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Installation Report for Arcturus (ARA):

An inland baseline station for the continuous measurement of atmospheric greenhouse gases

Henry Berko, David Etheridge, Zoe Loh, Tehani Kuske, Colin Allison, Rebecca Gregory, Darren Spencer, Rachel Law, Steve Zegelin and Andrew Feitz

CSIRO

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GEOSCIENCE AUSTRALIA
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by

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Executive Summary

An atmospheric greenhouse gas (GHG) monitoring station began operation in July 2010 near Emerald, Queensland. The station is part of a collaborative project between Geoscience Australia (GA) and CSIRO Marine and Atmospheric Research (CMAR) to establish and operate a high precision atmospheric monitoring facility for measurement of baseline greenhouse gases (GHG) in a high priority geological carbon dioxide storage region. The primary purpose of the station is to field test newly developed greenhouse gas monitoring technology and demonstrate best practice for regional baseline atmospheric monitoring appropriate for geological storage of carbon dioxide. The GHG records were to be used as a reference for monitoring of the atmosphere at a CO_2 storage project, providing a baseline to quantify typical variations in the area and a background against which any anomalies in the immediate vicinity of the storage might be detected.

The site chosen for the GHG atmospheric monitoring station is in the locality of Arcturus, 50 km southeast of Emerald in the Central Highlands, Queensland. Site selection was based on the recommendations of the Carbon Storage Taskforce’s National Carbon Mapping and Infrastructure Plan, regional assessments of prospective basins, regional atmospheric modelling, and consultation with key stakeholders. The key driver for the stakeholder consultation group was to support early projects for large scale onshore geological storage. Both the Bowen and Surat basins were identified as potential early mover onshore storage regions by the group and suitable for a regional atmospheric monitoring station. During early 2010, ZeroGen had an active exploration program for geological storage and the site was eventually located approximately 8km upwind from the boundary of ZeroGen’s most prospective storage area in the northern Denison Trough, part of the larger Bowen Basin.

The Arcturus site and environs is representative of the activities and ecology of Queensland’s Central Highlands and the greenhouse gas signals are likely be influenced by cropping, pasture, cattle production, and gas and coal activities. These same activities are also likely to be dominant sources of greenhouse gases in the Surat Basin. Importantly, the site is secure, can be accessed via an existing road, is not subject to flooding, and has easy access to electrical lines that only required the installation of a transformer on an electric pole. A long lead time for new electricity connections at remote sites (potentially greater than 12 months) was identified as a key risk to the project. Negotiations with the electricity supplier resulted in connection in less than 4 months. An access agreement was negotiated with the landowner to enable the installation of the monitoring station and access to the site.

The installed station comprises an air conditioned modified shipping container equipped with gas monitoring instruments, meteorological sensors and a 10 metre-mast. A new measurement technology, Wavelength Scanned Cavity Ring Down Spectroscopy (WS-CRDS), has been adopted for gas measurements. Two Picarro gas analysers were deployed to continuously monitor greenhouse gases and CO_2 isotopes. One unit measures isotopic ratios of carbon in CO_2 (^{12}C and ^{13}C) and water vapour while the other measures the concentrations of CH_4, CO_2 and water vapour. An automated weather station has been installed to measure wind speed, wind direction, temperature, humidity and rainfall. A solar powered eddy covariance flux tower was also installed at the site, some 250m south of the main station. The flux tower comprises two LI-COR open-path eddy covariance gas instruments: the LI-7500A measures atmospheric CO_2 and H_2O, and the LI-7700 measures atmospheric CH_4. 3D wind speed and direction are measured using a CSAT3 sonic anemometer (Campbell Scientific Inc). A wireless network connects the flux tower to the main station, although the flux tower can also be accessed independently via a modem should power in the

main station fail. Communication for remote access to the instruments in the station is provided via a router/modem fitted with a mobile phone SIM card and an external antenna. Any authorised remote PC running GoToMyPC software can access and control the PC in the container via the internet over the NextG network.

The total capital cost of the high precision station was $247,000 with an additional $133,000 for the eddy covariance tower (CH_4 and CO_2). Operating costs, excluding travel and staff time, are approximately $14,000 per year.

