NOAA's Integrated Ocean Observing System
High Frequency Radar Science Steering Team
Freshwater Performance Evaluation

Final Memorandum, 12 August 2012

Goal: To provide the NOAA/IOOS community with a clear assessment of the capabilities and limitations of high frequency (HF) radar surface current mapping in fresh water.

Background: Surface currents in the US EEZ have been repeatedly identified as a critical variable to meet many IOOS goals. Surface currents over salt water can be mapped with a radio frequency technique called variously HF Radar, surface current radar, or surface current mapping. Commercial versions of the systems include the CODAR SeaSonde system and the WERA system. The range and resolution of HF radar systems over salt water depend, primarily, on the frequency as well as the transmit power, antenna placement and design, and the ambient radio frequency noise levels. Typical ranges extend 40 km to 200 km offshore for broadcast frequencies between 25 MHz and 5 MHz, respectively.

Propagation of radiowave energy over fresh water is greatly reduced by the very poor conducting properties of fresh water. Historically, HF radar systems have not been deployed along fresh water bodies, such as the U.S. and Canadian Great Lakes, because of this limitation. However, in the context of IOOS, the Great Lakes Observing System (GLOS) shares the need to monitor surface currents with the regional associations distributed around the U.S. ocean coastline. Hence, there exists the desire to document the mapping capabilities of modern, commercial HF radar systems in the Great Lakes environment. This sub committee of the NOAA/IOOS HF radar Science Steering Committee was tasked with documenting the capability of HF radar systems in fresh water.

Actions Supported: The committee is aware of a relatively small literature base describing actual measurements with HF radar systems over fresh water or computations based on the theory of radiowave propagation. In reviewing that literature and discussing the problem with stakeholders in GLOS, it was decided that the highest priority activity should be a modern test of HF radar performance in the Great Lakes region paired with in situ wave observations. (Variable surface wave conditions were shown in earlier Great Lakes observations to have a more profound effect on HF radar performance than is typically observed over salt water.)

The sub committee passed along this recommendation to NOAA/IOOS and it was agreed that the program would assist GLOS to stage a test of HF radar performance. IOOS and GLOS worked with Codar Ocean Sensors, Ltd. to perform tests using the CODAR SeaSonde system deployed along the shore of Lake Michigan during the period 9-20 May 2011.

Results Obtained: It is the view of the subcommittee that the Lake Michigan fresh water HF radar experiment and the accompanying write up by Whelan et al. (2011)[1] represent the state-of-the-art in defining the capabilities of HF radar surface current mapping systems over fresh water. The Whelan et al. (2011) report is included here as Appendix 1. In addition to radial current mapping data results for the Lake Michigan location under a variety of wave conditions, the report presents the theoretically predicted propagation loss curves for both freshwater and seawater cases. There are exceptionally good matches between the predicted loss curves and the observed decay with range in the fresh water experiment for transmissions at 42 MHz (Figure 5) and 5 MHz (Figure 6). These results strongly support the use of the provided theoretical curves when estimating likely ranges that could be expected in freshwater settings. The report in Appendix 1 also includes references to the existing publications on fresh water applications of HF radar systems. In addition, we are aware of recent freshwater measurements in Lago di Garda, Italy conducted by scientists from the laboratory Oceanografia Geofisica Sperimentale (OGS) in Trieste (S. Cosoli, personal communication).

The Intermediate, Brackish Water Case: The subcommittee members are also aware of reports on HF radar observations for salinity conditions between fresh water and oceanic salinities. This includes the peer-reviewed publication of Gürgel et al. (1999)[2], which describes observations along the Dutch coast. In addition, observations under a range of salinity conditions have been reported on by Long et al. (2006)[3] for San Francisco Bay and by Updyke (2012) for Chesapeake Bay. The latter report is included here as Appendix 2. It includes a summary of the Long et al. (2006) findings. Those results are also summarized in Figure 1 below. The number of radial observations obtained, which is directly related to the maximum range, drops off steadily below about 23 ppt. For that data set, the range is effectively zero for salinities below 4 ppt.

Conclusions: The theoretical expectations for greatly reduced ranges for HF radar surface current mapping systems deployed in the Great Lakes region are borne out by the recent experiment on Lake Michigan. These results are consistent with others reported in the literature and with recent projections from observations in brackish water conditions. Given these results, the use of HF radar for surface current observations in the Great Lakes must be considered carefully. Any use of that technology should be compared with the alternatives, such as use of satellite tracked surface drifting buoys combined with data assimilating numerical models. The closed basin Great Lakes domains should make the modeling systems markedly more skillful than similar systems configured for open ocean coastal areas.

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[1] Whelan, C., L. Meadows, D. Barrick, R. Kroodsma, and C. Ruf, 2011: Great Lakes HF Radar Experiment May 9 to 20, 2011: Report to the Great Lakes Observing System.
[2] Gürgel, K.-W., H.-H. Essen, and T. Schlick, 1999: Tracking of fresh-water plumes in Dutch coastal waters by means of HF radar. *Proceedings IGARSS'99*, **5**, 2548-2550.
[3] Long, R., N. Garfield and D. Barrick. 2006. The Effect of Salinity on Monitoring San Francisco Bay Surface Currents using Surface Current Monitoring Instruments (SMCI). Presentation at the *California and the World Ocean '06 Conference*, September 17-20, Long Beach, California.
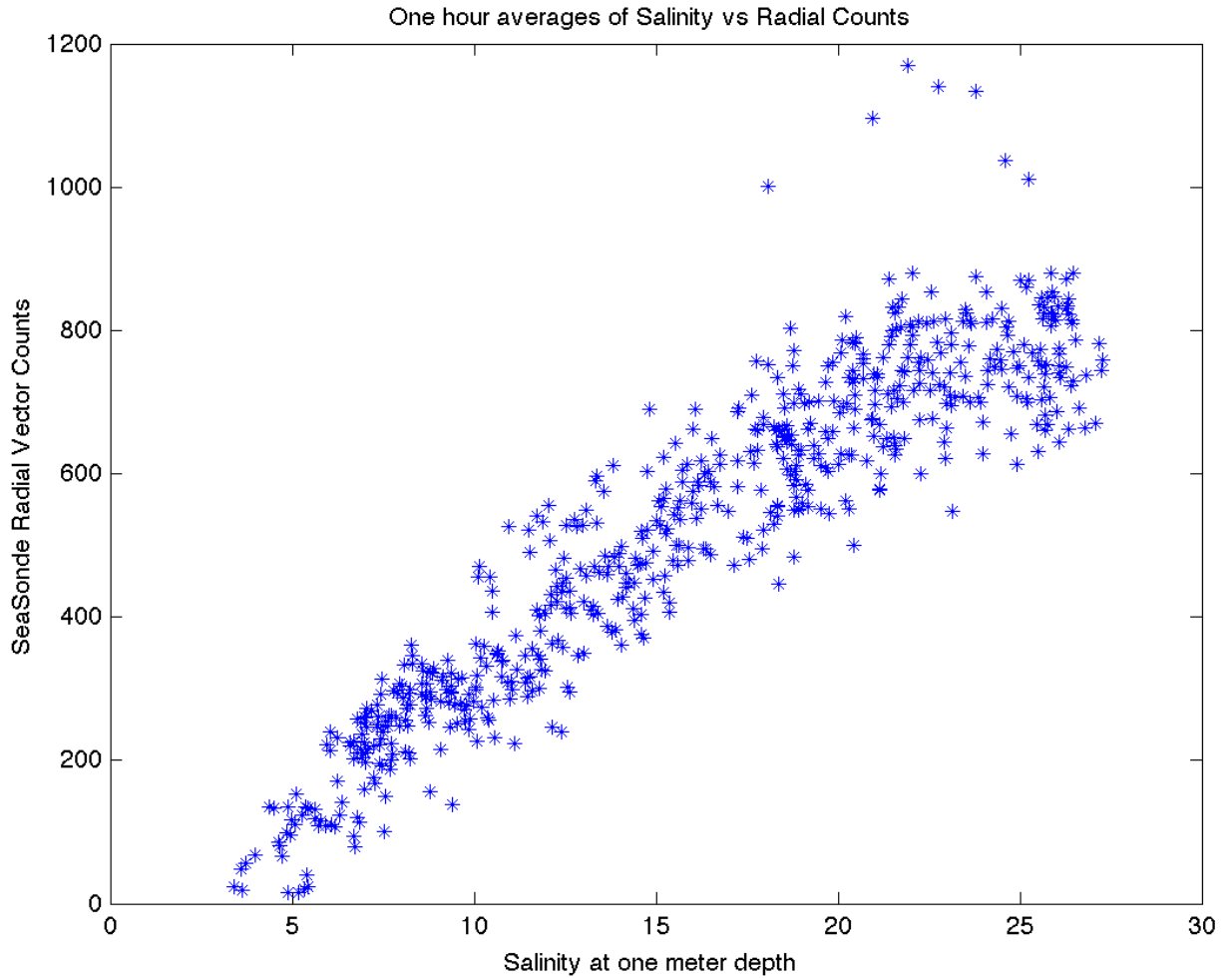
Figure 1. Radial counts versus salinity for 42 MHz CODAR Seasonde HF radar observations in San Francisco Bay indicating a steady decline in range for salinities below about 23 ppt (N. Garfield, personal communication).

Authors: This summary is submitted on behalf of the NOAA/IOOS HF Radar Science Steering Committee and endorsed by the members of the Committee's "Tiger Team" on freshwater performance: Jeffrey D. Paduan (Chair), Naval Postgraduate School, Chad Whelan, Codar Ocean Sensors, Ltd., and Teresa Updyke, Old Dominion University.

Appendix 1

Whelan et al. Report on HF Radar Testing in Lake Michigan

Great Lakes HF Radar Experiment
May 9 – 20, 2011

Report to Great Lakes Observing System[*]

Chad Whelan[1], Lorelle Meadows[2], Don Barrick[1], Rachael Kroodsma[2], Christopher Ruf[2]

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Introduction

With its ability to map surface currents over a variety of ranges and resolutions, High Frequency (HF) Radar has become an important tool in ocean observing systems around the world. Today, there are more than 120 systems operating along the coastlines of the U.S. providing near real-time current maps by Long Range systems to 200 km and with VHF systems providing resolutions of 250 – 500 m around ports and harbors. This data is made available to the public via the NOAA National Data Buoy Center (http://hfradar.ndbc.noaa.gov/) and is used by the U.S. Coast Guard for search and rescue operations.

