The upper limb of AMOC and wind stress curl variability

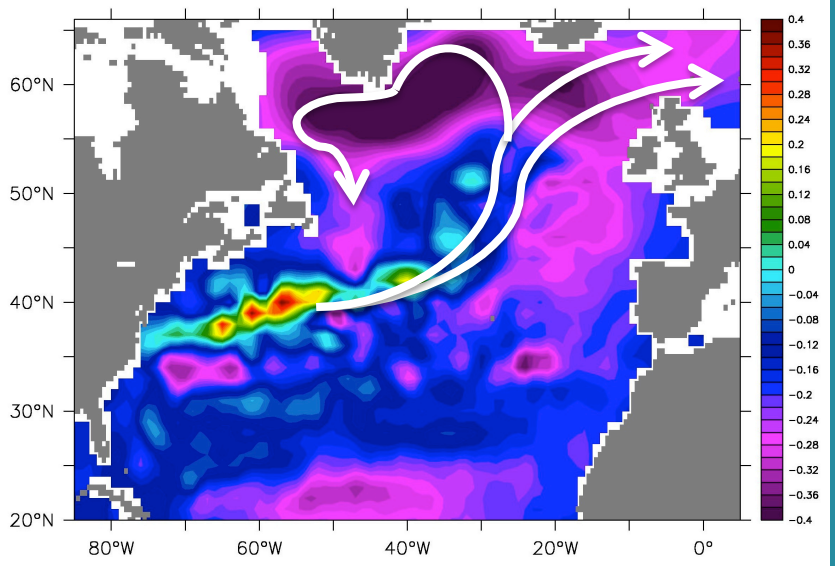
Sirpa Häkkinen (1), Peter B. Rhines (2) and Denise L. Worthen (1)

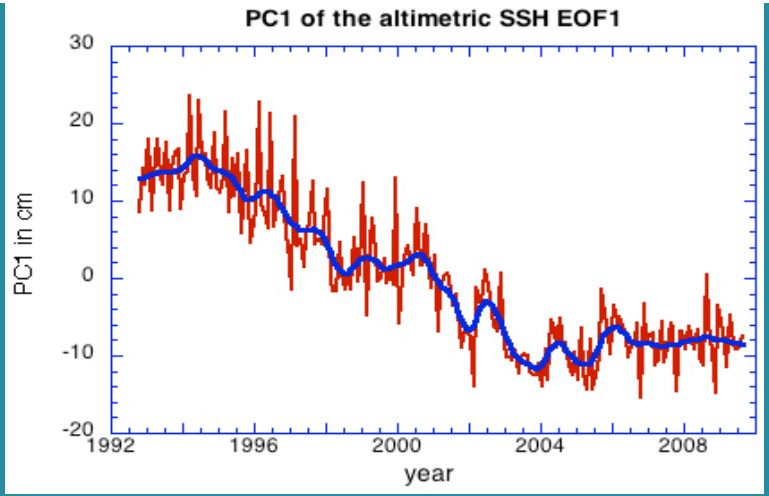
(1) NASA Goddard Space Flight Center, Code 614.2, Greenbelt, MD 20771

(2) University of Washington, Seattle, PO Box 357940, WA 98195

BACKGROUND

Update of Häkkinen and Rhines (2004): EOF 1 of the altimetric sea-surface height





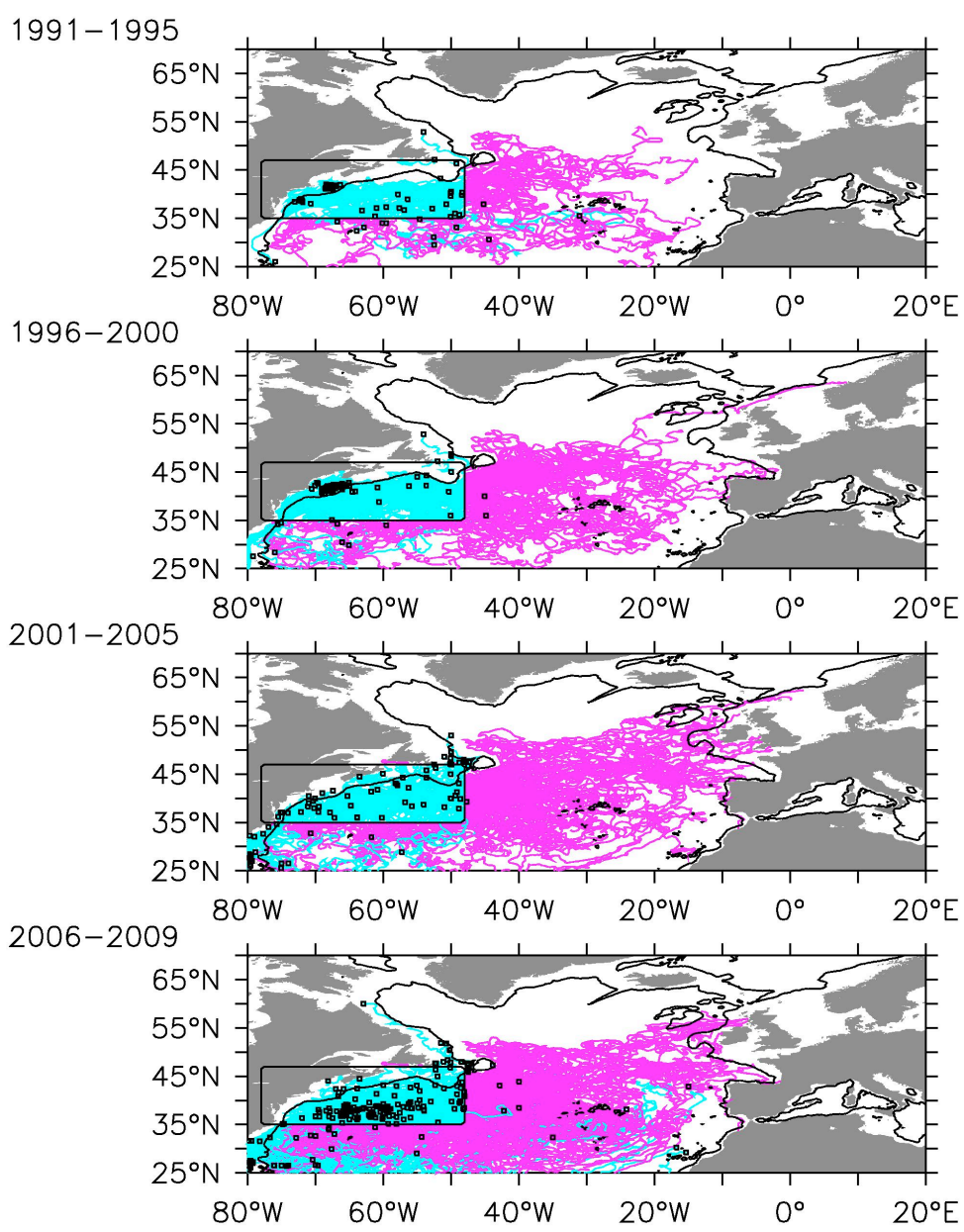
- WEAKENING and SHRINKING SUBPOLAR GYRE - FROM ALTIMETRY (*Hakkinen & Rhines* Science 2004) -> WESTWARD SHIFT OF THE SUBPOLAR FRONT (*Bersch* 2002; *Hatun et al.*, Science 2005)
- EXPANSION AND WEAKENING OF THE SUBTROPICAL GYRE FROM SATELLITE ALTIMETRY AND SEAWIFS (*McClain et al* 2004, *Polvina et al.* 2008)

- NO SUBTROPICAL SURFACE DRIFTERS ENTERED SUBPOLAR GYRE BEFORE 2002 (*Brambilla & Talley*, JPO 2006)
BUT THEY DID SO AFTER 2001 (*Hakkinen & Rhines*, JGR 2009)

- CHANGES IN THE UPPER LIMB OF THE AMOC ?
- COMMON FORCING WITH EARLIER EVENTS ?

