18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Towards validation of SMOS using airborne and ground data over the Murrumbidgee Catchment

S. Peischl[1], J.P. Walker[1], M. Allahmoradi[1], D. Barrett[2], R. Gurney[3], Y. Kerr[4], E. Kim[5], J. LeMarshall[6], C. Rüdiger[1], D. Ryu[1] and N. Ye[1]

[1]Department of Civil and Environmental Engineering, The University of Melbourne, Australia
[2] Sustainable Minerals Institute, The University of Queensland, Brisbane, Australia
[3] NERC Environmental Systems Science Centre, University of Reading, United Kingdom
[4] Biospheric Processes, CESBIO, France
[5] Hydrospheric and Biospheric Sciences Laboratory, NASA Goddard Space Flight Center, United States
[6] The Centre for Australian Weather and Climate Research, Bureau of Meteorology, Australia

Email: s.peischl@pgrad.unimelb.edu.au

Abstract: With the launch of the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite scheduled for mid 2009, the first long-term space-borne passive microwave observations at L-band (~ 1.4 GHz) will soon be available. Consequently, SMOS will be the first mission dedicated to global mapping of near-real-time surface soil moisture information. Though space-borne microwave instruments have measured global data at high frequencies (e.g. C- and X-band) for the last 20 years, this innovative L-band radiometer will use a new synthetic aperture concept that will provide observations at multiple incidence angles. Consequently, the observed brightness temperature data and derived soil moisture product must be validated. To achieve this, intensive field campaigns are being planned world-wide to support the satellite mission with reliable data from i) passive microwave airborne observations at L-band, ii) detailed ground measurements of surface soil moisture content and associated environmental parameters, and iii) long-term soil moisture monitoring network data from anchor sites (e.g. Murrumbidgee in Australia, Valencia in Spain, Upper Danube in Germany etc.). With the SMOS launch likely to take place in the later part of 2009, Australia is particularly well positioned for conducting the first intensive SMOS validation campaign during its spring.

The Australian Airborne Cal/val Experiment for SMOS (AACES) will provide one of the most comprehensive assessments world-wide, due to its combined airborne and in-situ data collection strategy across an extensive transect of the Murrumbidgee catchment in south-eastern Australia. This area is unique as it comprises a distinct variety of topographic, climatic and land cover characteristics, and therefore represents an excellent validation site for the land component of this satellite mission. Moreover, a large database of previous campaign measurements, continuous soil moisture monitoring stations, and meteorological data over the past seven years is available for this region.

A total of four airborne campaigns are planned to cover a 100 km x 500 km (more than 20 SMOS pixels) transect of the Murrumbidgee catchment in its entirety at 1 km resolution using an L-band radiometer. The primary airborne instruments will include the Polarimetric L-band Multibeam Radiometer (PLMR) and thermal infrared sensors, supported by surface soil moisture content, soil temperature and rainfall data from the Murrumbidgee monitoring network. This will be further complemented by intensive soil moisture observations with the Hydraprobe Data Acquisition System (HDAS), short-term soil moisture and temperature monitoring stations with additional leaf wetness and thermal infrared measurements, and extensive vegetation characterisation. The four separate month-long campaigns are planned to extend across a two year timeframe, enabling the effects of seasonal variation in vegetation condition and land cover change to be assessed in addition to soil moisture. Consequently, issues related to snow cover, litter, vegetation dynamics etc. will be assessed in relation to soil moisture retrieval. This paper outlines the airborne campaigns and related ground monitoring for the first SMOS validation campaign, together with some of the major science questions to be addressed. Persons interested in participating in these campaigns are encouraged to contact the authors.

