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)

Year 2002

Nov 11

Nov 13

Nov 15

Nov 17

US Tornado Outbreak:

Oil Tanker “Prestige” Disaster

Eastern Switzerland
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

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 Niño with moderate intensity

Composite 1948-2004

1958, N3.4=1.62

1966, N3.4=1.145

1973, N3.4=1.521

1987, N3.4=1.224

1992, N3.4=1.661
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.

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

Upper level westerlies over the Pacific storm track

Asia
120E

Cyclonic wave breaking

Equator

North America
120W

Mid-latitudes

Eddy activity

Anticyclonic wave breaking

Tropical heat & moist fluxes

Climatology
Warm events

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

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.
Introduction
Downstream development and wave breaking in a storm track environments.

Model Simulations
• The Control case
• Upstream Seeding
• SST anomaly
• SST and Seeding

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)
Zonal wind, pressure anomaly, air temperature and surface water vapor for the Control simulation.
ENSO warm phase anomalies from the NCEP/NCAR reanalysis
Experiment N2 anomalies
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)

> > > > > > La Nina

< < < < < < El Nino

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 ($z=300$HPa) 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.

![Graph showing average velocity over days with two lines: one for moderate seeding and one for strong seeding, with Z=8900m.](image)
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 backbone 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

* Anticyclonic 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*
Climate into the 21st Century, WMO
Climate into the 21st Century, WMO
Sea level pressure pattern Dec-March

The North Atlantic Oscillation

Winter NAO index based on Portugal – Iceland pressure difference
The NAO phenomenon

North-South dipole anomaly in pressure or geopotential fields

Jet displacement in the two different NAO phases

Zonal wind

From Hurrell et al. (2003)
Interannual evolution of the NAO index

From Hurrell et al. (2003)

1st EOF SLP over the Atlantic

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
  
  anticyclonic WB --- ridge in the Eastern Pacific

  
  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

\[ \partial_t \bar{u} \approx -\partial_y (u'v') \]

Anticyclonic Wave breaking

- \( u' > 0, \ v' > 0 \)
- \( u' < 0, \ v' < 0 \)
- Positive momentum fluxes
- \( u'v' > 0 \)
- Jet pushed poleward

Cyclonic Wave breaking

- \( u' > 0, \ v' < 0 \)
- \( u' < 0, \ v' > 0 \)
- Negative momentum fluxes
- \( u'v' < 0 \)
- Jet pushed equatorward

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 < 12 days)
Zonal wind, momentum fluxes and NAO

Regression on monthly NAO index

$U$ Black lines

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

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

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

Wave breaking occurs essentially prior to an NAO event
Cyclonic and anticyclonic wave breaking processes

(5)

high-frequency vorticity in upper levels

• **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

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 quasi-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.