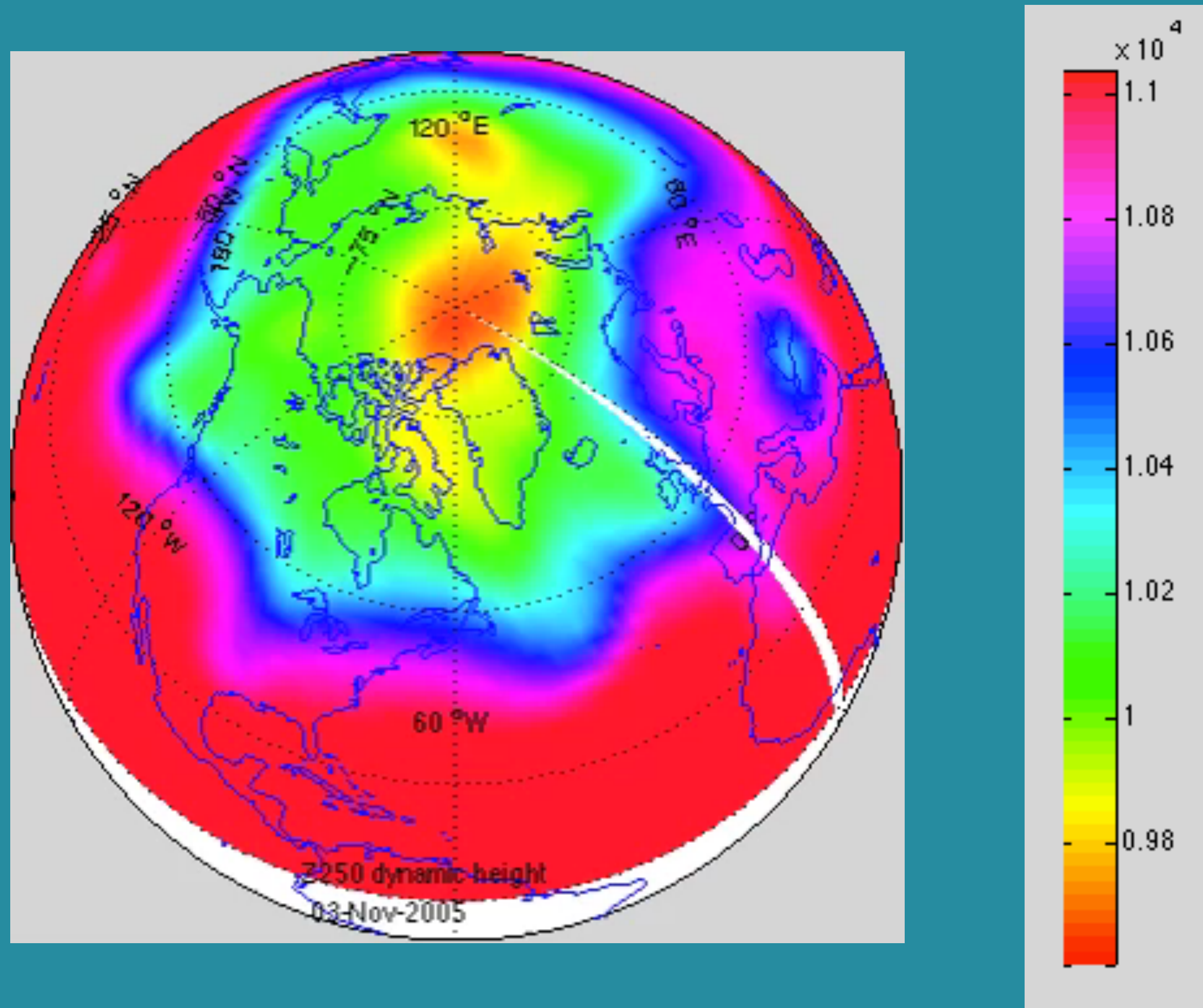
jet stream during cold European winter of 2005/6

(250HPa dyn. height)

frequent blocks over central Europe from late Dec to Mar



note apparent precursors
possibly as far upwind as the Gulf of Alaska

Atlantic multidecadal variability and sea-surface height: observations and atmospheric connections.

Sirpa Häkkinen[1] , Peter B. Rhines[2]
with Denise L. Worthen[1]
(1) NASA Goddard Space Flight Center, Code 614.1, Greenbelt, MD 20771
(2) University of Washington, Seattle, PO Box 357940, WA 98195

Climatic episodes of warm, saline northern Atlantic Ocean occur at decadal to century timescales. They co-vary with

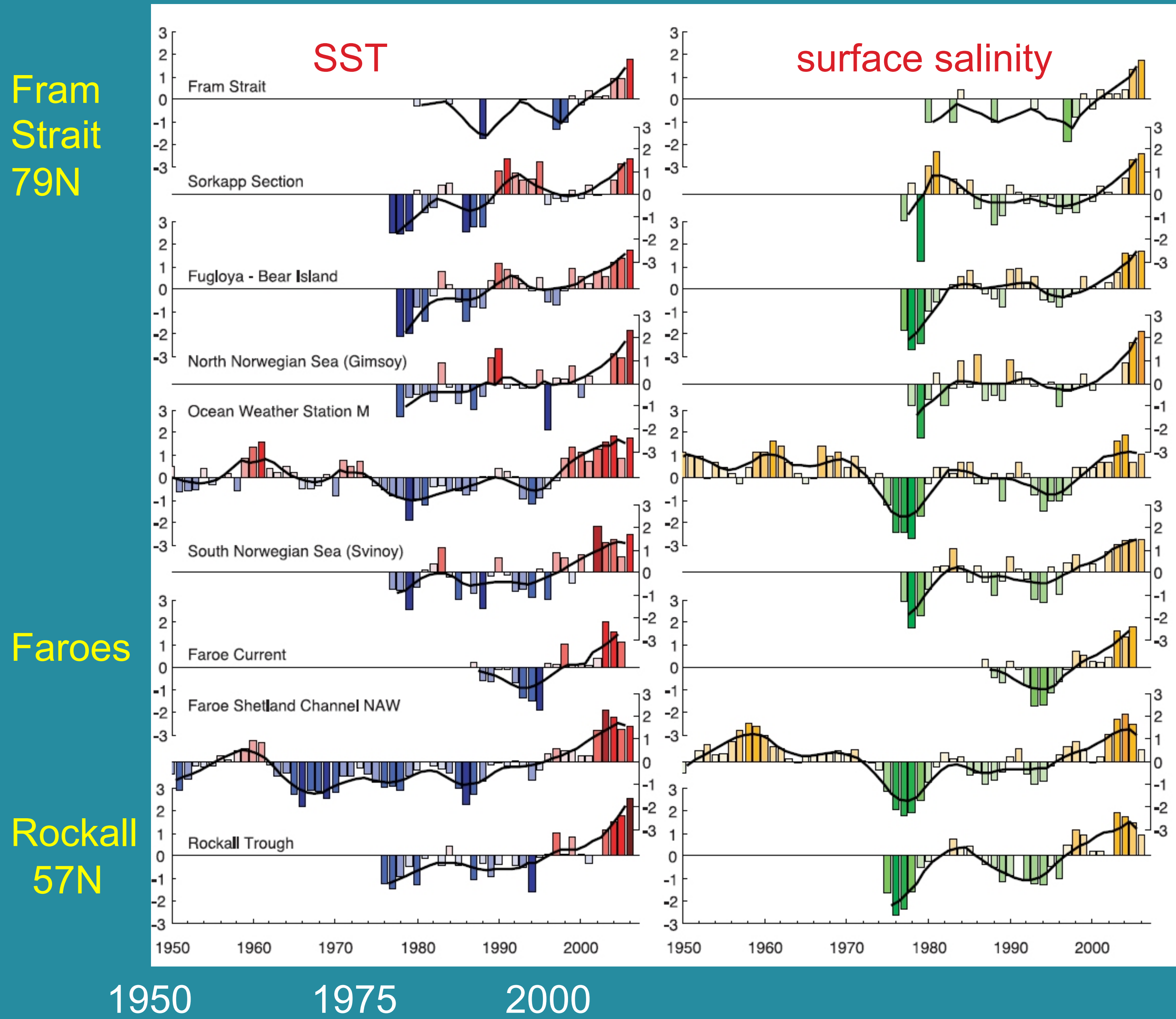
- weak subpolar ocean gyre,
- warm subpolar steric height anomaly
- increased advection of warm subtropical waters north to the subpolar gyre (strengthend AMOC merid heat transport)
- weak windstress-curl over the SP gyre

and

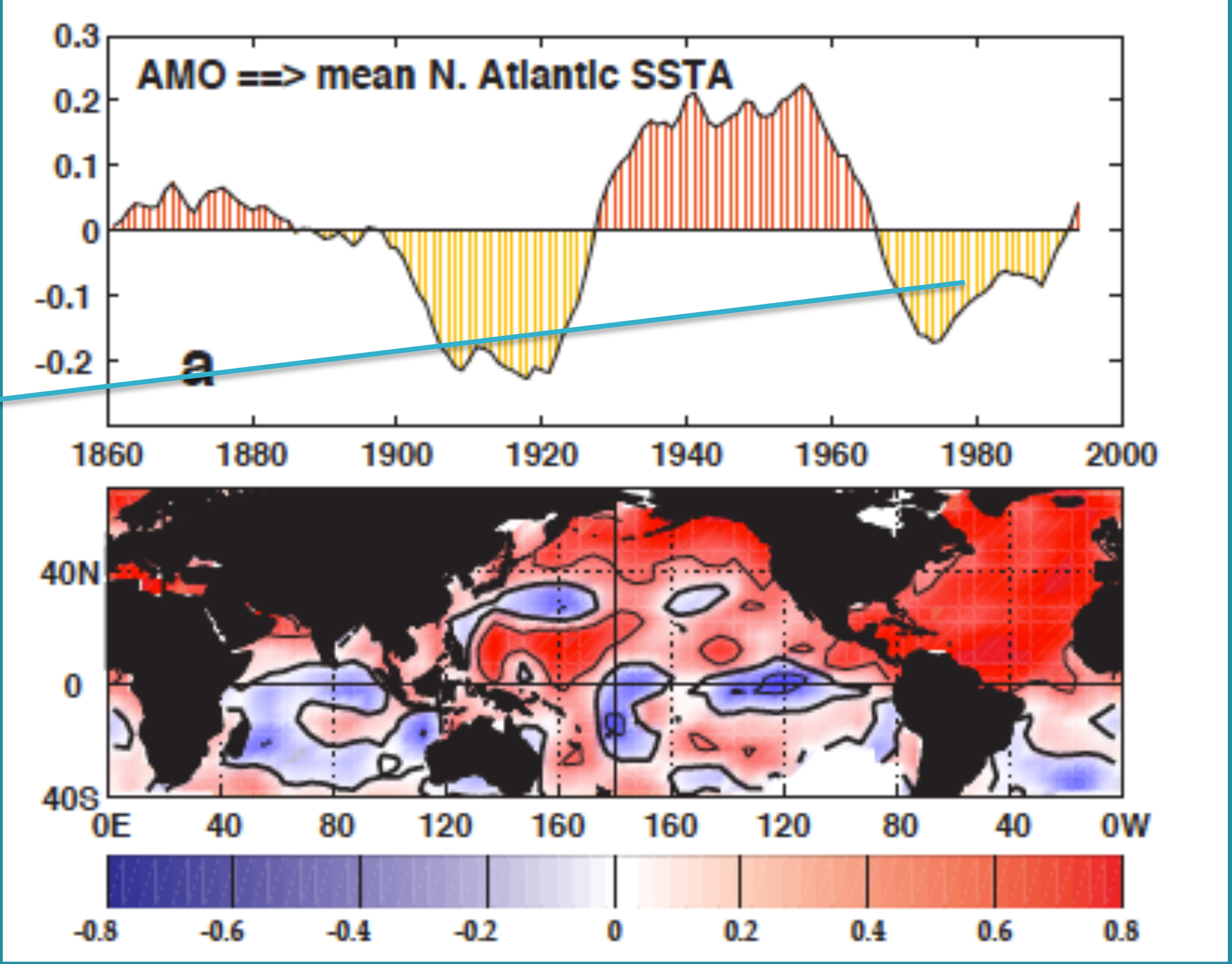
- extreme, breaking jet-stream meanders overhead => Atlantic blocking anticyclones (*Hakkinen & Rhines, Science* **2011**)
- positive feedback of warm oceanic SST on the atmospheric circulation (*Croci-Maspoli & Davies MWR 2009)*

Atlantic SST (sea-surface temperature) and salinity: extreme warming in late 1990s – 2000s

Holliday et al GRL 2008



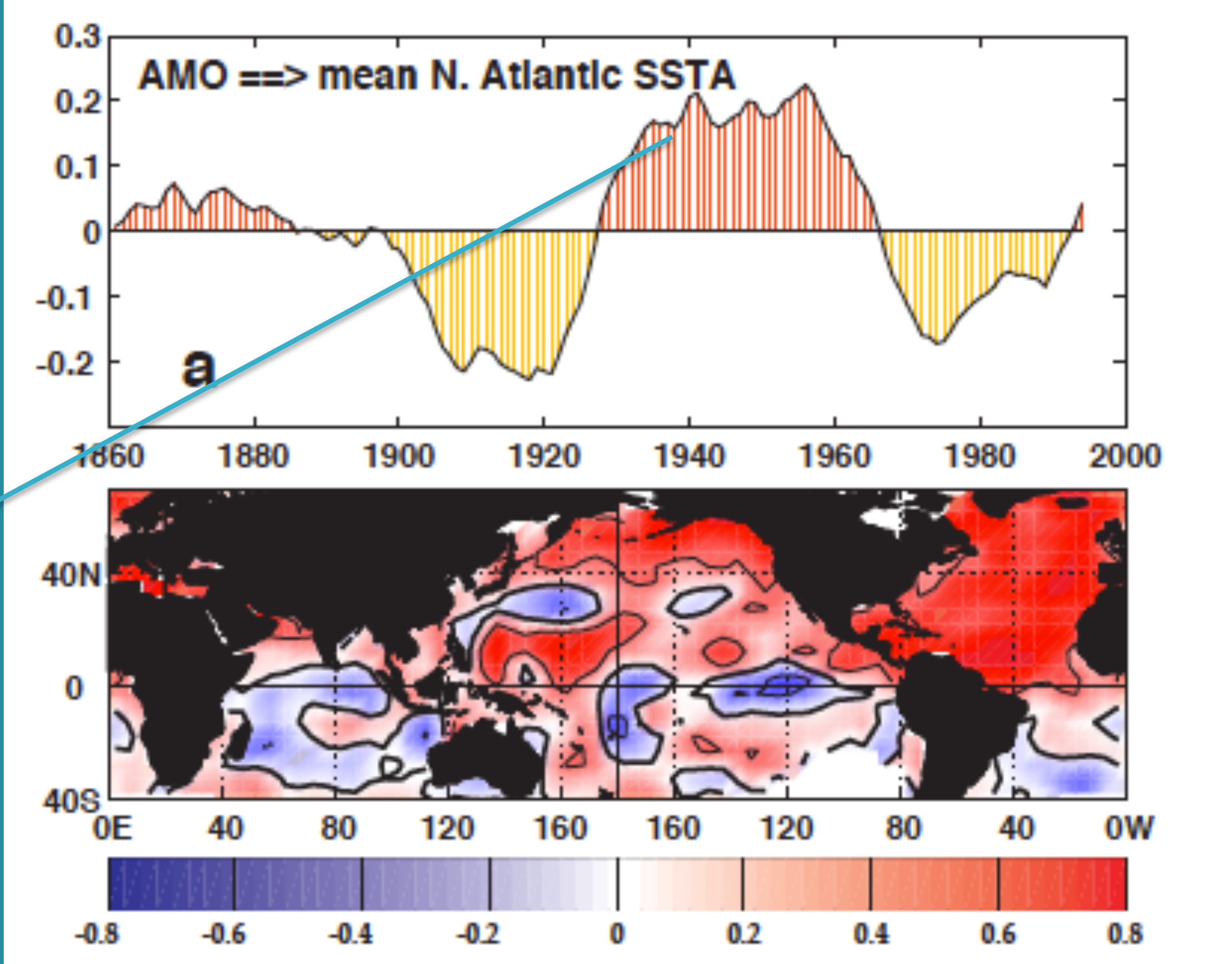
The last 15 years of warming join the longer timeseries of Atlantic SST variability



AMO/AMV index and spatial SST field based on Atlantic SST 'north of Equator', regressed on global SST; similar to 1st rotated EOF of N Atlantic SST *Enfield GRL 2001*

The last 15 years of warming join the longer timeseries of Atlantic SST variability

Early 20th C warming



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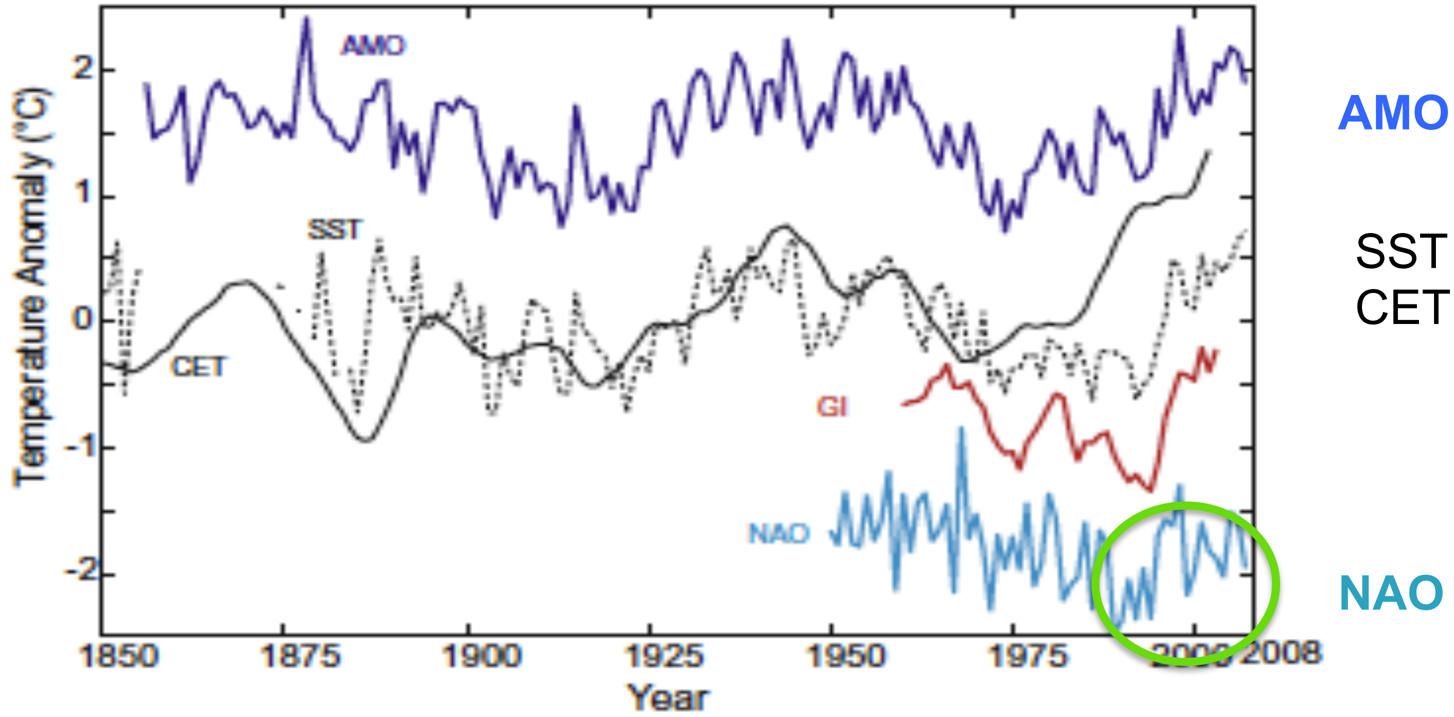
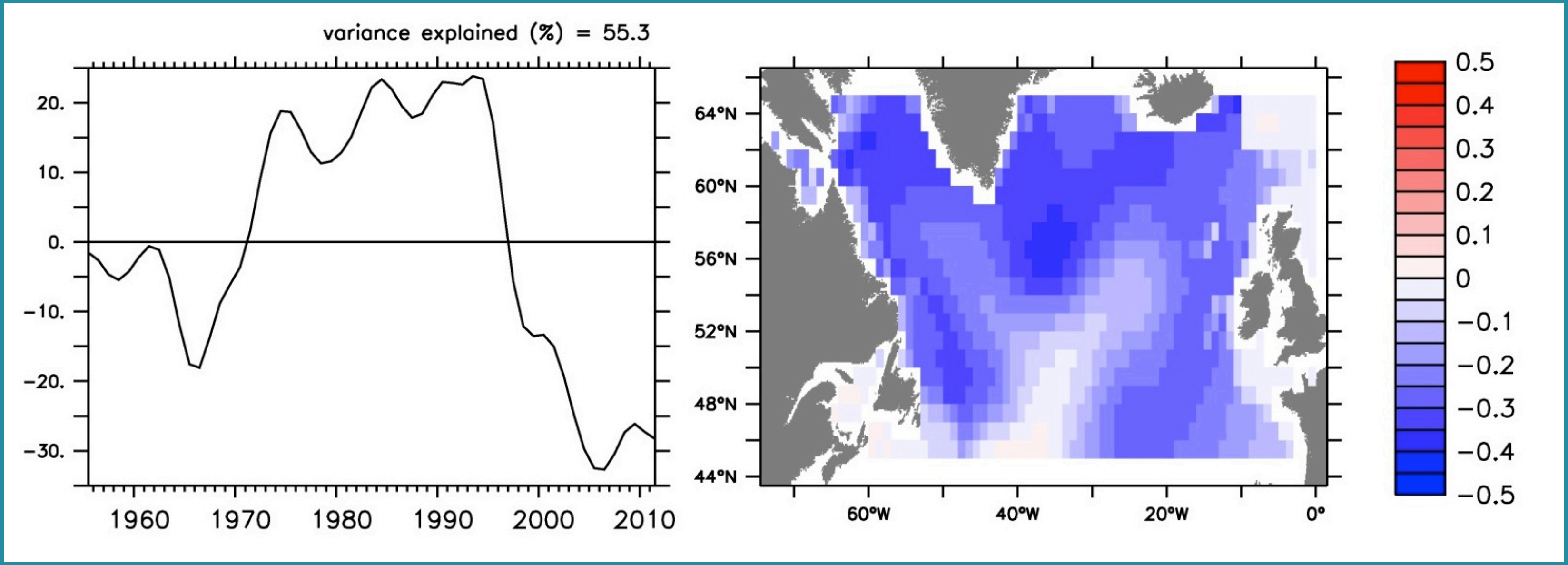


Fig. 3. Climate indices. Annual averages of: the Atlantic Multi-decadal Oscillation (AMO) (Enfield et al., 2001), the SST west of the British Isles (Rayner et al., 2006) (see text), the inverted gyre index (GI) (Hátún et al., 2005b) and the North Atlantic Oscillation (NAO, inverted) (http://www.cdc.noaa.gov) are shown. The Central England Temperature (CET) (Parker and Horton, 2005) during the spring months March and April has been plotted over the SST series. The CET is low-pass filtered using an 8-year filter width. The two temperature time series (black) are to scale, the others are not.

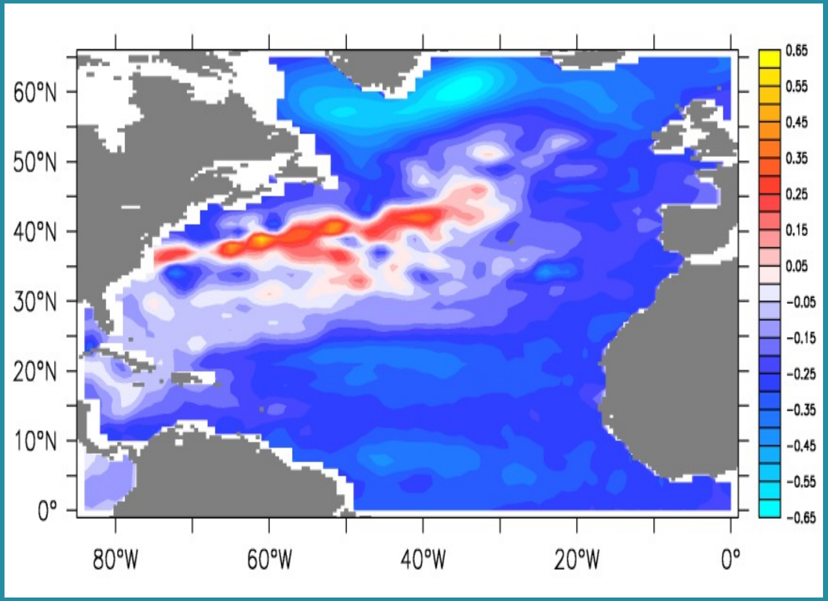
Hátún et al. Prog. in Oceanography 2009 connects these time series with ecosystem shifts, fisheries

Focus on the subpolar N Atlantic: water-column heat content EOF 1 (NODC WOA data)



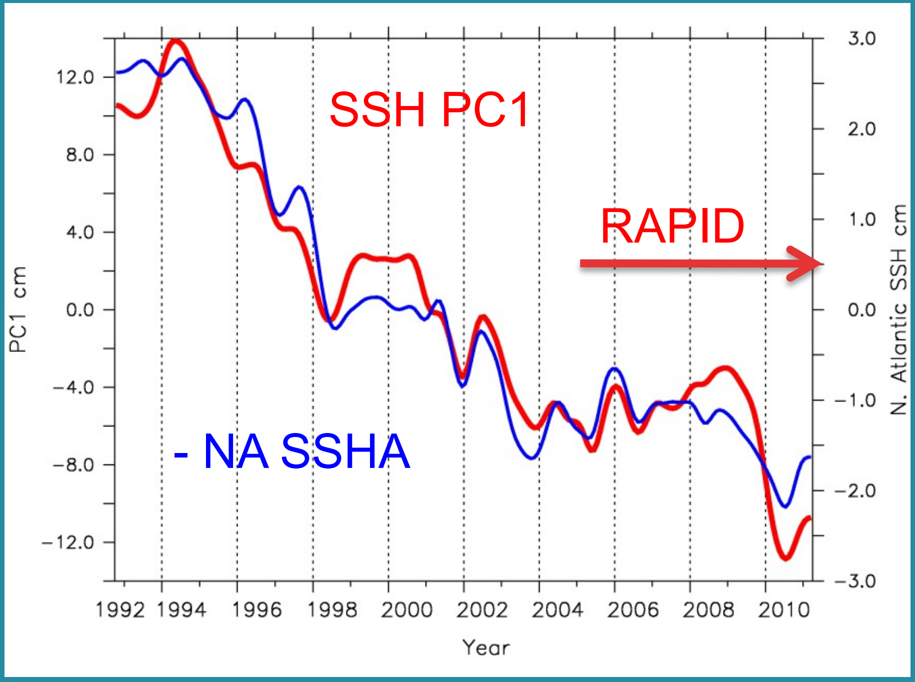
SEA SURFACE HEIGHT FROM ALTIMETRY

SSH INCREASE OF ~ 13cm IN THE IRMINGER SEA



SSH EOF1 17.5%

dual role of altimetry: surface geostrophic circulation and ocean water column heat content



The subpolar cyclonic gyre *weakened* and *warmed* steadily

DATA FROM NASA MEASURES PROJECT; PROVIDED BY BRIAN BECKLEY SAIC/ GSFC to 03/2011

SEA SURFACE HEIGHT FROM ALTIMETRY

SSH
INCREASE
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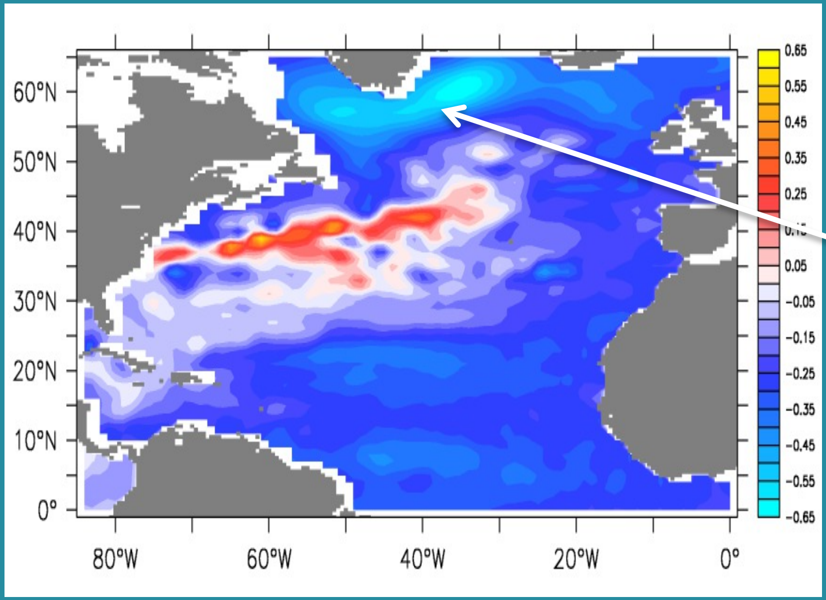

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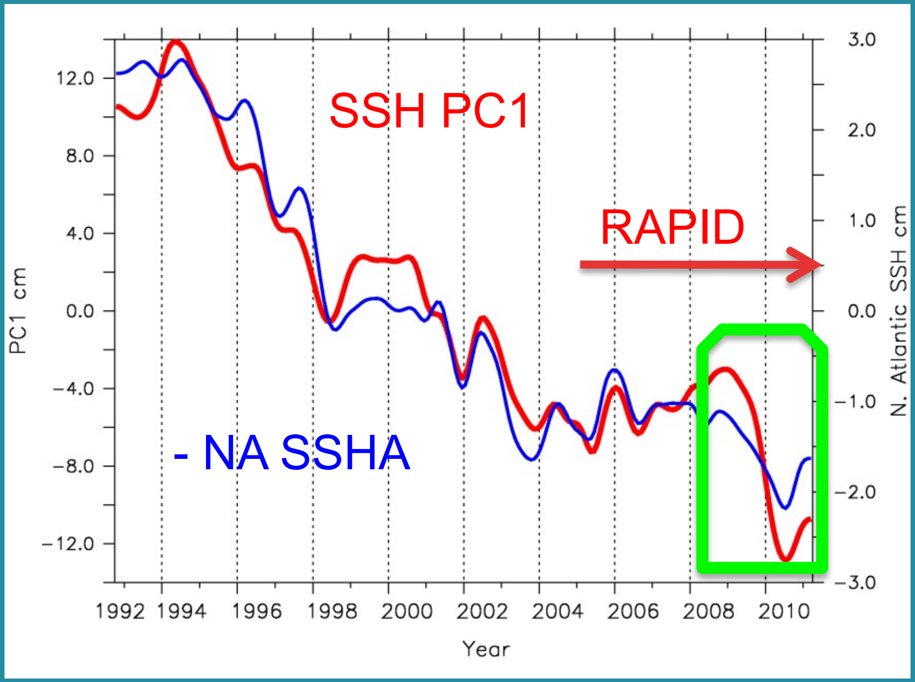

The subpolar cyclonic gyre *weakened* and *warmed* steadily

DATA FROM
NASA MEASURES
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GSFC to 03/2011

Europe freezes in cold winter weather

More than 120 deaths linked to temperatures as low as -32.5C, while 11,000 villagers are trapped by snow in Serbian mountains

Peter Walker
guardian.co.uk, Thursday 2 February 2012 16.23 EST

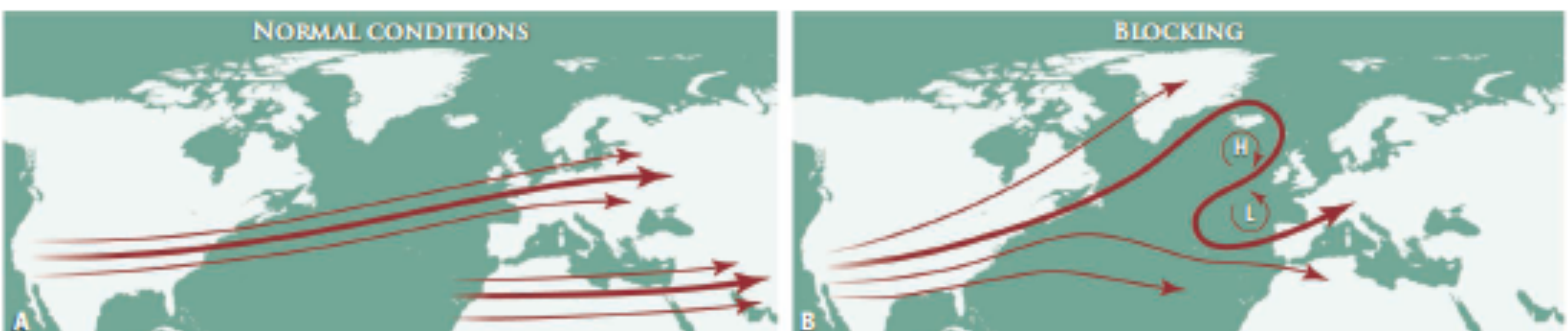
Goran Milat, one of those residents cut off, said: "We are thankful for this help. But the snow did what it did and we are blocked here until spring."

ATMOSPHERIC SCIENCE

Ocean Effects of Blocking

Tim Woollings

Short-term weather events may drive ocean variability on time scales of several decades.

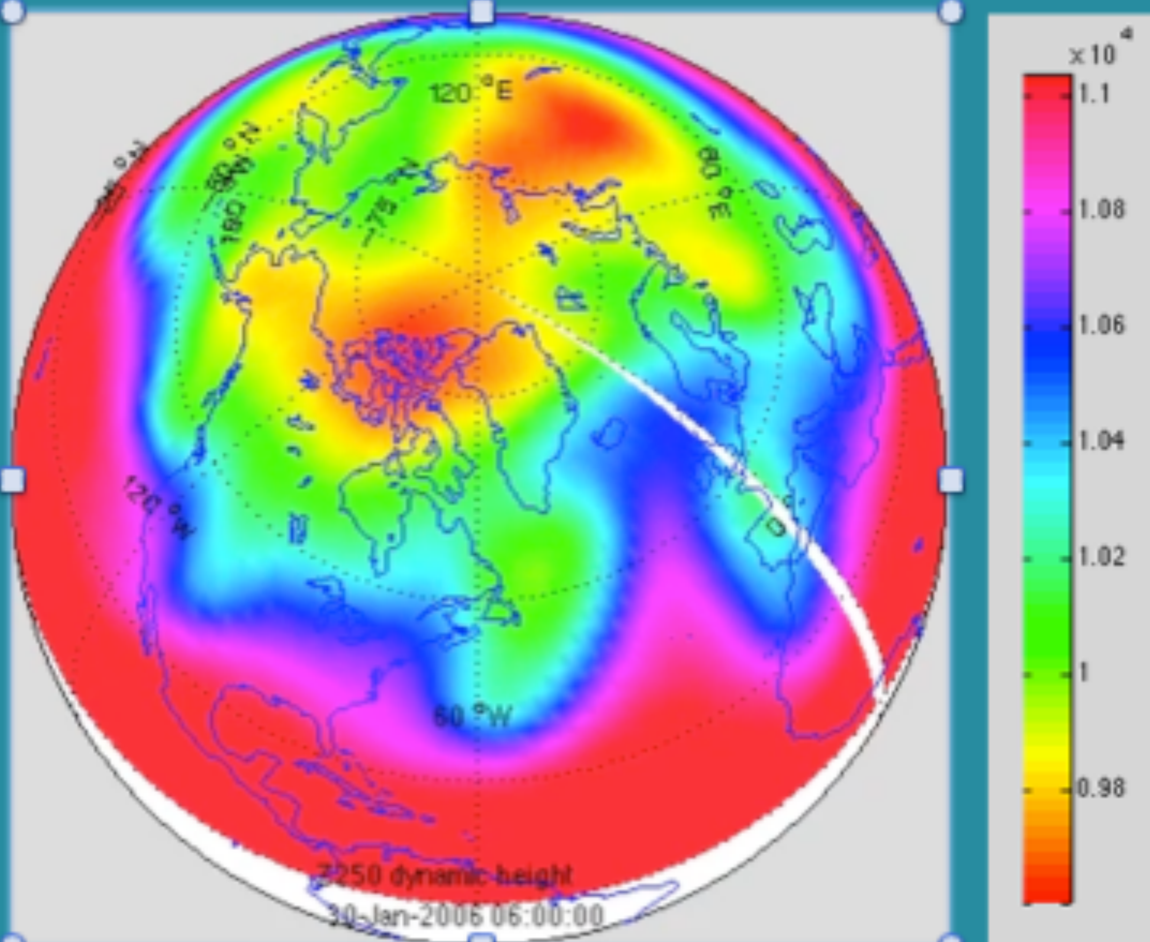


jet stream
during cold
European
winter of 2005/6

(250HPa dyn.
height)

frequent blocks
over central
Europe from
late Dec to Mar

note apparent
precursors
possibly as far upwi



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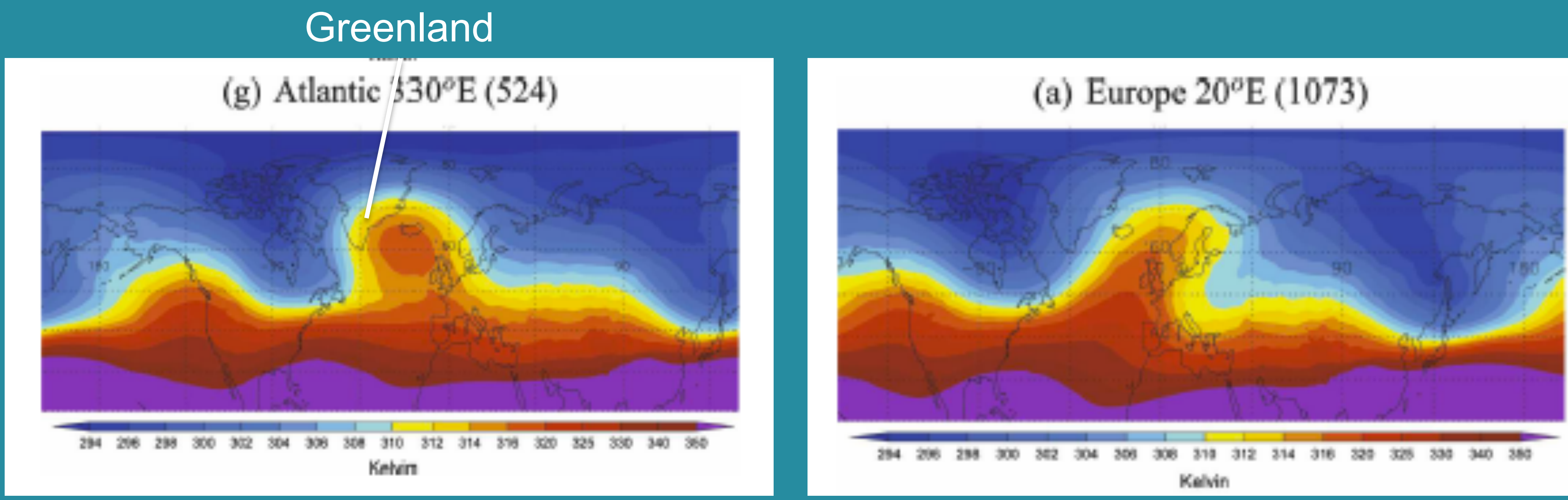


Hoskins & Tyrliss JGR 2008 cluster plots showing east-west locations of blocking

θ on PV-2 surface (tropopause): reversals are breaking Rossby waves on the jet stream, at the synoptic scale:
connected with both orographic (Rocky Mts)
and 'thermographic' (warm Atlantic heat content) forcing.

