Multi-resolution soil moisture retrieval from passive microwave sensors: A preliminary study

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Abstract Retrieval of near-surface soil moisture (SM) from L-band (1.4 GHz) passive microwave sensors has been demonstrated to be feasible from airborne platforms, through experiments, and from spaceborne platforms, through synthetic studies. Current retrieval techniques are based on inversion of radiative transfer models which simulate the microwave emission from the earth surface (the so-called "Brightness Temperature", T_B) given a specified soil moisture (SM), soil temperature, vegetation water content, surface roughness and so on. These models assume uniform conditions within each pixel, and have been developed from tower-mounted radiometers, with resolutions of the order of 10's of meters. The strong non-linearities involved in such models with respect to the parameters characterizing the land surface, stems the question whether the same model can be applied to heterogeneous pixels at satellite footprint scales (~40km), that is, whether the same field average SM is obtained by retrieving from high resolution footprints and from a single, low resolution footprint with T_B equal to their average (Figure 1). This study presents the preliminary analysis on a unique data set of independent multiple resolution L-band T_B with the objective to verify the transferability of current SM retrieval techniques across scales ranging from 10's meters to 10's kilometers. This is expected to be done by applying such techniques to T_B observations at different resolutions, including a 40km pixel simulated by aggregation of high resolution T_B observations, and comparing the resulting retrieved SM at satellite footprint scale. In preparation to that, in the present document the scaling properties of the T_B observations are analyzed to verify the implications of using a simple aggregation to a 40km footprint from high resolution observations. Moreover, the performance of the microwave emission model used is tested at control sites by comparing the observed T_B at different resolutions with those simulated by the model when fed with the observed land surface conditions as input.

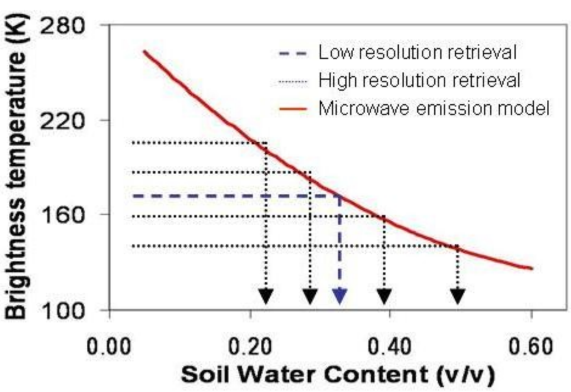

Figure 1 The problem of multi-resolution retrieval for a simple case of bare soil (Soil type= Silty clay loam, Soil temperature= 317.5 K)

Background

The upcoming lunch of ESA's Soil Moisture and Ocean Salinity (SMOS) mission will provide the first SM dedicated L-band global data set [1].The utilization of this novel technique on a space-borne platform poses several scientific questions yet to be answered. In particular the implications of applying the L-band SM retrieval algorithms developed from high resolution or point measurements to large scale (~40km for SMOS) heterogeneous scenes need to be properly assessed. Due to the lack of L-band space-borne data, as well as that of concurrent multiple resolution L-band observations, previous studies on this issue have relied mainly on the simulation of synthetic coarse scale pixels through radiative transfer models and land surface models. To date, only one study made use of independent observations to explore this issue: Jackson compared for the first time a limited number of independent T_B observation at resolution ranging from 100m to 1km in [2]. His results showed that the same average T_B was observed at different resolution over the study area. Moreover, he found that the same relationship between T_B and ground measurements of SM applied at all resolutions. His results are limited to vertically polarized T_B, not optimal for SM retrieval, small range of soil wetness conditions and land cover types (winter wheat and pasture). The present study addresses the same problem but making use of an extensive dataset of horizontally polarized T_B at resolution ranging from 90m to 1km, collected by the same sensor over a full range of wetness conditions and a variety of land cover types, including a variety of crops, native pasture and forested areas.

Data set description

The multi-resolution T_B observations and ground data used in this study were collected during the National Airborne Field Experiment (NAFE), which ran in November 2005 in the Goulburn River catchment, located in a semiarid area of South-Eastern Australia. The campaign included extensive airborne passive microwave observations together with spatially distributed and in-situ ground monitoring of SM, vegetation water content (VWC), soil temperature and other relevant land surface characteristics. Full details about the field campaign and the data collected can be found in [3]. The data which are relevant to the present study are briefly described hereby.

Ground Data

The area monitored during NAFE'05 was a rectangle of approximately 40km x 40km, centred in the northern part of the Goulburn catchment. This area was logistically divided into two focus areas, the "Merriwa" area in the eastern part of the catchment and the "Krui" area in its western part. The predominant land use is grazing on native pasture followed by open woodland and cropping, including Wheat, Barley, Lucerne, Sorghum and Oats. Eight farms were accessible for ground sampling. On

Table 1. Location and characteristics of the High Resolution (HR) areas. Standard deviation of VWC is the average in time.

