Project "Western Valley OverfloW" (WOW)

Abstract

The WOW project is a cooperation between Havstovan (Faroe Marine Research Institute, HAV) and the Danish Meteorological Institute (DMI) to 1) measure the overflow of cold water from the Arctic into the rest of the World Ocean through the Western Valley of the Iceland-Faroe Ridge, to 2) allow the effects of this flow to be adequately simulated in climate model projections of the thermohaline circulation and the heat transport towards the Arctic, and to 3) design a low-cost monitoring system for this flow.

Background

The Western Valley is the north-westernmost region of the Iceland-Faroe Ridge (IFR) and includes a relatively deep (appr. 400 m) passage across the ridge (Figure 1). Through this passage there is a flow of cold and dense overflow water from the Nordic Seas into the North Atlantic, which contributes to the deep limb of the North Atlantic thermohaline circulation (THC), also called the AMOC. The overflow through the Western Valley is part of the overflow across the IFR.

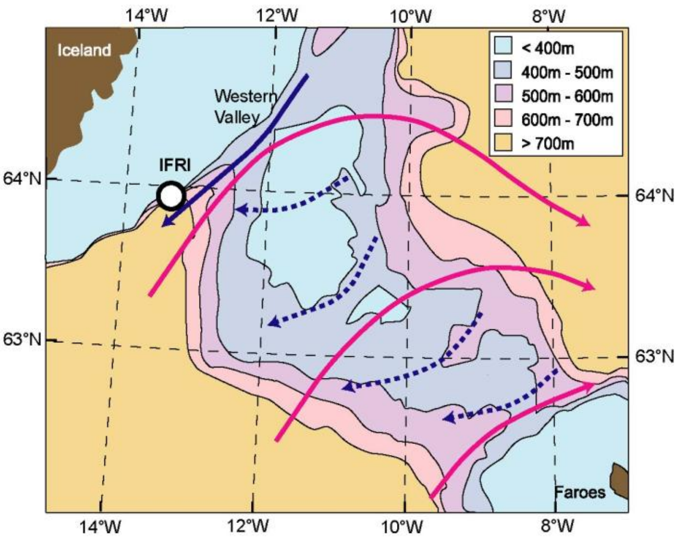

Figure 1. Bottom topography of the Iceland-Faroe Ridge. Red arrows indicate the warm Atlantic inflow (the IF-inflow) across the ridge. Blue arrows indicate persistent (continuous arrow) and more intermittent (broken arrows) overflow. White circle, labeled "IFRI", indicates the location of the moored ADCP, for which data are shown in Figure 2.

In the literature, the magnitude of the IF-overflow is generally cited to be about 1 Sv, as was originally suggested by the Danish oceanographer Frede Hermann (Hermann, 1967) from hydrographic observations. This would make it the third-most intense overflow (after Denmark Strait and Faroe Bank Channel) and a substantial contributor to the THC. Several attempts have therefore been made to estimate this overflow and its variation more accurately (Perkins et al., 1998; Østerhus et al., 2008; Beaird et al., 2013), but they have only been partly successful.

The intensive glider study by Beaird et al. (2013) probably gives the best estimate for the overflow across most of the IFR, but this technology is not well suited to quantify the strong bottom-intensified overflow through the Western Valley. For this component, we are therefore restricted to the estimates based on moored current meters, combined with hydrography. These estimates (Perkins et al., 1998; Olsen et al., 2015) do not provide any accurate value for the overflow volume transport, but they show clearly that it is persistent (Figure 2) and indicate that the mean overflow through the Western Valley (WV-overflow) may approach 1 Sv in magnitude (Olsen et al., 2015).

The WV-overflow is therefore an important, but as yet badly quantified, component of the THC, but it may also be a critical component for predicting future variations in the oceanic heat transport towards the Arctic under climate change. The oceanic heat transport across the Greenland-Scotland Ridge is carried by three branches of warm Atlantic water crossing the ridge towards the Arctic. The most important of these is the branch crossing the IFR, the IF-inflow, which increased its heat transport by 18% from 1993 to 2013 (Hansen et al., 2015).

Reliable projection of the IF-inflow and its heat transport will therefore be a critical component of any attempt to project Arctic climate conditions, but climate models have by their nature coarse resolutions that cannot distinguish between the IF-inflow and the IF-overflow. One consequence of this – as shown by Olsen et al. (2015) – is that the IF-inflow, determined by a climate model, will generally not be the real IF-inflow; but rather the net inflow = IF-inflow minus IF-overflow. Olsen et al. (2015) also showed that it is the IF-inflow close to the Western Valley that is badly represented in coarse resolution models.

