HF Radar Measurements of Waves: Comparing with *In situ* Measurements

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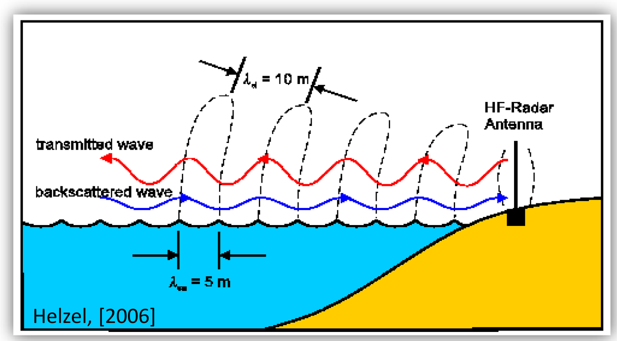
Abstract

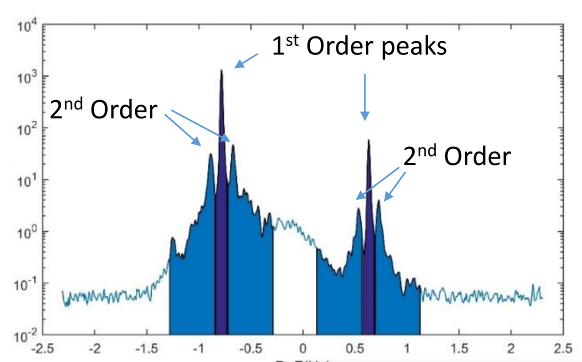
High frequency (HF) radars use electromagnetic (EM) waves to measure ocean surface parameters. Use of HF Radars for measuring sea surface currents is a well established method. The ability using HF Radars for measuring sea surface waves is examined in this work.

HF Radar data from a single station deployed on Cape Hatteras (NC) as part of the USGS Carolina Coastal Change Processes project in 2010 are analyzed. The data collected are compared with wave data collected using in situ sensors (ADCPs). The analysis presented attempts to establish the suitability and accuracy of VHF radars in terms of wave parameter measurements and its sensitivity to radar boresight angle, range, wave energy and ocean wave frequency.

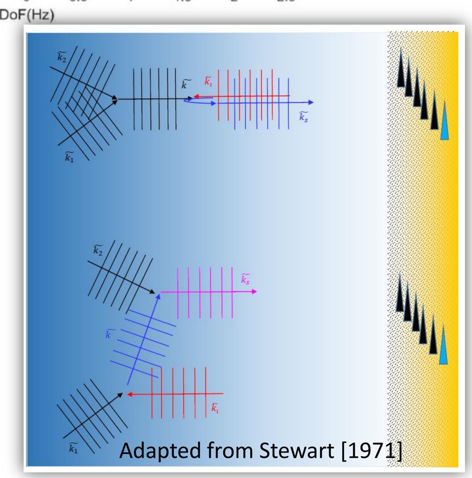
Radar Theory

EM waves emitted by the radars are backscattered by the surface of the ocean with wave length half that of the EM wave (Bragg scattering). Doppler spectrum of the backscattered signal is used to identify shifts in frequency due to ocean currents (1st Order peaks)





Nonlinear interaction between the EM and ocean waves (hydrodynamic and electromagnetic effects) cause the creation of 2nd Order peaks in the Doppler spectrum that surround the 1st order peaks. This part of the spectrum contains information about the ocean waves.