Keywords: *SMOS, AACES, soil moisture, remote sensing, Murrumbidgee, airborne, passive microwave*

1. INTRODUCTION

Soil moisture is a key variable in the water, carbon, and energy cycle. It controls not only the interactions at the soil-atmosphere interface by regulating the partitioning of rainfall into infiltration and runoff, but also the evapotranspiration and photosynthetic activity of plants (Western et al., 1999). Amongst available remote sensing techniques, including visible, thermal infrared and microwave, which have each been tested for measuring spatial and temporal variations of soil moisture, passive microwave remote sensing has proven to be the most promising, because of its all-weather capability, the direct relationship with soil moisture through the soil's dielectric constant, and the reduced sensitivity to land surface roughness and vegetation cover (Njoku et al., 2002). Though microwave data suffers from low resolution and attenuation effects of dense vegetation, microwave observations at L-band (~1.4 GHz) are preferred for near-surface soil moisture monitoring, since they are least affected by the vegetation and atmosphere when compared to shorter wavelengths (Wigneron et al., 2003).

The first passive microwave satellite dedicated to soil moisture observation will be the Soil Moisture and Ocean Salinity (SMOS) mission, scheduled for launch by the European Space Agency (ESA) in the second half of 2009. The baseline SMOS payload is an L-band two dimensional interferometric radiometer that aims to provide global maps of soil moisture with accuracy better than 4 % m^3/m^3 for vegetation water content less than 4 kg/m^2, with a temporal repeat at least once every 3 days, and with a spatial resolution better than 50 km (Kerr et al., 2001). Due to its new design and measurement technique, which uses aperture synthesis technology to simulate the large antenna size required for space-borne measurement at L-band, the SMOS brightness temperature values need to be calibrated and validated on different test sites. Moreover, because of the land surface heterogeneity that exists at 50 km scale in terms of topography, land cover type, and vegetation condition, the derived soil moisture products must also be validated globally. Experimental sites in Europe are limited to areas not larger than a single SMOS pixel and/or based on single aircraft transects through several SMOS pixels. Consequently the Australian Airborne Cal/val Experiment for SMOS (AACES) is expected to provide the most extensive validation of this new sensor. AACES plans to cover an entire 100 km x 500 km area of the Murrumbidgee Catchment in south-eastern Australia with 1 km resolution passive microwave L-band and supporting data, corresponding to about 20 independent SMOS pixels that are representative of a range of land surface conditions. This well-monitored catchment was also the focus of the very successful National Airborne Field Experiment (NAFE) in 2006, where a single SMOS pixel was monitored for a three week period (Merlin et al., 2008).

With the SMOS launch likely to take place in the later part of 2009, Australia is particularly well positioned for conducting the first intensive SMOS validation campaign during its spring. Data collected from the AACES field campaigns are expected to not only validate the SMOS brightness temperature data (level 1C product), but also validate (and improve) the SMOS derived soil moisture (level 2 product), by addressing several important research issues. First, the low spatial resolution of SMOS means that individual pixels will always consist of a range of surface types that contribute differently to the overall microwave response. Such characteristics have been shown to significantly affect the soil moisture retrieval, leading to errors greater than the SMOS target accuracy if not properly accounted for (R. Panciera, "Effect of Land Surface Heterogeneity on Satellite Near-Surface Soil Moisture Observations", PhD Thesis, Submitted, Department of Civil and Environmental Engineering, University of Melbourne). Second, the soil moisture retrieval from SMOS requires ancillary information on soil properties, vegetation transmissivity, soil effective temperature, and surface roughness, to name a few. While the dual polarised (and multi-angle) information from SMOS will allow joint retrieval of some ancillary parameters, several assumptions are still required, and the current approach of SMOS is to use soil temperature information from numerical weather prediction, which is known to be inaccurate. Consequently, SMOS assumptions and derived ancillary information need to be tested.

A series of four AACES campaigns are planned for the next two years, with one in each of the four seasons. The first of these campaigns is planned for the southern hemisphere spring of 2009, extending across the month of November. This will be followed by a summer campaign in February 2010, a winter campaign in August 2010 and finally an autumn campaign in April 2011. Each campaign will extend for between three to four weeks in duration, dependent upon the actual SMOS orbit coverage, being the length of time required to cover the Murrumbidgee transect (13 flights) once with flights that coincide with SMOS overpasses. Consequently, the huge amount of airborne and ground data collected across the catchment will characterise a range of vegetation and soil moisture conditions in response to seasonal variability and land cover types.

