FOREST HEIGHT AND BIOMASS ESTIMATION USING SPACE-BORNE POLARIMETRIC SAR DATA

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ABSTRACT

To demonstrate the potential of ALOS PALSAR data for polarimetric SAR interferometry (PolInSAR), a pair of PALSAR polarimetric scenes has been selected over Glen Affric, Scotland where various ground truth is available including digital terrain models (DTMs) and tree measurements. The overall coherence level is quite low due to the temporal decorrelation, relatively lower signal-to-noise ratio (SNR), and possible residual mis-registration between the two scenes. The results show that the low observed coherence level in forest in all lexicographic polarizations is a major problem challenging PolInSAR using PALSAR data. Additional data sets of forested areas in Kenai, Alaska and Edson, Alberta were similarly addressed with the same problematic results.

1. INTRODUCTION

The Polarimetric SAR Interferometry (PolInSAR) has proven itself as a valuable technology for bare-earth Digital Elevation Model (DEM) extraction beneath canopy and tree height estimation at L-Band frequencies. The Random Volume over Ground (RVoG) model proposed in [1] and elaborated in [2], permits a separation of ground and canopy scattering components of the interferometric phase. Through model inversion, the canopy height can be derived [3]. Additionally, the bare earth elevation beneath canopy can also be recovered at least in airborne repeat-pass cases where temporal decorrelation is not prohibitive [4]. While the PolInSAR results to date from airborne repeat-pass L-Band campaigns have been impressive, it is not clear to what extent it will be possible to derive similar results from ALOS data, owing to the much longer temporal baseline between acquisitions. The main purpose of the proposed work is to examine the feasibility of using PolInSAR techniques on ALOS PALSAR data to estimate ground elevation and forest canopy heights in forest conditions. The principal research site is chosen to be Glen Affric, Scotland where a variety of ground truth is available.

In the following sections the approach to the RVoG model and its application on L-Band PolInSAR data are discussed. A brief description of the test site and available ground truth is given in Section 3 followed by some details of the PALSAR data and our PolInSAR results from the data in Section 4, 5, and 6. Finally some discussions and conclusions are given in Section 7.

2. METHODOLOGIES

The key parameter in the PolInSAR RVoG model is the complex interferometric coherence, which has been generalized to integrate the polarimetric information [1-3]. The complex coherence, $\gamma(w)$, according to this model, is given by Eq. 1, where ϕ is the phase related to the ground topography, m is the effective ground-to-volume amplitude ratio (accounting for the attenuation through the volume) and w represents the optimized polarization state vector. $\tilde{\gamma}_V$ denotes the complex coherence for the volume alone (excluding the ground component), and is a function of the extinction coefficient σ for the random volume and its thickness h_V. It is important to note that m is polarization dependent while $\tilde{\gamma}_V$ is not.

$$\gamma(w) = \exp^{j\Phi}\left[\frac{\tilde{\gamma}_v + m(w)}{1+m(w)}\right] \quad (1)$$

Parameters in Eq. 1 can be recast, as in Eq. 2, which represents a line equation on the unit circle.

$$\gamma(w) = \exp^{j\Phi}\left[\tilde{\gamma}_v + \frac{m(w)}{1+m(w)}(1-\tilde{\gamma}_v)\right] \quad (2)$$

In the ideal case, the variation of m as a function of polarization, w, will therefore trace out a straight line which when projected onto the unit circle (limit of large m) provides the topographic phase as illustrated in Fig 1. The phase to height conversion is a simple scaling by vertical wave-number (Eq. 3). In the limit of m=0, the observed coherence is just $\tilde{\gamma}_V$ rotated by the topographic phase. The canopy height can be obtained from $\tilde{\gamma}_V$ by an inversion process [3]. Due to estimation errors, noise and other decorrelating effects, the straight line degenerates to a region surrounding the line. The lowest and highest values of coherence can be calculated through ‘constrained coherence optimization’ [5], forming the coherence region as illustrated in Fig. 1.

