A Ku-BAND ACTIVE/PASSIVE WIND VECTOR RETRIEVAL OVER THE OCEAN

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ABSTRACT

This work investigates the design of an innovative conical scanning Ku-band (13.4 GHz) scatterometer / radiometer for measuring ocean vector winds. The sensor design is based upon actual measurements obtained by the SeaWinds scatterometer and the Advanced Microwave Scanning Radiometer (AMSR), which operated simultaneously on JAXA’s Advanced Earth Observing Satellite-II (ADEOS-II) during 2003. This new design combines the conventional forward and aft-looking two-beam microwave scatterometer (SeaWinds) measurements with simultaneous linearly polarized passive microwave brightness temperatures. The unique aspect of this remote sensing technique is that it operates at a single microwave frequency, and it combines vertical and horizontal polarized microwave brightness temperatures with the scatterometer normalized cross sections to retrieve unambiguous ocean wind vectors. This technique has the potential to significantly improve the Ocean Vector Winds retrievals for future conical-scanning microwave scatterometers.

Index Terms—SeaWinds scatterometer, active/passive remote sensing, AMSR, ocean wind vector retrieval, ADEOS-II OVW simulation.

1. INTRODUCTION

Space-based microwave remote sensing is a major source of consistent long-time series of environmental observations for scientific and operational atmospheric, oceanic, and land applications.

A microwave scatterometer is a special purpose active remote sensor, which measures the absolute normalized radar cross section ($\sigma^0$) of the ocean surface. These measurements obtained from multiple (forward and aft) “azimuth-looks” can then be used to estimate the wind vector (speed and direction) over the ocean by means of the relation between $\sigma^0$ and the ocean surface wind vector (OVW) known as the geophysical model function (GMF). Due to the harmonic dependence of the GMF on relative wind direction, OVW retrieving algorithms produce multiple “possible” wind vector solutions or aliases. Median filtering signal processing techniques are used to select the “true” wind direction; but unfortunately these algorithms are not 100% successful in resolving the issue of the correct alias selection.

Therefore, this paper explores the feasibility of combining forward and aft-looking two-beam active normalized radar back scatter ($\sigma^0$) from SeaWinds with the passive vertical (V) and horizontal (H) polarized microwave brightness temperature ($T_b$) measurements to retrieve unambiguous ocean wind vectors in the Ku-frequency band. Simulation results for using this technique using actual SeaWinds sampling geometry and numerical weather model surface winds are presented.

2. OVERVIEW

2.1. Instruments

ADEOS-II carried five Earth observing sensors, including the Advanced Microwave Scanning Radiometer (AMSR) and the SeaWinds scatterometer. This was the first satellite mission (since SeaSat-A, 1978) that carried both a microwave scatterometer and a radiometer, which provided a unique opportunity of combining active and passive measurements for inferring ocean surface wind vectors.

AMSR was a conical scanning microwave radiometer that acquired brightness temperature measurements at eight discrete frequency bands between 6.9 and 89 GHz [1]. For this work, the 10.7 and 18.7 GHz channels were used to derive equivalent 13.4 GHz passive observations via radiative transfer modeling simulation.

SeaWinds was a Ku-band (13.4 GHz) scatterometer, which used a mechanically spinning parabolic reflector antenna with two-beams and two different incidence angles (V-pol @ 54° incidence angle and H-pol @ 46°) to acquire ocean measurements over the full 360° in azimuth [2]. To retrieve ocean surface wind vectors, SeaWinds collocates $\sigma^0$ measurements at vertical and horizontal polarizations into a 25-km wind vector cells (WVCs) over a wide swath (1800 km). As the satellite passed over a given WVC location, the
\( \sigma^0 \)'s were observed at four azimuth-look directions (i.e., pointing forward and aft at two different incidence angles).

