Measuring Offshore and Longshore Transport with Current Meter Arrays During Storm Events in Lake Michigan

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Introduction

Nearshore regions are the receiving areas for excess nutrient and toxic inputs due to agriculture, industry, and urban sewage effluents which can result in ecological stresses and human health concerns. In coastal regions the concentration gradients of biogeochemically important materials are often considerably higher in the offshore direction than in the longshore direction. Consequently, the cross-shore circulation is the primary mechanism responsible for the nearshore and offshore exchange of materials. A detailed investigation of this process is underway in Lake Michigan as part of a larger NSF/NOAA Episodic Events – Great lakes Experiment (EEGLE).

Both theory and observation have contributed to this investigation. Satellite imagery has suggested the recurrent presence of a coastal plume along the southern basin of Lake Michigan following storm events. Figure 1 is an example of one plume episode from March 1998.

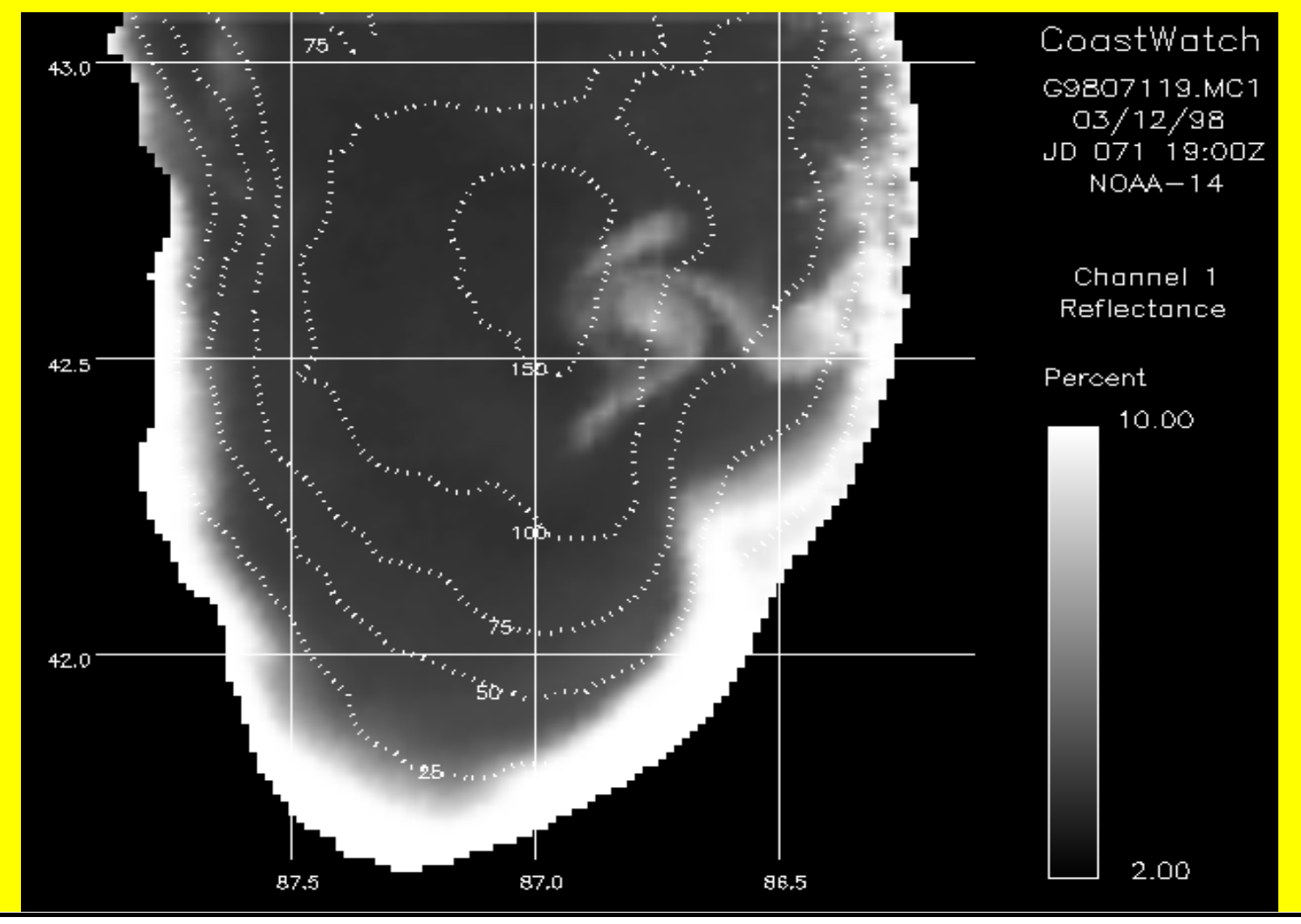

Figure 1. AVHRR satellite image of southern Lake Michigan after a storm event on 12 March 1998. The broad band of high reflectance along the coastal zone suggests widespread resuspension of sediments and some offshore transport along the eastern boundary. The 25, 50, 75, 100 and 150m depth contours are shown.

Wind driven transport dominates in the circulation of the Great Lakes. Studies have shown the response of an enclosed basin with a sloping bottom to a uniform wind stress consists of longshore, downwind currents in coastal waters, and a net upwind return flow near midlake. The streamlines of the flow fields form two counter-rotating gyres. In the northern hemisphere this results in a cyclonic gyre to the right of the wind and an anticyclonic gyre to the left. In this two gyre pattern there are regions in the coastal zone where offshore transport occurs due to a convergence of opposing longshore currents. Once the winds relax this circulation pattern begins to rotate cyclonically around the basin with a time period corresponding to the lowest mode vorticity wave of the basin. For a Coriolis parameter and geometry appropriate for Lake Michigan, this period is on the order of 3-5 days.