SURFACE DRIFTER TRACKS

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



Hakkinen and Rhines 2009

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

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

DATA

-Merged multi-mission altimetric sea surface height (ssh) from 1992- (AVISO)

- NCEP/NCAR Reanalysis surface stress data

- assimilated **SODA** model data

SODA Model details : 0.25^0 x 0.4^0 x 40 levels

1958-2007 (Carton & Giese, MWR 2008)

•**Mixing**: KPP, GM

•**Winds** : NCEP/NCAR daily stress with mean and variance correction based on Quikscat

•**Freshwater flux:** GPCP precipitation 1979-, bulk formula evaporation, seasonal river discharge. Relaxation to clim. salinity under ice.

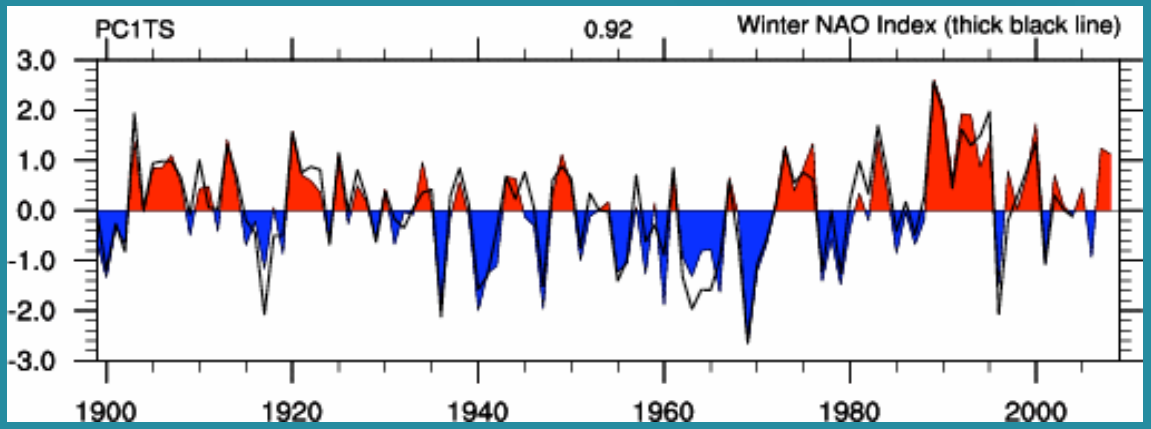
•**Heat flux**: Pretty much replaced by assimilation of mixed layer temperature

•**Sea ice**: Observed monthly cover 1979-

•**Hydrography :** World Ocean Database 2001, XBT, BT

Sea-surface elevation, ARGO, Seagliders not assimilated

NAO INDEX

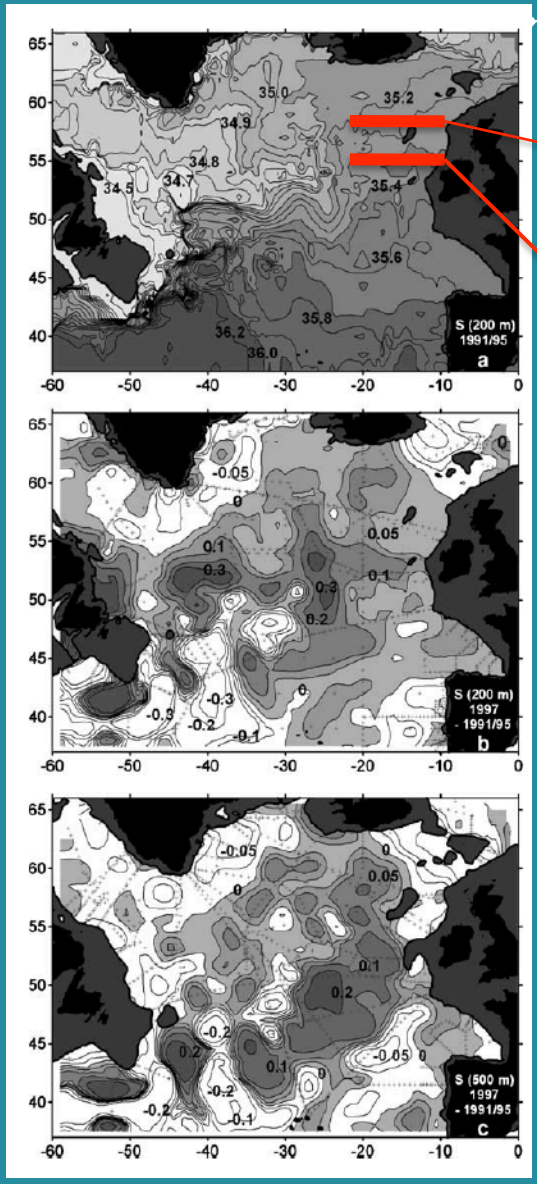


http://www.cgd.ucar.edu/cas/jhurrell/indices.info.html#naopcdjfm

- data divided into 5-year periods reflecting different NAO phases

1961-1965, 1966-1970 extremely negative NAO values
1971-1975 positive NAO, 1976-1980 negative NAO
1981-1985 weakly positive NAO
1986-1990 extremely positive NAO
1991-1995 strongly positive NAO index
1996-2000 mainly negative NAO and
2001-2005 a weak fluctuating NAO index, but mainly positive NAO

The warm, saline signal extends deeper than 500m



S 200m
1991-95

S 200m
1997-(1991-95)

