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Multi-polarization Envisat-ASAR images as a function of leaf area index (LAI) of White Poplar and Desert Date plantations

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The relationship between leaf area index (LAI) of plantations and multi-polarization Synthetic Aperture Radar (SAR) data (Envisat-ASAR) was investigated for White Poplar (Populus tomentosa Carr) and Desert Date (Elaeagnus angustifolius) in Heihe district, northwest China. The study showed that, for homogeneous White Poplar plantations, HH and HV polarization data (where H and V represent horizontal and vertical polarizations, respectively, and the first of the two letters refers to the transmission polarization and the second to the received polarization) were sensitive to LAI and the $r^2$ (logistic relationship fits) values between HH polarization and LAI, 0.56 and 0.58 on 25 and 28 June images respectively, was much higher than that for the other polarizations of VV, VH and HV. For Desert Date plantations, the heterogeneity of the forests results in a more complex backscattering than that for White Poplar. Incidence angle also plays an important role in SAR backscattering, so a suitable SAR mode should be chosen to avoid scattering saturation when the LAI and incidence angle exceed certain values. The logistic polarization ratios of HH/HV and VV/VH showed varying correlation with LAI over White Poplar plantations, probably due to incidence angle.

1. Introduction

Leaf area index (LAI), defined as half of the total all-sided green leaf area per unit ground surface area (Chen et al. 1997), is a key variable for understanding the biophysical processes of forest and crop canopies, and for predicting their growth and productivity. LAI plays a central role in various biophysical processes, such as plant transpiration and CO$_2$ exchange (Haboudane et al. 2004), and is widely used as an input parameter in many biophysical models in many fields, including hydrological, ecological, geomorphological and climate modelling (Wulder et al. 1998). Although direct measurements of LAI are considered to be the most accurate, they are time consuming, expensive and often not feasible for remote locations such as forest areas (Jonckheere et al. 2004). Optical remote sensing data have been used to estimate LAI of crops and forests using model-based and empirical approaches (Tang et al. 2007). Nonetheless, methods based solely on optical data will always have some limitations because the optical signal is insensitive to woody stand structure. More importantly, the use of optical data is restricted by the requirement of cloud-free daylight conditions (Manninen et al. 2005). Synthetic Aperture Radar (SAR) data
provides an alternative for LAI estimation over forest areas that are cloud-covered for most of the year. Models designed to explain the complex backscattering interaction mechanism of forests (Ulaby et al. 1990, Sun et al. 1991, Karam et al. 1992) suggest that LAI retrieval, especially for not overly-sparse canopies, should be feasible with C-band SAR data (Chauhan et al. 1991).

Although multi-band and multi-angle satellite SAR data have been used in LAI and biomass estimation (Paloscia 1998), the mechanism and use of multi-polarization data for forest LAI estimation, especially the effects of different canopy structures, are still unknown (Manninen et al. 2005, Chen et al. 2009). Therefore, the present study analysed the relationship between ground measurements on LAI values of two different plantations, White Poplar (*Populus tomentosa* Carr) and Desert Date (*Elaeagnus angustifolius*) and multi-polarization Envisat Advanced Synthetic Aperture Radar (Envisat-ASAR) data. They were selected to explore and compare the potential of LAI estimation using multi-angle and multi-polarization (HH, VV and HV, where H and V represent horizontal and vertical polarizations, respectively, and the first of the two letters refers to the transmission polarization and the second to the received polarization) SAR images.

2. Material and methods

2.1 Test site and ground measurements

The study area is located in the Yingke oasis district of the Heihe River Basin (38° 50′ N, 100° 30′ E), near the city of Zhangye, in Gansu province, in northwest China. The study area is composed of different ecosystems, including mountain, oasis and desert (Ma and Frank 2006). The oasis is dominated by irrigated farmland with winter wheat, corn, beet and other crops. In addition, deciduous forests, mostly White Poplar and Desert Date, were widely planted in this area for economic benefit and as a windbreak. White Poplar is chiefly planted in the forest plantations and therefore plots are relatively homogeneous. The chief benefit of the Desert Date forest is as a windbreak and to control drifting sand. Figure 1 shows the study area and the representative plantations.

