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CURRENTS IN NORTHEAST HAMILTON HARBOUR

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WATER INSTITUTE
NATIONAL DE RECHERCHE SUR LES EAUX

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Management Perspective

The Remedial Actio Plan for Hamilton Harbour calls for reduced nutrient loads. The Burlington Sewage Treatment Plant will be expanding in the next 5 years; loads are projected to increase from below the initial RAP goal to slightly above it for phosphorus. Due to the proximity of the outfall to the ship canal outlet into Lake Ontario "short circuiting" of the effluent has been hypothesized in the past. To understand the impact on the harbour of the expansion more information on the transport and fate of materials in the effluent is needed.

This report provides documentation of the flows at the STP outfall and is being used help interpret sediment tracer data for identification of contaminated sediment plumes related to STP outfalls.

Now that we know where the "plume" is likely to be, given the time of year and wind direction, we can begin to sample efficiently to determine the extent of short-circuiting of material in the effluent.

COURANTS DANS LE NORD-EST DU PORT DE HAMILTON

Sommaire à l'intention de la direction

Le Plan d'assainissement du port de Hamilton vise la réduction de la charge en éléments nutritifs. La station d'épuration des eaux usées de Burlington sera agrandie au cours des cinq prochaines années; on prévoit que les charges, qui sont en deçà de l'objectif initial du PA, atteindront une valeur légèrement supérieure dans le cas du phosphore. L'exutoire de la station se trouvant à proximité de la sortie du canal de navigation dans le lac Ontario, on a déjà émis l'hypothèse d'un « court-circuitage » des effluents. Afin de comprendre les impacts de l'agrandissement de la station sur le port, il faut plus d'information sur le transport et le devenir des matières contenues dans les effluents.

Le présent rapport fournit des renseignements sur les débits de l'exutoire de la station d'épuration et permet d'interpréter les données sur le marqueur de sédiments utilisé pour l'identification des panaches de sédiments contaminés liés aux exutoires des stations d'épuration.

Maintenant que nous savons approximativement à quel endroit se trouvera le « panache », selon le moment de l'année et la direction des vents, nous pouvons commencer à prélever des échantillons afin de déterminer l'ampleur du court-circuitage des matières contenues dans les effluents.

Abstract

Dispersal patterns of contaminated sediment around the Burlington Skyway Sewage Treatment Plant (STP) in NE Hamilton Harbour outfall were obtained in 1992 and 1996 using coprostanol, a conservative, sewage-indicator sterol, as a tracer. To obtain insight into the hydrodynamic processes behind the patterns, records of local currents measured near the outfall during 1991 – 1999 were assembled. Included were two periods where the vertical flow structure was also measured and showed significant temporal and depth-related variability. Surface currents were consistently in agreement with the prevailing wind, towards the northeast. Bottom flow was more divergent, but W and SW directions dominated. Wind data from local sites were examined to assist in projecting a current climate at the site. Discrepancies in the wind data from the Royal Botanical Gardens site decrease the confidence of these projections.

Résumé

Des profils de dispersion des sédiments contaminés au voisinage de la station d'épuration Skyway Burlington, au point de déversement dans le nord-est du port de Hamilton, ont été obtenus en 1992 et 1996 à l'aide du coprostanol (stérol indicateur conservatif présent dans les eaux usées) utilisé comme marqueur. Pour obtenir un aperçu des processus hydrodynamiques sous-jacents aux profils, on a regroupé les enregistrements de courants locaux mesurés à proximité de l'exutoire, entre 1991 et 1999. Ces données comportaient aussi deux périodes pendant lesquelles on a mesuré la structure verticale de l'écoulement, qui présentait une forte variabilité en fonction du temps et de la profondeur. Les courants de surface correspondaient régulièrement au vent dominant, de direction nord-est. L'écoulement de fond était plus divergent, mais les directions ouest et sud-ouest dominaient. Nous avons analysé les données sur les vents relevées aux sites locaux pour faire des prévisions du régime des courants. Des écarts dans les données sur les vents recueillies aux Jardins botaniques royaux diminuent le niveau de confiance dans ces prévisions.

CURRENTS IN NORTHEAST HAMILTON HARBOUR

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INTRODUCTION

A sewage treatment plant (STP) operated by the Region of Halton has an outfall in the northeast corner of Hamilton Harbour, at approximately 43°18.4'N and 79°48.5'W (O1 in Figure 1). The plant discharges treated effluent, 90,000 m^3 day^{-1} (Coakley et al., 2000), including significant amounts of particle-reactive organic and inorganic contaminants transported with the sediment phase. The spatial distribution of contaminated sediment has been studied to gain insight into pathways of possible contaminants from the STP (Coakley et al. 2000). Coprostonal, which occurs naturally in sewage effluent, was used as a tracer. To obtain insight into the hydrodynamic processes behind the tracer patterns, records of local currents collected near the outfalls were assembled for four periods from 1991 to 1999. Included were two periods where the vertical structure of the flow was measured in addition to the horizontal distribution. In this report the current data are examined along with wind data from neighbouring meteorological stations in an effort to understand the long term circulation patterns in this portion of the harbour. The current data are examined first. Then, because the wind is the main driving force for the currents in the harbour, the wind data for the four deployments are related to the currents. These data sets are then compared to a 10 year wind climate. Finally, the comments on the long-term current regime and its implications for the transport of sediment are made.

CURRENT DATA

The four data sets described in this report are summarized in Table 1, and the locations are shown in Figure 1. The first two deployments were part of earlier studies of the overall harbour. The last four rows of Table 1 represent two deployments, each with pairs of meters. The Hydra meter and the ADCP were placed out as a pair. The Hydra meter, a single point acoustic Doppler current meter, measured the current at 0.6 m above the bottom, and the ADCP (acoustic Doppler current profiler) measured the average current in several depth bins from top to bottom. Because of the characteristics of the ADCP, and its deployment configuration, the lowest bin on the first deployment was centred at a depth of 6.30 m, and for the second deployment at 6.75 m. The measurement depths for the Hydra meter, as determined from the pressure gauge in the instrument, were 7.2 m for the first deployment and 8.0 m for the second. In this report, the bottom current was characterized by the data from the Hydra meter, and the surface flow was represented by the data in the top depth bin of the ADCP meter.

Table 1. Summary of current meter deployments in NE Hamilton Harbour. The time interval is the interval between current meter readings.

Station/Year/ Julian Days	Meter Type	Latitude, °N	Longitude, °W	Measurement Depth, m	Water Depth, m	Time Interval, min.
A/1991/184-295		43°18'18"	79°48'44"	5	8 (sounding)	60
B/1993/162-314		43°18'25"	79°48'44"	7.2	8.2 (sounding)	60
C1/1999/162-166	Hydra	43°18'20"	79°48'41"	7.2	7.8 (pressure)	60
C2/1999/162-166	ADCP	43°18'21"	79°48'40"	6.3 (deepest; 0.5 m bins)	7.5 (sounding)	60
D1/1999/181-258	Hydra	43°18'25"	79°48'45"	8.0	8.6 (pressure)	60
D2/1999/181-258	ADCP	43°18'21"	79°48'40"	6.75 (deepest; 1.0 m bins)	8.0 (sounding)	30

The current meters generated a vast amount of data. These data were summarized in two ways to aid interpretation. The first method of viewing the current data is to group the data in terms of direction and speed ranges and plot these in a 'rose'. For this presentation, eight directions centred on north and every 45° were used, and speed bins thresholds of 0.02 (magenta), 0.05 (cyan), 0.1 (red), 0.2 (green), ... m/s were used. In addition, values less than 0.005 m/s were considered calm, and no direction assigned to them (circle with black circumference). The length of each segment is proportional to the percentage occurrence (see scale at the bottom of each panel). The second way of visualizing the effects of the currents was to compute trajectories. In this technique, the time series of velocity at the meter is used to simulate a trajectory that a parcel of water would have if, at each time step, it had the velocity measured at the current meter. The start of the trajectory is at (0,0) and represents the current meter location. The trajectory approximates the Lagrangian displacement of a parcel of water based on the Eulerian velocity at the site of the meter. This technique helps to visualize the effect of the time sequence of the velocities.

In addition to these summary views, the 1999 data sets were examined in the frequency domain. Both short and long term spectra were examined to look for wave signatures and signatures of longer scale limnological processes. No significant information was detected, so these approaches will not be discussed further in this report.

Currents in 1999

The current roses for the surface flows, represented by the top bin of the ADCP data are shown in Figures 2 and 3 for June and July to September respectively. The character of the flow in the two time periods is different; although they both trend towards the east or northeast, the flow in June was dispersed much more. The respective trajectories are in Figures 4 and 5. In June the net movement is towards the northeast, while in July to September it is to the east-northeast, giving a somewhat different view than the roses, from which it might be concluded that the July to September flow would be more northerly than the for June period. The more convoluted nature of the trajectory for June is indicative of the important contributions from a wider range of flow directions, as also evidenced in the rose.

