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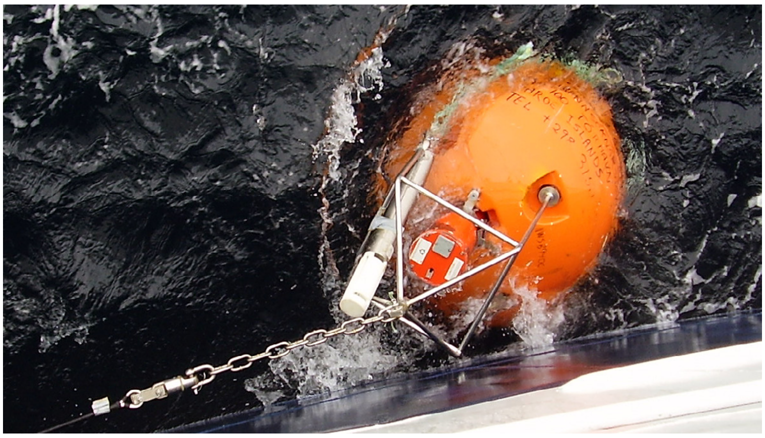
Faroe Bank Channel overflow
2012 – 2013

Tórshavn · March 2014



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HAVSTOVAN NR.: 14-01
TECHNICAL REPORT

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Abstract
Since November 1995, the overflow through the Faroe Bank Channel has been monitored by different kinds of instrumentation. A key element in the monitoring system is data from ADCPs that have been deployed at a fixed location on the sill of the channel, usually from early summer one year to early summer the next with 3 – 4 weeks servicing intervals. From the beginning, the ADCPs at this location have been RDI 75 kHz Broadband instruments, but an accident during the deployment in June 2012 resulted in loss of the instrument to be deployed. To maintain the monitoring, a new ADCP was deployed at the location in late September 2012 and this was an RDI Long Ranger instrument. When data from this instrument were analyzed, it became clear that the instrument showed a similar bias as when deployed earlier in the Denmark Strait, and that bias has also been seen in other Long Rangers with the same firmware version. The error in the Long Ranger data appears as a reduced current speed in a layer that may extend at least 200 m up from the bottom, that is most of the overflow plume. This would give erroneous volume transports, if used uncritically, but the accumulated knowledge about the velocity profile at the location may be used to adjust the measured Long Ranger profiles and derive transport values from them. Based on some - apparently realistic – assumptions, we have used this procedure to derive daily and monthly transport values for the Faroe Bank Channel overflow during the 2012 – 2013 deployment period. The overflow seems to have been weaker than average in this period, but not exceptionally so, and there is no indication of any persistent weakening.

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Introduction

The overflow through the Faroe Bank Channel (FBC-overflow) has been monitored since November 1995 with several types of instrumentation, but the most important component has been a series of ADCP measurements at a fixed site NWFB (61°25'N, 8°17'W, depth: 815 m) on the sill of the channel. It has been shown (Hansen and Østerhus, 2007) that the volume transport of FBC-overflow (defined as "kinematic" overflow) can be determined from the velocity profile at this site, solely.

Since the beginning, the ADCP at this site has been an RDI Broadband ADCP, but, due to instrument loss, this was replaced by an RDI Long Ranger ADCP in September 2012. Afterwards, it appeared that this instrument had problems in measuring the deep part of the overflow plume as has been observed for similar instruments in the Denmark Strait overflow (Nunes, pers. comm.).

The problem is illustrated in Figure 1, which compares the average velocity profile from the 2012 – 2013 Long Ranger deployment (red curve) with average profiles from the five previous deployments, using Broadband ADCPs (blue curves). We can find no physical explanation for such a change in the typical structure of the velocity profile as demonstrated in the figure. Assuming that the Broadband profiles are realistic, it seems clear that the Long Ranger has underestimated the speed of the deepest 200 m. Calculating volume transport from the Long Ranger profile without any adjustments would therefore give an erroneous result.

