КАРТЫ И ГИС В СЕЛЬСКОМ ХОЗЯЙСТВЕ И ЗЕМЛЕПОЛЬЗОВАНИИ

MAPS AND GIS IN AGRICULTURE AND LAND USE

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SENTINEL-1 SAR INTERFEROMETRY FOR AGRICULTURE: DESCRIPTION OF AN EXPERIMENT IN ORYOL, RUSSIA

ABSTRACT

In this work we describe an experiment to be carried out in the basin of Suhaya Orlitsa river (Oryol region, central part of European Russia) to compare in-situ measurements of soil moisture with estimates obtained using Synthetic Aperture Radar (SAR) interferometry. The Sentinel-1 mission of the European Space Agency (ESA), acquiring C-band SAR images regularly over all Earth regions since 2014 with a mean revisiting time of 6 days, is used. In-situ measurements of soil moisture are planned in a time interval of 3 hours in coincidence of each Sentinel-1 passage, using a temporal sampling of 15 minutes. Test measurements are planned at the end of the month of April, when the soil accumulates water. The aim of the experiment is to demonstrate the feasibility of using Sentinel-1 images to densify the network of in-situ measurements of soil moisture on the territory of Russia. The application of SAR interferometry is investigated as it requires less in-situ measurements than methods based on the use of radar cross-section and the inversion of models of electromagnetic scattering from natural surfaces. Examples of

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interferometric coherence and phase images obtained by processing Sentinel-1 images acquired on 20th September 2019 and 2nd October 2019 over the study area are shown.

KEYWORDS: Synthetic Aperture Radar (SAR), SAR Interferometry (InSAR), soil moisture, Sentinel-1

INTRODUCTION

The measurement of soil moisture by traditional techniques is carried out at a few selected locations in agricultural field where samples are collected. So traditional techniques are significantly time consuming and require the involvement of a number of specialists. Current applications in agriculture need almost real-time measurements and a knowledge of the spatial distribution of soil moisture instead of point-like measurement at a few sites.

Since the beginning of remote sensing, Synthetic Aperture Radar (SAR) was used to provide a possible solution to the problem of accurate soil moisture maps in agriculture. A recent publication describes the advantages in agriculture of products based on SAR remote sensing [*Liu et al.,* 2019]. The first approaches were based on the study electromagnetic scattering from natural surfaces to disentangle the effects of surface roughness and soil moisture on the radar cross-section [*Tsang et al.,* 2001 (a; b)]. Many papers have published providing approximate solutions to the problem of electromagnetic scattering from natural surfaces [*Fung,* 1994; *Chen, Fung,* 1995] and studying the importance of scale factor of scattering from fractal surfaces [*Franceschetti et al.,* 1999; *Mattia, Le Toan,* 1999]. Examples of application of L and C-band SAR images in agriculture have been published in the last twenty years [*Mattia et al.,* 2003; *Zhou et al.,* 2017; *Ouellette et al.,* 2017; *Khabbazan et al.,* 2019]. Recently, an interesting paper on the estimated of soil moisture from the radar cross-section of C-band SAR images has been published [*Beale et al.,* 2019].

However, all the above methods based on the use radar cross-section require many in-situ measurements of both soil moisture, as well as knowledge of its roughness properties and vegetation cover, to invert the scattering model and estimate soil moisture.

Recently, SAR interferometry (InSAR) has been proposed as an alternative technique to get estimates of soil moisture [*Zwieback et al.,* 2015; 2017; *Pichierri et al.,* 2018]. The main problem of this approach is the need to separate the different contributions to the interferometric phase, mainly terrain displacement and propagation delay in atmosphere. A way to get rid off of the problem to disentangle the above contributions and estimate soil moisture, consisting in processing of a set of three interferograms obtained by a sequence of three coherent SAR images acquired along the same orbit at different times, has been proposed [*De Zan et al.,* 2014; 2015; 2018; *Gruber et al.,* 2016]. In both cases, the main advantage of approaches based on SAR interferometry with respect to those using radar cross section is the reduction of the need collecting many in-situ data to invert a scattering model.

The launch of the European Space Agency (ESA) Sentinel-1 mission and the huge amount of C-band SAR data acquired regularly over all Earth regions with a mean revisiting time of 6 days and the interest raised by InSAR methods led to the organization of measurement campaigns to validate InSAR estimates of soil moisture [*Conde et al.,* 2018 (a; b); 2019].

In this paper we present a few preliminary results of an experiment to compare Sentinel-1 InSAR products with in-situ measurements of soil moisture. The basin of Suhaya Orlitsa river (Oryol region, central part of European Russia) was selected. A few studies on soil runoff, soil pollutants migration and microrelief structures detection and mapping on the arable slopes were previously conducted in this study area using in-situ data collected on the arable slopes [*Panidi et al.,* 2016; *Trofimetz et al.,* 2019]. High resolution maps of soil moisture can be used as a marker of microrelief structures and as a parameter of soil runoff model. For this reason, the same test area is used to validate the InSAR estimates of soil moisture.

