Modeling the Denmark Strait Overflow

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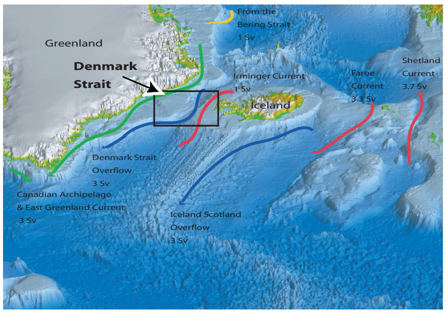
A. SCIENTIFIC MOTIVATION

The Denmark Strait is of uttermost importance as a dense water gateway connecting the North Atlantic and Nordic Seas. Commonly the volume exchange processes are not resolved in global climate models. Therefore, the through-flow dynamics for mean present-day conditions are investigated in high resolution modeling. The volume transport (overflow) through the Denmark Strait is limited by hydraulic constraints. This improves our understanding of overflow dynamics and might eventually allow to use hydraulic control as an overflow parameterization in coarse resolution global models.

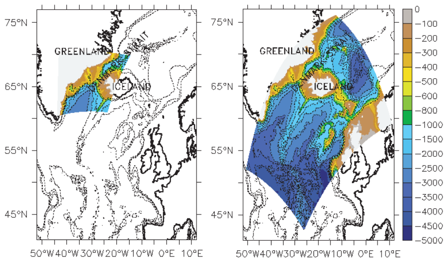


after Hansen & Osterhus (2000, Prog. Oceanogr.)

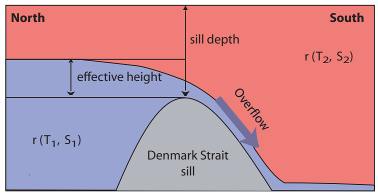
B. APPROACH

The Demark Strait is modeled by using a hierarchy of different model set-ups using the Regional Ocean Modeling System (ROMS)

1. Investigate hydraulic limitations with a process model and change upstream reservoir conditions systematically. The model domain is limited to Denmark Strait with a horizontal resolution of 5 km and 30 sigma levels (212x212x30 points) [left figure]
2. Use same grid but climatology from global model to include exterior information using open boundaries
3. Employ process model with extended domain including full Greenland-Scotland-Ridge (dx=dy=8km, 257x373x30 points) [right figure]



Hydraulic control of overflows



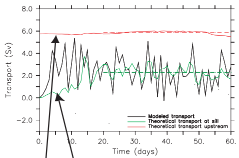
The maximum overflow Q_{max} is limited by hydraulic constraints. It is determined by the density contrast *dr* and hence the reduced gravity ($g' = g\ Dr/r_0$) across the sill and the height of the overflowing water mass above the sill (effective height H_{eff}). If the width of the passage is large compared to the Rossby radius then the transport is limited to:

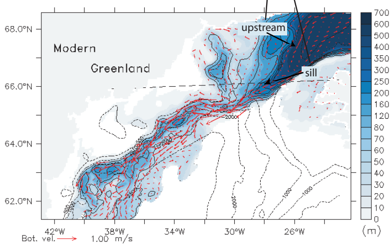
$$\text{Max. overflow } Q_{max} = 1/2\ g'\ H_{eff}^{\,2} / f_{Coriolis}$$

Whitehead (1998, Rev. Geopphys.)

C. MODERN TRANSPORT

Plume thickness and volume transport (calculated along dashed line) of dense water as obtained from process model. Hydraulic transport estimates are taken at the sill and upstream.

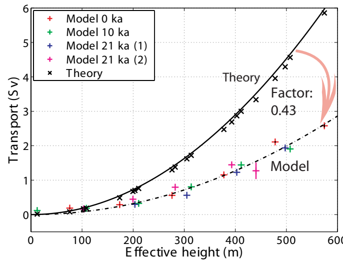




D. OVERFLOW PARAMETERIZATION

The upstream value can be taken as an upper bound which cannot be exceeded. Modeled and theoretical transport compare favorable, when appropriately scaled. The modeled transport is generally reduced to 44 % of the upstream estimate from hydraulic theory. This holds for Modern (0 ka), Postglacial (10 ka) and LGM (21 ka) conditions to within 2 %. The reduction is most likely due to the fact that the theory for rectangular openings is used and that frictional effects are neglected. However, this transport quantity is suitable to parameterize the overflow in coarse resolution models.

The theoretical estimate at the sill is important as a best estimate for the transport and might be useful for selecting future measurements sites. Moreover, Helfrich and Pratt (JPO, subm.) show that one can get an overflow estimate at the sill entrance, which is independent of the upstream circulation and hence overcomes the zero potential vorticity assumption used here.

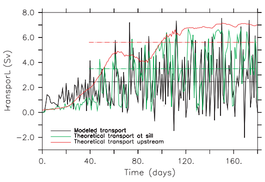


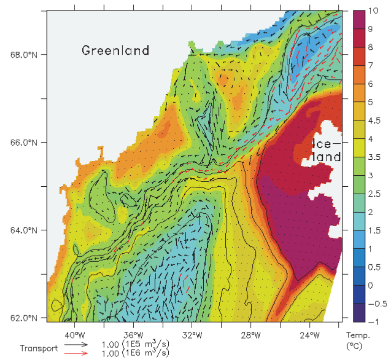
Summary of all process model experiments ($g' = 4.8\ 10^{-3}$ m/s²) showing transport as a function of effective height.

$$Q_{model} = 0.43\ Q_{max} = 0.43\ 1/2\ g'\ H_{eff}^{\,2} / f_{Coriolis}$$

E. DRIVEN BY GLOBAL MODEL RESULTS

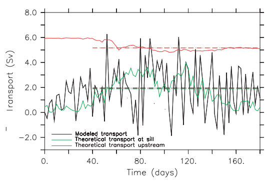
In coarse resolution models, resulting from improper overflow representation, the water mass properties in the Denmark Strait differ from observed values. Using global model results from Paul and Schäfer-Neth (Paleoceanography, 2003) as boundary conditions we find a ratio of 0.43 for modeled to theoretical transport, which is the same as for the process model.

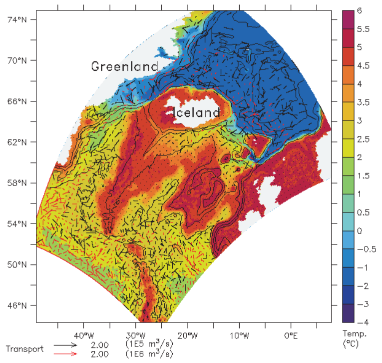




F. GOING FURTHER

The Denmark Strait is only one part of the Greenland-Scotland- Ridge. By including the full ridge we validate that the Dennmark Strait overflow is mainly determined by the regional density field. We find a transport ratio of $T_{mod}/T_{theo.}=0.42$ which corroborates the hydraulic model.





CONCLUSIONS

1. The Denmark Strait overflow can be parameterized for mean present-day conditions using hydraulic constraints.

The mean for realistic topography transport is described as being 43±2% of the maximum hydraulic transport for frictionless flow and rectangular cross-section.

2. The parameterization is robust concerning changes in resolution, boundary conditions and forcing.