Response of the Fram Strait transport to surface density forcing

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1. Introduction

Variations in the surface density flux field over the Arctic Ocean have the potential to change the exports of heat and fresh water through the Fram Strait. This may influence the thermohaline circulation at a global scale. A better understanding of the relationship between surface fluxes, ocean circulation and water mass properties is of particular importance in the Arctic due to the recent large-scale shift to warmer climatic conditions.

The atmospheric and oceanic output from a 1000 year simulation using the HadCM3 climate model (Gordon et al, 2000) with fixed pre-industrial greenhouse gases was used to examine the response of the Fram Strait volume transport to variations in the surface density fluxes in the Barents Sea.

2. The Barents Sea Density Flux

The total surface density flux, Fρ (kg m^{-2} s^{-1}) into the ocean is given by (Grist et al., 2007) :

$$F_\rho = F_T + F_S + F_{IM}$$

$$F_T = -\alpha \frac{Q_{net}}{C_P}$$ Thermal

$$F_s = \alpha\beta S \frac{E-P}{\left(1-S/1000\right)}$$ Net evaporation

$$F_{IM} = \rho\alpha\beta S \frac{I_M}{\left(1-S/1000\right)}$$ Ice melt/formation

where ρ is the density of water at the sea surface, C_P is the specific heat capacity of water, S is the sea surface salinity (psu), Q_{net} is the net heat flux (positive for heat gain by the ocean), E-P is the net evaporation at the ocean surface and I_M is the freshwater flux associated with ice formation or melt (negative for net freshwater input into the ocean i.e. as a result of ice melt). α and β are the thermal expansion and haline contraction coefficients.

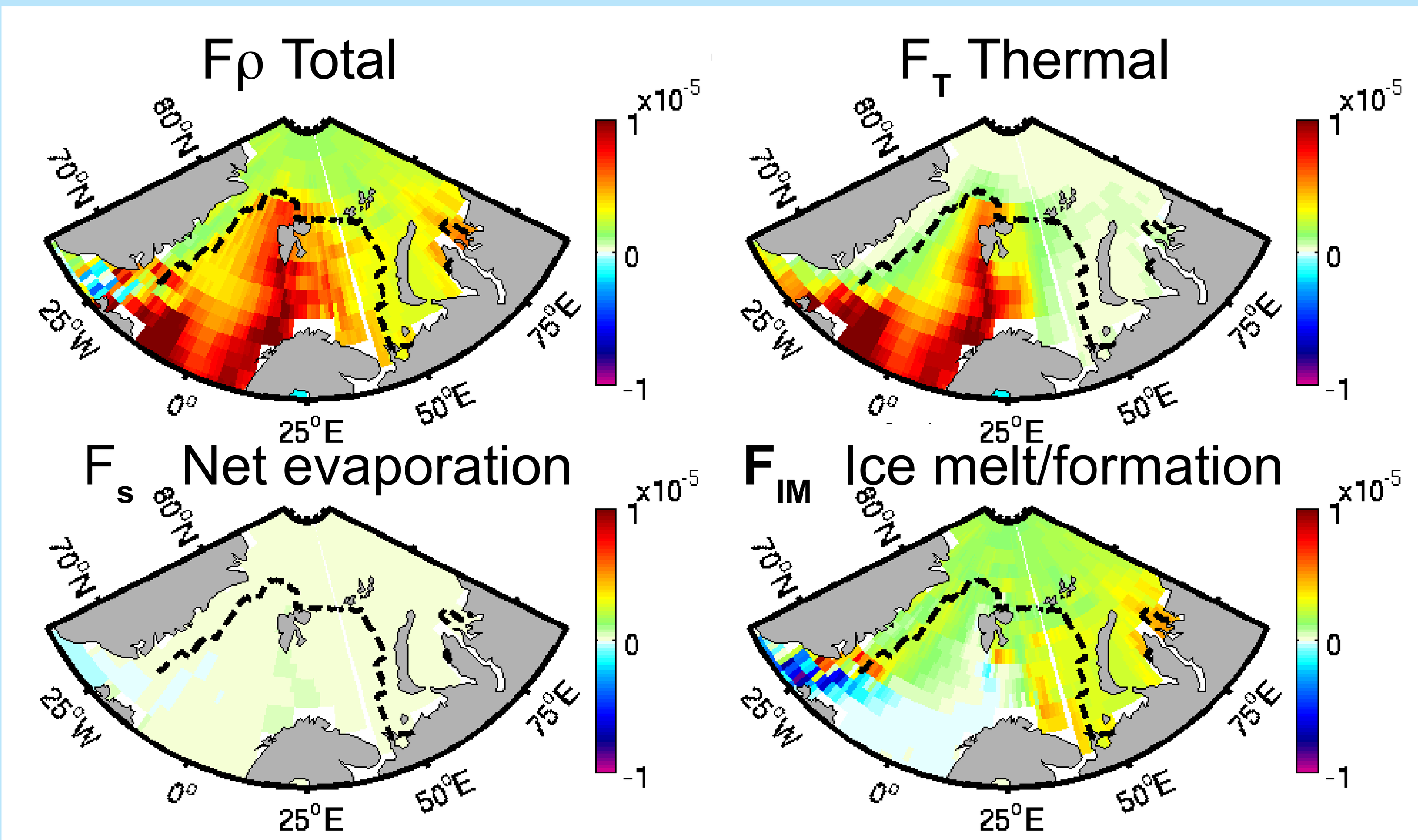

Fig. 1 The Annual winter (DJFM) mean Arctic surface density flux fields.

