Soil moisture retrieval via a Polarimetric Two-Scale and Two-Component scattering model

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Outline

- Introduction and motivations
- Scattering model
- Retrieval algorithm
- Preliminary results
- Conclusion

Introduction and motivations

- Soil moisture is related to soil dielectric constant
- Soil electromagnetic backscattering depends on soil dielectric constant

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In principle, it is possible to retrieve soil moisture from radar data

BUT

Electromagnetic backscattering is also strongly dependent on soil roughness and vegetation cover

Introduction and motivations

Problem:

separate dependencies on permittivity, roughness and vegetation

Need for accurate, general and simple scattering models

Approximate analytical methods for scattering evaluation

Introduction and motivations

In a previous work* we introduced the

Polarimetric Two-Scale Model (PTSM)

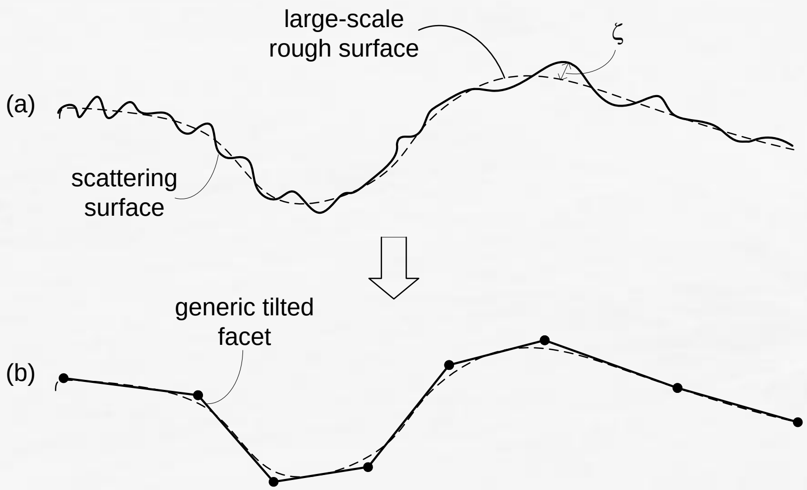
and, based on it, we devised a retrieval scheme for bare soils, making use of the SAR measured copol and crosspol ratios (or copol ratio and correlation coefficient)

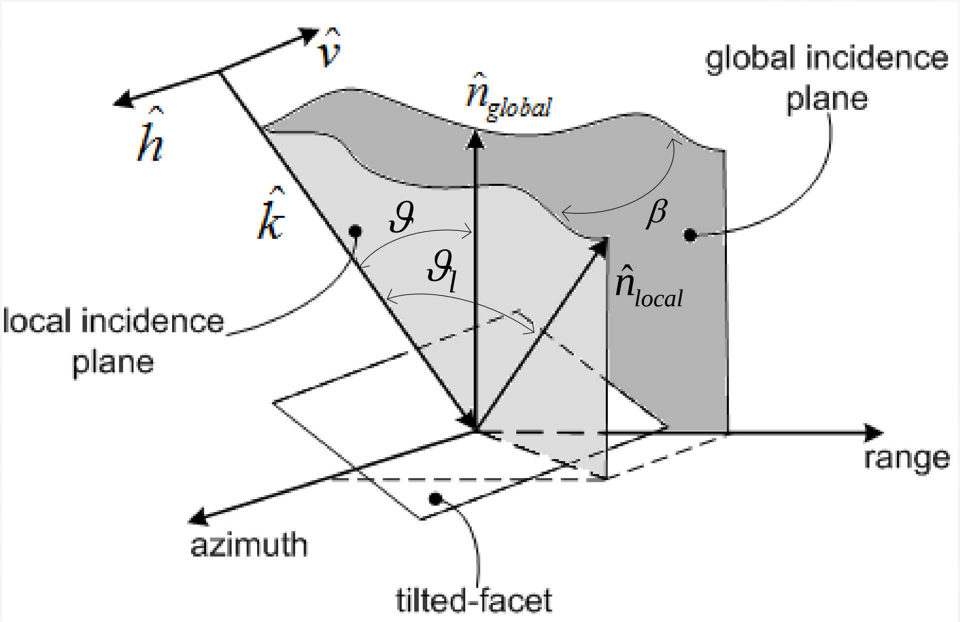
PTSM allows accounting for cross-polarisation and de-polarisation effects actually present in measured data even when surface scattering is the only present mechanism.

