Algorithm of Interferometric Coherence Estimation for Synthetic Aperture Radar Image Pair

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Abstract. Interferometric coherence is an important indicator of reliability for interferograms obtained by interferometric synthetic aperture radar (Interferometric SAR, InSAR). Areas with low coherence values are unsuitable for interferometric data processing. Also, it may be used as a classification parameter for various coverage types. Coherence magnitude can be calculated as an absolute value of the correlation coefficient between two complex SAR images with averaging in a local window. The problem in coherence estimation is in its dependence on phase slope caused by relief topography (topographic phase). A method for suppression of the topographic phase influence is proposed, based on the spatial phase derivation.
Keywords: Synthetic aperture radar images, InSAR systems, Coherence estimation

1 Introduction

Interferometric data processing for extraction of information about the Earth terrain and its changes becomes one of the general guidelines in the development of contemporary space-based radar systems together with the implementation modes of ultra-high spatial resolution (1-3 meters) and full–polarimetric processing. The method of space-based radar interferometry implies a joint processing of the phase fields obtained by simultaneous scattering of the terrain with two antennas or by non-simultaneous scattering with one antenna moved by two different parallel orbits [1, 4]. This method combines high accuracy of the phase measurements with high resolution of the synthetic aperture radars (SAR) technology. Technology of the differential SAR interferometry (InSAR) makes possible to get maps of the elevation changes between the radar passages. The stages of the interferometric processing are implemented in specialized software systems for the remote sensing data processing such as the SARscape, IMAGINE Radar Mapping, Photomod Radar, RadarTools. So we can talk about Information technology (IT) of the digital elevation models (DEM) generation by remote sensing data.

However, for practical application of these technologies, one has to overcome a number of significant problems. Two general problems of interferometry are the temporal and spatial decorrelation of the received data and the problem of phase unwrapping, *i.e.* a recovery of the absolute phase information from the relative phase, which is wrapped into $[-\pi, \pi]$-interval. Another important field of investigation in radar interferometry is selection of the most efficient processing algorithms and obtaining the experimental estimates of the generated DEM accuracy. This work is devoted to the first of the mentioned problems, *i.e.* to the data decorrelation (summary temporal and spatial) and its estimation.

2 Interferometric coherence

Interferometric coherence is an important indicator of suitability of the data scene obtained by a radar remote sensing system for the further processing and solving the final problem, *i.e.* generation of digital elevation model or terrain changes map. The coherence factor is calculated as the absolute value of the correlation coefficient between samples of two complex radar images (single-look data complex, SLC) got in the local windows

$$\hat{\gamma_0} = |\hat{\dot{\rho}_0}| = \frac{\Sigma \dot{z}_1(m,n) \cdot \bar{z}_2(m,n)}{\sqrt{\Sigma |\dot{z}_1(m,n)|^2 \cdot |\bar{z}_2(m,n)|^2}}, \tag{1}$$

where $z_{1(2)}(m,n)$ is the SLC samples ($\bar{z}_{1(2)}(m,n)$ are complex-conjugate samples) [2–5], $\hat{\gamma_0}$ takes values in interval $[0,1]$, near-zero values correspond to areas of high or full decorrelation, which are not suitable for interferometric data processing. The values higher than 0.5 mean good data correlation.

However, this approach entails some problems because, in fact, a random variable is estimated here, but not a random process. So, any phase gradients caused by both natural topography variability and by point-of-view geometry (remote sensing radar systems have a side-scattering configuration) lead to the degradation of the estimate (1). Its value depends on the slope and tends towards the value $|\rho_{12}(N)|_{\rho=0}$, *i.e.* a bias of the estimate for independent Gaussian values of the correlation coefficient (N is the number of samples) [3], which in practice takes the value about 0.1–0.3. Thus, coherence loses its properties as measure of the quality of the interferogram, its value becomes dependent on relation between topographic and fluctuation components of the phase.

3 Differential phase coherence estimate

To eliminate the effect described above, the following modification of the coherence estimate can be offered taking into account influence of the topographic component. Modified coherence evaluates not the samples $z_1(m,n)$ and $z_2(m,n)$ of the SLC–image pair, but the following values:

$$\dot{w}_1(m,n) = \dot{z}_1(m,n) \cdot \bar{z}_1(m+1,n),\ \dot{w}_2(m,n) = \dot{z}_2(m,n) \cdot \bar{z}_2(m+1,n), \tag{2}$$

where the new phase values of the $w_1(m,n)$ and $w_1(m,n)$ will characterize the slope of the topographic phase in the direction of growth of the m^{th} picture coordinate. So, this operation performs the phase derivation along one coordinate.