In short, the planned campaigns include: i) time series of soil moisture and temperature profiles, leaf wetness, and thermal infrared data from long-term and/or temporary monitoring stations; ii) point-based surface soil moisture and temperature observations, gravimetric soil and vegetation samples, and surface roughness profiles collected by ground teams; iii) airborne brightness temperature observations as well as thermal infrared data; and iv) spaceborne brightness temperature and soil moisture products from SMOS, complemented by high frequency microwave, thermal infrared, shortwave infrared and visible data from complementary satellites (e.g. WindSAT, MTSAT and MODIS). The details of the AACES campaigns are described in this paper.

2. STUDY AREA

The four AACES field campaigns will take place across the Murrumbidgee River Catchment (-33° to -37° S, 143° to 150° E), which is a sub-catchment of the Murray Darling Basin located in south-eastern Australia (Figure 1). The entire Murrumbidgee catchment covers a total area of approximately 82,000 km^2. Due to its distinctive topography with elevations ranging from 50 m in the west to 2000 m in the east, there exists a significant spatial variability in its climate (alpine to semi-arid), soil type, vegetation and land use (Figure 2).

The annual cumulative precipitation ranges from 300 mm in the west to 1900 mm towards the east (Australian Bureau of Meteorology, 1998). Accordingly, due to the drier climatic conditions in the west almost the same amount of water evaporates as rain falls, whereas in the higher elevated eastern parts of the catchment the actual evaporation rate represents only approximately half of the regional precipitation (Australian Bureau of Meteorology, 1998).

During the winter period, precipitation above about 1200 m typically falls as snow, with regions above 1400 m usually covered by snow for a few weeks of the year. Moreover, above 1800 m the snow cover can last for 4 months or more (Whetton et al., 1996; see Figure 2).

In general, there is a range of sand to clay soil types present, with the western plains areas dominated by fine textured soils which become coarser towards the east (McKenzie et al., 2000). Considering these aspects, the catchment is mainly used for agricultural purposes, including irrigation areas in the mid to lower Murrumbidgee, broad-acre cropping, and extensive grazing (Australian Bureau of Rural Science, 2006). The steeper parts in the east are predominantly characterized by a mixture of native eucalypt and exotic forestry plantations.

Overall the Murrumbidgee catchment offers a range of geographic diversity within a relatively confined area. This makes it an ideal validation site for the land component of the SMOS mission. Nevertheless, considering the size of the satellite footprint, there are still regions that are relatively homogeneous (especially the western part of the catchment) in regards to climate, soil type and vegetation when compared to other study sites in Europe and the United States.

