Tropical regional rainfall impacts under anthropogenic climate change

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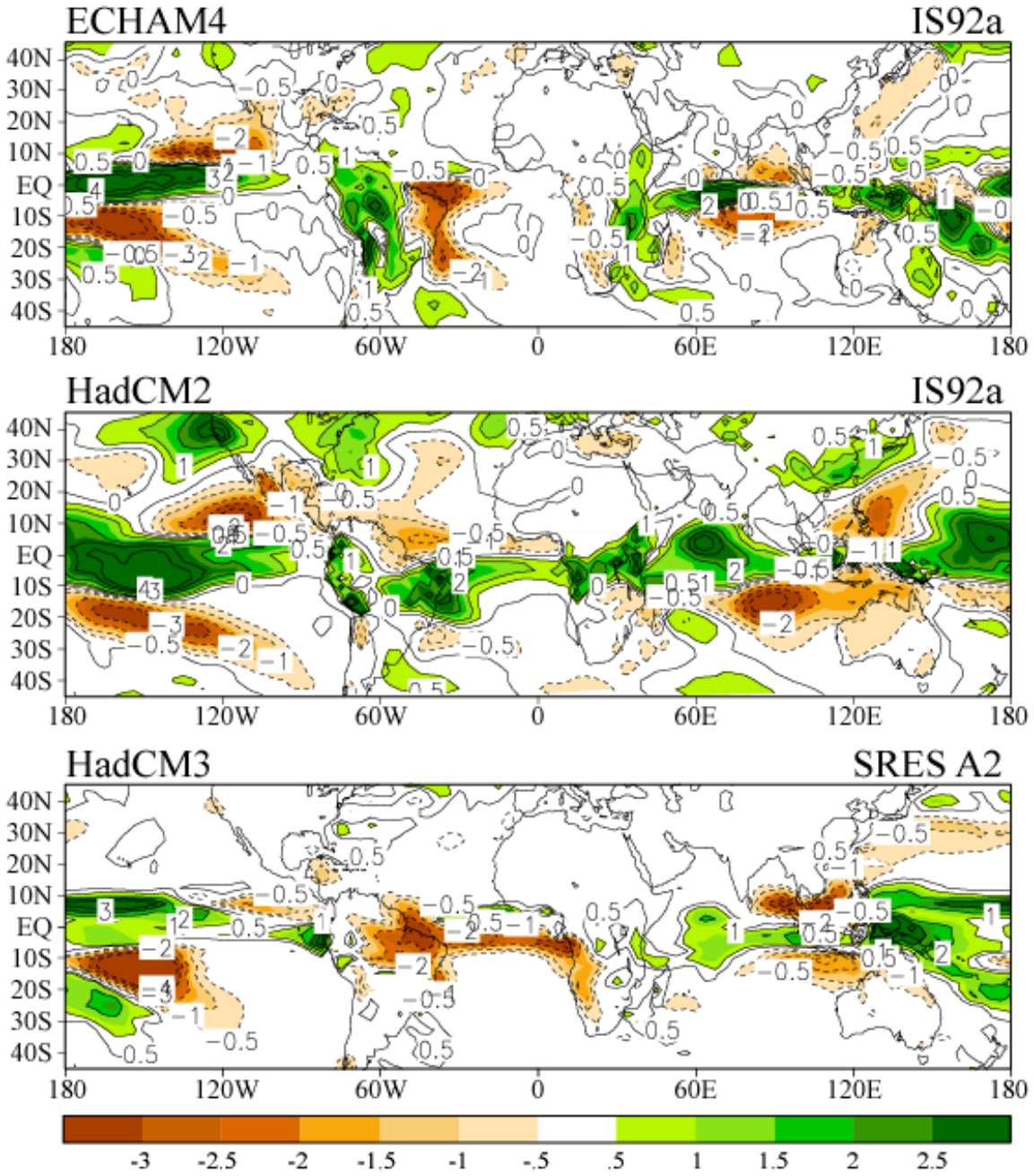
- **Moist dynamical mechanisms for convection zone regional response to global scale radiative forcing**
- **Greenhouse gas (Neelin et al 2003, GRL; Chou & N 2004, J Clim)**
- **Aerosol case (Chou et al 2005, J Clim subm)**

Global Warming case: GCM Precip. Anom.

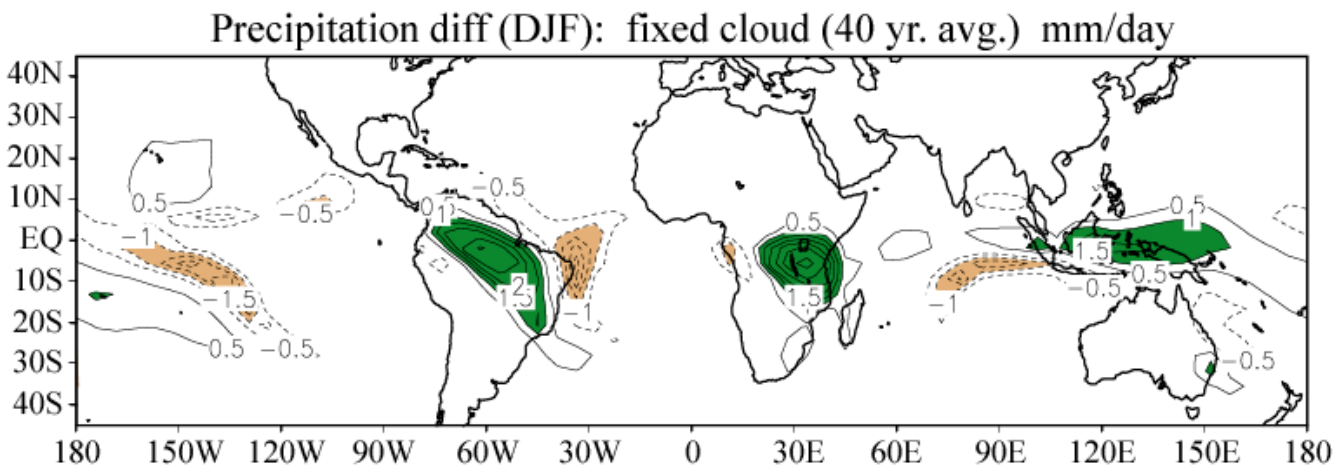
DJF precip. anom.
Three GCM
Greenhouse gas
scenarios for
2070-2090
rel. to 1961-1990 clim
(GHG forcing
dominant)



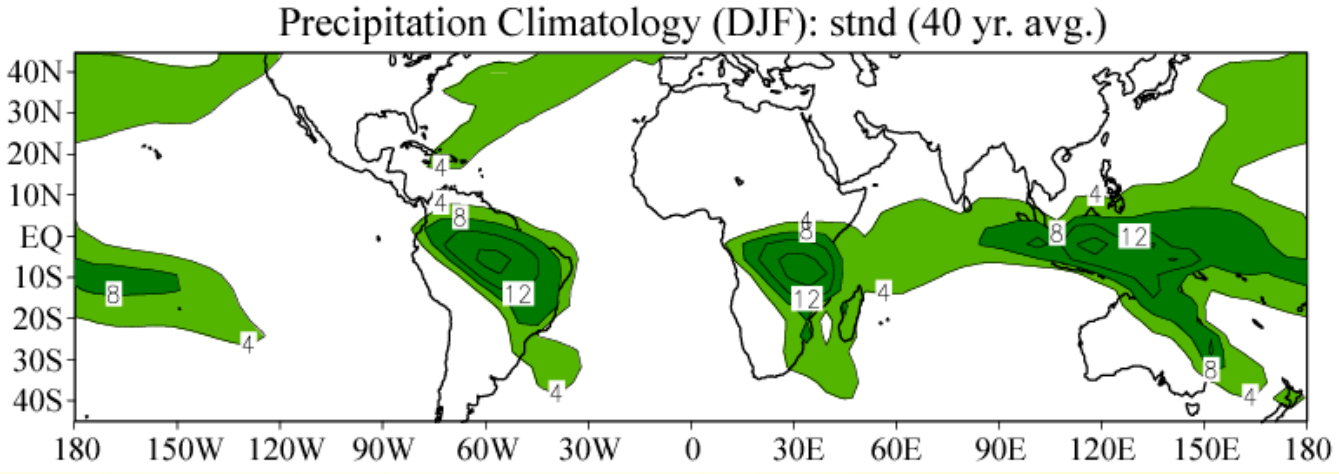
Neelin et al 2003

QTCM doubled CO_2 experiments
Qflux mixed-layer ocean

Dec - Feb
Precip change



Dec - Feb
QTCM Precip
climatology

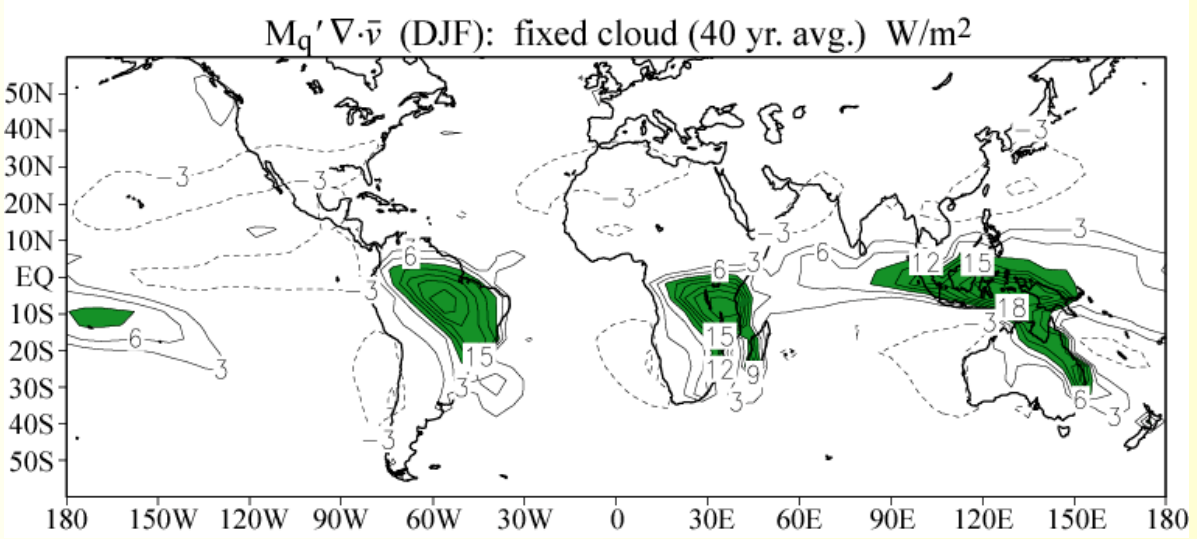


Neelin et al 2003; Chou & Neelin 2004

QTCM doubled CO_2 experiments
Moisture budget contributions

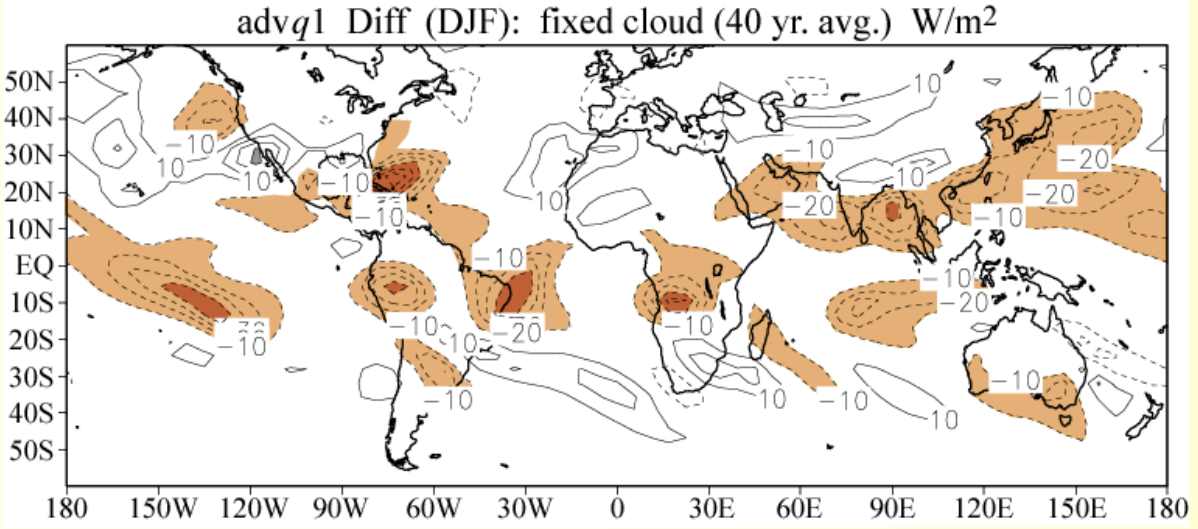
$M_q' \nabla \cdot \bar{v}$

Anomalous moisture convergence due to moisture anom. q'



