ABSTRACT

Different mechanisms for the impact of soil moisture on interferometric radar data have been proposed, but its magnitude, sign and even presence have barely been studied empirically and thus remain poorly understood. In this study the dependence of the phase and coherence magnitude on soil moisture was inferred empirically with regression techniques: this was done for two airborne data sets at L band. The phase dependence was significant ($\alpha = 0.05$) for more than 70% of the fields at HH polarization, its sign corresponding to an increase in optical path upon wetting. This trend was similar in both campaigns, whereas the prevalence of soil moisture-related decorrelation differs. These results are only consistent with a dielectric origin of the soil moisture effects, and not with soil swelling or the penetration depth hypothesis.

Index Terms— DInSAR, soil moisture, deformation, polarimetry

1. INTRODUCTION

Radar interferometry is frequently applied to study a broad range of phenomena as it is sensitive, in the presence of a spatial baseline, to the position of scatterers and, in the presence of a temporal gap, to displacements [3]. A possible influence of variations in soil moisture $m_v$ on the DInSAR signal was initially postulated by [3] due to an observed correspondence of the phase $\phi$ with agricultural fields. Dedicated observational studies have been scarce, especially controlled experiments [9, 6]; and a few mechanisms and parameterized models have been proposed as possible explanations. There is no consensus on the magnitude, sign and even presence of these effects: this pertains to both observations and models.

In view of these open questions, we analyze the influence of $\Delta m_v$ (measured in-situ) on both the coherence $|\gamma|$ and the phase $\phi$ using regression techniques for two L-band airborne campaigns in a model-independent fashion. These observational results are subsequently compared to the predictions made by the different explanations; we thus determine if these explanations are consistent with the data. The emphasis is placed on the mechanisms that give rise to the observable effects, rather than particular models and parameterizations, as

<table>
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<th>$\phi$</th>
<th>Null</th>
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<th>Pene</th>
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<tr>
<td>$\Delta m_v$</td>
<td>0</td>
<td>-</td>
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<td>+</td>
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<td>$</td>
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Table 1. Model predictions for the sign of the sensitivity of an observable on $m_v$: + positive, - negative, 0 no influence, ? not explicable.

the applicability and relevance of these explanations themselves are poorly understood.

2. THEORETICAL CONSIDERATIONS

Four hypotheses on the origins of these effects have been framed in the literature:

Null hypothesis (Null) No effects on phase $\phi$ or magnitude $|\gamma|$ of the coherence.

Soil swelling (Defo) Phase change due to upward displacement of the surface upon wetting. Note that it is expected only to occur for certain soils [10].

Penetration depth (Pene) $\phi$ arises due to changes in the penetration; no prediction about $|\gamma|$ [8].

Dielectric mechanism (Diel) Volume scattering in a medium whose background dielectric constant changes with $m_v$ predicts both decorrelation and $\phi$ [2].

The sign of the dependence of the interferometric observables on soil moisture changes for each of the models is summarized in Tab. 1 (in the $\exp i\omega t$ convention). It should be pointed out that these explanations, although distinct, are not necessarily mutually exclusive.

3. MATERIALS & METHODS

3.1. Data

The AGRISAR2006 data set (L-band, fully polarimetric, zero baseline, repeat period of 1-2 weeks) was collected in 2006 in northern Germany during one growing season [4]: it consists
of an agricultural scene (mainly wheat, maize and rape) in northern Germany. Relevant in-situ data (including soil moisture, wet biomass, vegetation height) were recorded in more than 10 fields.

The CanEx-SM10 campaign of June 2010 covers an agricultural site in Saskatchewan; it includes UAVSAR L-band acquisitions and in-situ measurements [5].

3.2. Methods

Four subROIs of 172 looks were chosen for each field. For each subROI we obtained three reference phases from persistent scatterers (ps) identified in the data – only the results for the closest ps are shown due to the small impact on the results.

The parameters of the regression model are estimated using weighted least squares (including a variance component term for the \( \phi \) models). For the coherence \( |\gamma| \in [0,1] \), which is invariant to the choice of master/slave, the following structure is postulated:

\[
\log(|\gamma_{ij}|) = \beta_0 + \beta_{m_v}\Delta m_v + \beta_t|\Delta t| + \beta_v|\Delta v| + \epsilon_{ij}
\]

i.e. the terms are assumed to affect \( |\gamma| \) in a multiplicative fashion, thus rendering negative coherences impossible. The error term of the \( i,j \) interferogram is denoted by \( \epsilon_{ij} \) (with expected value of zero), and \( t \) is the temporal separation. The vegetation biomass is referred to by \( v \) – this term is not present in the CanEx data set. The phase \( \phi \) is assumed to be governed by

\[
\phi_{ij} = \beta_{m_v}\Delta m_v + \beta_v\Delta v + \epsilon_{ij}
\]

where the absence of an intercept term is due to the expectation that no change in the exogenous variables corresponds to zero \( \phi \). Note that the confidence intervals reported in Sec. 4 rely on the noise being normally distributed.

