A combined optical-microwave method to retrieve soil moisture over vegetated areas

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ABSTRACT: A simple approach for correcting for the effect of vegetation in the estimation of the surface soil moisture (w_S) from L-band passive microwave observations is presented in this study. The approach is based on semi-empirical relationships between soil moisture and the polarized reflectivity including the effect of the vegetation optical depth which is parameterized as a function of the Normalized Vegetation Difference Index (NDVI) and the Leaf Area Index (LAI). First, the method was tested against in situ measurements collected over a grass site from 2004 to 2007 (SMOSREX experiment). Two polarizations (horizontal/vertical) and five incidence angles (20º, 30º, 40º, 50º and 60º) were considered in the analysis. The best w_S estimations were obtained when using both polarizations at an angle of 40º. The average accuracy in the soil moisture retrievals was found to be approximately 0.06 m3/m3, improving the estimations by 0.02 m3/m3 when the vegetation effect is not considered. The use of the NDVI and LAI indexes led to improved retrievals results and are compared in this study. Second, the proposed method was applied to the microwave observations acquired from the Soil Moisture Ocean Satellite (SMOS) and the optical observations acquired from the Moderate Resolution Imaging Spectroradiometer (MODIS) over eastern Australia in 2010 to evaluate its applicability to spaceborne remote sensing observations. The results indicate that information on vegetation (through a vegetation index such as NDVI) is useful for the estimation of soil moisture through the semi-empirical regressions which were calibrated over the eastern Australian.

Keywords: ***Soil moisture, L-band, NDVI, LAI, Surface Temperature***

Introduction

- **Soil moisture (w_S) plays a key role in the hydrological cycle and land-atmosphere interactions.**
- **Recently, the Soil Moisture and Ocean Salinity (SMOS) mission was launched. The SMOS baseline payload: L-band (1.4 GHz), 4% accuracy, 2-3 days, better than 50 km.**
- **Main difficulty → The presence of overlying vegetation (attenuation of soil emission)**
- **Optical – Microwave synergy appears as an alternative to estimate w_S using L-band and optical information.**

Main Objective

- **Proposed a simple method to estimate the w_S using combined microwave and optical data accounting for the vegetation effects.**

The Proposed Method

The method is based on the semi-empirical relationship proposed by Wigneron et al (2004)[1]:

$$\log\left(w_S\right) = c_0 \cdot \log\left(\Gamma\left(\theta, p\right)\right) + c_1\left(\theta\right) \cdot \tau\left(\theta, p\right) + c_2(\theta, p) \quad (1)$$

The optical depth can be often related to a vegetation indicator such as Normalized Difference Vegetation Index (NDVI) or Leaf Area Index (LAI), for instance:

$$\tau = f\,(NDVI) \cong a \; Veg \quad (2)$$

where *a* is a constant which accounts mainly for the effect of the vegetation structure and *Veg* is the vegetation indicator. Using equations (1) and (2), soil moisture is expressed as a function of the microwave reflectivity and a vegetation indicator:

$$\log\left(w_S\right) = a_0 \log\left(\Gamma\left(\theta, p\right)\right) + a_1 \cdot Veg + a_2\left(\theta, p\right) \quad (3)$$

where the regression coefficients are a_0, a_1 and a_2. For instance, considering eq. 3 at two different angles (denoted by indexes '1' and '2') both H and V polarizations and replacing the reflectivity with the ratio between the brightness and surface temperature (Γ =1-*Tb/Tc*), the retrieved soil moisture can be expressed:

$$\log(w_s) = a + b \cdot \log\left(1 - \frac{Tb_{\theta1,V}}{Tc}\right) + c \cdot \log\left(1 - \frac{Tb_{\theta2,V}}{Tc}\right) + d \cdot \log\left(1 - \frac{Tb_{\theta1,H}}{Tc}\right) + e \cdot \log\left(1 - \frac{Tb_{\theta2,H}}{Tc}\right) + f \; Veg \quad (4)$$

where *a, b, c, d, e* and *f* are regression coefficients for the equation.