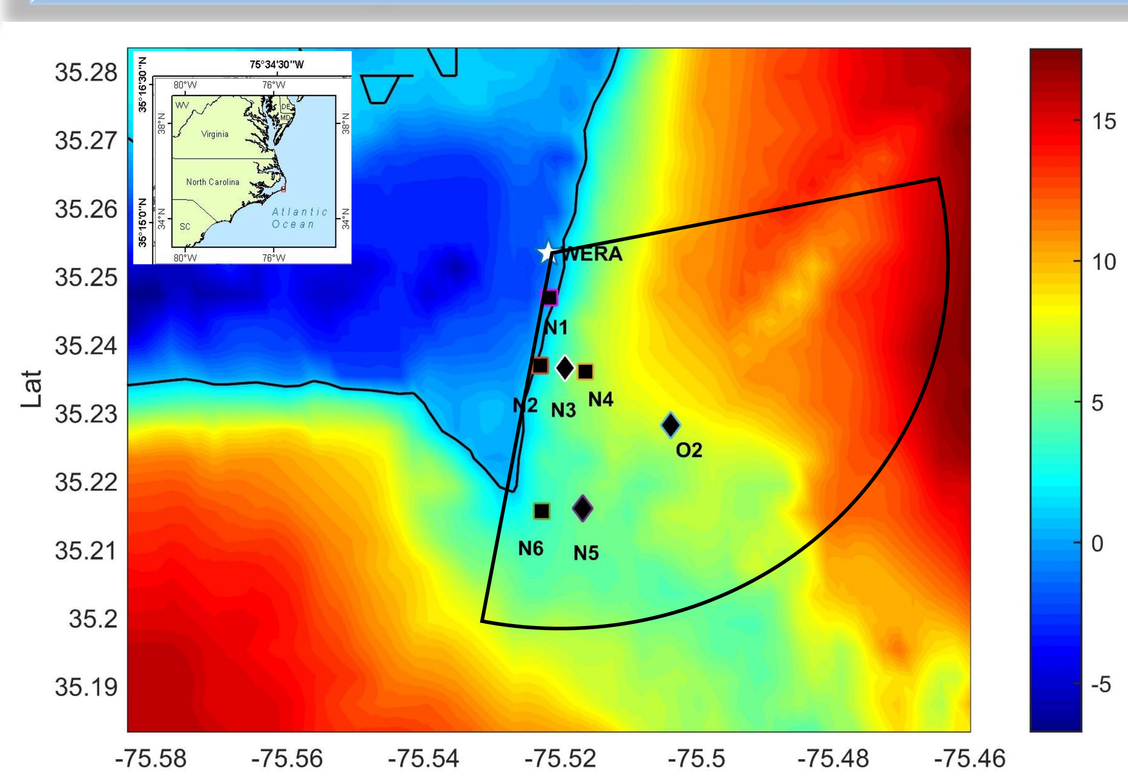


VHF WERA Radar Experiment

- Single very high-frequency (VHF, 48 MHz) Wellen Radar
- Deployed over a period of 28 days (Feb. – Mar. 2010)

Frequency operation	48 MHz
Raw range resolution	150 m
Processed range resolution	150 m
Number of array receivers	12
Transmit time	14.78 min
Repeating rate	30 min
Bandwidth	1000 kHz

Radar Coverage Area – In situ stations



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Model for the Extraction of Ocean Wave Spectrum

$$R(f) = \frac{\sigma_2(f_D - f_B)}{\int_{f_B-\Delta f}^{f_B+\Delta f} \sigma_1(f_D - f_B)\, df}$$

