Lagrangian pathways and transformation of the Denmark Strait Overflow Water in the Irminger Basin

Inga Koszalka*, T. W. N. Haine* and M. G. Magaldi+

*Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD, + ISMAR-CNR, Lerici, Italy

Abstract

We deploy over 10,000 Lagrangian particles at the Denmark Strait in a high resolution ocean model to study pathways and transformation of the Denmark Strait Overflow (DSO) in the Irminger Basin. Their trajectories show that:

(–) The mean position and density of dense waters cascading over the Denmark Strait sill evolve consistently with hydrographic observations. The sill particles transit the Irminger basin to the Spill Jet section (65.25N) in 5-7 days and to the Angmagssalik section (63.5N) in 2-3 weeks.

(–) There are distinct dense water pathways on the continental shelf. Particles can circulate on the shelf for several weeks before they spill off the shelf break, join the overflow from the sill and contribute significantly to the dense water overflow downstream (~ 25%).

(–) The density on particle trajectories decreases rapidly due to mixing with Atlantic waters along the continental slope. Intense mixing with the Polar Water occurs on the shelf. As a result, the overflow particles exhibit a wide range of densities downstream. Notably, the densest waters in the Irminger Basin originate from the shelf adjacent to the sill, not from the sill itself.

(–) The horizontal eddy diffusivities are largest on the shelf and downstream off the Spill Jet section. The vertical diffusivities are largest at the sill and at spilling locations along the shelf break.

Our study extends the conceptual view of the DSO in the Irminger Basin, and urges observational campaigns to verify these results and monitor the pathways of the different DSO components.

Motivation

The Denmark Strait Overflow (DSO) supplies one third of the North Atlantic Deep Water and is a key component of the global thermohaline circulation. Knowledge of the pathways of DSO through the Irminger Basin and its transformation there is still incomplete however. The Lagrangian framework is ideal for addressing these questions, but no Lagrangian observations of DSO exist. Instead, its evolution has been derived solely from sparse Eulerian (fixed-point) measurements. To fill this gap we use a high resolution ocean model and deploy over 10,000 Lagrangian particles in DSO at the Denmark Strait to study its pathways and transformation in the Irminger Basin.