Here we show a method to include PTSM in a physical decomposition model, to deal with (moderately) vegetated soils

*A. Iodice, A. Natale, D. Riccio, "Retrieval of Soil Surface Parameters via a Polarimetric Two-Scale Model", *IEEE Transactions on Geoscience and Remote Sensing*, vol. 49, no. 7, pp. 2531-2547, July 2011.

Soil surface scattering - PTSM





Randomly tiltet facet $\rightarrow$ random variation of the local incidence angle ϑ_l and random rotation β of the incidence plane

Scattering model

esa

Soil surface scattering - PTSM

SPM covariance matrix of a tilted rough facet:

$$R_{pqrs} = \left\langle S_{pq} S_{rs}^{*} \right\rangle_{|\zeta} = k^4 \cos^4 \vartheta_l \, \chi_{pq}(\vartheta_l, \beta) \, \chi_{rs}^{*}(\vartheta_l, \beta) W\left(2k \sin \vartheta_l ; \mathbf{s}\right)$$

$$\underline{\underline{\chi}}(\vartheta_l, \beta) = \underline{\underline{R}}_2(\beta) \cdot \begin{pmatrix} F_H(\vartheta_l) & 0 \\ 0 & F_V(\vartheta_l) \end{pmatrix} \cdot \underline{\underline{R}}_2^{-1}(\beta) \qquad \underline{\underline{R}}_2(\beta) = \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix}$$

$\mathbf{s}$ is a set of parameters describing small-scale roughness

NRCS and other entries of the covariance matrix of the overall surface can be obtained by averaging over ϑ_l and β.

Problems: what are the pdf's of ϑ_l and β? How can corresponding averages be analytically computed?

Scattering model

Soil surface scattering - PTSM

1) Surface azimuth and ground range slopes, *a* and *b*, of the large scale roughness (i.e., of the facets) are modeled as i.i.d. zero-mean Gaussian variables with σ standard deviation

$$a, b \sim \mathrm{N}\left(0, \sigma^2\right)$$

2) The following relations between surface slopes and ϑ_l and β are employed

$$\tan\beta = \frac{a}{-b\cos\vartheta + \sin\vartheta} \qquad \cos\vartheta_l = \frac{\cos\vartheta + b\sin\vartheta}{\sqrt{1+a^2+b^2}}$$

3) NRCS and other entries of the covariance matrix of the overall surface are then obtained by averaging directly over *a* and *b* the corresponding tilted facets expressions, after a second order expansion around *a*=0, *b*=0.

In this way we include the randomness of both ϑ_l and β, and their statistical behavior is derived from the surface statistical model.

Scattering model

Soil surface scattering - PTSM

$$\left\langle \left|S_{vv}\right|^2 \right\rangle \cong f_s(\varepsilon,\mathbf{s})\left(1-\delta_V(\varepsilon)\sigma^2\right)$$

$$\left\langle \left|S_{hh}\right|^2 \right\rangle \cong f_s(\varepsilon,\mathbf{s})\left|\beta(\varepsilon)\right|^2\left(1+\delta_H(\varepsilon)\sigma^2\right)$$

$$\left\langle S_{hh}S_{vv}^* \right\rangle \cong f_s(\varepsilon,\mathbf{s})\beta(\varepsilon)\left(1+\delta_{HV}(\varepsilon)\sigma^2\right)$$

$$\left\langle \left|S_{hv}\right|^2 \right\rangle \cong f_s(\varepsilon,\mathbf{s})\left(\delta_X(\varepsilon)\sigma^2\right)$$

$\Rightarrow$

$$\frac{\left\langle \left|S_{hh}\right|^2 \right\rangle}{\left\langle \left|S_{vv}\right|^2 \right\rangle} \cong \left|\beta(\varepsilon)\right|^2\left(1+\delta_{copol}(\varepsilon)\sigma^2\right)$$

$$\frac{\left\langle \left|S_{hv}\right|^2 \right\rangle}{\left\langle \left|S_{vv}\right|^2 \right\rangle} \cong \delta_X(\varepsilon)\sigma^2$$

