SEACOOS HF RADAR

The largest single equipment investment made by SEACOOS has been the purchase of HF radar. These systems hold great promise for delivering synoptic maps of ocean surface currents in the coastal ocean, out to as far as 150 km from the coastline.
In this context, long-term goals of using HF-radar technology in SEACOOS seek to improve our understanding of cross-shelf exchange processes and the ocean response to atmospheric frontal passages and storms. To address these goals, the HF-radar plan has three specific objectives:

1. Deploy and network coastal HF radars along for near real-time measurements of surface currents;

2. Establish experimental Radar Test Beds (RTB) where several radars are simultaneously deployed and are sampling the same regime simultaneously that includes in situ measurements from moorings and ships; and,

3. Disseminate raw and processed data via the World Wide Web.

For Phase-I implementation of the plan, three HF radars: North Carolina Shelf, West Florida Shelf (WFS) and East Florida Shelf (EFS) including developing RTB where multiple radars have been deployed to examine the advantages and disadvantages of the various radars. Phase-II plan encompasses deployment of HF Radar technology in South Carolina and Georgia.

Radar Test Bed Concept:

Radar systems have not been operating on a long-term basis, hence our decision to thoroughly test the adequacy of HF Radar technologies to perform in the southeast United States. In a broader context, we sought to develop a consistent strategy using *in situ* measurements with HF radars technologies, which is consistent with Ocean.US policy. Central to this theme, there is a requirement to understand temporal and spatial sampling issues for each HF surface current radar within the framework of radar test beds (RTB) defined as:

A coastal oceanic regime with large surface current signals with multiple scales and fronts that are resolvable in both space and time by the radar. In these regimes, the acquisition of long-time series of surface measurements are important to characterize advantages and disadvantages of coastal HF radar systems in mapping the vector surface current field in near-real time. The resulting statistics and analyses should be presented to the Ocean.US coastal ocean community in independent, unbiased reports and manuscripts for the purpose of understanding the capabilities of HF radar systems currently on the market. This approach in SEACOOS seeks to serve the coastal ocean community.

In addition to uncertainties about long-term performance, we also chose to compare the two basic types of HF radar available: direction-finding (DF: principle vendor is CODAR Ocean Sensors) and beam-forming (BF: available as the Wellen Radar, or WERA, sold by the Helzel Intelligente in

Hamburg, Germany). Both yield radial velocity estimates from a single installation (in a typical configuration) and the resulting Doppler spectra, but measure the backscattered surface signals in differing ways. The direction-finding system has seen wide use in recent years in coastal US waters and is viewed as a nearly turn-key system, whereas the BF system has only recently been marketed but can provide better spatial and temporal resolution of the surface currents and may also produce reliable estimates of the directional surface wave field (i.e. typically over half the surface current grid) by inverting the second-order returns in the Doppler spectra. A March-April 05 experiment is planned to test wave algorithms using the WERA-derived data in collaboration with colleagues from Europe (University of Sheffield, University of Hamburg) with a Tri-axys wave buoy from Georgia Tech and several acoustic Doppler current profilers (ADCPs).

Three SEACOOS groups now have operating systems: the University of Miami (WERA) on the EFS, the University of North Carolina at Chapel Hill (CODAR) on North Carolina Shelf, and the University of South Florida (CODAR) on the WFS. A fourth system (Phase –II) is being purchased in year 3 jointly by the University of South Carolina and the Skidaway Institute of Oceanography (TBD). Initially a side-by-side comparison of WERA and CODAR on the WFS was planned, but this unfortunately never occurred in full because of permitting and instrument delivery delays. Sequential operation of the two systems within a footprint that included the COMPS ADCP area indicated RMS differences between *in-situ* and remote sensed surface currents of 5-6 cm s^{-1} for the WERA and 7-10 cm s^{-1} for CODAR. The cause of the larger RMS differences with CODAR is not entirely clear but coarser resolution (and hence greater difference in sampling volume) is certainly one factor. Notwithstanding, these technology issues still need to be explored in support of the RTBs and Ocean.US. We briefly present the status of the three SEACOOS operating systems below.