Methods

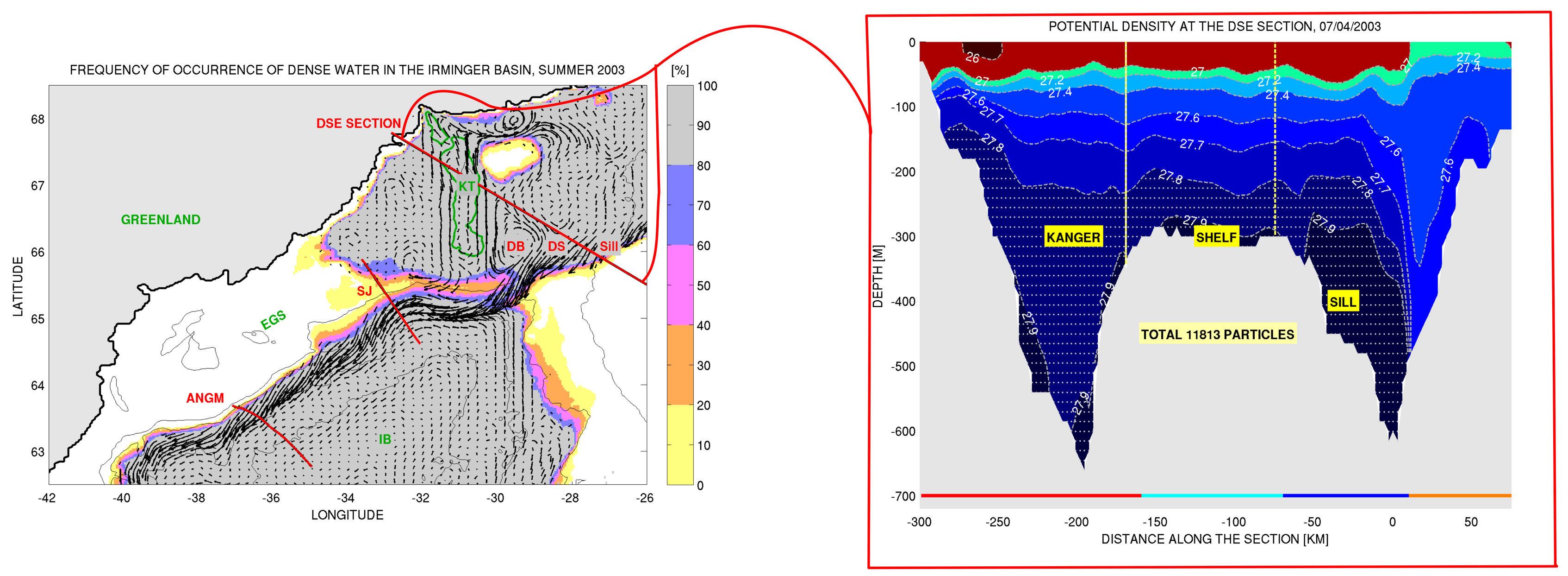
Model - MITgcm

- Highest spatial resolution to date of Irminger Basin: dx ~ 2km, max dz=15m (210 layers)
- Simulation period: summer 2003 (7/1 - 9/1)
- 3rd tracer advection with implicit diffusion KPP for vertical diffusion, Leith horizontal viscosity
- Forcing by NCEP fluxes & SeaWinds
- Model validated with observations (Magaldi etal 2011)

Numerical Lagrangian particles

- Trajectories integrated with model 3D velocities offline using MATLAB (ode23t) and dt=15min
- Boundary conditions - 'wall-sliding'
- Velocity & tracers linearly interpolated in space and time on particle positions

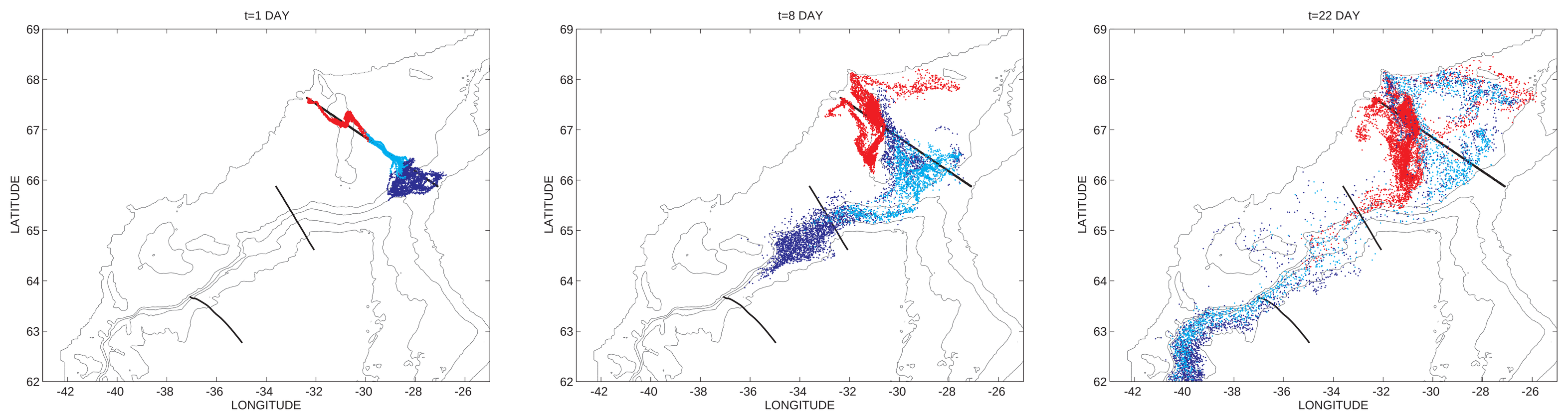
Model dense waters and the particle deployments



