

## Direct observations of the Iceland Basin cyclone at mid depths

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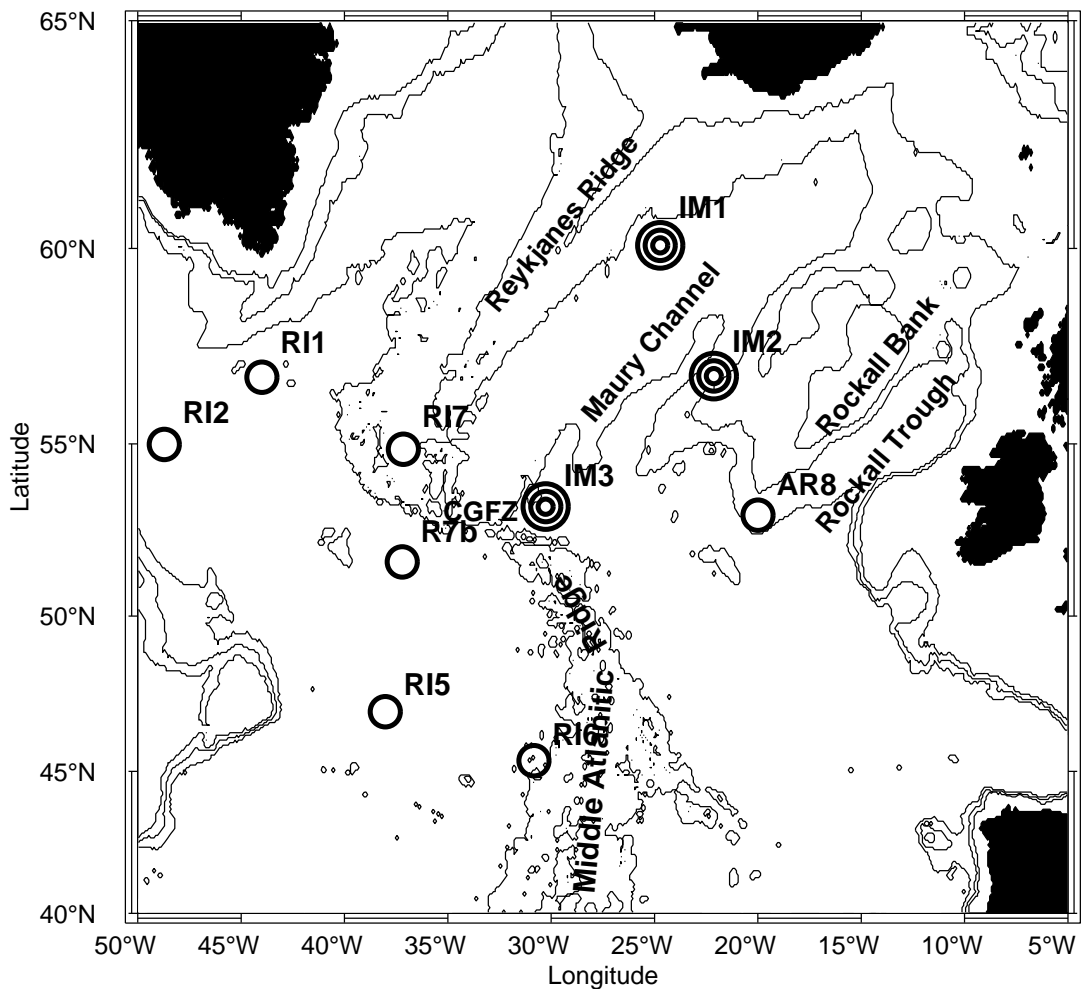
### Abstract:

In 1997 the *Institut für Meereskunde* started its RAFOS float program in the eastern North Atlantic. So far, a total of 47 isobaric floats were launched during three cruises at a nominal depth of 1500 m east of Charlie Gibbs Fracture Zone and in the central Iceland Basin. While 16 floats are still on mission the surfaced ones delivered 26 eddy-resolving trajectories. They allow a unique insight into the circulation pattern of the Labrador Sea Water invading the eastern basins. Pathways split into three branches east of the Middle Atlantic Ridge – one parallels the Ridge southwards, a second spreads zonally towards Porcupine Bank, the third fills the eastern side of the Iceland Basin. In fact, a series of stagnation phases and eddy rotations were recorded on the pathways along the western flanks of Hutton Bank. They are superimposed on a northeastward drift. At the tip of the Basin, floats experience a pronounced acceleration by incoming Iceland Scotland Overflow Water from the Faroe Bank Channel. In the course of the basin-wide cyclone the floats are swiftly advected along the Reykjanes Ridge. Finally, the depth keeping floats are detrained from the deepening Overflow core before the latter reaches Charlie Gibbs Fracture Zone. We expect the pertinent helical circulation and its fluctuations to effect directly transformation rates of all engaged watermasses.