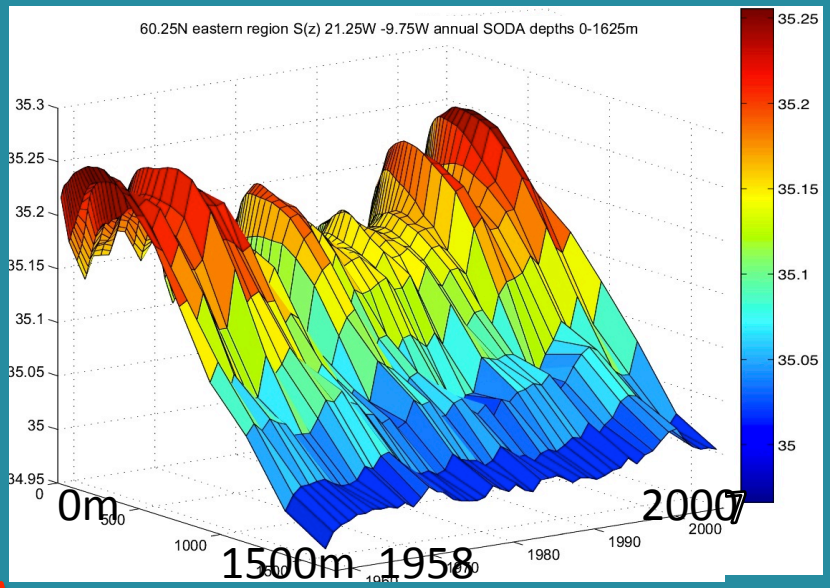
S 500m
1997-
(1991-95)