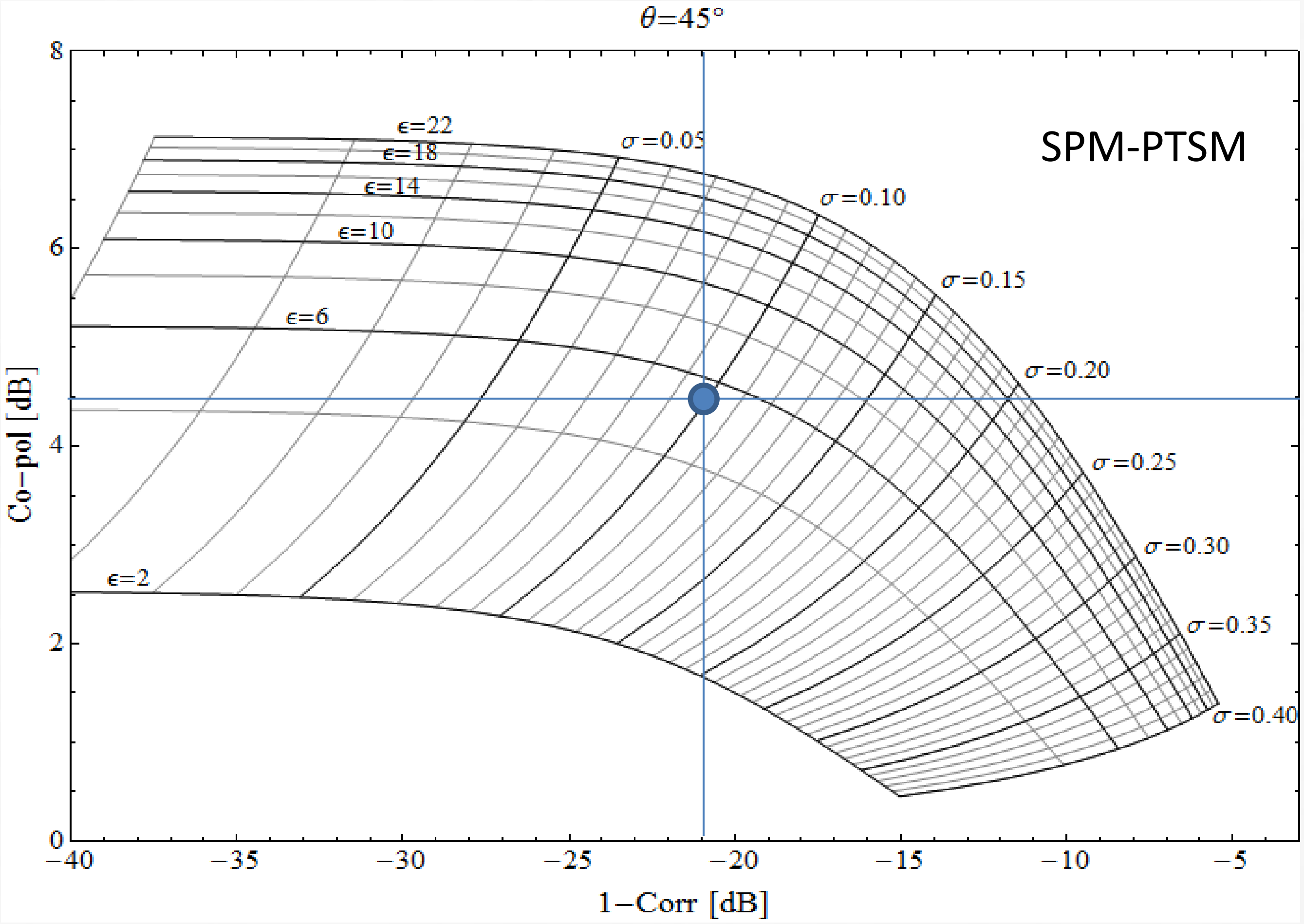
$$\frac{\left|\left\langle S_{hh}S_{vv}^* \right\rangle\right|}{\sqrt{\left\langle \left|S_{hh}\right|^2 \right\rangle\left\langle \left|S_{vv}\right|^2 \right\rangle}} \cong 1-\delta_{corr}(\varepsilon)\sigma^2$$