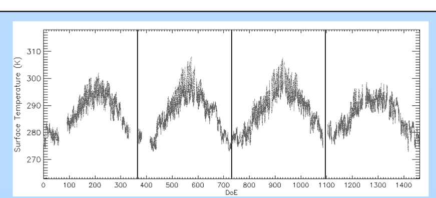
[1]J. –P. Wigneron. and co-authors. *Geosc. Rem. Sens.*, 1(4), 277 – 281, 2004

DATA (Calibration / Validation)

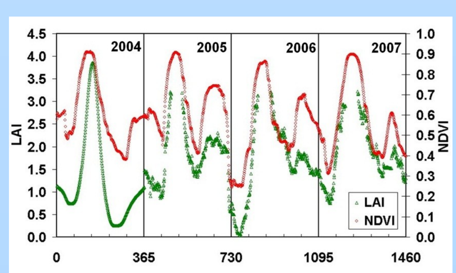
IN-SITU

SMOSREX

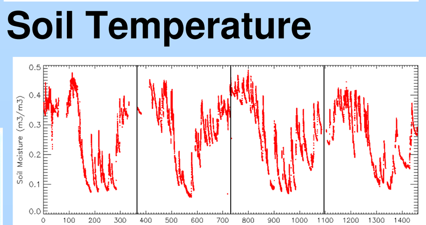
Period 2004 – 2007



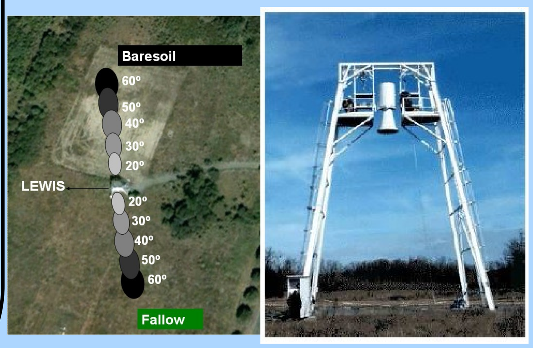
Soil Temperature



NDVI and LAI



Soil moisture



LEWIS Passive Microwave brightness temperature

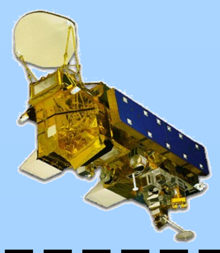
Equation (9)

$f(x)$

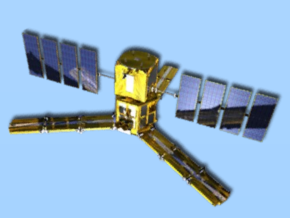
Data set

- Comparison between NDVI, LAI and NDVI=LAI=0
- Incidence angles: 40º and 20º-40º
- Best calibartion year, validation in the remaining data.

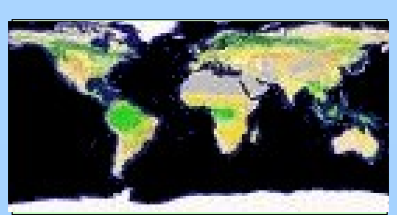
REMOTE SENSING



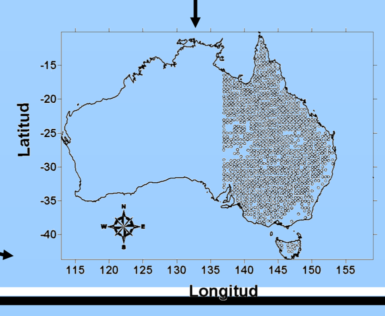
MODIS MOD13 (MOD13 NDVI 16 days)



SMOS Level-2 (TB at 42.5º)



ERA - Interim (Soil moisture 0-7 cm)



Data set

- Period September - December 2010
- Calibration (NDVI v/s NDVI = 0)

Results

Table 1 shows the coefficient of determination obtained in the calibration of the regression equations for NDVI and LAI. Both angle configuration are considered. Table 2 shows the results between measured and estimated w_S.

