HIGH RESOLUTION AIRBORNE SOIL MOISTURE MAPPING

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Abstract

Airborne remote sensing now provides a viable option for high resolution mapping of soil moisture, allowing larger areas to be covered in greater spatial and temporal detail than has hitherto been possible from traditional ground based techniques. This paper presents a demonstration of soil moisture mapping at 50m resolution with an L-band passive microwave radiometer, using data collected from the recent National Airborne Field Experiments (www.nafe.unimelb.edu.au). This intensive month-long field campaign involved regular flights across distances of up to 40km together with extensive ground validation data at specific farms. This is the first airborne remote sensing study to provide such high resolution soil moisture data. Results indicate a very good agreement of the retrieved and measured soil moisture spatial distribution, with an overall absolute retrieval error less than 5% v/v.

Introduction

Accurate knowledge of spatial variation in soil moisture at high resolution is critical for achieving sustainable land and water management. For example, information on soil moisture status is essential to optimise on-farm irrigation systems and enable efficient irrigation scheduling. The fundamental limitation is that spatial and temporal variation in soil moisture is difficult and time consuming to measure at high resolution across even moderate sized areas. For instance, with an already calibrated state-of-the-art ground based monitoring system it takes four people an entire day to monitor a 3 km^2 area at 50 m spacing.

A new airborne sensing system now provides the capability to economically map near-surface soil moisture at resolutions of up to 50 m across large areas, allowing greater areas to be covered in better spatial and temporal detail than has hitherto been possible from traditional ground based techniques. Brightness temperature measurements by the aircraft's Polarametric L-band Multibeam Radiometer (PLMR), together with ancillary information on soil temperature and vegetation water content, represent the input required for soil moisture measurement. Using such an airborne system, an area of 300 km^2 (two orders or magnitude greater size) can be mapped at 50 m resolution for an equivalent cost of the ground survey mentioned above, in just a few hours.

This paper shows results from such a soil moisture mapping system, using ground and airborne data collected during a recent month-long field experiment exhibiting a range of moisture conditions from wet to dry. The moisture mapping capability of this system is evaluated from extensive roving ground measurements made across one of the focus farms together with continuous measurements at an individual location on that farm.

Data

The airborne observations and ground data used in this study were collected during the National Airborne Field Experiment (NAFE) conducted during November 2005 in the Goulburn River catchment, being 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 soil moisture, vegetation water content, soil temperature, and other relevant land surface characteristics. Full details of the field campaign and the data collected can be found elsewhere (see www.nafe.unimelb.edu.au and Panciera et al., 2008). Consequently, only the pertinent details are described here.

Ground Data

The area monitored during NAFE'05 was an approximately 40km x 40km region, 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 the western part. This paper focuses on the data collected in the Krui area, with a particular emphasis on the Stanley focus farm (see Figure 1). The predominant land use in the Goulburn catchment is grazing on native pasture followed by open woodland. A considerable fraction of the area is used for cropping, including mainly wheat, barley and lucerne, with small amounts of sorghum and oats. Landuse in the

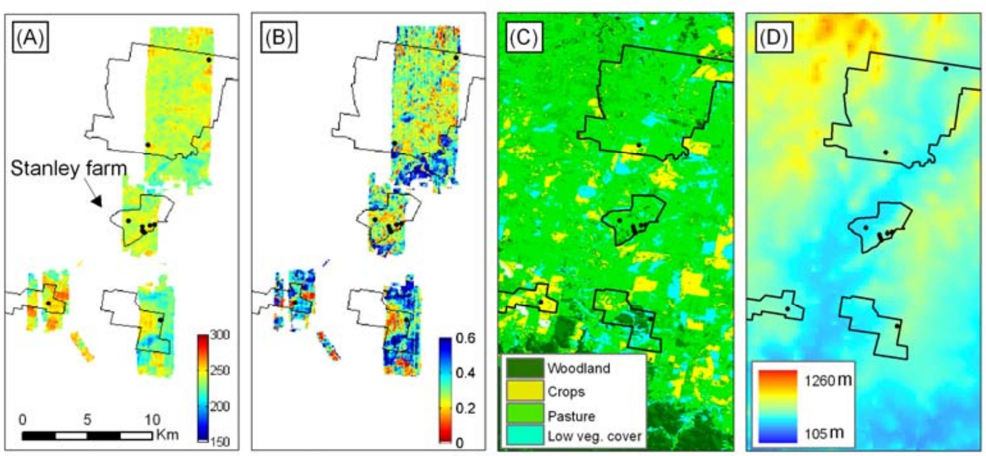

Figure 1.: Plots of a) H-polarized brightness temperatures and b) retrieved soil moisture at 50m resolution for the four experimental farms located in the Krui focus area on 1 November 2005, c) land use distribution and d) 250m resolution elevation data across the Krui focus area with the permanent soil moisture monitoring stations shown as black dots and focus farms outlined in black.

Krui area is fairly uniform throughout and dominated by native pasture and crops.

