Theories of low-frequency variability over Europe

Brian Hoskins

Department of Meteorology, University of Reading
Grantham Institute for Climate Change, Imperial College

The Agenda

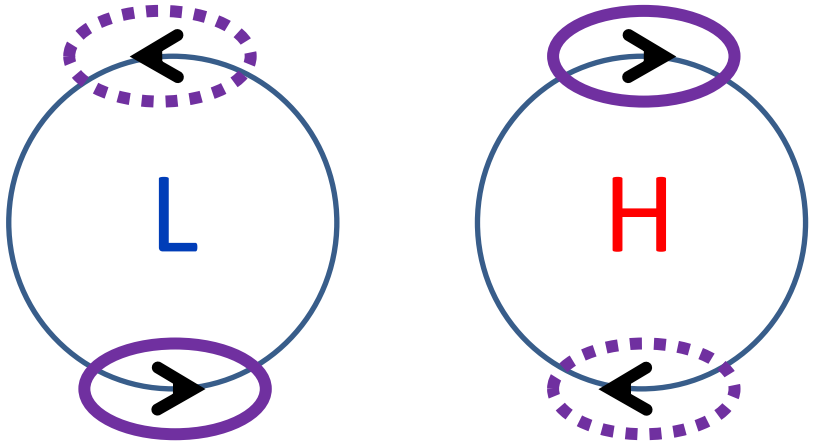
1. Synoptic eddy organisation & feedback
2. Rossby waves – horizontal propagation
3. Teleconnection patterns
4. Blocking
5. Events related to the Asian Summer Monsoon

1 Synoptic weather systems

For zonal flows and low frequency anomalies, synoptic weather systems

Are organised by the westerly flow

Feedback + on the barotropic motion, - on the baroclinic motion



More synoptic activity

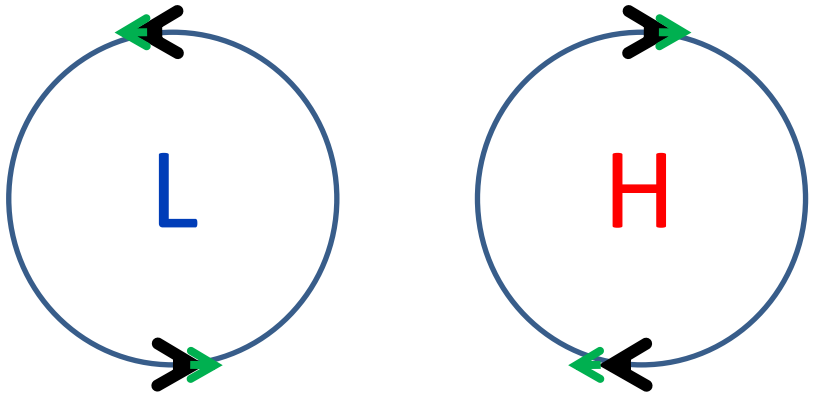
Less synoptic activity

Synoptic weather systems

For zonal flows and low frequency anomalies, synoptic weather systems

Are organised by the westerly flow

Feedback + on the barotropic motion, - on the baroclinic motion

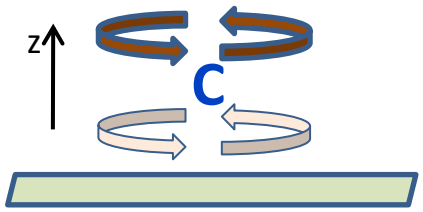


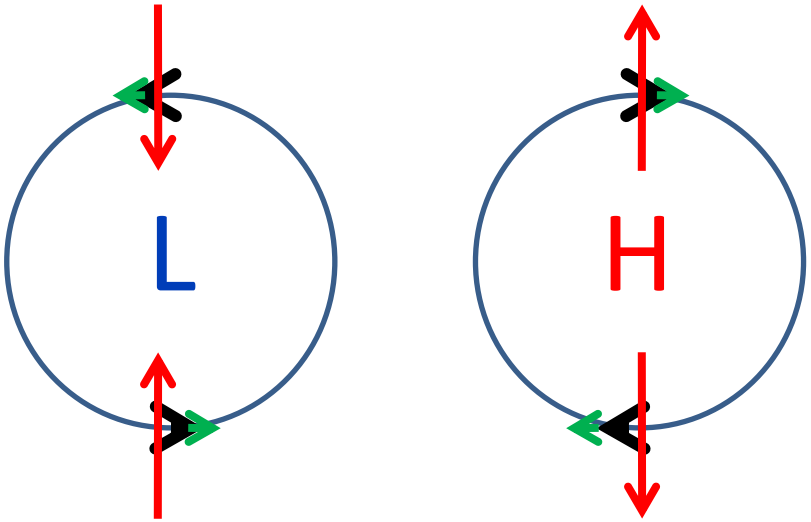
Synoptic weather systems

For zonal flows and low frequency anomalies, synoptic weather systems

Are organised by the westerly flow

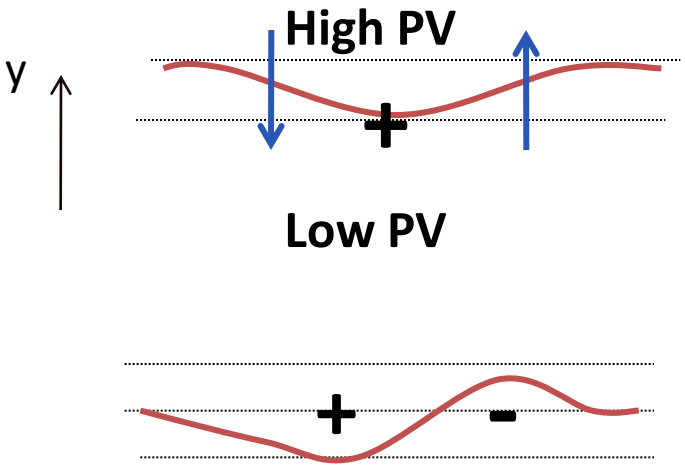
Feedback + on the barotropic motion, - on the baroclinic motion

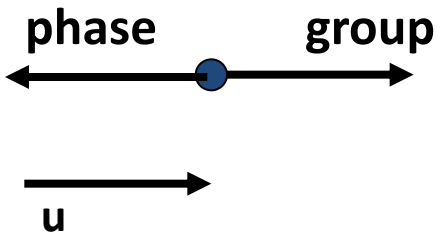




Therefore they act to counter the spin-down of the lower frequency anomalies due to surface friction

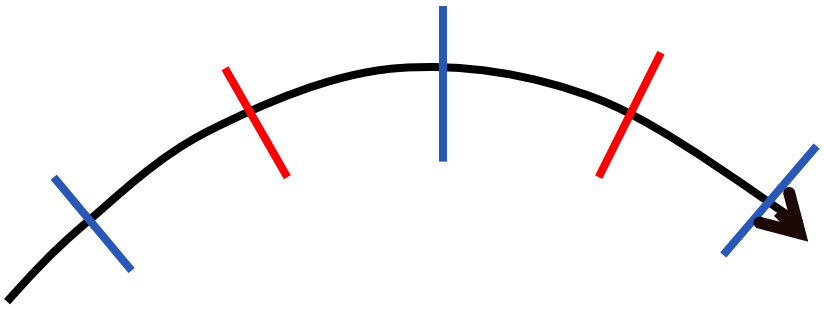
2. Rossby wave propagation - horizontal





Stationary waves possible on westerlies
Influence to the east

On the sphere and refracted by the ambient flow

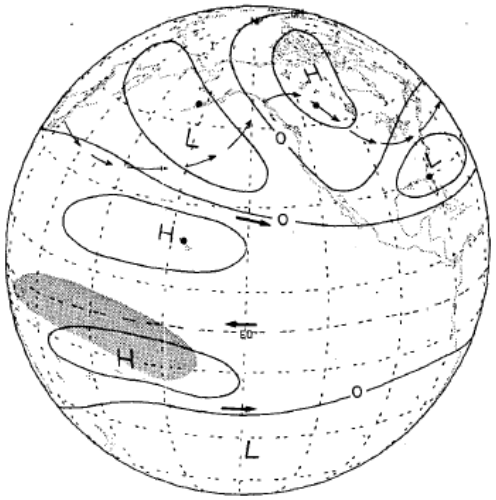


Strong jets can act as waveguides

Eddies can take barotropic energy from the mean in jet exit regions

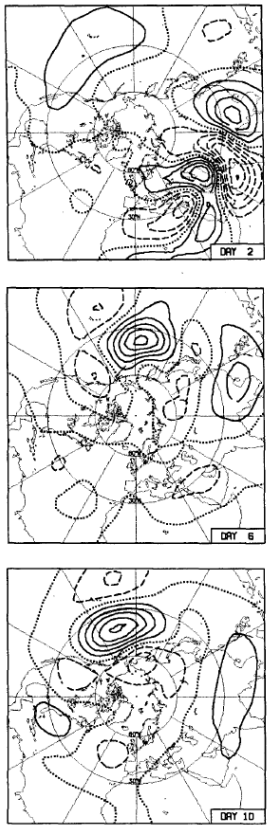
Forcing and Propagation of Rossby waves

Observations



Horel and Wallace (1981)

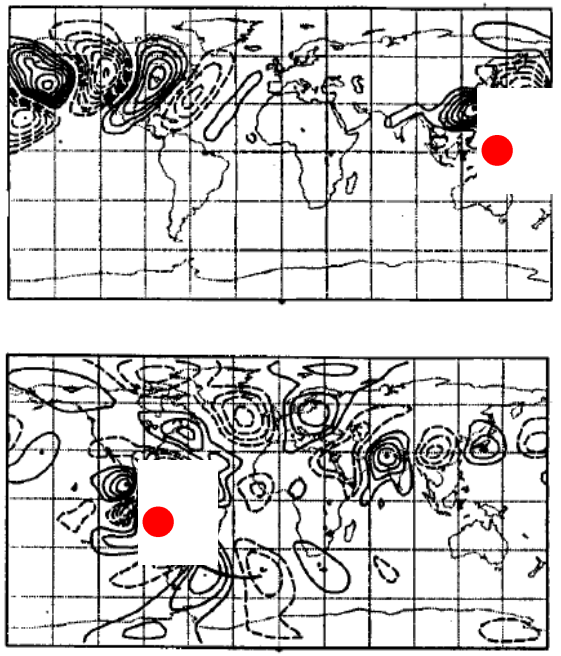
Initial perturbation
barotropic model
2-D basic state



Simmons, Wallace
& Branstator (1983)

Forced baroclinic model
3-D basic state

After 9 days



Ambrizzi and Hoskins (1997)

$$(\partial_t + \mathbf{v}_\psi \cdot \text{grad})\xi + \beta v_\psi = -\zeta D - \mathbf{v}_\chi \cdot \text{grad}\,\zeta$$

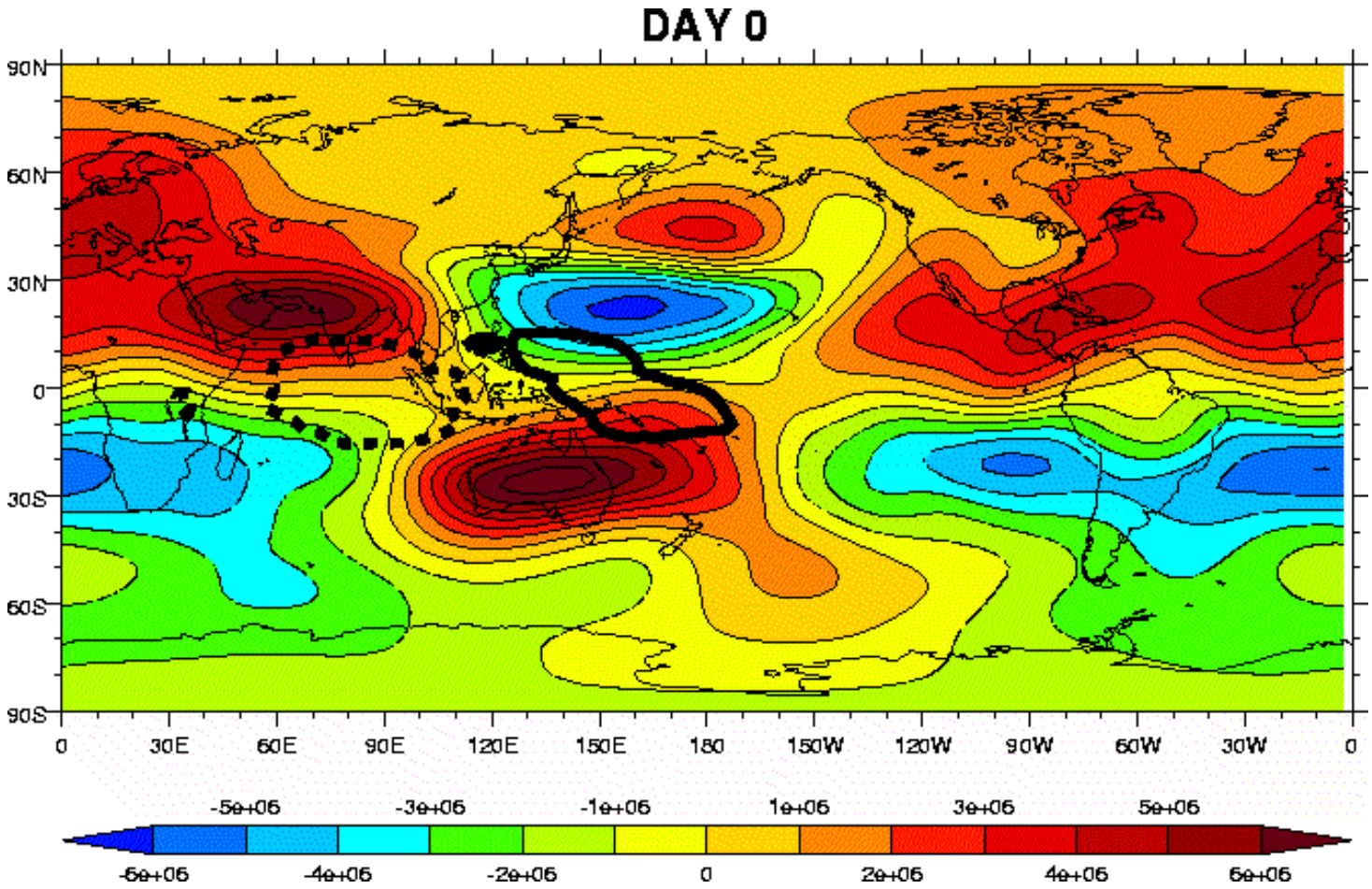
Rossby wave source

Sardeshmukh & Hoskins (1988)

