An Irminger Ring Mooring in the Labrador Sea, Preliminary Results

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Introduction

In September 2007, a heavily instrumented mooring was deployed in the eastern Labrador Sea near 60.6˚N, 52.4˚W in water about 3200 meters deep to study the structure and evolution of warm Irminger Rings for two years. The mooring was placed in the path of these rings, which drift southward from their formation site along the west coast of Greenland (Figure 1a). The mooring was equipped with nine MicroCats and eight acoustic current meters (RCM-11s) at depths between 100 and 3000 meters (Figure 1b). Two carousels attached to the mooring at about 500 meters depth contained 11 APEX profiling floats. Almost half of the floats were successfully launched into possible eddy events, with the longest eddy-float pair lasting about three and a half months. Preliminary analysis of the MicroCat and current meter data indicates that the mooring was in the path of about fourteen possible eddies during the two years it was in the water. Here we discuss Submerged Autonomous Lagrangian Platform (SALP) performance and present general oceanographic properties at the mooring site. We also present eddy structure from the mooring instruments, following the pathway of one mooring-recorded anticyclone using satellite data.

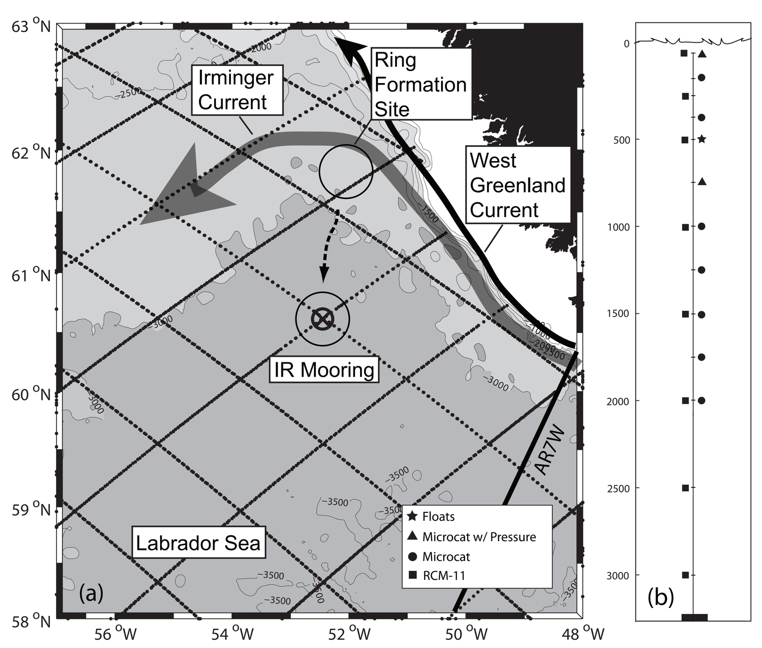

Figure 1.
(a) Chart showing the mooring location and current schematic, with the EKE maximum (from Lilly, et al., 2003) marked as a possible ring formation site. Outer circle represents an eddy with a 20 km radius. Satellite tracks are plotted as dotted lines. (b) Configuration of instrumentation of the IR mooring.

1. SALP Performance

The mooring contained two sensor-driven SALP carousels, which were designed to release floats into eddies based on temperature and pressure criteria indicative of an anticyclone at 500 meters depth. A controller inside the carousels was programmed to release the floats, one at a time, into passing rings based on a time-dependent set of criteria, including temperature/pressure, temperature alone, and timed release. The SALP was successful in releasing floats as designed, except in one case where a float was stuck in the carousel and could not deploy. This float was later deployed when the mooring was recovered, into an eddy. Five floats were able to tag eddies or possible meanders of the Irminger Current; the six other floats were released correctly, but either by timed release (no eddy), or in conditions which met the temperature alone criteria for an eddy, but was not an actual eddy event. The longest float-eddy match (not presented here) was approximately 3.5 months, from late September 2009 – mid-January 2010, with the float-tagged eddy travelling south south-west from the mooring site to the central Labrador Sea.

