Sensitivity of different scattering mechanisms to soil moisture and vegetation over corn fields in Argentina

Giovanni Anconitano[a], Olena Sarabakha[a], Si Mokrane SIAD[a], Nazzareno Pierdicca[a], Lorenzo G. Papale[b], Leila Guerriero[b], Mario A. Acuña[c]

[a]Department of Information Engineering, Electronics and Telecommunications (DIET), Sapienza University of Rome, Rome, Italy;
[b]Department of Civil Engineering and Computer Science Engineering (DICII), Tor Vergata University of Rome, Rome, Italy;
[c]Comisión Nacional De Actividades Espaciales (CONAE), Buenos Aires, Argentina

Objectives

- To **evaluate** the **capability** of a **fully polarimetric radar system** to highlight the **sensitivity** to **soil moisture** variation and **vegetation** changes by analysing a **time-series** of **SAR data** collected at **L-band** by the **SAOCOM-1A** mission over an **agricultural area** in Argentina (**Monte Buey**, Córdoba Province).

- To **apply** four **polarimetric SAR decompositions** (**Freeman-Durden FD** [1], **van Zyl VZ3** [2], **Generalized Freeman-Durden FDG** [3] and **Yamaguchi Y4R** [4]) to a stack of measured **covariance matrices** extracted from the **SAOCOM** data and **identify** canonical **scattering mechanisms** (**surface**, **double-bounce**, **volume**).

- To **compare** the **scattering contributions** from the **polarimetric decompositions** with those obtained by the **simulations** of the fully polarimetric **electromagnetic model** developed at **Tor Vergata University**.

[1] A. Freeman, S. L. Durden, "A Three-Component Scattering Model for Polarimetric SAR Data", *IEEE Trans. Geosci. Remote Sens.*, vol. 36, May 1998.

[2] J. J. van Zyl, "Application of Cloude's target decomposition theorem to polarimetric imaging radar data", *Optics & Photonics*, 1993.

[3] S. R. Cloude, "Decomposition theorems," in *Polarisation: Applications in remote sensing*, 2010, pp. 198-201.

[4] Y. Yamaguchi, A. Sato, W. Boerner, R. Sato, H. Yamada, "Four-Component Scattering Power Decomposition With Rotation of Coherency Matrix," *IEEE Trans. Geosci. Remote Sens.*, vol. 49, no. 6, pp. 2251-2258, June 2011.

Methodology - The Tor Vergata Model

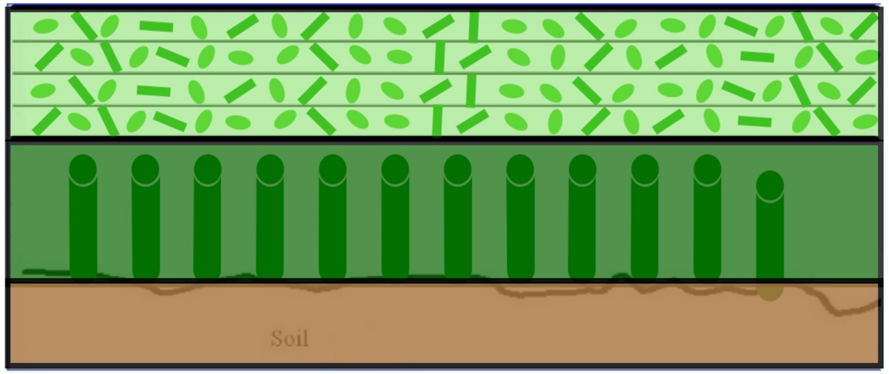
The **Tor Vergata Model** is based on the radiative transfer theory applied to discrete scatterers with simple shapes [5] and specific absorbing and scattering properties to model the plant structure elements.

The model takes as input:

- sensor configuration (signal frequency, incidence angle, polarization);
- soil properties (soil moisture and roughness);
- vegetation parameters (plant height and scatterers properties).

The "Matrix doubling" algorithm [6] models the scattering interactions of any order (e.g., attenuation and scattering effects) between each layer and sublayer.

Corn plant modelling

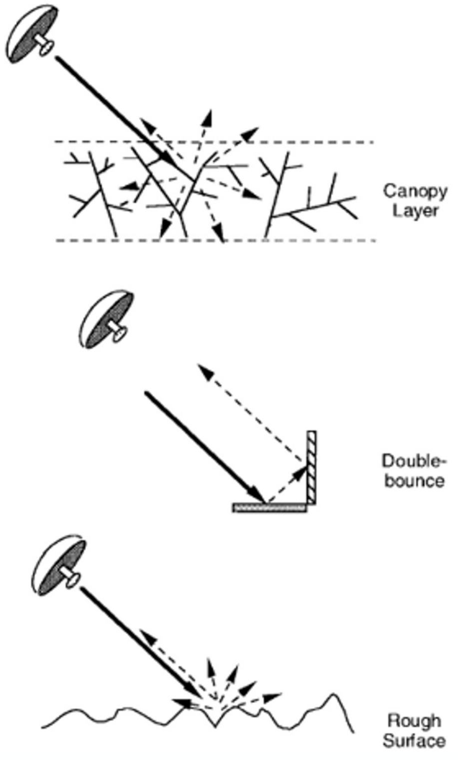


[5] L. G. Papale, F. Del Frate, L. Guerriero and G. Schiavon, "A Physics-Based ML Approach for Corn Plant Height Estimation with Simulated Sar Data," *IGARSS 2022 - 2022 IEEE IGARSS Symposium.*

[6] M. Bracaglia, P. Ferrazzoli, and L. Guerriero, "A fully polarimetric multiple scattering model for crops," Remote Sens. Env., pp. 170-179, 1995.

Methodology - Polarimetric SAR decompositions

The **covariance matrix C3** is **modeled** as a **combination** of **scattering mechanisms**.

