Dynamics of the high-frequency variability in Denmark Strait

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1. Motivation and background

Strong air-sea buoyancy forcing in the Nordic Seas converts warm subtropical-origin water near the surface to cold water that flows equatorward at depth, as part of the Atlantic Meridional Overturning Circulation. The newly-ventilated dense water enters the North Atlantic as overflow plumes through gaps in the Greenland-Scotland ridge. The largest overflow occurs in Denmark Strait, supplying the densest water to the Deep Western Boundary Current (Fig 1). While the transport of Denmark Strait Overflow Water (DSOW) is steady over seasons and years, it varies pronouncedly on timescales of a few days. Here we seek to better understand the nature and cause of the high-frequency variability.

2. Data and model

We use in-situ timeseries of ADCP velocity and bottom temperature from mooring DS1 in Denmark Strait (Fig. 1b), together with along-track absolute dynamic sea surface topography from CMEMS and sea surface temperature from MODIS. The time period considered for all datasets is 2006-2015. The model used is the MITgcm with a horizontal grid spacing of 2 km. A one-year simulation was run from September 2007 – August 2008, forced with ERA-interim atmospheric fields.

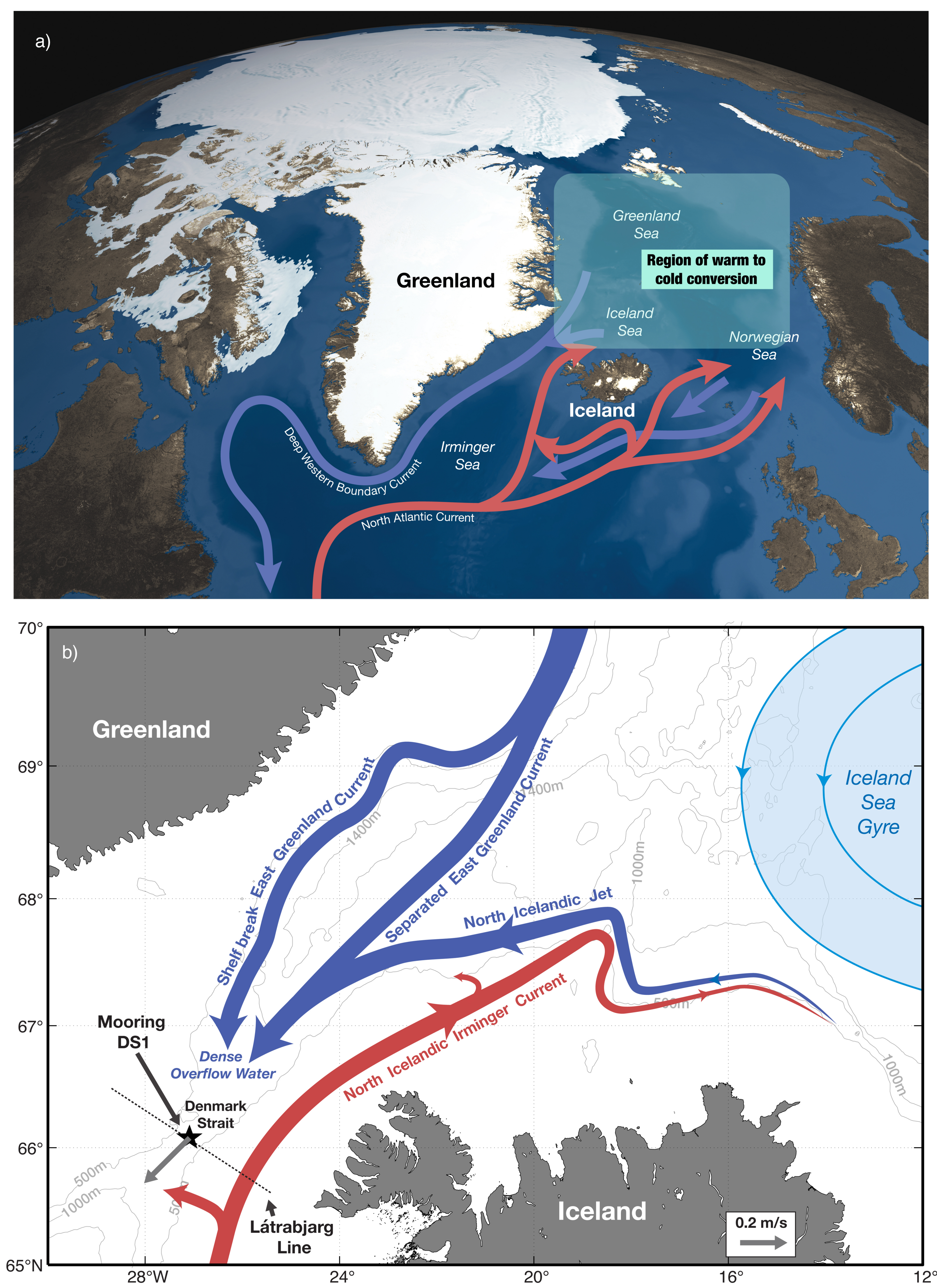