Note the wavetrain upwind (west) of the block

Winter 2005/6

NAO index

PV anomaly

EU temperature

cold episodes

blocking events

Croci-Maspoli & Davies
Mon Wea Rev 2009

study of cold EU winter of 2005/6

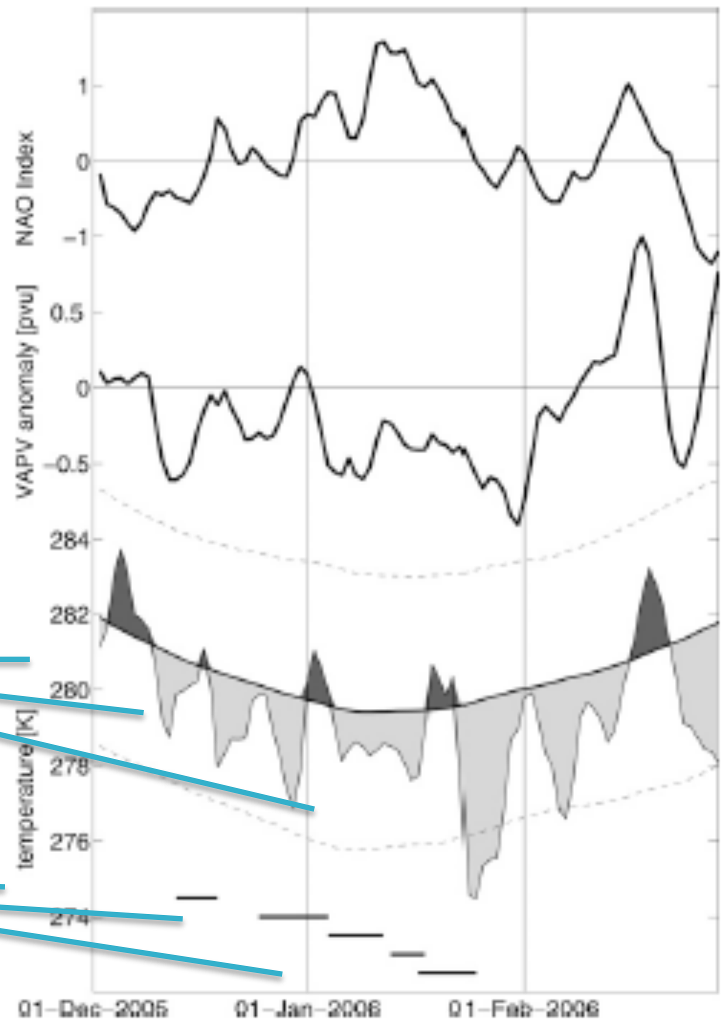
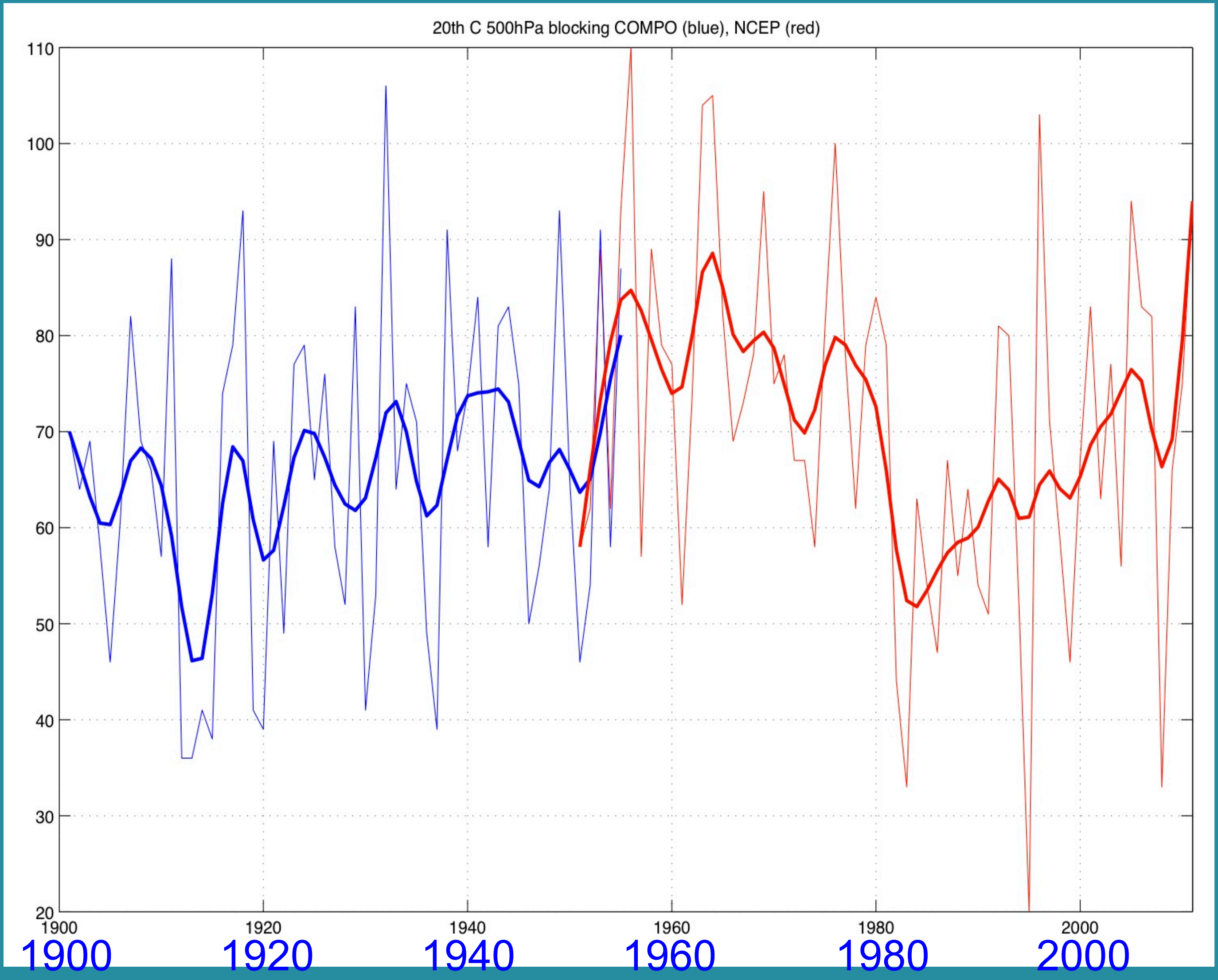


FIG. 5. The bottom curve represents the temporal evolution of the winters 2005/06 daily 2-m temperature (5-day running mean) over central Europe. Light (dark) gray shading indicates negative (positive) anomalies in respect to the ERA-40 climatology. Dashed contours represent ±1 standard deviation of the daily climatological mean. The middle thick black line indicates the mean VAPV distribution over the northern European region, and the top thick black line indicates the daily NAO index with arbitrary scaling. The five horizontal bars at the bottom signify the duration of the major blocking events in the Euro–Atlantic region.

Winter blocking days (NDJF) from Compo *et 26 al. QJRMS 2011*
20th C reanalysis (blue) and NCEP reanalysis (red)
Based on 500hPa index of extreme jet stream meanders
(Tibaldi & Molteni Tellus 1990*)*



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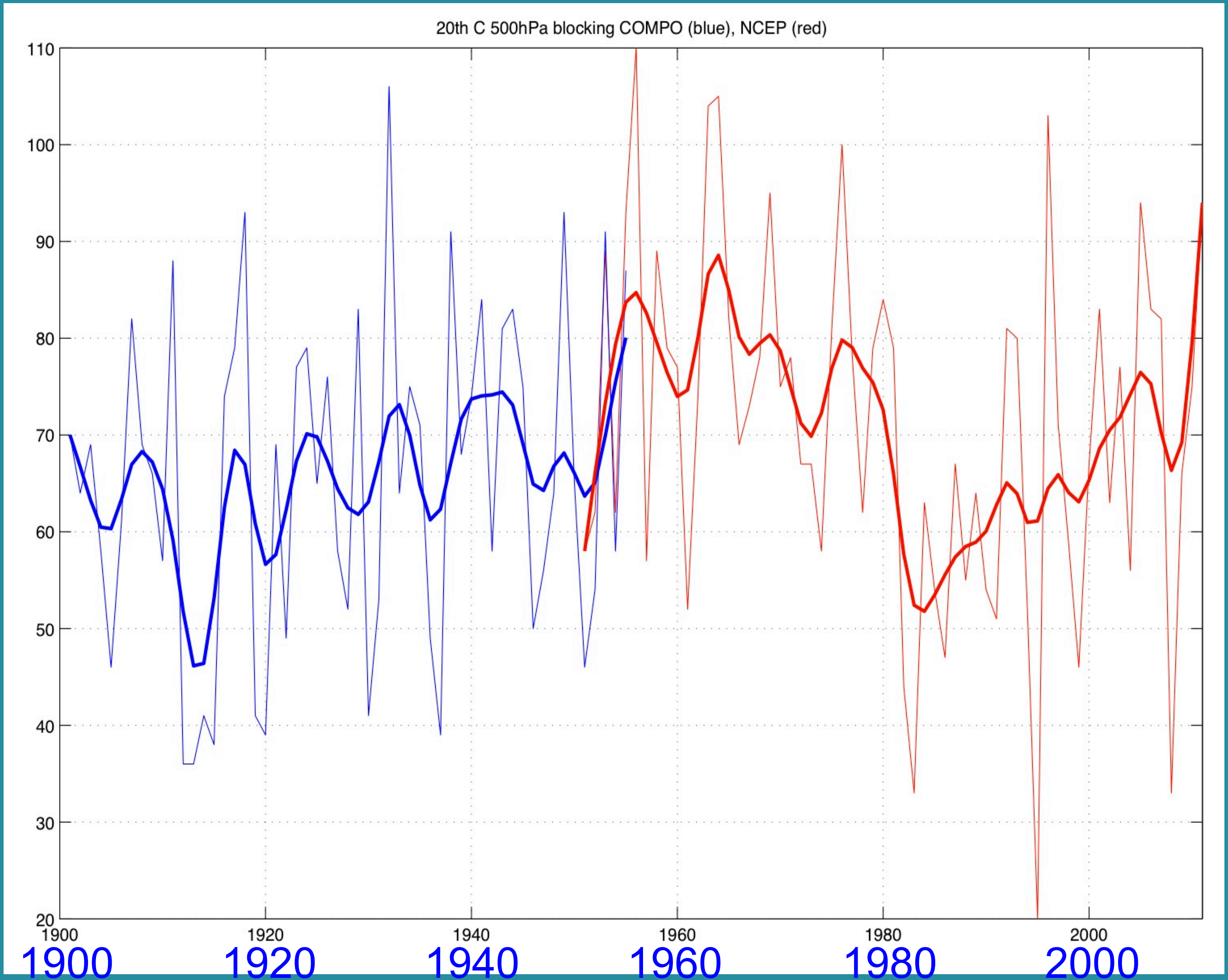
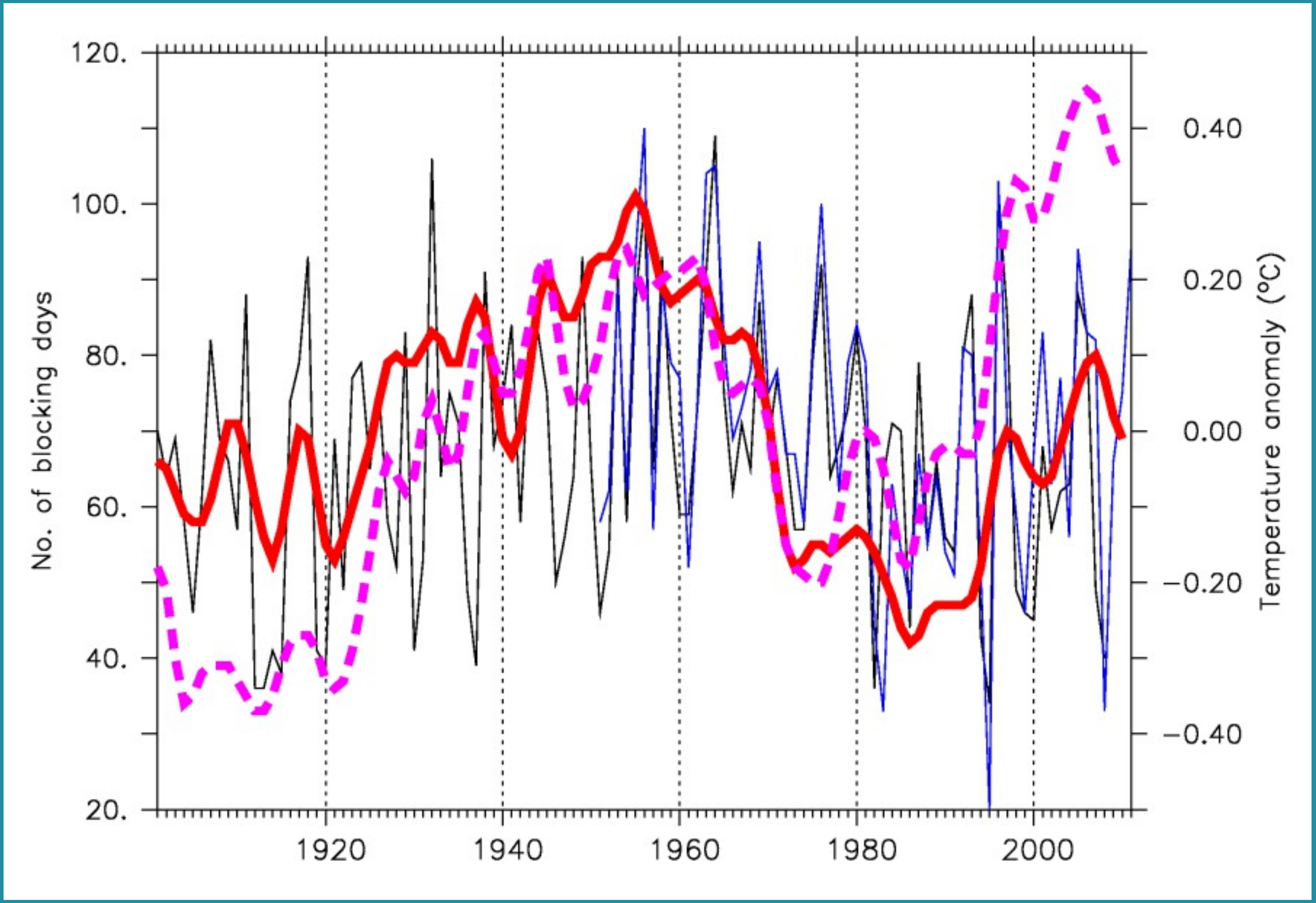


One way to make long-period atmospheric variability is to involve the ocean.

Conclusion I: Atlantic wintertime blocking comes in clusters, which vary over interannual-to-multidecadal timescale

AMV northern Atlantic SST index and Atlantic Blocking



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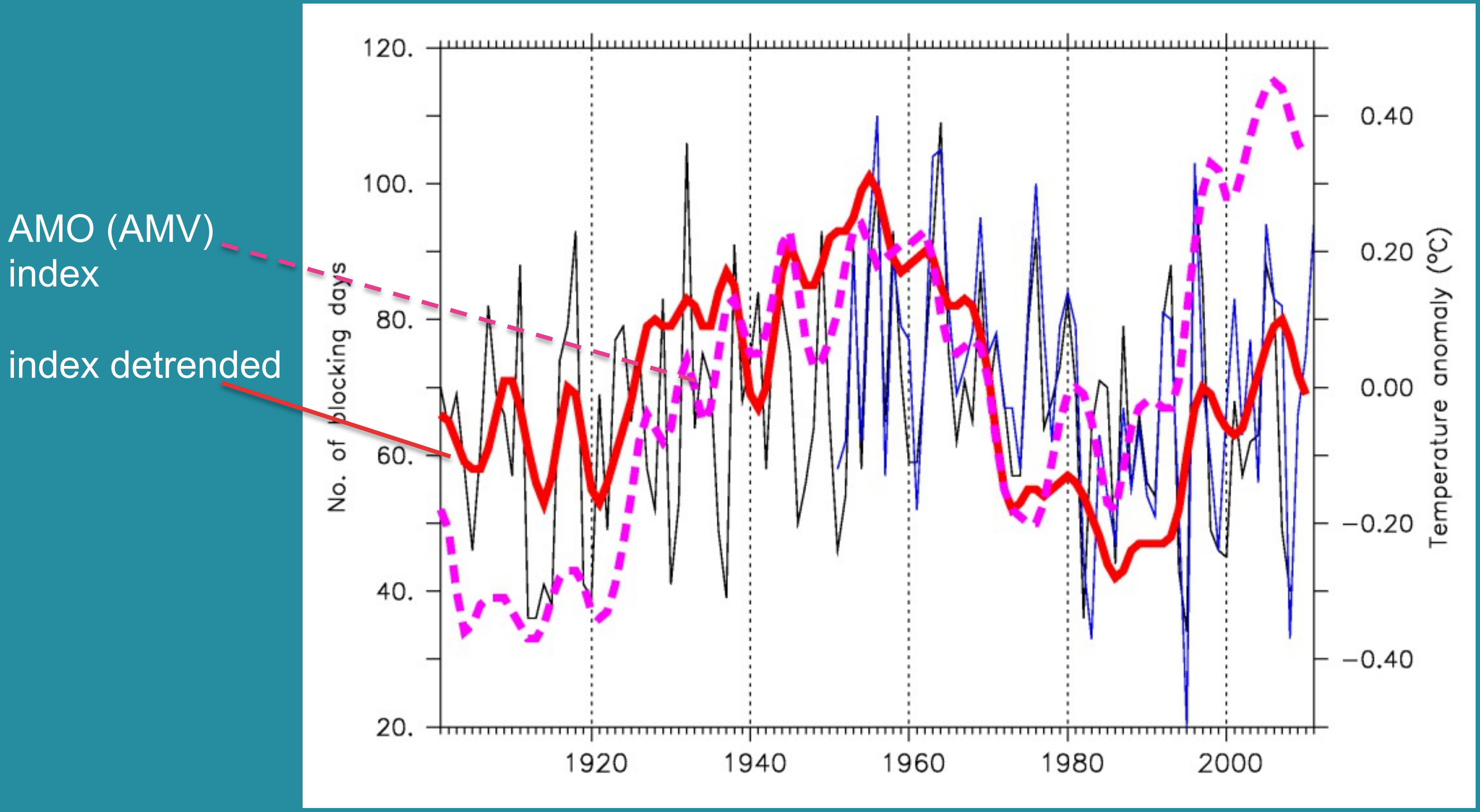

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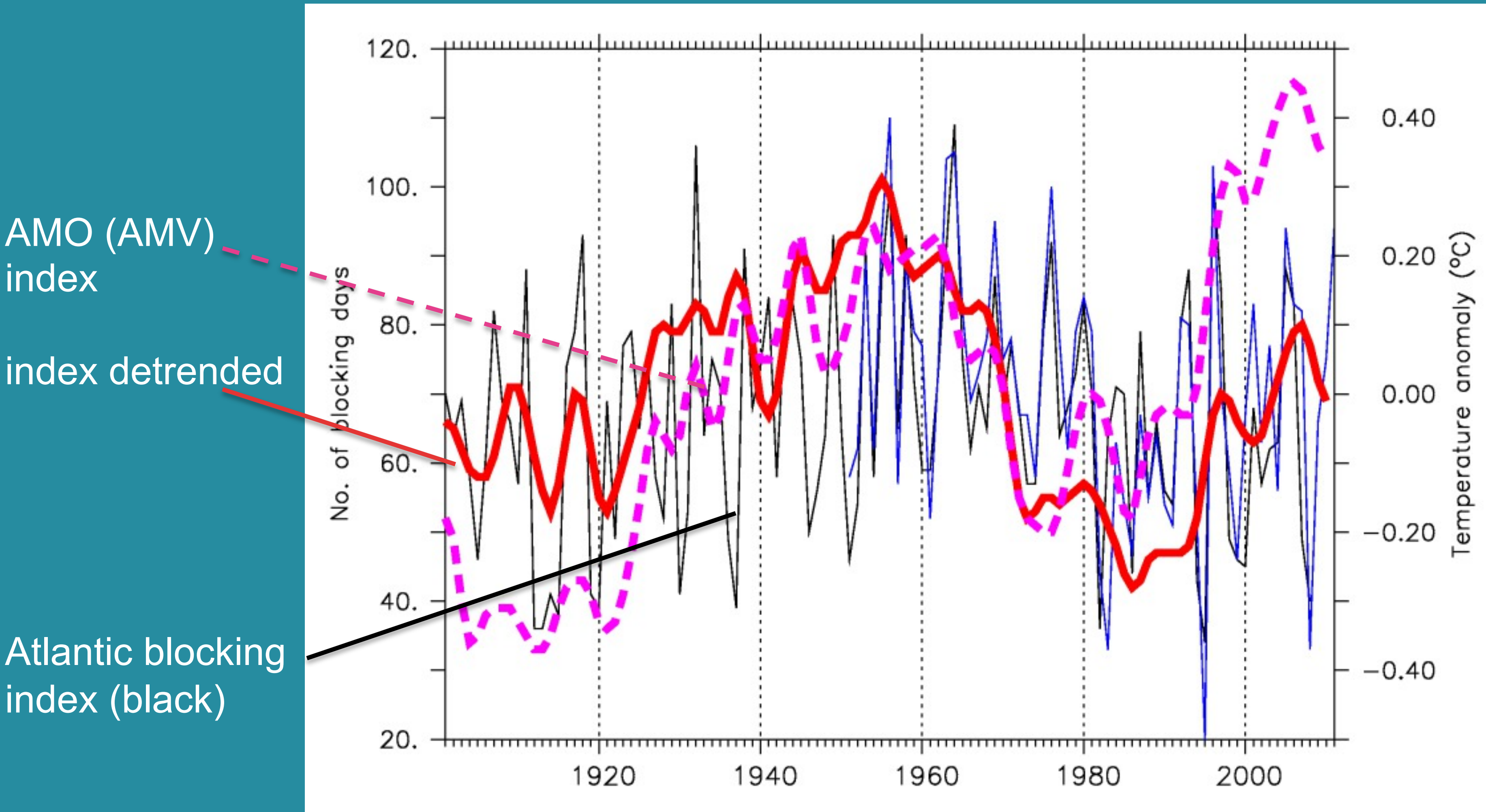

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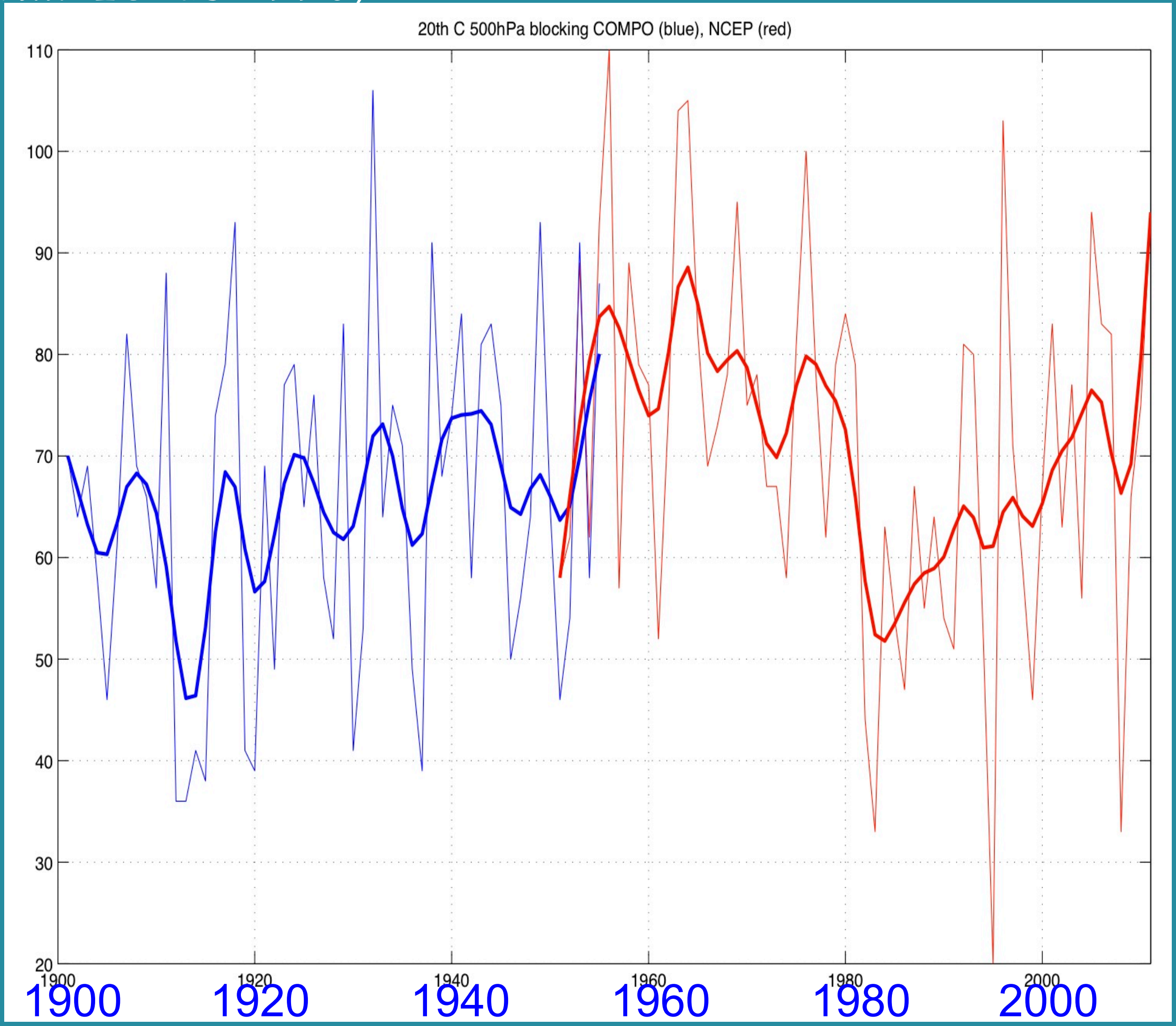


Conclusion II: at 10 – 50 year timescale of AMV, blocking corresponds with a warm subpolar Atlantic ocean

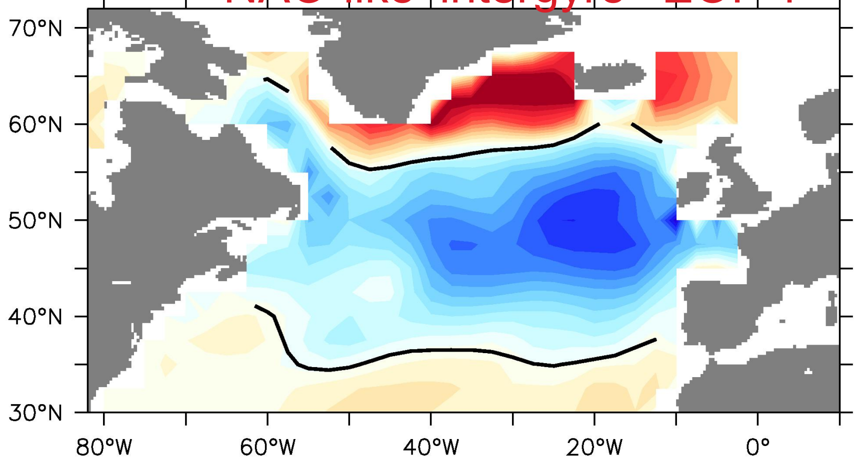
(ironically causing cold central Europe winters)

- Atmospheric forcing variability involves both east/west and north/south structure. Blocking, AMV , wind-stress curl and air/sea buoyancy flux all show subpolar centers of action west of England

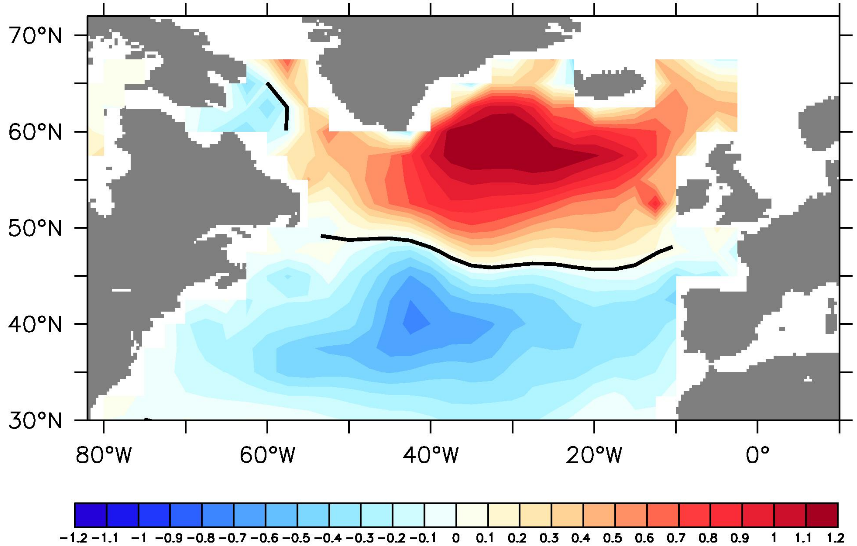
DJFM WIND STRESS CURL VARIABILITY

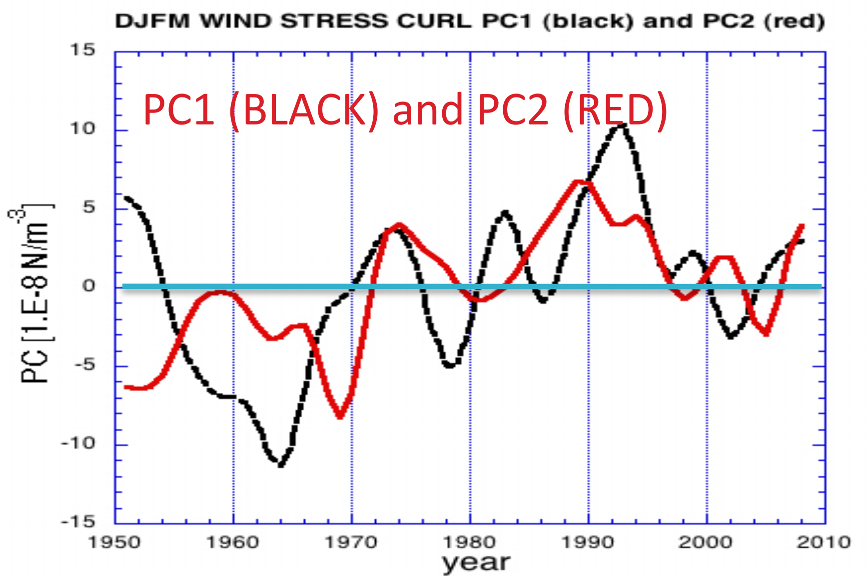
EOF1 (24%) and EOF2 (16%)

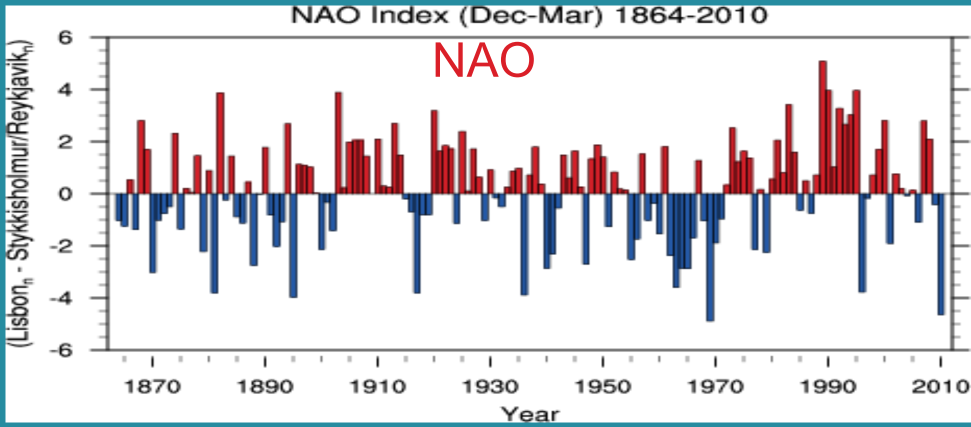
NAO-like 'intergyre' EOF 1



'Gyre Mode', EOF 2

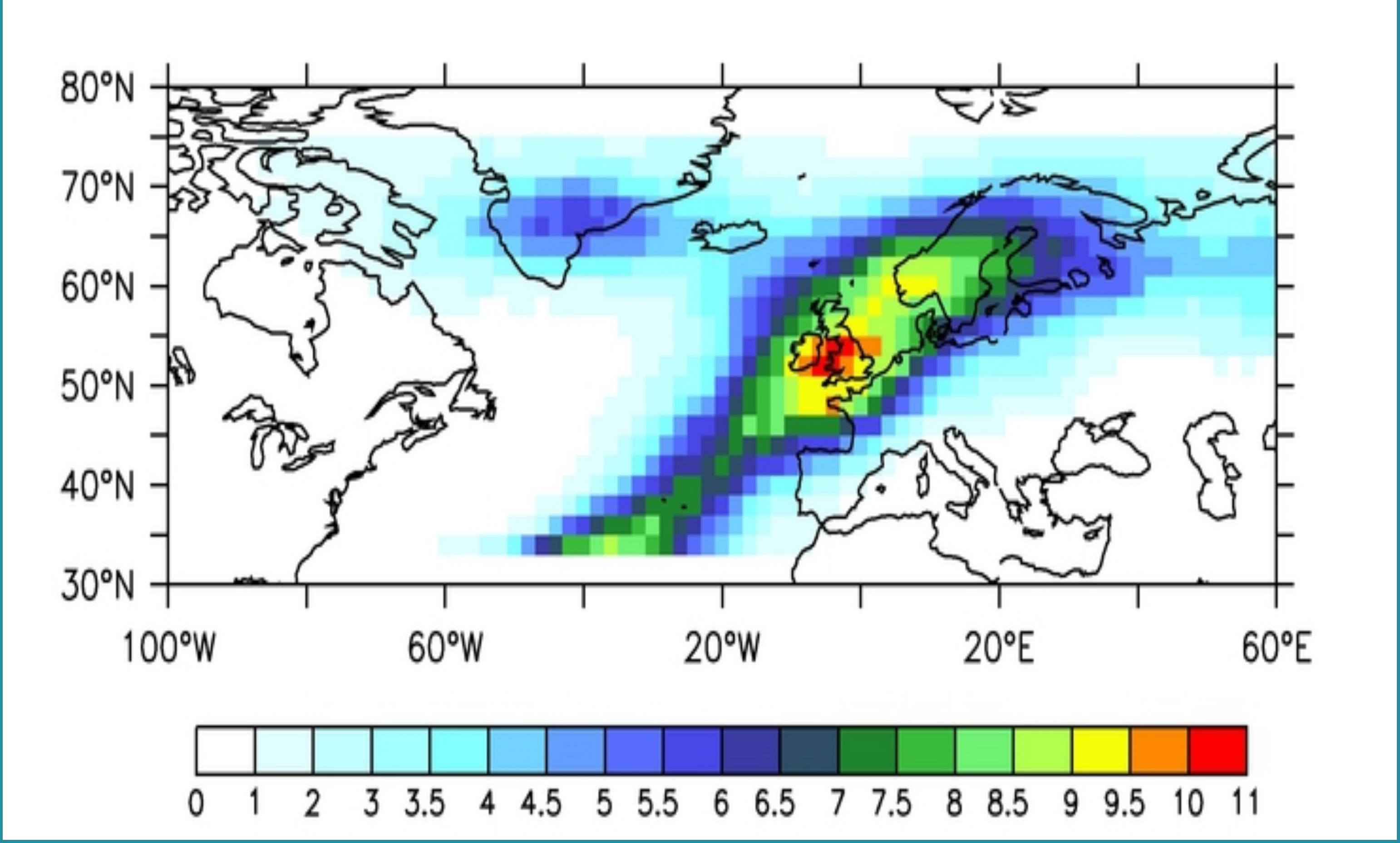






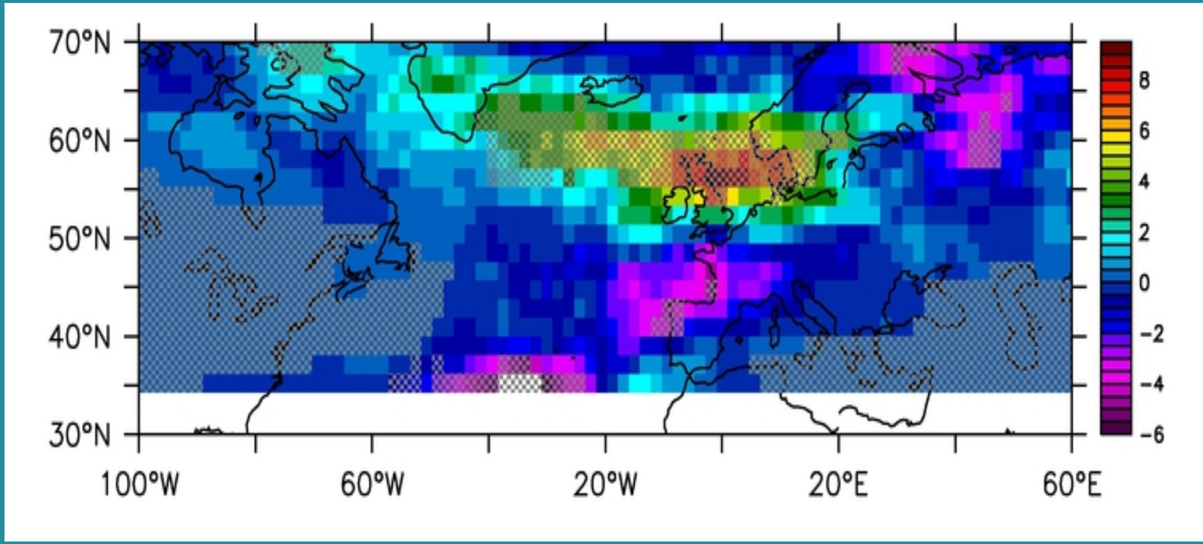
AVERAGE BLOCKING DAYS per winter, base on Scherrer et al,
modified from *Molteni & Tibaldi*, 1990)
(reversal of 500hPa gradient and requiring persistence of at least 5 days
in sector 45N-70N, 80W-30E)

From the 20th century
Reanalysis by Compo et al. (2011) European sector blocks are most frequent; Greenland (NAO type) blocks often follow EU blocks

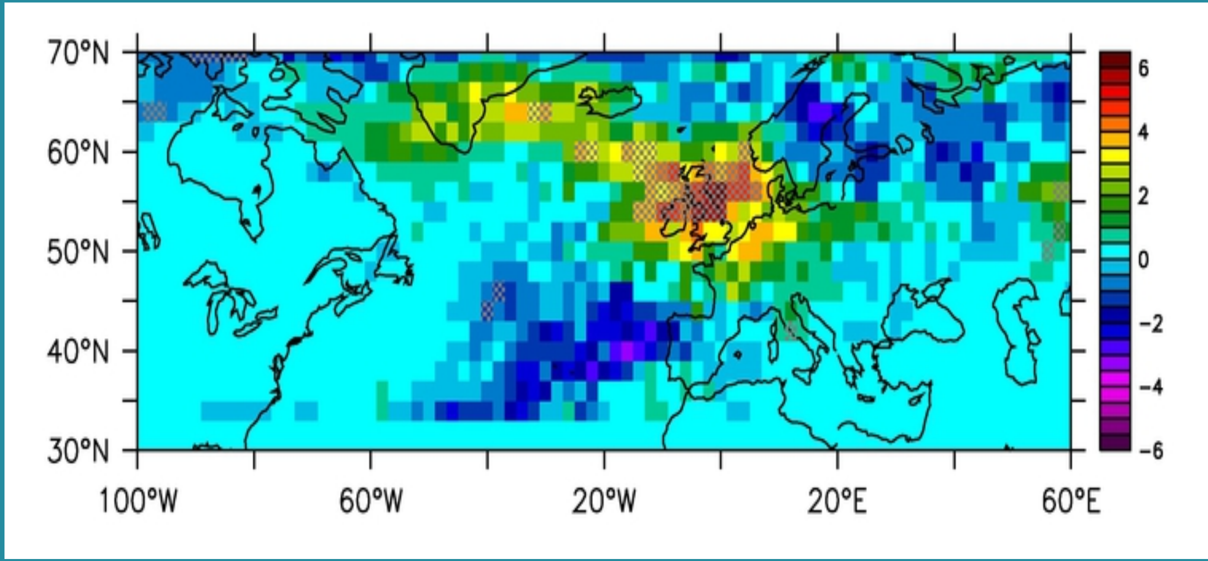


BLOCKING COVARIES WITH AMO/AMV SST

blocking days per winter (DJFM) regressed on AMO/AMV time series



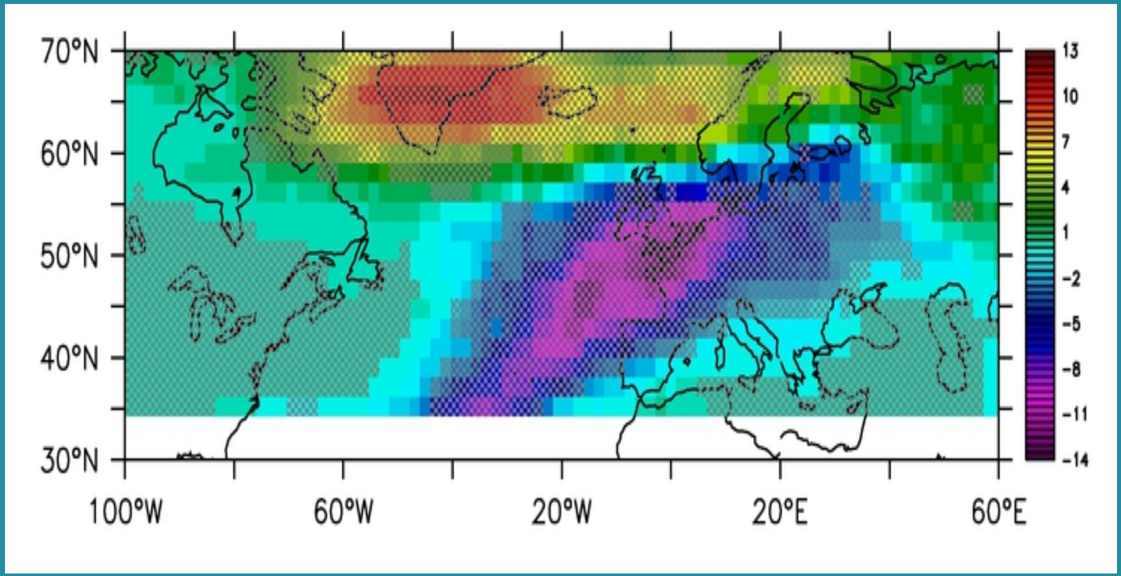
1939-1968 warm yrs minus 1900-1929 cold yrs



ATMOSPHERIC BLOCKING COVARIES WITH WIND-STRESS CURL

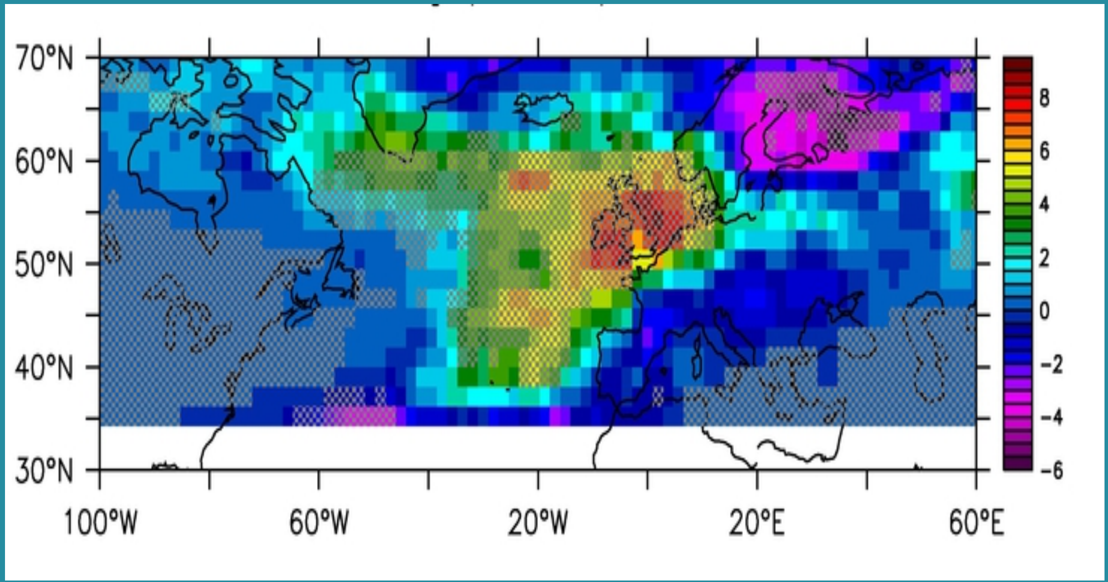
(blocking days based on negative minus positive wind curl time series)

PC1 (top) and PC2 (bottom)



NAO-like PC1

Greenland blocks



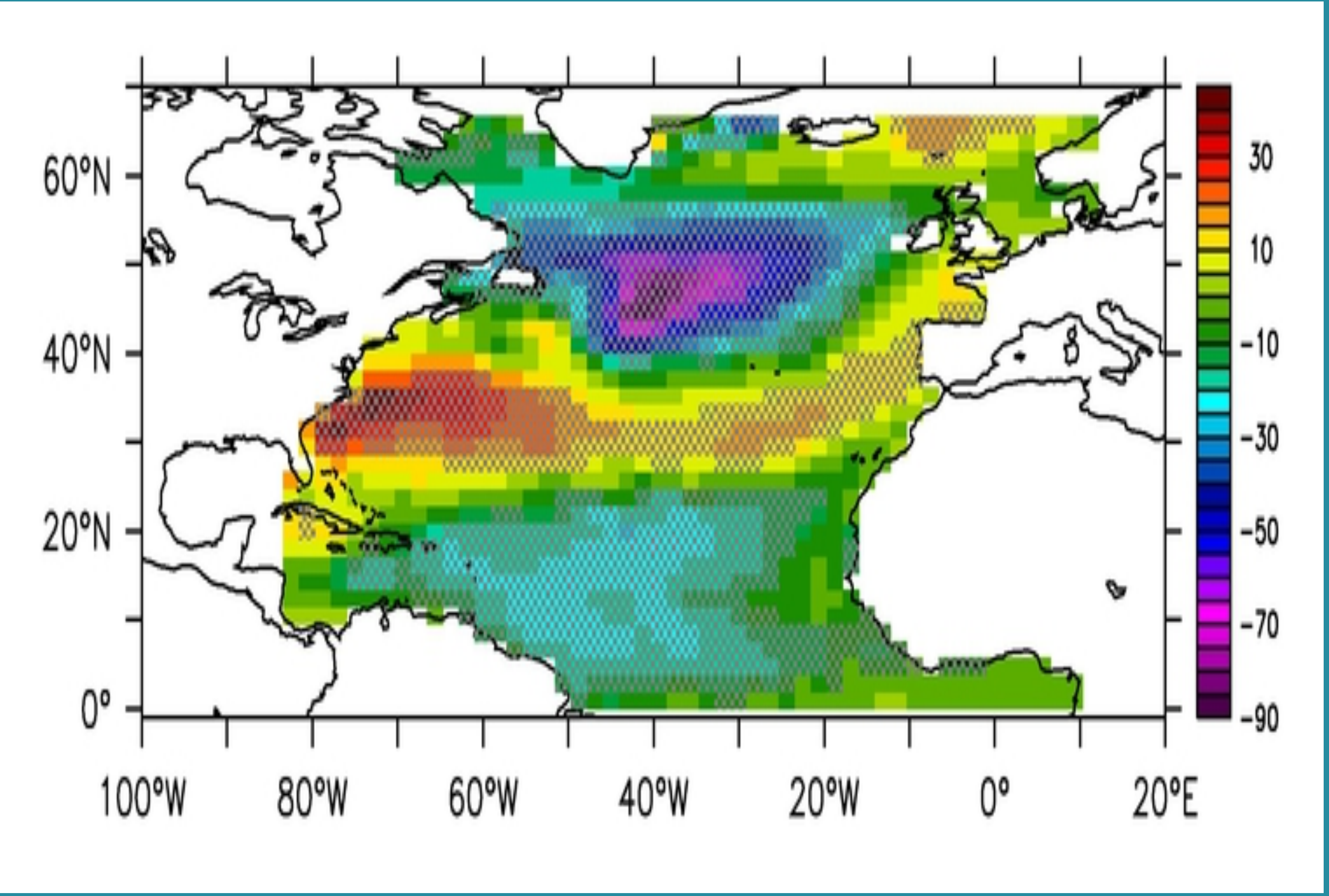
GYRE PC2

MODE

European blocks

60% of European blocks are followed by Greenland blocks: *Woollings et al JAS 2008*

AIR-SEA HEAT FLUX COMPOSITE CORRESPONDING to CURL PC2 (based on negative minus positive wind curl time series; positive curl => upward heat flux)



Conclusion III: the two principal EOFs of wind-stress-curl correlate with winter blocking frequency, separately Greenland (NAO-like) and European (gyre-mode) blocks.

