

Comparison of surface soil moisture from SMOS satellite and ground measurements

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A b s t r a c t. Soil moisture datasets at various scales are needed for sustainable land use and water management. The aim of this study was to compare soil moisture ocean salinity satellite and in situ soil moisture data for the Podlasie and Polesie regions in Eastern Poland. Both regions have similar climatic and topographic conditions but are different in land use, vegetation, and soil cover. The test sites were located on agricultural fields on sandy soils and natural vegetation on marshy soils that prevail in the Podlasie and Polesie regions, respectively. The soil moisture ocean salinity soil moisture data were obtained from radiometric measurements (1.4 GHz) and the ground soil moisture from sensors at a depth of 5 cm during the years 2010-2011. In general, temporal patterns of soil moisture from both satellite and ground measurements followed the rainfall trend. The regression coefficients, Bland-Altman analysis, concordance correlation coefficient, and total deviation index showed that the agreement between ground and soil moisture ocean salinity derived soil moisture data is better for the Podlasie than the Polesie region. The lower agreement in Polesie was attributed mostly to the presence of the widespread natural vegetation on the wetter marsh soil along with minor contribution of agriculturally used drier coarse-textured soils.

K e y w o r d s: surface soil moisture, SMOS and ground measurements, Bland-Altman analysis, concordance correlation coefficient, total deviation index

INTRODUCTION

Soil moisture (SM) significantly affects water and energy exchange at the land surface-atmosphere interface and thereby is one of the key variables in numerous disciplines such as hydrology, soil science, and climatology. It is the most important source of water for agricultural crops

and natural vegetation. Therefore, SM datasets of good quality at various scales are needed for sustainable land, crop, and water management and land surface modelling (Al Bitar *et al.*, 2012; Lipiec *et al.*, 2013; Smith *et al.*, 2012).

Several satellite missions have shown the potential of using space-borne microwave remote sensing radiometry for the evaluation of surface SM at a global scale. The main previous satellite missions in radiometry including the Scanning Multichannel Microwave Radiometer (launched in 1978) and the Advanced Microwave Scanning Radiometer (launched in 2002) were operated in the C-Band (frequency $f=4-8$ GHz, wavelength $\lambda=7.5-3.8$ cm) (Seneviratne *et al.*, 2010). The recently launched (November, 2009) soil moisture ocean salinity (SMOS) satellite from the European Space Agency (ESA) operates in the passive L-band microwave ($f=1-2$ GHz, $\lambda=30-15$ cm), which is a preferred frequency for soil moisture retrieval (Kerr *et al.*, 2001, 2010; Wagner *et al.*, 2006). This wavelength penetrates well through the atmosphere and clouds. The instrument probes the earth surface soil approximately to the top 5 cm (Kerr *et al.*, 2012). The new SMOS two-dimensional Y-shaped microwave imaging radiometer with aperture synthesis (MIRAS) and advanced multi-angle (from 0 to 55°) fully polarimetric system offers first-time opportunities for retrieving global soil moisture data with an accuracy of $0.04 \text{ m}^3 \text{ m}^{-3}$ or better and a spatial resolution of less than 45 km with a revisit time of approximately three days (Kerr *et al.*, 2001, 2010). SMOS provides geo-located data in the discrete global grid (DGG) hexagonal cells (ISEA4H9 system (Pinori *et al.*, 2008)). SMOS microwave L-band measurements are also related to water held in vegetation. Patton and Hornbuckle (2013) revealed that the change in SMOS data over the growing season could be related to crop yields.

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It is therefore essential at the present step of the mission to compare the SMOS SM products with in situ measurements. Results of such studies obtained so far in the soil moisture networks have confirmed that the SMOS-derived soil moisture products are a reliable and important source of data for monitoring water in soils (Lacava *et al.*, 2012). At the same time, the analyses revealed that soil moisture was very variable in space and time due to heterogeneous topography, soil and land cover properties, vegetation types, and climatic drivers that complicate comparisons between satellite pixels and point (in situ) measurements. Bircher *et al.* (2012) reported that land cover strongly influenced the SMOS soil moisture algorithm through both the choice of the retrieval model and high non-linearity of vegetation parameters.

Most recent papers also discuss scale effects due to the large gap between spatial scales of SMOS and estimations derived from ground based data on soil moisture (Bircher *et al.*, 2012; Dente *et al.*, 2012). The authors pointed out limitations associated with the number and spatial extent of distributed ground measurements to represent accurately the satellite scale. This leads to the deviations between satellite and ground-based measurements. To diminish the deviations, the in situ efforts should focus on separation of the respective contribution of these factors under a broad range of environmental conditions (Bircher *et al.*, 2012; Juglea *et al.*, 2010) before the planned refinement of the retrieval algorithm and data reprocessing (Dente *et al.*, 2012). This should allow one to obtain more consistent data and yield quantitative maps of global soil moisture dynamics that is one of the main objectives of the SMOS mission (Kerr *et al.*, 2012). The current and future datasets collected in several countries including Poland and available in the International Soil Moisture Network (ISMN, 2012) can be an important resource for validating and improving satellite-derived soil moisture products (Marczewski *et al.*, 2010).

