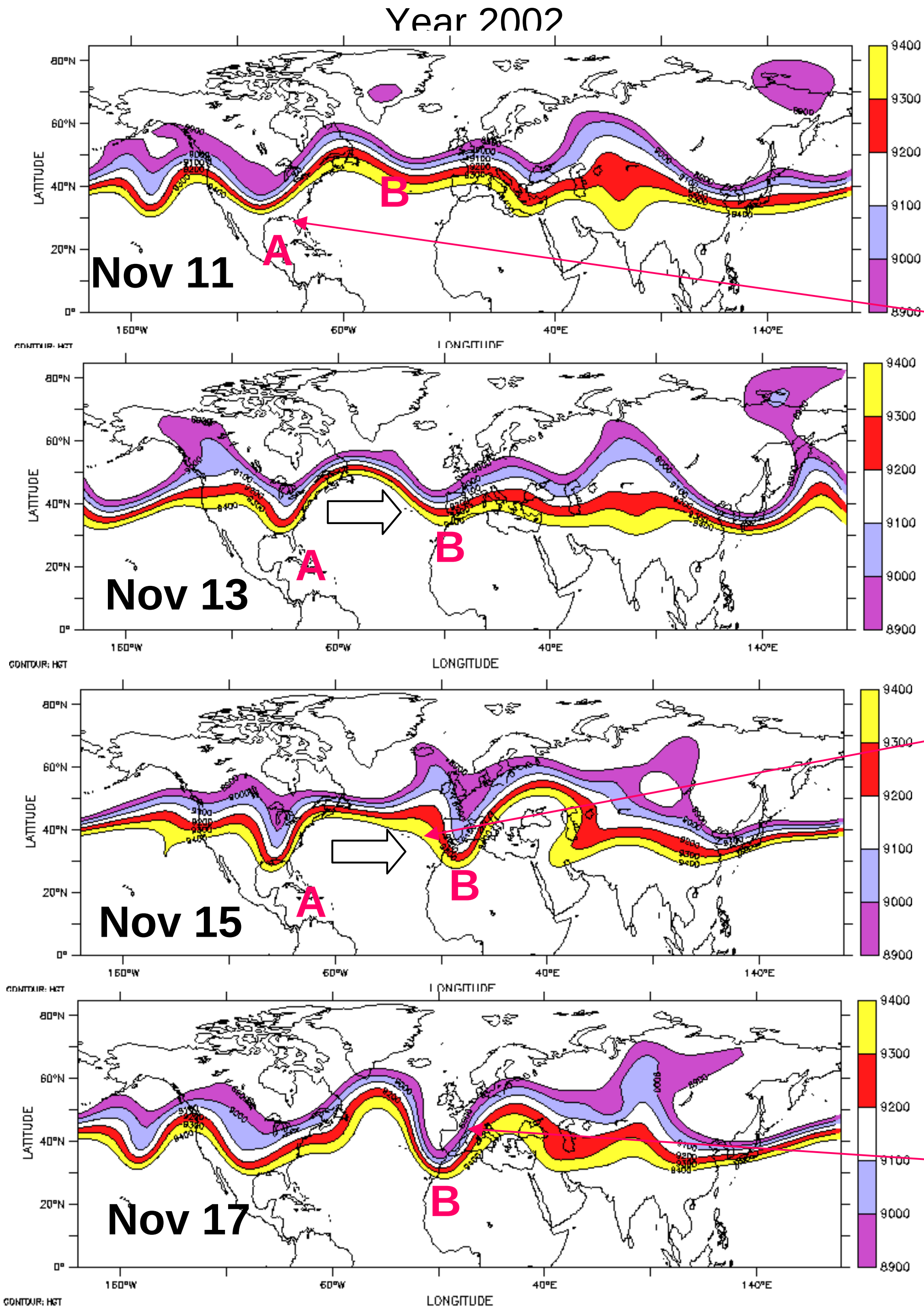
Lecture 4:

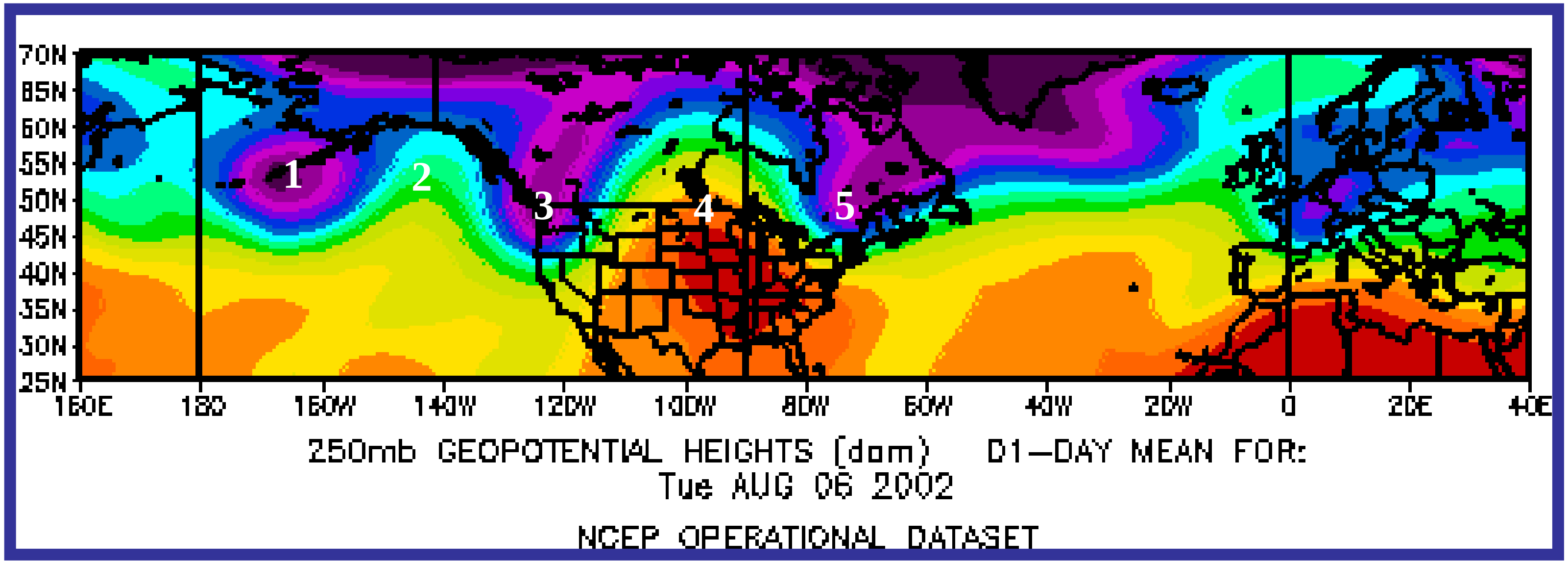
The Effects of Daily Weather on the Inter-annual Variability Patterns

- Extreme events, the power of one storm
- The middle latitudes response to Tropical heating The ENSO Cycle
- The North Atlantic Oscillation NAO

Oil Tanker "Prestige" Disaster



Strong Downstream development (between A and B)



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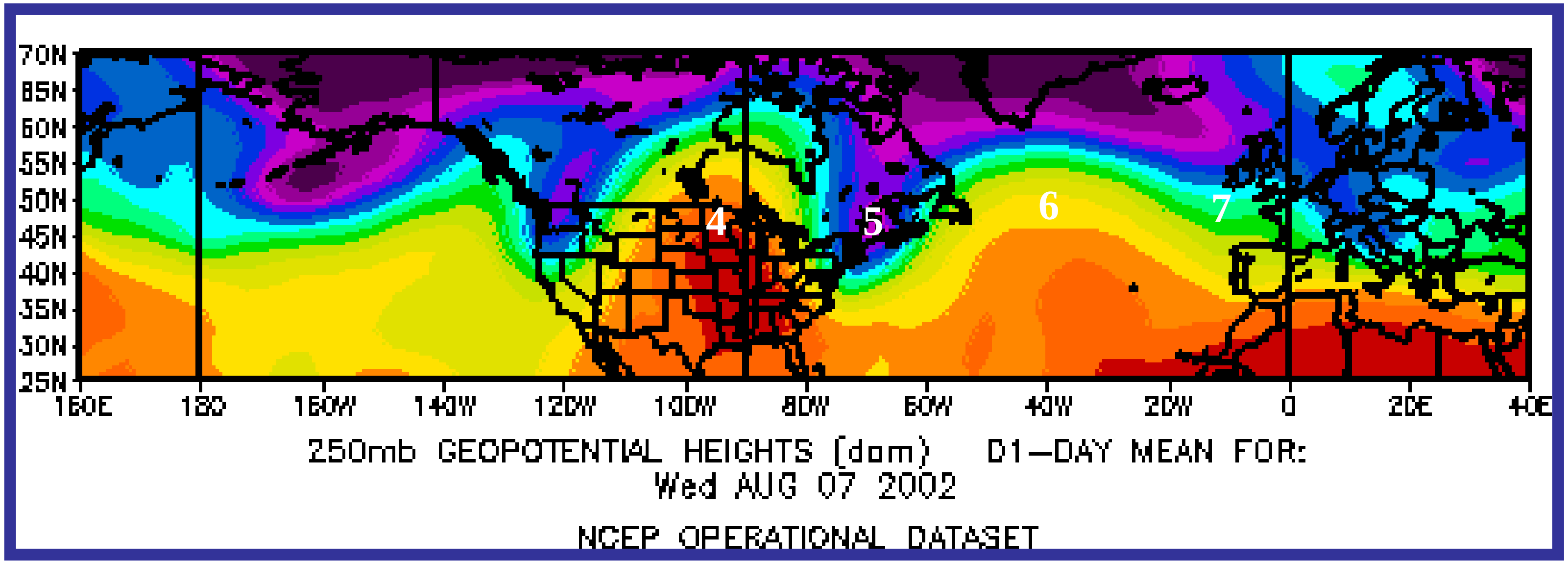
250mb GEOPOTENTIAL HEIGHTS (dam) D1-DAY MEAN FOR:
Tue AUG 06 2002
NCEP OPERATIONAL DATASET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250mb GEOPOTENTIAL HEIGHTS (dam) D1-DAY MEAN FOR:
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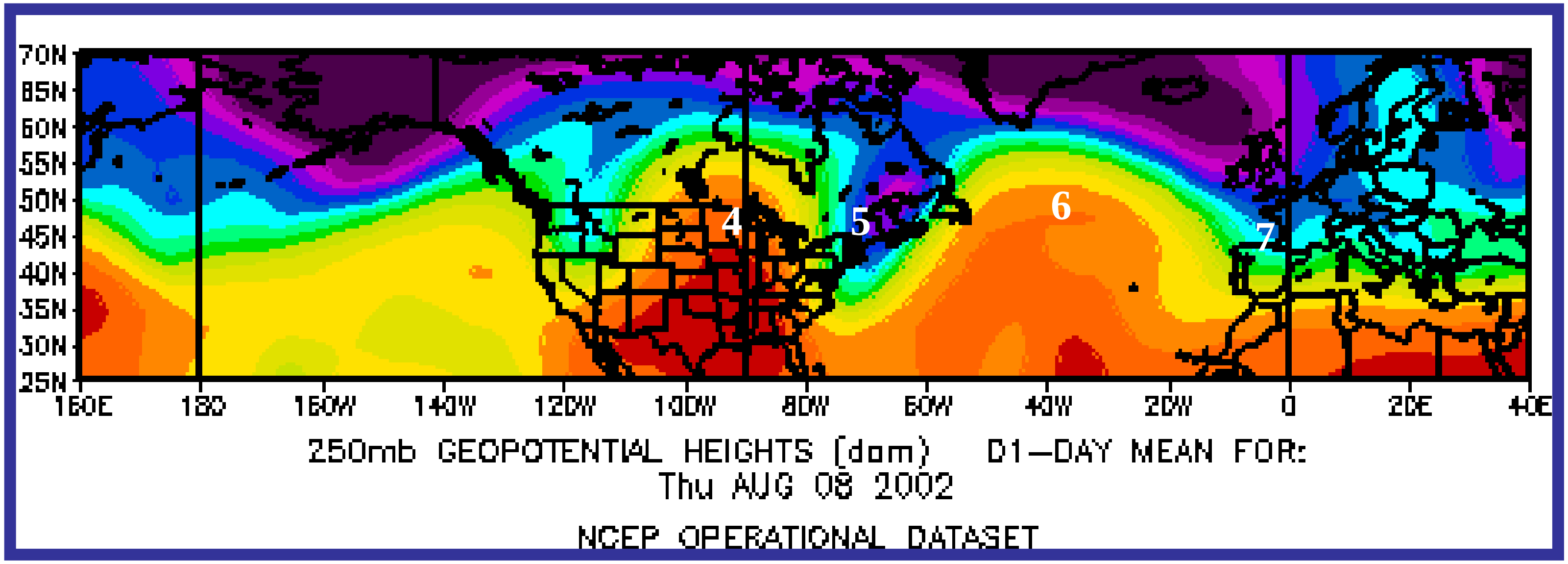
NCEP OPERATIONAL DATASET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250mb GEOPOTENTIAL HEIGHTS (dam) 01-DAY MEAN FOR:
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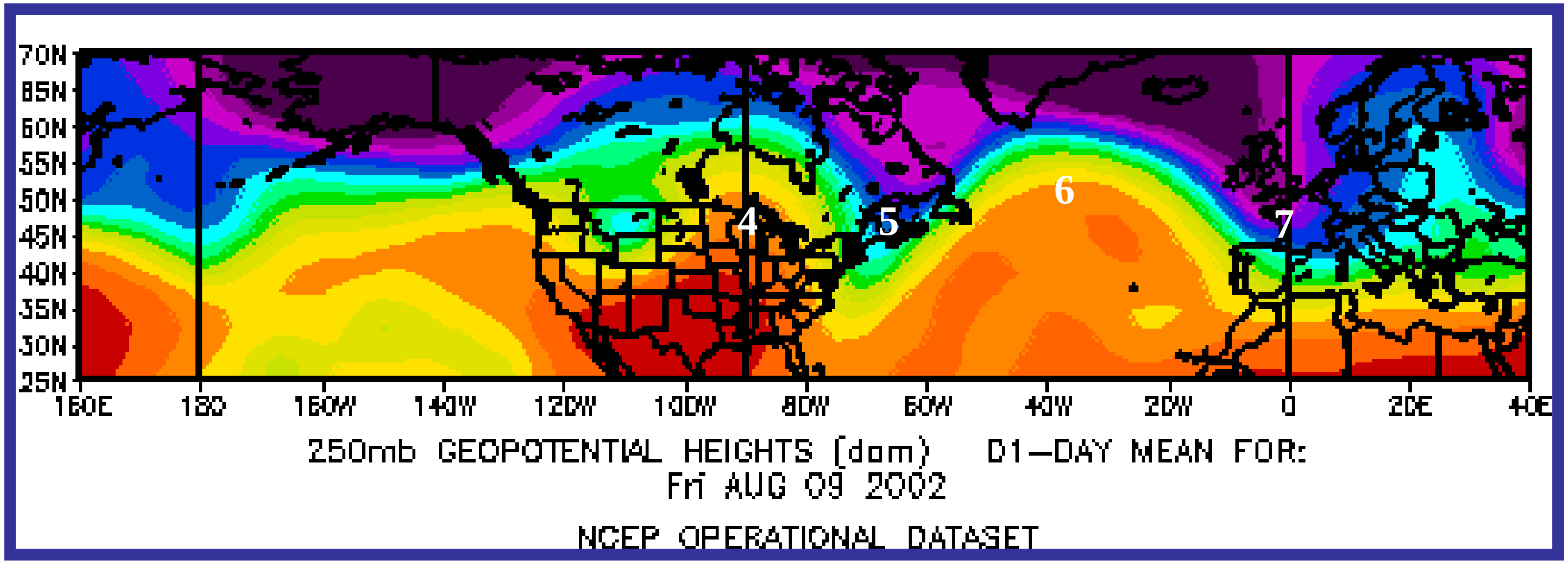
NCEP OPERATIONAL DATASET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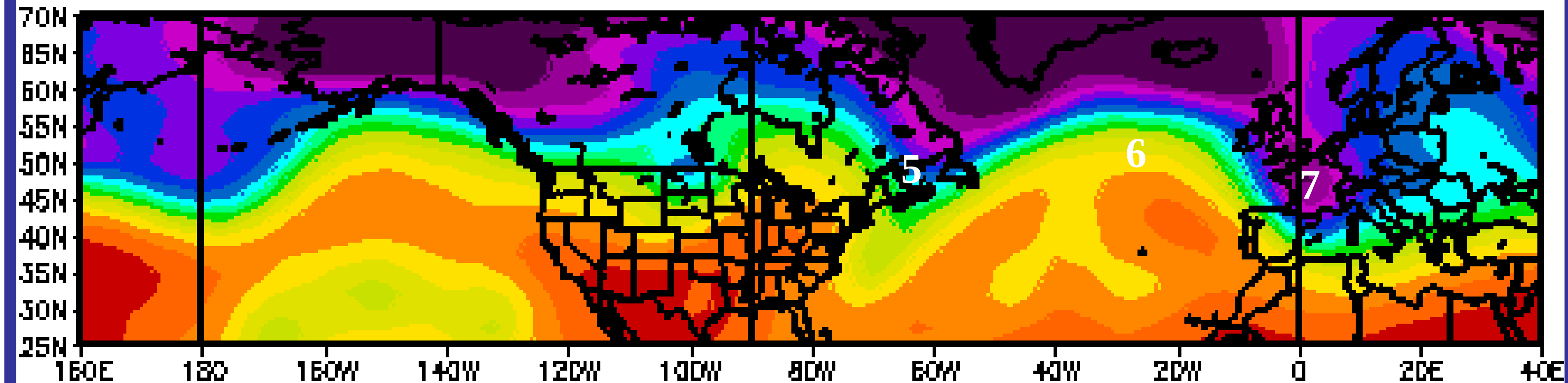
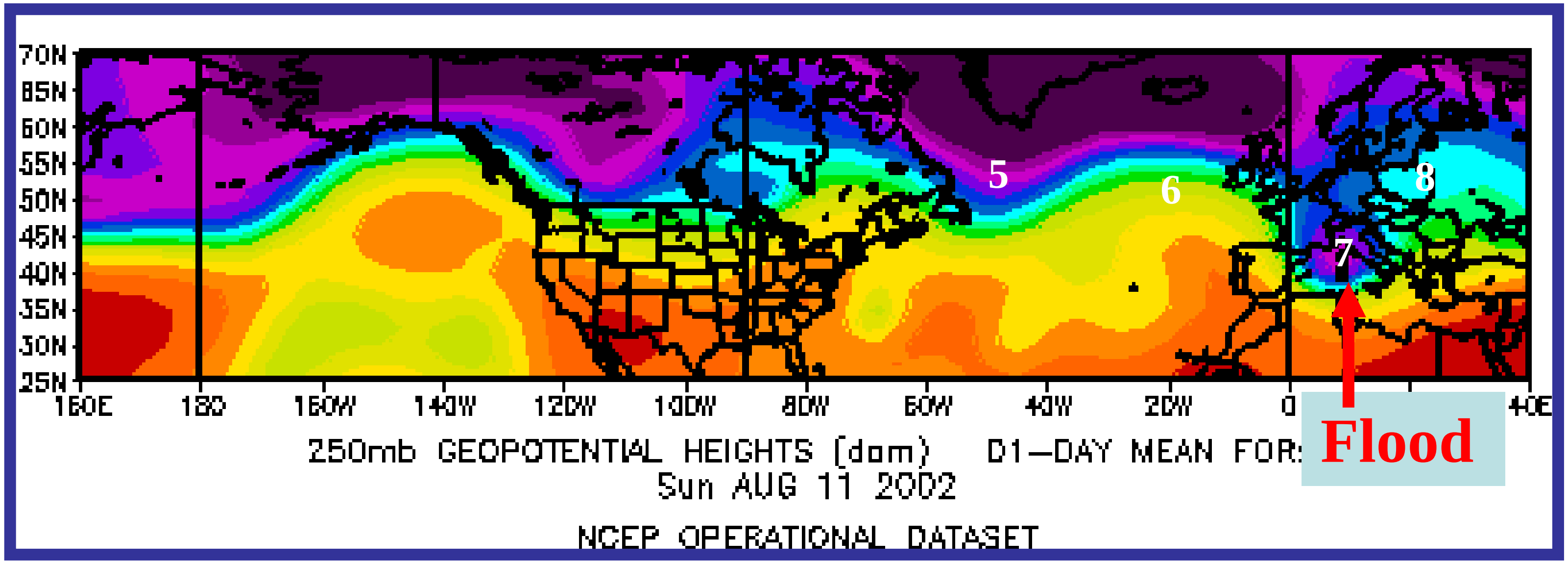
250mb GEOPOTENTIAL HEIGHTS (dam) D1-DAY MEAN FOR:
Fri AUG 09 2002
NCEP OPERATIONAL DATASET



