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Currents In Hamilton Harbour, April - May 1999

BY:

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CURRENTS IN HAMILTON HARBOUR, APRIL-MAY 1999

M G Skafel, AERB

ABSTRACT

The currents in Hamilton Harbour were measured with an ADCP from a vessel which cruised over a large portion of the harbour on 14 April 1999. The vertical structure of the flow was revealed using one metre high averaging bins for the data. Surface flow generally followed the wind directions prevalent on the day; while a significant return flow was observed in the deep central area of the harbour. A fixed current meter was also deployed near Randle Reef for five weeks. The flow at this meter was general small, but persistently in the opposite direction to the winds, suggesting that there was a return flow opposite in direction to a surface flow. There was evidence of wave action caused by waves propagating into the harbour from Lake Ontario, but of very small magnitude.

RÉSUMÉ

Les courants du port de Hamilton ont été mesurés au moyen d'un ADCP (profileur de courant à effet Doppler) installé à bord d'un navire qui a parcouru une grande partie du port, le 14 avril 1999. La structure verticale de l'écoulement a été établie à l'aide de fenêtres de moyennage des données d'environ un mètre de hauteur. L'écoulement de surface suivait généralement la direction des vents dominants ce jour-là; tandis qu'un important écoulement de retour a été observé dans la partie centrale profonde du port. Pendant cinq semaines, un courantomètre fixe a aussi été mouillé près du récif Randle. L'écoulement à cet endroit était généralement faible, mais se dirigeait de façon persistante dans la direction opposée aux vents, ce qui évoque la présence d'un écoulement de retour dont la direction est opposée à celle de l'écoulement de surface. On a abservé un mouvement dû aux vagues se propageant dans le port à partir du lac Ontario, mais que ce mouvement était de très faible amplitude.

CURRENTS IN HAMILTON HARBOUR, APRIL-MAY 1999

Management Perspective

The Remedial Action Plan for Hamilton Harbour calls for reduced nutrient loads and removal of some contaminated sediments. Good documentation of the processes responsible for the transport and fate of contaminants aids the management decision process.

A synoptic view of harbour currents, coupled with an extended times series of currents at one location has provided valuable insight into transport mechanisms throughout the harbour and in more detail in the vicinity of Randle Reef.

Additional measurements are planned for 2000.

COURANTS DANS LE PORT DE HAMILTON, AVRIL-MAI 1999

Sommaire à l'intention de la direction

Le Plan d'assainissement du port de Hamilton exige la réduction des apports en substances nutritives et l'extraction de certains sédiments contaminés. Une bonne documentation des processus responsables du transport et du devenir des contaminants facilite le processus de prise de décision quant à leur gestion.

Un aperçu synoptique des courants du port, joint à une longue série chronologique des courants à un endroit, ont été très précieux pour comprendre de l'intérieur les mécanismes de transport de ces substances dans tout le port et plus précisément aux alentours du récif Randle.

On prévoit effectuer des mesures supplémentaires en 2000.

CURRENTS IN HAMILTON HARBOUR, APRIL-MAY 1999

M G Skafel, AERB

INTRODUCTION

A joint study with C H Marvin (AERB) and E T Howell (MOEE) was undertaken to develop methodology to resolve trends in water quality in areas of spatial and temporal variability; to determine current status of contaminant levels in Hamilton Harbour surface water; to develop tools to predict trajectories of water masses which influence contaminant dispersion (Marvin et al. 2000). To that end a launch was outfitted with a suite of instruments: chlorophyll fluorimeter; hydrocarbon fluorimeter; transmissometer; conductivity/temperature probe; acoustic Doppler current profiler (ADCP). All devices produced real-time data, which, when calibrated, gave real-time concentration levels of a number of contaminants, and vertical profiles of the flow, all along a comprehensive cruise pattern in Hamilton Harbour on 14 April 1999. All data were geo-referenced using an on-board differential global positioning system (DGPS). In addition, a stationary current meter was operated at a site near Randle Reef from 13 April to 17 May 1999, to add a temporal dimension to the current data. The current data from the ADCP and the fixed current meter are summarized in this report, along with the wind conditions.

INSTRUMENTATION

The RD Instruments ADCP used on this cruise was a 1200 kHz Direct Reading Broad Band Acoustic Doppler Current Profiler. It was mounted over the side of the launch with the head 0.5 m below the water surface (Figure 1). There was considerable magnetic interference from the vessel, so that it was necessary to compute the compass deviation (Figure 2) for all directions and correct the ADCP current directions for this, as well as for the magnetic declination. This was done by comparing the vessel velocity based on DGPS observations and on the ADCP bottom track, both available at each time step. This method is susceptible to error caused by wind affecting the attitude of the vessel. Because the winds were light (Figure 3.), and only vessel speeds greater than 206 cm/s (4 kts) were used, it is believed that this source of error was not excessive.

The ADCP was set up to return average currents in 1.0 m bins, or vertical slices of the water column beneath the vessel, centred on depths 1.82, 2.82,..., 24.82 m, once every 10 seconds. The data were stored in a file, which also contained the DGPS longitude and latitude at the time of each measurement.

Currents in 13 m of water, just to the west of Randle Reef (at 43° 16' 39"N, 79° 50' 17"W), 0.6 m above the bottom, were recorded from 13 April to 17 May 1999, using a Sontek Hydra system. This system is a three axis acoustic Doppler current meter, which measures the flow in a small volume (about 2 cm^3) of water 18 cm from the meter head. In addition to the three components of flow, this system also recorded the pressure and temperature. It was operated in a burst mode, 512 scans at 2 Hz every 20 minutes. It was thus possible to search for surface wave events as well as mean and long period events.

Meteorological data from the NWRI Burlington Pier station and from the AES station at the Royal Botanical Gardens were obtained for the period.

CURRENTS DURING THE CRUISE

The winds were light from the west, veering to the northwest, during the five hour cruise on 14 April 1999 (Figure 3). The ADCP provided horizontal velocity measurements at 2505 locations in the harbour during the cruise. At each location, up to 24 one metre high vertical bins were sampled, depending on the depth at each station. To provide reasonably simple summary views of this data, a velocity vector at every 30th location has been plotted on a map of the harbour for a number of bins or averages of bins.

