# 30 Years of Denmark Strait Overflow observations linked with decadal wind stress and hydraulic forcing variability

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## 1 Introduction

The Denmark Strait Overflow (DSO) is the densest source of North Atlantic Deep Water, that forms the deep return flow of the Atlantic Meridional Overturning Circulation. Direct observations by ADCPs deployed at the 650 m deep sill exist for the period 1996-2006.

Here, the ADCP measurements are compared with upstream hydrographic profiles and NCEP wind stress data to obtain DSO transport estimates for the past decades.

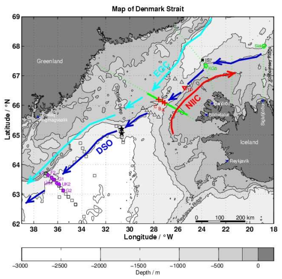


*Fig. 1: Denmark Strait. EGC: East Greenland Current. NIIC: North Icelandic Irminger Current. DSO: Denmark Strait Overflow. Mooring sites of Acoustic Doppler Current Profilers (ADCP) A,B,C at the sill; TP temperature sensor mooring and Kögur section (dotted green line with KG5) further upstream. Angmagssalik array with UK1 and UK2 current meter moorings 600 km downstream.*

## 2 Upstream Pathways

A large part of the DSO approaches the sill in a current confined to the Iceland shelf edge: A lagged temperature correlation between TP mooring site and ADCP B reveals an advection speed of 10 cm/s, consistent with direct current measurements (*Jónsson and Valdimarsson*, 2004). In contrast to the East Greenland Current, the „Iceland shelf edge current" persistently flows towards the sill; it represents the coldest waters of the later DSOW.

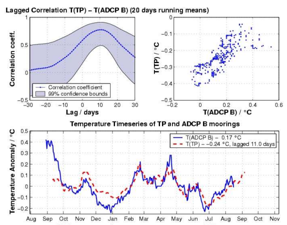


*Fig. 2: Lagged correlation of temperature timeseries at TP mooring 93 km upstream of the sill, and ADCP B at the sill. The time lag of 11 days corresponds to an advection velocity of 10 cm/s.*

## 3 Kögur section

Icelandic hydrographic standard section 200 km upstream of DS sill
- bottle data since 1950
- 4 times per year since ~1975
- full CTD profiles since ~1990

Dense water height normally largest at KG5 → depth of $\sigma_\Theta$ = 27.8 kg/m$^3$ used as hydraulic reservoir height estimate here.

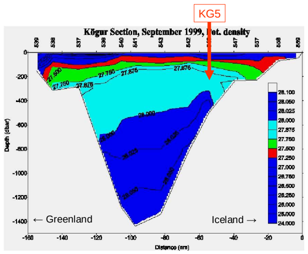


*Fig. 3: Kögur section - $\sigma_\Theta$ Sep 1999. Typically, the rise of the 28.0 and 27.8 isopycnals is located at station Kögur 5. For geographical location, see Fig. 1.*

