CONCURRENT ATMOSPHERE-LAND-OCEAN ANOMALIES

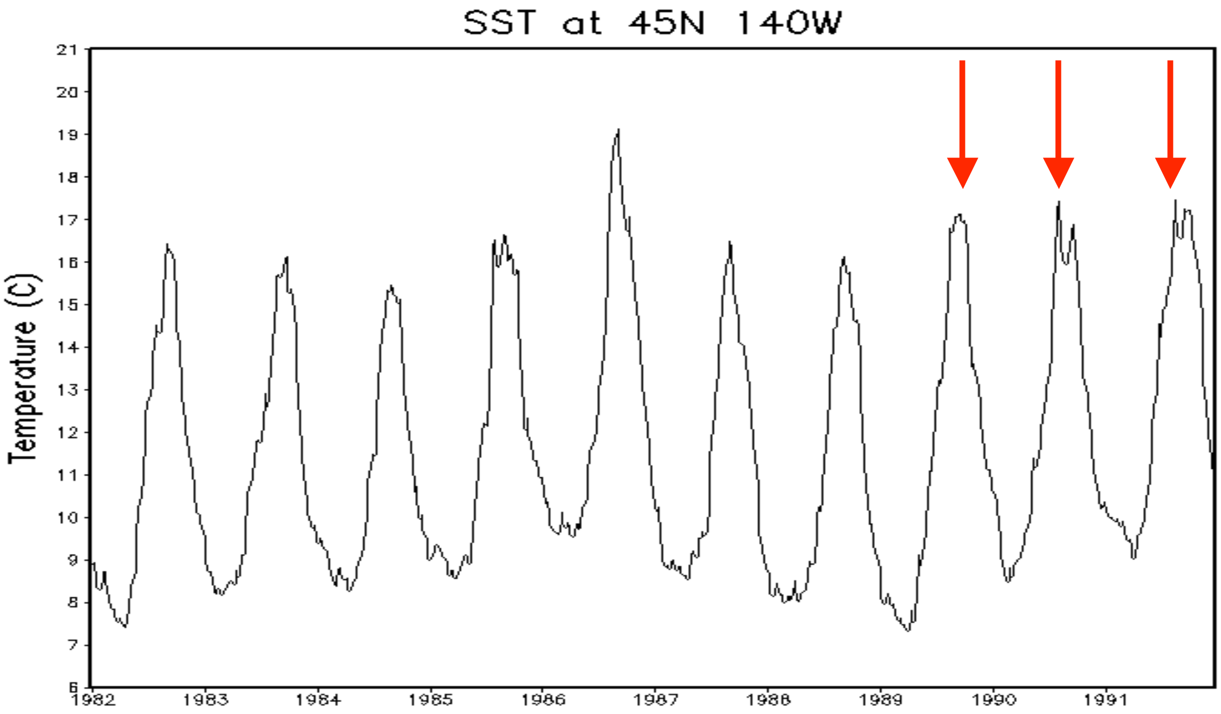
- Time series:
  - Removing short-lived transient anomalies and periodic modes
  - Selecting anomalies: Thresholds, duration
- Local relationships in two-ways and one-way interaction models
  - Empirical rule
  - Cross-correlation
  - Eigen structure
- Causal effects and Local Feedbacks

Timseries of SST and RV

- Ocean, land and atmosphere are here represented, respectively, by SST, ST and 850hPa RV

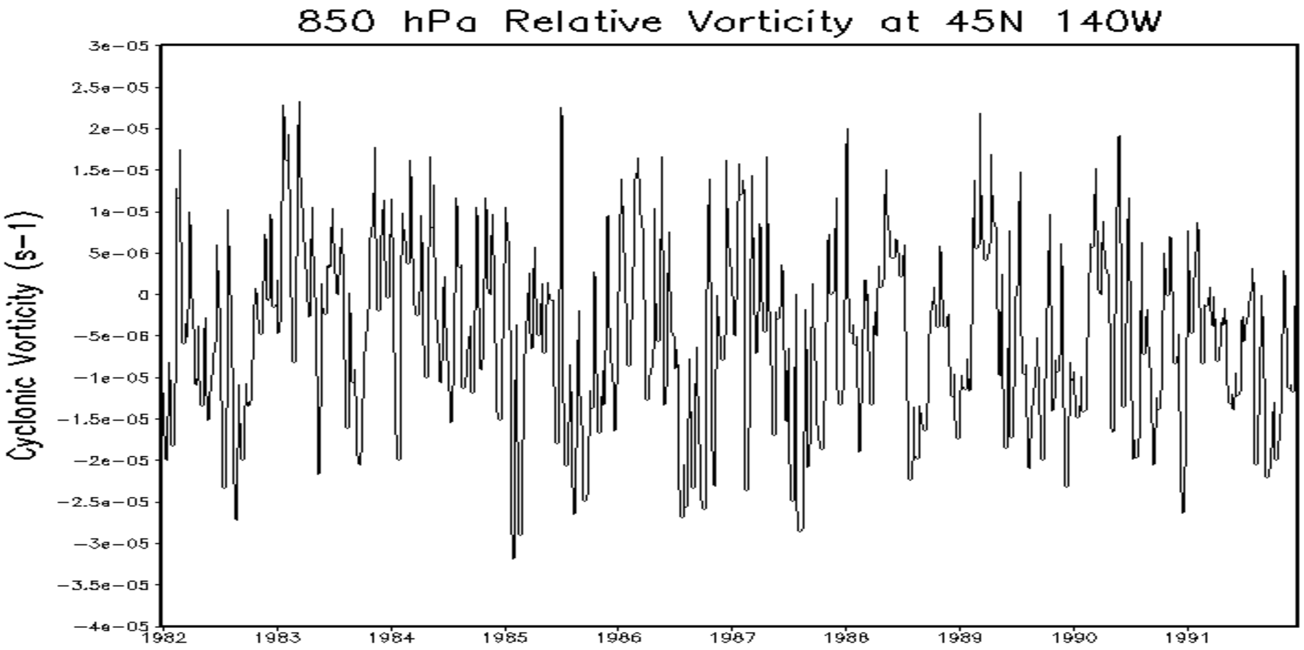
- Daily average data from the NNR. Period 1980-1999. AMIP run for same period.

- Five-days average is performed to the time series of data to filter out mesoscale and smaller-scale anomalies.



SST at 45N 140W

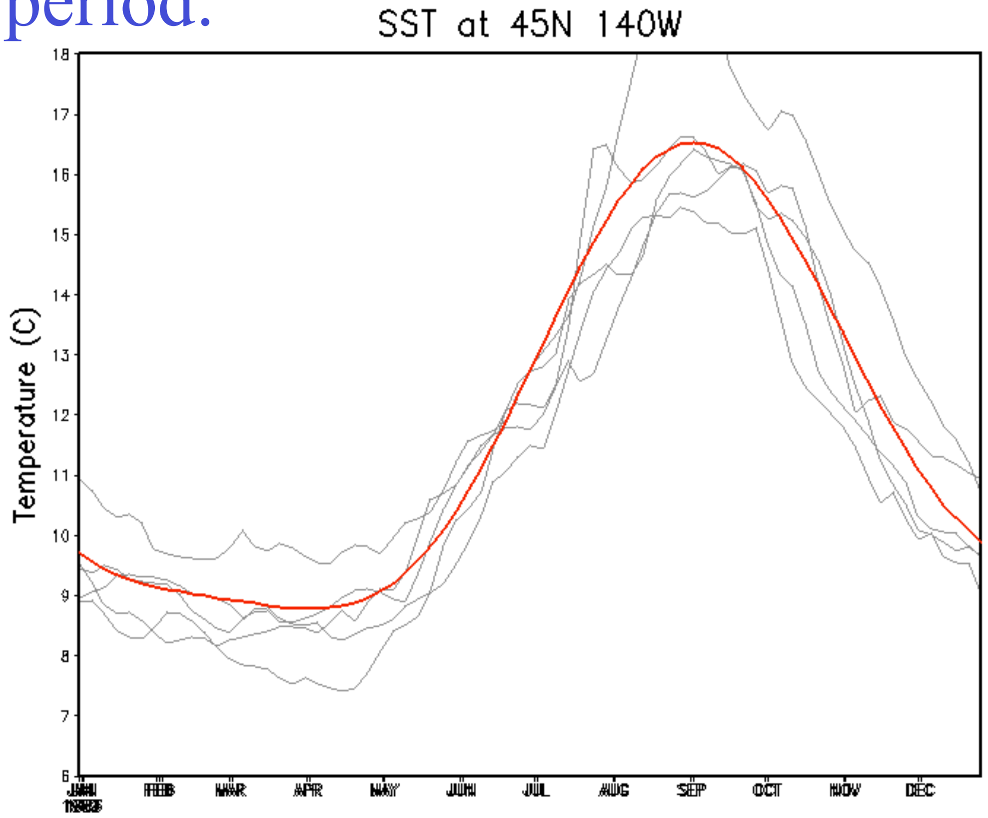
The times series of the SST shows a marked annual cycle, particularly in the extratropics.



850 hPa Relative Vorticity at 45N 140W

… to a much lesser degree, the time series of the relative vorticity also shows an annual cycle.

The structure of the annual cycle is easily seen for example by superimposing the time series into a one-year period:



The red curve was obtained through Fourier analysis of 20 years of 5-days average data. The first four years of data are superimposed in grey color.

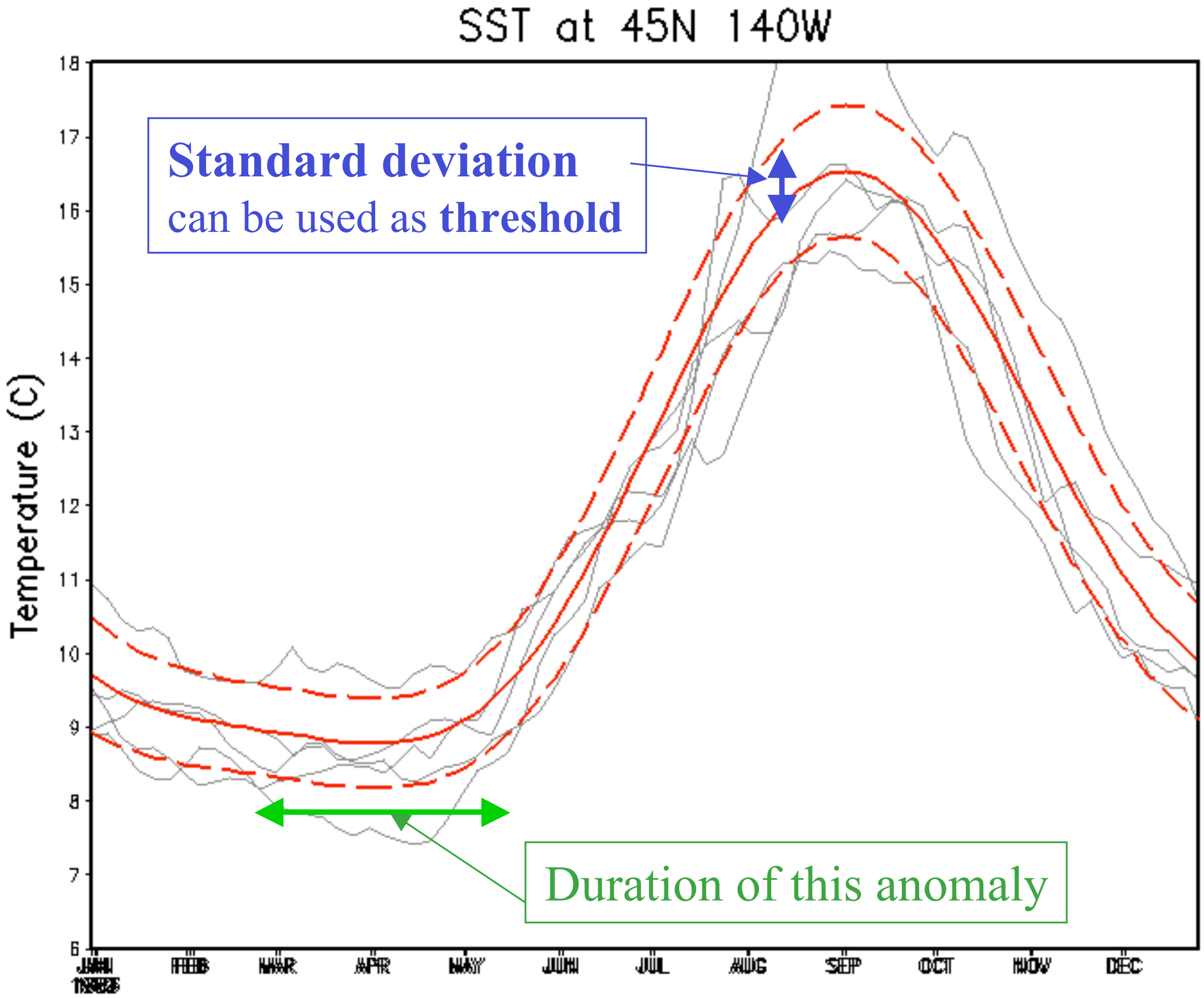
Annual and Semi-annual harmonics

$$Y = A_0 + \sum_{k=1}^{2} A_k \cos(\frac{2\pi}{T} t) + \sum_{k=1}^{2} B_k \sin(\frac{2\pi}{T} t)$$

where

$$A_0 = \frac{1}{N}\sum_{t=1}^{N} y(t), \quad A_k = \frac{2}{N}\sum_{t=1}^{N} y(t)\cos(\frac{2\pi k}{T} t), \quad B_k = \frac{2}{N}\sum_{t=1}^{N} y(t)\sin(\frac{2\pi k}{T} t)$$

