

Validation of Microwave Remote Sensing Products over Australia

C. Rüdiger^{a,*}, J.P. Walker^a, Y.H. Kerr^b

^a Department of Civil Engineering, Monash University, Clayton VIC 3800, Australia (chris.rudiger, jeff.walker)@monash.edu

^b Centre d'Etudes Spatiales de la Biosphère (Cesbio), CNES, 31400 Toulouse, France

With the recent launch of the Soil Moisture and Ocean Salinity (SMOS) mission, and the future Aquarius and Soil Moisture Active Passive (SMAP) missions being planned for 2011 and 2014, respectively, the remote sensing community is becoming engaged in airborne campaigns for their validation. Given the financial and logistical constraints on the area that can be covered by airborne simulators in such campaigns, scientifically sound advice on the fractional footprint coverage requirements by campaigns for these low resolution sensors is of paramount importance, to ensure the usefulness of the validation campaigns. Using high resolution airborne data from an extensive airborne campaign in south-eastern Australia the fractional coverage requirement for L-band passive microwave satellite missions is assessed. It is found that only in the case of particularly homogeneous areas can this fractional coverage be considerably reduced.

Keywords: soil moisture, microwave remote sensing, SMOS, ground validation, spatial requirements.

1. INTRODUCTION

The Soil Moisture and Ocean Salinity mission (SMOS), a satellite mission led by the European Space Agency (ESA), was launched on 2 November 2009. This mission constitutes the first satellite mission to be specifically dedicated to the observation of soil moisture from space (Kerr et al., 2010). In addition, two more soil moisture observing satellites will be launched over the coming years: Aquarius (Lagerloef et al., 2008) and the Soil Moisture Active Passive (SMAP; Entekhabi et al., 2010) missions which will add to and secure the legacy of SMOS.

However, as both, the design and the observation frequency of SMOS (L-band, 1.4GHz) have previously not been deployed in an operational manner in space, a large number of ground calibration and validation campaigns were required to take place across the globe, in order to verify the performance of SMOS (Delwart et al., 2008). Most of these campaigns designed to include extensive campaign efforts, both in terms of airborne and ground-based data acquisition. However, with the launch of more such satellites in the near future and given the limited financial and human resources to undertake such large field campaigns, it needs to be assessed whether campaigns of large scales are ultimately required for the purposes of calibrating and validating microwave remote sensing satellites.

As part of the Australian validation campaign organized for SMOS (Australian Airborne Cal/val Experiments for SMOS (AACES); Peischl et al., 2009), two airborne field campaigns were conducted across the Murrumbidgee River catchment in south-eastern Australia, using an airborne platform and intensive high-resolution ground-based soil moisture measurements. The campaigns were undertaken during the Austral summer and winter of 2010, covering an area of approximately 50,000km² at 1km resolution. Those data were then used to determine the minimum spatial coverage required to achieve an uncertainty in the average brightness temperature across a standard sized SMOS footprint of 4K (the design accuracy of SMOS). It was found that at least 50% of footprint need to be covered by airborne observations to reach this goal under normal conditions.

2. FIELD SITE AND OBSERVATIONS

2.1 Murrumbidgee River catchment

The data of this study were collected during the AACES campaigns, which took place from 18 January to 21 February and 8-26 September 2010 in the Murrumbidgee River Catchment in south-eastern Australia. The catchment was chosen for its spatial characteristics and the existing network of permanent soil moisture monitoring stations (Smith et al., submitted) and is located between 34° to 36° southern latitude and 143° to 150° eastern longitude. It includes a large variety of low level plains in the west and extends to the alpine conditions in the Australian alpine region (Figure 1). The plains of the western region are predominantly used for grazing, while the central part contains the Murrumbidgee and Coleambally Irrigation Areas, where cropping is the dominant land use. Finally, the catchment transitions into woody vegetation in the east. While the western half of the Murrumbidgee River catchment is flat, the eastern quarter is dominated by undulating to rugged alpine conditions.

The Murrumbidgee catchment displays a large spatial variability in climate, topography, soil type, vegetation type and land use, due to its distinctive topography changes and location. Consequently, this region is an ideal test bed for comprehensive validation studies of passive microwave missions, due to the diversity within this area and the large amount of complementary data from long-term monitoring sites.

