Moist teleconnection mechanisms

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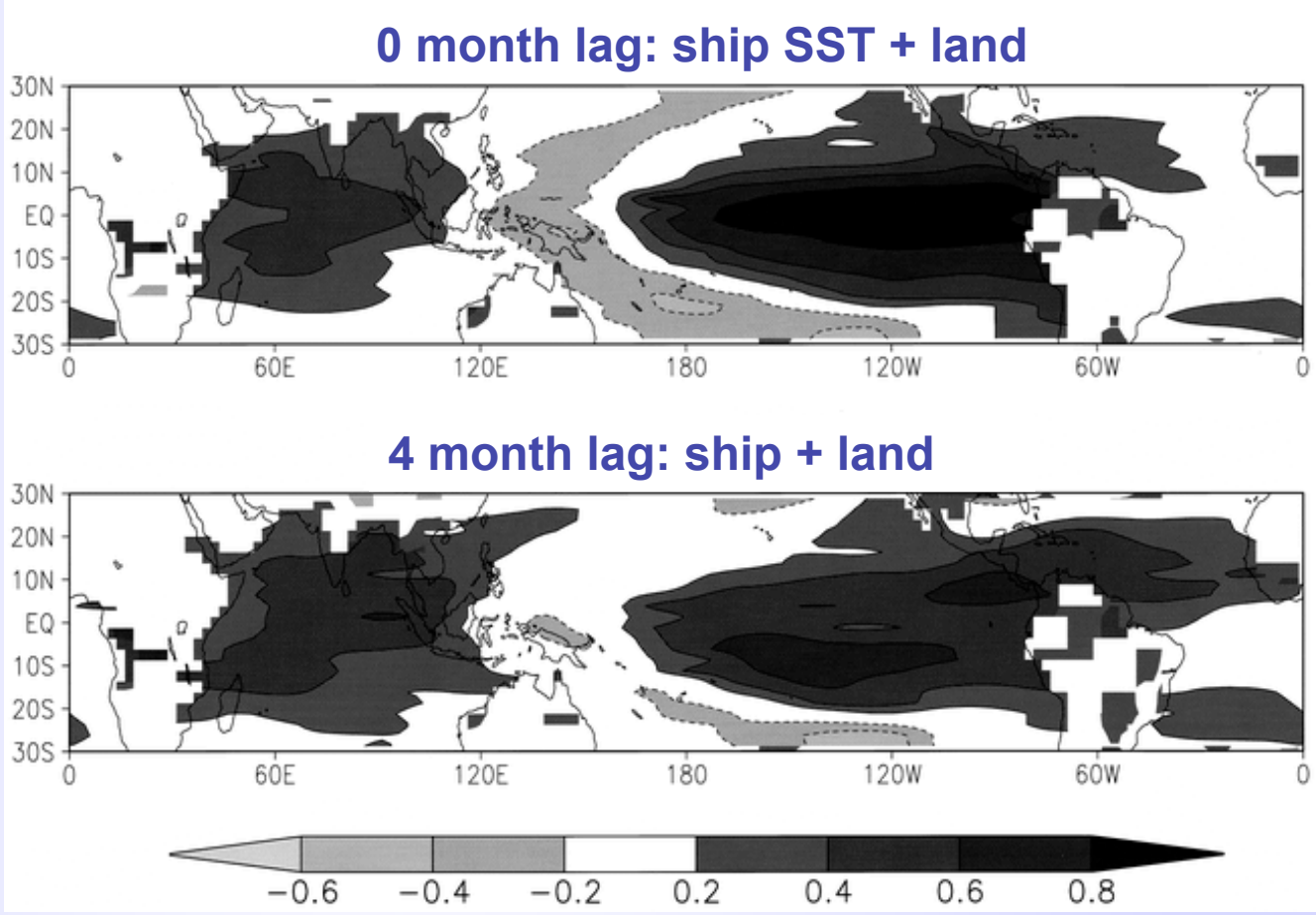
- **Tropical moist teleconnections: wave dynamics interacts with deep convection zones – theory?**
- **Remote precipitation anomalies associated with ENSO – mechanisms?**
- **Intermediate complexity climate model QTCM (Quasi-equilibrium Tropical Circulation Model)**

Remote tropical SST relationship to ENSO

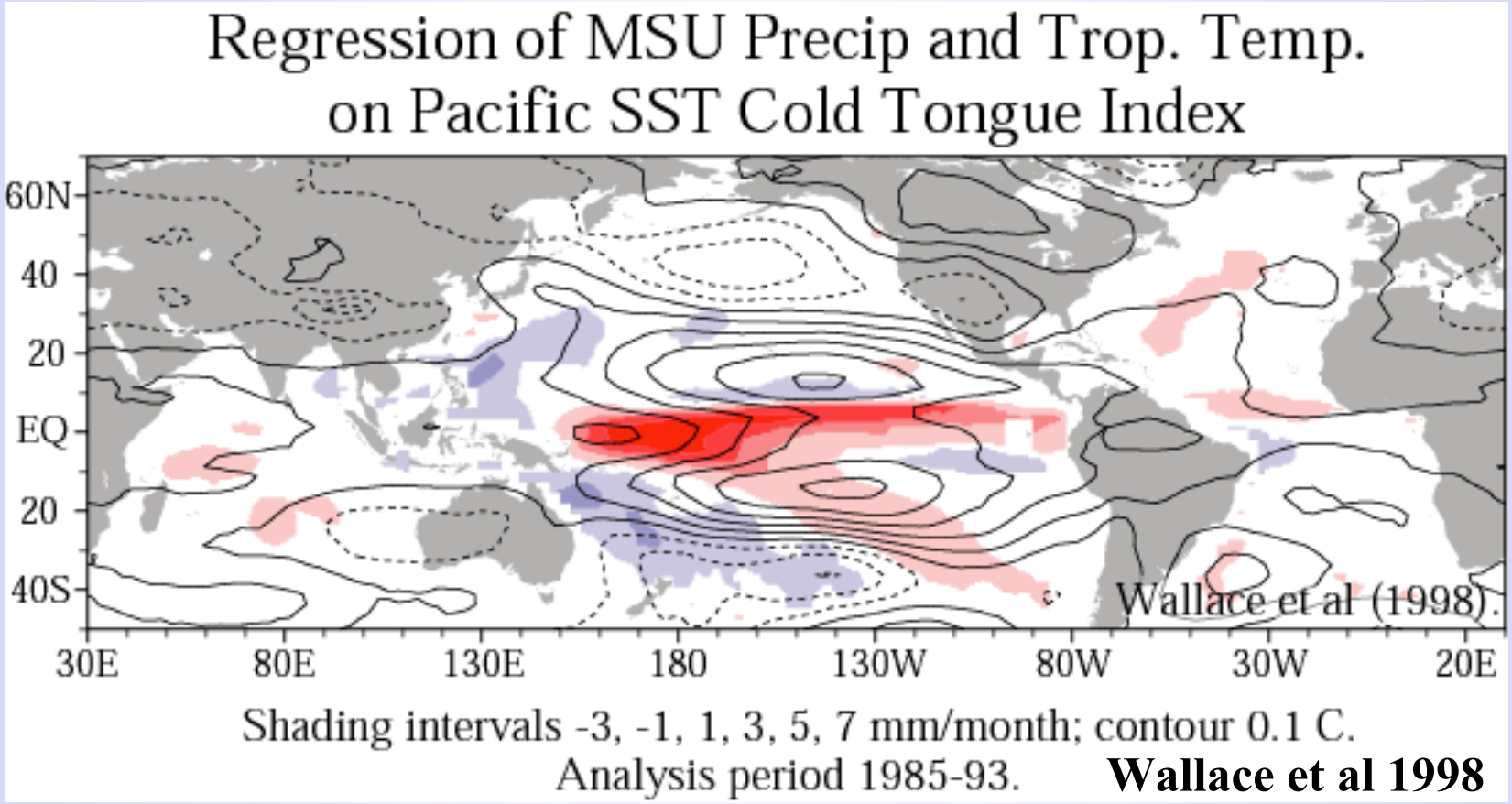
- Chiu and Newell 1983; Pan & Oort 1983, 1990; Kiladis & Diaz 1989; Tourre & White 1995; Enfield & Mayer 1997
- Lau & Nath 1996; Klein et al 1999; Alexander et al 2002: "Atmospheric bridge"



Klein et al 1999

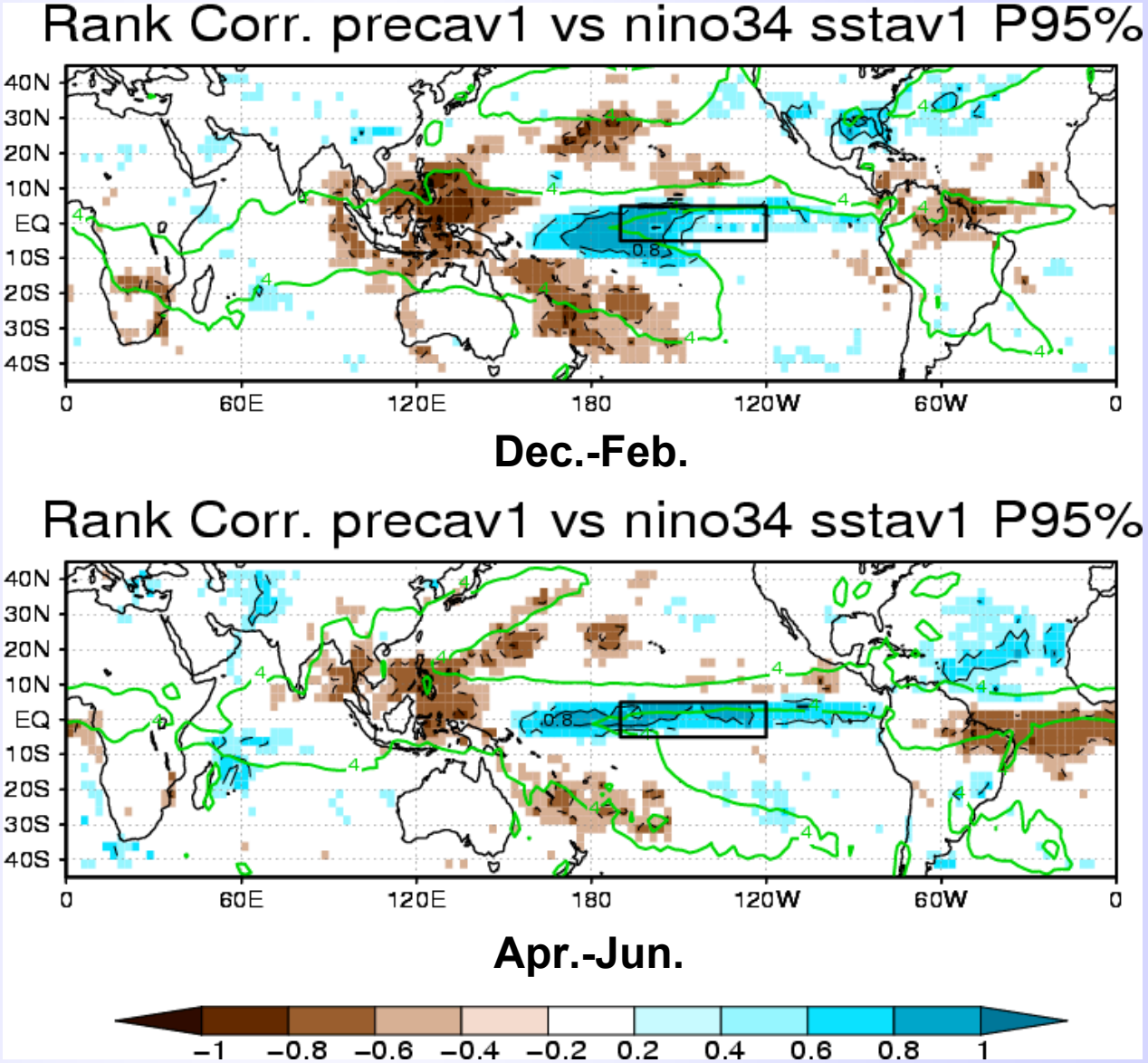
Tropical remote precip. relation to ENSO

- E.g., Ropelewski & Halpert (1987, 1989); Hastenrath (1990); Grimm et al 1998; Wallace et al 1998; Giannini et al (2000); Paegle & Mo 2002 …



Rank Correlation Precip to Nino3.4 SST

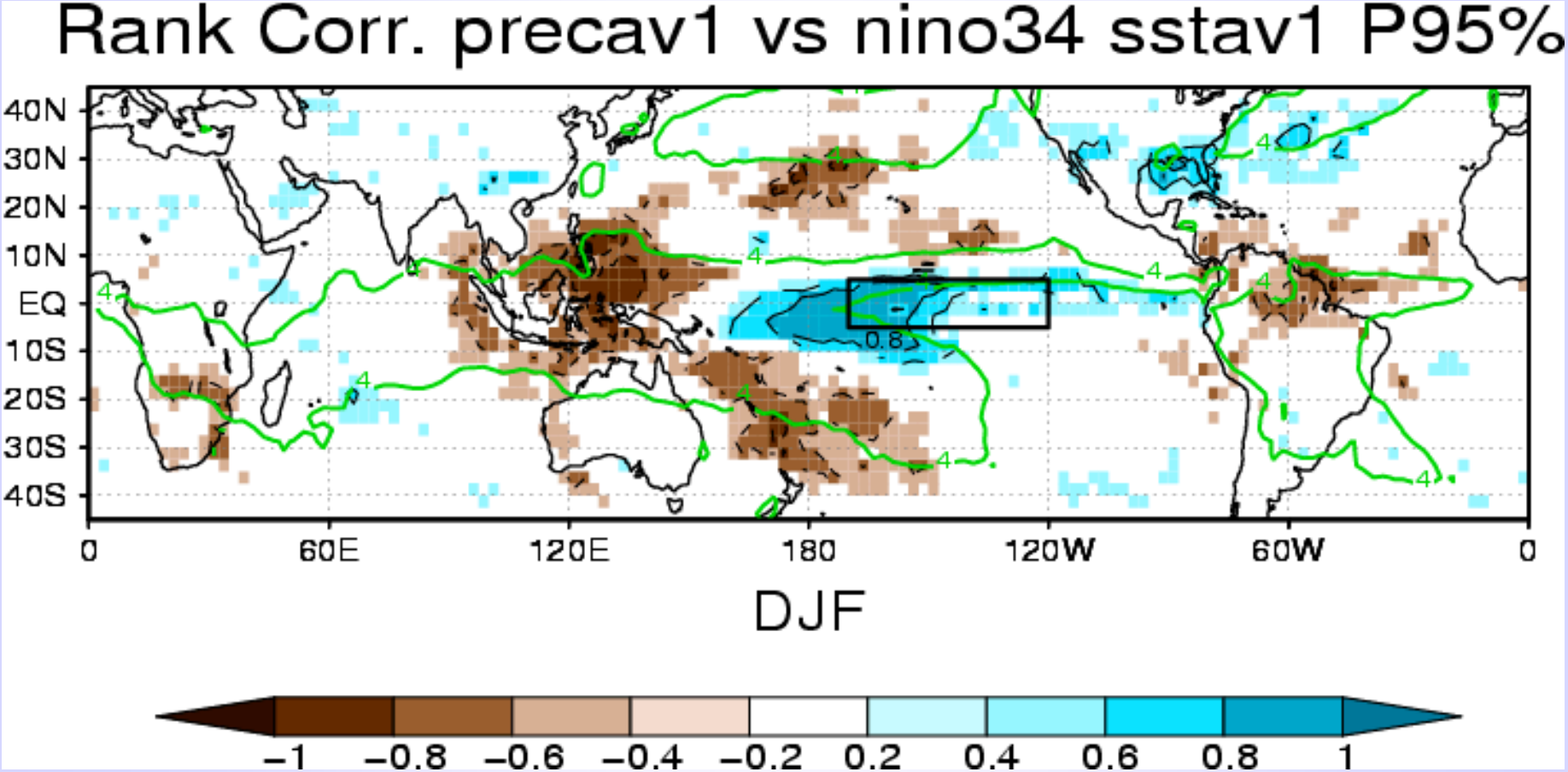
- CMAP Precip
- Reynolds OIv2 SST
- 1982-2003
- Clim. precip. as 4 mm/day contour (green) for reference



Munnich and Neelin 200X, in prep.

Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Jan.



