CROSS COMPARISON OF ALOS PALSAR L-BAND RETRIEVAL MODEL FUNCTIONS

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Abstract
We make a systematic comparison of wind speed computed from the Advanced Land Observing System (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) against wind speed analyses from an operational weather model. The standard deviation of the residual difference is very similar to results from C-band synthetic aperture radars (SARs) on Radarsat-2 and Envisat when compared against models, albeit with a systematic and easily removed bias. Results are limited to HH-polarization data. There is little available VV-polarization data over water.

Index Terms— synthetic aperture radar, wind speed, SAR, ALOS, PALSAR, L-band

1. INTRODUCTION
Since the late 1990s, the Johns Hopkins University Applied Physics Laboratory (JHU/APL) in conjunction with and with support from the National Oceanic and Atmospheric Administration has operated the APL/NOAA SAR Wind Retrieval System (ANSWRS) as part of the Alaska SAR Demonstration Project. C-band HH-polarization imagery from the Radarsat-1 and ERS-2 SARs are downloaded in real-time at the Alaska Satellite Facility (ASF) at the the University of Alaska, Fairbanks. ASF processes the data into SAR imagery. Subsequently, the ANSWRS converts the normalized radar cross section images into high-resolution (sub-kilometer) wind speed images that were then posted on the web. There are parallel sites posting these data running routinely at ASF, NOAA, and JHU/APL.

The basis of SAR wind speed retrieval is similar to that of all active microwave scatterometry from space. The normalized radar cross section, \( \sigma^0 \), is related to the near surface wind vector via an equation of the form

\[
\sigma^0 = A(f, p, \theta)U[f/p, \theta] + B(f, p, \theta)\cos\phi + C(f, p, \theta)\cos2\phi
\]

where \( U \) represents wind speed at 10-m height for neutral atmospheric stability, \( \theta \) is incident angle, and \( \phi \) is the relative angle between the radar look direction and the local wind. \( A, B, C \) and \( \gamma \) are coefficients that are functions of radar frequency (\( f \)), polarization (\( p \)), and incident angle.

During the past few decades, considerable effort has been devoted to understanding the fundamentals aspects of microwave scattering from the ocean surface. Such studies have lead to the development of new models for the ocean surface roughness spectrum [1] as well as novel analytical techniques for approximating \( \sigma^0 \) [2]. In spite of this effort, it still remains difficult to accurately predict the value of \( \sigma^0 \), especially for the HH-polarization for the microwave SAR frequency range (L- to X-band) relevant to the present satellite SAR systems [3]. Therefore, it is generally still necessary to tune the coefficients in Equation 1 using empirical data.

Notice that from Equation 1 that we can compute \( \sigma^0 \) from wind speed and direction. However, the inversion is not unique. A specific \( \sigma^0 \) is associated with many pairs of wind speed and direction. Conventional scatterometers like QuikSCAT reduce this ambiguity by measuring \( \sigma^0 \) of a single ocean area from several different aspect angles.

For SAR wind retrievals, independent estimates of the wind direction are used in the inversion of Equation 1 [4]. Such estimates can be obtained either from numerical weather models [5] or from linear features in the SAR images aligned with the wind [6, 7, 8, 9]. Here we use the former approach.

2. L-BAND MODEL FUNCTION
Because of the use of the C-band frequency for the Active Microwave Instrument (AMI) on ERS-1 and ERS-2, the C-band SAR on Radarsat-1, and the Advanced SAR (ASAR) on Envisat for wind retrieval, there has been considerable effort devoted to developing a geophysical model function (GMF) of the form of Equation 1 for that frequency. However, L-band is more problematic. For the short-lived Seasat satellite (1978), Gerling [6] demonstrated that though it’s SAR system was not formally calibrated, there was a clear correspondence between image intensity and wind speed. The JERS-1 L-band

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SAR was applied sporadically to wind measurement, but the model function resulting from the study of these data was limited to a single incident angle and related to digital numbers from a particular SAR image processor rather than calibrated \(\sigma^0\)-values [10].

