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On the Effect of Soil Moisture Phase Inconsistencies on Phase Estimators from Distributed Scatterers in InSAR Stacks

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Modelling closure phase evolution

A key parameter to characterize dielectrics is the tangent loss, i.e. the ratio between the imaginary part and the real part of the dielectric constant. Assuming that the tangent loss is constant while the moisture content of soils or woods varies in time, a small tangent loss allows for large phase evolution with a small change in the power balance between different scattering mechanisms or scattering surfaces. Large tangent losses instead cause a rapid change in the attenuation and consequently fast decorrelation, as different scatterers or surfaces suddenly appear or disappear. Values of the tangent loss appropriate for wood are compatible with the observations, though it has not been possible yet to invert a physical model.

Acknowledgement

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Additional material and references

Some figures showing sesonal effects and polarimetric effects on closure phases are to be found in the attached pdf.

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On the Effect of Soil Moisture Phase Inconsistencies on Phase Estimators from Distributed Scatterers in InSAR Stacks

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In time-series InSAR approaches exploiting multi-master stacks of interferograms (targeting mainly distributed scatterers), one of the key steps is a process called phase linking, phase triangulation, or equivalent single master phase estimation. This step is applied in order to estimate, for each pixel, an equivalent single-master (ESM) phase time-series from multi-master interferometric phases, preserving useful information and filtering noise. In principle, this estimation can be applied either after phase unwrapping, or before unwrapping.

A fundamental assumption common to all the existing methodologies is the principle of phase consistency. This means that out of the phases of N(N-1)/2 interferograms that can be formed out of N Single Look Complex (SLC) images, only N-1 are linearly independent. Although phase consistency does not hold for multilooked data, the general assumption made (whether implicit or explicit) is that inconsistencies are purely induced by random noise. In fact, the purpose of applying the ESM-phase estimation is to estimate a set of consistent interferometric phases (i.e. where phase consistency holds for every combination of three interferograms) from a stack of inconsistent multilooked interferograms.

However, recently it has been shown that there are also some mechanisms that can induce systematic phase inconsistencies, for example due to the variation in the soil moisture. The existence of such inconsistencies raises the question regarding the extent to which they affect the phase estimators. In other words, what would happen to the soil moisture effect by postulation/constraining the phase consistency in the estimation process? Is this effect filtered out, or may it leak into the final estimated phases?

Here, we evaluate and compare the sensitivity of different phase estimators (e.g., maximum likelihood estimator, integer least squares estimator, eigendecomposition-based methods, and least circular variance estimator) to the soil moisture inconsistencies via a simple simulation scenario based on an analytical model. We demonstrate the methods over pasture and agricultural areas in the Netherlands, and we discuss the implication of the observed soil moisture effects for applications in deformation monitoring.

Interferometric Phase As A Soil Moisture Signal

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Interferometric techniques for the retrieval of surface topography and surface movement are well understood. After appropriate image pre-processing, the interferometric phase is associated only with the parameter to be retrieved from the imagery. Over soils, this phase is classically considered to arise as a return from a fixed surface which can be regarded as impenetrable. Although there may be tacit recognition that the signal may be a combination of surface and sub-surface returns, the relative contributions are considered static.

Recent work, however, has identified a clear sensitivity of interferometric phase to soil moisture. The sensitivity can arise from both physical movement of the soil surface horizon and the dielectric contrast. Clay soils can be expected to show heave and slump in response to varying moisture, whereas sandy soils likely show little shrink or swell. Phase sensitivities from all soil types can be expected to have contributions from both the surface and sub-surface. For moderate moisture contents (>10%) the large dielectric contrast at the air/surface interface leads to a strong surface return. Sub-surface returns are heavily attenuated by the level of moisture in the volume. This phase signature is typically characterised by a dominant surface return slowly varying at a rate of several degrees per percent moisture change. As moisture content lowers, however, there can be an increasing volume return. The size of the sub-surface return depends upon the types of scattering features present in the volume. The source of these scattering centres is still open to question, but is associated with discontinuities in the volume such as rocks, air pockets, and layer boundaries. Subtle differences in the distributions and populations of these scatterers can produce markedly different phase histories.

Thus, at the very least, the moisture-phase sensitivity represents a noise term in conventional interferometric retrievals. In some observation scenarios it seems likely that the soil moisture phase may significantly distort the phase term, leading to erroneous retrievals of scene parameters. The presentation will provide results of laboratory and modelling studies which detail how the phase response of soils to moisture arises, identifying the components of the signal, and understanding how it impacts on conventional interferometric satellite applications.

Toward InSAR-Friendly Data Products

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Interferometric Synthetic Aperture Radar (InSAR) methods provide high resolution maps of surface deformation applicable to many scientific, engineering and management studies. Modern spaceborne satellites, perhaps today best exemplified by Sentinel-1A and B, provide long sequences of observations that we can reduce to many interferograms, which in turn provide the deformation histories of many points on the surface. InSAR measures mm-cm level surface deformation over large areas at fine resolution, and has been extensively applied in studies such as earthquake and volcano modeling [1-4], glacier mechanics [5,6], hydrology [7,8], and topographic mapping [9,10]. The InSAR technique combines interferometry and conventional synthetic aperture radar (SAR) to compute the phase differences between two single look complex (SLC) SAR images. Since the resulting interferometric phase is proportional to the change in range between the sensor location and a given point on the surface, a single interferogram contains phase signals from i) the local topography due to the spatial separation of the two sensor locations and ii) any radar line of sight displacements of the point occurring between the two SAR acquisition times.