An ocean-ice model study of the post-1995 collapse of the North Atlantic subpolar gyre

Mats Bentsen[1,2], Helge Drange[3,2], Katja Lohmann[4], Anne Britt Sandø[5,2], and Hjálmar Hátún[6]

[1]Nansen Environmental and Remote Sensing Center, Bergen Norway
[2]Bjerknes Centre for Climate Research, Bergen, Norway
[3]Geophysical Institute, University of Bergen, Norway
[4]Max Planck Institute for Meteorology, Hamburg, Germany
[5]Institute of Marine Research, Bergen, Norway
[6]Faroese Fisheries Laboratory, Torshavn, Faroe Islands

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Outline

- Ocean model and its configuration.
- Atmospheric forcing.
- Spinup procedure.
- Investigation of the post-1995 collapse of the sub polar gyre.

Ocean model and its configuration

The ocean model is MICOM with several modifications:

- Incremental remapping used for advection of layer thickness and tracers.
- Both temperature and salinity are prognostic variables.
- No linearization of the bottom pressure.
- New formulation of the pressure gradient force.
- New equation of state.
- Modified barotropic/baroclinic mode splitting.
- Parameterizations of shear instability and gravity current diapycnal mixing are included.
- Improved conservation.

Configuration

- Global domain, non-eddy resolving. Some experiments done with enhanced resolution in the North Atlantic/Arctic region.
- 35 isopycnic layers.
- Reference pressure at 2000 db.

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Atmospheric forcing

- Daily forcing fields from either NCEP/NCAR or ERA40 reanalysis.
- The reanalysis air-sea fluxes of momentum, heat, and freshwater are reproduced exactly if the models ocean state is identical to the ocean state of the reanalysis.
- When the ocean state differs, the turbulent fluxes are modified consistent with the Fairall et al. (1996) bulk parameterization and long-wave radiation is modified consistent with the Berliand and Berliand (1952) parameterization.
- The method is described in Bentsen and Drange (2000).

$$\tau^d = -\rho_a C_D^d \left(u_a^d\right)^2$$
$$Q_H^d = \rho_a c_p C_H^d u_a^d \left(T_s^d - T_a^d\right)$$
$$Q_L^d = \rho_a L_e C_E^d u_a^d \left(q_s^d - q_a^d\right)$$

$$\tau^m = -\rho_a C_D^m \left(u_a^d\right)^2$$
$$Q_H^m = \rho_a c_p C_H^m u_a^d \left(T_s^m - T_a^d\right)$$
$$Q_L^m = \rho_a L_e C_E^m u_a^d \left(q_s^m - q_a^d\right)$$

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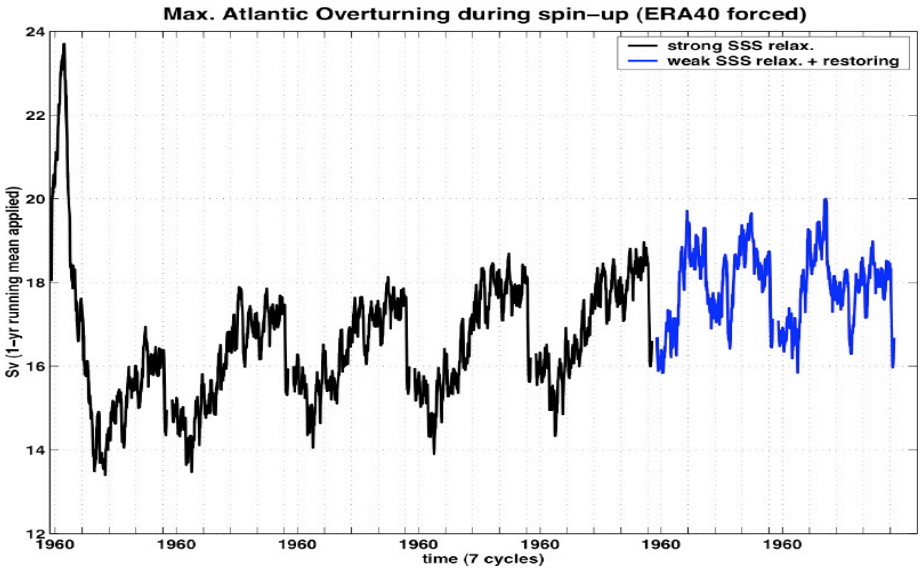
Spinup procedure

- Minimum full 4 reanalysis cycles with daily forcing; usually 6 full cycles (~300 yr).
- Starts with strong SSS-relaxation; 30 days e-folding time scale for 50 m thick mixed layer; limited to |ΔSSS<0.5| everywhere; no relaxation under sea-ice.
- Diagnose SSS-nudging when model is steady (5th or 6th cycle); applying diagnosed SSS-fluxes for the production runs with weak Newtonian relaxation (360 days time scale for 50 m ML and |ΔSSS<0.5|).
- Temperature relaxation is not used.



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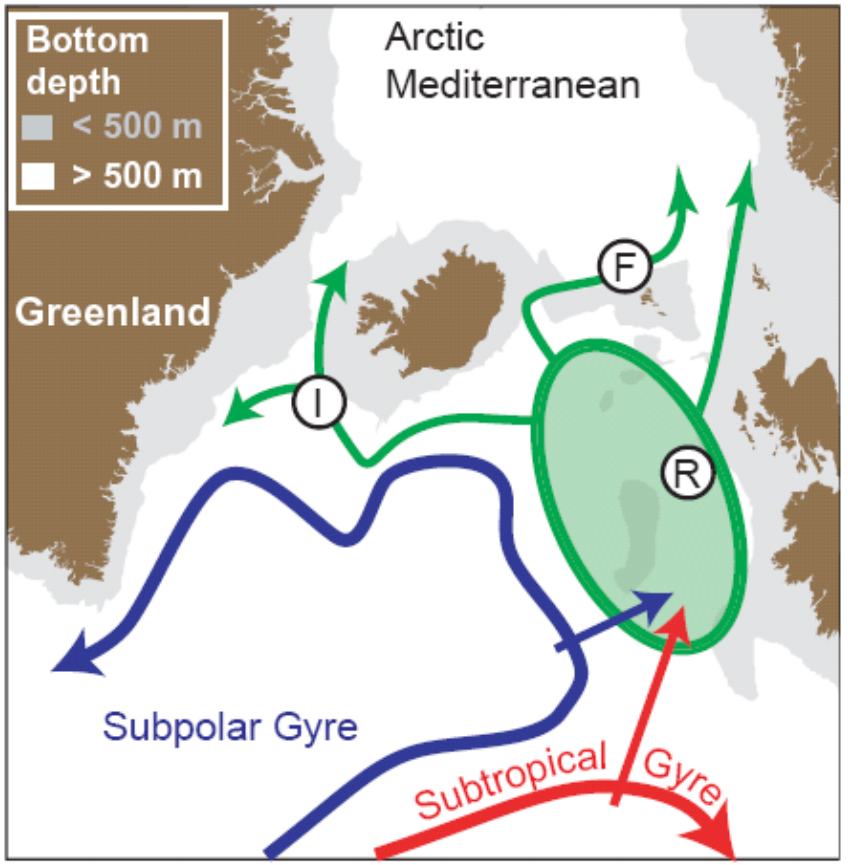
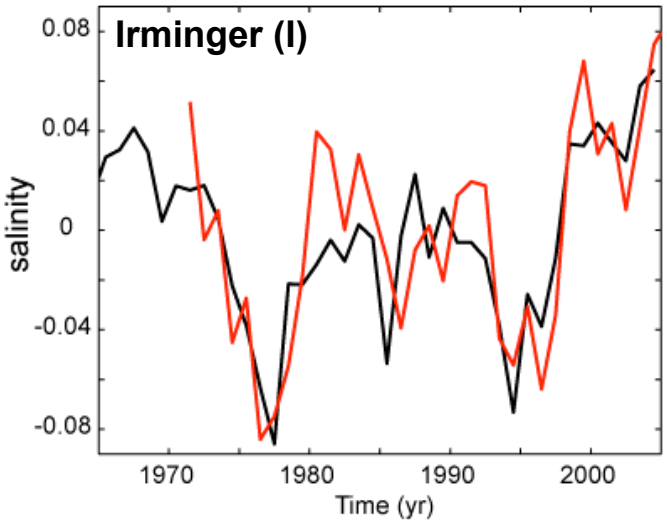
Hatun et al., *Science* (2005); *Prog. Ocenogr.* (2009)