A ‘well-shaped’ coherence region is normally close to an ellipse with high eccentricity. In repeat-pass interferometry, temporal decorrelation, thermal noise and baseline variation may fatten this region to be more circularly-shaped.

$$\Phi = K_z . h_v \tag{3}$$

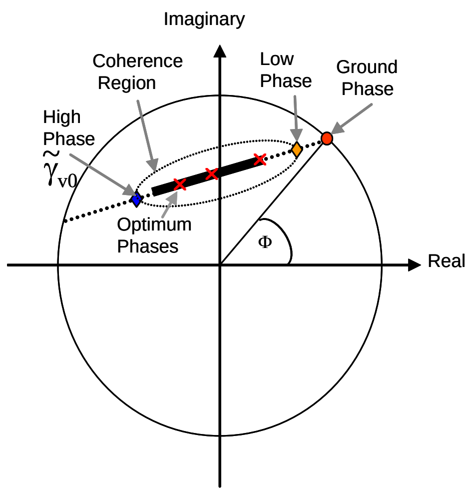

Fig. 1 The schematic view of unit circle for two-layer RVOG model.

3. STUDY AREA

The study area is part of Glen Affric, located in northwest Scotland, centred at 4.90° west and 57.28° north (Fig. 2). It is an upland area, dominated by moor land and woodlands, designated as a National Nature Reserve and recognized as being both a site for recreational activity and of ecological value. The UK Synthetic Aperture Radar and Hyper spectral Airborne Campaign (SHAC) over the highlands of Scotland took place in May 2000 [6-7]. Some interesting results of tree height estimation and topography retrieval using PolInSAR techniques based on the repeat-pass airborne L-Band datasets from this campaign have been presented in [6], where a unique dual-baseline technique was applied in order to get high sensitivity of the larger baseline by utilizing the higher coherence of the smaller baseline. The estimated tree height was found correlating very well with ground measurements. Several fully polarimetric classification models were also tested on this area in [7]. It has been shown that a good land-cover classification can be achieved using airborne L-Band PolInSAR data.

Fig. 2 A ground photo of the test site (Top) and its geographical location with PALSAR scene boundary (Bottom)

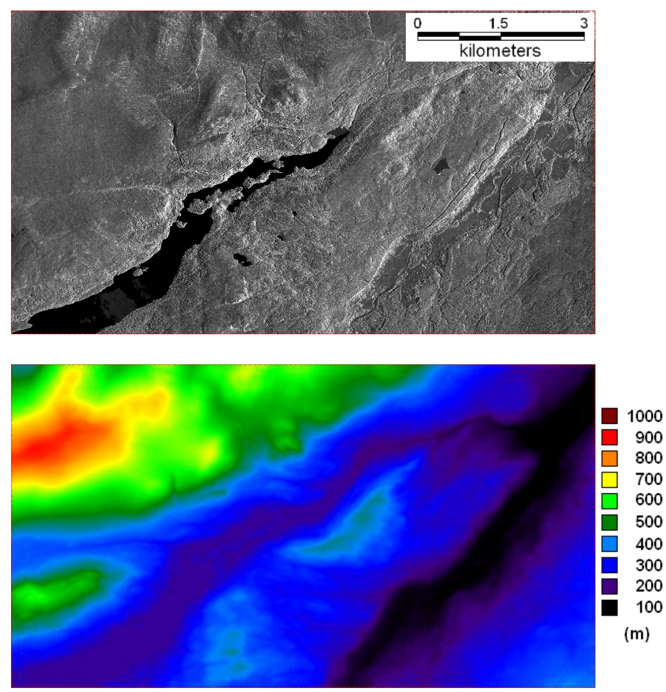

Fig. 3 X-Band ORI (Top) and DSM (Bottom)

During Intermap’s NextMAP UK program, X-Band HH InSAR data was acquired in this area in 2004. The ORI will be used as a planar reference in evaluating any geocoded L-Band data, while the DSM provides elevation reference on bare areas. Fig. 3 shows a subset of the X-Band ORI and DSM.

As we can see from the DSM, the area is quite hilly with relative elevation difference around 800m. The large relief in this area creates some potential problems in general

InSAR application alone. For example, the terrain slope will affect both *Kz* and incidence angle calculation. Special care must also be taken in applying a range spectral shift to the data. Finally the relief displacement in the image will be difficult to remove when geocoding the L-Band image. Due to the limited information we have, however, nothing has been done to account for the slope in this work.

In addition to the X-Band InSAR data, some tree measurements were taken at the location shown in Fig. 4, during the SHAC campaign.