In order to achieve these ranges, the electromagnetic signal must couple with the surface in order to propagate via groundwave beyond the horizon. For typical ocean surface water with salinity over 30 ppt, the higher conductivity favors HF coupling to the sea surface and allows the signal to travel significantly farther than over land or freshwater. Lowering the salinity has been shown to significantly reduce range performance of coastal ocean systems during periods of high freshwater discharge (Long, et al, 2006). For this reason, HF RADAR has not generally been considered suitable for freshwater measurements. Additionally, lakes often have limited fetch lengths, resulting in a shorter wavelength and less developed sea state than most ocean coasts. As with a radar in any location, some additional range can be gained by increasing transmit power or use of directional antennas, but these methods are only practical to increases of 20% - 40%.

Despite the limitations of HF radar on freshwater lakes, its potential utility was demonstrated by deployments of the University of Michigan Multi-frequency Coastal Radar (MCR) along Lake Michigan as part of the 1999-2001 Episodic Events Great Lakes Experiment (Vesecky et al, 1999; Meadows et al, 2000; Vesecky et al, 2000; Teague et al, 2000; Fernandez et al, 2000; Vesecky et al, 2001a; Vesecky et al, 2001b). During this experiment, the MCR produced surface current measurements up to a range of approximately 25 km offshore at times. These measurements showed strong

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correlation with both *in-situ* acoustic Doppler current measurements and numerical hind-casts of surface current conditions.

The goal of this field deployment was to deploy and test the propagation characteristics of a commercially available HF system over freshwater, operating at a range of frequencies, and operationally optimized for performance in a freshwater environment.

Field Activities

Although fetch-limited wave growth theory indicates a stronger potential for the existence of Bragg scattering components in the Great Lakes setting for higher frequency bands (above approximately 14 MHz), data return with the MCR was much greater (especially in range) for lower frequencies (on the order of 5 MHz) due to the increased natural power loss with propagation at higher frequencies. Successful retrieval out to 20 km in range for winds over the lake in excess of 3 m/s was repeatedly achieved. Based on these expectations and findings, the field deployment consisted of the installation and operation of two Seasonde HF radar units, manufactured by CODAR Ocean Sensors, operating at 42 MHz and 5.375 MHz, the top and bottom of the range of frequencies currently used for ocean measurements in the U.S..

The SeaSonde was chosen as it is the most commonly used HF radar system for current mapping with over 85 % of the worldwide market and its compact design makes it ideal for temporary deployments. A single basic unit consists of one omni-directional transmit/receive mast for 12 – 42 MHz bands or separate omni directional transmit antenna and receive mast for the 5 MHz band (Long Range) installed within tens of meters of the water. Each receive mast contains three antennas: two directional loop antennas and an omnidirectional dipole. The waveform used is a Frequency Modulated interrupted Continuous Wave (FMiCW) with effective radiated power of 40 W. Additional transmit antennas can be added to direct transmit signal energy when the field of view is 180˚ or less. Processing of Doppler spectra is done on site to provide radial current maps in near real time. More information can be found at http://www.codar.com. In addition to the Seasonde antennas deployed, the University of Michigan, as a student project, built a three element loop antenna array tuned for 5.375 MHz. The purpose of the array was to test range improvement with directional transmit antenna gain.

Site selection for the deployment was based on an evaluation of the dominant environmental conditions over the lake in the month of May, the target month for the deployment. An evaluation of detailed hindcast wave data, available through the NOAA Great Lakes Coastal Forecasting System for Lake Michigan was performed. Figure 1 provides a gross evaluation of the wave climate along the Lake Michigan coastline of the State of Michigan. In May, the northern portion of Lake Michigan experiences a much higher likelihood of significant wave events in excess of 0.5 m (significant wave height); approximately twice as frequent as the southern end of Lake Michigan. Based on this analysis and the availability of property accessible to the lake at low elevation, Point Betsie was chosen as the deployment site.
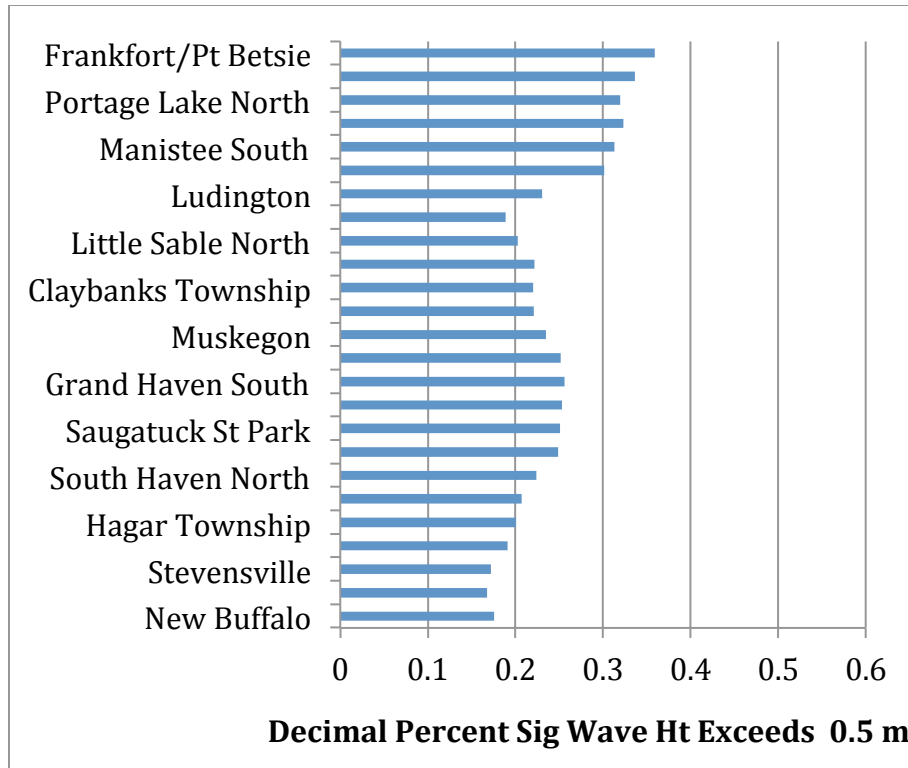
Figure 1. Gross climatology of Lake Michigan waves for May, averaged for 2006 through 2010. Based on Great Lakes Coastal Forecasting System hindcast estimates of wave conditions in Lake Michigan.

Point Betsie, Michigan, is host to a historic lighthouse with a fog signal outbuilding that were made available for our deployment by the Friends of Point Betsie Lighthouse Association. Figure 2 provides a site diagram showing the positioning of each of the radar components and an overall location map. The radar systems were set up on May 9 and antenna transmission was tested through the following day under relatively low wind and wave conditions. The systems were then operated near continuously, with some switching between the SeaSonde and UM 5 MHz transmitters, from May 11 through May 19. On May 20, the systems were dismantled. Propagation measurements were made on May 12, 18 and 19 by setting the systems to transmit and measuring the received signal strength at various distances offshore. The SeaSonde systems were calibrated on May 11. Photos of equipment installation can be found in the Appendix.

Figure 2. Site map showing overall position of Point Betsie on Lake Michigan (http://www.ngdc.noaa.gov/mgg/image/michiganlarge.jpg) and detailed layout of antennas overlaid on air photo (Google Earth).

Environmental Data

To complement and support the HF data acquisition, two additional data sources were employed. For in-situ instrumentation, an acoustic Doppler current profiler (ADCP) was deployed to collect wave and near surface current measurements offshore of Point Betsie. Unfortunately, this instrument malfunctioned approximately 2 days into the deployment, collecting environmental data only during the setup period. A second source of environmental data was obtained via the hind-cast model available through the Great Lakes Coastal Forecasting System of the National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory (see: http://www.glerl.noaa.gov/res/glcfs/).   During the time period of the field deployment the National Data Buoy Center Northern Lake Michigan Buoy was not in place. Figure 3 provides a time series overview of the model-reported environmental conditions in the vicinity of the ADCP deployment site.
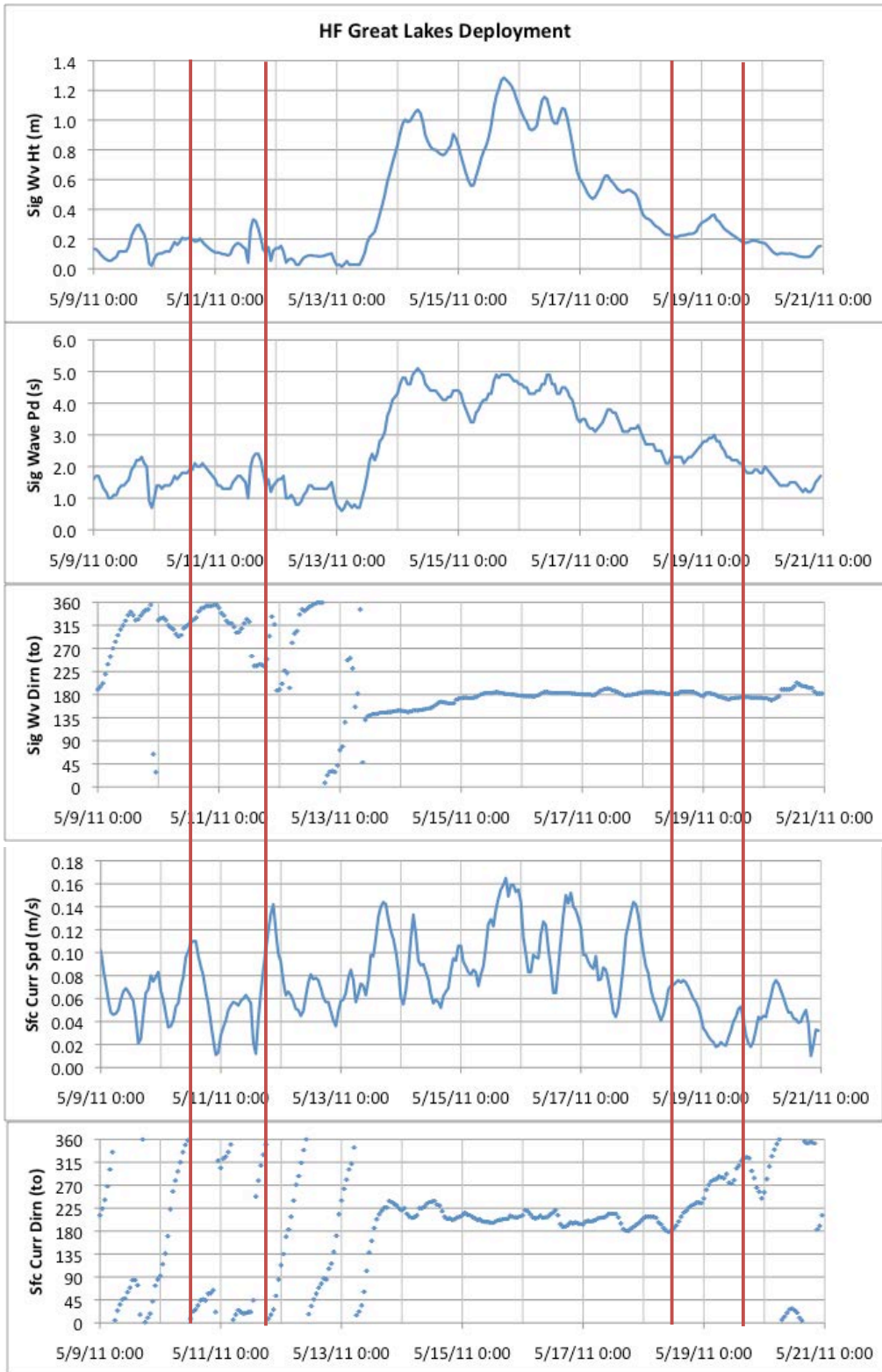
Figure 3. Wave and current conditions during HF Great Lakes Deployment. Times in GMT. Vertical red lines indicate approximate times of transmission measurements.