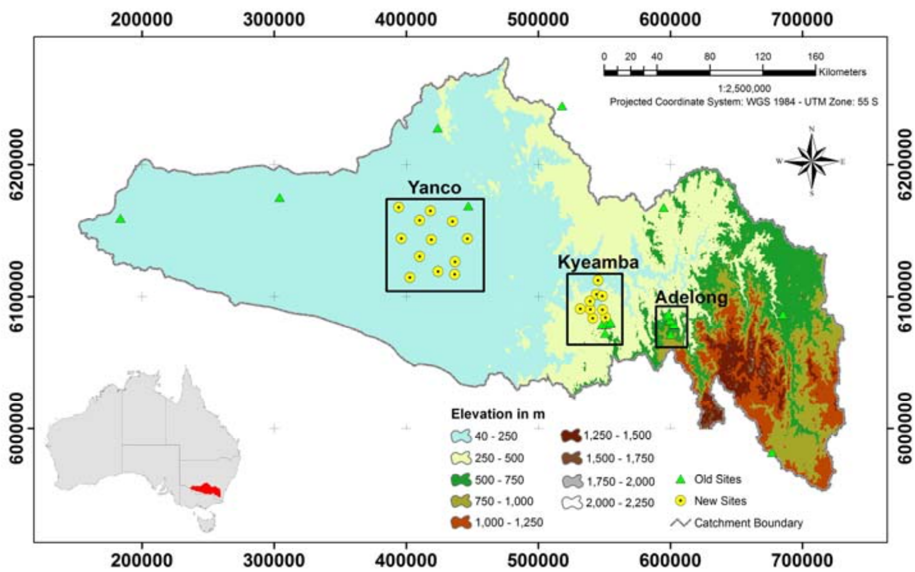

Figure 1. Murrumbidgee River catchment showing elevation and soil moisture monitoring network, together with names of areas having intensive monitoring. Note also that elevations above 1200 m are subject to periodic snow cover.