In 1997 the Institut für Meereskunde started its float program in the northern North Atlantic. It covers the region north of 50°N and east of the Middle Atlantic Ridge up to the southern approaches to Iceland (Fig.1). In contrast to the open boundary to the south, the deep Iceland Basin is closed to the north. The Iceland Scotland Ridge acts as a natural barrier for watermass exchanges between the open North East Atlantic and the Norwegian Sea.

On its eastern margin the upper levels of the water column host warm and salty waters from the northern most extension of the subtropical gyre. Separated by the increasingly meandering flow of the North Atlantic Current and its Subpolar Front, the western side of the Basin is dominated by the fresher subpolar regime (Rossby et al., 2000).

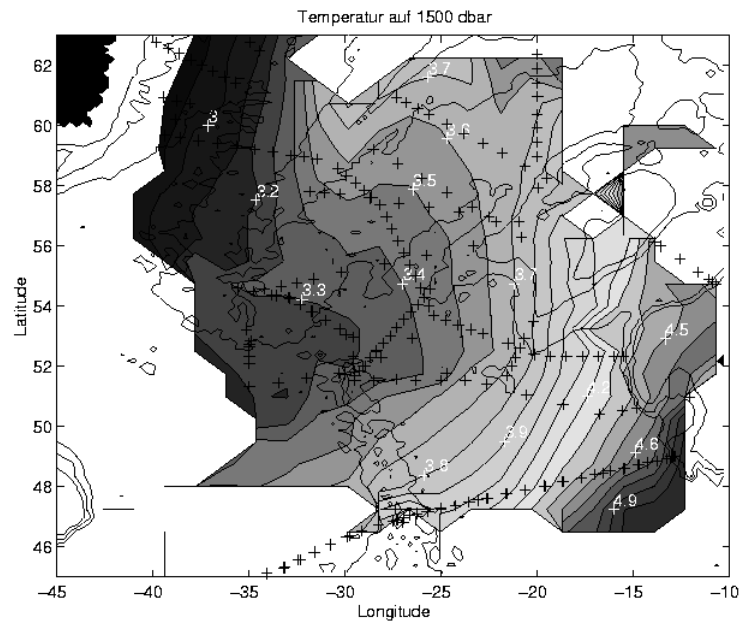
Not only does one find pronounced watermass exchanges across the Subpolar Front, but also between contributing watermasses at intermediate levels (1000 - 1800 m). The primary watermass there originates from the Labrador Sea where it has been formed convectively during previous winters. The conventional spreading picture, recently confirmed by a snapshot of the total CFC inventory in the subpolar gyre in the year 1997 (Rhein et al, 2000), suggests this freshly ventilated low-salinity water enters the eastern basins through the Charlie Gibbs Fracture Zone (Fig.1). The latter constitutes a natural gap in the Middle Atlantic Ridge near 52°N.