The aims of the paper were:

- to compare the SMOS satellite SM with in situ soil moisture data collected in the Podlasie and Polesie regions (Eastern Poland) located under similar climatic and topographic conditions but having different land and soil cover;
- to test the suitability of the Bland-Altman plot, concordance correlation coefficient (CCC), and total deviation index (TDI) for comparison of ground and satellite measurements.

MATERIALS AND METHODS

The study was carried out in two adjacent regions - Podlasie (N 51° 59' 24", E 22° 33' 37") and Polesie (N 51° 23' 43", E 23° 11' 54") in Eastern Poland. The climate in both regions is continental with high temperatures during summer and long and frosty winters.

The average annual air temperature in the Podlasie region is about 7.3°C. During 50-year (1949-1998) observations, the warmest month was July (17.7°C) and the coldest January (-3.6°C). Distribution of precipitation

throughout the year indicates the occurrence of the highest rainfall in June and July (over 70 mm) and the lowest (less than 30 mm) in January, February, and March. Rainfalls are substantially higher during summer (212 mm) than in winter (83 mm). Rainfall during the growing season (April-September), 350.9 mm, accounted for 65.4% of the annual precipitation and ranged from 224 to 530 mm over the 50 years.

The long-term average annual temperature in Polesie was 7.3°C. The coldest month was January (-4.1 °C) and the warmest July (17.9°C). The average long-term annual total precipitation was 542 mm and, in extremely dry and wet years, it reached 424 and 778 mm, respectively (Usowicz *et al.*, 2009). The annual sum fluctuated in a wide range from 78 to 153% with respect to the long-term average. Summer half-year precipitation of the hydrological year (May-October), which is decisive for growth and crop production, has a distinct advantage over the winter half-year (November to April). The summer and winter half-year rainfalls were 349 mm (64.4%) and 193 mm (35.6%) of the annual sum. The autumn (September-November) sum of precipitation was higher than that for spring (March-May). The maximum monthly precipitation was recorded in July and June (70-85 mm) and the minimum in January and February (20-30 mm). Yearly precipitations consist mostly of rainfalls with a proportion of solid precipitation below 17% and average duration of snow cover 70-75 days during the year.

The topography in both regions is mostly flat, with little variation in absolute altitudes (less than 20 m). Soils derived from loose sands, loamy sands, and loams prevail in Podlasie, whereas in Polesie a large area is occupied by marshy soils along with peat-lands and sands. The prevailing land cover type in Podlasie is arable land with the most frequent crops: barley, grass, and winter wheat, and additionally maize and potatoes (intermixed with forest and shrub/grassland), whereas in the Western Polesie the prevailing natural vegetation forest and shrub/grassland is intermixed with arable land (Fig. 1 from CORINE, CLC6). Part of the Polesie region belongs to the Poleski National Park with well-preserved exceptional richness of unique flora and fauna and harsh character built over millenniums. A characteristic feature of the Park is the worldwide rarest high peat bogs called Krowie Bagno (Cow Marsh). Specification of the land use is given in Table 1 and the map in Fig. 1, based on CORINE classes (CLC6).

For further analyses, two Areas of Interests (AOI) in Polesie and Podlasie were chosen (violet shapes in Fig. 1). These shapes are composed of 7 DGG SMOS 'pixels' to meet the area corresponding to the radiometric spatial resolution of SMOS. Ground measurements were performed in the smallest scales as indicated by the rectangles (RECT) in Fig. 1. Land use specification from CORINE (CLC6) indicates that Polesie, compared to the Podlasie region, is characterized by larger contribution of pastures and existence of inland marshes (Table 1). The data from CORINE may be useful for interpretation of differences between satellite

