HF Radar Measurements of Near-Surface Currents During 1999 Episodic Events

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1999 HF Radar Deployment

The objective of the HF Radar Observation portion of the EEGLE Project is to obtain real-time measurements of key air and water variables. These parameters are necessary for the identification and quantification of the physical processes generating cross-margin transport of biologically important material during episodic events in the Great Lakes. In particular, the HF Radar has been utilized to provide observations of near-surface current and current shear (leading to estimations of wind direction and wave height) over an area of about 1000 square km adjacent to the Lake Michigan shoreline near St. Joseph/Benton Harbor, Michigan.

In 1998, the feasibility of utilizing the University of Michigan Multi-frequency Coastal Radar (MCR) units to detect near-surface currents over fresh water was tested and proven. This two week pilot deployment, during low energetic wind and wave conditions, showed the capability of the radar to detect near-surface current and current shear consistent with ADCP measurements and wind forcing conditions (Fernandez, et al, 1999).

In 1999, two MCR units were simultaneously deployed in St. Joseph, Michigan with geographic observational ranges designed to encompass several moored current meters and other in-situ instrumentation (Fig. 1). The 1999 observational effort consisted of a 6-week deployment period from 27 March through 18 May. In addition to the deployment of the MCR systems, an Aanderaa Coastal Monitoring (UM Met) buoy was also deployed to measure surface and atmospheric environmental characteristics from 25 February through 15 June. This suite of instrumentation provided a coherent package with which to observe changes in environmental parameters and surface dynamic characteristics during the early spring. In particular, the HF Radars were capable of obtaining near-surface current and current shear measurements during the small episodic sediment suspension events (*above right*) as well as the progression of the vernal thermal front (*below right*).

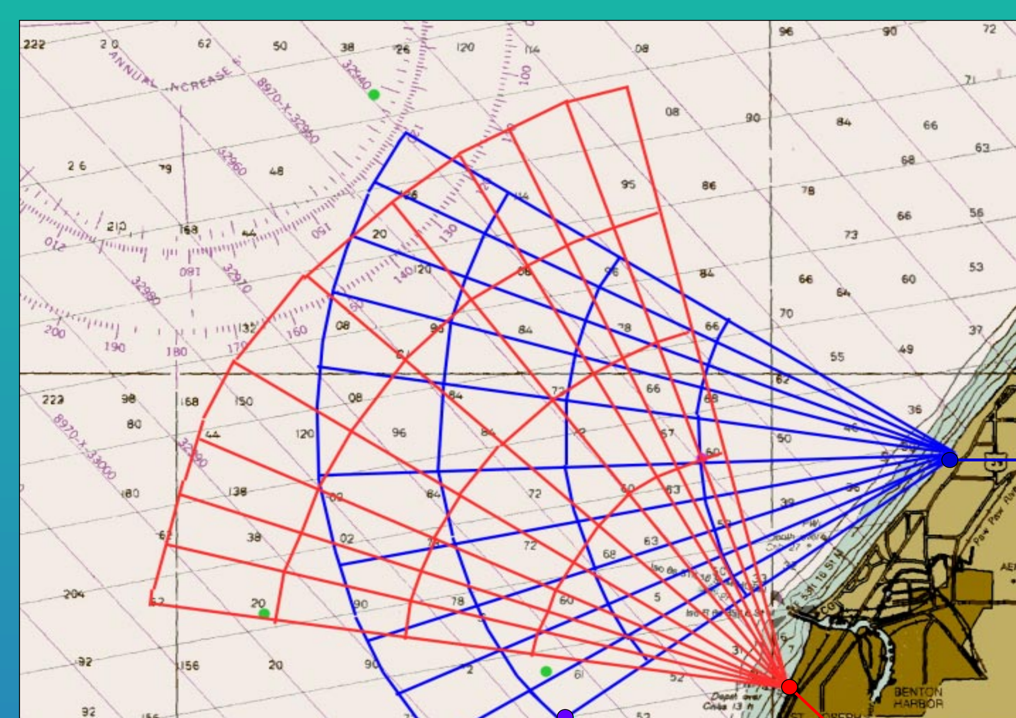

Fig. 1. Site map showing North and South MCR HF Radar sites and portion of radial measurement grids in blue and red, respectively. The purple dot indicates the location of the UM Met Buoy and green dots show GLERL ADCP mooring sites.

Fig. 2. The North HF Radar site located on Whirlpool Foundation property showing the receive antenna array. Electronic instrumentation was housed in a temporary construction trailer nearby.

