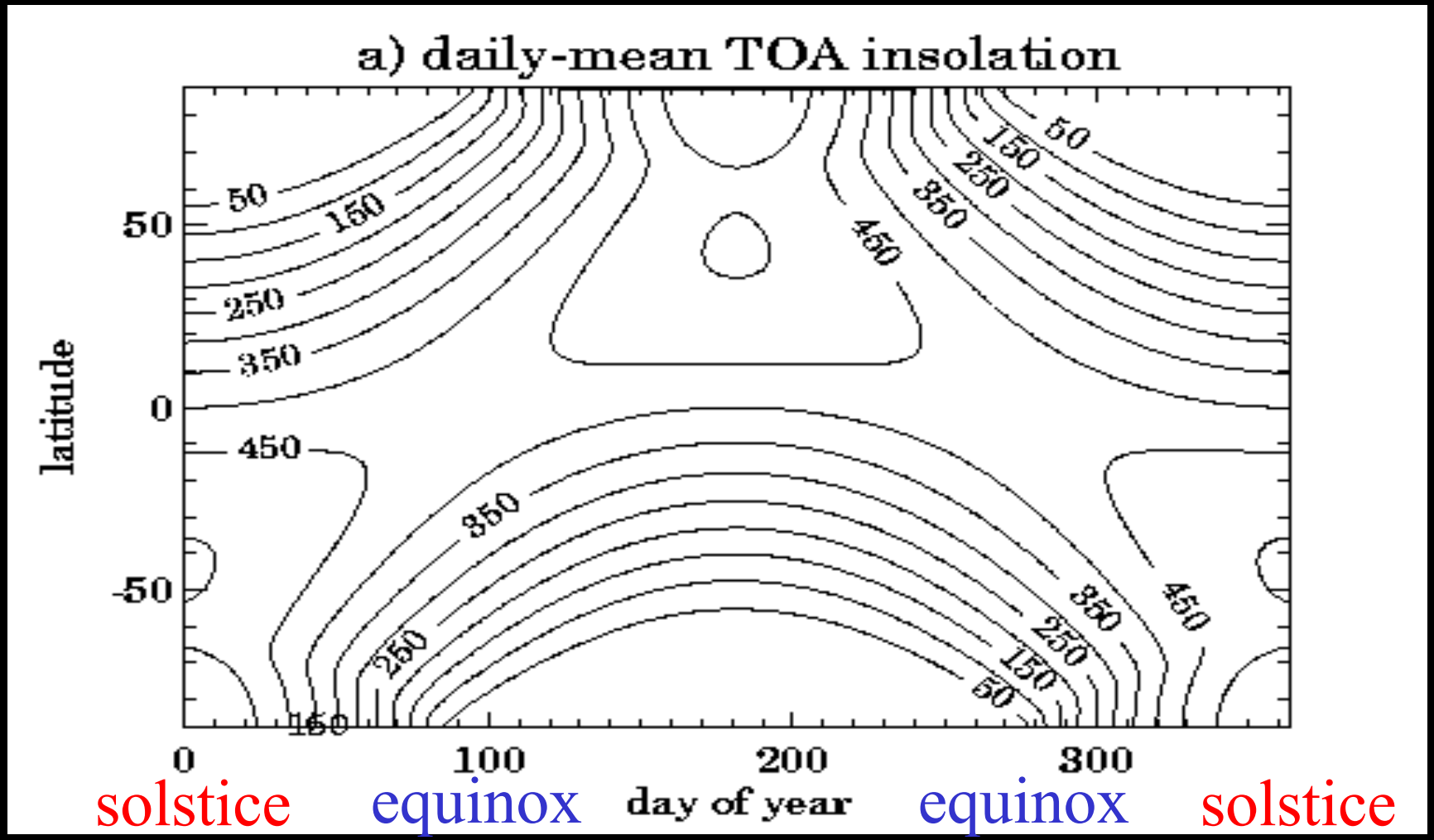
Strides, steps and stumbles in the annual march of the seasons

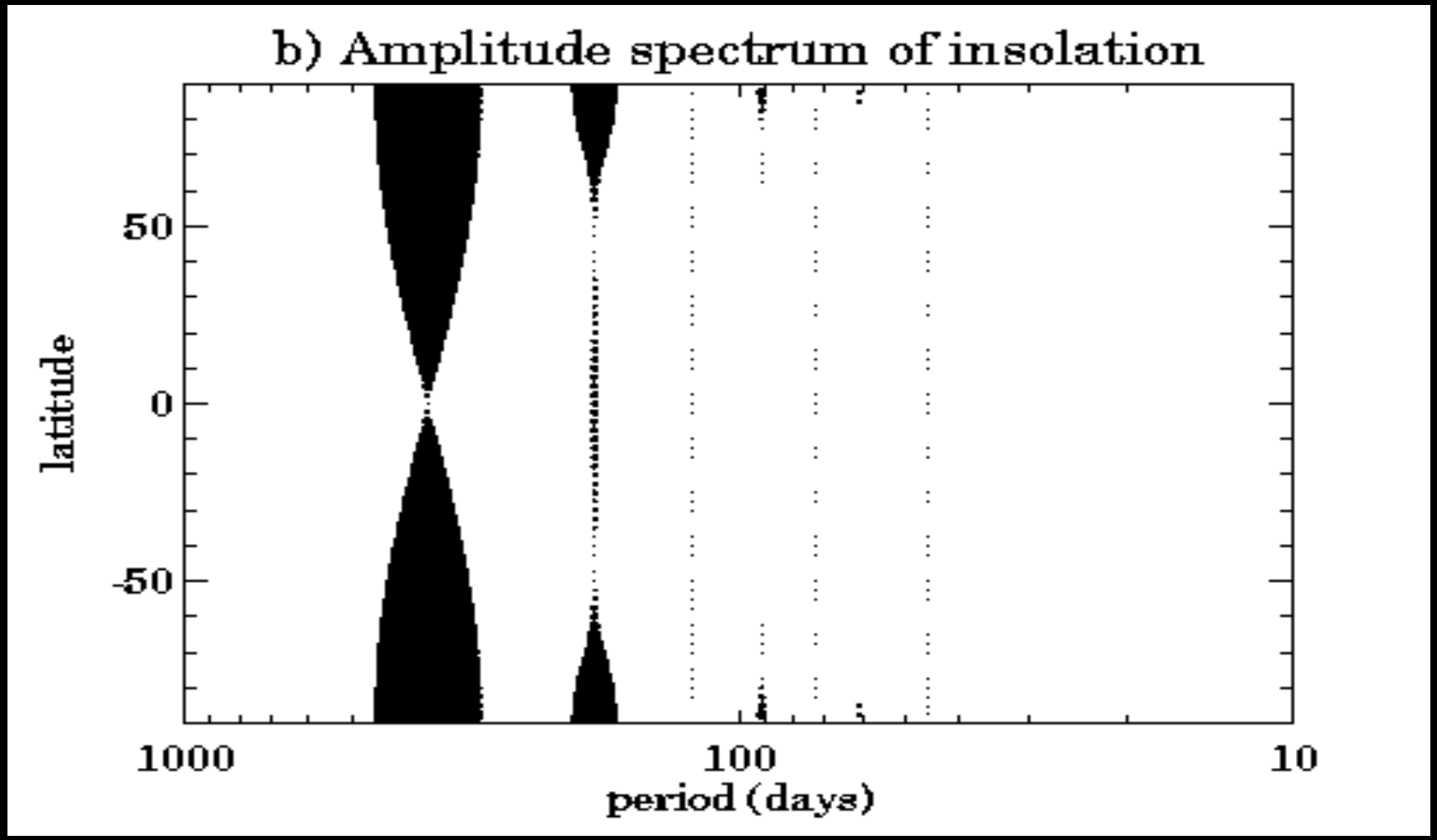
1. Astronomical signal, processed by Earth
2. Large data sets, processed by computer
3. Strides: annual, semiannual, terannual…
4. Steps: monsoon onsets, etc.
5. Stumbles (a.k.a. “singularities”)

- Software demo (free release in 2004)

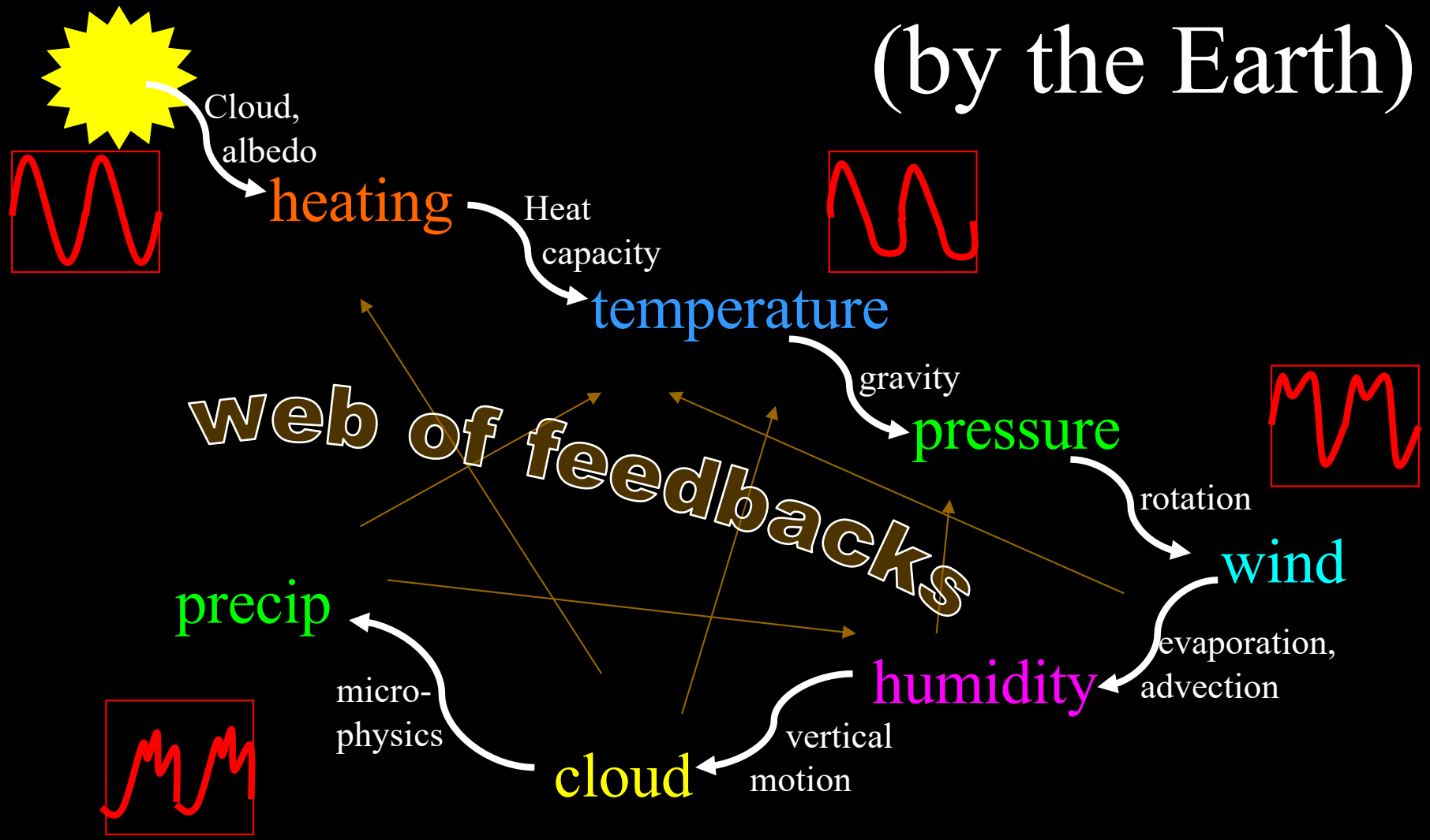
Astronomical forcing (spherical Earth, circular orbit)



Temporal Fourier spectrum of annual insolation



Annual cycle signal processing (by the Earth)



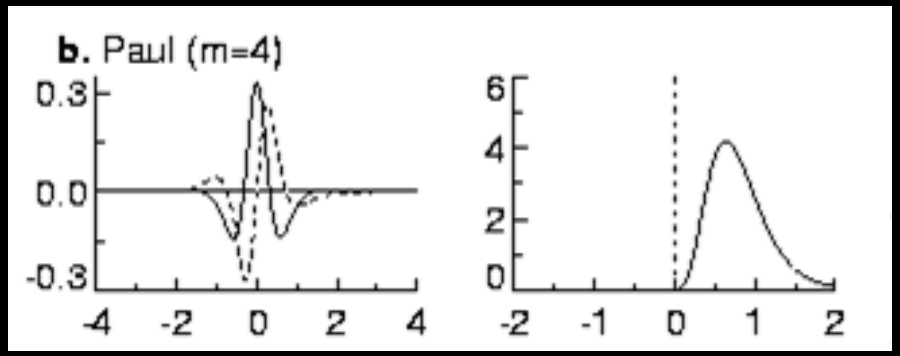
Annual cycle signal processing (by the computer)

1. Form a mean daily climatology (reanalysis, OLR, CMAP global precipitation, models):

   →var (365 calendar days; lat, lon, level, dataset)

1. Remove mean, annual + semiannual harmonics
   → mean, 2 amplitudes, 2 phases
2. Wavelet analysis of remainder
3. Collect real + imaginary wavelet power peaks
   → {dates, periods, amplitudes, significances}

