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Validación a largo plazo de datos de nivel 3 de tierra de SMOS con medidas de ELBARA-II en la Valencia Anchor Station

Fernandez-Moran, R.*[1], Wigneron, J.-P.[2], Lopez-Baeza, E.[1], Miernecki, M.[2], Salgado-Hernanz, P.[1], Coll, M. A.[1], Kerr, Y. H.[3], Schwank, M.[4]

[1] *University of Valencia. Faculty of Physics. Dept. of Earth Physics and Thermodynamics. Climatology from Satellites Group. Calle Dr. Moliner, 50, Burjassot. 46100 Valencia, Spain.*

[2] *INRA, UR1391 ISPA, F-33140 Villenave d'Ornon, Centre INRA Bordeaux Aquitaine, France.*

[3] *CESBIO, CNES/CNRS/IRD/UPS, UMR 5126, 18 Avenue Edouard Belin, Toulouse, France.*

[4] *Swiss Federal Research Institute WSL, Birmensdorf, Switzerland.*

Resumen: La misión de SMOS (*Soil Moisture and Ocean Salinity*) se lanzó el 2 de Noviembre de 2009 con el objetivo de proporcionar datos de humedad del suelo y salinidad del mar. La principal actividad de la conocida como *Valencia Anchor Station* (VAS) es asistir en la validación a largo plazo de productos de suelo de SMOS. El presente estudio se centra en una validación de datos de nivel 3 de SMOS en la VAS con medidas *in situ* tomadas en el periodo 2010-2012. El radiómetro ELBARA-II está situado dentro de los confines de la VAS, observando un campo de viñedos que se considera representativo de una gran proporción de un área de 50×50 km, suficiente para cubrir un *footprint* de SMOS. Las temperaturas de brillo (TB) adquiridas por ELBARA-II se compararon con las observadas por SMOS en las mismas fechas y horas. También se utilizó la inversión del modelo L-MEB con el fin de obtener humedades de suelo (SM) que, posteriormente, se compararon con datos de nivel 3 de SMOS. Se ha encontrado una buena correlación entre ambas series de TB, con mejoras año tras año, achacable fundamentalmente a la disminución de precipitaciones en el periodo objeto de estudio y a la mitigación de las interferencias por radiofrecuencia en banda L. La mayor homogeneidad del *footprint* del radiómetro ELBARA-II frente al de SMOS explica la mayor variabilidad de sus TB. Los periodos de precipitación más intensa (primavera y otoño) también son de mayor SM, lo que corrobora la consistencia de los resultados de SM simulados a través de las observaciones del radiómetro. Sin embargo, se debe resaltar una subestimación por parte de SMOS de los valores de SM respecto a los obtenidos por ELBARA-II, presumiblemente debido a la influencia que la pequeña fracción de suelo no destinado al cultivo de la vid tiene sobre SMOS. Las estimaciones por parte de SMOS en órbita descendente (6 p.m.) resultaron de mayor calidad (mayor correlación y menores RMSE y bias) que en órbita ascendente (6 a.m., momento de mayor humedad de suelo).

Palabras clave: espesor óptico de la vegetación, humedad del suelo, L-MEB, rugosidad del suelo, temperatura de brillo.

Towards a long-term dataset of ELBARA-II measurements assisting SMOS level-3 land product and algorithm validation at the Valencia Anchor Station

Abstract: The Soil Moisture and Ocean Salinity (SMOS) mission was launched on 2nd November 2009 with the objective of providing global estimations of soil moisture and sea salinity. The main activity of the Valencia Anchor Station (VAS)

