SMAST Technical Report 09-0205

Transient Tidal Eddy Motion Project

CODAR Data Report: SPRING 2008

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1. General Information

Pairs of high frequency radar measurements, such as CODAR, have been shown to provide maps of surface currents over extensive region of the coastal ocean. This report describes CODAR-derived surface current measurements acquired during May 2008 in support of an MIT Sea Grant-supported investigation of transient tidal eddy motion east of Cape Cod in the Great South Channel section of the western Gulf of Maine (Figure 1). A University of Massachusetts Dartmouth's (UMassD) CODAR, at the National Park Service's Cape Cod National Seashore station near Nauset, MA and a Rutgers University CODAR installation at the Coast Guard station on Nantucket Island are used to produce hourly surface current maps described here. Hydrographic and Acoustic Doppler Current Profile (ADCP) measurements were also made.

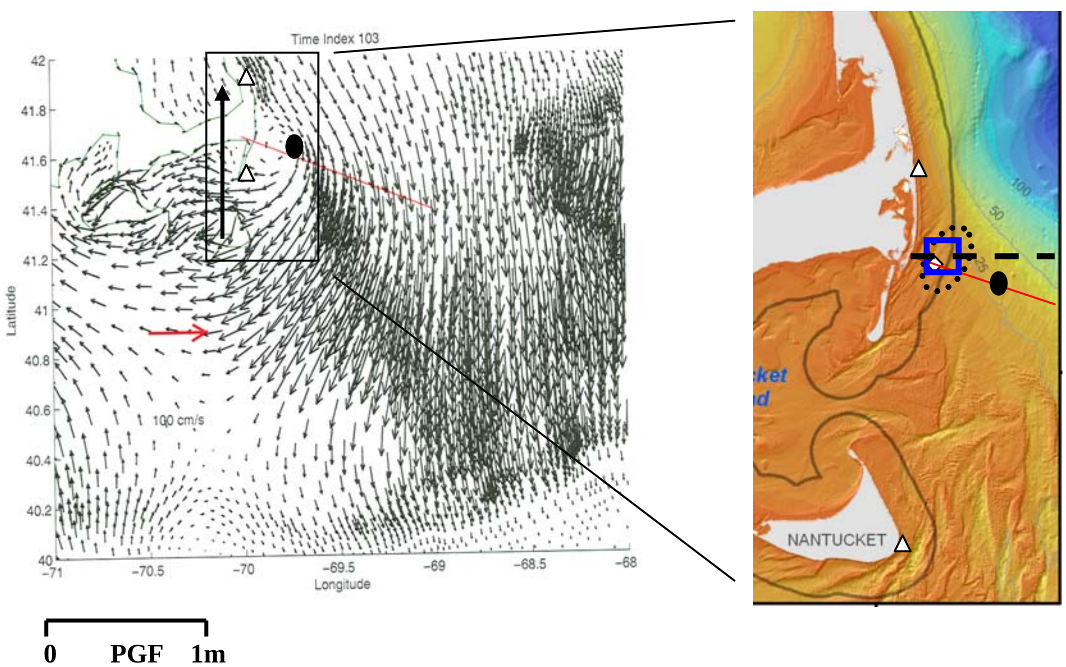

Figure 1 (right) The site of the field measurement program with elements: the Nauset and Nantucket CODAR sites (triangles), water property measurement transect (black dashed), AUV sampling box (blue), bottom-mounted ADCP/pressure 30m mooring site (diamond); and the NSD mooring site (filled oval); all relative to a schematic eddy and the reference transect (solid red) against a background of regional bathymetry (Courtesy of B. Butman USGS). **(left)** A model simulation of the full separation of the ebb flow envelop that frames a small clockwise eddy near the coast at 1.55^{hr} before the "change of tide" from ebb to flood flow. The pressure gradient force vector (PGF; northward arrow) is derived from the model sea level difference between the indicated model mesh nodes (triangles; with PGF–scale below). The current scale and reference transect are shown in red. The filled oval marks the NSD mooring site, at which proxy tidal current predictions are made (see below);

2. The Measurements

A. CODAR Surface Current Measurements

The tidal eddy motion of interest was discovered in surface current maps derived from a pair of 5 MHz long-range CODARs facing eastward from Nauset and Nantucket, MA respectively (Figure 2). The CODAR-derived surface current maps are produced as follows.

