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ERS and ENVISAT SAR coherence properties of boreal forests

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ABSTRACT: ERS SAR and ENVISAT ASAR C-band long-term coherence is likely to be affected by strong decorrelation in forested areas. Nonetheless, under winter conditions it is possible that open areas and, to a lesser extent, sparse forests retain some coherence. For this purpose we formed 35 and 70-days either ERS SAR or ENVISAT ASAR winter coherence images for several test sites in Finland and Siberia. Because of temporal decorrelation, forests appear totally decorrelated whereas open areas present high coherence as long as the environmental conditions are stable with temperatures below the freezing point. Open areas with weak topography can still exhibit high coherence for perpendicular baselines up to 1 km. Compared to 1-day coherence the dependency of coherence upon stem volume decreased. These results suggest that forest/non-forest mapping using ERS and ASAR repeat-pass winter coherence is feasible.

1 INTRODUCTION

The repeat-pass ERS SAR interferometric (InSAR) coherence can provide precise information on land cover and be used to retrieve biophysical properties of vegetated areas. Several studies have highlighted that the contrast between open areas and densely vegetated areas is higher when the repeat-pass interval is short because of weaker temporal decorrelation (Beaudoin *et al.* 1996, Floury *et al.* 1996, Smith *et al.* 1996). For this reason in forestry applications the 1-day ERS-1/2 coherence has been preferred. Long-term coherence, corresponding to coherence from image pairs with temporal baseline of at least a nominal cycle of 35 days, has instead been used only for mapping land covers that do not suffer from temporal decorrelation over long periods (e.g. urban areas or arid land surfaces) (Strozzi & Wegmüller 1998, Wegmüller *et al.* 2000, Weydahl 2001). Currently only long-term coherence (from ERS-2 SAR and ENVISAT ASAR) can be obtained.

In boreal forests the most favorable environmental conditions for forestry applications using 1-day ERS-1/2 coherence are stable frozen conditions between acquisitions with a dry snow cover since the forest/non-forest contrast is high and consistent in time (Santoro *et al.* 2002, Pulliainen *et al.* 2003). In the boreal zone such conditions are likely to span a long period of time so that it is in theory possible to obtain long-term coherence images with a good contrast between open areas and dense vegetation.

In this study we report on investigations focused on ERS SAR and ENVISAT ASAR long-term coherence acquired during winter from several forested areas in Finland and Siberia. Previous investigations of 1-day and long-term coherence for these areas have been reported in (Strozzi *et al.* 2000, Engdahl *et al.* 2003, Eriksson *et al.* 2003). We first describe the test areas, the satellite datasets and the weather data for the period of acquisition. Then we discuss on the properties of the coherence images and relate coherence values to land cover classes. Finally we give an outlook on possible applications and future investigations.

2 TEST AREAS

The test area in Finland, Tuusula, is located 20 km northeast of Helsinki and covers 16×16 km^2. The area is mainly covered with forests and agricultural areas, which represent 80% of the total area. In winter the fields are bare, thus resembling open areas. Two small towns and two lakes are the other significant land covers. Small bogs and mires are also present. The forests are typical of the southern boreal forest zone, mostly including coniferous species (Scots pine and Norwegian spruce) and a few birch stands. Forests are under continuous management. In Siberia two test areas (Bolshe-Murtinsky and Shestakovsky-Primorsky) are located in the southern boreal forest zone with predominance of coniferous forest cover. A third test area, Tura, is instead located at the transition zone between taiga and tundra. This test site is covered with sparse taiga forest, being out of the productive forest belt. The areas are predominantly covered with natural forest, which are at different levels of growth. Clear cuts and fire scars are also present. Compared to Tuusula the test areas are much larger (order of thousand of km^2) and topography is more mixed.

3 REFERENCE DATA

3.1 *Ground data and weather statistics*

For Tuusula we had a land cover map at 25 m pixel size and forest inventory data for 210 forest stands available (Hallikainen *et al.* 1997). The forest inventory data consisted of a digital forest stand mask and measurements of several biophysical parameters, including stem volume. For the Siberian test areas we had available an extensive GIS database consisting of several thousand polygons for each of which the land cover class was specified and forest parameters values were provided, if measured. The polygons were much larger than at Tuusula. For Bolshe-Murtinsky and Shestakovsky-Primorsky the on-ground measurements originated from regular surveys; the last update took place in 1996–1998. Because of its remote location, for Tura we had only land class information available, which in addition was last updated in 1980. From the GIS, digital forest masks at pixel size of 25 m for Bolshe-Murtinsky and 100 m for Shestakovsky-Primorsky and Tura were generated. Daily weather data acquired at several weather stations nearby the test areas were available in form of temperature (max-min values or 3-hours acquisition), snow depth, precipitation and weather conditions.