* *Autor para la correspondencia: roberto.fernandez@uv.es*

is currently to assist in a long-term validation of SMOS land products. This study focus on a level 3 SMOS data validation with in situ measurements carried out in the period 2010-2012 over the VAS. ELBARA-II radiometer is placed in the VAS area, observing a vineyard field considered as representative of a major proportion of an area of 50×50 km, enough to cover a SMOS footprint. Brightness temperatures (TB) acquired by ELBARA-II have been compared to those observed by SMOS at the same dates and time. They were also used for the L-MEB model inversion to retrieve soil moisture (SM), which later on have been compared to those provided by SMOS as level 3 data. A good correlation between both TB datasets was found, improving year by year, mainly due to the decrease of precipitations in the analyzed period and the mitigation of radio frequency interferences at L-band. The larger homogeneity of the radiometer footprint as compared to SMOS explains the higher variability of its TB. Periods of more intense precipitation (spring and autumn) also presented higher SM, which corroborates the consistency of SM retrieved from ELBARA-II's observations. However, the results show that SMOS level 3 data underestimate SM as compared to ELBARA-II's, probably due to the influence of the small soil fraction which is not cultivated in vineyards. SMOS estimations in descending orbit (6 pm) had better quality (higher correlation, lower RMSE and bias) than the ones in ascending orbit (6 am, when there is a higher soil moisture).

Key words: brightness temperature, L-MEB, soil moisture, soil roughness, vegetation optical depth.

1. Introduction

The *Soil Moisture and Ocean Salinity* (SMOS) is the second *European Space Agency* (ESA) *Earth Explorer Mission* launched on 2nd November 2009 with the objective of providing global estimations of soil moisture and sea surface salinity (Kerr *et al.*, 2010).

In the framework of SMOS data and product validation, ESA selected the *Valencia Anchor Station* (VAS) for the installation of one of the ELBARA-II radiometers in September 2009, under the responsibility of the *Climatology from Satellites Group* of the University of Valencia. Since then, the radiometer has been continuously operating except for some interruptions caused by short power failures or minor spare parts replacements. This has permitted the acquisition of a robust dataset that has recently been approved to continue for a long-term basis during the lifetime of the mission.

The VAS constitutes an area of about 50×50 km, sufficiently large to cover a SMOS *pixel*. It is placed over a large semi-arid plateau at about 80 km west of the city of Valencia. The ELBARA-II radiometer can measure brightness temperatures and is placed at a vineyard field in the "*Finca El Renegado*" (Caudete de las Fuentes, Valencia) which has been named as MELBEX-III (*Mediterranean Ecosystem L-Band Characterization Experiment*) site (39°31'18.18''N, 1°17'29.64''W, altitude 800 m). This place is considered as representative of a SMOS pixel with respect to the vine land use which accounts for about 65-70% of the whole SMOS pixel (Wigneron *et al.*, 2012, Schwank *et al.*, 2012), while the scrubland area, that represents only about 20%, does not change so much along the year (Cano *et al.*, 2010). The interest of this site, apart from its significant homogeneity, is the possibility of studying two totally different land use states since the vine phenological cycle extends from April to October, leaving the area under bare soil conditions the rest of the year. This study aims at the validation of both brightness temperatures (period 2010 - 2012) and soil moisture (SM) obtained by SMOS (year 2012), using the data acquired by the ELBARA-II radiometer and other *in situ* measurements from the VAS area.

2. Materials and methodology

In this study, we used SMOS level 3 data and *in situ* measurements obtained from MELBEX-III site.

The main vegetation type present in the VAS 50×50 km area corresponds to vineyards (around 65%), pine trees, scrubs and other Mediterranean ecosystem species such as olive and almond trees. There are also small towns and villages and the topography is relatively flat with small undulations of about 2%. The climate is semi-arid of continental Mediterranean type with temperatures between –15°C and 45°C. Precipitations are scarce (450 mm per year), mainly developing in spring and autumn.

Table 1. ELBARA-II measurements.

Measurement	Time	Angles (°)
Angular scans	Each 30 min	30, 35, 40, 45, 50, 55, 60, 65, 70
Fixed angle	At HH:10, HH:20, HH:40, HH:50	45
Sky calibration	midnight	150

ELBARA-II is a dual polarization L-band microwave radiometer with two measuring channels, namely 1400-1418 MHz and 1409-1427 MHz. It uses a 23.5 dB gain horn antenna that can move changing its inclination. It is mounted on a 15 m height platform to continuously observe brightness temperatures in both polarizations (TBv, TBh). The radiometer has a measuring protocol by which every day it takes a sky calibration measurement at 23:55 h with an inclination angle of 150° (relative to nadir). Besides, it also regularly measures every half hour at different angles as showed in Table 1. The ELBARA-II footprint has been analyzed in detail in Schwank *et al.* (2012).