Rank Correlation Precip to Nino3.4 SST

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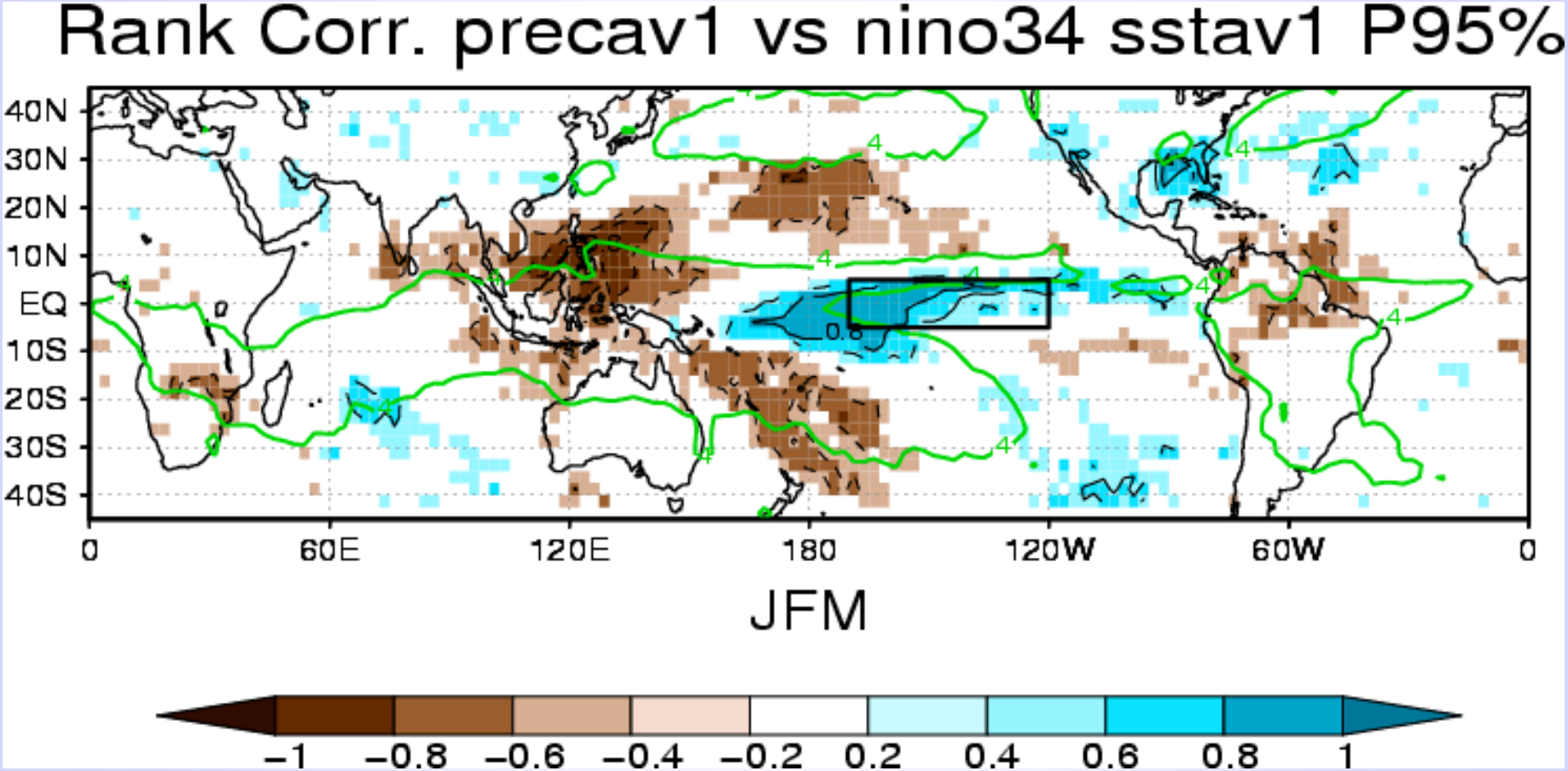
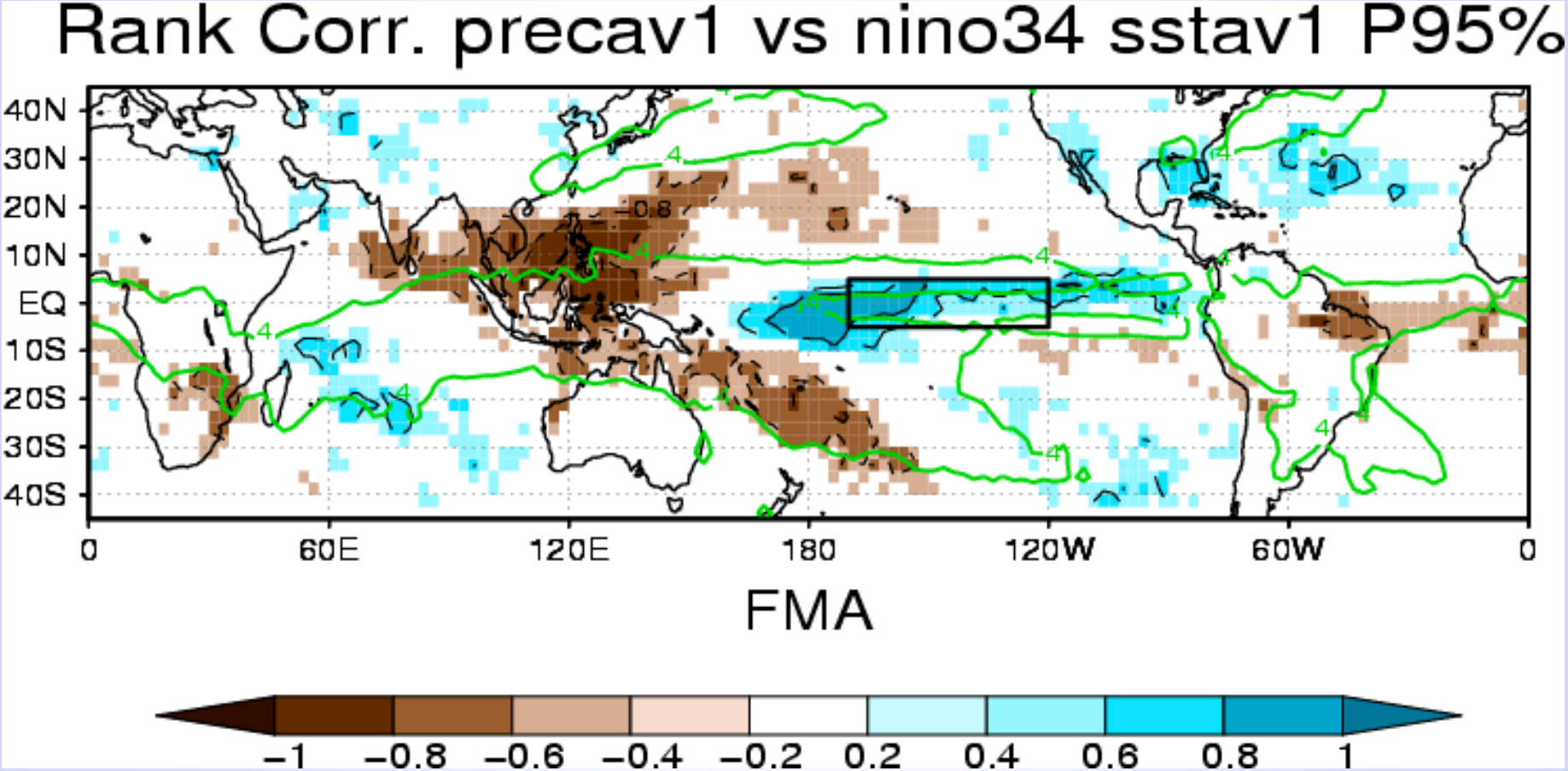


Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Mar.



Rank Correlation Precip to Nino3.4 SST

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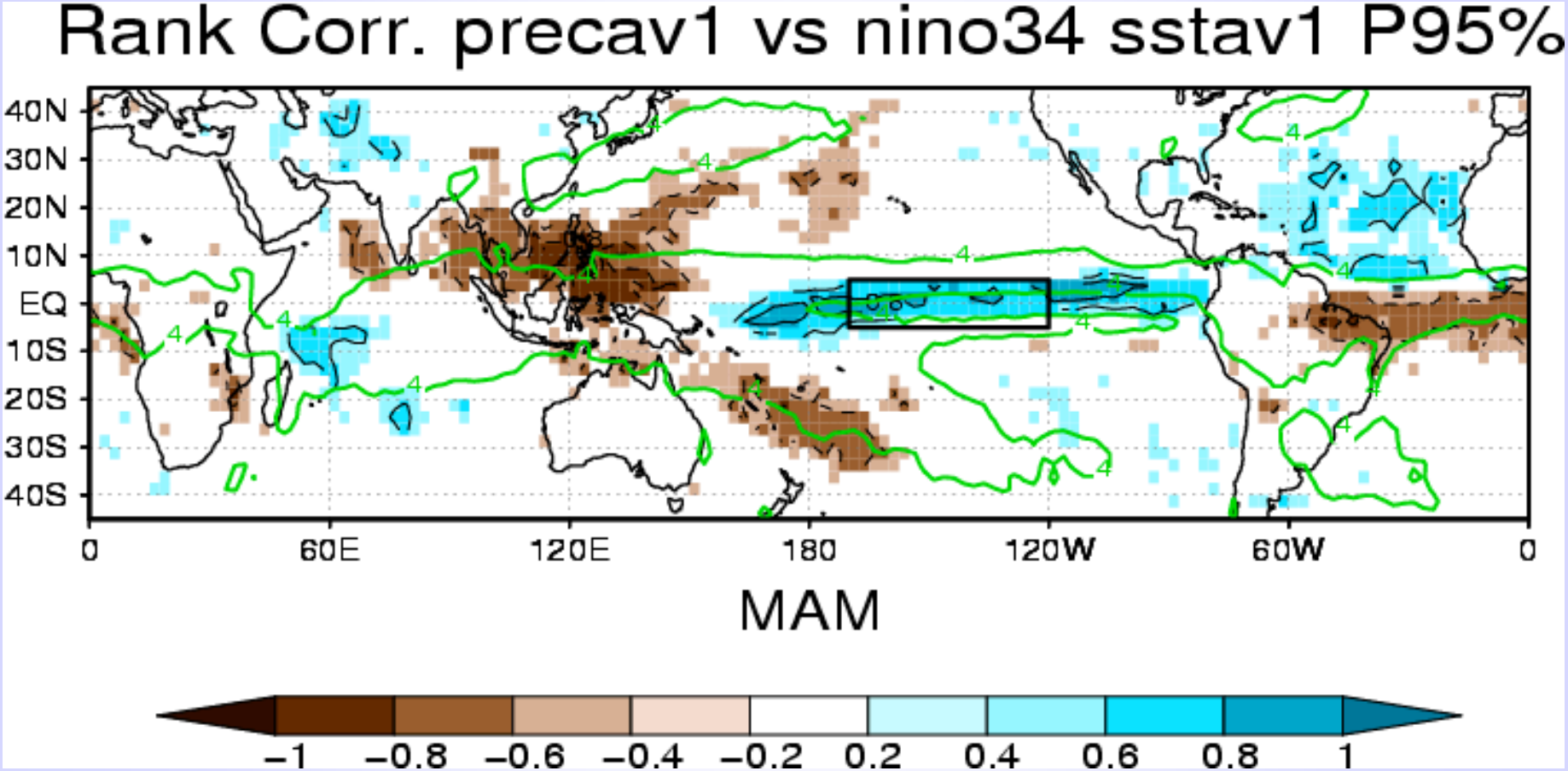

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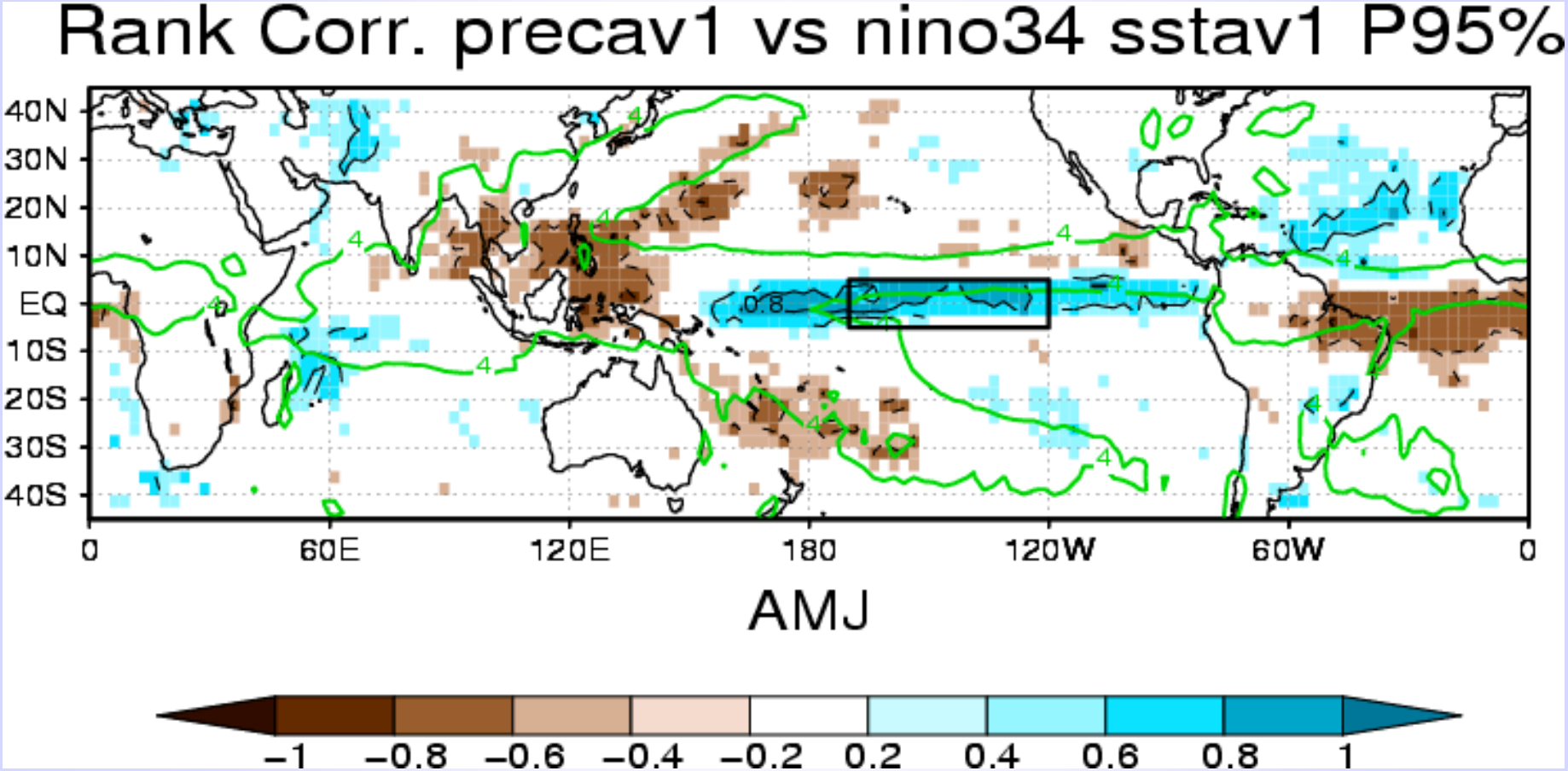
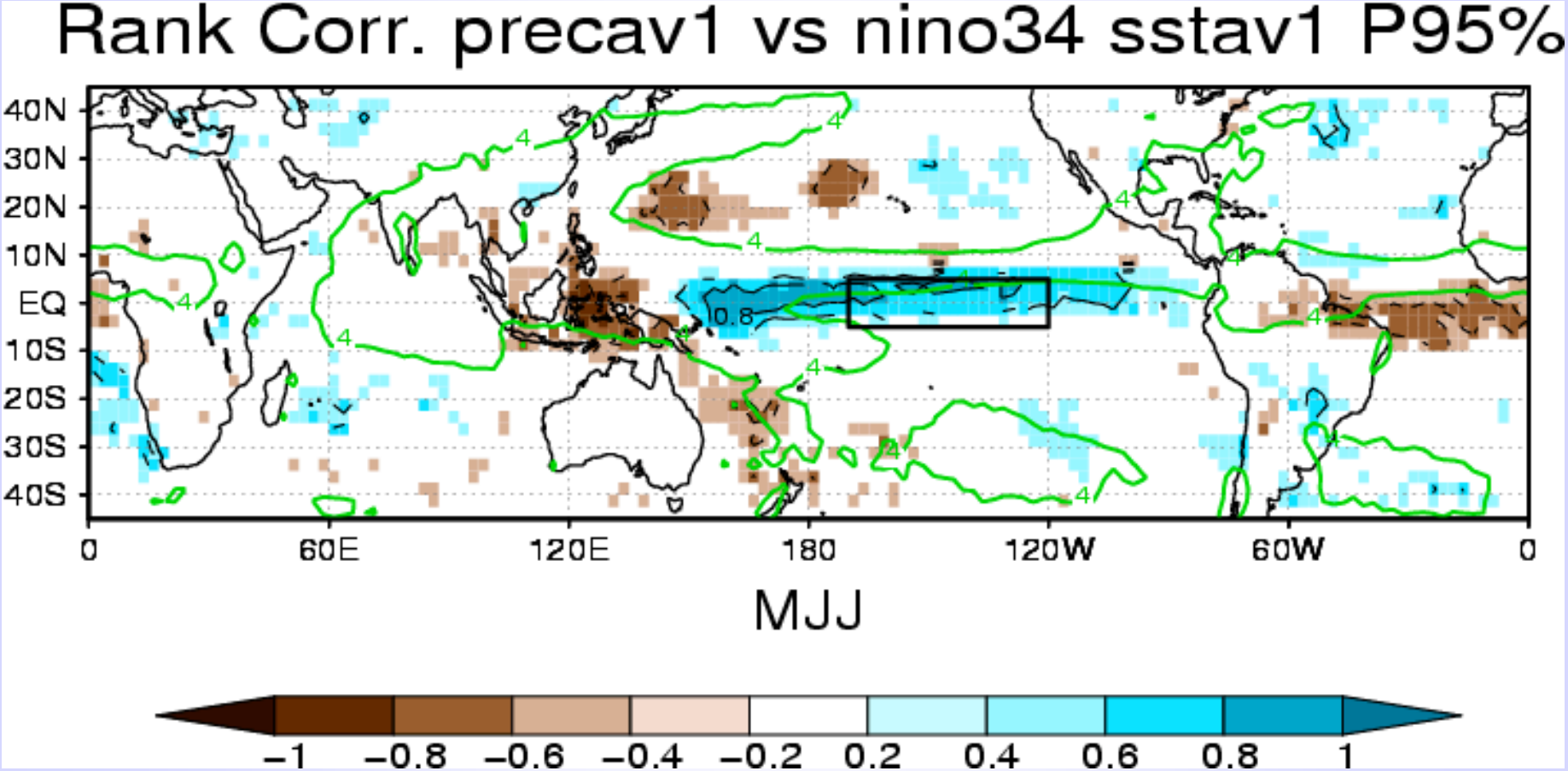