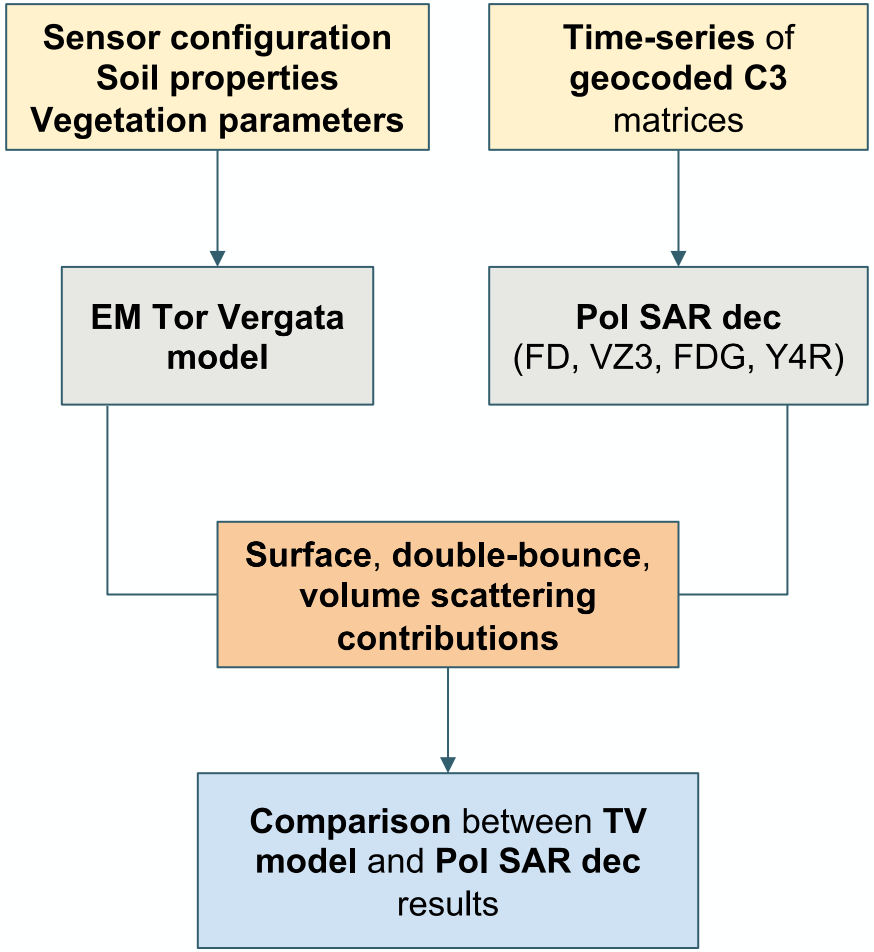


Sketch of the three scattering mechanisms: canopy scatter (top), double-bounce scatter (middle) and surface scatter (bottom) [1].

Decomposition	Type	C_3 matrix / powers
FD	Model-based	$C_3^{tot} = C_3^{surf} + C_3^{dbl} + C_3^{vol}$ $P_{tot} = P_{surf} + P_{dbl} + P_{vol}$
VZ	Eigenvalues/eigenvectors based	
GFD	Hybrid	
Y4R	Model-based	$C_3^{tot} = C_3^{surf} + C_3^{dbl} + C_3^{vol} + C_3^{hel}$ $P_{tot} = P_{surf} + P_{dbl} + P_{vol} + P_{hel}$

Main characteristics of the 4 polarimetric decompositions considered for the analysis

Workflow



Definition and **collection** of the **input** for both the **EM Tor Vergata model** and the **polarimetric SAR decompositions** (a **time-series** of **geocoded C3 matrices** extracted from **L-band full-pol SAOCOM-1A** images).

Simulations of the **EM Tor Vergata model** and **application** of **4** different **polarimetric decompositions** (**FD**, **VZ3**, **FDG**, **Y4R**).

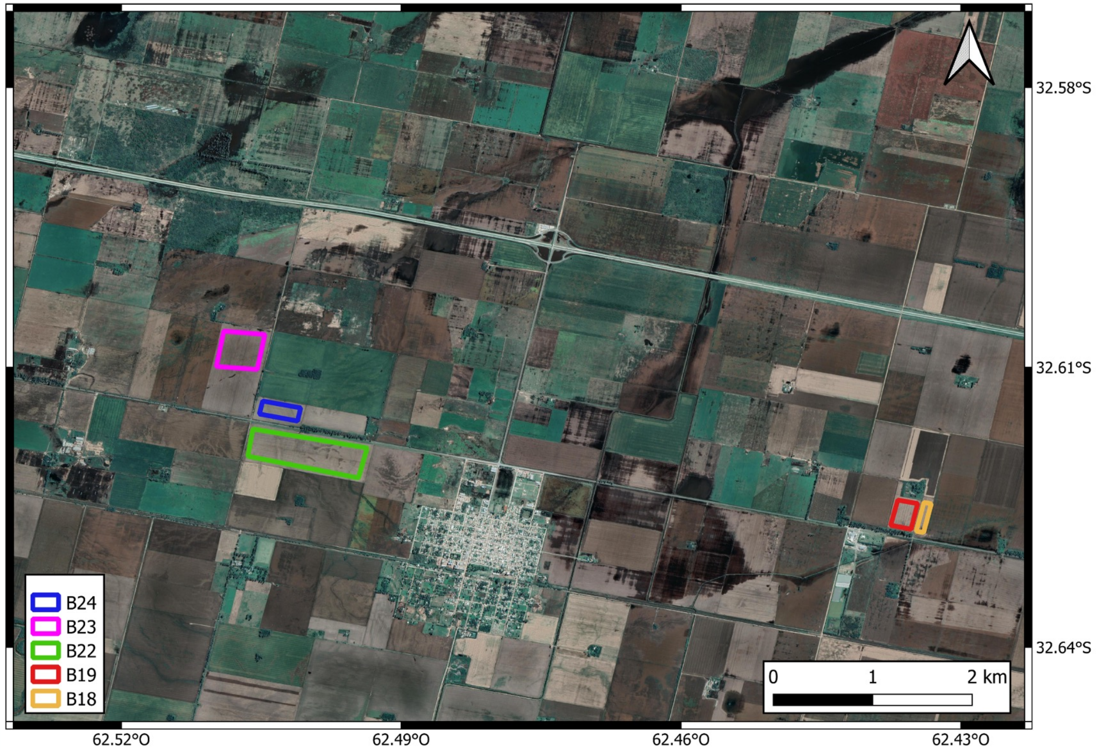
Extraction of **scattering mechanisms** (**surface**, **double-bounce**, **volume**): **powers** for all the four decompositions and **multi-polarization backscattering coefficient (HH, VV)** for FD and VZ3.

Comparison between the **results** obtained from the **TV model** and the application of the **polarimetric SAR decompositions**.

Case study and datasets

- A **time-series** of **SAOCOM-1A SLC descending images** (**October 2019 - February 2020**).
- **5 corn fields** (ID: B18, B19, B22, B23, B24) over an agricultural area in the **Monte Buey site** (Córdoba Province, Argentina).
- **Field campaign** conducted by CONAE to collect in-situ data such as **soil moisture**, **plant height**, and **growth stage**.
- The **NDVI** derived from **Sentinel-2** and **linearly interpolated** into the **SAOCOM dates** is also used as a proxy of the vegetation.