Fig. 1: (a) Schematic of the warm inflow and cold outflow from the Nordic Seas. (b) Schematic of the dense water pathways feeding Denmark Strait (blue arrows) and the warm subtropical-origin water entering the Iceland Sea (red arrow). Mooring DS1 is marked and the 10-year mean current vector of the overflow layer is shown. The Látrabjarg Line is a CTD section spanning Denmark Strait that is regularly occupied.

3. Three modes of variability

Previous studies [1,2] have identified two mesoscale processes by which DSOW flows through Denmark Strait, known as "boluses" and "pulses" (Fig. 2a,b). The former is associated with a raising of the overflow water interface, while the latter occurs when the overflow layer thins and accelerates. Pulses are also associated with a seaward deflection of the warm North Icelandic Irminger Current (NIIC).

Our data reveal a third process which we refer to as warm water "flooding events". These occur when the NIIC propagates far offshore and advects subtropical-origin water northward through the deepest part of the strait (Fig 3). Flooding events happen on average once a month; we argue that they are associated with extreme occurrences of pulses (Fig 3a).

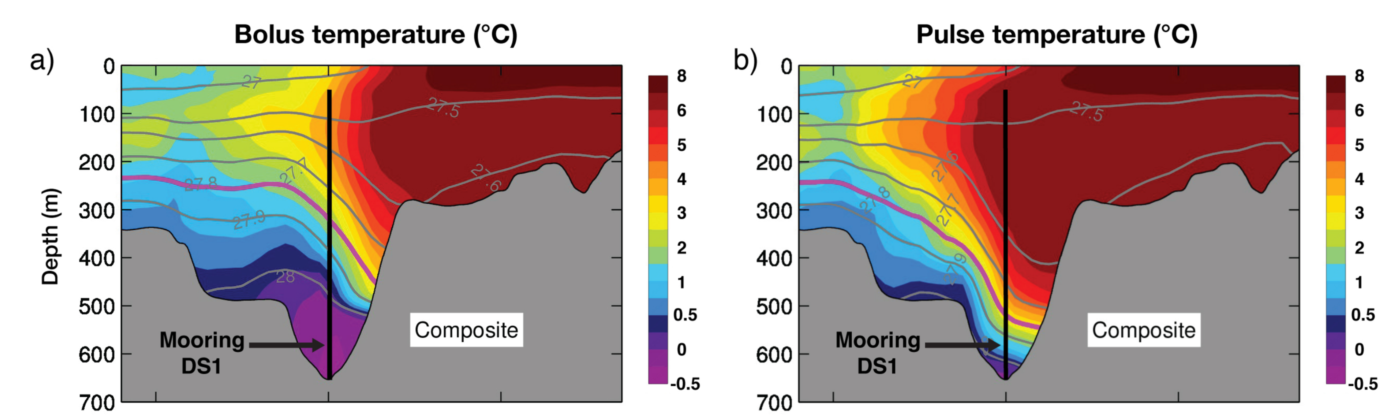

Fig. 2: Composite vertical section of temperature (color, °C) overlain by density (contours, kg m-3) for (a) a bolus in Denmark Strait, and (b) a pulse in Denmark Strait. The thick magenta line denotes the overflow water interface. The vertical black line denotes the velocity range of the mooring. The two composites were constructed using historical occupations of the Látrabjarg CTD Line (see Fig. 1b).

