

On the Imaging of Surface Gravity Waves by Marine Radar: Implications for a Moving Platform

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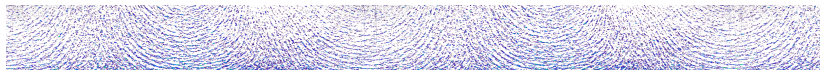
October 28, 2013

Outline

- 1** Introduction
- 2** Data Overview
- 3** Moving Platform Challenges and Solutions
- 4** Preliminary Results
- 5** Conclusions

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Introduction



- Marine radars were developed for ship detection → Sea clutter first analyzed as noise (e.g. Croney '66)
- Today, marine radar data are being used to determine fully-directional wave spectra (Young et al. 1985) as well as phase-resolved maps of the surface elevation (Borge et al. 2004)
- Surface currents and bathymetry may be obtained as a by-product of the wave analysis (Senet et al. 2001, Bell 1999)
- In addition, marine radar data have been used to study internal waves (Watson and Robinson 1990, Lund et al. 2012), winds (Dankert et al. 2003, Lund et al. 2012), oil spills (Gangeskar 2004), ...

Motivation

- Previous studies, focused on fixed platform data (e.g. from light houses or oil rigs), established marine radar as reliable wave and current sensor (Borge and Soares 2000, Wyatt et al. 2003)
- Recent results suggest that shipboard marine radar wave height estimates cannot be trusted (Stredulinsky and Thornhill 2011)
- Wave and current retrieval from ships remains challenging due to:
 - Ship-motion-induced Doppler shift leads to aliased wave energy
 - Jittering wave signal due to changing ship heading
 - Results' dependency on angle between analysis box and waves
- Study goals:
 - Develop new techniques that address ship-motion-related marine radar wave and current retrieval issues
 - Demonstrate possibility to reliably determine waves and currents from shipborne marine radar data

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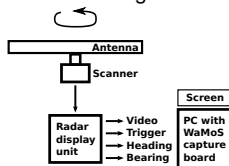
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System Specs

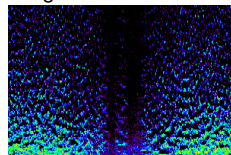
Radar antenna:



Hardware diagram:



Polar backscatter image:

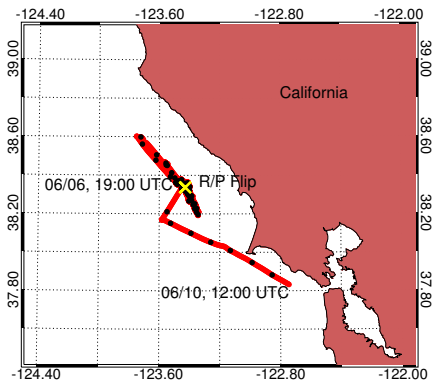


- Furuno marine X-band radar operating at 9.4 GHz with HH-polarization and grazing incidence angle
- Pulse length of $0.07 \mu\text{s}$ (short pulse mode) \rightarrow 10.5 m range resolution
- Antenna length of 8 feet \rightarrow 0.75° antenna beam width
- 1.5 s antenna rotation period
- Wave Monitoring System (WaMoS) sampling up to 4 km with cell size of 0.2° in azimuth and 7.5 m in range

Hi-Res Experiment

High Resolution Air-Sea Interaction (Hi-Res), off San Francisco, 2010.

Map of Hi-Res experiment:



R/P Flip:



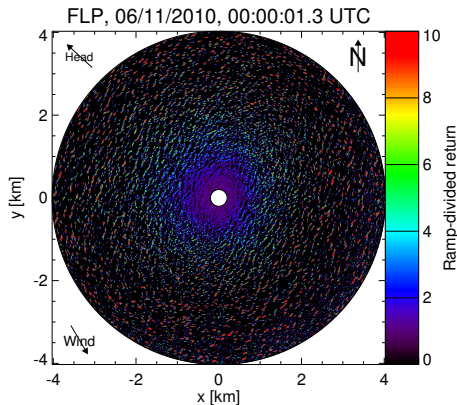
R/V Sproul:



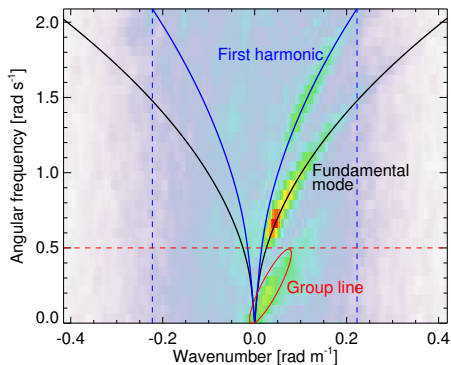
Source: ucsd.edu

Marine Radar Image and Spectrum

Ramp-corrected marine radar image:



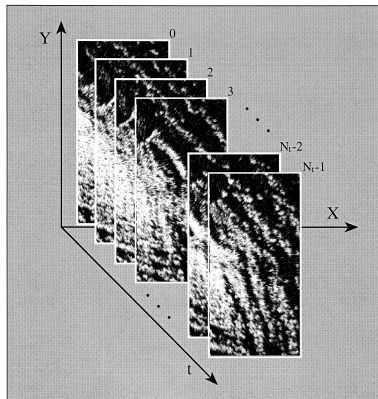
Frequency-wavenumber slice through center of 3D image spectrum:



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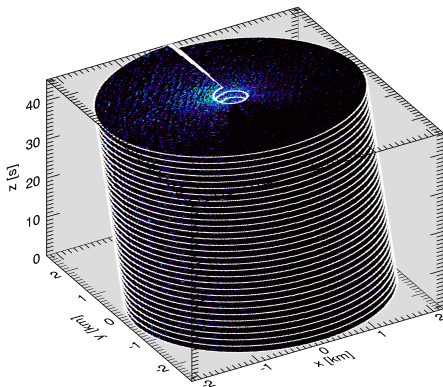
Marine Radar Image Data Concept

Traditional approach (snapshot simplification):



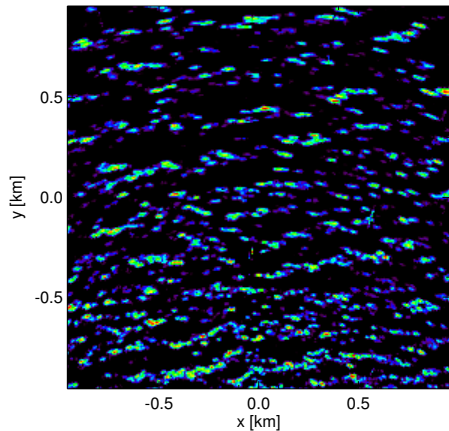
Source: Borge et al. 1999

Accurate view (spiraling data stream):

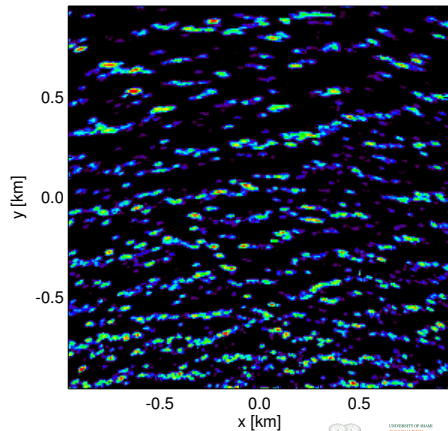


Antenna Heading Correction

Pre-correction wave analysis window
at $t = 0$ s:

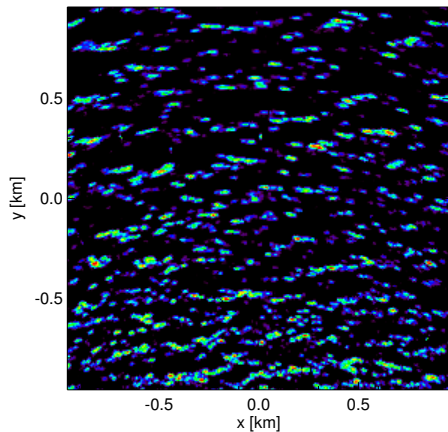


Pre-correction wave analysis window
at $t = 6$ s:

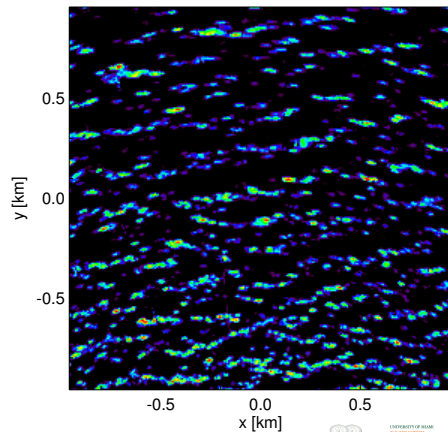


Antenna Heading Correction

Pre-correction wave analysis window
at $t = 1.5$ s:



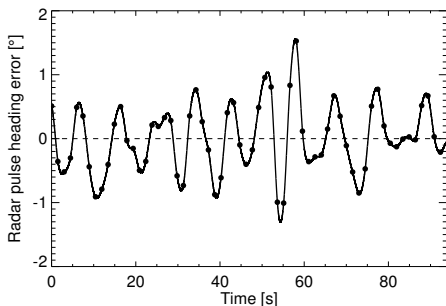
Pre-correction wave analysis window
at $t = 7.5$ s:



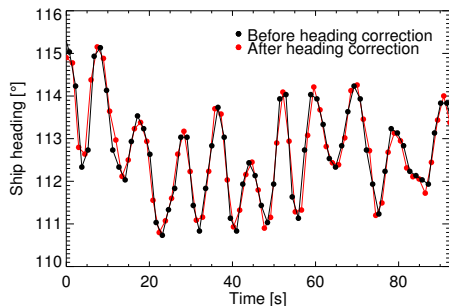
Antenna Heading Correction

Extension of Bell and Osler's (2011) wave-signature-based heading correction.

Heading errors:

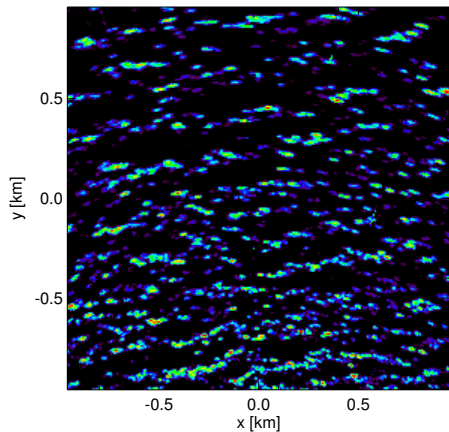


Heading pre- and post-correction:

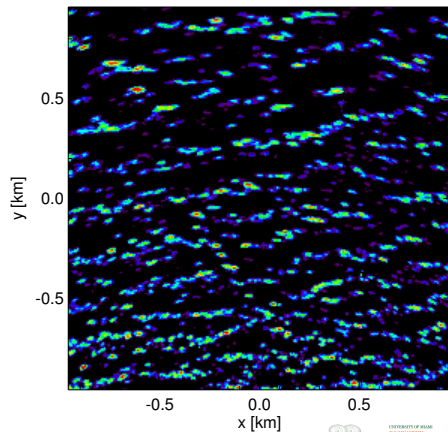


Antenna Heading Correction

Post-correction wave analysis window
at $t = 0$ s:

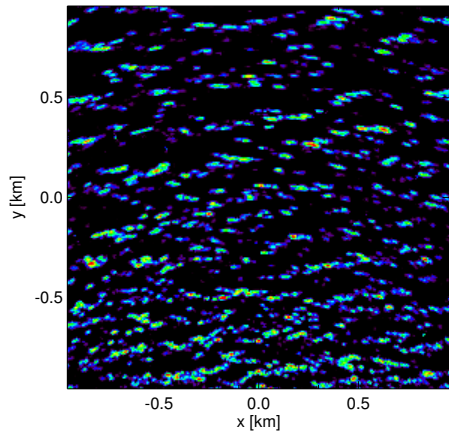


Post-correction wave analysis window
at $t = 6$ s:

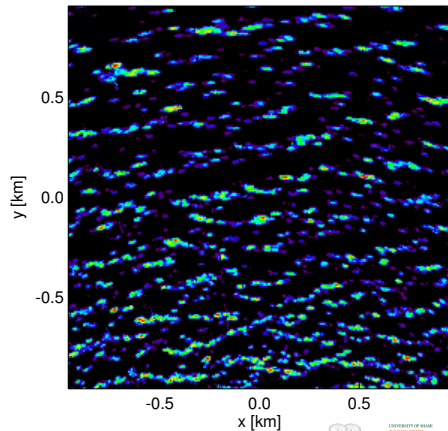


Antenna Heading Correction

Post-correction wave analysis window
at $t = 1.5$ s:



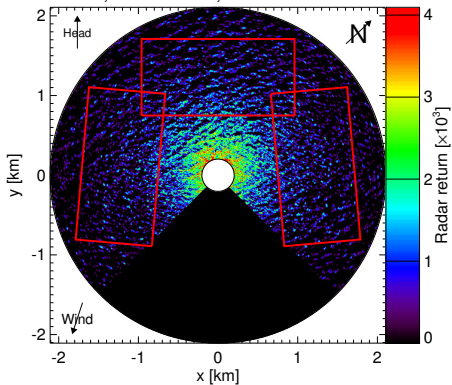
Post-correction wave analysis window
at $t = 7.5$ s:



Dependency of Results on Analysis Box Position

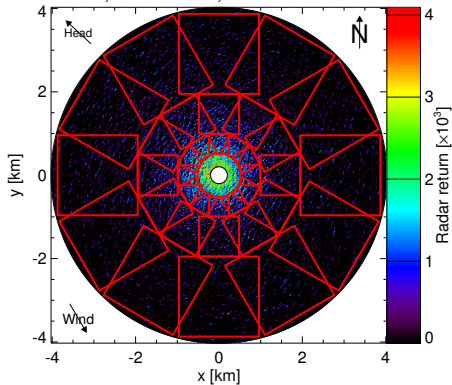
Traditional analysis window setup:

FLP, 06/11/2010, 00:00:01.3 UTC

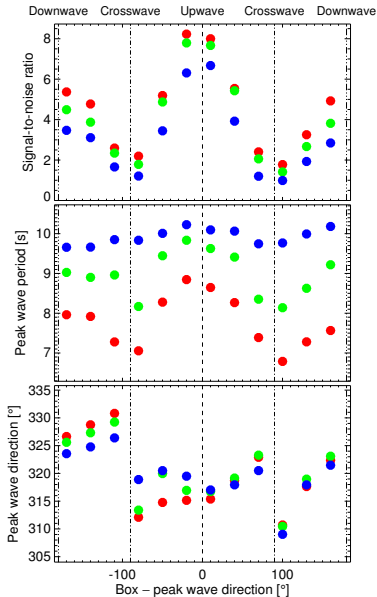


Test setup:

FLP, 06/11/2010, 00:00:01.3 UTC

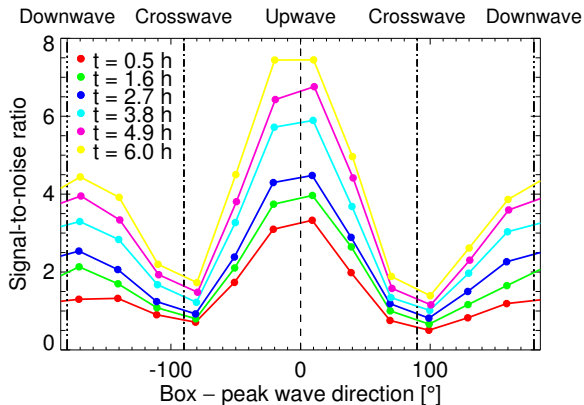


Dependency of Results on Analysis Box Position



Color legend:
Near range,
mid range,
far range.