Fig. 3. The South HF Radar site located at St. Joseph Waterworks showing the receive antenna array, high band and low band transmit antennas. Electronic instrumentation was housed in the Waterworks building immediately north of the antennas

Fig. 4. The University of Michigan Aanderaa Coastal Monitoring (UM Met) Buoy deployed 2/25/99 through 6/15/99 near the A01 ADCP mooring. Provided 10 minute interval measurements of wind speed and direction, air temperature, water temperature, current speed and direction at -1m and significant wave height and period.

The figures above detail the MCR deployment sites and coverage areas, as well as the Aanderaa Coastal Monitoring (UM Met) Buoy location. The northern MCR site was located on coastal property owned by the Whirlpool Foundation (Fig. 2). This site operated from March 30 through May 17. The southern MCR site was located at the St. Joseph Waterworks plant (Fig. 3). Data was collected from March 27 through May 18. Both sites operated on a 30-minute data acquisition interval, comparable to the ADCP data acquisition in the field of coverage. Both the City of St. Joseph and the Whirlpool Foundation provided logistical support for these operations. The simultaneous deployment of these two MCR systems provided the opportunity to construct a current vector field from the two independently obtained radial current fields.

In addition to the MCR's, the HF Radar Laboratory also deployed an Aanderaa Coastal Monitoring Buoy (Fig. 4) from 25 February through 15 June. This buoy obtained point measurements of wind speed and direction, significant wave height and associated period, air and sea temperature and current speed and direction (1m below the surface) at 10-minute intervals. The met buoy was moored near GLERL's bottom-mounted A01 ADCP.

The deployment period of the MCR's encompassed three small episodic events evident in the satellite imagery recorded as part of the EEGLE Project: April 10-13, April 23-25 and April 29-May 2. All three of these events coincide with sustained winds of greater than 8 m/s from the northeast to north, accompanied by wave heights which grew in excess of 0.6m. The April 23-25 event is shown above right.

In addition to the Episodic Events described above, the UM Met Buoy and MCR's were also deployed during the progression of the vernal thermal front through the observational area. The presence of the bar as detected by MCR near-surface current radials is shown below right.

Episodic Plume Event

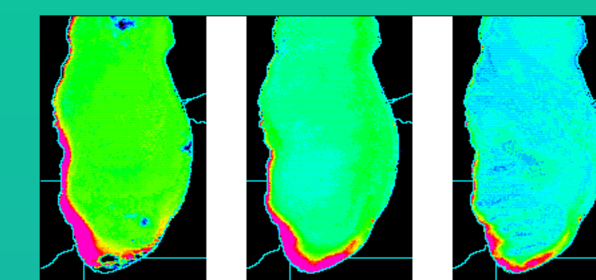

Fig. 5. AVHRR reflectance (Ch1 - Ch2) images from April 23, 24 and 25 at 2000Z showing presence of suspended material in the nearshore zone.

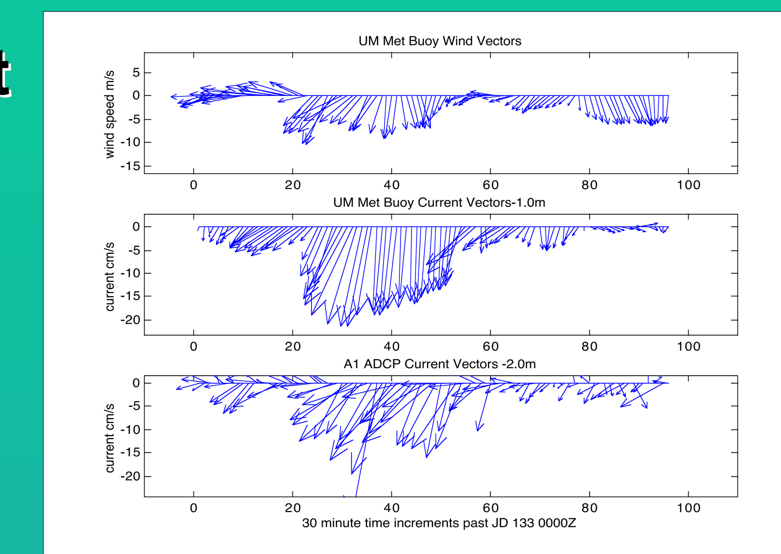

Fig. 6. Comparison of wind and current conditions at UM Met Buoy and GLERL A01 ADCP mooring, April 23-24 (JD113-114). Notice the strong southerly flow event between time increments 20 and 60. The two instruments compare well at approximately 3% of the wind speed.