The roses for the Hydra meter, representing the bottom flow, for the June 1999 and July to September 1999 deployments are shown in Figures 6 and 7. Both have diffuse distributions, with most of the flow in the two quadrants north and west of a SW-NE axis. Much less flow is evident to the east, southeast and south. The corresponding trajectories are shown in Figures 8 and 9. The tortuous nature of the trajectories is an indication of the dispersed nature of the currents, however the trajectories clearly show the dominant direction of the flow in each case, approximately to the WNW, more to the north in June and more to the west in July to September.

It is readily apparent from Figures 2 to 9 that there is a marked difference between the flow at the surface and at the bottom. It is important to know what the flow structure is in between, for example, does the flow turn clockwise or counterclockwise from top to bottom. Turning clockwise would indicate more transport to southerly directions, and vice versa. Examination of the data from the ADCP depth bins reveal that the flow in fact turns counterclockwise, incrementally in each ascending depth bin. The roses and trajectories for the depths of 4.8 (June) and 4.75 (July to September) are shown in Figures 10 and 11 (These are at the same relative depth as the 1991 data and will be compared to that data later). Similarly, roses and trajectories for 6.3 and 6.75 m depth are shown in Figures 12 and 13 (to be compared later to 1993 data). All of these examples indicate considerable variability of the flow, but with a counterclockwise turning of the flow from top to bottom, suggesting more transport north and west in the interior of the flow.

Currents in 1991 and 1993

The only other current data available for sites near the outfalls are two data sets, one gathered in 1991 and one in 1993. Both the 1991 and 1993 data sets give information at one depth in contrast to the full vertical structure revealed in 1999. The roses for these are shown in Figures 14 and 15 and the corresponding trajectories in Figures 16 and 17. The flow in 1991 appears to be much more variable than the flow at the corresponding depth in 1999 (Figures 10 and 11), although the main direction is generally to the northwest, which is similar to 1999. In 1993, the flow is dominantly to the west and northwest in contrast to 1999 (Figure 13) when the flow was much more varied.

Current Summary

The impression of the flow at the outfalls is a complicated one. Clearly, the flow, as revealed by the 1999 current meter data, cannot be regarded as vertically homogeneous. The surface flows were towards the east and northeast (Figures 4 and 5); the bottom flows were more varied, but the dominant or net flows were westerly and northwesterly (Figures 8 and 9). Flows at intermediate depths were to the west and north of these two directions, exemplified by the mean interior flows in Figures 18 and 19, and the roses at specific depths in Figures 10 to 13. While the above mentioned flow directions dominated, there were, nevertheless, flows in all directions as the roses and the tortuous nature of the trajectories indicates. The flows in 1991 and 1993 both showed similar characteristics to the flow in 1999 at the corresponding depths. They all had wide spread direction contributions. The dominant directions were approximately the same, although the June 1999 direction appears slightly more northerly.

It is of interest to examine the length scales of the trajectories. In Figure 5, for example, it is computed that a surface particle would travel over 100 km to the east-northeast during the July to September deployment. The shoreline in that direction is only about 400 m away. At the bottom, during the same period, the trajectory extends about 40 km to the west-northwest (Figure 9), and the shoreline is about 1300 m away. Clearly, these trajectories are not realized, but they serve to indicate the persistence of the flow. They also demonstrate that there is potential for circulation that is of the scale of the harbour (of the order of ten kilometres) within a few weeks. Another characteristic of the flow is the significant variation in direction with depth, which will result in high shears and enhanced mixing of the water. The major surface trajectory direction is toward the east and northeast, and given the orientation (southeast) of the nearshore bathymetry and shoreline on which it impinges, most of this flow would be deflected along the shore toward the southeast. Likewise, the mid-depth and bottom other trajectories would be deflected by the north shore bathymetry and shoreline orientation toward the west and southwest.

WIND DATA

There are three meteorological stations near the study site: Burlington Pier (AES and NWRI - both on the lake side of the bridges), Hamilton Airport, and the Royal Botanical Gardens (RBG), in Burlington. None of the sites is ideal for this study. The Burlington Pier site is closest, but only the winds from the north through the east to the southeast are unobstructed by the bridges. Hamilton Airport is farthest from the site and, in recent years, data are not available through the night. This leaves the RBG site. It is intermediate in distance and has some (anecdotal) evidence that the site has some obstructions, which may affect the quality of the wind data. Nevertheless data from the RBG were available for all of the deployments, and in addition, a long enough record is available to develop a reasonable wind climate database. Thus, the RBG data were used throughout this study. In this study, the wind directions are reported as **direction to**, rather than the normal meteorological convention of direction from, so that they conform to the convention used for the currents.

Winds during Deployments

The winds for the two 1999 deployments are summarized in the wind rose plots, Figures 20 and 21. During these periods, the winds were mostly to the east and southeast. The dominant direction was 45 to 90° clockwise to the dominant surface currents at the same times.

The winds for 1991 and 1993 are shown in Figures 22 and 23. The dominant direction was to the northeast, and significant wind to the east, southeast and southwest. By comparison to the 1999 data, these winds were 45 to 90° counterclockwise.

The summaries of the winds for 1999 are distinctly different from the two for 1991 and 1993, the latter being quite similar to each other. It turns out that the RBG anemometer instrument and site were both changed sometime after the end of 1996. Up until that time the site was on a mast on top of the headquarters building, above the tree canopy (See Figure 24a). Sometime after 1996 the site was moved to a south-facing slope of a hill at the Arboretum, about two kilometres to the west. The anemometer is on a mast, estimated to be about 10 m high. There are trees within a few tens of metres to the south and southwest that appear to be higher than the anemometer. To the north, within about 100 m there is a long building of two or three stories. In short, the new site is unsuitable for estimating wind conditions in the harbour or for anywhere, except at the site of the anemometer (See Figure 24b).

Wind Climate

Data from the RBG station were summarized to produce a wind climate from 1986 to 1995. The wind rose is shown in Figure 25. The dominant direction was to the northeast, followed by the southwest. There were also significant numbers of occurrences to the southeast and east. The wind roses for the 1991 and 1993 deployments have similar shapes to the ten-year climate rose. On this criterion, the winds in the deployments in 1991 and 1993 may be considered typical of the wind climate. In contrast, the winds in 1999 (Figures 20 and 21) were not as representative of the long term winds. In 1999, the dominant winds were to the southeast and east in contrast to the northeast and east. Furthermore, there was no secondary peak on either 1999 rose, while the ten-year climate and 1991 and 1993 records have a significant one to the southwest.

The variability of the wind climate from year to year was investigated by plotting the wind rose for each year, 1986 to 1999. Each year from 1986 to 1995 had the dominant direction to the northeast, and the next most important direction to the southwest. Most also had significant winds to the southeast and to the east. That is, the roses all were similar to the long-term rose, Figure 25. The roses for 1998 and 1999 (Figure 26) were quite different, but consistent with each other, and with the roses for the 1999 deployment periods (Figures 20 and 21). Firstly, there were many more 'calms'. Secondly, the dominant direction was to the southeast, with a second peak to the west. The change in the character of the wind summaries in 1998 and 1999 ties in well with the fact that the anemometer site had been changed.

The wind data from the Hamilton Airport and the Burlington Pier sites for the 1999 deployments were examined. Their summaries were similar to the 1986-1995 wind rose for the RBG. This is taken as providing additional evidence that the wind climate did not change in 1999, but rather the anemometer site change caused the change in the data characteristics.

CURRENT CLIMATE

The current data in 1999 and that from 1991 and 1993 are all consistent. That impression of the flow indicates the surface flow is dominantly to the northeast, flow at intermediate depths are more disperse,

and turned more and more counterclockwise with increasing depth. The bottom flow is also more disperse than the surface flow, and it is mainly to the west-northwest.

The winds are the main driving force for the currents, so that they can be used to project at least qualitatively a picture of the current climate. Unfortunately, the wind summary for 1999 (and 1998), when the best current data were measured, is distorted compared to the long-term average, as noted above. However, it is probably reasonable to assume the wind climate hasn't changed given that the variation in the summaries is quite small prior to the year the anemometer site was changed. On that assumption, the current summaries from 1999 provide a reasonable picture of the long-term current patterns at the outfall site.

REFERENCES

Coakley, J P, Skafel, M G, Marvin, C H, and Bachtiar, T 2000 Transport of sewage-contaminated sediment in northeastern Hamilton Harbour. J Great Lakes Res, submitted.

