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VERIFICATION AND ASSIMILATION OF THE SMOS DATA

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ABSTRACT

Intensive airborne and in situ observations were performed in southern France for the SMOS CAL/VAL, from April to July 2010. The modelling tools, the experimental set-up and first results are described.

1. INTRODUCTION

SMOS (Soil Moisture and Ocean Salinity), launched in November 2009, represents a new step in Earth observation. For the first time in 30-y of passive microwave remote sensing (apart from a few days in the 70's, from Skylab), the L-band natural emission of terrestrial surfaces will be observed from space. Over land, the advantage of L-band is a higher sensitivity to soil moisture over vegetated areas, compared with higher frequencies. SMOS should produce a signal highly sensitive to soil moisture.

Currently, the soil moisture analysis systems used for NWP (Numerical Weather Prediction) applications are based on observed screen-level variables, namely air temperature and relative humidity at two meters above the ground. However, observations having a more direct link with soil variables are required. New spaceborne observation techniques are able to provide such variables like surface soil moisture (SSM) estimates at a global scale.

CNRM was involved in the SMOS preparatory studies, and contributed to the implementation of experimental infrastructures. In particular, the SMOSMANIA soil moisture network was deployed in southern France (now 21 stations), based on the operational infrastructure of Météo-France. Albergel et al. (2009) have shown that the SMOSMANIA in situ SSM observations can be used to assess satellite SSM products. In the framework of the SMOS CAL/VAL, in spring 2010, the SMOSMANIA observations were complemented by airborne observations of the CAROLS L-band radiometer, following an Atlantic-Mediterranean transect in southwestern France. Finally, an extended Kalman filter able to assimilate satellite data sensitive to soil moisture and to vegetation biomass was implemented in the SURFEX land surface modelling platform of Météo-France, in the framework

of the geoland2 project, co-funded by the European Commission within the GMES initiative in FP7.

The CAL/VAL will permit to specify the observation and model errors of the Land Data Assimilation System, which are critical parameters. In particular, the CAROLS data will permit to study the spatial heterogeneity issue affecting the SMOS pixel (spatial resolution of 30-50km), in the context of data assimilation into a finer resolution (1 to 8km) model. The assimilation of surface soil moisture products will be compared with the assimilation of the brightness temperatures. In the latter assimilation experiments, the multi-angular capacity of SMOS will be exploited thanks to a radiative transfer model.

2. MODELLING TOOLS

The SIM model suite SAFRAN-ISBA-MODCOU provides a synthetic SSM data set, from January 2007 to December 2008. SAFRAN (Système d'analyse fournissant des renseignements atmosphériques à la neige, Durand et al., 1993) is a mesoscale atmospheric analysis system providing gridded surface meteorological variables. It was initially developed to provide an analysis of the atmospheric forcing in French mountainous areas for avalanche forecasting. SAFRAN analyses ten parameters: 10-m wind speed, 2-m relative humidity, 2-m air temperature, cloudiness, incoming solar radiations, snowfall and rainfall. Hence, it provides an analysis for the main atmospheric forcing parameters using information from more than 1000 meteorological stations and more than 3500 daily rain gauges throughout France. For each variable analysed, an optimal interpolation method is used to assign values to given altitudes within the zone. A detailed description of the SAFRAN analysis over France is presented in Quintana-Segui et al. (2008). They also show that a good correlation between the SAFRAN database and in situ observations exists.

The land surface scheme used in SIM is ISBA. It is the land surface model used in the NWP, research and climate models of Météo-France. In the ISBA version used in SIM, the soil hydrology is based on the force restore approach. The soil is represented by one bulk

reservoir corresponding to the maximum rooting depth, including a thin surface layer, and regardless of the actual root development, according to Deardorff (1978). In the SIM system, the soil layer and soil moisture dynamics are modelled within a three soil-layer model (Boone et al., 1999), together with the explicit multilayer snow model (Boone and Etchevers, 2001). The soil and vegetation parameters used by ISBA are derived from a global database of soils and ecosystems, the ECOCLIMAP database (Masson et al., 2003). In SIM, the ISBA parameters, provided at a resolution of 1 km by ECOCLIMAP, are aggregated at the spatial resolution of the model, i.e. 8 km. MODCOU is a hydrogeological model that computes the spatial and

temporal evolution of the piezometric level of multilayer aquifers (Ledoux et al., 1989).