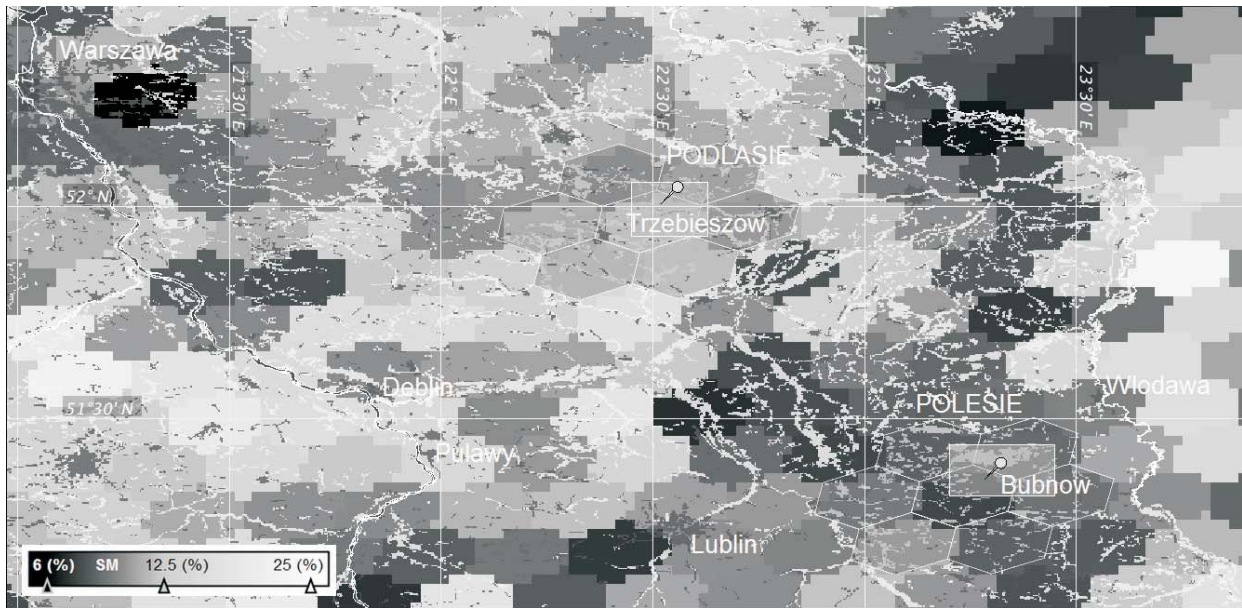


Fig. 1. Central-eastern region of Poland between the Bug and Vistula rivers. Two hexagonal shapes depict areas of interest (AOI) for Podlasie and Polesie in particular SMOS DGG pixels. Rectangular windows show selected areas of Polesie and Podlasie which were measured for soil physical properties. Area of each soil test field is comparable to the area of a single DGG SMOS pixel. The grey scale background presents SMOS L2 data values for SM, within the scale and histogram on the inset. The foreground overlay of CORINE CLC6 classes given by shapes is used for exemplification of forests and inhabited areas in broad regional scales.

T a b l e 1. Specification of the land use for the Podlasie and Polesie regions

Regions	Land use (%)				
	All	Podlasie		Polesie	
Pixels		7_DGG	1_RECT	7_DGG	1_RECT
No. of (MERIS) pixels considered	484 656	17 929	2 337	17 667	3 081
clc6_313_Mixed_forests	7.25	6.78	2.95	11.00	7.85
clc6_311_Broad_leaved_forests	5.63	3.58	5.61	5.66	6.69
clc6_312_Coniferous_forests	14.69	11.42	7.74	5.42	3.38
clc6_222_Fruit_trees_plantations	1.25	0.15	0	0.02	0
clc6_141_Green_urban	0.09	0	0	0	0
_classes of clc6_HIGH_VEG	$\Sigma=28.91$	$\Sigma=21.93$	$\Sigma=16.30$	$\Sigma=22.10$	$\Sigma=17.92$
clc6_111_112_121_131_132_133 _Urban_industrial_inhabited	4.69	3.44	3.00	1.44	0.65
clc6_512_Water_bodies	0.44	0.21	0	1.09	1.95
clc6_243_Agro_natural_veg	0.40	0	0	0	0
clc6_231_Pastures	12.86	16.36	21.01	17.50	26.10
clc6_411_Inland_marshes	0.21	0	0	1.59	5.28
clc6_412_Peat_bogs	0.04	0	0	0.75	0.10
_classes of clc6_LOW_VEG	$\Sigma=13.52$	$\Sigma=16.36$	$\Sigma=21.01$	$\Sigma=19.84$	$\Sigma=31.48$
_other LOW_VEG	52.45	58.06	59.69	55.53	48.00
cross check (%)	$\Sigma =100$	$\Sigma =100$	$\Sigma =100$	$\Sigma =100$	$\Sigma =100$

and ground soil moisture data. Table 1 shows the land use in fractions and demonstrates roughly how the heterogeneity of the target land contributes to real estimations depending on AOI location and the scale of AOI.

The automatic agro-meteorological stations (white pins in Fig. 1) are operated by the Institute of Agrophysics (Lublin, Poland) and located on most extensively occurring (representative) agricultural fields on sandy soil and the natural vegetation on the marsh soil for the Podlasie and Polesie regions, respectively (Marczewski *et al.*, 2010). Those stations are localized in the central part of the chosen AOIs. The Polesie natural vegetation consists mostly of grass, shrubs, heather, and stunted forest trees. Soil moisture was measured in the years 2010 and 2011 using calibrated soil moisture ThetaProbe ML2x sensors connected to DL2e Data Logger (Delta-T Devices Ltd) at a depth of 5 cm every 10 min. The sensors were calibrated with consideration of soil texture, bulk density, and temperature. During 2010/2011, winter temporal soil freezing disturbed the moisture measurements. For this reason, data from 2010 and 2011 are separated by a 'winter break' and examined separately. Rainfall data, collected at the stations, were also used. For each year, the mean and standard deviation were calculated. The minimum and maximum values with approximate dates of occurrence were specified.

Determination of the soil textural composition, reaction (pH), and organic matter content at a depth 0-10 cm was performed at 464 and 86 sampling points within the Podlasie and Polesie regions, respectively rectangles in Fig. 1. The ground sampling points were located on most representative areas of the land use conditions.

SMOS observations were available from the beginning of 2010 (the satellite was launched in November 2009). Soil moisture is given by SMOS in the relative volumetric measure ($\text{m}^3 \text{m}^{-3}$) with precision of about $0.04 \text{m}^3 \text{m}^{-3}$. Soil moisture values are retrieved from the brightness temperature of natural electromagnetic emission in the spectral window (1.400-1.427 GHz). Data is collected in approximately 3.5-day cycles, which within the swath width of 1000 km observations enables one to estimate trends in temporal changes in 7 days. The SMOS orbit is Sun-synchronous: ascending passes repeatedly occur about the local sunrise time, and descending passes about the local sunset time. We used only ascending data because they were less noisy.

