The National Airborne Field Experiment Data Sets

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EXTENDED ABSTRACT

The National Airborne Field Experiment's (NAFE) were a series of intensive experiments recently conducted in different parts of Australia. These hydrologic-focused experiments have been designed to answer a range of questions which 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. While the data collected have a specific focus on soil moisture, they are applicable to a wide range of hydrologic activities.

The NAFE'05 experiment was undertaken in the Goulburn River catchment (New South Wales, Australia) during November 2005, with the objective of providing high resolution data for process level understanding of soil moisture retrieval, scaling and data assimilation. The NAFE'06 experiment was undertaken in the Murrumbidgee catchment (NSW, Australia) during November 2006, with the objective of providing data for SMOS (Soil Moisture and Ocean Salinity; a dedicated soil moisture satellite to be launched in 2008) like soil moisture retrieval, downscaling and data assimilation.

To meet these objectives, the Polarimetric L-band Multibeam Radiometer (PLMR), a thermal imager, full-wave transform lidar, tri-spectral scanner and digital camera were flown onboard a small aircraft, together with coincident ground data collection on soil moisture, rock coverage and temperature, surface roughness, land surface skin and soil temperature, vegetation dew amount and vegetation water content.

Each campaign was 3 to 4 weeks in duration and encountered favourable meteorological conditions, meaning that data was collected across a range of soil moisture conditions. Moreover, data was collected across diverse landcover and landuse settings in two different climatic regimes. The data described in this paper are available on the World Wide Web at www.nafe.unimelb.edu.au.

1. INTRODUCTION

Data on land surface hydrologic states is vital to understanding the earth's water, energy, and carbon cycles. Moreover, soil moisture knowledge is critical in weather and climate prediction, where model initialisation with hydrospheric state measurements has been shown to bring significant improvements in forecast accuracy and reliability (Conil *et al.*, 2007). Hydrologic state observations will also benefit climate-sensitive socioeconomic activities, such as water management, agriculture, flood and drought monitoring, and policy planning, by extending the capability to predict regional water availability and seasonal climate. However, accurate hydrologic data are lacking, due to i) an inability to economically monitor spatial variations from traditional point measurement techniques, ii) large uncertainties in model predictions, and iii) the immaturity that still exists in hydrologic remote sensing technology; for example the first dedicated soil moisture satellite mission will not be launched until 2008 (Kerr *et al*., 2001).

To progress hydrologic remote sensing and address some of the important questions that remain unanswered (Walker *et al*, 2005), it is essential that field campaigns with coordinated satellite, airborne and ground-based data collection be undertaken, giving careful consideration to the diverse data requirements for the range of questions that exist. Moreover, it must be recognised that such invaluable data sets do not come without considerable effort and cost. Thus it is increasingly important that scientists collaborate nationally and internationally on the collection and subsequent analysis of such data to share in the burden and reap the benefits of more extensive data sets than are possible from individual efforts. To this end, two 3 to 4 week-long National Airborne Field Experiments (NAFE) have been undertaken in collaboration with scientists from diverse backgrounds (soil moisture, runoff, evapo-transpiration, carbon, bushfires, etc) and organisations. While the data collected are applicable to a wide range of potential applications, there has been a particular focus on the remote sensing of soil moisture, which is also the focus of this paper.

NAFE'05 and NAFE'06 were two intensive experiment campaigns recently conducted in different parts of Australia in November 2005 and 2006 respectively. These experiments were designed to answer such questions as: i) estimation of surface soil temperature and vegetation water content from routine remote sensing data; ii) impact of dew, topography, surface roughness and surface rock on surface soil moisture retrieval; iii) transferability of current radiobrightness equations across scales ranging from 10's meters to 10's kilometres (see Panciera *et al.*, this issue); iv) downscaling of low resolution passive microwave observations of surface soil moisture; v) impact of mixed pixel responses including flood irrigation, urban areas and mixed vegetation types; and vi) retrieval of root zone soil moisture estimates from surface soil moisture observations. 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. While the NAFE'05 objective was to provide high resolution data for process level understanding of soil moisture retrieval, scaling and data assimilation, the NAFE'06 objective was to provide data for SMOS (Soil Moisture and Ocean Salinity) like soil moisture retrieval, downscaling and data assimilation.