The 30-min TBv and TBh values for each inclination angle were obtained by using an ESA Phyton toolbox routine that processes the original ELBARA-II raw data (Völksch *et al.*, 2011). The routine has also a robust quality control filter to detect RFI (Radiofrequency Interference) measurements and filter out TB in consequence. This anomalies are detected by statistical analysis and by comparing the TB with different thresholds (TB above the temperature of the air or lower than 50 K). Since ELBARA-II uses two measuring channels, RFI are also detected if both measurements differs more than 0.2 K.

Since 2010, Spanish authorities have done important efforts to switch off microwave systems violating the protected part of the L-Band, which has contributed to decrease RFI significantly. Very few RFI effects have been detected over the VAS for the period analyzed.

The MELBEX-III site also contains a full DAVIS meteorological station and two Delta-T ML2x soil moisture probes: ThetaProbe 17702, placed close to a vine stump and ThetaProbe 17701, placed in the middle of two vine rows. They measure SM every 10 min. Both of them are close to the ELBARA-II radiometer.

The transformation of ELBARA-II TB values into soil moisture (SM) and vegetation optical depth (TAU) is carried out by the L-MEB inversion model (Wigneron *et al.*, 2007), which is the basis of the SMOS retrieval algorithm (Kerr *et al.*, 2012). The inversion is based on the minimization of a cost function (CF) using a least-squares iterative algorithm which requires some model input parameters, namely SM, TAU, soil and vegetation effective temperature, T_G, T_C, scattering albedo ω_P, roughness parameters —H_R, Q_R, N_{RV}, N_{RH}— and structural vegetation parameters —tt_H, tt_V— (Equation 1).

$$x = \frac{\sum (TB_{mes} - T^{*}B)^2}{\sigma(TB)^2} - \sum \frac{\sum (P_i^{ini} - P_i^{*})^2}{\sigma(P_i)^2} \qquad (1)$$

where TB_{mes} is the value measured by ELBARA-II, σ(TB) is the standard deviation associated with the brightness temperature measurements, P_i^* (i=1,… N) is the value of the retrieved parameter (SM, TAU and tt_v); P_i^{ini} (i=1,…N) is the initial value of each parameter in the retrieval process and corresponds to *a priori* estimate of the parameter P_i; $\sigma(P_i)$ is the standard deviation associated with this estimate and T*B is the simulated brightness temperature.

In the cost function, TBs every 30-min for angles smaller or equal to 55° were considered. For groups of missing angular scans, retrievals were not made when separation between angles was not at least 10°.

The arithmetic mean soil moisture of the two ThetaProbes was used as an input parameter to the model (Wigneron *et al.*, 2012), but a high σ (SM) value was set so SM was considered a free parameter in the retrieval. The TAU value was initially set to 0.05 (winter value). σ (TAU) was fixed to 0.02, and in each retrieval, the last TAU retrieved was used as input for the next one. This is due to the fact that TAU is not supposed to change abruptly as SM does after precipitations. The soil effective temperature T_G was assumed to be equal to the vegetation canopy T_C, and consequently the composite soil-vegetation surface temperature T_{GC} was considered as input for the L-MEB inversion. This value was obtained from the ERA-INTERIM 0-7 cm soil temperature product, with a temporal resolution of 3 hours and a spatial resolution of 1.5°.

Soil roughness parameters were considered constant for the whole year 2012 and were obtained through *in situ* measurements taken by means of a 2 m needle board. This board has 201 needles, 1 cm spacing, free to move vertically following the soil elevation profile. Roughness measurements followed the protocol: 8 repetitions, considering two different rows in the along and across directions of the radiometer field of view (perpendicular and parallel to the vine rows). The standard deviation of surface heights σ and autocorrelation length L_c was processed from each measurement. Then, the parameter $Z_s=\sigma^2/L_c$ was obtained. Each day of measurement, an average value of the 8 measurements was obtained, and H_R, Q_R, N_{RV} were calculated using equations 2-6 from Lawrence *et al.* (2013).

$$H_R = 1.762\left(1 - \exp\left(\frac{-Zs}{1.85}\right)\right), Zs < 1.1894 \quad (2)$$

$$H_R=0.836, Zs >1.1894 \quad (3)$$

$$Q_R=0.050\ H_R \quad (4)$$

$$N_{RH}=0 \quad (5)$$

$$N_{RV}=0 \quad (6)$$

A new average of the roughness parameters for all dates was calculated and used for the retrieval: H_R=0.606, Q_R=0.0303, N_{RV}=0, N_{RH}=0. Vegetation parameters were set as: ω_P=0.02, tt_H=1, tt_V=free. These assumptions followed Wigneron *et al.* (2012) previous work.

