

Australian Airborne Cal/val Experiments for SMOS (AACES)

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Experiment Plan

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1 Overview and Objectives

With the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) satellite successfully launched on 2 November 2009, the first long-term space-borne passive microwave observations at L-band (~ 1.4 GHz) will soon become available. Consequently, SMOS is 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 30 years, this innovative L-band radiometer uses a new synthetic aperture concept that provides observations at multiple incidence angles. Consequently, the observed brightness temperature data and derived soil moisture product must both 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, Midi-Pyrenees in France etc.). With the SMOS launch being in the northern hemisphere autumn, Australia is particularly well positioned for conducting the first intensive SMOS validation campaign during its growing season.

The Australian Airborne Cal/val Experiments 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 (Figure 1-1). 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 (NAFE'06), and continuous soil moisture monitoring station (OzNet) and meteorological data over the past seven years, is available for this region.

Compared to the planned European validation campaigns, 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 seasonal 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.

The AACES campaigns have been made possible through a series of infrastructure (LE0453434, LE0560930, LE0882509 and LE0989062) and research (DP0879212) funding from the Australian Research Council, and are relying upon the collaboration of a large number of scientists from throughout Australia and around the world, Europe in particular, with salary and travel support provided by their national funding agencies. Initial campaigns, setup, and maintenance of the study catchment were funded by research grants from the Australian Research Council (DP0343778 and DP0557543) and the CRC for Catchment Hydrology.

This document outlines the airborne and related ground monitoring for the Australian SMOS validation campaigns, with a particular emphasis on the first campaign. Supplements to this plan will be produced for the subsequent campaigns, describing only the variations from this first baseline campaign.

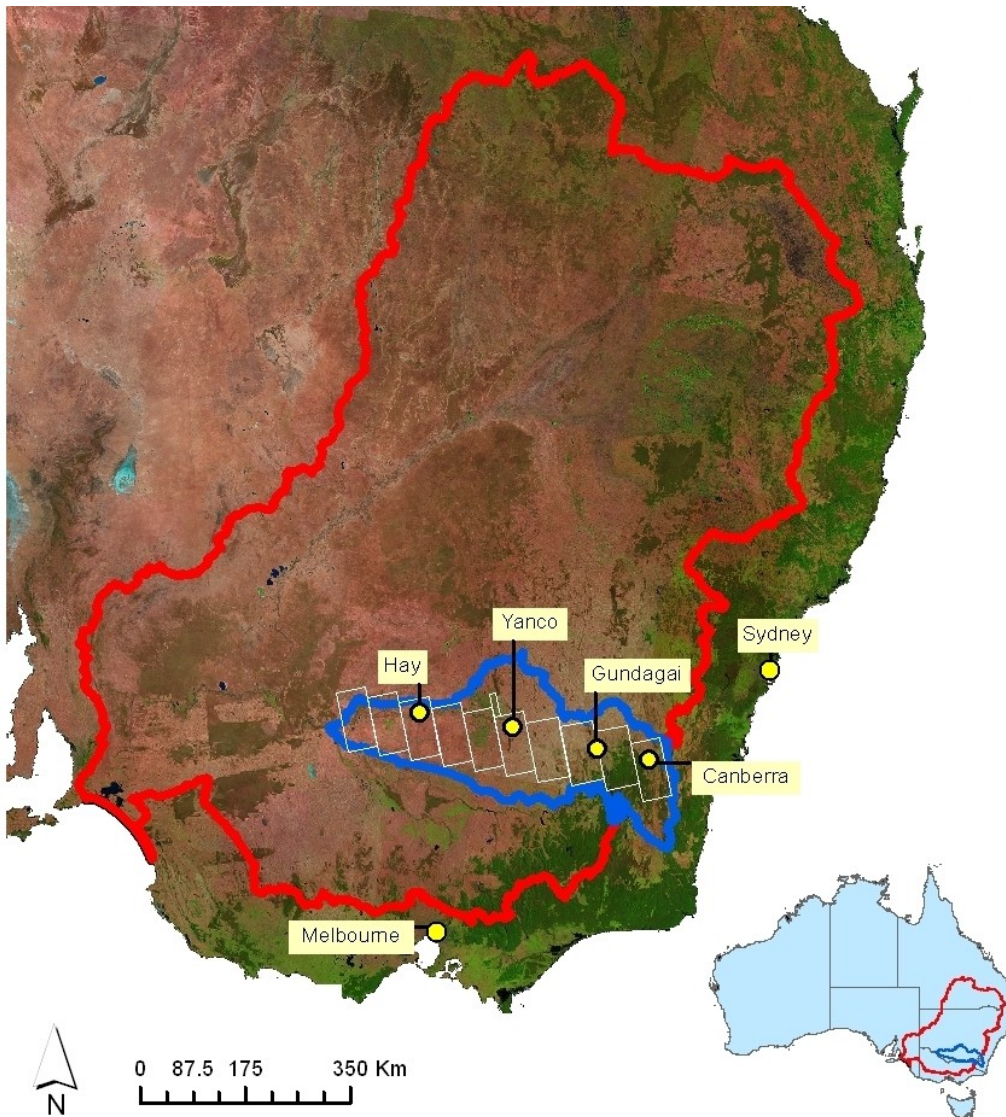


Figure 1-1: Location of the AACES transect (white) within the Murrumbidgee Catchment (blue) and the Murray Darling Basin (red). Also shown are some relevant towns and cities.

1.1 Overview

Internationally there has been significant anticipation for the launch of SMOS. Moreover, there is considerable expectation that SMOS will deliver soil moisture data globally on a better than 3 day repeat cycle with an error of less than $0.04\text{m}^3/\text{m}^3$ for areas with vegetation water content less than $4\text{kg}/\text{m}^2$, and that this information will translate into improved numerical weather prediction skill, more accurate flood forecasting, and best practice agricultural management, to name a few. However, SMOS is a new generation technology that is relatively untested, and is the first dedicated soil moisture mission at L-band. Consequently, field campaigns are essential to both validate the brightness temperature maps and the derived soil moisture products provided by SMOS.

The commissioning phase of SMOS is scheduled to last only 6 months, after which the mission will be considered “operational”. Consequently, it is important that at least one extensive validation campaign be conducted during the post-launch commissioning. Moreover, the first 8 weeks post-launch are dedicated to switching on and commissioning the

payload itself, so the optimal time for a campaign is from week 9 of the commissioning phase. During this later part of the commissioning, data will be acquired all the time but with dual and full polarisation alternating week about (Wednesday to Wednesday) and with sky calibrations conducted during one orbit (over the ocean to minimise side lobes) per week (every Wednesday). At the end of the commissioning period a decision must be made by ESA to measure either dual or full polarisation data only, with sky calibrations conducted fortnightly. Consequently, the optimal time for a SMOS validation campaign is January/February 2010, for an area of diverse soil moisture and land cover etc conditions. Being 2 months after launch also allows sufficient time to confirm SMOS orbit dependent campaign parameters and to mobilise international collaborators which could not be performed with certainty pre-launch.

The first of the planned series of four AACES campaigns is able to meet these requirements, because of its location in the southern hemisphere and that the campaign is designed to cover a large transect with significant variability in conditions. The campaigns are planned to cover a 100km × 500km (more than 20 independent SMOS pixels) transect of the Murrumbidgee catchment in its entirety at 1 km resolution using an L-band radiometer, with flights timed to coincide with SMOS overpasses. The primary airborne instruments will include the Polarimetric L-band Multibeam Radiometer (PLMR), thermal infrared and multi-spectral sensors, supported by surface soil moisture content, soil temperature and rainfall data from the Murrumbidgee (OzNet) monitoring network. This will be further complemented by short-term soil moisture and temperature monitoring stations with additional leaf wetness and thermal infrared measurements, intensive soil moisture observations with the Hydraprobe Data Acquisition System (HDAS), and extensive vegetation characterisation, at a number of focus farms.

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.

1.2 Objectives

The AACES campaigns have a number of complimentary objectives that will allow for validation of both SMOS, and a soil moisture monitoring and prediction system called MoistureMap, currently under development at the University of Melbourne. MoistureMap will provide predictions of soil moisture at 1km resolution through utilisation of high resolution land surface modelling constrained by remote sensing data such as SMOS. Specifically, these campaigns will allow validation of:

- SMOS Level 1C brightness temperatures at 50km resolution,
- SMOS Level 2 soil moisture products at 50km resolution,
- SMOS downscaled soil moisture to 1km resolution,
- MoistureMap soil moisture predictions at 1km resolution,
- In-situ monitoring stations representation of soil moisture at 1km and 50km resolution, and
- Coupled MoistureMap L-MEB brightness temperature predictions at 1km resolution.

Consequently, a novel cross validation strategy will be used to validate SMOS brightness temperatures and derived soil moisture products, utilising a combination of long term in-situ observations, high resolution model predictions, and airborne observations at L-band. Using this comprehensive cross validation strategy (Figure 1-2), a number of compromising

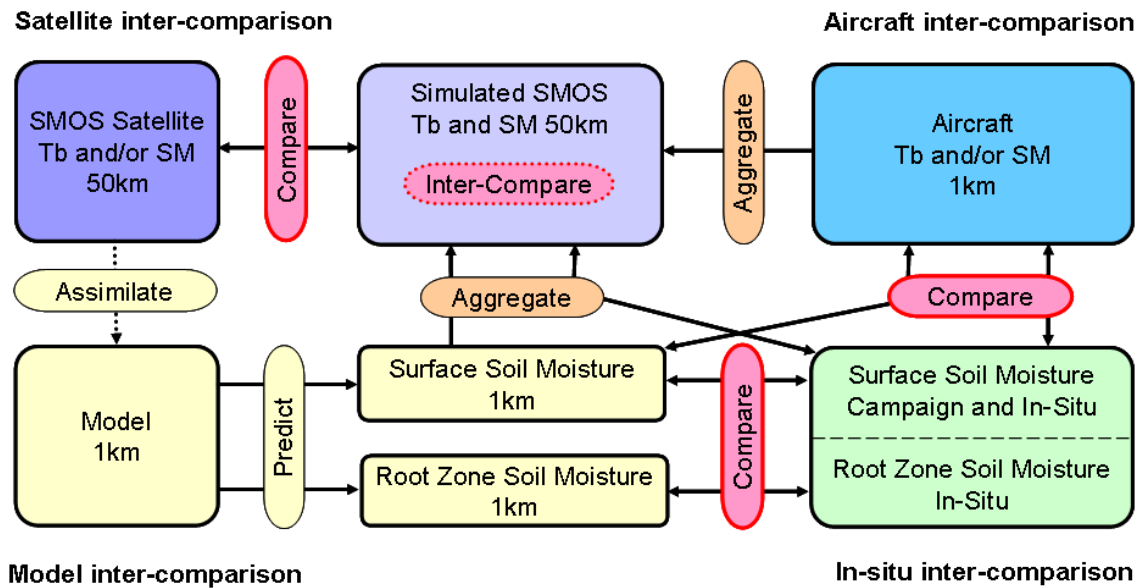


Figure 1-2: The cross validation strategy for SMOS.

assumptions can be avoided, including the accuracy of models and representativeness of point measurements, aircraft transects, and/or single SMOS pixels. Moreover, these campaigns will allow long term validation to be undertaken using in-situ observations and model predictions, underpinned by extensive airborne and ground validation activities. A SMOS inter-comparison analysis using in-situ observations, model predictions and airborne data will be undertaken in terms of both observed brightness temperatures at a range of incidence angles and the derived soil moisture product. Eventually, SMOS data will be assimilated into the land surface model and its surface and rootzone soil moisture impact assessed using both airborne and in-situ data.

1.3 General Approach

The AACES campaigns are planned to cover a large part of the Murrumbidgee River catchment in entirety four times (one within each season). 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 × 50 km in size, of which each will be mapped within a single day (Figure 1-3). The airborne observations will be undertaken at approximately 3000 m (AGL) altitude to provide passive microwave data and derived soil moisture content with a 1 km spatial resolution. The primary aircraft instrument will be the PLMR, used in across-track configuration (pushbroom) to map the surface with three viewing angles ($\pm 7^\circ$, $\pm 21.5^\circ$ and $\pm 38.5^\circ$) to each side of the flight direction, achieving a swath width of about 6 km.

Approximately 4 weeks are required to map the study transect once with coincident SMOS coverage. Moreover, approximately 4 to 5 hours of flight time is required to cover each patch once, including a partial repeat pass of the first flight line and a partial overlap of the adjacent patch. Consequently, all flights will be conducted such that they are centred on the 6am local overpass time of SMOS. All flights will be operated out of Naranderra airport, while the ground crew will systematically make their way across the catchment staying at each of Hay, Yanco, Gundagai and Yass in turn. Intensive ground measurements are also scheduled to coincide with SMOS overpass times as closely as practical. The core ground sampling

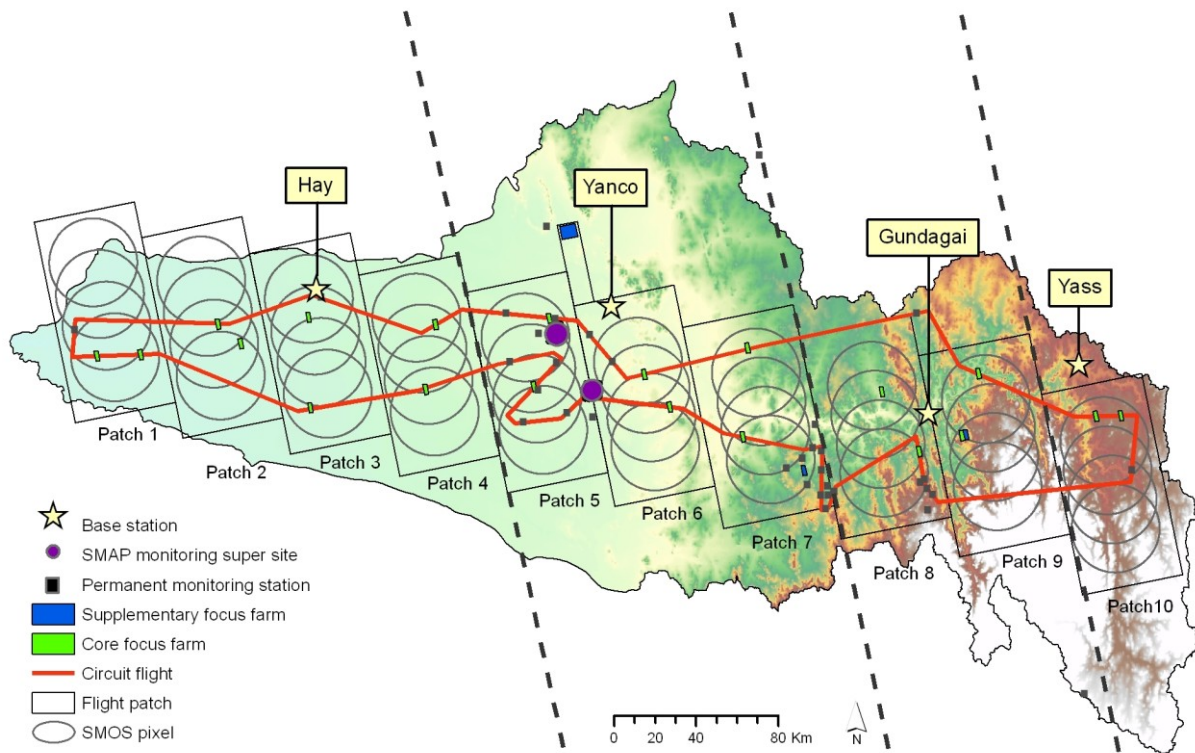


Figure 1-3: AACES overview showing the location of the 10 flight patches (black rectangles) and circuit flight (red) overlaying the SMOS pixels (circles), locations of core (green rectangles) and supplementary (blue rectangles) focus farms, permanent in-situ monitoring locations (black squares) and in-situ monitoring super sites (purple circles), and the operation bases for ground and air crew within the Murrumbidgee catchment. The dashed black lines show the delineation of monitoring areas according to ground crew operations base.

activities described here will be further supplemented with ground sampling by colleagues at CSIRO Land and Water Griffith, and at the Department of Natural Resources, Wagga Wagga.

2 Airborne Observing Systems

Airborne measurements will be made using a small single engine aircraft, including the Polarimetric L-band Multibeam Radiometer (PLMR; <http://www.plmr.unimelb.edu.au>), thermal infrared, and multi-spectral sensing instruments. This infrastructure will allow passive microwave (~1km), land surface skin temperature (~20m and 1km) and vegetation index (~1km) observations to be made across large areas.

The aircraft (Figure 2-1) can carry a typical science payload of up to 250kg (120kg for maximum range) with cruising speed of 150-270km/h and range of 9hrs with reserve (5hrs for maximum payload). The aircraft ceiling is 3000m or up to 6000m with breathing oxygen equipment, under day/night VFR or IFR conditions. The aircraft can easily accommodate two crew; pilot/scientist plus scientist.

Aircraft instruments are typically installed in an underbelly pod or in the wingtips. Aircraft navigation for science is undertaken using a GPS driven 3-axis autopilot together with a cockpit computer display that shows aircraft position relative to planned flight lines using the OziExplorer software. The aircraft also has an OXTS (Oxford Technical Solutions) Inertial plus GPS system (two antennae on the fuselage) for position (georeferencing) and attitude (pitch, roll and heading) interpretation of the data. When combined with measurements from a base station, the RT3003 (Figure 2-2) can give a positional accuracy of 2cm, roll and pitch accuracy of 0.03° and heading accuracy of 0.1°. Without a base station the positional accuracy is degraded to about 1.5m (www.oxts.com).



Figure 2-1: Experimental aircraft showing a wingtip installation in the left inset, and the cockpit with cockpit computer display in the right inset.



Figure 2-2: The RT3003 OXTS Inertial + GPS system. Refer to www.oxts.com for more information.

2.1 Polarimetric L-band Multibeam Radiometer

The PLMR (Figure 2-3) measures both V and H polarisations using a single receiver with polarisation switch at incidence angles $\pm 7^\circ$, $\pm 21.5^\circ$ and $\pm 38.5^\circ$ in either across track (pushbroom) or along track configurations. In the normal pushbroom configuration the 3dB beamwidth is 17° along track and 14° across track resulting in an overall 90° across track field of view. The instrument has a frequency of 1.413GHz and bandwidth of 24MHz, with specified NEDT and accuracy better than 1K for an integration time of 0.5s, and 1K repeatability over 4 hours. It weighs 46kg and has a size of $91.5\text{cm} \times 91.5\text{cm} \times 17.25\text{cm}$.



Figure 2-3: View of PLMR with the cover off.



Figure 2-4: Thermal imager (left) without the 80° FOV lens attached and thermal infrared radiometers (right).

2.2 Thermal Infrared

During flight there will be six thermal infrared radiometers together with a thermal imager (Figure 2-4).

The thermal imager is a FLIR ThermoCam S60 with spectral range 7.5 to 13 μ m, accuracy $\pm 2^{\circ}\text{C}$ or $\pm 2\%$ of reading and thermal sensitivity of 0.08 $^{\circ}\text{C}$. It has an 80° \times 60° FOV lens with 1.3mrad IFOV, resulting in approximately 20m data from a 3000m flying height. The thermal imager looks very similar to a digital video camera, with a weight of 2kg and size of 10cm \times 12cm \times 22cm, without the 80° FOV lens fitted.

The thermal infrared radiometers are the 8.0 to 14.0 μ m Everest Interscience 3800ZL (see www.everestinterscience.com) with 15° FOV and 0-5V output (-40°C to 100°C). The six radiometers are installed at the same incidence angles as PLMR so as to give coincident footprints with the PLMR observations. The nominal relationship between voltage and temperature is given by the manufacturer as $V = 1.42857 + (0.03571428 * T)$.

2.3 Multi-Spectral

The multispectral measurements are made using an array of 15° FOV Skye 4-channel sensors (Figure 2-5), each with 0-5V signal output (<http://www.skyeinstruments.com>). When installed these sensors are configured in a similar way to the Everest thermal infrared radiometers (Figure 2-4), such that the six downward looking sensors have the same incidence angle and footprints as for the six PLMR beams. However, to correct for incident radiation,



Figure 2-5: Multi-spectral sensors; downward looking sensor without the field of view collar attached (left) and upward looking sensor with cosine diffuser fitted (right).

an upward looking sensor with cosine diffuser is also installed. Each sensor weighs approximately 400g and has a size of 8.2cm × 4.4cm without the cosine diffuser or field of view collar attached. Two arrays of 4 channel sensors are installed, with the following (matched) spectral bands:

Sensor VIS/NIR (SKR 1850A)

Channel 1	MODIS Band 1	620 – 670nm
Channel 2	MODIS Band 2	841 – 876nm
Channel 3	MODIS Band 3	459 – 479nm
Channel 4	MODIS Band 4	545 – 565nm

Sensor SWIR (SKR 1870A)

Channel 1	MODIS Band 6	1628 – 1652nm
Channel 2		2026 – 2036nm
Channel 3	MODIS Band 7	2105 – 2155nm
Channel 4		2206 – 2216nm

2.4 Visible

A high resolution digital SLR camera, a digital video camera, and a Pika-II hyperspectral camera are available to the campaign (Figure 2-6).

The digital camera is a Canon EOS-1Ds Mark III that provides 21MegaPixel full frame images. It has a 24mm (23°) to 105mm (84°) variable zoom lens.

The digital video camera is a JVC GZ-HD5 with 1920 × 1080 (2.1 MegaPixel) resolution and 10× optical zoom. Also available is a HD-6600PRO58 wide angle conversion lens to provide full swath coverage of PLMR.

The Pika-II is a compact low-cost hyperspectral imaging spectrometer manufactured by Resonon, Inc (see <http://www.resonon.com>). It acquires data between 400 nm and 900nm at a spectral resolution of 2.1nm. Across track field of view is ~53° using the current Schneider Cinegon 1.8/4.8mm compact lens, with 640 cross-track pixels. It weighs approximately 1kg and has a size of 10cm × 16.5cm × 7cm.

Because of the nil/low light conditions during the campaign flight times, only partial coverage of the study area would be acquired. Consequently it is not planned to collect visible data from these instruments during the campaigns.

2.5 Other

Also available to the campaigns are a RIEGL LMS-Q560 airborne laser scanner that incorporates full waveform digitising of the return laser pulses (see www.riegl.co.at), and an AisaDUAL 400 to 2500nm (Eagle/Hawke) hyperspectral scanner (see www.specim.fi).



Figure 2-6: Canon EOS-1DS Mark 3 (left), video camera (centre) and Pika II (right).

However, because of the particular limitations in terms of maximum sensor flight altitude, sensor field of view, and lighting conditions, it is not practical to use these instruments together with the PLMR in the context of the AACES campaigns. An L-band SAR will also be available to the campaigns by the end of 2009, but due to potential RFI influences and other logistical issues it is not planned to use this instrument in the first AACES campaign, at least.

3 Relevant Satellite Observing Systems

Satellite observing systems of relevance for soil moisture remote sensing are listed below. Two categories are distinguished, according to whether the sensor operates in the microwave or in the optical domain. While passive and active microwave sensors are able to provide direct estimates of near-surface soil moisture, optical data can be used in synergy for direct soil moisture retrieval and/or downscaling.

3.1 Microwave Sensors

3.1.1 Soil Moisture and Ocean Salinity (SMOS)

The SMOS (<http://www.esa.int/esaLP/LPsmos.html>) satellite was launched on 2 November 2009, making it the first satellite to provide continuous multi angular L-band (1.4 GHz) radiometric measurements over the globe. Over continental surfaces, SMOS provides near-surface soil moisture data at ~50km resolution with a repeat cycle of 2-3 days. The payload is a 2D interferometer yielding a range of incidence angles from 0° to 55° at both V and H polarisations, and a 1,000km swath width. Its multi-incidence angle capability is expected to assist in determining ancillary data requirements such as vegetation attenuation. This satellite has a 6:00am/pm equator overpass time (6:00am local solar time at ascending node). Due to the synthetic aperture approach of this satellite, brightness temperature observations will be processed onto a fixed hexagonal grid with an approximately 12km node separation. While the actual footprint size will vary according to position in the swath, incidence angle, etc, it will be approximately 42km diameter on average. The SMOS overpass times for the Murrumbidgee Catchment have been determined from the ESOV software and are provided in Table 3-1. This information is critical for scheduling of coincident aircraft flights and ground sampling.

Table 3-1: SMOS ascending (morning) overpass coverage for the Murrumbidgee Catchment. Dates are in UTC (ie. local dates are +1 day) and calculations are for 17 November 2009 orbital parameters.

Date	Patch									
	1	2	3	4	5	6	7	8	9	10
2010/1/1	•	•	•	•	•	•	•	•	•	•
2010/1/2									•	•
2010/1/3										
2010/1/4	•	•	•	•	•	•	•	•	•	•
2010/1/5										
2010/1/6	•	•	•	•	•	•	•			
2010/1/7						•	•	•	•	•
2010/1/8										
2010/1/9	•	•	•	•	•	•	•	•	•	•
2010/1/10										
2010/1/11	•	•	•	•	•	•				
2010/1/12				•	•	•	•	•	•	•
2010/1/13										
2010/1/14	•	•	•	•	•	•	•	•	•	•
2010/1/15										
2010/1/16	•	•	•							
2010/1/17		•	•	•	•	•	•	•	•	•
2010/1/18										
2010/1/19	•	•	•	•	•	•	•	•	•	•
2010/1/20									•	•
2010/1/21	•									

2010/1/22	•	•	•	•	•	•	•	•	•
2010/1/23									
2010/1/24	•	•	•	•	•	•	•		
2010/1/25						•	•	•	•
2010/1/26									
2010/1/27	•	•	•	•	•	•	•	•	•
2010/1/28									
2010/1/29	•	•	•	•	•				
2010/1/30				•	•	•	•	•	•
2010/1/31									
2010/2/1	•	•	•	•	•	•	•	•	•
2010/2/2									
2010/2/3	•	•	•	•					
2010/2/4		•	•	•	•	•	•	•	•
2010/2/5									
2010/2/6	•	•	•	•	•	•	•	•	•
2010/2/7								•	•
2010/2/8	•								
2010/2/9	•	•	•	•	•	•	•	•	•
2010/2/10									
2010/2/11	•	•	•	•	•	•	•		
2010/2/12						•	•	•	•
2010/2/13									
2010/2/14	•	•	•	•	•	•	•	•	•
2010/2/15									
2010/2/16	•	•	•	•	•				
2010/2/17					•	•	•	•	•
2010/2/18									
2010/2/19	•	•	•	•	•	•	•	•	•
2010/2/20									
2010/2/21	•	•	•	•					
2010/2/22			•	•	•	•	•	•	•
2010/2/23									
2010/2/24	•	•	•	•	•	•	•	•	•
2010/2/25									•
2010/2/26	•								
2010/2/27	•	•	•	•	•	•	•	•	•
2010/2/28									

3.1.2 Aquarius

Aquarius (<http://aquarius.gsfc.nasa.gov>) is also an L-band microwave satellite, but it is designed specifically for measuring the global sea surface salinity. However, it can also be used for soil moisture retrieval, but with a much lower spatial resolution (150km) than SMOS, and with a longer repeat time (8 days). The science instruments will include a set of three L-band radiometers and an L-band scatterometer (to correct for the ocean's surface roughness), meaning that it can also be used to explore active-passive retrieval of soil moisture. This mission is currently scheduled to launch in 2010 with a 3-year lifetime. Consequently, it is likely that the later AACES campaigns can be scheduled to coincide with overpasses by Aquarius, and this synergy between SMOS and Aquarius should be leveraged by AACES if possible.

3.1.3 Soil Moisture Active Passive (SMAP)

SMAP (<http://smap.jpl.nasa.gov>) is NASA's soil moisture mission, and will use a combined radiometer and high-resolution radar to provide a soil moisture product at better than 10km

resolution. Additionally, it will provide information on freeze-thaw state. SMAP will consist of a combined radar and radiometer system operating at 1.26GHz (with VV, HH, and HV polarisations) and 1.41GHz (H, V and U polarisations), respectively. The radar and radiometer of SMAP will share the aperture of a single feed horn and reflector, which will rotate conically about the nadir axis to form a constant incidence angle with the surface of 39.3°. Radar acquisition will be at 1km resolution (and averaged to 3km) with coincident 40km radiometer measurements across a 1,000km wide swath. Due to the peculiarities of radar measurement, no high resolution radar data will be obtained within the 300km band of the swath centred on the nadir track. SMAP is currently scheduled for launch in 2014, and campaigns to develop SMAP retrieval algorithms are the focus of a separate project where coincident airborne active and passive measurements will be made. However, carriage of an L-band radar together with PLMR is under consideration for the later AACES campaigns, and synergies with SMAP campaigns will be leveraged where practical.

3.1.4 Advanced Microwave Scanning Radiometer for EOS (AMSR-E)

The AMSR-E (<http://www.ghcc.msfc.nasa.gov/AMSR/>) sensor is a passive microwave radiometer operating at 6 frequencies ranging from 6.925 to 89.0GHz. Both horizontally and vertically polarized radiation are measured at each frequency with an incidence angle of 55°. The ground spatial resolution at nadir is 75km × 45km for the 6.925GHz channel (C-band). The AMSR-E is one of six sensors onboard Aqua, which was launched in 2002. It has a 1:30am/pm equator crossing orbit with 1-2 day repeat coverage. Several surface soil moisture products are available globally. AMSR-E brightness temperature data can be downloaded free of charge from the NSIDC web site (<http://nsidc.org/data/amsre/order.html>) or other Distributed Active Archive Center's (DAAC's). While the current AMSR sensor continues to outlive its expected lifetime, a follow-on mission is planned by JAXA for the near future. AMSR-E coverage for the Murrumbidgee Catchment during the first AACES campaign is summarised in Table 3-2.

Table 3-2: AMSR-E overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch										
			1	2	3	4	5	6	7	8	9	10	
2010/1/1	3:58:32	234	●	●	●	●	●	●	●	●	●	●	●
2010/1/1	15:01:10	210		○	○	●	●	●	●	●	●	●	●
2010/1/2	4:41:59	189	●	●	●	●	●	●	●	○			
2010/1/2	15:43:48	224	●	●	●	●	●	●	●	●	●	●	●
2010/1/3	3:46:26	208			○	●	●	●	●	●	●	●	●
2010/1/3	14:49:28	153								○	○	●	●
2010/1/4	4:29:26	226	●	●	●	●	●	●	●	●	●	●	●
2010/1/4	15:31:29	230	●	●	●	●	●	●	●	●	●	●	●
2010/1/5	3:34:42	141									○	●	●
2010/1/6	4:16:53	246	●	●	●	●	●	●	●	●	●	●	●
2010/1/6	15:19:11	231	●	●	●	●	●	●	●	●	●	●	●
2010/1/7	16:02:38	149	●	●	○	○							
2010/1/8	4:04:29	242	●	●	●	●	●	●	●	●	●	●	●
2010/1/8	15:06:59	224	●	●	●	●	●	●	●	●	●	●	●
2010/1/9	4:48:13	152	●	●	●	○							
2010/1/9	15:49:53	210	●	●	●	●	●	●	●	●	○	○	
2010/1/10	3:52:16	224	●	●	●	●	●	●	●	●	●	●	●
2010/1/10	14:55:04	189				○	○	●	●	●	●	●	●
2010/1/11	4:35:31	211	●	●	●	●	●	●	●	●	●	○	○
2010/1/11	15:37:27	229	●	●	●	●	●	●	●	●	●	●	●

2010/1/12	3:40:19	183						○	●	●	●	●	●
2010/1/12	14:43:42	95										○	○
2010/1/13	4:22:59	238	●	●	●	●	●	●	●	●	●	●	●
2010/1/13	15:25:10	230	●	●	●	●	●	●	●	●	●	●	●
2010/1/14	3:29:10	36											○
2010/1/14	16:09:11	70	○										
2010/1/15	4:10:29	247	●	●	●	●	●	●	●	●	●	●	●
2010/1/15	15:12:53	230	●	●	●	●	●	●	●	●	●	●	●
2010/1/16	4:54:42	80	○										
2010/1/16	15:56:01	187	●	●	●	●	●	○					
2010/1/17	3:58:10	235	●	●	●	●	●	●	●	●	●	●	●
2010/1/17	15:00:48	211		○	○	●	●	●	●	●	●	●	●
2010/1/18	4:41:39	187	●	●	●	●	●	●	○				
2010/1/18	15:43:27	224	●	●	●	●	●	●	●	●	●	●	●
2010/1/19	3:46:04	209		○	●	●	●	●	●	●	●	●	●
2010/1/19	14:49:05	155							○	○	●	●	
2010/1/20	4:29:04	227	●	●	●	●	●	●	●	●	●	●	●
2010/1/20	15:31:08	229	●	●	●	●	●	●	●	●	●	●	●
2010/1/21	3:34:20	143									○	●	●
2010/1/22	4:16:32	246	●	●	●	●	●	●	●	●	●	●	●
2010/1/22	15:18:49	231	●	●	●	●	●	●	●	●	●	●	●
2010/1/23	16:02:17	148	●	●	○	○							
2010/1/24	4:04:07	243	●	●	●	●	●	●	●	●	●	●	●
2010/1/24	15:06:37	225	●	●	●	●	●	●	●	●	●	●	●
2010/1/25	4:47:52	151	●	●	●	○							
2010/1/25	15:49:31	210	●	●	●	●	●	●	●	○	○		
2010/1/26	3:51:55	224	●	●	●	●	●	●	●	●	●	●	●
2010/1/26	14:54:42	189				○	○	●	●	●	●	●	●
2010/1/27	4:35:10	210	●	●	●	●	●	●	●	●	●	○	
2010/1/27	15:37:05	230	●	●	●	●	●	●	●	●	●	●	●
2010/1/28	3:39:57	185					○	●	●	●	●	●	●
2010/1/28	14:43:19	98										○	○
2010/1/29	4:22:38	237	●	●	●	●	●	●	●	●	●	●	●
2010/1/29	15:24:48	230	●	●	●	●	●	●	●	●	●	●	●
2010/1/30	3:28:45	48											○
2010/1/30	16:08:52	65	○										
2010/1/31	4:10:07	248	●	●	●	●	●	●	●	●	●	●	●
2010/1/31	15:12:31	230	●	●	●	●	●	●	●	●	●	●	●
2010/2/1	4:54:23	75	○										
2010/2/1	15:55:39	187	●	●	●	●	●	○					
2010/2/2	3:57:49	235	●	●	●	●	●	●	●	●	●	●	●
2010/2/2	15:00:26	212		○	●	●	●	●	●	●	●	●	●
2010/2/3	4:41:18	187	●	●	●	●	●	●	○				
2010/2/3	15:43:05	224	●	●	●	●	●	●	●	●	●	●	●
2010/2/4	3:45:43	209		○	●	●	●	●	●	●	●	●	●
2010/2/4	14:48:43	156							○	●	●	●	
2010/2/5	4:28:43	226	●	●	●	●	●	●	●	●	●	●	●
2010/2/5	15:30:46	230	●	●	●	●	●	●	●	●	●	●	●
2010/2/6	3:33:57	146								○	●	●	
2010/2/7	4:16:11	245	●	●	●	●	●	●	●	●	●	●	●
2010/2/7	15:18:28	231	●	●	●	●	●	●	●	●	●	●	●
2010/2/8	16:01:56	146	●	●	○	○							
2010/2/9	4:03:46	243	●	●	●	●	●	●	●	●	●	●	●
2010/2/9	15:06:16	224	●	●	●	●	●	●	●	●	●	●	●
2010/2/10	4:47:32	149	●	●	●	○							
2010/2/10	15:49:10	209	●	●	●	●	●	●	●	○	○		
2010/2/11	3:51:33	225	●	●	●	●	●	●	●	●	●	●	●
2010/2/11	14:54:19	191				○	○	●	●	●	●	●	●

2010/2/12	4:34:49	210	●	●	●	●	●	●	●	●	○	
2010/2/12	15:36:44	229	●	●	●	●	●	●	●	●	●	●
2010/2/13	3:39:35	186					○	●	●	●	●	●
2010/2/13	14:42:56	100									○	○
2010/2/14	4:22:17	237	●	●	●	●	●	●	●	●	●	●
2010/2/14	15:24:26	230	●	●	●	●	●	●	●	●	●	●
2010/2/15	3:28:20	56										○
2010/2/15	16:08:32	61	○									
2010/2/16	4:09:46	248	●	●	●	●	●	●	●	●	●	●
2010/2/16	15:12:09	230	●	●	●	●	●	●	●	●	●	●
2010/2/17	4:54:04	70	○									
2010/2/17	15:55:18	185	●	●	●	●	○					
2010/2/18	3:57:28	234	●	●	●	●	●	●	●	●	●	●
2010/2/18	15:00:04	212		○	●	●	●	●	●	●	●	●
2010/2/19	4:40:57	186	●	●	●	●	●	○				
2010/2/19	15:42:44	223	●	●	●	●	●	●	●	●	●	●
2010/2/20	3:45:21	210		○	●	●	●	●	●	●	●	●
2010/2/20	14:48:20	158						○	●	●	●	●
2010/2/21	4:28:22	226	●	●	●	●	●	●	●	●	●	●
2010/2/21	15:30:24	230	●	●	●	●	●	●	●	●	●	●
2010/2/22	3:33:35	147								○	●	●
2010/2/23	4:15:50	245	●	●	●	●	●	●	●	●	●	●
2010/2/23	15:18:06	231	●	●	●	●	●	●	●	●	●	●
2010/2/24	16:01:35	144	●	●	○	○						
2010/2/25	4:03:25	243	●	●	●	●	●	●	●	●	●	●
2010/2/25	15:05:54	225	●	●	●	●	●	●	●	●	●	●
2010/2/26	4:47:11	147	●	●	●	○						
2010/2/26	15:48:48	209	●	●	●	●	●	●	○	○		
2010/2/27	3:51:11	226	●	●	●	●	●	●	●	●	●	●
2010/2/27	14:53:57	192				○	○	●	●	●	●	●
2010/2/28	4:34:28	209	●	●	●	●	●	●	●	●	○	
2010/2/28	15:36:22	229	●	●	●	●	●	●	●	●	●	●

3.1.5 WindSat

WindSat (<http://www.nrl.navy.mil/WindSat/>) is a multi-frequency polarimetric microwave radiometer with similar frequencies to the AMSR-E sensor, with the addition of full polarisation for 10.7, 18.7 and 37.0GHz channels and the lack of an 89.0GHz channel. Developed by the Naval Research Laboratory, it is one of the two primary instruments on the Coriolis satellite launched on 6 January 2003. WindSat is continuing to outlive its three year design life, with data free of charge to scientists from <http://www.cpi.com/twiki/bin/view/WindSat/WebHome>. WindSat coverage for the Murrumbidgee Catchment during the first AACES campaign is summarised in Table 3-3.

Table 3-3: WindSat overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch										
			1	2	3	4	5	6	7	8	9	10	
2010/1/1	8:53:14	154	●	●	●	●	●	○	○				
2010/1/1	20:13:37	100	●	○									
2010/1/2	8:35:14	186	●	●	●	●	●	●	●	●	●	●	●
2010/1/2	19:55:29	170	●	●	●	●	●	●	●	●	○	○	
2010/1/3	8:17:28	173		○	●	●	●	●	●	●	●	●	●
2010/1/3	19:37:49	172	●	●	●	●	●	●	●	●	●	●	●

2010/1/4	8:00:32	88										○	●
2010/1/4	19:20:23	153						○	○	●	●	●	●
2010/1/6	9:06:20	47	○										
2010/1/7	8:47:50	169	●	●	●	●	●	●	●	●	●	○	
2010/1/7	20:08:03	137	●	●	●	○	○						
2010/1/8	8:29:50	188	●	●	●	●	●	●	●	●	●	●	●
2010/1/8	19:50:10	171	●	●	●	●	●	●	●	●	●	●	●
2010/1/9	8:12:16	162				○	●	●	●	●	●	●	●
2010/1/9	19:32:31	171	●	●	●	●	●	●	●	●	●	●	●
2010/1/10	19:15:19	131								○	○	●	●
2010/1/12	9:00:35	116	●	●	○								
2010/1/13	8:42:28	178	●	●	●	●	●	●	●	●	●	●	●
2010/1/13	20:02:37	157	●	●	●	●	●	○	○				
2010/1/14	8:24:31	184	●	●	●	●	●	●	●	●	●	●	●
2010/1/14	19:44:53	171	●	●	●	●	●	●	●	●	●	●	●
2010/1/15	8:07:09	144							○	●	●	●	●
2010/1/15	19:27:16	169		○	●	●	●	●	●	●	●	●	●
2010/1/16	19:10:27	90										○	●
2010/1/18	8:55:07	145	●	●	●	●	○	○					
2010/1/18	20:15:35	71	○	○									
2010/1/19	8:37:06	184	●	●	●	●	●	●	●	●	●	●	●
2010/1/19	19:57:15	168	●	●	●	●	●	●	●	○	○		
2010/1/20	8:19:17	176	○	●	●	●	●	●	●	●	●	●	●
2010/1/20	19:39:35	172	●	●	●	●	●	●	●	●	●	●	●
2010/1/21	8:02:10	112										○	●
2010/1/21	19:22:05	160				○	○	●	●	●	●	●	●
2010/1/24	8:49:45	162	●	●	●	●	●	●	●	○			
2010/1/24	20:09:56	124	●	●	○	○							
2010/1/25	8:31:44	188	●	●	●	●	●	●	●	●	●	●	●
2010/1/25	19:51:58	172	●	●	●	●	●	●	●	●	●	●	○
2010/1/26	8:14:05	168			○	●	●	●	●	●	●	●	●
2010/1/26	19:34:19	172	●	●	●	●	●	●	●	●	●	●	●
2010/1/27	19:17:01	142							○	○	●	●	●
2010/1/29	9:02:37	95	●	○									
2010/1/30	8:44:24	174	●	●	●	●	●	●	●	●	●	●	○
2010/1/30	20:04:30	150	●	●	●	●	○	○					
2010/1/31	8:26:26	186	●	●	●	●	●	●	●	●	●	●	●
2010/1/31	19:46:43	172	●	●	●	●	●	●	●	●	●	●	●
2010/2/1	8:08:58	153						○	●	●	●	●	●
2010/2/1	19:29:05	172	○	○	●	●	●	●	●	●	●	●	●
2010/2/2	19:12:05	112										○	○
2010/2/4	8:57:06	135	●	●	●	○	○						
2010/2/4	20:17:53	17	○										
2010/2/5	8:39:04	182	●	●	●	●	●	●	●	●	●	●	●
2010/2/5	19:59:09	165	●	●	●	●	●	●	○	○			
2010/2/6	8:21:12	179	●	●	●	●	●	●	●	●	●	●	●
2010/2/6	19:41:29	172	●	●	●	●	●	●	●	●	●	●	●
2010/2/7	8:03:57	129								○	●	●	●
2010/2/7	19:23:55	166			○	○	●	●	●	●	●	●	●
2010/2/8	19:07:24	55											○
2010/2/10	8:51:44	156	●	●	●	●	●	●	○				
2010/2/10	20:11:59	106	●	○	○								
2010/2/11	8:33:44	187	●	●	●	●	●	●	●	●	●	●	●
2010/2/11	19:53:53	171	●	●	●	●	●	●	●	●	●	○	○
2010/2/12	8:16:00	173		○	●	●	●	●	●	●	●	●	●
2010/2/12	19:36:14	173	●	●	●	●	●	●	●	●	●	●	●
2010/2/13	7:59:08	81											○
2010/2/13	19:18:51	152						○	○	●	●	●	●

2010/2/15	9:04:50	59	○									
2010/2/16	8:46:25	169	●	●	●	●	●	●	●	●	○	
2010/2/16	20:06:31	140	●	●	●	○	○					
2010/2/17	8:28:25	188	●	●	●	●	●	●	●	●	●	●
2010/2/17	19:48:40	172	●	●	●	●	●	●	●	●	●	●
2010/2/18	8:10:53	161				○	●	●	●	●	●	●
2010/2/18	19:31:02	172	○	●	●	●	●	●	●	●	●	●
2010/2/19	19:13:53	129							○	○	●	●
2010/2/21	8:59:12	119	●	●	○							
2010/2/22	8:41:06	179	●	●	●	●	●	●	●	●	●	●
2010/2/22	20:01:11	159	●	●	●	●	●	○	○			
2010/2/23	8:23:11	182	●	●	●	●	●	●	●	●	●	●
2010/2/23	19:43:29	172	●	●	●	●	●	●	●	●	●	●
2010/2/24	8:05:50	142						○	●	●	●	●
2010/2/24	19:25:53	170		○	○	●	●	●	●	●	●	●
2010/2/25	19:09:08	86									○	○
2010/2/27	8:53:48	147	●	●	●	●	●	○				
2010/2/27	20:14:12	77	○	○								
2010/2/28	8:35:48	184	●	●	●	●	●	●	●	●	●	●
2010/2/28	19:55:56	169	●	●	●	●	●	●	●	○	○	

3.1.6 Advanced SCATterometer (ASCAT)

The ASCAT (<http://www.esa.int/esaME/ascat.html>), operating at C-band, provides continuity to the ERS-1 and ERS-2 scatterometers. The ASCAT is onboard the Metop satellite, which was launched into a sun synchronous orbit on 19 October 2006 and has been operational since May 2007. ASCAT operates at a frequency of 5.255GHz in vertical polarization. Its use of six antennas allows the simultaneous coverage of two swaths on either side of the satellite ground track, allowing for much greater coverage than its predecessors. It takes about 2 days to map the entire globe. A 50km resolution soil moisture product is now operational from ASCAT, available from EUMETSAT. ASCAT coverage for the Murrumbidgee Catchment is summarised in Table 3-4.

Table 3-4: ASCAT overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch									
			1	2	3	4	5	6	7	8	9	10
2010/1/2	12:19:28	100	●	●	●	●	●	○				
2010/1/2	23:38:06	78	●	○	○							
2010/1/3	11:58:21	105				○	●	●	●	●	●	●
2010/1/3	23:17:14	99	○	●	●	●	●	●	●	●	●	●
2010/1/4	22:56:52	66									○	○
2010/1/7	12:16:05	105	●	●	●	●	●	●	○			
2010/1/7	23:34:43	90	●	●	●	○						
2010/1/8	11:55:03	102						○	●	●	●	●
2010/1/8	23:13:55	100		○	○	●	●	●	●	●	●	●
2010/1/9	22:53:55	30										○
2010/1/12	12:12:43	109	●	●	●	●	●	●	●	●	○	
2010/1/12	23:31:22	98	●	●	●	●	○					
2010/1/13	11:51:48	96							○	●	●	●
2010/1/13	23:10:37	100			○	○	●	●	●	●	●	●
2010/1/16	12:30:46	37	○									
2010/1/17	12:09:23	108	●	●	●	●	●	●	●	●	●	○
2010/1/17	23:28:05	99	●	●	●	●	●	○	○			
2010/1/18	11:48:37	84								○	●	●

2010/1/18	23:07:21	100					○	●	●	●	●	●
2010/1/21	12:27:14	74	●	○								
2010/1/22	12:06:04	107	●	●	●	●	●	●	●	●	●	●
2010/1/22	23:24:49	99	●	●	●	●	●	○	○			
2010/1/23	11:45:32	63										○
2010/1/23	23:04:07	98						○	●	●	●	●
2010/1/26	12:23:53	88	●	●	●	○						
2010/1/26	23:42:48	21	○									
2010/1/27	12:02:43	109		○	●	●	●	●	●	●	●	●
2010/1/27	23:21:34	100	●	●	●	●	●	●	●	○		
2010/1/28	23:00:56	91							○	○	●	●
2010/1/31	12:20:34	97	●	●	●	●	○					
2010/1/31	23:39:15	66	○	○								
2010/2/1	11:59:26	108			○	●	●	●	●	●	●	●
2010/2/1	23:18:19	100	●	●	●	●	●	●	●	●	●	○
2010/2/2	22:57:50	78								○	○	●
2010/2/5	12:17:16	103	●	●	●	●	●	○	○			
2010/2/5	23:35:55	84	●	●	○							
2010/2/6	11:56:13	104					○	●	●	●	●	●
2010/2/6	23:15:05	100	○	○	●	●	●	●	●	●	●	●
2010/2/7	22:54:53	54									○	○
2010/2/10	12:13:59	107	●	●	●	●	●	●	○			
2010/2/10	23:32:38	94	●	●	●	○	○					
2010/2/11	11:53:01	100						○	●	●	●	●
2010/2/11	23:11:52	100		○	○	●	●	●	●	●	●	●
2010/2/15	12:10:43	109	●	●	●	●	●	●	●	●	○	
2010/2/15	23:29:23	99	●	●	●	●	○	○				
2010/2/16	11:49:52	92							○	●	●	●
2010/2/16	23:08:39	100				○	●	●	●	●	●	●
2010/2/19	12:28:44	55	○									
2010/2/20	12:07:29	108	●	●	●	●	●	●	●	●	●	○
2010/2/20	23:26:12	99	●	●	●	●	●	○				
2010/2/21	11:46:48	78									○	●
2010/2/21	23:05:30	99					○	○	●	●	●	●
2010/2/24	12:25:23	79	●	●	○							
2010/2/25	12:04:14	108	○	●	●	●	●	●	●	●	●	●
2010/2/25	23:23:01	100	●	●	●	●	●	●	○			
2010/2/26	11:43:51	52										○
2010/2/26	23:02:21	97						○	○	●	●	●

3.1.7 Phased Array type L-band Synthetic Aperture Radar (PALSAR)

The PALSAR (<http://www.eorc.jaxa.jp/ALOS/about/palsar.htm>) is an active microwave sensor aboard the Advance Land Observing Satellite (ALOS, www.nasda.go.jp/projects/sat/alos/index_e.html). The sensor operates at L-band with HH and VV polarisation (HV and VH polarisations are optional). The sensor is beam steerable in elevation and the ScanSAR mode, which allows obtaining a wider swath than conventional SARs. ALOS was launched in 2004 into a sun-synchronous orbit at the altitude of 700km, providing a spatial resolution of 20m for the fine resolution mode (swath width of 70km) and 100m for the ScanSAR mode (swath width of 360km). The repeat cycle is 46 days and the local time at descending node is about 10:30am. PALSAR coverage for the Murrumbidgee Catchment is summarised in Table 3-5 and Table 3-6 for 20m and 100m resolution products respectively.

Table 3-5: PALSAR overpass coverage for the Murrumbidgee Catchment; 20m resolution product. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch											
			1	2	3	4	5	6	7	8	9	10		
2010/1/3	0:30:39	25	○	○	○									
2010/1/4	13:12:32	28			○	○								
2010/1/5	0:13:35	25									○	○		
2010/1/6	12:55:12	25											○	
2010/1/9	13:18:55	24	○											
2010/1/10	0:19:50	26						○	○	○				
2010/1/11	13:01:31	27								○	●	○		
2010/1/15	0:26:05	24			○	○								
2010/1/16	13:07:52	27						○	○					
2010/1/17	0:09:01	25										○	○	
2010/1/20	0:32:17	26	○	○										
2010/1/21	13:14:13	28		○	○									
2010/1/22	0:15:13	26								○	○	○		
2010/1/23	12:56:49	29										○	○	
2010/1/27	0:21:27	25				○	○	○						
2010/1/28	13:03:09	27								○	○			
2010/2/1	0:27:39	25		○	○	○								
2010/2/2	13:09:28	28				○	○							
2010/2/3	0:10:35	23										○	○	
2010/2/6	0:33:53	13	○											
2010/2/7	13:15:49	27	○	○										
2010/2/8	0:16:45	27						○	○	○				
2010/2/9	12:58:23	29								○	●	○		
2010/2/13	0:22:58	24				○	○							
2010/2/14	13:04:41	28						○	○					
2010/2/15	0:06:06	9											○	
2010/2/18	0:29:07	27	○	○	○									
2010/2/19	13:11:00	28			○	○								
2010/2/20	0:12:01	27									○	○	○	
2010/2/21	12:53:39	24											○	
2010/2/24	13:17:18	25	○											
2010/2/25	0:18:13	25						○	○	○				
2010/2/26	12:59:52	28									○	○		

Table 3-6: PALSAR overpass coverage for the Murrumbidgee Catchment; 100m resolution product. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch											
			1	2	3	4	5	6	7	8	9	10		
2010/1/1	12:48:49	43												○
2010/1/3	0:30:17	69	●	●	●	●	○							
2010/1/4	13:12:09	75	●	●	●	●	●	●	○					
2010/1/5	0:13:13	69					○	○	●	●	●	●		
2010/1/6	12:54:51	70								○	●	●	●	
2010/1/8	0:36:36	59	●	○	○									
2010/1/9	13:18:31	70	●	●	●	○								
2010/1/10	0:19:28	69		○	○	●	●	●	●	●	●	○		
2010/1/11	13:01:07	75						○	●	●	●	●	●	
2010/1/12	0:02:40	47										○	○	
2010/1/14	13:24:57	44	○											
2010/1/15	0:25:43	68	●	●	●	●	●	●	○					
2010/1/16	13:07:28	76		○	●	●	●	●	●	●	●	○		

2010/1/17	0:08:39	69							○	●	●	●
2010/1/18	12:50:21	57									○	●
2010/1/20	0:31:56	69	●	●	●	○						
2010/1/21	13:13:50	74	●	●	●	●	●	○				
2010/1/22	0:14:51	69				○	○	●	●	●	●	●
2010/1/23	12:56:28	73						○	●	●	●	●
2010/1/25	0:38:16	49	○	○								
2010/1/26	13:20:11	65	●	●	○							
2010/1/27	0:21:05	69		○	●	●	●	●	●	○	○	
2010/1/28	13:02:46	74				○	●	●	●	●	●	●
2010/1/29	0:04:07	59									○	●
2010/2/1	0:27:17	69	●	●	●	●	●	○				
2010/2/2	13:09:06	74	○	●	●	●	●	●	●	○		
2010/2/3	0:10:12	69						○	○	●	●	●
2010/2/4	12:51:51	65								○	●	●
2010/2/6	0:33:30	66	●	●	○	○						
2010/2/7	13:15:25	72	●	●	●	●	○					
2010/2/8	0:16:24	70			○	○	●	●	●	●	●	○
2010/2/9	12:58:00	75						○	●	●	●	●
2010/2/9	23:59:50	22										○
2010/2/11	0:39:55	26	○									
2010/2/12	13:21:44	59	●	○								
2010/2/13	0:22:36	69	○	●	●	●	●	●	○	○		
2010/2/14	13:04:19	74			○	●	●	●	●	●	●	○
2010/2/15	0:05:33	65								○	●	●
2010/2/16	12:47:22	39										○
2010/2/18	0:28:46	69	●	●	●	●	○					
2010/2/19	13:10:36	75	●	●	●	●	●	●	○			
2010/2/20	0:11:40	69					○	○	●	●	●	●
2010/2/21	12:53:17	70							○	●	●	●
2010/2/23	0:34:59	62	●	○	○							
2010/2/24	13:16:54	70	●	●	●	○						
2010/2/25	0:17:51	69			○	●	●	●	●	●	○	○
2010/2/26	12:59:28	75					○	●	●	●	●	●
2010/2/27	0:01:03	43									○	○

3.1.8 Advanced Synthetic Aperture Radar (ASAR)

The ASAR (<http://envisat.esa.int/instruments/asar/>) instrument is operating at C-band and provides both continuity to the ERS-1 and ERS-2 mission SARs and next generation capabilities in terms of coverage, range of incidence angles, polarisation, and modes of operation. The resulting improvements in image and wave mode beam elevation steering allow the selection of different swaths, providing swath coverage more than 400km wide using ScanSAR techniques. ScanSAR is a Synthetic Aperture Radar (SAR) technique that combines large-area coverage and short revisit periods with a degraded spatial resolution compared to conventional SAR imaging modes. ASAR can provide a range of incidence angles ranging from 15° to 45° and can operate in alternating polarisation mode, providing two polarisation combinations (VV and HH, HH and HV, or VV and VH). The ASAR is onboard the EnviSat satellite, which was launched into a sun synchronous orbit in March 2002. The exact repeat cycle for a specific scene and sensor configuration is 35 days. ASAR coverage for the Murrumbidgee Catchment is summarised in Table 3-7.

Table 3-7: ASAR overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch										
			1	2	3	4	5	6	7	8	9	10	
2010/1/3	12:36:33	83	○	●	●	●	●	●	●	●	●	○	
2010/1/3	23:50:13	76	○	●	●	●	●	●	●	●	○	○	
2010/1/6	12:42:19	84	●	●	●	●	●	●	○				
2010/1/6	23:55:53	76	●	●	●	●	●	○					
2010/1/9	12:48:07	77	●	●	●	○							
2010/1/10	0:01:34	73	●	●	○	○							
2010/1/10	12:16:43	41											○
2010/1/10	23:30:24	61										○	●
2010/1/12	12:53:56	57	●	○									
2010/1/13	0:07:24	45	○										
2010/1/13	12:22:06	74								○	●	●	
2010/1/13	23:35:54	76							○	●	●	●	
2010/1/16	12:27:44	83					○	●	●	●	●	●	
2010/1/16	23:41:33	76				○	○	●	●	●	●	●	
2010/1/19	12:33:31	82			○	●	●	●	●	●	●	○	
2010/1/19	23:47:13	77		○	●	●	●	●	●	●	○	○	
2010/1/22	12:39:17	84	●	●	●	●	●	●	●	○			
2010/1/22	23:52:53	77	●	●	●	●	●	●	○				
2010/1/25	12:45:04	80	●	●	●	●	○	○					
2010/1/25	23:58:33	76	●	●	●	○	○						
2010/1/26	23:27:39	40											○
2010/1/28	12:50:51	69	●	●	○								
2010/1/29	0:04:18	63	●	○	○								
2010/1/29	12:19:11	65										○	●
2010/1/29	23:32:57	72							○	○	●	●	
2010/2/1	12:24:45	80						○	●	●	●	●	
2010/2/1	23:38:33	76					○	○	●	●	●	●	
2010/2/4	12:30:27	84				○	●	●	●	●	●	●	
2010/2/4	23:44:13	77			○	●	●	●	●	●	●	○	
2010/2/7	12:36:14	84	○	●	●	●	●	●	●	●	○		
2010/2/7	23:49:54	76	○	●	●	●	●	●	●	○			
2010/2/10	12:42:01	83	●	●	●	●	●	●	○				
2010/2/10	23:55:33	76	●	●	●	●	○	○					
2010/2/13	12:47:48	76	●	●	●	○							
2010/2/14	0:01:14	73	●	●	○	○							
2010/2/14	12:16:20	48											○
2010/2/14	23:30:02	64								○	○	●	
2010/2/16	12:53:38	53	○	○									
2010/2/17	0:07:06	37	○										
2010/2/17	12:21:46	76							○	●	●	●	
2010/2/17	23:35:34	76						○	○	●	●	●	
2010/2/20	12:27:25	83					○	●	●	●	●	●	
2010/2/20	23:41:12	77				○	●	●	●	●	●	●	
2010/2/23	12:33:12	82		○	●	●	●	●	●	●	●	○	
2010/2/23	23:46:53	76	○	○	●	●	●	●	●	●	○		
2010/2/26	12:38:58	83	●	●	●	●	●	●	●	○			
2010/2/26	23:52:33	76	●	●	●	●	●	●	○				

3.2 Optical Sensors

3.2.1 MODerate resolution Imaging Spectroradiometer (MODIS)

The MODIS (<http://modis.gsfc.nasa.gov>) instrument is a highly sensitive radiometer operating in 36 spectral bands ranging from 0.4 μ m to 14.4 μ m. Two bands are imaged at a nominal resolution of 250m at nadir, five bands at 500m, and the remaining 29 bands at 1km. MODIS is operating onboard Terra and Aqua. Terra was launched in December 1999 and Aqua in May 2002. A $\pm 55^\circ$ scanning pattern at 705km altitude achieves a 2,330km swath that provides global coverage every one to two days. Aqua has a 1:30am/pm equator crossing time while Terra has a 10:30am/pm equator crossing time, meaning that MODIS data is typically available on a daily basis. MODIS data are free of charge and can be accessed online at <http://lpdaac.usgs.gov/main.asp>.

In general, the range of surface temperature values is dependent on the time of acquisition, and is greater for Aqua. The downscaling approaches based on optical data requires a strong coupling between surface temperature and surface soil moisture, which commonly occurs in areas where surface evaporation is not energy limited and when solar radiation is relatively high (usually between 11am and 3pm). Therefore MODIS on Aqua (1:30pm) is more relevant than MODIS on Terra for downscaling purposes. MODIS coverage for the Murrumbidgee Catchment is summarised in Table 3-8 for Aqua and Table 3-9 for Terra.

Table 3-8: MODIS Aqua overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered \circ or fully covered \bullet .