Sub-index k **denotes harmonics, *T* is the number of time intervals within a year and *N* is the length of the time series.** **For example, to compute the annual and semi-annual mode (*Y*) of the SST from 20 years of daily data in a given point, substitute: y(t)=SST(t), T=365, and N=20*365 to obtain A_0, A_1, A_2, B_1, and B_2, then substitute in the first equation to obtain *Y*.**



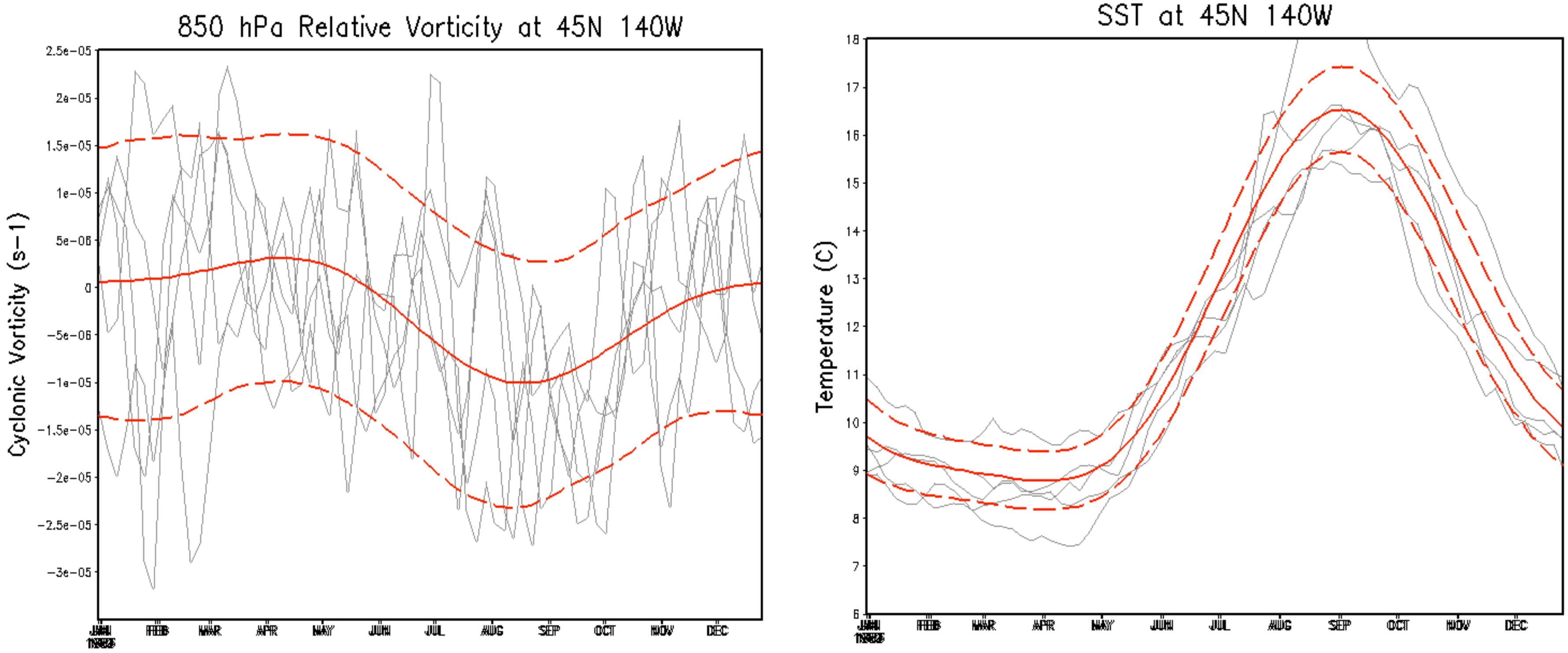
SST at 45N 140W

Standard deviation
can be used as **threshold**

Duration of this anomaly

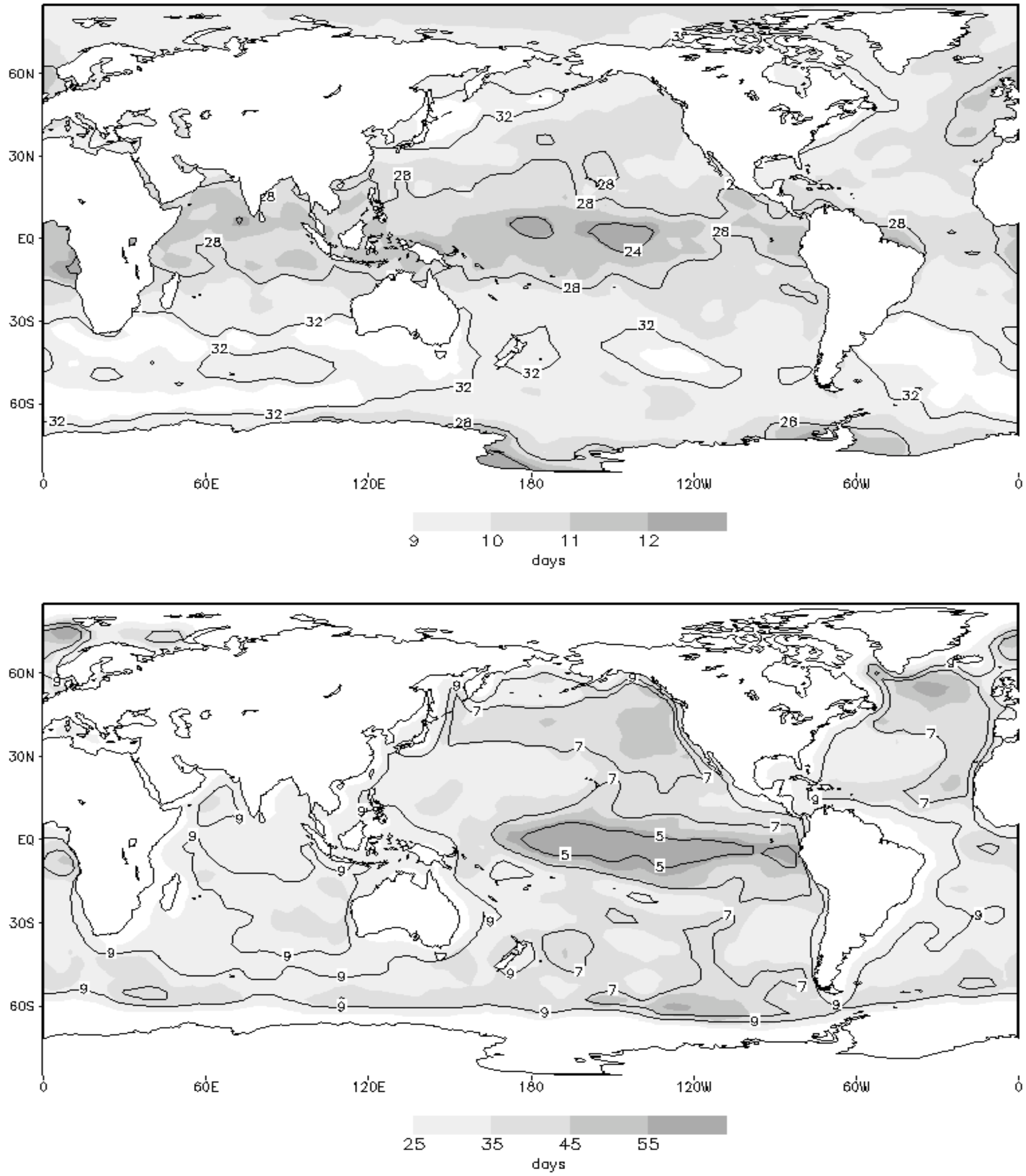
A standard deviation with respect to the annual cycle is then computed, which serves as a threshold to single out high-amplitude anomalies and measure their duration.

Amplitude of the annual cycle, standard deviation and typical durations between SST and 850hPa RV anomalies.



The red curves were obtained based on 20 years of 5-days average data for the SST (left) and the low-level vorticity (right) at the same geographical location. The first four years of data are superimposed in grey color.

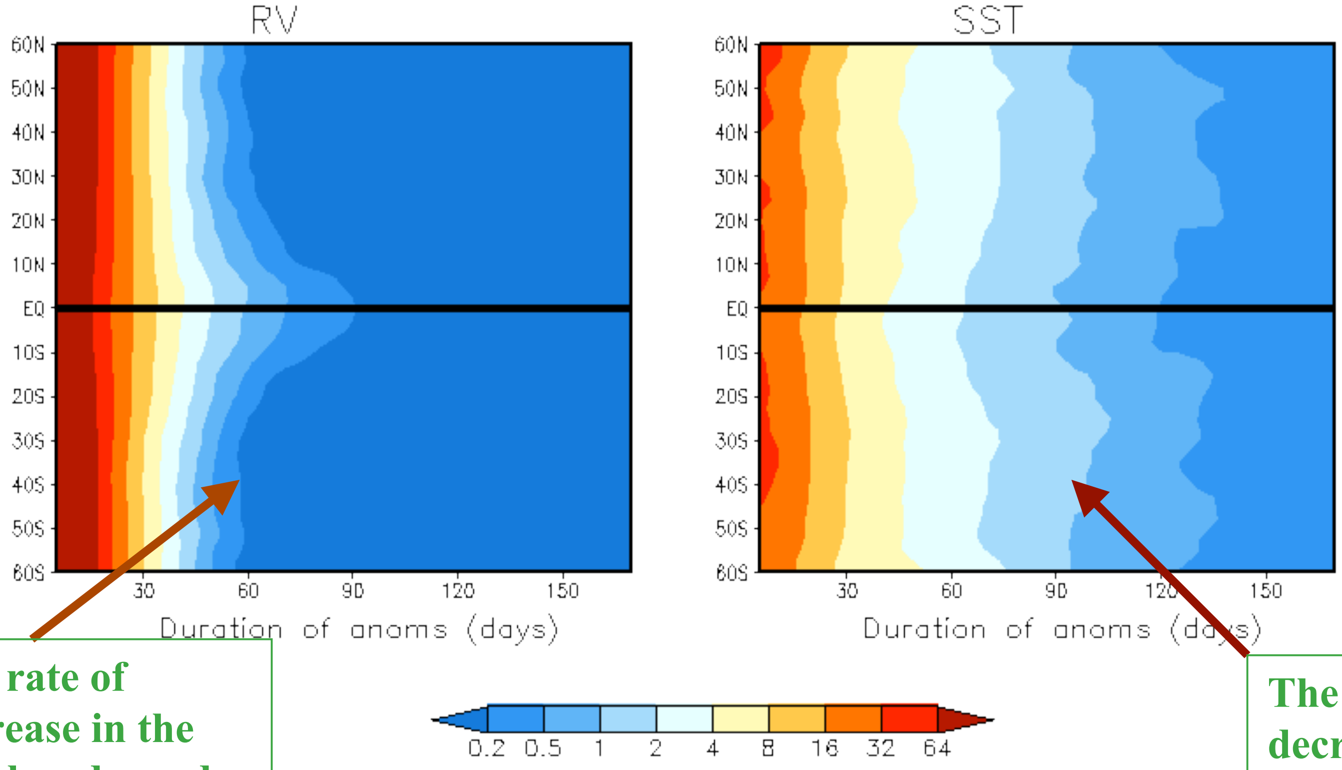
Geographical distribution of anomalies



Annual number (contours) and average life span (shades)

Zonally averaged number of anomalies

Selecting anomalies that exceeded one quarter of the standard deviation (w.r.t. the annual cycle) we counted the number of cases occurring in each grid point over the ocean as a function of their duration. We then computed the zonal average number of cases:

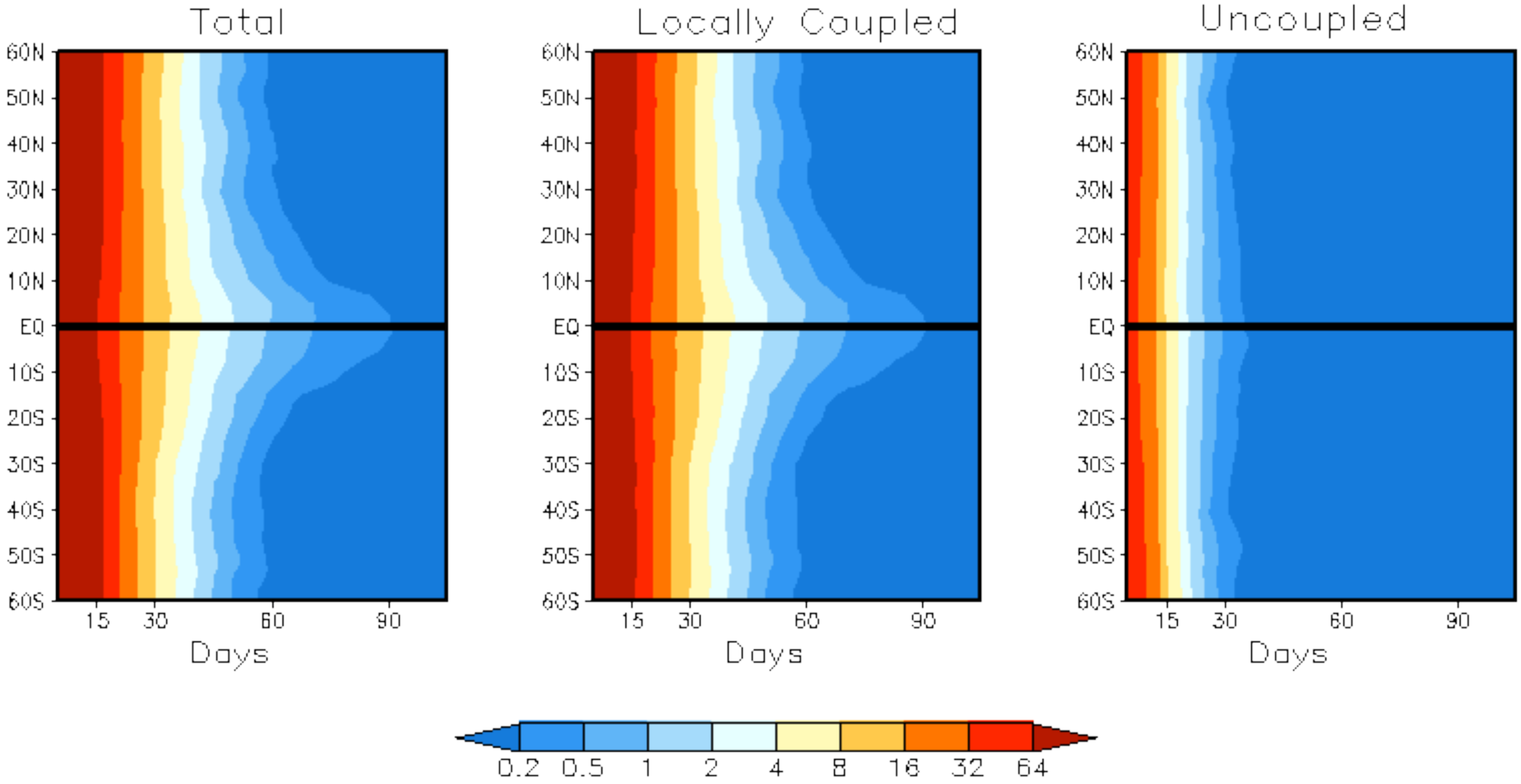


The rate of decrease in the number depends on latitude

colors denote the number of cases

The rate of decrease in the number is smaller than in the atmosphere

Duration of coupled anomalies



colors denote the number of cases

Practically all long-lasting atmospheric anomalies are locally coupled with SST anomalies.

Questions

What are the geographical regions where atmospheric anomalies tend to drive ocean and vice versa in the reanalysis?

How these regions compare with regions in a one-way interaction (AMIP) model?

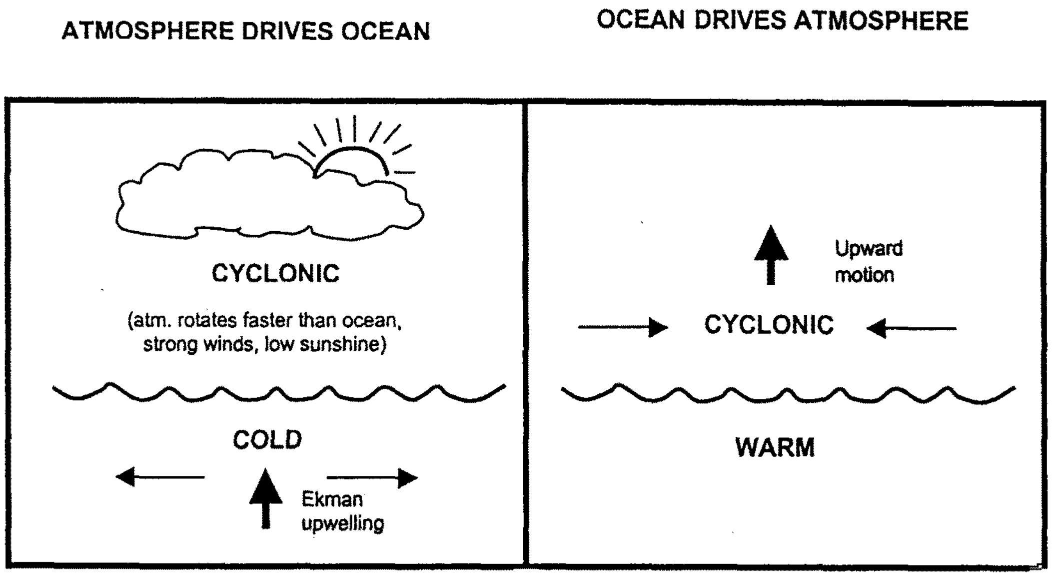
How can we diagnose the forcing direction in locally coupled anomalies?

Dynamical rule approach

1. Select high-amplitude long-lasting anomalies in the time series of atmospheric and oceanic data (threshold technique).
2. Select those anomalies that simultaneously occur in both fields and according to the anomalies’ duration.
3. Apply the diagnostic rule to locally coupled anomalies on a case-by-case basis .
4. Generate frequency distribution maps for atmosphere-driving and ocean-driving anomalies.

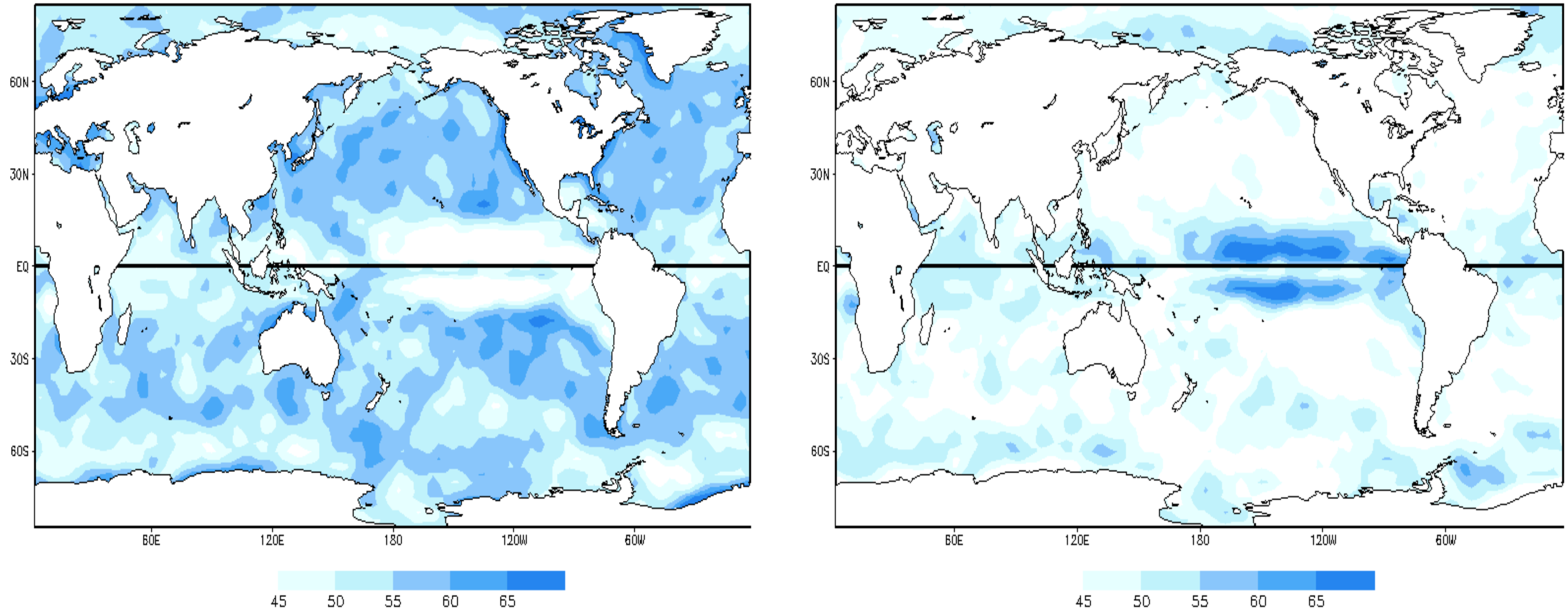
Driving direction in locally coupled anomalies

Schematic of the Mo and Kalnay's Dynamical Rule



When applying this rule to the locally coupled anomalies we obtain:

Percentage Number of Anomalies



Atmosphere-driving anomaly cases

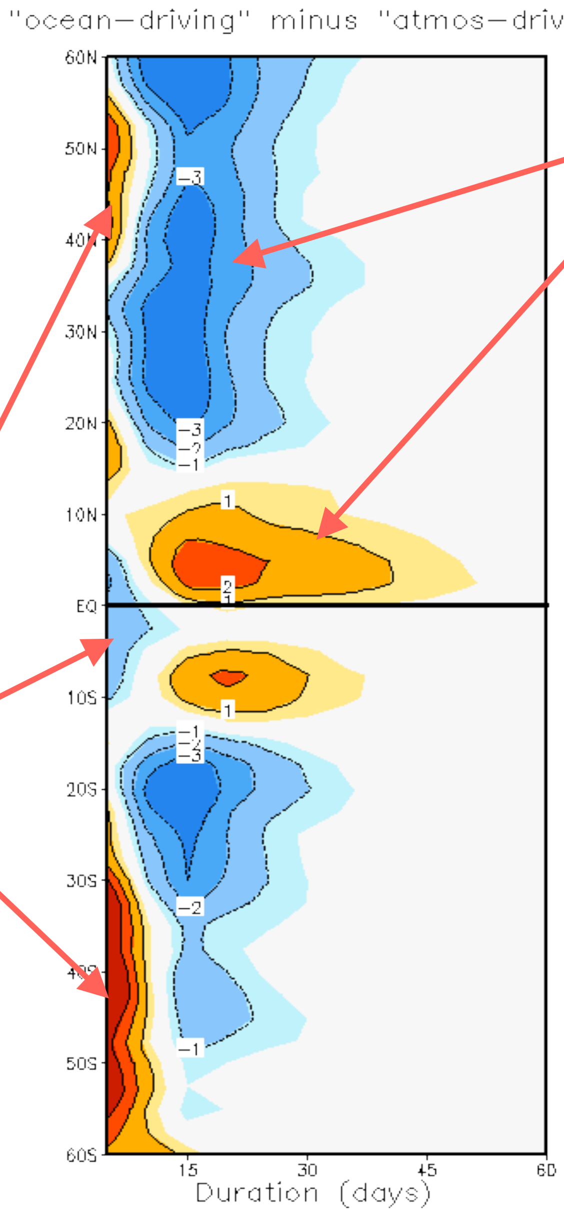
Ocean-driving anomaly cases

Anomalies lasting at least 15 days

Atmosphere-driving cases predominate in the extratropics!