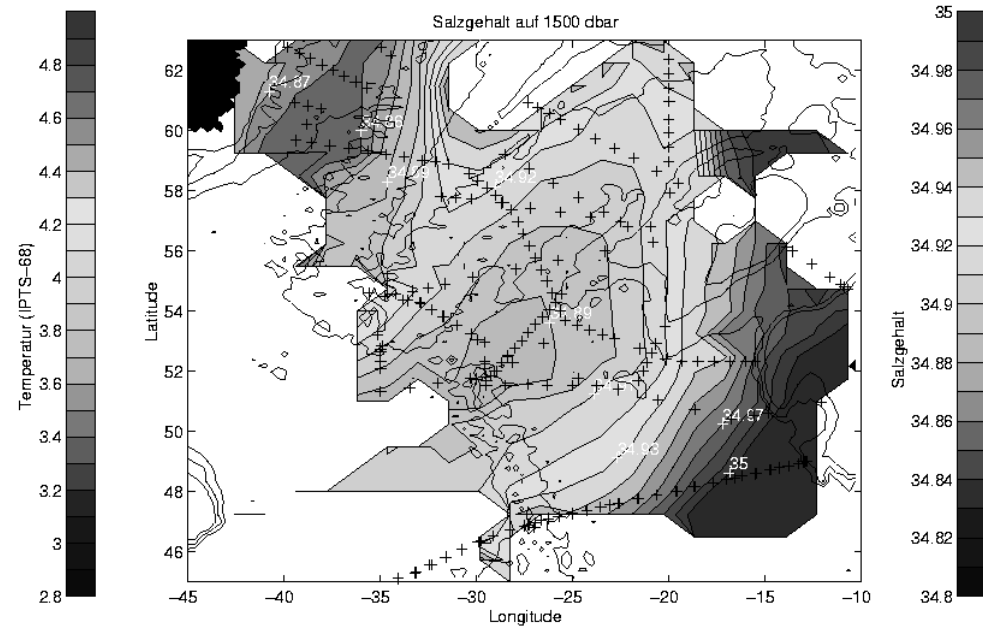
**Fig.1:** Array of moored RAFOS sound sources that have been used for float tracking at IfM Kiel from 1997 on. IM - Institut für Meereskunde (German), AR - ARCANE (French), RI - University of Rhode Island (USA). For orientation the 1000, 2000 and 3000 m isobaths are included.

A second source of mid-depth waters emanates from the warm and salty Mediterranean outflow in the Gulf of Cadiz. How far northward this watermass can invade the Rockall Through and the Iceland Basin still remains an open question (Bower et al., 2000). Finally, Iceland Scotland Overflow Water at its northern end adds salt to Labrador Sea Water layer. Further mixing components at intermediate depths arise from adjacent strata, i.e. Subpolar Mode Water from above and Lower Deep Water from below. The resulting horizontal distribution of salinity and temperature at 1500 m depth is displayed in Figure 2. The plot was drawn from hydrographic surveys taken between 1997 and 1998.

The main goal of our effort comprises the circulation and the fluctuations of watermasses at the intermediate levels of the Iceland Basin. For our studies in this melting pot of watermasses we have chosen conventional isobaric RAFOS floats.



(a)



(b)

**Fig. 2:** Horizontal temperature in °C (a) and salinity (b) distribution at the level of the Labrador Sea Water (1500 m) in the eastern basins of the North Atlantic. Note the pronounced penetration of this cold and low saline watermass across the Middle Atlantic Ridge at 53°N (Charlie Gibbs Fracture Zone). On the southeastern side the Labrador Sea Water tongue encounters warm and much more saline Mediterranean Water originating from the Gulf of Cadiz.

Our Lagrangian observations started in the summer of 1997. Three RAFOS sources were moored in the central Iceland Basin (Tab. 1). The sources are part of the present internationally coordinated RAFOS array of the NE Atlantic. It dates back to 1990 when the Institut für Meereskunde in Kiel started its first RAFOS observations in the Iberian Basin (Zenk et al., 1992). More information on the array's evolution during the EUROFLOAT campaign and the other experiments like AMUSE, ARCANÉ etc. can be found on a web site maintained by Thierry Reynaud from Ifremer, Brest (<<http://www.ifremer.fr/lpo/eurofloat/index.html>>).

**Table 1:** Details on RAFOS sound sources in the Iceland Basin

Mooring		Ping time UTC	Approximate launch position		Launch date	Maintenance date
Code	IfM No		Lat.	Long.		
IM1	V384	1:00	60°N	25°W	29/5/1997	29/6/1999
IM2	V385	0:30	57°N	22°W	24/5/1997	—
IM3	V388	1:30	53°N	30°W	21/5/1997	10/8/1998

Jointly with similar instrumentation from the American Atlantic Circulation and Climate Experiment (ACCE), the French ARCANÉ project and the terminated EUROFLOAT initiative, these sound sources reflect the backbone for our eddy-resolving observations of circulation patterns at roughly 1500 m depth. (Fig.1). By the ICES Annual Science Conference 2000 we will have visited the region four times (Tab. 2). In total, 47 floats manufactured by SeaScan, Inc. of Falmouth, Massachusetts were launched. 29 instruments surfaced on time, two did not show up, and one float was deaf. For all but three floats, the nominal target depth was 1500 m. While writing this note (July 2000), 16 floats are still on mission. Presently our data set consists of about 33 float years (fy). Daily readings of instantaneous float positions centred at 01:00 UTC together with on board temperature and pressure observations were processed in the laboratory in Kiel. Initially pre-programmed mission lengths varied initially between 15 - 18 months. More recently they were extended up to two years under water.