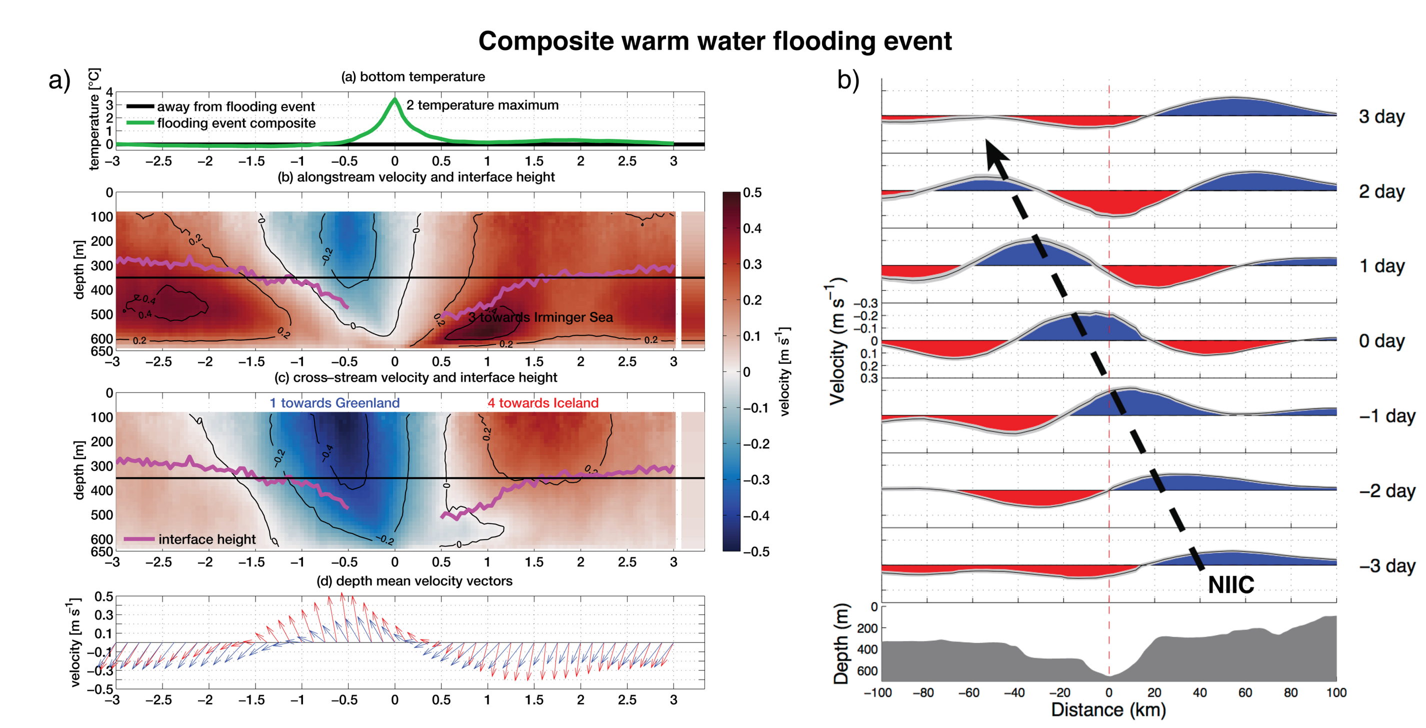

Fig 3: (a) Composite warm water flooding event from the DS1 mooring data. Time goes from three days before the peak warming to three days after. The top panel is near-bottom temperature. The second panel is along-strait velocity where positive is southward. The third panel is cross-strait velocity where positive is towards Iceland. The thick magenta line is the overflow water interface. The bottom panel is the vertically averaged flow in the upper layer (red) and the overflow layer (blue). The peak northward flow occurs roughly a half day before the peak warming. Note the period of enhanced deep along-strait velocity roughly one day later, which occurs as the across-strait velocity changes sign. This is characteristic of an overflow pulse [2]. (b) Composite warm water flooding event seen in the satellite-derived surface absolute geostrophic velocity. The NIIC propagates westward in conjunction with the event (denoted by the dashed arrow).

4. Frontogenesis

The model accurately captures the main currents in Denmark Strait (Fig 4). It reveals that the hydrographic front in the strait is subject to baroclinic instability, which, if unchecked, would spin down the flow. The temperature and salinity tendency equations indicate that the front is maintained by mean advection in the strait, while the eddies act to relax the front (Fig 5). The surface convergence in the model agrees well with that determined from the satellite observations (Fig 6).

