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NAO-Ocean circulation interactions in a coupled general circulation model

BELLUCCI Alessio

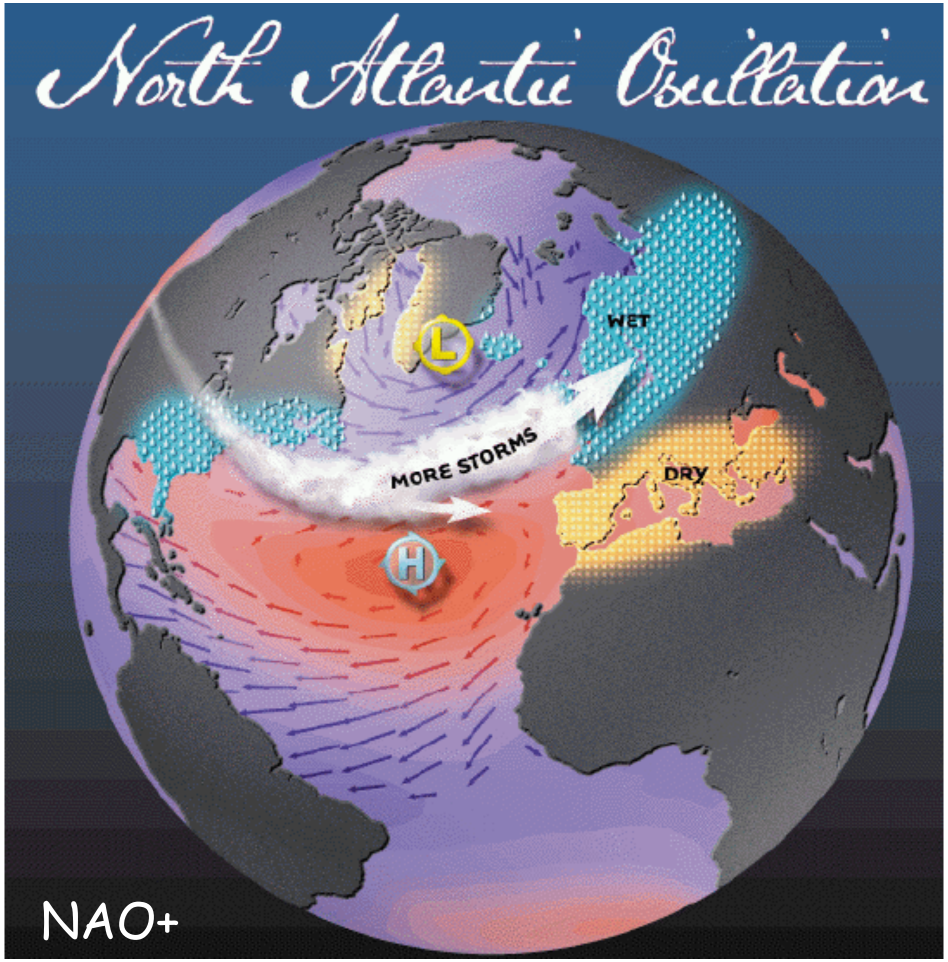
Centro Euro Mediterraneo per i Cambiamenti Climatici CMCC
Istituto Nazionale di Geofisica e Vulcanologica INGV
Via Aldo Moro, 44
40127 Bologna
ITALY

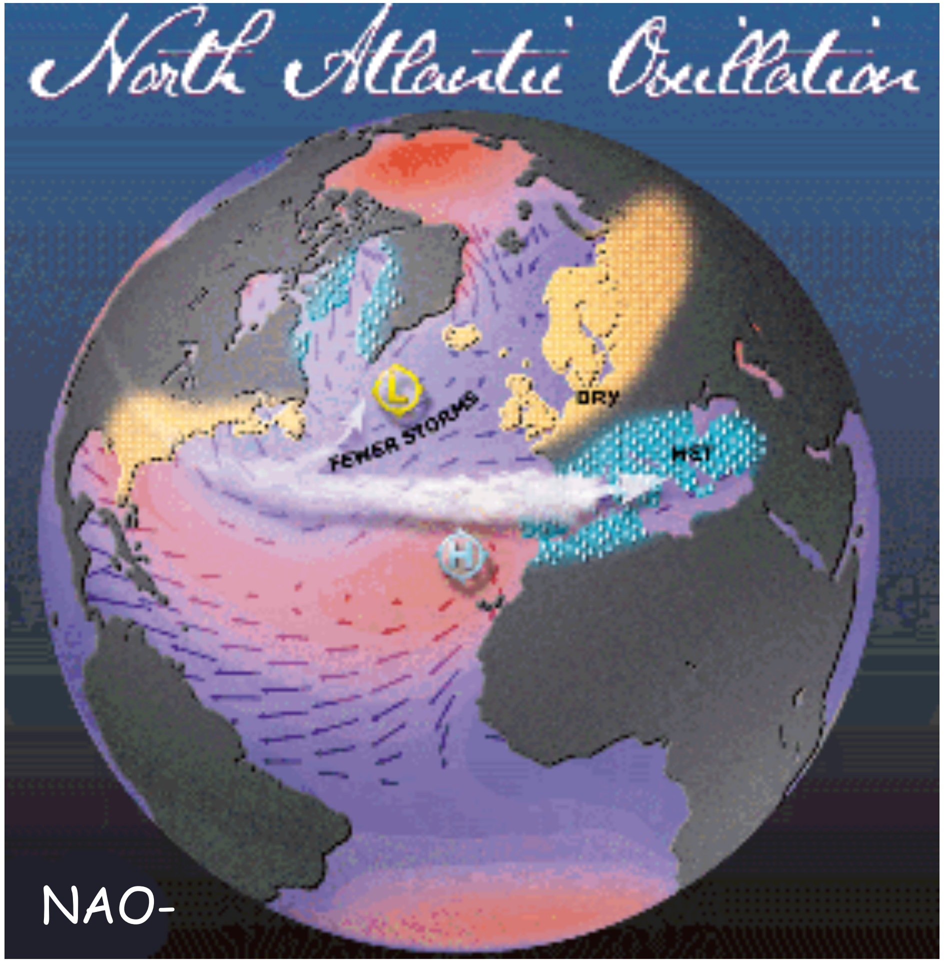
NAO-ocean circulation interactions in a coupled general circulation model.

Alessio Bellucci
Centro Euro-Mediterraneo per i Cambiamenti Climatici, Bologna, Italy
(bellucci@bo.ingv.it)

Motivations and Aims

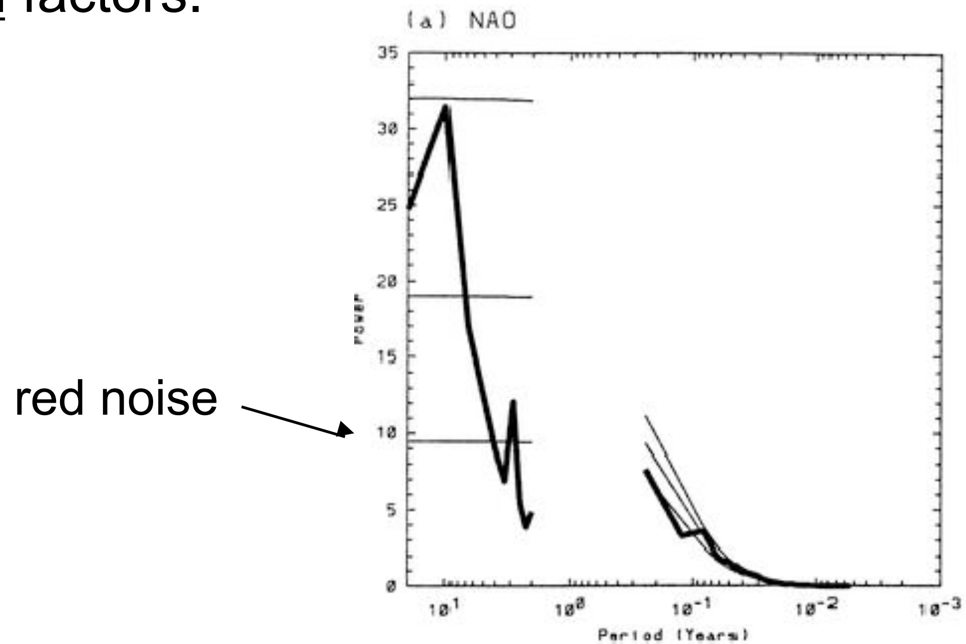
• According to a simple interpretation (the climate noise paradigm) the relevant space-time scales of NAO are determined by processes which are **internal** to the atmosphere.





Motivations and Aims

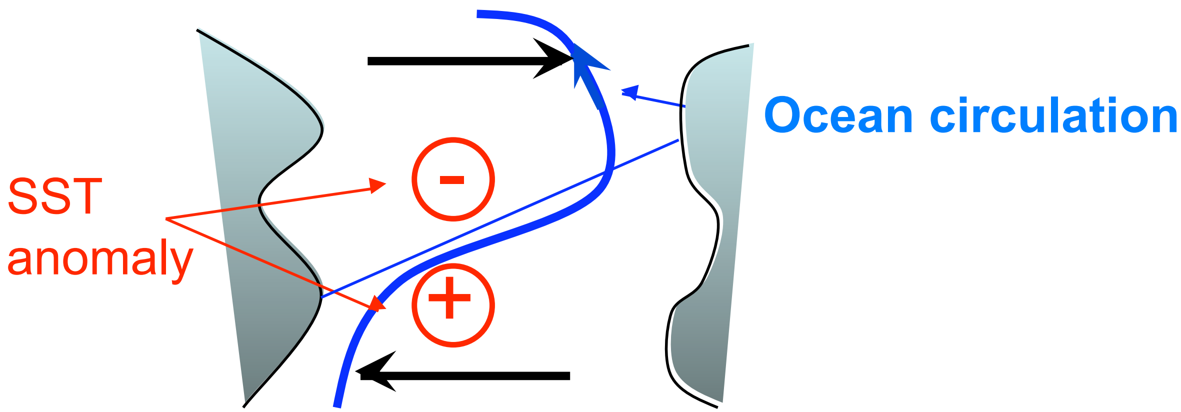
•However, departures from a red noise hypothesis are evident in the spectrum of the observed NAO, showing enhanced power around decadal and near-biennial time-scales, suggesting the involvement of **external** factors.