HF Radar on the Outer Banks of North Carolina:

A CODAR Ocean Sensors Long-Range HF Radar was installed along the Outer Banks in late summer 2003 and has been operating more or less continuously since that time. Two antenna sets are deployed on the Outer Banks, one at the US Army Corps of Engineers Field Research Facility (FRF) in Duck (June, 2003), the other at the US Coast Guard Station at Buxton (August, 2003). Both sites have considerable man-made structures, which complicates the deployments but provide needed power and communications infrastructure. The FRF site has been relatively problem free (save for communications problems) and the installation has only required occasional servicing (an antenna relocation following Hurricane Isabel in late 2003). The Buxton site has been much more problematic and has required regular maintenance as a result of initial permitting issues (with the National Park Service) and because of severe erosion at the site beginning in early summer 2004. Coverage has varied widely. The variability can be attributed, in part, to changing antenna locations, radio interference, and ocean conditions, but it is now clear that both sites, at these frequencies (4.5-5 MHz) suffered from moderate to severe noise contamination. Recent software upgrades that enable new visualization tools have allowed us to begin a thorough investigation of this problem. We are first documenting the nature of the noise and its variability in time and with receive frequency.

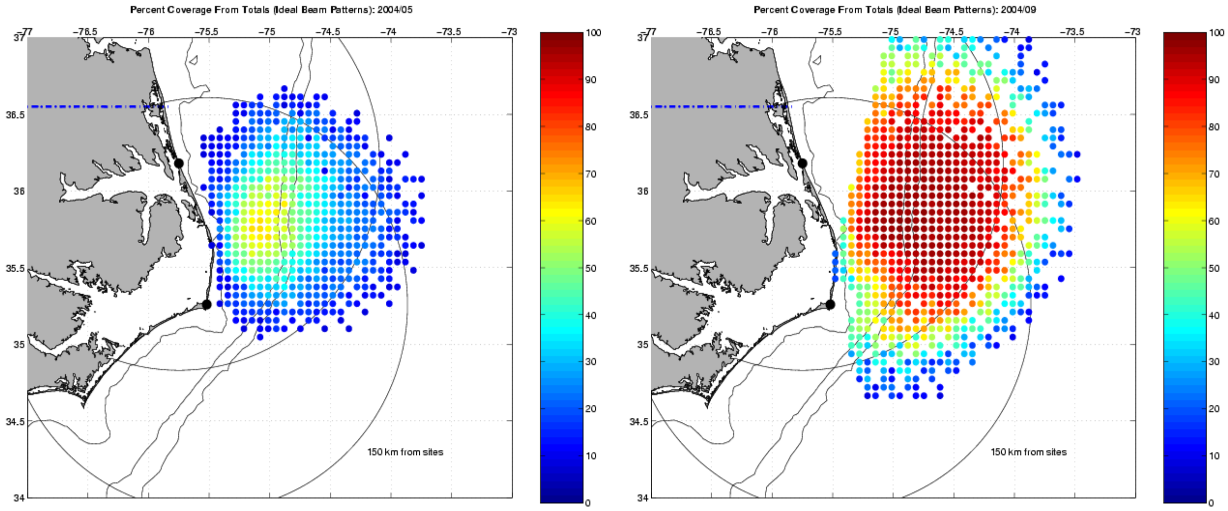

Figure 1: Percent coverage maps for May (left) and September (right) 2004 are markedly different.

Despite these challenges we have been able to produce maps of ocean surface currents off the Outer Banks that include at least the landward edge of the Gulf Stream with some regularity (Figure 2). Initial quality assessments suggest the system captures the subtidal along-shelf flow field reasonably well but tends to under-predict cross-shelf currents. The spatial variation in tidal currents on the shelf is reasonably well captured and compares favorably with model predictions and previous field results with the exception that the velocities are under estimated by 10-30%. This is likely a function of the degree of temporal averaging employed in the processing. We are exploring whether it is best to adjust the processing scheme or can correct the magnitude *a posteriori.*

HF Radar in the Straits of Florida (EFS):