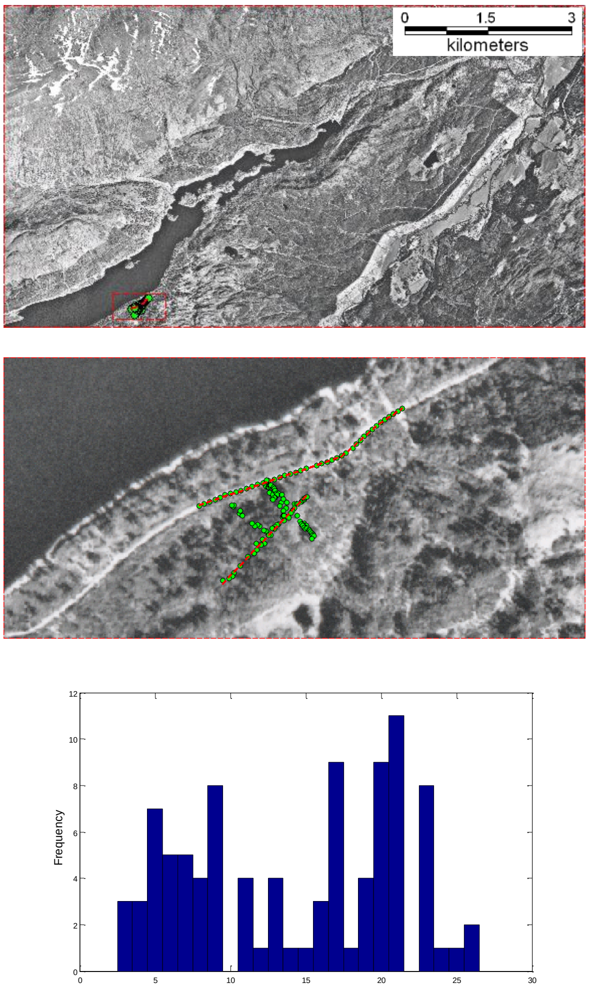

Fig. 4 Location of tree measurement on airphoto: overview (Top), zoom-in (Middle), and the histogram of measured tree heights (Bottom)

From Fig. 4, both the close-look airphoto and histogram of tree heights, we can see that the area is not a homogenous forest. The measured tree heights are ranging from 3m to 26m with a mean of 14.3m and standard deviation ±6.8m. This is also evident from the ground photo taken in the tree transect area which shows a varied topography and irregular crown (Fig. 5).

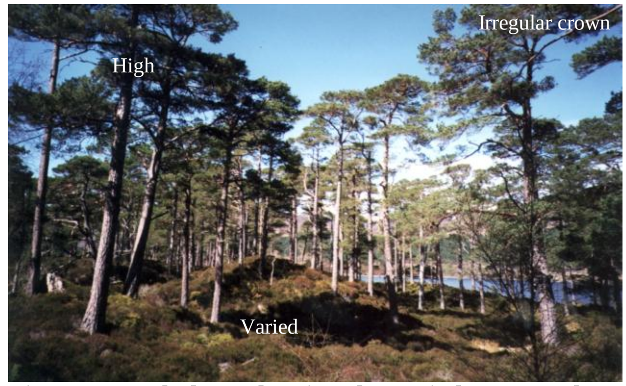

Fig. 5 Ground photo showing the varied topography, irregular crown and high canopy

4. PALSAR DATA

Two scenes of PALSAR PLR Level 1.1A data have been used in this work. The acquisition dates are June 3, 2007 and April 18, 2007 respectively. The June 3 scene is used as master pass and the April 18 as slave. The calculated baseline is about 267m horizontally and 271m vertically. The vertical wave number (*Kz*) is about 0.065 radians/m, which is quite small requiring an accurate phase calculation in model inversion.

Before running PolInSAR, the slave SLCs have to be resampled to match the master's azimuth spacing as well as scene starting point. Further subpixel coregistration was done using an array of patches approach. Fig. 6 shows an overview of the master HH image. The subset around the Glen Affric Lake was used in our following PolInSAR analysis.

5. POLINSAR RESULTS

Due to many missing items in the provided datasets, especially those for geocoding, at the time of writing this paper we are unable to geocode any of our PolInSAR results. Therefore the results provided here are all in slant range geometry.