DJF global circulation anomalies associated with an MJO cycle

Cycle from 2 EOFs of 20-200 day filtered OLR: heavy contours

Regressed ψ_{200}: colours



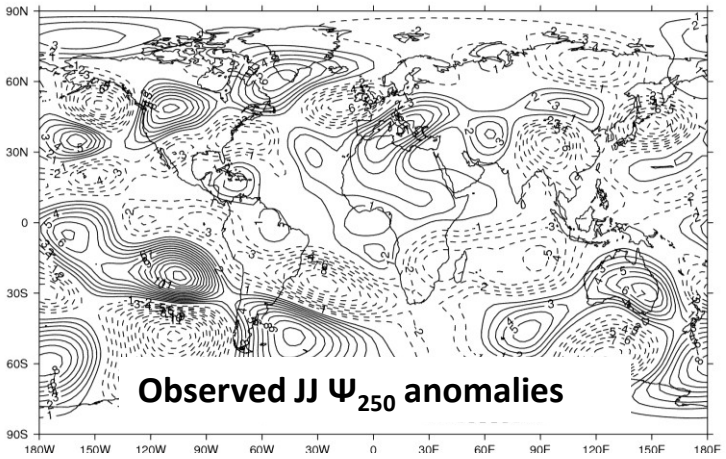
Matthews, Hoskins & Masutani (2004)

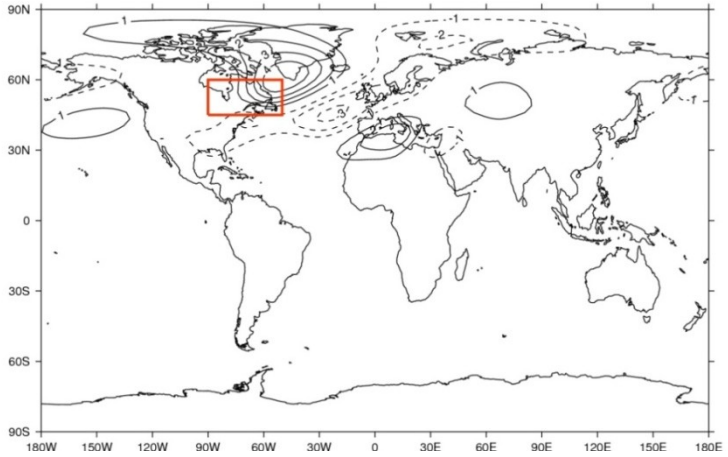
Summer 2007: experiments with a time dependent 3-D baroclinic model

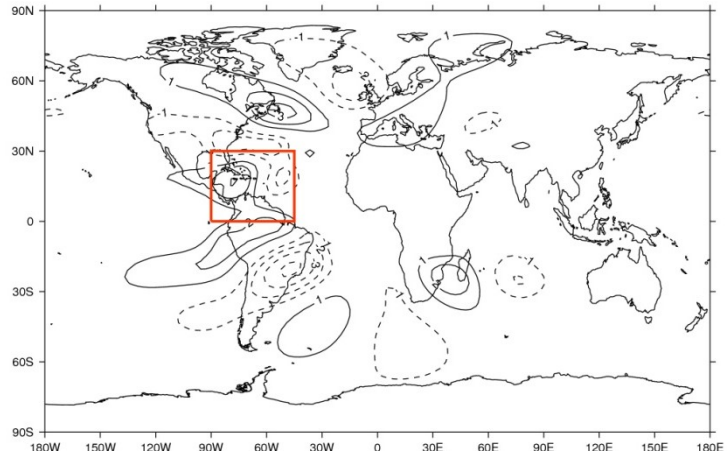
Ricardo Fonseca

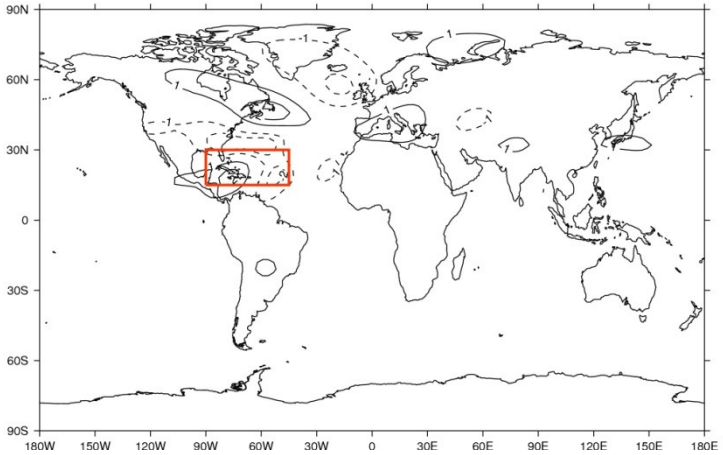
Damping only. Climatological flow specified and balanced by a forcing.

Relaxation to observed anomaly in specified regions: show Ψ_{250} anomaly at day 30