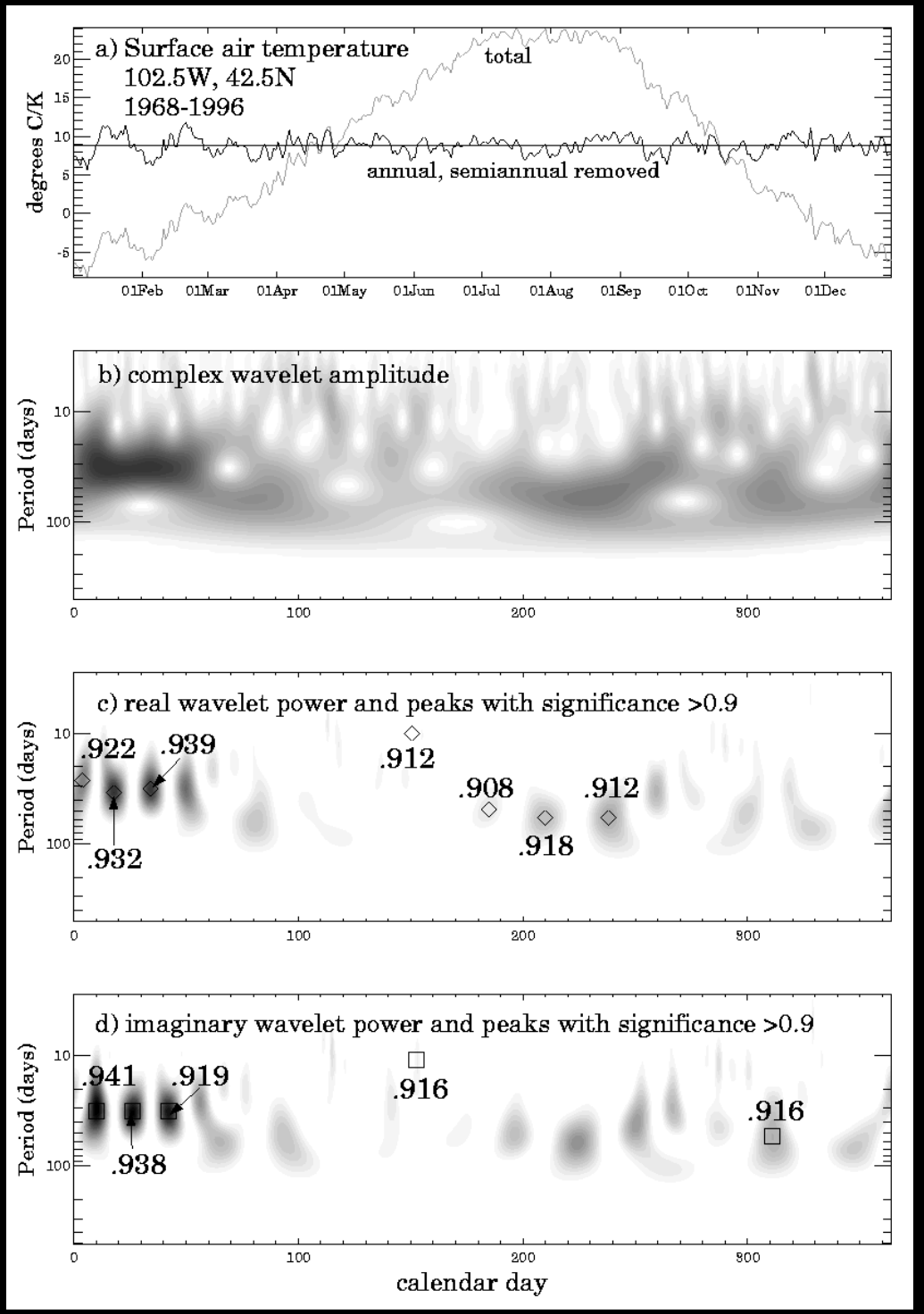
Wavelet example



Paul wavelet

- Sharp time localization
- → broad in frequency
- Real part: max/min
- Imaginary part: rise/fall

(Torrence and Compo 1998 BAMS)



Signal processed. Now what??

Fourier and wavelet coefficients form a supplement (index) to 365d climatology.

About the same size as the data!

?? What to do with all this information ??

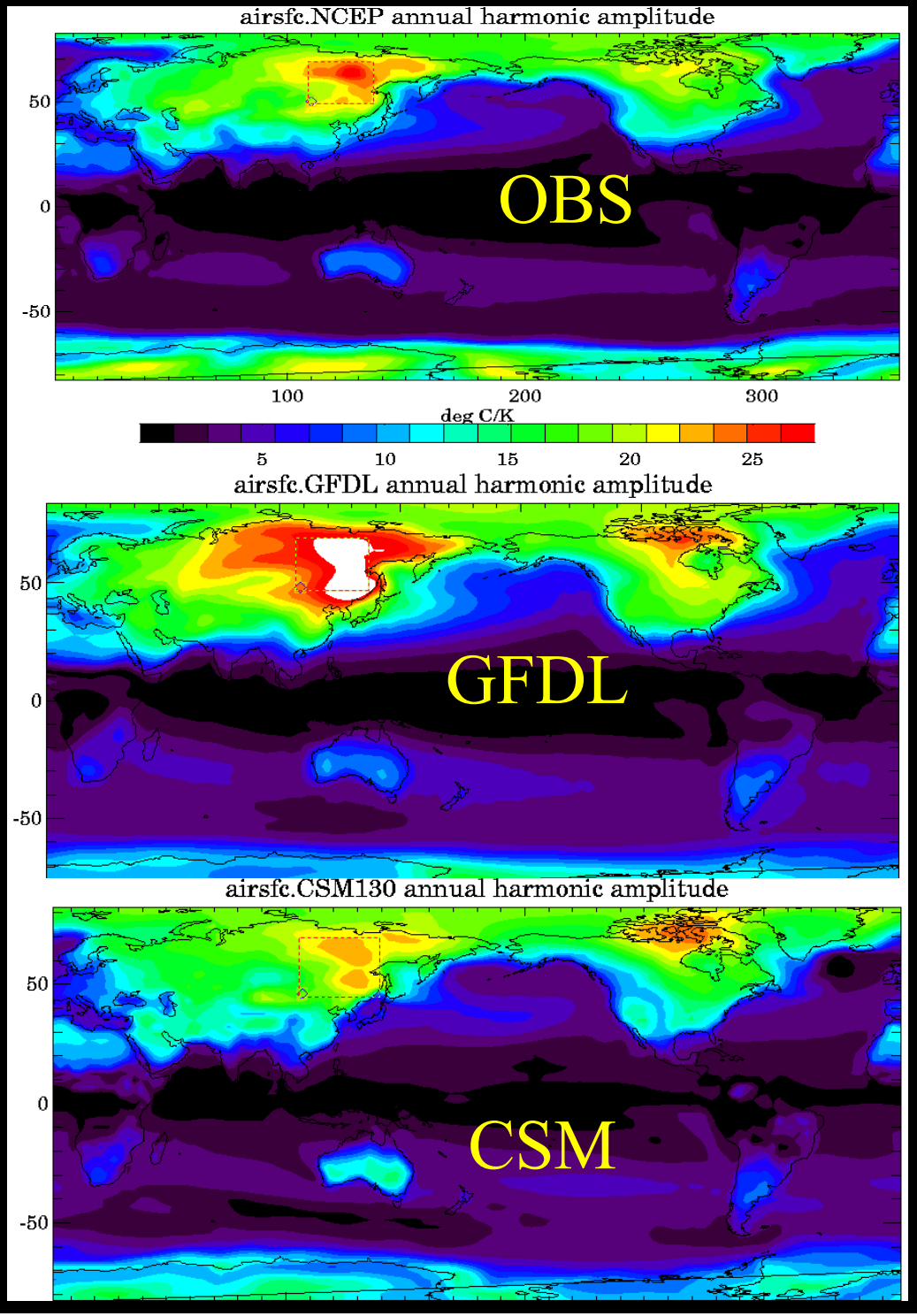
interactive GUI visualization tool

Outline of examples

1. Annual
   - "Easy" (local, thermal): T_{sfc}
   - Nonlocal: Z_{250}
2. Semiannual
   - Nonlinear: angular momentum and u_{250}
   - Storm tracks: 250mb $v'_{<9d}$
3. Terannual
   - Double summer rains, oceanic subtropical highs
4. Beyond
   - Monsoon onsets, etc. --live GUI demo

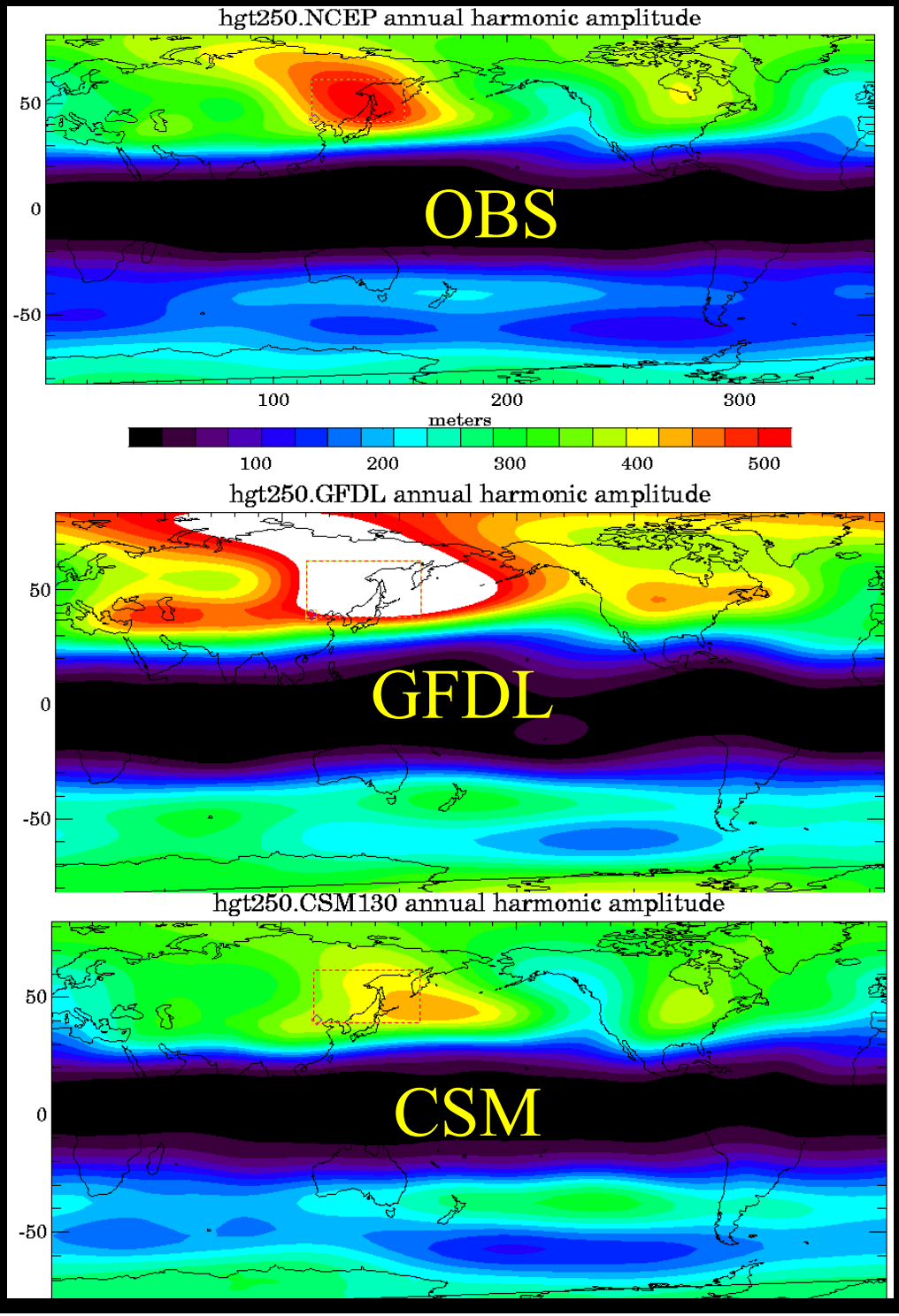
Simplest: annual harmonic of surface air T

(mainly, how cold is winter?)



Cold winter → low tropospheric thickness?

annual harmonic of Z_{250}



Temperature → thickness?
Not so simple…

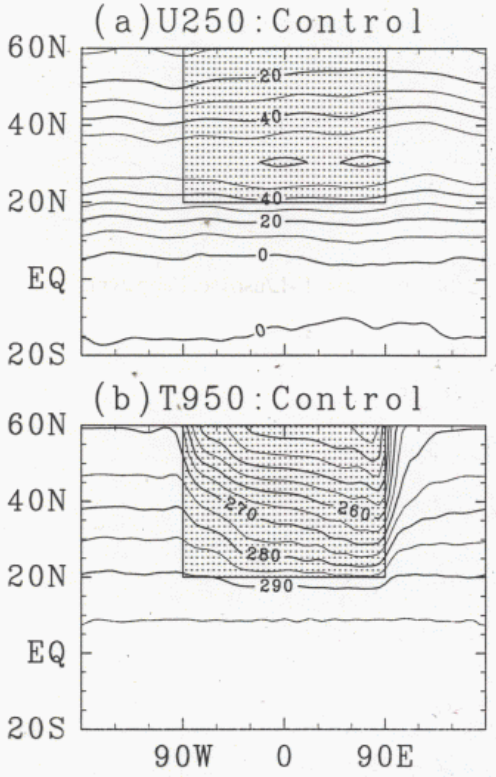


Figure 1. (a) Time-averaged zonal wind speed at 250 hPa, and (b) temperature at 950 hPa in the control run with the continent shaded. Land surface is flat at the sea level.

the surface, the upper westerly wind velocity is largely zonally uniform (Fig. 1a) in the control run. As expected, both the model baroclinicity (Linzen and Farrel, 1980) and the eddy heat flux display a local maximum east of the continent (not shown). The GCM has been run at a higher T42 resolution to improve its representation of transient eddies, but the westerly winds in the upper troposphere remain nearly constant in the zonal direction (not shown).