Observed and simulated salinity anomalies at three locations in the northern North Atlantic





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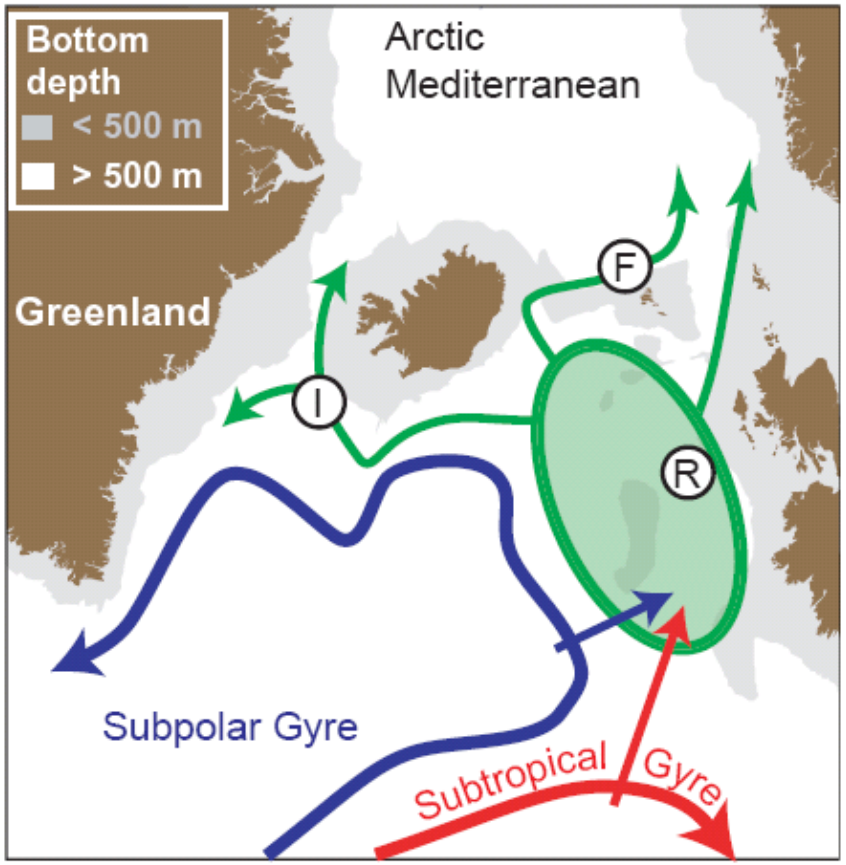
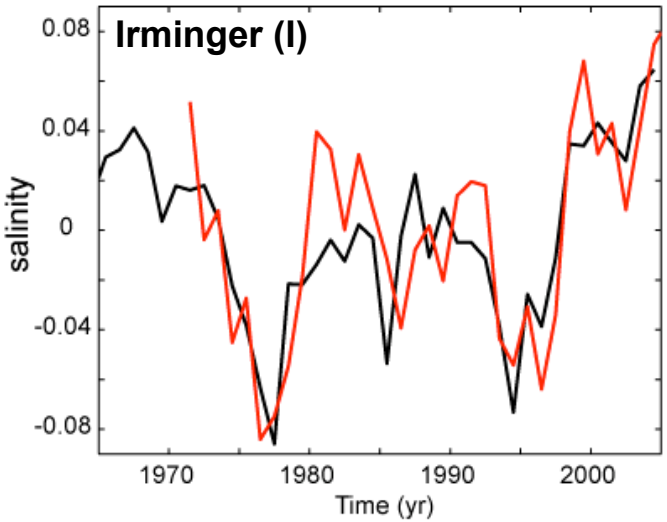
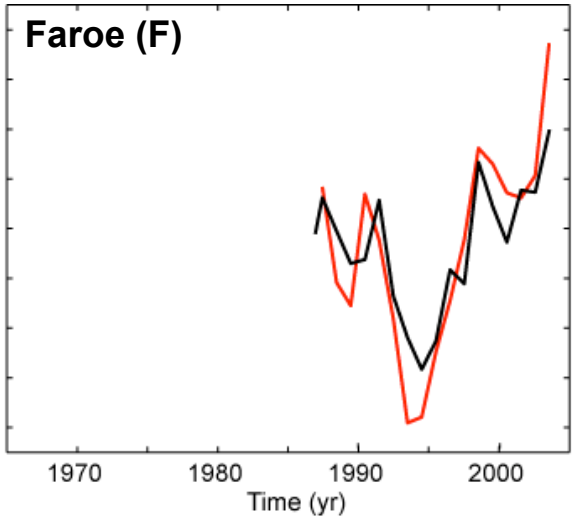
Observed and simulated salinity anomalies at three locations in the northern North Atlantic





