Teleconnections and ENSO
-the tropical problem
(with implications for midlatitudes)

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- **Review of some processes in teleconnections**
  Esp. for midlatitudes, hints at importance of subtropics
- **Drought/relative descent anomalies surrounding El Niño**
  Teleconnection vs. Local SST anomalies
- **Quasi-equilibrium Tropical Circulation Model**
  QTCM: an intermediate complexity atmospheric model
  (quasi-equilibrium convective closures used in derivation)
- **Traditional picture: descent by radiative cooling due to temperature anomalies**
  Experiments ⇒ not true in main regions of dry anomalies
  Moist Static Energy Budget Analysis ⇒ Other Mechanisms

What was simple about the tropics? Dynamics underlying recent success in interannual climate prediction

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- **The placid and forgiving tropical ocean**
- **Intermediate and hybrid coupled models: How did we get away with those atmospheric models?**
- **The gross moist stability; stability at large-scales for moist convective motions**
- **But … the harder problems remain**

Quasi-equilibrium Tropical circulation model:

- Primitive equations projected onto vertical basis functions from convective quasi-equilibrium analytical solutions
- for Betts-Miller (1986) convective scheme, accurate vertical structure in deep convective regions for low vertical resolution
- baroclinic instability crudely resolved
- less than 5min/yr on a Sun 2 at 5.6x3.75 degree resolution
- GCM-like parameters but easier to analyze

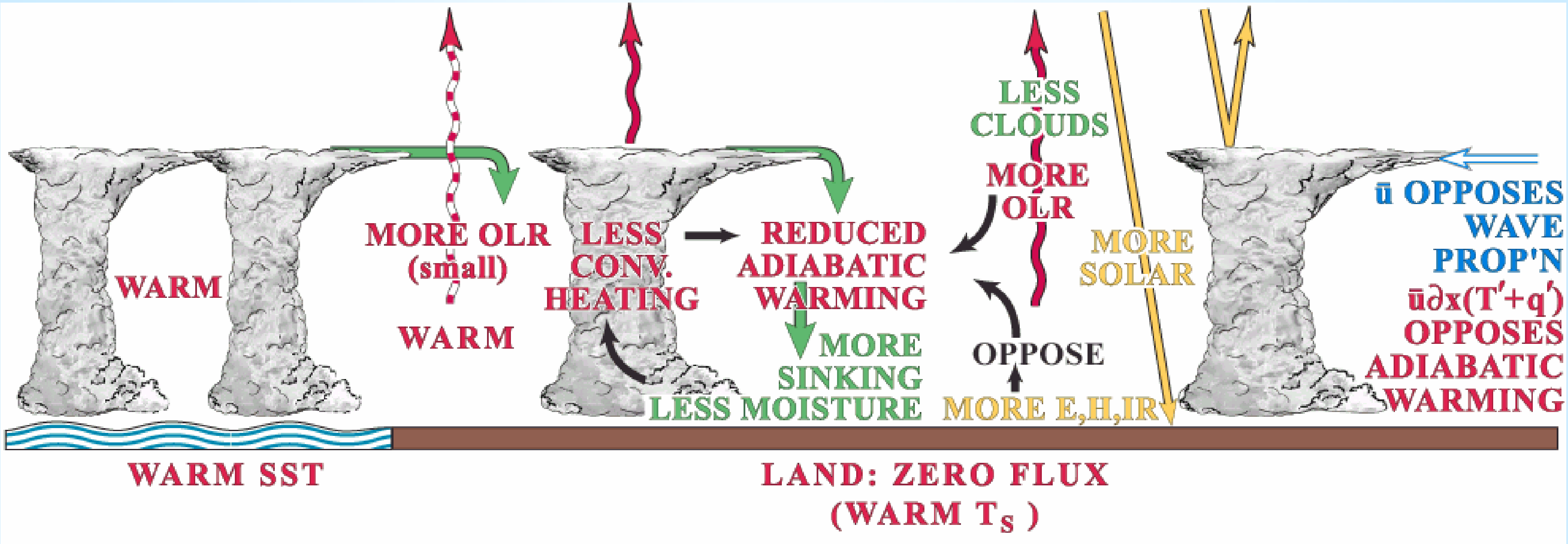
Radiation/cloud parameterization:

- Longwave and shortwave schemes simplified from GCM schemes (Harshvardhan et al. 1987, Fu and Liou 1993)
- deep convective cloud, CsCc fraction param. on precip

Simple land model:

- 1 soil moisture layer; evapotranspiration with stomatal/root resistance dep. on surface type (e.g., forest, desert, grassland)
- low heat capacity; Darnell et al 1992 albedo

Some processes in tropical teleconnections

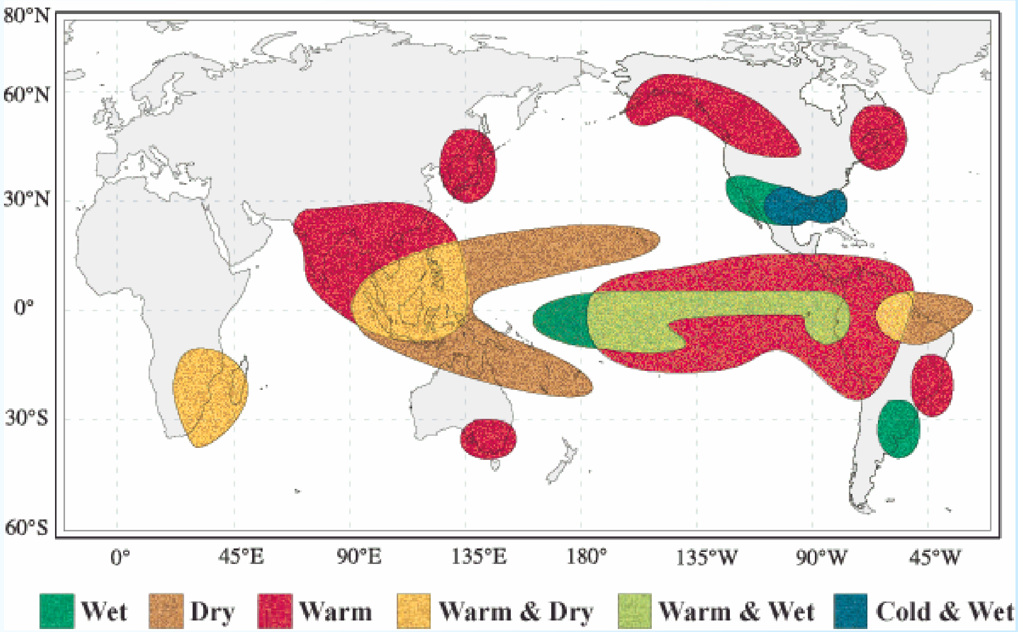


- Convection & I.R. Cloud-Rad. Feedbacks
  - Reduce effective static stability
  - Reduce length scale over which descent occurs
  - Tendency to increase descent anomalies

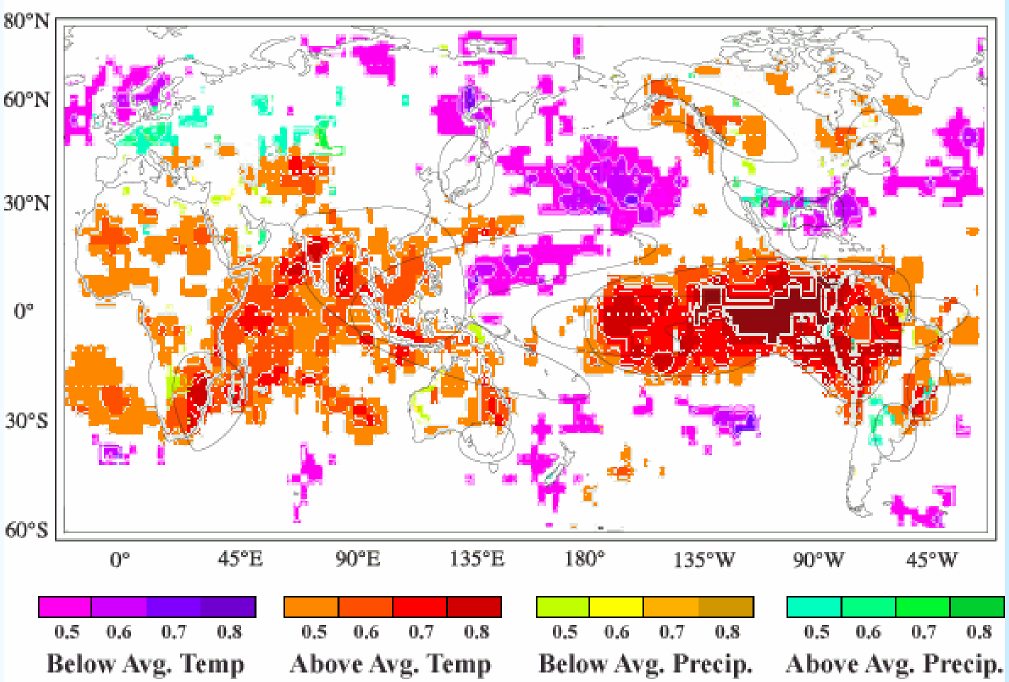
- Land-Surface Feedback Returns Flux Anomalies to Atm.
- Combined with Shortwave Cloud-Radiation Feedbacks
  - Increase effective static stability
  - Increase length scale over which descent occurs
  - Tendency to reduce descent anomalies

Warm episode relationships Dec.-Feb.