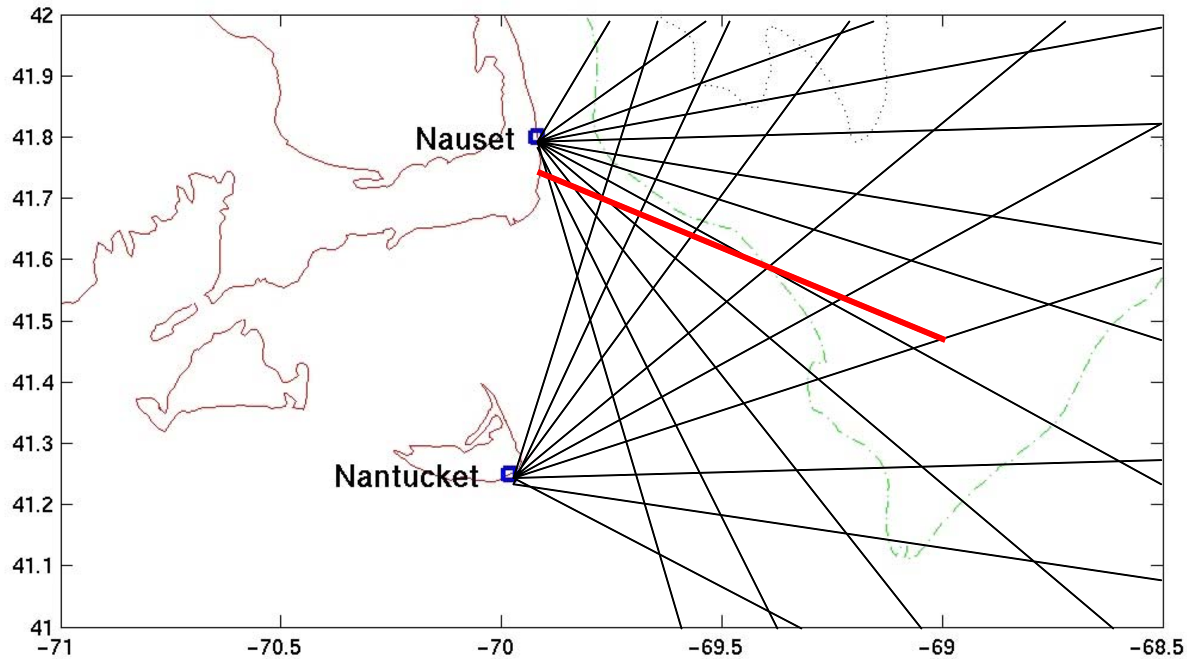

Figure 2 A schematic of radial patterns associated with the Nauset and Nantucket CODAR sites. The nominal spatial resolution of the CODAR-derived radial surface currents is 6 km. The southeastward-trending transect (bold line) is the typical trajectory of tidal eddy motion. The 100 m (dot-dash) and 200 m (dotted) isobaths are indicated.

Every second the 100-watt CODAR transmits a 40µsec sweep frequency radar pulse/blank pair eastward from Cape Cod (and Nantucket) through an approximate 150-degree azimuth. Portions of those radar transmissions are Bragg-backscattered from surface ocean waves in the "field of view" to the CODAR site receiver. The *nominal* radial range cells for a 5 MHz CODAR are about 6km is between about 5 km beyond the beach out to about 200km (~100nm). With an approximate 15^{o} angular resolution, a 5 MHz CODAR site has an offshore array or "grid" of 330 curvilinear cells (average size of 6km x 6km) from which to receive backscatter signals. While this nominal coverage/resolution for a CODAR site may seem good for a lot of applications, operationally the CODAR domain-coverage is highly variable; depending on local wave and electromagnetic propagation conditions (e.g., Figure 3) as discussed below.

The radial components of the ocean surface velocity are estimated along each of about 10 radial directions by the CODAR technology which uses the Doppler frequency-shift in the Bragg-backscattered signal (Crombie, 1955; Barrick, 1972; Barrick et al., 1977). Because the transmitted energy is backscattered from surface gravity waves, the 5 MHz CODAR radial current estimates represent a weighted average of the currents within the upper one meter of the water column (Stewart and Joy, 1974).

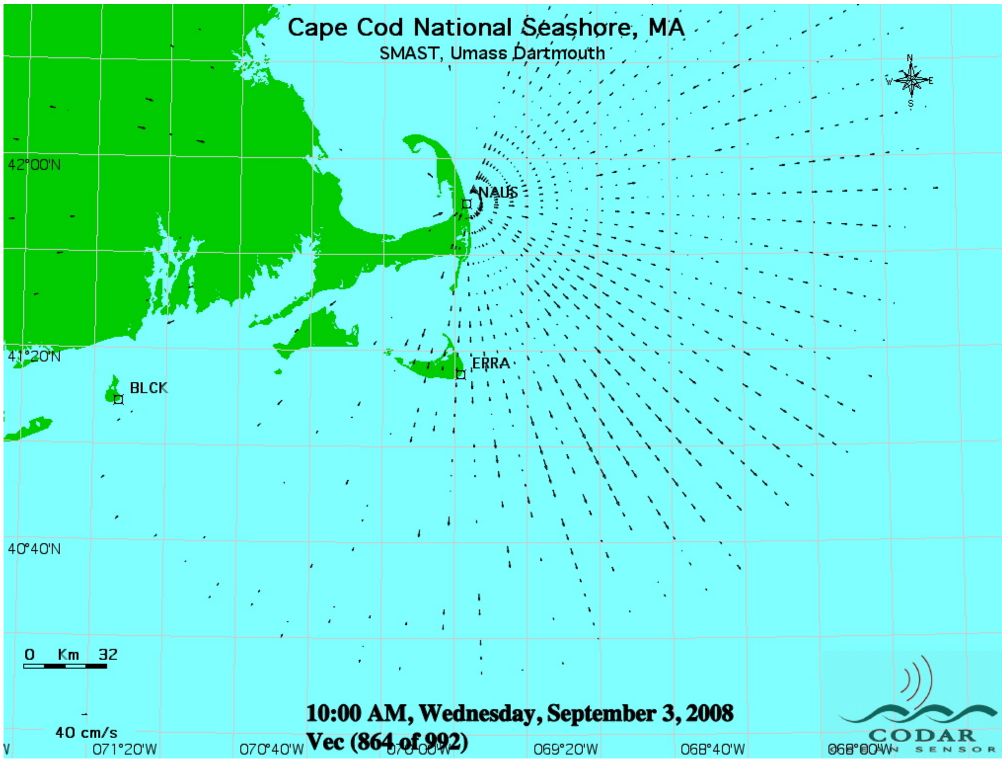

Figure 3 A typical radial surface current grid pattern (black arrows) for the SMAST CODAR installation at the National Park Service's Cape Cod National Seashore in Eastham, MA.

The radial currents in the overlap region offshore and between two adjacent CODAR sites (see Figure 2) are geometrically-resolved (see Figure 4), using the CODAR Ocean Sensors software package, into an rectilinear array of total surface current vectors.

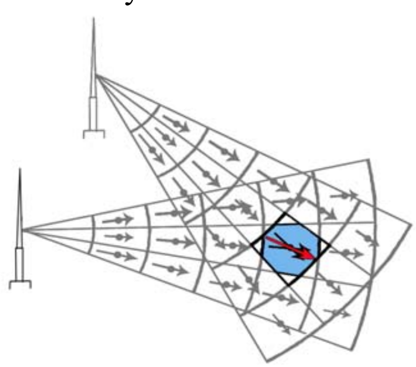

Figure 4 Total current vectors (red) are resolved from the measured radial currents (gray) from pair of CODAR sites.

However in practice, the processing of 1 second backscattered returns from the ocean is a very noisy business. Experience (Kohut and Glenn, 2003) has shown that the noise in the returned radar signal can be reduced sufficiently with an hour of averaging to produce meaningful radial surface current estimates with statistical uncertainties of about ±5 cm/sec.