Finally, the ISBA land surface model is a component of the SURFEX (<http://www.cnrm.meteo.fr/surfex/>) modelling platform of Météo-France, together with a land data assimilation system based on of the Extended Kalman Filter (EKF) technique. Mahfouf et al. (2009) transformed the data assimilation system used in previous studies to a comprehensive EKF for operational use within the limited area NWP system ALADIN of Météo-France (Bubnova et al., 1995). This new EKF version was upgraded to allow the joint assimilation of remotely sensed LAI and SSM observations, as described in Albergel et al. (2010).

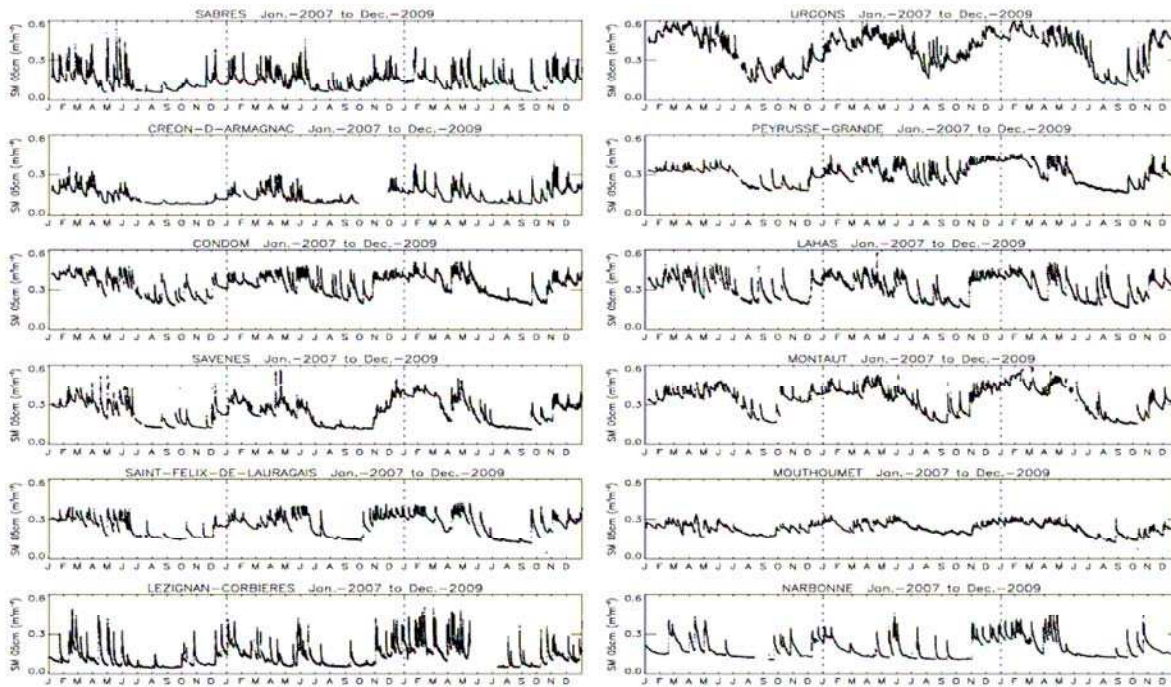


Figure 1. Volumetric soil moisture measured for 12 stations of the SMOSMANIA network over a 3-year period (from January 2007 to December 2009), at a depth of 5 cm.