Date	Start Time	Duration(s)	Patch										
			1	2	3	4	5	6	7	8	9	10	
2010/1/1	3:57:27	368	●	●	●	●	●	●	●	●	●	●	●
2010/1/1	15:00:01	348	●	●	●	●	●	●	●	●	●	●	●
2010/1/2	4:40:46	335	●	●	●	●	●	●	●	●	●	●	●
2010/1/2	15:42:43	355	●	●	●	●	●	●	●	●	●	●	●
2010/1/3	3:45:17	347	●	●	●	●	●	●	●	●	●	●	●
2010/1/3	14:48:05	315	●	●	●	●	●	●	●	●	●	●	●
2010/1/3	16:27:29	111	○	○									
2010/1/4	4:28:14	363	●	●	●	●	●	●	●	●	●	●	●
2010/1/4	15:30:25	359	●	●	●	●	●	●	●	●	●	●	●
2010/1/5	3:33:16	313	●	●	●	●	●	●	●	●	●	●	●
2010/1/5	5:12:40	137	●	○									
2010/1/5	14:36:23	258				○	●	●	●	●	●	●	●
2010/1/5	16:14:04	254	●	●	●	●	●	○	○				
2010/1/6	4:15:45	378	●	●	●	●	●	●	●	●	●	●	●
2010/1/6	15:18:06	361	●	●	●	●	●	●	●	●	●	●	●
2010/1/7	3:21:30	248					○	●	●	●	●	●	●
2010/1/7	4:59:32	257	●	●	●	●	●	●	●	○			
2010/1/7	14:25:09	151								○	○	●	
2010/1/7	16:01:17	315	●	●	●	●	●	●	●	●	●	●	●
2010/1/8	4:03:24	376	●	●	●	●	●	●	●	●	●	●	●
2010/1/8	15:05:54	355	●	●	●	●	●	●	●	●	●	●	●
2010/1/9	3:10:28	87											○
2010/1/9	4:46:52	315	●	●	●	●	●	●	●	●	●	●	●
2010/1/9	15:48:44	348	●	●	●	●	●	●	●	●	●	●	●
2010/1/10	3:51:10	359	●	●	●	●	●	●	●	●	●	●	●
2010/1/10	14:53:50	335	●	●	●	●	●	●	●	●	●	●	●
2010/1/11	4:34:19	351	●	●	●	●	●	●	●	●	●	●	●
2010/1/11	15:36:22	359	●	●	●	●	●	●	●	●	●	●	●
2010/1/12	3:39:05	333	●	●	●	●	●	●	●	●	●	●	●
2010/1/12	14:42:00	291	○	○	●	●	●	●	●	●	●	●	●

2010/1/12	16:20:28	201	●	●	●	○						
2010/1/13	4:21:48	373	●	●	●	●	●	●	●	●	●	●
2010/1/13	15:24:05	360	●	●	●	●	●	●	●	●	●	●
2010/1/14	3:27:10	286		○	●	●	●	●	●	●	●	●
2010/1/14	5:05:50	209	●	●	●	●	○					
2010/1/14	14:30:31	213						○	○	●	●	●
2010/1/14	16:07:27	290	●	●	●	●	●	●	●	●	○	
2010/1/15	4:09:23	380	●	●	●	●	●	●	●	●	●	●
2010/1/15	15:11:48	359	●	●	●	●	●	●	●	●	●	●
2010/1/16	3:15:36	195							○	○	●	●
2010/1/16	4:53:00	290	●	●	●	●	●	●	●	●	●	○
2010/1/16	15:54:48	334	●	●	●	●	●	●	●	●	●	●
2010/1/17	3:57:06	368	●	●	●	●	●	●	●	●	●	●
2010/1/17	14:59:40	347	●	●	●	●	●	●	●	●	●	●
2010/1/18	4:40:25	334	●	●	●	●	●	●	●	●	●	●
2010/1/18	15:42:21	356	●	●	●	●	●	●	●	●	●	●
2010/1/19	3:44:56	347	●	●	●	●	●	●	●	●	●	●
2010/1/19	14:47:42	317	●	●	●	●	●	●	●	●	●	●
2010/1/19	16:27:10	106	○	○								
2010/1/20	4:27:53	363	●	●	●	●	●	●	●	●	●	●
2010/1/20	15:30:03	359	●	●	●	●	●	●	●	●	●	●
2010/1/21	3:32:55	313	●	●	●	●	●	●	●	●	●	●
2010/1/21	5:12:20	134	●	○								
2010/1/21	14:36:01	259			○	○	●	●	●	●	●	●
2010/1/21	16:13:43	253	●	●	●	●	●	○	○			
2010/1/22	4:15:23	379	●	●	●	●	●	●	●	●	●	●
2010/1/22	15:17:44	361	●	●	●	●	●	●	●	●	●	●
2010/1/23	3:21:08	250					○	●	●	●	●	●
2010/1/23	4:59:11	256	●	●	●	●	●	●	○	○		
2010/1/23	14:24:46	153								○	○	●
2010/1/23	16:00:55	315	●	●	●	●	●	●	●	●	●	●
2010/1/24	4:03:03	376	●	●	●	●	●	●	●	●	●	●
2010/1/24	15:05:32	356	●	●	●	●	●	●	●	●	●	●
2010/1/25	3:10:04	94										○
2010/1/25	4:46:31	315	●	●	●	●	●	●	●	●	●	●
2010/1/25	15:48:23	347	●	●	●	●	●	●	●	●	●	●
2010/1/26	3:50:49	359	●	●	●	●	●	●	●	●	●	●
2010/1/26	14:53:28	335	●	●	●	●	●	●	●	●	●	●
2010/1/27	4:33:58	350	●	●	●	●	●	●	●	●	●	●
2010/1/27	15:36:01	358	●	●	●	●	●	●	●	●	●	●
2010/1/28	3:38:43	334	●	●	●	●	●	●	●	●	●	●
2010/1/28	14:41:38	292	○	○	●	●	●	●	●	●	●	●
2010/1/28	16:20:07	199	●	●	●	○						
2010/1/29	4:21:26	374	●	●	●	●	●	●	●	●	●	●
2010/1/29	15:23:43	360	●	●	●	●	●	●	●	●	●	●
2010/1/30	3:26:48	288		○	●	●	●	●	●	●	●	●
2010/1/30	5:05:29	208	●	●	●	●	○					
2010/1/30	14:30:08	215						○	○	●	●	●
2010/1/30	16:07:06	288	●	●	●	●	●	●	●	●	○	
2010/1/31	4:09:01	381	●	●	●	●	●	●	●	●	●	●
2010/1/31	15:11:26	360	●	●	●	●	●	●	●	●	●	●
2010/2/1	3:15:14	197							○	●	●	●
2010/2/1	4:52:39	289	●	●	●	●	●	●	●	●	●	○
2010/2/1	15:54:27	333	●	●	●	●	●	●	●	●	●	●
2010/2/2	3:56:44	369	●	●	●	●	●	●	●	●	●	●
2010/2/2	14:59:18	348	●	●	●	●	●	●	●	●	●	●
2010/2/3	4:40:04	334	●	●	●	●	●	●	●	●	●	●
2010/2/3	15:41:59	356	●	●	●	●	●	●	●	●	●	●

2010/2/4	3:44:34	348	●	●	●	●	●	●	●	●	●	●
2010/2/4	14:47:20	317	●	●	●	●	●	●	●	●	●	●
2010/2/4	16:26:50	102	○									
2010/2/5	4:27:32	363	●	●	●	●	●	●	●	●	●	●
2010/2/5	15:29:41	359	●	●	●	●	●	●	●	●	●	●
2010/2/6	3:32:33	314	●	●	●	●	●	●	●	●	●	●
2010/2/6	5:12:00	130	●	○								
2010/2/6	14:35:38	261			○	○	●	●	●	●	●	●
2010/2/6	16:13:22	251	●	●	●	●	●	○	○			
2010/2/7	4:15:02	379	●	●	●	●	●	●	●	●	●	●
2010/2/7	15:17:23	360	●	●	●	●	●	●	●	●	●	●
2010/2/8	3:20:46	252					○	●	●	●	●	●
2010/2/8	4:58:51	254	●	●	●	●	●	○	○			
2010/2/8	14:24:23	156								○	○	●
2010/2/8	16:00:34	314	●	●	●	●	●	●	●	●	●	●
2010/2/9	4:02:41	377	●	●	●	●	●	●	●	●	●	●
2010/2/9	15:05:10	356	●	●	●	●	●	●	●	●	●	●
2010/2/10	3:09:40	100										○
2010/2/10	4:46:10	314	●	●	●	●	●	●	●	●	●	●
2010/2/10	15:48:01	347	●	●	●	●	●	●	●	●	●	●
2010/2/11	3:50:27	360	●	●	●	●	●	●	●	●	●	●
2010/2/11	14:53:06	336	●	●	●	●	●	●	●	●	●	●
2010/2/12	4:33:37	350	●	●	●	●	●	●	●	●	●	●
2010/2/12	15:35:39	359	●	●	●	●	●	●	●	●	●	●
2010/2/13	3:38:21	335	●	●	●	●	●	●	●	●	●	●
2010/2/13	14:41:16	293	○	○	●	●	●	●	●	●	●	●
2010/2/13	16:19:46	197	●	●	●	○						
2010/2/14	4:21:05	373	●	●	●	●	●	●	●	●	●	●
2010/2/14	15:23:21	360	●	●	●	●	●	●	●	●	●	●
2010/2/15	3:26:26	289		○	●	●	●	●	●	●	●	●
2010/2/15	5:05:09	206	●	●	●	●	○					
2010/2/15	14:29:45	217						○	○	●	●	●
2010/2/15	16:06:45	287	●	●	●	●	●	●	●	○		
2010/2/16	4:08:40	380	●	●	●	●	●	●	●	●	●	●
2010/2/16	15:11:04	360	●	●	●	●	●	●	●	●	●	●
2010/2/17	3:14:52	199							○	●	●	●
2010/2/17	4:52:18	288	●	●	●	●	●	●	●	●	●	○
2010/2/17	14:19:16	18										○
2010/2/17	15:54:05	333	●	●	●	●	●	●	●	●	●	●
2010/2/18	3:56:23	369	●	●	●	●	●	●	●	●	●	●
2010/2/18	14:58:56	348	●	●	●	●	●	●	●	●	●	●
2010/2/19	4:39:43	333	●	●	●	●	●	●	●	●	●	●
2010/2/19	15:41:38	355	●	●	●	●	●	●	●	●	●	●
2010/2/20	3:44:12	349	●	●	●	●	●	●	●	●	●	●
2010/2/20	14:46:58	318	●	●	●	●	●	●	●	●	●	●
2010/2/20	16:26:31	97	○									
2010/2/21	4:27:11	362	●	●	●	●	●	●	●	●	●	●
2010/2/21	15:29:19	360	●	●	●	●	●	●	●	●	●	●
2010/2/22	3:32:11	315	●	●	●	●	●	●	●	●	●	●
2010/2/22	5:11:40	127	●	○								
2010/2/22	14:35:16	261			○	○	●	●	●	●	●	●
2010/2/22	16:13:01	250	●	●	●	●	●	○	○			
2010/2/23	4:14:41	378	●	●	●	●	●	●	●	●	●	●
2010/2/23	15:17:01	361	●	●	●	●	●	●	●	●	●	●
2010/2/24	3:20:24	253					○	●	●	●	●	●
2010/2/24	4:58:30	253	●	●	●	●	●	○	○			
2010/2/24	14:24:00	158								○	○	●
2010/2/24	16:00:12	314	●	●	●	●	●	●	●	●	●	●

2010/2/25	4:02:20	377	●	●	●	●	●	●	●	●	●	●	●
2010/2/25	15:04:48	356	●	●	●	●	●	●	●	●	●	●	●
2010/2/26	3:09:16	105											○
2010/2/26	4:45:49	313	●	●	●	●	●	●	●	●	●	●	●
2010/2/26	15:47:39	347	●	●	●	●	●	●	●	●	●	●	●
2010/2/27	3:50:06	359	●	●	●	●	●	●	●	●	●	●	●
2010/2/27	14:52:44	336	●	●	●	●	●	●	●	●	●	●	●
2010/2/28	4:33:16	349	●	●	●	●	●	●	●	●	●	●	●
2010/2/28	15:35:17	359	●	●	●	●	●	●	●	●	●	●	●

Table 3-9: MODIS Terra overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch										
			1	2	3	4	5	6	7	8	9	10	
2010/1/1	1:20:06	110	○	○									
2010/1/1	13:20:50	364	●	●	●	●	●	●	●	●	●	●	●
2010/1/2	0:23:01	359	●	●	●	●	●	●	●	●	●	●	●
2010/1/2	12:25:53	313	●	●	●	●	●	●	●	●	●	●	●
2010/1/2	14:05:16	139	●	○									
2010/1/2	23:29:00	258				○	●	●	●	●	●	●	●
2010/1/3	1:06:41	254	●	●	●	●	●	○	○				
2010/1/3	13:08:21	379	●	●	●	●	●	●	●	●	●	●	●
2010/1/4	0:10:43	361	●	●	●	●	●	●	●	●	●	●	●
2010/1/4	12:14:08	247					○	●	●	●	●	●	●
2010/1/4	13:52:09	258	●	●	●	●	●	●	●	○			
2010/1/4	23:17:46	151								○	○	●	
2010/1/5	0:53:54	315	●	●	●	●	●	●	●	●	●	●	●
2010/1/5	12:56:01	377	●	●	●	●	●	●	●	●	●	●	●
2010/1/5	23:58:31	355	●	●	●	●	●	●	●	●	●	●	●
2010/1/6	12:03:07	83											○
2010/1/6	13:39:29	316	●	●	●	●	●	●	●	●	●	●	●
2010/1/7	0:41:21	348	●	●	●	●	●	●	●	●	●	●	●
2010/1/7	12:43:48	358	●	●	●	●	●	●	●	●	●	●	●
2010/1/7	23:46:28	334	●	●	●	●	●	●	●	●	●	●	●
2010/1/8	13:26:57	351	●	●	●	●	●	●	●	●	●	●	●
2010/1/9	0:29:00	359	●	●	●	●	●	●	●	●	●	●	●
2010/1/9	12:31:43	332	●	●	●	●	●	●	●	●	●	●	●
2010/1/9	23:34:38	291	○	○	●	●	●	●	●	●	●	●	●
2010/1/10	1:13:05	202	●	●	●	○							
2010/1/10	13:14:25	374	●	●	●	●	●	●	●	●	●	●	●
2010/1/11	0:16:42	360	●	●	●	●	●	●	●	●	●	●	●
2010/1/11	12:19:48	286		○	●	●	●	●	●	●	●	●	●
2010/1/11	13:58:27	211	●	●	●	●	○						
2010/1/11	23:23:09	213						○	○	●	●	●	
2010/1/12	1:00:05	289	●	●	●	●	●	●	●	●	○		
2010/1/12	13:02:01	380	●	●	●	●	●	●	●	●	●	●	●
2010/1/13	0:04:26	359	●	●	●	●	●	●	●	●	●	●	●
2010/1/13	12:08:16	192							○	○	●	●	
2010/1/13	13:45:37	291	●	●	●	●	●	●	●	●	●	●	○
2010/1/14	0:47:26	334	●	●	●	●	●	●	●	●	●	●	●
2010/1/14	12:49:44	368	●	●	●	●	●	●	●	●	●	●	●
2010/1/14	23:52:18	347	●	●	●	●	●	●	●	●	●	●	●
2010/1/15	13:33:02	336	●	●	●	●	●	●	●	●	●	●	●
2010/1/16	0:34:59	355	●	●	●	●	●	●	●	●	●	●	●
2010/1/16	12:37:34	347	●	●	●	●	●	●	●	●	●	●	●
2010/1/16	23:40:20	316	●	●	●	●	●	●	●	●	●	●	●

2010/1/17	1:19:46	110	○	○								
2010/1/17	13:20:30	364	●	●	●	●	●	●	●	●	●	●
2010/1/18	0:22:41	359	●	●	●	●	●	●	●	●	●	●
2010/1/18	12:25:33	312	●	●	●	●	●	●	●	●	●	●
2010/1/18	14:04:55	139	●	○								
2010/1/18	23:28:39	258				○	●	●	●	●	●	●
2010/1/19	1:06:20	254	●	●	●	●	●	○	○			
2010/1/19	13:08:01	379	●	●	●	●	●	●	●	●	●	●
2010/1/20	0:10:22	361	●	●	●	●	●	●	●	●	●	●
2010/1/20	12:13:47	247					○	●	●	●	●	●
2010/1/20	13:51:48	258	●	●	●	●	●	●	○			
2010/1/20	23:17:24	152							○	○	●	
2010/1/21	0:53:32	316	●	●	●	●	●	●	●	●	●	●
2010/1/21	12:55:40	376	●	●	●	●	●	●	●	●	●	●
2010/1/21	23:58:09	356	●	●	●	●	●	●	●	●	●	●
2010/1/22	12:02:45	84										○
2010/1/22	13:39:08	315	●	●	●	●	●	●	●	●	●	●
2010/1/23	0:40:59	348	●	●	●	●	●	●	●	●	●	●
2010/1/23	12:43:26	358	●	●	●	●	●	●	●	●	●	●
2010/1/23	23:46:06	334	●	●	●	●	●	●	●	●	●	●
2010/1/24	13:26:35	351	●	●	●	●	●	●	●	●	●	●
2010/1/25	0:28:37	359	●	●	●	●	●	●	●	●	●	●
2010/1/25	12:31:20	333	●	●	●	●	●	●	●	●	●	●
2010/1/25	23:34:15	291	○	○	●	●	●	●	●	●	●	●
2010/1/26	1:12:42	202	●	●	●	○						
2010/1/26	13:14:02	374	●	●	●	●	●	●	●	●	●	●
2010/1/27	0:16:19	360	●	●	●	●	●	●	●	●	●	●
2010/1/27	12:19:25	286		○	●	●	●	●	●	●	●	●
2010/1/27	13:58:03	212	●	●	●	●	○					
2010/1/27	23:22:45	214						○	○	●	●	●
2010/1/28	0:59:41	290	●	●	●	●	●	●	●	○		
2010/1/28	13:01:37	380	●	●	●	●	●	●	●	●	●	●
2010/1/29	0:04:02	359	●	●	●	●	●	●	●	●	●	●
2010/1/29	12:07:52	192							○	○	●	●
2010/1/29	13:45:13	292	●	●	●	●	●	●	●	●	●	○
2010/1/30	0:47:02	334	●	●	●	●	●	●	●	●	●	●
2010/1/30	12:49:20	368	●	●	●	●	●	●	●	●	●	●
2010/1/30	23:51:53	348	●	●	●	●	●	●	●	●	●	●
2010/1/31	13:32:38	335	●	●	●	●	●	●	●	●	●	●
2010/2/1	0:34:34	356	●	●	●	●	●	●	●	●	●	●
2010/2/1	12:37:09	347	●	●	●	●	●	●	●	●	●	●
2010/2/1	23:39:56	315	●	●	●	●	●	●	●	●	●	●
2010/2/2	1:19:21	110	○	○								
2010/2/2	13:20:05	364	●	●	●	●	●	●	●	●	●	●
2010/2/3	0:22:15	359	●	●	●	●	●	●	●	●	●	●
2010/2/3	12:25:08	312	●	●	●	●	●	●	●	●	●	●
2010/2/3	14:04:30	139	●	○								
2010/2/3	23:28:14	257				○	●	●	●	●	●	●
2010/2/4	1:05:54	254	●	●	●	●	●	○	○			
2010/2/4	13:07:35	379	●	●	●	●	●	●	●	●	●	●
2010/2/5	0:09:56	361	●	●	●	●	●	●	●	●	●	●
2010/2/5	12:13:21	247					○	●	●	●	●	●
2010/2/5	13:51:22	258	●	●	●	●	●	●	○			
2010/2/5	23:16:59	150							○	○	●	
2010/2/6	0:53:06	316	●	●	●	●	●	●	●	●	●	●
2010/2/6	12:55:14	376	●	●	●	●	●	●	●	●	●	●
2010/2/6	23:57:43	355	●	●	●	●	●	●	●	●	●	●
2010/2/7	12:02:20	81										○

2010/2/7	13:38:41	316	●	●	●	●	●	●	●	●	●	●
2010/2/8	0:40:32	348	●	●	●	●	●	●	●	●	●	●
2010/2/8	12:42:59	359	●	●	●	●	●	●	●	●	●	●
2010/2/8	23:45:39	334	●	●	●	●	●	●	●	●	●	●
2010/2/9	13:26:07	352	●	●	●	●	●	●	●	●	●	●
2010/2/10	0:28:10	359	●	●	●	●	●	●	●	●	●	●
2010/2/10	12:30:53	332	●	●	●	●	●	●	●	●	●	●
2010/2/10	23:33:48	290	○	○	●	●	●	●	●	●	●	●
2010/2/11	1:12:14	203	●	●	●	○						
2010/2/11	13:13:34	374	●	●	●	●	●	●	●	●	●	●
2010/2/12	0:15:51	360	●	●	●	●	●	●	●	●	●	●
2010/2/12	12:18:58	284		○	●	●	●	●	●	●	●	●
2010/2/12	13:57:35	213	●	●	●	●	○					
2010/2/12	23:22:18	212						○	○	●	●	●
2010/2/13	0:59:13	290	●	●	●	●	●	●	●	○		
2010/2/13	13:01:09	380	●	●	●	●	●	●	●	●	●	●
2010/2/14	0:03:33	360	●	●	●	●	●	●	●	●	●	●
2010/2/14	12:07:24	191								○	●	●
2010/2/14	13:44:44	292	●	●	●	●	●	●	●	●	●	○
2010/2/15	0:46:33	334	●	●	●	●	●	●	●	●	●	●
2010/2/15	12:48:51	368	●	●	●	●	●	●	●	●	●	●
2010/2/15	23:51:24	347	●	●	●	●	●	●	●	●	●	●
2010/2/16	13:32:09	335	●	●	●	●	●	●	●	●	●	●
2010/2/17	0:34:04	356	●	●	●	●	●	●	●	●	●	●
2010/2/17	12:36:40	347	●	●	●	●	●	●	●	●	●	●
2010/2/17	23:39:26	315	●	●	●	●	●	●	●	●	●	●
2010/2/18	1:18:49	114	○	○								
2010/2/18	13:19:35	364	●	●	●	●	●	●	●	●	●	●
2010/2/19	0:21:45	359	●	●	●	●	●	●	●	●	●	●
2010/2/19	12:24:38	312	●	●	●	●	●	●	●	●	●	●
2010/2/19	14:03:59	141	●	○	○							
2010/2/19	23:27:44	257				○	●	●	●	●	●	●
2010/2/20	1:05:23	255	●	●	●	●	●	○				
2010/2/20	13:07:05	379	●	●	●	●	●	●	●	●	●	●
2010/2/21	0:09:25	361	●	●	●	●	●	●	●	●	●	●
2010/2/21	12:12:51	246					○	●	●	●	●	●
2010/2/21	13:50:51	259	●	●	●	●	●	●	○			
2010/2/21	23:16:28	149								○	○	●
2010/2/22	0:52:35	316	●	●	●	●	●	●	●	●	●	●
2010/2/22	12:54:43	376	●	●	●	●	●	●	●	●	●	●
2010/2/22	23:57:11	356	●	●	●	●	●	●	●	●	●	●
2010/2/23	12:01:51	75										○
2010/2/23	13:38:09	317	●	●	●	●	●	●	●	●	●	●
2010/2/24	0:40:01	348	●	●	●	●	●	●	●	●	●	●
2010/2/24	12:42:28	358	●	●	●	●	●	●	●	●	●	●
2010/2/24	23:45:07	334	●	●	●	●	●	●	●	●	●	●
2010/2/25	13:25:35	352	●	●	●	●	●	●	●	●	●	●
2010/2/26	0:27:38	359	●	●	●	●	●	●	●	●	●	●
2010/2/26	12:30:21	332	●	●	●	●	●	●	●	●	●	●
2010/2/26	23:33:16	290	○	○	●	●	●	●	●	●	●	●
2010/2/27	1:11:40	205	●	●	●	○						
2010/2/27	13:13:02	374	●	●	●	●	●	●	●	●	●	●
2010/2/28	0:15:18	360	●	●	●	●	●	●	●	●	●	●
2010/2/28	12:18:25	284		○	●	●	●	●	●	●	●	●
2010/2/28	13:57:02	214	●	●	●	●	○					
2010/2/28	23:21:45	211						○	○	●	●	●

3.2.2 MTSAT-1R

The Multi-functional Transport Satellite (MTSAT) series fulfils a meteorological function for the Japan Meteorological Agency and an aviation control function for the Civil Aviation Bureau of the Ministry of Land, Infrastructure and Transport. The MTSAT series (<http://www.jma.go.jp/jma/jma-eng/satellite/index.html>) succeeds the Geostationary Meteorological Satellite (GMS) series as the next generation of satellites covering East Asia and the Western Pacific. This series provides imagery for the Southern Hemisphere every 30 minutes at 4km resolution in contrast to the previous hourly rate, enabling the Japan Meteorological Agency to more closely monitor typhoon and cloud movement. The MTSAT series carries a new imager with a new infrared channel (IR4) in addition to the four channels (VIS, IR1, IR2 and IR3) of the GMS-5. Since this data is always available no coverage table is required.

3.2.3 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

ASTER (<http://asterweb.jpl.nasa.gov/>) provides high resolution visible (15m), near infrared (30m) and thermal infrared (90m) data on request. ASTER is onboard Terra and has a swath width of about 60km. ASTER is being used to obtain detailed maps of land surface temperature, reflectance and elevation. An order for ASTER data has been placed by an ASTER science team member to obtain data for mid January to end of February 2010. ASTER coverage for the Murrumbidgee Catchment is summarised in Table 3-10.

Table 3-10: ASTER overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch											
			1	2	3	4	5	6	7	8	9	10		
2010/1/2	0:25:48	25		○	○	○								
2010/1/3	13:11:22	26			○	○								
2010/1/4	0:13:30	26								○	○	○		
2010/1/5	12:58:52	27									○	○		
2010/1/9	0:31:48	22	○											
2010/1/10	13:17:29	23	○											
2010/1/11	0:19:31	23					○	○						
2010/1/12	13:04:57	26					○	●	○					
2010/1/13	0:07:14	23												○
2010/1/18	0:25:27	26		○	○	○								
2010/1/19	13:11:01	27			○	○								
2010/1/20	0:13:09	26								○	○	○		
2010/1/21	12:58:31	26									○	○		
2010/1/25	0:31:26	21	○											
2010/1/26	13:17:06	23	○											
2010/1/27	0:19:07	24					○	○						
2010/1/28	13:04:33	27					○	●	○					
2010/1/29	0:06:51	22												○
2010/2/3	0:25:02	25		○	○	○								
2010/2/4	13:10:36	26			○	○								
2010/2/5	0:12:43	26								○	○	○		
2010/2/6	12:58:05	26									○	○		
2010/2/10	0:30:58	22	○											
2010/2/11	13:16:38	24	○											
2010/2/12	0:18:39	24					○	○	○					
2010/2/13	13:04:05	26					○	○	○					
2010/2/14	0:06:22	23												○

2010/2/19	0:24:32	25		○	○	○						
2010/2/20	13:10:05	27			○	○						
2010/2/21	0:12:13	25						○	○	○		
2010/2/22	12:57:34	26							○	○		
2010/2/26	0:30:26	22	○									
2010/2/27	13:16:06	23	○									
2010/2/28	0:18:06	24					○	○	○			

3.2.4 Landsat

Landsat (<http://landsat.usgs.gov/http://landsat7.usgs.gov/programdesc.html>) satellites collect data in the visible (30m), panchromatic (15m), mid infrared (30m) and thermal infrared (60 to 120m) regions of the electromagnetic spectrum. These data have an approximately 16 day repeat cycle with a 10:00am equator crossing time. This data is particularly valuable in land cover and vegetation parameter mapping. Due to an instrument malfunction onboard Landsat 7 in May 2003, the Enhanced Thematic Mapper Plus (ETM+) is now only able to provide useful image data within the central ~20km of the swath. As Landsat 5 Thematic Mapper is still in operation it is being increasingly relied upon. The approximate scene size is 170 × 183 km. The Landsat coverage for the Murrumbidgee Catchment is summarised in Table 3-11 and Table 3-12. While there is no budget allocation for purchasing Landsat data, it is useful to keep these overpasses in mind for future reference.

Table 3-11: Landsat 5 overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch									
			1	2	3	4	5	6	7	8	9	10
2010/1/1	0:05:00	39	●	○								
2010/1/2	12:50:41	40	●	○								
2010/1/2	23:52:44	41				○	●	●	○			
2010/1/4	12:38:11	45				○	●	●	●	○		
2010/1/4	23:40:29	41									○	●
2010/1/6	12:25:48	38									○	●
2010/1/9	23:58:49	41	○	○	●	○	○					
2010/1/11	12:44:24	45	○	●	●	●	○					
2010/1/11	23:46:33	42						○	○	●	○	○
2010/1/13	12:31:55	44							○	●	●	○
2010/1/17	0:04:56	38	●	○								
2010/1/18	12:50:38	40	●	○								
2010/1/18	23:52:40	41				○	●	●	○			
2010/1/20	12:38:07	45				○	●	●	○	○		
2010/1/20	23:40:24	42								○	○	●
2010/1/22	12:25:44	39									○	●
2010/1/25	23:58:44	41	○	○	●	○	○					
2010/1/27	12:44:20	45	○	●	●	●	○					
2010/1/27	23:46:28	42						○	○	●	○	○
2010/1/29	12:31:51	44							○	●	●	○
2010/2/2	0:04:50	39	○	○								
2010/2/3	12:50:34	39	●	○								
2010/2/3	23:52:34	41			○	○	●	●	○			
2010/2/5	12:38:03	44				○	●	●	○			
2010/2/5	23:40:19	41								○	○	●
2010/2/7	12:25:39	39									○	●
2010/2/10	23:58:38	41	○	●	●	○	○					
2010/2/12	12:44:15	45	○	●	●	●	○					

2010/2/12	23:46:22	42						○	○	●	○	
2010/2/14	12:31:47	43							○	●	●	○
2010/2/18	0:04:45	37	○	○								
2010/2/19	12:50:28	38	●	○								
2010/2/19	23:52:28	41			○	○	●	●	○			
2010/2/21	12:37:57	44				○	●	●	○			
2010/2/21	23:40:12	42								○	○	●
2010/2/23	12:25:32	39									○	●
2010/2/26	23:58:32	41	○	●	●	○	○					
2010/2/28	12:44:08	45	○	●	●	○	○					
2010/2/28	23:46:16	41						○	○	●	○	

Table 3-12: Landsat 7 overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch									
			1	2	3	4	5	6	7	8	9	10
2010/1/1	23:59:13	42	○	○	●	○	○					
2010/1/3	12:44:48	45	○	○	●	●	○					
2010/1/3	23:46:57	42						○	○	●	○	○
2010/1/5	12:32:18	45							○	●	●	○
2010/1/9	0:05:19	40	●	○								
2010/1/10	12:51:01	40	●	○								
2010/1/10	23:53:03	41				○	●	●	○			
2010/1/12	12:38:30	45				○	●	●	●	○		
2010/1/12	23:40:48	41									○	●
2010/1/14	12:26:08	37										○
2010/1/17	23:59:07	42	○	○	●	○	○					
2010/1/19	12:44:42	45	○	○	●	●	○					
2010/1/19	23:46:51	42						○	○	●	○	○
2010/1/21	12:32:12	45							○	●	●	○
2010/1/25	0:05:12	39	●	○								
2010/1/26	12:50:53	41	●	○								
2010/1/26	23:52:55	41				○	●	●	○			
2010/1/28	12:38:22	45				○	●	●	●	○		
2010/1/28	23:40:40	41									○	●
2010/1/30	12:25:59	38									○	●
2010/2/2	23:58:58	41	○	○	●	○	○					
2010/2/4	12:44:33	45	○	○	●	●	○					
2010/2/4	23:46:41	42						○	○	●	○	○
2010/2/6	12:32:02	45							○	●	●	○
2010/2/10	0:05:01	39	●	○								
2010/2/11	12:50:42	41	●	○								
2010/2/11	23:52:44	41				○	●	●	○			
2010/2/13	12:38:11	45				○	●	●	●	○		
2010/2/13	23:40:28	41									○	●
2010/2/15	12:25:47	38									○	●
2010/2/18	23:58:45	42	○	○	●	○	○					
2010/2/20	12:44:20	45	○	○	●	●	○					
2010/2/20	23:46:28	42						○	○	●	○	○
2010/2/22	12:31:48	46							○	●	●	○
2010/2/26	0:04:47	39	●	○								
2010/2/27	12:50:28	41	●	○								
2010/2/27	23:52:30	41				○	●	●	○			

3.2.5 Compact High Resolution Imaging Spectrometer (CHRIS)

CHRIS (www.chris-proba.org.uk) provides remotely-sensed multi-angle data at high spatial resolution and in superspectral/hyperspectral wavelengths. The instrument has a spectral range of 415-1050 nm, and provides observations at 19 spectral bands simultaneously, with a spatial resolution of 20m at nadir and a swath width of 14km. CHRIS is on board ESA's Project for On-Board Autonomy (PROBA). The PROBA satellite is on a sun-synchronous elliptical polar orbit since 2001 at a mean altitude of about 600km. CHRIS coverage for the Murrumbidgee Catchment is summarised in Table 3-13.

Table 3-13: CHRIS overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch									
			1	2	3	4	5	6	7	8	9	10
2010/1/1	23:23:21	18		○								
2010/1/6	11:53:46	17							○			
2010/1/7	12:04:45	17		○								
2010/1/8	23:02:59	16									○	○
2010/1/9	23:13:46	16					○	○				
2010/1/10	23:24:32	18	○									
2010/1/15	11:54:52	17						○				
2010/1/16	12:05:51	16	○									
2010/1/17	23:04:10	19									○	
2010/1/18	23:15:00	15				○	○					
2010/1/23	11:44:57	16										○
2010/1/24	11:55:56	16					○					
2010/1/26	23:05:24	18								○		
2010/1/27	23:16:13	15			○	○						
2010/2/1	11:46:02	16									○	
2010/2/2	11:57:00	16				○						
2010/2/4	23:06:37	17							○	○		
2010/2/5	23:17:24	15		○	○							
2010/2/10	11:47:06	17								○		
2010/2/11	11:58:05	16			○							
2010/2/12	22:57:07	10										○
2010/2/13	23:07:49	15						○	○			
2010/2/14	23:18:34	15	○	○								
2010/2/19	11:48:14	16							○			
2010/2/20	11:59:13	17		○								
2010/2/21	22:58:10	13									○	○
2010/2/22	23:08:56	15					○	○				
2010/2/23	23:19:42	15	○									
2010/2/28	11:49:27	16						○				

3.2.6 Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2)

AVNIR-2 (<http://www.eorc.jaxa.jp/ALOS/about/avnir2.htm>) is a visible and near infrared radiometer onboard ALOS. AVNIR-2 is a successor to AVNIR that was onboard the ADvanced Earth Observing Satellite (ADEOS), which was launched in August 1996. Its instantaneous field-of-view is the main improvement over AVNIR. AVNIR-2 also provides 10m spatial resolution images, an improvement over the 16m resolution of AVNIR in the multi-spectral region. Improved CCD detectors (AVNIR has 5,000 pixels per CCD; AVNIR-2 7,000 pixels per CCD) and electronics enable this higher resolution. The pointing angle of

AVNIR-2 is +44° and -44°. AVNIR-2 coverage for the Murrumbidgee Catchment is summarised in Table 3-14.

Table 3-14: AVNIR-2 overpass coverage for the Murrumbidgee Catchment. Times are in UTC and calculations are for 6 November 2009 orbital parameters. Shows patches as partly covered ○ or fully covered ●.

Date	Start Time	Duration(s)	Patch									
			1	2	3	4	5	6	7	8	9	10
2010/1/1	5:23:00	29						○	○			
2010/1/1	16:38:23	26				○	○	○				
2010/1/5	5:11:46	18										○
2010/1/5	16:27:13	25									○	○
2010/1/8	5:28:34	28			○	○	○					
2010/1/8	16:43:48	27		○	○	○						
2010/1/12	5:17:11	28								○	○	
2010/1/12	16:32:38	27						○	○	○		
2010/1/15	5:34:07	26	●	○								
2010/1/15	16:49:15	18	○									
2010/1/16	16:21:44	6										○
2010/1/19	5:22:44	28					○	○	○			
2010/1/19	16:38:04	25				○	○	○				
2010/1/23	5:11:22	25										○
2010/1/23	16:26:52	27								○	○	○
2010/1/26	5:28:16	29		○	●	○						
2010/1/26	16:43:28	27	○	○	○							
2010/1/30	5:16:54	27							○	○		
2010/1/30	16:32:19	25					○	○	○			
2010/2/2	5:33:48	23	○									
2010/2/3	16:21:11	22										○
2010/2/6	5:22:25	29				○	●	○				
2010/2/6	16:37:43	27			○	○	○					
2010/2/10	5:11:01	30									○	○
2010/2/10	16:26:31	27							○	○	○	
2010/2/13	5:27:57	29	○	●	○							
2010/2/13	16:43:07	27	○	○								
2010/2/17	5:16:34	28						○	●	○		
2010/2/17	16:31:57	26					○	○	○			
2010/2/21	16:20:46	26									○	○
2010/2/24	5:22:04	30			○	●	○					
2010/2/24	16:37:20	27		○	○	○						
2010/2/28	5:10:43	28								○	○	
2010/2/28	16:26:10	25							○	○		

4 Study Area

The Australian Airborne Cal/val Experiments for SMOS (AACES) will take place across the entire Murrumbidgee River Catchment located in south-eastern Australia (-33° to -37°S, 143° to 150°E). As illustrated in Figure 4-1, there are a total of 38 soil moisture profile stations distributed across the catchment (see also <http://www.oznet.unimelb.edu.au>), with clusters of 5 or more surface soil moisture probes at several of these in the Yanco monitoring area. Moreover, parts of the catchment (Yanco and Kyeamba) have already been the focus of a previous and very successful campaign in 2006, called the National Airborne Field Experiment (NAFE; see <http://www.nafe.unimelb.edu.au>), which tested amongst other things the suitability of the area for SMOS calibration and validation purposes (Merlin et al., 2008; Azcurra and Walker, 2009).

Due to its distinctive topography, the Murrumbidgee catchment exhibits a significant spatial variability in climate, topography, soil, vegetation and land cover. Due to the diversity within this confined area, the large amount of complementary data from long-term monitoring sites, and the past airborne field experiment, this region is an ideal test bed for the comprehensive validation of SMOS described here, and is highly complementary to the current study sites in other countries. Moreover, 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. The following sections give a general introduction of the Murrumbidgee Catchment and the operational soil moisture network. Further details on the Yanco, Kyeamba, Livingstone Creek and Yenda areas can be found in Walker et al. (2006).

4.1 Murrumbidgee Catchment

The Murrumbidgee River is one of the major rivers of New South Wales and the Australian Capital Territory. It originates in the Fiery Range of the Snowy Mountains and travels approximately 1,690km westwards to confluence with the River Murray. The entire catchment is one of 25 major sub-catchments of the Murray Darling Basin, comprising an area of about 82,000km². The geographic boundaries are represented by the Great Dividing Range in the east, the River Murray Valley to the south and the Lachlan River Valley to the

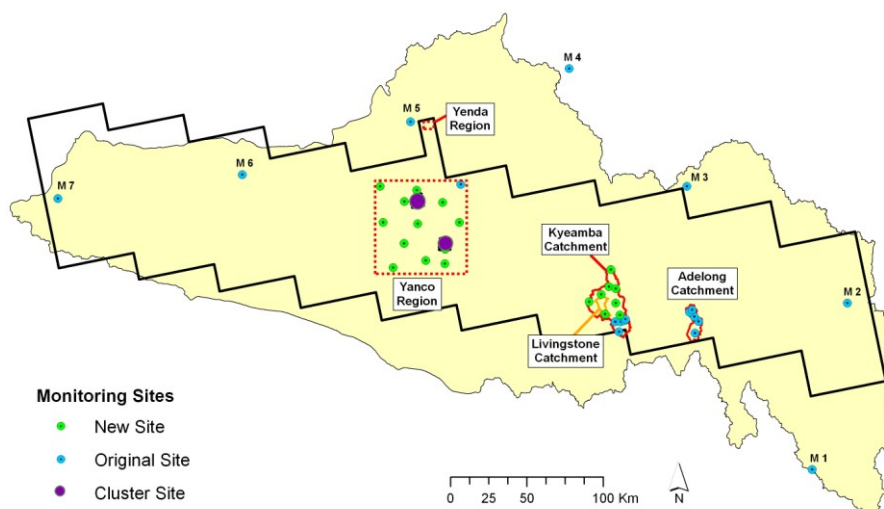


Figure 4-1: Murrumbidgee River catchment showing soil moisture monitoring network, together with AACES transect and key sub catchments/localities.

north. Due to its highly spatial variability in terms of physical characteristics, the catchment is usually divided into three management areas: lower, mid and upper Murrumbidgee. There are many tributaries joining the Murrumbidgee along its course, which is regulated by more than 20 dams or weirs.

4.1.1 Topography

The Murrumbidgee catchment is characterised by plains in the west with elevations around 50m, to steep mountainous regions towards the east with elevations in excess of 2,100m in the Snowy Mountains (Figure 4-2). The western plains show a few geological outcroppings with elevations up to 250m above sea level, while the highest point of the catchment is in the south east, with an elevation of about 2,220m. This is quite close to Mount Kosciuszko, the highest mountain in Australia.

4.1.2 Climate

Temporal climatic variations are primarily associated with elevation, varying from semi-arid in the west to temperate in the east, and resulting in a general distribution into four categories (Figure 4-2). The total averaged annual rainfall for the entire Murrumbidgee river catchment is about 530mm, with a mean annual precipitation of 300mm in the west and about 1,900mm towards the east in the Snowy Mountains. The actual evapotranspiration is equivalent to precipitation in the west but represents only half of the precipitation in the east.

Long term averaged precipitation data for the Murrumbidgee Catchment shows a relatively constant rate of rainfall across the year, with a slight increase in winter and decrease in summer (Figure 4-3). In contrast, the total evaporation rate fluctuates significantly depending on the seasonal conditions, with the monthly potential evapotranspiration dropping from 200mm during the summer to 25mm during the winter. Consequently, during May to August there is potentially recharge since the evapotranspiration rate is less than the amount of precipitation. The AMSR-E and model estimated monthly average spatial variation of soil moisture and “water availability”, a proposed proxy for soil moisture, is shown in Figure 4-4 and Figure 4-5 for a dry and wet year respectively. These plots show an expected increase in water availability during winter and decreased water availability in summer, with a tendency for wetter conditions in the east than in the west. A more detailed assessment of seasonal soil moisture variation in surface and root zone layers is presented in a subsequent section based on long-term soil moisture monitoring in the Murrumbidgee catchment.

During the winter period, precipitation above 1,200m typically falls as snow, with regions above 1,400m usually covered by snow for a few weeks of the year. Moreover, above 1,800m the snow cover can last for four months or more (Whetton et al., 1996; see Figure 4-2).

4.1.3 Geology and Soil

Soils in the Murrumbidgee vary from sand to clay, with the western plains being dominated by finer-textured soils and the eastern slopes being dominated by medium-to-coarse textured soils (McKenzie et al., 2000). Figure 4-2 shows the geology and the related soil texture distribution across the Murrumbidgee Catchment. While, there are more detailed soil texture maps available for some parts of the Murrumbidgee Catchment, particularly in the Kyamba area (Chen and McKane, 1997), this is the best information available for the catchment as a whole. Also shown is a plot of the predicted soil water holding capacity of the A-horizon (top soil) derived from soil mapping within the Murrumbidgee River basin. It is a measure to determine the amount of water which is stored in the soil and available for plants to use. The given capacities are based on the difference in volumetric water content between permanent wilting point and field capacity, converted into a depth of water, by using the depth of the A horizon as a reference.

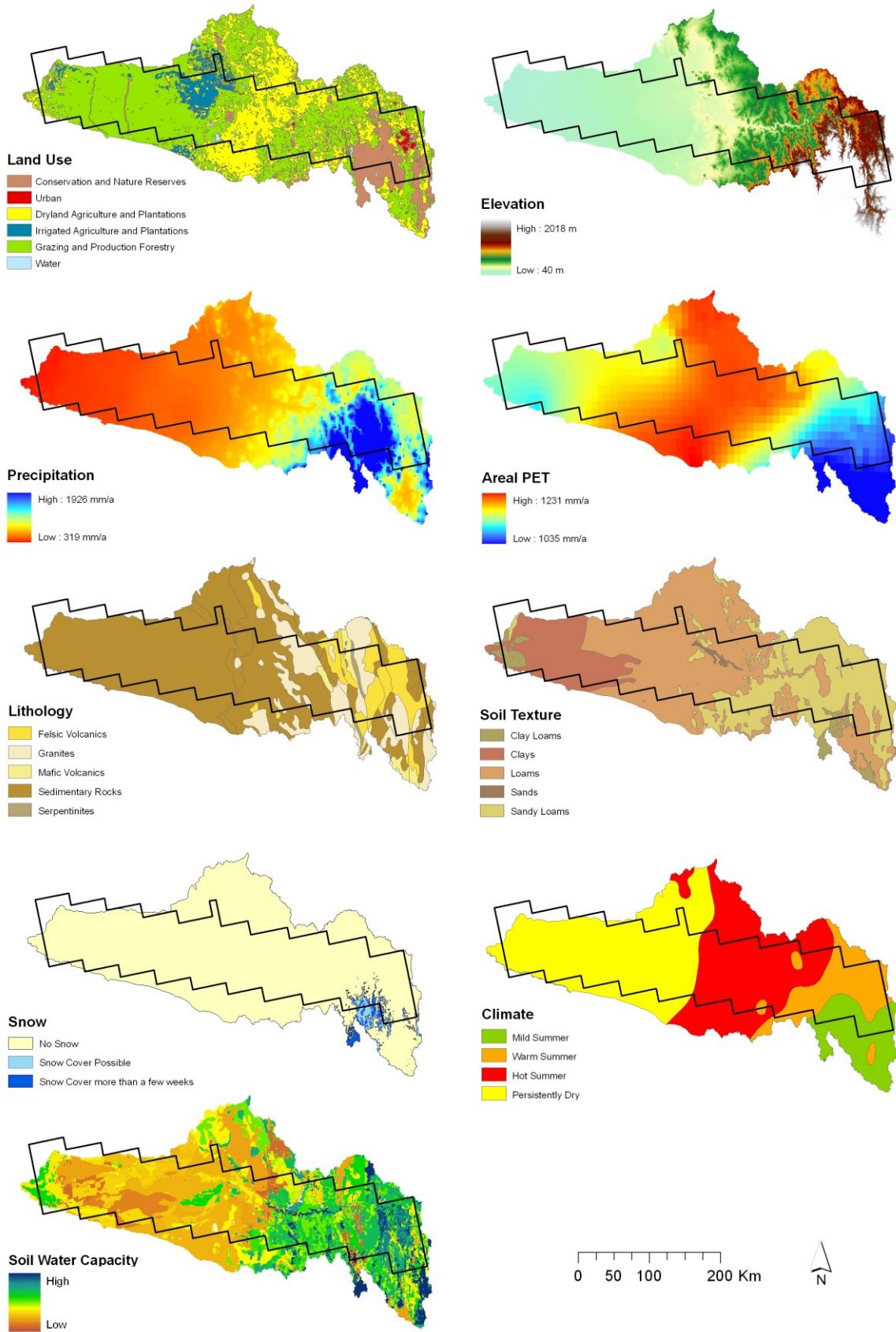


Figure 4-2: Climatic, soil and land use diversity across the Murrumbidgee catchment. Overlain is the outline of the flight boxes to be monitored by the AACES campaigns (data sources: Australian Bureau of Meteorology, Australian Bureau of Rural Science, and Geoscience Australia).

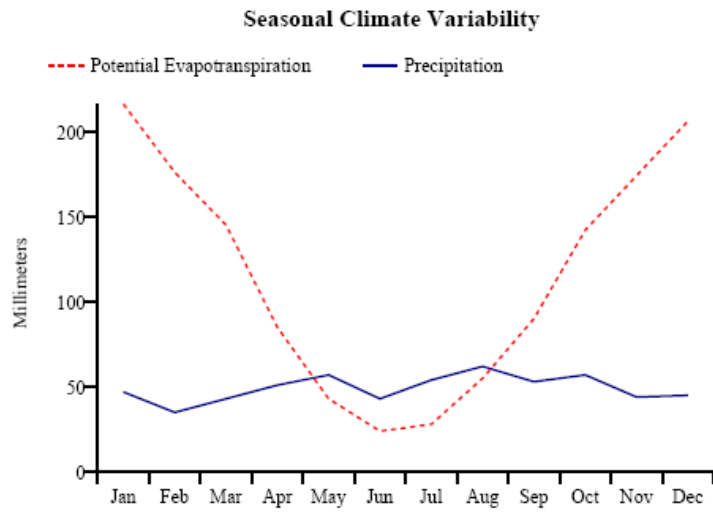


Figure 4-3: Seasonal climate variability of the Murrumbidgee Catchment (Australian Bureau of Meteorology).

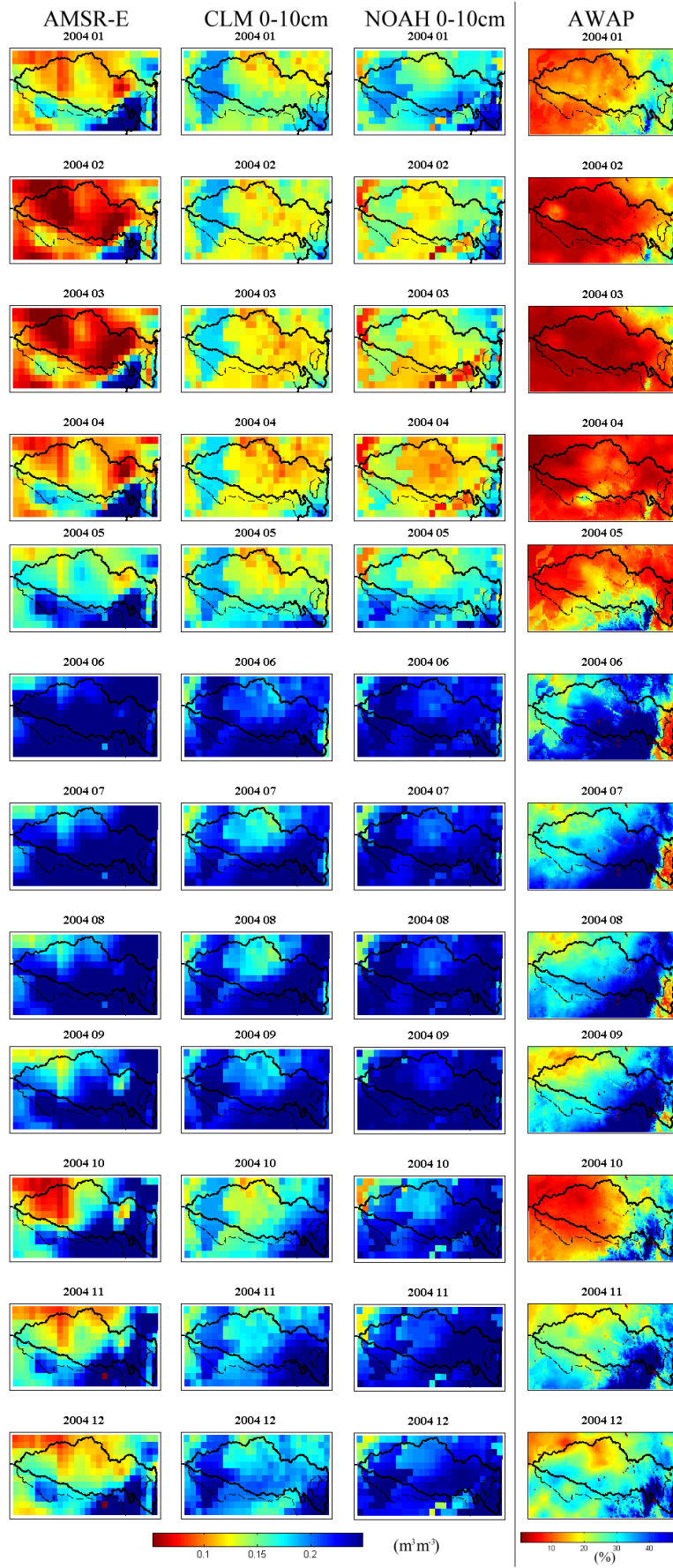


Figure 4-4: Monthly average soil moisture estimates for the Murrumbidgee River Basin during 2004, representing a “dry year” (Source: Yi Liu, personal communication).

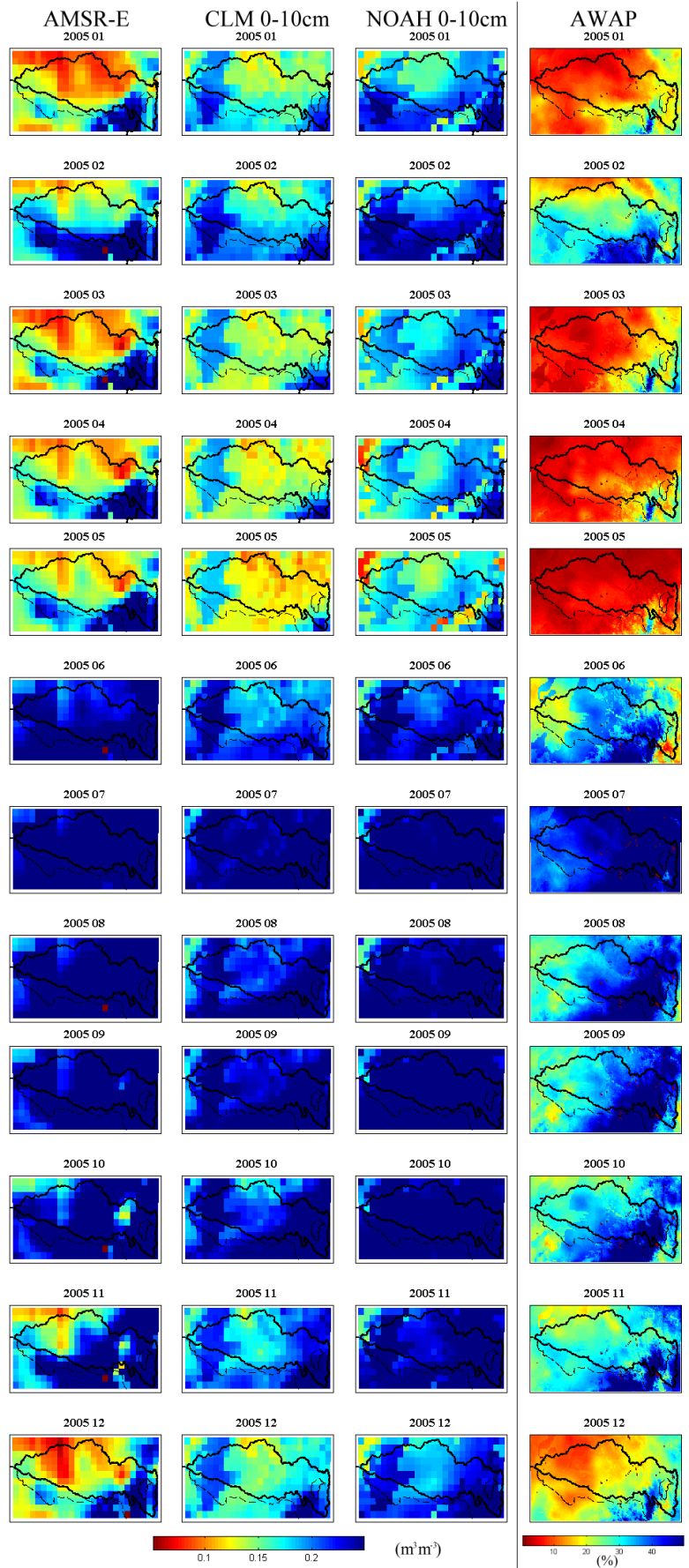


Figure 4-5: Monthly average soil moisture estimates for the Murrumbidgee River Basin during 2005, representing a “wet year” (Source: Yi Liu, personal communication).

4.1.4 Vegetation and Land Use

Land use in the catchment is predominantly agricultural with the exception of steeper parts, which are dominated by a mixture of native eucalypt forests and exotic forestry plantations. Agricultural land use varies greatly in intensity and includes pastoral, more intensive grazing, broad-acre cropping, and intensive agriculture in irrigation areas along the mid-lower Murrumbidgee. Figure 4-2 gives an overview of the general land use classification in the Murrumbidgee catchment, showing that grazing is predominant in the west and particularly scattered in the east, whereas dryland cropping dominates the mid Murrumbidgee catchment. Irrigation sites are mainly located in the south of Griffith.

The areal coverage of the major land use types is listed in Table 4-1. The catchment is comprised of about 52% pasture, followed by about 21% arable and 18% silvicultural land use. The other land use types represent less than 9% of the total catchment area.

The Normalized Difference Vegetation Index (NDVI) is an indicator of vegetation vigour and hence reflects vegetation health, soil moisture availability, available energy for photosynthesis and stage of the growing cycle. Consequently it varies seasonally and this cycle is presented in Figure 4-6.

Table 4-1: Land use types in the Murrumbidgee River Basin (Australian Bureau of Rural Science, 2008).

Land Use Type	Area (km ²)	Area (%)
closed forest	1,310	1.6
open forest	13,381	16.4
plantation	1,148	1.4
woodland	4,537	5.6
woody pasture	1,107	1.4
shrubby pasture	5,534	6.8
pasture	34,406	42.2
irrigated pasture	1,402	1.7
winter crops	13,704	16.8
summer/fodder crops	2,260	2.8
irrigated crops	1,141	1.4
cotton	2	<0.1
horticulture	330	0.4
irrigated horticulture	158	0.2
bare ground	54	0.1
intensive use	312	0.4
water	819	1.0

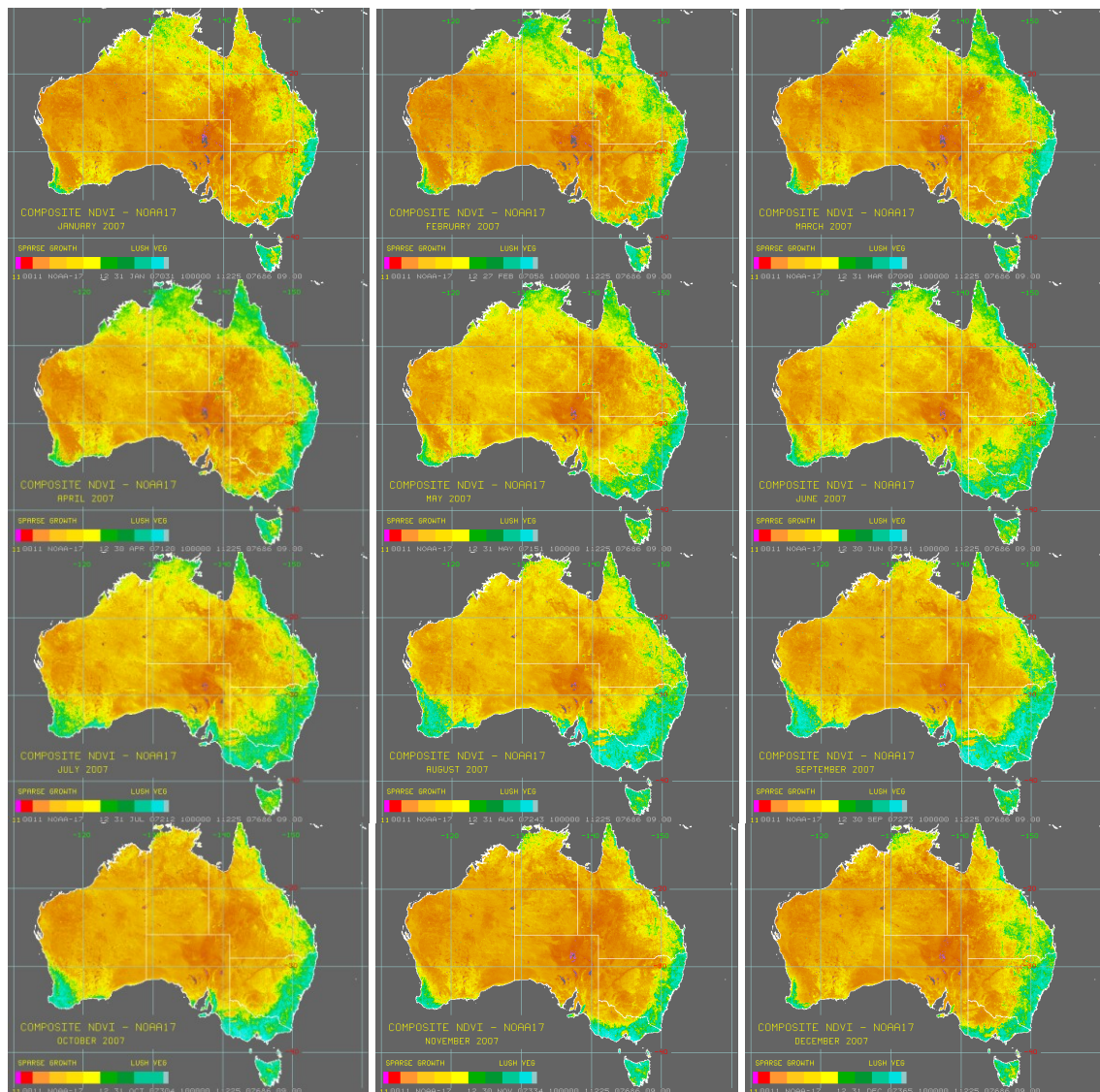


Figure 4-6: Normalised Difference Vegetation Index (NDVI) product processed from the Advanced Very High Resolution Radiometer (AVHRR) during January 2007 – December 2007 (Australian Bureau of Meteorology).

