HF Radar surface current measurements in the Mississippi Sound compared to in-situ measurements by ADCP and Lagrangian GPS Surface drifters.

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Abstract[1] - **High Frequency Radars are unique and powerful tools for measuring surface currents. Ocean Technologies, LLC (OT) operates and maintains two HF Radar sites on the Mississippi Gulf Coast. Surface current vector data in the combined coverage area of the two sites are collected and disseminated to the web in near real time by OT (www.oceantech.net). These HF Radar systems installed along the coast of the Mississippi Sound, provide two-dimensional vector current estimates over an area of ~520 km^2. Conventional and widely accepted methods to measure surface currents include Acoustic Doppler Current Profiler (ADCP) and Lagrangian GPS Surface Drifter (also called Davis Drifters). This study evaluates the performance of the HF Radar measurements in the MS Sound against in-situ measurements by ADCP's and results of Davis Drifters deployments.**

I. INTRODUCTION

The advantage of OT's HF Radars is their capability to sample a large region of ocean surface synoptically at a resolution of 1 km on an hourly basis. These data are available within the hour for further use as a self-standing product or as supporting data in other projects. OT provides data and graphical representations in form of maps of dynamic flow features that greatly enhance the understanding of important small-scale oceanic processes. Data collected with the HF Radar systems in the MS Sound have already revealed a more detailed and complex current field than expected by the scientific community involved in the Northern Gulf Littoral Initiative (NGLI) efforts.

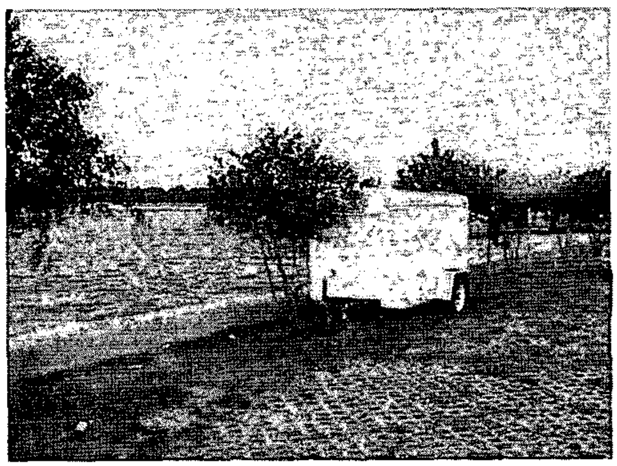
Figure 1: Instrumentation Trailer at President Site

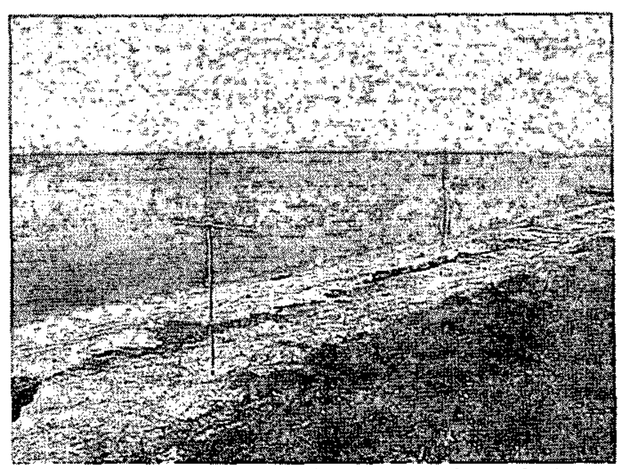
Figure 2: Receive and Transmit Antenna at Ocean Springs Site

[1] This work was funded by the Naval Oceanographic Office (NAVO contract # N62306-01-M-B017).

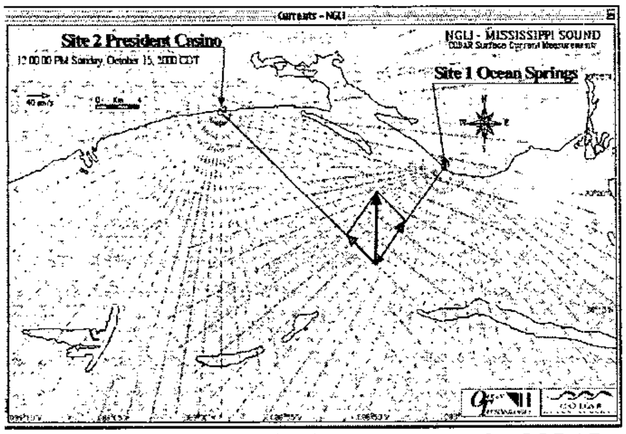

Figure 3: Radial and combined coverage areas for CODAR System

compared to Davis Drifters and upward looking, bottom mounted ADCP's. It is important in such a comparison that the two instruments compared, are measuring the same physical quantities, which in this case proves to be a difficulty. HF Radar measures near surface currents integrated over the first 100 cm in depth, averaged over one km^2 and again averaged over a 70-minute time period. Davis drifters store their GPS positions every 30 minutes, and the ADCP's are measuring currents every second for later averaging and data processing procedures. Davis Drifters might have possible inaccuracies due to their physical length in the water column and their antennae extending