$$f_s(\varepsilon,\mathbf{s}) = k^4\cos^4\vartheta\, F_V(\vartheta;\varepsilon)\, W\left(2k\sin\vartheta;\mathbf{s}\right) \qquad \beta(\varepsilon) = \frac{F_H(\vartheta;\varepsilon)}{F_V(\vartheta;\varepsilon)}$$

$$\delta_{copol}(\varepsilon) = \delta_H(\varepsilon) + \delta_V(\varepsilon) \qquad \delta_{corr}(\varepsilon) = \tfrac{1}{2}\delta_H(\varepsilon) - \tfrac{1}{2}\delta_V(\varepsilon) - \mathrm{Re}\left\{\delta_{HV}(\varepsilon)\right\}$$

Scattering model

PTSM based Copol - Corr chart for ϑ=45°



Scattering model

Volume scattering from vegetation

The vegetation layer which covers the scattering surface is modeled by a cloud of randomly oriented thin dipoles.

For a uniform distribution of the orientation angle:

$$\left\langle \left|S_{vv}\right|^2 \right\rangle = f_v(\mathbf{u})$$

$$\left\langle \left|S_{hh}\right|^2 \right\rangle = f_v(\mathbf{u})$$

$$\left\langle S_{hh} S_{vv}^* \right\rangle = \frac{1}{3} f_v(\mathbf{u})$$

$$\left\langle \left|S_{hv}\right|^2 \right\rangle = \frac{1}{3} f_v(\mathbf{u})$$

$\mathbf{u}$ is a set of parameters describing the dipole cloud

Scattering model

Overall (surface + volume) scattering

$$\left\langle \left| S_{vv} \right|^2 \right\rangle \cong f_s(\varepsilon, \mathbf{s})\left(1 - \delta_V(\varepsilon)\sigma^2\right) + f_v(\mathbf{u})$$

$$\left\langle \left| S_{hh} \right|^2 \right\rangle \cong f_s(\varepsilon, \mathbf{s})\left|\beta(\varepsilon)\right|^2\left(1 + \delta_H(\varepsilon)\sigma^2\right) + f_v(\mathbf{u})$$

$$\left\langle S_{hh} S_{vv}^* \right\rangle \cong f_s(\varepsilon, \mathbf{s})\beta(\varepsilon)\left(1 + \delta_{HV}(\varepsilon)\sigma^2\right) + \frac{1}{3} f_v(\mathbf{u})$$

$$\left\langle \left| S_{hv} \right|^2 \right\rangle \cong f_s(\varepsilon, \mathbf{s})\left(\delta_X(\varepsilon)\sigma^2\right) + \frac{1}{3} f_v(\mathbf{u})$$

Retrieval algorithm

Modified copol ratio and modified correlation coefficient

$$\frac{\left\langle |S_{hh}|^2 \right\rangle - 3\left\langle |S_{hv}|^2 \right\rangle}{\left\langle |S_{vv}|^2 \right\rangle - 3\left\langle |S_{hv}|^2 \right\rangle} \cong |\beta(\varepsilon)|^2 \left(1 + \delta_{copol}(\varepsilon)\sigma^2 - \delta'_{copol}(\varepsilon)\sigma^2\right)$$