Spatial resolution of SMOS is estimated not less than 40 km. This, more or less, corresponds to the area of 7 DGG pixels, as chosen before to be AOIs.

In order to relate SMOS retrieved soil moisture to the situ measurements, a linear regression model was suggested. Studies in areas of other scientific disciplines, for example in medicine, indicate that sometimes the simple regression analysis (the strength of the relation between two estimates as given by the coefficient of determination (R^2)) is not sufficient to draw correct conclusions about the effecti-

veness of a new method. This is because correlation is best used when the reference method is low in error. However, both SM measurement techniques used in this study may have an inherent error.

Therefore, the Bland-Altman approach (Bland and Altman, 1986, 1999; Krouwer, 2008) was also adopted to plot the agreement between the in situ measured SM values with the SMOS data and to reveal the relationship between the differences and the magnitude of measurements.

The Bland-Altman plot (Bland and Altman, 1986, 1999), or a difference plot, is a graphical method to assess an agreement between two methods of measurement. This plot is widely used in medical statistics, biostatistics, and analytical chemistry. Researchers from other fields can easily recognise that it is identical to a Tukey mean-difference plot. In this graphical method, the differences (or alternatively the ratios) between the two methods are plotted against the averages of the two methods. Additionally, horizontal lines are drawn at the mean difference, and at the limits of agreement, which are defined as the mean difference plus and minus 1.96 times the standard deviation of the differences.

The Bland-Altman method assumes that two methods that measure the same physical quantity use the same scale of measurement. This implies that when plotted, the points should line up along the line $y = x$ (line of identity) (Deming, 1943). In our study, we will compare large-scale SMOS SM to small-scale ground SM data from local test sites. It is worth stressing that a high correlation does not automatically imply that there is good agreement between the two methods.

The SM differences between two methods were normally distributed and 95% of these differences were anticipated to lie between mean -1.96 SD and mean +1.96 SD, identified as 95% limits of agreement (Bland and Altman, 1999; Borg *et al.*, 2012; Krouwer, 2008).

The concordance correlation coefficient (Lin, 1989) evaluates the degree to which pairs of observations fall on the 45° line through the origin. Lawrence Lin has developed the following formula for the concordance correlation coefficient:

$$\rho_c = \frac{2\rho\sigma_x\sigma_y}{\sigma_x^2 + \sigma_y^2 + (\mu_x - \mu_y)^2}, \quad (1)$$

where: ρ is the Pearson correlation coefficient between the two variables, μ_x and μ_y are the means for the two variables and σ_x^2 and σ_y^2 are the corresponding variances.

The concordance correlation coefficient ρ_c contains a measurement of precision ρ and accuracy C_b :

$$\rho_c = \rho C_b, \quad (2)$$

ρ measures how far each observation deviates from the best-fit line and is a measure of precision, and C_b is a bias correction factor that measures how far the best-fit line deviates from the 45° line through the origin and is a measure of accuracy.

The total deviation index (TDI) describes a boundary such that a majority of the differences in paired measurements are within the boundary *ie* a probability interval. Lin (2000) derived the cumulative probability function of the square of the paired-measures difference variable, which is assumed to follow a non-central chi-squared distribution. Since the resulting equation turned out to be complicated, he derived further approximation with more desirable properties based on the asymptotic theory of the mean squared deviation (MSD).

RESULTS AND DISCUSSION

As can be seen in Table 2, the top layer of soils in Podlasie contains on average: 71.9, 26.4, 1.7% of sand, silt, and clay, respectively. The minimum contents of the respective fractions were 45, 4, and 0%, respectively, and the maximum 95, 54, and 8%. The reaction of the soils in the region was generally acidic or neutral, with average pH 4.3 in KCl and 4.8 in H₂O. The minimum pH of the soils were 3.5 (in KCl) and 3.9 (H₂O), and the maximum 6.9 and 7.2, respectively. The mean soil organic matter content was low; it amounted to 0.8% (layer 0-10 cm) and ranged from 0.002 to 3.8%.

The soils in the Polesie region have, on average, 82.9% of sand, 15.5% of silt, and 1.6% of clay. The minimum and maximum contents of these fractions were 58, 3, and 0% and 96, 31, and 15%, respectively. The reaction of the soils was in general neutral, with mean pH of 6.2 in KCl and 6.6 in H₂O. The minimum pH values of the soils were 3.7 (in KCl) and 4.7 (in H₂O), and maximum 7.7 and 7.8, respectively. The mean content of soil organic matter in Polesie was 3.2% and it varied from 0.4 to 48.8%.

The above data indicate that, on average, the soils of Polesie, compared to those of the Podlasie region, are slightly richer in sand and poorer in silt and substantially higher in organic matter (by almost 4 times).