After each retrieval of SM, TAU and ttv, the RMSE between ELBARA-II TB and the simulated TB was calculated to filter simulations with high error. Maximum RMSE was set to 12 K.

Soil roughness and LAI (*Leaf Area Index*) measurements were systematically obtained to better adapt the model to the field conditions along the year 2012, thus improving its performance in retrieving SM and TAU. ELBARA-II TBs and the simulated SM and TAU were compared to SMOS level 3 data. The correlation coefficient (R), root mean square error (RMSE) and bias were then calculated.

All SMOS level 3 products distributed by CATDS (*Centre Aval de Traitement des Données SMOS*) are resampled to the spatial resolution of 25 km in the EASE Grid (*Equal-Area Scalable Earth Grid*). The format of the level 3 data files is NetCDF. For this study, the daily product *One-Day Soil Moisture Global Map, P11P* was chosen. This product contains previously filtered data that gives the optimum daily SM estimation considering the different satellite re-visits. For the estimation of a specific daily value, CATDS takes into account the values for ascending and descending orbit in the three days before and after the pass. This product also provides TB (incidence angle of 42.5°) and TAU, among other parameters.

For the validation of SMOS TBs, the ELBARA-II TBs used were those with 40° incidence angle. Since the CATDS level 3 data are given separately for ascending (6 am) and descending orbit (6 pm), these times were taken into account for the comparisons with the radiometer measurements.

Daily precipitation data were obtained from the Jucar River Basin Authority (*Confederacion Hidrográfica del Júcar*) close rain gauge of Caudete de las Fuentes at about 3 km from the MELBEX-III site.

3. Results

3.1. TB for ELBARA-II and SMOS (level 3)

The evolution of TB measured by the ELBARA-II radiometer at the MELBEX-III site during the period 2010 - 2012 has been compared to that estimated by SMOS (considering both ascending and descending orbits data). Figure 1 shows this comparison that also includes daily precipitation data in the area. Before analyzing the results, it should also be considered that the SMOS pixel extends over a larger and less homogeneous area than that observed by ELBARA-II over the vineyard field. According to Cognard *et al.* (1995), the justification of less abrupt TB variations on a more heterogeneous area are in the impact produced by the different land cover, roughness, texture and precipitation. Thus, it is justified that ELBARA-II

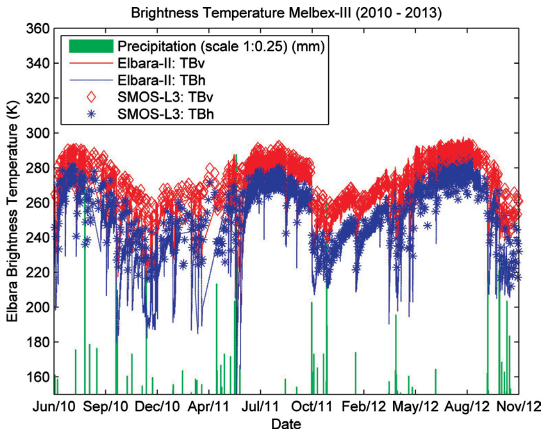

Figure 1. Comparison of ELBARA-II and SMOS L3 TBs. Para la interpretación de los colores consultar edición digital disponible en http://dx.doi.org/10.4995/raet.2015.2297.