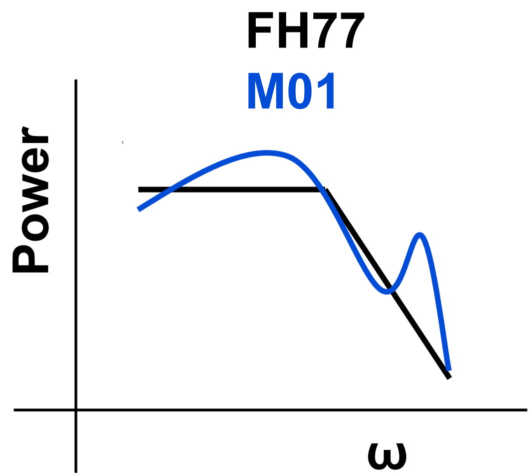


Power spectrum of 300 mb gph PC1 [Feldstein,2000]

•Among the external forcings which may potentially affect the NAO variability **what is the role of the ocean?**

•Marshall et al. (2001; M01) inspected the **interplay between NAO and ocean circulation** within a **theoretical framework** and suggest that both ocean gyre and/or thermo-haline circulation may determine coupled ocean-atmosphere interactions on decadal timescales. [***delayed oscillator*** **model**]





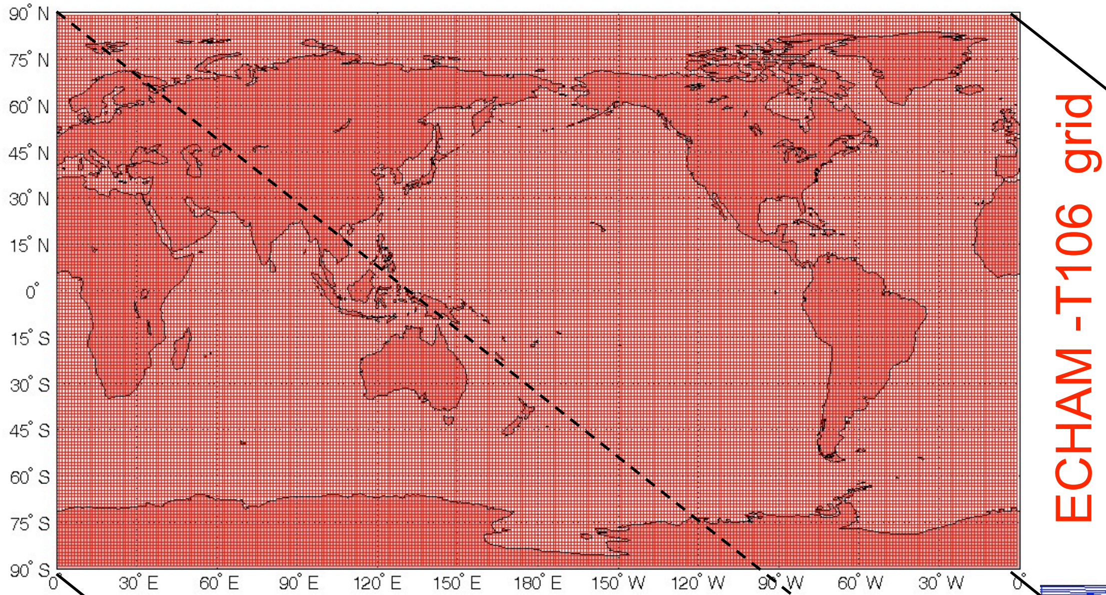
$dT/dt = F + \lambda T + \psi$

•So far, this issue has been mostly inspected within **simplified experimental settings** (analytical models , intermediate complexity models)

• Aim of this work is to investigate the role of ocean circulation in NAO low frequency variability within the context of a **full-fledged coupled sea-ice-OAGCM.**

SINTEX-G (SXG) MODEL (Gualdi et al., 2008)

- ATM: ECHAM4 T106 and 19 hybrid sigma-pressure levels
- OCE: ORCA2 2°x2°cosφ w/ increased resolution near the Equator, 31 levels
- ICE: LIM thermodynamic-dynamic snow sea-ice model



