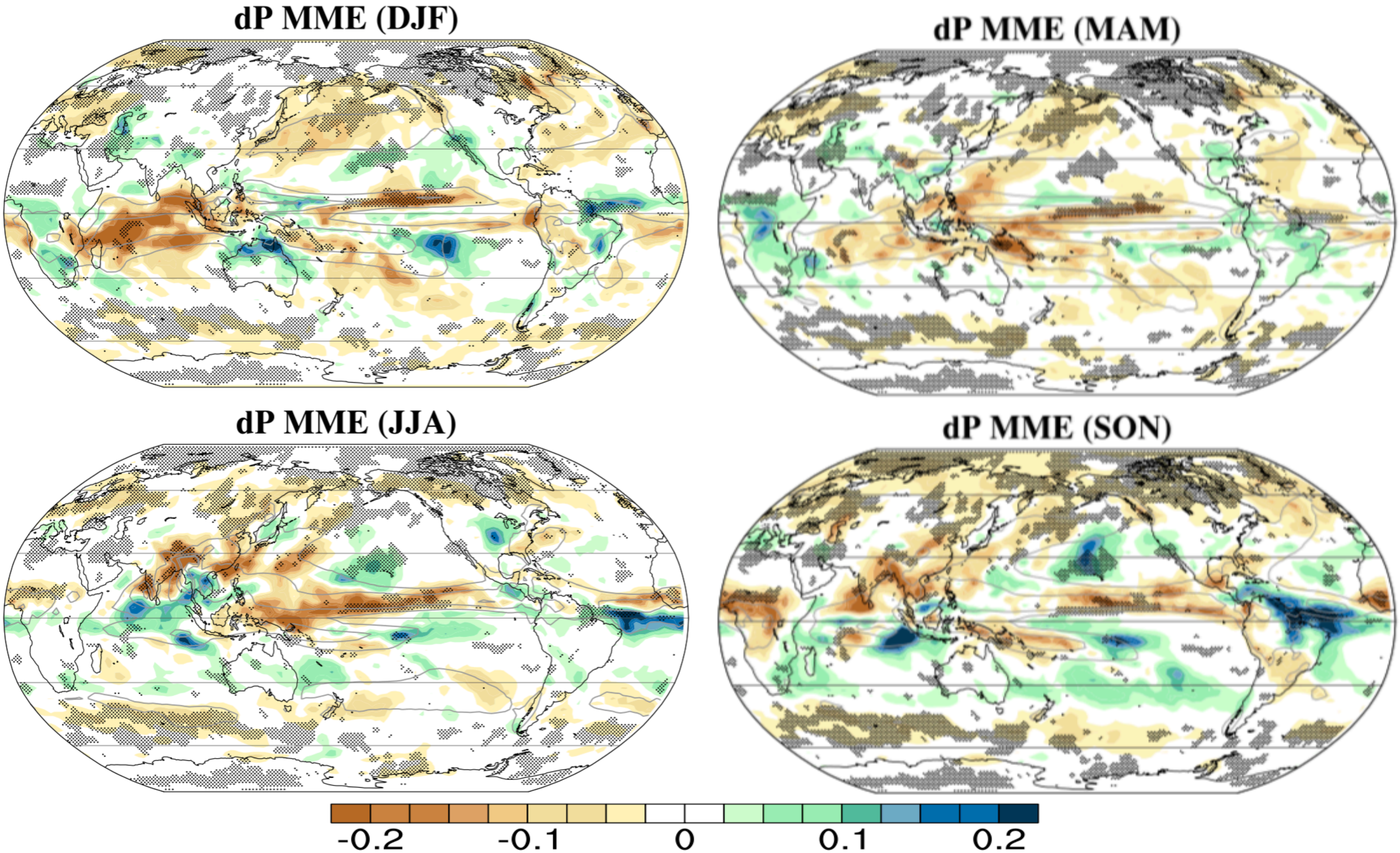


Fig. S1. Little Ice Age (1600-1850 CE) minus Medieval Climate Anomaly (950-1200 CE) change in globally averaged TOA energy fluxes (ΔR) associated with the forcings (volcanic, land use, solar, greenhouse gas), SW feedbacks (surface albedo, SW cloud, SW q, SW residual) and LW feedbacks (Planck, lapse rate, LW q, LW cloud, LW residual). The globally averaged surface energy flux (ΔE_{sfc}) is also plotted. Decomposition of SW and LW feedbacks was not performed for CSIRO due to the implementation of the volcanic forcing (see text for details), while decomposition of LW feedbacks was not performed for HadCM3 due to data availability.

