SHIPBOARD STUDIES OF L-, C-, AND X-BAND BACKSCATTER AND SURFACE WIND FORCING DURING NORCSEX'91

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Abstract - During November of 1991, microwave scattering measurements of the ocean were obtained from a research vessel in support of coastal ocean studies in coordination with the commissioning phase of the newly launched ERS-1 spacecraft. The NORwegian Continental Shelf EXperiment provided in situ shipboard observations of wind-wave-current interactions and radar backscatter in coincidence with ERS-1 synthetic aperture radar (SAR) acquisitions. Insight gained from the in situ observations will be used in the interpretation of the oceanographic and meteorological features found in SAR imagery.

INTRODUCTION

Operations during NORCSEX '91 were conducted off the west coast of Norway at a location of about 64° 30' N and 9° E and centered on the Haltenbanken, a sea mount which rises to 200 meters above the coastal plane (see Fig. 1 in [1]). The primary objective of NORCSEX '91 was to validate the ability of the newly launched European Space Agency ERS-1 synthetic aperture radar (SAR) to detect ocean surface features and near-surface atmospheric conditions. These features include surface current boundaries, wind fronts, temperature fronts, internal waves, surface wave field and near-surface wind speed and direction. In this paper the results of a case study performed using in situ meteorology and scatterometer data in conjunction with SAR imagery are described.

SENSOR DESCRIPTION

Measurements of the microwave scattering from the ocean surface were conducted from above the wheelhouse of the University of Bergen Research Vessel Hakon Mosby (HM) using a four-channel scatterometer which operates at 1.5, 5.25, and 9.38 GHz (Fig. 1). The primary polarization used was VV, which corresponds to that of the ERS-1 SAR, and incidence angles were 23° and 50°. The scatterometer was operated in the frequency-modulated continuous-wave mode to lessen the dependence on platform motion (i.e. Doppler effects). An angle filter is used in data processing to limit data results to the viewing angles desired. System operating parameters are presented in Table 1.

Fig. 1. Photograph showing antenna array of the radar scatterometer mounted atop the wheelhouse of the R/V Hakon Mosby (lower left corner), and hot-film probe mounted at extreme tip of boom extending forward of the Hakon Mosby’s mast (top right corner).

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TABLE 1.

SCATTEROMETER SYSTEM PARAMETERS

<table>
<thead>
<tr>
<th>FREQUENCY (GHz)</th>
<th>1.5</th>
<th>5.25</th>
<th>9.38</th>
</tr>
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<tbody>
<tr>
<td>WAVELENGTH (cm)</td>
<td>20</td>
<td>5.7</td>
<td>3.2</td>
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<tr>
<td>EFFECTIVE ANTENNA CELL SIZE (m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ = 55°</td>
<td>3.2</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>θ = 25°</td>
<td>1.8</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>BANDWIDTH (MHz)</td>
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<td>525</td>
<td>575</td>
</tr>
<tr>
<td>POLARIZATION</td>
<td>HH</td>
<td>HH</td>
<td>HH</td>
</tr>
<tr>
<td></td>
<td>VV</td>
<td>VV</td>
<td>VH</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HV</td>
</tr>
<tr>
<td>INCIDENCE ANGLE (°)</td>
<td>CALM SEAS</td>
<td>ROUGH SEAS</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRECISION AT 40° (dB)</td>
<td>±1.1</td>
<td>±3.0</td>
<td>±2.6</td>
</tr>
<tr>
<td>ACCURACY (dB)</td>
<td>±1</td>
<td>±1</td>
<td>±1</td>
</tr>
<tr>
<td>DATA RATE (Hz)</td>
<td>DETAILED STUDIES</td>
<td>SHORT RUNS (1 HOUR)</td>
<td>LONG RUNS (&gt; 1 Hr)</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>10</td>
<td>1-3</td>
</tr>
<tr>
<td>SHIP SPEED (m/s)</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOOK DIRECTION</td>
<td>Starboard</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1: Effective resolution cell size = Area^1/2
2: H signifies horizontal polarization and V signifies vertical polarization.
3: Assumption of a stationary surface. Precision actually better than indicated due to moving surface.

