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Soil moisture change estimation using InSAR coherence variations with preliminary laboratory measurements

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Dear editor,

The repeat pass InSAR (interferometric synthetic aperture radar) technique has been successfully applied in topography mapping and terrain motion monitoring by means of Differential InSAR (DInSAR) for many years. There are several factors could influence the observed interferometric coherence, including the system spatial decorrelation, the additive noise, and the scene decorrelation which takes place between the two acquisitions. Among those decorrelation sources of the scene, volume scattering and terrain deformation are usually taken into considerations. However, soil moisture change, which happens within the time interval of two acquisitions, has not yet been thoroughly studied. The decorrelation caused by temporal changes of soil moisture, on one hand, is a serious source of error for deformation products which should be removed correctly, but on the other hand, provides significant information for estimating soil moisture changes.

Previous studies investigating the relationship between InSAR complex coherence and the changes of soil moisture content have found promising results, both on amplitude and phase. It is found that the changes in soil moisture decrease the coherence amplitude, and are highly related to the interferometric phases [1–4]. However, the exact relationship between complex coherence and soil moisture change has not been revealed for applications, although a few scattering models have been just proposed in recent two years [5–7]. Besides, the inversion methods of soil moisture changes using InSAR information are under investigation.

In this letter, we focus on the coherence amplitude analysis with soil moisture value variations, and the method to estimate these variations. Firstly, the experiment implemented is introduced, and then the processing results are presented to show the consistency of coherence with the moisture changes. Particularly, the influences of frequency and selection of master image issues are discussed. Thereafter, the flowchart of proposed method is given. And the temporal decorrelation sources which could influence the coherence in application are considered in the end.

The experiment was designed and implemented in the anechoic chamber of Science and Technology on Electromagnetic Scattering Laboratory

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in China. The chamber provides a highly controlled radar measurement environment. Figure S1(a) shows the geometry configuration of the system, while Figure S1(b) presents the picture of soil sample in its measurement position, within a cylinder container of 1 m inside diameter above the turntable base. This container is made of polystyrene foam. Its dielectric constant is very small, close to 1, hence its influence on scattering can be neglected. Inside, the depth of soil sample is 15 cm, with slightly roughness on the surface.

Radar measurement was carried out in step frequency mode from 2–8 GHz at 10 MHz interval, with the distance of 8.722 m between antenna and the centre of soil surface. In order to increase the SNR of the scattered wave by soil, the measurements were taken for each azimuth angle with interval of 0.1° for whole range of 360°. In our designed experiment, the incidence angle is set to be 30°.

The soil sample with different water contents was observed for 9 times totally lasting for two days. There are 4 time measurements in the first day and 5 times in the second day. For each day between each measurement, water was added into the soil sample, so the soil moisture should increase accordingly, except the time interval between the 4th and 5th measurements, because there is no watering activity during the night. In order to assure the stable state of water in soil, each time there were 20 min left between watering behavior and microwave measurement. TDR 300 was used for the ground truth measurement of soil volumetric water content after every microwave measurements. And five sample values of different positions in container were recorded and averaged for further comparison.

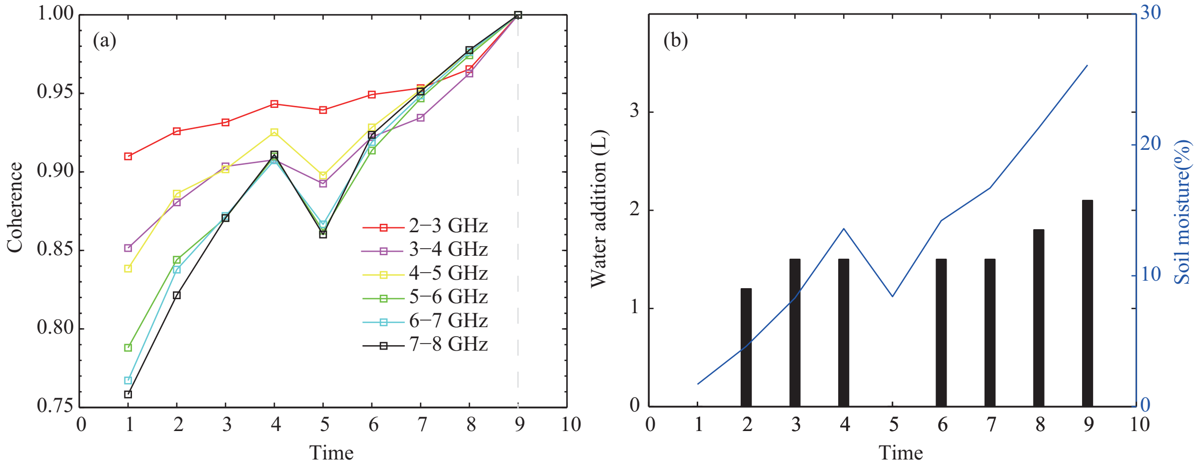
The radar data is firstly processed for circular SAR imaging. Then the ninth image is selected as master, and the coherence between each image with master is calculated for different subfrequency as shown in Figure 1(a). HH polarization data is used here. In comparison, the soil water content measured by TDR 300 together with the amount of water addition is given in Figure 1(b).