This total current vector resolution process introduces more uncertainty into the CODAR surface current estimates beyond that statistical uncertainty associated with backscatter alone. A few of the other factors introducing uncertainty in CODAR-derived current estimates include, uncertain knowledge of the antenna beam pattern, geometric dilution of precision (GDOP) due to radial current vector intersection angle variation, and meteorological conditions. These different factors contributing to CODAR surface current estimate uncertainty are discussed next.

Antenna Pattern Calibration: The uncertainty of surface radial currents derived from an individual CODAR stations depends on how well the shape of the antenna pattern for that particular site is known. Thus an antenna beam pattern (ABP) calibration was conducted for the Nauset site according to the protocol presented in Appendix. The measured antenna pattern is shown in Figure 5. The variations in the loops affect the accuracy of the current estimates including both the bearing and magnitude. The bearing is determined by comparing the returned signal received by the two loops so variations in the pattern from the ideal would result in the system recording the incoming signal to be coming from a different direction. Once measured, the "real" antenna beam pattern is then substituted for the default "ideal" antenna beam pattern that is used by the CODAR site computer to produce more accurate radial surface current estimates (e.g., Figure 3).

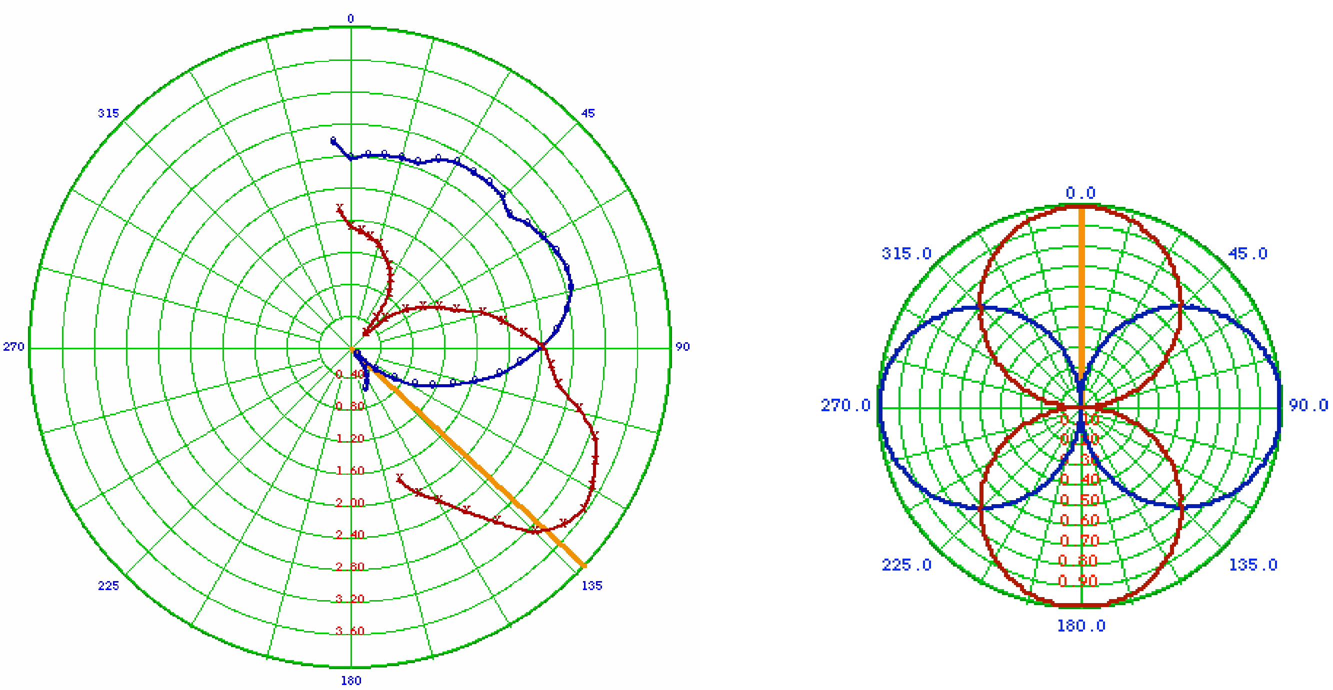

Figure 5 The Nauset CODAR site antenna pattern derived from the data collected during an on-beach calibration (left) and an ideal pattern (right), orange line shows the reference angle. (Graphic is courtesy of CODAR Ocean Systems).

Geometric Dilution Of Precision (GDOP): However, there is current estimate uncertainty due to many factors with this resolution process. The GDOP part of that uncertainty depends solely on the angle between the radials from the two CODAR stations (Barrick, 2006). Since the geometry of the radials in the joint domain of a pair of CODAR sites is fixed, the normalized GDOP uncertainty field can be known apriori (Chapman et al., 1997). More specifically, the normalized GDOP error coefficients for the respective northward and eastward velocity components are:

$$\sigma_n /\sigma = [2\ (\sin^2\alpha\ \sin^2\theta + \cos^2\alpha\ \cos^2\theta)/\ \sin^2\ (2\theta)]^{1/2}$$

$$\sigma_e /\sigma = [2\ (\cos^2\alpha\ \sin^2\theta + \sin^2\alpha\ \cos^2\theta)/\ \sin^2\ (2\theta)]^{1/2}\ ;$$

where σ is the statistical uncertainty of the radial current components (assumed to be equal here); α is the average angle (clockwise with respect to east) of the 2 CODAR site radial directions; and 2θ is the relative angle between the 2 CODAR site radials that are being resolved into total vectors.

The skill/uncertainty in resolving the total current vector from radials (each with their own measurement uncertainly) varies with the relative angular orientation of the radials; with perpendicular usually best and parallel being the worst. One region in the coverage area has especially large errors both GDOP and otherwise, is the area directly between the two CODAR stations, referred to as the baseline, where the radials are not only parallel, but in directly opposite directions. The GDOP-related error is nearly infinite and it is impossible to calculate a two dimensional vector in such situation with any precision

The normalized GDOP uncertainty field for the Nauset-Nantucket CODAR domain is shown in Figure 6. To obtain the uncertainty distribution for the total current distribution for any one hourly map (i.e., realization), the GDOP uncertainty error coefficients for northward (σ_n /σ) and eastward (σ_e /σ) vector components are multiplied by the statistical uncertainty (or standard deviation σ) of the corresponding current estimate. Estimating σ is discussed next.