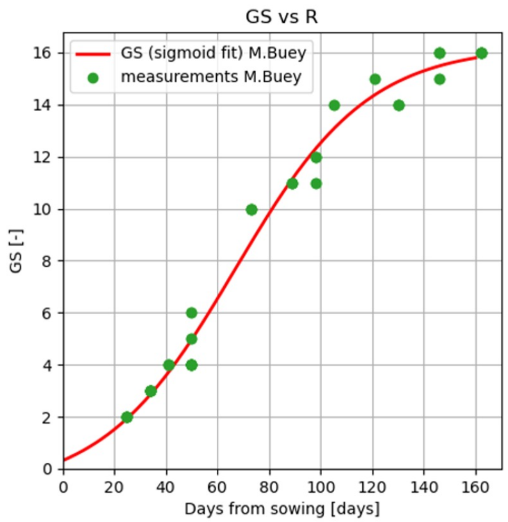
SAOCOM-1A acquisitions		
13/10/2019	30/11/2019	17/01/2020
29/10/2019	16/12/2019	02/02/2020
14/11/2019	01/01/2020	18/02/2020



Site of interest: it is a core validation site for the SMAP mission and the validation of the SAOCOM products generated by CONAE.

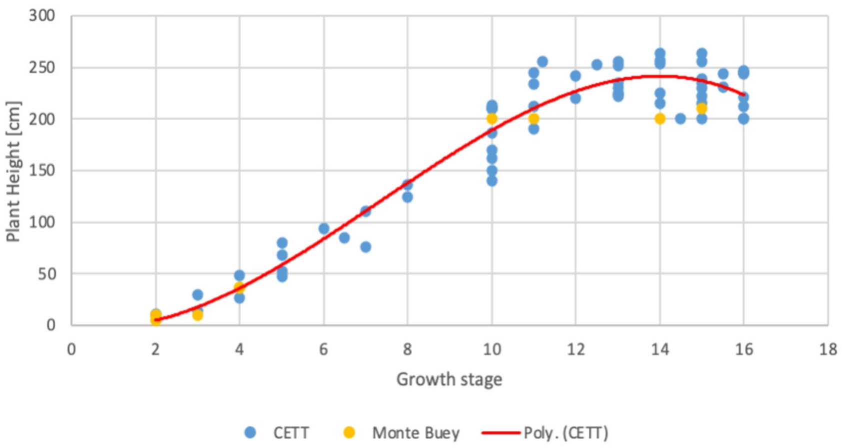
Tor Vergata model: parameters estimation

Plant height derivation

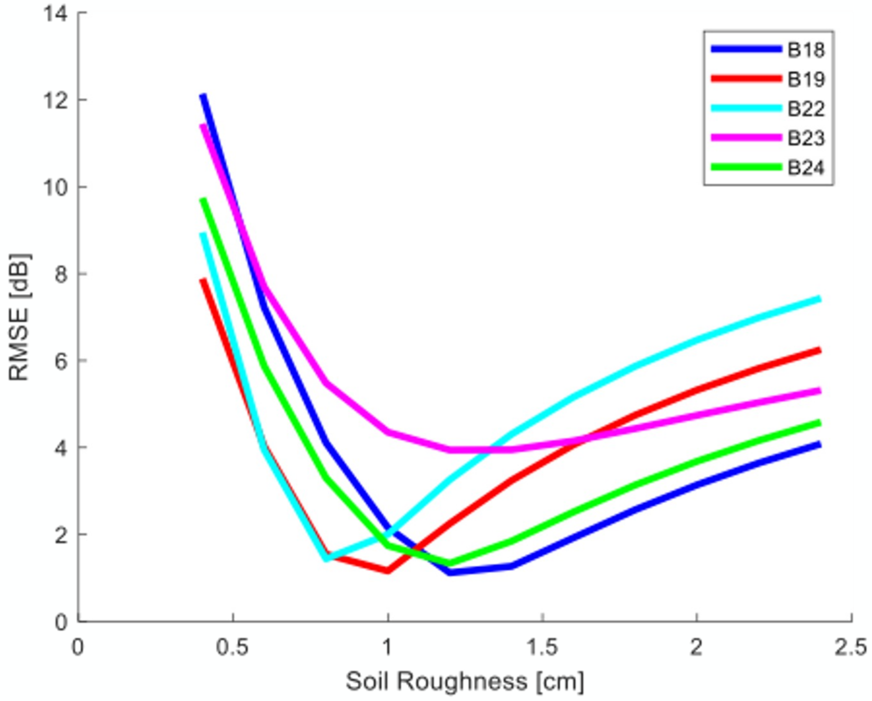


The **Growth Stage (GS)** missing values are derived by interpolating measured data with a **sigmoid** function.

Consequently, a relation between **GS** and **Plant height** is derived.



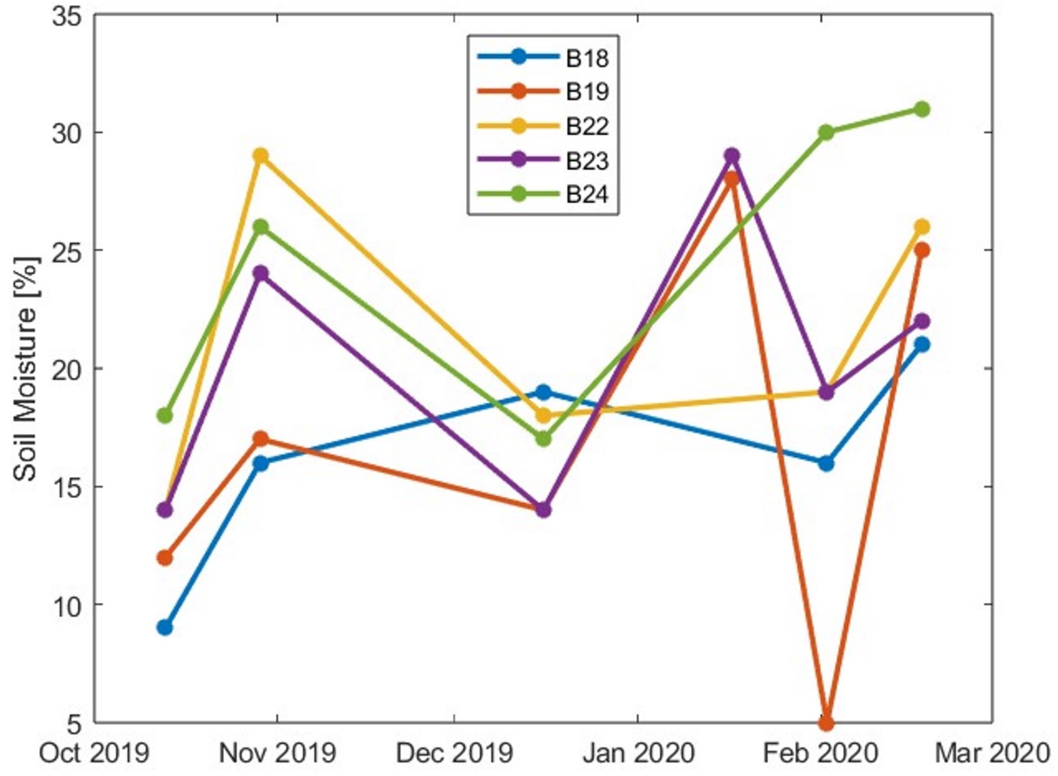
Surface roughness estimation



The **optimal surface roughness** is derived by looking at which value returns the **minimum Root Mean Square Error** between the **measured SAOCOM data** and the **modeled backscattering coefficient**.