Favourable meteorological conditions during the campaign periods allowed data collection for a range of soil moisture conditions throughout the respective spring growing seasons (Fig. 1). This paper summarises the data collected during these two campaigns. The data described in this paper are currently being analysed at various institutions around the world, and are available on the web at www.nafe.unimelb.edu.au.

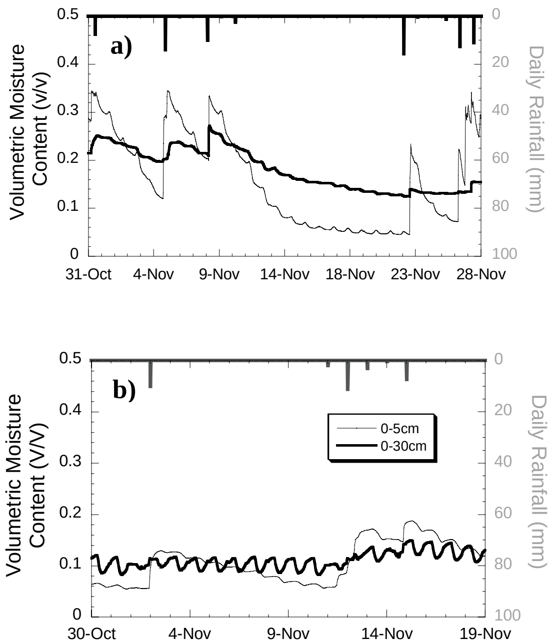

Figure 1. Typical rainfall and soil moisture conditions encountered across the study regions during a) NAFE'05 and b) NAFE'06.

2. STUDY REGIONS

The two NAFEs have been undertaken in diverse climatic, topographic and landuse settings. These are the Goulburn River catchment for NAFE’05 and the Murrumbidgee River catchment for NAFE’06. The existing network of monitoring sites (Fig 2.) and data management systems in each region provided an ideal basis for the ground-based soil moisture and meteorological measurements that supported these campaigns.

2.1. Goulburn Catchment

The semi-arid 6,500km^2 Goulburn River catchment in the Upper Hunter region of New South Wales (Rüdiger *et al.*, 2007) is an experimental catchment with joint monitoring by the Universities of Newcastle and Melbourne since 2001. The catchment has a total of 26 continuous soil moisture profile monitoring sites, with 20 of these concentrated in two focus sub-catchments (the Krui and Merriwa Rivers) and 7 of those in a 175ha microcatchment (Fig. 3a). There are also a number of climate and streamflow recording stations (see www.sasmas.unimelb.edu.au). This catchment was specifically selected and instrumented for remote sensing-related studies. Field work undertaken in the Goulburn River catchment during NAFE’05 was limited to the northern cropping and grazing area.

2.2. Murrumbidgee Catchment

The 80,000km^2 Murrumbidgee catchment ranges from semi-arid to alpine conditions and covers a range of soil and vegetation types typical of much of south eastern Australia. It has been the focus of a joint project with the Bureau of Meteorology and the University of Melbourne for improving land surface representation in the Bureau of Meteorology numerical weather prediction model (Western *et al.*, 2002). Monitoring in this catchment was upgraded in 2003 for validating terrestrial water storage retrieval from combined remote sensing measurement of surface soil moisture and temporal variation in the earth’s gravity field. There are now a total of 38 continuous soil moisture profile monitoring sites across the entire Murrumbidgee catchment, with 13 of these located in each of the two focus study areas; the 2,500km^2 Yanco area and the 600km^2 Kyeamba Creek catchment (Fig. 3b). There are also climate and streamflow recording stations (see www.oznet.unimelb.edu. au).

