Remote Sensing of Environment 115 (2011) 2887–2896

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

A survey of temporal decorrelation from spaceborne L-Band repeat-pass InSAR

Razi Ahmed [a], Paul Siqueira [a,*], Scott Hensley [b], Bruce Chapman [b], Kathleen Bergen [c]

[a] Department of Electrical and Computer Engineering, University of Massachusetts, Amherst, MA, USA
[b] Jet Propulsion Laboratory, Pasadena, CA, USA
[c] School of Natural Resources and Environment, University of Michigan, Ann Arbor, MI, USA

ARTICLE INFO

Article history:
Received 14 April 2009
Received in revised form 19 December 2009
Accepted 12 March 2010
Available online 13 May 2011

Keywords:
InSAR
Temporal decorrelation
DESDynI
SIR-C
L-Band

ABSTRACT

In this paper we quantify the effects of temporal decorrelation in repeat pass synthetic aperture radar interferometry (InSAR). Temporal decorrelation causes significant uncertainties in vegetation parameter estimates obtained using various InSAR techniques, which are desired on a global scale. Because of its stochastic nature temporal decorrelation is hard to model and isolate. In this paper we analyze temporal decorrelation statistically as observed in a large swath of SIR-C L-Band InSAR data collected over the eastern United States, with a repeat pass duration of one day in October 1994 and a near zero perpendicular baseline. The very small baseline for this particular pair makes the effect of volumetric scattering on correlation magnitude statistics nearly imperceptible, allowing for a quantitative analysis of temporal effects alone. The swath analyzed in this paper spans more than a million hectares of terrain comprised primarily of deciduous and evergreen forests, agricultural land, water and urban areas. The relationships of these different land-cover types, phenology and weather conditions (i.e. precipitation and wind) on the measures of interferometric correlation is analyzed in what amounts to be the most geographically extensive analysis of this phenomenon to date.

© 2011 Elsevier Inc. All rights reserved.

1. Introduction

The DESDynI (Deformation Ecosystem Structure and Dynamics of Ice) mission, recommended by the National Research Council (NRC) Decadal Survey (National Research Council, 2007), will use spaceborne radar and lidar instruments to address issues in ecological, cryospheric and solid earth sciences. Repeat orbit interferometric synthetic aperture radar (InSAR), one of the radar components of DESDynI, is being considered in order to allow studies in the above three fields using a single instrument. In principle, a radar interferometer can obtain very accurate height estimates by measuring the path length difference of the scattered electric field received by two antennas separated by some distance, called a baseline, and relating it to scatterer height (Li & Goldstein, 1990; Rodriguez & Martin, 1992; Rosen et al., 2000) through a simple geometric transformation. The sensitivity of the interferometer to height increases with increasing baseline lengths. Large baselines on a single platform (or on two platforms, as in a tandem mission), however, increases system cost and complexity considerably. Repeat orbit interferometers on the other hand rely on the proximity of two satellite overpasses to synthesize a baseline. Such a system utilizes a single antenna, hence a small platform, and is therefore less expensive and more realizable. In this case the interferometric pair is formed by a repeat-pass observation of the satellite, the baseline is formed by a slight change ($\approx$1 km) in the satellite orbit. If the baseline of an InSAR system is zero (or nearly so) the instrument can detect very minute changes of the target from one pass of the satellite to another. This allows for studies of ice dynamics and earth deformation, two of the three applications of the DESDynI mission. Large baselines, however, help in accurately estimating ground topography and the height and vertical profile of volume scattering targets such as forests.

The knowledge of forest tree heights leads to better estimates of above ground carbon stocks and contributes to our understanding of the carbon cycle. Improving our understanding of carbon stocks from spaceborne radar observations can take on one of four different approaches. First, it has been shown (Wu, 1987; Le Toan et al., 1992; Dobson et al., 1992) that above ground biomass estimates can be obtained directly from radar backscatter. This however is limited by issues of saturation (Imhoff, 1995), where increasing biomass does not increase backscatter intensity proportionately at high biomass levels. Techniques in radar interferometry can also provide estimates of carbon stocks through measurements of forest height and vertical structure. The topographic sensitivity of an interferometer can be used to invert for tree heights if knowledge of the true ground surface and canopy penetration characteristics are available (Kellendorfer et al., 2004; Walker et al., 2007; Simard et al., 2006). Polarimetric techniques in interferometry (Cloude & Papathanassiou, 1998; Treuhaft & Cloude, 1999; Papathanassiou & Cloude, 2001; Cloude, 2006) can be employed to measure structure over forested terrain. Interferometric correlation magnitude has also been shown to contain information of tree heights

* Corresponding author.
E-mail addresses: ahmed@mirsl.ecs.umass.edu (R. Ahmed), siqueira@ecs.umass.edu (P. Siqueira).

0034-4257/$ – see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.rse.2010.03.017

and stem volumes (Hagberg et al., 1995; Askne et al., 1997; Santoro et al., 2007).

Any repeat pass InSAR observation is susceptible to changes in the scene during the two acquisitions (Papathanassiou & Cloude, 2003; Santoro et al., 2007). This particular loss of coherence, or temporal decorrelation, is an important contributor to the uncertainty in forest heights and structure estimates from InSAR measurements. In the following, we provide an extensive analysis of this form of error source for repeat pass interferometry. This is done by first clearly defining the quantity and then demonstrating how it may be calculated from interferometric observations. We then perform this analysis over an extensive geographic region. The L-Band data-set, shown in Fig. 2, collected by the SIR-C shuttle mission which flew over the eastern US in October 1994 is analyzed in conjunction with the National Land Classification Dataset (NLCD 1992). It is shown that weather, wind, and seasons all play a role of varying degrees on temporal decorrelation.

