An Irminger Ring Mooring in the Labrador Sea

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Introduction:

Deep ocean convection is limited to a small number of isolated regions worldwide, including the Labrador Sea, but it has a profound impact on the ocean's thermohaline circulation and climate. While the convection process itself has been studied intensively over the last decade, the restratification of the water column after convection, which will directly impact convection during subsequent winters, is not as well-studied. It has recently been suggested that the decay of coherent, long-lived, anticyclonic eddies shed from the warm, salty Irminger Current west of Greenland are potentially important in restratifying the interior Labrador Sea. The goal of this research is to collect new information on the initial structure of Irminger Rings and on the evolution of their core properties as they propagate across the Labrador Sea.

We deployed one densely instrumented mooring in the northeastern Labrador Sea near the eddy formation site in September 2007 to document the full water column hydrographic and velocity structure of new rings where they detach from the boundary. The mooring also serves as the "launch pad" for the automatic release of a profiling float into an eddy core each time an eddy sweeps by the mooring.

1. Mooring Design

The densely instrumented mooring (**Figure 1**) is designed to resolve the vertical structure of Irminger Rings. Seabird Microcats and Aanderaa RCM-11 instruments are distributed over the 3000 meter mooring length, and measure salinity, temperature, and pressure, as well as current speed and direction.

Figure 1

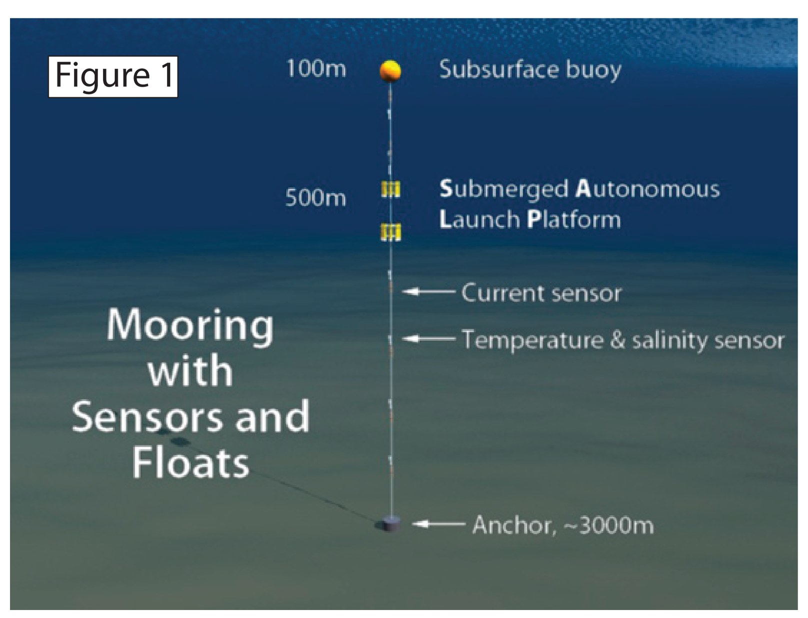


Figure 2

WHOI engineers Jim Valdes and Dave Wellwood load the Submerged Autonomous Launch Platform (SALP) with APEX floats (**Figure 2**). The prototype SALP is designed to launch floats when triggered by passing temperature and pressure anomalies, which indicate that an Irminger Ring is passing by the mooring. After release, the floats profile once every five days, and drift at a nominal 300 meter 'park depth'.

