Analysis of Radar Data Collected During 2013 R/V Melville Cruise

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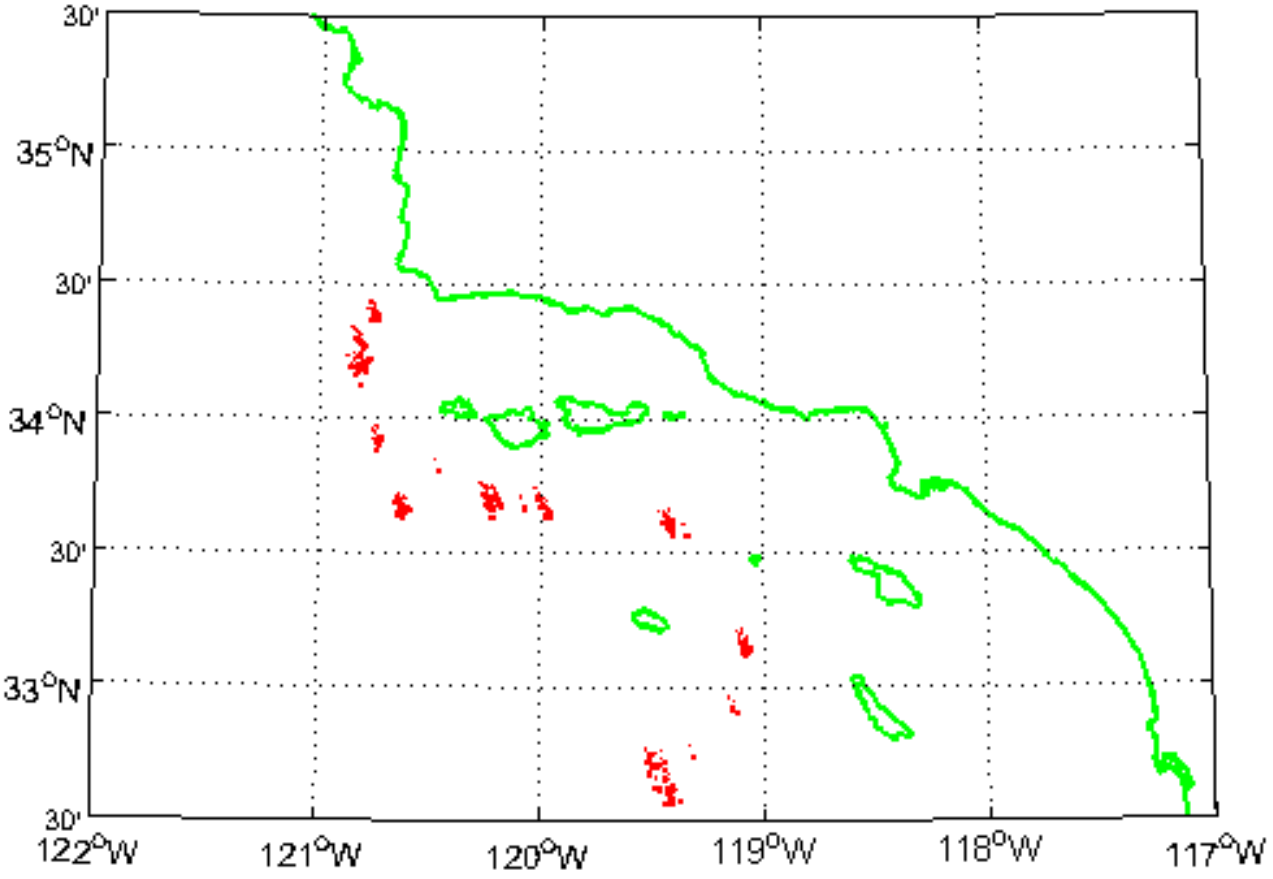
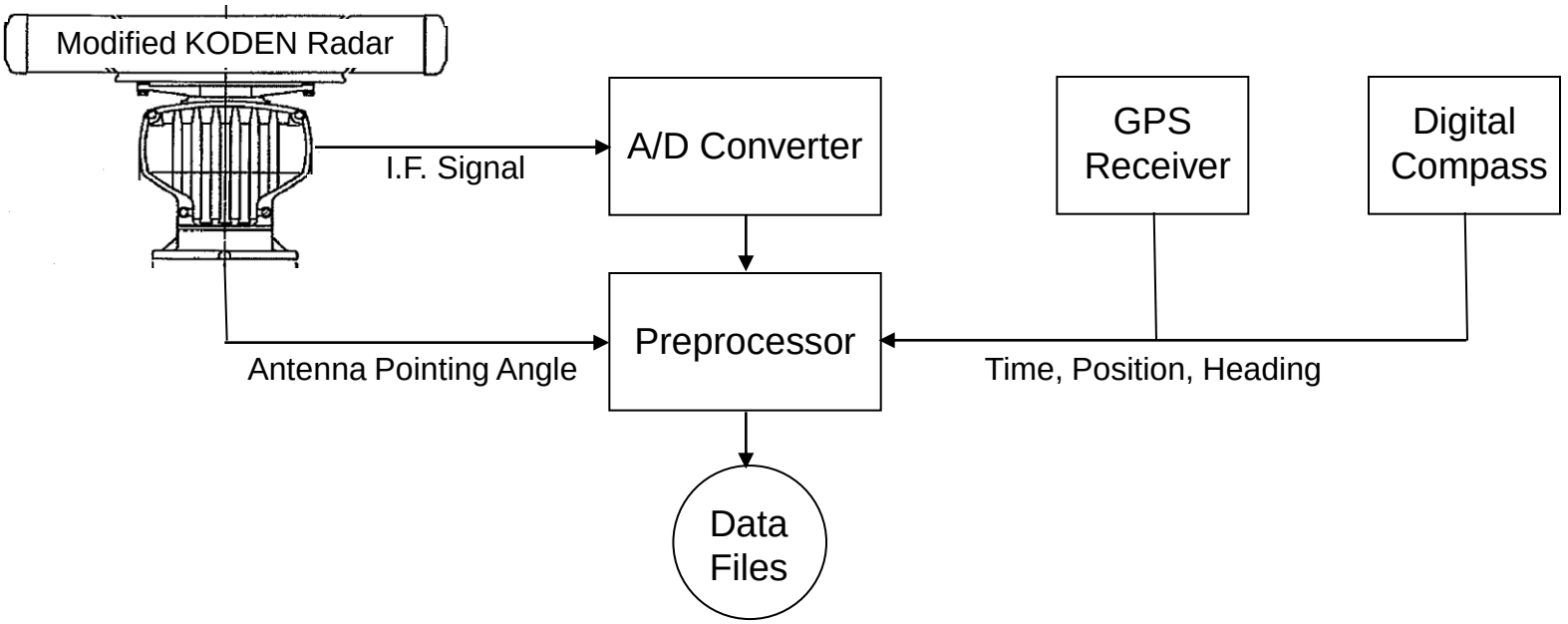
OSU Collaborators: J. Johnson, A. O'Brien, G. Smith, …
SIO Collaborators: A. de Paolo , E. Terrill

R/V Melville Tracks 9/10 - 9/18/2013

during radar operation



UM/OSU Radar System



25 kW X-band (9.4 GHz), 0.08 μsec pulse width, 2 kHz PRF

L.O. replaced by OSU to improve Doppler performance

16-bit 160 MSPS AlazarTech ADC, 6.4 μsec (960 m) sampling interval

V-pol antenna 30.3 m above water during Melville cruise

Backscattered Power Measurements

Received Power: $P_r(r,\phi) \propto P_t A_e \rho_r \frac{\sigma_o}{r^3}$

Range Integration: $A(\phi) = \frac{1}{\pi r_m^{\,2}} \sum_r P_r(r,\phi) r^3 \Delta r$

Fourier Fitting : $a_0 = \frac{1}{2\pi} \sum_\phi A(\phi) \Delta\phi$

$$a_n = \frac{1}{\pi} \sum_\phi A(\phi) \cos(n\phi) \Delta\phi \qquad b_n = \frac{1}{\pi} \sum_\phi A(\phi) \sin(n\phi) \Delta\phi \qquad n = 1, 2$$

$$\hat{A}(\phi) = a_0 + a_1 \cos(\phi) + b_1 \sin(\phi) + a_2 \cos(2\phi) + b_2 \sin(2\phi)$$

