On the recent time history and forcing of the inflow of Atlantic Water to the Arctic Mediterranean

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Introduction

The amounts of heat and salt carried northward by Atlantic Water (AW) across the Greenland–Scotland Ridge (GSR) are substantial, and both quantities are of importance for the regional climate, water mass and ice distribution of the Nordic Seas and Arctic Ocean, and possibly for the deep mixing and water mass modifications and transformations taking place in the region.

Large anomalies in the properties of the inflowing AW to the Arctic Mediterranean have been observed over the last few decades (Hansen and Østerhus, 2000; Turrell et al., 2003). However, with regards to volume transports, measurement based estimates are scarce prior to the '90s. While the time series from current measurements and hydrography available for the latest decade show almost negligible interannual transport variations through the passages (Orvik and Skagseth, 2003; Hansen et al., 2003), model studies show interdecadal and interannual variations of 1-2 Sv (Nilsen et. al., 2003; Zhang et al., 2004). In the study by Nilsen et al. (2003) the transport variability was strongly linked to an atmospheric pattern resembling the North Atlantic Oscillation (NAO), via anomalous Ekman transports and barotropic adjustment processes.

Model results also suggest that there is a tight link between the inflow in the Faroe Shetland Channel (FSC) and the outflow through the Denmark Strait (DS) (Nilsen et al., 2003). The atmospheric pattern found to be the main driving force for the transport variations consists of variability in both east Greenland northerlies and north Atlantic westerlies. Together with the strong barotropic component and topographic control of the Nordic Seas' ocean circulation, this kind of synchronous atmospheric variability can explain the strong DS-FSC correlation found (R=0.74).

The main inflow branches to the Nordic Seas go over the Iceland Faroe Ridge (IFR) and through the FSC, and their volume transports have been found to have a negative correlation (Mork and Blindheim, 2000; Nilsen et al., 2003). It has been indicated that this out of phase relationship is connected to the changing position of the NAO's northern center of action.

Hansen et al. (2001) found indirect evidence of a reduction in overflow through the FBC of 0.5 Sv over the last 50 years, implying that the Atlantic inflow has been reduced to a similar degree. The model results from Nilsen etal. (2003) show a similar reduction in the inflow and points to the inflow over the IFR as the reduced branch.

In this study, we will quantify variations of key quantities of the inflow based on available observations and observation-based time series, and assess to which degree state-of-the-art OGCMs are able to reproduce the observed anomalies. Furthermore, a series of model sensitivity experiments will be presented that addresses the relative role of wind and buoyancy forcing of the anomalies. Finally, assessments of possible changes in the 21st century climate system of the Nordic and Barents Seas will be given.

Methods and Results

The model system used in this study is a synoptic forced, global version of the Miami Isopycnic Coordinate Ocean Model (MICOM, Bleck et al., 1992). Dynamic-thermodynamic sea ice modules are included. The model has 24 model layers with potential density ranging from 23.54 to 28.10. The configuration uses stretched grids with focus in the North Atlantic-Arctic region (Bentsen et al., 1999), with 80 km grid spacing in the Nordic Seas, as well as a 20 km model for this area nested within the global. The atmospheric forcing was by daily fields from the NCEP/NCAR reanalysis from 1948 to present (Kalnay et al., 1996).

Hydrographic data from a section through the Faroe Current north of the Faroes (Hansen et al., 2003) are used to study the IFR inflow in the period 1987-2001. There is a clear seasonality in the hydrography of this section, and both the temperature and the salinity have maxima around August-October (Figure 2). The interannual variability in this period consists of a temperature and salinity minimum around 1994, a maxima around 1998-1999, and since 2002 both salinity and temperature have risen to the highest values on record (Figure 3).