**Table 2:** Inventory of cruises towards the Iceland Basin in the frame of SFB 460<sup>\*)</sup> of Kiel University.

Ship	Cruise	Duration	No of floats launched
METEOR	39/2	14 /5- 8/6/1997	17
POSEIDON	242	2 - 21/8/1998	22
METEOR	45/2	11/6 - 8/7/1999	8
POSEIDON	261	27/6 - 17/7/2000	(10)

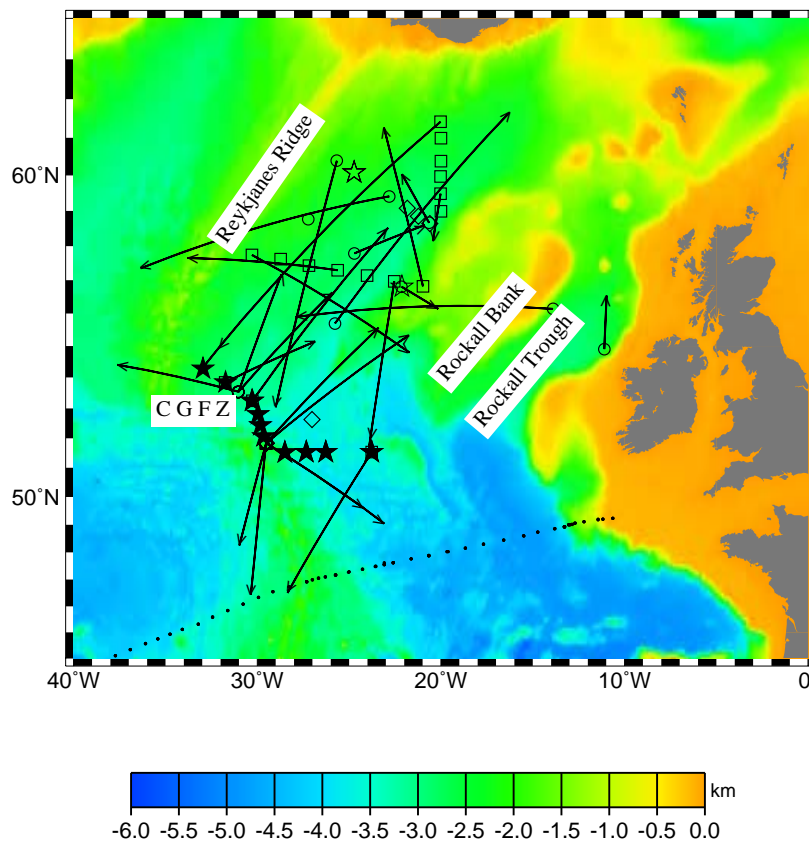
At the main entrance for Labrador Sea Water east of Charlie Gibbs Fracture Zone delayed releases by multiples of three months were arranged by the newly developed float park concept (Zenk et al., 2000). A "park" consists of a number of dual release RAFOS floats. Their first

<sup>\*)</sup> SFB (Sonderforschungsbereich) stands for an accelerated research initiative comprising intensive observations and modelling efforts of fluctuations in the thermohaline circulation in the subpolar gyre of the North Atlantic.