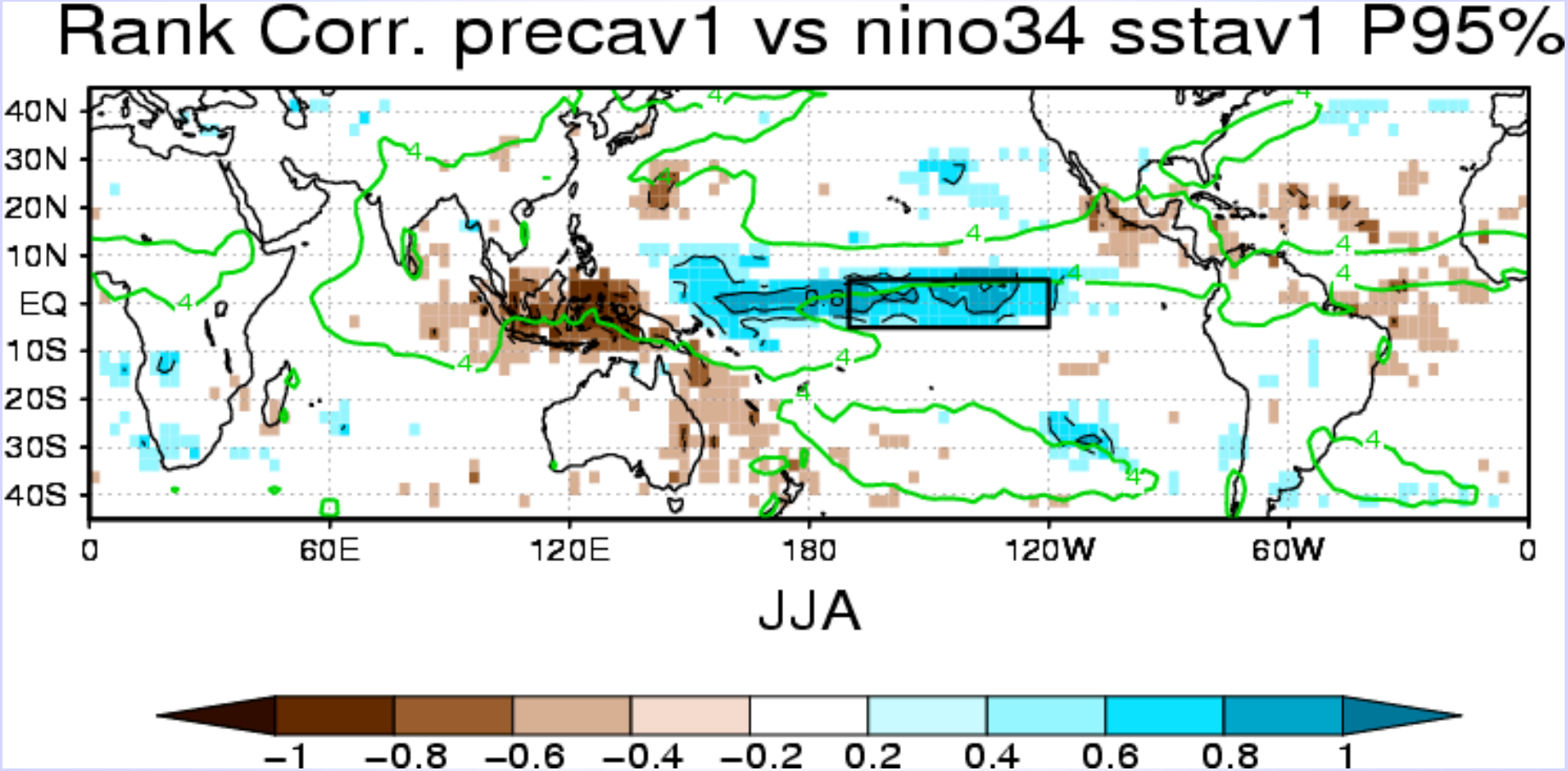
Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Jun.



Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Jul.



Rank Correlation Precip to Nino3.4 SST

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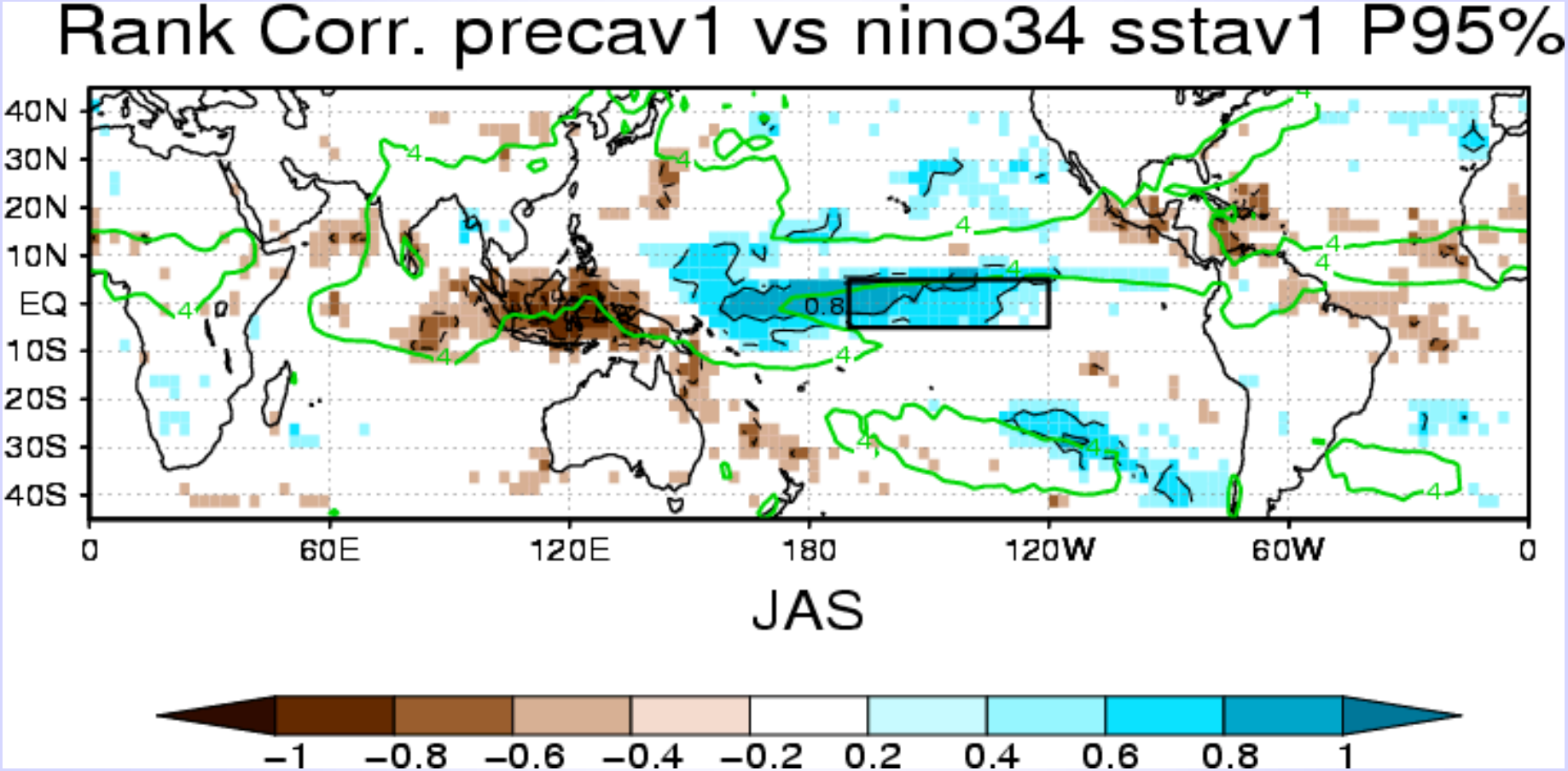

Rank Correlation Precip to Nino3.4 SST

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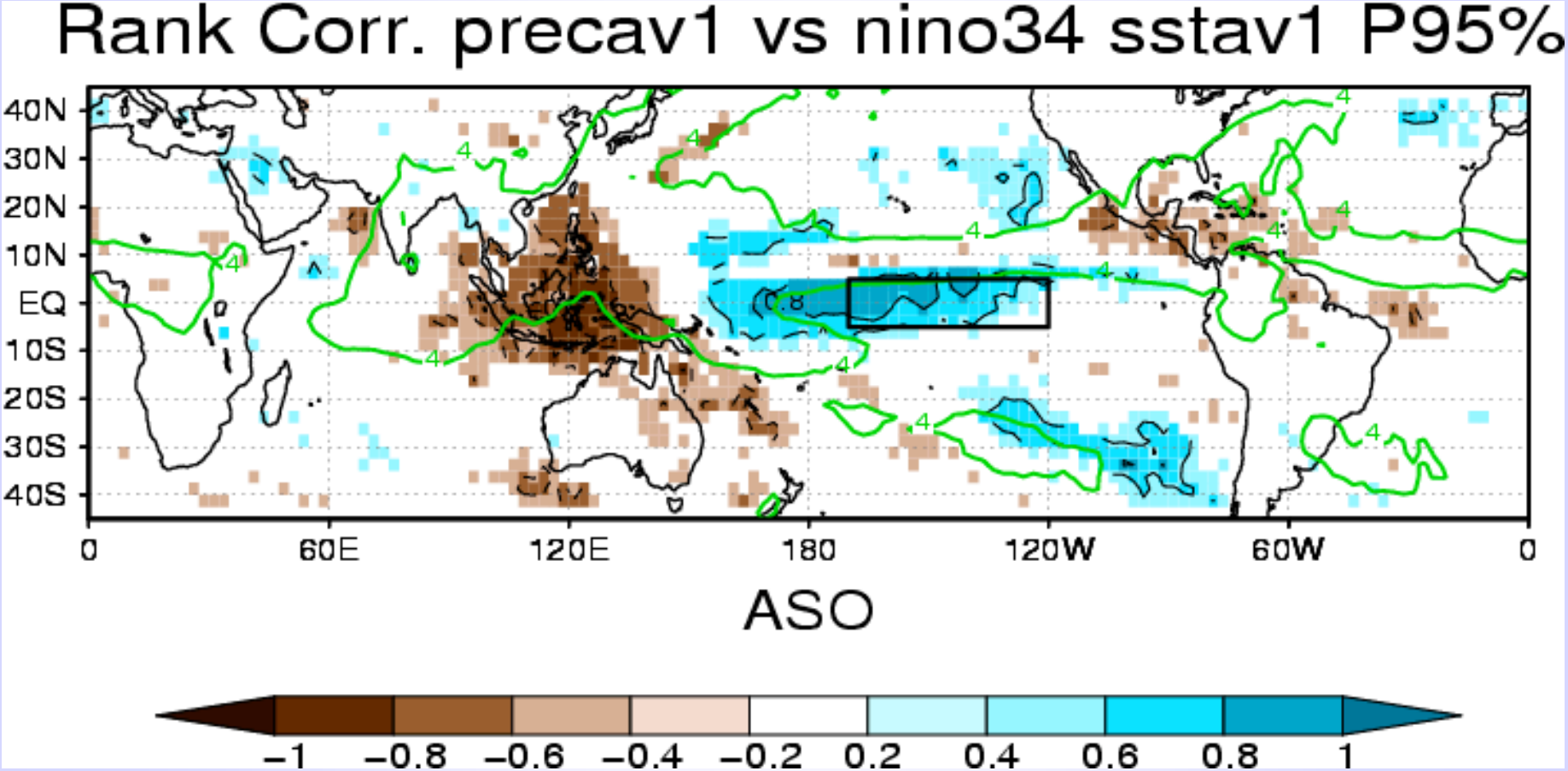
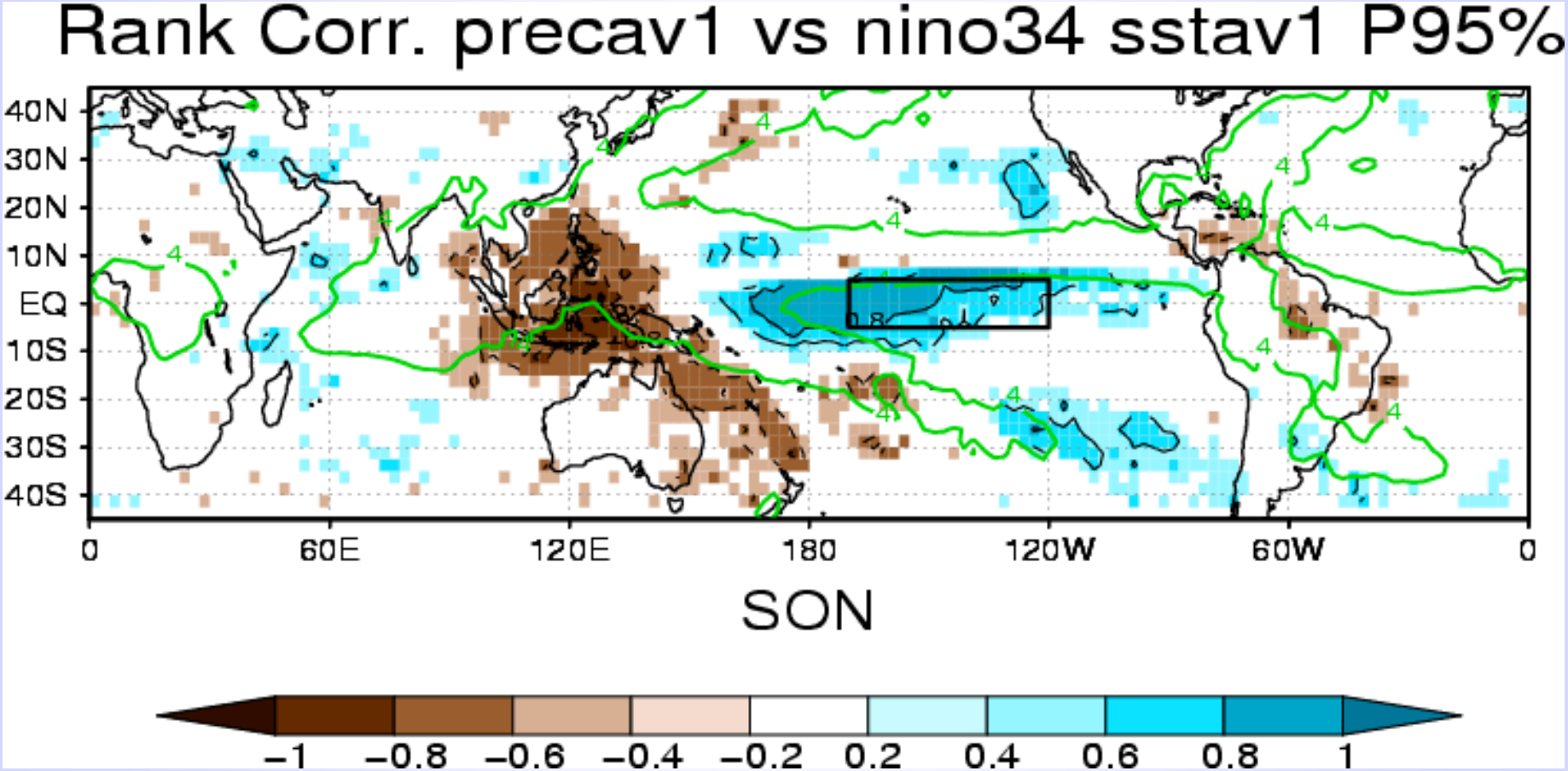


