# COMBINING FULL WAVE-FORM LASER SCANNING, HYPER-SPECTRAL SCANNING AND OTHER REMOTE SENSING AND IN-SITU INSTRUMENTATION ON A SMALL AND ENVIRONMENTALLY FRIENDLY AIRBORNE PLATFORM - TECHNOLOGY AND SOME EXAMPLES FROM RECENT SURVEYS

**Jorg M Hacker**

Airborne Research Australia/Flinders University
PO Box 335, Salisbury South 5106, Adelaide, South Australia
Phone +61 (0)8 8182 4000, Fax +61 (0)8 8285 6710
jorg.hacker@flinders.edu.au

**Wolfgang Lieff**

Airborne Research Australia/Flinders University
PO Box 335, Salisbury South 5106, Adelaide, South Australia
Phone +61 (0)8 8182 4000, Fax +61 (0)8 8285 6710
wolfgang.lieff@flinders.edu.au

**Lutz Bannehr**

Hochschule Anhalt (FH)
Fachbereich Architektur, Facility Management und Geoinformation
Institut für Geoinformation und Vermessung
Bauhausstraße 8, D-06846 Dessau
Phone +49 (0)340 5197 1611, Fax +49 (0)340 5197 3733
bannehr@afg.hs-anhalt.de

## Abstract

The combination of data from different remote sensing instruments is one of the most powerful tools available for monitoring and assessing the types, condition and health of land and water on the local (“meters to 100’s of meters”) and regional (“kilometers to 10’s of kilometers”) scales. Two of the most prominent data sources for such a combination are an airborne hyper-spectral scanner and a state-of-the-art full waveform-resolving airborne LIDAR (“*wLIDAR*”), preferably flown simultaneously on the same platform. Typical examples of applications for the combination of hyper-spectral and *wLIDAR* data are the determination and assessment of vegetation types; canopy health; canopy height; canopy and understorey architecture (e.g. leaf area index, *LAI*) and very high-resolution (“cm-range”) ground topography, even if mostly obscured by vegetation. Typical quantities that can be derived using suitable extraction, analysis and parameterization algorithms are carbon storage in vegetation; fire fuel load, both coarse and fine fuels; plant and/or life-form; biodiversity (by means of identifying stands of different spectral and structural characteristics); plant growth rates; occurrence of invasive species; topographic analysis and many others.

Over recent years, the only research-oriented and university-based research flight facility in Australia, *ARA - Airborne Research Australia*, together with a team of university-based partners, has been able to set-up a unique and comprehensive set of airborne remote sensing and airborne in-situ capabilities and used these in many science and science-related projects all over Australia and internationally.

The current toolkit consists of (1) a *wLIDAR* for 3D-resolution terrain and vegetation structure; (2) a hyper-spectral scanner to determine the spectral characteristics of the underlying surface in the 400 to 970nm (in cooperation with L Bannehr); (3) thermal IR-imager for surface temperature; (3) a Polarimetric L-Band Multibeam Radiometer (*PLMR*) for soil moisture and sea surface salinity at 50m spatial resolution; and as the latest addition, (4) a Polarimetric L-Band Imaging Synthetic aperture radar (*PLIS*) which not only gives even higher spatial resolution soil moisture (10m) and salinity, but is capable of defining vegetation structure in more detail and also allows to derive water roughness – which, together with the other sensors, will then allow a more reliable estimation of soil moisture and water salinity.

Also available are in-situ sensing capabilities of evaporation and other surface/vegetation/atmosphere exchange parameters ($CO_2$ and water vapour fluxes), as well as instrumentation for measuring solar and terrestrial radiation, energy balance, and wind, amongst other variables. Finally, there are a whole range of other in-situ sensors for quantities, such as *CO*, $CH_4$, $NO_x$, $NO_y$ Ozone, particles, photo-synthetically active radiation (*PAR*) and a gas-chromatograph for Volatile Organic Compounds (*VOC*) and more (in collaboration with B Neininger, MetAir, Switzerland).

All of the sensors are flown on modern small and cost-efficient research aircraft, so-called *SERA*s ("*Small Environmental Research Aircraft*"). The combination of the airborne sensing instrumentation available at the *ARA National Facility*, is unique world-wide and unmatched by any Australian (commercial or non-commercial) entity. As such, it has been enabling investigations of features of the environment in ways that are not available from any other combination of sensors.

The presentation at the Conference will give a few examples from recent work. One of the two *ARA SERA*s (a Diamond Aircraft *HK36TTC-ECO-Dimona*) equipped with the *wLIDAR* and the hyper-spectral scanner will be available for inspection by the delegates at Darwin Airport during the Conference.