Shown in Fig. 7 are, from top to bottom, the HH image of master pass, the Pauli decomposition image from the master pass, and the optimized coherence image. The red dashed lines are the digitized forest boundaries based on the Pauli image.

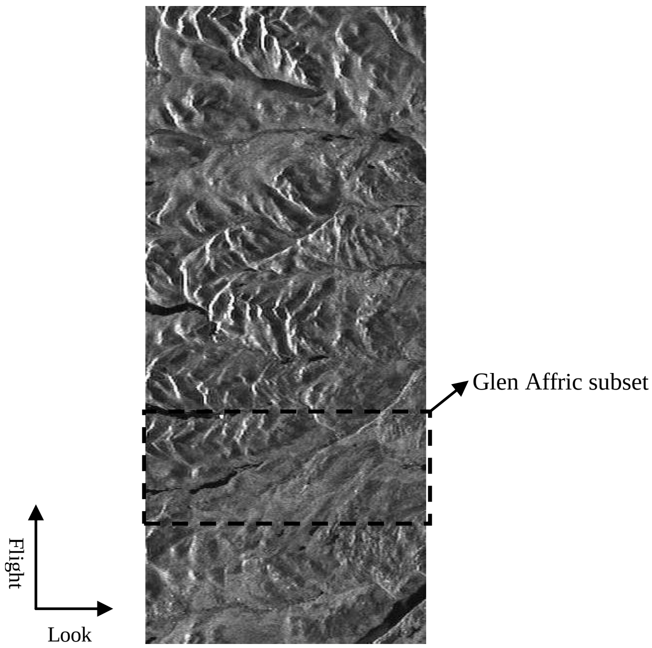

Fig. 6 Overview of PALSAR L-Band HH image *from master scene*

The Pauli image in Fig. 7 does give us some ideas of the forest extent in the area, although not much information in terms of tree height. The optimum coherence (and also the lexigraphical ones as shown in the profiles in Fig. 8) is generally high in non-forested areas and low in forested areas.

Fig. 8 shows the profiles of lexigraphical coherences along the line shown in Fig. 7.The profile runs from a “bare” area into a forest with two narrow “bare” areas and a lake in between before transiting into another “bare” area again. The average coherences from two co-polarized channels on “bare” areas are in the range of 0.8 to 0.9, which is low for good InSAR applications. This might be due to the following reasons: 1) the fact that the “bare” areas are not truly “bare” as indicated in some of the ground photos, where a 1-2 meters under story is usually seen; 2) the SNR decorrelation on HHHH and VVVV channels, which was estimated around 0.96; 3) Some residual misregistration.

The co-polarized coherence in forest areas is as low as 0.2-0.6. The main cause of this is the temporal decorrelation as the temporal baseline for this pair is 46 days. The temporal decorrelation induced by wind might be the main source of it. The low coherence in forest area makes the PolInSAR model inversion very challenging because the coherence region is often circularly shaped. Moreover, due to the imaging geometry of this pair the vertical wave number is quite small and the model inversion is very sensitive to phase errors. Fig. 9 shows two examples of coherence regions calculated from the data.