Freshwater vs. Seawater Prediction

The range over which any radar is capable of making measurements is a function of the signal-to-noise ratio (SNR) of the target. In the case of HF radar for current mapping, the targets are the surface waves. The equation for determining the SNR for any target is given as:

$$ SNR = P_T \frac{G_T D_R F^4 \lambda^2 \sigma_t \tau}{(4\pi)^3 R^4 kT F_a} $$

where:

P_T.....average radiated power

G_T....transmit antenna power gain

D_R....receive antenna directivity

λ.......radar wavelength

τ ......coherent FFT processing time

σ_t .....radar cross section of water surface within radar cell

R .....range to radar cell

kT ...internal receiver thermal noise spectral density (4×10^{-21} W/Hz)

F_a ....factor by which external noise exceeds internal receiver noise;

F .....normalized one-way field strength attenuation factor

The last parameter, F, is the only factor in the equation for SNR that changes for freshwater vs. seawater. F depends on frequency, surface material dielectric constant, distance, surface roughness (sea state) and includes diffraction over spherical earth. The normalization is such that this factor is unity for flat, perfectly conducting surface and/or very short distances. Values for F for freshwater and seawater can be calculated accurately from GRWave, the program recommended by ITU/NATO and the accepted standard for 40 years. A comparison of freshwater to seawater range performance for three different frequencies is shown in figure 4. Typical values for transmit power, antenna gain and wave state accounts for the range of distances plotted on each curve.
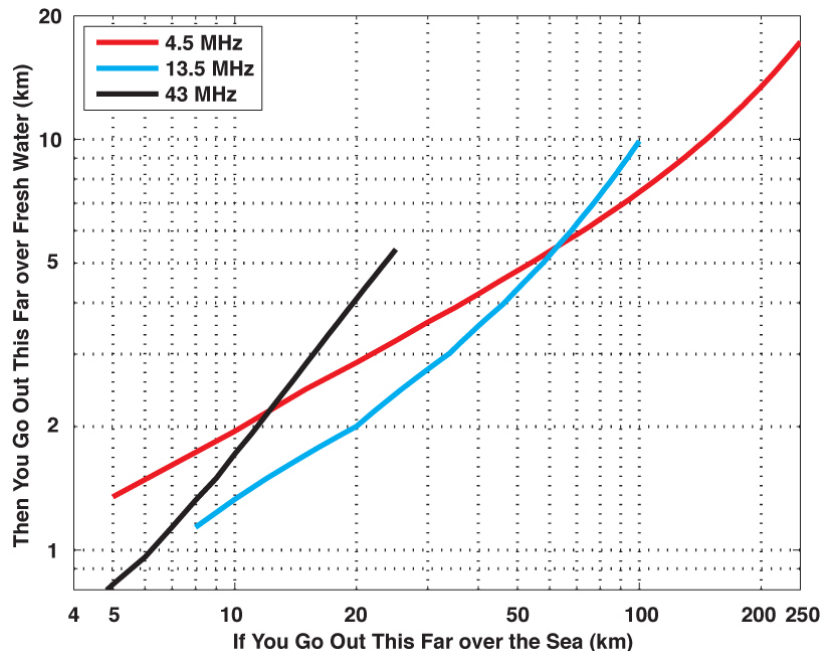

Figure 4: Ratio of range achieved over seawater vs. freshwater

Propagation Tests

Three boat transects were performed on May 12, 18 & 19 to measure the one-way propagation loss over fresh water. For each transect, the radar was set to continuous wave (CW) mode, generating a signal at a single frequency without the sweeping or pulsing that are necessary for processing Doppler-shifted echoes. The 42 MHz SeaSonde transmitted with an effective radiated power (ERP) of approximately 100 Watts. The Long Range SeaSonde transmitted with 25 Watts ERP when using the standard SeaSonde omnidirectional monopole transmit antenna and 116.9 Watts ERP when connected to the University of Michigan (UM) directional transmit array. Measurements for the 42 MHz SeaSonde were made with the same settings for all three transects. For the 5 MHz band, the May 12 transect was performed using the UM transmit array and the May 18 and 19 transects were performed using the SeaSonde transmit antenna. The waves in all transects were 0.2 m or less as produced by hindcast model.

The Ruf Lab portable spectrum analyzer was used to measure the received power at the peak of the spectrum. For the 5 MHz radar, the spectrum analyzer center frequency was set at 5.375 MHz with a span of 1 kHz and a resolution bandwidth (RBW) of 10 Hz with 101 points. For the 42 MHz radar, the spectrum analyzer center frequency was set at 42 MHz with a span of 1 kHz and a RBW of 10 Hz with 101 points. 100 sweeps were averaged in order to drive down the noise. First, the spectrum analyzer was connected to the antenna and the data file was saved that included the 100 averaged sweeps. A 50 ohm load was connected to the spectrum analyzer and the 100 averaged sweeps was taken. To process the data, the peak power level was selected along with the value of the power of the load at that same frequency and the difference between the antenna and load was taken. This process was performed at 1 km intervals from 1-8 km, 2 km intervals from 8-16 km, and 4 km intervals from 16-32 km.

The results of these measurements are shown in figures 5 and 6 for 42 and 5 MHz, respectively. Measured transect data are plotted over theoretical propagation loss curves for freshwater and seawater. All predicted curves and measured data sets are individually normalized relative to their values at 1 km, the closest measurement range. Normalization is done to eliminate differences in transmit power levels, transmit antenna gains, receive antenna gain and spectrum analyzer gain. Daily differences of approximately a dB or so are expected with different wave states and ground moisture levels between antenna and water. Measurements made using the SeaSonde transmit antennas were all within ±1 dB of each other on the respective frequencies. On May 12, the 5 MHz system transmitted from the UM directional transmit antenna. With increased transmit power possible due to precision tuning (manually performed daily) and 5-6 dB from directional gain in the boresight direction led to a 10 dB increase in overall signal strength throughout all ranges. It should be noted that in order to compare overall performance, the loss from 0 – 1 km must also be added. For 42 MHz, propagation loss over the first km is 8 dB more than seawater and is 20 dB more than seawater in the 5 MHz band.
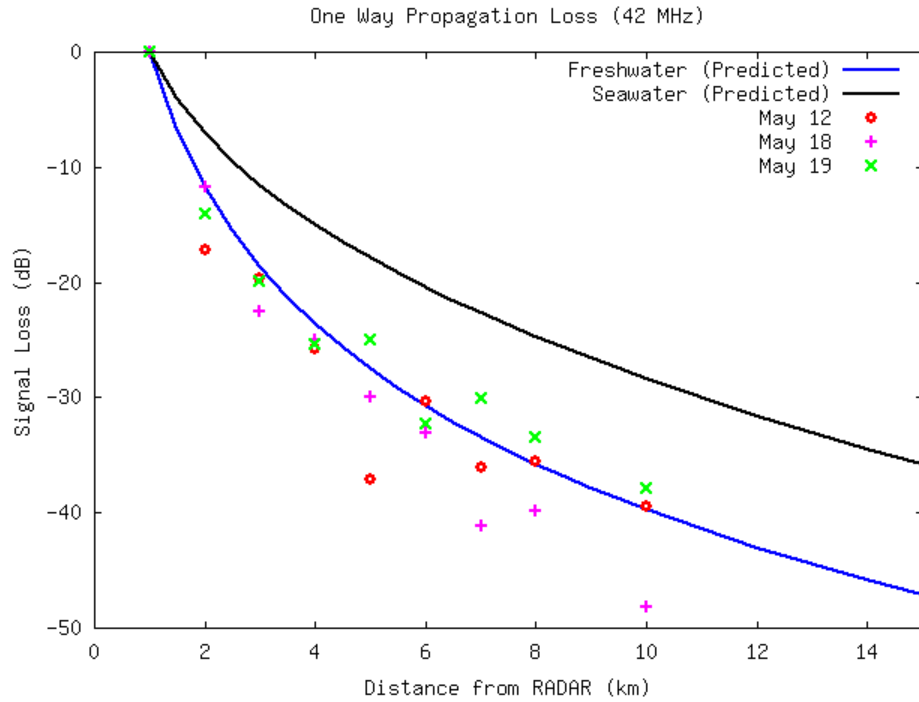
Figure 5: One-way propagation loss for 42 MHz. Data sets and theoretical curves are all normalized individually relative to values measured or predicted at 1 km range.
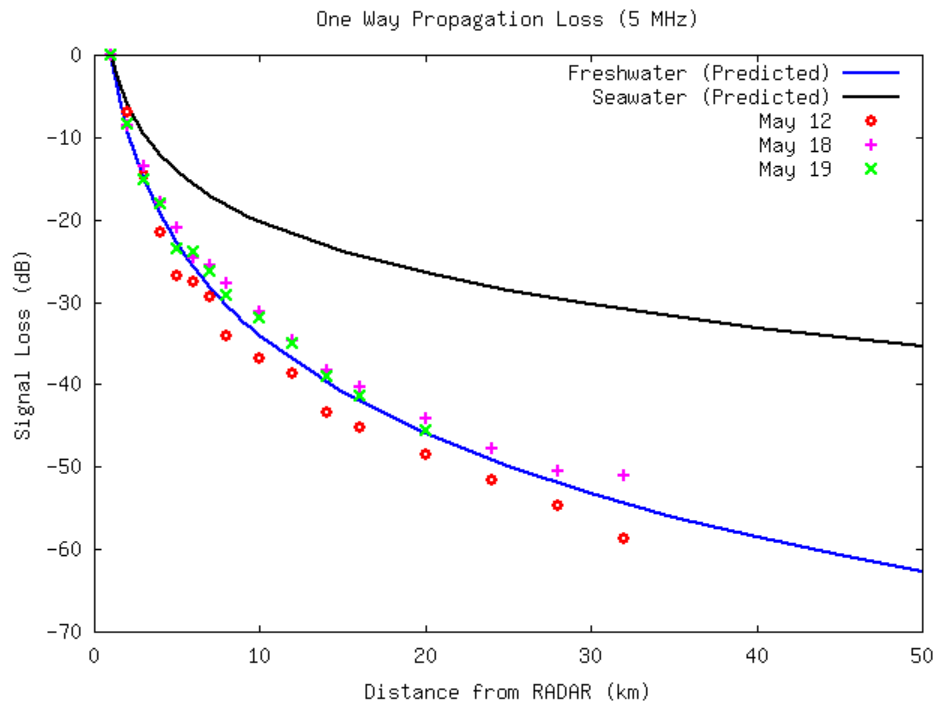