Bersch, Yashayaev, Koltermann OD2007

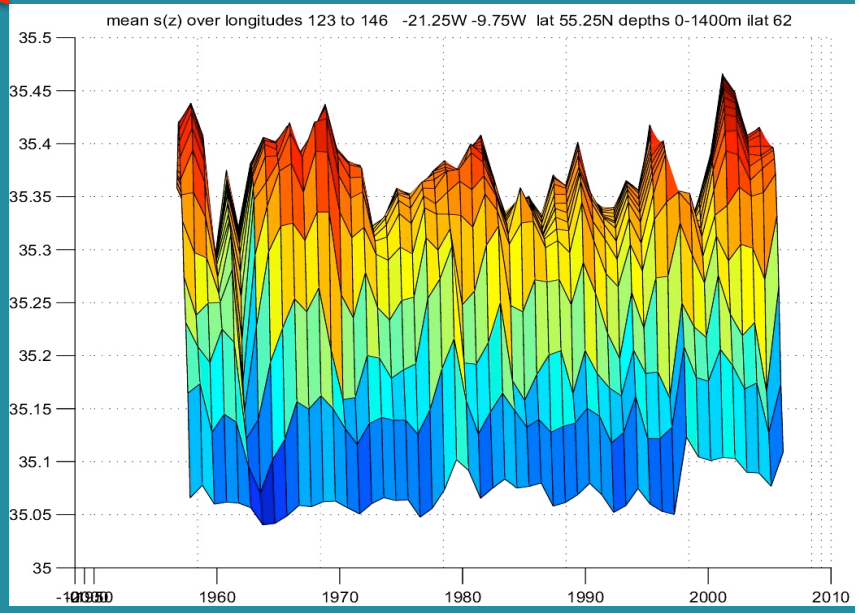
SODA assimilation

salinity vs depth and time 21W-10W

60N

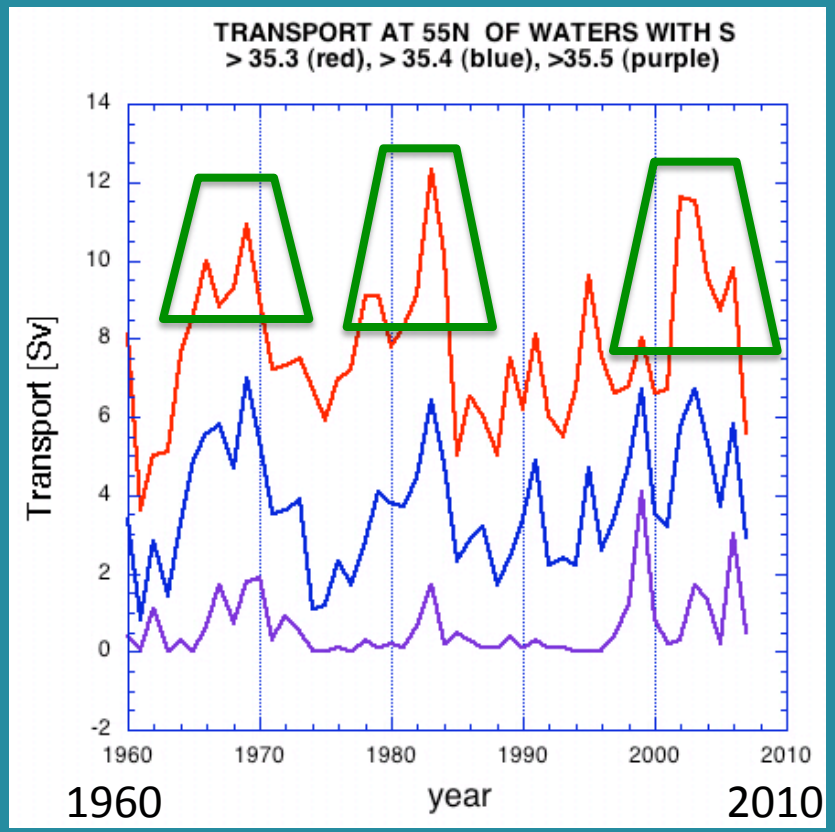


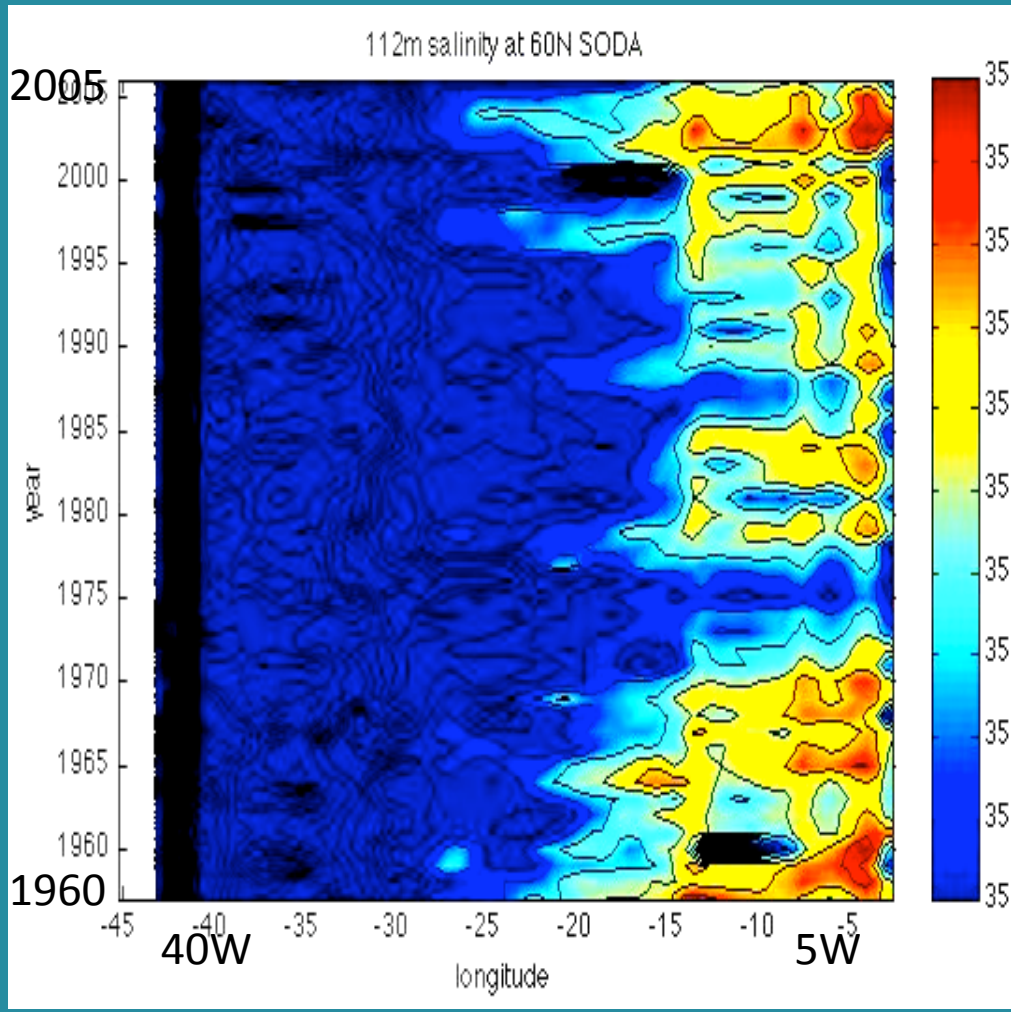
55N



WATER MASSES AT 55-60N (SODA)