250mb GEOPOTENTIAL HEIGHTS (dam) 01-DAY MEAN FOR:
Sat AUG 10 2002

NCEP OPERATIONAL DATASET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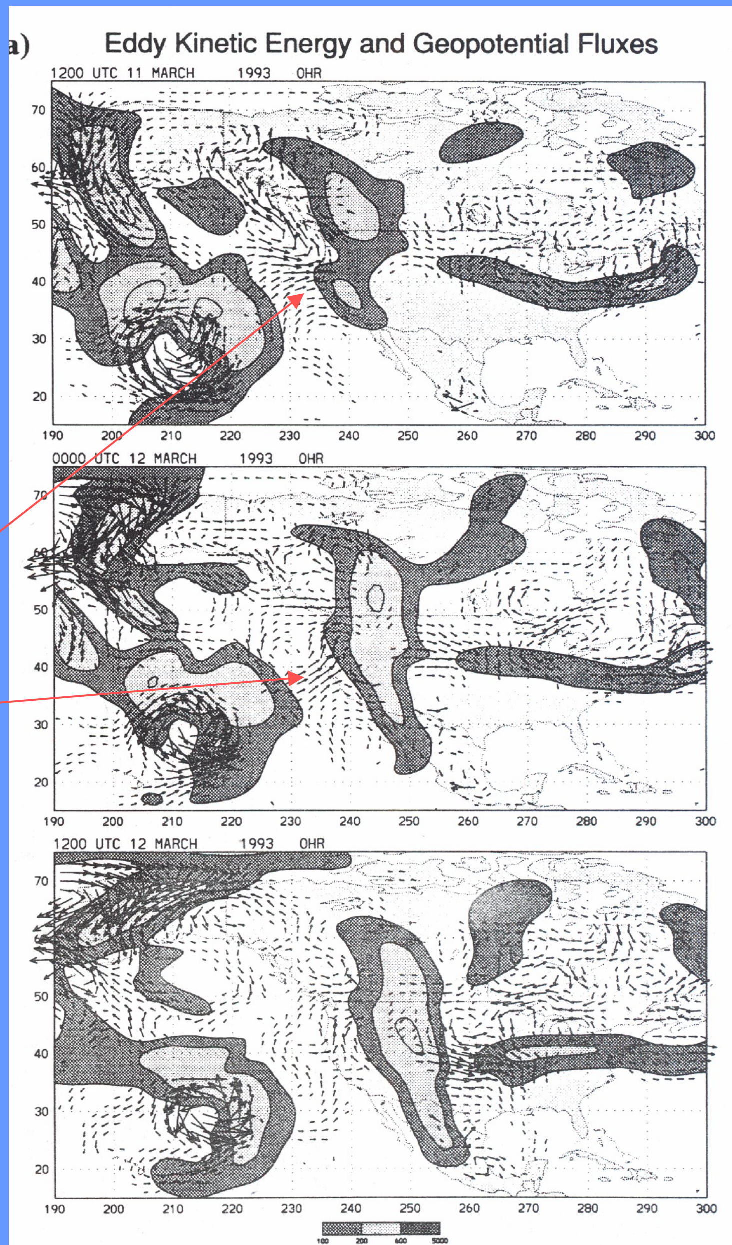
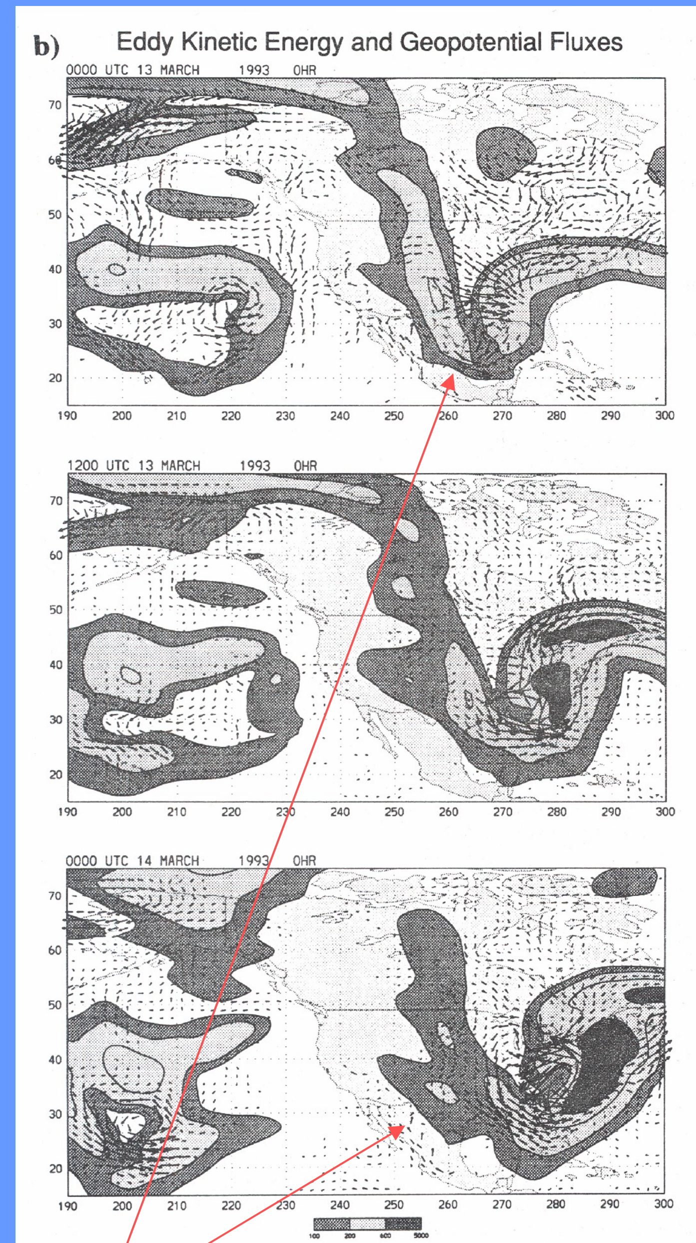
Flood
250mb GEOPOTENTIAL HEIGHTS (dam) D1–DAY MEAN FOR:
Sun AUG 11 2002
NCEP OPERATIONAL DATASET

Dresden Germany

An intense storm over the eastern Pacific flux energy developing a center over the western US.

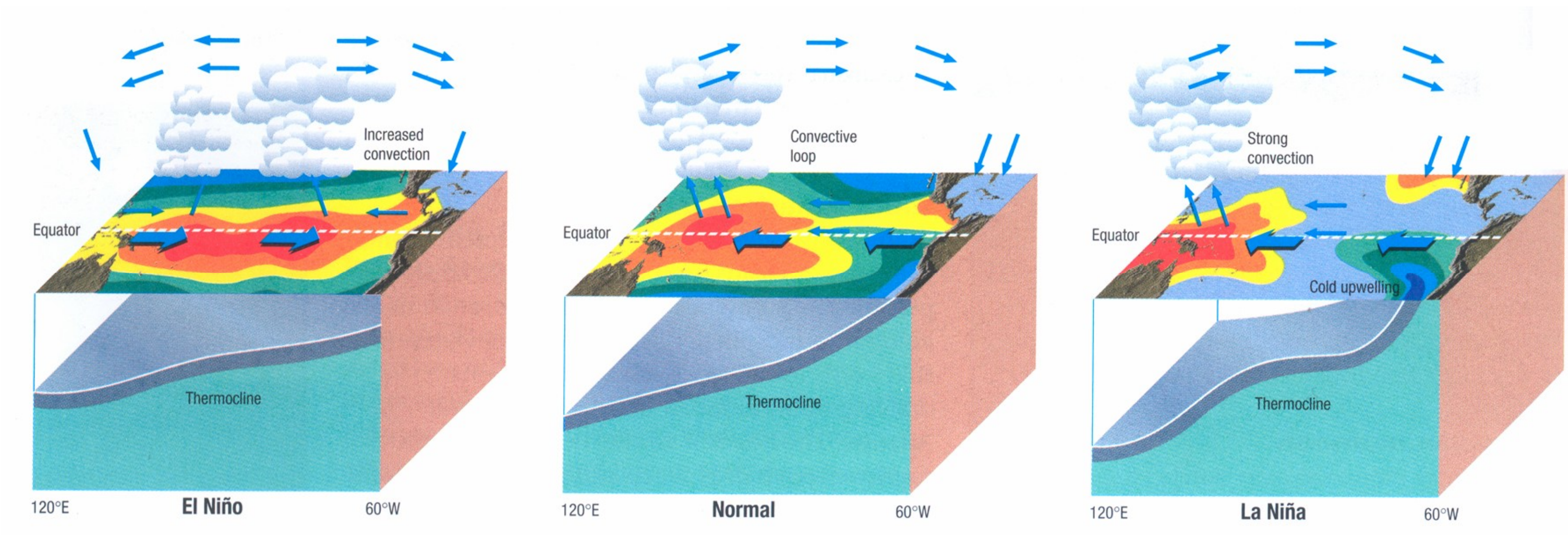




The storm over the US, due to the warm waters over the Gulf has an explosive development (more than 24 mb in 24h, This baroclinic development is called Class B cyclogenesis.)

The ENSO Cycle: El NINO

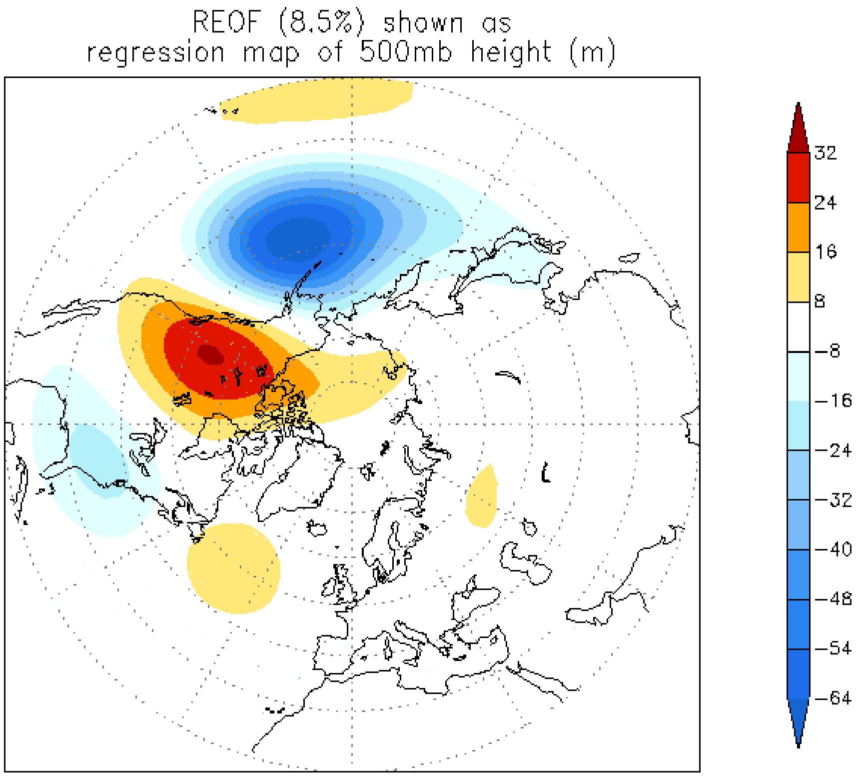
I.Orlanski 2005: A new look to storm trac variability, *Jour. Atmos Science.*

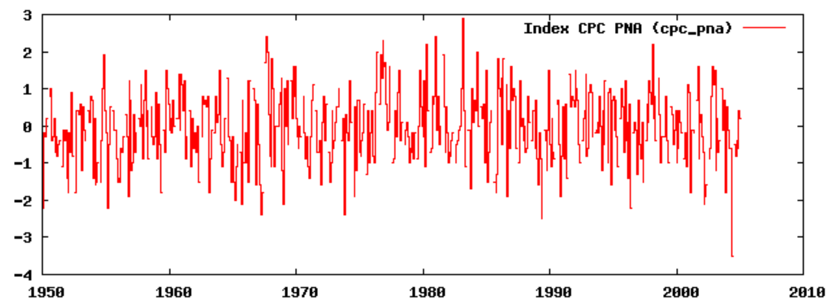


Climate into the 21st Century, WMO

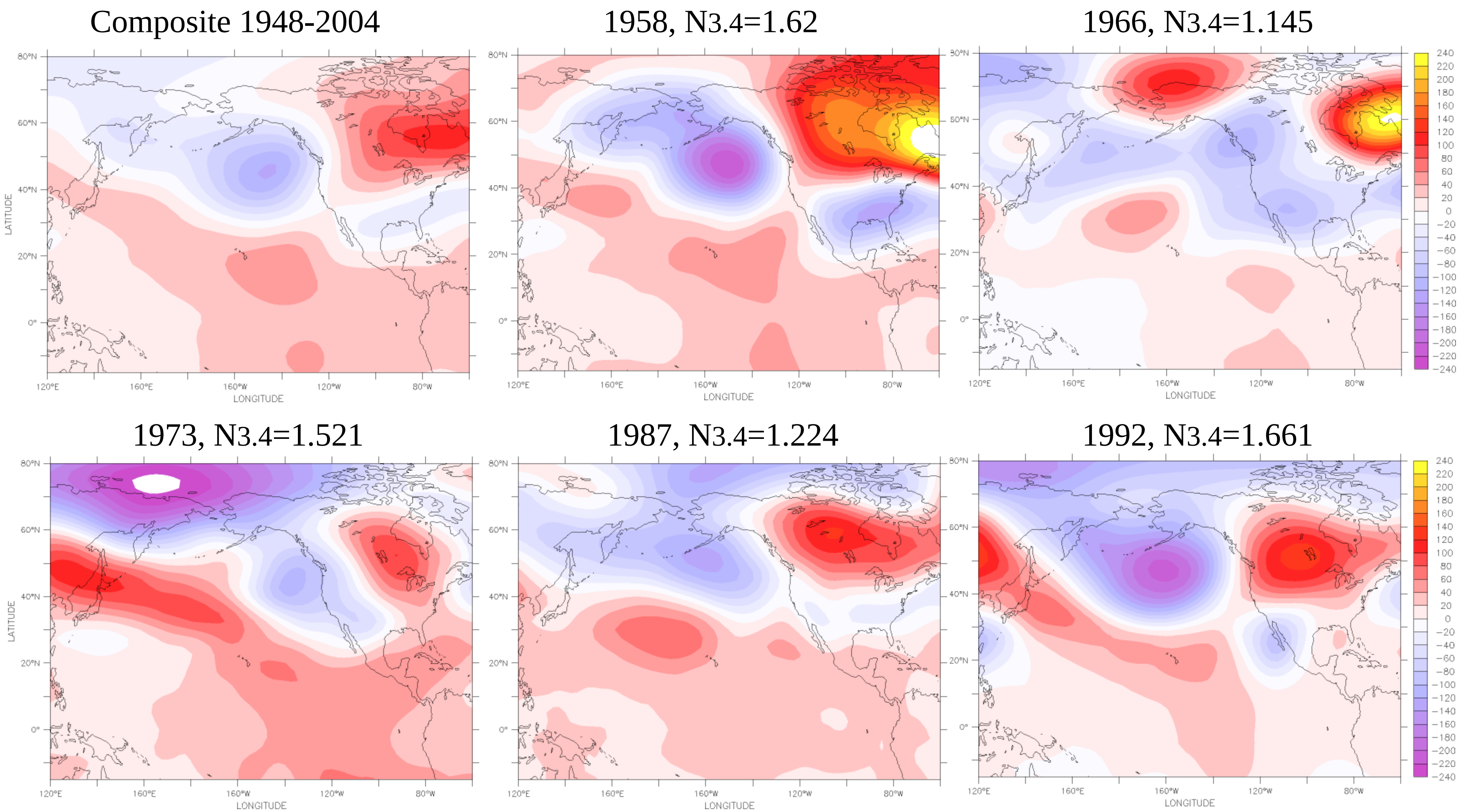
Variability – Pacific/North American Pattern (PNA)

- Determined by pressure/height anomalies at several different points across the Pacific into North America (<1yr-4yrs)
- Atmospheric flow near the west coast of North America is out of phase with the flow of the Eastern Pacific and Southeast United States

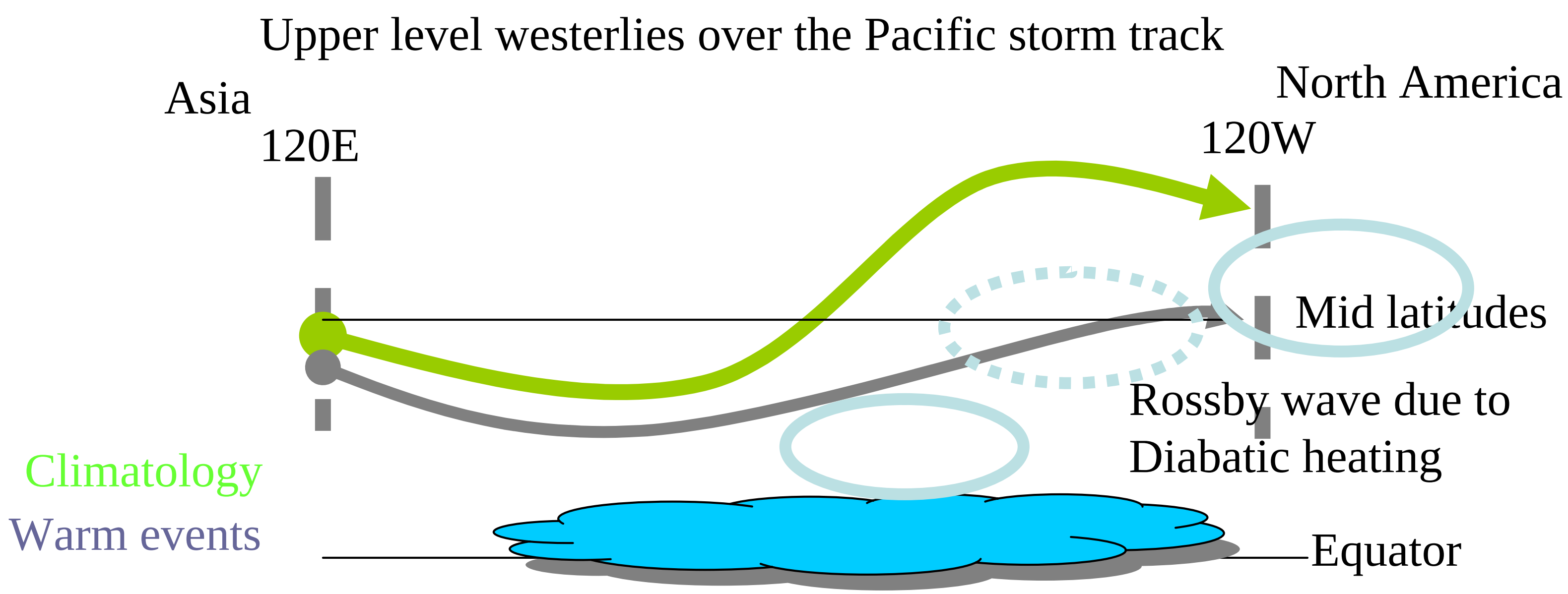




300 hPa height anomalies for 5 different El Nino with moderate intensity NCEP/NCAR Reanalysis, January 1968-1992 climatology.