4. Tropical forcing

In the real world, SST varies quite substantially in the zonal direction. In the tropics, highest SSTs are found in the so-called warm water pool south of the eastern Eurasian continent, which can locally enhance the subtropical westerlies as suggested by experiments under the realistic land-sea distribution (Appendix). We add a zonally varying component

$$T'(\lambda,\phi) = A \sin\lambda \exp\left\{-\frac{1}{2}\left(\frac{\phi - \phi_0}{10}\right)^2\right\}, \qquad (1)$$

to the tropical SST field. Here, λ is longitude, ϕ is latitude, $\phi_0 = 8°S$, and A is 2.5 K. In this case, a warm pool is located to the south of continent's east coast as in observations.

The GCM now generates substantial zonal variations in upper-level westerlies (Fig. 2a), while the SAT field is similar to that in Fig. 1b (not shown). Therefore, the control run rules out extratropical land-sea distribution as a major component of thermal forcing for subtropical jet core. Instead, it implicates the tropical forcing.

To further demonstrate the controlling effect of tropical SST forcing, we shift the tropical warm water pool onto the western side of the continent by setting $A = -2.5$K. The

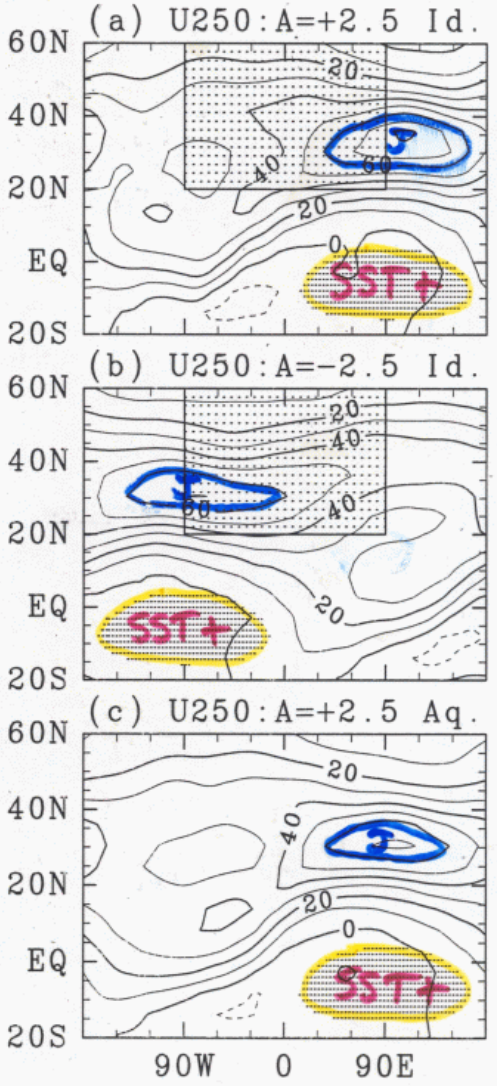


Figure 2. Same as Fig. 1a but for (a) the eastern and (b) western equatorial warm water pool runs, and (c) the Aqua Planet run. The heavy shade in the tropics denotes SST ≥ 301.5K.

Hadley cell: subtropical jets depend on tropical heating {nonlinear: ~(lat)^4}

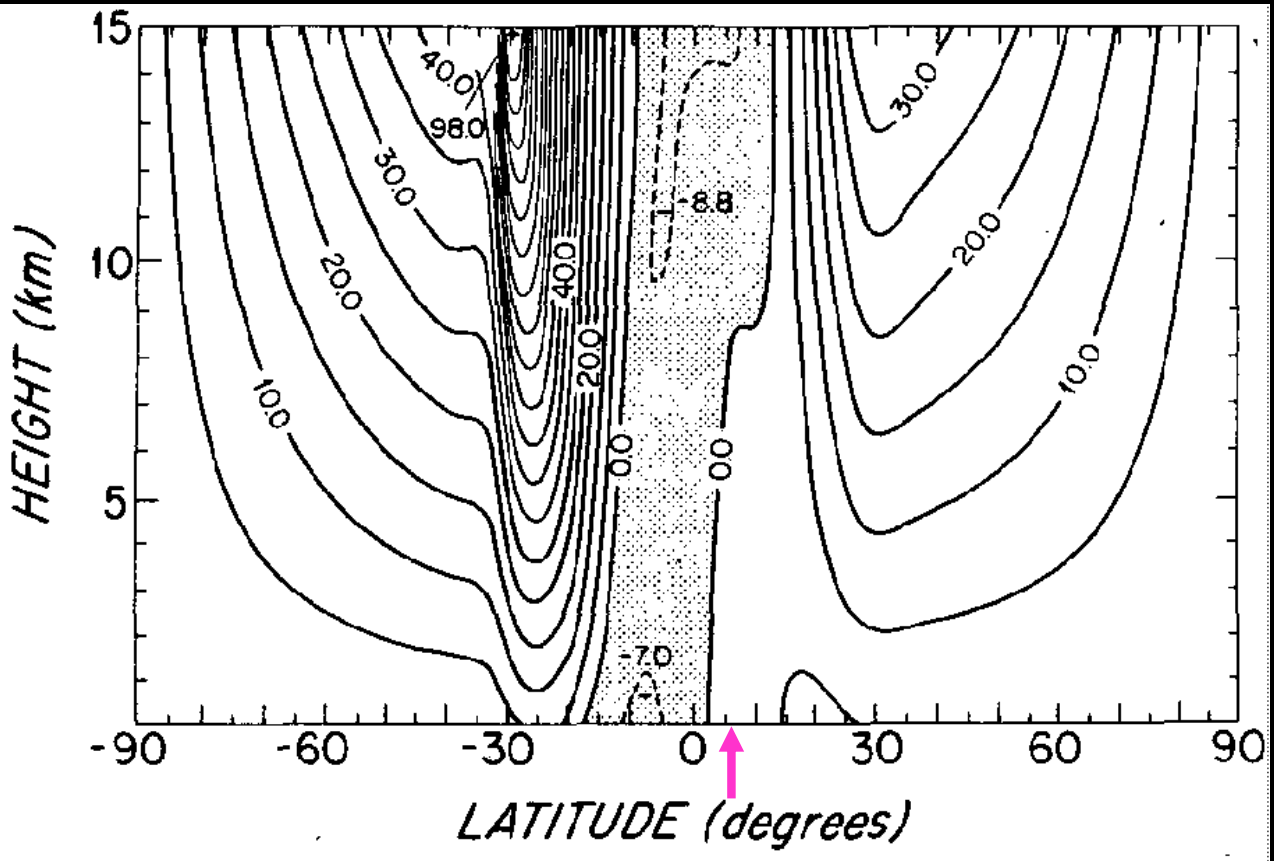


FIG. 10. The calculated zonal wind for $\phi_0 = 6°$ in m s^{-1}.

(Lindzen and Hou 1988)

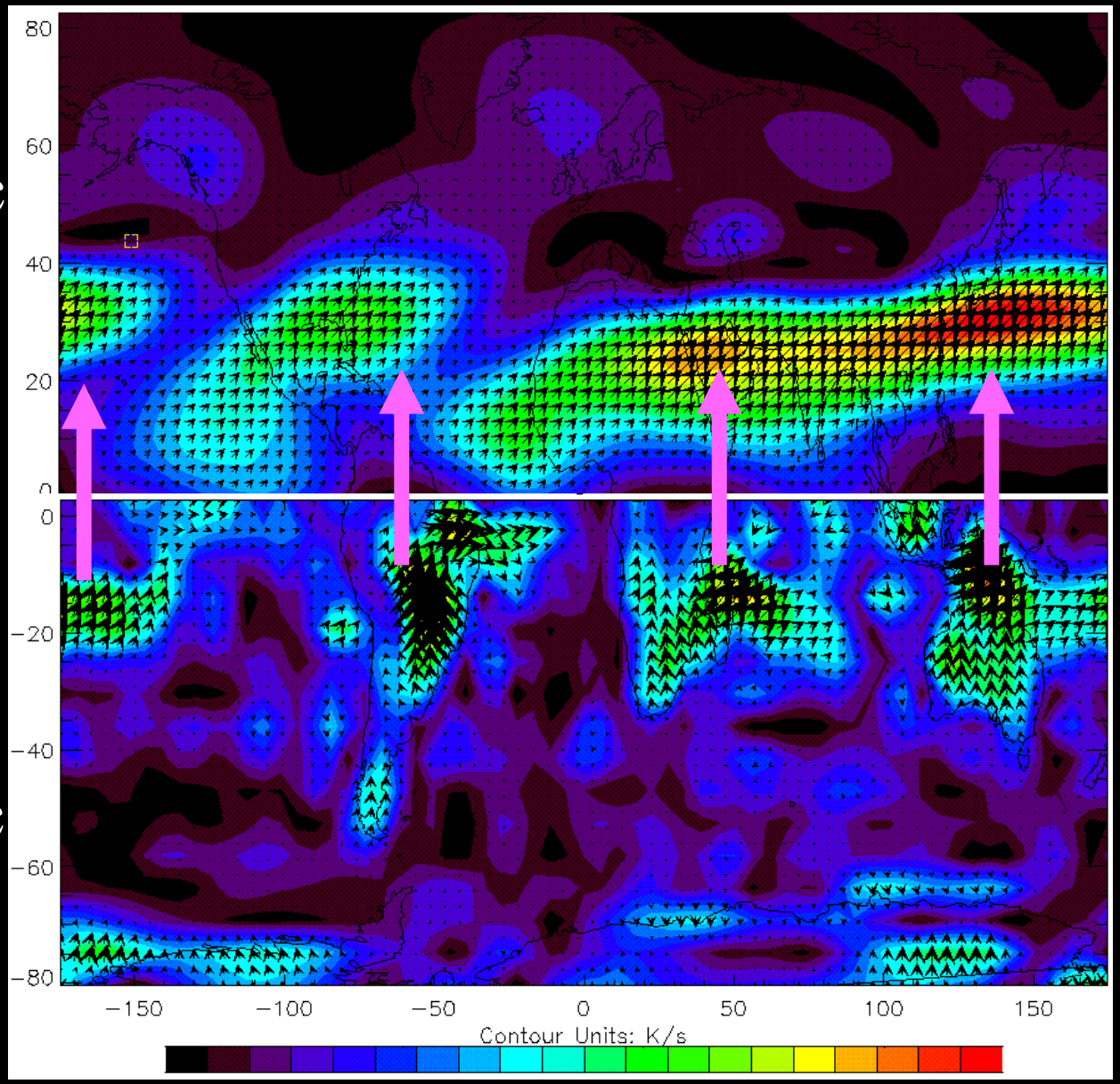
Local Hadley cells?

Annual Harmonic of u at 200 hPa

Jan 1

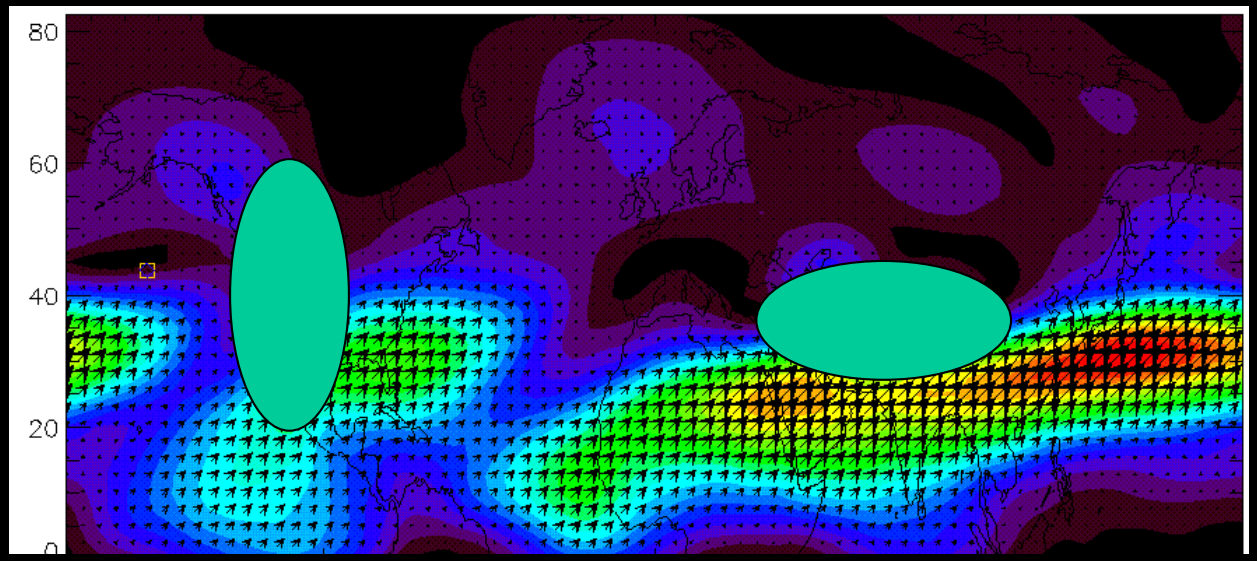
Apr 1

Annual Harmonic of atmos. heating



Effects of mountains?