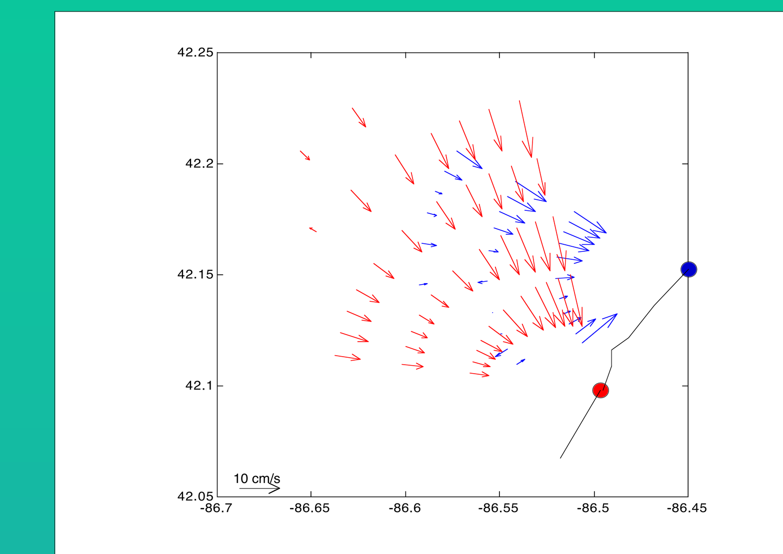

Fig. 7. Composite plot of current radials from the two MCR sites on April 23 (JD 113) at 2000Z. A strong southerly flow, consistent with the ADCP measurements is evident. The green circle indicates the position of the HF current time-series plotted to the right.

During the MCR deployment, there were three small plume events associated with strong winds. The second of these events occurred April 23-25, as shown in the AVHRR reflectance images (Fig. 5). Wind data from the UM Met Buoy is displayed in Fig. 6. This event began with strong winds from the east which initiated sediment resuspension along the western and southern shores of Lake Michigan from Wisconsin to Michigan. A wind shift from the north resulted in the movement of this plume to the southern extreme of the lake and the plume subsequently dissipated.

Fig. 6 also shows the current conditions at the UM Met Buoy and the nearby GLERL A01 ADCP mooring. The current data for the UM Met Buoy was obtained at -1m water depth and averaged over a 1 hour interval. The ADCP data is from the top bin located at -2m. The two current time-series' compare well showing characteristic near-surface currents of approximately 3% of the wind speed.

As demonstrated by last year's pilot experiment, the MCR requires a significant wave height of approximately 0.36 m and a current over 3 cm/s in order to obtain reliable current radial estimates over fresh water. These general conditions were met approximately 70% of the time during this event. Fig. 7 shows radial current vectors obtained simultaneously from each MCR site at 2000Z on April 23, corresponding to the left AVHRR image in Fig. 5. This diagram shows a dominant southerly flow, consistent with the ADCP measurements. Due to the direction of wave propagation, nearly orthogonal to the radar look direction, the northern MCR site had difficulty discerning current radials in the southern portion of its sample grid.

The green dot in Fig. 7 indicates the position at which the radial grid was sampled, approximately 5 km offshore, for the construction of the current vector time-series shown in Fig. 8. The absence of data during the first 10 hours of this series indicates the inability of the northern MCR site to obtain reliable radial current estimates. This was due to the fact that the wind was blowing from the east, resulting in the development of a coastal boundary layer immediately adjacent to shore. This layer is typically 10 km in width, thus precluding the development of appreciable wave heights at the time-series site, only 5 km offshore. Once the wind shifted to the north, the MCR site exhibited a strong southerly flow, approximately 3% of the wind speed, consistent with the ADCP observations and the plume dynamics exhibited in Fig. 5. Later, when the wind died down, the HF current estimates again became more sporadic.

With the aerial extent of coverage and the multi-frequency measurements evident in this example, it is possible to generate current vector diagrams throughout several events for comparison with in-situ sampling of bio-geo-chemical constituents and model hind-casts.

