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Measurement of flow north of the Faroe Islands June 1986

by

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Abstract

A line of moorings with current meters were deployed northwards from the Faroe Islands for ten days in the beginning of June. Simultaneous hydrography was observed by faroese and norwegian ships. A preliminary report of the current measurements will be given in this contribution describing the flow in the upper layers and giving a preliminary estimate of the transport of Atlantic water between Iceland and the Faroes into the Norwegian Sea. A total of 2.9 Sv (10^6 m^3/sec) of Atlantic water was found to flow between Faroes and the surface front at about 63°30 N. The remaining part of the area was very roughly estimated to transport an additional 0.9 Sv giving a total flow for this period of 3 - 4 Sv.

Introduction

The flow of water out of the Atlantic into the Norwegian Sea is of considerable interest both from a basic Oceanographic point of view and as a part of the climatic problem. Attempts to arrive at a quantitative estimate of the transport value have been made for several decades without a satisfactory conclusion. Estimates based on balance constraints (Worthington 1970, McCartney and Talley 1984) have given values higher by a factor of 2 to 5 than those arrived at by direct measurement, using either geostrophy (Tait 1957) or current meter data (Dooley and Meincke 1981), which is not surprising taking into account the large uncertainties inherent in previous attempts at direct estimation (Hansen 1985). Recently this picture has changed somewhat by the publication by Gould et al. (1985) of a transport value amounting to 7.5 Sv (10^6 m^3/sec) flowing northeastwards over the slope north of Shetland. This estimate, based on yearlong direct current measurements, is very close to Worthingtons original estimate of 8 Sv flowing between Iceland and Shetland, but, as the authors point out, their section is over a limited part of the Faroe Shetland Channel not covering the southwestward going flow in the Faroe side of the channel, their transport value included other water than Atlantic and they considered only "positive" flow, i.e. flow towards the northeast. Most of these simplifications would tend to increase the transport, so the cited number is probably an overestimate.

Thus there is still a discrepancy between the measured transport and the balance estimate by Worthington, although there may be consistency with the smaller balance estimates by McCartney & Talley (1984). There is, however, another possibility, namely that there is, in addition to the Faroe Shetland Channel flow, a flow between Iceland and the Faroes considerably larger, than has been generally assumed.

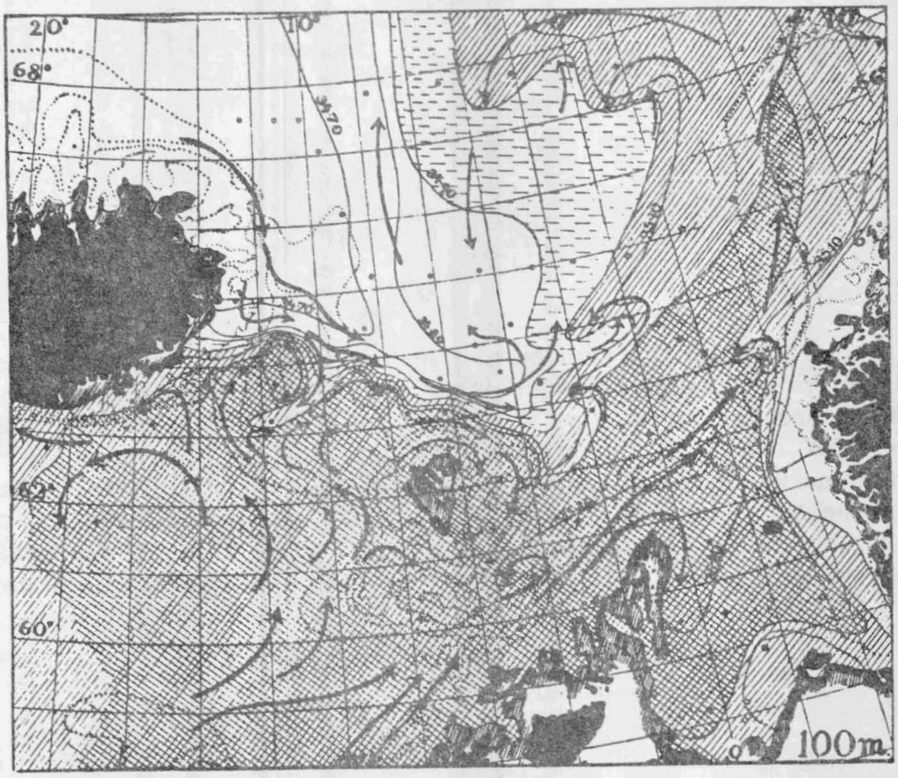

Fig.1. Horizontal distribution of salinity at 100 m, May 1904. The arrows indicate the circulation pattern according to Helland Hansen and Nansen (1909).

The warm water over the Iceland Faroe Ridge (IFR) derives from the Iceland Basin. The path of the Atlantic water, as it approaches the IFR, is not much better known today, than it was early in this century (Fig.1). The horizontal distribution of temperature and salinity along the ridge axis appears quite homogeneous on the ridge proper (Meincke 1972), but changes when approaching the shallower areas in both the Icelandic and the Faroese end of the ridge. On the Faroese end a high salinity core is often found, which appears to be a continuation of a core north of Faroe Bank.

Further towards the east this core is much more evident, and an oft repeated north south section about 6 degrees west (Tait 1957 and contributions by F.Hermann and K.P.Andersen in Ann. Biol. for the years 1948-1957) always shows this core (Fig.2a) with steeply sloping isolines indicating a strong flow. Thus there is some evidence of both a concentrated flow along the northern flank of Faroe Bank continuing on the northern Faroe slope and also a broader flow over the ridge, both of these concentrating east of the ridge at about 6 degrees W. This pattern is in good agreement with Helland Hansen and Nansens (1909) circulation map (Fig.1).