Figure 6: One-way propagation loss for 5 MHz. Data sets and theoretical curves are all normalized individually relative to values measured or predicted at 1 km range.

Surface Wave Echoes

Except for the periods when the transects were performed, both the 42 MHz and 5 MHz SeaSondes were configured to collect and process Bragg echo from surface waves into a map of the polar projection of surface currents. These measurements began on Monday evening, May 9, and continued until the systems were dismantled on Friday, May 19. The 5 MHz Bragg echo data was effectively only usable the last three days of the experiment, May 17 – 19, due to the high noise in the first few range cells caused by the ringing that occurred in the UM transmit array.

An example of a 5 MHz SeaSonde Doppler spectrum from Lake Michigan is shown in figure 7. The thin peak at 0 Hz (middle of the plot) is echo from stationary objects that do not produce Doppler frequency shift (buildings, land, etc.) as well other energy in the system that is mixed down to 0 Hz in Doppler processing. The Bragg echo due to waves of half the radar wavelength traveling toward and away from the radar can be seen in the thin peaks on the positive (right) and negative (left) of 0 Hz, respectively. The Bragg energy on the positive side was always stronger in this experiment so it was used as the measure of range performance of the system.
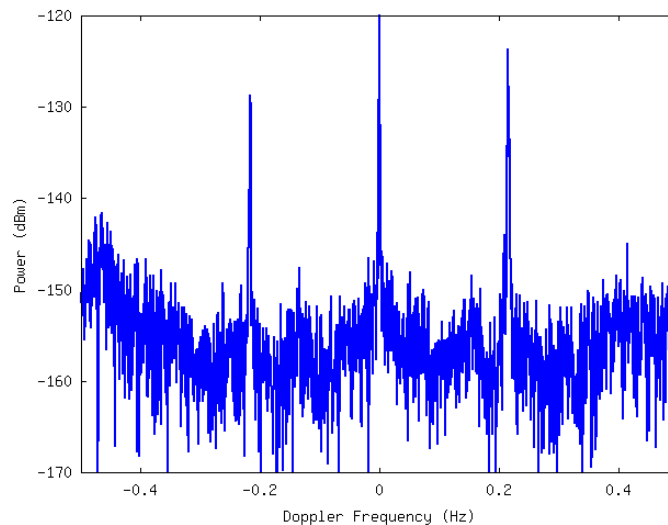

Figure 7: Example 4.57 MHz Doppler Spectra at 6 km offshore of Pt Betsie

Surface Wave Echoes – 42 MHz

Figure 8 shows the 42 MHz SeaSonde SNR during wave states when significant waveheight as produced by hindcast model varied between 0.6 and 1.0 m on May 14 & 15. Individual measurements are plotted in blue with the mean values plotted as red curve. Standard SeaSonde cutoff of 6 dB is plotted as green. Effective range is 7 – 8 km. Low SNR in range cells below 2 km are due to improper setting of Transmit Blank Delay, which is the time delay following a transmit pulse before the system begins receiving echoes. This is normally set to 8.55 μs for long range systems such that no echoes are received from ranges less than 1.28 km. Since Long Range HF Radars typically have range resolutions of 3 – 10 km, depending on frequency license, this is well below range resolution. For higher resolution systems, Transmit Blank Delay should be set lower.
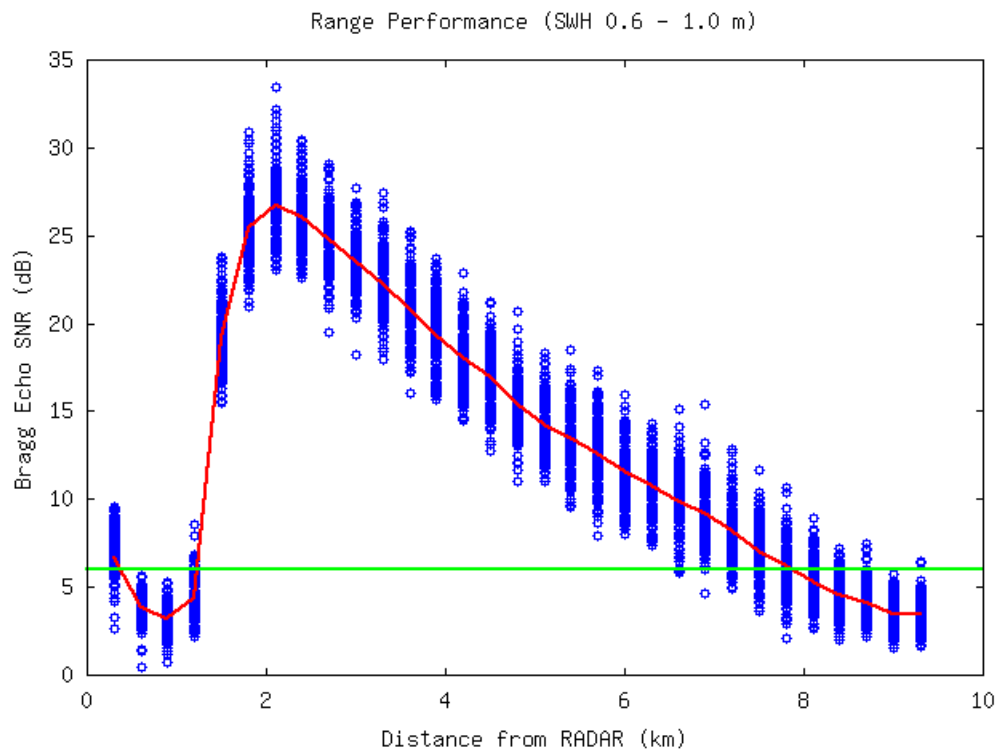
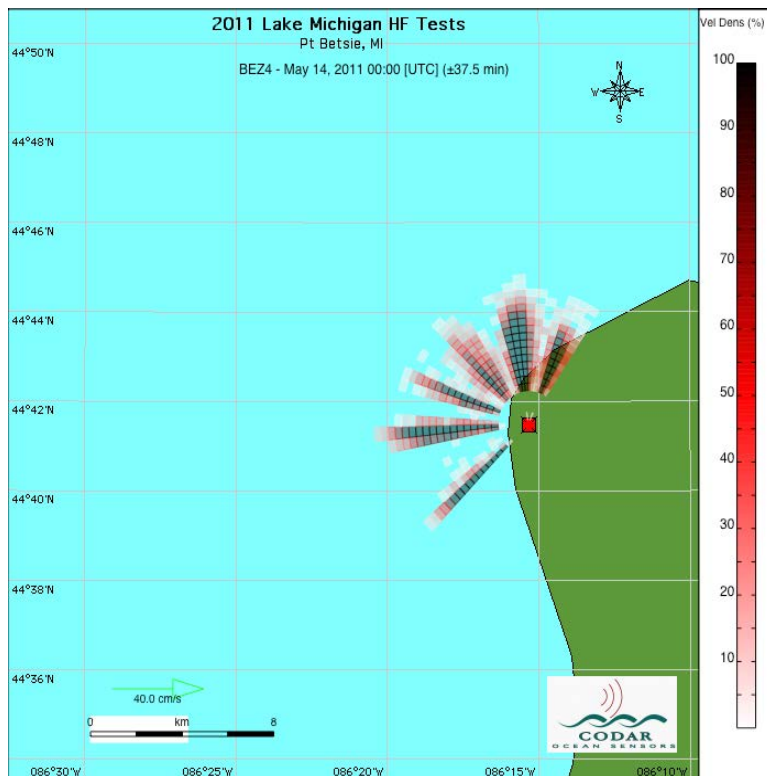Figure 8: Surface Echo SNR vs. range for 42 MHz on May 14 & 15

Figure 9: Radial distribution for 42 MHz on May 14 & 15

The radial distribution for 42 MHz SeaSonde when significant waveheight as produced by hindcast model varied between 0.6 and 1.0 m on May 14 & 15 is shown in Figure 9. The color is a measure of the percentage of the time a vector solution is found at a given range and bearing with darker colors indicating higher percentage of returns. Radial solutions are consistently found out to 4-5 km as the echo strength suggests. Azimuthal gaps are due to antenna interactions with near field environment. The 42 MHz antenna was installed on a sloped concrete seawall that presumably contained metal reinforcement. Different placement would eliminate these gaps.