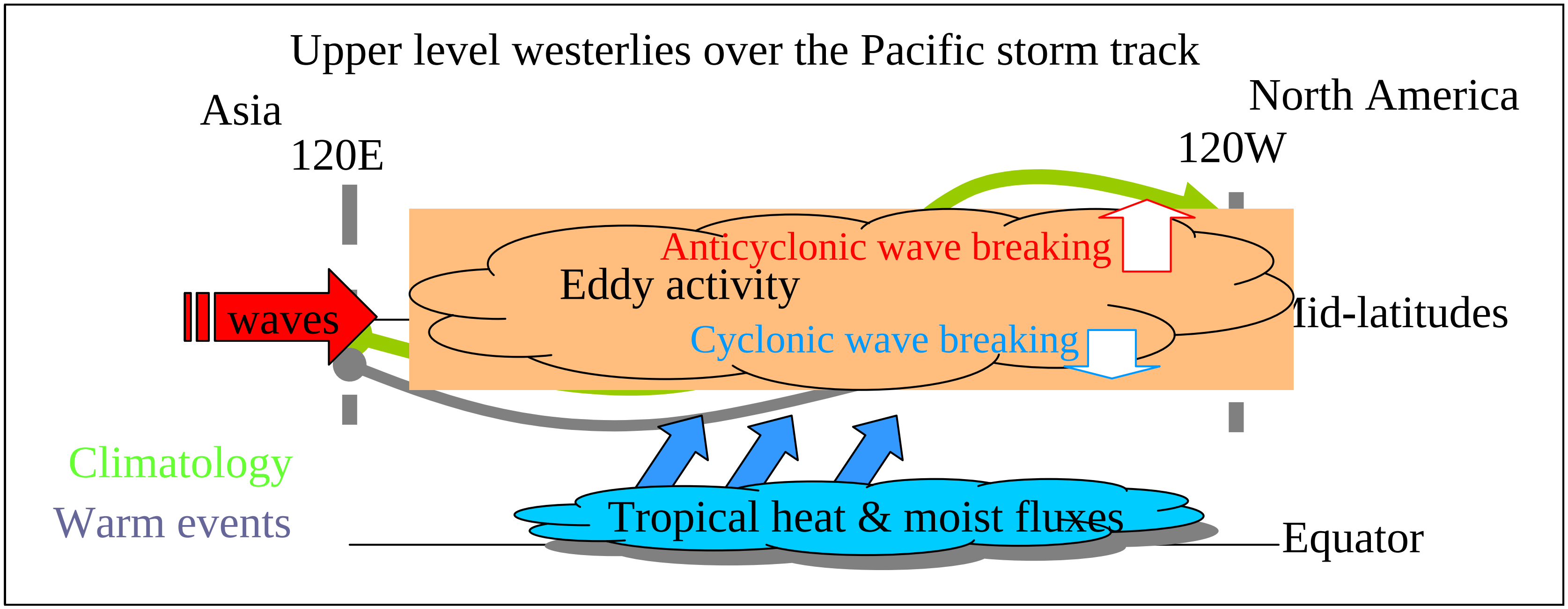
Basic Teleconnections



Tropical SST affects the circulation in distinct places around the globe and tends to be organized in well defined “teleconnection patterns” like the “Pacific/North American Pattern” (PNA).
(e.g., Horel and Wallace 1981, Wallace and Gutzler 1981.)
Many features of this response can be simulated with a barotropic model where SST is replaced by some upper level divergence.
(B. Hoskins and D. Karoly 1981., A. J. Simmons 1982).

The observed estimate of the fraction of year-to-year PNA sector variability explained by ENSO is indeed limited by the intrinsic atmospheric variability. Hoerling and Kumar 2002.

The role of daily weather on the inter-annual variability of storm tracks



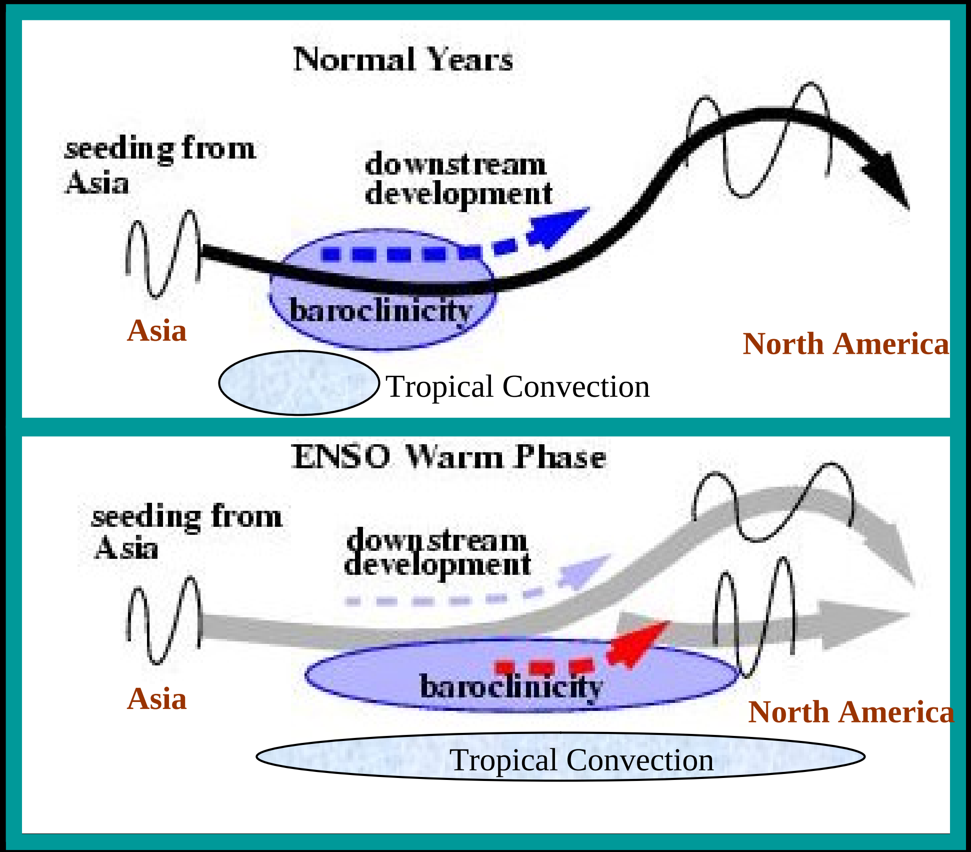
Basic processes of the high frequency (daily weather) important for feedback to the permanent circulation

a) Baroclinicity:
land sea contrast, heat and moisture fluxes.
b) Downstream development:
Wave activity at the entrance of the storm track.
c) Wave breaking:
cyclonic or anticyclonic wave breaking

Orlanski I. J.A.S 2005

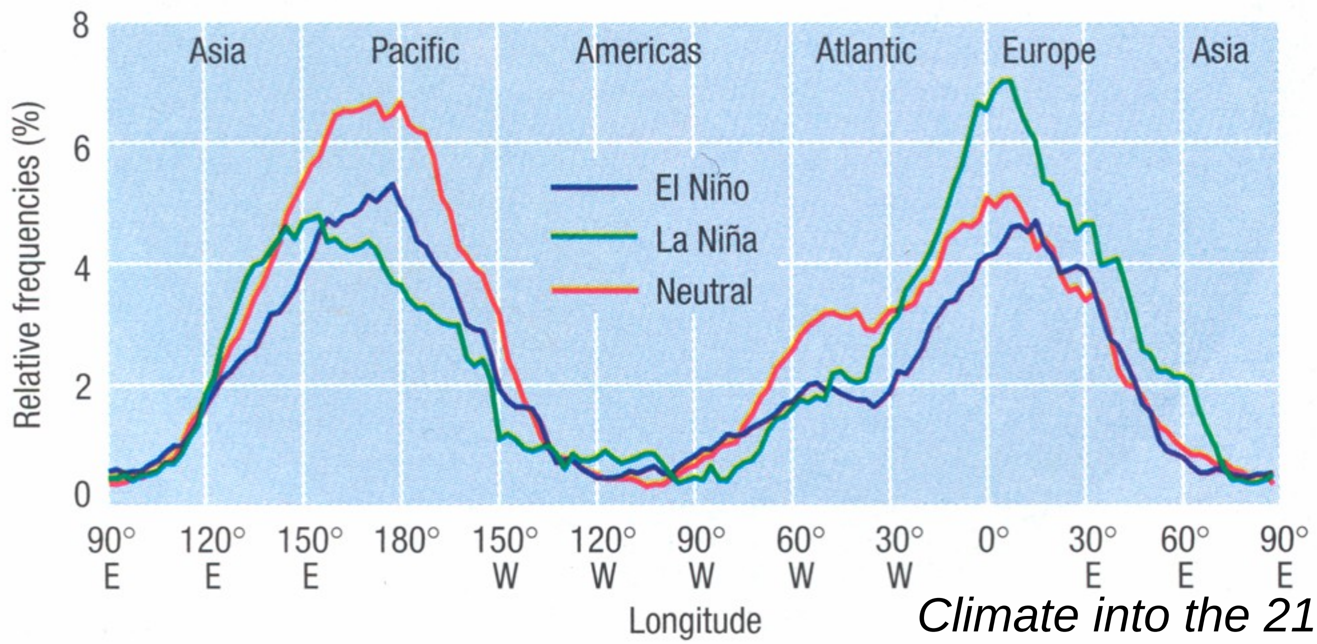
The Variability of the Pacific Storm Track due to:

a) Variability of eddies entering from Asia.
b) Variability of the tropical SST



Orlanski I. 1998: On the poleward deflection of storm tracks, J. Atmos. Sci 55, 128-154
Orlanski I. 2003: Bifurcation in Eddy life cycle: Implications for Storm track Variability. J. Atmos. Sci 60, 993-1021.
Orlanski I. 2004: A new look to the Pacific storm track variability: Sensitivity to tropical SST and natural variability. In Preparation.

This plot shows for the Northern Hemisphere the frequency of mid-latitude atmospheric blocking as a function of longitude for the interval 1958–98 for El Niño, La Niña and neutral periods. Note the tendency towards more frequent blocking over Western Europe (around 0°) during La Niña episodes.



Climate into the 21st Century, WMO

Introduction

Downstream development and wave breaking
in a storm track environments.

Model Simulations

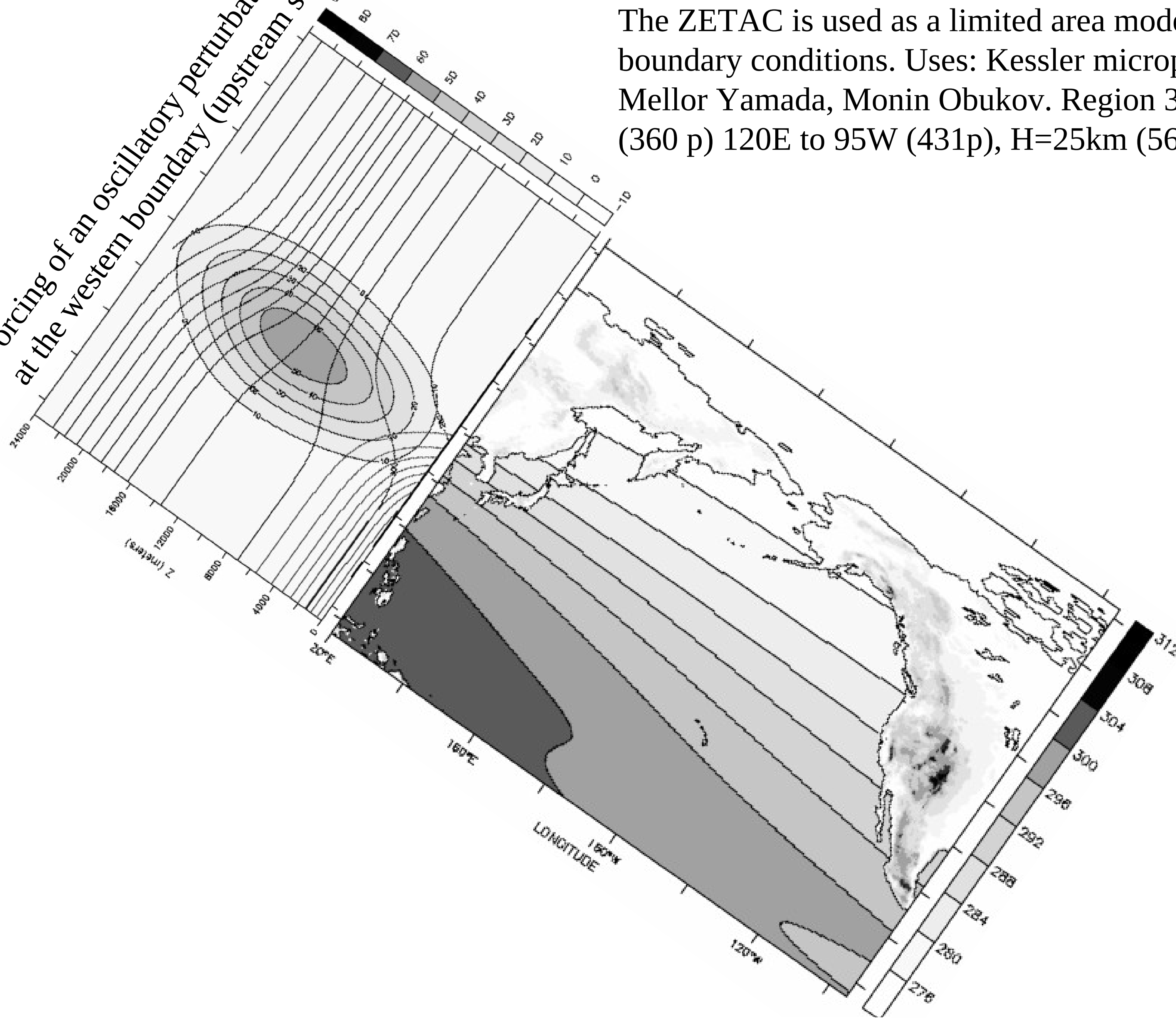
- The Control case
- Upstream Seeding
- SST anomaly
- SST and Seeding

I.Orlanski 2005: A new look to storm trac variability, *Jour. Atmos Science.*

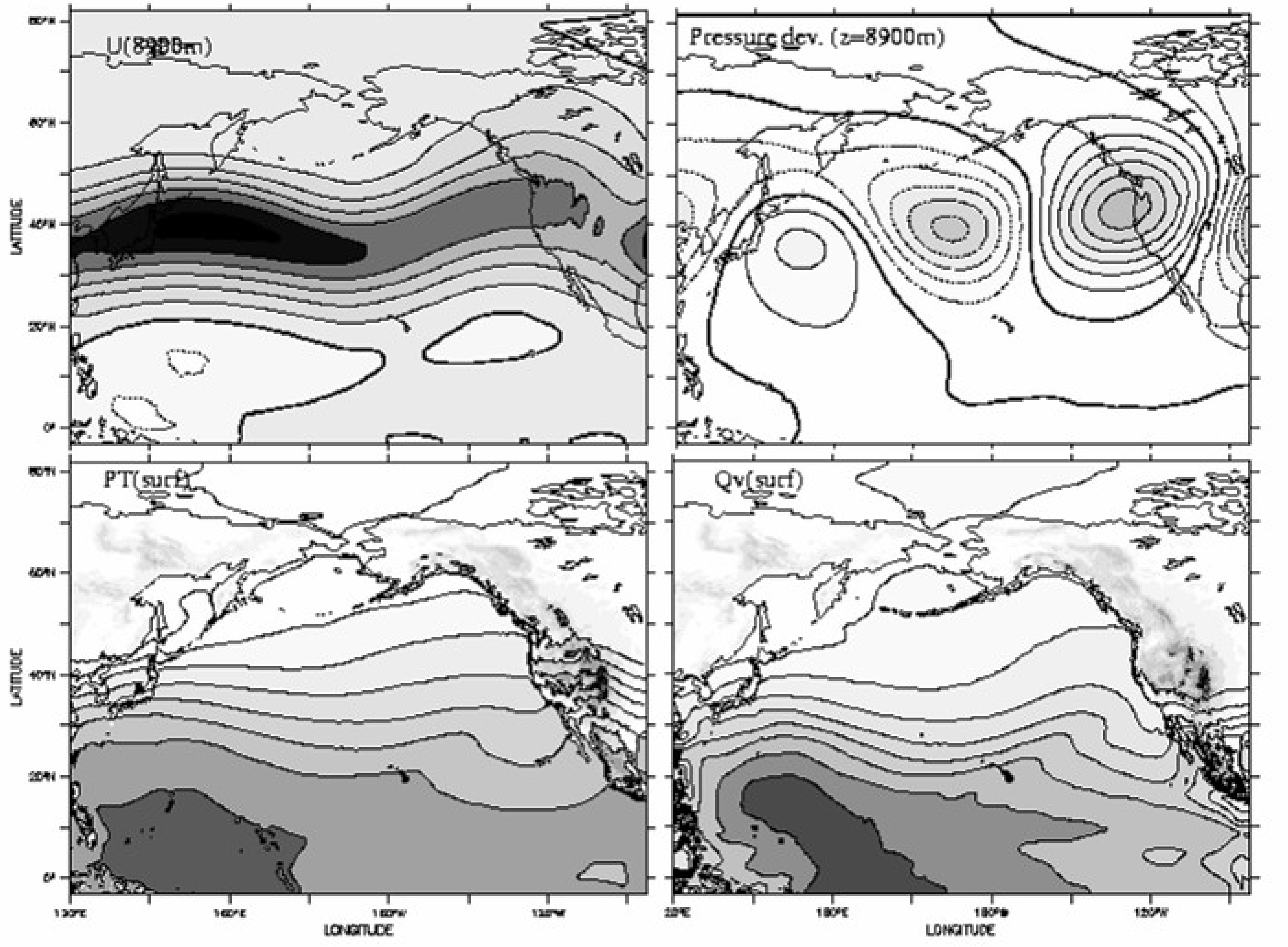
Experimental setup

The ZETAC is used as a limited area model with open boundary conditions. Uses: Kessler microphysics, Mellor Yamada, Monin Obukov. Region 3S 82.5N (360 p) 120E to 95W (431p), H=25km (56 levels)

Forcing of an oscillatory perturbation at the western boundary (upstream seeding)



Zonal wind, pressure anomaly, air temperature and surface water vapor for the Control simulation.



