HF Radar Observations of Surface Currents on Lake Michigan During EEGLE 1999

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Abstract – The University of Michigan Multifrequency Coastal Radar (MCR) was used as part of the 1999 Episodic Events Great Lakes Experiment (EEGLE) to measure surface currents on Lake Michigan near St. Joseph, Michigan. High surface-wave loss over fresh water and generally calm wind and wave conditions during the 8-week experiment limited the radar range to less than 10 km. The radar measurements which were obtained showed good agreement (to within about 5 $\mathrm{cm\,s^{-1}}$) with nearby acoustic Doppler current profiler (ADCP) current meter measurements at 2 m depth. Measurements from the MCR, ADCP and a wind buoy are compared.

INTRODUCTION

The Episodic Events Great Lakes Experiment (EEGLE) is a comprehensive, multiyear study of the resuspension of bottom sediments during intense wind events on Lake Michigan. This process, driven by sustained high winds blowing from the north, leads to increased pollutant levels in the lake due to the scour, suspension and dispersal of heavy metals and other toxic materials from the lake bottom. The University of Michigan Multifrequency Coastal Radar (MCR) was deployed as part of this experiment to augment various *in-situ* acoustic Doppler current profilers (ADCPs), buoys, and ship observations. The radar coverage area overlays the mooring locations of several ADCP instruments to allow current maps to be constructed over the regions between the ADCP mooring locations. Two radars, operating between 4.8 MHz and 21.8 MHz, were installed at St. Joseph, Michigan on the southeast shore of Lake Michigan. One site was at lake level at the St. Joseph waterworks facility, and the other site was about 7 km away on a bluff about 25 m above the water surface, as shown in Fig. 1. Although the fresh water radar echoes were much weaker than those typically obtained over salt water, usable echoes were seen out to about 10 km range, with stronger signals from the site at water level.

High-frequency (HF, 3–30 MHz) radar systems have been used for several decades to measure surface currents in the top two meters of the ocean [1, 2, 3, 4], but they have seen very little use on fresh water. Primarily this is because the surface-wave propagation of HF signals over fresh water suffers much higher loss than over highly-conducting salt water. For instance, for 5 MHz at a range of 6 km, the loss over fresh water is nearly 40 dB more than over salt water [5, 6]. In addition, fresh-water lakes usually offer a much smaller fetch over which the wind can interact with the water surface, so the resulting waves are much smaller than in the open ocean, resulting in a smaller radar cross section and scattered signal. As a result, usable radar signals from fresh water lakes are seen only under the right conditions. In contrast, there is almost no time when scattered HF signals are completely absent from the open ocean.

A short field experiment on Lake Michigan in early spring of 1998 in moderately strong winds showed that weak but usable echoes could be obtained at 4.8 and 6.8 MHz for short ranges of less than 10 km. For EEGLE, the interesting times are precisely the times of sustained high winds from the north, and these would have a moderately long fetch on Lake Michigan, so it appeared that HF radar could contribute to EEGLE. There are some limitations, however, because the low signal levels required processing using beam formation rather than direction finding, and the limited receive antenna aperture resulted in wide beamwidths at the lower frequencies which limited the

This work was supported through the University of Michigan under NSF/OCE contract 97-26683. Radar construction was supported under ONR contract N00014-97-1-0375.

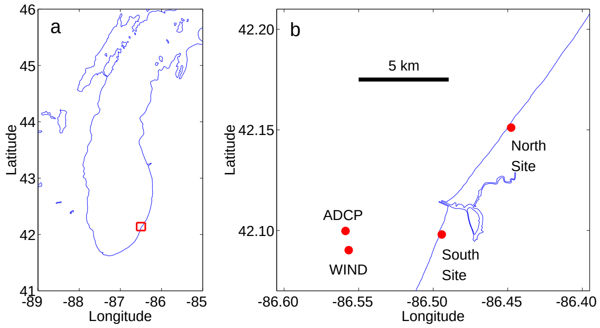

Figure 1: Overview (a) and detail (b) of the EEGLE experiment on the southeastern shore of Lake Michigan. The south site was at water level and the north site was on a bluff about 25 m above the water. ADCP and wind buoys were moored about 5 km offshore.

directional resolution. Also, the absolute currents were quite low (typically 10 cm s^{-1} or less), so the finite frequency resolution of the radar resulted in only a few frequency bins covering the expected range of currents. Finally, the EEGLE experiment occurred near the peak of the sunspot cycle, so the ionospheric conditions favored the propagation of considerable external interference from other users of the HF spectrum (point-to-point communications, broadcast, etc.), as well as occasional reflection of the HF radar signal itself because of range ambiguities for ranges greater than 135 km.

