FOREST INVENTORY USING INTERFEROMETRIC SAR TECHNIQUES

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ABSTRACT

In this work the feasibility of interferometric coherence images for forest inventory was studied. Coherence images over our test site in Kalkkinen (130 km north of Helsinki) were produced from four ERS-1/2 Tandem SLC image pairs. Additionally, a normalized sum of the four coherence images was computed. All images were visually interpreted by comparing them with a base map, SPOT Pan image, and stand inventory data. Our results indicate that the coherence over boreal forest during winter is considerably higher than during other seasons. Therefore, ERS-1/2 Tandem interferograms acquired during winter seem to be ideal for DEM generation over boreal forests. Forest and non-forest may be visually discriminated from each other and discrimination between different forest types is also possible provided that the average scene coherence is not too low. Summation of normalized coherence images was found to produce images that are better suited for visual land-use and forest classification than a single coherence image.

1. INTRODUCTION

Traditional forest inventory is both expensive and time-consuming. In theory, remote sensing methods offer a good alternative and/or a supporting method for traditional forest inventory and, therefore, the utilization of remote sensing techniques has been subject of intensive investigations during the past few years. Satellite digital images, e.g. Landsat TM, have even been applied with success for operational large-scale applications, such as national forest inventory of Finland [1] . However, the Landsat TM-based estimates are rather inaccurate and there is a problem of getting cloud-free images in northern latitudes suggesting that the emphasis of development work should concentrate more on new radar-based methods. It has been shown that multi-temporal ERS-1/2 SAR PRI images do not provide accurate enough information for national forest inventory [2] . Recent advances in SAR interferometry, however, have shown an improved capability to monitor forest areas. Wegmüller et al. [3] demonstrated that the interferometric coherence, together with the backscatter intensity and the backscatter intensity change, has proved to be a useful tool for the classification of the land-surface classes. Hagberg et al. [4] suggested also that tree height and density of forests can be estimated using the interferometric phase information.

The main objective of the on-going Tandem AO project (AOT.SF301) is to evaluate the feasibility and usefulness of ERS-1/2 SAR Tandem interferometry for estimating forest resources, especially for national forest inventory. Special emphasis is in the evaluation of accuracy and cost-benefit analysis of interferometric SAR techniques compared to the present methods. This paper presents the first preliminary results from interferometric coherence images concentrating mainly on the seasonal effects on interferometric coherence.

2. SAR INTERFEROMETRY

SAR interferometry was first introduced by Graham in 1974 [5] . Previously, only the backscattered radar power was used and the information contained in the *phase* of SAR images was discarded. A SAR interferometer is formed by relating the signals from two spatially separated radar antennas. In repeat-pass satellite interferometry the SAR interferometer is formed by relating two complex SAR-images of the target area taken at separate times from a nearly exactly repeating orbit. The physical separation of the antennas at the time of the imaging is called the *interferometric baseline*. If the baseline exceeds a critical length (~ 1300 m for ERS-1/2) the complex images become totally uncorrelated and interferometry is no longer possible. In repeat-pass interferometry also the *temporal separation* between successive radar takes affects the amount of correlation in the interferogram. Depending on land surface type the images generally become uncorrelated when the temporal separation is long enough.

A SAR interferogram is formed by cross-correlating two complex SAR images taken with slightly differing viewing angles, and multiplying one image with the complex conjugate of the other. The two images must be co-registered to sub-pixel accuracy. *Interferometric phase*, or the phase difference between the two images, is related to the difference in the path lengths from the two antenna positions to the ground thus permitting generation of digital elevation models (DEMs) [5] .

