Potential for phase-based surface moisture estimation with C-band SAR data

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Abstract

Soil moisture estimation with synthetic aperture radar (SAR) images is currently based on the amplitude of backscattered signal. However, there are evidences that soil or vegetation moisture can influence the SAR interferometric phase (InSAR), in fact, moisture effects are suspected to be a considerable nuisance when the goal is the precise estimation of ground deformation using InSAR. A moisture retrieval method based on the interferometric phase, both for improving ground deformation and surface moisture measurements, has in the past been presented and to some extend validated. In this paper we will show our first inversion results based on Sentinel-1 C-band images; we compare incoherent and coherent methods; we conclude that the possibility of integrating incoherent and coehrent soil moisture estimation is becoming realistic and should therefore be thoroughly investigated.

1 Phase-Based SAR Moisture Estimation

The effects that soil or vegetation moisture temporal changes can produce on the synthetic aperture radar (SAR) interferometric phase (InSAR) and coherence have been largely ignored in the past. Operational algorithms to derive soil moisture from SAR images currently make use only of the intensity of backscattered signals. The possibility of exploiting moisture effects on the phase to estimate surface moisture is only recently being studied. This is also particularly interesting in the context of future geosynchronous missions like Hydroterra, that will be capable of a very frequent revisit, with high interferometric coherence.
A novel soil or vegetation moisture estimation algorithm based on synthetic aperture radar (SAR) interferometric closure phases has been presented in [1]. The algorithm is based on a model, presented in [2], that relates moisture changes to the phase. In this paper we apply for the first time the algorithm to a C-band stack of Sentinel-1 images acquired over the region of Apulia, Italy. We also compare the phase algorithm with a more traditional backscatter-based method [3, 4, 5]. Figure 1 shows an example of the backscatter-based moisture.
The phase contribution in interferograms which is due to moisture changes is very small, when compared to geometrical, deformation, and troposphere terms. In order to remove stronger terms and measure moisture effects we exploit the closure phases. A closure phase, or phase triplet, is the sum of the three interferograms related to three images:

$$\Delta\phi_{123} = \Delta\phi_{12} + \Delta\phi_{23} + \Delta\phi_{31}, \tag{1}$$

where $\Delta\phi_{123}$ is the closure phase and $\Delta\phi_{12}$ is the interferogram between image one and two. The sum in (1) is equal to zero for linear phase contributions, like the geometrical term, deformation, and atmosphere. According to our model, the effect of the moisture is non-linear and won't therefore be deleted in the summation in (1). The closure phase provides then an information about the sum of three moisture phase contributions. With N images there are $(N-1)(N-2)/2$ independent phase closures, which can be inverted to estimate $N-1$ moistures.

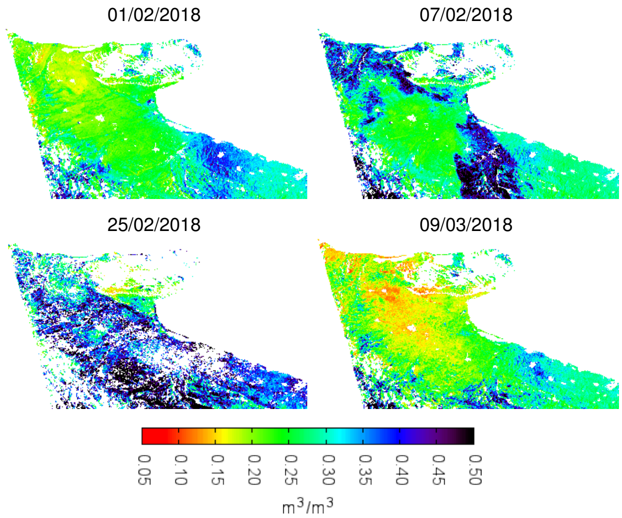

Figure 1 Soil moisture estimation with Sentinel-1 backscatter images.

1.1 Forward model

Firstly we apply the phase model to the moisture that has been estimated with the backscatter method, obtaining the InSAR phase terms which are due to moisture changes. We then calculate triplets of interferograms to

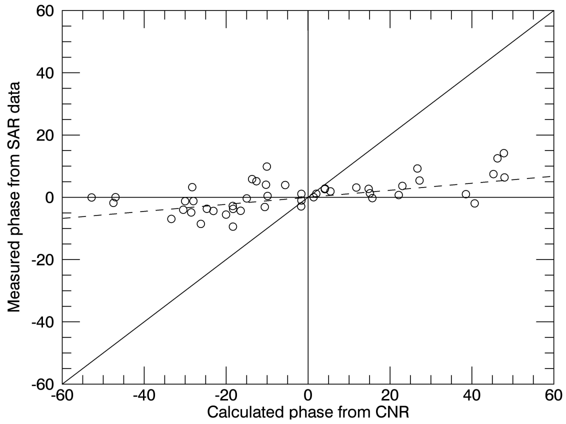

Figure 2 Forward problem. On the x-axis the closure phases modeled from the inversion based on backscatter. On the y-axis the observed closure phases.

obtain phase closures: both with the modeled phases from the backscatter-based moisture, and with real Sentinel-1 data. We compare the results in Figure 2. The correlation coefficient between the two sets is 0.62, indicating a good correspondence. This means that the model can relate the closure phases measured from the images to moisture changes, derived from the backscatter. The scaling between the two phase sets, clearly visible in the figure, is not a concern and indicates a need for model calibration.