THE EXPERIMENT

The location of the experiment is shown in Fig. 1. The two MCRs were installed at the St. Joseph waterworks and at nearby Benton Harbor on a site made available by the Whirlpool Corporation. An ADCP was moored about 5 km from St. Joseph and measured *in-situ* currents at 1 m depth intervals starting at 2 m below the water surface. Winds were recorded on an offshore buoy as indicated in the figure, as well as at the waterworks site. Transmit antennas were omnidirectional, consisting of quarter-wave monopoles, and eight air-core loops spaced 6.9 m apart (0.5 wavelength at 21.8 MHz) were used as the receiving array. Signal processing used conventional beamsteering and centroid calculations to estimate currents.

During 1999, the radar experiment ran from 27 March to 18 May with the equipment operating for most of that interval. However, winds often were low and usable signals were seen for only about 200 hours during the experiment. Figure 2 shows the signal-to-noise ratio at 13.4 MHz. The “signal” was the average energy in a band of frequencies around the Bragg frequency corresponding to a current of ± 0.5 m s^{-1}, and “noise” was the average energy in a band of frequencies about 0.1 Hz wide near the Nyquist frequency of 0.7 Hz. Current estimates were attempted whenever this ratio was at least 5 dB. The radar range bins were spaced 3 km apart, with the first bin generally blocked because of overloading by the direct signal, and very little usable energy seen beyond 9 km. The best signals usually were from a range of 6 km, which is roughly the spacing between the two sites, so it is not always possible to combine the measurements from the two sites to get a total vector. The comparisons here will be between the ADCP and the radial current component from the southern site.

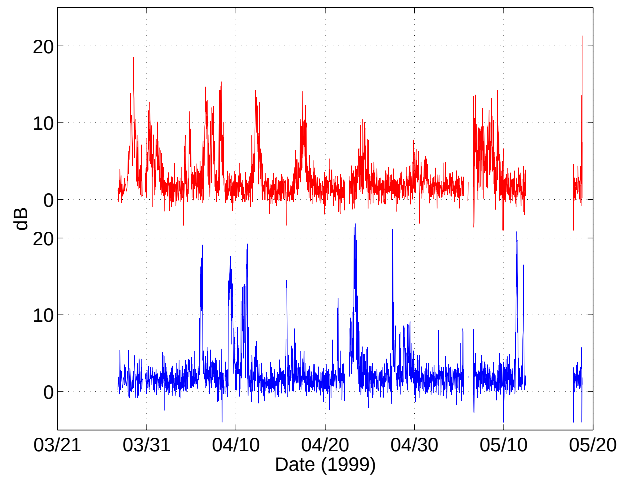

Figure 2: Signal-to-noise ratio for range bin 2 (6 km) in the direction of the ADCP at 13.4 MHz at the southern site for the entire experiment in 1999. Approaching Bragg band shown at top and receding Bragg band shown at bottom. All times are in UT.

Table 1: RMS differences between MCR and ADCP current measurements.

Freq	N_t	N_a	RMS_a	N_r	RMS_r
4.8	2150	243	0.068		
6.8	2150	339	0.057	58	0.045
13.4	2150	172	0.043	115	0.041

ADCP AND WIND COMPARISONS

Figure 3 shows a comparison of the MCR estimates of the radial component of current in the direction from the ADCP with the ADCP measurements in the same direction at a depth of 2 m. The MCR estimates are sparse because they could only be made when the SNR was above 5 dB. When they could be estimated the agreement is generally good. Note that the current magnitudes are all very small, with most values below 10 cm s^{-1}. Previous experiments suggest that differences between HF radar and *in-situ* buoys often are around 5 cm s^{-1}, so the currents here are just barely resolvable by the radar system. The HF radar measurements are averaged over a 3×3 km or larger resolution cell, while the ADCP measurements are at a specific point in this rather large resolution cell, so some difference between the two techniques for current measurement is anticipated.