2.2. Active/passive OVW retrieval

This technique develops an OVW retrieving algorithm by combing active and passive measurements of a single frequency Ku-band channel. Previous investigations using SSMI and AMSR discovered that a linear combination between the V and H brightness temperatures contained robust wind directional signals [3, 4]. These brightness temperature combinations are nearly independent of the atmospheric conditions and are therefore a function of sea surface temperature (SST), wind speed, and relative wind direction (\( \gamma \)). The linear combination of V- and H-pol \( T_b \)'s may be abbreviated as \( "AV-H" \), where A is a constant depends on the frequency channel used [4]. For our simulation, we assume that the passive measurements are made simultaneously on the scatterometer V-pol antenna beam at 54° incidence angle. The passive wind directional signal geophysical model function at 13.4 GHz was developed by frequency scaling of measurements from AMSR 10.6 and 18.7 GHz channels.

When these conventional dual-polarized radar backscatter from SeaWinds (forward and aft-looks) were combined with the \( AV-H \) measurements, the OVW retrieval uses the maximum likelihood estimation (MLE) approach to minimize the objective function (\( \Omega \)) of the combined measurements given by (1) with the SST known a priori.

\[
\begin{align*}
\Omega &= \sum_{\rho = V, H} \frac{(AVH_{\text{meas}} - AVH_{\text{mod}}(Wspd, Wdir, SST))^2}{\text{Variance}_{\text{meas}}} \\
&+ \sum_{\rho = V, H} \frac{(\sigma^0 - \text{GMF}(Wspd, Wdir))_{\text{pol}}^2}{\text{Variance}_{\text{meas}}} \\
&= \sum_{\rho = V, H} (\frac{(AVH_{\text{meas}} - AVH_{\text{mod}}(Wspd, Wdir, SST))^2}{\text{Variance}_{\text{meas}}} + \frac{(\sigma^0 - \text{GMF}(Wspd, Wdir))_{\text{pol}}^2}{\text{Variance}_{\text{meas}}})
\end{align*}
\]

The first summation represents the normalized residual of the \( AV-H \) brightness temperature between measured and modeled signal, where the squared-residual is normalized by the variance of the \( T_b \) measurements. The second summation represents the residual between the measured \( \sigma^0 \) and the scatterometer GMF, where the squared-residual was also normalized by the corresponding \( \sigma^0 \) variance. Given the SST, and the active/passive measurements, the wind vector aliases are found by searching for the solutions that correspond to the local minima of the objective function in (1).

Due to the bi-harmonic nature of the model functions, there were multiple solutions or ambiguities (aliases) found. These ambiguities were ranked according to the inverse values of the objective function, i.e., the first ranked (most likely) solution is the solution that resulted in the lowest minimum value in (1); multiple solutions (up to four) were kept. In the SeaWinds Project data processing algorithms, an addition step of wind alias selection is used; however for this paper we stop at the alias rankings. Our objective is to demonstrate that combining active/passive measurements results in improved skill in the rankings, and it is envisioned that a similar alias selection algorithm would be used to further improve the final selection skill.

2.3. Monte-Carlo simulation

A block diagram for the active/passive OVW retrieval simulation is shown in Fig. 1. This Monte-Carlo simulation was performed based on the NOAA National Center for Environmental Prediction (NCEP) ocean winds analysis products, which were collocated with wind vector cells of an actual ADEOSS-II pass. When the simulation was executed under a noise-free condition, the true solution (pairs of wind speed and direction) and the first ranked retrieved estimates were identical. In order to statically analyze the results in a realistic manner, Monte-Carlo simulation was conducted with random Gaussian noise added for both the active and passive measurements.

Figure 1: Simulation block diagram
The scatterometer measurements noise, which is a function of the SNR is based on the instrument geometry and the hardware design, can be modeled as \[ Z = \sigma^2 (1 + K_{PC} \eta) \] (2)

where \( K_{PC} \) is the normalized standard deviation of the communication or signal noise, and \( \eta \) is a Gaussian random number with a zero mean. The passive measurements, V- and H-pol noise-free brightness temperatures were corrupted by adding Gaussian noise with a standard deviation of 0.2 K (\( \Delta T \)); active/passive retrieval results were completed and comparisons made with the NCEP as “surface truth” to assess the technique performance.