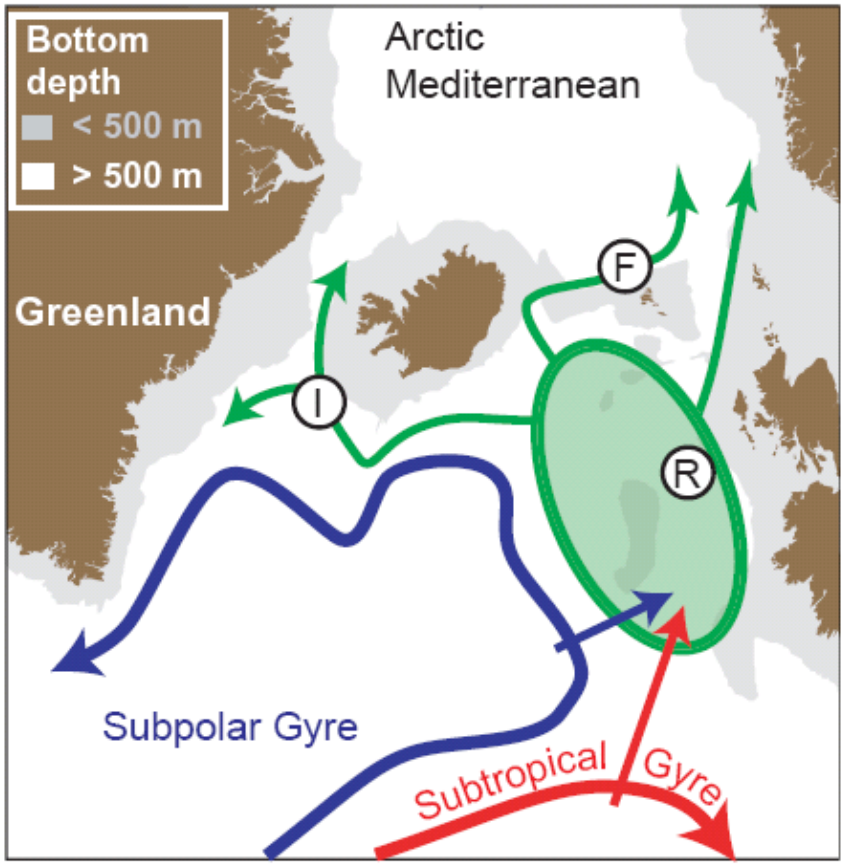


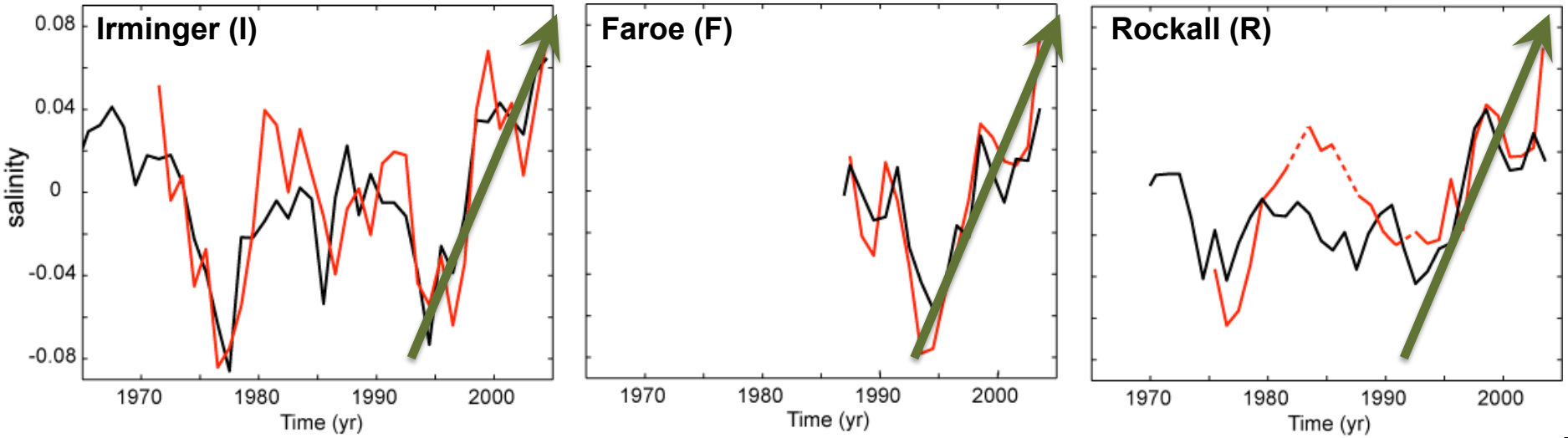
Hatun et al., *Science* (2005); *Prog. Ocenogr.* (2009)

Observed and **simulated** salinity anomalies at three locations in the northern North Atlantic

Why post-95 change?

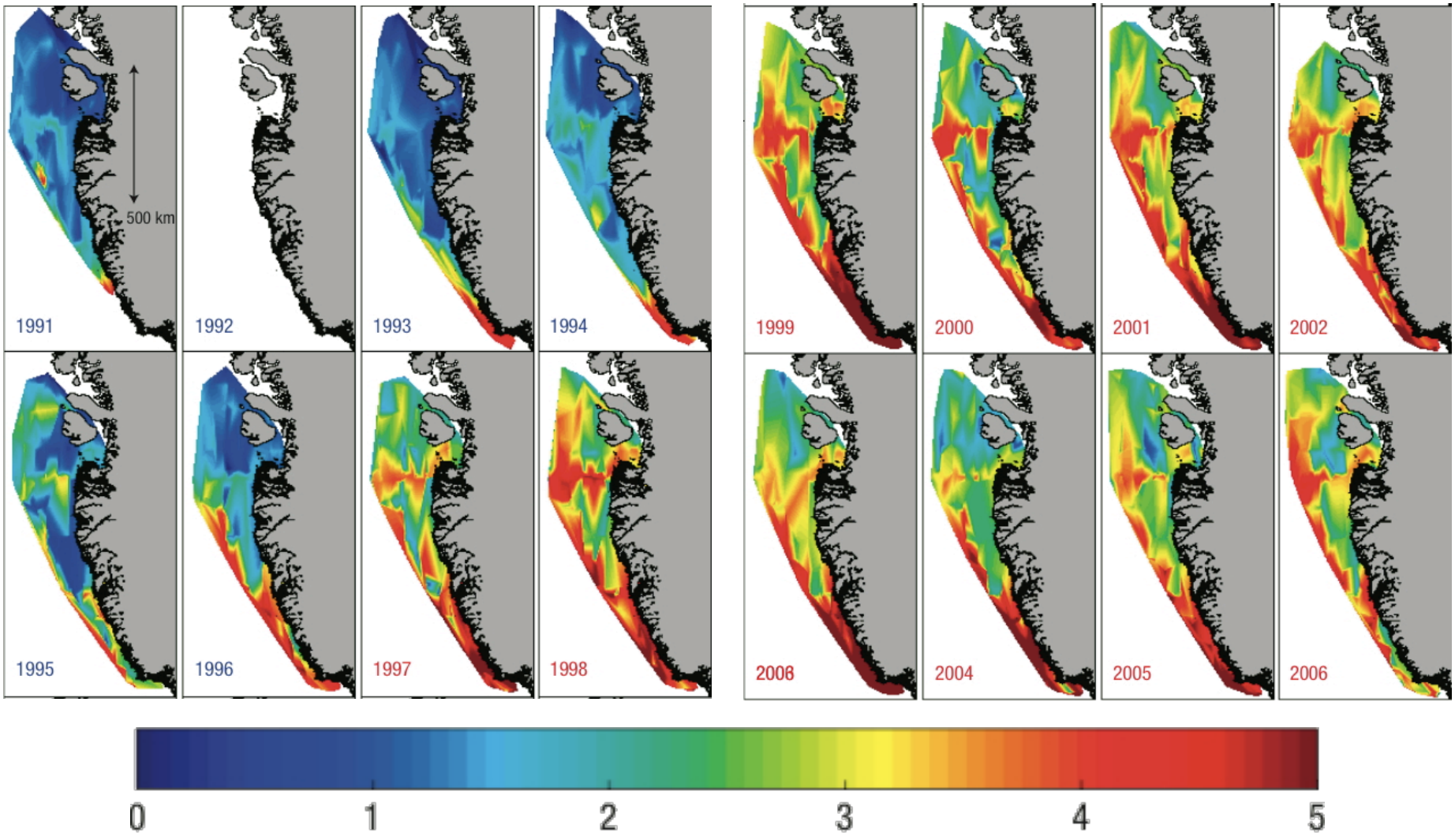
(T, S, marine biota)