$(v \cdot \nabla q)'$

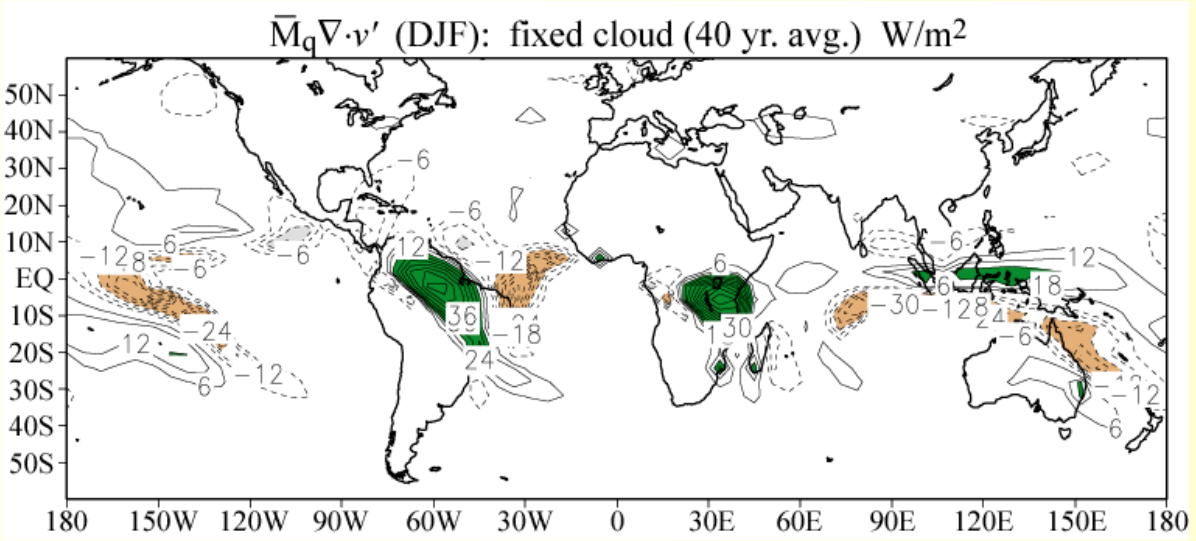
Anomalous moisture advection



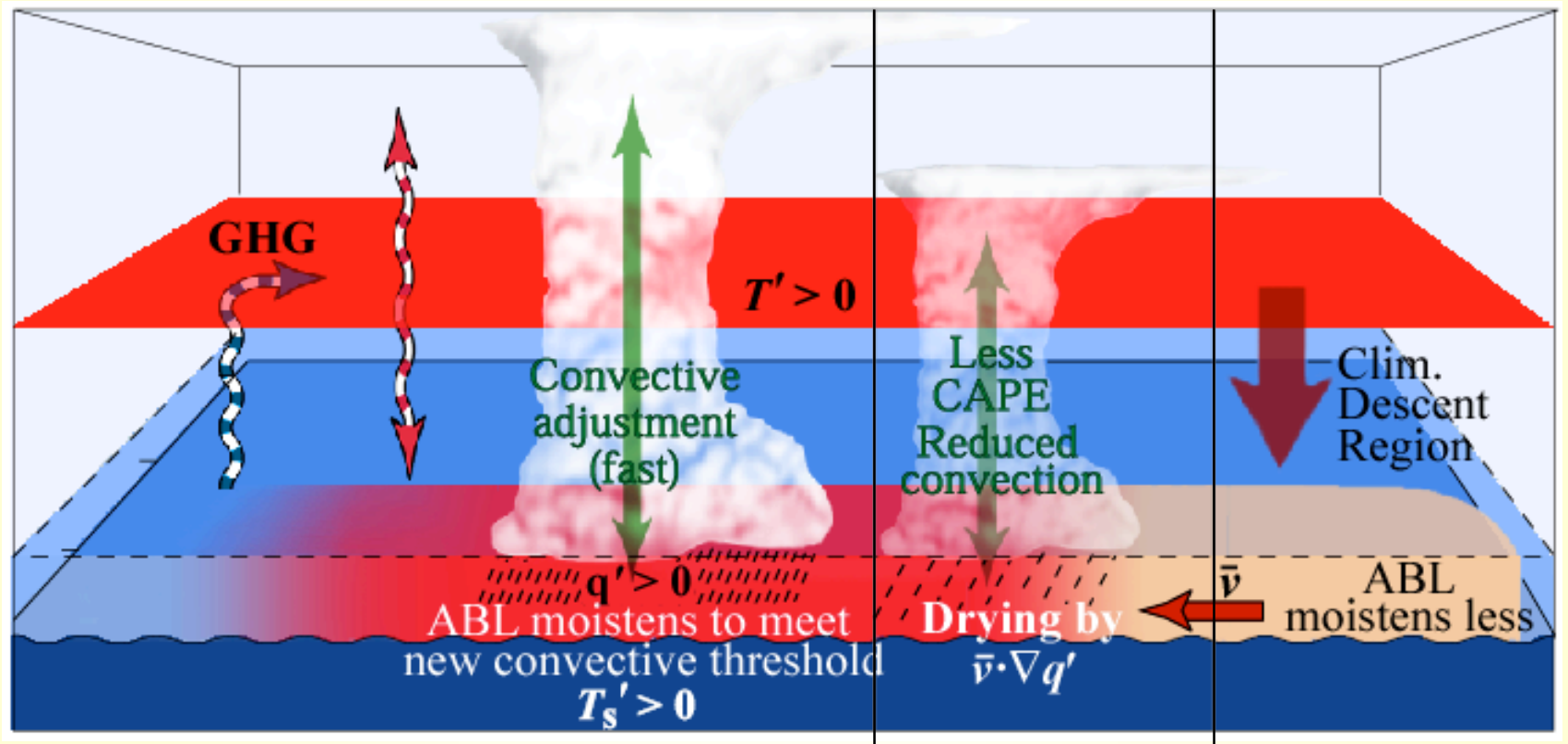
QTCM doubled CO_2 experiments
Moisture budget contributions

$\bar{M}_q \nabla \cdot v'$

Anomalous moisture convergence due to anomalous divergence (GMS multiplier effect feedback)

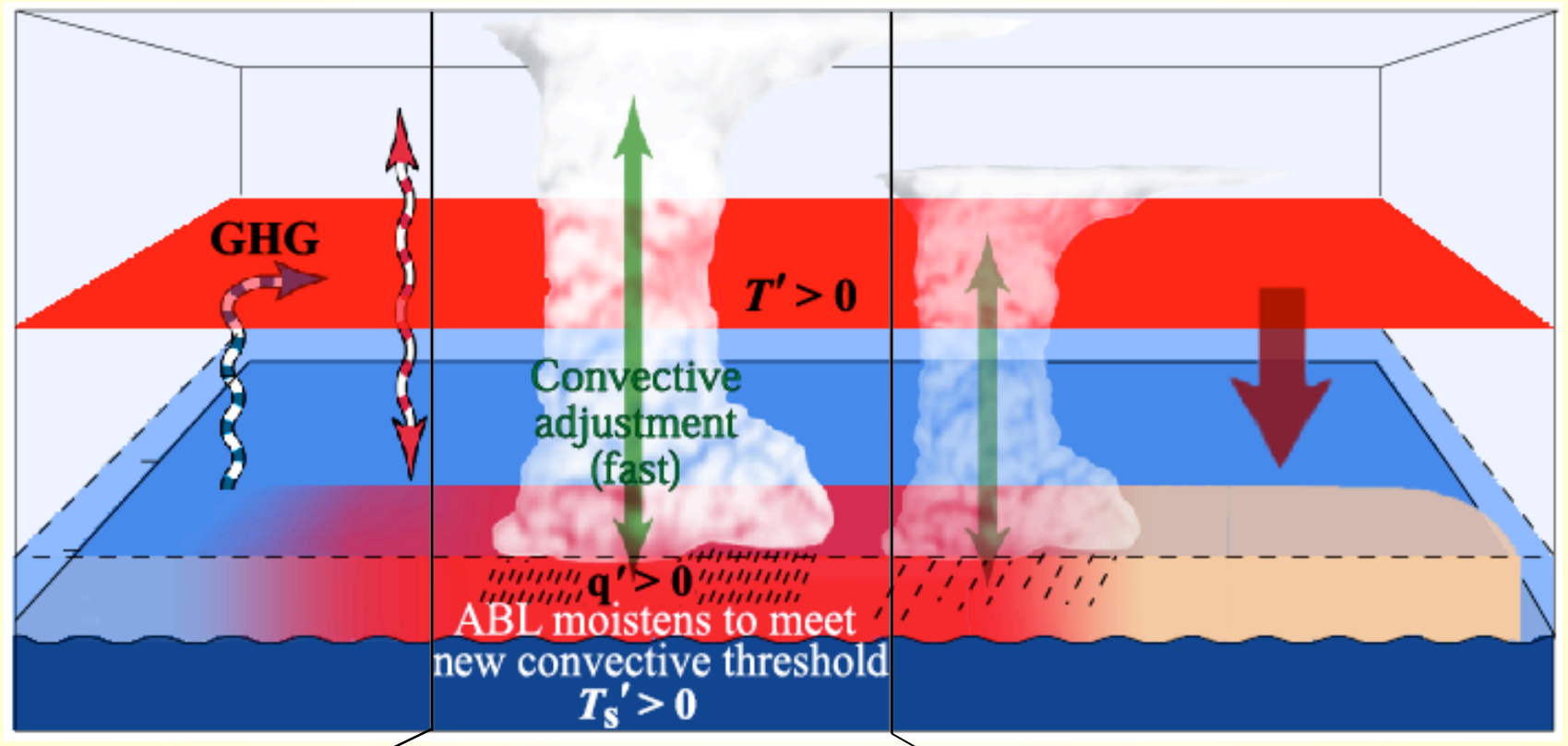


The "upped-ante" mechanism



Neelin, Chou & Su, 2003 GRL

The M′ (anomalous Gross Moist Stability) mechanism



Center of convergence zone: incr. moisture ⇒ lower gross moist stability ⇒ incr. convergence

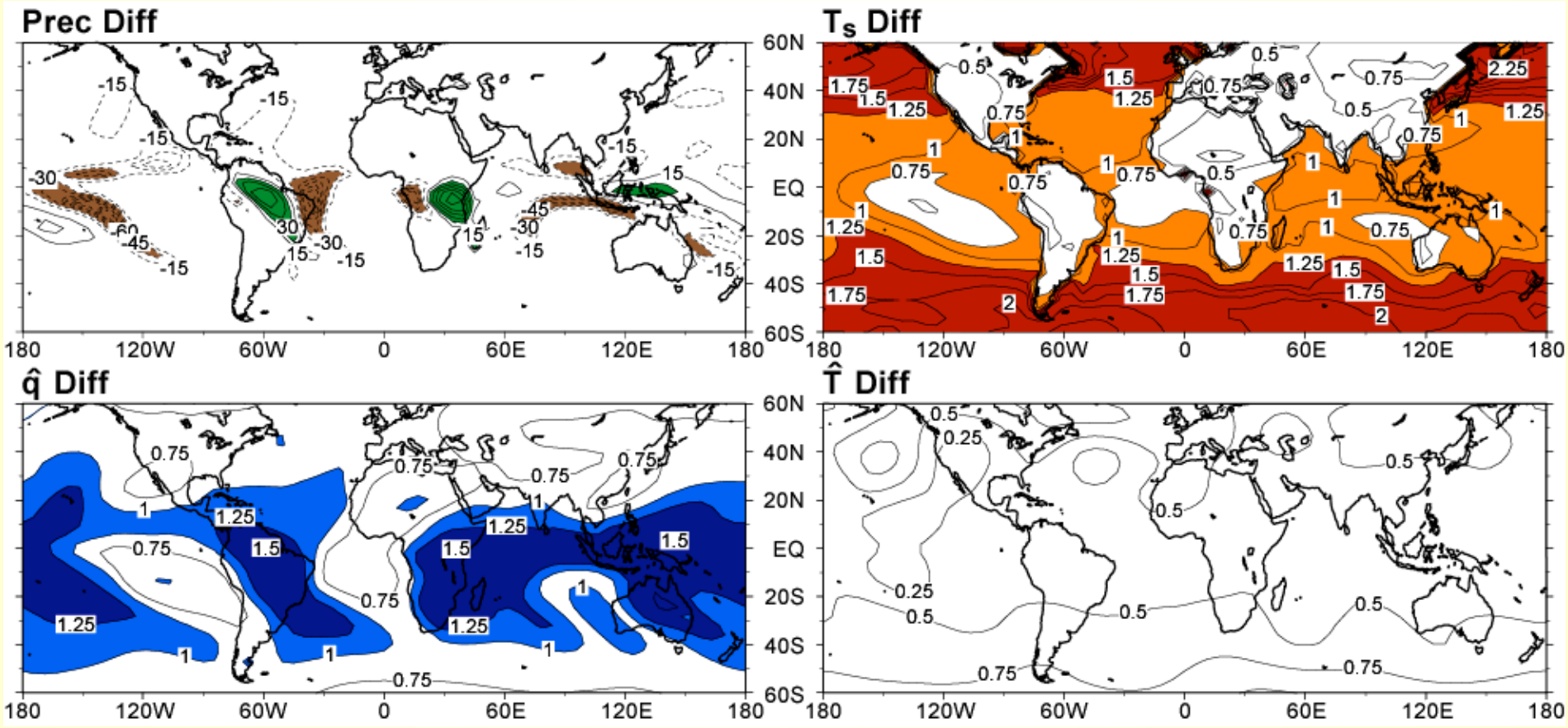
Chou & Neelin, 2004

Anomalous Gross Moist Stability (M′) mechanism

- Moist Static Energy transport by divergent flow $\approx M\nabla\cdot v$
- $M = M_s - M_q$
  - M_s: increases with increasing moisture, tends to reduce M
  - M_q: may partially compensate if cloud top rises
- $\bar{M}\nabla\cdot v' + M'\nabla\cdot\bar{v} = F'_{net} - (v\cdot\nabla q)' + \ldots$
  - $\bar{M}$: increases to compensate
  - M': reduced
- $P' \approx \frac{\bar{M}_q}{\bar{M}}\nabla\cdot\bar{v}(-M')$
- Mechanism increases convergence & precip. in strong convergence zones: "rich-get-richer"

