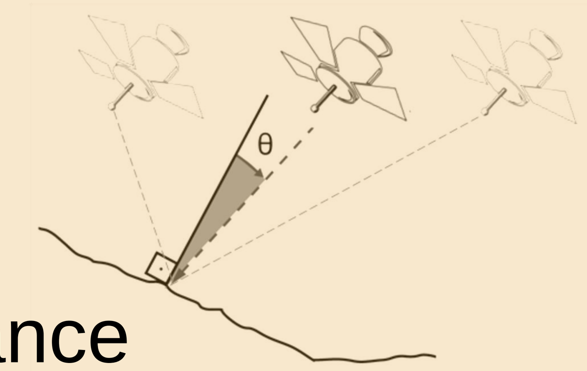
Towards soil moisture retrieval using multi-incidence angle observations

Sandy Peischl[1], Jeffrey Walker[1], Dongryeol Ryu[2] and Yann Kerr[3]

[1]Department of Civil Engineering, Monash University, Australia (E-mail: Sandy.Peischl@monash.edu)

[2]Department of Civil and Environmental Engineering, The University of Melbourne, Australia; [3]Biospheric Processes, CESBIO, France



Introduction

The relationship between soil moisture and observed passive microwave emission at multiple look angles is investigated using airborne L-band data from a recent field experiment in Australia conducted under the NAFE (National Airborne Field Experiment) campaign in 2006 [1]. The study area shows a unique diversity in land cover and was intensively monitored for soil and vegetation characteristics. Hence, this extensive dataset is particularly suitable for assessing the multi-angle soil moisture retrieval capability of the Soil Moisture and Ocean Salinity (SMOS) mission launched by the European Space Agency (ESA) on 2nd November 2009.

Data

The NAFE campaign was undertaken for a three-week summer period in November 2006 in the Murrumbidgee River catchment in south-eastern Australia (Figure 1). In operational use was the Polarimetric L-band Multi-beam Radiometer (PLMR) mounted on the aircraft in an along-track configuration, meaning three beams were looking in the forward direction and three beams backwards. This setup provided quasi-simultaneous multi-incidence angle observations at 500m resolution for the same location on earth, while the aircraft was moving along its flight track. The transect was flown twice a week, alternatively at 6am/6pm for comparison with SMOS overpass times. The covered terrain was reasonably flat, with a range of vegetation and soil conditions (Table 1). Corresponding ground sampling activities within an area of approximately 1x3 km at numerous focus farms included near surface-soil moisture (SM, 0-5 cm), profile soil temperature, vegetation temperature, vegetation water content (VWC) and biomass measurements. Additional soil moisture profile and soil temperature data were available from permanent monitoring sites (Figure 2).

Table 1: Characteristics of the three NAFE'06 focus farms that were covered by multi-incidence angle flights.

Farm	Land Cover	Soil Type	Sand Content [%]	Clay Content [%]	Vegetation Water Content* min-max [kg/m²]	Soil Moisture min-max* [m³/m³]
Y1	native grass + agriculture (wheat)	Silty Loam	54	13	0.09-1.02	0.04-0.16
Y7	native grass	Silty Loam	38	25	0.03-0.17	0.02-0.12
Y10	native grass	Silty Loam	63	9	0.03-0.17	0.01-0.13