Basic meteorology measurements (wind speed and direction, air temperature, humidity, atmospheric pressure) were made using a Coastal Climate Weatherpak mounted on the mast of the HM. Surface-layer turbulence parameters were also obtained using hot-film anemometry measurements applied to the inertial-dissipation method [2]. The hot-film probe was located on a boom extending forward of the HM's mast to minimize the effects of flow distortion (Fig. 1).

DATA COLLECTION

The experiment data collection was conducted from 7 to 28 November 1991. ERS-1 SAR data takes of the experiment site were obtained every 3 days. The Haltenbanken site was located in almost the exact center of the SAR swath which has a width of 100 km. Radar backscatter, basic meteorology, surface-layer turbulence and ocean surface observations were obtained simultaneously from the HM on a continuous 24 hours-a-day basis. The meteorology and scatterometer data presented here have been averaged over ten minute intervals. The radar backscatter data used in this study are from 1030 UTC 13 November to 0500 UTC 14 November 1991.

RADAR BACKSCATTER RESPONSE

The radar backscatter response is known to be dependent upon the orientation of the radar look direction with respect to the wind-generated surface wave field. This response in its simplest form may be described using a three-term Fourier series:

\[ σ_0 = a_0 + a_1 \cos(θ_{inc}) + a_2 \cos(2θ_{inc}). \]

The \( a_0 \) represents an azimuthally average cross section, \( a_1 \) the upwind-downwind symmetry, and \( a_2 \) the crosswind modulation. The backscatter is also known to be a function of wind speed, incidence angle, polarization, and frequency. The need to improve the characterization of the backscatter azimuth response is recognized [3]. Briefly, the backscatter is expected to have relative minima near azimuth angles of 90° and 270° (radar looking parallel to the wave field), and relative maxima near 0° and 180° (radar looking into and away from the wave field, respectively). Since wind-wave slopes are normally steeper on the upwind side, the 0° azimuth angle backscatter maxima is expected to be slightly higher than the 180° maxima. During NORCSEX '91 experiments were conducted during which the HM steamed slowly in a circle to test the azimuth dependence of the backscatter. Since these studies have not been completed, results are interpreted here only for backscatter data within constant azimuth angle ranges. Azimuth angles were calculated assuming the backscatter-producing waves were parallel to the true wind direction. The azimuth angle ranges used in this study were +/- 15° of 45° and 75°.

The relationships between radar backscatter and near-surface wind-related parameters are of great importance. Considerable work has
addressed the relationships between radar backscatter and the surface-layer wind speed (U), neutral wind speed (UN) and friction velocity (U*) [3, 4, 5]. The friction velocity is of particular interest because it describes the momentum flux from the atmosphere to the ocean.

A power law relationship may be used to relate the wind-related variable and radar backscatter (σ⁰):

\[ \sigma^0 = C[U \cdot f_{s1}(Z/L) \cdot f_{s2}(Z_0) \cdot f_{ws}(\text{short wave slope}) \cdot f_{ws}(\text{long wave slope})] ^\gamma \]

where C is the wind scaling constant, U is the wind-related variable, and \( \gamma \) is the wind vector exponent. This generalized form also includes stability dependence (fₚ), and parameters which describe the long and short wave modulations (fₚₛ) on backscatter. In this study the relationship between the radar backscatter and neutral wind speed and friction velocity are examined. Friction velocity values were obtained by both inertial-dissipation methods and bulk estimates using Smith's formulations [6].