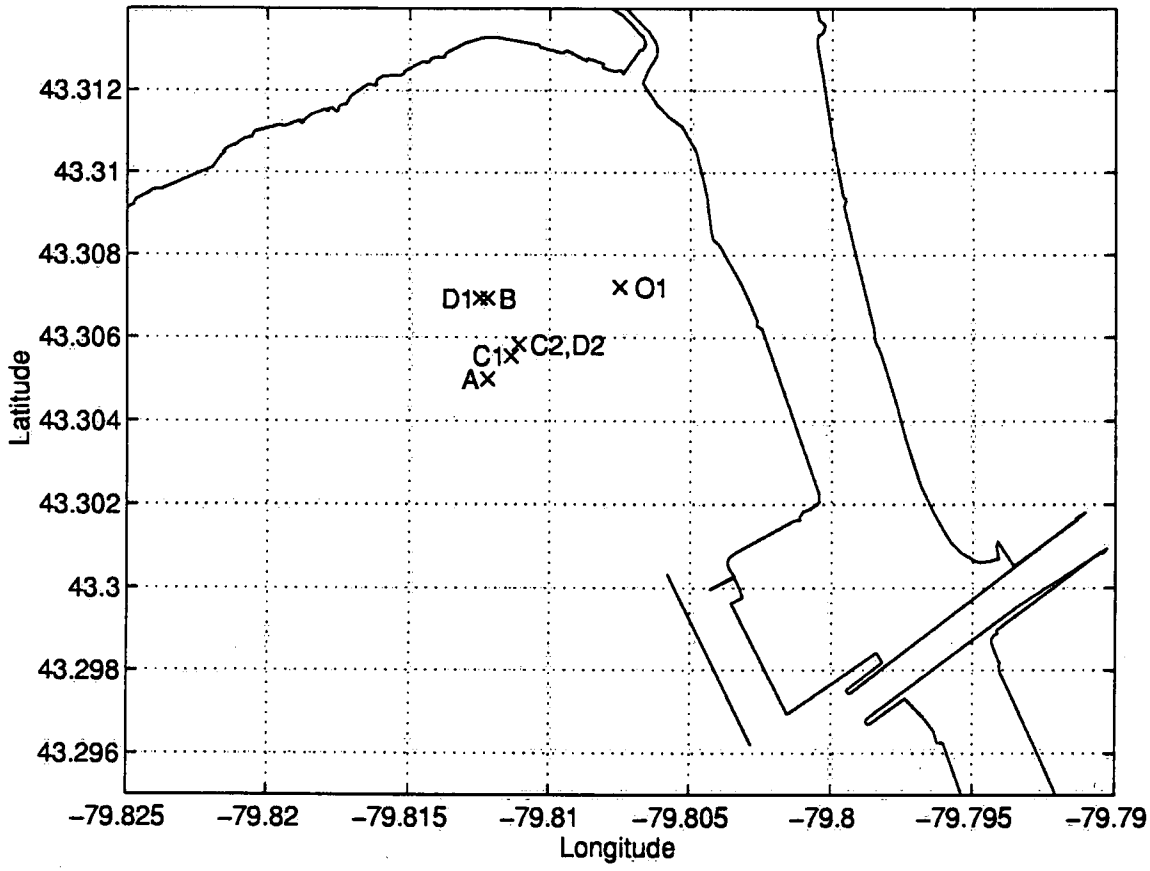

Figure 1. Locations of current meters: letters correspond to the letters in the first column of Table 1. O1 marks the locations of the STP outfall.

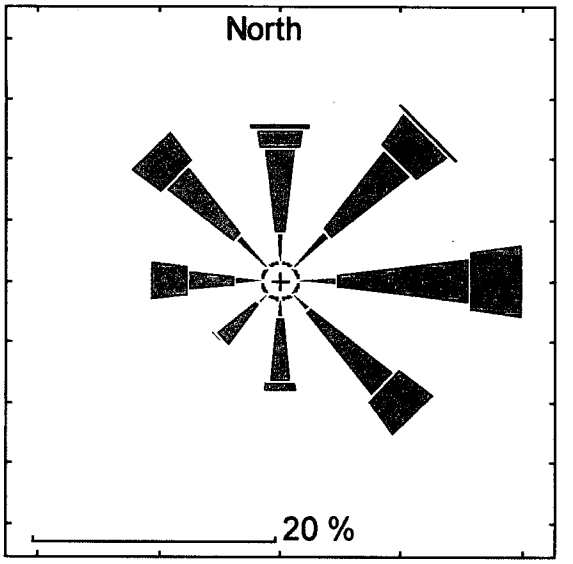

Figure 2. Rose for the surface current during the June 1999 deployment. The circle are calms (<=0.005), the radial bins are 0.02, 0.05, 0.10, 0.20,... m/s.

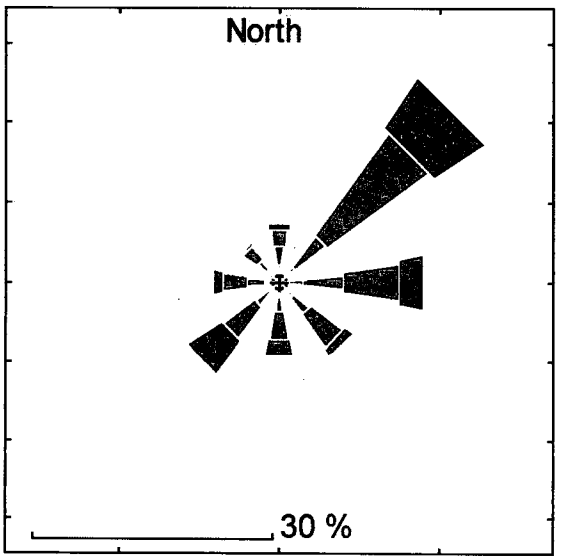

Figure 3. Rose for the surface current during the July to September 1999 deployment. The circle are calms (<=0.005), the radial bins are 0.02, 0.05, 0.10, 0.20,... m/s.

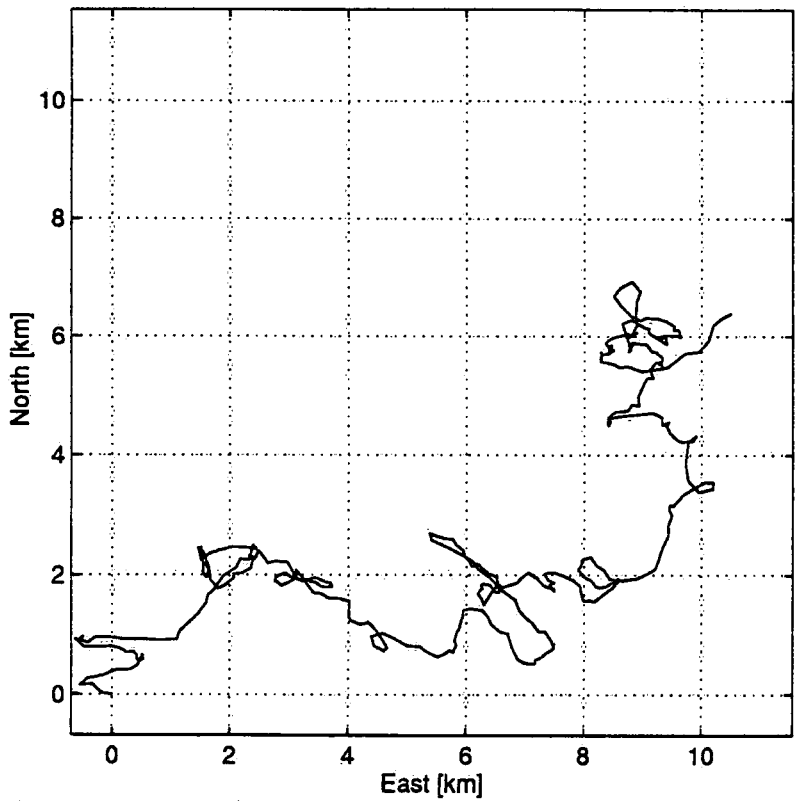

Figure 4. Trajectory for the surface current during the June 1999 deployment.

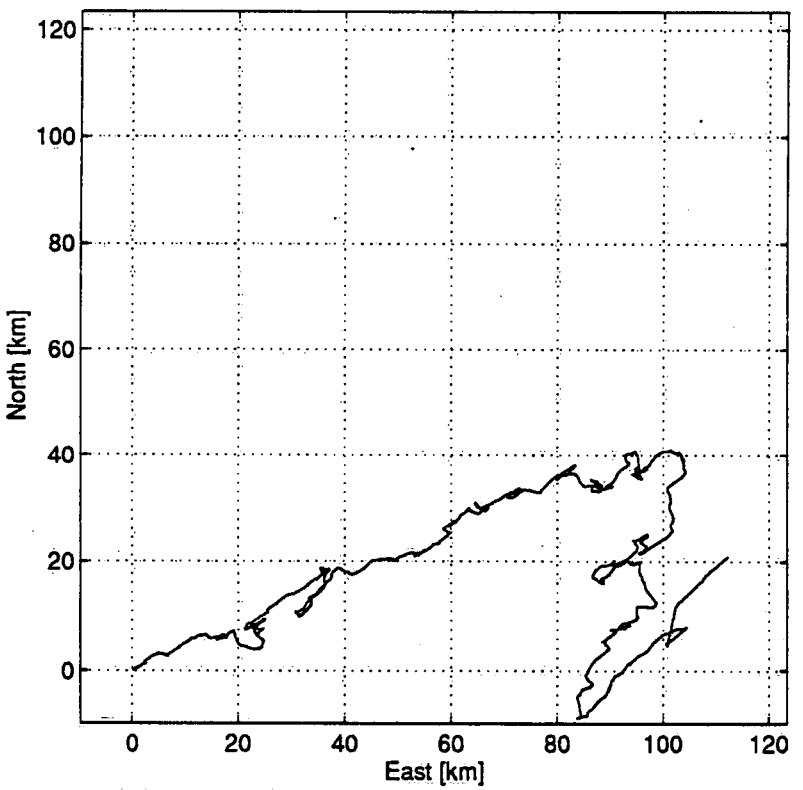

Figure 5. Trajectory for the surface current during the July to September 1999 deployment.