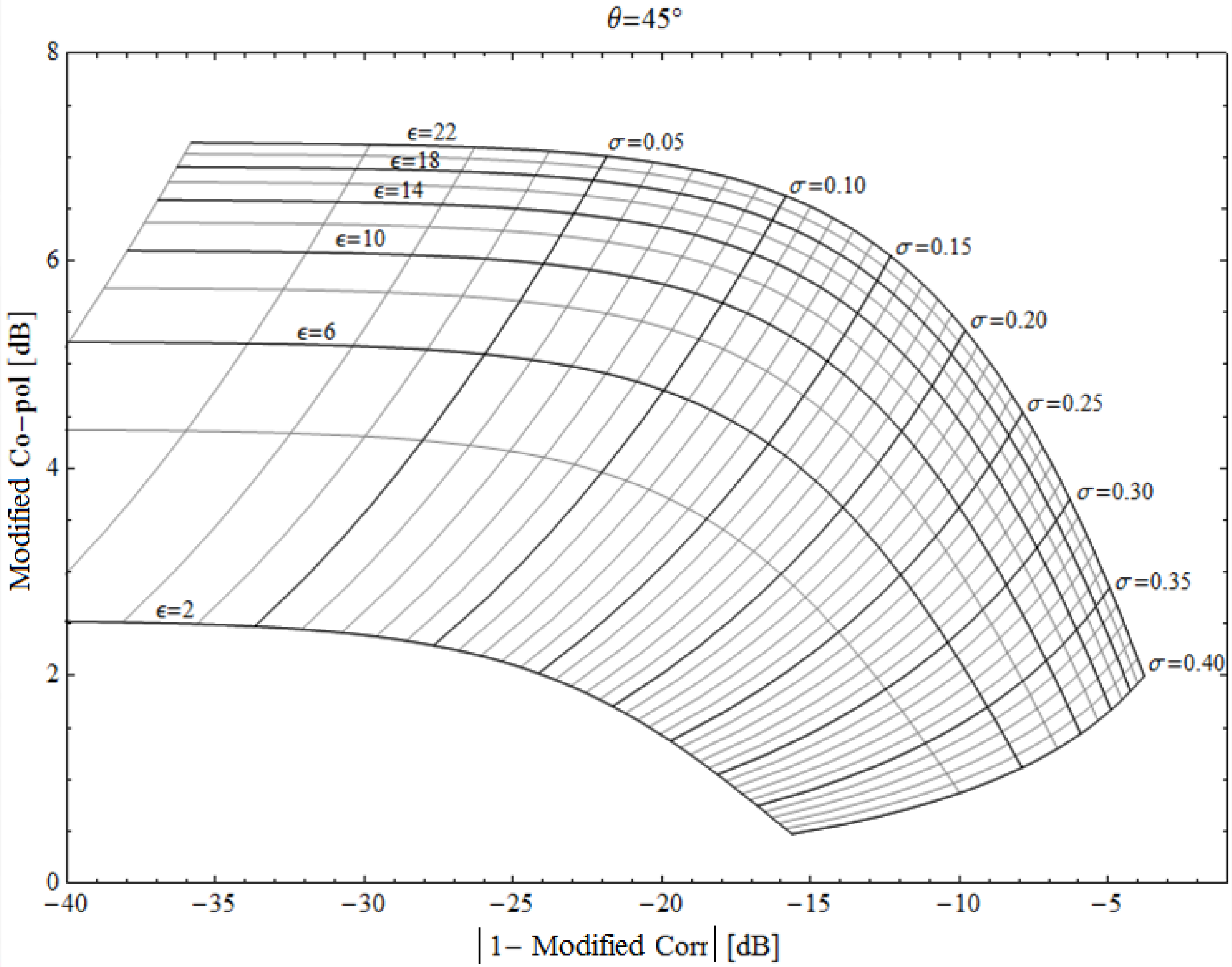
$$\frac{\left| \left\langle S_{hh} S_{vv}^* \right\rangle - \left\langle |S_{hv}|^2 \right\rangle \right|}{\sqrt{\left(\left\langle |S_{hh}|^2 \right\rangle - 3\left\langle |S_{hv}|^2 \right\rangle\right)\left(\left\langle |S_{vv}|^2 \right\rangle - 3\left\langle |S_{hv}|^2 \right\rangle\right)}} \cong 1 - \delta_{corr}(\varepsilon)\sigma^2 + \delta'_{corr}(\varepsilon)\sigma^2$$

$$\delta'_{copol}(\varepsilon) = 3\delta_X(\varepsilon)\left(\frac{1}{|\beta(\varepsilon)|^2} - 1\right) \qquad \delta'_{corr}(\varepsilon) = \frac{1}{2}\delta_X(\varepsilon)\left(\frac{3}{|\beta(\varepsilon)|^2} + 3 - \mathrm{Re}\left\{\frac{2}{\beta(\varepsilon)}\right\}\right)$$

Note: the modified correlation coefficient is not a correlation coefficient and hence it is not restricted to be smaller than unity.