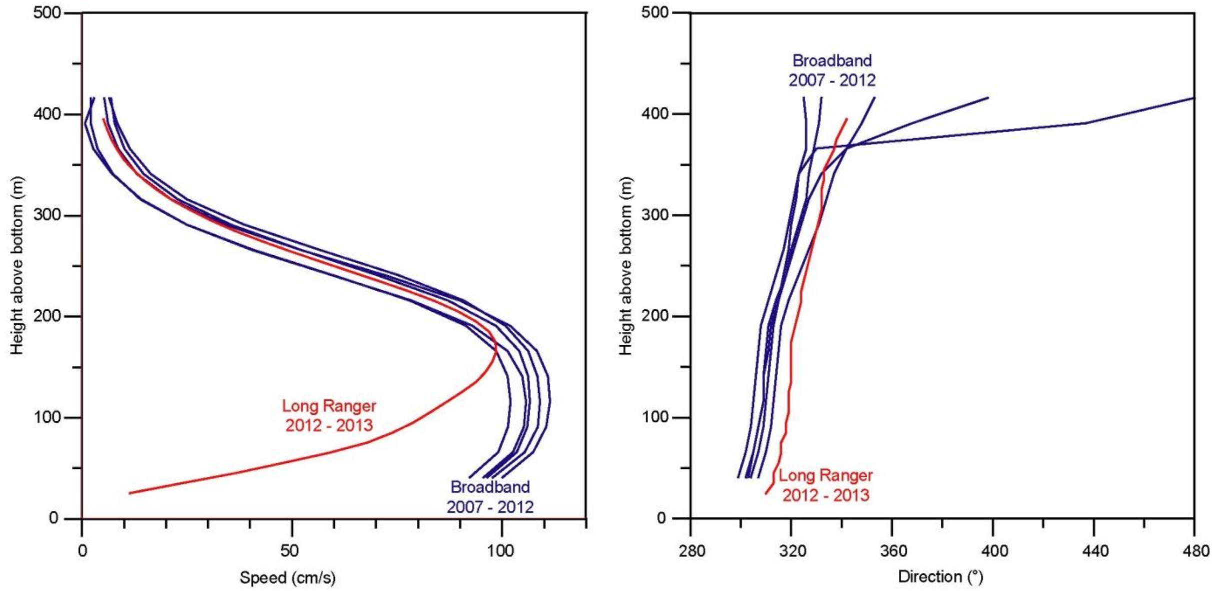

Figure 1. *Average profiles of vectorially averaged speed (left) and direction (right) for six ADCP deployments at site NWFB from summer 2007 to summer 2013 using Broadband (blue curves) and Long Ranger (red curve) ADCPs.*

Figure 1 indicates, however, also that the error decreases with distance from the bottom and above 200 m, the Long Ranger profile is very similar to the Broadband profiles, both as regards the magnitude and direction. This raises the hope that this part of the profile is correct, not only for the average through the whole deployment but perhaps also for short-term averages so that a time series of FBC-overflow volume transport can be generated from the 2012 – 2013 deployment. This report documents the – in our opinion fairly successful – effort to do that.

Observational material

In addition to the 2012 – 2013 Long Ranger deployment (Mortensen et al., in prep.), we use data from 18 deployments with Broadband ADCPs at site NWFB in the period 1995 – 2012. Details of the deployments and data treatment are given in Hansen and Østerhus (2007). Ensembles were collected every 20 minutes, but, in the following analysis, we use de-tided daily averaged velocity profiles consisting of 5703 daily averaged Broadband profiles with bin length 25 m and 227 daily averaged Long Ranger profiles with bin length 10 m. We focus on the along-channel component of the velocity, defined as the velocity component towards 304°. The core velocity is typically a few degrees clockwise of this direction (Figure 1), but it is chosen because it is perpendicular to a section used to calculate transport (Hansen and Østerhus, 2007).

The typical velocity profile at NWFB

The along-channel velocity profile on a given day may be characterized by two parameters: the core (maximum) velocity v_c and the interface height h_i, where we – following Hansen and Østerhus (2007) – define the interface to be at the level where the along-channel velocity has been reduced to one half the core velocity (Figure 2).