ENSO warm phase anomalies from the NCEP/NCAR reanalysis

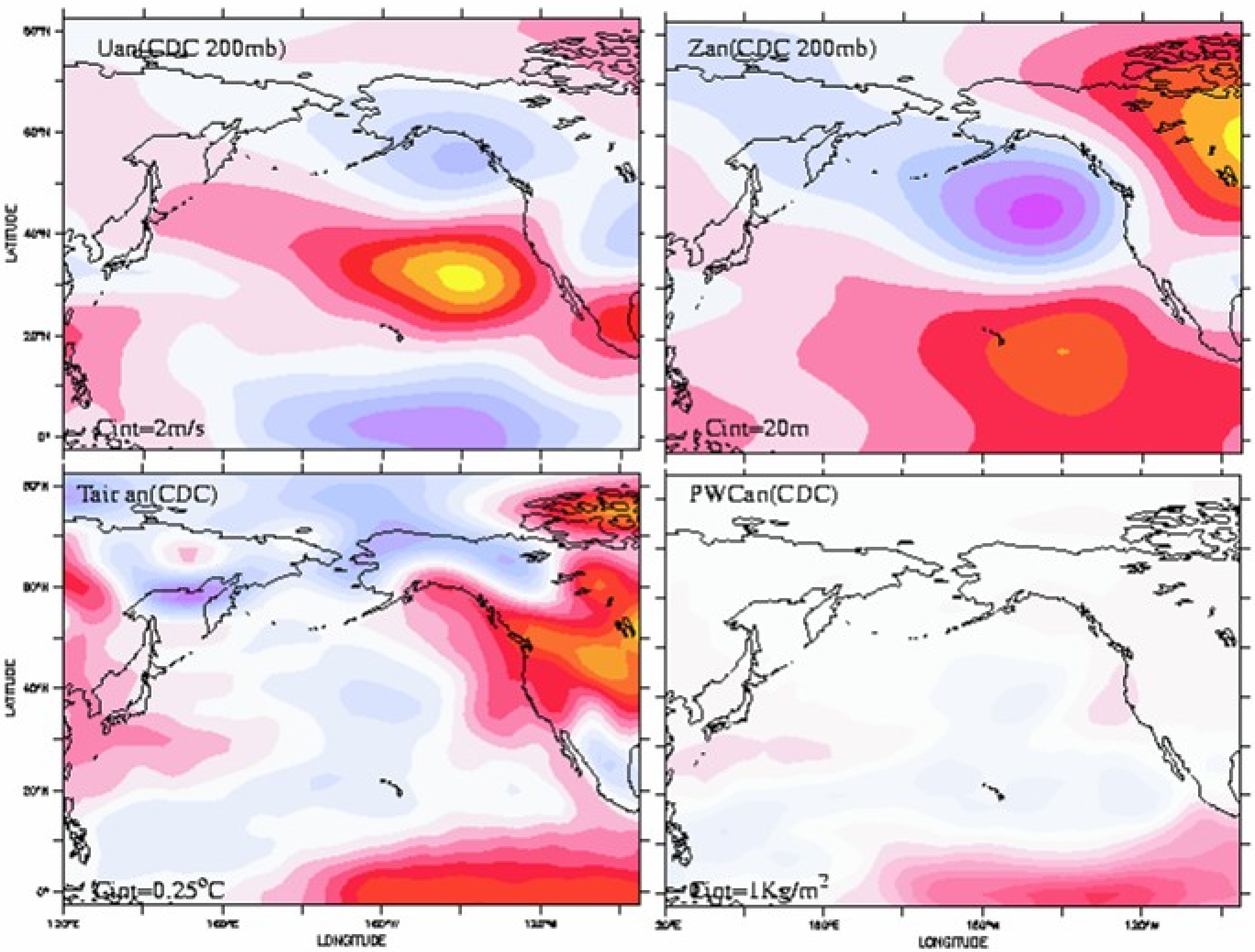


fig 11

Experiment N2 anomalies

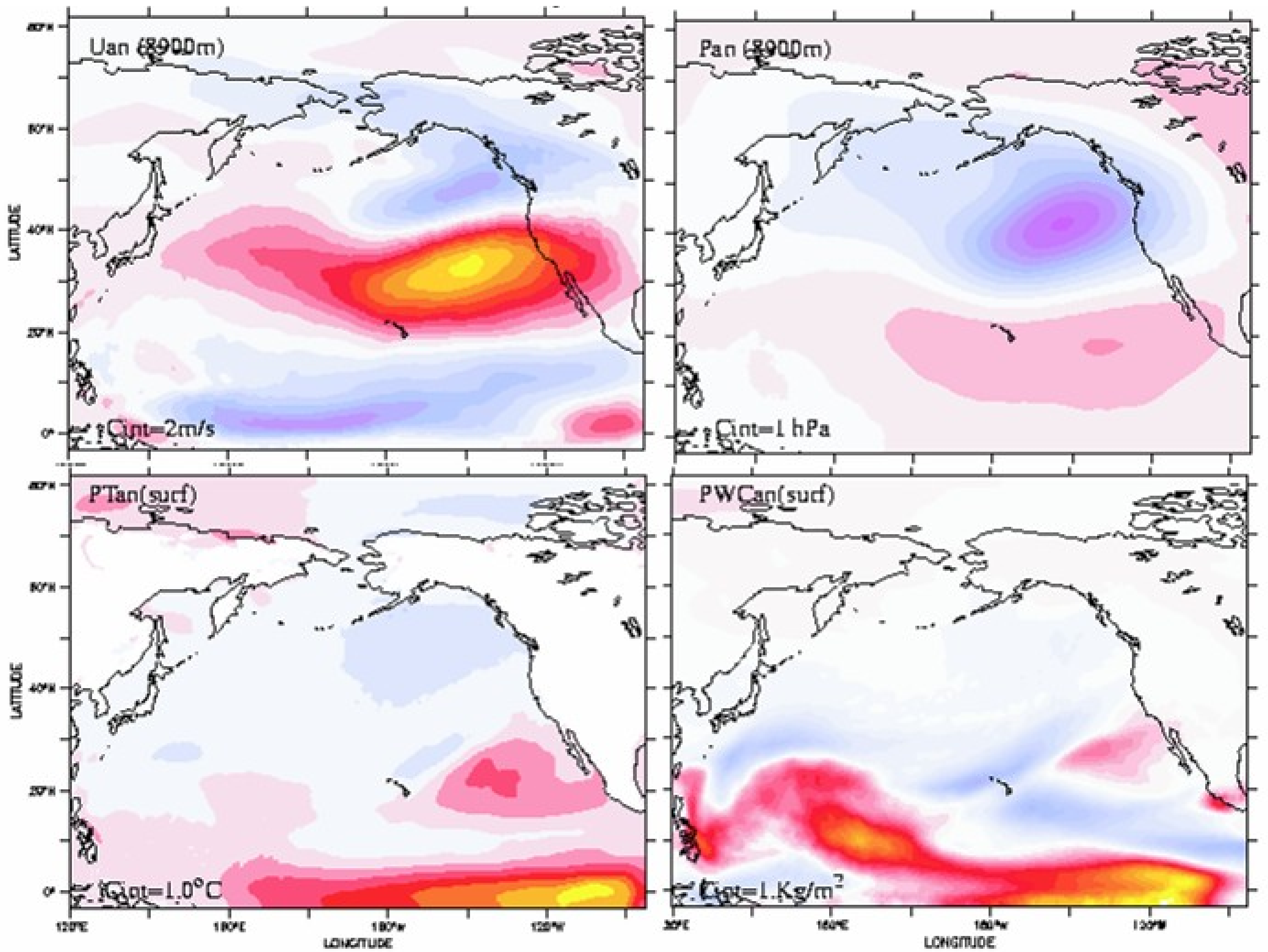
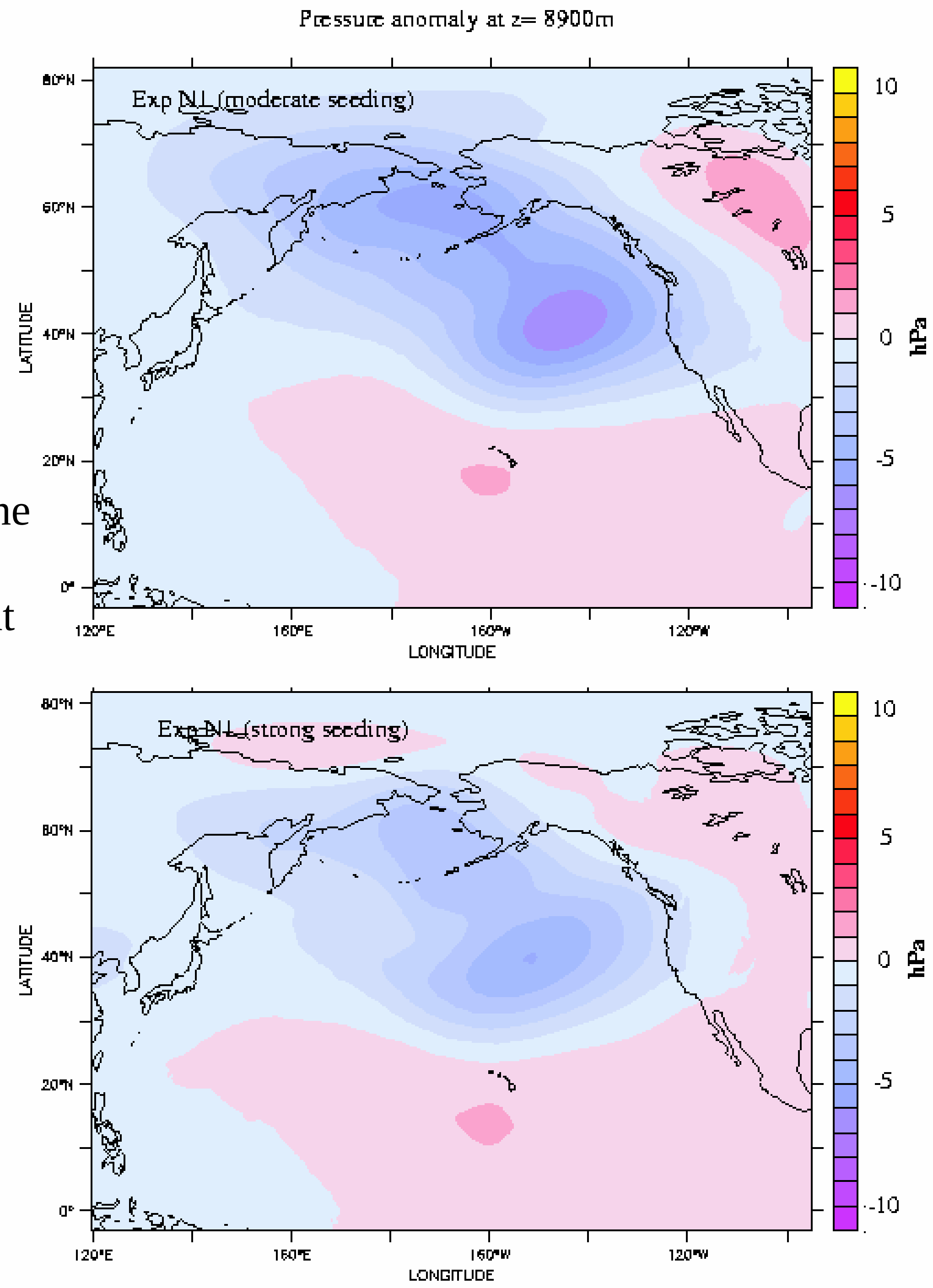


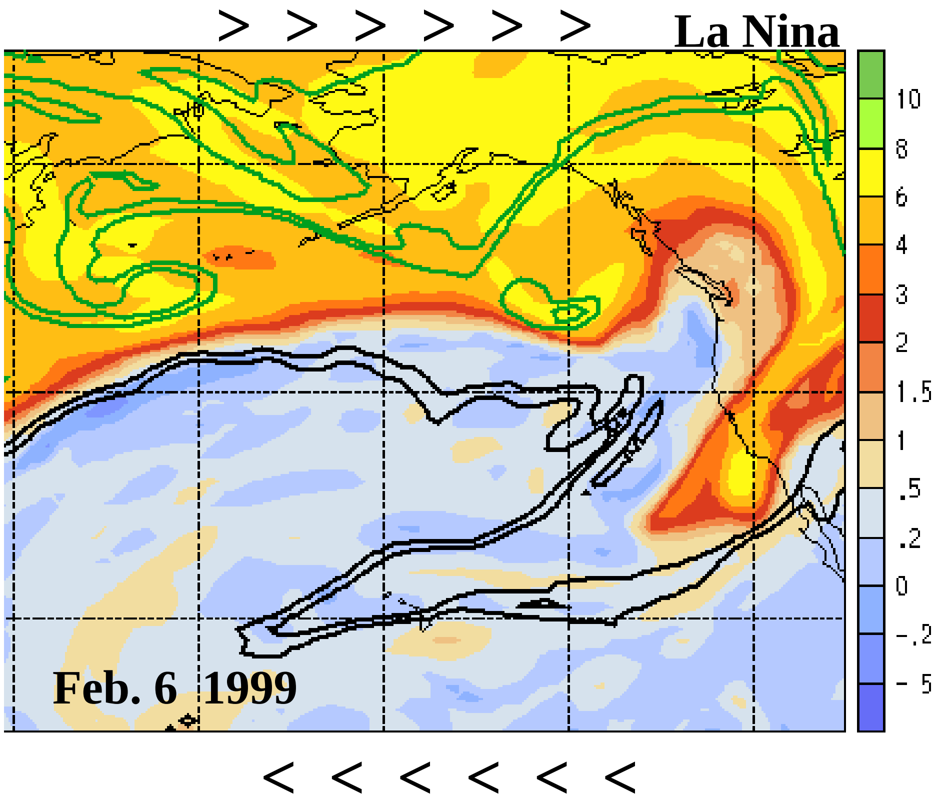
fig 12

The upper level pressure anomalies for the simulations with the same SST anomaly but different upstream seeding shows that with stronger seeding the PNA pattern is still being produced but much weaker

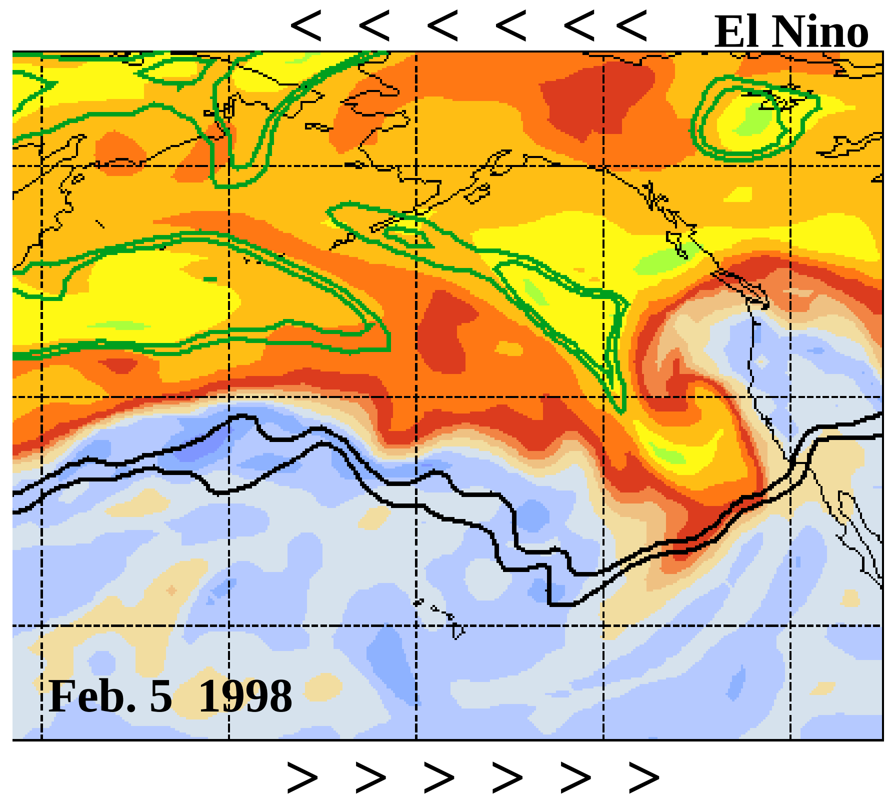


The influence of ENSO on baroclinic life cycles (Shapiro,et al. 2001)

Life Cycle 1 (LC1)



Life Cycle 2 (LC2)

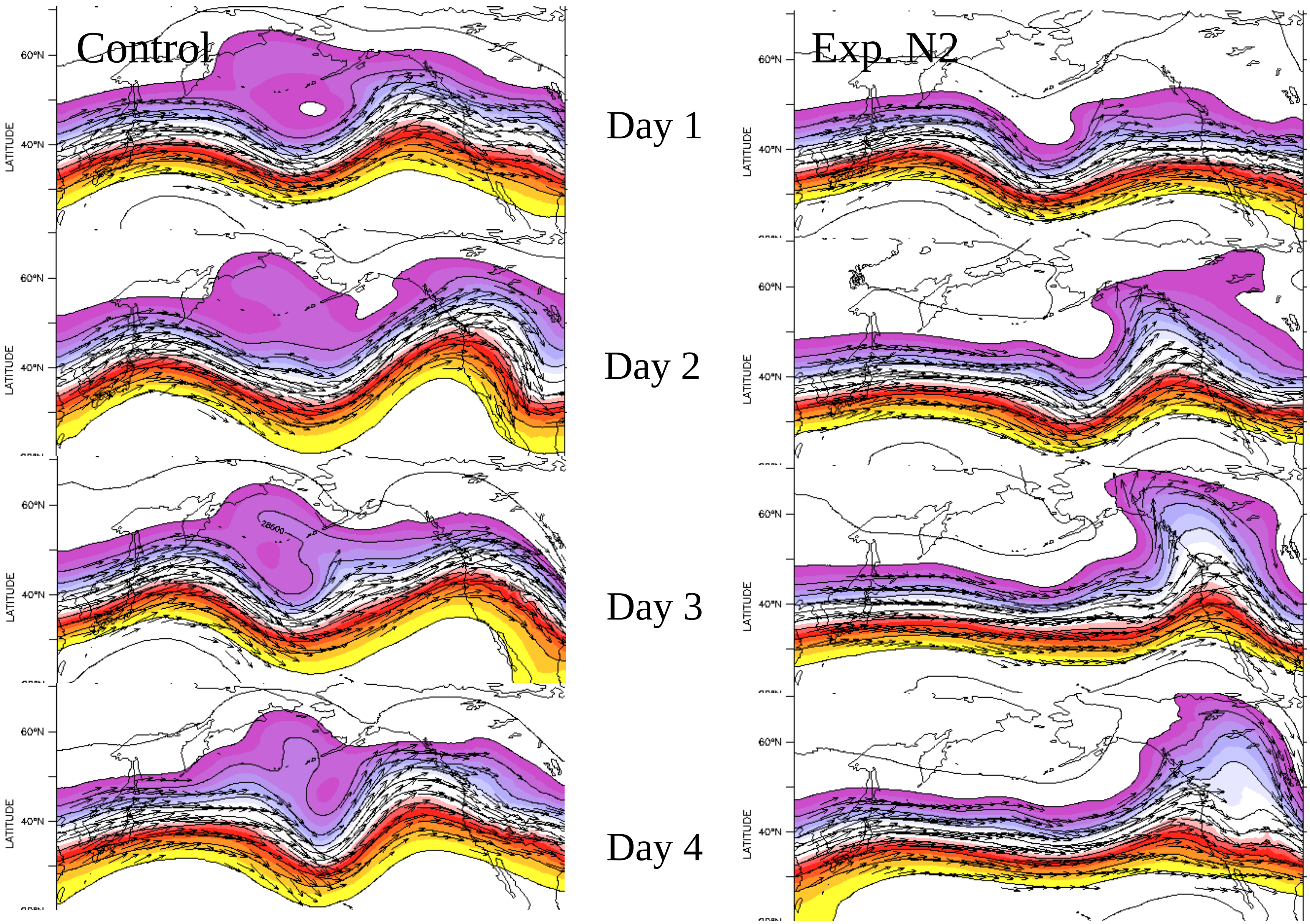


Number of days in the period 16 January - 28 February

	1999	1998
LC1	25	2
LC2	2	27

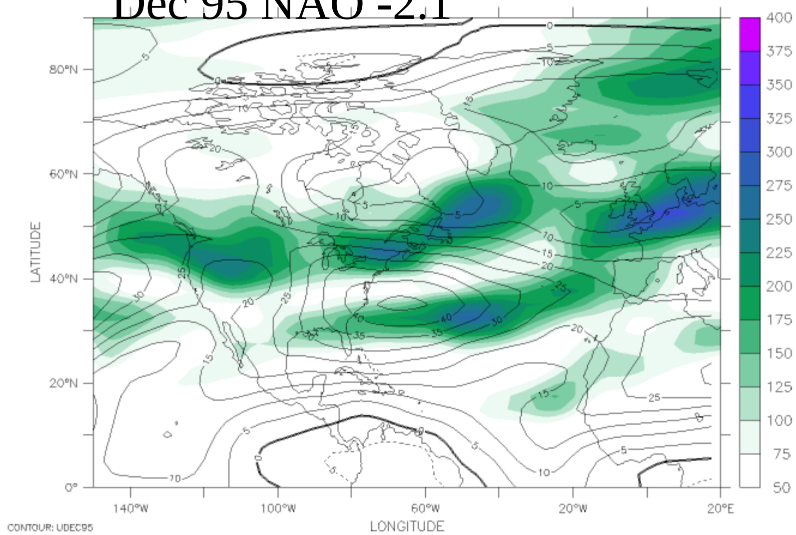
Type of wave-breaking for the Control and with SST anomalies (N2)

Pressure contours and wind vectors (z=8900m)

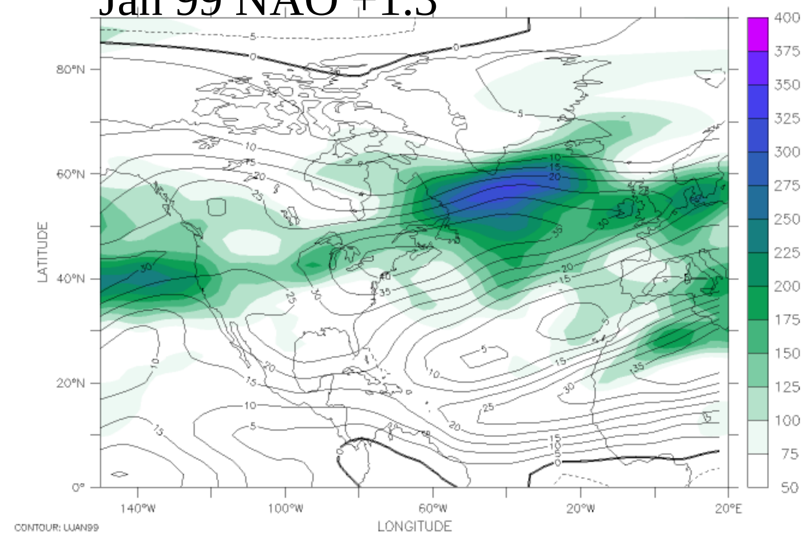


Eddy Kinetic Energy and Zonal Wind (z=300 HPa)