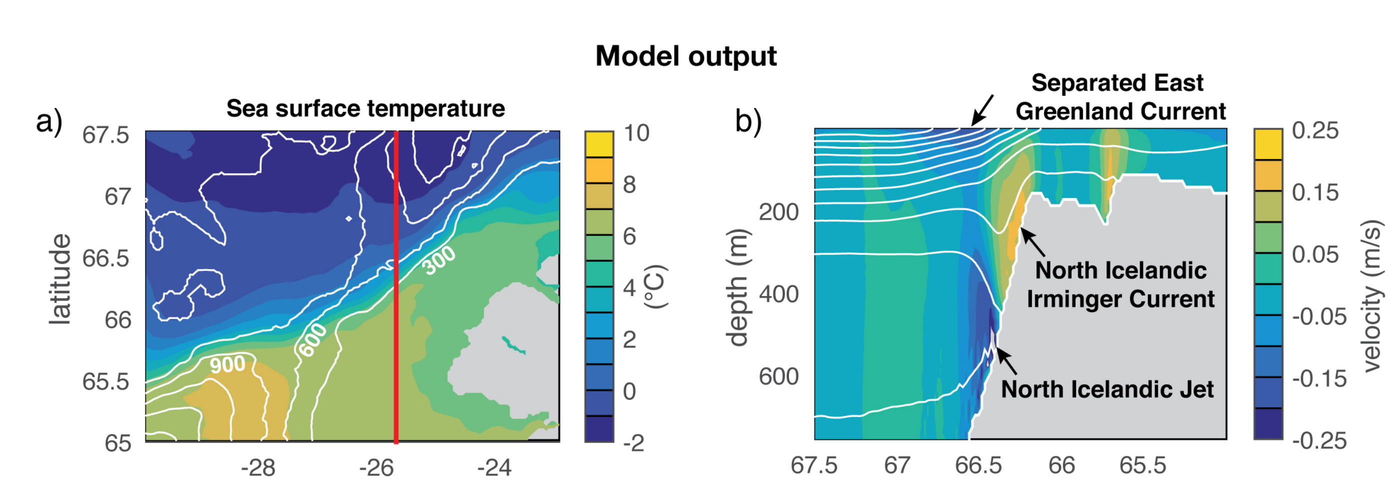

Fig. 4: (a) Mean sea surface temperature in the model (color, °C). The contours are isobaths. (b) Mean zonal velocity (m/s, color) overlain by density (contours) for the meridional section indicated by the red line in (a). Positive velocity is eastward. The three main currents on the Iceland slope are labeled.

