ADCP Arrays Reveal Details of Deep Overflow Plume

Year-long Study Clarifies Downstream Changes in Transport and Mixing

Teledyne RD Instruments

Instruments

Products:
Self-contained ADCPs: 75, 150, 300 kHz

Application:
Measuring volume transport and entrainment

Project:
Downstream changes in FBC overflow plume

Principles:
Ilker Fer, Elin Darelius, Jenny Ullgren

Organizations:
University of Bergen, Norway

Data Collection Date:
2012

Location:
Faroe Bank Channel, N. Atlantic

Overview

Efforts to understand changes in the global climate system have put a spotlight on the deep ocean. Scientists are now focused on the water properties and volumes of confluent flows that form the deep circulation. Although this circulation is global in extent, its source waters are localized to high latitudes in each hemisphere.

During conducive atmospheric conditions over Nordic Seas, dense surface waters sink in vertical plumes to form deep currents that move equatorward. At specific sites en route—termed *overflows*—these currents are more prone to mix with and *entrain* ambient waters. Scientists want to learn how these exchanges alter the signature of water joining the larger-scale deep circulation.

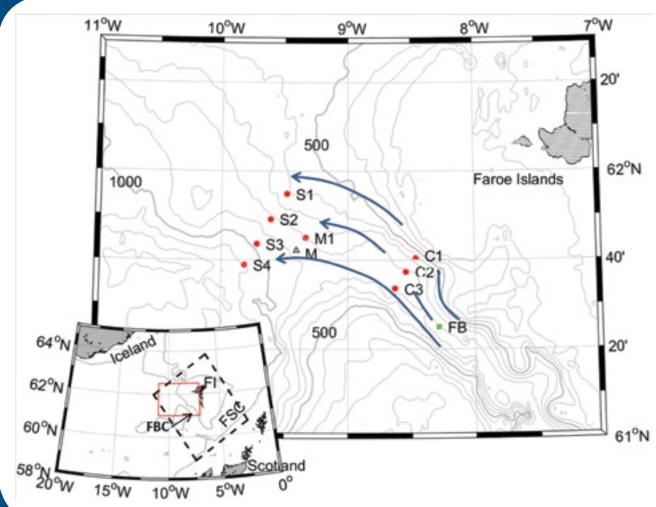
For more than two decades, Nordic oceanographers have used Teledyne RDI ADCPs to monitor the volume transport of one of these deep flows through the Faroe Bank Channel (FBC) in the subpolar North Atlantic.

Recently, researchers at University of Bergen (Norway) examined how the FBC overflow characteristics change due to intense mixing and entrainment after the deep plume departs the FBC.

Teledyne RDI ADCP mounted on a hydrographic rosette, ready to be lowered to the seabed.

Credit: I. Fer et al. (Univ. Bergen) 2016.
PDF: https://goo.gl/WCGPyc

Part of their work was to deploy ADCP-based mooring arrays to span the plume at two sections for a year. The resulting data set permitted close inspection of the plume's temporal and structural changes in the first 100 km where it accelerates down the topographic slope.



Map of mooring array near Faroe Bank Channel.

Credit: E. Darelius et al. (Univ. Bergen) 2015. goo.gl/nEYUoY

Situation

Climate discussions of the global ocean's overturning circulation emphasize water supplied from high-latitude regions. Indeed, Overturning in the Subpolar North Atlantic Program (OSNAP) scientists recently published unexpected observations about the high-latitude supply that differed substantially from computer models. Important aspects of this supply are its location, amount, and water properties.

In Nordic Seas, cold, dense waters sink to form deep currents that move southward. Before feeding the larger-scale global circulation, these flows cross subsea barriers only at specific sites—overflows—by moving through deep topographic channels.

During these transits, the dense waters form distinguishable plumes that travel rapidly along the seabed. These plumes can mix with and entrain ambient waters, an exchange that alters the water properties and volume of the plume. Knowing more about these changes is important for understanding the final composition of the North Atlantic layer in the deep global circulation.

About one-third of the densest waters contributing to this water mass layer pass through Faroe Bank Channel (FBC) in the subpolar North Atlantic. The overflow water travels as a remarkable seabed plume— about 250 m thick—that moves at speeds up to 1 m/s. The top of the plume is distinguished by a marked density interface and high velocity shear, characteristics that control mixing processes. A key advantage of ADCP profiles is that they describe both water current velocity and its vertical shear.

