Validation of Marine Radar's Multi-Directional Wave Retrieval Capabilities

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Outline

• Motivation / Demonstrate Marine Radar Wave Retrieval's Strengths (and Acknowledge Weaknesses)
• Data Overview / ITOP Field Experiment
• Methodology / Advanced Shipboard Marine Radar Wave Retrieval
• Results / Multi-Directional Radar Wave Measurements and WW3 Model Validation
Motivation

- Marine X-band radar (MR) wave spectra based on spatio-temporal backscatter measurements
- Technique's advantages over traditional buoy point measurements:
  - MR spectra resolve multi-directional seas directly without use of a model function (e.g. MLM)
  - Measurement periods of 1-2 min allow sea state changes on short temporal scales
- Disadvantages: Wave energy estimate requires calibration and “modulation transfer function”
- Goal of this study: Demonstrate MR's strength in terms of multi-directional wave retrieval
ITOP Experiment


R/V Roger Revelle cruise tracks and EASI–ASIS wave buoy locations:
ITOP Experiment

(a) MR image example,
(b) R/V Roger Revelle with EASI–ASIS buoy,
(c) MR hardware diagram:
WW3 and EASI Reference Data

(a) EASI wave buoy, WW3 (b) $H_s$ and (c) $T_p$ for study area:

Credit: Henry Potter
Methodology

Steps to obtain a 2D wavenumber spectrum:
(1) Radar image sequence $\rightarrow$ FFT $\rightarrow$ 3D wavenumber-freq. spectrum
(2) Near-surface current fit (Young et al. 1985, Senet et al. 2001)
(3) Dispersion filtering, freq.-integration, MTF (Nieto-Borge et al. 2004)

Marine radar image sequence (a) and corresponding 3D spectrum (b):
Advancements

(1) Analysis over whole radar field of view → Eliminates results’ dependency on azimuth (Lund et al. 2014)
(2) Near-surface current “calibration” for shipborne data (Lund et al. 2015)
(3) Use of signal-to-noise ratio (a) versus power (b) → Clear distinction of wave signal from background noise
(4) Wavenumber-dependent current fit (Lund et al. 2015, submitted) → Dispersion filter accounting for vertical current shear
WW3 Model Validation

Time series and comparison statistics of EASI-N wave measurements and WW3 model results:

<table>
<thead>
<tr>
<th></th>
<th>r</th>
<th>Bias</th>
<th>RMS</th>
<th>σxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hs [m]</td>
<td>0.94</td>
<td>-0.15</td>
<td>0.49</td>
<td>0.46</td>
</tr>
<tr>
<td>Tp [s]</td>
<td>0.60</td>
<td>-0.19</td>
<td>1.76</td>
<td>1.75</td>
</tr>
<tr>
<td>Tm0 [s]</td>
<td>0.85</td>
<td>-0.73</td>
<td>0.96</td>
<td>0.62</td>
</tr>
<tr>
<td>Θp [°]</td>
<td>0.76</td>
<td>-2.67</td>
<td>46.75</td>
<td>46.67</td>
</tr>
</tbody>
</table>

For a validation of EASI wave results, cf. Collins et al. (2014)
MR–WW3 Comparison

Time series and comparison statistics of MR wave measurements and WW3 model results:

<table>
<thead>
<tr>
<th></th>
<th>r</th>
<th>Bias</th>
<th>RMS</th>
<th>σxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hs [m]</td>
<td>0.91</td>
<td>0.00</td>
<td>0.65</td>
<td>0.65</td>
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<tr>
<td>Tp [s]</td>
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<td>1.26</td>
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<tr>
<td>Tm0 [s]</td>
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<td>2.39</td>
<td>0.71</td>
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<tr>
<td>θp [°]</td>
<td>0.90</td>
<td>-8.09</td>
<td>31.93</td>
<td>30.89</td>
</tr>
</tbody>
</table>

Note: Heavy rain negatively affected MR wave height estimates
EASI vs. WW3 Mean Direction

EASI:

WW3:
MR vs. WW3 Mean Direction

MR:

WW3:
EASI vs. WW3 Spreading

EASI:

WW3:
MR vs. WW3 Spreading

MR:

WW3:
Mean Spreading

- Synthetic peak frequency function of mean period (Rogers and Wang, 2007)
- ITOP measurements dominated by swells and mixed seas → Metric includes multiple wave systems
- Long low-amplitude wave measurements by buoys problematic due to weak acceleration
- Noise in surface elevations causes positive bias in spread (Kuik et al., 1988)
Spectral Partitioning

MR (a) and WW3 (b) spectral partitioning based on Hanson and Phillips (2001).
Partitioning Example 1

Black border corresponds to least energetic, red to most energetic partition. Gray dashed line marks wind sea (Donelan, 1985).
Partitioning Example 2

Black border corresponds to least energetic, red to most energetic partition. Gray dashed line marks wind sea (Donelan, 1985).
Partitioning Example 3

MR: 10/17/2010, 15:24 UTC; 12.8 ms\(^{-1}\); 55%

WW3: 10/17/2010, 15:30 UTC; 11.1 ms\(^{-1}\)

Black border corresponds to least energetic, red to most energetic partition. Gray dashed line marks wind sea (Donelan, 1985).
Partitioning Example 4

MR: 10/21/2010, 20:01 UTC; 9.7 ms\(^{-1}\); 58%

WW3: 10/21/2010, 20:00 UTC; 9.6 ms\(^{-1}\)

Black border corresponds to least energetic, red to most energetic partition. Gray dashed line marks wind sea (Donelan, 1985).
Partitioning Example 5

Black border corresponds to least energetic, red to most energetic partition. Gray dashed line marks wind sea (Donelan, 1985).
Black border corresponds to least energetic, red to most energetic partition. Gray dashed line marks wind sea (Donelan, 1985).
Summary

• Validated WW3 peak wave and directional parameters with EASI buoy measurements

• MR and WW3 peak wave parameters compare well (but bias in mean period indicates MTF shortcomings)

• Good qualitative agreement regarding spreading and mean direction

• Used spectral partitioning to track multi-directional wave systems, demonstrated excellent MR–WW3 agreement

• Future work / outlook:
  • Improve existing empirical MTF
  • Explore alternatives to SNR-based MR significant wave height estimates (e.g. exploit shadowing)
Acknowledgements

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Publications:

• Lund, B.; Collins III, C. O.; Graber, H. C.; Terrill, E. & Herbers, T. H. C: Marine radar ocean wave retrieval's dependency on range and azimuth. Ocean Dynam., 2014, 64, 999-1018