Air-sea heat flux is also well correlated with EOF-2, the 'gyre mode'.

Severe blocking winters are less well correlated with NAO.

warm branch of

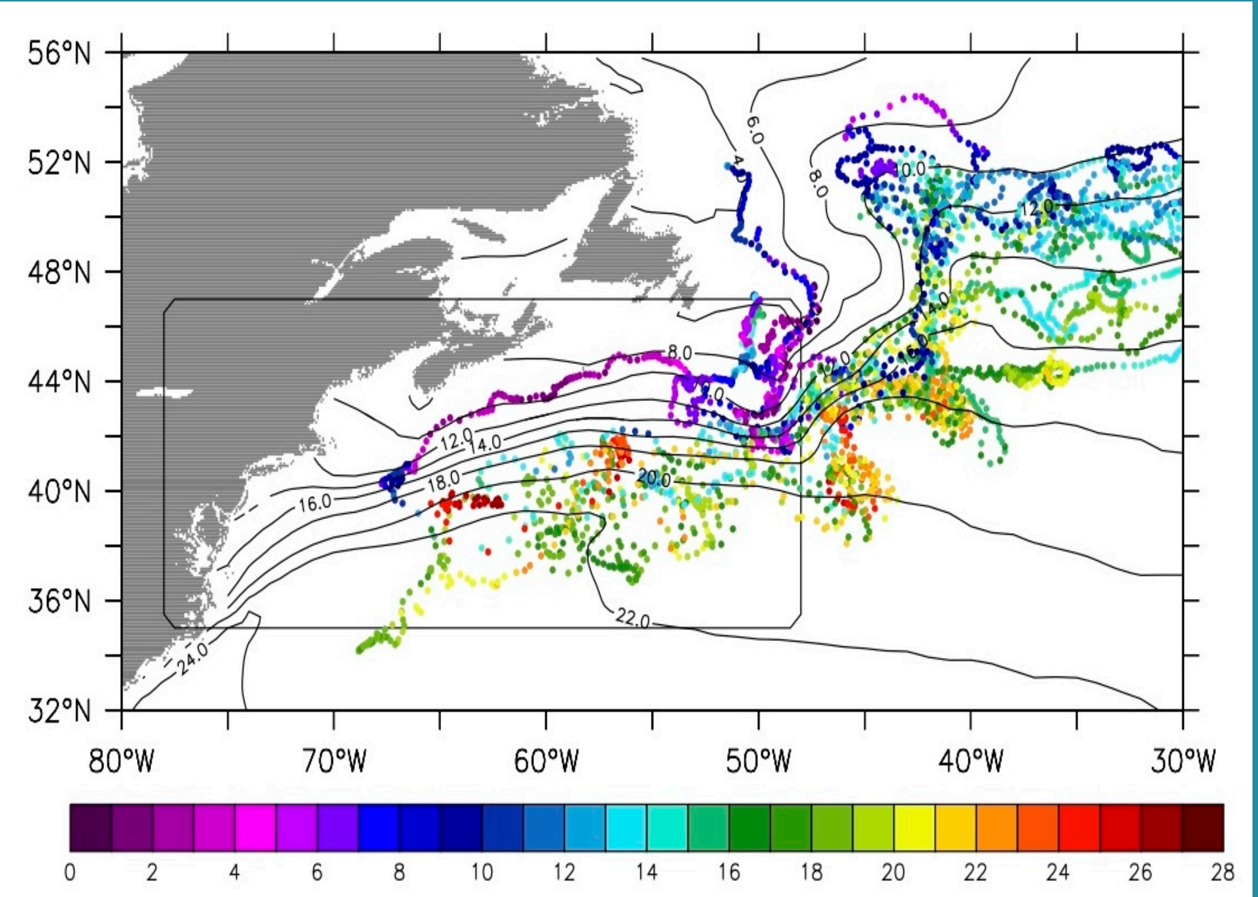
What is the relation between AMO/AMV and ^ AMOC?

What is the relation between AMO/AMV and ^ warm branch of AMOC?

surface drifter tracks passing from subtropical gyre warm water north to subpolar gyre (Rockall Trough).
SST in color:

Sparse yet mostly between 1996 and 2005

(*Hakkinen & Rhines JGR 2009)*



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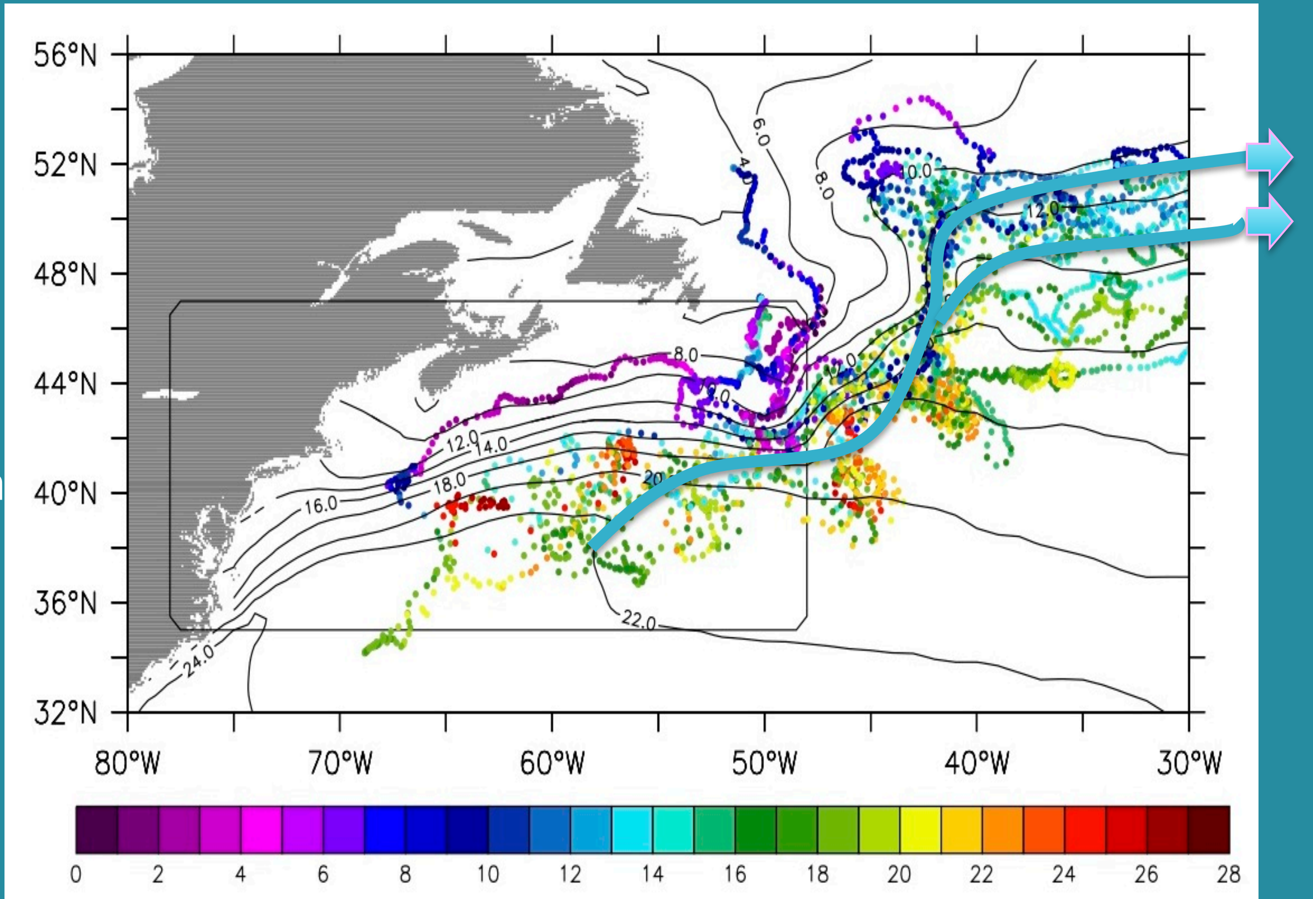
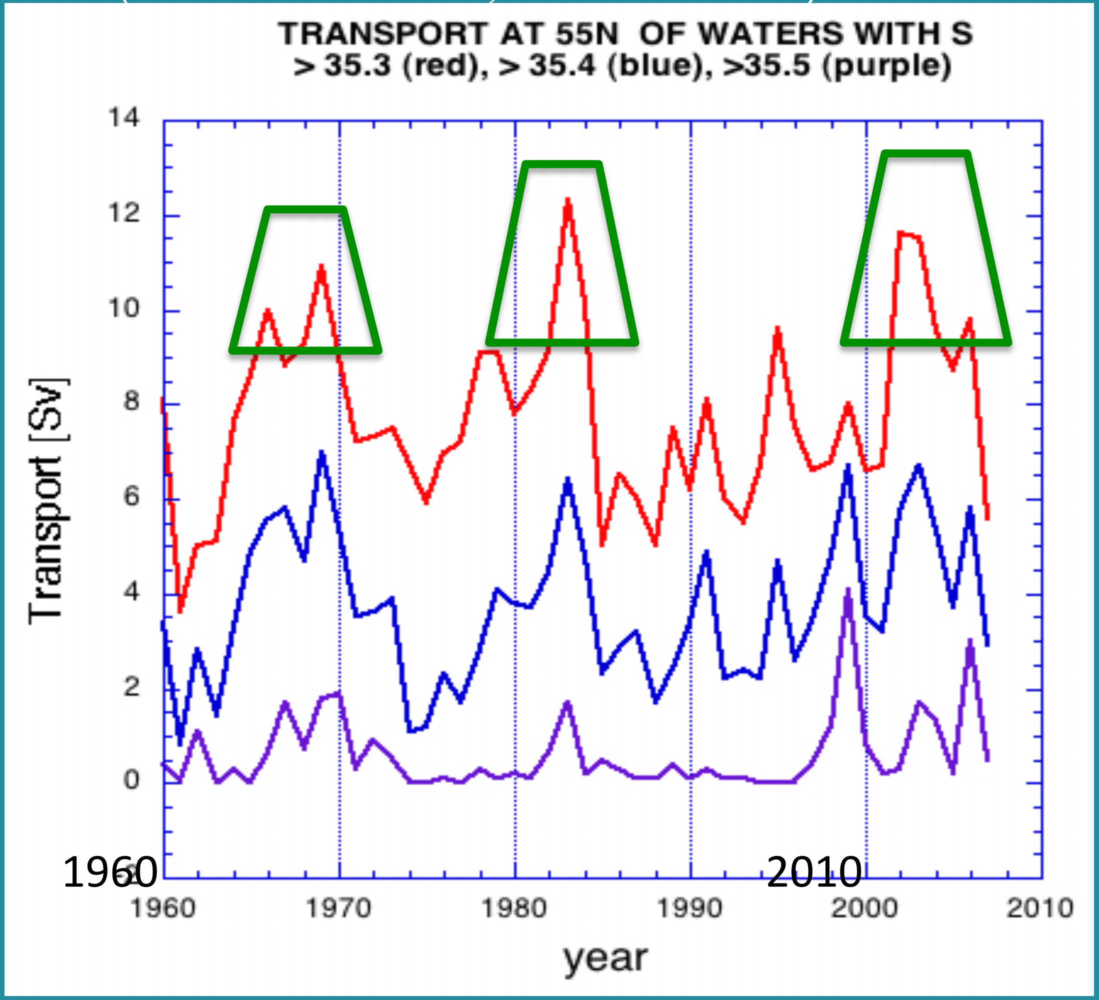
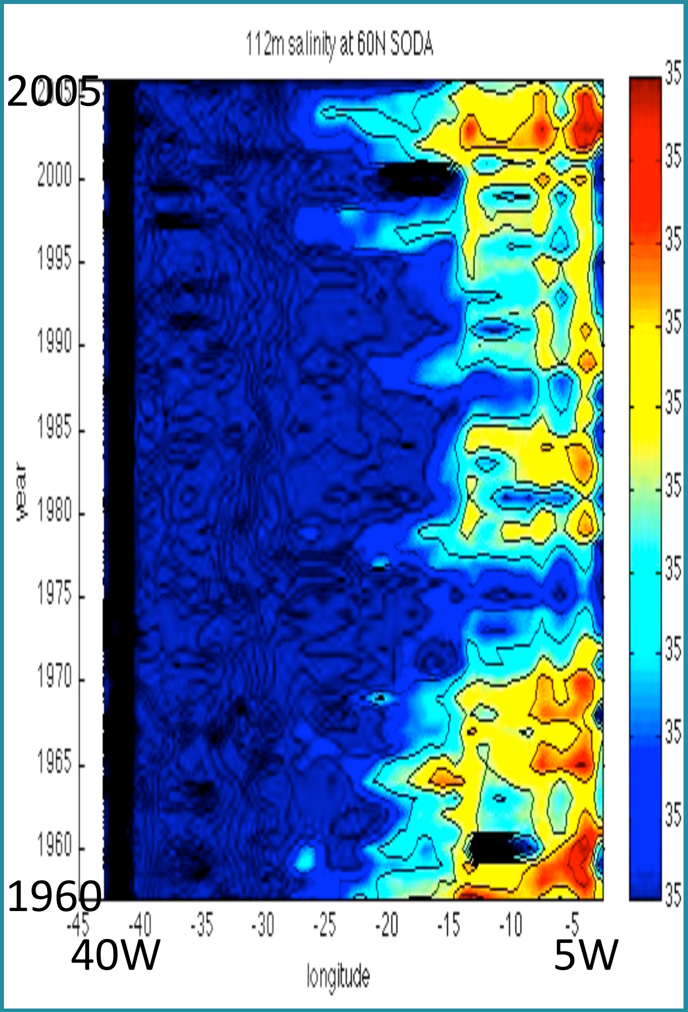


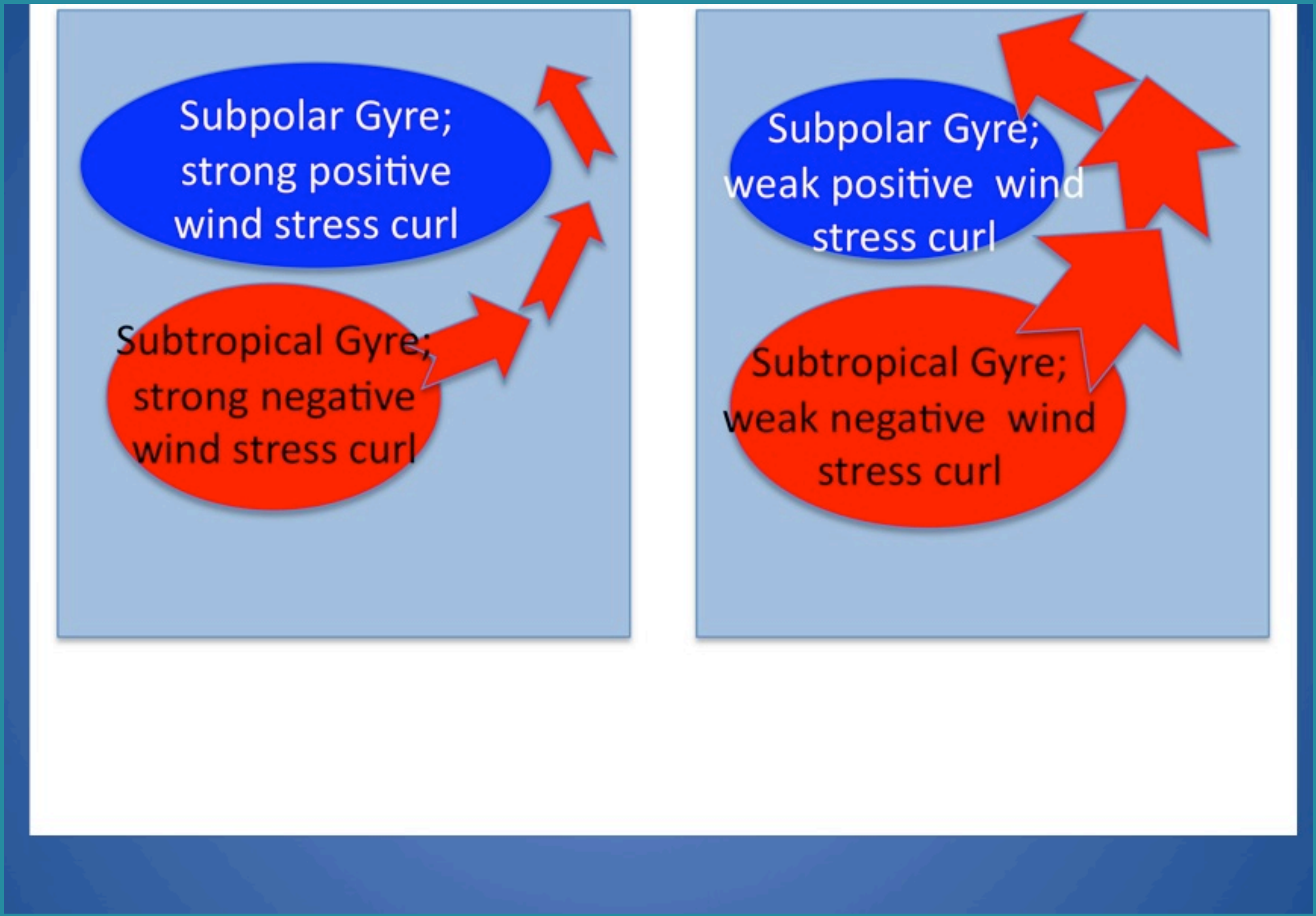
Warm AMOC branch:
Poleward salinity transport at 55-60N (*Hakkinen & Rhines JGR 2011)*
from SODA reanalysis 0.25⁰ x 0.4⁰ x 40 levels 1958-2007

(*Carton & Giese, MWR* 2008)



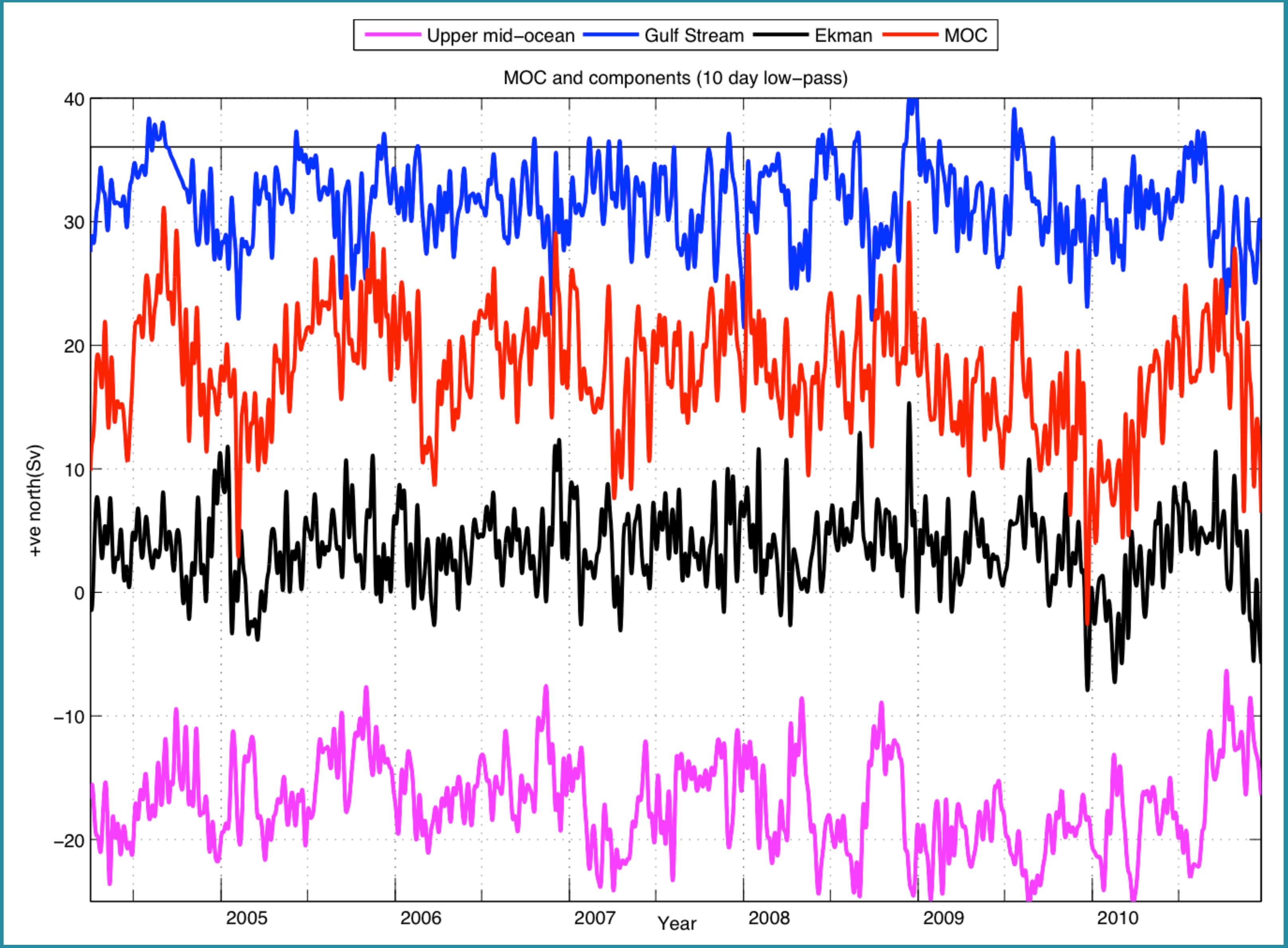
Monthly data





Despite the diverse model results, the connection between AMV and AMOC seems to exist in the recent dramatic warming of the subpolar Atlantic: the warm branch of AMOC (northward flowing warm, saline waters from subtropics to subpolar latitudes) has occurred (*Hakkinen & Rhines, JGR 2011).*

RAPID AMOC (Sv.) at 26.5N with Ekman/GS related 2010 event



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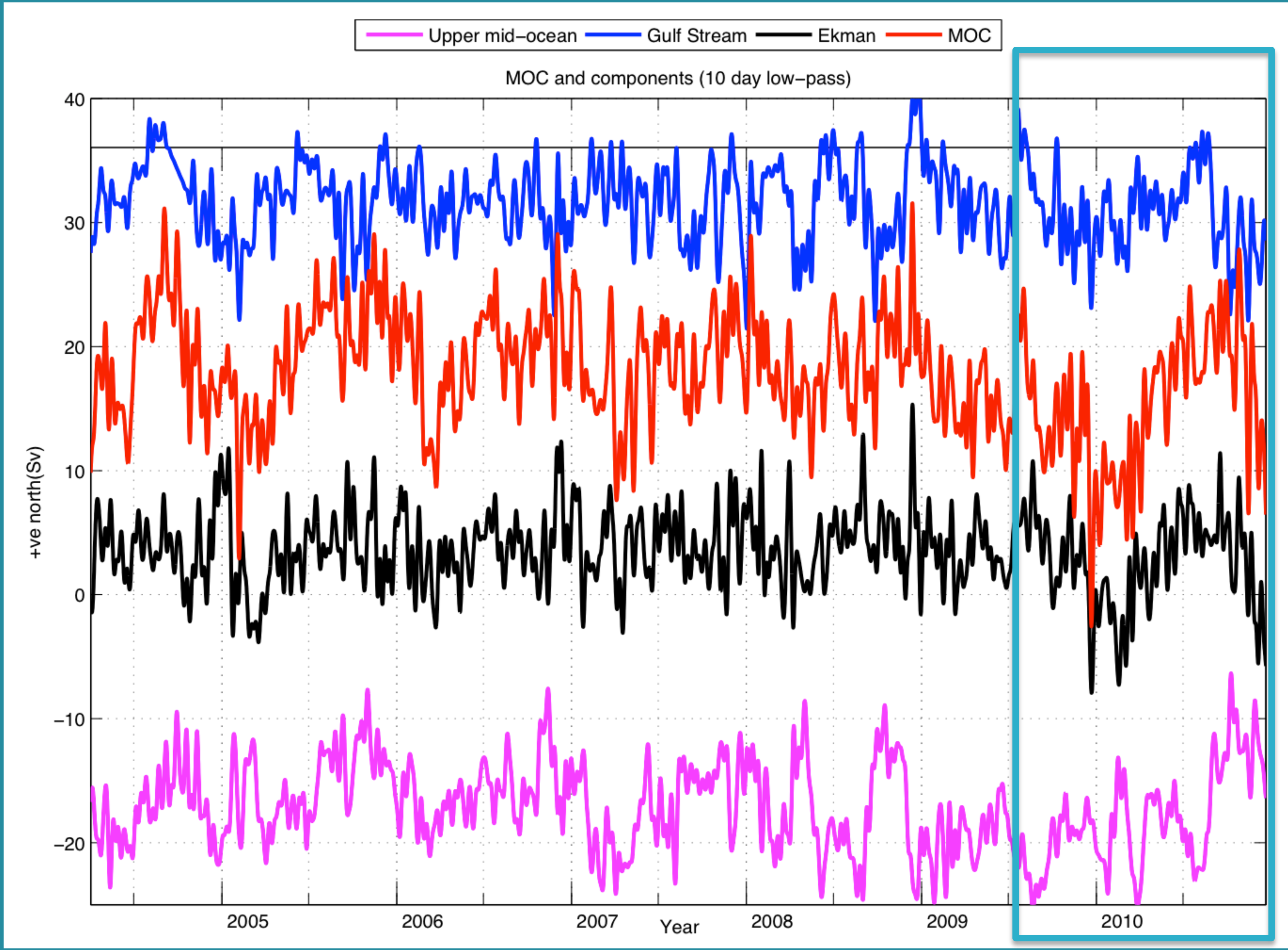
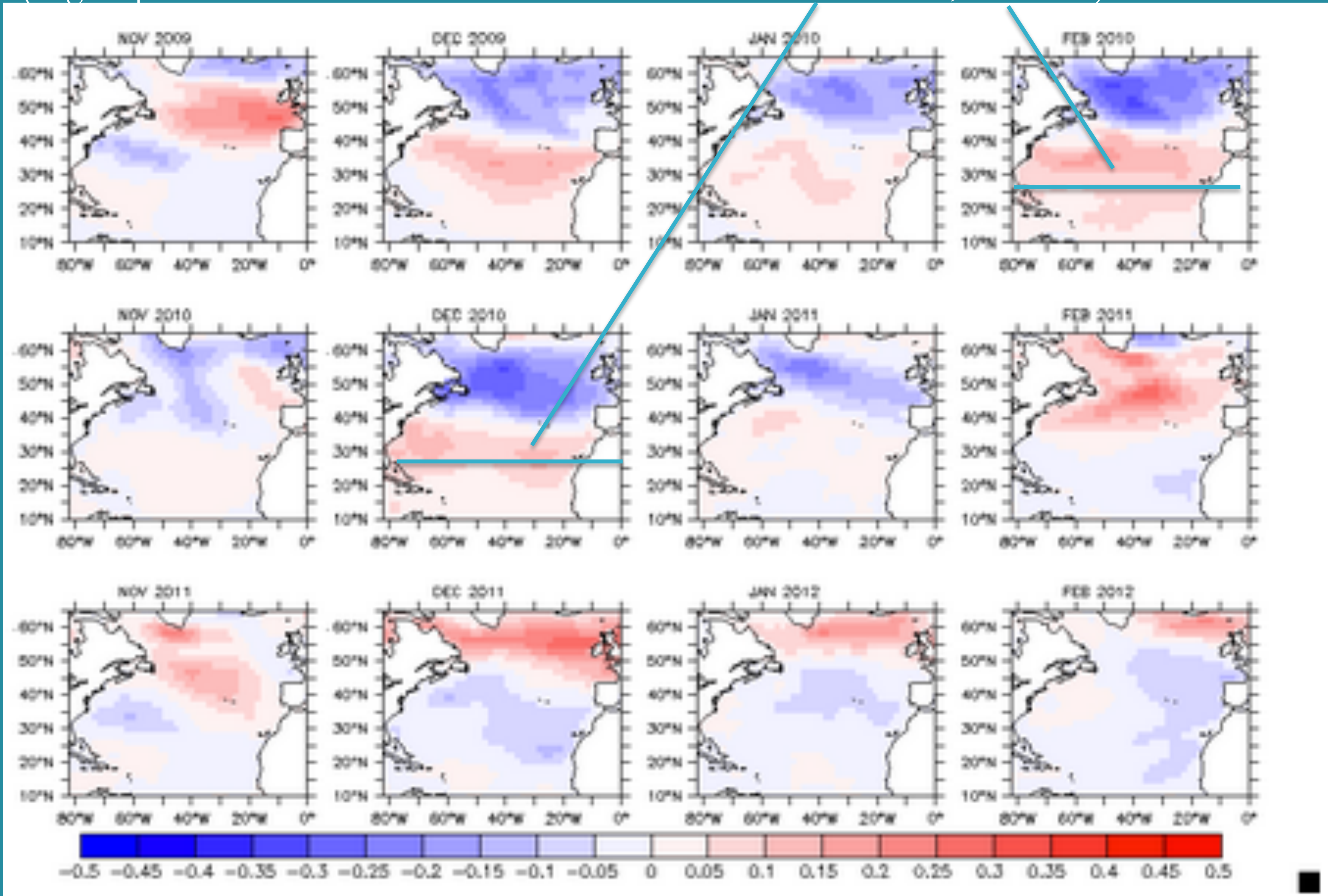


Eastward wind-stress anomaly: Nov 2009 to Feb 2012

(large dip in Ekman contribution to AMOC at 26.5N in Dec 2010, Feb 2010)



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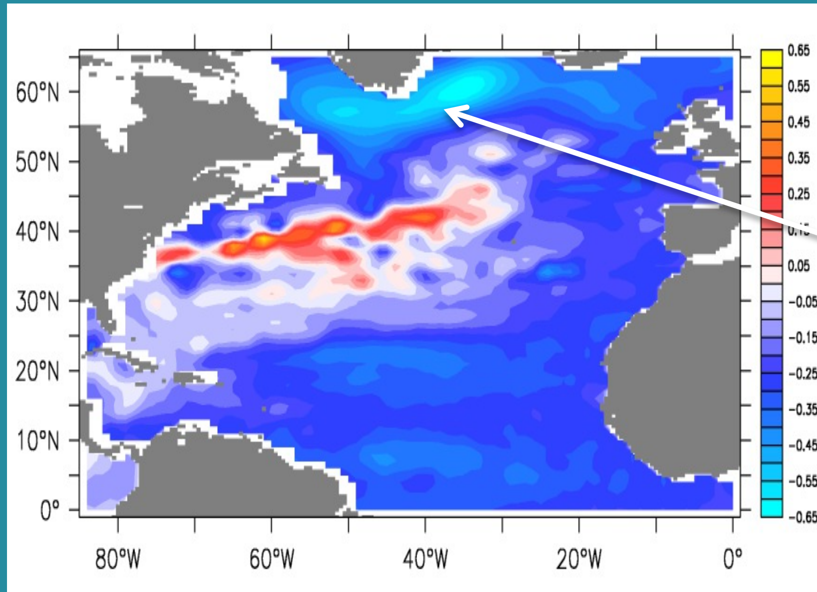

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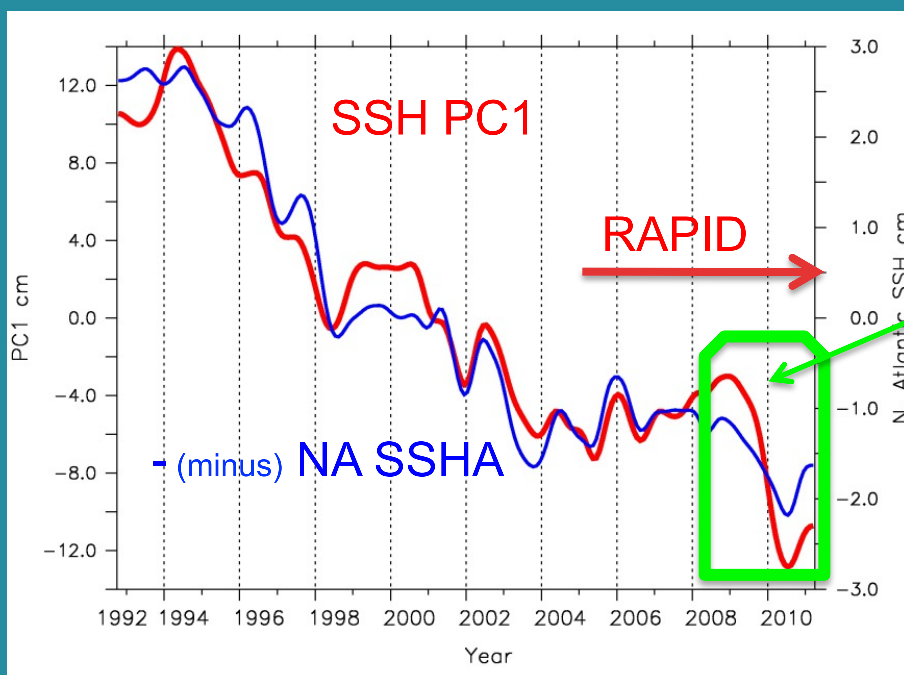

RAPID event precursor
in subpolar/Gulf Stream SSH

DATA FROM
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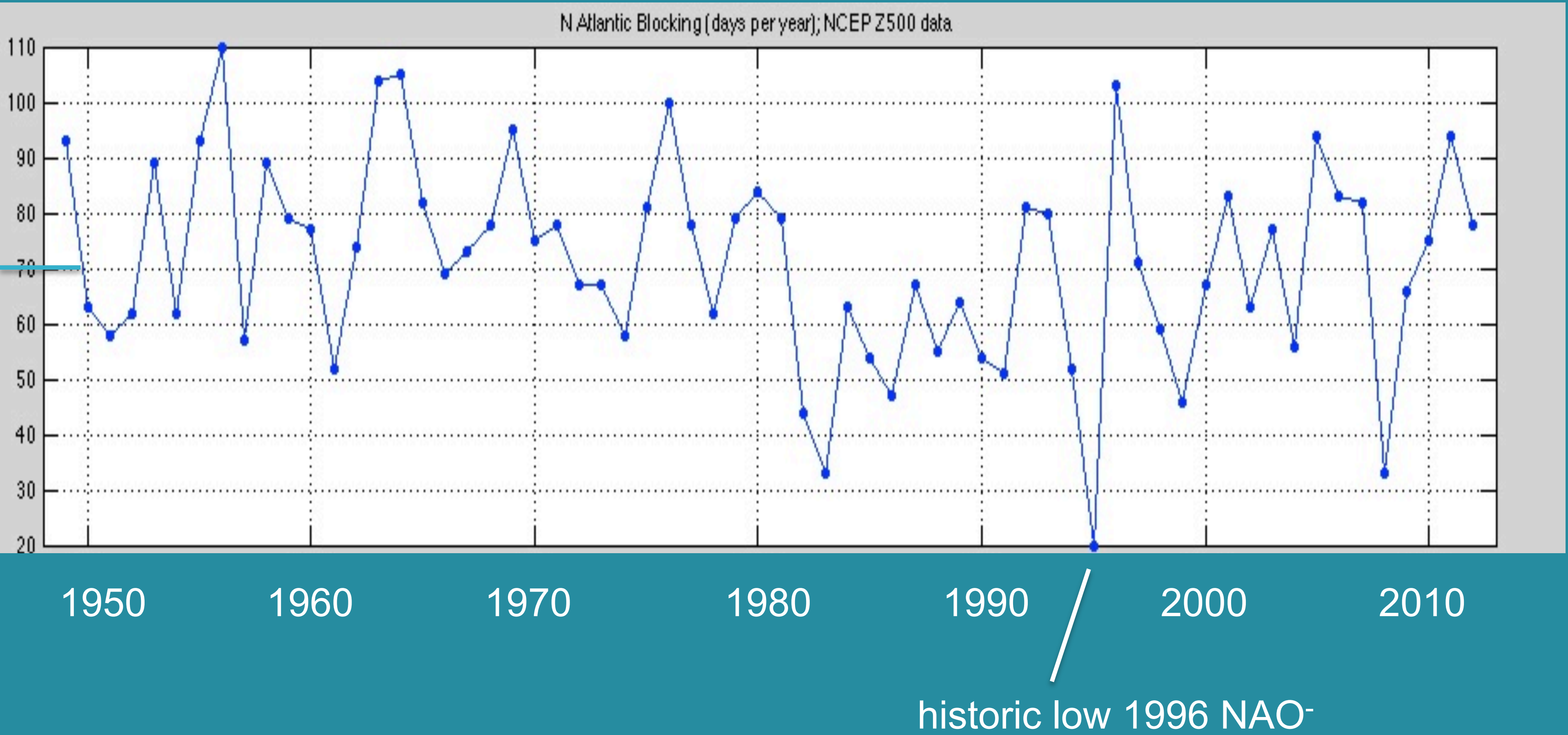
PROJECT; PROVIDED
BY BRIAN BECKLEY SAIC/
GSFC to 03/2011

Blocking frequency (days per winter) .. NCEP data



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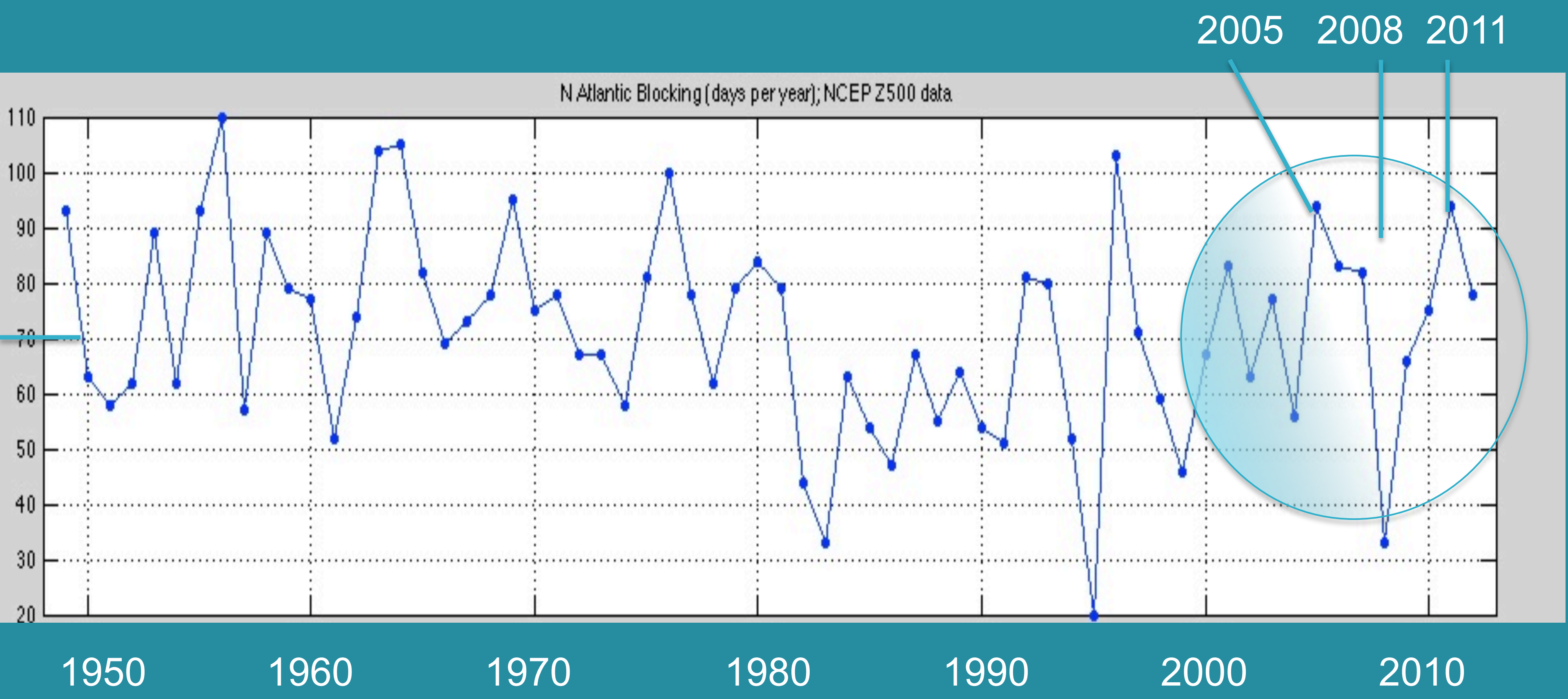

Conclusion I: Clusters of Atlantic wintertime blocking vary over 10-50 year (multi-decadal) timescale

Conclusion II: at 10 – 50 year timescale, warm Atlantic ocean corresponds to increased blocking episodes, weak subpolar gyre circulation (and, ironically, cold central Europe winters)

Conclusion III: the two principal EOFs of wind-stress-curl correlate with winter blocking frequency, separately Greenland and European blocks. These EOFs and other combinations of EOFs

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Conclusion IV: the warm, northward flowing branch of AMOC meridional circulation has been active in creating the most recent AMV warm period in the subpolar Atlantic: *Hakkinen & Rhines JGR 2009, 2011.* Extreme atmospheric blocking events occurred in the late 2000s, corresponding to sudden lurches of $AMOC_{26.5N}$.