It can be seen that there is good agreement between the real soil moisture and the coherence level for the whole time period. Basically, the coherence amplitude increases with the addition of water gradually, except that the fifth measurement (the first one on the second day) is lower than the one before. This is because that the water contained in soil evaporated during the night and no water is added before the fifth observation. Besides, the consistency can be observed in all different sub-frequencies although the sensitivity as well as the coherence level is not the same. Generally, the higher frequency with smaller wavelength is more sensible to small size disturbance thus results in large temporal de-correlation [8]. On the other side, the lower frequency (2–3 GHz) has much higher coherence level but lower sensitivity. There should be a compromise in application. However, even for the S-band data, the coherence variations can correctly reflect the sign of soil moisture change. Considering the temporal decorrelations existed in airborne/spaceborne data which would definitely reduce the coherence level, lower frequency with high coherence is preferable.

It is found that the selection of master image is of great importance. This is because of the non-linearity of coherence with the increase of soil moisture. Specifically, when the initial soil is very dry, small amount of water content change will result in large decorrelation which induces low coherence. But when the initial soil is wet, the same amount of moisture variation will lead to smaller decorrelation and relatively high coherence. Therefore, if the dry soil image is selected as master, the whole coherence levels between this master with other temporal images are totally in a lower level, which is not good for processing as well as differentiation. For instance, in Figure 1(a) the coherence level of 7–8 GHz data is from 0.76 to 0.98 when the ninth image (with wettest soil sample) is selected as the master image. Nevertheless, if the first image (with driest soil sample) is chosen as master instead, then the coherence level of the same frequency data ranges from 0.76 to 0.79. Obviously, the image with relative wet soil should be chosen as the master.

In fact, there exist several practical limitations of the proposed method in real application. The terrain displacement or atmospheric delays should be taken into account when airborne/spaceborne platform is considered. Since the time span of concerned soil moisture change is from a couple of days to tens of days, the slow displacements of terrain surface usually on the level of several centimeters per year could be reasonably neglected. As to the decorrelation from atmospheric effects, it is generally considered that using scenes acquired under anti-cyclonic conditions and/or at night can help reduce atmospheric effects rather than daytime acquisitions.

Figure S1(c) presents the processing flowchart. If we know or could measure the soil moisture change between two time moments, then it is possible to estimate all the other changes of the whole observation period. For example, the variation between the first and the final measurement is known



Time interval	2–9	3–9	4–9	5–9	6–9	7–9	8–9
Estimated from 2–3 GHz	20.1	18.6	15.4	16.4	13.8	12.6	9.4
Estimated from 3–4 GHz	19.6	15.9	15.2	17.7	12.8	10.8	6.1
Estimated from 4–5 GHz	17.2	14.9	11.3	15.4	10.8	7.2	3.7
Estimated from 5–6 GHz	18.0	14.9	10.4	15.8	10.0	6.1	3.0
Estimated from 6–7 GHz	17.0	13.4	9.7	14.0	8.5	5.4	2.5
Estimated from 7–8 GHz	18.0	13.1	9.0	14.1	7.7	4.9	2.3
Averaged	18.3	15.1	11.8	15.6	10.6	7.8	4.5
Measured	21.5	17.8	12.5	17.7	11.9	9.4	4.8

(c)

Figure 1 (Color online) (a) Coherence variations of 9 measurements; (b) soil moisture changes of 9 measurements; (c) comparison between estimation and measurement.

to be 24.4%, then the moisture changes estimated from 2–8 GHz radar measurement during the other time intervals are shown in Figure 1(c). It is seen that the averaged values of them is quite close to the ground truth measurements obtained by TDR equipment.

In this letter, a method to estimate soil moisture changes with InSAR coherence variations is reported, and preliminarily analyzed with laboratory data sets. In fact, coherence amplitude not only show the extent of the variations in soil water content, but also severely influence the quality of interferometric phase. However, the phases are too unstable to be utilized directly. Hence more experiments should be implemented with the consideration of combining coherence amplitude and phase information in future.

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