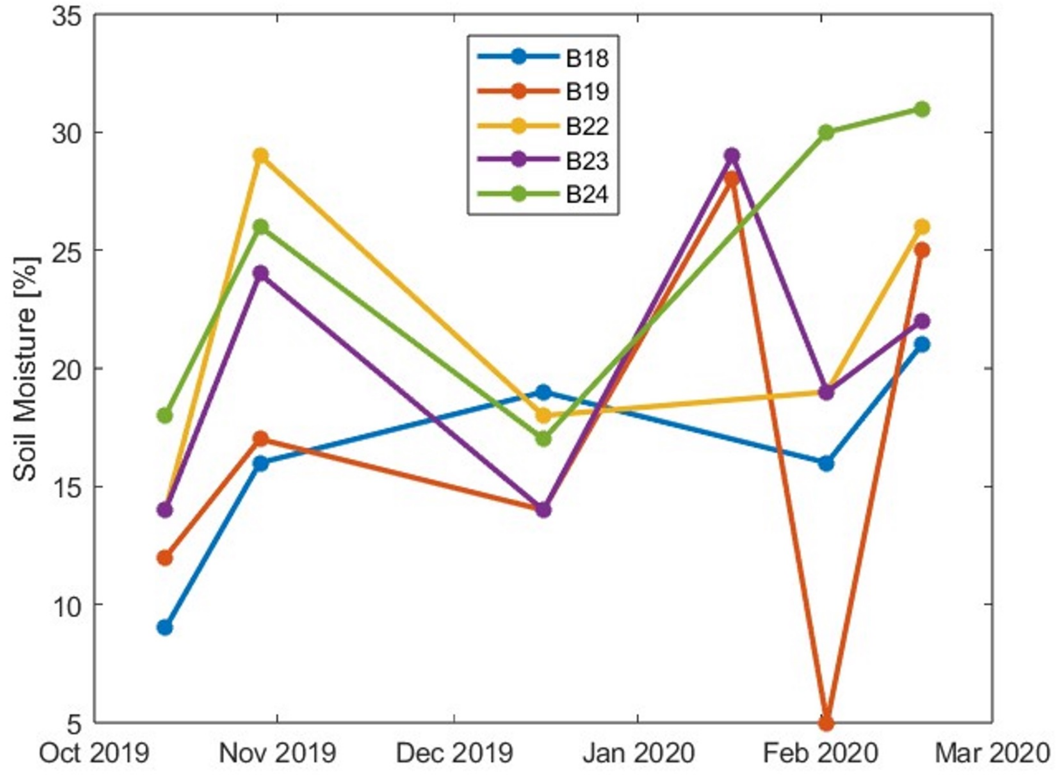
Tor Vergata model: simulated and measured data