There are few studies conducted in Russia on the comparisons of satellite measurements of soil moisture with in-situ measurements due to the lack of synchronous in-situ measurements

of soil moisture for the territory of Russia [*Borodina et al.*, 2014]. A reason for this work is the need to demonstrate the application of Sentinel-1 data as a means to provide estimates of soil moisture over Russia, where the density of ground observation network has decreased dramatically since the late 1980's.

MATERIALS AND METHODS OF RESEARCHES

In this section we describe the study area and the plan for in-situ measurements of soil measurements. Furthermore, we provide a short introduction to SAR interferometry and its use to estimate soil moisture.

The first experimental soil moisture data have to be collected at two locations on the arable slope (fig. 1), which are the down part of thalweg of the plowed ravine (center point — 53°00'02.33"N 35°57'32,93"E), and the arable watershed surface (52°59'53.94"N 35°56'59.69"E). The catchment area value at the point #2 is 220000 m^2 approx., distance between the sampling locations is 660 m. Measurement of soil moisture is planned in every 15 minutes at the number of points within 1 m radius around the central points of measurement locations, so the number of measurements during 3-hour period (centered at the satellite measurement time) at each point will be 12. Measurements of soil moisture in the arable horizon (0–20 cm) of thalweg of the ravine on May of 2010 showed that the soil moisture was varied in the within 7–25 % (the field was plowed). In the sub-arable horizon (20–40 cm layer), moisture was varied within 8–33 %. These data suggest that the test measurements should be made at the end of April, when the soil accumulates water.

Fig. 1. Ground test area; markers show planned soil sampling locations: 1 — down part of thalweg, 2 — watershed surface; satellite image — May 16, 2003; image © — Maxar Technologies / Google Earth

SAR interferometry relies on the processing of two coherence SAR images of the same area acquired along the same orbit but at different acquisition times t_1 and t_2, named master and slave acquisition times, respectively. These two images are co-registered and used to compute the interferometric coherence γ_{12}

$$\gamma_{1,2} = \frac{\left|\left\langle S_1 \cdot conj(S_2)\right\rangle\right|}{\sqrt{\left\langle\left|S_1\right|^2\right\rangle \cdot \left\langle\left|S_2\right|^2\right\rangle}}, \quad (1)$$

and the interferometric phase $\Delta\varphi_{12}$

$$\Delta\varphi_{1,2} = \text{atan}\left\langle S_2 \cdot conj(S_1)\right\rangle \quad (2),$$

where <·> denotes the spatial average operator and S_1 and S_2 are the two coherent complex-values SAR images acquired at times t_1 and t_2, respectively [*Massonnet, Feigl*, 2018]. The main application of SAR interferometry has been the measurement of terrain displacements. The Line-of-Sight (LoS) displacement $D_{1,2}$ of a point P in the scene, occurred in the time interval [t_1, t_2] is related to the interferometric phase $\Delta\varphi_{1,2}$ by the relationship:

$$D_{1,2} = \frac{\lambda}{4\pi}\Delta\varphi_{1,2} \quad (3),$$

where λ is the radar wavelength. However, the interferometric phase $\Delta\varphi_{12}$ contains also contribution due to the temporal variations of propagation delay of SAR signal in the atmosphere and of soil moisture. In this work we will process coherent SAR images with a temporal baseline of six days to neglect the contribution of terrain displacements to the interferometric phase. Furthermore, the different spatial scales of phase variations due to propagation in the atmosphere and soil moisture are used to identify the phase contribution due to soil moisture at the scale of the field. A few natural scatterers, e.g. building or any other surface, not characterized by temporal changes of soil moisture are used to locally correct for phase contribution to due to propagation in the atmosphere.

RESULTS OF RESEARCH AND THEIR DISCUSSION

In this section we report the first results obtained by processing Sentinel-1 data over the study area. The aim is to start accumulating knowledge on the interferometric properties of the test area and the surrounding agricultural fields. An interferometric couple of Sentinel-1 images, acquired on 20th September 2019 and 2nd October 2019 was selected to consider a case of shortest temporal baseline of six days and avoiding the winter season to reduce the impact of possible decorrelation effects due to snow cover.

As first step, fig. 2 displays the coherence map and compares it with a ©Google Earth image to identify specific targets on the earth surface such as the Oryol city, the river and the agricultural fields. It worth noting the interferometric products, both coherence and interferogram, are displayed in SAR geometry using pixel. The validation of InSAR results with in-situ measurements will require the further step of geolocation of Sentinel-1 results. The test area where in-situ measurement will be collected is within the red rectangle reported on both the ©Google Earth image and Sentinel-1 coherence map. The inspection of the coherence map shows that a few fields with a high coherence ($\gamma > 0.8$) are present and could be of interest to install in-situ sensors to measure soil moisture. The selected test area within the red rectangle seem to include terrain patches with both high and low coherence differently from other agricultural fields characterized by a spatially homogeneous high interferometric coherence.