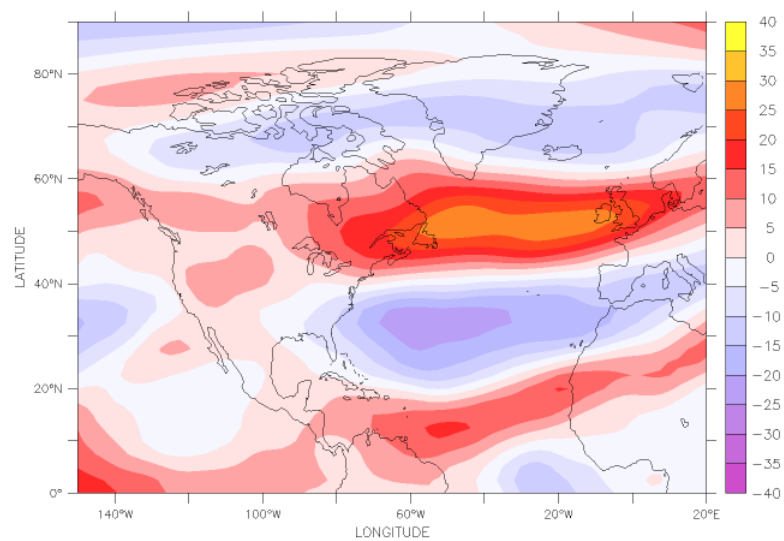
Dec 95 NAO -2.1



Jan 99 NAO +1.3

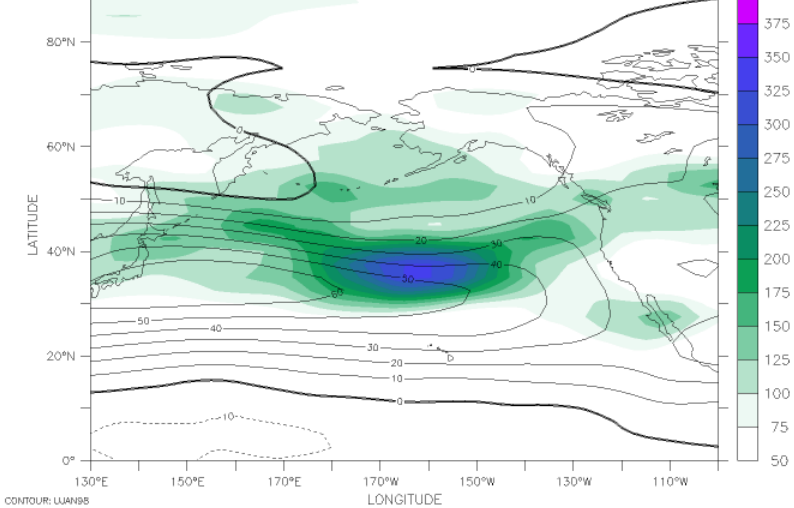


Zonal Wind Difference (z=300HPa) Jan 99- Dec 95

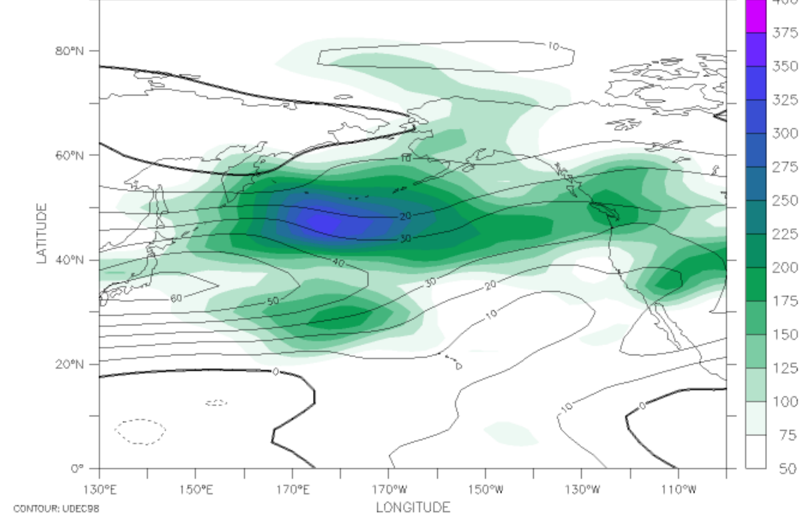


Eddy Kinetic Energy and Zonal Wind (z=300 HPa)

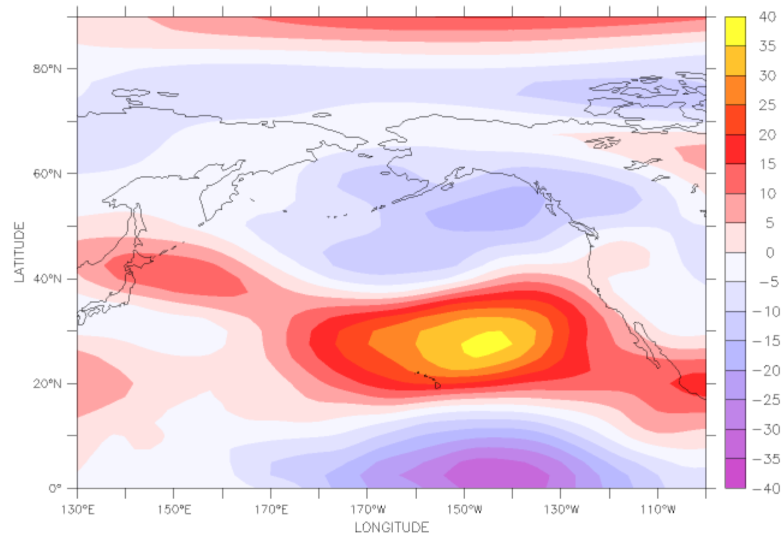
Jan 98 Nino +2.8



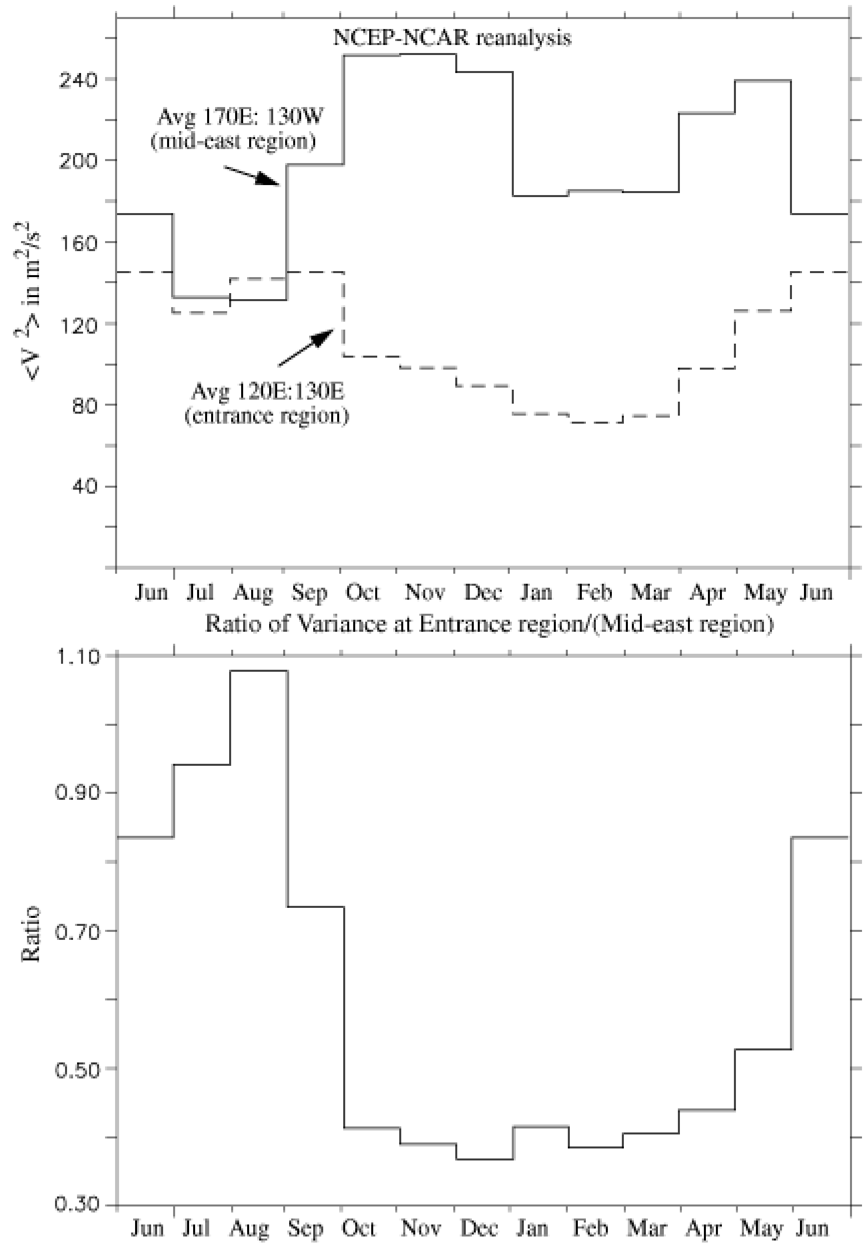
Dec 98 Nina -1.8



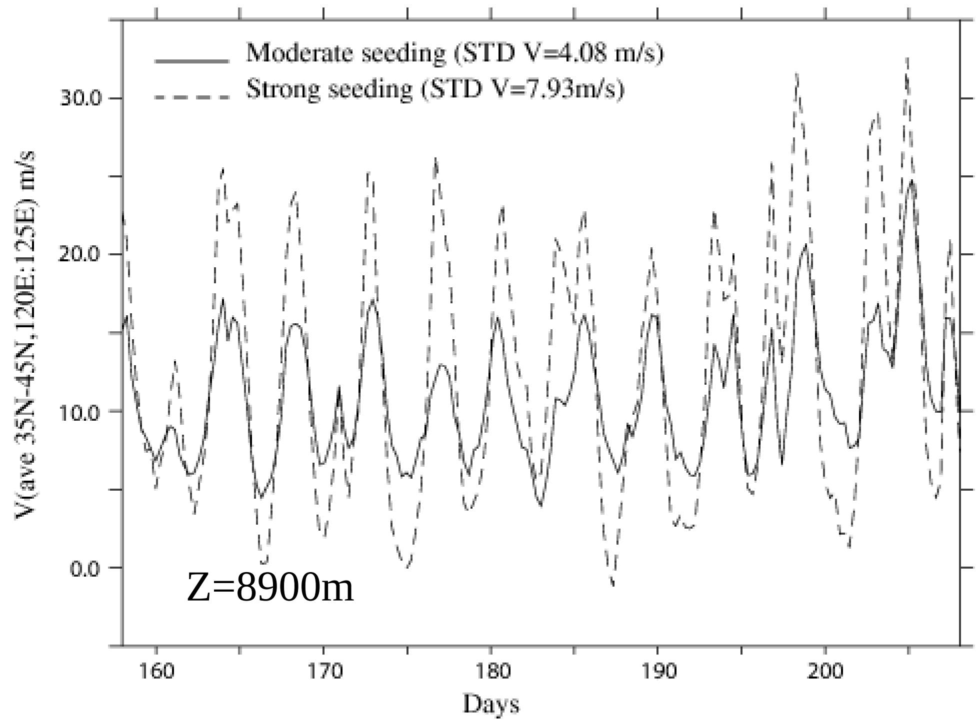
Zonal Wind Difference (z=300HPa) Jan 98- Dec 98

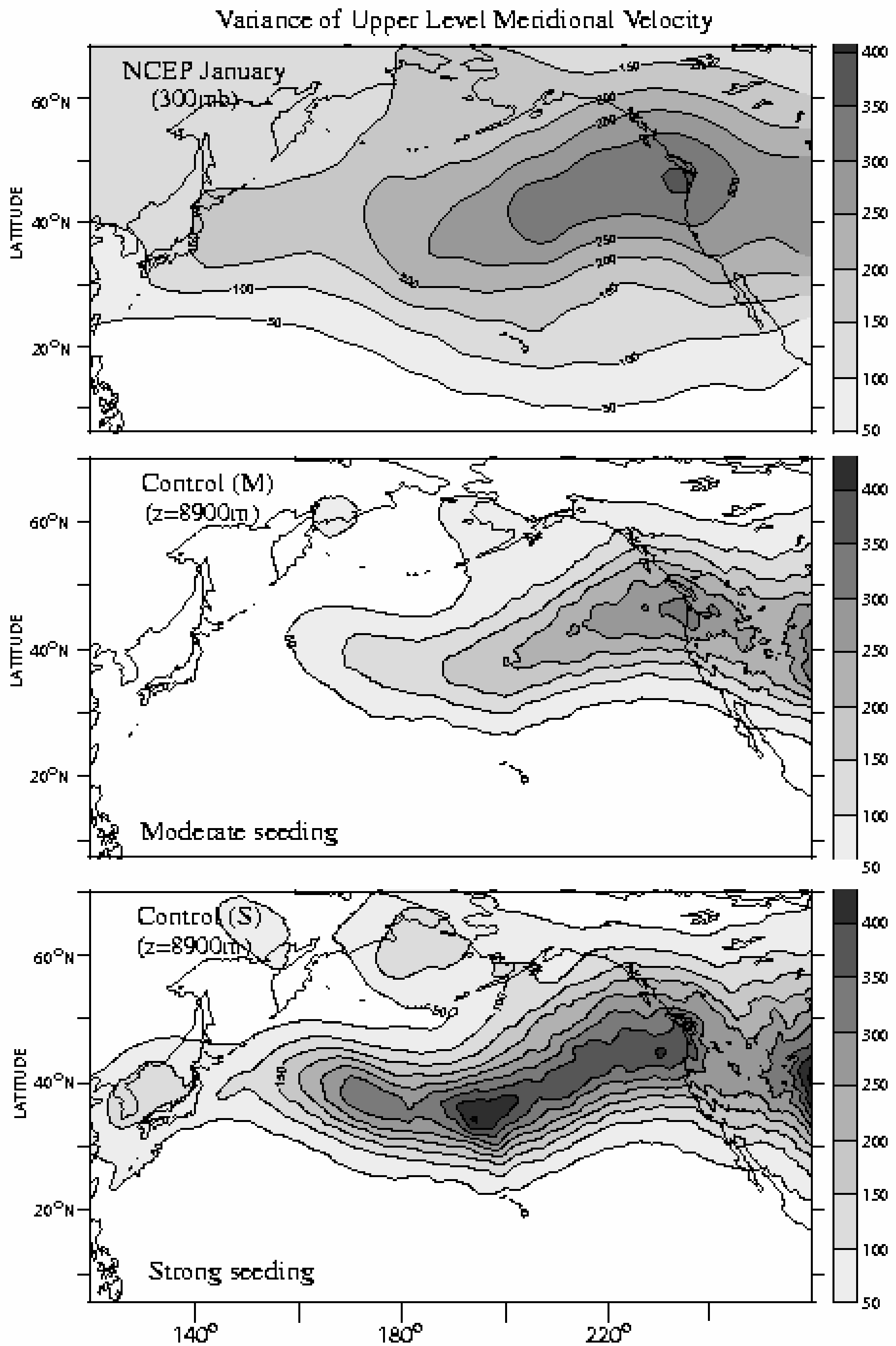


Monthly climatological values of the meridional velocity variance (200hPa) along the Pacific storm track. The data is averaged over a 30N-50N meridional band.



The control parameter for the western boundary seeding is the intensity of the meridional velocity at the entrance of the storm track.

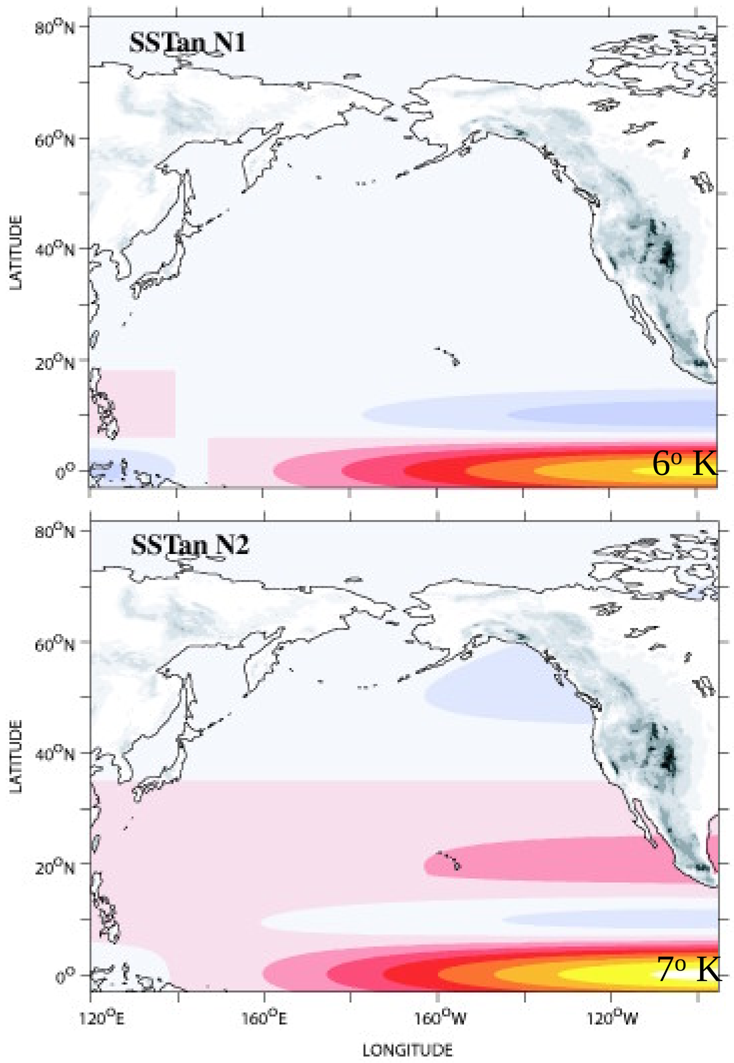



Variance of Upper Level Meridional Velocity
NCEP January
(300mb)
Control (M)
(z=8900m)
Moderate seeding
Control (S)
(z=8900m)
Strong seeding
LATITUDE
60°N
40°N
20°N
140°
180°
220°
400
350
300
250
200
150
100
50

SST anomalies used in the simulations (moderate for N1 and strong for N2)

These SST anomalies are added to the SST used for the control simulation.

Note: The rather large value of the anomalies was because I thought it was required for a realistic simulation of the deep convection in the tropics with a 18km resolution model. However, since then we have used observed SST and produced very similar deep convection over the tropics.

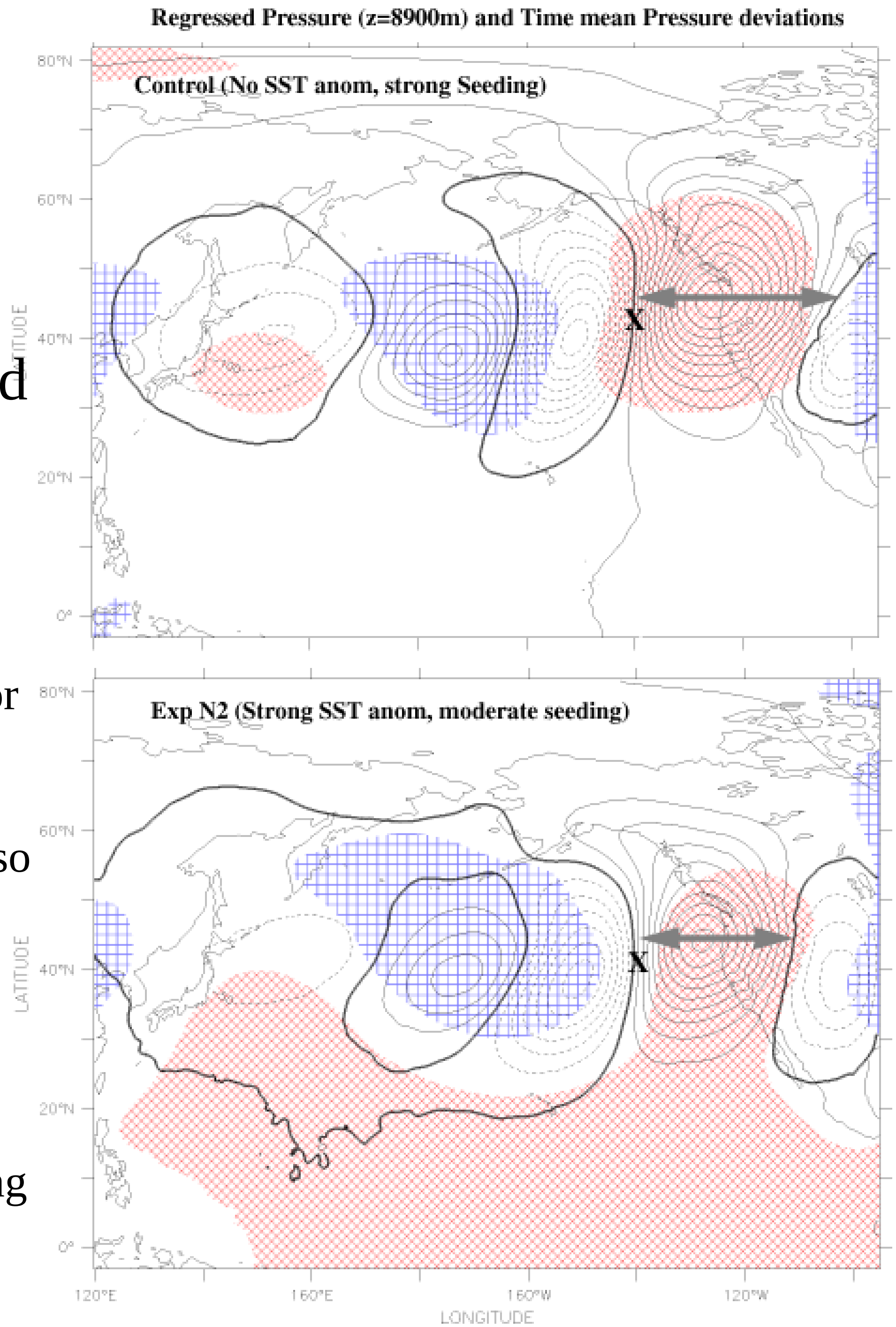


Type of wave-breaking

Scale differences between waves emanating from the west coast and those regenerated in the mid-ocean.