3. THE SMOSMANIA SOIL MOISTURE NETWORK

The SMOSMANIA soil moisture network has several objectives including: (i) the validation of the operational soil moisture products of Météo-France, produced by the hydrometeorological SIM model (Habets et al., 2005, 2008), (ii) the validation of new versions of the ISBA land surface model of Météo-France, (iii) ground-truthing of airborne Cal/Val campaigns in support of the SMOS mission and (iv) the evaluation of remotely

sensed soil moisture products. Twelve stations (Fig. 1) of the existing automatic weather station network of Météo-France (RADOME) in southwestern France were equipped with soil moisture probes at four depths (5, 10, 20 and 30 cm). The RADOME stations observe air temperature and relative humidity, wind speed and precipitation. Downwelling shortwave radiation is also measured at some stations. The twelve stations of the SMOSMANIA network are located along a 400 km transect between the Mediterranean Sea and the Atlantic Ocean following the climatic gradient between the two

coastlines. The soil moisture measurements are in units of m^3m^{-3} , they are derived from capacitance probes: ThetaProbe ML2X of Delta-T Devices, easily interfaced with the RADOME stations. A ThetaProbe provides a signal in units of volt and its variations is virtually proportional to changes in the soil moisture content over a large dynamic range (White et al., 1994). In order to convert the voltage signal into a volumetric soil moisture content, site-specific calibration curves were developed using in situ gravimetric soil samples, for each station, and each depth i.e., 4 calibration curves per station (Calvet et al., 2007, Albergel et al., 2008). The ThetaProbes were installed in 2006 and have produced continuous observations since then, with a sampling time of 12 minutes. In 2008, nine additional RADOME stations were equipped with ThetaProbes and therefore the SMOSMANIA network now includes 21 stations (<http://www.ipf.tuwien.ac.at/insitu/>, <http://www.hymex.org>).

4. THE CAROLS AIRBORNE OBSERVATIONS

CAROLS (Combined Airborne Radio-instruments for Ocean and Land Studies) is an experimental set-up designed to perform a series of airborne campaigns for the preparation and the implementation of the land and ocean SMOS CAL/VAL. A number of instruments are installed on the ATR-42 French research aircraft of CNRS-INSU, CNES and Météo-France, operated by Unité Mixte de Service SAFIRE (Service des Avions Français Instrumentés pour la Recherche en Environnement, UMS 2859) of CNRM. The key sensor of CAROLS is a full-polarization L-band radiometer designed and operated by LATMOS. The instrument has two antennas: nadir and side-looking ($\sim 35^\circ$).

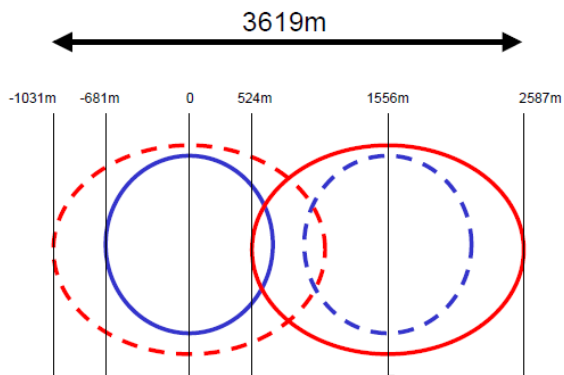


Figure 2. The 3.6km-large transect sampled by the CAROLS L-band radiometer at 2000m a.g.l. through the nadir and side-looking antennas (blue and red, respectively), for the outward and return flights (solid and dashed lines, respectively).

Over the SMOSMANIA transect, observations were made at springtime in 2009 and in 2010 at 2000m a.g.l. and covered strips of 1.4km and 2km for the nadir and side-looking antennas, respectively. From the Atlantic to the Mediterranean, the strips were sampled twice so that the nadir and side-looking strips overlapped and formed two parallel strips with biangular observations (0° and 35°), covering a 3.6km-large transect (Fig. 2). The flights were performed from Toulouse to the Atlantic Ocean and from Toulouse to the Mediterranean Sea (Fig. 3). During the 2010 SMOS CAL/VAL campaign, 17 flights were performed along the SMOSMANIA transect, of which 3 concerned the western part of the transect, only: 15 April, 28 April, 3 May, 6 May (western part only), 8 May (western part only), 9 May, 19 May (western part only), 21 May, 26 May, 31 May, 4 June, 8 June, 13 June, 18 June, 22 June, 26 June, 1 July.