Signal-to-Noise Ratio Dependency on Box Orientation

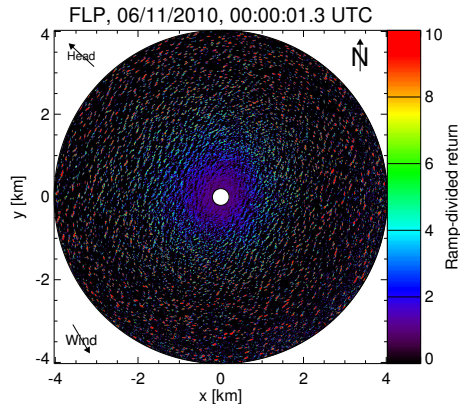


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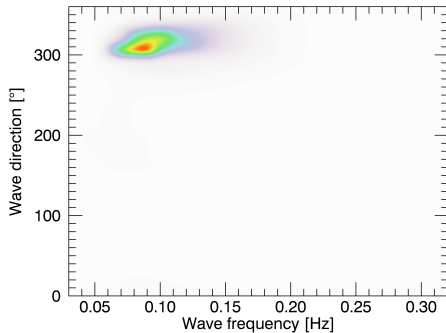
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Example of Marine Radar Wave Spectrum

Ramp-corrected radar image:

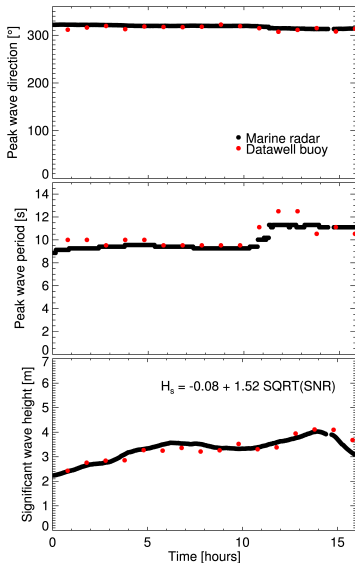


Marine radar frequency-direction spectrum:

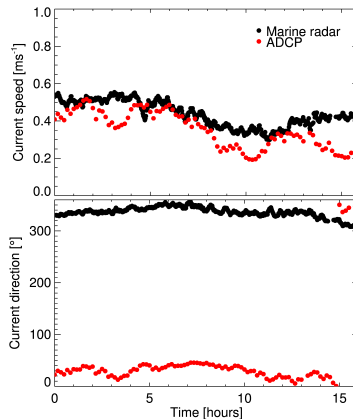


Comparison with Datawell Buoy and ADCP Data

Time series of waves:



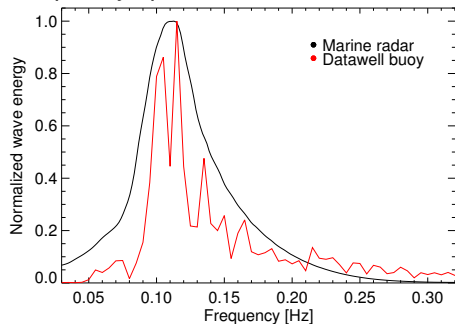
Time series of currents:



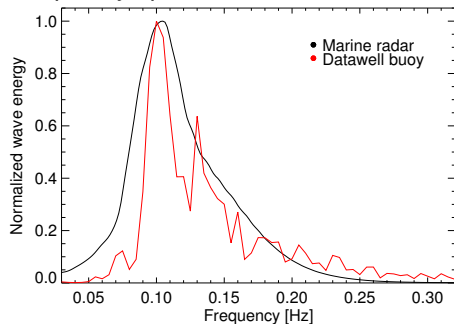
Datawell buoy data courtesy of
Thomas Herbers.

Comparison with Datawell Wave Spectra

Frequency spectrum at $t = 0$ h:



Frequency spectrum at $t = 5$ h:



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- Identified ship-motion-related marine radar wave and current retrieval issues and proposed solutions:
 - Aliasing due to Doppler-shift from vessel motion
 - Geo-referencing
 - Jittering wave signal due to Gyro compass errors
 - Antenna heading correction
 - Wave retrieval dependency on range and antenna look direction
 - Correction function
- Shipborne marine radar waves and currents are in good agreement with measured and modeled reference data
- Current research focuses on modeling of wave signal's dependency on range and antenna look direction

Acknowledgment

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