Associated warming off the coast of Greenland

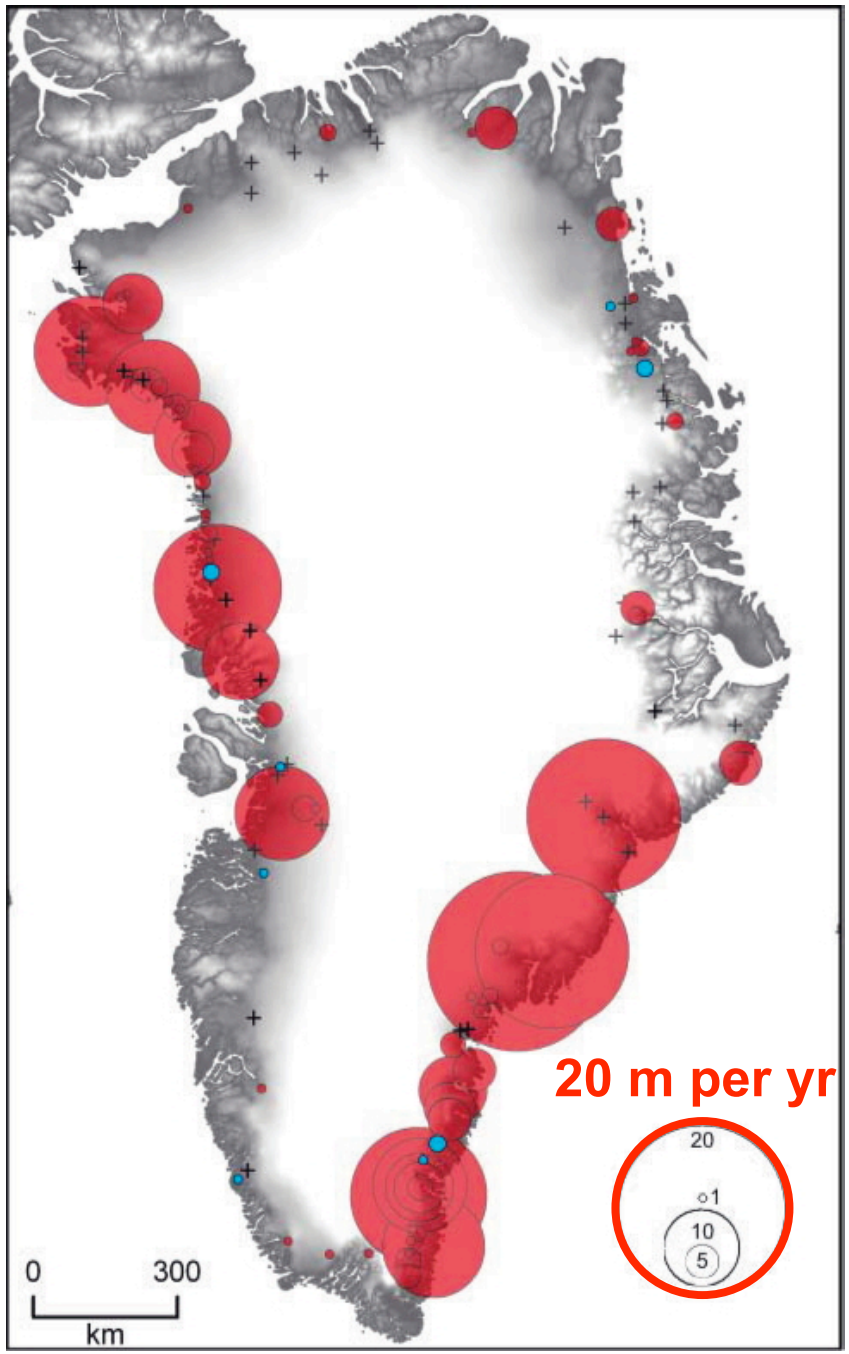
(150-600 m)



Holland et al. (2008)

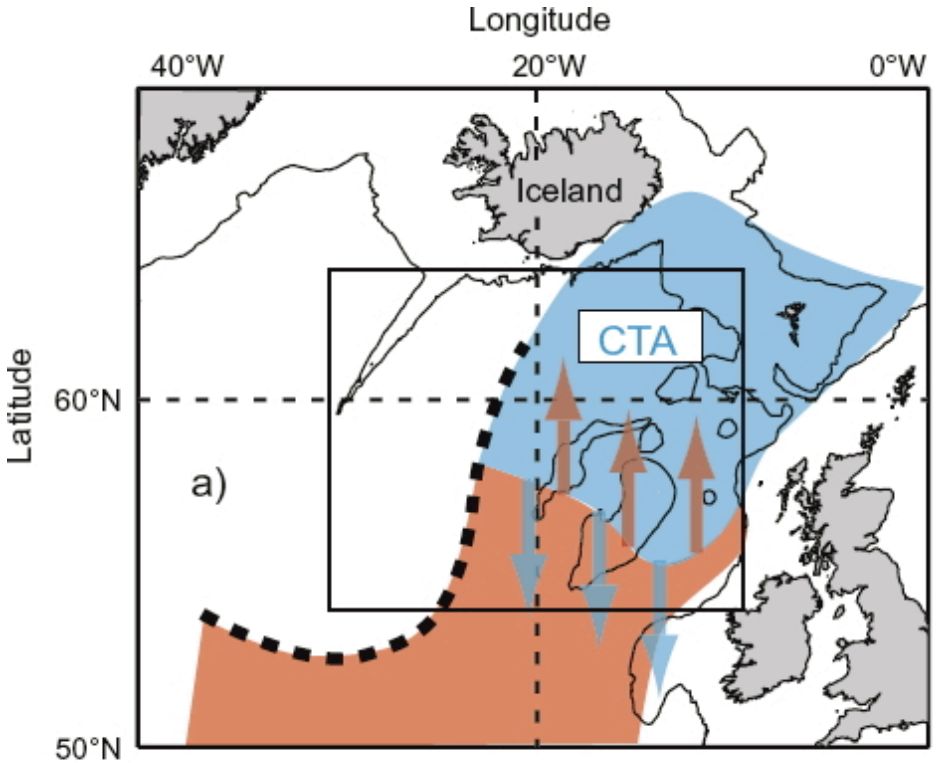
…contributing to the (dynamic) thinning of the outlet glaciers on Greenland

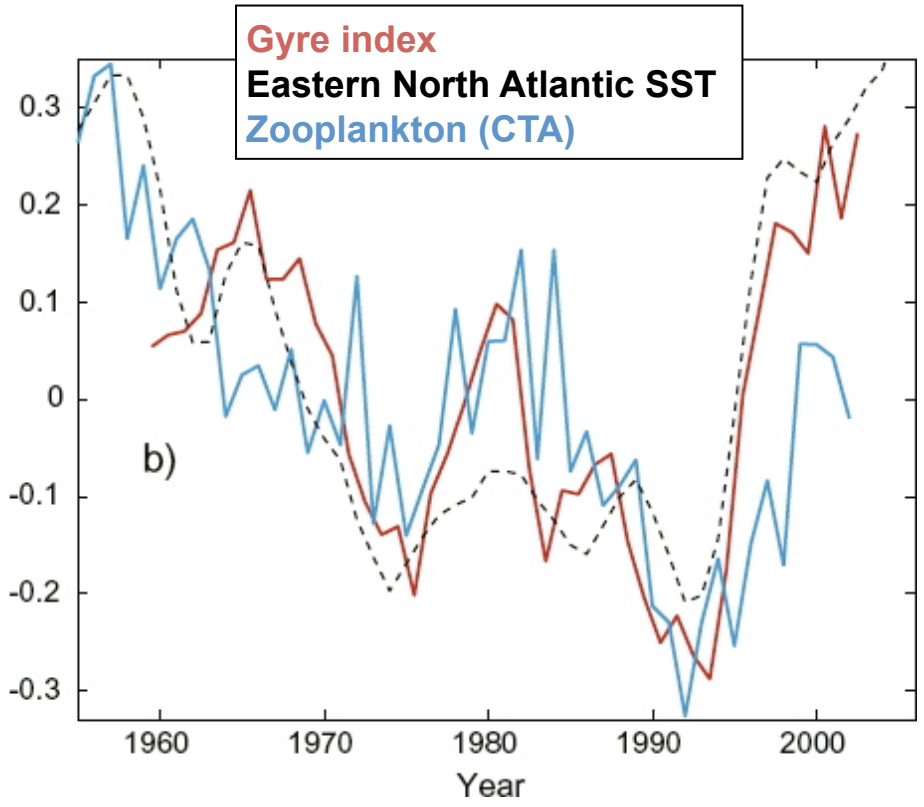
(m per year)



Pritchard et al., *Nature* (2009)

…and direct impact on the marine ecosystem, here abundance of zooplankton





Hatun et al, Prog. Oceanogr. (2009)

(CTA = Cold Temperature Assemblages)

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Q1: How does the SPG respond to a persistent, decadal time scale positive – or negative – NAO forcing?