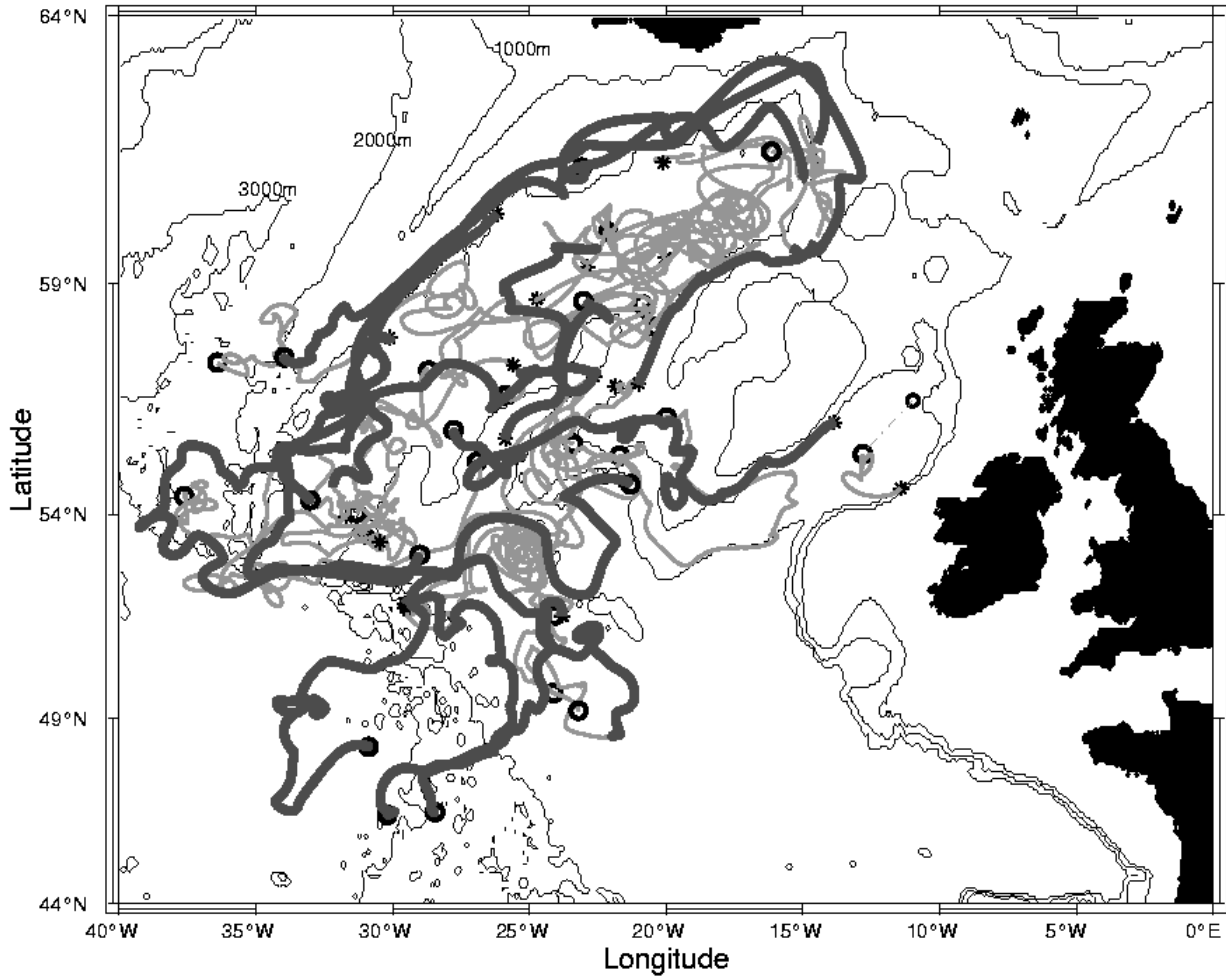
release block keeps the instruments temporarily moored on the sea bed. The second block achieves the conventional release of a drop weight at the mission's end.

It is of interest to compare our current harvest of 33 fy with the original requirements of the past World Ocean Circulation Experiment (WOCE) float program. It had called for 5 fy per  $5^\circ \times 5^\circ$  square of the ocean. In our case we count approximately  $5^\circ \times 3^\circ$  (longitude x latitude), resulting in 75 necessary fy/box or 44% of the projected coverage. Together with the spacious float campaigns of our American, British and French colleagues we can already state that the WOCE goals in respect to float coverage in the North Atlantic including the Iceland Basin will definitely be met by the end of the series of on-going experiments.