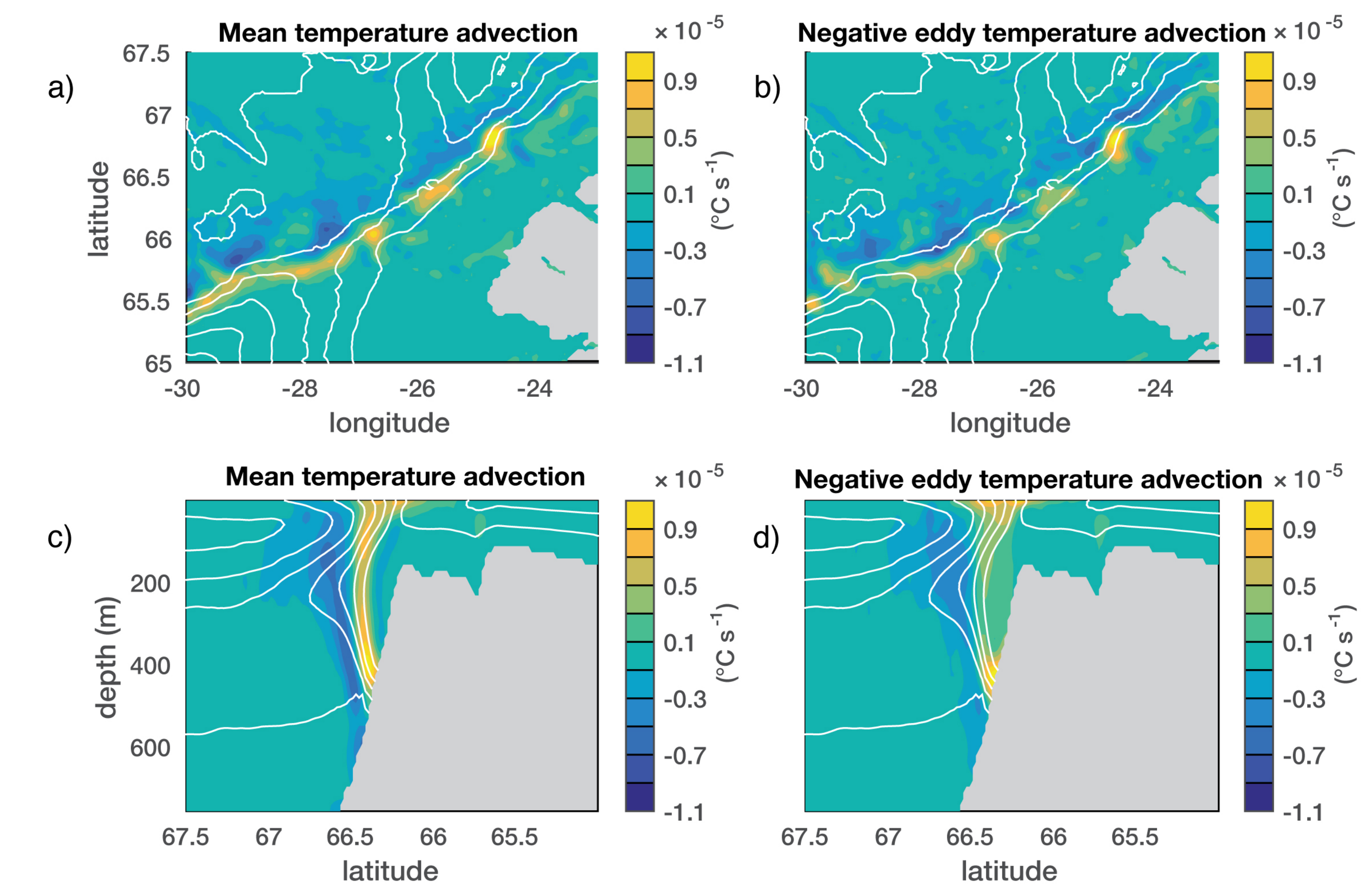

Fig. 5: Top row: Contributions to the temperature tendency equation at 50 m depth (°C s-1) in the model due to (left) mean temperature advection and (b) negative of the eddy temperature advection. The contours are isobaths. Bottom row: Contributions to the temperature tendency equation in the model across the meridional section indicated by the red line in Fig. 4a, due to (a) mean temperature advection and (b) negative of the eddy temperature advection. The contours are temperature.