Once these two parameters are known for a given day, the rest of the velocity profile is approximately given by the equation:

$$v(z,t) = \frac{v_c(t)}{\langle v_c \rangle} \cdot F\left(\frac{\langle h_i \rangle}{h_i(t)} \cdot z\right) \qquad (1)$$

where *v(z,t)* is the along-channel velocity at height *z* above bottom on day *t*, while *F(z)* is a characteristic function indicated by the black curve in Figure 2. *F* only depends explicitly on *z* and the temporal variation is determined by the two scaling factors: $v_c(t)$ and $h_i(t)$, which have average values: $\langle v_c \rangle = 105.5$ *cm/s* and $\langle h_i \rangle = 257$ *m*. To determine the function *F*, we calculated a function $f_j(z)$ for each day *j* in the Broadband data set as:

$$f_j(z) = \frac{\langle v_c \rangle}{v_{cj}} \cdot v_j\left(\frac{\langle h_i \rangle}{h_{ij}} \cdot z\right) \qquad (2)$$

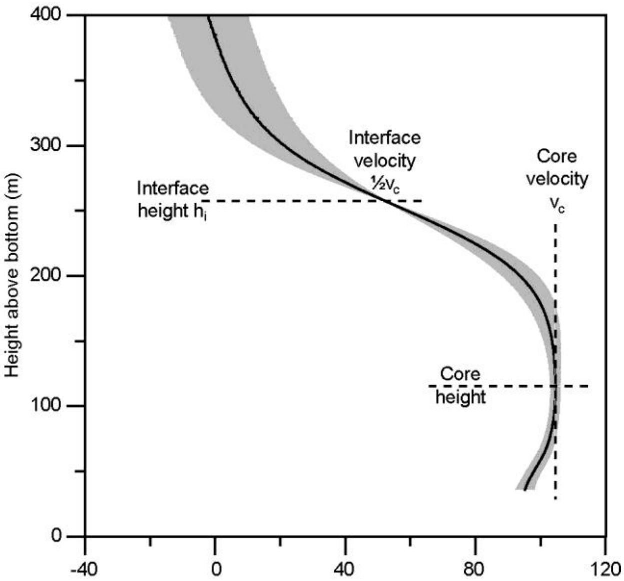

Figure 2. *The typical along-channel velocity profile at NWFB. The black curve is the average form of function F and the gray area indicates the standard deviation.*

where $v_j(z)$ is the observed along-channel velocity profile for day *j*. By interpolating linearly between bins, the function $f_j(z)$ was determined for each meter every day. Averaging over all 5703 days in the Broadband data set, the characteristic form of the function *F* was found. As seen in Figure 2, the standard deviation from this average is small below the interface, verifying that Eq. (1) is a good approximation.

Figure 3 shows distributions of the height and strength of the core, defined as the maximum along-channel velocity, for both the Broadband (blue) and the Long Ranger (red) data. The core height of the Long Ranger data is clearly biased too high, consistent with Figure 1. The core velocity of the Long Ranger data seems rather to be biased too low, although it is more consistent with the

Broadband data. Comparing with Figure 1, this is consistent with more realistic measurements in the upper part of the core, where high velocities are measured at greater height.