5. ADDITIONAL SOIL MOISTURE OBSERVATIONS

The 21 SMOSMANIA stations for an extensive network covering a relatively large regional climatic gradient. The average distance between two SMOSMANIA neighbouring stations is about 45km. In order to characterize the spatial heterogeneity of SSM within a SMOS pixel, additional manual observations were performed at the south-west of Toulouse, close to the Lahas SMOSMANIA station, and to the SMOSREX experimental site (De Rosnay et al., 2006), at three sites (Fig. 4): “Le Mona” (mixed crop types on hilly terrain), “Lahage” forest, “Bérat” (maize on flat terrain). Manual transects of SSM observations were made with portable ThetaProbes at about 200 predefined spots at six dates: 15 April, 28 April, 26 May, 8 June, 18 June, and 1 July.

6. FIRST RESULTS

Figure 6 shows SSM values retrieved from the CAROLS biangular V- and H-polarized brightness temperatures (TB) in 2009, throughout the SMOSMANIA transect. The CAROLS TB is used to retrieve SSM by inverting the L-band microwave emission model of the biosphere (LMEB) radiative transfer model (Wigneron et al., 2007), using a method based on Saleh et al. (2007). The SSM retrievals are compared with the in situ observations at the closest SMOSMANIA stations and with the manual observations at Le Mona, Lahage and Bérat.

Figure 6 shows the 2010 time series of nadir TB over the SMOSMANIA station of Lahas, together with the daily precipitation observed by the station.



Figure 3. The SMOSMANIA CAROLS flight plan in southwestern France (red line). The SMOSMANIA stations are indicated, as well as the SMOSREX site (SMX).

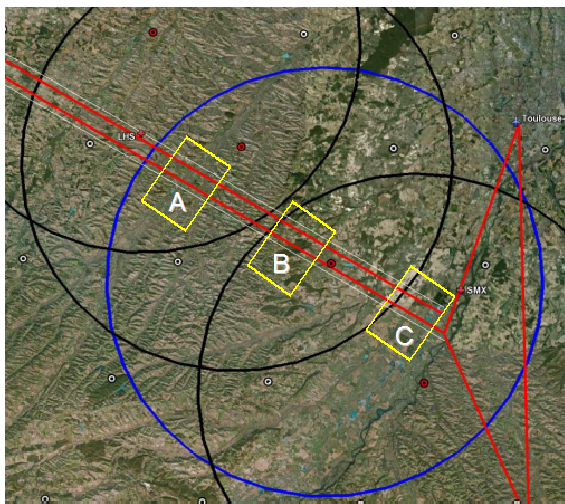


Figure 4. The 3 sites with additional annual SSM observations between the Lahas station and SMOSREX (LHS and SMX, respectively): (A) Le Mona, (B) Lahage, (C) Bérat.



Figure 5. Example of manual SSM transect at the Le Mona site ("A" in Fig. 4).