3.2 *SAR imagery and processing*

From six 1-day ERS-1/2 acquisitions between January and March 1996 over Tuusula we could form all possible interferometric pairs, thus resulting in eight 35-days pairs and four 70-days pairs. Table 1 reports dates, temporal (Δt) and perpendicular baseline (B_n). Throughout the first repeat-pass cycle the temperature was below the freezing point and the snow depth remained almost constant. During the second repeat-pass cycle the temperature raised and oscillated around 0° C with the day-night cycle for about two weeks. On the two acquisition dates in March the temperature was below 0° C. Snow depth increased by about 20 cm. In Siberia coherence could be formed only from ENVISAT ASAR Image Mode images, which were acquired during winter 2002–2003 over some areas and then again during winter 2003-2004 over the whole region (see Table 2). Compared to Tuusula, the baseline was much longer since ENVISAT has not been conceived primarily for SAR interferometry. Weather statistics reported temperatures below 0° C and increase of snow depth (5-20 cm) throughout the repeat-pass interval for most image pairs.

InSAR processing and geocoding was done using the Gamma ISP, DIFF and LAT packages (Wegmüller *et al.* 1998). The coherence was estimated from SLC data using an adaptive window size (3 to 9 pixels squared) and taking into account the phase slope and

Table 1. Interferometric pairs over Tuusula. ''Fr'' and ''Unfr'' stand respectively for Frozen and Unfrozen conditions throughout the acquisition interval. ''Fr/Unfr'' means that temperature oscillated around the freezing point during this interval.

Pair type	Date 1	Date 2	Δt (days)	B_n (m)	Weather flag
Tandem	1996-01-08	1996-01-09	1	– 29	Fr
	1996-02-12	1996-02-13	1	85	Fr
	1996-03-18	1996-03-19	1	81	Fr
1 repeat-pass cycle	1996-01-08	1996-02-12	35	132	Fr
	1996-01-08	1996-02-13	36	220	Fr
	1996-01-09	1996-02-12	34	– 160	Fr
	1996-01-09	1996-02-13	35	– 248	Fr
	1996-02-12	1996-03-18	35	– 14	Fr/Unfr
	1996-02-12	1996-03-19	36	68	Fr/Unfr
	1996-02-13	1996-03-18	34	– 102	Fr/Unfr
	1996-02-13	1996-03-19	35	– 20	Fr/Unfr
2 repeat-pass cycles	1996-01-08	1996-03-18	70	118	Fr/Unfr
	1996-01-08	1996-03-19	71	200	Fr/Unfr
	1996-01-09	1996-03-18	69	– 146	Fr/Unfr
	1996-01-09	1996-03-19	70	228	Fr/Unfr

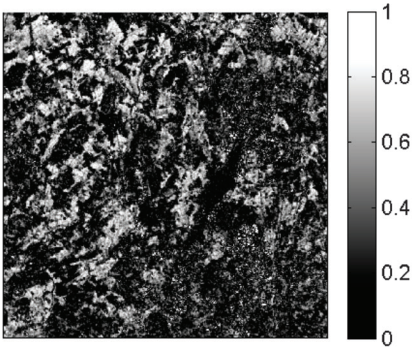
Table 2. Interferometric pairs over the test areas in Siberia. For the meaning of "Fr", "Unfr" and "Fr/Unfr" see Table 1. "Fr + Unfr_1" resp. "2" indicate frozen conditions except on the first (resp. second) acquisition when temperature was above 0° C.