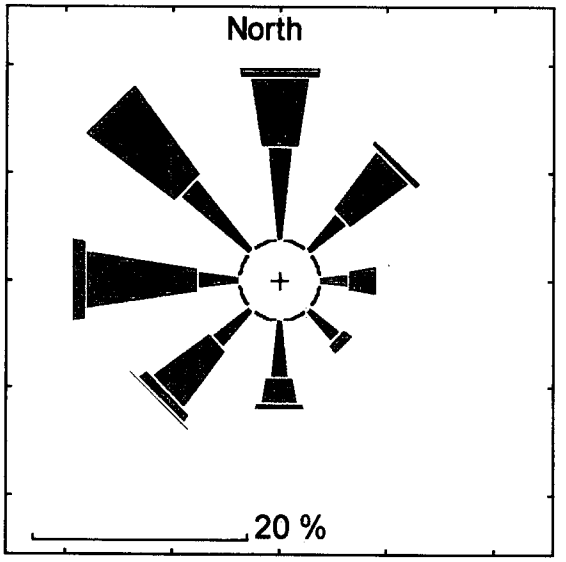

Figure 6. Rose for the bottom current during the June 1999 deployment. The circle are calms (<=0.005), the radial bins are 0.02, 0.05, 0.10, 0.20,... m/s.

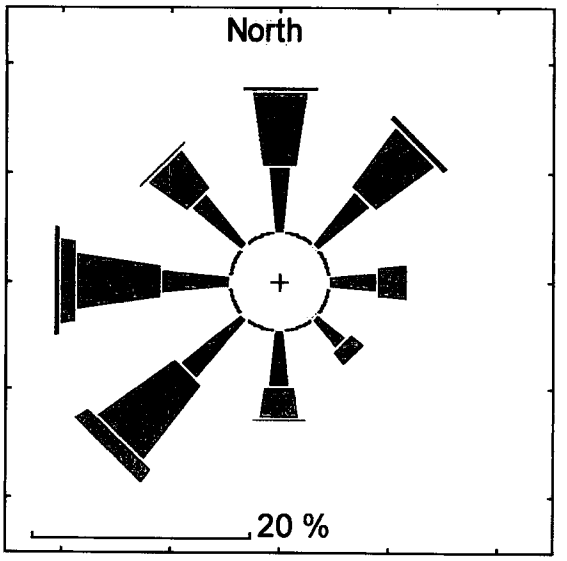

Figure 7. Rose for the bottom current during the July to September 1999 deployment. The circle are calms (<=0.005), the radial bins are 0.02, 0.05, 0.10, 0.20,... m/s.

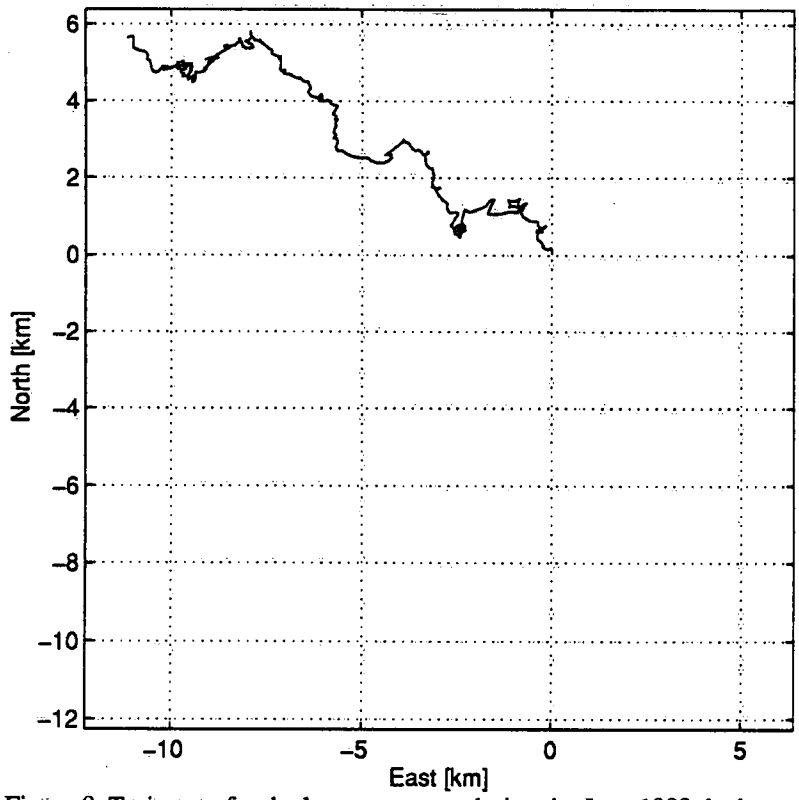

Figure 8. Trajectory for the bottom current during the June 1999 deployment.

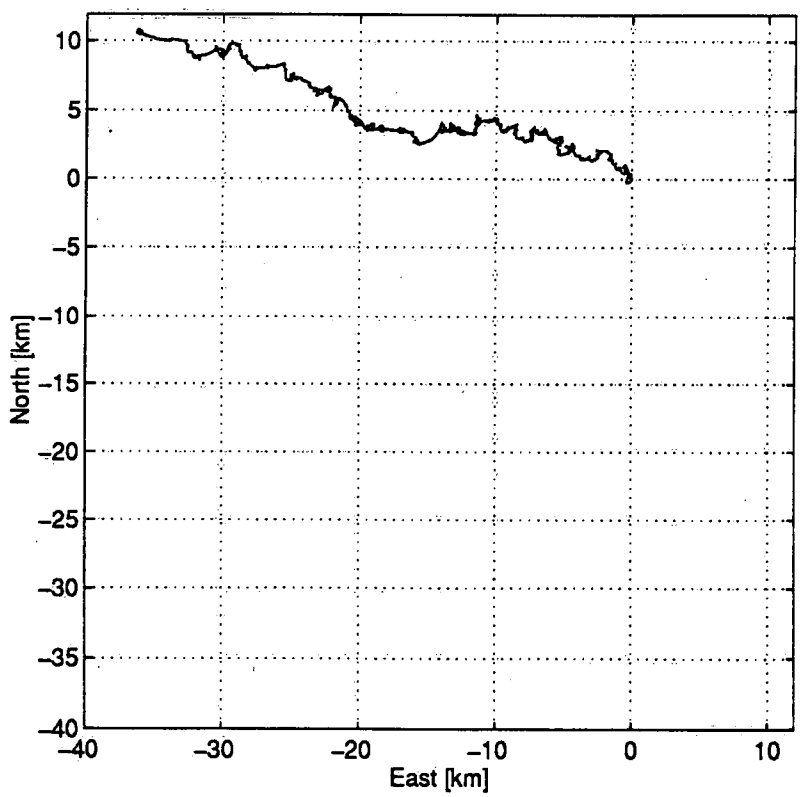

Figure 9. Trajectory for the bottom current during the July to September 1999 deployment.

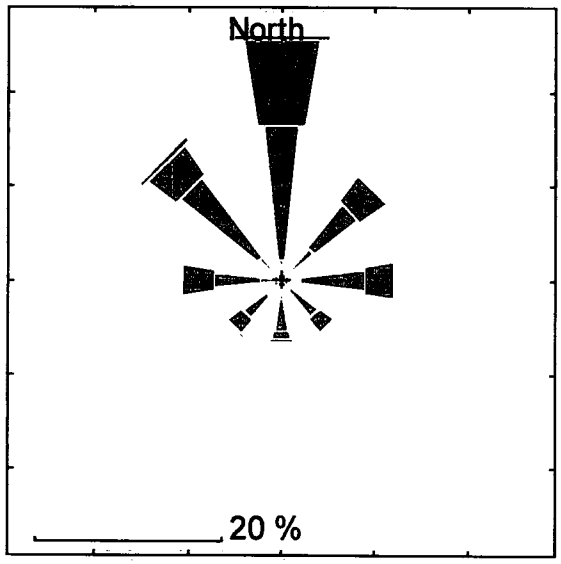

Figure 10a. Rose for the current at 4.8 m depth during the June 1999 deployment. The circle are calms (<=0.005), the radial bins are 0.02, 0.05, 0.10, 0.20,... m/s.