Schematic of precipitation and temperature regions during DJF El Niño

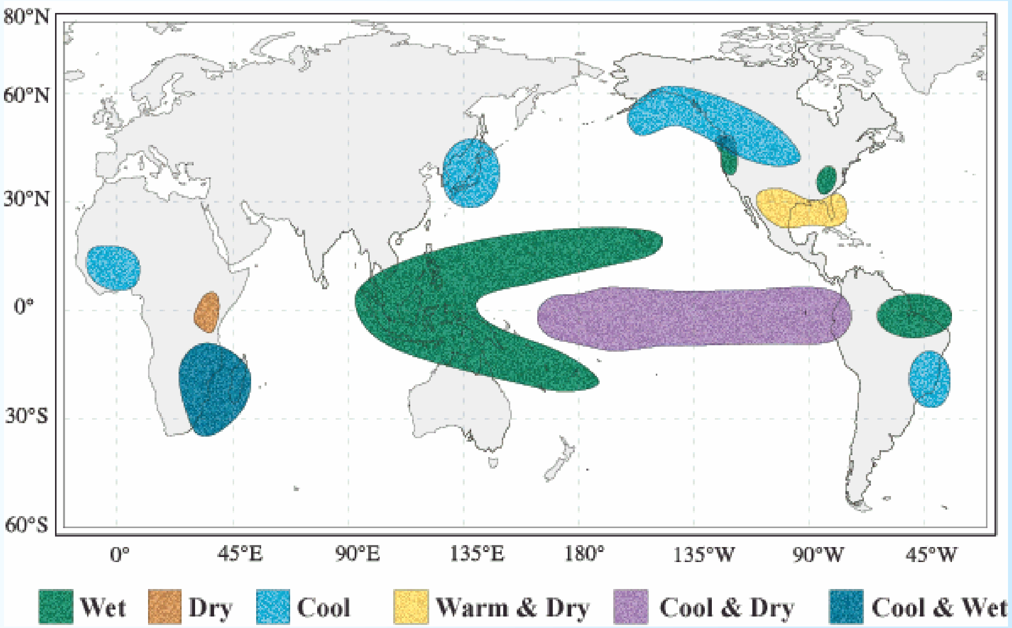


Composite of "Above & Below - Normal" precipitation and temperature probabilities for DJF associated with El Niño (max. 10 NINO3 DJF 1950-1994)

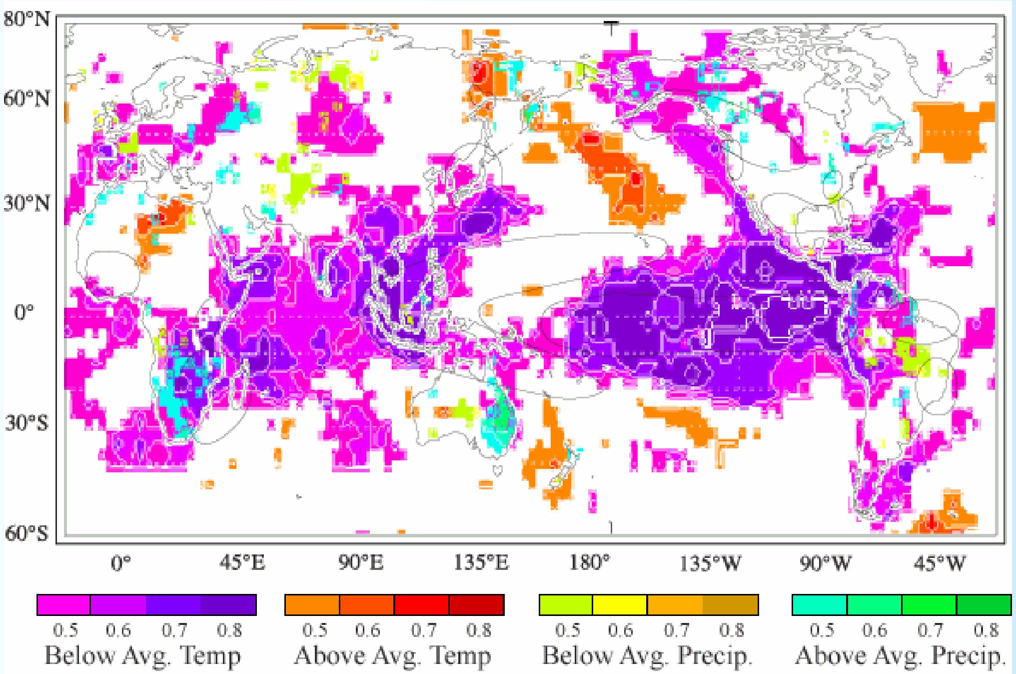


Cold episode relationships DJF

Schematic of precipitation and temperature regions during DJF La Niña



Composite of "Above & Below - Normal" precipitation and temperature probabilities for DJF associated with La Niña (min. 10 NINO3 DJF 1950-1994)

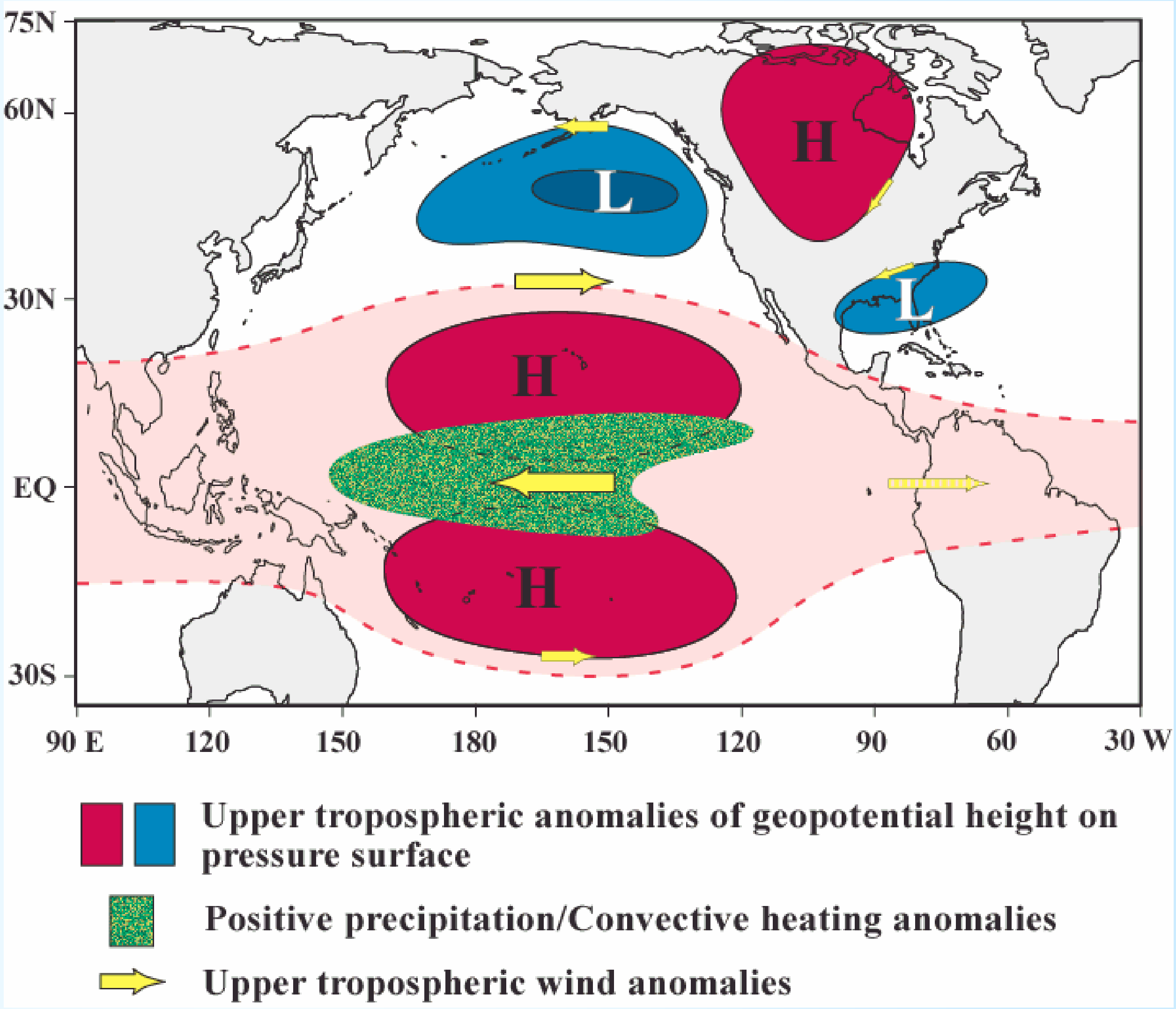


Pacific - North American sector Response to El Niño

La Niña: opposite sign to a first approximation
(but weaker, esp. over N. America)

Mid-latitude response:
barotropic, same sign through depth of troposphere

Tropical response:
baroclinic, opposite sign at low levels



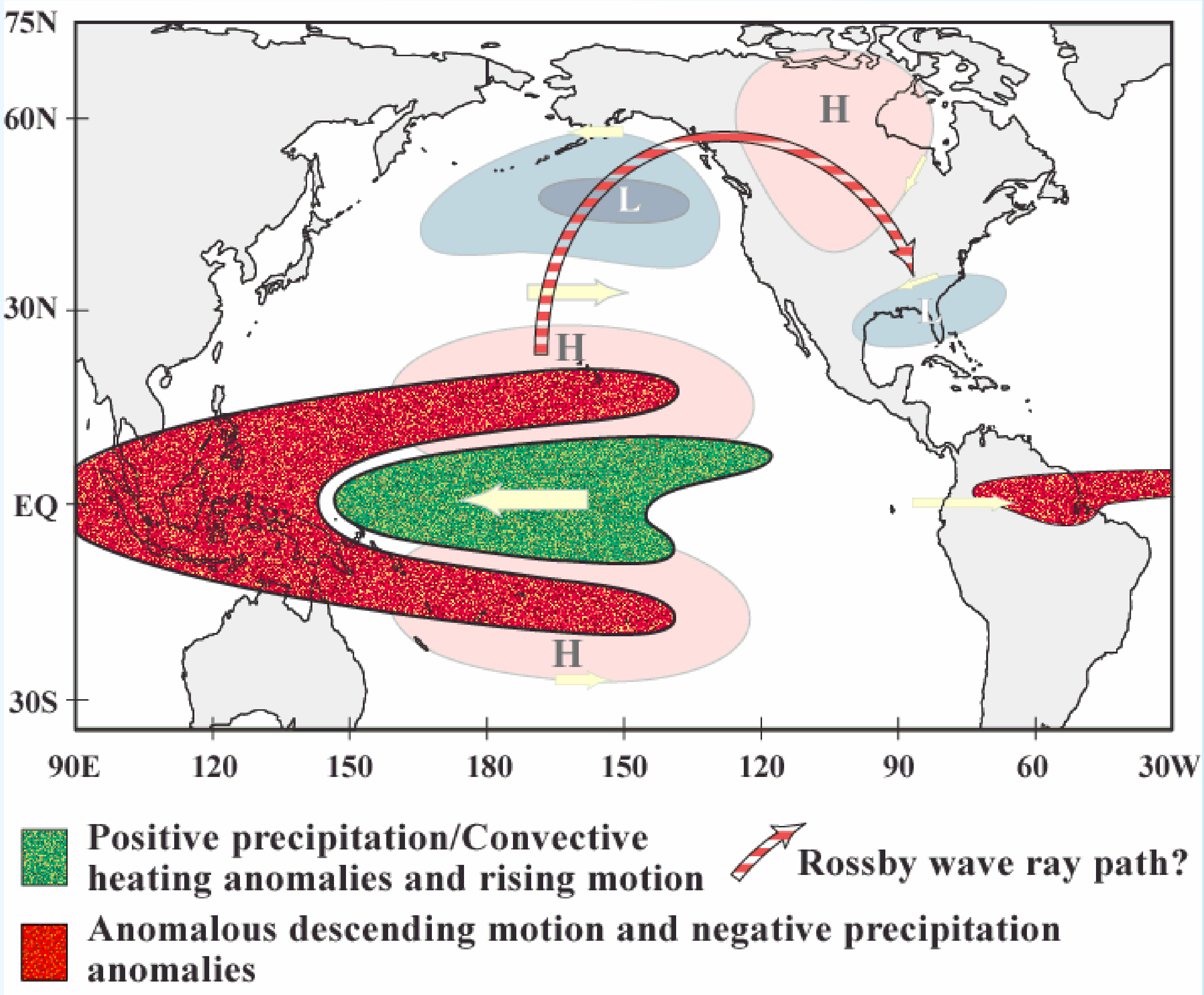
Refs: J.M. Wallace et al 1998,
K. Trenberth et al 1998

