A POLARIMETRIC TWO-SCALE MODEL FOR SOIL MOISTURE RETRIEVAL

Antonio Iodice, Antonio Natale, Daniele Riccio
Dipartimento di Ingegneria Biomedica Elettronica e delle Telecomunicazioni,
Università di Napoli "Federico II"
Via Claudio 21, 80125 Napoli, Italy.
email: {iodice; antonio.natale; Daniele.Riccio}@unina.it

1.INTRODUCTION

Valuable applications require knowledge of key ground physical parameters (i.e., permittivity, ground roughness, soil moisture content, vegetation biomass-index, ecc…) relevant to wide natural areas; remote sensing technologies are the best candidates to provide this information at a relatively high resolution and in a comparatively short time. In particular, using multi-angle and/or multi-polarimetric Synthetic Aperture Radar (SAR) data allows us to estimate ground parameters, by means of retrieval techniques that employ reliable and realistic (but not too involved) electromagnetic scattering models. Already existing simple methods, e.g., the Small Perturbation Method (SPM), do not take into account depolarization and cross-polarization effects, then it is necessary to devise a new model which provides a good matching with measured data, just retaining an acceptable complexity.

To this aim, we develop a theoretical model to describe the scattering from a bare soil surface and we use it to perform an effective inversion method to estimate both the relative dielectric constant ε (and, hence, the soil moisture content m_v) and the ground roughness. In our model, we assume that the bare soil scattering surface is composed of slightly rough randomly-tilted facets, for which the SPM holds. Such a random tilt causes a random drift of the local incidence angle and a random rotation of the local incidence plane, see Figure 1: unlike other similar already existing approaches (see, e.g., [1]), we account for both these effects, and their statistical modeling is not arbitrarily chosen, but we derive it from a proper statistical description of the scattering surface.

Here, we refer to our method as "Polarimetric Two-Scale Model" (PTSM).

2.THEORETICAL BACKGROUND

We consider a bare soil surface as composed of large-scale variations on which a small-scale roughness is superimposed, so that we have a two-scale model of the surface. The large-scale roughness is locally treated by replacing the surface with a slightly rough tilted facet, whose slope is the same of the smoothed surface at the center of the pertinent facet. Facets sizes are greater than the electromagnetic wavelength, but much smaller than sensor geometric resolution. We model both large- and small-scale roughness as stochastic processes. As for the former, we assume that the facet slopes along range and azimuth directions are independent identically distributed zero-mean σ^2-variance Gaussian random variables: this assumption only requires that the large-scale roughness is a Gaussian stationary-increment process, so that it is compatible with both classical and fractal surface models. The small-scale roughness is modeled as a fractional Brownian motion (fBm) random process.

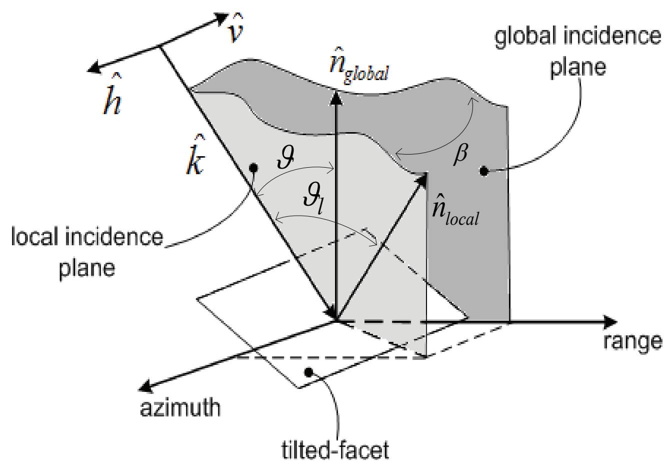

Figure 1: rotation of local incidence plane due to facet tilt

The facet random tilt gives rise to a random rotation of the local incidence plane, which turns into a random rotation of the scattering matrix; in addition, it also causes a local stochastic drift of the incidence angle that contributes to increase the amount of randomness of the scattering with respect to other models [1]. Note that both these effects can be expressed in function of azimuth and range slopes [2]; accordingly, to evaluate the normalized radar cross sections (NRCS) $\sigma°_{hh}$, $\sigma°_{vv}$ and $\sigma°_{hv}$ of the overall surface, we can compute second order statistical averages of the scattered field with respect to such slopes.