This implies that the future heat transport of the IF-inflow, as projected by climate models, will have to be modified; but at present there is no method for doing this. Such a method will need better understanding of the WV-overflow and its variations and will need model optimization of the exchanges across the ridge as a whole. Since the IF-inflow is the dominant inflow branch, the total oceanic heat transport towards the Arctic will be affected and the atmospheric transport, as well due to the compensation (Bjerknes compensation), which is especially important in this region (Shaffrey and Sutton, 2006).

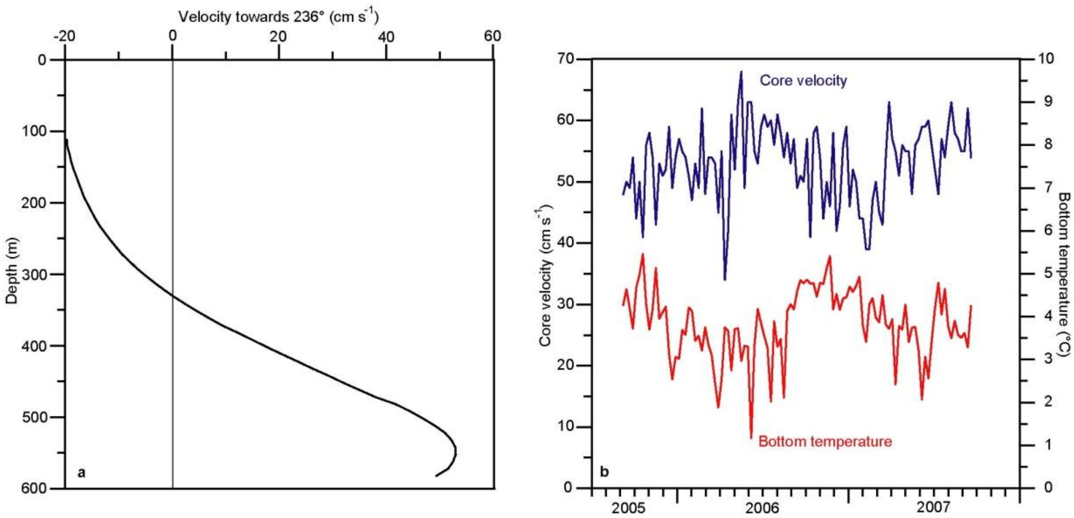

Figure 2. Results from the ADCP at site IFRI (Figure 1) that measured velocity profiles and bottom temperature from September 2005 to October 2007. (a) Vectorially averaged velocity profile towards 236°. (b) Weekly averaged velocity towards 236° for bin 4, approximately 60m above the bottom (blue) and weekly averaged bottom temperature (red).

Objectives

- Measure character and volume transport of the WV-overflow and their variations from summer 2016 to summer 2017.
- Combine results from the field experiment and historic data to extend the results to long-term estimates and to evaluate a recently proposed relationship between the WV-overflow and sea level east of Iceland.
- Develop methods to allow more accurate projections of oceanic heat transport towards the Arctic in climate models.
- Design a future low-cost monitoring system of the WV-overflow.

Project plan

The project work is divided into four distinct, but interlinked, phases:

Phase 1: *A dedicated field experiment to measure the WV-overflow from summer 2016 to summer 2017.*
This involves the deployment of two Acoustic Doppler Current Profilers (ADCPs) and two bottom temperature sensors (BTs) across the valley (Figure 3). Since there is heavy fishery all along the IFR, all the sensors have to be protected against trawls and other fishing gear.

HAV has two ADCPs in bottom mounted frames (Figure 4, left panel) that have been used for many years in other experiments in the region. They are presently deployed in the Faroe-Shetland Channel but will be available in summer 2016 except for the (very unlikely) possibility that they are both lost. The bottom mounted ADCPs will be deployed in June 2016 by R/V Magnus Heinason and will be recovered by a German research vessel in summer 2017. Both frames will measure temperature and at least one of them also salinity.

Together with the ADCPs, we will deploy two BTs in special trawl-protected frames that have been developed and tested by HAV during the last two years (Figure 4, right panel). These units are placed on the bottom and left there. Their data may be uploaded acoustically, whenever a research vessel passes. The bottom temperature data from the BTs during the field experiment will be uploaded by the German research vessel in summer 2017.