2.2 Airborne Data

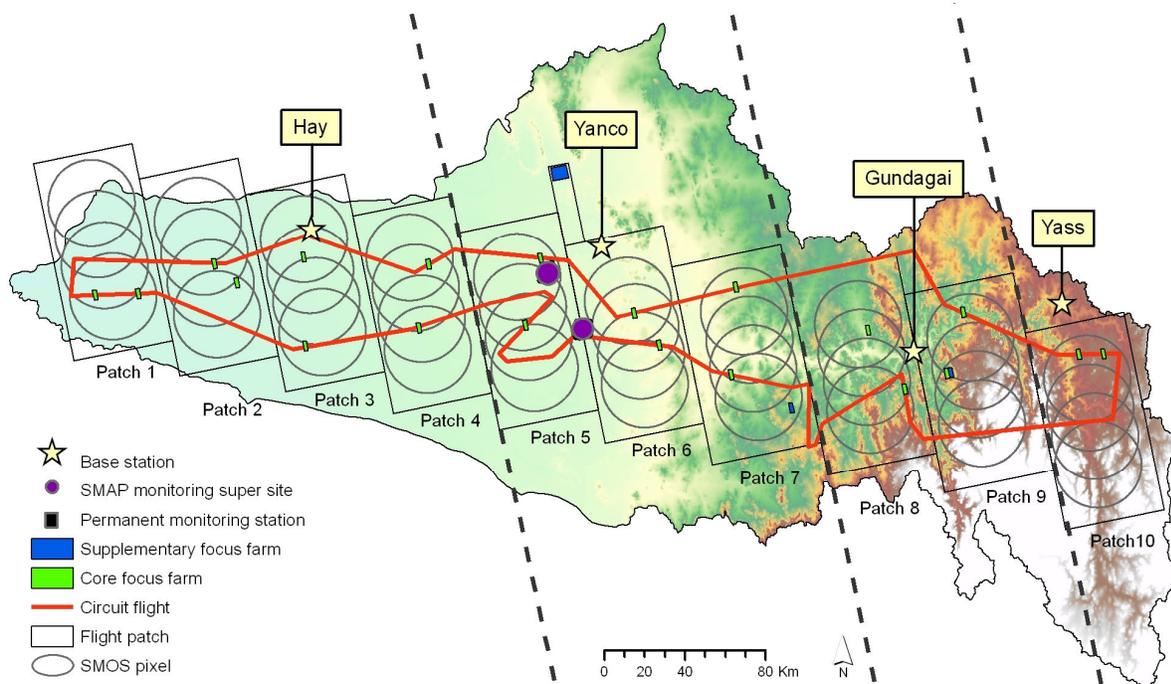


Figure 1. Overview of the AACES daily flight patches and the included SMOS footprints (circles) and the focus farms of the ground-based measurements. The background shows the variability of the surface elevation.

The data analysed here are vertically and horizontally polarised passive L-band brightness temperatures, obtained by deploying the Polarimetric L-band Multi-beam Radiometer (PLMR) at 1.413 GHz (± 12 MHz) (Pancier et al., 2008). The same instrument has been used previously for the development of the SMOS soil moisture retrieval algorithm throughout the NAFE campaigns (Pancier et al., 2008; Merlin et al., 2009). The microwave data used here were obtained by flying the aircraft at an altitude of approximately 3000m above ground level, resulting in a nominal ground resolution of 1km for each of the six across track pixels.

The flights were scheduled so that they took place over a 4-5 hour window, coinciding with the local SMOS ascending overpass time of ~ 6 am. The brightness temperatures were corrected by using the diurnal variation in soil moisture and temperature observed at the permanent monitoring stations. In addition, to correct for angular differences within the six beams, the mean of the data collected with each beam was scaled to the mean of the data collected with the outer PLMR beams (38°), as suggested by Jackson (2001).

Two independent complete SMOS footprints were observed during each flight, being for an area of 50km x 100km (Figure 1), or a total of four footprints as the SMOS data grid is computed on a regular grid of 15km spacing, resulting in an

overlap of individual SMOS footprints each being on average of ~ 42 km in diameter. To cover the entire catchment, 10 flights were undertaken (with a reduced number of 5 during the winter campaign, covering the central five focus areas). The flight lines were aligned with the SMOS grid, so that the maximum number of entire SMOS pixels may fall within the focus areas.

The first four flights were undertaken under very dry and hot conditions, due to the preceding dry summer. However, two significant rain events (5 Feb and 13 Feb, before the flights across P05 and P08, respectively), lead to a significant wetting and subsequent dry-down of large parts of the catchment. The was found to be advantageous for the present study as these weather conditions made it possible to assess the spatial variability of soil moisture under a varying range of environmental conditions, including hot and dry through to humid and cool. Due to the Australian winter of 2010 having been considerably wet and therefore resulting in high soil moisture content throughout the catchment, a significant amount of vegetation cover was found, which significantly contrasted the surface conditions between summer and winter campaigns, further broadening the spectrum of different surface conditions. Figure 2 shows the horizontally polarized brightness temperature data sets of the summer campaign as an example, with the decreased brightness temperatures towards the east in response to rainfall being clearly obvious.