Numerical models have been successful in describing this circulation pattern (Figure 2).

The major hypothesis of our study is that the two-gyre vorticity wave response to storm events is a major mechanism for nearshore-offshore transport in the Great Lakes.

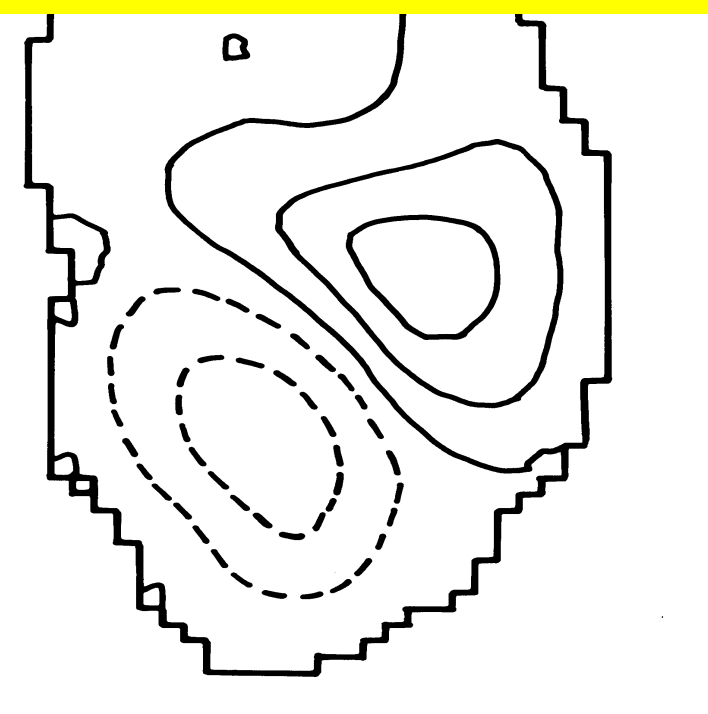

Figure 2. Numerically calculated counter-rotating gyres in southern Lake Michigan (Schwab, 1983). The dashed lines indicate cyclonic circulation and the stagnation point. lies near the southeast coast.

Measurement Strategy

Field observations are designed to both attempt direct observation of gyre induced offshore transport and to provide a data base to test the fine-scale adequacy of hydrodynamic models. The observation program on Lake Michigan is concentrated along the southeast coast of the lake where the coastal plume most frequently appears in AVHRR images to diverge offshore. All mooring locations are shown in Figure 3.