*across the entire focus farm

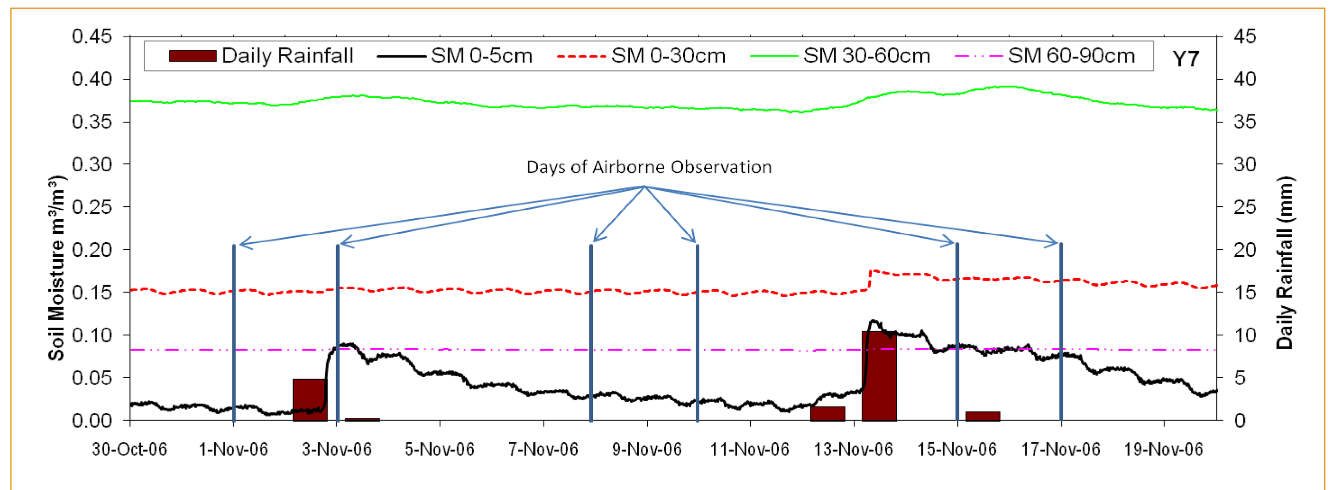


Figure 2: Example of soil moisture profile and rainfall data recorded near focus farm Y7 during NAFE'06