HR area	topography	land cover	VWC [Kg/m^2] (Min-Max)	% sand	% clay
Stanley	sloping south	Native	0.2-0.4	6	54
Roscommon	flat	Native	0.8-0.2	67	15
Dales	sloping/creek	Native	0.5-0.3	31.5	51
Merriwa Park	gently sloping	Wheat	1.5-0.6	21	36
Midlothian	flat	Fallow (50%)/ Lucerne (50%)	1.5-0.2	10	69
Cullingral	flat	Wheat(50%)/ Barley(50%)	1.8-0.5	72	6.5
Illogan	flat	Oats(60%)/ Barley(40%)	2.0-0.5	23	26
Pembroke	gently sloping	Native(20%) /Barley(80%)	3.0-1.0	6	71

each farm, a small "high resolution" (HR) areas of 150m x 150m was chosen for detailed fine scale ground sampling of SM, soil temperature and VWC. The HR areas were chosen so that they included as much as possible of the variety of land covers and topography present in the area (Table 1). Top 5 cm SM was monitored at each HR area a grid of 12.5m spaced points, with a core of 75m x 75m sampled at 6.25m. The surrounding areas were sampled at decreasing resolutions of 62.5m, 125m, 250m and 500m up to the farm extension, with nested grids centred to the HR area. This provided high resolution ground "truth" for the aircraft observations taken over the area at all resolutions. Each HR area was sampled once a week, concurrently with multiple resolution aircraft observations over the area. VWC was sampled by taking biomass samples at 16 location within the HR area once a week. The range of VWC experienced by each HR area during the campaign is indicated in Table 1, together with the average spatial standard deviation.

Polarimetric L-band Multi-beam Radiometer Data

A total of 16 Multi-resolution flights were conducted between October 31 and November 25, 4 per week alternatively over the Krui and Merriwa area. The radiometer used was the Polarimetric L-band Multi-beam Radiometer (PLMR). The PLMR measures both vertically and horizontally polarized T_b at incidence angles +/-7°, +/-21.5° and +/-38.5° in either across track ("push-broom") or along track configurations. For the multi-resolution mapping, the PLMR instrument was installed in "push-broom" configuration, meaning that at each aircraft location 6 measurements were taken at 6 different angles across the aircraft flying direction. The focus area was covered with parallel, North-South oriented flight lines, overlapping each other of at least 1 full pixels. For each flight, 4 sets of observations were collected at 4 different altitudes in descending order (3000m, 1500m, ~750m and ~200m AGL), resulting in L-band maps at approximately 1km, 500m, 300m and 90m mean spatial resolutions.

Results and discussion

Scaling of Brightness Temperatures

The first analysis conducted was to compare the average T_B for each of the 4 maps on a daily basis. These are shown, for each mapping day on the Krui, in figure 2a. Also plotted is the standard deviation across the area for the lowest (1km) and highest (90m) resolution. Minimum values of T_B were measured at the beginning of the month, after heavy rainfall had occurred (i.e., wet conditions), while increasing T_B were recorded during the inter-storm period before November 21. The Standard deviation of the T_B fields is instead higher on wet conditions, and notably higher for the 90m data then for 1km data. This is expected as higher resolution data are able to resolve finer spatial details. The effect of resolution on the area-averaged

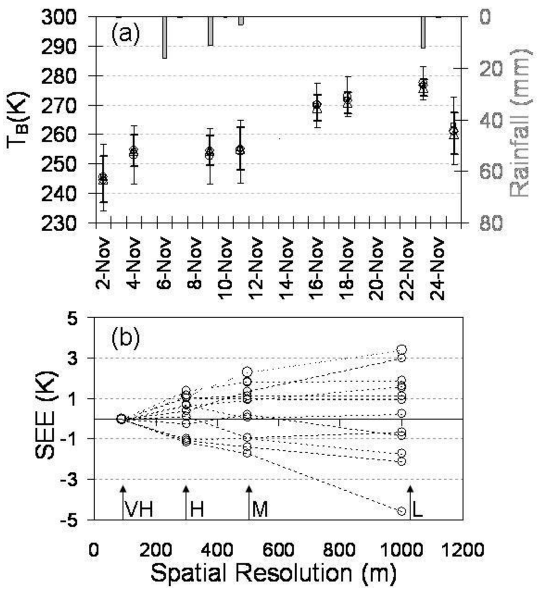

Figure 2. Temporal series of a) average T_B over the Krui area and b) Standard Error of Estimate; L (1km data, circles), M (500m data, diamonds) and H (300m data, squares) data for both focus areas, bold error bars are for VH (90m) data, solid error bars for L data.