Atwood et al.,
J. Clim (2016)

Seasonal precip changes (LIA – MCA)



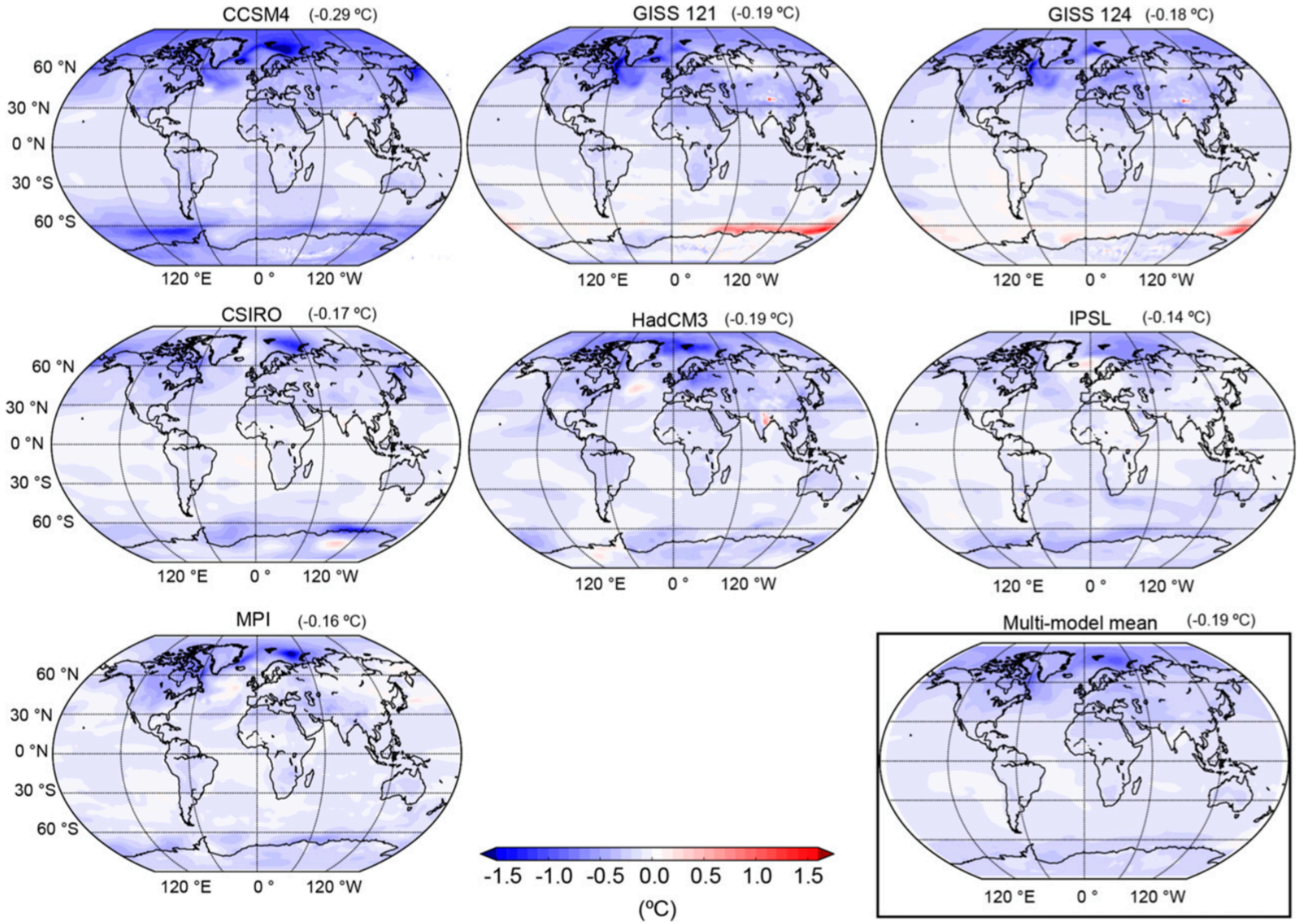


FIG. 4. LIA (1600–1850 CE) minus MCA (950–1200 CE) surface air temperature changes in the CMIP5–PMIP3 simulations. The value in parentheses next to each model name represents the global mean surface temperature change.