As indicated by the coefficient of variation (CV), the highest variability was recorded in the content of organic matter (187.2%) and clay fraction (104.9%) in Polesie. The corresponding CV values in Podlasie were significantly lower, namely 47.2 and 67.5%. In both regions, the lowest variability was observed for the sand fractions (CV 9.1-12.9%).

As can be seen from Table 3, there was more rainfall (by about 10%) in Polesie than Podlasie in both years. In both regions, the precipitations were higher (by about 10%) in

Table 2. Statistics of soil texture, reaction (pH), and organic matter content (OM) at a depth of 0-10 cm for the Podlasie and Polesie regions

Parameters	% content of fractions			pH _{KCl}	pH _{H₂O}	OM (%)
	Sand 1-0.05	Silt 0.05-0.002	Clay <0.002			
(mm)						
Podlasie						
Number of points	464	464	464	464	464	464
Mean	71.9	26.4	1.7	4.3	4.8	0.8
Standard deviation	9.3	9.0	1.1	0.7	0.7	0.4
Coefficient of variation (CV)	12.9	34.0	67.5	16.9	14.8	47.2
Skewness	0.067	-0.085	1.565	1.719	1.312	1.461
Kurtosis	-0.471	-0.419	3.690	2.506	1.350	8.145
Minimum	45.0	4.0	0.0	3.5	3.9	0.002
Maximum	95.0	54.0	8.0	6.9	7.2	3.8
Polesie						
Number of points	86	86	86	87	87	87
Mean	82.9	15.5	1.6	6.2	6.6	3.2
Standard deviation	7.6	6.7	1.7	1.2	0.9	6.0
Coefficient of variation (CV)	9.1	43.5	104.9	20.2	12.8	187.2
Skewness	-0.667	0.381	5.834	-0.521	-0.487	5.636
Kurtosis	0.271	-0.635	44.53	-1.274	-1.107	39.81
Minimum	58.0	3.0	0.0	3.7	4.7	0.4
Maximum	96.0	31.0	15.0	7.7	7.8	48.8

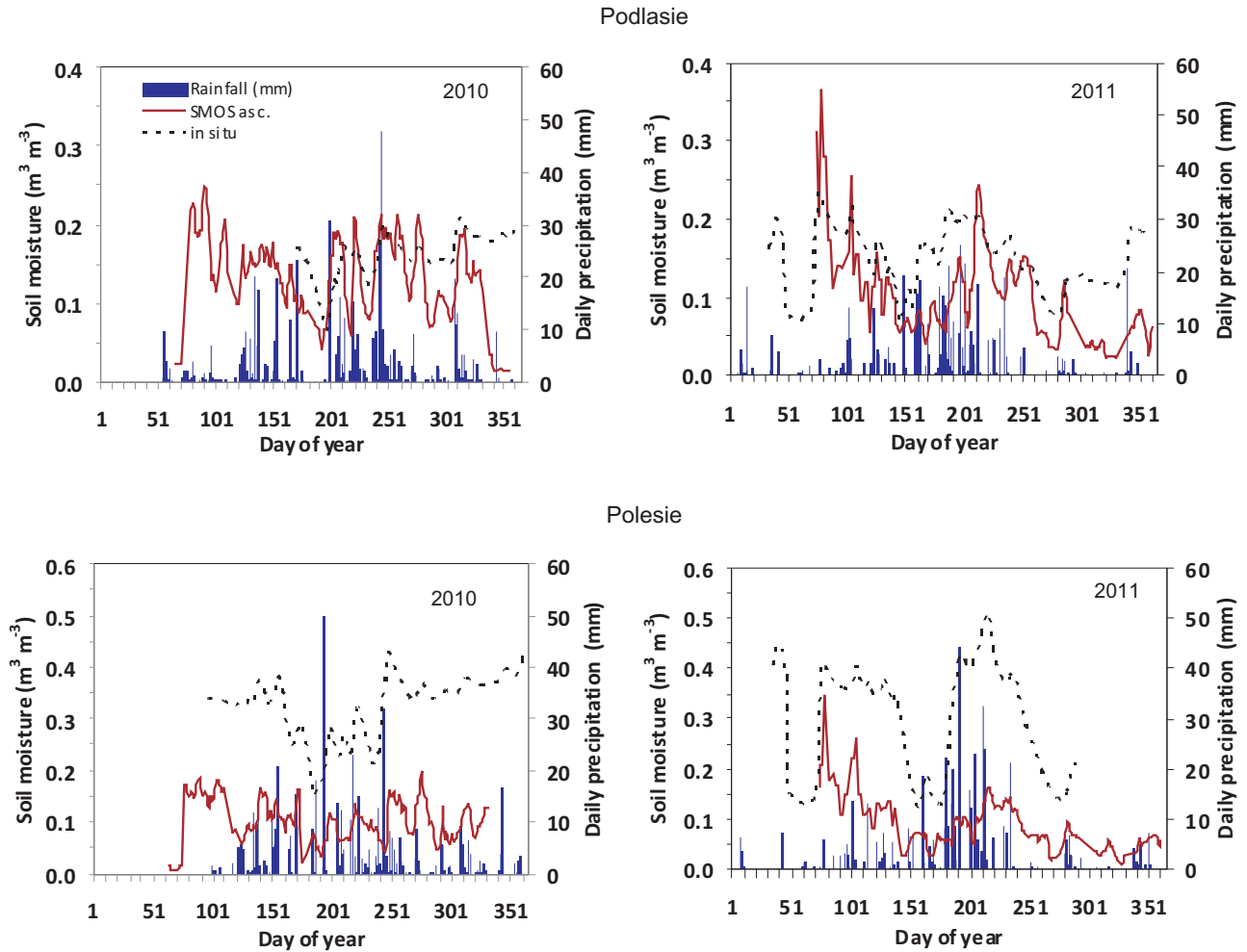


Fig. 2. Temporal SM SMOS and SM in-situ SM values with the daily precipitation data measured on the test sites.

compared. Irrespective of the region, the determination coefficients were appreciably greater in the less rainy year 2011 than in 2010.