Response to imposed T change in CAPE

- $T' = 1.5$ C added to temperature only inside convection scheme
- Mimics $2xCO_2$ moisture and regional precip response
- DJF Precip (W/m^2), surface temp, moisture (K), tropospheric mean temp

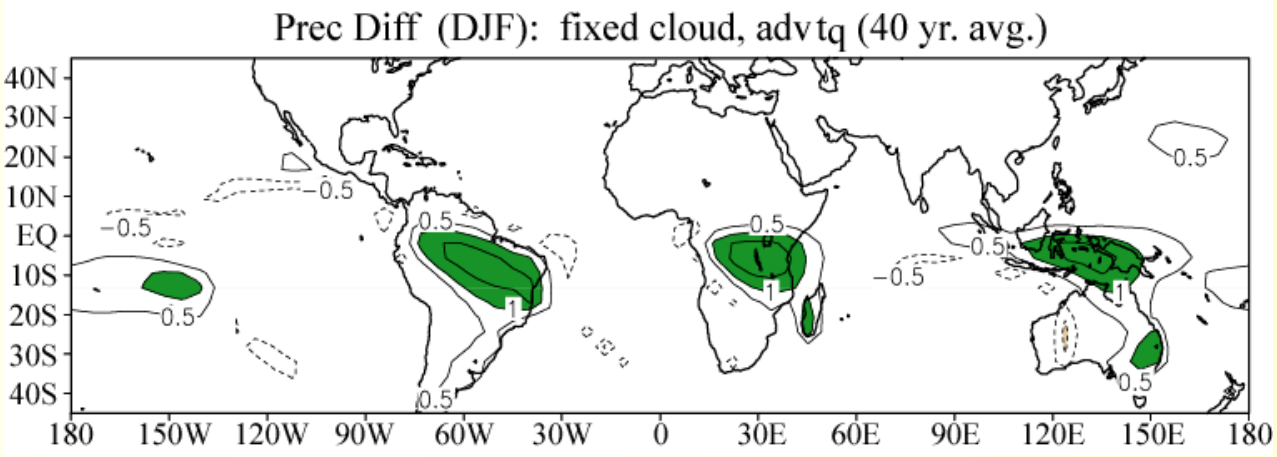


Chou & Neelin, 2004, J Clim

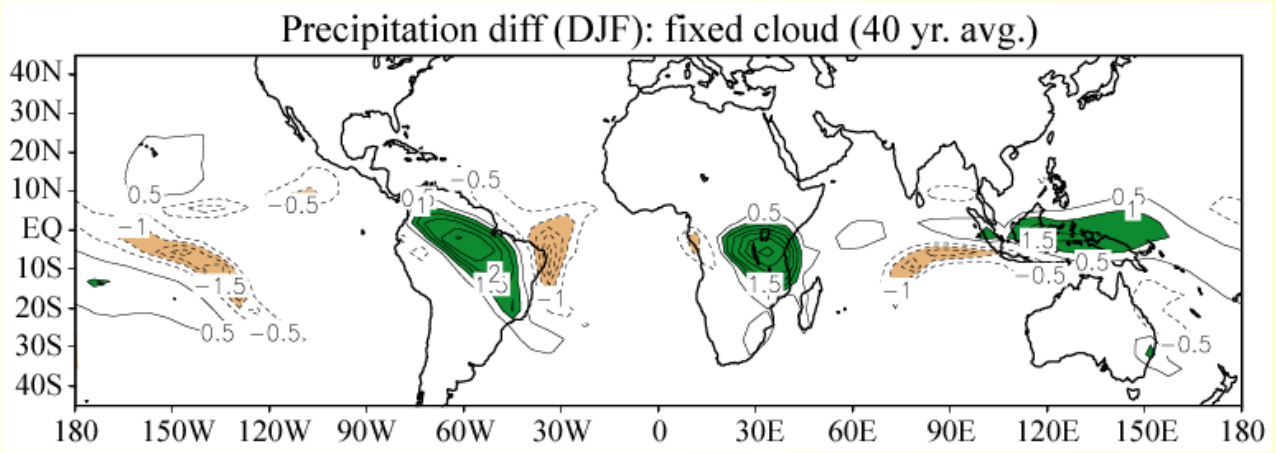
QTCM 2xCO_2 Expt. suppressing change in moisture advection

(testing the upped-ante mechanism)

Experiment
2xCO_2 Precip. change
(mm/day)



Control
2xCO_2 Precip. change



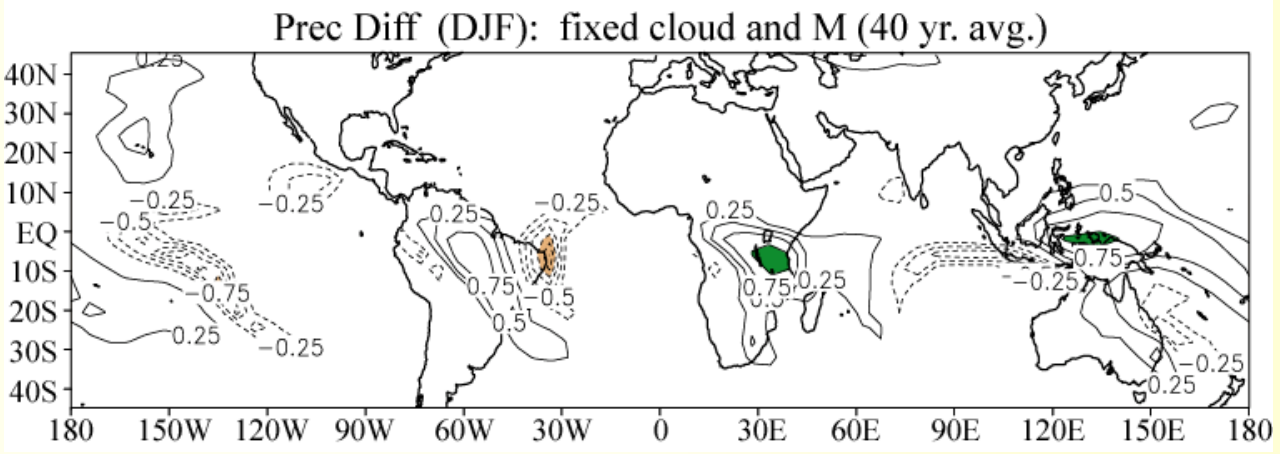
Neelin, Chou & Su, 2003 GRL

QTCM 2xCO_2 Expt. suppressing change in gross moist stability, M

(testing the M′ mechanism)

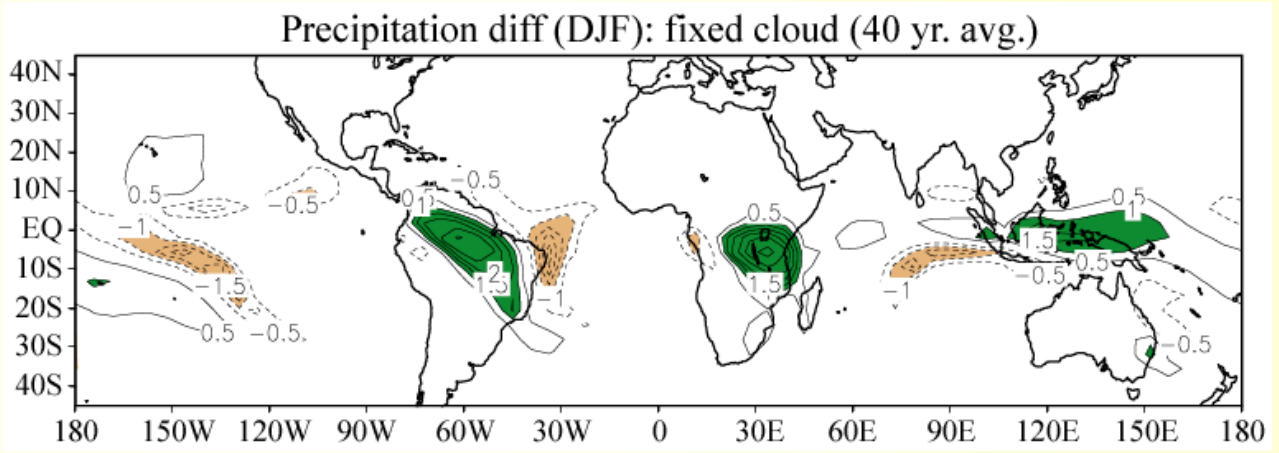
Experiment

2xCO_2 Precip. change (mm/day)



Control

2xCO_2 Precip. change

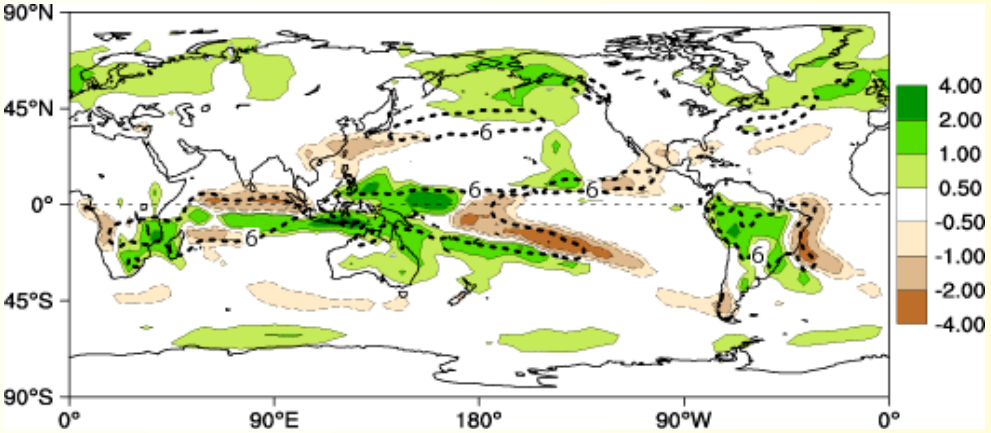


Chou & Neelin, 2004, J Clim

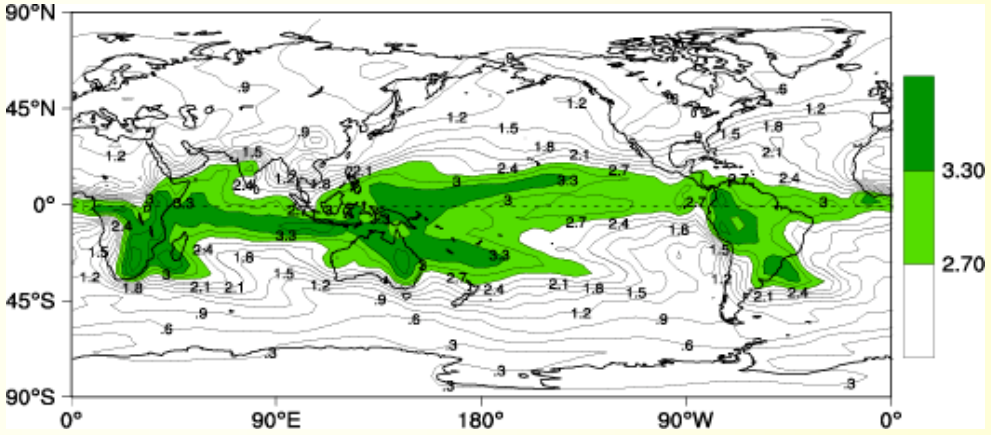
ECHAM4 + ocean mixed layer 2xCO2 equilib.