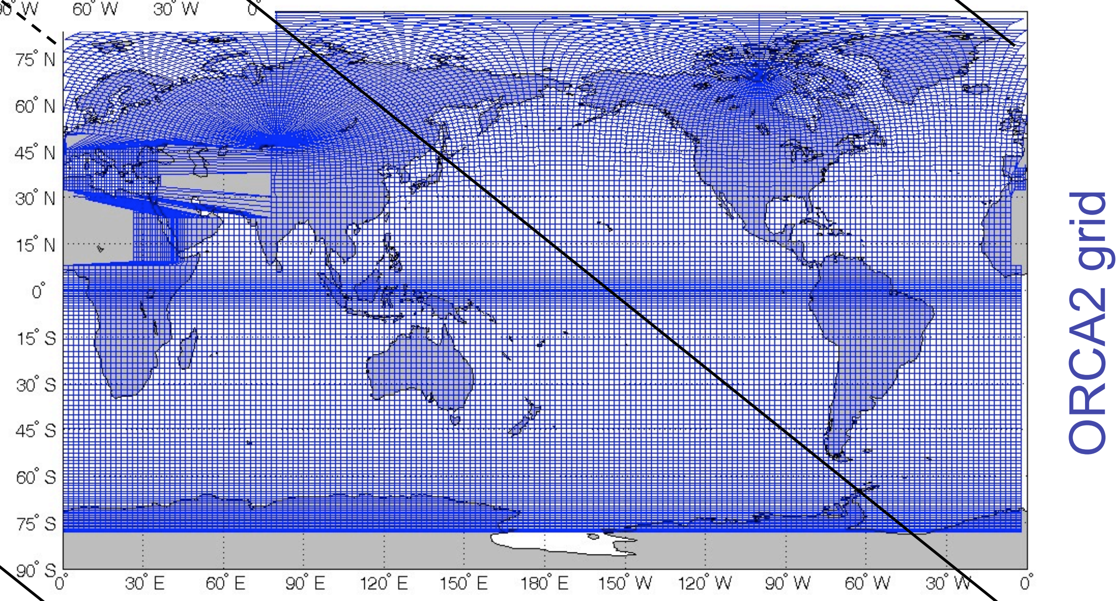
ECHAM T106 domain: 320x160x19

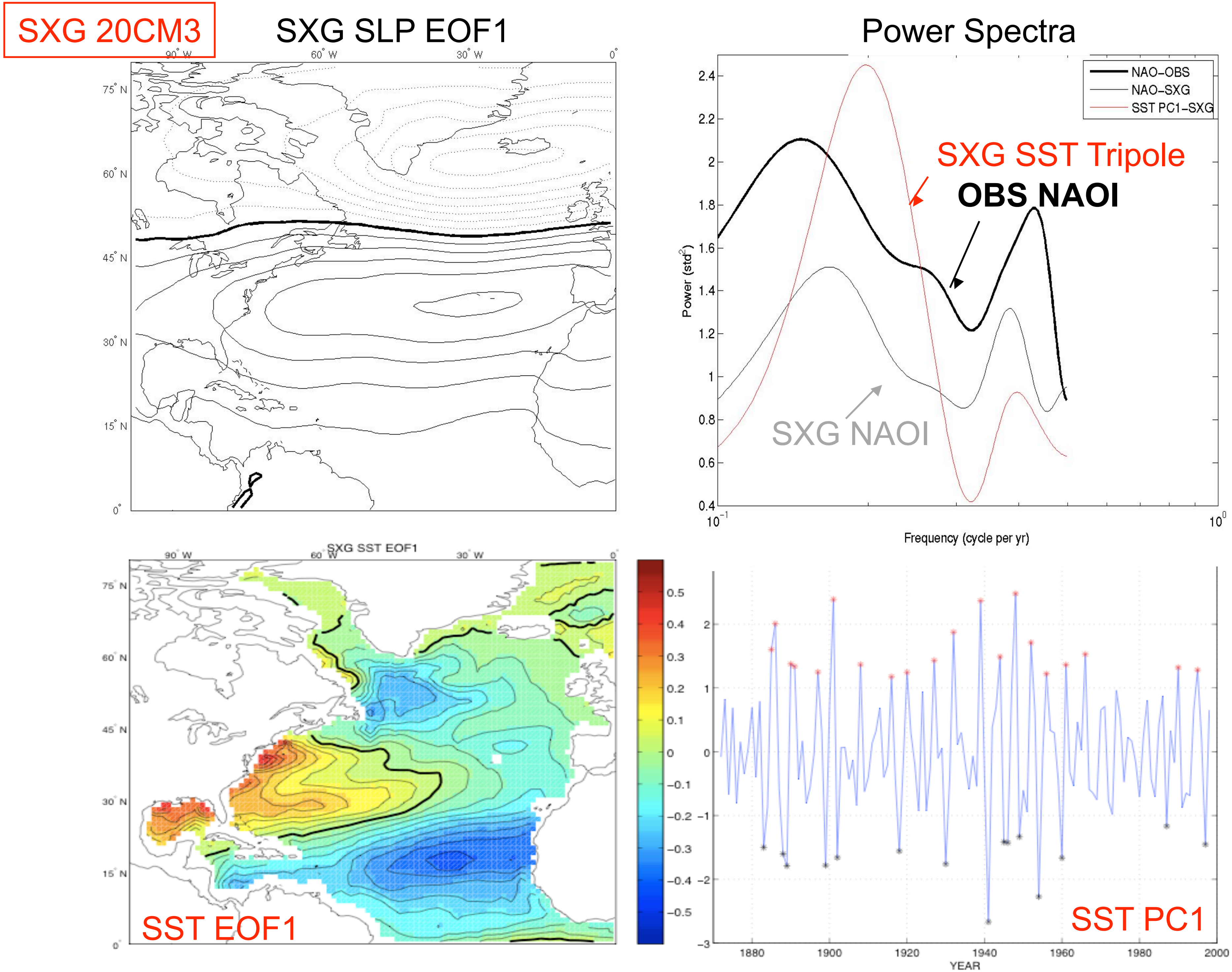
1.125°

ORCA2 domain: 149x182x31

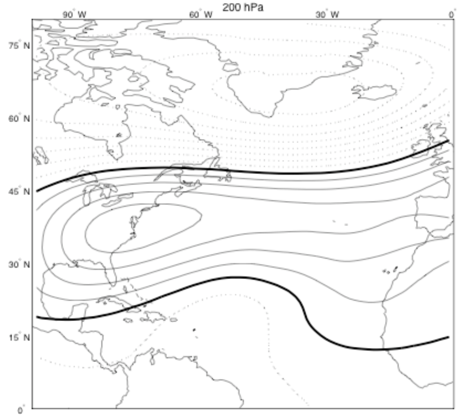
2° longitude

0.5° - 2° latitude

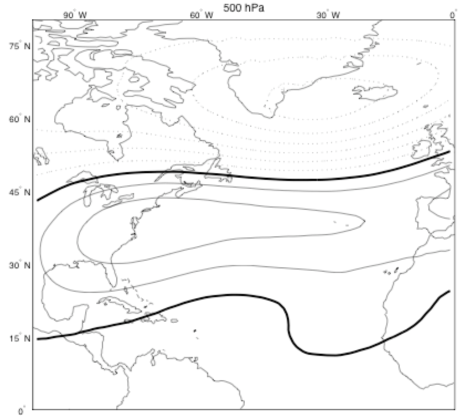



SXG 20CM3
SXG SLP EOF1
Power Spectra
NAO-OBS
NAO-SXG
SST PC1-SXG
SXG SST Tripole
OBS NAOI
SXG NAOI
Power (std^2)
Frequency (cycle per yr)
SXG SST EOF1
SST EOF1
SST PC1
YEAR

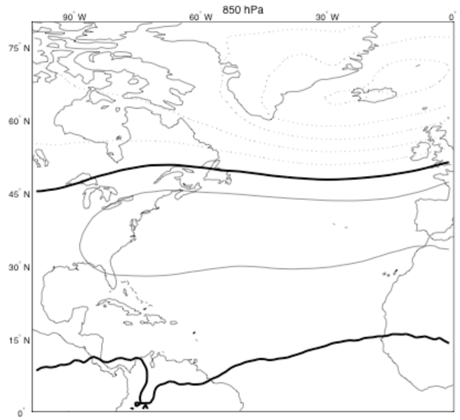
Composites of winter (JFM) GPH anomalies keyed to the NAOI (positive phase): **equivalent barotropic response**.



200 hPa



500 hPa

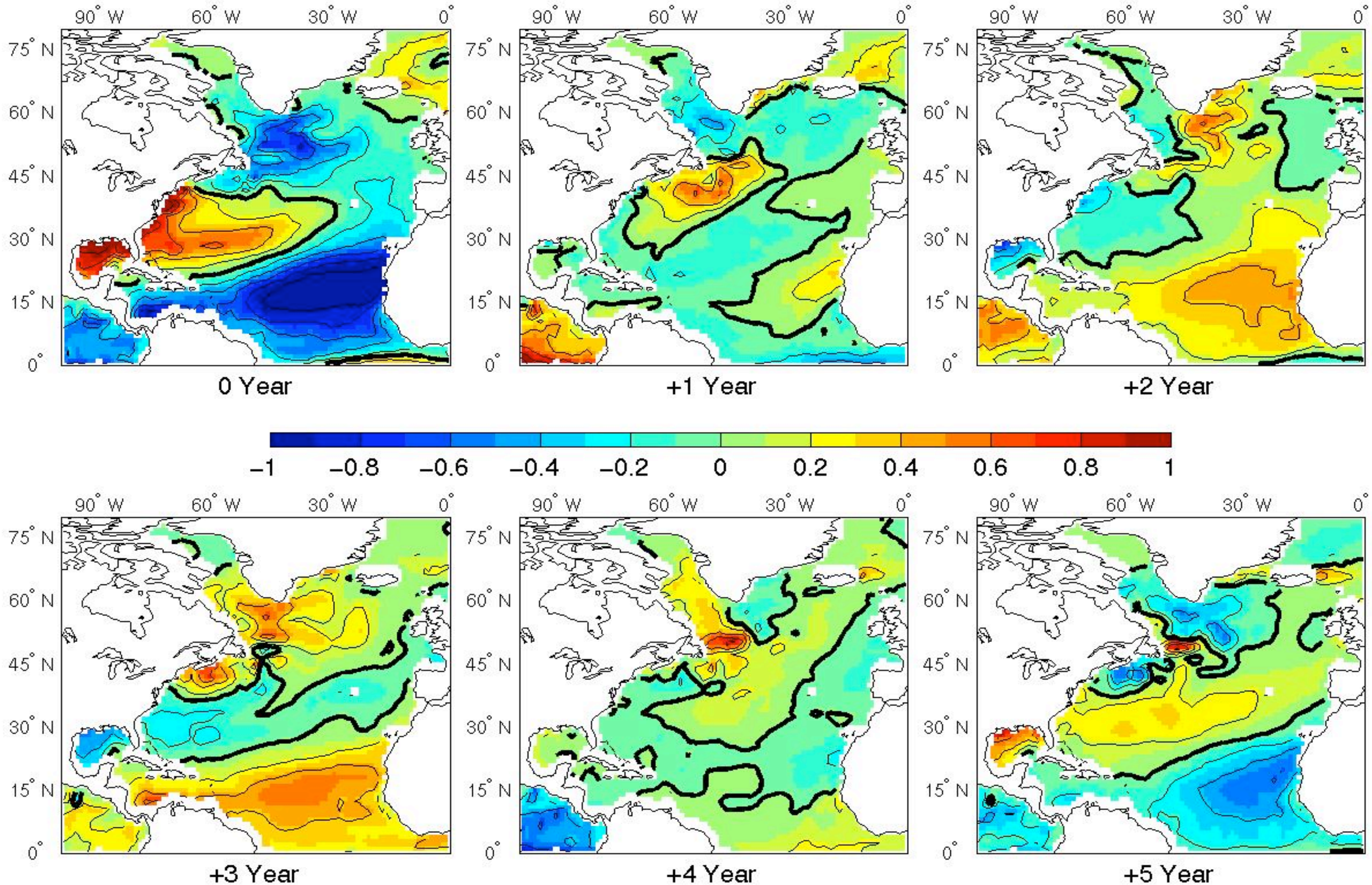


850 hPa

C.i.=10 m

zg_response

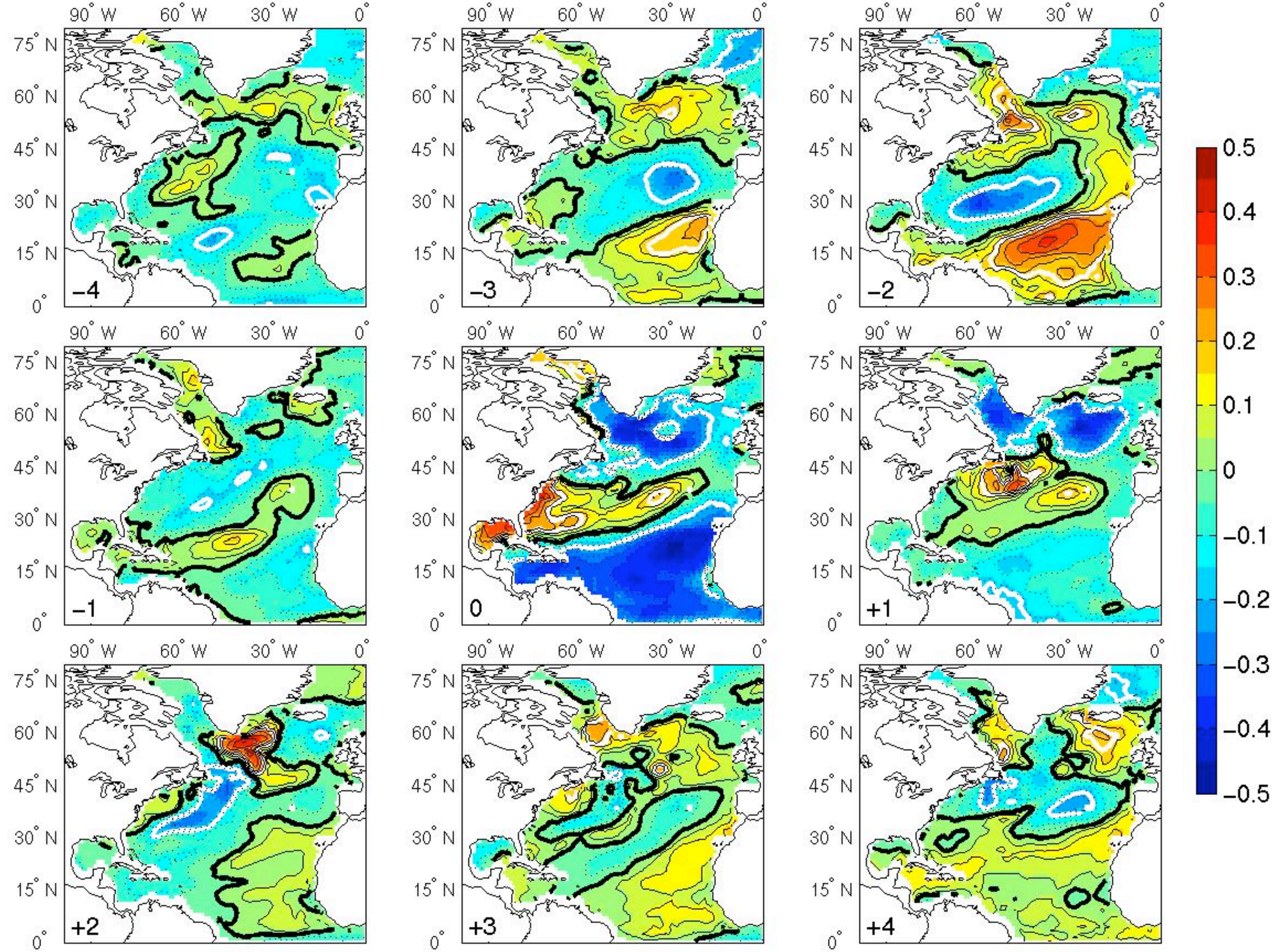
SST Composite maps (keyed to the SST PC1)