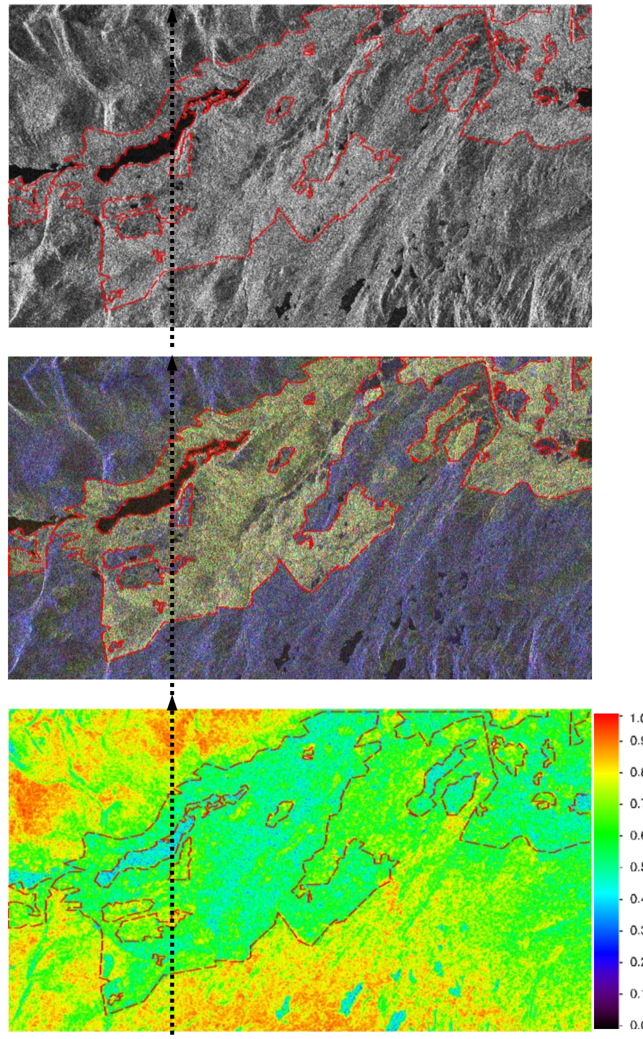

Fig. 7 Digitized forest boundaries overlaid on master’s HH image (Top), Pauli image (Middle), optimized coherence image (Bottom). Looking direction is to the right. The vertical dotted lines are the approximate location of the profile used in Fig. 8.

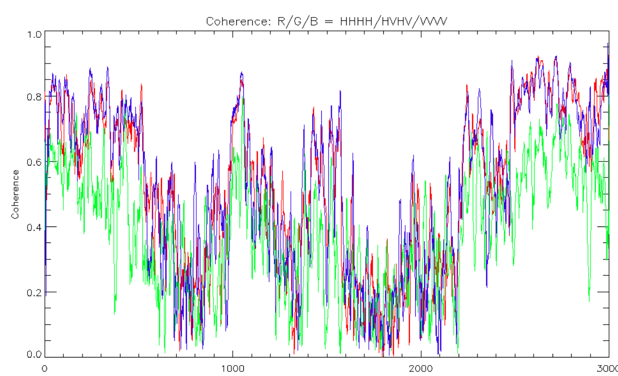

Fig. 8 Coherence profile along the line shown in Fig. 7: Red: HHHH, Green: HVHV, Blue: VVVV.

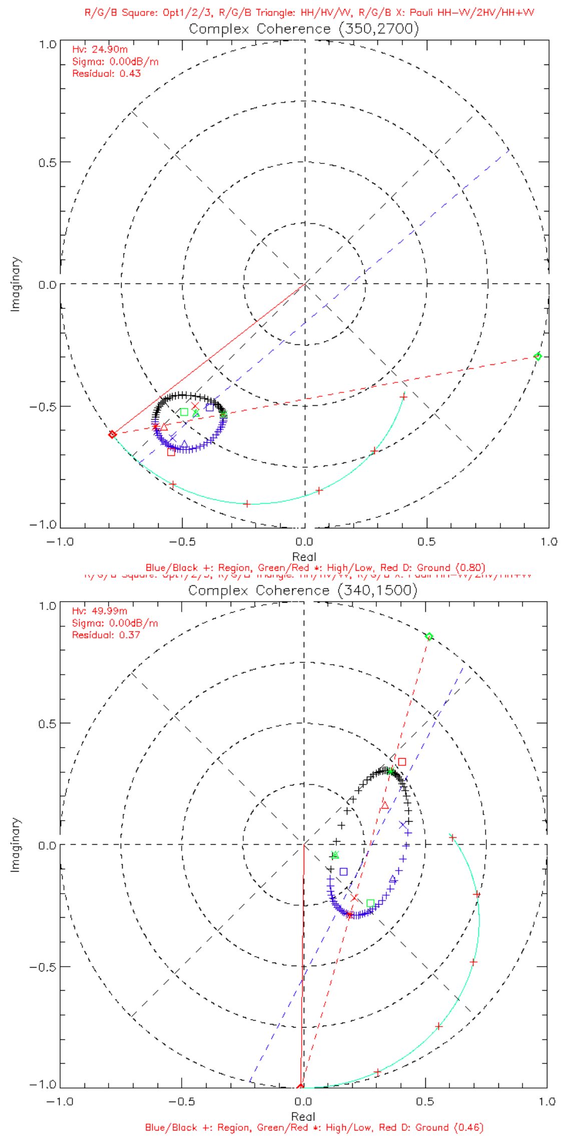

Fig. 9 Typical coherence regions on "bare" areas (Top) and forested areas (Bottom)

The coherence region in Fig. 9 (Top) is plotted in the "bare" area located at almost the end of the profile line shown in Fig. 7. Although the Optimum 1, HHHH, and VVVV coherences are reasonably high (~ 0.85), the HVHV coherence is quite low (~0.62). This results in a circular and large coherence region, while ideally it should be much smaller and up to the unit circle (as the coherences are close to one). The low coherence in these cross-polarized channels in "bare" areas is partially due to the SNR decorrelation which is estimated to be around 0.68.