INTEGRATED SALT TRANSPORT

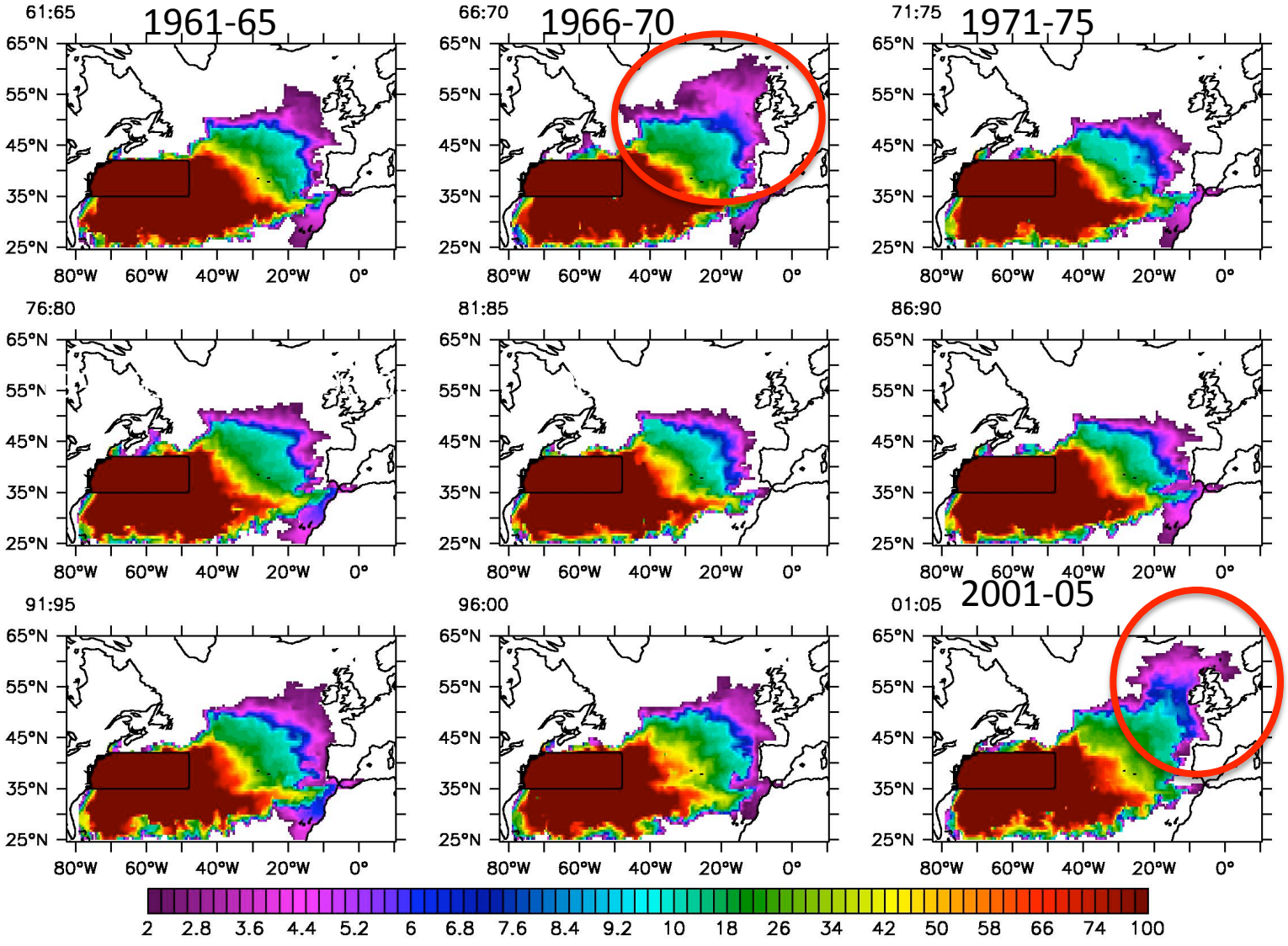




Monthly data

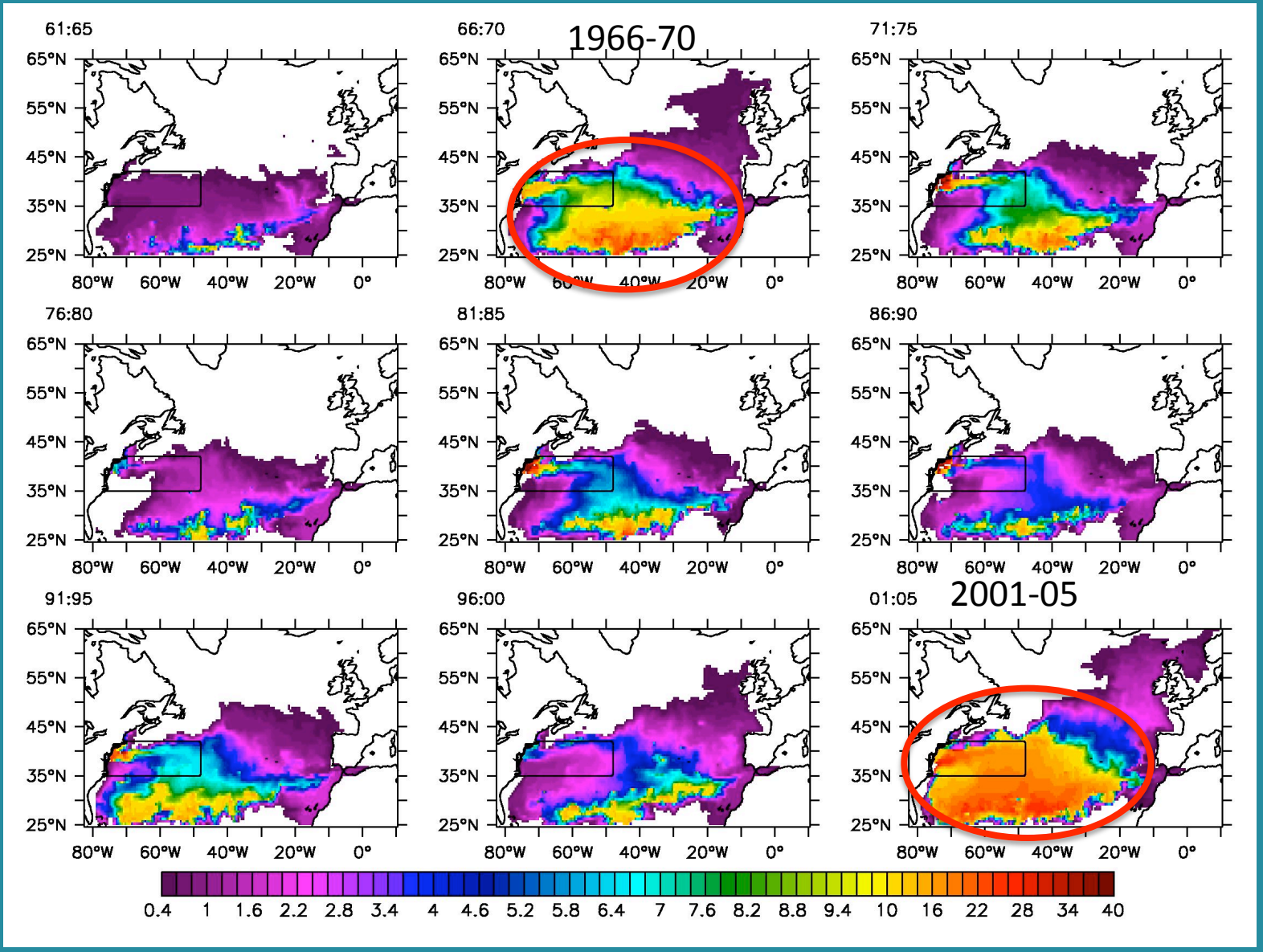
TRACER ADVECTION IN THE 15M 5-YEAR AVERAGE VELOCITY FIELD

SODA VELOCITY DATA: TRACER KEPT CONSTANT IN THE GS BOX (left),



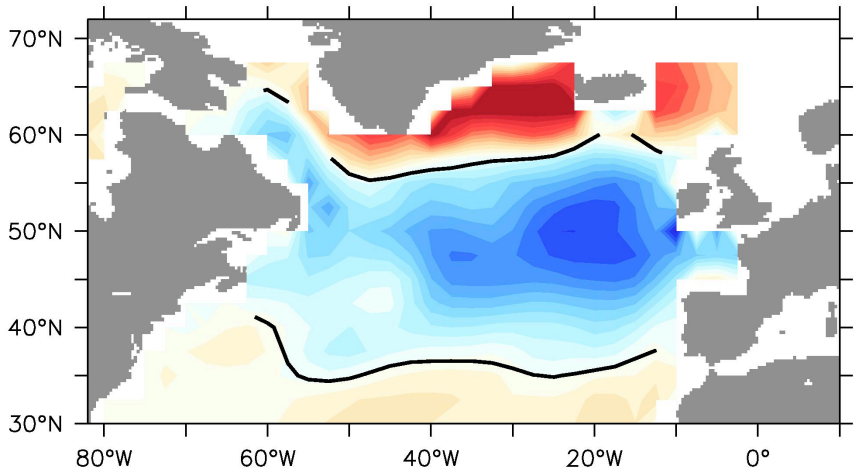
TRACER ADVECTION IN THE 15M 5-YEAR AVERAGE VELOCITY FIELD

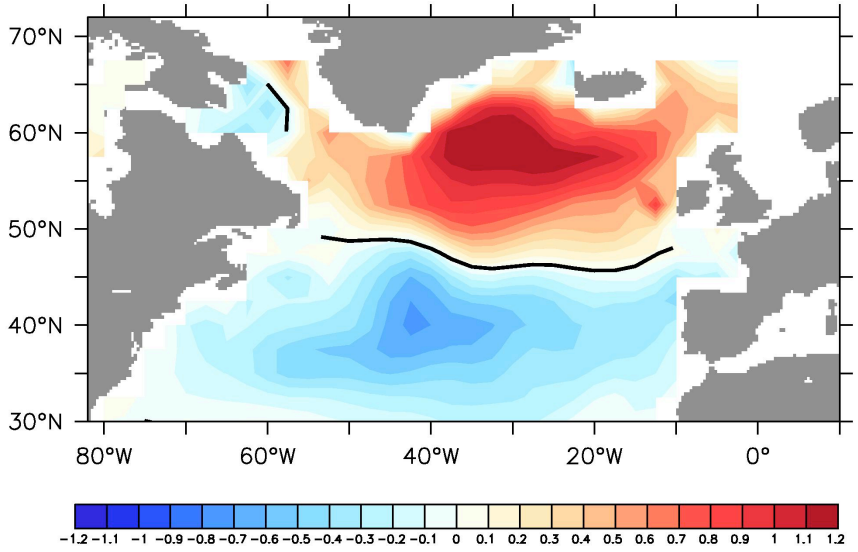
SODA VELOCITY DATA: TRANSIENT TRACER RELEASE FROM THE GS BOX



DJFM WIND STRESS CURL VARIABILITY

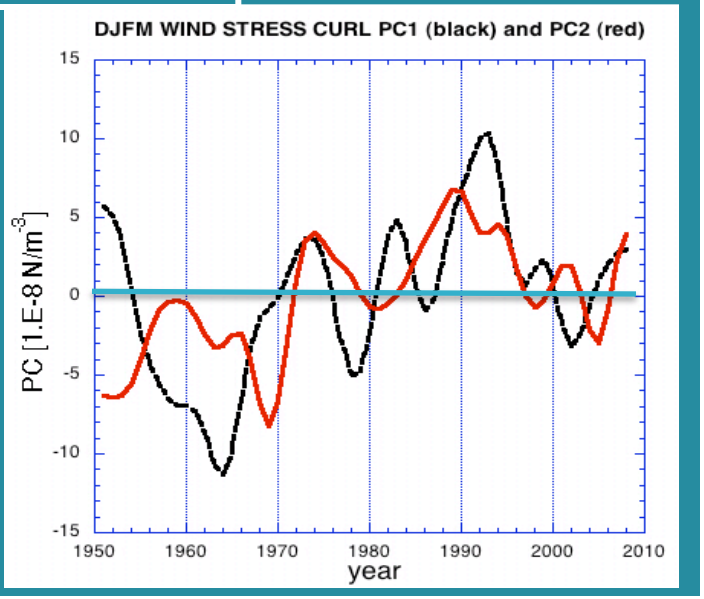
EOF1 (24%) and EOF2 (16%)