The University of Miami uses the WERA HF radar system. The WERA system transmits a frequency modulated continuous wave (FMCW) chirp and avoids the 3 km blind range in front of the radar. The horizontal resolution of WERA is a function of the chirp characteristics as listed in the Table for both a high-resolution and long-range version. For a transmission frequency of 16 and 30 MHz, Bragg wavelengths are 9.4 and 5 m, respectively. The transmitter is arranged to encompass about a 120 deg swath. WERA also has the flexibility to be configured into a direction finding array (such as CODAR) where 4 antennae may be set up in a square or a linear array can be set up consisting of 4n antennae or channels using beam forming techniques (We have been testing the direction finding mode at the US Navy Test Facility in Ft. Lauderdale with mixed results).

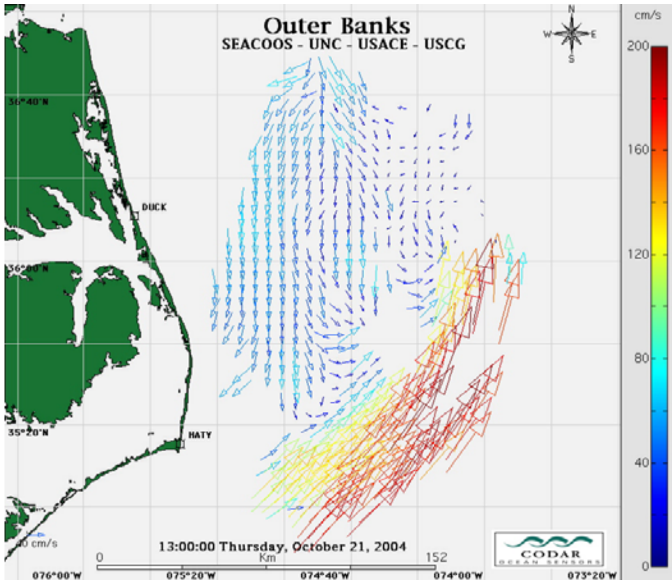

Figure 2: Surface current map from mid-day, October 21, 2004 revealing the location of the Gulf Stream and vigorous southward flow on the shelf.

While the cited range for WERA (16 MHz) is 80 km in beam forming (BF) mode (linear array), the EFS deployment is actually getting ranges of almost 100 km at least 50% of the time. The bin resolution is currently set at 1.2 km, however, WERA can go down to 750 m since bandwidth has been approved by the Federal Communication Center (FCC). Temporal sampling can be as low a few minutes as the system is FMCW as opposed to a pulsed radar (i.e. OSCR). This sampling feature makes WERA particularly attractive in high current gradient regimes where time scales of surface current variability are less than an hour as shown in Figure.3. Note the anticyclone on the east side of the Florida Current jet axis. These coherent ocean features tend to be transient as they advect through the radar domain, consistent with their known dynamics.

Capabilities of the WERA system

	High-Resolution	Long-Range
Operation range (km)	45	80
Range cell resolution (km)	0.3-0.6	0.6-1.2
Measurement depth (m)	0.4	0.8
Measurement cycle (min)	< 10	< 10
Radial current (cm s^{-1})	2	2
Vector current (cm s^{-1})	5	5
Vector direction (°)	± 3	± 3
Operating frequency (MHz)	30	16
Transmit elements (Yagi)	4	4
Receive elements (BF)	8-16	8-16
Receive elements (DF)	4	4
Transmitter Peak Power (W)	30	30

Rosenstiel School of Marine and Atmospheric Sciences is currently operating three WERA HF radars in Key Largo, Key Biscayne (Crandon Park) and Ft. Lauderdale. The deployments were completed in summer 2004. The radars provide measurement of currents on the ocean's surface over a large area of the ocean off Miami, FL. The image below depicts hourly averaged surface currents plotted on a 2.4 km grid. Our working range is reduced during periods of strong winds of 22 m s^{-1} and high waves as observed during hurricane Jeanne.