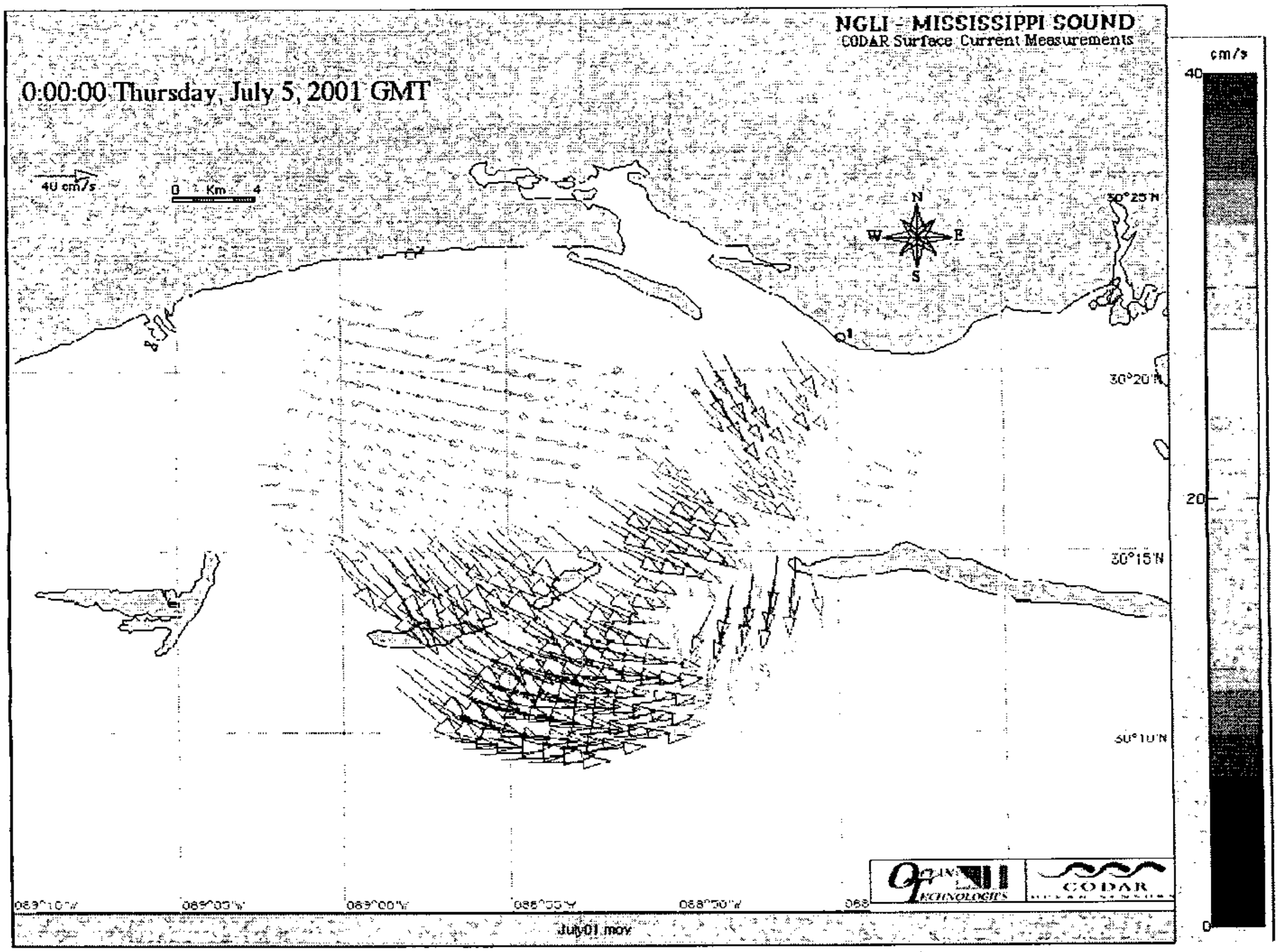

Figure 4: Total Current Vectors. Color-coded vectors display current direction and speed.

When evaluating the accuracy of HF Radar, the typical procedure is to compare side-by-side measurements of the radar with other instruments of known accuracy. In this study, HF Radar was above the water surface, thus being under the influence of current shear, waves and surface wind. Upward looking ADCP's in general have the lowest accuracy in the uppermost bin near the surface. This study, to the authors knowledge, is a first in HF Radar work, were HF Radar measurements have been compared against an extended amount of time series surface drifter data with GPS positions stored at 30 min resolution, in addition to data from time series deployments of ADCP's during the same time frame.