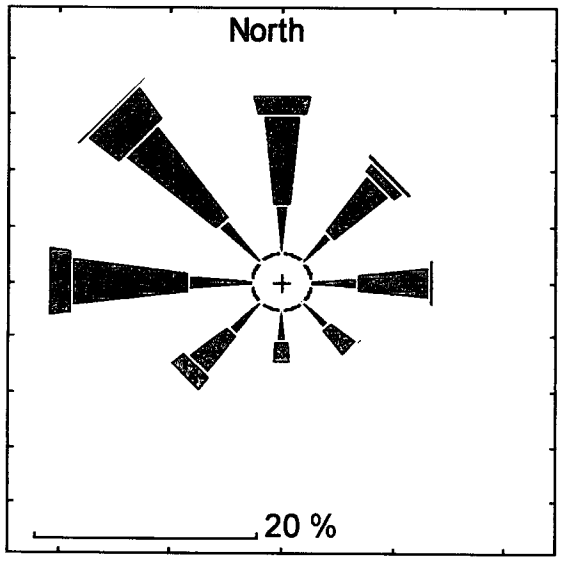

Figure 10b. Rose for the current at 4.75 m depth during the July to September 1999 deployment. The circle are calms (<=0.005), the radial bins are 0.02, 0.05, 0.10, 0.20,... m/s.

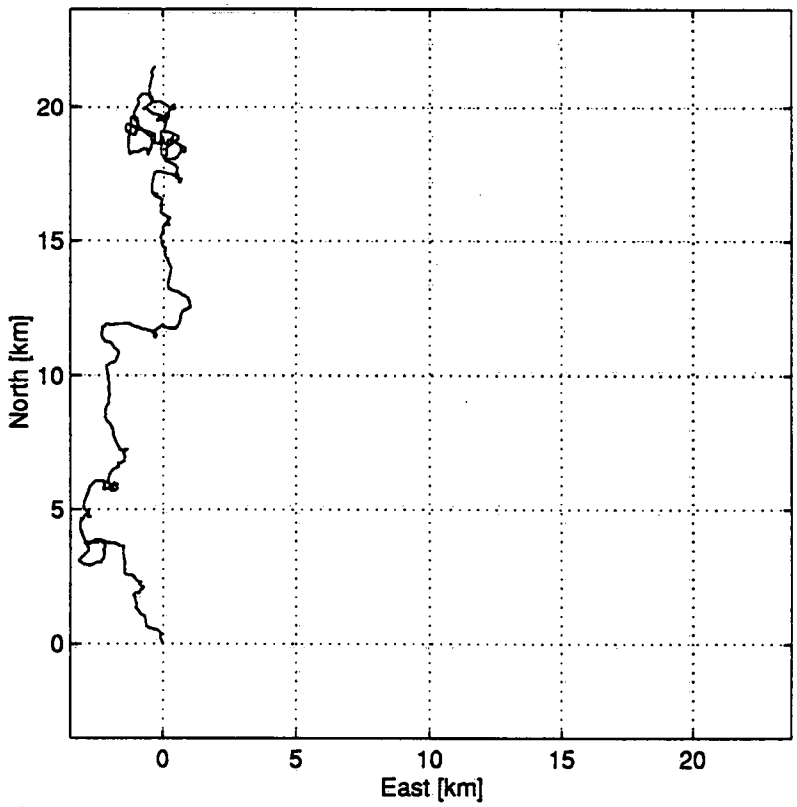

Figure 11a. Trajectory for the current at 4.8 m depth during the June 1999 deployment.

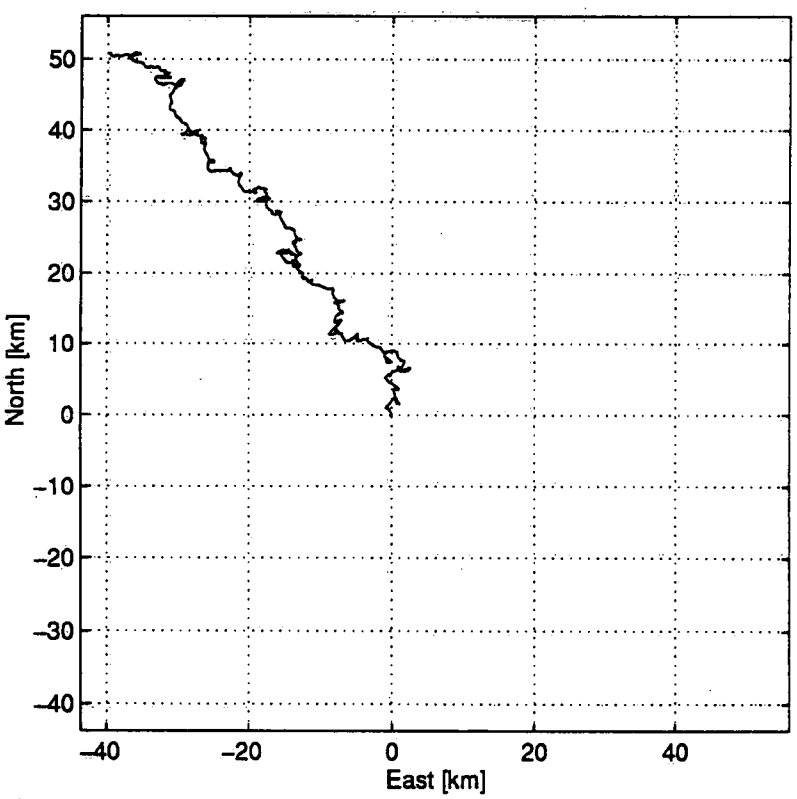

Figure 11b. Trajectory for the current at 4.75 m depth during the July to September 1999 deployment.

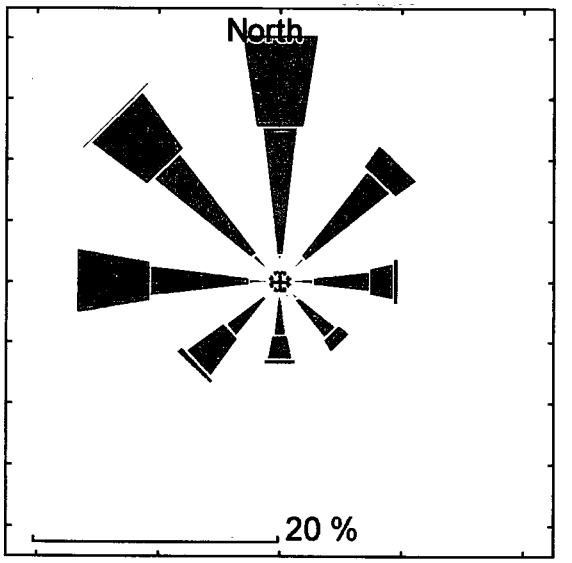

Figure 12a. Rose for the current at 6.3 m depth during the June 1999 deployment. The circle are calms (<=0.005), the radial bins are 0.02, 0.05, 0.10, 0.20,... m/s.

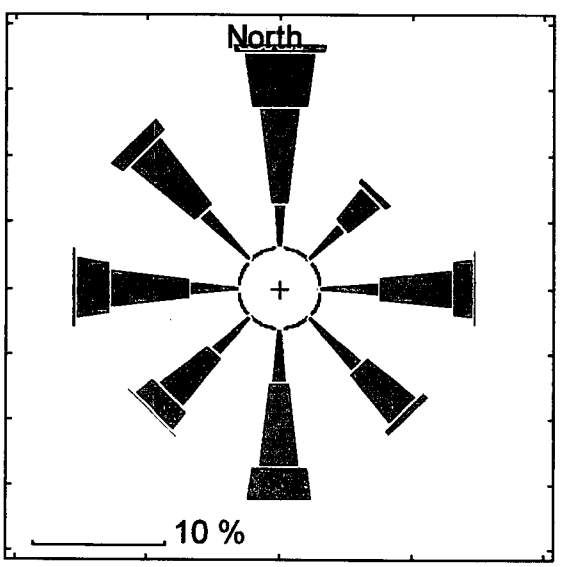

Figure 12b. Rose for the current at 6.75 m depth during the July to September 1999 deployment. The circle are calms (<=0.005), the radial bins are 0.02, 0.05, 0.10, 0.20,... m/s.