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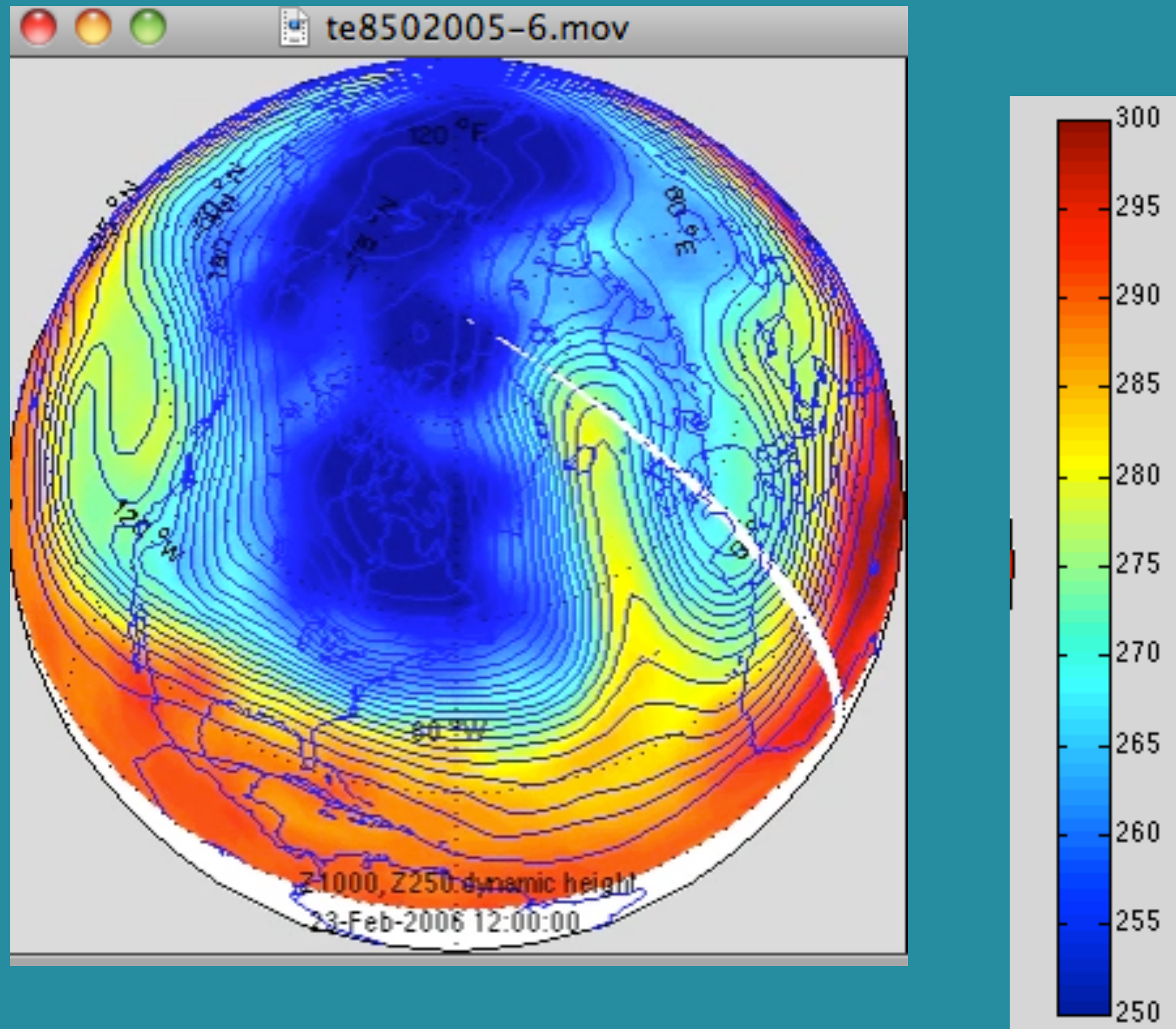
The End

2005/6 winter

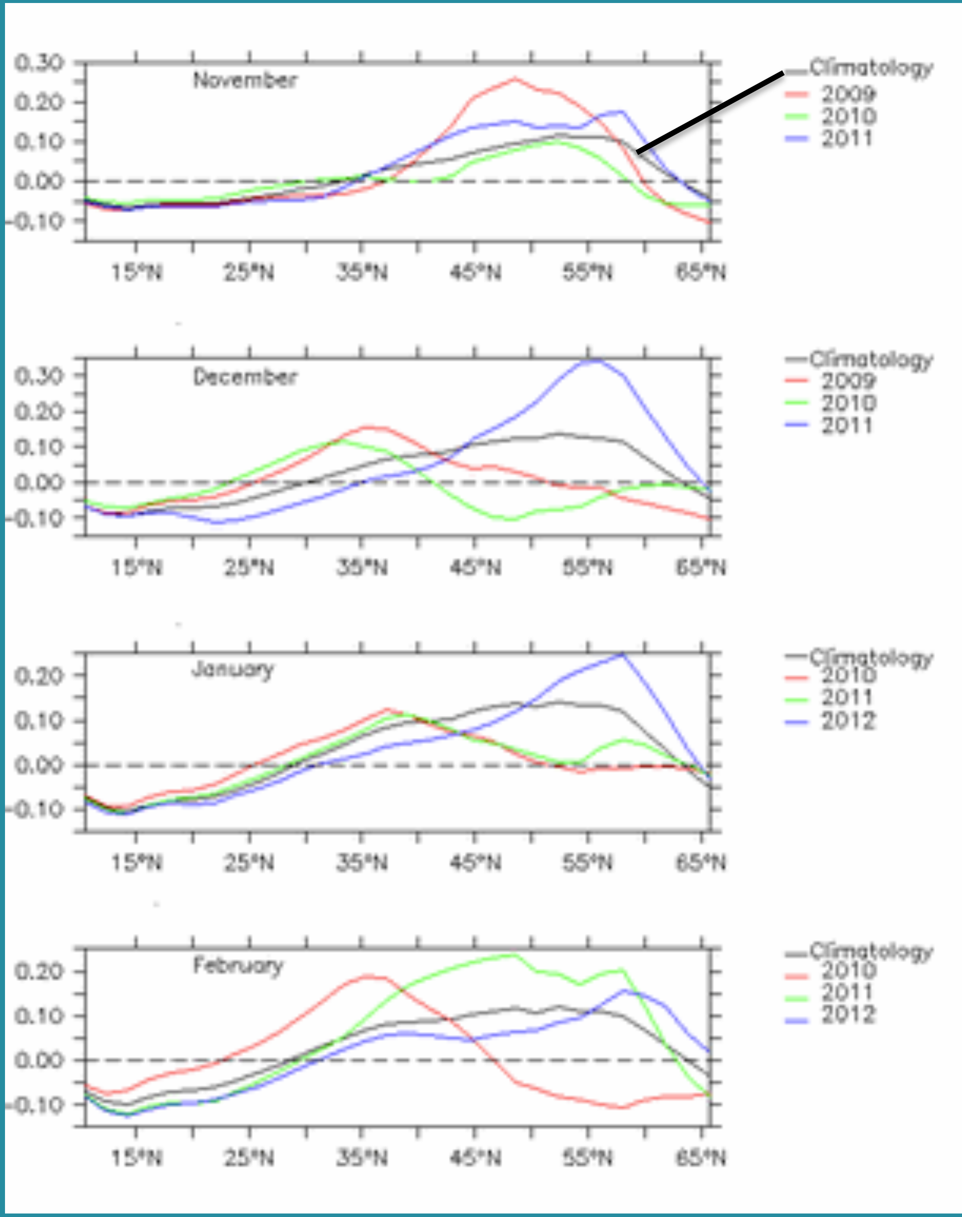
Z250 dyn height (contours); Z850 temperature (colors)



SUPPLEMENTAL MATERIAL !

Eastward winter wind-stress averaged over N Atlantic vs. latitude:

dips in 2009, strengthens in 2010, 2011



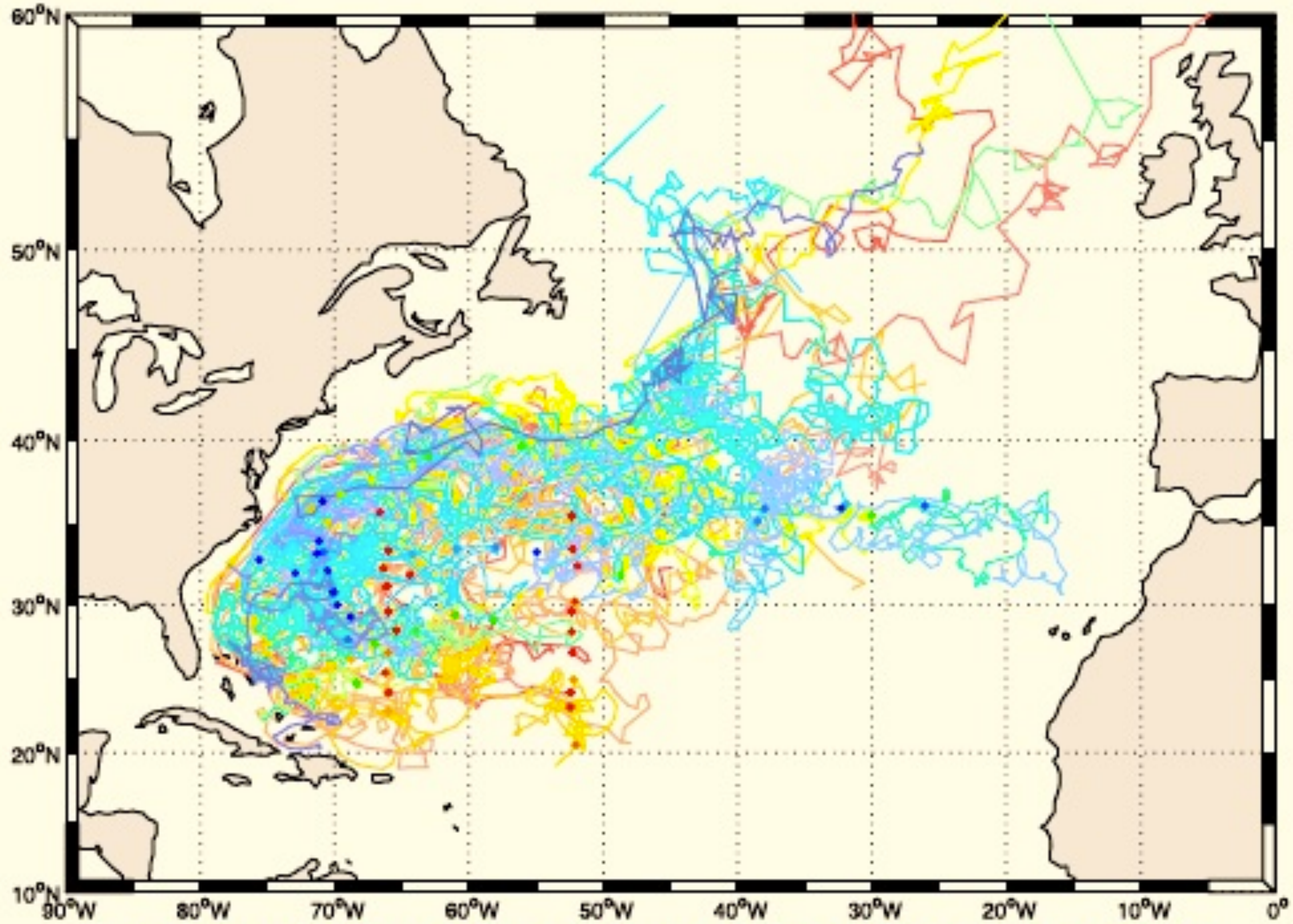
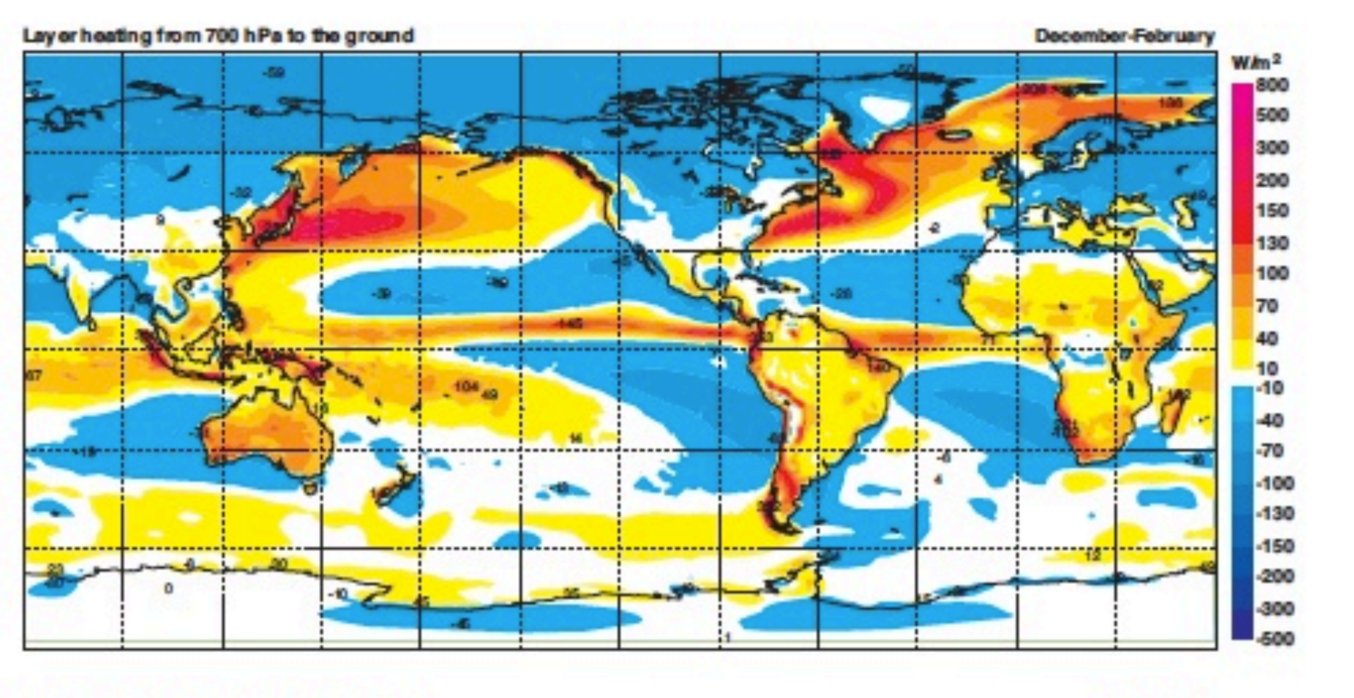


Figure 2. Trajectories of the 71 floats used in this study, during July 1997–December 2002. Bold dots indicate the deployment position for each float. Different colors are assigned to each float. Trajectory and deployment position for each float have the same color.

ERA40 atlas:

diagnosed heating of the lower atmosphere (DJF)
heating integrated 700hPa to the ground



largely due to warm ocean

Winter 2005/6
NAO index

PV anomaly

EU temperature

cold episodes

blocking events

Croci-Maspoli & Davies
Mon Wea Rev 2009
study of cold EU winter of 2005/6

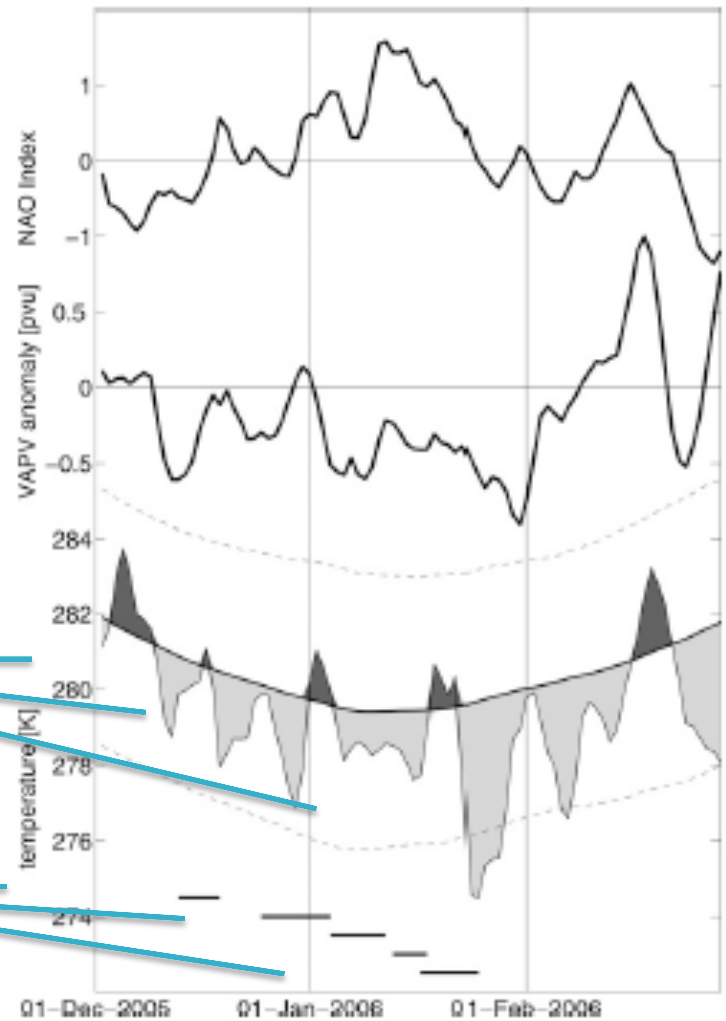


FIG. 5. The bottom curve represents the temporal evolution of the winters 2005/06 daily 2-m temperature (5-day running mean) over central Europe. Light (dark) gray shading indicates negative (positive) anomalies in respect to the ERA-40 climatology. Dashed contours represent ±1 standard deviation of the daily climatological mean. The middle thick black line indicates the mean VAPV distribution over the northern European region, and the top thick black line indicates the daily NAO index with arbitrary scaling. The five horizontal bars at the bottom signify the duration of the major blocking events in the Euro–Atlantic region.

Ocean SST forcing of atmospheric blocks

Intensification of blocking anticylonic ridge by upward ocean heat/moisture flux

Atmos. simulation with prescribed air/sea fluxes

Blocking intensity (PVU)

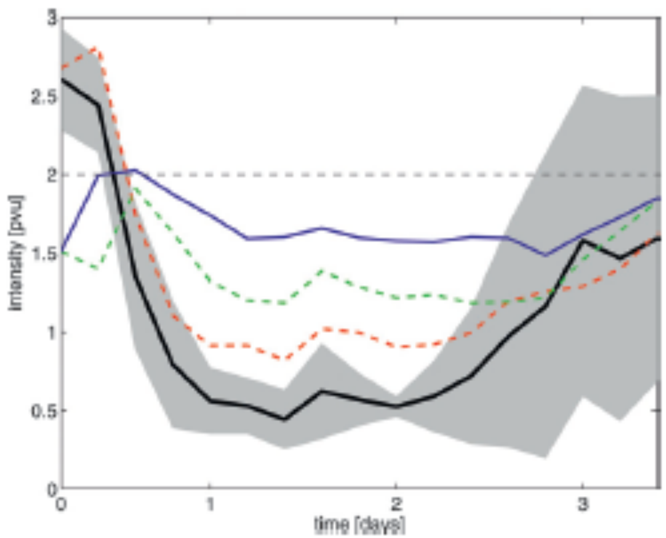
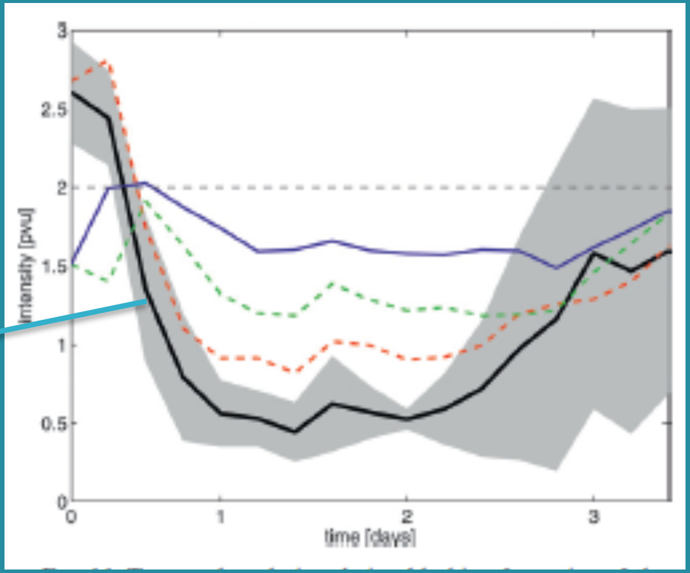


FIG. 11. Temporal evolution during blocking formation of the mean PV at 315 K of the five winter 2005/06 blocks for different CHRM scenario runs. The black thick contour represents the control run, the red contour represents the scenario with reduced SST (SSTM3), the green contour represents the scenario with reduced relative humidity (HUM10), and in blue the combination of the former is shown (SSTM3HUM10). The gray shading represents one standard deviation of the control run of the five blocks.

Intensification of blocking anticylonic ridge by upward ocean heat/moisture flux: time evolution of intensity of block (PV minimum)

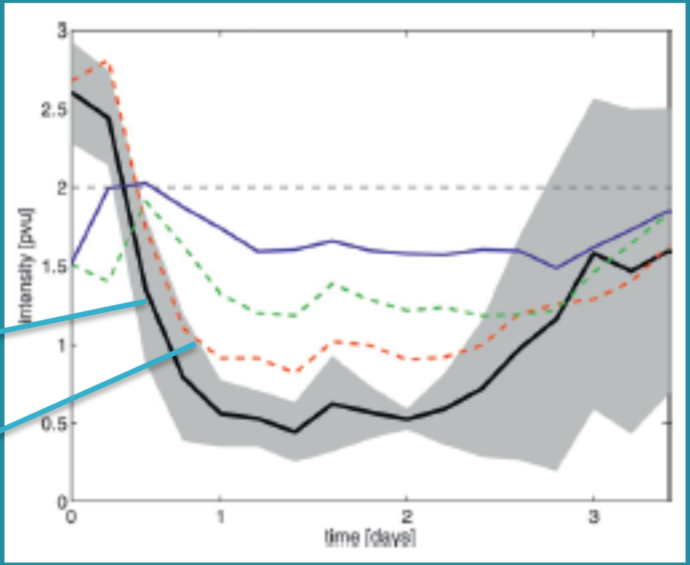
strong block
(control with SST heating, evap)



Intensification of blocking anticylonic ridge by upward ocean heat/moisture flux: time evolution of intensity of block (PV minimum)

strong block:
(control with SST heating, evap)

remove heating

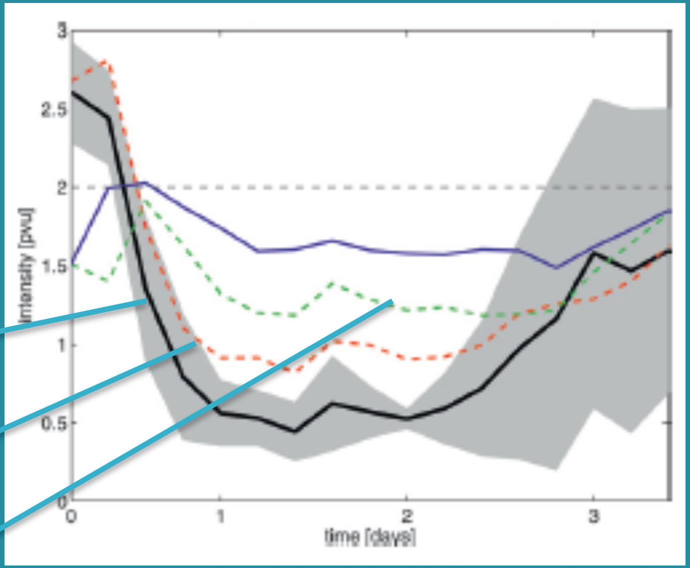


Intensification of blocking anticylonic ridge by upward ocean heat/moisture flux: time evolution of intensity of block (PV minimum)

strong block:
(control with SST heating, evap)

remove heating

remove evaporation



Blocking intensity (PVU)

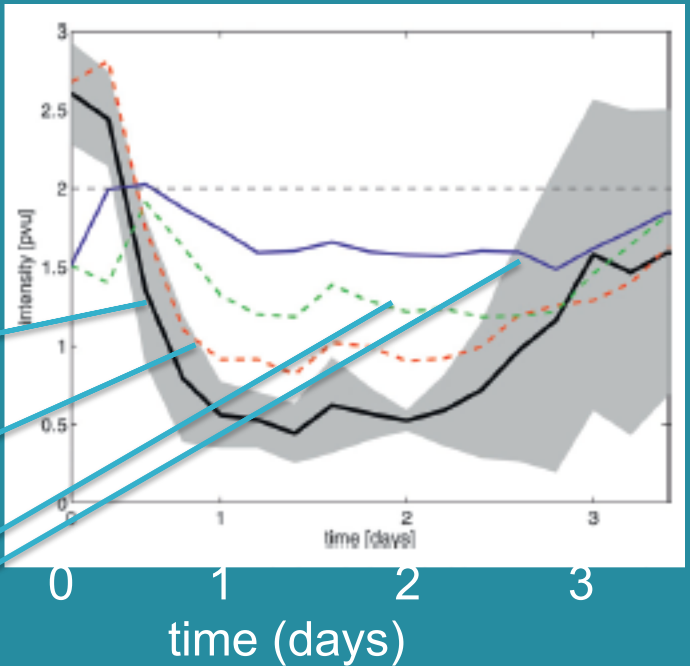
Intensification of blocking anticylonic ridge by upward ocean heat/moisture flux: time evolution of intensity of block (PV minimum)

strong block:
(control with SST heating, evap)

remove heating

remove evaporation

remove both



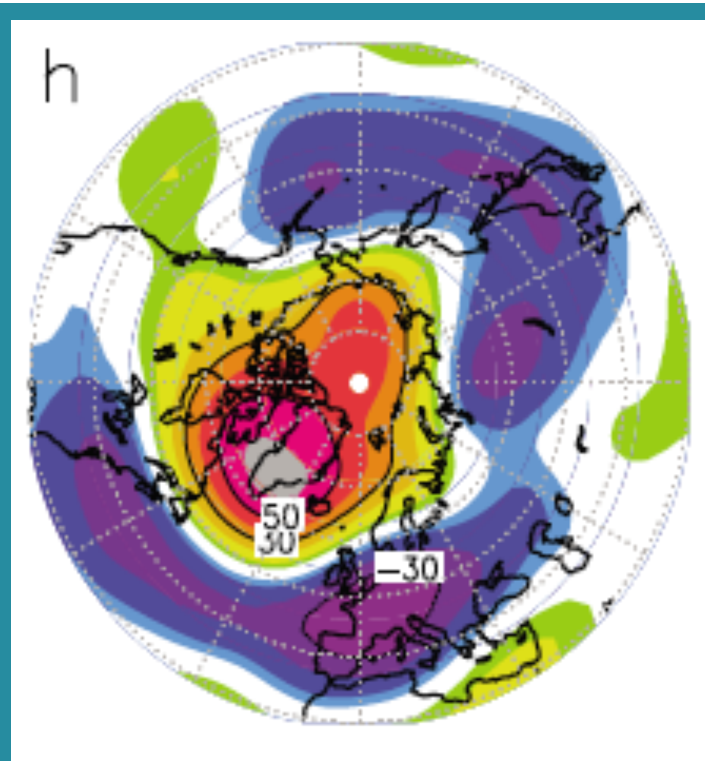
Other evidence for ocean forcing of atmospheric blocking

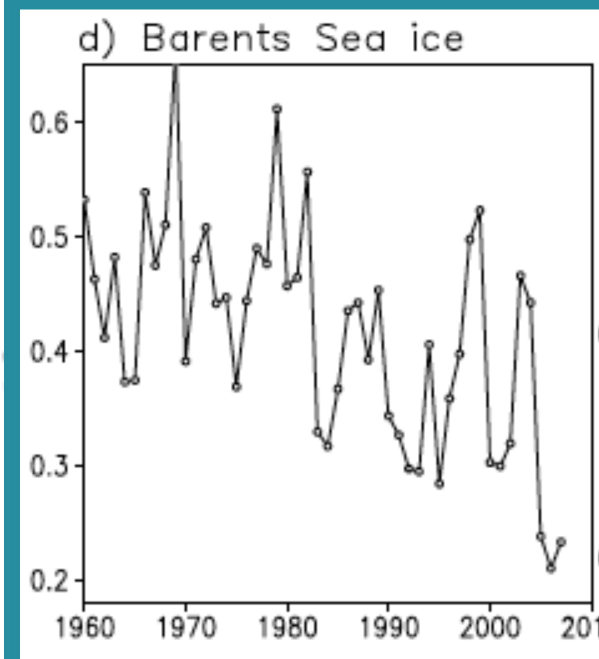
Petoukhov & Semenov J.Geophys.Res. 2011

A link between reduced Barents-Kara sea ice and cold winter extremes over northern continents

Vladimir Petoukhov[1] and Vladimir A. Semenov[2,3]

change in 250 hPa dyn height due to reduced Barents Sea icecover from 80% to 60%





Croci-Maspoli &Davies MWR 2009 *Anticylonic breaking=> block*

Cloud images with 315K PV contours

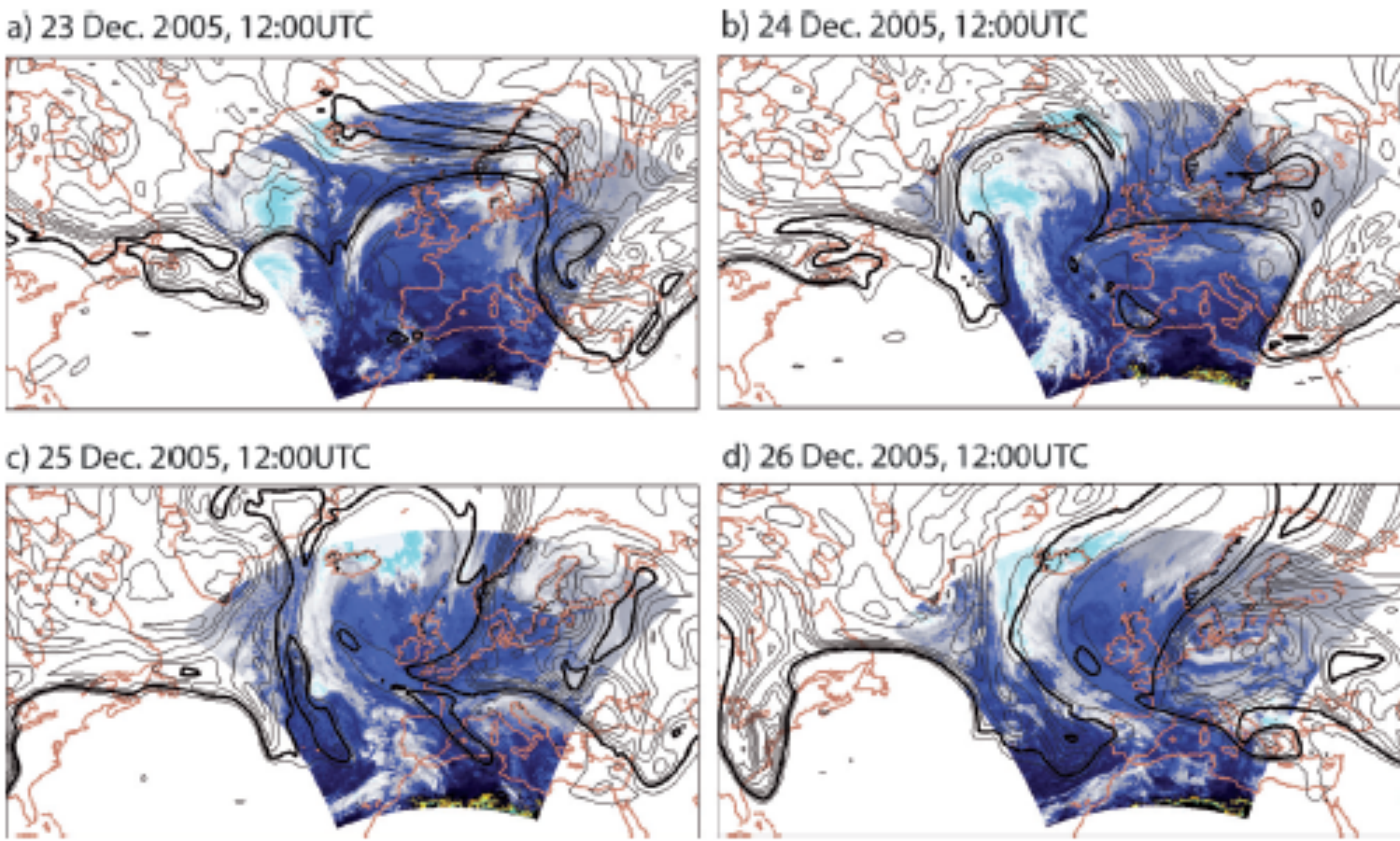


FIG. 7. Infrared satellite image sequence from blocking formation to the mature blocking stage at 1200 UTC 23 Dec 2005–26 Dec 2005. Superimposed are PV contours at 315 K with the 2-PVU isoline in boldface (from 1 to 8 PVU with 1-PVU spacing). Note the cloud band on the upstream side of the block during formation.