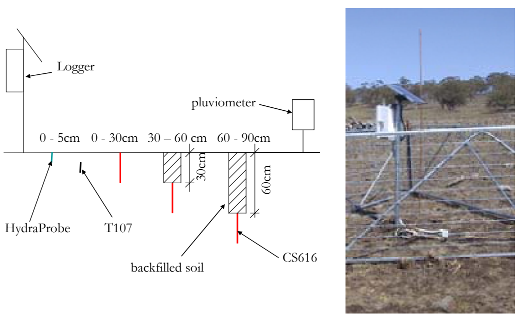

Figure 2. Long-term soil moisture, temperature and precipitation measurements in the study catchments.

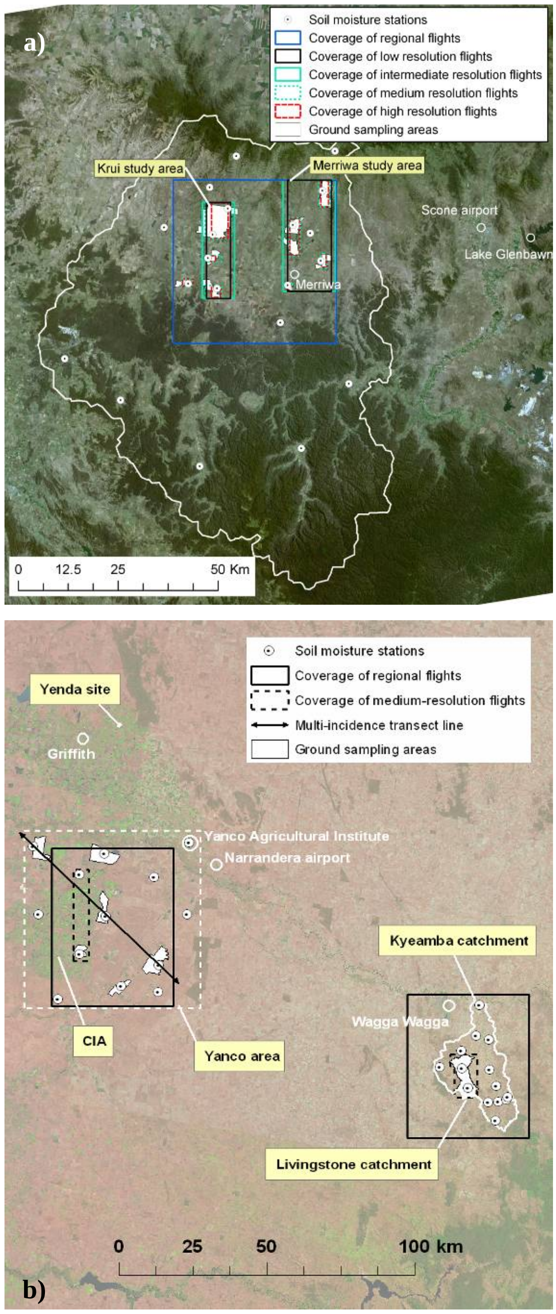

Figure 3. Maps showing location of the study sites, flight coverages and focus farms for ground sampling in a) NAFE’05 and b) NAFE’06.