Fig. 2 shows scatter plots with linear regressions between radar backscatter values for the X-VV, C-HH, and L-VV bands, and the logarithm of the neutral wind speed, for both the 45° and 75° azimuth angle ranges. For both azimuth angles, the regression slopes and correlation coefficients are highest for the X-VV band and lowest in the L-VV band. For all three bands, the regression slopes and correlation coefficients are uniformly higher for the azimuth angle range centered about 45° than for the 75° range. This is expected, since a relative minima in backscatter response occurs at azimuth angles near 90°, as noted above. The regressions between the radar backscatter and the bulk friction velocities are very similar to the neutral wind speed regressions, and are not shown here.

Fig. 3 shows scatter plots and linear regressions between the radar backscatter and the logarithm of the inertial-dissipation measured friction velocities. For every radar band and azimuth angle range, the slopes and correlation coefficients of the friction velocity regressions are lower than, or at best equal to, the neutral wind speed regressions. This is contrary to expectations, as earlier studies have shown that the friction velocity correlated best with radar backscatter [4]. The best linear relationship between backscatter and the logarithm of friction velocity is the L-VV band in the 45° azimuth angle range.

**13 NOVEMBER WIND FRONT**

On 13 November a wind front in the Haltenbanken region was imaged by SAR (at 2110 UTC) and transited by the HM (at about 2230 UTC). A weather map of the NORSEX region for 0000 UTC 14...
Fig. 3. Scatter plots showing linear regressions of radar backscatter (in dB) for X-VV (top), C-HH (middle) and L-VV (bottom) bands versus 10\*\log(u*dis) for azimuth angle ranges centered on 45° (left) and 75° (right).

November is shown in Fig 4. The SAR image of this wind front for 2110 UTC 13 November is shown in Fig. 5. A step change in backscatter intensity from about -18 dB to -5 dB is observed in the ERS-1 SAR-derived intensity scan obtained from the far right-hand side of the image (Fig. 6). The HM was operating in the region shown in the SAR image during the period from 3 hours before the SAR take to 3 hours after. The frontal boundary was crossed by the HM at approximately 2230 UTC. Wind and temperature information obtained on board the HM is shown in Fig. 7. Winds were light (2-3 meters per second) prior to encountering the front for the period from 1800 to 2130

Fig. 4. Weather map of the NORCSEX region for 0000 UTC 14 November 1991. The black dot indicates the position of the Hakon Mosby.

Fig. 5. ERS-1 SAR image of the NORCSEX region for 2110 UTC 13 November 1991.
UTC 13 November. By 2230 UTC the wind speed had increased to about 5 meters per second. Between 1900 13 November and 0000 UTC 14 November the wind direction changed from easterly to west-north-westerly. A 1 °C increase in sea surface temperature (8 °C to 9 °C) was observed between 2030 and 2200 UTC in the transition region of the front. We do not believe this change in sea temperature caused the step change in SAR backscatter intensity. The air temperature remained steady at about 4-5 °C during the entire period of the wind front crossing.

A time series of the 10 minute averaged neutral wind speed and radar backscatter responses for the L-VV, C-VV, and X-VV bands is shown in Figure 8. Backscatter predictions, based on the linear regressions between the backscatter and the logarithm of neutral wind speed, presented above, are also shown. The correlation between the neutral wind speed and the backscattering values are very good, especially for the X-VV band, which had the highest regression slope and correlation coefficient. Donelan and Pierson [7] have shown that the wind speed threshold...
for significant radar backscatter, at the radar incidence angles and sea temperatures in this case study, is about 2.5 meters per second for the L and C bands, and about 3.5 meters per second for the X band. This behavior is apparent in the backscatter time series, as during the period from 1800 to 2130 UTC 13 November, when the wind speeds were below 3 meters per second, the backscatter values dropped significantly, especially for the X band (below 25 dB).

A time series of the radar backscatter and dissipation and bulk friction velocities is shown in figure 9. The correlation between radar backscatter and friction velocity is not as good as the neutral wind speed. This is especially true during the period between 1800 and 2130 UTC 13 November, when the wind speed was below 3 meters per second, which makes both radar backscatter and friction velocity measurements suspect.

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REFERENCES