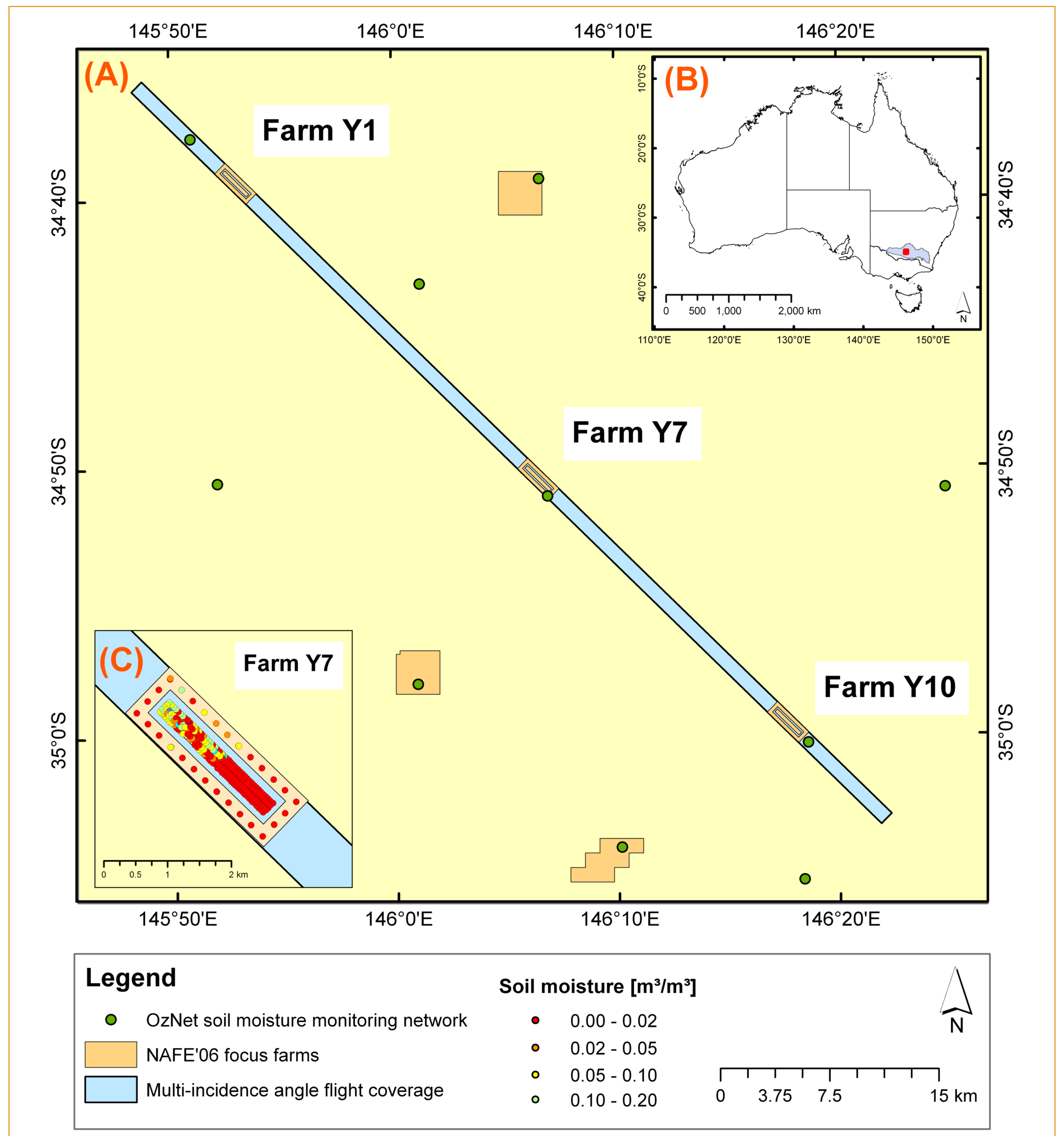


Figure 1: (A) Location of the OzNet soil moisture monitoring network, the NAFE'06 focus farms and the transect flown by the aircraft in multi-incidence angle flight mode. (B) Location of the NAFE'06 study area within the Murrumbidgee River catchment, Australia. (C) Example of the high-resolution ground sampling of near-surface soil moisture (0-5 cm) across focus farm Y7 on the 1st of November 2006.

Methodology

The radiative transfer model used in this study is known as the tau-omega model accounting for vegetation attenuation (Υ_{veg}) and scattering effects (ω) of the overlying vegetation layer on the soil emission (e_p) at a given polarization (p):

$$T_{b_p} = e_p \cdot T_{soil} \cdot \Upsilon_{veg} + (1-\omega) \cdot T_{veg} \cdot (1-\Upsilon_{veg}) + (1-e_p)(1-\omega) \cdot T_{veg} \cdot (1-\Upsilon_{veg}) \cdot \Upsilon_{veg}$$

where T_{bp} represents the composite brightness temperature and T the effective temperature of either soil or vegetation [Kelvin], respectively. The L-band Microwave Emission of the Biosphere model (L-MEB [2]), which is one of the core algorithms of SMOS [3], was used to retrieve from multi-incidence angle airborne T_{bp} measurements (of one PLMR footprint capturing about 20 measurements for each polarization) the following parameters: i) soil moisture (SM) and ii) vegetation water content (VWC). Subsequently, the retrieved parameters were used to generate brightness temperatures at a range of angles in order to compare the model performance with the angular signatures observed by the airborne radiometer. The parameter retrieval and comparison were made for four observation dates at focus farm Y7.

Results

The angular signature observed by the airborne L-band radiometer follows a distinct trend for H- and V- polarization with increasing incidence angle (Figure 3), and by using the available angular variety across one footprint, multiple parameters can be retrieved simultaneously. The comparison in Table 2 shows that i) for the early morning observations, the parameters match well with the ground data, whereas ii) for the late afternoon data sets higher soil moisture values and in one case a lower VWC value were retrieved. For the 3rd November data set, the model adds the additional moisture in response to a small rain event on the previous day, but overcompensates as the VWC is not similarly increased.

The predicted T_{bp} responses based on the retrieved SM and VWC values are presented together with the PLMR observations in Figure 4 (the corresponding RMSE is given in Table 2). Apart from the 3rd November dataset, where the forward model produces significant lower T_{bp} estimates than observed, there is an overall good agreement; even though the retrieved SM from the afternoon data of the 10th November was higher compared to the in-situ data.

Future work will widen the analysis to a number of footprints, which will also include observations made over a different focus farm with similar soil and vegetation conditions. Moreover, the effect of other parameters such as vegetation temperature, surface roughness and the b-parameter can be investigated to better understand why the accuracy of the soil moisture retrieval seems to decrease for the afternoon overpasses.