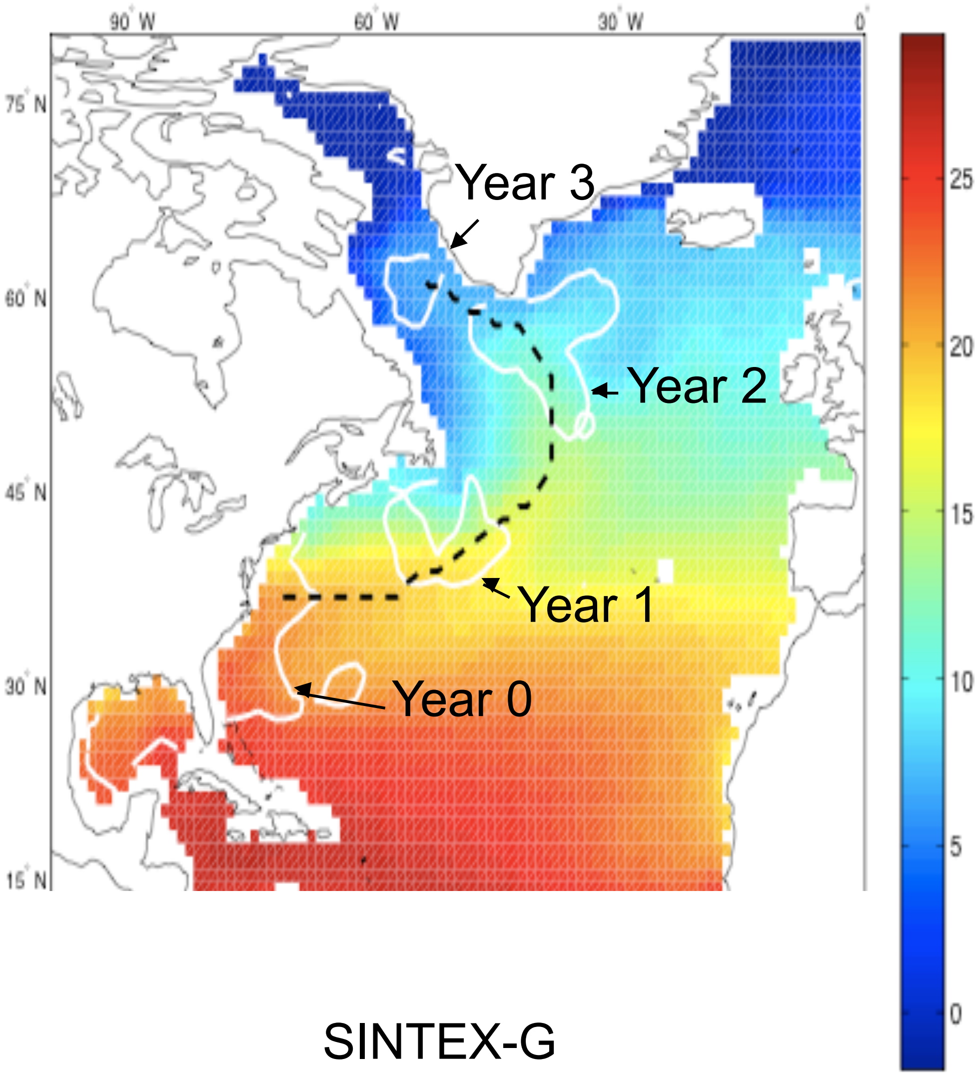


Re-emergence of the tripole in a 5 years time.

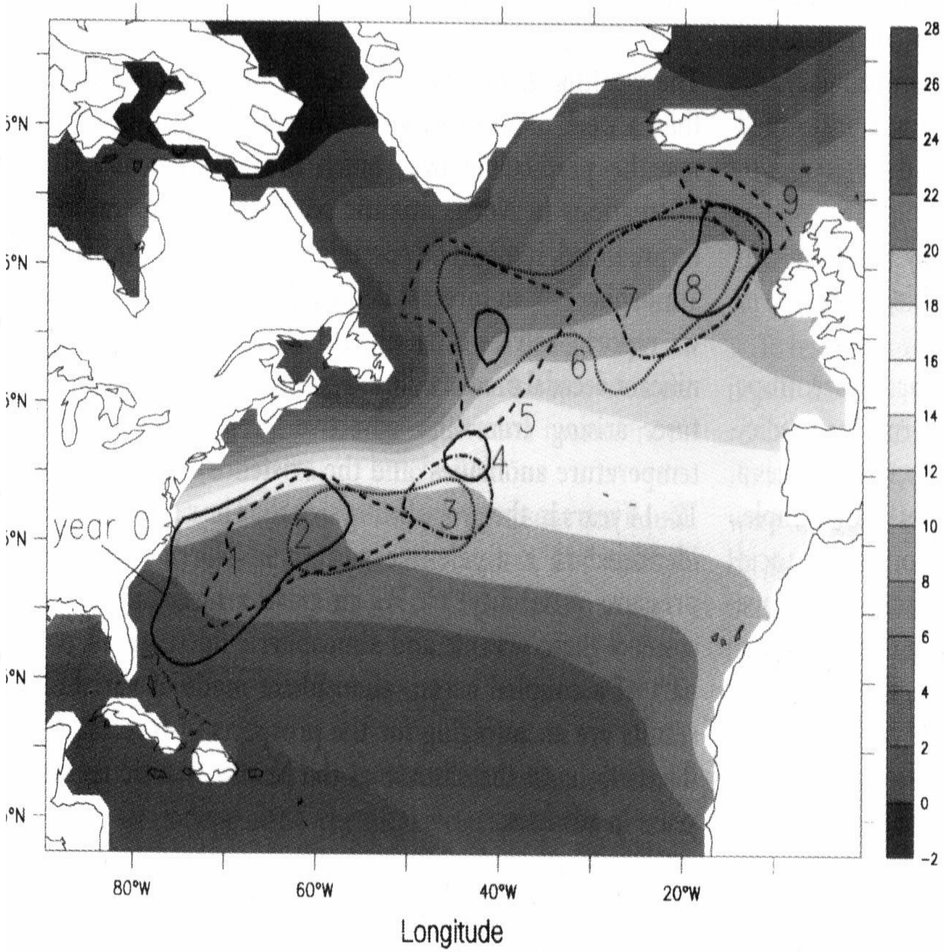
Thermal inertia of the mixed layer accounts for an ocean memory of a few months (Frankignoul et al. 1998). If the tripole reappears (instead of undergoing an exponential decay) an additional process must be at work.

Lead-lag Correlation Analysis of NAOI/SST (NAOI leading for positive time lags)