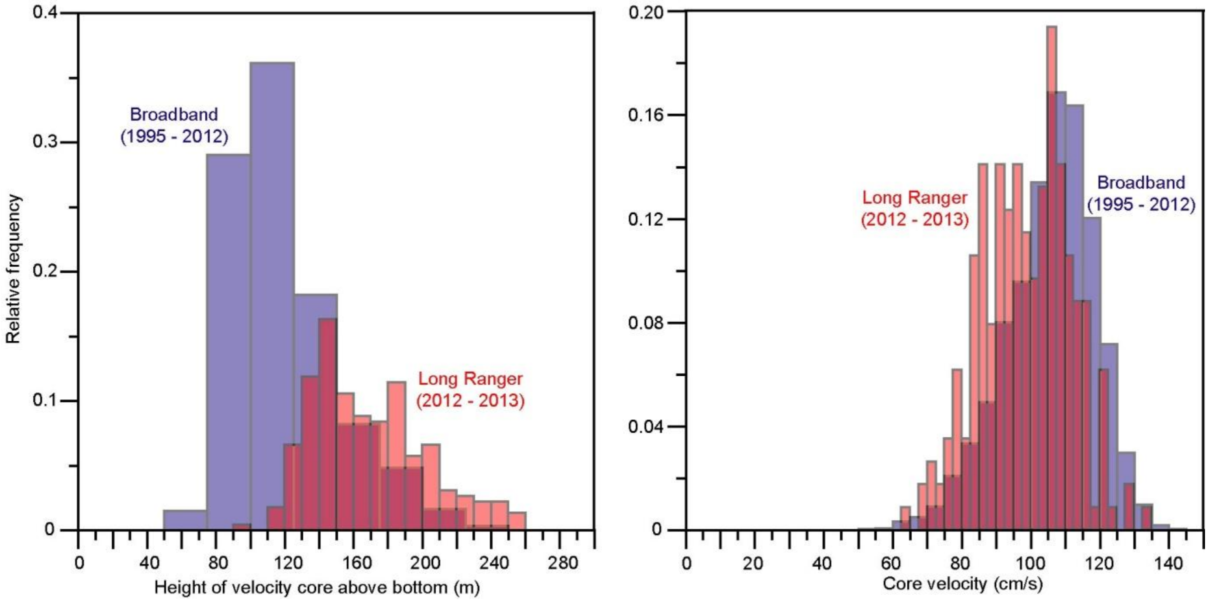

Figure 3. *Frequency distribution of the height of the velocity core (left) and the core (maximum) along-channel velocity (right) for the Broadband data (blue) and the Long Ranger data (red) based on daily averaged profiles. The histogram fill colours are semi-transparent and the dark red (red + blue) columns indicate overlap between Broadband and Long Ranger distributions.*

The variation of the Long Ranger profiles is illustrated in Figure 4 by the average profile as well as four extreme profiles.

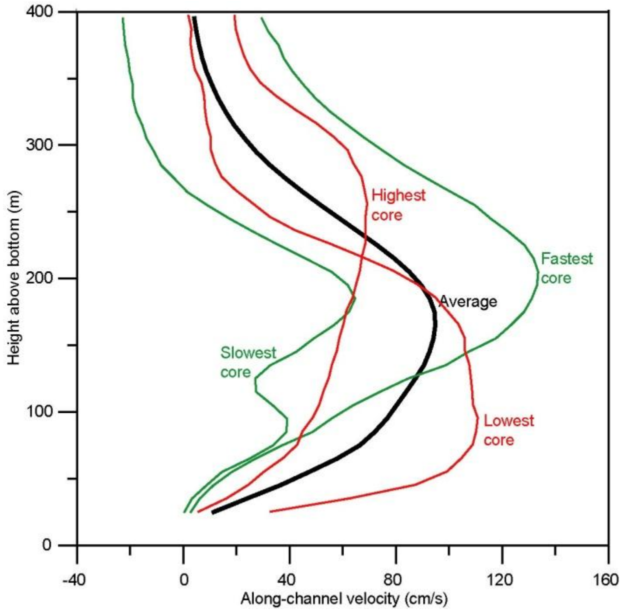

Figure 4. *Average and extreme along-channel velocity profiles from the 2012 – 2013 Long Ranger deployment based on daily averaged data. The thick black curve shows the average profile. The red curves show the two days with highest and lowest location of the velocity core, respectively. The green curves show the two days with strongest and weakest core (maximum) velocity, respectively.*

Adjusting the Long Ranger velocity profiles

The average profiles in Figure 1 clearly indicate that the bottom part of the Long Ranger profile has too low speeds. The current direction seems, however, realistic over the whole depth interval although, perhaps, with a 10° bias at depth. Above ~200 m, the Long Ranger speed also follows the Broadband speed profiles. This inspires the hope that the Long Ranger velocity profiles are accurate above a certain distance from the bottom. Figure 1 indicates that this distance is around 200 m but, from Figure 4, it seems likely that the distance may vary from day to day. From this, we have adjusted the daily averaged along-channel velocity profiles from the 2012 – 2013 Long Ranger deployment based on the following assumptions:

- Each daily averaged Long Ranger along-channel velocity profile is similar to one of the 5703 profiles measured by Broadband ADCPs in the 1995 – 2012 period. Specifically, this means that it can be described by Eq. (1) - that is it follows the black curve in Figure 2 – with scaling factors v_c and h_i that occurred on one of the 5703 days.