The field campaign was conducted in the oasis district on 14 and 17 June 2008 for White Poplar and in the Jiulongjiang forest farm, in the eastern part of the oasis, on 28 June 2008 for Desert Date and White Poplar. Twenty-one White Poplar and 15 Desert Date sample plots were selected; each was larger than about 3000 m² in area. The biophysical parameters measured in the artificial forests include diameter at breast height (DBH), height, crown diameter, density, LAI and leaf water content (LWC). LAI was measured in all sample plots, and the remaining parameters were measured on selected plots. In each sample plot, the parameter information acquired was detailed and recorded. Table 1 provides the statistics of the measured parameters for the two plantations. In each sample plot, five to ten representative trees were measured using a measuring tape and averaged to get DBH and crown diameter. The height was measured with a laser altimeter (Trupulse360, Laser Technology Inc., Colorado, USA). Tree density was estimated from the number of trees in a 10 × 10 m area. Fresh leaf samples in each area were weighed (fresh weight, F), then oven-dried at 60°C until a constant weight (dry weight, D) was obtained. The LWC was calculated from:

\[
LWC = \frac{F - D}{D}
\]
\[ LWC = \left( \frac{F-D}{F} \right) \times 100\% \]  

The LAI-2000 (LI-Cor Inc., Lincoln, Nebraska) was used to measure LAI in the field campaign. For the LAI sampling, measurements were made at three random positions around the centre of the forest plot. The LAI-2000 measurements were made around each position so that instrument readings were taken at each point. The value of LAI, averaged over these three individual points using the instrument, was used as reference value for this plot. The latitude and longitude of each plot was determined by global positioning satellite (GPS) measurements.

Table 1. Statistics of the measured parameters for White Poplar and Desert Date plantations. Min., maximum; Max., maximum; MSD, mean standard deviation.

<table>
<thead>
<tr>
<th>Tree Species</th>
<th>Statistic</th>
<th>LAI</th>
<th>DBH (cm)</th>
<th>Height (m)</th>
<th>Crown diameter (m)</th>
<th>Tree density (trees/m²)</th>
<th>LWC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Poplar</td>
<td>No. of samples</td>
<td>21</td>
<td>20</td>
<td>6</td>
<td>14</td>
<td>21</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>[Min., Max.]</td>
<td>[0.6,4.13]</td>
<td>[2.87,13.54]</td>
<td>[14,17.2]</td>
<td>[0.96,6.15]</td>
<td>[0.03,6]</td>
<td>[0.54,0.79]</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>1.87</td>
<td>7.59</td>
<td>15.6</td>
<td>2.90</td>
<td>0.57</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>MSD</td>
<td>1.07</td>
<td>3.40</td>
<td>1.17</td>
<td>1.48</td>
<td>1.29</td>
<td>0.08</td>
</tr>
<tr>
<td>Desert Date</td>
<td>No. of samples</td>
<td>15</td>
<td>15</td>
<td>5</td>
<td>15</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>[Min., Max.]</td>
<td>[0.44,1.99]</td>
<td>[6.05,28.11]</td>
<td>[3.83,11.4]</td>
<td>[1.92,11.03]</td>
<td>[0.02,0.12]</td>
<td>[0.65,0.76]</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>1.39</td>
<td>12.11</td>
<td>8.79</td>
<td>5.91</td>
<td>0.06</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>MSD</td>
<td>0.48</td>
<td>5.36</td>
<td>3.27</td>
<td>2.35</td>
<td>0.04</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Figure 1. Location of the study area near the city of Zhangye (5 July 2008, Envisat-ASAR VV polarization).
2.2 Envisat-ASAR images

The ASAR instrument on board the Envisat satellite is a C-band instrument, and it features enhanced capability in terms of coverage, range of incidence angles, polarization and modes of operation. In this study, four Envisat-ASAR satellite images, acquired on 19 June, 25 June, 28 June and 5 July 2008, respectively were used (see table 2), which were nearly coincident with the ground measurement. The European Space Agency free software ‘BEST’ (ESA 2008) was used to extract the radar intensity data and to calibrate the data to a backscattering coefficient ($\sigma_0$). The intensity and backscattering coefficient images were geo-referenced to a historical processed SPOT image with quadratic polynomial resampling with less than 1.0 pixel error.