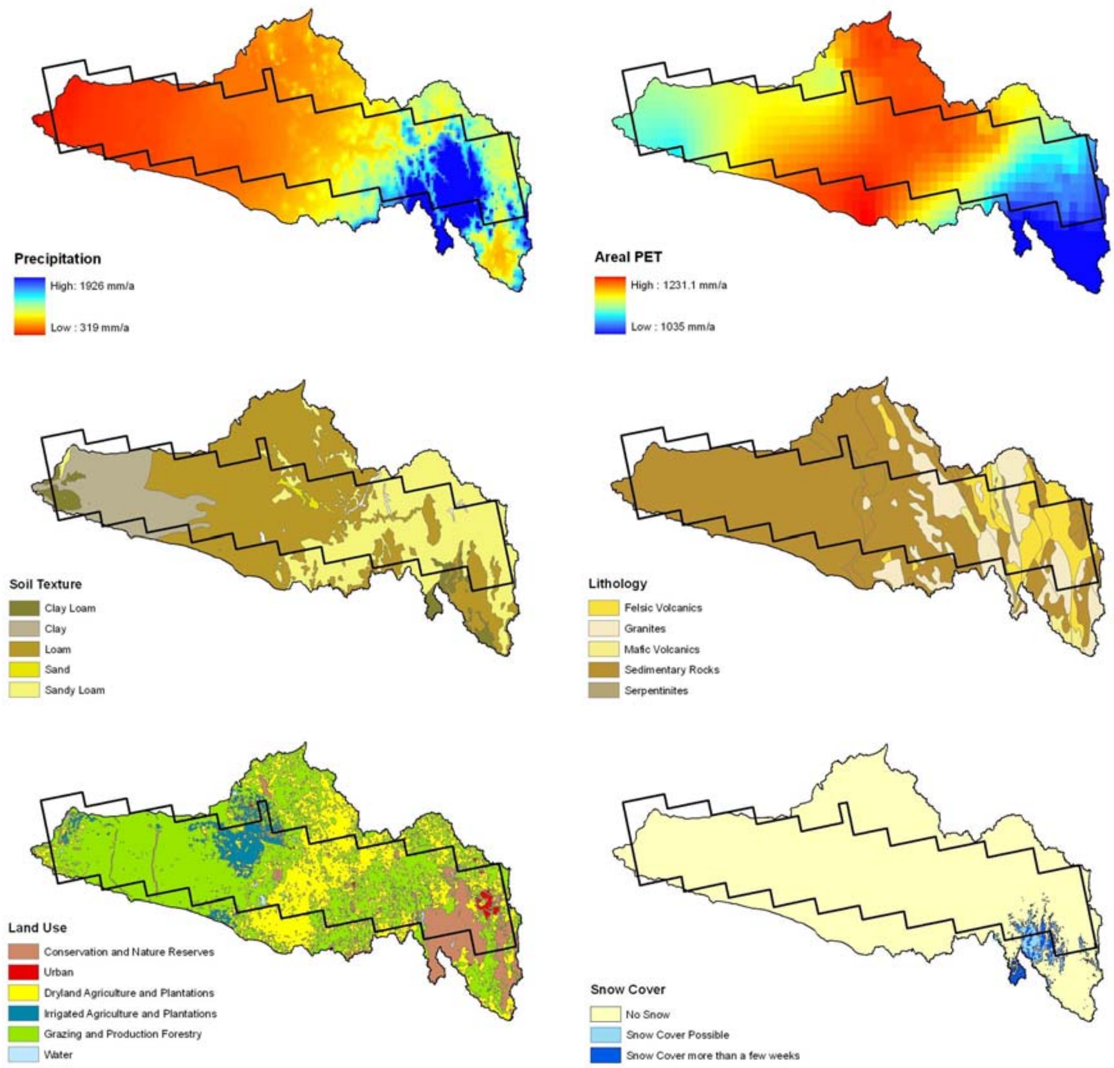

Figure 2 . Topographic, climatic, soil and land use diversity across the Murrumbidgee catchment. Overlain is the proposed transect to be monitored by the AACES campaigns.

3. INSTRUMENTATION AND SAMPLING STRATEGY

The AACES campaigns are planned to cover a large area of the Murrumbidgee River catchment in entirety four times (one within each season). Compared to European validation test sites, which will comprise a single SMOS pixel or transects through a few SMOS pixels with a number of repeat flights over a few months, the Australian campaigns will focus on accurately mapping the spatial variability across an area comprising about 20 independent SMOS pixels, with temporal variability assessed according to season. Thus, features such as climatic, topographic and seasonable changes will be mapped on a much larger spatial and temporal scale than the equivalent campaigns elsewhere. Consequently, these experiments will contribute to comprehensive validation of SMOS brightness temperature and soil moisture, and are highly complementary to the planned activities in other countries.

3.1. Airborne Measurements

The AACES campaigns will map an area of 100 km x 500 km across the Murrumbidgee river catchment at 1 km resolution using an L-band radiometer, repeated in each of the four seasons. Given the approximately 50 km sized SMOS pixels, the study transect has been aligned with the SMOS fixed grid and subdivided into ten patches approximately 100 km x 50 km in size, of which each will be mapped within a single day (Figure 3). The flight coverage's have been designed to include a minimum of 5 km overlap between each patch, thus ensuring continuity between the different flights and full coverage of the SMOS pixels. Moreover, it also allows an assessment of any brightness temperature change from the previous flight to be undertaken.

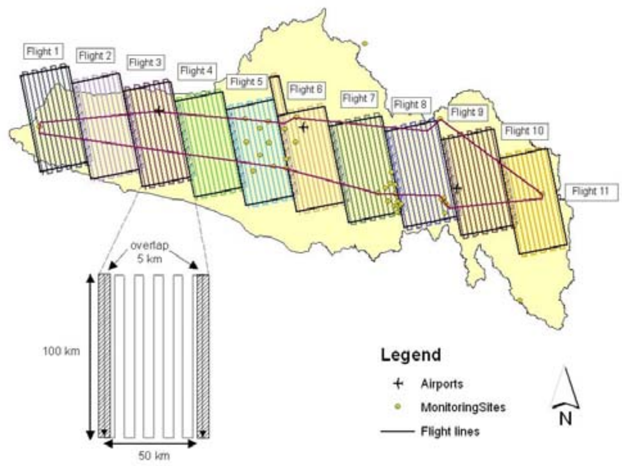

Figure 3. Schematic of the airborne sampling strategy showing flight patterns for each patch and a circuit flight throughout the transect.

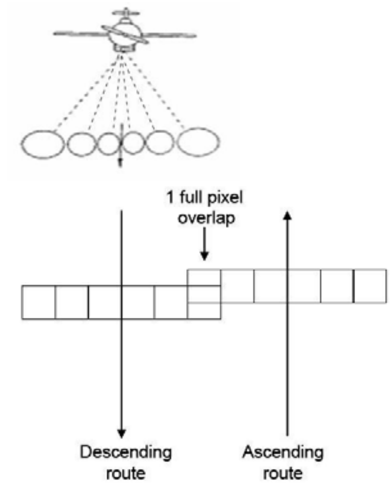

Figure 4. The pushbroom concept showing the 6 PLMR beams with a 1 beam overlap between flight lines (Walker and Panciera, 2005).