4. RESULTS

4.1. Exploratory data analysis

Several scatter plots of the observables versus \( m_v \) are shown in Fig. 1. These were chosen to be fairly representative (except \( \phi \) of 307a, which exhibits the closest correspondence to \( \Delta m_v \)). The phase values (Fig. 1a)-d)) show a positive, approximately linear trend with \( \Delta m_v \).

4.2. Regression results

The coefficients \( \beta \) of both phase and correlation are plotted in Fig. 2 for the Agrisar campaign. For \( \log|\gamma| \) they are usually negative, but not necessarily significantly different from zero. The differences between the polarizations are relatively small: the significance can be more pronounced for HH (e.g. fields 230, 222) and the fits tend to be worse for HV (e.g. 250, 222) – with corresponding impact on the width of the confidence intervals. Note that there can be sizeable differences both within fields (e.g. HV 230) or between fields of the same crop (e.g. 102 and 460).

The phase relations reveal more pronounced differences between the polarizations: the \( \beta_{\Delta m_v} \) tend to be positive (especially when significantly different from zero): this is particularly evident at HH as opposed to VV (e.g. 101, 440) or HV (e.g. 140). The inter- and intrafield discrepancies in the results for \( |\gamma| \) and \( \phi \) can be pronounced, both regarding the location estimate and its spread.

The same analysis – except for the lack of vegetation terms – for the CanEx data also reveals a positive dependence of \( \phi \) on \( m_v \), albeit with different (and exceedingly variable) magnitudes, see Fig. 3. The field 201, for instance, for which \( m_v \) is almost constant, is characterized by large \( \beta_{\Delta m_v} \) for \( \phi \) and confidence intervals thereof, when compared to field 307: its \( m_v \) time series shows more variation, and also the intra-field variation is more pronounced.

5. DISCUSSION

The observed positive (and significant) phase dependencies are only consistent with the dielectric explanation, but not with the penetration depth or soil swelling mechanisms. The positive sign was also observed in two X-band experiments by [9], whereas [6] found the opposite trend. The decorrelation is also related to changes in \( m_v \); this relation is more pronounced in CanEx data set, where the time difference between the acquisitions is shorter and thus the vegetation less variable. This is also consistent with a dielectric mechanism. The influence of vegetation dynamics on decorrelation was also observed by [1] in agricultural fields in Ireland at both C and L band: the effect of soil moisture changes was small in comparison. Furthermore, the magnitude of the decorrelation due to \( m_v \) is similar to the ones obtained by [7] in a laboratory experiment at higher frequencies.

The \( \beta_{\Delta m_v} \) for the phase \( \phi \) tend to be larger for HH than for VV, and there are also differences in the quality of fit, cf. Fig. 2. These appear to be related to the crop and are consistent with the notion that the vegetation influence is larger for VV for vertically oriented crops. Note that there is also a significant impact on HV, which is not expected – to first order – for surface scattering. The terms \( \beta_{\Delta v} \), which express the dependence of \( \phi \) on changes in biomass, tend to be positive as well (not shown): this is also consistent with a dielectric mechanism, wherein the optical path within the canopy is related to the total amount of vegetation.

The results shown in Fig. 2 and 3 were obtained by making certain assumptions and decisions pertaining to the stochastic model in the regressions, the choice of reference phase and the representation of the vegetation. Empirical sensitivity analyses (not shown) reveal that the overall impact of these implementational details is limited.
Fig. 1. Scatter plots of the observables versus $m_v$. The colour encodes the temporal difference $\Delta t$ in days and differs for Agrisar/CanEx.

Fig. 2. The soil moisture coefficients of the regression models for the magnitude (top row) and phase (bottom row) of the complex coherence grouped according to the fields in the AGRISAR campaign: for each field there are four subROIs v-y. The error bars indicate the 95% confidence intervals, diamonds a significant deviation from 0.
Fig. 3. The soil moisture coefficients of the regression models of the CanEx campaign, cf. Fig. 2 for a description.

6. CONCLUSIONS

The analysis of the $\phi$ as a function of $\Delta m_v$ shows that the observed relation is consistent with the dielectric hypothesis, and not with the other mechanisms proposed in the literature. The estimated soil moisture related decorrelation is not as conclusive, especially in the AGRISAR campaign.

These inferences only relate to the two L band data sets analyzed: their generality can only be established with additional studies – the soil type (swelling behaviour), radar frequency and properties of the vegetation cover appear to be particularly relevant. Due to the size of the phase excursions of up to $\phi \approx \pi$, these soil moisture effects need to be considered in repeat-pass InSAR studies, in particular when deformations of distributed targets are inferred, or for e.g. the derivation of digital elevation models.

7. REFERENCES