Atwood et al., J. Clim (2016)

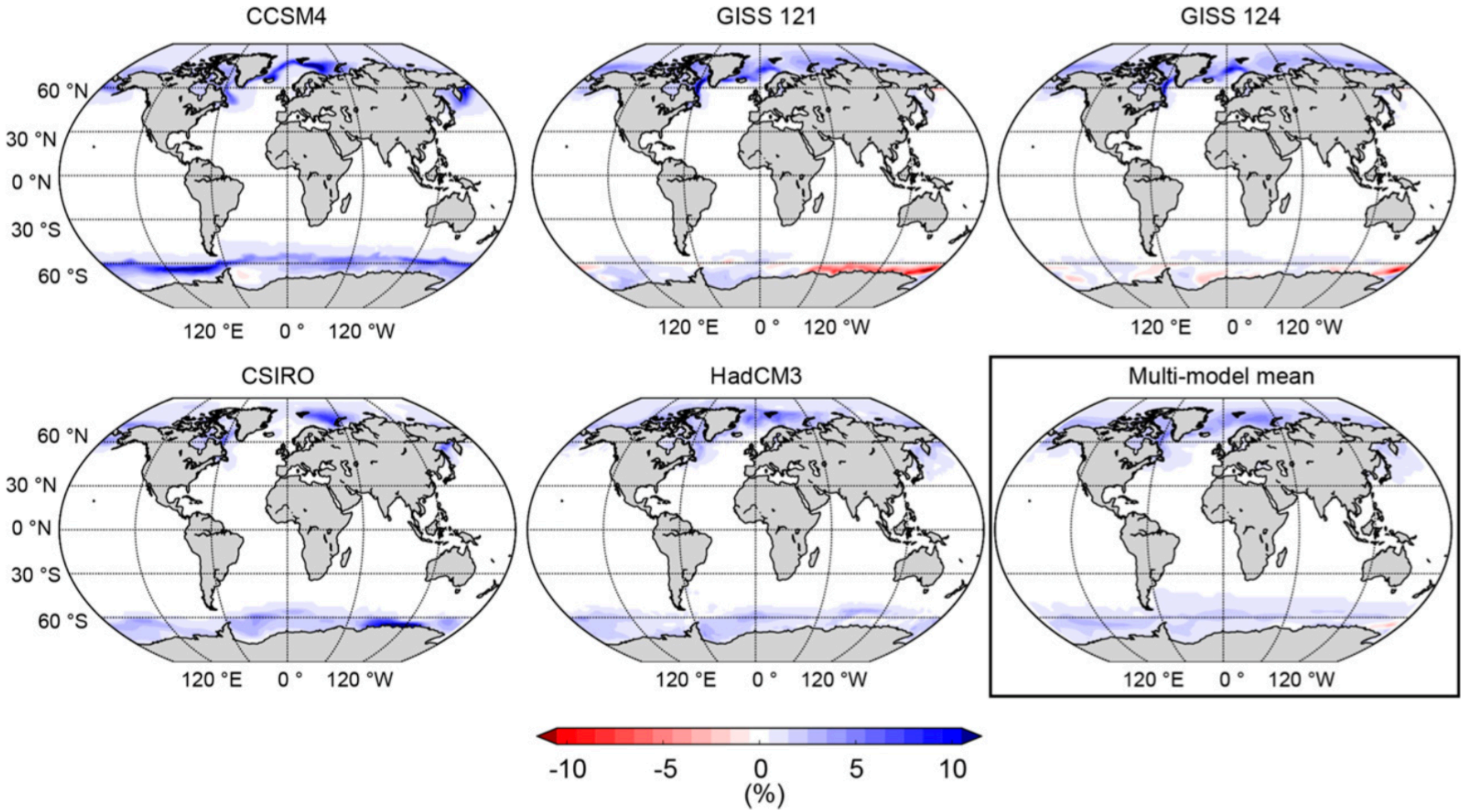


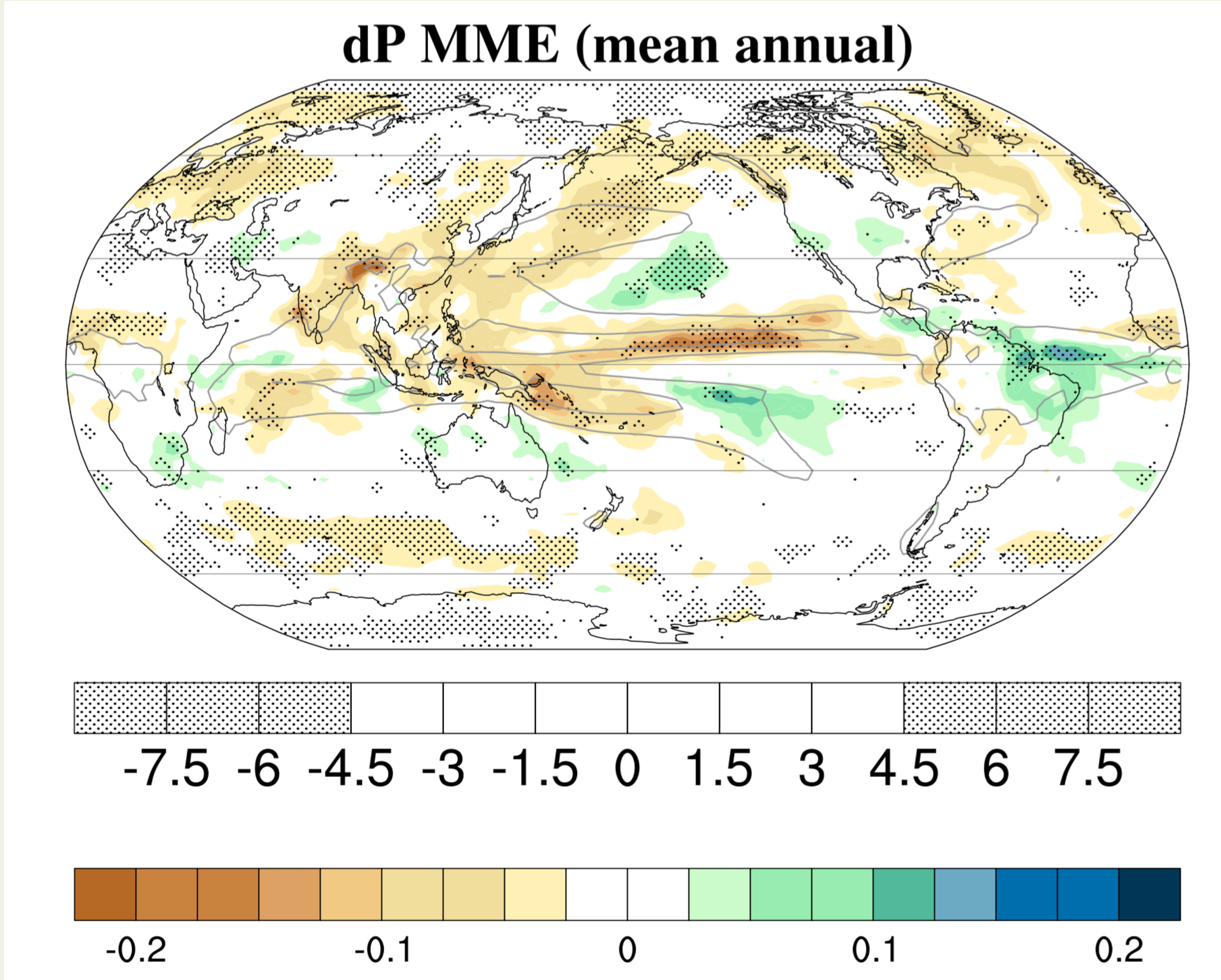
FIG. 5. As in Fig.4, but for sea ice