There will also be three repeated circuit flights throughout the study transect (flight 11); one each at the start, middle, and end of the campaign. This will capture temporal variability within the experimental site and allow comparison with the European validation strategies.

Scheduling of exact flight dates will depend on the actual SMOS coverage of the study transect, which is dependent on the actual launch date. However, preliminary flight planning analysis has shown that between 3 and 4 weeks will be required to map the study transect once with coincident SMOS coverage. Moreover, approximately 4 hours of flight time is required to cover each patch once, including a repeat pass of the first flight line. Consequently, all flights will be conducted such that they are centred on the 6am overpass time of SMOS.

The airborne observations will be undertaken at approximately 3000 m (AGL) altitude to provide passive microwave data with a 1 km spatial resolution. The aircraft will be equipped with the Polarimetric L-Band Multibeam Radiometer (PLMR) and thermal infrared sensors (TIR). The PLMR instrument will be used in across-track configuration (pushbroom, see figure 4) to scan the surface with three viewing angles (±7°, ±21.5° and ±38.5°) to each side of the flight direction, achieving a swath width of about 6 km. The PLMR operates with a frequency of 1.413 GHz and a bandwidth of 24 MHz in both V- and H-polarisations.

During the campaign, pre- and post-flight calibration of PLMR will be undertaken using a blackbody chamber as a warm target and the sky as cold target. Results of these calibrations will be used to compute daily adjustment coefficients to correct the raw brightness temperature data from PLMR. Moreover, PLMR will be flown over a large water body as an additional in-flight calibration check, using temperature and salinity measurements of the water body to model the water emission.

3.2. Ground Measurements

A well instrumented monitoring network with stations throughout the entire Murrumbidgee catchment has been operational since 2001. The network was upgraded in 2003 and 2006 to now provide a total of 38 monitoring stations with surface soil moisture measurements. This monitoring network provides an ideal basis for the validation of both space- and airborne soil moisture observations, with the majority of stations located within three focus areas: Yanco, Kyeamba and Adelong (Figure 1).

All monitoring stations make the following measurements: i) rainfall using a tipping bucket rain gauge; ii) soil moisture profiles using three vertically installed Campbell Scientific water content reflectometers (a mix of CS615 and CS616 sensors) across three different depths (0-30 cm, 30-60 cm and 60-90 cm), with a supplementary Hydraprobe for 0-5 cm ('03 sites) or CS615 installed at an angle for 0-7 cm ('01 sites); and iii) soil temperature at 2.5 cm and 15 cm depth (Smith et al., The Murrumbidgee soil moisture monitoring network data set. Submitted to Water Resources Research, 2009). Additionally, several stations collect information on deeper soil temperature, soil suction and groundwater. Consequently, this monitoring network provides an ideal basis for long term validation of SMOS and is an excellent source of data for planning the field campaign timing.

In order to validate the aircraft soil moisture retrievals at 1km resolution, account for soil moisture variability and the representativeness of single (or groups of) station measurements (see Azcurra and Walker, 2009), intensive ground based monitoring of soil moisture and related variables are planned as an essential part of the AACES campaigns. Consequently, a minimum of two focus farms have been identified for each patch of the Murrumbidgee transect (Figure 5). In this way the ground teams will follow the aircraft across the study transect once during each campaign.