Hydrography from sections in the FSC have been merged to produce a century long time series (Turrell et al., 1993). The resulting AW inflow temperature series is shown together with our simulated temperatures in Figure 4. The overall mean values are 9.29ºC and 9.73ºC, respectively, and the model is seen to match the data points more often than not. Fitting a cosine to the observed and simulated time series gives the same seasonal amplitudes (1.32ºC), and the seasonality is thus simulated in a correct way. Time series from the Rockall Trough, one pathway by which AW reaches the FSC, are similar to the IFR inflow, also showing a warming and salinification of the inflow in the latter half of the '90s (Figure 5).

The mean simulated volume transports through the gaps compare fairly well with the measurement based estimates (Table 1), and for the time of available measurement based transports, the model reproduces the mean, the annual cycle, as well as variability down to weekly timescales (Figure 6).

The relative role of surface wind stress for the variability of water exchanges between the North Atlantic and the Nordic Seas in the second half of the 20th century is investigated using model integrations with zero, half, normal and double wind stress forcing.

The model shows increasing northward flows through the FSC and across the IFR, and southward flow through the DS, with stronger wind forcing (Figure 7). The results from the zero and double wind stress experiments differ in northward Atlantic flow through the FSC and IFR by ~2 Sv through each gap, and in southward DS flow with as much as 3.8 Sv (not shown). Furthermore, for the normal and double wind stress simulations, the inflow over the IFR is found to have a negative trend over the 50 years, while the FSC inflow show an increased inflow.

The dominant influence of the atmospheric variability pattern found in Nilsen et al. (2003) on the oceanic transports are further substantiated, as the magnitude of the SLP regression patterns are found to be dominant in all simulations with wind stress, dependent on the magnitude of the applied wind stress, and non-existent in the zero wind stress simulations.

The atmospheric variability pattern of SLP variability showing strongest influence on the transport variability in the IFR differs from the corresponding regression pattern for the FSC (Figure 8a,b). The former does not contain variability in the east Greenland northerlies and has more meridional wind variability in the north Atlantic. In fact, the IFR-pattern is similar to the to the NAO-pattern prior to the '70s while the FSC-pattern is similar to the post '70s NAO (Figure 8c,d). Combined with the knowledge that the NAO has increased into a more positive phase over the last decades, this might explain the simulated trends in the two gaps.

Conclusions

Comparisons from the Rockall Trough, the IFR and the Svinøy Section show that the simulated long-term hydrographic conditions and the volume transports of northward flowing AW are, indeed, realistic.

Model experiments using different strength wind stress forcing show increased Atlantic inflow and increased variability with increased wind stress magnitudes. The model also indicates that normal wind forcing is responsible for 3 Sv of the modeled 9.5 Sv total Atlantic inflow to the Nordic Seas. Furthermore, the normal and double wind stress introduce trends in the FSC (positive) and IFR (negative), which may be related to the strengthened the NAO and westward shift of its northern center of action, over the last 50 years.

This NAO shift and increase represents a strengthening of the cyclonic atmospheric circulation over the North Atlantic. With a continued strengthening, we may expect a stronger inflow of AW to the Nordic

Seas. Based on the model results and observational data, the increase will likely occur through the FSC, while there may actually be a reduced inflow over the IFR (see also Mork and Blindheim, 2000; Nilsen et al., 2003). Such a shift in the inflow path might result in increased Atlantic inflow to the Barents Sea (see Figure 1), and a warmer and thicker Atlantic layer in the Arctic. Less AW to the western branch of the NwAC, might lead to less AW to the Greenland Gyre, reducing its contribution to the DW formation. Furthermore, the strengthened cyclonic circulation over the Nordic Seas leads to more Polar Water export through the Fram Strait, inhibiting DW formation, freshening the oceans, and ultimately leading to fresher overflows to the Atlantic Ocean.