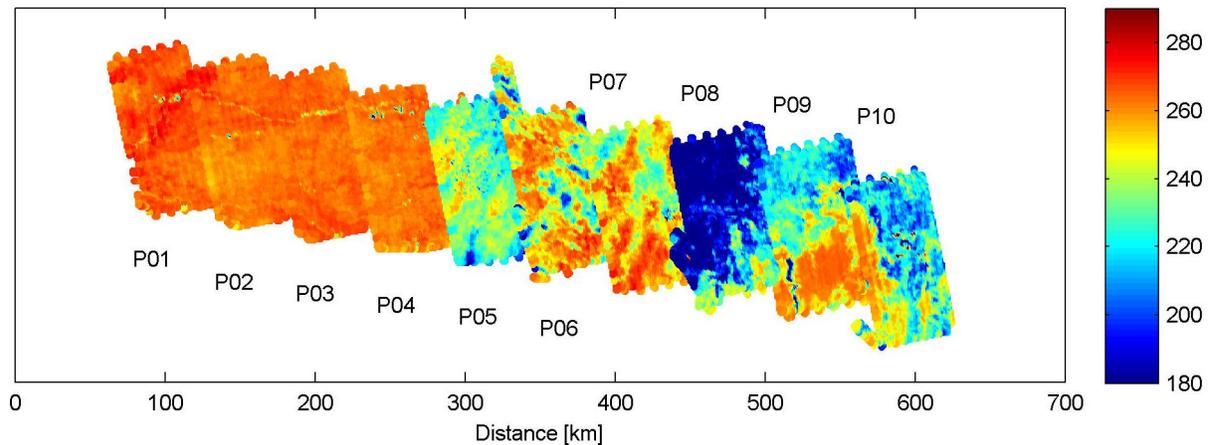


Figure 2. Brightness temperatures collected during the summer AACES campaign throughout Jan/Feb 2010. The rain events took place before the P05 and P08 flights and are clearly discernible due to the reduced brightness temperatures of those flights.

3. RESULTS

The surface conditions encountered at the start of the first campaign resulted in very small spatial variability of the observed brightness temperature across the first four focus area, typical of semi-arid catchments in many regions of the world. On the other hand, the patchiness of rainfall, variation in topography, soils and land use, and the forested areas in the focus areas towards the east, resulted in a more typical spatial variability for more temperate regions in the six eastern flights over the catchment.

To study the fraction of the microwave satellite footprint coverage required to accurately estimate the spatial mean a sub-sampling technique was used that assesses all possible combinations of partial footprint coverage by flight lines through a passive microwave footprint. The mean of the observed brightness temperatures observed across the total footprint were used as a reference value with 4K uncertainty limits (equal to the design accuracy of SMOS). For each possible flight line combination, the mean and standard deviation of the sampled data were then calculated. The fractional coverage requirement for each individual area was then identified, when the 90% confidence interval was within the defined 4K requirement. Plotting this value against the spatial variability of the entire footprint shows that the relationship between the fractional coverage required to achieve the 4K uncertainty appears to be linearly related (Figure 3). Given the large range of environmental conditions and the different seasons of acquisition, this result is not a coincidence and can be seen as representative of various climates throughout the world.

4. DISCUSSION AND CONCLUSION

This paper has used a large amount of airborne data to assess the spatial coverage requirements for airborne calibration and validation campaigns of microwave satellite missions. Through statistical analyses, it is shown that a minimum 50% coverage of the total footprint size is typically required to ensure that the correct footprint mean is estimated with an expected sampling error of less than 4K; the design sensitivity of SMOS and also the uncertainty requirement for passive microwave measurements over land to achieve a soil moisture error less than $\sim 0.02 \text{ m}^3/\text{m}^3$. Only in the case of particularly homogeneous areas can this fractional coverage be considerably reduced. Consequently, if campaigns are undertaken with

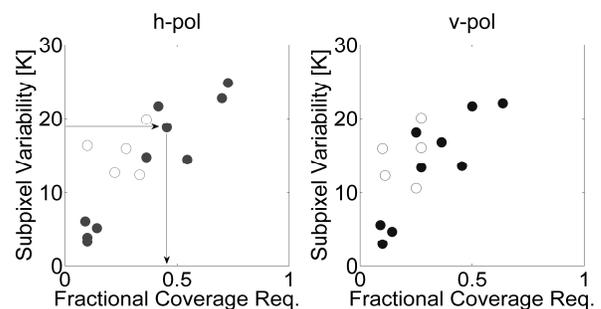


Figure 3. Comparison of the spatial variability of the SMOS-size footprint against the areal coverage required to achieve a sampling uncertainty of less than 4K. The errors show, as an example, the requirement to cover 50% of the area for a footprint with 20K spatial variability.

fractional footprint coverage less than 50%, it will be necessary to demonstrate a low spatial variability in expected microwave emission to avoid necessitating careful attention to up-scaling of the airborne data such that significant footprint average biases are avoided.