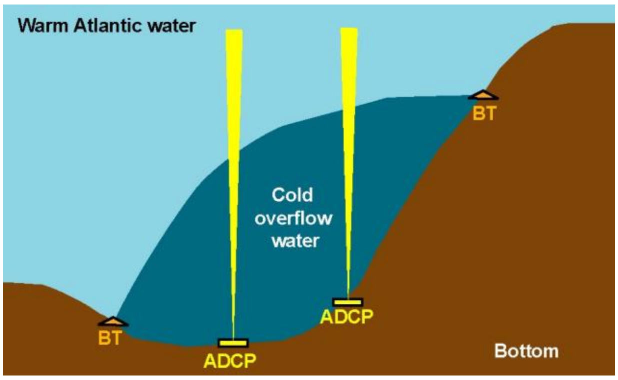

Figure 3. Schematic deployment plan for the field experiment. The two ADCPs will measure vertical and horizontal variation of both overflow and inflow velocity. The two BTs are primarily intended to determine the boundaries of the overflow plume.

Phase 2: *Analysis of observations and design of future monitoring system.*
In this phase, we will analyze observations from the dedicated field experiment and from historic data. The aim is to establish a long-term average value for the WV-overflow volume transport, its temperature and salinity characteristics, and to link their variations to other parameters that have been or may be monitored regularly.

Analogous to the two main overflows (e.g., Hansen and Østerhus, 2007), we expect the WV-overflow to be hydraulically controlled. If that is the case, the overflow transport ought to depend on the pycnocline depth east of Iceland and it has recently been suggested (Olsen et al., 2015) that this depth is linked to sea level height, which is monitored by satellite altimetry. By combining the results from the field experiment with historic data, WOW will test these relationships.

One aim of this effort will be to allow better estimates of historic variations of the WV-overflow, but also to lay the foundations for future monitoring of this overflow branch. During the last two decades, joint efforts by many groups have led to an established monitoring system for most of the branches exchanging water, heat, and salt between the Arctic and the rest of the World Ocean. HAV is monitoring the main Atlantic inflow branch between Iceland and Faroes and has recently optimized the system so that it is much less costly to maintain (Hansen et al., 2015). Together with Scotland, HAV is also monitoring the branch between Faroes and Scotland (Berx et al., 2013), while Iceland is monitoring the third Atlantic inflow branch. HAV is also monitoring the Faroe Bank Channel overflow (Hansen and Østerhus, 2007) while Germany and Iceland monitor the Denmark Strait overflow. Exchanges through the Bering Strait and Canadian Archipelago have been monitored by USA and Canada. This leaves two remaining branches: The East Greenland Current, which is very difficult to monitor due to ice conditions, and the IF-overflow.

Monitoring all of the IF-overflow with in situ instrumentation would also be very difficult, but most likely, the WV-overflow is both the dominant and the most variable component of the total IF-overflow and also the component most likely to affect modelling of the IF-inflow. With the observational data from the field experiment, the hydraulic control mechanism can be tested and used to establish methods for estimating the overflow from a simpler system of observations. If this is successful, we will design a low-cost monitoring system, based mainly on bottom-mounted trawl-proof sensors that can be interrogated acoustically by research vessels passing by, combined with satellite altimetry. The two BTs, deployed in 2016, will remain and could be included in the implementation of monitoring after termination of WOW.