Passage	Dir	Model	Observation	References
DS	N	1.1	1.0	Hansen & Østerhus (HØ, 2000)
	S	6.9	4.3	HØ (2000), Fissel et al. (1988)
IFR	Net	2.2	2.3	HØ (2000)
FSC	N	4.3	4.4	Orvik & Skagseth (2003)
	S	1.1	2.6	HØ (2000), Turrell et al. (1988), Østerhus et al. (1999), Ellett (1998)

Table 1: Simulated (80 km configuration) and observation-based mean northward (N) and southward (S) volume transports in Sv (10^6 m^3s^{-1}) over the GSR. The model transports are mean values for the periods of available observations, typically from the 1990s.

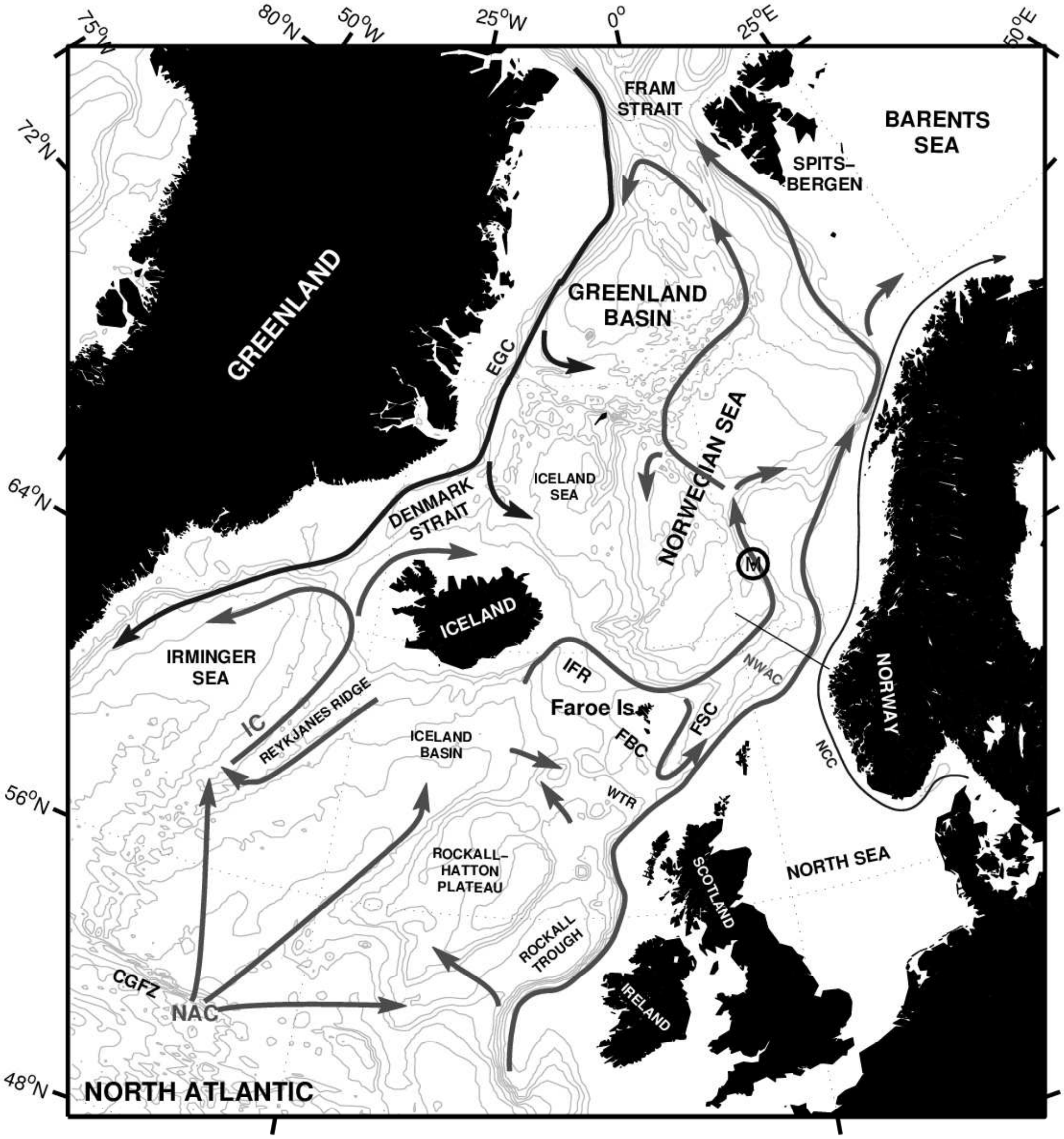

