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National Airborne Field Experiments for Soil Moisture Remote Sensing

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Abstract: Remote sensing technology has a huge potential for improving hydrologic prediction through soil moisture measurement. This is particularly so given that the first dedicated soil moisture satellite is to be launched in 2007; the Soil Moisture and Ocean Salinity (SMOS) mission. However, targeted field experiments must be undertaken now so that immediate use can be made of this data when it becomes available. Therefore a series of National Airborne Field Experiments (NAFE) are being planned and conducted throughout south-eastern Australia. The first of these experiments was undertaken in the Goulburn Catchment of the Upper Hunter during November 2005, and the second experiment will be undertaken in the Murrumbidgee Catchment during November 2006. The ultimate objective of these campaigns is to mature soil moisture retrieval algorithms, downscaling and data assimilation, such that 1km near-surface and root-zone soil moisture mapping can become an operational product from SMOS. The idea is that higher resolution remote sensing data from MODIS may be used to downscale the 50km SMOS pixels to 1km resolution. While the first campaign had a specific focus on providing high resolution data for process level understanding of these objectives, the second campaign is focussed on practical application to the SMOS mission. To this end a light aircraft is being used to collect SMOS-type data using a Polarimetric L-band Multibeam Radiometer (PLMR), together with supporting instruments (thermal imager, tri-spectral scanner, lidar and digital photographs). Moreover, extensive ground soil moisture data is collected for verification purposes. This paper describes the airborne field experiment to be undertaken in the Murrumbidgee catchment and its role in maturing this important catchment state variable. See www.nafe.unimelb.edu.au for more detailed information on these experiments.

Keywords: Soil moisture, remote sensing, airborne, satellite, catchment hydrology

1. INTRODUCTION

The National Airborne Field Experiments (NAFE) are a series of intensive experiments being conducted in different parts of Australia. These experiments have been designed to answer questions on: i) estimation of surface soil temperature and vegetation water content; ii) impact of dew, topography, surface roughness, surface rock and standing water on surface soil moisture retrieval; iii) transferability of current radiobrightness equations across scales ranging from 10's metres to 10's kilometres; iv) downscaling of low resolution passive microwave observations of surface soil moisture; and v) retrieval of root zone soil moisture estimates from surface soil moisture observations [Walker et al., 2005]. Such questions can only be resolved through carefully planned and executed field experiments in well instrumented basins together with intensive ground and airborne measurements of the appropriate type and spatial/temporal resolution.

The month-long NAFE'05 experiment was undertaken in the Goulburn River catchment during November 2005, with the objective to provide high resolution data for process level understanding of soil moisture retrieval, scaling and data assimilation. To meet this objective, the Polarimetric L-band Multibeam Radiometer (PLMR), a thermal imager and a tri-spectral scanner were flown onboard a small environmental research aircraft at four different altitudes from 625 ft to 10,000 ft AGL, resulting in L-band data at 62.5m, 250m, 500m and 1km resolution; thermal infrared data at approximately 1.25m, 5m, 10m and 20m resolution; and visible and near-infrared data at approximately 1m resolution on one occasion. Flights were targeted across a 40km x 40km area containing 18 soil moisture profile monitoring sites. On one day per week the entire area was flown while on the remaining four days two sub-areas containing four extensively instrumented and ground monitored farms each were flown on alternate days. Coincident ground data at the farms was collected on nested spatial scales of 6.25m to

1km. Additionally, data was collected on rock coverage and temperature, surface roughness, skin and soil temperature, dew amount, and vegetation water content.

The 3-week long NAFE'06 experiment will be undertaken in the Murrumbidgee catchment during November 2006, with the objective to provide data for SMOS (Soil Moisture and Ocean Salinity) [Kerr et al., 2001] level soil moisture retrieval, downscaling and data assimilation. The details of this experiment plan are described in this paper.

While these experiments have a particular emphasis on the remote sensing of soil moisture, they are open for collaboration from interested scientists from all disciplines of environmental remote sensing and its application.

2. STUDY REGIONS

The 100,000km^2 Murrumbidgee catchment located in south-east Australia (Fig. 1) has a climate range from semi-arid to alpine and covers soil and vegetation types typical of much of Australia. Together with the existing network of 38 soil moisture monitoring stations (Fig. 2; see www.oznet.unimelb.edu.au), this makes the Murrumbidgee ideally suited for NAFE'06.