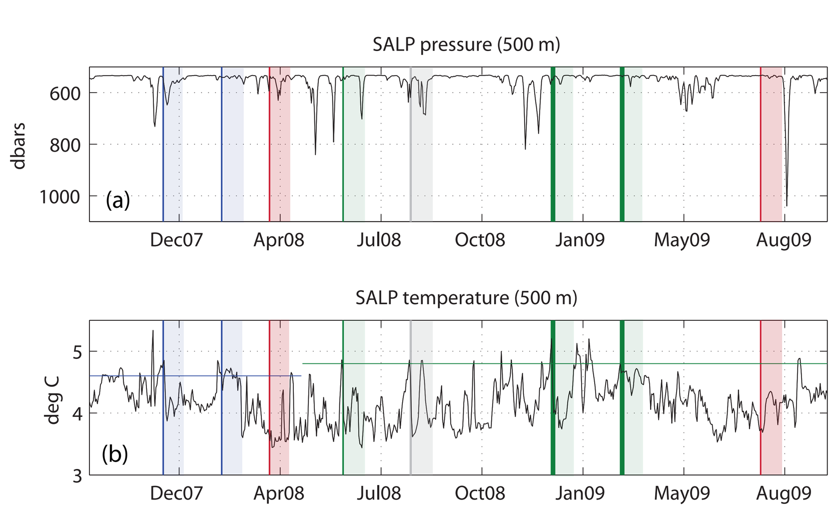

Figure 2.
SALP pressure (a) and temperature (b) records, with SALP release events. Each release event is marked as a vertical line, with a patch following the event marking the 'lock-out period', when no floats were allowed to release. Release events are color coded as follows: blue, temperature-pressure criteria; green, temperature alone; red, timed release; gray, float failed to launch from carousel. After one year the master and slave carousels became independent, so floats were released from both carousels when the SALP controller criteria were met (thick lines, December 2008 and March 2009).

2. Initial Mooring Results

All mooring instruments successfully recorded two years worth of temperature, salinity and velocity data, from 100 to 3000 meters depth. Mean velocities were east southeast at 100 meters depth, and turned cyclonically with depth until north northwest at 3000 meters depth (Figure 3). Mean u-velocities were approximately 1-3 cm/second eastward, and v-velocities were between -1 cm/s southward at the surface to 3.5 cm/s northward at 3000 meters depth. Table 1 shows the details of mean velocities and standard deviations with depth. The eastward direction of the mean current between 100 and 2000 meters depth is in agreement with the objectively mapped mean circulation at 700 meters depth from direct velocity measurements (Lavender et al., 2000). Mean velocity displacement vectors turning to the north below 2000 meters may be influenced by the northward velocity of the Irminger Current, which leans along the slope to the east of the current meter location (Figure 1a). At all depths, the variability present in the actual velocity records (thin lines in Figure 3) outside the mean contain small loops, caused by eddies passing over the mooring site.

The potential temperature and salinity at the mooring (Figure 4, top two panels of each year) show an annual cycle of heating and freshening, specifically, the upper water column (100-1000 meters) is warm and salty from late summer through mid-winter, then becomes colder and fresher through the late winter and spring. The warming and later cooling of the upper layer appears to be delayed by 1-2 months in 2008 compared to 2009 at this location.