mono-angular configuration 40 - VH- NDVI = 0								
calibration year	N	*a*	*b* (TbV20)	*c* (TbV40)	*d* (TbH20)	*e* (TbH40)	*f* (NDVI)	R^2
2004	516	1.559		1.811		-0.763		0.861
2005	979	0.733		1.719		-1.157		0.654
2006	800	1.337		1.815		-0.956		0.794
2007	1243	1.035		1.424		-0.607		0.584
mono-angular configuration 40 - VH- accounting for NDVI								
calibration year	N	*a*	*b* (TbV20)	*c* (TbV40)	*d* (TbH20)	*e* (TbH40)	*f* (NDVI)	R^2
2004	516	1.144		1.814		-0.795	0.642	0.888
2005	979	0.126		2.028		-1.302	1.81	0.869
2006	800	1.345		2.176		-1.162	0.87	0.875
2007	1243	0.474		1.292		-0.392	1.162	0.788
Bi-angular configuration 20-40 - VH- NDVI = 0								
calibration year	N	*a*	*b* (TbV20)	*c* (TbV40)	*d* (TbH20)	*e* (TbH40)	*f* (NDVI)	R^2
2004	516	-0.73	-6.456	3.356	5.85	-2.826		0.901
2005	979	1.323	0.687	0.447	1.51	-1.893		0.798
2006	800	0.423	-4.641	2.144	4.941	-1.888		0.883
2007	1243	0.572	-0.829	0.925	2.348	-1.844		0.771
Bi-angular configuration 20-40 - VH- accounting for NDVI								
calibration year	N	*a*	*b* (TbV20)	*c* (TbV40)	*d* (TbH20)	*e* (TbH40)	*f* (NDVI)	R^2
2004	516	-0.538	-5.152	3.064	4.616	-2.396	0.382	0.909
2005	979	0.529	0.046	1.412	1.107	-1.797	1.432	0.899
2006	800	0.473	-4.076	2.624	3.771	-1.582	0.776	0.92
2007	1243	0.319	-1.271	1.359	1.869	-1.235	0.806	0.811

mono-angular configuration 40 - VH-LAI = 0								
calibration year	N	*a*	*b* (TbV20)	*c* (TbV40)	*d* (TbH20)	*e* (TbH40)	*f* (LAI)	R^2
2004	516	1.559		1.811		-0.763		0.8608
2005	979	0.733		1.719		-1.157		0.6544
2006	800	1.337		1.815		-0.956		0.7945
2007	1243	1.035		1.424		-0.607		0.5841
mono-angular configuration 40 - VH- accounting for LAI								
calibration year	N	*a*	*b* (TbV20)	*c* (TbV40)	*d* (TbH20)	*e* (TbH40)	*f* (LAI)	R^2
2004	516	1.506		1.955		-0.931	0.098	0.8884
2005	979	0.867		2.171		-1.362	0.340	0.8368
2006	800	1.480		2.082		-1.140	0.091	0.8151
2007	1243	0.815		1.326		-0.364	0.242	0.7089
Bi-angular configuration 20-40 - VH- LAI = 0								
calibration year	N	*a*	*b* (TbV20)	*c* (TbV40)	*d* (TbH20)	*e* (TbH40)	*f* (LAI)	R^2
2004	516	-0.730	-6.456	3.356	5.850	-2.826		0.901
2005	979	1.323	0.687	0.447	1.510	-1.893		0.798
2006	800	0.423	-4.641	2.144	4.941	-1.888		0.883
2007	1243	0.572	-0.829	0.925	2.348	-1.844		0.771
Bi-angular configuration 20-40 - VH- accounting for LAI								
calibration year	N	*a*	*b* (TbV20)	*c* (TbV40)	*d* (TbH20)	*e* (TbH40)	*f* (LAI)	R^2
2004	516	-0.271	-5.058	3.103	4.565	-2.456	0.051	0.907
2005	979	1.249	1.165	1.065	0.062	-1.378	0.259	0.876
2006	800	0.399	-5.223	2.672	5.002	-1.839	0.100	0.893
2007	1243	0.532	-1.119	1.103	2.339	-1.671	0.068	0.775

Table 1.- Regression coefficient and R2 using NDVI (right) and LAI (left)

		40º VH				20 and 40º VH			
		NDVI		NDVI=0		NDVI		NDVI=0	
	N	Bias	RMSE	Bias	RMSE	Bias	RMSE	Bias	RMSE
2004	3022	0.0415	0.064	0.0445	0.075	-0.0105	0.0642	-0.032	0.0912
2005	2559	-0.0068	0.0677	-0.0199	0.0518	-0.018	0.0831	-0.0405	0.0955
2006	2738	-0.0015	0.0577	0.0053	0.0638	-0.0073	0.0617	-0.0064	0.0652
2007	2295	-0.0009	0.0531	0.006	0.0571	0.0231	0.0538	0.0504	0.0782