4.2 Soil Moisture Monitoring Network

The Murrumbidgee catchment is equipped with a wide-ranging soil moisture monitoring network which was established in 2001 and upgraded with 20 additional sites in 2003 (<http://www.civenv.unimelb.edu.au/oznet/mdbdata/document.html>) and an additional 24 surface soil moisture only probes in 2009. At present, the network consists in total of 38 continuously operating soil moisture profile stations (excluding the additional surface soil moisture stations recently installed) distributed across the whole catchment, with three focus areas (Yanco, Kyeamba and Adelong) comprising about two-third of the existing monitoring sites (Figure 4-1 and Table 4-2).

Each profile soil moisture station of the Murrumbidgee monitoring network measures the soil moisture at 0-30cm, 30-60cm and 60-90cm with water content reflectometers (Campbell Scientific). Additionally, the “new” sites were upgraded in April 2006 to include a 0-5cm soil moisture measurement from a Hydraprobe (Stevens Water; <http://www.stevenswater.com/catalog/stevensProduct.aspx?SKU=70030>), 2.5cm soil temperature from thermistors (Campbell Scientific model T-107) and telemetry, while all the “original” sites include a

Table 4-2: Overview of existing profile soil moisture stations. Sensor depth refers to mid-point of sensor installation; see also Figure 4-7. Logged values for soil moisture, temperature and suction are the average of readings taken every minute over the indicated logging frequency.

Site ID	Lat	Lon	site installed	soil moisture		soil temperature		soil suction		rain gauge
				sensor depth (cm)	logging frequency	sensor depth (cm)	logging frequency	sensor depth (cm)	logging frequency	logging frequency
Murrumbidgee										
M1	-36.29303	148.97057	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations
M2	-35.30500	149.20100	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations
M3	-34.62987	148.03650	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations
M4	-33.93827	147.19618	Sep-01	4,15,45,56	30 min	4,15,45,59	6 min accumulations	4,15,45,59	30 min	6 min accumulations
M5	-34.65837	143.54863	Sep-01	4,15,45,72	30 min	4,15,45,62.5	6 min accumulations	4,15,45,62.5	30 min	6 min accumulations
M6	-34.54712	144.86700	Sep-01	4,15,45,71	30 min	4,15,45,70	6 min accumulations	4,15,45,66	30 min	6 min accumulations
M7	-34.24900	146.07000	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations
Yanco										
Y1	-34.62888	145.84895	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y2	-34.65478	146.11028	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y3	-34.62100	146.42400	Sep-01	4,15,42	30 min	4,15,42	6 min accumulations	4,15,42	30 min	6 min accumulations
Y4	-34.71943	146.02003	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y5	-34.72835	146.29317	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y6	-34.84262	145.86692	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y7	-34.85183	146.11530	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y8	-34.84697	146.41398	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y9	-34.96777	146.01632	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y10	-35.00535	146.30988	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y11	-35.10975	145.93553	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y12	-35.06960	146.16893	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Y13	-35.09025	146.30648	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Kyeamba										
K1	35.49322	147.55912	Sep-01	4,15,45,75	30 min	4,15,45,74	6 min accumulations	4,15,45,74	30 min	6 min accumulations
K2	-35.43525	147.53052	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations
K3	-35.43408	147.56893	Sep-01	4,15,45,58.5	30 min	4,15,45,58.5	6 min accumulations	4,15,45,56.5	30 min	6 min accumulations
K4	-35.42688	147.60000	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations
K5	-35.41928	147.60408	Sep-01	4,15,45,66	30 min	4,15,45,66	6 min accumulations	4,15,45,63.5	30 min	6 min accumulations
K6	-35.38978	147.45720	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
K7	-35.39392	147.56618	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
K8	-35.31627	147.34387	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
K9	-35.31982	147.43633	Apr-01				DPI operated			
K10	-35.32395	147.53480	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
K11	-35.27202	147.42902	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
K12	-35.22750	147.48500	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
K13	-35.23887	147.53330	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
K14	-35.12493	147.49740	Sep-03	15, 45, 75	20 min	3, 15	20 min	-	-	individual tips
Adelong										
A1	-35.49749	148.10649	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations
A2	-35.42831	148.13163	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations
A3	-35.39969	148.10108	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations
A4	-35.37311	148.06608	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations
A5	-35.36019	148.08543	Sep-01	4,15,45,75	30 min	4,15,45,75	6 min accumulations	4,15,45,75	30 min	6 min accumulations

0-7cm soil moisture measurement from a water content reflectometer installed on an angle from the surface.

In November 2009, an additional 24 soil moisture monitoring stations were installed, increasing the observation density around station Y4 and Y7. These new stations provide additional information on the surface soil moisture (0-5cm via Hydraprobes) and three temperature measurements (1cm, 2.5cm, and 5cm).

The reflectometers used for the soil moisture measurements consist of a printed circuit board connected to two parallel stainless steel rods that act as wave guides. They measure the travel time of an output pulse to estimate changes in the bulk soil dielectric constant. The period is converted to volumetric water content with a calibration equation parameterised with soil type and soil temperature. Such sensors operate in a lower range of frequencies (10-100MHz) than Time Domain Reflectometers TDR (700-1000MHz). Soil moisture sites also monitor precipitation (tipping bucket raingauge TB4-L) and soil temperature (CS T107 and Unidata 6507A).

All stations in the Yanco region except for the one located at the Yanco Research Station, and all stations in the Kyeamba Creek catchment except for five, were installed throughout late 2003 and early 2004 (new sites). The eighteen other stations have operated since late 2001 (original sites). Figure 4-7 illustrates the differences between the original and new sites. The original sites use the water content reflectometer CS615 (Campbell, <http://www.campbellsci>.

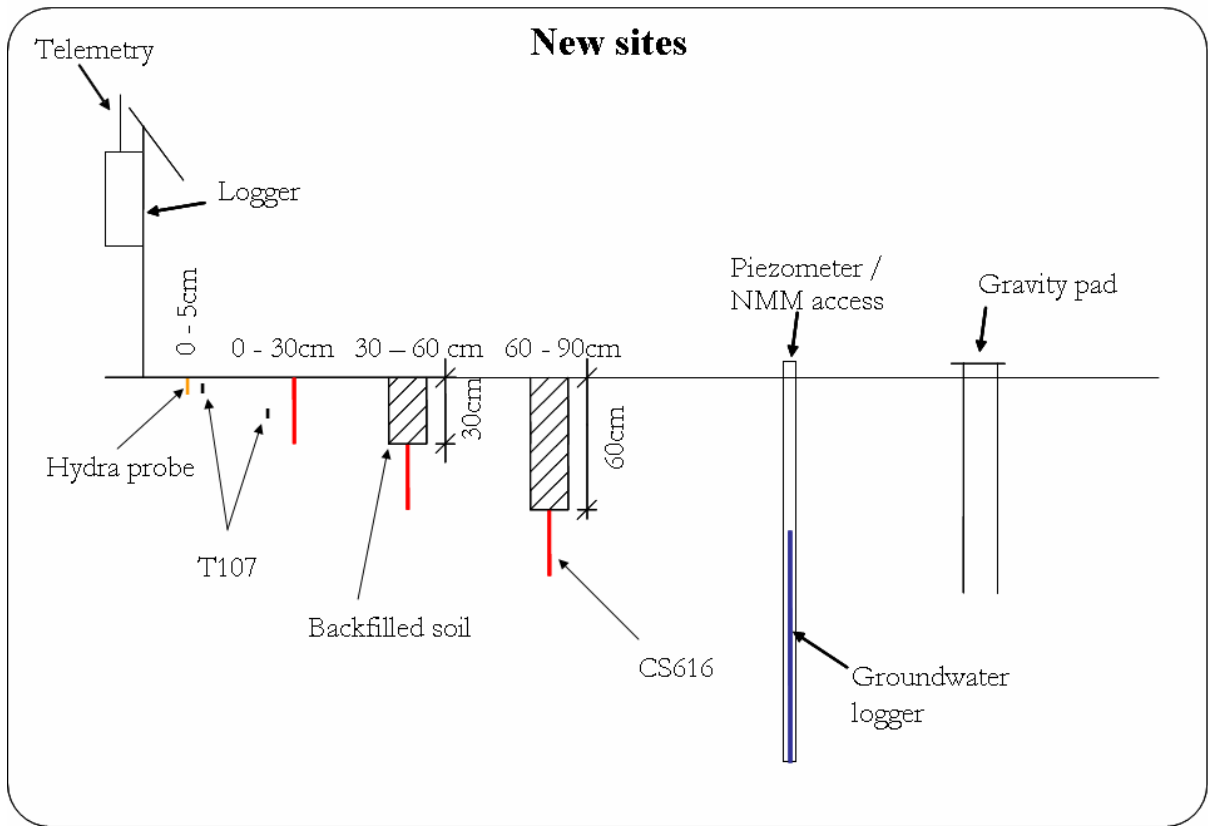
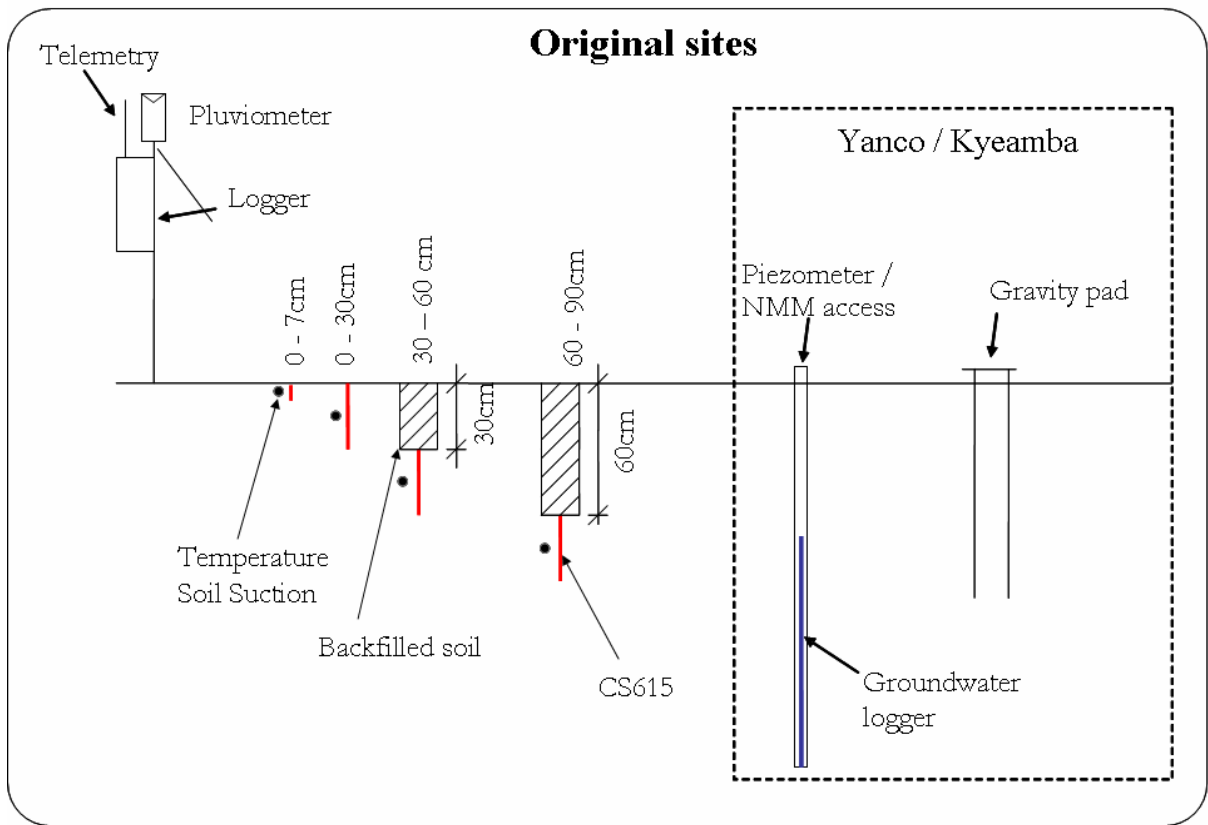


Figure 4-7: Typical equipment at the original (2001) and new (2003) soil moisture sites in the Murrumbidgee catchment. Each site provides continuous data of rainfall, soil moisture at 0-5cm (or 0-7cm), 0-30cm, 30-60cm and 60-90cm and soil temperature and accommodates periodic measurements of groundwater and TDR soil moisture measurements.

[com/cs615-1](http://www.campbellsci.com/cs615-1)), while the new sites use the updated version CS616 (Campbell, <http://www.campbellsci.com/cs616-1>), which operates at a somewhat higher measurement frequency (175 MHz compared with 44 MHz). The original sites also monitor soil temperature and soil suction (in the 60-600 kPa range) at the midpoint of the four layers 0-7cm, 0-30cm, 30-60cm and 60-90cm, whereas the new sites only monitor soil temperature from T-107 thermistors (Campbell, <http://www.campbellsci.com/107-1>) at the midpoint of 0-5cm and 0-30cm layers.

Sensor response to soil moisture varies with salinity, density, soil type and temperature, so a site-specific sensor calibration has been undertaken using both laboratory and field measurements for both reflectometers and hydraprobes (Western et al., 2000; Yeoh et al., 2008). As the CS615 and CS616 sensors are particularly sensitive to soil temperature fluctuations the T-107 temperature sensors were installed to provide a continuous record of

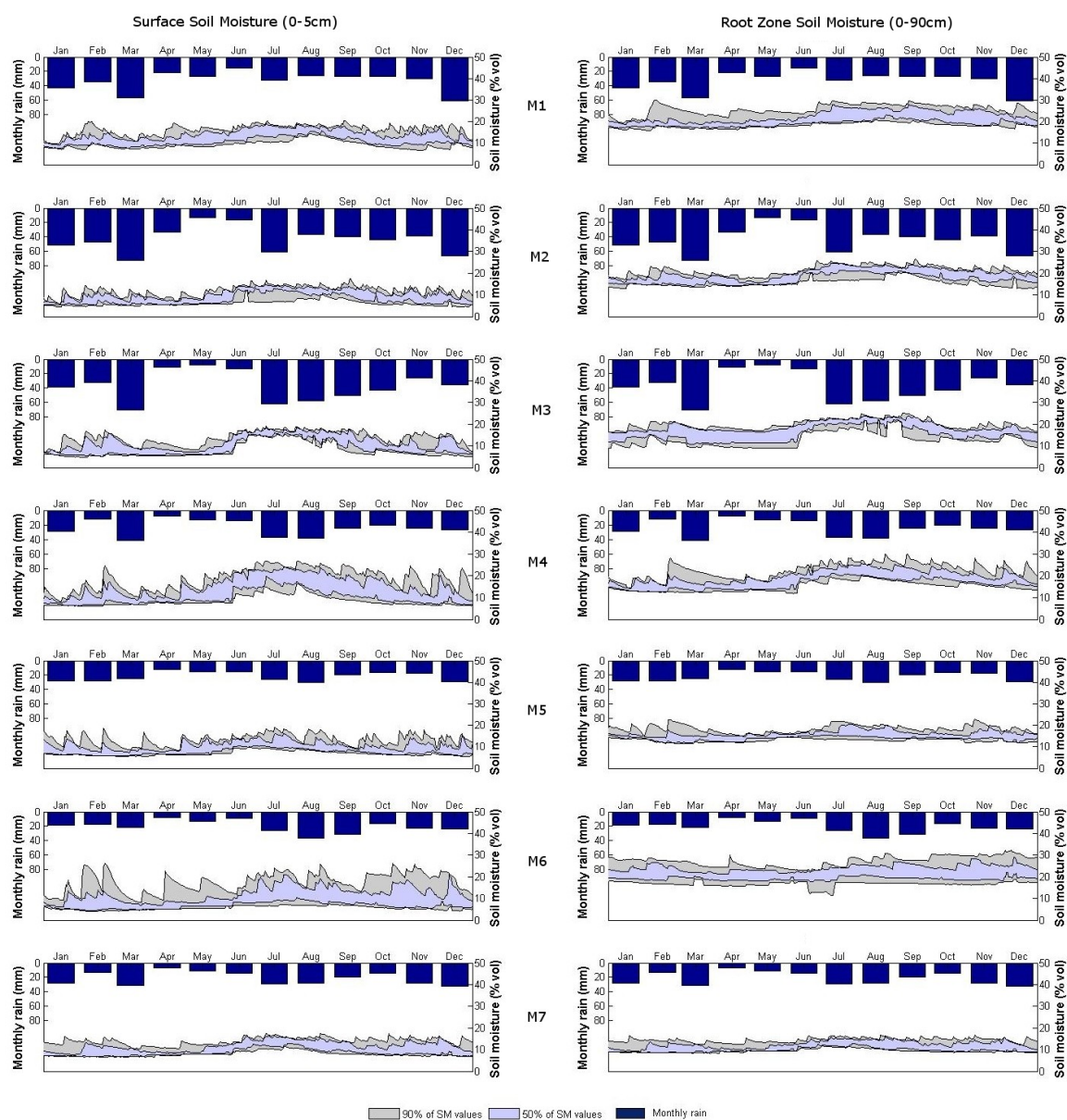


Figure 4-8: Monthly average precipitation and soil moisture variability (left: surface soil moisture 0-5cm; right: root zone soil moisture 0-90cm) across the catchment based on data derived from the Murrumbidgee monitoring network stations M1-M7 (see Figure 4-1). The shaded areas show the 50 and 90 percentile limits.

soil temperature at midway along the reflectometers. Deeper temperatures are assumed to have the same characteristics across the Yanco and Kyeamba sites and are therefore estimated from detailed soil temperature profile measurements made at the original soil moisture sites. Calibration relationships between the sensor observations, coinciding TDR measurements and thermogravimetric measurements have been established for both sensors. The average root mean square error was found to be $0.03\text{m}^3/\text{m}^3$ for both the CS616 and the Hydraprobe (Merlin et al., 2007; Yeoh et al., 2008).

Figure 4-8 shows the seasonal variability of rainfall and soil moisture conditions across the entire catchment captured by seven of the monitoring sites. The surface soil moisture within the top 5cm varies significantly between the different sites resulting in a range of about $0.05\text{-}0.25\text{m}^3/\text{m}^3$ (using the upper and lower limit defined by 50% and 90% respectively based on all observations collected within the past eight years). Note that moisture conditions are typically slightly wetter during winter (July-August), which dries over the following months towards the driest conditions typically in Autumn (April-June). Comparable seasonal variations are recorded for the root zone soil moisture. These historic data show that there is a good chance of dynamic soil moisture conditions in January-February.

A detailed description of the additional monitoring stations operated by the NSW Department of Environment and Climate Change within the Livingstone Creek and near Tumut can be found in the NAFE'06 workplan (Walker et al., 2006).

5 Air Monitoring

The Polarimetric L-band Multibeam Radiometer (PLMR) and supporting instruments (thermal imager, thermal radiometers and multispectral radiometers) will be flown aboard a high performance single engine aircraft to collect complete coverage of airborne data across the AACES transect once during each campaign. The flights have been specifically designed to cover a number of SMOS pixels that represent a wide range of land surface and climatic conditions typical of much of Australia. While the AACES transect will only be covered in entirety once during each campaign, these flights will be supplemented by a series of transect flights throughout the catchment. A transect flight is planned for the start, middle and end of each campaign. The complete transect coverage ensures that aircraft data fully capture the spatial variability contributing to the SMOS observations and that a sufficient number of SMOS pixels are monitored to allow meaningful statements be made in relation to SMOS data and derived products, while the transect flight captures the temporal variation throughout the course of the catchment.

The aircraft will be based at Narrandera Airport and operate approximately every alternate day from there. A total of 85 mission hours have been estimated for a single campaign. An overview of the planned flights is given in Figure 5-1 and a detailed flight schedule with planned flight time provided in Table 5-1.

All flights will be conducted at a **nominal 10,000ft AGL**, yielding microwave, thermal and multi-spectral data at approximately 1km resolution. Moreover, the PLMR will be used in mapping mode to collect brightness temperature data with a single incidence angle for each pixel across the entire flight area, covering 40 independent SMOS pixels in entirety. In order

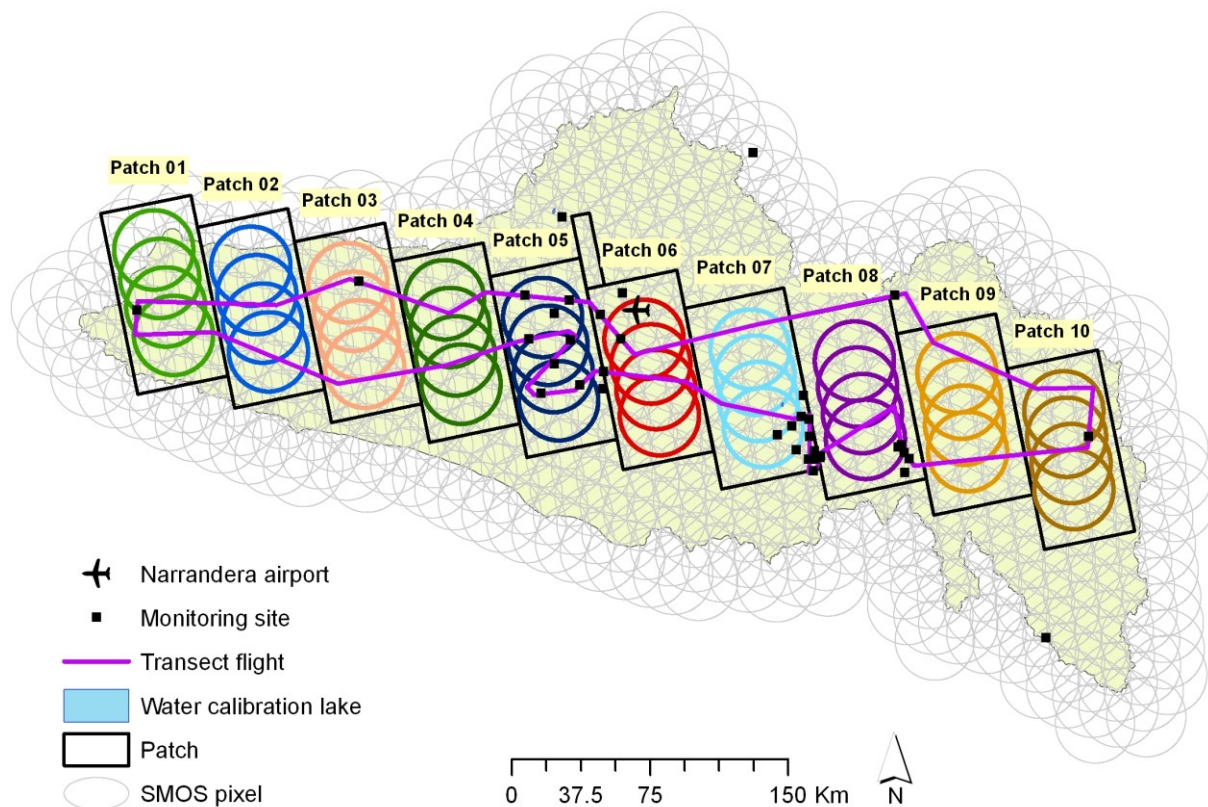


Figure 5-1: Schematic of campaign design showing aircraft coverage of SMOS footprints (circles).

Table 5-1: Flight schedule together with estimated flight duration, ground level and flight altitude information to achieve a 10,000ft AGL nominal flight altitude.

Date/Time (UTC)	Flight	Altitude (ASL)	Duration (hrs)
19/01/2010 16:36	T00	10,400/12,000/10,400 ft	6.5
21/01/2010 16:38	P01	10,200 ft	7.0
24/01/2010 16:50	P02	10,250 ft	6.6
27/01/2010 17:04	P03	10,300 ft	6.2
29/01/2010 17:04	P04	10,350 ft	6.2
1/02/2010 16:58	T00	10,400/12,000/10,400 ft	6.5
4/02/2010 16:36	P05	10,400 ft	6.1
6/02/2010 16:46	P06	10,500 ft	6.4
9/02/2010 16:45	P07	10,800 ft	6.7
12/02/2010 16:41	P08	11,100 ft	6.6
14/02/2010 16:29	P09	11,950 ft	7.0
17/02/2010 16:37	P10	12,000 ft	6.7
19/02/2010 16:36	T00	10,400/12,000/10,400 ft	6.5

to coincide with SMOS overpasses, all flights will be **centred on approximately 6:00am** local solar time (20:00 UTC). The two flight types; i) SMOS pixel coverage and ii) SMOS pixel transect are described in detail in the following sections. Moreover, detailed flight plans, flight line coordinates, and flight schedule are provided in Appendix E for each flight.

5.1 SMOS Pixel Coverage Flights

The AACES campaigns will map an area of approximately 100km × 500km across the Murrumbidgee River catchment at a nominal 1km resolution. Given the approximately 50km sized SMOS pixels, the study transect has been aligned with the SMOS L1C fixed grid and subdivided into ten patches approximately 100km × 50km in size, of which each will be mapped within a single day (Figure 5-2). The flight coverage has been designed to include a minimum of 6km overlap between each patch (by repeating a flight line of the earlier flight), thus ensuring continuity between the different flights and full coverage of the SMOS pixels (Figure 5-3). Moreover, the overlap allows an assessment of brightness temperature change from the previous flight in response to soil moisture and/or effective temperature variation. Scheduling of flight dates has been based on the actual SMOS coverage of the study transect, according to the logistical constraints discussed in a later section. All flights will originate out of Narrandera Airport (474ft ASL). The average surface elevation under the flight routes has been used to determine the optimum flight altitude across each patch and transect flight to maintain the target 1km spatial resolution of airborne data. A maximum flight altitude of 12,000ft AGL was adopted as some electronic devices onboard the aircraft have not been designed for unpressurised operation above 10,000ft.

The ferry flights to and from the originating airport have been designed such that the aircraft passes over at least one permanent monitoring station before and after covering the patch. If practical, the aircraft track will also pass over focus farms located outside of the target patch. A partial repeat of the first flight line will also be performed, to identify any brightness temperature changes between the start and the end of the flight over the patch. Finally, the flight will complete with a low level pass over a lake for calibration purposes. This cannot be repeated at the start of the flight due to the early departure and night flying requirements. The details for each flight are included in Appendix E.

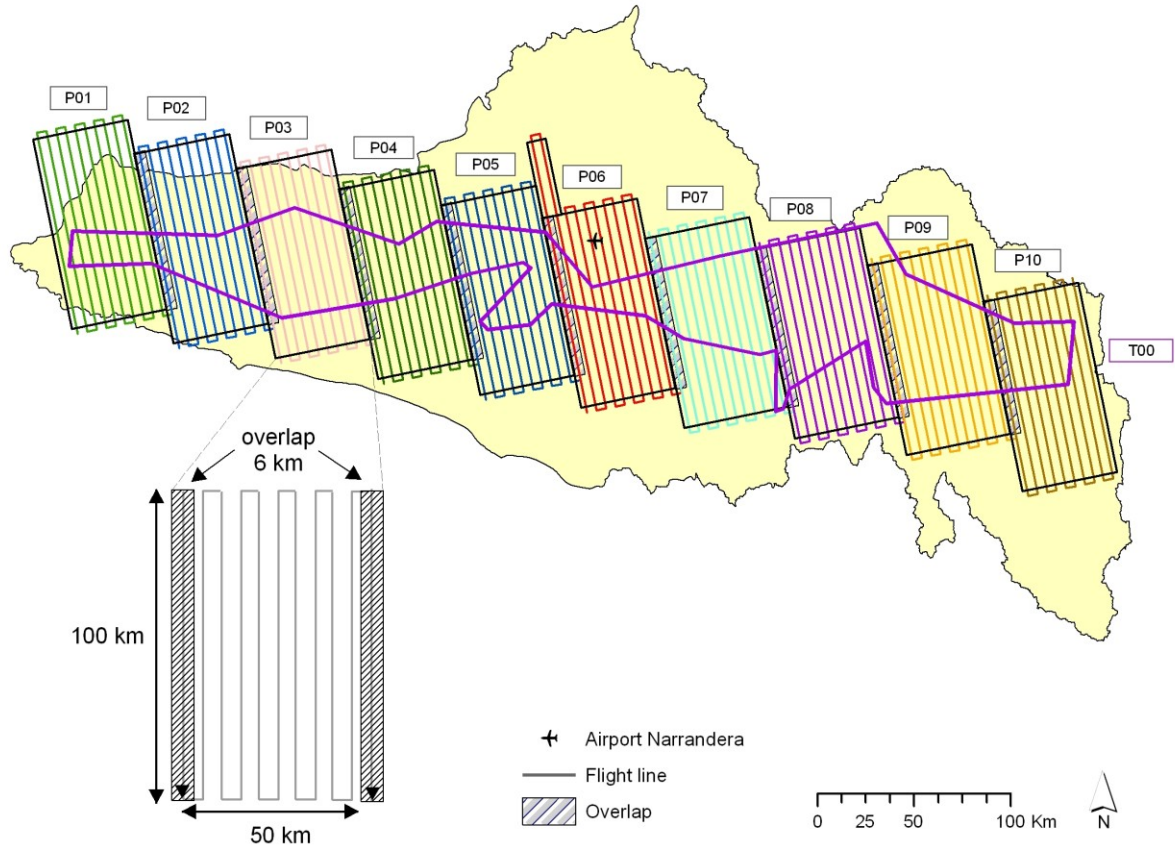


Figure 5-2: Schematic of the airborne sampling strategy showing flight patterns for each patch and the transect flight across the entire catchment.

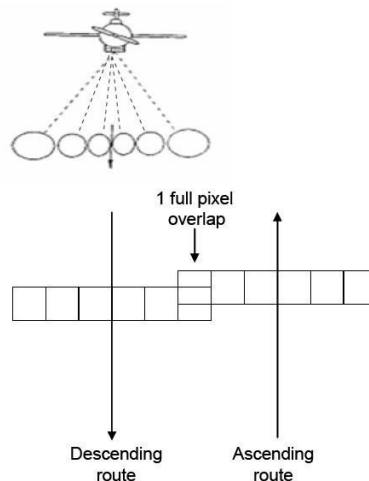


Figure 5-3: The pushbroom concept showing 6 PLMR beams with a 1 beam overlap between flight lines (Walker and Panciera, 2005).

5.2 SMOS Pixel Transect Flights

Additional to the full SMOS pixel coverage are three transect flights throughout the study region (Flight T00, see Figure 5-4); one each at the start, middle, and end of the campaign. The purpose of these flights is to capture temporal variability within the experimental transect, give a snapshot overview of the entire transect, and allow comparison with the

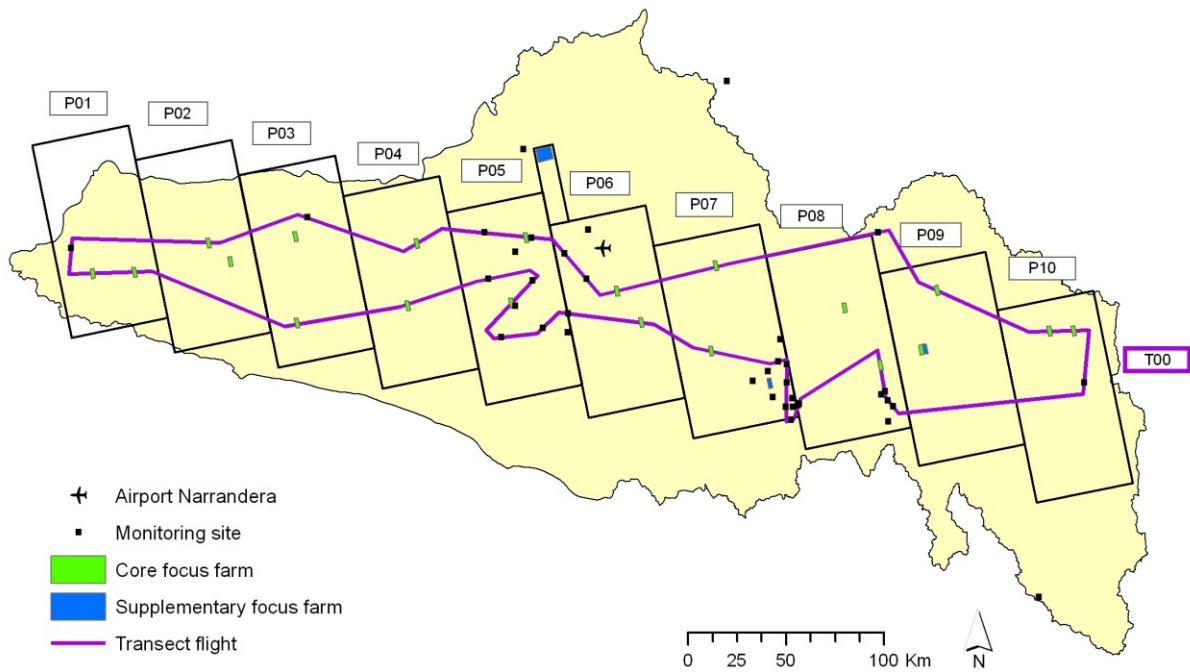


Figure 5-4: Overview of transect flight showing route over focus farms and permanent monitoring stations.

European validation strategies. This transect flight has been designed to pass through as many permanent monitoring stations and focus farms as practical, to provide comparative ground-based data. Moreover, this flight has been designed to repeat the first ~12 km of the circuit for assessing temporal variation during the flight. The flight concludes with a calibration flight over Lake Wyangan for sensor calibration. The details for this flight are included in Appendix E.

5.3 Calibration

The normal operating procedure for PLMR is to perform a “warm” and “cold” calibration before, during and after each flight. The before and after flight calibrations are achieved by removing PLMR from the aircraft and making brightness temperature measurements of a calibration target and the sky (see Figure 5-5). The in-flight calibration is accomplished by measuring the brightness temperature of the sky during a series of steep turns (if possible) and of a water body. Lake Wyangan will be used as a cold target for in-flight calibration of PLMR when covering the western patches (P01-P06 and T00), while Lake Albert will be used for the eastern patches (P07-P10; see Figure 5-1).

As all flights will commence in the dark, flights over water storages will only be conducted on the return to Narrandera airport at the end of the flight. Given the relatively small size of the water storages, PLMR will be flown at the lowest permissible altitude (500ft for Lake Wyangan and 1,000ft for Lake Albert) so as the swath of the instrument (300m at 500ft) will be totally included within the lake boundary along a distance of around 1km. Calibration flights are illustrated in Figure 5-6.

Ground requirements for over-water flights include monitoring of the water temperature and salinity within the top 1cm layer of water. Both quantities will be monitored continuously during the campaign using a UNIDATA 6536B[®] temperature and salinity sensor connected to a logger, located at 34.218S and 146.022E for Lake Wyangan and 35.167S and 147.373E for Lake Albert. Furthermore, transects of water temperature and salinity in the top 1cm layer



Figure 5-5: Upper left: undertaking a sky cold point calibration with PLMR; upper right: undertaking a warm point calibration with the calibration box shown in the inset; lower left: the buoy used to monitor water temperature and salinity; lower right: undertaking a boat transect of water salinity and temperature.

will be undertaken with a handheld temperature and salinity meter (Hydralab Quanta[®]) at the start and end of periods using the respective lakes, coincident with flights. This will involve making north-south and east-west transects at 100m spacing centred on the monitoring station. The purpose of these measurements is to check for spatial variability. Rodger Young will be responsible person for these measurements.

5.4 Flight Time Calculations

In order to provide an estimate of the total flight time, climb/turn and cruise speeds of the aircraft were assumed to be 110 and 140Kts, respectively. The climb rate was assumed to be 300ft/min and the time to descend from maximum altitude to ground level was set to a minimum of 10min. To account for turns, the flight lines were extended 2km beyond the measurement area and a further 5km added to represent the connecting transect between two adjacent flight lines. The estimated time to conduct each flight is given in Table 5-1.

5.5 Flight Schedule

The primary objective of the AACES campaign is to evaluate SMOS. Consequently, all flights have been scheduled to coincide with SMOS overpass dates. Additionally, logistical constraints in relation to ground crew and subsequent analysis require that:

1. work is conducted systematically from one end of the transect to the other, and
2. adjacent flights are made in as rapid succession as possible.

However, SMOS coverage is typically either for the left half, right half, and in some cases, the entire transect. Consequently, the campaign dates and sequencing of flights has been based on this constraint, with the circuit flight requiring complete SMOS coverage of the campaign transect.

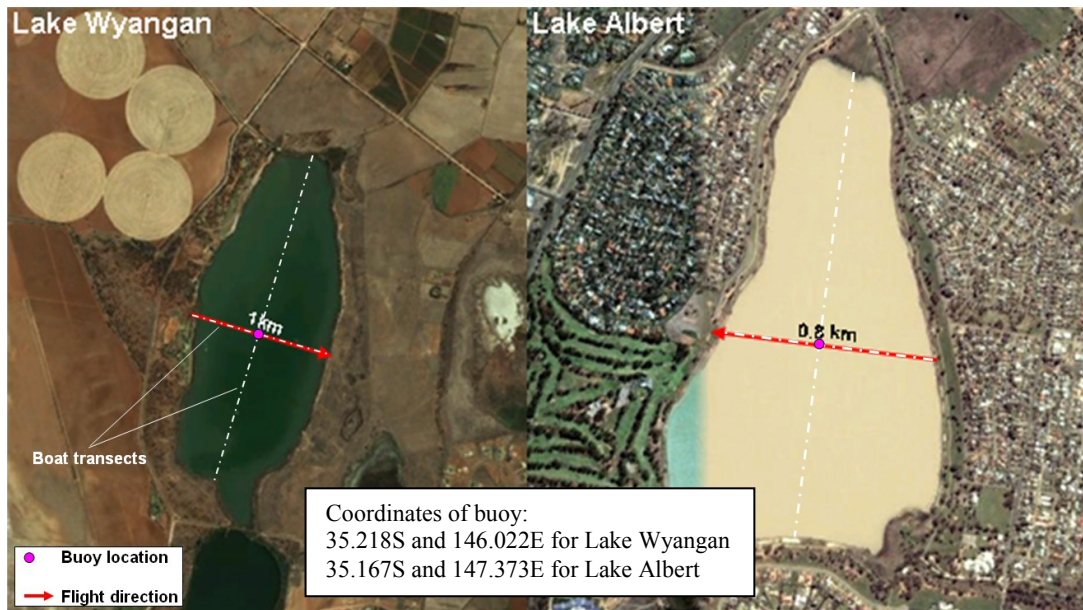


Figure 5-6: Calibration flight (red line) and boat transects (white lines) over Lake Wyangan and Lake Albert.

A secondary objective includes the evaluation of other satellite soil moisture products and use of other satellite data for ancillary input and downscaling. Consequently a summary of all satellite overpasses coinciding with AACES flights is given in Table 5-2, but little consideration could be given to matching other satellite overpasses due to the heavy constraints of matching with SMOS overpasses and achieving the shortest possible campaign duration.

Table 5-2: Summary of satellite acquisitions that coincide with aircraft coverage of the AACES flights. Here P is for 0 to 12 UTC and A is for 12 to 24 UTC; shaded columns are the time of aircraft over-flight. The symbology ● indicates fully covered while ○ indicates partly covered. Check tables in chapter 3 for satellite coverage on other campaign dates.

Date (Local)	1/22		1/25		1/28		1/30		2/5		2/7		2/10		2/13		2/15		2/18	
Flight	P01		P02		P03		P04		P05		P06		P07		P08		P09		P10	
	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
SMOS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
AMSR-E		●	●	●	●		●		●		●	●	●	●	●	●				●
WindSat			●	●			●		●	●			○	●					●	●
ASCAT		●			●				●		●		●					○		
PALSAR(L)	●		○												○	●	●			
PALSAR(H)																				
ASAR		●		●		○			●		●		○			○			●	
Aqua	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Terra	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ASTER																				
Landsat-5									●					●						
Landsat-7			○											○		○				
CHRIS					○															
AVNIR-2																				

Transect on 20th January

Patch	01		02		03		04		05		06		07		08		09		10		
	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	
SMOS	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
AMSR-E		•		•		•		•		•		•	○	•	○	•	•	•	•	•	•
WindSat	•	○	•	•	•	•	•	•	•	•	•	•	•	•	○	•	○	•			•
ASCAT																					
PALSAR(L)	•		•		○																
PALSAR(H)	○		○																		
ASAR			○		•		•		•		•		•		•		○		○		
Aqua	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Terra	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
ASTER					○		○						○		○		○				
Landsat-5							○		•		•		○		○						
Landsat-7											○		○		•		○		○		
CHRIS																					
AVNIR-2							○		○		○										

Transect on 2nd February

Patch	01		02		03		04		05		06		07		08		09		10		
	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	
SMOS	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
AMSR-E	•	•	•	•	•	•	•	•	•	•	○	•		•		•		•		•	•
WindSat	○		○		•		•		•		•		•		•		•		•		•
ASCAT	•		•		•		•		•		•		•		•		•		○		
PALSAR(L)																					
PALSAR(H)																					
ASAR																					
Aqua	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Terra	•	○	•	○	•		•		•		•		•		•		•		•		•
ASTER																					
Landsat-5	○		○																		
Landsat-7																					
CHRIS								○													
AVNIR-2		○																			

Transect on 20th February

Patch	01		02		03		04		05		06		07		08		09		10		
	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	
SMOS	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
AMSR-E	•		•	○	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
WindSat													○		○		•		•		
ASCAT																					
PALSAR(L)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
PALSAR(H)					○		○								○		○		○		
ASAR										○		•		•		•		•		•	•
Aqua	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Terra		•		•		•	○	•		•		•		•	○	•		•		•	•
ASTER																					
Landsat-5					○		○		•		•		○								
Landsat-7		○		○		•		•		○											
CHRIS				○																	
AVNIR-2																					

6 Ground Monitoring

This chapter should be read in conjunction with Chapter 7 where ground sampling protocols are presented, and Chapter 8 where logistics are discussed.

Ground monitoring for the AACES campaigns is designed specifically to validate the aircraft soil moisture retrievals at 1km resolution, which will subsequently be used to characterise the OzNet soil moisture monitoring networks ability to represent the average surface soil moisture content at the spatial resolution of SMOS pixels, and to validate the SMOS soil moisture product itself for each of the SMOS pixels covered by the transect. Consequently, the ground monitoring component of this campaign consists of (Figure 6-1):

1. Network of continuous soil moisture monitoring stations as described in Chapter 4,
2. Supplementary monitoring stations located at focus farms,
3. High resolution spatial soil moisture mapping at focus farms, and
4. Supporting data at focus farms.

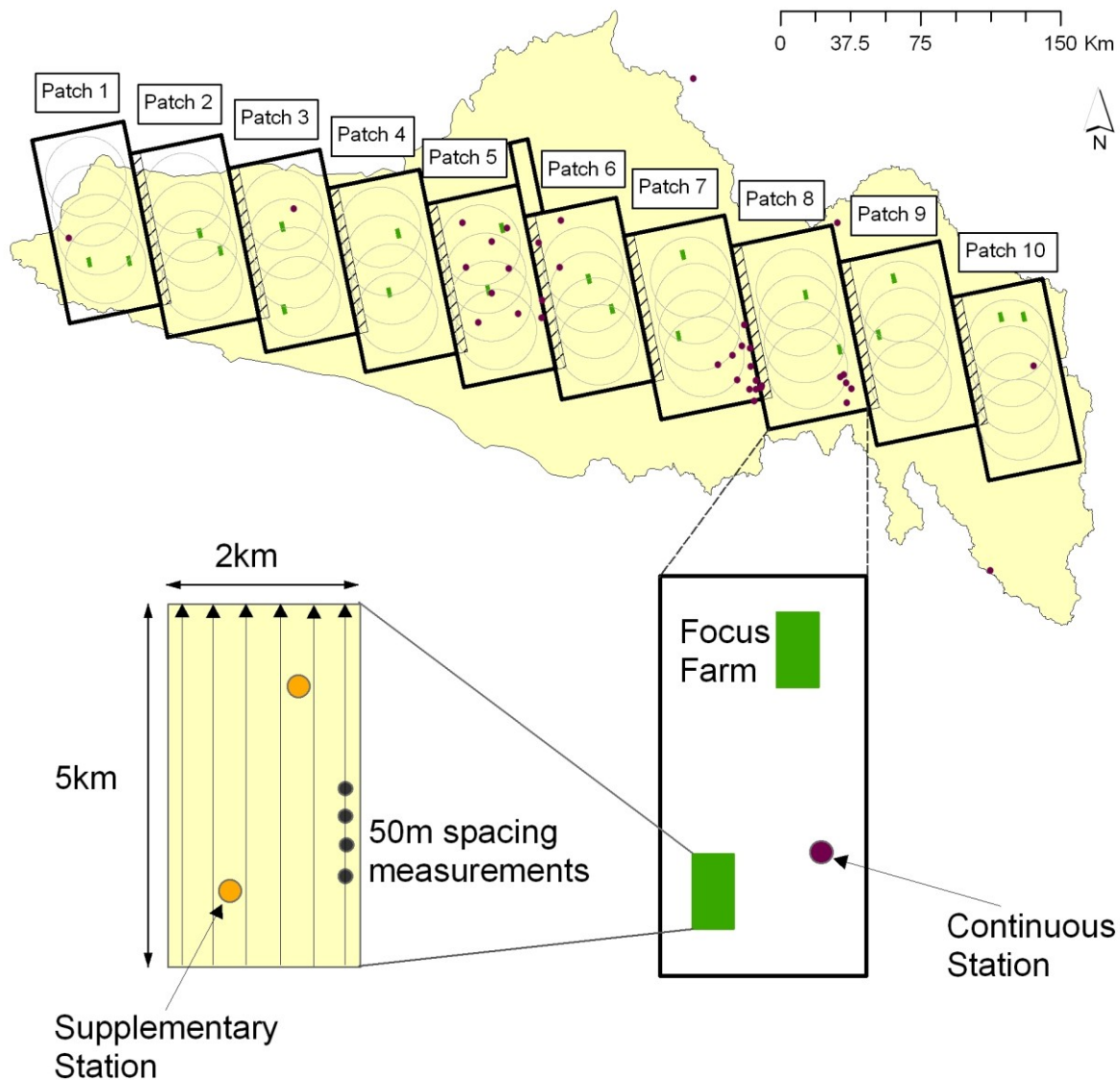


Figure 6-1: Schematic of the ground sampling strategy within the identified focus farms of each patch.

For logistical reasons, the AACES transect has been divided into 10 patches as discussed in Chapter 5, with each patch being the focus of a single day of ground monitoring and coincident aircraft/SMOS coverage. Moreover, a total of two focus farms have been selected for each patch. A third supplementary focus farm is included for patches where our national collaborators have expressed an interest to participate and support our ground monitoring activities. These collaborators include CSIRO Griffith (patch 6) and the NSW Department of Environment, Climate Change & Water at Wagga Wagga (patch 7 and patch 9). A schematic summary of the ground soil moisture monitoring is provided in Figure 6-1 and a ground sampling schedule included in Table 6-1, showing that the ground crew will systematically make their way from one end of the catchment to the other, following the aircraft.

Table 6-1: Schedule for ground monitoring activities. Refer also to Chapter 8 for further details.

Local Time	Day	Aircrew Flight type	Patch	Ground crew Activity	Patch	Base station
18.01.10	Mon			Arrival at study area		
19.01.10	Tue			Briefing/Training		
20.01.10	Wed	T00	all	Reconnaissance 1/ full "practice sampling" 1	1	Hay
21.01.10	Thu	-		Break		
22.01.10	Fri	P01	1	SM/Veg sampling 1		
23.01.10	Sat	-	2	Reconnaissance 2	2	
24.01.10	Sun	-		Break		
25.01.10	Mon	P02	2	SM/Veg sampling 2		
26.01.10	Tue	-	3	Reconnaissance 3	3	
27.01.10	Wed	-		Break		
28.01.10	Thu	P03	3	SM/Veg sampling 3		
29.01.10	Fri	-	4	Reconnaissance 4	4	
30.01.10	Sat	P04	4	SM/Veg sampling 4		
31.01.10	Sun	-		Move to Yanco		
01.02.10	Mon	-	5	Reconnaissance 5	5	Yanco
02.02.10	Tue	T00	all	SM/Veg sampling 5		
03.02.10	Wed	-		Break		
04.02.10	Thu	-		Break		
05.02.10	Fri	P05	5	SM/Veg sampling 5		
06.02.10	Sat	-	6	Reconnaissance 6	6	
07.02.10	Sun	P06	6	SM/Veg sampling 6		
08.02.10	Mon	-	7	Reconnaissance 7	7	
09.02.10	Tue	-		Break		
10.02.10	Wed	P07	7	SM/Veg sampling 7		
11.02.10	Thu	-		Move to Gundagai		
12.02.10	Fri	-	8	Reconnaissance 8	8	Gundagai
13.02.10	Sat	P08	8	SM/Veg sampling 8		
14.02.10	Sun	-	9	Reconnaissance 9	9	
15.02.10	Mon	P09	9	SM/Veg sampling 9		
16.02.10	Tue	-		Move to Yass		
17.02.10	Wed	-	10	Reconnaissance 10	10	Yass
18.02.10	Thu	P10	10	SM/Veg sampling 10		
19.02.10	Fri	-		Break		
20.02.10	Sat	T00	all	SM/Veg sampling 10		
21.02.10	Sun			Return to Melbourne		

6.1 Focus Farms

Focus farms have been identified on the basis of background information that includes climate, topography, soil type and land use, as discussed in Chapter 4. An additional constraint for farm selection was accessibility and travel time from the ground crew operations base. Consequently the focus farms represent locally the dominant soil and vegetation type and are within themselves fairly homogeneous, yet capturing the variability that exists across the patch while being practically accessible by road. The dominant features of each patch in the AACES transect are summarised in Table 6-2, showing that focus farms represent the main soil and land use types present within the patch.

The focus farms have been selected to provide ground truth for several 1km resolution PLMR pixels along the flight track. Consequently, the farm monitoring transects are 2km in width, 5km in length, and aligned with the flight direction, to allow for ground monitoring of a minimum of four independent PLMR pixels per farm. The 2km width provides an allowance for any potential misalignment of the PLMR beams due to misalignment of the aircraft with planned flight tracks, variations in ground altitude and/or zero-roll/yaw flight due to cross wind. Additionally, focus farm transects have been located within the inner 2 beams of planned PLMR coverage, meaning that the focus farm transect cannot be entirely missed between adjacent flight lines for the same reasons. By designing the focus farm transect locations, orientation, and dimensions in this way, complete ground coverage of individual PLMR pixels along the focus farm transect is guaranteed.

A total of 20 focus farms have been identified across the entire campaign transect, and the key characteristics of these farms are summarised in Table 6-3. Figure 6-2 shows a collage of photos giving a visual summary of the different characteristics of each focus farm transect. Detailed directions to each focus farm are provided in Appendix F and aerial images of each focus farm transect are included in Appendix G.

6.2 Supplementary Monitoring Stations

Permanent monitoring stations will also be supplemented by two identical temporary monitoring stations at each focus farm. Due to limited equipment, these stations will be moved across the study transect, with stations set up during the teams site reconnaissance that is scheduled at least the 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 (MEA LWS v1.1), two soil moisture sensors (Delta-T Thetaprob; 0-6cm and

Table 6-2: Summary of soil type and land use fractions for each patch of the AACES transect. The soil texture and land use represented by focus farms is indicated in orange (Australian Bureau of Rural Science, 2001).

Patch	soil texture – areal percentage						land use – areal percentage					
	clay loam	clay	loam	sand	sandy loam	undefined	conservation and nature reserve	urban	dryland agriculture and plantation	irrigated agriculture and plantation	grazing and production forestry	water
1	30.5	62.7	0.1	6.2	0.5	-	2.8	0.1	11.0	6.4	77.4	2.2
2	-	100	-	-	-	-	1.4	<0.1	0.1	1.6	96.6	0.3
3	-	65.5	34.5	-	-	-	2.6	<0.1	0.1	0.6	96.5	0.2
4	-	16.8	83.2	-	-	-	0.2	<0.1	1.7	8.6	89.1	0.3
5	-	-	98.9	-	-	1.1	0.2	0.3	16	38.4	42.7	2.4
6	-	-	81.8	4.9	13.1	0.2	3.0	0.4	54.2	7.3	34.1	1.0
7	-	-	62.2	2.4	34.8	0.6	1.6	0.5	55.7	0.5	41.4	0.3
8	-	-	29.2	-	67.9	2.9	3.5	0.1	41.4	0.3	54.7	-
9	4.3	-	17.4	-	77.6	0.7	38.4	0.2	23.4	0.2	36.6	1.2
10	0.5	-	21.7	-	77.6	0.2	33.7	8.0	28.3	0.2	29.6	0.2

*orange shading represents soil/land use type which is covered by the two focus farms in each box respectively

Table 6-3: Summary of soil, land use and climate for each focus farm together with reasons for selection and logistics information on farm altitude, ground crew operation base to service the focus farm and estimated travel time (Australian Bureau of Rural Science, Australian Bureau of Meteorology, and GeoscienceAustralia).

Patch/ Farm	Soil Texture	Major Land use	Land Use Comments	Rainfall (mm/a)	PET (mm/a)	Elevation (m)	Base station	Travel time (~ x min)	
1/1	Clay loams	Grazing	• Volunteer, naturalised, native or improved pastures	338	1146	60	Hay	100 (118km)	
1/2	Clays	Grazing/ Cropping	• Volunteer, naturalised, native or improved pastures/ • Cropping - continuous or rotation	343	1145	69		80 (99km)	
2/3	Clays	Grazing	• Volunteer, naturalised, native or improved pastures	353	1159	78		42 (56km)	
2/4	Clays	Grazing	• Volunteer, naturalised, native or improved pastures	358	1161	78		80 (59km)	
3/5	Loams	Grazing	• Rangeland grazing	367	1177	88		15 (18km)	
3/6	Clays	Grazing/ Cropping	• Volunteer, naturalised, native or improved pastures/ • Cropping - with a fixed irrigation system not used at the time of mapping	370	1183	85		50 (60km)	
4/7	Loams	Grazing	• Rangeland grazing	407	1185	105		120 (85km)	
4/8	Loams	Grazing	• Rangeland grazing/ • Volunteer, naturalised, native or improved pastures	399	1196	102		130 (116km)	
5/9	Loams	Grazing	• Volunteer, naturalised, native or improved pastures/ • Tree-Shrub Cover - Native forest	423	1193	129	Yanco	~38 (40km)	
5/10	Loams	Grazing/ Cropping	• Volunteer, naturalised, native or improved pastures, Irrigated Pastures/ • Cropping - continuous or rotation - irrigated, Irrigated rice	415	1141	123		~85 (90km)	
6/11	Loams	Cropping/ Grazing	• Cropping - continuous or rotation/ • Volunteer, naturalised, native or improved pastures, with previous evidence of cultivation/ • Farm dam	463	1220	151		~38 (40km)	
6/12	Loams	Cropping/ Grazing	• Cropping - continuous or rotation/ • Volunteer, naturalised, native or improved pastures, with previous evidence of cultivation	405	1222	180		~60 (64km)	
7/13	Loams	Cropping/ Grazing	• Cropping - continuous or rotation/ • Volunteer, naturalised, native or improved pastures, with previous evidence of cultivation, • Sown, improved perennial pastures / • Farm dams	510	1222	206		~90 (84km)	
7/14	Loams	Cropping/ Grazing	• Cropping - continuous or rotation/ • Volunteer, naturalised, native or improved pastures, with previous evidence of cultivation, • Sown, improved perennial pastures / • Farm dams	568	1219	196		~95 (114km)	
8/15	Sandy loams	Grazing/ Cropping	• Volunteer, naturalised, native or improved pastures, with previous evidence of cultivation, Irrigated pastures • Sown, improved perennial pastures / • Cropping - continuous or rotation/ • River/Drainage system	572	1211	237		Gundagai	~32 (30km)
8/16	Sandy loams	Grazing	• Volunteer, naturalised, native or improved pastures, • Sown, improved perennial pastures • Farm dams/Floodplain swamp • Conservation Area- Lands fenced and treated for land degradation problems	819	1167	293			~34 (34km)
9/17	Loams	Grazing	• Volunteer, naturalised, native or improved pastures, • Cropping - continuous or rotation	726	1167	320	~34 (23km)		
9/18	Sandy loams	Grazing	• Volunteer, naturalised, native or improved pastures, • Sown, improved perennial pastures • Farm dams	1100	1156	407	~46 (48km)		
10/19	Sandy loams	Grazing	• Volunteer, naturalised, native or improved pastures, • Sown, improved perennial pastures • Vineyard/Farm dams	723	1141	575	Yass	~45 (36km)	
10/20	Sandy loams	Grazing	• Volunteer, naturalised, native or improved pastures, • Tree-Shrub Cover - Softwood plantation	693	1137	645		~53 (46km)	

23-29cm) and four soil temperature sensors (MEA6507A; 2.5cm, 5cm, 15cm and 40cm depth) in order to provide time series data during the sampling period (Figure 6-3).

Such measurements will be used 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. The proposed locations of supplementary monitoring stations in the focus farm transect are indicated in Appendix G, and will be confirmed with actual field conditions that exist at the time of the campaign. Moreover, these stations will be located in representative areas on the basis of dominant vegetation type(s) and topography.

Within each of the focus farms a 2km × 5km area (oriented along the direction of flight lines) has been established and subdivided by six ground sampling “transect” lines, each 5km in length and 330m apart (Figure 6-4). Ground teams will make three surface soil moisture measurements (within a radius of 1m) every 50m along these transects using the Hydraprobe Data Assimilation System (HDAS; see Appendix A). This will allow the effect of random errors in local scale soil moisture measurements to be minimised. 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.

Additional to soil moisture, a number of other ancillary information will be entered and recorded in the HDAS system for each sampling site. This information includes:

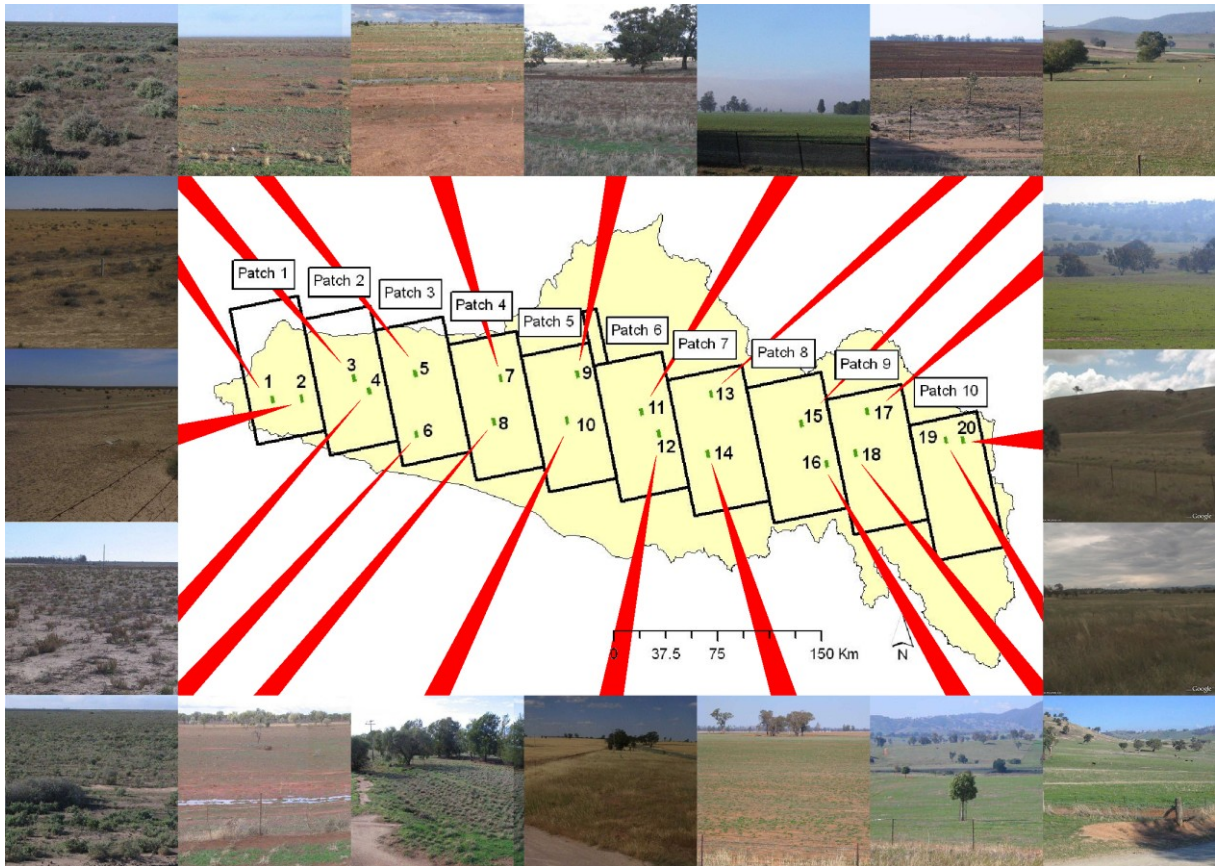


Figure 6-2: Collage of photographs for focus farms.