Left: Occurrence frequency of model dense waters ($\sigma_\theta \geq 27.8$) in the Denmark Strait/East Greenland Shelf (EGS)/Irminger Basin (IB). Superimposed are mean dense water current vectors. The hydrographic sections are: Denmark Strait Extended (DSE), DS Sill, Spill Jet (SJ) and the Angmagssalik array (ANGM). The Dohrn Bank (DB) and the Kangerdlugssuaq Trough (KT) are marked. Right: A snapshot density along DSE with marked particle deployments. The particles were released along the section in ($\sigma_\theta \geq 27.8$) layer in 10 sets separated by 12h, starting 7/1. They are classified according to the release site in 3 groups: SILL, SHELF and KANGER.

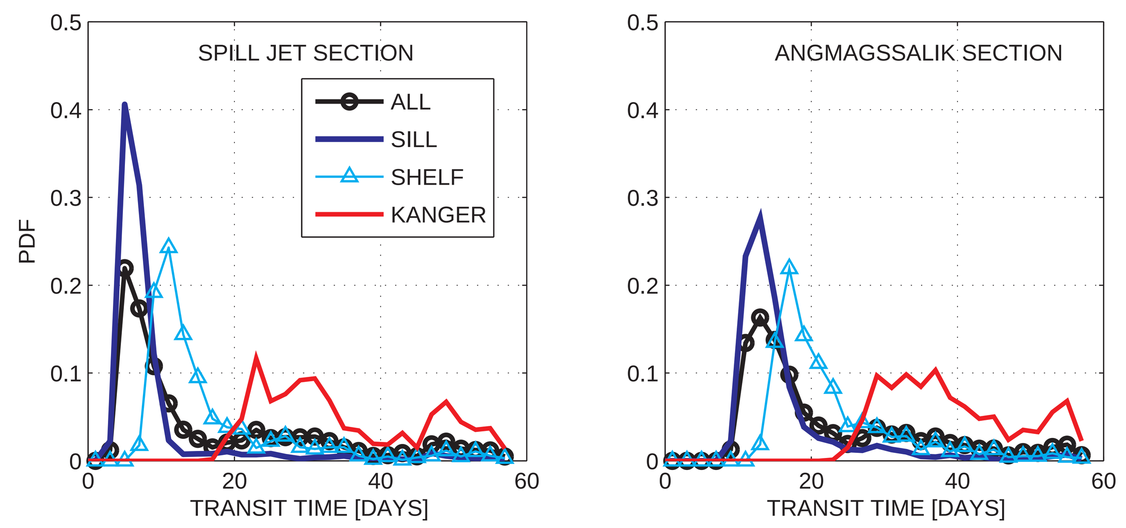
Results

The DSO particles



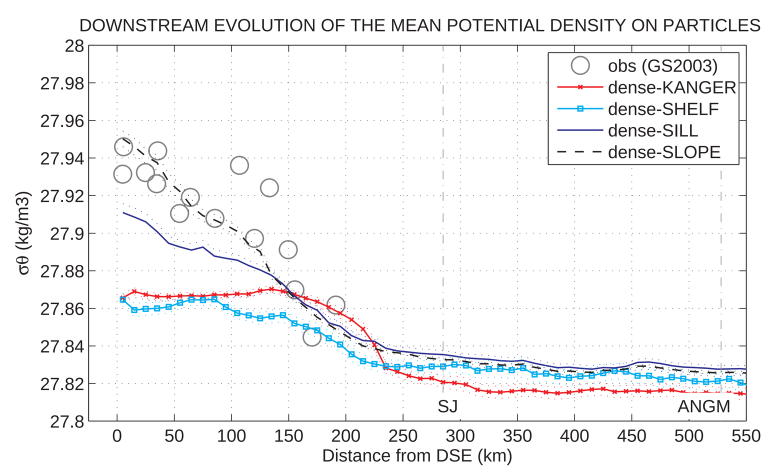
Snapshots of particle positions at day 1, 8 and 22 projected onto a horizontal plane.