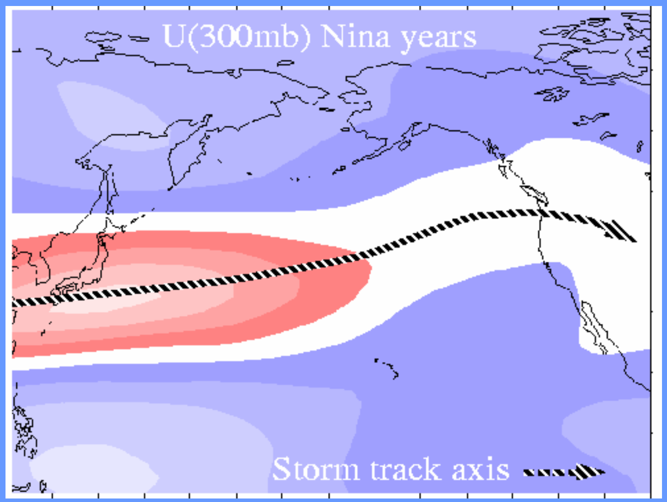
The figures on the right show the regressed pressure (contour) over the eastern Pacific for the Control no SST, strong seeding and N2 with strong SST and moderated seeding. For comparison the mean pressure anomaly is also shown (hatching).

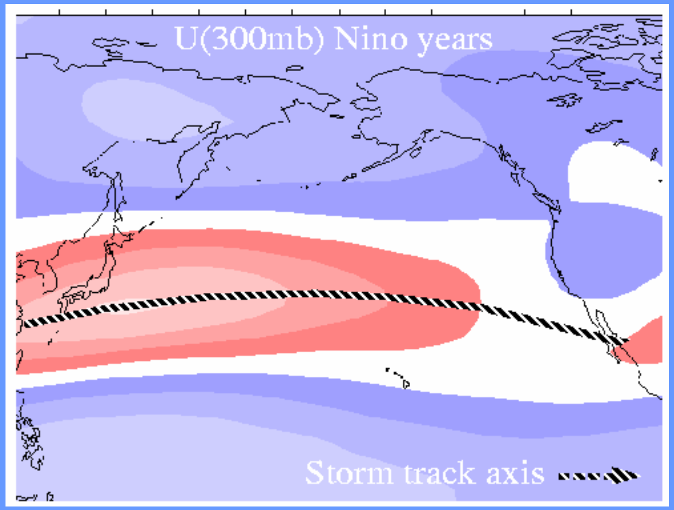
A strong suggestion that the mean anomalies are produced by the high frequency eddies is the fact that the scales of the regressed fields are very similar to those for the corresponding mean anomalies.



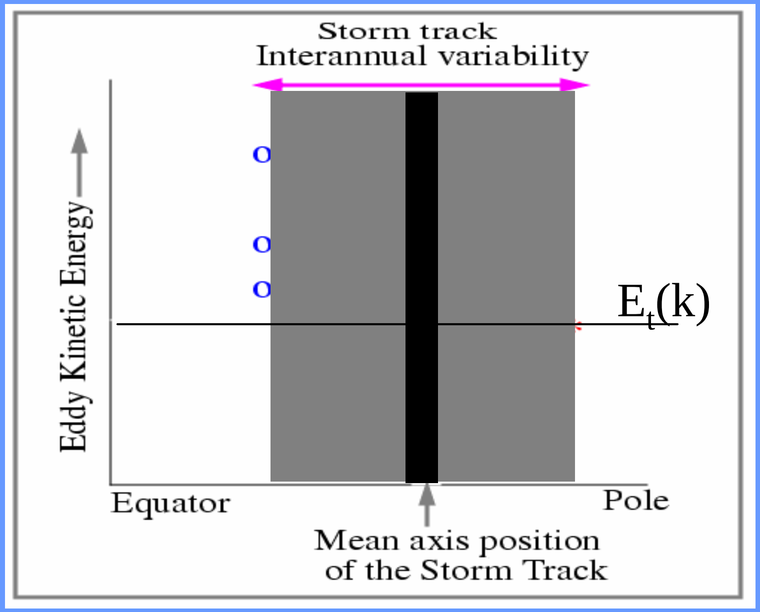
Storm tracks are the back bone of weather and climate in the extratropical regions of the globe. Large differences are observed due to the inter-annual variability of the storm-tracks (see Figures a and b) and it is suspected that the different behaviors of the baroclinic eddy life-cycles are partly responsible for those changes.

[1] The bifurcation of eddy life cycle: Implications on Storm Track variability JAS 2003





Type of upper level wave-breaking



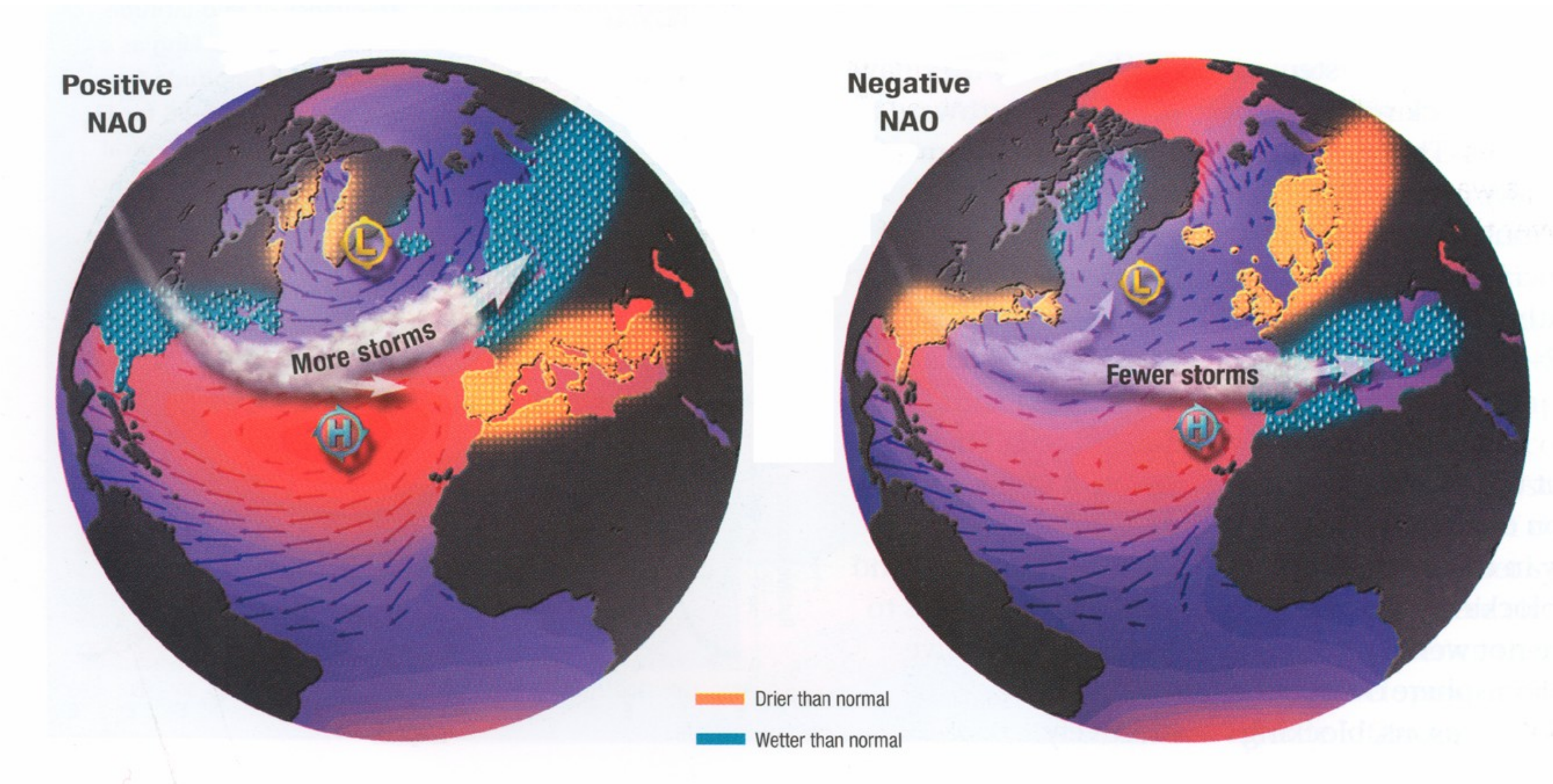
* Anticyclnic wave breaking

o Cyclonic wave breaking

The level of energy E_t required for switching from anticyclonic to cyclonic breaking increases with wavelength.

Characteristics of the Atlantic Storm-Track Eddy Activity and its Relation with the North Atlantic Oscillation

G. Rivière And I. Orlanski 2007, *Jour. Atmos. Sciences*



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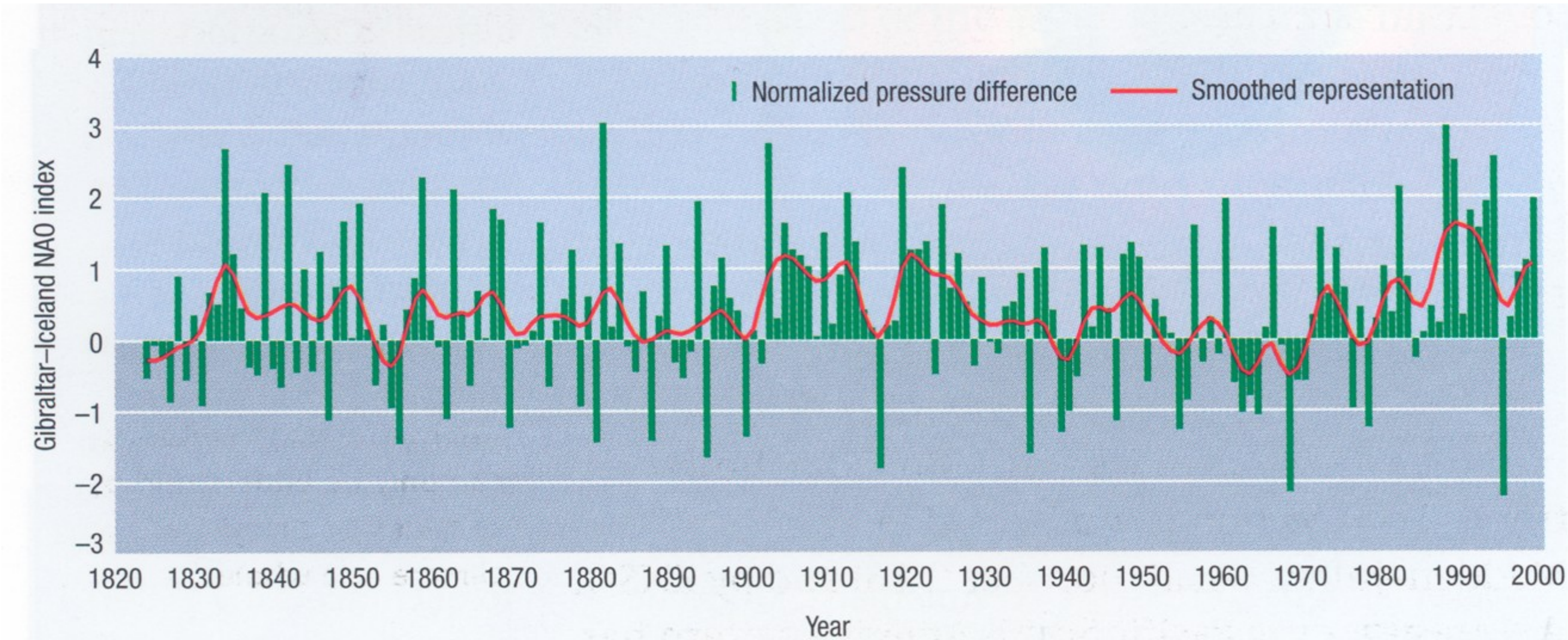
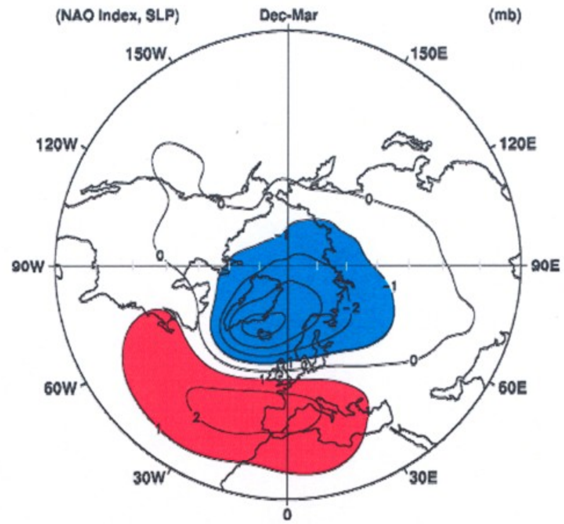


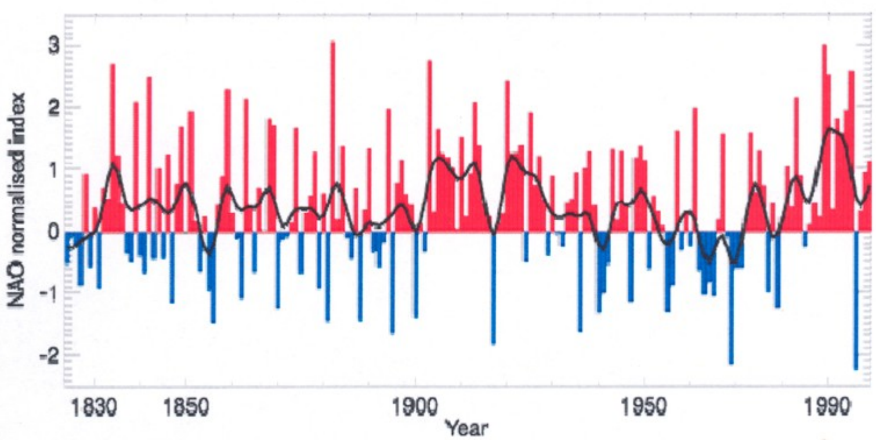
Climate into the 21st Century, WMO

The North Atlantic Oscillation

Sea level pressure pattern Dec-March

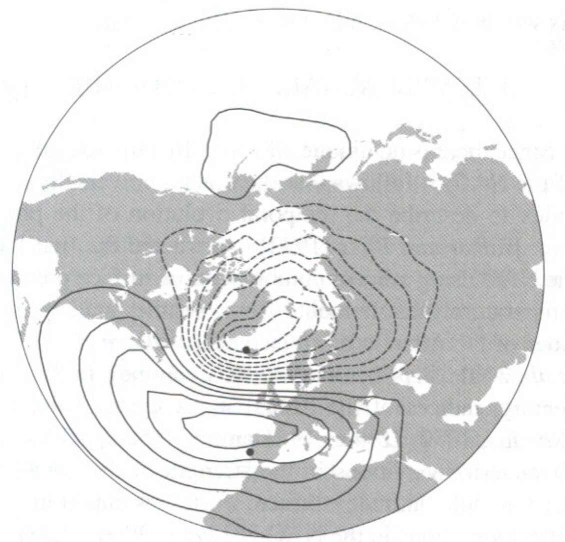


Winter NAO index based on Portugal – Iceland pressure difference



The NAO phenomenon

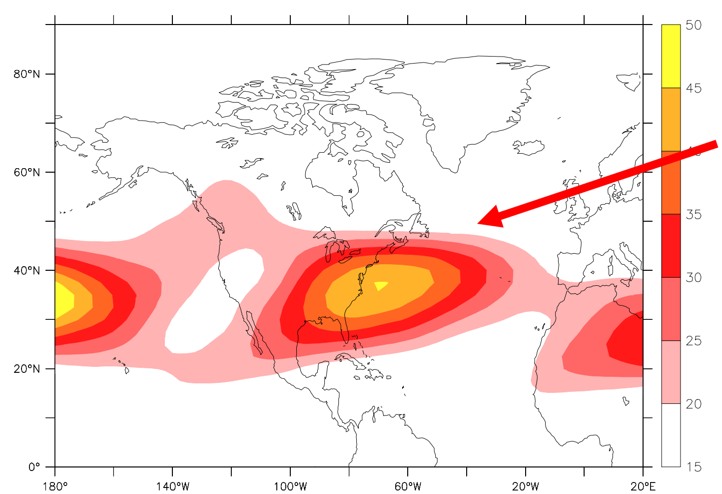
North-South dipole anomaly in pressure or geopotential fields



1st EOF SLP over the Atlantic

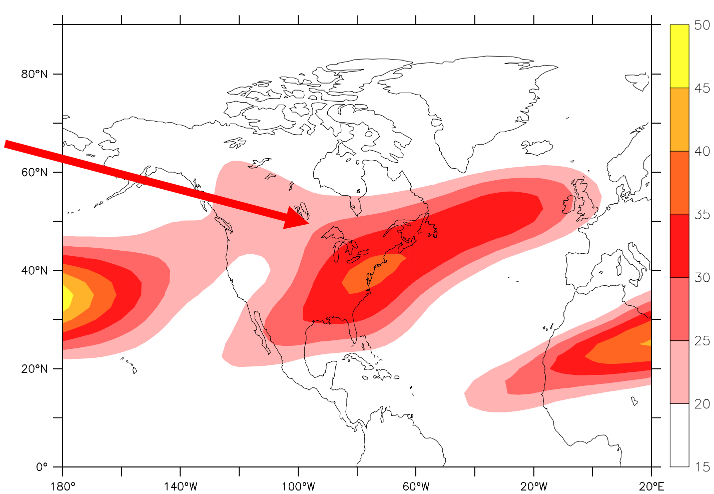
From Hurrell et al. (2003)

Jet displacement in the two different NAO phases



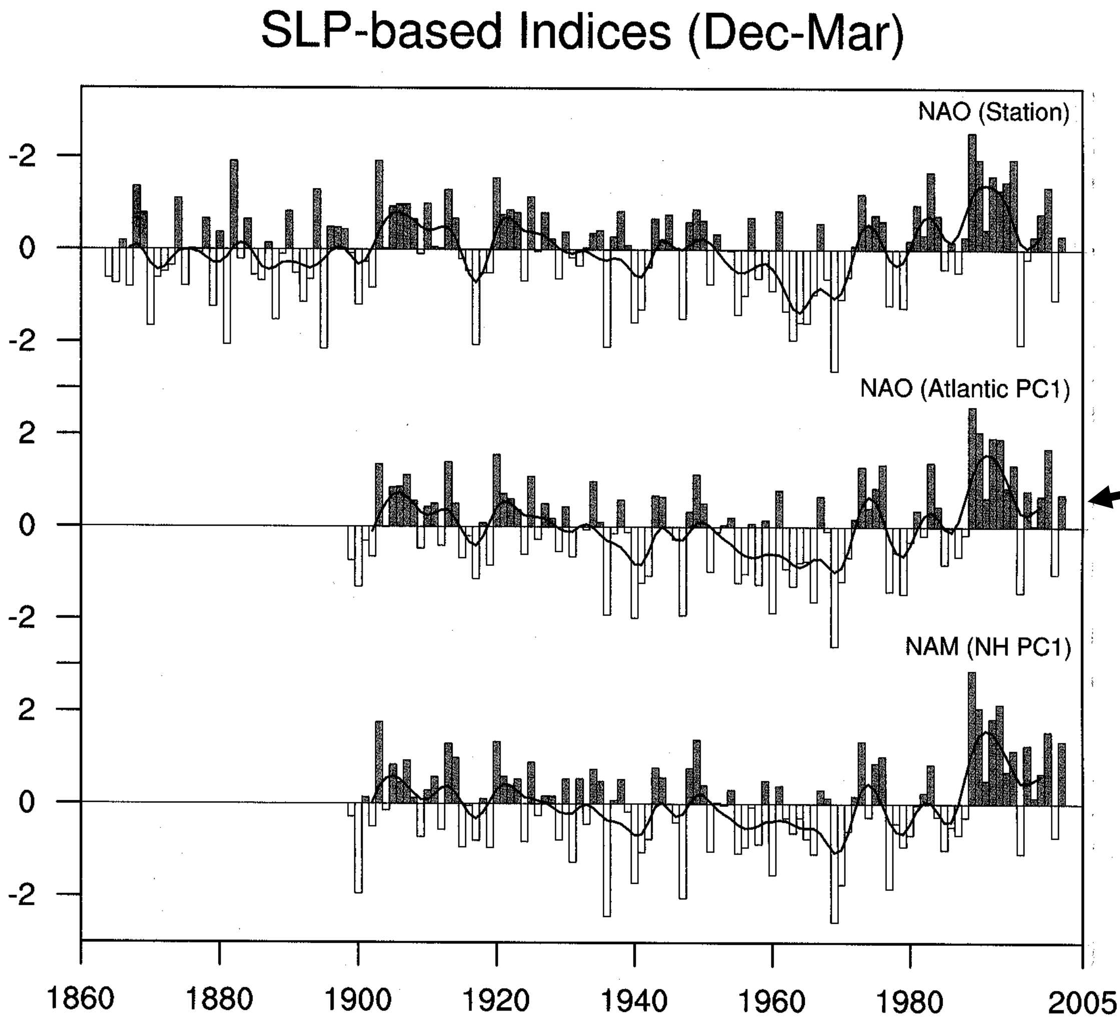
Negative NAO

Zonal wind



Positive NAO

Interannual evolution of the NAO index



1st EOF SLP over the Atlantic

From Hurrell et al. (2003)