2. SALP Algorithm

The SALP controllers are pre-programmed to release a float whenever a ring is detected at the mooring. Since the rings have a distinct warm core that is 1-1.5°C warmer than the background, temperature at the depth of the warm core (e.g., 500 m) is a robust indicator of a ring. But since the water property anomalies extend radially beyond the velocity core, there is some risk of a float being released on the eddy flank and quickly separated from the eddy, or in a warm filament. A more robust test that depends on both temperature and velocity ensure that floats are released within the trapped fluid of a warm eddy core. The method takes advantage of the very strong relationship between vertically averaged velocity and mooring tow down. **Figure 3** illustrates the approximate vertical displacement of a mooring as a Gaussian-shaped eddy with a maximum vertically averaged azimuthal velocity of 50 cm/s at a core radius of 20 km passes the mooring at four different radii. The two slices through the eddy's velocity core (at Y = 0 and 10 km, heavy solid and dashed lines) result in two ~150-m tow-downs of the mooring, **Figure 3c**, whereas the two slices at the edge of and outside the core (thin solid and dashed lines, Y = 20 and 30 km) produce a single tow-down. This tow-down is represented schematically in **Figure 4**, where the mooring tilts in the eddy velocity maxima, measuring a higher pressure, and the mooring is again upright in the quiet eddy interior.

Figure 3

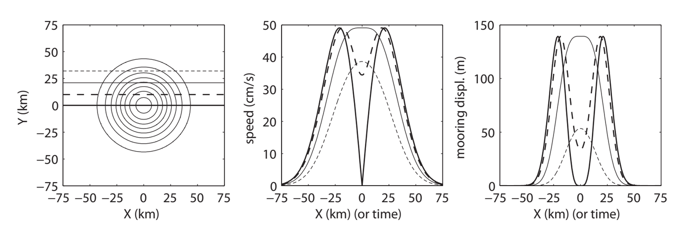


Figure 4

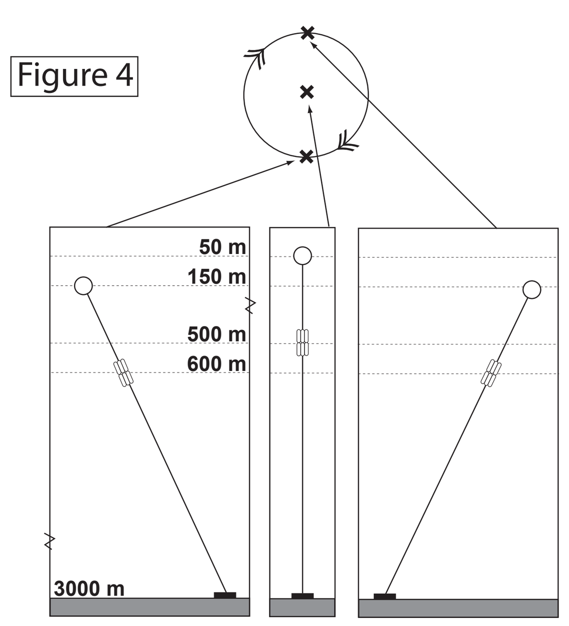


Figure 5

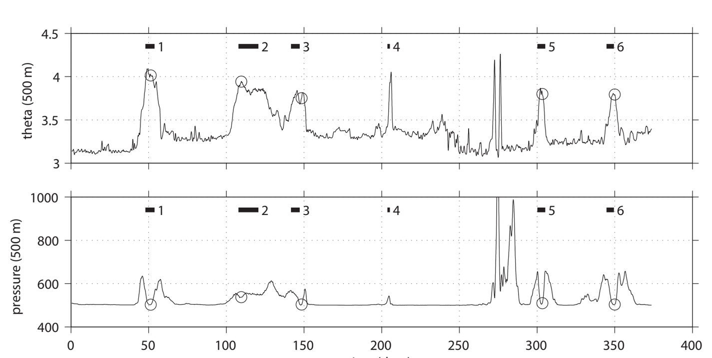


Figure 5 shows results from a test of the float release algorithm on the Bravo mooring data from the central Labrador Sea: (**a**) potential temperature and (**b**) pressure at the 500-m instrument for one year during 1998-1999. Numbered horizontal bars indicate Irminger Ring events as identified by Lilly et al. (2003). Open circles show hypothetical float releases based on our algorithm. **Figure 5** shows that both single- and double-peaked pressure signatures were present in the Bravo mooring data when Irminger Rings passed by. Events 1, 5 and 6 have the predicted signature of an isolated Irminger Ring core: a double peak in pressure accompanied by a single temperature maximum. Using our algorithm, floats would have been correctly deployed within the cores of eddies 1, 5 and 6, as well as in the more complex events 2 and 3 (which represent two rings interacting).