TABLE I
Summary of Drifter Deployments

Drifter	# of deployments	Drifter	# of deployments
19280	4	19478*	6
19294	4	19479	5
19295	3	19626	2
19297	4	20080	1
19302*	2	20091	2
19304	5	20155	2
19442	5	20293	1
19443	2	20294*	1
19444	1	20347	3

TABLE II
Initial rms for individual Drifter deployments vs. CODAR

MMYY Drifter Number	Speed cm/sec	Direction degrees	Number of Samples
1200-19479	12.27	81.62	241
1200-19478	7.15	52.48	85
1200-19442	13.86	84.79	82
1200-19304	12.48	72.17	370
1200-19297	7.00	64.21	111
1200-19295	12.25	48.09	31
1200-19280	9.06	78.19	76
0601-19297	28.32	89.43	40
0201-19479	9.67	61.14	183
0201-19478	11.18	73.33	143
0201-19442	15.56	67.15	91
0201-19304	12.93	54.67	66
0201-19302	11.26	81.25	120
0201-19297	11.92	67.94	140
0201-19295	16.15	69.77	51
0201-19280	11.24	69.71	197
All Drifters	12.64	69.75	2027

II. METHODS AND RESULTS

During a 10-month period in 2000 and 2001, surface currents were measured in the Mississippi Sound using remote and in-situ measurement techniques. Two 25 MHz HF Radar sites were established, one in Ocean Springs and the other in Biloxi (see Figures 1 through 4). Maximum range for these systems was determined as 28 km. The barrier islands in the pathway of the radar sites have a low profile and are narrow enough that they did not absorb the emitted energy. Current vectors were collected for a limited range south of the islands. The radars at these sites synoptically sampled a combined area of 520 km^2 on an hourly schedule starting in September 2000 through June 2001. These HF Radar measurements integrate current measurements vertically from the surface to about 100 cm depth and horizontally over a 5 degree by 1 km (radial distance) area.

TABLE III
RMS error for individual ADCP deployments per 25 cm depth interval

ADCP SN	0 - 25 cm	25 – 50 cm	50 – 75 cm	75 – 100 cm	Total RMS	Total # of samples
Speed cm/sec						
1436	13.81	14.17	15.24	12.61	13.94	7438
14863	21.27	21.40	21.52	22.48	21.67	9039
1486	6.87	7.19	7.53	7.59	7.29	1591
1505	6.64	6.67	6.60	7.35	6.82	2658
Direction degree						
ADCP SN	0 - 25 cm	25 – 50 cm	50 – 75 cm	75 – 100 cm	Total RMS	Total # of samples
1436	75.27	73.75	71.72	58.17	69.73	7438
14863	46.92	46.25	45.98	46.10	46.31	9039
1486	39.26	37.46	33.83	28.33	34.72	1591
1505	44.93	38.18	37.34	33.41	38.46	2658

Electromagnetic radar waves are transmitted and received at 2 Hz using line of sight and groundwave propagation. After 256 seconds, raw cross spectra of the return signals are written to memory on a Macintosh computer. Every 10 minutes the cross spectra are averaged into a combined file which is stored for further analyses.

Hourly a radial velocity file is available in which seven of these 10-minute cross spectra files are averaged, containing latitude and longitude, u and v components of the current of each 1 x 1 km grid point in the coverage area.

Eighteen Lagrangian GPS Surface Drifters (Model 104A, Mini GPS drifters, made by Brightwaters Instrument Corp.) were deployed between the dates 12/03/00 and 10/03/01within the combined coverage area of the radar sites. Many of the drifters were deployed multiple times (see table 1). Three drifters were never recovered (marked with *). These surface drifters acquired and stored GPS positions every 30 minutes in onboard memory and telemetered the data via the ARGOS satellite system several times per day back to ARGOS from where they were automatically distributed. Near real time tracking of the drifters allowed for relocation of the drifters back into the coverage area, once they had left the CODAR domain.

In addition to the surface drifters, four bottom mounted, upward looking high Acoustic Doppler Current Profilers (ADCP, resolution, 1200 kHz, 25 cm bin size, made by RD Instruments) were deployed at four distinct locations in the HF Radar coverage area using trawl resistant bottom mounts (TRBM) (for positions see Figure 7). Two ADCP's (SN 14863 and 1436) were deployed in the low confidence area of the HF Radar systems, at locations in the channels of Little Dog Key and Dog Key Pass between Horn and East Ship Island. The other two ADCP's (SN: 1486 and 1505) were deployed in the high confidence area of the CODAR coverage area.