The Bland-Altman plots (Fig. 4) show that a good agreement was found for Podlasie where SMOS data were only slightly underestimated, on average (bias) in the order of $0.034\text{--}0.055\text{ m}^3\text{ m}^{-3}$ in both years. However, the underestimation by SMOS was appreciably greater for the Polesie region ($0.202\text{--}0.217\text{ m}^3\text{ m}^{-3}$). These results from both regions are consistent with findings from a range of validation locations under different site conditions (Al Bitar *et al.*, 2012; Bircher *et al.*, 2012; Dall'Amico *et al.*, 2012; Gherboudj *et al.*, 2012). From the Bland-Altman plots, it is also possible to observe that at lower soil moisture contents (left side in reference to the intersection point of the regression line with mean difference line) differences are in general greater and lower than the bias value for Podlasie and Polesie, respectively. However, at higher soil moisture contents (right side in reference to the intersection point of the regression line with mean difference line), the reverse

was true. The range of the 95% limits of agreement (± 1.96 SD lines) in 2010 was approximately $0.2\text{ m}^3\text{ m}^{-3}$ in both regions, whereas in the drier 2011 it slightly decreased (to about $0.18\text{ m}^3\text{ m}^{-3}$) and appreciably increased (up to about $0.3\text{ m}^3\text{ m}^{-3}$) for Podlasie and Polesie regions, respectively. The Bland-Altman plots show that a majority of the points are within the limits of agreement both in the Podlasie and Polesie regions.

Larger values of the concordance correlation coefficient (CCC) and those lower of the total deviation index (TDI) in Podlasie than Polesie (Table 4) indicate that agreement between ground measured and SMOS derived soil moisture data is better in the former. The agreement can be classified as 'moderate' for Podlasie and 'fair' for Polesie.

Overall, analysis of the results performed using regression coefficients, Bland-Altman plots as well as the CCC dispersions and TDI clearly indicates that the agreement between ground and SMOS derived soil moisture is better for Podlasie than the Polesie region. It is worth noting that the values of the assessment parameters are reproducible in