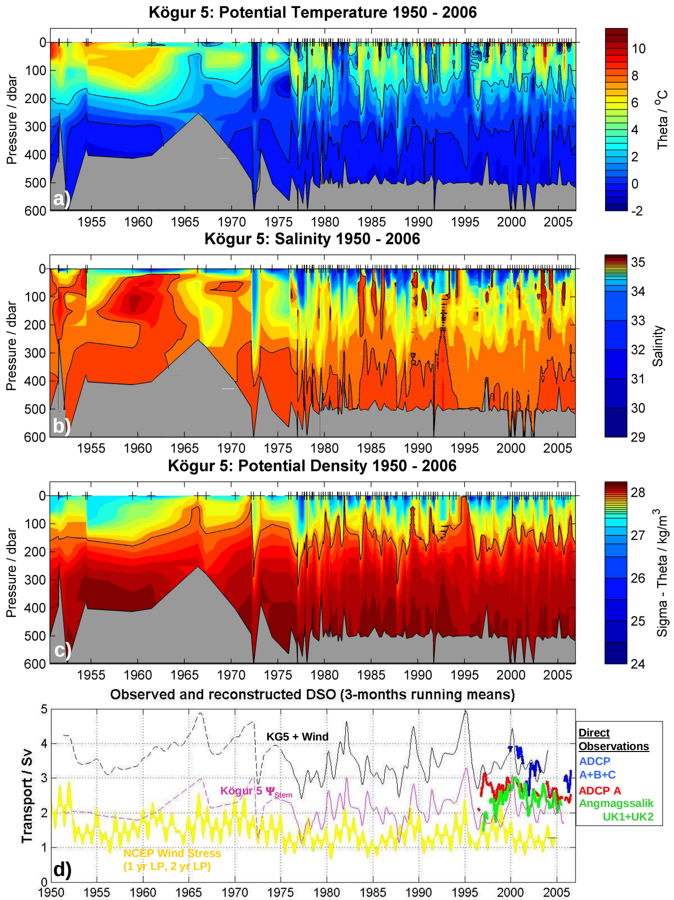


*Fig. 4: Time series at Kögur 5 1950 – 2006. „+" signs denote actual sampling dates. When KG5 was not occupied, data from around 1 Rossby radius (15 km) were taken – therefore the changing bottom depth, particularly in the early years before the KG5 site was fixed. a) Θ; black contours mark 0°C and 2°C isotherms. b) Salinity; black contour marks 34.9 isohaline. c) $\sigma_\Theta$; black contour marks 27.8 isopycnal. d) Total transport time series of DSO. An enlarged graphic of 1996 – 2006 is provided by Fig. 5.*
*Direct observations: Sill array: **ADCP A only**, **ADPC A+B+C**. Angmagssalik array: **UK1+UK2**.*
*Reconstructions: Density driven flow Kögur 5 ($\Psi_{Stern}$). Residual flow, regressed on NCEP Wind stress (note positive correlation between both). Black line marks DSO reconstruction: Sum of KG5+NCEP.*

## 4 Timeseries at Kögur 5: Θ / *S* / $\sigma_\Theta$ from 1950 to 2006

Despite of aliased short-term variability, interannual signals are evident (Fig. 4):

| | |
|---|---|
| **Temperature** | warm surface water maxima mid-80s and 2001-2005<br>cold bottom water minima mid-80s and end-90s |
| **Salinity** | overall freshening of subsurface waters<br>overflow waters: S minima ~1984 and 1994-2000. |
| **Density** | 27.8 isopycnal (upper DSOW boundary): maximum height ~1965-1972 and mid-90s (correlated with local wind stress) |

## 5 Forcing of DSO: Hydraulics

The density-driven overflow plume is hydraulically controlled (downstream descent, *F*=1, geostrophic balance; *Macrander et al.*, 2005,2007). Since PV≠*const*., maximum transport is calculated according to *Stern* (2000):

$$\Psi_{Stern} = 9/16 \;\; 1/2 \;\; g'/f \;\; h_{eff}^2$$

with $h_{eff}$ = height of 27.8 isopycnal above sill.

**Average values 1999-2004:**

| | |
|---|---|
| DSO transport (ADCP measured) | 3.4 Sv |
| Hydraulic transport (KG5 $\Psi_{Stern}$) | 1.9 Sv |
| => residual transport | 1.5 Sv |

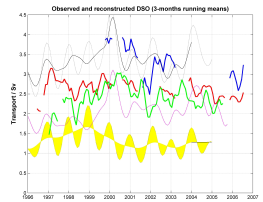


*Fig. 5: DSO transport time series 1996 –2006. **Magenta: Kögur5-$\Psi_{Stern}$**, **Yellow: residual transport**, here empirically determined from Iceland Sea NCEP wind stress (1yr, 2 yrs low pass). Black: Reconstructed transport $\Psi_{Stern}$ + wind stress. Compare with direct observations: ADCP A+B+C, ADCP A only, Angmagssalik array UK1+UK2.*

## 6 Forcing of DSO: Wind stress

The residual transport of 1.5 Sv corresponds to the observed 20 cm/s mean barotropic velocity due to the cross-strait surface height gradient and is likely wind-driven.

NCEP wind stress is largest over Denmark Strait and Iceland Sea. 1999 – 2004, local wind stress decreased by 20%, as did the residual transport. Correlation analysis suggests a time lag of 10 – 80 days depending on the distance to the DS sill.

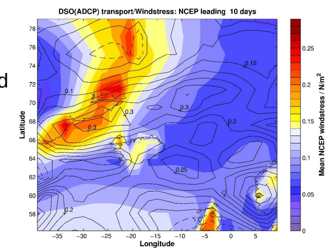


*Fig. 6: Correlation of DSO transport 1999-2004 and NCEP wind stress (leading 10 days; black contours and labels). Colours in background: Average NCEP wind stress. Highest amplitude of correlated wind stress in Denmark Strait and Iceland Sea.*

## 7 Overflow transport reconstruction and decadal estimates

- Hydraulically controlled transport 1975-2006 varies between 1 Sv and 3 Sv
- Positive correlation reservoir height – local wind stress found
- Reconstructed DSO transport consistent with direct observations 1996 – 2004.
- Indication of positive correlation with NAO and/or Iceland Sea Wind Stress on interannual – decadal timescales, to be validated against numerical models

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NCEP/NCAR Reanalysis Project: http://www.ncep.noaa.gov

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