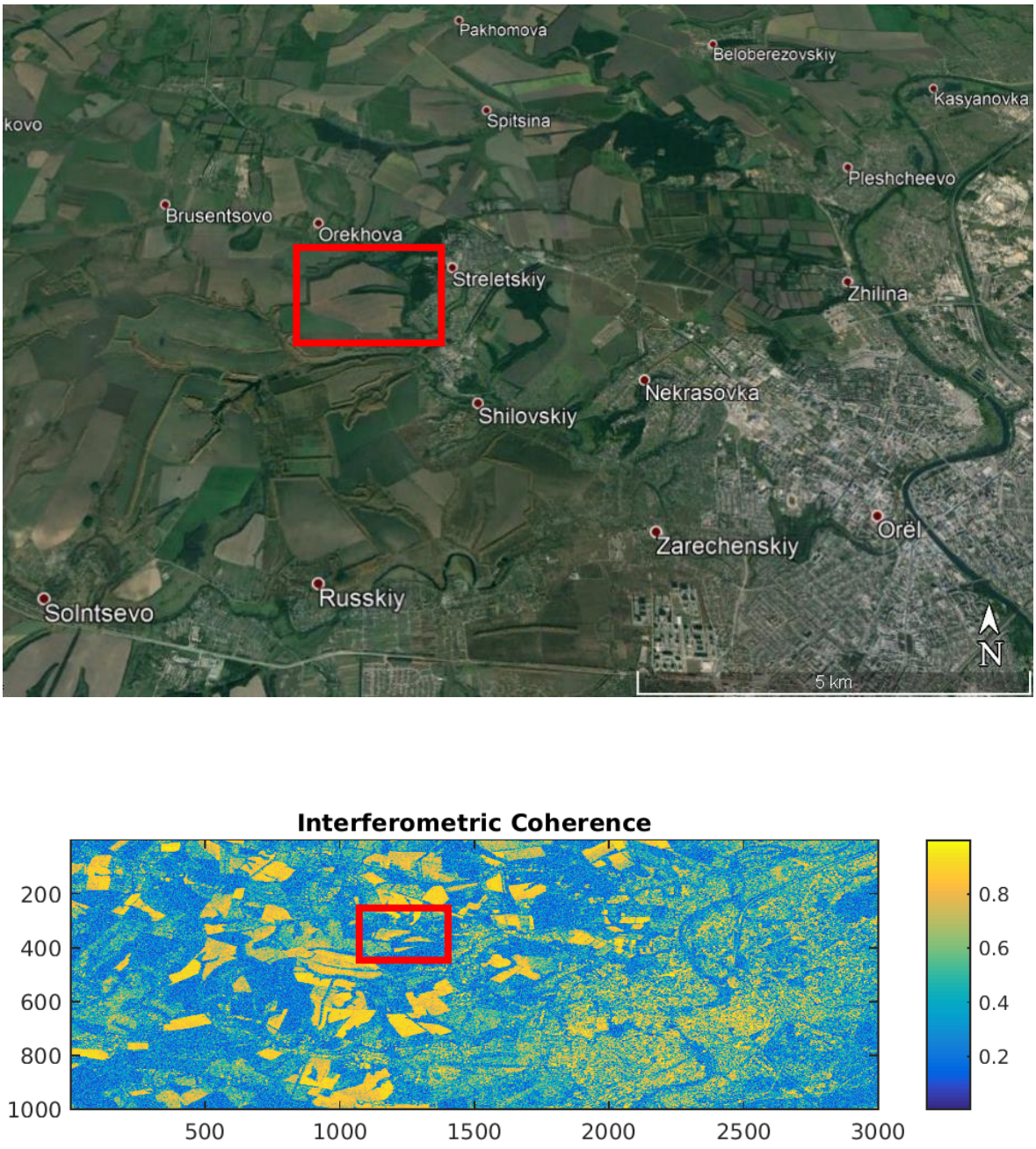

Fig. 2. (top) Google Earth image of the study area;
(bottom) corresponding Sentinel-1 coherence map in azimuth/range pixels. Sentinel-1 images were acquired on 20th September 2019 and 02 October 2019 along the descending orbit 65. The ground test area reported fig. 1 is shown within the red rectangle

As second step, fig. 3 shows in more detail around the test area both the coherence map of fig. 2 and the corresponding interferogram. A 10x10 multilook window was used to reduce the phase noise. A phase fringe can be observed due to the temporal change of propagation delay in atmosphere of SAR signal at the master and slave acquisition times. The mitigation of this effect will be needed to provide accurate estimates of soil moisture. A practical solution could be provided by the identification of few buildings or other targets different from agricultural fields where temporal changes of soil moisture are not expected. These targets will be used to disentangle the phase contribution due to soil moisture and propagation delay in atmosphere.