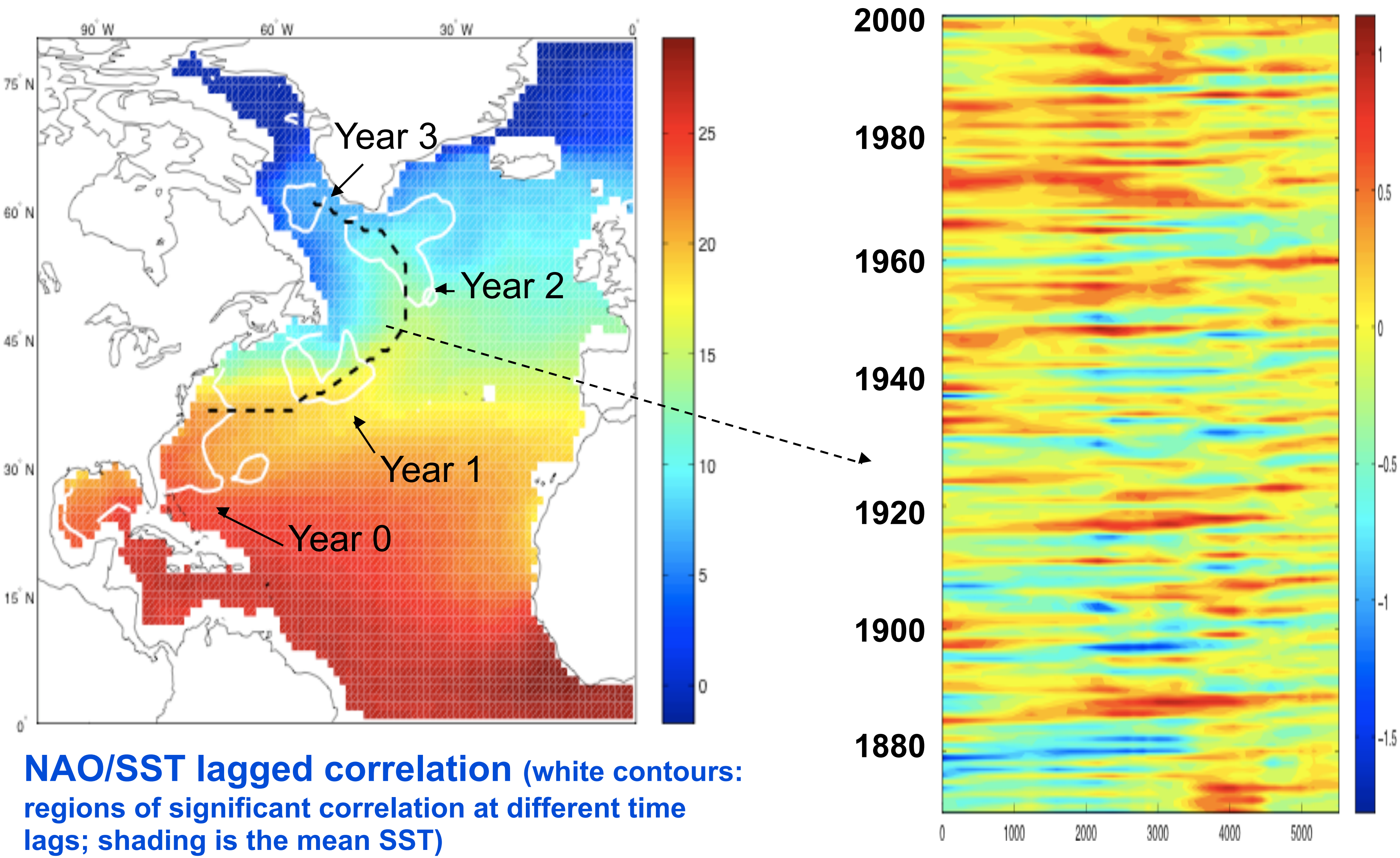


SINTEX-G



Sutton and Allen, 1997

NAO/Ocean Circulation Interactions

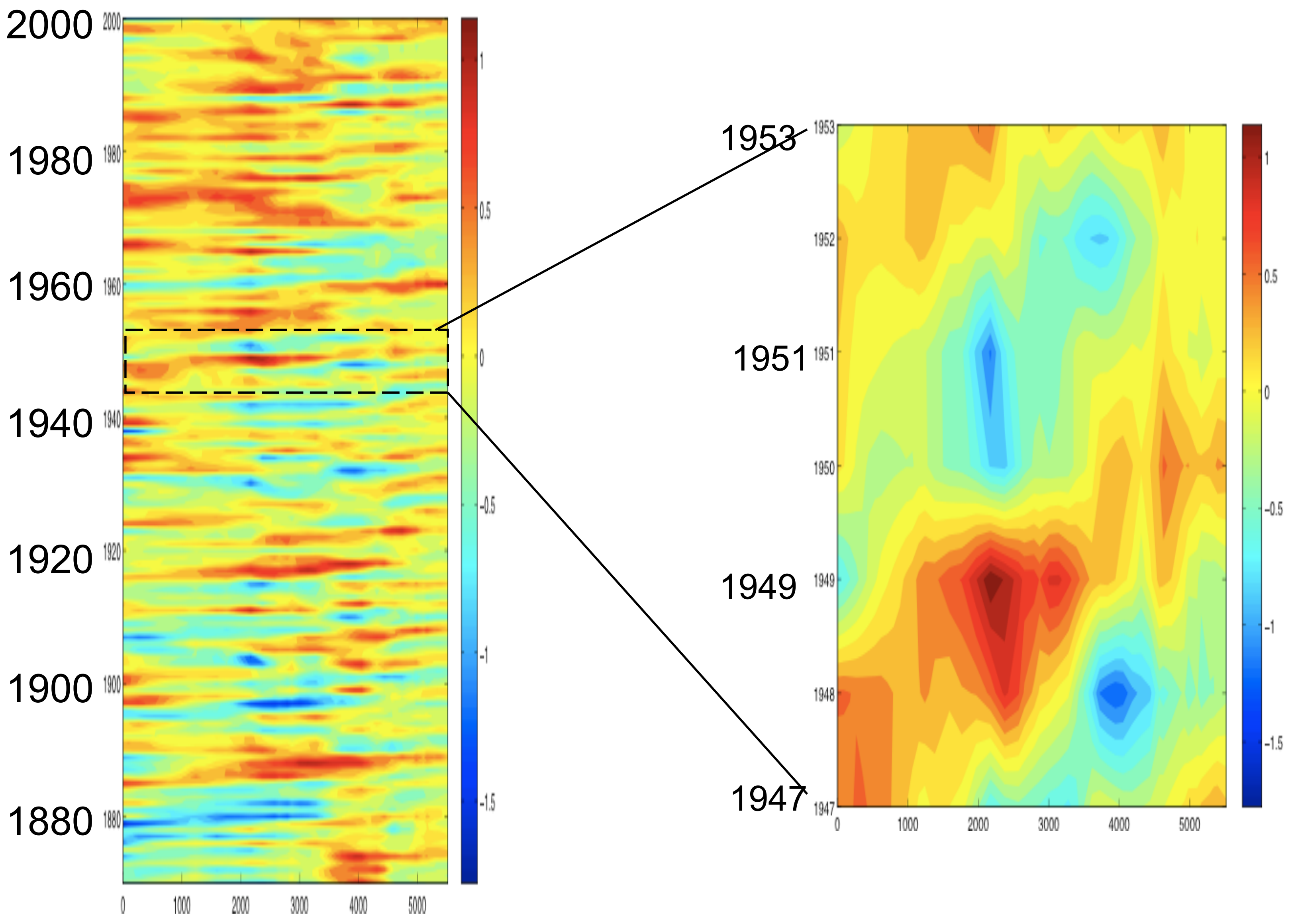


NAO/SST lagged correlation (white contours: regions of significant correlation at different time lags; shading is the mean SST)

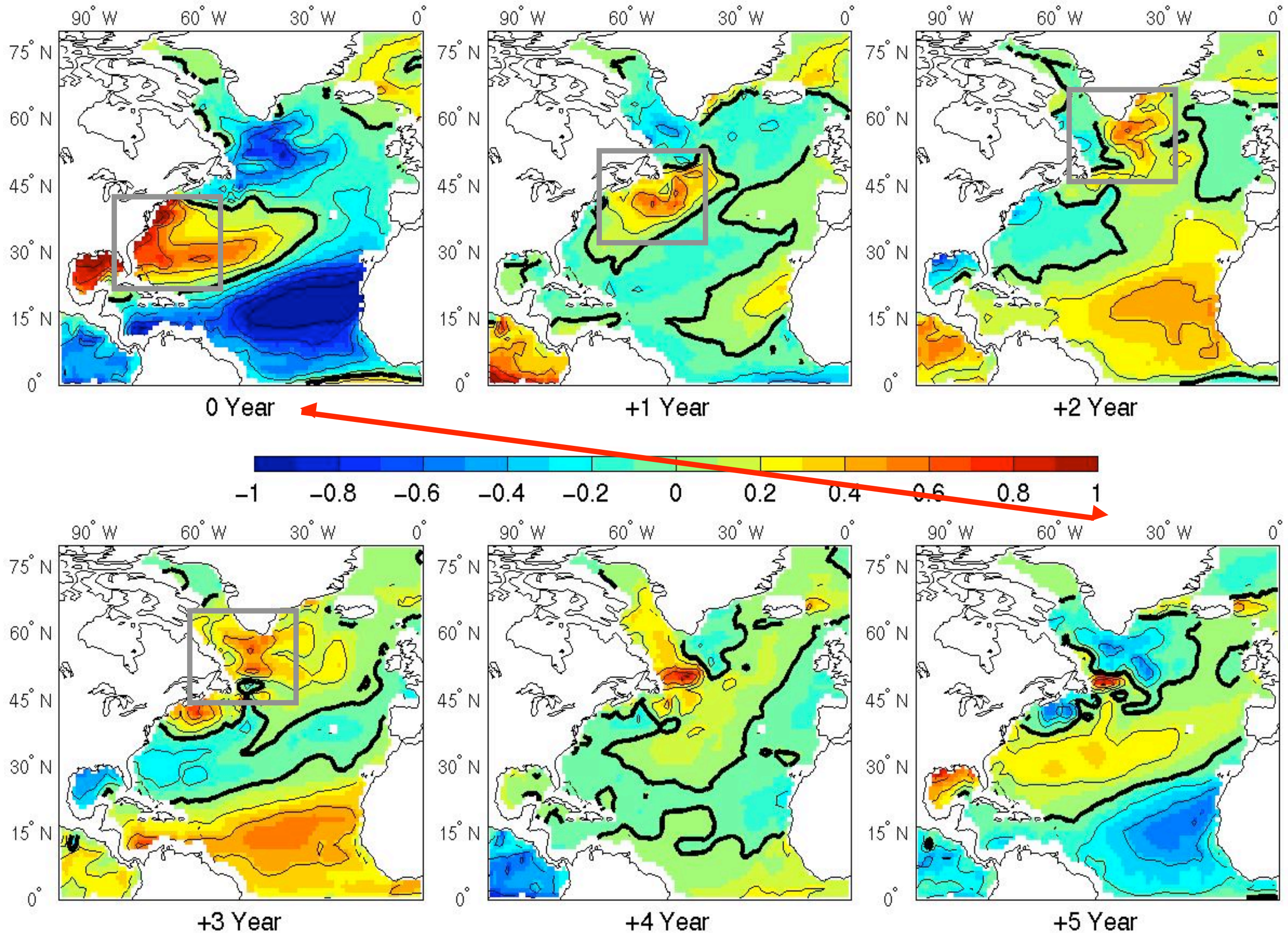
SST Along-track Hovmoeller diag

Warm (cold) thermal anomalies generated during positive (negative) NAO episodes are propagated by lateral advection to the high latitudes.

Along-track SSTA hovmoller diagram (NAC pathway).



NAO/Ocean Circulation Interactions

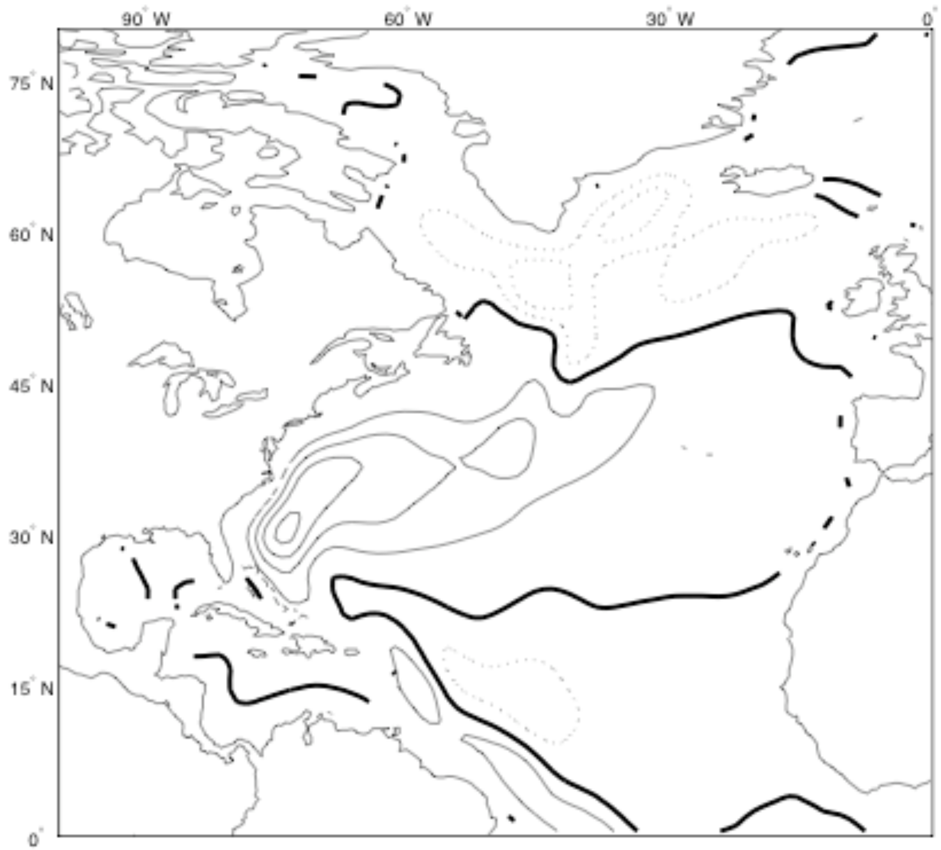


SST Composite maps keyed to the SST PC1. (Years with PC1 > 1 std minus years with PC1 < -1 std for different time-shifts). Note the re-emergence of the tripole after 5 yr.