### Table 2. Envisat-ASAR data parameters.

<table>
<thead>
<tr>
<th>Date</th>
<th>Polarization</th>
<th>Mode (incidence angle)</th>
<th>Resolution (m)</th>
<th>Pixel size (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 June</td>
<td>VV/VH</td>
<td>AP/IS6 (39.1–42.8°)</td>
<td>30</td>
<td>12.50 × 12.50</td>
</tr>
<tr>
<td>25 June</td>
<td>HH/HV</td>
<td>AP/IS3 (26.0–31.4°)</td>
<td>30</td>
<td>12.50 × 12.50</td>
</tr>
<tr>
<td>28 June</td>
<td>HH/HV</td>
<td>AP/IS1 (15.0–22.9°)</td>
<td>30</td>
<td>12.50 × 12.50</td>
</tr>
<tr>
<td>5 July</td>
<td>VV/VH</td>
<td>AP/IS7 (42.5–45.2°)</td>
<td>30</td>
<td>12.50 × 12.50</td>
</tr>
</tbody>
</table>

AP: Alternating Polarisation; IS: Image Swath

3. Results and discussion

The relationship between LAI and four different SAR polarization data was investigated for White Poplar (figure 2) and Desert Date (figure 3) plantations and the $r^2$ (logistic relationship fits) values of logistic regression were calculated. For the two types of images (VV, VH polarizations images on 19 June and 5 July 2008, and HH, HV polarizations images on 25 June and 28 June 2008), the like-polarized (HH, VV) backscattering coefficients were greater than for cross-polarization (HV, VH). Studies have shown that the major differences between like-polarized and cross-polarization result from crown volume-backscattering parameters such as albedo and leaf permittivity (Ulaby et al. 1986). Therefore, for forest, volume backscattering from crown was the key component of backscattering, especially for White Poplar in this study area.

For White Poplar forests, the correlation values ($r^2$) between HH polarization and LAI were 0.56 and 0.58 for 25 and 28 June images, respectively; these values were higher than for the other polarizations (VV, VH and HV). HV polarization resulted in correlations of 0.13 and 0.27 for the 25 and 28 June images, respectively. For VV and VH polarization, the correlation with LAI was poor. However, for the Desert Date forests, nearly all the correlation values were low. This may be due to the effect of different roughness values within this class. White Poplar is generally much more homogeneous than Desert Date, as is illustrated by figure 1. From figures 2 and 3, we can see that there is little difference between HH and VV polarization values about the mean value of −10.00 dB. However, HH polarization values increased with LAI, while VV polarization seemed saturated with LAI. It was thought that the incidence angle has a relatively large influence on this phenomenon (Ulaby et al. 1990), as the two types of forests were considered to vary only minimally during the time of image acquisition. There were large incidence angles for the
two VV polarization images (table 2). For large incidence angles and high LAI, the $\sigma^0$ values become saturated, similar to the performance of vegetation index (VI) variation with LAI in optical remote sensing (Clevers and van Leeuwen 1996). Therefore, there should be an appropriate incidence angle between the relationships for forest LAI estimation based on $\sigma^0$ in this study. For the SAR operated in the C-band, the penetrability is limited compared with some longer bands, and the saturation phenomenon appears easily, especially for thick forest. Therefore, if the LAI of forests was estimated using Envisat-ASAR data, the radar mode that corresponds to the incidence angle should be chosen carefully. In this article, incidence angles of 20–30° were found to be suitable. The logistic polarization ratio data is somewhat correlated with LAI, especially for HH/HV polarization for White Poplar forests, and the $r^2$ values reached 0.29 and 0.40 (see figure 2). The polarization ratio accounts for the LAI estimation compared to single polarization data, as it eliminates the radiometric noise (Chen et al. 2009). However, because of the influence of
other factors, an uncertainty exists in the relationship between the LAI and the logistic polarization ratio, such as the VV/VH for White Poplar forests, when the incidence angles are large (figure 2).

4. Conclusions

Homogeneity of forest land cover plays a large role in the consistency of the relationship between LAI and SAR backscattering data. In White Poplar forests planted in regular plantations, relatively high correlation was obtained. For less homogeneous forests, such as Desert Date, the SAR backscattering data is much more complex. For White Poplar forests, there are relatively large differences between the two types of images. In this study, it was deduced that the differences probably resulted from the SAR mode (incidence angle). The logistic polarization ratio was also studied and, for White Poplar forests, there is a clear correlation between LAI and HH/HV.
polarization, but this association was not found for VV/VH polarization; this is also probably due to the different incidence angles of the two types of images. For SAR backscattering data, there is also a saturation phenomenon when the LAI and SAR incidence angles exceed specific values. In the present study, over the forest regions, the incidence angles of SAR data of 20–30° were found to be suitable.

In this study, only the relationship between LAI and SAR backscattering coefficients was investigated. However, other factors, such as LWC, play an important role in SAR backscattering data, but because there was no precipitation during the study period, constant LWC values were assumed. This research was primarily focused on White Poplar and Desert Date plantations on flat sites, and topographic relief was not taken into consideration. Natural forests in mountain areas will be studied in the next stage.

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References