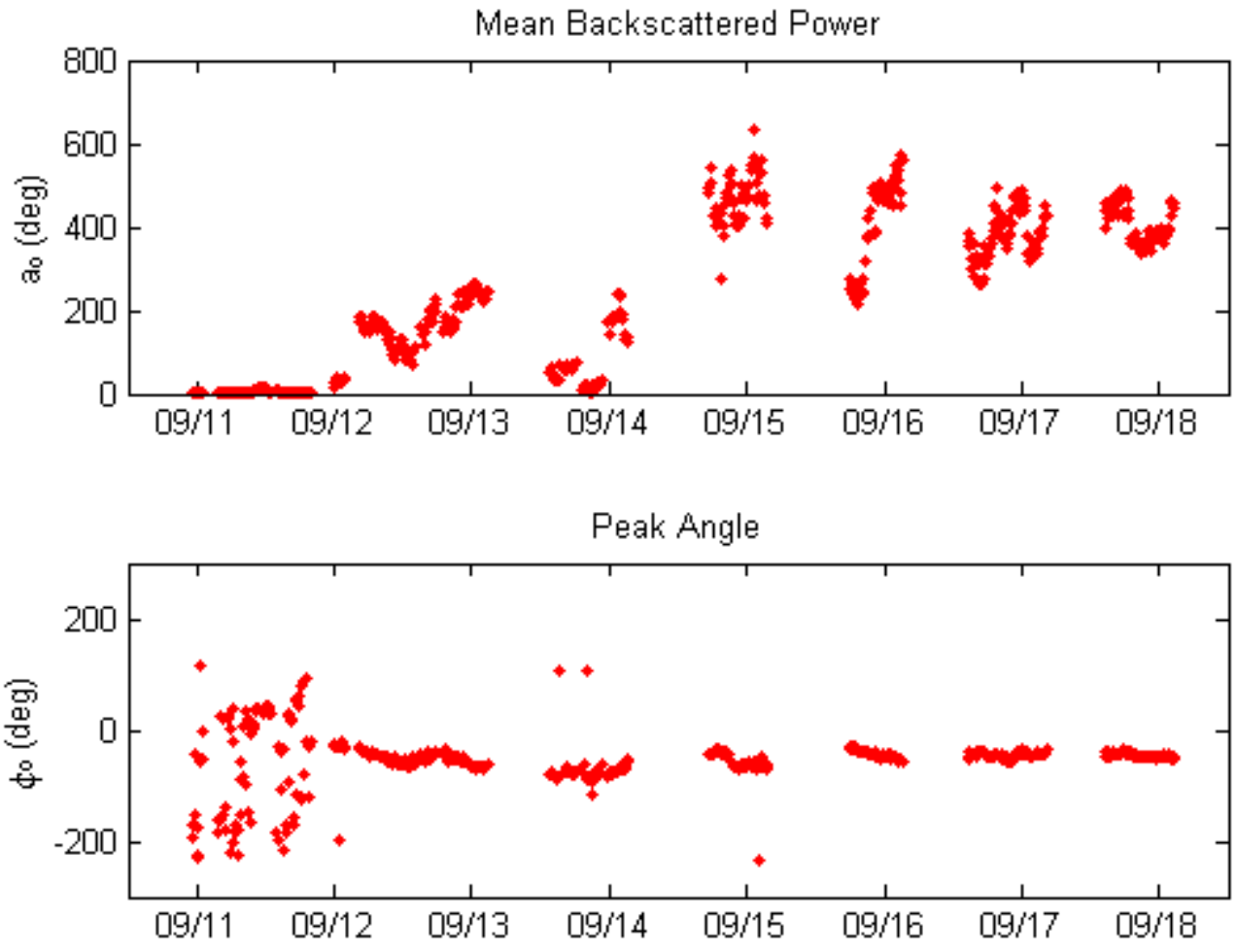
$$\hat{A}(\phi) = a_0 + c_1 \cos(\phi - \phi_1) + c_2 \cos[2(\phi - \phi_2)]$$

$$c_1 = a_1 \Big/ \sqrt{a_1^2 + b_1^2} \quad c_2 = a_2 \Big/ \sqrt{a_2^2 + b_2^2} \quad \phi_1 = \tan^{-1}(b_1/a_1) \quad \phi_2 = \tfrac{1}{2}\tan^{-1}(b_2/a_2)$$

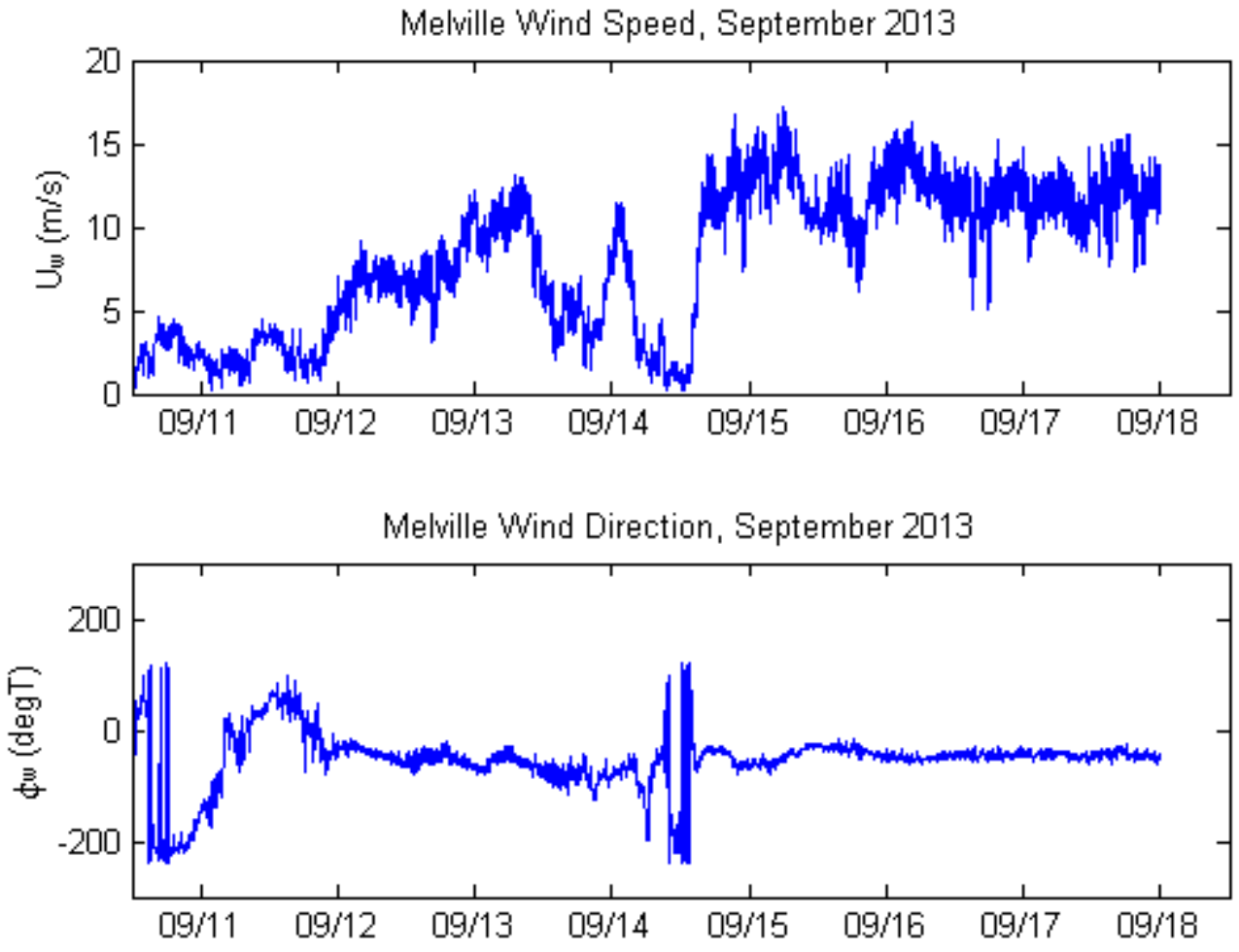
Peak Backscattered Power

- Peak Power is at $A'(\phi) = -c_1 \sin(\phi - \phi_1) - c_2 \sin[2(\phi - \phi_2)] = 0$
- Peak Angle is between ϕ_1 and $\phi_2' = \phi_2 + n\pi$ where n is chosen so that $|\phi_1 - \phi_2'| < \pi / 2$
- Maximum is located by comparing $\hat{A}(\phi_1)$, $\hat{A}(\phi_2')$, and $\hat{A}(\phi_3)$ where $\phi_3 = (\phi_1 + \phi_2') / 2$
- Smallest value is thrown out and the process is repeated until the difference between these values is smaller than a specified ε