		40º VH				20 and 40º VH			
		LAI		LAI=0		LAI		LAI=0	
	N	Bias	RMSE	Bias	RMSE	Bias	RMSE	Bias	RMSE
2004	3022	0.025	0.061	0.045	0.075	-0.023	0.073	-0.032	0.091
2005	2559	-0.017	0.070	-0.020	0.052	-0.035	0.097	-0.041	0.096
2006	2738	0.009	0.060	0.005	0.064	-0.008	0.066	-0.006	0.065
2007	2295	0.019	0.060	0.006	0.057	0.046	0.074	0.050	0.078

Table 3.- Bias, σ and RMSE between measured and retrieved w_S using NDVI (left) and Lai (right)

In most cases, for mono and bi-angular configuration, the use of NDVI or LAI improves the regression compared with NDVI or LAI equal to 0. Figure 1 and 2 shows the observed and retrieved soil moisture between 2005 and 2007 using the calibration coefficients retrieved in 2004.

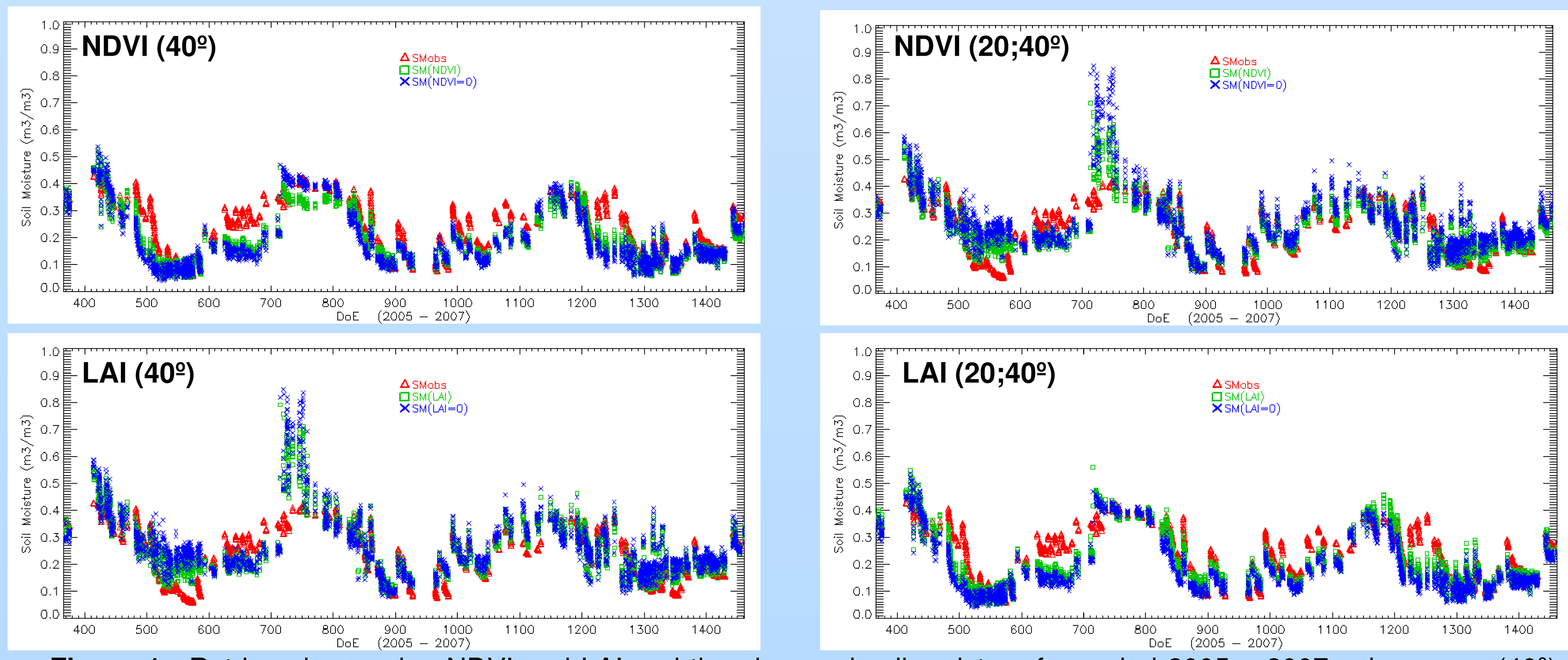
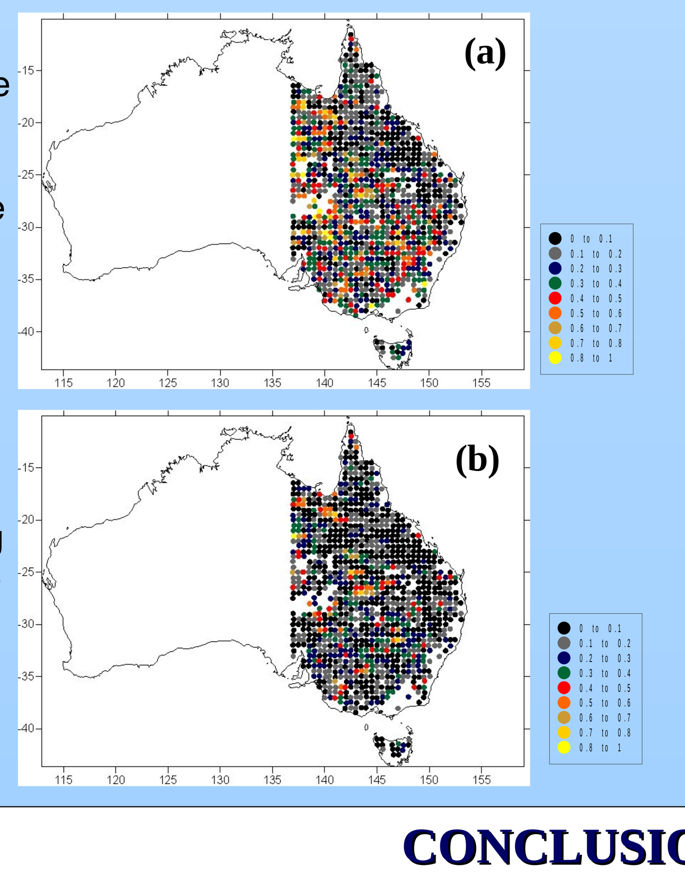