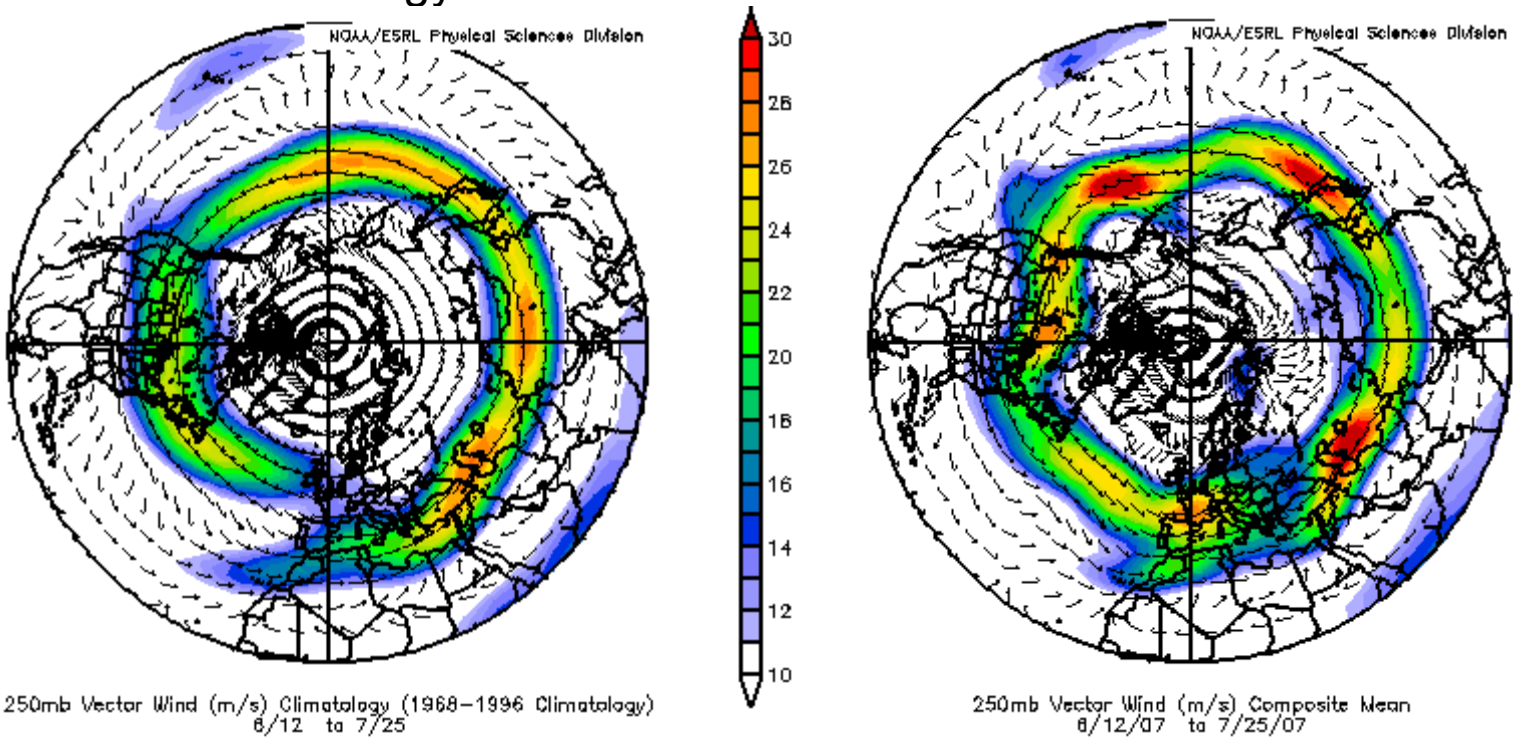




Summer 2007 UK floods - 250hPa v

Average from 12 June to 25 July

Climatology



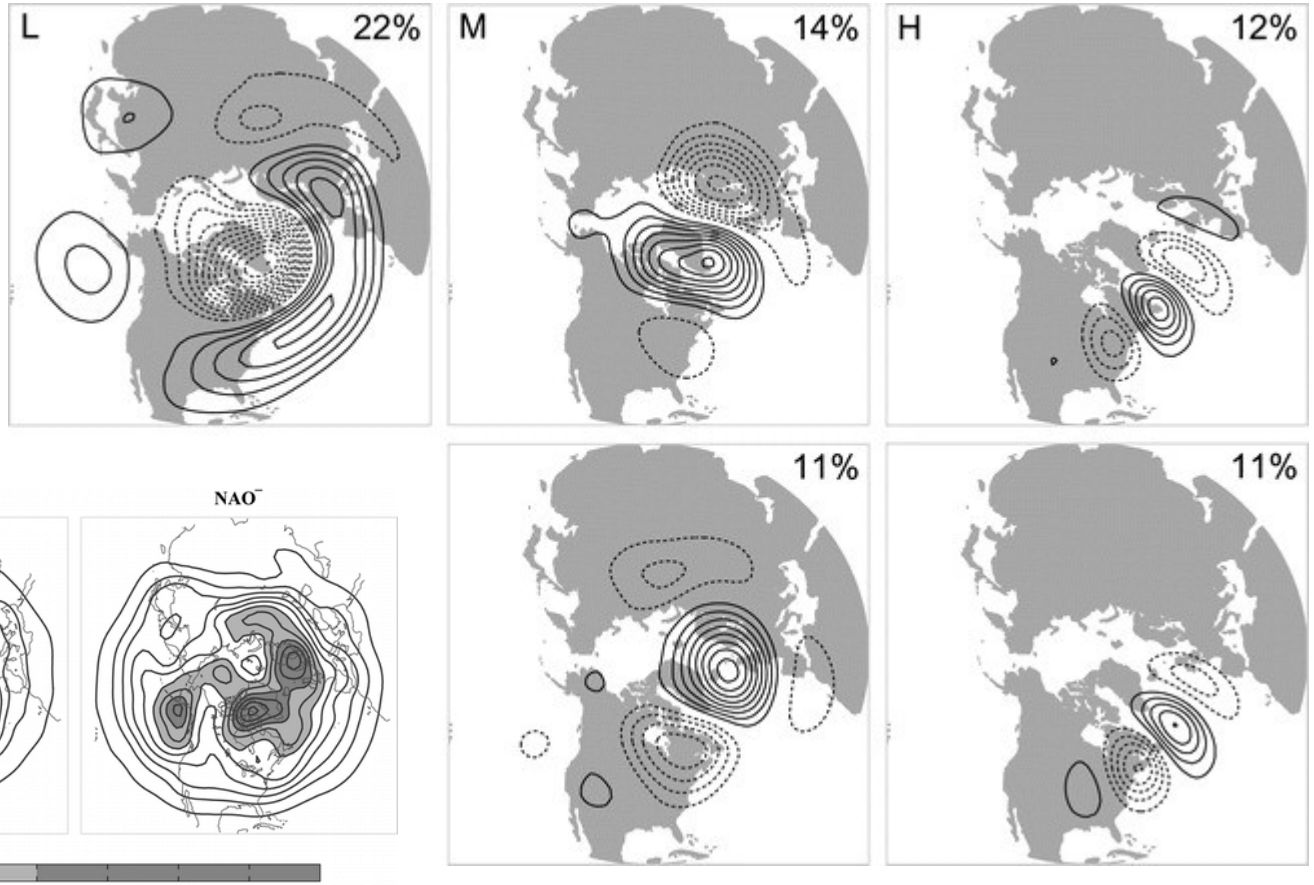
2007

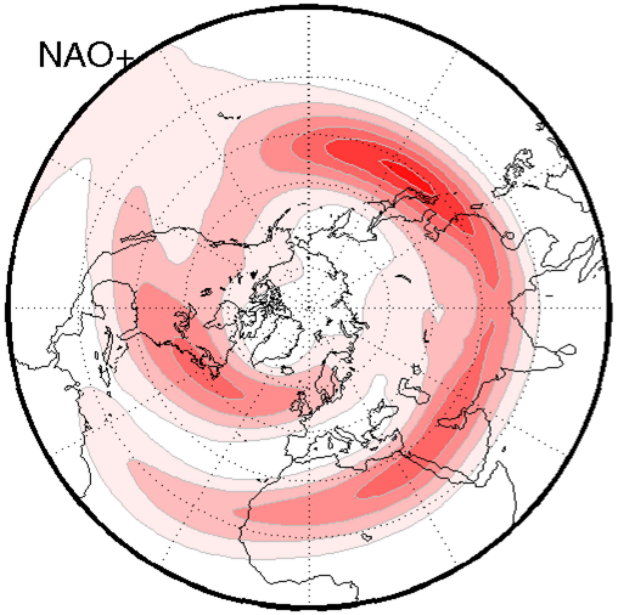
Blackburn et al, 2008

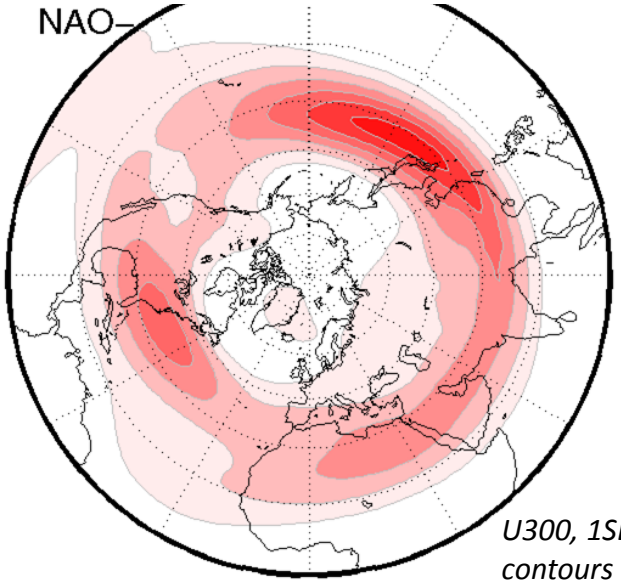
3. Leading DJF Z_{500} EOFs in the Atlantic Sector

Rennert & Wallace (2009)

> 30d **6-30 d** **<6d**

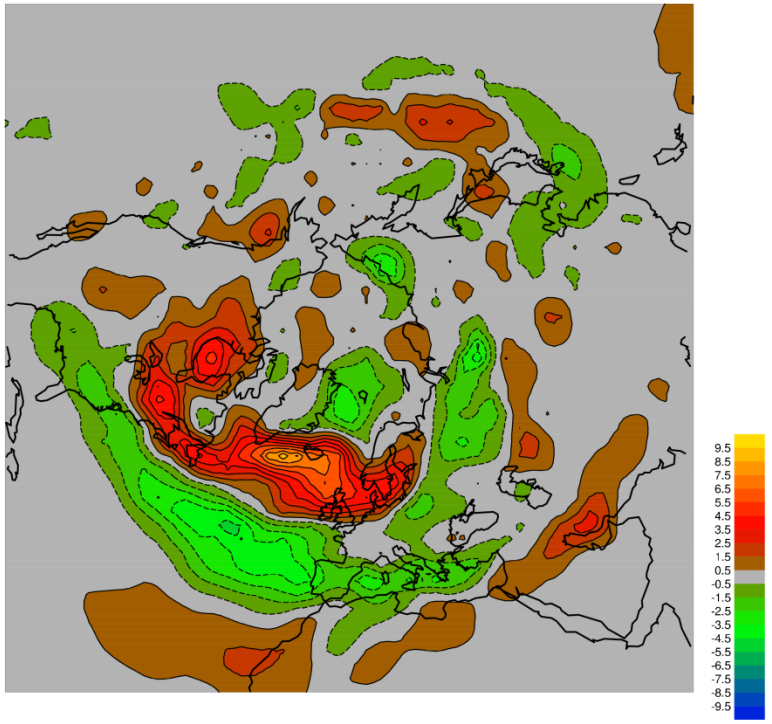






U300, 1SD daily comps, contours 10m/s

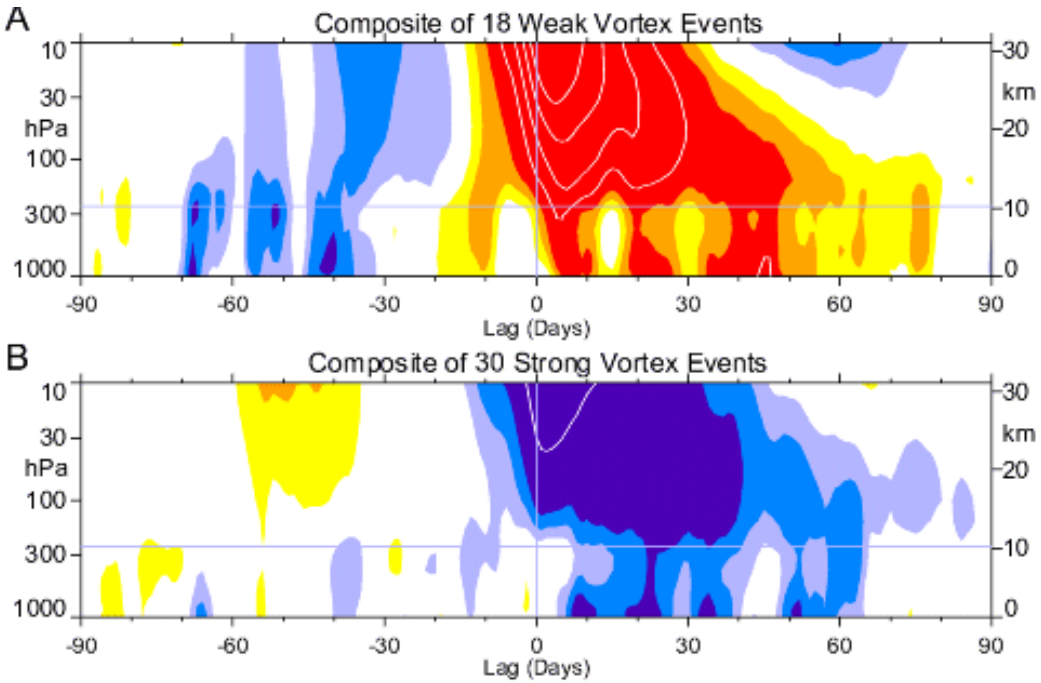
The North Atlantic Oscillation (NAO) describes synchronous variations in the strength and orientation of the jet and storm track.



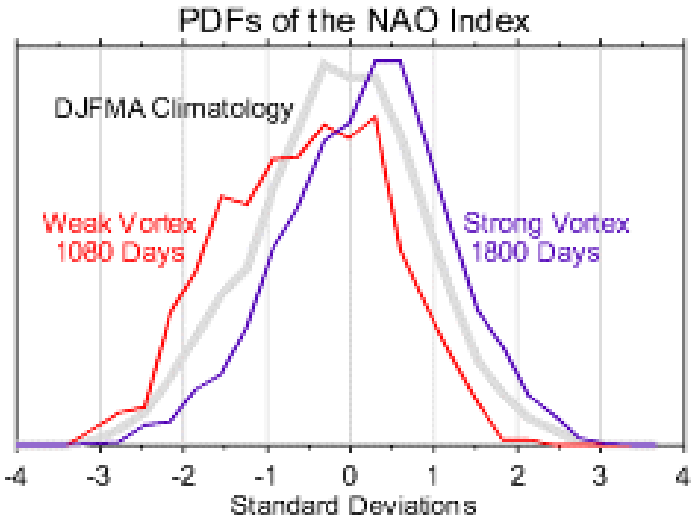
Track density regressed on NAO index; Hoskins & Hodges ?

The stratospheric connection

Composites of EOF1/annular behaviour for weak and strong 10 hPa vortex events



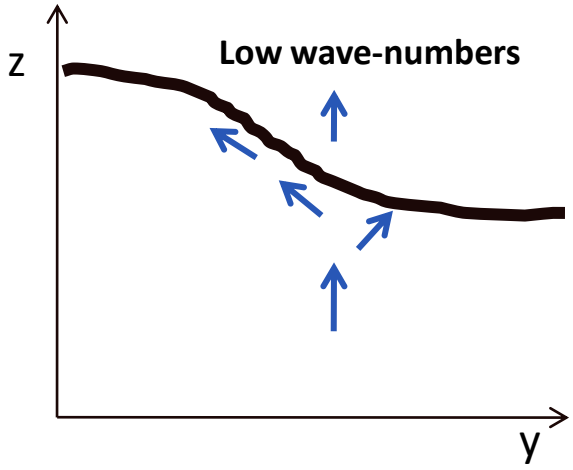
PDFs of the NAO index

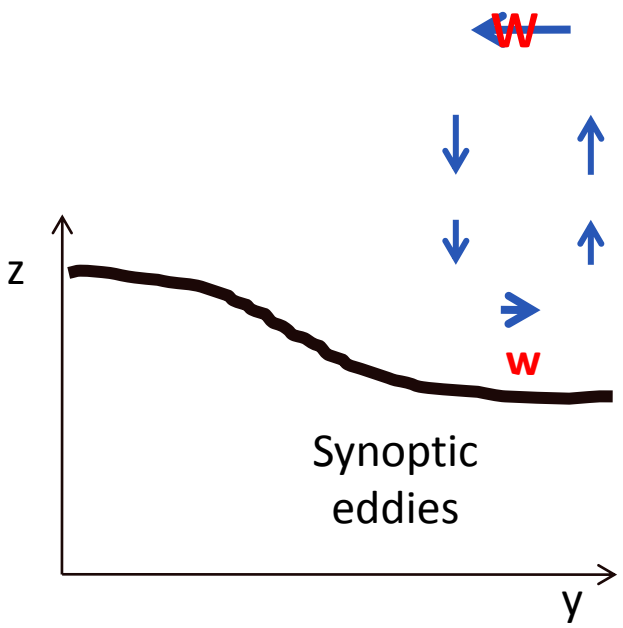


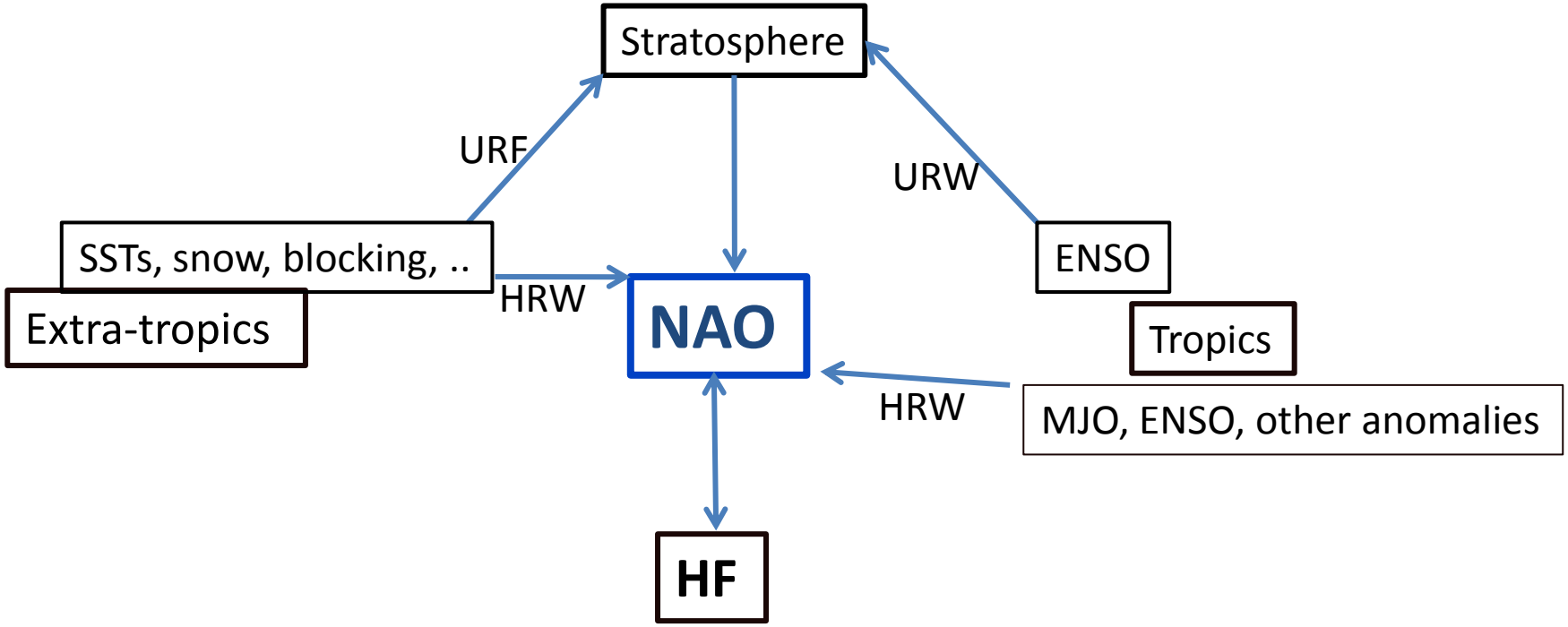
Baldwin & Dunkerton (2001)