Four farms were chosen for ground sampling in the Krui area and are indicated in Figure 1. Each farm contained a small "high resolution" area of 150m x 150m for detailed ground sampling of soil moisture (see lower panels of Figure 2), soil temperature and vegetation water content. The high resolution areas were selected to include a variety of land cover, topography and other defining features. Top 5 cm soil moisture was monitored at each high resolution area on a 12.5 m grid, with a core of 75 m x 75 m sampled on a 6.25 m grid. The surrounding areas were sampled at decreasing resolutions of 62.5 m, 125 m, 250 m and 500 m to the extremity of the farm (64 km^2 in one instance). Each farm was sampled once a week, concurrently with aircraft observations over the area. Vegetation water content was sampled by taking biomass samples. Near-surface soil moisture and soil temperature were also continuously monitored at each farm, in most cases within 1 km of the high resolution area.

Airborne Data

A total of eight high resolution flights were conducted across the Krui area between October 31 and November 25. These flights type were conducted each Tuesday and Thursday. The passive microwave instrument used was the Polarimetric L-band Multibeam Radiometer (PLMR). The PLMR measured both V and H polarised brightness temperature at incidence angles +/-7°, +/-21.5° and +/-38.5° across-track. The focus area was covered with parallel north-

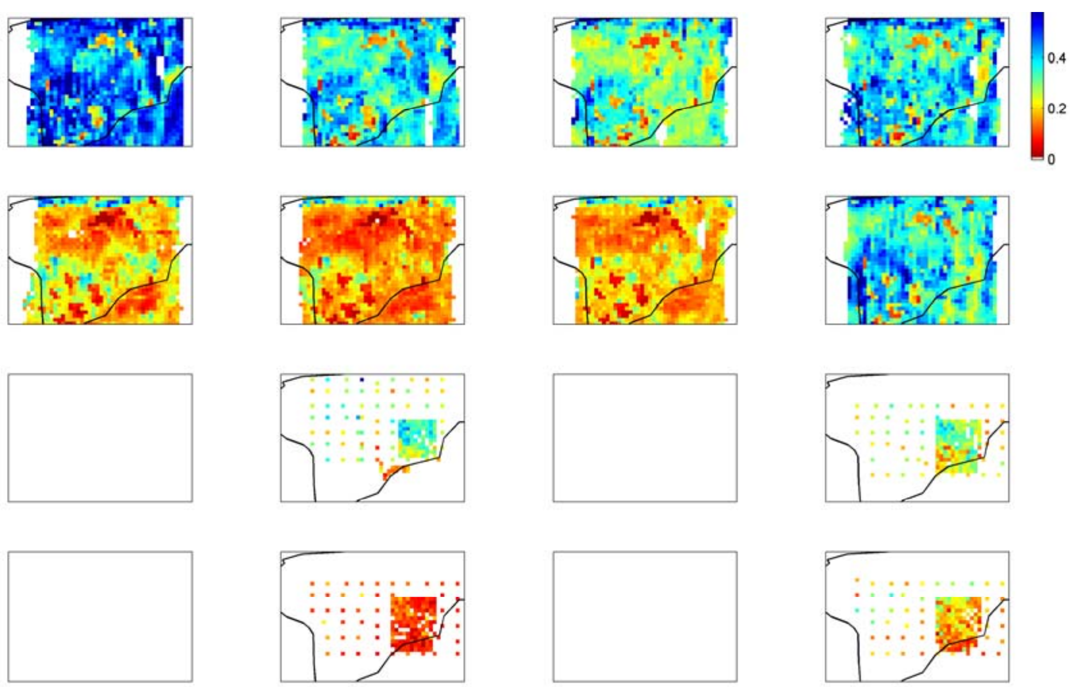

Figure 2: Time sequence of remotely sensed (top 2 rows) and ground measured (bottom 2 rows) soil moisture for the Stanley farm on the 8 over-flight dates during the field campaign.

south oriented flight lines, each overlapping by at least one full pixel.

For each flight, microwave observations were made at an altitude of ~150 m AGL, resulting in L-band brightness temperature maps at nominally 50 m spatial resolution (see Figure 1a). However, the actual resolution achieved varied across the flight coverage due to variations in terrain elevation. To avoid data gaps due to pixel size variations, flight altitudes were varied slightly for each farm to yield the nominal pixel resolution at the farms maximum terrain elevation. This is the first airborne remote sensing study to provide such high resolution soil moisture data.

In order to obtain maps of soil moisture from PLMR brightness temperatures, the aircraft observations were first referenced to the same incidence angle, 38.5º in this case, corresponding to the PLMR outer beams. The brightness temperature data was then binned to a regular grid by simple average of all observations falling within each grid cell. For each pixel, landcover type was estimated using a 30m LandSat Thematic Mapper land cover classification (validated against visual ground observations at specific sites). Vegetation specific radiative transfer parameters were then assigned to each cell from tables of best estimates for each parameter at L-band (Wigneron, Personal Communication). In this case ancillary data on soil temperature and soil texture were determined from data collected at the focus farm monitoring stations, though this could be estimated from the aircraft thermal infrared observations and available soil maps respectively. Soil moisture was then retrieved together with vegetation optical depth using the bi-polarised observations and standard tau-omega model (Wigneron et al., 2007), thus accounting for the soil and vegetation contribution to the observed brightness temperature signal.