- land cover type,
- vegetation canopy height,
- a visual observation of dew presence and characteristics, and
- a visual estimate of surface rock cover fraction.

This and other ancillary information only needs to be entered once for each of the three replicates at each measurement location. Further details on this ancillary information are included below and in Chapter 7 where measurement protocols are presented.

6.2.1 Land cover classification

Land cover information can be used to support the interpretation of remotely sensed data in various ways. In particular, it has been used to interpolate vegetation water content information. It is therefore important to characterise the main land cover types in the study area at the time of the campaign, to derive a land cover map from satellites like LandSat. Land cover will be characterised by visual observation, assigning every sample location to one of the predefined subclasses. Photographs of the typical vegetation types found in the catchment are included in Figure 6-6, which may be a useful reference for identifying the vegetation types encountered in the focus farms.

6.2.2 Canopy height

Information on canopy height can also be used to interpolate vegetation water content information. In particular, it gives an estimate of vegetation amount and/or crop maturity. Consequently, canopy height will be estimated to the nearest decimetre.

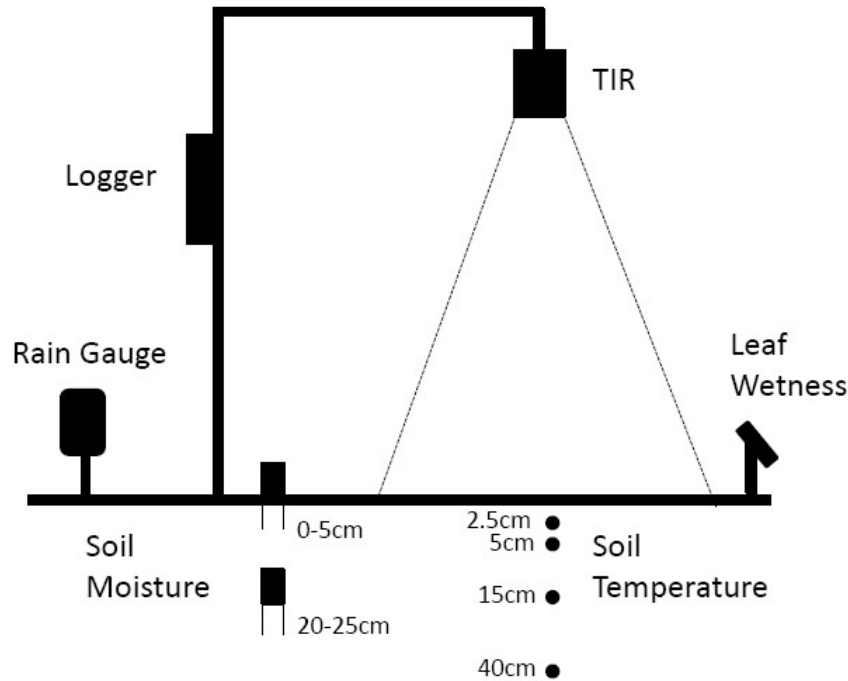


Figure 6-3: Schematic of the temporary monitoring station.

6.2.3 Dew

The presence of dew on vegetation at the time of morning SMOS overpass is likely to affect the passive microwave observation and subsequent retrieval of soil moisture. In order to support the leaf wetness measurements made by the supplementary monitoring stations and quantitative dew measurements made by the vegetation team, the soil moisture sampling team will be required to make a visual estimate of the leaf wetness conditions during the early hours of the day to assist with both SMOS and PLMR interpretation. These measurements only need be recorded until the dew has dried off.

6.2.4 Surface rock cover

The effect of surface rock cover on microwave emission of the soil is still unclear and has not received special attention, despite the fact that large parts of the earth's surface have significant fractional surface rock coverage. The percentage of surface rock cover will be estimated visually at all sample sites. A standard fractional coverage chart is included in Figure 6-5 to assist with visual estimation of fractional cover.

6.3 Vegetation Sampling

Vegetation water content (g of water per m²) is an important parameter for modelling land surface emission at L-band and will be derived from destructive vegetation samples taken at several sampling locations. Moreover, surface spectral reflectance data is valuable in developing methods to estimate the vegetation water content and other canopy variables. Spectral observations made concurrent with biomass sampling will therefore provide the essential information needed for larger scale mapping using aircraft and satellite observations. In addition, reflectance measurements made concurrent with MODIS overpasses allow the validation of MODIS reflectance estimates based upon correction algorithms. During AACES, the Fieldspec3 developed by ASD (<http://www.asdi.com/products/fieldspec-3>) will

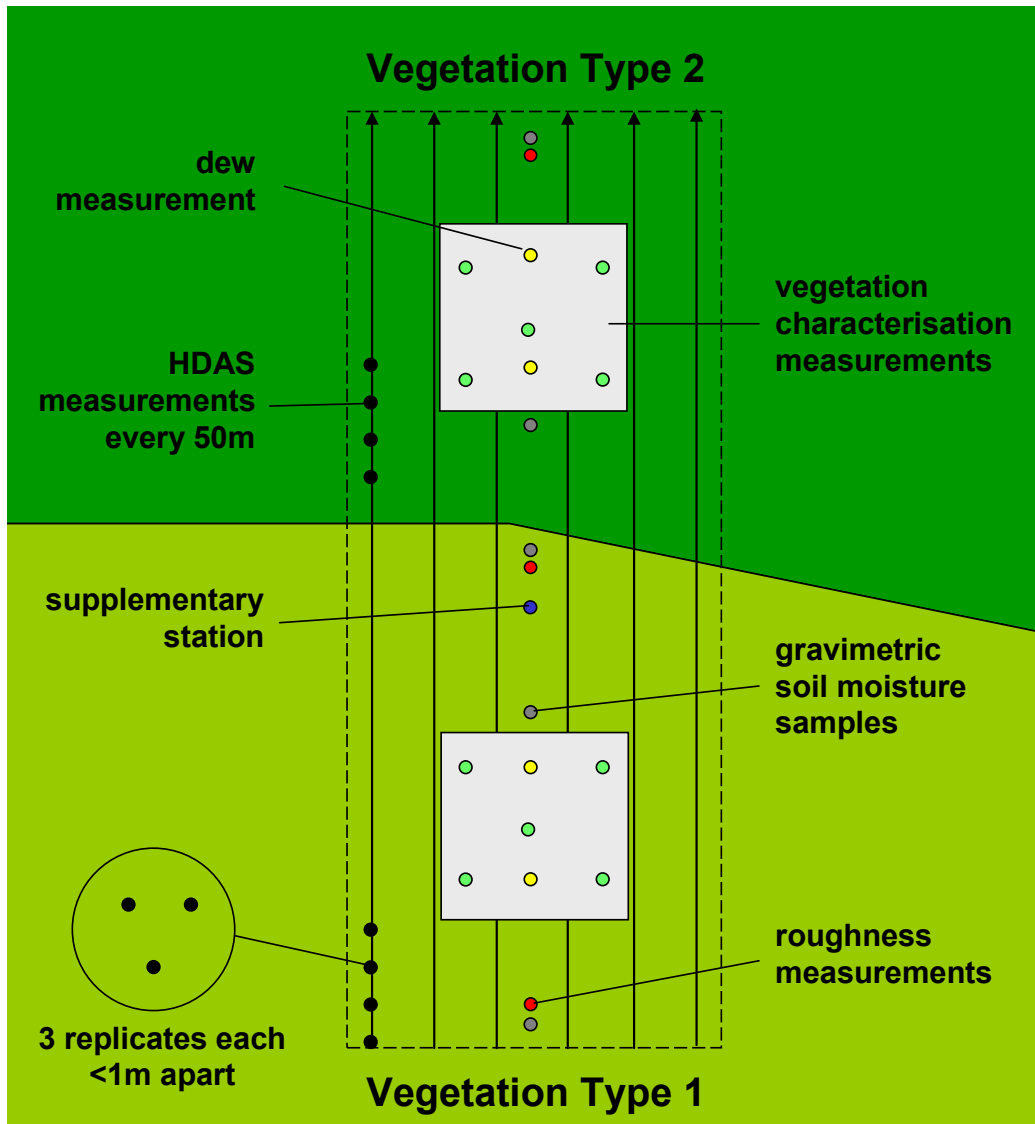


Figure 6-4: Schematic of focus farm sampling strategy.

be used to make spectral measurements, and leaf area will be measured with a Licor LAI-2000.

The objective of this vegetation sampling is to develop algorithms to extrapolate vegetation water content measurements made at focus farms to entire PLMR pixels and subsequently to entire SMOS pixels, using airborne and satellite spectral data. Consequently, it is important to characterise all dominant vegetation types at various stages of maturity and vegetation water content throughout the AACES transect. While the exact sampling locations and strategy adopted in the field will be left to the vegetation teams, following are some recommendations of the general approach to be followed.

Vegetation samples for biomass, vegetation water content and surface reflectance/LAI measurements will be collected in 1km boxes which represent 1km resolution PLMR pixels. Within each 1km box, the major vegetation types will be characterised by making measurements at a minimum of 5 sampling locations distributed within homogeneous crops/paddocks. Figure 6-4 illustrates the rationale of the vegetation sampling locations according to the 1km box classification and the major vegetation types. Vegetation samples should be repeated for each vegetation type or maturity across the focus farm transect. Additional vegetation sampling should be performed outside the focus farm transect and/or

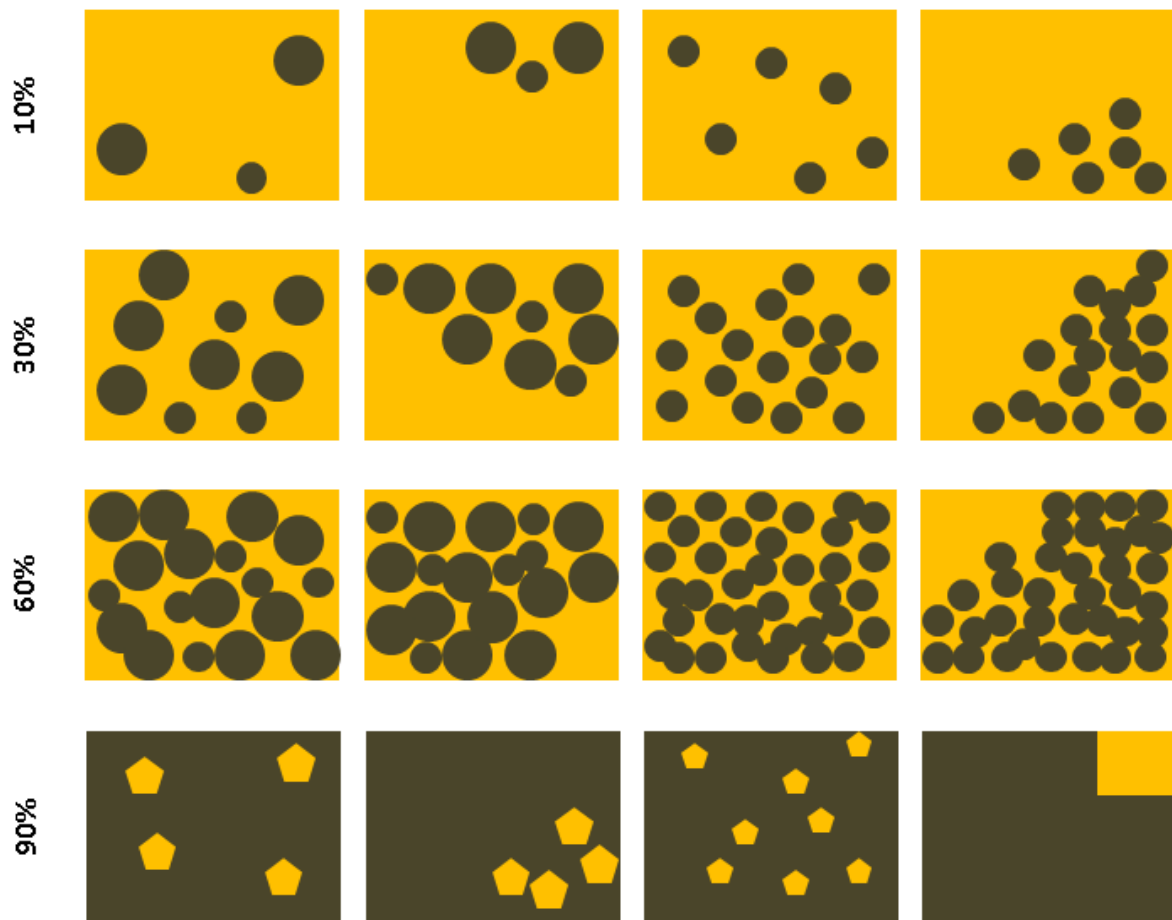


Figure 6-5: Standard fractional coverage chart to aid visual estimation of fractional surface rock cover fraction (brown=rock; orange=soil).

focus farms when a major vegetation type is not represented by the focus farm transect. **These measurements will be made during the hours of 10am and 2pm eastern standard time, which are optimal for spectral observations.**

To assist with interpolation of vegetation water content information and derivation of a land cover map of the region, the vegetation type will be recorded for each vegetation sampling area. Moreover, vegetation canopy height and row spacing (in the case of row crops) will be recorded.

6.4 Supporting Data

Vegetation teams are additionally in charge of collecting a range of supporting data, including:

- Quantitative dew samples,
- Soil roughness measurements,
- Gravimetric soil moisture samples, and
- Soil texture samples.

Further details on this supporting data are included below and in Chapter 7 where measurement protocols are presented.

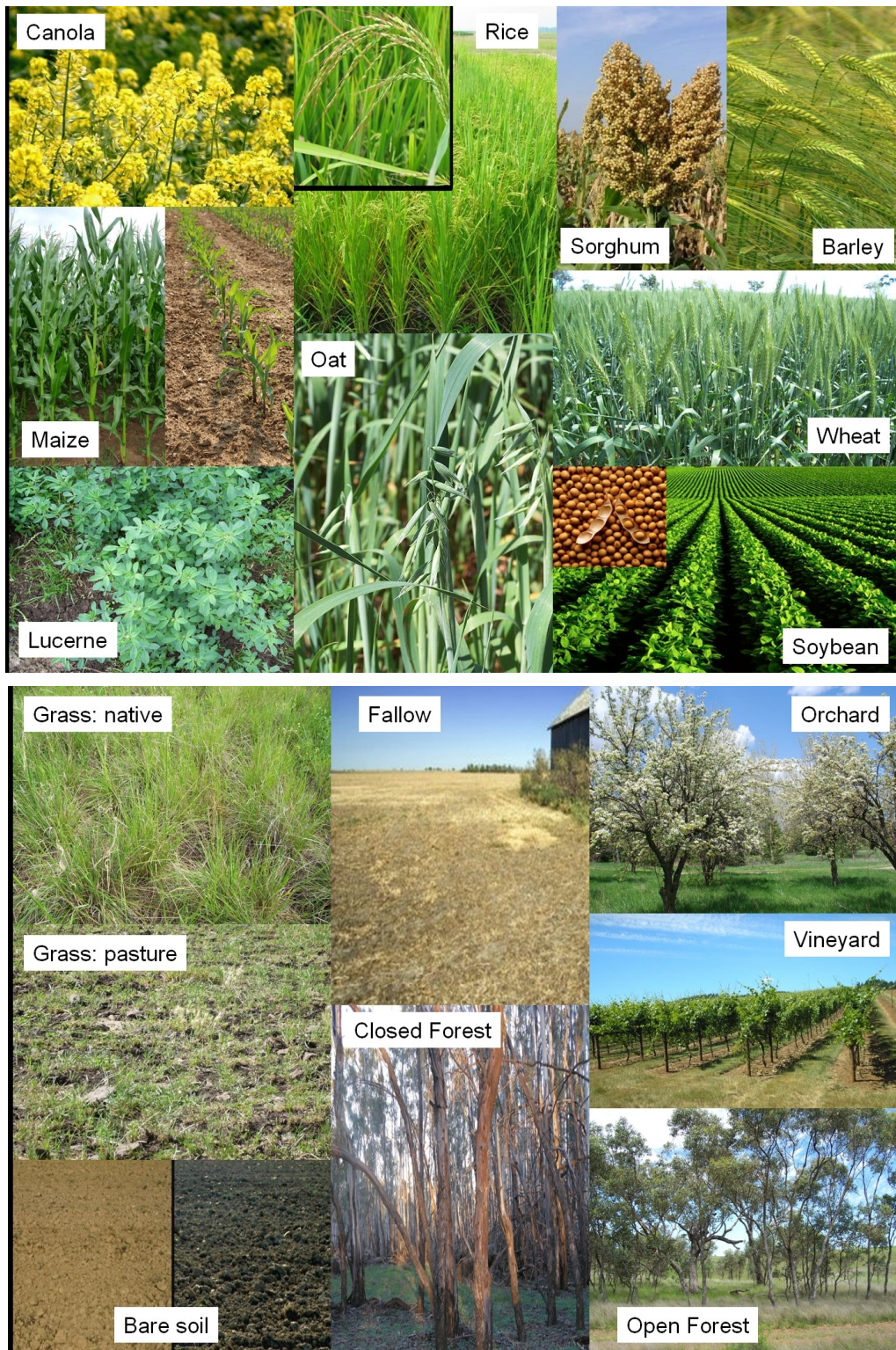


Figure 6-6: Photos of expected vegetation types within the focus farms highlighting features that will be useful for identification.

6.4.1 Dew

The presence of dew on vegetation at the time of morning SMOS overpass is likely to affect the passive microwave observation and subsequent retrieval of soil moisture. In order to support the leaf wetness measurements made by the supplementary monitoring stations and qualitative measurements made by the soil moisture team, the **vegetation team will make**

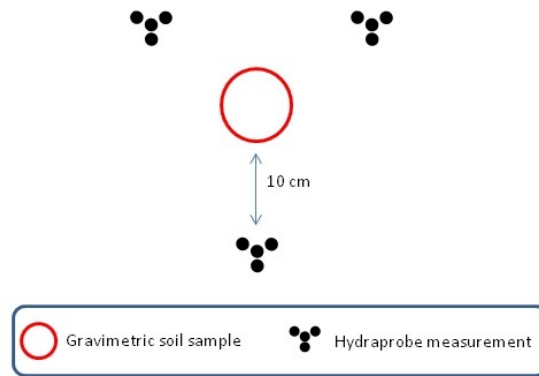


Figure 6-7: A minimum of three Hydraprobe measurements should be made in a radius of 10 cm around the gravimetric soil sample.

quantitative dew measurements during the half hour either side of the SMOS overpass (5:30am to 6:30am eastern standard time). A minimum of two dew measurements should be made per vegetation type. Suggested locations of the dew measurements are illustrated in Figure 6-4 and in Appendix G.

6.4.2 Soil surface roughness

Surface roughness affects the microwave emission from the soil by effectively increasing the surface area of electromagnetic wave emission. Although its effect on observations at L-band frequency has been shown to be difficult to quantify, it is important to characterise the spatial variation of this parameter across the different land cover types. It will be estimated at a minimum of 3 locations on each farm to capture the different roughness characteristics according to land cover type. **These measurements do not need to be made coincident with SMOS or PLMR overpass dates, so may be made on the preceding day(s)** to minimise workload during intensive monitoring activities. Suggested locations of the roughness measurements are illustrated in Figure 6-4 and in Appendix G.

6.4.3 Gravimetric soil samples

While a generic calibration equation has been derived for the conversion of Hydraprobe voltage readings into a soil moisture value (Merlin et al., 2007), this equation should be confirmed for the specific soil types and soil moisture conditions encountered on the focus farms. Consequently, this equation will be evaluated from a comparison of Hydraprobe readings with gravimetric measurements.

Volumetric soil samples will be collected for each focus farm with the gravimetric water content computed from the weight of a known soil sample volume before and after drying. Preferably, the Hydraprobe readings are made in the sample being taken. If this proves not to be possible due to moist soil sticking to the probe, a minimum of 3 Hydraprobe readings should be made at not more than 10cm from the soil sample (see Figure 6-7). For every farm a minimum of 5 soil samples will be collected along the focus farm transect to represent the range of soil types and soil moisture conditions encountered. **These measurements do not need to be made coincident with SMOS or PLMR overpass dates, so may be made on the preceding day(s)** to minimise workload during intensive monitoring activities. Suggested locations of the soil samples are illustrated in Figure 6-4 and in Appendix G.

6.4.4 Soil textural properties

Information on soil textural properties is very important for modelling soil microwave emission, as it strongly affects the dielectric behaviour of the soil. Moreover, the information from available soil texture maps is typically poor. Consequently, soil gravimetric samples will

be archived for later laboratory soil textural analysis determination of fraction of sand, clay and silt if required.

6.5 Supplementary Focus Farms

The supplementary focus farms are being operated by the NSW Department of Environment and Climate Change and CSIRO Land and Water. The farms are located near Griffith (Yenda; CSIRO) and Wagga Wagga (Livingstone Creek and Tumut; DECC). The sites have been described in detail in the NAFE'06 field plan so are only named here. The ground sampling strategies, while not identical to the general AACES campaign, will consist of similar measurements across the focus farms. Soil moisture measurements will be undertaken with handheld Delta-T Devices Thetaprobes, along with vegetation and gravimetric soil samples for calibration and validation purposes.

7 Sampling Protocols

Field work in the Murrumbidgee catchment will consist of collecting data in the 20 focus farms involved in the experiment, and archiving the information collected during the sampling days. Most of the data collected on the ground will be assisted by an iPAQ[®] Pocket PC. The iPAQ[®] system will be used both to store the observations and to visualize the real-time position via a GPS receiver and GIS software.

The ground crew will be comprised of two teams (A and B), each including soil moisture and vegetation sub-teams. A list of team participants is included in Chapter 8 together with a daily work schedule. It is important to note that all sampling devices and field notes should be referenced to Universal Time Coordinated (UTC); local time in the Murrumbidgee is UTC+10, or UTC+11 during daylight savings (October to April).

The campaign is comprised primarily of reconnaissance days and sampling days, with an occasional “rest” day (see Table 6-1). However, the main activities will take place on sampling days with only half-days required on reconnaissance days. The purpose of reconnaissance days are primarily to ensure readiness for the sampling days, including equipment preparation, familiarisation with the next focus farm to be sampled, taking samples as required (roughness specifically, but could also include gravimetric soil samples and additional vegetation samples), as well as installing the temporary monitoring stations. All field participants are REQUIRED to attend all reconnaissance days.

Both teams will work simultaneously on the two focus farms within the same patch of the Murrumbidgee transect; the area being mapped by the aircraft. A measurement grid (transects) will be uploaded on the iPAQ[®] screen to improve the accuracy and efficiency of the ground sampling; see also guidelines on farm mobility in Chapter 8. The soil moisture measurements will take place along six parallel transects each 330m apart and 5km in length. Soil moisture sampling will involve navigating from one end of the 5km long predefined sampling transect to the other, and taking a series of measurements at the predefined sampling locations. Sampling will be assisted by use of a GPS receiver, which displays the real-time position on the same iPAQ screen that shows the predefined locations. Once the sampling site has been located, the ground measurements of soil moisture and related meta data (presence of dew, vegetation height and type, rock cover fraction and sample location) are automatically stored into a GIS file on the iPAQs storage card; see Appendix A for more details on the sampling system to be used. Vegetation, gravimetric and roughness sampling will also be made along this same 5km transect with position and other pertinent information stored in the iPAQ GIS system.

Coincident with soil moisture sampling activities, the vegetation team will start with dew measurements early in the morning (5.30am until 6.30am Australian Eastern Standard Time; AEST, UTC+10), to coincide with SMOS overpass times; see schedule of work program in Chapter 8 and summary of daily activities in Appendix H. This will be followed by gravimetric sampling for probe calibration and roughness sampling until 10am (AEST). Between 10am and 2pm (AEST) is the optimal time for spectral measurements, so this time will be dedicated to vegetation destruction sampling and coincident spectral sampling. The remainder of the day will be used by the vegetation team to complete any remaining tasks, assisted by the soil moisture team if they have already completed their sampling transect.

This Chapter describes the protocols that will be used for the soil moisture and vegetation sampling in order to assure consistency in collecting, processing and archiving the collected

data. Measurement record sheets are provided in Appendix I for logging data other than the HDAS measurements.

7.1 General Guidance

Sampling activities are scheduled for most days, but may be postponed by the ground crew coordinator if it is raining or very likely to rain, there are severe weather warnings, or some other logistic issue arises. In this case the remaining campaign schedule may be revised accordingly to still enable complete coverage of the AACES transect.

Each team will make use of a campaign vehicle to access the farms. The soil moisture teams will walk along pre-established transects on the focus farms to take hydraprobe readings on the soil moisture sampling grid. They will be dropped off at one end of a sampling transect and picked up at the far end by members of the vegetation team. The vegetation team will drive across the farms to undertake their sampling activities, walking to sampling points where driving is not feasible or practical; only qualified personnel are permitted to drive the 4WDs across the farms.

Some general guidance is as follows:

- **Leave all gates as you find them!!**
- Do not mess up farm tracks.
- **Do not drive through crops.**
- All farmers in the area are aware of our presence on their property during the campaign. However, if anyone questions your presence, politely answer identifying yourself as a scientist working on a University of Melbourne soil moisture study with satellites. If you encounter any difficulties **just leave** and report the problem to the group leader. A copy of the campaign flyer distributed to farmers is included in Appendix J to assist you should this situation arise.
- Sampling will be conducted every 2 or 3 days depending on SMOS overpass time. The sampling team leader on occasion may cancel if there is severe weather or a logistic issue arises.
- Count your paces and note your direction. This helps greatly in locating sample points and gives you something to do while walking.
- Although gravimetric and vegetation sampling are destructive, try to **minimize your impact** by filling holes and minimizing disturbance to surrounding vegetation. Leave nothing behind!
- When sampling on cropped areas, always try to sample or move through a field **along the row direction** to minimize impact on the canopy.
- Please be considerate of the landowners and our hosts. **Don't block** roads, gates, and driveways. Keep sites, labs and work areas clean of trash and dirt.
- Beware of the possible presence of stock in the sampling areas.
- **Watch your driving speed**, especially when entering towns (town speed limits are typically 50km/h and highway speeds 100km/h). Be courteous on dirt and gravel roads, lower speed means less dust and stone.
- Drive carefully and maintain a low speed (~5 km/h) when going through tall grass fields. Hidden boulders, trunks or holes are always a danger. Also check for vegetation accumulation on the radiator.
- When parking in tall grass for prolonged periods of time, turn off the engine. Only diesel vehicles should be used in paddocks as catalytic converters can be a fire hazard.
- Some of the sampling sites may have livestock. Please be considerate towards the cattle and do not try to scare them away.

- **For your own security, carry a mobile phone or UHF radio. Check the mobile phone coverage over your sampling area** and be aware of the local UHF security frequencies (if relevant) as well as the team frequency (typically **channel 38**).
- In case of breakdown of any part of the sampling equipment, **report as soon as practical** to the group leader; not later than the end of the day.

7.2 Soil Moisture Sampling

Soil moisture sampling teams are in charge of collecting:

- 0-5cm soil moisture data using the Stevens water Hydraprobe[®] instrument at each sampling location (minimum of 3 independent measurements per site)
- Information about land use, vegetation type, canopy height, rock cover fraction and presence of dew at each sampling location (only required once per site)
- GPS location at each sampling location

The hydraprobe measurements will be made on grids of 50m × 330m spacing using a Hydraprobe Data Acquisition System (HDAS) developed at the University of Melbourne. The planned sampling transects for each farm will be loaded onto the iPAQ[®], and visible with the ArcPad GIS software. Sampling involves navigating along the sampling transect through the use of the GPS receiver, which displays the real-time position on the same ArcPad screen. Once the GPS cursor is located at the predefined sampling point, hydraprobe measurements can be made and stored in the iPAQ[®].

The information about vegetation type, canopy height, presence of dew and rock cover fraction will be stored in the iPAQ[®] by prompting the values into forms, following the hydraprobe readings. For further details on the HDAS operation see Appendix A.

7.2.1 Field Equipment

Each soil moisture team will be equipped with the items listed below:

- 1 vehicle; will also share a second vehicle with the vegetation team
- 1 hardcopy of the farm sampling plan

Each person of the soil moisture teams will be equipped with a HDAS that consists of the items listed below:

- 1 iPAQ[®] pocket PC
- 1 wireless GPS receiver
- 1 Stevens water Hydraprobe[®] and sampling pole
- 1 Bum bag
- 1 Gel cell battery (12 V)
- 1 Gel cell battery connector
- 12V/5V adapter
- 1 Spare gel cell battery (AAA 1.5 V; only for BT-GPS).

Additionally, each person will be assigned a field book and pens. The field book is to be used for comments and must be returned at the end of the campaign.

Each person will be individually responsible for the use and care of their assigned equipment throughout the campaign, and must report any damage to the group leader immediately so that actions can be taken to repair or substitute the damaged item. Each person is also responsible

for charging their own batteries each day and downloading/uploading their own iPAQ data. **Please do not interchange equipment of your own accord.**

7.2.2 Hydraprobe Data Acquisition System (HDAS)

The iPAQ has been programmed to automatically read the hydraprobe at the desired sampling location when a specific command is sent from the iPAQ, and store the probe readings in a file together with the GPS coordinates provided by the GPS device. This is achieved with the “ArcPad” software, a geographic information system for handheld devices. The ArcPad program stores the readings of the probe with the coordinates given by the GPS device. All the necessary commands will be given through the ArcPad screen, with basically no need to access any ArcPad menu items. On the ArcPad screen there will be 5 visible layers:

- Main roads of the Murrumbidgee catchment
- Farm boundaries and water courses etc
- Grid of planned sampling locations
- Grid of actual sampling locations: this is the file that will be edited every time a soil moisture reading is taken.
- GPS position indicator

It is important to check daily BEFORE sampling starts that the iPAQ time is set to the correct UTC time as the time information will be used to interpret the data. Additionally, **it is necessary to recharge each iPAQ after each sampling day**, in order to avoid any malfunctions. At each sampling location the following information will be selected from pre-defined drop down lists, in addition to a free-form comment if desired. The vegetation **canopy height** is selected from a list with 10cm increments up to a maximum height of 1.5m, **rock cover** fraction is selected from a list with 10% increments, and vegetation type and dew amount selected from the lists below:

Vegetation Type (dryland, irrigated:drip, irrigated:spray, irrigated:flood)

bare soil
fallow
grass: native
grass: pasture
crop: barley
crop: canola
crop: lucerne
crop: maize
crop: oats
crop: rice
crop: sorghum
crop: soybean
crop: wheat
crop: other
orchard
vineyard
woodland: open
woodland: closed
water body
building
other

Dew Amount

none
small droplets
medium droplets
large droplets
film

Note: A copy of the HDAS manual is included in Appendix A, together with a 1-page “cheat sheet”.

Downloading iPAQ data

Each person should make a backup of the iPAQ files before downloading, by making a copy of the “hydra.*” files to another folder on the SD card of the iPAQ. The backup folder will be named “My device/SD Card/Backup/DDMMFL” (where DD is day, MM is month, FL is first and last initials of user).

Download the ArcPad files named “hydra.*” into the required folder on the PC provided for the team (see section 7.5); note that each team will have its own dedicated download PC for the duration of the experiment. The downloading will be done with the software Microsoft ActiveSync (or a direct SD card reader):

1. Connect the iPAQ to the computer through the iPAQ USB cable
2. Start Microsoft ActiveSync
3. Establish a “Guest” partnership between the iPAQ and the computer: Navigate to the /SD card/Murrumbidgee folder on the iPAQ
4. Copy the FIVE FILES named “hydra.*” and paste them into the appropriate folder on the computer as instructed in the archiving section later in this chapter.

7.3 Vegetation Sampling

The vegetation sampling team are in charge of collecting:

- Vegetation and litter destruction samples
- Reflectance measurements
- LAI measurements
- Information about vegetation type, canopy height and row spacing
- GPS location of the actual sampling points

Vegetation teams are additionally in charge of collecting:

- Quantitative dew samples; minimum 2 samples per vegetation type
- 0-5cm gravimetric soil samples together with HDAS measurements (minimum 5 samples per farm along the 5km transect)
- Soil roughness measurements (3 measurements sites per focus farm)
- GPS location at each sampling site.

The coordinates (and shape files) of the farm boundaries together with boundaries of sampling areas and proposed sampling locations will be provided to the vegetation team. Sampling will involve navigating along the transect area using a GPS receiver and iPAQ running ArcPad. Vegetation measurements/samples should be made in the first instance in the

sampling area, but definitely within the focus farms, unless arrangements are made with additional landholders so as to cover all vegetation types.

The 0-5cm gravimetric soil samples will be taken at a minimum of 5 locations per farm along the 5km transect, covering the range of soil types and soil moisture contents encountered during ground sampling. The respective team leader will be responsible for this task throughout the entire campaign. **This important task may not be delegated to another team member.**

Roughness measurements will also be made at various points along the 5km transect. To facilitate the roughness sampling, it is recommended to take those measurements near the vegetation sampling areas.

7.3.1 Field Equipment

The vegetation team will be equipped with the items listed below:

- 1 vehicle
- 1 hardcopy of the farm sampling plan
- 2 vegetation sampling kits
- 2 soil sampling kits
- 2 dew sampling kits
- 1 iPAQ-GPS kit
- 1 ASD FieldSpec-3
- 1 LAI-2000 device
- 1 roughness profiler (shared between teams)
- 1 field book
- Pens, permanent markers

7.3.2 Dew Samples

Dew Sampling Kit (per sampling point)

- 3 plastic bags
- 3 paper towels
- surgical gloves (dry, not powdered or oiled)
- leaf area scanner

Dew Sampling Preparations

The bags containing the paper **towels have to be pre-weighed**, as drying may result in mass loss which could bias the results. The preparation will take place the day before the sampling and consists of preparing each sampling bag with 1 paper towel and marking each bag according to the intended sampling site. The prepared bags must be weighed and the weight marked on the dew sampling sheet.

Dew Sampling Protocol

Dew sampling will be performed, following the methodology described by Kabela et al. (2009):

1. the sampling person will don surgical gloves to avoid contamination of the sample towels;

2. a) for crops, the measurements will be performed by pressing the paper towel carefully to both sides of ONE leaf for about 10 seconds. This has to be performed at 1/3 and 2/3 of the total height of the plant, using one sample bag for each height. In case of large leaves (eg. corn), more towel can be used. However, care has to be taken that only the prepared packages (one bag and one towel) are used and that the towels are not put into the same bag. To ensure sufficient dew packs, double the estimated number of packs required should be prepared the day before.
- b) for grasslands, the measurements are also to be taken from 1/3 and 2/3 of the canopy (for fallow and other multiple leaved grasses; otherwise sample the full leaf), if the stem is sufficiently long. For short grasses, the same towel should be used for the leaves within an area of 10cm x 10cm and the sampling repeated for another two locations within 10m, inclusive a repetition of the LAI measurements. For short grasses, the average value of dew calculated for the different locations is to be averaged.

Note: in high vegetation, two team members are required to perform the sampling together, as any splashing from other parts of the vegetation has to be avoided.

3. expose paper towel of 3rd bag for 10 seconds to the air (control to correct for atmospheric absorption);
4. remove the leaf and scan it (for later determination of leaf surface area);
5. mark the sample site with a stake and flag;
6. revisit the same site later to determine the LAI, using the LICOR-2000;
7. all data have to be entered on the dew sampling form.

Dew Sampling Check-in

All data will be entered on the dew sampling form by the vegetation team members. Consequently, only the bags and the data will be transferred to the base camp courier. No further processing is required at YIA.

The weight of the dew is determined as the wet weight recorded after return from the field, less the weight of the sampling bag and towels determined the day before. Averaged values for bag and towel weights should not be used as the variability may introduce relatively large errors given the small amount of dew typically measured. Also, the weight gain of the control sample is to be subtracted from the total water content, to correct for any water gained from exposure to the outside air.

The data from dew sampling (ie. grams of water on the leaf, leaf size as determined with the scanner, and the LAI for scaling) and their respective sample ID will be stored in an Excel worksheet named “AACES_CampaignID_Dataset\Raw_Data\Patch#_DD-MM\Sampling_Day_DD-MM\Farm_#\Vegetation_Sampling\Dew_P#F#_DD-MM-YY.xls,” where CampaignID is the respective identifier, # is farm number, DD is day, MM is month, P indicates patch, and F indicates focus farm.

The total dew amount (g/m^2) is determined as

$$\text{dew} = \frac{\text{weight of water on the two leaves}}{\text{total one sided surface area of the two leaves}}, \quad (7-1)$$

where, weight of water is the water measured in the field for the two leaves in g and surface area is the single sided leaf area of the two leaves sampled in m^2 .

7.3.3 Surface Reflectance Data

The ASD (Figure 7-1) consists of one photodiode array for the 350-1000nm spectral range and two separate photodiode arrays for the 1000-2500nm range. Its sampling rate is 1.4-2nm with a spectral resolution from 3nm (at 700nm) to 10nm (from 1400nm). The radiometer uses fiberoptic cables as light transducers.

In the post-processing the bands required to simulate the various multi-spectral space-borne instruments will be selected for the calculation of the various indices.

Reflectance data will be collected for each vegetation sampling location (Figure 7-2) just **prior to vegetation removal** using the following sampling scheme. The user has to make sure that the radiometer is well above the plant canopy, and take a reading every meter for 5 meters. Repeat, for a total of 5 replications located 1 meter or 1 row apart. See Appendix B for detailed instructions on how to operate the ASD and download the data upon returning from the field.



Figure 7-1: The ASD FieldSpec 3 hyperspectral sensor (photo courtesy of ASD Inc.).

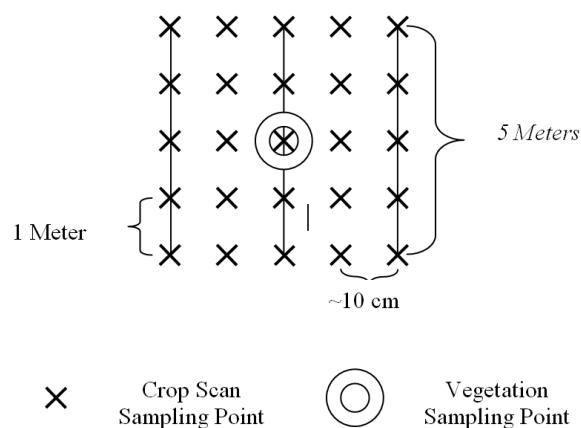


Figure 7-2: Illustration of the surface reflectance protocol.

7.3.4 Leaf Area Index

The LAI-2000 (see Figure 7-3) will be set to average 4 points into a single value so one observation is taken above the canopy and 4 beneath the canopy; in the row, $\frac{1}{4}$ of the way across the row, $\frac{1}{2}$ of the way across the row and $\frac{3}{4}$ of the way across the row. This gives a good spatial average for row crops of partial cover. For grasses, weeds and non-row crops, five sets of measurements (each set consisting of 1 above the canopy and 4 beneath the canopy) will be made. These should be made just before taking the biomass sample. For short vegetation, LAI will be derived from the destruction samples as described below.

If the sun is shining, the observer needs to stand with their back to the sun and put a black lens cap that blocks $\frac{1}{4}$ of the sensor view in place and positioned so the **sun and the observer are never in the view of the sensor**. The observer should always note if the sun was obscured during the measurement, whether the sky is overcast or partly cloudy with the sun behind the clouds. If no shadows could be seen during the measurement, then the measurement is marked “cloudy”, if shadows could be seen during the measurement then the measurement is marked “sunny”. Conditions should not change from cloudy to sunny or sunny to cloudy in the middle of measurements for a sample location. Also, it is important to check the LAI-2000 internal clock each day to verify they are recording in GMT. See Appendix C for detailed instructions on how to operate the LAI-2000.

Additionally, the vegetation samples taken within the 50cm × 50cm quadrant will be passed through a leaf area scanner, to determine the full leaf area for the sample. These data can then be used to compare the observed and measured leaf area indices.

Downloading LAI-2000 files to a PC Using HyperTerminal

Before beginning use functions 21 (memory status) and 27 (view) to determine which files you want to download. Make a note of their numbers.

1. Connect wire from LAI-2000 (25pin) to PC port (9 pin).
2. Run HyperTerminal on the PC (Start | Programs | Accessories | Communications | HyperTerminal | LAI2000.ht)
3. On the LAI-2000, go to function 31 (config i/o) and conFig. I/O options. Baud=4800, data bits=8, parity=none, xon/xoff=no.
4. On the LAI-2000, go to function 33 (set format) and setup format options. First we use Spdsheet and take the default for FMT.
5. In HyperTerminal go to Transfer | Capture text. Choose a path and filename (LAIMDDFL.SPR, where MM is month, DD is day, FL is first and last initials of user and SPR for spreadsheet data files) to store the LAI data. Hit Start. HyperTerminal is now waiting to receive data from the LAI-2000.



Figure 7-3: The LAI-2000 instrument.

6. On the LAI-2000, go to function 32 (print) and print the files. 'Print' means send them to the PC. You will be asked which file sequence you want. Eg. Print files from:1 thru:25 will print all files numbered 1-25. Others will not be downloaded.
7. Once you hit enter in function 32, lines of text data will be sent to HyperTerminal. The LAI-2000 readout will say 'Printing file 1, 2, etc'. Check the window in HyperTerminal to ensure the data is flowing to the PC. This may take a few minutes, wait until all the desired files have been sent.
8. In HyperTerminal go to Transfer | Capture text | Stop.
9. On the LAI-2000, go to function 33 (set format) and setup format options. Now set to Standard, Print Obs = yes
10. In HyperTerminal go to Transfer | Capture text Choose a path and filename (LAIDMMFL.STD, where DD is day, MM is month, FL is first and last initials of user and STD for standard data files) to store the LAI data. Hit Start. HyperTerminal is now waiting to receive data from the LAI-2000.
11. On the LAI-2000, go to function 32 (print) and print the files. 'Print' means send them to the PC. You will be asked which file sequence you want. Eg. Print files from: 1 thru 25 will print all files numbered 1-25. Others will not be downloaded.
12. In HyperTerminal go to Transfer | Capture text | Stop.
13. Using a text editor (like notepad) on the PC, open and check that all the LAI data has been stored in the text file specified in step 3. Make a back up of this file according to the archiving instructions later in this chapter.
14. Once you're sure the LAI values look reasonable and are stored in a text file on the PC, use function 22 on the LAI-2000 to delete files on the LAI-2000 and free up its storage space.

Note: The above instructions assume that HyperTerminal has been configured to interface with the LAI-2000, i.e. the file LAI2k.ht exists. If not, follow these instructions to set it up.

1. Run HyperTerminal on the PC (Start | Programs | Accessories | Communications | HyperTerminal | Hypertrm
2. Pick a name for the connection and choose the icon you want. Whatever you pick will appear as a choice in the HyperTerminal folder in the start menu later. Hit OK.
3. Connect using com1 or com2. Choose which is your com port, hit OK. Setup Port settings as follows: Bits per second = 4800, Data Bits = 8, Parity = none, Stop bits = 1, Flow control = Hardware. Say OK.
4. Make sure the wire is connected to the LAI-2000 and the PC and proceed with step 3 in the download instructions above. When finished and leaving HyperTerminal you will be prompted to save this connection.

7.3.5 Vegetation Destruction Samples

At least five vegetation samples will be taken per vegetation type, at each of the reflectance/leaf area index sampling locations across the monitoring transect per day, making sure that all significant vegetation types and growth stages encountered across the farm are included. These vegetation samples will be weighed at sample check-in on return to the operations base, and then passed to the laboratory assistant for drying and further analysis.

Note: Vegetation sample should only be taken after the spectral and LAI measurements have been made.

Vegetation destruction sampling kit

- 0.5m × 0.5m quadrant to obtain vegetation samples
- vegetation clipper
- scissors
- gloves
- plastic bags
- rubber bands
- permanent markers

Vegetation destruction sampling protocol

The procedure for vegetation biomass sampling is as follows:

1. Note and record type of vegetation to be sampled (e.g. crop, native grass, improved pasture) using the predefined list in the HDAS (see section 7.2.2), its height and row spacing if relevant.
2. Randomly place the 0.5m × 0.5m quadrant on the ground within area to be sampled
3. Label bag provided using a permanent marker with the following information: **Patch_ID / Farm_ID / Team_No. / DD-MM-YY / Sample_ID. For example, P1 / F2 / T1 / 17-01-10 / Veg / 01.** Take photo of area to be sampled prior to removal of vegetation
4. Record sample location with GPS and sample location reference number in iPAQ
5. Remove all aboveground biomass within the 0.5m × 0.5m quadrant using vegetation clipper and scissors provided
6. Place vegetation sample into labelled bag provided
7. Close bag with sample using rubber bands provided and place this bag into a second bag to ensure that no moisture will be lost
8. Take photo of sample plot following removal of aboveground biomass.

Vegetation destruction sample check-in

All vegetation samples are processed to obtain a wet and dry weight. It is the responsibility of both teams to deliver the vegetation samples to the operations base at the end of the day, fill out a sample sheet, one sheet per day per team, and record a wet weight for each sample. All vegetation samples taken on one day will be put in a sampling box of the team together with the record sheet for transfer to the laboratory for drying. The procedure for determining the wet weight is as follows:

Wet Weight Procedure

1. Turn on balance.
2. Tare.
3. Obtain wet weight in g to two decimal places by weighing sample in the bags.
4. Record wet weight on the vegetation sample drying form.
5. Record wet weight in the computer excel file.

7.3.6 Gravimetric Soil Moisture Samples

At least five soil samples should be collected per day along the sampling transect, making sure that all soil types and the complete range of soil moisture encountered on the farm are included. These gravimetric soil samples will be weighed at sample check-in on return to the operations base, and then passed to the laboratory assistant for drying and further analysis.

Gravimetric soil moisture sampling kit

- sampling ring (approximately 7.5cm diameter and 5cm depth)
- hammer, plywood sheet and block
- garden trowel
- blade
- gloves
- plastic bags
- rubber bands
- permanent markers

Gravimetric soil moisture sampling protocol

1. Take a minimum of 3 soil moisture readings with the hydraprobe immediately adjacent to the soil to be sampled, plus 1 reading in the soil sample if conditions permit
2. Remove vegetation and litter.
3. Place the ring on the ground
4. Put the wooden base horizontal on top of the ring and use the hammer to insert the ring in the ground, until its upper edge is level with the ground surface.
5. Use the garden trowel to dig away the soil at the side of the ring. The hole should reach the bottom of the ring (5cm) and should be sufficiently large to fit the spatula in
6. Use the spatula to cut the 0-5cm soil sample at the bottom of the ring
7. Place the 0-5cm soil sample in the plastic bag ensuring that no soil is lost and seal with the rubber band provided, then place this bag into a second bag.
8. Label the internal plastic bag as Patch_ID / Farm_ID / Team_No. / DD-MM-YY / Sample_type / Sample_ID. For example, P1 / F2 / T1 / 17-01-10 / Soil / 01.

Gravimetric soil moisture sample check-in

All gravimetric soil moisture samples are processed to obtain a wet and dry weight. It is the responsibility of each team to deliver the samples to the operations base, fill out a sample form (one form per sampling or reconnaissance day per team) with the wet weight for each sample, and transcribe this data to the excel file provided. All gravimetric soil moisture samples taken on one day will be put in a sampling box together with the sample form for transfer of the samples to the laboratory for drying. The procedure for determining the wet weight is as follows:

Wet Weight Procedure

1. Turn on balance.
2. Tare.
3. Obtain wet weight in g to two decimal places by weighing sample in the bags.
6. Record wet weight on the soil sample drying form.
7. Record wet weight in the computer excel file.

7.3.7 Soil Surface Roughness Measurement

Three soil roughness measurements will be made along each farm transect. Due to limited roughness measurement equipment, the roughness profiler will need to be shared between



Figure 7-4: Pin profiler for surface roughness measurements.

teams and coordinated accordingly. It is suggested that teams alternate between using the roughness profiler on sampling days and on reconnaissance days.

Soil roughness procedure

Soil roughness measurements will be made using a 1m long drop pin profiler with a pin separation of 25mm (see Figure 7-4). The same measurements will be made at 3 different locations within each of the 20 focus farms. At each soil roughness sampling location, **2 lots of consecutive readings (to simulate a 2m long profile) will be performed in North-South and East-West orientations, respectively.**

The procedure for one measurement is as follows:

1. Note in the roughness sampling form the position and orientation of the roughness measurements.
2. Position the profiler making sure that all the pins touch the soil surface. The pins **MUST NOT** be inserted into the ground or be resting on top of vegetation.
3. Take a photograph of the roughness profiler clearly showing the level of the pins, with farm and sample location/direction clearly indicated in the photograph.
4. Note the photo identification number in the roughness sampling form for cross reference.
5. Note on the roughness sampling form the height reached by each pin, as read on the background grid.
6. Pins have to be read from left to right, and indicated on the field book with sequential numbers from 1 to 41.
7. Move the profiler to the second metre and repeat.
8. Change the profiler orientation and repeat.

Archiving soil roughness data

Soil roughness data, sampling GPS location and orientation will be stored in an Excel worksheet named “AACES_Campaign_ID\Raw_Data\Patch#_DD-MM\Sampling_Day_DD-

MM\Farm_#\Vegetation_Sampling\Dew_P#F#_DD-MM-YY.xls” where Campaign_ID is the identification of the campaign, # is the patch number, DD is day, MM is month, P indicates patch and F indicates focus farm. This data must be typed up at the end of the sampling day or at latest the subsequent day, and archived according to the instructions later in this chapter. The photos must also be renamed as Ruf#_P#F#_DD-MM-YY.jpg and stored in the same directory as the xls file.

7.4 Laboratory Procedures

Laboratory work for soil moisture, dew, vegetation water and vegetation biomass determination will be conducted by a dedicated person based at the Yanco Agricultural Institute facilities, where ovens etc are readily available. The laboratory procedures for each of these sample measurements are summarised below.

7.4.1 Biomass and vegetation water content determination

Drying Procedure

1. Process the samples for each sampling day in numeric order, carefully emptying contents into the trays provided.
2. Place the used bags in order. The labelled bags will be used for permanently storing the samples after the drying procedure is finished.
3. Place the samples in the ovens to dry at 40°C and leave in the ovens until a constant weight is reached; typically 2-3 days. Record the day and time on the vegetation sample drying form when you start and end the drying.

Dry Weight Procedure

1. Remove samples for a single data sheet and place on the heat mat. These samples will be hot. Wear the gloves provided.
2. Turn on balance.
3. Tare.
4. Obtain the dry weight in g to two decimal places and record on sheet.
5. Process the samples for each farm/sampling day in sample numeric order, returning samples to the original plastic bags and store in the assigned sample box.
6. Load new samples into oven as relevant.

The dry/wet weight data of vegetation samples and their associated sample ID will be stored in an excel worksheet AACES_CampaignID_Dataset\Raw_Data\Patch#_DD-MM\Sampling_Day_DD-MM\Farm_#\Vegetation_Sampling\Veg_P#F#_DD-MM-YY.xls where CampaignID is the respective identifier, # is number, DD is day, MM is month, P indicates patch, and F indicates focus farm.

7.4.2 Gravimetric Soil Moisture Determination

Drying Procedure

1. Process the samples for each farm/sampling day in numeric order, carefully emptying contents in the trays provided.

2. Place the used bags in order. The labelled bags will be used for permanently storing the samples after the drying procedure is finished.
3. Place the samples in the ovens to dry at 105°C and leave in the ovens for at least 24 hours. Record the day and time on gravimetric soil sample drying form when you start and end the drying.

Dry Weight Procedure

1. Remove samples for a single data sheet and place on heat mat. These samples will be hot. Wear the gloves provided
2. Turn on balance.
3. Tare.
4. Obtain dry weight in g to two decimal places and record on gravimetric soil moisture sample drying form.
5. Process the samples for each sampling day in sample numeric order, returning samples to the original plastic bags and store in the assigned sample box.
6. Load new samples into oven as relevant.

The dry/wet weight data of soil samples and their associated sample ID will be stored in an excel worksheet named AACES_CampaignID_Dataset\Raw_Data\Patch#_DD-MM\Reconnaissance_Day_DD-MM\Farm_#\HDAS_Calibration_DD-MM\Soil_P##_DD-MM-YY.xls where CampaignID is the respective identifier, # is number, DD is day, MM is month, P indicates patch, and F indicates focus farm.

7.5 Data Archiving Procedures

All data collected during the sampling days will be downloaded on a PC computer and backed up on external hard drives immediately upon return to the AACES base. There will be one computer dedicated for each team, specifically for downloading and archiving operations. It is the responsibility of each team to download all data collected with the iPAQs into the appropriate folders (see Figure 7-5 to Figure 7-8), and to insert into the relevant Excel worksheets all the data collected in the field books and on lab data sheets. The only exception is the results from laboratory processing (ie. dry weights for vegetation water content and biomass, and soil gravimetric moisture). These sheets will be completed by the dedicated laboratory person. Daily data will be backed up on both DVD's and external hard disk drive. **It will be the responsibility of the team leaders to confirm that all data have been collected, downloaded and archived into the correct folders, and subsequently make a back up of the data at the end of each sampling day.** A copy of the data archive will be collected regularly for further processing and archiving activities.

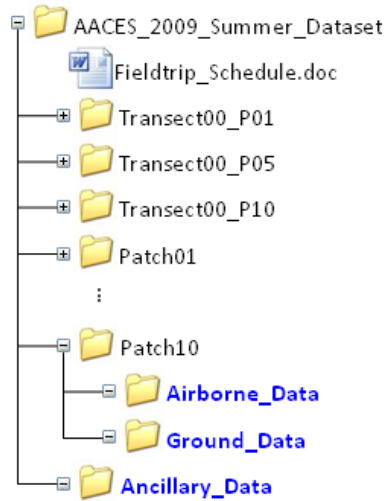


Figure 7-5: Tree diagram of the general AACES file structure.

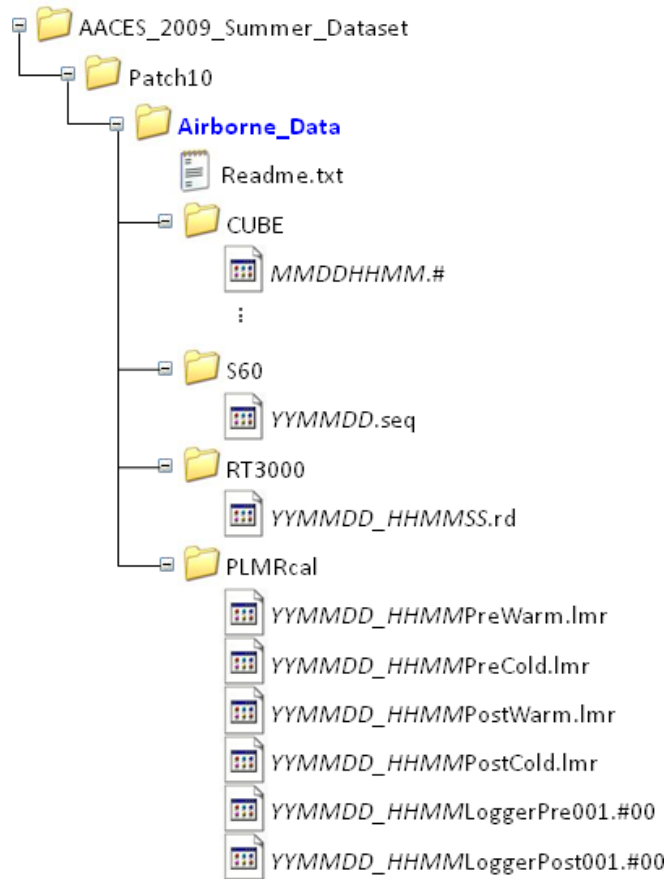


Figure 7-6: Tree diagram of the general AACES file structure for airborne data.

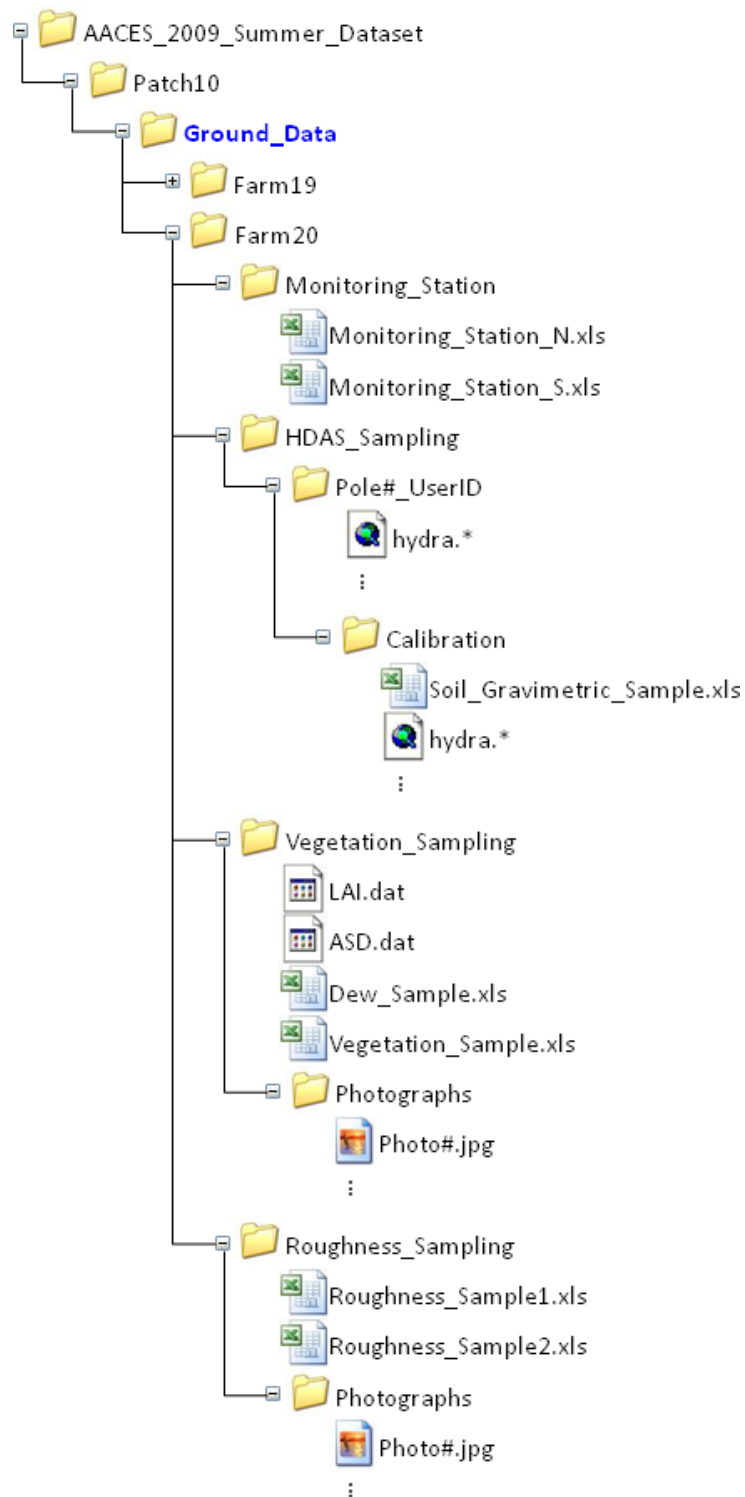


Figure 7-7: Tree-diagram of the general AACES structure for ground data.

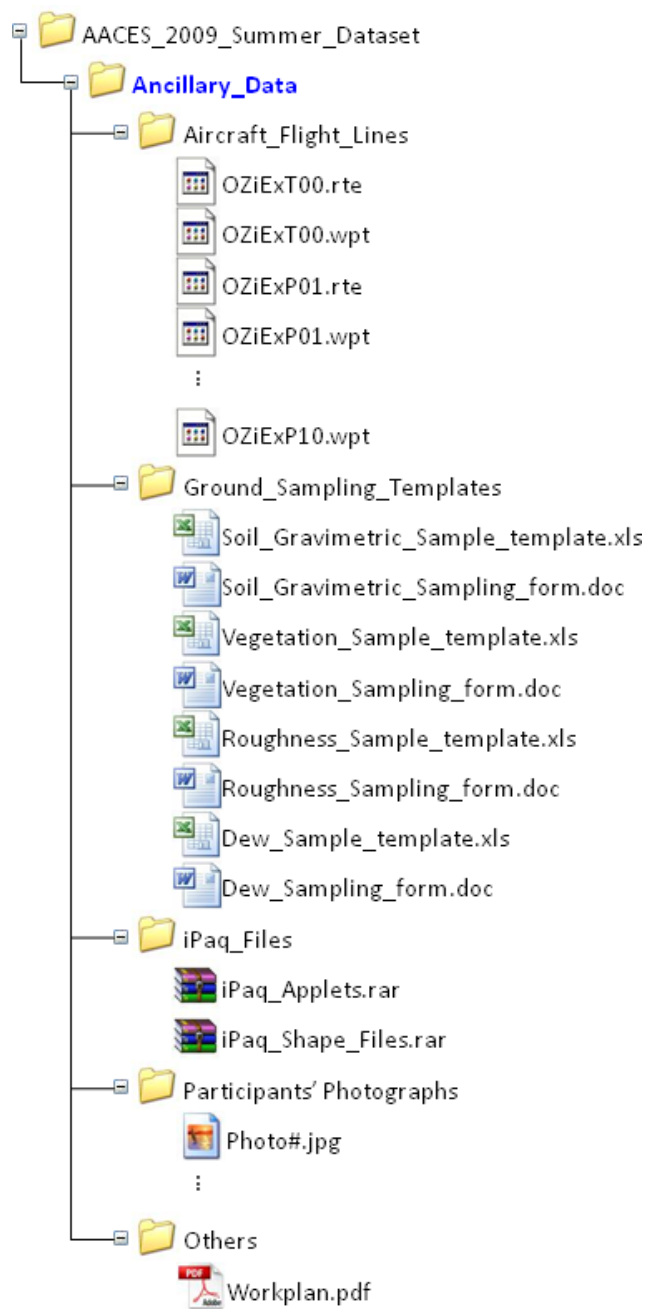


Figure 7-8: Tree-diagram of the general AACES structure for ancillary data.