## Introduction

As highlighted by the most recent State of the Environment Report (2006, www.environment.gov.au/soe), the availability of the latest technology is a necessary requirement for researchers to assess and monitor the state of the environment. Of particular importance is the state of vegetation, soil, and inland and coastal water bodies. In terms of applications of data from airborne surveys, the most powerful tool is a fusion of various remote and in-situ sensing technologies. To readily achieve representative, valid and reliable assessments of the status and development of natural resources, such technologies need to be accessible and affordable to as many research teams as possible.

Collection of coincident data from multiple airborne sensors enables direct and accurate comparison of the methods employed and products derived from different sensors and platforms. Also, advanced classification methods are emerging based on combining information from multi-sensor surveys. Providing researchers with access to high quality well characterized remotely sensed data enables advances in the development of these advanced methods. Other scientific pursuits also benefit from such multi-sensor data. One example is ecosystem modeling. Multi-sensor remotely sensed data provide model inputs including elevation and aspect, topographic roughness, soil/mineral type, soil moisture, characteristics of water bodies, presence, volume, cover and type of vegetation, and heat flux. All of these can be used to infer ecosystem parameters and change, such as the potential for soil to be denuded by wind or surface water flow, impacts of floods, crop/pasture potential, possible spread of diseases and pests, and carbon/nutrient fluxes.

Combining multiple sensors in one package is the power of this facility and enables 'state-of-the-art' assessment of land-atmosphere exchange of mass and energy, assessment and monitoring of landscape and water body composition and health. It is offering the Australian environmental research community a unique package of integrated instrumentation not available by any other means.

## Some Examples

### Airborne Remote Sensing of Soil Moisture

Soil moisture is one of the most important parameters for land surface studies, farm management issues and the exchange of energy and water vapour between the Earth's surface and the atmosphere. Remotely sensing soil moisture is possible, in principle, but it is still more a research field rather than an operational tool. Most of such sensing is being attempted using satellite measurements coupled with parameterisations which normally have to make rather dramatic assumptions to yield a value for soil moisture. There are only very few airborne sensors that can be used for soil moisture and most of them require rather large airborne platforms to carry them.

The arguably smallest airborne soil moisture sensing capability world-wide is the Polarimetric L-Band Multibeam Radiometer (*PLMR*), which was set up by a consortium of Australian university researchers over the past few years (under the leadership of A/Prof. JP Walker (University of Melbourne). The PLMR was integrated into one of ARA/Flinders University's Small Environmental Research Aircraft (*SERA*) and has since been the key instrument in a number of field campaigns in Australia (and lately also in Europe).

The PLMR is usually combined with other remote sensing instrumentation, such as *wLidar*, a tri-spectral scanner (*TSLS*) and digital still and video cameras, sometimes flown on the same platform.

The *PLMR* (designed and manufactured by ProSensing Inc., *USA* – www.prosensing.com) takes (passive) measurements in the L-Band (1.4GHz), using six across-track antennas in a push-broom manner. The antennas point at +/-8, +/-22 and +/-38 degrees from nadir and have a beam width of approximately 15 degrees. Depending on several parameters, amongst them the type and density of the vegetation cover, one can resolve soil moisture down to about 10cm below the surface.

The first study using this instrument was flown in May 2005 near Waikerie, SA. Some of the results are displayed in Figures 1 and 2.

Figure 1 shows the aircraft with the *PLMR* installed below the fuselage, a typical part of the Waikerie landscape, and the area of the survey. The survey was flown at different altitudes (60m, 250m, 500m and 1,000m AGL) to test the resolution and consistency of the measurements. Data from these tests is displayed in Figure 2 (top right), together with data from other remote sensing instrumentation flown simultaneously in the *SERA* (bottom right), the Tri-Spectral Scanner and a digital stills camera (*Canon EOS1Ds*).