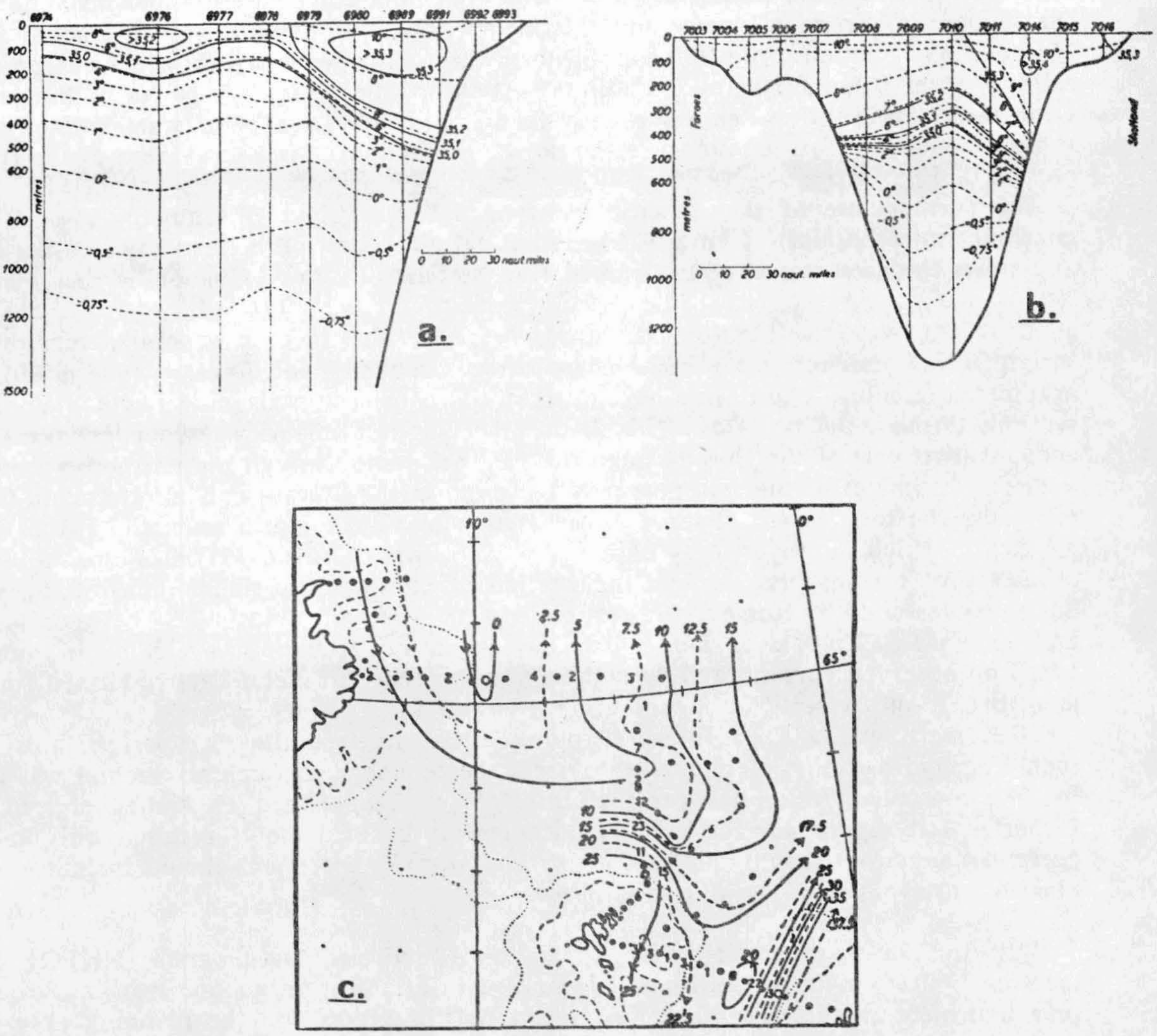

Fig.2 Hydrographic investigations in August 1948 by R/V Dana (Hermann 1948). a.: Vertical section from the Faroes northwards. b.: Faroe Shetland section. c.: Station map showing dynamic topography relative to 1000 metres, figures between stations show the velocity in cm/sec.

Over the northeastern flank of the Ridge Fig.1 agrees well with the dynamic current computations from the Overflow-60 dataset (Bogdanov et al. 1967), but not over the southwestern flank. The dynamic method is, however, very difficult to use on a ridge, and Fig.1 is in substantial agreement with the available information from drift bottle experiments and direct current measurements. This flow has been denoted the Faroe Current by Hansen and Meincke (1984). Its core seldom exceeds 35.3×10^{-3} in salinity and 9°C in temperature by much. Probably it represents fairly undiluted water from the eastern part of the Iceland Basin and the term MNAW (Modified North Atlantic Water) seems to have originated with this watermass.

The Subarctic Front is inclined and the frontal boundary surface deepens as one goes southwards and westwards. It hits the IFR on the top and the Faroe slope at depths of 300 to 500 m (Fig.2a). Below the Faroe Current there is a layer of water from the East Icelandic Current giving a salinity minimum between the overlying MNAW and the NSW (Norwegian Sea Water), which is found in increasing amounts from about 500 m and downwards. The water of the salinity minimum varies in composition. Usually it is found to be mostly NI/AI water (North Icelandic/ Arctic Intermediate) but also EIW (East Icelandic Winter) water has been found (Meincke 1978).

East of about 5 degrees W the surface isolines tend to diverge horizontally (Fig.1), and a cold tongue protruding far towards the Faroese shelf is a common, altough irregular, feature, which may be connected to the well documented meandering and instabilities of the Subarctic Front (Hansen and Meincke 1979, Willebrand and Meincke 1980). Hydrographic sections from the Faroes northwards thus generally show a wedge of high salinity water presumably fairly undiluted Atlantic water (Fig. 2a). North of the surface front terminating the wedge one usually finds in addition a layer of water, which by its salinity contains a fair amount of Atlantic water. This layer is also evident in the typical section of Fig. 2a.