Precip. anom. rel. to control

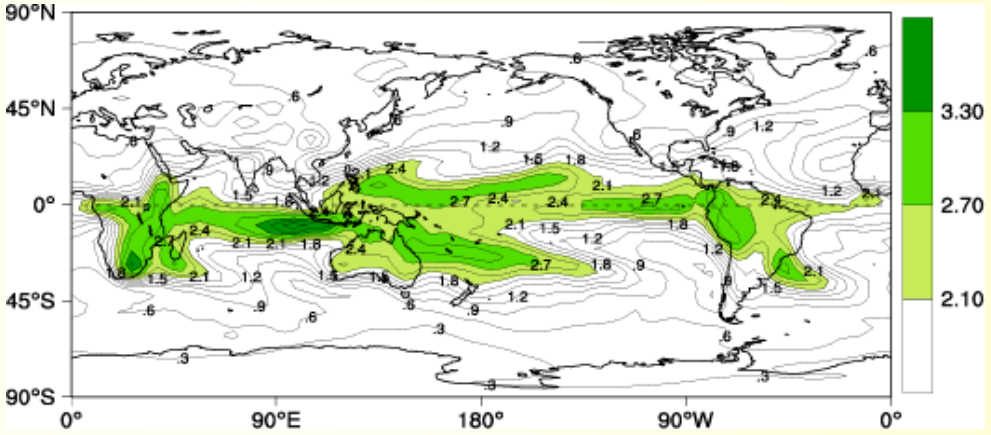
--- Clim. Precip. (6 mm/day contour)



Moisture anom. (1000-900 hPa)



Moisture anom. (900-700 hPa)



Chou et al, in prep.

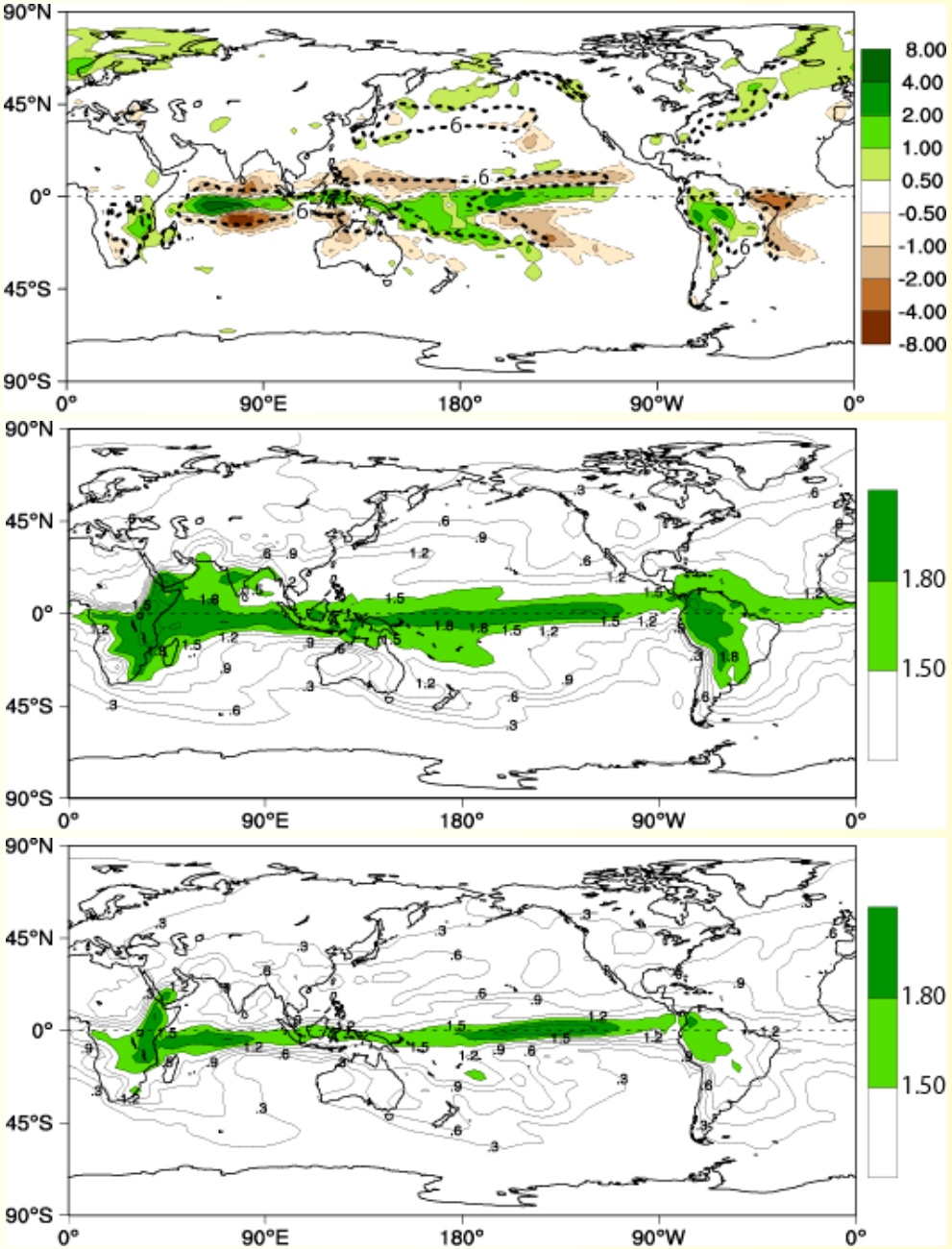
ECHAM4/OPYC3 2030-2050 IS92a (GHG only)

Precip. anom. rel. to control

--- Clim. Precip. (6 mm/day contour)

Moisture anom. (1000-900 hPa)

Moisture anom. (900-700 hPa)

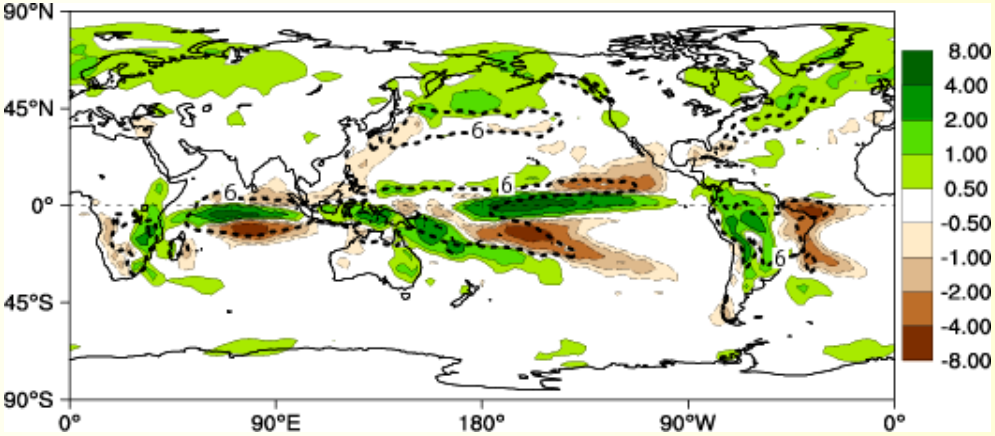


Chou et al, in prep.

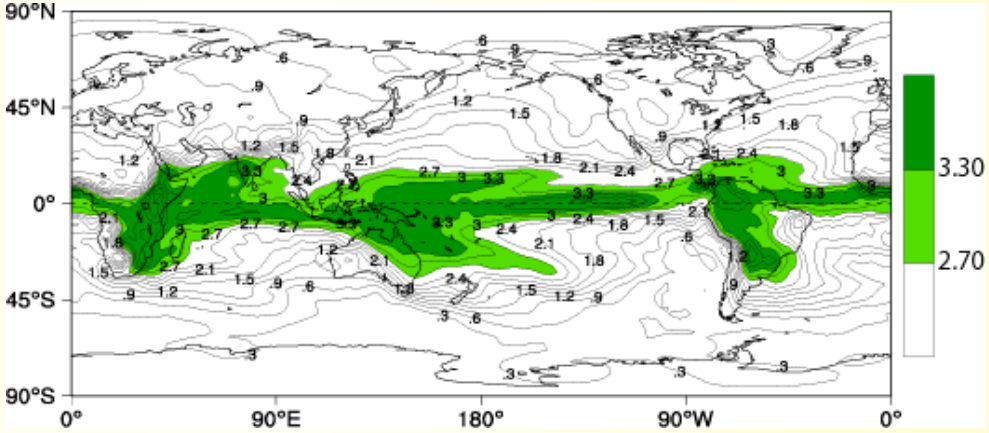
ECHAM4/OPYC3 2070-2099 IS92a (GHG only)

Precip. anom. rel. to control

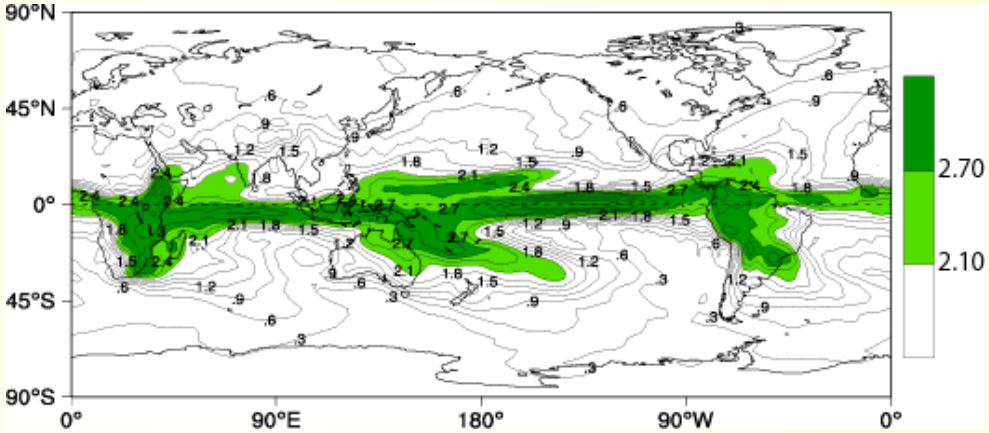
--- Clim. Precip. (6 mm/day contour)



Moisture anom. (1000-900 hPa)



Moisture anom. (900-700 hPa)



Aerosol case: remote and local response

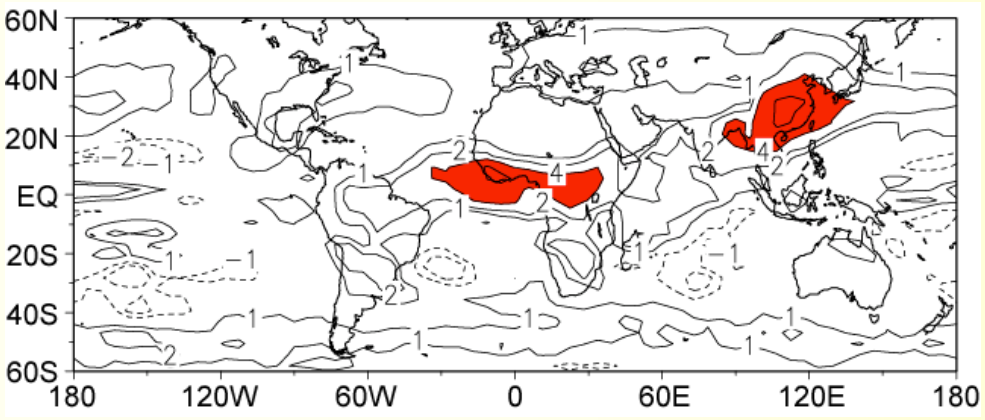
- Shortwave radiative forcing anomaly from ECHAM4 runs with present day (PD) minus pre-industrial (PI) aerosol (Feichter et al 2004, J. Clim.)
  - ➢ specify in QTCM
  - ➢ simulation adequately reproduces tropical precip and temperature
  - ➢ analyse mechanisms
- Do remote effects operate by same mechanisms as GHG warming but with opposite sign?
- Estimate of indirect aerosol effects included per Lohmann et al (1999, 2000, JGR)

Chou, Neelin, Lohmann and Feichter, 2005, JClim. subm.