Adding east/west centers of variability to NAO

Beyond NAO: accounting for east-west shifts
East Atlantic pattern + NAO
500 HPa dyn. height

Woollings, Hannachi & Hoskins
QJRMS 2010

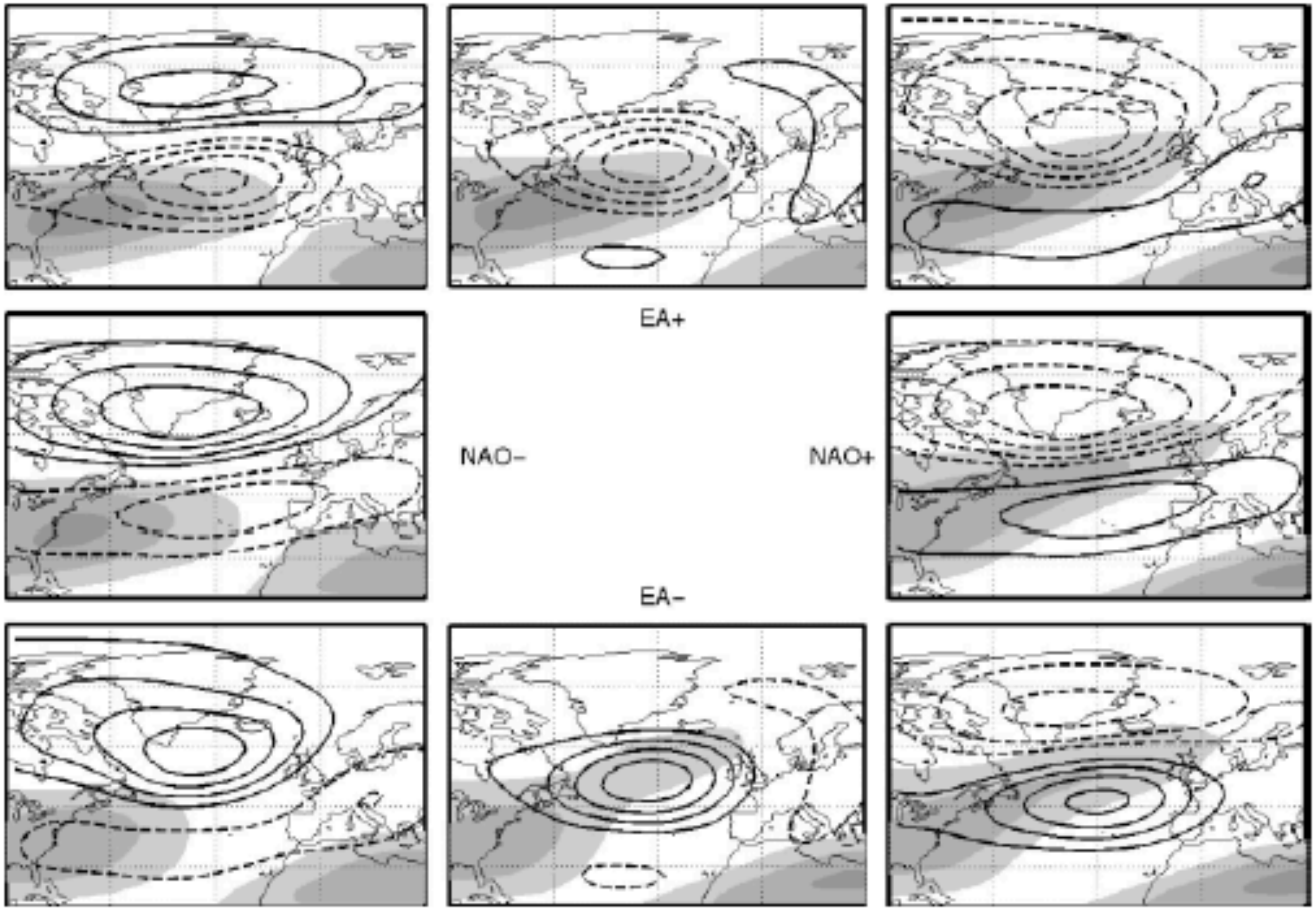
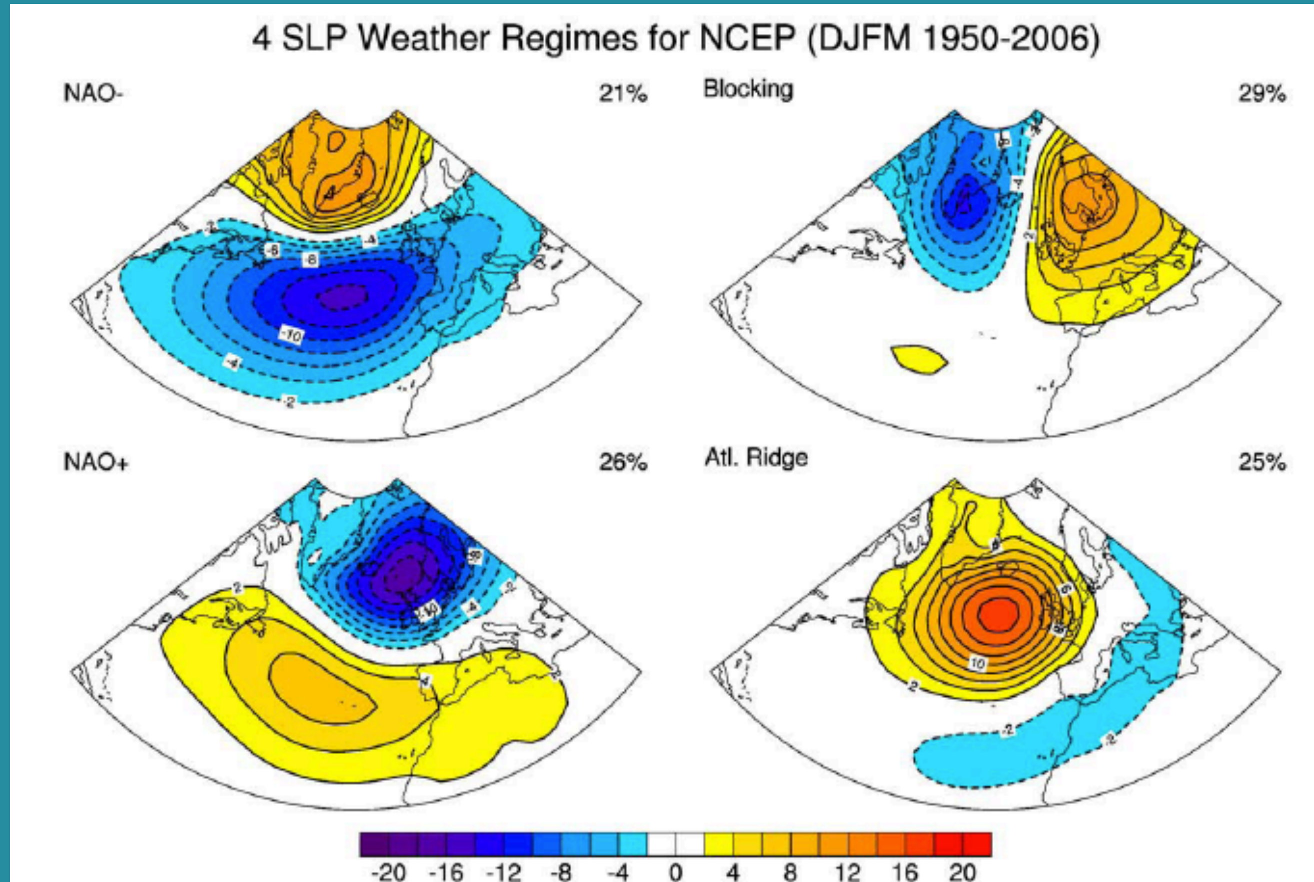


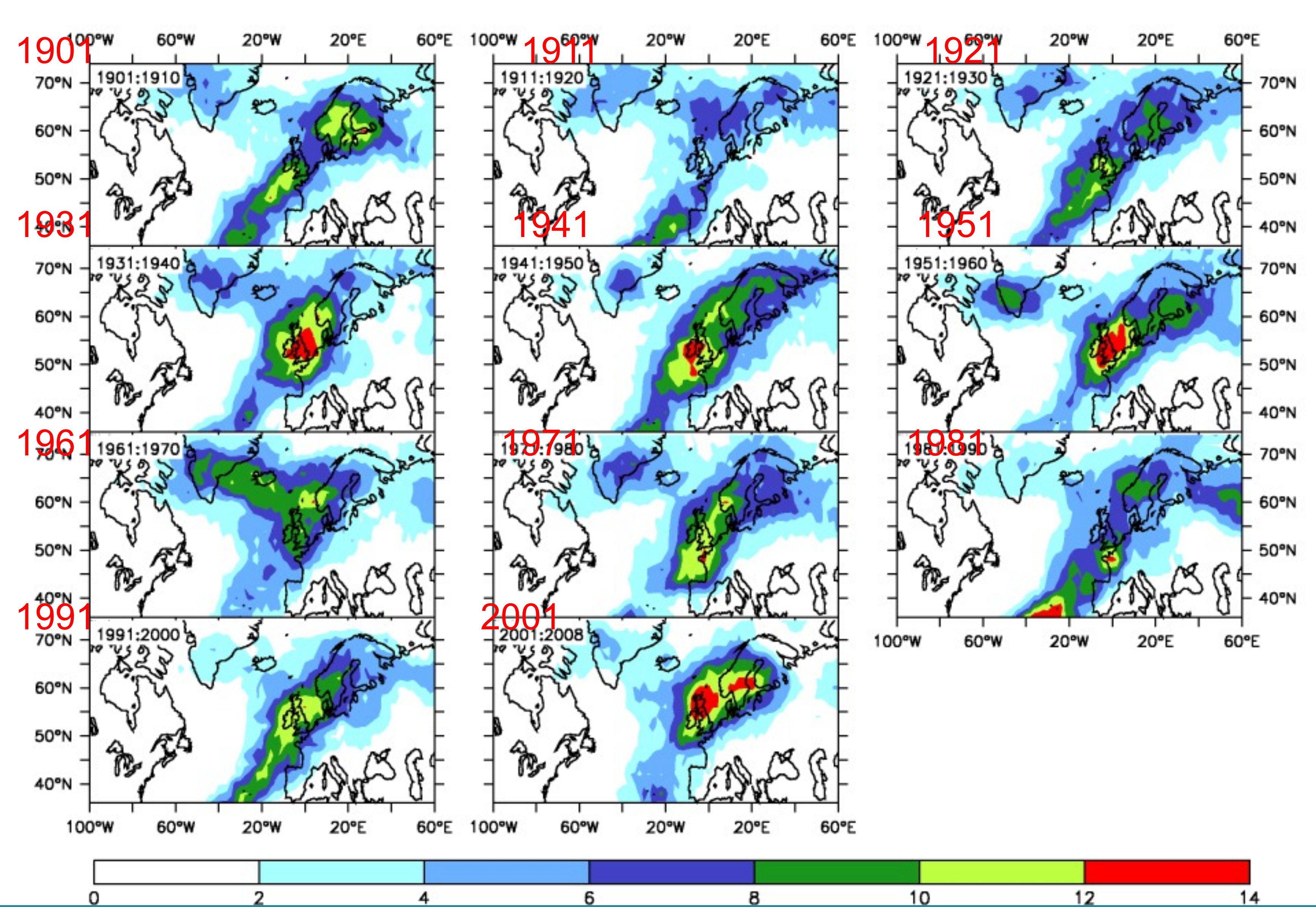
Figure 10. Summary of the circulation at different locations in NAO/EA space. The horizontal axis of the grid of plots is the NAO and the vertical axis is the EA. Z500 anomalies are contoured every 20 m per standard deviation of the principal component time series, and 300 hPa zonal wind is shaded every 10 m s^{-1} starting at 20 m s^{-1}. The corner plots are given by adding the respective NAO and EA maps and scaling by $1/\sqrt{2}$.

Hurrell & Deser
J Marine Sys 2010

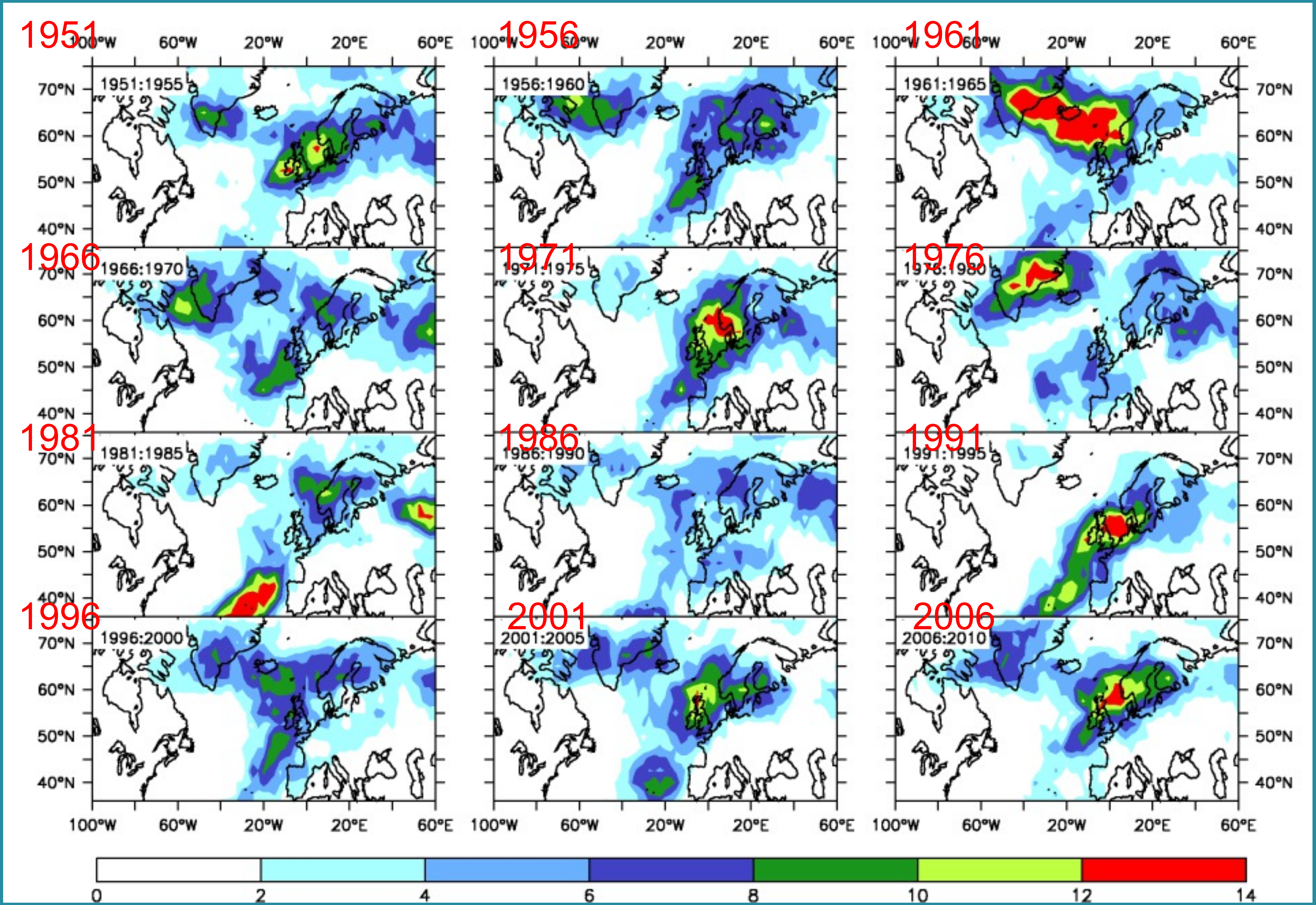


Deser & Hurrell J. Marine Sys 2010

10 year averages; VARIABILITY OF BLOCKING FREQUENCY BY DECADE CALCULATED FROM THE 20TH CENTURY REANALYSIS BY COMPO ET AL (2011)



5-year averages; PENTADAL BLOCKING VARIABILITY BASED ON NCEP REANALYSIS



Greenland blocks
 ~ the negative phase NAO- ,
(anticyclone
over Greenland, warm
moist air flowing into
Labrador Sea, cold EU)

Woollings et al. QJRMS 2010:
High-latitude jet has
three preferred latitudes,
and NAO- is the 'southern jet'
case: then the high- and low-
latitude jet streams merge into one
in the $0-60^0$W sector

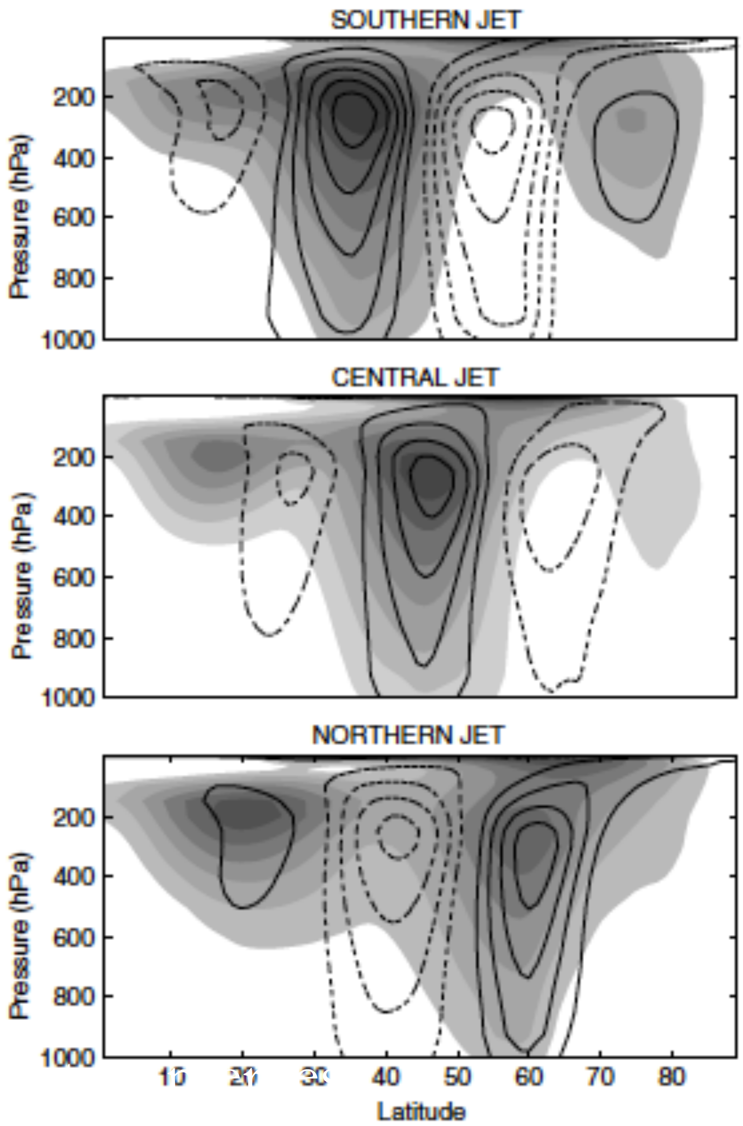
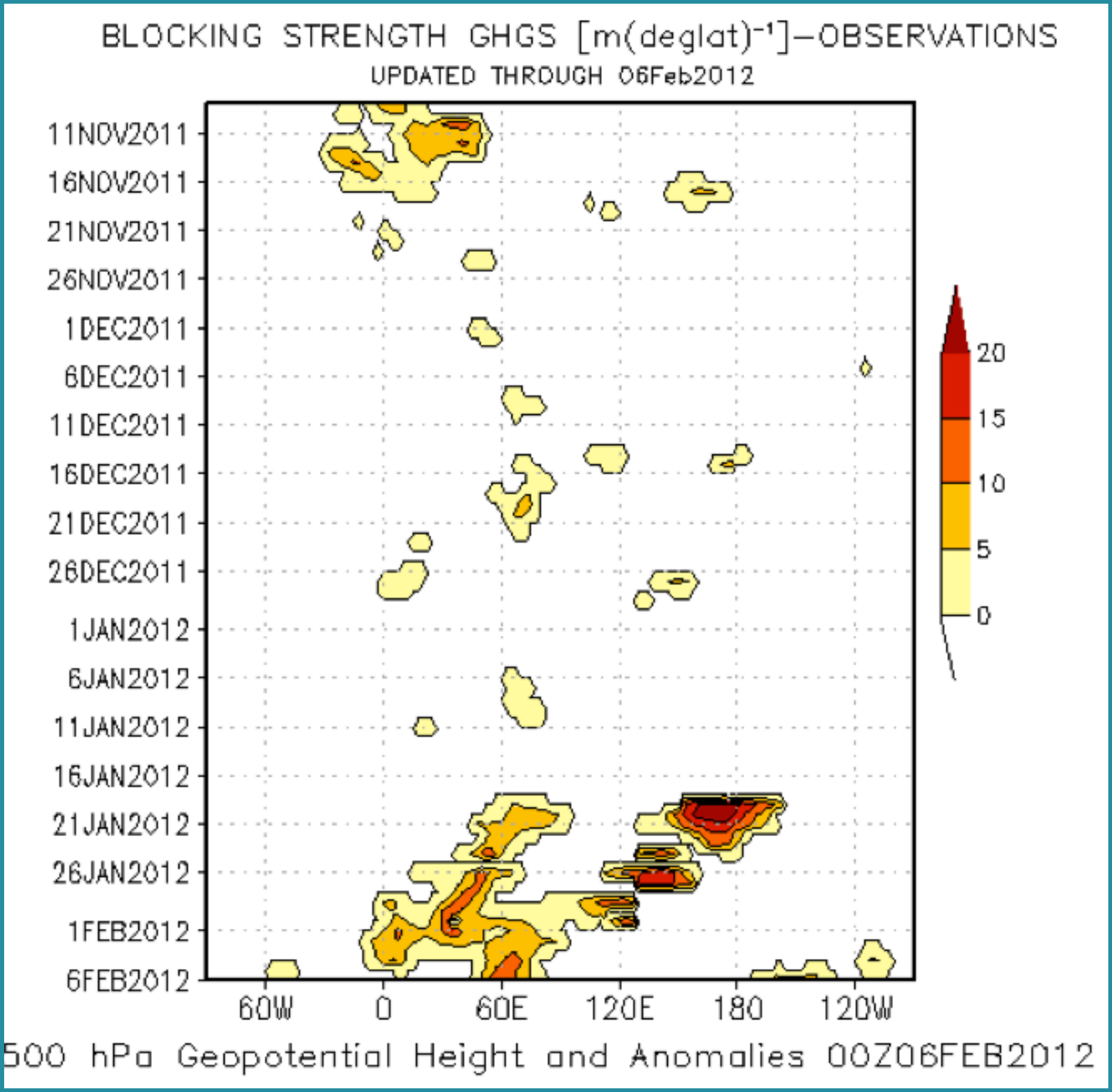


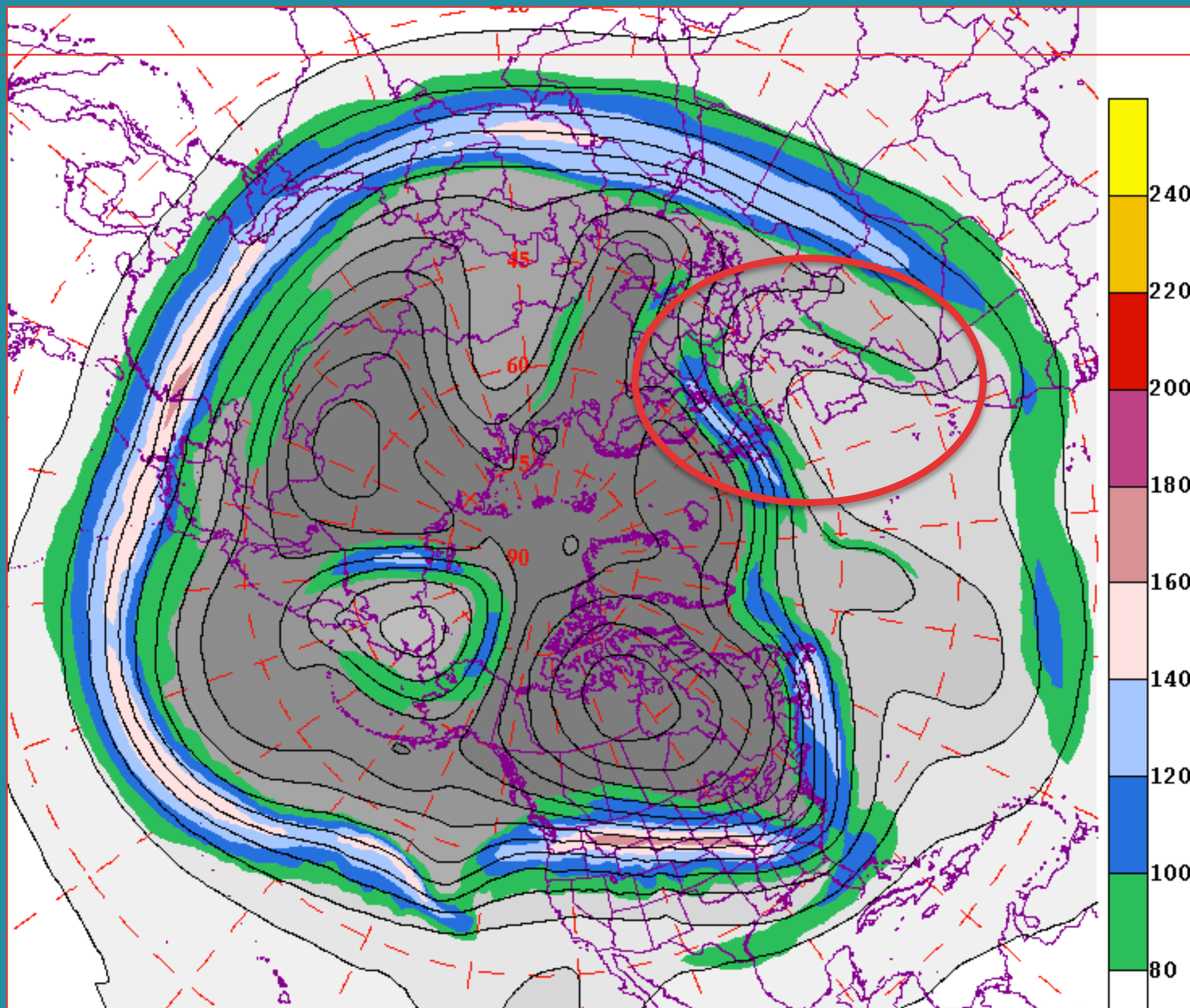
Figure 5. Composites of the zonal wind averaged over 0–60°W for the three jet stream locations. Shading shows the full field contoured every 5 m s^{-1}, with the lowest contour drawn at 5 m s^{-1}. Contour lines show anomalies from the DJF climatology at 3 m s^{-1} intervals, with negative contours dashed and the zero contour omitted.

This winter.. migration of blocking westward

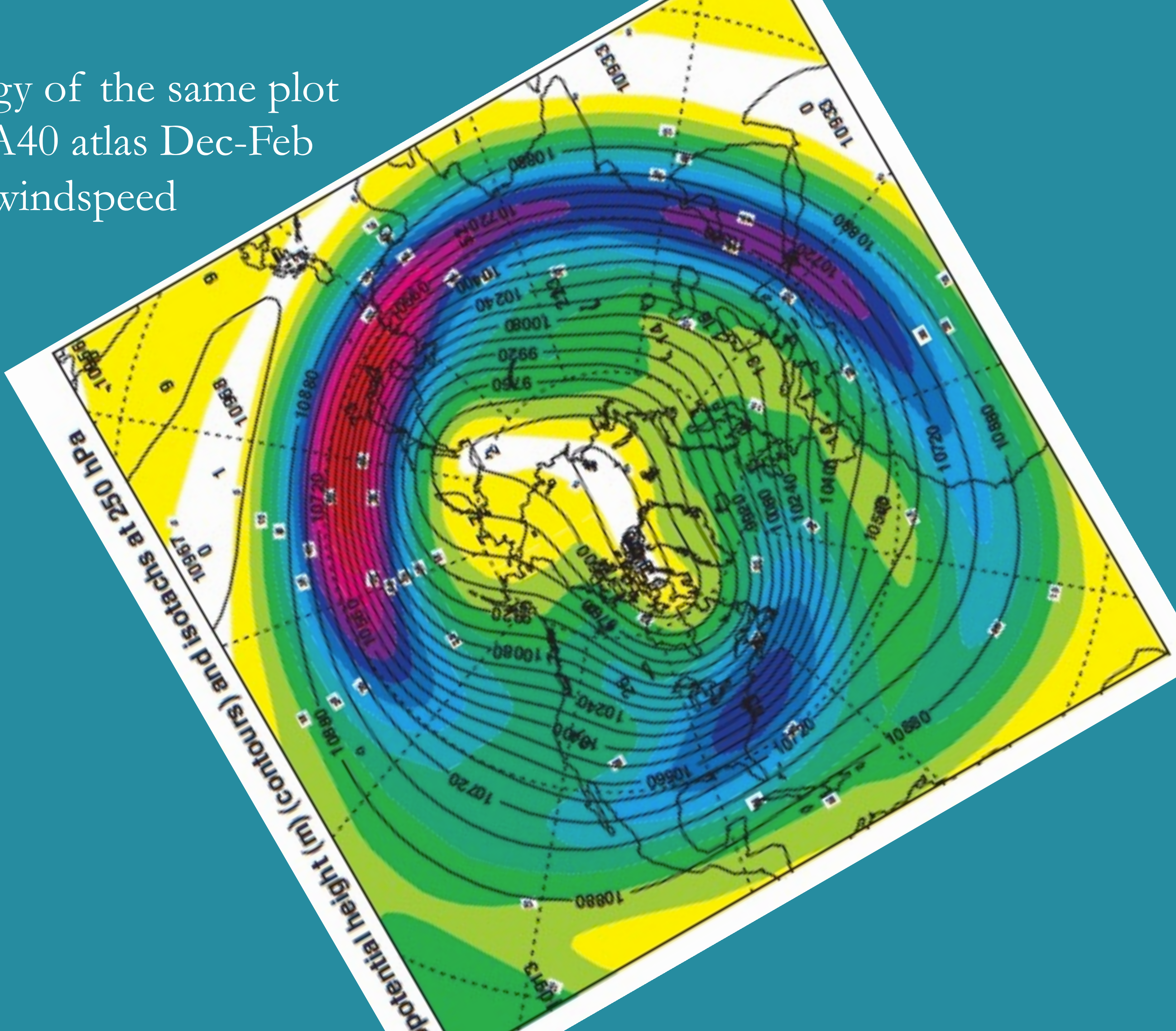


http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/block.shtml#current

18 Jan 2012 Z250, during the current EU block/cold & snow wind speed: note the spiral maximum reaching low latitude over Africa



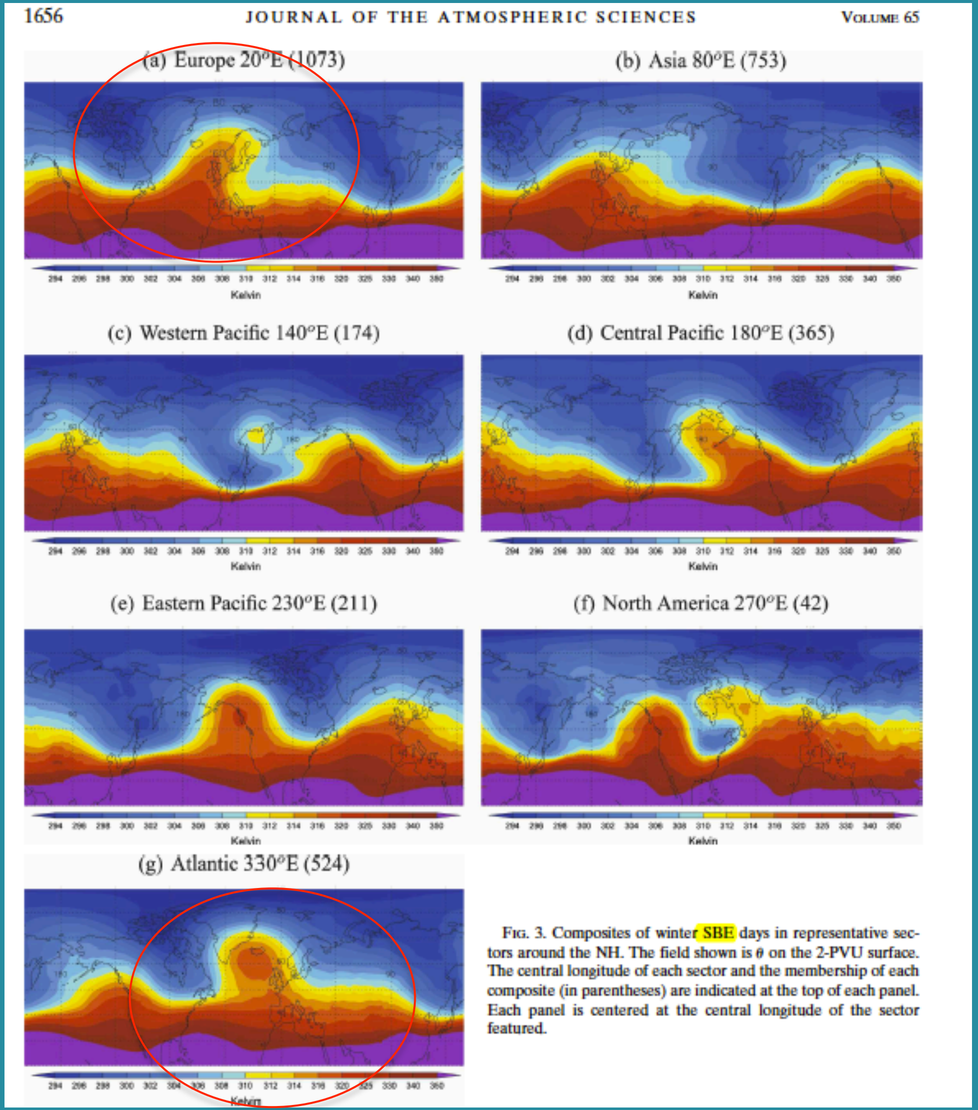
climatology of the same plot
from ERA40 atlas Dec-Feb
Z250 & windspeed



Following the longitude of blocking: anticyclonic Rossby waåve meanders & breaking

Hoskins & Tyrliss JGR 2008

cluster plots in various sectors


1656 JOURNAL OF THE ATMOSPHERIC SCIENCES VOLUME 65

(a) Europe 20°E (1073)

(b) Asia 80°E (753)

(c) Western Pacific 140°E (174)

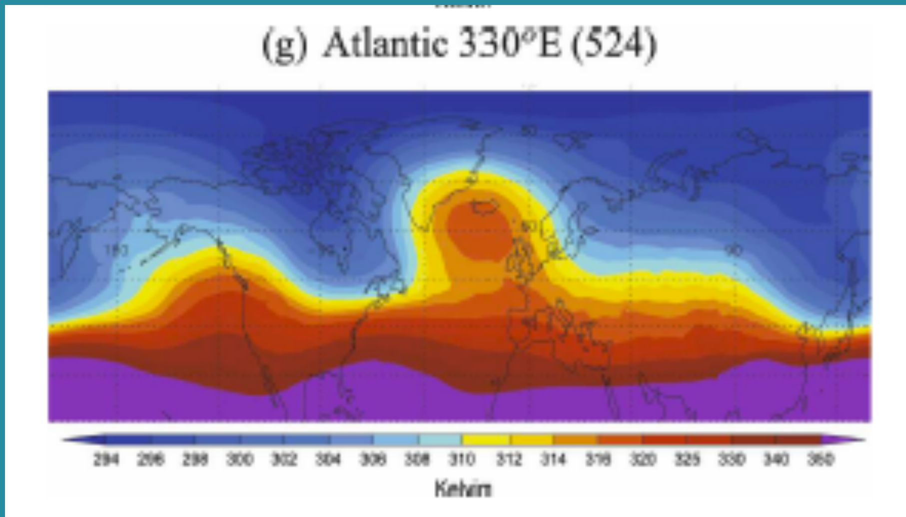
(d) Central Pacific 180°E (365)

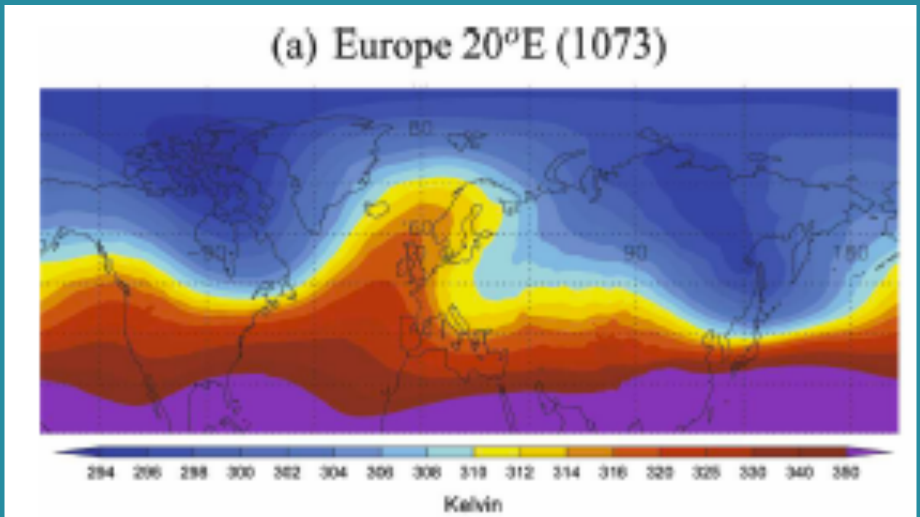
(e) Eastern Pacific 230°E (211)

(f) North America 270°E (42)

(g) Atlantic 330°E (524)

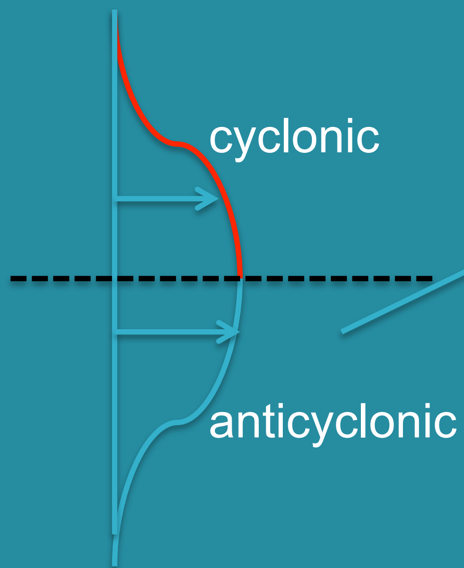
FIG. 3. Composites of winter SBE days in representative sectors around the NH. The field shown is θ on the 2-PVU surface. The central longitude of each sector and the membership of each composite (in parentheses) are indicated at the top of each panel. Each panel is centered at the central longitude of the sector featured.





θ on PV-2 surface (tropopause)

connections with both orographic (Rocky Mts) and ‘thermographic’ (warm Atlantic heat content) forcing. Note the wavetrain upwind of the block



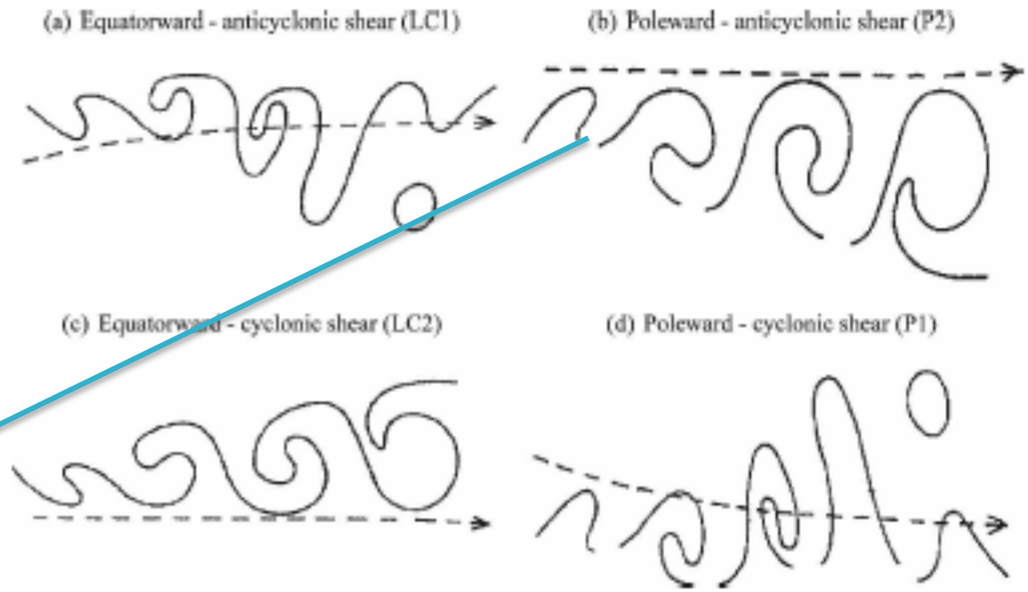
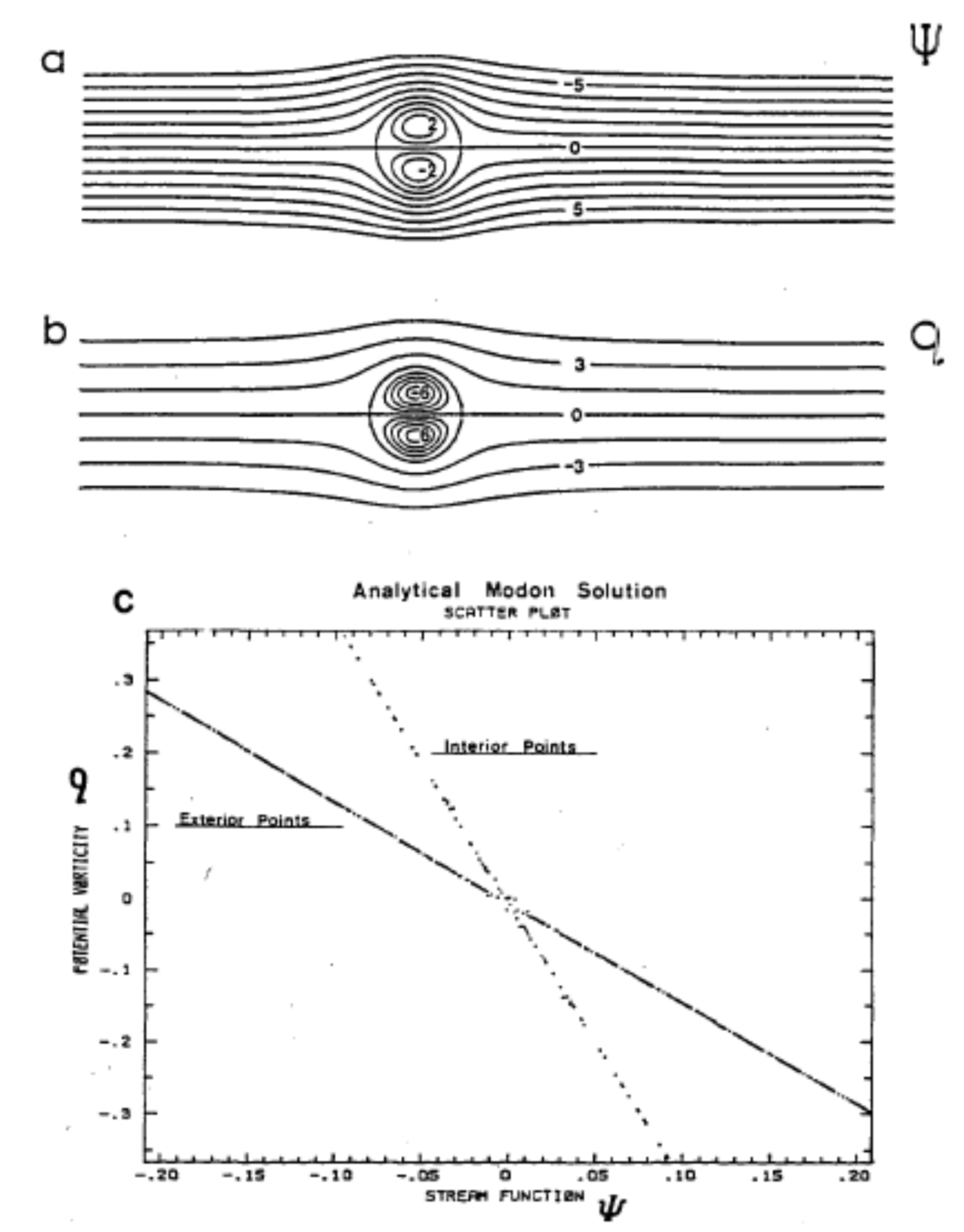


FIG. 1. Schematic illustration of four types of wave breaking showing the deformation of a representative θ contour on the dynamical tropopause during wave breaking. The two upper schematics show the evolution of (a) an equatorward extrusion of low-θ air and (b) a poleward extrusion of high-θ air within a zone of background anticyclonic wind shear. The two lower schematics show the evolution of (c) an equatorward extrusion of low-θ air and (d) a poleward extrusion of high-θ air within a zone of background cyclonic wind shear. The arrow marks the position of the midlatitude jet. The initial stages of each development, in which the wave-breaking nature is different in LC1 and P1, correspond to the left-hand side of each figure. The schematics and the notation for LC1 and LC2 are taken from Thorncroft et al. (1993), and those for P1 and P2 from Peters and Waugh (1996).

Why does blocking persist?

