Supplementary materials to 'Explanation of InSAR Phase Disturbances by Seasonal Characteristics of Soil and Vegetation'

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This document contains:

S1. Scripts used to derive the results of this study

S2. Details of InSAR and microwave radar theory

S1. Scripts used to derive the results of this study

All scripts are written in the Matlab®2018b coding software and are available from a GitHub repository:

`https://github.com/rogierwesterhoff/InSARPhaseAmplitudeCoherence/`.

This folder contains:

1. Main file for experiment I and II: 'calcPhaseAmplitudeCoherence.m'
2. Main file for experiment III: 'calcLOSDisplacementPastureOverAYear.m'.
3. Matlab file 'em_propagation_2lyrs.m', called in all experiments.
4. Excel file 'YearInAPaddock.xlsx'.

S2. Details of InSAR and microwave radar theory

This section contains a more detailed description of electromagnetic wave propagation, including reflection and transmission, and InSAR coherence theory, deemed useful as background information to the article; more comprehensive explanations of InSAR methods are given by [1, 2].

Material properties

Satellite interferometric SAR signals are electromagnetic waves that are mainly measured in three approximate frequencies: L-band (1-2 GHz), C-band (4-6 GHz), or X-band (8-10 GHz). In a vacuum or in air, approximate wavelengths are 15-30 cm, 5-7.5 cm and 3-4 cm, respectively.

Electromagnetic wave propagation is affected by three material properties [3]: magnetic permeability μ (=$\mu_r\mu_0$); electrical conductivity σ; and dielectric permittivity $\varepsilon = \varepsilon_r\varepsilon_0$, often just called permittivity. It is assumed here that for most of earth's materials μ does not play a significant role. Permittivity of the free space, i.e. vacuum is called ε_0 (=8.854187817.. x 10^{12} F/m), and ε_r is called the relative permittivity or dielectric constant. Permittivity becomes complex when it has conductivity $\sigma \neq 0$ embedded and is then defined as [4, 5]:

$$\hat{\varepsilon} = \varepsilon - j\frac{\sigma}{\omega} \triangleq \varepsilon' - j\varepsilon'', \tag{1}$$

where:

- $\hat{\varepsilon}$ is the complex dielectric constant;
- ε is the 'static dielectric constant', i.e., the real part of the dielectric constant which is only affected by temperature, pressure and composition [5], and not by conductivity. In other words, $\hat{\varepsilon}$ equals ε in a dielectric medium (where $\sigma = 0$), but not in a lossy medium (where $\sigma \neq 0$);

- ω is the angular frequency (=$2\pi f$, with f the frequency in Hz);
- ε' and ε'' are the real and imaginary parts of $\hat{\varepsilon}$, respectively.

Vegetation depolarises microwave backscatter, as multiple scattering occurs in all directions against the leaves and stalks (possibly via the ground) [6, 7]; it also attenuates the backscatter, as more signal will be scattered in all directions, and thus less to the satellite [8]; and lastly, it causes a phase disturbance, where the transmitted H field will lag the E field, since vegetation has a conductivity $\sigma > 0$. Dielectric properties change with different vegetation types and growth. They can be estimated by a 'mixing model', where the permittivity of different substances occurring in one volume are averaged [9]. For example, [10] introduced a linear model for the dielectric constant of a vegetation:

$$\varepsilon_{veg} = \varepsilon_r + \nu_{fw}\varepsilon_{fw} + \nu_{bw}\varepsilon_{bw}, \tag{2}$$

where ε_r is the dielectric constant of the actual plant fibre, volume fractions are given by ν and the dielectric properties of free water (ε_{fw}, water free to move within the plant) and bound water, water inhibited by the plant molecules [11]. At C-band frequencies, [12] measured values for corn leaves that varied, from low to high moisture values, in between 1 and 43 for ε' and 0 and 13 for ε''. [10] found similar values and also separated for the effect of stalks and leaves. For volumetric moisture M_v of 0.65 for leaves (l) and 0.47 for stalks(s), they found:

$$\hat{\varepsilon}_l = \varepsilon_0 \left(27 - j7\right), \tag{3a}$$

$$\hat{\varepsilon}_s = \varepsilon_0 \left(14 - j4\right). \tag{3b}$$

Coherence of recurring InSAR imagery

As common in interferometric SAR (InSAR) processing coherence between different satellite overpasses is calculated with a correlation coefficient [13, 14], such as:

$$\hat{\gamma} = \frac{\sum_{i=1}^{N} x_i y_i*}{\sqrt{\sum_{i=1}^{N} \mid x_i \mid^2}\sqrt{\sum_{i=1}^{N} \mid y_i \mid^2}} \tag{4}$$

where x and y are amplitudes of two different satellite overpasses, and N is the number of spatial samples that are tested. The * denotes the complex conjugate value. Coherences can vary in between -1 and 1, but often the absolute value is taken [14]. Commonly, absolute coherences lower than 0.3 are removed from further analysis [15].

In our study, coherence between satellite interferometric data and a reference measurement (t=0) was calculated [14] for all experiments. For experiment I, coherence was calculated relative to a dry sand. For experiment II coherence was calculated relative to a light grass vegetation. For experiment III coherence was calculated relative to the first measurement of Table 2 of the main document.

Absolute coherences smaller than 0.3 were designed to be filtered out. However, that was not needed, since no measurements in the shown experiments had coherence lower than 0.77.

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