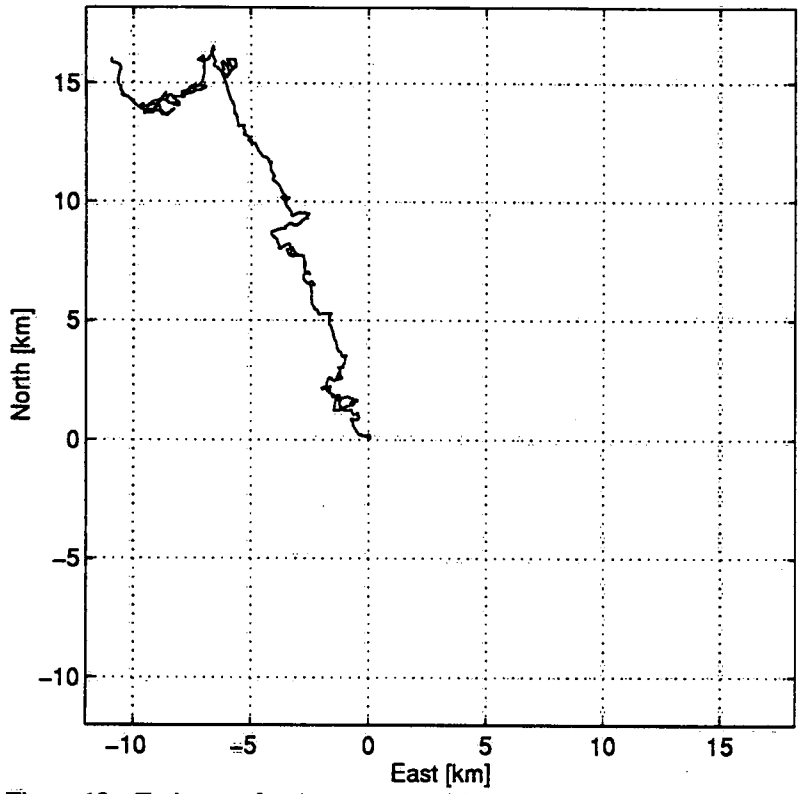

Figure 13a. Trajectory for the current at 6.3 m depth during the June 1999 deployment.

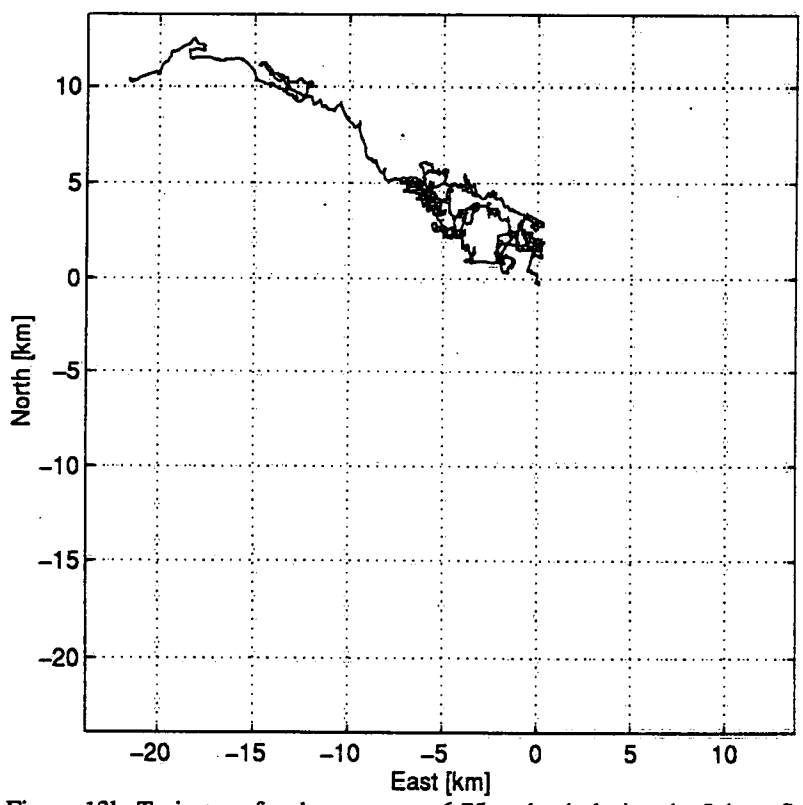

Figure 13b. Trajectory for the current at 6.75 m depth during the July to September 1999 deployment.

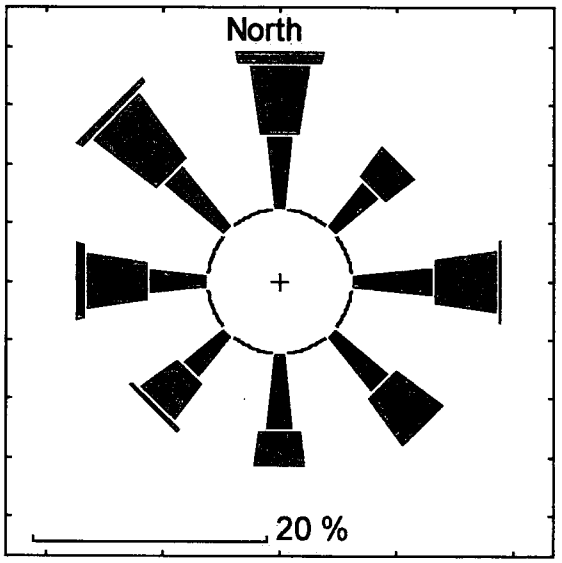

Figure 14. Rose for the current at 5 m depth during the 1991 deployment. The circle are calms (<=0.005), the radial bins are 0.02, 0.05, 0.10, 0.20,... m/s.

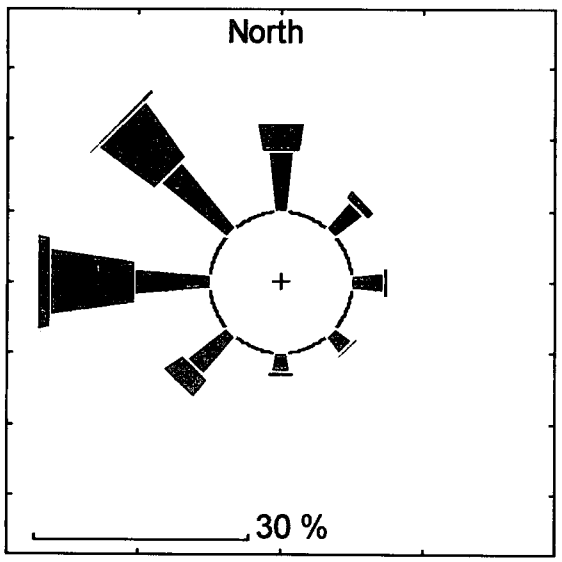

Figure 15. Rose for the current at 7.2 m depth during the 1993 deployment. The circle are calms (<=0.005), the radial bins are 0.02, 0.05, 0.10, 0.20,... m/s.

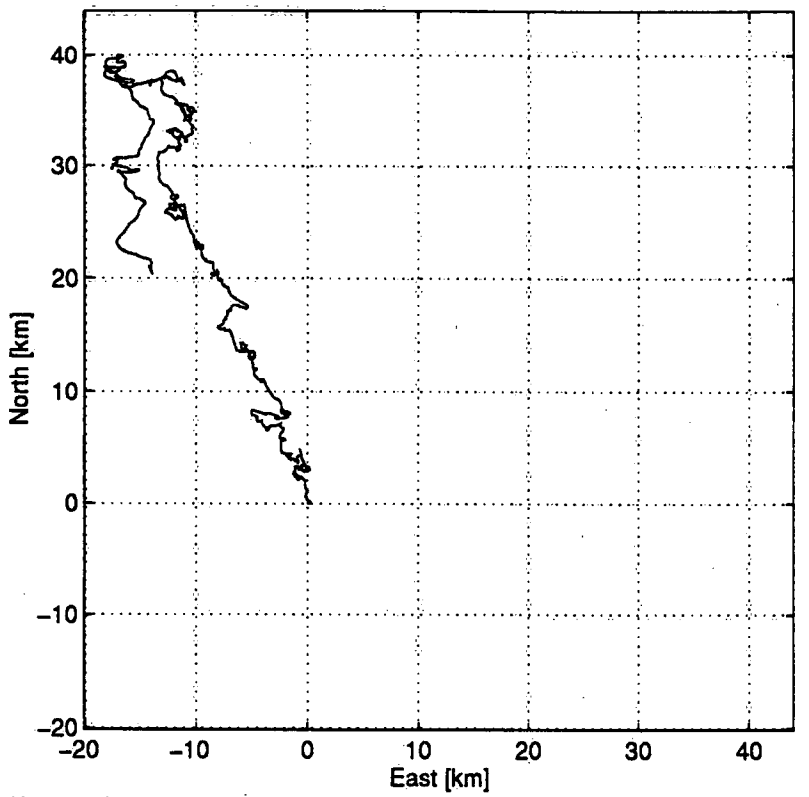

Figure 16. Trajectory for the current at 5 m depth during the 1991 deployment.