Dynamics of Pacific – North American sector
Response to El Niño

Baroclinic wave dynamics ➡ anomalous descent, spreads warming of troposphere

Upper level divergence ➡ barotropic Rossby wave source (subtropical)

Stationary Rossby wave dynamics (tends to set wavelength, turning latitude) but **modified …**

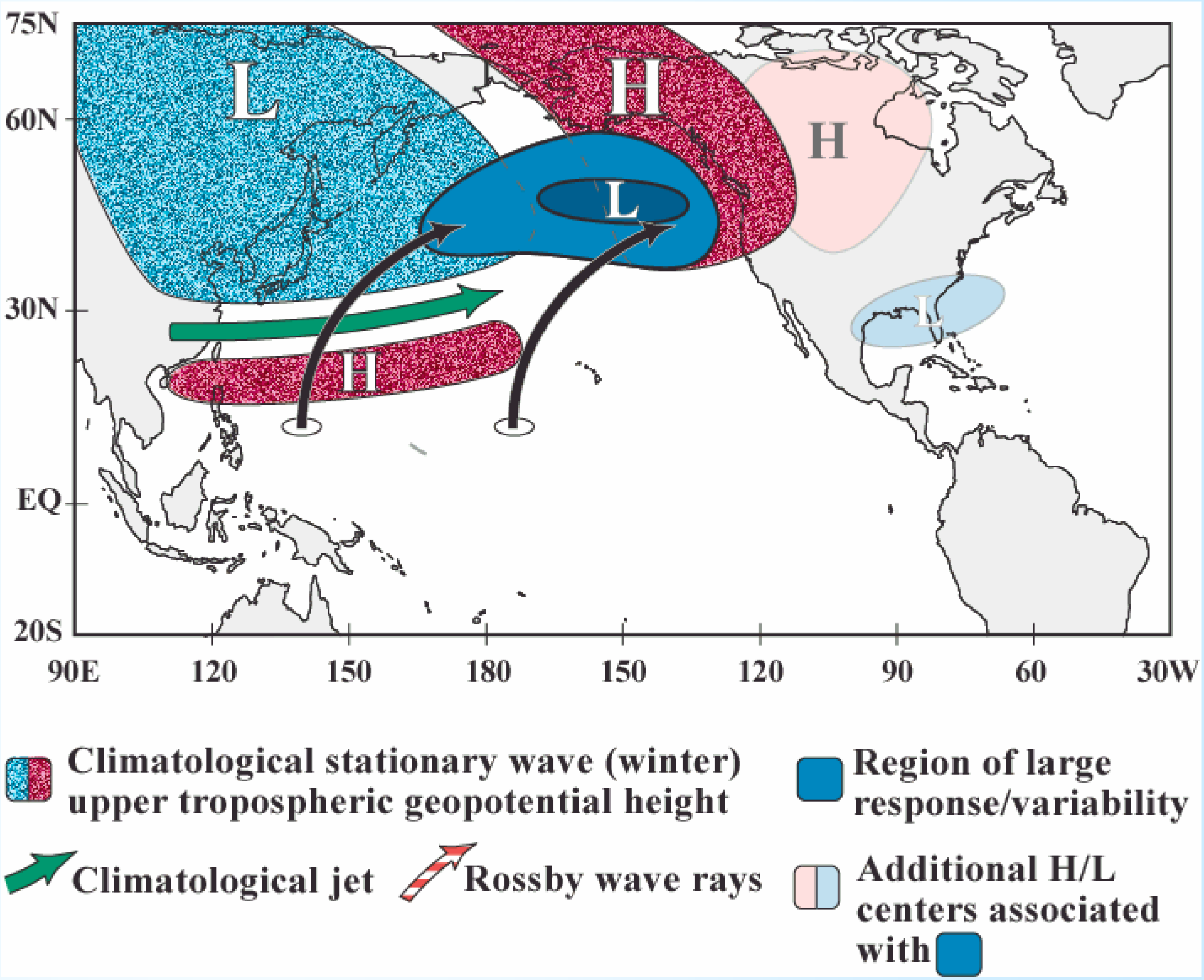


Refs: B. Hoskins & co., D. Karoly, I. Held & co., M. Salby, R. Garcia 1980s

Dynamics of mid-latitude response

Interaction with climatological stationary waves

- Rossby wave trains from different source locations produce large response in favored location (plus additional H/L centers in a favored pattern)
- Similar patterns in atmospheric low-frequency variability

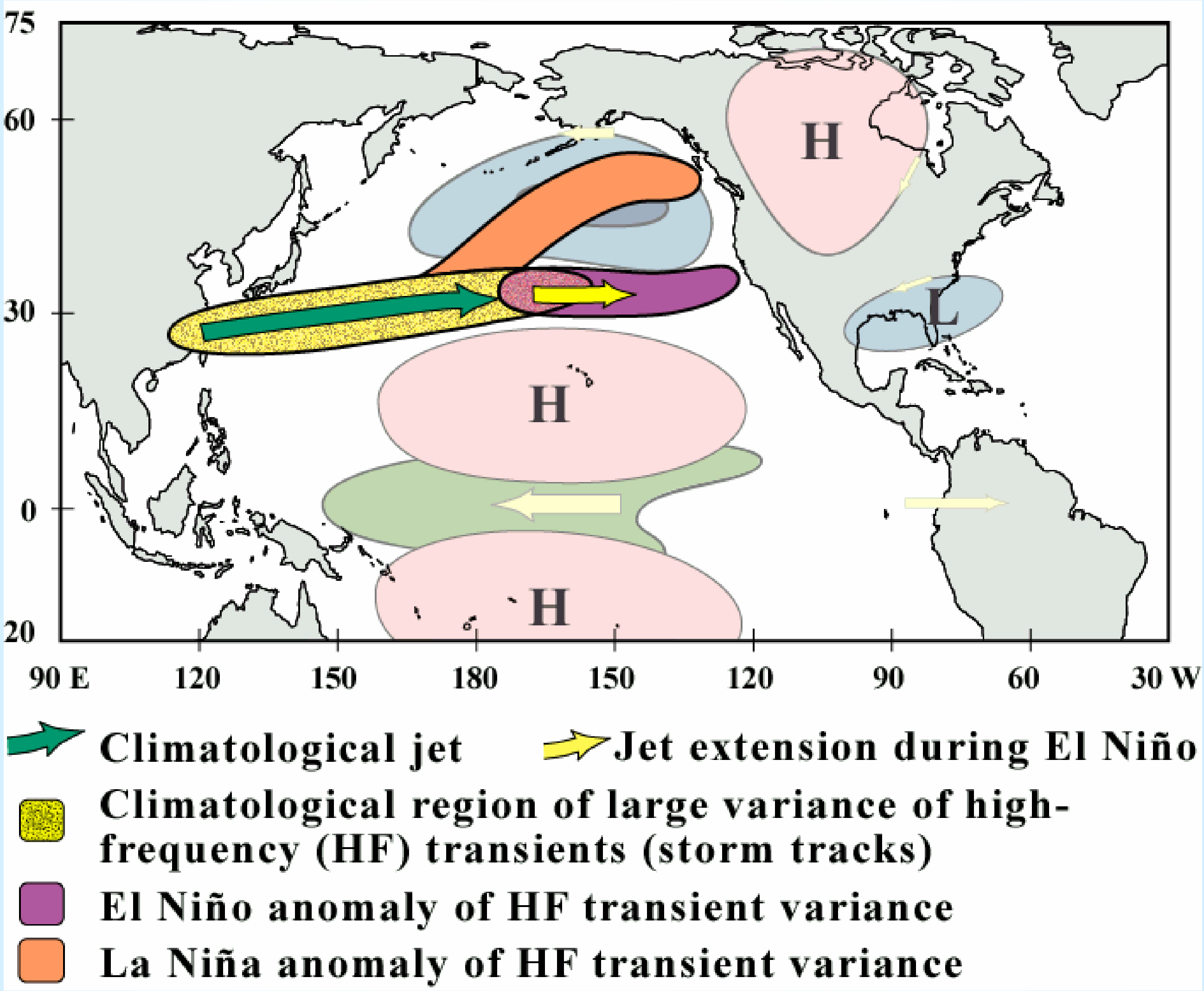


Impact on low-frequency variability (7-60 days)

- Decreases in region of lg. response during El Nino, increases during La Nina

Refs: A.J. Simmons, J.M. Wallace, G. Branstator 1983, Branstator 1990, J. Geisler et al 1985, T. Palmer & Mansfield 1986, A. Navarra 1990, M. Kimoto & M. Ghil 1993, W.Y. Chen & H. Van den dool 1997, A. Kumar & M.P. Hoerling 1998