Test area	Date 1	Date 2	Δt (days)	B_n (m)	Weather flag
Tura	2003-03-07	2003-04-11	35	409	Fr/Unfr
	2003-12-10	2004-01-14	35	765	Fr
	2003-12-29	2004-03-08	70	– 331	Fr
	2004-01-14	2004-02-18	35	– 1002	Fr
	2004-01-17	2004-02-21	35	– 735	Fr
Bolshe-Murtinsky	2003-12-22	2004-01-26	35	640	Fr + Unfr_1
	2003-01-23	2004-02-27	35	– 593	Fr/Unfr
Shestakovsky-Primorsky	2003-03-29	2003-05-03	35	– 156	Fr + Unfr_2
	2004-01-21	2004-02-25	35	– 488	Fr
	2003-02-06	2004-03-12	35	900	Fr/Unfr

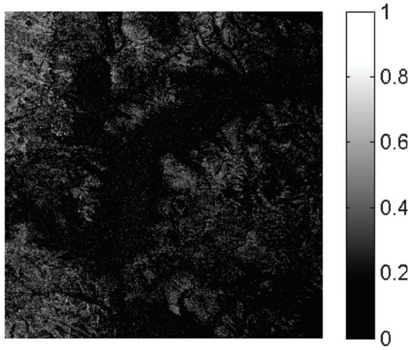
the texture of the averaged backscattering coefficient. The final pixel size of the geocoded images was adapted to the one of the forest masks. For each stand mean values of coherence and backscatter were computed. To reduce border effects, edge erosion of the forest masks and the land cover map was applied.

4 RESULTS

Figure 1 illustrates two examples of 35-days coherence images over Tuusula and Shestakovsky-Primorsky for stable frozen conditions. In general, the coherence of forested areas was always at the bias level (0.1–0.2) whereas over open areas the coherence

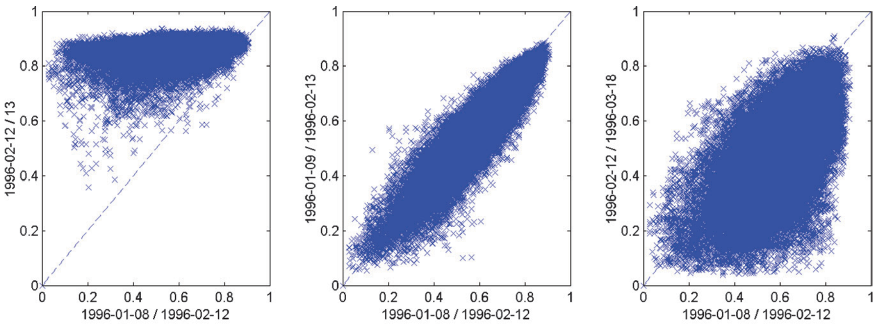


(a)



(b)

Figure 1. Coherence images acquired over Tuusula on 1996-01-08/1996-02-12 (a, 16 × 16 km^2) and Shestakovsky-Primorsky on 2004-01-21/2004-02-25 (b, 82 × 70 km^2). High coherence areas correspond to open areas, low coherence areas correspond to forests and water surfaces (lakes and rivers).



(a) (b) (c)

Figure 2. Scatterplots of 1- v. 35-days coherence (left), 35-days coherence for same environmental conditions (middle) and different environmental conditions (right) for open areas at Tuusula.

was retained (0.6–0.9) despite of the long-term interval. Compared to Tuusula, where the perpendicular baseline did not exceed 250 m, the longer baseline of the Shestakovsky-Primorsky pair could explain the lower coherence of the open areas (see Table 2). Nonetheless, even for the image pair with perpendicular baseline of -1002 m we could observe coherence over open areas of the order of 0.4-0.6 as long as the areas were without topographic features.

The effect of the temporal interval between acquisitions is illustrated in Figure 2 where different coherence values for open areas at Tuusula are compared. Figure 2a shows the effect of the decrease of coherence when going from 1- to 35-days interval between acquisitions. Despite the conditions between acquisitions were in both cases stable frozen, the coherence of the fields was in most areas significantly lower after 35-days. The spread of the co-plotted coherence should be due to heterogeneous variations of the snow conditions throughout the 35-days interval. The largest differences (top left area) appeared in areas where probably farming activities took place. The 35-days image pairs acquired under the same environmental conditions were instead characterized by high consistency, as shown in Figure 2b where two pairs acquired during the first repeat-pass cycle have been compared. Finally, when the environmental conditions associated with the two image pairs were different, the coherence showed some variability as illustrated in Figure 2c where two 35-days coherence datasets from each of the repeat-pass cycles have been co-plotted. The spread should be related to heterogeneous variations of the properties of the snow cover; the largest differences (bottom right area) were probably caused by farming activities during the second repeat-pass cycle.

