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TECHNICAL REPORT

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Abstract
The inflow of warm and saline Atlantic water across the Iceland-Faroe Ridge into the Norwegian Sea is the main branch of Atlantic inflow to the Nordic Seas. Since summer 1997, the volume transport of Atlantic water carried by this branch has been monitored by an array of moored ADCPs combined with regular CTD observations on a section along 6°05'W, extending northwards from the Faroe shelf. The traditional method for estimating Atlantic water transport requires input from at least three ADCPs straddling the Atlantic water flow, but from the deployment summer 2012 to summer 2013, it was only possible to recover two ADCPs. When the data from these two ADCPs are combined with data from satellite altimetry, we find, however, that it is possible to generate a fairly accurate time series of Atlantic water transport. From 1st July 2012 to 1st May 2013, the average Atlantic water transport was 3.3 Sv, which is slightly less than the long-term average, but not the lowest transport for similar periods in the past.

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Introduction

The inflow of Atlantic water to the Nordic Seas between Iceland and Faroes (IF-inflow) crosses the Iceland-Faroe Ridge (IFR) and continues in a boundary current, the Faroe Current, north of the Faroes (Figure 1a). Since the late 1980s, the hydrographic properties of this flow have been monitored on a section (section N) along 6°05'W and, since 1997, volume transport through this section has been monitored by an array of moored ADCPs (Figure 1).

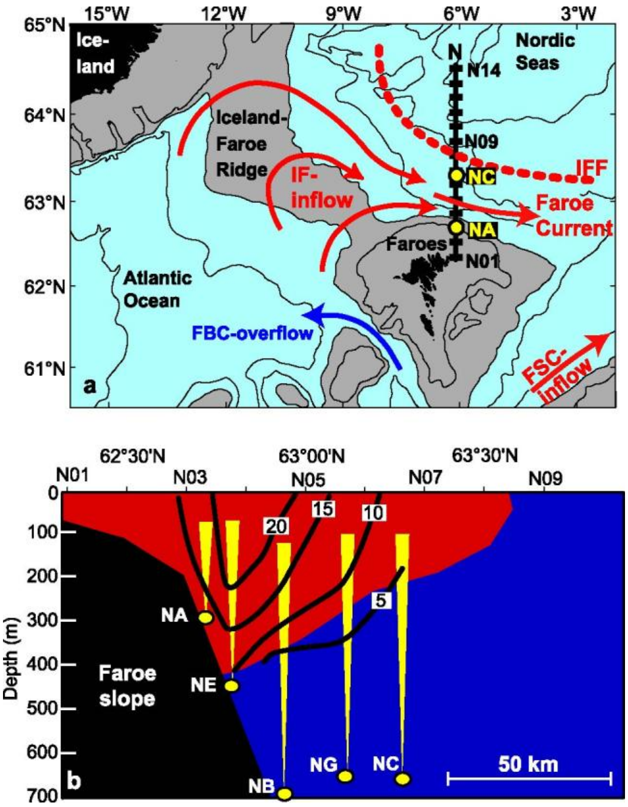

__Figure 1.__ Geographical setting and characteristics of the IF-inflow and observational system. __(a)__ Bottom topography (gray areas shallower than 500 m). Red arrows show the two main Atlantic inflow branches, the IF-inflow, which is bounded by the Iceland-Faroe Front (IFF), and the inflow through the Faroe-Shetland Channel (FSC-inflow). The black line with rectangles labeled N01 to N14 is a standard section with fixed CTD stations. Yellow circles indicate the southernmost (NA) and northernmost (NC) ADCP mooring locations. __(b)__ The southern part of the standard section with the red area indicating water of salinity >35.00 on average 1997–2001 (based on Hansen et al., 2003). Thick black lines show average eastward velocities from summer 2000 to summer 2001 with values in cm s^{-1} (based on Hansen et al., 2003). Yellow circles indicate moored ADCPs with typical ranges indicated by yellow cones.

The hydrographical standard stations have remained fixed throughout the monitoring period but the ADCP locations have varied, partly by design and partly due to instrument failure and loss. Until summer 2012, the ADCP array always included at least three moorings covering the width of the current. From summer 2000, these were NA, NB, and NG (Figure 1b) and the calculations of volume transport were based on that. For the 2012 – 2013 deployment period, only two ADCPs (at sites NA and NB) were, however, recovered (Mortensen et al., in prep.).