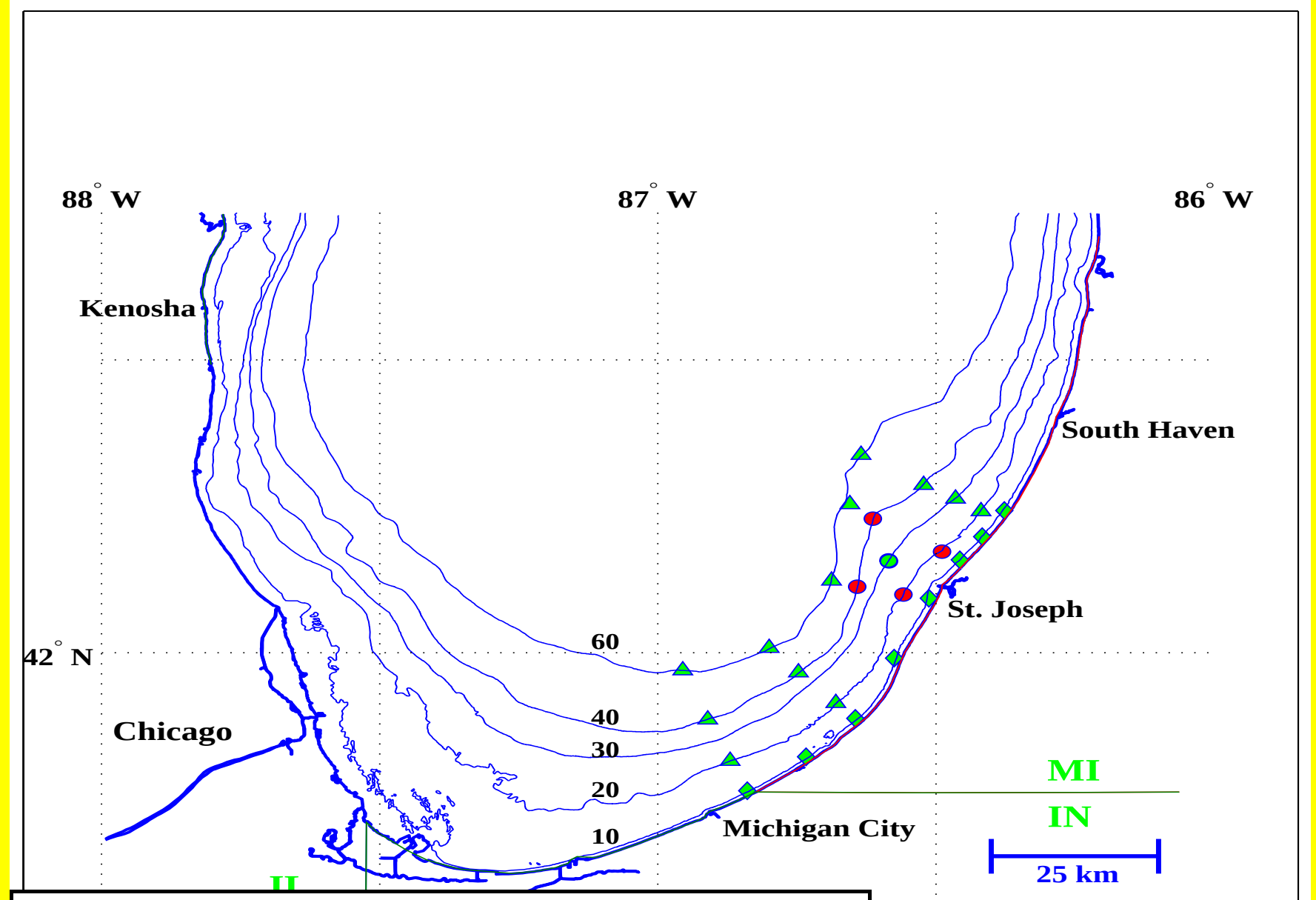

Figure 3. Southern Lake Michigan mooring locations.
▲ = Vector Averaging Current Meters (VACM).
♦ = Smart Acoustic Current Meters (SACM).
● = Acoustic Doppler Current Profilers (ADCP).
● = location of ADCP data shown in Figures 10 – 13.
The 10, 20, 30, 40, and 60 m depth contours are also shown.

Measurement Tools

Figure 4. A VACM mooring being deployed near Michigan City, Indiana.

Figure 5. August 1998. An ADCP being readied for deployment near St. Joseph, Michigan.

Figure 6. October 1998. A diver cleans fine sediment off of the ADCP transducer head that was deployed in August.

Figure 7. A SACM as configured for shallow water deployment. All SACMs were deployed along the 12 m depth contour.

Figure 8. Meteorological station on the St. Joseph pier. Similar sites have been installed at Michigan City and Kenosha, Wisconsin.

A Late Winter Storm

- **The strongest wind event that occurred between January and May of 1998 began on March 9 (Figure 9). Strong winds developed out of the north with peak hourly wind speeds of nearly 25 m s^{-1} being observed. Northerly winds persisted for two days accompanied with falling air temperatures and an increase in atmospheric pressure.**
- **The ADCP data from the four sites identified in Figure 3 and displayed in Figures 10 – 13 show both the local and large scale response to the storm.**
- **The high echo intensities shown in the top panel of Figures 10 –13 correlates well with the storm's timing and suggest that sediment resuspension occurred at each of these moorings. Not surprisingly higher intensities are seen in the 20 m than in the 40 m stations.**
- **Data from both of the 20 m depth moorings (Figures 10 and 12) are mostly in phase with the wind forcing with maximum, southerly directed, currents of nearly 50 cm s^{-1} seen shortly after the peak wind event.**
- **The 40 m depth mooring data (Figures 11 and 13) show more of the large, basin scale storm response with maximum, northerly directed, currents of nearly 65 cm s^{-1}. In contrast with the shallow water moorings the peak currents seen here occur after the major wind forcing relaxes.**