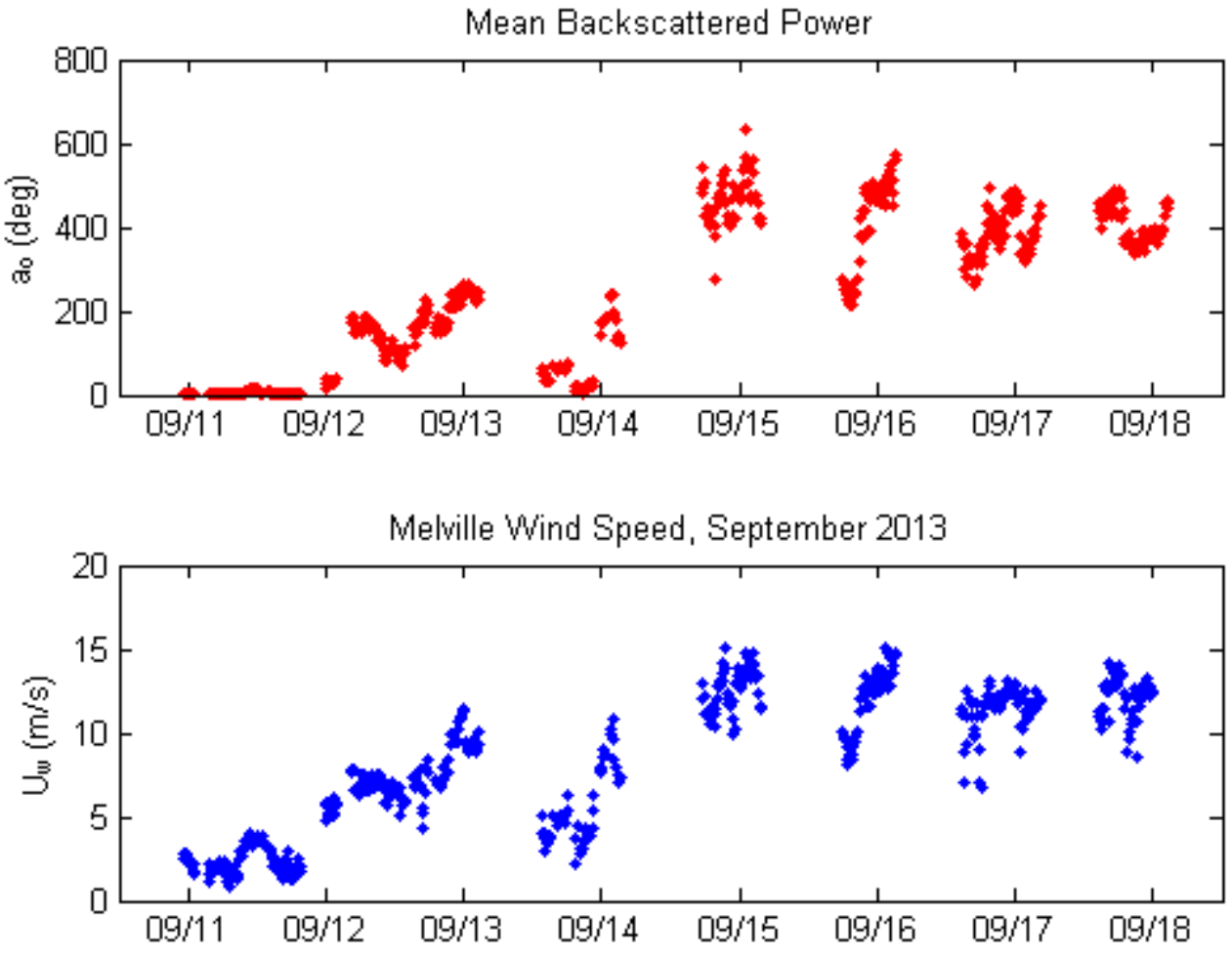
Backscattered Power Data



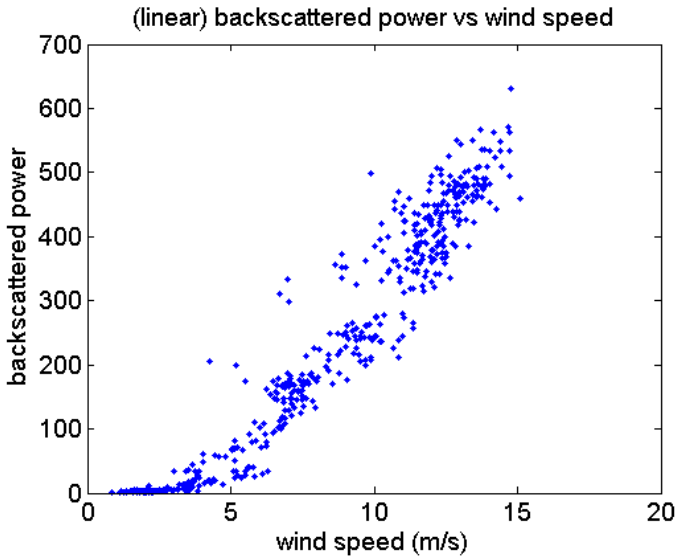
R/V Melville Wind Speed Measurements

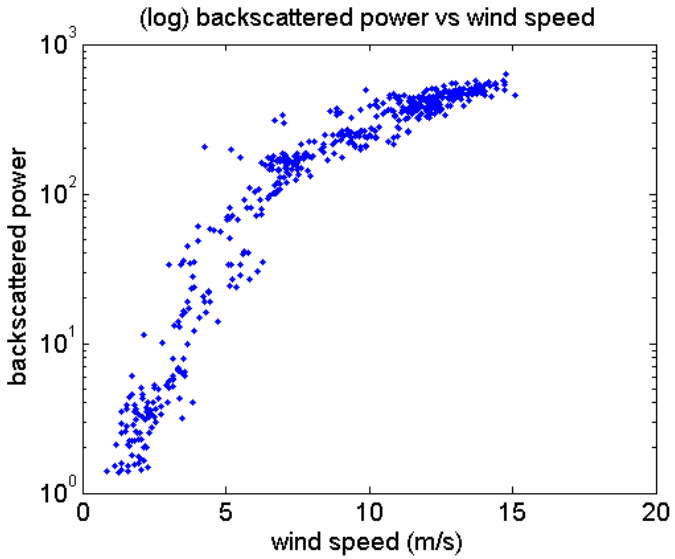


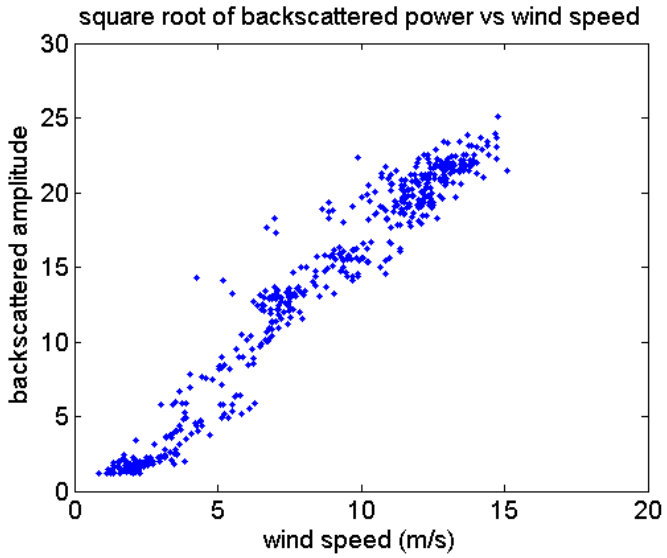
Resampled Wind Speed & Power Data



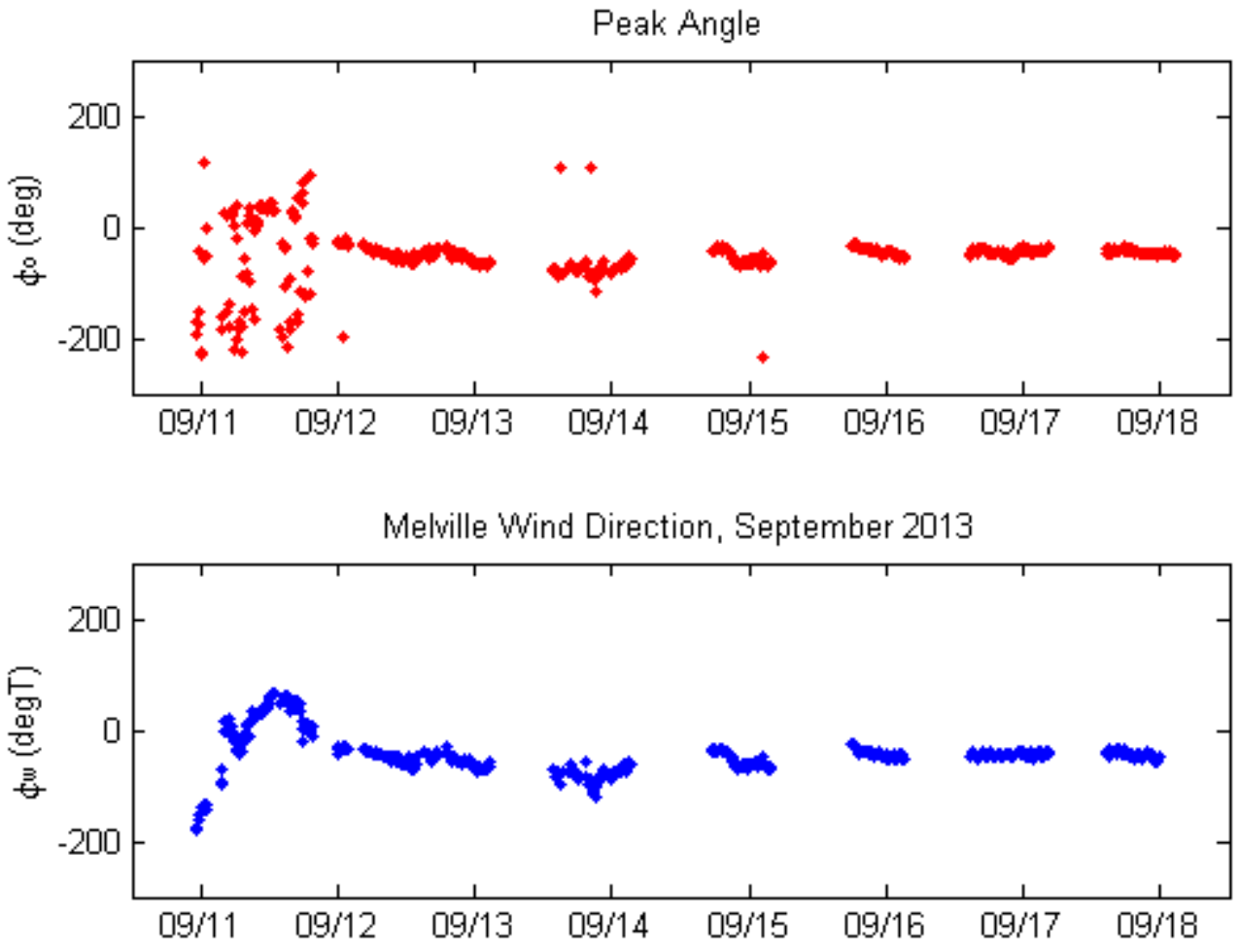
Backscattered Power vs Wind Speed



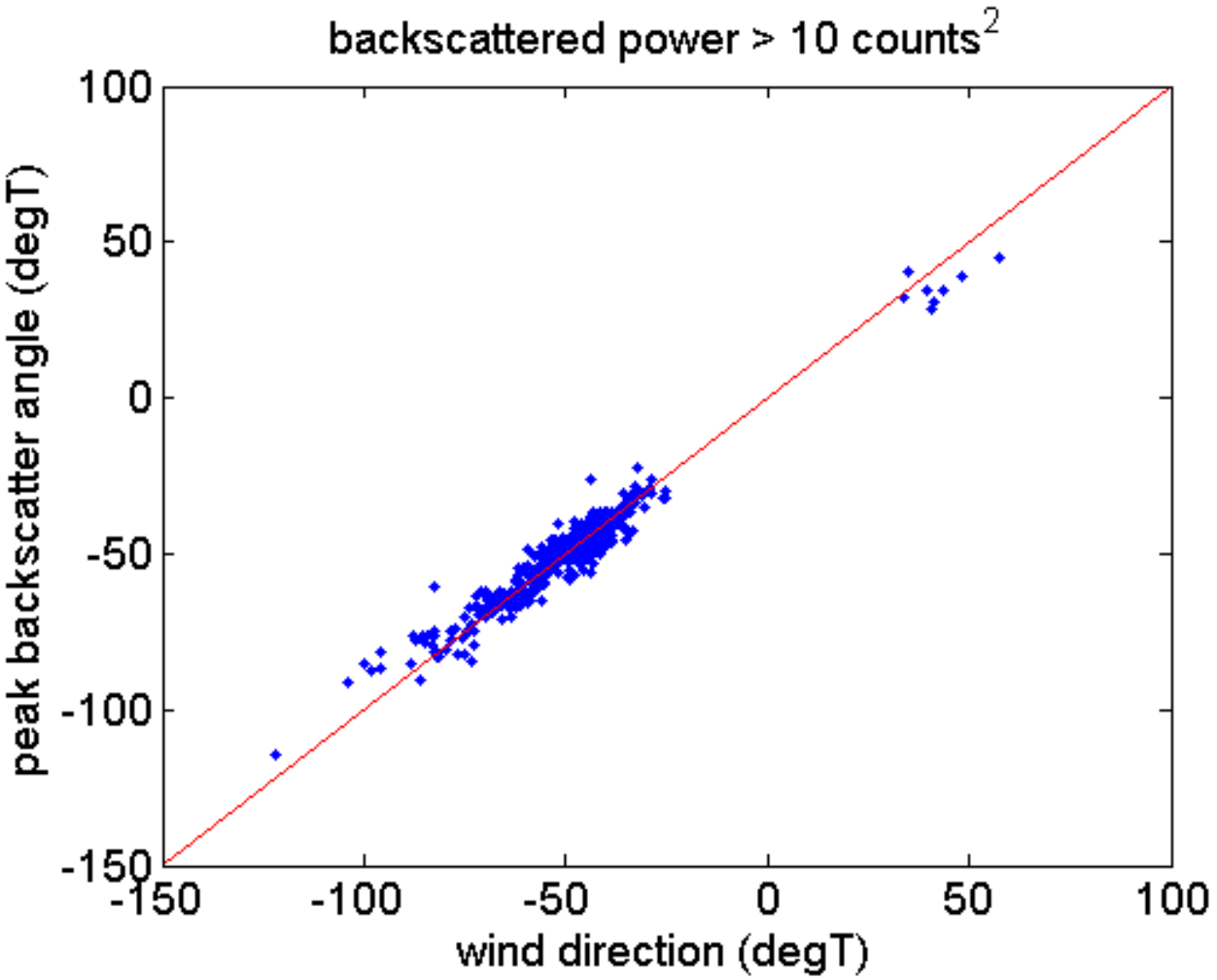




Resampled Wind Direction & Peak Angle Data



Peak Angle vs Wind Direction



Radar Wave Processing - 1

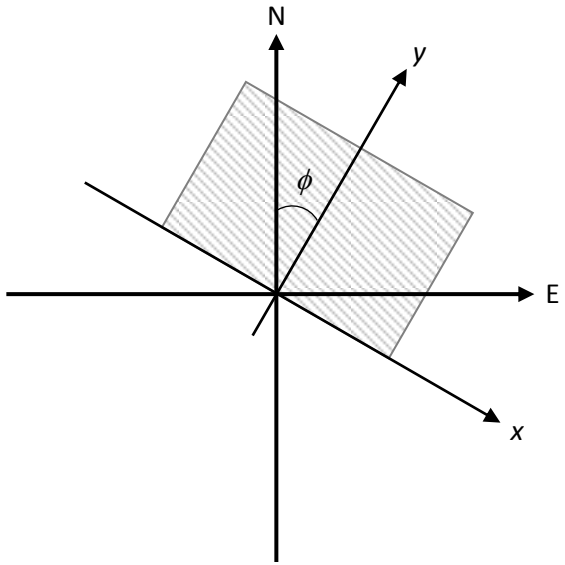
- The wave height spectrum is calculated as

$$S(k,\phi) = \frac{\left\langle |F_u(k,\phi)|^2 \right\rangle}{2\pi^2 \omega^2 A}$$