This might not be too serious if it were possible to generate the rest of the velocity field from the two successful ADCPs only. To investigate that, we did an EOF analysis of the velocity field for the whole period from summer 2000 to summer 2012, during which succesful ADCP records were acquired at all three sites NA, NB, and NG (Figure 1b).

The first two EOF modes, which together account for about two thirds of the variance, are seen to be focused at site NB and NG, respectively, whereas the third mode has its focus at NA (Figure 2). This indicates that the velocities at NB and NG are not closely related. There is an indication of a negative relationship between NA and NG, but it seems rather weak. These conclusions are consistent with the coherence analyses documented in Figure 15 of Hansen et al. (2003). Based on this, it does not seem possible to generate realistic time series for the velocity at NG from the velocities at NA and NB only, but satellite altimetry should give some information on the velocity field around NG.

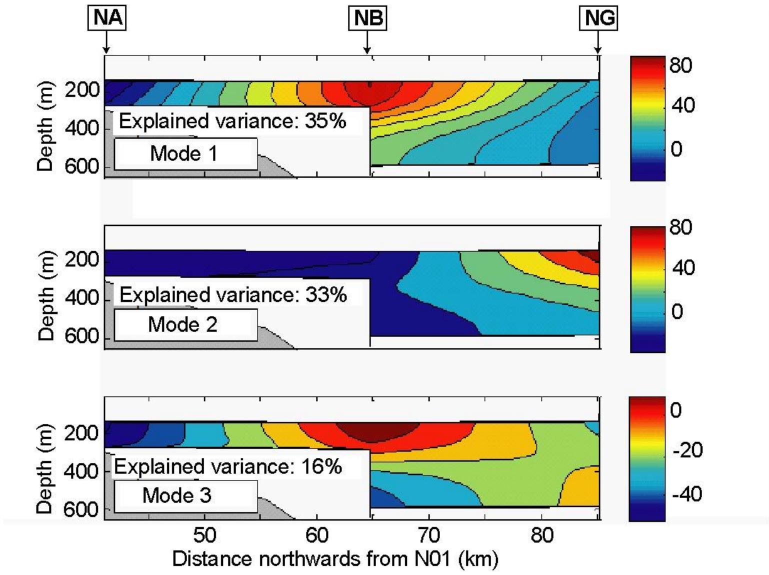

Figure 2. *The first three EOF modes of the velocity field on the section based on daily averaged velocity profiles from the ADCP sites at NA, NB, and NG for the period 2000 to 2012.*

We have therefore combined the data from the successful ADCP moorings with altimetry data to produce volume transport of Atlantic inflow 2012 - 2013. The method is based on a regression analysis of the historical time series. Within NACLIM, it is planned to redesign the monitoring system north of the Faroes, reducing the number of expensive moorings while including data from cheaper bottom temperature loggers and from altimetry. This process will involve a thorough re-analysis of all the hydrographic and ADCP data and will presumably lead to a new transport time series for the whole period from 1997. The present transport values for 2012 – 2013 should therefore be considered preliminary.

Traditional method for calculating Atlantic water transport

Throughout the monitoring period, ADCPs have been deployed at several different locations on the section (Hansen et al., 2003). Five of these have had several deployments, covering periods of at least four years. From south to north, these mooring sites are labeled NA, NE, NB, NG, and NC (Figure 1b). Sites NA and NB have been measured throughout the period from summer 1997 to summer 2013. Site NC was measured from summer 1996 to summer 2000, when it was replaced by NG to give better coverage of the main flow. NG was measured from summer 2000 to summer 2012, but the mooring could not be recovered in summer 2013 and is presumably lost. The final site NE was measured from summer 2000 to summer 2001 and from summer 2004 to summer 2011, when the mooring was lost.

In addition to the ADCP data, hydrographic sections were acquired typically four times a year or more during the monitoring period. These data may be used to distinguish Atlantic water from waters of Arctic origin on the section and they have been combined with the ADCP data in the algorithms traditionally used to calculate Atlantic water volume transport. The algorithms do not require explicit use of hydrographic data, since Hátún et al. (2004) have shown that much of the variations of the hydrographic fields on the section can be explained by variations in the velocity field.