8 Logistics

AACES activities will be supported by a ground crew, aircraft crew and support crew. While the aircraft activities will be solely conducted from the Narrandera Airport, for logistical reasons the ground crew will be required to systematically make their way across the Murrumbidgee Catchment. The support crew, limited by available laboratory facilities and a need to provide support to the ground crew, will be split between the central operations base that is co-located with the aircraft crew base at the Yanco Agricultural Institute (YAI) and with the ground crew base. In addition to providing accommodation facilities, the YAI has agreed to provide logistics support in terms of laboratory, storage and office space, as well as internet access in the office. The ground crew will be based at Cobb Inlander Motel in Hay, the YAI at Yanco/Leeton, Gundagai Motel in Gundagai, and Yass Motel in Yass respectively. Further details on the campaign logistics are provided in the sections that follow.

As with the past NAFE experiments, contributors to the AACES field campaigns are expected to cover their own travel, accommodation, meals and incidental expenses. However, we have endeavoured to minimise your expenses by

- offering an airport pick-up service in Melbourne,
- coordinating vehicles for all essential transportation during the campaign, and
- arranging budget yet practical and comfortable accommodation with facilities for breakfast and lunch preparation etc.

If you plan to rent your own vehicle and are prepared to use it also for field activities, please let us know. If you wish to have more luxurious accommodation than what we are organising here, please make your own arrangements and let us know immediately, but please keep in mind the logistics of team-based sampling activities.

In return for your participation in the AACES campaign, you will have access to all collected data as described in the earlier chapters of this document. However, to minimise the possibility of any conflict (with PhD student theses in particular) and to manage optimal use of the data, a short 1-2 page “proposal” should be submitted to Jeff Walker, stating explicitly what data you would like to use and how, BEFORE the campaign activities commence. This does not limit your use of other data types or use of the data for alternative activities as your research evolves, but prior notification to changes in data usage is requested. Notification and copies of all publications arising from use of the data are also requested, along with acknowledgement of the Australian Research Council funding for these campaigns (DP 0879212) and reference to the paper that describes this data set; the current reference is Peischl et al. (2009), but a journal paper will also be published once the first campaign has been completed.

One of the ground crew members, Rodger Young, will be dedicated to instrument repair and general technical support. Breakdowns and instrument faults MUST be reported to him at the end of each day so that we can ensure fully functional teams. Another ground crew member, Ye Nan, will be dedicated to ground data archiving and processing support. Your HDAS data and ground samples MUST be archived according to the instruction in this work plan promptly at the end of each sampling day, either directly or via your team leader, so he can further process the data and samples, thus ensuring the early availability of quality data at the end of the campaign.

8.1 Teams

Ground crew sampling operations will be undertaken by 2 teams acting independently, and will be coordinated by Chris Rüdiger with the assistance of Jeff Walker¹ and Sandy Peischl. Each of the two ground teams have been assigned ten of the twenty focus farms across the AACES transect, and consist of both “soil moisture” and “vegetation” sub teams. Table 8-1 indicates the composition of each team and the focus farms assigned to each group. The aircraft crew will operate from the Narrandera airport and be coordinated by Jeff Walker. Those people supporting the aircraft component are indicated in Table 8-2. There are also several support people, and these are indicated in Table 8-3. Contact details for all participants are given in Chapter 9.

Table 8-1: AACES ground crew.

Team	Farms	Team members	Primary Task	Transport	Team leader
A	1,3,5,8,9,12,13,15,18,19	Chris R. Anna W. Mateusz L. ³ Simone B. Arnaud M./Claire G. Ulrike P. Channah B. Roosanne S. Jane L. ³	Vegetation Vegetation Vegetation Soil moisture Soil moisture Soil moisture Soil moisture Soil moisture Soil moisture	Landcruiser Dual Cab 1	Chris
B	2,4,6,7,10,11,14,16,17,20	Sandy P. ³ Sandra S. Delphine L. Ole K. Marianne V. Ranmalee H. Andrew F. Derek B.	Vegetation Vegetation Soil moisture Soil moisture Soil moisture Soil moisture Soil moisture Soil moisture	Dual Cab 2 Dual Cab 3	Sandy

1. Soil moisture: See Table H.1

2. Vegetation: See Tables H.2 and H.3

3. First Aid person

Table 8-2: AACES aircraft crew.

Person	Task	Transport
Jeff Walker	PLMR general	Econ Veh 1
Jon Johanson	PLMR general	
Mahdi Allahmorahdi	PLMR cal and processing Assisting Ye Nan (see below)	Econ Veh 2
Ed Kim	Aircraft support	

¹ Since Jeff Walker will be coordinating the aircraft activities from YIA, his direct involvement in the field activities will be limited. Please feel free to phone him if you have any concerns at any time during the campaign.

Table 8-3: AACES support crew.

Person	Task	Location	Transport
Rodger Young	Equipment maintenance Logger downloads Lake transects	With field crew	Uni Truck
Ye Nan	Sample and data collection from field Soil and veg drying in lab Ground and air data archive	Yanco	Shared with Econ Veh 1/2

8.2 Operation Bases and Accommodation

Accommodation details for all participants are summarised in Table 8-4. This is followed by a brief overview of the accommodation and support facilities available at each of the four operations bases.

Table 8-4: Accommodation logistics for the AACES participants.

Name	Responsible organisation	Location	In	Out	Nights	Price/night	Total/person
Allahmoradi Mahdi	UoM	Yanco/Inga	18/01/2010	21/02/2010	34	35	1190
Betgen, Channah (sharing with Vreugdenhil & Schrooten)	ESA	Hay	18/01/2010	31/01/2010	13	40	520
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	35	175
		Yass	16/02/2010	21/02/2010	5	40	200
Bircher, Simone (shared with Port)	ESA	Hay	18/01/2010	31/01/2010	13	70	910
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	65	325
		Yass	16/02/2010	21/02/2010	5	71	355
French, Andrew	USDA	Gundagai / Yass	14/02/2010	21/02/2010	7	71	355
Gruhier, Claire (sharing with Leroux)	ESA	Yanco/Inga	3/02/2010	11/02/2010	8	35	280
		Gundagai	11/02/2010	16/02/2010	5	65	325
		Yass	16/02/2010	21/02/2010	5	71	355
Hitiamillage, Ranmalee (shared with Lai)	UoM	Hay	18/01/2010	31/01/2010	13	40	520
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	35	175
		Yass	16/02/2010	21/02/2010	5	40	200
Johansson, Jon	UoM	Yanco/ Amaroo	18/01/2010	21/02/2010	34	82.5	2805
Kim, Ed	UoM	Yanco/ Amaroo	18/01/2010	21/02/2010	34	82.5	2805
Klimczak, Olaf (sharing with Peischl)	UoM	Hay	18/01/2010	31/01/2010	13	40	520
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	35	175
		Yass	16/02/2010	21/02/2010	5	40	200
Lai, Jane (sharing with Hitiamillage)	UoM	Hay	18/01/2010	31/01/2010	13	40	520
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	35	175
		Yass	16/02/2010	21/02/2010	5	40	200
Leroux,	ESA	Hay	18/01/2010	31/01/2010	13	70	910

Delphine (sharing with Gruhier)		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	65	325
		Yass	16/02/2010	21/02/2010	5	71	355
Lukowski, Mateusz	ESA	Hay	18/01/2010	31/01/2010	13	70	910
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	65	325
Mialon, Arnaud	ESA	Yass	16/02/2010	21/02/2010	5	71	355
		Hay	18/01/2010	31/01/2010	13	70	910
		Yanco/Inga	31/01/2010	4/02/2010	4	35	140
Peischl, Sandy (sharing with Klimczak)	UoM	Hay	18/01/2010	31/01/2010	13	40	520
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	35	175
Port, Ulrike (sharing with Bircher)	ESA	Yass	16/02/2010	21/02/2010	5	40	200
		Hay	18/01/2010	31/01/2010	13	40	520
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
Rüdiger, Chris	UoM	Gundagai	11/02/2010	16/02/2010	5	35	175
		Yass	16/02/2010	21/02/2010	5	40	200
		Hay (shared)	18/01/2010	21/01/2010	3	40	120
Ryu, Dongryeol	UoM	Hay	21/01/2010	31/01/2010	10	70	700
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	65	325
Schrooten, Roosanne (sharing with Betgen and Vreugdenhil)	ESA	Yass	16/02/2010	21/02/2010	5	71	355
		Hay	18/01/2010	26/01/2010	8	70	560
		Hay	18/01/2010	31/01/2010	13	40	520
Slowinska, Sandra (sharing with Wojciga)	ESA	Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	35	175
		Yass	16/02/2010	21/02/2010	5	40	200
Vreugdenhil, Marianne (sharing with Betgen and Schrooten)	ESA	Hay	18/01/2010	31/01/2010	13	70	910
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	65	325
Walker, Jeffrey	UoM	Yass	16/02/2010	21/02/2010	5	71	355
		Hay	18/01/2010	31/01/2010	13	40	520
		Yanco/Amaroo	18/01/2010	21/02/2010	34	82.5	2805
Wojciga, Anna (sharing with Slowinska)	ESA	Hay	18/01/2010	31/01/2010	13	70	910
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	65	325
Ye, Nan	UoM	Yass	16/02/2010	21/02/2010	5	71	355
		Hay (shared)	18/01/2010	20/01/2010	3	40	120
		Yanco/Inga	31/01/2010	11/02/2010	31	35	1085
Young, Rodger	UoM	Hay	18/01/2010	31/01/2010	13	70	910
		Yanco/Inga	31/01/2010	11/02/2010	11	35	385
		Gundagai	11/02/2010	16/02/2010	5	65	325
		Yass	16/02/2010	21/02/2010	5	71	355



Figure 8-2: Hay accommodation at the Cobb Inlander Motel

8.2.1 Hay Cobb Inlander Motel

Mark & Colleen
 83 Lachlan Street, Hay, NSW 2711
 Phone (02) 6993 1901
 Fax (02) 6993 3406

Amenities:

- Free Parking
- ALL ROOMS non-smoking
- Air conditioned rooms
- AM/FM clock/radio in rooms
- Refrigerator in rooms
- Toaster
- Microwave
- Wireless internet (\$15 for a 14 day 1GB internet access card)
- Television
- Restaurant on site
- Swimming pool

8.2.2 Yanco Agricultural Institute

The Yanco Agricultural Institute (YAI, <http://www.agric.nsw.gov.au/reader/yanco>) is an 825ha campus located at Yanco, in the Murrumbidgee Irrigation Area. The centre is just 10 minutes drive from downtown Leeton, and 20 minutes drive from the town of Narrandera, junction of the Sturt and Newell Highways (see location in Figure 8-3).



Figure 8-3: Location of the YAI at Yanco.

YAI shares the site and resources with the Murrumbidgee Rural Studies Centre (MRSC, <http://www.mrsc.nsw.edu.au>), formerly known as the Murrumbidgee College of Agriculture.

Both MRSC and YAI are run by the NSW Department of Primary Industries.

During AACES, the YAI will make available a lab space (see Figure 8-4 and Figure 8-5) with all the equipment needed for pre-sampling and post-sampling operations, including scales for sample weighing, ovens for drying soil and vegetation samples, storage spaces for processed samples and field equipment etc.

The aircraft crew will also be based in YAI and operate the aircraft out of the Narrandera Airport (see Figure 8-6).

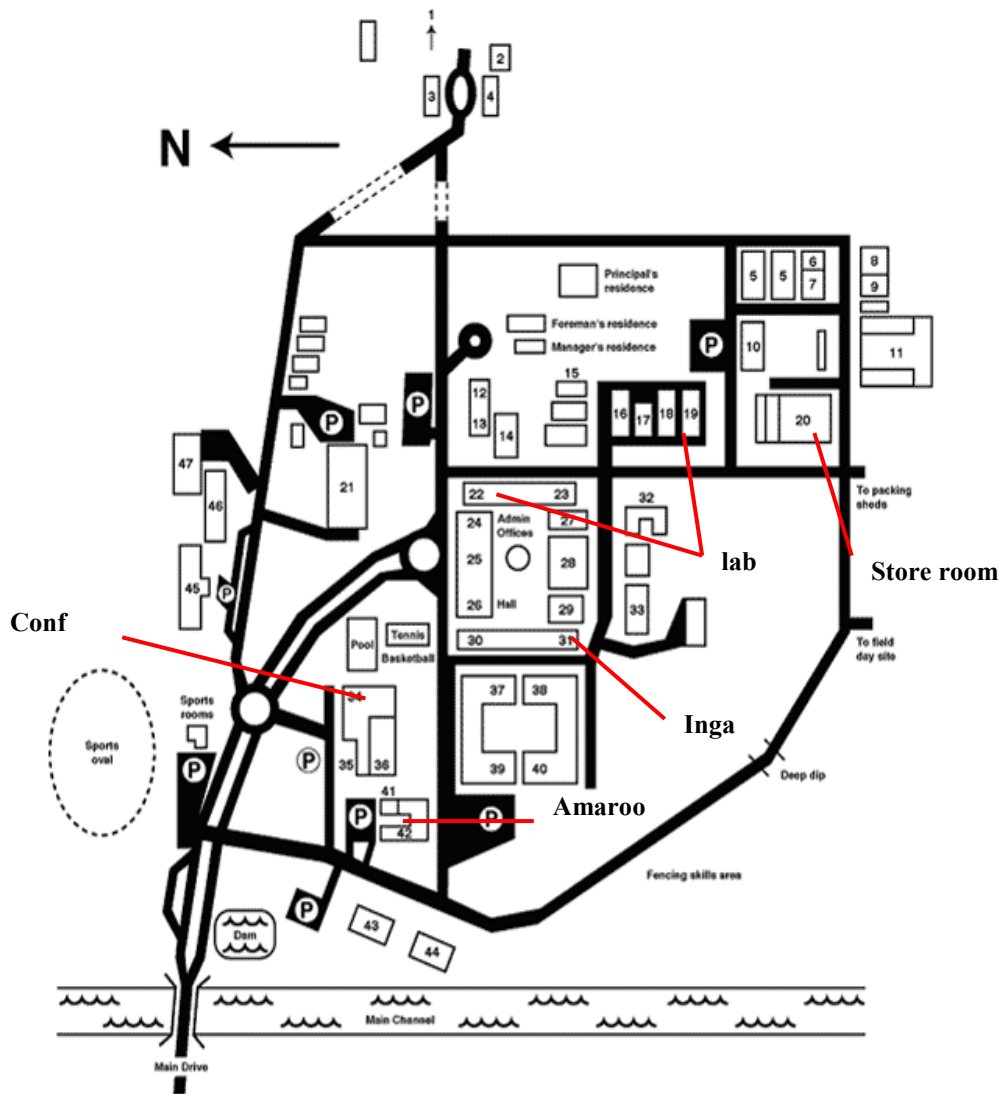
With its park-like setting, the YAI campus swimming pool is a delightful place to cool off at the end of the day, and the nearby barbecue and picnic facilities are perfect for outdoor get-togethers. Tennis and basketball courts and a football oval are also part of the extensive outdoor facilities. Also available are two types of accommodation.

'Amaroo' motel-style accommodation

Amaroo, meaning 'a quiet place', features 15 bed and breakfast (continental) motel-style rooms (see location No.42 on the map in Figure 8-4). Each room has a queen bed and a single bed, ensuite, TV, toaster, tea and coffee making facilities, bar fridge, and heating and cooling (Figure 8-7). The motel rooms are situated around a central courtyard connected to a conference facility. Price is \$82.50/night/person for single room and \$105/night/room for double room (incl. breakfast).

'Inga' Bunk house accommodation

Inga bunk house accommodation is self-catered with continental breakfast provided. Rooms have a double bunk, wardrobe and desk (Figure 8-8). Linen and towels are provided. Inga (No.31 on map in Figure 8-4) has 13 double rooms and one single room. The bunk house has a kitchen with microwave, toaster, kettle and fridge. Barbecue facilities are available on site by request. A free laundry, lounge room and shared single-sex bathroom facilities are also featured. Cost is \$35/night/person (+\$5.50 for breakfast). It may be necessary to share a room, depending on final numbers.



- | | | |
|---------------------------------|----------------------------------|---|
| 1. Beef Section | 17. Rice Store | 33. Accommodation (Doongara) |
| 2. Security Officer's Residence | 18. Woolclassing Room | 34. Continuing Education/Conf Rm 1 |
| 3. Shearing Shed | 19. Agronomy Room | 35. Advisory Offices |
| 4. Animal Demonstration Bldg | 20. Store/Farm Foreman's Office | 36. College Teaching Centre |
| 5. Maintenance Workshops 1 & 2 | 21. Research Laboratory | 37. Accommodation (Pearson East) |
| 6. Teaching Workshop 4 | 22. Research Officers (Pelde) | 38. Accommodation (Heath East) |
| 7. Mechanics Workshop | 23. Agronomy Rooms (Kulu) | 39. Accommodation (Pearson West) |
| 8. Teaching Workshop 5 | 24. Irrigation Services | 40. Accommodation (Heath West) |
| 9. Teaching Workshop 3 | 25. Administration | 41. Amaroo Conference Centre |
| 10. Teaching Workshop 2 | 26. Recreation Hall | 42. Accommodation (Amaroo) |
| 11. Farm Machinery Compound | 27. Conference Room 2 | 43. Lecture Rm 5/Soils Laboratory |
| 12. Offices | 28. Dining Room | 44. Teaching Wshp 1/Hydraulics Lab |
| 13. Lecture Rooms 1 & 2 | 29. Gymnasium | 45. National Vegetable Industry Centre |
| 14. Library | 30. Accommodation (Calrose) | 46. Food Industry Training Centre |
| 15. Glasshouses | 31. Accommodation (Inga) | 47. Food Industry Training Centre (Factory) |
| 16. Lecture Room 4 | 32. Administrative Paving Centre | |

Figure 8-4: Map of the YAI campus. ACES participants will be accommodated in the bunk house “Inga” (31) and in the Motel “Amaroo” (42). A lab space (22) will be made available for the duration of the campaign, as well as a storage shed (20) and an office.



Figure 8-5: Lab space and storage shed at the YAI.



Figure 8-6: Narrandera airport and hangar facility.



Figure 8-7: Motel at MRSC.



Figure 8-8: Bunk house at MRSC.



Figure 8-9: Yass accommodation at the Yass Motel.

8.2.3 Gundagai Motel

Gundagai Motel
 Cnr West/Sheridan Streets, NSW 2722
 Phone (02) 6944 1066
 Fax (02) 6944 2095

Gundagai Motel is just a short walk to a public swimming pool, shops and golf course.

Amenities:

- Car park
- Cots Available
- All rooms include air conditioning and private facilities

8.2.4 Yass Motel

Yass Motel
 40 Laidlaw Street, Yass, NSW 2582
 Phone (02) 6226 1055

The Yass Motel is located 1km north of Yass Post Office, close to swimming pool, sports oval and supermarket.

Amenities:

- Ground floor units
- Air conditioned rooms
- Licensed restaurant open 6.30pm to 8.30pm 5 days
- Hours of Reception: 7.30am - 10.00pm Daily
- Disabled Access: Wheelchair access
- Guest Facilities: Car park, Cots Available, Guest Laundry, Movie Hire, Restaurant Licensed, Spa.

8.3 Meals

Meal arrangements are left to individuals to organise. However, following are some suggestions to facilitate organisation:

Breakfast: continental breakfast can be provided upon request (additional cost), but you may wish to supplement this depending on your appetite and dietary requirements. Moreover, on sampling days the breakfast room may not be open in time for your early departure.

Lunch: no facilities will be open in time on sampling days for buying lunch prior to departure for the field. Moreover, there are typically no facilities near to the sampling areas themselves for buying lunches, nor are you likely to pass any shops on the way to your sampling site. You should therefore pre-purchase from the supermarket beforehand the supplies you will need to make your lunch in the morning (or night before if you are not a morning person) prior to leaving for the field.

Dinner: apart from the supermarket (if you wish to cook your own meal), you will be able to purchase a meal from a nearby restaurant or hotel. When at YIA the only options for dinner are to drive into Yanco (2km), Leeton (5km) or Narrandera (20km).

8.4 Internet

Internet access will be available to AACES participants when at MRSC (see N36 on map in Figure 8-4). An office with internet access will be available with key access for the participants. During the passage of the field crew, access to the computer labs is available. A password will be provided for login on these computers. When at the other locations, wireless internet access is often available at the accommodation, however there will be a charge associated with this. At Hay, an internet access card can be purchased for \$14. Alternatively, internet access is available at the Public Library in Gundagai and Hay, located approximately 100m from the hotel.

8.5 Travel Logistics

Please plan your travel to arrive at least a day before the scheduled training sessions to allow you to get settled, and please allow a few extra days on the end of the campaign in case of rescheduling due to rainfall on sampling days or other logistical problems. We recommend you plan to be in the Murrumbidgee catchment from 18 Jan to 21 Feb 2010.

8.5.1 Getting there

In terms of booking flights, international participants should fly into Melbourne (or Sydney/Canberra) and

- a) get a lift to Hay from Melbourne on the "Melbourne Shuttle" -- see below, or
- b) if you are planning to have a rental car, arrange to pick it up in Sydney, Canberra or Melbourne and drive direct to Hay (~driving time is around 4-8hrs, depending on your place of departure; some people may want to car pool!); for detailed driving directions we recommend to visit www.whereis.com and search for the best route (and please let us know if this is the case).

Note 1: The "**shuttle**" (basically the AACES participants in the campaign vehicles) will be able to transport the participants from Melbourne on the Monday before the campaign starts (departure will be early in the morning; details TBA) and return on 21 February 2010 (arrival sometime in the afternoon). Please book your flights and make your Melbourne accommodation arrangements accordingly. We strongly recommend you arrive at least two days earlier, in order to adapt to the different time and climate zone. Also, please send a request to ride the shuttle and a copy of your travel itinerary to Chris Rüdiger (crudiger@unimelb.edu.au) at least 2 weeks prior to the campaign start date.

Note 2: All ground crew are required to attend the **extensive training session** on 19/20 January 2010. This 2-day session will cover all aspects of the field trip, from an overview of the sites, to sampling methods (incl. field exercises), farm etiquette, and first aid measures.

8.5.2 Getting around

Information on navigating from the operations base to the focus farms and on which days are provided in Appendix F, together with directions on how to navigate the focus farms.

8.6 Daily Activities

The meeting point for the bi-daily group assembly and team preparation will be determined by the team leaders according to the available facilities. At the end of the day, each group member will need to coordinate with their team leader (as relevant) to:

- download their HDAS data and have it checked for completeness,
- check-in their gravimetric samples and any associated information; samples must be weighed, details entered on the hardcopy pro-forma (see Appendix I) provided (any additional information should be written down and attached to the check-in sheet and not simply passed word-of-mouth) AND entered in the excel pro-forma provided,
- check-in their roughness data; must be typed in the excel pro-forma provided (hard copy pro-forma is also to be submitted),
- check-in all vegetation samples and spectral etc information; samples must be weighed and details entered on the hard copy pro-forma provided as well as entered in the excel pro-forma provided, and
- check-in the instruments used, ensuring ALL electronic devices are recharged overnight and any repairs needed reported to BOTH your team leader and Rodger Young (do not wait until the next sampling day!!).

Team leaders will in turn report to Rodger Young for technical/equipment repairs, to Ye Nan for data archiving, and to Jeff Walker for general updates etc. Team leaders will also be responsible for confirming ALL data is appropriately recorded/archived at the end of each sampling day. Daily sampling operations will proceed as per the following schedule:

Reconnaissance Days

- **10:00am** Gathering of the teams at the meeting room
Briefing; review activities of the following day on the notice board
Preparation of the instruments and tools for the sampling
Undertake farm reconnaissance activities
Undertake any sampling activities (veg, soil moisture calibration etc)
Relocate base station (and make roughness measurement if required)²
- **6:30pm** Dinner and free time

Sampling Days (AEST)

- **As req'd** Final preparations and teams departure for the sampling location
- **5:30am – as req'd** Soil moisture transect sampling; soil moisture team
- **5:30am – 6:30am** Dew sampling operations; vegetation team
- **6:30am – 10:00am** Gravimetric sampling (and roughness); vegetation team
- **10:00am – 2:00pm** Vegetation spectral, destruction etc sampling; vegetation team
- **2:00pm – as req'd** Finish gravimetric sampling (and roughness); all
- **5:00pm** Latest arrival of teams to the base

² As only one roughness board is available teams will need to alternate between doing this activity on sampling days or on reconnaissance days.

Table 8-5: Schedule of training sessions.

Date	Time	Location	Activity	Coordinator
Training Day 1	9:00am-9:30am	Hay	AACES Presentation	Jeff
	9:30am-10:00am	Hay	Logistics and Code of Conduct/Safety Briefing	Chris
Tea break				
	10:20am-11:20am	Hay	Sampling strategies	Sandy
	11:20am-11:50am	Hay	HDAS tutorial and procedures	Mahdi
	11:50am-12:20pm	Hay	Post-work day check-in & downloads	Ye Nan
	12:20pm-13:15pm	Hay	Lunch	
	13:15pm-5:00pm	Hay	HDAS practice Roughness Gravimetric sampling	Team leaders + Mahdi & YeNan
Training Day 2	10:00am-11:00am	Farm 1	Farm reconnaissance	Team leaders
	11:00pm-3:00pm	Farm 2	HDAS dry-run Vegetation sampling	Team leaders

Report instrumentation issues etc to the team leaders as required
 Weighing soil and vegetation samples for drying
 Data downloading and archiving on the computers
 Recharge of electronic devices
 Refuel vehicles and check oil
 Dinner and free time

- **6:30pm**

8.7 Training Sessions

A 2-day training session has been scheduled to ensure all AACES participants are familiar with the project objectives, the sampling strategy and the use of all the instruments involved in the sampling. The training session is scheduled for **19/20 January 2010**. The training session will be held in the function room of the Cobb Inlander Motel at Hay on 19 January with all the participants, and by teams at the respective farms on 20 January, with the schedule and activities indicated in Table 8-5.

Training on instrument use will include:

- Overview of the campaign logistics, ground sampling and flight schedule,
- Overview of the “code of conduct” on farms, first aid, driving on unsealed farm tracks,
- Use of the University of Melbourne Hydraprobe Data Acquisition System (HDAS) including a primer on iPAQ basics,
- Vegetation height estimation,
- Vegetation type recognition,
- Dew amount recognition,
- Rock fraction estimation,
- Gravimetric soil sampling, and
- Surface roughness measurements.

As vegetation sampling activities will be undertaken directly by the team leaders and an assistant, no dedicated training sessions are scheduled for the vegetation sampling.

8.8 Farm Access and Mobility

Farms will be accessed regularly for the ground sampling operations. Transport from the ground operations base to the farm (and in some case across the farm) for sampling will be done using the team 4WD vehicle. Please note that 4WD driving on off-road areas and farm tracks can lead to injury and death, and requires extreme attention and care, and should only be undertaken after appropriate training. Driving through cultivated areas should be avoided at all times, due to the serious damage the transit could cause to crops.

The sampling locations have been organised so that only reasonably accessible areas will be the object of the sampling. Each soil moisture team member will choose one of the 6 soil moisture transects. Starting from one end, the 6 soil moisture team members should proceed “side-by-side” from one end of the transect to the other. These team members will be collected from the far end of the transect so that they do not need to make the return trip. **It is recommended that team members keep their two adjacent team mates in sight at all times to ensure their safety; stay at least in pairs.** Try and team up with someone that has a similar pace to you. It is also recommended that all team members have a mobile phone to facilitate communication with each other in case of emergency and for logistics reasons. As there will be poor or no mobile phone coverage at many farms, each team member will be issued with a small UHF radio for team communication, as an additional security measure. These have a range of 3-4km and a channel for communication will be announced at the training session. The team leader will also have a satellite phone available if needed.

It is the responsibility of the team leader to ensure that all points have been measured at the end of each day prior to leaving the field. Following are some recommendations to make the sampling as uniform and consistent as possible between different farms, different days, and different participants:

- Use the GPS as a guide rather than the sole means of navigation. Try and find a distant object that represents the end of your transect and walk towards it. Calibrate your step and pace out the distance between sampling points; allow more steps when going up hill and less when coming down. This will help minimise “chasing” the GPS position which is only accurate to about 20m.
- Take the samples at the location indicated on the screen map: exception to this rule might be the case of a sampling point falling within an undesirable location which might create local soil moisture conditions not representative of the site (e.g. an isolated tree in a vast short grass area, or in a creek bed). In this case, shift the sampling far enough to capture the average site conditions (up to 25m).

Remember that AACES activities are allowed by the property owners on the basis that no damage will be caused to the properties. In particular:

- Use gates when transiting between paddocks. The location of (some) gates etc are identified on the maps in Appendix F.
- When you open a gate, SHUT IT immediately after you crossed the fence and make sure that the locking system is securely positioned.
- In the case of heavy rain, stop sampling and wait for better weather conditions. If rain appears to “set-in”, return to the operations base.
- Be aware of the presence of stock on most of the farms during the sampling activities. Most of the animals are harmless cows and sheep, which will generally keep their distance unless they are being hand fed, in which case they may be a nuisance but not dangerous.

8.9 Communication

Communication between team members, teams and experiment coordinators is essential both from a logistic and safety point of view. In every team there will be at least one mobile phone with the team leader. Moreover, each team member will have a hand-held UHF radio on a pre agreed channel; **normally channel 38**. Additionally, working together as a team, or at least in pairs, will ensure that contact within the individual team members is maintained. Ensure that each team member can be accounted for each half an hour. If a team member cannot be accounted for, search initiation should be immediate. On most farms the mobile phone coverage is extensive, while on some it is poor, and thus use of UHF radio, visual contact, and other means of communication will be more important.


8.10 Safety

There are a number of potential hazards in doing field work. Common sense can avoid most problems. However, the following has some good suggestions. Remember to:

- Always work in teams of two
- Carry a phone and/or UHF radio
- Know where you are. Keep track of your position on the provided farm map.
- Stay on your sampling transect and wait there when you get to the end.
- Do not approach, touch or eat any unidentified objects in the field.
- Dress correctly; long pants, long sleeves, hiking boots, hat etc
- Use sunscreen.
- Carry plenty of water for hydration.
- Notify your teammate and supervisors of any pre-existing conditions or allergies before going into the field.
- Beware of harvesting machinery. When sampling on crop, always make sure your presence is noted and watch out for moving harvesting machines.
- Beware of snakes. Always wear sturdy hiking boots and long work pants to avoid penetrating bites. Refer to <http://www.australianfauna.com/australiansnakes.php> for detailed info about the most common of Australian snake species. Treat all Australian snakes as potentially deadly. In 99.9% of all encounters, the snake will try to avoid any human contact (see First Aid note).
- Do not run through high grass or uneven ground to avoid injuries.
- The temperature used for the soil drying ovens is 105°C. Touching the metal sample cans or the inside of the oven may result in burns. Use the safety gloves provided when placing cans in or removing cans from a hot oven. Vegetation drying is conducted at lower temperatures that pose no hazard.

8.11 Getting Around

The Riverina Regional Tourism website at www.visitriverina.com.au has a wealth of information on the region, including how to get to the Riverina (with details for travelling by plane, train and coach), events calendar, organised tours, self-drive tours, walking tracks, wineries, towns in the region, art galleries, eating out, and sporting facilities.

 Australian Red Cross

First aid for snake bite.

Use the pressure immobilisation technique for a bite on a limb.

-apply firm pressure over the bite site

-apply broad bandage to keep pressure on bite site.

-immobilise limb

(for bites on the head or trunk do not use this technique but keep the patient still and get medical aid asap)

Monitor the airways, breathing and circulation of the patient. Be ready to give Expired Air Resuscitation (mouth to mouth) or CPR.

Keep the patient very still and reassure.

Start transport to the nearest medical centre or call and meet an ambulance.

Do not cut the bite

Do not suck the bite.

Do not wash the bite.

Do not apply a tourniquet

9 Contacts

9.1 Primary

The primary contacts for AACES campaigns are:

A/Prof Jeffrey Walker

03 8344 5590

0413 023 915

j.walker@unimelb.edu.au

Dr Chris Rüdiger

03 8344 5628

0410 131 407

crudiger@unimelb.edu.au

Dept. of Civil and Environmental Engineering
The University of Melbourne
Parkville 3010 VIC

For all matters relating to overall coordination of the campaign and aircraft operations contact A/Prof Walker. For matters relating to specific ground sampling operations contact Dr Rüdiger. For maintenance issues and issues relating to farm access contact Mr Young. Field contact numbers are provided in the participants table below. The satellite phone numbers are: +61 147 168 758 and 0011 872 761 151 283 (those are only used for emergencies, for calls, please contact the participants via the hotel in the evening).

9.2 Participants

An alphabetical listing of contact details for all participants is provided in the table below (^a aircrew, ^g ground crew).

Name		Email	Phone Number
AACES participants			
Allahmoradi, Mahdi ^a	UoM	m.allahmoradi@pgrad.unimelb.edu.au	0400 020 149
Bacon, Derek ^g	BoM	d.bacon@bom.gov.au	
Betgen, Channah ^g	VUA	cbn320@student.vu.nl	
Bircher, Simone ^g	DTU	subi@space.dtu.dk	
Frost, Andrew ^g	BoM	a.frost@bom.gov.au	
Gruhier, Claire ^g	Cesbio	claire.gruhier@cesbio.cnes.fr	
Hitiamillage, Ranmalee ^g	UoM	ranmalee@gmail.com	
Johanson, Jon ^a	UoM	info@flymore.com	
Kim, Edward	NASA	edward.j.kim@nasa.gov	
Klimczak, Olaf ^g	UoM	olaf.klimczak@gmail.com	0451 056 908
Lai, Jane ^g	UoM	j.lai10@ugrad.unimelb.edu.au	0430 133 636
Leroux, Delphine ^g	Cesbio	delphine.leroux@cesbio.cnes.fr	
Łukowski, Mateusz ^g	PAN	m.lukowski@ipan.lublin.pl	
Mialon, Arnaud ^g	Cesbio	mialon@cesbio.cnes.fr	
Peischl, Sandy ^g	UoM	s.peischl@pgrad.unimelb.edu.au	0416 974 837
Port, Ulrike ^g	ZMAW	rikas@gmx.net	
Rüdiger, Chris ^g	UoM	crudiger@unimelb.edu.au	0410 131 407
Ryu, Dongryeol	UoM	dryu@unimelb.edu.au	0403 257 335
Schrooten, Roosanne ^g	VUA	rsn440@student.vu.nl	
Słowińska, Sandra ^g	WP	sanhall@wp.pl	

Vreugdenhil, Mariette ^g	VUA	mvl210@student.vu.nl	
Walker, Jeffrey ^a	UoM	j.walker@unimelb.edu.au	0413 023 915
Wójciga, Anna ^g	PAN	a.wojciga@ipan.lublin.pl	
Ye, Nan ^{a, g}	UoM	n.ye@pgrad.unimelb.edu.au	0433 060 369
Young, Rodger ^g	UoM	riy@unimelb.edu.au	0417 504 593
Collaborators			
De Jeu, Richard	VUA	Richard.de.jeu@falw.vu.nl	
Hornbuckle, John	CSIRO	John.Hornbuckle@csiro.au	
Kerr, Yann	Cesbio	Yann.kerr@cesbio.cnes.fr	
Loew, Alexander	ZMAW	Alexander.loew@zmaw.de	
Lymburner, Leo	GA	Leo.Lymburner@ga.gov.au	
Marczewski, Wojciech	PAN	wmar@cbk.waw.pl	
Renzullo, Luigi	CSIRO	Luigi.Renzullo@csiro.au	
Shoemaker, Vic	DECC	victor.shoemark@industry.nsw.gov.au	
Skuo, Niels	DTU	ns@space.dtu.sk	
Sumerrell, Greg	DECC	Gregory.Summerell@environment.nsw.gov.au	
van Dijk, Albert	CSIRO	Albert.Vandijk@csiro.au	

9.3 Emergency

Emergency number in Australia 000

NSW Poisons information centre 131 126

Hospitals details are provided in the table below.

<i>Nearest hospital and location</i>	<i>Farm ID</i>	<i>Distance (km)</i>	<i>Travel time (min)</i>
Balranald District Hospital Court St Balranald, NSW 2715 Ph: (03) 5020 1606	1	17	12
	2	41	38
Hay District Hospital 351 Murray St Hay, NSW 2711 Ph: (02) 6990 8700	3	60	46
	4	59	86
	6	16	14
	6	61	44
Jerilderie District Hospital Newel Highway Jerilderie, NSW 2716 Ph: (03) 5886 1300	7	101	116
Hay District Hospital 351 Murray St Hay, NSW 2711 Ph: (02) 6990 8700	8	87	85
Narrandera District Hospital Cnr Douglas and Adams Streets Narrandera, NSW 2700 Ph: (02) 6959 1166	9	48	34
	10	70	67
	11	21	22
Lockhart District Hospital Hebden St Lockhart, NSW 2656 Ph: (02) 6920 5206	12	27	31
Coolamon-Ganmain Hospital Buchanan Drive Coolamon, NSW 2701 Ph: (02) 6927 3303	13	23	47
Wagga Wagga Base Hospital	14	37	34

Edwards St Wagga Wagga, NSW 2650 Ph: (02) 6938 6666			
Junee District Hospital Button St Junee, NSW 2663 Ph: (02) 6924 1122	15	30	33
Tumut District Hospital Simpson St Tumut, NSW 2720 Ph: (02) 6947 1555	16	23	32
	18	25	38
Gundagai District Hospital O'Hagen St Gundagai, NSW 2722 Ph: (02) 6944 1022	17	55	54
Calvary Public Hospital Mary Potter Circuit Cnr Belconnen Way & Haydon Drive Bruce, ACT Ph: (02) 6201 6111	19	31	47
	20	31	48

9.4 Land Owners

A complete list of contacts for land owners or managers who have provided access to their properties during AACES campaigns is provided in the table below:

Farm	Contact	Address	Phone
1/1	Mr [Name] [Address] [Postcode]	[Address] [Postcode]	[Phone]
1/2	Mr [Name] [Address] [Postcode]	[Address] [Postcode]	[Phone]
2/3	Mr [Name] [Address] [Postcode]	[Address] [Postcode]	[Phone]
2/4	Mr [Name] [Address] [Postcode]	[Address] [Postcode]	[Phone]
	Mr [Name] [Address] [Postcode]	[Address] [Postcode]	[Phone]
3/5	Mr [Name] [Address] [Postcode]	[Address] [Postcode]	[Phone]
3/6	Mr [Name] [Address] [Postcode]	[Address] [Postcode]	[Phone]
3/6	Mr [Name] [Address] [Postcode]	[Address] [Postcode]	[Phone]
4/7	Mr [Name] [Address] [Postcode]	[Address] [Postcode]	[Phone]
4/8	Mr [Name] [Address] [Postcode]	[Address] [Postcode]	[Phone]

5/9
5/10

6/11

6/12

7/13

7/14

7/14

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9.5 Logistics

Accommodation

Hay:

Cobb Inlander Motel
Mark & Colleen
83 Lachlan Street, Hay, NSW 2711
Phone (02) 6993.1901
Fax (02) 6993.3406

Yanco:

Murrumbidgee Rural Studies Centre
NSW Department of Primary Industries
PMB, Yanco NSW 2703
Phone: (02) 6951 2775
Fax: (02) 6951 2620

Gundagai:

Gundagai Motel
Cnr West/Sheridan Streets, NSW 2722
Phone (02) 6944 1066
Fax (02) 6944 2095

Yass:

Yass Motel
40 Laidlaw Street, Yass, NSW 2582
Phone (02) 6226 1055

Rental Car

Flight Crew cars:

Avis Griffith (Wyangang Service Centre)
94 Banna Ave.
Griffith, NSW
Phone (02) 6964 2266; AVIS Australia: 136 333
Booked cars: 2x Toyota Yaris or similar (to be returned to Wagga Wagga Airport) for pick-up on 18 Jan (4pm) and return 22 Feb.
Booking reference: 4366 0715 AU0 & 4366 0826 AU6 (booked under Christoph Rudiger).

4WDs:

60-66 Islington St
Collingwood, VIC 3066
phone: 03 8415 1622
email: gmartyn@bus4wdhire.com.au
Booked cars: 1 Landcruiser Troopcarrier and 3 Hilux Dual Cabs

Narrandera Airport

Council person in charge:

Andrew Pearson

phone: (02) 6959 5550

email: Andrew.pearson@narrandera.nsw.gov.au

Airport groundsman:

Albert Pope (nickname Doona)

phone: 0428 690 518

Laboratory Facilities Contact

Hay:

Shane McGuthick

Hayfield Field Station

Phone: (02) 6993 2281

Mobile: 0429 932 281

Yanco:

Agricultural Institute

Narrandera Road

Yanco NSW 2703

Phone: (02) 6951 2652

Gundagai:

Mason Crane (Senior Research Officer)

Gundagai Wildlife Office

117 Sheridan St.

Gundagai, NSW 2722

Phone: (02) 6944 4586

Mobile: 0427 770 594

10 References

- Australian Bureau of Meteorology: Gridded rainfall data, based on the standard rainfall climatology (1961-1990), areal potential evapotranspiration data (ET) and climate zones data according to Koeppen classification are publicly available from: <<http://www.bom.gov.au>>.
- 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, Digital Atlas of Australian Soils and Soil Water Capacity data are publicly available from: <<http://adl.brs.gov.au/mapserv/landuse/>>.
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Appendix A: Operating the HDAS

A1. HDAS Cheat Sheet

HDAS Quick Instruction!

1. iPAQ Bluetooth Manager

- Before starting ArcPad, turn on the Bluetooth connection using iPAQ Wireless program. Follow numbered steps in figure 1 to turn it on, and manually connect to the GPS device.

Note: There is a default GPS Bluetooth connection with the same name as your iPAQ label. Initialisation between the iPAQ and your GPS (with the same label) has already been done. Using the steps provided here you are just going to turn on your embedded Bluetooth device in the iPAQ and make the connection between the iPAQ and predefined GPS device. If your iPAQ battery goes flat you may need to create a new connection for your GPS.

FYI: we are using more than one brand of GPS in the field campaign, and they have different power plugs (pin plug and mini USB).

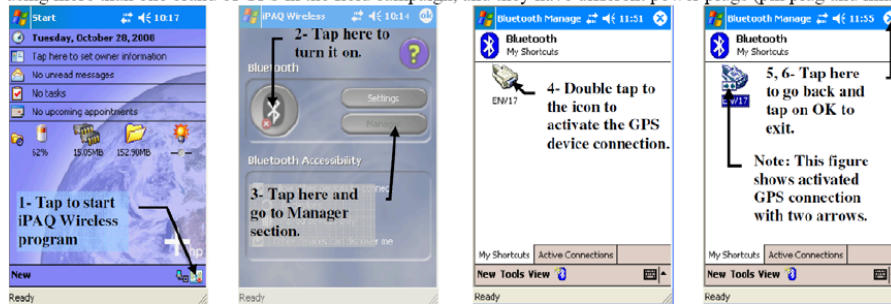


Figure 1. Activating Bluetooth device and manually bonding the GPS with iPAQ.

2. HDAS

2.1. Hydra Probe

- Make sure power cable is connected to the Hydra Probe.
- Check Hydra Probe sensors prongs regularly to confirm they are straight and not broken! Clean the sensor prongs after each measurement!
- There is a power connection for the iPAQ in the bum bag holding the 12V gel cell battery. Make sure it is connected properly and you can see the orange lamp blinking on the top right hand corner of the iPAQ.
- Attach the iPAQ to Hydra Probe pole in a safe fashion to prevent the damage.

2.2. GPS

- There is a power cable for the GPS which should be connected to it when its battery power becomes low. Continuous power connection to the GPS is not recommended as it destroys the battery life.
- Turn on your GPS before starting ArcPad software.
- There are two lamps on the GPS; the red one indicates power status and the blue one indicates Bluetooth connection and when it is steady blue means good GPS satellite signal coverage. Therefore, GPS with power on does not mean you have accurate GPS position.
- There are several parameters that can affect the required time to have accurate position (position fixed!) from GPS, so please make sure GPS position is accurate before taking the measurement (see section 2.3).
- Turn off the GPS device when you are not going to sample for more than 15 minutes.

2.3. ArcPad

- Before starting this section, make sure embedded Bluetooth and GPS devices are already turned on.
- Tap on start icon to see the menu. Tap on ArcPad 7.1.1 icon to open the program (see figure 2).
- If there is no ArcPad 7.1.1 icon in the menu, go to Programs and load the software from there.

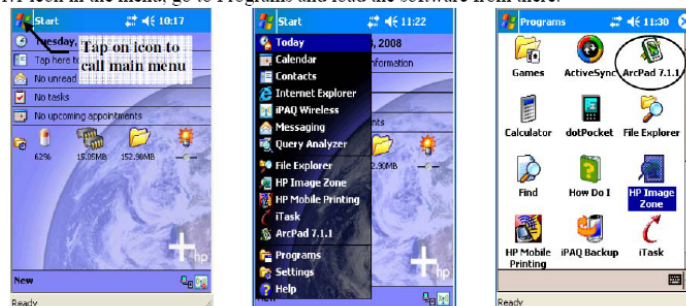


Figure 2. Starting ArcPad software

The following steps will explain how to take measurements using the ArcPad user interface for Hydra Probe. Figure 3 illustrates the general commands and tool buttons for HDAS.

- First, you need to add hydra and hydraGRID shapefiles to ArcPad using icon in the second toolbar.
- Symbol indicates your GPS position is lost or is not accurate; you need to have position fixed symbol () before sampling.
- When you tap on the icon you can see a message box which says hydra files loaded. Tap on OK.

- Now the first icon in the second (HDAS) toolbar is active.

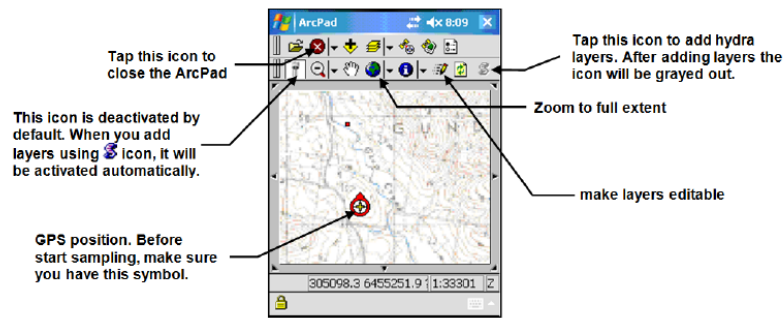


Figure 3. Customised toolbars for HDAS in ArcPad

- Tap on icon to activate the HDAS tool button.
- Put the Hydra Probe into the ground at the sampling point, tap in the screen and wait for 5 seconds. Tapping on touch screen will start an event procedure that will communicate with the Hydra Probe and GPS to gather both position and soil moisture related data.
- After a few seconds, a form with collected data will appear in the screen.
- Fill out all of the sheets as described in figure 4. After tapping on button, all the information will be stored in hydra layer automatically, so there is no need to save ArcPad document for saving the sampling points' information.

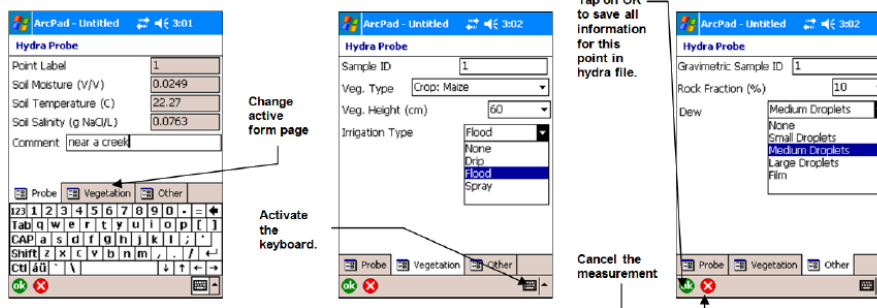


Figure 4. HDAS data entry pages with instructions

3. Troubleshooting

- "Error 55: Your connection to GPS has not been established." This means there is no active GPS in the vicinity of the iPAQ or the GPS is not bonded with the iPAQ properly. Please refer to the first and second sections of this cheat sheet to establish the connection.
- "Hydra Probe Reading Error: Check connection cable between iPAQ and Hydra Probe." Ensure that the Sync cable connected (to the iPAQ) in order to receive data from the Hydra Probe!
- In case an iPAQ halts for a long time, there is a reboot hole in bottom of the iPAQ to restart the device (use stylus pen). Please note using power bottom on top of the screen just activates sleep mode!

Note: As iPAQ's screen is rather fragile, please tap on the screen gently, and never use something else to tap on it!

4. General iPAQ maintenance

- There is a checklist in each HDAS box, so check your components against the checklist to make sure you have all of them before going out for sampling.
- Do not mix components of different HDAS units; use only components with the same label. i.e. ENV17. This is especially important for the GPS and iPAQ.
- If possible connect the iPAQ to a charger every night during the field campaign to be sure that it will be fully charged before going out the next day.

Negligence in charging iPAQ regularly will cause problems for the iPAQ, meaning you have to wait for more than 30 minutes to recharge the iPAQ and in the worst case you may have to reinstall ArcPad and copy HDAS related files again.

Note: In case of flat battery, not all models of iPAQ will loose their software. So for those iPAQs which will loose software (iPAQs with red dot), a restore point has been created, so the user can restore the iPAQ with all software ready to use again following the below steps: Start → Programs → iPAQ Backup → Restore

5. Data Management

- Be sure you make a copy of your data which is stored in the "SD card" folder every day to the data archive in the field laptop.
- There are predefined folders for all iPAQs with subfolders according to sampling date, so you can just copy data in the relevant folder and subfolder considering date of sampling.
- Microsoft ActiveSync is essential to be able to copy these files to laptop if operation system is Windows XP.

The Hydra Probe Data Acquisition System (HDAS): User Guide

Rocco Panciera, Mahdi Allahmoradi, Olivier Merlin, Rodger Young
and Jeffrey Walker

Department of Civil and Environmental Engineering
The University of Melbourne



November 2009

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1. Introduction to the HDAS

The Hydra Probe Data Acquisition System (HDAS) is a spatially enabled soil moisture, temperature and salinity measurement platform that logs all relevant information into GIS format using ArcPad[®]. The HDAS was developed by the Department of Civil and Environmental Engineering at the University of Melbourne and is composed of a Stevens Water Hydra Probe[®], a Bluetooth GPS receiver and an iPAQ[®] pocket PC (Fig. 1).

The pocket PC is used to:

- display a map of the sampling area;
- communicate with the GPS receiver to get the real time position;
- display the sampling position on a background map;
- communicate with the Hydra Probe to take readings of soil moisture, soil temperature and soil salinity;
- obtain metadata including sample date, time and ID;
- input any additional observations such as vegetation type and general comments;
- store the metadata, position and Hydra Probe readings in a GIS shape file; and
- display the location of the recorded Hydra Probe measurements on the map.

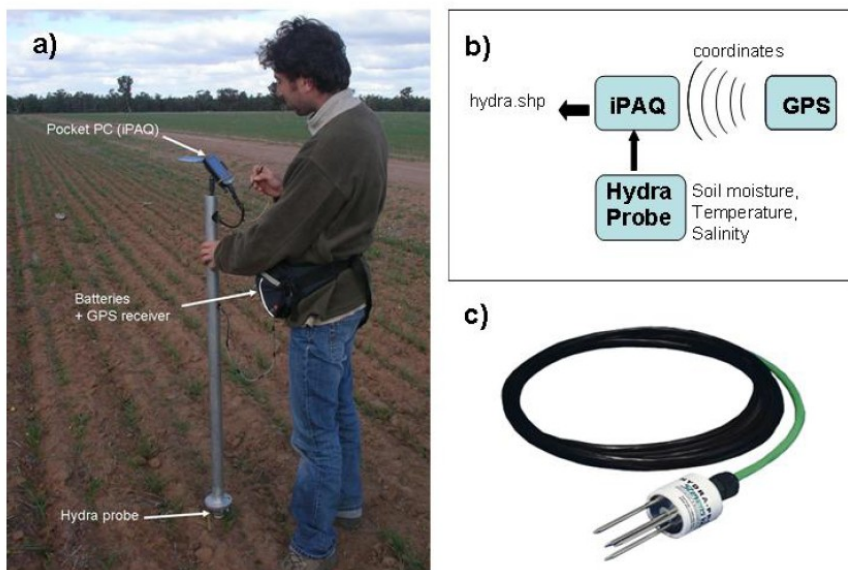


Figure 1. a) The Hydra Probe Data Acquisition System (HDAS), b) schematic of the HDAS system functionality, and c) the Stevens' Hydra Probe.

The Stevens' Hydra Probe is a soil sensor for measuring soil moisture, temperature and salinity (for details, see Hydra Soil Moisture Probe User's manual in the "Documentation" folder that accompanies this manual). The instrument determines soil moisture and salinity by making a high frequency (50 MHz) complex dielectric constant measurement. A complex dielectric constant measurement resolves simultaneously the capacitive and conductive parts of a soil's electrical response. The capacitive part of the response is most indicative of soil moisture while the conductive part reflects predominantly soil salinity. Temperature is determined from a thermistor incorporated in the probe head. As a soil is wetted, the low dielectric constant component of air is replaced by the much higher dielectric constant component of water. Thus, as a soil is wetted, the capacitive response (which depends upon the real dielectric constant) increases steadily. Through the use of appropriate models, the dielectric constant measurement can be directly related to soil moisture. The dielectric constant of moist soil has a small, but significant, dependence on the soil temperature while soil conductivity varies strongly with temperature. The soil temperature measurement that the Hydra Probe makes is used to remove temperature effects, and the raw voltages measured by the probe converted to soil moisture using some circuitry in the probe head. A soil type option can be set when programming the circuitry of each probe; Sand, Silt or Clay. In the case that no knowledge of the soil type is available, it is recommended by the manufacturer that the option "silt" be chosen. This affects the calculation of soil moisture output made internally by the Hydra Probe. Nevertheless, in the current version of the HDAS system described in this document the soil type option is not used, as a processing approach that is independent of soil type is applied to the raw Hydra Probe dielectric measurements, thus making the soil moisture output unaffected by the soil type option setting. However, site specific calibration of the probe is still recommended.

2. How to use this manual

This manual covers a variety of information, ranging from simple use of the system through to general guidance on customisation of the acquisition software for a particular application. Consequently the manual has been organised as follows:

- If you simply need to operate a HDAS system which has been already set-up for your study area: go to section 3
- If you need to set-up the physical HDAS system: go to section 4;
- If you need to set-up the HDAS system software: go to section 5;
- If you need to adapt the HDAS system software to your specific needs: go to section 6;
- If you are having trouble with using the HDAS system: go to section 7;
- For details about the HDAS soil moisture output, its calibration and expected accuracy: go to section 8.

NOTE: *The HDAS system software provided with this manual has been developed using several iPAQ makes with Pocket PC operating system Windows Mobile 2003, Windows CE 2005 and Windows Mobile 6, with ArcPad version 6.0.3 and 7.1.1. The software provided may not work with other makes of iPAQ or versions of software.*

Quick Reference to HDAS Use (refer to Fig. 2)






- Copy ALL files provided with the HDAS package from the folder “Applets” on the computer to the IPAQ folder “\Program Files\ArcPad\Applets”;
- Click on  icon to load/create hydra and hydraGRID shape files.
- Activate the Hydra Probe by tapping the  icon;
- With  icon depressed, tap anywhere on the screen to interrogate the probe;
- View the Hydra Probe readings and fill in other information in the ArcPad forms as desired (see Fig. 3 on Page 11);
- Fill in metadata as required by navigating through the tabs for other data pages;
- Store the measurement with the spatial coordinates tapping the  icon at the bottom of the form or cancel the reading by tapping the  icon;
- The coordinates stored are those from the GPS if activated (points will be saved in the file names “hydra”), or the position on the screen if the GPS is not activated (points will be saved in the file named “hydraGRID”);
- Move to the next sampling location and tap on the screen to take another reading.
- All data collected are stored in the “hydra.shp” and “hydraGRID.shp” shapefiles in the iPAQ folder “\SD card”.





Figure 2. General layout of the iPAQ (left) and HDAS sampling screen (right).

3. Using the HDAS system

This section guides the user step-by-step through the operation of the HDAS system, from turning on the iPAQ device to downloading the data collected with the HDAS. This section assumes that the HDAS has already been set up and all the necessary files and software have been loaded on the iPAQ. If that is not the case, refer to sections 4 and 5 before reading this section.

3.1. Navigating the iPAQ

This section describes how to navigate the iPAQ and use the ArcPad to operate the HDAS (for numbers/icons refer to Fig. 2):

- To turn the iPAQ on/off: use the button at the top right corner of the device (1). NOTE that the iPAQ goes into sleep mode after a couple of minutes when on battery power. To revive it, press the on/off button again.
- To access any program (eg. ArcPad or file explorer), use the “Start” button on the top left corner (2) and select the program from the drop-down list. NOTE: Only recently used programs are available from this list; all programs are available in the folder “Programs”.
- To change iPAQ settings like sleeping time, screen brightness, battery saving options etc, select “Settings” from the “Start” menu.
- To minimise ArcPad, tap the  icon on upper right corner of the ArcPad window. NOTE: this does not exit the program, which can be maximised by tapping the program icon on the bottom toolbar of the main windows screen.
- To exit ArcPad, tap  icon on the top toolbar.

3.2. Bonding the iPAQ to a GPS device

The GPS device needs to be bonded with the iPAQ BEFORE the HDAS system can be used. Virtually any GPS device can be used with the HDAS system, provided it can be connected with the particular iPAQ used and that it can be read from ArcPad. There are some known issues with the connection of ArcPad and some brands of GPS devices (see *ESRI support website*: <http://support.esri.com/index.cfm?fa=homepage.homepage>). The configuration described in this section is valid for Bluetooth devices only. The ArcPad settings for GPS communication are set automatically by the HDAS software. However, these settings are indicated in Table 2.

Automatic Bonding

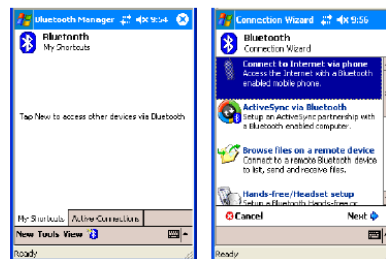
The HDAS system software has been configured to automatically search for any GPS receivers (those using Bluetooth protocol) within range every time the user starts ArcPad. A list of available devices will then be prompted to the user for the appropriate one to be selected. This is useful if a particular GPS device is not used all the time. However, it is recommended that a specific GPS device be used, and consequently the manual bonding procedure detailed in the next section is the preferred option.

Manual Bonding

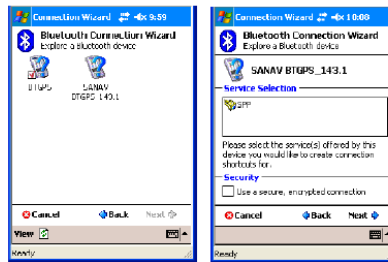
1. Turn on your GPS device.
2. Tap the “Wireless Connection”  icon on the IPAQ desktop;
3. Activate Bluetooth by tapping the “Bluetooth” icon. Make sure that the “All devices” option is checked;



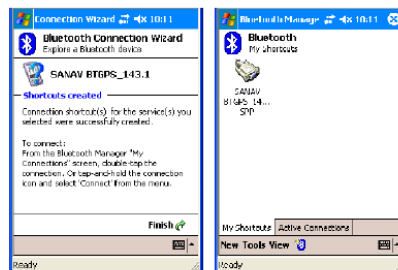
4. Select “Manager”;
5. Select “New” at the bottom right corner of the screen and scroll down until “Explore a Bluetooth device”. Tap “Next” on the bottom right;



6. Wait for the GPS device to be detected and its icon displayed in the blank page. This might take a few minutes. **NOTE: in this phase, ALL Bluetooth devices that are switched on and within the range of action of Bluetooth will be shown. Make sure to identify the correct GPS device if multiple systems are in range.**
7. Tap on the GPS icon;
8. A wizard will appear with the services offered by the GPS receiver. Select the service that is available (SPP) and tap “Next”;



9. An information page will appear confirming that the selected GPS and the iPAQ are now bonded. Review the information and tap “Finish”. The GPS can now be seen in the “My Shortcuts” tab.








NOTE: The bond between iPAQ and GPS device is temporary and can be interrupted (for example, if the GPS device battery goes flat or the GPS device stays out of range for a prolonged period).