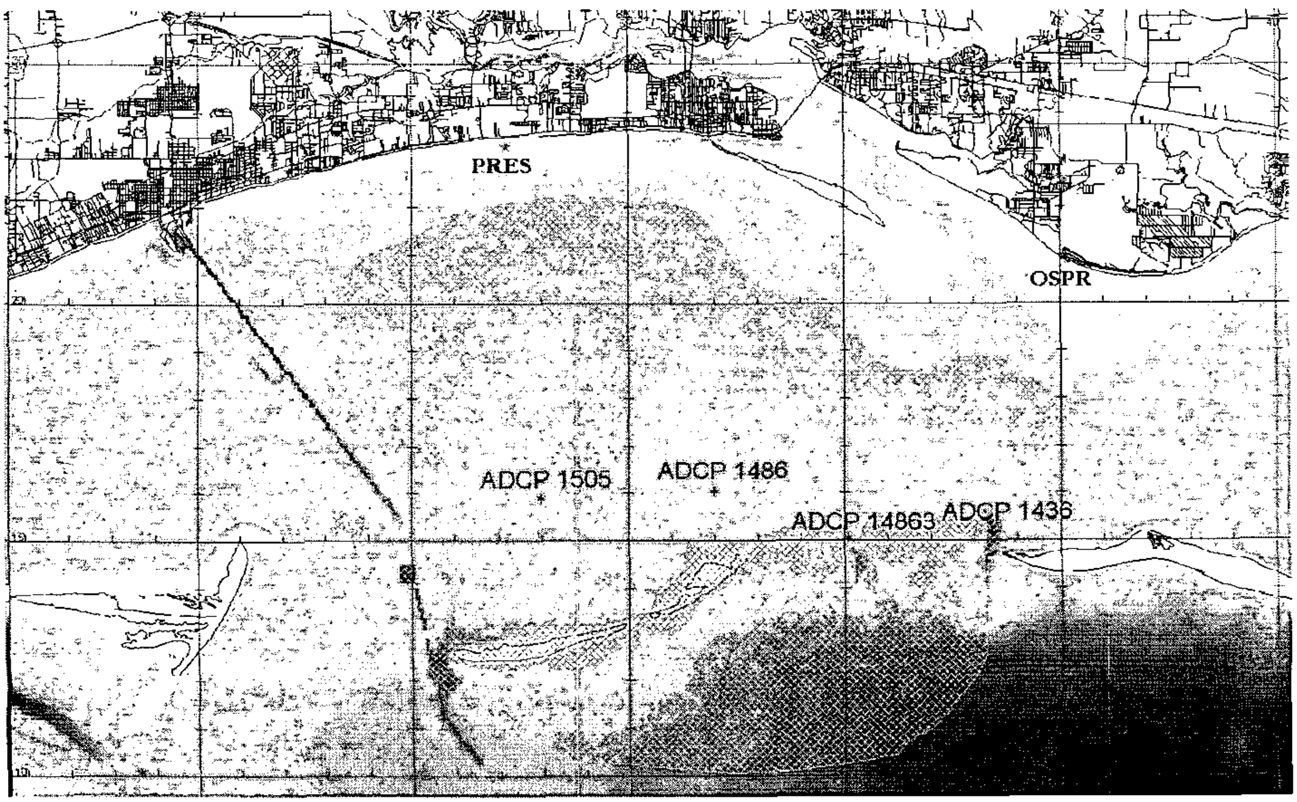

Figure 5: Locations of ADCP deployments during December 2000 to July 2001 NGLI deployments. The yellow area depicts the CODAR coverage during the experiment.

In this study, we compared coincident near-surface current data from the four separate ADCP deployments and 16 individual drifter deployments with surface current data from OT's HF Radar systems. Drifter and ADCP data sets were filtered for coincident time and spatial CODAR coverage. 2,027 synchronized data points were available for the drifter (see table 2) and 20,726 for the ADCP measurements (see table 3). Initial comparison of surface drifter and CODAR data resulted in an rms of 7.0 to 28.3 cm/s for individual deployments and 12.64 cm/sec and 69.75 degree averaged over all deployments (see table 2).

To estimate an overall performance of the Davis

A direct comparison of CODAR data with high resolution (1200 kHz, 25cm bin size) ADCP's resulted in rms values of 6.82 to 21.86 cm/sec in speed and 34.72 to 69.73 degree direction (see table 3). The two deployment sites in the high confidence coverage area of the HF Radar coverage have rms values of 6.82 and 7.29 cm/sec