Response to ENSO: storm tracks and subtropical jet



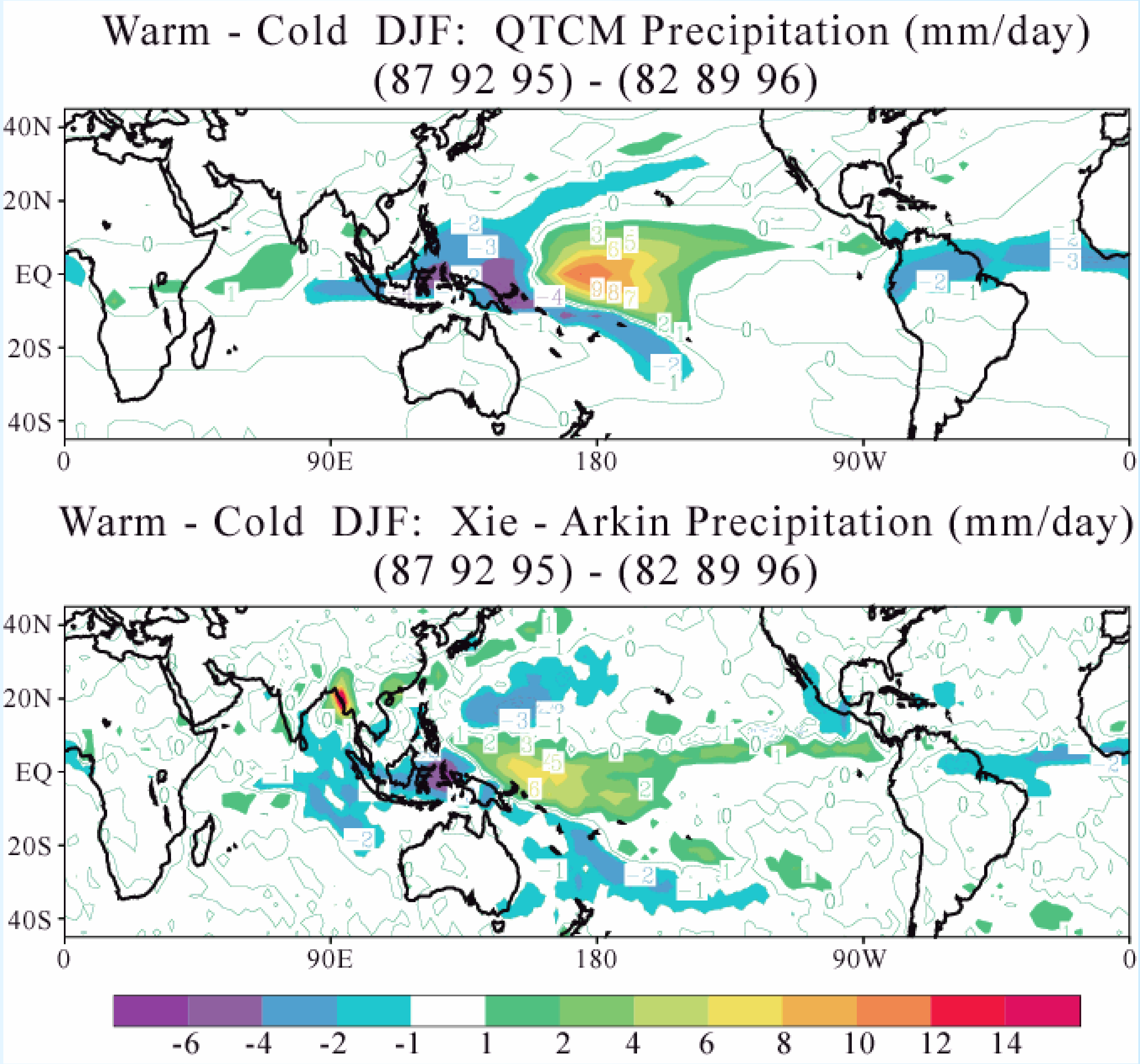
ENSO Composite

Intermediate complexity atmospheric model

QTCM: Quasi-equilibrium tropical circulation model

Response to observed SST

Observed



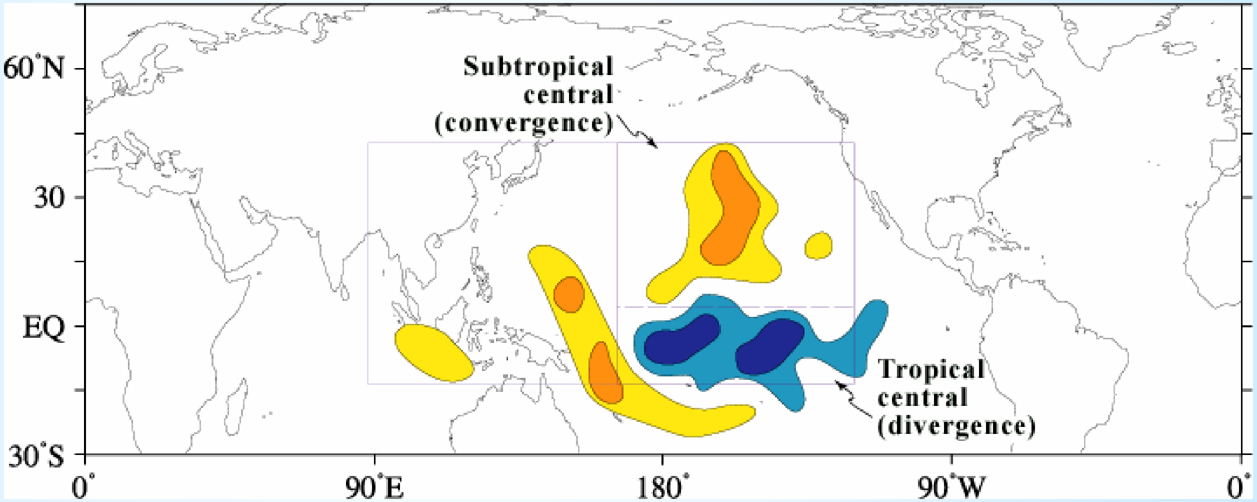
Warm - Cold DJF: QTCM Precipitation (mm/day)
(87 92 95) - (82 89 96)

Warm - Cold DJF: Xie - Arkin Precipitation (mm/day)
(87 92 95) - (82 89 96)

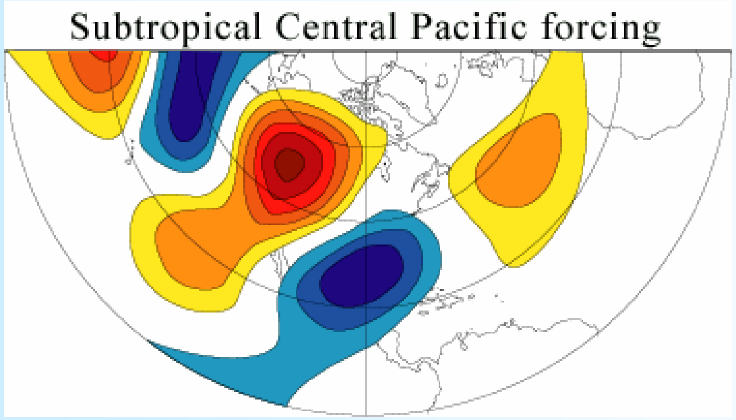
Subtropical vs. Tropical Forcing (by divergence and transients)

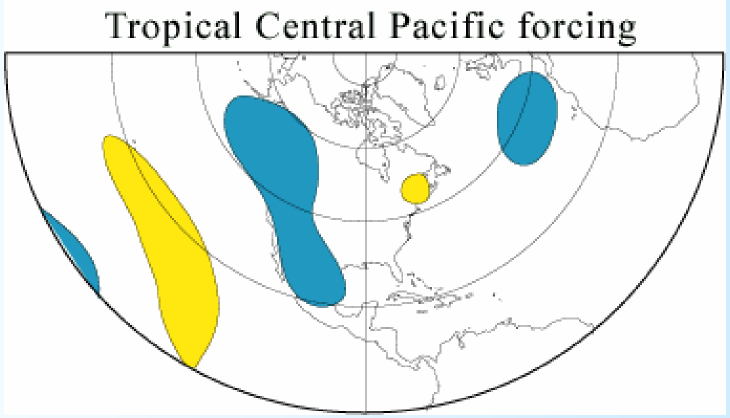
$$v\cdot\nabla\zeta + \beta v' + \ldots = -f\Delta' + \text{transients}' \ \ldots$$

Schematic of upper level divergence in GCM response to El Niño SST



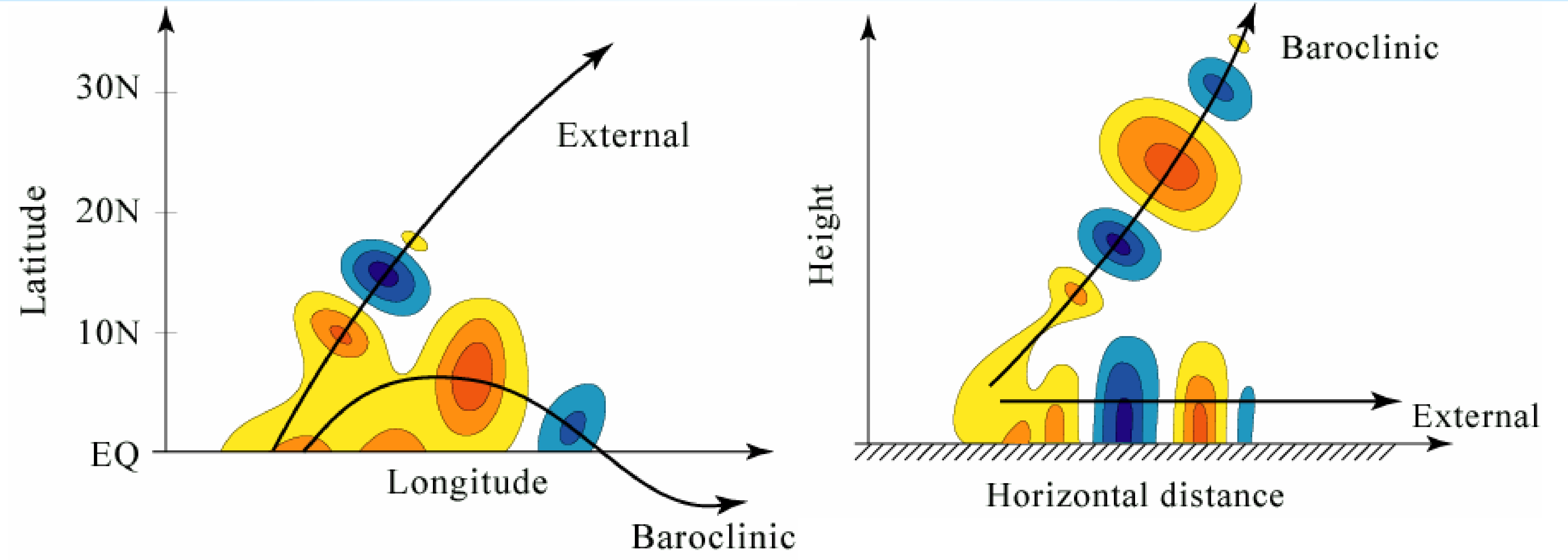
Barotropic model stream function response to :


Subtropical Central Pacific forcing


Tropical Central Pacific forcing

Held and Kang (1987) diagnosis of GFDL R15 GCM [See also Sardeshmukh and Hoskins (1988)]

External mode (equivalent barotropic) versus baroclinic mode dispersion of tropically excited disturbances for "dry" dynamics



After Salby and Garcia (1987).
See also, e.g., Karoly and Hoskins (1982), Simmons (1982), Held et al. (1985), Webster and Chang (1988), Chang and Webster (1995), Ting (1996)