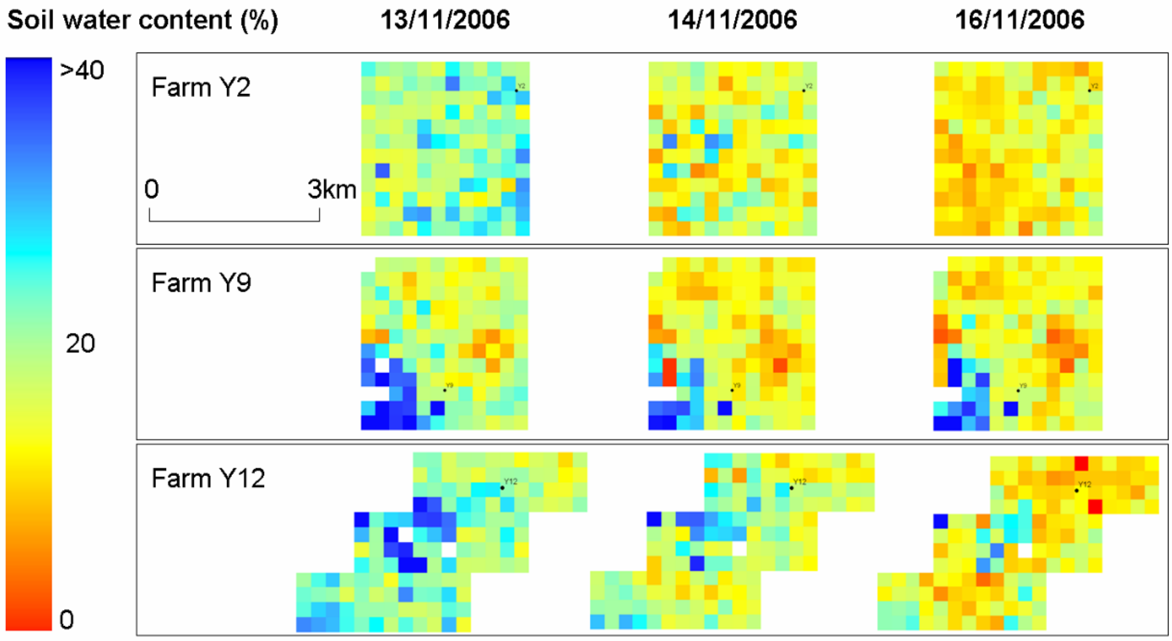

Figure 4. Example of the 250m resolution ground measured soil moisture data during NAFE'06.

3. GROUND MEASUREMENTS

Ground-based monitoring of near-surface soil moisture and temperature was undertaken at focus farms (having different characteristics) in each study area. These farms are shown in Fig. 3. Near-surface soil moisture and temperature measurements were made using a Hydraprobe Data Acquisition System developed at the University of Melbourne, which interfaces a Hydraprobe with an electronic fieldbook running GIS and connection to GPS for real-time position and data logging. The soil moisture sensor used is accurate to within 3.5%v/v (Merlin *et al.*, this issue). These roving measurements have been made on predefined grids on each farm, in order to collect data across a range of soil, vegetation and terrain conditions. Grid sizes ranged from 6.25m within 150m focus areas through a range of decreasing resolutions to 1km for the largest of farms in NAFE'05. In NAFE'06 grid sizes ranged from 50m for 3km x 1km areas during high-resolution flights to 250m for 3km x 3km areas (see Fig. 4) on farms for low-resolution flights.

Continuous logging of near-surface soil moisture and temperature, together with thermal infrared and dew measurements were made at a number of focus farms during each campaign to verify that soil moisture was not changing significantly across the day, and to derive relationships between soil temperature and thermal infrared observations. Moreover, a rock was instrumented for temperature during NAFE'05 to better understand the impact of surface rock on microwave emission.

Vegetation reflectance and leaf area index were also measured together with biomass and vegetation water content sampling with the objective to develop relationships for vegetation water content and biomass estimation from remote sensing data. Observations of dew, fractional coverage of surface rock, soil properties and surface roughness were also made to account for those factors in soil moisture retrieval.

4. AIRBORNE MEASUREMENTS

Airborne measurements were made using a small, low-cost, two-seater motor glider from the Airborne Research Australia national facility (Fig. 5), equipped with the Polarimetric L-band Multibeam Radiometer (PLMR) and thermal imager. This new infrastructure has allowed for the first time, very high-resolution passive microwave (~50m) and land surface skin temperature (~1m) observations to be made across large areas together with a range of other

Figure 5. The Diamond ECO-Dimona aircraft with PLMR mounted under the fuselage, and thermal imager, digital camera and NDVI scanner in an underwing pod.

supporting data, including a full-wave transform lidar, tri-spectral (green, red and near infrared) scanner and 11MegaPixel digital camera (Fig. 6).