This advective mechanism increases the long term memory of the SST, and the <u>re-emergence of the SST tripole</u>, on multiannual time-scales.

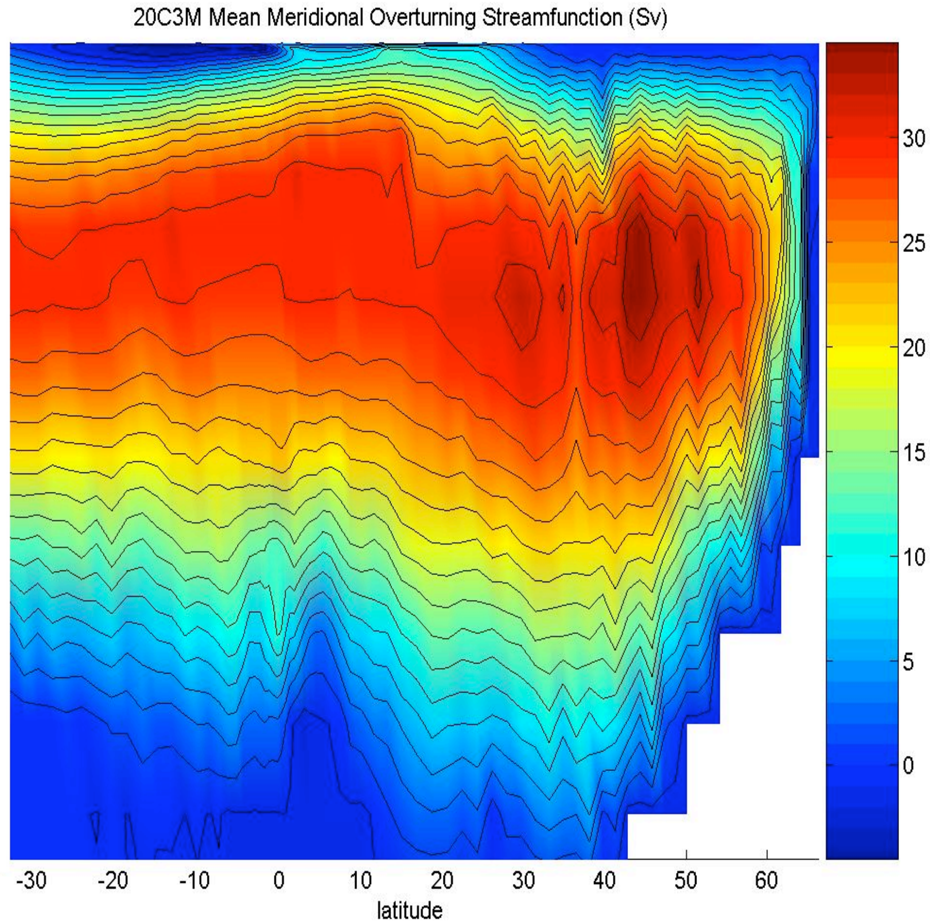
The role of ocean circulation in the meridional heat transport.

Gyre circulation

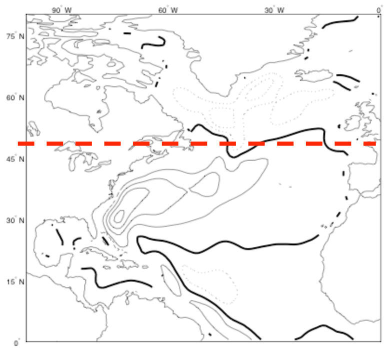


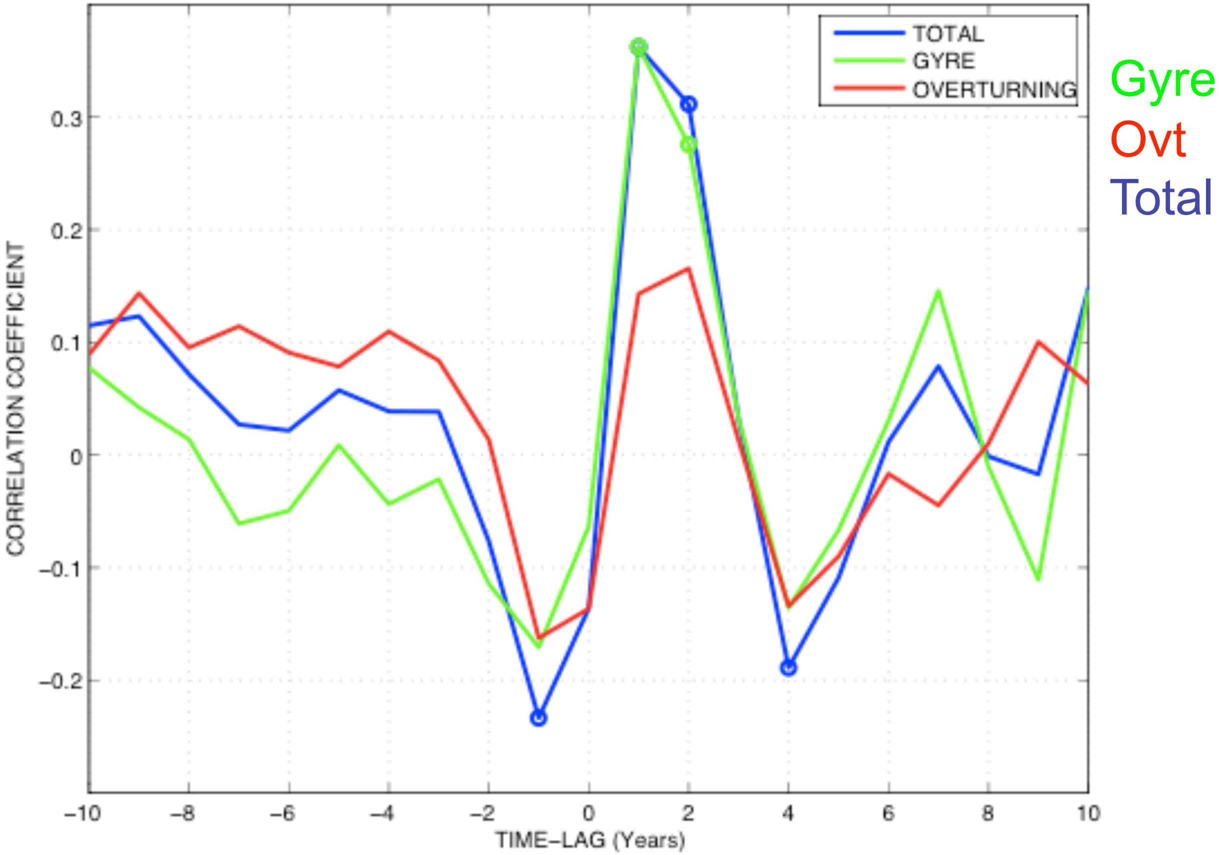
c.i. : 10 Sv.

Meridional overturning circulation



NAOI/Meridional Heat Transport lagged correlation at the cross-gyre boundary (51N). [NAOI leads for positive lags.]