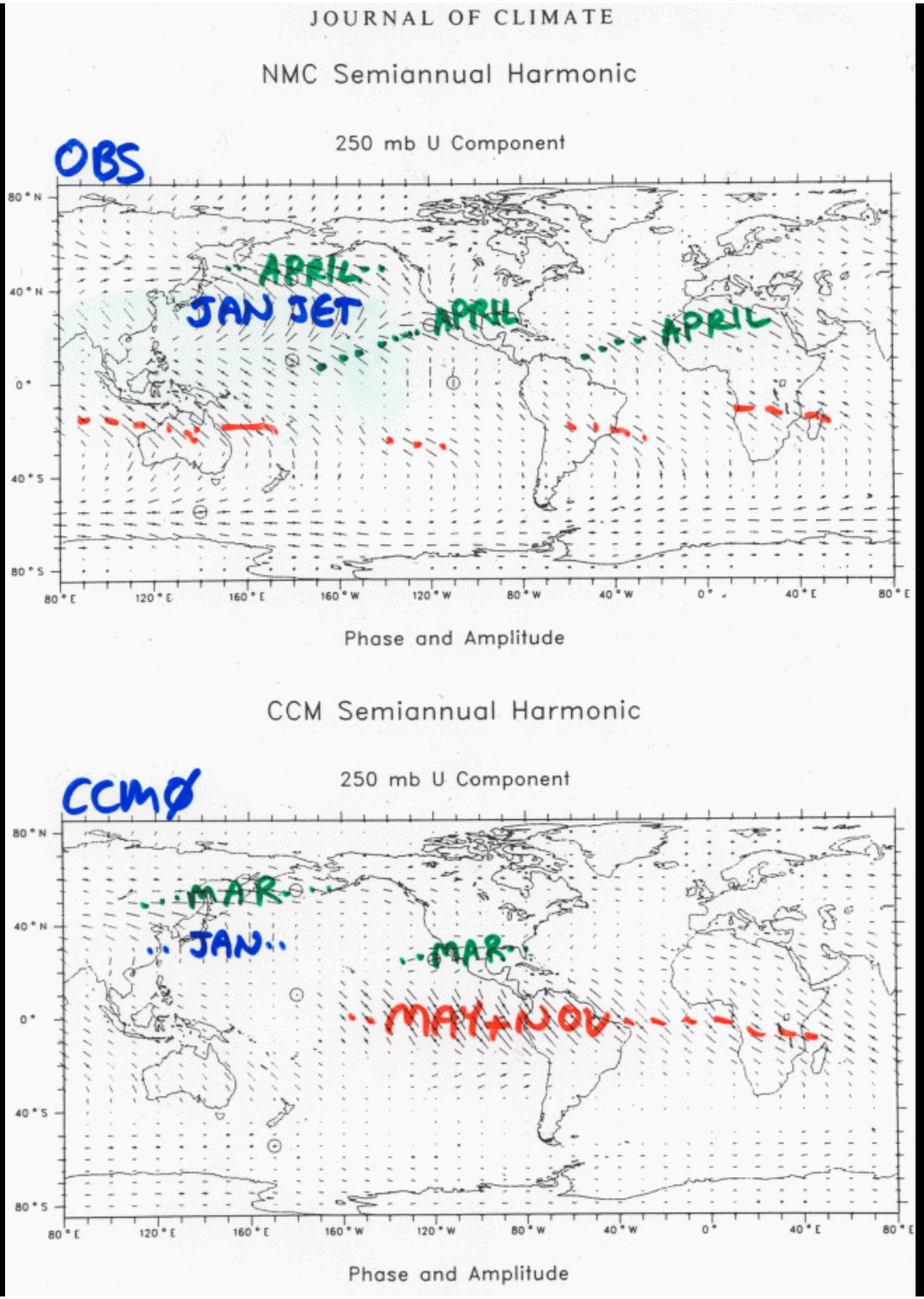
Annual Harmonic Of u at 200 hPa



Earth has too many coincidences: tropical hot spots at same longitude as eastern parts of NH continents, east of NH mountains. All play some role in dynamics of annual harmonic.

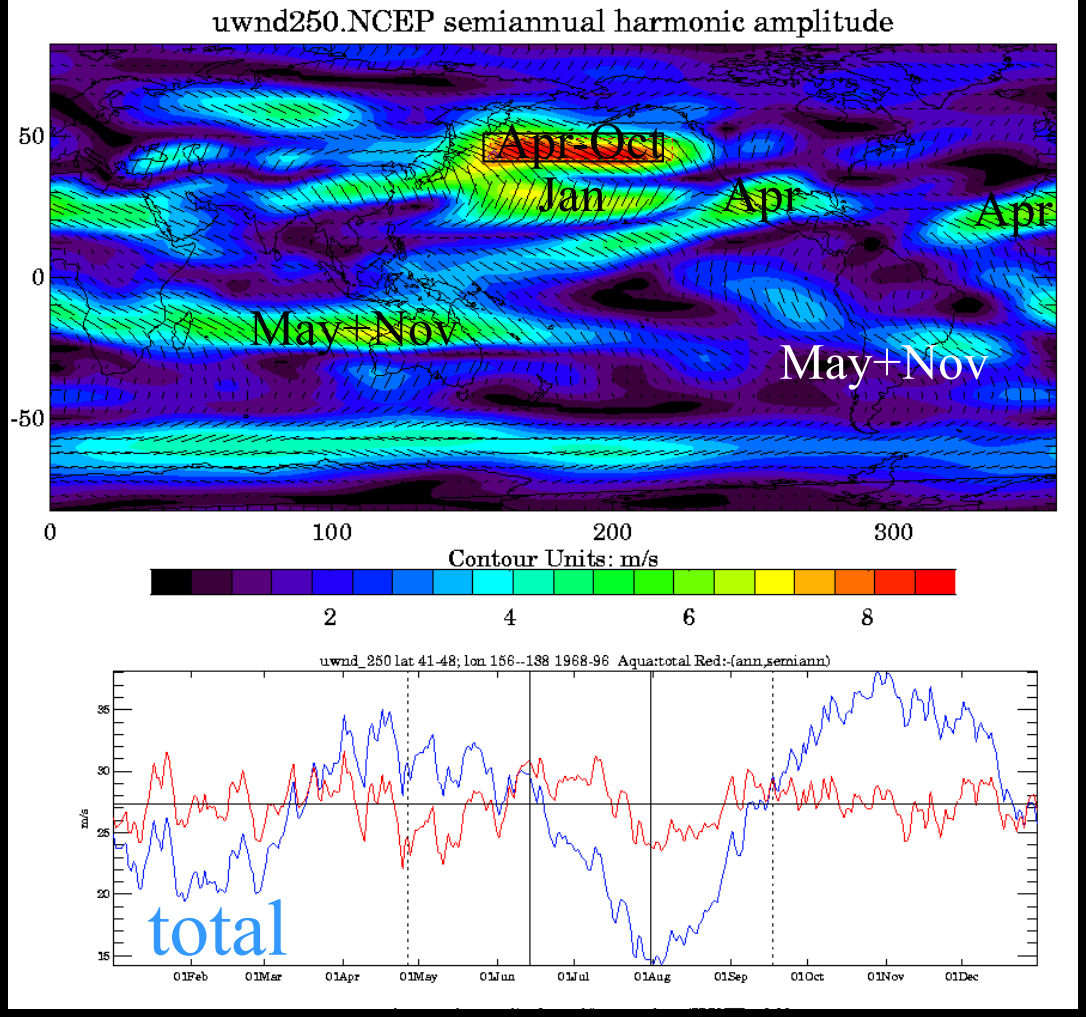
Semiannual harmonic of 250 hPa zonal wind

(Weickmann & Chervin 1988)

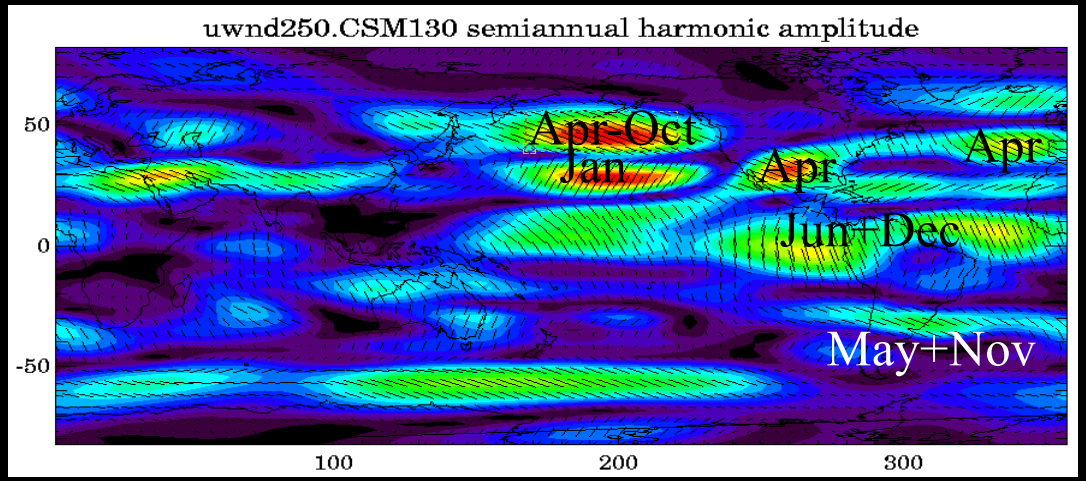


Semiannual harmonic of 250 hPa zonal wind

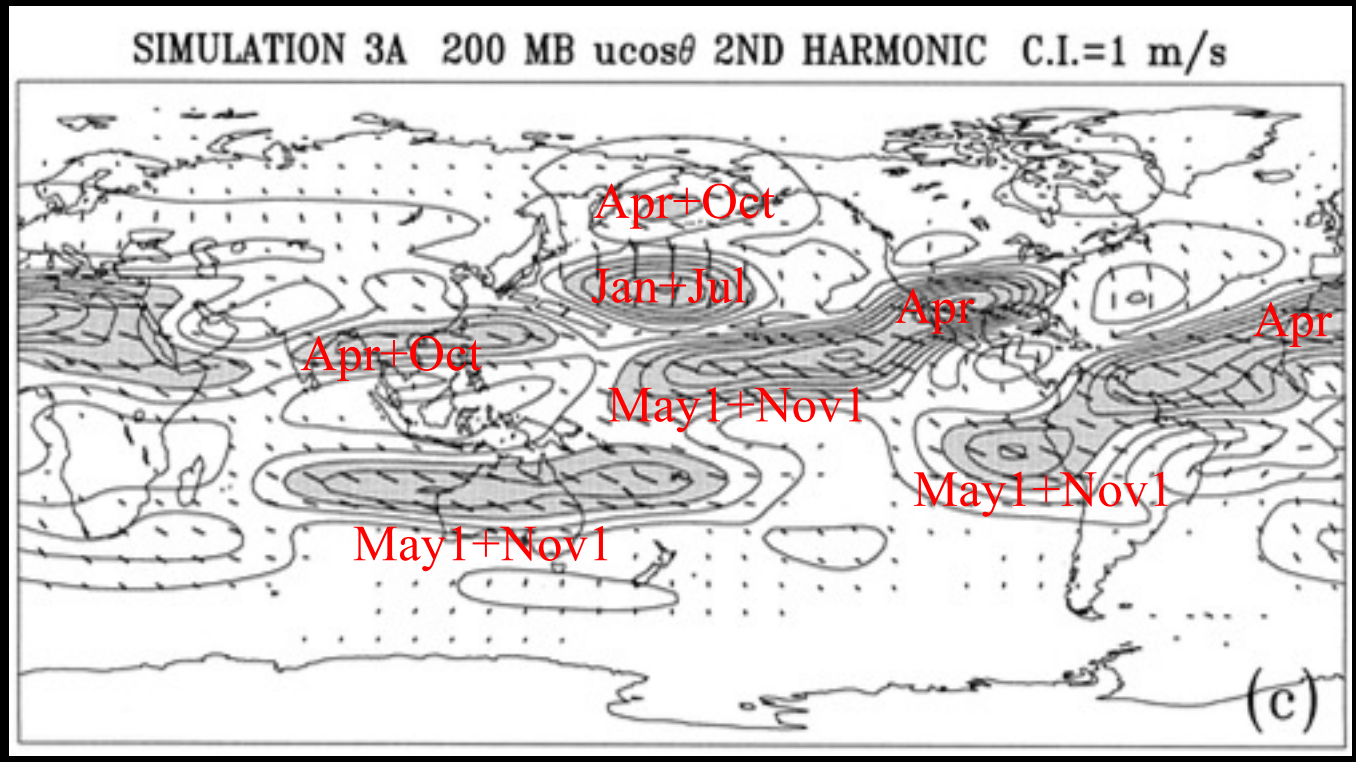
OBS



CSM



Huang and Sardeshmukh (2000)