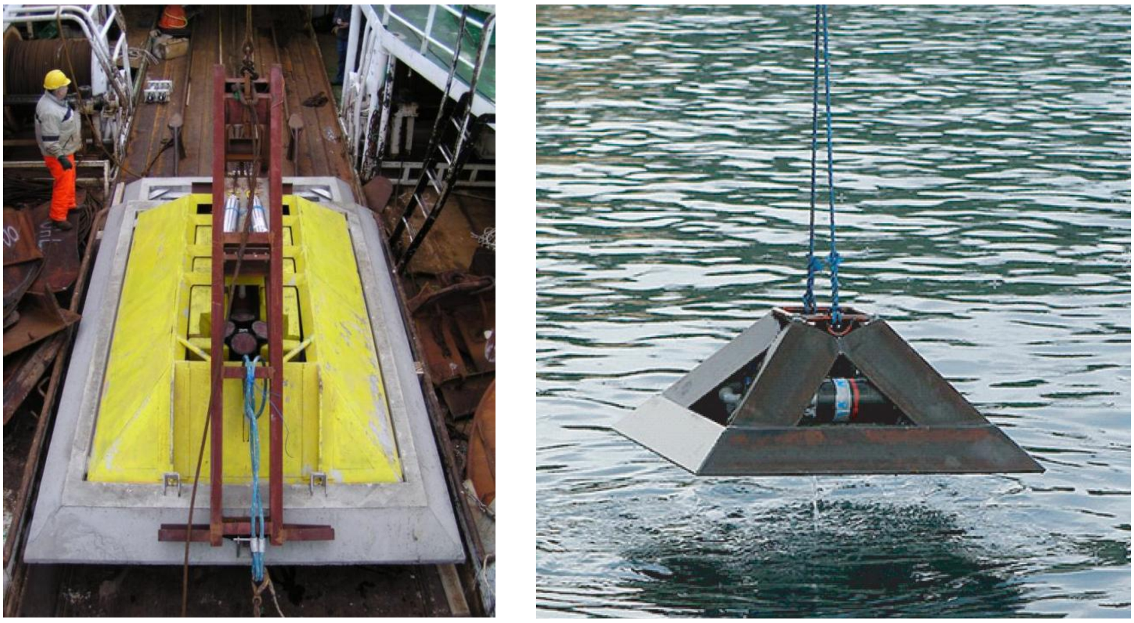

Figure 4. Left panel: An ADCP in a trawl-protective frame (yellow) onboard R/V Magnus Heinason, ready for deployment. Right panel: A bottom temperature measuring unit (BT) including temperature sensor, acoustic modem, and batteries in a trawl-protective frame.

<u>Phase 3:</u> *Enhance the ability of climate models to project oceanic heat transport towards the Arctic.*
This phase addresses the optimization and tuning of the model overflow across the IFR that is now feasible due to concurrent measurements of all three most significant overflows across the GSR for the full seasonal cycle.

Global climate models integrate the coupled feedbacks between individual components of the climate system and allow predictions on seasonal to centennial time-scales. This is achieved at the expense of regional detail and builds on parameterizations of unresolved processes. In the ocean, inadequate resolution is in part also compensated for by optimization of model ocean bottom topography to represent critical straits and channels at least with realistic sill depths. This is the case for the narrow Faroe Bank

Channel (~10 km) and partly also for the Denmark Strait, both of which are essential gateways for dense water exchange between the Arctic and the North Atlantic as part of the THC.

To the extent that observational data have been available to guide the optimization, such tuning has shown to be successful due to the nature of the energetic flows responding to basin scale forcing (Olsen et al., 2008, Hansen et al., 2010). However, for the IF- and the WV-overflow in particular this has yet not been pursued, in part due to the lack of observational evidence for a systematic overflow transport here. Moreover, even CMIP5 type climate models have a resolution, which does not justify distinction of more than the two major outflows. New model systems including EC-Earth V3 to be used for future climate projections at the Danish Meteorological Institute will have sufficient detail in the representation of the region that such tuning can be pursued. Activities include:

- Simulation with realistic (optimized) and exaggerated sill depth of the WV introduced in the coarse ocean bathymetry.
- Assessment of water mass properties and entrainment rates of modelled and observed overflow.
- Synthesis of the linkage between WV-overflow and Atlantic inflow across the IFR.
- Evaluation of the impact of WV-overflow on heat transport towards the Arctic in coupled simulations considering the full Greenland-Scotland Ridge exchange system and atmospheric compensation (Bjerknes compensation).

Phase 4: Dissemination

All the observations acquired during the field experiment will be made freely available on the Faroese Environmental Data website (www.envofar.fo) after quality control. We will also engage with the Polar Portal (www.polarportal.dk), funded under DANCEA, and offer to deliver annually updated time-series of volume, heat, and salt exchanges across the Iceland-Scotland Ridge to be displayed on the portal.

Project results and specific recommendations for model improvements and research focus will be shared with the EC-Earth model consortium where there are strong Nordic interests. Several Nordic climate centres contribute to the model development and with specific research interest in North Atlantic ocean processes.

DMI will advertise a master project related to the WOW project to be carried out within the department for Climate and Arctic Research and in collaboration with the University of Copenhagen. The project will exploit the new observational data and advance from the outlined model simulations and results.

With offset in the new results from WOW, we will take initiative to a white paper on the recommendations for coordination of ocean climate monitoring of the various branches exchanging water, heat, and salt between the Arctic and the rest of the World Ocean. Drafting this paper will involve several international experts and identify the required contribution from Denmark and the Faroe Islands to this important ongoing international effort (which has up to now been research driven). The paper will be distributed to relevant national agencies and ministries, as well as AMAP.

Literature

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