Integration of measured soil moisture

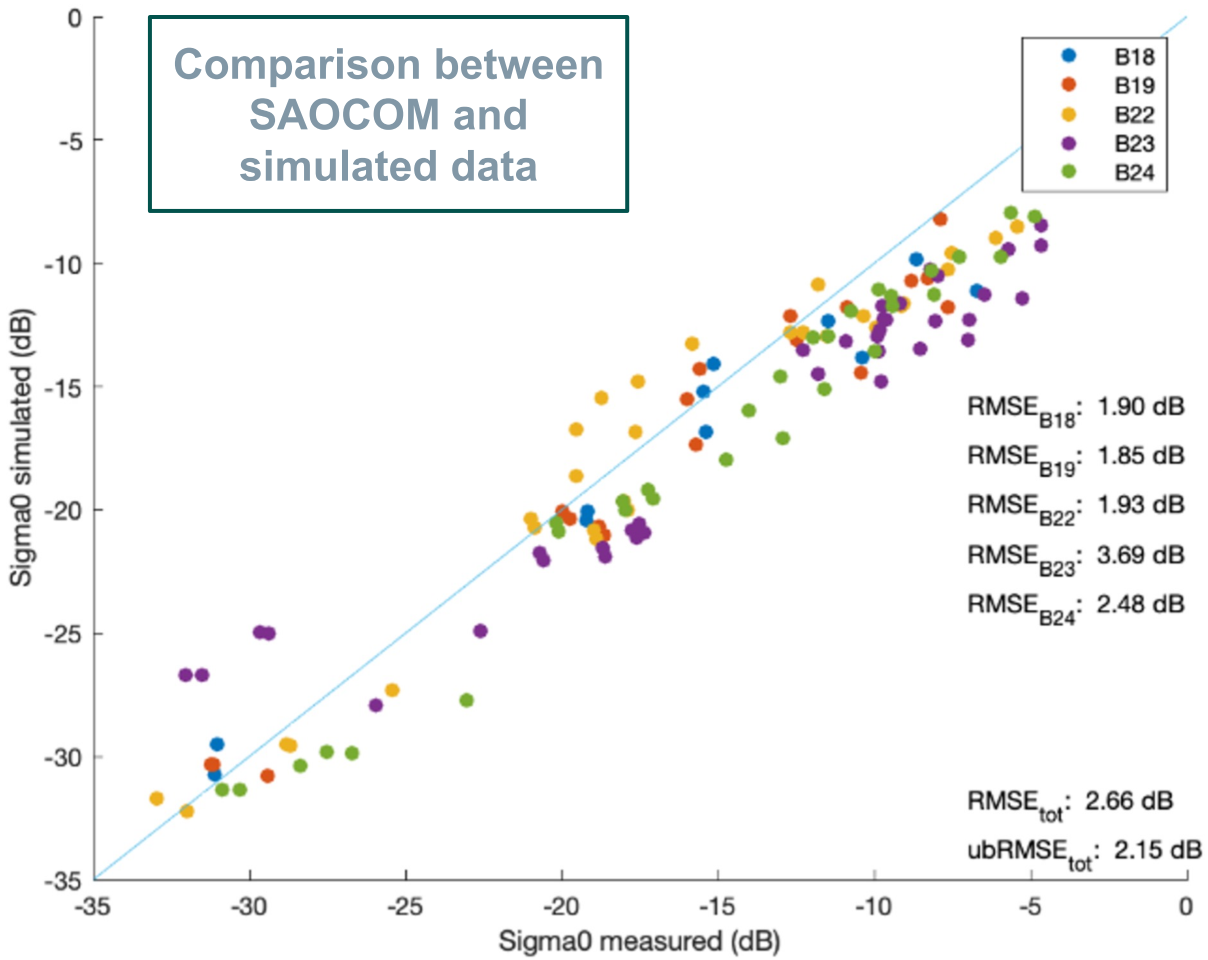


Tor Vergata model: simulated and measured data

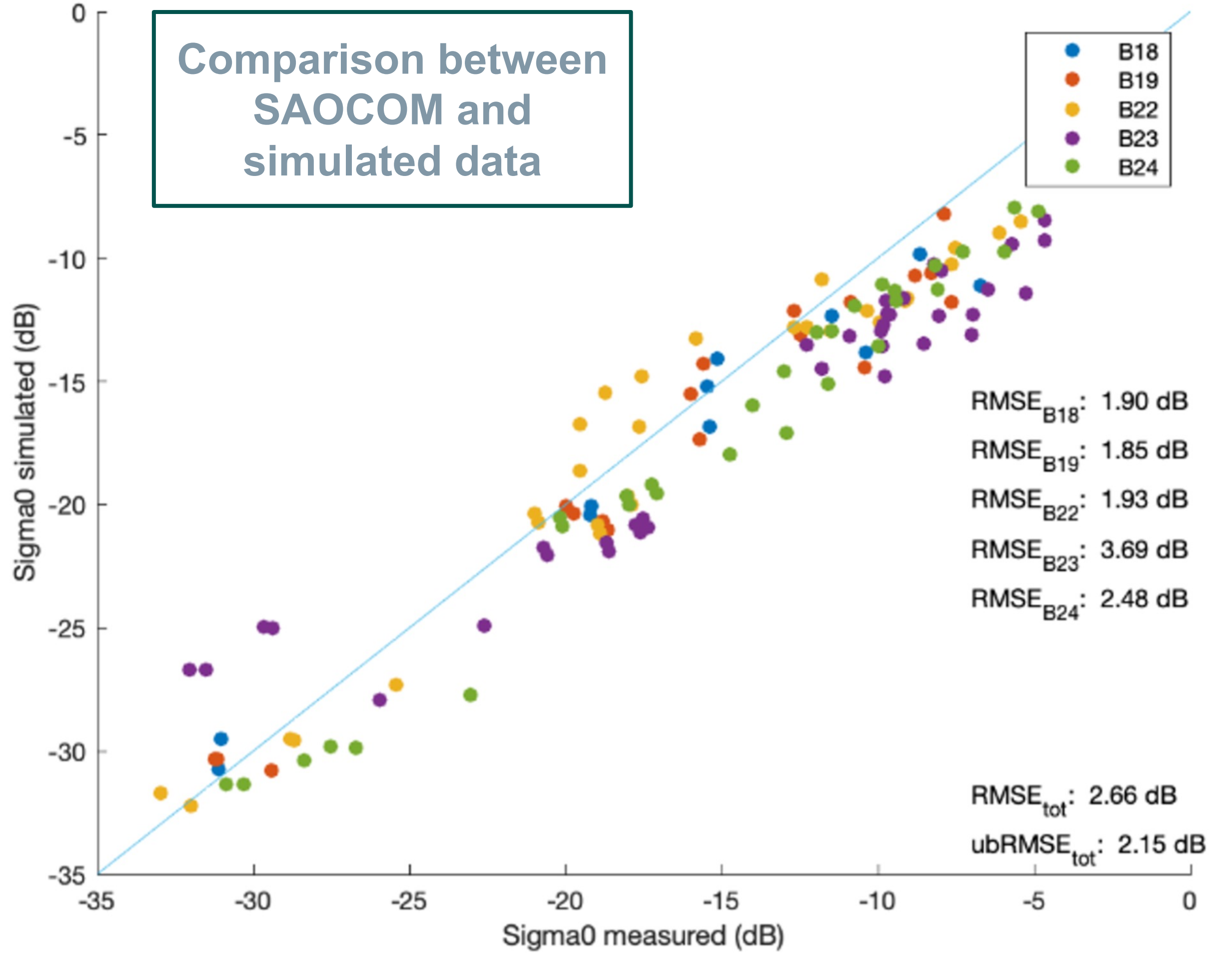
Integration of measured soil moisture



Comparison between SAOCOM and simulated data

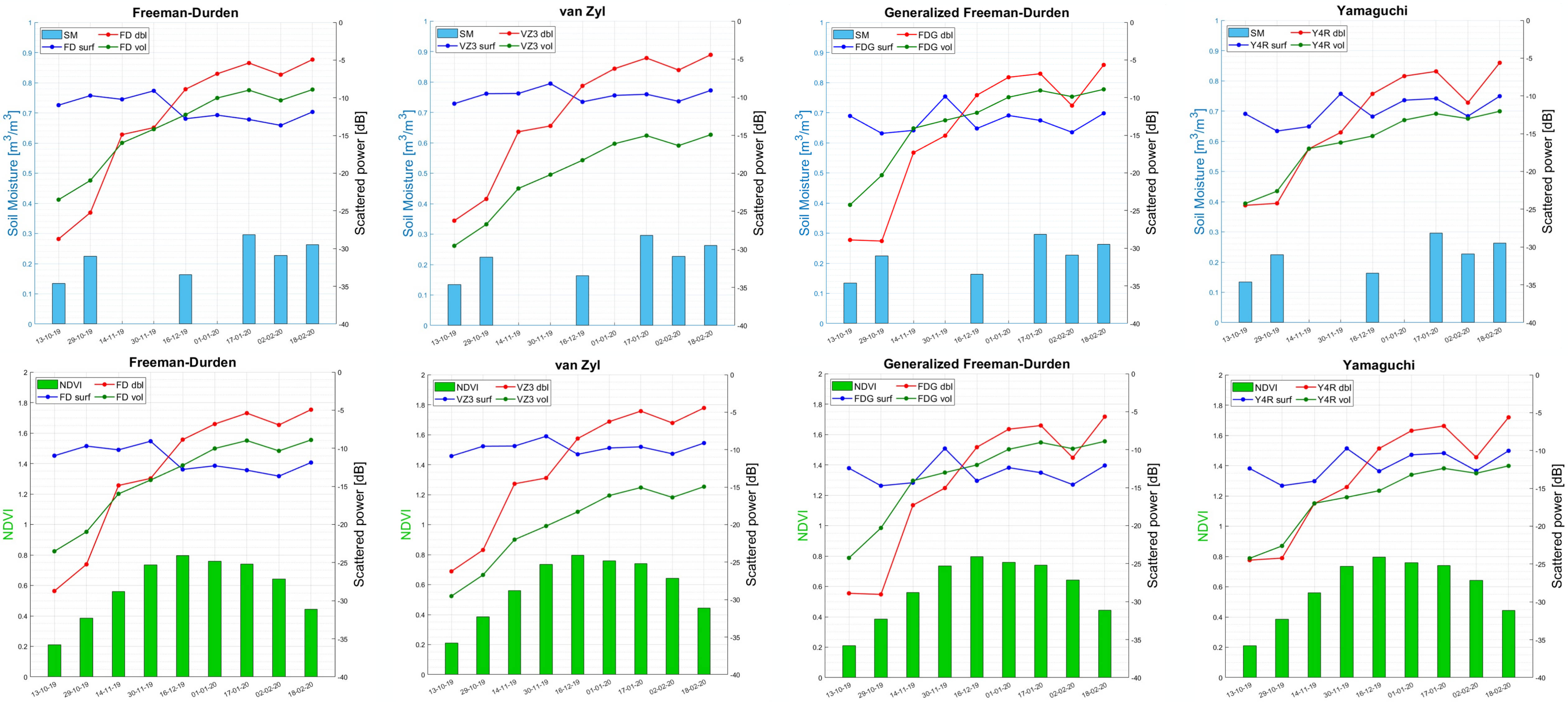


Tor Vergata model: simulated and measured data

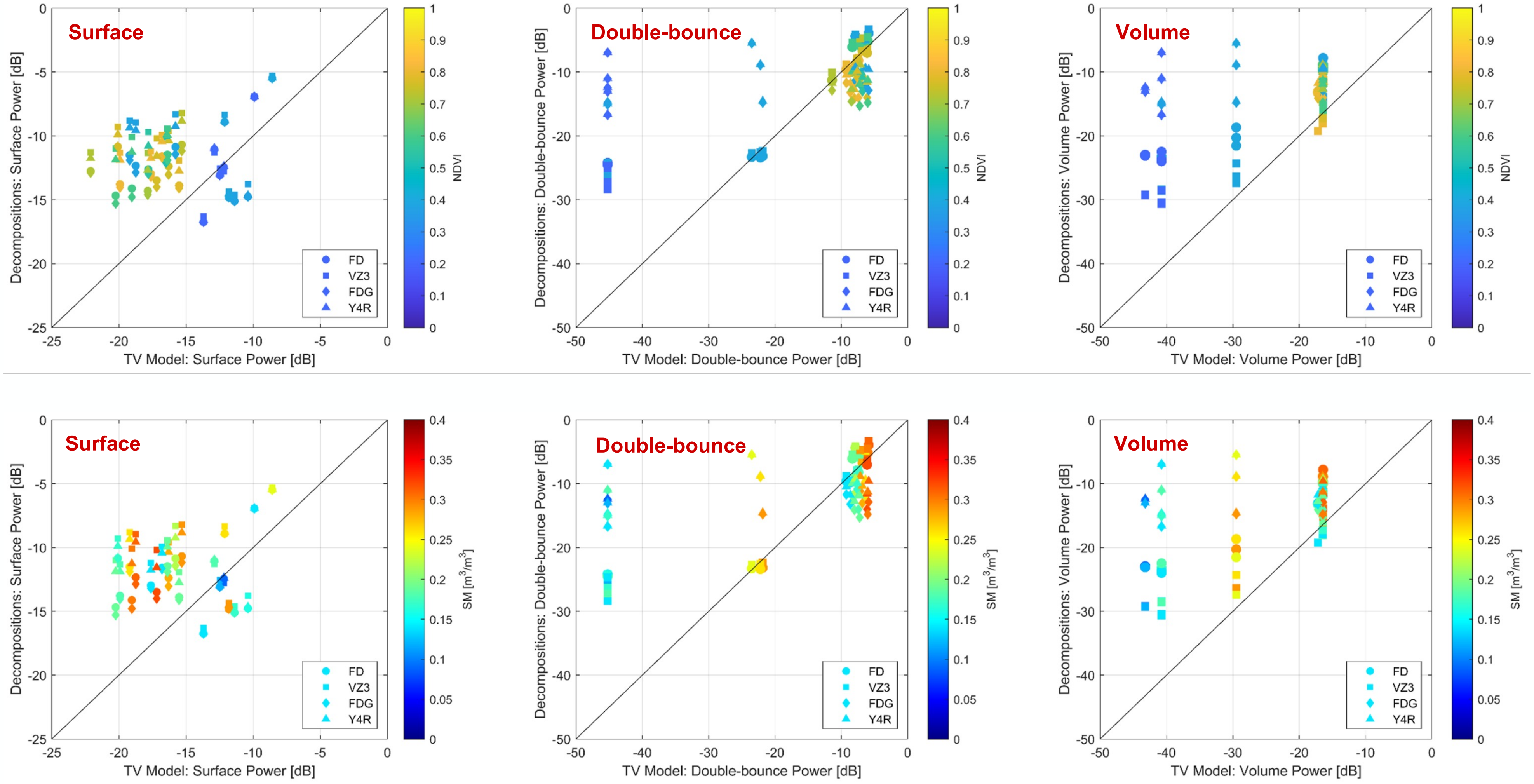


- Once all the input data are defined, a point by point comparison was performed.
- The simulated data follow the same dynamic range of the SAOCOM data.
- The lowest backscattering coefficients correspond to bare soils and the highest to well developed fields.
- The highest RMSE is obtained for field B23.
- In general, the model slightly underestimates the backscatter values. An unbiased RMSE equal to 2.15 dB is obtained.