The further fate of the Atlantic water is not very clear. Presumably a part of it continues into the Norwegian Sea (Fig.1) but certainly part of it turns towards the south and flows southwards east of the Faroes into the Faroe Shetland Channel.

In recent western literature the transport over the IFR is generally regarded as insignificant compared to the FSC transport (e.g. Coachman and Aagaard 1974 p. 90). The arguments remain obscure, however. Certainly a visual comparison of two contemporary sections through the two flows (Fig.2) does not support this view especially taking into account, that part of the flow through the FSC has come through the northern section.

A few estimates of the transport may be found in the literature. Thus Hermann (1948) estimated the total transport through the section of Fig.2a, north from the Faroes to be 4.5 Sv, of which, however, only part was Atlantic water. Tait (1957) also cites a number of geostrophic transports through this section of considerably smaller magnitude, while Sukhovey (as cited by Rossov 1972) estimated a transport of almost 10 Sv between Iceland and the Faroes. There does not seem to have been any attempt to evaluate the transport based on observed current, and with the amount of current meter data published for this area, that is hardly realistic at present.

Thus there was a need for an experiment to measure the transport of this flow including hydrographic sections with current meter moorings. Such an attempt was made in 1982 as a collaboration between the University of Copenhagen (G. Kullenberg) and the Fisheries Laboratory in Tórshavn. That attempt, unfortunately, resulted only in lost current meters, but taught the lesson, that any future experiment should include careful planning to avoid such loss due to fisheries.

With this in mind the Nordisk Kollegium for Fysisk Oceanografi (NKFO) at its meeting in Reykjavík september 1984 decided to establish an ad hoc working group to plan a project in this area. The first result of this group was the planning of a pilot experiment to evaluate the importance of the Faroe current to the water and heat transport to the Norwegian Sea.

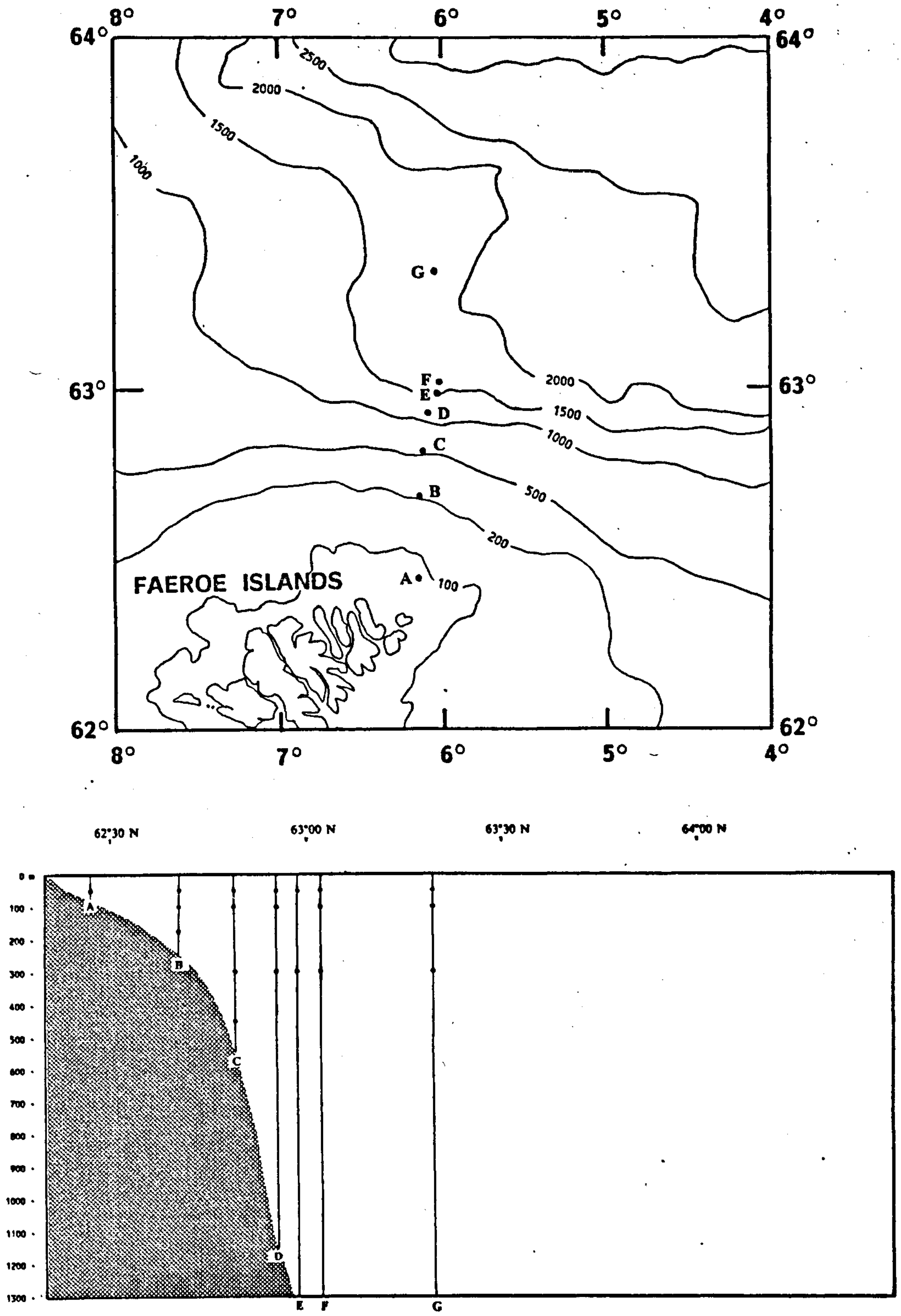

Fig.3. Current meters recovered north of the Faroes June 1986 (only instruments above 500 m depth are shown).