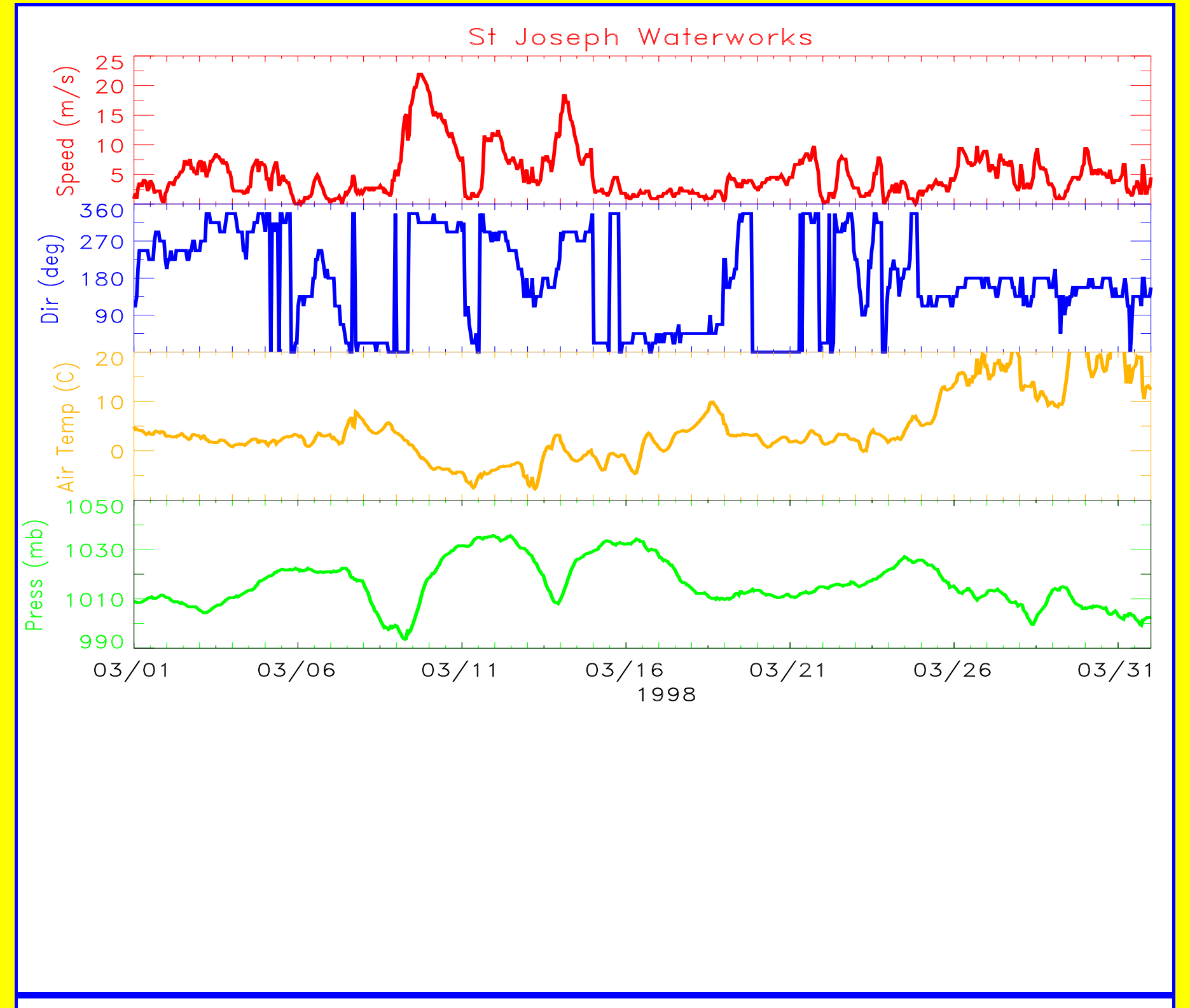

Figure 9. Meteorological data for the month of March 1998. Data are from meteorological sensors on top of the St. Joseph waterworks facility. A major late winter storm is shown.

Time Averaged Currents

Figures 14 and 15 show the vertically averaged and time averaged currents calculated from the March 1998 ADCP data.

Figure 14 shows the 4 day time averaged (March 9-12) current vectors. The strong impact of this March storm on cross-isobath transport is evident with the current vectors from the 20 m stations suggesting a nearshore flow convergence resulting in offshore transport.

The current magnitudes were 6, 14, 9, and 13 cm s^{-1} for A1, A2, A4, and A5, respectively.