Table 1 summarizes the RMS differences between the MCR measurements of the radial component of current in the direction of the ADCP, for approaching and receding waves at

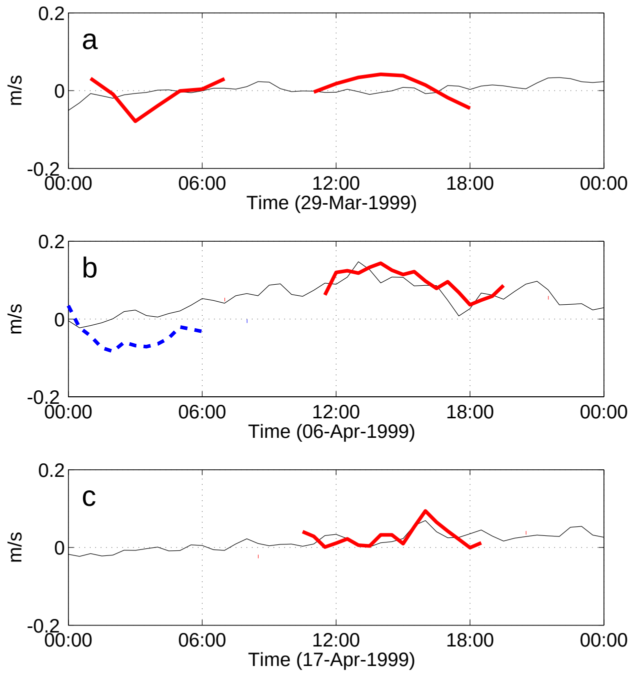

Figure 3: ADCP current component (thin lines) in the direction of the southern MCR site and the MCR estimate (thick lines) of the radial current near the ADCP using 13.4 MHz signals at the southern site on (a) 29 March, (b) 6 April and (c) 17 April 1999. MCR estimates from approaching waves are shown solid red, and those from receding waves are shown dashed blue.

the 3 lowest radar frequencies, and the corresponding current component measured by the ADCP at 2 m depth. The MCR and ADCP measurements agree to within about 5 $cm\,s^{-1}$, with somewhat better agreement at the higher radar frequencies for which the antenna beamwidth is narrower. The maximum currents measured by either method were low, usually less than 10 $cm\,s^{-1}$ with a few isolated spikes of 20 $cm\,s^{-1}$.

The wind magnitude measurements from the University of Michigan buoy are shown in Fig. 4. Usually the local winds were on the order of 6–8 $m\,s^{-1}$and only occasionally exceeded 10 $m\,s^{-1}$. Comparing Figs. 2 and 4, it can be seen that the times of higher SNR correspond roughly to times of high wind at the buoy, but the agreement is not perfect. However, the radar responds to waves that are generated by wind blowing over a long fetch, and these winds are farther away than the local wind buoy.

Summary

The MCR was used for about 8 weeks during the 1999 EEGLE experiment at Lake Michigan. Usable radar echoes were seen about 15% of the time when the wind velocity and fetch were sufficiently high. MCR current measurements during those times compared well with ADCP measurements in the radar field of view, with RMS differences on the order of 5 $cm\,s^{-1}$. Absolute currents were small, on the order of 10 $cm\,s^{-1}$ or less. The EEGLE observations were continued in the spring of 2000 under more energetic conditions than in 1999 and are expected to yield more extensive data.

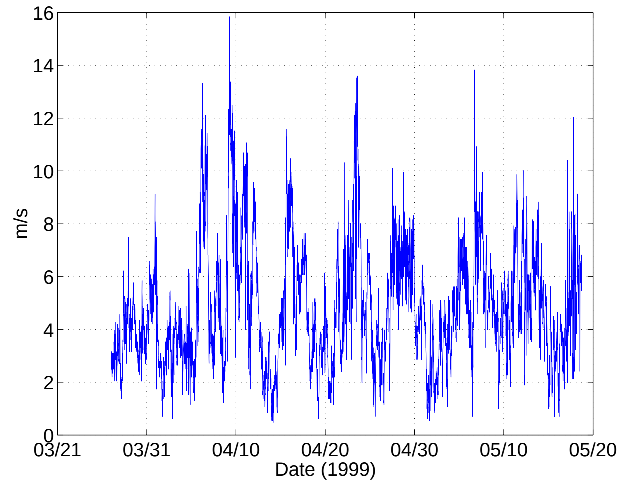

Figure 4: Wind speed from University of Michigan buoy.

Acknowledgment

The authors thank the City of St. Joseph, Michigan and specifically the St. Joseph Waterworks (Michael O'Malley, director) as well as the Whirlpool Corporation (Robert Deaton, Plant Coordinator) for allow us to place HF radar field sites on their property. The cooperation extended well beyond permission to much help in site preparation and maintenance.

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