1.2 Model inversion

We apply the inversion algorithm described in [1] to 11 Sentinel-1 images, therefore using 55 interferograms and 45 closure phases. Since the data exploited in the inversion -i.e. the phase triplets- are relative to temporal differences of moisture, there are ambiguities in the inversion. Specifically, closure phases can estimate the temporal moisture variation from one date to the next but cannot establish in which date the moisture is highest, they connect the highest moisture to the lowest continuously in a cyclic way. We usually use the interferometric coherence as additional data in the inversion to separate the wettest images from the driest. Unfortunately with the C-band dataset this step of the inversion resulted to be less reliable than when applied to L-band data. We then took the information about which the wettest image is from the backscatter-based moisture inversion. Other than this information, the two estimation (phase- and backscatter-based) are independent. Figure 3 shows the results averaged on a scene-level, whereas Figure 4 shows the full scene for four example dates.

2 Conclusion

The soil moisture estimated with Sentinel-1 interferograms correlates with a coefficient of 0.9 with the one estimated from backscatter. In the final paper we are going to present the spatial variation of the temporal correlation between the two results. In the future we plan to investigate how the two methods can be combined to exploit the respective strengths.

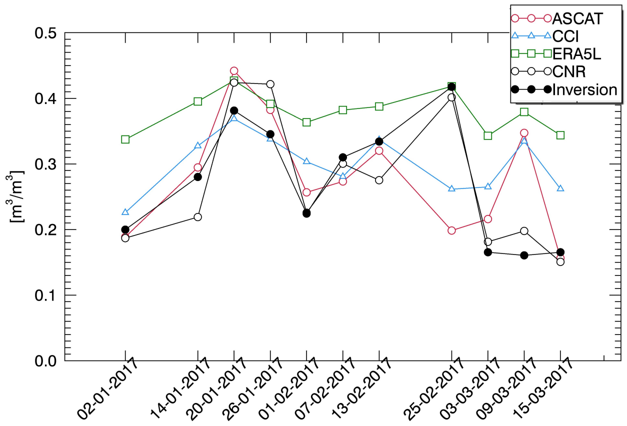

Figure 3 Averaged soil moisture estimation with Sentinel-1 interferograms compared to other techniques.

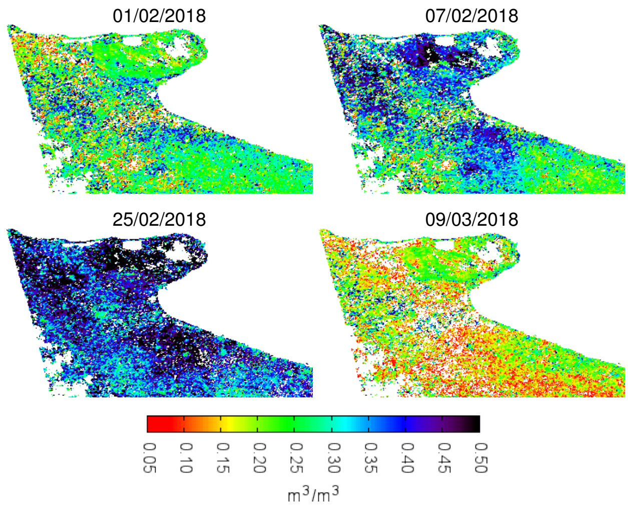

Figure 4 Soil moisture estimation with Sentinel-1 interferograms.

3 Literature

[1] F. De Zan, G. Gomba: Vegetation and soil moisture inversion from SAR closure phases: First experiments and results. Remote sensing of environment, 2018.

[2] F. De Zan, A. Parizzi, P. Prats-Iraola and P. López-Dekker, "A SAR Interferometric Model for Soil Moisture," in IEEE Transactions on Geoscience and Remote Sensing, vol. 52, no. 1, pp. 418-425, Jan. 2014.

[3] Balenzano A., F. Mattia, G. Satalino, M. W. J. Davidson, “Dense temporal series of C- and L-band SAR data for soil moisture retrieval over agricultural crops”, IEEE Jou. of Selected Topics in Applied Earth Obs. and Remote Sensing (J-STARS), Vol. 4, No. 2, pp. 439-450, June 2011.

[4] Balenzano A., G. Satalino, F. Lovergine, M. Rinaldi, V. Iacobellis, N. Mastronardi, F. Mattia, “On the use of temporal series of L- and X- band SAR data for soil moisture retrieval. Capitanata plain case study”, European Journal of Remote Sensing, Vol. 46, pp. 721-737, 2013.

[5] Satalino G., A. Balenzano, F. Mattia, and M. W. J. Davidson, “C-band SAR Data for Mapping Crops Dominated by Surface or Volume Scattering”, Geosci. and Remote Sensing Letters, Vol. 11, Issue 2, pp. 384-388, Feb. 2014.