The thermal term (F_T) tends to increase the density (positive density flux corresponds to net heat loss) with high values in the Norwegian Sea and the South of Svalbard. By comparison the net evaporation, F_S, is two orders of magnitude smaller.

The contribution of ice melt in the annual mean is largely confined to a region centred on the Denmark Strait. In the rest of the region F_{IM} is positive due to brine rejection associated with ice formation. The dashed line indicates the maximum winter ice extent.

3. The Fram Strait

Over the 1000 year period of the model simulation the model predicts an annual southwards net transport of 11.3 Sv and 10.5 Sv northwards. Agreeing well with the measurements of Schauer et al., (2004).

Total density flux over the Barents Sea (~30-50°E, 70-80°N) shows a correlation maximum (r=0.54) with southward deep water (σ>27) winter (DJFM) volume transport through the Fram Strait.

The thermal and net evaporation terms are similar in pattern to the total density flux over the Barents Sea.

The ice melt term F_{IM} in the eastern side of the Barents Sea is correlated with the the southward deep water winter Fram Strait volume transport. However, on the western side of the Barents Sea increases in F_{IM} reduce the transport.

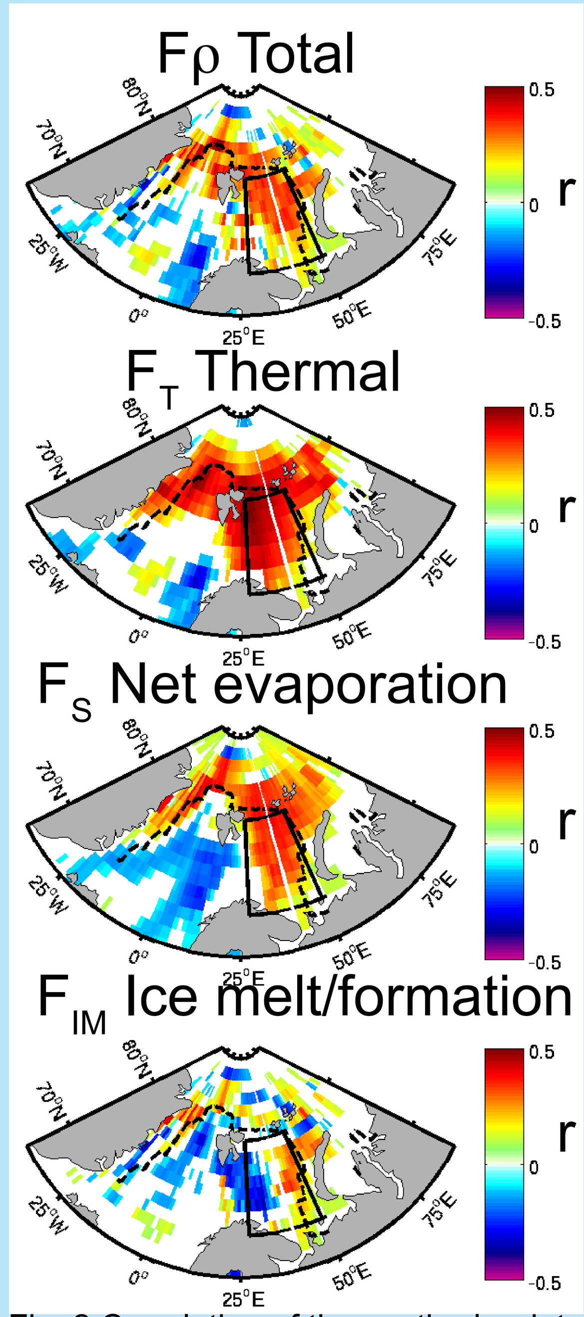

Fig. 2 Correlation of the southerly winter transport through the Fram Strait with the mean winter surface density.

4. Controlling factors

As the total surface density flux in the Barents Sea increases the Fram Strait southwards deep winter volume transport increases, predominantly due to heat loss (F_T) in the western Barents Sea.

Over the whole Barents Sea F_{IM} does not contribute to the net Fram Strait southwards deep winter volume transport. This is due to F_{IM} acting in opposite senses in the eastern and western sides of the Barent Sea, resulting in cancelation.