Material

This project took place during the first half of June 1986. Its main aim was to get a preliminary estimate of the transport value. To realize that aim a total of seven moorings were deployed more or less along a line following the 6°05´ W longitude (Fig.3). The moorings had from 2 to 4 current meters each which were all of them Aanderaa meters except for the two shallowest moorings which had also some SD2000 Sensordata (Gytre) instruments.

The complete mooring section was out for 10 days from June the 5th to June the 14th. This period is short for an estimate of a typical transport value, but from previous experience the risk of instrument loss from fisheries is so great that it was decided rather to get as many as possible of the instruments back and consider the transport value as only a preliminary number.

In addition to the moorings two research vessels did hydrographic surveys in the area in the observational period. The faroese ship R/V Magnus Heinason steamed back and forth along the mooring section taking CTD stations and chemistry and alerting the fishing fleet to the moorings while the norwegian R/V Haakon Mosby covered a larger area doing CTD and seasoar sections in addition to other work.

The current meters were contributed from most nordic countries and scientists from Norway, Sweden, Finland, Denmark, Faroes and Iceland were on the two ships.

The care taken with the moorings paid off in that all of them were recovered succesfully and nearly all the current meters had functioned properly, so a fairly complete current section was obtained allowing an estimate of the transport value during the period.

The data material obtained is still in a fairly early stage of processing and will not be ready for final analysis for some time, but this problem is very acute at the present and a preliminary estimate of the transport will be important for several observational programs which are now in the planning stage. We therefore decided in this paper to publish a preliminary estimate of the transport value. The final analysis will probably lead to some revision of the estimate, but hardly by very much and as the shortness of the observational period in any case makes the estimate questionable we find it suitable to present a preliminary number at the earliest stage possible.

Results

We will not present the total amount of hydrographic data observed during the project, but will consider only those observations which were along the current meter section. R/V Haakon Mosby made one hydrographic section and Fig.4 shows potential temperature, salinity and density from this section.

The other vessel, R/V Magnus Heinason, made altogether 6 CTD sections along the same line (Fig.5). Three of these are shown in Fig.6. For all of these sections it should again be stressed that final processing and calibration may change especially the salinity values and derivaties from them somewhat so the graphs are only preliminary, but the main features pertinent to the present problem will hardly be affected.

The data from the current meters have been edited and calibrated. The measurements below 500 m depth will not be discussed here at all. Fig.7 shows progressive vector diagrams from all the moorings at 50m depth and 300m depth respectively (170m for mooring B). Furthermore 25-hour running means have been calculated.