concentration. Sea ice data were not available for IPSL.

Atwood et al.,
J. Clim (2016)

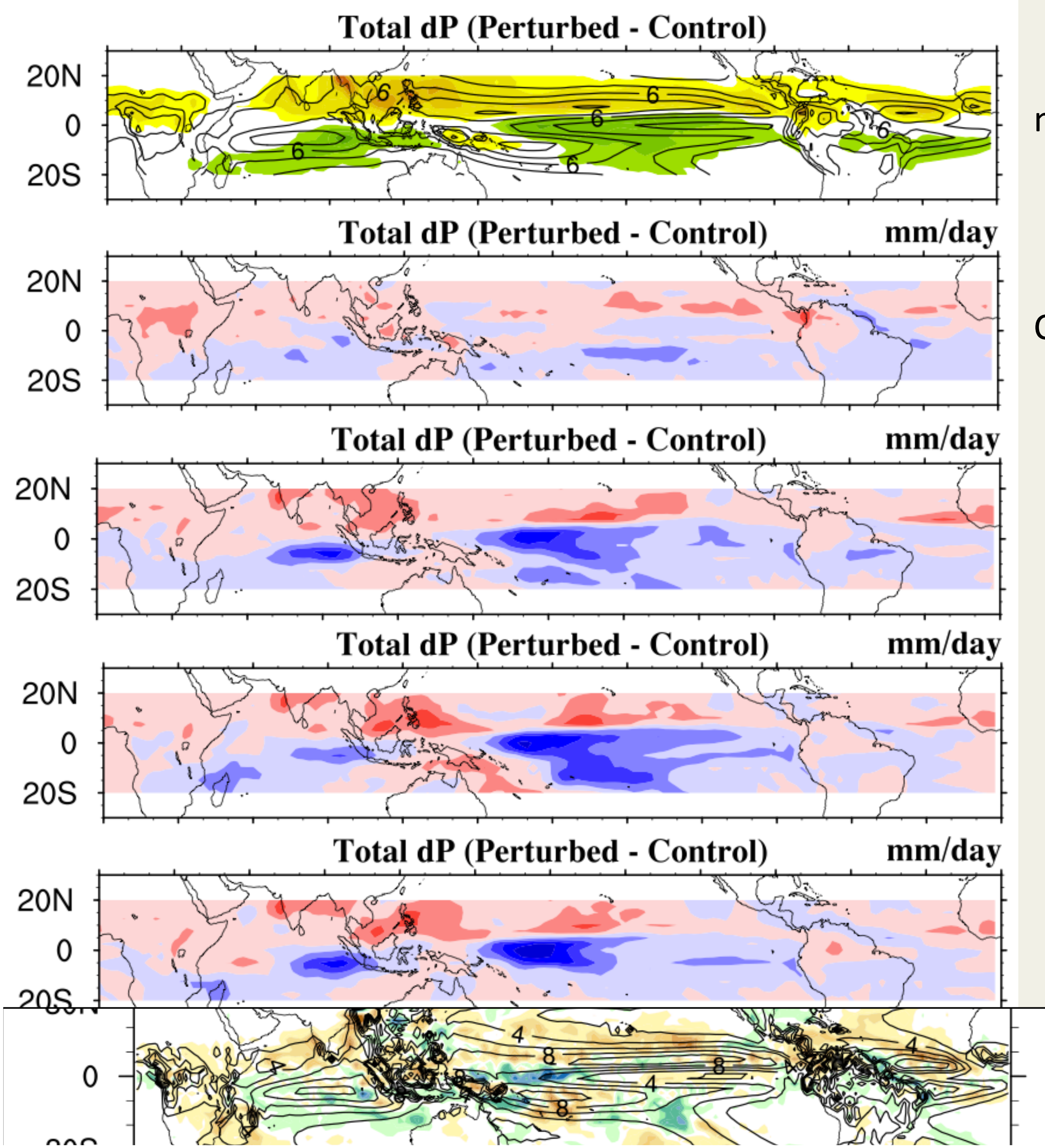
Multi-model precip changes (LIA – MCA)