Figure 1: The northern North Atlantic and the Nordic Seas. Isobaths are drawn for every 500 m. Schematic upper layer currents are based on literature. See text for abbreviations. Circled M shows the position of Ocean Weather Station M and thin line indicates the Svinøy Section. From Furevik and Nilsen (2004).

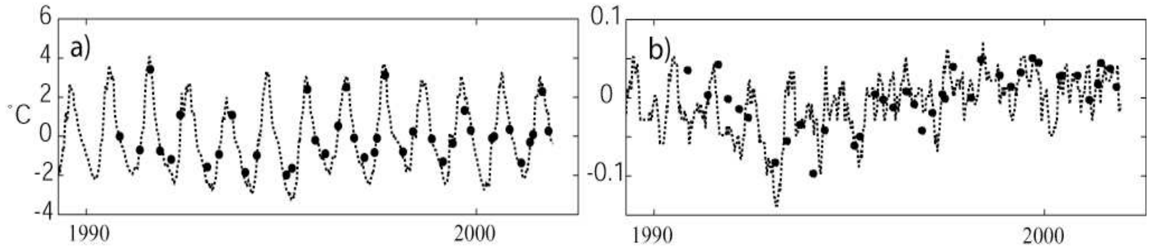

Figure 2: Simulated (dotted line) and observed (points) section maximum of temperature (a) and salinity (b) in the Faroe North Section.

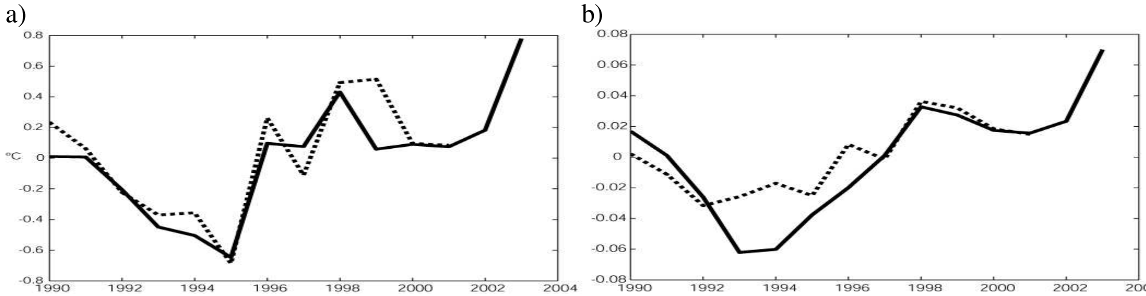

Figure 3: De-seasoned observed (full line) and simulated (dotted line) temperature (a) and salinity (b) in the core of the Faroe Current.