In order to accomplish this aim, assuming small values for the facet slopes, we perform the second order MacLaurin expansion for the *hh*, *vv* and *hv* facet NRCS entries, thus obtaining, after averaging over the facets' slopes, that:

$$
\begin{cases}
\left\langle \sigma^0_{HH} \right\rangle_{|a,b} = \dfrac{4}{\pi}\left[C^{HH}_{0,0} + \left(C^{HH}_{2,0} + 2\dfrac{\mathrm{Re}\left\{C^{HV}_{0,0}\right\} - C^{HH}_{0,0}}{\sin^2 \vartheta} + C^{HH}_{0,2} \right)\sigma^2 \right] \\
\left\langle \sigma^0_{VV} \right\rangle_{|a,b} = \dfrac{4}{\pi}\left[C^{VV}_{0,0} + \left(C^{VV}_{2,0} + 2\dfrac{\mathrm{Re}\left\{C^{HV}_{0,0}\right\} - C^{VV}_{0,0}}{\sin^2 \vartheta} + C^{VV}_{0,2} \right)\sigma^2 \right] \\
\left\langle \sigma^0_{HV} \right\rangle_{|a,b} = \dfrac{4}{\pi}\left(C^{HH}_{0,0} + C^{VV}_{0,0} - 2\,\mathrm{Re}\left\{C^{HV}_{0,0}\right\}\right)\dfrac{\sigma^2}{\sin^2 \vartheta}
\end{cases} ,
$$

where $C^{p,q}_{k,n-k}\ \ \forall p,q \in \{H,V\}$, whose full expressions will be reported in the full-length paper, are Taylor series coefficients, that depend on the permittivity ε and on the radar look-angle ϑ; with $\langle \cdot \rangle_{|a,b}$ we denote the statistical mean with respect to the random variables *a* and *b* (i.e., the azimuth and range slopes, respectively).

3.RETRIEVAL METHOD, RESULTS AND VALIDATION

Once the NRCS's are computed, they can be used to build up numerical charts based on the co- and cross-polar ratios (i.e, the ratios between $\sigma°_{vv}$ and $\sigma°_{hh}$ or between $\sigma°_{hv}$ and $\sigma°_{vv}$, respectively), parameterized by the relative dielectric constant ε (or the soil moisture content m_v) and the large-scale roughness σ. These charts, an example of which is shown in Figure 2, can be used to get the soil moisture content and the large-scale roughness from a pair of co-pol, cross-pol measured data, obtained for instance using polarimetric SAR images. Of course, this operation can be performed in an automatic unsupervised way, by making use of a numerical code able to create soil moisture maps of sensed scenes simply comparing processed input SAR data with look-up tables built up from the above mentioned charts.

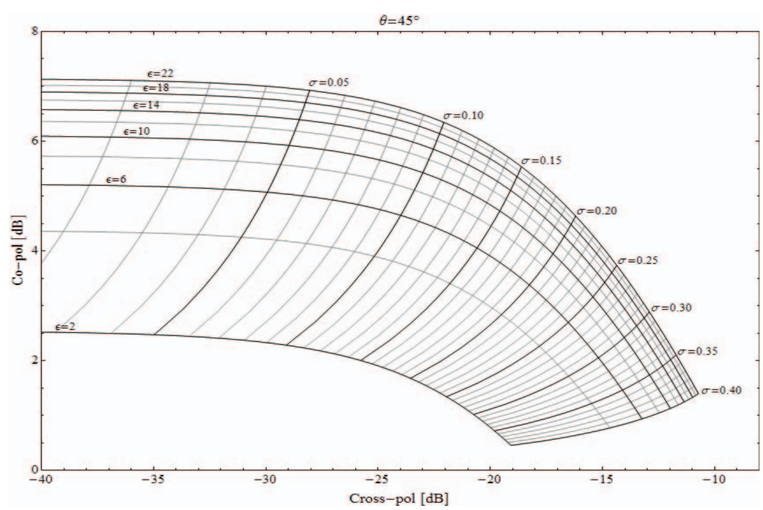

Figure 2: PTSM based Co-pol Cross-pol chart for ϑ=45°

A wide variety of scattering data at different frequencies, incidence angles, surface roughness and soil moisture contents, in conjunction with the corresponding ground truth, has been used to validate our retrieval method, and this material will be shown both in the full-length paper and at the conference. In all practical cases results obtained by using the PTSM are in a better agreement with measurements than those obtained by using already existing similar models.

Future works are addressed to further validation tests, to be conducted by using measurement campaigns that are planned at times of acquisition of available SAR sensors, like ALOS/PALSAR or COSMO/SkyMED. In addition, in order to extend soil moisture retrieval also to vegetated areas, an effort can be made to include the PTSM in one of the available physical-based polarimetric scattering decomposition methods [3-4].

References

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