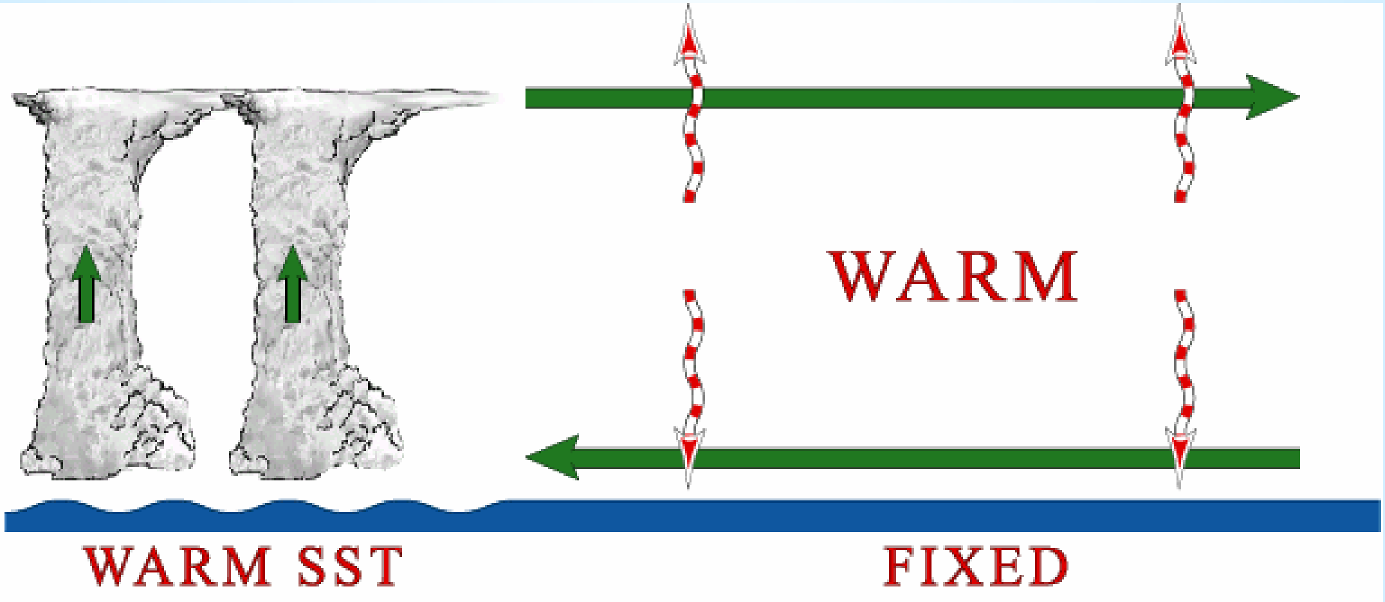
Relative descent in neighboring regions due to warm SST (previous theory)

Previous theory

- Increased convective heating over warm SST
- Warming spread by wave dynamics (e.g., Gill, 1980)

Greater Longwave cooling µ T'

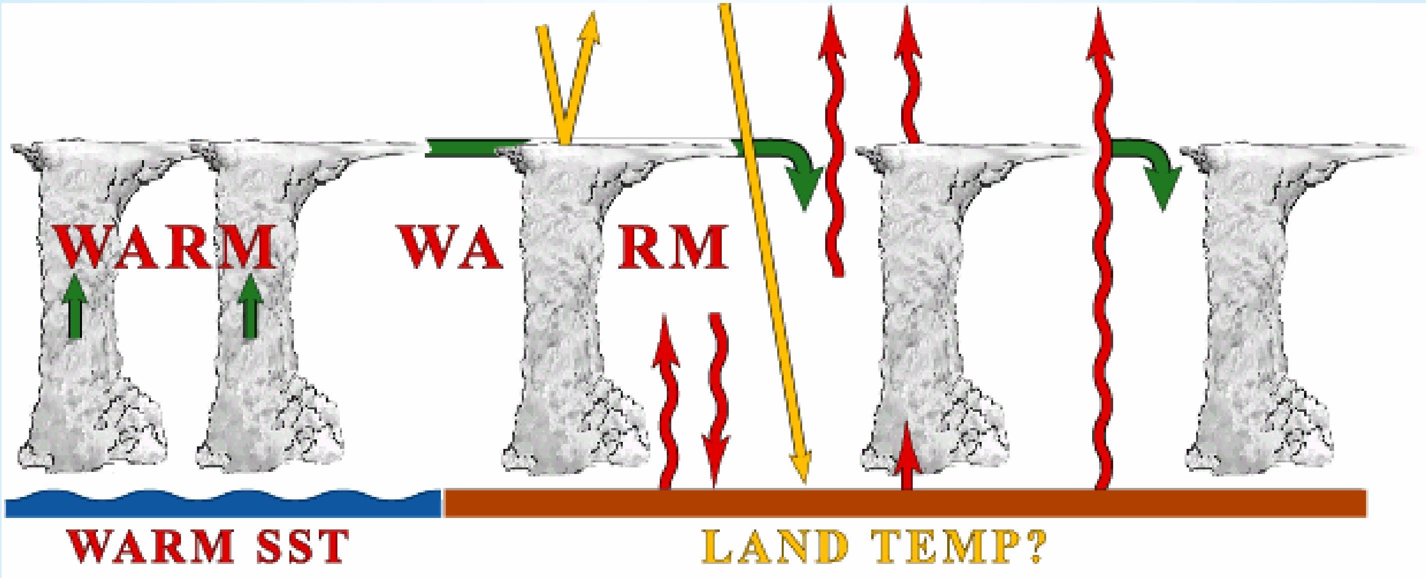
Balanced by descent against dry static stability

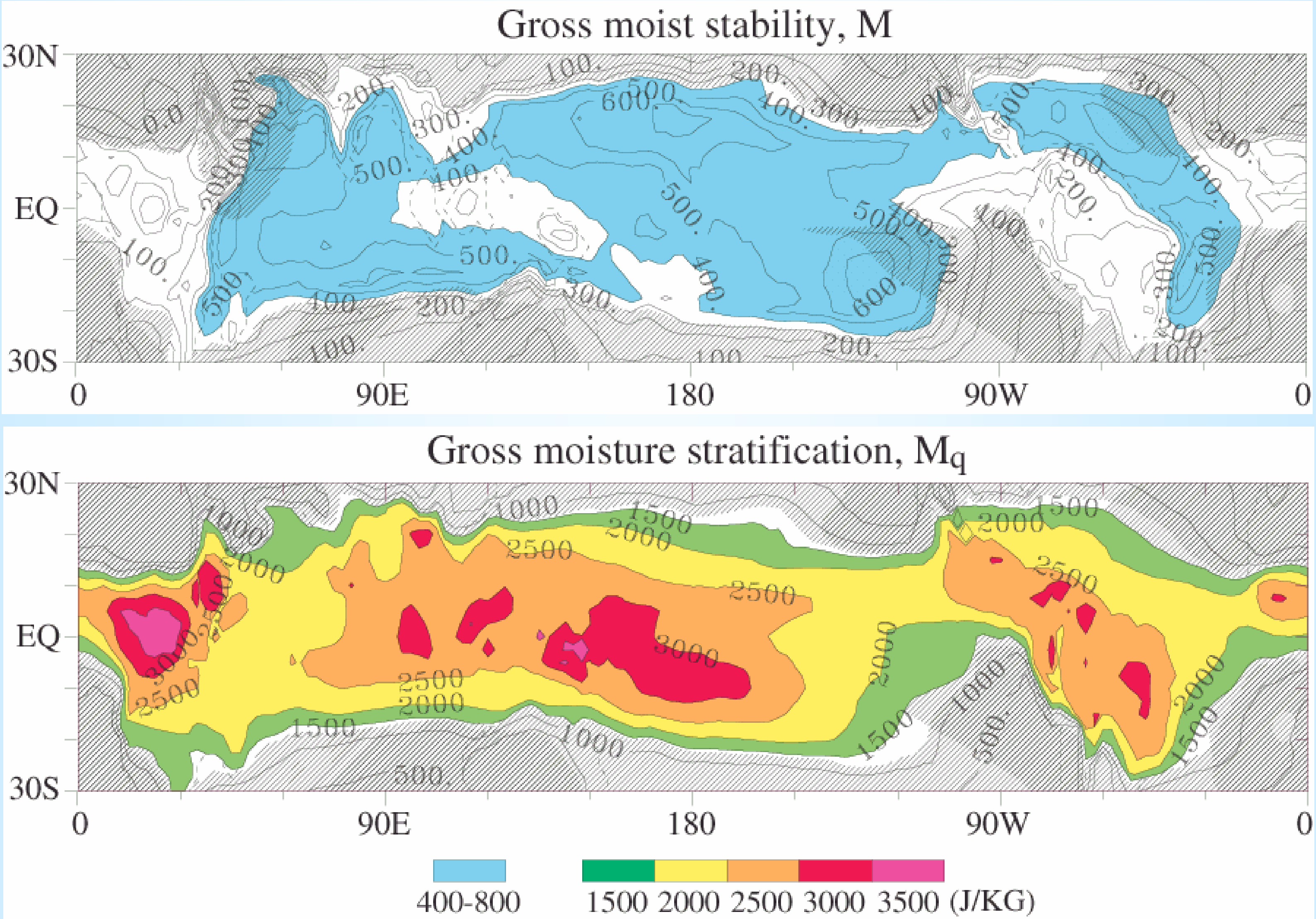


Relative descent in neighboring regions due to warm SST

Problems

- Important descent anomalies are in convection zones and/or over land.
  - ➢ Convective feedbacks
  - ➢ Cloud-Radiative feedbacks
  - ➢ Land temperature and surface-flux feedbacks




Gross moist stability, M

Gross moisture stratification, M_q

$$M = M_s - M_q,\ M \approx {}^{1}\!/_{5}\, M_s$$

$$M_s = \text{Gross dry stability} \propto \text{dry static stability}$$

ECMWF data, Annual average
Yu et al., 1998

Temperature *T* and Moisture *q* equations

dry static energy $s = T + \phi$

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

convective heating

vertical velocity

Fluxes: longwave radiation(R), solar(S)
sensible(SH), latent heat(L)

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

moisture source/sink

Energy constraint in vertical integral ⟨ ⟩

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

⟨Moist static energy equation⟩

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

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

Net energy flux into column

Moist static energy
$h = s + q$

Temperature T and Moisture q equations

Dry static energy: $s = T + \theta$

Convective heating

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

Vertical velocity

Fluxes: Longwave radiation (R), solar (S), sensible (SH), latent heat (L)

$$(\partial_t + v\cdot\nabla)q + \omega\partial_p q - \partial F_L = Q_q$$

Moisture source/sink

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

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

$\langle$Moist static energy equations$\rangle$

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

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

Moist static energy: $h = s + q$

Net energy flux into column

Precip anomaly (convective heating) by moisture budget:

$$\boxed{P' = (-M_q \nabla\cdot v)' + \langle v\cdot\nabla q\rangle' + E'}$$

ENSO WARM	**128 (100%)**	**=**	**104 (81%)**	**+**	**4 (3%)**	**+**	**24 (19%)**
NORTH DRY	**-35 (100%)**	**=**	**-24 (69%)**	**-**	**15 (43%)**	**+**	**1.8 (-5%)**
SOUTH DRY	**-34 (100%)**	**=**	**-26 (76%)**	**-**	**1.3 (4%)**	**-**	**6 (18%)**

Moist Static Energy Budget

$$\boxed{(M\nabla\cdot v)' + \langle v\cdot\nabla T\rangle' + \langle v\cdot\nabla q\rangle' = F_{rad}' + E' + H'}$$

ENSO WARM	**53**	**-**	**3**	**-**	**4**	**=**	**13**	**+**	**24**	**+**	**12**
NORTH DRY	**-24**	**+**	**4***	**+**	**15***	**=**	**-5**	**+**	**2**	**-**	**3**
SOUTH DRY	**-15**	**-**	**0.0**	**-**	**1**	**=**	**-5**	**-**	**6****	**-**	**1**