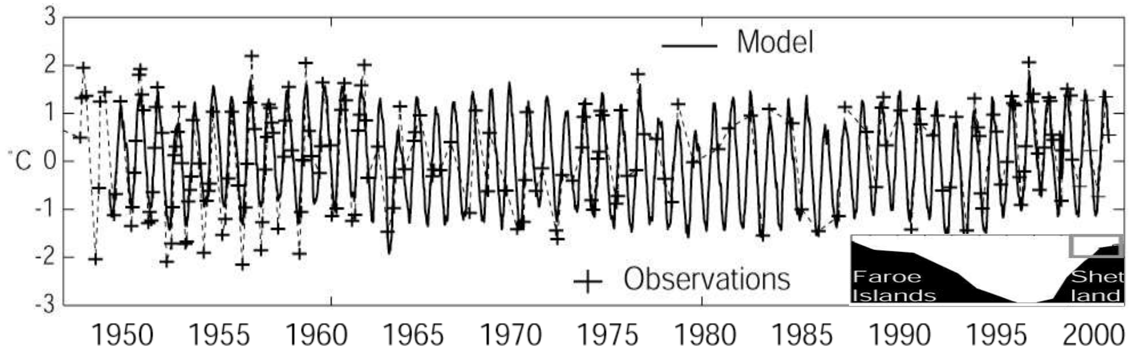

Figure 4: Temperature series of the FSC inflow 1948-2002, calculated as spatial averages over the grey frame in the inlay (Hátún et al., 2004).

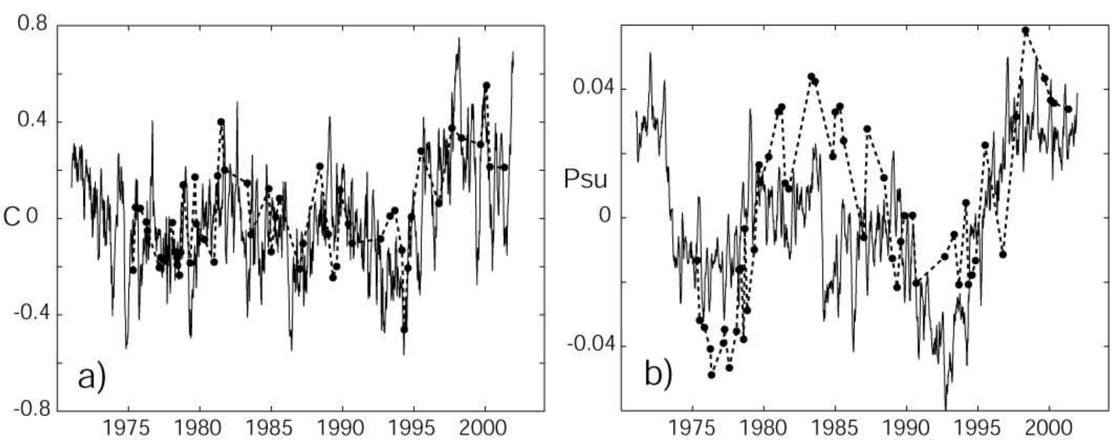

Figure 5: De-seasoned anomalies of temperature (a) and salinity (b) horizontally averaged over the uppermost 800 m in the Ellett Section in the Rockall Trough (Holliday et al., 2000; points on dashed lines) and the simulated time series processed in a similar way (Hátún et al., 2004; full lines).