Figure 1.- Retrieved w_S using NDVI and LAI and the observed soil moisture for period 2005 – 2007 using mono (40º) and bi-angular (20º and 40º) configuration.

Figure 2 and 3 shows the influence of the NDVI in the regression equations. This Vegetation index improves the statistical relationship over the Eastern Australia.

Figure 2.- R^2 of the regression equations computed from the SMOS, MODIS and ERA-interim data for eastern Australia from September to December (a) setting NDVI=0 and (b) accounting for the NDVI in the regression equation.



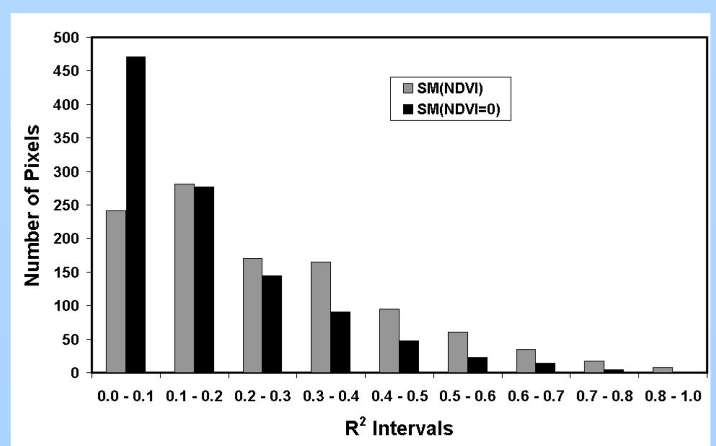


Figure 3.- Number of pixels for each R2 intervals from the regression calibration using the NDVI (SM(NDVI) and the NDVI set equal to zero (SM(NDVI=0)).

CONCLUSIONS

This study shows that vegetation dynamics provided by vegetation indexes measured in the optical domain (such as the NDVI or LAI) could be useful to improve the w_S retrievals. As in the calibration and the validation steps, it was necessary to have an estimate of soil moisture that could be considered as a reference. The statistical retrievals do not allow to choice which vegetation index (LAI or NDVI) is the best indicator of vegetation cover.