Q2: How linear is the response of the SPG forced with positive – or negative – phases of the NAO?

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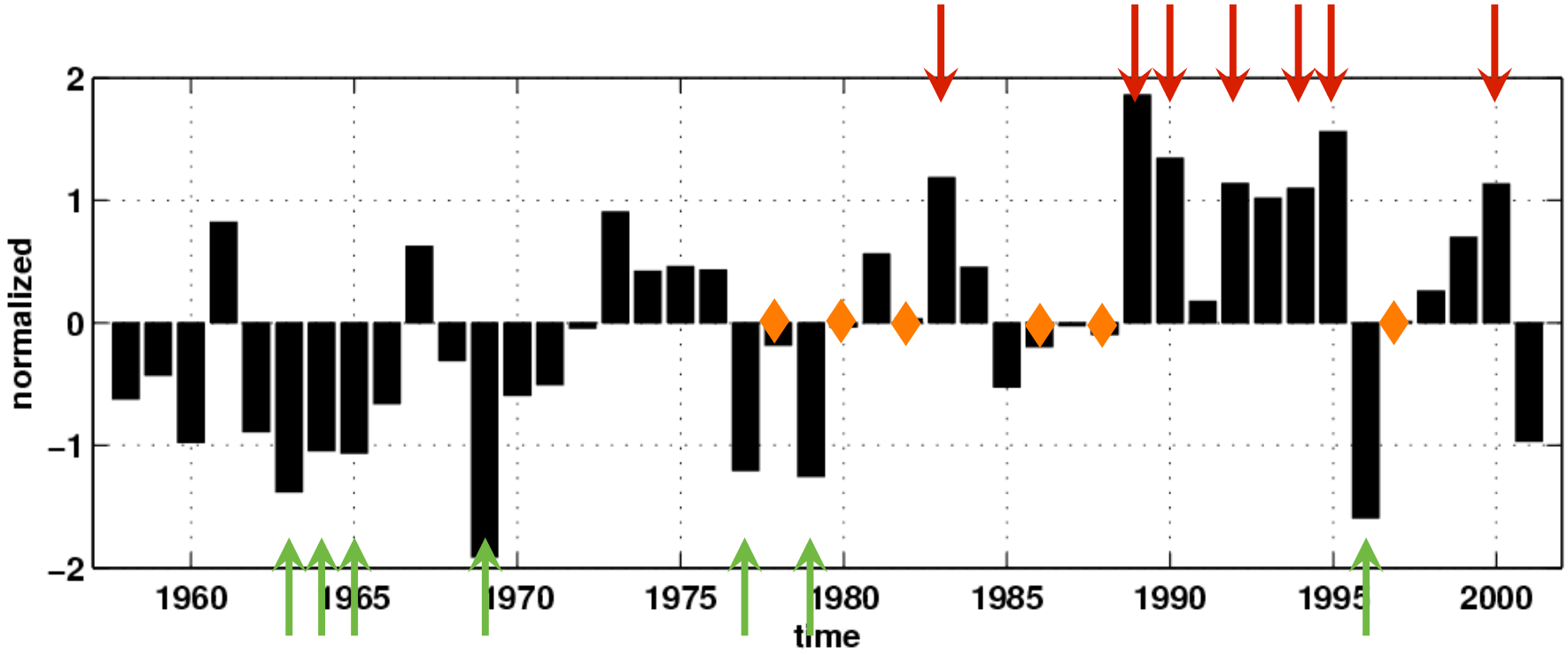
NAO index based on ERA40

NAO+ **NAO-** **NAOn**



Force ocean model with repeating
(i) **NAO+**, (ii) **NAO-** or (iii) **NAOn** fields for 40 years

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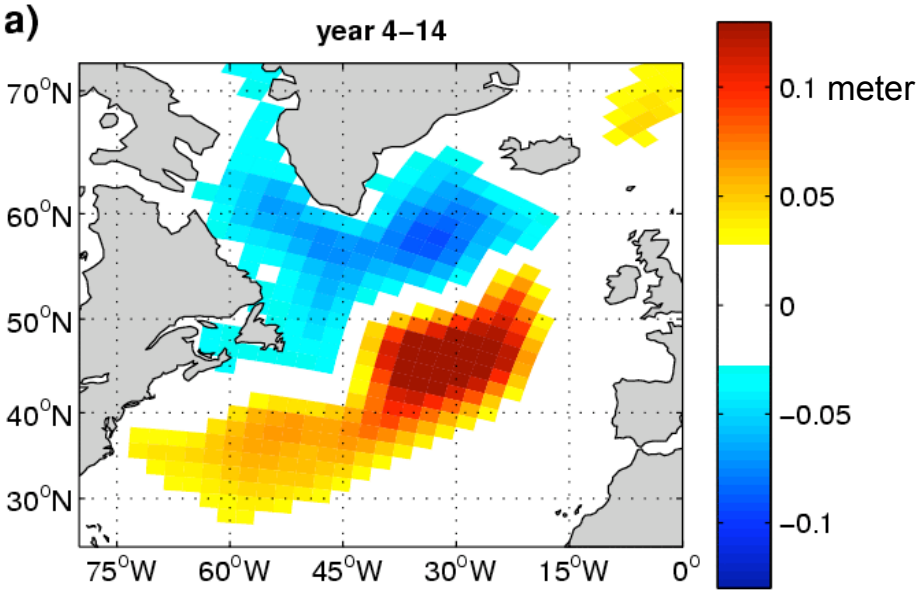
Sea surface height, NAO+ minus NAOn

(starting from 1961)