Understanding the NAO mechanism is crucial for climate change prediction

Understanding the NAO

• **Historically**, study of its interdecadal / interannual variability has been emphasized by looking at the role of low-frequency external forcing.

ex: ocean (e.g., Rodwell et al. 1999)
stratosphere (e.g., Thompson et al. 2002)
greenhouse - gas forcing (e.g., Shindell et al. 1999)

• **More recently**, intraseasonal time scales processes are shown to be very important

➔ intrinsic time scale 10 days (Feldstein, 2003)
➔ role of wave breaking (Benedict et al., 2004; Franzke et al. 2004)

↓

High-frequency synoptic eddies are fundamental to the NAO

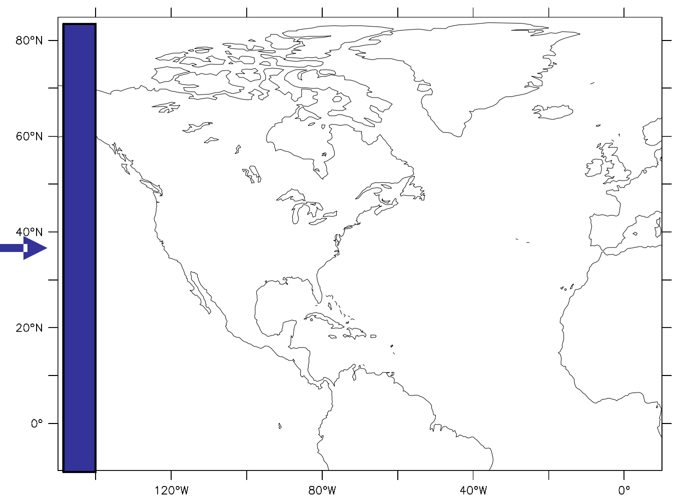
Our methodology

- **NCEP/NCAR reanalysis**: daily dataset from 1950 to 1999
- **ZETAC high resolution non hydrostatic regional model**:

Area: Atlantic domain (150W- 10E, 10S-85N)

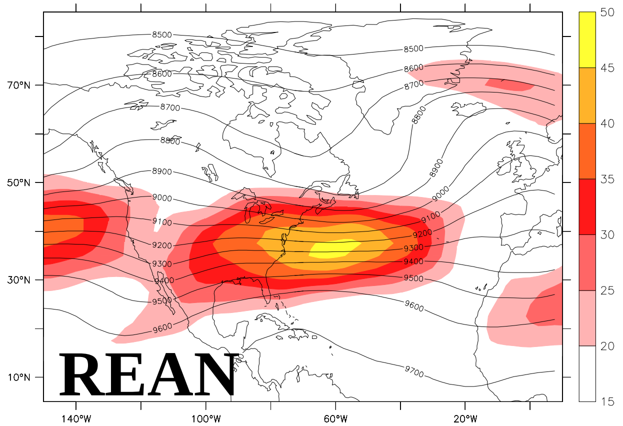
Relaxation toward a given flow

(jet + waves : flow from reanalysis)

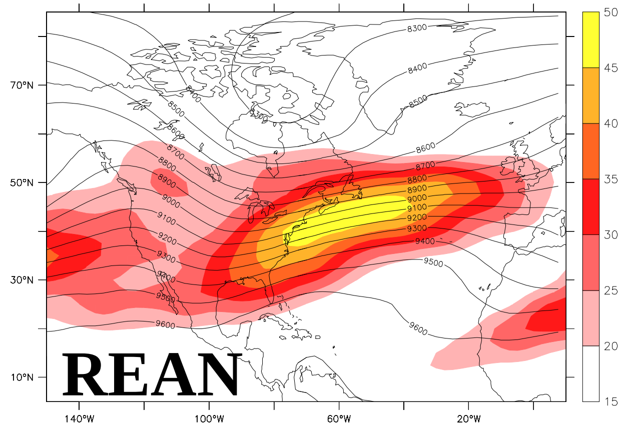


Boundaries: ocean surface: prescribed SST
lateral open boundaries

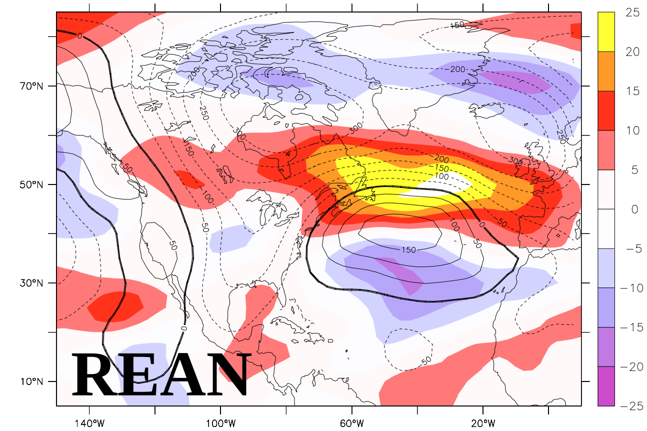
Effect of the waves coming from the Eastern Pacific



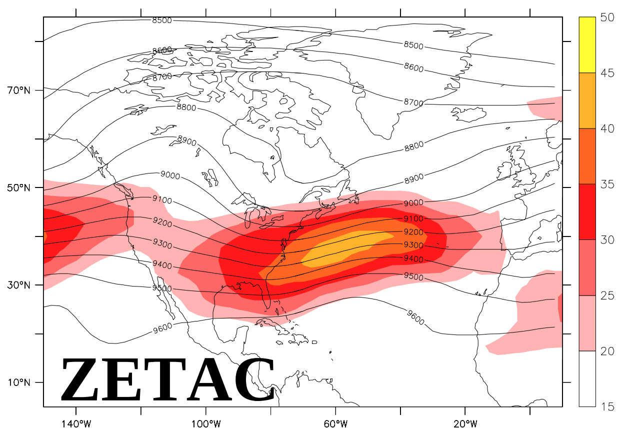
(a) December 87



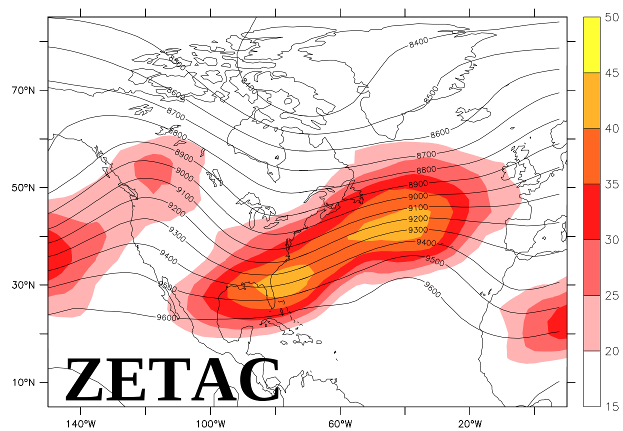
(b) January 88



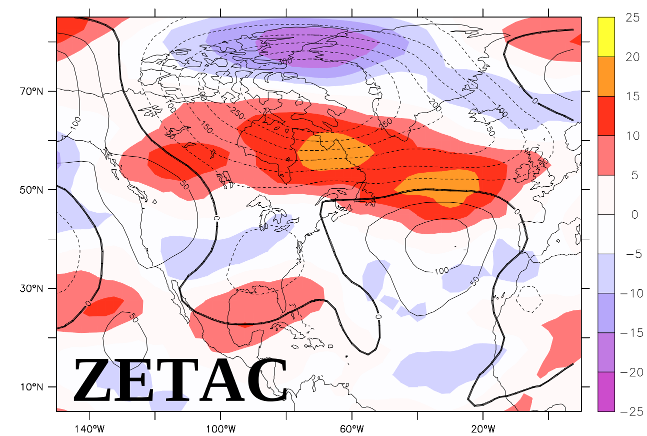
(b) – (a)



(c) December 87 control



(d) December 87 modified
with January 88 boundary



(d) – (c)

The role of the waves and their breaking

Few studies show that wave breaking is related to jet displacement:

- Thorncroft et al (1993) primitive equations study

  (cyclonic WB --- equatorward shift of the jet; anticyclonic WB – poleward shift)

- Orlanski (2003) theoretical study (SW model + zetac)

  (importance of the low-level baroclinicity and moisture to determine WB)

- Orlanski (2005) Implication for the PNA teleconnection

  cyclonic WB --- trough in the Eastern Pacific

  antcyclonic WB --- ridge in the Eastern Pacific

- Benedict, Lee, Feldstein (2004), Franzke, Lee, Feldstein (2004)

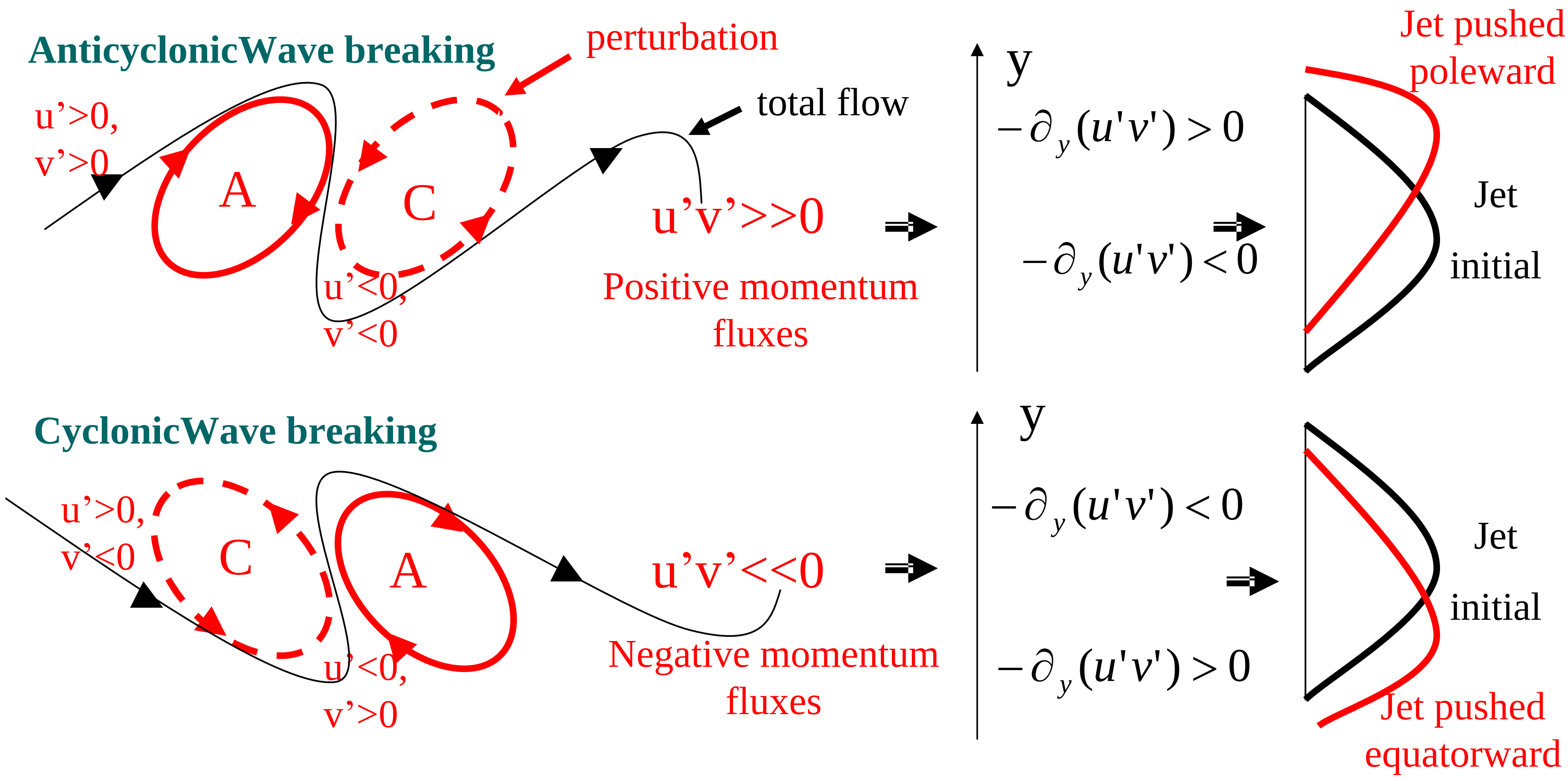
  cyclonic WB --- negative NAO

  anticyclonic WB --- positive NAO

How the wave break is crucial for the jet displacement

Relation between wave breaking and jet displacement

$$\partial_t \overline{u} \approx -\partial_y (u'v')$$



The sign of the meridional momentum fluxes gives the form of the wave breaking

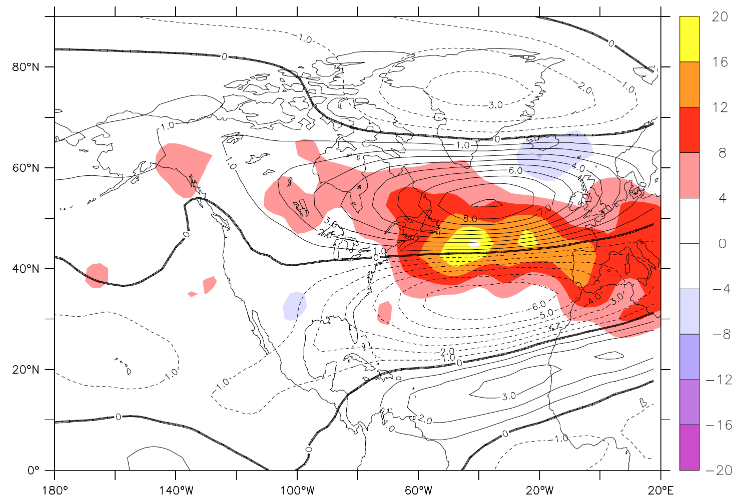
In what follows, primes will correspond to the high-frequency component of the total flow (periods< 12days)

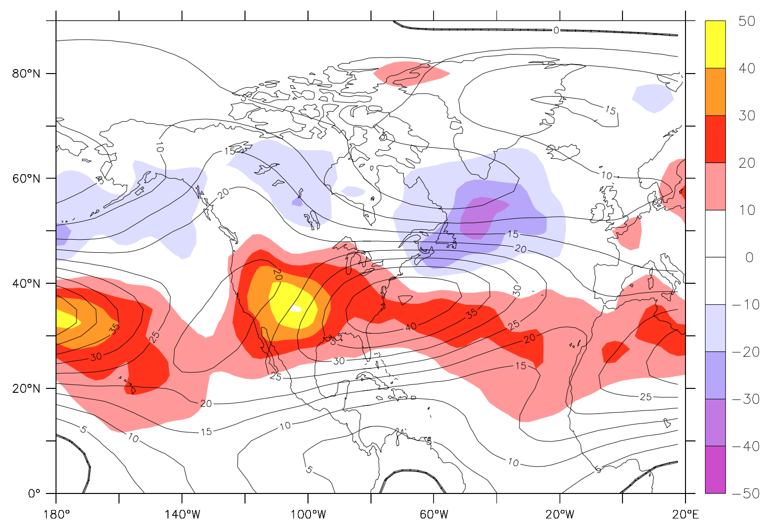
Zonal wind, momentum fluxes and NAO

Regression on monthly NAO index

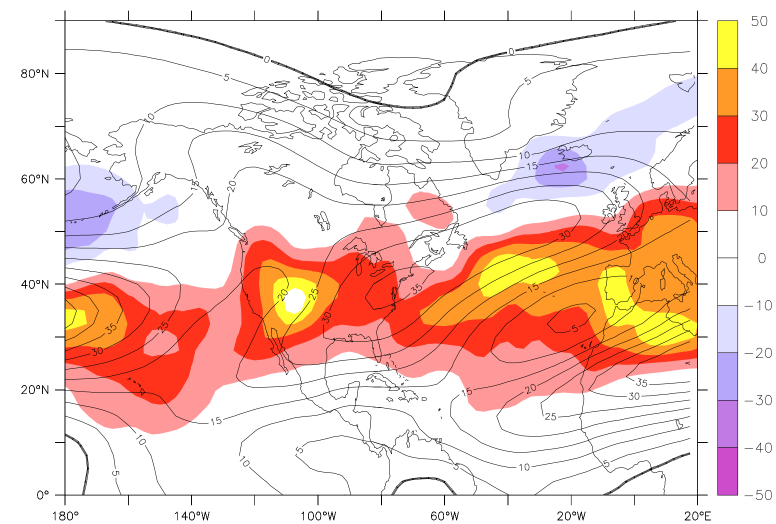
U Black lines

$U_{hf}V_{hf}$ Color shadings





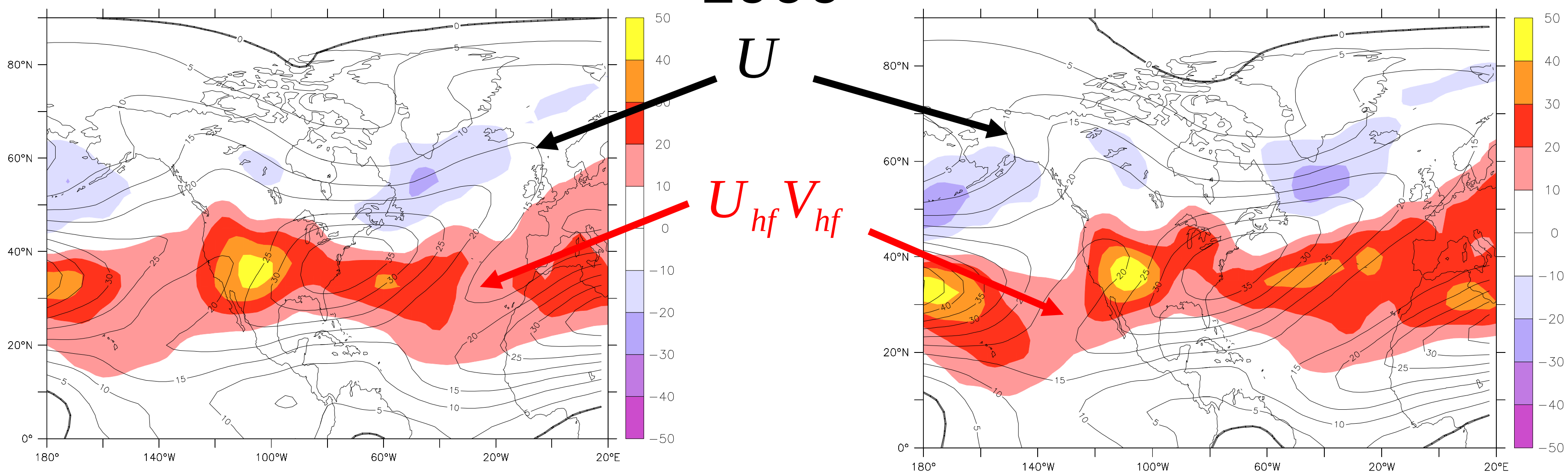
Negative NAO composite



Positive NAO composite

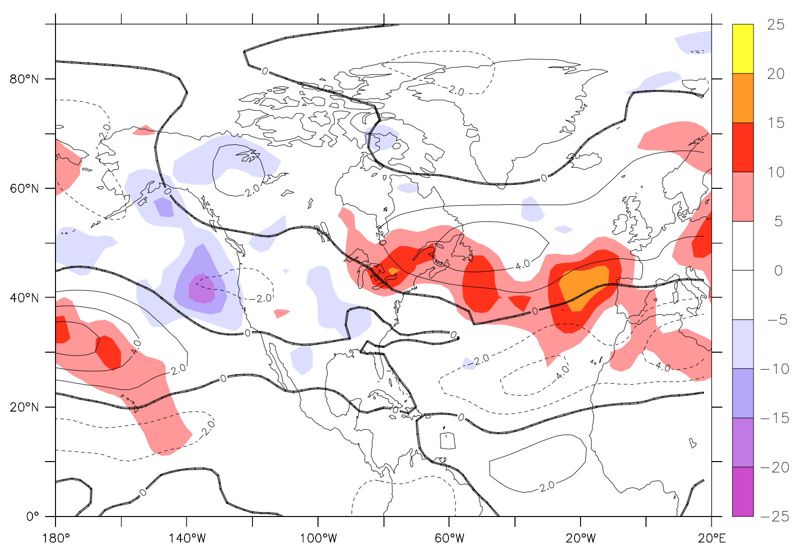
The NAO index is strongly correlated with the sign of the high-frequency meridional momentum fluxes over the Atlantic