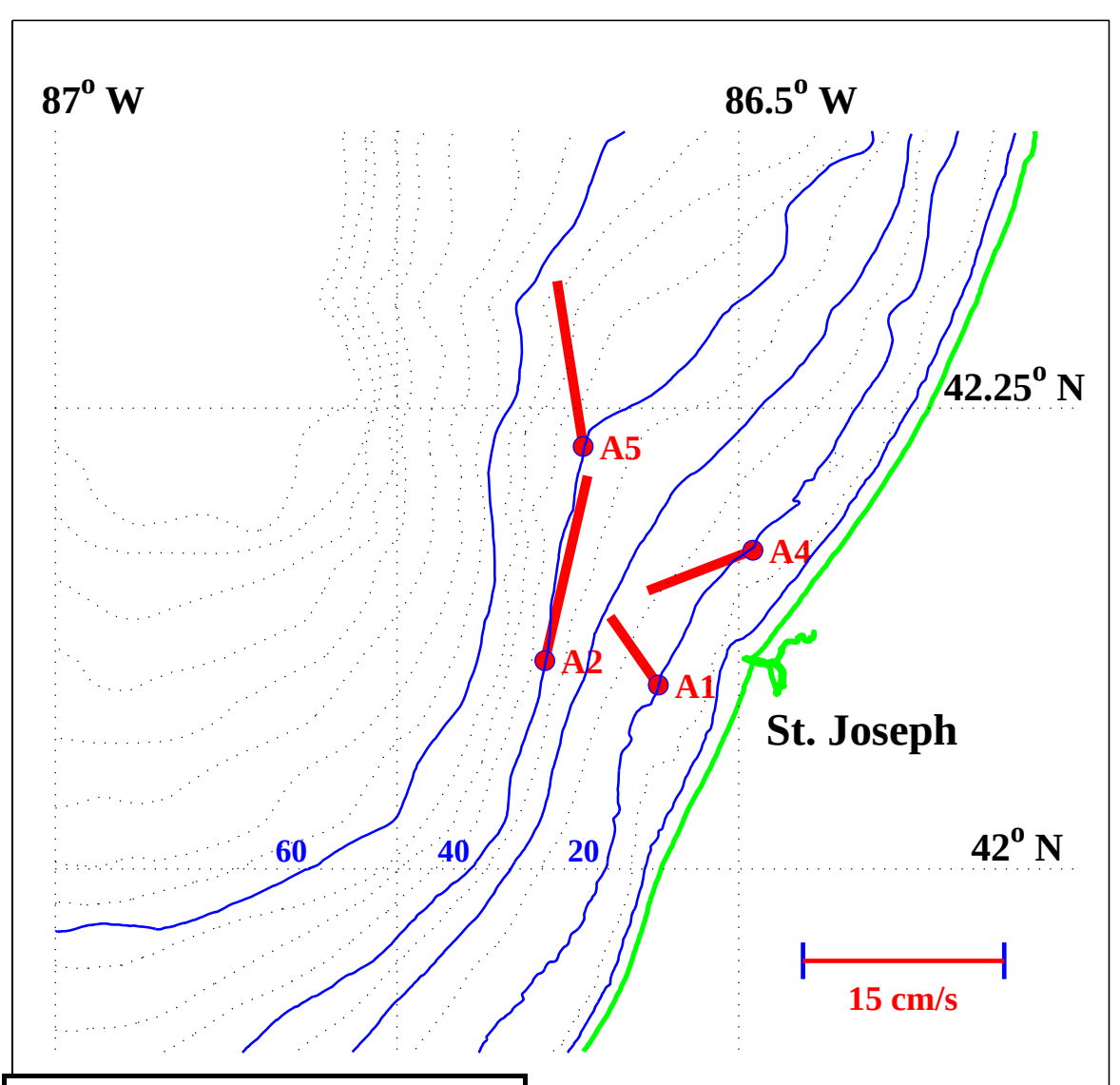

Figure 14. Averaged current vectors from March 9 – 12.

Figure 15 shows the calculated current vectors when averaged over the month of March. In general, the flow field follows the bathymetry and is strongest at the 40 m stations. The current magnitudes were 3, 6, 1, and 5 cm s^{-1} for A1, A2, A4, and A5, respectively.

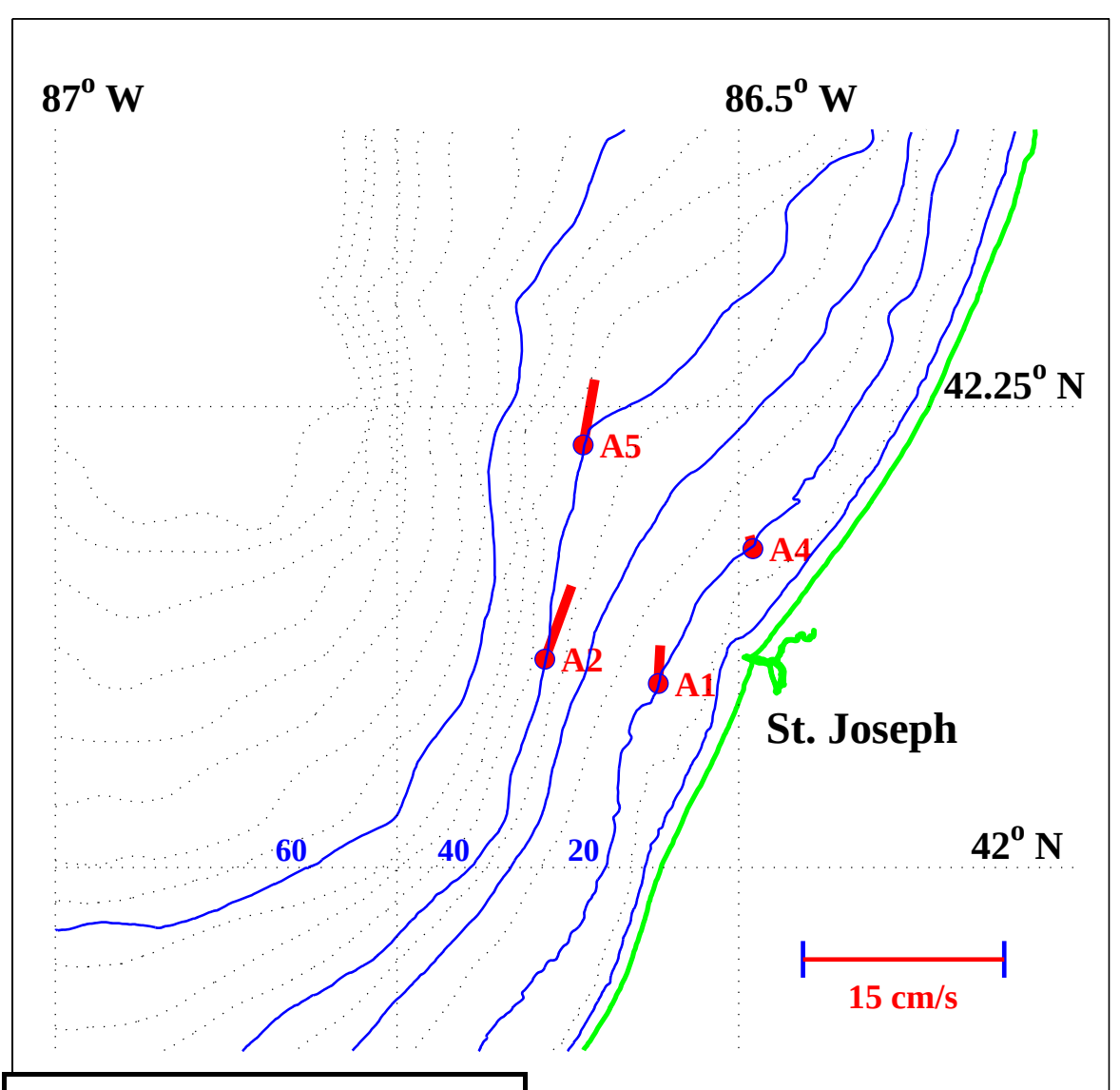

Figure 15. Averaged current vectors from March 1 – 31.

Future Work

Work is continuing on analyzing data from these moorings and the VACM moorings as well. In addition intensive Lagrangian experiments are planned to help resolve even more of the large scale flow features.

