# AN EVALUATION OF SOIL MOISTURE DOWNSCALING TECHNIQUES USING L-BAND AIRBORNE OBSERVATIONS

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## ABSTRACT

Airborne and ground-based field experiments have proven that L-band radiometers have a high sensitivity to changes in surface soil moisture and sea surface salinity. The European Space Agency (ESA) will launch the Soil Moisture and Ocean Salinity (SMOS) mission in November 2009 to globally map these two variables using a novel L-band 2-D radiometer concept. SMOS observations are expected to be highly accurate but, due to technological limitations, their spatial resolution is limited to 40-km. This resolution is adequate for many global applications but restricts the uses of the data in regional studies over land, where a resolution of 1-10 km is needed. In this study, specific deconvolution techniques for the spatial resolution enhancement of future SMOS data will be evaluated using airborne data acquired with the UPC Airborne RadIometer at L-band (ARIEL) over the Ebro river mouth. A land-sea mask of the area will be included as ancillary information in the reconstruction process and the performance of the different methods will be assessed in terms of radiometric sensitivity and coast line width. Hence, this study will also explore the feasibility of obtaining coastal retrievals from SMOS observations.

## 1. INTRODUCTION

The Soil Moisture and Ocean Salinity (SMOS) mission of the European Space Agency (ESA) will be launched in November 2009 and is aimed at monitoring, globally, surface soil moisture and sea surface salinity from radiometric L-band observations [1]. Soil moisture is a critical state variable of the terrestrial water cycle and the factor that links the global water, energy and carbon cycles. Sea surface salinity, jointly with sea surface temperature, determines the water density and regulates the global ocean circulation currents that moderate the Earth climate system. However, there are no currently observing systems that monitor these two key variables, being SMOS an unprecedented initiative to provide global soil moisture and surface salinity mapping. SMOS observations are expected to be highly accurate but, due to technological limitations, their spatial resolution is limited to 40-km. This resolution, while adequate for many global applications, is a limiting factor to its application in regional scale studies, particularly over land, where a resolution of 1-10 km is needed [2].

In [3], a deconvolution scheme was proposed to improve the spatial resolution of future SMOS data. Different deconvolution techniques using improved Wiener, Constrained Least Squares and wavelet filters that may include different levels of auxiliary information in the reconstruction process were presented and applied to simulated SMOS brightness temperatures ($T_B$) from the SMOS End-to-end Performance Simulator. With these techniques, the product spatial resolution and radiometric sensitivity was improved in a 49% over soil pixels and in a 30% over sea pixels.

In order to obtain $T_B$ datasets within the SMOS preparatory activities, several field experimental campaigns using the UPC Airborne RadIometer at L-band (ARIEL) have been conducted [4]. By using ARIEL airborne observations over the Ebro river mouth, this paper is devoted to evaluate and adjust soil moisture downscaling techniques using real data, prior to their application to SMOS. In Section 2 a brief overview of the overall airborne system is given and the Ebro river mouth field experiment is described. The deconvolution technique of [3] has been adapted for its application to ARIEL L-band $T_B$ data over the Ebro river mouth, using a land-sea mask of the area as ancillary information. The downscaling strategy is described on Section 3 and first results showing the coast line width and the radiometric sensitivity obtained with the different methods are presented on Section 3.

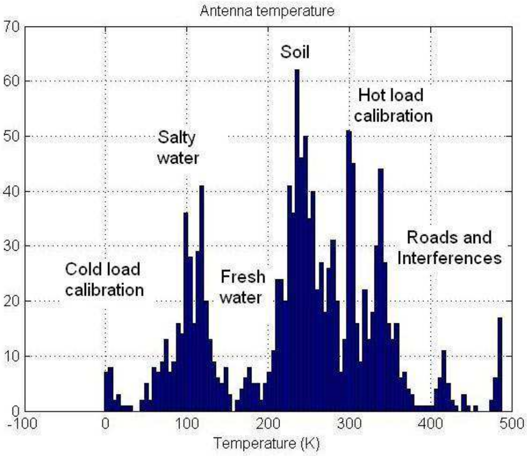
## 2. AIRBORNE OBSERVATIONS

### 2.1. Airborne System Overview

ARIEL is a light-weight L-band Dicke radiometer, with a radiometric sensitivity of 0.71 [K] [5]. It is mounted on a remotely controlled aircraft of 2.5-m wingspan and approximately 45 minutes of flight autonomy. The aircraft with the ARIEL radiometer can be seen in Fig. 1(a).

A system composed by a GPS, a 3-axes inclinometer, gyros and accelerometers are used to determine the posi-

(a)




(b)

**Fig. 1**. (a) The aircraft with the ARIEL radiometer after a test flight. (b) Retrieved antenna temperature histogram.

tion and the attitude of the aircraft. This system is used to properly geo-reference the radiometric measurements, which are stored in a flash memory aboard for latter processing. Radiometric calibration is performed by measuring with the antenna pointing to an absorber (hot load) and to the sky (cold load) before and after the flight.