3. RESULTS

The scatterometer azimuthal viewing geometry varies across the swath, which results in different wind vector retrieval performance. For example, in the middle of the swath (along the satellite ground track) and at the edge of the swath there is unfavorable azimuth diversity between the forward and aft looks, which results in higher retrieval errors. Fortunately, the addition of passive measurements improves the wind vector retrievals; and in this paper, an end-to-end simulation of an active/passive instrument was performed for the ADEOS-II orbit and actual NCEP wind field conditions.

Using SeaWinds geometry, wind speeds and directions were sampled at each WVC location. Then, the geophysical model functions were used to produce active \( \sigma^0 \) and passive \( T_b \) observations. For the simulation, both “active only” and active/passive retrieval results were analyzed for various conditions (e.g., varying wind speeds, relative wind directions, cross track locations, etc.) spanning a wide range of parameter space. Possible solutions (ambiguities) were determined as the local minima of the likelihood function given in (1); and for evaluation purposes, the comparisons with the NCEP surface truth was performed separately by alias ranking. Figures 2 and 3 show a comparison of 1st ranked active and active/passive retrievals with the corresponding NCEP wind speeds and directions respectively.
An important metric of the scatterometer wind retrieval algorithm is the ability to retrieve the correct wind vector from possible aliases, which is referred to as the “instrument skill” (percentage of time that the selected wind vector is closest to the true wind vector) [6]. For active retrievals, the ranking skill varies systematically across the measurement swath, depending on measurement signal to noise ratio and the relative azimuth look directions of the antenna beams.

The following tables (Table-1 for wind speed and Table-2 for wind direction) give the means and standard deviations of the scalar differences between the 1st ranked wind solution and the corresponding NCEP surface truth for an orbit of SeaWinds data. Results are presented for both active alone (conventional SeaWinds) and combined active/passive ocean surface wind vector retrievals.

Table 1 Wind Speed Retrieval Statistics

<table>
<thead>
<tr>
<th>Wind speed (m/s)</th>
<th>Active</th>
<th>Active/Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean difference</td>
<td>STD</td>
</tr>
<tr>
<td>0-4</td>
<td>0.3</td>
<td>0.44</td>
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<tr>
<td>4-8</td>
<td>0.13</td>
<td>0.41</td>
</tr>
<tr>
<td>8-12</td>
<td>0.09</td>
<td>0.65</td>
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<tr>
<td>12-20</td>
<td>0.01</td>
<td>0.7</td>
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</table>

Table 2 Wind Direction Retrieval Statistics

<table>
<thead>
<tr>
<th>Wind speed (m/s)</th>
<th>Active</th>
<th>Active/Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean difference</td>
<td>STD</td>
</tr>
<tr>
<td>0-4</td>
<td>0.70</td>
<td>32.43</td>
</tr>
<tr>
<td>4-8</td>
<td>0.33</td>
<td>15.90</td>
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<tr>
<td>8-12</td>
<td>0.16</td>
<td>10.08</td>
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<tr>
<td>12-20</td>
<td>0.5</td>
<td>9.84</td>
</tr>
</tbody>
</table>

4. SUMMARY

A novel active/passive microwave wind retrieval algorithm was developed using simulation based upon actual SeaWinds and AMSR measurements on ADEOSS-II. The use of the linear $T_b$ combination (AV-H) alone is not sufficient for reliable retrieval of ocean surface wind vector; however, when used with conventional dual-look (forward and aft) scatterometer measurements, statistics show improved wind vector retrievals compared to NCEP numerical weather model analyses. Results from a single orbit simulation demonstrate that the first ranked wind vector solution from the active/passive retrievals are significantly better than the wind vector measurement requirement of ± 2 m/s and ± 20° (one sigma). Thus, the results are encouraging and this novel wind vector retrieval technique demonstrates an alternative option for future satellite missions.

REFERENCES