Stern (*J Marine Res 75*) modon resists Rossby wave radiation which will tear apart (disperse a single low or high pressure vortex. Potential vorticity has isolated extrema, with PV linearly related to streamfunction

And…it alters the westward propagation speed. With the anticyclone north of the cyclone, the dipole can propagate westward relative to the mean flow, hence standing still.



Blocking ideas:

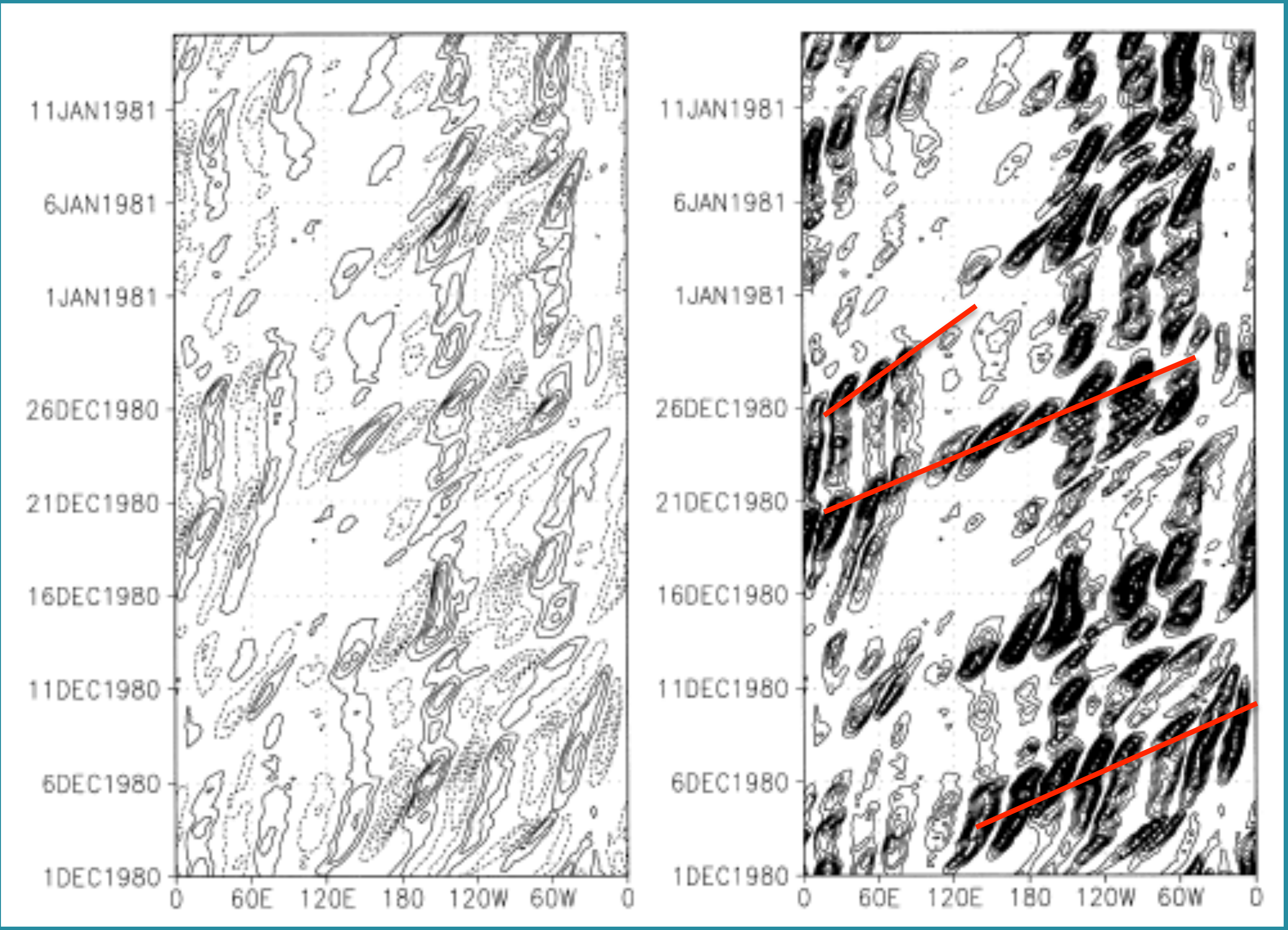
Orographic stationary waves … mountains
'Thermographic' stationary waves…l warm ocean forcing

Natural tendency for large amplitude waves to slow their phase propagation

Slower westerlies => shorter Rossby wavelength for stat. waves.
topog drag slows westerlies, shrinking length scale and blocks move from EU to Greenland

Orographic vorticity (lee cyclones) remains strong with weak westerlies…causing more dramatic jet stream meanders for relatively weak jet streams.

'Billiard ball effect': downstream development, group velocity ~ 50^0 longitude per day of individual systems (*Chang & Orlanski*)



v $\qquad\qquad$ v^2

The billiard ball effect: downstream development of storms in the 300 hPa waveguide (20^0 wide) *Chang, Lee & Swanson* J Clim 2002. Often, synoptic systems originating in western Pacific lead to chains of systems reaching across N America to Europe.

Latif & al. J. Climate 2004 ECHAM 10-50km grid ocean T42 (2.5x2.5^0) atmosphere

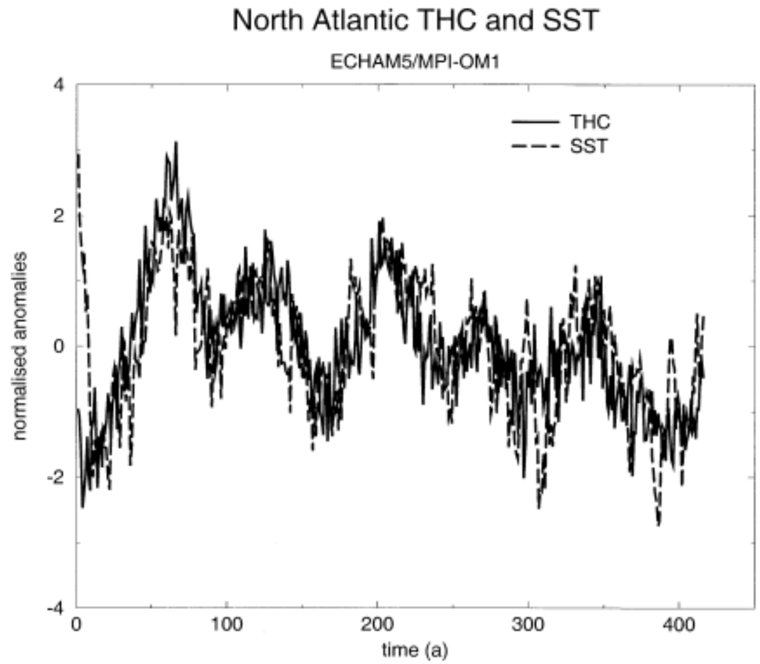


FIG. 3. Time series of simulated annual mean North Atlantic SST anomalies (40°–60°N and 50°–10°W, dashed line) and annual mean anomalies of the maximum overturning at 30°N (full line), a measure of the strength of the model's thermohaline circulation. Note that both time series are highly correlated at time scales beyond several years, indicating that the low-frequency variations of the THC can be monitored by SSTs. Both time series were normalized with their respective standard deviations. The standard deviation of the SST index amounts to 0.6°C and that of the THC index to 1.9 Sv.

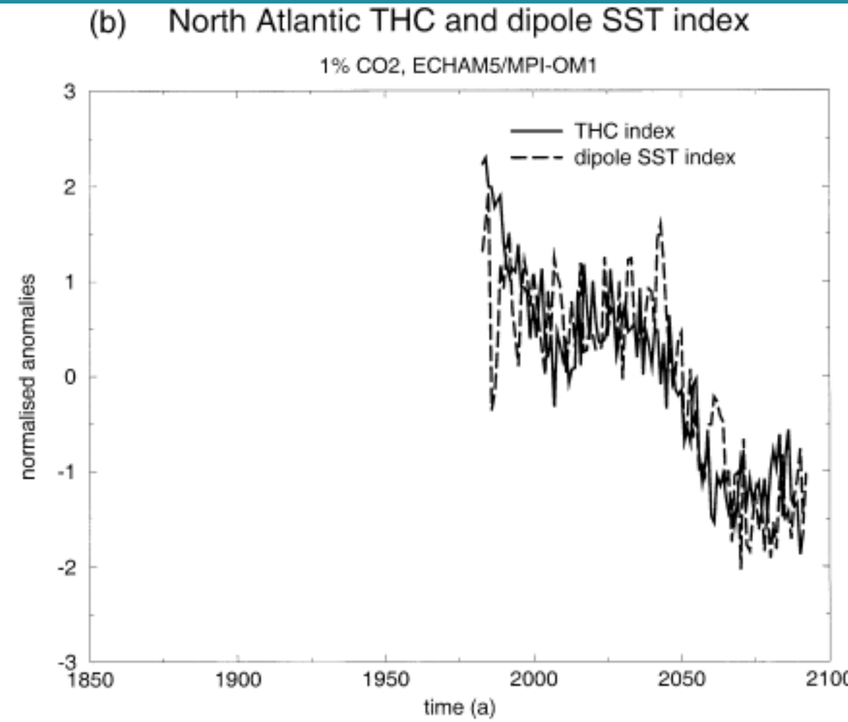


FIG. 5. (b) Time series of the simulated annual mean Atlantic dipole SST index (dashed line) and annual mean anomalies of the maximum overturning at 30°N (full line) in the longest of the greenhouse warming simulations. The dipole SST index is deÆned as the difference between North Atlantic (40°–60°N and 50°–10°W) and South Atlantic (10°–40°S and 30°W–10°E) SST. The time has been adjusted to ease comparison with panel (c).

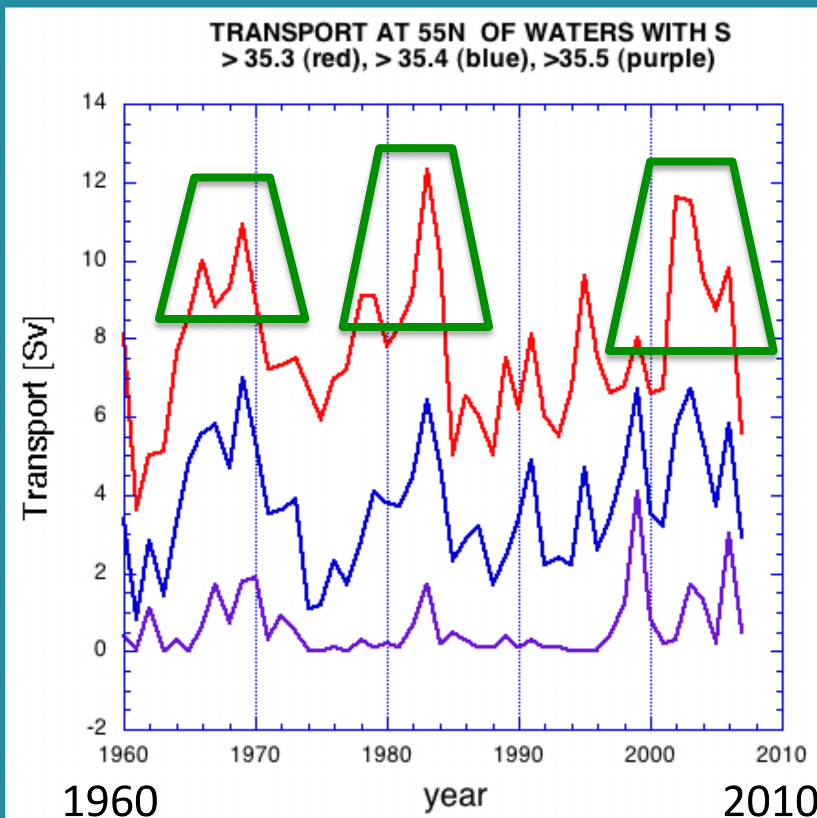
meridional overturning at 30N tracks SST anomalies (40N-60N)
Higher resolution models often behave differently.

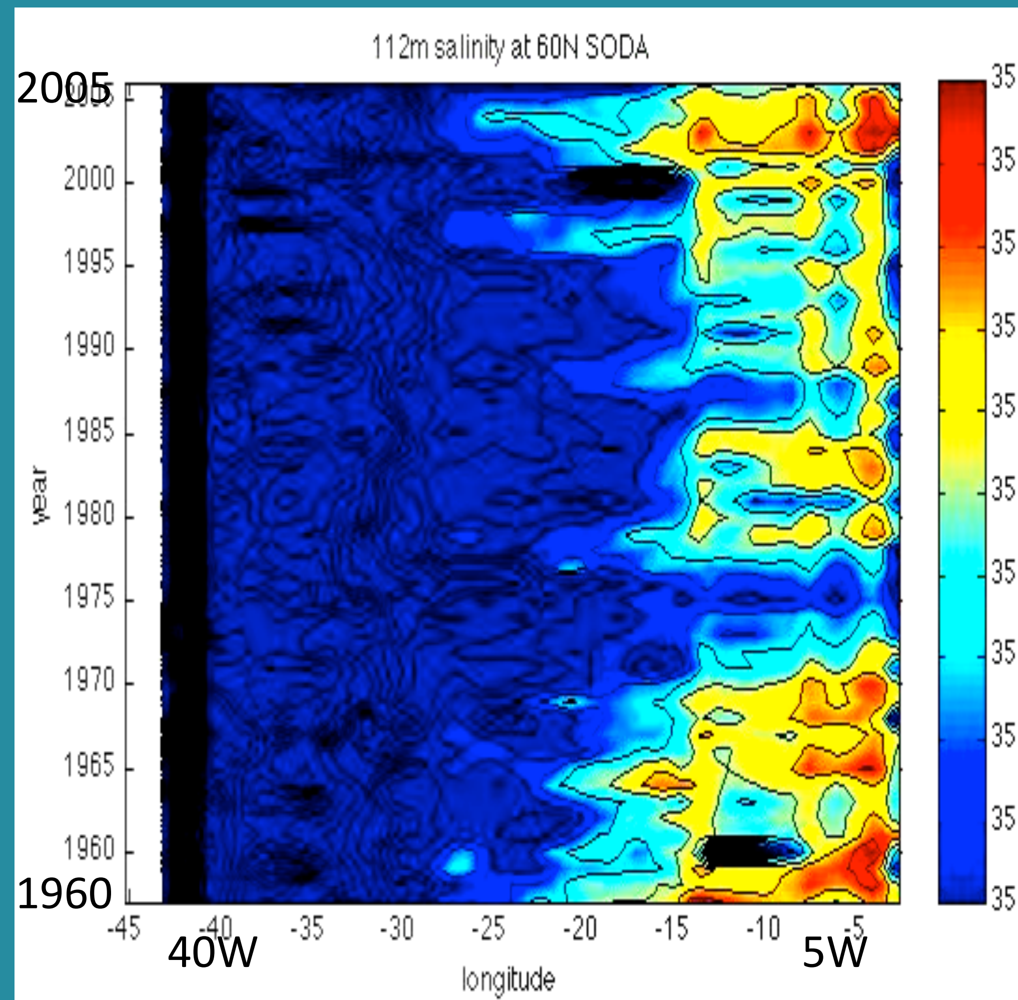
WATER MASSES AT 55-60N (SODA)

SODA Model details : 0.25^0 x 0.4^0 x 40 levels 1958-2007

(Carton & Giese, MWR 2008)

INTEGRATED SALT TRANSPORT

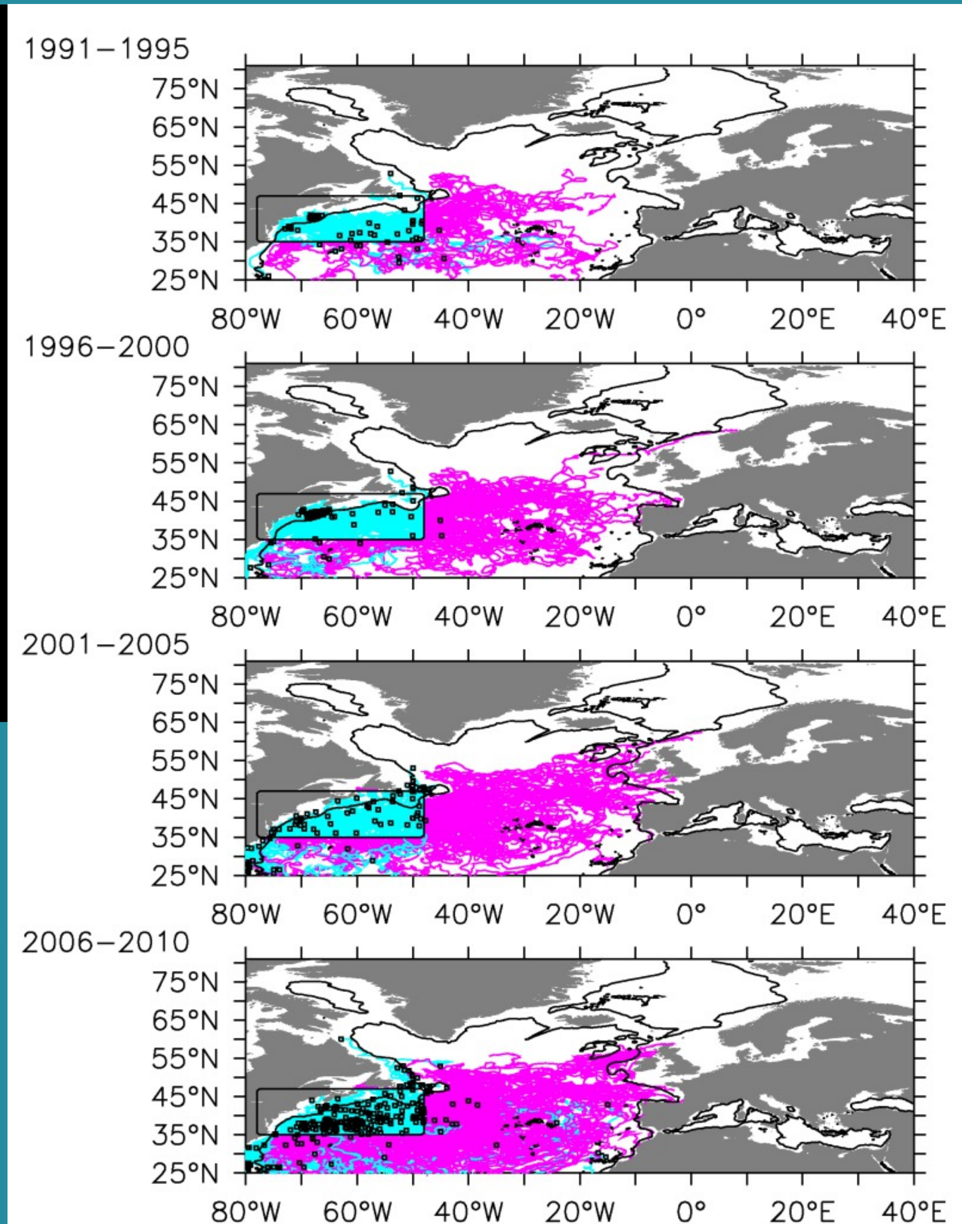




Monthly data

SURFACE DRIFTER TRACKS

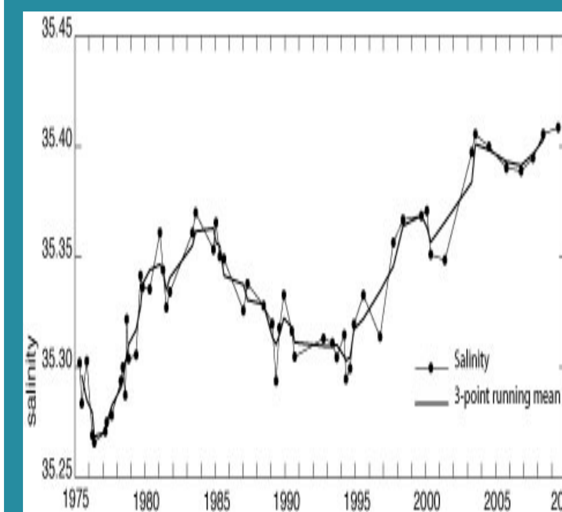
GULF STREAM BOX 78ºW-48ºW 35ºN-47ºN, same as in Brambilla and Talley (2006)



Drifters are present in the Gulf Stream box in the given time period but tracks leaving the box could be in the next time period

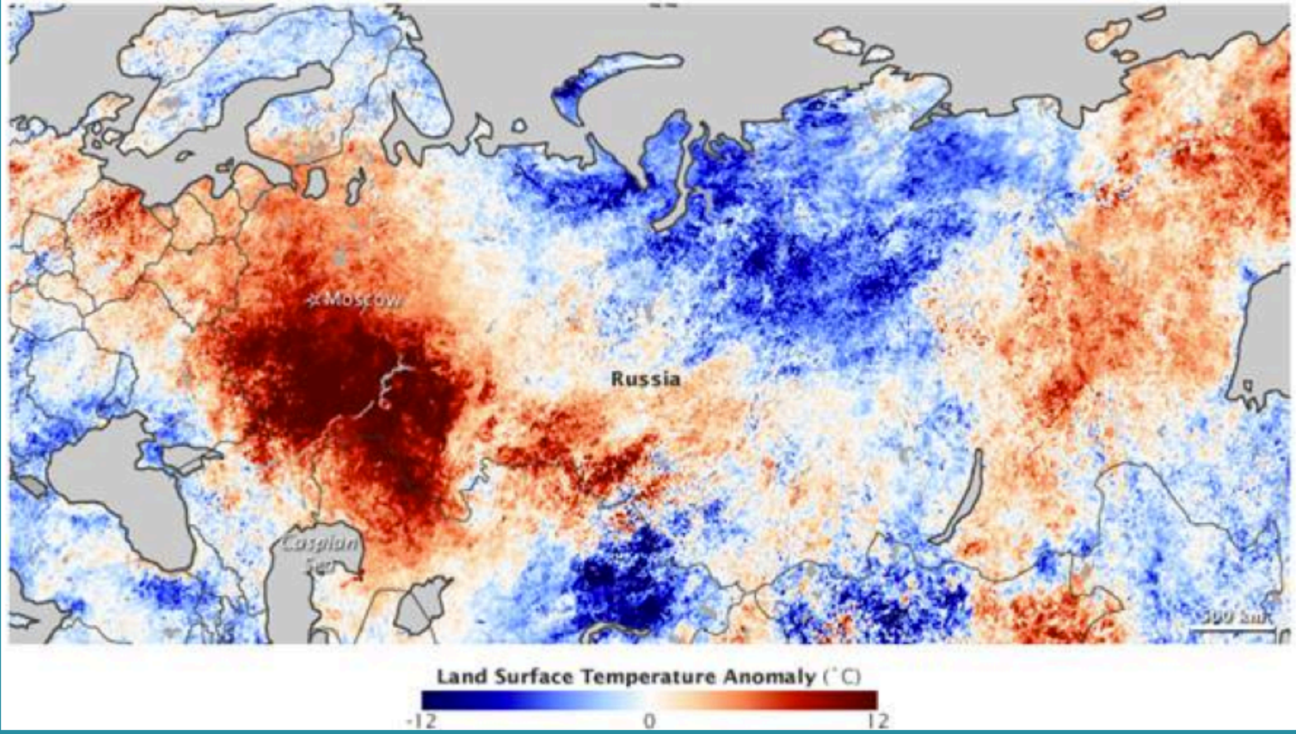
Hakkinen and Rhines JGR 2009, 2011

ELLETT LINE
SALINITY AT ROCKALL
http://www.noc.soton.ac.uk/obe/PROJECTS/EEL/latestresults.php



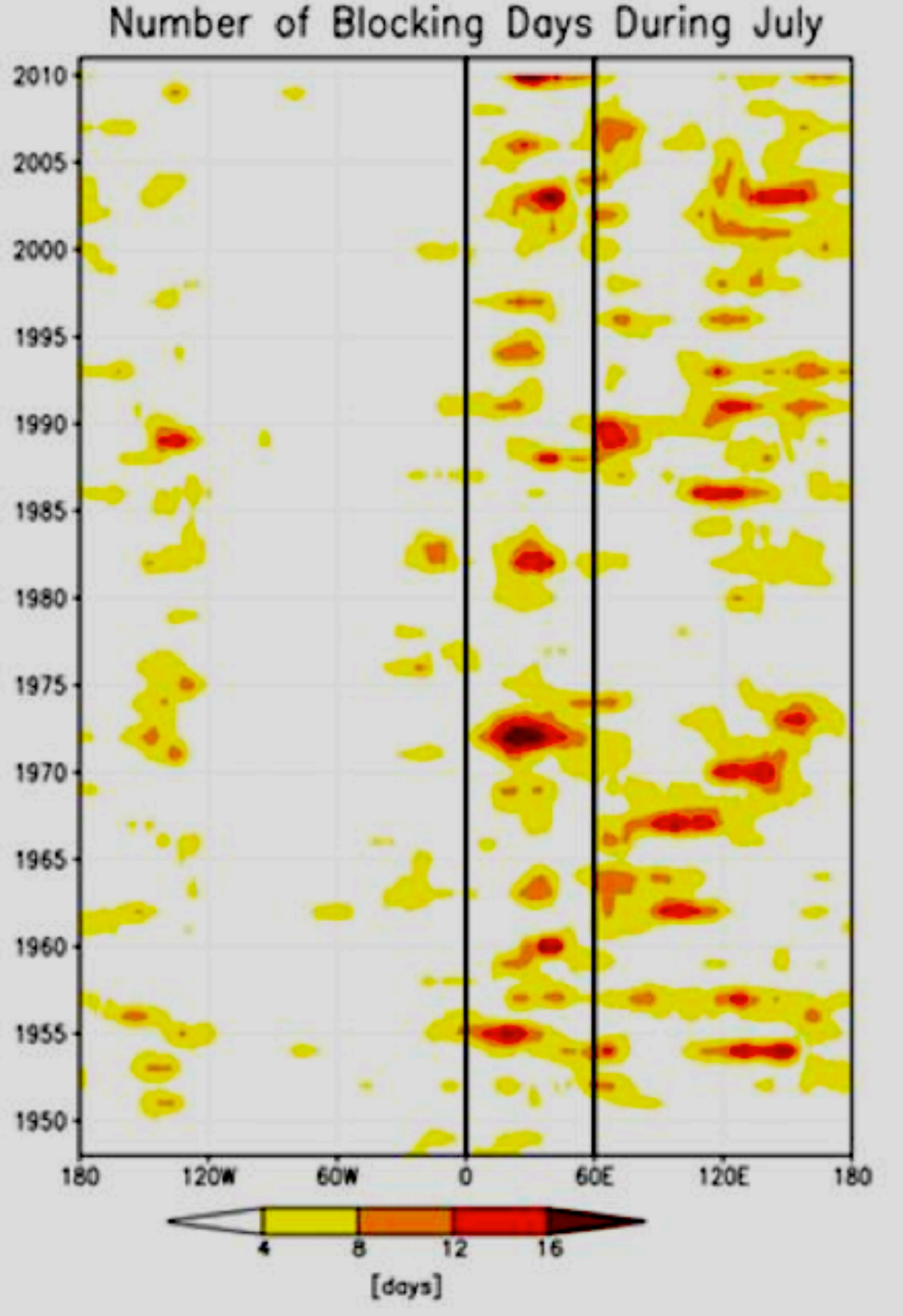
Summer 2010 heat wave in Russia: blocking related
(NOAA dismisses immediate connection with global warming)

The heat wave was concentrated in western Russia – Siberia experienced much cooler than normal temperatures. The following figure shows temperature anomalies for July 20-27 relative to the average for the same dates 2000-2008 [http://earthobservatory.nasa.gov/IOTD/view.php?id=45069]

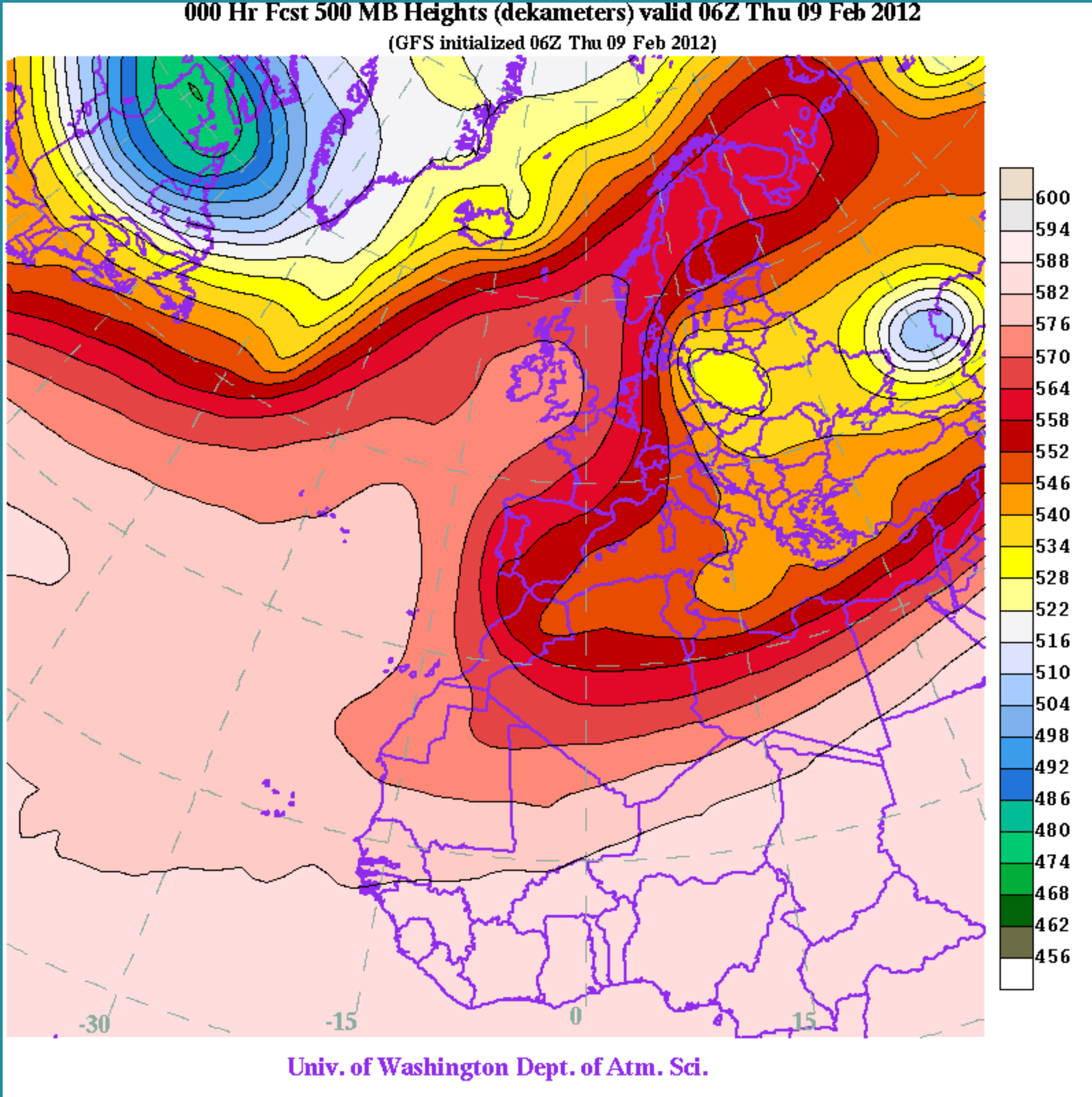


http://www.noaanews.noaa.gov/stories2011/20110309_russianheatwave.html

"The **heat wave was due primarily to a natural phenomenon called an atmospheric "blocking** pattern", in which a strong high pressure system developed and remained stationary over western Russian, keeping summer storms and cool air from sweeping through the region and leading to the extreme hot and dry conditions. While the blocking pattern associated with the 2010 event was unusually intense and persistent, its major features were similar to atmospheric patterns associated with prior extreme heat wave events in the region since 1880, the researchers found."

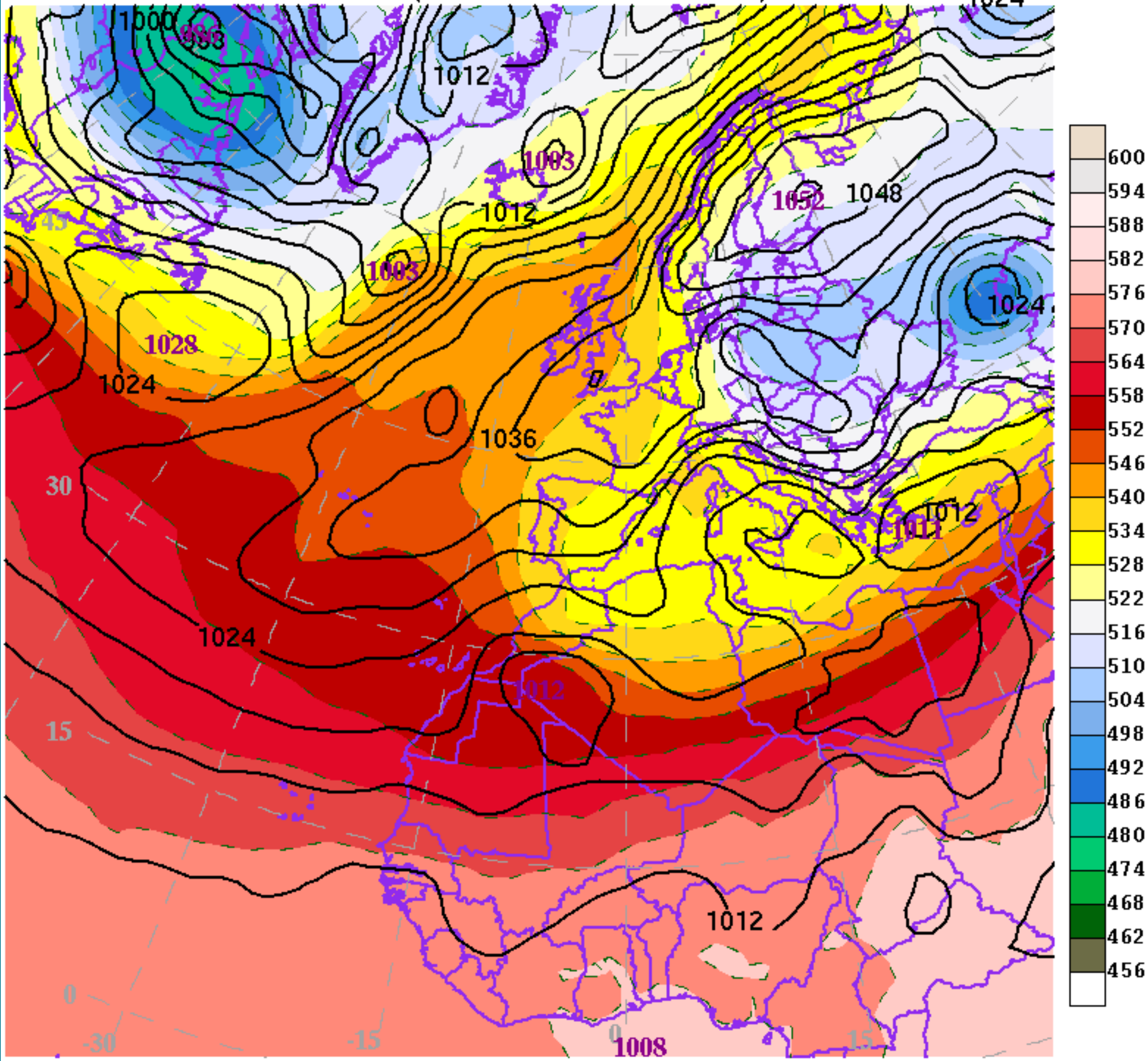


Number of Blocking Days During July
2010
2005
2000
1995
1990
1985
1980
1975
1970
1965
1960
1955
1950
180
120W
60W
0
60E
120E
180
4
8
12
16
[days]


000 Hr Fcst 500 MB Heights (dekameters) valid 06Z Thu 09 Feb 2012
(GFS initialized 06Z Thu 09 Feb 2012)
600
594
588
582
576
570
564
558
552
546
540
534
528
522
516
510
504
498
492
486
480
474
468
462
456
-30
-15
0
15
Univ. of Washington Dept. of Atm. Sci.

000 Hr Fcst 1000-500 MB Thickness (dekameters)/SLP (mb) valid 06Z Thu 09 Feb 2012

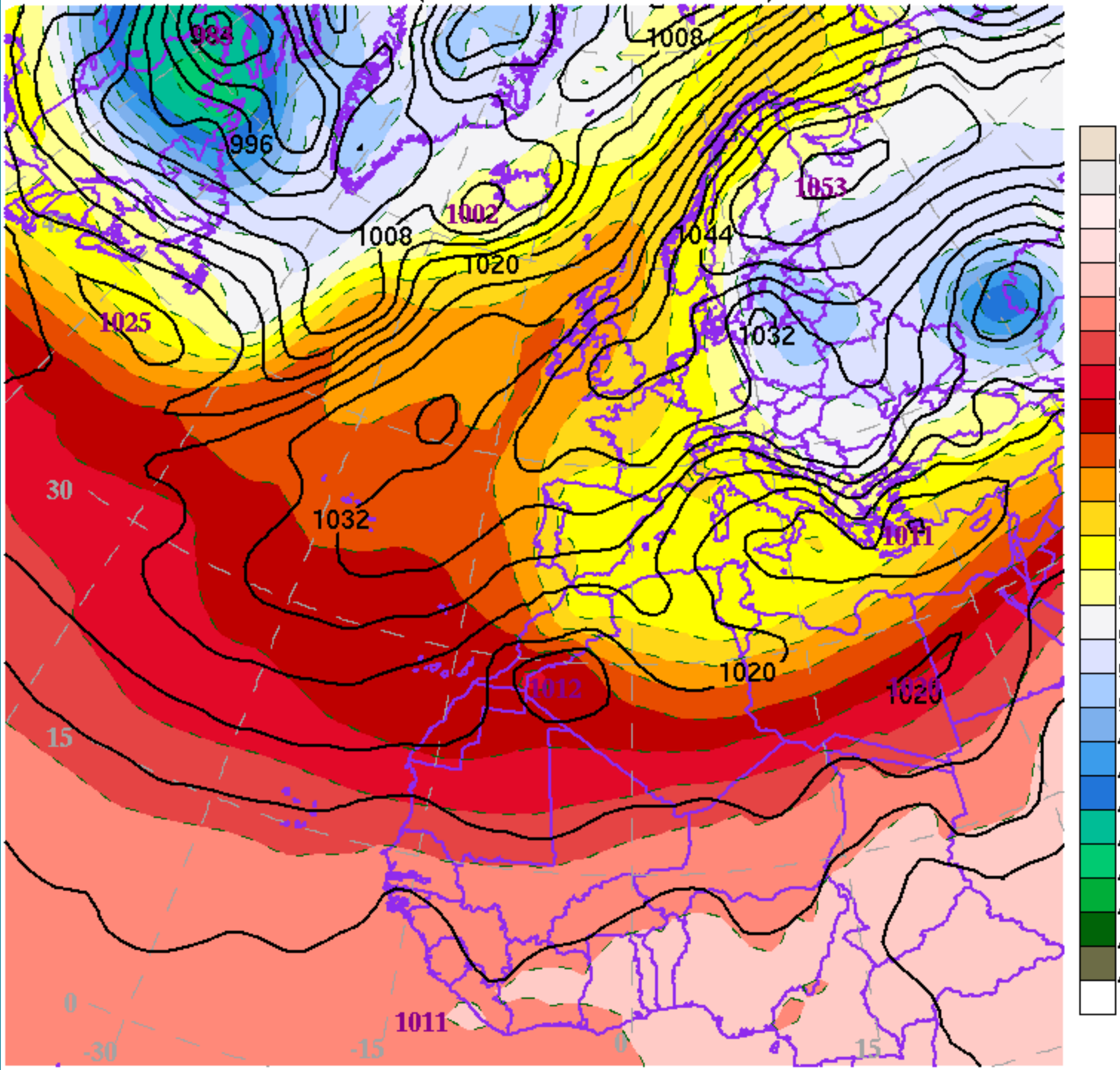
(GFS initialized 06Z Thu 09 Feb 2012)



Univ. of Washington Dept. of Atm. Sci.