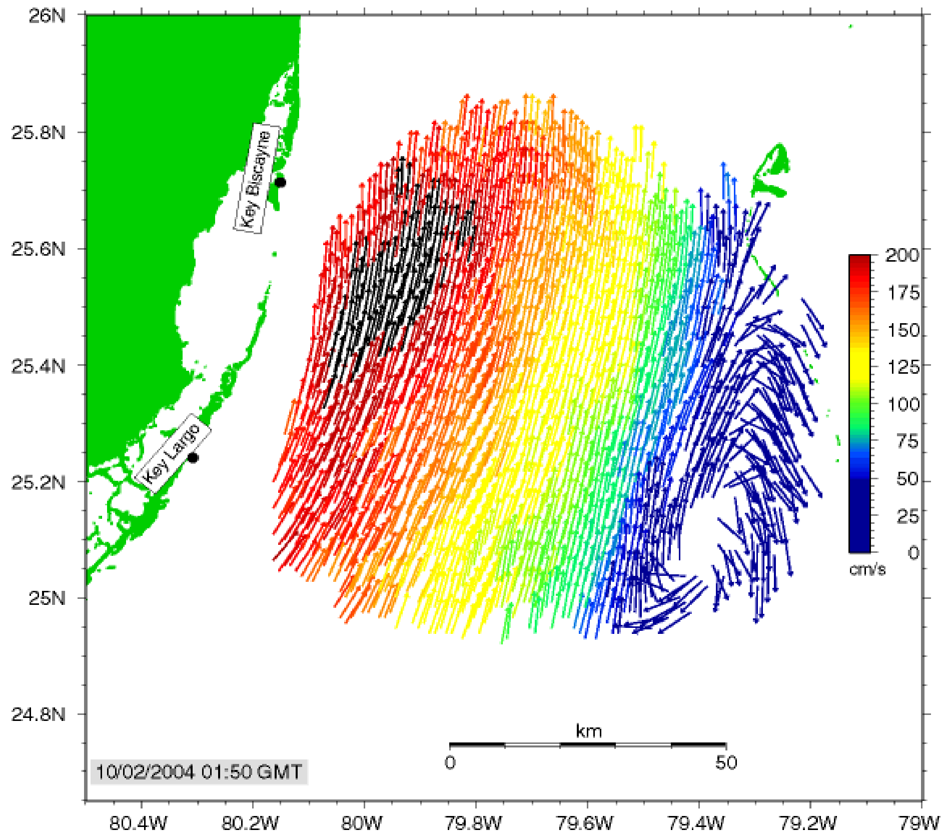

Figure 3: WERA-derived surface currents in the Straits of Florida when an anticyclonic eddy was observed on the right side of the Florida Current jet. Color refers to strength of the current in cm s^{-1}.

HF Radar on the West Florida Shelf (WFS):

The University of South Florida is operating CODAR at two sites (Reddington Shores and Venice). Similar to other installations, permitting has been a significant challenge on the WFS and delayed installation many months (Figure 4). Special accommodations were made at the Reddington Shores location to appease the county park by camouflaging the transmit antenna as a flag pole and constructing a small building for the electronics that mimicked existing structures at the site, delaying installation until September 2003. The Venice installation, coordinated with Rutgers University, was delayed for more than 1 year due to permitting issues associated with siting on the USCG station. It was finally installed in April 2004. Both sites are currently functional but suffered downtime in the summer due to lightning strikes.

Preliminary comparisons of radial velocities with in-situ ADCP observations suggest RMS errors of 7-10 cm s^{-1} for the Reddington Shores site. Similar to the NC installation, coverage has been highly variable in time. Nevertheless results indicate a distinct transition in the flow field between the inner and middle shelf.