As a consequence, after the launch of ALOS there was no ready, well-accepted GMF for the relationship between wind speed and direction and L-band \(\sigma^0\). Using ALOS PALSAR comparisons with the QuikSCAT scatterometer wind vector measurements, Isoguchi and Shimada [11] have recently developed an empirical first-generation L-band model function. Here, we integrate this model function into ANSWRS and compare resulting wind speeds with the NOGAPS (Navy Operational Global Prediction System) wind speeds.

### 3. MODEL COMPARISONS

When compared with meteorological models, SAR wind speeds generally show larger residuals than those from similar comparisons against buoys or other \textit{in situ} instrumentation. Not only are models imperfect, but many times there can be significant temporal separation (as much as six hours) between the time of the model analysis and the SAR data acquisition time. Previous analysis [12] suggests that such temporal difference can produce a residual wind speed difference of 3 m/s or so.

The large number of SAR-model comparisons potentially available make it possible to determine systematic trends in SAR wind measurements. ASF, the North American data node for ALOS, has provided us with a number of ground-range projected PALSAR images so that we could validate ALOS PALSAR wind retrievals. To maximize the span of wind speeds, we deliberately selected ALOS scenes for which the NOGAPS model predicted relatively high winds.

Figure 1 is a plot of retrieved PALSAR wind speed from ANSWRS versus model wind speed. We used the Isoguchi-Shimada [11] L-band model function and the NOGAPS wind directions for the retrievals. The SAR wind speeds (finer than 1-km resolution) were averaged over a 25 km diameter area to be more directly comparable to the model winds. The standard deviation of the differences is about 3.6 m/s. The Radarsat-1 and Envisat SARs at C-band have demonstrated residuals smaller than 2 m/s when compared against buoys and QuikSCAT. However, when compared against the NOGAPS model, C-band residuals are about 4 m/s [5]. Thus, we believe our ALOS results are promising even though the PALSAR wind speeds are biased high by about 5 m/s.

If we multiply the PALSAR \(\sigma^0\)-values by 0.616 and then perform the wind speed retrieval, we can largely eliminate the bias in Figure 1. Figure 2 is a plot of SAR versus model wind speed retrievals after the application of this \(\sigma^0\) correction. This result is consistent with the finding that the Isoguchi-Shimada [11] is biased high compared with the NRCS from L-band data from airborne SAR systems [3]. Based on this result, we suggest the Isoguchi-Shimada model function multiplied by the correction factor 0.616 as an effective GMF for PALSAR L-band wind retrieval.

### 4. INCIDENT ANGLE DEPENDENCE

In order to examine our L-band wind retrievals a little further, we compare the accuracy of the retrievals as a function inci-
dent angle. Table 1 lists the retrieval accuracies for different incident angle ranges. The results suggest that some residual incident-angle dependency remains in the L-band model function since the bias in the retrievals is higher at the low and high extremes of the incident angle ranges. Hence there is room for further improvement.

Table 1. Standard deviations and biases between ALOS PALSAR wind speed retrievals and the NOGAPS model for different incident angle ranges in units of m/s. All $\sigma^0$-values have been modified by the 0.616 factor.

<table>
<thead>
<tr>
<th>Incident Angle</th>
<th>All</th>
<th>15°–25°</th>
<th>25°–35°</th>
<th>35°–45°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Std Dev</td>
<td>3.50</td>
<td>2.25</td>
<td>2.97</td>
<td>3.87</td>
</tr>
<tr>
<td>Mean</td>
<td>-0.85</td>
<td>2.50</td>
<td>-0.60</td>
<td>-0.94</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

We have systematically compared ALOS PALSAR wind retrievals with the NOGAPS model predictions using the Isoguchi-Shimada [11] L-band HH-polarization model function. When used with scaled $\sigma^0$-values in ANSWSRS, the ALOS PALSAR produces wind speed residuals comparable to the residuals when using C-band data from either Radarsat-1 or Envisat. This is a very hopeful sign. When sorted by incident angle, there remain clear biases for wind speed retrievals. Hence, it may be possible to improve the L-band function still further. Although ALOS was designed primarily as a land sensing system, we believe continued improvement of wind speed retrievals over the ocean could be achieved with the availability of more over ocean imagery at VV- as well as HH-polarization.

6. REFERENCES