Decadal trend of the NAO between 1950 and 1999



(a) 1950-1975 DJF average

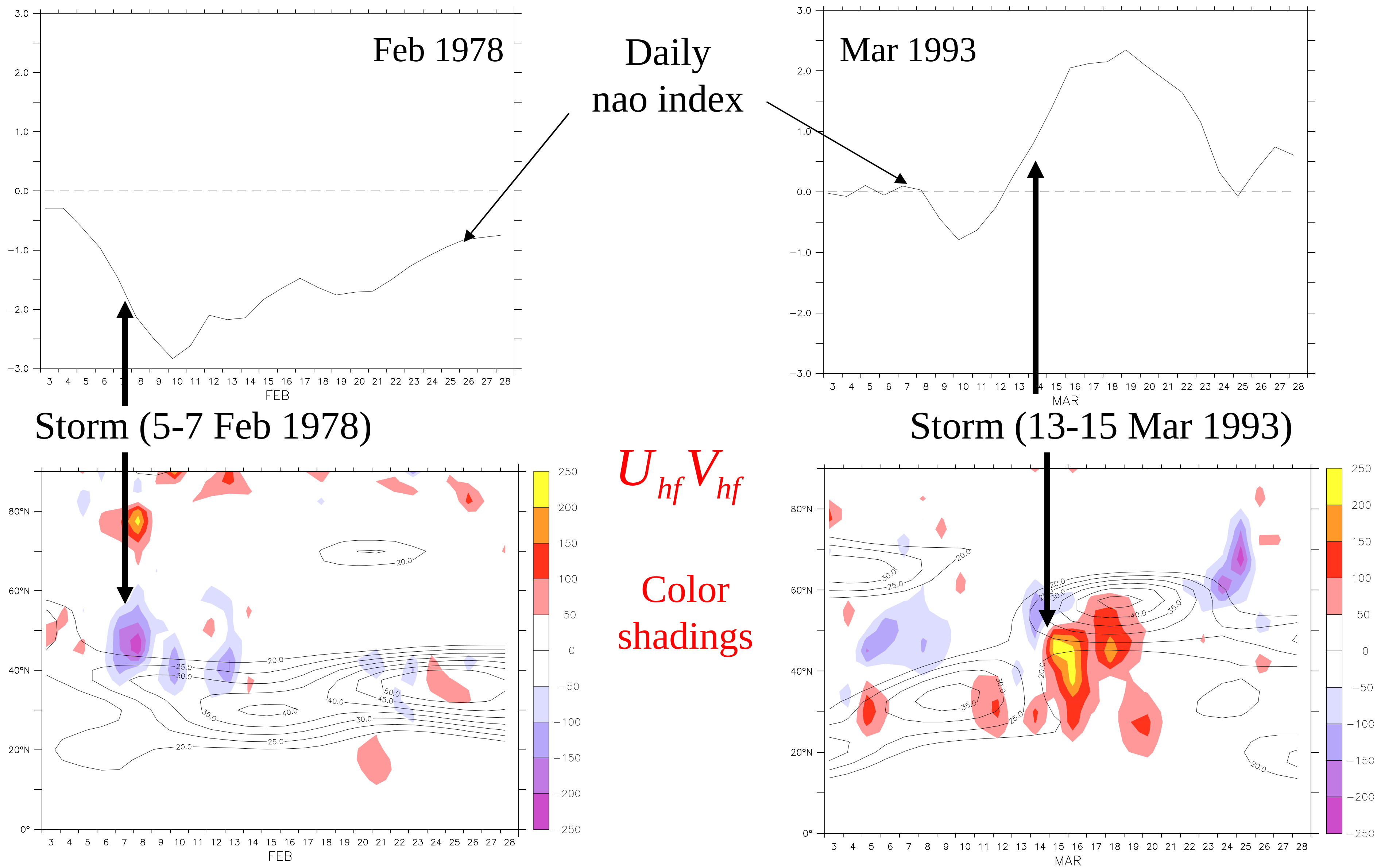
(b) 1976-1999 DJF average



(b)-(a)

More anticyclonic wave breaking is present during the 80s-90s than during the 50s-60s

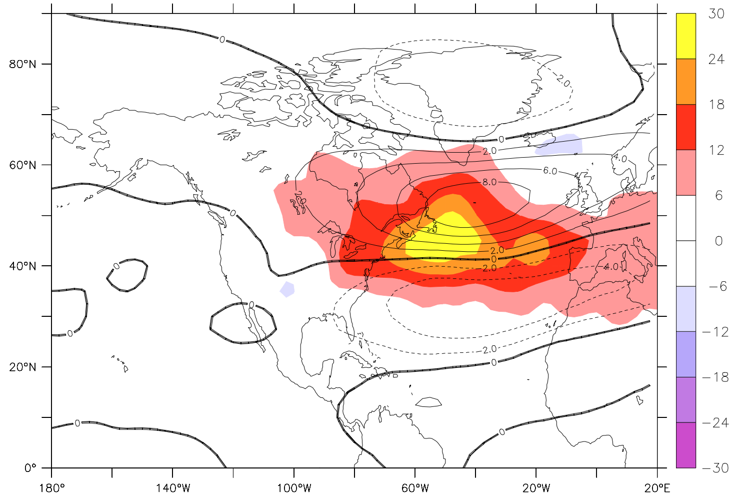
Single storms effect



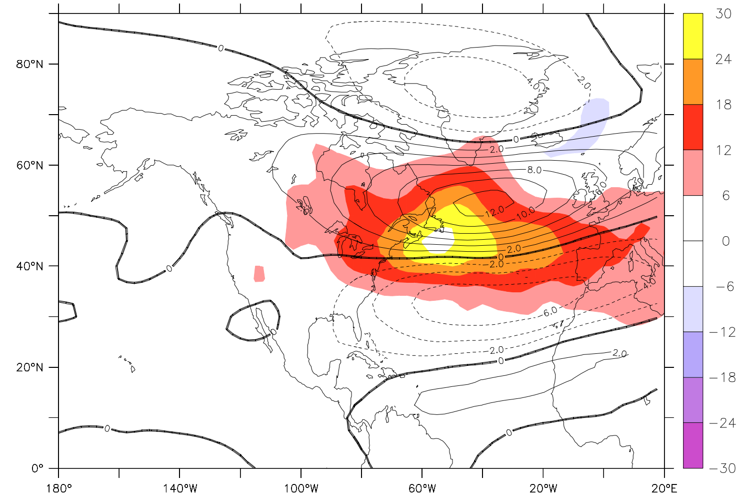
One storm can be responsible for the sign of the NAO during an entire month !

Time-lag regressions on daily NAO index

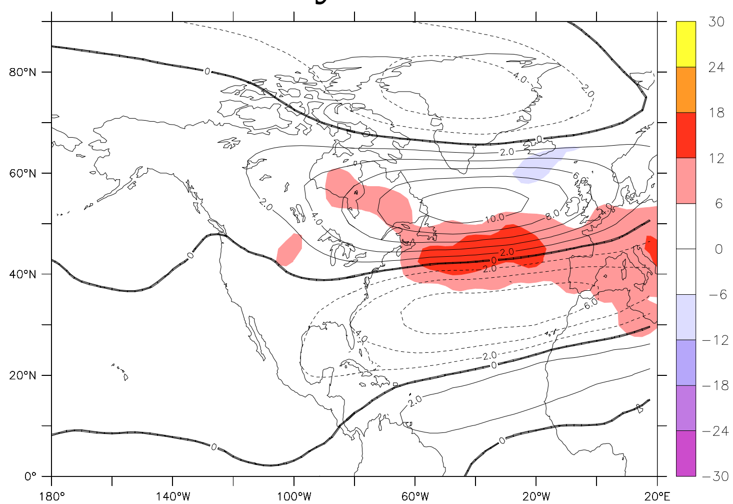
Zonal wind (black contours) and meridional momentum fluxes (color shadings)



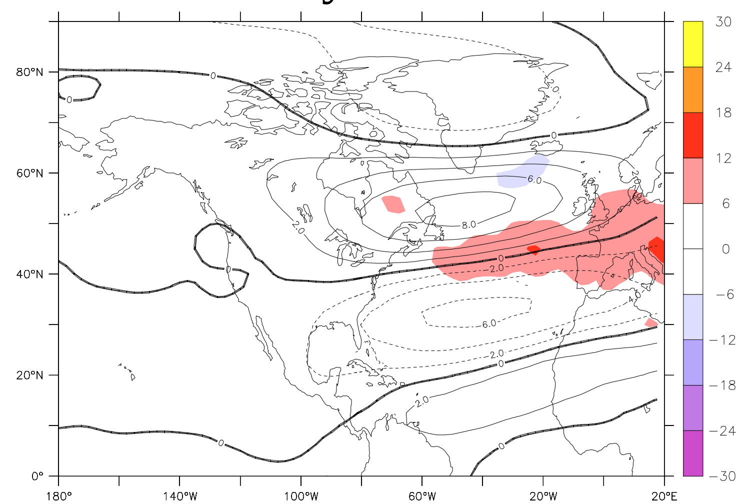
Day - 4



Day - 2



Day + 2

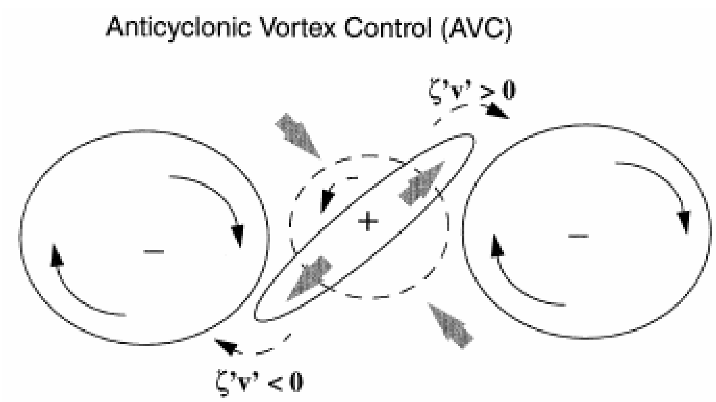


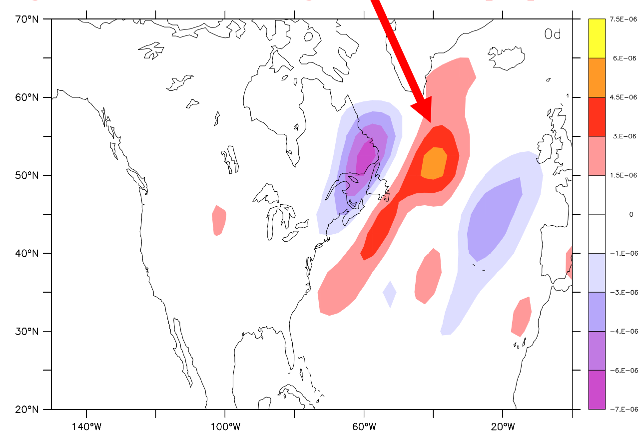
Day + 4

Wave breaking occurs essentially prior to an NAO event

Cyclonic and anticyclonic wave breaking processes (5)

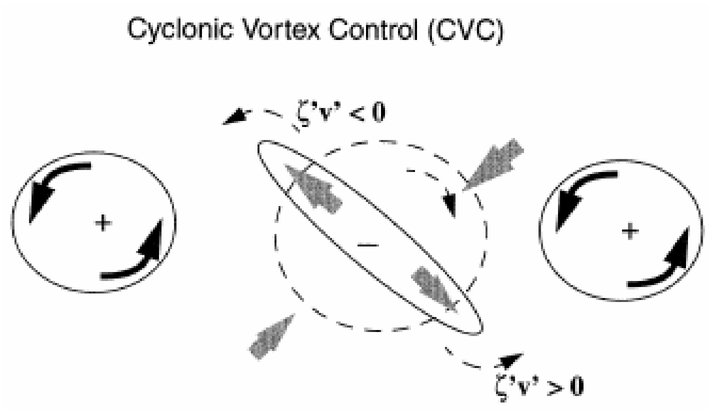
high-frequency vorticity in upper levels

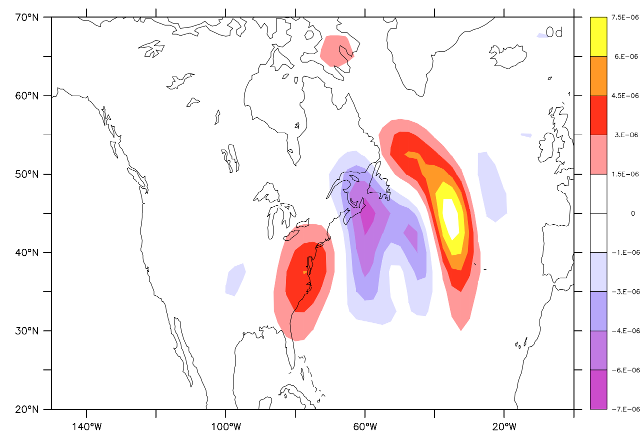




Anticyclonic wave breaking, Day 0 of the regression

From Orlanski (2003)





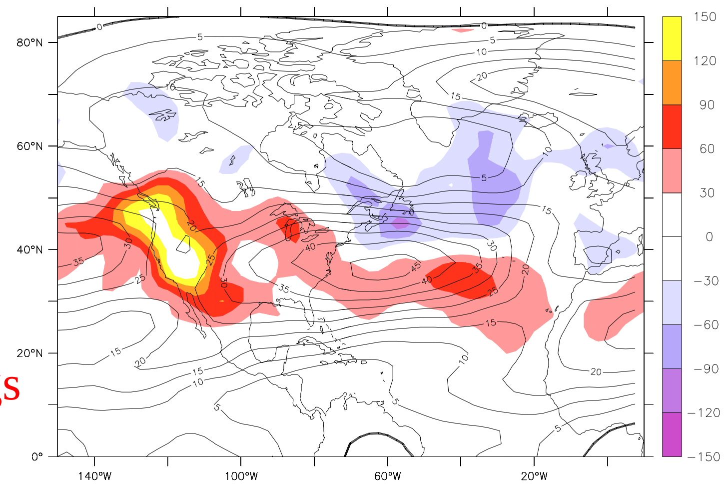
Cyclonic wave breaking, Day 0 of the regression

- **Anticyclonic WB**: anticyclones are strong and are stretching the cyclones.
- **Cyclonic WB**: reverse situation. Strong cyclonic development is present, and cyclones are responsible for the deformation of the anticyclones.

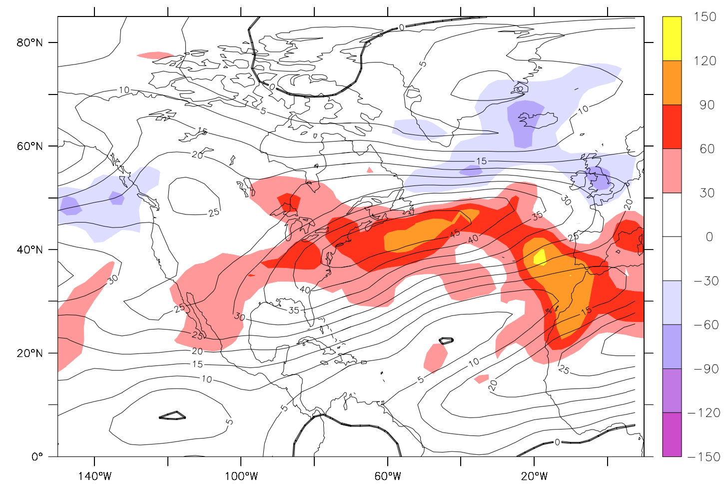
Return to the two consecutive months with opposite NAO phases (Dec 87, Jan 88) and to the ZETAC solutions

U
Black lines

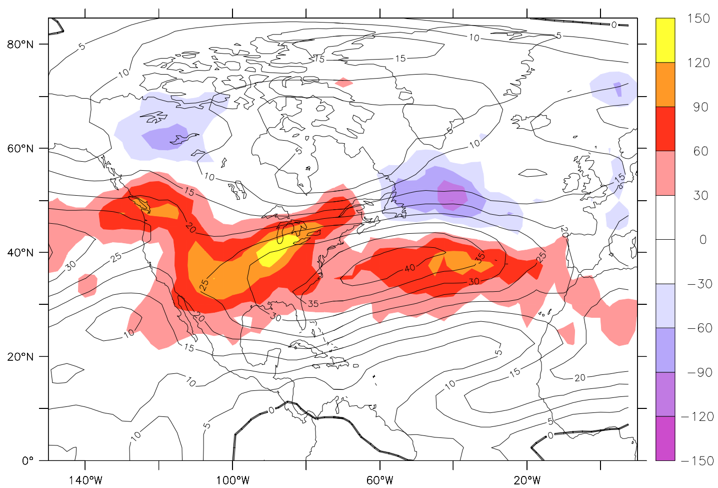
$U_{hf}V_{hf}$
Color shadings



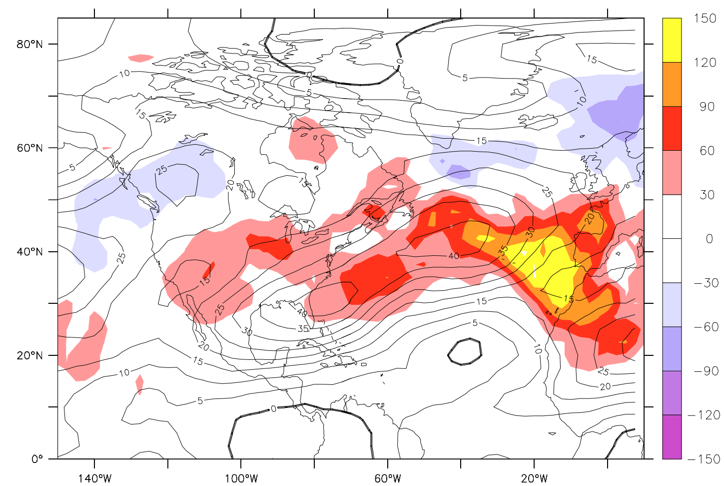
Reanalysis Dec 87



Reanalysis Jan 88



Zetac Dec 87 control



Zetac Dec 87, Bdy of Jan 88

The model reproduces quite well the location and the sign of the wave breaking

Conclusions

Synoptic eddies and their breaking play a crucial role in the NAO phenomenon

- Anticyclonic WB pushes the jet poleward ⇒ Positive NAO.
- Cyclonic WB pushes the jet equatorward ⇒ Negative NAO.
- High-frequency meridional momentum fluxes is a useful parameter to quantify WB.

What are the properties of the waves that make them break cyclonically or anticyclonically ?

- Large-scale (small-scale) waves break anticyclonically (cyclonically).
- Waves in intermediate frequencies “5d – 12d” (very-high frequencies “<5d”) break anticyclonically (cyclonically).
- Cyclonic WB has explosive cyclone development in the low levels (explained by strong surface moisture fluxes)

Reminding question: relation between NAO and EL NINO ?

- Cor(NAO,NINO)~ -0.14 weakly negative
- Over 8 strongest El Nino, 5 correspond to negative NAO

⇒ Could be understood !

But the question of the trend: why strong El Nino in the 80s-90s occur during the decades where NAO tends to be more positive ?

Things to remember from Lecture 4.

- The role of the high frequency eddies in modeling quasi-stationary modes.
- Even single extreme events can produce enough forcing to revert the phase of qausi-stationary mode .
- These effects because are tied to waves, their effect could be far away. In contrast topographic features produce its effect in the neighborhood of the source.
- High-frequency eddies tend to transport momentum poleward (anticyclonic wave breaking) pushing the jet poleward. Whereas other waves could transport momentum equatorward (cyclonic wave breaking) positioning the westerly jet on the south of the eddy activity.