The PLMR measures both vertical (v) and horizontal (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 has a spectral range 7.5 to 13µm, accuracy +/–2°C or +/–2% of reading, thermal sensitivity 0.08°C and 80° × 60° field of view lens with 1.3mrad instantaneous field of view. 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 optical data will allow the development of soil moisture downscaling algorithms from spatially averaged data at a ground resolution that can be adequately monitored using ground-based techniques.

During NAFE '05, an Aero-Commander also operated by Airborne Research Australia, carried

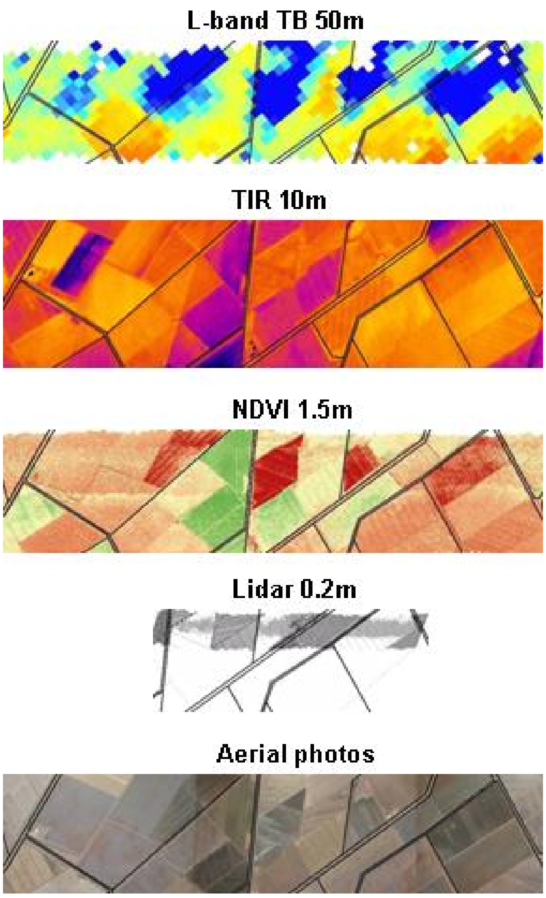

Figure 6. Example of multi-sensor airborne data collected during NAFE'06.

the European L-band passive microwave radiometer EMIRAD-2, designed specifically for SMOS algorithm development.

A total of approximately 100hrs of mission flights were conducted during each of the NAFE'05 and NAFE'06 campaigns using the PLMR and supporting instruments. Full coverage of the same ground area was guaranteed by allowing a full PLMR pixel overlap between adjacent flight lines for the median ground altitude of the area.

4.1. NAFE'05 Flights

Five flight types were conducted for NAFE'05: i) regional, ii) multi-resolution, iii) multi-angle, iv) dew and v) aerial photography.

Regional flights were performed over the entire 40km x 40km study area for comparison with C-band data from the AMSR-E mission, evaluate the Goulburn catchment for SMOS validation, and simulate a SMOS pixel. These flights were undertaken once per week for the campaign, yielding four maps of L-band microwave data at a nominal ground resolution of 1km.

The multi-resolution flight types were specifically designed to address L-band scaling issues by acquiring observations of the same area at various resolutions. Due to the long flight time required, the entire study area could not be covered during these flights. Consequently, two areas of approximately 10km x 30km were the focus of alternate multi-resolution flights; Merriwa and Krui. Multi-resolution flights were undertaken four times per week, alternating between the two focus areas. For each flight, the focus area was covered at four different altitudes in descending order, resulting in L-band maps at nominally 1km, 500m, 250m and 62.5m spatial resolutions (see example in Fig. 7) and thermal infrared maps at approximately 20m, 10m, 5m and 1.25m resolution.