000 Hr Fcst 1000-500 MB Thickness (dekameters)/SLP (mb) valid 00Z Thu 09 Feb 2012

(GFS initialized 00Z Thu 09 Feb 2012)



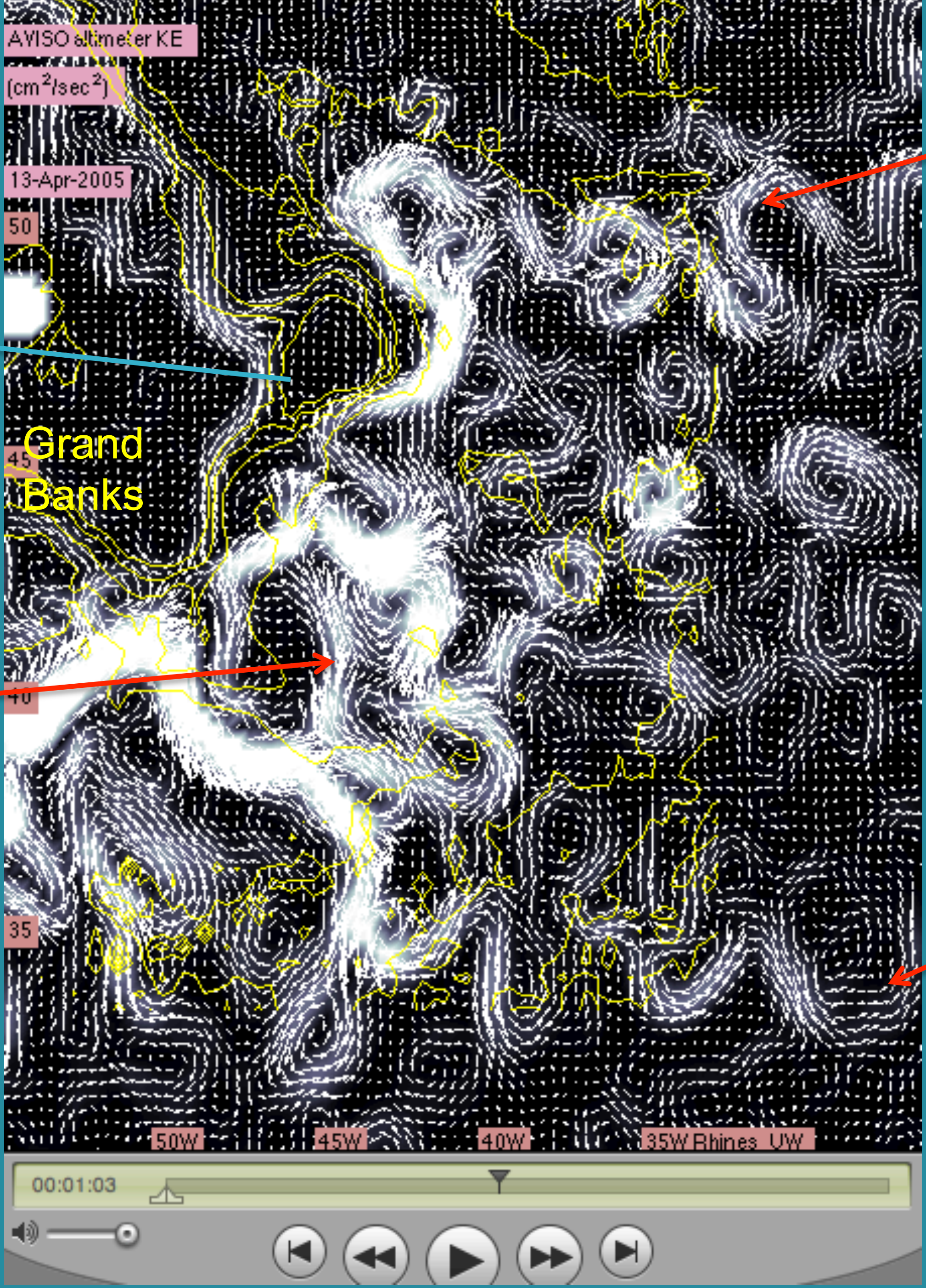
Univ. of Washington Dept. of Atm. Sci.

Black Sea

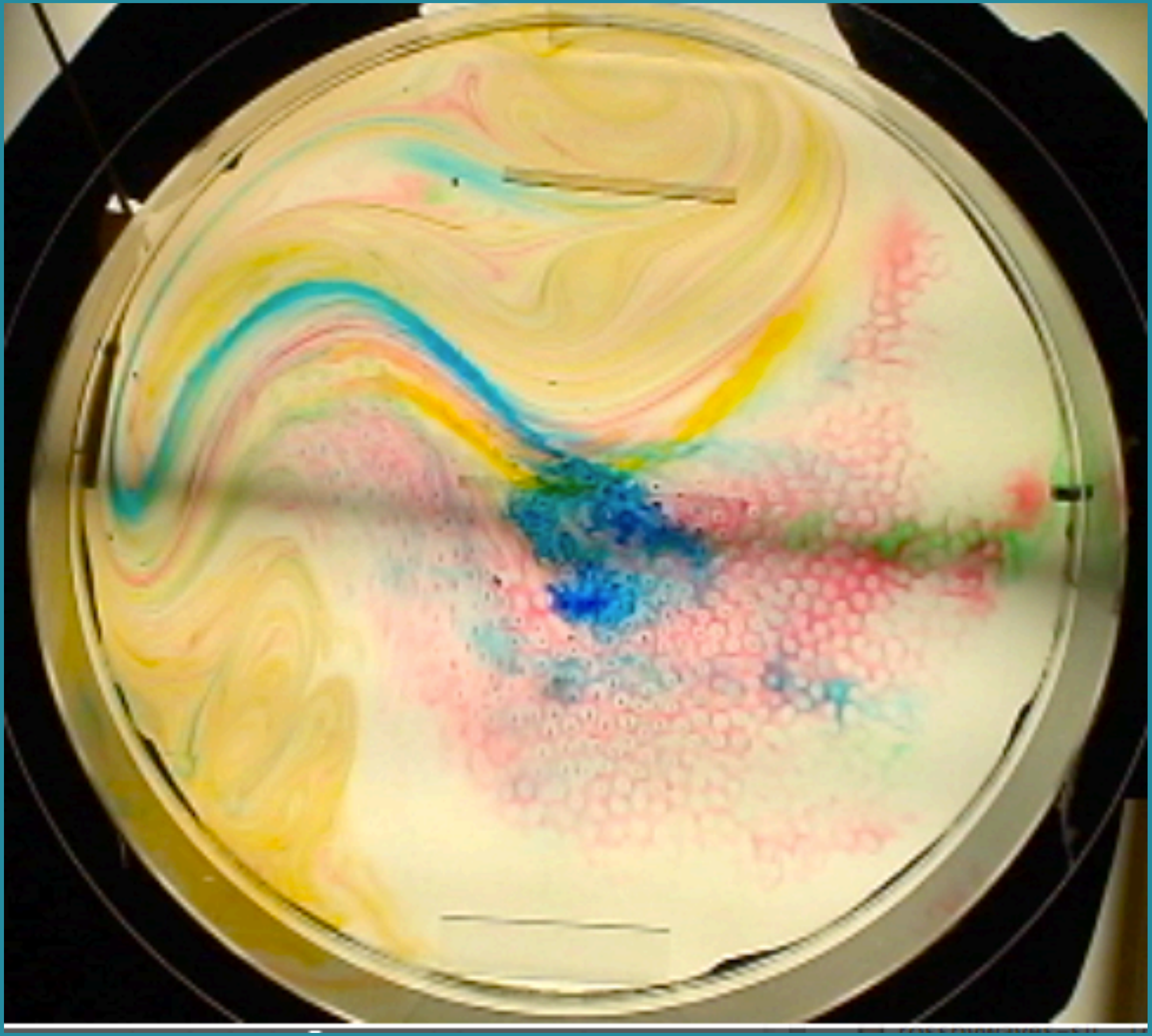
Spain

Early 20th C warming:
Cod 1930s in Greenland

Harry van Loon and Danish weather stations (Godthab/Huuk)



Charlie-Gibbs
Fracture Zone
Flemish
Cap
Mann
Eddy
Azores
Current
AVISO altimeter KE
(cm2/sec2)
13-Apr-2005
50
45
40
35
Grand
Banks
50W
45W
40W
35W Rhines UW
00:01:03

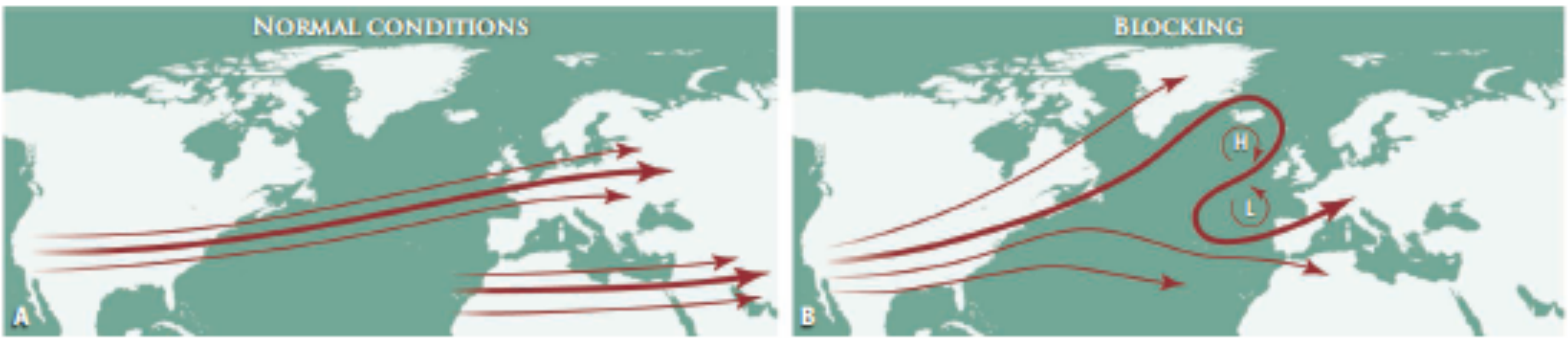


ATMOSPHERIC SCIENCE

Ocean Effects of Blocking

Tim Woollings

Short-term weather events may drive ocean variability on time scales of several decades.



Atmospheric Blocking and Atlantic Multidecadal Ocean Variability

Sirpa Häkkinen,[1,*] Peter B. Rhines,[2] Denise L. Worthen[3]

Atmospheric blocking over the northern North Atlantic, which involves isolation of large regions of air from the westerly circulation for 5 days or more, influences fundamentally the ocean circulation and upper ocean properties by affecting wind patterns. Winters with clusters of more frequent blocking between Greenland and western Europe correspond to a warmer, more saline subpolar ocean. The correspondence between blocked westerly winds and warm ocean holds in recent decadal episodes (especially 1996 to 2010). It also describes much longer time scale Atlantic multidecadal ocean variability (AMV), including the extreme pre–greenhouse-gas northern warming of the 1930s to 1960s. The space-time structure of the wind forcing associated with a blocked regime leads to weaker ocean gyres and weaker heat exchange, both of which contribute to the warm phase of AMV.

Science
14 Nov 2011

Wood, Overland, Jónsson &Smoliak GRL 2010

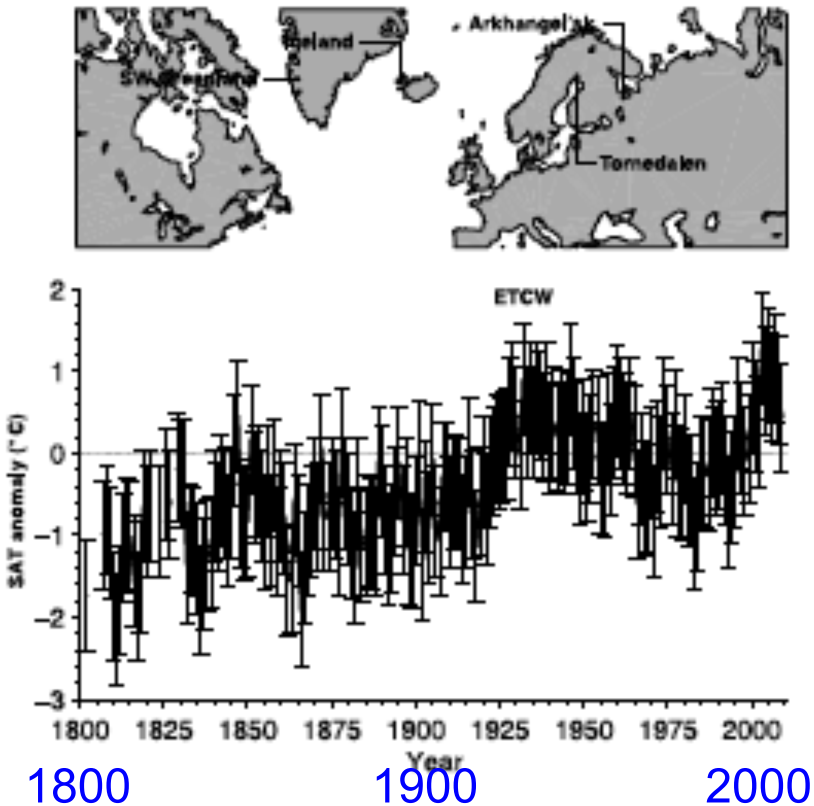
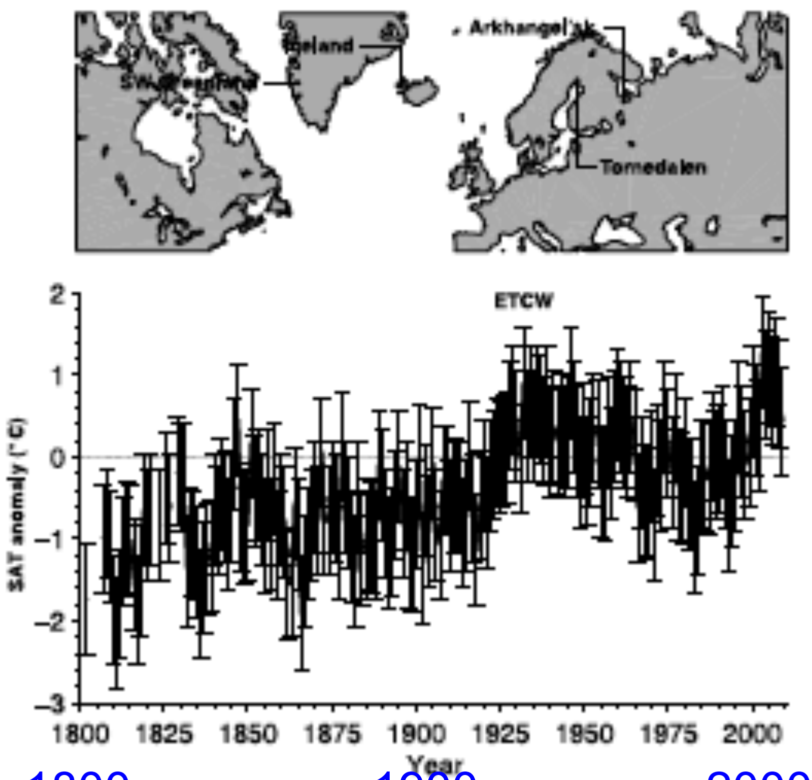


Figure 1. Extended annual mean SAT record for the Atlantic-Arctic boundary region (T_{NA}). 95% confidence limits are shown. Decadal-scale variations are emphasized with a 2-way Butterworth low-pass filter constructed to remove frequencies higher than 0.1 cycles year^{-1} (bold black line). The early 20th century warming (ETCW) episode is marked. Regions represented by station-based com-



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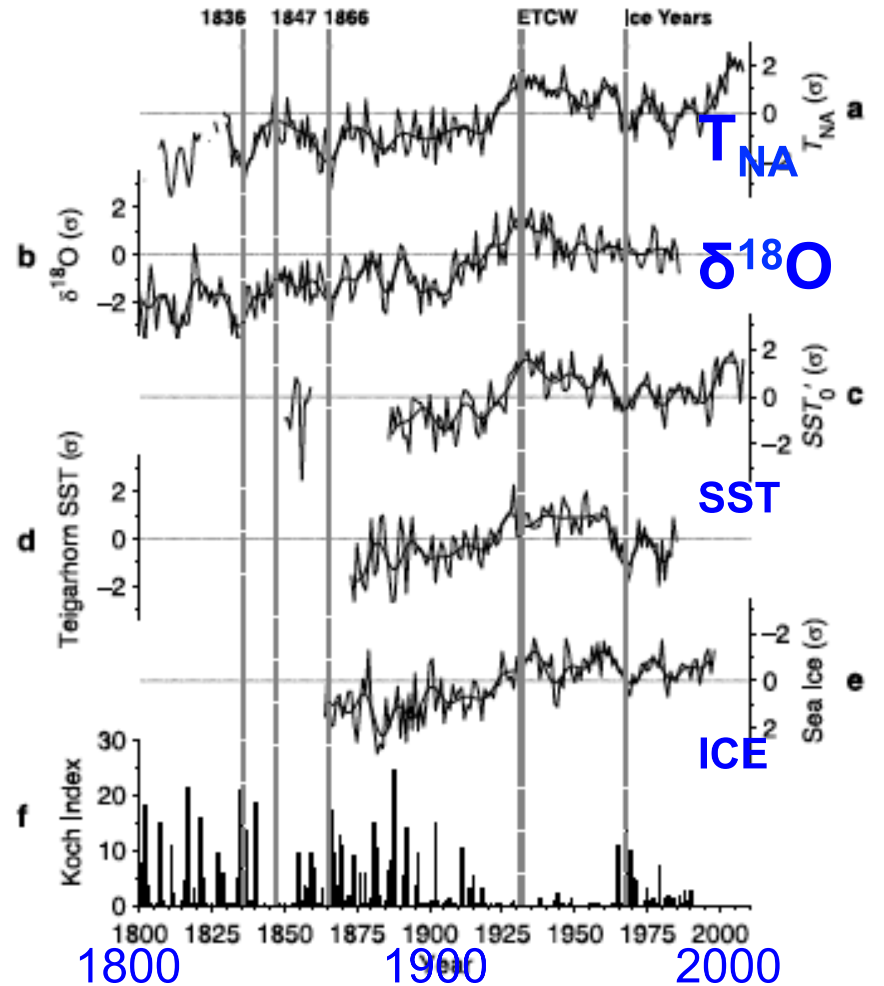


Figure 2. Concurrent variations in multiple climate records. (a) T_{NA}. (b) Mean δ^{18}O. (c) SST_0'. (d) Teigarhorn SST′. (e) Mean sea ice index (inverted). (f) Koch (Iceland) sea ice index [*Wallevik and Sigurjónsson*, 1998]. A low-pass filter was applied as in Figure 1 (bold black lines). Notable deflections are marked with dashed gray lines. The

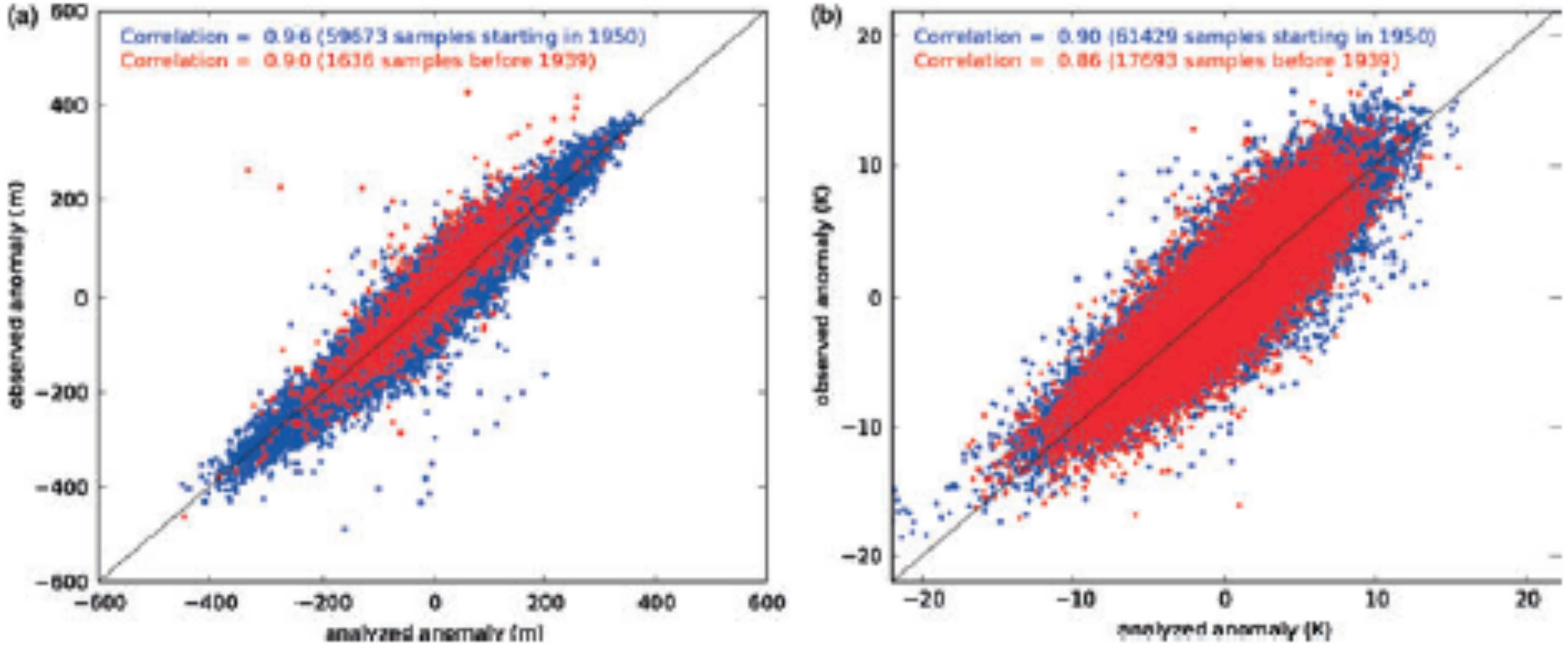


Figure 5. Comparison of (a) 500 hPa geopotential height anomalies (m) and (b) 850 hPa air temperature anomalies (K) at Lindenberg, Germany (52.22°N, 14.12°E) from upper-air observations in the Comprehensive Upper Air Historical Network (CHUAN; Stickler *et al.*, 2010) and 20CRv2 analyzed anomalies interpolated to the time and location of the observations. Anomalies are with respect to the mean annual cycle of the period shown. Blue dots show anomalies from 1950 to present, and red dots show anomalies from data spanning 1905 to 1938. There are no observations from this station in the CHUAN compilation from 1938 to 1949. The number of red dots prior to the commencement of regular radiosoundings at the Lindenberg Observatory (Dubois *et al.*, 2002) in 1932 is (a) 1166 and (b) 13 715.

How good is the early 20th C reconstruction of 500 hPa height?
Red dots: 1905-1938 ; blue dots: 1950-present Kite, aircraft, pilot balloon upper air obs vs. Compo *et al.* reanalysis

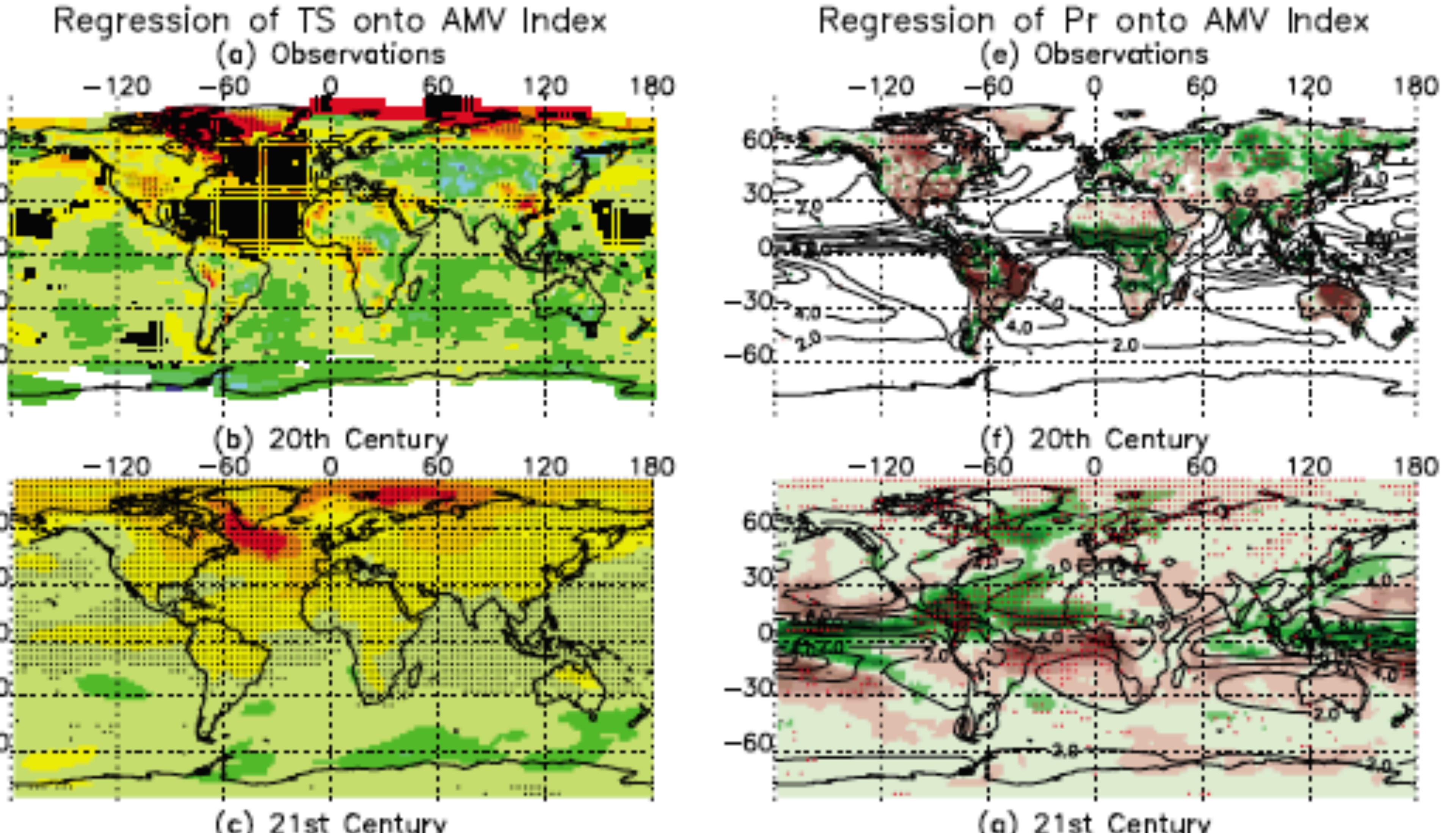
(which uses only SLP and ocean SST obs)

Ting, Seager, Kushnir & Li GRL 2011: subpolar Atlantic max

SST (left) and Precipitation regressed on AMV timeseries

Tropical ocean/atmosphere interaction is well established

Nward shift of Atl ICTZ => more Sahel P,



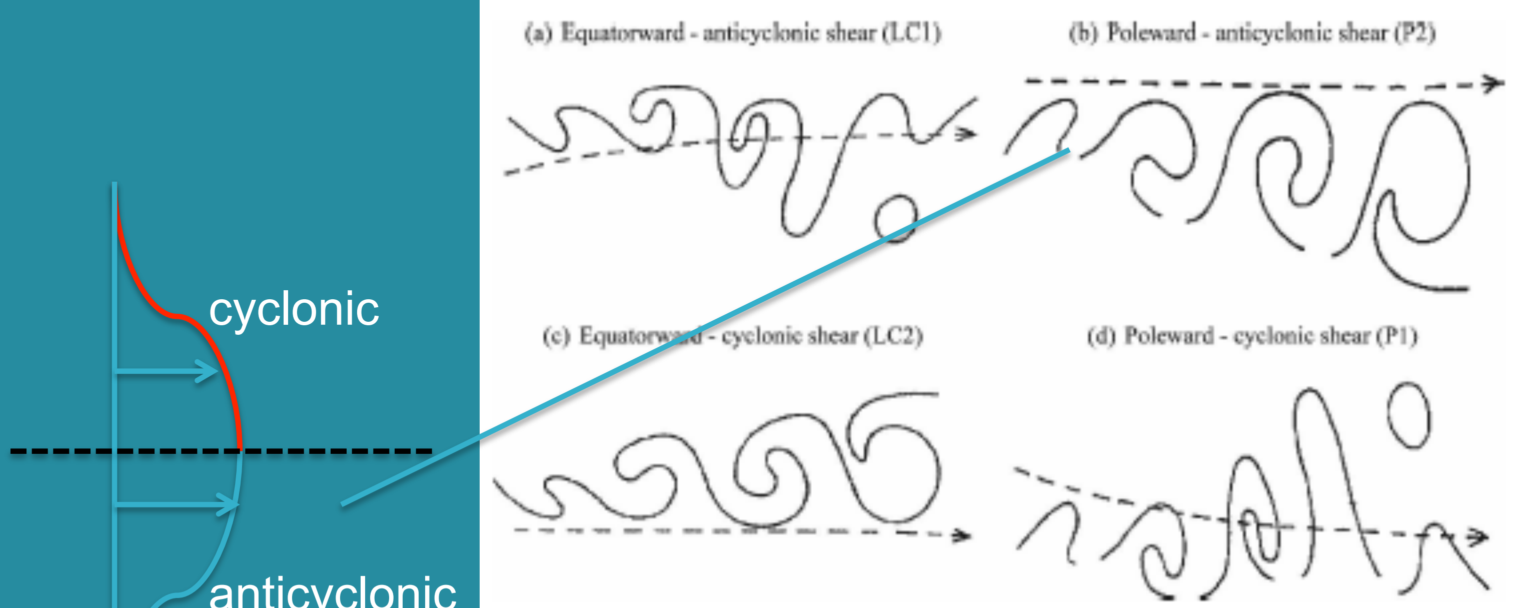
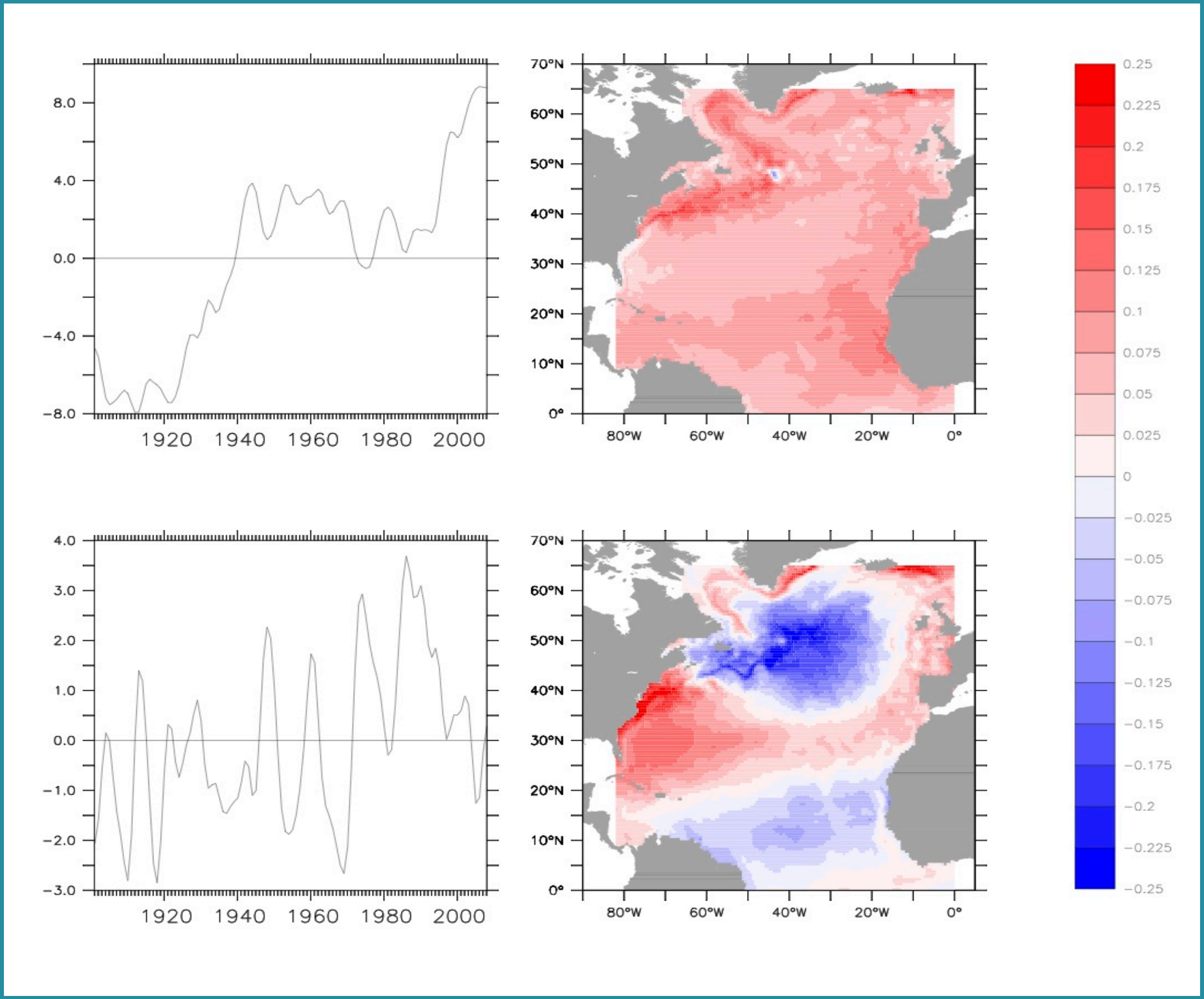


FIG. 1. Schematic illustration of four types of wave breaking showing the deformation of a representative θ contour on the dynamical tropopause during wave breaking. The two upper schematics show the evolution of (a) an equatorward extrusion of low-θ air and (b) a poleward extrusion of high-θ air within a zone of background anticyclonic wind shear. The two lower schematics show the evolution of (c) an equatorward extrusion of low-θ air and (d) a poleward extrusion of high-θ air within a zone of background cyclonic wind shear. The arrow marks the position of the midlatitude jet. The initial stages of each development, in which the wave-breaking nature is different in LC1 and P1, correspond to the left-hand side of each figure. The schematics and the notation for LC1 and LC2 are taken from Thorncroft et al. (1993), and those for P1 and P2 from Peters and Waugh (1996).

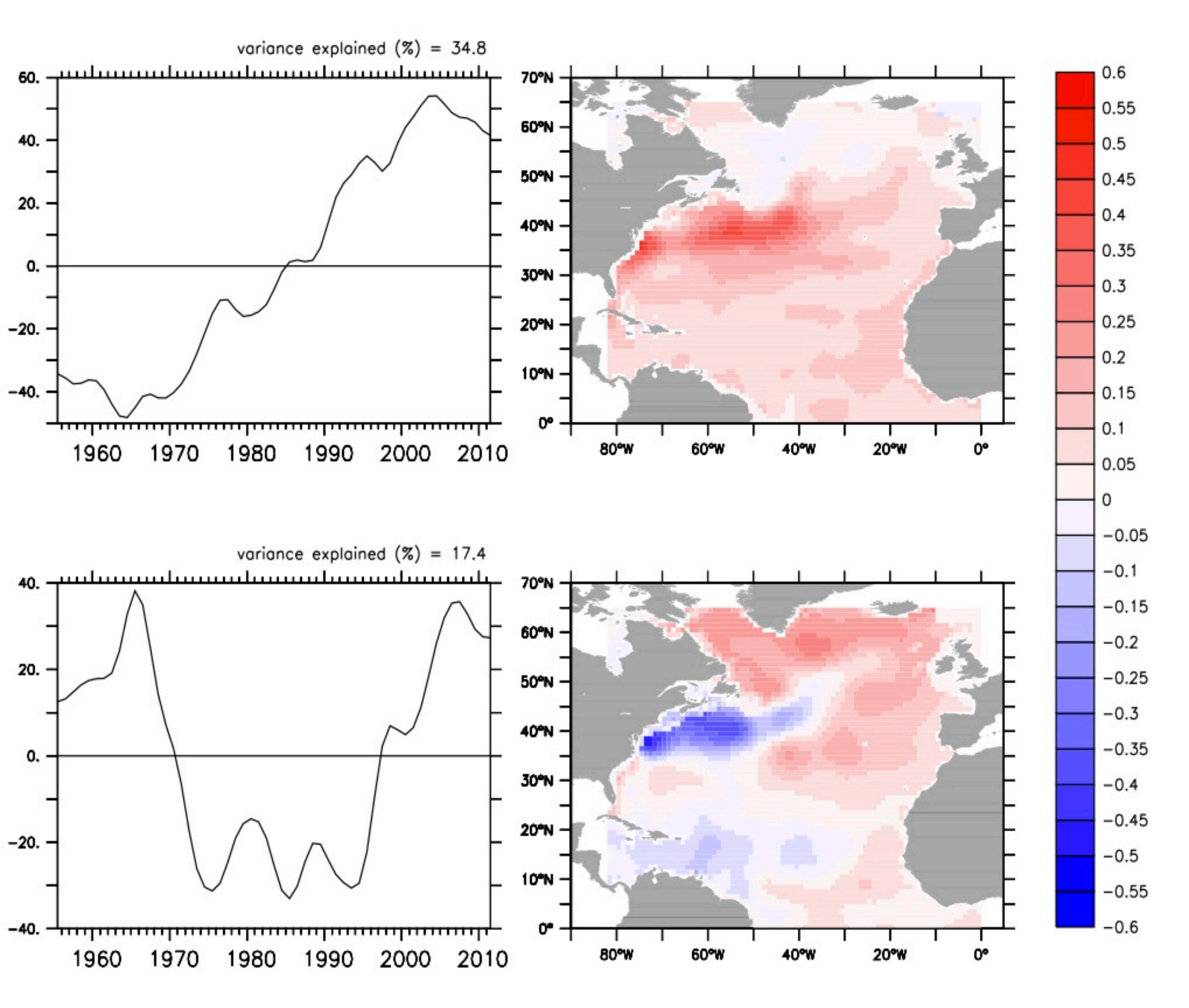
SST EOFs 1 and 2; PC 1 and 2
Hadley Ctr SST

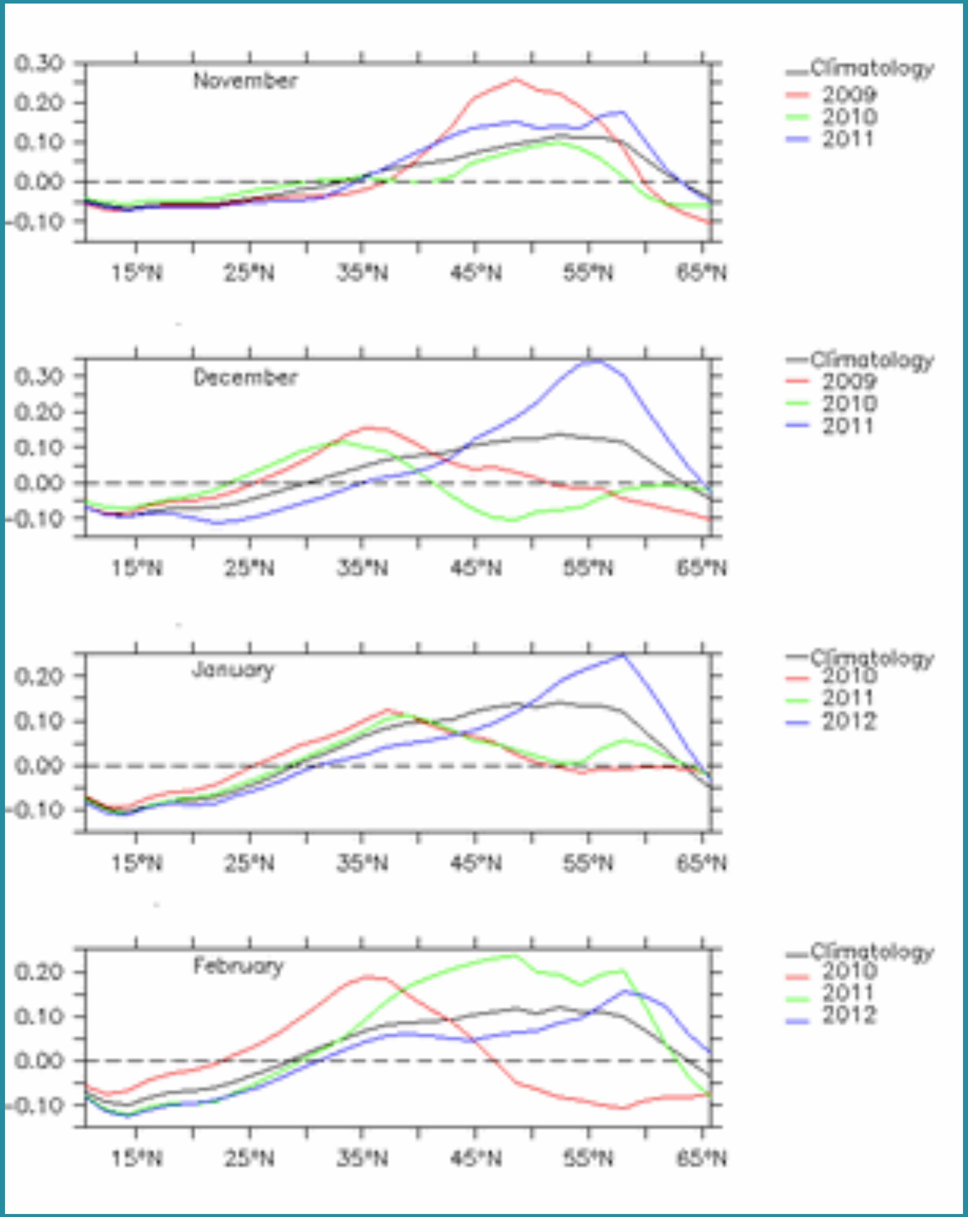


EOF 1 and 2; PC 1 and 2
for ocean water colom heat content. (NODC WOA)

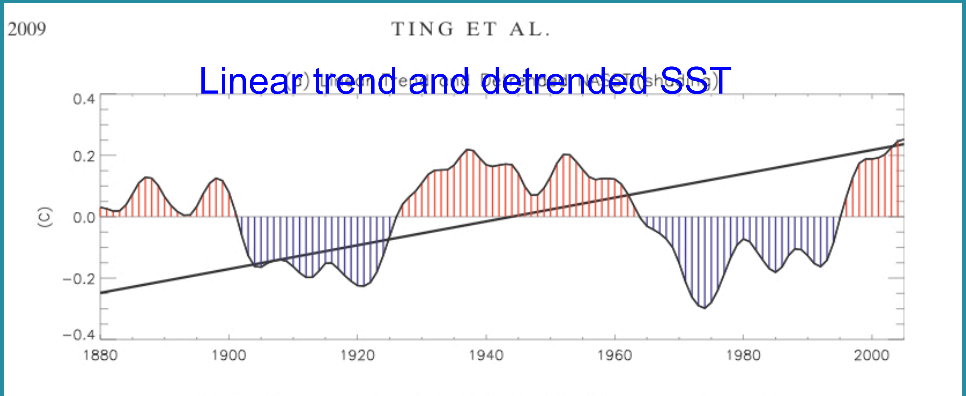
EOF 1
trend like
warming

EOF 2
AMV like
recent
warming

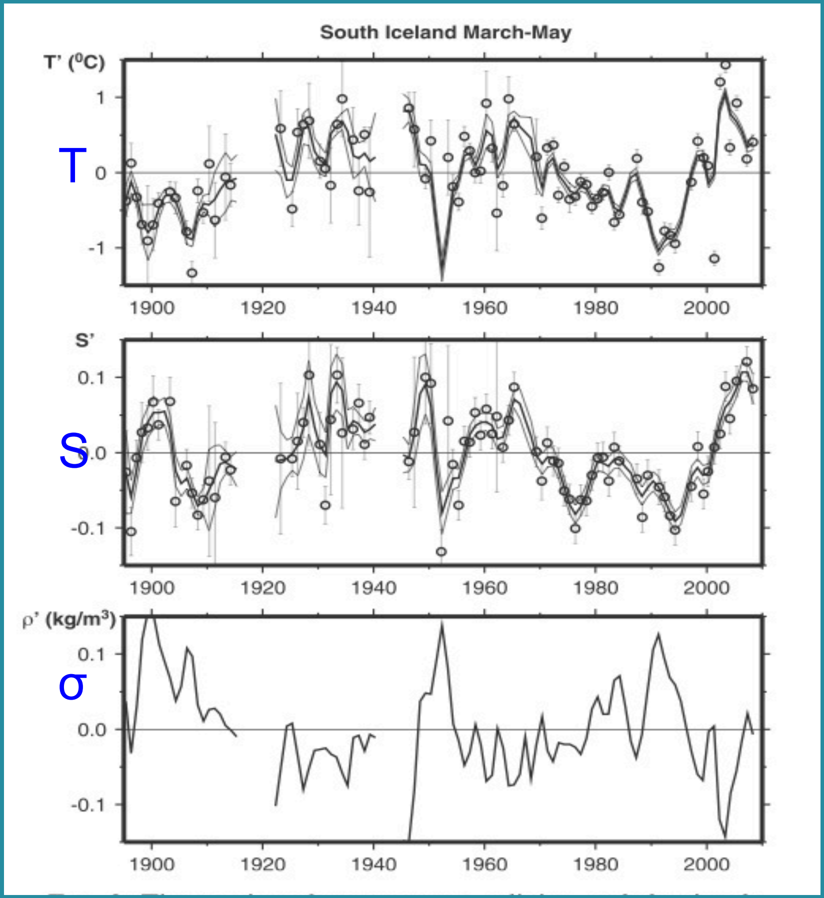



November
Climatology
2009
2010
2011
December
Climatology
2009
2010
2011
January
Climatology
2010
2011
2012
February
Climatology
2010
2011
2012
15°N
25°N
35°N
45°N
55°N
65°N

ATLANTIC MULTIDECADAL VARIABILITY



Ting et al 2009



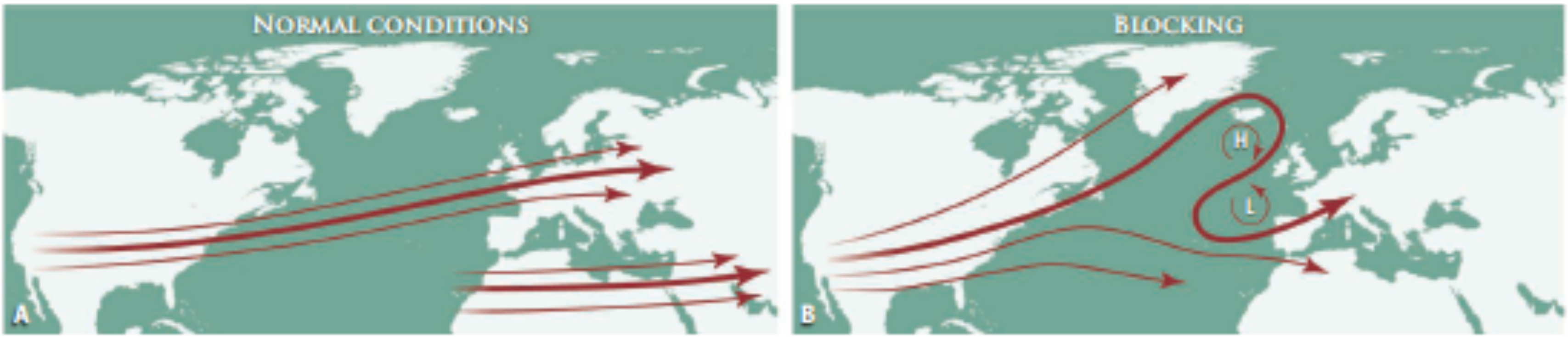
locally, south of Iceland: Reverdin 2010

ATMOSPHERIC SCIENCE

Ocean Effects of Blocking

Tim Woollings

Short-term weather events may drive ocean variability on time scales of several decades.