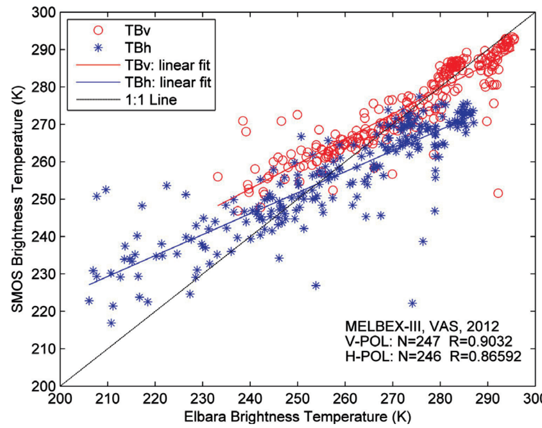

Figure 2. Correlation between ELBARA-II and SMOS L3 TBs (2012). Para la interpretación de los colores consultar edición digital disponible en http://dx.doi.org/10.4995/raet.2015.2297.

is more sensitive to the periods of rain, in which the decrease in TBh is more noticeable. In parallel, the summer months present higher values of TB, due to the absence of rainfall, mainly recorded in spring and especially autumn. This behavior is observable in the 3 years of data which are presented, with high TB values in summer, low in winter and very variable in the spring and autumn months.

For each year (2010, 2011, 2012), statistics between both sets of measurements were calculated using the specific ELBARA-II ones at SMOS overpassing time and they are shown in Table 2. Yearly precipitations were: 538.2 mm (2010), 375.2 mm (2011) and 294.2 mm (2012). This way, the driest year show higher R (R>0.90 in 2012, R<0.63 in 2010) and lower RMSE (RMSE<7 K in 2012, RMSE>20 K in 2010) and lower absolute value of bias (|bias|<1.8 K in 2012, |bias|>11 K in 2010). Furthermore, SMOS tends to overestimate TB (positive bias) in both vertical and horizontal polarizations (except in 2012 in which at horizontal polarization bias=–1.7 K). As presented in Figure 2, drier conditions (larger TB values) lead to higher correlations, especially in vertical polarization, in which the RMSE is also lower (5 K for TBv and 7 K for TBh in 2012).

3.2. SM for ELBARA-II and SMOS (level 3)

All ELBARA-II 30 min-TBs were computed to retrieve SM and TAU. Figures 3 and 4 show the evolution of SMOS SM in ascending (6 am) and descending orbit (6 pm) and that obtained by L-MEB inversion of ELBARA-II TBs at the same time. Furthermore, the information of the Theta Probes measurements and precipitations during the period 2010 - 2012 is displayed, proving the consistency of the retrievals.

In spite of the difference between the values obtained for SMOS and ELBARA-II, a trend is clearly shown in the SM in both cases: there exists a significant increase of SM in spring and autumn, in correspondence with the rainy periods in the area. It can be seen that SMOS underestimates SM values as compared to ELBARA-II's. This difference can be attributed to the homogeneity of

Table 2. Statistics for SMOS TB (mixing ascending and descending orbits) and ELBARA-II TB

	2010		2011		2012	
Polarization	H	V	H	V	H	V
No. of data	148	148	251	251	247	246
Bias [K]	12	11	8	8	-1.6	1.8
R	0.63	0.61	0.67	0.68	0.87	0.90
RMSE [K]	25	20	19	15	7	5

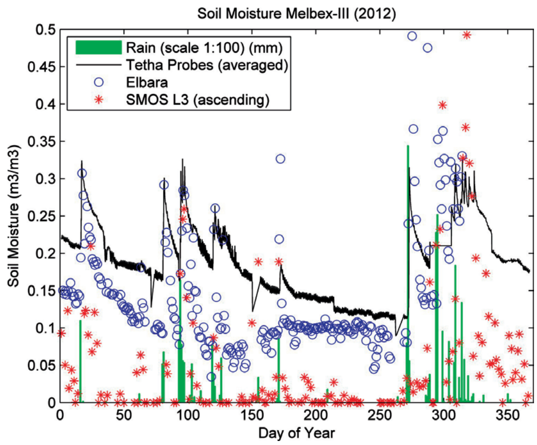

Figure 3. Comparison between SMOS SM (ascending orbit) and ELBARA-II SM. Para la interpretación de los colores consultar edición digital disponible en http://dx.doi.org/10.4995/raet.2015.2297.