NOTE: It is not uncommon to have problems receiving a valid GPS signal from the GPS receiver (i.e. no “position fix” is available). First check that the GPS receiver has a lock on the GPS satellites as indicated by a status light; it may take several minutes for this to occur after first turning the GPS receiver switch to on. If the GPS status light is active and the problem persists, un-bond the GPS device from the iPAQ by removing the GPS device icon in the Bluetooth manager connection list, then re-bond the GPS as described in section 3.2 and repeat the connection procedure above.

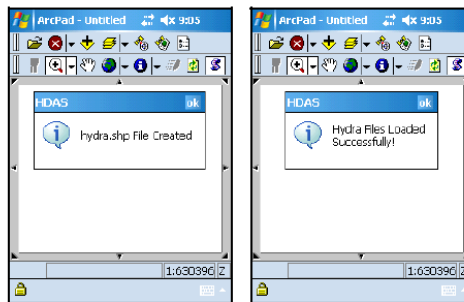
3.3. Starting the HDAS system

Follow the procedure outlined below to start the HDAS:

1. Start ArcPad by tapping the  icon on the top left corner of the iPAQ screen and selecting "ArcPad" from the list. **NOTE: If ArcPad is not listed there, go to "Programs" and select "ArcPad" from there.**
2. Load the ArcPad map file with , or individually the background map and sampling locations shape files (if you have them) with the  icon.
3. Click on the  icon: This will load the hydra and hydraGRID shapefiles used to store the HDAS data if these exist in the folder "\SD Card"; if the files do not already exist in this folder, new hydra and hydraGRID shapefiles will be created in it. **NOTE: the Hydra Probe icon cannot be activated until the hydra and hydraGRID shapefiles have been loaded or created using the  icon.**


NOTE: When the hydra and hydrGRID shapefiles already exist in the "\SD Card" folder, old records will NOT be overwritten, but rather the new records will be appended at the end of the file.

4. Windows will confirm that the files have been created, after which the "Hydra Probe" icon  can be activated.



3.4. Taking a Hydra Probe reading

Follow the procedure outlined below to take a Hydra Probe reading:

1. Select the "Hydra Probe" icon  on the bottom left corner of the HDAS Toolbar menu to activate the program that reads the Hydra Probe values. **NOTE:** this icon must look "depressed" in order to take a reading of the Hydra Probe.
2. Navigate to the sampling point by moving to the desired location in the landscape.
3. Insert the Hydra Probe vertically in the ground, until the base of the Hydra Probe head is firmly at the ground surface level. Be sure to not create air gaps when

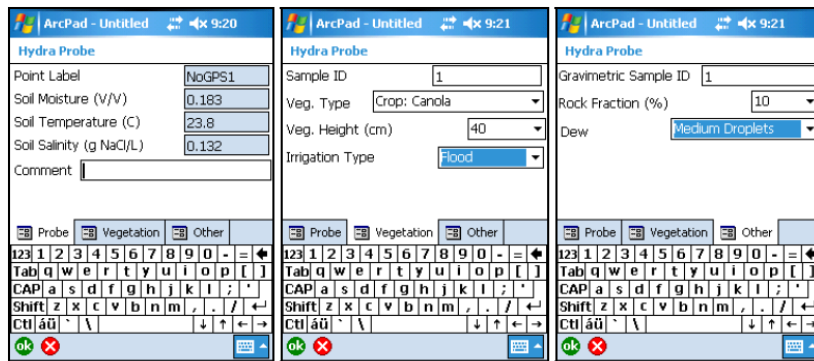


Figure 3. General layout of the pages in the HDAS form: a) Probe readings page; b) Vegetation page and c) Extra page.

inserting the probe. Apply steady pressure to the footplate to assist with insertion in hard soils.

4. Take a Hydra Probe reading by tapping anywhere on the screen and wait for 5-10 seconds. **Be patient!** DO NOT tap anything on the iPAQ screen during this time.
5. After 5-10 seconds, a form appears in ArcPad containing three pages (see Fig. 3), each containing several text boxes.

“Probe” page

- Point sequential number – AUTOMATIC
- Hydra Probe soil moisture reading (in volumetric water content fraction) – AUTOMATIC
- Hydra Probe soil temperature reading (in degrees Celsius) – AUTOMATIC
- Hydra Probe soil salinity reading (in g of NaCl per litre) – AUTOMATIC
- Comment text box – MANUAL

“Vegetation” page

- Vegetation Sample ID – MANUAL
- Vegetation type text box, to be chosen from a drop down list – MANUAL;
- Vegetation Height (cm) – MANUAL;
- Irrigation Type, to be chosen from a drop down list – MANUAL

“Other” page

- Gravimetric sample ID – MANUAL.
- Rock cover fraction (in %), to be chosen from a drop down list – MANUAL
- Dew status, MANUAL

6. Navigate throughout the three pages and fill in the desired text boxes. NOTE: there is no specific order required when completing the forms in order to

NOTE: Before the form appears, an error message might be displayed warning that the measured soil dielectric constant is out of a specific range. This in general means that the soil volume sampled by the probe is disrupted or with significant air gaps affecting the reading. After pressing "OK" on the error window, it is suggested to cancel the current point by tapping the ❌ on the bottom of the form, insert the probe carefully at a different location and repeat the reading.

successfully save the points. Nevertheless, apart from the point sequential number the AUTOMATIC fields cannot be changed/deleted.

7. The user can:

- Accept the point by tapping the OK icon on the bottom left corner of the form (Fig.3). This will store the point and measurement taken.

NOTE: In case the GPS is turned off at the time of taking a reading, the reading will be saved in the shapefile "hydraGRID", with coordinates corresponding to the location tapped on the ArcPad screen by the user with the sequential label "NoGPS". A warning of this will be displayed upon saving the point "The GPS is off! The Point will be saved into hydraGRID.shp using coordinates for the location you tapped on the screen.

- Cancel the point by tapping the ❌ icon on the bottom left corner of the form (Fig.3). This will discard the current record permanently.

3.5. Creating and deleting points manually

To create a point in the shape file without reading the Hydra Probe:


- Click on the 🛠 icon in the second ArcPad toolbar (see Fig.2), then choose the layer that you need to make editable (i.e. hydra.shp). After selecting the desired layer, a new toolbar will appear as the uppermost toolbar.
- The user can create a point using either screen coordinates (by tapping the 📍) or GPS coordinates (by tapping the 📍).
- Once the user has tapped on the screen, the attribute table of the selected layer will appear. After filling the desired fields click the OK icon to save the point. **NOTE: To make the layer non editable, click again on the 🛠 icon and choose the name of layer, then the edit toolbar will disappear.**

To delete a point in the shape file:

- Click on the 🛠 icon in the second ArcPad toolbar (see Fig.2), then choose the layer that you need to make editable (i.e. hydra.shp). After selecting the desired layer, a new toolbar will appear as the uppermost toolbar.
- Tap on the ▼ icon to activate the selection mode;
- Select the point to be deleted by tapping on it **once**;
- Tap on the ❌ icon and click "Yes".




3.6. Review the values stored at a location

To review a point in the shape file:

- Tap on the  button in the second ArcPad toolbar (see Fig.2);
- Tap on the point to be reviewed;

3.7. Editing the values stored at a location

The values stored at a location are saved into fields of the hydra or hydraGRID shape files and can be edited manually:

- Click on the  icon in the second ArcPad toolbar (see Fig.2), then choose the layer that you need to make editable (i.e. hydra.shp). After selecting the desired layer, a new toolbar will appear as the uppermost toolbar.
- Tap on the  icon to activate the selection mode.
- Select the point to be edited by tapping on it **twice**.
- Tap on a field in the layer's attribute table to select it.
- Edit the selected field by using the keyboard (the keyboard appears when clicking on the  icon at the bottom of the screen).

3.8. Downloading the data

The Hydra Probe files "hydra.shp" and hydraGRID.shp" are saved by the HDAS into the IPAQ subdirectory called "SD card". For information on how to establish a connection between the iPAQ and a computer, see section 5.1. Once a connection is established, the Hydra Probe files "hydra.shp" and hydraGRID.shp" can be downloaded by simple copy/paste from "SD card" to the computer.

3.9. Displaying the data

To display data from HDAS, the user can use commercial software like ArcGIS. Alternatively, the "hydra.shp" and hydraGRID.shp" shapefiles can be converted to kml format using freeware software (i.e. <http://shape2earth.com/default.aspx>) and visualized in GoogleEarth. This includes a colour bar for data interpretation.

4. HDAS physical and electrical system setup

The components listed in Table 1 and illustrated in Fig. 5 are required to set up the HDAS system. All the electronic devices, including iPAQ, Hydra Probe and GPS receiver, are powered by a small 12V gel cell battery carried in a bum bag. This provides sufficient power for day-long sampling with the system in a field portable configuration.

The HDAS system components are to be assembled as follows (numbers refer to Fig. 5):

- Connect the Hydra Probe signal cable (1) to the “RS485” side of the CONV485 adaptor (2);
- Connect the “RS232” side of the CONV485 adaptor (3) to the iPAQ Split sync (RS232/USB) cable (4);
- Connect the 5V iPAQ power cable (5) to the iPAQ Split sync (RS232/USB) cable;
- Neatly thread the Hydra Probe and iPAQ cables through the pole assembly;
- Firmly attach the Hydra Probe at the bottom of the pole assembly (6);
- Mount the iPAQ cradle (7) on the top of the pole assembly;
- Place the GPS receiver, power adapters, gel cell battery and any loose cable in the bum bag (8) which is to be carried around the waist. ***IMPORTANT: Make sure that the battery terminals will not be short circuited!!***
- Connect the 12V/5V power adaptor (9) to the gel cell battery;
- Connect the iPAQ 5V power cable and the GPS power cable to the 12V/5V power adaptor (9);
- Connect the Hydra Probe power socket (10) to the 12V power cable directly connecting to the gel cell;
- Mount the iPAQ in the iPAQ cradle (7), attach the iPAQ Split sync (RS232/USB) cable (4) to the iPAQ bottom serial port (11) and power the iPAQ by connecting the 5V iPAQ power cable (5) into the proper connector on the socket at the end of the iPAQ Split sync.

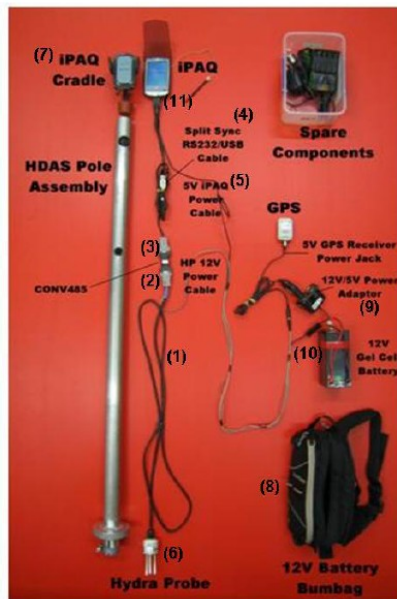
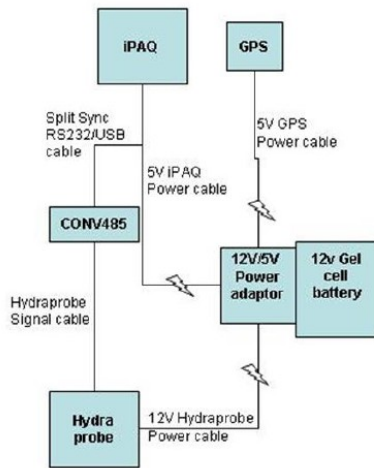


Figure 5. The HDAS electrical setup

Table 1. The HDAS components.

Component	Origin	Comments
HP iPAQ hx2100 (with 5V power cable)	Commercially available	Must have RS232 output cable
GPS receiver (with 5V power cable)	Commercially available	Must use Bluetooth and have NMEA protocol
12V/7AH gel cell battery	Commercially available	
Bumbag	Commercially available	
Aluminum pole	Custom made	
iPAQ cradle	Commercially available	
(CONV485/DB9) DB9 RS232 to RS485 Converter	Commercially available	
12V/5V power adaptor	Made from commercial components	
Split sync (RS232/USB) cable	Modified from commercially available ¹	
Stevens Water Hydra Probe® II – RS485	Cable modified from commercially available ¹	

¹ For detailed diagrams on how to modify these items refer to section 9 of this manual.

5. HDAS software and file system setup

Use of the HDAS relies on two connections:

- Hydra Probe to iPAQ through the sync cable, and
- GPS receiver to iPAQ through Bluetooth

Setting up of the HDAS system requires connection of the iPAQ with a desktop or laptop computer and preparation of spatial database on the computer. The following two sections illustrate how to achieve these tasks.

5.1. Connection with a desktop computer

If the OS is Windows XP, the software ActiveSync needs to be installed to enable download/upload of data from/to the iPAQ. ActiveSync is provided in the folder "Software" in the HDAS software package (is also freely available from Microsoft website). *NOTE: If the OS running on the computer is either Windows Vista or Windows 7, there is no need for installation of specific software to enable connection to the iPAQ.*

- Install Microsoft ActiveSync® on the desktop computer (only when OS is Windows XP).
- Turn on the iPAQ, connect it to the computer and establish a connection.
- Access the iPAQ file system through the "Connect" command in ActiveSync®.
- To install ArcPad software on the mobile device, please refer to the ArcPad deployment section in the software manual.
- To exchange files with the iPAQ, simply copy and paste them between the iPAQ and the desktop PC folders.

5.2. Preparation of spatial data in ArcGIS

A variety of spatial data can be imported into ArcPad to serve as background information to your spatial acquisition system (eg topographic maps, road networks, predefined sampling locations, etc). The process of getting spatial data into the ArcPad environment requires the availability of ArcGIS installed on a desktop computer, and involves the following steps:

- Upload your spatial data into ArcGIS.
- Load all the layers you want to be part of your spatial acquisition system.
- Use the "Get data for ArcPad" command to create an ArcPad map file with all the desired layers. All the files will be saved into the folder "Data for ArcPad".
- Connect your iPAQ to the desktop computer using ActiveSync® (see section 5.1).

- Copy and paste the folder “Data for ArcPad” as your desired working directory on your iPAQ. Note: it is recommended your working directory be on the storage card in case of complete battery depletion.

5.3. Connection with the Hydra Probe


The iPAQ communicates with the Hydra Probe through its serial port, generally called COM1 (located at the bottom of the iPAQ). The GIS software ArcPad® manages the communication with the Hydra Probe and therefore needs to be installed on the iPAQ. It is recommended that ArcPad version 7.1.1 be used.

Table 2. ArcPad serial port (AUX tab) and GPS settings.

AUX tab	
Serial port	Com1
Baud rate	9600
Parity	None
Rts control	Enable
Dtr control	Enable
Data bits	8
Stop bits	1
GPS tab	
Serial port	Com8
Baud rate	4800
Parity	None
Rts control	Disable
Dtr control	Disable
Data bits	8
Stop bits	1
Infrared checkbox	Checked

The ArcPad settings regarding the serial communication with the Hydra Probe and the GPS receiver are set automatically by the HDAS software. However, they have been indicated in Table 2, and can be changed using the Arcpad menu (or through the configuration file ArcPadPrefs.apx, see next section).

5.4. HDAS Data Files and Scripts

The only action normally required by the user to set up the HDAS system files and script on the iPAQ is to **copy all the files provided in the HDAS software package (“Applets folder”)** to the iPAQ subdirectory `\Program Files\ArcPad\Applets`. **These files will then be automatically placed in the correct folders** when the  icon is clicked upon opening ArcPad (see section 3.3). However, this section describes the function and location of each file and script in the iPAQ file system for the user’s benefit. The files


that must be uploaded on the iPAQ in order to run the HDAS system are listed below, grouped by folder on the iPAQ where they will be located (all files are included in the HDAS file package in the "Applets" folder):

REQUIRED FILES

In \Program files\Arcpad\Applets

1. Visual Basic script file "**hydra_code.vbs**" and Arcpad applet file "**hydra_applet.apa**": These files contain the VB routines and forms that ArcPad uses to interrogate the Hydra Probe, and they must be the only .vbs and .apa files in this folder as ArcPad loads them automatically on start up.
2. Parameter file "**Parameters.dbf**": This table contains 5 parameters that are used in the HDAS soil moisture calculations explained in section 8. The file can be edited in order to use custom parameters.
3. Vegetation parameter file "**VegPars.dbf**", which includes all the items of the dropdown list in the Vegetation and Other pages of the HDAS form should be placed in "\Program Files\ArcPad\Applets" directory. The User can edit this file to have customised list of vegetation type etc in the HDAS forms.
4. Bitmap file "**Hydra_icon**": This file is required in order to have the Hydra Probe button icon properly displayed as in Fig. 2.

In \SD Card directory

Note: When opening ArcPad there is  icon that either loads existing hydra and hydraGRID shape files or creates new ones automatically if these shapefiles do not already exist in the "\SD Card" subdirectory.

OPTIONAL FILES

In Custom working directory

5. A shapefile with any name, containing pre-established sampling locations can be loaded into you ArcPad working directory.
6. An **image** of the monitoring area (i.e. topographic map) can be loaded into the desired ArcPad working directory to help with navigation. It is recommended that the image be in MrSid compressed format to optimise the performance of ArcPad.

NOTE: *The coordinate systems of all the files loaded on the iPAQ MUST be the same for ArcPad to display them. A simple trick to do this is to open the image file on a desktop version of ArcPad, then create a new file "hydra.shp" into this project and save the whole project as a .apm map file.*

7. An ArcPad map file (*.apm) can be created and loaded into the ArcPad working directory, containing the shapefiles “**hydra.shp**” and “**hydraGRID.shp**”, together with the shape file for pre-established sampling locations and the image file. This file simplifies the management of all the files and setting by grouping them into a single file. NOTE: An .apm file can be created using the desktop ArcPad by loading all the desired files and then choosing “save map as” from the “folder” menu.

In “My Documents” directory

8. ArcPadPrefs.apx should be stored in My Documents to be able to customise port specifications.

5.5. Restoring ArcPad Settings for HDAS

To restore the default ArcPad functionality the ArcPadPrefs.apx file must be deleted from the My Documents folder in the iPAQ.

5.6. iPAQ Backup

It is highly recommended to perform a complete system backup on the iPAQ, so that any data or software lost as a consequence of battery discharge can be restored. To perform a backup, go to Start→Programs→Backup iPAQ. *NOTE: this function is not available on all iPAQ models.*

6. Customising the HDAS system

A lot of changes can be made to the HDAS system, some of which could require complex programming and different set-ups of the electronic devices involved. This section simply serves as a reference for the resources and actions that are needed in order to customise the system for some of the most simple and obvious changes.

6.1. Different data acquisition and storing

The files that control the communication and storing of data between the iPAQ, the GPS, and the Hydra Probe are:

- The ArcPad applet file “**hydra_applet.apa**”: determines the structure and entries of the ArcPad forms that are displayed, and the custom toolbars. It also calls the visual basic script file for processing tasks.
- The visual basic script file “**hydra_code.vbs**”: contains the VB commands to process tasks like opening the serial port, interrogating the probe etc. as well as processing the calculation for the calibration of the Hydra Probe output (see section 8)
- The default configuration file “**ArcPadPrefs.apx**”. Determines the visibility of the inbuilt toolbars and sets the COM port settings for the communication with the Hydra Probe and the GPS.
- The default configuration file “**VegPars.dbf**”. Determines the content of the drop-down lists in the HDAS forms (for vegetation type and height, irrigation status, dew and rock fraction %)

These files are saved into the applets folder on your iPAQ (\Arcpad\Applets). These files can be modified within the ArcPad Application Builder software (a default component of the ArcPad installation package). Most applications require very simple Visual Basic Scripting knowledge. Please refer to the ArcPad Application Builder help to learn more about customising these files.

The files where the data are stored are:

- Shapefile “hydra.shp” when the GPS is turned on
- Shapefile “hydraGRID.shp” when the GPS is turned off

Table 3 shows the structure of the hydra and hydraGRID shape file fields in the current HDAS system setup. The record format and whether the record value is updated automatically or is prompted by the user are also indicated.

Table 3. Structure of the files hydra and hydraGRID shp files.

FIELD NAME	DESCRIPTION	FORMAT	INPUT
DATE	Date of acquisition	MM/DD/YY	Automatic
TIME	Time of acquisition	HH.MM.SS. AM/PM	Automatic
POINT ID	Sequential number of sample	Integer	Automatic
LATITUDE	Geographic latitude [dd.dd or dd.mm.ss]	Decimal	Automatic
LONGITUDE	Geographic longitude [dd.dd or dd.mm.ss]	Decimal	Automatic
ELEVATION	Elevation [m]	Decimal	Automatic
TEMP_C	Soil temperature [C]	Decimal	Automatic
CONDUCT	Soil conductivity [S/m]	Decimal	Automatic
CONDUCT_TC	Temperature corrected soil conductivity (S/m)	Decimal	Automatic
SALINITY	Soil salinity [g of NaCl/l]	Decimal	Automatic
REAL_DC	Real dielectric constant	Decimal	Automatic
REAL_DC_TC	Temperature corrected real dielectric constant	Decimal	Automatic
IMAG_DC	Imaginary dielectric constant	Decimal	Automatic
IMAG_DC_TC	Temperature corrected imaginary dielectric constant	Decimal	Automatic
CAL_MOISTU	HDAS calibrated soil moisture [v/v]	Decimal	Automatic
COMMENT	User comment	Text	User-prompted
VEG TYPE	Vegetation type at sampling location	Text	User-prompted
IRRI_TYPE	Irrigation Type	Text	User-prompted
VEG_HEIGHT	Height of vegetation [cm]	Decimal	User-prompted
VEG ID	Vegetation sample #	Integer	User-prompted
SOIL ID	Soil sample #	Integer	User-prompted
ROCK_FRAC	Rock fraction [%]	Decimal	User-prompted
DEW	Dew Presence	Text	User-prompted

6.2. Different iPAQ or GPS

The HDAS system was developed with HP iPAQ hx2100 series running Windows Mobile 2003 and Windows CE 2005, Windows Mobile 6 using ArcPad® version 6.0.3 and ArcPad® 7.1.1. Use of different iPAQ models and software versions might create problems that cannot be entirely predictable. To solve these problems please refer to the ESRI support website: <http://support.esri.com/>.

Important issues to consider when testing new configurations are:

- Known bugs of ArcPad new releases. Check on the ESRI support website for known problems of every ArcPad release and service pack patches that fix these problems.
- Serial ports on the iPAQ. Serial ports are internally addressed by the iPAQ's OS with the code COMX. ArcPad refers to the port as named by the OS. In general, the bottom port (Hydra Probe serial cable) is addressed as COM1, and the Bluetooth port (GPS) as COM8, but that can change between iPAQs. If so, the correct port name needs to be substituted in the ArcPad AUX and GPS settings (see Table 2).
- GPS data protocol. Every GPS device has a communication protocol which has to be set in the "protocol" page of ArcPad settings. New GPS devices with different, un-supported protocols can still be used, but some C/C++ programming is required in this case (see ArcPad Application Builder help).

7. Troubleshooting

7.1. iPAQ troubleshooting

The iPAQ doesn't respond to any input.

Perform a soft reboot of the device by pressing the button on the bottom side of the device with the iPAQ pencil. The GPS connection will then have to be re-established and ArcPad started again. No data will be lost.

The iPAQ is dead, the battery indicator doesn't blink despite the battery being properly connected.

The iPAQ battery is too low. Extract the battery, leave it disconnected from the device for 5 minutes, re-insert the battery and leave charging for at least 30 minutes, until the battery indicator starts blinking again.

The iPAQ doesn't connect to my desktop computer.

Make sure you are using the latest version of Microsoft ActiveSync. Make sure the iPAQ cable is properly connected to the desktop computer. There is no need for Microsoft ActiveSync if your OS is Windows Vista or later.

I can't see find the ArcPad software in my iPAQ.

If the iPAQ batteries have gone completely flat the software might have been lost from the system. ArcPad and HDAS files can be restored using the iPAQ "Backup" function (generally found under Start→programs→ iPAQ Backup), and by performing a "restore" of the latest system backup. **NOTE: this will only restore ArcPad and the HDAS files if a complete backup of the system has been performed prior to sampling; see section 5.6.**

7.2. GPS troubleshooting

The iPAQ doesn't connect with the GPS device.

Make sure the GPS device is turned on and charged.

There is no GPS icon in the Bluetooth manager.

The GPS device hasn't been bonded with the iPAQ. Make sure the GPS device is turned on and charged. To bond the GPS device, tap "new" and select "explore a Bluetooth device". When the GPS device is detected, tap the serial port option "SPP serial port". When the bond is confirmed, tap "finish" and connect to the GPS device as explained above in "Connect the GPS to the iPAQ connection".

ArcPad Error: no fix GPS position.

The GPS device is unable to determine a fix position. Stay in place and wait for a few minutes until a fix position is achieved. Make sure the GPS status light is active and the GPS is bonded to the iPAQ.

ArcPad Error: too many data are received from your GPS device.

Press ok and Ignore.

7.3. ArcPad troubleshooting

ArcPad Error appears when I try to interrogate the probe.

Error windows might appear while interrogating the probe through ArcPad. These error messages are self explaining and can help user to fix the problem. Usually, these are associated with lack of power to the probe or disconnection of one of the HDAS components. If the error persists, please do the following:

- Check that all the connections are firm
- Check that the battery adaptor is firmly connected to the battery
- Check that the iPAQ USB serial port is firmly connected
- Check that the iPAQ is turned on and not low in battery
- Check that all the system components are powered properly

8. HDAS soil moisture calculation

The HDAS output stored in the “hydra” and/or “hydraGRID” shapefiles includes a range of probe output quantities at each reading point. These include four voltage readings which are interpreted as soil characteristics including the real and imaginary components of the soil-water mixture dielectric constant, soil conductivity, soil temperature, soil moisture and soil salinity. All these quantities are calculated internally by circuitry on the probe head and stored in the “hydra” or “hydraGRID” shapefiles as output from the probe. Note that these outputs are unaffected by soil type option to which each probe is initialized. For details about these calculations, please refer to the Hydra Probe manual included in this package.

The accuracy of the standard Hydra Probe soil moisture output has been found by several independent field tests to be poorer than the stated manufacturer accuracy; this was observed particularly in clay soils characterised by warm temperatures. Moreover, in clay soils, the Hydra Probe standard output showed highly reduced sensitivity to changes in soil moisture over approximately 30% v/v moisture content. Therefore, the current version of the HDAS system described in this document provides an advanced soil moisture output (CAL_MOISTU in Table 3). This is calculated by the HDAS software using the calibration developed by [1]-[3]. This soil moisture value, and NOT the Hydra Probe standard output, is also what is displayed on the IPAQ screen during sampling.

This robust calibration is implemented in the HDAS software together with a soil temperature correction developed and tested by [4]. In particular, the soil moisture value stored in the “CAL_MOISTU” field in Table 3 is calculated using equation (3) in [4] from the real dielectric constant, which has been temperature corrected using equation (1) in [4]. Although in [4] an even more refined calibration equation has been developed, which takes into account the difference between soil type by use of the loss tangent (2) in equation (4), this was not used in the current HDAS system. The reason for that is that the use of (4) requires two assumptions: (i) that the loss tangent at saturation is known for the particular soil sampled and (ii) that the loss tangent does not change with soil moisture content. Since the HDAS system is a roving device, likely to be used on a variety of soils, these assumptions cannot always be verified in the field. Therefore, the more robust equation (3) was implemented in the system.

This advanced soil moisture product exhibits better accuracy over a variety of soils (+/- 3.5%v/v) than that from the manufacturer’s soil type dependent relationship. It is also more stable with respect to variations in soil temperature, particularly for clay soils. A detailed description of the calibration equations can be found in [4], a copy of which is included in this HDAS file packaged in the “documentation” folder. However, we want to draw attention to two important issues to be considered when using this advanced soil moisture product:

- The two main steps of the calibration are 1) Correction of the output real and imaginary dielectric constant (REAL_DC and IMAG_DC in Table 3) for soil

temperature effect and 2) calculation of soil water content as a function of the corrected value of the dielectric constant. Both steps involve the use of parameters derived from experimental data. Although the soil samples used to derive these parameters cover a wide range of soil types, some error in the calculation of soil moisture might remain. Soil specific calibration of these parameters is recommended (see later in this section for details on how to apply custom parameters).

- In the case of very low values of measured real dielectric constant (less than 2.5), the resulting calibrated soil moisture value (CAL_MOISTU in Table 3) might be negative. This is generally due to a bad insertion of the probe tines in the soil which creates air gaps in the volume sampled, therefore reducing the value of soil dielectric constant (for air the value is ~1 and for dry soil ~2.5). In this case the soil moisture value is set automatically to zero by the HDAS software. *It is recommended that readings with the real part of the soil dielectric constant (REAL_DC in Table 3) less than 2.5 be removed from any analysis.*

8.1. Custom calibration

To use customized calibration curves different than the one currently implemented in the HDAS system, the user can change the subroutine “calibration” at line 227-242 of the visual basic script file “hydra_code.vbs.

If independent estimation of soil water content (e.g. gravimetric soil samples) and soil temperature is available, the parameters used in the HDAS calibration and soil temperature correction equations described in [4] can be calculated for the specific soil type(s) present in the study area and updated in the file Parameters.dbf (see section 5.4). This operation will ensure the custom parameters are used to calculate the HDAS soil moisture output both displayed on the IPAQ screen when sampling and subsequently saved in the output files.

These parameters include:

- Parameter DCZERO: not currently used
- Slope (SLKAPPA) and offset (OFFKAPPA) of linear regression for parameter “K”, in equation (1) in [4], for soil temperature correction. Default values are respectively 0.011 and 0.0065;
- Slope (SLCONSTA) and offset (OFFCONSTA) of the calibration equation (3) in [4], for soil moisture calculation. Default values are respectively 11.0 and -18.0;

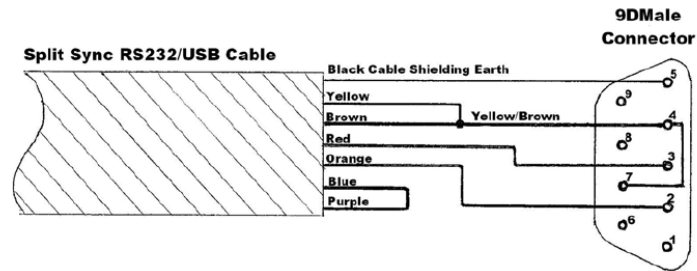
To change the default parameters, simply open the “parameters.dbf” file with Microsoft Excel, edit the values of the parameters (see Table 4) and save the file.

Table 4. Content of the parameters file

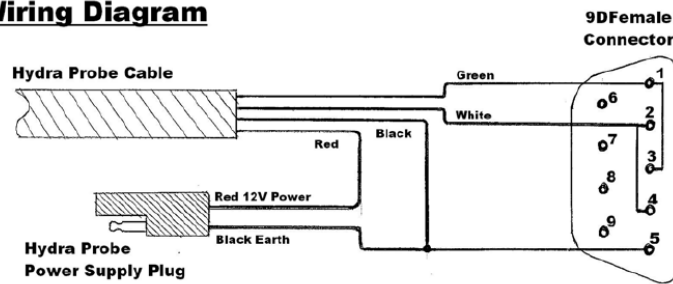
DCZERO	SLKAPPA	OFFKAPPA	SLCONSTA	OFFCONSTA
2.7000	0.0110	-0.0065	11.0	-18.0

9. Wiring diagrams

iPAQ Split Sync RS232/USB Connector **Wiring Conversion Diagram**



Hydra Probe Connector **Wiring Diagram**



10. References

- [1] Seyfried, M., and Murdock M., 2004. Measurement of soil water content with a 50-MHz soil dielectric sensor. *Soil Sci. Soc. Am. J.*, 68:394-403.
- [2] Seyfried, M.S., and Murdock, M.D., 2002. Effects of soil type and temperature on soil water content measurements using a soil dielectric sensor. P1-13. In I.C. Paltineanu (ed.) First international symposium on soil water measurement using capacitance and impedance, Beltsville, MD. 6-8 Nov. 2002.
- [3] Seyfried, M.S., Grant, L.E., Du, E. and Kumes, K., 2005. Dielectric loss and calibration of the Hydra Probe Soil Water Sensor *Vadose Zone J.*, 4:1070-1079.
- [4] Merlin, O., Walker, J., Panciera, R., Young, R., Kalma J. and Kim, E., 2007. Soil Moisture Measurement in Heterogeneous Terrain, in *International Congress on Modelling and Simulation (MODSIM)*. 2007: Christchurch, New Zealand.

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Appendix B: Operating the ASD Field Spec

Notes provided by CSIRO

ASD FieldSpec® Pro HandHeld Cookbook

NLWRA ASD instrument system: setup and use

Version 1.3: Hannalie Botha, Rebecca Edwards and Paul Daniel, CSIRO Land and Water, August 26, 2008.

Version 1.4: Paul Daniel, CSIRO Land and Water, September 24 2008.

Version 1.5: Shanti Reddy, Geoscience Australia, 1 October 2008.

NOTE: First time users should read the HandHeld FieldSpec® User's Guide before they proceed with the Cookbook.

1. System Components - Item description – Each system contains the following components housed within 3 separate cases.

1.1. Small grey case (Field Case #1, weight 5kg, size LxWxD 480x360x150mm) contains:

- FieldSpec® Handheld Pro (325-1075nm)
- HH Full Sky Irradiance Cosine Receptor
- SMA, FieldSpec HH Adapter
- 7.5 Deg HH FOV Lens Foreoptic
- HH Communication Cable (USB to 9-pin serial – with instrument SN number)
- Cable USB to GPS via serial RS-232 Adapter
- Small circular Spectralon x1 (not used normally)
- Neoprene sample mat (black) x1

1.2. Large grey pelican case (Field Case #2, weight 13.5kg, size LxWxD=550x460x260mm) contains:

- ClearPETG Controller Computer BellyBoard
- ASD Approved Field Controller Computer (IBM X61 Thinkpad)
- Field Reference Panel: Spectralon, 5x5in(12.7x12.7cm) Cal White
- Pistol Grip for HH FOV foreoptics
- 2.0m VNIR Low OH Fibreoptic Jumper Cable (fibre-optic cable)
- Battery, Aux. Thinkpad X61 (x2)
- Battery hand held Li-Lion (x3)
- Tripod, Alum. Lt. Weight All Purpose
- GPS, ASD Approved NMEA 0183 Compliant (Garmin ETrex Vista)
- Computer Power Supply (with instrument SN)
- ASD-HH Mains Power Supply (with instrument SN)

1.3. Yellow pelican case (Lab Case, weight 12kg, size LxWxD=600x500x220 mm) contains:

- Lab Reference Panel: Spectralon, 5x5in(12.7x12.7cm) Cal White
- Tripod Pro Lamp x2
- Pro-Lamp 14.5V spare Bulb x2
- Pro-Lamp DC Power Supply x2

- HH Battery Charger, Lithium Ion x3
- HH Battery charger Power Supply x3
- Tripod, SLIK Mini-Pro III (small tripod)
- Tripod, Alum. Lt. Weight All Purpose
- Power cables x3
- ASD System documentation and Garmin GPS user manual

2. Instrument assembly:

- 2.1. **Load ASD FieldSpec® batteries** – sockets are located at either side of the ASD back panel (instrument can run on one battery or two, depending on length of field work). Remove the batteries from its compartment when the system is not used for several days.
- 2.2. **Battery Life** – Generally up to 5 hours per battery for the spectrometer, and up to 3 to 4 hours per battery for the IBM Thinkpad.
- 2.3. **Charging the batteries** – see FieldSpec® User Guide page 21.
- 2.4. **Connect instrument communication cable** securely to the laptop using the silver USB cable with the instrument serial number on the DB9 connector. *This cable should be connected into the USB port **on the left hand side** of the field laptop. No need to turn the computer on at this stage.*
- 2.5. **If using the ASD-HH as a Handheld unit (the standard method of deployment):**
 - 2.4.1. Attach the required foreoptic by screwing onto the ASD optical input. Relevant foreoptic configurations are listed in Section 4.1.
 - 2.4.2. If using the RCR (irradiance foreoptic) attach a camera mounting plate (**not supplied**) to the spectrometer, clip to a solid tripod stand and then level the RCR using the in-built bubble level.
- 2.5. **If using the ASD-HH with the extension optic-fibre (good for hard-to-reach places, but BE CAREFUL WITH THE FIBRE!):**
 - 2.5.1. **Attach fibreoptic coupling** (circular metal knurled, threaded adaptor) to ASD optical input.
 - 2.5.2. **Attach optical fibre SMA screw connector** to fibre-optic coupling taking care not to sharply bend the fibre-optic cable. Slide bare fibre side of the fibre-optical cable through the back of the pistol-grip until it clicks into place. The end of the fibre-optic cable should finish virtually flush with the polished end of the pistol grip.
 - 2.5.3. **Attach 7.5° foreoptic** to the front of the pistol grip (7.5 Deg HH FOV Lens Foreoptic).
- 2.6. **Turn on the ASD instrument** using the orange power button on back (a green power on light will light up) before turning on computer.

Allow the instrument to warm up for at least 10 minutes for reflectance measurements and 30 minutes for radiometric measurements.

NOTE1: Check that all unit numbers (ASD serial number, USB cable, fore-optics etc.) match. Valid unit numbers are 1496 and 1497.

NOTE2: Be careful not to create sharp bends in the fibre-optic cable. Minimum advisable bend radius is 10cm (ie, a coil of 20cm diameter).

- 2.7. **Turn computer on** and ignore warnings during boot up sequence (hit 'No' or 'Cancel' when prompted by start-up messages, back-up routines or software upgrades). In particular, DO NOT run the finger-print security system!

3. GPS Start Up:

- 3.1. **Connect the communication cable to the GPS and switch it on** (see below for directions) to allow satellite detection and to locate correct position, but DO NOT connect it to the computer until the ASD is operating through the RS³ software.
 - 3.1.1. GPS Start Up Sequence – Turn the unit on
 - 3.1.1.1. Press and hold the **Power** button (lower button on RHS of unit).
 - 3.1.1.2. Press the **Page** button (upper button on RHS of unit) to acknowledge the copyright.
 - 3.1.1.3. Carefully read the warning message and press the **Page** button again to acknowledge and proceed to the Satellite Page.
When the GPS unit has acquired enough satellite signals to determine your location, a "Ready to Navigate" message and your location coordinates are shown.
- 3.2. **Synchronize Computer time and GPS time**
 - 3.2.1. On the laptop, select Control Panel/Date and time on the laptop. Set computer time to match GPS. To view GPS time press the **Page** button repeatedly until the time and date page is displayed.
- 3.4. **Create your Data Folder** on the laptop where you wish to save spectra files in Windows explorer by right-clicking on Windows 'Start' and selecting New Folder, etc. Name your folder with a traceable label, such as the study area name, and the month/year.
- 3.5. **Launch the instrument software** by double-clicking the RS³ icon on the desktop. Use the high contrast icon to allow better computer display screen visibility when collecting outdoor spectra. Start spectrometer software by selecting the **High-Contrast RS³** icon. When RS³ is started communications status messages will appear briefly at the lower RH corner of the screen and the ASD-HH spectrometer will beep once, when communication is established.
- 3.6. **Connect and Activate the GPS** (do this once the GPS has a positional fix).
 - 3.6.1. **Plug the GPS comms lead** into the forward-most USB port on the RHS of the controlling laptop (the port closest to the operator). If the GPS comms is plugged into the adjacent, rear-most USB port the operator may lose control of the mouse/pointing device!
 - 3.6.2. In the RS³ software click on 'GPS', then 'Enabled'. The message 'Com 4 port invalid' will appear – this is normal – just press 'OK' to continue. The padlock symbol at the lower LHS of the screen should unlock and a moving sine-wave icon should appear if data is being received from the GPS. Coordinates should be displayed on the bottom bar.

NOTE: The GPS coordinates corresponding to each spectrum taken will now be saved to a 'log' file that is labelled with the date of acquisition. Even though RS³ only displays the GPS position to a limited accuracy, full accuracy coordinates are logged to the GPS log file.

4. Instrument Configuration:

- 4.1. Open the **control/Adjust Configuration** (a popup window will appear). Enter the following details:

Choose relevant **foreoptic** configuration (select from drop-down list):

Bare fibre (instrument only)

7.5° (instrument with 7.5° field of view foreoptic attached)

RCR (instrument with cosine radiance foreoptic attached)

Bare jumper (instrument with bare optical fibre attached)

Jumper w/7.5° (instrument with optical fibre, pistol grip and 7.5° fore optic attached)

Jumper w/RCR (instrument with optical fibre, pistol grip and cosine radiance fore optic attached)

- 4.2. Choose number of samples for **Spectrum, Dark Current** and **White Reference**, (set at 50 for very bright conditions). Instrument noise contribution to the spectrum is reduced as the number of Samples-per-spectrum is increased but this also increases the time taken to collect each spectrum. ASD recommends a spectrum sample value between 10 and 25. It is good practice to set the white reference sample setting to twice the spectrum sample setting.

NOTE: DO NOT check the Absolute Reflectance box, as this assumes the use of a specific, calibrated Spectralon® Panel. More accurate panel corrections can be done in the post-processing of spectra, especially if the field panel becomes dusty during a day of measurement.

Select OK to accept details and to close the window. Follow the instructions below to begin collecting data.

- 4.3. Open the Spectrum save screen by selecting **ALT S** or **Control/Spectrum Save**. Enter the following details:

Specify **path name**: The directory folder where files are to be saved (as created above). ASD recommends using the current month, day and year.

Base Name: The name used for each data file collected (to comply with DOS protocol : <= 8 alphanumeric characters long)..

Starting Spectrum Number (normally this begins at .000)

Number of files to save each time the spacebar, Save button, Remote Trigger, or **Begin Save** button is pressed (normally select 1 file to be saved each time)

Desired **interval time** between saves (normally set to 0).

Comments: Document weather conditions, sample type, etc.

Select **OK** to accept details and to close the window or select **Begin save** to immediately save spectrum or spectra.

NOTE 1: When the ASD-HH unit has been connected to the controlling laptop, switched on and communications been established via the RS³ software; the spectrometer will take measurements continuously to the settings in RS³ (default or as set by the operator) – however the spectra are not being automatically saved to file. The user can elect to save any particular spectrum to file by pressing the space bar, pressing one of the red 'Acquire Spectrum' buttons on the spectrometer (the spectrometer will 'beep' when saving) or by selecting 'Spectrum', 'Save' in the menu.

NOTE 2: Spectra are saved to the Base Name (user-entered, as above) with the 5-digit extension incrementing with each successive spectrum, eg first spectrum may be SEAGRASS.00000, whilst the next will be SEAGRASS.00001, etc. The name of the spectrum displayed at the bottom left-hand corner of the RS³ screen is the NEXT spectrum to be saved (NOT the last spectrum already saved).

NOTE 3: When the space-bar is pressed the spectrum that will be saved is the one that is currently being collected by the instrument at the time the space-bar was depressed (NOT the spectrum already displayed at that time, which is from the previous complete scan).

5. Taking Reflectance Measurements

- 5.1. Point the bare fibre or attached foreoptic at the white reference (check that there is no self-shading on the panel and that the panel is horizontal). Optimise the instrument response during the brightest illumination conditions likely to be experienced in the immediate future (ie, if mixed cloud and sun, do the Optimisation when the sun disk is free of cloud) by selecting **Control O** or the **Opt** button on the screen. After optimizing and collecting a dark current, the graph will display measurements in raw Digital Numbers (DN) and plot them against wavelength in nm.
- 5.2. To begin taking Reflectance measurements point the foreoptic at the panel (as for the Optimisation, above) and press **F4** (or the **WR** button on the screen) to collect a White Reference spectrum. Another dark current reading is automatically performed during this process; you'll hear the optical shutter clicking closed in the spectrometer during this measurement. This reference spectrum is saved to an internal file by RS³ and all subsequent target spectra are automatically divided by the values in the Reference file and displayed as Reflectance. The graph Y-axis will automatically switch to Reflectance once the white reference panel measurement has been made.
- 5.3. To obtain a reflectance measurement of your target of interest, point the bare fibre (or the attached foreoptic) at the target. Press the spacebar (or one of the red Acquire Spectrum buttons on the spectrometer) to save the spectrum data to file. The instrument beeps when the data is saved. Use ViewSpec Pro for viewing and post-processing ASD format files.

6. Best Practices

- 6.1. The more samples taken, the less instrument noise there is and the more time it will take. For the most accurate results, ensure that the correct foreoptic is being used for the application. Ensure that the Field-of-View is only capturing reference and/or target data and nothing extraneous. The remote Cosine Receptor has a Field-of-View of 180° (ie, a complete sky hemisphere) and nearby objects that obscure any part of the sky hemisphere (trees, light poles, buildings or indeed the operator) can influence the values collected. Re-optimize if illumination conditions (i.e. cloud cover, sun position, etc.) change substantially or if a detector is saturating.
- 6.2. Take a new white reference every 10-15 minutes, or whenever a reflectance measurement of the panel (against itself) shows departure from a straight line at value 1.0. You will need to take a white reference more often if the illumination, viewing, or atmospheric conditions are variable.

Appendix C: Operating the LAI-2000

Plug the sensor cord into the port labelled "X" and tighten the two screws.

Place a black view-cap over the lens that blocks 1/4 of the sensor view; that 1/4 that contains the operator. Place a piece of tape on the view cap and body of the sensor so if the cap comes loose it will not be lost.

Turn on the logger with the "ON" key (The unit is turned off by pressing "FCT", "0", "9".)

Clear the memory of the logger -

Press "FILE"

Use "↑" to place "Clear Ram" on the top line of display

Press "ENTER"

Press "↑" to change "NO" to "YES"

Press "ENTER"

General items –

When changing something on the display, get desired menu item on the top line of display and then it can be edited.

Use the "↑" and "↓" to move items through the menu and the "ENTER" key usually causes the item to be entered into the logger.

When entering letters, look for the desired letter on the keys and if they are on the lower part of the key just press the key for the letter; if the desired letter is on the upper part of the key then press the "↑" and then the key to get that letter.

Press "BREAK" anytime to return to the monitor display that contains time, file number or sensor readings on one of the five rings that are sensed by the LAI-2000.

Do not take data with the LAI-2000 if the sensor outputs are less than 1.0 for readings above the canopy.

To Begin -

Press "SETUP"

Use "↑" to get "XCAL" on the top line of the display and press "ENTER"

Following XS/N is the serial number of the sensor unit, enter appropriate number

Check or put appropriate cal numbers from LICOR cal sheet into the 5 entries.

Final press of "ENTER" returns you to "XCAL"

Use "↑" to get to "RESOLUTION"

Set it to "HIGH"

Use "↑" to get to "CLOCK"

Update the clock (set to local time using 24 hr format)

Press "OPER"

Use "↑" to get "SET OP MODE" on top line of display

Choose "MODE=1 SENSOR X"

Enter "↑", "↓", "↓", "↓", "↓" in "SEQ"

Enter "1" in "REPS"

Use "↑" to get to "SET PROMPTS"

Put "SITE" in first prompt

Put "LOC" in second prompt

Use “↑” to get to “BAD READING”
Choose "A/B=1"

Press “**BREAK**”

Display will contain the two monitor lines

Use “↑” and “↓” to control what is displayed on the top line in the monitor mode, time, file number or sensor ring output 1 through 5 for the X sensor. (If FI is selected, then the file number is displayed)

Use the “→” and “←” to control what is displayed on the bottom line of the monitor mode, time, file number or sensor ring output 1 through 5 for the X sensor. (If X2 is selected, then ring #2 output is displayed)

Press “**LOG**” to begin collecting data

Type in the response to the first prompt (if “**ENTER**” is pressed the same entry is kept in response to the prompt).

Type in the response to the second prompt (if “**ENTER**” is pressed the same entry is kept in response to the prompt).

Place the sensor head in the appropriate position above the canopy, level the sensor and press the black log button on the handle of the sensor (a beep will be heard when the black button is pushed). Hold the sensor level until the second beep is heard.

For grasslands:

1. Place the sensor head in the appropriate position above the canopy, level the sensor and press the black log button on the handle of the sensor (a beep will be heard when the black button is pushed). Hold the sensor level until the second beep is heard.
2. Place the sensor below the plant canopy in one corner of your sampling area level the sensor and press the black log button on the sensor handle and keep level until the second beep.
3. Repeat for the other 3 corners

Repeat steps 1-3 so that you have a total of 5 sets of measurements.

For Row crops:

1. Place the sensor head in the appropriate position above the canopy, level the sensor and press the black log button on the handle of the sensor (a beep will be heard when the black button is pushed). Hold the sensor level until the second beep is heard.
2. Place the sensor below the canopy in the row of plants, level the sensor and press the black log button on the sensor handle and keep level until the second beep.
3. Place the sensor one-quarter (1/4) of the way across the row and record data again.
4. Place the sensor one-half (1/2) of the way across the row and record data again.
5. Place the sensor three-quarters (3/4) of the way across the row and record data again.

Repeat steps 1-5 so that you have a total of 5 sets of measurements.

The logger will compute LAI and other values automatically. Using the “↑” you can view the value of the LAI.

NOTE: You will record the “SITE” and “LOC” along with the LAI value on a data sheet.

The LAI-2000 is now ready for measuring the LAI at another location. Begin by pressing “**LOG**” twice. The file number will automatically increment. When data collection is complete, turn off the logger by pressing “**FCT**”, “**0**”, “**9**”. The data will be dumped onto a laptop back at the Field Headquarters.

Appendix D: Equipment List

The following tables list all the items of equipment that will be required for AACES, grouped per person, team and operation base

GENERAL TEAM EQUIPMENT FOR GROUND CREW	SOIL MOISTURE SUB-TEAM (6 people)	VEGETATION SUB-TEAM (2 people)	PER TEAM (8 people)	TOTAL (2 TEAMS)
4WD vehicle	1	1	2	4
soil sampling kit	-	1 + 1 spare	2	4
vegetation sampling kit	-	1 + 1 spare	2	4
dew sampling kit	-	1 + 1 spare	2	4
roughness sampling kit	-	-	share 1	1
HDAS units	6 + 1 spare	-	7	14
ArcPad sampling shapefiles				
hardcopy farm map	6	2	8	16
copy of workplan	1	1	2	4
two-way UHF radio	6	2	8	16
Pencil	6 + 12 spare	2 + 4 spare	24	48
field book	6	2	8	16
first aid kit	1	1	2	4
first aid book	1	1	2	4
water jerry can (25l)	1	1	2	4
sunscreen bottle	2	1	3	6
insect repellent	2	1	3	6
fly net/hat	6	2	8	16
Torch	6	2	8	16
satellite phone	-	1	1	2

GROUND CREW BASE EQUIPMENT	TOTAL
satellite phone	2
scale	1
spare HDAS unit	1
spare Hydraprobe	2
spare iPAQ	2
spare GPS	2
spare 12V/5V dual-sockets adapter	6
spare HDAS wiring harness	6
spare sampling recording form	40
spare spool of wire	1
desktop computer	1
backup dvd	50
backup hard drive	1
power board	5
gel cell battery charger	4
extension lead	5
white board	1
white board markers	10
computer projector	1

SOIL MOISTURE SUB-TEAM EQUIPMENT	PER SUB-TEAM	TOTAL (2 TEAMS)
complete HDAS units	6 + 1 spare	14
spare gel cell battery	6	12
spare iPAQ	1	2
spare GPS	2	4

VEGETATION SUB-TEAM EQUIPMENT	PER SUB-TEAM	TOTAL (2 TEAMS)
vegetation sampling kit	2	4
veg clipper	2	4
pair of scissors	2	4
vegetation quadrant	2	4
ruler/tape	2	4
LICOR-2000	1	2
surface reflectance kit	1	2
vegetation sampling recording form	10	20
big plastic bag	300	600
rubber band	300	600
compass	1	2
ASD	1	2
dew sampling kit	2	4
filter papers	300	600
sealable plastic bags	300	600
dew sampling recording form	10 + 10 spare	40
surgical gloves	50	100
soil sampling kit	2	4
soil sample ring	2	4
garden trowel	2	4
blade	2	4
spatula	2	4
wooden block	2	4
plywood sheet	2	4
hammer	2	4
soil sampling recording form	10 + 10 spare	40
small plastic bag	300	600
rubber band	300	600
roughness sampling kit	-	share 1
roughness profiler	-	share 1
camera	1	2
compass	-	share 1
water level	-	share 1
roughness sampling recording form	10 + 10 spare	40
sampling equipments		
gloves	2	4
clipboard	1	2
markers for sampling bags	4	8
iPAQ-GPS kit	1 + 1 spare	2

MONITORING STATION	PER STATION	PER FARM	PER PATCH
Monitoring stations	1	2	4
TIR sensor		1	2
dew sensor	1	2	4
stands	1	2	4
soil temp sensor	4 + 4 pre-installed	16	32
starlogger and logger box	1	2	4
starlogger download cable	-	1 + 1 spare	4
gel cell battery	3	6	12
downloading laptop	-	1	2
rain gauge	1	2	4
theta probe	2	4	8
solar panel	1	2	4
Installation kit	-	1	2
starlogger screwdriver	-	1	2
terminal strip screwdriver	-	1	2
duck tape roll	-	1	2
wire stripper	-	1	2
wire cutter	-	1	2
hammer	-	1	2
field laptop	-	1	2
mattock	-	1	2
pole driver	-	1	2
sealant	-	2 rolls	4

AIR CREW BASE EQUIPMENT – YANCO	
laptops	1
aircraft hard drive	1
backup hard drive	1
colour printer	1
power boards	5
extension leads	5
gel cell battery	2
gel cell battery charger	1
field book	2
way point and route files	-
dry air	1

CALIBRATION LAKE	
UNIDATA salinity/temp sensor unit	1
gell cell battery	3
floating station	1
field book	2
GPS unit	1
handheld sal/temp sensor	1
Boat + oars	1
laptop for lake station	1
life jacket	2

LAB EQUIPMENT	TOTAL
scale	1
aluminium tray (small + big)	300
weight recording form	60
sample storage boxes	4
desktop computer	1
sample storage boxes	4

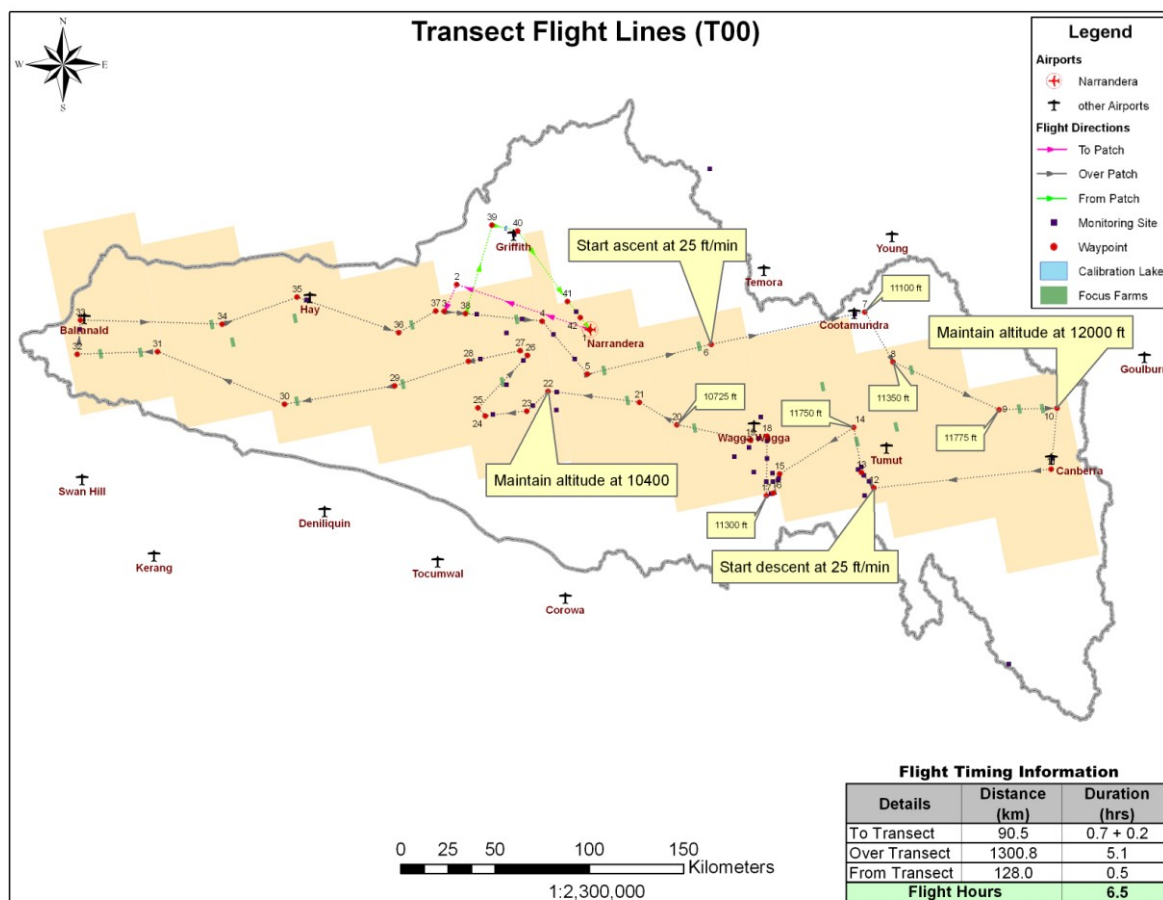
Appendix E: Flight Lines

Figures and tables are provided for each flight across the Murrumbidgee transect, showing the sequencing of the flight lines, coordinates, and expected flight duration. Flight line information is also provided in OziExplorer format as a single waypoint file and series of route files; one per flight. A summary of the flight schedule is also repeated below.