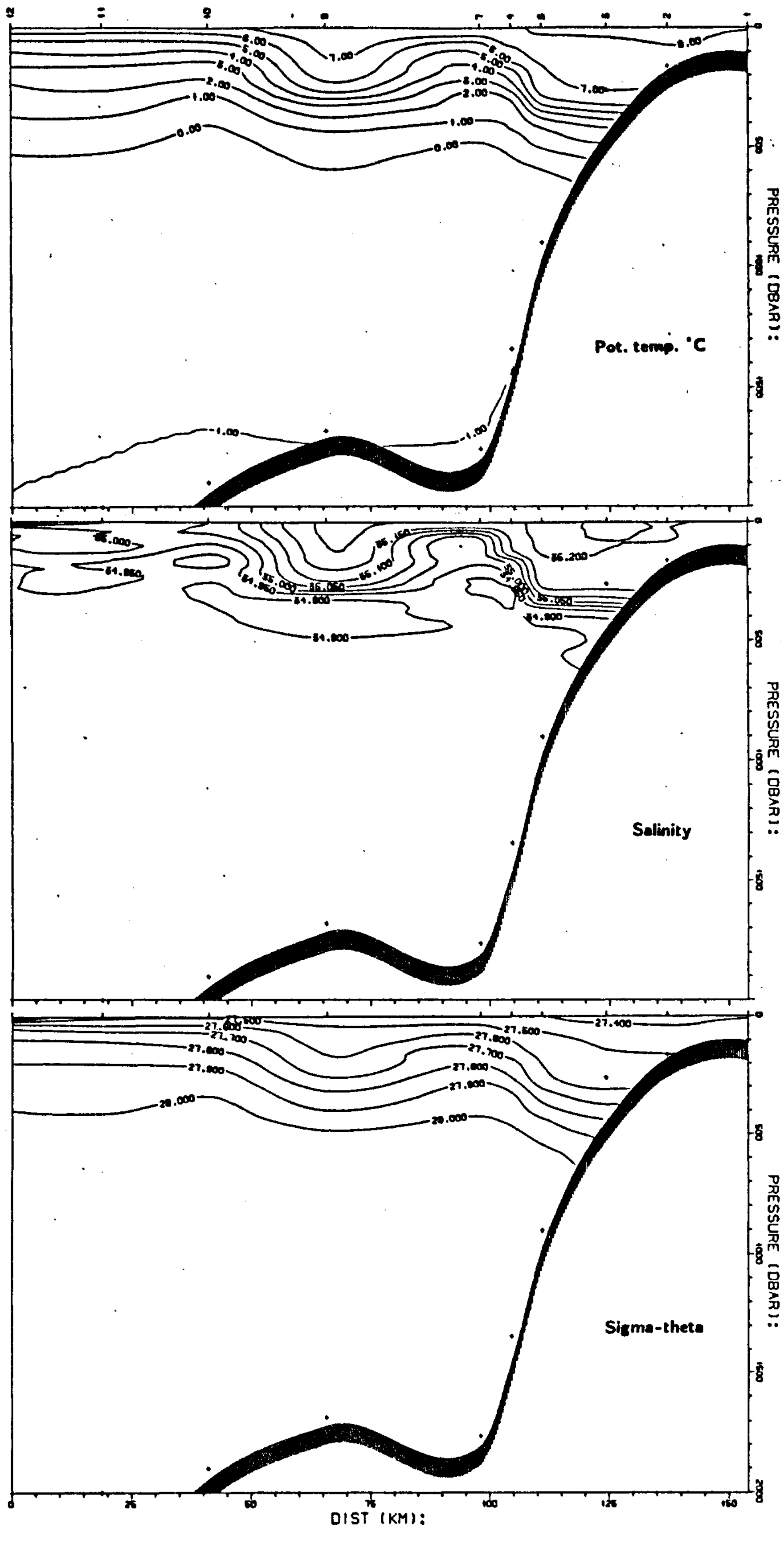

Fig.4. CTD section made by R/V Haakon Mosby on the 3d. of June along the current meter moorings (Preliminary data).

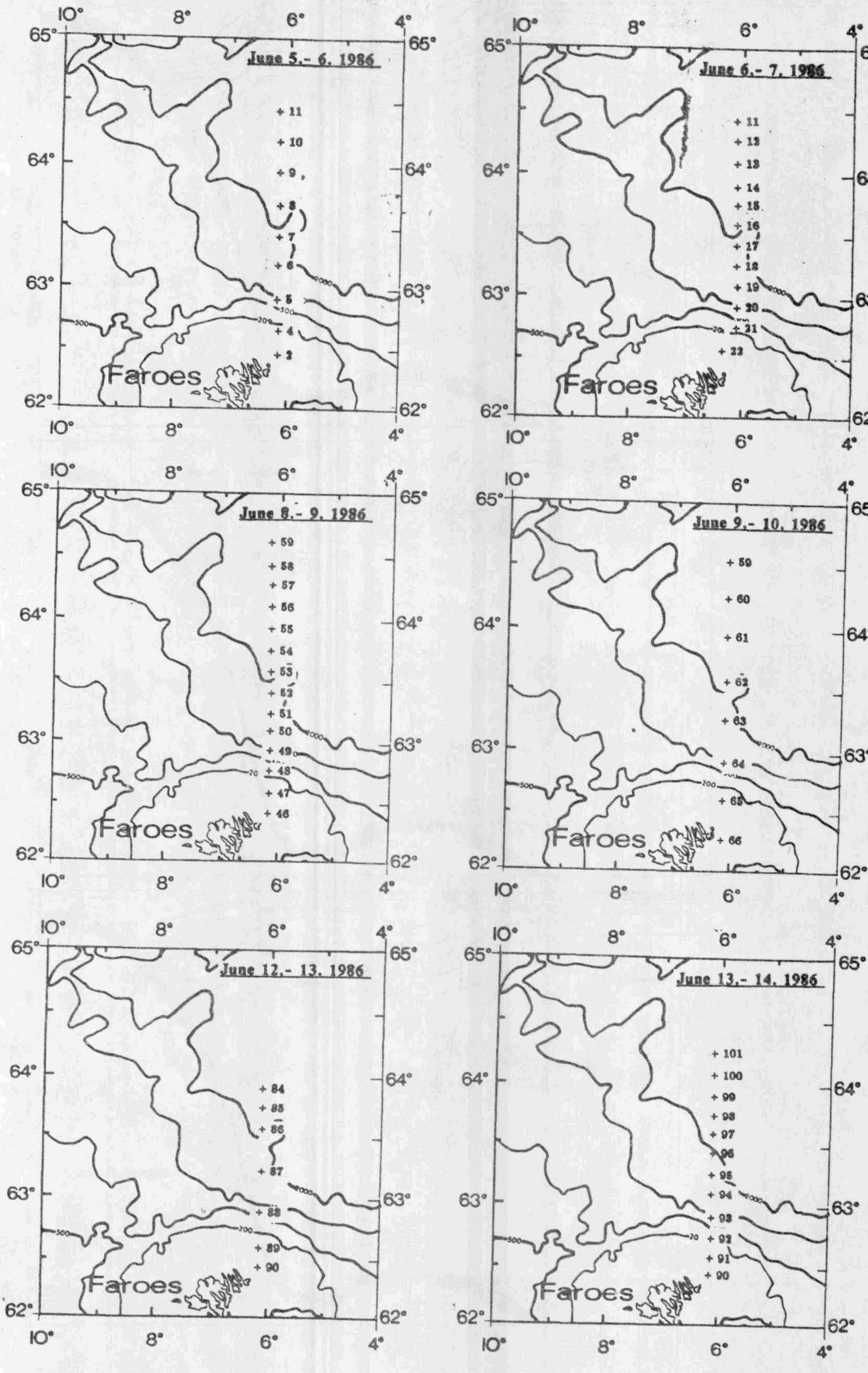

Fig.5. CTD stations made by R/V Magnus Heinason along the current meter moorings. Sections are shown in Fig.6.