Climate variations across the catchment are primarily associated with elevation, with average annual precipitation ranging from 300mm in the west to 1900mm in the Snowy Mountains. While the evapotranspiration is approximately equal to precipitation in the west, it is only about half of the precipitation in the east [Bureau of Meteorology, 1998]. Soils in the Murrumbidgee vary from sands to clays, with the western plains being dominated by finer-textured soils and the eastern half of the catchment being dominated by medium-to-coarse textured soils [Western et al., 2002;

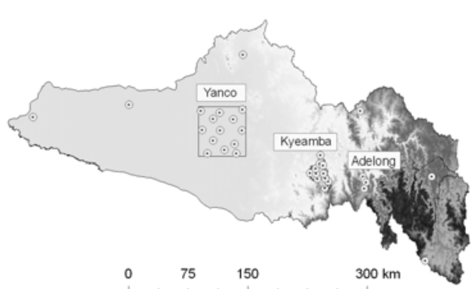

Figure 1. The Murrumbidgee soil moisture monitoring network. The background shows elevation which varies from 50m in the west to over 2100m in the east.

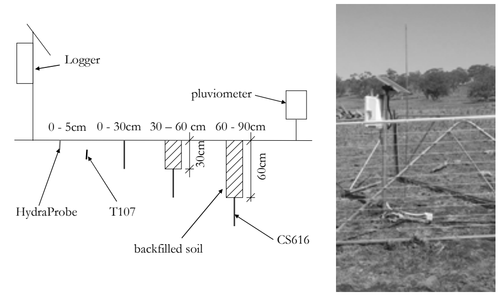

Figure 2. Schematic and photograph of a typical long term soil moisture, temperature and precipitation measurement station in the Murrumbidgee catchment.

McKenzie et al., 2000].

Landuse in the catchment is predominantly agricultural with the exception of steeper parts of the catchment, which are a mixture of native eucalypt forests and exotic forest plantations. Agricultural landuse varies greatly and includes pastoral and intensive grazing, broad-acre cropping, and intensive agriculture in irrigation areas along the mid-to-lower Murrumbidgee.

The NAFE'06 study regions have been chosen to include the Yanco area, Kyeamba Creek catchment, and the Yenda study site (Fig. 3), yielding a diverse range of climatic, topographic

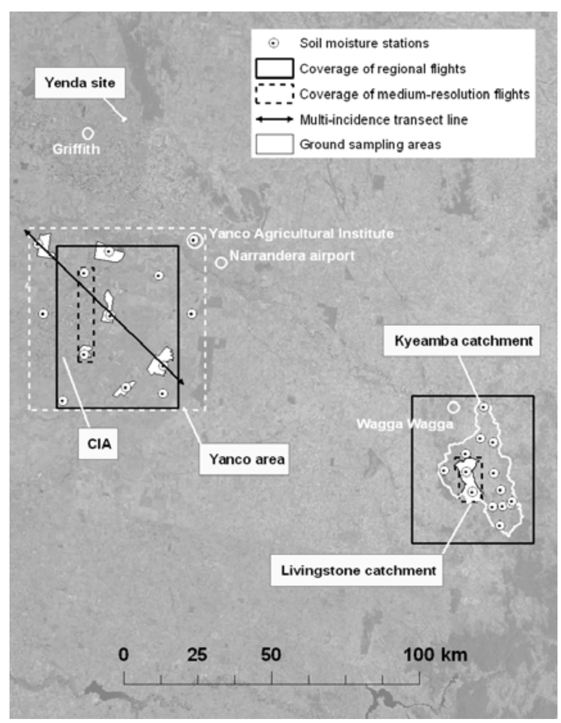

Figure 3. Map showing the location of the three study sites included in NAFE'06, the coverage of flights, and farms involved in ground sampling.

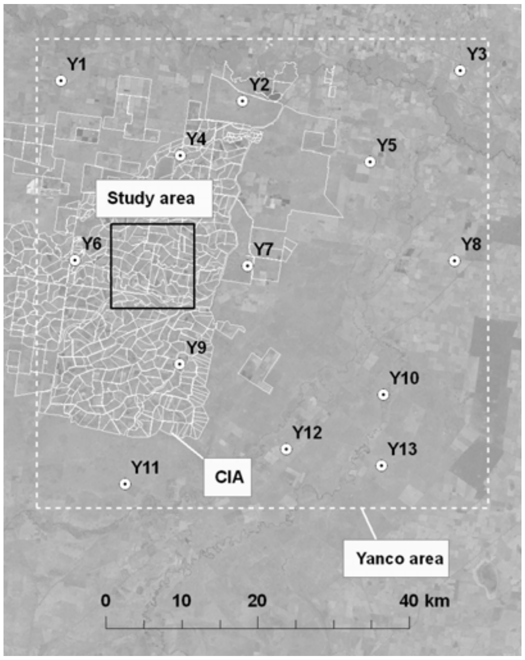

Figure 4. The Yanco area showing the CIA and 120 km^2 area used for spatial analysis of standing water impact expected in November.

and land use settings. However, the primary focus will be on the Yanco area.