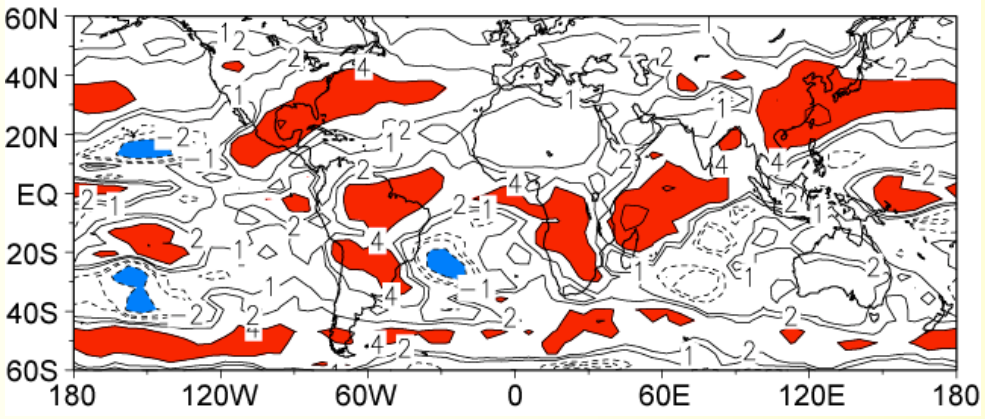
Aerosol Forcing anomalies Dec-Feb ECHAM4

Present Day – Pre-Industrial

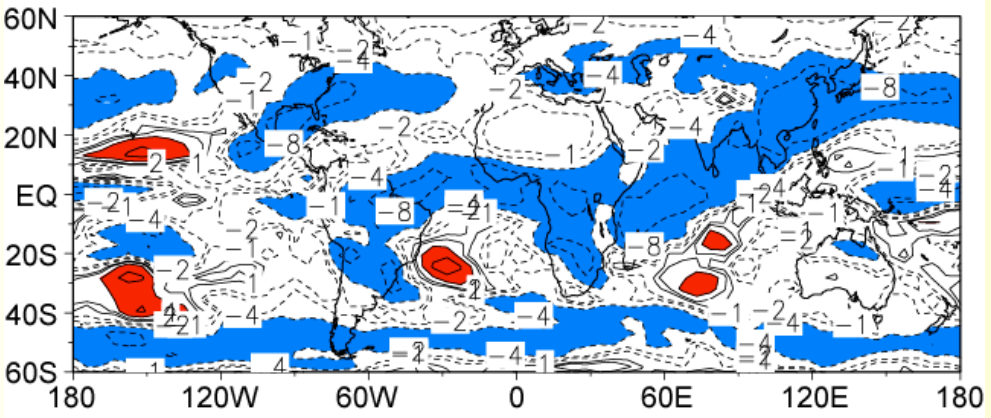
Solar atmos. absorption
(W/m²)



Solar reflection at TOA
(W/m²)



Net sfc. solar absorption
(W/m²)

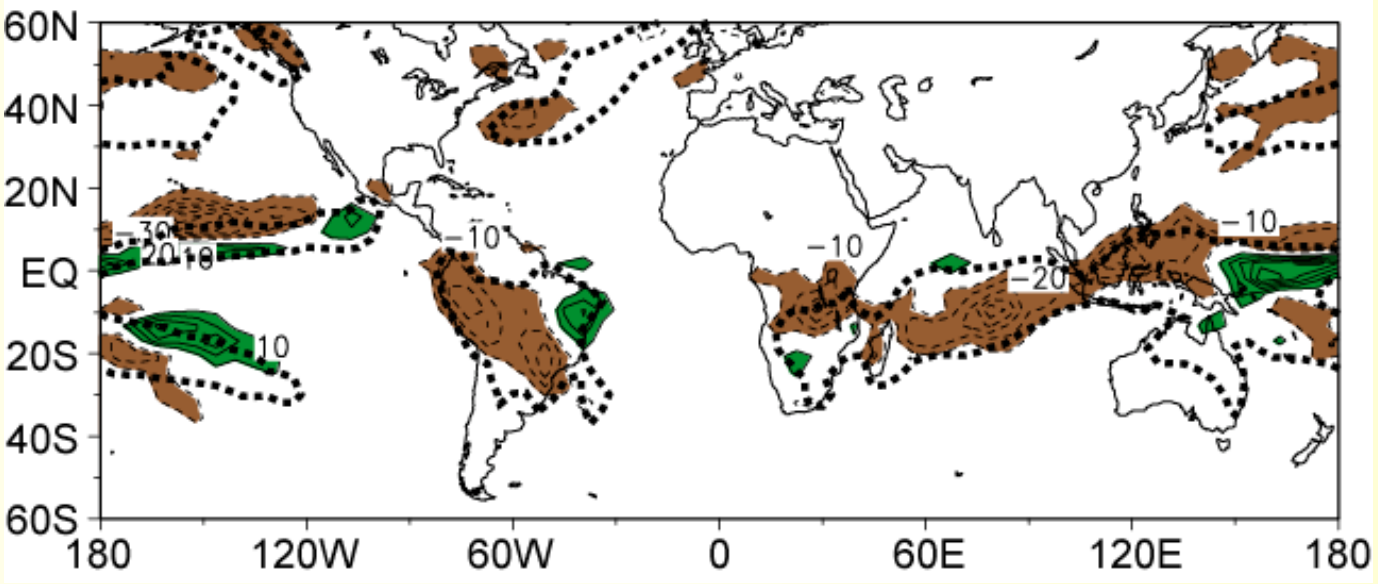


Prec. & Temp. anomalies Dec-Feb ECHAM4

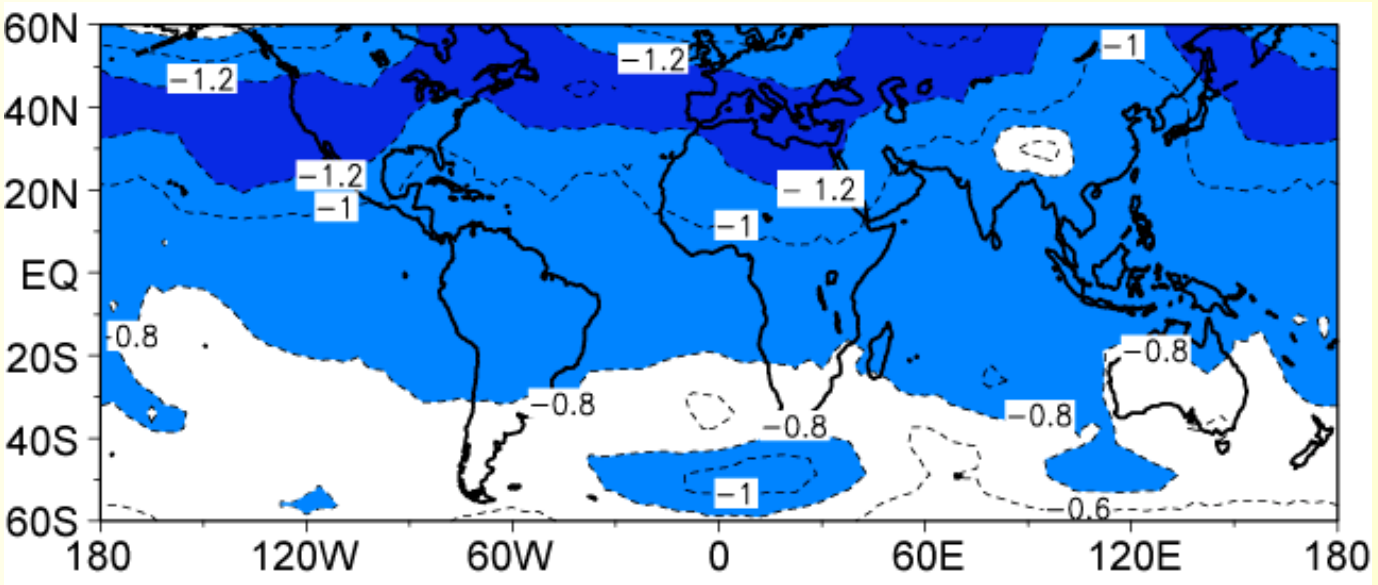
Present Day – Pre-Industrial aerosol

Precipitation
(shaded ±10 W/m²)

--- Clim. Precip.
(150 W/m² contour)



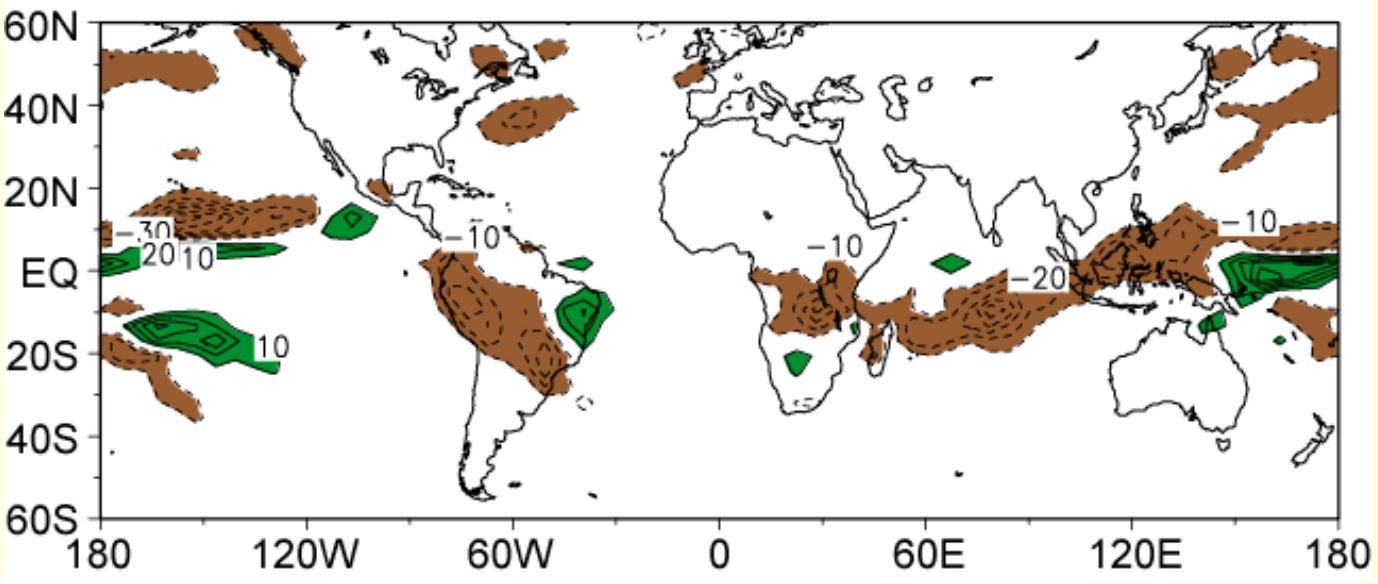
Tropospheric Temperature
(850-200hPa)
shading below -0.8C



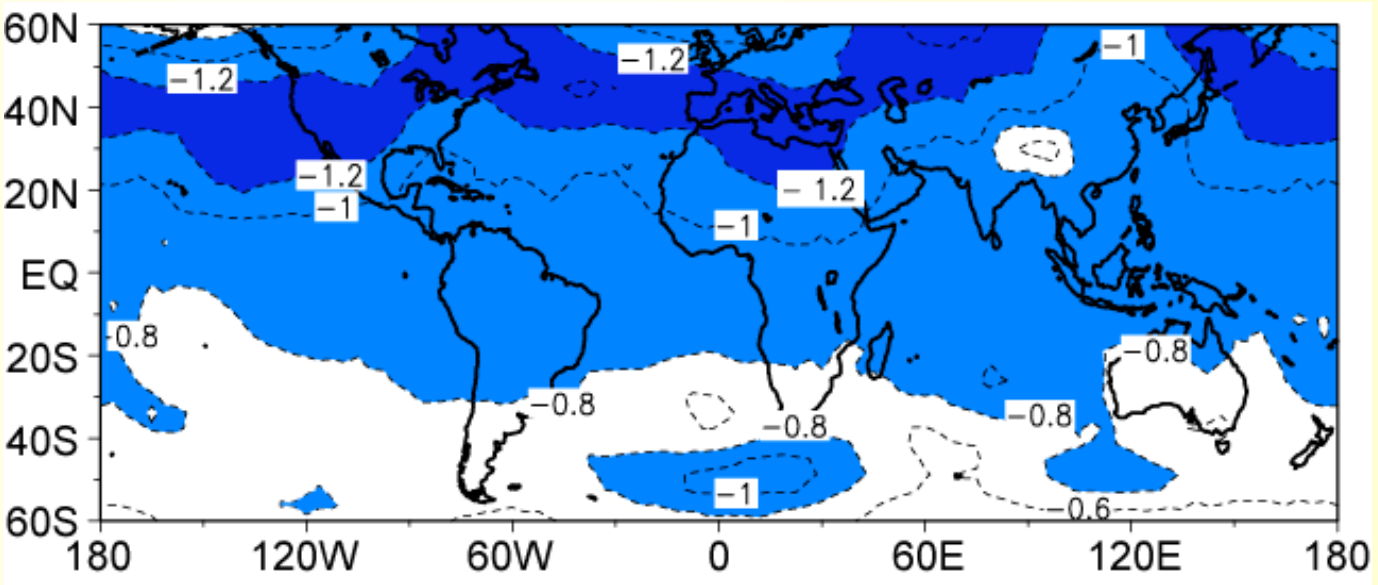
Prec. & Temp. anomalies Dec-Feb ECHAM4

Present Day – Pre-Industrial aerosol

Precipitation
(shaded ±10 W/m²)