During LIA:

- Drier N. branch of ITCZ
- Eastward shift of SPCZ
- Wetter eq. Atlantic/drier Sahel
- Drier EASM/ISM



*Stippling: 5/6 models agree on the sign of ΔP



multi-model volcanic forcing

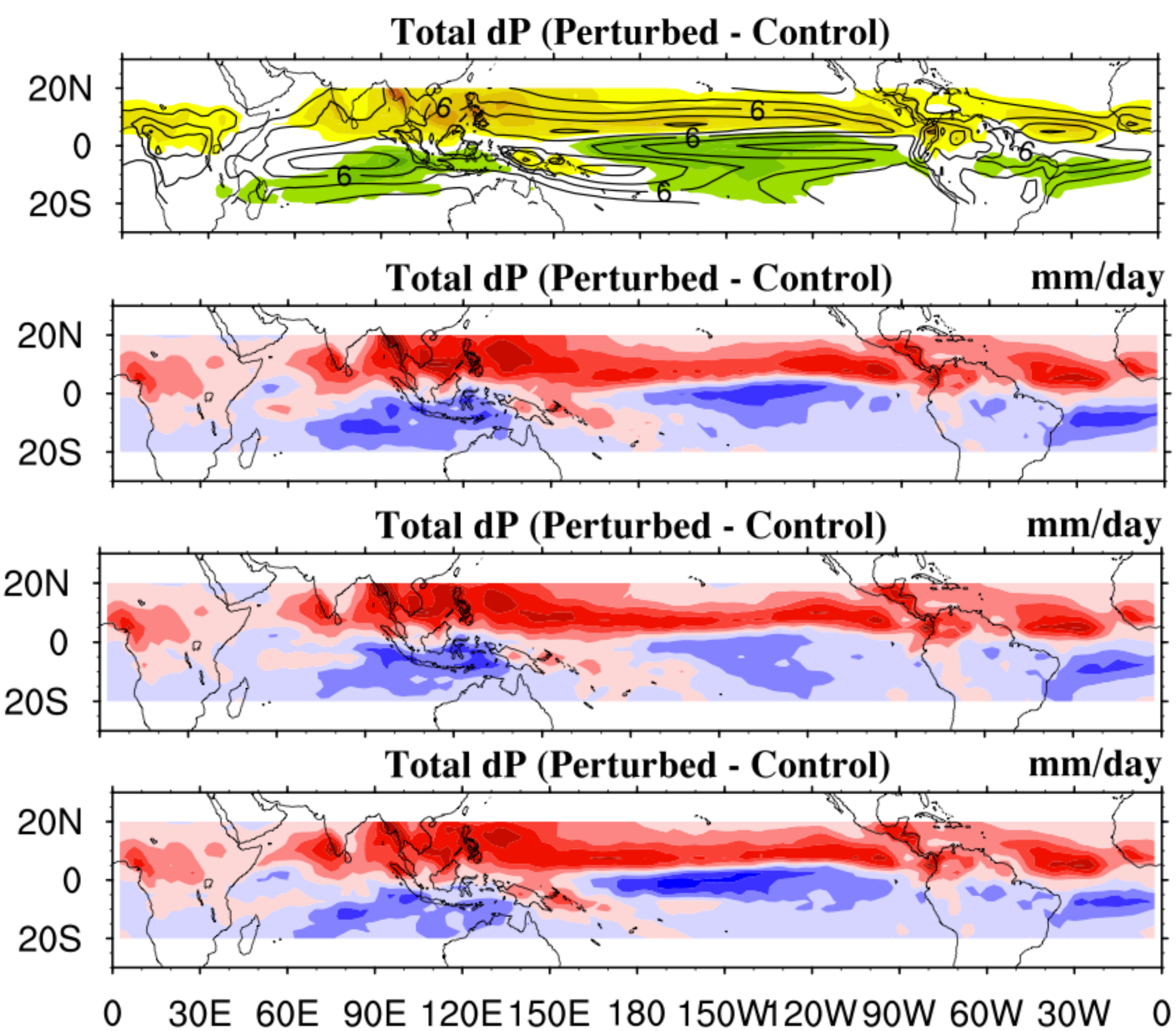
CCSM4 LM (NH volcanic events)