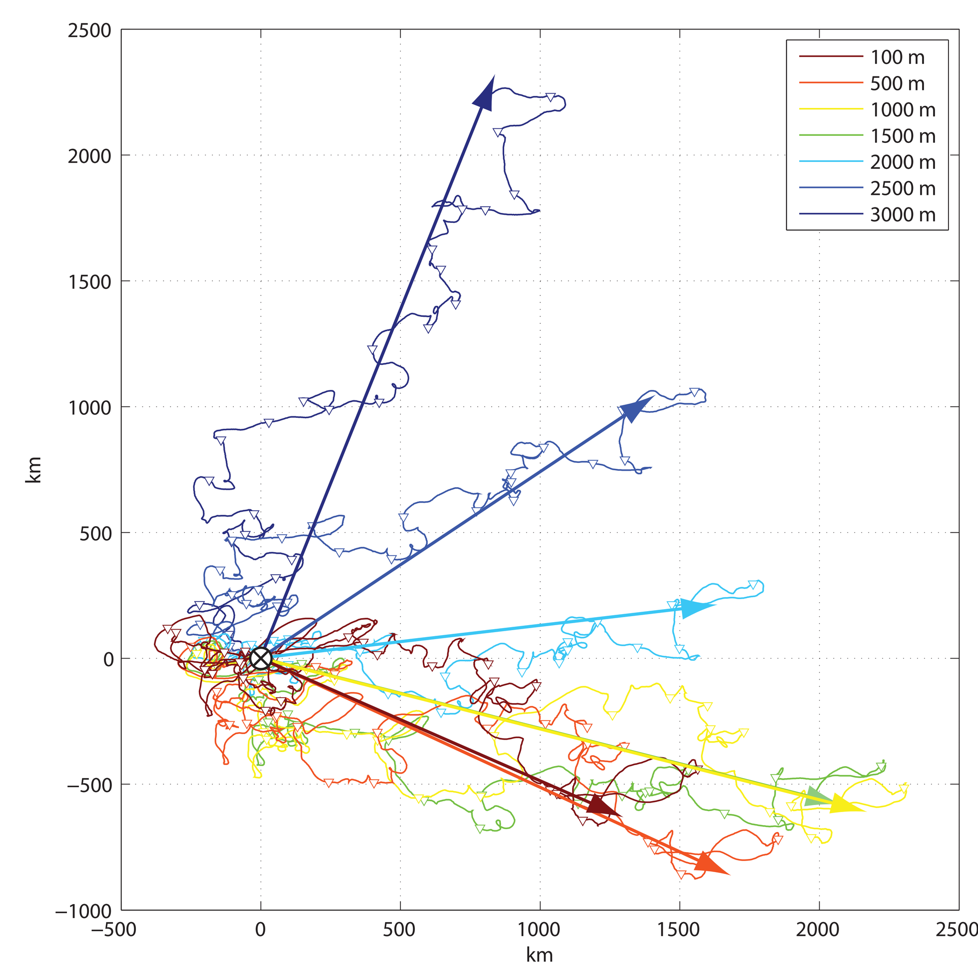

Figure 3.
Progressive vector diagram of the current meter velocity measurements. Both the mean velocity (displacement vector) and the actual velocity record (thin line) in show for each instrument, in the same color (see legend on plot for color identification). The origin is marked as a circle-x, and the first day of each month is marked as an open triangle. Velocities have been de-tided using the t_tide toolbox (Pawlowitz, et al., 2002).

depth (m)	mean u-velocity (cm/s)	u-velocity st. dev. (cm/s)	mean v-velocity (cm/s)	v-velocity st. dev. (cm/s)
100	1.90	16.94	-0.92	14.17
500	2.51	13.62	-1.29	11.91
1000	3.27	12.36	-0.92	10.85
1500	3.13	11.60	-0.87	9.76
2000	2.42	10.36	0.32	8.64
2500	2.10	10.14	1.55	7.92
3000	1.27	9.76	3.50	7.74

Table 1.
Velocity mean and standard deviation for each current meter from 100 to 3000 meters depth.

Reference:
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3. Eddies present in two-year mooring record

The mooring was in the path of several eddies during the two year period it was in the water. The data indicate that the mooring recorded ~14 possible anticyclones, with six the first year, and eight the second year. We count an event as an anticyclonic eddy if the velocity, either u or v, underwent a sharp change from positive to negative over the water column from 100-1500 meters (usually deeper) uniformly, and that the positive and negative velocities were stronger on either side of the zero crossing than the ambient flow, with the strong velocities diminishing within a few days (~5) time. Concurrent with the velocity events are bowl-shaped isopycnals caused by warm and salty water anomalies between 200 and 700 meters. This number of eddies is generally in agreement with the eddy generation rate estimated by Lilly et al. (2003) of ~6 eddies / year. The anticyclones at the mooring site appear to be more likely to have cold and freshwater caps during the spring and summer seasons, which is similar to the finding of Rykova et al. (2008).

An example anticyclone is presented in Figure 5 and 6. The anticyclone passed over the mooring in August 2008, in about 10 days, affecting the velocity profile to 3000 meters (Figure 4). The mooring was placed in water 3217 m deep, so it is possible that this eddy was felt through the entire water column. Using a translation speed of 5 cm/s (Lilly et al., 2003), the diameter of the eddy is about 45 km, with the meridional component of the azimuthal velocity over 40 cm/s (azimuthal velocity will be much greater). The anticyclone has a bowl-like shape at the surface (Figure 5), with cooler temperature, but not a distinct fresh-water cap found in the newly formed eddies observed by Hátún et al. (2007). Near-real time sea level anomaly images (Figure 6) show this eddy originating southwest of the mooring site, moving in an arc cyclonically through the mooring site, and then diminishing as it heads into the interior Lab Sea. Maximum surface signature is between 15 and 20 cm/s.

