EXTRACTING VEGETATION PARAMETERS FROM POLARIMETRIC INTERFEROMETRIC SAR-DATA

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RESUMEN: Este artículo discute las posibilidades de utilizar la polarimetría e interferometría en datos radar de apertura sintética (SAR) para extraer parámetros de vegetación. Se presentan dos métodos diferentes que han sido introducidos recientemente. El primer método consiste en una aproximación multifrecuencial y el segundo es la inversión de un modelo de dispersión. El principio de ambos es explicado y su comportamiento es demostrado utilizando resultados experimentales respecto al parámetro de altitud de la vegetación. Finalmente las características de los dos métodos son resumidas.

Palabras Clave: Polarimetría, Interferometría, Inversión de Modelos, Multifrecuencia

ABSTRACT: The present article discusses the possibility to use SAR-interferometry and polarimetry to extract vegetation parameters. For this purpose two different recently introduced methods are presented. The first one consists of a multifrequency approach, the second one on the inversion of scattering models. The principle of both approaches is explained and their performance is demonstrated by showing experimental results concerning the parameter vegetation height. Finally the main characteristics of both approaches are resumed.

Keywords: polarimetry, interferometry, model inversion, multifrequency

INTRODUCTION

SAR-interferometry for topographic mapping is a technique that has been developed to operational standard in the last decade. The advantage of SAR sensors compared to other electromagnetic sensors with a high resolution (i.e. optical) are, that they provide their own illumination and their performance is not limited by clouds. SAR-interferometry is performed by measuring the coherent backscattering of monochromatic radiation from the earth surface with two locally slightly separated antennas. By multiplying the resulting two SAR images a phase image, the so called interferogram, is obtained. This interferogram depends directly from the respective distance of the scatterers to the antennas. By reconstructing the geometry of the scattering process for each resolution cell a topographic map is obtained. This map gives a three dimensional information about the location of the scatterers.

This technique was used for example last year in the SRTM mission to survey more than 60 per cent of the earth surface. In large areas of the earth surface the presence of vegetation lifts the effective scattering phase centre and therefore the height of the topographic map. Although a comparable mapping accuracy with conventional methods cannot be achieved assuming comparable outlay, it is desirable to be capable to extract also information about the vegetation canopy particularly as many geoscientific applications consider phenomenas that are related directly or indirectly with the vegetation on the earth surface. For these disciplines a continuous measurement and monitoring of relevant vegetational parameters would be required.

In order to enhance the information content of interferometric SAR measurements several possibilities exist. Multi-baseline, the interferometric observation is performed from more than just two different antenna positions. Multi polarization, the polarization of the transmitted radiation can be varied. Multi frequency, the frequency of the monochromatic radiation can be varied. All of these methods lead to a set of independent measurements of each resolution cell in a SAR image. The measured values are typically electromagnetic variables like amplitudes and phases of a corresponding resolution cell. Unfortunately they do not give direct access to an interesting vegetation parameter. In order to extract exactly these vegetation parameters the whole process of scattering and SAR image and interferogram formation has to be known in a way that an inverse function of this process uses the measured values as input parameters to calculate the vegetation parameters. As this process is much to complex an exact solution of this inversion process can not be formulated, and other methods have to be developed to extract vegetation parameters from the measured values. In the recent years first methods have been developed to extract the vegetation parameters. In this papers such methods are presented and discussed concerning their applicability and limitations.

MULTIFREQUENCY METHOD

The most commonly used frequency-bands in SAR-interferometry are the X- and the C-band. Radiation of these frequencies does not strongly penetrate vegetation, so that an InSAR derived digital elevation model (DEM) of a vegetated area in these frequencies includes both the vegetation height and the bald earth topography. The idea is to use additionally a frequency of longer wavelength which is capable to penetrate vegetation. Consequently the location of the effective scattering centre concerning this frequency is expected to be closer to the ground. The difference in the vertical location of the effective scattering phase centre of the two frequencies can be utilized to calculate a difference DEM between the two resulting single frequency DEMs. For vegetation height estimations the difference of such DEMs should correlate with the vegetation height. In the ideal case the effective scattering centre of one frequency is located at the surface of the vegetation, whereas the phase centre of the other one is at the ground. If so the values of the difference DEM represent the vegetation height. Such an approach has been performed with interferometric data of the experimental SAR (E-SAR) system of DLR (Ulbricht, 1999).