2.1 The Yanco Area

The Yanco area is a 60km x 60km area lying in the broad western plains of the Murrumbidgee, where the topography is flat with very few geological outcroppings. According to Hornbuckle and Christen [1999], soil types can be categorised into five groups; clays, red brown earths, transitional red brown earths, sands over clay and deep sands.

Approximately one third of the Yanco area is the Coleambally Irrigation Area (CIA), an intensive agricultural area of approximately 95,000ha and more than 500 farms (Fig. 4). The principal summer crops grown in the CIA are rice, maize, and soybeans, while winter crops include wheat, barley, oats, and canola. Elsewhere is dominated by wheat and pasture.

In November, rice crops are usually flooded by about 30cm of irrigation water, and the presence of this standing water is expected to have a significant impact on the brightness temperature of a microwave pixel. Assuming that the microwave emission of a mixed water-land pixel can be aggregated linearly, a rough computation indicates that 5% areal coverage by water will have the effect of underestimating the microwave emission by about 4 to 8K depending on the surface conditions of the

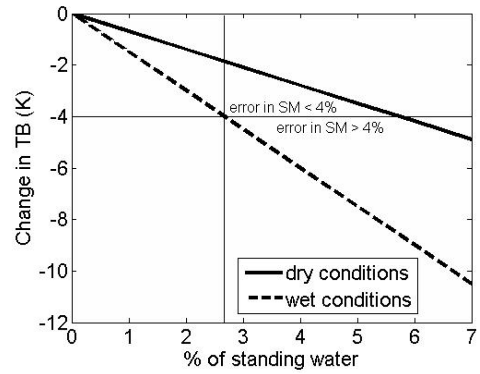

Figure 5. Effect of standing water on passive microwave data assuming a brightness temperature (TB) of water of 110K and a TB of land of 180K (wet conditions) or 260K (dry conditions).

unsubmerged land. Figure 5 illustrates the effect of standing water on observed brightness temperature for assumed land values in the range 180-260K, suggesting that as little as 2.5% submerged land may result in greater than 4%v/v error in retrieved soil moisture.

To estimate the extent of rice crops to be expected during the NAFE'06 campaign, and consequently the impact on airborne passive microwave measurements, a spatial analysis was conducted with the Landsat ETM imagery used in Van Niel et al. [2003, 2005]. Water was classified at 25m resolution from the images available in October-November 2000 (21 Oct, 30 Oct, 6 Nov, 22 Nov) and 2001 (8 Oct, 17 Oct, 2 Nov, 9 Nov, 25 Nov).

In this analysis a 25m resolution ETM pixel was assumed to be standing water if the reflectance of band 5 had a value below 0.150. The percentage of standing water within a 1km pixel was then estimated by aggregating the flooded ETM pixels. To account for uncertainty in the actual resolution of airborne data (due to changes in aircraft attitude) and side lobe effects the ETM pixels were also aggregated to 2km. A sample of results from this analysis is given in Fig. 6 for a representative area of the CIA (Fig. 4). This analysis showed that the timing of irrigation onset ranges from mid to end October, and that the number of pixels with standing water achieves its maximum at the beginning of November. While it was found that approximately 15% of pixels are expected to be free of standing water at 1km resolution, when taking into account possible side lobe effects, not more than a few percent of pixels are expected to be free of standing water. Confirmation of the water impact on microwave data and the development of algorithms for its

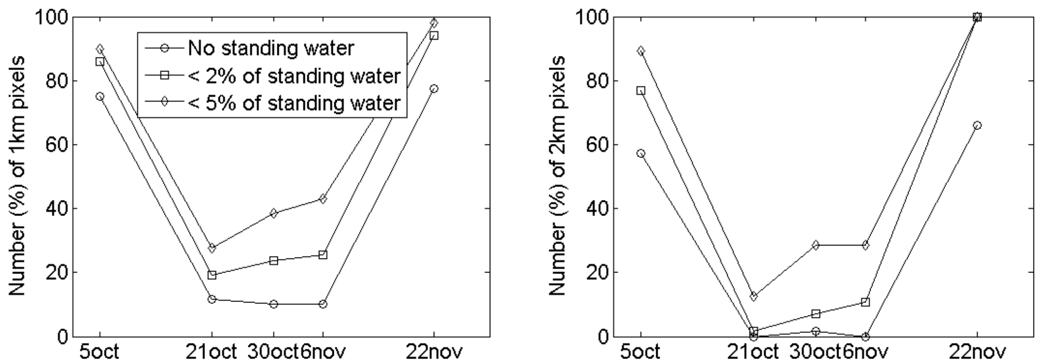

Figure 6. Percentage of 1km and 2km pixels affected by 0, less than 2% and less than 5% of standing water for a representative region of the CIA in 2000.

subsequent removal are one important aspect of the experiment.