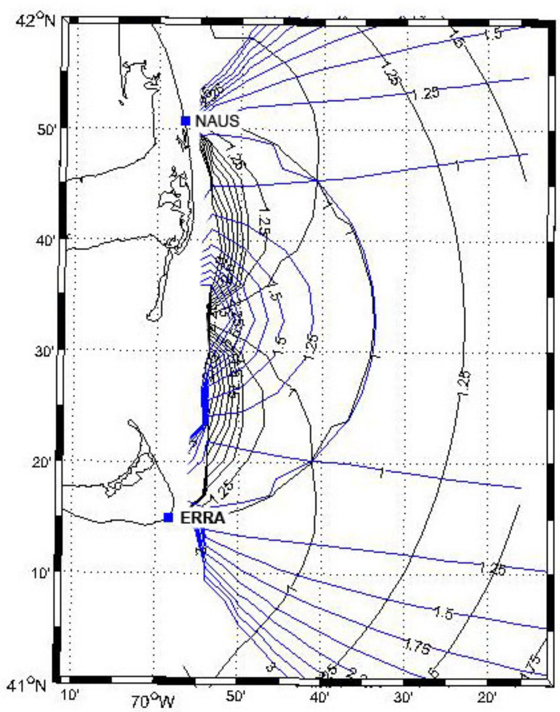

Figure 6 The GDOP error coefficient distributions for the northward (black) and eastward (blue) current components of the total current derived from the associated Nauset (NAUS) and Nantucket (ERRA) CODAR site radial current vectors.

CODAR Coverage Variability: In the real world, the CODAR receivers are not able to distinguish the Bragg-backscatter signal relative to a time-space variable background noise in each of the curvilinear cells all the time (Figure 3) In our western Gulf of Maine study region, the weather has a particularly strong effect on the numbers of current estimates from a particular cell. Rain and high sea states raise the background noise level relative to the backscattered signal. This condition inhibits the resolution of the Doppler peaks and thus the current estimates. Conversely, during times with low sea states (with wave heights < 0.6m), the backscattered signals are not strong enough to be resolved from the low background noise to estimate currents.

The variation in CODAR-derived current coverages is illustrated in Figure 7. The better coverages for the 29 and 30 May 2008 above are more typical than the low ones encountered for our 6 and 7 May 2008 field exercises below. The better the coverages the lower the noise levels from which the Doppler peaks are resolved.

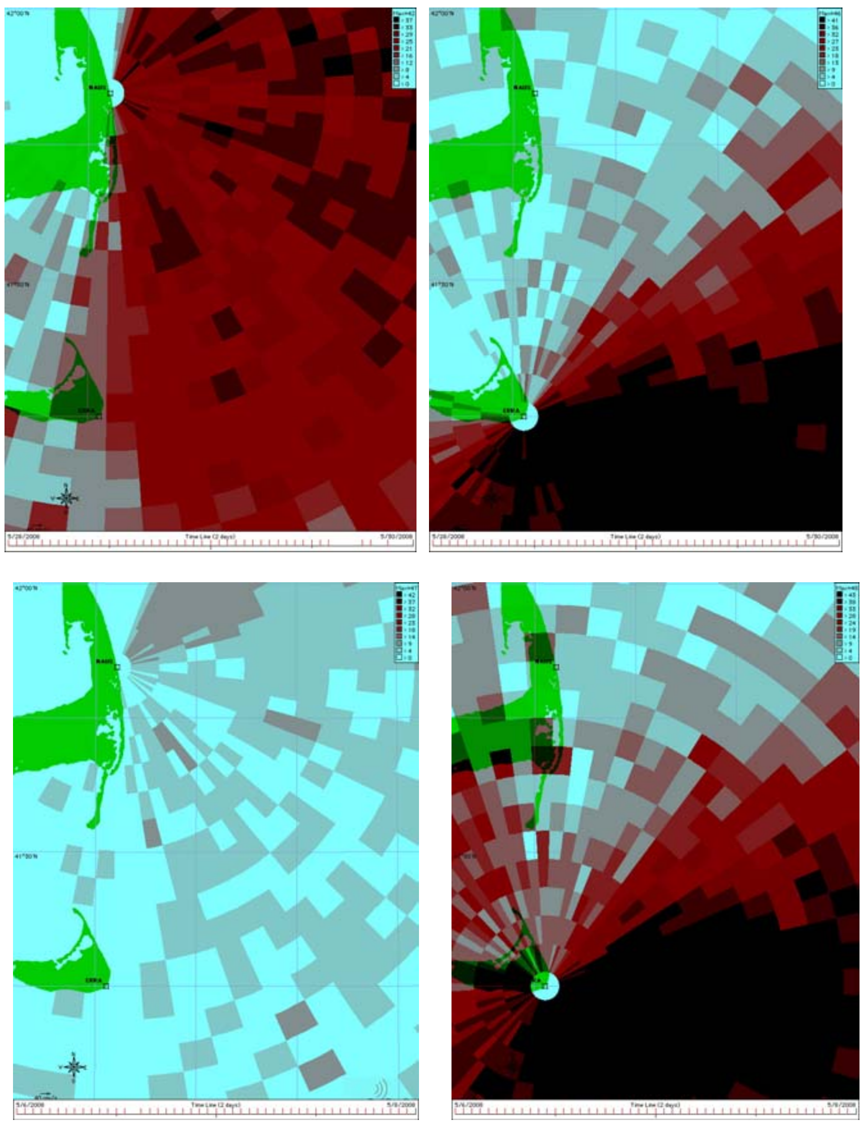

Figure 7 The distribution of CODAR radial surface current estimates per grid cell with darker reds corresponding to higher numbers (see upper right legend). The coverages for **(left)** Nauset and **(right)** Nantucket on **(upper)** 29-30 May 2008; and **(lower)** 6-7 May 2008 .

The quantitative statistical uncertainty associated with coverage return is graphically illustrated for each total current estimate displayed in Figure 8. Hourly surface current maps like this are displayed on the screen of the CODAR Combining Computer in our OCEAN Observation Laboratory (OCEANOL). On these maps are surface current estimates that are color-coded according to the total standard deviation of the returns that went into that current estimate. In this depiction, blues indicate higher confidence corresponding to lower standard deviations (or noise). Such maps are useful for rapid diagnosis of reduced coverage due to weather or a station operational problems (such as in the case of a lightning strike); allowing for prompt repairs and minimized downtime.