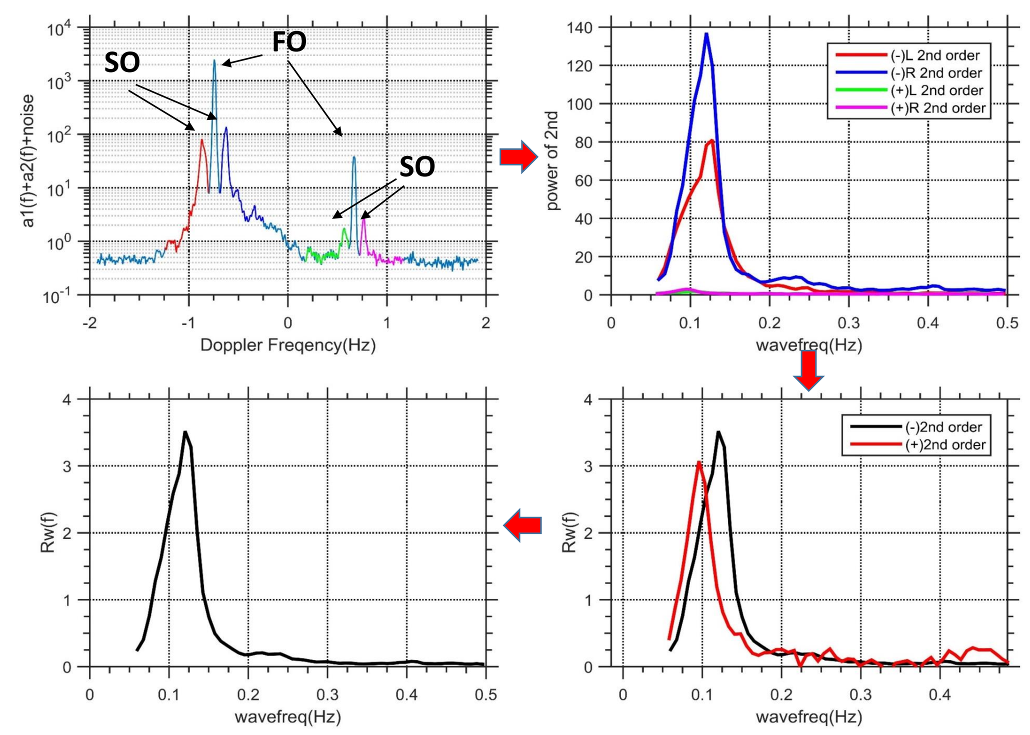
R(f) is ratio of σ_2 and σ_1, 2nd and 1st cross section spectra respectively. f_D and f_B are Doppler and Bragg frequency. Barrick [1977], Heron et al [1998].

Assuming that the interaction between ocean and EM waves is ocean wave frequency dependent. α(f) regression factor can be developed that relates the ocean waves $S(f)_{insitu}$ to the 2nd order spectrum:

$$\alpha(f) = \frac{S(f)_{insitu}}{R(f)}$$

Method

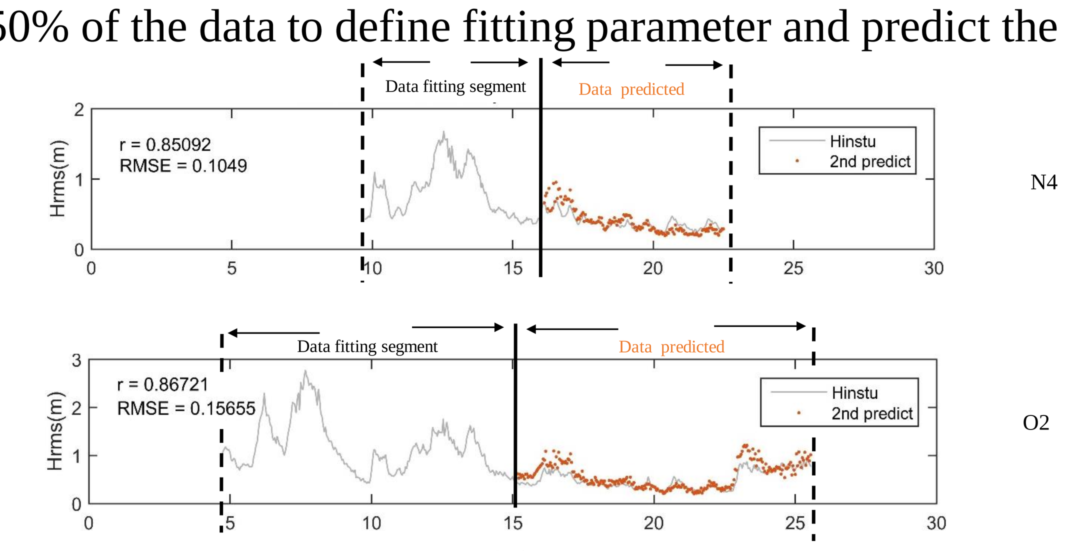
1. Separate 1st Order (FO) and 2nd Order spectra (SO).
2. Capture all energies in FO and SO bands.
3. Normalize SO by FO spectra after average SO in each side of Doppler spectrum.
4. Select only SO spectra in strong side of Doppler spectra.