  where $F_u(k,\phi)$ is the polar Fourier transform of the radial velocity, ω is the wave frequency, and $A = 3\pi(r_2^2 - r_1^2)/16$ is the effective measurement area (Lyzenga , 2017)

- The apparent wave frequency is computed from frame-to-frame changes in the phase of the Fourier transform, and the spectrum is set to zero at wavenumbers corresponding to negative frequencies (receding waves)
- For comparison with buoy measurements, the wave spectrum is converted from wavenumber to frequency coordinates, and is integrated to obtain the significant wave height

Polar Fourier Transform



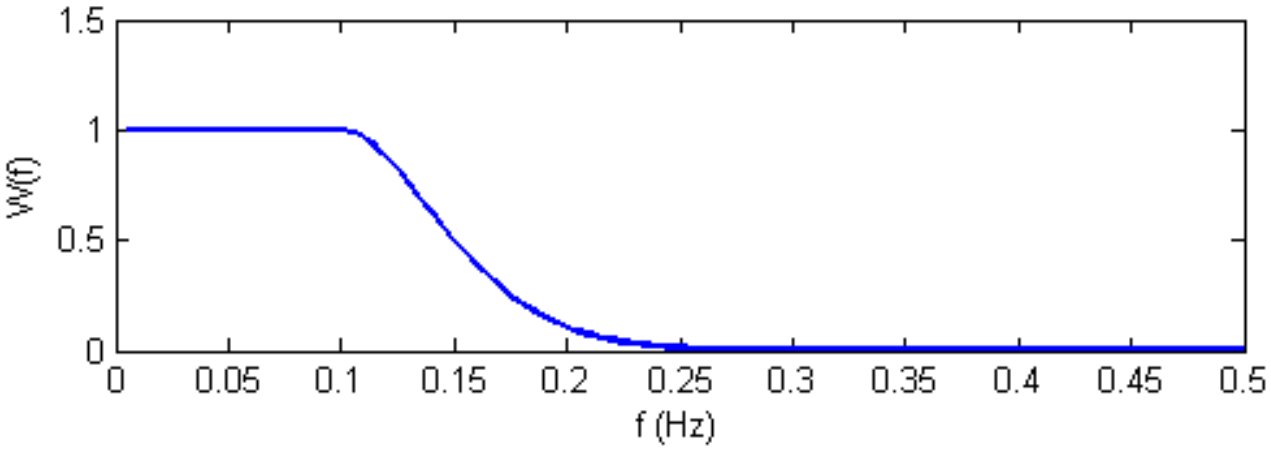
- The 2D Fourier transform in the ϕ direction is given by

$$F_u(k,\phi) = \int_{-x_m}^{x_m} \int_{0}^{y_m} u_r(x,y)\, e^{-iky}\, dx\, dy = \int_{0}^{r_m} \int_{-\pi/2}^{\pi/2} u_r(r,\phi')\, e^{-ikr\cos(\phi-\phi')}\, r\, dr\, d\phi'$$

- Noise is minimized by multiplying $u_r(r,\phi')$ by $\cos\phi'$ to match the angular dependence of the radial velocity for waves propagating in the ϕ direction

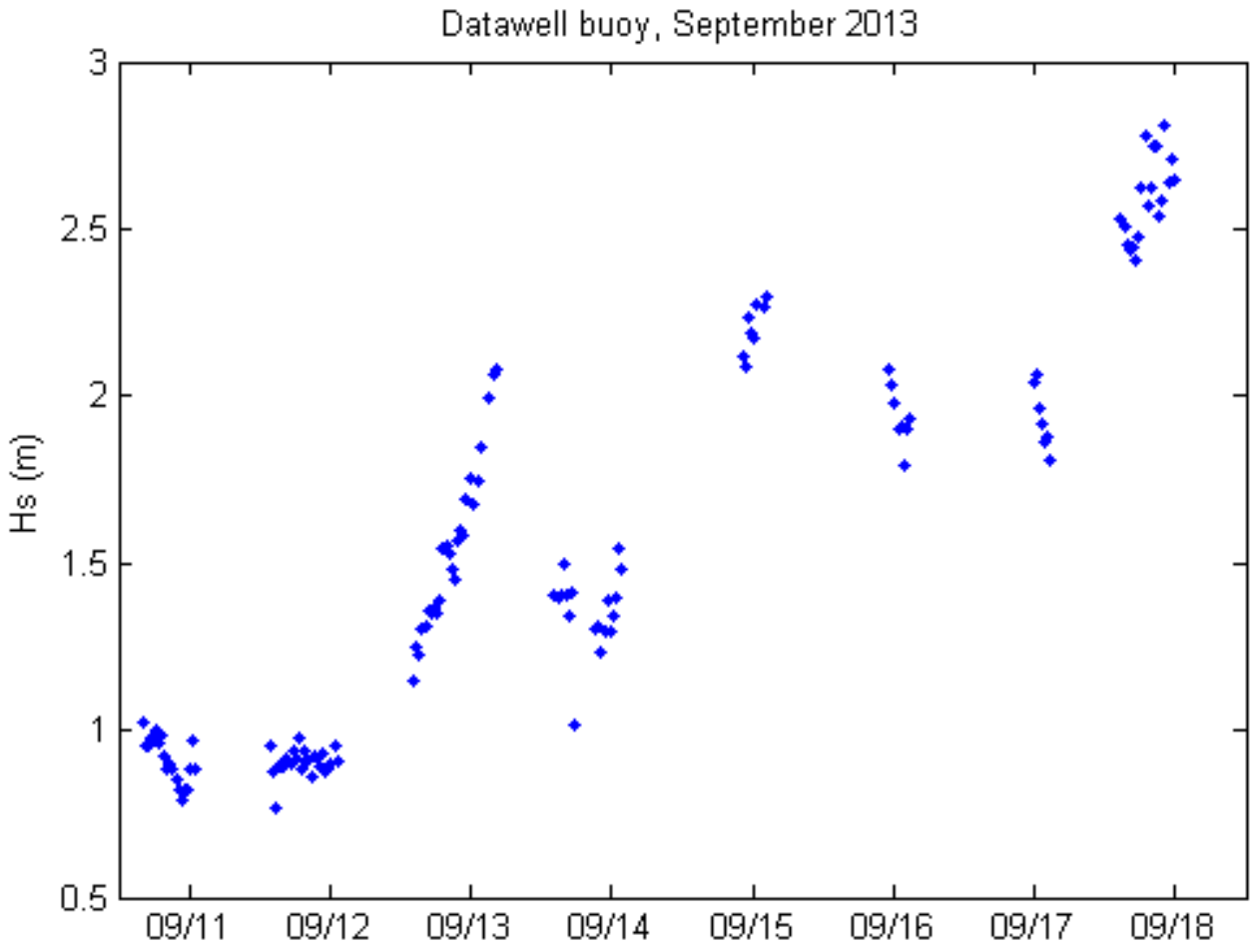
Radar Wave Processing - 2

- Radar-derived wave spectrum is truncated at high frequencies or wavenumbers, presumably due mainly to spatial resolution effects