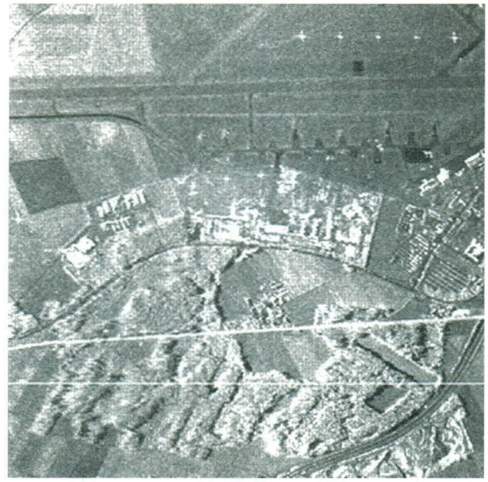

Figure 1. X-band amplitude image of the test-site. The white line corresponds to the rangeline plot in the next figure.

In this experiment the X-band has been used as frequency that is reflected at the vegetation surface. As the DEM generation of interferometric X-band data of the E-SAR is operational the input consisted of a geocoded X-band DEM of an area including a forest in the neighbourhood of the DLR. An X-band SAR image of the test-site can be seen in (Figure 1). As frequency that penetrates vegetation interferometric repeat pass data of the same test-site has been acquired in L-band and in P-band. From both L- and P-band data sets repeat pass DEMs have been generated. The results show, that in both L- and P-band the effective scattering phase centre is far below the one in X-band.

Figure 2. Plot of the difference DEM between X-band and P-band.

The resulting difference DEM between the P-band and the X-band DEM can be seen in (Figure 2). It resembles well to the three dimensional contour of the forest in the test-site. In order to see whether the numerical values of the difference DEM correspond with the vegetation heights, hypsometric measurements have been performed at 14 different locations of the forest. The locations have been chosen in dependence on the local tree height and the local type of forest. The local average tree height ranges from 16m to almost 30m. The 14 locations are partly coniferous and partly deciduous forest areas. An analytical expression that represents the relation between the difference DEM heights and the hypsometric tree heights for both of the difference DEM has been derived with a linear regression. It leads to equation 1 in the L-band case and to equation 2 in the P-band case.

$$h_{arbol} = 1.8\,m + 0.79 \cdot h_{diffDEM} \qquad (1)$$

$$h_{arbol} = 3.3\,m + 0.70 \cdot h_{diffDEM} \qquad (2)$$

The corresponding correlations r^2 are 0.53 in the L-band case, and 0.75 in the P-band case. If the locations of the hypsometric measurements are weighted, even better correlation coefficients r^2 of 0.78 (L-band) and 0.85 (P-band) are obtained. Although it is likely that the ratio is dependent on absolute tree height and tree species, further analysis of both L- and P-band did not show any measurable dependence.

As a resume the tree height estimation using the P-band/X-band combination seems to be more stable than the one using the L-band/X-band combination.

MODEL INVERSION METHODS

In case of random media, like vegetation, the electromagnetic interaction of waves is a complex process, that is sensitive to a large number of parameters. Consequently, as already mentioned in the introduction, the exact reconstruction of this process as well as the interferogram formation process cannot be formulated and calculated easily. Instead of this a scattering model can be formulated that is much simpler than the exact process, which calculates output values (i.e. amplitudes and phases), that correspond to the measured real data. Comparison of the real values with the modelled ones and inversion of this simple scattering model leads to the required set of vegetation parameters (Papathanassiou, 1999); (Sagues, 2000). The main difficulty in this approach is the formulation of the scattering model in such a simplicity that it is possible to invert it, while at the same time the resulting vegetation parameters are complex enough to describe the demanded vegetation characteristics.

All of the currently existing approaches (Papathanassiou, 1999), (Sagues, 2000) model the interferometric coherence, and use non-linear inversion algorithms to extract the vegetation parameters. The number of extractable vegetation parameters is limited by the number of independent measurement values. Our scattering model (Sagues, 2000) consists of a random medium above a solid ground. Simulations show that two of the originally four considered scattering contributions can be neglected. The resulting scattering model includes direct backscattering from the random media as well as from the ground and is equivalent to the one in (Papathanassiou, 1999). The number of vegetation parameter is four plus one additional per additional polarization channel. Equation 3 shows the expression for the coherence γ_i of polarization channel i, with ϕ_{int} interferometric phase of the ground, K_p extinction coefficient, d vegetation height, and M_i ground to volume backscattering ratio.

$$\gamma_i = \frac{e^{i\phi_{\text{int}}}}{K_p} \cdot \left[\frac{e^{\chi \cdot d} - 1}{\chi} + M_i d \right] \qquad (3)$$

The necessary independent measured real values to invert this model can either be provided by fixed polarization multibaseline data, or by fixed baseline multipolarization data. Both techniques have been experimentally tested using laboratory as well as outdoor measurements. The laboratory data has been acquired in the anechoic chamber of the Joint Research Centre (JRC) in Ispra using a maize sample and a sample of small pine trees with a height of about 1.8m. Both of the samples have been measured using multiple frequencies. In Figure 3 and Figure 4 the extracted height of the maize sample is plotted against the frequency.