Normal and Abnormal ocean-atmos coupling

“Abnormally coupled” anomalies have shorter duration

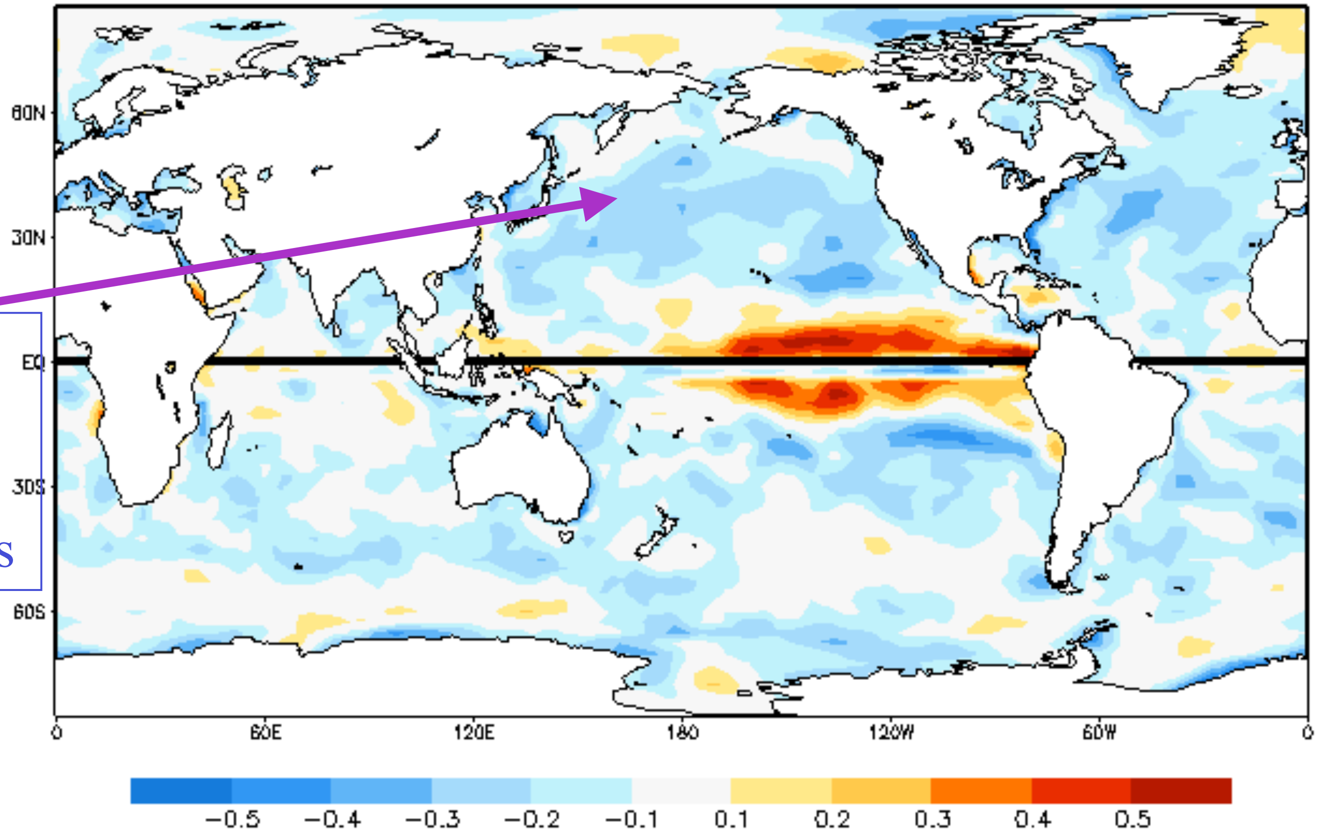


“Normal Coupling”

In the extratropics anomalies with “cyclonic over cold” and “anticyclonic over warm” relationship tend to last longer.

In the tropics “cyclonic over warm” and “anticyclonic over cold” tend to last longer.

Cross-correlation Low-level Cyclonic Vorticity and SST

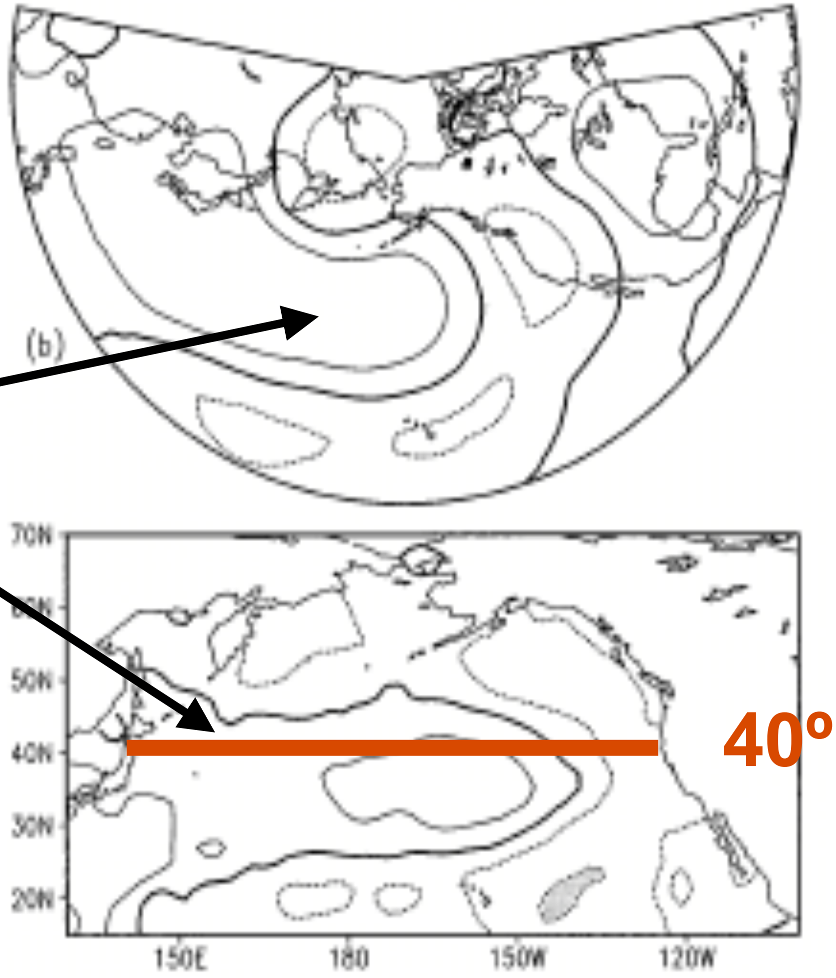


Negatively correlated in the Extratropics

Monthly reanalysis data 1950-1998 (anomalies w.r.t. annual cycle)

Leading mode of covariability

North Pacific



Anticyclonic over Warm:
Atmosphere driving

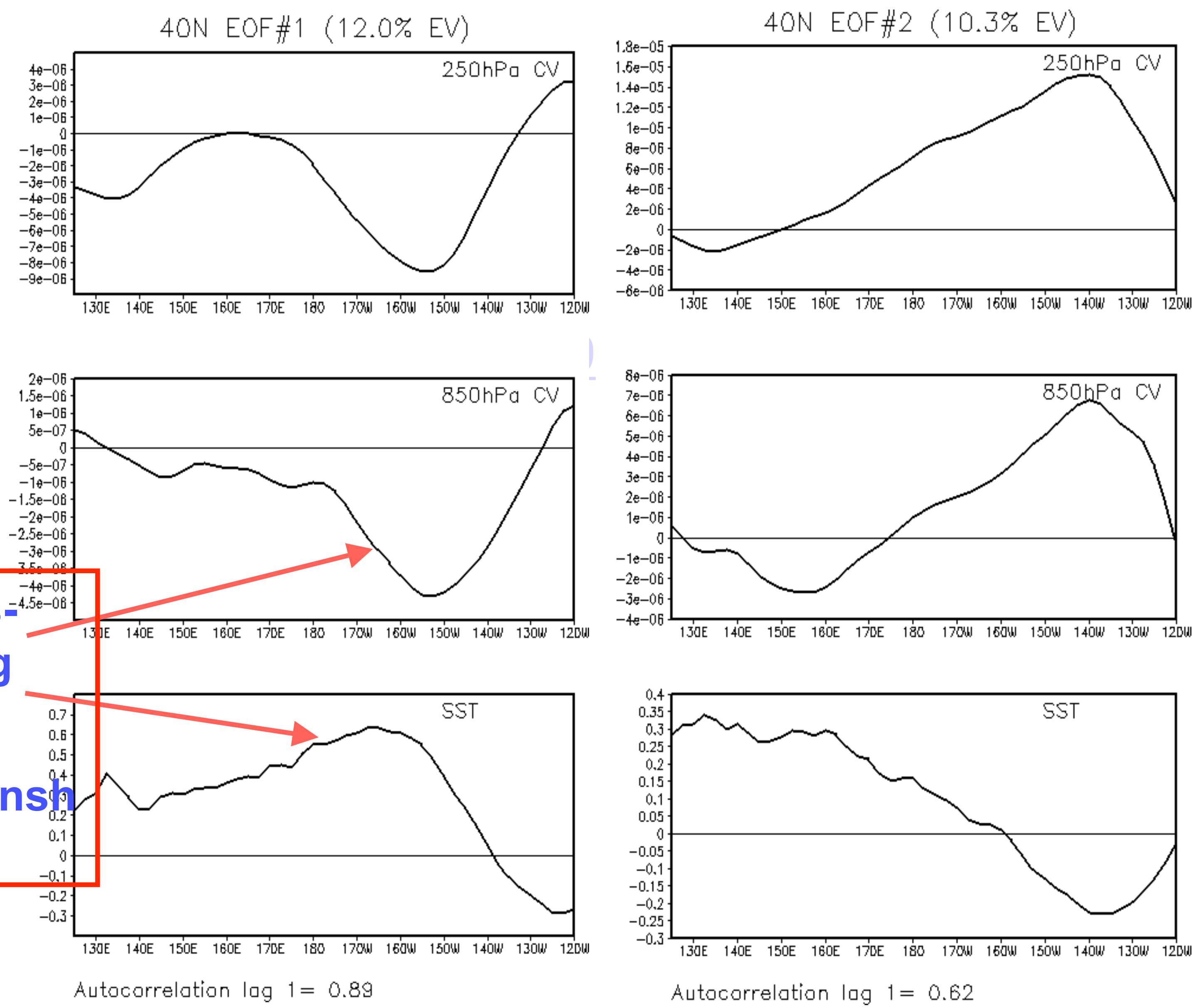
500 hPa height

40ºN

SST

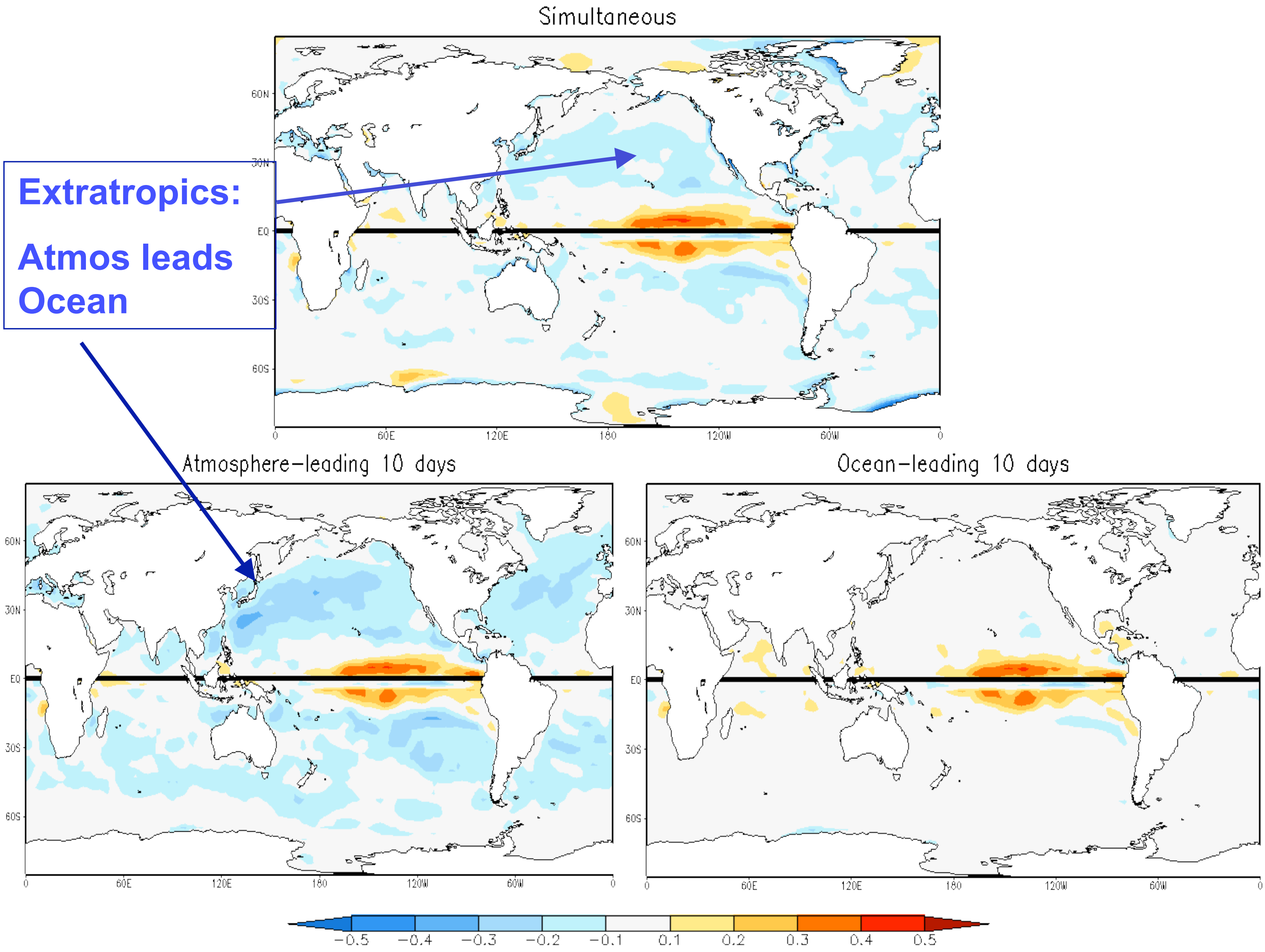
Deser and Timlin 1997

North Pacific Basin-wide modes of covariability



Atmos-driving

Phase relationship



Extratropics:

Atmos leads Ocean

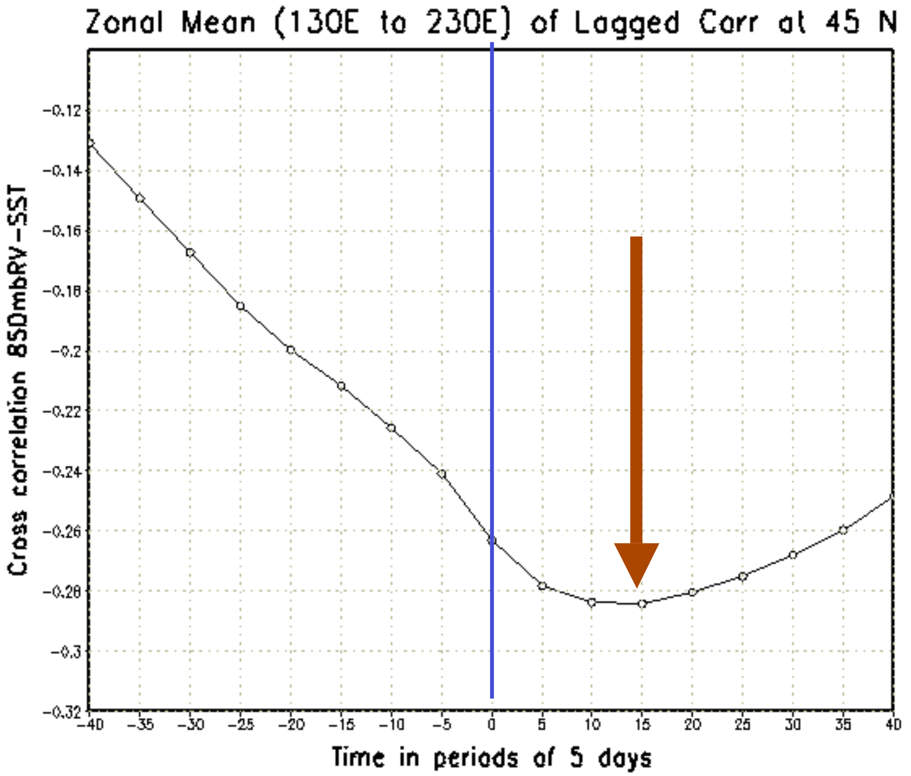
Simultaneous

Atmosphere-leading 10 days

Ocean-leading 10 days

Atmosphere tends to lead

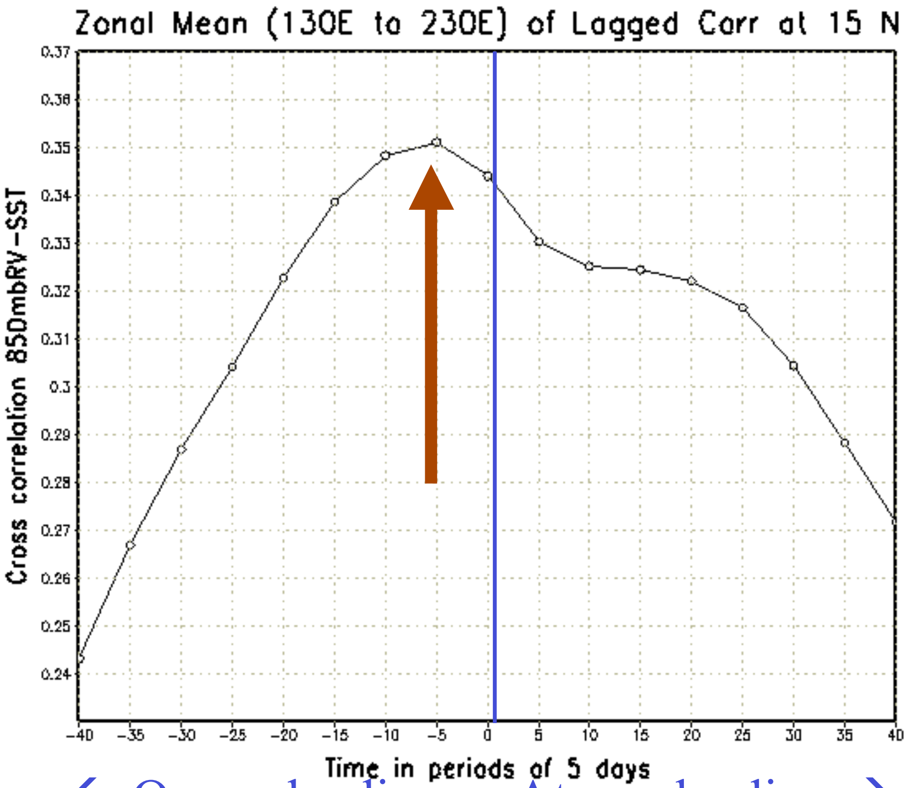
EXTRATROPICS



← Ocean-leading Atmos-leading →

Ocean tends to lead

TROPICS



← Ocean-leading Atmos-leading →

Diagnostic rule

- The geographic distribution of the forcing direction obtained from the diagnostic rule is:
  - Independent on the reanalysis data set used
  - Very similar in the daily, five-day average, and monthly data (no shown).
  - Consistent with Lag-lead correlation technique
  - Consistent with basin-wide modes of variability
- **Knowing the simultaneous phase relationship in a given time we can estimate the local forcing direction.**

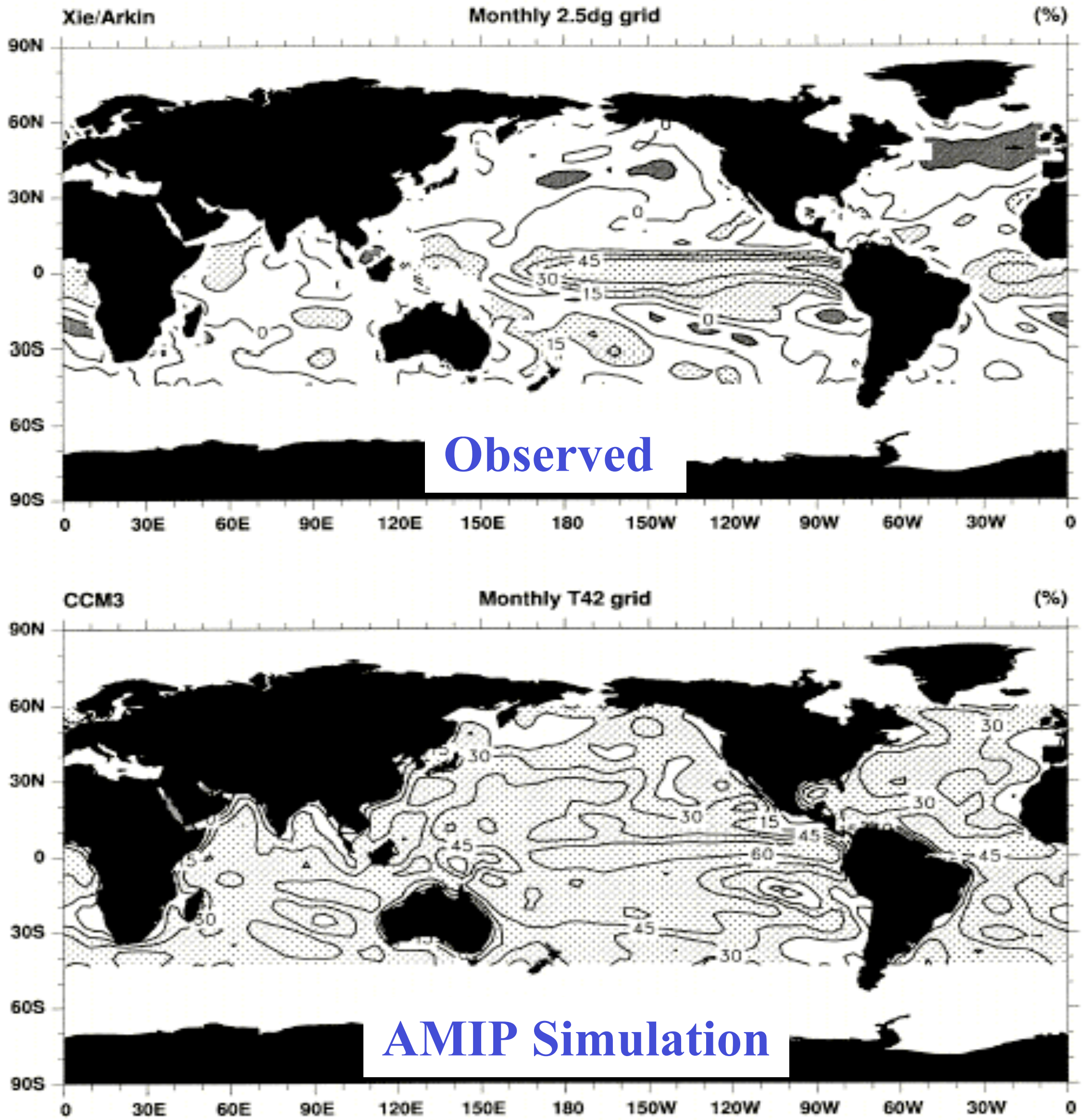
AMIP: one-way interaction scheme

- Atmospheric GCM run with prescribed observed SST (AMIP runs) are usually assumed to be the upper limit for potential predictive skill (“perfect SST”).

- However, they assume (incorrectly) that the ocean *always forces* the atmosphere.

Cross-correlation SST- Precipitation

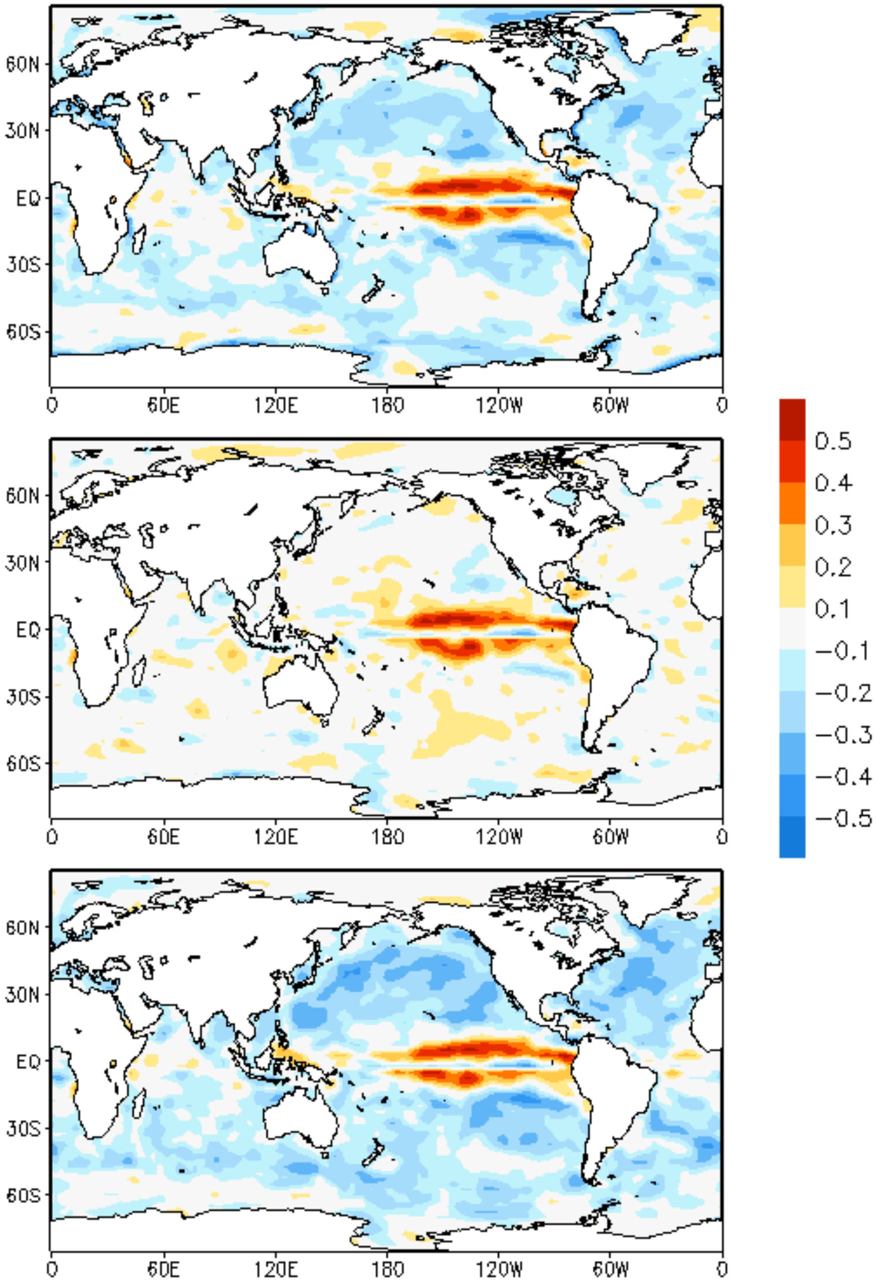
The one-way interaction scenario could yield even a wrong sign in the coupling fluxes!