Travel times



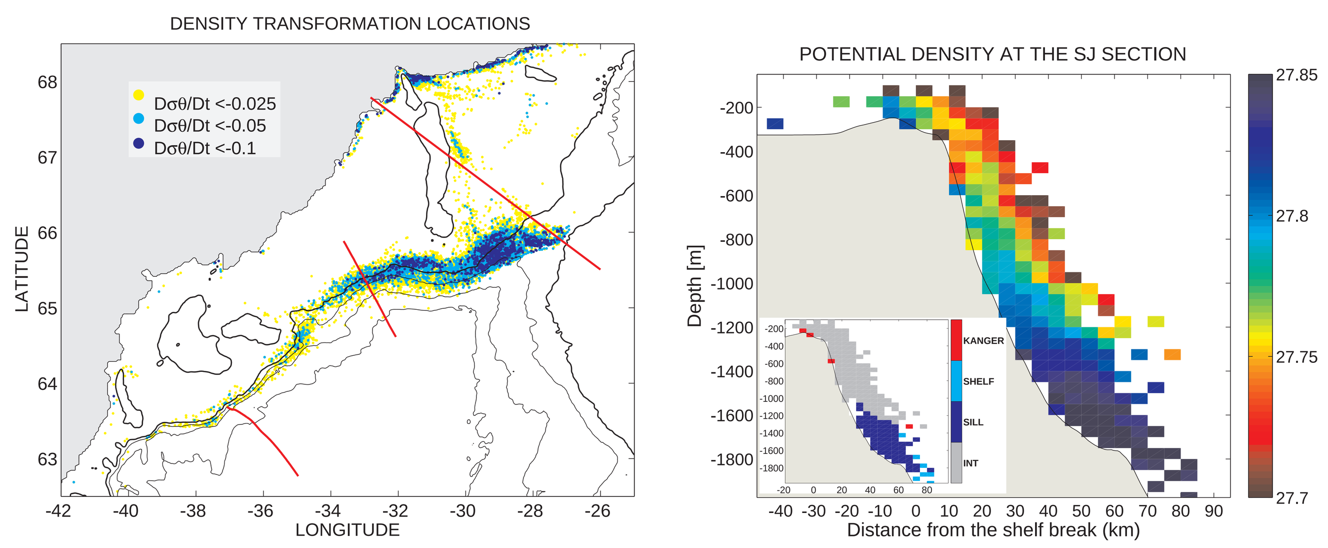
Transit time distributions from the Denmark Strait to the Spill Jet and the Angmagssalik sections. The modal transit times for SILL particles to these sections are 5-6 days and 2-3 weeks, respectively. The SHELF particles recirculate before spilling over the shelf break and joining the sill overflow; their modal transit is longer by about a week. The KANGER particles recirculate in the DS for several weeks, their transit time distributions are broad.

