INTERFEROMETRY, VEGETATION, AND SAR INTEGRATION TIME

Stephen Hobbs and Davide Bruno
Cranfield Space Research Centre, Cranfield University, Cranfield, MK43 0AL, GB

ABSTRACT

We discuss coherence during imaging and between images as a function of the integration time accounting for the loss of coherence due to vegetation motion. The method outlined allows the loss of coherence either during imaging or the mutual coherence between images to be predicted for various systems imaging crop canopies such as wheat (coherence loss for the signal due to vegetation only). There appear to be significant benefits for interferogram quality by using longer integration times than are available with current LEO SAR.

Key words: integration time; SAR; vegetation; coherence.

1. INTRODUCTION

Vegetation motion causes loss of coherence for conventional SAR interferometry. Integrating the signal for longer periods should average out the motion resulting in better interferograms. This article discusses issues to help quantify this improvement.

The results are useful for quantifying the performance of imaging systems using long integration times, such as SAR from geosynchronous orbit [1, 2]. The issue is discussed using data and parameterizations of vegetation motion in wind (since this is an important cause of loss of coherence over timescales up to several days), and from the perspective of measurement physics.

2. MEASUREMENT PHYSICS

Figure 1 illustrates three timescales involved in typical measurement processes. For a low Earth orbit SAR, the timescales are typically (e.g. Radarsat-2, Table 1) $s = 0.24\ s$, $\Delta = 3\ \text{days (re-image)}$ to 24 days (orbit repeat for interferometry), $T = \text{several years}$. Thus the orbit dynamics mean that $s < \Delta$ which is not ideal from a measurement physics perspective. Any processes with significant variance at frequencies between $1/\Delta$ and $1/s$ are poorly measured, and in fact this variance causes errors when the measurement is used to represent the mean over the interval $\Delta$ [3].

For interferometry, it is necessary to combine two images separated by a multiple of the orbit repeat period. If the signal has components which vary incoherently on timescales longer than $s$ but shorter than the time between images then this variation causes loss of coherence. Increasing $s$ by using a long integration time may average out the incoherent part of the signal, and then when these images are used for interferometry their mutual coherence will be improved.

Table 1. Mission parameters for current LEO radars ($\lambda$ is the antenna length, $\theta$ the assumed incidence angle, $h$ the orbit height, and $s$ the resulting sampling time).

<table>
<thead>
<tr>
<th>Mission</th>
<th>$\lambda$</th>
<th>$l$</th>
<th>$\theta$</th>
<th>$h$</th>
<th>$s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrasar-X</td>
<td>3.11</td>
<td>4.8</td>
<td>20</td>
<td>514</td>
<td>0.25</td>
</tr>
<tr>
<td>Cosmo-Skymed</td>
<td>3.12</td>
<td>5.7</td>
<td>38</td>
<td>620</td>
<td>0.31</td>
</tr>
<tr>
<td>Radarsat-2</td>
<td>5.55</td>
<td>15.0</td>
<td>20</td>
<td>798</td>
<td>0.24</td>
</tr>
<tr>
<td>Envisat ASAR</td>
<td>5.62</td>
<td>10.0</td>
<td>20</td>
<td>800</td>
<td>0.36</td>
</tr>
<tr>
<td>ALOS PALSAR</td>
<td>23.6</td>
<td>8.9</td>
<td>24</td>
<td>692</td>
<td>1.47</td>
</tr>
</tbody>
</table>

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3. COHERENCE DURING IMAGING

Signal coherence during imaging determines how much power is focussed and how much power contributes to clutter. The following sections discuss coherence for that part of the signal due to vegetation only. The total signal includes power backscattered by other scene elements (e.g., surface). One interpretation of coherence is as the fraction of the power scattered by static parts of the scene, which can be used to estimate coherence for the total signal if the relative strength of the different scattering mechanisms can be quantified separately.

3.1. Short integration time

Motion of vegetation during the SAR integration period causes defocussing of the signal. If the motion is steady then the apparent target’s position is displaced in azimuth due to the Doppler shift; if the motion is incoherent then it adds to the clutter. Figure 2 shows how measured statistics of wheat plant motion vary with the length of the averaging window used using the plant motion dataset of [4]. These data show that with typical (X- and C-band) SAR sampling times of a fraction of a second, a large part of the motion is imaged coherently, even though over longer timescales the motion becomes incoherent. Taller vegetation (e.g., trees) is likely to have longer correlation times and so even with L-band imaging from low Earth orbit, there will be significant focussing of motion which becomes incoherent over longer periods.

3.2. Long integration time

Using parameterizations from [4] the motion over longer integration times can be estimated and then used to quantify the fraction of power scattered incoherently during imaging. The motion is projected along the slant range and then expressed as phase variance ($\langle X^2 \rangle$, assumed to have a zero-mean Gaussian distribution). Expected coherence ($\gamma$) is obtained from phase variance using Eq. 1 [5]. Figure 3 illustrates this method used to estimate coherence statistics, and Figure 4 shows results using this method and annual wind statistics for Cranfield (central England, GB, 1996-97). Based on these results, expected coherence when imaging vegetation such as wheat is high at L-band, but much lower for X-band. This trend is as expected, and is quantified using this method.

$$\gamma = \langle e^{iX} \rangle = e^{-\langle X^2 \rangle/2} \quad (1)$$

4. COHERENCE BETWEEN IMAGES

The coherence expected between images is improved by using a longer averaging time, although this also increases the power contributing to clutter. Prati et al. [1] show that the expected signal to clutter ratio for long integration times is mainly determined by the integration time $T_0$, the azimuth resolution $\rho_a$, the fraction of power

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Schematic representation of the method used to estimate coherence statistics from wind statistics, plant motion parameterizations, and radar parameters.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4.png}
\caption{Cumulative probability of coherence magnitude for radars of several wavelengths imaging a crop of height 80 cm (based on parameterizations of the motion of mature wheat); integration time = 15 min, typical GEO SAR viewing geometry.}
\end{figure}
scattered incoherently $\Gamma$, the target coherence time $\tau_c$ and the instantaneous illuminated beamwidth $D$.

$$SCR = \frac{T_0\rho_a}{\Gamma\tau_c D}$$  \hspace{1cm} (2)

Results such as those of Figure 4 help determine $\Gamma$, and thus the likely $SCR$ for different imaging systems.

5. DISCUSSION AND CONCLUSIONS

The methods presented here allow the benefits of long integration times to be quantified in terms of the coherence expected for signals from vegetation. Combining this with a backscatter simulation model to quantify the relative cross-sections of different scene elements - soil, stalks, leaves, etc. - allows the total signal coherence to be estimated. L-band images have highest coherence, since a given amplitude of motion corresponds to less phase variation, the higher coherence means less incoherent power contributing to clutter, and the mobile target elements have lower RCS anyway at L-band than for shorter wavelengths. Indications are that significant benefits for interferogram quality are possible from longer integration times.

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REFERENCES