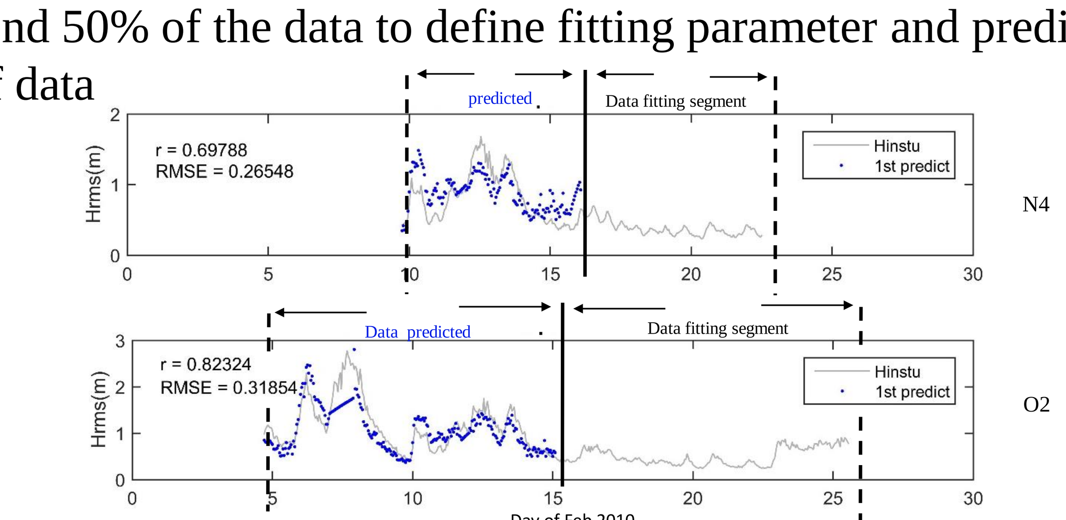
Investigating of Method Validity

Use 50% of the data to define fitting parameter and evaluate using the other 50%

1. Use first 50% of the data to define fitting parameter and predict the second 50% of data



2. Use Second 50% of the data to define fitting parameter and predict the first 50% of data

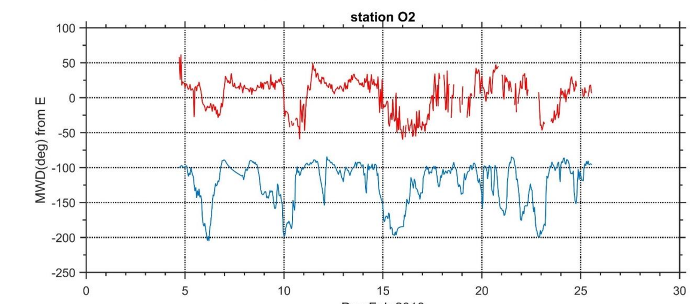


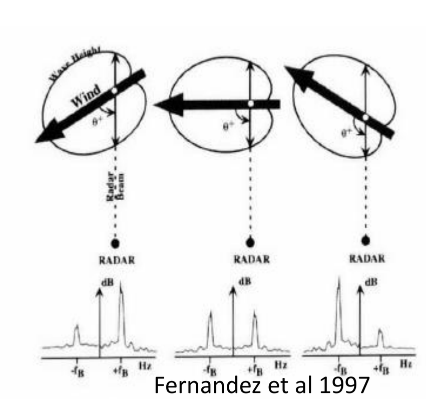
Ocean Wave Direction Estimation

Using ratio of FO spectra (peak areas)for both side of Doppler spectrum $\sigma_1(+f_B)$, $\sigma_1(-f_B)$ Fernandez et al [1997].

$$\theta_w = \theta_0 - 2\, arctan\left(S_1^{\frac{1}{2s}}\right) \qquad S_1 = \frac{\sigma_1(+f_B)}{\sigma_1(-f_B)}$$