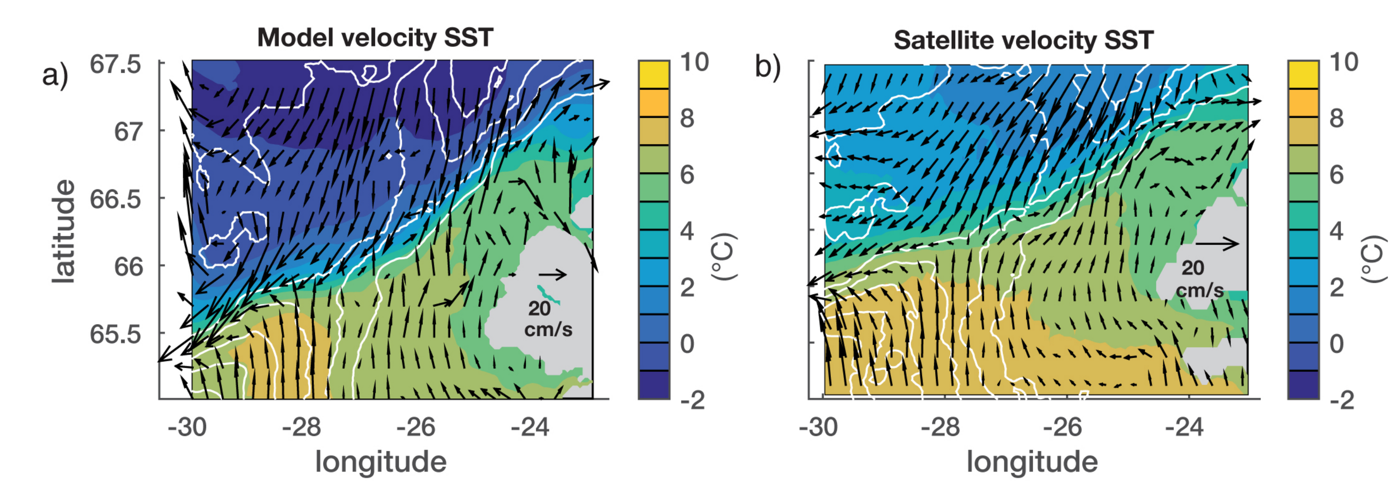

Fig. 6: (a) Mean sea surface temperature (color, °C) and mean surface vectors in the model. The contours are isobaths. (b) Same as (a) using the satellite data.

5. Relation of frontal dynamics to overflow water variability

The hydrographic front in the strait undergoes meanders that propagate to the southwest. The model reveals that boluses tend to coincide with meander troughs, while flooding events (and hence pulses) occur during meander crests (Fig 7). This indicates that the three modes of variability observed in Denmark Strait are part of a single dynamical process associated with the instability of the hydrographic front. Our study thus provides a unifying view of the high-frequency variability of DSOW entering the North Atlantic.

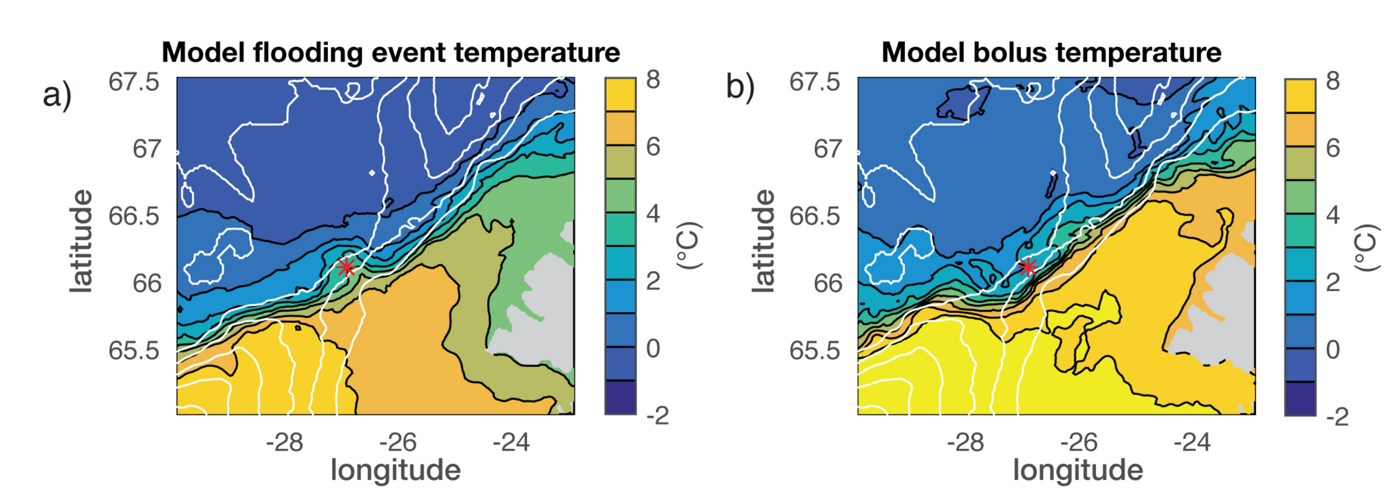

Fig. 7: Composite averages of sea surface temperature (color, °C) from the model for (a) periods when warm water flooding events were present, and (b) periods when DSOW boluses were present. The contours are isobaths. The red asterisk is the location of the DS1 mooring.

6. References

[1] Mastropole, D., R.S. Pickart, H. Valdimarsson, K. Våge, K. Jochumsen, and J.B. Girton. Hydrographic structure of overflow water passing through Denmark Strait, 2017. Journal of Geophysical Research, 122, 306-321, doi: 10.1002/2016JC012007.

[2] von Appen, W-J., D. Mastropole, R.S. Pickart, H. Valdimarsson, S. Jonsson, J.B. Girton, On the nature of the mesoscale variability in Denmark Strait, 2017. Journal of Physical Oceanography, 47, DOI: http://dx.doi.org/10.1175/JPO-D-16-0127.1.