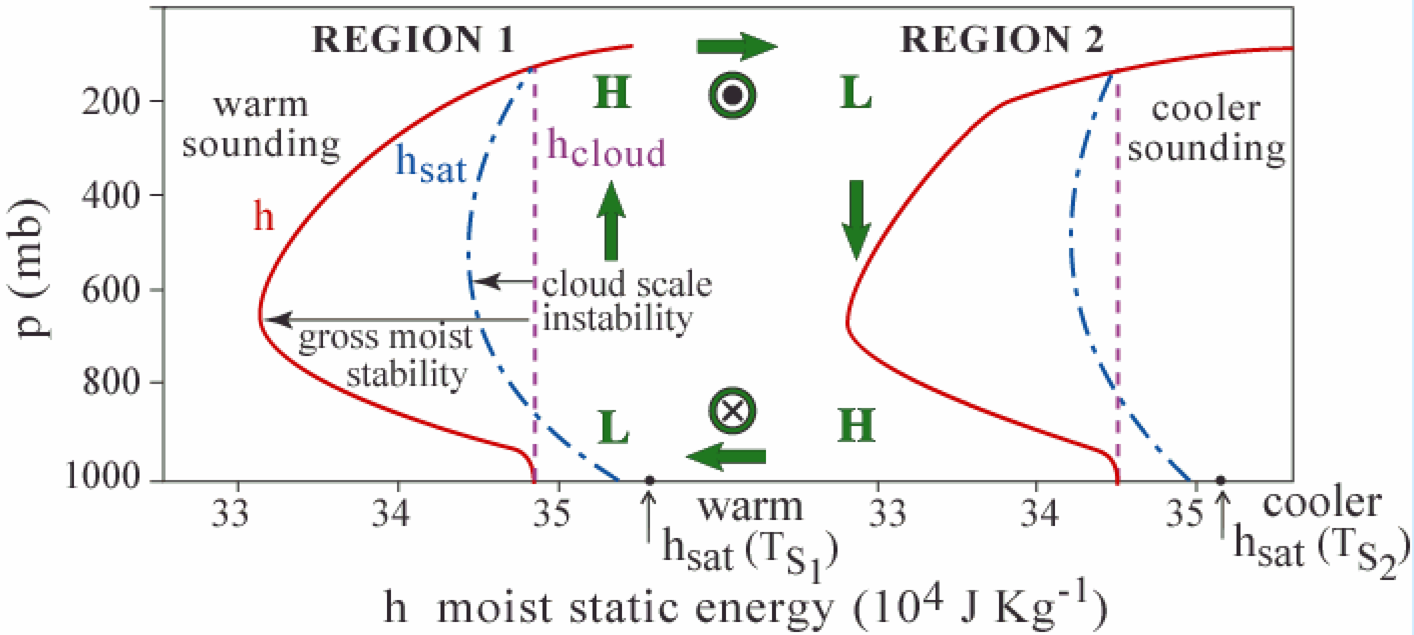
( )* mostly due to v'

( )** mosstly due to $(q_{sat} - q_s)'$

A' = POSPAC – CONTROL (INCLUDES AVERAGE OF NONLINEAR TRANSIENTS)

Temperature T and Moisture q equations 2

Q_c constrains temperature through deep column
→ baroclinic pressure gradients

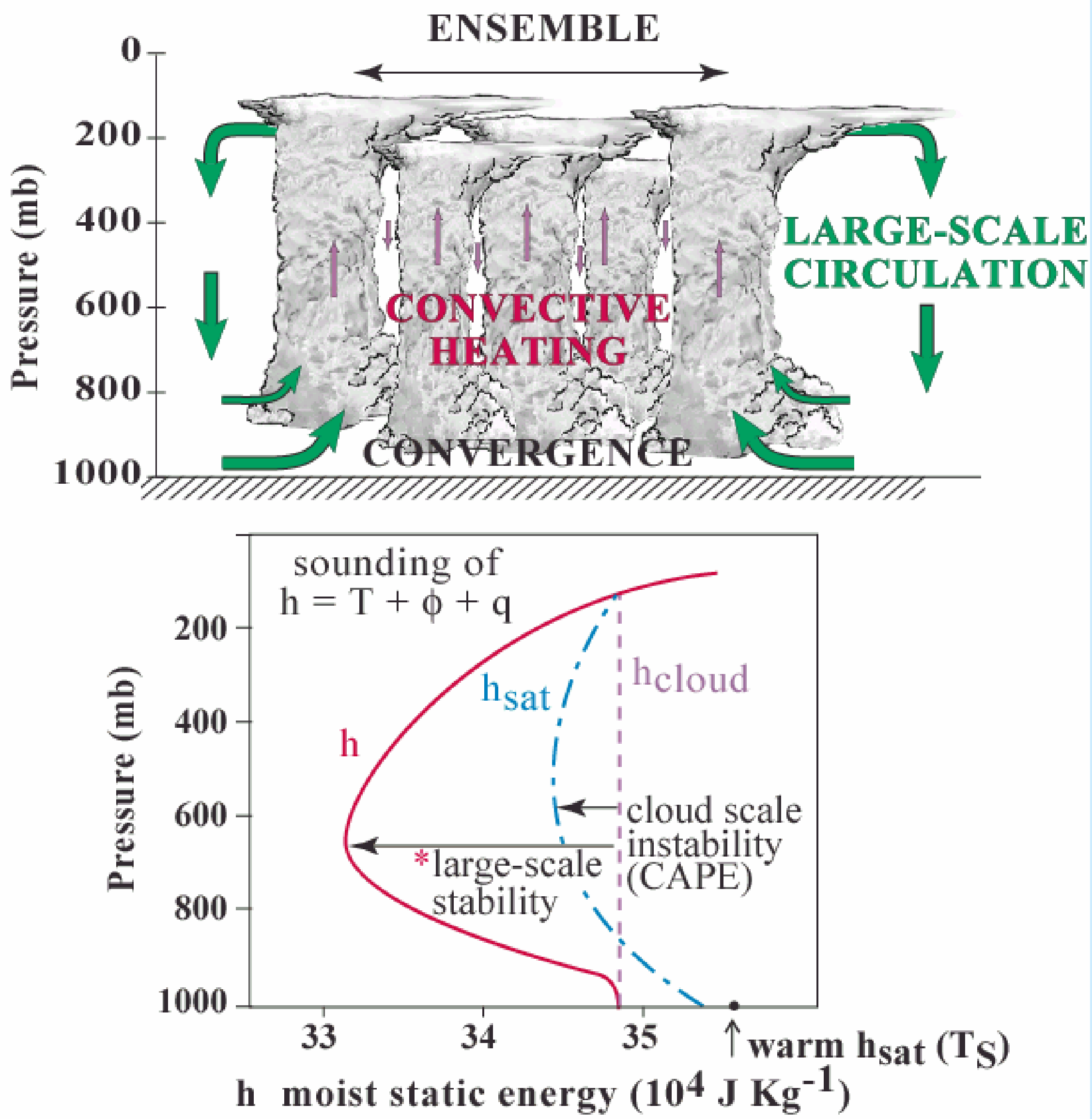


Moist convection interacting with large-scale dynamics

- **Convective Quasi-Equilibrium:**
  Fast convective motions reduce Convective Available Potential Energy (CAPE)
  - ➢ Constrains temperature through deep column
  - ➢ Baroclinic pressure gradients

- **Gross moist stability at large scales**

Refs: Arakawa & Schubert 1974; Emanuel et al 1994; Neelin & Yu 1994; Brown & Bretherton 1997; Neelin & Zeng 2000

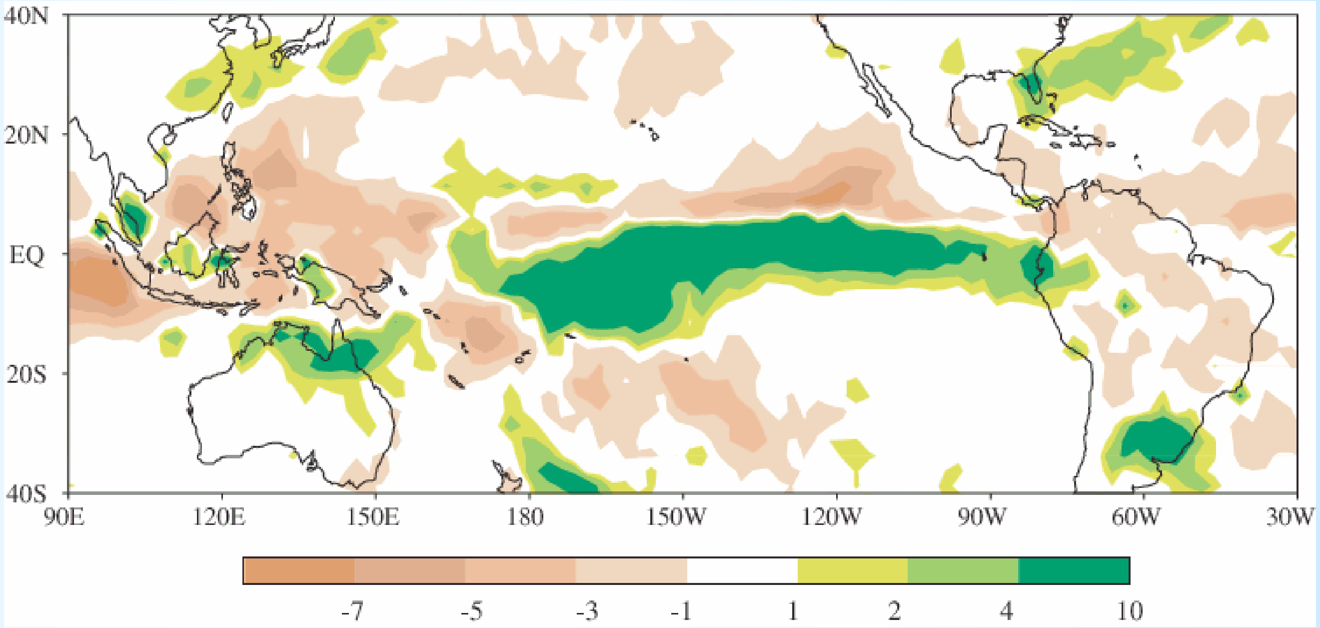


(After Neelin (1997))