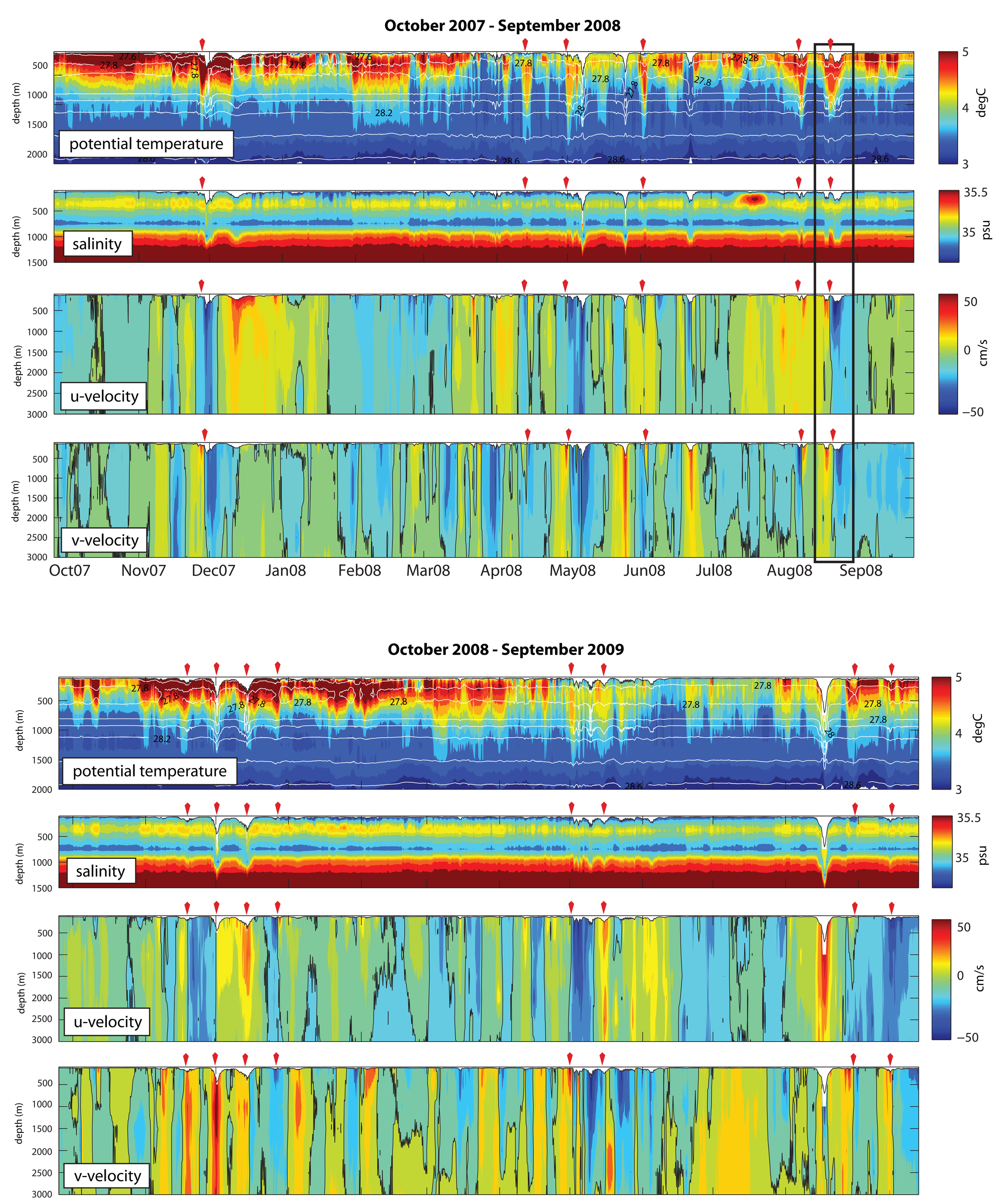

Figure 4.
Potential temperature, salinity and u- and v-velocity records for the two year period October 2007 – September 2009. The record has been divided into one-year segments: October 2007-September 2008 and October 2008-September 2009. σ-0 data are contoured in white over the potential temperature data. Possible eddies have been identified with red markers on each panel (see text). A box marks the eddy discussed in the next panel. Please note that the y-axis depth ranges of the different properties (potential temperature, salinity and velocity) are unique for each variable.