The surface flow (represented by the top bin) is shown in Figure 4. In general, the surface flow over most of the harbour, including Windermere Arm, followed the prevailing wind during the cruise, towards the east and southeast. There was a strong shore parallel flow to the southeast in Lake Ontario at the mouth of the canal. The bottom flow (represented by the bottom most bins containing good data) is show in Figure 5. The bottom flow, in contrast to the surface flow, had a strong westerly flow in the centre of the harbour, which appeared to split near LaSalle Park forming both a clockwise and a counter clockwise gyre. There was also a strong flow out of Windermere Arm. The flow was generally mixed elsewhere. There was a strong bottom flow out of the canal into Lake Ontario.

The flow at intermediate depths was examined by looking at selective depth-averaged values. The average was only computed if there were valid data at that site. For example, if the defined depths are below the measured bottom, a dot is returned to the plot, rather than an arrow. Figure 6 shows the average of the 2.82 and 3.82 bins. The current speeds were lower than the surface flow, but the directions were similar in the central part of the harbour. There was a low flow out of Windermere Arm at this depth, as well as some flow out of the harbour into the lake. Figure 7 shows the averages for the bins centred at 4.82 and 5.82 m depth. The flows were mixed, especially in the central basin. The outflow from Windermere Arm appears to be increasing with depth. A tongue of northerly flow is evident at the northwest corner of the Stelco property. In Figure 8, the average flow at 6.82 and 7.82 depths is shown. The current was similar to that at the depth immediately above. The average flow for 8.82 and 9.82 m depth bins is shown in Figure 9. The flow was small and mixed; in the central basin there was some westerly flow (which was much more predominant at the bottom). Figure 10 shows the average flow in the 10.82 and 11.82 depth bins; it was similar to the flow shown in Figure 9. The westerly flow in the central basin and along the north side of the Stelco property was well established. The flow averaged at greater depths down to the deepest depths had a similar character to the bottom flow (Figure 5), so are not reproduced here.

BOTTOM CURRENT AT RANDLE REEF

The wind conditions at the Burlington Pier during the five weeks that the Hydra current meter was deployed are summarized in the wind rose in Figure 11. Note that the wind direction is reported as **direction to**, not direction from, so that it conforms to the convention used for the currents. The wind was predominantly from the northeast and east. The next most important direction was from the west, the direction at the start of the ADCP cruise.

The Hydra deployment is summarized by the current rose and the trajectory, shown in Figure 12 a and b. (In the trajectory plot, 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. It approximates the Lagrangian displacement of the 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.) The flow at the Hydra was in all directions, but was primarily to the northeast. Comparison to the wind data, Figure 11, suggests that the flow at the location of the Hydra meter was in a return flow regime in response to surface flow in the general direction of the winds.

The vector time series of the velocities measured by the Hydra on 14 April 1999 are shown in Figure 13. The shaded block on the abscissa indicates the time when the ADCP passed close to the Hydra. The flow at the Hydra site was mostly to the northeast and east on 14 April, but was changing rather rapidly about the time the ADCP passed the area. The current vectors from the ADCP during its passage close to the Hydra are shown in Figure 14a, along with three Hydra current vectors that bracket in time the ADCP readings. The ADCP results present a complex, apparently unsteady, velocity field, which is confirmed by the relatively large change in velocity at the Hydra during the same time period (40 minutes). Figure 14b shows the depths of the ADCP bottom velocity measurements as well as the bottom depth, as well as the same for the Hydra. The abscissa length is 0.01° longitude, or about 820 m, and the depth ranges from about 5 to 20 m, so the bottom relief is quite large in that area.

SPECTRAL ANALYSIS

The data from the Hydra system were analyzed in the frequency domain to determine if any typical driving mechanisms were evident. Figure 15a shows the long-term spectra of both the east and north velocities. There is evidence of a diurnal oscillation and one at about 7 hours. There was no evidence of free surface modes of Lake Ontario (5.2 and 3.2 hours: Rao and Schwab 1976), Helmholtz resonance between the harbour and open lake (2.5 hours: Freeman et al. 1974), nor exchange flows between the harbour and Cootes Paradise (1.8 hours: Hamblin 1998, Skafel 2000).

All of the individual bursts of data from the Hyrda were analyzed, and some were found to have some energy at wave periods typical of the Great Lakes. From these spectra it was possible to estimate the spectra of the water surface elevation. A typical spectrum is shown in Figure 15b. The waves were very small, but the peak of the spectrum was typical for the western end of Lake Ontario during an easterly or northeasterly storm. They have propagated in through the Burlington Ship Canal, across the harbour to the site. Using this information the bottom stress at 3 m (typical of the depth on Randle Reef) was estimated to be about 0.01 Pa. This value is roughly an order of magnitude less than the critical value for cohesive sediment quoted in the literature (Stone and Krishnappan 1998, Ravens and Gschwend 1999, Haralampides et al. 1999). It is unlikely that waves propagrating in from Lake Ontario would resuspend sediment on Randle Reef.

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Hamblin P F 1998 Exchange flows in lakes. In: Physical Processes in Lakes and Oceans. J. Imberger, (Ed). American Geophysical Union, Coastal and Estuarine Studies, Volume 54, 187-198

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Figure 1.The vessel 'Monitor VI', showing frame on starboard side with ADCP, in raise position.