3. Mooring Placement

In addition to finetuning the mooring algorithm to release when an Irminger Ring passed over it, the mooring had to be placed in a location that would have the best chance of a Ring passing over it. Lilly et al. (2003) (**Figure 6**) identified about 2000 eddy-like along-track SSH anomalies, with amplitude > 10 cm, in TOPEX/Poseidon altimetric data from the Labrador Sea during 1994-2000. A localized maximum in eddy observations is located in the northeastern Labrador Sea where the 3000 m isobath diverges from the west coast of Greenland, near 61.5°N, 52°W (**Figure 6a**). It is presumed to be the most common site of eddy formation, which is thought to be triggered by destabilization of the boundary current as it flows over the steep continental slope there. **Figure 6a** further shows an extension of the highest anomaly concentration southward along a relatively narrow corridor toward the Bravo site.

Figure 6

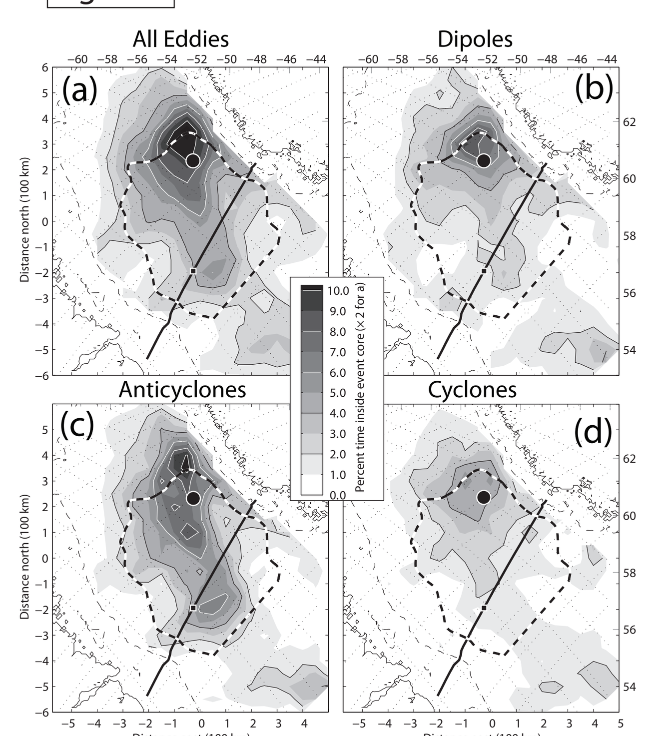
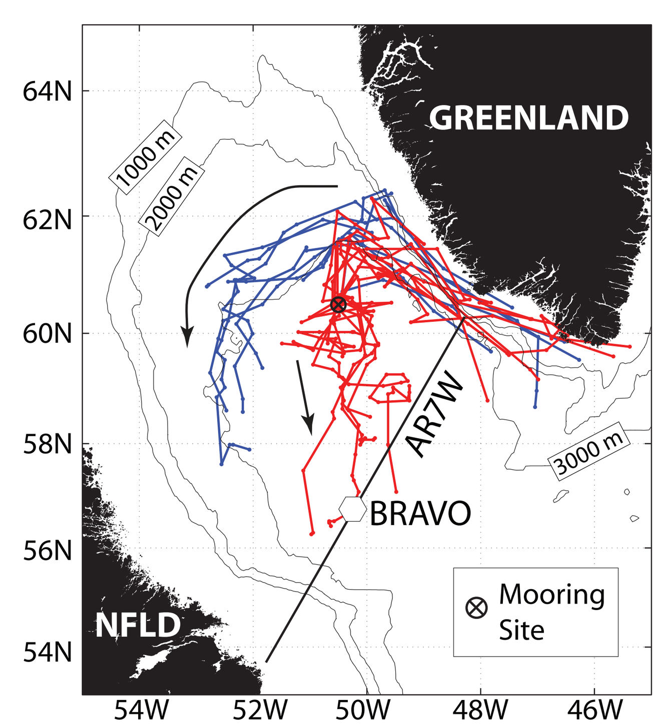