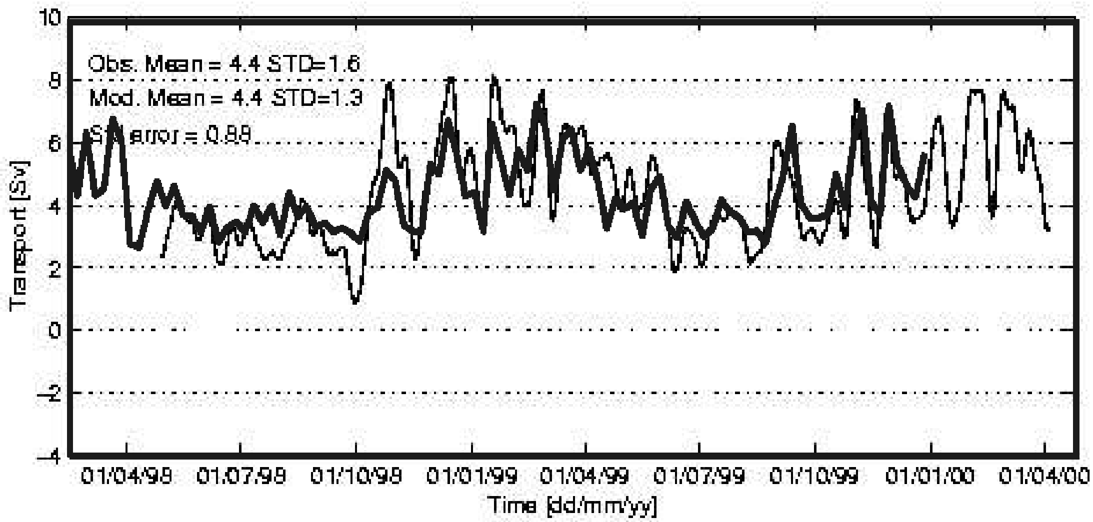

Figure 6: Simulated inflow through the FSC (thick blue/grey line) compared with seven days low pass filtered transport estimates for the eastern branch of the NWAC, from current meter measurements and hydrography at the Svinøy Section (thin black line; Orvik and Skagseth, 2003).

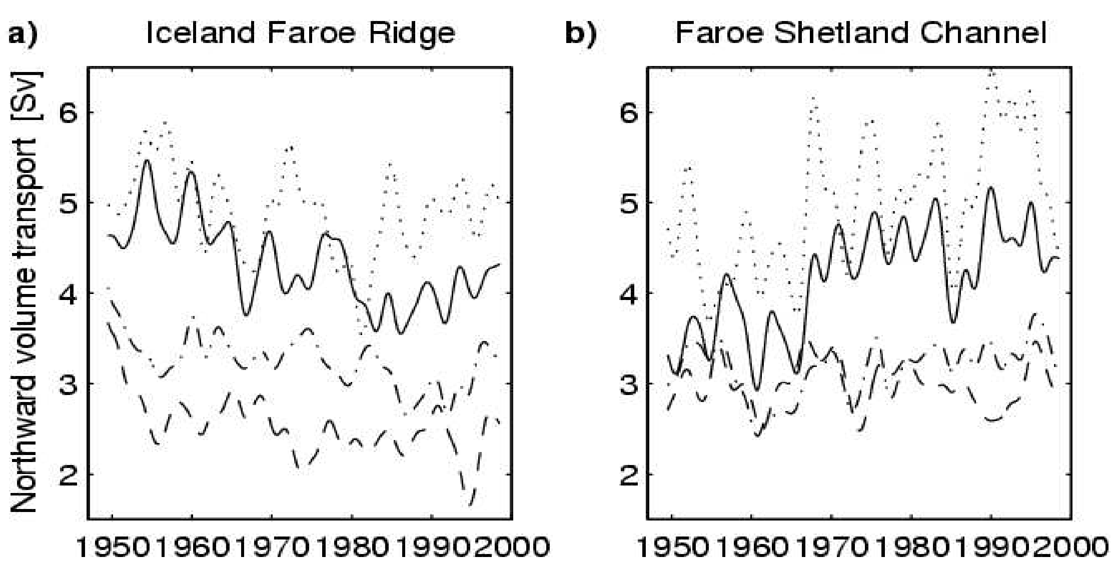

Figure 7: Temporal variation of the 3-years low-pass filtered simulated inflow through the IFR (a) and FSC (b) for normal (full line), zero (dashed), half (dash-dotted), and double (dotted) wind stress.