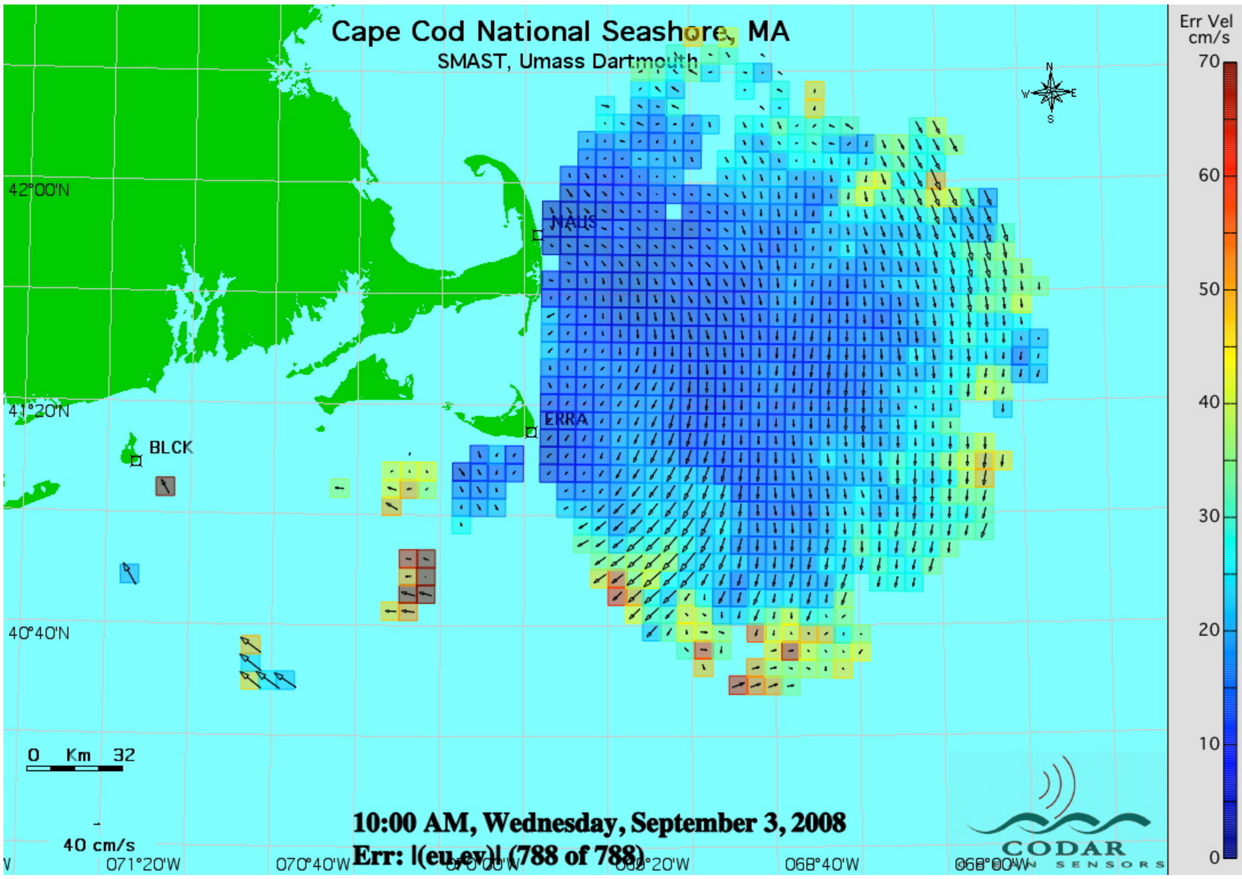

Figure 8 An example of an hourly surface current map that is displayed on the screen of our CODAR Combining Computer. The vector in each of the rectilinear grid cells indicates the current magnitude and direction, while the color indicates the standard deviation of the backscatter returns (legend to right) that went into its computation.

3. The Data

The following hourly CODAR-derived surface current maps were obtained during the 6 and 7 May 2008 field exercises; and the day before our 30 May field exercise.

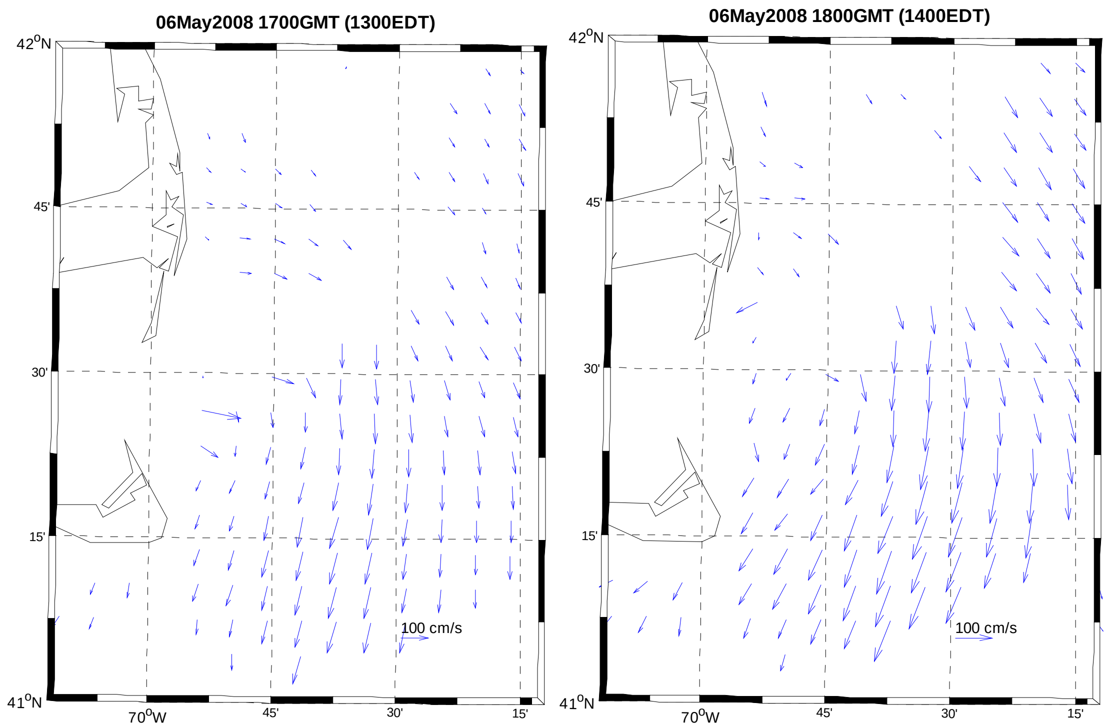

Figure 8a The CODAR-derived surface current field for 1700 & 1800 GMT 6 May 2008.