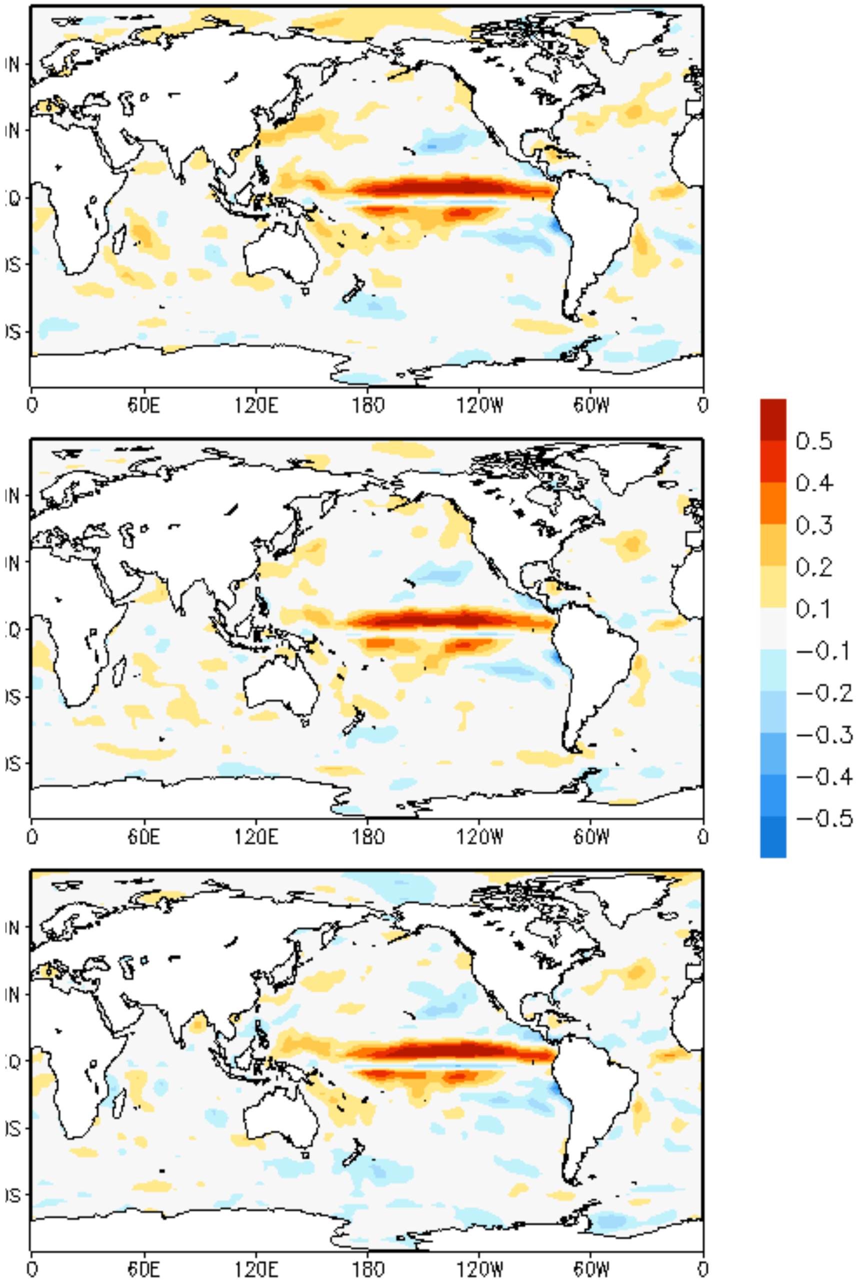
Hurrell and Trenberth, BAMS 1999

CCF CYV-SST

ly **NCEP/NCAR Reanalysis**

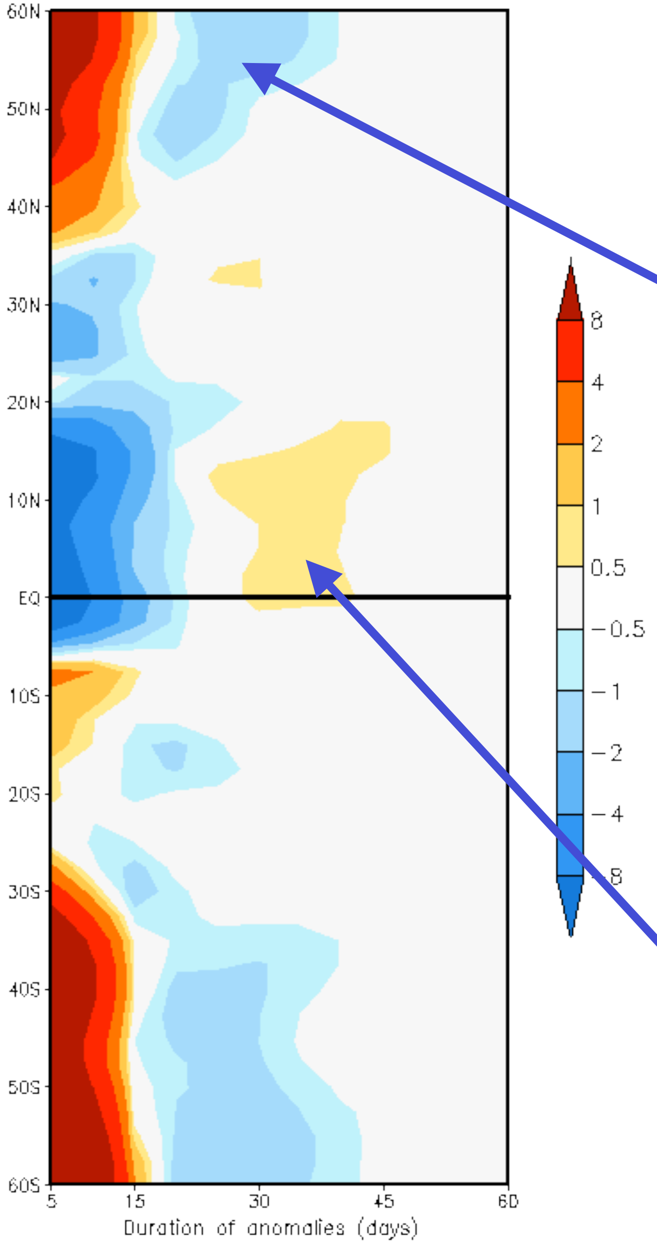


Monthly **AMIP** run



AMIP simulation of anomalies

Number of cases of AMIP simulated minus Reanalysis

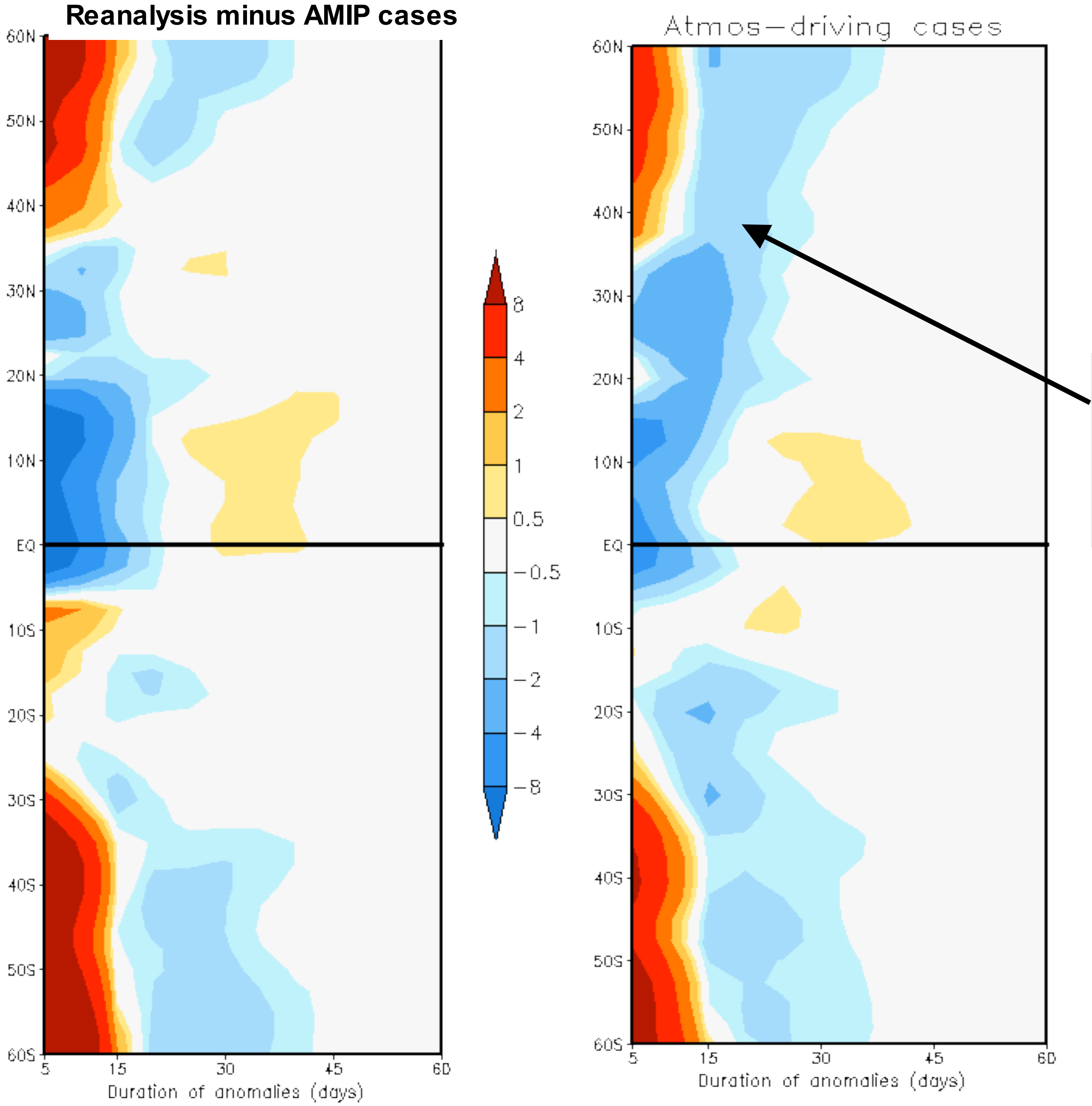


Ignoring the atmosphere's feedback leads to:

Fewer long-lasting simulated anomalies than observed in the extratropics

More long-lasting simulated anomalies in the tropics

AMIP simulation of anomalies



Reanalysis minus AMIP cases

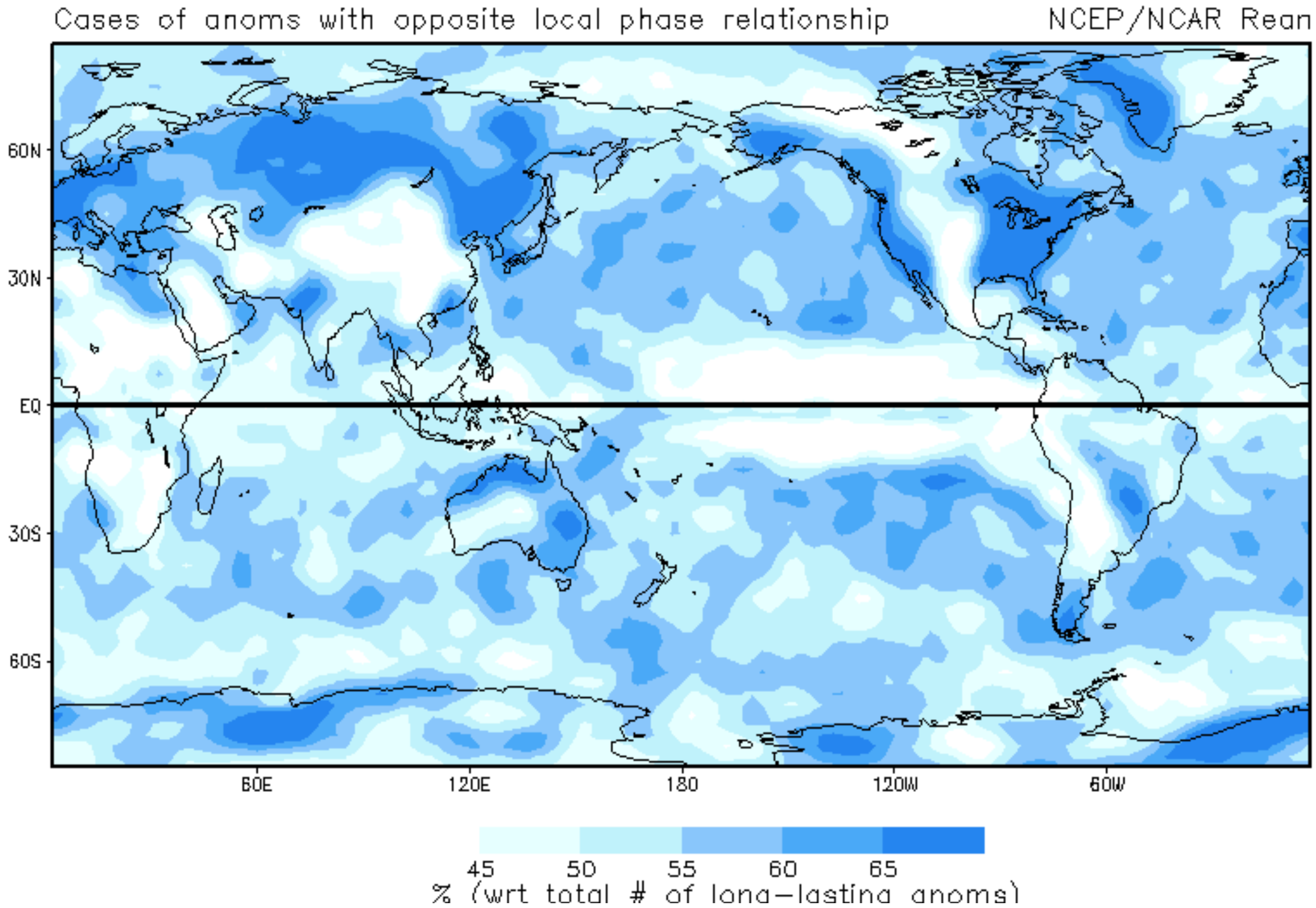
Atmos—driving cases

AMIP ignores these cases in the extratropics

Normal coupling and AMIP run

- Atmosphere-driving in the extratropics and ocean-driving in the tropics constitute the “normal coupling”.
- There are “abnormal coupled anomalies” (atmosphere-driving in the tropics and ocean-driving in the extratropics), but they are invariably short-lived.
- As a result, in AMIP runs (where the ocean is <u>always</u> forcing the atmosphere) there are too many long lasting anomalies in the tropics, and too few in the extratropics

Distribution of 15-days or longer-lasting anomalies

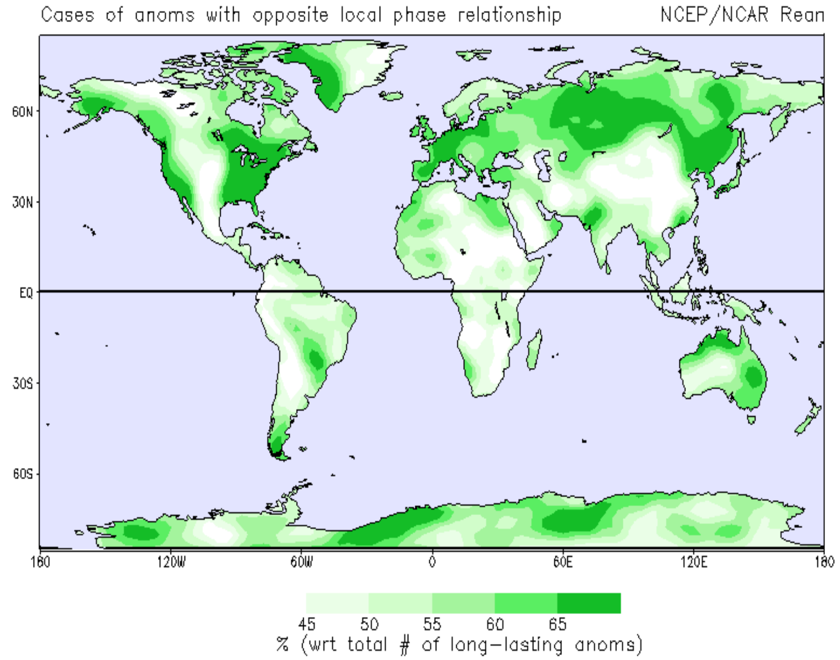


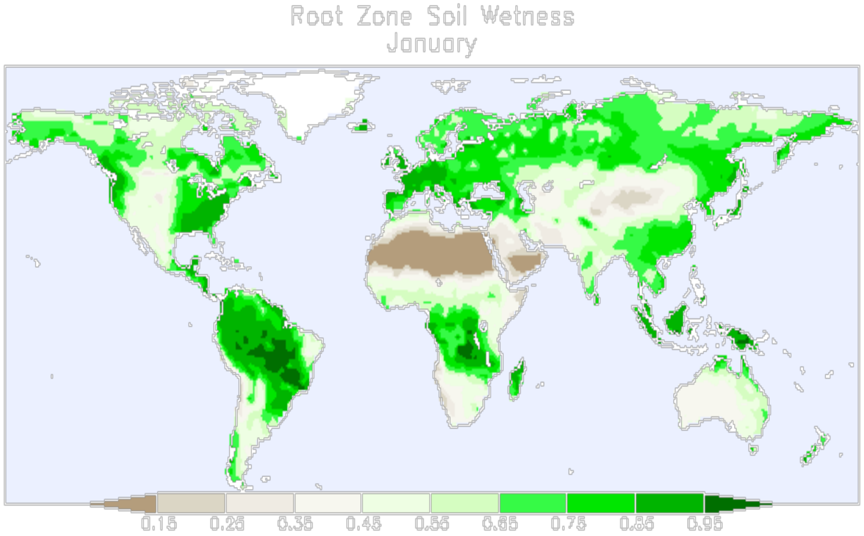
Long lasting anomalies have a preferential local phase relationship between vorticity and surface temperature

Local phase relationship and Soil Moisture

Relationship
Low-level circulation-Skin Temperature

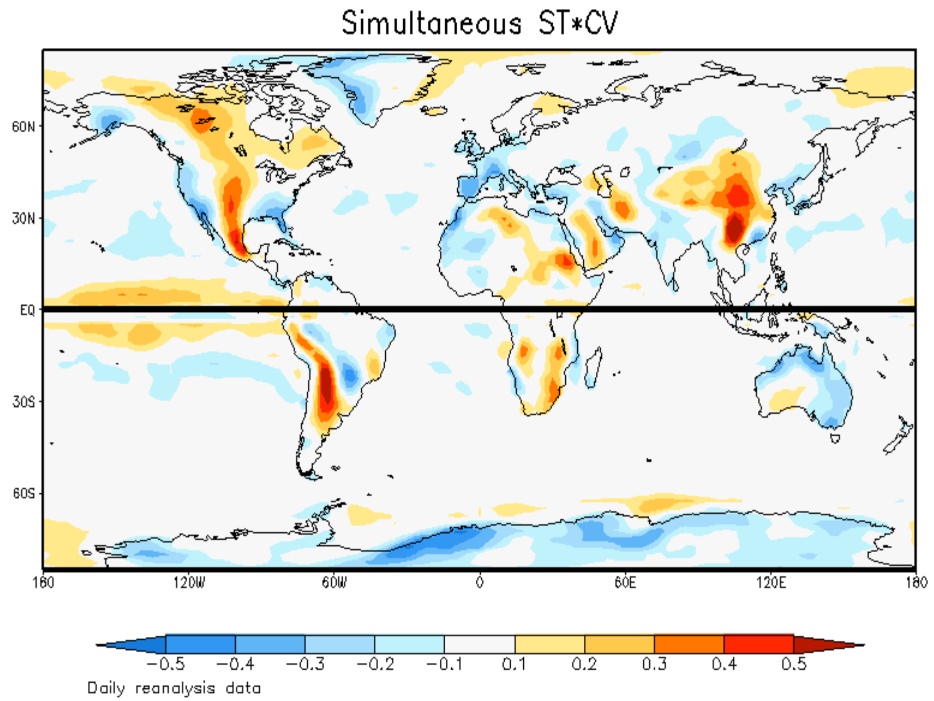
Soil Moisture



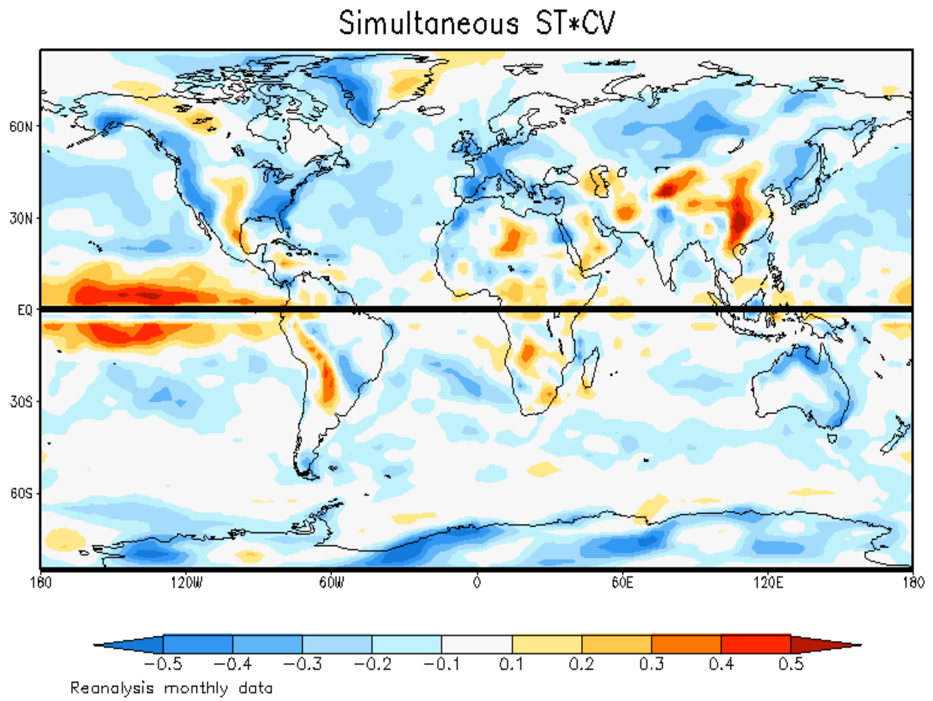


Cross-correlation 850hPa CV and ST

Daily



Monthly



Energy- and moisture-limited regions

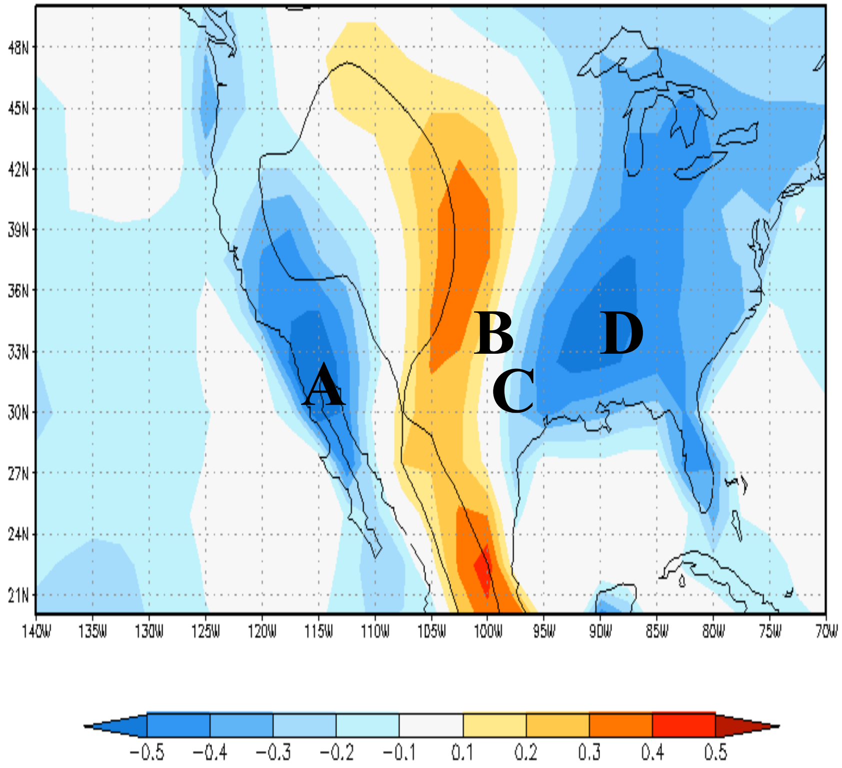
Considering the ST-Precipitation feedback:

The vegetative and wet region of the SE US requires large amounts of energy to induce significant changes in ST.