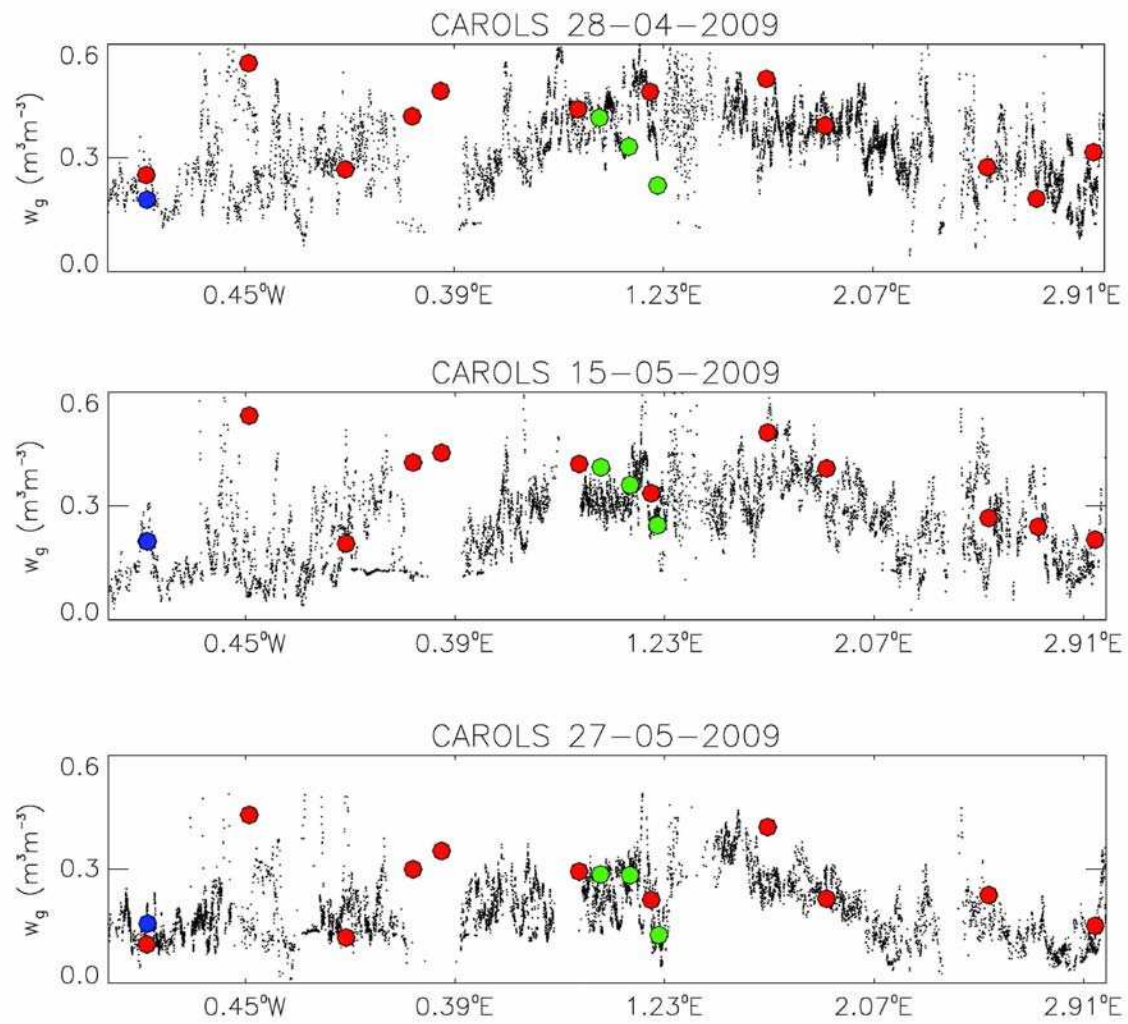


Figure 6. SSM retrievals (w_g) based on the CAROLS TB in 2009, along the SMOSMANIA transect (small black dots) and the in situ SSM observations of the SMOSMANIA stations (red dots), from left to right the Le Mona, Lahage, Bérat sites (green dots), and additional observations in the Les Landes forest, by INRA/EPHYSE (blue dot).

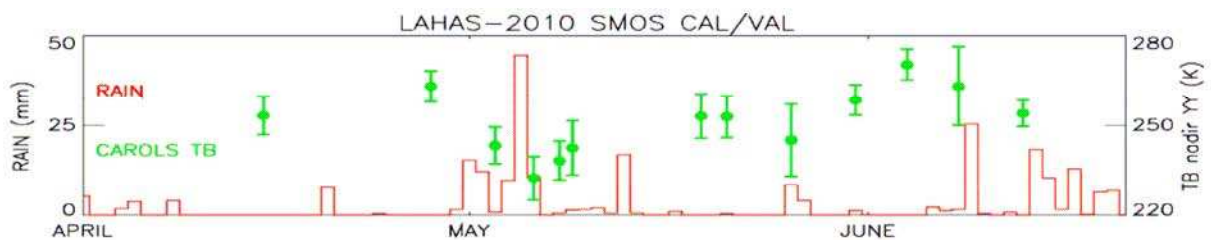


Figure 7. CAROLS nadir TB over the Lahas SMOSMANIA station from April to June 2010 (green dots). The daily precipitation measured by the Lahas station is represented by the red line.

7. ACKNOWLEDGEMENTS

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