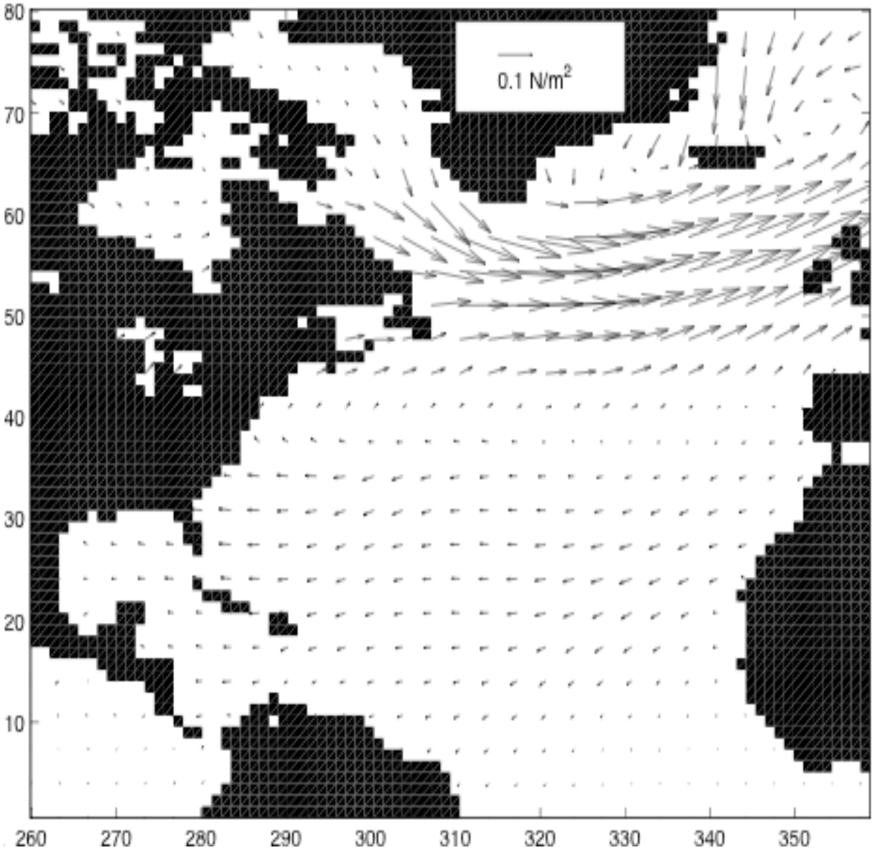




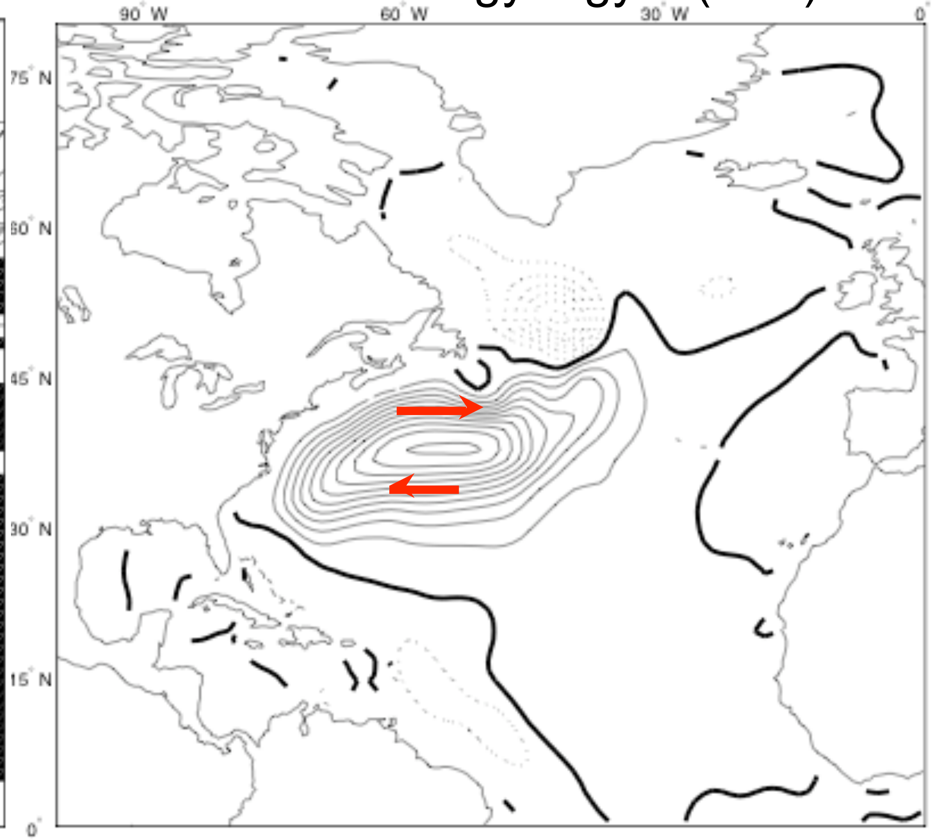
Correlation is larger for the gyre contribution. Max. correlation for both ovt and gyre is achieved in 1-2 yrs and is positive. Hence, NAO+ drives a delayed poleward heat transport which concurs to a warming of the SPG.
A warming in the subpolar region pushes the NAO towards a negative phase (NAO-) which in turn produces a weaker northward heat transport, restoring cooler conditions at the northern latitudes.

The anomalous gyre circulation response to the NAO wind-stress.

Composite of JFM wind stress :NAO+ minus NAO-



Ψ EOF1:Inter-gyre gyre (IGG).

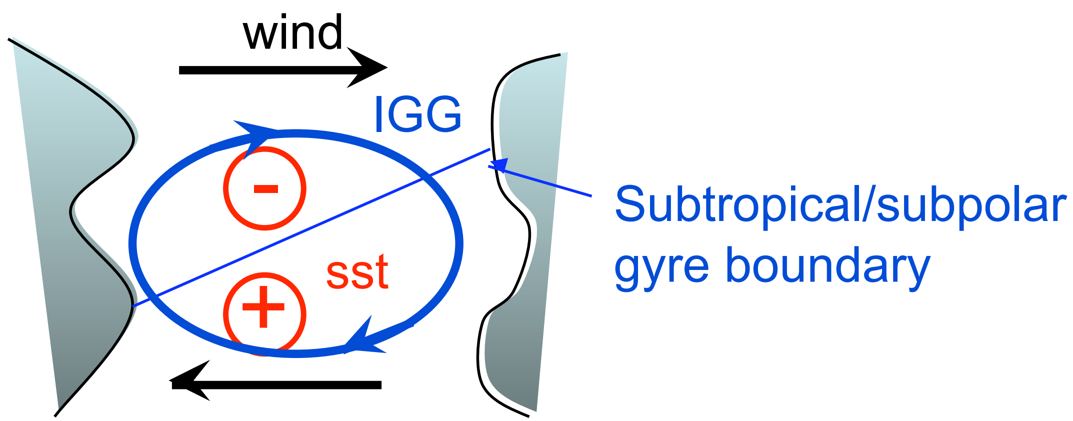


Inter-gyre gyre: consistent with the barotropic streamfunction anomaly driven by NAO wind-curl as predicted by Sverdrup balance:

$$\Psi(x,\phi) = -\frac{a\tan\phi}{\rho_0}\int_{x_E}^{x}\mathbf{k}\cdot(\nabla\times\frac{\boldsymbol{\tau}}{f})dx'$$

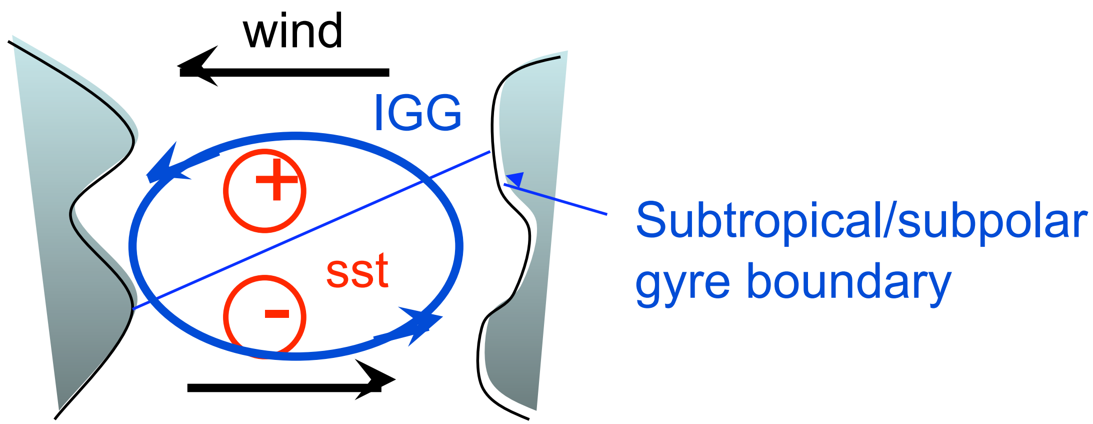
During a NAO+ phase the IGG contributes to the warming of high latitudes, hence weakining the SST meridional gradient.
(ocean circulation/NAO negative feedback)

NAO+

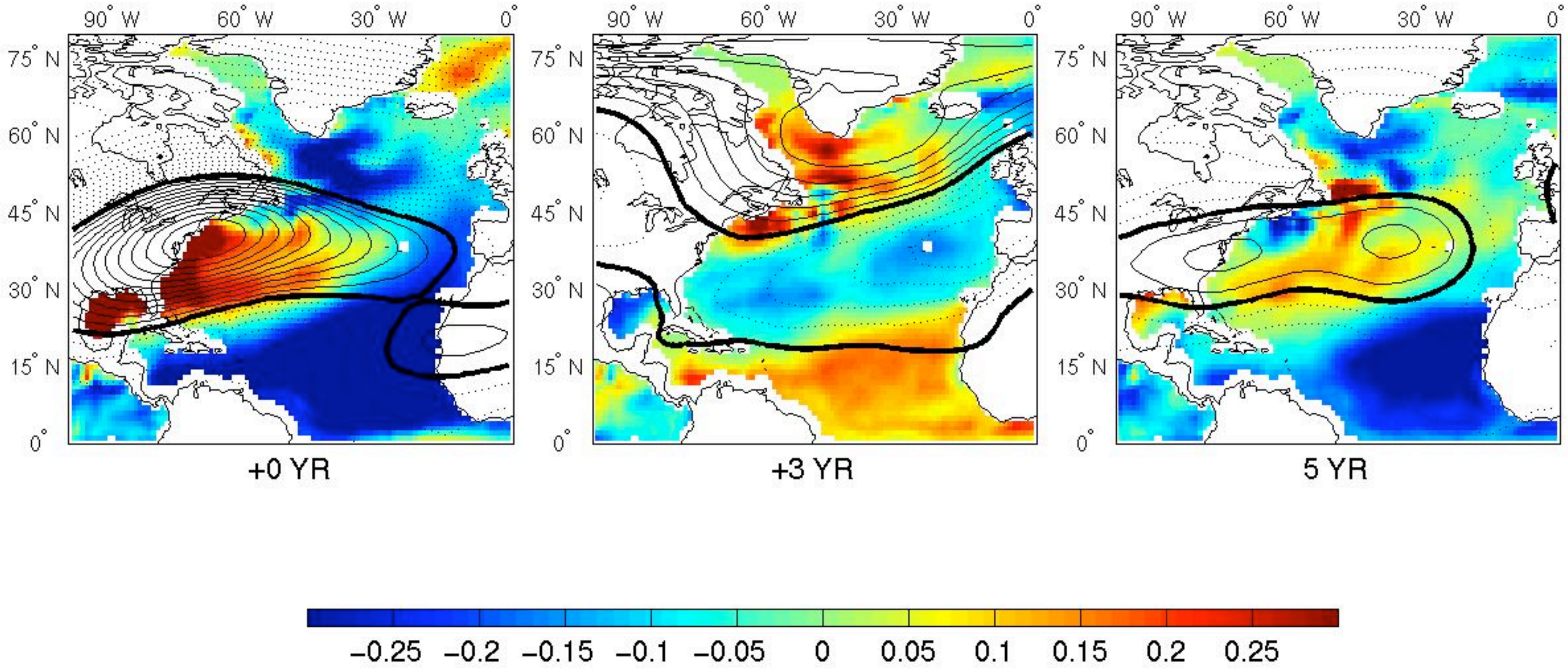


Once the northern SST dipole has reversed its sign, there are favourable conditions for the NAO to enter into a negative phase
(SST/NAO positive feedback)

NAO-



Composite maps of 200 hPa GPH and SST keyed to the SST PC1 (computed for years when SST PC1> 1 std)



GPH c.i.: 5 m

Conclusions

- Results from a full-fledged sea-ice-ocean-atmosphere GCM suggest that midlatitude variability in the North Atlantic sector on multi-annual time-scales is determined by an oscillatory mode involving covarying changes in SST and atmospheric circulation with a typical NAO-like pattern.