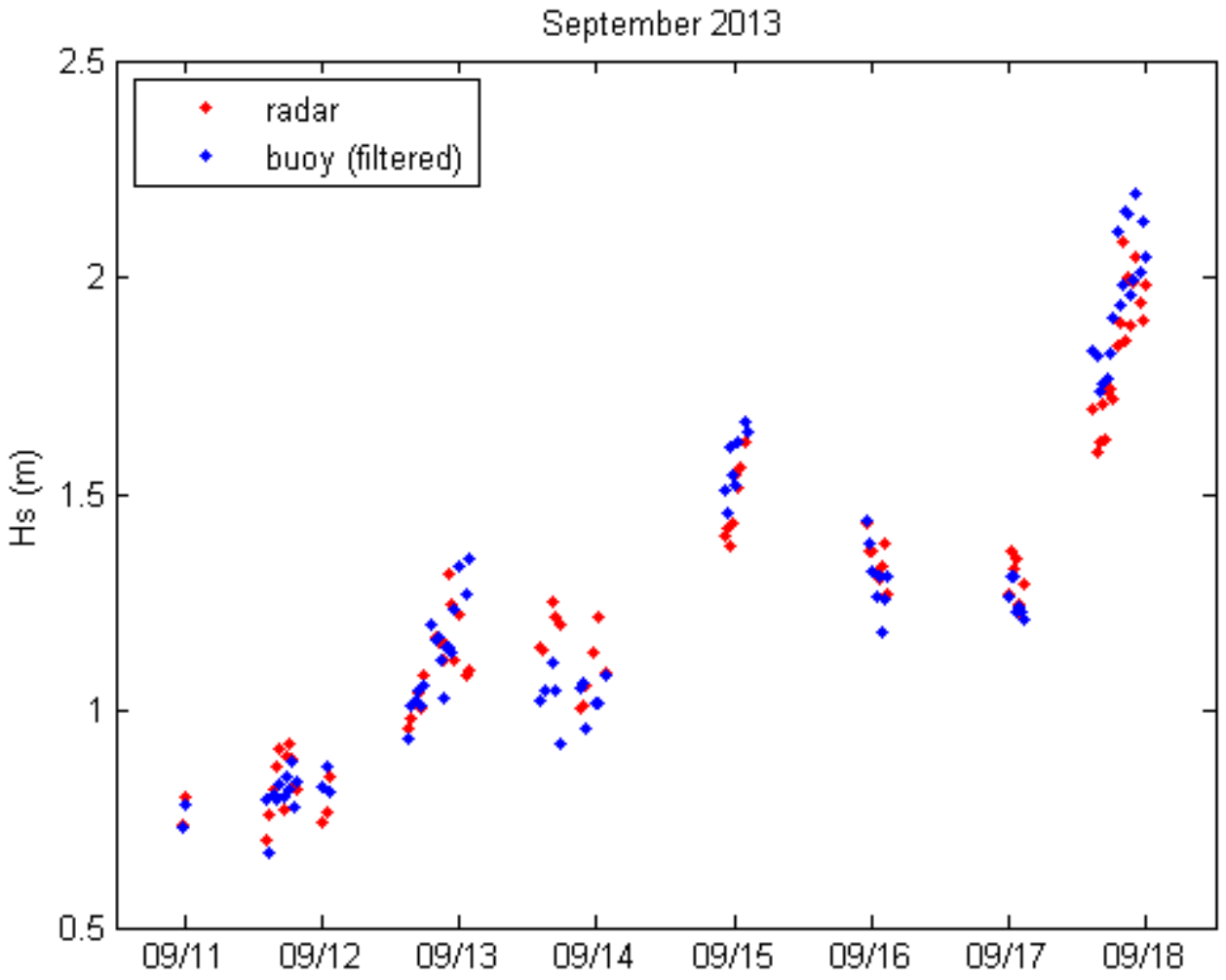


- Buoy-measured wave spectrum is multiplied by this cutoff function for comparison with the radar measurements