In June 2010, the ZeroGen project determined that the geology of the northern Denison Trough was not viable for large scale CO_2 storage. This meant that Arcturus was no longer providing atmospheric baseline measurements for a potential geological storage region. Nevertheless, the stakeholders agreed that there is a clear benefit to continuing the project as there was no alternative onshore storage assessment program in Australia, and many of the project objectives could still be realised, including field-testing and evaluating a new generation of greenhouse gas monitoring technology in remote environments; understanding a complex greenhouse gas baseline; and developing methods for leak detection and quantification. The station generates data that could be used for developing procedures that will assist in the planning and implementation of a national atmospheric monitoring network and provides data for the purpose of estimating regional and national greenhouse gas budgets. Preliminary results demonstrate that significant methane enhancements are being detected that can be attributed to coal mine emissions in the area. The World Meteorological Organization (WMO) has accepted Arcturus (designated ARA) as a regional Global Atmospheric Watch (GAW) station.

1 Introduction

The capture and geological storage of carbon dioxide is an important part of the Australian Government's strategy to reduce Australia's greenhouse gas emissions (Carbon Storage Taskforce, 2009). In order for this strategy to be effective, the community needs to be assured that carbon dioxide capture and geological storage (CCS) is safe and secure. Regulators, carbon managers and project operators will require evidence that significant leakage to the atmosphere is not occurring. Geoscience Australia was allocated funding in the 2007 Federal Budget for implementation and management of monitoring and verification programs in order to assist the Federal Government with the early deployment of CCS. Funding covered a four year period from July 2007 to June 2011.

Atmospheric monitoring is an effective technique for assuring regulators, carbon markets and the public that geological storage of greenhouse gases is a safe and secure greenhouse gas emission mitigation technology (Jenkins et al., 2012). When combined with information on wind flow and modelling of atmospheric and environmental processes, atmospheric measurements can detect and quantify gas fluxes on a range of scales, from local point sources up to a broad regional coverage.

Potential leaks from CCS storage operations are likely to be masked by environmental and anthropogenic influences on atmospheric concentrations of greenhouse gases, especially in terrestrial settings. Monitoring for potential leaks is assisted by the establishment of a baseline record, that is, data that enables an understanding of the pre-existing atmospheric conditions and can be used as an ongoing reference for denser infill monitoring around a site. The baseline quantifies the potentially large changes in atmospheric greenhouse gas levels that can occur over hourly, diurnal, synoptic, seasonal and annual timescales. Early field testing of monitoring equipment, and an early start to baseline measurements in regions where geological storage of CO_2 is likely to occur, could reduce the risk of delays in the deployment of CCS.

GA and CMAR entered into a collaborative agreement in June 2009 under the National Collaboration Framework and formed the Baseline Atmospheric Monitoring for Geological Storage of Carbon Dioxide Project. The project involves the establishment and operation of one high precision atmospheric monitoring facility for measurement of baseline greenhouse gases within a prospective geological storage region. A major objective of the project is proof of concept for the remote operation of Wavelength Scanned Cavity Ring Down Spectroscopy technology for baseline monitoring of atmospheric greenhouse gases. The project outputs will inform decisions about the future requirements for atmospheric monitoring and verification of greenhouse gas storage operations in Australia.

2 Site Selection

2.1 STAKEHOLDER CONSULTATION

A stakeholder consultation process was used to guide site selection for the project. The first stakeholder consultation meeting on Monitoring and Verification for Carbon Capture and Storage (CCS) was held at Geoscience Australia (GA) in February 2009. At this meeting, GA sought and obtained the support of stakeholders from the Department of Resources, Energy and Tourism (RET) and State/Territory representatives present to establish a trial baseline Atmospheric Monitoring station. Following development of a collaborative project agreement between GA and CSIRO in June 2009, the project team then prepared selection criteria and a technical briefing document for site selection. The briefing document and technical appendices were sent to members of a specially convened site selection stakeholder consultative group in October 2009. The stakeholder group consisted of representatives from each of the States, GA, RET, CSIRO and the CO2CRC, and its purpose was to provide guidance on prioritising the site selection from a national scale to 1 or 2 potential regions.

2.2 SELECTION CRITERIA

GA and CSIRO developed four main selection criteria to be used for assessing the suitability of the sites:

1) likelihood and size of future CO_2 storage in the region;
2) suitability of the location in providing baseline atmospheric information for monitoring of CO_2 storage and other GHG sources;
3) extent of existing natural and anthropogenic GHG sources that could reduce the detection of new GHG signals; and
4) availability of infrastructure.

For each of these criteria, detailed attributes were identified as outlined in Table 1. A description of each individual criterion is located in Appendix A.