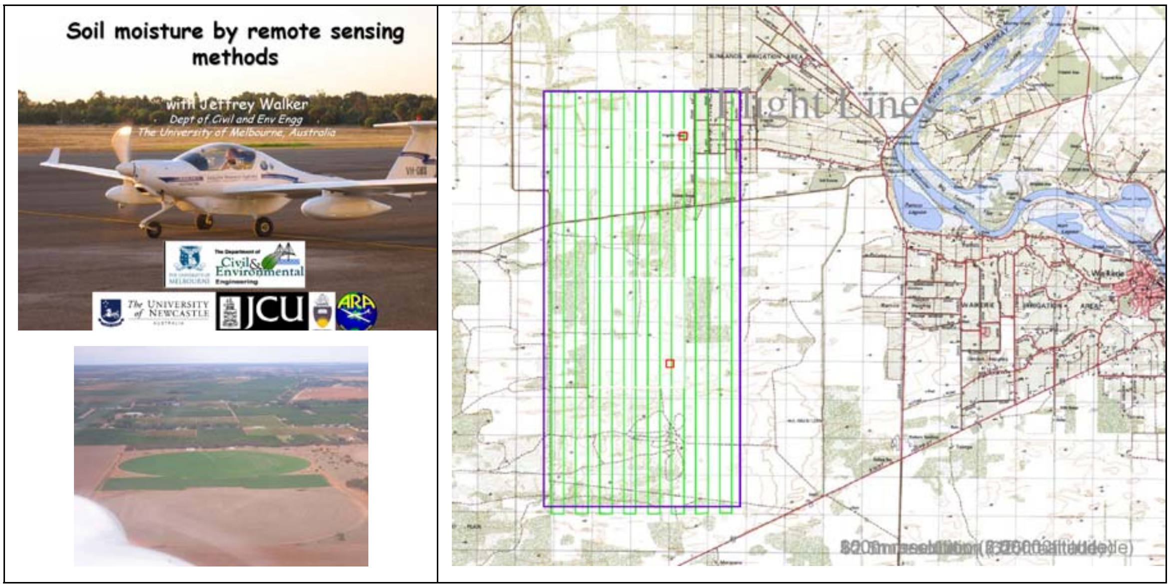


Figure 1: Left top: The ECO-Dimona with the PLMR fitted inside the belly pod; left bottom: one of the irrigation circles surveyed in the Waikerie Irrigation Area; right: survey pattern over the Waikerie Irrigation Area.

The PLMR, together with the *wLIDAR*, Tri-Spectral Camera, IR-imager and digital stills camera was flown more recently during two *ARC*-funded (*Australian Research Council*) large field campaigns (*NAFE05* and *NAFE06* – see *www.nafe.unimelb.edu.au*) under the leadership of A/Prof. JP Walker. The two campaigns took place near Scone/*NSW* and near Narrandera/*NSW* in November 2005 and November 2006, resp. Two *ARA SERA*s were used simultaneously to determine a wide range of landscape-related features. An example of data taken during *NAFE06* from the various airborne sensors is displayed in Figure 3.

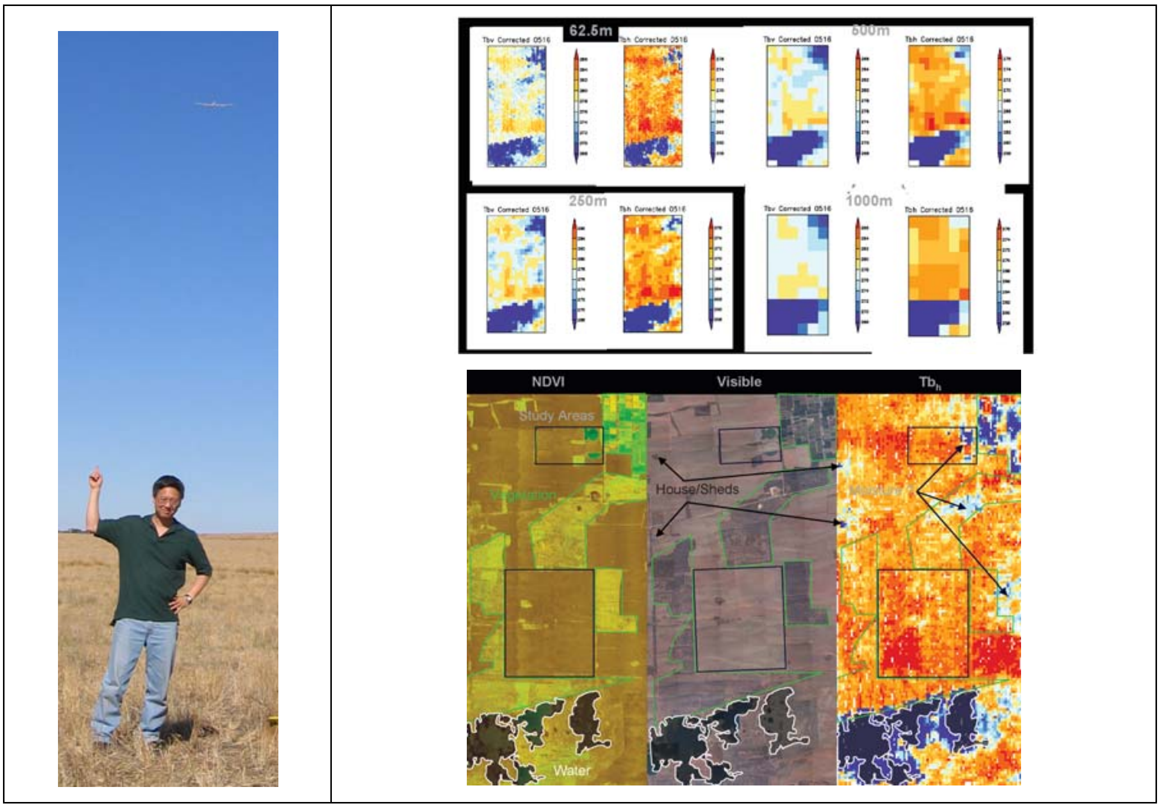


Figure 2: Left: Ed Kim (*NASA*) pointing to the *ECO-Dimona* flying overhead; top right: soil moisture maps of the Waikerie Irrigation Area at different resolution; bottom right: *NDVI* (normalised differential vegetation index) image, visible image and soil moisture image of the survey area (analyses: courtesy of Dr. J Walker, University of Melbourne).