3. COHERENCE

The correlation coefficient or *coherence* between two complex SAR images Z_1 and Z_2 is defined as the magnitude of the complex correlation [6] :

$$\gamma = \frac{E\left[Z_1 Z_2^*\right]}{\sqrt{E\left[|Z_1|^2\right]E\left[|Z_2|^2\right]}} \tag{1}$$

In equation (1), the expectation value operator *E* is in practice approximated with a sampled average over *n* samples. Sampled coherence over statistically uniform areas may be computed using:

$$|\gamma| = \frac{\left|\sum_n Z_1 Z_2^*\right|}{\sqrt{\sum_n |Z_1|^2 \sum_n |Z_2|^2}} \tag{2}$$

The interferometric phase in SAR interferograms contains information about the topography of the target area. Unless the topography is flat, this topography-induced phase must be removed. The topography-compensated coherence estimator is:

$$|\gamma| = \frac{\left|\sum_n Z_1 Z_2^* e^{-i\phi}\right|}{\sqrt{\sum_n |Z_1|^2 \sum_n |Z_2|^2}} \quad (3)$$

where f is the topography-induced phase. The accuracy of the estimator (3) depends on the accuracy of the topography-compensation. Best results can be achieved by using a high-resolution DEM, if available [7] .

The statistical confidence of the sampled coherence depends on the number of *independent* samples *n* that are used in the coherence estimation. Assuming flat or compensated topography, the standard deviation of the estimated coherence is given by [4] :

$$\sigma_\gamma = \frac{1-|\gamma|^2}{\sqrt{2n}} \quad (4)$$

From equation (4) it can be seen that a large number of independent samples must be included in order to achieve an acceptable precision at low coherence areas. It is also known that the coherence estimators (2) and (3) are biased towards higher values especially at low coherence areas when *n* is small. As always, there is a tradeoff between estimation precision and achievable spatial resolution.

The correlation coefficient or coherence is a quantitative measure that is directly related to the amount of noise present in the SAR interferogram. The values of coherence range between 0 (*incoherence*) and 1 (*perfect coherence*). As long as there is some degree of coherence between the two images, interference phenomena such as fringes may be observed in the interferogram. When coherence is high, the amount of noise superimposed on the interferometric fringes is small and the observed speckle patterns in the interfering SAR images are similar [8] .

Several different effects contribute to the decorrelation properties of various land surfaces [4,8] . In repeat-pass INSAR surveys with short baselines the temporal decorrelation caused by changes in the target area between the two radar passes and volume scattering in the vegetation layer are the most important causes of decorrelation. The coherence is generally low over forested areas and high over open fields which makes discrimination between forest and non-forest possible [3,4] .

4. THE TEST SITE

Our three test sites are located in southern Finland, Teijo (130 km west of Helsinki), Porvoo (30 km east of Helsinki) and Kalkkinen (130 km north of Helsinki) representing a variety of different forest types and covering about 10000 hectares of forest land. Kalkkinen is the main area of activities with a large multi-source, multi-temporal remote sensing data set. From the 5000-hectare test area in Kalkkinen the following information is collected: field inventory data (ground truth), remote sensing data, and GIS information.

Field inventory data were collected by Uusimaa-Häme Forestry Center in summer 1996. About 100 parameters describing stand characteristics such as stem volume per hectare, basal area per hectare, mean tree height and tree species are measured for each stand (homogeneous forest areas of about one hectare in size). In order to evaluate the accuracy of field inventory, 40 stands were extremely carefully checked by sample plot measurements. The average value of the stem volume per hectare of the Kalkkinen test site is 141 m^3/ha. GIS information includes a digital elevation model (DEM), digital land-use map and base map 1:20000. Air/soil/vegetation temperature and precipitation monitoring statistics in selected areas have been gathered.

In this paper the first coherence images from the Kalkkinen test site are investigated.

5. THE INTERFEROMETRIC DATA SET

According to [3] the best results with SAR interferometry in forest mapping are expected using image pairs which have a short baseline and a short temporal separation between image acquisitions. Therefore, we used ERS-1/2 Tandem single look complex (SLC) image pairs which have a temporal separation of 24 hours and which also meet the baseline requirement in high latitudes. The pixel dimension in ERS-1/2 SLC images is such that one pixel in range direction corresponds to four pixels in azimuth direction. The precise orbital information used in the project was received from D-PAF. The chosen interferometric image pairs of the Kalkkinen test site are listed in Table 1.