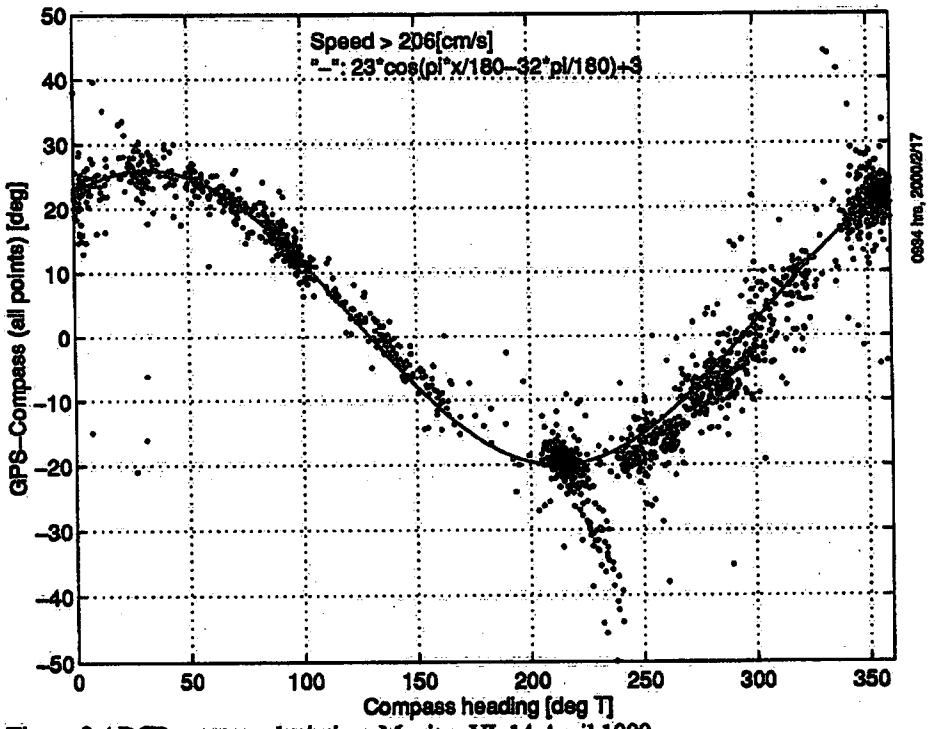

Figure 2 ADCP compass deviation: Monitor VI, 14 April 1999

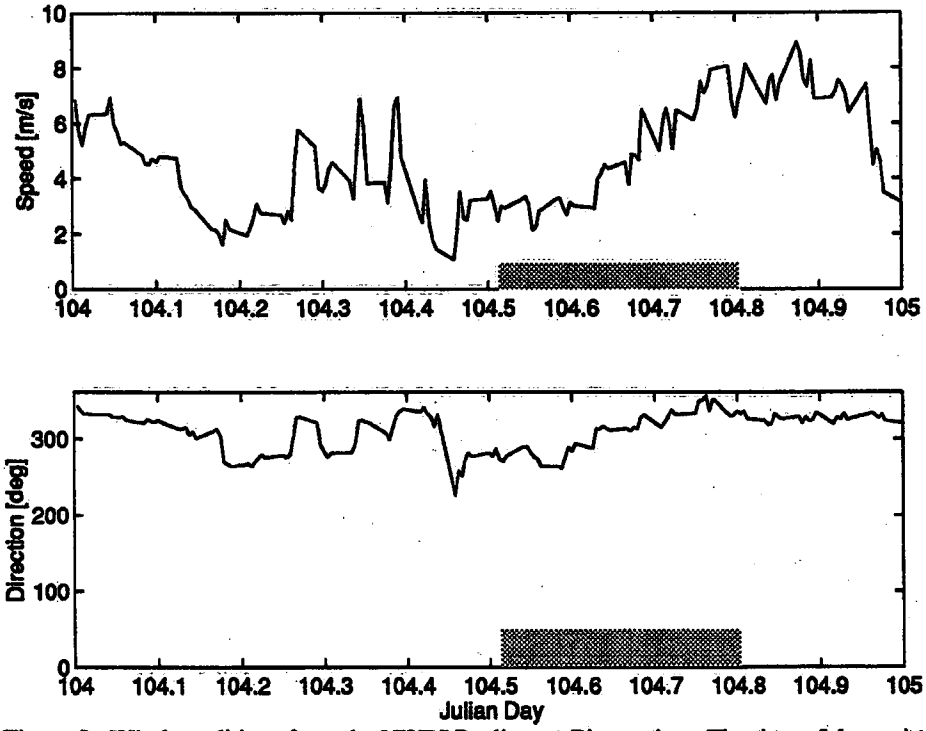

Figure 3. Wind conditions from the NWRI Burlington Pier station. The time of the cruise is indicated by the horizontal bars (GMT).

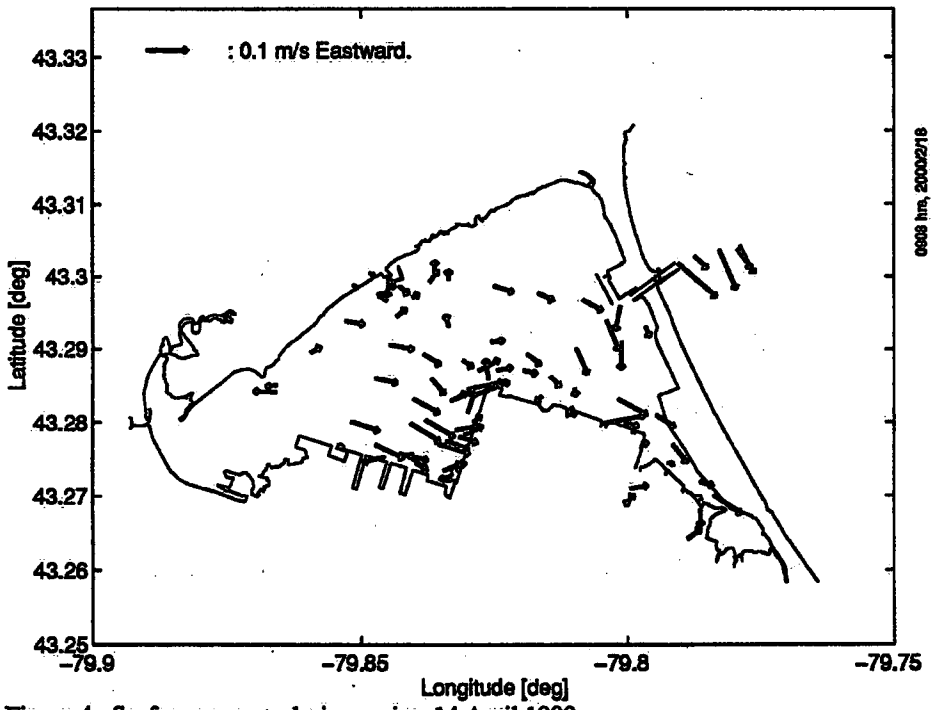

Figure 4. Surface currents during cruise, 14 April 1999.