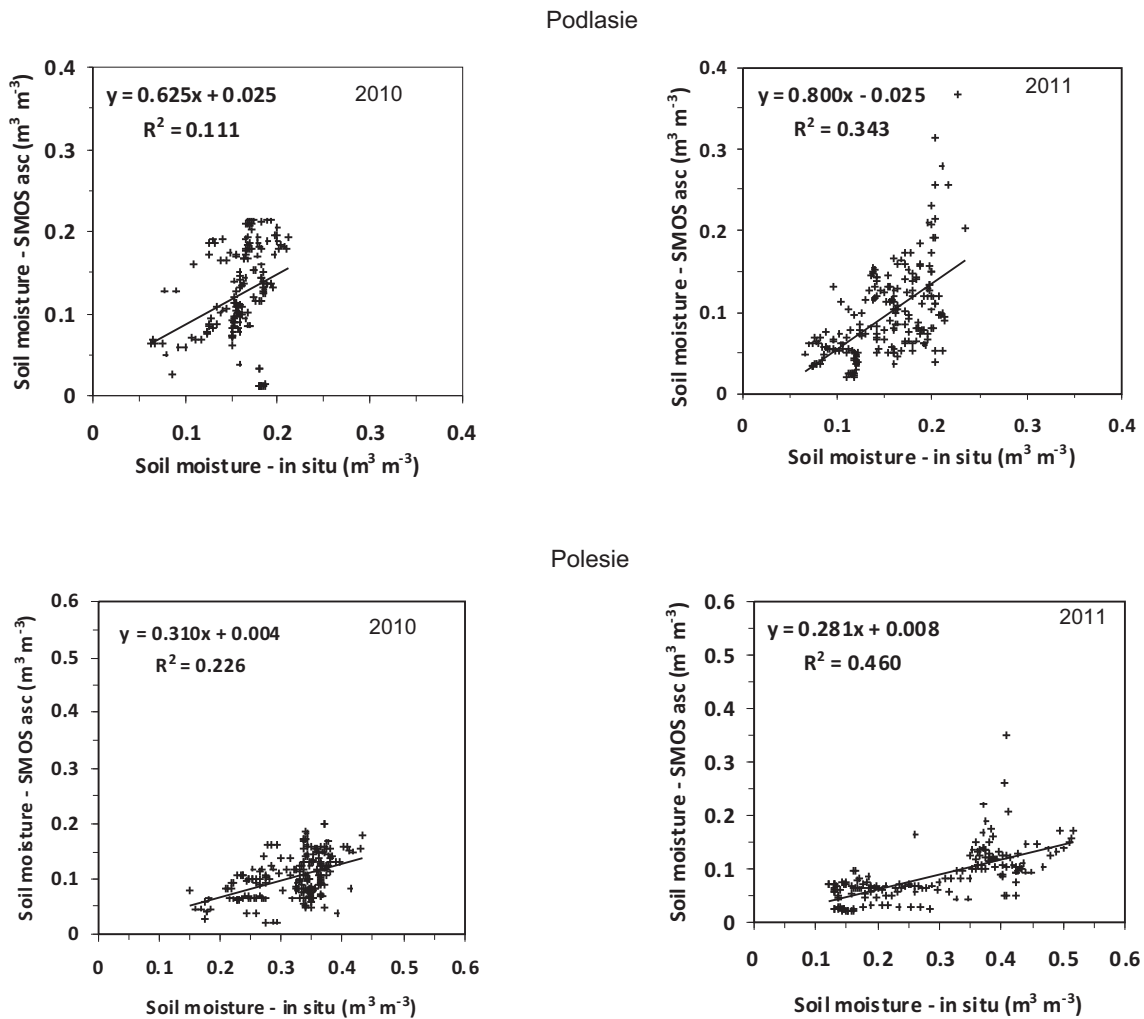


Fig. 3. Linear regression of SM measured by SMOS and SM measured on the ground. Both SM values are considered in 7-day averages (over the rectangular 7-day window) in 7-day steps.

both years for each region. The greater discrepancy in the SM between the in situ and SMOS data in the Polesie than Podlasie region can be due to diverse land use structure in spite of the soil moisture measurement station being located in the most representative natural vegetation on the marsh soil. The natural vegetation in the Polesie region was accompanied by a minor proportion of agriculturally used coarse-textured mineral soils. As shown by supplementary (ancillary) ground measurement campaigns in 2010-2011 (50-100 measurement points in each region), the SM in the points representing the typical natural vegetation varied from 0.20 to 0.65 m³ m⁻³ depending on the measurement time, whereas on the coarse-textured points it ranged barely from 0.02 to 0.3 m³ m⁻³. Consequently, the mean SMOS soil moisture, as integrated for the whole pixel, was substantially lower than the ground measured SM. These results reveal

a significant effect of the patchy land use, resulting in large gradients of SM, on the validation results of the satellite data in the Polesie region. In the case of the Podlasie region, however, with more uniform land use structure and soil cover, the SM varied from 0.03 to 0.35 m³ m⁻³ and the differences between ground measured and SMOS derived soil moisture contents were much smaller. Also greater differences in ground compared to SMOS derived soil moisture contents between the regions investigated may have been influenced by heterogeneous soil and land cover in the Polesie region rather than climate, which was not much different.

The CCC or Interclass Correlation Coefficient can be interpreted as follows: 0-0.2 indicates poor agreement, 0.3-0.4 indicates fair agreement, 0.5-0.6 indicates moderate agreement, 0.7-0.8 indicates strong agreement, and 0.8 indicates almost perfect agreement.