Date/Time (UTC)	Flight	Altitude (ASL)	Duration (hrs)
19/01/2010 16:36	T00	10,400/12,000/10,400 ft	6.5
21/01/2010 16:38	P01	10,200 ft	7.0
24/01/2010 16:50	P02	10,250 ft	6.6
27/01/2010 17:04	P03	10,300 ft	6.2
29/01/2010 17:04	P04	10,350 ft	6.2
1/02/2010 16:58	T00	10,400/12,000/10,400 ft	6.5
4/02/2010 16:36	P05	10,400 ft	6.1
6/02/2010 16:46	P06	10,500 ft	6.4
9/02/2010 16:45	P07	10,800 ft	6.7
12/02/2010 16:41	P08	11,100 ft	6.6
14/02/2010 16:29	P09	11,950 ft	7.0
17/02/2010 16:37	P10	12,000 ft	6.7
19/02/2010 16:36	T00	10,400/12,000/10,400 ft	6.5

Flight T00

altitude 10,400/12,000/10,400 ft (ASL) and duration 6.5 hrs

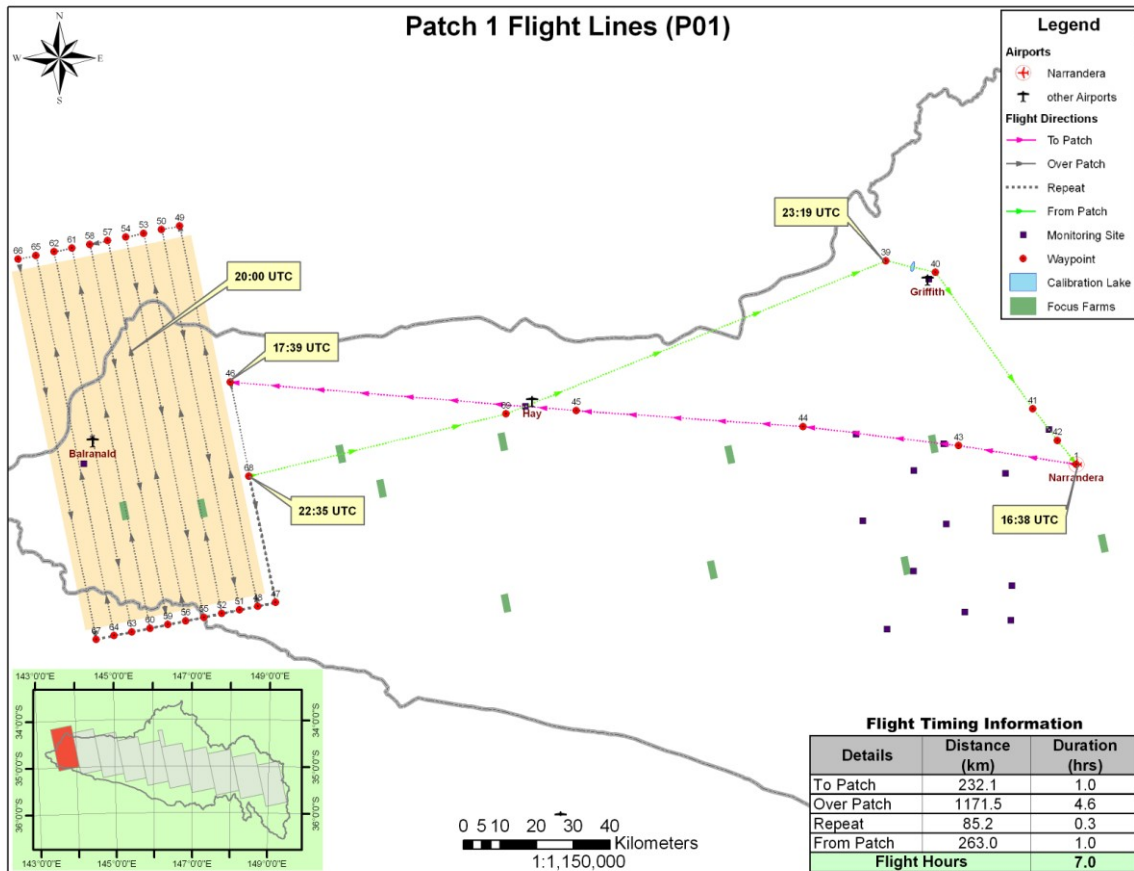


Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	22	146° 15.615' E	35° 0.022' S
2	145° 44.136' E	34° 29.118' S	23	146° 8.078' E	35° 5.689' S
3	145° 39.735' E	34° 36.832' S	24	145° 53.554' E	35° 6.910' S
4	146° 13.672' E	34° 39.902' S	25	145° 51.063' E	35° 4.633' S
5	146° 29.380' E	34° 55.225' S	26	146° 8.543' E	34° 49.724' S
6	147° 12.513' E	34° 46.672' S	27	146° 6.032' E	34° 48.305' S
7	148° 5.870' E	34° 37.112' S	28	145° 47.949' E	34° 51.253' S
8	148° 15.903' E	34° 51.417' S	29	145° 22.143' E	34° 57.920' S
9	148° 53.149' E	35° 4.550' S	30	144° 43.613' E	35° 2.629' S
10	149° 13.321' E	35° 3.790' S	31	143° 59.780' E	34° 46.551' S
11	149° 11.790' E	35° 21.332' S	32	143° 31.879' E	34° 46.571' S
12	148° 9.713' E	35° 27.607' S	33	143° 33.362' E	34° 36.801' S
13	148° 5.306' E	35° 23.169' S	34	144° 22.586' E	34° 39.186' S
14	148° 2.466' E	35° 10.262' S	35	144° 48.731' E	34° 31.978' S
15	147° 36.654' E	35° 23.799' S	36	145° 23.774' E	34° 42.697' S
16	147° 34.507' E	35° 29.279' S	37	145° 36.755' E	34° 36.596' S
17	147° 31.978' E	35° 30.034' S	38	145° 47.133' E	34° 37.515' S
18	147° 32.089' E	35° 13.026' S	39	145° 56.639' E	34° 12.162' S
19	147° 26.338' E	35° 14.146' S	40	146° 5.458' E	34° 13.942' S
20	147° 0.549' E	35° 9.740' S	41	146° 22.625' E	34° 34.239' S
21	146° 47.503' E	35° 3.304' S	42	146° 26.992' E	34° 38.922' S

Route:
1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,1

Flight 1

altitude 10,200 ft (ASL) and duration 7.0 hrs

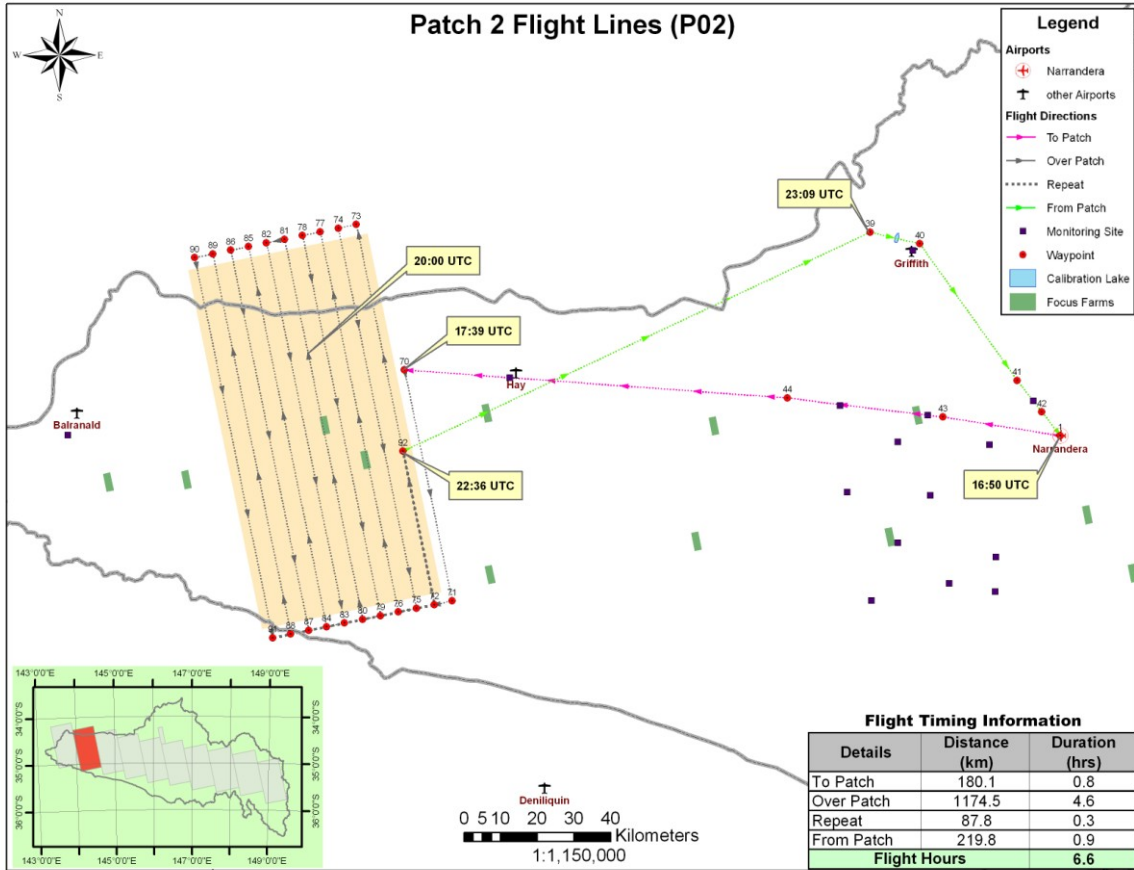


Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	54	143° 41.759' E	34° 6.256' S
39	145° 56.639' E	34° 12.162' S	55	143° 53.525' E	35° 2.717' S
40	146° 5.458' E	34° 13.942' S	56	143° 50.286' E	35° 3.177' S
41	146° 22.625' E	34° 34.239' S	57	143° 38.557' E	34° 6.713' S
42	146° 26.992' E	34° 38.922' S	58	143° 35.354' E	34° 7.168' S
43	146° 9.306' E	34° 39.565' S	59	143° 47.047' E	35° 3.635' S
44	145° 41.560' E	34° 36.516' S	60	143° 43.808' E	35° 4.092' S
45	145° 1.113' E	34° 33.603' S	61	143° 32.151' E	34° 7.622' S
46	143° 59.540' E	34° 28.134' S	62	143° 28.947' E	34° 8.074' S
47	144° 6.473' E	35° 0.863' S	63	143° 40.568' E	35° 4.548' S
48	144° 3.237' E	35° 1.328' S	64	143° 37.328' E	35° 5.002' S
49	143° 51.363' E	34° 4.877' S	65	143° 25.743' E	34° 8.525' S
50	143° 48.162' E	34° 5.338' S	66	143° 22.539' E	34° 8.975' S
51	143° 60.000' E	35° 1.793' S	67	143° 34.087' E	35° 5.454' S
52	143° 56.763' E	35° 2.256' S	68	144° 2.356' E	34° 42.120' S
53	143° 44.961' E	34° 5.798' S	69	144° 48.547' E	34° 33.879' S

Route: 1,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,47,68,69,39,40,41,42,1

Flight 2

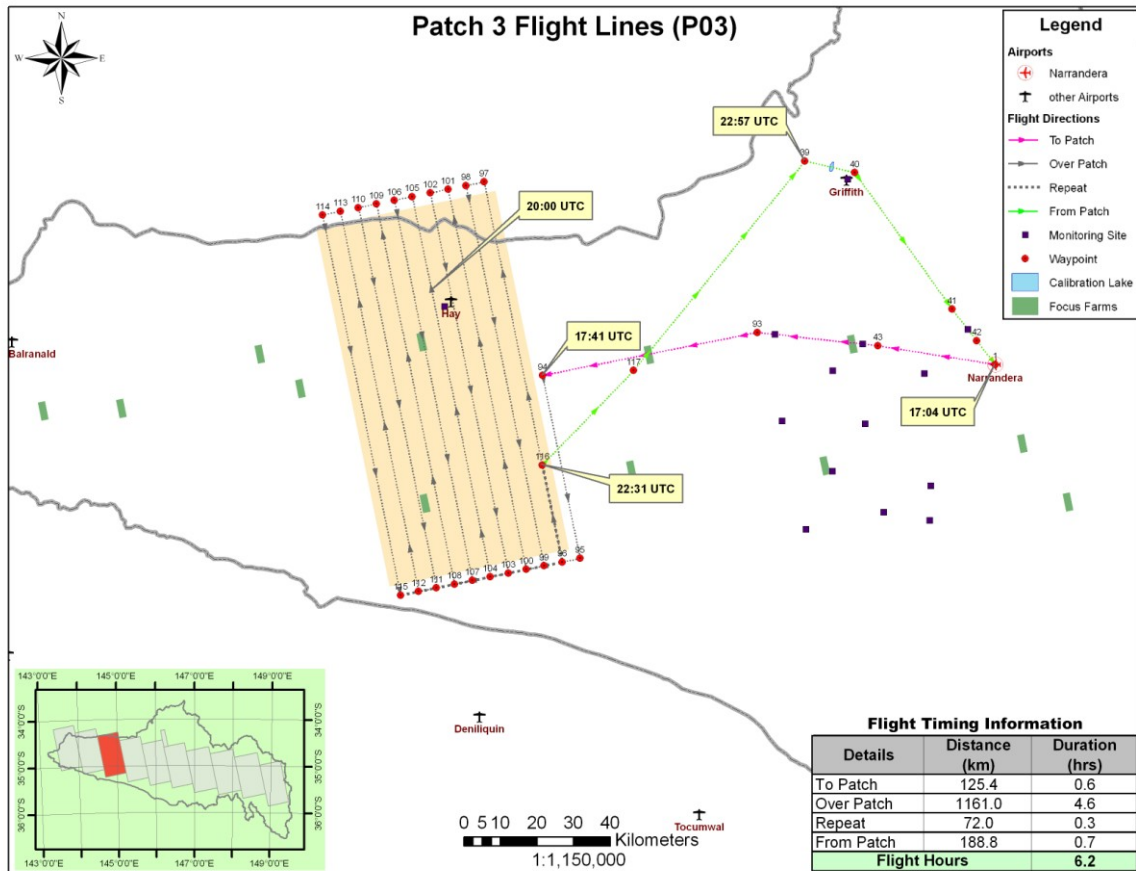
altitude 10,250 ft (ASL) and duration 6.6 hrs



Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	82	144° 9.369' E	34° 12.035' S
43	146° 9.306' E	34° 39.565' S	83	144° 21.461' E	35° 8.467' S
44	145° 41.560' E	34° 36.516' S	84	144° 18.221' E	35° 8.939' S
70	144° 33.308' E	34° 31.313' S	85	144° 6.165' E	34° 12.504' S
71	144° 40.893' E	35° 5.602' S	86	144° 2.960' E	34° 12.971' S
72	144° 37.655' E	35° 6.083' S	87	144° 14.980' E	35° 9.410' S
73	144° 25.384' E	34° 9.670' S	88	144° 11.738' E	35° 9.880' S
74	144° 22.182' E	34° 10.146' S	89	143° 59.755' E	34° 13.437' S
75	144° 34.418' E	35° 6.563' S	90	143° 56.549' E	34° 13.901' S
76	144° 31.179' E	35° 7.041' S	91	144° 8.497' E	35° 10.347' S
77	144° 18.979' E	34° 10.620' S	92	144° 32.676' E	34° 43.327' S
78	144° 15.777' E	34° 11.093' S	39	145° 56.639' E	34° 12.162' S
79	144° 27.941' E	35° 7.518' S	40	146° 5.458' E	34° 13.942' S
80	144° 24.701' E	35° 7.993' S	41	146° 22.625' E	34° 34.239' S
81	144° 12.573' E	34° 11.565' S	42	146° 26.992' E	34° 38.922' S
Route:					
1,43,44,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,72,92,39,40,41,42,1					

Flight 3

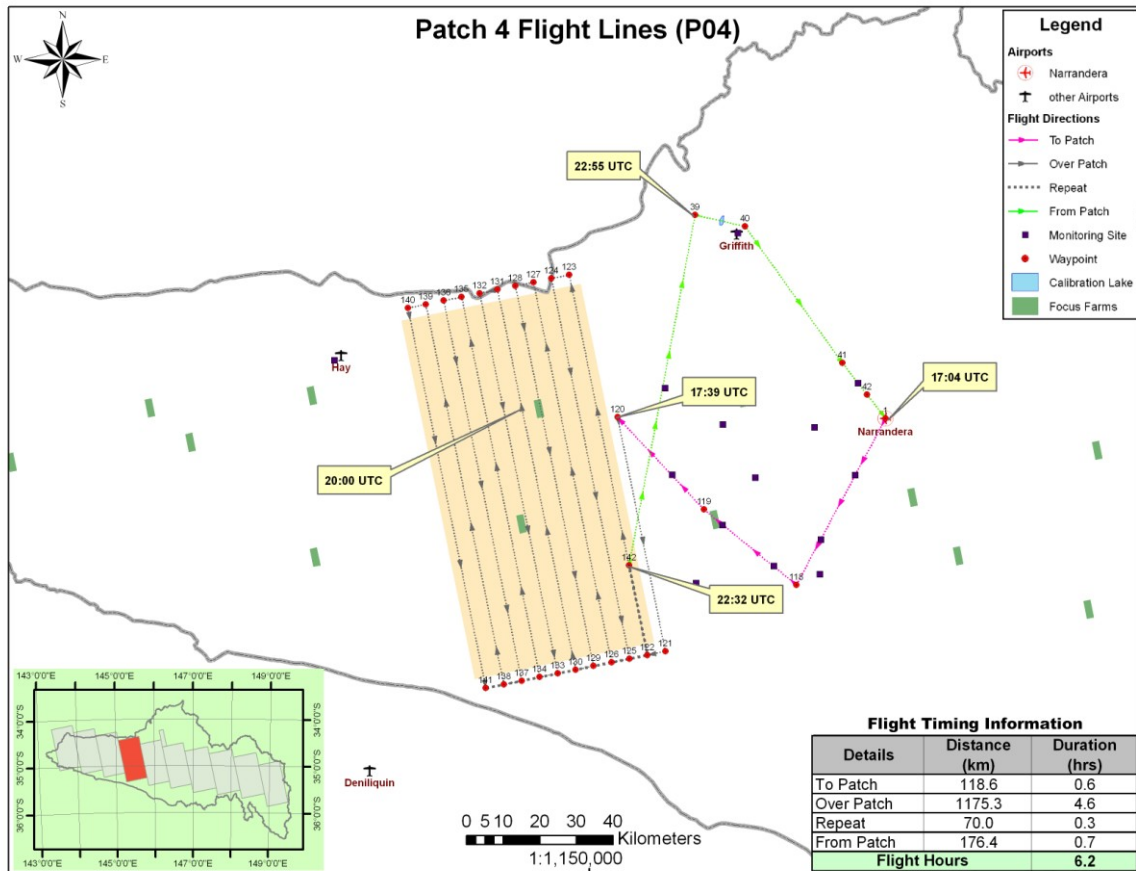
altitude 10,300 ft (ASL) and duration 6.2 hrs



Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	103	145° 2.485' E	35° 12.388' S
39	145° 56.639' E	34° 12.162' S	104	144° 59.245' E	35° 12.879' S
40	146° 5.458' E	34° 13.942' S	105	144° 46.715' E	34° 16.493' S
41	146° 22.625' E	34° 34.239' S	106	144° 43.511' E	34° 16.978' S
42	146° 26.992' E	34° 38.922' S	107	144° 56.004' E	35° 13.369' S
43	146° 9.306' E	34° 39.565' S	108	144° 52.763' E	35° 13.856' S
93	145° 47.790' E	34° 37.410' S	109	144° 40.305' E	34° 17.462' S
94	145° 9.293' E	34° 43.298' S	110	144° 37.100' E	34° 17.944' S
95	145° 15.439' E	35° 10.411' S	111	144° 49.521' E	35° 14.342' S
96	145° 12.201' E	35° 10.908' S	112	144° 46.279' E	35° 14.827' S
97	144° 59.529' E	34° 14.539' S	113	144° 33.893' E	34° 18.425' S
98	144° 56.326' E	34° 15.029' S	114	144° 30.687' E	34° 18.904' S
99	145° 8.963' E	35° 11.403' S	115	144° 43.036' E	35° 15.310' S
100	145° 5.724' E	35° 11.897' S	116	145° 8.946' E	34° 56.538' S
101	144° 53.123' E	34° 15.519' S	117	145° 25.621' E	34° 42.784' S
102	144° 49.919' E	34° 16.007' S			
Route: 1,43,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,96,116,117,39,40,41,42,1					

Flight 4

altitude 10,350 ft (ASL) and duration 6.2 hrs

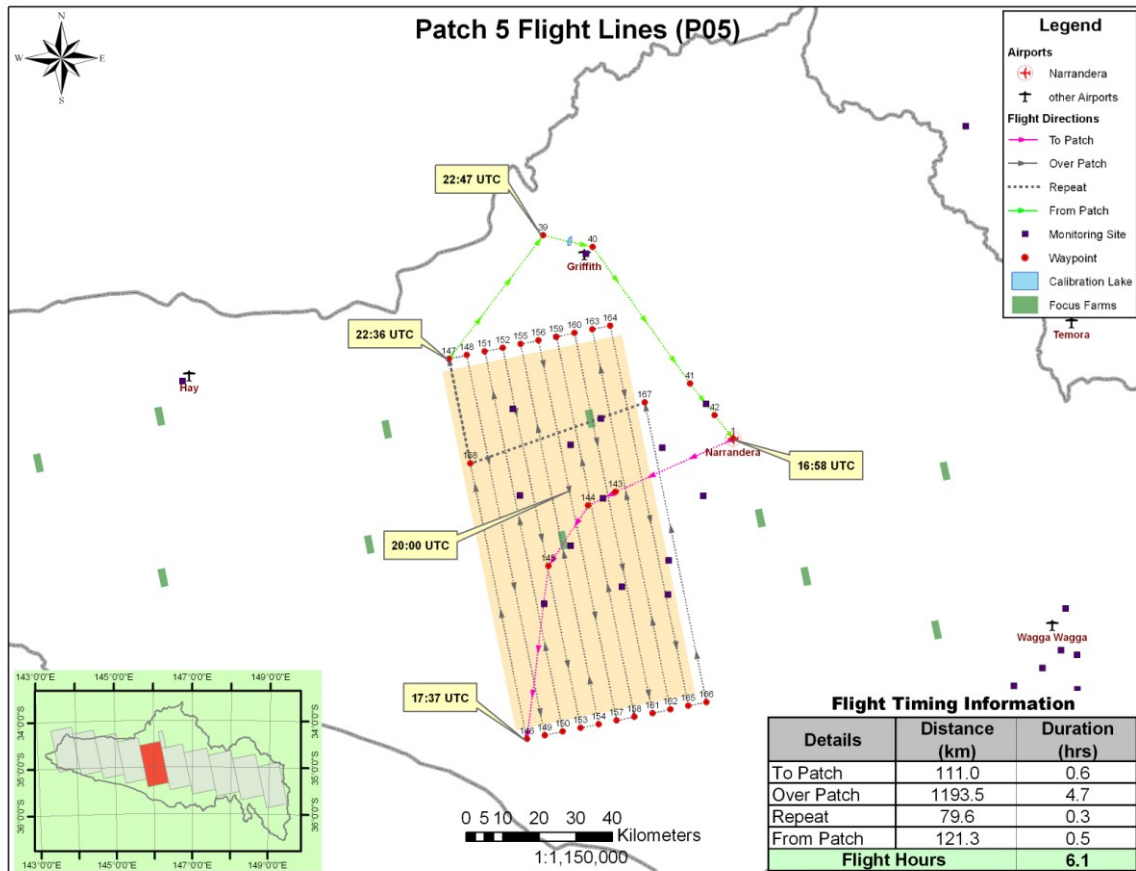


Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	128	145° 24.490' E	34° 22.315' S
39	145° 56.639' E	34° 12.162' S	129	145° 37.465' E	35° 18.647' S
40	146° 5.458' E	34° 13.942' S	130	145° 34.224' E	35° 19.154' S
41	146° 22.625' E	34° 34.239' S	131	145° 21.284' E	34° 22.816' S
42	146° 26.992' E	34° 38.922' S	132	145° 18.078' E	34° 23.317' S
118	146° 14.103' E	35° 6.967' S	133	145° 30.982' E	35° 19.659' S
119	145° 57.632' E	34° 55.710' S	134	145° 27.740' E	35° 20.162' S
120	145° 42.379' E	34° 41.933' S	135	145° 14.871' E	34° 23.815' S
121	145° 50.424' E	35° 16.608' S	136	145° 11.664' E	34° 24.313' S
122	145° 47.186' E	35° 17.120' S	137	145° 24.496' E	35° 20.664' S
123	145° 34.103' E	34° 20.802' S	138	145° 21.253' E	35° 21.164' S
124	145° 30.899' E	34° 21.308' S	139	145° 8.456' E	34° 24.808' S
125	145° 43.946' E	35° 17.630' S	140	145° 5.248' E	34° 25.303' S
126	145° 40.706' E	35° 18.140' S	141	145° 18.008' E	35° 21.663' S
127	145° 27.695' E	34° 21.812' S	142	145° 44.078' E	35° 3.842' S

Route:
1, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 122, 142, 39, 40, 41, 42, 1

Flight 5

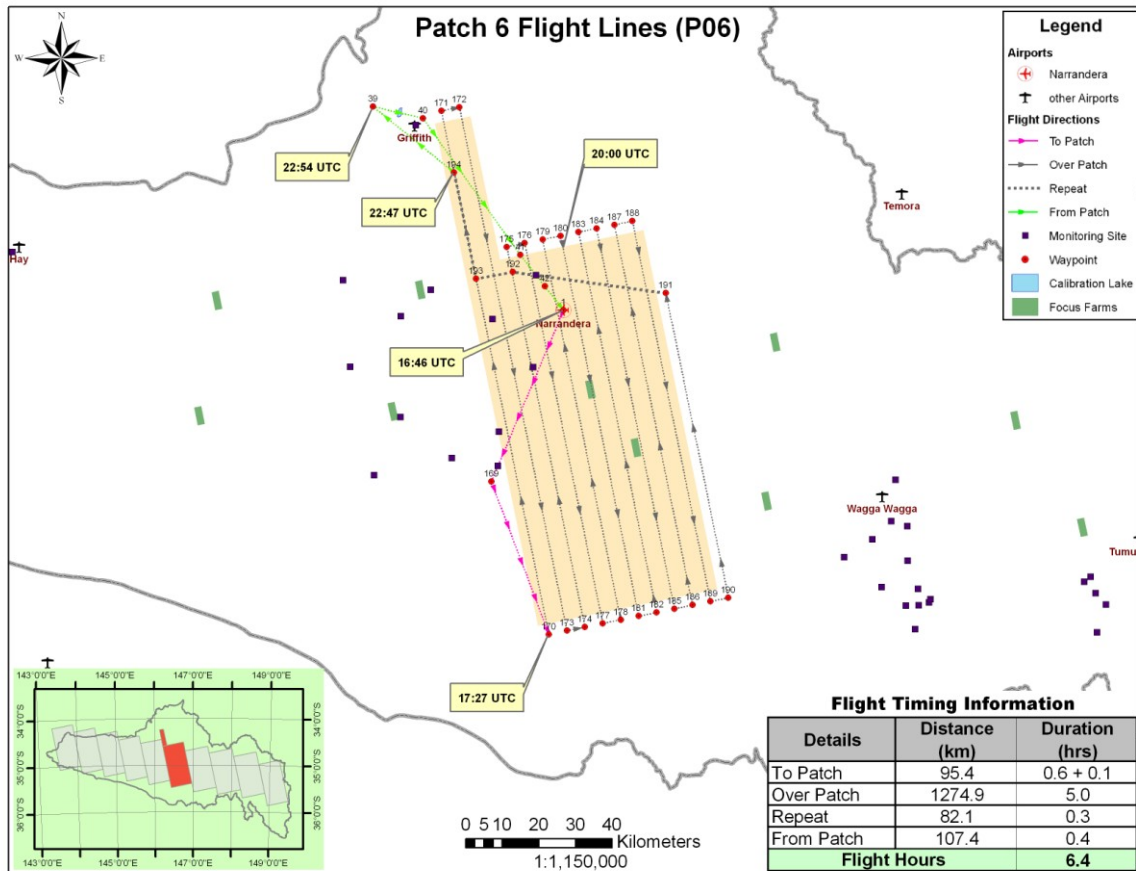
altitude 10,400 ft (ASL) and duration 6.1 hrs



Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	154	146° 5.742' E	35° 24.470' S
39	145° 56.639' E	34° 12.162' S	155	145° 52.431' E	34° 28.182' S
40	146° 5.458' E	34° 13.942' S	156	145° 55.638' E	34° 27.667' S
41	146° 22.625' E	34° 34.239' S	157	146° 8.983' E	35° 23.950' S
42	146° 26.992' E	34° 38.922' S	158	146° 12.225' E	35° 23.428' S
143	146° 9.143' E	34° 50.167' S	159	145° 58.843' E	34° 27.150' S
144	146° 4.217' E	34° 52.153' S	160	146° 2.048' E	34° 26.632' S
145	145° 56.979' E	35° 1.047' S	161	146° 15.465' E	35° 22.904' S
146	145° 52.767' E	35° 26.537' S	162	146° 18.705' E	35° 22.380' S
147	145° 39.602' E	34° 30.236' S	163	146° 5.253' E	34° 26.113' S
148	145° 42.809' E	34° 29.719' S	164	146° 8.457' E	34° 25.592' S
149	145° 56.012' E	35° 26.022' S	165	146° 21.945' E	35° 21.854' S
150	145° 59.256' E	35° 25.506' S	166	146° 25.183' E	35° 21.326' S
151	145° 46.017' E	34° 29.208' S	167	146° 14.500' E	34° 36.990' S
152	145° 49.224' E	34° 28.695' S	168	145° 43.195' E	34° 45.725' S
153	146° 2.499' E	35° 24.989' S			
Route: 1,143,144,145,146,147,148,149,150,151,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,167,168,147,39,40,41,42,1					

Flight 6

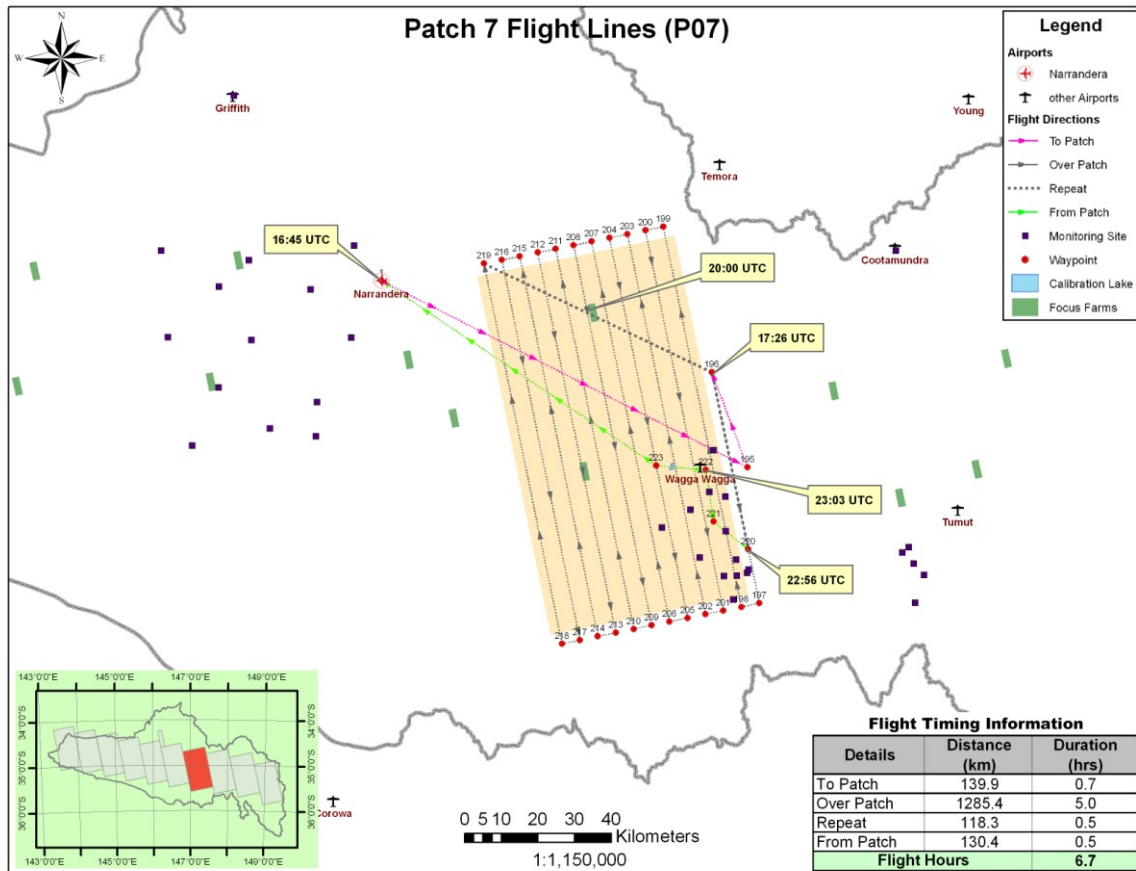
altitude 10,500 ft (ASL) and duration 6.4 hrs



Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	180	146° 29.845' E	34° 31.467' S
39	145° 56.639' E	34° 12.162' S	181	146° 43.594' E	35° 27.689' S
40	146° 5.458' E	34° 13.942' S	182	146° 46.834' E	35° 27.152' S
41	146° 22.625' E	34° 34.239' S	183	146° 33.050' E	34° 30.935' S
42	146° 26.982' E	34° 38.911' S	184	146° 36.254' E	34° 30.402' S
169	146° 17.161' E	35° 7.722' S	185	146° 50.073' E	35° 26.613' S
170	146° 27.382' E	35° 30.354' S	186	146° 53.312' E	35° 26.073' S
171	146° 8.766' E	34° 12.868' S	187	146° 39.458' E	34° 29.868' S
172	146° 11.968' E	34° 12.345' S	188	146° 42.661' E	34° 29.332' S
173	146° 30.626' E	35° 29.824' S	189	146° 56.550' E	35° 25.532' S
174	146° 33.869' E	35° 29.293' S	190	146° 59.788' E	35° 24.988' S
175	146° 20.227' E	34° 33.053' S	191	146° 48.607' E	34° 39.973' S
176	146° 23.433' E	34° 32.525' S	192	146° 21.266' E	34° 36.766' S
177	146° 37.111' E	35° 28.760' S	193	146° 14.679' E	34° 37.740' S
178	146° 40.353' E	35° 28.225' S	194	146° 10.920' E	34° 21.982' S
179	146° 26.640' E	34° 31.997' S			
Route: 1,169,170,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,39,40,41,42,1					

Flight 7

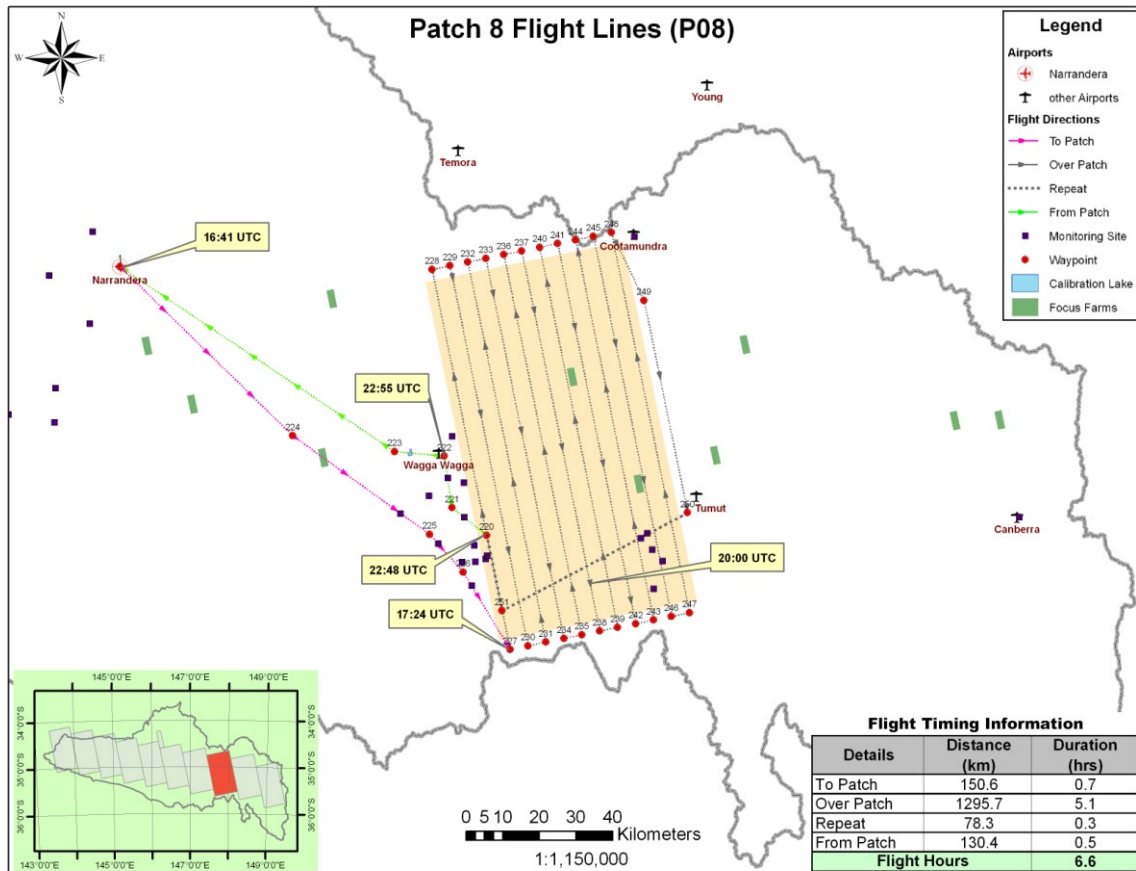
altitude 10,800 ft (ASL) and duration 6.7 hrs



Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	209	147° 18.806' E	35° 33.416' S
195	147° 35.956' E	35° 9.996' S	210	147° 15.565' E	35° 33.968' S
196	147° 29.463' E	34° 55.991' S	211	147° 1.436' E	34° 37.806' S
197	147° 38.235' E	35° 30.076' S	212	146° 58.230' E	34° 38.350' S
198	147° 34.999' E	35° 30.637' S	213	147° 12.324' E	35° 34.518' S
199	147° 20.659' E	34° 34.513' S	214	147° 9.082' E	35° 35.067' S
200	147° 17.458' E	34° 35.065' S	215	146° 55.023' E	34° 38.893' S
201	147° 31.762' E	35° 31.195' S	216	146° 51.816' E	34° 39.434' S
202	147° 28.524' E	35° 31.753' S	217	147° 5.839' E	35° 35.614' S
203	147° 14.255' E	34° 35.616' S	218	147° 2.595' E	35° 36.160' S
204	147° 11.051' E	34° 36.166' S	219	146° 48.607' E	34° 39.973' S
205	147° 25.286' E	35° 32.309' S	220	147° 36.179' E	35° 22.131' S
206	147° 22.046' E	35° 32.863' S	221	147° 29.906' E	35° 18.054' S
207	147° 7.847' E	34° 36.714' S	222	147° 28.461' E	35° 10.414' S
208	147° 4.642' E	34° 37.261' S	223	147° 19.536' E	35° 9.792' S
Route: 1, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 196, 220, 221, 22, 223, 1					

Flight 8

altitude 11,100 ft (ASL) and duration 6.6 hrs

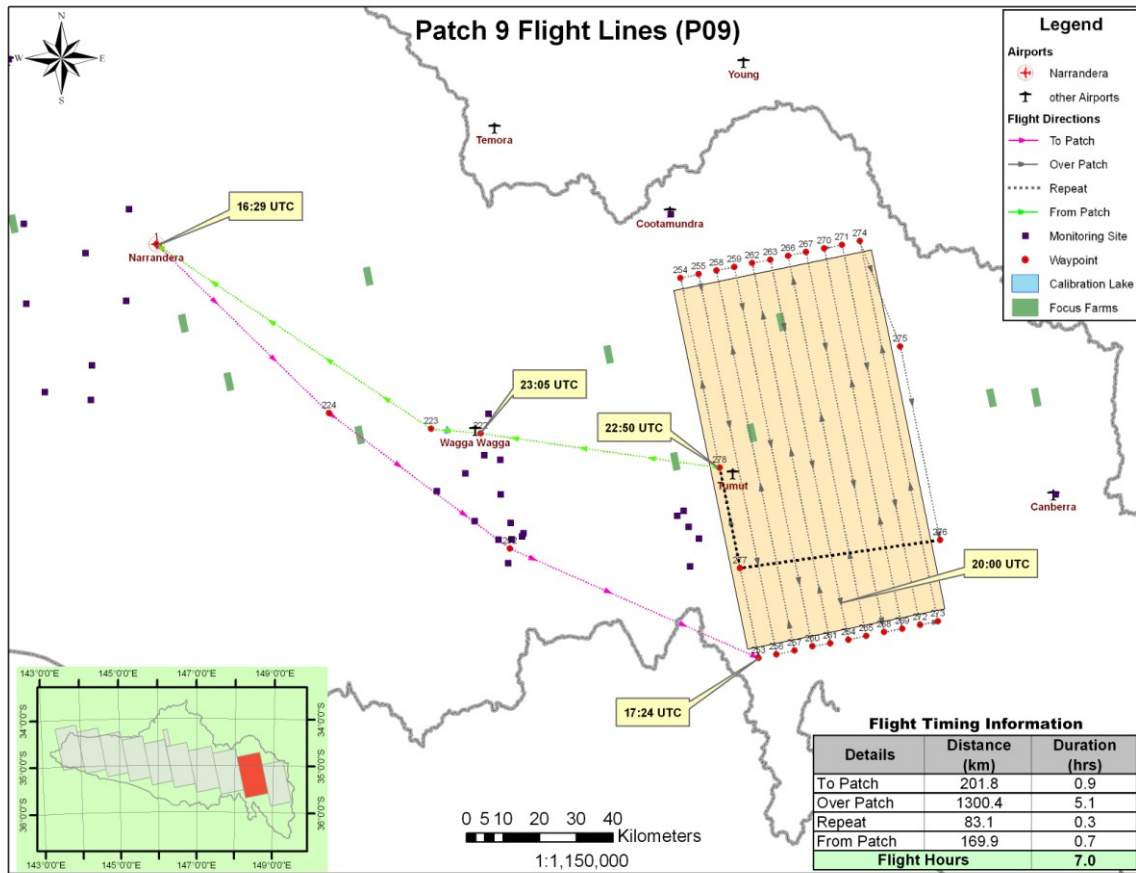


Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	236	147° 38.936' E	34° 40.618' S
220	147° 36.177' E	35° 22.124' S	237	147° 42.139' E	34° 40.057' S
221	147° 29.906' E	35° 18.054' S	238	147° 56.741' E	35° 36.134' S
222	147° 28.461' E	35° 10.414' S	239	147° 59.978' E	35° 35.563' S
223	147° 19.536' E	35° 9.792' S	240	147° 45.341' E	34° 39.494' S
224	147° 1.174' E	35° 7.469' S	241	147° 48.543' E	34° 38.929' S
225	147° 25.871' E	35° 21.995' S	242	148° 3.215' E	35° 34.992' S
226	147° 31.959' E	35° 27.551' S	243	148° 6.450' E	35° 34.419' S
227	147° 40.544' E	35° 38.962' S	244	147° 51.743' E	34° 38.363' S
228	147° 26.116' E	34° 42.851' S	245	147° 54.943' E	34° 37.796' S
229	147° 29.322' E	34° 42.295' S	246	148° 9.685' E	35° 33.845' S
230	147° 43.785' E	35° 38.399' S	247	148° 12.919' E	35° 33.269' S
231	147° 47.025' E	35° 37.835' S	248	147° 58.143' E	34° 37.227' S
232	147° 32.527' E	34° 41.738' S	249	148° 4.104' E	34° 47.214' S
233	147° 35.732' E	34° 41.179' S	250	148° 12.364' E	35° 18.492' S
234	147° 50.264' E	35° 37.269' S	251	147° 39.053' E	35° 33.227' S
235	147° 53.503' E	35° 36.702' S			

Route:
1,224,225,226,227,228,229,230,231,232,233,234,235,236,237,238,239,240,241,242,243,244,245,246,247,248,249,250,251,220,221,222,223,1

Flight 9

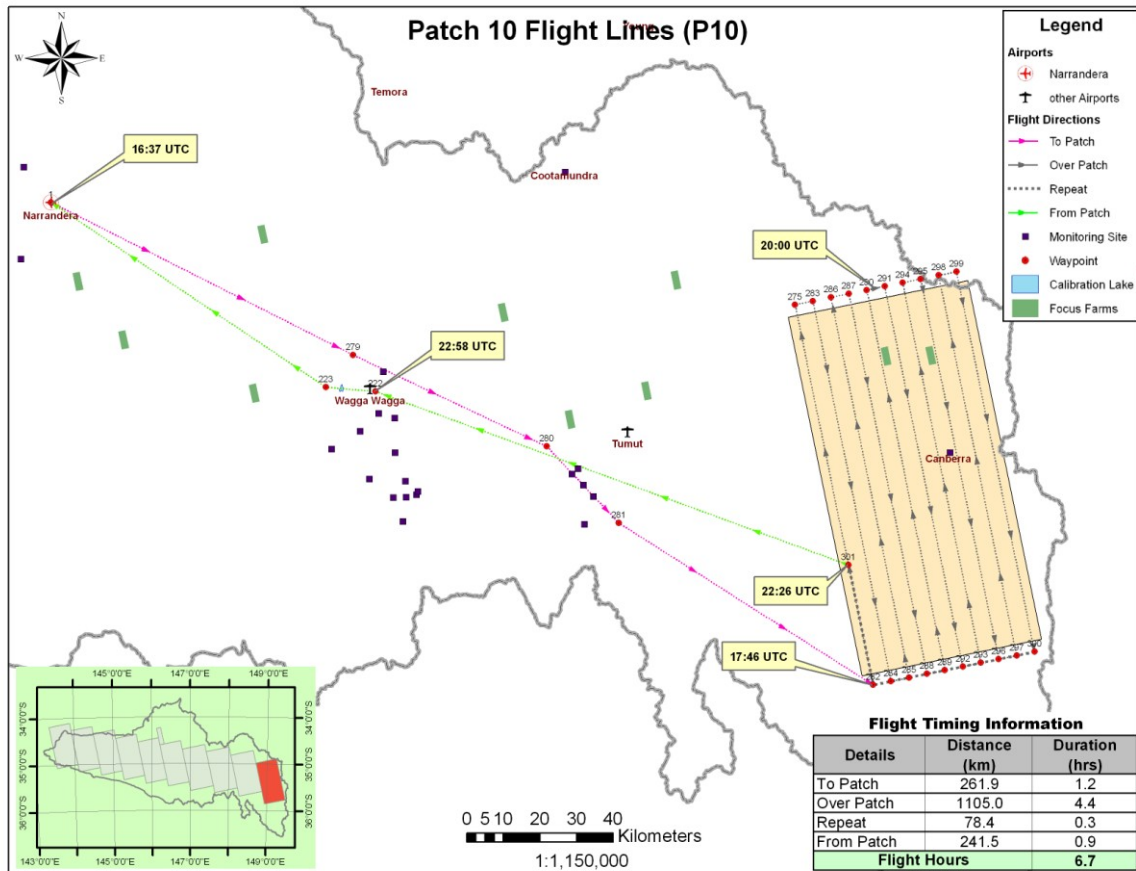
altitude 11,950 ft (ASL) and duration 7.0 hrs



Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	264	148° 35.169' E	35° 40.326' S
222	147° 28.461' E	35° 10.414' S	265	148° 38.403' E	35° 39.739' S
223	147° 19.536' E	35° 9.792' S	266	148° 23.317' E	34° 43.756' S
224	147° 1.174' E	35° 7.469' S	267	148° 26.517' E	34° 43.175' S
252	147° 33.873' E	35° 27.432' S	268	148° 41.626' E	35° 39.109' S
253	148° 18.982' E	35° 43.240' S	269	148° 44.871' E	35° 38.560' S
254	148° 4.104' E	34° 47.214' S	270	148° 29.715' E	34° 42.593' S
255	148° 7.308' E	34° 46.641' S	271	148° 32.913' E	34° 42.009' S
256	148° 22.221' E	35° 42.660' S	272	148° 48.103' E	35° 37.969' S
257	148° 25.459' E	35° 42.079' S	273	148° 51.334' E	35° 37.376' S
258	148° 10.511' E	34° 46.067' S	274	148° 36.110' E	34° 41.424' S
259	148° 13.714' E	34° 45.491' S	275	148° 43.651' E	34° 56.910' S
260	148° 28.663' E	35° 41.373' S	276	148° 51.419' E	35° 25.371' S
261	148° 31.933' E	35° 40.912' S	277	148° 15.427' E	35° 29.981' S
262	148° 16.916' E	34° 44.914' S	278	148° 11.491' E	35° 15.206' S
263	148° 20.131' E	34° 44.390' S			
Route: 1,224,252,253,254,255,256,257,258,259,260,261,262,263,264,265,266,267,268,269,270,271,272,273,274,275,276,277,278,2,22,223,1					

Flight 10

altitude 12,000 ft (ASL) and duration 6.7 hrs



Point ID	Longitude	Latitude	Point ID	Longitude	Latitude
1	146° 30.293' E	34° 42.454' S	289	149° 11.971' E	35° 50.439' S
222	147° 28.461' E	35° 10.414' S	290	148° 56.466' E	34° 54.541' S
223	147° 19.536' E	35° 9.792' S	291	148° 59.668' E	34° 53.945' S
275	148° 43.651' E	34° 56.910' S	292	149° 15.208' E	35° 49.835' S
279	147° 24.409' E	35° 5.024' S	293	149° 18.443' E	35° 49.230' S
280	147° 59.372' E	35° 18.338' S	294	149° 2.869' E	34° 53.348' S
281	148° 12.519' E	35° 29.515' S	295	149° 6.069' E	34° 52.750' S
282	148° 59.018' E	35° 52.840' S	296	149° 21.677' E	35° 48.624' S
283	148° 46.856' E	34° 56.320' S	297	149° 24.911' E	35° 48.015' S
284	149° 2.257' E	35° 52.242' S	298	149° 9.269' E	34° 52.150' S
285	149° 5.496' E	35° 51.642' S	299	149° 12.467' E	34° 51.549' S
286	148° 50.060' E	34° 55.728' S	300	149° 28.144' E	35° 47.406' S
287	148° 53.264' E	34° 55.135' S	301	148° 54.127' E	35° 35.197' S
288	149° 8.734' E	35° 51.041' S			
Route: 1,279,280,281,282,283,284,285,286,287,288,289,290,291,292,293,294,295,296,297,298,299,300,282,301,222,223,1					

Appendix F: Getting to the Farms

The following sketches give directions for how to get from the ground operations base to the 20 focus farms (identified as patch/farm) and how to navigate the farm.

Farm 1/1



Team A

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
20.01.10	Reconnaissance	Hay	1	1	118	1h 40min
22.01.10	Sampling	Hay	1	1	118	1h 40min

Farm 1/2



Team B

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
20.01.10	Reconnaissance	Hay	1	2	99	1h 20min
22.01.10	Sampling	Hay	1	2	99	1h 20min

Farm 2/3



Team A

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
23.01.10	Reconnaissance	Hay	2	3	56	42min
25.01.10	Sampling	Hay	2	3	56	42min

Farm 2/4



Team B

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
23.01.10	Reconnaissance	Hay	2	4	59	1h 20min
25.01.10	Sampling	Hay	2	4	59	1h 20min

Farm 3/5

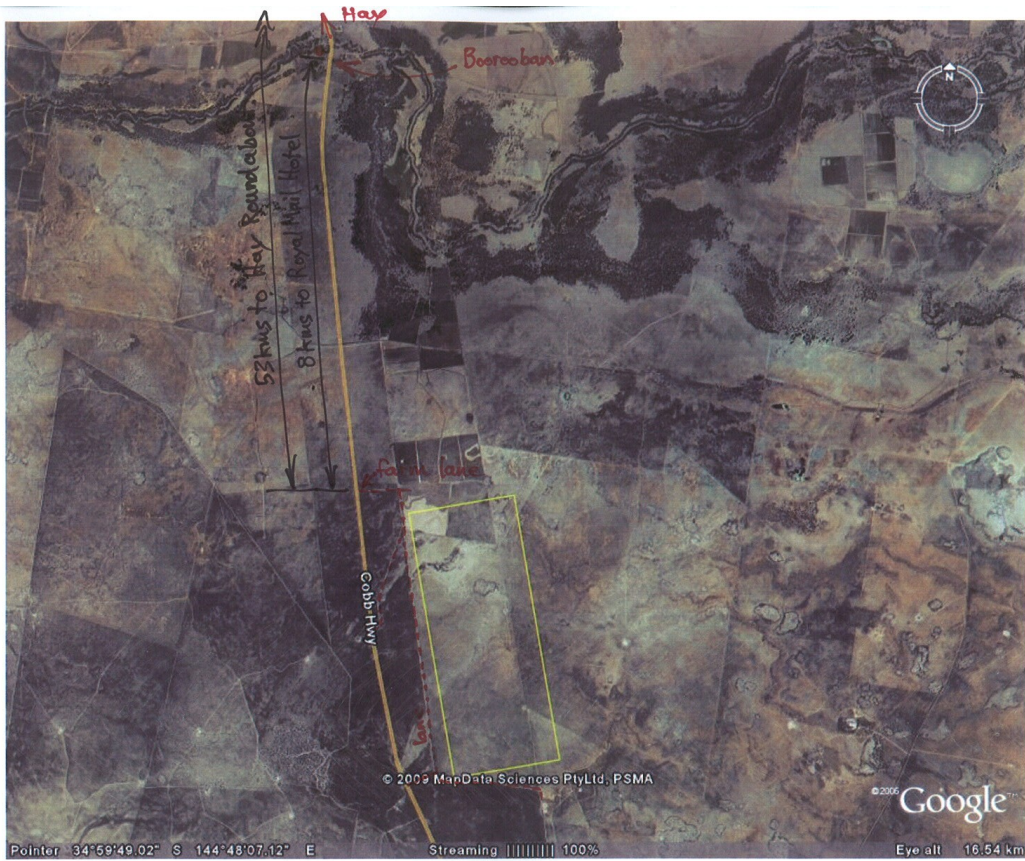


Patch
3/5

Team A

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
26.01.10	Reconnaissance	Hay	3	5	18	15min
28.01.10	Sampling	Hay	3	5	18	15min

Farm 3/6

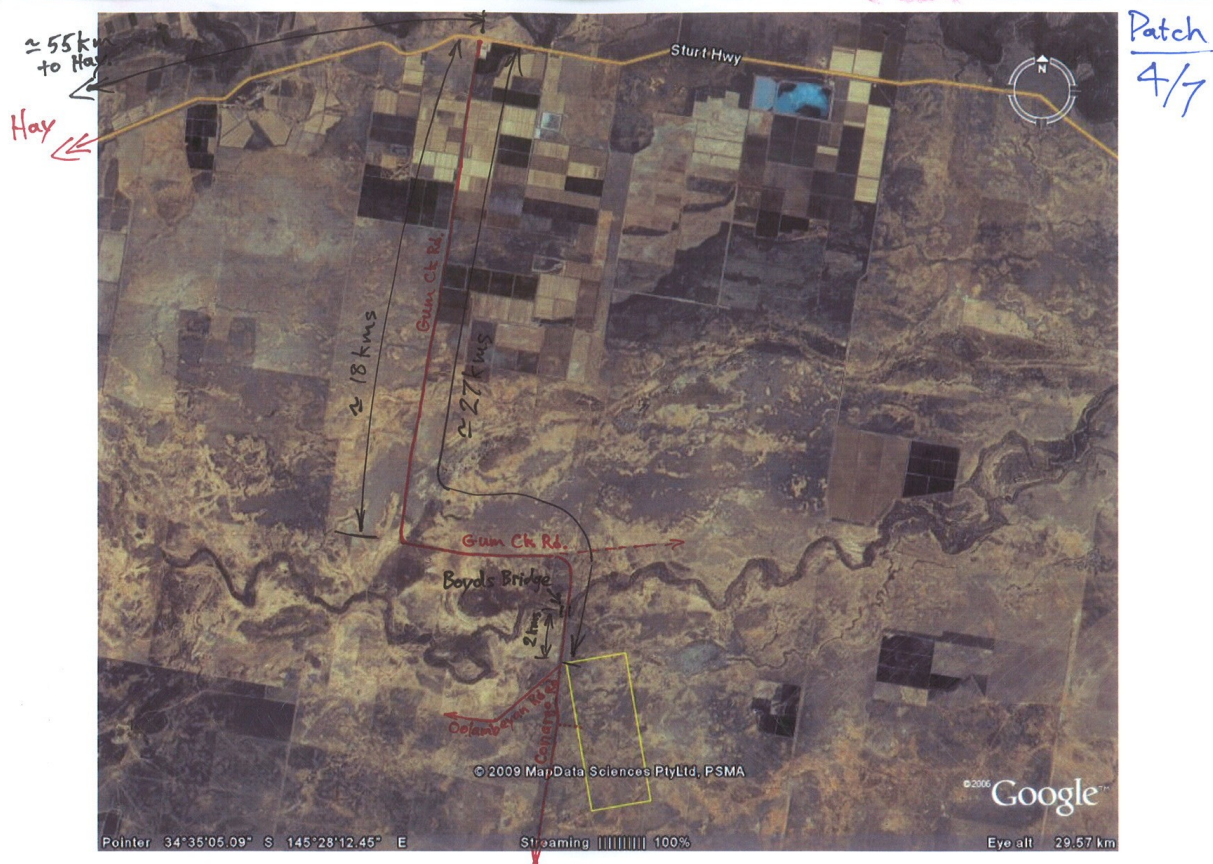


Patch
3/6

Team B

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
26.01.10	Reconnaissance	Hay	3	6	60	50min
28.01.10	Sampling	Hay	3	6	60	50min

Farm 4/7



Team B

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
29.01.10	Reconnaissance	Hay	4	7	85	2h
30.01.10	Sampling	Hay	4	7	85	2h

Farm 4/8



Patch
4/8

Team A

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
29.01.10	Reconnaissance	Hay	4	8	116	2h 10min
30.01.10	Sampling	Hay	4	8	116	2h 10min

Farm 5/9



Team A

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
01.02.10	Reconnaissance	Yanco	5	9	40	38min
02.02.10	Sampling	Yanco	5	9	40	38min
05.02.10	Sampling	Yanco	5	9	40	38min

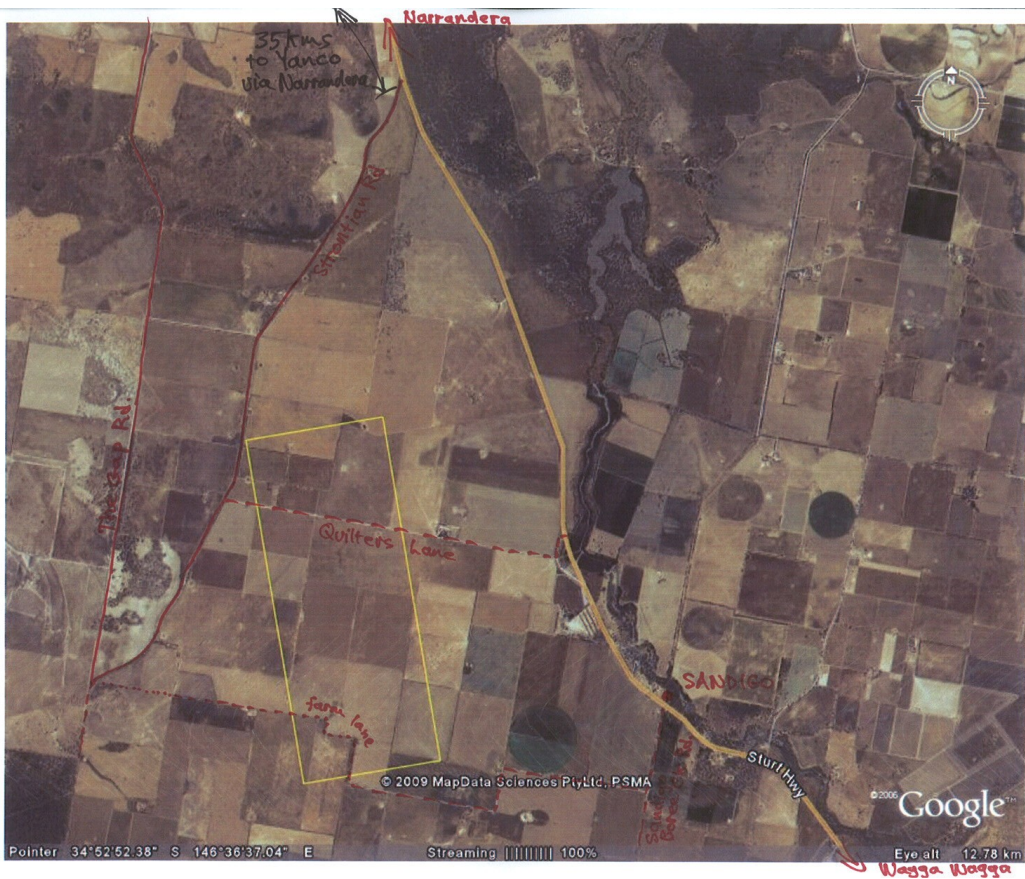
Farm 5/10



Team B

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
01.02.10	Reconnaissance	Yanco	5	10	90	1h 25min
02.02.10	Sampling	Yanco	5	10	90	1h 25min
05.02.10	Sampling	Yanco	5	10	90	1h 25min

Farm 6/11

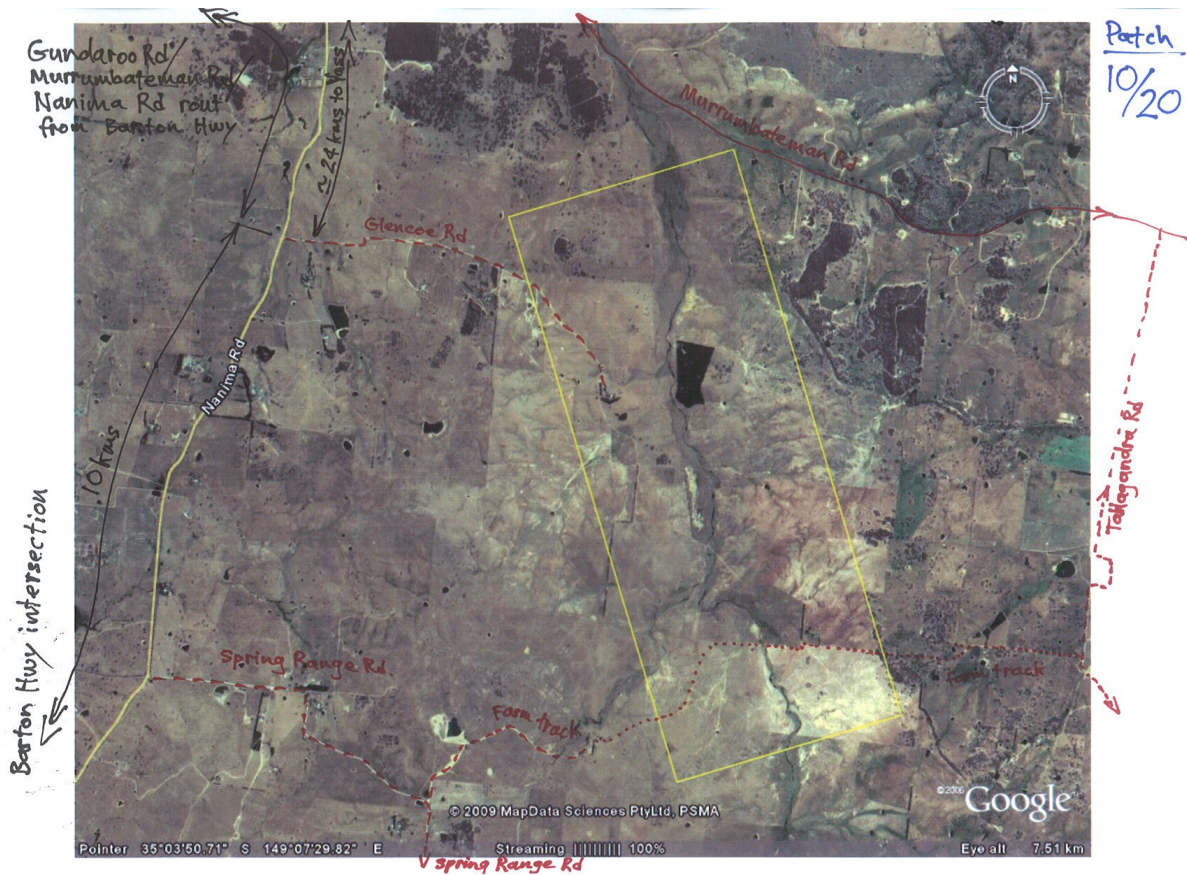


Patch
6/11

Team B

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
06.02.10	Reconnaissance	Yanco	6	11	40	38min
07.02.10	Sampling	Yanco	6	11	40	38min