- Anomalous wind-driven circulation associated with the NAO wind-torque is responsible for carrying heat through the subtropical/subpolar gyre boundary, which in turn modulates the northern lobes of the SST tripole.

- The MOC appears to be less efficient in driving the NAO-induced poleward cross-gyre heat transport.

- Present results are qualitatively consistent with the **delayed-oscillator paradigm** (Marshall et al. 2001; Czaja and Marshall 2001).

For more details:

Clim Dyn
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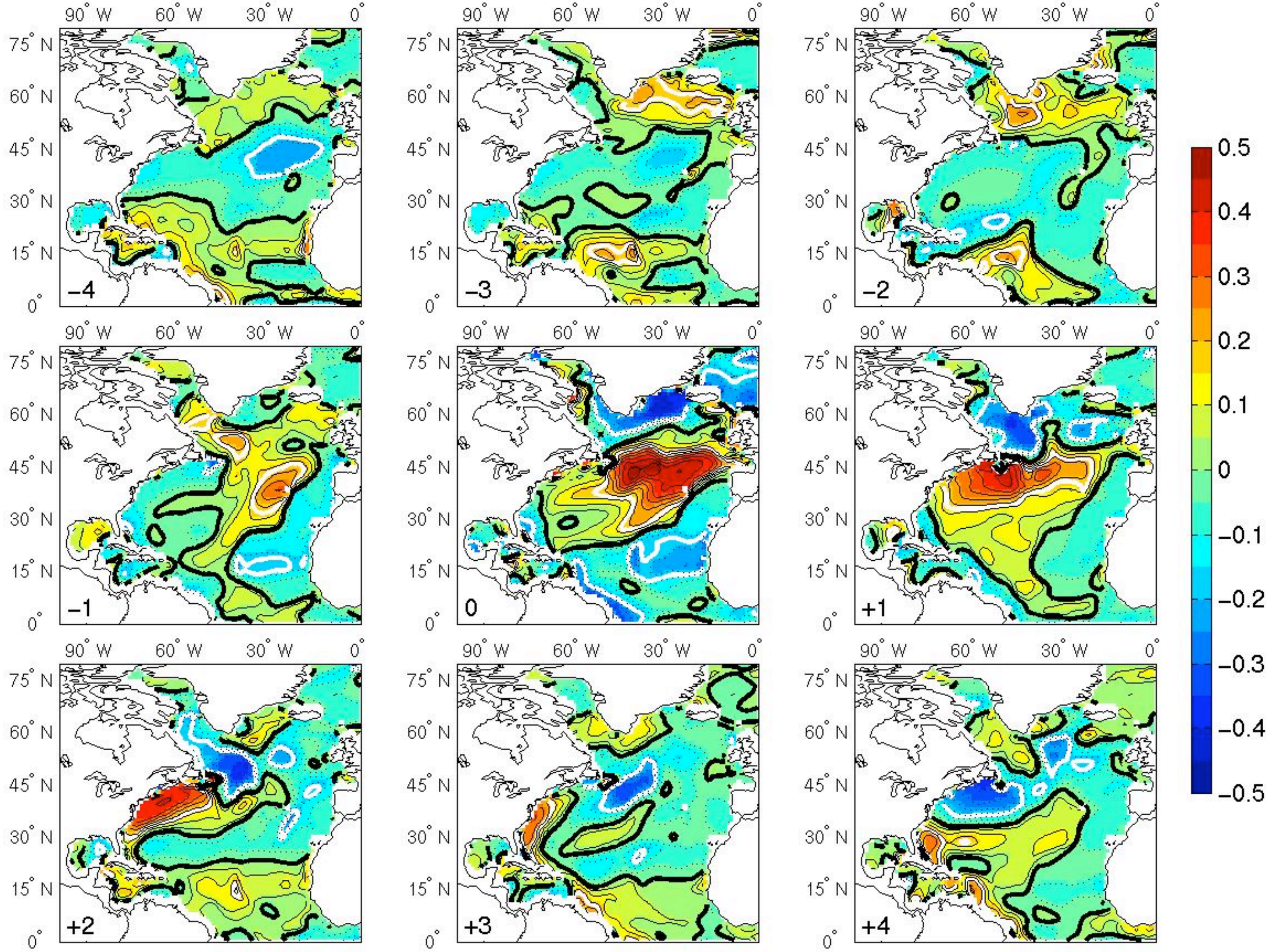
NAO–ocean circulation interactions in a coupled general circulation model

A. Bellucci · S. Gualdi · E. Scoccimarro ·
A. Navarra

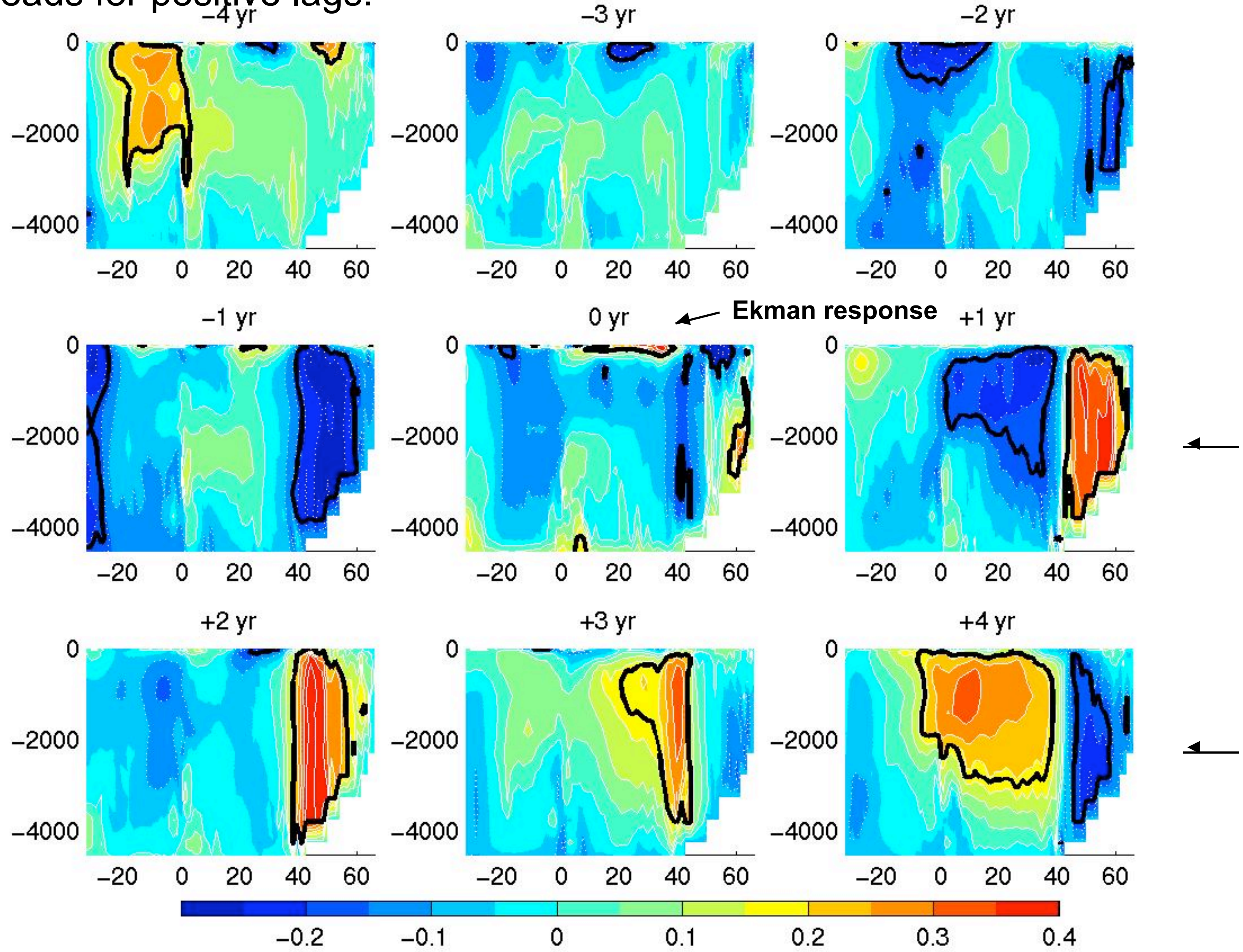
In press :Bellucci et al. Climate Dynamics (2008), 31:759-777.

Thank you!

Correlation maps of NAOI and barotropic streamfunction for several time lags. NAO leads for positive lags.



Correlation maps of NAOI and Meridional Mass Transport for several time lags. NAO leads for positive lags.



Ekman surface response at lag 0. Dipole at lags>0.

Delayed Oscillator: Parameter estimate

$$d\Delta T/dt = -\lambda^*\Delta T - f^*g^*\Delta T(t-1/2)$$

R = f*g*/λ* :Ratio between *gyre efficiency* (g*f*) and damping SST *damping* (λ*)

MODEL (SINTEX – G) R = 0.1 → Very damped!
OBS(Czaja and Marshall,2001) R = 0.4