Troposphere-Stratosphere Interaction

Vertical propagation
of Rossby Waves





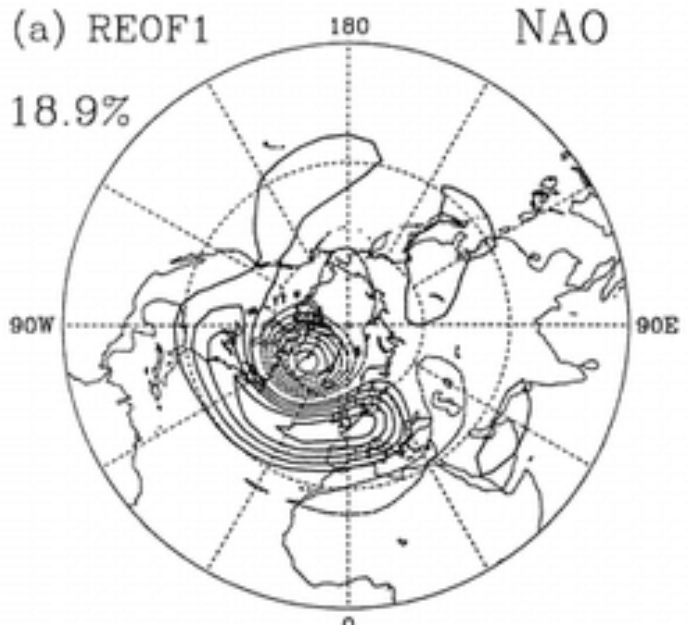

Stratosphere
URF
URW
SSTs, snow, blocking, ..
Extra-tropics
HRW
NAO
ENSO
Tropics
HRW
MJO, ENSO, other anomalies
HF

Do monthly-seasonal teleconnection patterns reflect dynamics on these time-scales?

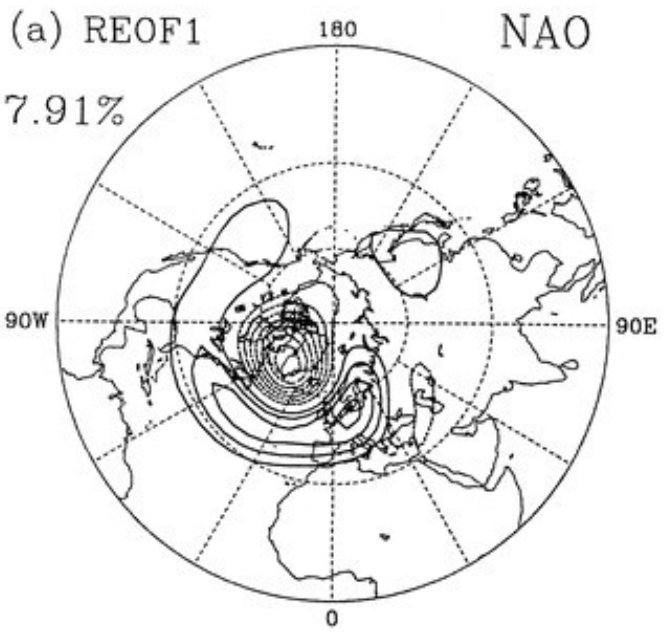
Feldstein (2000)