Results

Figure 1 shows an example of the high resolution soil moisture maps made across the four focus farms in the Krui area for one of the eight high resolution flights made during the month-long experiment. A time series of the eight spatial maps for the Stanley focus farm are given in Figure 2 together with the coincident ground survey maps made of that farm on four occasions. The spatial patterns in these plots show how the more highly elevated hill tops are typically drier than the lower valley bottoms, as expected, and a good general agreement with the ground data, keeping in mind that ground data are in most cases individual point measurements while the airborne sensor gives an integrated measurement over an area of approximately 2,500 m^2.

The time series comparison between airborne, field and in-situ measurements across the Stanley focus farm in Figure 3 also shows a good agreement across

Table 1: Error statistics for Stanley farm when comparing aircraft retrieved soil moisture for ground pixels with more than ten point measurements.

Date	Mean Soil Moisture (v/v)	Root Mean Square Error (v/v)	Bias (v/v)
3-Nov	0.44	0.0334	0.0004
10-Nov*	0.35	0.0906	0.0693
17-Nov	0.11	0.0273	0.0152
24-Nov	0.31	0.0416	-0.026

* 2.4mm of rainfall was recorded during the course of this day

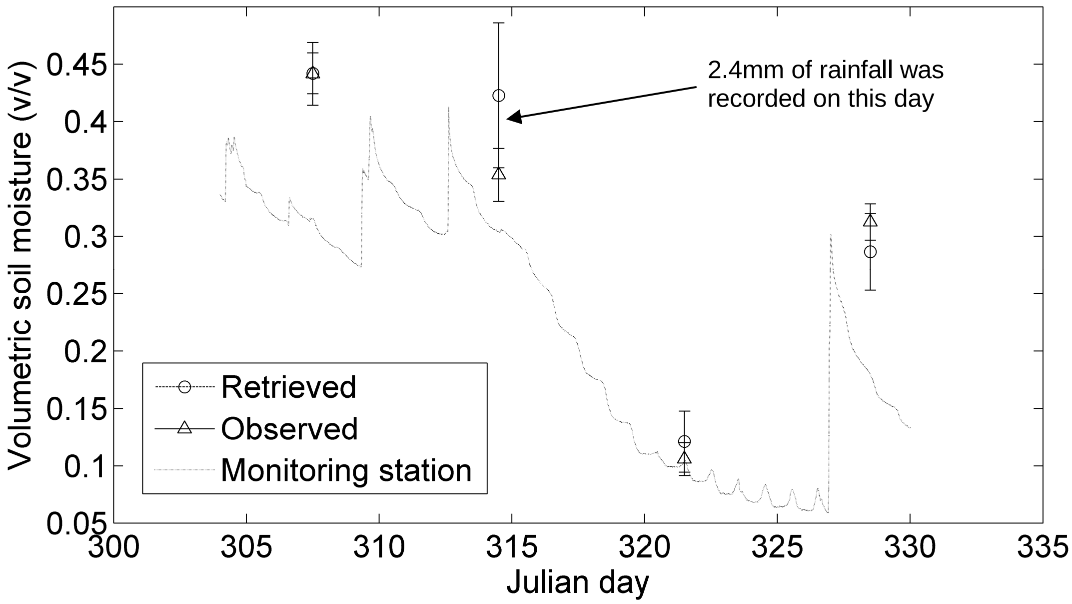

Figure 3: Time series soil moisture comparison between the permanent soil moisture monitoring site at a single point on the Stanley farm, together with the mean and range of soil moisture data from both ground measurements and aircraft estimates (only using ground pixels having more than ten point measurements).

the range of soil moisture conditions encountered. While the in-situ station data is consistently lower than the field and remotely sensed averages, there is a good temporal correlation. Moreover, not only is there a good agreement between the mean moisture conditions measured on the ground and by the aircraft, but there is also a good agreement with the range of moisture conditions encountered as shown by the whiskers. A quantitative comparison between the airborne and field soil moisture data in Table 1 shows an overall retrieval error less than 5% v/v for days when it was not raining. These results therefore suggest that airborne passive microwave remote sensing provides a viable tool for high resolution soil moisture mapping across large areas, with an accuracy and detail that is not achievable from traditional ground based approaches.

Conclusions

This study has demonstrated that near-surface soil moisture may be measured at resolutions as high as 50 m across large areas with a lower cost and equivalent accuracy to that of traditional ground survey techniques. It is shown that an accuracy of better than 5% v/v can be achieved for days when it is not raining.

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