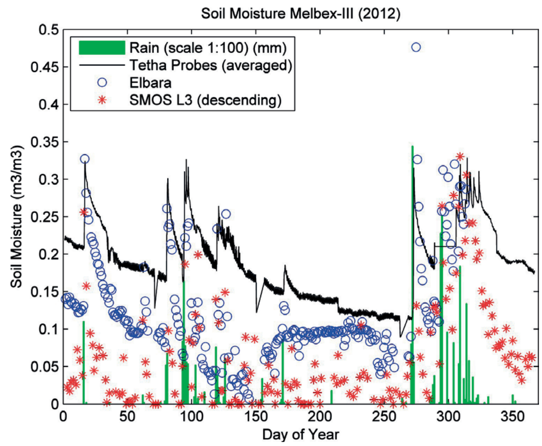

Figure 4. Comparison between SMOS SM (descending orbit) and ELBARA-II SM. Para la interpretación de los colores consultar edición digital disponible en http://dx.doi.org/10.4995/raet.2015.2297.

the field observed by ELBARA-II, opposite to the greater heterogeneity offering a wider area seen by SMOS. This fact suggests the necessity of a future analysis of the small non-nominal fraction measured by SMOS (i.e. the natural Mediterranean forested cover). The use of better model input parameters in the short future will likely improve the ELBARA-II results as well. For that, LAI (related to vegetation optical depth, TAU) and soil roughness are currently been measured.

Table 3 provides a more direct comparison between both SM datasets at the ascending orbit data and descending orbit time. As shown, the descending orbit presents a higher correlation (R=0.75) than the ascending one (R=0.59) and also lower RMSE and bias.

The L-MEB inversion from TB measurements also allowed the extraction of TAU for the whole year 2012. Although the ELBARA-II TAU estimations are consistent with the phenological cycle of the vineyard, the SMOS TAU is clearly affected by a higher heterogeneity, which makes SMOS and ELBARA-II incomparable from the point of view of the vegetation optical thickness.

4. Conclusions

The dataset so far obtained by the ELBARA-II radiometer observations over the vine MELBEX-III site at the *Valencia Anchor Station* is adequate for the long-term validation of SMOS soil moisture products. The VAS area is also adequate for this validation exercise thanks to the reasonably homogeneous conditions at SMOS scale. Continuous measurements of soil and vegetation parameters are under way to improve the characterization of the significant parameters influencing the validation process of SMOS. Further studies should focus on the SMOS soil moisture retrieval for the non-nominal fraction (Mediterranean forested cover) at the VAS.

In this study, during 2010 - 2012, brightness temperatures obtained from the ELBARA-II microwave radiometer over a vineyard field, have been compared to those from SMOS level 3 data over the Valencia Anchor Station area. The correlation

Table 3. Statistics for SMOS SM (ascending and descending orbits separated) and ELBARA-II SM.

Orbit	no. of data values	R	bias [m^3/m^3]	RMSE [m^3/m^3]
Ascending	81	0.59	-0.096	0.061
Descending	115	0.75	-0.068	0.045

obtained is significantly high and improves year by year (R>0.61 in 2010, R>0.67 in 2011, R>0.87 in 2012). Results are consistent with precipitations, since TB steepest decreases are found at the heaviest rainfall events, especially for ELBARA-II data, due to the significant homogeneity of the vineyards measured by the radiometer. This improvement could be related to the decrease of precipitations in the period analyzed but also to the decrease of RFI during this time.

Soil moisture and optical thickness estimations at L-band were calculated from the ELBARA-II dataset over all the year 2012 based on the L-MEB model inversion. When comparing ELBARA-II simulated SM to the corresponding SMOS SM at ascending and descending orbit time (6 am and 6 pm respectively), a parallel evolution is found which also follows the rhythm of the precipitation events occurred in the area. In spite of this, SMOS underestimates SM as compared to ELBARA-II. For the year 2012, a better correlation was found at descending orbit (drier moment) between the SM datasets, while also bias and RMSE were lower at that time. The values of TAU from SMOS are not comparable to the retrieved ones at ELBARA-II scale, due to the heterogeneities observed at SMOS scale that produce a TAU mixing effect. This study suggests that drier conditions will usually lead to best estimations of SM from SMOS while the efforts to mitigate RFI at L-band also lead to significant improvements as showed in this long term analysis of TB.