Rotated EOFs

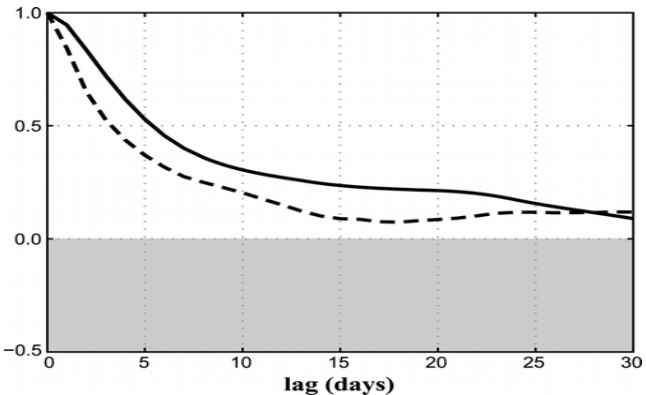
Seasonal data



Daily data



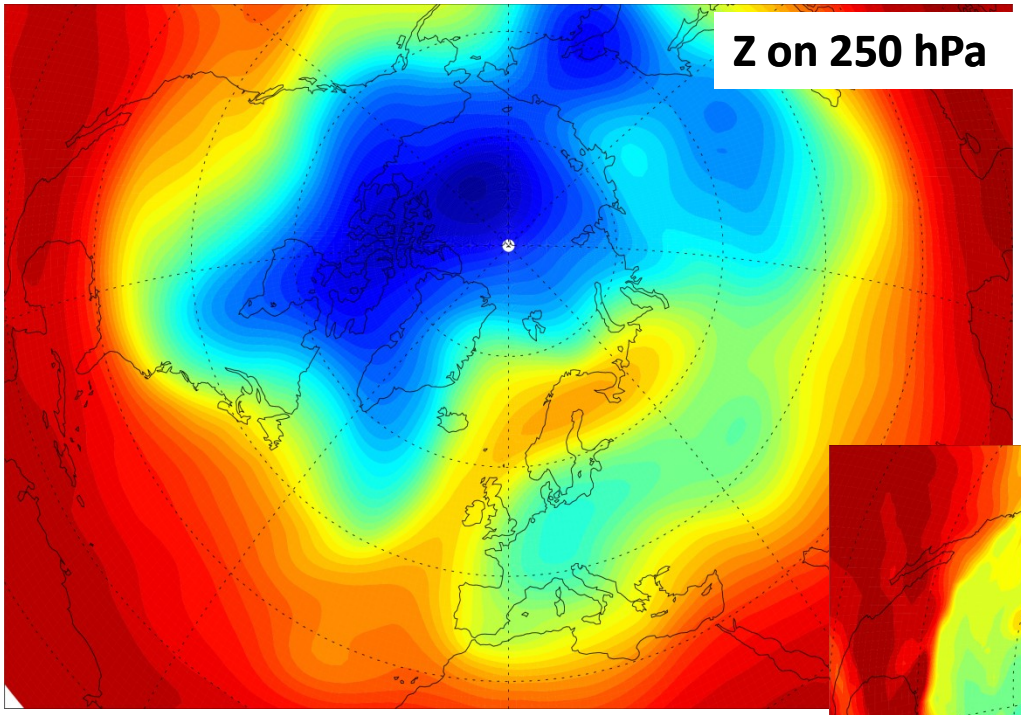
Autocorrelation of daily NAO

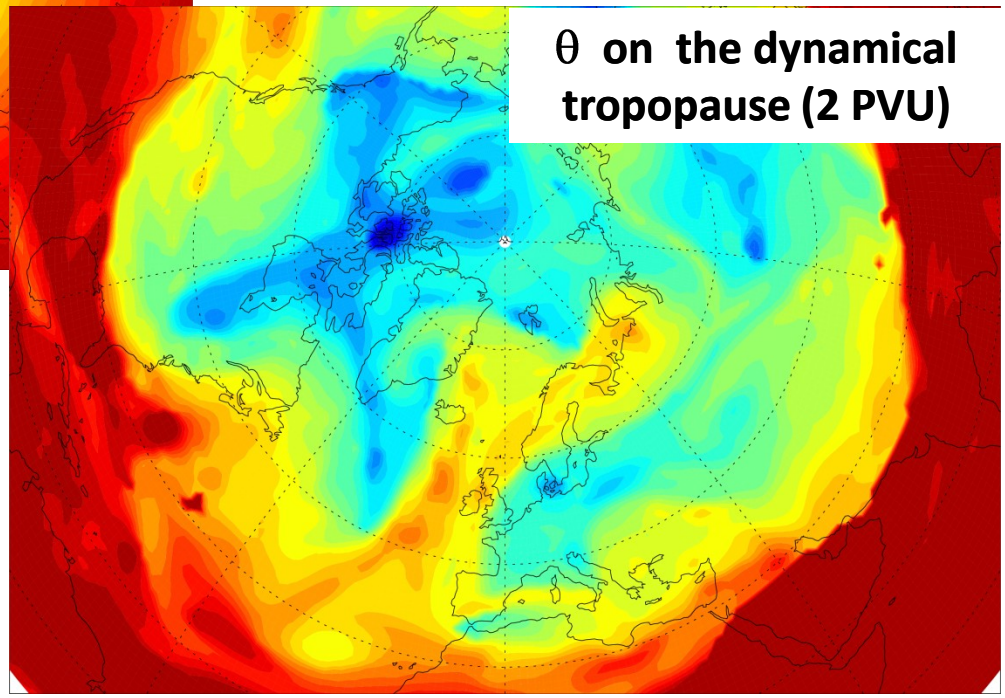


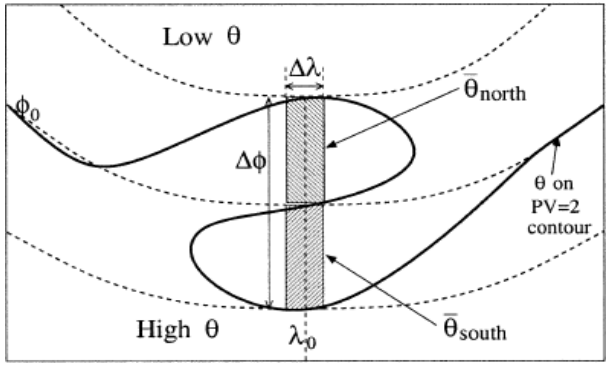
4. Blocking

A Typical European Block: 20 November 1993 12 UTC

Tyrlis & Hoskins JAS 2008







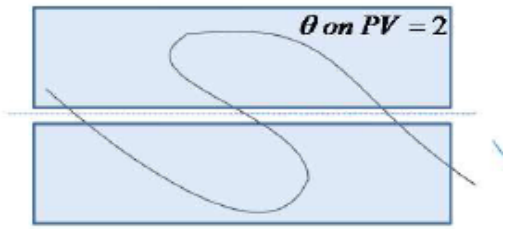
$B = \theta_{north} - \theta_{south}$

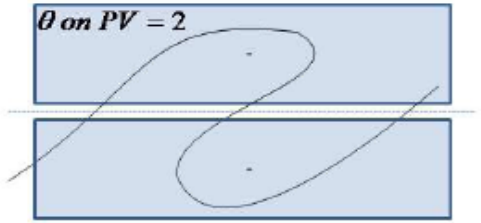
Further Blocking Diagnostics

Giacomo Masato

Direction of wave-breaking

Cyclonic

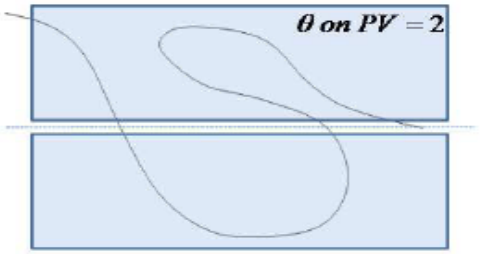


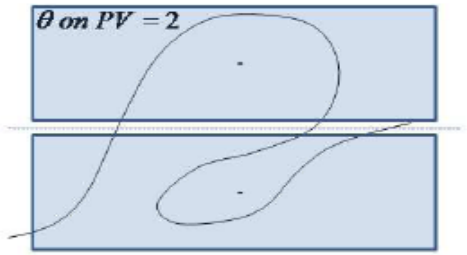


Anticyclonic

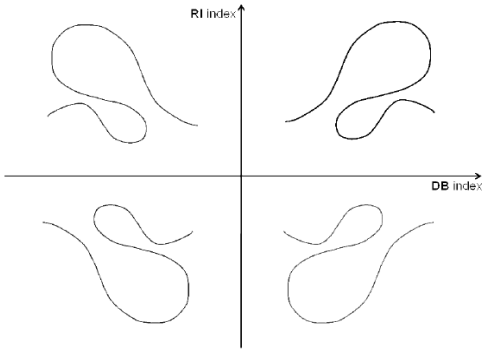
Relative Intensity

Cold

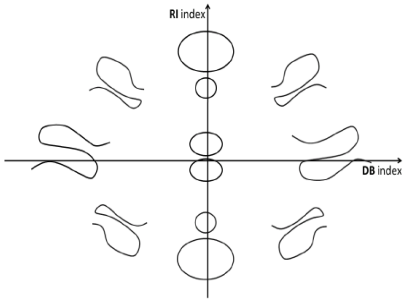


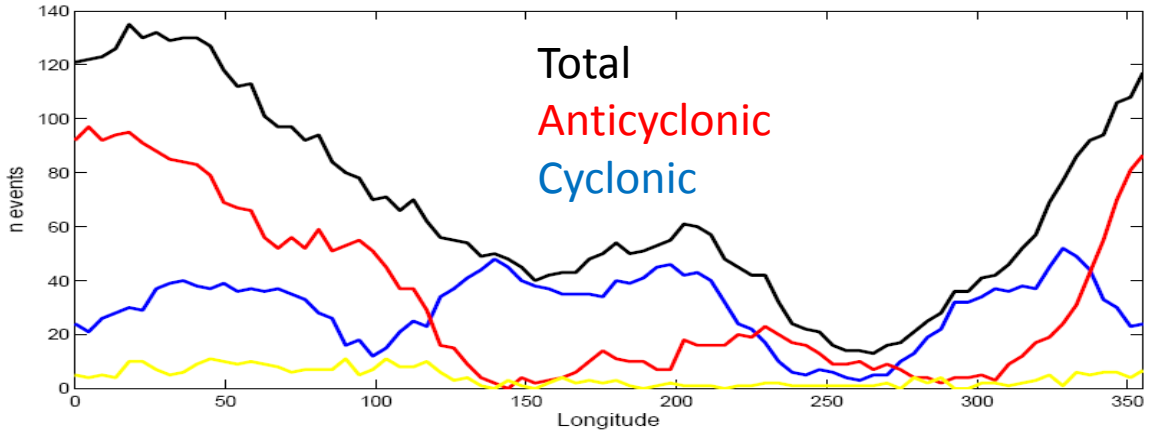


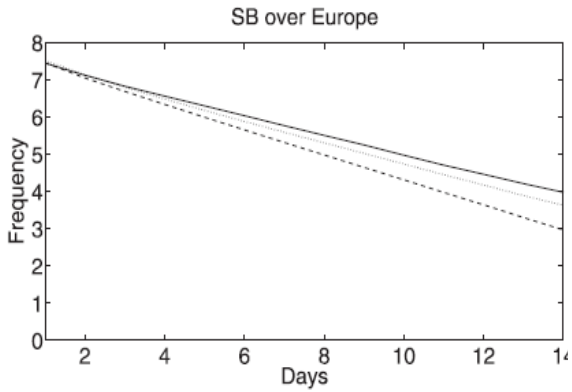
Warm

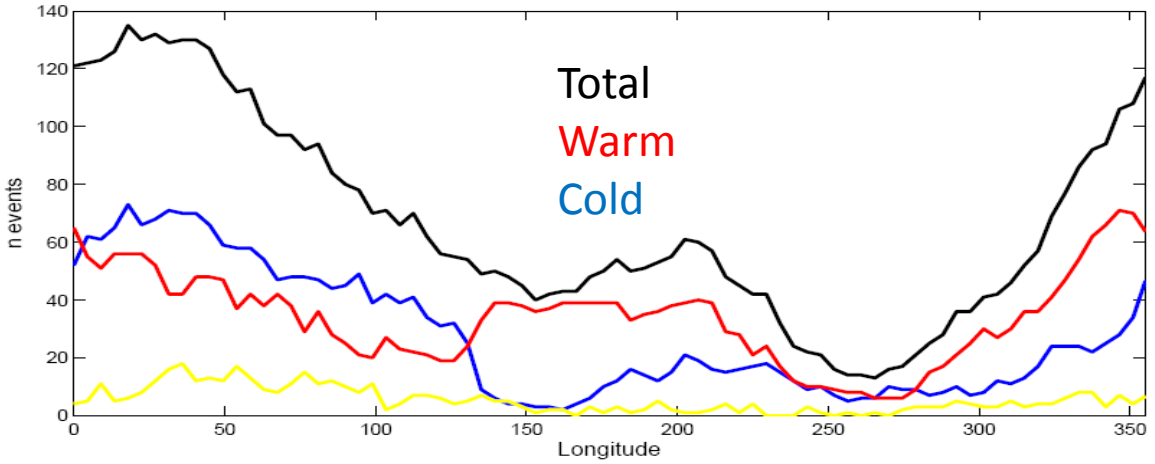


Blocking frequencies with longitude

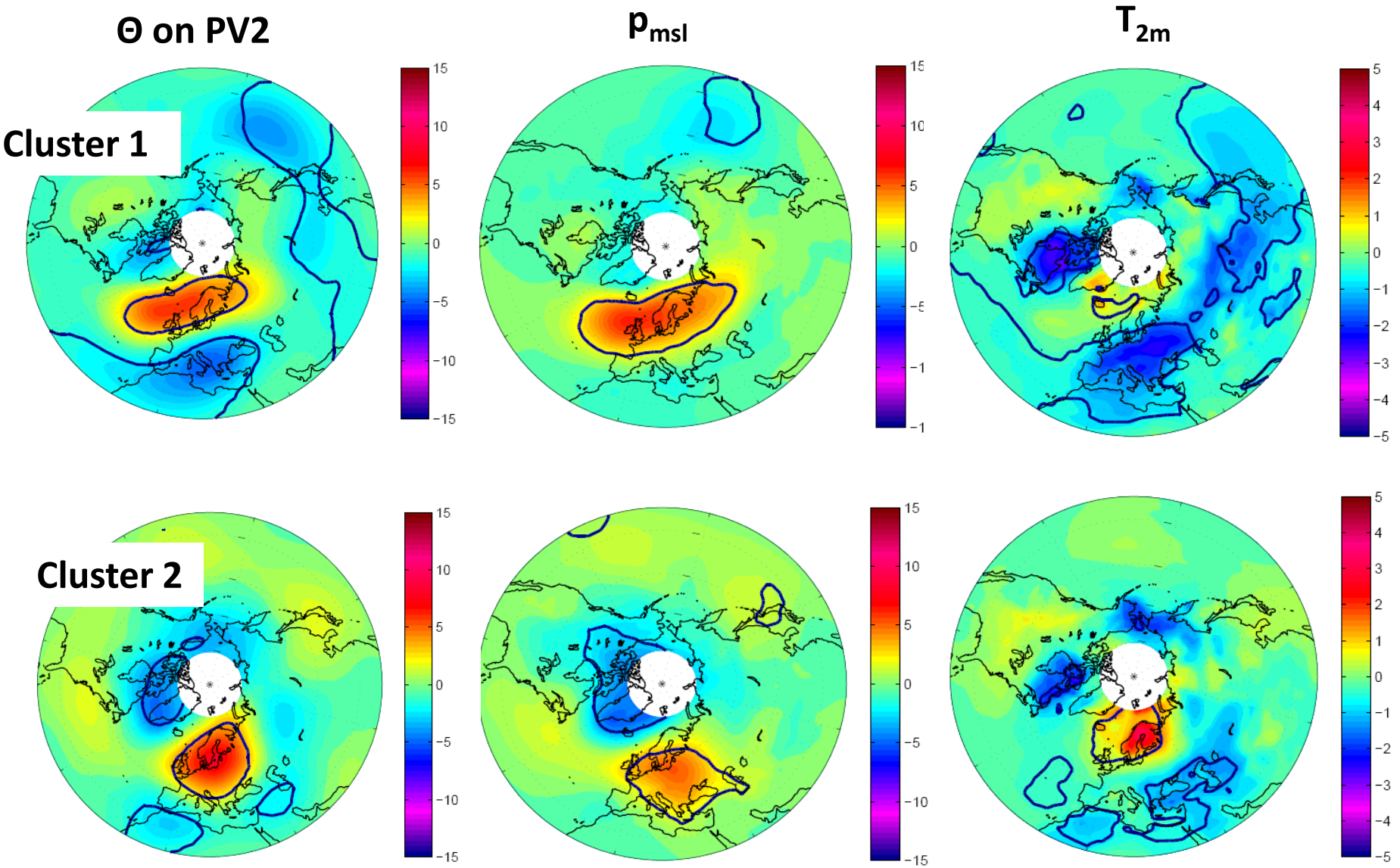






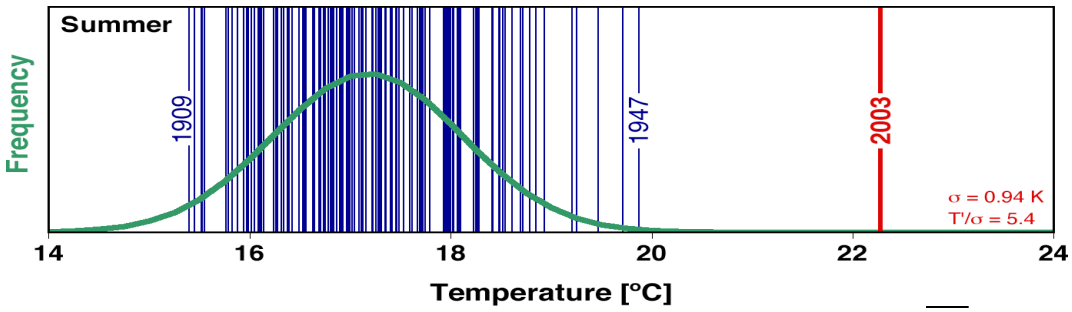


Cluster analysis for European Winter Blocking



Giacomo Masato

Summer 2003: record European warmth

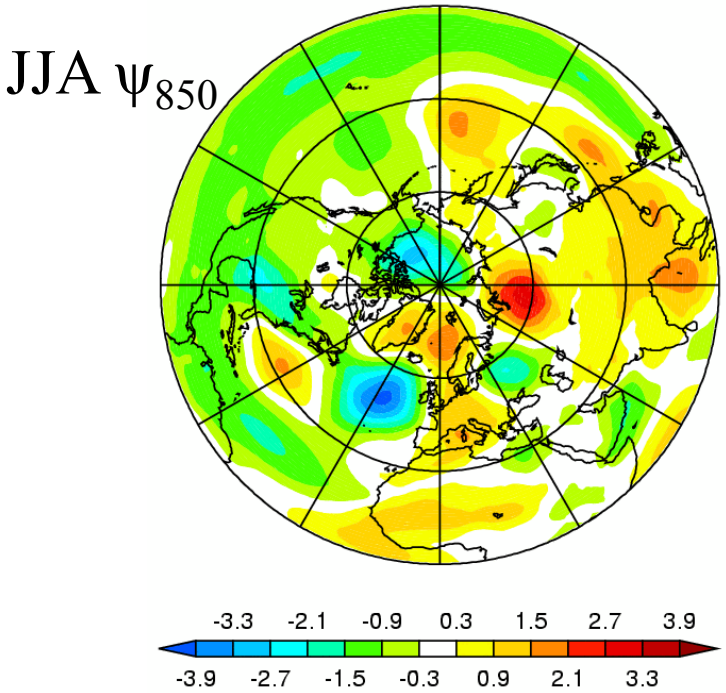


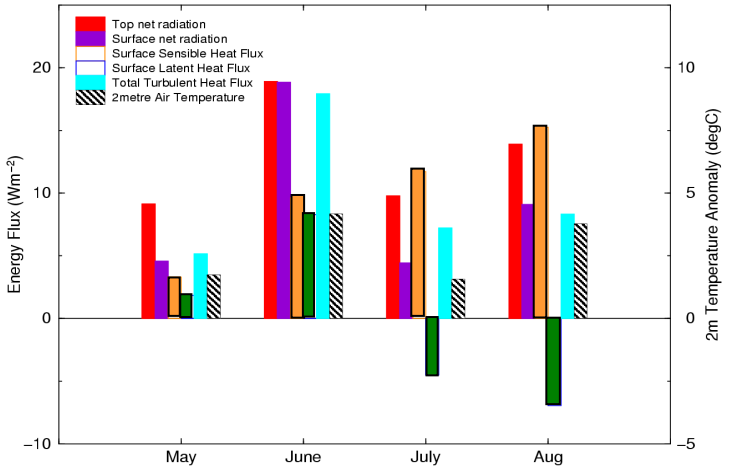
Swiss Temperature Series 1864-2003 (mean of 4 stations)