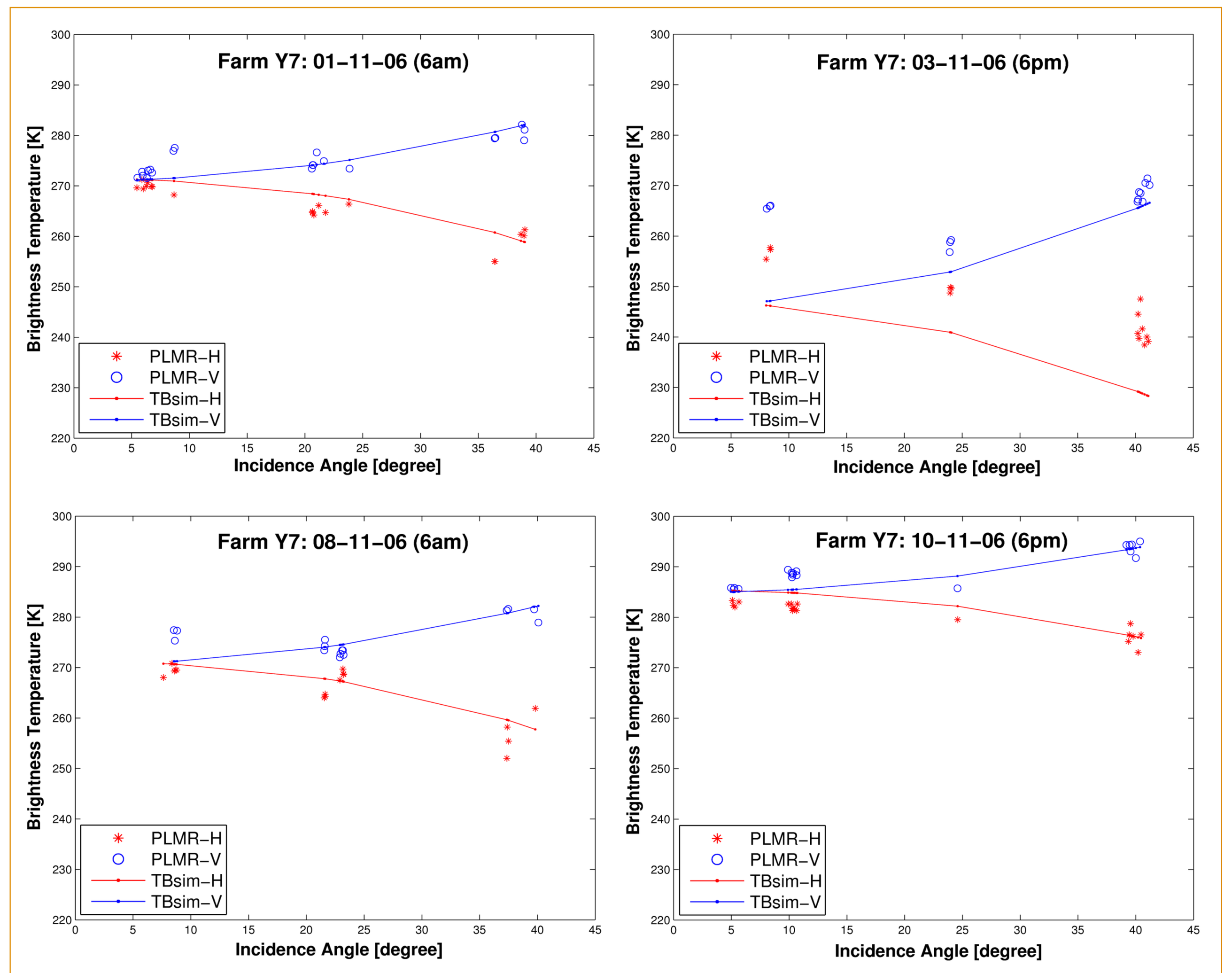


Figure 4: Comparison of the angular behaviour exhibited by the airborne observed brightness temperature data against simulated brightness temperatures. The latter were calculated using the L-MEB model and the retrieved values for soil moisture and vegetation water content instead of the actual ground measurements for the corresponding date (compare with Table 2).