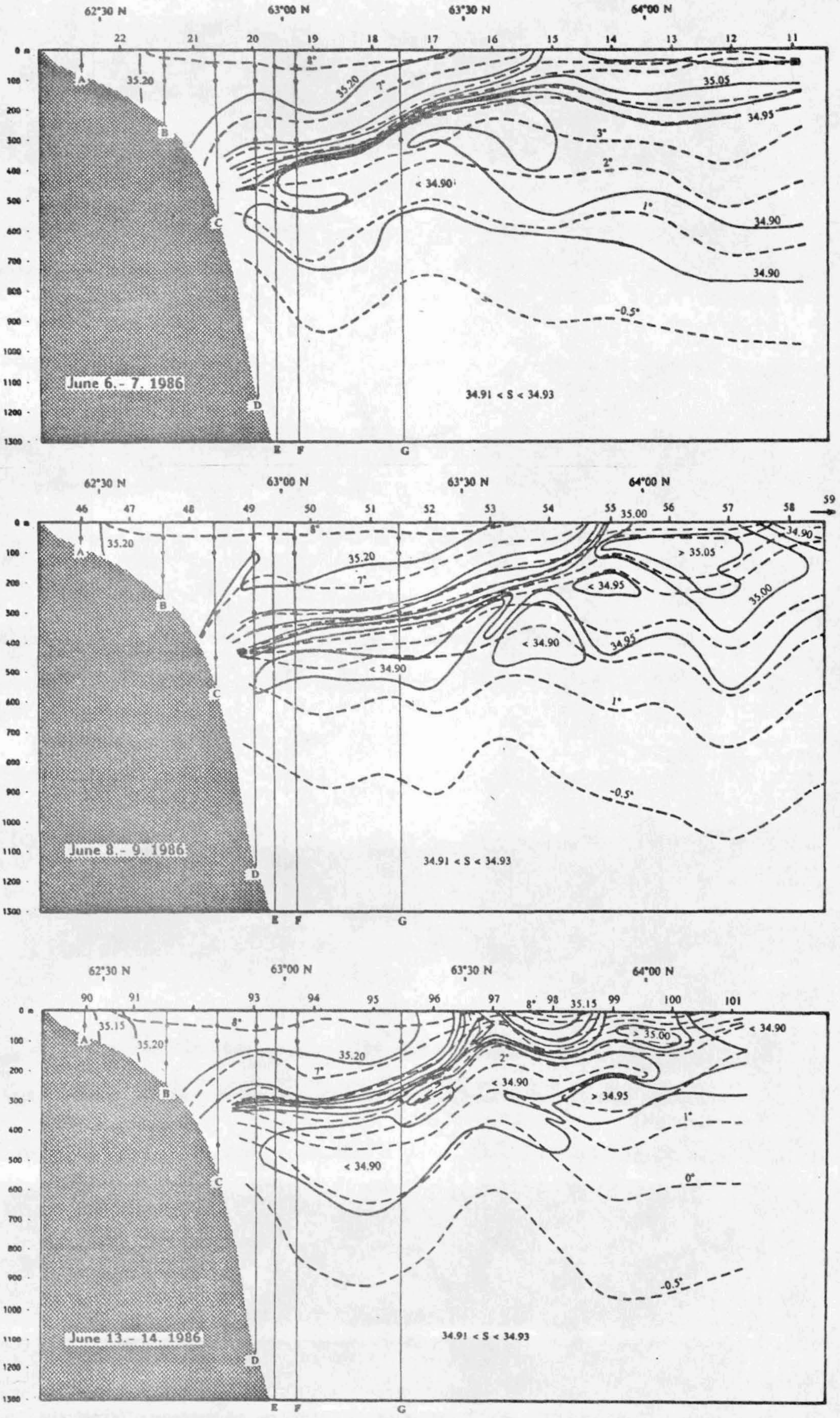

Fig.6. CTD sections made by R/V Magnus Heinason at three different times. Numbers above the sections are stationnumbers shown in Fig.5 (Preliminary data).