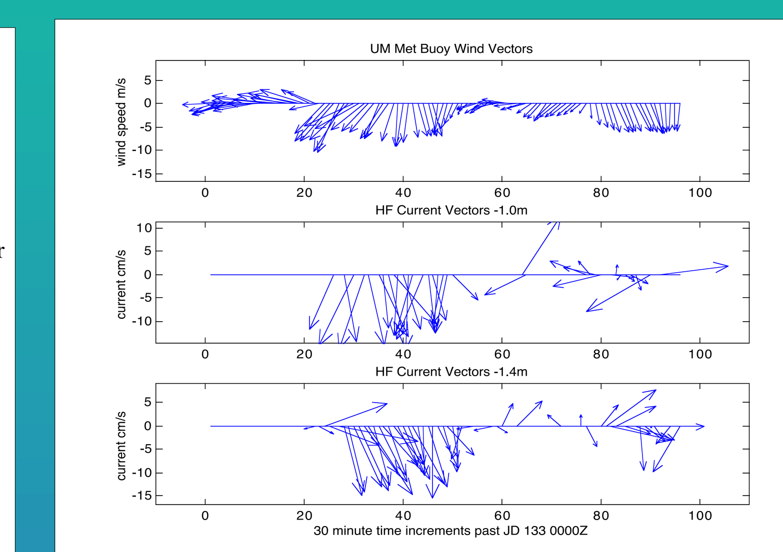

Fig. 8. Comparison of wind at UM Met buoy and current conditions at an HF Radar grid point approximately 5 km offshore of St. Joseph, April 23-24 (JD 113-114). These results compare well with the ADCP measurements shown above.

The 1999 Vernal Thermal Front

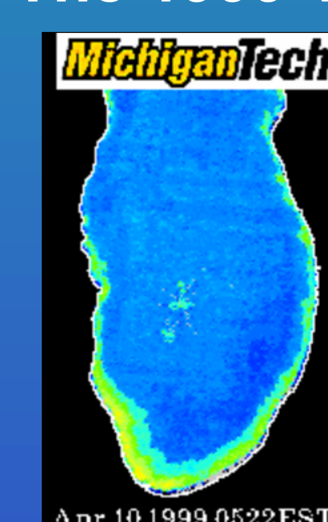

Fig. 9. AVHRR surface temperature image of southern Lake Michigan during thermal front development (JD 100).

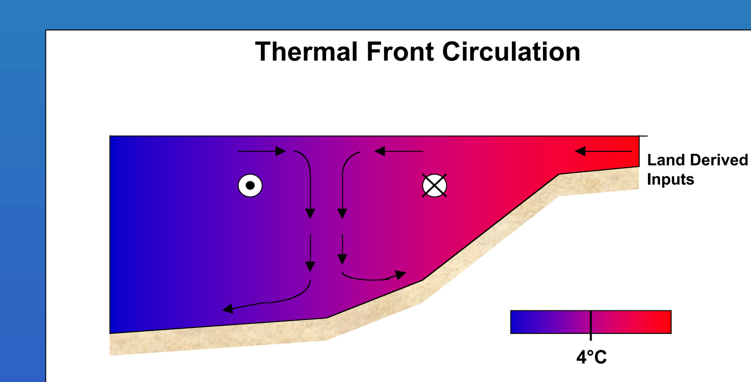

Fig. 10. A schematic of thermal front circulation showing surface convergence at or near the 4° isotherm accompanied by a strong northerly flow of the inshore waters, and a weak southerly flow offshore.

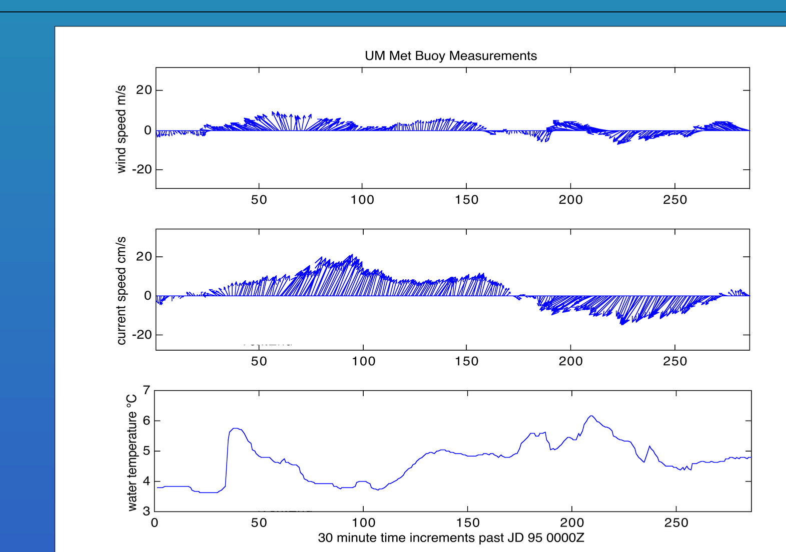

Fig. 11. Time-series of near-surface environmental conditions as recorded by the UM Met Buoy April 5-10 (JD 95-100). Notice the passing of a strong thermal gradient on April 5 under light wind conditions followed by a mixing event.