Precipitation and SST anomalies December 1997

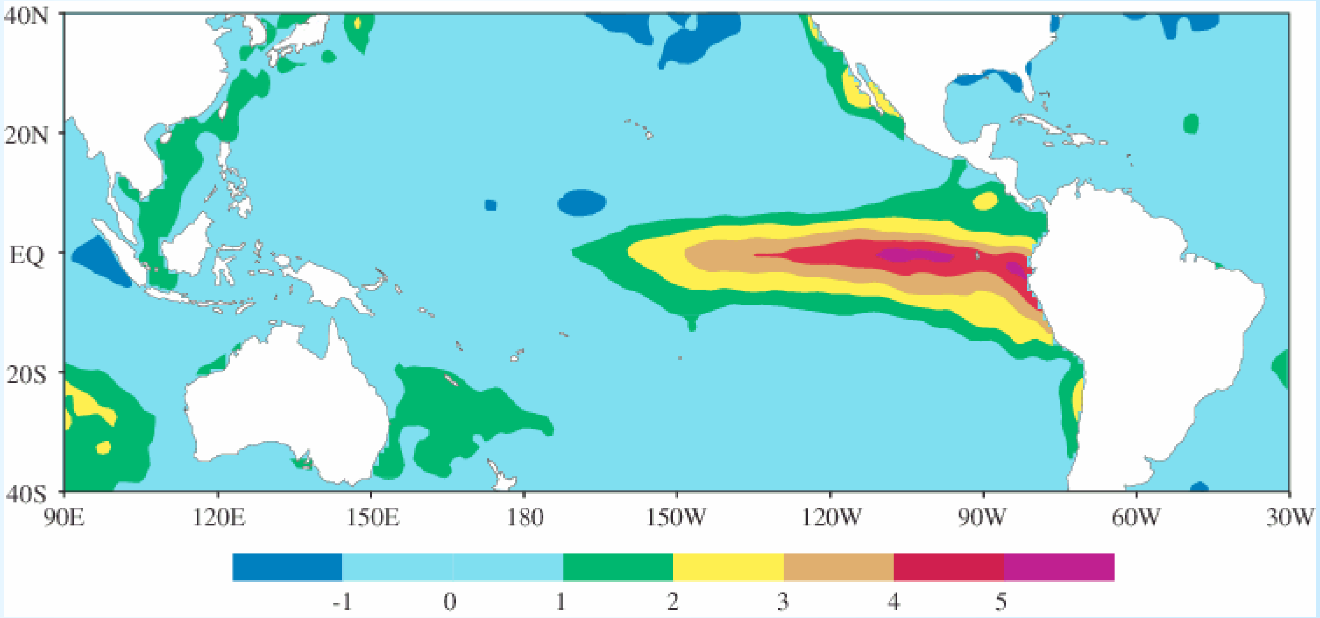
Precipitation Anomaly

(Data courtesy P. Xie and P.A. Arkin, NOAA)



SST Anomaly

(Reynolds' data set)



For thought:

- Moist static energy budget can be useful diagnostic for phenomena with most convection and radiative/surface flux feedbacks
- Operational analysis data sets do not have consistent energy budgets

  (current data assimilation procedures typically do not include convervation constraints)

Simple atmospheric models used in ENSO studies

- **Various parameterizations of convective heating anomalies on SST anomalies gave acceptable results for ENSO**
  - » **Including linear, constant coeff.**
  - » **Non of simple or intermediate atmospheric models had parcel stability-based convective schemes**
    - e.g., Zebiak and Cane (1987), Lindzen and Nigam (1987), Neelin and Held (1988), Kleeman (1991), …

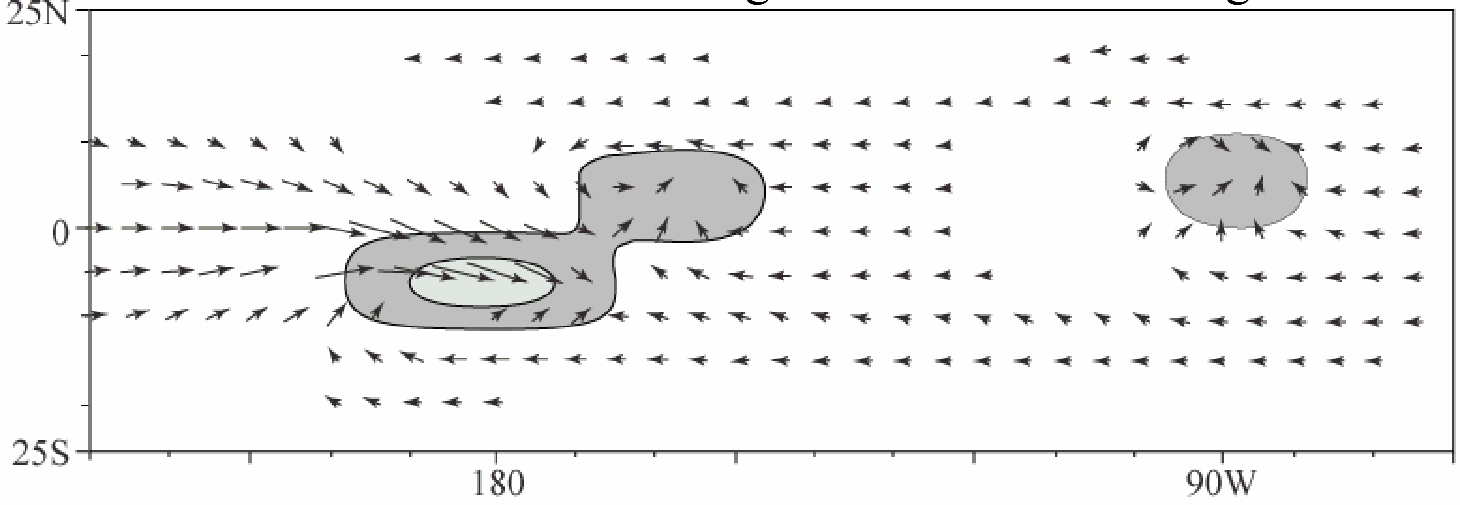
- **Also linear, emperical models for wind stress anomaly from SST anomaly**
    - e.g., Latif and Flugel (1991)

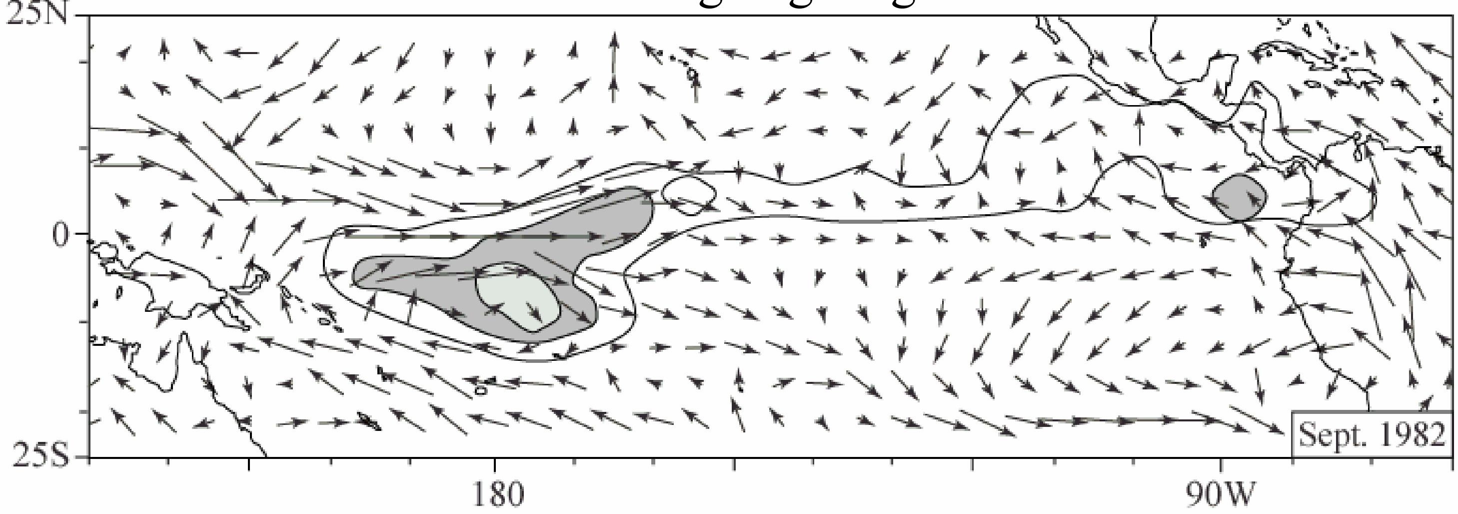
- **Simple atmospheric models assume large-scale convective-dynamical response is a stable, steady state response to SST**
  - » **Does moist convective atmosphere behave this way?**
  - » **If so, why?**

- **"Gross moist stability" gives a partial answer**

  but …

Gill (1980) model


Low-level wind anomalies from given convective heating anomalies


ECMWF 850mb wind and outgoing longwave radiation anomlies

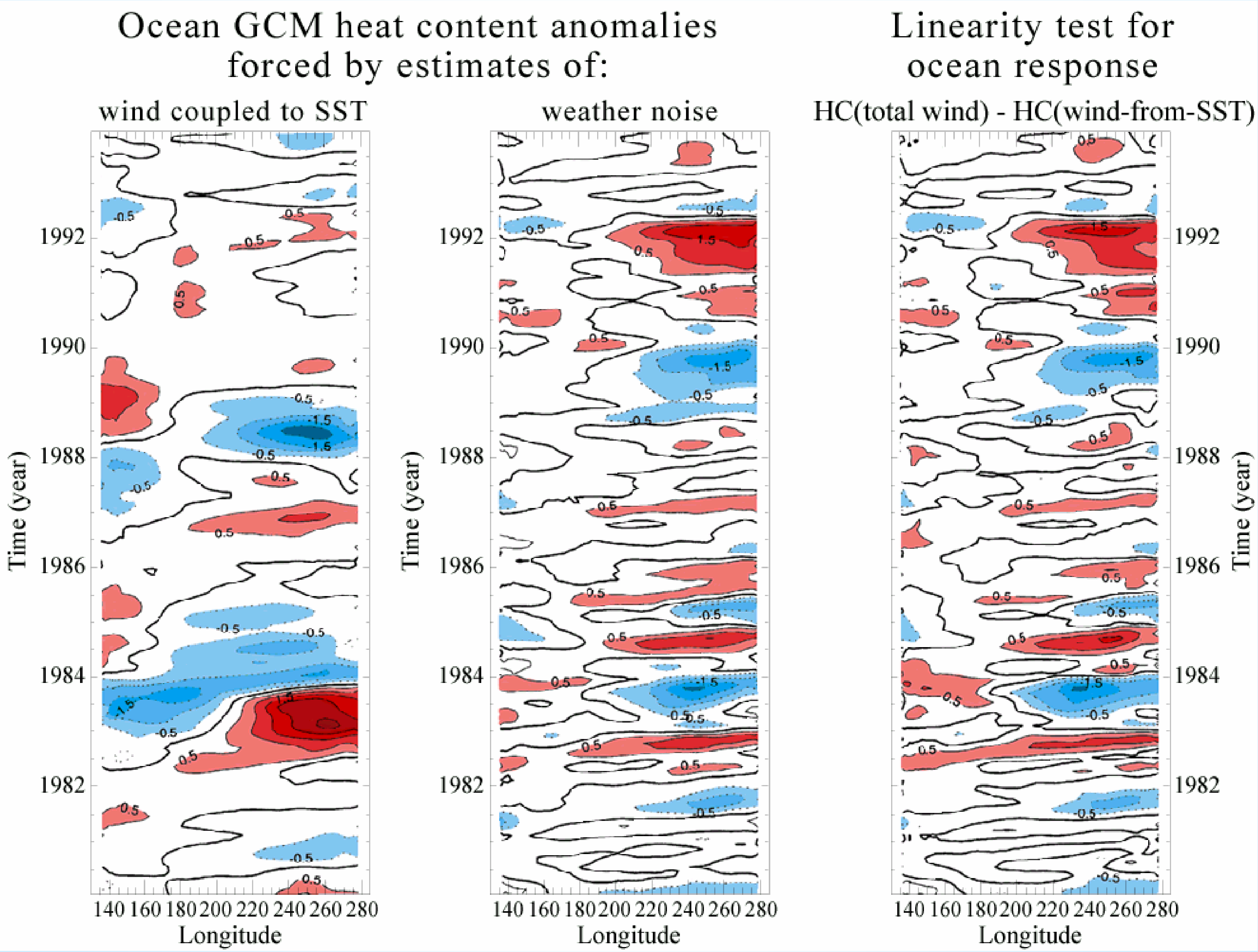
The placid and forgiving equatorial ocean

- Scale separation between turbulent mixing and large-scale dynamics
  - » Variability primarily wind forced
  - » Adiabatic dynamics dominant in ENSO anomaly prediction
  - » Leading balance along equator:
    Upper ocean pressure gradient ~ wind stress
  - ❖ Thermocline depends on intergral in longitude of stress

- To a first approximation, ENSO problem did not require:
  - » accurate heat flux anomalies
  - » wind anomalies at exact longitude on Equator
  - » models with consistent energy budgets (!)
  - » models with meteorologically based convective parameterizations

- But …

Title?