Figure 3 illustrates the separability of forest land cover classes. Long-term coherence separates forest from non-forest, whereas the backscatter and even less the backscatter change do not contribute with significant information. This suggested that classification of forest/non-forest areas can be achieved with a simple threshold algorithm. Figure 4a shows the result of thresholding the mean of all coherence and all backscatter images acquired during the first repeat-pass cycle. The agreement between the classified map and the reference land cover map is high for what concerns the identification of forests

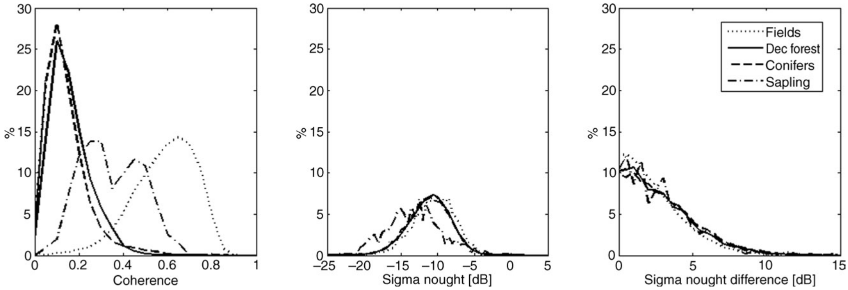
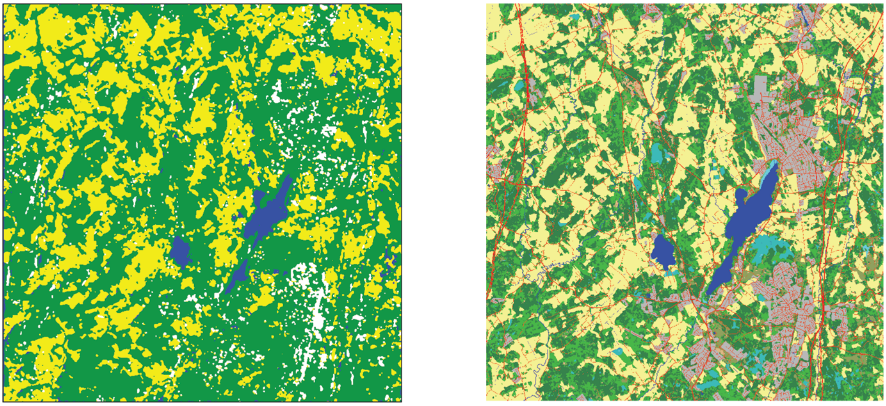


Figure 3. Histograms of coherence, backscatter and backscatter change for the 1996-01-08/ 1996-02-12 image pair acquired over Tuusula.

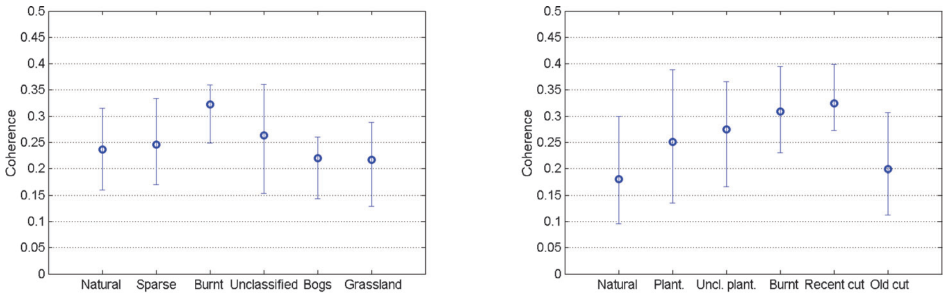


(a) (b)

Figure 4. (a) Long-term InSAR land cover map (4 classes: open areas in yellow, forests in green, water surfaces in blue and urban areas in white), (b) reference land cover map (10 classes).

and open areas. Misclassification of urban areas is due to the fact that these are typically characterized by few buildings and high percentage of urban vegetation.

Figure 5 illustrates the coherence span of the main land classes for two image pairs characterized by stable frozen environmental conditions. At Tura burnt areas showed higher coherence than other land classes. Taking into account that the reference data is rather old compared to the satellite data, a certain margin of error has to be considered. At Shestakovsky-Primorsky coherence increased when going from vegetated to non-vegetated areas. The difference between recent and old clear cuts is related to the date of the last inventory. Old cuts took place before the last inventory (1996–1998) so that these stands were covered by young vegetation in 2004. Recent cut refers instead to stands to be harvested after the inventory, i.e. a couple of years before ASAR image acquisition.



(a) (b)

Figure 5. Coherence as a function of land class at Tura (a, 2003-12-29/2004-03-08) and Shestakovsky-Primorsky (b, 2004-01-21/2004-02-25). Circles represent mean values, bars the 10th– 90th percentile interval.