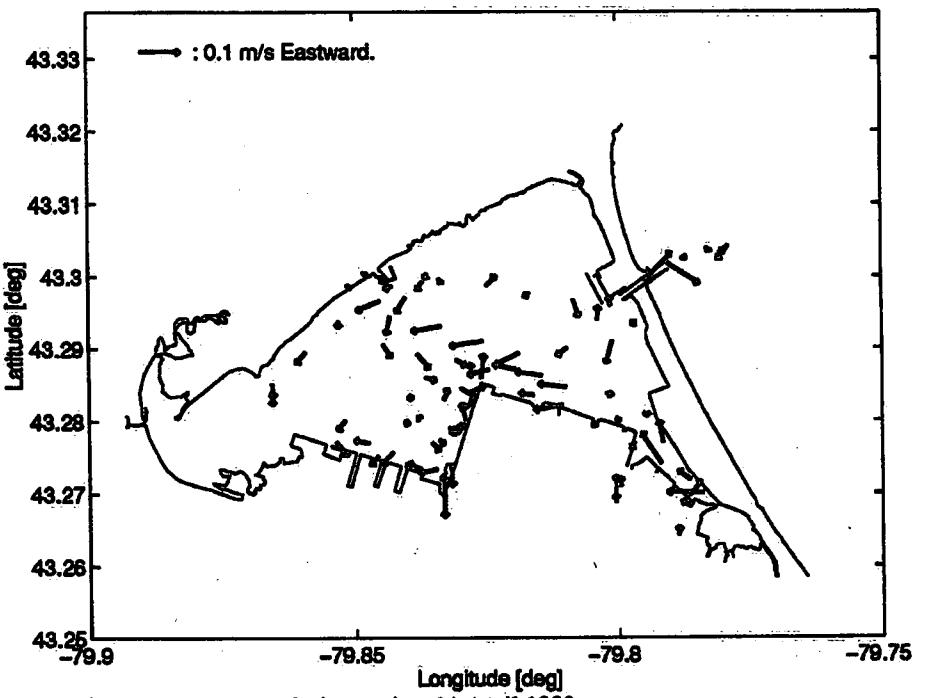

Figure 5. Bottom currents during cruise, 14 April 1999.

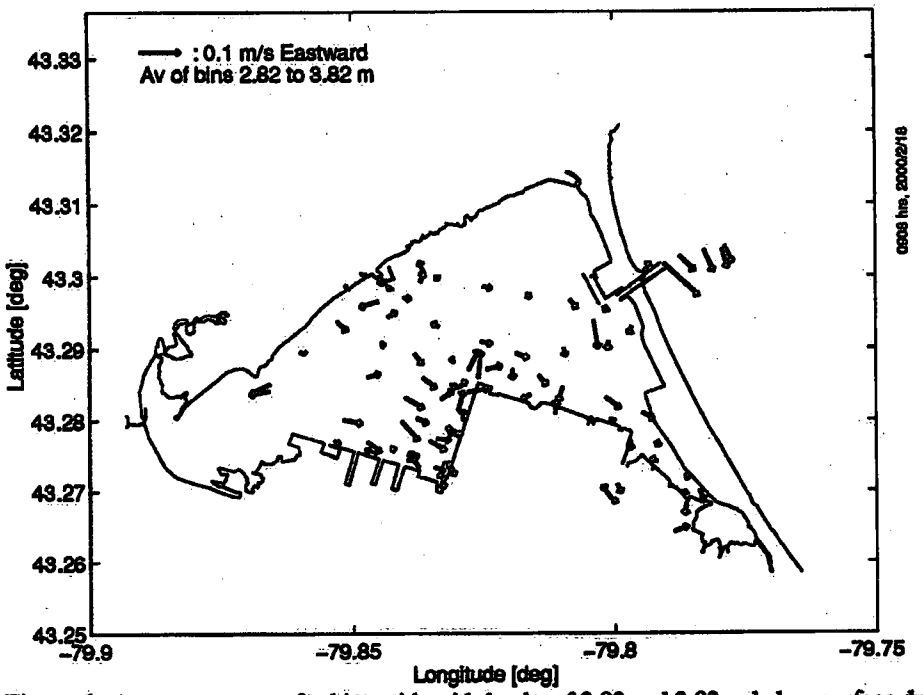

Figure 6. Average currents for bins with mid-depths of 2.82 and 3.82 m below surface during cruise, 14 April 1999.

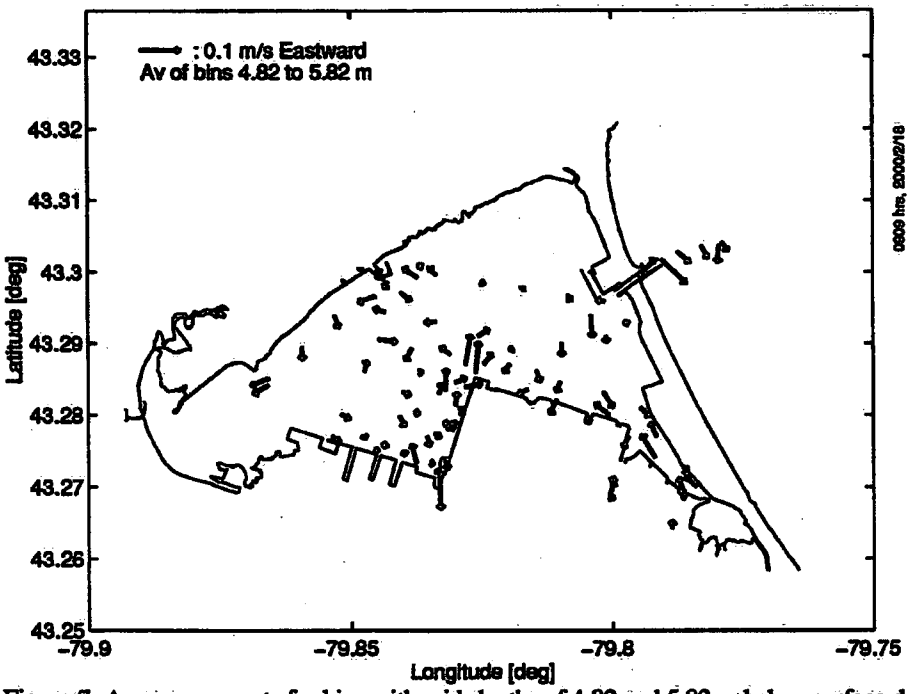

Figure 7. Average currents for bins with mid-depths of 4.82 and 5.82 m below surface during cruise, 14 April 1999.