Farm 6/12



Team A

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
06.02.10	Reconnaissance	Yanco	6	12	64	1h
07.02.10	Sampling	Yanco	6	12	64	1h

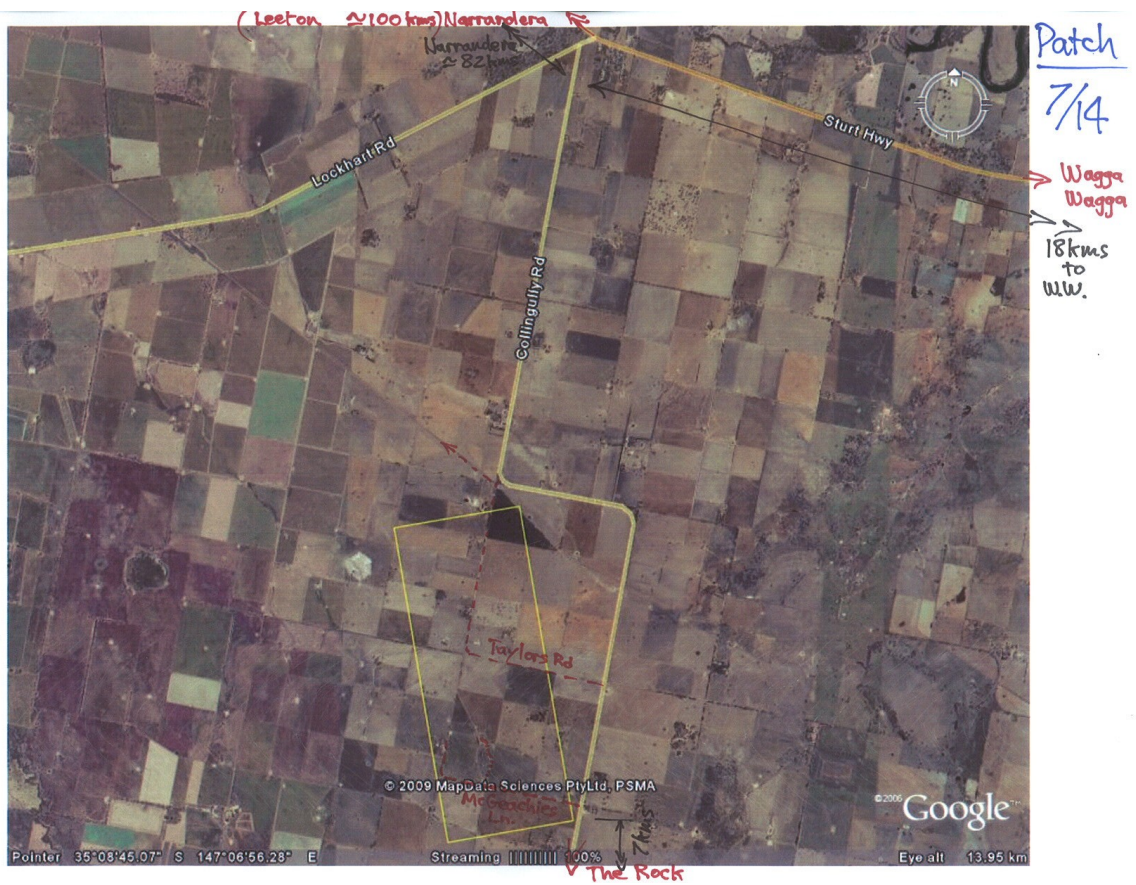
Farm 7/13



Team A

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
08.02.10	Reconnaissance	Yanco	7	13	84	1h 30min
10.02.10	Sampling	Yanco	7	13	84	1h 30min

Farm 7/14



Team B

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
08.02.10	Reconnaissance	Yanco	7	14	114	1h 35min
10.02.10	Sampling	Yanco	7	14	114	1h 35min

Farm 8/15



Team A

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
12.02.10	Reconnaissance	Gundagai	8	15	30	32min
13.02.10	Sampling	Gundagai	8	15	30	32min

Farm 8/16



Team B

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
12.02.10	Reconnaissance	Gundagai	8	16	34	34min
13.02.10	Sampling	Gundagai	8	16	34	34min

Farm 9/17



Team B

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
14.02.10	Reconnaissance	Gundagai	9	17	23	34min
15.02.10	Sampling	Gundagai	9	17	23	34min

Farm 9/18



Team A

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
14.02.10	Reconnaissance	Gundagai	9	18	48	46min
15.02.10	Sampling	Gundagai	9	18	48	46min

Farm 10/19

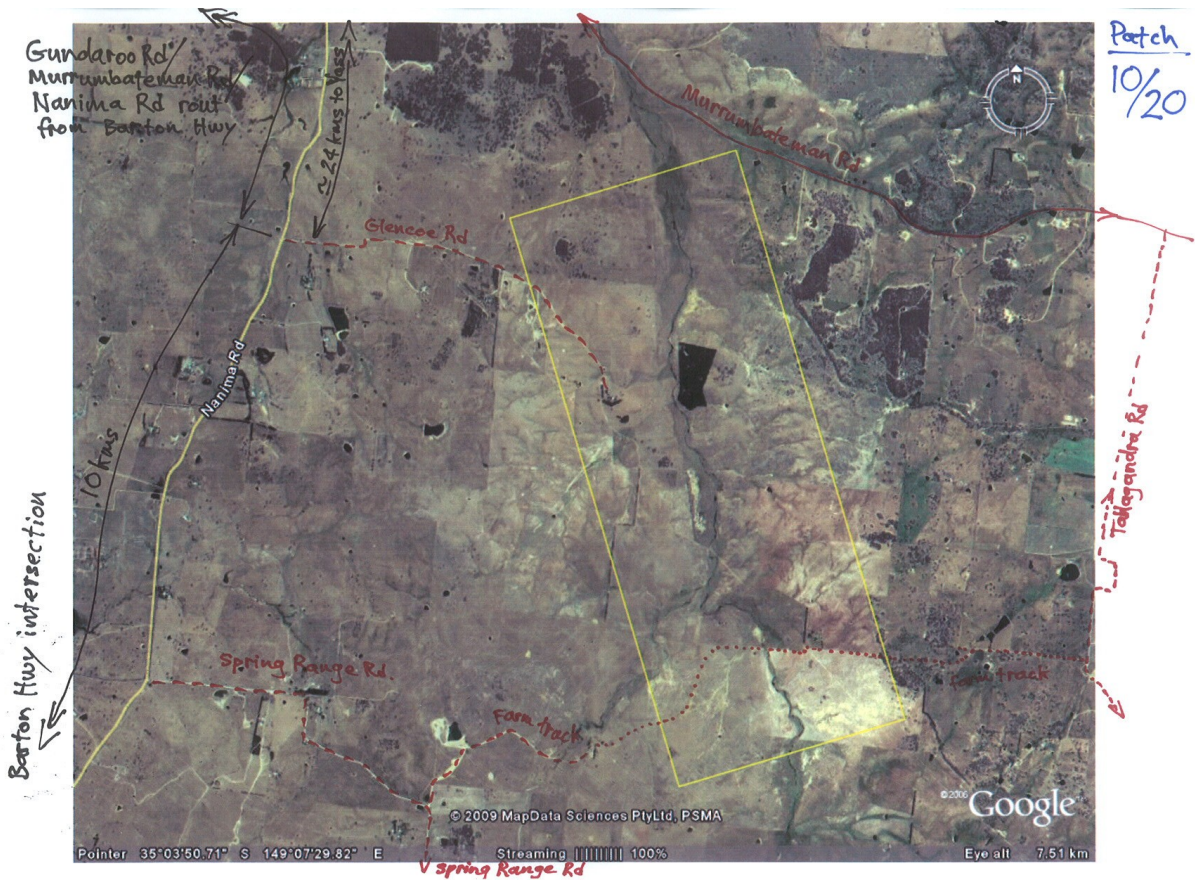


Patch
10/19

Team A

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
17.02.10	Reconnaissance	Yass	10	19	36	45min
18.02.10	Sampling	Yass	10	19	36	45min
20.02.10	Sampling	Yass	10	19	36	45min

Farm 10/20



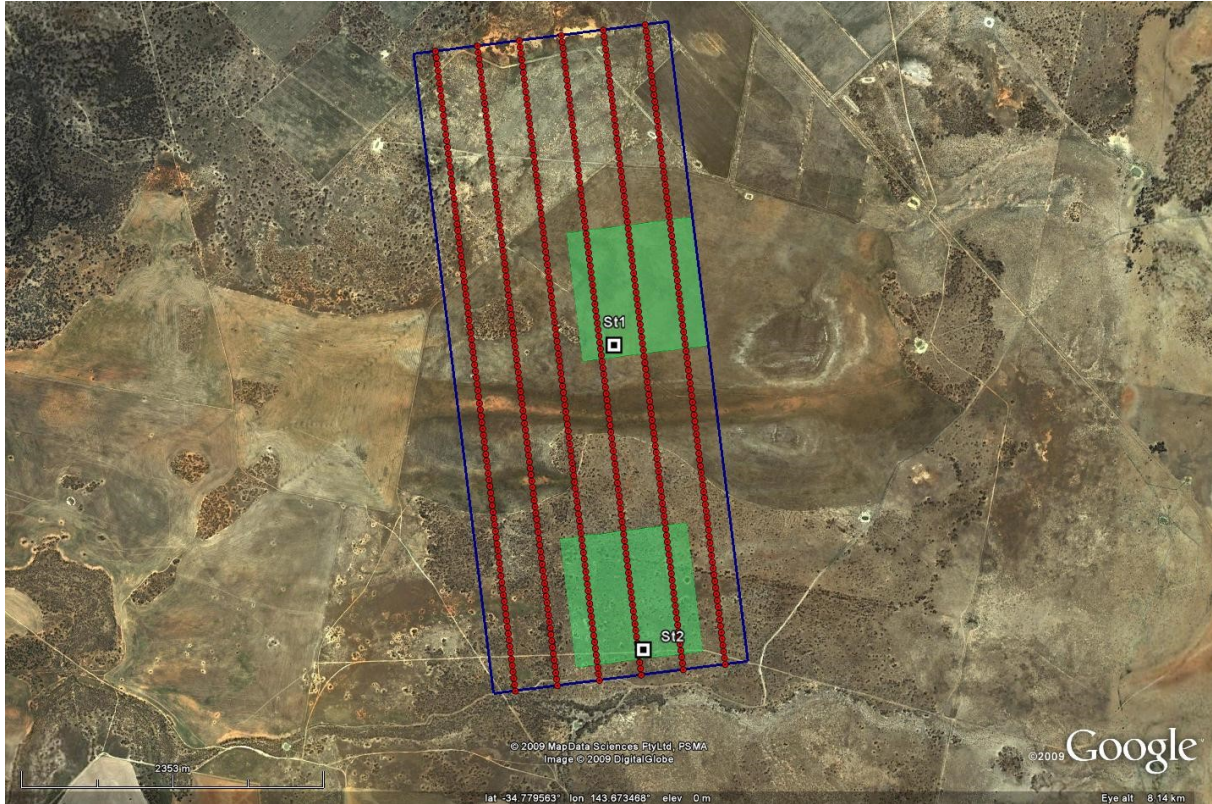
Team B

Date	Activity	Operation Base	Patch Number	Farm ID	Distance km	Travel time
17.02.10	Reconnaissance	Yass	10	20	46	53min
18.02.10	Sampling	Yass	10	20	46	53min
20.02.10	Sampling	Yass	10	20	46	53min

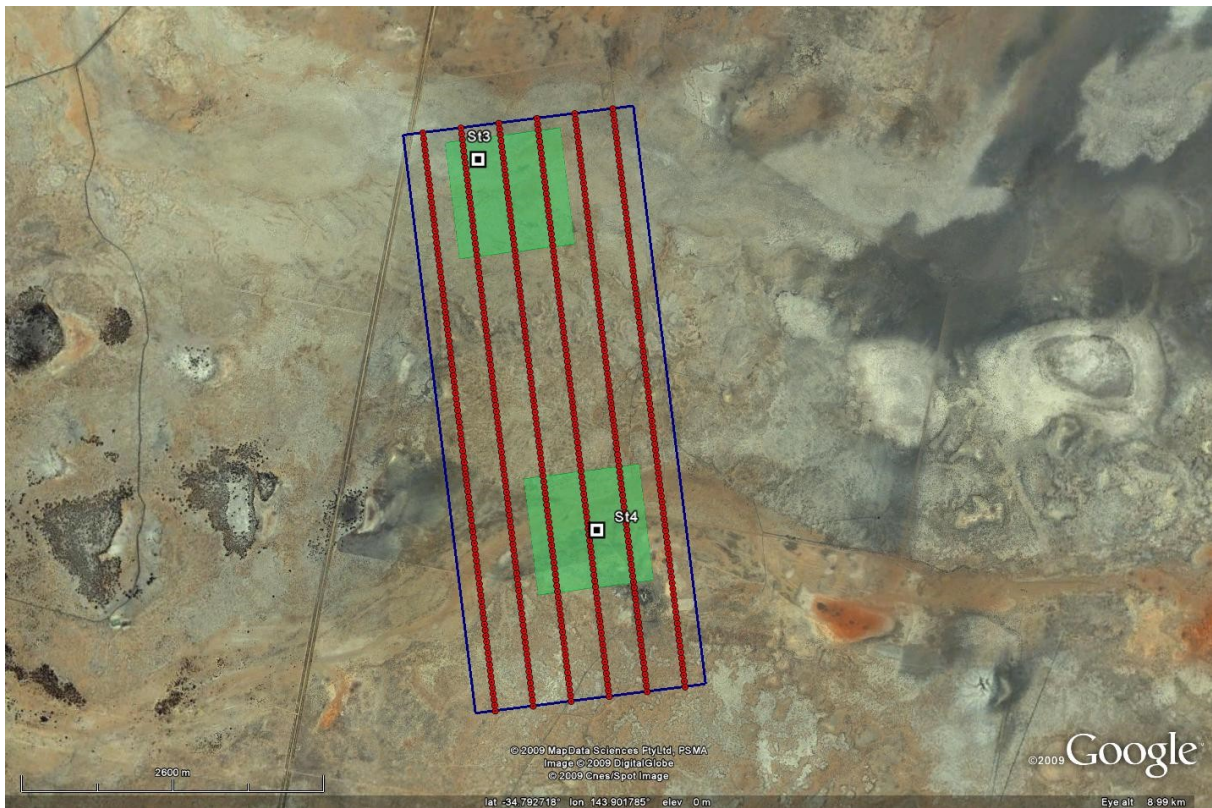
Appendix G: Farm Overviews

The following sketches overview the soil moisture sampling transects, temporary monitoring station locations and proposed vegetation sampling areas for each of the 20 focus farms (identified as patch/farm).

Farm 1/1



Farm 1/2

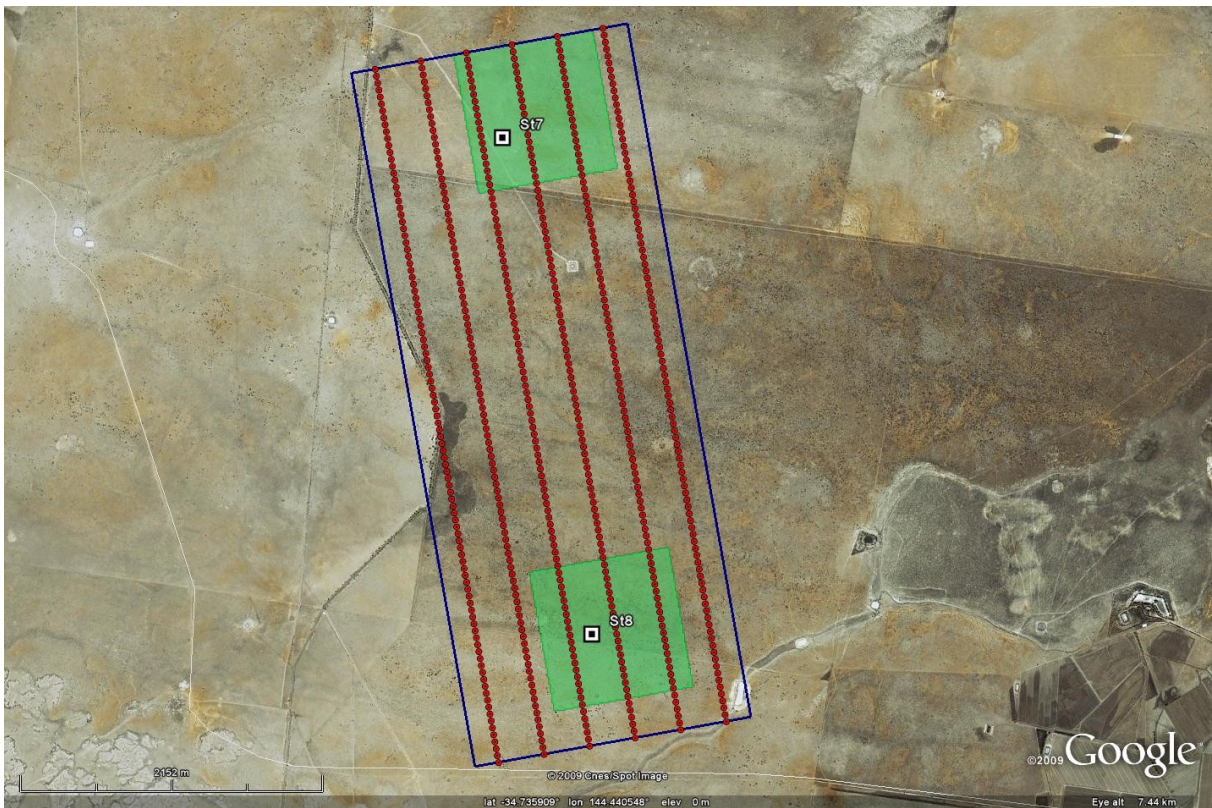


blue rectangle - boundary of focus farm; red points - HDAS sampling points; white points - temporary monitoring stations; green square - proposed vegetation/dew/roughness sampling area

Farm 2/3

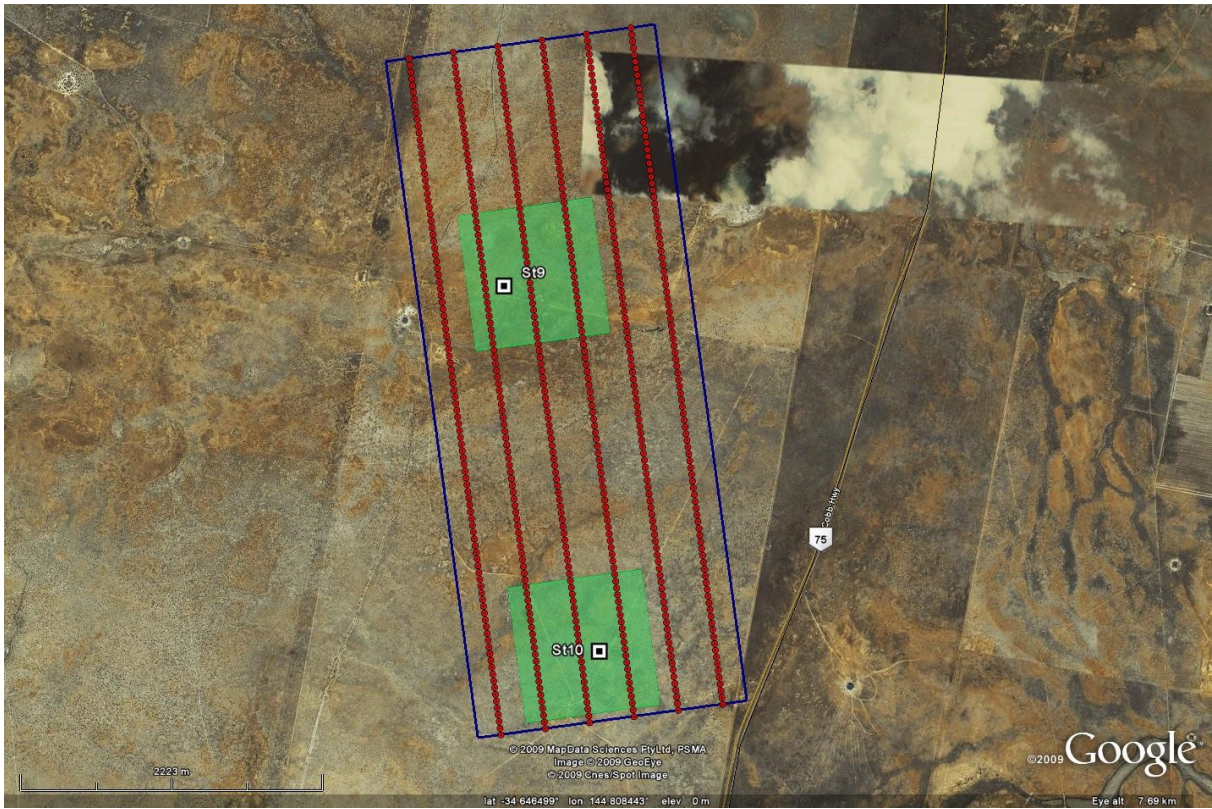


Farm 2/4

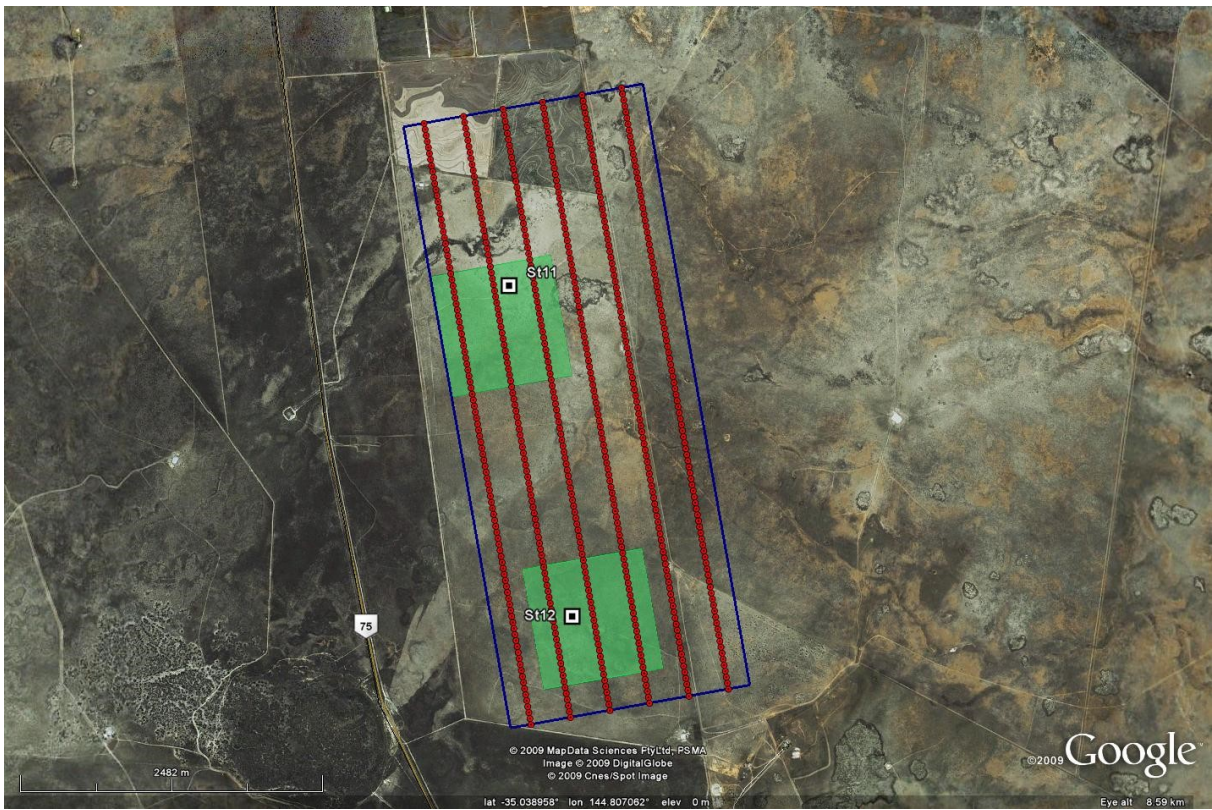


blue rectangle - boundary of focus farm; red points - HDAS sampling points; white points - temporary monitoring stations; green square - proposed vegetation/dew/roughness sampling area

Farm 3/5

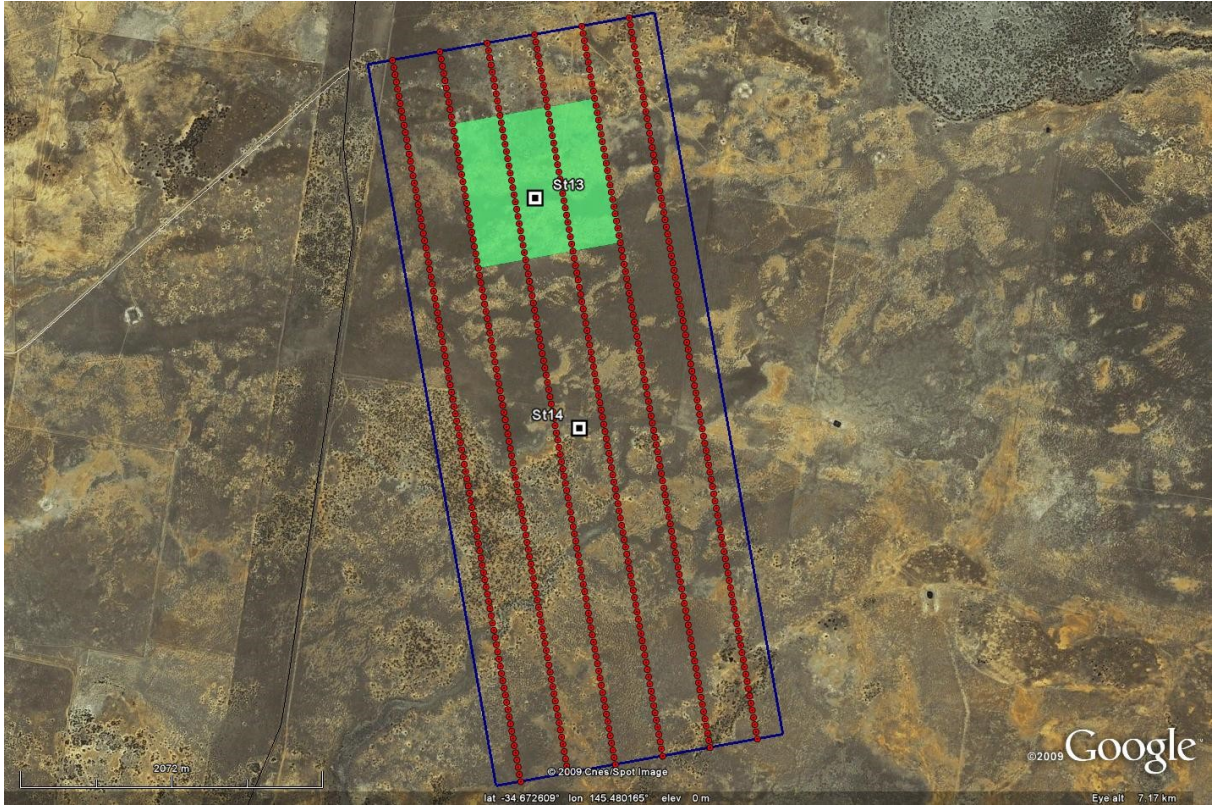


Farm 3/6

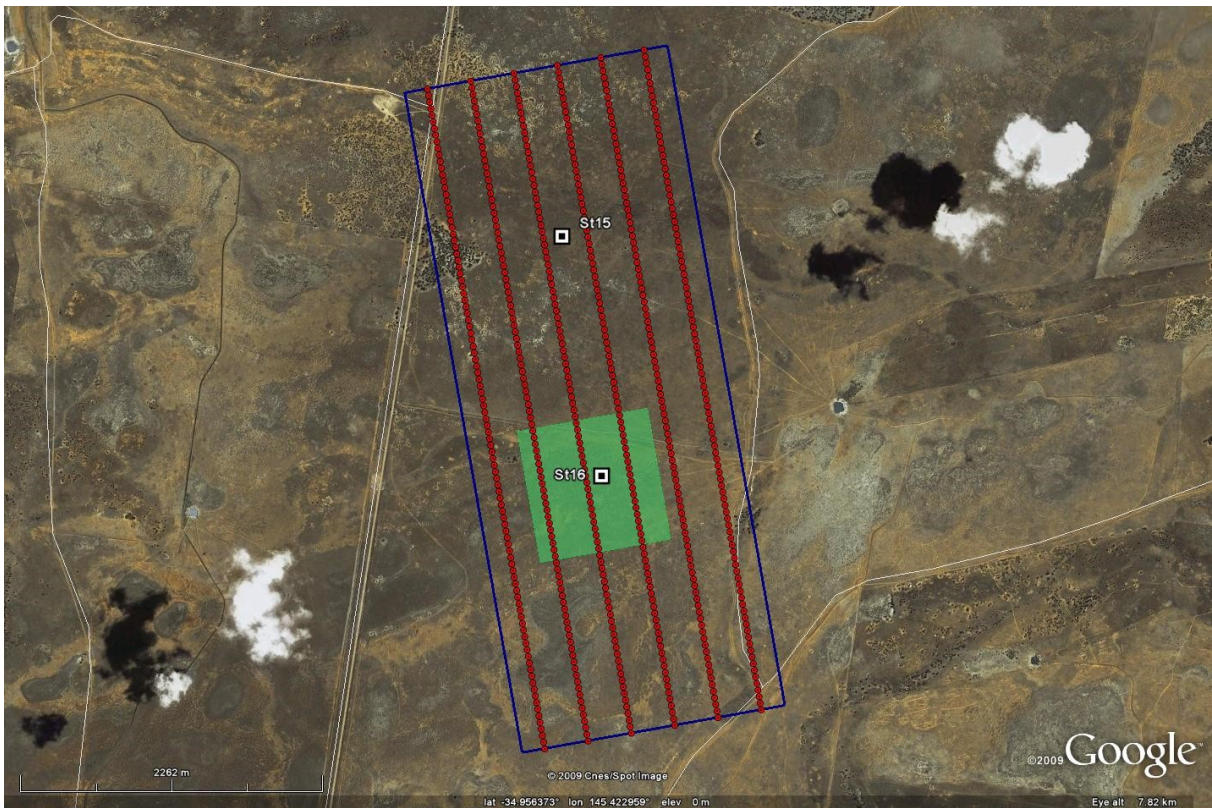


blue rectangle - boundary of focus farm; red points - HDAS sampling points; white points - temporary monitoring stations; green square - proposed vegetation/dew/roughness sampling area

Farm 4/7



Farm 4/8

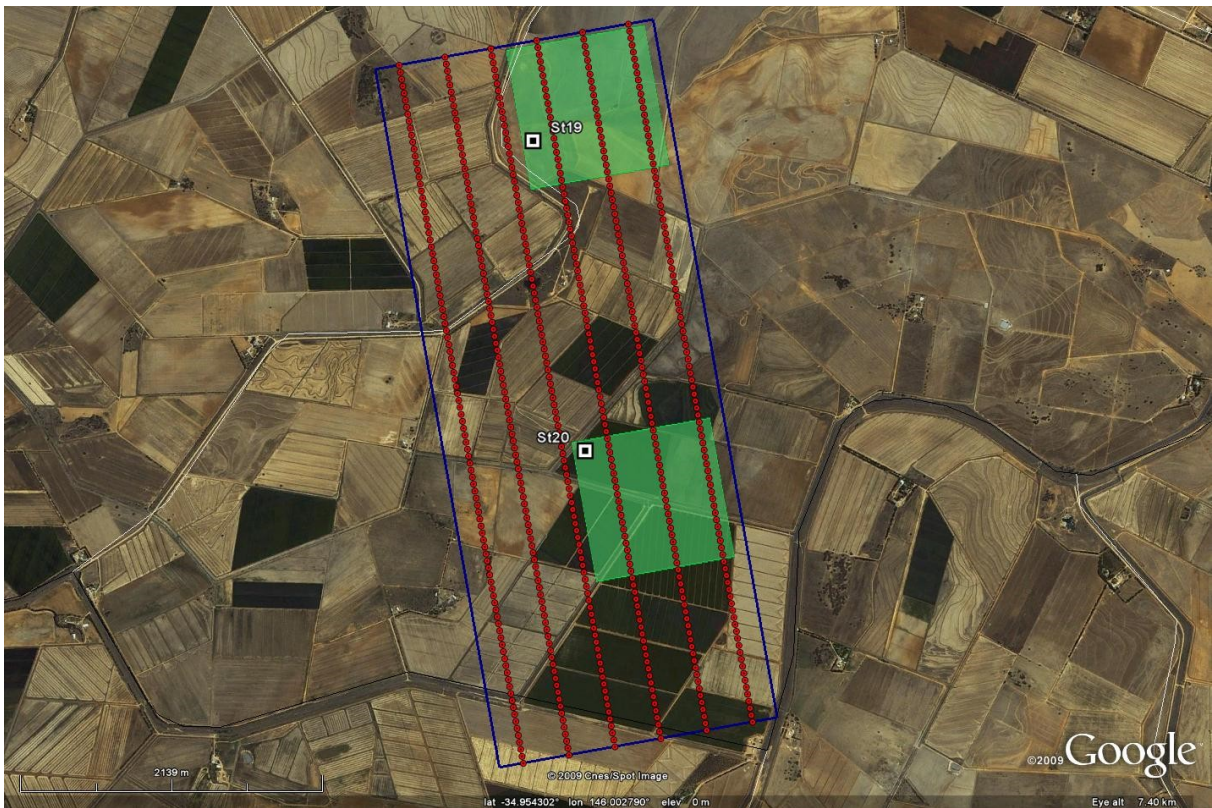


blue rectangle - boundary of focus farm; red points - HDAS sampling points; white points - temporary monitoring stations; green square - proposed vegetation/dew/roughness sampling area

Farm 5/9



Farm 5/10



blue rectangle - boundary of focus farm; red points - HDAS sampling points; white points - temporary monitoring stations; green square - proposed vegetation/dew/roughness sampling area

Farm 6/11

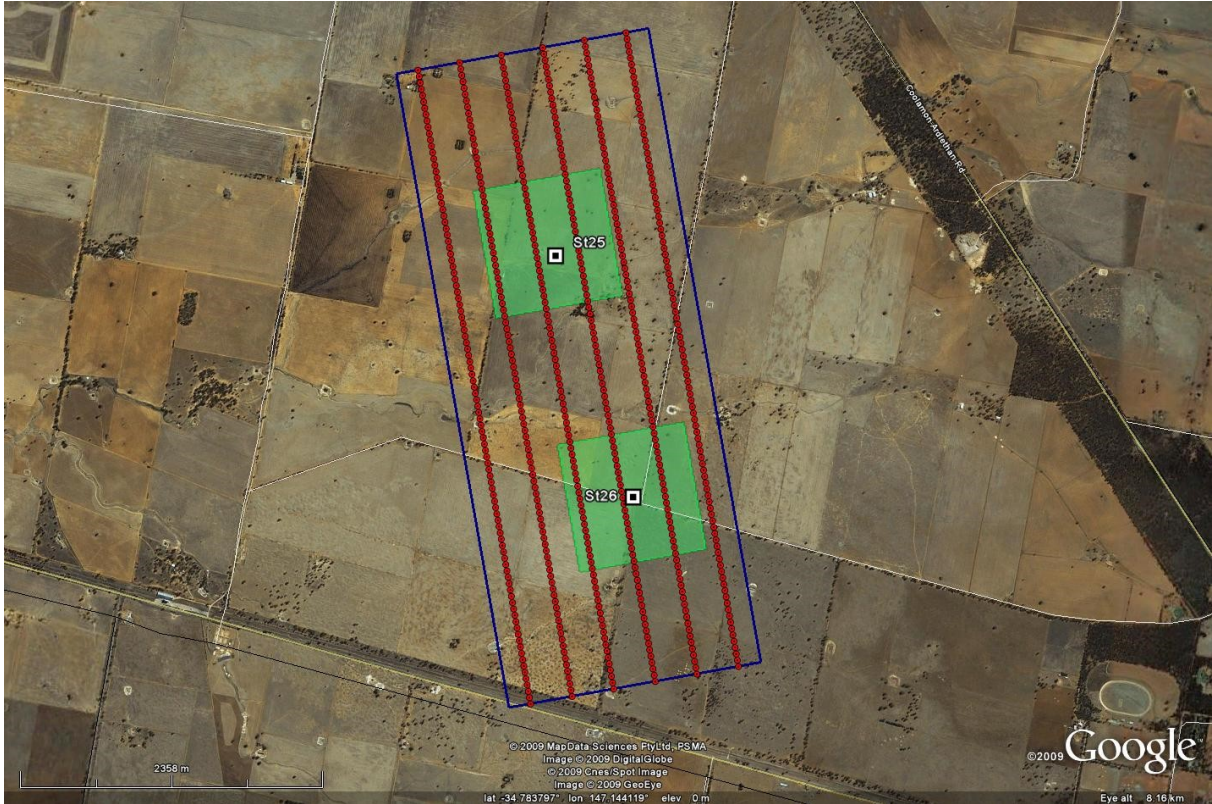


Farm 6/12

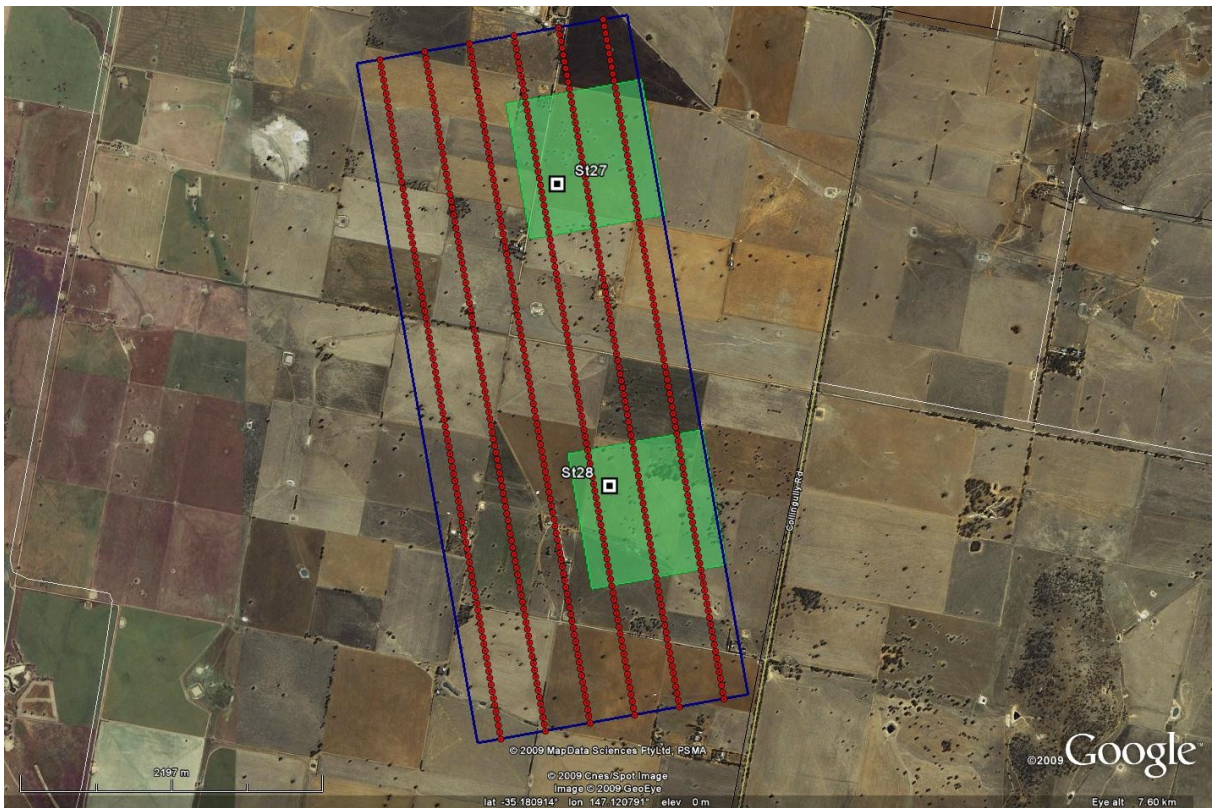


blue rectangle - boundary of focus farm; red points - HDAS sampling points; white points - temporary monitoring stations; green square - proposed vegetation/dew/roughness sampling area

Farm 7/13

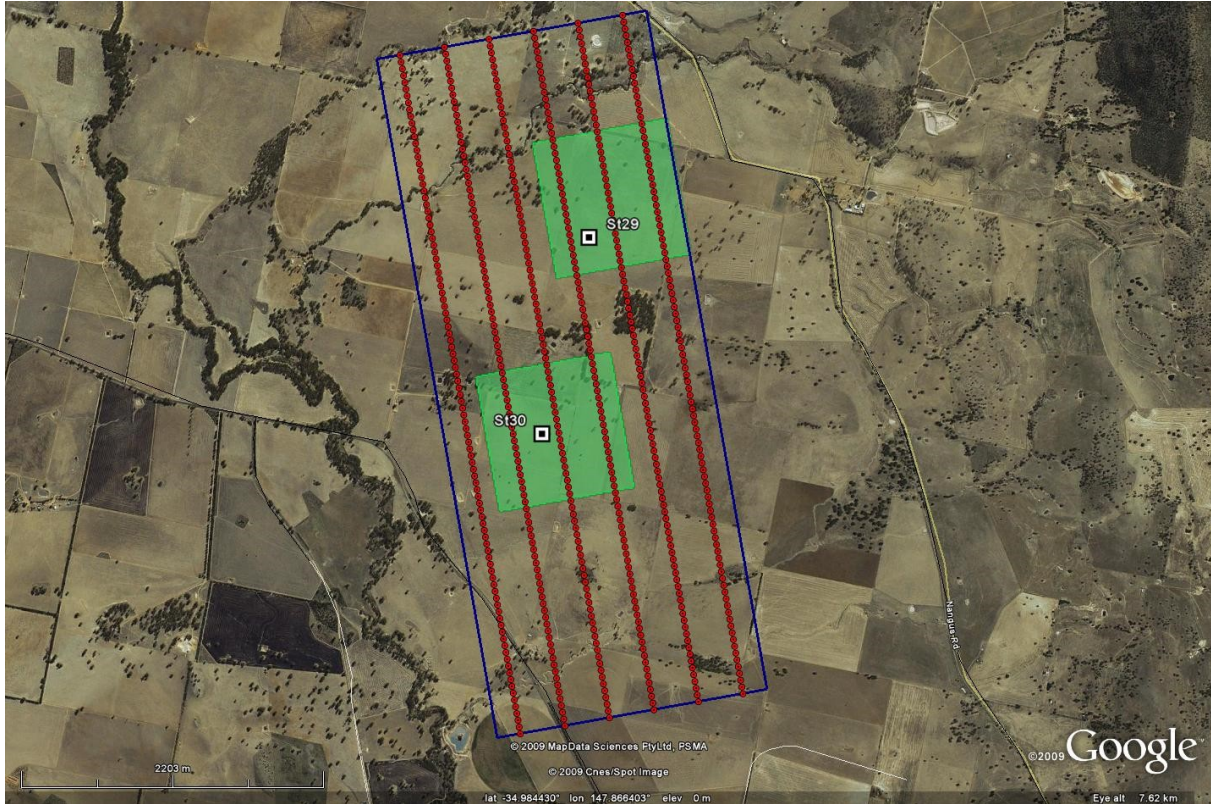


Farm 7/14



blue rectangle - boundary of focus farm; red points - HDAS sampling points; white points - temporary monitoring stations; green square - proposed vegetation/dew/roughness sampling area

Farm 8/15

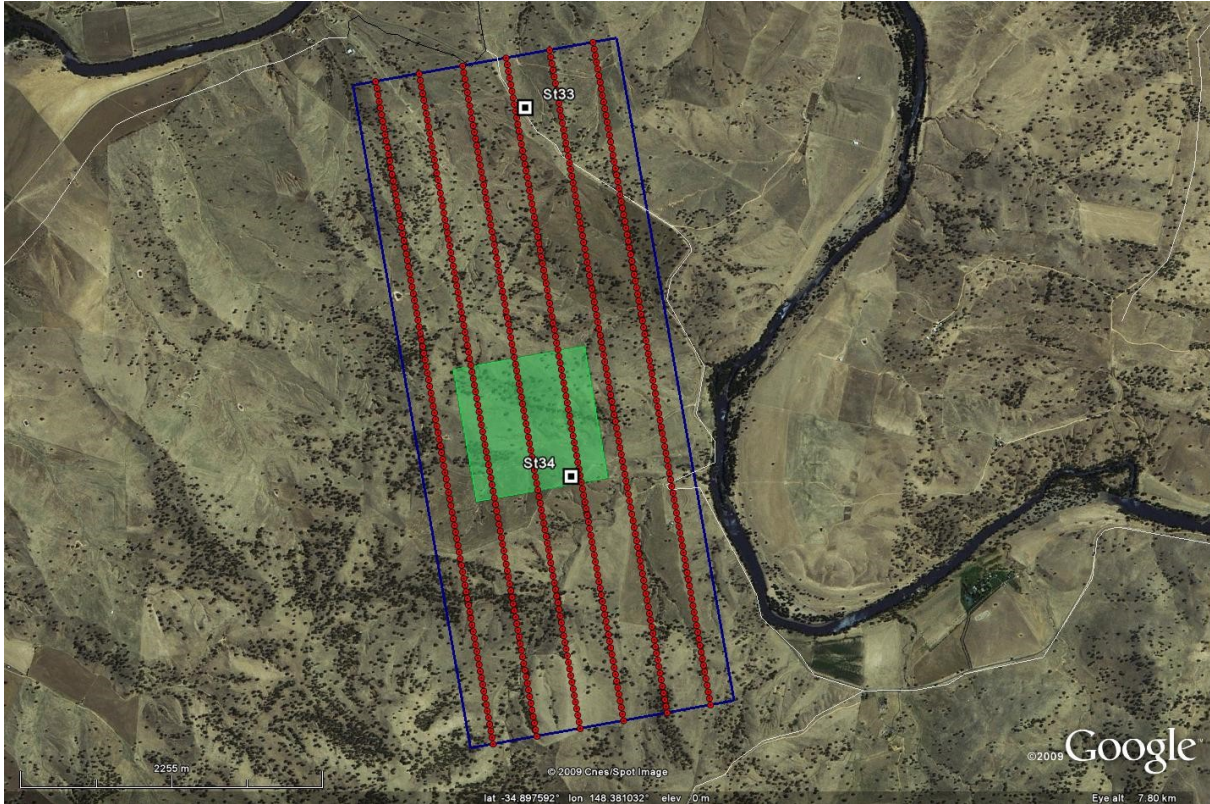


Farm 8/16

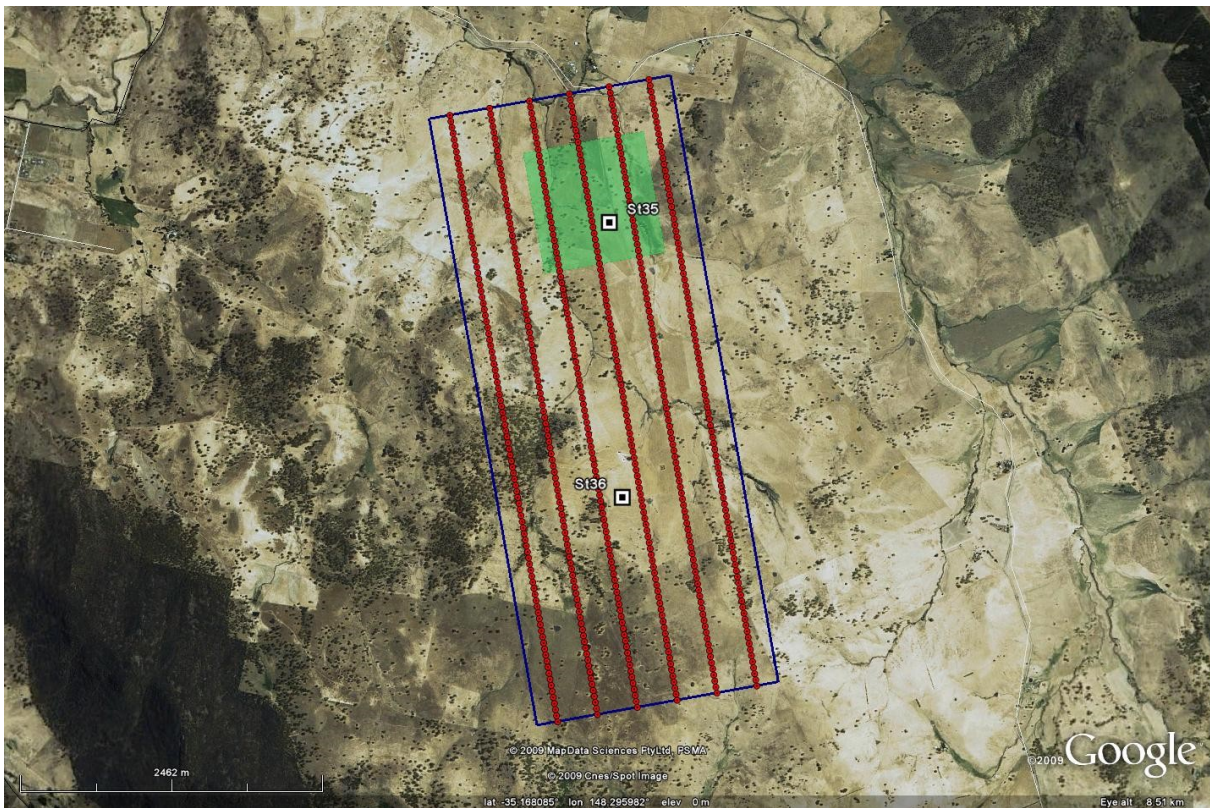


blue rectangle - boundary of focus farm; red points - HDAS sampling points; white points - temporary monitoring stations; green square - proposed vegetation/dew/roughness sampling area

Farm 9/17



Farm 9/18

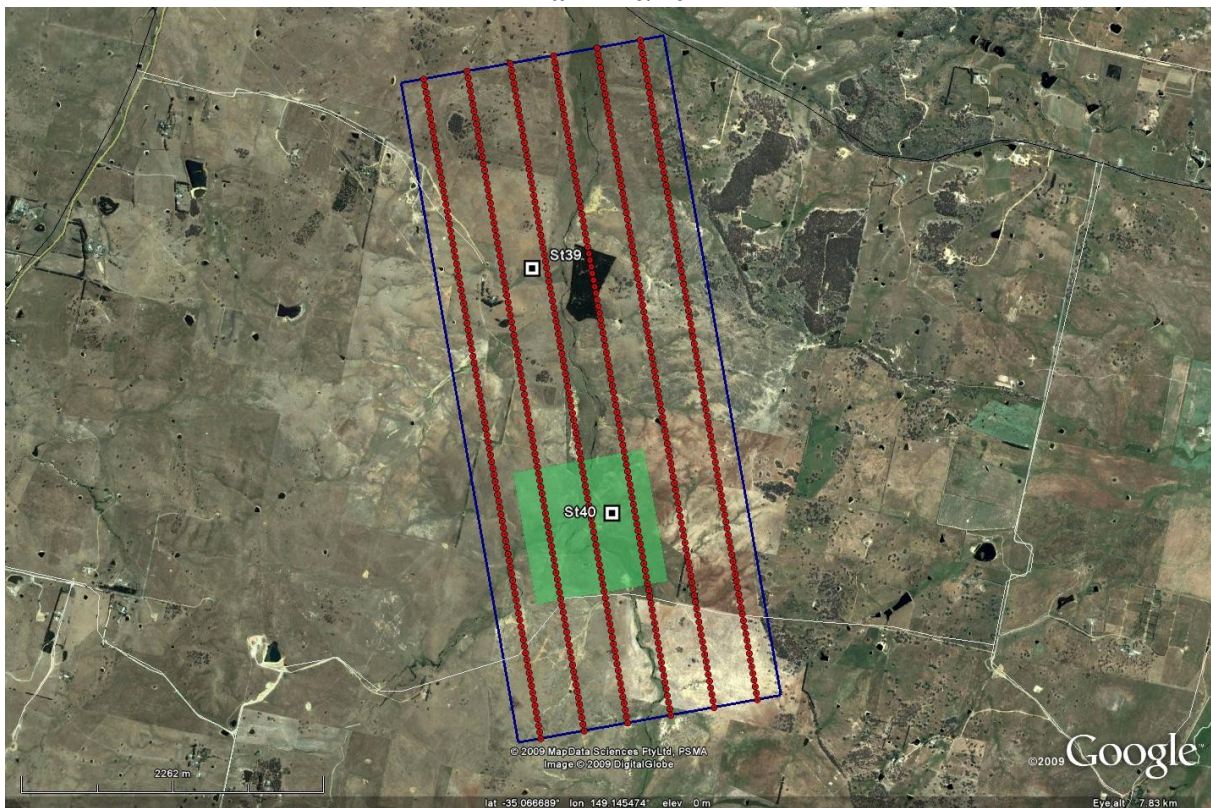


blue rectangle - boundary of focus farm; red points - HDAS sampling points; white points - temporary monitoring stations; green square - proposed vegetation/dew/roughness sampling area

Farm 10/19



Farm 10/20



blue rectangle - boundary of focus farm; red points - HDAS sampling points; white points - temporary monitoring stations; green square - proposed vegetation/dew/roughness sampling area

Appendix H: Team Task Summary

Table H.1: Soil moisture sampling task sheet; one of six 5km long transects per person.

Measurement	Extent	Point Spacing	Number of Samples
Hydraprobe readings	5km	50m	3 per point
Land use	5km	50m	1 per point
Vegetation type	5km	50m	1 per point
Canopy height	5km	50m	1 per point
Presence of dew	5km	50m	1 per point
Rock cover fraction	5km	50m	1 per point

Table H.2: Vegetation sampling task sheet; for each vegetation type along farm transect.

Measurement	Extent	Spacing	Number
Vegetation samples*	1km × 1km	Paddock scale	5 per vegetation type
Surface reflectance	1km × 1km	Paddock scale	25 per vegetation sample
LAI	1km × 1km	Paddock scale	1 per vegetation sample, consisting of 5 readings
Vegetation type	1km × 1km	Paddock scale	1 per vegetation sample
Canopy height	1km × 1km	Paddock scale	1 per vegetation sample
Row spacing	1km × 1km	Paddock scale	1 per vegetation sample

* It is important that the sample be collected ONLY after completing all the other vegetation measurements.

Table H.3: Supplementary sampling task sheet; central 5km long transect.

Measurement	Extent	Spacing	Number
Dew	5km	Paddock scale	2 per vegetation type
Gravimetric samples*	5km × 2km	1km	Min. 5 per farm
Soil roughness	5km	2.5km	3*2 directions per farm

* Responsibility of designated person; task cannot be delegated. Strict quality control is essential.

Appendix I: Sample Pro-forma Sheets

The following tables are the pro-forma sheets to be used for dew, vegetation water content, soil moisture calibration check of the Steven's Water Hydraprobe and surface roughness.

ROUGHNESS SAMPLING

Surface roughness sampling form

UTC Date:		Location:		Team:		Operator ID:	
DD / MM / YY		Patch Farm					
UTC Time:		Latitude:		Longitude:			
HH : MM							
Direction & ID		N - S - 1	N - S - 2	E - W - 1	E - W - 2		
Pin profiler reading (mm)	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	9						
	10						
	11						
	12						
	13						
	14						
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	39						
	40						
	41						
Photo ID							

Appendix J: AACES Flyer

Murrumbidgee Soil Moisture Satellite Validation

The European Space Agency will launch the world's first dedicated soil moisture satellite in September this year, and the Murrumbidgee Catchment has been selected as the validation site for this important mission! A proven ability to monitor soil moisture from space will have important implications in weather forecasting and water resources management, especially for farmers with broad-acre crops.

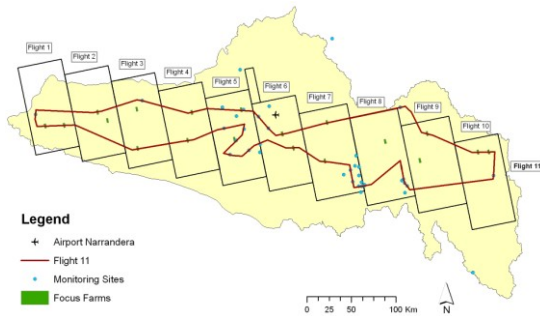


Fig. 1. Location of the SMOS validation transect across the Murrumbidgee Catchment.

Taking advantage of this new satellite, researchers at the University of Melbourne are **developing a soil moisture monitoring, predication and reporting system called MoistureMap**, which aims to provide farmers a friendly web-based tool to help with more efficient management of their water resources. However, the data from this satellite must first be validated. This requires making aircraft measurements, supported by ground measurement, of the surface soil moisture content in carefully selected areas, together with a small number of soil and vegetation samples.

A total of four validation campaigns are envisaged over the next two years, covering the complete range of soil moisture and vegetation conditions. Airborne and ground measurements will be made across a 500km × 100km transect of the Murrumbidgee Catchment (Fig. 1), and **we would like to use your farm as one of the strategic ground validation sites. In return, you will have access to all the data collected in the campaigns.**

We expect to complete the measurements required on your farm in 2-3 days for each campaign. During this intensive measurement period, a short-term monitoring station will be installed to measure soil moisture and supporting information at one point. Further details of the measurements to be made are given below for your information.

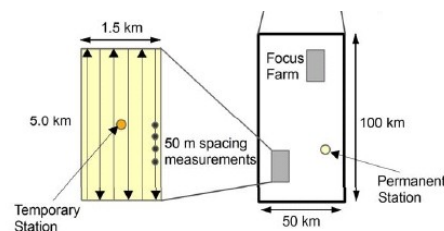


Fig. 2. Typical soil moisture transect lines across a 5kmx1.5km focus farm.

Intensive Soil Moisture Measurements

This is the primary measurement we will make on your farm. It involves use of a non-destructive soil moisture probe, having four 5cm long tines that are stuck in the ground and measured using some electrical circuitry. No soil will be removed during this measurement. Using an integrated GPS, the field technicians will navigate along six transects 250m apart (total width 1.5km), taking measurements every 50m for up to 5km in length (Fig. 2). For calibration purposes, a total of 5 gravimetric samples will be taken across this sampling area. The size of these samples is about 7.5cm × 5cm, taken from the surface of the soil (Fig. 3).



Fig. 3. Soil moisture probe and soil sampling example.

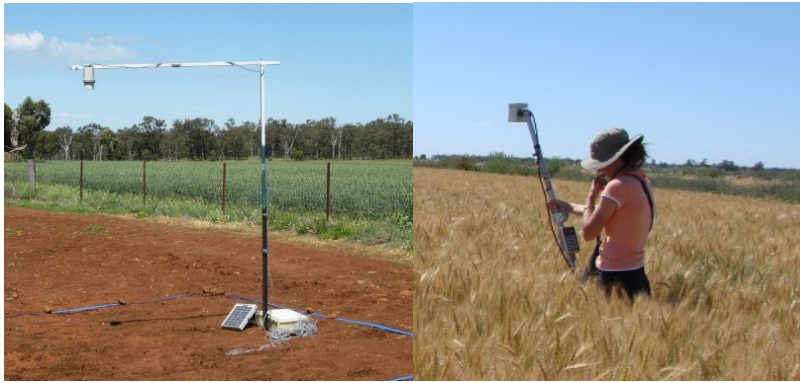


Fig. 4. Short term monitoring station with thermal infrared sensor observing the surface temperature (left) and non-destructive vegetation measurements with a CropScan (right).

Short Term Monitoring Station

The short term monitoring station will include a soil moisture sensor at two depths, soil temperature at five depths, a dew sensor and a thermal infrared sensor (Fig. 4). This station will be located in a representative area of the intensive soil moisture measurement area. These stations will be installed for about 2-3 days only and then entirely removed. A 40cm deep and 25cm wide pit will need to

be excavated by hand to allow the installation of these sensors.

Vegetation Sampling

Vegetation sampling is required to determine the vegetation water content of the plants in order to estimate soil moisture from the aircraft and satellite. Assuming that vegetation conditions are relatively uniform across the sampling area, only five samples will be required. Additional to non-destructive spectral measurements, each sample will require complete removal of vegetation to ground level from within a 40cm × 40cm area (Fig. 5). This will then allow calibration of the spectral data for estimating the vegetation water content at other locations.



Fig. 5. Typical vegetation sampling within a 40cm x 40cm area.

General Note on Property Access

Permission to access your property will be treated with the utmost respect, minimising any impact on the soil and vegetation. The science team undertaking this study has collaborated with a large number of farmers in the Goulburn River and Murrumbidgee catchments in the past, and all participants are intimately aware of the requirements for a good collaboration with local property owners. We are happy to put you in contact with other collaborating farmers to discuss their past experience if you desire.

Contact Details

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