Retrieval algorithm

Modified Copol - Modified Corr chart for ϑ=45°

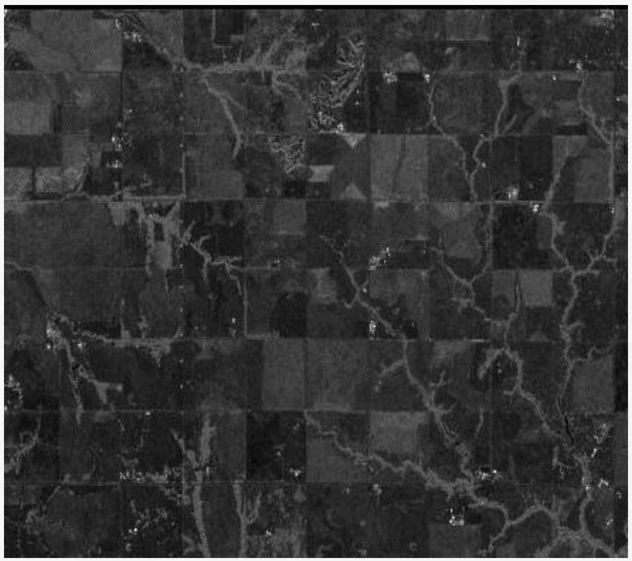


Preliminary results

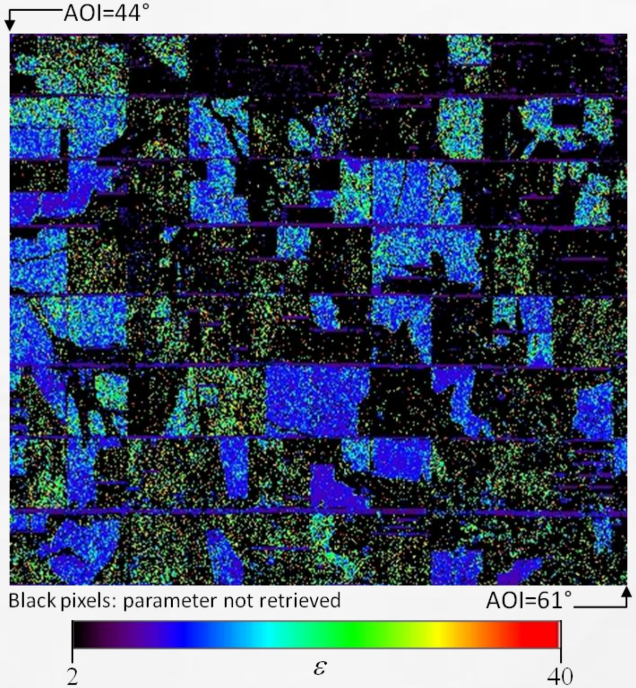
Employed dataset

AIRSAR L-band data, Little Washita*: comparison with ground measurements

Optical image acquired on August 2003 relevant to the considered scene, with the indication of "in situ" measurement sites.



VV channel of the AIRSAR acquisition of July 5, 2003.



Permittivity map obtained using the copol-corr method, pertinent to the AIRSAR acquisition of July 5, 2003.

* T. J. Jackson, M. H. Cosh, *SMEX03 watershed ground soil moisture data: Oklahoma*, 2006, freely available online at http://nsidc.org/data/amsr_validation/soil_moisture/smex03.

Preliminary results

Employed dataset

Photograph of site LW22 taken on July 3, 2003.

Photograph of site LW29 taken on July 8, 2003.

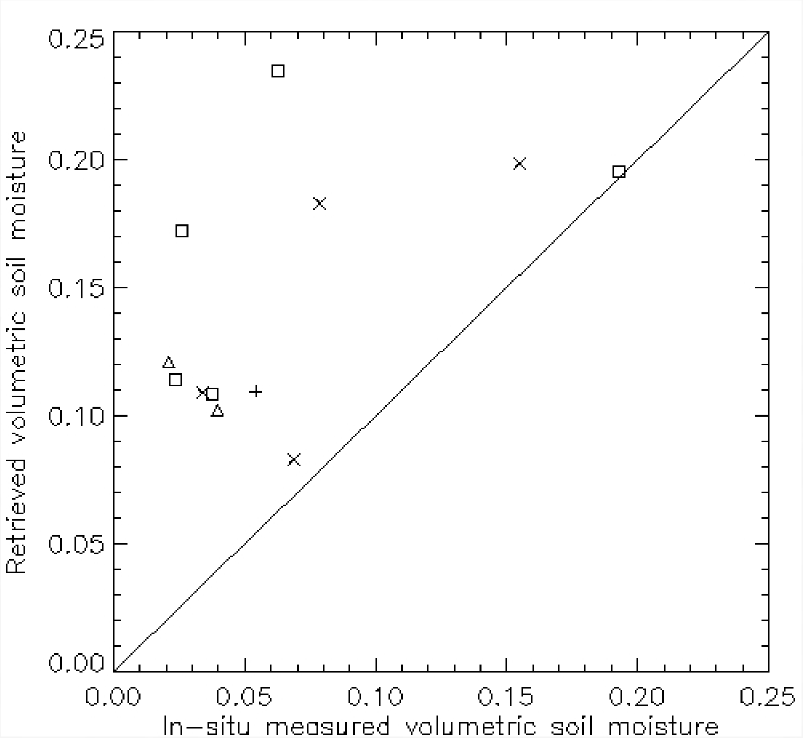
Sites LW21 and LW22 are bare soil fields.