- Each daily averaged Long Ranger along-channel velocity profile is accurate above a certain distance H from bottom. This distance may vary from day to day and is characterized by a strong reduction in the vertical velocity shear. Specifically, we assume that this occurs when the along-channel velocity difference between two neighbouring Long Ranger bins is 25% of the maximum velocity difference between neighbouring bins. The choice of 25% is fairly arbitrary, but the results are not very sensitive to this.

Based on these assumptions, we have adjusted the daily averaged Long Ranger profiles. For each day, we first determine a depth interval, in which we assume that profile to be accurate. To escape interference from variations in upper-layer flows, the shallow limit of this interval is defined by the level (bin) at which the along-channel velocity exceeds 30 cm/s. The deep limit of the interval is at the distance H from bottom where the shear has been reduced to 25% of the maximum shear, as assumed above.

When the depth interval has been determined, we fit the along-channel Long Ranger velocity in this interval to Eq. (1) with the function *F(z)* as determined by the Broadband ADCPs (Figure 2), choosing that combination of scaling factors v_c and h_i from the 5703 days that gives the smallest least squares error. The distributions of core height and velocity based on the adjusted profiles are shown in Figure 5.

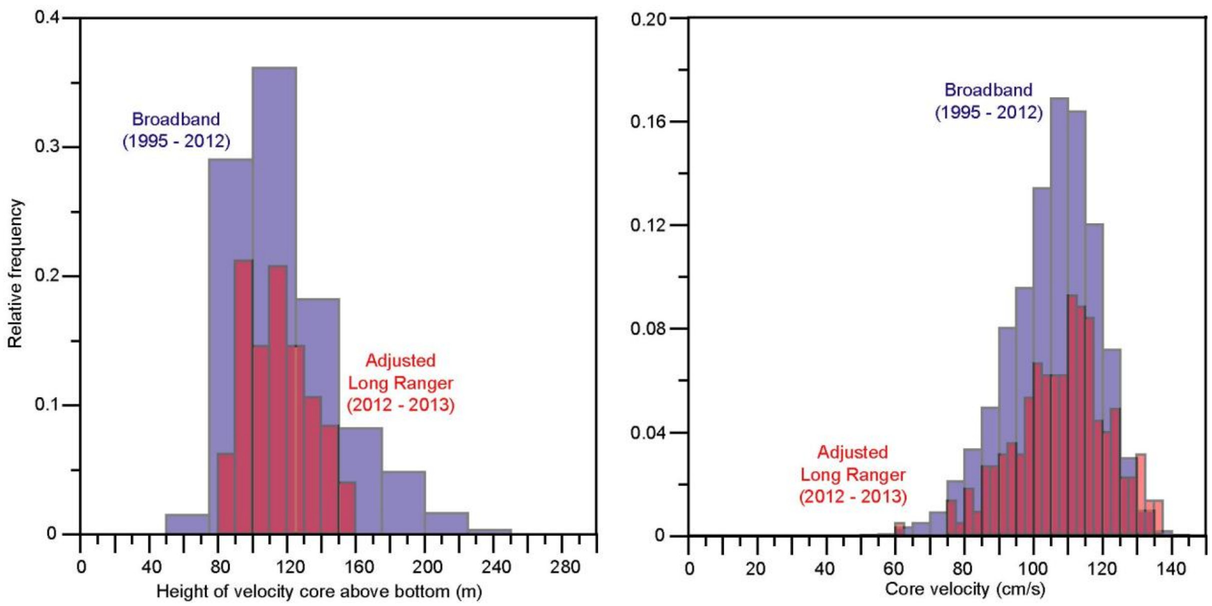

Figure 5. *Same as Figure 3, but with adjusted core heights and velocities instead of those measured by the Long Ranger.*

Comparing the distributions of the adjusted values for the Long Ranger (red) and the Broadbands (blue) in Figure 5, we find a reasonable correspondence. The adjusted Long Ranger core height may perhaps lack the maximum values measured by the Broadbands, whereas the core velocity may have too many extremely high values, but these biases should compensate somewhat and, overall, the distributions look quite similar.

We have therefore calculated daily averaged volume transport values for the kinematic overflow during the 2012 – 2013 deployment period following the procedure described by Hansen and Østerhus (2007), but using the adjusted Long Ranger profiles instead of those measured. The distribution of daily averaged transport in this period is quite similar to that based on the Broadband ADCPs in the 1995 – 2012 period (Figure 6).