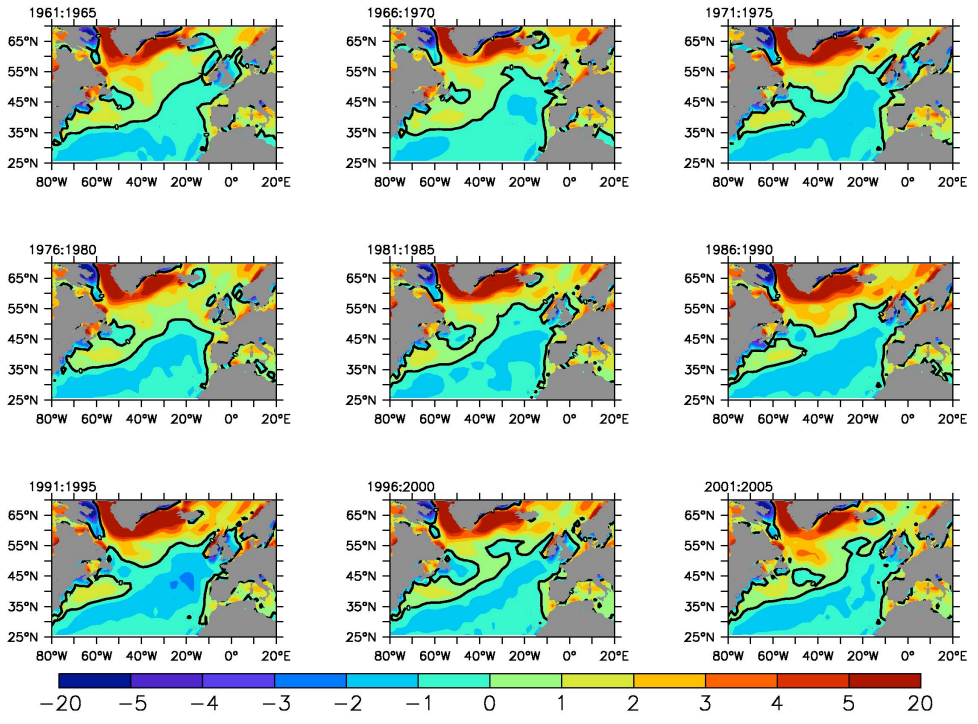


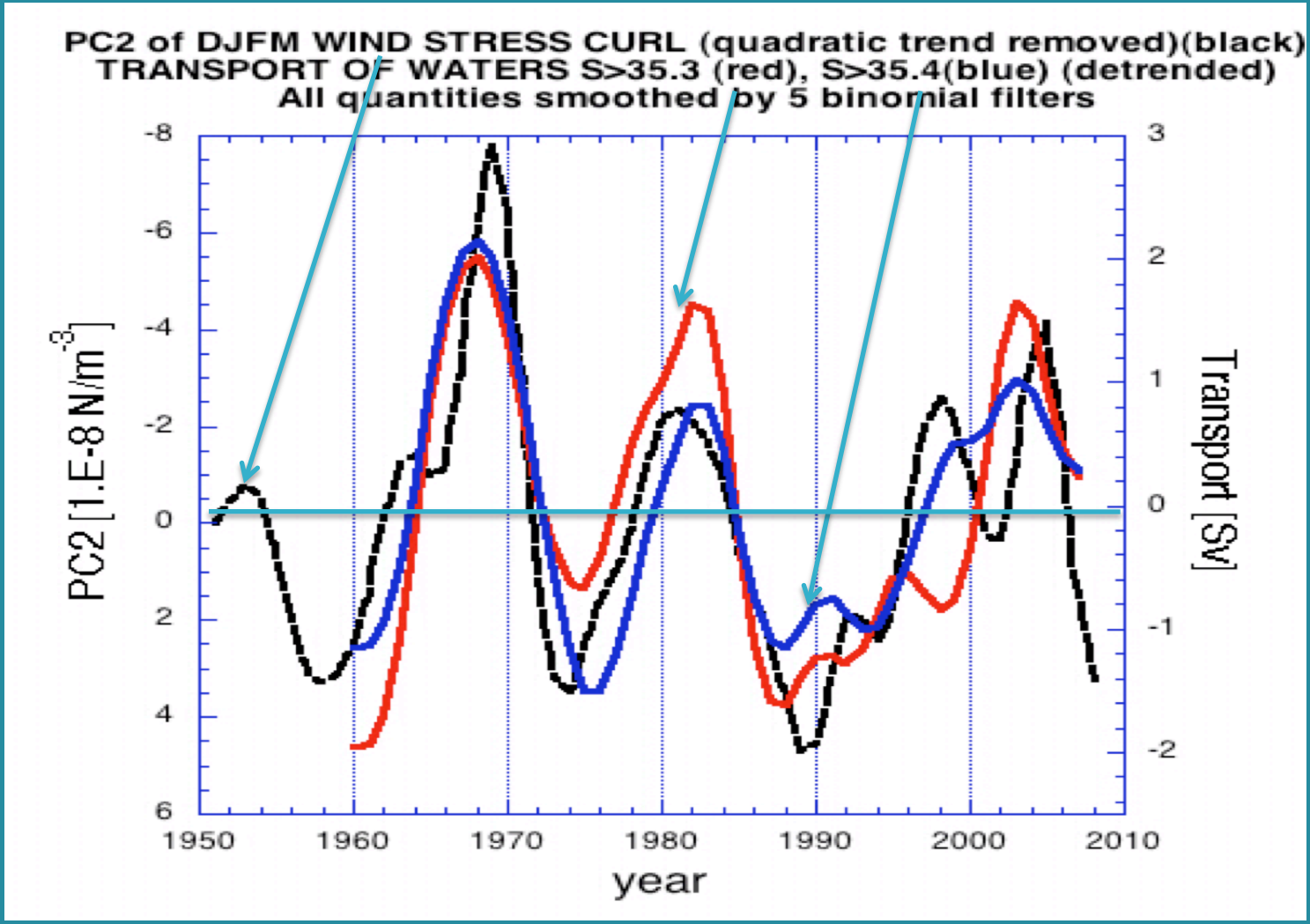


PCs (right)

DJFM CURL FIELDS FROM NCEP (below)







MAXIMUM TRANSPORT WHEN SUBTROPICAL AND SUBPOLAR CURL ANOMALIES ARE ASSOCIATED WITH THE WEAKENED GYRES

TRACER ADVECTION IN UPPER LAYER of a isopycnal 2-layer HIM model (Hallberg, 2000) driven by 2-gyre zonal windstress

EXPERIMENTS AFTER 50 year spin-up:

- 5 years of 20% stronger wind stress curl than in spin-up
- 5 years of 20% weaker wind stress curl than in spin-up

TRACER ADVECTION IN UPPER LAYER of simple isopycnal 2-layer HIM model driven by 2-gyre zonal windstress