The location of the Fig. 9 (Bottom) coherence region is to the south of the lake and almost in the middle of the profile shown in Fig. 7. This area is where some tree measurements were taken during the SHAC campaign. The measured tree height is about 14.3m in average. However, the estimated tree height from this coherence region exceeds the 50m limit, which is obviously overestimated. The reasons again are: 1) the temporal decorrelation is decreasing all the coherences (and coherence regions) to a very low level, which leads to overestimation in the phase diversity; 2) The SNR decorrelation makes the coherence region larger than it should be which adds additional overestimation to the phase diversity. 3) The height ambiguity is very large (~100m) and the model inversion is thus sensitive to any residual phase errors.

6. ADDITIONAL TEST RESULTS

In this work, two more datasets were downloaded and processed. The first one is an InSAR pair with HH polarization only acquired in December 2007 and February 2008 respectively over Kenai, Alaska, USA. The calculated coherence magnitude is very low with a mean 0.23 and a standard deviation 0.13 for a 3000 x 3000 non-forested subset. The second dataset is a PolInSAR pair acquired in November 2007 and August 2008. This was the only available PolInSAR pair near to our targeted test site Edson, Alberta, Canada, where we have ground truth and our own airborne single-pass L-Band PolInSAR datasets. Because of the large time difference between two acquisitions, the resulting coherence is too low for a meaningful PolInSAR analysis.

7. CONCLUSIONS

The main objective of this research was to validate the functionality and application of PolInSAR, specifically the RVoG model, for L-band fully polarimetric interferometric data from ALOS PALSAR. The intent was to estimate the ground elevation beneath canopy and to extract the tree height in forest. It was shown that due to the nature of repeat-pass interferometry, the observed coherence was much lower than what we had expected, which makes the model inversion very difficult. It is hoped that these issues can be re-addressed with ALOS2 when available, with a higher chance of success.

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9. REFERENCES

[1] Treuhaft, R. N. and Siqueira, P. R., (2000). Vertical structure of vegetated land surfaces from interferometric and polarimetric data, *Radio Science*, vol. 35, pp. 141–177, 2000.

[2] Papathanassoiu, K. P. and Cloude, S. R., (2001). Single-Baseline Polarimetric SAR Interferometry, *IEEE trans. on Geoscience and Remote Sensing*, Vol. 39, pp. 2352-2363.

[3] Cloude, S. R., Papathanassiou, K. P., (2003). Three-stage inversion process for polarimetric SAR interferometry, *IEE Proc. Radar Sonar Navig.* Vol. 150, pp. 125~134, June 2003.

[4] Mercer, B., Zhang, Q., Lumsdon, P., (2007). L- And P-Band Polarimetric InSAR for DEM Extraction Beneath Tropical Canopy Using INDREX-II Data Sets. Proceedings of Advanced SAR Workshop 2007, September 11-13, 2007, Vancouver, Canada.

[5] Tabb, M., Orrey, J., Flynn, T., Carande, R., (2002). Phase Diversity: A Decomposition for Vegetation Parameter estimation using Polarimetric SAR Interferometry, *Proceedings of EUSAR 2002*, pp. 721-724.

[6] Woodhouse, I., Cloude, S., Papathanassiou, K., Hutchinson, C., (2003). Evaluating PolInSAR Tree Height and Topography Retrievals in Glen Affric. PolInSAR 2003. January 14-16, 2003. ESRIN, Frascati, Italy.

[7] Lumsdon, P., Cloude, S., Miller, D., Mathews, K., (2005). The 3D visualization of land-cover in Glen Affric Scotland using Polarimetric SAR Interferometry. Proceedings of International CEOS SAR CAL/VAL Workshop, September 28-30, 2005, Adelaide, Australia.