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References

Cano, A., Saleh, K., Wigneron, J. P., Antolín, C., Balling, J. E., Kerr, Y. H., Kruszewski, A., Millán-Scheiding, C., Schmidl Søbjærg, S., Skou, N., López-Baeza, E. 2010. The SMOS Mediterranean Ecosystem L-Band characterisation EXperiment (MELBEX-I) over natural shrubs. *Remote Sensing of Environment*, 114(4), 844-853. http://dx.doi.org/10.1016/j.rse.2009.11.019

Cognard, A. L., Loumagne, C., Normand, M., Olivier, P., Ottlé, C., Vidal-Madjar, D., Louahala, S., Vidal, A. 1995. Evaluation of the ERS 1/Synthetic Aperture Radar Capacity to Estimate Surface Soil Moisture: Two-Year Results Over the Naizin Watershed. *Water Resources Research*, 31(4), 975-982. http://dx.doi.org/10.1029/94WR03390

Kerr, Y. H., Waldteufel, P., Richaume, P., Wigneron, J. P., Ferrazzoli, P., Mahmoodi, A., Al Bitar, A., Cabot, F., Gruhier, C., Juglea, S. E., Leroux, D., Mialon, A., Delwart, S. 2012. The SMOS soil moisture retrieval algorithm. *IEEE Transactions on Geoscience and Remote Sensing*, 50(5), 1384-1403. http://dx.doi.org/10.1109/TGRS.2012.2184548

Kerr, Y. H, Waldteufel, P., Wigneron, J. P., Delwart, S., Cabot, F., Boutin, J., Escorihuela, M. J., Font, J., Reul, N., Gruhier, C., Juglea, S. E., Drinkwater, M. R., Hahne, A., Martin-Neira, M., Mecklenburg, S. 2010. The SMOS mission: new tool for monitoring key elements of the global water cycle. *Proceedings of the IEEE*, 98(5), 666-687. http://dx.doi.org/10.1109/JPROC.2010.2043032

Lawrence, H., Wigneron, J. P., Demontoux, F., Mialon, A., Kerr, Y. H. 2013. Evaluating the Semiempirical H - Q Model Used to Calculate the L-Band Emissivity of a Rough Bare Soil. *IEEE Transactions on Geoscience and Remote Sensing*, 51(7), 4075-4084. http://dx.doi.org/10.1109/TGRS.2012.2226995

Schwank, M., Wigneron, J. P., Lopez-Baeza, E., Völksch, I., Mätzler, C., Kerr, Y. H. 2012. L-Band Radiative Properties of Vine Vegetation at the MELBEX III SMOS Cal/Val Site. *IEEE Transactions on Geoscience and Remote Sensing*, 50(5), 1587-1601. http://dx.doi.org/10.1109/TGRS.2012.2184126

Völksch, I., Wiesmann, A. and Schwank, M., 2011. Calibration Algorithms and Documentation (D2). GAMMA, Gümligen

Wigneron, J. P., Kerr, Y., Waldteufel, P., Saleh, K., Escorihuela, M. J., Richaume, P., Ferrazzoli, P., de Rosnay, P., Gurney, R., Calvet, J.C., Grant, J. P., Guglielmetti, M., Hornbuckle, B., Mätzler, C., Pellarin, T., Schwank, M. 2007. L-band Microwave Emission of the Biosphere (L-MEB) Model: description and calibration against experimental data sets over crop fields. *Remote Sensing of Environment*, 107(4), 639-655. http://dx.doi.org/10.1016/j.rse.2006.10.014

Wigneron, J. P., Schwank, M., López-Baeza, E., Kerr, Y., Novello, N., Millan, C., Moisy, C., Richaume, P., Mialon, A., Al Bitar, A., Cabot, F., Lawrence, H., Guyon, D., Calvet, J. C., Grant, J. P., Casal, T., de Rosnay, P., Saleh, K., Mahmoodi, A., Delwart, S., Mecklenburg, S. 2012. First Evaluation of the simultaneous SMOS and ELBARA-II observations in the Mediterranean region. *Remote Sensing of Environment*, 124, 26-37. http://dx.doi.org/10.1016/j.rse.2012.04.014