Evolution of polarimetric decompositions



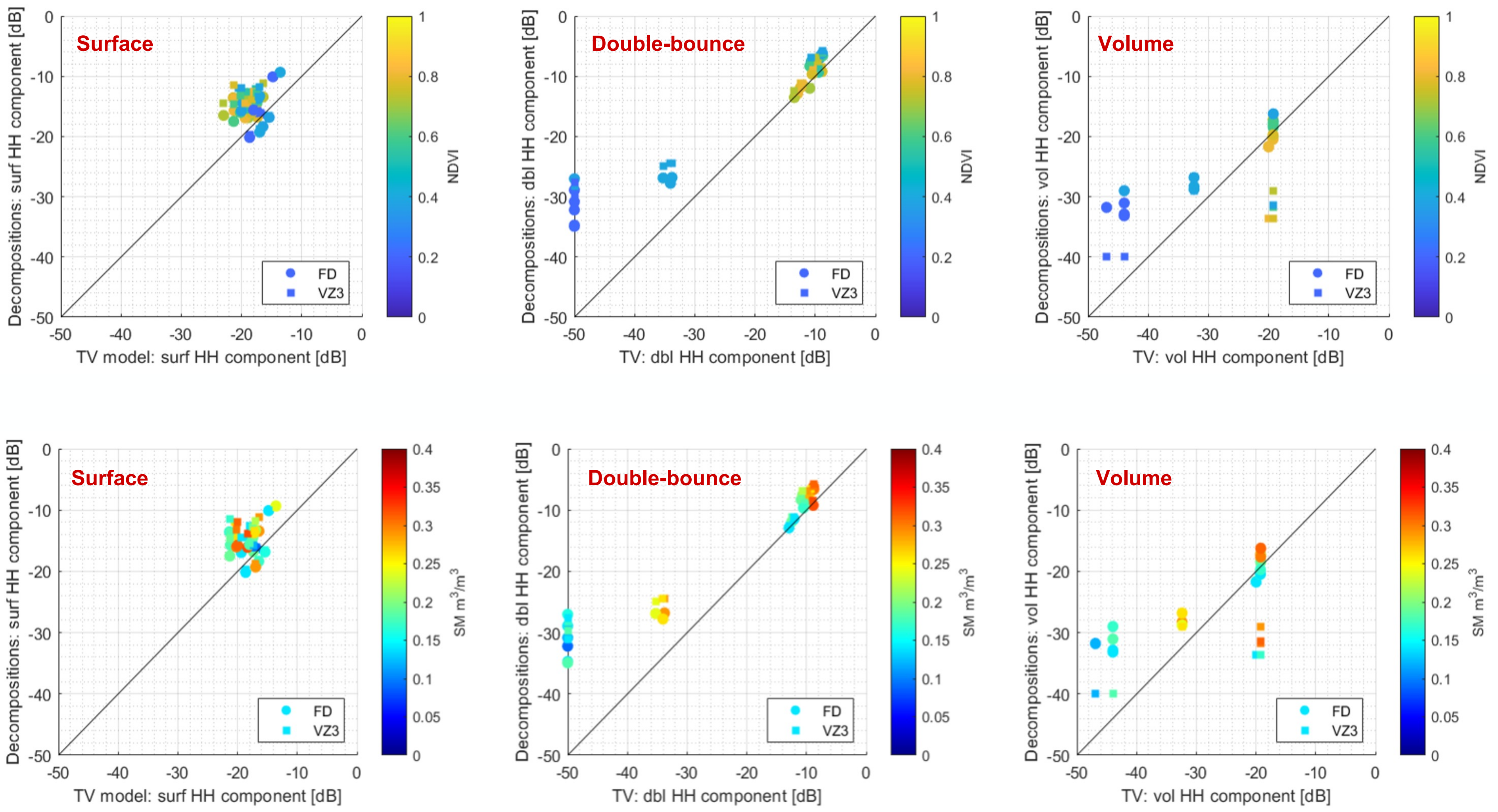
PolSAR - TV model comparison based on NDVI and SM



- For the double-bounce power, there is a good agreement between the results for medium and high NDVI values while, for the surface power, when the NDVI is low there is a good agreement between the results except for a bias.

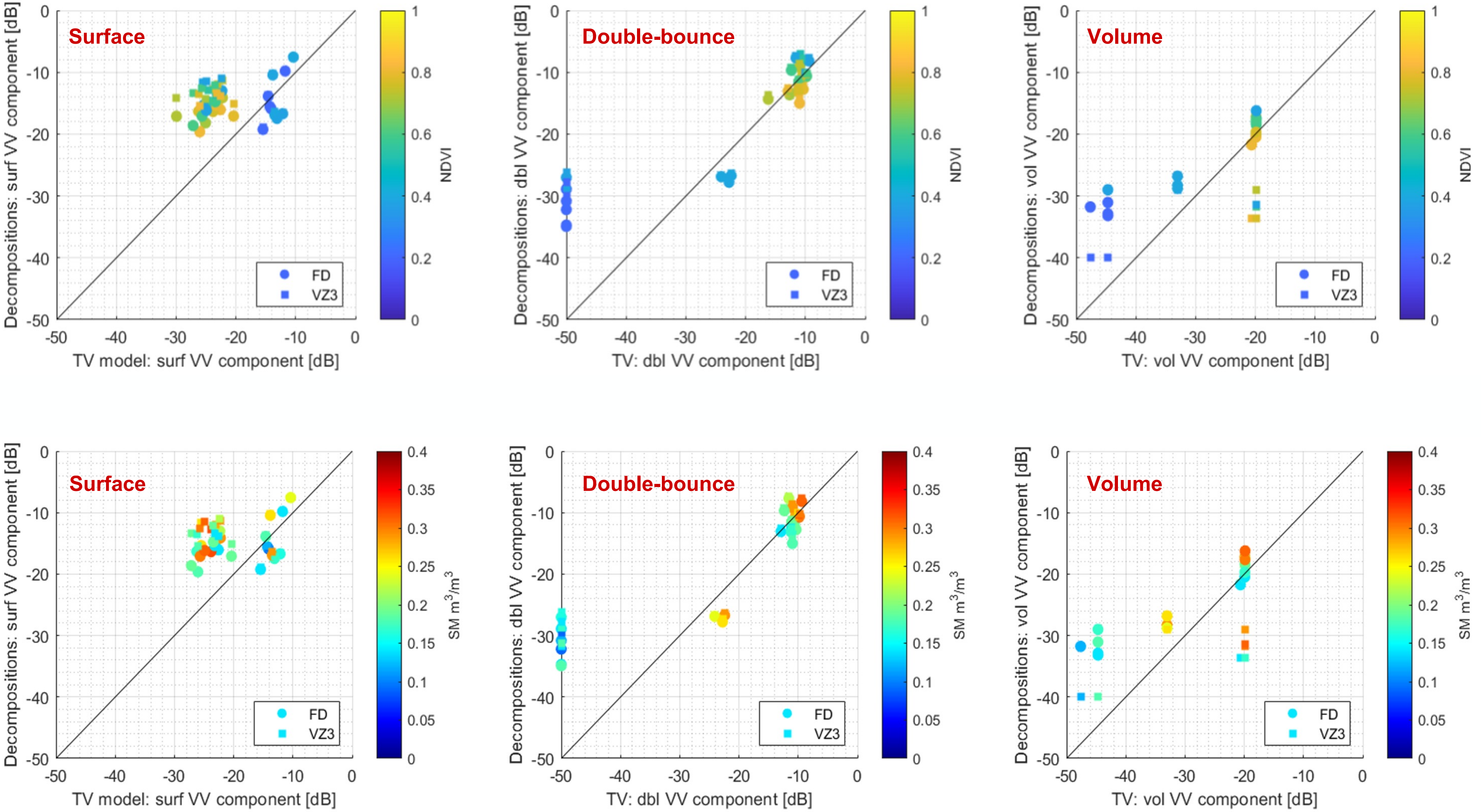
- When the vegetation is high the polarimetric decompositions return higher soil values.