Leaving the confines of the FBC, the plume accelerates down the sloping topography and spreads out. At the same time, there is intense mixing and entrainment.

Researchers at University of Bergen deployed an impressive field program to examine these phenomena. They aimed to examine the processes, evolution, and variability of how the overflow plume changes downstream from FBC.

For capturing a time-series view of both currents and shear, the researchers installed year-long moorings that carried eight ADCPs by Teledyne RDI.

Highlights:

- Cold, dense waters cross subsea ridges only at specific sites—overflows
- In FBC, the overflow plume is about 250 m thick and moves at speeds to 1 m/s
- The top of the plume is distinguished by a marked density interface and high shear
- Beyond the FBC, the overflow plume accelerates down the sloping topography and spreads out
- The water properties of the overflow plume change after mixing with and entraining ambient waters

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Solution

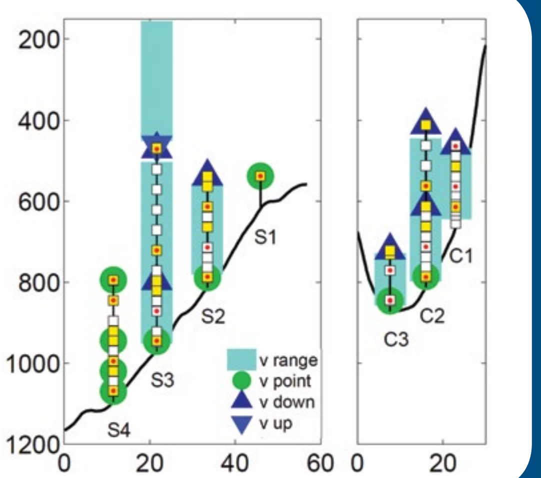
The field program used a range of sensors and methods. Researchers wanted to see motions across diverse time and spatial scales. In particular, the researchers used multiple moored ADCPs to span the whole plume. Mooring observations were merged with satellite observations and computer-modeling results.

Downstream of the Faroe Bank Channel, mooring arrays were deployed in two lines, located in different terrain. The first was in a confined channel (C) about 25 km from the main sill. The second was 85 km downstream on the slope (S) where the flow is less constrained. Moreover, by that distance, turbulent motions prevail with enhanced mixing in the plume. Adjacent moorings were about 10 km apart.

The moorings carried Teledyne RDI ADCPs at various frequencies: 75, 150, and 300 kHz. For measuring the full water column, researchers mounted both up- and down-looking ADCPs in one float at site S3. To support mixing studies, three 300 kHz ADCPs sat in the core of the plume and profiled its upper interface with high resolution, in time and height.

Drag forces due to strong currents within the plume were expected to pull moored instruments to greater depths. Therefore, ADCPs at lower levels were housed in elliptical floats that reduce drag.

To examine such blow-over effects on the moorings, the researchers used Richard Dewey's software for Mooring Design and Dynamics. They constructed time series of the vertical position and tilt of the instruments using measured currents as input. Ground truth was provided by records from pressure sensors.



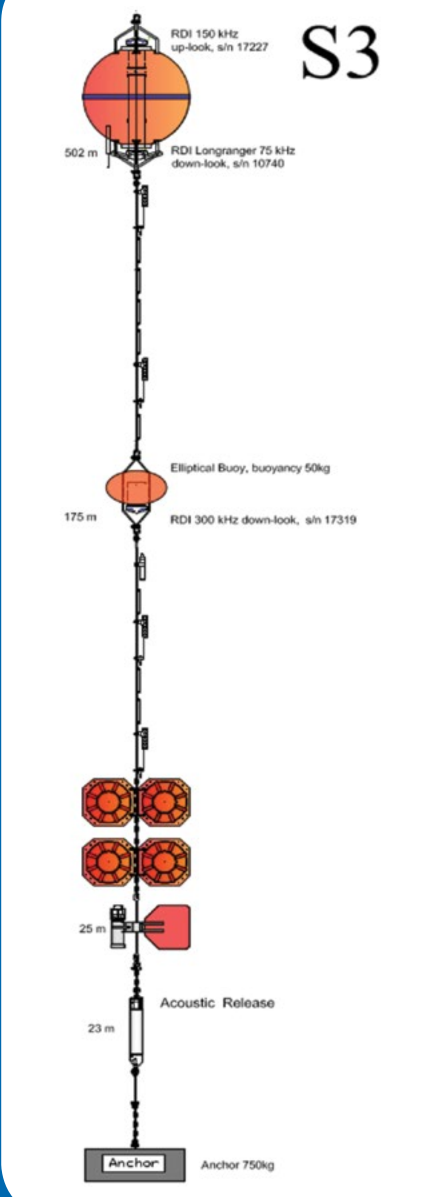
Mooring layout at Slope (S) and Channel (C) sections. ADCPs: blue triangles. Depth (m); distance (km).