A total of six multi-angle flights were performed specifically to investigate the science question of multi-incidence angle retrieval of soil moisture. These flights were undertaken over three of the focus farms in the Merriwa study area with a pixel size of approximately 250m.

The effect of dew deposited on vegetation on soil microwave emission was assessed with two early morning flights in the 30km x 20km focus area of the Merriwa catchment, prior to a scheduled flight later in the day. This allowed comparison of the microwave signal before and after the dew dry off.

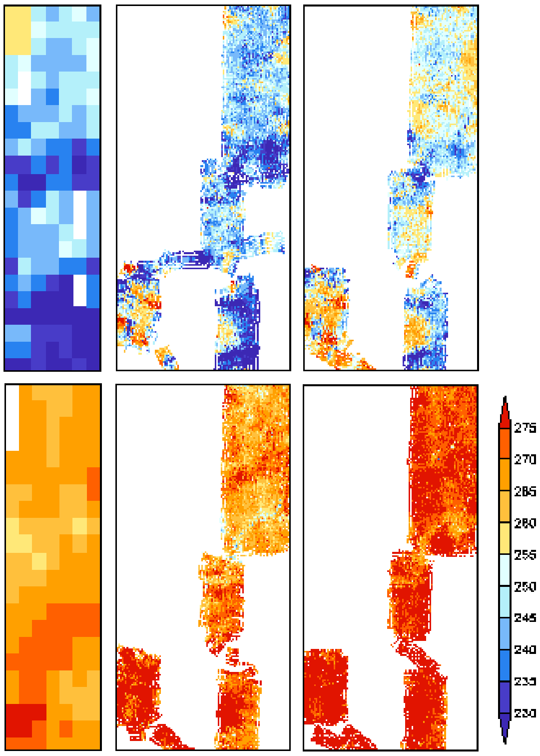

Figure 7. Example of h-polarised multi-resolution brightness temperature in the Krui Creek catchment at 1km (left panels) and 62.5m (right panels) resolutions during each of the four weeks of the NAFE'05 campaign; the two panels to the left at different resolutions are for the same dates as those immediately to the right.

4.2. NAFE'06 Flights

Four flight types were conducted for NAFE'06: i) scaling, ii) multi-angle, iii) multi-sensor, and iv) mixed-pixel.

Scaling flights were undertaken for the entire 40km x 55km study area in Yanco and 40km x 50km study area in Kyeamba for comparison with C-band data from the AMSR-E mission, evaluate the areas for SMOS validation, and simulate SMOS pixels for downscaling developments. These flights were undertaken on alternate days for the Yanco area (Fig. 8) and once per week for the Kyeamba area, yielding eleven and three maps of L-band microwave emissions respectively at a nominal ground resolution of 1km.

Multi-angle flights were performed for the specific purpose of simulating multi-angle SMOS data and to subsequently improve the multi-incidence angle soil moisture retrieval algorithms. These flights were undertaken twice per week along a single 75km transect through the Yanco study area, with a nominal PLMR ground resolution of 500m. Mapping flights of the 1km wide transect were also made on the same day with a nominal PLMR ground resolution of 50m. The six transect flights were specifically designed to go through a range of vegetation types and were flown alternatively at 6am and 6pm to simulate SMOS am and pm overpass times.

Multi-sensor airborne data were also collected for several focus areas, including the Yanco multi-angle transect, Yanco medium resolution region in the Coleambally Irrigation Area (CIA), Livingstone Catchment in the Kyeamba Creek study area, and the Yenda vineyard. These flights included PLMR data from 50m to 250m resolution, thermal infrared data from 1m to 5m resolution, and tri-spectral line scanner, lidar and digital camera data at better than 1m resolution. In addition to providing data for multi-sensor soil moisture retrieval algorithm development, these data will allow water balance assessment of the Livingstone Creek catchment, and water stress assessments of the intensive agriculture applications in the Yenda site.