Figure 7



We extended the analysis of the altimetric data for the 2001-2006 time period to document any changes in eddy pathways since the Lilly study. **Figure 7** shows the two dominant pathways of anticyclones that originated along the west coast of Greenland for the 2001-2006 time period. These anticyclonic anomalies were identified manually from daily satellite images to create continuous eddy trajectories. The eddies that left the boundary current and travelled into the interior Labrador Sea (**red**) further strengthened our decision to place the mooring at its current site.

Reference:

Lilly, J., P. Rhines, F. Schott, K. Lavender, J. Lazier, U. Send, and E. D'Asaro, 2003. Observations of the Labrador Sea Eddy field. Progress in Oceanography, 59(1):75-176.

Acknowledgements:

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4. SALP and APEX Float Performance

Eight APEX floats released from the mooring, and one from the ship during the deployment cruise, are shown in **Figure 8**, which illustrates the float launch date, duration and mode of release. All floats but one have been released as programmed and are still profiling. One float failed to launch for unknown reasons. Initially, floats were programmed to release when both temperature and pressure criteria were met. After 9 months, at the start of the second fall season (2008), the SALP was programmed to relax criteria to a simple temperature criterion. Two floats remain to launch, and will release when the SALP next registers a temperature of over 5°C.

The floats released from the mooring are programmed to profile every five days and park at 300 m between profiles, whereas ARGO floats in the area profile every 15 days and are parked at 1000 m. The different sampling scheme was chosen to ensure that the APEX floats are engaged with mesoscale activity of the upper ocean.

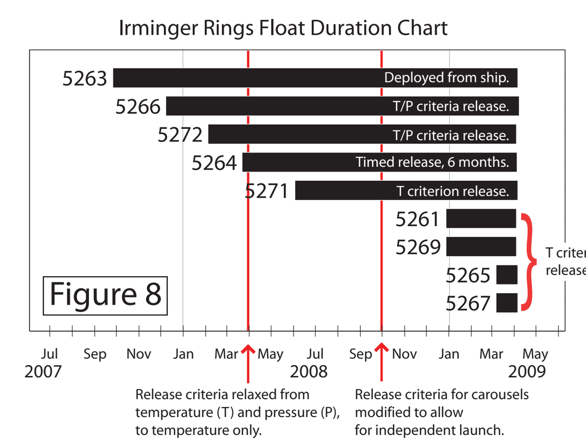
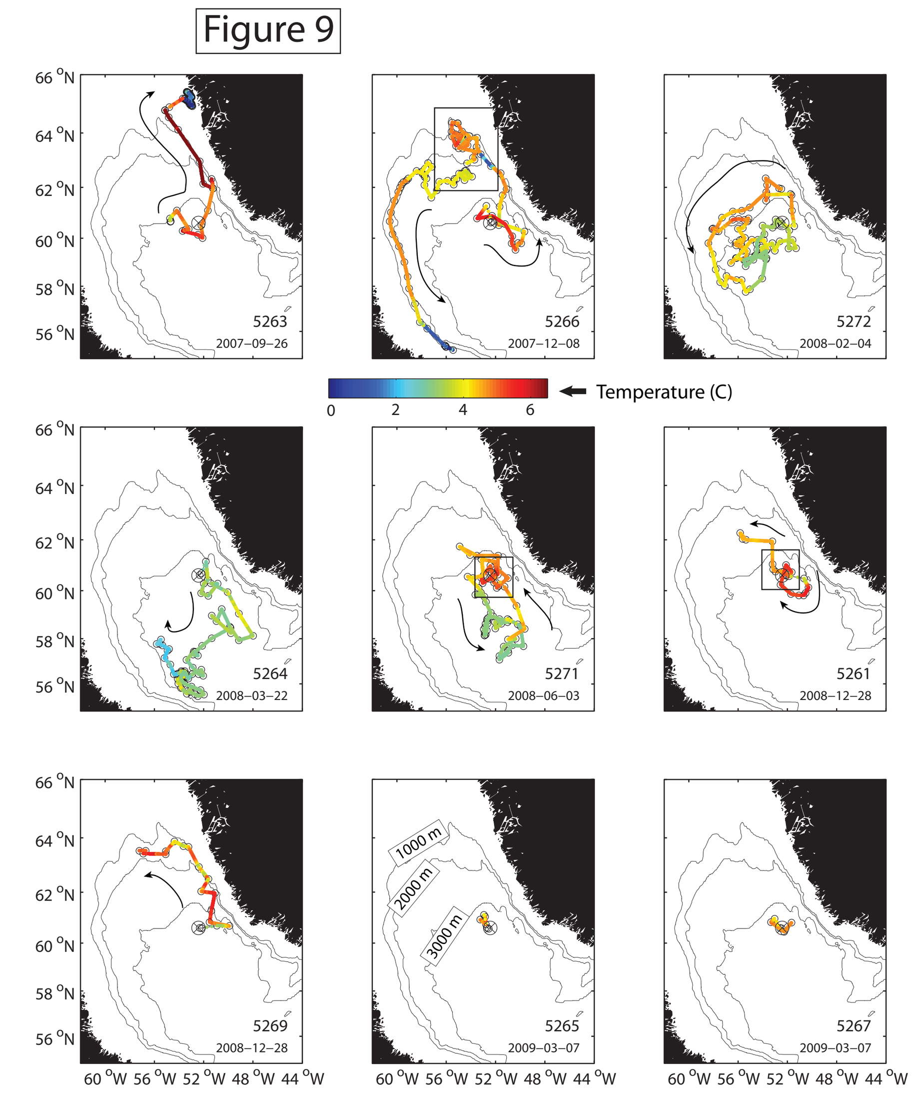


