Observations of Atlantic Water subduction below Polar Water at a submesoscale front in Fram Strait

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INTRODUCTION

Atlantic Water flows northward in the West Spitsbergen Current and is still present at the surface there (Fig. 1b). Some of the Atlantic Water flows northward around Svalbard into the Arctic Ocean (Fig. 1a magenta). The other part recirculates westward, and is eventually transported southward in the East Greenland Current (Fig. 1 cyan-yellow). However, from central Fram Strait onwards, Atlantic Water is found below water of polar origin (which often carries sea-ice with it) and thus needs to be subducted (moved vertically) by some process. Baroclinic instability and mesoscale eddies have been suspected to contribute to the subduction of the Atlantic Water below Polar Water (von Appen et al., 2016; Hattermann et al., 2016). Another process may be subduction at submesoscale fronts.

SUBDUCTION OF TMAX

Fig. 1: (a) Pathways of numerical particles in an eddy resolving numerical model. (b) Depth [m] of the temperature maximum. (Hattermann et al., 2016)

DENSE SURFACE FRONT

Fig. 2: Circulation in a dense filament front at the ocean surface under strain. (McWilliams, 2016)

Heavy fluid in the center of the front is subducted by the ageostrophic secondary circulation.

SURVEY OUTLINE

Here we present submesoscale resolving observations collected at a front in Fram Strait in summer 2017. Data from an OceanScience Seabird Underway CTD is combined with 150 kHz RDI shipboard ADCP measurements along 6 parallel cross-frontal sections.

SECtIONS

Fig 8: Sections of potential temperature with potential density overlain in black and 27.8 kg/m$^3$ and 27.9 kg/m$^3$ isopycnals in magenta. Southwestern most section is plotted on bottom, final anomalous northeastern most section is plotted on top.

Fig 9: Sections of along-front velocity with potential density overlain. Positive values are into the page.

Fig 10: Sections of cross-front velocity with potential density overlain. Positive values are to the right. A mean cross-frontal velocity of 0.1 m/s to the right has been subtracted.

KINEMATICS/DYNAMICS

Central Fram Strait (~2500 m water depth) is far away from any boundary currents. Wind forcing was weak. Rossby number:

- $\frac{\Delta x}{\lambda} \approx \frac{0.5 \text{ m/s}}{500 \text{ m}}$
- $Ro = \frac{\frac{\Delta x}{\lambda}}{f} \approx 1$

Submesoscale with possibility of strong ageostrophic secondary circulation

Frontal jets (primary circulation) were in geostrophic balance.

Scaling the subduction:

- Assume an inward flow of 0.05 m/s of 100 m depth
- Assume that the subduction takes place over 8000 m which is the width between the along-front velocity maxima
- Then the vertical velocity is 1800 m/s = 108 m/day or 72 m in 16 hours
- Over 16 hours (transect A to C), the 27.9 (27.925) kg/m$^3$ were observed to have moved down by 50 (90) m
- Thus the observations are kinematically consistent with Fig 2 even though the front was not at the ocean surface, but rather below a strong halocline

Drifter: A drifting sediment trap that averages the flow over the top 400 m was deployed twice:

- Deployment 1 (near center): 8 km in 18 h $\approx 0.1$ m/s
- Deployment 2 (near frontal jet): 26 km in 21 h $\approx 0.35$ m/s

- Emphasizes the huge scale and large region of impact of the phenomenon compared to the Rossby radius and observation area

Biological station sampling showed that Atlantic and Polar species were in close proximity.

Mixed water showed highest phytoplankton concentrations.

Active freshwater forcing by melting ice?

CONCLUSIONS

Our interpretation is that a strong along-frontal jet exceeding 0.5 m/s leads to an ageostrophic secondary circulation with a downwelling component in the Atlantic Water and an upwelling component in the Polar Water as in Fig 2. The large-scale horizontal gradient with AW at the surface in the eastern and at depth in the western Fram Strait provides the energy for the circulation. The circulation then achieves the subduction of AW below PW and the energetic circulation also leads to mixing between the two water masses. The secondary circulation also leads to surface velocities which advect sea-ice to the frontal location which resulted in a long (~50 km) narrow (~500 m wide) ice tongue. This ice tongue makes the fronts visible in satellite radar imagery.

Observations from a second front and satellite radar imagery suggest that, at least in summer, such fronts may be common features in central Fram Strait with implications for the representation of the recirculation in numerical models.

REFERENCES


McWilliams, J. C., 2016: Submesoscale currents in the ocean. Proceedings of the Royal Society of London A, 472, 20150815