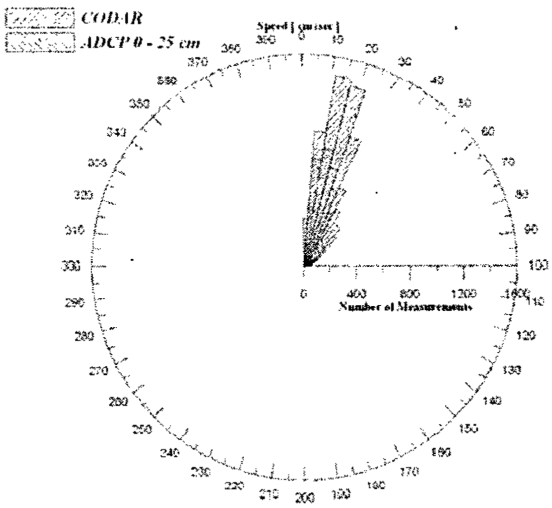

Fig. 6: Spectrum of 5 cm/sec bins of ADCP bin 0-25 cm depth compared to CODAR

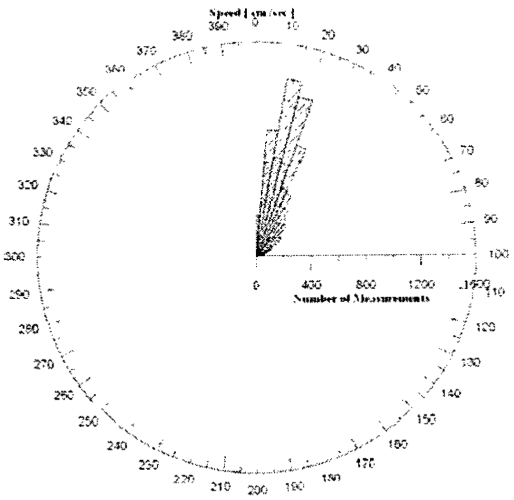

Fig. 7: Spectrum of 5 cm/sec bins of ADCP bin 25-50 cm depth compared to CODAR

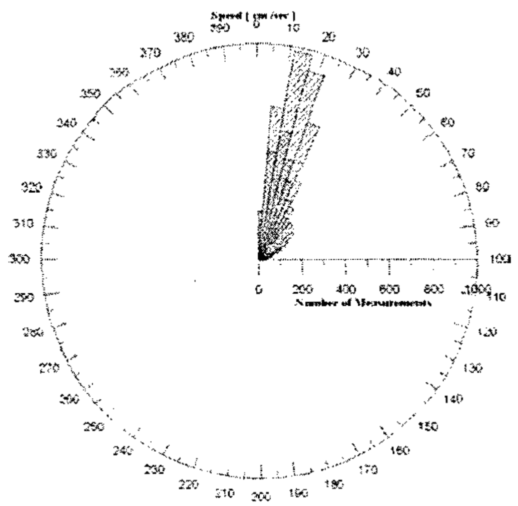

Fig. 8: Spectrum of 5 cm/sec bins of ADCP bin 50-75 cm depth compared to CODAR

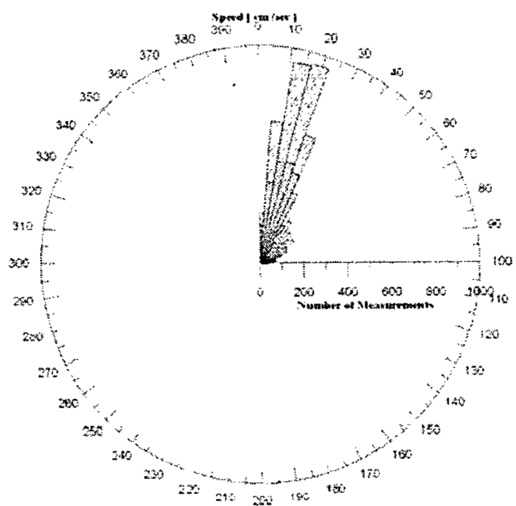

Fig. 9: Spectrum of 5 cm/sec bins of ADCP bin 75-100 cm depth compared to CODAR

drifters, groups of two or three were deployed at the same position and time. In general the tracks agreed well with each other, however, in some instances they showed variations over time (for one example of these paths see Fig. 17).

compared to the two sites in the low confidence area in the passes between West Ship and Horn Island with rms values of 13.94 and 21.67 cm/sec. The comparison of the directional spectrum of the ADCP vs. HF Radar showed rms values of 34.72

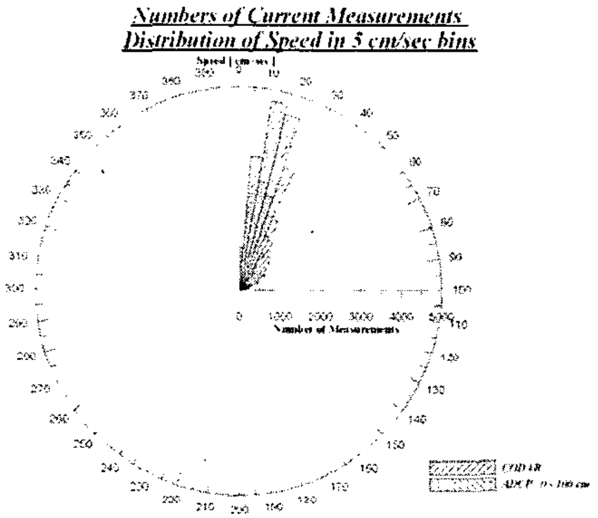

Fig. 10: Total Numbers of Current Measurements of HF Radar and ADCP's. Radius of graph showing the number of samples in bin and angle showing the speed in cm/sec in this bin.

