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)

Climate Systems Interactions Group

www.atmos.ucla.edu/~csi
Remote tropical SST relationship to ENSO


Klein et al 1999
Tropical remote precip. relation to ENSO


Regression of MSU Precip and Trop. Temp. on Pacific SST Cold Tongue Index

Wallace et al 1998
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

3-mon. mean centered on: Feb.

Rank Corr. precav1 vs nino34 sstav1 P95%
Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Mar.

Rank Corr. precav1 vs nino34 sstav1 P95%
Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on:  Apr.

Rank Corr. precav1 vs nino34 sstav1 P95%
Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: \textbf{May}
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 Corr. precav1 vs nino34 sstav1 P95%
Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Aug.

Rank Corr. precav1 vs nino34 sstav1 P95%
Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Sept.

Rank Corr. precav1 vs nino34 sstav1 P95%
Rank Correlation Precip to Nino3.4 SST

3-mon. mean centered on: Oct.

Rank Corr. precav1 vs nino34 sstav1 P95%
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)
ENSO precip. anoms: obs. vs. atm. models

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

- See also Sperber and Palmer 1996, Gianninni 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


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;...
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**

Main descent anomalies occur in subregions with various cooling mechanisms; \( V' \cdot \nabla (q+T), E' \) due to \( V' \), ...

Atmospheric wave dynamics tends to spread warming, reducing pressure gradients, creating non-local \( T', V' \)

Energy input from ocean to atmosphere

Su & Neelin, 2002
**ENSO teleconnections to regional precip. anomalies**

*• 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…

(from AGU 1998; IUGG 1999)
Observed anomalies during July-Nov 1997

Precipitation (mm/day)

Tropospheric Temperature
QTTC anomalies forced by Pacific positive SST anomalies July-Nov 1997

Precipitation (mm/day)

Tropospheric Temperature

Ensemble of 10
Temperature $T$ and Moisture $q$ equations

\[
(\partial_t + \mathbf{v} \cdot \nabla)T + \omega \partial_p s - \partial_p R + \partial_p S - \partial_p F_{SH} = Q_c \quad \text{convective heating}
\]

\[
(\partial_t + \mathbf{v} \cdot \nabla)q + \omega \partial_p q - \partial_p F_L = Q_q \quad \text{moisture source/sink}
\]

Energy constraint in vertical integral $\langle \rangle$

\[
\langle Q_c \rangle = -\langle Q_q \rangle
\]

\[\langle \text{Moist static energy equation} \rangle\]

\[
\langle (\partial_t + \mathbf{v} \cdot \nabla)(T + q) \rangle + \langle \omega \partial_p h \rangle - F_{\text{net}} = 0
\]

Transport of moist static energy by divergent flow
\[
\approx (\text{measure of divergence}) \times \text{gross moist stability}
\]

Net energy flux into column

Moist static energy
\[h = s + q\]
QTCM POSPAC-Fluxes

Surface temperature

Net surface flux

Net flux into atmospheric column
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
Radiative cooling anom. (top of atmosphere) due to temp. anom.

Mean wind advection of moisture anomaly $\mathbf{v} \cdot \nabla q'$
The “upped-ante” mechanism

Neelin, Chou & Su, 2003
QTCM experiments suppressing various mechanisms

Precipitation Anomalies

Control

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

\( (v \cdot \nabla q)' \)

\( T' \) contribution to CAPE
Other mechanisms

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

Perturbation **MSE budget + ocean mixed layer / land**

$\bar{M} \nabla \cdot \nu' = -M' \nabla \cdot \nu - (\nu \cdot \nabla q)' - c \partial_t T_s' + F_{\text{net}}' + (\nu \cdot \nabla T)' \ldots$

Yields precip anoms as $T' \Rightarrow q' \Rightarrow \nabla q', M'; \nu', q' \Rightarrow E' \ldots$

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

- **Upped-ante Rich-get-richer**
- **GMS multiplier effect**
- **Rad cooling, (v·∇T)’ ocean transp, …**
- **SST disequilibrium**
**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

$$(c_{eff}^2 - \bar{u}_u \bar{u}_h) \partial_x u'_1 = \kappa F_{eff}^{net'} - \bar{u}_h F'_u$$

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

$M_{eff}$ effective moist stability including cloud feedbacks

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

$\bar{u}_h$, $\bar{u}_u$ 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

$(\mathbf{v} \cdot \nabla T)'$

(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. anom.
• Convective QE mediation ⇒ links ABL q with tropospheric T
• GMS multiplier effect: MS energy budget terms ⇒ ∇⋅v' ⇒ precip' via moisture convergc. anom.
• Cloud feedbacks as modification to effective static stability $M_{eff}$
• Upped-ante mechanism:
  • regions of negative precipitation anom. during warming
  • at margins of convection zones with climatological wind inflow from dry zone: $T' + QE \Rightarrow q' \Rightarrow v\cdot\nabla q'$
• Moist wave mechanisms: $(c_{eff}^2 - u_u u_h);$ weak damping $(T', q', u')$
• [M' mechanism; v' mechanisms, .... ]
• Surface flux mechanisms: $T' + QE \Rightarrow q' \Rightarrow E' ; v' \Rightarrow E' ;$ ....
  • Surface heat fluxes & SST only while SST in disequilibrium with $T (\partial_t$ SST or ocean transport anom.)
Title page

Obs. Precip-ENSO corr.

QTTCM analysis

End show