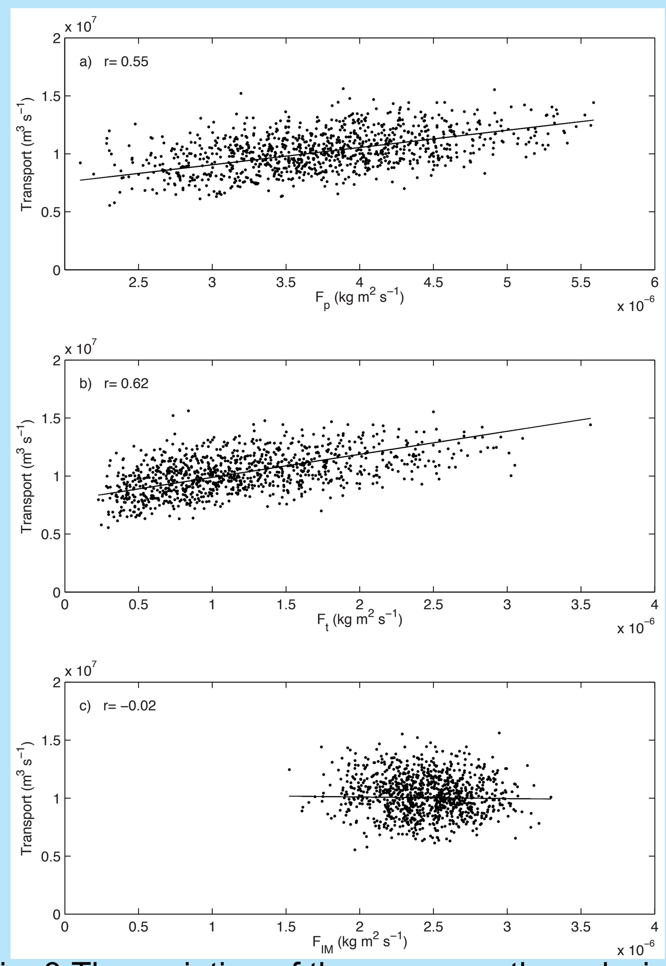

Fig. 3 The variation of the mean southward winter transport through Fram Strait with the Barents Sea mean winter surface density.

5. Composite analysis

The 10 winters of strongest (SY) and weakest (WY) total density flux were identified. The differences of SY and WY composites from the annual mean winter transport suggest that:

SY- southwards flowing water below 250 m in the Fram Strait was colder by up to 0.5 °C and fresher (reduction of 0.05).

WY- Water in the top 1000m tends to be warmer by 0.5 C and fresher (increase of 0.02). The deep water below 2000m is colder and fresher.

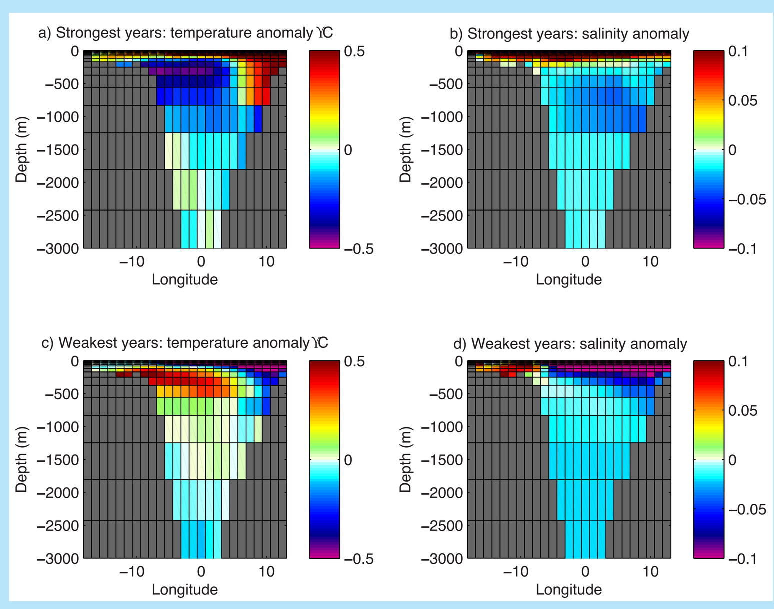

Fig. 4 The The differences of strongest and weakest composites from the annual winter mean.

6. Conclusions

The model suggest that increases in the winter surface density flux in the Barents Sea are associated with increased winter southward deep water transport through the Fram Strait. This is primarily driven by heat loss to the atmosphere in the ice free western Barents Sea.

Surface density fluxes due to ice formation in the eastern Barents Sea contribute to the Fram Strait volume transport, but are balanced by ice melt in the Eastern Barents Sea which have the opposite effect on the Fram Strait transport.

The density flux in the Barents Sea plays an important role in controlling transports of heat and freshwater through Fram Strait and water mass properties.

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