Data from both the first Lagrangian experiment and the full set of all fixed moorings will become available in late 1999. These data will then be used to study the circulation through objective analyses, empirical models and the three-dimensional hydrodynamic modeling effort.

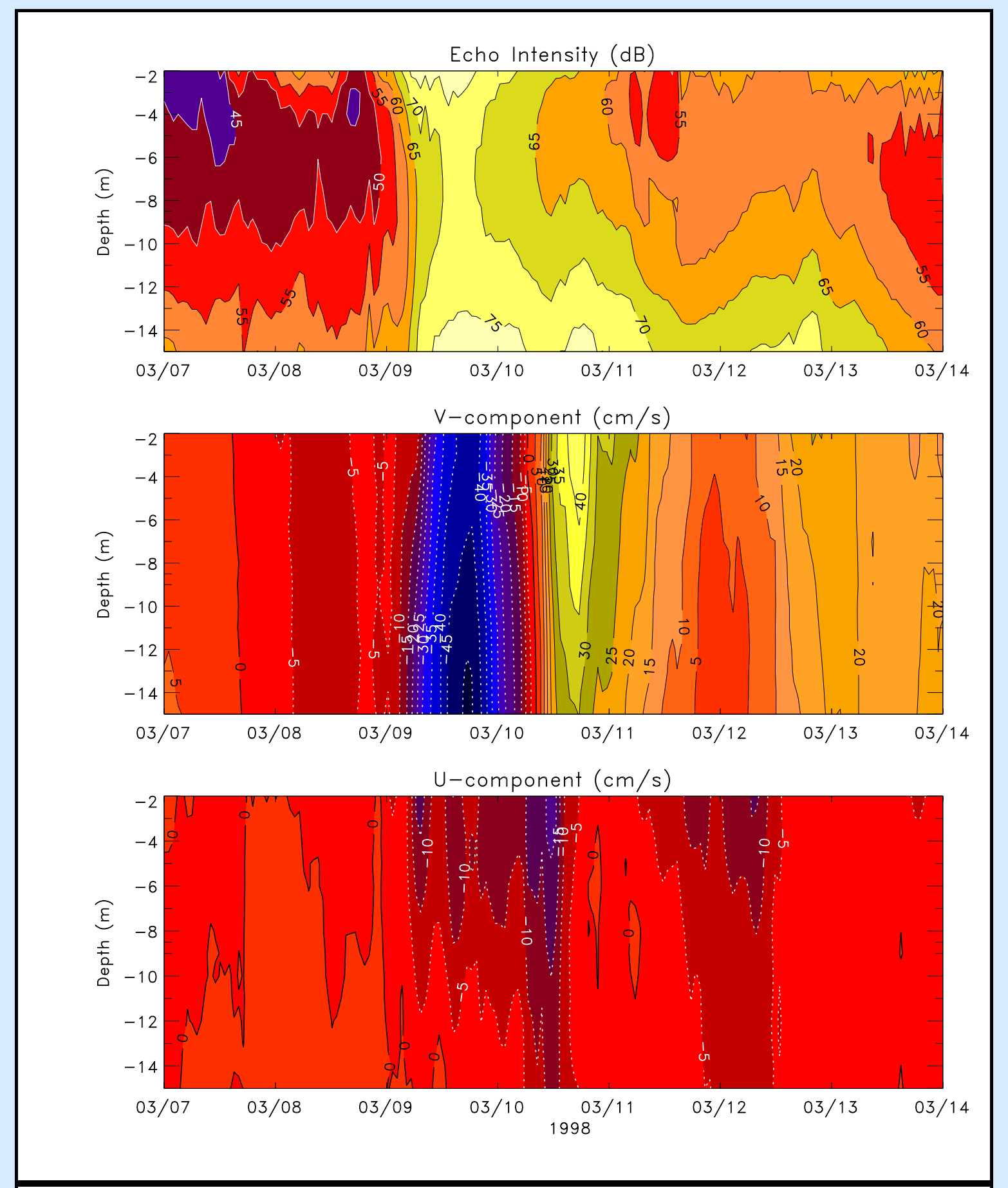

Figure 10. ADCP data from the south, 20 m depth mooring (A1). Data were rotated so that the +V direction is the northerly longshore component, and +U is the easterly onshore component. The negative V and U components refer to the southerly longshore and offshore components, respectively. This same convention applies to Figures 11 – 13.