The apparent decrease towards the end of November is believed to be an artefact of the processing, with rice plant growth above the water occurring from mid November [Van Niel et al, 2003], as rice crops in the CIA are not drained before late February.

2.2 The Kyeamba Catchment

Kyeamba Creek is a third-order catchment with an area of 600 km^2, located 100km to the east of the Yanco area. The major surface drainage features are Kyeamba, Livingstone and O'Briens Creeks. Average annual rainfall is 650mm, with a gradient decreasing from the highlands in the south to the confluence with the Murrumbidgee in the north. Land use is dominated by cattle grazing, with limited sheep grazing and some irrigation of crops and vegetables. The three dominant soil types are hard neutral red soils, hard alkaline and neutral yellow mottled soils, and hard neutral red soils with red earths [McKenzie et al., 2000].

Elevation ranges from 180m in the north near the confluence with the Murrumbidgee River to 620m in the south, with more than 90% of the catchment having an elevation range from 200m to 400m. The Livingstone subcatchment has the same elevation pattern but at a smaller spatial scale.

The catchment is gauged at two locations, hence providing the opportunity for nested catchment studies. Additionally, a 3D eddy correlation flux tower operates near the centre of the catchment, and a focus farm near the confluence of Livingstone and O'Briens Creek has 8 additional soil moisture profile sites, 7 stream gauges, a weather station, and a Bowen ratio system. Topography, soil and vegetation in the Livingstone Creek are reflective of the Kyeamba Creek catchment, providing a good basis for extrapolating results from any detailed studies undertaken in the subcatchment. Moreover, the Kyeamba and Livingstone catchments are well suited to studies of catchment water balance.

2.3 The Yenda Site

The Yenda site is an experimental farm operated by CSIRO in Griffith, located 40km north of the Yanco area. It is composed of two adjacent vineyards of 14 and 12 ha. The bigger vineyard is flood irrigated while the other is drip irrigated; both have separate irrigation supply, surface drainage and subsurface drainage. Soil types, vine and floor management practices are similar for both vineyards, and typical of vineyards in the area. These vineyards are being used to undertake detailed measurements of water balance and water flux components at detailed spatial and temporal resolution. This information will be used to develop on-ground relationships which can be linked to data gathering capabilities at larger spatial scales.

3. AIRBORNE MEASUREMENTS

Airborne measurements will be made using a small, low-cost, two-seater motor glider from the Airborne Research Australia national facility (Fig. 7) together with the recently acquired PLMR and thermal imager. This allows very high resolution passive microwave (~50m) and land surface skin temperature (~1m) observations to be made across large areas. There is no other capacity world-wide to make such high resolution measurements together with a range of other supporting data including a full waveform lidar, tri-spectral scanner for NDVI and 11MegaPixel digital camera.

The aircraft can carry a typical science payload of up to 120kg with cruising speed of 92-

Figure 7. The Diamond ECO-Dimona aircraft showing bulkheads under the fuselage for mounting PLMR, with thermal imager, digital camera and tri-spectral scanner and lidar in an underwing pod. The foreground shows PLMR undergoing a sky calibration.

203km/h and range of 4-8hrs or 800-1500km. The PLMR measures both V and H polarisations using a single receiver with polarisation switch at incidence angles +/–7°, +/–21.5° and +/–38.5° in either across track (pushbroom) or along track configurations. The thermal imager is a FLIRTS ThermaCam S60 with spectral range 7.5 to 13μm, accuracy +/–2°C or +/–2% of reading, thermal sensitivity 0.08°C and 80° × 60° FOV lens with 1.3mrad IFOV. While the thermal measurements provide the near-surface soil temperature data for soil moisture retrieval, the dual polarisation microwave measurements enable simultaneous solution of soil and vegetation moisture content [Owe et al., 2001]. The high resolution thermal and NDVI data also allow the development of soil moisture downscaling algorithms, and remote sensing of evapotranspiration.