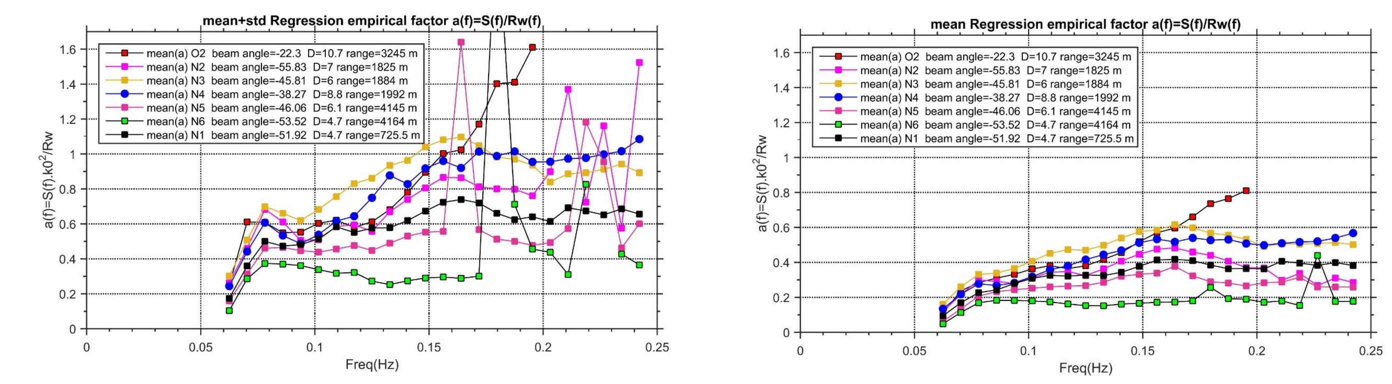
θ_w is estimated mean wave direction. θ_0 is angle of radar look direction. $\sigma_1(+f_B)$, $\sigma_1(-f_B)$ are approaching and receding 1st order



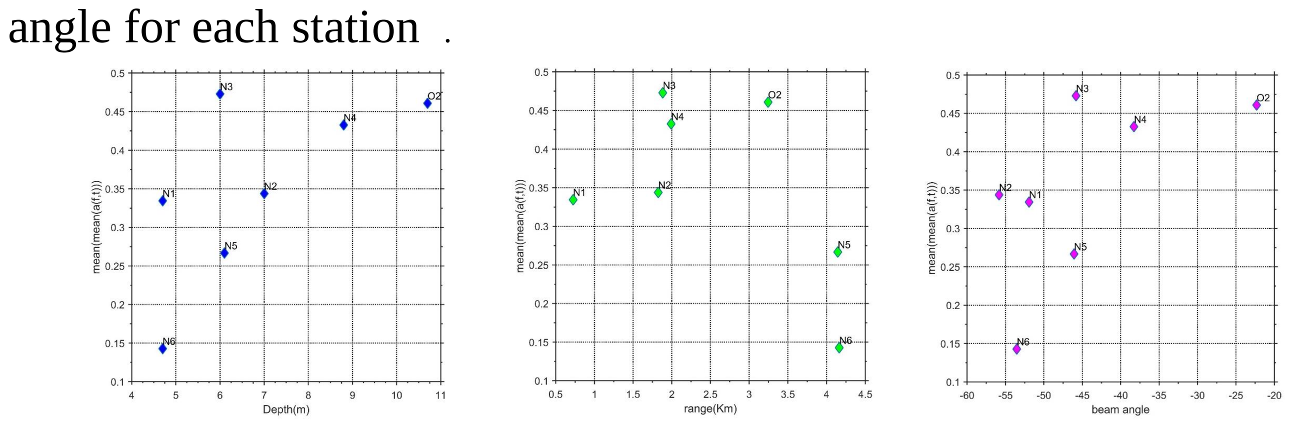


Dependencies of regression factor α(f)