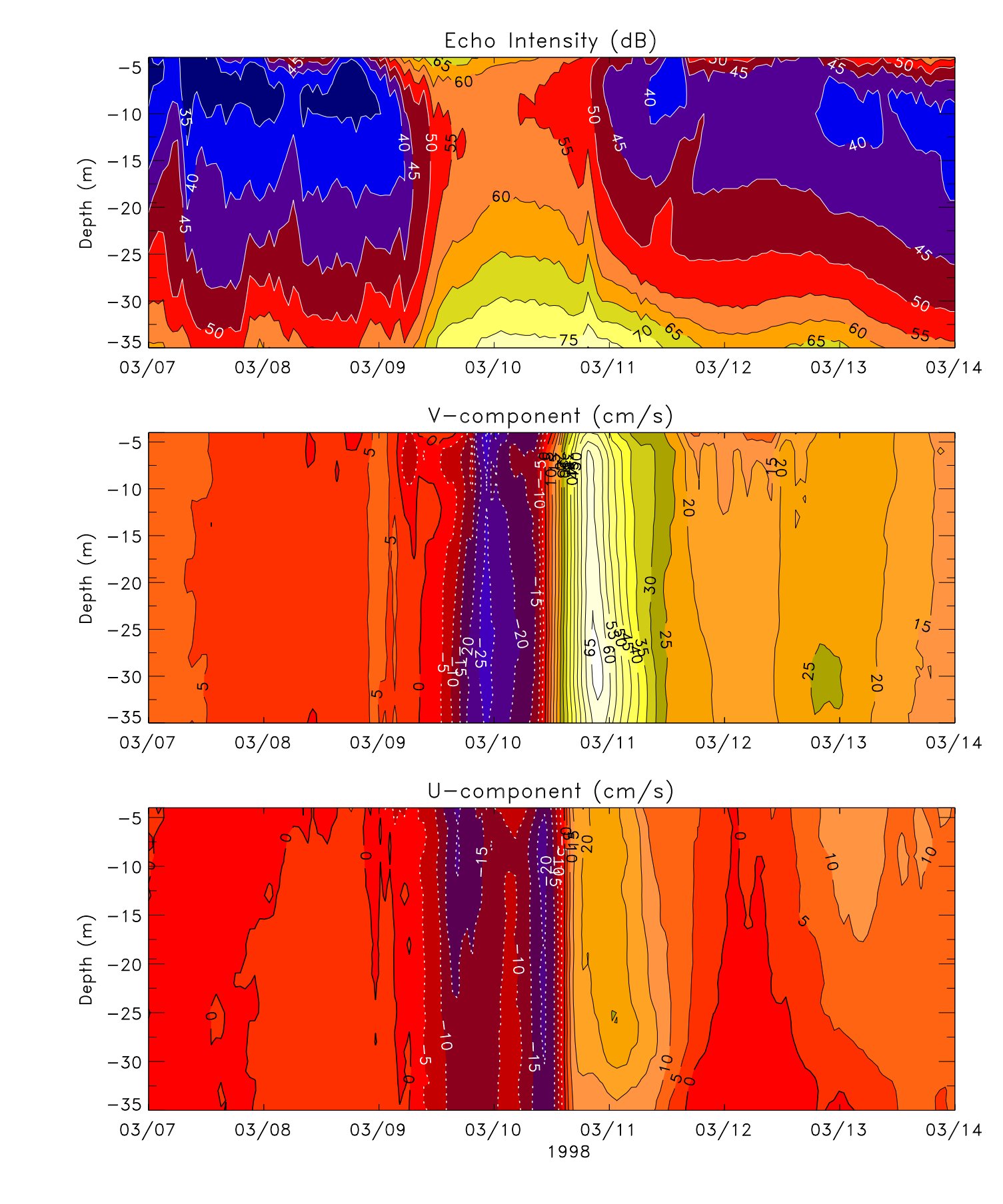

Figure 11. ADCP data from the south, 40 m depth mooring (A2).