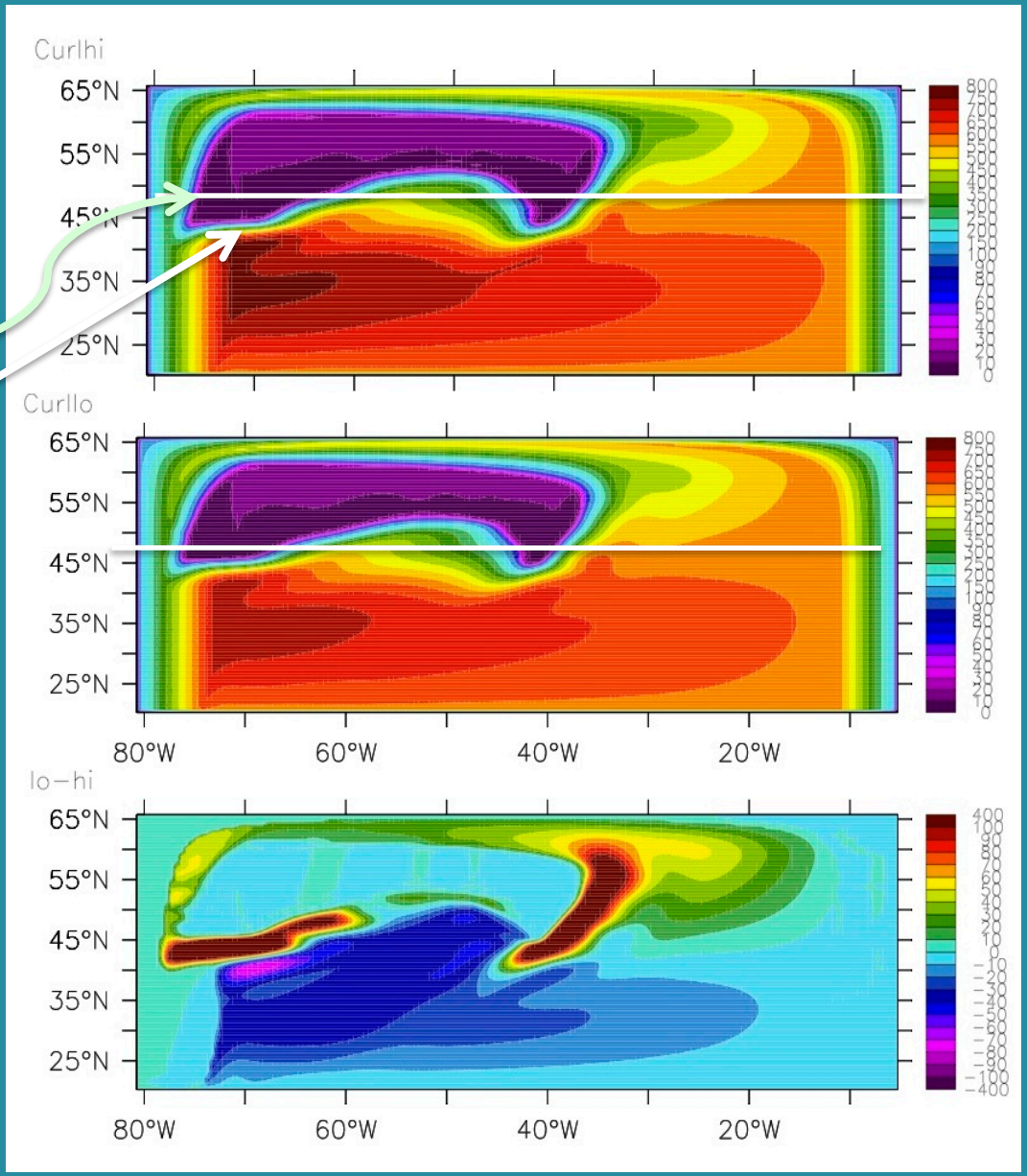
upper layer thickness: strong wind stress

outcropping of density surface

zero wind-curl line

weak windstress

difference



Thicker Upper Layer -> higher SSH
->
Need to revisit SODA SSH

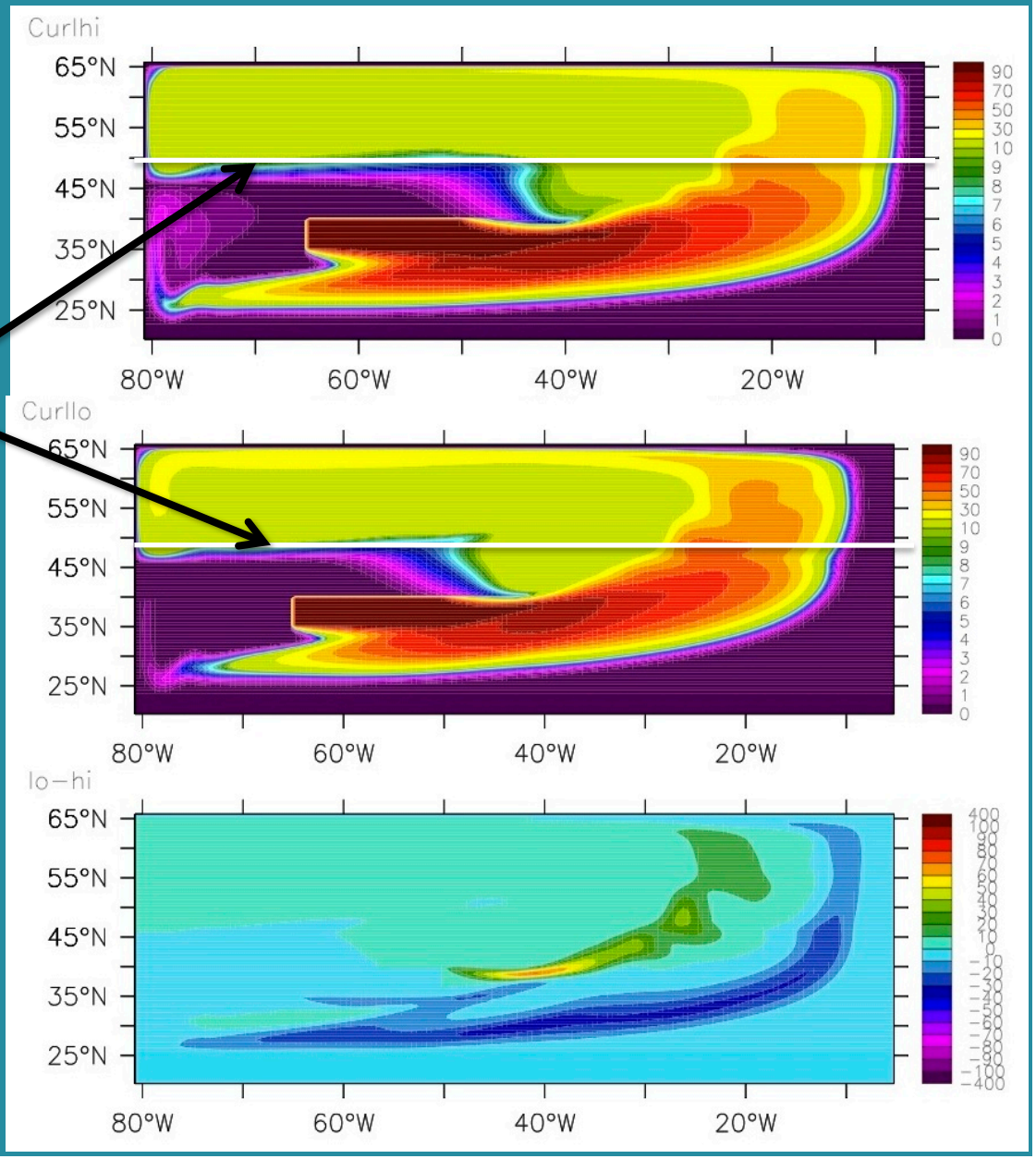
Tracer released in subtropical gyre penetrates subpolar gyre even with strictly zonal wind-stress; outcropping of cold layer forces transport from subtropics to subpolar gyre