REFERENCES

S. Delwart, C. Bouzinac, P. Wursteisen, M. Berger, M. Drinkwater, M. Martín-Neira, and Y.H. Kerr, "SMOS validation and the COSMOS campaigns," *Geosci. Remote Sens.*, vol. 46, no. 3, pp. 695-704, 2008, doi:10.1109/TGRS.2007.914811.

D. Entekhabi, E.G. Njoku, P.E. O'Neill, K.H. Kellogg, W.T. Crow, W.N. Edelstein, J.K. Entin, S.D. Goodman, T.J. Jackson, J. Johnson, J. Kimball, J.R. Piepmeier, R.D. Koster, N. Martin, K.C. McDonald, M. Moghaddam, S. Moran, R. Reichle, J.C. Shi, M.W. Spencer, S.W. Thurman, L. Tsang, and J. Van Zyl, "The Soil Moisture Active Passive (SMAP) mission," *Proc. IEEE*, vol. 98, no. 5, pp. 704-716, 2010, doi:10.1109/JPROC.2010.2043918.

T.J. Jackson, "Multiple Resolution Analysis of L-Band Brightness Temperature for Soil Moisture," 39, 151-164, 2001.

Y.H. Kerr, P. Waldteufel, J.-P. Wigneron, S. Delwart, F. Cabot, J. Boutin, M.-J. Escorihuela, J. Font, N. Reul, C. Gruhier, S.E. Juglea, M.R. Drinkwater, A. Hahne, M. Martín-Neira, and S. Mecklenburg, "The SMOS Mission: New tool for monitoring key elements of the global water cycle," *Proc. IEEE*, vol. 98, no. 5, pp. 666-687, 2010, doi:10.1109/JPROC.2010.2043032.

G. Lagerloef, F.R. Colomb, D. Le Vine, F. Wentz, S. Yueh, C. Ruf, J. Lilly, J. Gunn, C. Yi, A. Decharon, G. Feldman, and C. Swift, "The Aquarius/SAC-D Mission: Designed to meet the salinity remote-sensing challenge," *Oceanography*, 21(1), pp. 68-81, 2008.

O. Merlin, J.P. Walker, J.D. Kalma, E.J. Kim, J. Hacker, R. Panciera, R. Young, G. Summerell, J. Hornbuckle, M. Hafeez, and T. Jackson, "The NAFE'06 data set: Towards soil moisture retrieval at intermediate resolution," *Adv. Water Res.*, vol. 31, pp. 1444-1455, 2008, doi:10.1016/j.advwatres.2008.01.018.

R. Panciera, J.P. Walker, J.D. Kalma, E.J. Kim, J. Hacker, O. Merlin, and M. Berger, "The NAFE'05/CoSMOS Dataset: Towards SMOS Soil Moisture Retrieval, Downscaling and Assimilation," *Geosci. Remote Sens.*, vol. 46, no. 3, pp. 736-745, 2008, doi:10.1109/TGRS.2007.915403.

S. Peischl, J.P. Walker, M. Allahmoradi, D. Barrett, R. Gurney, Y. Kerr, E. Kim, J. Le Marshall, C. Rüdiger, D. Ryu, and N. Ye, "Towards Validation of SMOS Using Airborne and Ground Data over the Murrumbidgee Catchment," in: R.S. Anderssen, R.D. Braddock, and L.T.H. Newham (Eds.), *Proc. International*

Congress on Modelling and Simulation (MODSIM). Modelling and Simulation Society of Australia and New Zealand, Inc., Cairns, Australia, 13-17 July, 2009, pp. 3733-3739.

A.B. Smith, F.H.S. Chiew, K.M. Ellett, R.B. Grayson, R.C. Pipunic, H. Richter, V. Shoemark, L. Siriwidena, G. Summerell, J.P. Walker, A.W. Western, and R.I. Young, "The Murrumbidgee Soil Moisture Monitoring Network Data Set," *Water Resour. Res.*, In Review.

ACKNOWLEDGEMENTS

Christoph Rüdiger and the flights for the AACES field campaign were supported by an Australian Research Council Discovery Project grant (DP0879212).