This indicates that the volume transport based on adjusted Long Ranger profiles may be realistic and Figure 7 extends the time series of monthly averaged kinematic overflow transport to include the 2012 – 2013 deployment period.

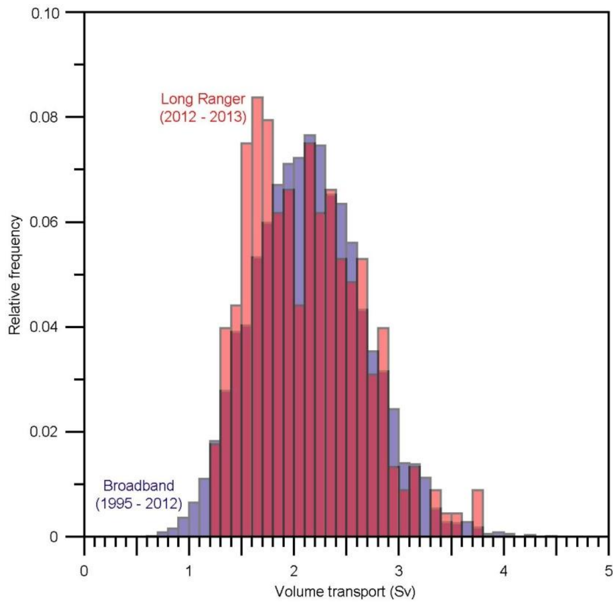

Figure 6. *Distribution of daily averaged volume transport of kinematic overflow through the Faroe Bank Channel based on Broadband ADCPs in the 1995 – 2012 period (blue) and adjusted Long Ranger values in the 2012 – 2013 period. The histogram fill colours are semi-transparent and the dark red (red + blue) columns indicate overlap between Broadband and Long Ranger distributions.*

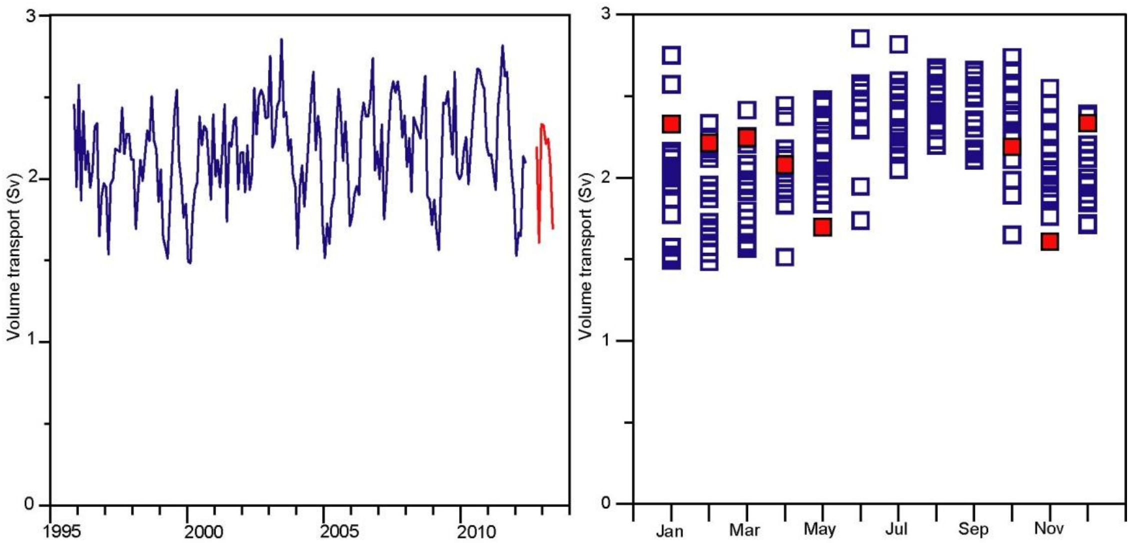

Figure 7. *Monthly averaged kinematic overflow volume transport through the Faroe Bank Channel based on Broadband ADCPs (blue) and adjusted Long Ranger measurements (red) plotted against time (left) and against month (right).*

When plotted against time, the monthly averaged transport based on the adjusted Long Ranger profiles (red in Figure 7 left) is seen to be within the variations of the values based on Broadband ADCPs (blue), although in the lower range. This is also the impression from Figure 1. When plotted against the month (Figure 7 right), it appears that the November 2012 and May 2013 values both are low compared to the values previously measured for those months with Broadband ADCPs, but the dataset does not allow any statistical inference from this. Although based on assumptions and approximations, Figure 7 seems to be our best estimate for the FBC-overflow in the 2012 – 2013 period and it indicates no dramatic changes in the transport.