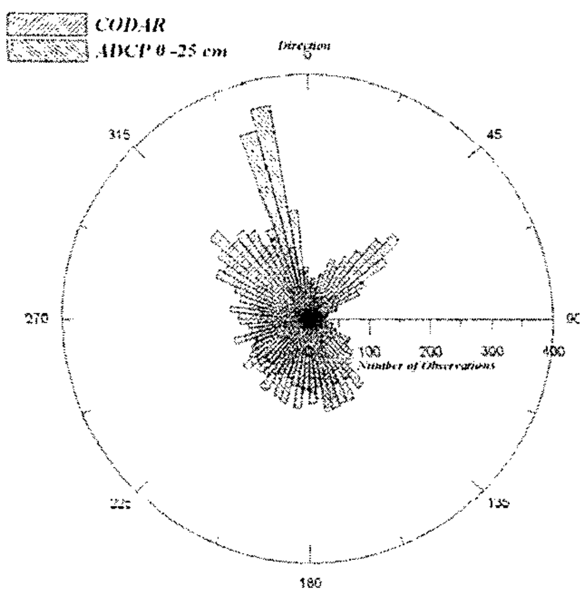

Fig. 11: Directional Spectrum of ADCP bin 0-25 cm depth compared to CODAR

and 38.46 degrees in the high confidence area compared to 46.31 and 69.73 degree in the low confidence area based on 1,591 to 9,039 individual sample points per site. Figure 7 shows the location of the ADCP mooring sites relative to the local bathymetry in the CODAR coverage area. ADCP's 1505 and 1486 were located in the high confidence area and relatively smooth and even bathymetry. ADCP's 14863 and 1436 were in the center of narrow deep channels which focus the current in two dominant directions, visible in the directional spectrum of the ADCP data (Figures 11 to 14). Bathymetry is changing rapidly in the vicinity of the two later ADCP sites, located in the low confidence section of the HF Radar coverage.

Figures 6 through 9 show the sample distribution of HF Radar vs. all ADCP measurements within each ADCP vertical bin, starting at Figure 6 with the surface bin from 0 to 25 cm depth, and ending at figure 9 with 75 to 100 cm depth. Most of the HF Radar samples are in the 0 to 30 cm/sec range whereas the ADCP has a broader range of measured speeds, in the range from 0 to 75 cm/sec, with most of the values being in the range of 0 to 45 cm/sec.

Figure 10 depicts all ADCP measurements from 0 to 100 cm depth combined and the coincident HF Radar measurements. Measurements are plotted in 5 cm/sec bins. HF Radar and ADCP's have the most measurements in the 0 to 30-cm range; however, the ADCP's are seeing additional measurements in the above 30-cm/sec range where

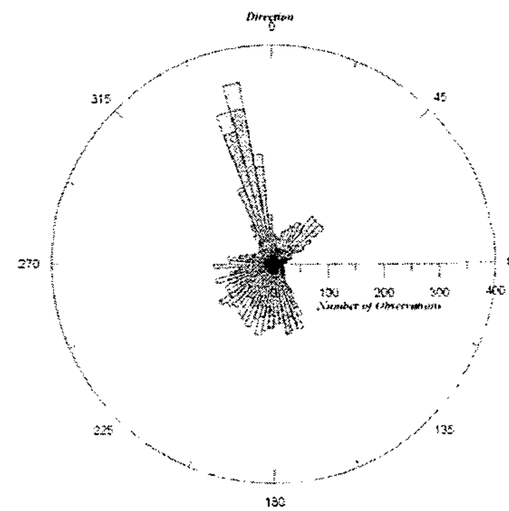

Fig. 12: Directional Spectrum of ADCP bin 25-50 cm depth compared to CODAR

the HF Radar is seeing fewer measurements.

Figs. 11 to 14 show the directional spectrum of individual ADCP depth bins compared to coincident HF Radar measurements. Note the roughly +45 and +90 degree offset of ADCP values compared to HF Radar at the surface (Fig. 11) and the better alignement of data in the second bin