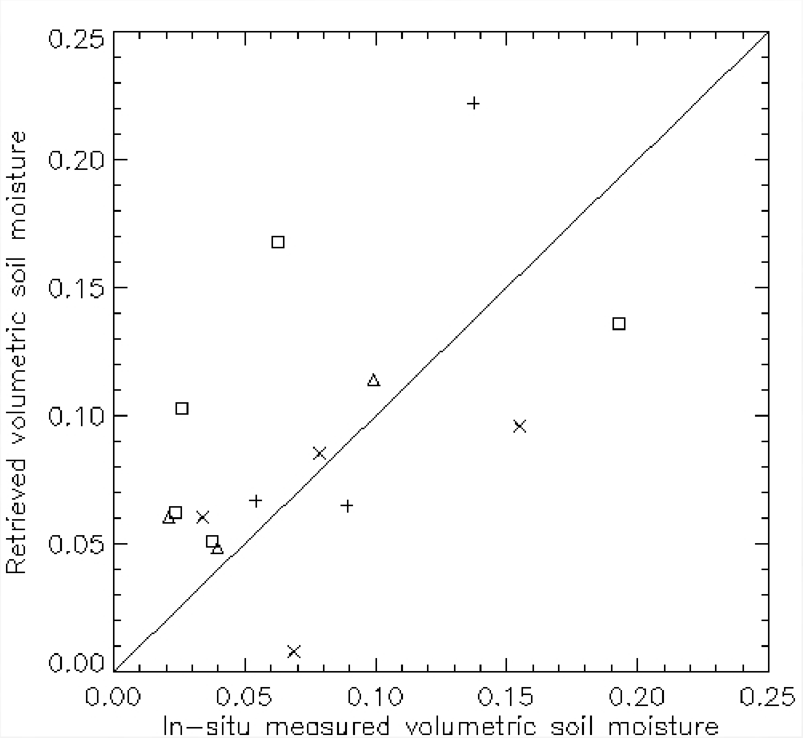
Sites LW20, LW27, LW28 and LW29 are moderately vegetated soil fields.

Preliminary results

Comparison with ground measurements

POLARSCAT and AIRSAR L-band data, vegetated soil fields





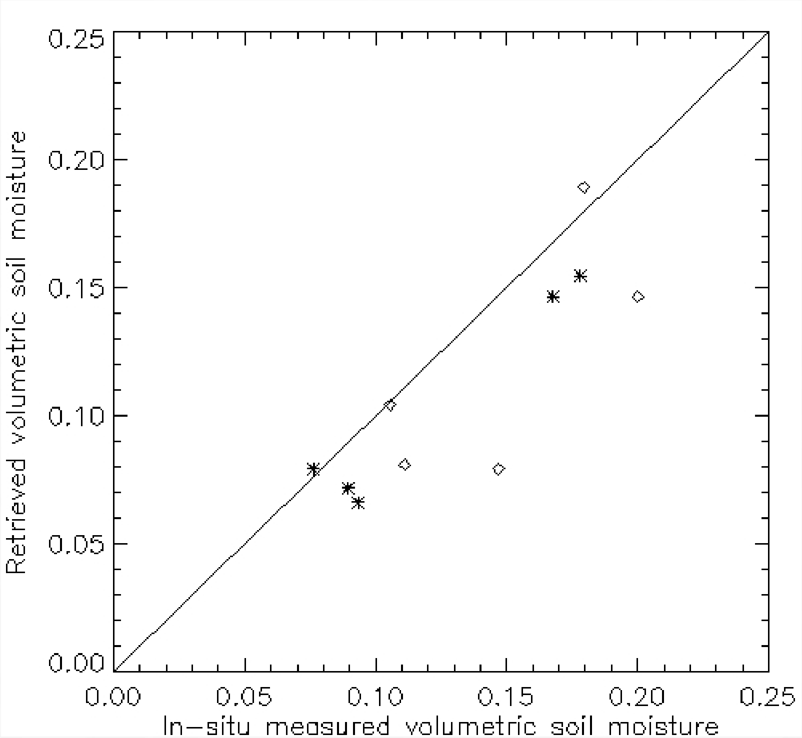
Retrieval results obtained through the copol-corr method for LW20 (plus signs), LW27 (triangles), LW28 (squares) and LW29 (crosses) measurement sites (ME = +0.117, ESD = 0.075, R = 0.61).