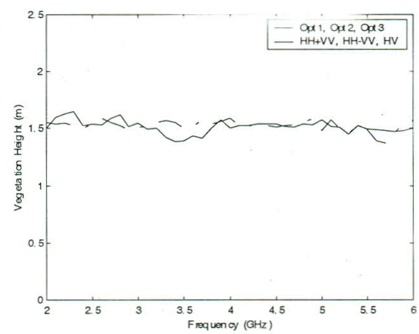

Figure 3. Extracted height of maize using multi polarization data

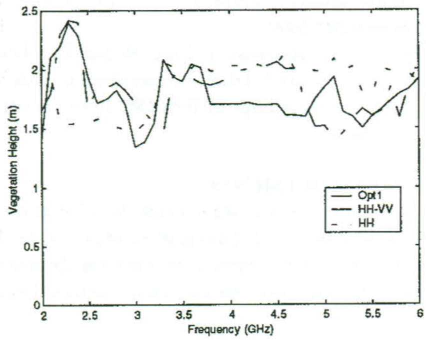

Figure 4. Extracted height of maize using multi baseline data

The extracted vegetation height using the multipolarization approach shows an almost constant value of 1.5m over the whole range of frequencies independent of the employed polarization base. The extracted height using the multibaseline approach shows comparable values but with some variations in dependence of frequency and polarization base. For the pine sample only the multi polarization approach has been considered. The results are shown in Figure 5. The results are comparable to the one of the maize sample with the difference that the optimum base (Papathanassiou, 1999) seems to yield the most stable result in dependence of the frequency. Because there are no existing estimations of the real data, plots of the other extracted parameters cannot be validated and are not shown here.

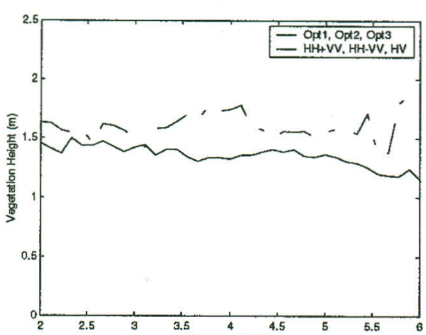

Figure 5. Extracted height of pines.

The outdoor measurements were performed on a sorghum field of apparently 1.4m height, using the C-SAR scatterometer of UPC (Sagues, 2000). As this scatterometer operates as an interferometric repeat-pass system, a modified inversion algorithm had to be used in order to eliminate the temporal decorrelation that is present in the data due to the time interval between the acquisition of corresponding interferometric data takes (Sagues, 2000). The extracted height values of 1.44m using data in the pauli base as input and 1.30m using data in the optimum polarization base as input are shown in correspond well with the real height of the sorghum field.

DISCUSSION

Two methods with the purpose of vegetation parameter extraction from interferometric polarimetric SAR data have been presented. Experimental results show that both methods provide good estimates of the vegetation height.

The necessary hardware for the multifrequency method is a double frequency interferometric SAR-system with two frequencies that differ strongly in their capability to penetrate vegetation. The general suitability of frequencies for this approach is expected to be dependent on the density of vegetation and needs to be investigated. The results obtained with the X-band/P-band combination look best. As the main limitation of the method is currently the restricted precision of a DEM based on airborne repeat-pass data, an enhancement of the accuracy is expected if the data input for the two necessary single frequency DEMs excludes these restrictions. Beside the vegetation height no other parameter can be extracted without further information. A dependence of the extracted height value on the type of vegetation has not been observed in the experimental results. For the inversion approach an interferometric SAR-system is needed that can acquire either multibaseline or fully polarimetric data. Both data input sets provide the necessary number of independent measurements for the inversion of a simplified scattering model. As the extracted parameters should give information about the whole vegetation a frequency needs to be applied, that is scattered in the whole vegetation volume. The applicability of the model is expected to be dependent on the description accuracy regarding the real vegetation. The main restriction of the model inversion is the limited mathematical stability in the behaviour of the used nonlinear inversion algorithms. The iteration result and the convergence of these algorithms depend strongly on the initial values. In the experiment the random volume model provided good height estimates for several low vegetation samples. Other publications show (Papathanassiou, 1999) that this model is also suitable for forest. Beside the height other vegetation parameters have been extracted which at present cannot be validated.

Both methods can contribute to a future global spaceborne system for vegetation monitoring. The determination of the characteristics of such a system that provides best performance needs further investigations.

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