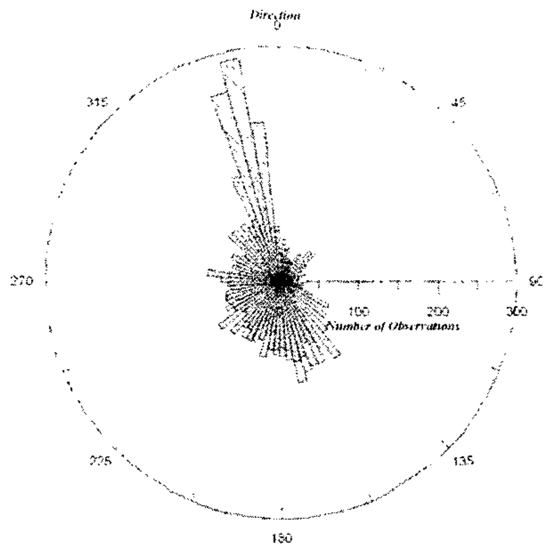

Fig. 13: Directional Spectrum of ADCP bin 50-75 cm depth compared to CODAR

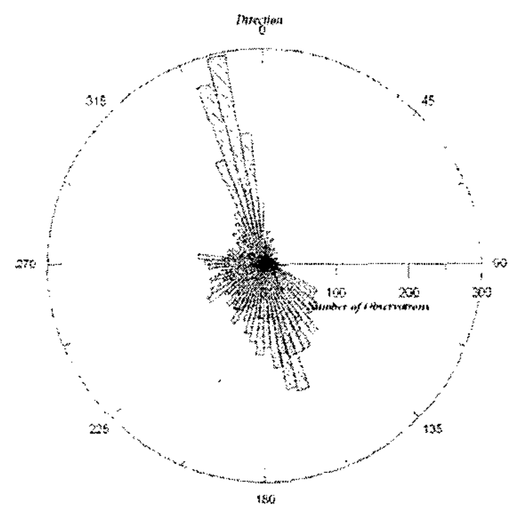

Fig. 14: Directional Spectrum of ADCP bin 75-100 cm depth compared to CODAR

(25 to 50 cm depth), with decreasing agreement in greater depths (Figures 12 and 13). Currents at 45 degree are almost absent at the 75 to 100 cm depth (Fig. 14).

Fig. 15 depicts all drifter tracks collected and used in this study. Only positions coincident in time and space with HF Radar measurements were used for analyses. Also shown are the drifter tracks of three drifters (19295, 19297, 19479) released at the same time and position (enhanced view in figure 17 showing deviations in individual tracks. Interestingly two of the drifters (19295 and 19297) joined up again and were recovered together.

Fig. 16 is a geo-spatial plot of rms speed error as compared to surface drifter data within the HF Radar coverage. Errors were grouped into 5 cm/sec bins and plotted per grid point in the combined HF Radar coverage. Only grid points with coincident HF Radar and drifter coverage were considered for this plot. Errors above 20 cm/sec were combined into one bin for representation purposes.

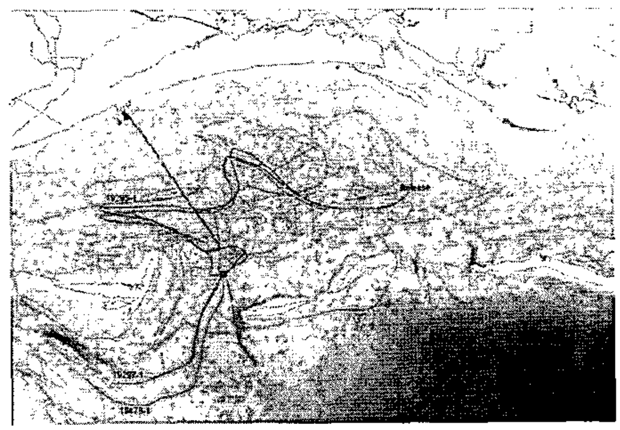

Fig. 15:All Drifter tracks within the CODAR coverage area during the 2000 and 2001 cruises

Fig. 16: Individual CODAR Grid Cells compared to surface drifters showing the color coded rms error for the individual location (see color bar on lower right corner)

III. CONCLUSIONS / RECOMMENDATIONS

Results of this study show clearly that measurements of surface currents in the high confidence area measured with HF Radar produce speeds and directions well within the error range published in previous HF Radar validations (e.g. [1], [2], [3]).

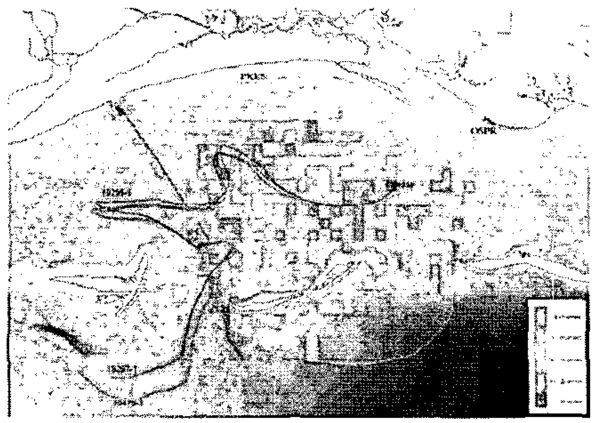

Fig. 17: Three drifters deployed at the same time and location, showing variation in their individual drifter paths over the entire deployment time. Colored squares depict individual rms in speed for radar coverage grid cell.

[1] studying the accuracy of the OSCR radar, found that differences between HF Radar and *in-situ* data can be attributed to three terms:

$\sigma^2_{diff} = \sigma^2_{HF} + \sigma^2_{in\text{-}situ} + \sigma^2_{physics}$, where

σ_{diff} = Total rms difference between the measurements,

σ_{HF} = rms error associated with the HF Radar measurement;

$\sigma_{in\text{-}situ}$ = rms error associated with the *in-situ* (drifter, ADCP) measurement;

$\sigma_{physics}$ = rms difference in the physical parameters measured by the HF Radar and the *in-situ* instruments.

"*... the radar derived radial velocity errors are more likely on the order of 7-8 cm/s. Further analysis of the underlying causes suggests that most of the differences can be accounted for in terms of surface current variability in space, depth and time, as well as errors in the in-situ and radar derived currents.*" [1]

[4] found a total rms difference at the radial level between ADCP and SeaSonde measurements of 6.7 cm/s. Based on [1] estimates of 50% of the total rms error being attributed to the radial SeaSonde sites, [4] concluded that the error at the radial level must be less by several cm/s than the above reported 6.7 cm/s.