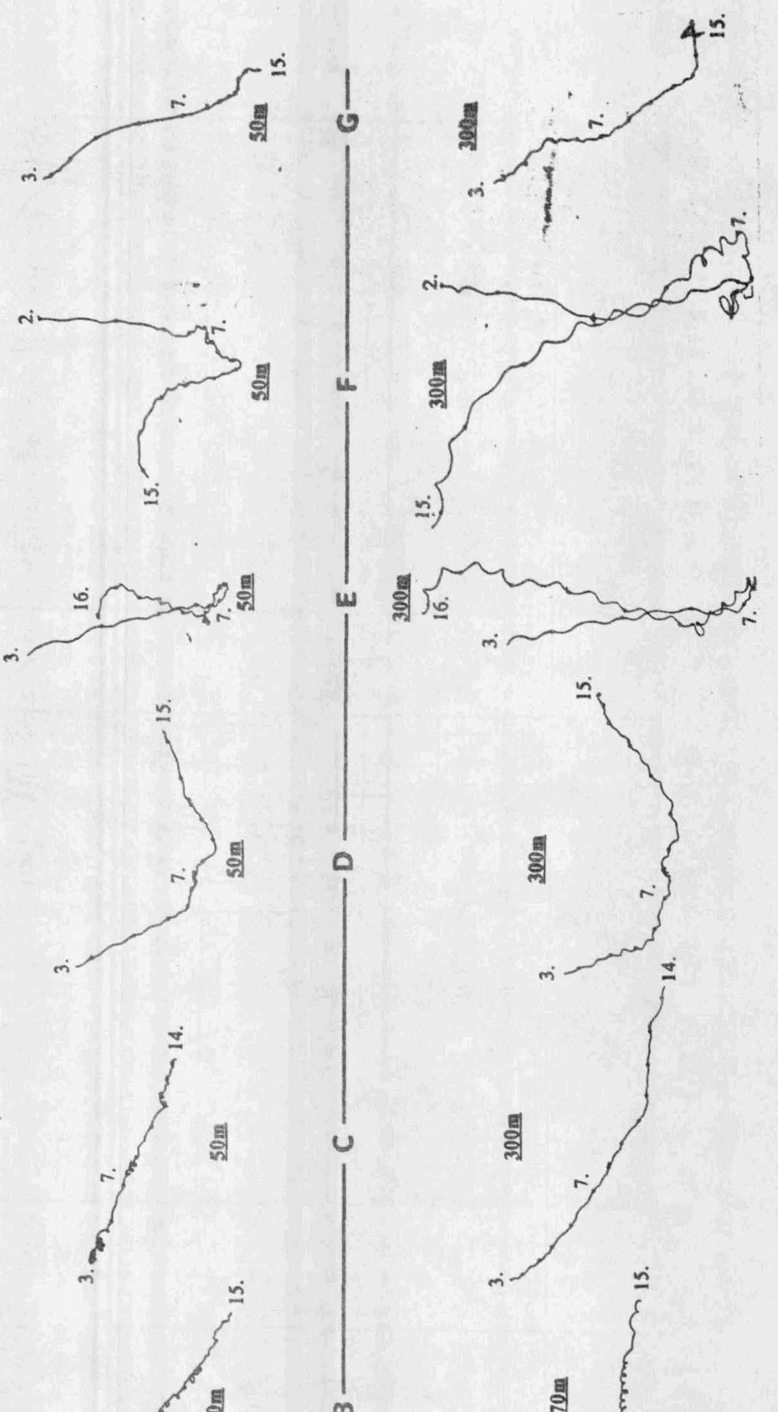

Fig.7 Progressive vector diagrams of current from the uppermost current meter and the meter at 300 m (or the deepest) for each mooring. Mooring locations are seen in Fig.3. Numbers indicate the date in June.

Discussion

The sections (Fig.4 and Fig.6) show a typical hydrographic situation consistent with available published data (Tait 1957 and Annales Biologiques from different years) with high salinity water from the Atlantic in a wedge shaped region along the Faroe slope. The water in this wedge was fairly homogeneous and bounded by a sharp frontal surface going from the Faroe slope at depths about 400m and reaching the surface between 63°30 N and 64°00 N.

Below the wedge the salinity minimum indicated water from the East Icelandic Current interleaved between the Atlantic water and the Deep Norwegians Sea Water characterized by its stable salinity values around 34.92×10^{-3}. Fairly undiluted water from the East Icelandic Current was evident in the surface in the northernmost part of some of the hydrographic sections in Fig.6 and between this water and the surface front further south the uppermost 200m showed a mixture of this water and water from the Atlantic with up to 50% of Atlantic water.

Another expected feature was the large variability both spatially and temporally. This is evident in Fig.6 and indeed makes an unambiguous representation of isolines impossible. Most important for the present discussion are the larger scale movements. Comparing Fig.7 to Figs. 4 and 6, it is seen that the flow was fairly barotropic in the upper 300m throughout the measurement period. In the beginning of the period the flow was directed towards the east or south-east past all the current meters in the southern part of the section while it was more towards the south in the northern part. Around the 7th of June this changed. The innermost and outermost moorings (A,B,C and G) continued to have the same flow, but moorings E and F experienced a reversal of the flow while the current turned 90° at mooring D. This was consistent with the hydrography as the temperature and salinity and hence also density sloped in the "opposite" direction between mooring D and F in the later part of the period. A detailed analysis is difficult from only one section, but apparently an eddy or meander (Hansen and Meincke 1979) propagated through the section. It is evident as a cold water dome north of mooring F (station 7) in Fig.4. As it decayed or moved out of the section it moved southwards so that its northern flank was between moorings D and F (Fig.6). Thus the reversal of flow in this region probably indicate only the cyclonic flow around this feature.

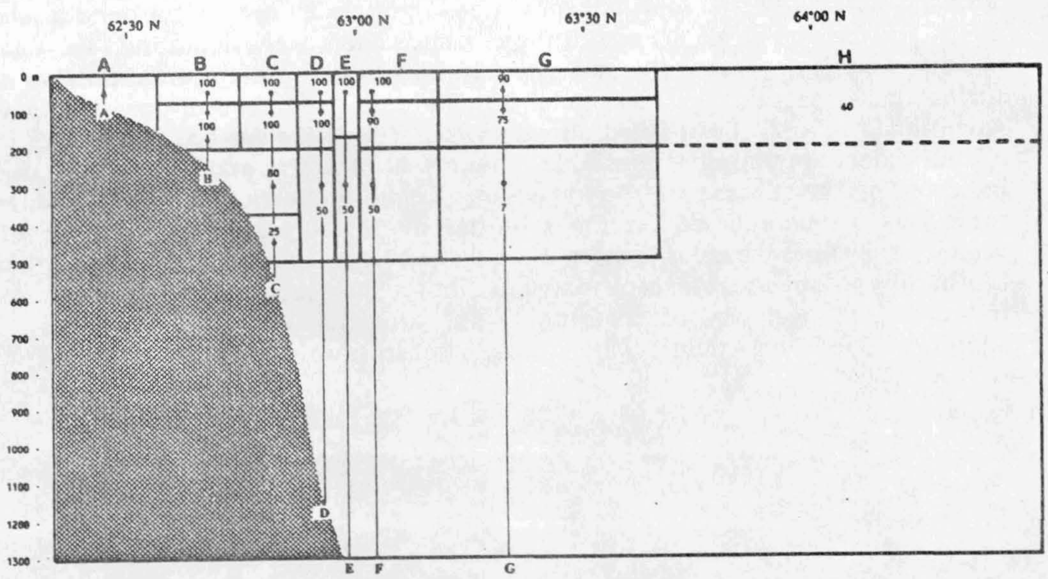

Fig.8. Subareas chosen around each current meter which were used for transport calculation. Numbers in each area represent the percentage of Atlantic water in that area during the measurement period (see text).

Using the computed 25-hour running mean flow velocities we have estimated the water transport. To this end the current meter section was divided into subareas around each instrument (Fig.8). The dividing lines between the subareas have as a rule been put midway between the meters vertically and horizontally. The northernmost subareas around mooring G are extended to 63°40 N which is considered a mean position of the surface front for the period (Fig.6). The bottom subarea was limited by the 500m depth, which is close to the sill depth of the IFR. The transport through each subarea was obtained as the product of the area and the mean flow velocity perpendicular to the section (east component).

Summing all values gave a total transport of water amounting to *4.7 Sv* (10^6 m^3/s) for the cross section from Faroes out to 63° 40 N and down to 500 meters depth.