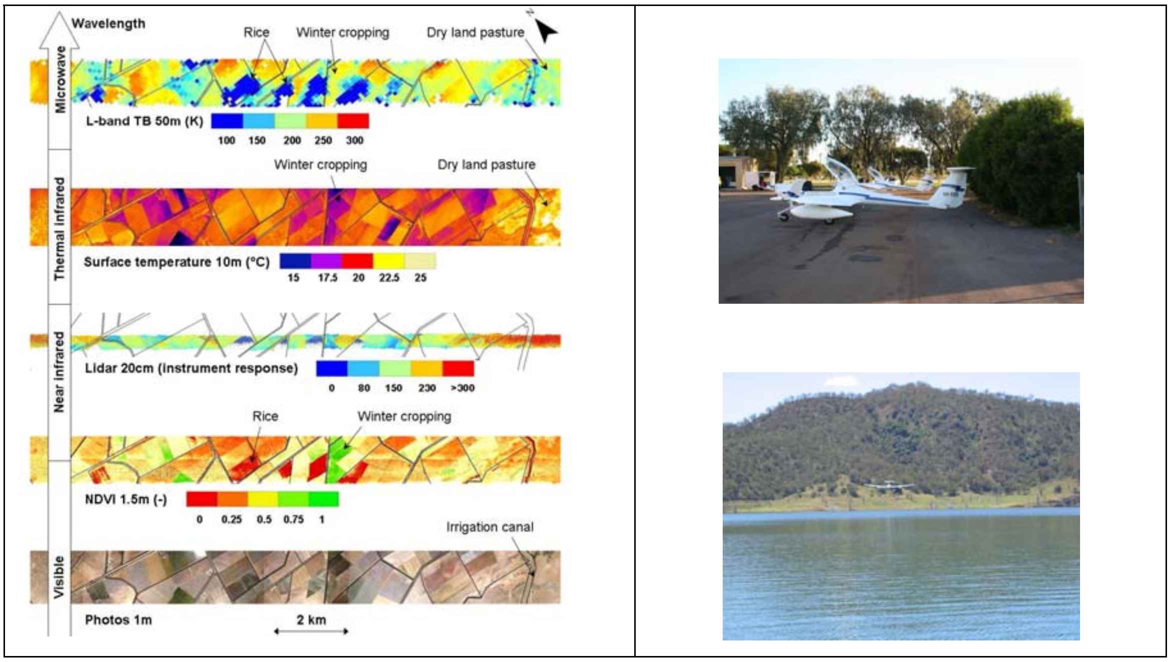


Figure 3: Left: Sample of multi-spectral/multi-resolution airborne data acquired on 3 November2006 over the "*Yanco Transect*" near Narrandera/*NSW* (from Merlin et al., 2008); top right: the two *ARA SERA*s parked at Scone Airport, *NSW*; bottom right: low level calibration run with the *PLMR* over a lake.

**Airborne Sensing of Native Vegetation in the Chowilla Floodplains, SA**

Funded by *Land & Water Australia*, in early 2007, a project was flown in South Australia to demonstrate the combination of *wLIDAR* and hyper-spectral scanner data, mainly in the context of native vegetation monitoring. Over three months, several sites were flown, amongst them the Chowilla Floodplains and the Banrock Station Wetlands in the South Australian Riverland; the Adelaide City Parklands; areas of mangroves at the Adelaide coastlines; mound spring areas in the far north of South Australia; and some native forest areas in the Adelaide Hills.

A *Riegl Q560 wLIDAR* was flown together with a *SPECIM AISA+ Eagle* hyper-spectral scanner and the *ARA* Tri-Spectral Scanner were flown simultaneously on one of the *ARA SERA*s.

Examples of data from the project displayed in Figures 4 to 6.