Pair no.	Acquisition dates	Normal baseline	Average scene coherence
1	17-18.7.1995	0 m	0.157
2	21-22.8.1995	72 m	0.233
3	30-31.10.1995	49 m	0.201
4	8-9.1.1996	78 m	0.547

Table 1. Interferometric pairs used in this study.

The average scene coherences were estimated using a window size of 9 x 36 pixels. The reason for the low average coherences is that the test scene in Kalkkinen is basically a mosaic of boreal forests and lakes. Pair number 4 differs from the other pairs in that it was acquired during winter time when the ground was frozen and snow-covered and the lakes were partially covered with ice.

6. INTERFEROMETRIC PROCESSING

The coherence images used in this study were produced from ERS-1/2 Tandem SLC images using the ISAR-Interferogram Generator software developed in Politecnico di Milano. The ISAR-software is distributed free of charge to the members of the ESA Fringe Group. ISAR software co-registers the two SLC images to the required sub-pixel accuracy, substracts the flat terrain phase term from the interferogram and performs common-band filtering in order to reduce baseline decorrelation. If needed, ISAR software also estimates the local directional slopes (the instantaneous frequency of the interferometric phase). In coherence estimation the ISAR software uses a Gaussian estimator window in order to reduce the deleterious effect of bright reflectors.

As mentioned earlier, there is always a trade-off between estimation precision and spatial resolution when the size of the coherence estimator window is decided. Small estimator window sizes produce high resolution estimates with large error margins. Since the forest stand size in the Kalkkinen test area is small (ca. 1 ha) and in the preliminary phase of this project only visual interpretation of coherence images was done, a rather small coherence estimator window size of 5 x 20 pixels (~50 physical looks) was chosen. The dimensions of the estimator window reflect the difference in pixel size in range and azimuth directions.

At the time of writing this report, the DEM of the Kalkkinen test site was not available to us so we approximated the terrain with a plane. The effects of this approximation on the estimated coherence should be small or negligible because the terrain height differences in the test area were small (<30m) and the baselines were short.

In post-processing, the coherence images were averaged in the azimuth direction and resampled so that the resulting pixel size was equal in both range- and azimuth directions.

7. COHERENCE IMAGES

Four coherence images were computed from the interferometric data set, one from each Tandem image pair. Additionally, a normalized sum of all coherence images (1 to 4) was computed. Here, normalization refers to the procedure of dividing the pixel values in each of the coherence images with the average scene coherence before summation. All the images were contrast stretched to two standard deviations in the data and visually compared with a SPOT Pan image. The following observations were made:

Coherence image 1 (Figure 1a):

The average scene coherence of 0.157 was very low, probably due to wind that had disturbed the scatterers in the vegetation layer. Highest coherences were observed over some fields and forest clear-cuts. Due to the low overall coherence boreal forest was not well discriminated from open water.

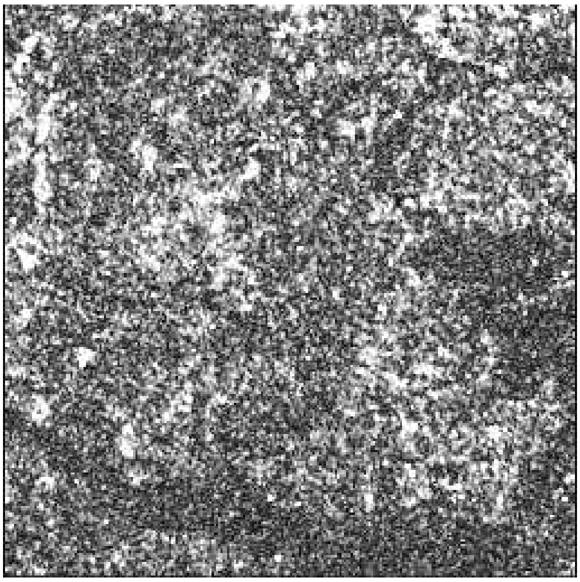

Figure 1a: Coherence of image pair 1.