Yr 4-14: Intensified gyre

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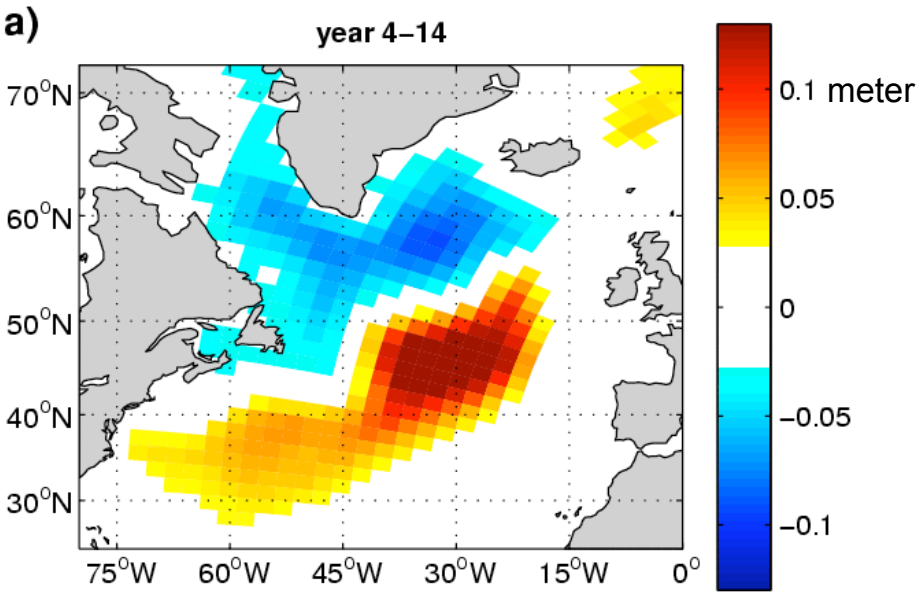
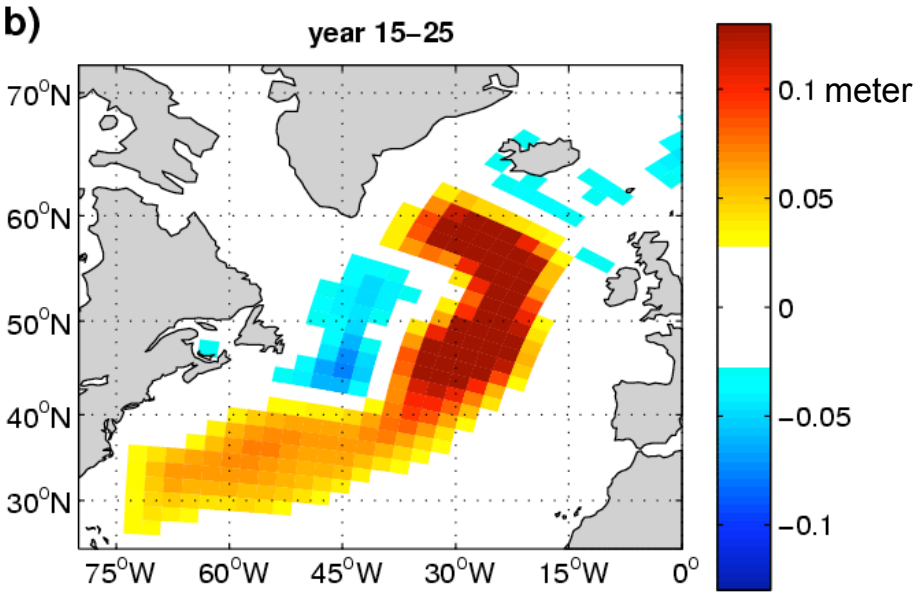
Sea surface height, NAO+ minus NAOn

(starting from 1961)



Yr 4-14: Intensified gyre



Yr 15-25: Weakened gyre

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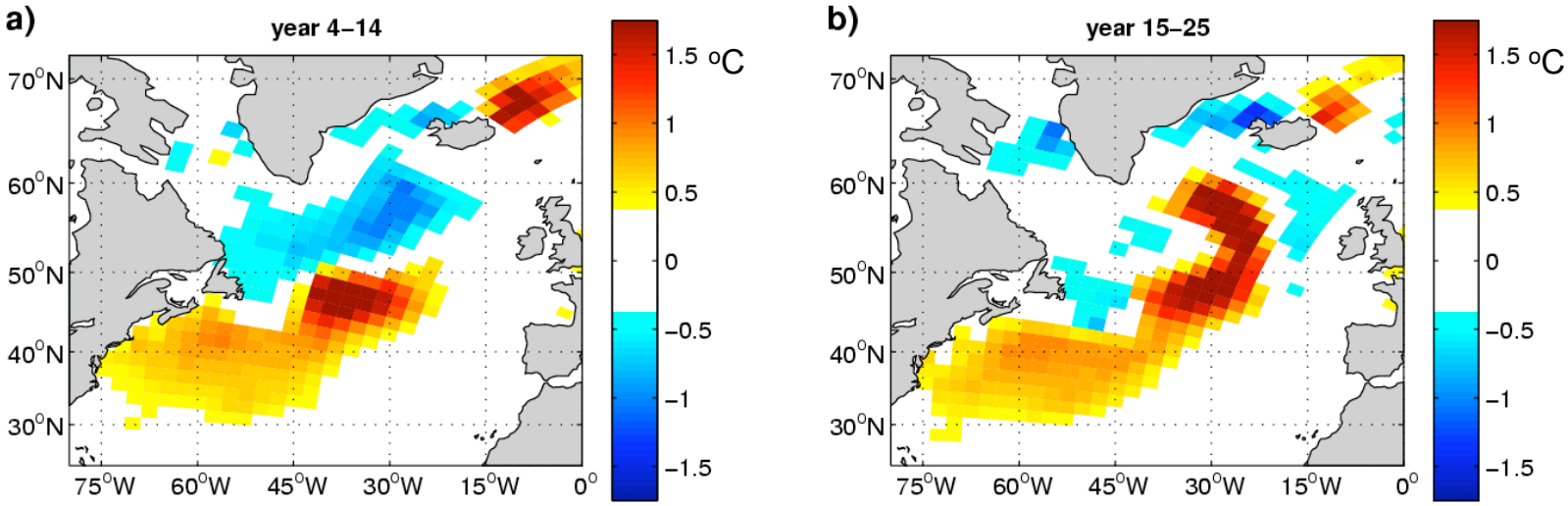
Mixed layer T and S, NAO+ minus NAOn

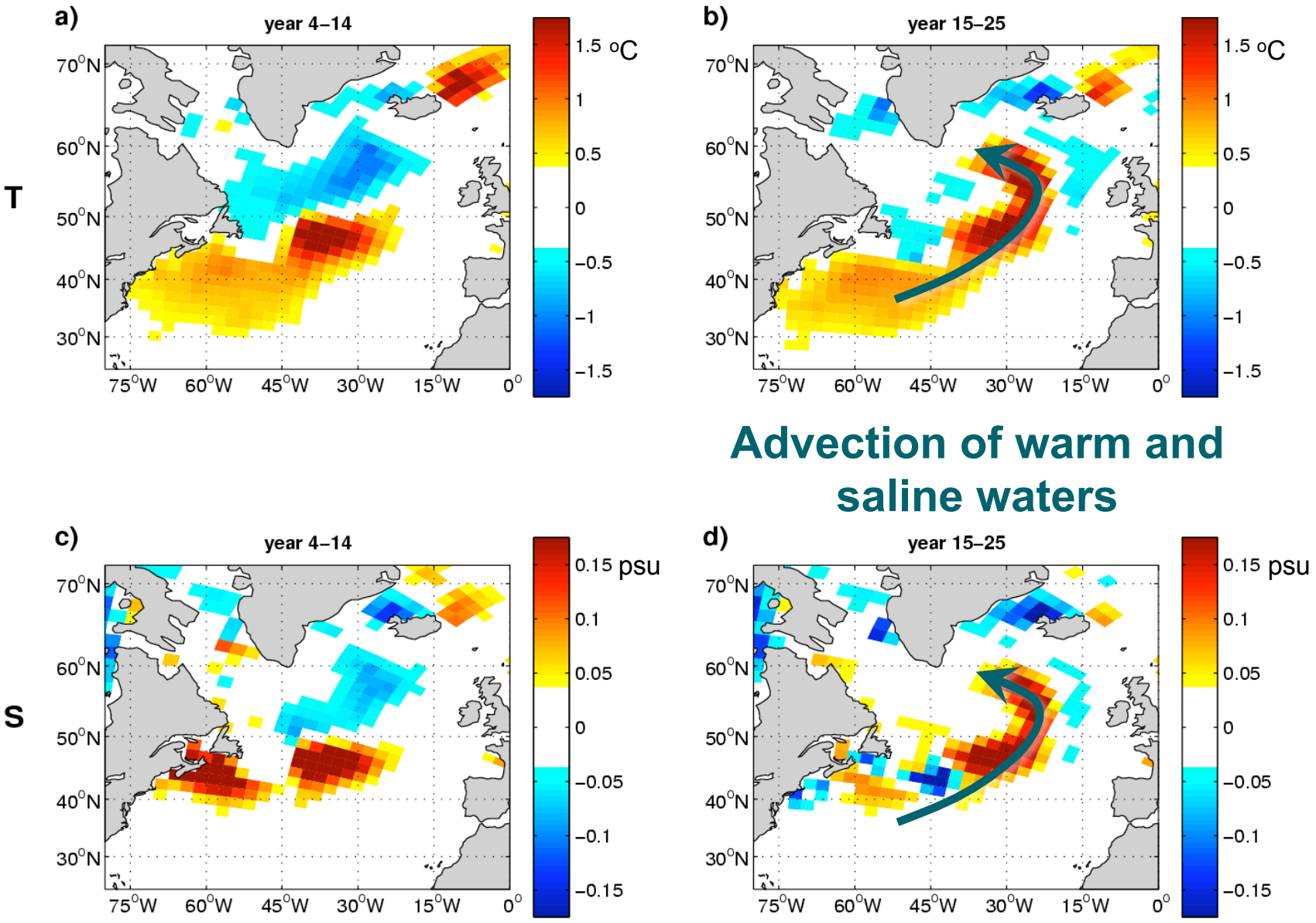
(starting from 1961)