Ensemble-mean density evolution and comparison with the data



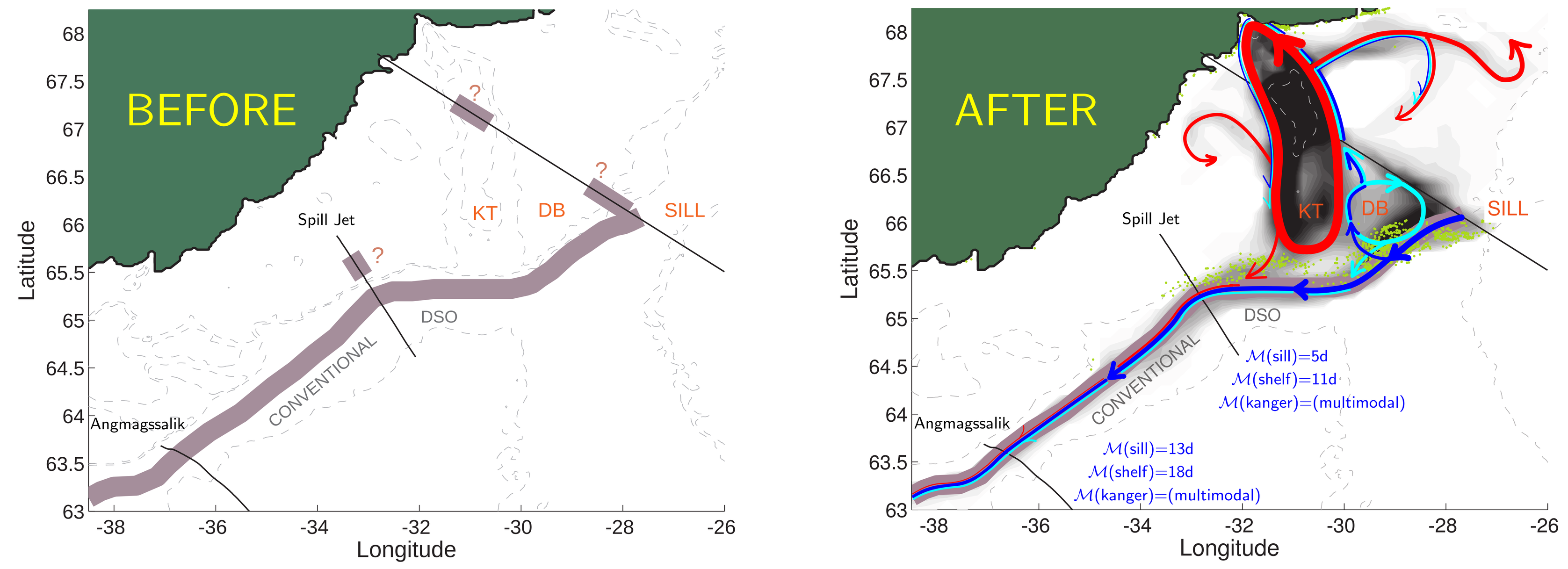
Evolution of the mean particle density with distance from the DSE for the three deployments groups (SILL, SHELF and KANGER) as well as dense particles recorded over a seabed deeper than 600 m (SLOPE). Superimposed with circles are the observations from Girton & Sanford (2003) that should be compared to SLOPE particles.