Retrieval results obtained through the modified copol-corr method for LW20 (plus signs), LW27 (triangles), LW28 (squares) and LW29 (crosses) measurement sites (ME = +0.033, ESD = 0.068, R = 0.53).

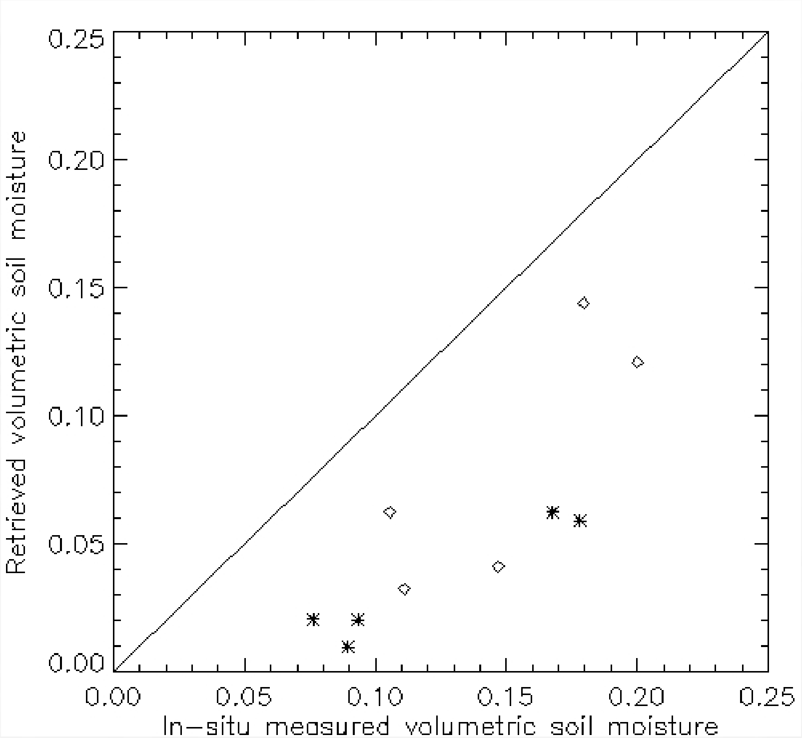
Preliminary results

Comparison with ground measurements

POLARSCAT and AIRSAR L-band data, bare soil fields



Retrieval results obtained through the copol-corr method for LW21 (asterisks) and LW22 (diamonds) measurement sites (ME = –0.023, ESD = 0.022, R = 0.85).



Retrieval results obtained through the modified copol-corr method for LW21 (asterisks) and LW22 (diamonds) measurement sites (ME = –0.078, ESD = 0.025, R = 0.81).

Conclusion

Summary

- A PTSM-based soil moisture retrieval scheme relying on co-pol/cross-pol charts or co-pol/corr charts was devised in previous work. It provides reliable results for bare soils.

- Inclusion of PTSM in a two-component physical decomposition model has been presented here, to extend the range of validity of the retrieval scheme to moderately vegetated soils.

- Modified co-pol and modified corr have been defined, which in principle are independent of the volumetric scattering component.

- Validation is being performed by using experimental data from measurement campaigns available in literature.

Future work

- Continuing validation.
- Using coherency, rather than covariance, matrix elements.
- Refining models.