To process the data, radiometer's raw output voltages are first converted into antenna temperatures through calibration. Second, $T_B$ are obtained from antenna temperatures, taking into account the the contributions of the atmosphere [6]. Then, the $T_B$ are geo-referenced and the pixels geographically coincident are combined on a regular grid to conform an image. The last step is to overlap this image in an aerial photography using Google Earth (Fig. 2).

### 2.2. Ebro river mouth field experiment

The test site of this field experiment has been the Ebro river mouth, located 180 km South from Barcelona, because of the large variety of scenarios that can be found in a reduced area: dry soil (ground), moist or flooded soils (rice fields), dry sand, fresh water (small ponds), and salt water (sea). It is one of the largest wetland areas (320 $km^2$) in the western Mediterranean region and is in intensive agricultural use for rice. Flights were performed over the Marquesa beach sea shore and land. The diversity of this area can be noticed on the antenna temperature histogram shown in Fig. 1(b).

Flights were conducted during daylight conditions and sun effects on the data must be accounted for. Particularly, sea and fresh water had a higher antenna temperature than expected and in some cases fresh water appeared to be hotter than land. Also, due to some problems with the inclinometer and inertial memories, the attitude data was not recorded. Nevertheless, as weather conditions were adequate, the aircraft remained almost constant and it can be assumed that the incidence of the antenna beam is perpendicular to the surface sensed.

## 3. DOWNSCALING STRATEGY

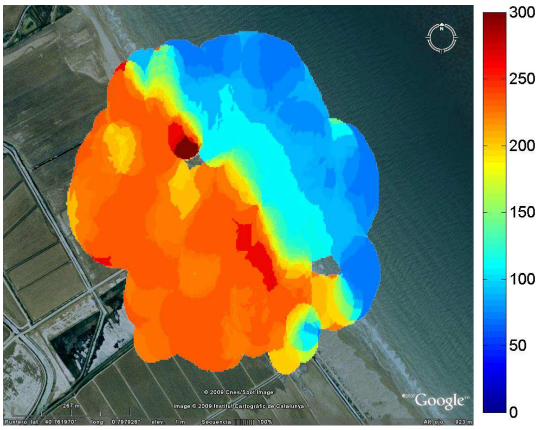
Flights at different heights were performed over the Ebro River Mouth with the ARIEL radiometer so that L-band observations over this area at different spatial resolutions were obtained. ARIEL $T_B$ images obtained at heights between 40 and 170-m, and between 170 and 300-m are shown on Fig. 2(a) and (c), respectively. As a rule of thumb, ARIEL observations have a radius of approximately $1/3$ times the flight height. Thus, the observations on Fig. 2(a) have a radius between $\sim$ 13 and 57-m, and the observations on Fig. 2(c) have a radius between $\sim$ 57 and 100-m.

In this study, the Wiener, Constrained Least Squares (CLS), Wiener model, and CLS model filters described in [3] have been applied to the $T_B$ image on Fig. 2(c) to explore the possibility of improving its spatial resolution. To do so, the effective antenna pattern function of the ARIEL radiometer has been approximated by a 2-D Gaussian function with the observations' mean radius as half-width value.

A Root Mean Square Error (RMSE) metric has been used to assess the radiometric sensitivity achieved with the different methods. It is computed in each case with respect to the $T_B$ image in Fig. 2(a). The filter's parameters have been selected by optimizing the RMSE over soil pixels.

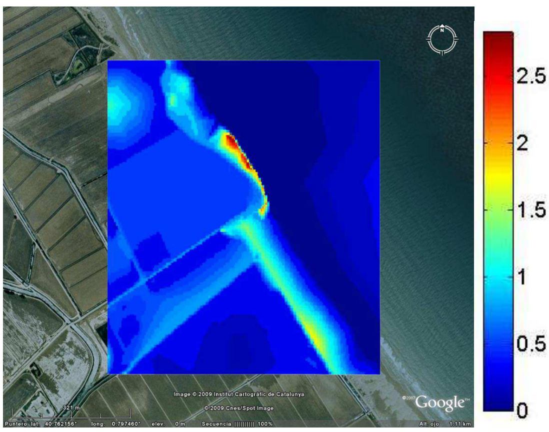
A $T_B$ model has been obtained from the 5-m resolution Digital Elevation Model (DEM) shown on Fig.3: a land-sea mask have been first derived from the DEM to define the model sea-soil transition and constant values of 120 [K] and 220 [K] have been afterwards assigned to sea and soil pixels, respectively. This model has been included as auxiliary information on the Wiener model and CLS model filters. Furthermore, to explore the maximum capabilities of these two filters, the image on figure 2(a) has been used as $T_B$ model on a best-case version of these filters.


(a)




(c)

**Fig. 2**. ARIEL Retrieved $T_B$ [K] geo-referenced on Google Earth obtained at heights (a) between 40 and 170-m, and (c) between 170 and 300-m.