Figure 10 shows the 42 MHz SeaSonde SNR during wave states when significant waveheight as produced by hindcast model varied between 0.2 and 0.4 m on May 19. Individual measurements are plotted in blue with the mean values plotted as red curve. Standard SeaSonde minimum SNR threshold of 6 dB is plotted as green. Effective range is 4 - 5 km. The radial distribution for this period is shown in figure 11. The range of radial solutions match the effective range determined by signal strength, as expected. Additionally, the distribution was more sparse in bearing at the lower wave state, possibly due to weaker wind-driven currents.
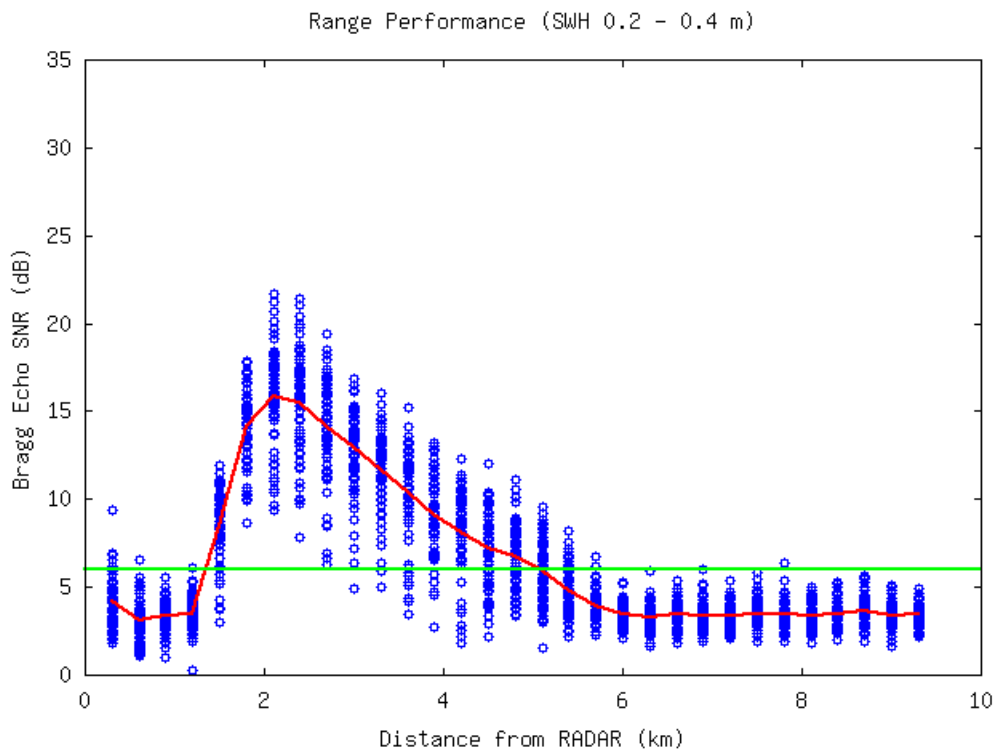

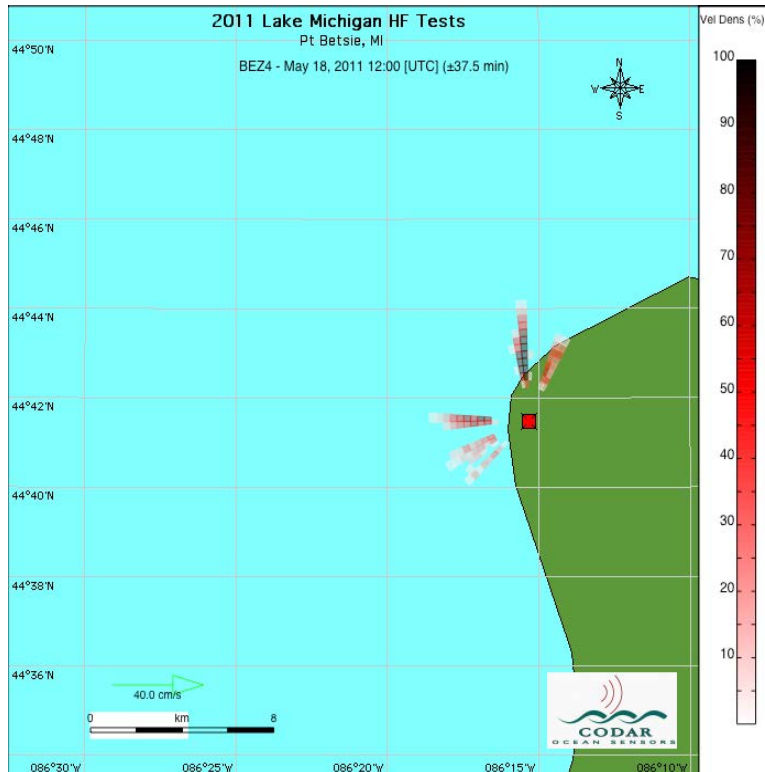Figure 10: Surface echo SNR vs. range for 42 MHz on May 19

Figure 11: Radial distribution for 42 MHz on May 19

Surface Wave Echoes – 5 MHz (Long Range)

Data collected at 5.375 MHz from May 10 – May 17 was plagued with high radio noise confined to the first 10 - 12 range cells. Unfortunately, this is exclusively where the Bragg echo was expected. The noise was only observed when the system was transmitting. Cal Teague first determined that it was most likely due to ringing that occurred in the UM transmit antenna array as a response to the tuning employed which increased efficiency and narrowed the bandwidth of the antenna. For a more detailed explanation, please see Teague, 2011. This ringing was evident whether the UM antenna was connected to the transmitter or not, due to its close proximity to the SeaSonde transmit antenna. The choice was made to transmit only from the SeaSonde antenna for data collection and to switch to 4.57 MHz.

The amount of data collected at 4.57 MHz was limited to only a few days, so we do not have the same variety of wave states to compare range performance. In addition, operation at 5 MHz has the added challenge of fluctuating external background radio noise. This is primarily due to diurnal ionospheric variations which make skywave propagation more favorable in the evening when ionosphere layers are at their lowest heights. This allows radio noise from man made and natural sources, like lightning storms, to travel much farther. At Pt Betsie, the background RF noise level at 4.57 MHz increased approximately 10 dB from day to evening as shown in figure 12.
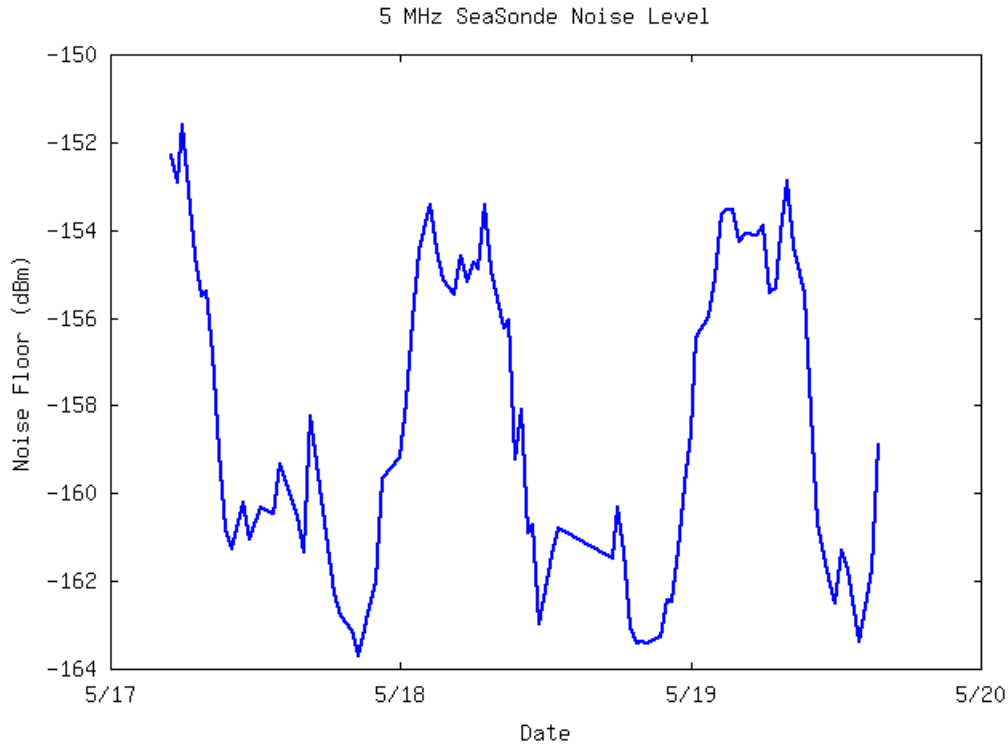
Figure 12: Diurnal 10 dB variation in external noise level observed at 4.57 MHz around Pt Betsie. Time is in GMT.

Figure 13 below shows the 5 MHz SeaSonde SNR during wave states with significant waveheight varying between 0.2 and 0.5 m during May 17 - 19 as produced by hindcast model. Individual measurements are plotted in blue. Green and black curves are six hour means around 20:00 GMT (low external noise) on May 17 and 18, respectively. Magenta and red curves are six hour means around 06:00 GMT (high external noise) on May 8 and 19, respectively. Effective range during low noise period is 18 km vs. 9 km or less during high noise periods. The external noise, in this case, had a greater effect on range than did the wave state.