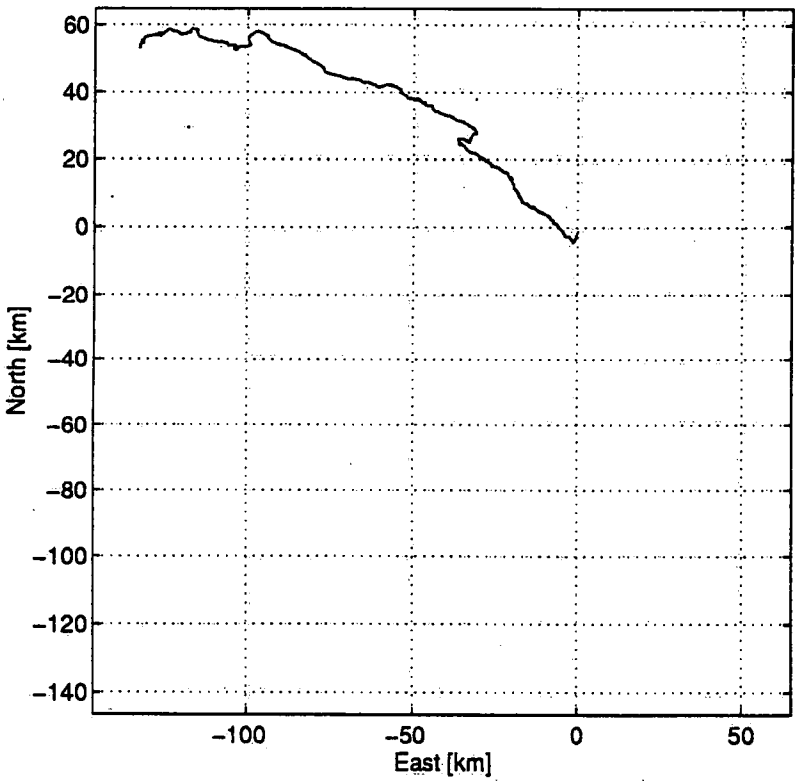

Figure 17. Trajectory for the current at 7.2 m depth during the 1991 deployment.

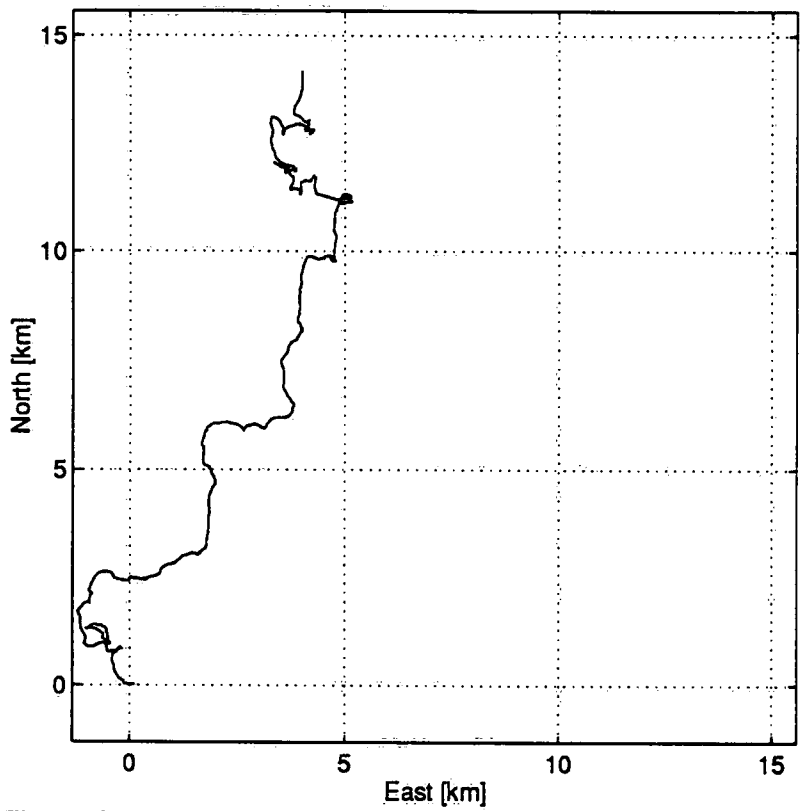

Figure 18. Trajectory for the average current (1.3 to 6.3 m depth) during the June 1999 deployment.

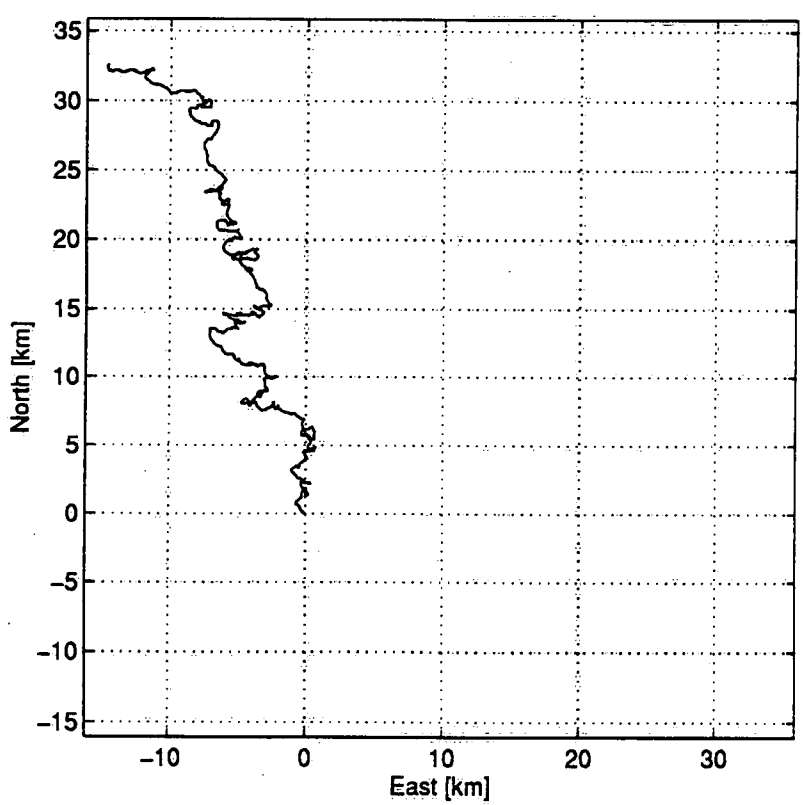

Figure 19. Trajectory for the average current (1.75 to 6.75 m depth) during the July to September 1999 deployment.

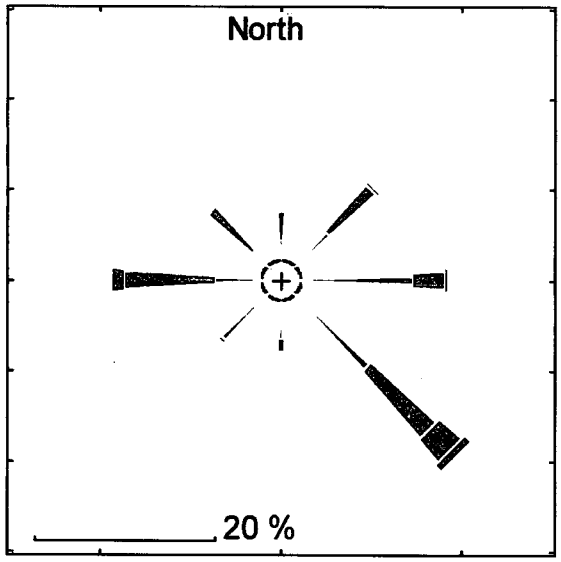

Figure 20. Rose for the RBG winds for the June 1999 deployment. The circle are calms (<=1), the radial bins are 5, 10, 15, 20,... km/hr.

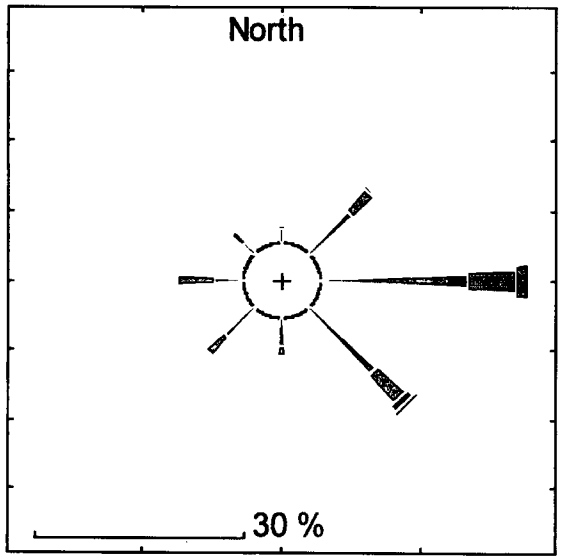

Figure 21. Rose for the RBG winds for the July to September 1999 deployment. The circle are calms (<=1), the radial bins are 5, 10, 15, 20,... km/hr.

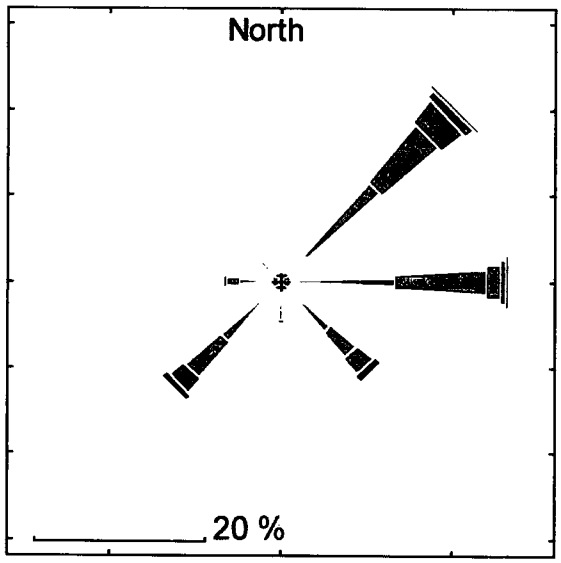

Figure 22. Rose for the RBG winds for the 1991 deployment. The circle are calms (<=1), the radial bins are 5, 10, 15, 20,... km/hr.