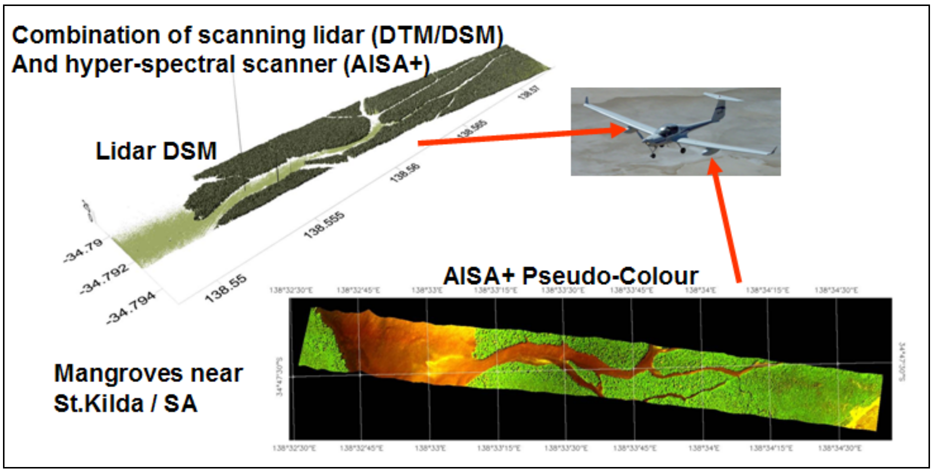


Figure 4: Scans from overflights of mangroves near St. Kilda, SA.

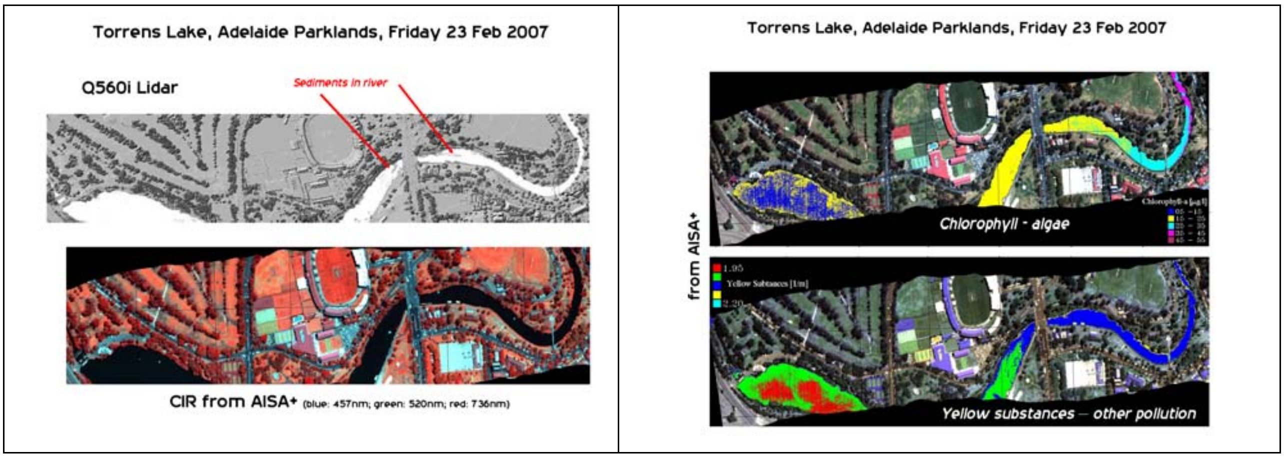


Figure 5: Examples of simultaneous images from a hyper-spectral scanner and airborne lidar – a section of the River Torrens in the Adelaide Parklands. Left: Lidar *DSM* (top) and composite IR (*CIR*) image from the hyper-spectral scanner; right: water contents of the river as derived from the hyper-spectral data.