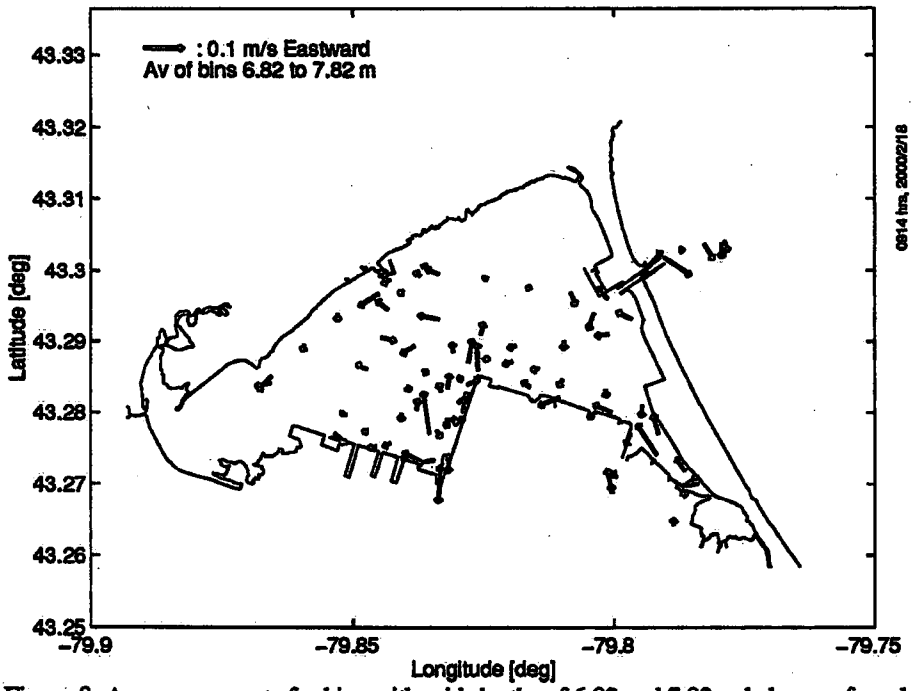

Figure 8. Average currents for bins with mid-depths of 6.82 and 7.82 m below surface during cruise, 14 April 1999.

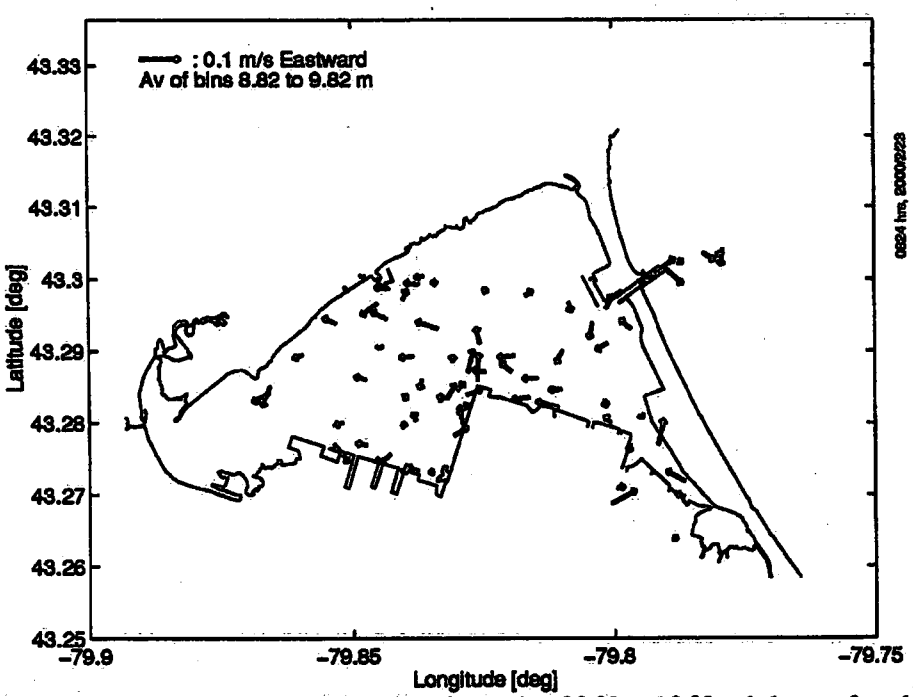

Figure 9. Average currents for bins with mid-depths of 8.82 and 9.82 m below surface during cruise, 14 April 1999.

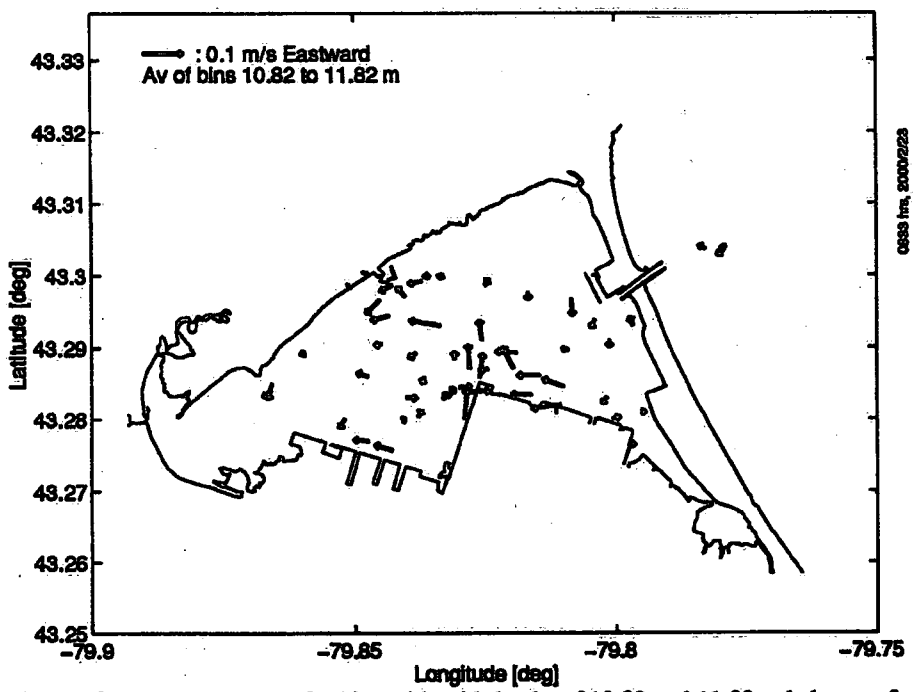

Figure 10. Average currents for bins with mid-depths of 10.82 and 11.82 m below surface during cruise, 14 April 1999.