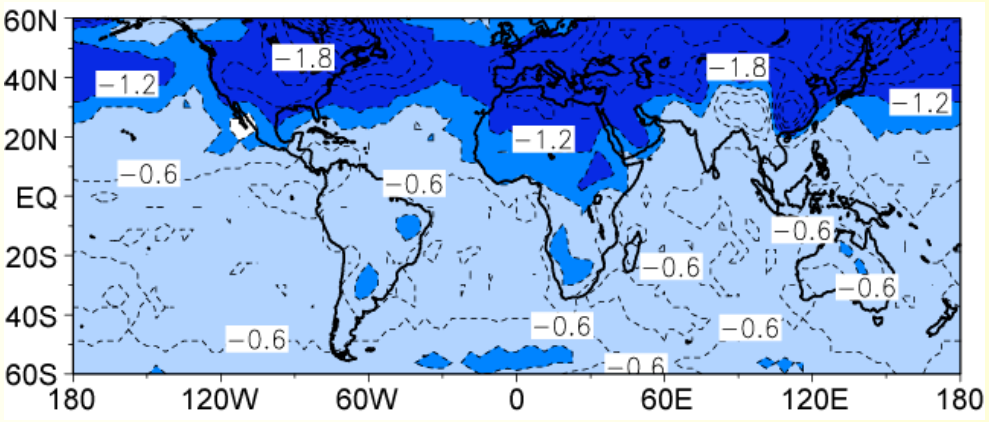


Tropospheric Temperature
(850-200hPa)
shading below -0.8C

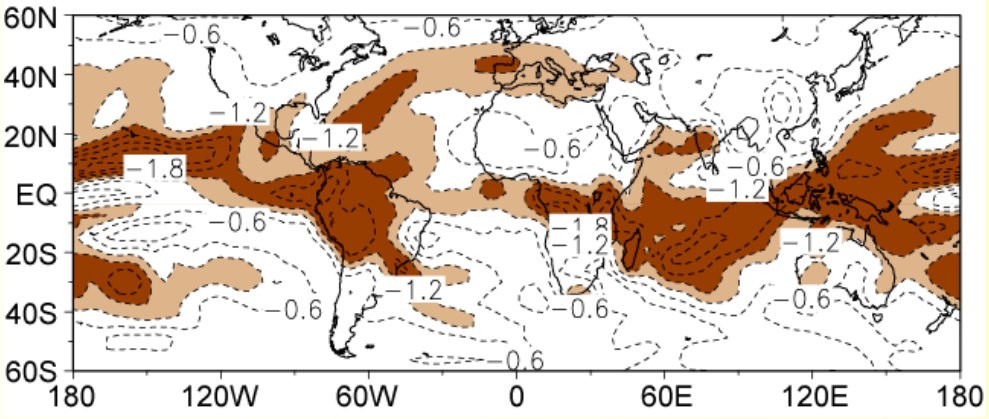


Aerosol forced anomalies Dec-Feb ECHAM4

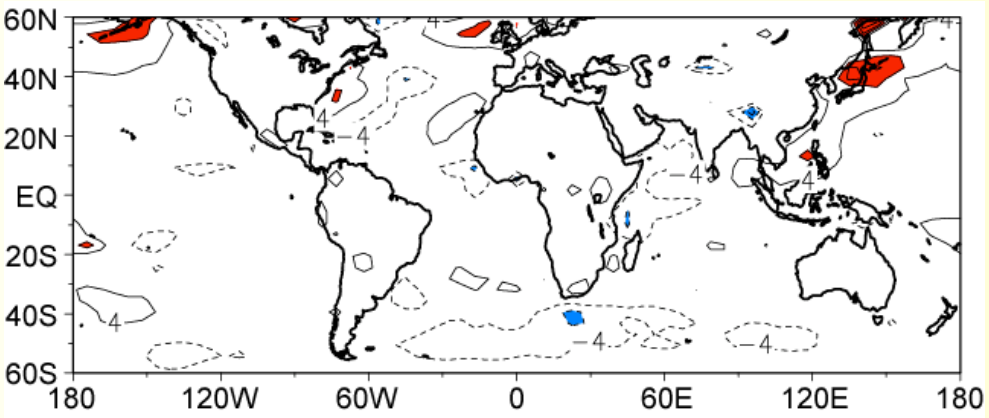
Temperature (1000hPa)
(W/m²)



Moisture (1000-700hPa)
(W/m²)



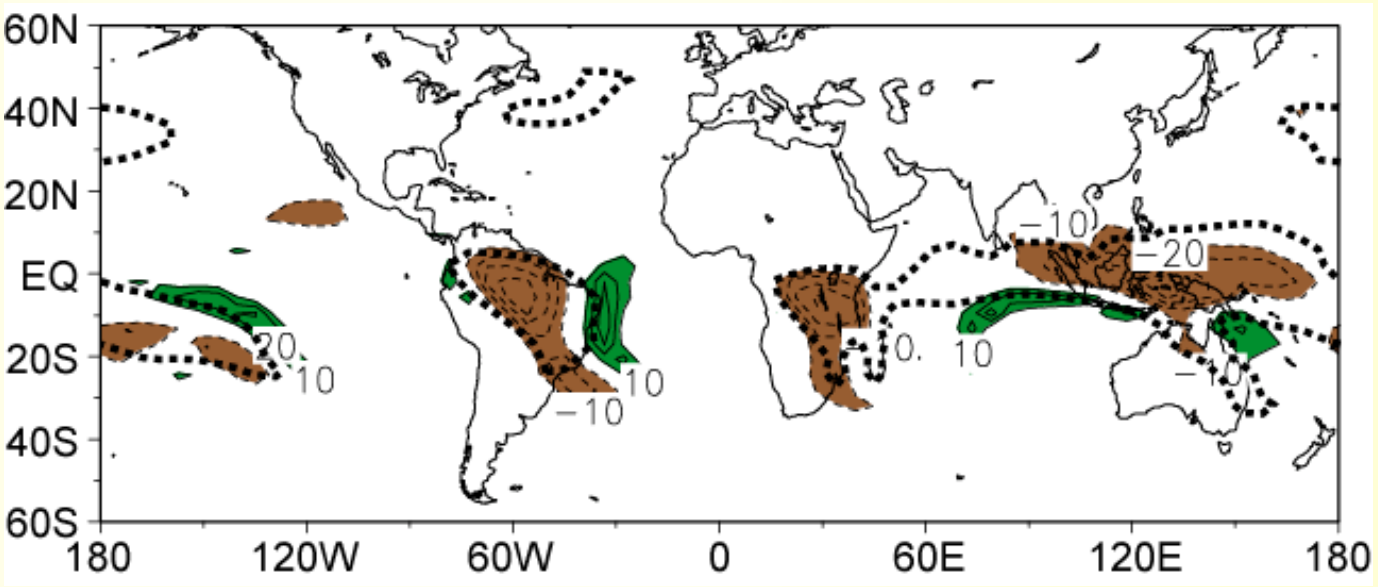
Net sfc. flux
(W/m²)



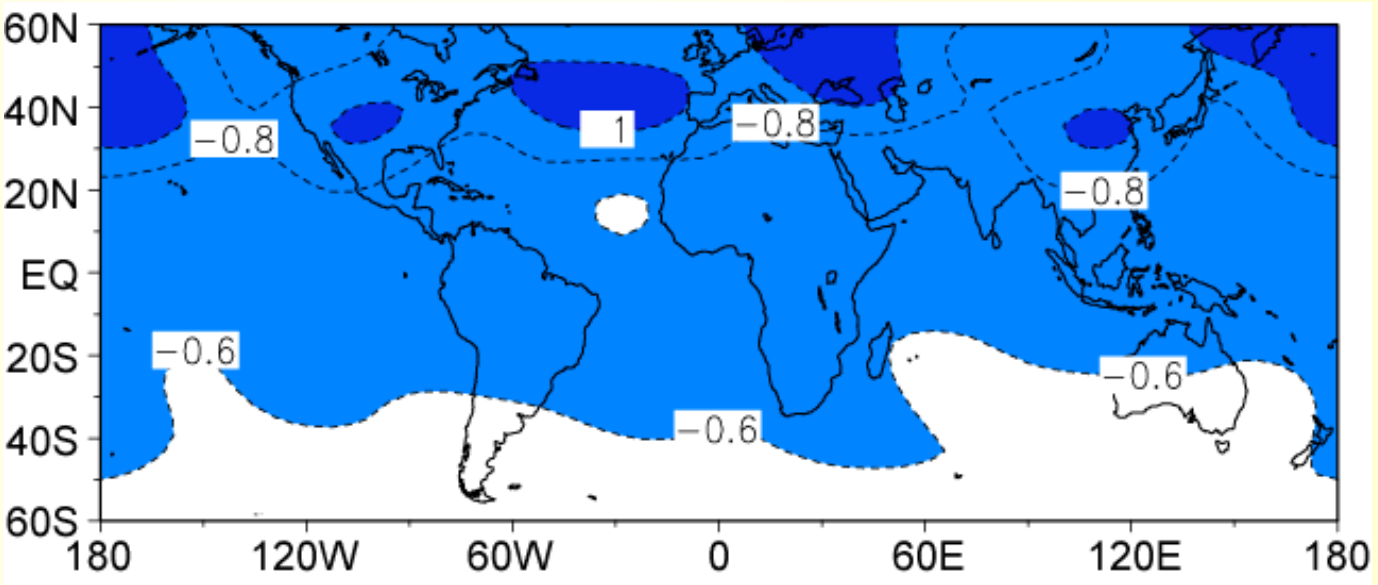
Prec. & Temp. anomalies Dec-Feb QTCM

Present Day – Pre-Industrial

Precipitation
(shaded ±10 W/m²)
--- Clim. Precip.
(150 W/m² contour)



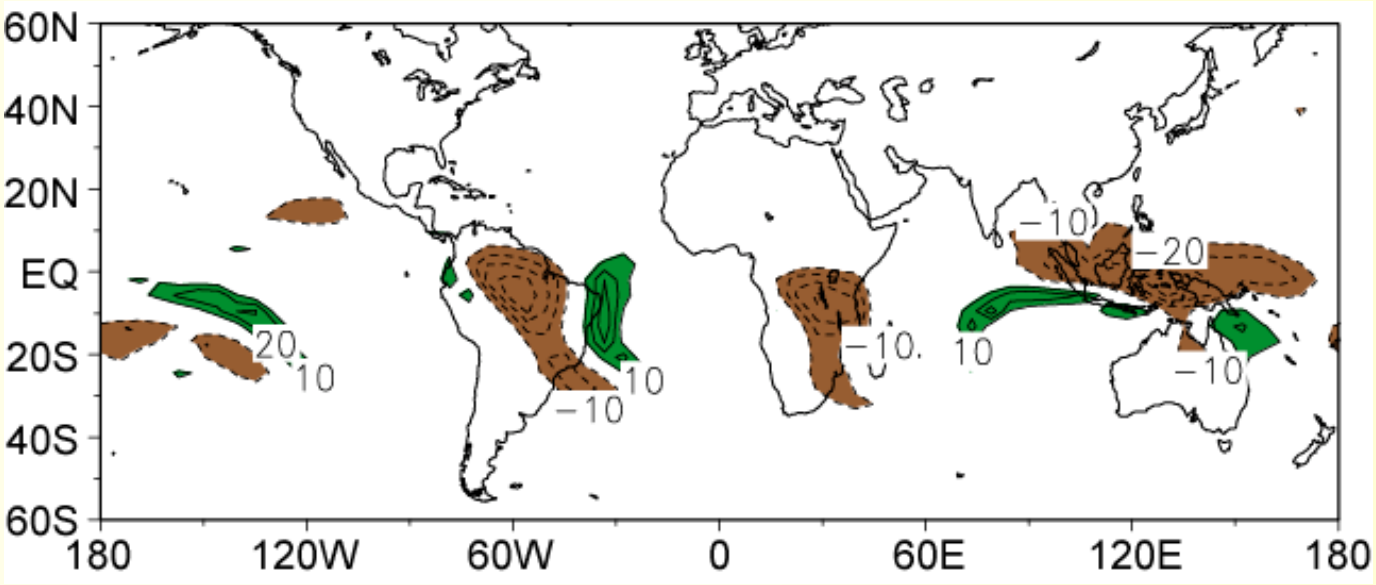
Tropospheric Temperature
(850-200hPa)
shading below -0.6C