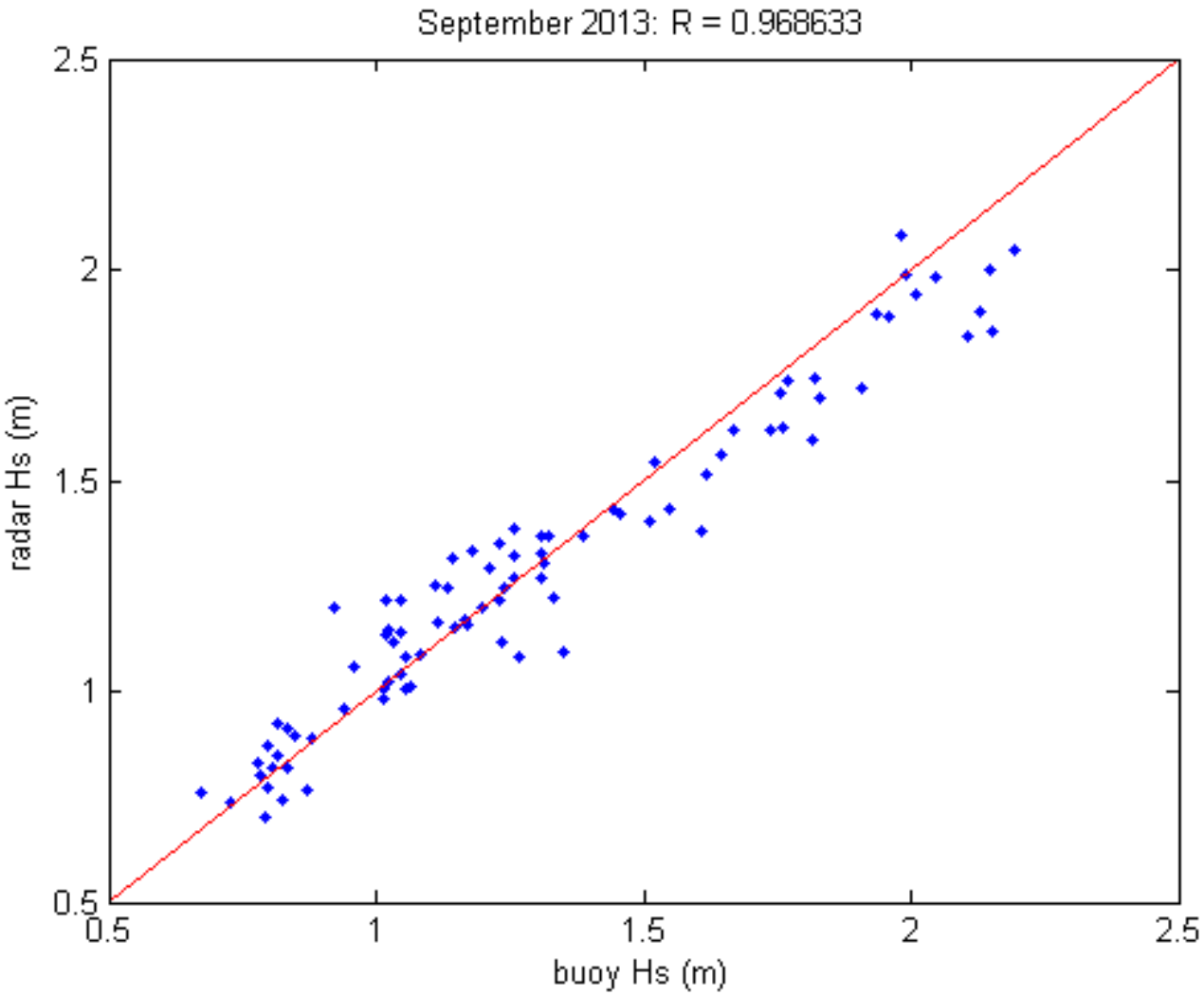
Datawell Buoy Wave Measurements



Radar and (Filtered) Buoy Wave Heights

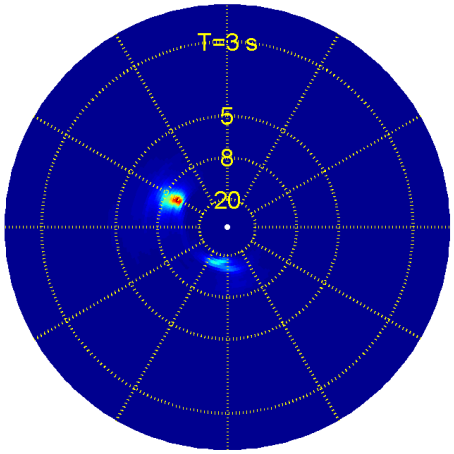


Radar vs Buoy Wave Heights

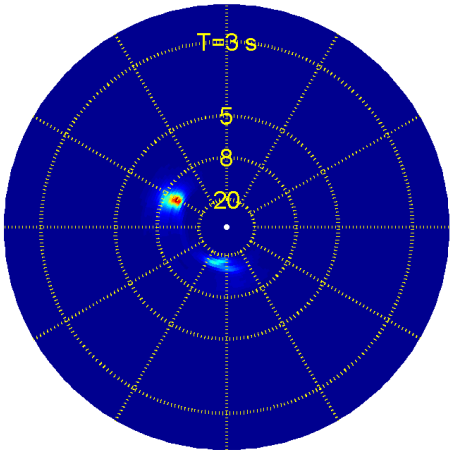


Spectral Comparisons – Set 1 (9/12)

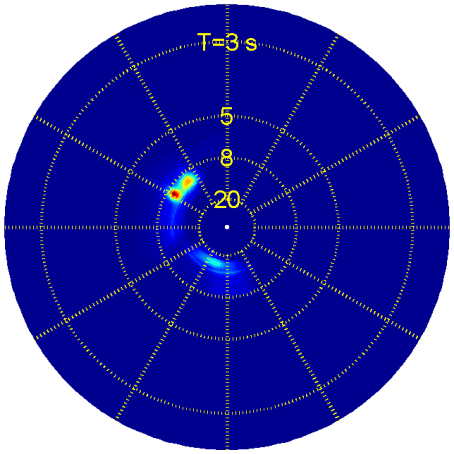
raw buoy



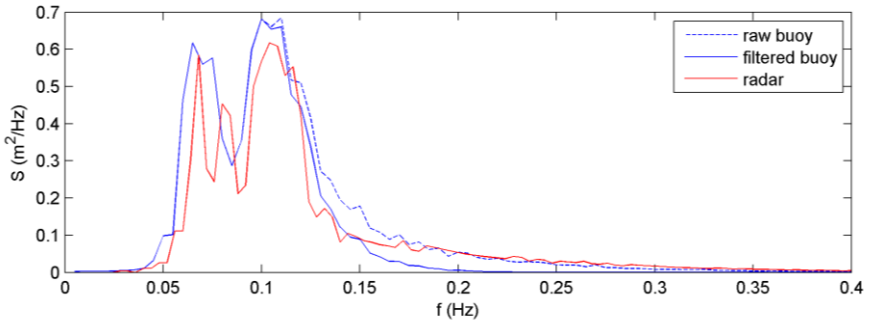
filtered buoy



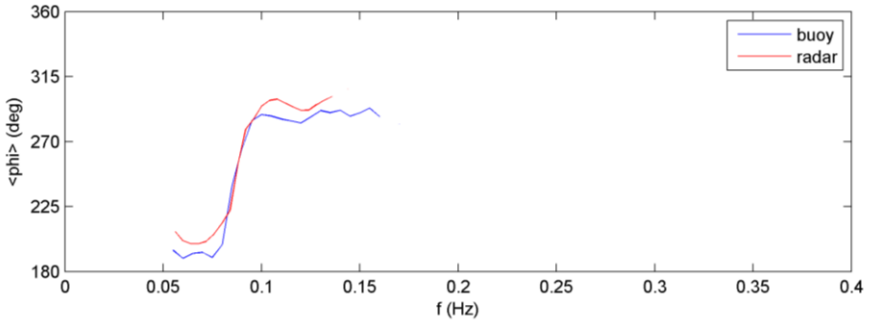
radar



1D spectrum

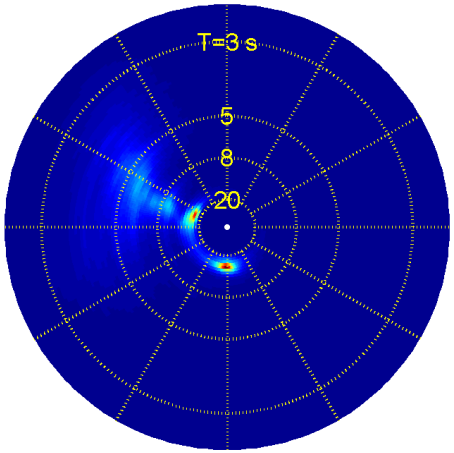


mean wave direction

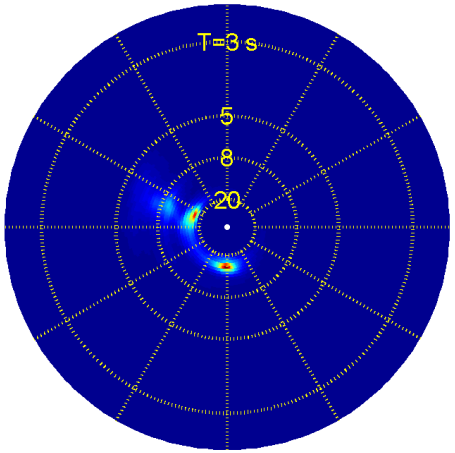


Spectral Comparisons – Set 2 (9/13-14)