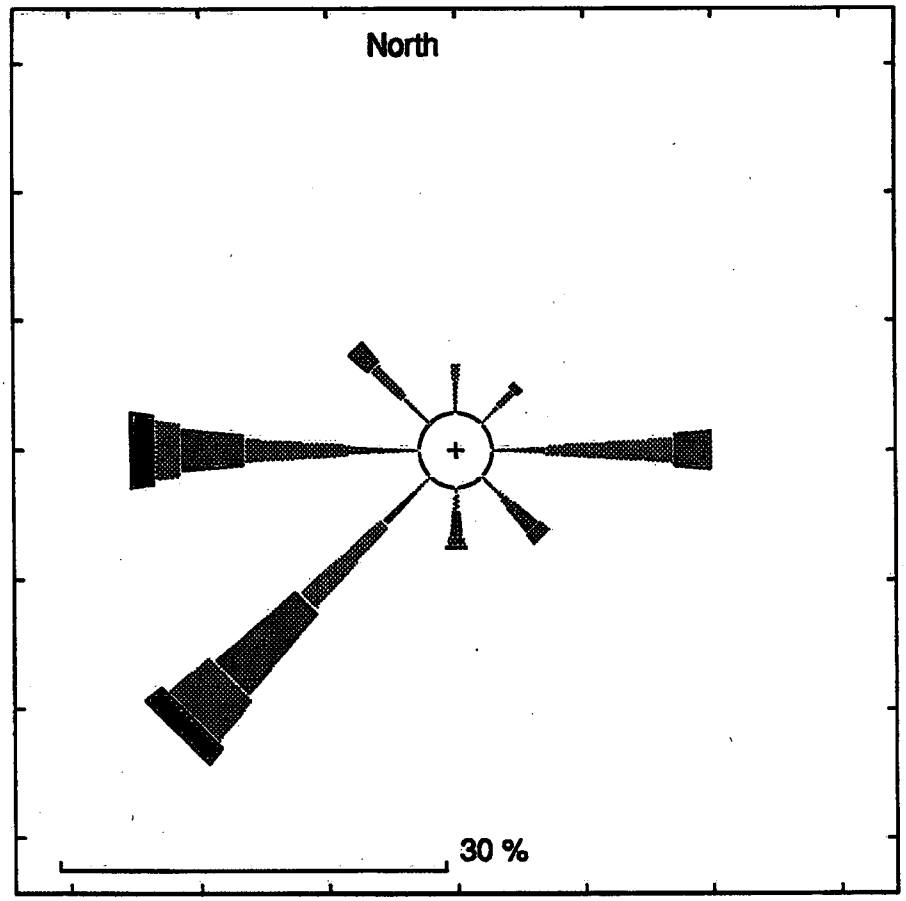

Figure 11. Wind rose from the Burlington Pier Station for 13 April to 17 May 1999. The circle represents calms (<=0.5), the radial bin boundaries are at 2, 4, 6,... m/s. The number of hourly readings was 840.

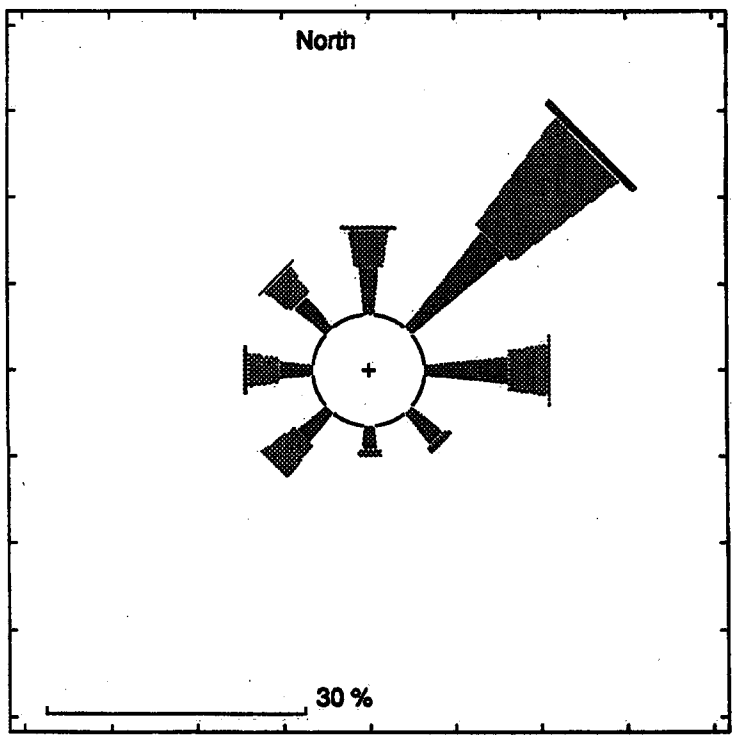

Figure 12a. Hydra current rose, 13 April to 17 May 1999. The circle represents calms (<=0.005), the radial bin boundaries are at 0.2, 0.5, 1.0,... m/s. The number of twenty minute readings was 2487.

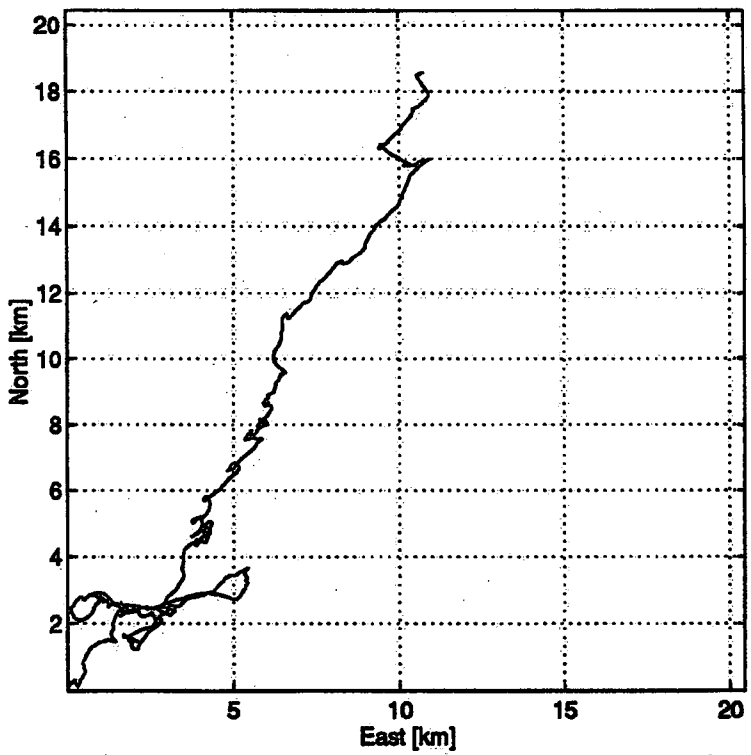

Figure 12b. Computed particle trajectory based on the time series of velocity readings from the Hydra current meter.