PolSAR - TV model comparison: Sigma0-HH



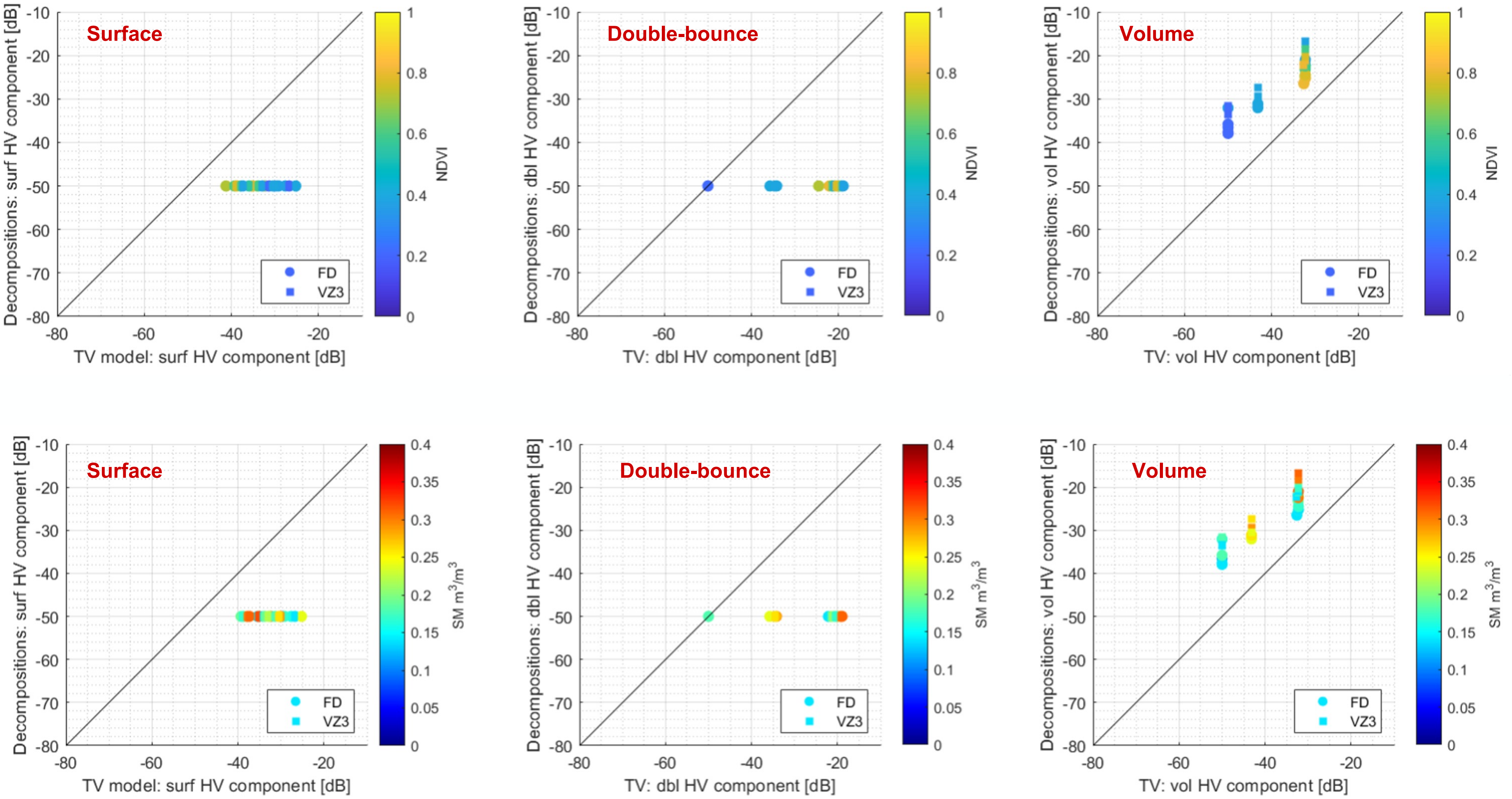
- In the HH polarization, the results are similar to those obtained with the powers for double-bounce and volume.
- There is a slight difference with respect to the powers for the surface component: the points of the scatterplot seem to be closer to the one-to-one line.
- The HH component presents the same trends as previously seen: double-bounce and volume agree for well-developed vegetation, while surface has better accordance for low vegetation.

PolSAR - TV model comparison: Sigma0-VV



- In the VV polarization, the behaviour of double-bounce and volume components are consistent with the HH polarization.
- The main difference lies in the surface component: the model seems to apply a much higher attenuation [~10dB] with respect to the decompositions.
- The higher attenuation in the VV polarization with respect to the HH polarization can be related to the way the model represents the corn stalks.

PolSAR - TV model comparison: Sigma0-HV



- In the HV polarization, the surface and double-bounce components are theoretically null for both the decompositions. In order to be able to compare them to the model, an arbitrary low value [-50dB] has been assigned to both components of the decompositions.
- On the other hand, the model provides significant values for surface and double-bounce in the HV polarization.
- Besides a bias, there is a good agreement for the volume component.

Conclusions and future works

Conclusions:

- Concerning the surface scattering, the TV model and the polarimetric decompositions show a fairly good agreement when the vegetation is not well-developed and plant height is low.
- Both volume and double-bounce from the TV model and the polarimetric decompositions show a fairly good agreement when the plant is developed.
- It can be observed that the model provides a higher attenuation, due to the presence of the vegetation, especially for the VV polarization.
- The polarimetric decompositions don’t take into account the contribution of the cross-polarization HV for the surface and double-bounce scattering mechanisms.

Future works:

- Application of other polarimetric SAR decompositions to the SAOCOM data.
- Use of semi-empirical models, such as the Water Cloud Model, to simulate the different scattering mechanisms.
- Application of the polarimetric decompositions to a set of simulated covariance matrices.

Thank you for your attention!