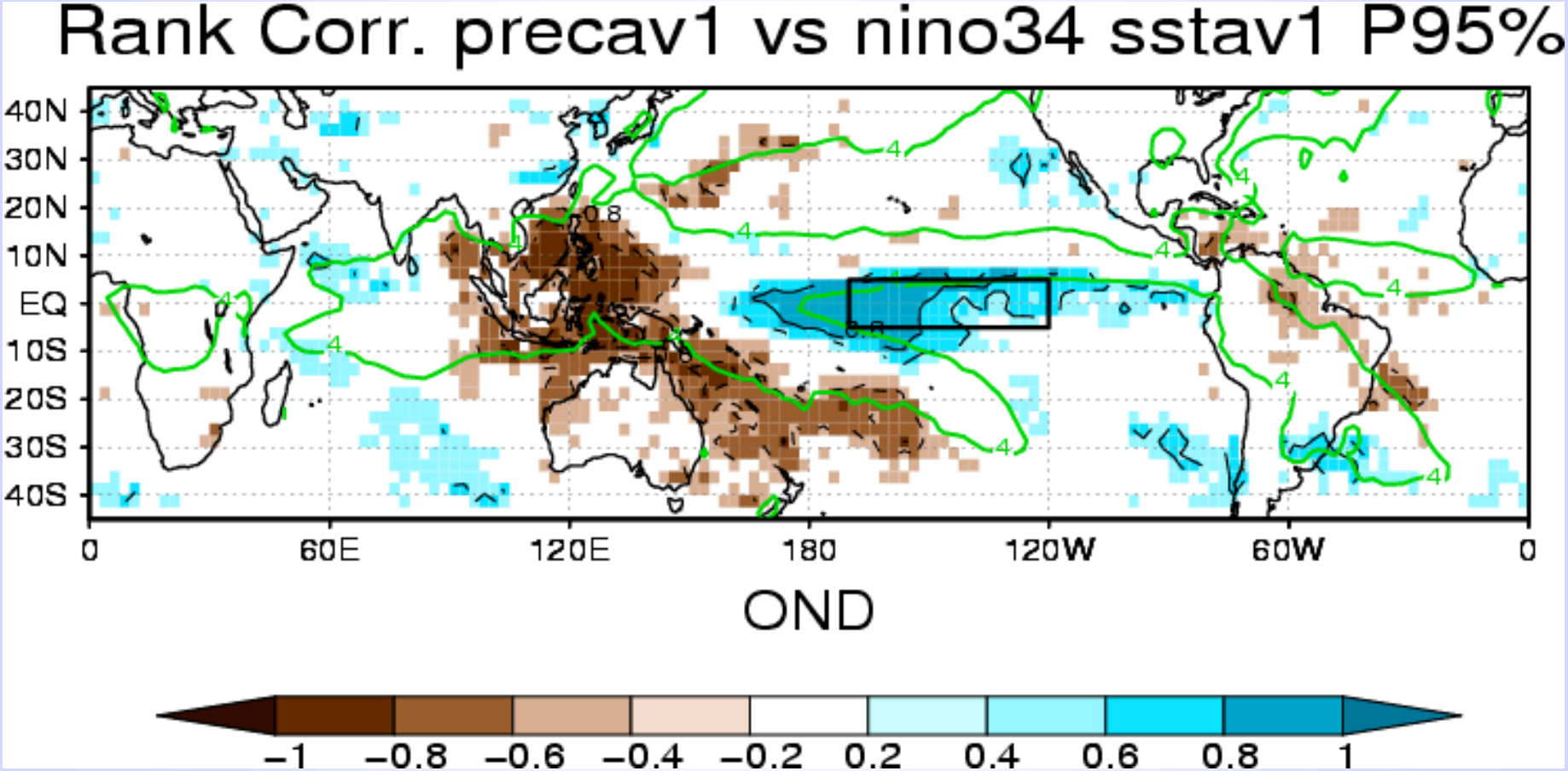
Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Oct.



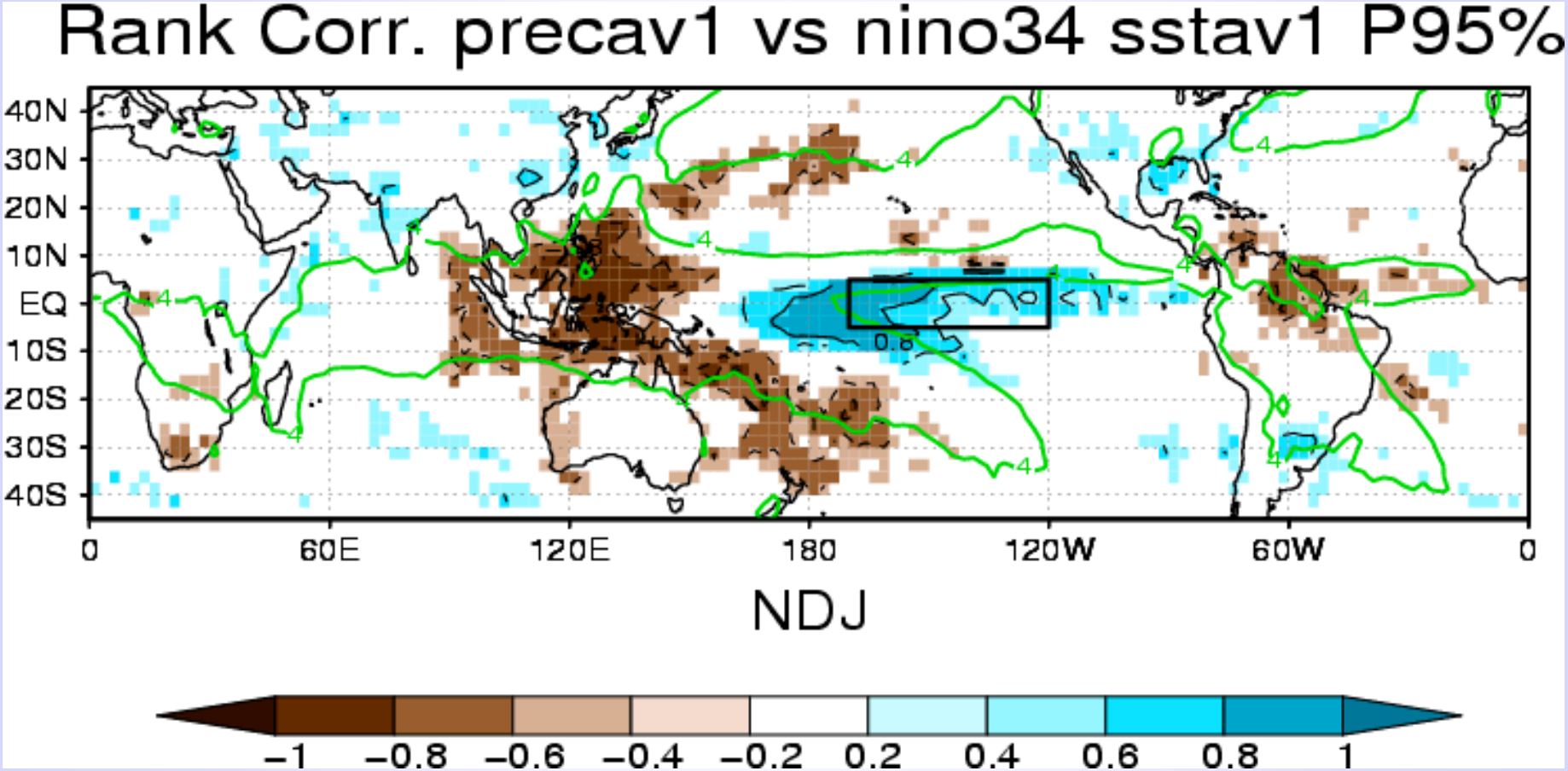
Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Nov.

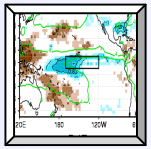


Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Dec.



Repeat sequence

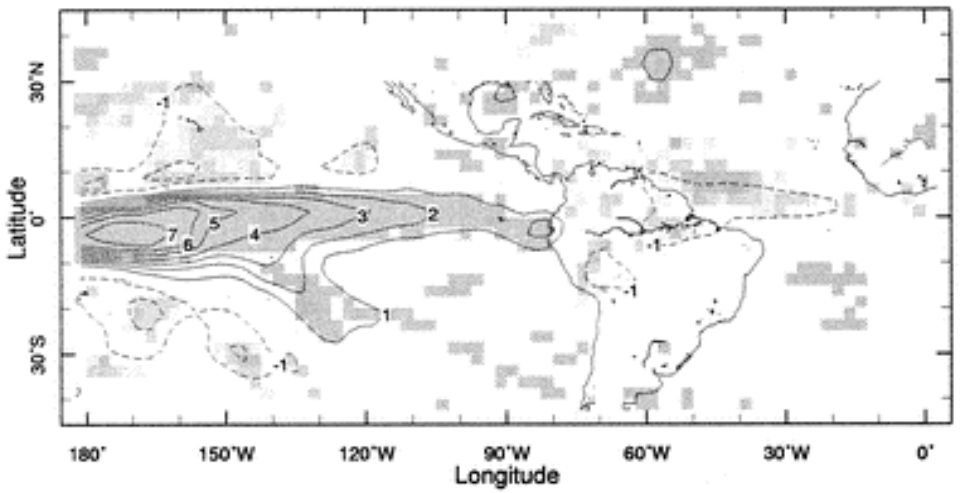


Courtesy, M. Munnich

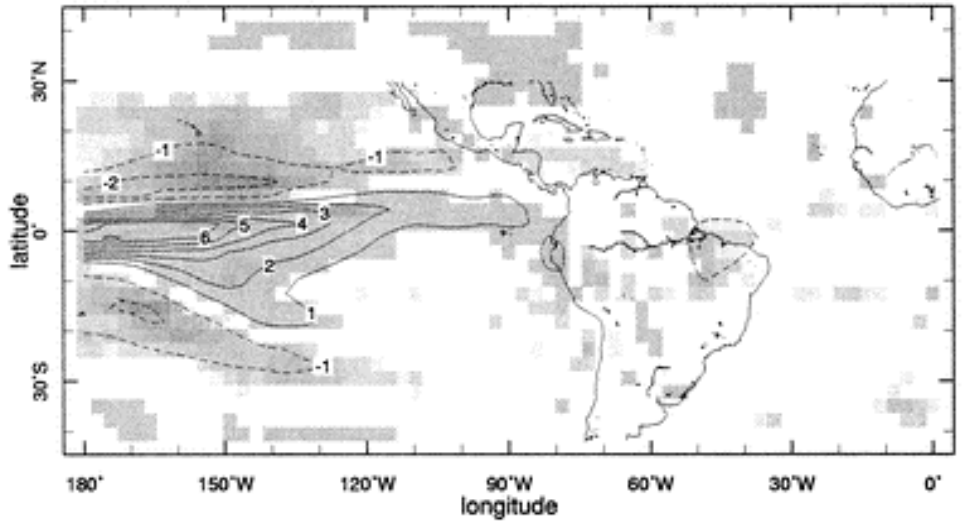
Model Precip relation to ENSO

Giannini et al 2001; Pacific vs Atlantic influences; CCM Goga and TAGA runs

(see also, e.g., Saravanan and Chang 2000; Chiang et al 2002)