T



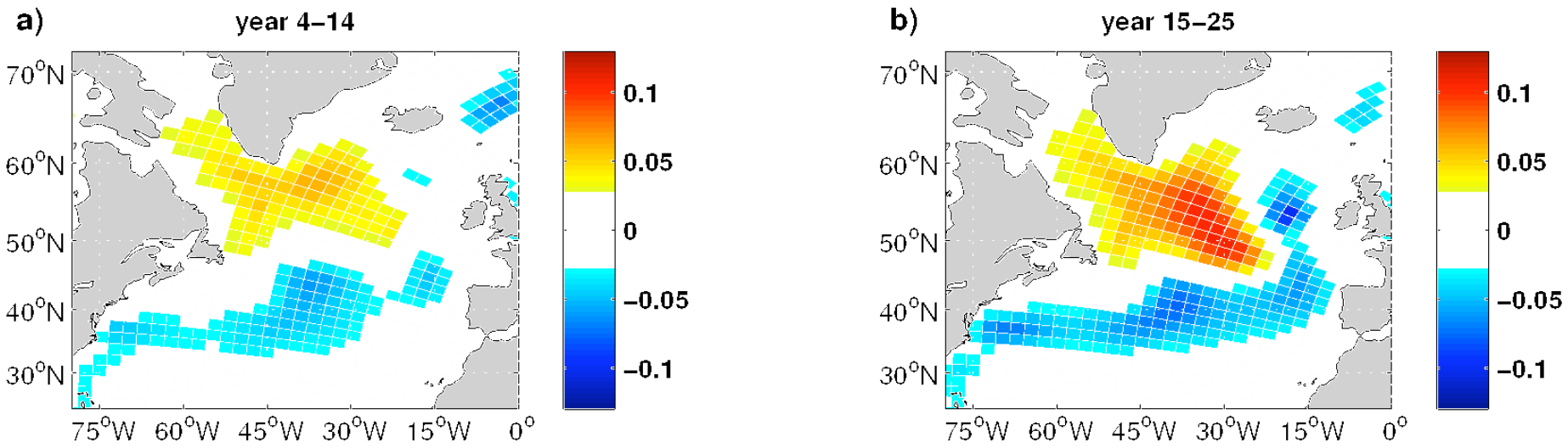
Mixed layer T and S, NAO+ minus NAOn

(starting from 1961)



Advection of warm and saline waters

Sea surface height, NAO- minus NAOn



Gradual weakening

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Conclusions (1)

- **NAO+ forcing →**
  - Initial strengthening of SPG
  - After ~10 years replaced by weakening
  - Advection of warm water counteracts local cooling

- **NAO- forcing →**
  - Gradual weakening of SPG, approaching a minimum value

- **Asymmetry →**
  - Potentially misleading to look at (NAO+ minus NAO-)

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Q3: What caused the abrupt drop in the SPG after 1995?

Q4: What is the role of the actual ocean initial state?