Laki ensemble 3

Laki ensemble 2

Laki ensemble 1

GISS 121 LM (NH volc events)



multi-model volcanic forcing

GISS 128 LM (NH volc events)

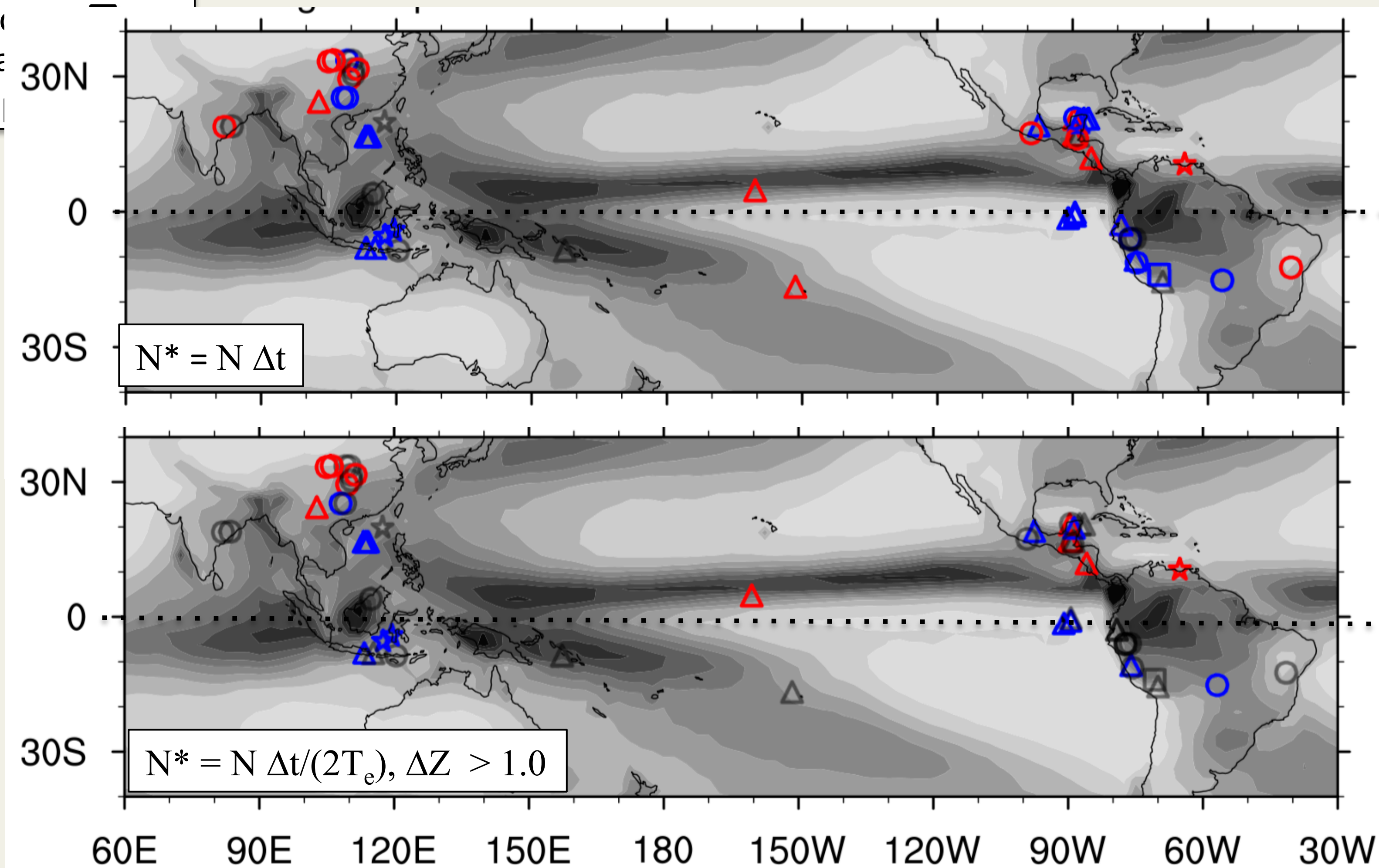
GISS 125 LM (NH volc events)