OBS warm ENSO JFM(+1) PRCP



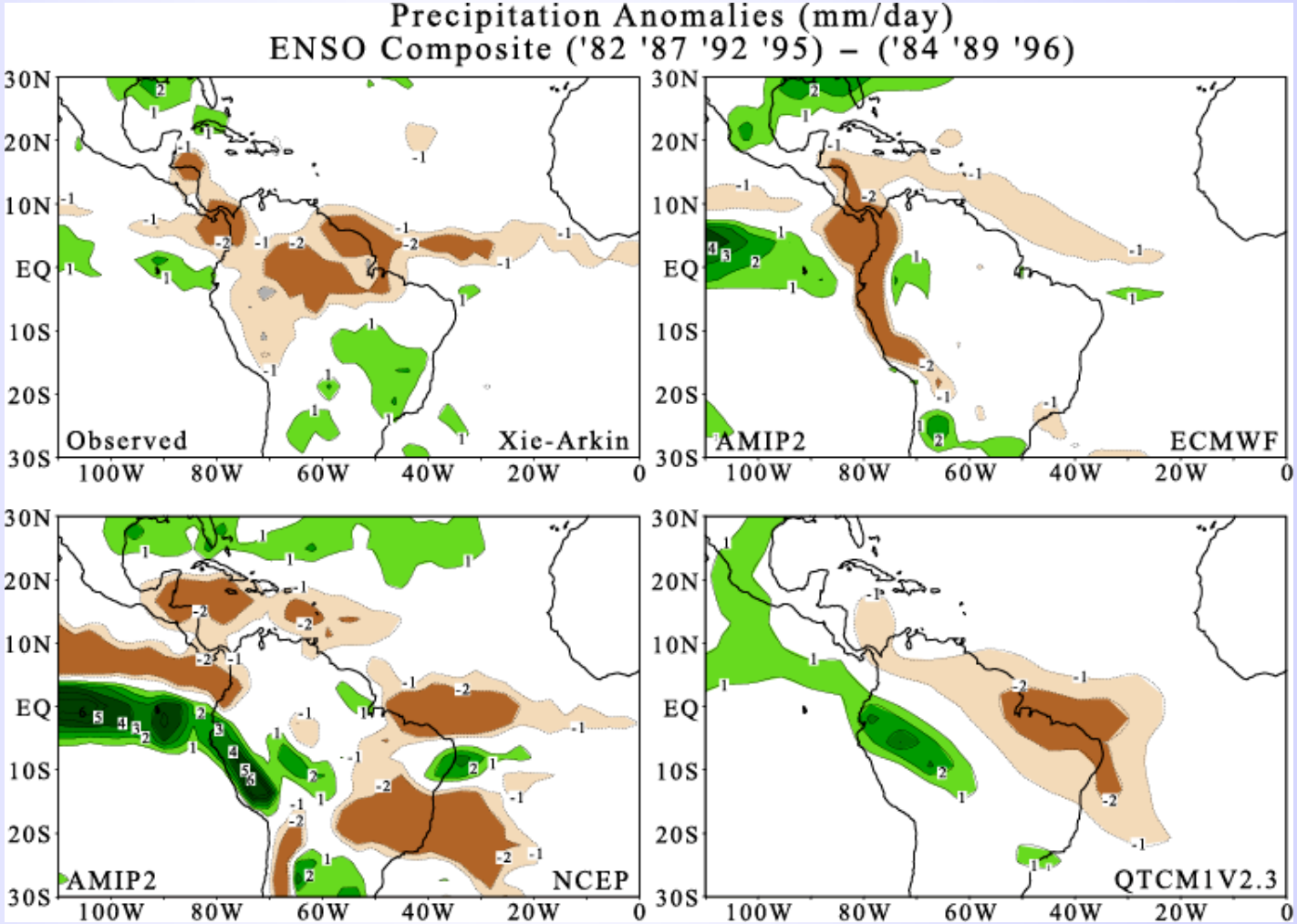
GOGA warm ENSO JFM(+1) PRCP

Giannini et al 2001

ENSO precip. anoms: obs. vs. atm. models

- Warm-cold composite for Xie-Arkin obs, ECMWF-AMIP2, NCEP-AMIP2, QTCM

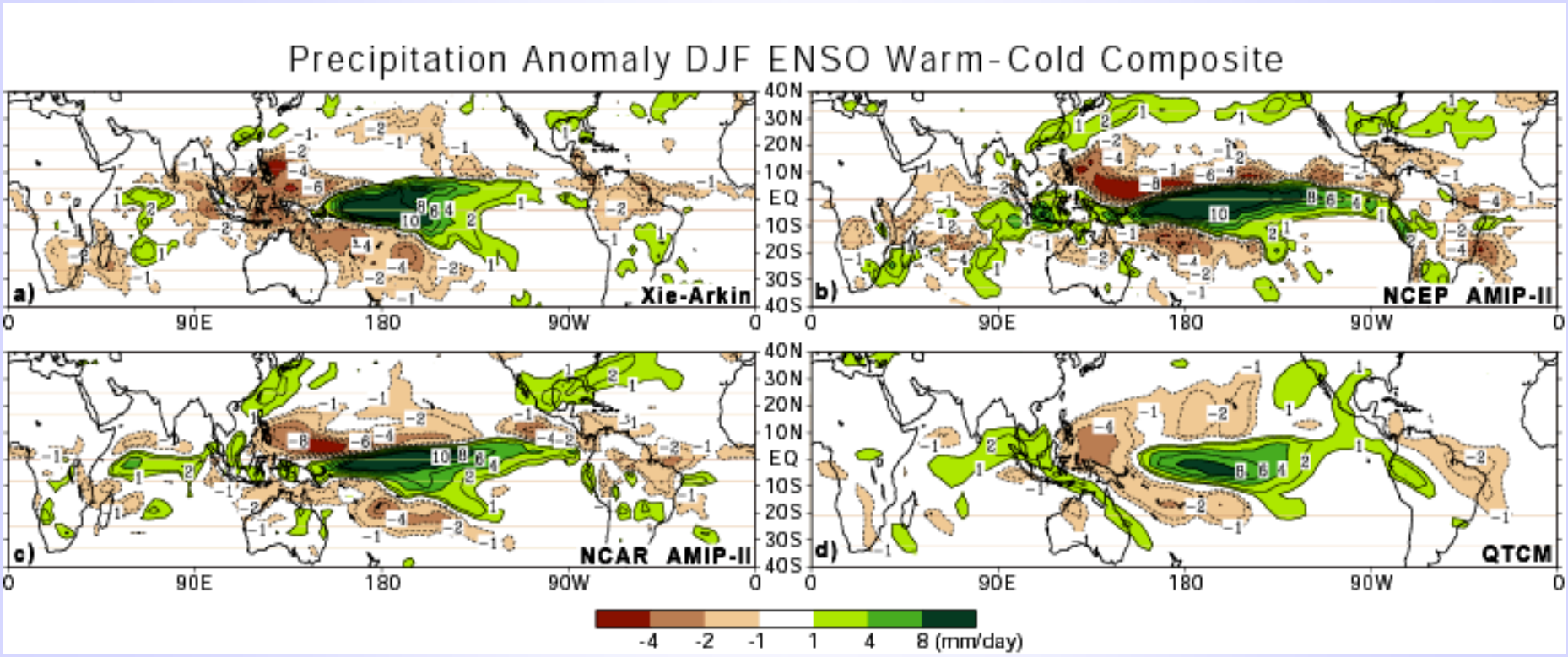
- See also Sperber and Palmer 1996, Giannini et al 2001; Saravanan & Chang, 2000



(El Nino avg 1982-83, 87-88, 92-93, 95-96 – La Nina avg 1984-85, 89-90, 96-97)

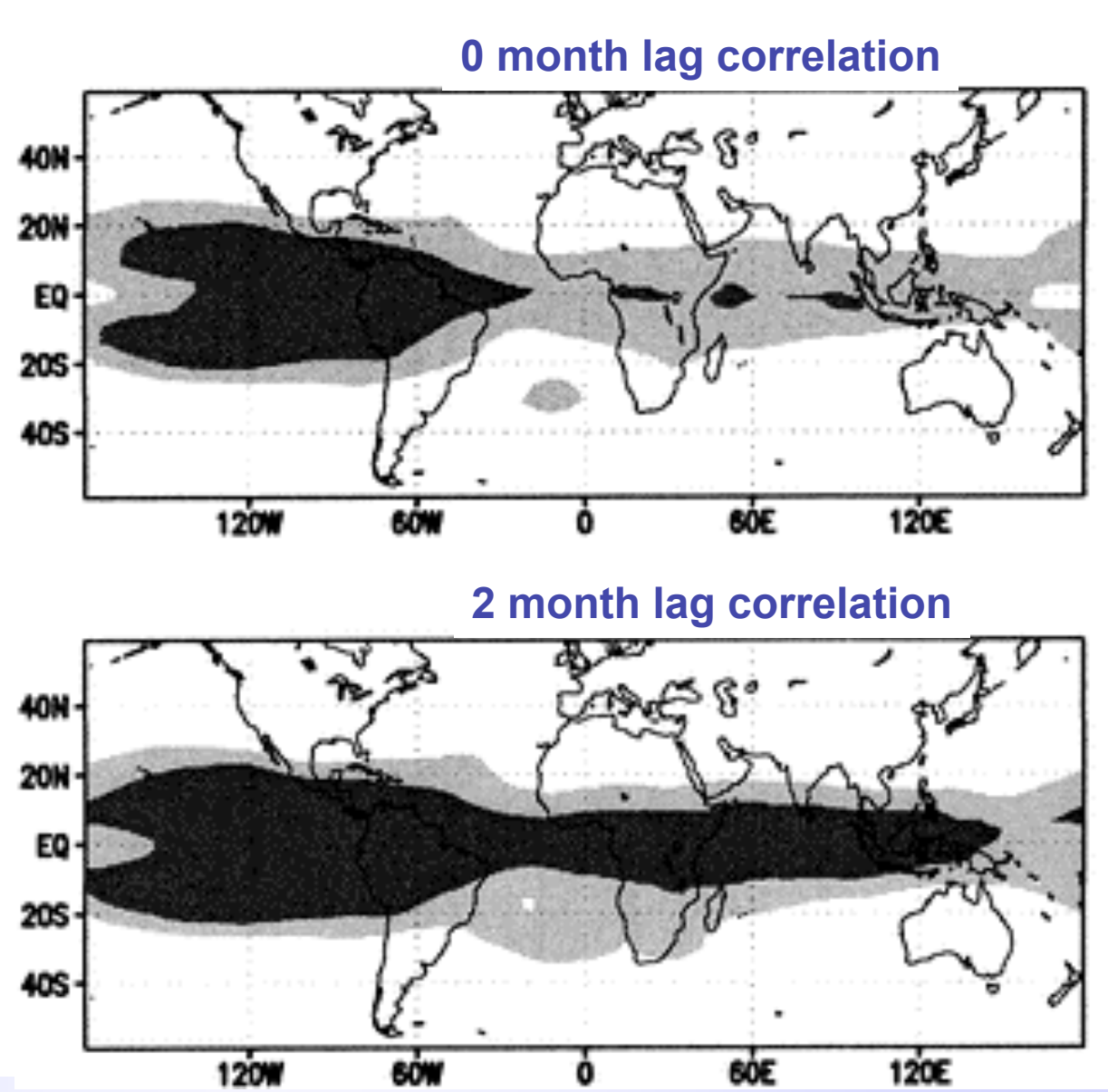
ENSO precip anoms: obs vs atm models

- Warm-cold composite for Xie-Arkin obs, NCEP-AMIP2, NCAR-AMIP2, QTCM



Tropospheric temp. relation to ENSO

- Chiang and Sobel (2002)
- See also Newell and Weare (1976); Salby & Garcia 1987; Yulaeva & Wallace (1994); Kumar & Hoerling (2003); Su and Neelin 2003



Chiang and Sobel (2002)

Convective quasi-equilibrium (QE) implications

- Convective motions reduce CAPE (convective available potential energy)
  - ➢ Constrains T profile & links T to ABL, moisture, surface fluxes
  - ➢ convection vs. wave dynamics in baroclinic pressure gradients

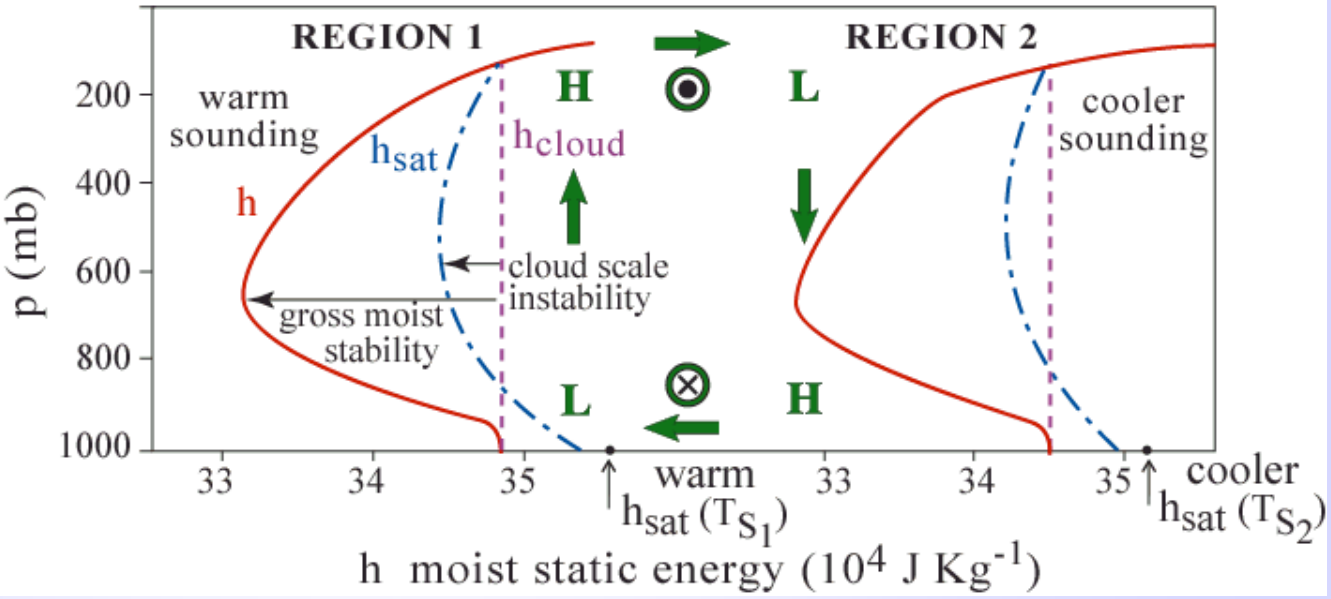
- **Gross moist stability at large scales**

QE: Arakawa & Schubert 1974; Emanuel et al 1994; Brown & Bretherton 1997

GMS, QE implications: Neelin & Yu 1994; Neelin 1997; Yu et al 1997; Neelin & Zeng 2000

ENSO: Yu & Neelin 1997; Zeng et al 2000; Su et al 2001; Chiang et al 2001; Giannini et al 2001; Chiang & Sobel 2002; Su & Neelin 2002;….

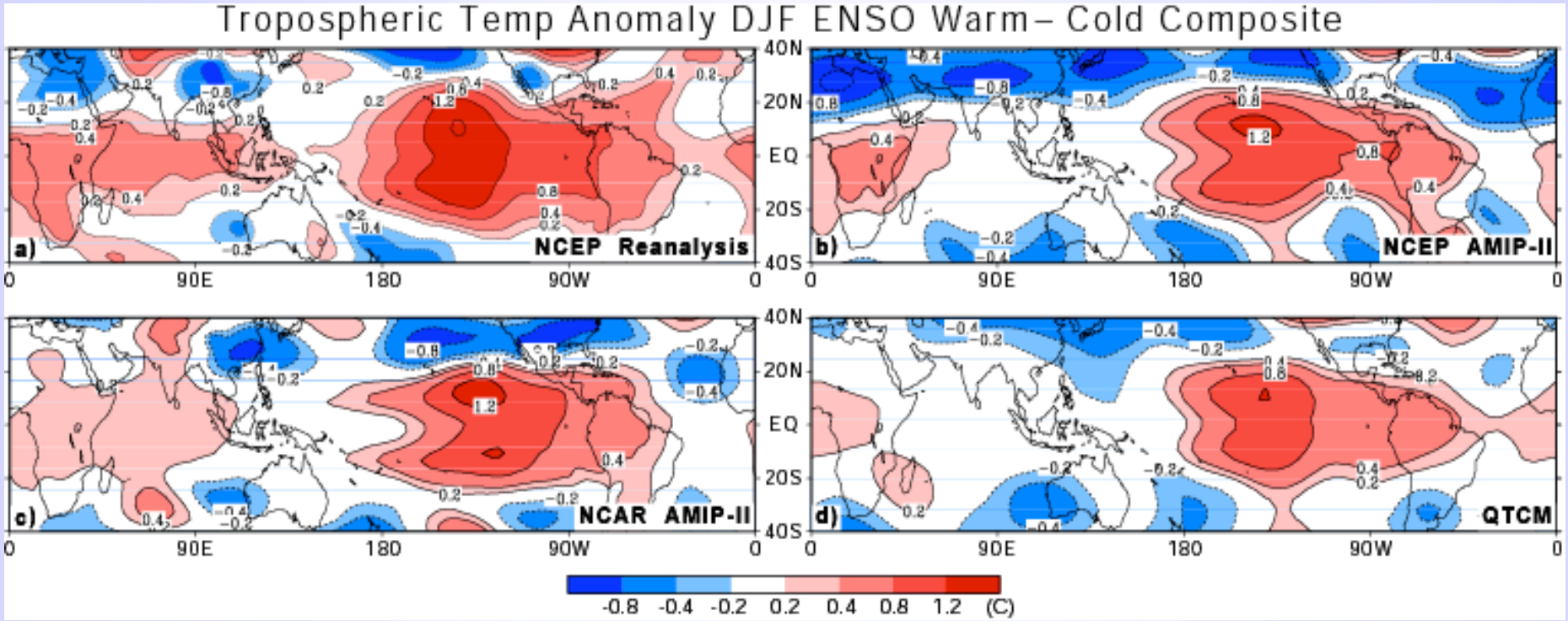
Wave dynamics vs. QE vs. surface fluxes



Neelin (1997)