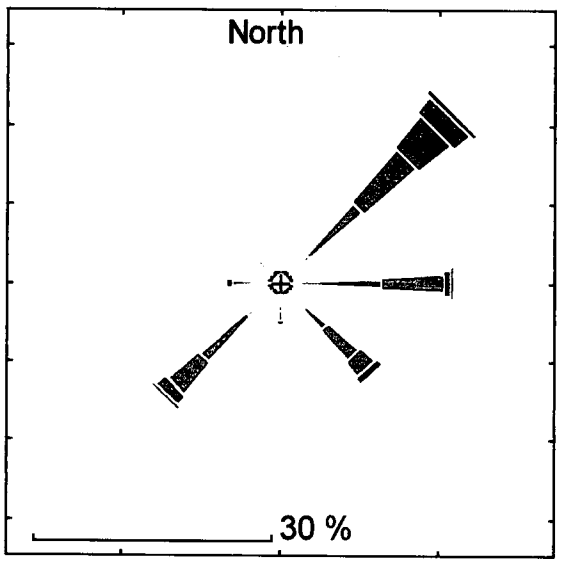

Figure 23. Rose for the RBG winds for the 1993 deployment. The circle are calms (<=1), the radial bins are 5, 10, 15, 20,... km/hr.

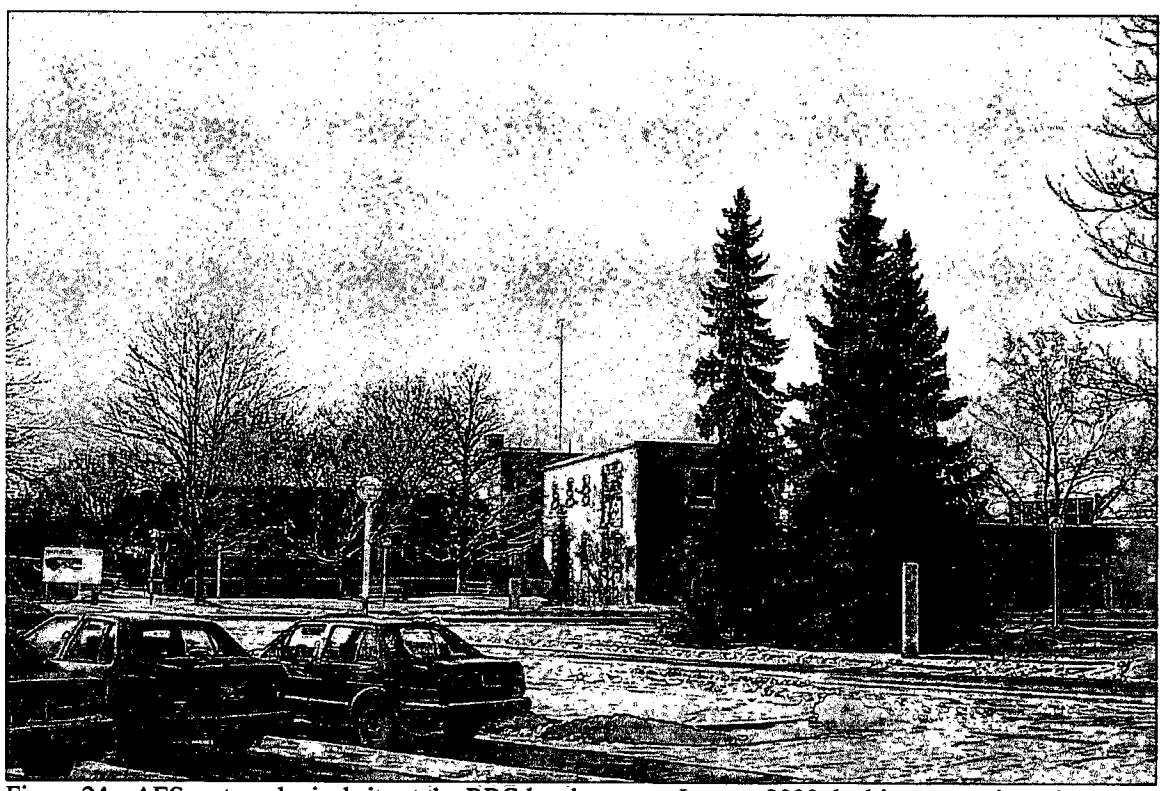

Figure 24a. AES meteorological site at the RBG headquarters, January 2000, looking approximately W. The anemometer mast is on the roof of the main building, in the centre of the photo. (Photo: M G Skafel)

Figure 24b. AES meteorological site at the RBG arboretum, January 2000, looking approximately NNW. The anemometer mast is in the fenced area, left of centre in the photo. (Photo: M G Skafel)

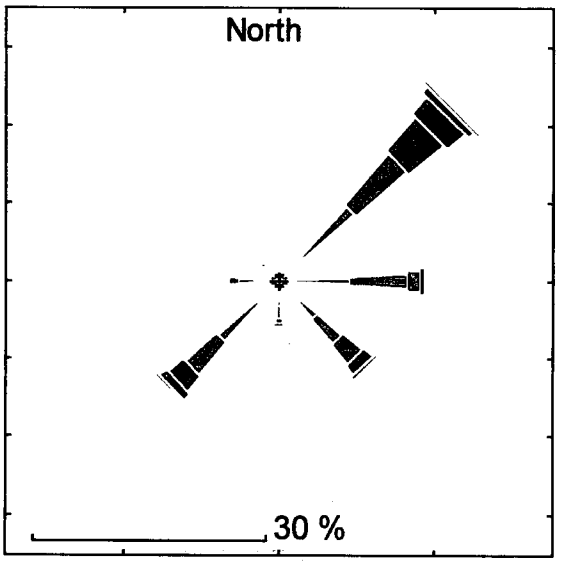

Figure 25. Rose for the RBG winds for 1986 to 1995. The circle are calms (<=1), the radial bins are 5, 10, 15, 20,... km/hr.

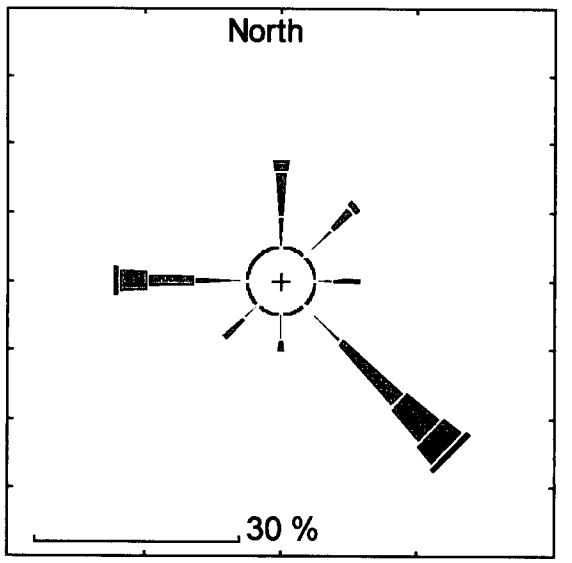

Figure 26a. Rose for the RBG winds for 1998. The circle are calms (<=1), the radial bins are 5, 10, 15, 20,... km/hr.

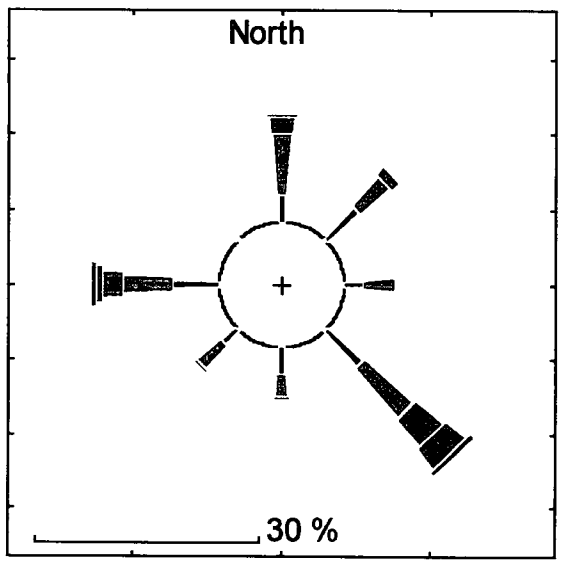

Figure 26b. Rose for the RBG winds for 1999. The circle are calms (<=1), the radial bins are 5, 10, 15, 20,... km/hr.

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