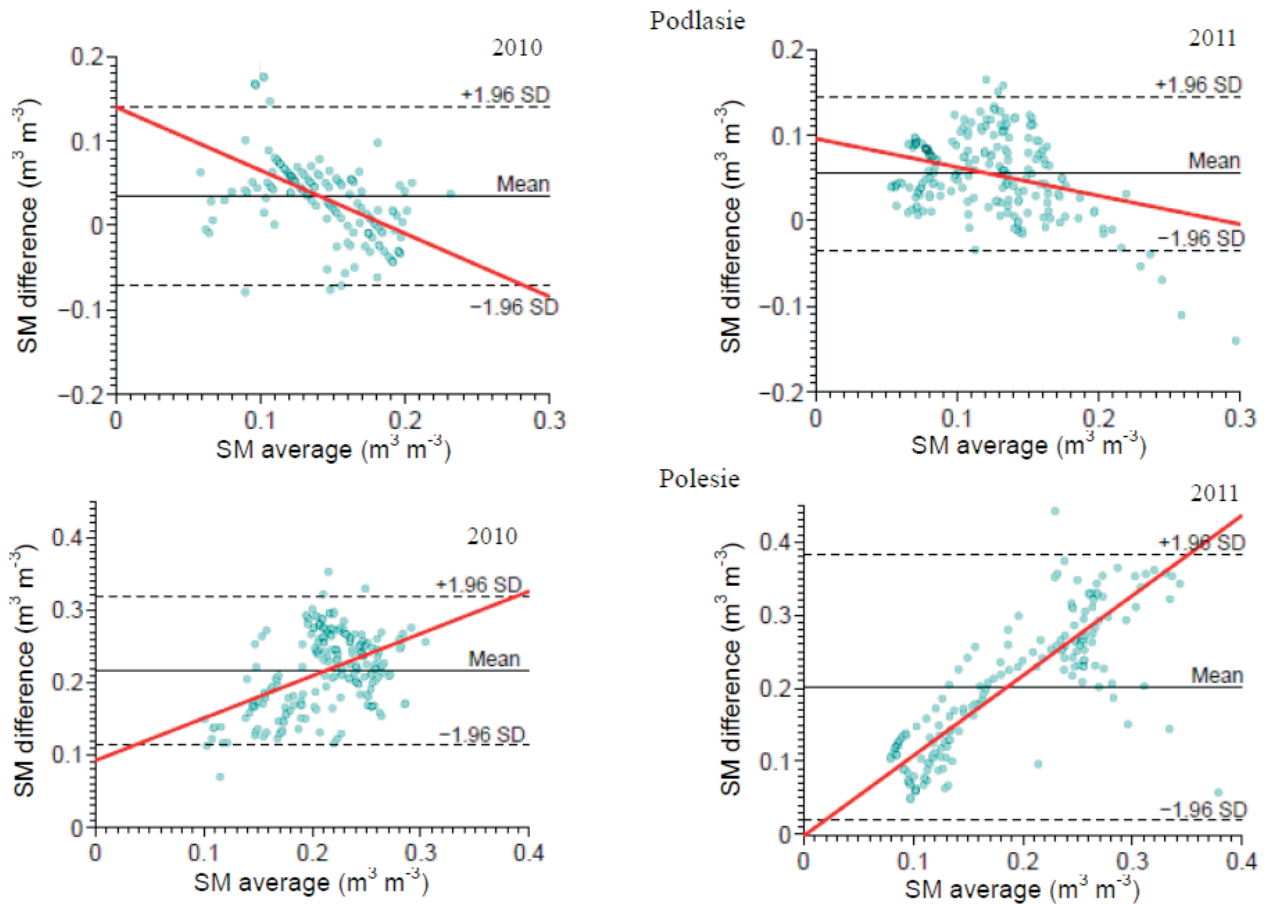


Fig. 4. Bland-Altman plots comparing SM in-situ ground based values to SM based on SMOS, derived for Podlasie and Polesie. Outer lines indicate a 95% level of agreement. The central line shows average values of differences. ‘SM difference’ means the difference between in-situ and SMOS data, in ascending orbits (SM in-situ – SM SMOS asc.) ‘SM average’ means respectively (SM in-situ + SM SMOS asc)/2).

Table 4. Concordance correlation coefficient (CCC) and total deviation index (TDI) results

Podlasie		Polesie	
2010	2011	2010	2011
$\rho_c = 0.305$	$\rho_c = 0.558$	$\rho_c = 0.435$	$\rho_c = 0.464$
Total deviation index			
0.11	0.12	0.37	0.37

CONCLUSIONS

1. Two areas under study were chosen for their representativeness of two larger regions constituted under similar climatic and topographic conditions in Eastern Poland, within different land uses and soil cover. Soil moisture ocean salinity data on soil moisture were compared to the ground based in situ data over the years 2010 and 2011. The in situ measurements were performed on most extensively occurring (representative) agricultural fields on sandy soil and the natural vegetation on marsh soil for the Podlasie and Polesie

regions, respectively. Soil moisture ocean salinity data reproduced ground based soil moisture spatial patterns on scales of a region corresponding to more than several (eg 7) DGG pixels.

2. It was shown that the temporal patterns of soil moisture from both satellite and ground measurements followed the rainfall trend in both regions. Soil moisture ocean salinity estimations of soil moisture appeared to be underestimated with respect to ground based soil moisture data.

3. The Bland-Altman plots revealed that the average difference (bias) between ground and soil moisture ocean salinity derived soil moisture and the 95% limits of agreement (± 1.96 SD) lines were lower for Podlasie than the Polesie region. In both Podlasie and the Polesie region, a majority of the points were within the limits of agreement.

4. Analysis of the results based on regression coefficients, the concordance correlation coefficient and the total deviation index showed that the agreement between ground and soil moisture ocean salinity derived soil moisture was better for Podlasie (classified as moderate) than Polesie (classified as fair) both in 2010 and 2011. This could be ascribed to the fact that the dominant natural vegetation with relatively wet soils in the Polesie region was accompanied by agriculturally used dry areas on coarse-textured soils. However, in the case of Podlasie, both land and soil covers were much more uniform.

5. The results of this study address the strong influence of the different land and soil cover under similar climate conditions as a potential error source in validation of soil moisture ocean salinity soil moisture results. The results of this study were needed for creating quantitative proofs on the relevance of soil moisture ocean salinity data to soil moisture in Poland. The study excludes the expectation that higher versions of the processing algorithm in soil moisture ocean salinity provides full agreement with the ground data, because soil moisture ocean salinity is aimed at creating areal measures of soil moisture and studying long term and long distance trends, which is not always available directly on the ground.

6. There is a well justified expectation that soil moisture ocean salinity data may provide a good database for estimating the sub-surface soil water content in absolute measures (Mg or m^3 of water), within a temporal averaging window of 7 days, and spatial integration in discrete global grid pixels covering the scale of the entire country or a larger region. Such data should be very useful in agrophysics, hydrology, and environmental research. Current activities will focus on the effect of the representativeness of the measurement sites using ground data from a recently established soil moisture and temperature network in Eastern Poland.

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