Schär et al. 2004, Nature, **427**, 332-336

Anomalies in Heat Budget over Europe

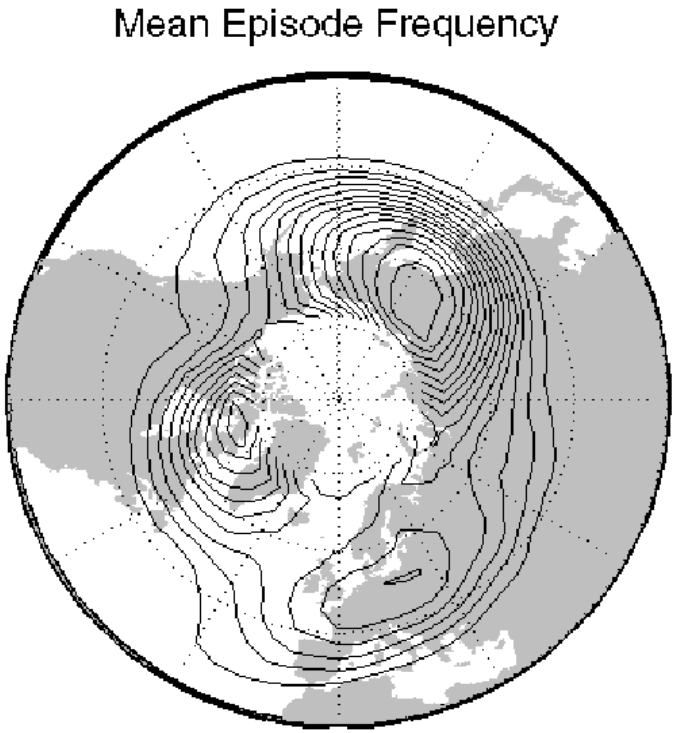
surface sensible heat flux surface latent heat flux





Black, Blackburn, Harrison, Methven & Hoskins (2004)

Wave-Breaking Frequencies Dec-Feb

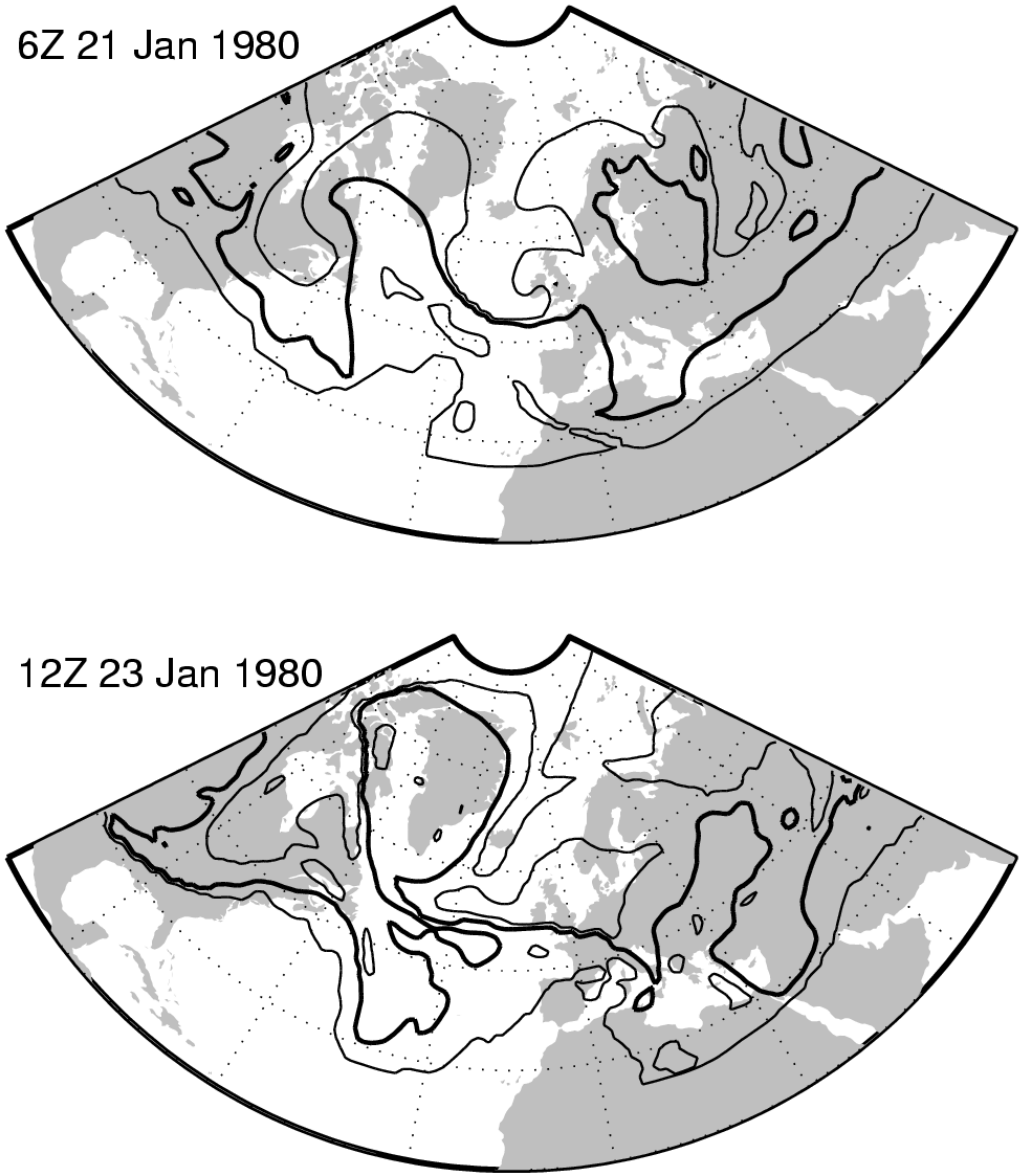


Mean

(c.i. 0.05)