Strong wind-curl

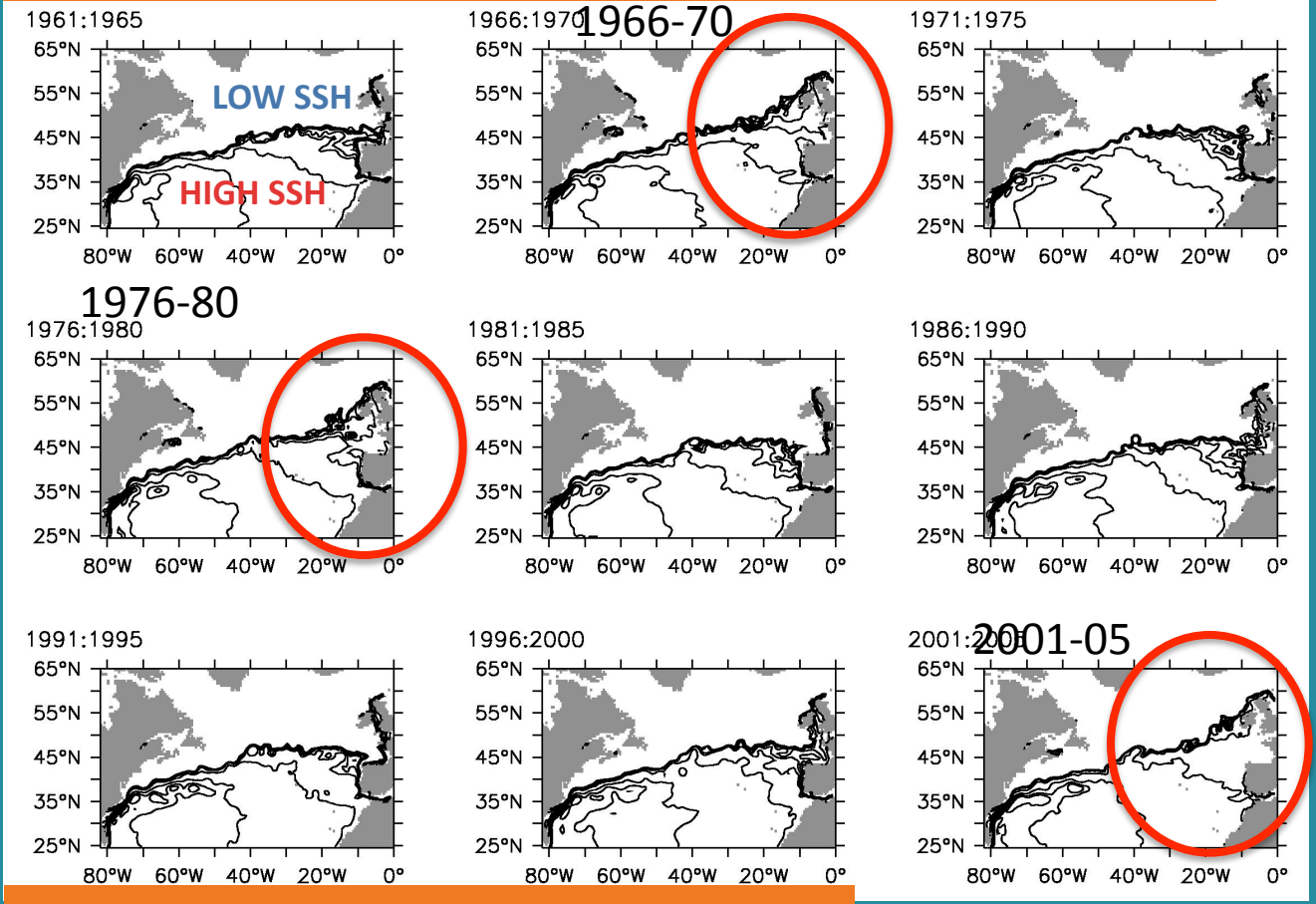
zero-curl

weak wind-curl

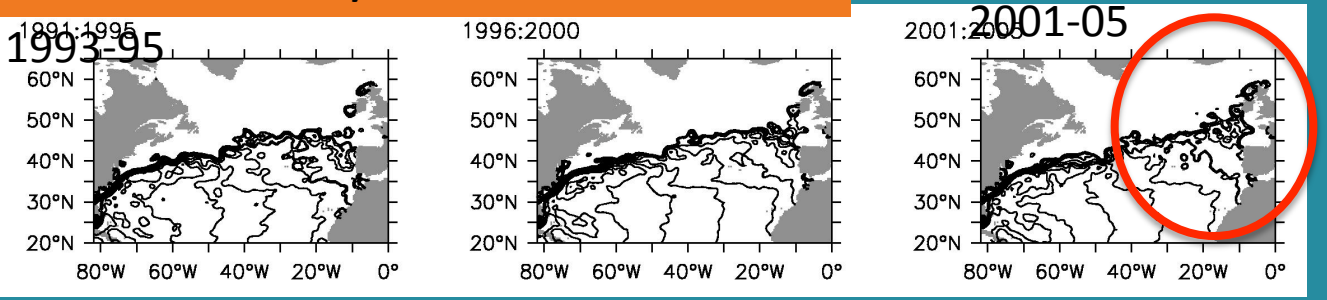
Weak-strong curl difference



SODA : STREAMFUNCTION/SSH PATHS STARTING SOUTH OF CAPE HATTERAS



STREAMFUNCTION/SSH PATHS FROM AVISO



Conclusions

Penetration of subtropical waters northward to the subpolar gyre 'appears' as a **strengthened upper limb of the AMOC** after 2000 in the SODA model assimilation (has not happened since 1960s)

- unclear if the net upper layer transports have changed, clearly the sources of the North Atlantic Current have shifted towards more subtropical origin as confirmed by tracer simulations, satellite altimetry, sea-surface drifters, OSCAR surface currents (*Hakkinen & Rhines*, JGR 2009)

The forcing: The first two EOFs of wind stress curl correlated in broad terms with the three recent warming-high salinity periods in the NE Atlantic (1960s, 1980, 2000s)

-The first mode PC follows closely NAO-index, however the spatial pattern of the second mode resembles climatologic North-Atlantic SLP pattern

- The second mode appears as the modulation of the climatologic forcing pattern of the two gyres and hence dominates the gyre response such that weak gyres => strong warming of subpolar gyre.

Changes in the NAC source waters may not be of immediate significance to AMOC but can have a delayed effect in increasing water mass modification in the Nordic Seas as happened in the 1960s and early 1970s