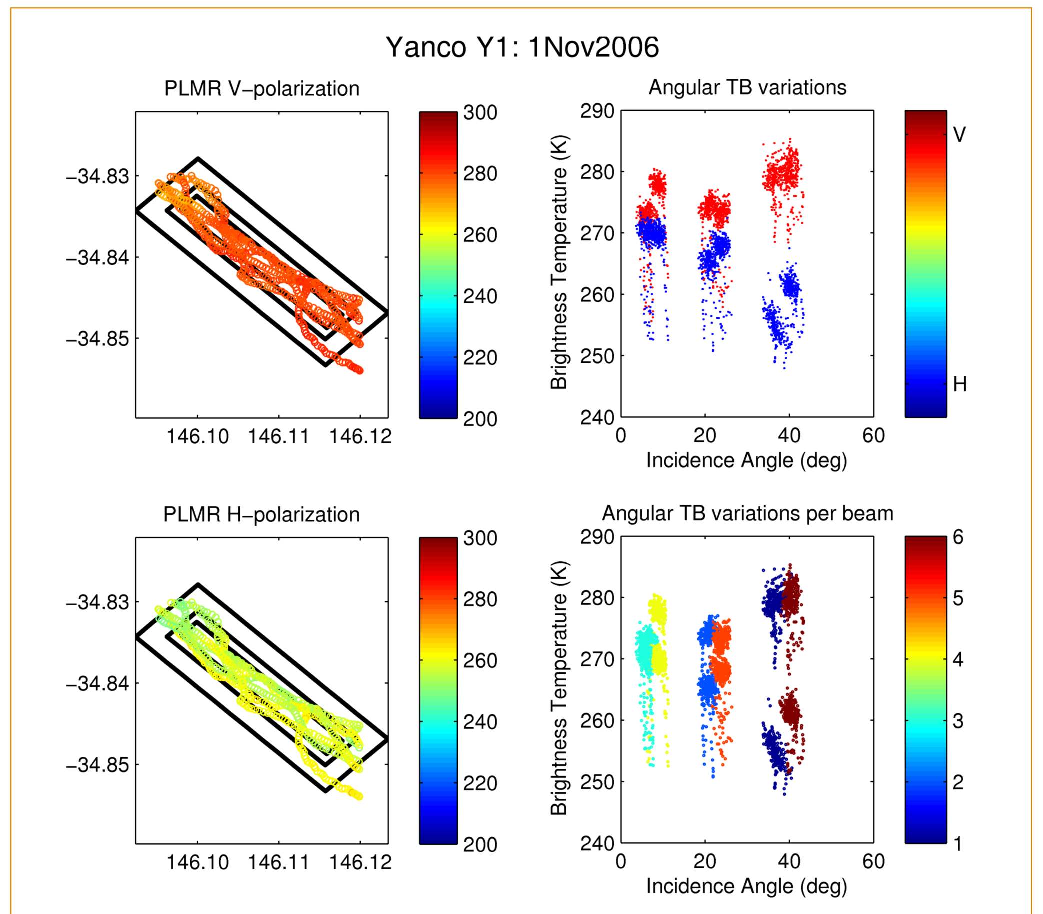


Figure 3: Left: Airborne observed multi-angle L-band brightness temperatures at 38.5° over focus farm Y7 on 1st of November 2006 for V- and H-polarization in Kelvin. The outline of the outer boundary of the focus farm and the outline of the inner high-resolution ground sampling is shown in the background. Right: Angular signatures of the measured brightness temperatures for both polarizations (top) and per beam across the entire focus farm (bottom) .

Table 2: Comparison of ground measurements of soil moisture and vegetation water content against values retrieved from the multi-angle airborne observations at different dates/times. The RMSE is calculated from the i) actual airborne brightness temperatures and ii) the simulated brightness temperatures estimated by the L-MEB forward model using the previously retrieved soil moisture and vegetation water content data as new forward model input.

Flight Day	Ground Measurement		Retrieved Parameter		RMSE [K]
	Soil Moisture [m³/m³]	Vegetation Water Con. [kg/m²]	Soil Moisture [m³/m³]	Vegetation Water Con [kg/m²]	
01-11-06 (6am)	0.02	0.03	0.05	0.03	2.43
03-11-06 (6pm)	0.12	0.17	0.21	0.03	4.61
08-11-06 (6am)	0.05	0.03	0.04	0.03	2.91
10-11-06 (6pm)	0.05	0.03	0.11	0.03	2.29

Acknowledgements

This study has been conducted within the framework of the MoistureMap project which is funded by the Australian Research Council (DP0879212). Furthermore, the data used in this work and collected during NAFE'06 has been made possible through earlier funding by the ARC and the good will of many volunteers.

References

[1] O. Merlin, J. P. Walker, J. D. Kalma, E. J. Kim, J. Hacker, R. Panciera, R. Young, G. Summerell, J. Hornbuckle, and M. Hafeez, "The NAFE'06 data set: Towards soil moisture retrieval at intermediate resolution," *Advances in Water Resources*, vol. 31, pp. 1444-1455, 2008.

[2] J.P. Wigneron, Y. Kerr, P. Waldteufel, K. Saleh, M. Escorihuela, P. Richaume, P. Ferrazzoli, P. de Rosnay, R. Gurney and J. Calvet, "L-band Microwave Emission of the Biosphere (L-MEB) Model: Description and calibration against experimental data sets over crop fields." *Remote Sensing of Environment* 107(4), 639-655, 2007.

[3] Y. Kerr, P. Waldteufel, P. Richaume, P. Ferrazzoli, and J. Wigneron, "SMOS level 2 Processor for Soil Moisture Algorithm Theoretical Based Document (ATBD)," CESBIO, Toulouse, SO-TN-ESL-SM-GS-0001, v3.a., Oct. 15, 2008, Report.

MONASH University
Engineering