Water property transformation



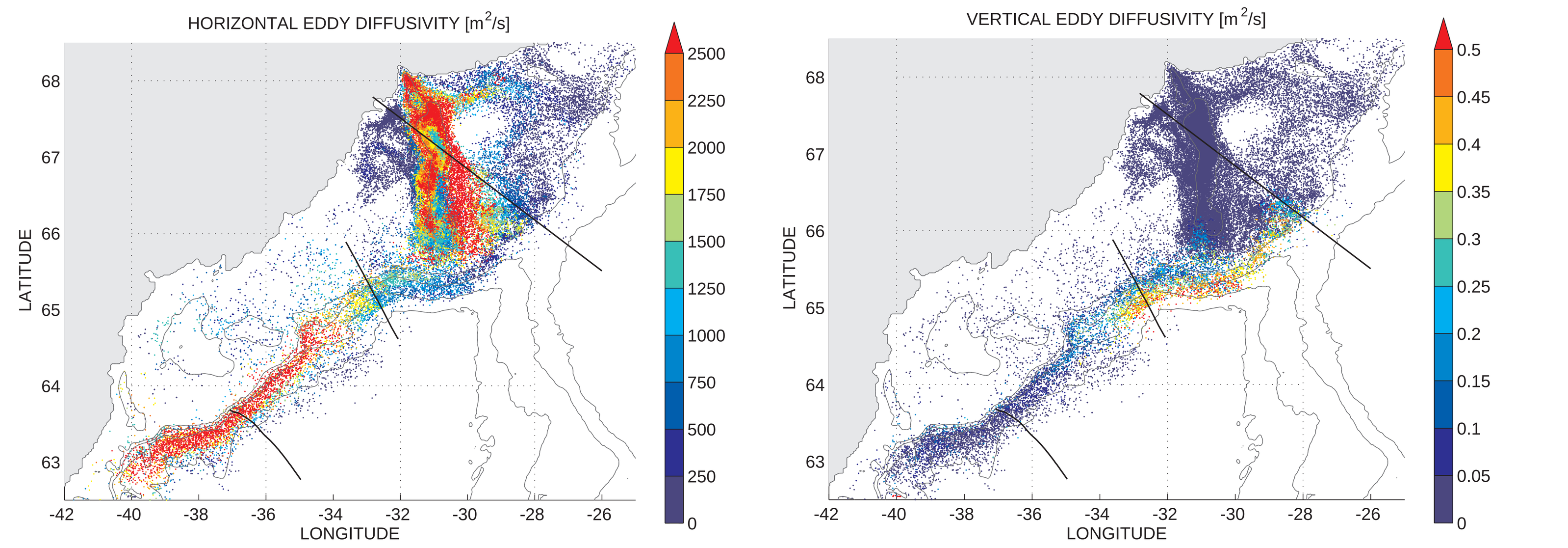
Left: Particle positions when density transformation rate is high; $D\sigma_\theta/Dt \leq$ -0.025, -0.05 and -0.1 $kg\,m^{-3}\,day^{-1}$. Along the slope (spilling locations) the transformation is high due to mixing with warm and salty Atlantic Waters. On the shelf the freshening suggests mixing mixing with Polar Waters. Right: Average σ_θ on particles at the SJ section. The inset shows the dominant contributions from the deployment sets to the bins with $\langle\sigma_\theta\rangle \geq 27.8$. Note significant transformation to intermediate waters (gray bins) and that the SHELF particles dominate in bins with densest & deepest waters.

Dense water pathways revealed by the Lagrangian study



The DSO pathways derived from hydrographic observations before our study (left) and the view emerging from trajectories of the Lagrangian particles (right). The distribution of dense particles in the domain is shown in gray. At the Denmark Strait, dense water is found in the sill (blue), on the adjacent shelf (cyan), and in the Kangerdlugssuaq Trough (KT; red). Over 60 days these different water masses spread according to the arrows. There is cyclonic recirculation in the KT and anticyclonic recirculation on the Dohrn Bank (DB). Some of this recirculating water spills over the continental shelf break.

Work in progress: Mixing processes



Horizontal and vertical eddy diffusivities estimated from particle velocities using a recently proposed clustering method (Koszalka & LaCasce, 2010). The horizontal diffusivities are elevated on the shelf and downstream off the SJ section. The highest vertical diffusivities co-locate with the dense water crossing the sill and spilling off the shelf break.

Conclusions

- Pathways of dense waters on the shelf are mapped providing context for hydrographic observations. They reveal the importance of the anticyclonic recirculation on the Dohrn Bank (DB) and the cyclonic flow in the Kangerdlugssuaq Trough (KT).
- The strongest transformation occurs: 1) upon the DSO cascading the sill (with IC/AW), and 2) at dense water spilling locations along the shelf break. Following the transformation, the DSO particles exhibit a wide spectrum of densities in the Irminger Basin.
- Mixing with PSW causes the transformation on the shelf and may be a mechanism to transmit the FW variability to the Atlantic.
- The modal travel times for the sill-DSO are 5 days to the SJ section and 2-3 weeks to Angmagssalik. Particles seeded and recirculating on the shelf arrive one week later, and the dense waters from KT spill near SJ section at ~ 25-day intervals.
- KANGER and SHELF releases contribute to the pool of dense particles at Angmagssalik with 25%. The particles released on the shelf are separated from mixing with IC, thus preserving their densities and contributing to the densest water at the SJ section.
- Planning an observational study to corroborate these model results.

The paper

A publication with results presented here has been submitted to J. Phys. Oceanography.] The draft is available at blaustein.eps.jhu.edu/~koszalka/:

Contact: Inga Koszalka (inga.koszalka@jhu.edu)