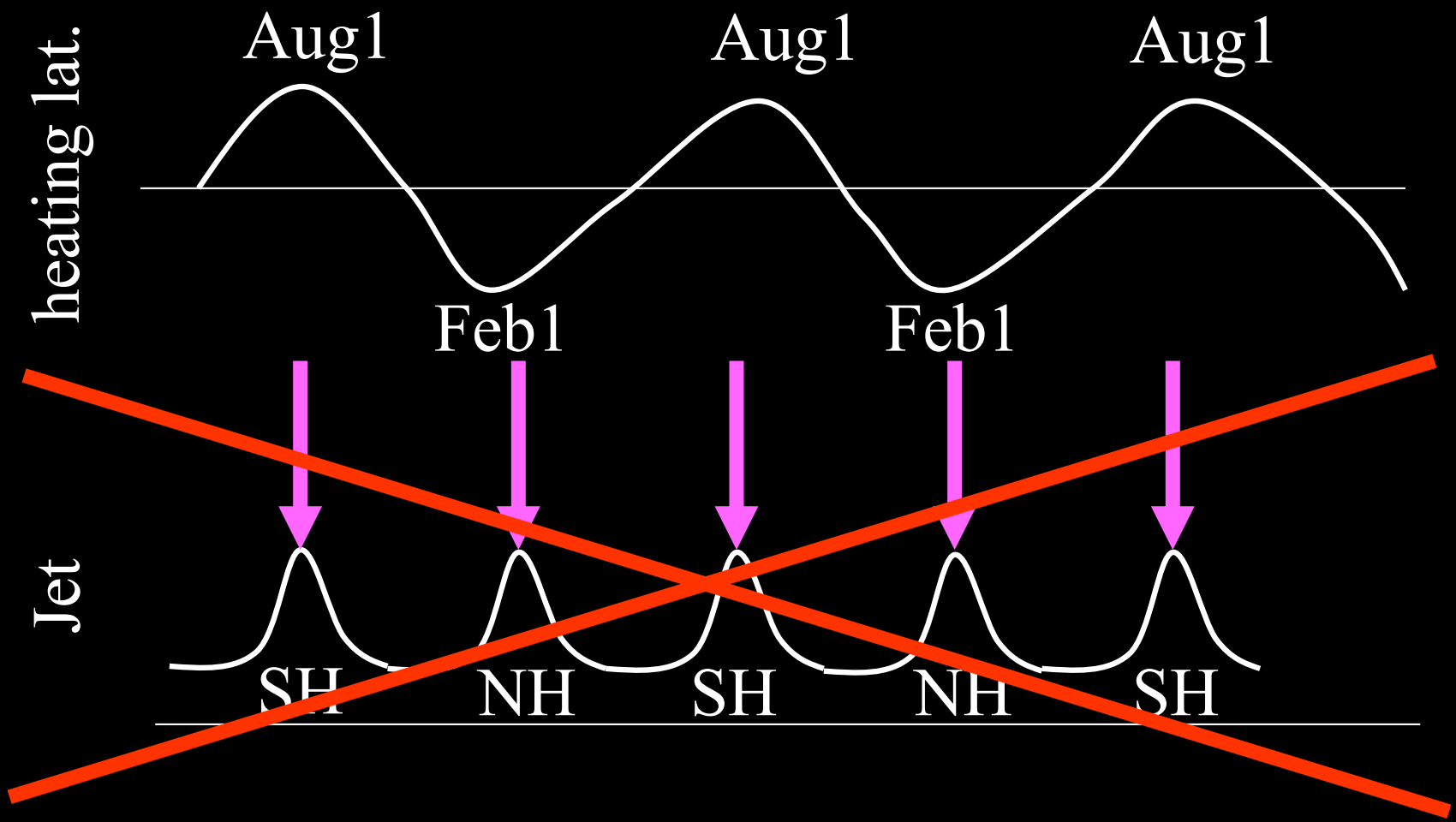


The semi-annual harmonic of angular momentum ucosθ, forced by the mean plus annual harmonic of specified divergence, in a divergent barotropic model.

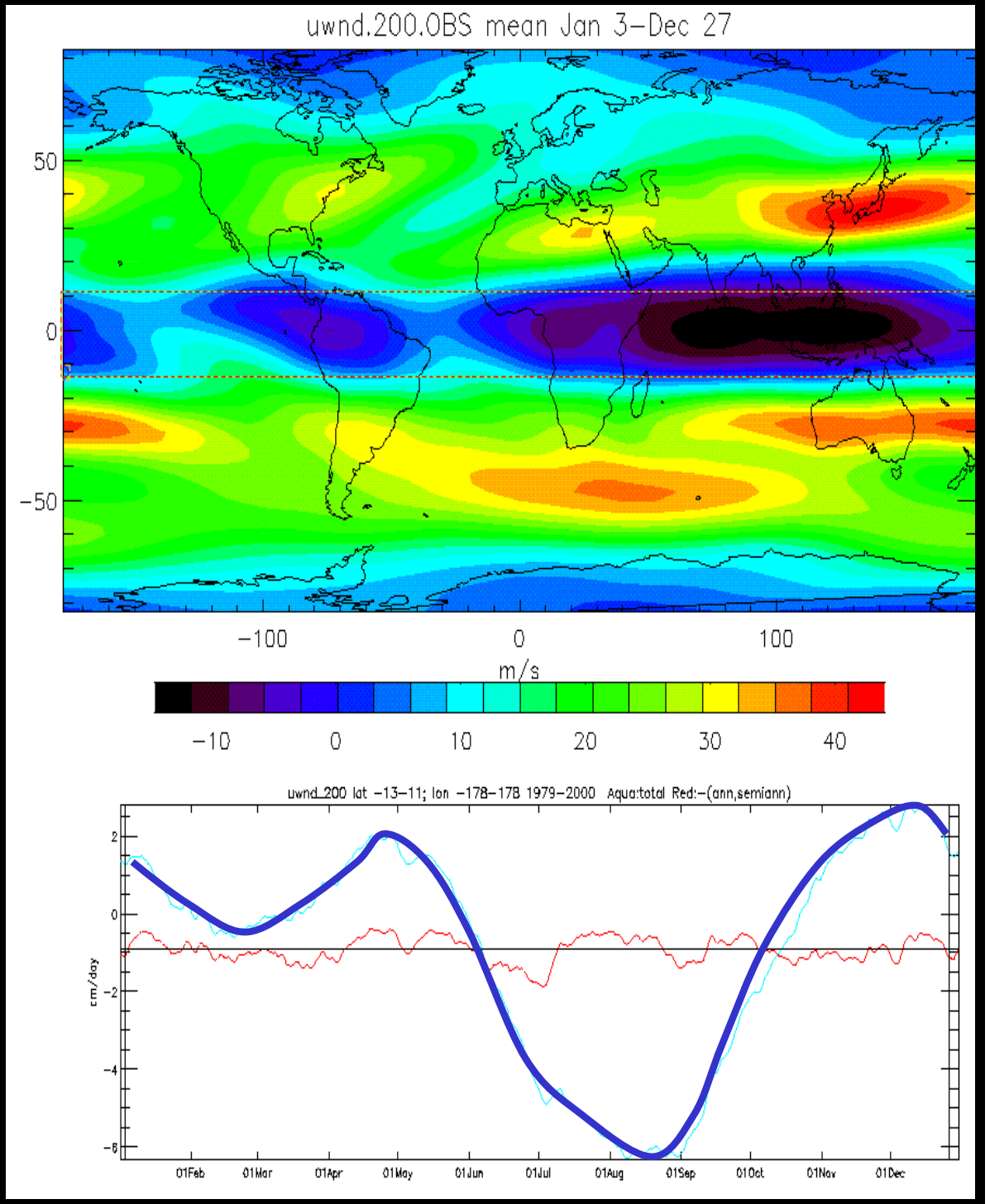
Semiannual component must have simple, nonlinear dynamics.

But why is nonlinear effect strongest in spring/fall rather than summer/winter??

Hadley nonlinearity, ~(lat)^4 of Q?
No, that's Feb-Aug, not Apr-Oct…



semi-annual variation of angular momentum lies in equatorial easterlies, not westerly jets



Semiannual eddy (storm) activity

Midwinter Suppression of Baroclinic Wave Activity in the Pacific

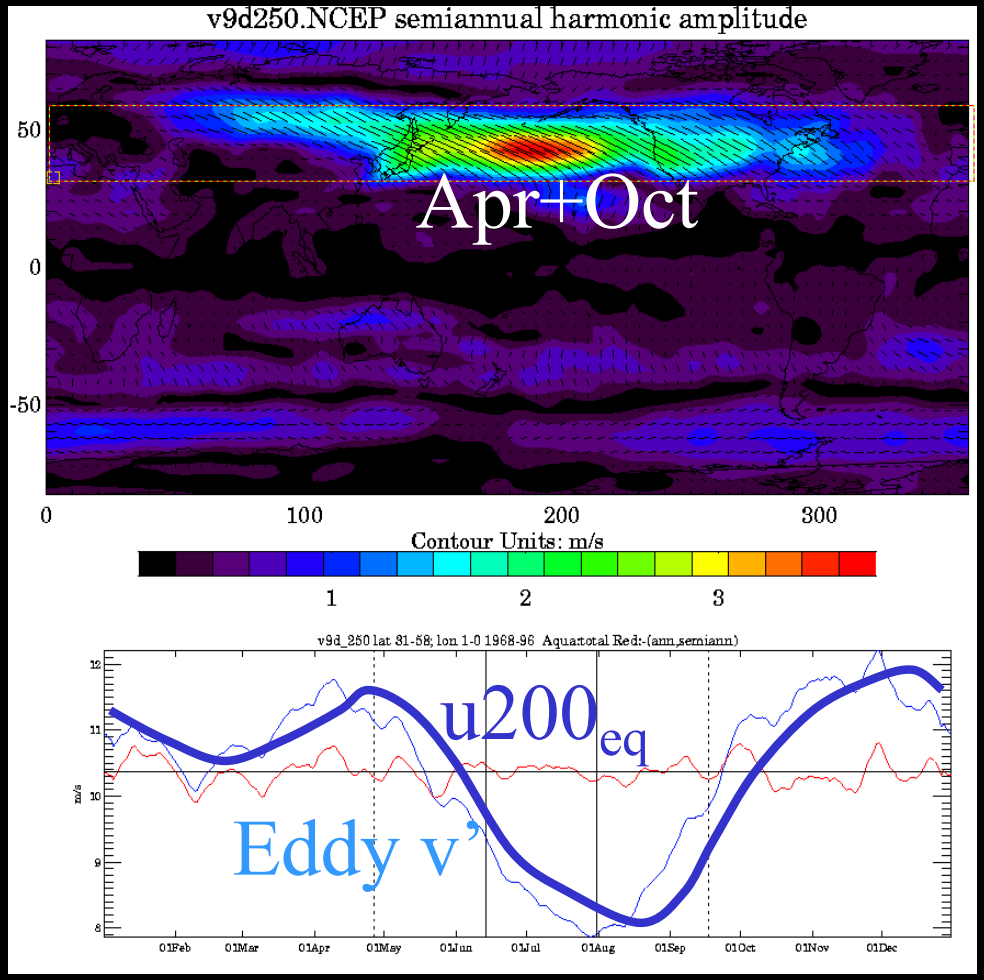
Nakamura 1992

ABSTRACT

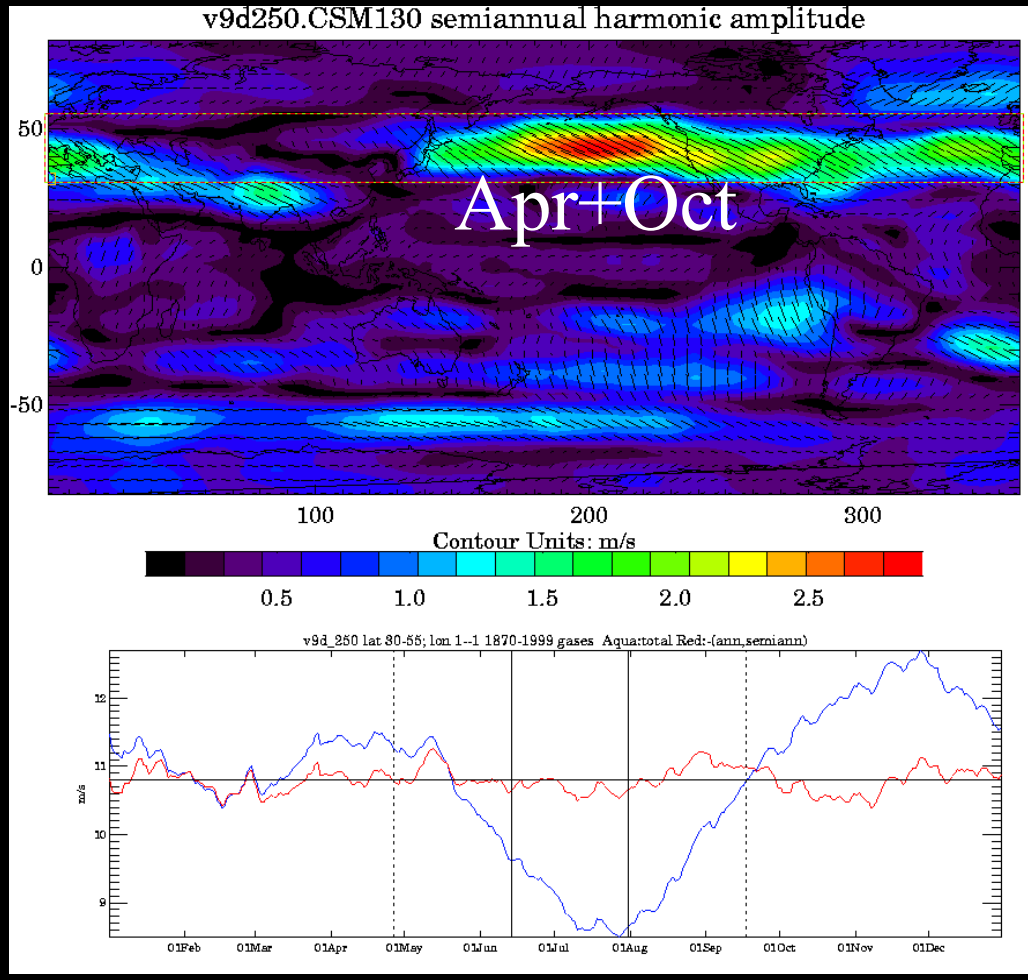
Seasonal variations in baroclinic wave activity and jet stream structure in the Northern Hemisphere are investigated based upon over 20 years of daily data. Baroclinic wave activity at each grid point is represented for each day by an envelope function, the lowpass-filtered time series of the squared highpass-filtered geopotential height. Baroclinic wave activity over the Atlantic exhibits a single maximum in January, whereas in the Pacific it exhibits peaks in late autumn and in early spring and a significant weakening in midwinter, which is more evident at the tropopause level than near the surface. This suppression occurs despite the fact that the low-level baroclinity and the intensity of the jet stream are strongest in midwinter. Based on the analysis of 31-day running mean fields for individual winters, it is shown that over both the oceans baroclinic wave activity is positively correlated with the strength of the upper-tropospheric jet for wind speeds up to 45 m s 1. When the strength of the westerlies exceeds this optimal value, as it usually does over the western Pacific during midwinter, the correlation is negative: wave amplitude and the meridional fluxes of heat and zonal momentum all decrease with increasing wind speed. The phase speed of the waves increases with wind speed, while the steering level drops, which is indicative of the increasing effects of the mean flow advection and the trapping of the waves near the surface.