As detailed in Hansen et al. (2003, 2010), the traditional method requires current velocity data from at least three ADCP sites. Before summer 2000, these sites were NA, NB, and NC. After that, data from NA, NB, and NG were used. When data from NE were available, they were included (Hansen et al., 2003). For the 2012 – 2013 deployment period, only data from NA and NB are available and the usual algorithm can therefore not be employed, but we have acquired satellite altimetry data that were produced by Ssalto/Duacs and distributed by Aviso, with support from Cnes (http://www.aviso.oceanobs.com/duacs/). From these data, we generated time series of weekly averaged sea level height anomaly (MSLA) at 17 grid points along 6°W longitude, i.e., almost on top of the section, from 62.308°N to 64.686°N, spanning the Atlantic water flow through the section.

Regression analysis

We have used a regression method to combine the ADCP and altimetry data into volume transport estimates. To do that, we assume that the historical time series of daily averaged Atlantic water transport from summer 2000 to summer 2012, generated by the traditional method using ADCP data from NA, NB, and NG, gives a reliable estimate of the real transport. From this series, we have generated a time series of weekly averaged Atlantic water transport, where the weeks are the same as those in the altimetry data set. This time series is labeled $q_A(t)$. We also generated two time series of weekly averaged velocities at NA and NB. Thus $u_{NA}(t)$ represents the eastward velocity at site NA averaged over the top 300 m. Similarly, $u_{NB}(t)$ represents the eastward velocity at site NB averaged over the top 300 m. In addition, we used the time series $h_i(t)$ of sea level height at altimetry grid point i for i = 1 to 17. In the first instance, we regressed $q_A(t)$ linearly on $u_{NA}(t)$ and $u_{NB}(t)$.

$$q_A(t) = q_0 + \alpha \cdot u_{NA}(t) + \beta \cdot u_{NB}(t) + \varepsilon(t) \qquad (1)$$

The constants q_0, α, and β were determined by the regression analysis. The residual $\varepsilon(t)$ had a variance that was only 28% of the variance of $q_A(t)$, which implies that the regression explains (R^2 =) 0.72% of the variance of $q_A(t)$. This is surprising, taking into account the previously claimed lack of relationship between the velocity at NG and those at NA and NB. The explanation is that, usually, there is only a small fraction of the Atlantic inflow passing through the section close to NG (Hansen et al., 2003).

To estimate this part of the transport, we then regressed the residual $\varepsilon(t)$ on the differences between MSLA values at two grid points, trying all pairs among the 17 altimetry grid points along the section. The highest correlation coefficient was found for the MSLA difference $\Delta h(t)$ between the grid point at latitude 62.921°N and the point at latitude 63.223°N. This is reasonable, since site NG is located at 63.099°N, between the two grid points. We also tried other ways to use the altimetry data, but without increasing the R^2 value. Our final estimate for Atlantic water transport based on $u_{NA}(t)$, $u_{NB}(t)$, and altimetry is therefore:

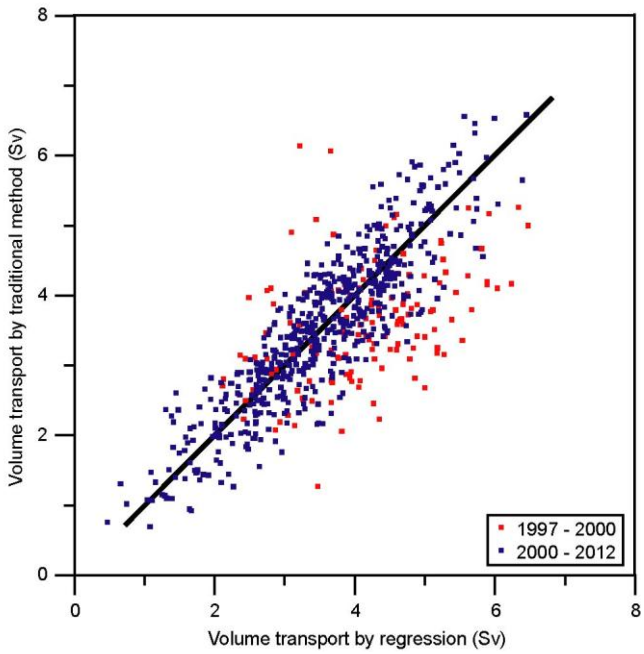

Figure 3. *Weekly averaged Atlantic water transport calculated by the traditional method ($q_A(t)$) plotted against the transport ($q'_A(t)$) calculated from the regression Eq. (2). Blue squares are for deployments between summer 2000 and summer 2012. Red squares are for the deployments before summer 2000. The thick black line indicates equality.*

$$q'_A(t) = 1.76 + 0.0382 \cdot u_{NA}(t) + 0.0794 \cdot u_{NB}(t) + 0.066 \cdot \Delta h(t) \qquad (2)$$

where the velocities $u_{NA}(t)$ and $u_{NB}(t)$ are measured in cm·s^{-1}, the MSLA difference between the above-mentioned grid points $\Delta h(t)$ is measured in cm, and the result is in Sv. Eq. (2) explained (R^2 =) 78% of the variance of $q_A(t)$ for the period from summer 2000 to summer 2012, which included 573 weeks of data.