Atmospheric Blocking and Atlantic Multidecadal Ocean Variability

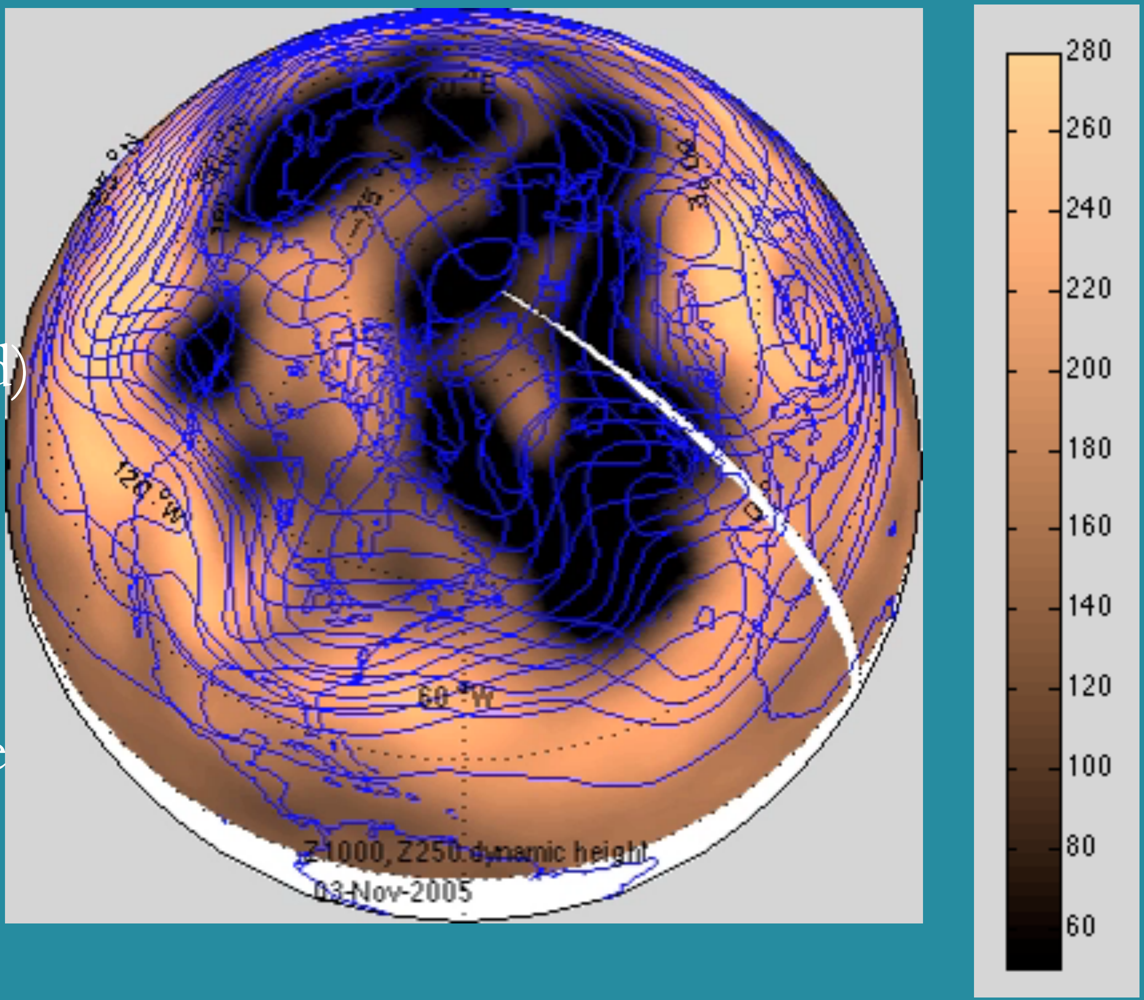
Sirpa Häkkinen,[1*] Peter B. Rhines,[2] Denise L. Worthen[3]

Atmospheric blocking over the northern North Atlantic, which involves isolation of large regions of air from the westerly circulation for 5 days or more, influences fundamentally the ocean circulation and upper ocean properties by affecting wind patterns. Winters with clusters of more frequent blocking between Greenland and western Europe correspond to a warmer, more saline subpolar ocean. The correspondence between blocked westerly winds and warm ocean holds in recent decadal episodes (especially 1996 to 2010). It also describes much longer time scale Atlantic multidecadal ocean variability (AMV), including the extreme pre–greenhouse-gas northern warming of the 1930s to 1960s. The space-time structure of the wind forcing associated with a blocked regime leads to weaker ocean gyres and weaker heat exchange, both of which contribute to the warm phase of AMV.

Science
14 Nov 2011

video:
The same jet-stream level height field (Z250) as contours and lower troposphere height (shaded)

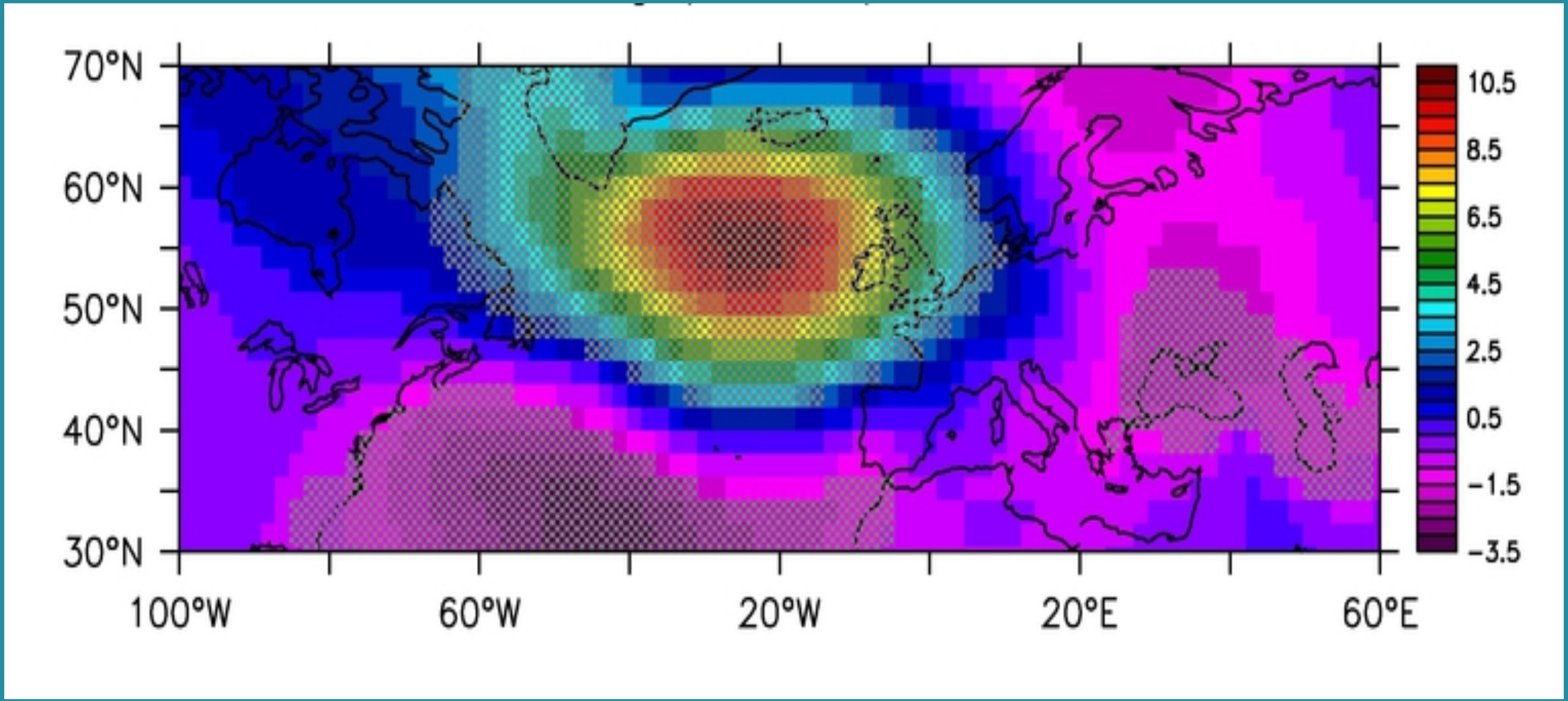
The Atlantic storm track is very active, with a persistent low in eastern Canada on the upwind side of the blocking pattern



colors: Z1000 hPa height (dark = cyclonic L, light = anticylonic, H)
contours: Z250

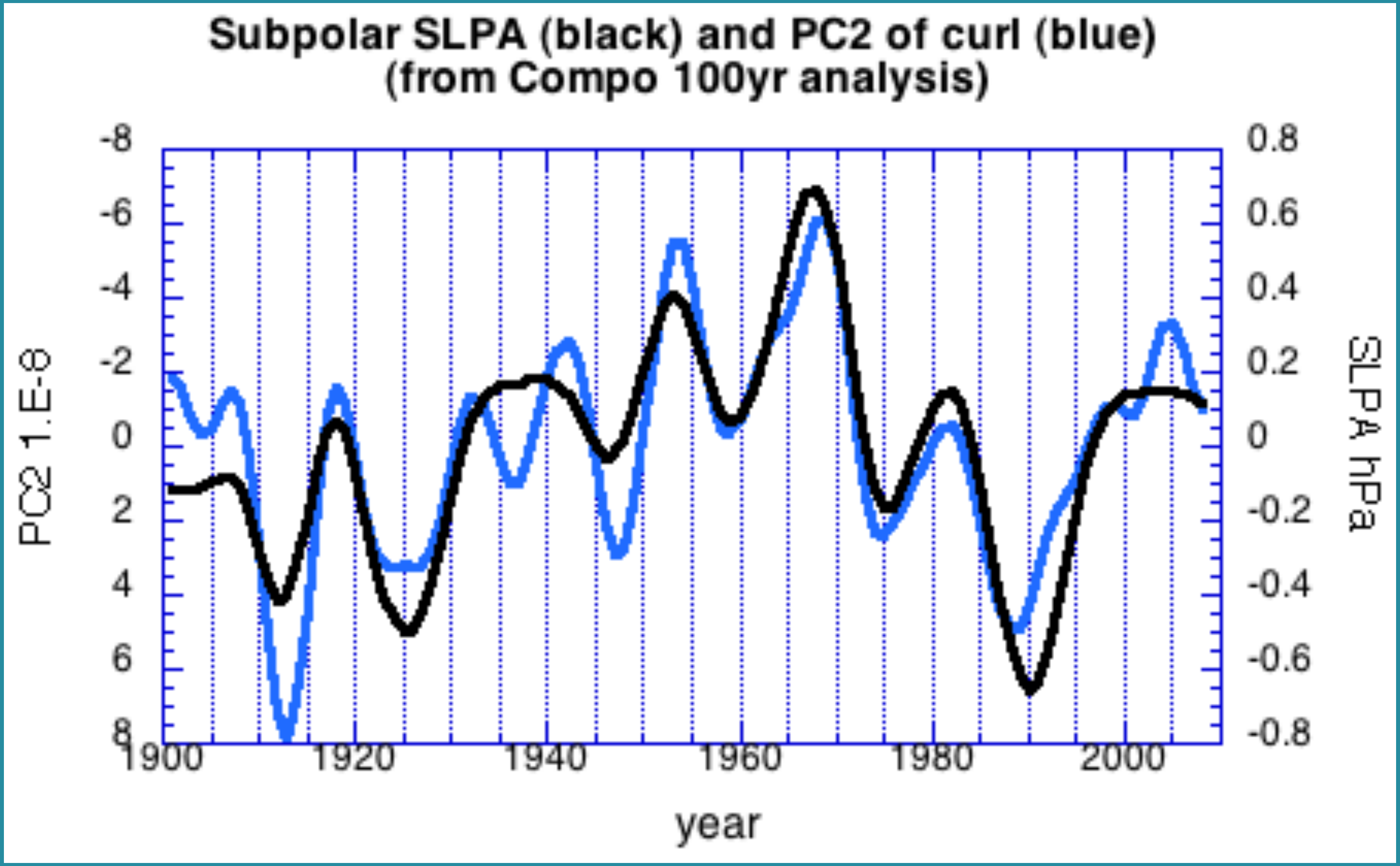
1 Feb 2006 block 26 Feb EU block 3 Mar Gnld block, twirling Cycls

COMPOSITE SLP CORRESPONDING NEGATIVE - POSITIVE EXTREMES OF WIND STRESS CURL PC2



Data from **the 20th century Reanalysis by Compo et al. (2011)**

100 yr timescale: note 1990s-2000s increase, unlike NAO

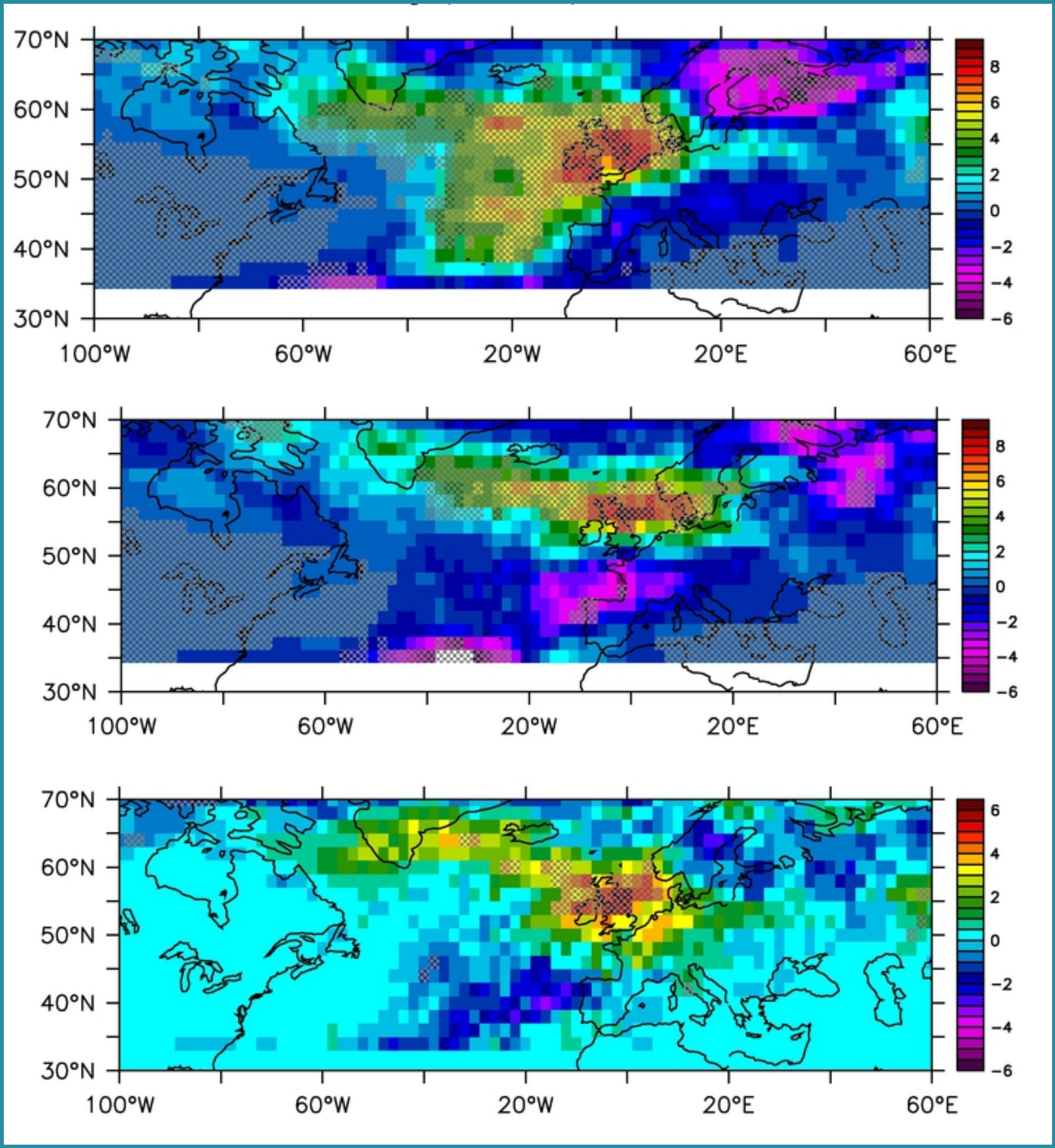


together, various BLOCKING COMPOSITES

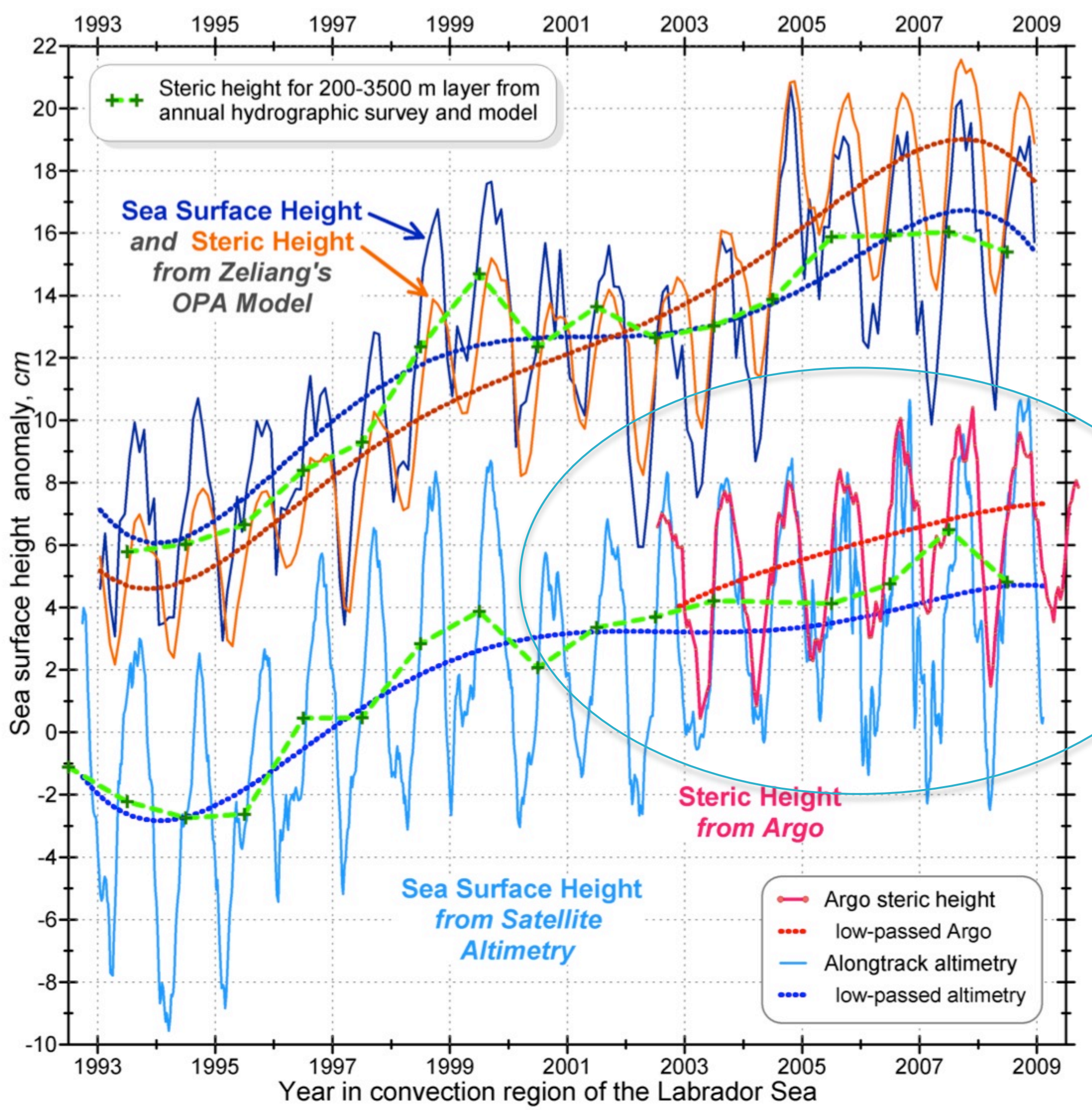
Gyre mode PC2 wind curl time series

AMO time series

1939-1968 warm yrs minus 1900-1929 cold yrs



Igor Yashayaev:
central Labrador Sea SSH and steric height (ARGO)

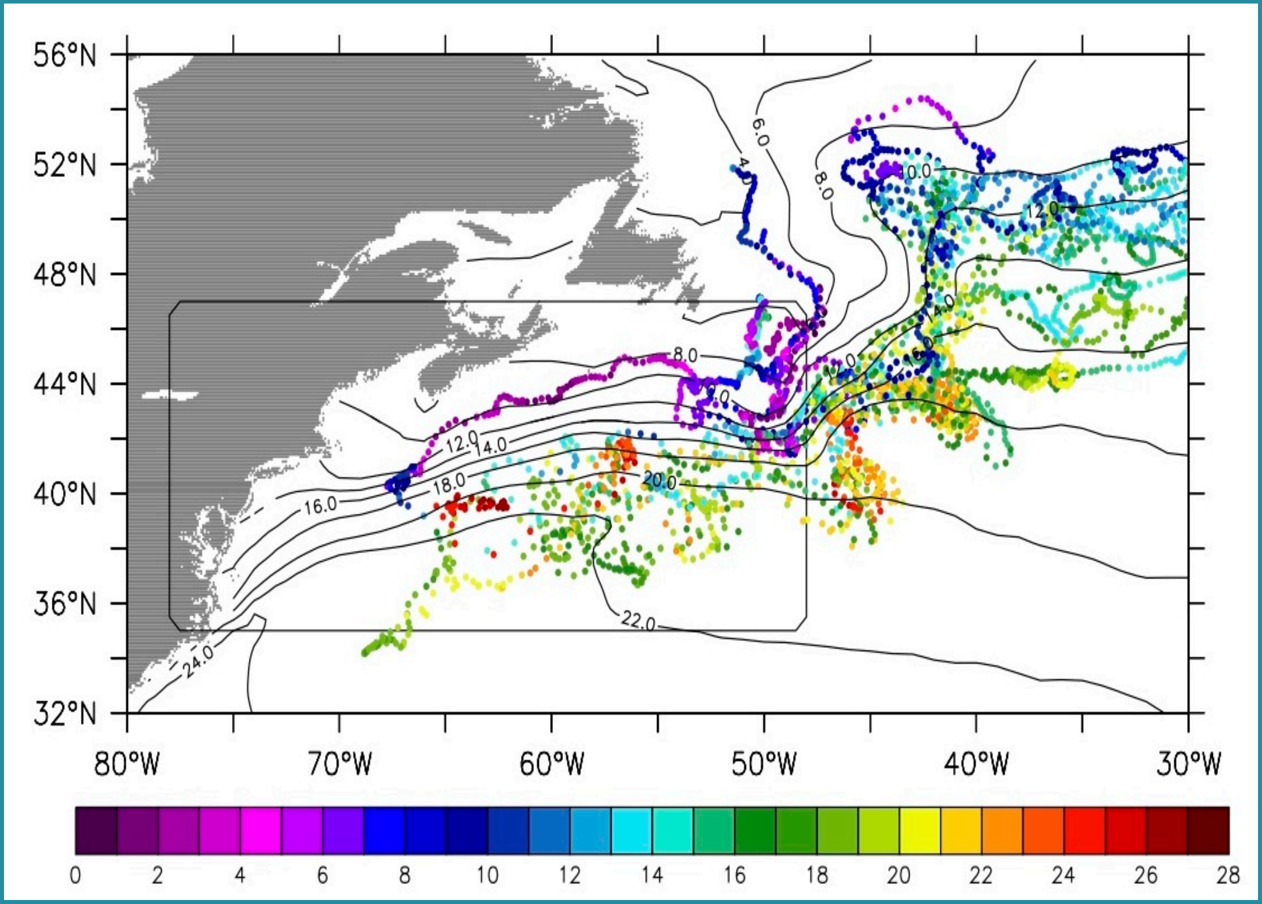


The magnitude of seasonal changes in the sea surface height (SSH) exceeds the seasonal magnitude of the steric height (SH).

SH, in its turn, shows a stronger trend (growth) in the recent years …

Is this something that warns us about horizontal mass redistribution in the North Atlantic associated with changes in circulation and gyre strength??

Surface drifters launched in subtropics which reached subpolar Rockall Trough (temperature in color).



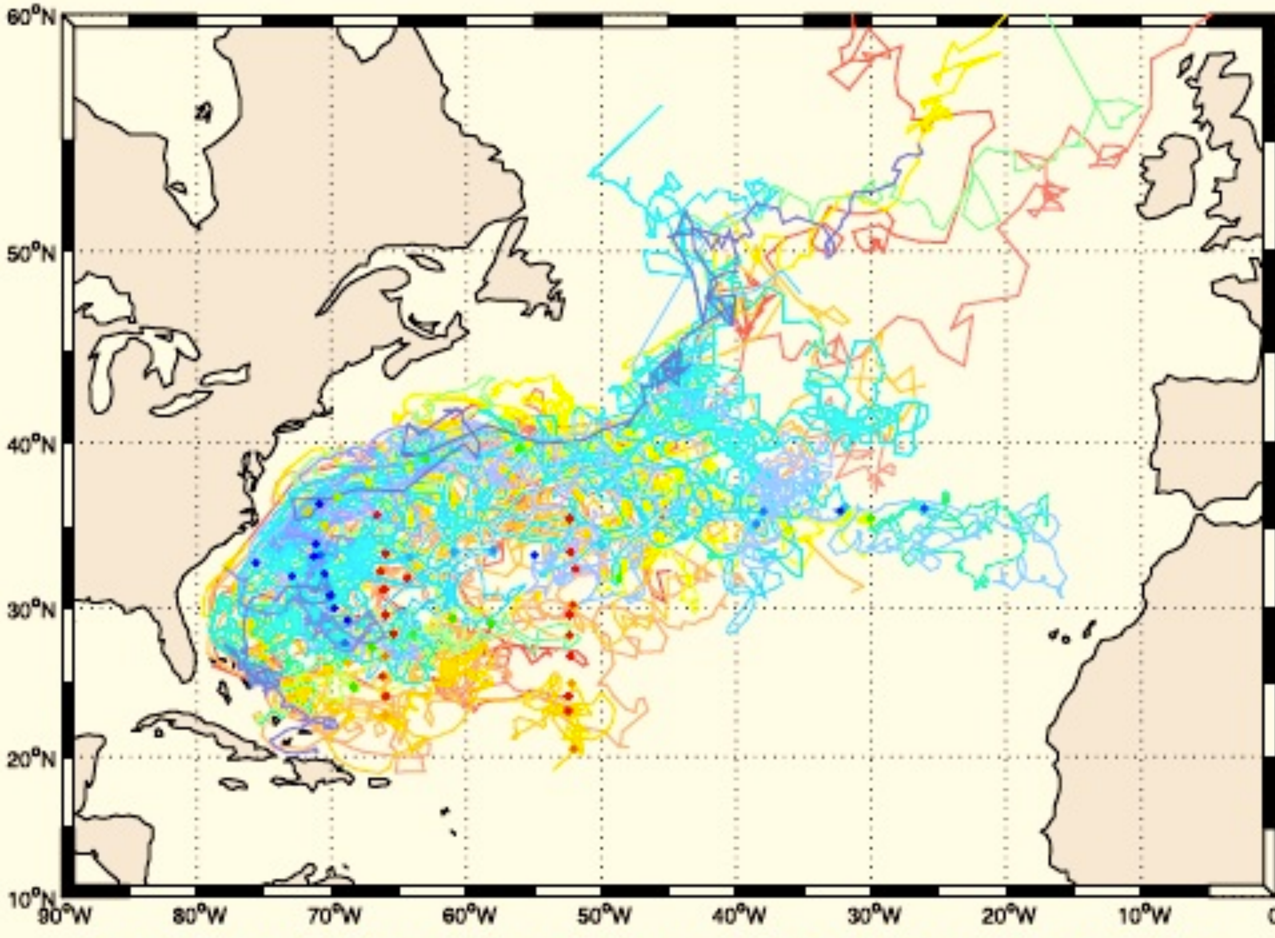


Figure 2. Trajectories of the 71 floats used in this study, during July 1997–December 2002. Bold dots indicate the deployment position for each float. Different colors are assigned to each float. Trajectory and deployment position for each float have the same color.

Latif & al. J. Climate 2004   ECHAM 10-50km grid ocean
T42 (2.5×2.5^0) atmosphere

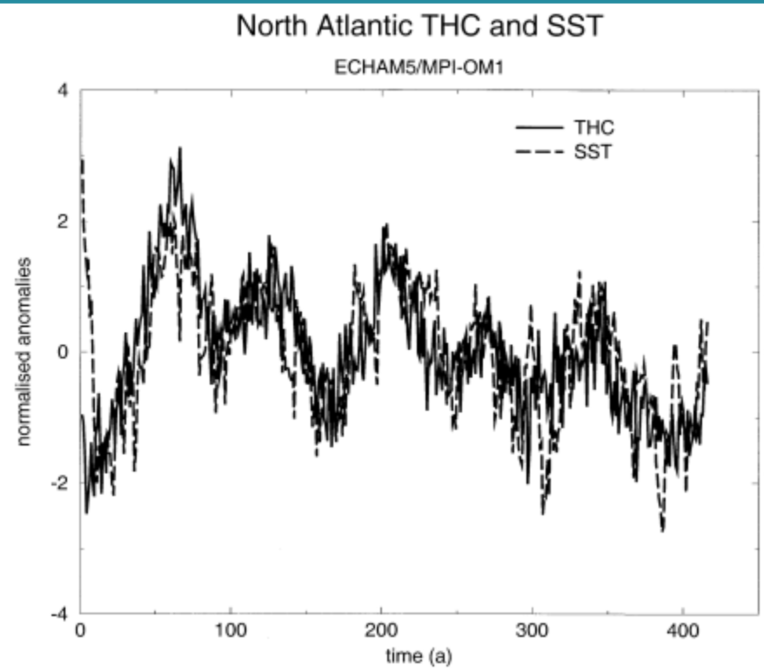


FIG. 3. Time series of simulated annual mean North Atlantic SST anomalies (40°–60°N and 50°–10°W, dashed line) and annual mean anomalies of the maximum overturning at 30°N (full line), a measure of the strength of the model's thermohaline circulation. Note that both time series are highly correlated at time scales beyond several years, indicating that the low-frequency variations of the THC can be monitored by SSTs. Both time series were normalized with their respective standard deviations. The standard deviation of the SST index amounts to 0.6°C and that of the THC index to 1.9 Sv.

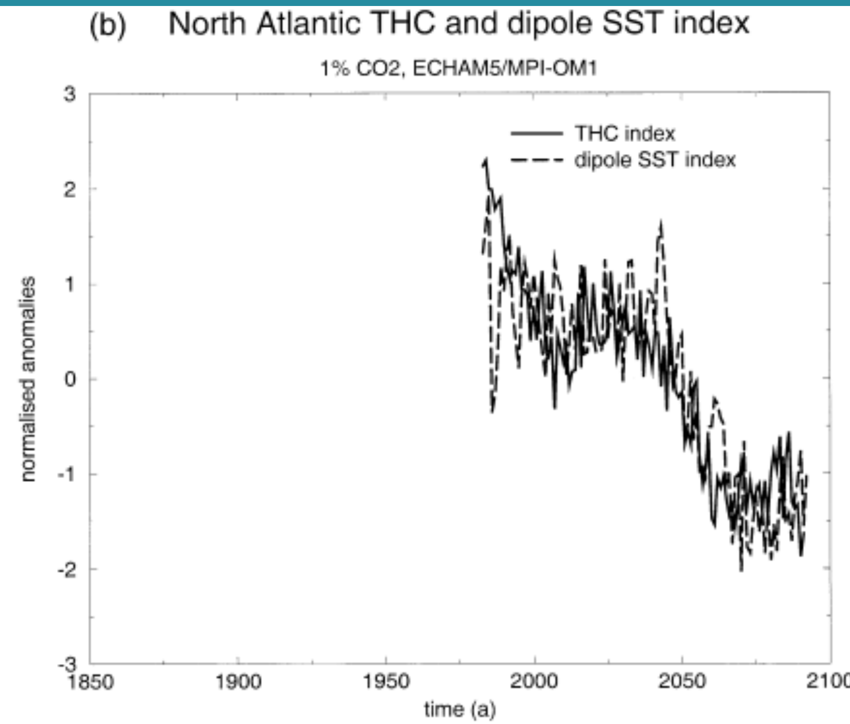


FIG. 5. (b) Time series of the simulated annual mean Atlantic dipole SST index (dashed line) and annual mean anomalies of the maximum overturning at 30°N (full line) in the longest of the greenhouse warming simulations. The dipole SST index is deÆned as the difference between North Atlantic (40°–60°N and 50°–10°W) and South Atlantic (10°–40°S and 30°W–10°E) SST. The time has been adjusted to ease comparison with panel (c).

meridional overturning at 30N tracks SST anomalies (40N-60N)
Higher resolution models often behave differently.

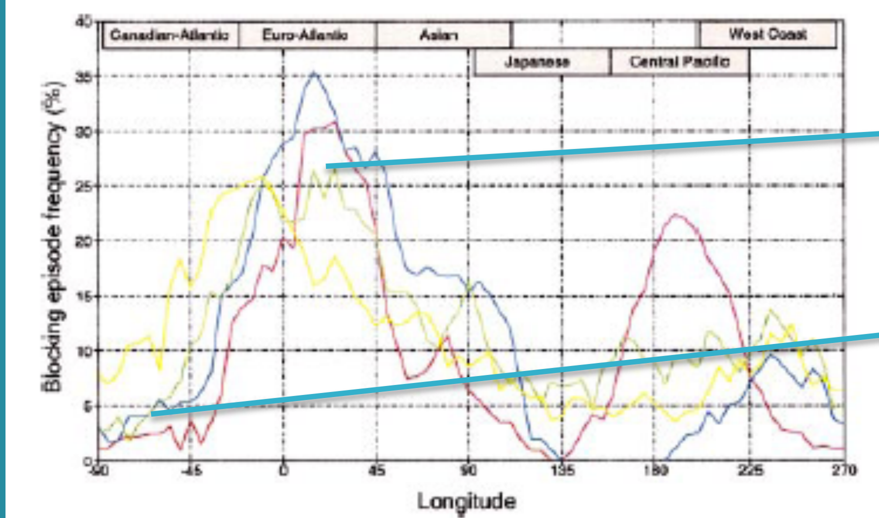


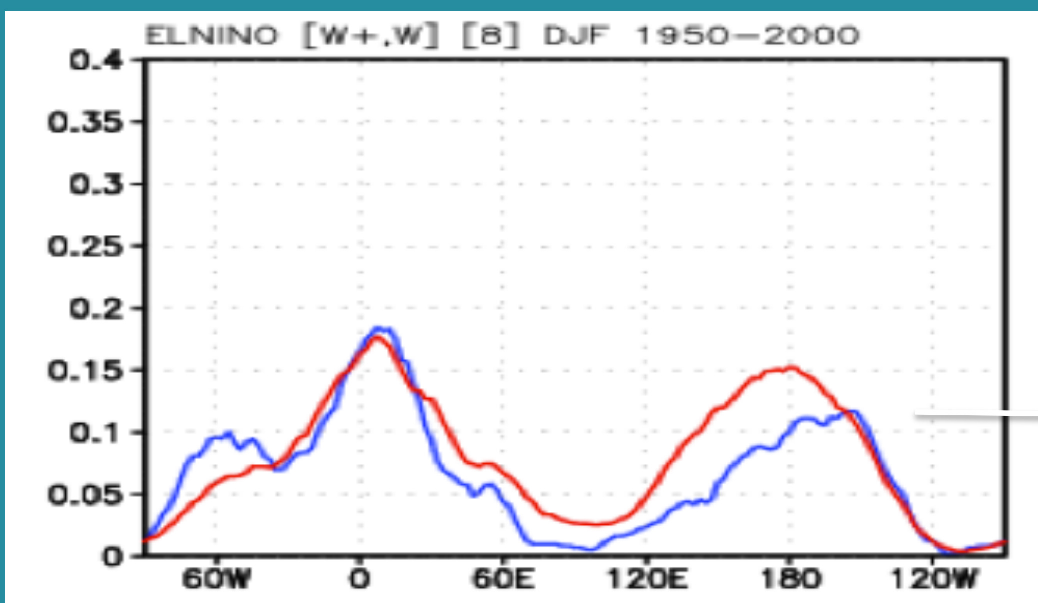
FIG. 8. Blocking episode frequency against longitude for JJA (red), SON (blue), DJF (green), and MAM (yellow) between Jun 1996 and May 2001. Also shown are the longitudinal positions of the sectors defined in the text.

European sector blocking is more common than Greenland (Atlantic sector) blocking (frequency of blocking plotted against longitude)

But, cold EU winters associate with Atlantic blocks

Croci-Maspoli et al. J.Clim 2011

Greenland blocks often follow soon after EU blocks (*Woollings 2010)*



NOAA 500hPa blocking frequency (red: climatol, blue: el Niño

- adds: wedge of cold subduction
- SPMW formation there
- high EKE/MKE eddy stirring (Azores trit)
- old PV SPG