Credit: J. Ullgren et al. (Univ. Bergen) 2016. http://bit.ly/30ly1PJ

Results

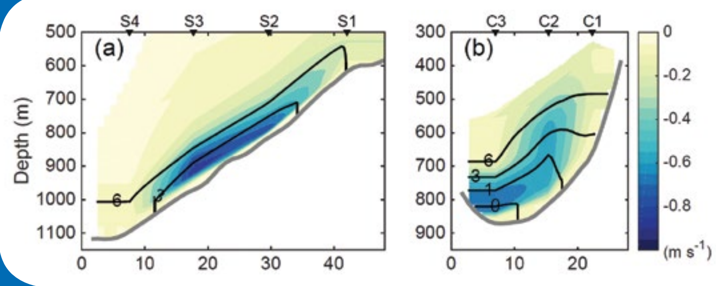
The researchers wanted to capture the downstream changes of the overflow plume—especially its structure and variability. At the two lines, temperature data provided signatures for defining the plume's form and extent. Current speeds showed similar structure. See figure on left.

At the Channel section, the seabed plume—identified by temperature less than 3° C—was spatially confined and had speeds near 1 m/s.



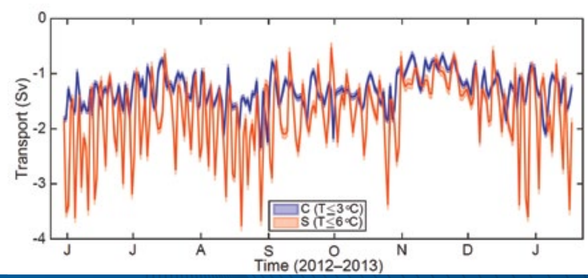
Mooring Design. At S3, three Teledyne RDI ADCPs were installed, using top and mid-water buoys.

Credit: I. Fer et al. (Univ. Bergen) 2016.
PDF: https://goo.gl/WCGPyc



Velocity structure of overflow plume with (isolines of) temperature. Left: Slope section (3°, 6°). Right: Channel section (0°, 1°, 3°, 6°). Distance (km).

Credit: J. Ullgren et al. (Univ. Bergen) 2016. http://bit.ly/30ly1PJ



Time series of water volume carried across ADCP mooring lines at Channel (blue) and Slope (red) sections.

Credit: J. Ullgren et al. (Univ. Bergen) 2016. http://bit.ly/30ly1PJ

At the Slope section, the plume showed distinct differences: wider spread, 50% thinner, and warmer temperature (< 6° C) due to entrained warmer water and intense mixing. High-speed currents in the plume's core were slightly faster due to moving downslope—but occupied much less depth.

At the downstream section, the time series of overflow currents showed pronounced variability. Strong eddy motions, varying with 3–5 day periods, dominated the ADCP time series. Striking fluctuations, seen in the figure above, point to the need for a year-long deployment to assess average conditions.

Prior studies concluded that volume transport of the FBC overflow doubles due to entrainment. Yet a key finding in this study was persistent detrainment from the bottom layer of the overflow waters. Although the expected substantial entrainment into the plume was also recorded, the total transport (overflow and modified overflow together) did not change between Channel and Slope sections. This result suggests the FBC overflow might contribute less to the deep global circulation than previously expected.

As well as recording features of the plume, ADCP profiles showed background currents reached through the water column; these barotropic signals matched patterns observed in satellite altimetry data.

Capturing any changes in the volume and makeup of the cold, dense overflow plumes is demanding. Yet this information is vital for improved understanding of the mechanisms of the deep circulation.

For climate studies, sustained measurements from moored ADCP arrays provide a unique time-series view of these deep, narrow, and strong flows.

References:

I. Fer, E. Darelius, J. Ullgren, and A. Peterson, CRUISE REPORT-Cruise HM 2012610, 2016. PDF: goo.gl/WCGPyc

J. Ullgren, E. Darelius, and I. Fer, 2016. Volume transport and mixing of the Faroe Bank Channel overflow from one year of moored measurements. http://bit.ly/30ly1PJ

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