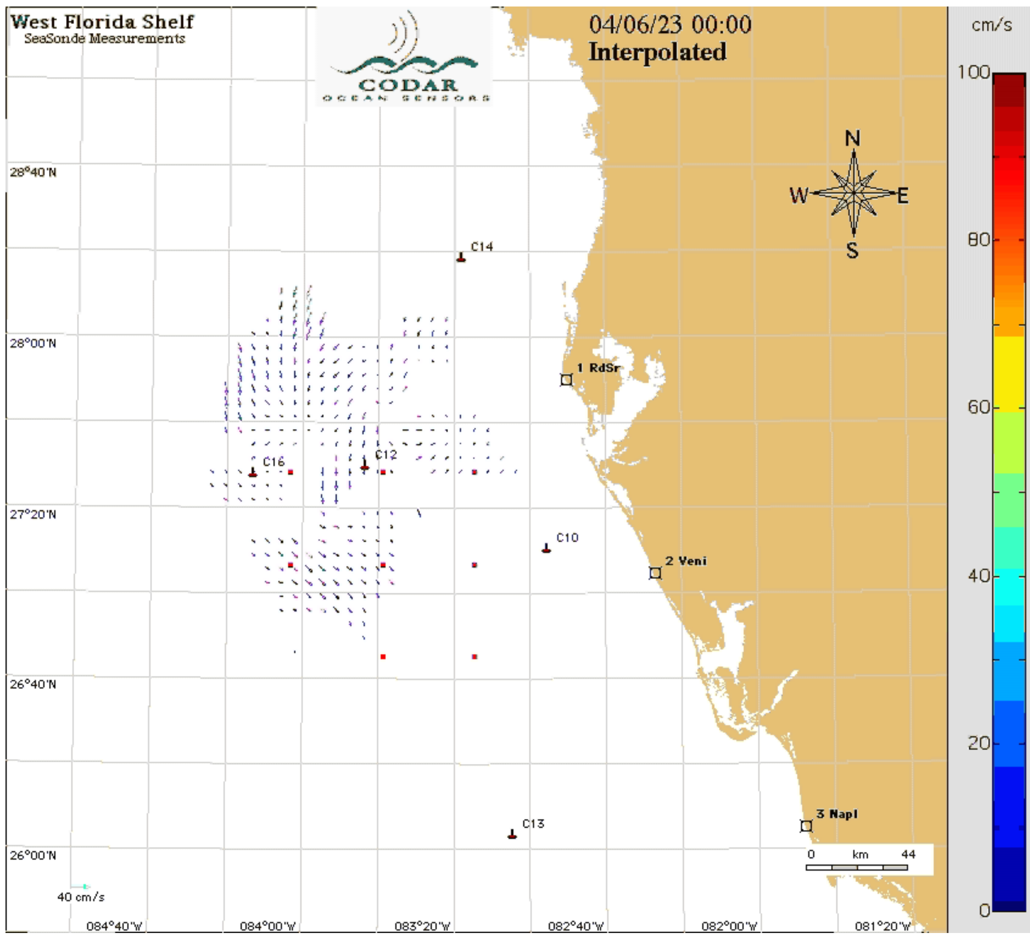

Figure 4: CODAR -derived surface currents on the WFS, overlaid on the positions of moorings in the COMPS array.

Summary (Lessons Learned):

Given the escalating interest in mapping coastal surface currents (Ocean.US), SEACOOS is making significant inroads to understanding the advantages and disadvantages of HF-radar technology. While claims have been made about "turn-key" systems, quality control on the radial and vector current data requires more effort to ensure the highest quality products. A second important issue for all radars is that when there are no Bragg waves (usually under very calm atmospheric conditions), HF radars will not accurately measure surface currents (our west coast colleagues in Oregon and California do not face this problem as coastal winds are usually quite energetic). This problem is accentuated for the lower frequencies (i.e. longer Bragg waves) than the systems in the 25 to 50 MHz range (shorter Bragg waves).

Finally, cited ranges are often problematic (Figure 1). This is an issue when groups want to sample ocean features located well offshore (i.e. Gulf Stream off Georgia). Thus, SEACOOS radar groups are learning valuable lessons that will feedback to hopefully the national program prior to full-up implementation of the Surface Current Mapping Initiative. Thus, research is needed to continue to understand and develop robust systems capable of not only measuring currents, but also waves and winds. Such efforts complement the Ocean.US Surface Current Mapping Initiative particularly in the radar test bed framework. SEACOOS and eventually SECOORA will provide valuable guidance for national efforts on HF radar technology.