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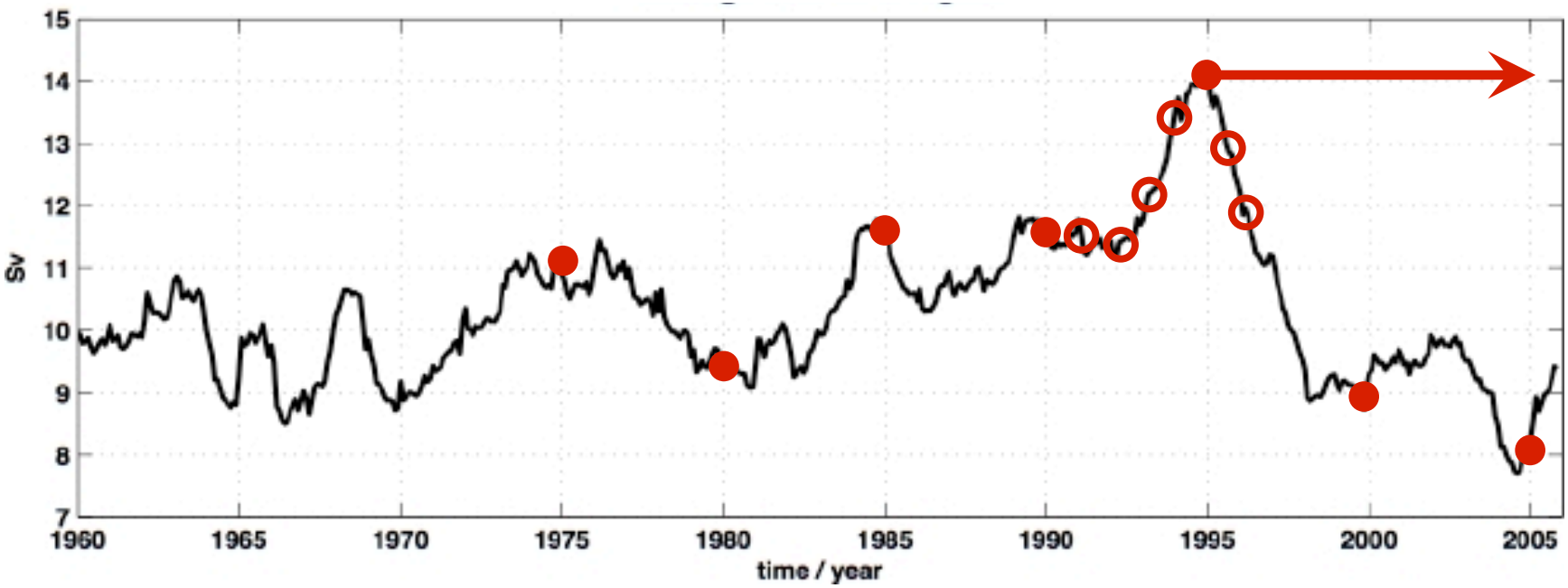
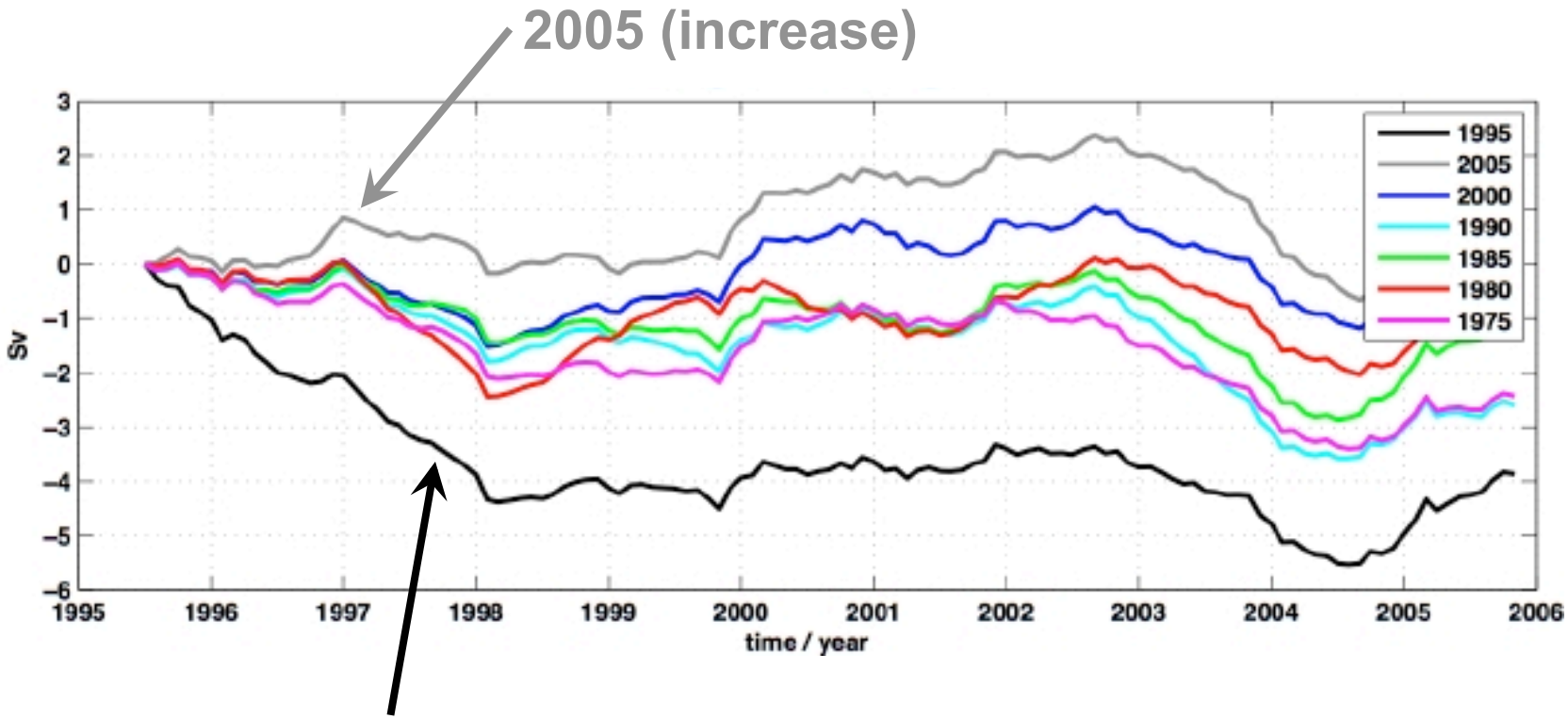
Sensitivity experiments

- same model as before.

- **post 1995 forcing** applied to initial conditions from 1975, 1980, 1985, 1990, 2000, 2005, and every year between 1991 and 1997



Post 1995 forcing (I)



Control integration
(1995; “real model world”)

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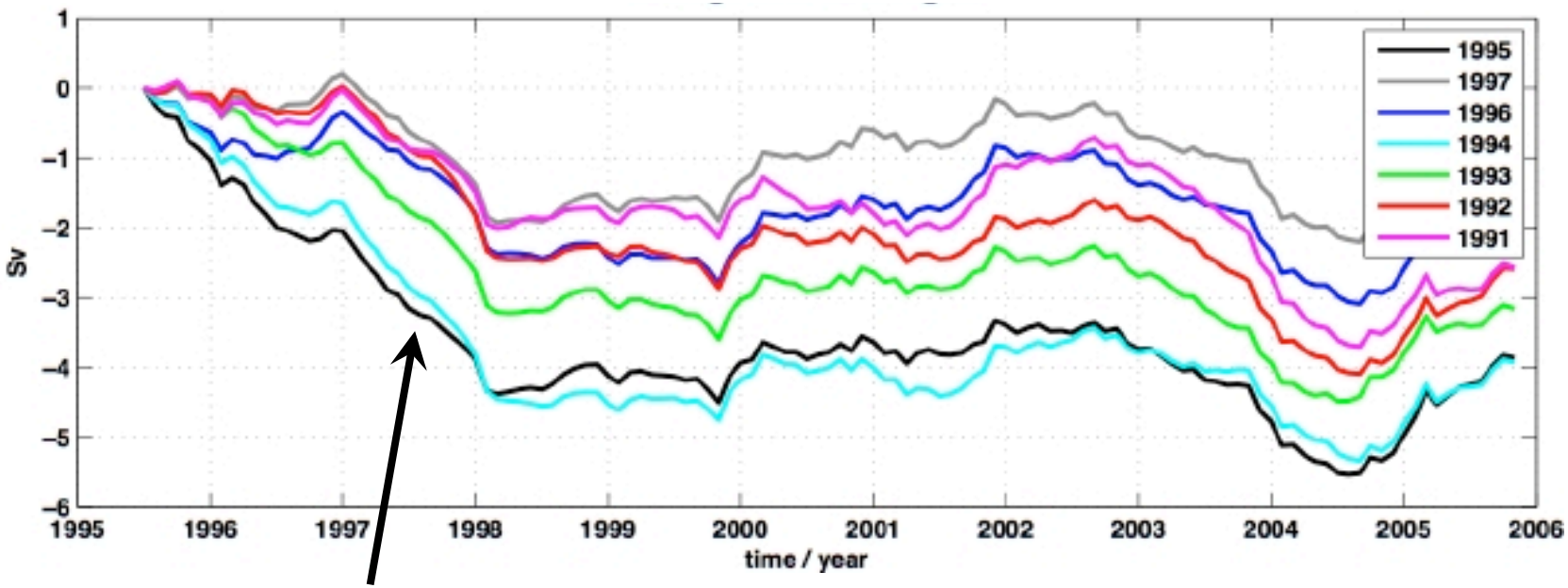
Post 1995 forcing (II)



Control integration
(1995; “real model world”)

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Conclusions (2)

- **SPG drop in 1995 →**

  SPG at maximum strength and approaching break-down after a long period with NAO+ forcing

  NAO forcing changed from high to low value the winter 1995/96

  The combined effect lead to an unprecedented collapse of SPG

- **Note**

  SPG would also have collapsed in 1994 with post-1995 forcing

  Otherwise no collapse for the period 1960-2005 with post-95 forcing

  SPG would have increased in 2005 even with post-95 forcing

- **Predictability**

  Ocean initial state of crucial importance

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