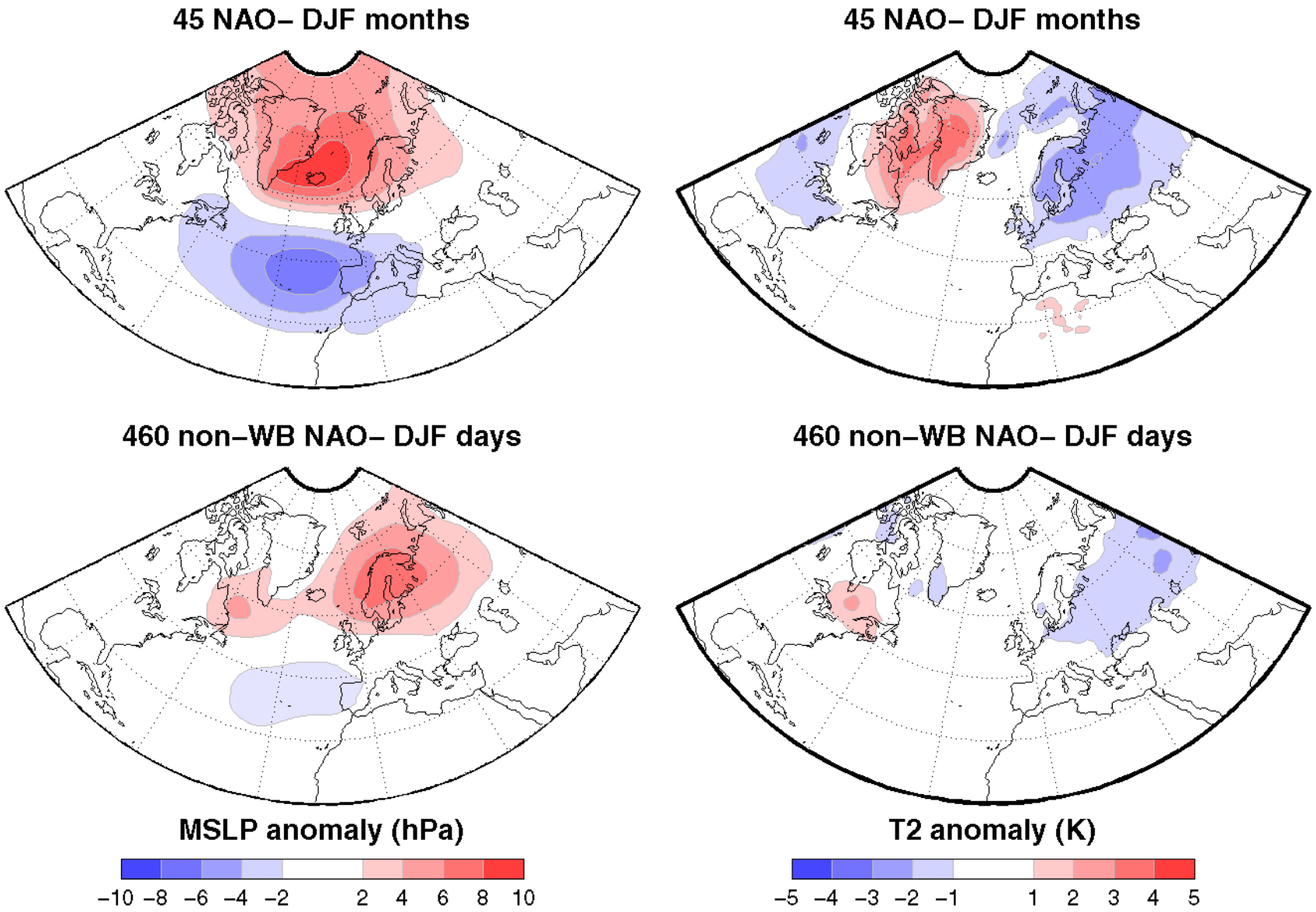
Woollings et al JAS 2008

The onset of a typical Rossby wave-breaking event



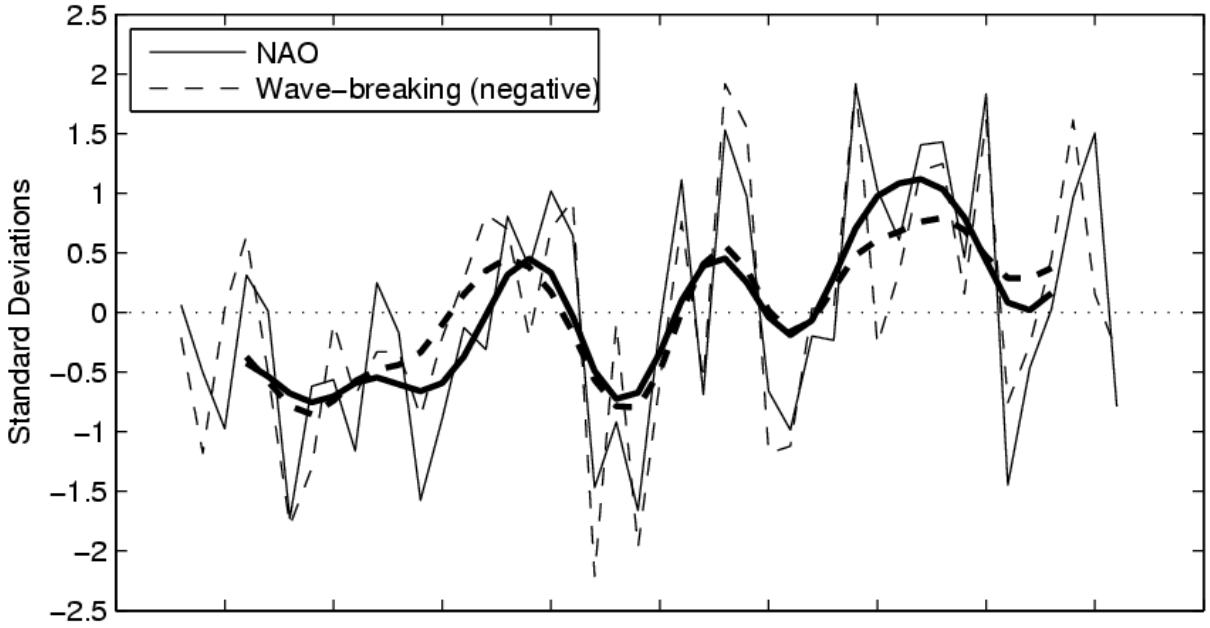
Woollings et al JAS 2008

Contribution of Wave-Breaking to NAO- Anomalies



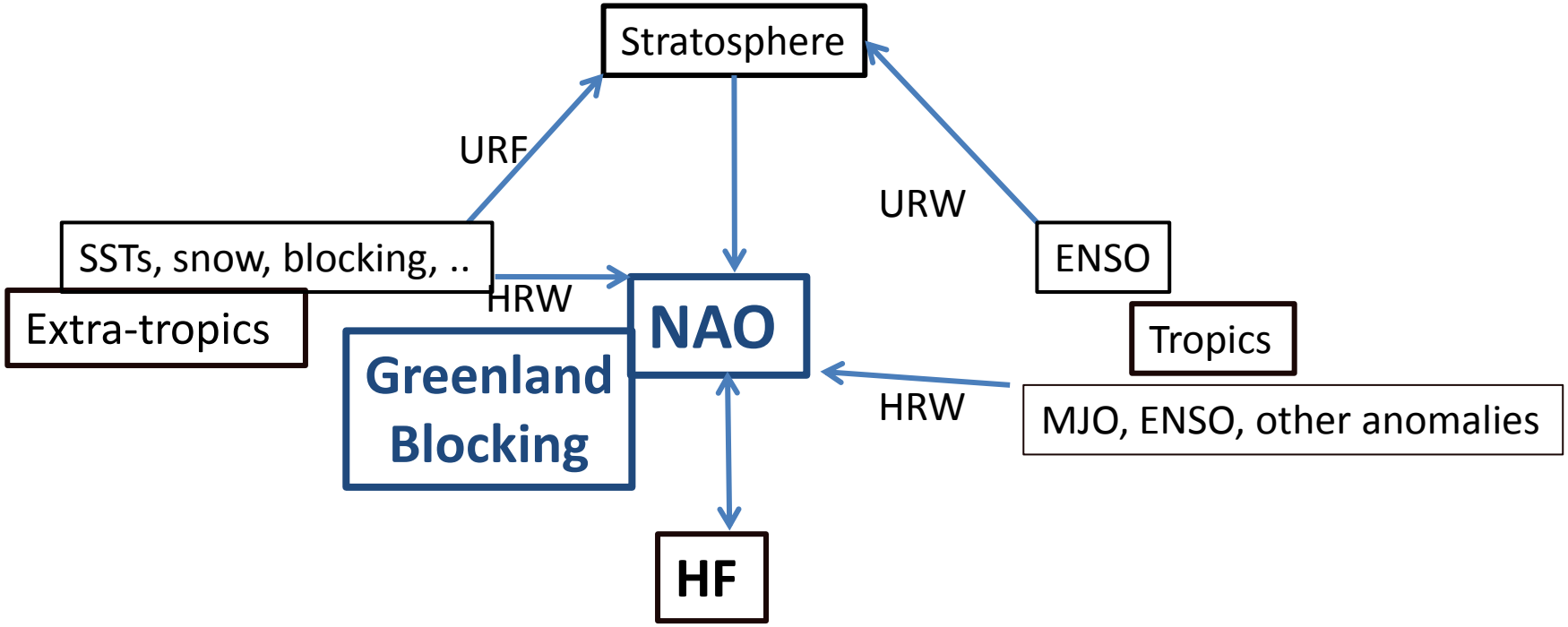
Woollings et al JAS 2008

Seasonal NAO and wave-breaking frequency time series



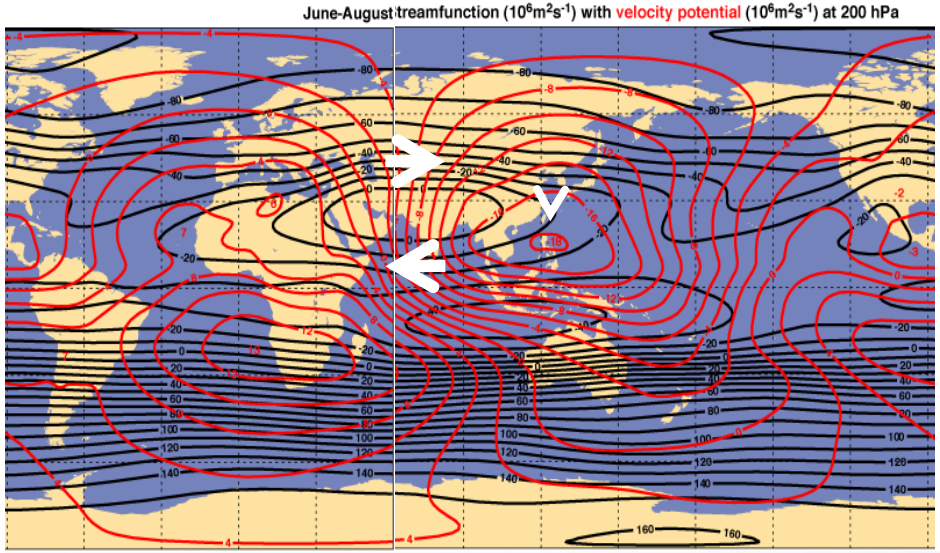
Correlations 0.84 & 0.93

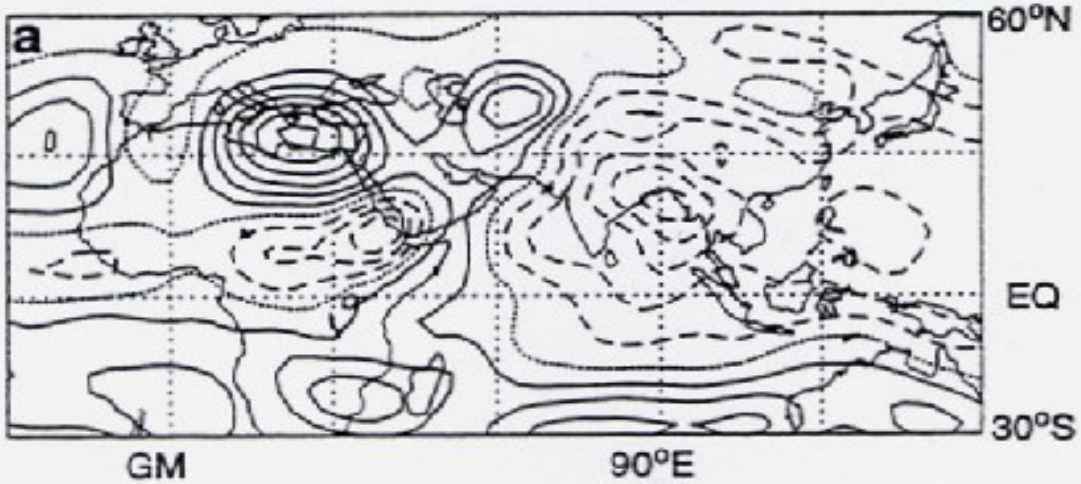
Woollings et al JAS 2008


Stratosphere
URF
URW
SSTs, snow, blocking, ..
Extra-tropics
HRW
NAO
Greenland Blocking
ENSO
Tropics
HRW
MJO, ENSO, other anomalies
HF

5. Events related to the Asian Summer Monsoon

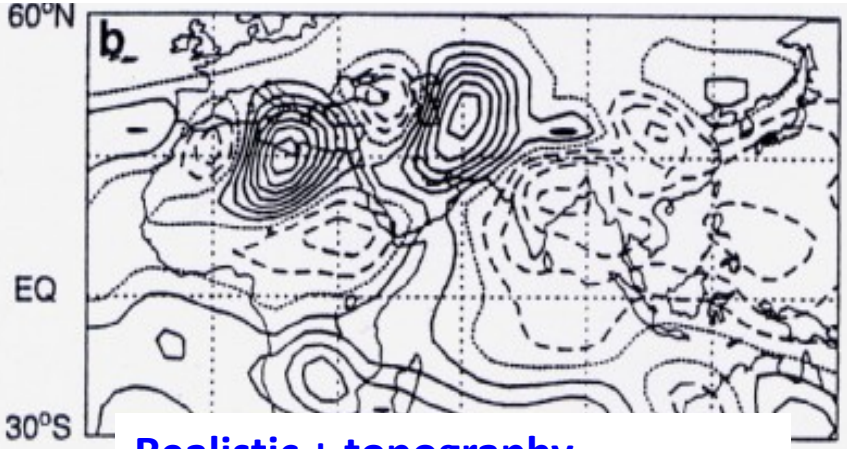
Observed JJA upper ψ, χ and mid w



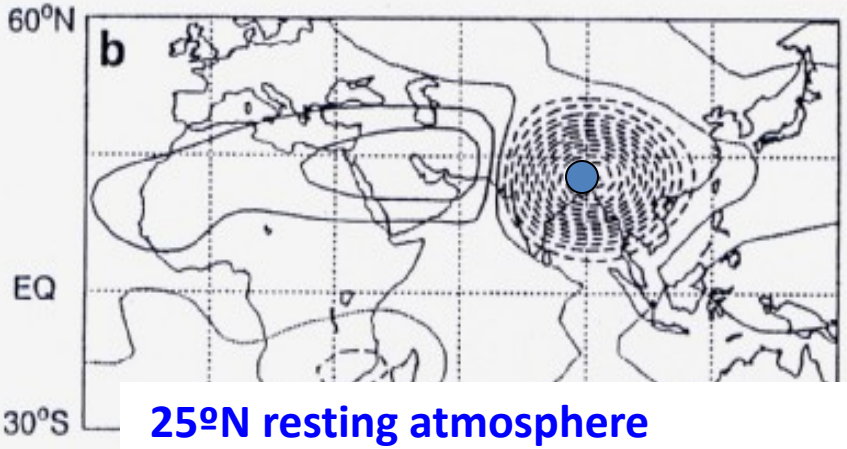


Compensating descent in a range of situations

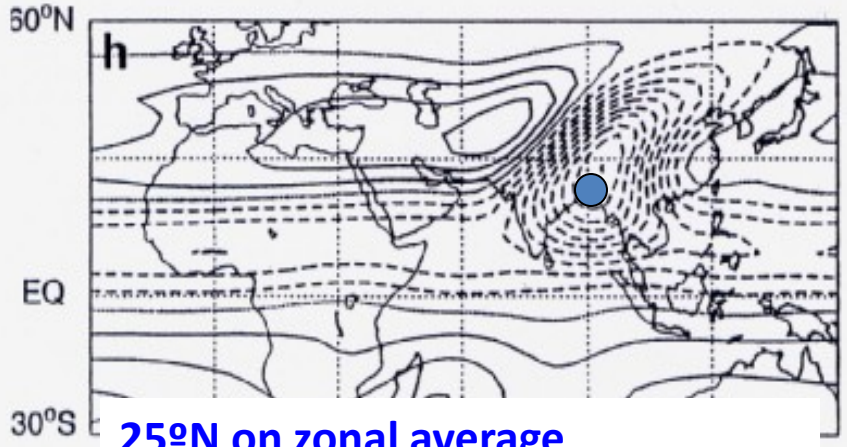
Rodwell & Hsokins (1996)