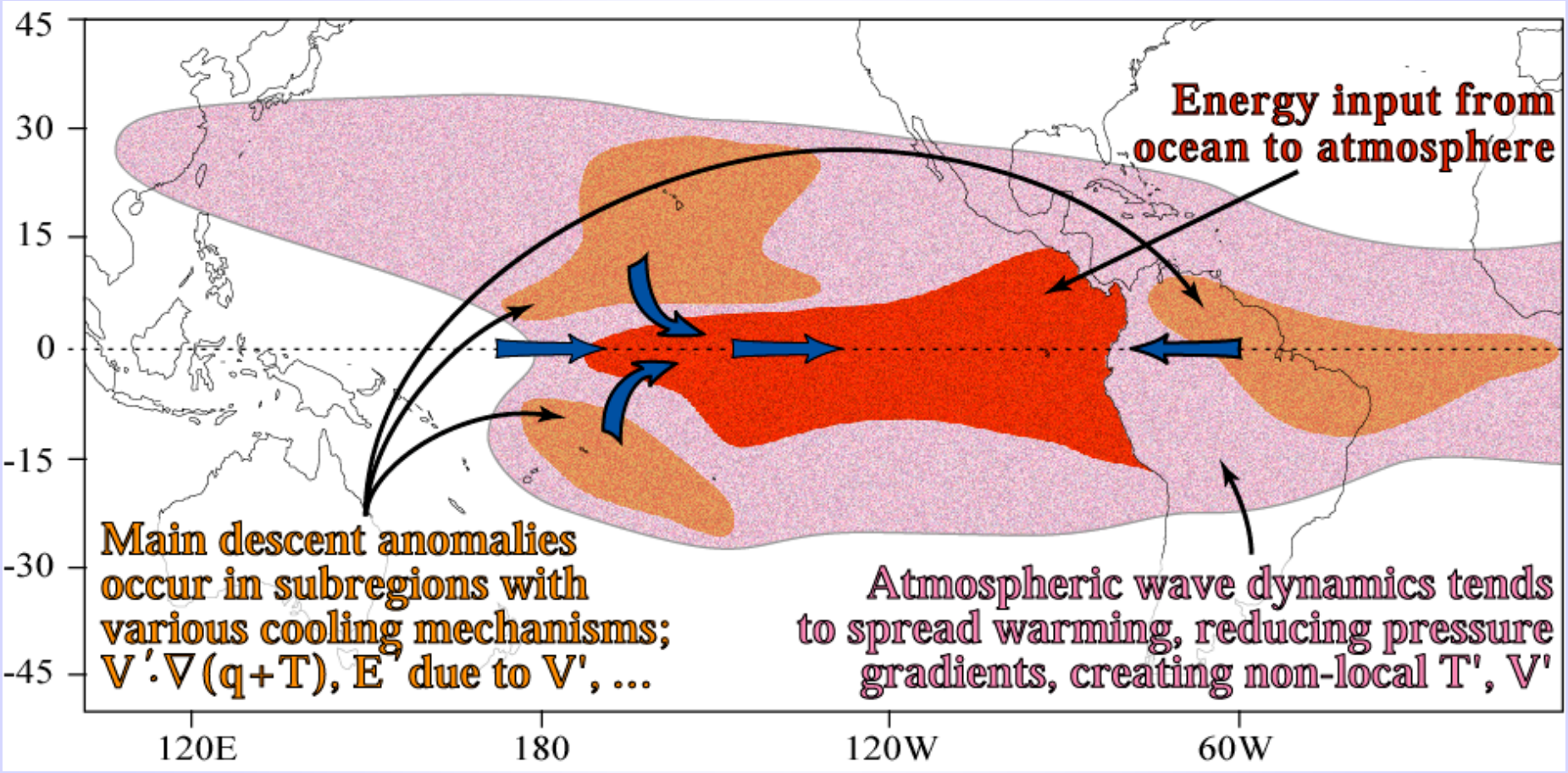
ENSO tropospheric temperature anomalies

- Warm-cold composite
- NCEP reanalysis vs. atm models driven by obs SST (AMIP2): NCEP-AMIP2, NCAR-AMIP2, QTCM



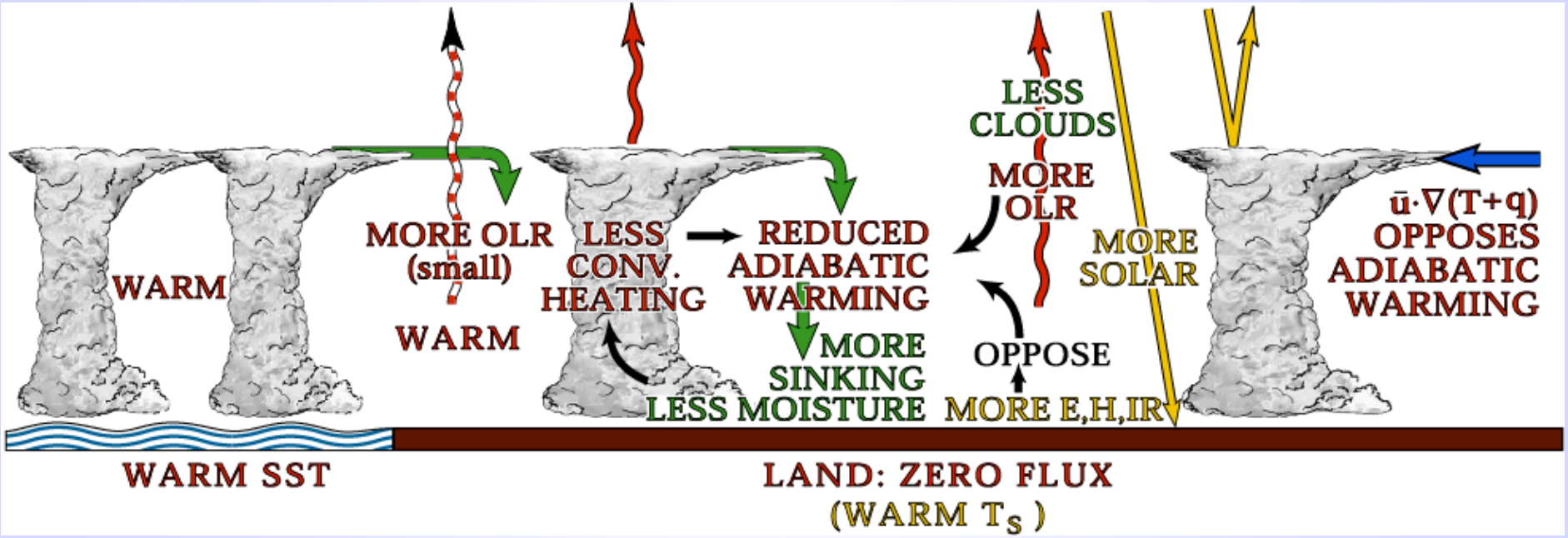
(El Nino avg 1982-83, 87-88, 92-93, 95-96 – La Nina avg 1984-85, 89-90, 96-97)

ENSO teleconnections to regional precip. anomalies



Su & Neelin, 2002

ENSO teleconnections to regional precip. anomalies



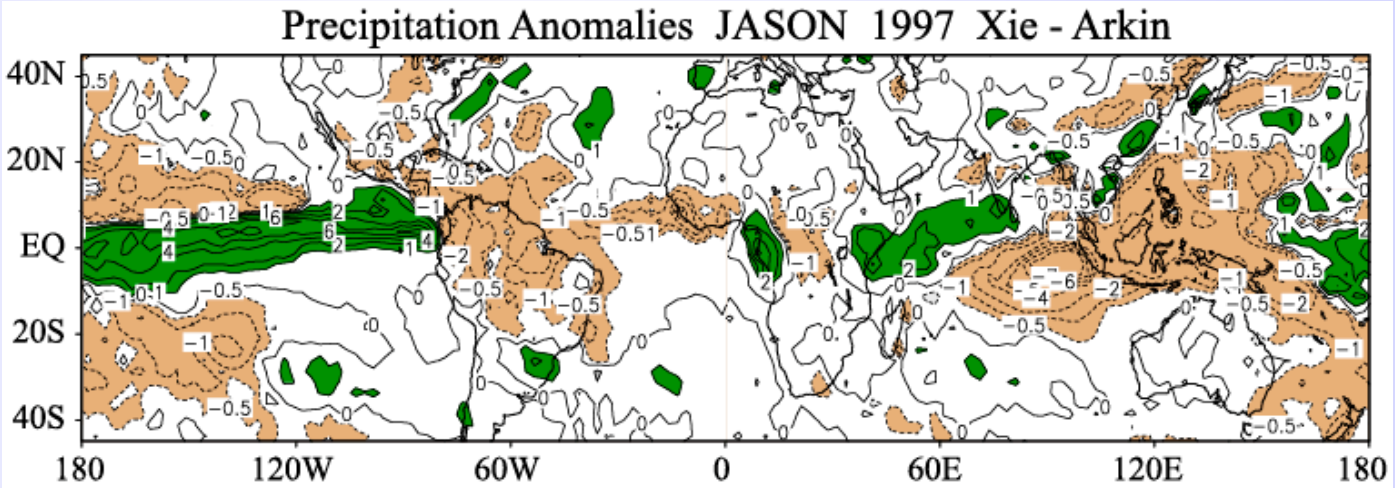
(from AGU 1998; IUGG 1999)

- **a small zoo of mechanisms with moist convective and cloud radiative feedbacks**

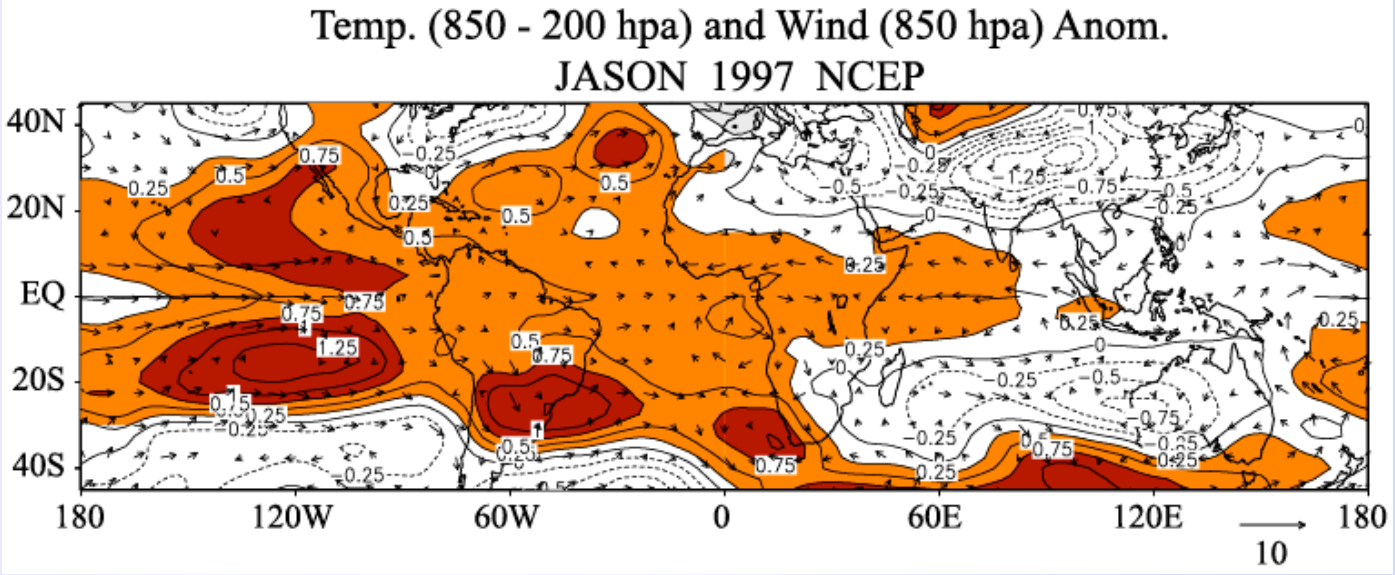
Zeng & Neelin 1999; Giannini et al 2001; Su et al 2001; Bretherton & Sobel 2002; Chiang and Sobel 2002; Chiang et al 2002; Su and Neelin 2002; Neelin et al 2003; Neelin and Su 2004 subm…

Observed anomalies during July-Nov 1997

Precipitation
(mm/day)

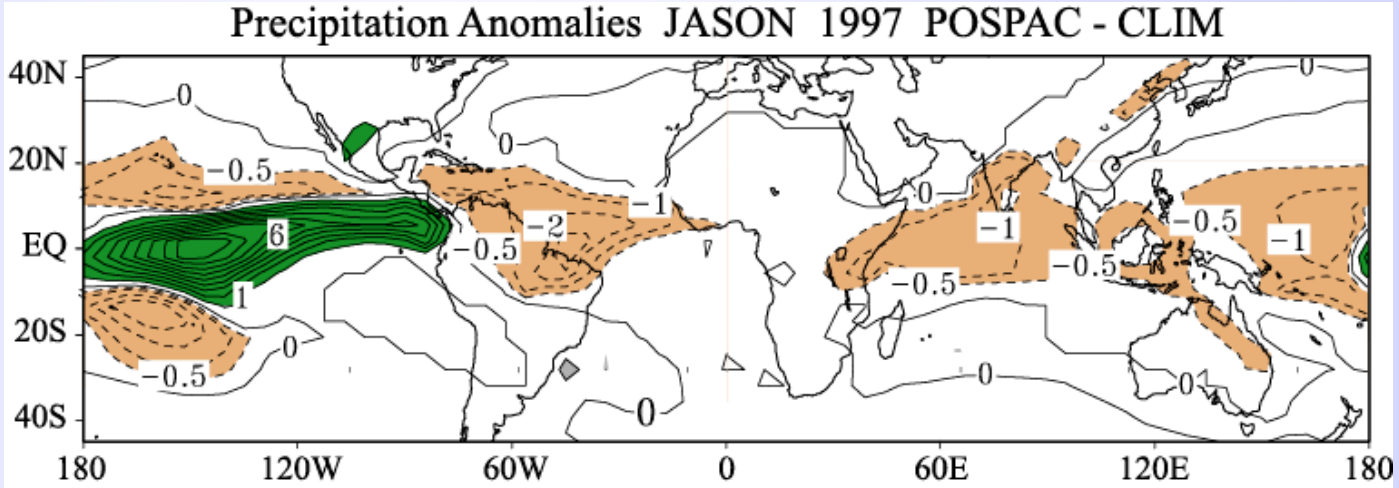


Tropospheric Temperature

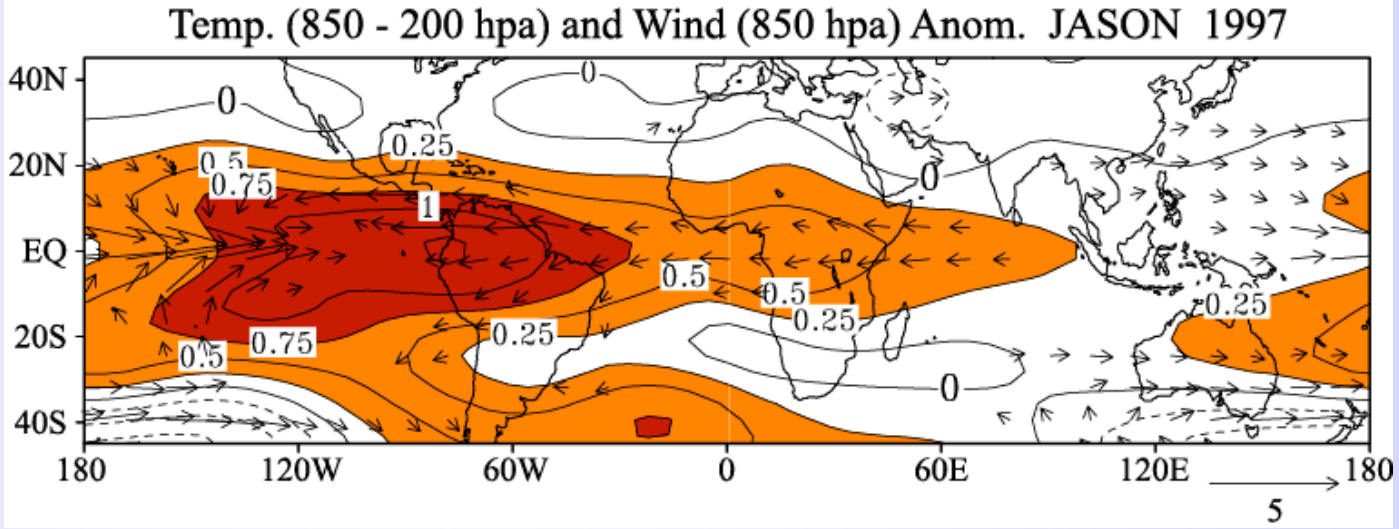


QTCM anomalies forced by Pacific positive SST anomalies July-Nov 1997

Precipitation
(mm/day)



Tropospheric Temperature



Ensemble of 10

Temperature T and Moisture q equations

dry static energy $s = T + \phi$

$$(\partial_t + \mathbf{v} \bullet \nabla)T + \omega\partial_p s - \partial_p R + \partial_p S - \partial_p F_{SH} = Q_c$$

Q_c: *convective heating*

ω: *vertical velocity*

R, S, F_{SH}: *Fluxes: longwave radiation(R), solar(S) sensible(SH), latent heat(L)*

$$(\partial_t + \mathbf{v} \bullet \nabla)q + \omega\partial_p q - \partial_p F_L = Q_q$$

Q_q: *moisture source/sink*

Energy constraint in vertical integral $\langle\ \rangle$

$$\langle Q_c \rangle = -\langle Q_q \rangle$$

$\langle$Moist static energy equation$\rangle$

$$\langle(\partial_t + \mathbf{v} \bullet \nabla)(T + q)\rangle + \langle\omega\partial_p h\rangle - F_{net} = 0$$

Transport of moist static energy by divergent flow
≈ (measure of divergence)
x gross moist stability