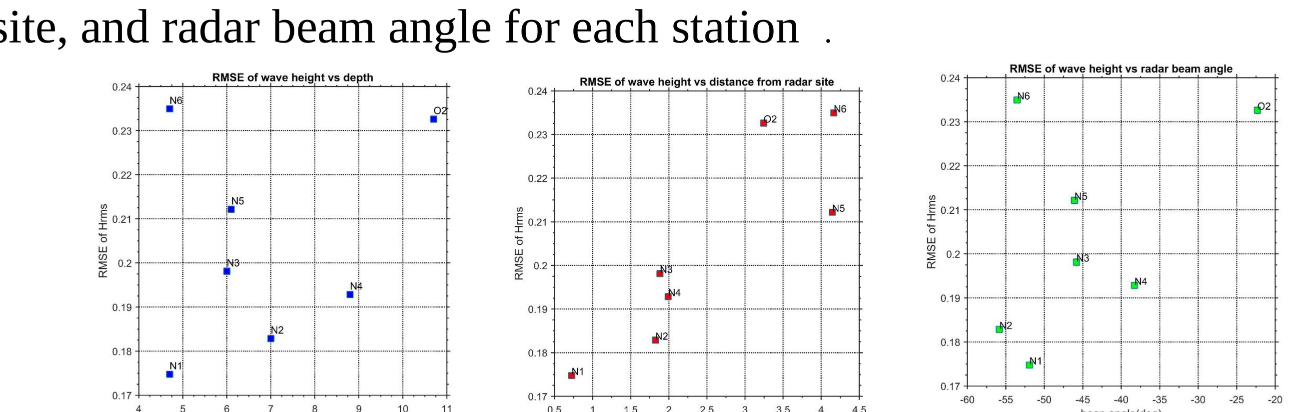
(a) Dependency of regression factor on ocean wave frequency



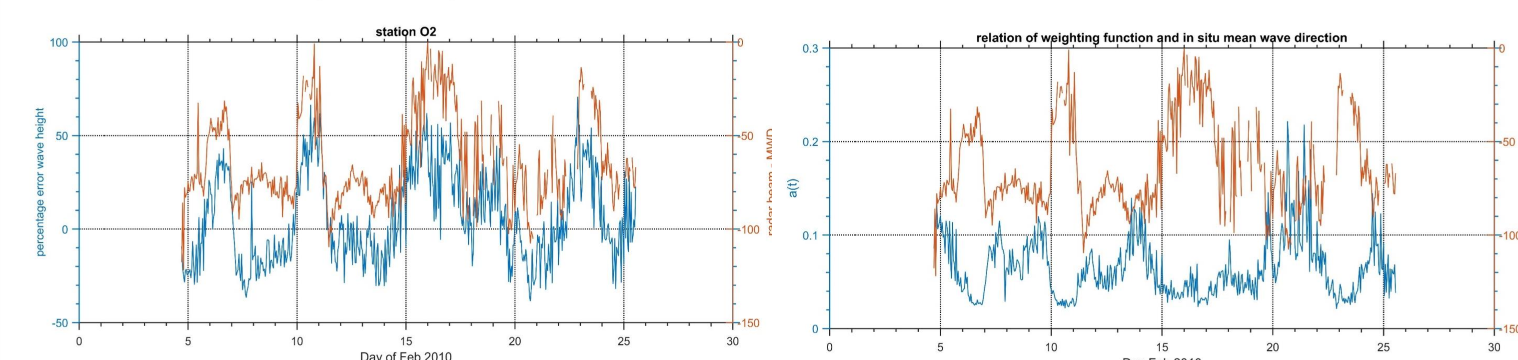
(b) Dependency of a(f) on water depth, range from radar site, and radar beam angle for each station .



(c) Correlation of RMSE of ocean wave height with depth, distance from radar site, and radar beam angle for each station .



(d) Correlation of the percentage error of wave height and regression factor with cross angle (angle from radar beam to Mean wave direction).



Conclusion

- The accuracy of extracted ocean wave height depends on effect of three dominant factors ;water depth, radar beam angle, and radar range. RMSE of ocean wave height increases with depth increases for most stations and also it increases with increasing range, range is distance from radar site to station in ocean. While RMSE of ocean wave height decreases with radar beam angle increases for most stations.
- The followed regression method shows accuracy with 10-15% error for measuring ocean wave height.
- The regression Method shows validity of using less data (two weeks) to predict wave height.

References

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