Figure 9



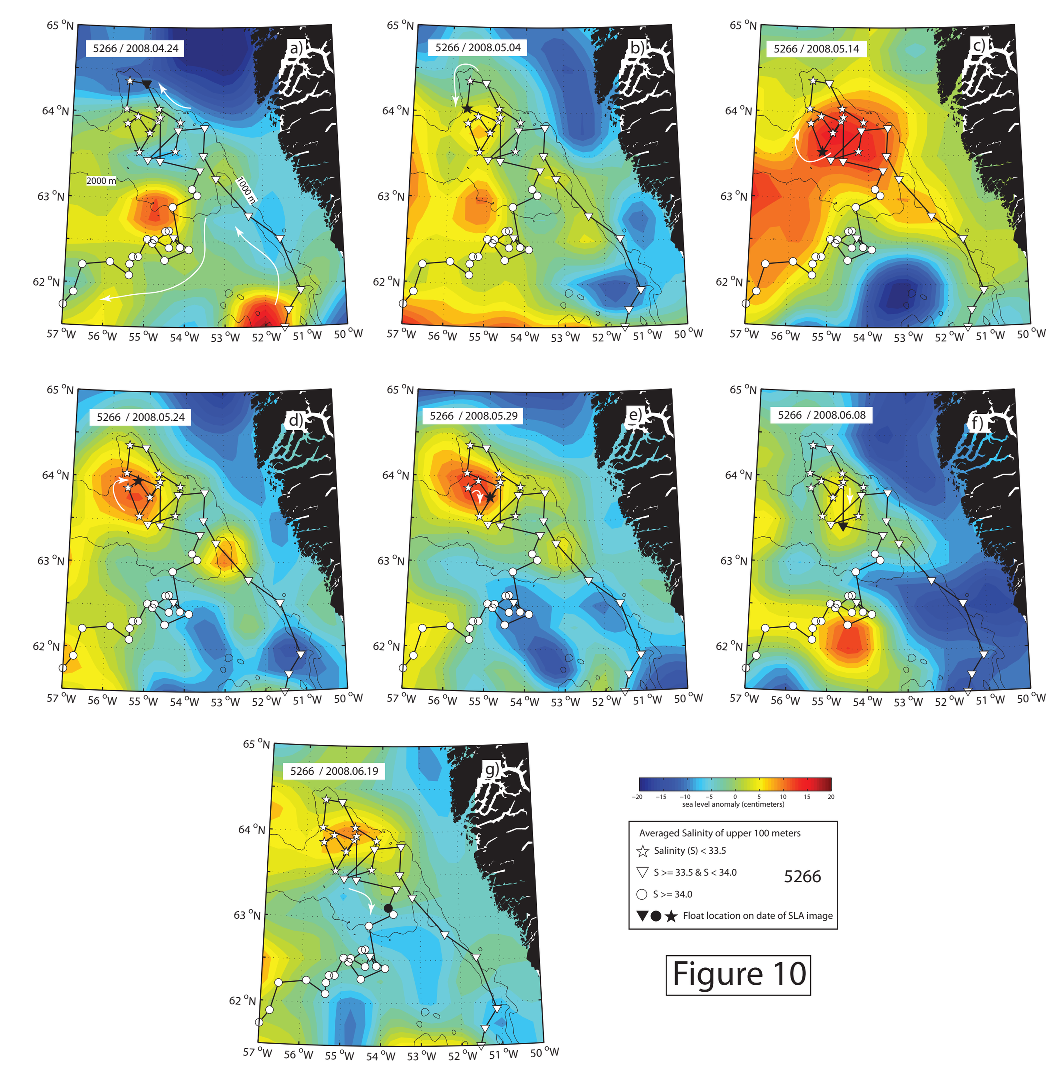
Trajectories of the nine floats launched to date (**Figure 9**). The longest trajectory (first launched) is shown in upper left, and the most recent release in the lower right. The trajectory has been color-coded by temperature measured by the float at its park depth, nominally 300 meters. Profile locations are shown as open black circles underneath the color trajectory. The mooring site/ launch location is shown as a circle-x, and release date and float number in the lower right corner of each subplot. Three floats (5261 5266 5271) have boxes that designate the location of eddy observation shown in Figures 10 and 11.

Summary:

The sensor-driven SALP has released floats using temperature and pressure criteria as expected, a testament to the usefulness of the SALP technology. Out of the eleven floats that were on the original carousel, two remain to launch, and will be triggered as the next warm temperature anomaly passes by the mooring. A preliminary look at the profiling float data suggests that new anticyclonic eddies do contain a relatively freshwater cap. The mooring and its instruments will be recovered in September 2009, and the floats will continue to circulate in the Labrador Sea for up to two more years. The complete data set will give us a new look at the characteristics of recently formed Irminger Rings, including the evolution of the Irminger Rings over time.

5. Freshwater cap on anticyclones

Initial results show that anticyclones do trap relatively fresher water in their surface layer. An anticyclone tagged by APEX float 5266 (**Figure 10**) in the northeast section of the Labrador Sea between the 1000 and 2000 meter isobath can be seen in a series of sea level anomaly (SLA) images from April through June 2008. The float remained with the eddy for approximately 25 days, from 4 May 2008 through 29 May 2008. The chronological series of plots shows the decrease in upper layer (0-100 meter) mean salinity as the float moves into the anticyclone, makes one loop, and then the subsequent increase in salinity as the float leaves the anticyclone on 8 June. This decrease of upper layer salinity in an eddy suggests the generation of a freshwater capped anticyclone. This eddy may eventually bring its cap of relatively fresh water into the interior Labrador Sea, although the float did not "stick" with the eddy.



A similar event (**Figure 11**), but near the mooring site, with two floats entrained. In this series of SLA images, only the current positions of the floats and 10 day float tails are depicted, for clarity. At least one float (5271) is entrained in the outer flank of an anticyclone as it passes over the mooring site. The salinity thresholds are higher, but the trend is similar: The upper 100 meters of the water profile contains lower average salinity than outside the eddy.