Net energy flux into column

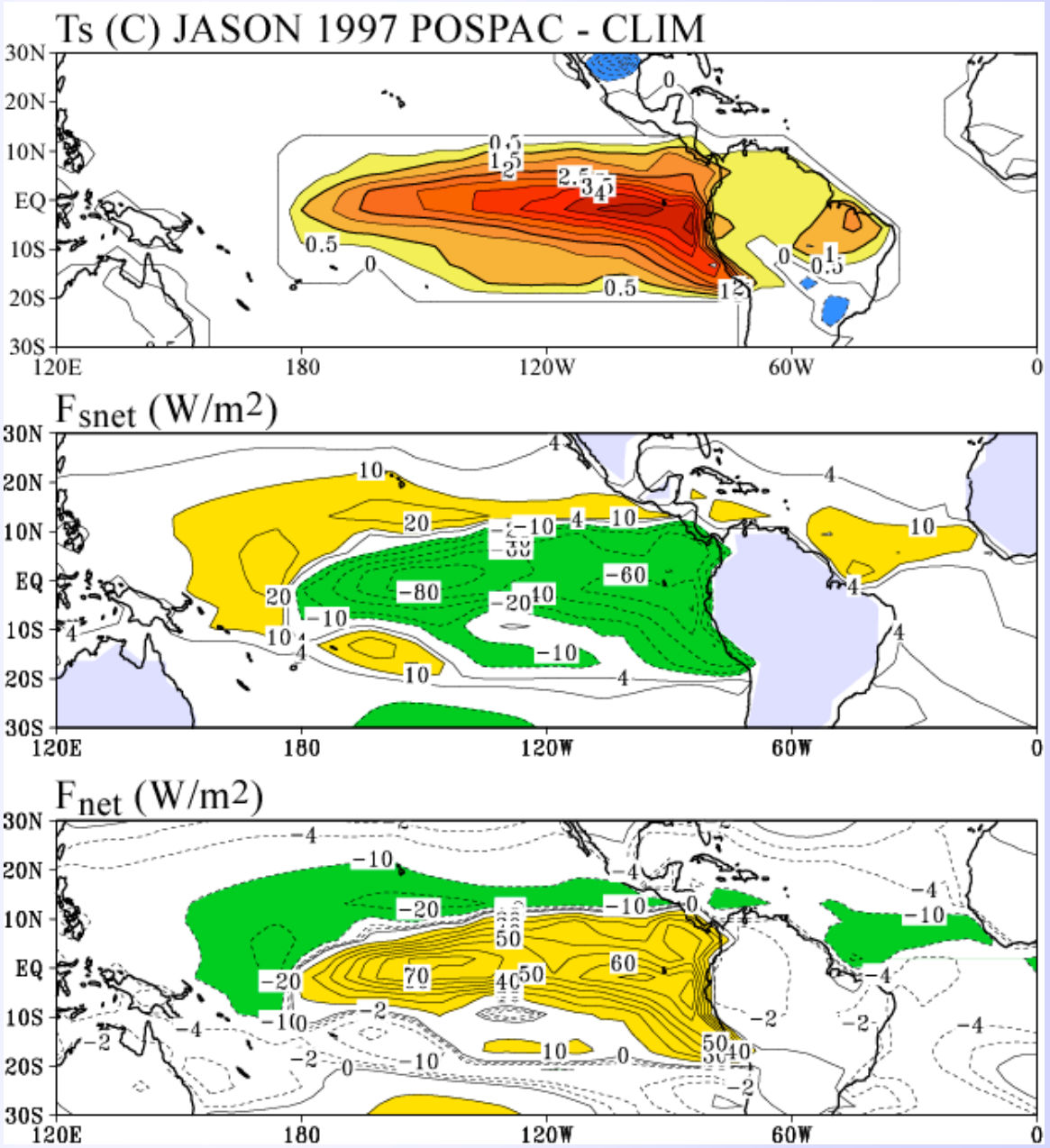
Moist static energy $h = s + q$

QTCM POSPAC-Fluxes

Surface temperature

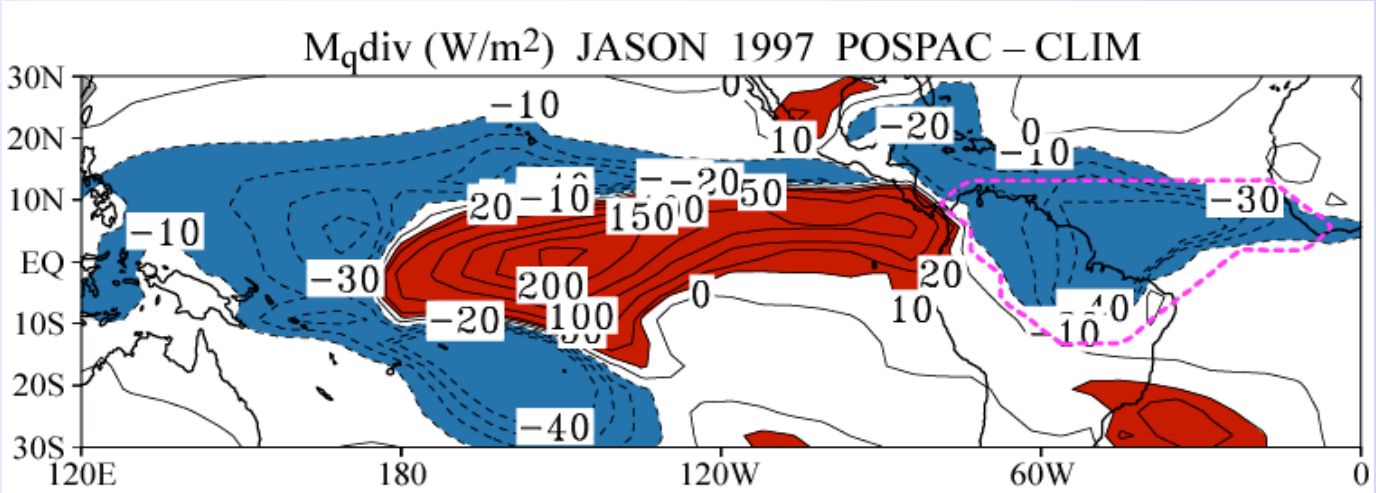
Net surface flux

Net flux into atmospheric column

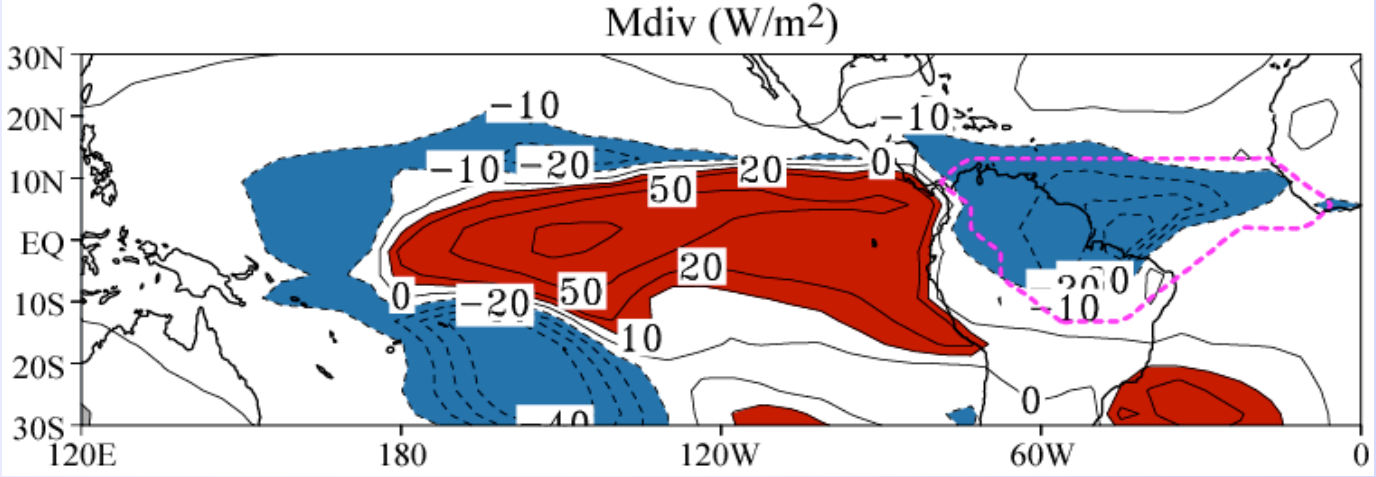


QTCM July-Nov 1997: Anomaly budget contributions

Moisture convergence $M_q \nabla \cdot v$ (by divergent flow)



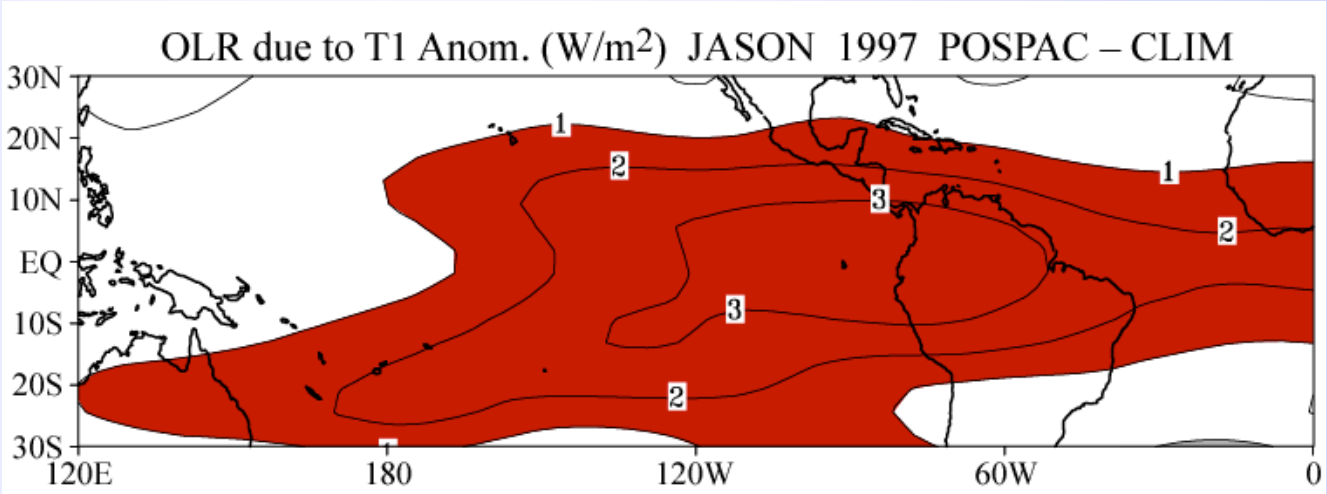
Moist static energy divergence* $M \nabla \cdot v$



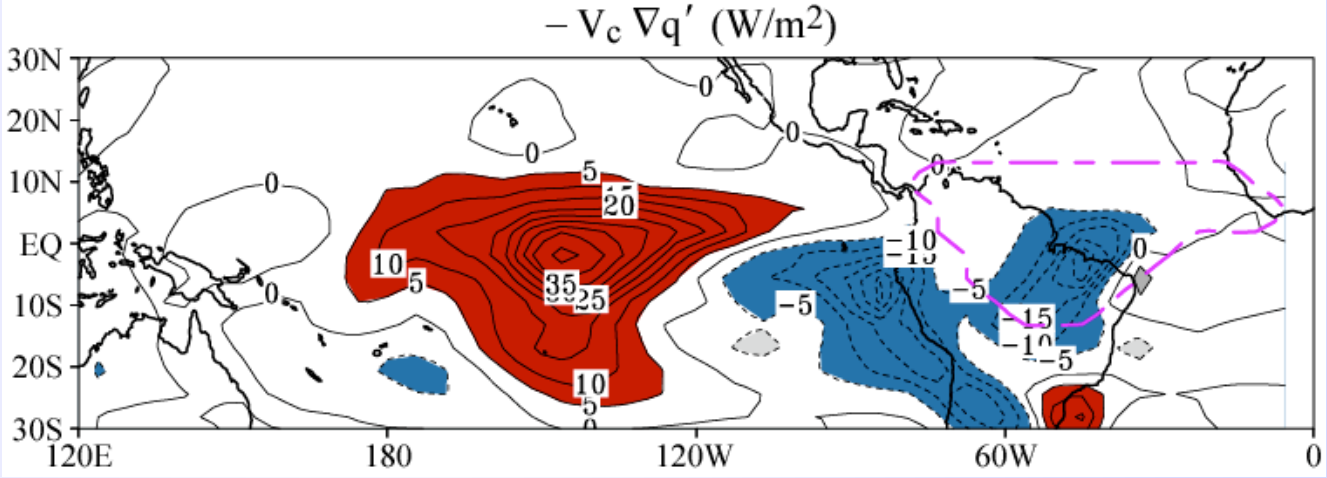
* Gross moist stability $M=M_s-M_q$ is an effective stability that includes partial cancellation of adiabatic cooling by diabatic heating

QTCM July-Nov 1997: Anomaly budget contributions

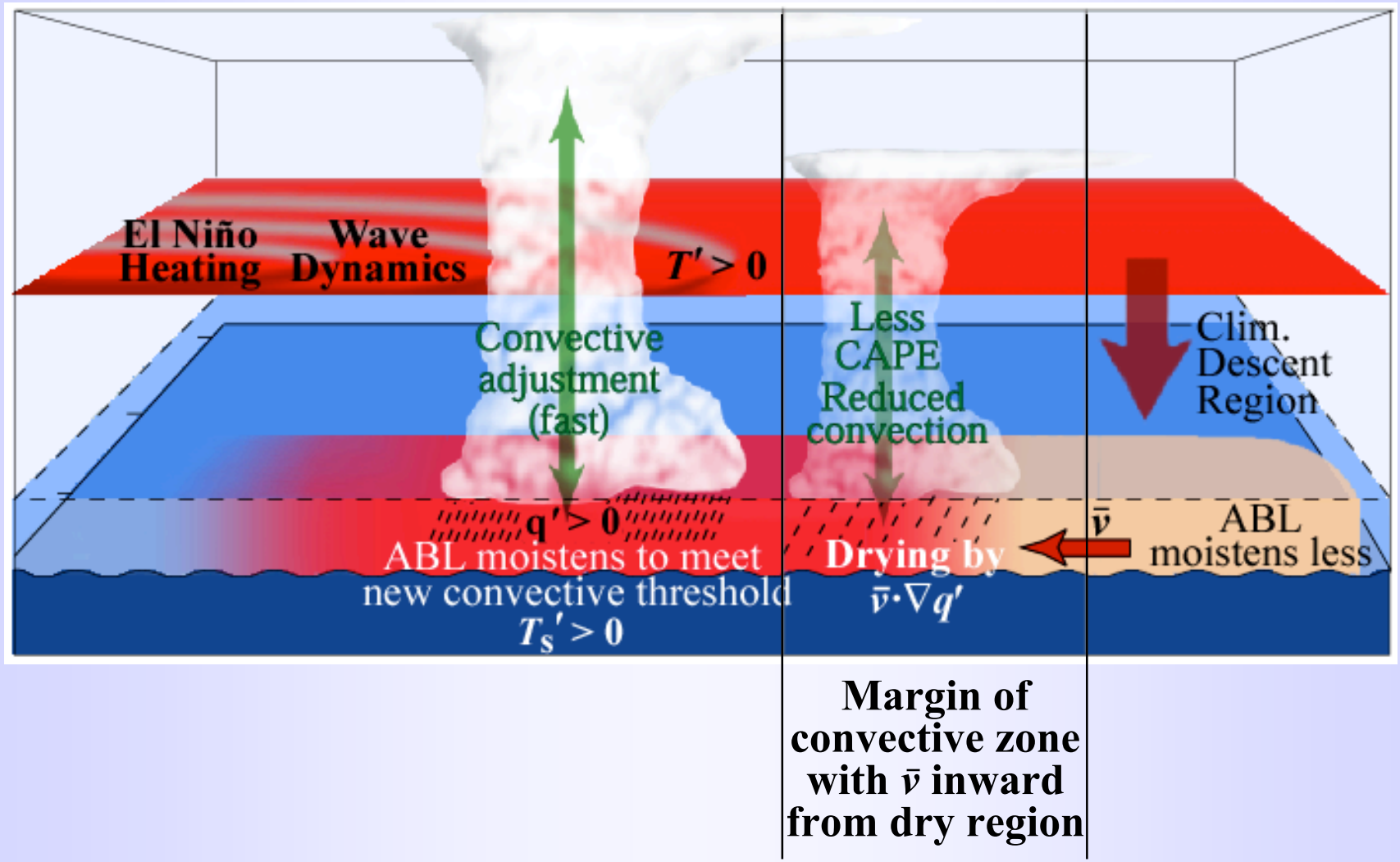
Radiative cooling anom. (top of atmosphere) due to temp. anom.