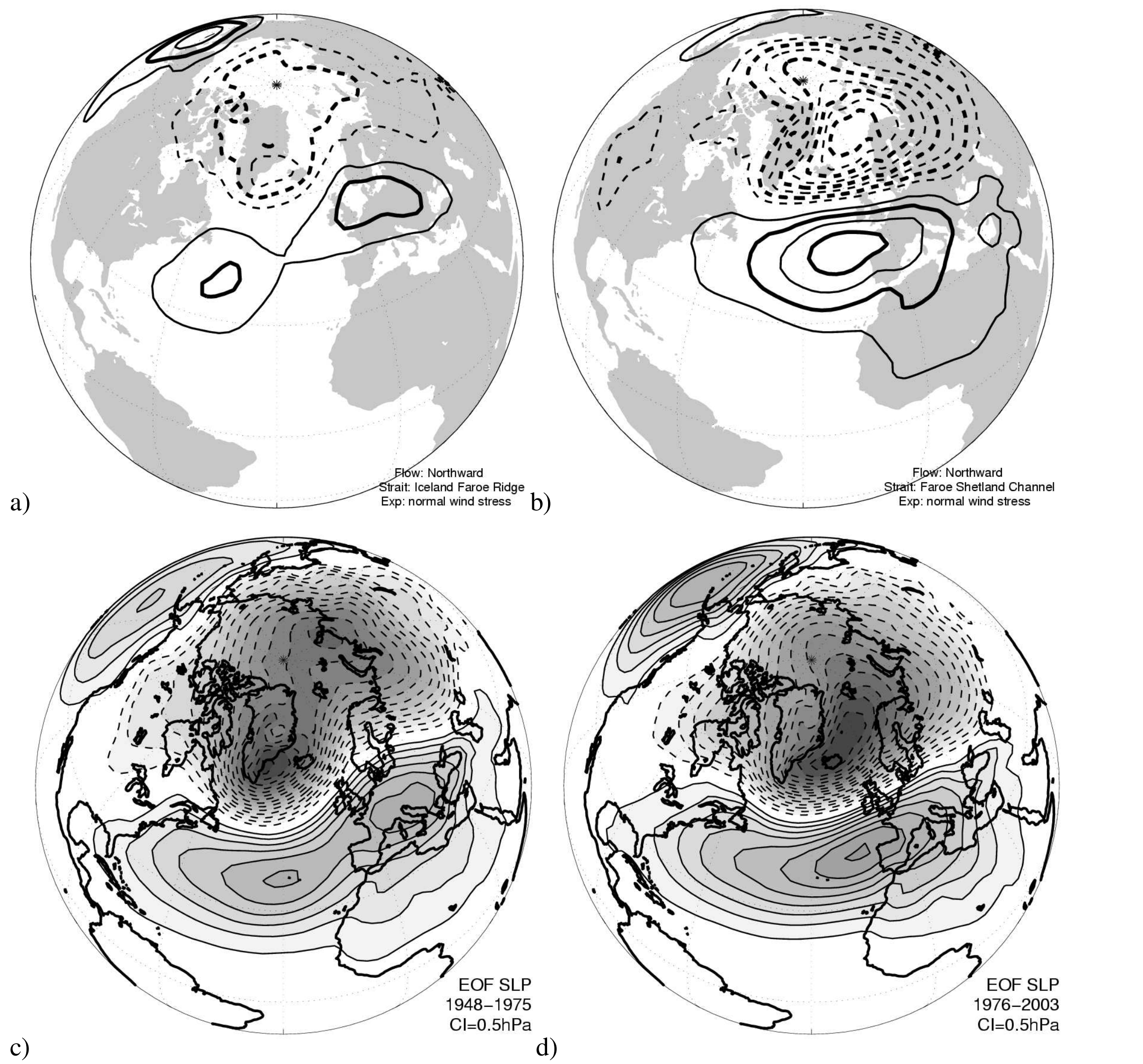

Figure 8: Upper panels: Regression maps showing the NCAR/NCEP winter (December–March) mean SLP regressed on standardized simulated inflow through IFR (a) and FSC (b). Isolines are drawn at 0.5 mb intervals. Correlations in the centers of action reach 0.6 (northern) and 0.5 (southern) and are highly significant. Lower panels: The leading mode of variability of the winter-mean SLP for the periods 1948–1975 (c) and 1976–2003 (d). The principal components are calculated from the NCEP/NCAR reanalysis data for the Atlantic sector (90±W–30±E, 20±N–80±N). Solid lines are positive, dashed lines negative.

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