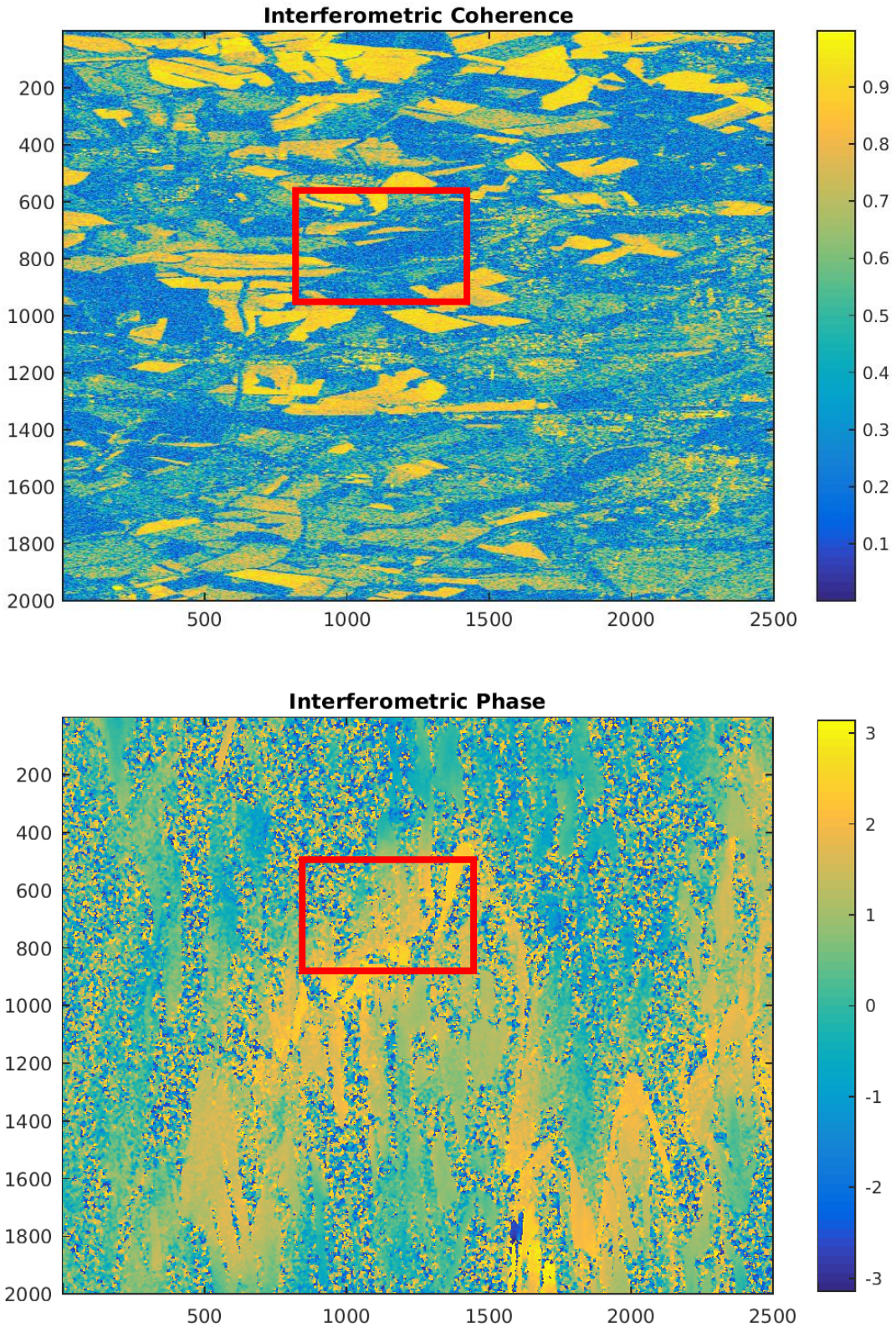

Fig. 3. (top) Detail of coherence map in fig. 2;
(bottom) corresponding interferogram. Both are in azimuth/range pixels.
The ground test area reported fig. 1 is shown within the red rectangle

CONCLUSIONS

In this work we described an experiment that will be carried out in the basin of Suhaya Orlitsa river (Oryol region, central part of European Russia) to compare in-situ measurements of soil moisture with estimates obtained using Synthetic Aperture Radar (SAR) interferometry. As first results, we show examples of interferometric coherence and phase images obtained by processing Sentinel-1 images acquired on 20th September 2019 and 2nd October 2019 over the study area are shown.

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