(a)

**Fig. 3**. Digital Elevation Model [m] of the Marquesa beach area at 5-m spatial resolution, geo-referenced on Google Earth.

**Table 1**. RMSE between the different $T_B$ images and the highest resolution $T_B$ image at 40-170-m height, over soil and sea pixels

| | 170-300-m height | Wiener | CLS | Wiener model/best | CLS model/best |
|---|---|---|---|---|---|
| Soil | 28.5 | 26.6 | 24.8 | 23.4/11.4 | 22.5/11.7 |
| Sea | 24.5 | 23.4 | 24.0 | 26.8/12.4 | 22.1/14.6 |

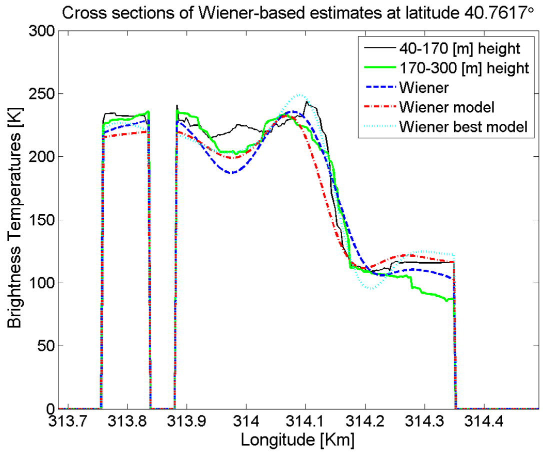
## 4. FIRST RESULTS

To evaluate the spatial resolution achieved with the different algorithms, cross-sections at a constant latitude of the image obtained from ARIEL observations at heights 40-170-m, 170-300-m, and of the images resulting from the application of Wiener-derived and CLS-derived filters to the 170-300-m height image, are presented on Fig. 4. It can be observed that the coast line is sharply defined when Wiener and CLS model filters are used, which can lead to better coastal retrievals. It can also be observed that the highest definition is obtained when the 40-170-m height image is used as $T_B$ model (best case). Therefore, it appears that the more accurate the $T_B$ model used on the filter, the sharper the coast-line definition of the resulting image. However, further studies will be needed to quantify the spatial resolution enhancement obtained when applying the different methods.

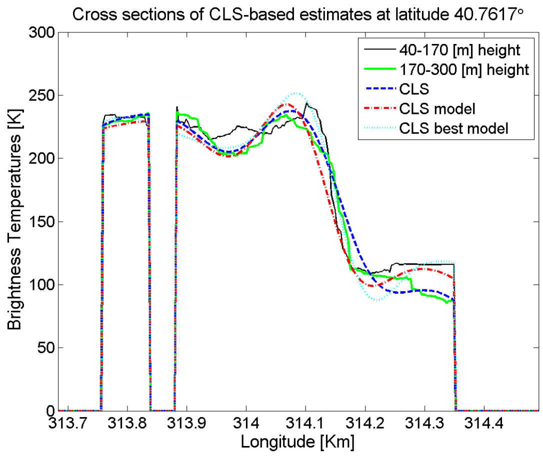
The RMSE between the different $T_B$ images obtained and the image of highest spatial resolution (Fig. 2(a)), which is used as ground-truth data, are listed in Table 1. From these first results, it can be observed that all methods satisfactory improve the radiometric sensitivity of the observations over soil pixels. Over sea pixels, though, the methods practically do not achieve any improvement or even worsen the results. Note that this fact can possibly be due to the fact that the filter's parameters are set by optimizing the RMSE over soil pixels and not over sea pixels. Regarding the effect of adding the $T_B$ model, it can be noticed to considerably improve the RMSE over soil pixels. This improvement is specially remarkable both over soil and sea pixels when the $T_B$ image in Fig. 2(a) is used as $T_B$ model (best case). Thus, the RMSE obtained with the methods which include a $T_B$ model also relies on the effectiveness of the model they use.

## 5. CONCLUSION

Preliminary results of the application of the downscaling algorithms in [3] to airborne field experimental data over the Ebro river mouth have been presented. These algorithms are based on the possibility of improving the spatial resolution of radiometric observations by suitably adding auxiliary information on the image reconstruction process, using a deconvolution-based approach. It has been confirmed that with these methods it is possible to improve the radiometric sensitivity of the observations as well as to improve the coast line definition. Further work will be performed in order to optimize the performance of the algorithms in terms of the best radiometric sensitivity and spatial resolution that can be obtained over soil and sea pixels. An overview of the downscaling strategy and a complete evaluation of the results will be presented at the conference.




(a)




(b)

**Fig. 4**. (a) Cross-sections of the image obtained from ARIEL observations at heights 40-170-m, 170-300-m, and of the images resulting from the application of Wiener-derived filters to the 170-300-m height image. (b) Cross-sections of the image obtained from ARIEL observations at heights 40-170-m, 170-300-m, and of the images resulting from the application of CLS-derived filters to the 170-300-m height image.

## 6. ACKNOWLEDGEMENT

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