Similarly, one can use the gradients along the n^{th} coordinate. Expression for the coherence estimation using values (2) looks as follows:

$$\hat{\gamma_1} = \sqrt{\frac{\Sigma \dot{w}_1(m,n) \cdot \bar{w}_2(m,n)}{\sqrt{\Sigma |\dot{w}_1(m,n)|^2 \cdot |\bar{w}_2(m,n)|^2}}}. \quad (3)$$

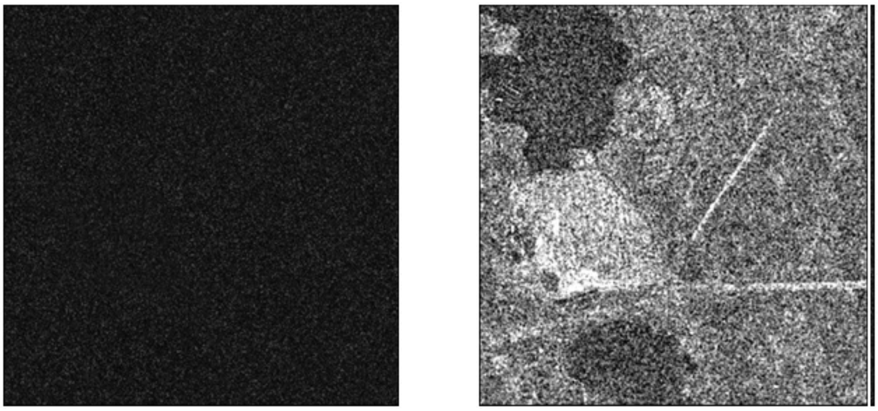
Although this estimate is non-Gaussian, it is wealthy, and it can be shown that it is insensitive to the linear phase trend.

4 Experimental results

Test now the work of the coherence estimation algorithms for RADARSAT–1 data (wavelength 56 mm). Figure 1 presents a fragment of the radar image of an area with surfaces of different reflectance including surfaces with volume scattering and the water surface, which has generally low coherence. Signal differential phase for the given fragment has a slope in the horizontal direction of the order of 0.3 radians per sample (due scattering geometry). The coherence maps of the fragment were constructed using conventional estimate $\hat{\gamma_0}$ and modified estimate $\hat{\gamma_1}$ with the sampling size 11×11 are presented in Figs. 2a, 2b.

Fig. 1. A RADARSAT-1 radar image scene

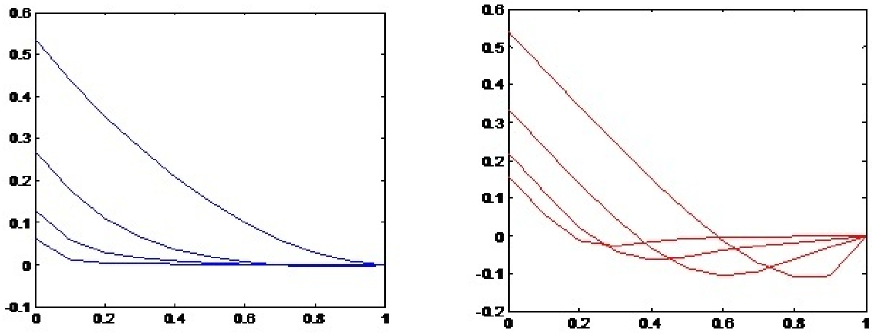
One can see that the first map is degraded since different surfaces give the same low coherence values regardless on the surface type. The map obtained



a) Traditional estimate $\hat{\gamma}_0$ b) Modified estimate $\hat{\gamma}_1$

Fig. 2. Coherence map calculated

using modified estimate (Fig. 2b) has a good sensitivity to the surface type. However, the estimate has a larger bias at low values than the $\hat{\gamma}_0$, and, so, it requires increasing the sample value towards to $\hat{\gamma}_0$ (Fig. 3a, 3b). A quantitative accuracy assessment for the scene is not available because of poor reference DEM for this territory.



a) Traditional estimate $\hat{\gamma}_0$ b) Modified estimate $\hat{\gamma}_1$

Fig. 3. Coherence estimates biases for different sample sizes (N=2, 5, 10, 25)

5 Conclusion

A modified method for estimation of spatial coherence of the interferometric radar images pairs is developed. The method consists in calculation of the correlation between pairs of complex multiplications of neighbour elements. The research is implemented on radar images RADARSAT–1. The result shows that the modification allows one to solve the problem of estimate degradation under the differential phase trend, which always takes place in side-scattering radar systems.

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