Semiannual harmonic of running 9-day stdev. of meridional wind

OBS



CSM



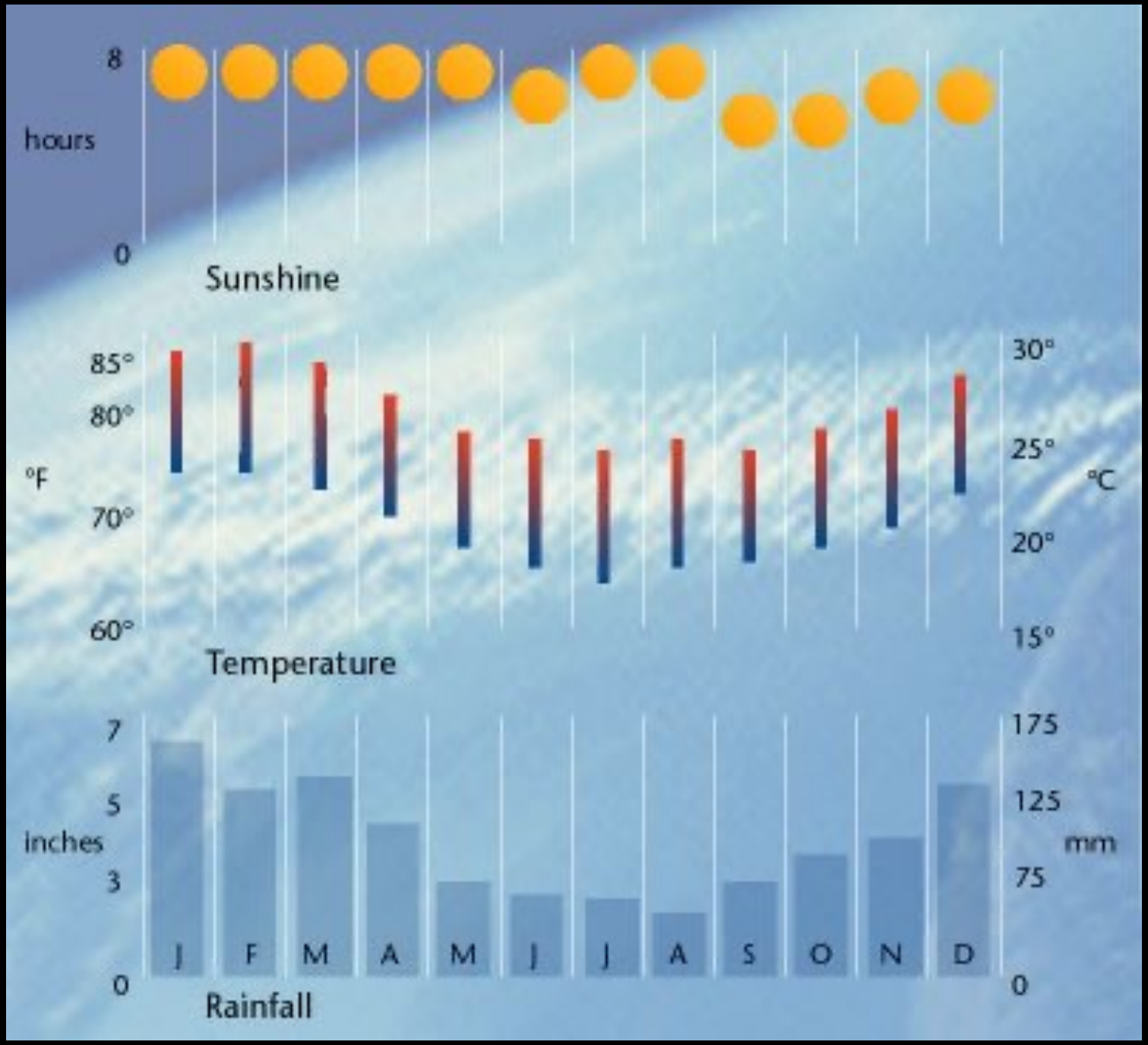
Beyond the semiannual

- Summer rains have sub-seasonal structure (& nonlinear dynamics)

-or-

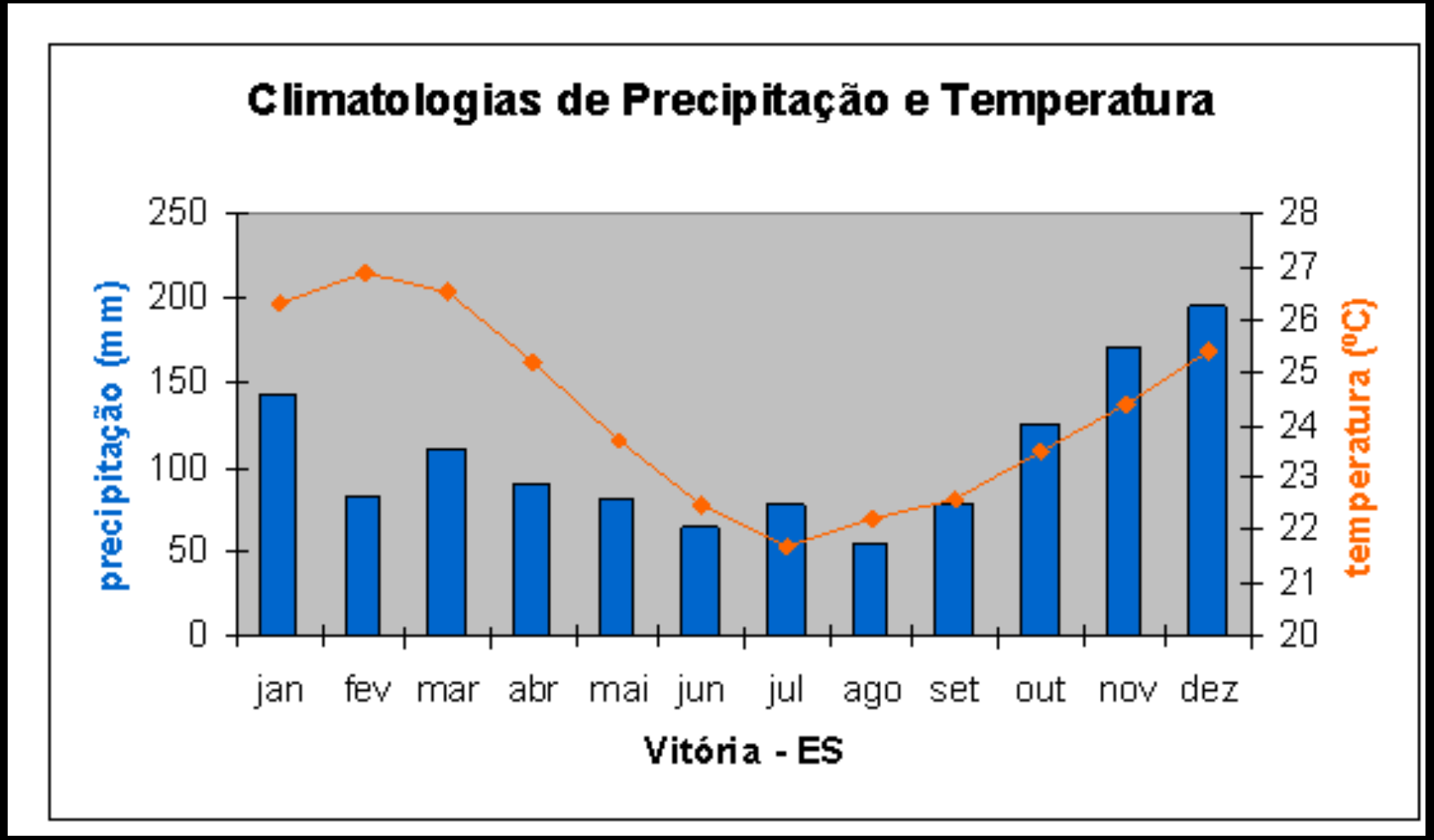
- A naïve person ‘discovers’ the monsoons

SP & Rio clim.



Source: Hotel inter-continental Web site

Better data (I assume!)

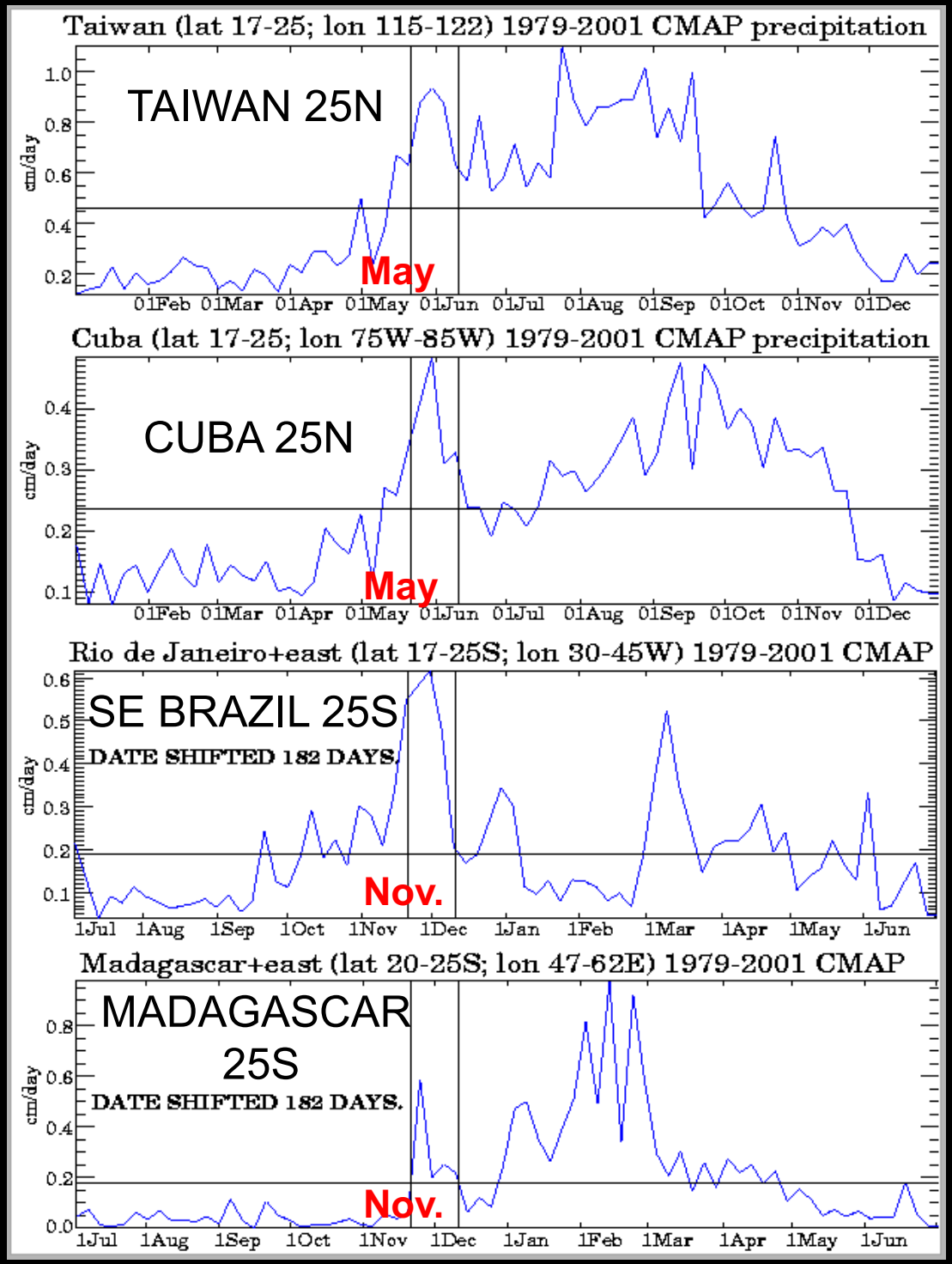


Source: CPTEC Web site

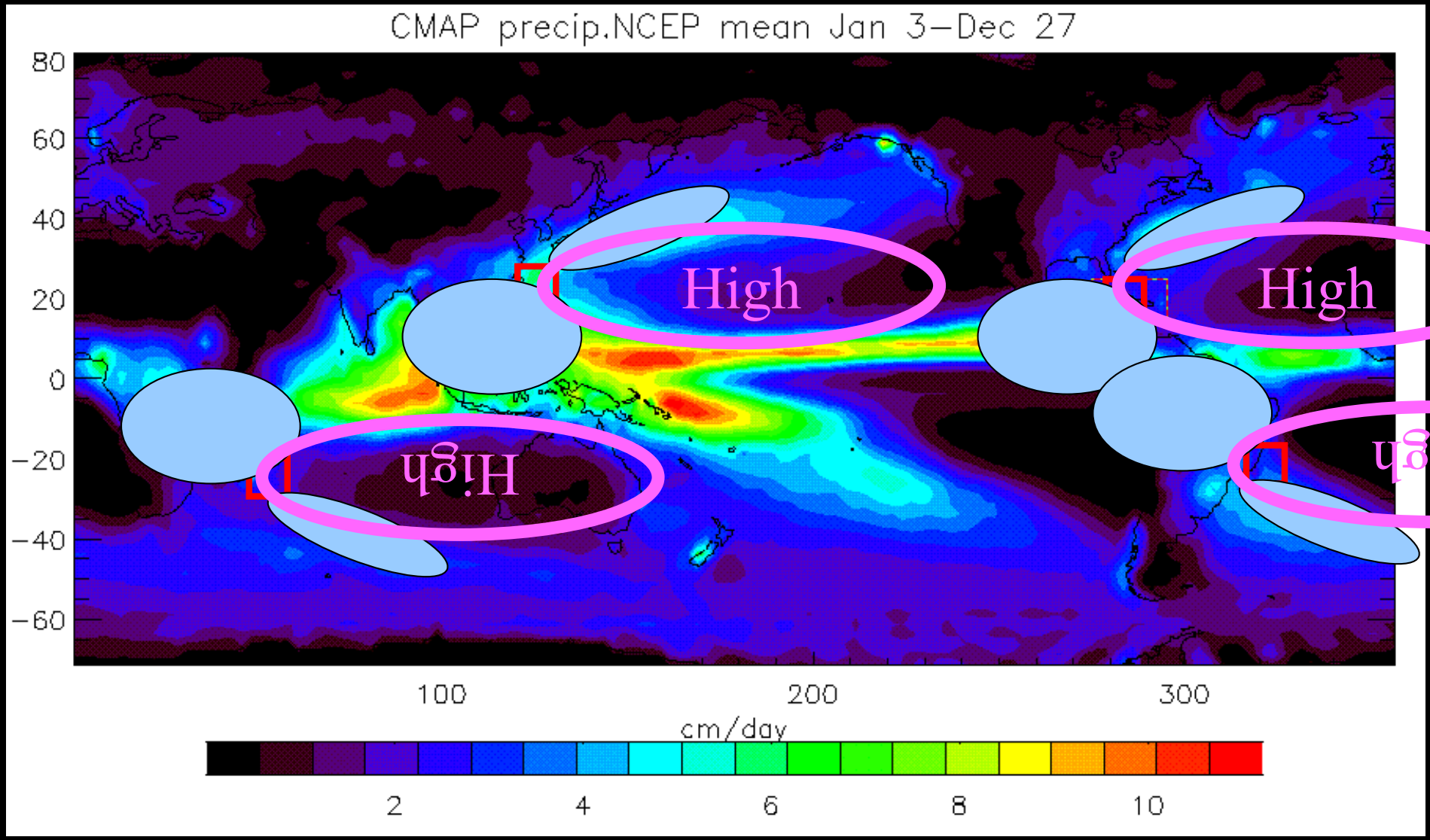
CMAP rainfall climatologies:

Stories include:

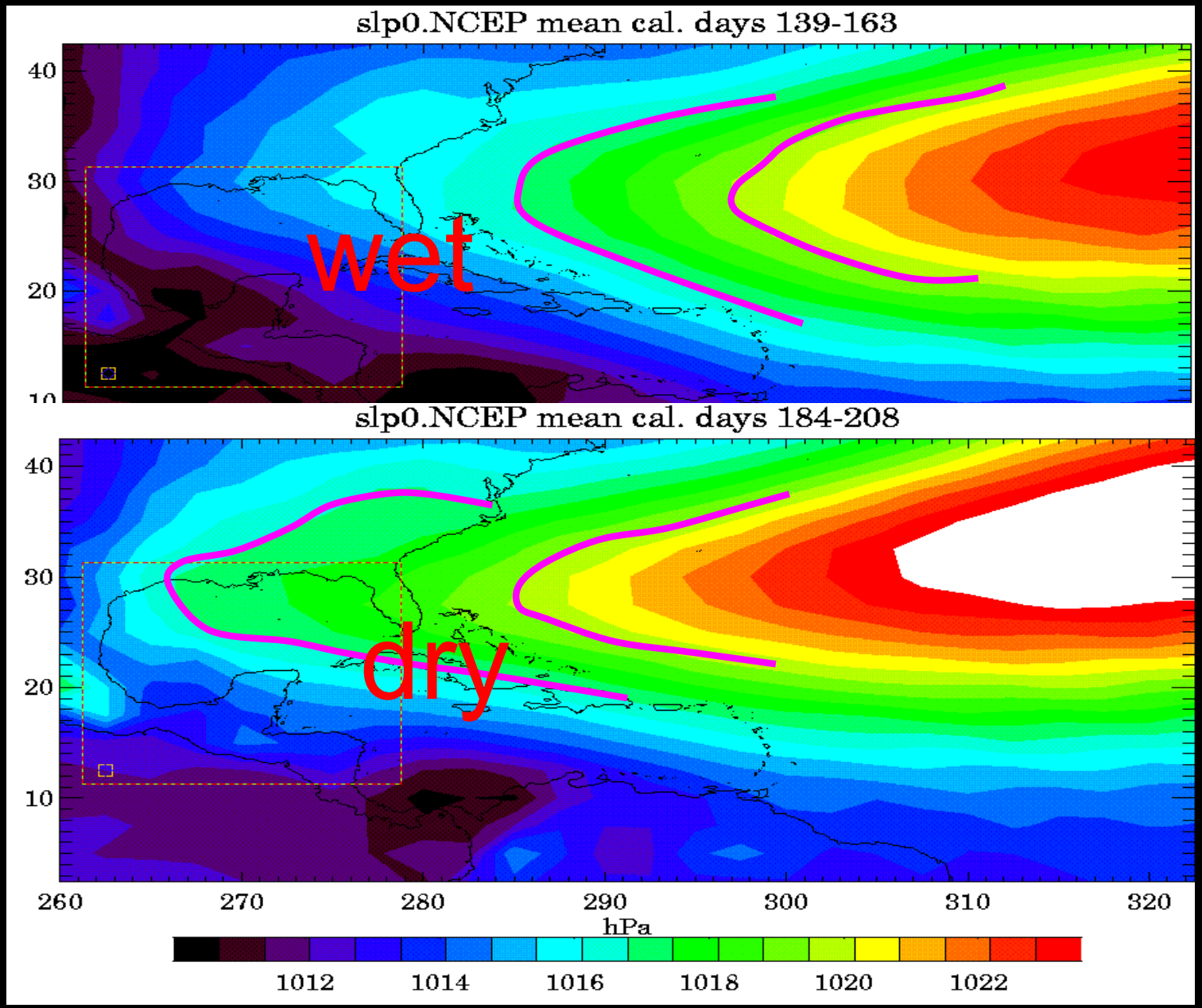
1. The ITCZ passes over twice.
2. First peak is frontal, 2nd is tropical cyclones (NH).
3. Warm season is wet, midsummer drought is the real question.



Where are those boxes? W. subtropical oceans



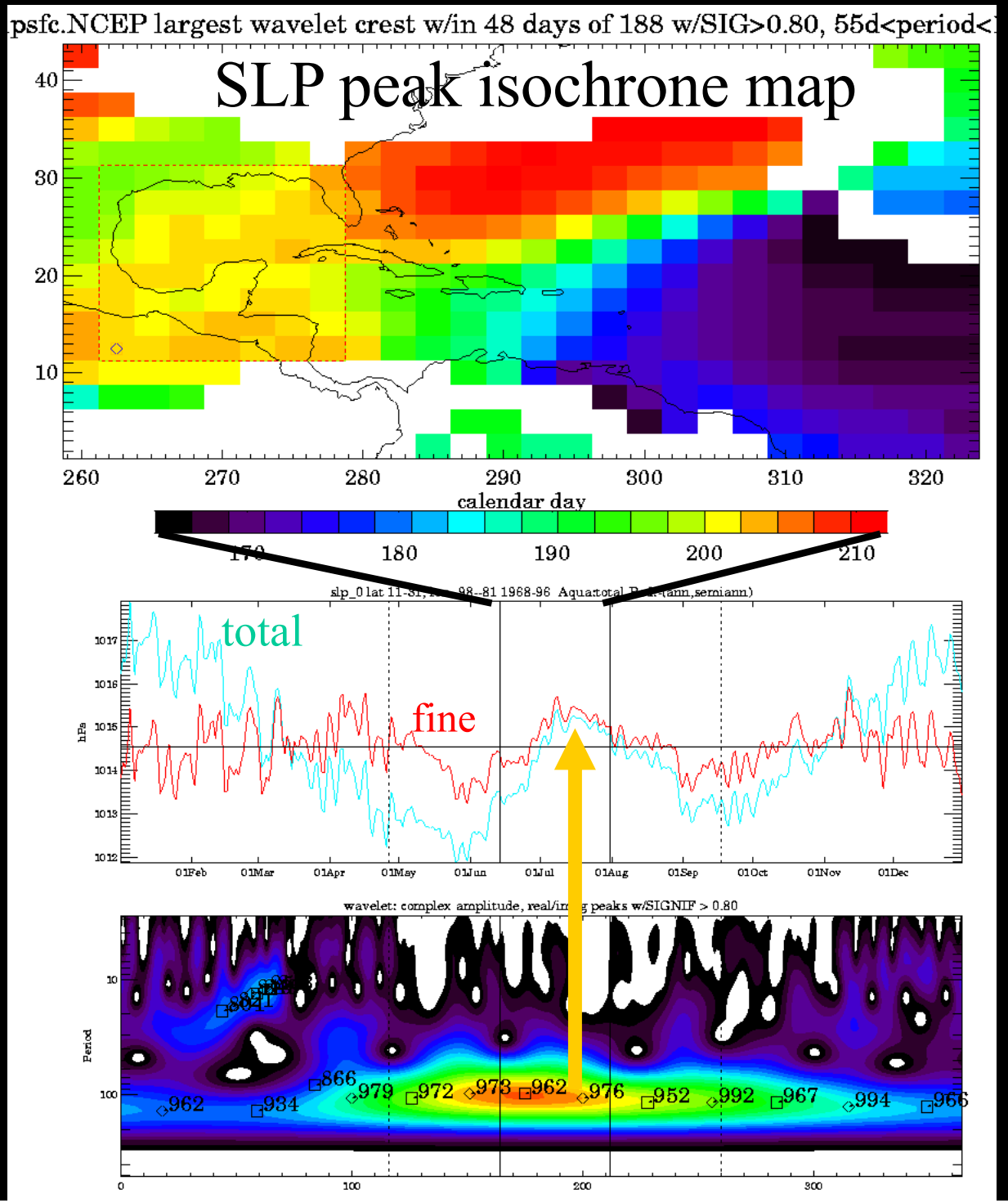
Midsummer high in W. Atlantic



21 May-
10 June

3-27
July

Atlantic High in summer (~100d period, as H surges into IAS in July)

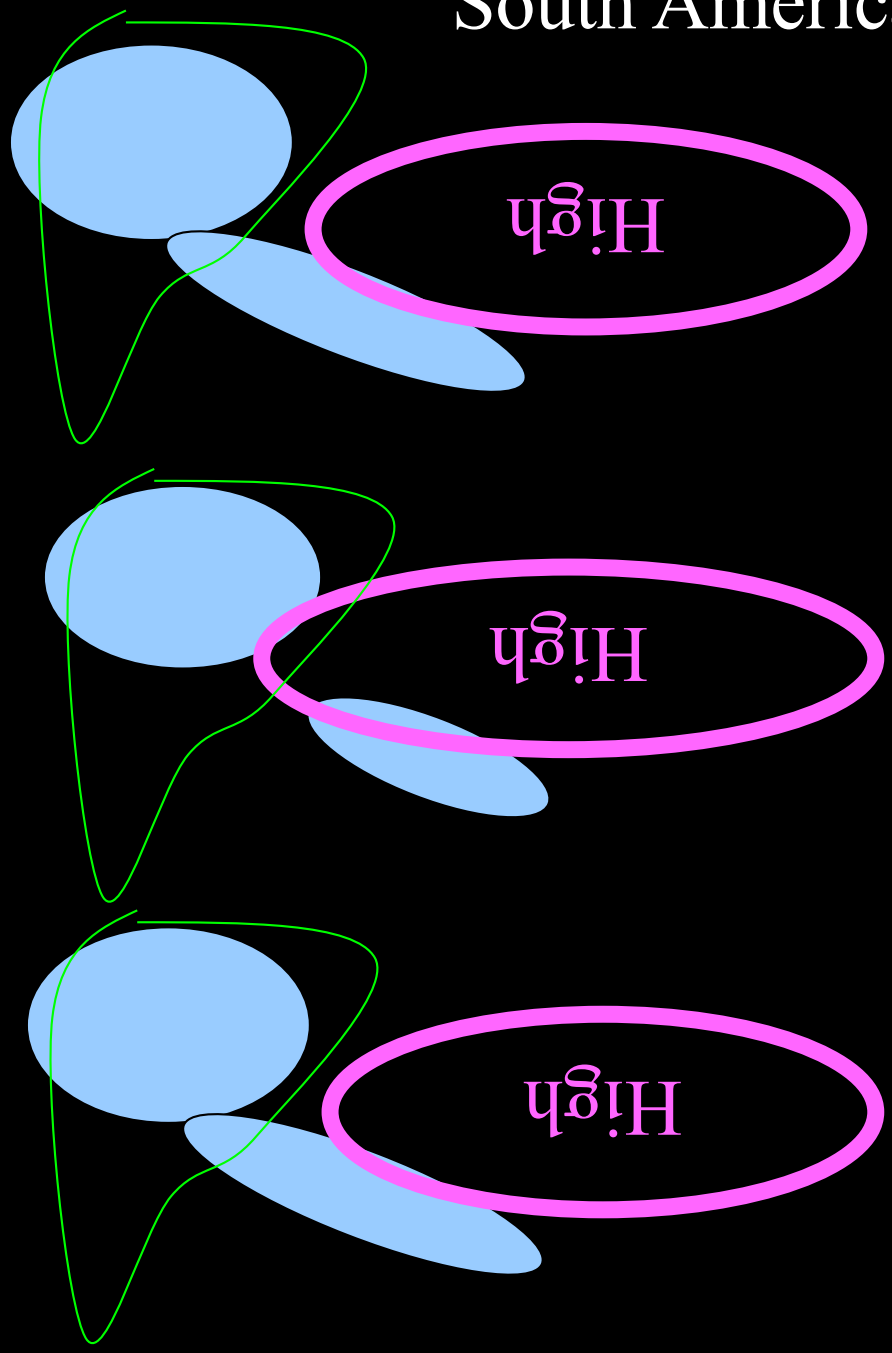


Early summer

Middle summer

Late summer

South American version --?