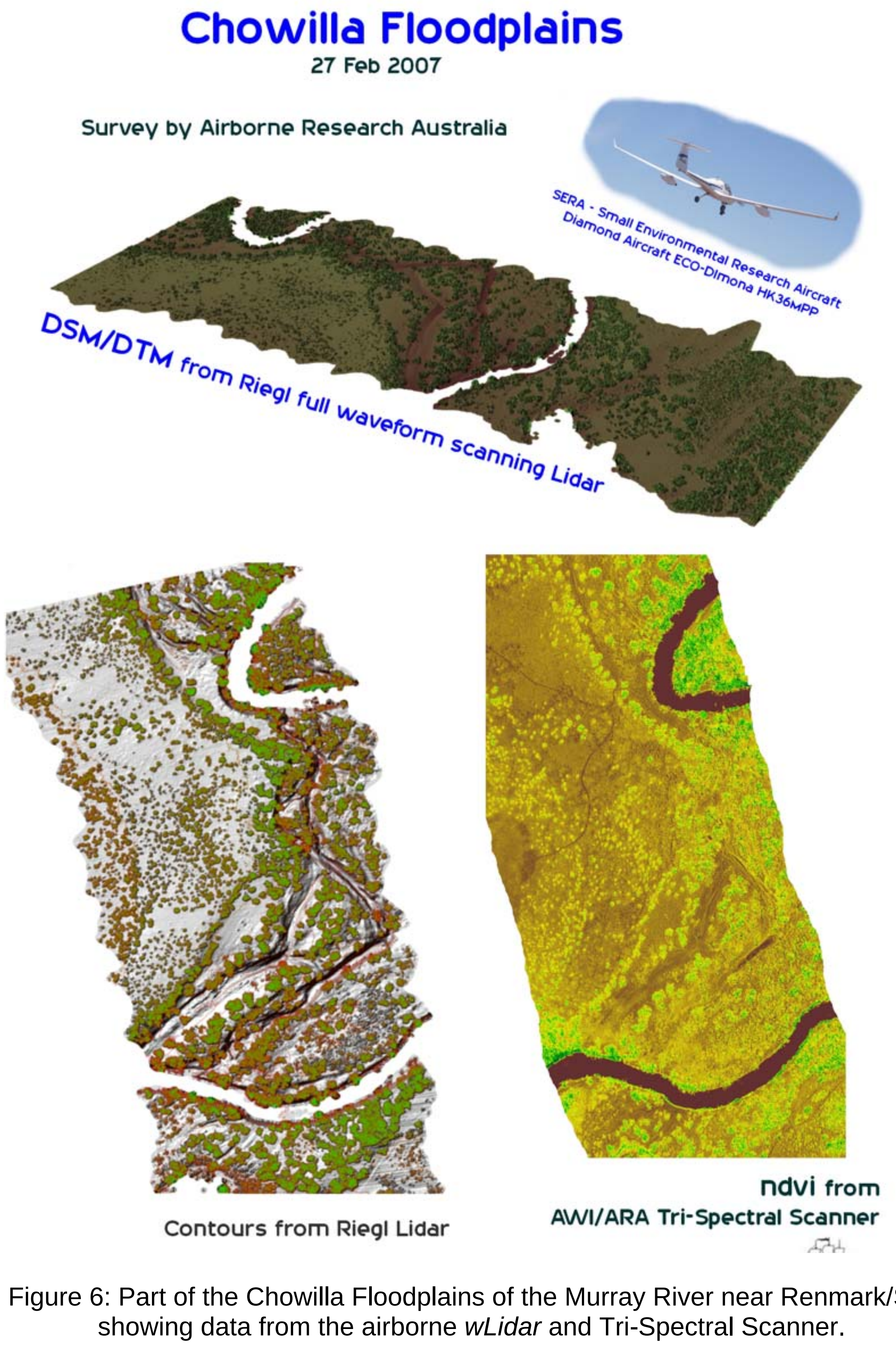


Figure 6: Part of the Chowilla Floodplains of the Murray River near Renmark/SA, showing data from the airborne *wLidar* and Tri-Spectral Scanner.

## Airborne Sensing of Gully Erosion in the Gulf of Carpentaria Region

The *Riegl Q560 wLidar* together with the *ARA Tri-Spectral Scanner,* a digital stills camera and oblique HD-video was flown during an extensive aerial study of river gully systems in the region around the Gulf of Carpentaria in Far North

Queensland. The study was a collaboration with Griffith University, Brisbane (Dr. A Brooks).

The aim of the project was to quantitatively map the extend and shapes of gully systems along the major rivers in Far North Queensland, the Mitchell, Gilbert, Nicholson and Leichhardt Rivers. The team from ARA/Flinders University consisted of the crew of two of the survey aircraft (one of *ARA's SERAs*), a ground-crew of three in a Toyota Landcruiser and a tent. More than 6,000km of river landscape were surveyed over a two week period yielding the most complete lidar/airborne sensing data sets of the gully systems in the area.

The survey route and some examples of the collected data are displayed in Figures 7 to 11.