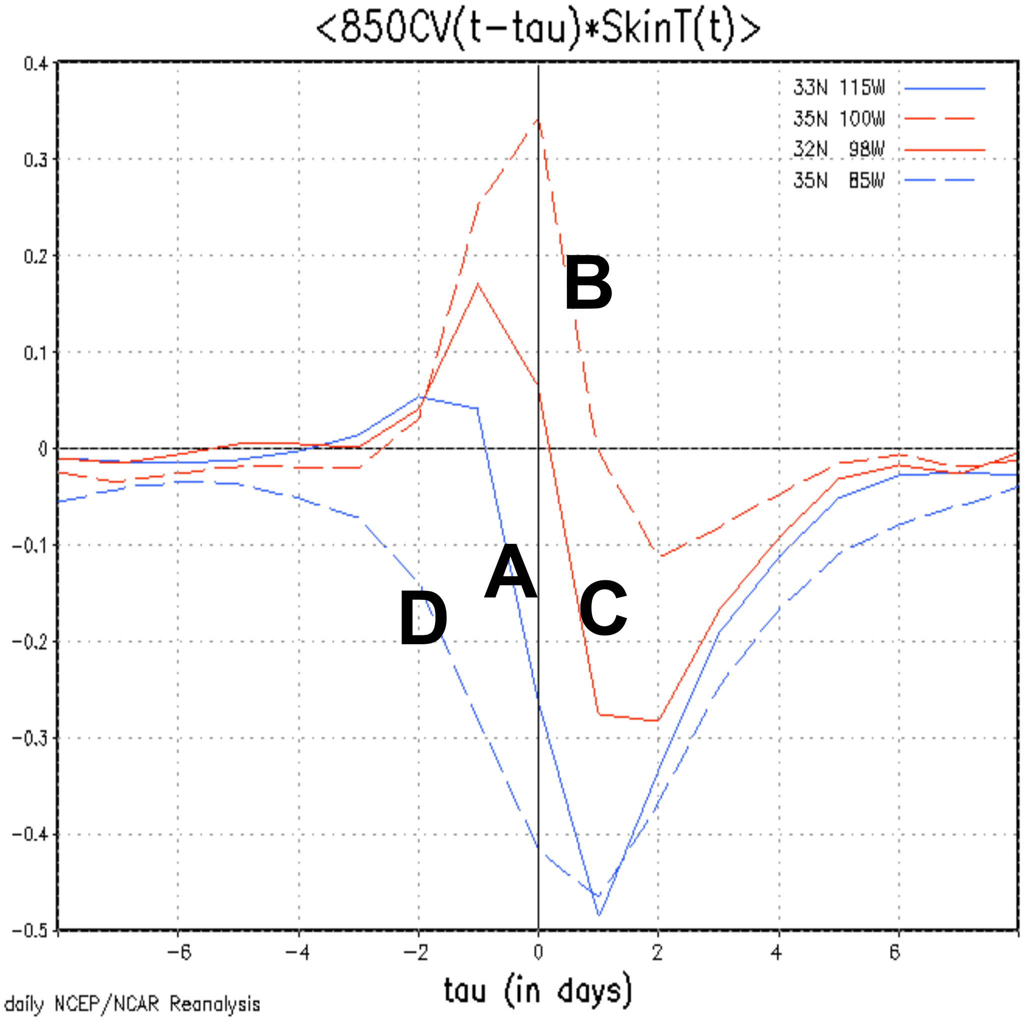
The very dry region of the SW US requires large amounts of moisture to produce changes in the precipitation regime.

Regional differences over the U.S.

May-October 20 years



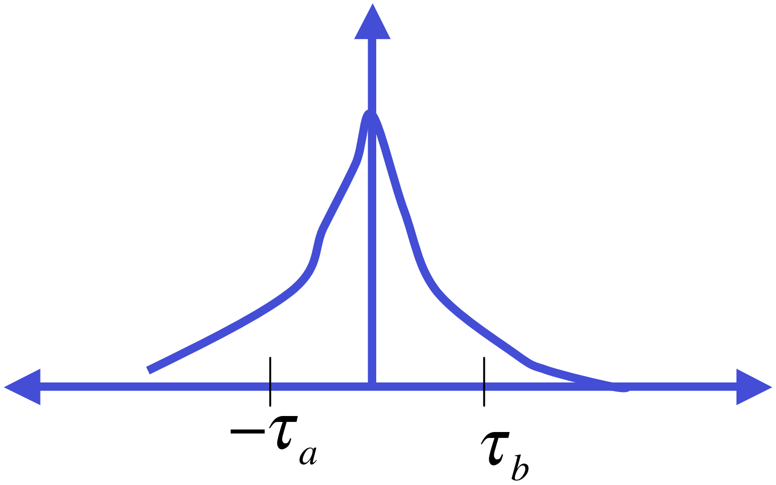
Five-day average data from N/N Reanalysis



1980–1998 daily NCEP/NCAR Reanalysis

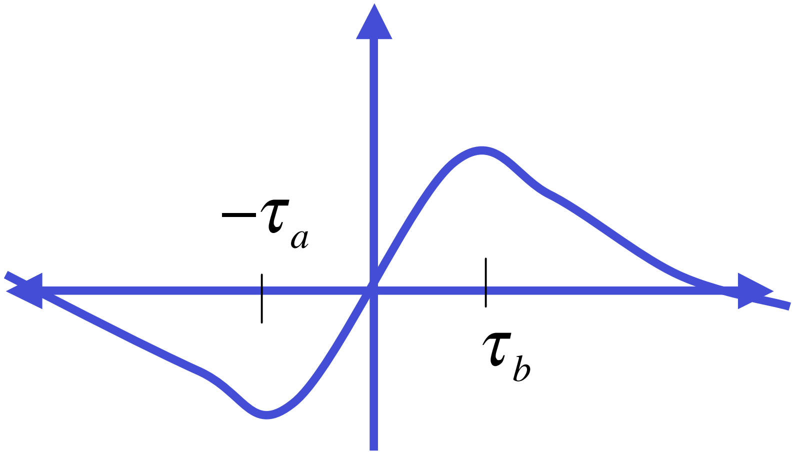
Interpretation of correlation as a function of Lag

Symmetric: Either positive feedback or a third element is causing both to vary.



At $t=-\vartheta_a$: U>0 produces V>0, in turn, at a later time ($t=\vartheta_b$), V>0 produces U>0.

Asymmetric: Negative feedback.



At $t=-\vartheta_a$: U>0 produces V<0, at a later time ($t=\vartheta_b$)
V<0 would necessarily imply U<0.

Land-Atmosphere coupling

- There is a preferential phase relationship of long-lasting anomalies over the continents.
- Over the very wet and very dry regions, the normal coupling is characterized by "cyclonic over cold" "anticyclonic over warm".
- Over regions to the east of high range mountains, such as the Rockies, the normal coupling is "cyclonic over warm"

Appendix 1

To download Reanalysis data from CDC's public web page go to http://www.cdc.noaa.gov/cdc/reanalysis

And select the file, domain, period of time, etc. This automatically generates either a figure or a data set, which can be downloaded using instructions provided in the webpage or via FTP:

ftp.cdc.noaa.gov/Public/www

Login as anonymous and enter your e-mail as password. The file downloaded has a NetCDF format. GrADS can read this type of files.

APPENDIX 2

```
 SUBROUTINE AVEF(x,j2,id,igp,iys,idy,xanc)
c     This subroutine computes the annual and semiannual
c     harmonics of a time series X
c     igp           number of gridpoints
c     id            length of the time series (e.g., 3650 if 10years of
c                   daily data)
c     idy           number of elements in the year (e.g. 365 days)
      real x(id,igp)
      real xanc(idy,igp)    !annual cycle for each gridpoint
c
      xa0cum = 0
      xa1cum = 0
      xa2cum = 0
      xb1cum = 0
      xb2cum = 0
      x2pi = 2*3.1415926536
      do 10 k=1,id
        xa0cum = xa0cum + x(k,j2)
        xa1cum = xa1cum + x(k,j2)*cos(x2pi*k/float(idy))
        xa2cum = xa2cum + x(k,j2)*cos(x2pi*2*k/float(idy))
        xb1cum = xb1cum + x(k,j2)*sin(x2pi*k/float(idy))
        xb2cum = xb2cum + x(k,j2)*sin(x2pi*2*k/float(idy))
10      continue
      xa0 = xa0cum/float(id)
      xa1 = 2*xa1cum/float(id)
      xa2 = 2*xa2cum/float(id)
      xb1 = 2*xb1cum/float(id)
      xb2 = 2*xb2cum/float(id)
c
      do 20 k=1,idy
       xanc(k,j2)=xa0 + xa1*cos(x2pi*k/float(idy)) +
     . xa2*cos(x2pi*2*k/float(idy)) + xb1*sin(x2pi*k/float(idy)) +
     . xb2*sin(x2pi*2*k/float(idy))
20      continue
      return
      end
```

FORTRAN Code to compute lag and lead cross-correlation Using IMSL libraries available in the Department’s Alpha computers

```fortran
      INTEGER    IPRINT, MAXLAG, NOBS,IMEAN,ISEOPT
      PARAMETER (NOBS=1387)  !Full time series (5-day running mean)
      PARAMETER (ngp=144*69) !igp=144 ilt=69  equator's latitude = 35
      PARAMETER (IPRINT=0, MAXLAG=8, IMEAN =1, ISEOPT=1)!Bartlet Gral.
case
      PARAMETER (nvd=4+2*MAXLAG+1)  !number of variables to display
      PARAMETER (idy= 73)       !periods in a year 73*5 = 365
c
c     Variable declaration
      real X(NOBS),XMEAN,XBAR         ! Relative Vorticity
      real Y(NOBS),YMEAN,YBAR         ! Skin Temperature
      real       CC(-MAXLAG:MAXLAG), CCV(-MAXLAG:MAXLAG),
     &           SECC(-MAXLAG:MAXLAG)
      real cyv(ngp,NOBS),skt(ngp,NOBS)
      real accyv(ngp,idy),acskt(ngp,idy)
      real z(nvd,ngp)
c
      EXTERNAL CCF
c----------------------  INPUT UNITS  --------------------
      open(10,file='cyv5day.grd',
     &status='old',access='direct',form='unformatted',recl=ngp)
      open(15,file='ac.grd',
     &status='old',access='direct',form='unformatted',recl=ngp)
      open(20,file='skt5day.g.grd',
     &status='old',access='direct',form='unformatted',recl=ngp)
      open(25,file='ac.grd',
     &status='old',access='direct',form='unformatted',recl=ngp)
c
c----------------------  OUTPUT UNITS  --------------------
      open(30,file=‘ccf.vt.grd',status=
     &  'unknown',access='direct',form='unformatted',recl=ngp)
c---------------------------------------------------------------
       irec=1
      do k=1,idy
        read(15,rec=irec)(accyv(i,k),i=1,ngp) !annual cycle
        read(25,rec=irec)(acskt(i,k),i=1,ngp) !annual cycle
        irec=irec+1
      enddo
```

```fortran
      irec=1
      do k=1,NOBS
        read(10,rec=irec)(cyv(i,k),i=1,ngp) !cyv
        read(20,rec=irec)(skt(i,k),i=1,ngp) !skt
        irec=irec+1
      enddo

c
      l=1
      do i=1,ngp
        do k=1,NOBS
          ka = mod(k,idy)
          if(ka.eq.0)ka=idy
          x(k)= cyv(i,k) - accyv(i,ka)
          y(k) = skt(i,k) - acskt(i,ka)
c
        enddo
        CALL CCF(NOBS, X, Y, MAXLAG, IPRINT, ISEOPT, IMEAN, XMEAN
     &    YMEAN, XVAR, YVAR, CCV, CC, SECC)
        z(1,l) =xmean
        z(2,l) =ymean
        z(3,l) =xvar
        z(4,l) =yvar
        n2 = 1
        do n=-MAXLAG,MAXLAG
          z(4+n2,l) =cc(n)
          n2=n2+1
        enddo
        l=l+1
      enddo
c
      irec=1
      do k=1,nvd
        write(30,rec=irec)(z(k,l),l=1,ngp)
        irec=irec+1
      enddo
c
      stop
      end
c
C source /usr/local/src/vni-3.0/CTT3.0/ctt/bin/cttsetup.csh
CC f90 ccfvt.1000.f $LINK_FNL
C a.out > salida.s
```

To compute the SVD decomposition call the following IMSL subroutine: DLSVRR

To find this and other subroutines with examples go to: http://gams.nist.gov/

References

1. Deser and Timlin, 1997:Atmosphere-Ocean interaction on the weekly timescales in the North Atlantic and Pacific, *J. Climate*, *10*, 393–408.
2. Hurrel and Trenberth, 1999:Global SST analyses: Multiple problems and their implications for climate analysis, modeling and reanalysis, *Bull. Amer. Meteor. Soc.*, *80*, 2661–2678,
3. Mo and Kalnay, 1991:Impact of the sea surface temperature anomalies on the skill of monthly forecasts, *Mon.Wea.Rev.*, *119*, 2771–2793.
4. Pena, Kalnay and Cai, 2002: Statistics of coupled ocean and atmospheric anomalies. Nonlinear Processes in Geophys., 10, 245-251.