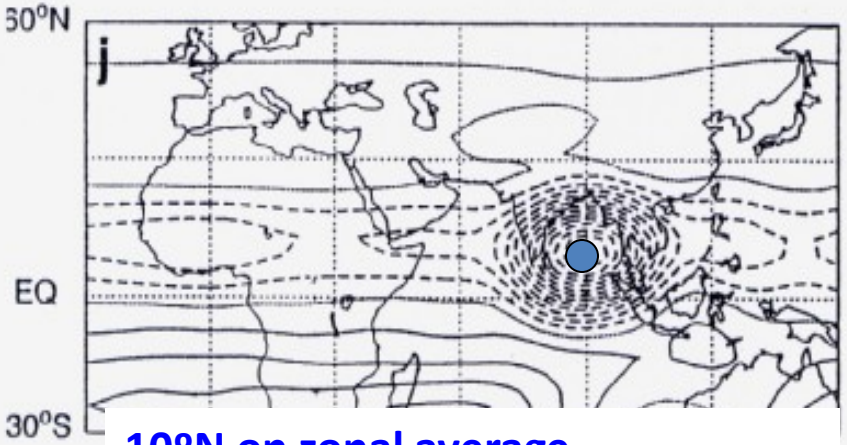
Realistic + topography



25ºN resting atmosphere



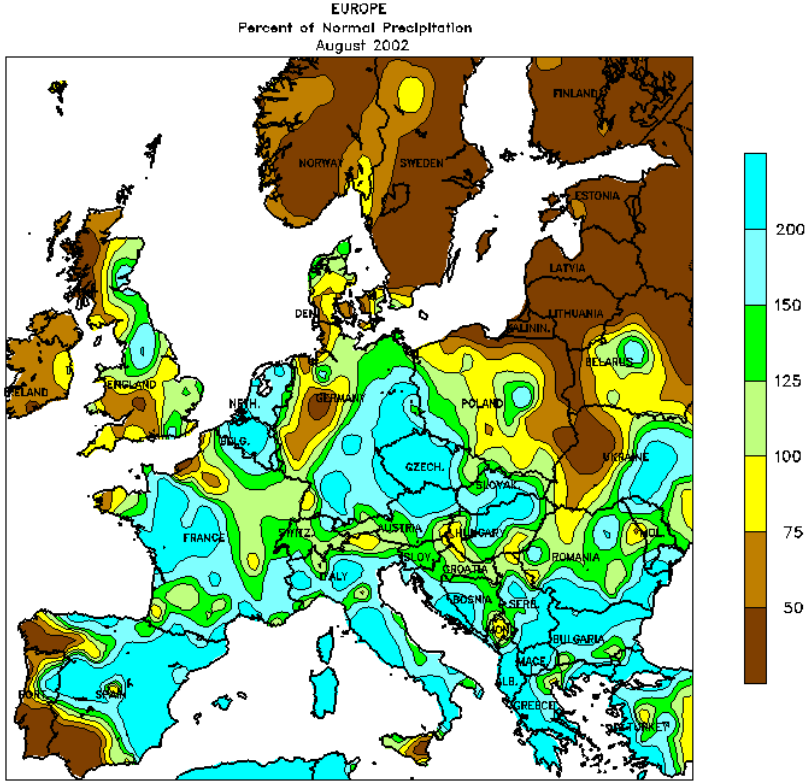
25ºN on zonal average



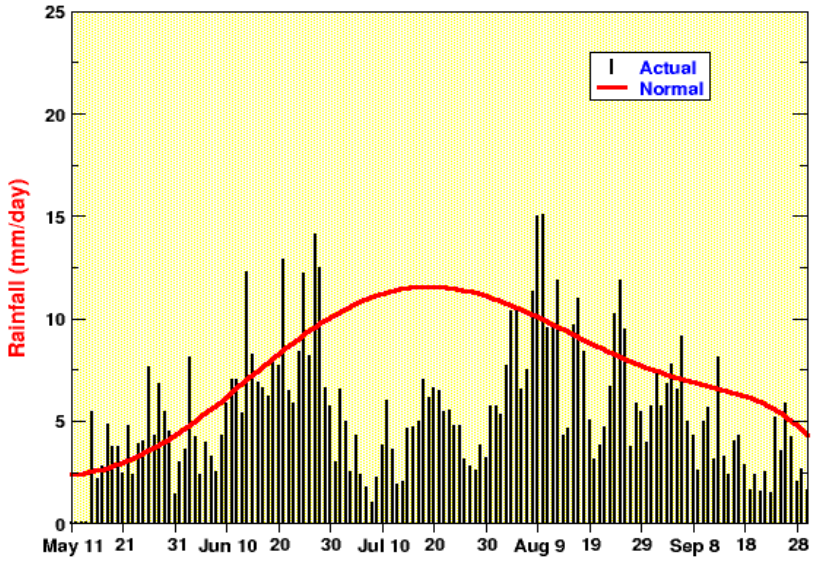
10ºN on zonal average

Summer 2002

Flooding in Central Europe



Drought in India



Blackburn & Hoskins (2006)

Summer：Quasi-biweekly oscillation of Tibetan High

Krishnamurti et al. ,1973; Krishnamurti and Bhalme, 1976; Shun, 1979; Tao and Ding, 1981

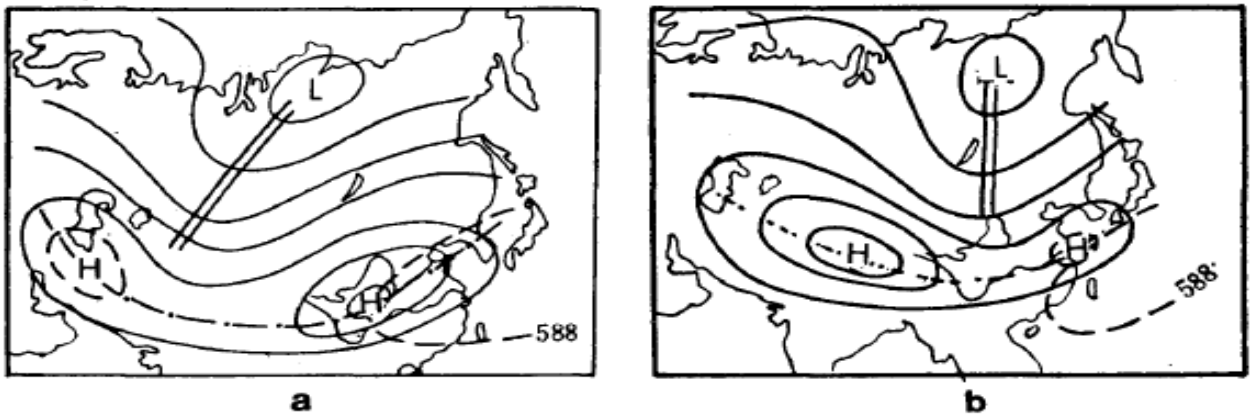
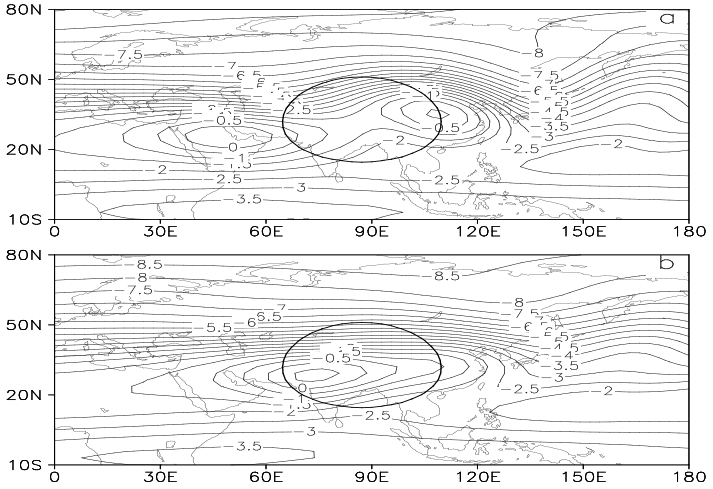


FIG. 6. Two major patterns of the Tibetan high at (a) 200 mb; and (b) 100 mb.

Tao and Zhu (1964)

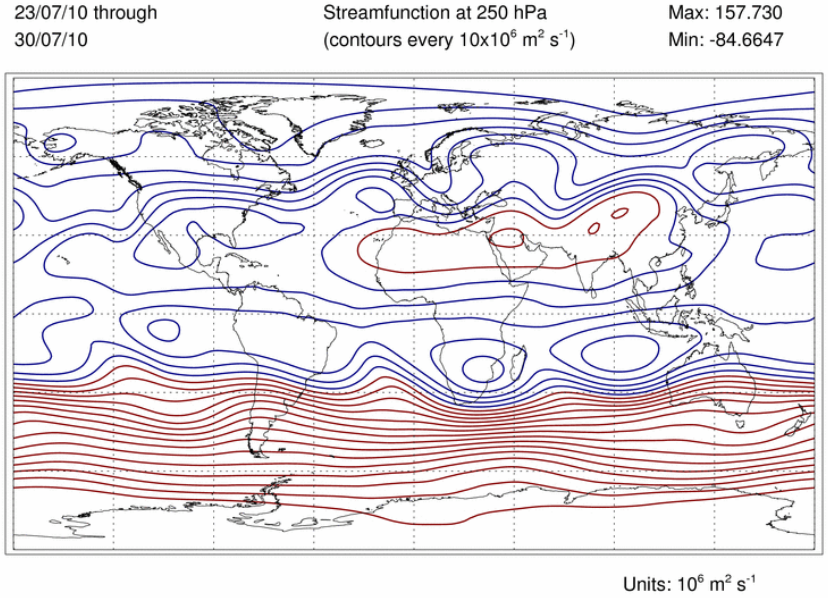
Instability of low PV strip as it extends westwards from idealised Tibetan Plateau heating in a 3-D baroclinic model

Liu, Hoskins & Blackburn (2007)

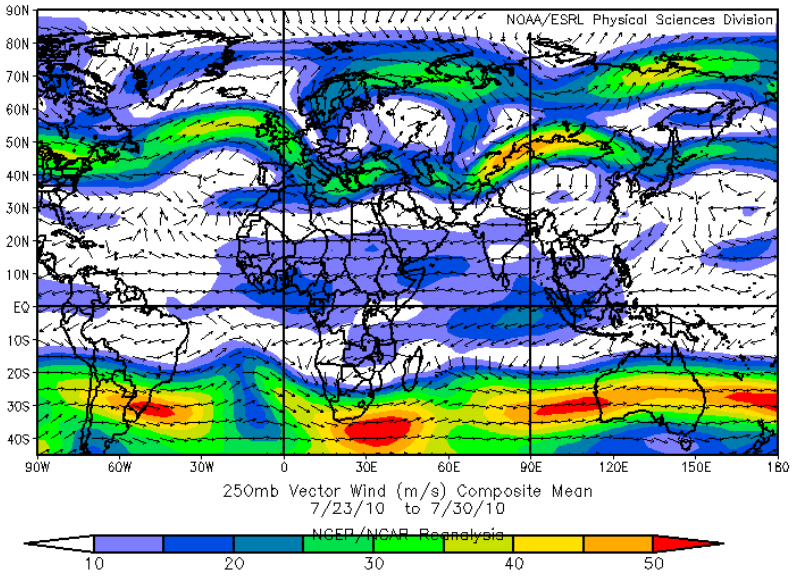


The events of July 2010

Mean fields at 250 hPa for 23-30 July



Stream function

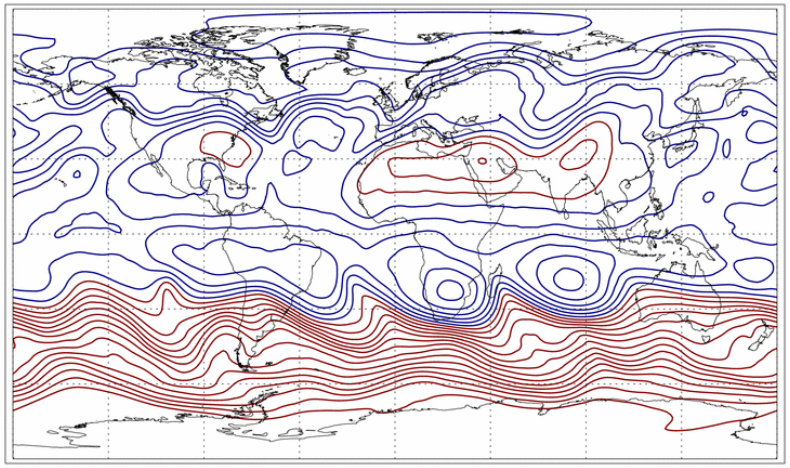


Wind

23/07/10 at 06:00 GMT
Friday

Streamfunction at 250 hPa
(contours every 10x10^6 m^2 s^{-1})

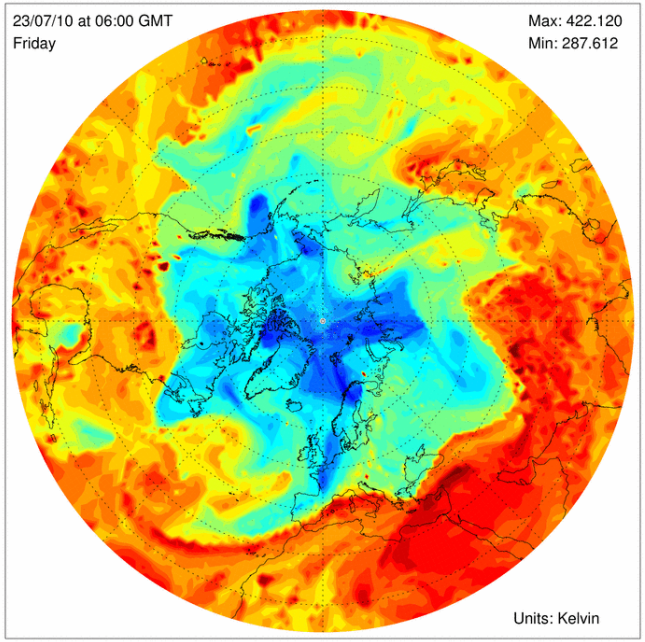
Max: 166.844
Min: -83.3583



Units: 10^6 m^2 s^{-1}

Theta on PV=2

< 290 298 306 314 322 330 338 346 354 362 370 378 386 <



Theories of low-frequency variability over Europe

1. Synoptic eddy organisation & feedback
2. Rossby waves – horizontal propagation
   - Theory
   - MJO
   - Summer 2007
3. Teleconnection patterns
   - NAO
   - stratosphere connection
   - climate noise?
4. Blocking
   - N Hemisphere
   - European
   - Greenland
   - Summer 2003
5. Events related to the Asian Summer Monsoon
   - Summer 2002
   - bi-weekly oscillation
   - Summer 2010

The Hypothesis:

- NAO+ can be viewed as describing the basic (2-jet) state
- NAO- can be viewed as describing the state in which Rossby wave breaking is frequent (1-jet)

The West Pacific Pattern is similar but, particularly on decadal time-scales, is influenced by ENSO, PNA…

External forcings have a direct effect that makes wave-breaking more or less likely or changes its location and so produces "an NAO" response.

Woollings et al JAS 2008