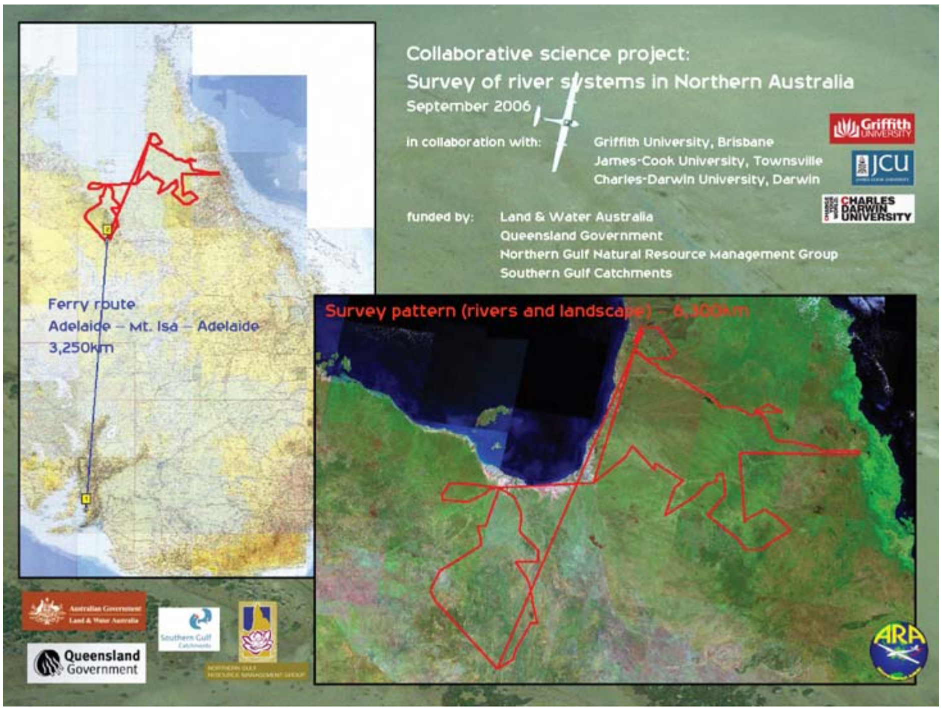


Figure 7: Flight path of the GEM project

Figure 8: The survey aircraft and ground team at Wrotham Park Resort Airstrip in Far North Queensland

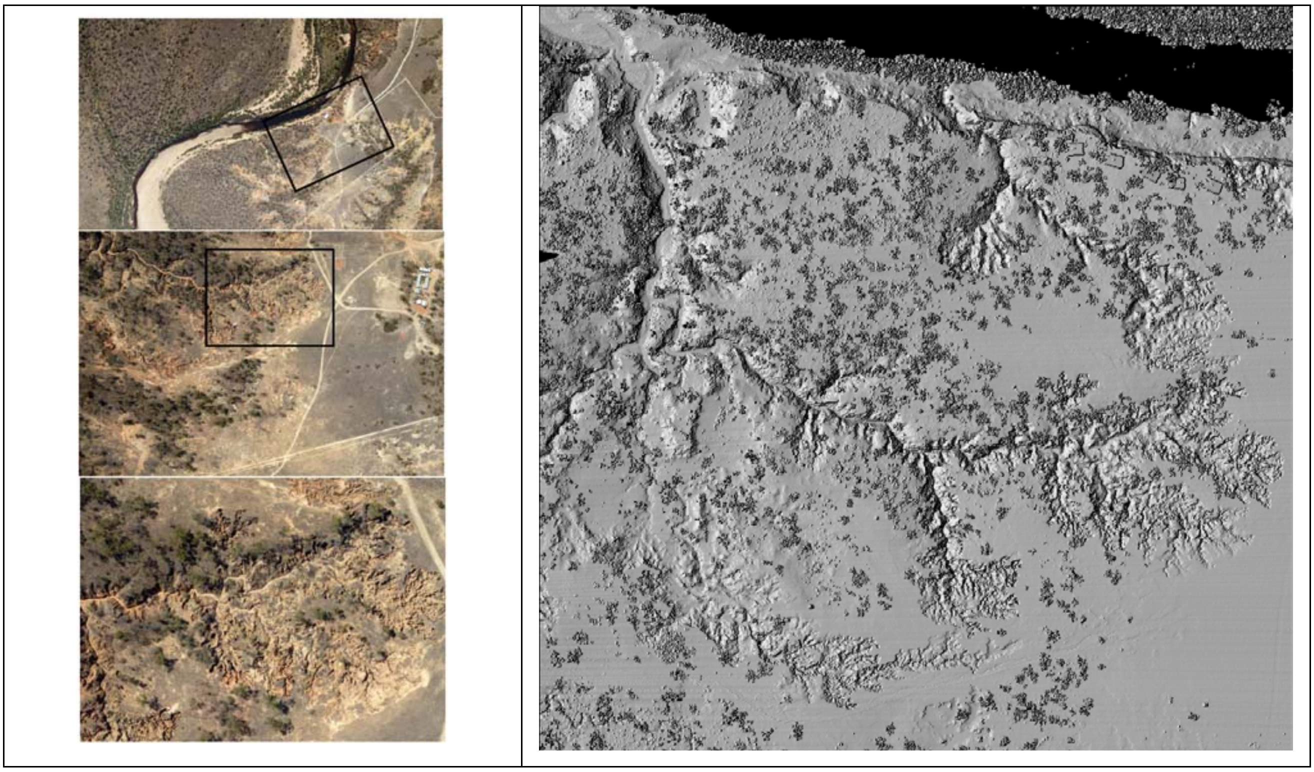

Figure 9: Gully erosion along the Mitchell River near Wrotham Park Resort. Left: Aerial photo showing increasing detail from top (full extent) to bottom (zoomed to gully); right: Laser scanner image of part of the gully shown in the top left image -note the buildings in the top right corner of the image