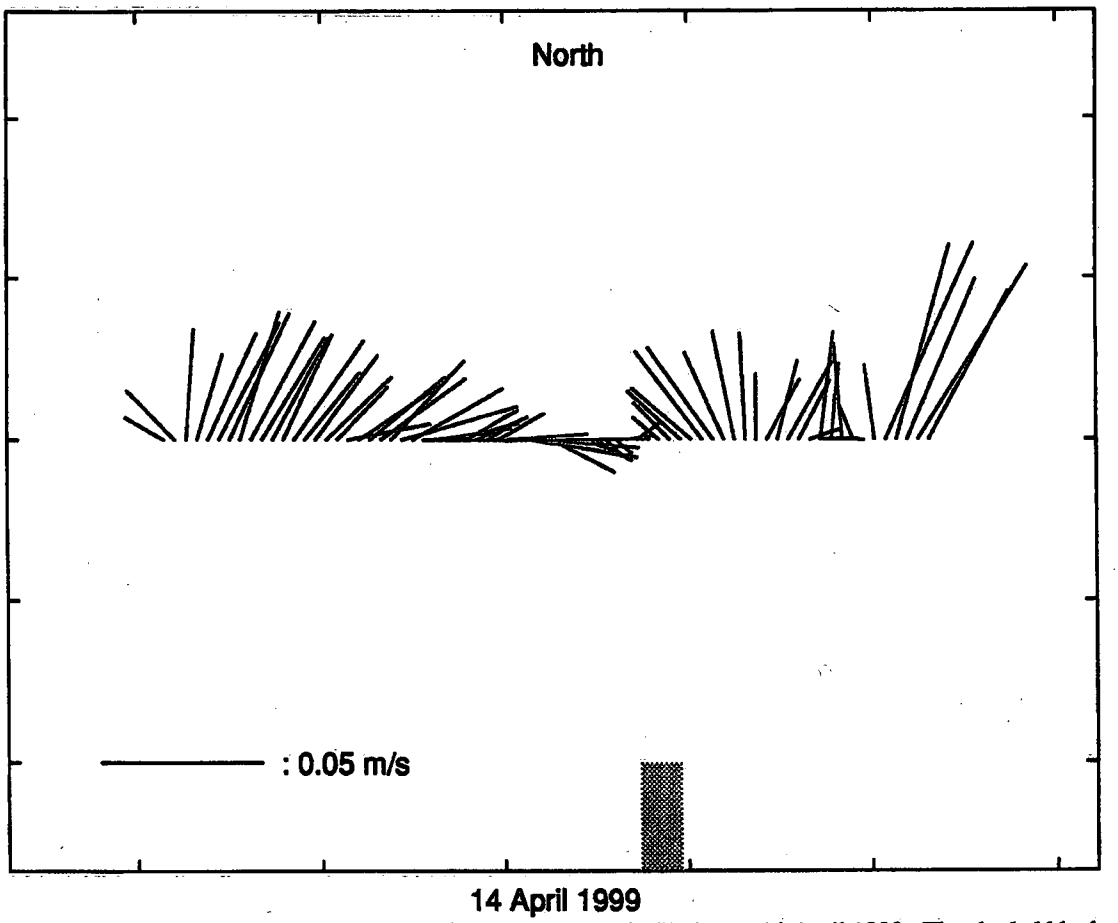

Figure 13. Vector time series of the velocities measured by the Hydra on 14 April 1999. The shaded block on the abcissa indcates the time when the ADCP passed close to the Hydra.

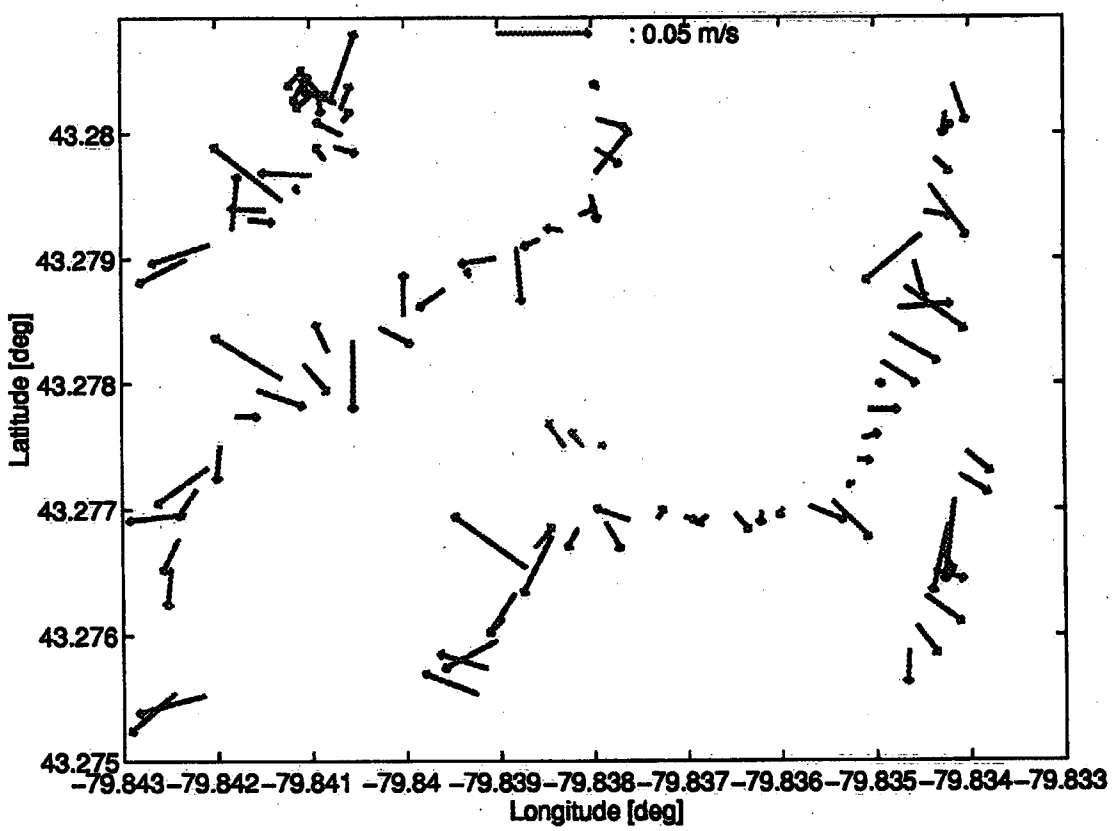

Figure 14a. Bottom current vectors from the ADCP (red) in the vicinity of the Hydra, and three current vectors from the Hydra bracketing the time of the ADCP vectors, 14 April 1999, near Randle Reef.