GISS 122 LM (NH volc events)

Southward precip shift from MCA → LIA

Drier LIA
Wetter LIA
No change

$\overline{(1500\text{-}1850)}$ CE – $\overline{(950\text{-}1200)}$ CE



In LIA:

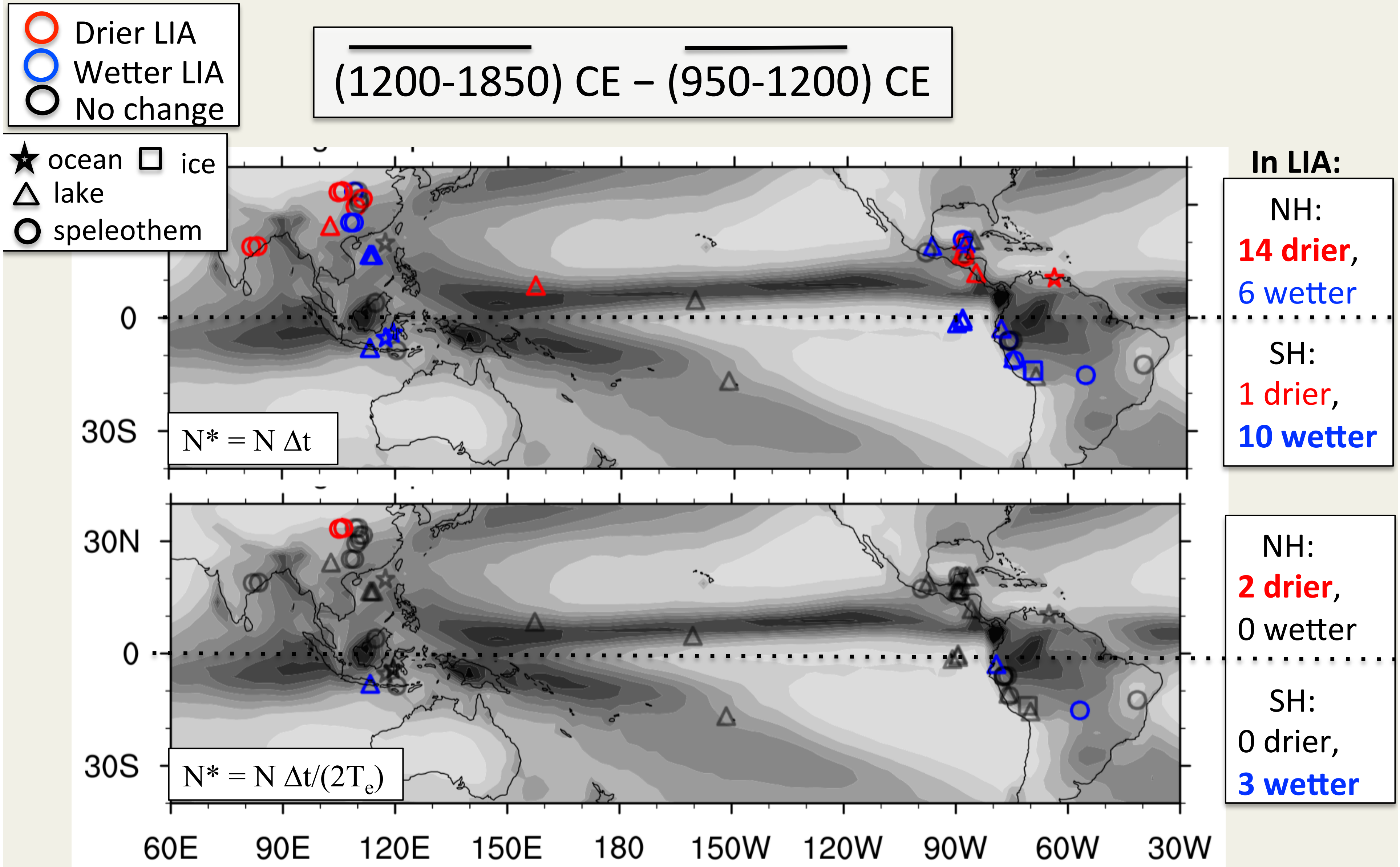
NH:
13 drier,
7 wetter

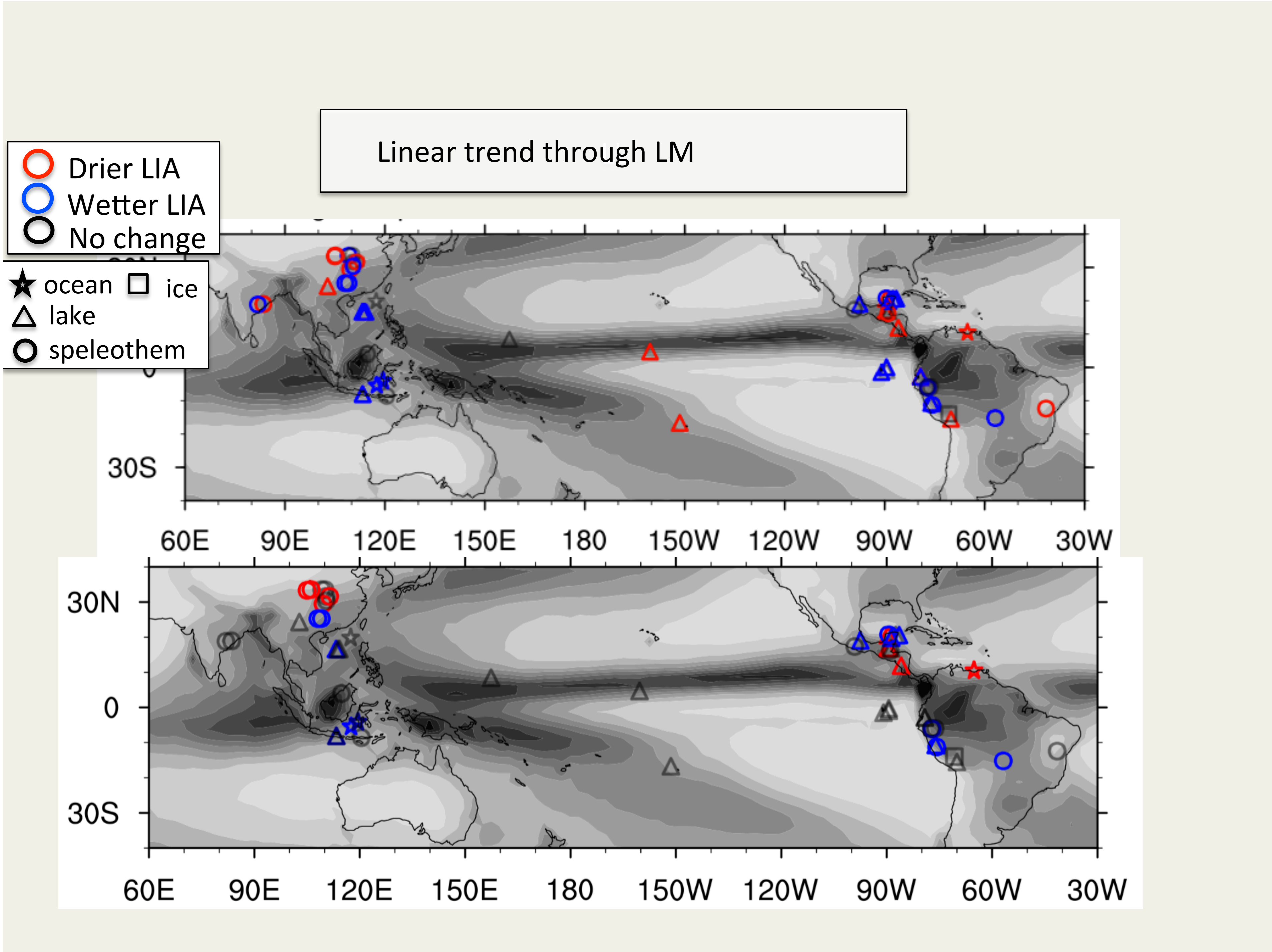
SH:
2 drier,
10 wetter

NH:
2 drier,
1 wetter

SH:
0 drier,
2 wetter

Similar for "LIA" period from 1200-1850 AD





Linear trend through LM
Drier LIA
Wetter LIA
No change
ocean
ice
lake
speleothem
30S
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
30N
0
30S
60E
90E
120E
150E
180
150W
120W
90W
60W
30W