T_B is shown in Figure 2b in terms of the Standard Error of Estimate (SEE, defined as the error, in Kelvin, committed in using the area-averaged T_B of low resolution data (1km, 500m and 300m) to estimate the area-average T_B of high resolution data (90m). The 90m data are therefore used as a benchmark to evaluate the ability of low resolution T_B to capture significant land surface spatial variability. By definition, the SEE for the 90m data is therefore zero. Figure 2b displays the SEE as a function of the spatial resolution of observation for each day of mapping over the Krui and Merriwa areas. The plot shows a general increase of SEE going towards lower resolution data. Overall, the difference in area-averaged T_B when using 1km resolution mapping appears inferior to 3K. On a moderate vegetated area, this would correspond approximately to an error of soil moisture inferior to 1%v/v. Note that the increase in SEE has a similar magnitude between the 90m and 300m data and the 300m and 500m data, and then is generally not significant between the 500m and 1km data. This supports the extrapolation of these results to satellite footprint scales, and gives confidence that a simple linear aggregation can be used to simulate realistic 40km, SMOS-type footprint over the area, with an error of less then 3K.

Microwave Emission Model

The model used follows the formulation of [4]. It calculates the dielectric constant from the T_B correcting for the vegetation masking and the surface roughness. It then calculates the volumetric soil moisture through a dielectric mixing model using soil texture information. The performance of the model was tested focusing on the eight HR areas. These sites were chosen as the land surface conditions were well known and all the variables contributing to the microwave emission had been carefully monitored (Table 1). To this end, the model was fed with the values of soil temperature, soil type, vegetation water content and surface roughness monitored at each HR area in order to simulate T_B over a range of SM content. This was compared with aircraft observations of the HR areas at 90m and 1km resolution on the four dates at which each HR area was sampled. Results are shown in Figure 3. The model outputs are shown for the maximum and minimum VWC experienced by each area during the 4 weeks of sampling. The results indicate that the microwave emission model reproduces very well the relationship between T_B and soil moisture as observed at different resolutions. Given that the observations are not expected to fall along one individual model run, as they are generally associated with different days and therefore different land surface conditions, the important result is that the observations fall within the limits defined by the model for the variety of land surface conditions considered.

Conclusions

The results of this preliminary analysis suggest that aircraft data can be reliably averaged up to satellite footprint resolutions for the purpose of synthetic satellite scaling studies and satellite verification when that data becomes available. It was also verified that the microwave emission model used is consistent with multiple resolution aircraft observations over the full range of land cover and climatic conditions experience by the study area. This can be therefore reliably used to investigate algorithm scaling issues.

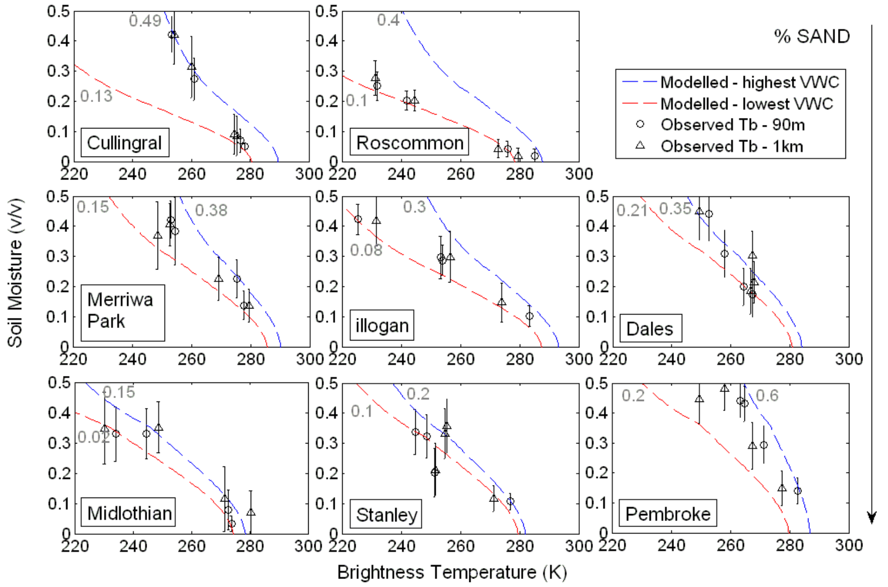

Figure 3 Comparison of modelled and observed brightness temperatures at the 8 high resolution areas, ordered per increasing sand percentage (top to bottom) and optical depth (left to right). The vertical error bars indicate the standard deviation of the ground measured soil moisture. The numbers in gray indicate the value of

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