2. Formulation

The interferometric correlation is defined as

$$\gamma = \frac{\langle E_1 E_2^* \rangle}{\sqrt{\langle |E_1|^2 \rangle \langle |E_2|^2 \rangle}} \quad (1)$$

where γ is interferometric correlation, E_1 and E_2 are electric fields received by the two antennas as shown in Fig. 1. In the case of a repeat orbit interferometer, E_1 would be the scattered field received at the first and E_2 field received at the second pass of the instrument. This observed correlation can be broken down to its components as (Zebker & Villasenor, 1992)

$$\gamma_{obs} = \gamma_{geom} \cdot \gamma_{thermal} \cdot \gamma_{vol} \cdot \gamma_{temp} \quad (2)$$

where γ_{geom} reflects slight changes of the radar viewing geometry from both ends of the interferometer, while $\gamma_{thermal}$ and γ_{vol} are the contributions of system thermal noise and volumetric scattering respectively and γ_{temp} represents temporal decorrelation. Among these components, because of its stochastic and non-stationary nature, temporal decorrelation is the hardest to model, isolate and analyze in vegetated areas. Furthermore, to better manage tradeoffs and resources for a repeat pass InSAR design, it is important to understand this effect to better quantify this potentially dominant error source, especially as it applies to estimating tree heights and vegetation structure on global scales.

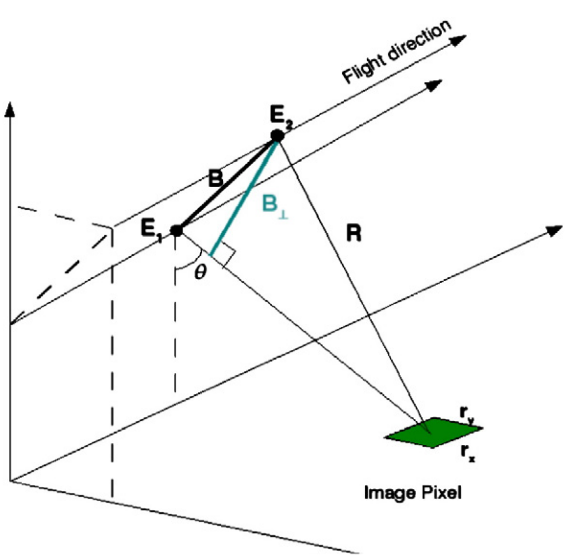

Fig. 1. Typical configuration for a repeat orbit interferometric SAR (InSAR). E_1 and E_2 represent position of the radar for the two passes separated by the baseline, B. The InSAR maps pixels of resolution r_x, r_y in range and azimuth from a look angle of θ. Difference in phase of an electric field scattered from the pixel at the two antennas is used to derive height estimates.

2.1. Components of interferometric correlation

In order to analyze the effect of temporal decorrelation, other components that contribute to overall observed correlation must either be absent or corrected for. The contributions from $\gamma_{thermal}$, γ_{geom} and γ_{vol} can all be mathematically modeled (Zebker & Villasenor, 1992; Li & Goldstein, 1990; Rodriguez & Martin, 1992). A discussion of these effects follows.

Additive thermal noise in interferometric data reduces coherence. This is referred to as $\gamma_{thermal}$. Assuming that additive noise is incoherent with the received signal and different in both interferometric channels, it can be shown that thermal effects can be modeled as a function of the signal to noise ratios (SNR)

$$\gamma_{thermal} = \frac{1}{\sqrt{1 + SNR_1^{-1}}\sqrt{1 + SNR_2^{-1}}} \quad (3)$$

where SNR_1 and SNR_2 are the signal to noise ratios for the two channels. The observed correlation can be corrected for thermal effects by using $\gamma_{thermal}$ estimates obtained using Eq. (3) as simply

$$\gamma_{gvt} = \frac{\gamma_{obs}}{\gamma_{thermal}} \quad (4)$$

where γ_{gvt} is the combined effect of volumetric, spatial and temporal effects. Respective SNR estimates required in Eq. (3) are obtained, in this case, from the intensity images of each pass.

Geometric decorrelation, $1-\gamma_{geom}$, sometimes referred to as baseline decorrelation, is reflective of the loss of coherence in an interferogram due to slight changes in the viewing geometry. It is intuitive that two radar returns will not be fully correlated if a scatterer is viewed from two different angles. This change of viewing angles is proportional to the projected interferometric baseline. Geometric decorrelation is broken down further into spatial, $\gamma_{spatial}$, and rotational, γ_{rot} effects, where the former is a function of the across-track component, while the latter is a function of the along-track component of the interferometric baseline. Because the orbits of spaceborne sensors are essentially parallel, when InSAR observations are processed to a common Doppler frequency, rotational effects are essentially zero (i.e. $\gamma_{rot} = 1$). Hence the geometric correlation is given by

$$\gamma_{geom} = 1 - \frac{2B_{\perp} r_y \cos\theta}{\lambda R} \quad (5)$$

where $B_{\perp}$ is the perpendicular baseline in the look direction, θ is the look angle, r_y is the range resolution of the radar, λ is the wavelength and R is range to the target.

As one can see in Eq. (5) the geometric correlation coefficient tends to unity when the perpendicular baseline nears zero. Conversely, complete decorrelation occurs at critical baselines (Zebker & Villasenor, 1992) as in

$$B_{\perp,crit} = \frac{\lambda R}{2 r_y \cos\theta}. \quad (6)$$

The volumetric decorrelation in interferometric data is reflective of scattering of radar signals from multiple heights within each resolution element. The observed correlation signature can be modeled as the

Download English Version:

https://daneshyari.com/en/article/4459237

Download Persian Version:

https://daneshyari.com/article/4459237

Daneshyari.com