Coherence image 2 (Figure 1b):

Coherence image 2 is quite similar to the coherence image 1. Due to more favourable conditions the average scene coherence was higher. The highest observed coherences were in the same range as in coherence image 1. Some fields had larger coherence than in image 1, suggesting farming activity that had taken place after acquisition of image pair 1. Dense forest was visually discriminated from sparse forest.

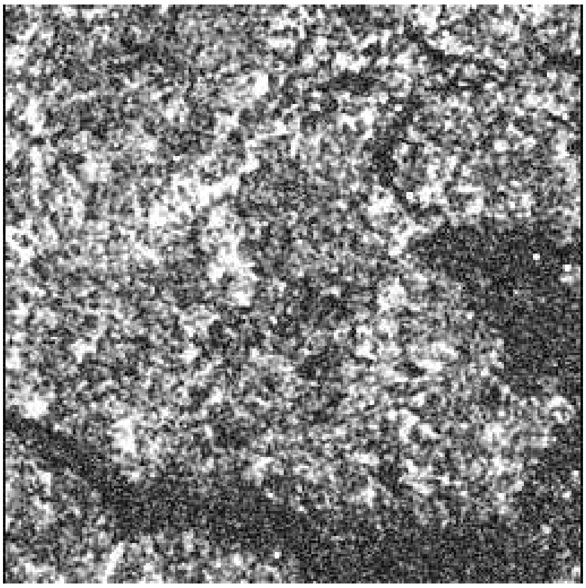

Figure 1b: Coherence of image pair 2.

Coherence image 3 (Figure 1c):

Due to windy conditions the coherence was low over most of the image. Coherences over some fields were significantly higher than over the rest of the image. It is reasonable to assume that in these areas the ground was almost completely vegetation-free due to recent farming activity.

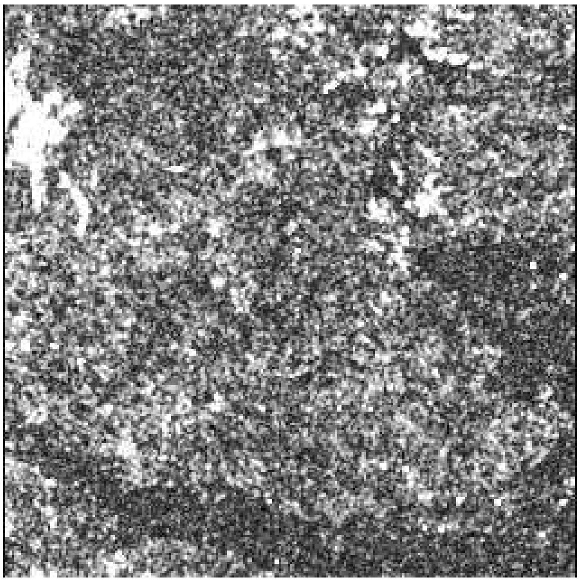

Figure 1c: Coherence of image pair 3.

Coherence image 4 (Figure 1d):

This winter-time coherence image had by far the highest average coherence in our data set. This is because the ground was frozen and covered with snow, the lakes were partially covered with ice and the dedicuous trees had lost their leaves. Generally the coherence over forest was at least two times higher compared with the other coherence images. Coherence over fields and clear-cuts was also higher than in the other images, but to a lesser degree, thus reducing the contrast between them and the forest stands. Dense forest was visually discriminated from sparse forest. The generally high coherence reduced both the coherence estimation error and bias.

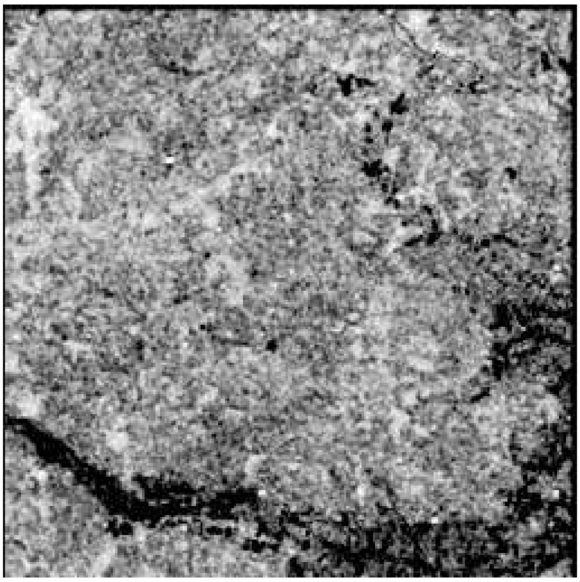

Figure 1d: Coherence of image pair 4.