Mixed-pixel data were obtained from flights over the Yanco and Kyeamba study areas, with a major urban center (Wagga Wagga) located in the north east of the Kyeamba region and the CIA in the Yanco region. Moreover, the Yanco region included a mix of pasture and cropping areas and different crop types. Mixed-pixel microwave emission is expected to create a significant challenge for SMOS soil moisture retrieval from many parts of the world, and these data will allow such issues to be explored in detail. In particular, standing water in rice paddies in the CIA was specifically targeted by medium (250m) resolution flights in that region.

5. CONCLUSIONS

The data described in this paper are available at http://www.nafe.unimelb.edu.au. The web site provides all the information needed for interpretation of these data, along with general information on the catchments, photographs of the landscape, sampling methods and full experiment plans. Due acknowledgement in any publication or presentation arising from the use of these data is required.

6. ACKNOWLEDGEMENTS

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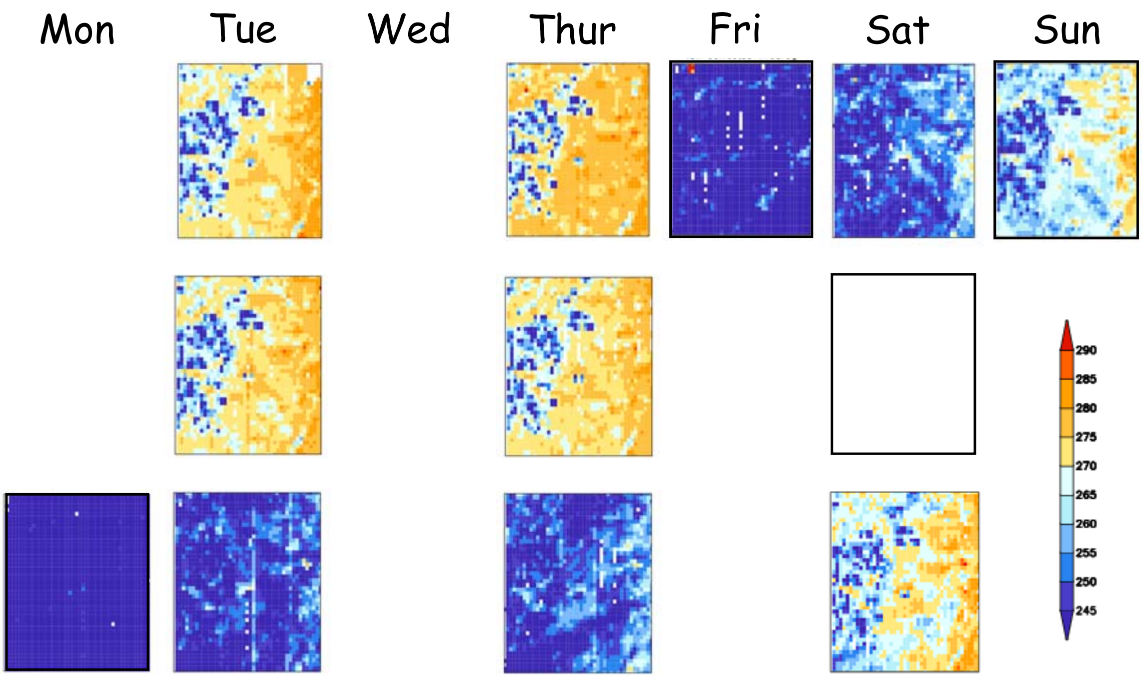

Figure 8. Summary of h-polarised multi-temporal brightness temperature data at 1km resolution across the Yanco study area for the 3-week campaign, showing the observed temporal variation in soil moisture content. The region in the left of the panels is the Coleambally irrigation area, and the panels outlined in bold are opportunistic variations from the planned flights.

of a large number of farmers to allow access to their land. Initial setup and maintenance of the study catchments was funded by research grants (DP0209724, DP0343778 and DP0556941) from the Australian Research Council, the CRC for Catchment Hydrology and NASA.

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