This is however not the number we are seeking as it contains not only the Atlantic flow. The innermost subarea around mooring A contains water of mainly Atlantic origin, but most of this water is within the mixing front separating the shelf waters from the outer waters. As this water probably is recirculated on the shelf to a large degree we will not include this subarea in the transport value.

Furthermore the other subareas contain other watermasses not deriving from the Atlantic. A complete solution of this problem requires a water mass analysis beyond the scope of this preliminary report. We can get, however, a fairly good estimate of the percentage of Atlantic water by considering only the salinity. There are indeed at least three separate water masses involved, but two of these have quite similar salinities of about 34.90×10^{-3} as compared to the higher salinity of the Atlantic water. We have considered water of salinities above 35.20×10^{-3} to be 100% Atlantic water, water of salinity below 34.90×10^{-3} to have no Atlantic water and inbetween these two limits the percentage of Atlantic water was considered a linear function of salinity. With this procedure we have used the salinities of the CTD sections (Figs.4 and 6) to estimate typical percentages for each subarea. The percentages chosen, shown in Fig.8, are to some degree subjective, but in the present context good enough for a transport estimate. Multiplying the percentages by the transport through each subarea we get an estimate of the Atlantic water transport.

In Fig.9 the transport has been summed for each vertical subsection (labeled as the moorings, Fig.8) and plotted against time. The figure also shows the transport of Atlantic water through the whole section. The short-period variations in the hydrography are reflected in the transportvalues for each subsection, but as the different subsections did not vary coherently, the total transport was relatively more stable around a mean value of *2.9 Sv* for the one week, where all the current meters were operating.

This value is at present the best estimate we can give for the Atlantic flow through the current meter section. We must note, however, that this section does not include all the Atlantic flow. It has been noted already that north of the surface front there is a layer of mixed water containing appreciable amounts of Atlantic water. In Fig.8 this has been indicated by the subarea H. The value 40% for the proportion of Atlantic water again is a subjective estimate based on the salinities of Figs.4 and 6. The choice of a typical velocity for this subarea is a more difficult problem. Considering the layer as a whole it can hardly go anywhere except eastwards, but at present we can only guess at velocities. If we use the velocity of mooring G for this area also (about 10cm/s), we get an additional 0.9 Sv of Atlantic water through subsection H.

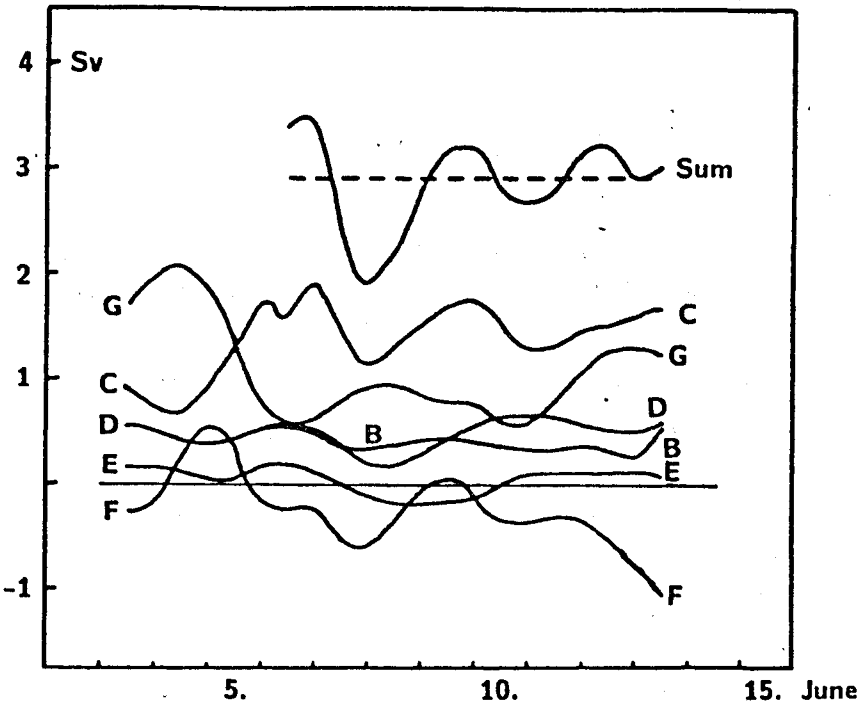

Fig.9. The transport of Atlantic water through each subsection (shown in Fig.8) during the measurement period. Sum denotes the total transport trough sections B to G (H not included) and the mean of the total is also shown by a broken line.

Conclusion

We thus find a a flow amounting to 2.9 Sv through the section covered by the current meter moorings and additionally 0.9 Sv through the remaining part of the area giving a total flow of 3.8 Sv of Atlantic water between Iceland and the Faroes. A quarter of this passes north of the current meter section and is not well documented. The remainder should be fairly reliable for the observational period. The shortness of that period, little more than one week, urges that the value found be used with the greatest caution.

There seems, however, to be no evidence that the situation was not normal and the order of magnitude of the transport found is thus in our opinion correct. We therefore feel justified in stating that:

> *The flow of Atlantic water between Iceland and the Faroes is not insignificant compared to the transport through other pathways. Rather it may be of the same order of magnitude as the flow through the Faroe Shetland Channel and the inconsistency may be resolved, which has been between measured transport of Atlantic water into the Norwegian Sea and balance estimates of this quantity. Combining our estimate for the transport between Iceland and Faroes with recent estimates of the transport between Faroes and Shetland (Gould et al. 1985) the total flow of Atlantic water appears to be sufficient to satisfy the published balance estimates (Worthington, 1970, McCartney and Talley, 1984).*

It would be of great interest to have these conclusions checked by experiments of longer duration.

Acknowledgement

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Litterature

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