Early summer

Middle summer

Late summer

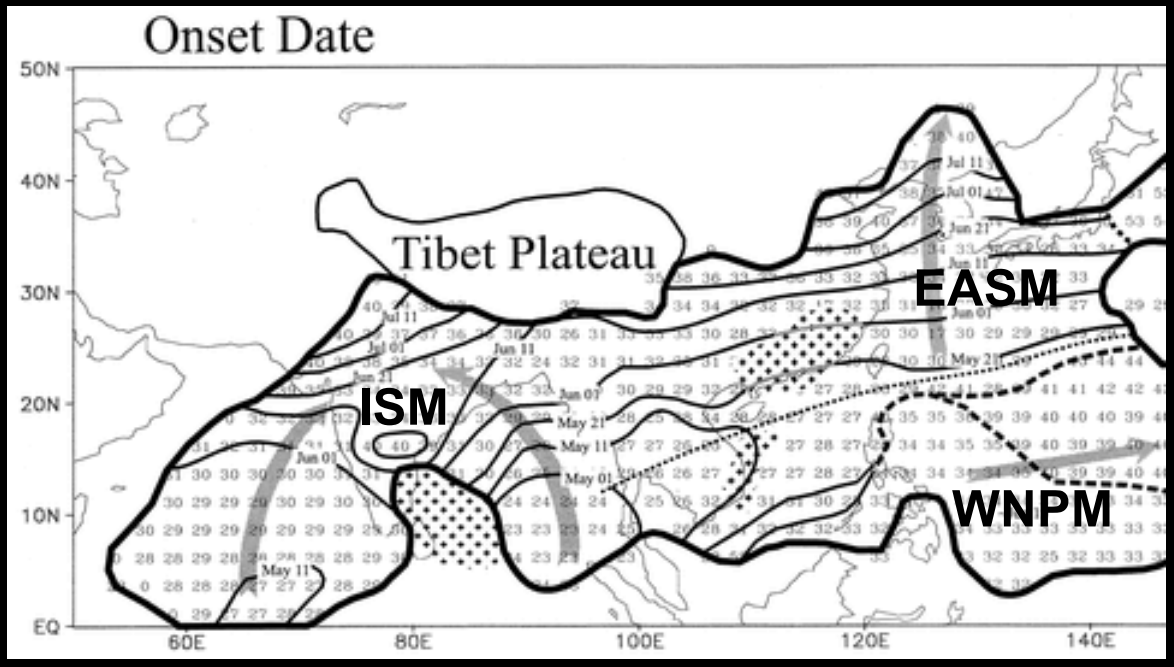
Final slide

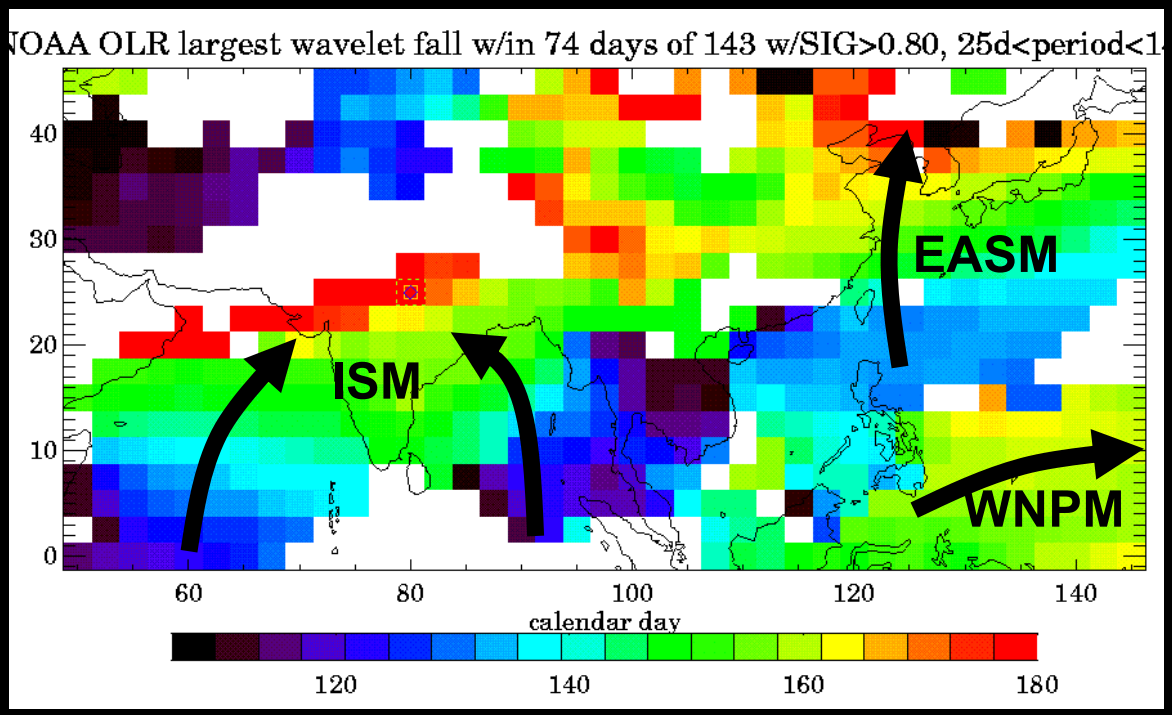
Annual cycle

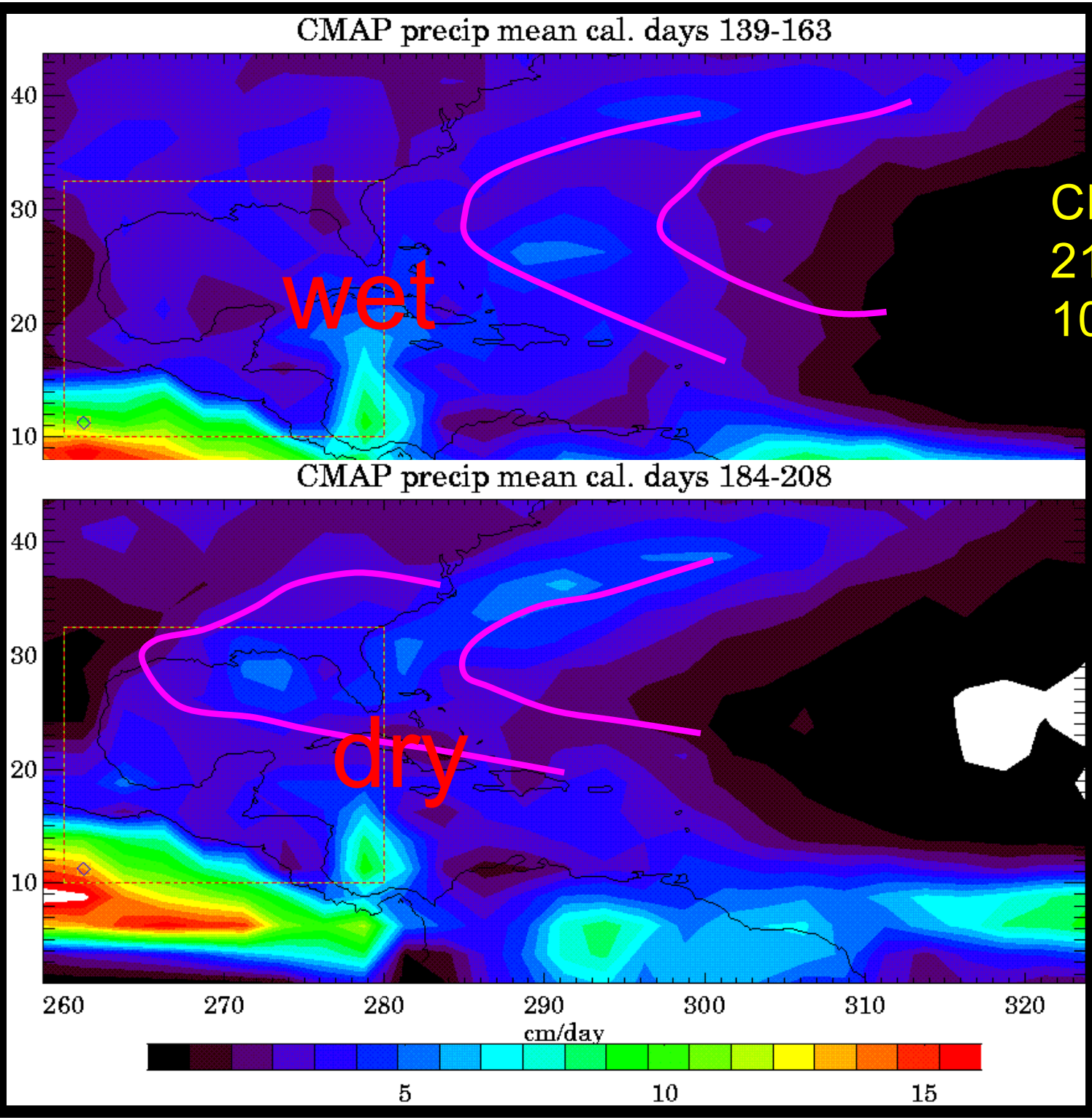
- Holds many mysteries yet
- Involves nonlinear dynamics
  - Formally certain for periods < semiannual
  - Shown for semiannual by Huang & Sardeshmukh
  - Likely for annual harmonic (but must get quantitative)
- Encompasses monsoons in a global framework
- Makes a graded suite of tests for GCMs
- Nice opportunities for model experimentation
  - Few-year runs suffice for significance
  - A way to test un-initialized (climate) models

Linho and Wang 2002

current method

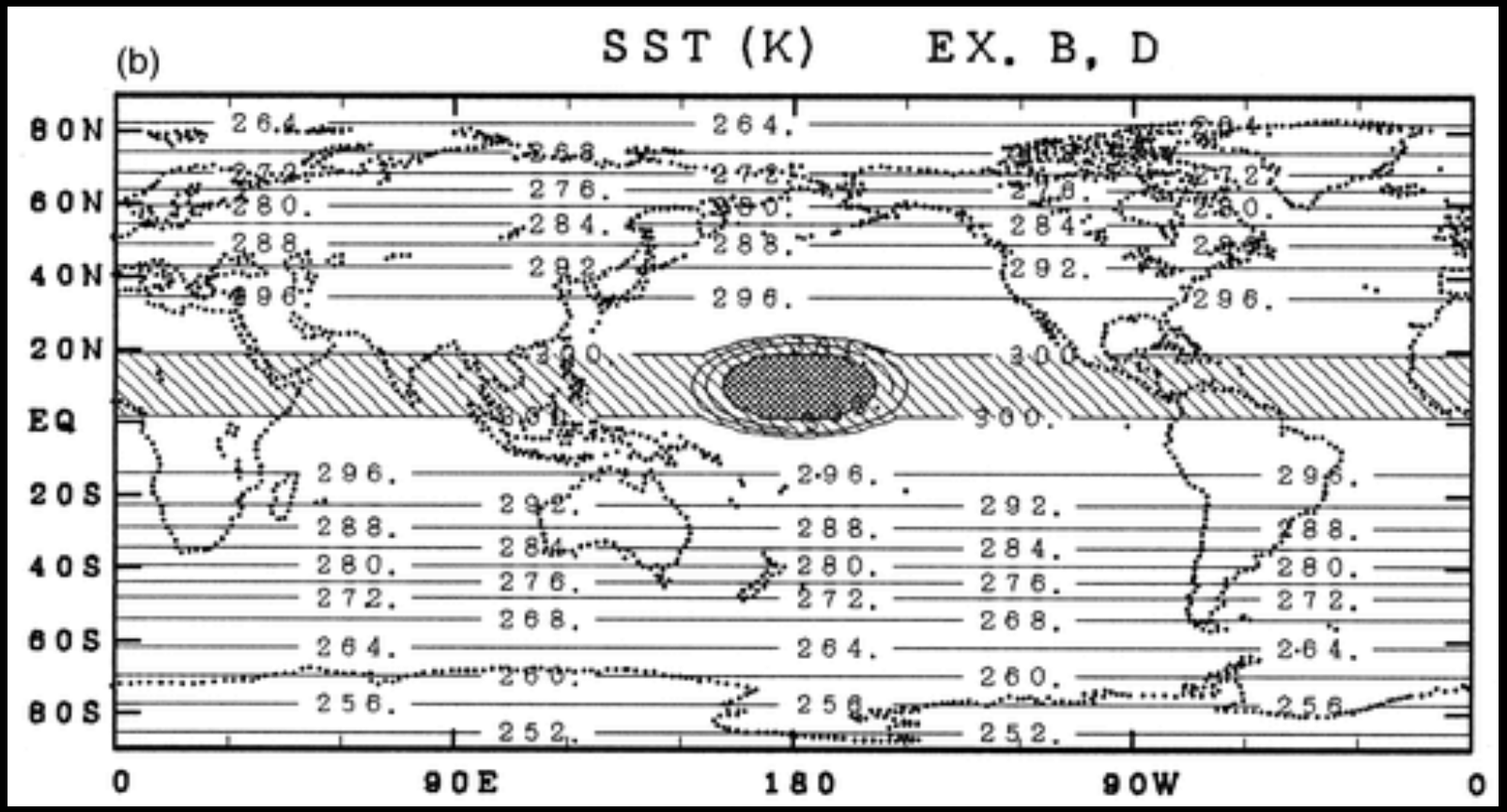





CMAP precip mean cal. days 139-163
40
30
20
10
wet
CMAP
21 Mayo-
10 Junio
CMAP precip mean cal. days 184-208
40
30
20
10
dry
3-27
Julio
260
270
280
290
300
310
320
cm/day
5
10
15

Kodama 1999 aqua-GCM experiments

NH Spring-like background SST with warm pool



Kodama: tropical – extratropical interactions (stronger in spring/fall than in high summer, when H severs link)