It should be noted that the radio bandwidth required to achieve the 3 km resolution at 5 MHz was 50 kHz. Bandwidth this wide has been approved in other countries, like Australia, but in the U.S. only for specific scientific deployments only. Operational systems are limited to 25 kHz bandwidth, resulting in 6 km range resolution. Radial distribution for the Long Range system is shown in figure 14.
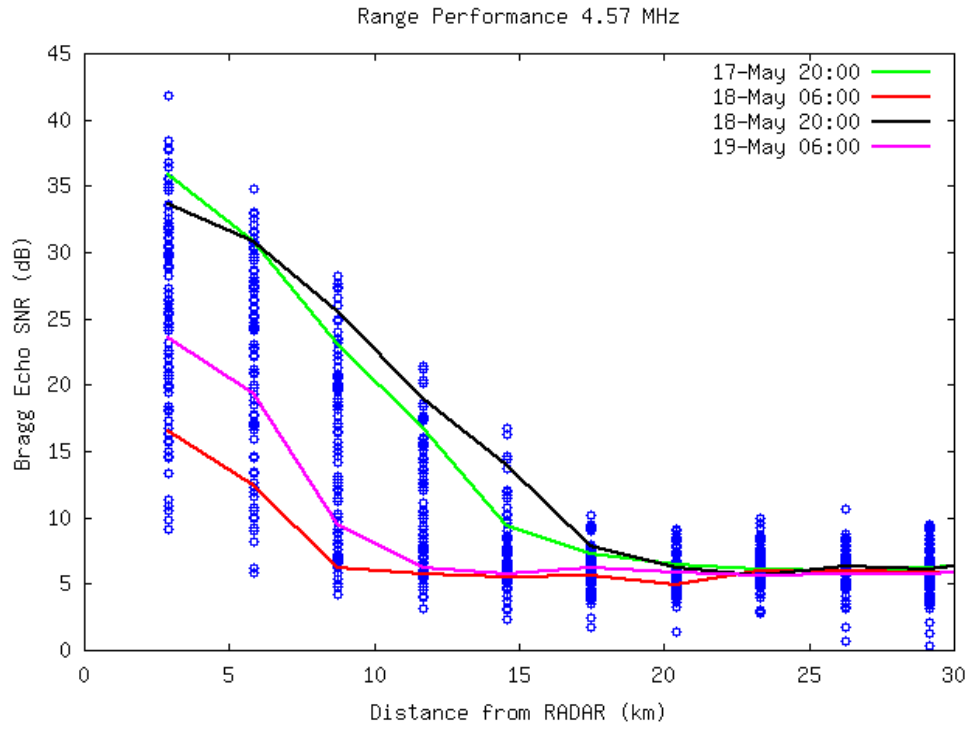
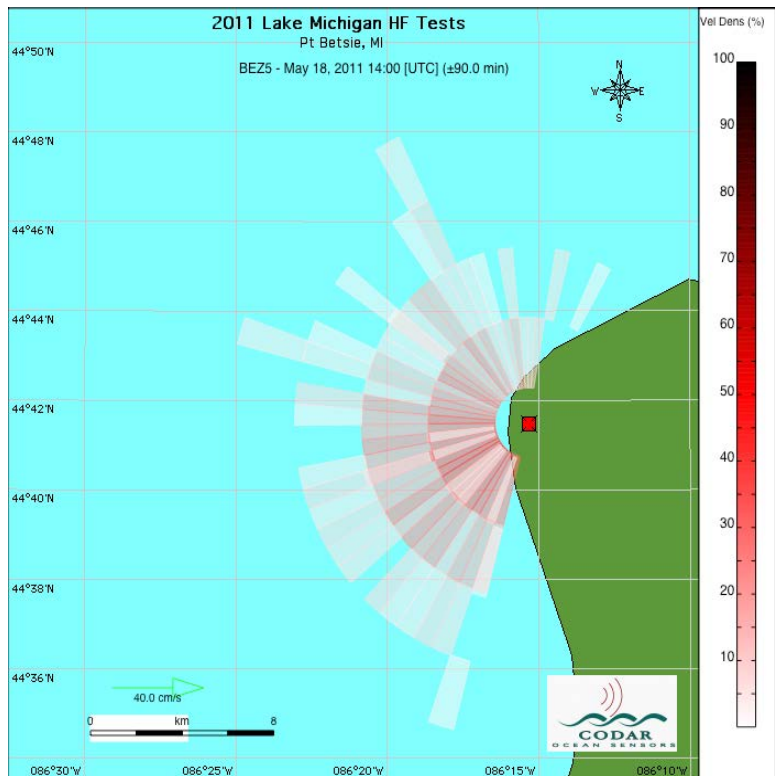Figure 13: Surface echo SNR vs. range for 5 MHz on May 17 – 19

Figure 14: Radial distribution for 5 MHz on May 17 – 19

Conclusions

Two SeaSonde HF Radar systems were successfully deployed at Pt Betsie on the eastern shore of Lake Michigan during the period May 9 – 20, 2011. Doppler spectra for surface wave echoes were collected continuously in the 42 MHz and 5 MHz bands simultaneously with resolutions of 300 m and 3 km, respectively. In addition, tests were conducted on May 12, 18 and 19 to measure one-way propagation loss over freshwater.

Range performance on freshwater is highly dependent on wave conditions. At 42 MHz, effective range achieved varied between 4 and 8 km, depending on wave state, which varied between .2 and 1.0 m significant wave height. During periods of lower energy (waves and currents), azimuthal gaps that existed due to near-field antenna interactions were enhanced. At only the highest wave heights, some second order Doppler spectra was visible that could be used for determining wave parameters and could be investigated further.

Although limited to only a few days of the entire deployment, operation in the 5 MHz band had effective ranges between 3 and 18 km when significant waveheight varied between .2 and .5 m. Effective range at 5 MHz was further limited by diurnal external background Rf noise oscillations of 10 dB which amounted to range reduction of 6 – 9 km. No second order Doppler spectra were ever visible during this period. Waveheights greater than .5 m occur approximately 35% of the time at Pt Betsie based on the multi-season average and less at other locations. Coupled with the diurnal noise variation in the 5 MHz band, ranges of 18 km or greater are predicted to be achieved approximately 20% of the time for a standard SeaSonde configuration.

Increased power and directional antenna gain do increase range as demonstrated by the UM directional transmit antenna during the propagation tests of May 12. 10 dB gain in the boresight direction was achieved due to both increased input power with a better match and directional gain. This would amount to approximately 6-9 km of additional range. As with any tuned antenna, care needs to be taken to ensure the proper bandwidth is available for the range resolution required.

Ultimately, the propagation tests indicate that the currently available models for theoretical predictions of propagation loss can be used to estimate ranges in fresh water.

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Vesecky, J., J. Drake, M. Plume, L. Meadows, Y. Fernandez, P. Hansen, C. Teague, K. Davidson and J. Paduan, "Multifrequency HF Radar Observations of Surface Currents: Measurements from Different Systems and Environments," Proceedings of Oceans 2001, IEEE, p. 842-948, 2001b.

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Acknowledgements

Appendix: Installation Photos

42 MHz SeaSonde Transmit/Receive Mast

Long Range 5 MHz SeaSonde Transmit Antenna

University of Michigan Transmit Antenna Array

SeaSonde electronics and processing laptops side by side for both frequencies

UM students preparing boat for SeaSonde Calibration

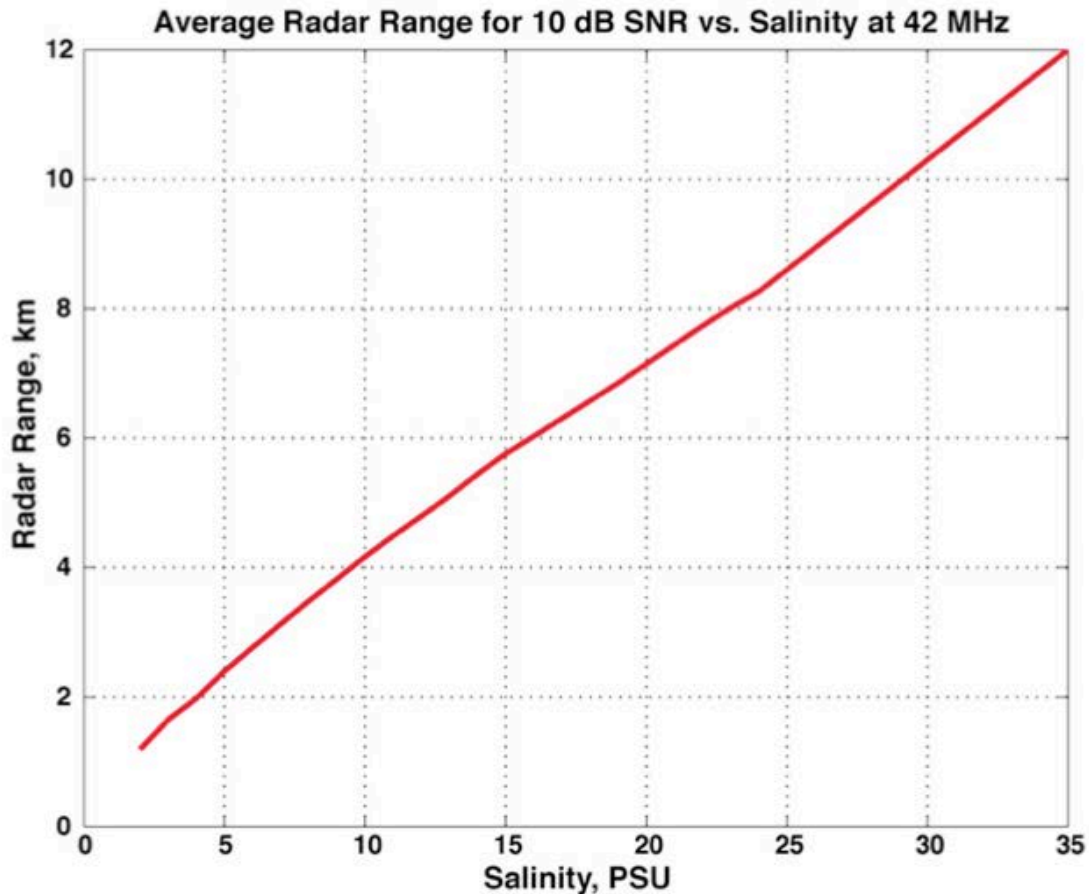SeaSonde 5 MHz receive antenna in front of Pt Betsie Lighthouse

Appendix 2

Updyke Report on HF Radar Performance in Brackish Water Conditions

# HF Radar Observations in Brackish Water Environments

Teresa Updyke
Old Dominion University
August 2012

Brackish water is less conductive than saltwater and has a smaller refractive index. As water becomes fresher and its refractive index becomes smaller, electric field interactions are set up at the boundary of the air-water interface which cause more radiowave energy to be forced into the water and lost for current measurement purposes. An HF radar measuring currents in fresh or brackish water will have a shorter range due to the greater signal attenuation. (Long, et al, 2006)

The graphs below, copied from Long et al, 2006, present estimated radar range versus salinity for four common SeaSonde operating frequencies. A radar signal to noise ratio threshold of 10 dB was used and the radar maximum range was assumed at 35 PSU.