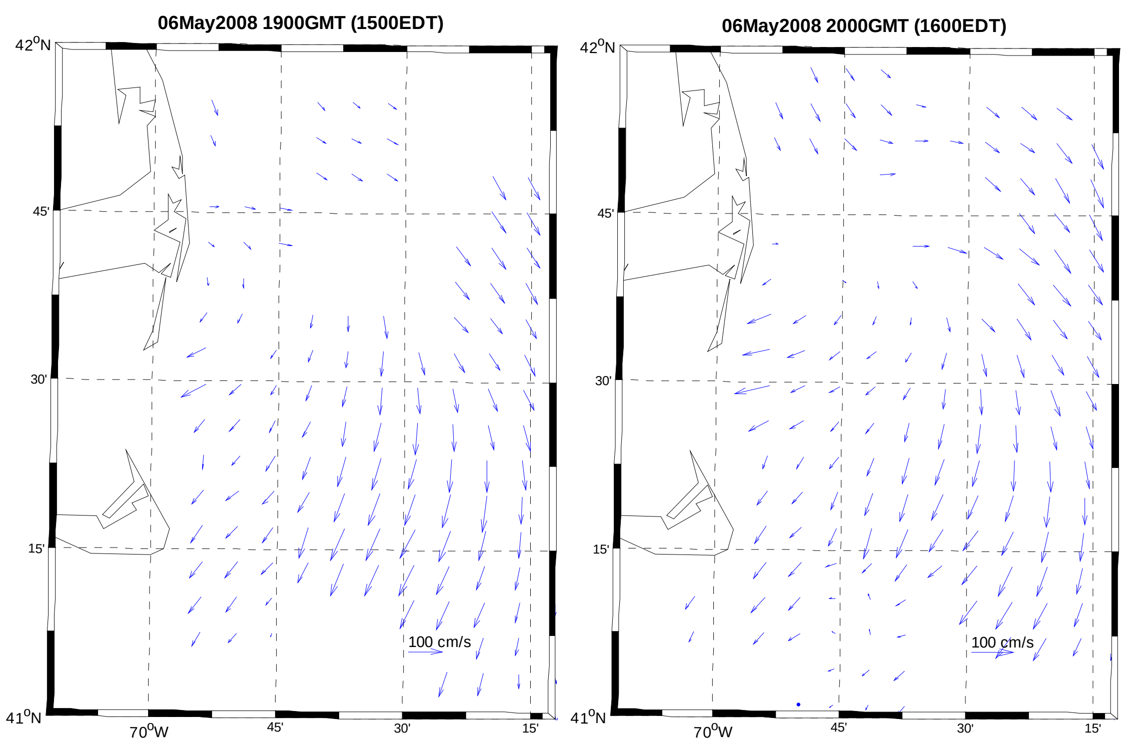

Figure 8b The CODAR-derived surface current field for 1900 & 2000 GMT 6 May 2008.

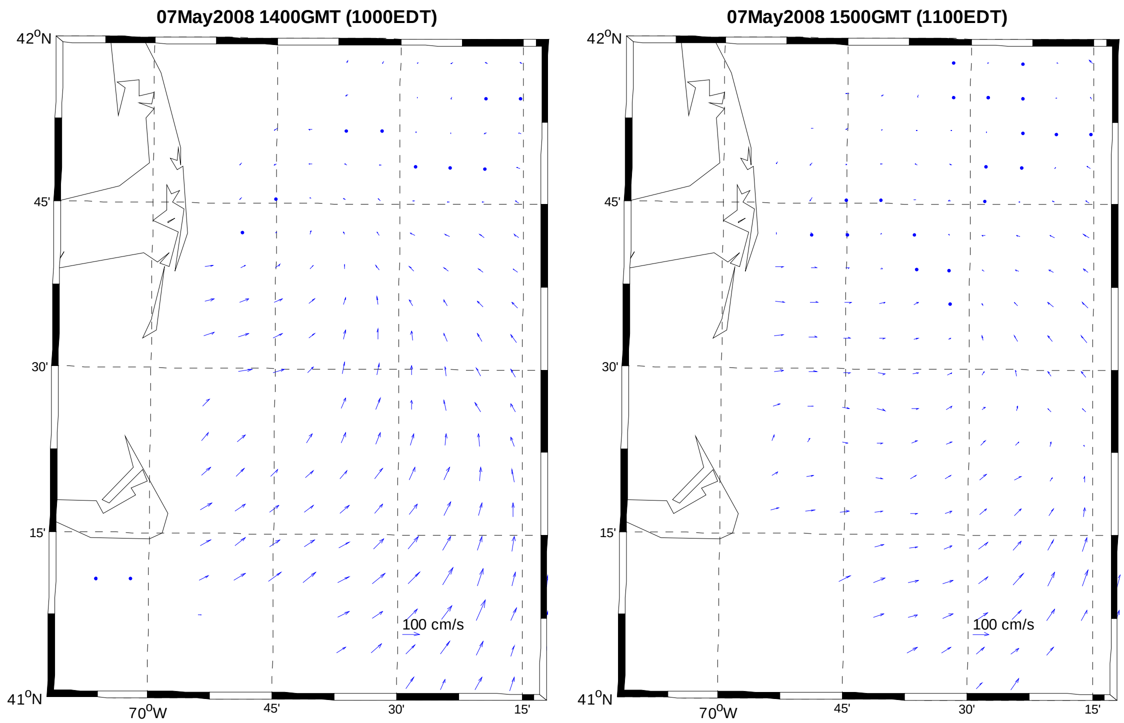

Figure 9a The CODAR-derived surface current field for 1400 & 1500 GMT 29 May 2008.