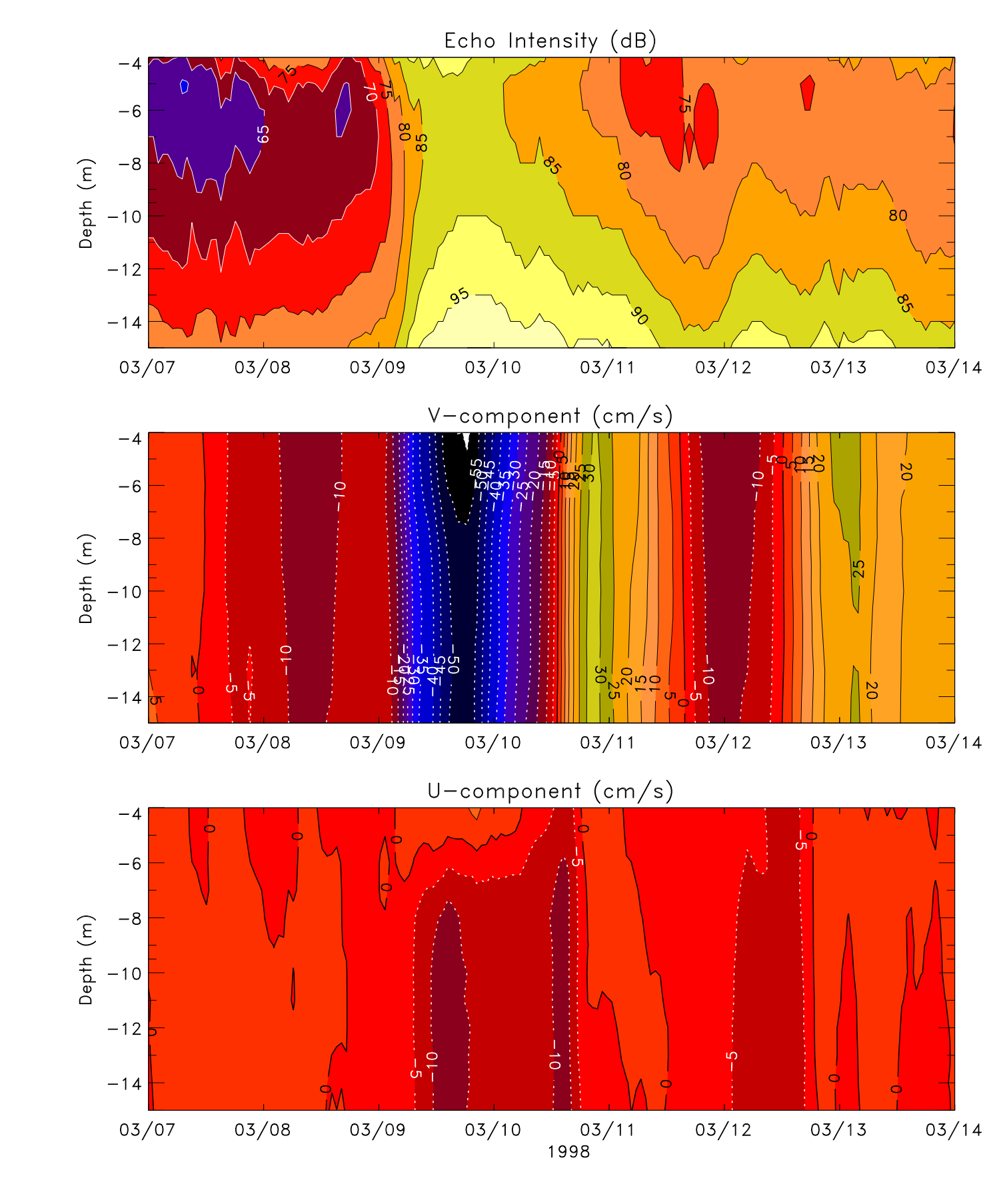

Figure 12. ADCP data from the north, 20 m depth mooring (A4).

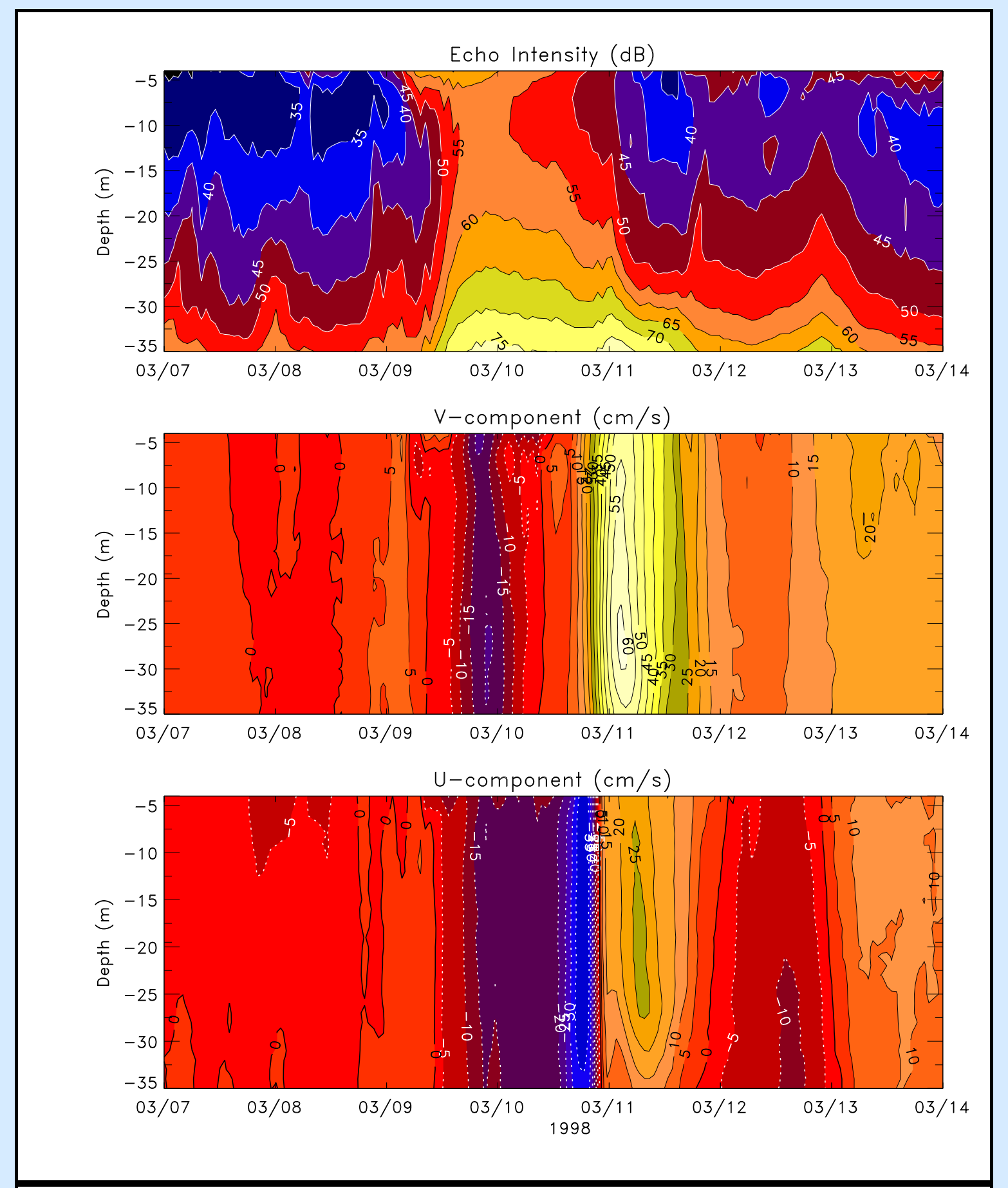

Figure 13. ADCP data from the north, 40 m depth mooring (A5).