Average Radar Range for 10 dB SNR vs. Salinity at 25 MHz

Average Radar Range for 10 dB SNR vs. Salinity at 13 MHz

Average Radar Range for 10 dB SNR vs. Salinity at 4.5 MHz
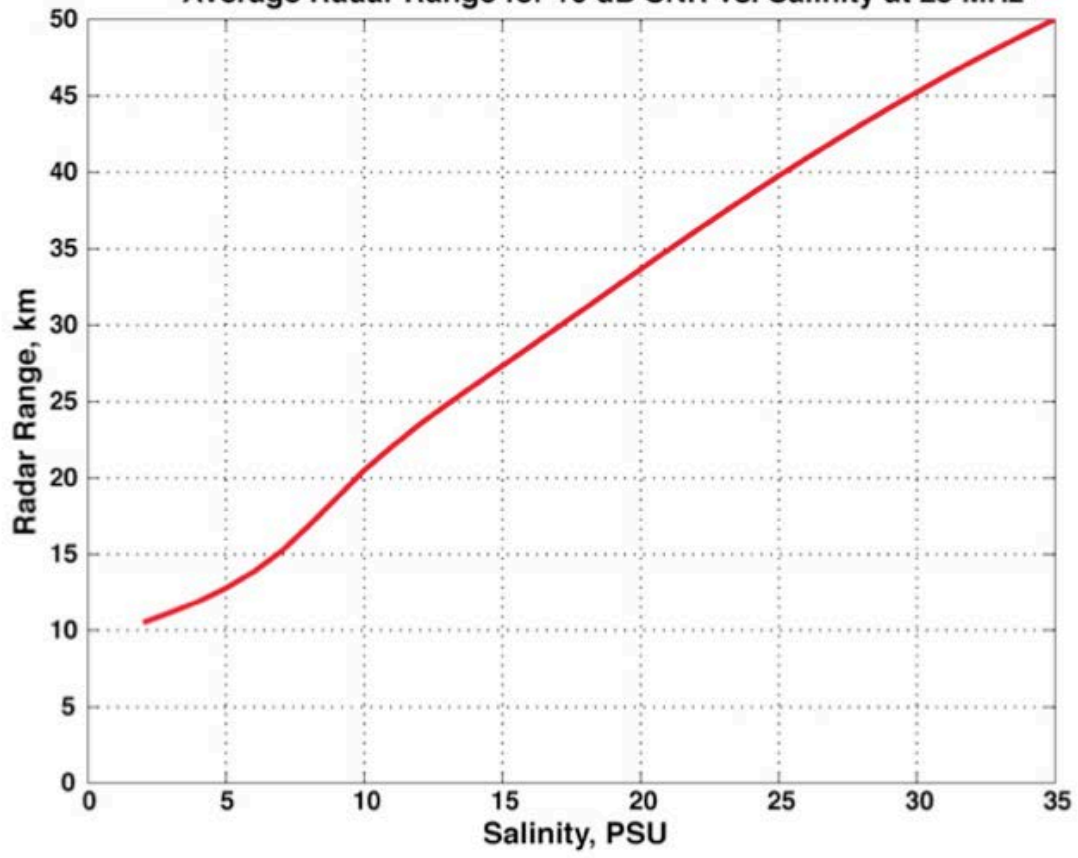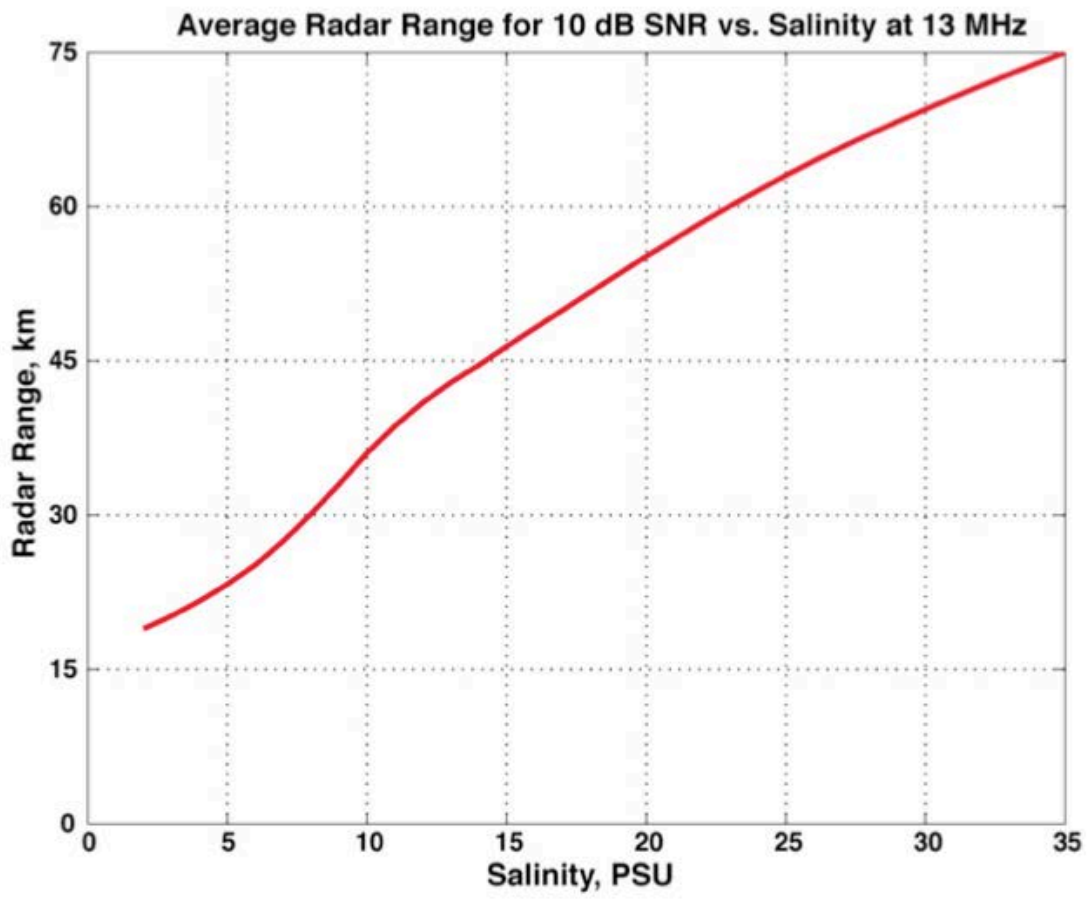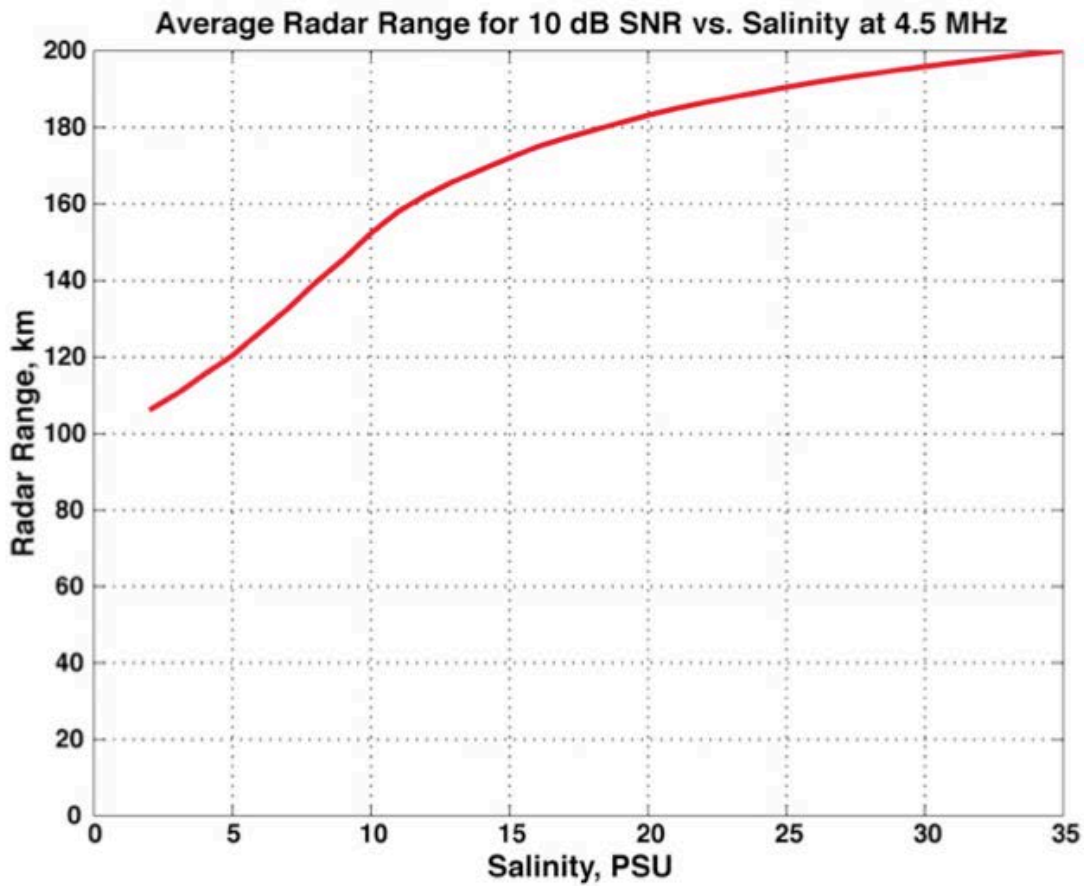
Field Observations and Analysis

An analysis of the performance of two 25 MHz SeaSonde systems operating in the lower Chesapeake Bay provided an opportunity to examine the relationship between radar range and salinity in a real world setting. The radar sites, VIEW and CPHN, have been operating for several years under a wide range of salinity conditions and both provide similar data coverage throughout the lower Bay. VIEW is located closer to the mouth of the James River while CPHN is sited closer to the ocean (Figure 1).