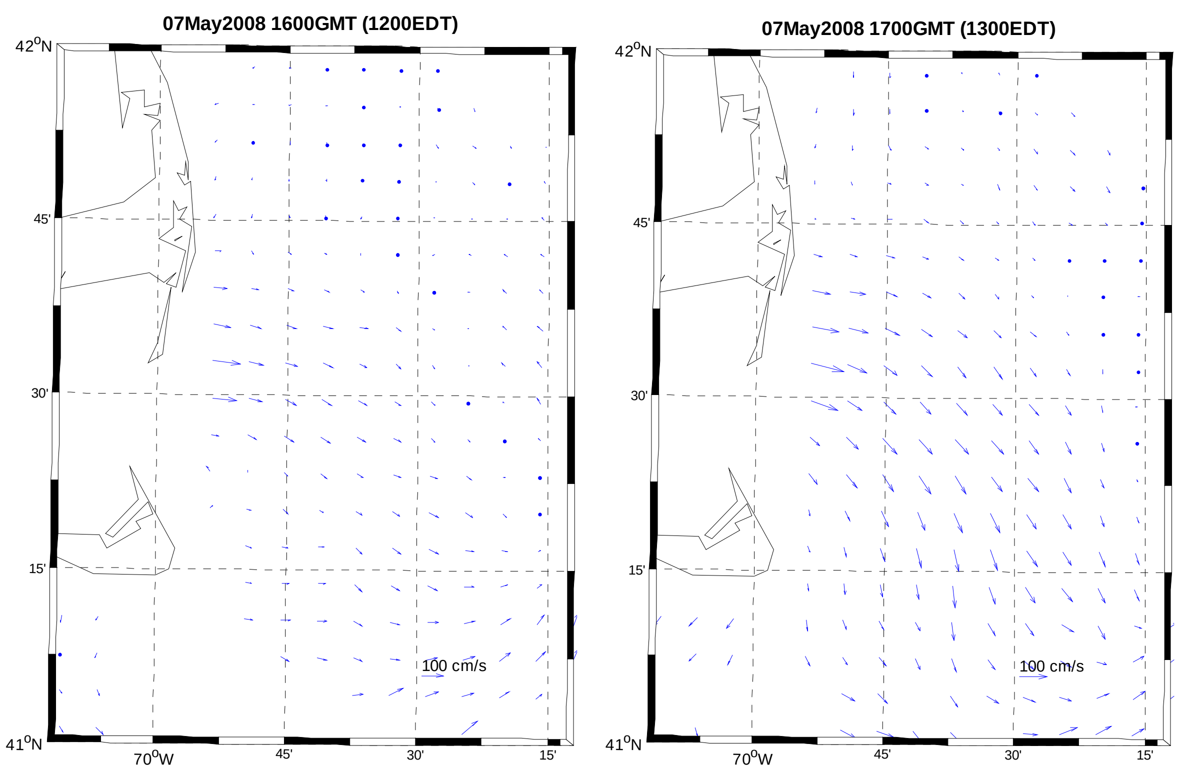

Figure 9b The CODAR-derived surface current field for 1600 & 1700 GMT 29 May 2008.

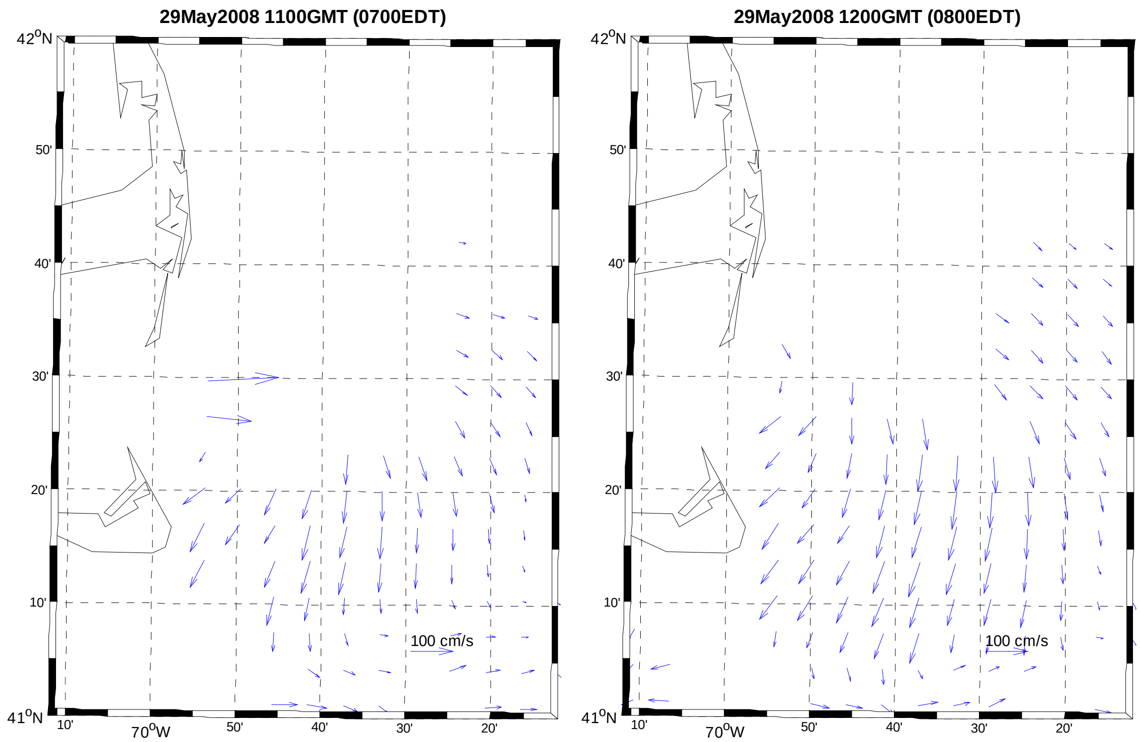

Figure 10a The CODAR-derived surface current field for 1100 & 1200 GMT 29 May 2008. These CODAR maps in Figure 10a depict the approximate currents at 1150 & 1250 GMT on 30 May 2008