To meet the SMOS downscaling objective of this experiment, the PLMR and thermal imager will be flown at an altitude of 10,000 ft AGL to provide 1km resolution passive microwave (and 20m TIR) data across a 40km x 55km area of the Yanco study site every 2-3 days, and across a 40km x 50km area that encapsulates the Kyeamba catchment once per week (Fig. 3). This will both simulate two SMOS pixels and provide the 1km soil moisture data required for downscale verification, allowing downscaling and near-surface soil moisture assimilation techniques to be tested with remote sensing data which is consistent with that from current (MODIS) and planned (SMOS) satellite sensors. Additionally, a transect will be flown across the Yanco study area (Fig. 3) twice a week to provide both 1km multi-angular passive microwave data for SMOS algorithm development, and on the same day, 50m resolution passive microwave data for algorithm verification. By flying at 6am and 6pm, both SMOS overpass times can be tested.

The PLMR and thermal imager will also be flown at medium (250m PLMR) spatial resolution once per week across a region of the CIA in the Yanco study area, and the Livingstone Creek subcatcment of the Kyeamba catchment. This will allow for detailed studies of the standing water impact in the CIA and provide data on water balance in the Livingstone Creek. Additionally, a high resolution (50m PLMR) flight will be made across the Yenda site during the first and third weeks of the campaign. An NDVI, lidar and aerial photo flight will be undertaken along the Yanco transect, medium resolution areas of Yanco and Kyeamba, and Yenda during cloud-free days in the first and third weeks of the campaign.

4. GROUND MEASUREMENTS

Additional ground-based monitoring of near-surface soil moisture will be undertaken at focus farms (having different characteristics) in each study area, with a particular focus on the Yanco area (only Yanco measurements will be discussed here). These farms are shown in Fig. 3. The near-surface soil moisture measurements will be made using the Hydraprobe Data Acquisition System (HDAS; Hydraprobes® connected to an electronic fieldbook (iPAQs®) running ArcPAD® and bluetooth connection to GPS for real-time position and data logging). These roving measurements will be made on grids of 50m to 250m spatial resolution on each farm (Fig. 8), in order to collect data across a range of soil, vegetation and terrain conditions.

Continuous logging of near-surface soil moisture and temperature, and thermal infrared will be made for a single point at focus farms to verify that soil moisture is not changing significantly across the day, and to derive relationships between near-surface soil temperature and thermal infrared observations. Observations of dew, vegetation water content, fractional coverage of surface rock, soil properties, and surface roughness will also be made to account for those factors in soil moisture retrieval from the airborne and satellite measurements.

5. CONCLUSIONS

Interested parties have been invited to participate in these planned field experiments and reap the benefits of collaboration. In particular, people with an interest in remote sensing of evapotranspiration and precipitation, or other under represented areas of

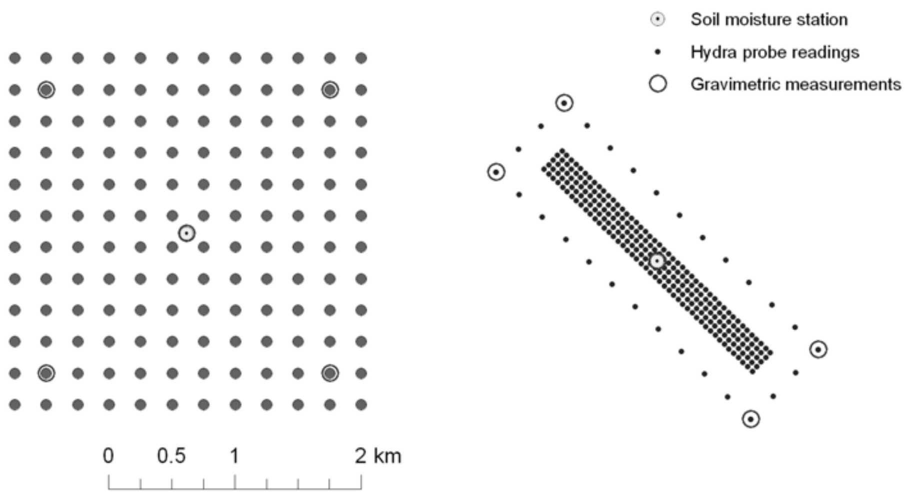

Figure 8. Schematic of soil moisture sampling during a) regional days and b) transect days.

environmental remote sensing that can utilse the high resolution passive microwave, thermal infrared, near infrared, visible and/or lidar data to be collected, were especially welcomed.

6. ACKNOWLEDGEMENTS

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