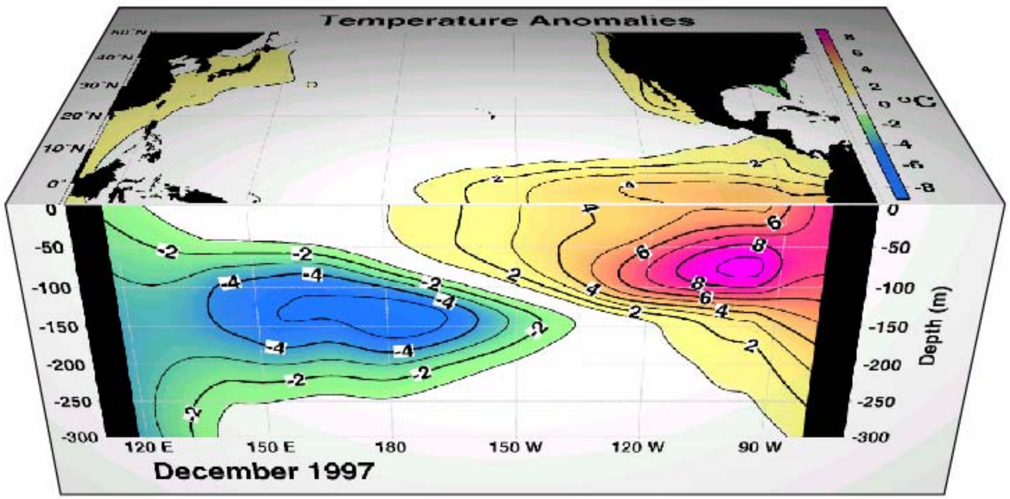


After Syu & Neelin, 2000

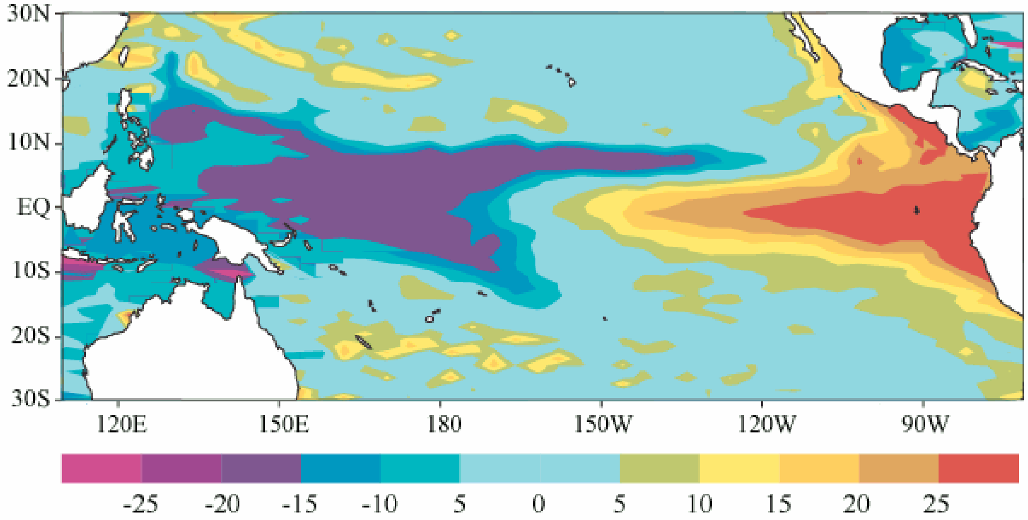
Surface temperature, subsurface temperature and sea level height anomalies during El Nino

- **Thermocline anomaly evolution at large-scales only weakly non linear despite turbulent mixing**
- **Governed by past history of wind stress (uncoupled/coupled)**

e.g., Cane and Sarachik, Philander et al. 1980s, Battisti and Hirst 1989, Jin and Neelin 1993



Courtesy D. Pierce, SIO. TOGA-TAO subsurface data; Reynolds' SST data

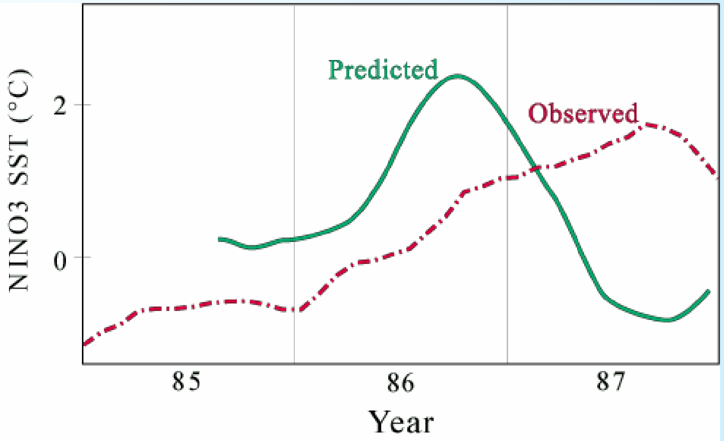


Data from TOPEX/POSEIDON

First published coupled model forecast of El Nino: Cane-Zebiak model with data to Jan. 1986

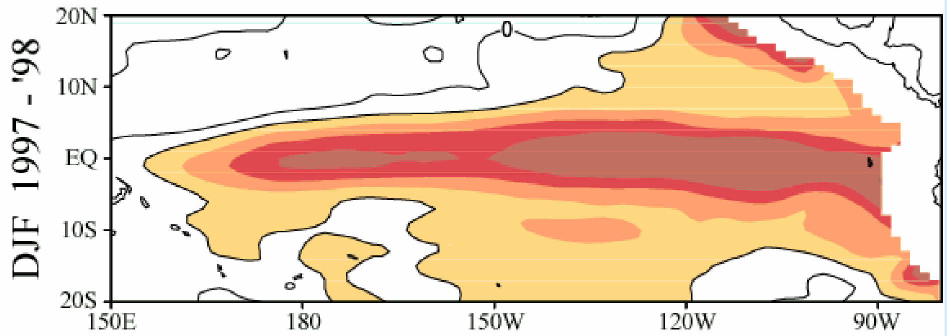
First published coupled model forecast of El Nino: Cane-Zebiak model with data to Jan. 1986

(Cane et al., Nature, June 1986)

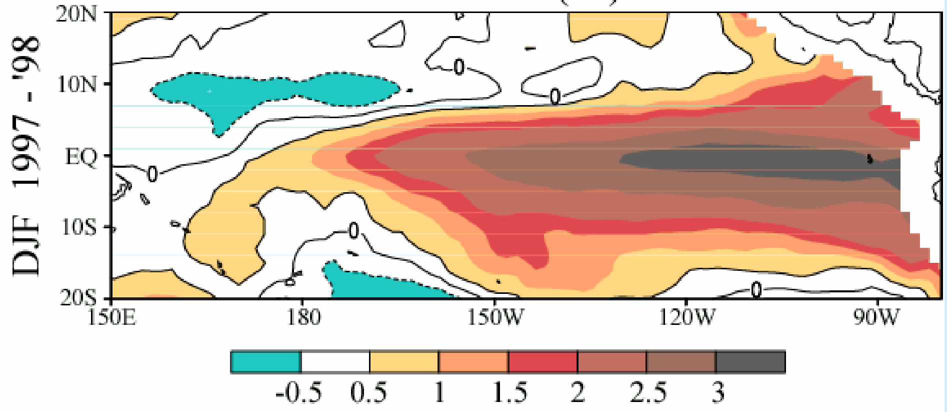


National Centers for Environmental Prediction forecast from March 1997 vs. observed

(After Barnston et al., 1999)



Observed (°C)



The buts …

- To a first approx., ENSO anomaly problem did not require:
  - Accurate heat flux anomalies
  - Wind anomalies at exact longitude on Equator
  - Models with consistent energy budgets
  - Models with meteorologically based convective parameterizations
- But for modeling climatology, atmospheric effects on surface heat fluxes crucial. Feedbacks between wind error and SST error akin to those in El Nino.
  - Hence long road in coupled general circulation model (GCM) climate drift; see inter comarisons: Neelin et al 1992; Mechoso et al 1995; Meehl et al 2000 (CMIP); Latif et al 2001 (ENSIP) STOIC (2001);

continued …

Scribbled notes

- to do retrospective quickly have to take particular slide
- sometimes useful to go back and lock at a prblem where field had some success and ask why? models clever? or something simple about system?
- in this case sys. to int cl. pred.
- in this – intermediate simple and hcm played influental
- fair to say 1st sim. forecast @@ from icm
- Something simple enough about sys@ to access qualatatively in less complex models
- Does rais question, particularly when look critically at atm.
- … self-critically or icmer looking at what does as community
- … “buts”

The buts … (cont.)

- **Gross moist stability** helps explain why moist convective atmosphere at large-scales behaves as if stably stratified
- **But** current modeling and observational evidence does not explain what sets its value;
- **But** stable stratification does not exclude weather variability and weather noise appears a crucial limit to ENSO prediction
- **But** cloud-radiative feedbacks and surface flux feedbacks appear important to ENSO tropical teleconnections
- **But** midlatitude teleconnections from ENSO affected by interactions with stationary waves, storm tracks, …

➢ More meteorology in climate prediction now than earlier

“Weather prediction at the millenium: Juvenile or geriatric?”

Meteorology: Geriatric
Oceanography: Middle-aged
Climate dynamics: Callow
Meteorology as applied to Climate dynamics: Juvenile

Proposal:

That on the occasion of its 150th anniversary, the Royal Meteorological Society adopt a new name:

The Royal Society for Meteorology, Oceanography, and Climate dynamics (RSMOC)