The correspondence between transport calculated from Eq. (2) and by the traditional method for this period is illustrated by the blue squares in Figure 3. For the period before summer 2000, the red squares in Figure 3 indicate a less good correspondence. In this period, there was no ADCP at NG, but instead at NC (Figure 1). Site NC was abandoned in favour of NG in 2000 because NC was considered to be too far from the core of the flow. Thus, it may well be that the transport based on Eq. (2) is a better estimate than the traditional series, based on the ADCP at NC in this period. This will be addressed within the planned re-analysis of the whole data set including hydrography, ADCP data, and altimetry data to be carried out within NACLIM.

Atlantic water transport summer 2012 – summer 2013

Using Eq. (2), we have generated a time series of weekly averaged Atlantic water transport for the period with ADCP observations at NA and NB, starting on the 18th of June 1997 until the 8th of May 2013 although with gaps each summer, typically of 3 – 4 weeks during mooring turnaround, and a few other gaps due to mooring or instrument failure. Before the summer of 2000, this series tends to have higher values than the traditional method (Figure 4), as already indicated in Figure 3. After that, the transport values based on Eq. (2) are highly consistent with the traditional method and for the period after summer 2012, they remain our best estimate, although they should, as mentioned, be considered preliminary.

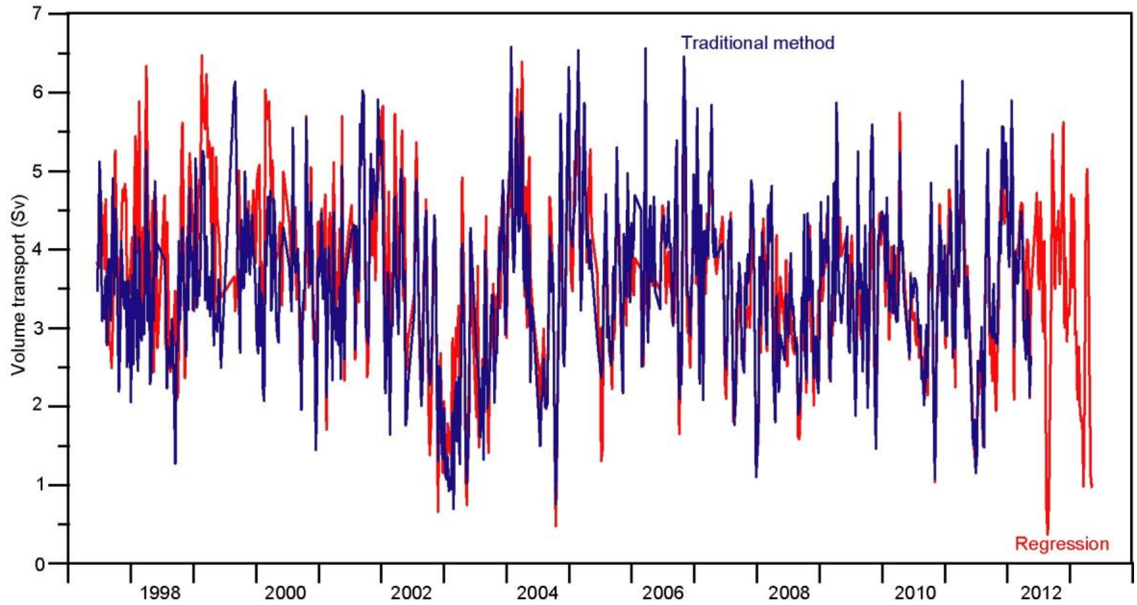

Figure 4. *Weekly averaged volume transport of Atlantic water through the section, based on the traditional method (blue) and based on Eq. (2) (red).*

The average Atlantic water transport from 1st July 2012 to 1st May 2013, during the last deployment period, was 3.3 Sv, which is slightly less than the long-term average transport (3.5 Sv), but this is only the fourth-lowest July – May average in the whole series from 1997 to 2013.

Acknowledgements

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