Quantifying the Long Ranger error

Assuming that the preceding analysis is correct, we can estimate the error in the measured Long Ranger along-channel velocity profiles by subtracting the measured profile from the adjusted profile: $v_{err}(z,t) = v_{adj}(z,t) - v_{meas}(z,t)$. The error will depend on the distance from bottom *z* and we get one profile every day, so it depends on time *t*, as well. One might hope that inspection of the error would show a consistent picture, which could support the analysis and adjustment procedure and perhaps also help correct other deployments with the same instrument or even other Long Rangers having the same problem.

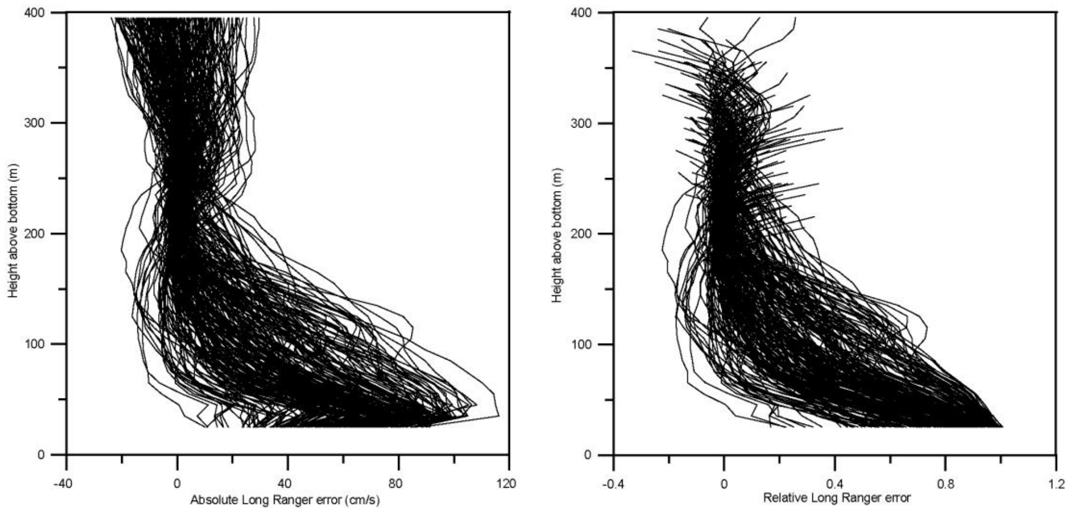

Figure 8. *Variation of the Long Ranger error $v_{err}(z,t)$ (left) and its relative value $v_{err}(z,t)$ / $v_{adj}(z,t)$ (right). Each trace represents one day in the 2012 – 2013 deployment period. Relative error is not plotted when $v_{adj}(z,t) < 30$ cm/s.*

Unfortunately, neither the absolute value of $v_{err}(z,t)$ nor its relative value compared to the adjusted profile show any consistent variation, except that the relative value almost always decreases with height above bottom through the overflow layer (Figure 8). Perhaps an analysis based on single ensembles rather than daily averaged profiles can yield more information on this problem but, so far, Figure 8 does not give any obvious prescription for how to correct Long Ranger profiles with this problem more generally.

Acknowledgements
The Long Ranger ADCP used in the 2012 – 2013 deployment was borrowed from Institut für Meereskunde in Hamburg and discussions with Nuno Nunes were very helpful. The measurements during the 2012-2013 deployment and the analysis of the results have been carried out within the framework of and supported by the European Union 7th Framework Programme (FP7 2007-2013) under grant agreement n. 308299 NACLIM Project. This work has also been supported by NAACOS, which is a program funded by the Danish government.

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