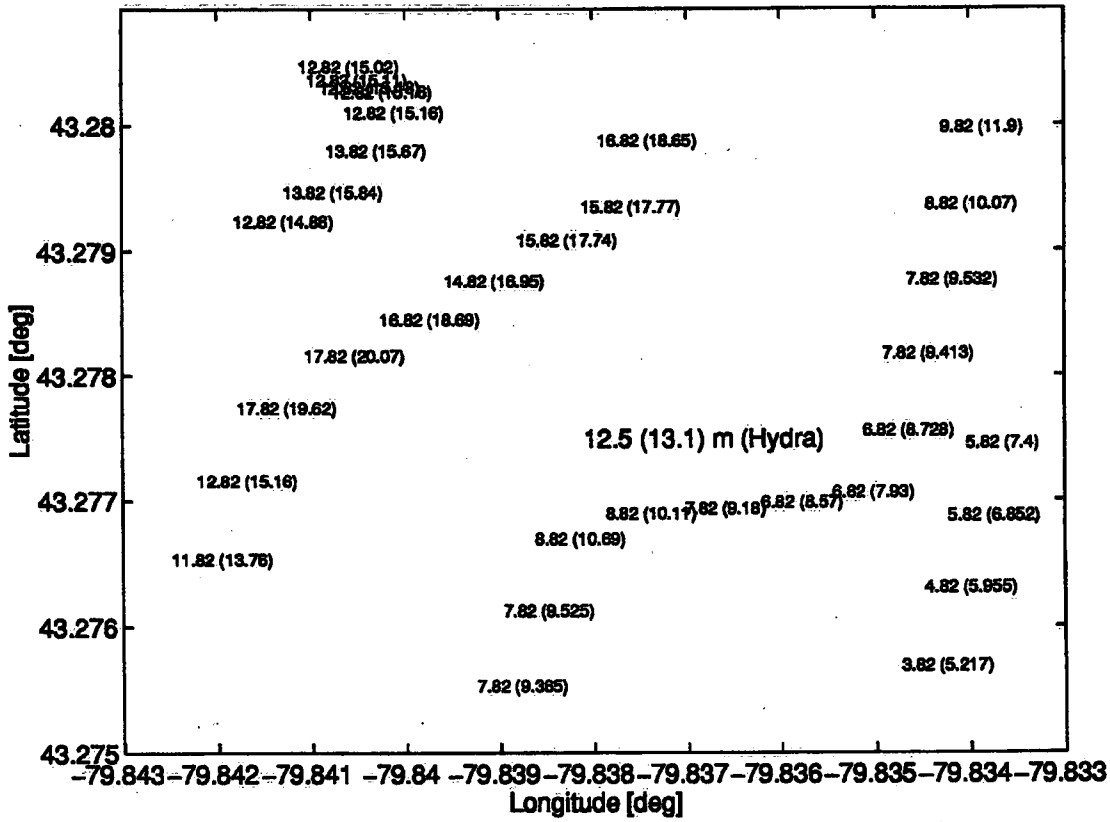

Figure 14b. Depths in metres of the ADCP bottom most valid bin (water depth in parentheses), similarly for the Hydra, for the currents shown in Figure 14a. The location for each measurement is at the bottom left-hand corner of the first digit of the depth.

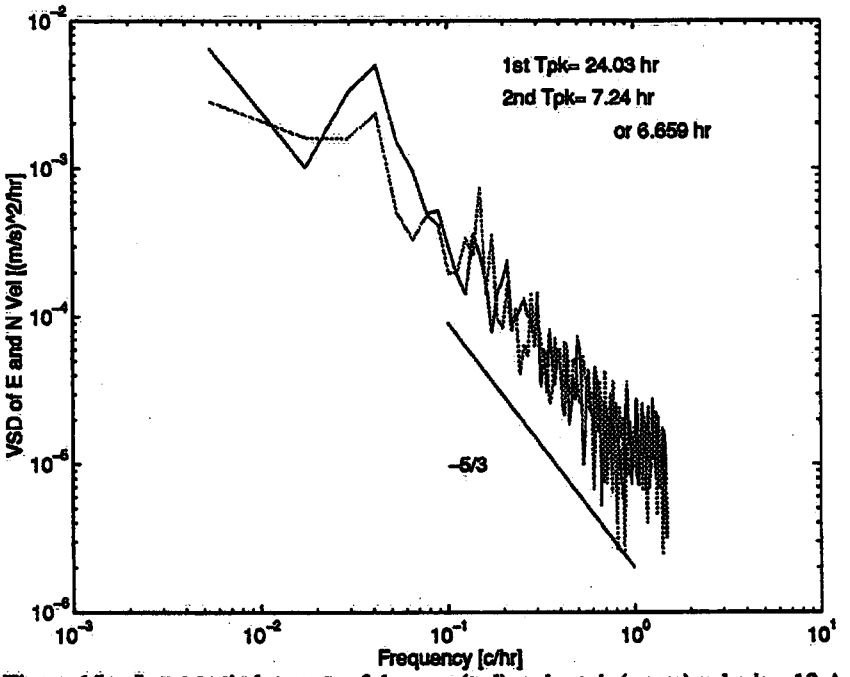

Figure 15a. Long period spectra of the east (red) and north (green) velocity, 13 April to 17 May 1999.

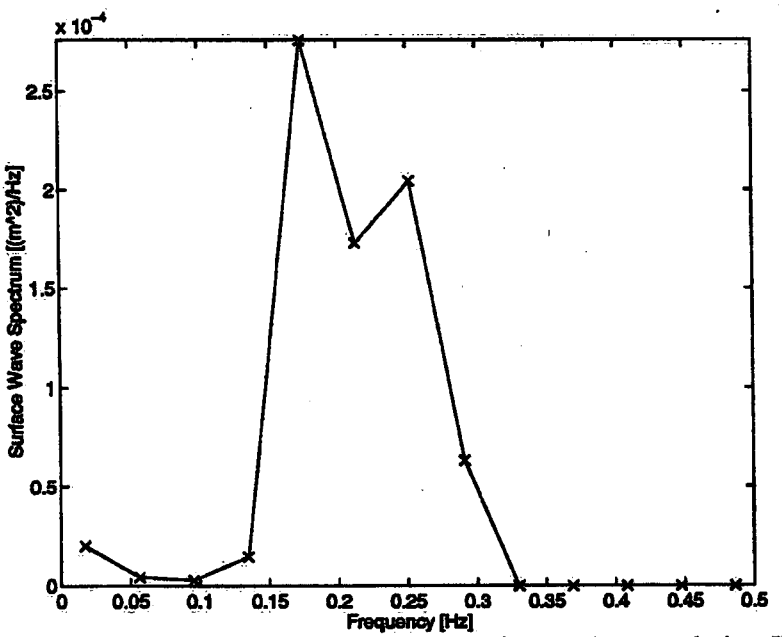

Figure15b. Example wave spectrum computed from the bottom velocity. H_{mo}=0.02 m; Tp=5.8 s.

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