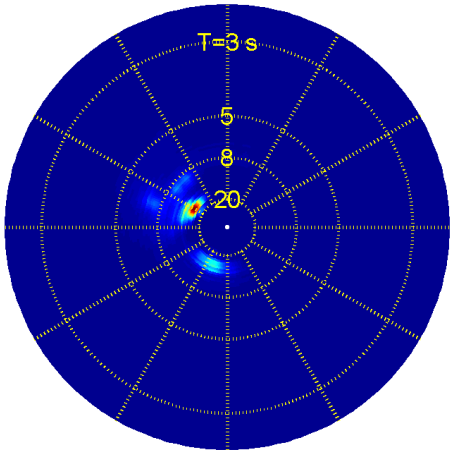
raw buoy



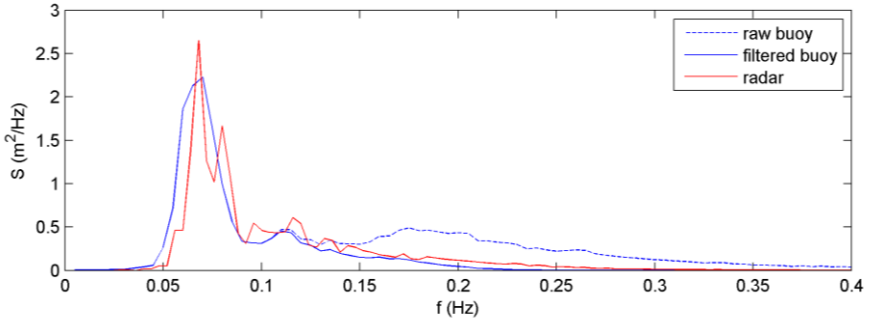
filtered buoy



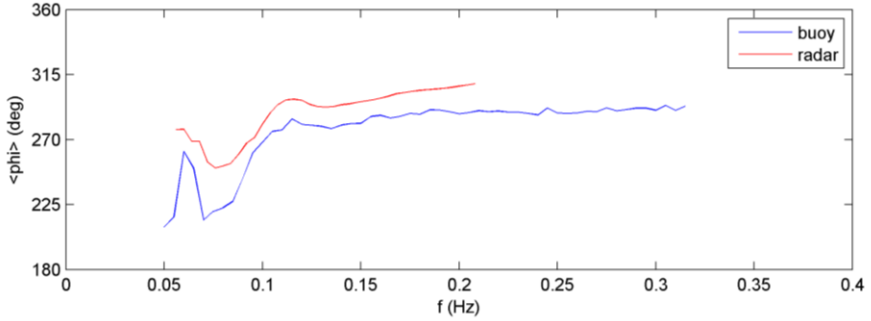
radar



1D spectrum

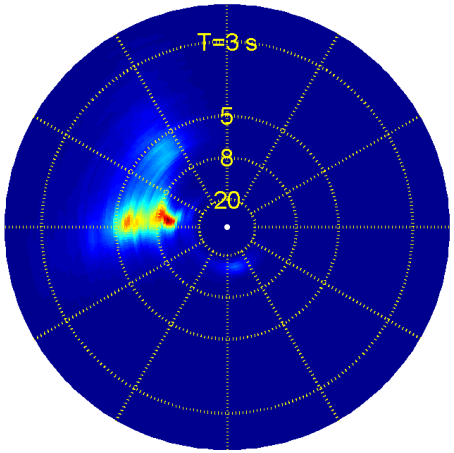


mean wave direction

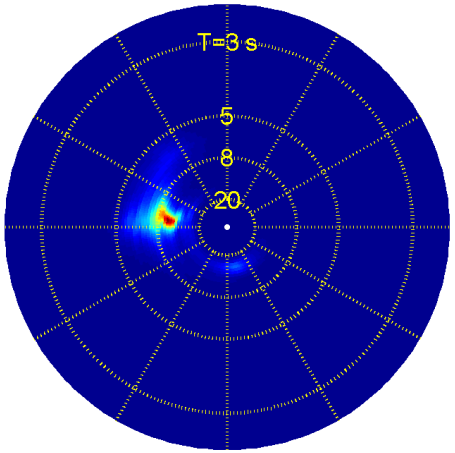


Spectral Comparisons – Set 3 (9/15-17)

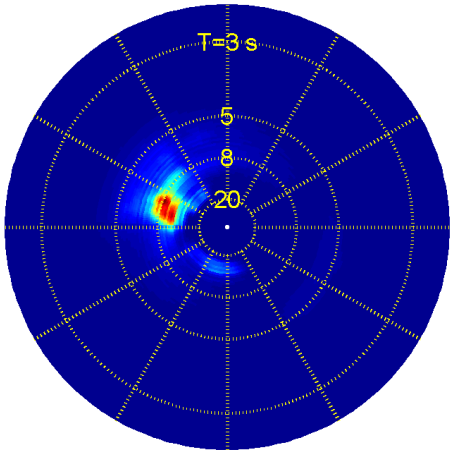
raw buoy



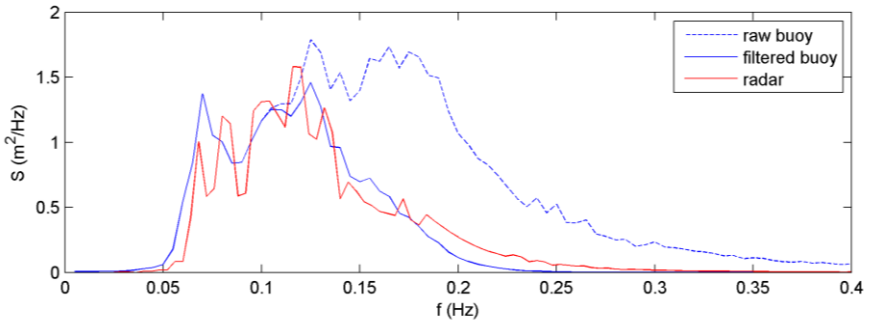
filtered buoy



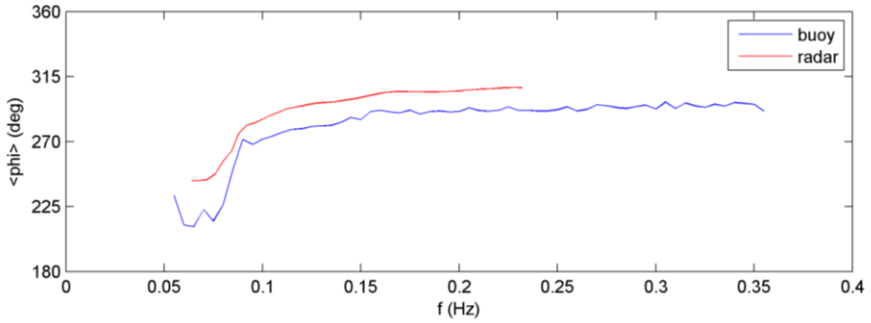
radar



1D spectrum

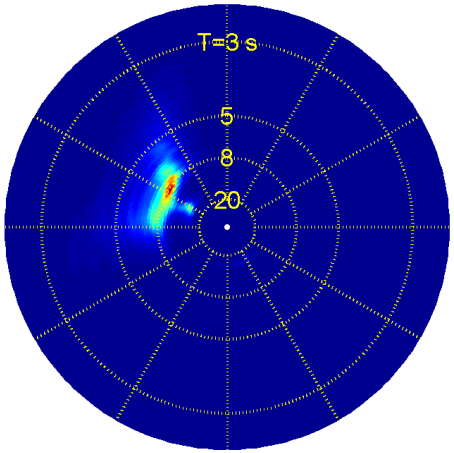


mean wave direction

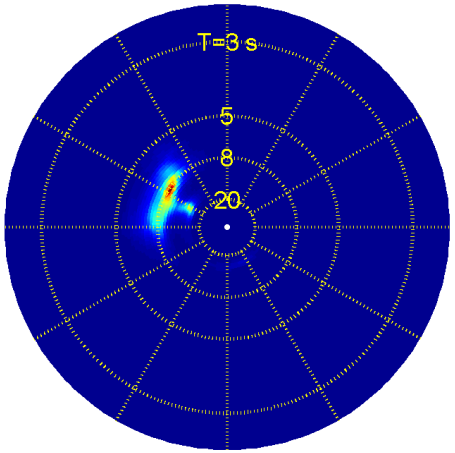


Spectral Comparisons – Set 4 (9/18)

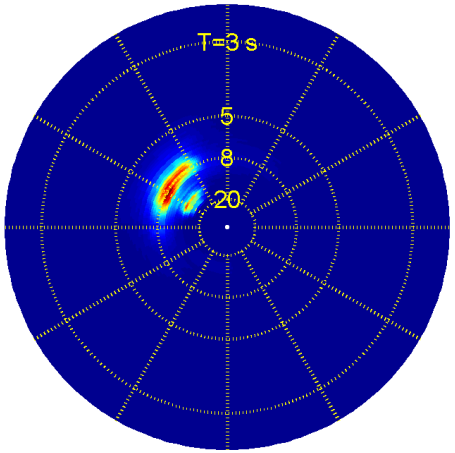
raw buoy



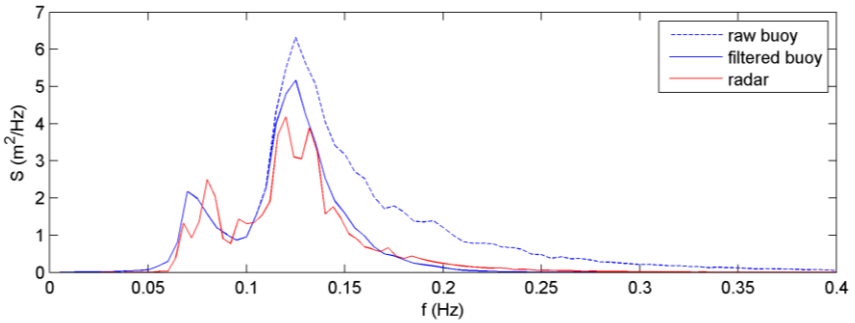
filtered buoy



radar



1D spectrum



mean wave direction