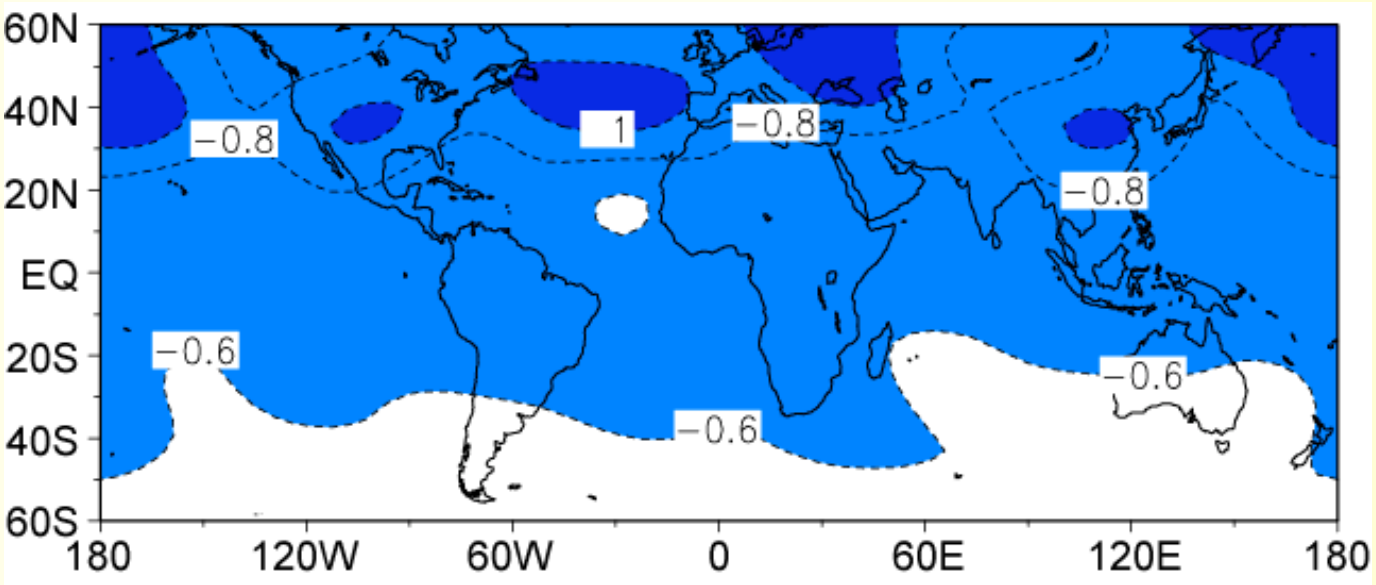
Prec. & Temp. anomalies Dec-Feb QTCM

Present Day – Pre-Industrial

Precipitation
(shaded ±10 W/m^2)



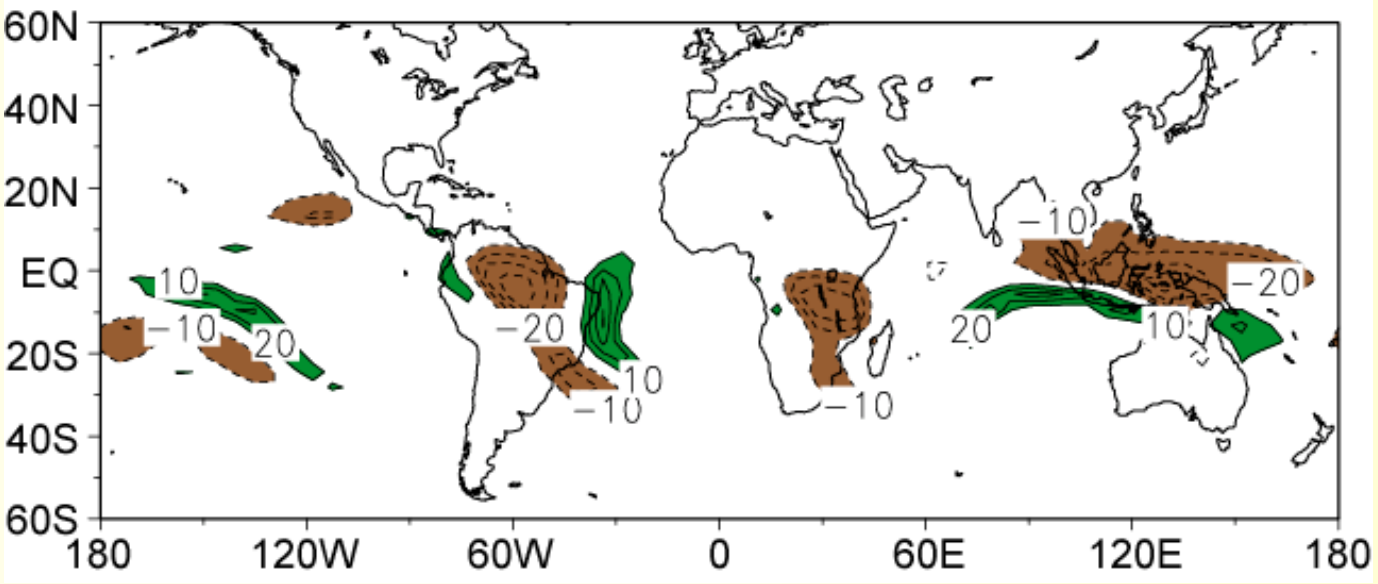
Tropospheric Temperature
(850-200hPa)
shading below -0.6C



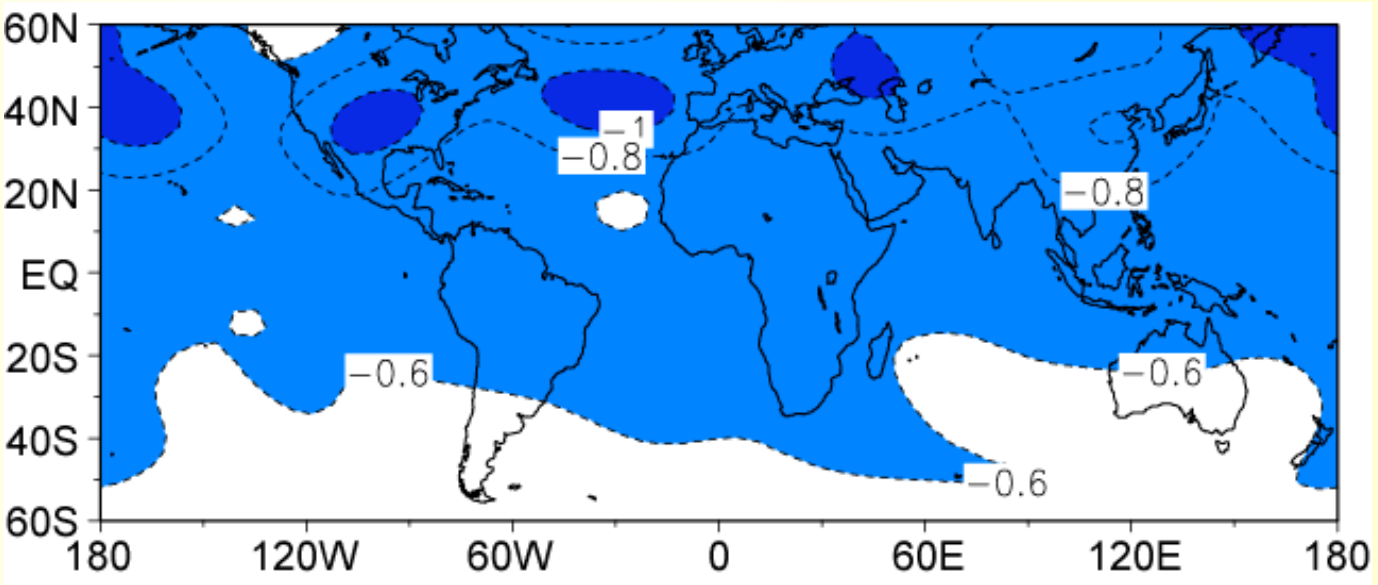
No absorption case Dec-Feb QTCM

Aerosol TOA reflection anom. only

Precipitation
(shaded ±10 W/m²)



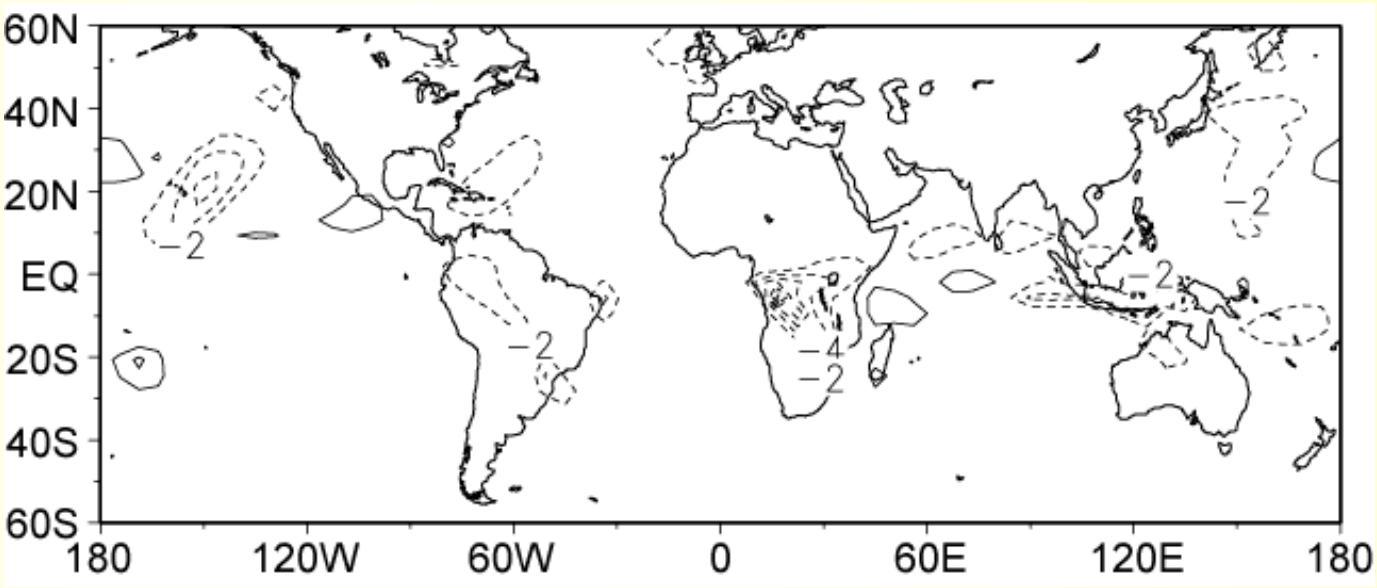
Tropospheric Temp. anom.
(850-200hPa)
shading below -0.6C



Absorption only case Dec-Feb QTCM

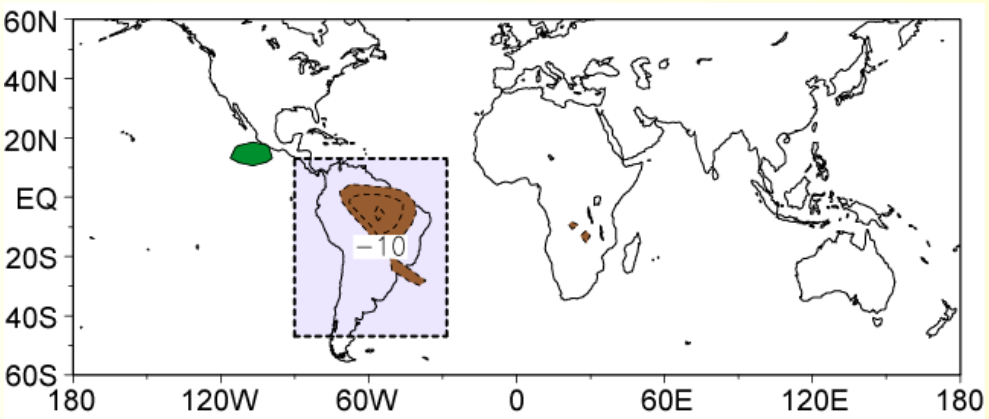
Precipitation anomalies
(shaded ±10 W/m^2 contour 2 W/m^2)