Focus farms have been identified on the basis of background information including climate, topography, soil, vegetation and accessibility. Consequently, these focus farms represent locally the dominant soil and vegetation type and are within themselves fairly homogeneous, yet capture the variability that exists across the patch. A total of 20 focus farms have been identified across the entire campaign transect. Within each of these focus farms a 1.5 km by up to 5 km transect (oriented along the direction of flight lines) will be established and subdivided by six ground sampling lines, each a minimum of 3 km in length and 250 m apart (Figure 5). Ground teams will make three surface soil moisture measurements (within a radius of 1 m) every 50 m along these transects using the HDAS system. Concurrently, additional information about vegetation type and height, dew presence, land use and rock fraction will be visually observed and recorded. To facilitate comparisons between SMOS, airborne observations, and the detailed ground measurements, ground soil moisture sampling will take place as early in the morning as practical. Specifically, quantitative dew measurements will be made at the 6 am SMOS overpass time.

To maximise the efficiency of limited personnel currently involved in ground sampling, vegetation sampling is scheduled for the days when there are no coincident SMOS and aircraft flights (approximately every alternate day). Vegetation sampling is expected to include destructive samples of vegetation water content (VWC) and dry biomass together with leaf area index (LAI) and spectral measurements.

For calibration purposes, a minimum of five gravimetric surface soil samples will be collected at each focus farm. Moreover, at least two surface roughness profiles in north-south and east-west directions of 2 m length will be conducted at each focus farm.

Permanent monitoring stations will also be supplemented by temporary monitoring stations at each farm. Due to limited equipment, these stations will be moved across the study transect, with stations set up at least one day before airborne observations of the focus farm. These short-term monitoring stations will be instrumented with a raingauge, thermal infrared sensor, leaf wetness sensor, surface soil moisture thetaprobe (0-5 cm) and two soil temperature sensors (2.5 cm and 50 cm depth) in order to provide time series data during the sampling period (Figure 6). Such measurements will be useful for identifying the presence or absence of dew, and verifying the assumptions that i) effective temperature has not changed throughout the course of the aircraft measurements; ii) vegetation and soil temperature are in equilibrium; and iii) soil moisture has not changed significantly during ground sampling.

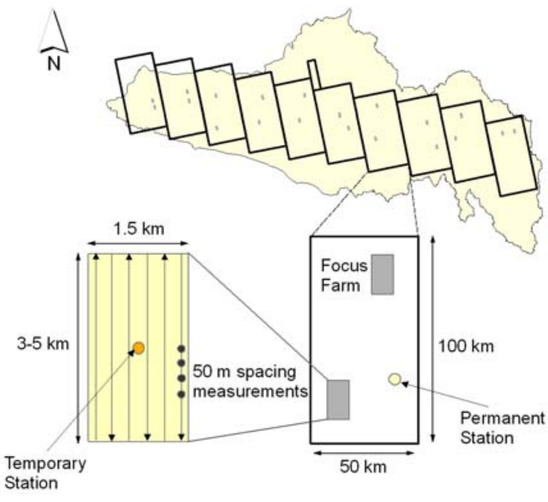

Figure 5. Schematic of the ground sampling strategy within the identified focus farms of each patch.

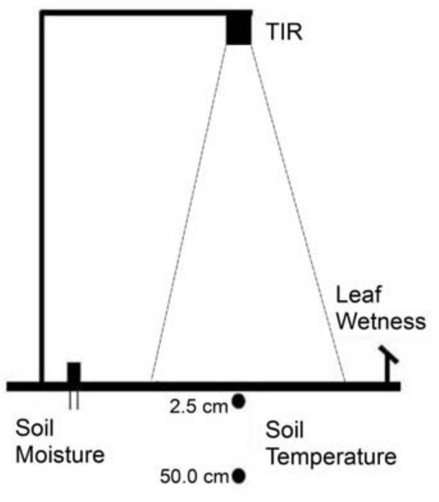

Figure 6. Schematic of the temporary monitoring station.