Mean wind advection of moisture anomaly $v \cdot \nabla q'$



The "upped-ante" mechanism

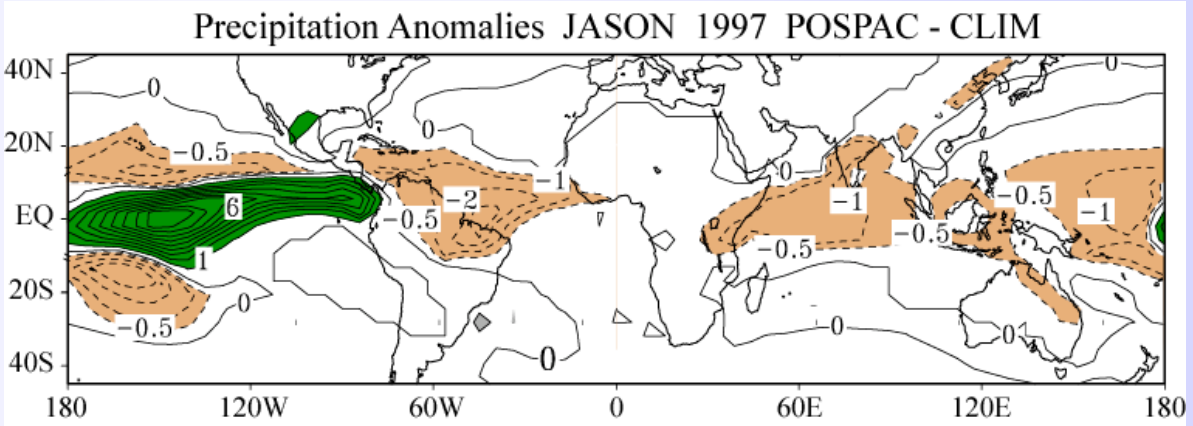


Neelin, Chou & Su, 2003

QTCM experiments suppressing various mechanisms

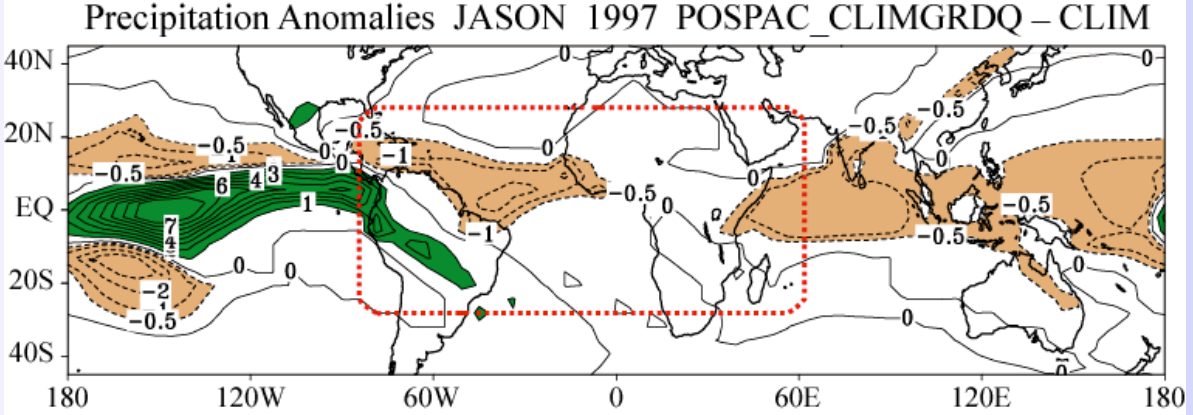
Precipitation Anomalies

Control

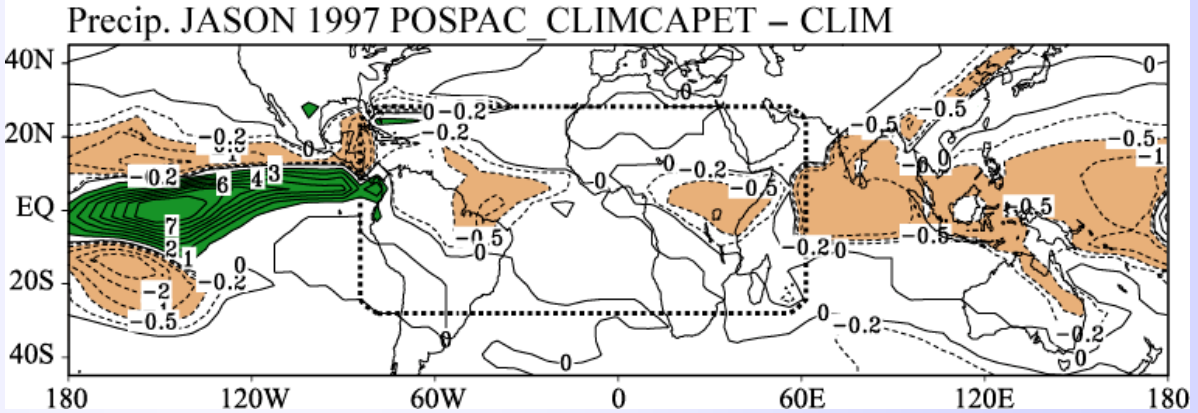


Anomaly $(\ )'$ term suppressed in region:

$(v \cdot \nabla q)'$



T' contribution to CAPE



Other mechanisms

- Moist Static Energy transport by divergent flow ≈ $M\nabla\cdot v$
- 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, …

Kelvinoid solution

Baroclinic zonal wind eq for anoms. u_1 (if v_1 negligible)

$$\partial_t u_1' + \bar{u}_u \partial_x u_1' + \kappa \partial_x T_1' = F_u$$

$\bar{u}_u$ projection of the mean wind, F_u projection of vertical momentum flux (incl. surface drag; small)

With MSE eq., under convective QE, steady solution

$$(c_{eff}^2 - \bar{u}_u \bar{u}_h)\, \partial_x u_1' = \kappa F_{eff}^{net\,\prime} - \bar{u}_h F_u'$$

c_{eff} effective moist phase speed $\propto M_{eff}^{1/2}$

M_{eff} effective moist stability including cloud feedbacks

$\bar{u}_h$ term from $\langle v \cdot \nabla T' \rangle + \langle v \cdot \nabla q' \rangle$

$\bar{u}_h$, $\bar{u}_u$ easterly: reduce eastward ph. speed => incr. descent

F_{eff}^{net} net flux of Rad, SH, E into atm column with cloud fb moved to M_{eff}

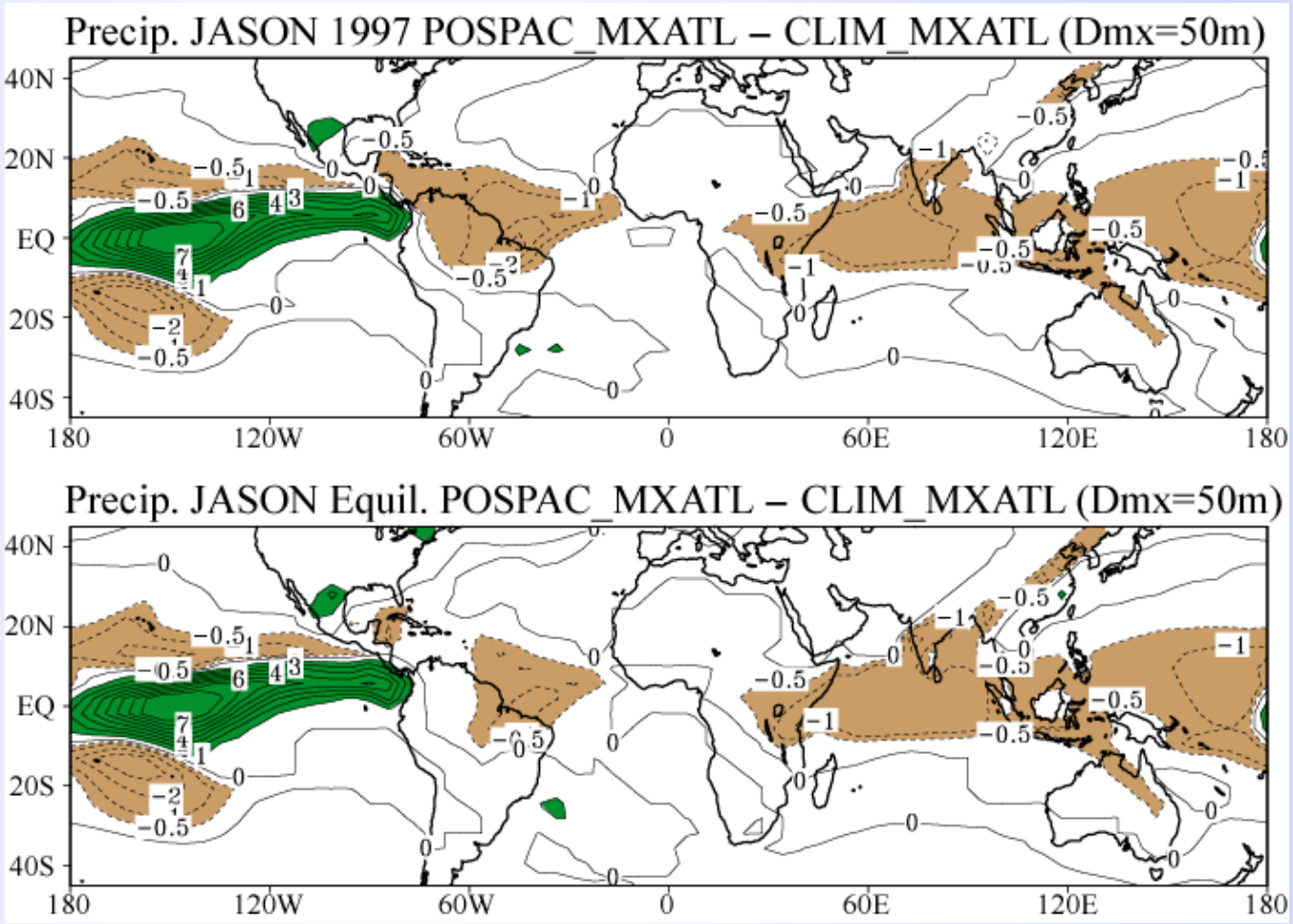
Neelin & Su J Clim, subm

Mixed layer ocean in Atlantic: 1st year vs equilibrium

Precipitation anomalies

- Positive 1997 El Nino Jul.-Nov. SST anom in Pacific: tropical Atlantic 50m ML SST is adjusting

- Long term equilibrium with El Nino SST anom artificially sustained



(anomalies relative to climatology of ML Atlantic, clim. SST elsewhere)

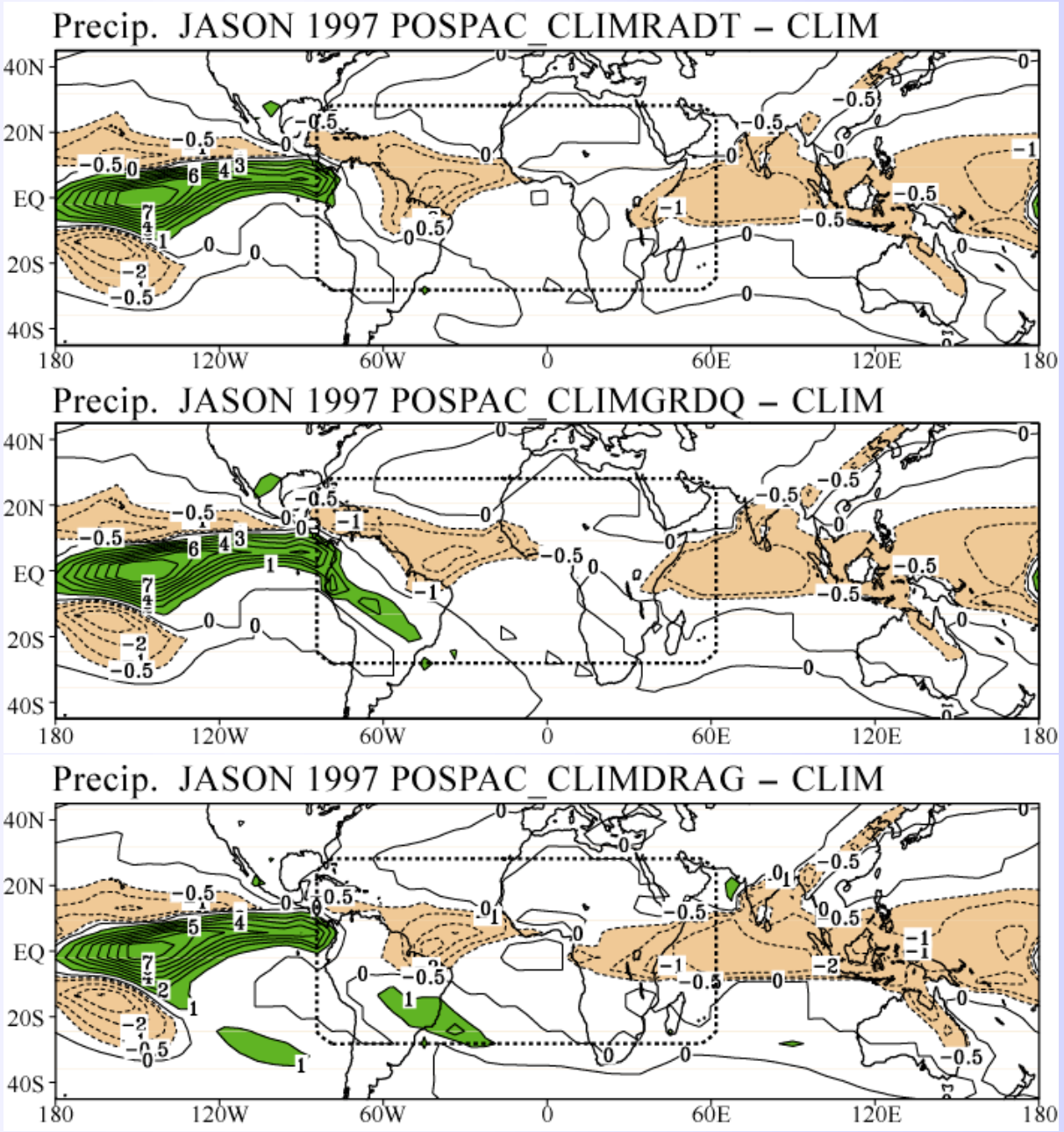
QTCM experiments suppressing various mechanisms

Precipitation Anomalies
Anomaly $(\ )'$ term suppressed in region:

T' radiative effects

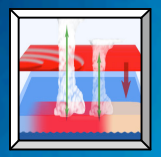
$(v \cdot \nabla T)'$

(surface stress)'

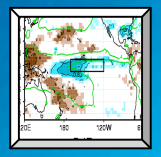


Summary: moist teleconnection mechanisms

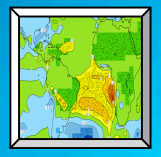
- **ENSO SST ⇒ Pacific warm troposphere ⇒ wave dynamics ⇒ interaction with remote convection zones ⇒ a small zoo of mechanisms for precip. anoms.**
- **Convective QE mediation ⇒ links ABL q with tropospheric T**
- **GMS multiplier effect: MS energy budget terms ⇒ $\nabla\cdot\boldsymbol{v}'$ ⇒ precip′ via moisture convergc. anom.**
- **Cloud feedbacks as modification to effective static stability M_{eff}**
- **Upped-ante mechanism:**
  - **regions of negative precipitation anoms during warming**
  - **at margins of convection zones with climatological wind inflow from dry zone:** $T' + \text{QE} \Rightarrow \boldsymbol{q}' \Rightarrow \boldsymbol{v}\cdot\nabla\boldsymbol{q}'$
- **Moist wave mechanisms: $(c_{eff}^2 - u_u u_h)$; weak damping (T', q', u')**
- **[M' mechanism; $\boldsymbol{v}'$ mechanisms, ….]**
- **Surface flux mechanisms:** $T' + \text{QE} \Rightarrow \boldsymbol{q}' \Rightarrow E'$; $\boldsymbol{v}' \Rightarrow E'$ ….
  - **Surface heat fluxes & SST' only while SST in disequilibrium with T (∂_t SST or ocean transport anom.)**



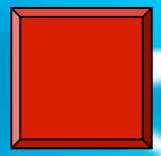
Title page



Obs. Precip-ENSO corr.



QTCM analysis



End show