Figure 3 shows logistical details and some integral results of our observations with floats in the Iceland Basin. Different launch events according to Table 2 are denoted by different symbols ( $\circ$  1997,  $\square$  1998,  $\diamond$  1999). The displacement vectors shown connect launch and surface positions of individual floats. Symbols without vectors label floats that are still on mission. Note the general alignment of displacement vectors with the main axis of Maury Channel, i.e. the deep trough on the eastern side of the Iceland Basin. They seem to be antiparallel with a preferred south-westerly direction on the eastern side of the Reykjanes Ridge. At the southern end of our area under investigation a southward export of water is suggested by the vectors. The region represents an extension of the EUROFLOAT launch sites. This study area terminated in 1998. It focused on the frontal exchange at mid depth between the Mediterranean and Labrador Sea Waters in the eastern limb of the subtropical gyre (Speer et al., 1998).



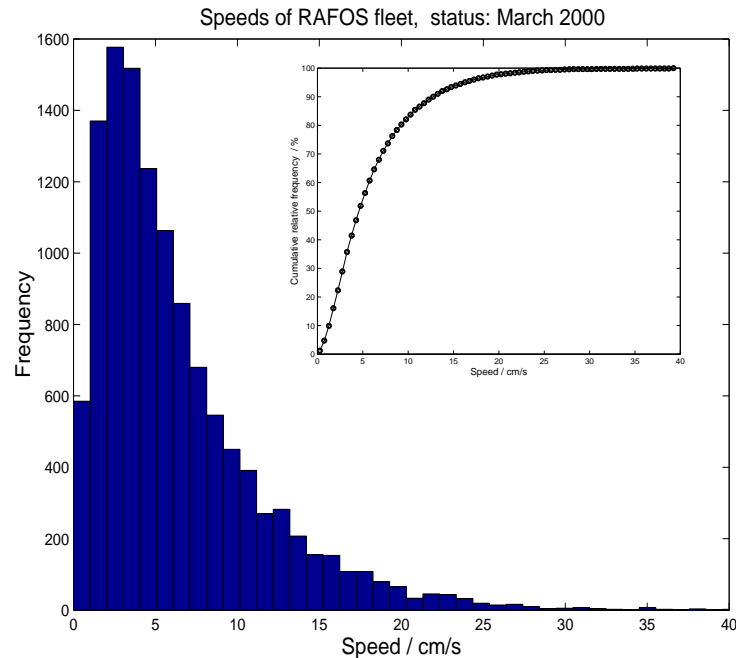
**Fig.3:** Topographic chart of the Iceland Basin. Included are locations featuring RAFOS sound sources (open stars) and current meter mooring sites (bold stars), launch (open symbols) and surface positions (arrow tips) from three float seeding cruises according to Table 1 and 2. On the average displacement vectors represent mission length of 15 months. The lower dotted line denotes WOCE section A2.



**Fig.4:** Summary diagram of all available float trajectories (status: April 2000). To enhance the underlying bi-modal structure of the intermediate flow at approximately 1500 m depth we use bold and thinner lines for the plotted pathways. Bold curves denote the preferably steady flow regime on the western side of the Iceland Basin. The more eddy coiled regions in the centre and on the eastern side are represented by thin curves. Black stars stand for launch, big circles for surface positions of RAFOS floats. Where tracking was disturbed we use a thin dashed line. The 1000, 2000, and 3000 m isobaths are included for orientation

More details are contained in the "spaghetti" diagram in Figure 4. We have separated our set of trajectories into two preliminary modes. On the eastern side of the Iceland Basin floats show a well developed tendency towards stagnation or rotation with only little or no significant translations. Here on the more chaotic eddy side of the Basin floats are under the influence of the low-salinity Labrador Sea Water. The hydrographic situation differs totally on the western side of the Basin where they are swiftly advected along the Reykjanes Ridge. As a result we infer a well organised steady and swifter flow south of Iceland and along the northern partition of the Ridge. The immediate watermass up there consists of Iceland Scotland Overflow Water which entrains and absorbs the outskirts of the northern most extensions of Labrador Sea Water. The imminent Lagrangian temperature and pressure time series of our float records will help to study this mixing process in more detail.