Anoms an order of magnitude smaller

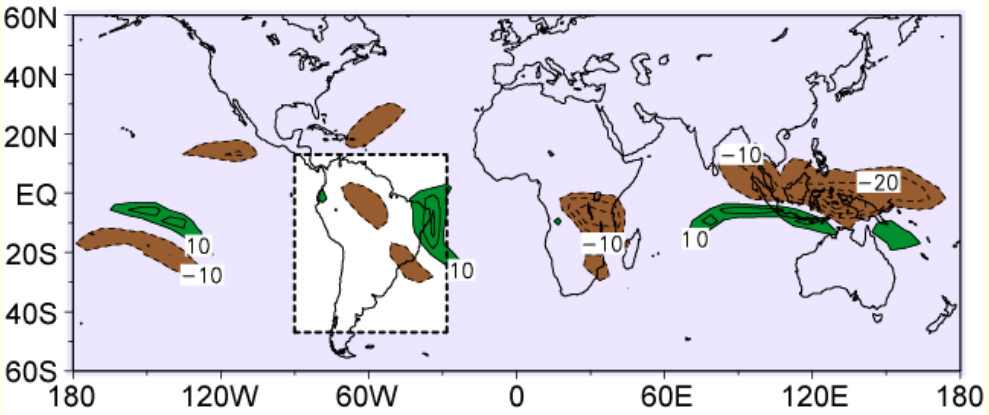


Aerosol Forcing by region Dec-Feb QTCM

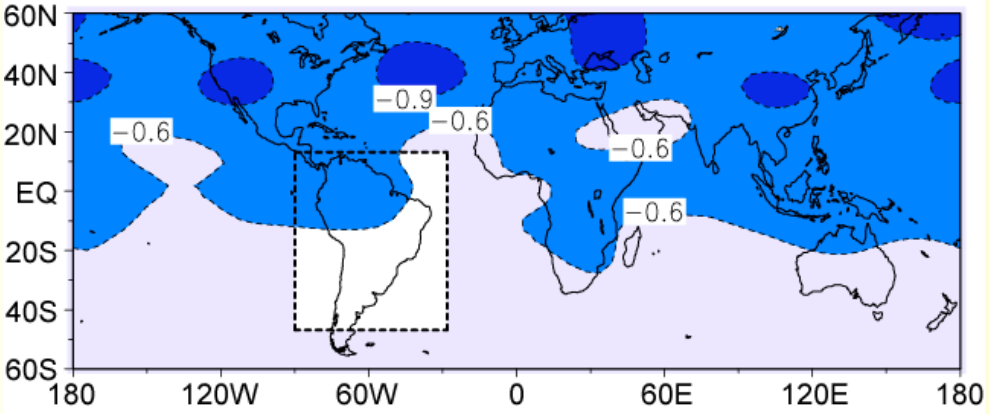
Precipitation anom
(W/m²)
(Forcing within box)



Precipitation anom
(W/m²)
(Forcing outside box)



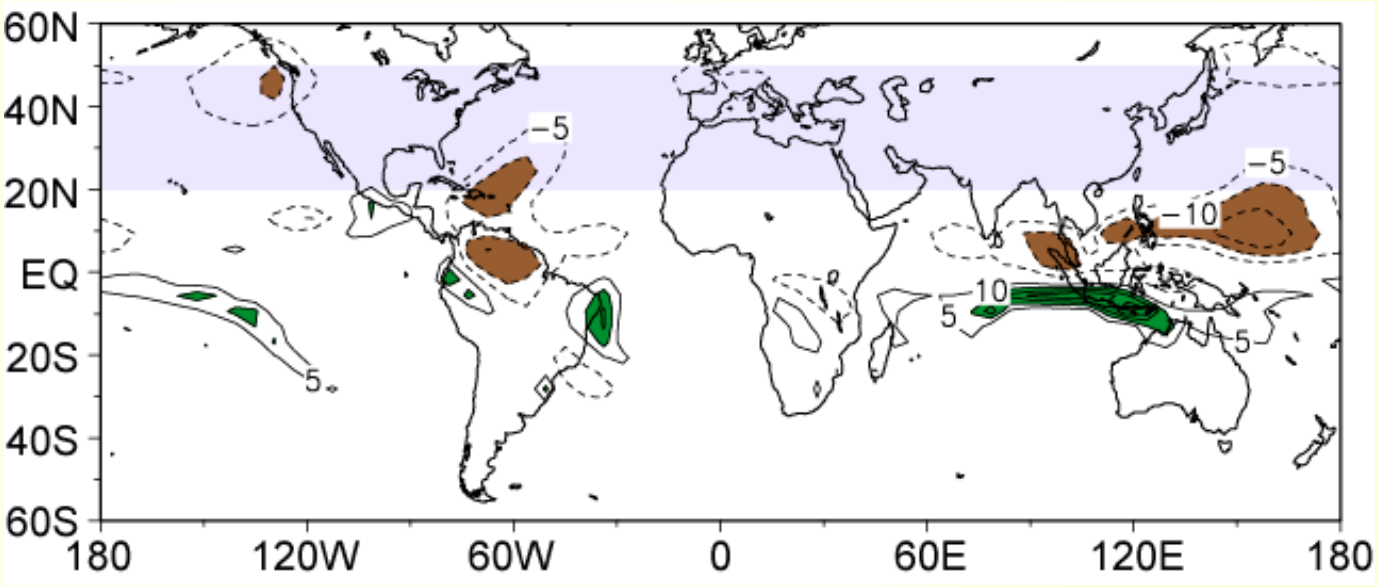
Temperature anom
(850-200hPa)
(Forcing outside box)



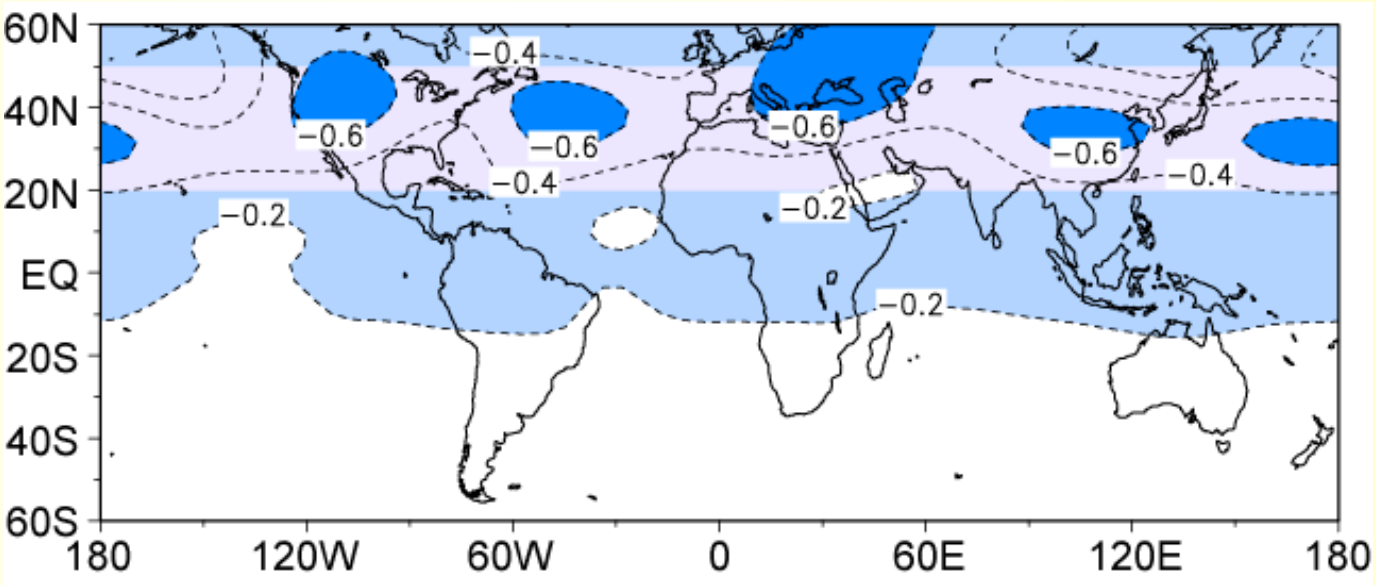
Aerosol Forcing by region Dec-Feb QTCM

Aerosol Forcing 20N-50N

Precip. anom.
(shaded ±10 W/m^2)



Tropospheric Temp. anom.
(850-200hPa)
shading below -0.2C



Other mechanisms

- Moist Static Energy transport by divergent flow $\approx M\nabla\cdot v$
- Gross Moist Stability $M = M_s - M_q$, (M_q inc. with moisture)

Perturbation MSE budget + ocean mixed layer / land

$$\bar{M}\,\nabla\cdot v' = -M'\nabla\cdot\bar{v} - (v\cdot\nabla q)' - c\partial_t T_s' + F_{top}^{net\,\prime} + (v\cdot\nabla T)' \ldots$$

Yields precip anoms as $T' \Rightarrow q' \Rightarrow \nabla q'$, M'; v', $q' \Rightarrow E'$ etc.

$$P' \approx \frac{\bar{M}_q}{\bar{M}}\left[-(\bar{v}\cdot\nabla q)' + \nabla\cdot v(-M') - c\partial_t T_s' + \cdots\right]$$

GMS multiplier effect

Upped-ante Rich-get-richer

SST disequilibrium

Rad cooling, $(v\cdot\nabla T)'$
ocean transp, …

Summary: Tropical regional rainfall impacts…

- QTCM analysis & expts., coord. with ECHAM4 analysis
- $2XCO_2$, mixed-layer (ML) ocean case
  - ⇒ upped-ante and M' mechanisms [SST′ ~by-product in eqbm]
- transient GHG, coupled oc-atm case: similar + some regions where ocean transport′ ⇒ sfc heat flux′ ⇒ precip′
- Aerosol SW forcing case (ECHAM4 forcing into QTCM+ML)
  - nonlocal via cool T′ ⇒ upped-ante and M' mechanisms
  - Local SW aerosol effects, TOA reflection ⇒ negative precip′
- upped-ante mechanism:
  - precipitation anomaly regions at margins of convection zones
  - negative in GHG warming; nonlocal positive in aerosol cooling
- anomalous gross moist stability (M') mechanism:
  - positive precip' in strong precip regions in GHG warming; nonlocal negative in aerosol cooling

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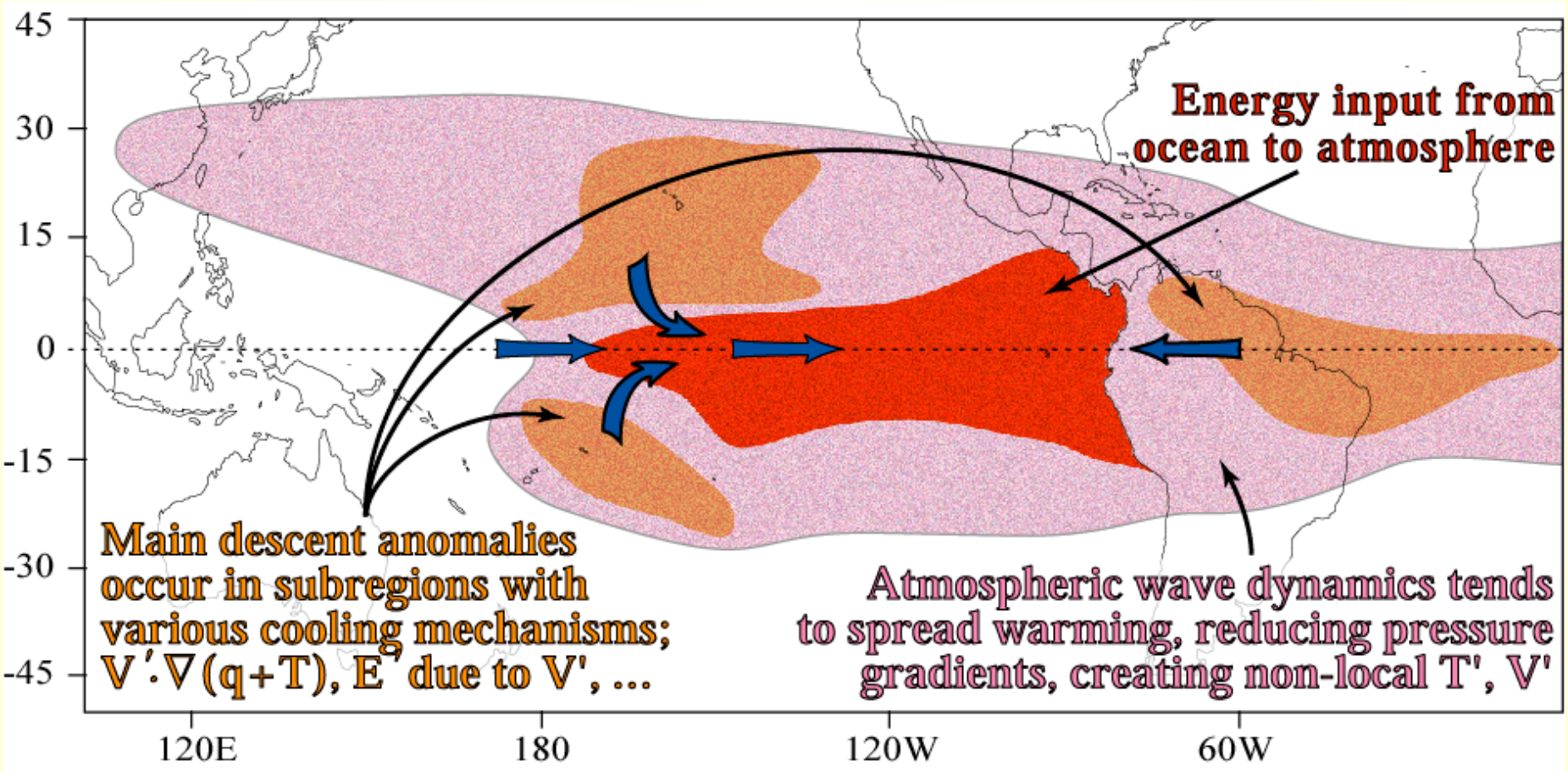
ENSO teleconnections: widespread warming yields regional precip. anomalies by "zoo" of mechanisms



Su & Neelin, 2002