Normalized coherence-sum image (Figure 1e):

The normalized coherence-sum image was better suited for visual land-use classification than any of the coherence images alone. The image was in a good agreement with the SPOT Pan image and as expected, the coherence diminished with increasing biomass. The summing of a larger number of coherence images with high average coherences should improve the correlation between estimated coherence and biomass.

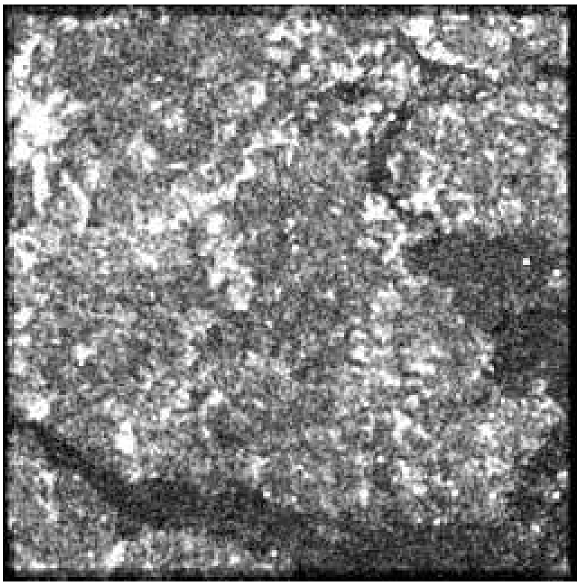

Figure 1e: Normalized coherence-sum of image pairs 1-4.

8. CONCLUSIONS

The potential of ERS-1/2 Tandem interferometric coherence images for forest classification was studied. The following conclusions were made based on visual interpretation of coherence imagery:

- The coherence over boreal forests during winter is considerably higher than during other seasons. Therefore, ERS Tandem interferograms acquired during winter seem to be ideal for DEM generation over boreal forests.
- Forest may be discriminated from non-forest and higher average scene coherences imply better discrimination between forest types.
- Summation of several normalized coherence images produces images that are better suited for visual land-use and forest classification than a single coherence image.
- SAR interferometric coherence images provide complementary information to the SAR intensity images. This may observed by comparing the coherence images and the ERS-2 intensity image acquired January 9, 1996 (Figure 2).

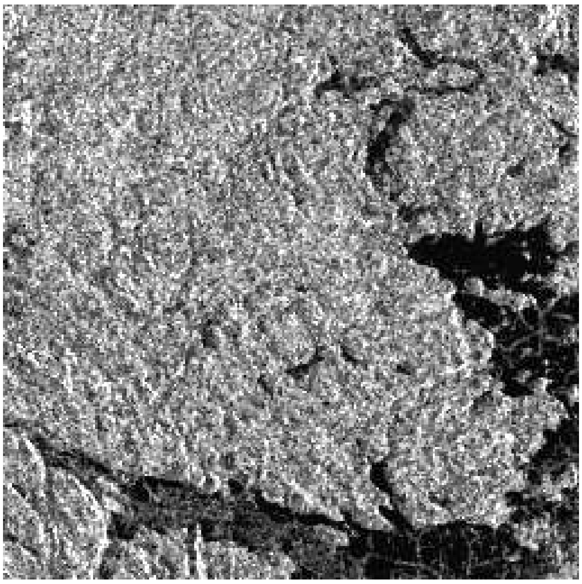

Figure 2: ERS-2 intensity image (Jan. 9, 1996).

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