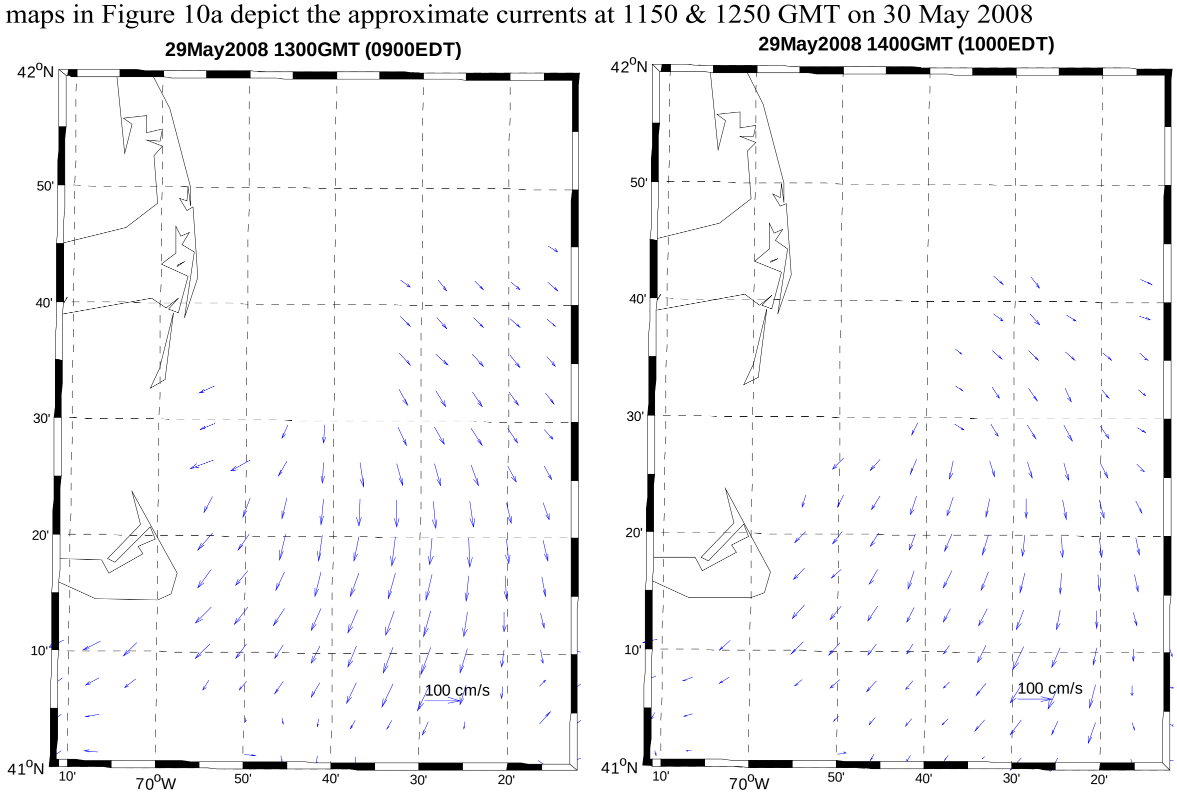

Figure 10b The CODAR-derived surface current field for 1300 & 1400 GMT 29 May 2008.These CODAR maps depict the approximate currents at 1350 & 1450 GMT 0n 30 May 2008.

APPENDIX : CODAR Antenna Beam Pattern Calibration

The uncertainty of surface radial currents derived from individual CODAR stations depends on how well the shape of the antenna pattern for that particular site is known. Thus CODAR site antenna pattern calibrations are performed using the following calibration protocol:

1. The CODAR site transmitter is turned off;
2. A portable transponder/antenna is set to the frequency of the site;
3. The portable transponder is moved in approximate semicircular tracks at some distance from the CODAR site; sending its signal to the CODAR receive antenna from a location that is recorded precisely by a GPS unit;
4. The calibration can be done using a boat and/or by walking the semicircles on the nearby beach. Ideally, both walking and boat calibrations are used to get the maximum amount of data over the largest possible area.
    - The advantage of the boat method is that it can get farther out (1-2 kilometers) from the CODAR site; allowing more data and thus a finer resolution of the measured antenna pattern;
    - Walking calibrations are similar to a boat calibrations, have the disadvantage of fewer data and thus a potentially reduced antenna pattern resolution. There is also the possibility of more interference from local sources such as buildings or other antennae. The advantage of the walking calibration is that a more complete arc can be covered than with a boat that is limited by shallow water near the beach;
    - Normally four semicircular tracks are made with the transponder/GPS;
5. The GPS tracks are uploaded using the CODAR SeaSonde software which combines the tracks with the time- series data collected by the CODAR receiver to determine the antenna beam pattern of the site. The software plots the shapes of the four loops of the receive antenna as well as allows for correcting for errors in the calibration tracks.

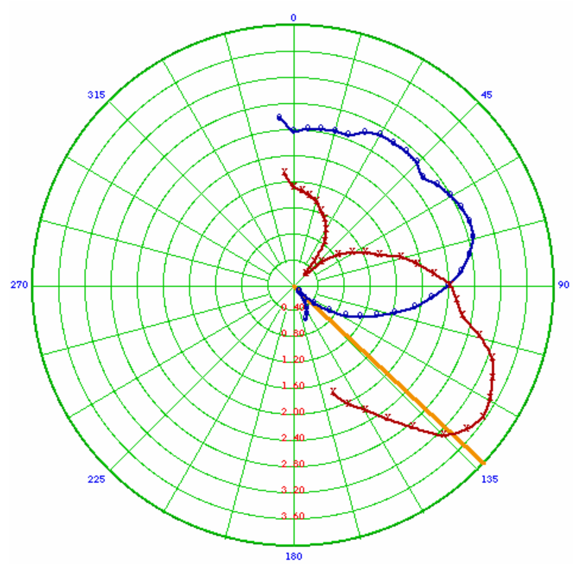

Figure A-1. The Nauset CODAR site antenna pattern derived from the data collected during an on-beach calibration. (Courtesy of CODAR Ocean Systems).

4. Acknowledgements

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5. References

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