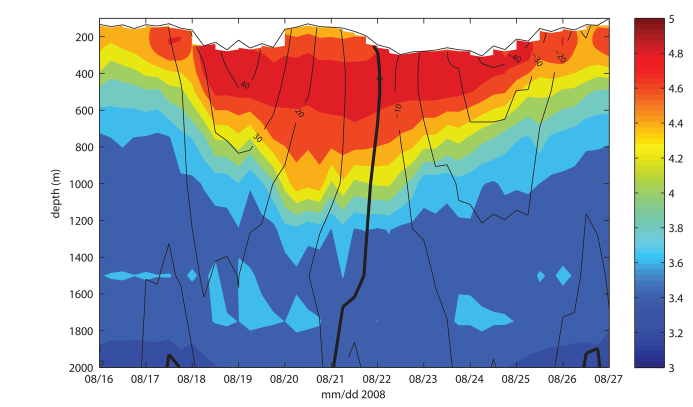

Figure 5.
Potential temperature and v-velocity (black contours) of an anticyclone measured by the mooring, August 16 – 27, 2008.

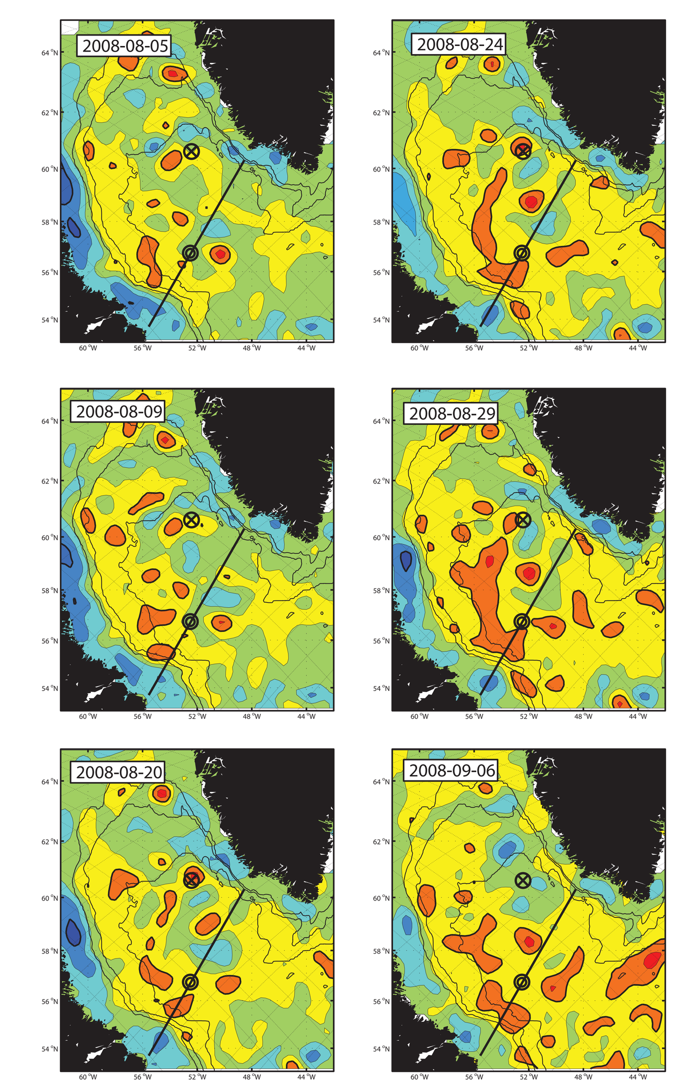

Figure 6.
Near-real time sea level anomaly from AVISO for the time spanning the anticyclone shown in Figure 5. Contours are drawn every 5 cm, with thick black lines demarking the +/- 10 cm contour. Satellite tracks are shown as thin black lines, and mooring location is marked as a circle-x.

Summary:

The Irminger Ring mooring was successful in that it recorded ~fourteen anticyclones at the mooring site in two years. The SALP algorithm worked to successfully to release floats as designed, and almost half of the floats were trapped in an eddy upon release, although some very briefly. Mean velocity at the mooring site was generally eastward, with a cyclonic shift from southeast to northeast as depth increased. Initial examination of the mooring data shows that the anticyclones generally did have freshwater caps as they passed over the mooring in spring and summer, and often perturbed the water column to 3000 meters. We will continue to extract information from these data, with the specific objectives of

(1) determining the full water column hydrographic and velocity structure as well as heat and salt content of newly formed Irminger Rings that have entered the interior Labrador Sea,

(2) documenting the modification of Irminger Ring core properties by atmospheric forcing and lateral mixing as the rings transit the Labrador Sea, and

(3) improving estimates of the heat and salt fluxes associated with Irminger Rings by combining the new in situ measurements with SSH observations.