Both of the above mentioned studies were performed in unrestricted offshore waters with water depth exceeding those in the Mississippi Sound. Local bathymetry plays an important factor in this comparison especially during deployment of ADCP's for HF Radar verification. The MS Sound is relatively shallow with an even bathymetry.

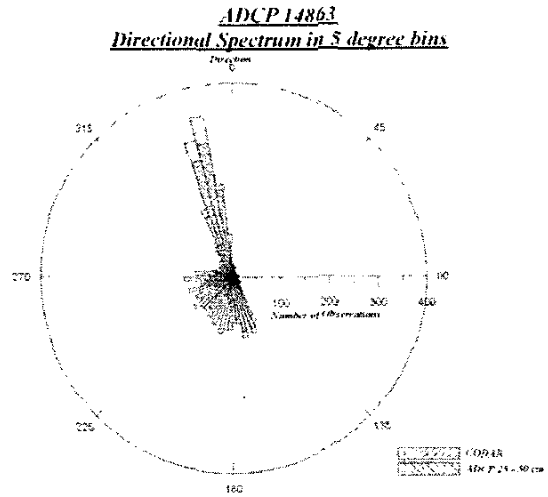

Fig. 18: Directional spectrum of current observations at 25 to 50 cm depth in Dog Key Pass.

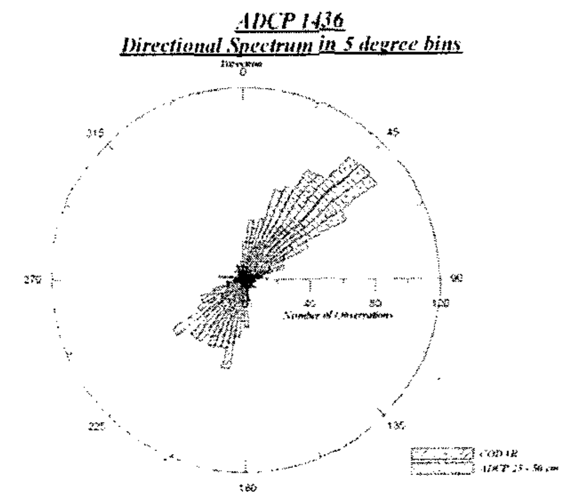

Fig. 19: Directional spectrum of current observations at 25 to 50 cm depth in Little Dog Key Pass.

Currents are strongly affected by the tidal cycle. Tidal ranges vary between 0 to about 2 ft in height. Tidal in and outflow takes place through narrow and relatively deep channels between the barrier islands. Two ADCP's deployed within the MS Sound correlated very well to the HF Radar measurements. Two of four ADCP sites, however, were in the passes (Little Dog Key Pass and Dog

Key Pass) between Horn and East Ship Island. Most of the flow in and out of the Sound follows the direction of these narrow deep channels in the passes (see Figures 18 and 19). The area the ADCP measures, however is only a fraction of an HF Radar grid cell, thus enhancing the error for these locations drastically. The water around these passes is being funneled towards the deeper section of the passes, due to the higher current speeds. This produces a variety of current vectors focusing onto the pass, which are being averaged by the HF Radar to produce one current vector for the entire grid cell.

If ADCP's are deployed in a physically small, but dominant feature with highly restricted and fast flowing currents, correlation between the two instruments decreases. Both instruments measure, in this case, physically the same water mass. However, these bodies of water are not uniform in their horizontal flow field. Variations are on a smaller scale than the minimum resolution of the area averaged by the HF Radar. Resolution of the ADCP's can resolve the small-scale variability in the current field. These different scales of measuring surface currents produce an averaged current vector for the HF Radar, and spot measurements of the ADCP.

Cross checking the validity of Drifter data by deploying multiple drifters at the same time and location, yielded interesting results. Individual drifters, in some instances followed different paths of speed and direction.

Based on this study, the use of HF Radar to determine current speed and direction within narrow and highly variable passages between islands for transport calculations has to be limited to their ability to resolve current fields in the horizontal dimension. HF radar systems with a higher frequency than the 25 MHz system used in this study, are more suitable to increase the spatial resolution of the radar system thus resulting in a closer depiction of the local surface current field. Arrays of ADCP's across a pass seem to be more efficient in measuring these areas of high variability on small horizontal scales. The use of ADCP's and Lagrangian Davis drifters to support HF Radar measurements is encouraged to estimate rms errors for new coverage areas and to acquire initial current measurements for until the radar systems have been installed and calibrated.

Surface current data collected in this study describe a very dynamic environment, largely influenced by tides, river runoff and winds. This kind of environment and the objective of the study required techniques to measure the current field mutually supportive and complementary. The performance of the HF radar system, operated in this area protected by barrier islands, under brackish conditions, with moderate waves, produced total current vector data within the published error margin for radial currents.

Acknowledgments

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