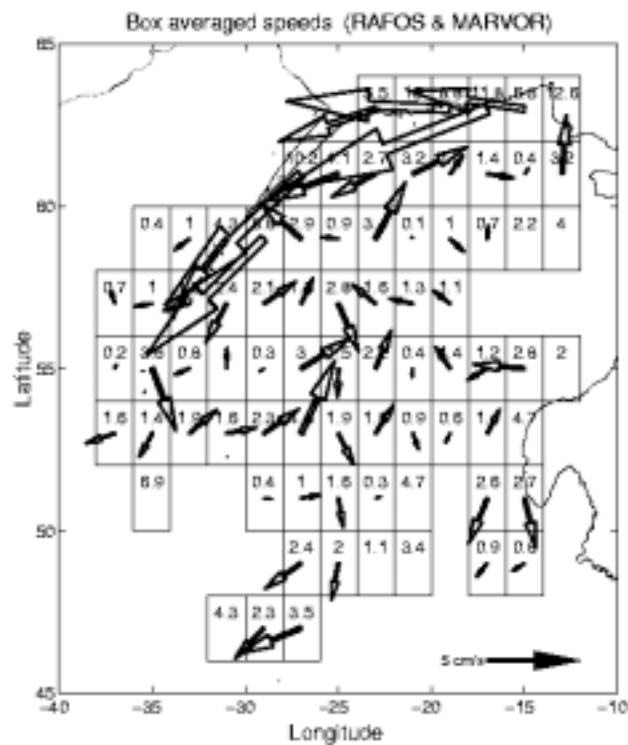
A presentation of all daily speed values is given in Figure 5. We recognise a pronounced peak in the frequency distribution of the whole float fleet in the range 2 - 4 cm s<sup>-1</sup>. Less frequent speeds of >11 cm s<sup>-1</sup> are typical for the northern and north-western rims of the Iceland Basin.



**Fig.5:** Frequency distributions and its integral (insert) of daily speeds at 1500 m from all floats shown in Fig. 2. Data represent almost 33 float years.

South of about 58°N the Overflow Water still seems to behave like a contour current. While it sinks farther down the flanks of the Ridge our floats at 1500 m depth are detrained from the deeper levels of this fast moving vein when finally reaching the Charlie Gibbs Fracture Zone. The general cyclonic circulation at the intermediate level in the Iceland Basin is closed potentially by a new vintage of Labrador Sea Water. Once the floats are captured by such a repeat eastward interbasin exchange event they are advected towards the western approaches of Europe again.

Labrador Sea Water reaches the eastern basins through the Gibbs Fracture Zone (Fischer and Schott, 2000). Hereafter it diverges into three branches, an eastward limb and two opposing more meridionally aligned limbs, as reported by Paillet and co-workers (1999). In Figure 6 we demonstrate the kinematics of the great Iceland Basin cyclone by preliminary box averages of our Lagrangian vectors supplemented with the EUROFLOAT data from the first year (Speer et al., 1998). Only boxes with at least two different floats and a minimum residence time of 21 days per 2°x2° box contain a vector. Its size is proportional to its scalar speed. Independent of duration of float visits and the number of floats per box numerical speed values for all boxes of our data are also included.



**Fig.6:** Non-synoptic Eulerian vector averages at approximately 1500 m from our RAFOS data (status: March 2000) and from the MARVOR data set obtained during the first EUROFLOAT year (Speer et al., 1998). In addition, current speeds are given numerically. As a reference for vector scaling we include the arrow on the bottom right side. For orientation we repeat the 1000 m isobath (see also Fig. 1).

The most obvious results obtained for the 1500 m level in the Iceland Basin so far are:

- For the first time we can confirm the well developed cyclonic circulation by direct long-term Lagrangian current observations.
- The obtained advection pattern can be separated into two different geographical and hydrographical modes. In the centre and on the eastern side of the Basin eddies with little or practically no translation tendency prevail. These regions of chaotic currents enhance local mixing by the availability of eddy kinetic energy. They further degenerate Labrador Sea Water as a characteristic watermass. On the opposing side, i.e. on the flanks of the Reykjanes Ridge we find persistent currents with higher amounts of mean kinetic energy. It is here that the newly formed Iceland Scotland Overflow Water consolidates after heavy dilution by entrainment farther upstream (Østerhus et al., 1999).
- The outflow core sinks as it parallels the Reykjanes Ridge leaving a level with lower currents behind when approaching the Charlie Gibbs Fracture Zone.

We look forward to receiving further data from our experiment which also includes an Eulerian component from five current meters (see Fig.1, bold stars), and to analysing them jointly with our colleagues and their data from adjacent depths in this exciting region of the North Atlantic.



## Acknowledgements

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