4. SUMMARY

This paper has presented an overview of the Australian Airborne Cal/val Experiment for SMOS (AACES) scheduled to start in the spring of 2009. Against the background of the upcoming launch of the SMOS satellite, and the inevitable need for brightness temperature and derived soil moisture validation, these campaigns will provide one of the most comprehensive datasets. In addition to validating approximately 20 independent SMOS pixels in their entirety with validated 1 km airborne passive microwave observations at L-Band and derived soil moisture, the data will cover a range of topographic, climatic and geomorphologic characteristics, as well as varying soil texture, vegetation condition, vegetation type, and land use.

Interested parties are invited to participate in these planned field campaigns and benefit from collaborating in such an important validation activity. In particular, people with a focus on remote sensing of soil moisture, vegetation, evapotranspiration and precipitation or related areas of environmental remote sensing that can contribute to the data set, and utilise the collected ground and airborne data, are invited to join our team.

ACKNOWLEDGEMENTS

The AACES campaigns are funded by an Australian Research Council Discovery Project grant (DP0879212) as part of the MoistureMap project. Initial setup and maintenance of the Murrumbidgee monitoring network was funded by the Australian Research Council (DP0343778, DP0557543) and by the CRC for Catchment Hydrology. Airborne sensors were also funded by Australian Research Council through infrastructure grants (LE0453434 and LE0560930). Furthermore, this project leverages the very successful National Airborne Field Experiments also made possible through funding from the Australian Research Council grants indicated above.

REFERENCES

Australian Bureau of Meteorology (1998), Gridded rainfall data, based on the standard rainfall climatology (1961-1990). National Climate Centre, Bureau of Meteorology, Melbourne.

Australian Bureau of Rural Sciences - Department of Agriculture, Fisheries and Forestry, "Land Use of Australia, Version 3 - 2001/2002", Resource publication on 2006-09-21, accessed 18 February 2009, from <http://adl.brs.gov.au/mapserv/landuse/>.

Azcurra, C. and J.P. Walker (2009), Towards SMOS validation in south-eastern Australia. 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009.

Kerr, Y.H., P. Waldteufel, J.P. Wigneron, J.M. Martinuzzi, J.M. Font and M. Berger (2001), Soil moisture retrieval from space: The Soil Moisture and Ocean Salinity (SMOS) mission. IEEE Transactions on Geoscience and Remote Sensing, 39(8): 1729−1735.

McKenzie, N.J., D.W. Jacquier, L.J. Ashton and H.P. Cresswell (2000), Estimations of soil properties using the Atlas of Australian Soils. CSIRO Land and Water Technical Report 11/00.

Merlin, O., Walker, J.P., Kalma, J.D., Kim, E., Hacker, J., Panciera, R., Young, R., Summerell, G., Hornbuckle, J., Hafeez, M., and Jackson, T. (2008), The NAFE'06 Data Set: Towards Soil Moisture Retrieval at Intermediate Resolution. Advances in Water Resources, In Press. doi:10.1016/j.advwatres.01.018.

Njoku, E.G., W.J. Wilson, S.H. Yueh, S.J. Dinardo, F.K. Li, T.J. Jackson, V. Lakshmi and J. Bolten (2002), Observations of soil moisture using a passive and active low-frequency microwave airborne sensor during SGP99. IEEE Transactions on Geoscience and Remote Sensing, 40(12): 2659-2673.

Walker, J. P. and R. Panciera (2005), National Airborne Field Experiment 2005: Experiment Plan. Department of Civil and Environmental Engineering, The University of Melbourne.

Western A., Grayson R., and Green T., (1999), The Tarrawarra project: High resolution spatial measurement, modelling and analysis of soil moisture and hydrological response. Hydrological Processes: 13(5), 633–652.

Whetton, P.H., M.R. Haylock and R. Galloway (1996), Climate change and snow-cover duration in the Australian Alps. Climatic Change, 32(4): 447-479.

Wigneron, J.P, J. Calvet, T. Pellarin, A. Van de Griend, M. Berger and P. Ferrazzoli (2003), Retrieving near-surface soil moisture from microwave radiometric observations: current status and future plans. Remote Sensing of Environment 85, 489-506.