Figure 1. Radar (yellow) and NOAA station (orange) locations in the lower Chesapeake Bay.

An initial cursory comparison of conductivity and maximum radar range time series clearly illustrated the strong correlation between the two variables (Figure 2). The systems' maximum ranges were defined as the range at which the number of radial vectors fell below 20% of the average vectors per range. Conductivity measurements were provided by the NOAA PORTS Sewells Point station located in the James River and the NOAA PORTS station at the first island of the Chesapeake Bay Bridge Tunnel. Conductivities were observed at a depth of 3 to 4 meters below mean low low water (Mark Bushnell of NOAA CO-OPS Chesapeake Bay office, personal communication). Note that the 25 MHz radar signal would only sense conductivity in the upper 10 to 20 cm of the water column (Don Barrick, president and founder of CODAR Ocean Sensors, personal communication) and over a wide area.
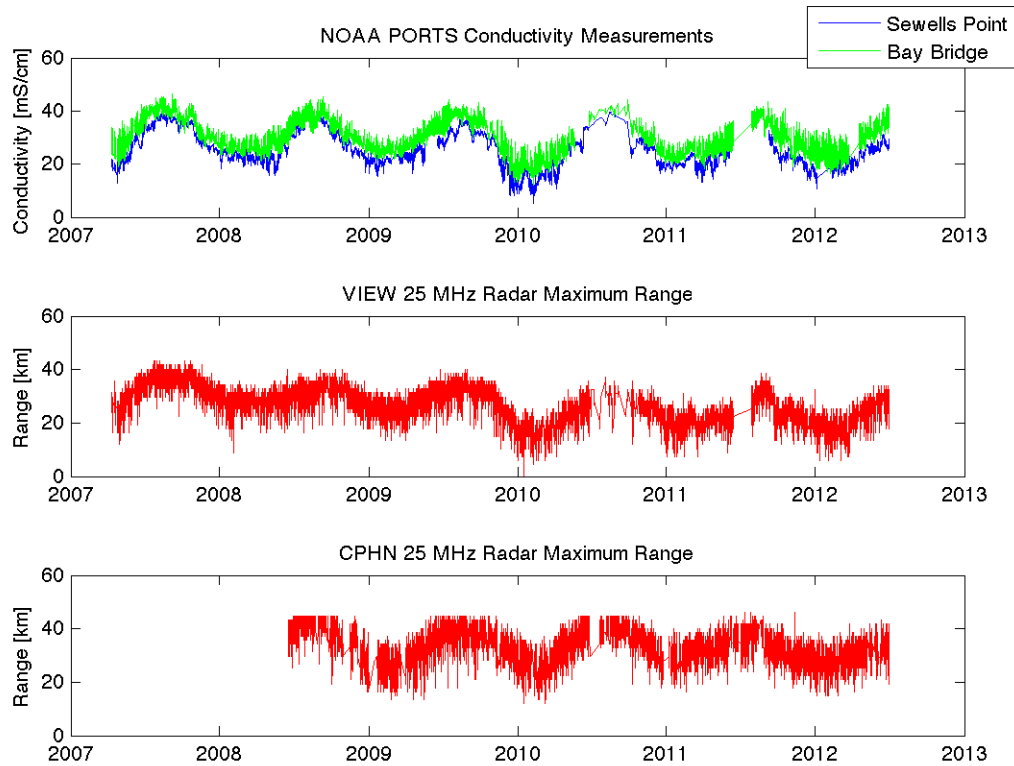
Figure 2. Time series of conductivity and radar maximum range.

Further analysis confirmed that the relationship between salinity and the radar range is similar to that predicted by theory (Figures 3 and 4). In order to minimize the influence of other factors on the maximum range, data were only included in the analysis during times when the following radar diagnostic criteria were met:

Transmit forward power > = 40 watts
Monopole background noise < -140 dBm
Loop1 background noise < -140 dBm
Loop2 background noise < -140 dBm

Conductivity and temperature at the NOAA PORTS stations were used to compute salinity. Salinity data were interpolated to times of radar radial map timestamps and then "binned" by rounding to the whole number. For each salinity bin, the average maximum radar ranges were calculated. The results were limited to salinities where the number of radar data points met a minimum sample size criteria of 400. Figures 3 and 4 compare the salinity/range relationships at VIEW and CPHN with the model predicted relationship from the "average radar range for 10 dB vs salinity at 25 MHz" plot provided by Long et al 2006. While the absolute values for the relationships are different, the slopes of least squares fit lines to the radar data are very similar to the slope of the model curve. Differences in the

absolute values can be expected due to differences between measured salinity and salinity at the surface, differences in radar signal strength and other factors affecting performance that are specific to the individual radar site.
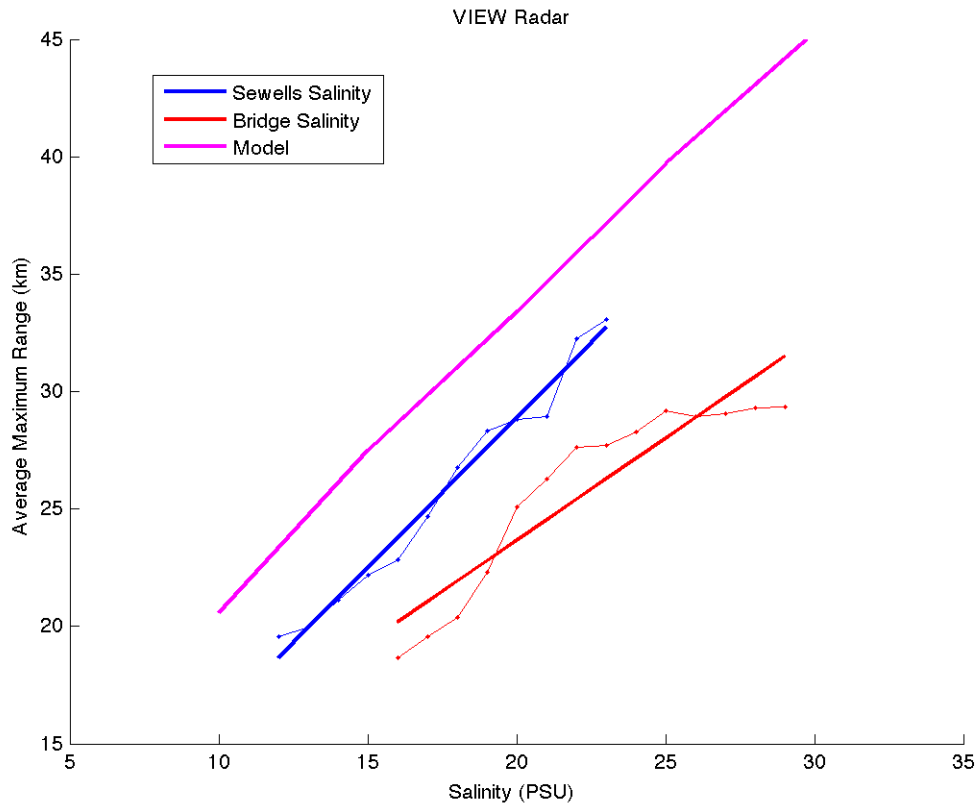

Figure 3: VIEW station analysis covers the time period April 10 2007 20:00 UTC to June 30 2012 23:00 UTC. Model curve is sourced from Long et al 2006.
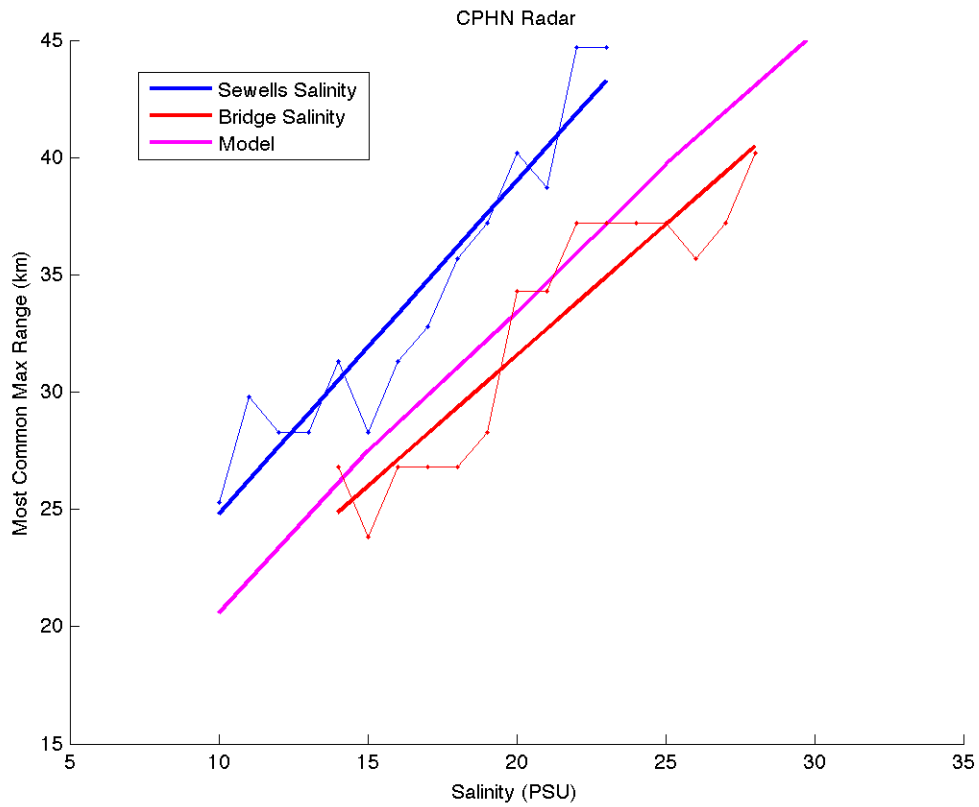
Figure 4. CPHN station analysis covers the time period June 18 2008 00:00 UTC to June 30 2012 23:00 UTC. Model curve is sourced from Long et al 2006.

References

Long, R., N. Garfield and D. Barrick. 2006. The Effect of Salinity on Monitoring San Francisco Bay Surface Currents using Surface Current Monitoring Instruments (SMCI). Presentation at the *California and the World Ocean '06 Conference*, September 17-20, Long Beach, California.