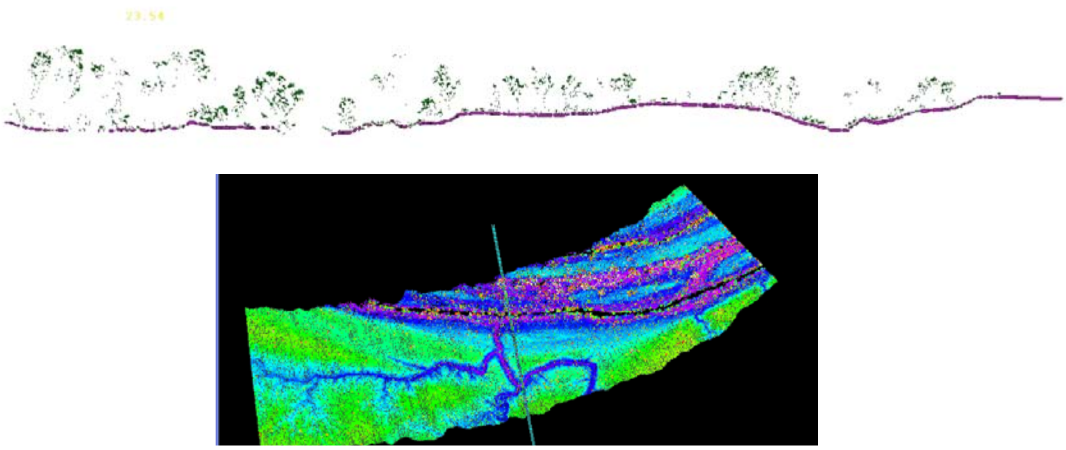

Figure 10: Airborne lidar data from one of the tile near Wrotham Park. Top: cross section along the line shown in the bottom diagram; bare soil lidar returns are shown in purple; bottom: lidar tile showing horizontal extent of part of the gully system.

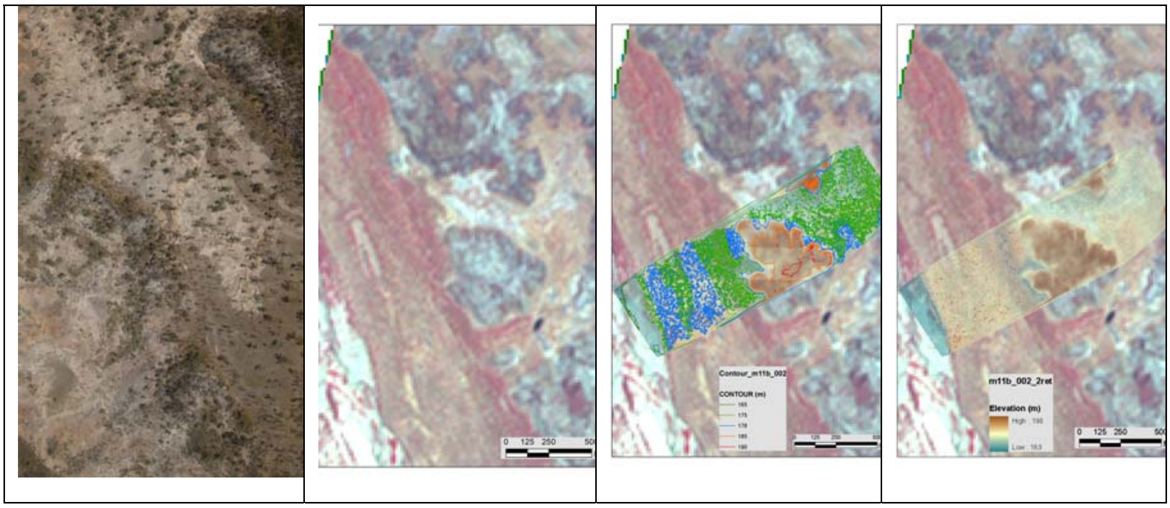

Figure 11: Close-up of a gully system at the Mitchell River.
From left to right: Aerial photo; *ASTER*-image; *ASTER*-image with Airborne Lidar-derived contours overlaid; *ASTER*-image with *wLIDAR*-derived *DEM* overlaid
*(courtesy Jon Knight, Griffith University)*

## Conclusion

It has been shown that various combinations of state-of-the-art airborne remote sensing instrumentation integrated into a small and environmentally friendly aerial platform are a very powerful and cost-efficient tool that offers researchers unprecedented means to study the environment. The capabilities at Australia's National Research Aircraft Facility *ARA – Airborne Research Australia* are unmatched world-wide in terms of availability of instrumentation and cost-efficient operation.

## References

Merlin, O., Walker, J.P., Kalma, J., Kim, E., Hacker, JM., Panciera, R., Young, R., Summerell, G., Hornbuckle, J., Hafeez, M. and Jackson, T., 2008: The NAFE'06 data set: Towards soil moisture retrieval at intermediate resolution. In press in: *Advances in Water Resources*.