In large lakes, the spring transition from weak to strong stratification is characterized by the formation of a coastal thermal front. This transition is dominated by high gradients in the temperature, nutrient and plankton fields associated with the front. Such a thermal boundary is evident in Fig. 9. A combination of solar warming, boundary heat flux, coastal bathymetry and surface wind stress causes the frontal system to develop. Initial warming begins in the shallow nearshore waters where the offshore edge of the frontal system is marked by a nearly vertical 4°C isothermal surface separating the cold well-mixed offshore water from the warmer stratified water. As the colder offshore water warms to 4°C, the temperature of maximum density of fresh water, this leads to the formation of a locally dense lens of water. This dense water sinks to the bottom, causing adjacent surface waters to converge and inducing a rapid horizontal thermal gradient across the boundary. Based on hydrodynamic considerations for a large rotating basin subject to heating at the surface, Mortimer (1971) predicted a surface convergence accompanied by a strong northerly flow of inshore waters and a weak southerly flow offshore (see Fig. 10). This has been borne out by recent field and numerical investigations.

The UM Met buoy, approximately 5 km offshore, recorded the passage of this thermal boundary as a sharp rise in temperature during a low wind period on April 5 (Fig. 11). Following this passage of the front, a strong wind event served to mix the nearshore waters, decreasing the strong thermal gradient evident in Fig. 11. The effect of such a wind event is to broaden the frontal zone, mixing the two water bodies with subsequent re-development of the front further offshore. On April 8, a continuous shore-perpendicular CTD transect off St. Joseph showed that the 4°C isotherm was located approximately 5 km from shore. However, the well mixed deep water body, at a temperature of about 2.8°C commenced about 15 km offshore. Thus, the high winds induced a mixed frontal zone at least 10 km wide. Fig. 12 provides an MCR current radial map of currents at –1.4m effective depth at 0530Z on April 9. This diagram also shows the CTD transect and measured surface temperature gradient. It is interesting to note the evidence of convergence along a region approximately 15 km offshore at the offshore extent of the mixed zone. Also, the evidence of northerly flow of the inshore waters is consistent with thermal front theory and past measurements.

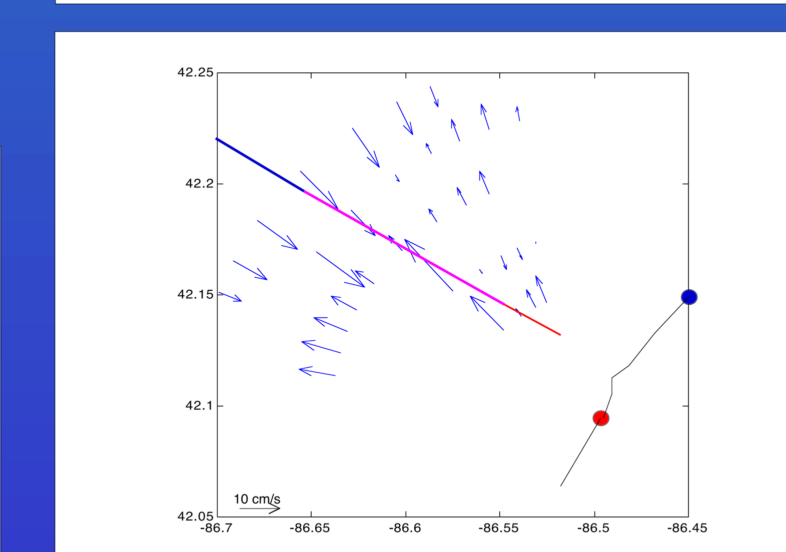

Fig. 12. HF radial currents at -1.4 m effective depth from the south MCR site on April 9 (JD 99) at 0530Z(time interval 203). The line shows the continuous surface CTD transect obtained on April 8 (JD 98). The red portion of the line is water above 4° C, blue is at or below 2.8°C and purple represents the transition zone of the front. Note the correspondence of the surface flow convergence with the thermal transition zone.