For this reason recent cuts were likely to resemble open areas without significant vegetation cover.

5 DISCUSSION AND CONCLUSIONS

In this study we have analyzed the signatures of C-band repeat-pass ERS SAR and ENVISAT ASAR long-term coherence of forest land cover classes. Multi-temporal and multi-baseline 1-day, 35-days and 70-days winter coherence were formed for several test areas in Finland and Siberia. When the frozen environmental conditions keep stable throughout the acquisition period, coherence can be high over open areas whereas forests appear completely decorrelated. The effect of the baseline on coherence of open areas is low as long as the open areas are rather flat. Burnt areas and recent clear cuts can be distinguished from forests, retrieval of forest stem volume instead does not seem to be feasible. The results suggest that long-term ERS SAR and ENVISAT ASAR winter coherence can be used for forest/non-forest mapping and detecting forest cover changes. Image pairs with relatively short baselines should be preferred. Further work shall focus on understanding in a more quantitative way the coherence of open areas. The properties of long-term coherence of snow cover should be analyzed as this is prejudicial for the applications devised in this paper.

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REFERENCES

Beaudoin, A., Castel, T. & Rabaute, T. 1996. Forest monitoring over hilly terrain using ERS INSAR data, *Proc. 'Fringe 96'*. ESA Publications Division, Noordwijk, The Netherlands: 105–115.

Engdahl, M., Pulliainen, J. & Hallikainen, M. 2003. Land-cover classification using multitemporal ERS-1/2 InSAR data, *IEEE Transactions on Geoscience and Remote Sensing* 41 (7, part 1) 1620–1628.

Eriksson, L., Le Toan, T., Wiesmann, A., Grippa, M., Wegmüller, U. & Schmullius, C. 2003. SAR repeat-pass coherence in winter for boreal forest applications. A first comparison between ASAR and JERS-1 SAR, *Proc. 'Fringe 03'*. ESA Publications Division, Noordwijk, The Netherlands: CD-ROM.

Floury, N., Le Toan, T., Souyris, J.-C., Singh, K., Stussi, N., Hsu, C.C. & Kong, J.A. 1996. Interferometry for forest studies, *Proc. 'Fringe 96'*. ESA Publications Division, Noordwijk, The Netherlands: 57–70.

Hallikainen, M., Hyyppä, J., Koskinen, J., Roschier, M. & Ahola, P. 1997. EUFORA Campaign plan, Version 2. Laboratory of Space Technology, Helsinki University of Technology, Helsinki, Finland.

Pulliainen, J., Engdahl, M. & Hallikainen, M. 2003. Feasibility of multi-temporal interferometric SAR data for stand-level estimation of boreal forest stem volume, *Remote Sensing of Environment* 85 397–409.

Santoro, M., Askne, J., Smith, G. & Fransson, J.E.S. 2002. Stem Volume Retrieval in Boreal Forests with ERS-1/2 Interferometry, *Remote Sensing of Environment* 81 (1) 19–35.

Smith, G., Dammert, P.B.G. & Askne, J. 1996. Decorrelation mechanisms in C-Band SAR interferometry over boreal forest, *Proc. SPIE 2958*. SPIE Publications, Bellingham, WA: 300–310.

Strozzi, T. & Wegmüller, U. 1998. Delimitation of urban areas with SAR interferometry, *Proc. IGARSS'98*. IEEE Publications, Piscataway, NJ: 1632–1634.

Strozzi, T., Dammert, P.B.G., Wegmüller, U., Martinez, J.-M., Askne, J.I.A., Beaudoin, A. & Hallikainen, M.T. 2000. Landuse mapping with ERS SAR interferometry, *IEEE Transactions on Geoscience and Remote Sensing* 38 (2) 766–775.

Wegmüller, U., Werner, C. & Strozzi, T. 1998. SAR interferometric and differential interferometric processing, *Proc. IGARSS'98*. IEEE Publications, Piscataway, NJ: 1106–1108.

Wegmüller, U., Strozzi, T., Farr, T. & Werner, C.L. 2000. Arid land surface characterization with repeat-pass SAR interferometry, *IEEE Transactions on Geoscience and Remote Sensing* 38 (2) 776–781.

Weydahl, D.J. 2001. Analysis of ERS SAR coherence images acquired over vegetated areas and urban features, *International Journal of Remote Sensing* 22 (14) 2811–2830.