The project team compiled data to evaluate criteria 2-4 for three example sites. The sites were selected based on earlier recommendations from the stakeholder consultation meeting on Monitoring and Verification for Carbon Capture and Storage (CCS) in February 2009. The example sites covered the Cooper and Surat basins and a third site, in the Denison Trough, was added based on exploration progress. For each of these example sites, data on density of forest cover, type of vegetation, availability of power and telecommunications, height of nearby towers and evaluation of nearby anthropogenic sources were compiled (see Appendices B to G). The expected contributions to the atmospheric CO_2 changes from the terrestrial ecosystem (respiration emission and photosynthetic uptake), ocean fluxes and fossil fuel emissions were modelled for each site, to provide estimates of the background variations. Emissions from CCS leakage would be more easily detected in regions of low background variance. The project team compiled basic information for criterion 1 but relied on the expertise of the stakeholder group to provide a more accurate assessment of this criterion.

A key criterion for site selection is whether the potential geological storage reservoir is offshore. The atmospheric signal associated with a given seafloor leakage rate is presently less well known than for a land-atmosphere release. It is most likely dependent on the offshore site characteristics such as water depth, ocean dynamics and chemistry. The atmospheric signal for an offshore reservoir leak would be smaller than for the same leak rate onshore, but the background atmospheric variations would also be smaller. The resulting signal to noise and therefore the utility of atmospheric monitoring in this situation is not yet known. Given these uncertainties, the low level of development and relatively high cost of offshore monitoring techniques, and the lack of an offshore storage project to use as a monitoring platform, it was decided not to pursue a coastal monitoring site under this project. However, much of Australia's potential CCS storage capacity is offshore (Carbon Storage Taskforce, 2009) and techniques for monitoring the ocean and overlying atmosphere will need to be adapted for that purpose.

Table 1: Selection criteria used to assess sites

#	SELECTION CRITERIA
1	**Likelihood and size of future CO_2 storage in the region**
	Size of acreage release or the storage
	Likelihood that storage will occur
	Proximity to likely storage sites
	Risk of leakage
	Timing, how well advanced is the project?
2	**Suitability of the location in providing baseline atmospheric information for monitoring of CO_2 storage and other GHG sources**
	Flux footprint/ fetch
	Current and future land use; ease of permitting (free from heritage, native title and commercial constraints)
	Proximity and quality of a BoM weather station
	Wind climatology/ prevailing winds
	Suitability of atmospheric monitoring for onshore vs offshore monitoring
	Opportunity to provide regional GHG data from presently data sparse region
3	**Extent of existing natural and anthropogenic GHG sources that could reduce the detection of new GHG signals**
	Vegetation/ecosystem emissions
	Source discrimination from background eg. Biogenic C_3/C_4 carbon compared to CCS carbon, natural or introduced tracers
	Impact of anthropogenic CO_2 sources. location and intensity of sources-energy, agricultural (incl. biomass burning), etc
4	**Availability of infrastructure**
	Power supply (mains, wind, solar or generator)
	Support staff (e.g. caretaker, landowner, GA, CSIRO etc)
	Accessibility for operations, showcasing (roads, airport etc)
	Cost (capital and operating)
	Security (likelihood of loss)
	Telecommunication (for real time transmission)
	Availability of tall towers

2.3 SUMMARY OF CONSULTATION PROCESS AND OUTCOMES

The project team met with the Stakeholder Consultative Group in October 2009. The criteria supplied for the example sites were considered sufficient by the consultation group. Criterion 1 (i.e. likelihood and size of future CO_2 storage in a region) was considered the most significant for selection by the stakeholder group and particularly whether regions were likely to be early movers in terms of geological storage. Using a basin ranking map for CO_2 storage potential developed by the Carbon Storage Taskforce (2009), all highly suitable onshore regions were ranked in terms of a priority for a baseline station. The rankings from the stakeholder consultation group are provided in Table 2 below. Stakeholders agreed that highly ranked offshore sites (e.g. Gippsland, offshore Otway Basin, Bonaparte NT, Bonaparte WA) be excluded on the basis that the effectiveness of atmospheric monitoring for offshore sites is uncertain.

Table 2: Summary of rankings of high priority onshore basins suitable for siting an atmospheric baseline monitoring station (October 2009)

BASIN	EARLY MOVER?	SIZE	PRIORITY RANKING
Canning	possible	Considered not relevant – all potentially large storage sites	5
Galilee	x		4
Bowen	✓✓✓		**1**
Surat	✓		**2**
Cooper/Eromanga	x		6
Perth	x		3

In terms of where onshore geological storage may first occur, both the Surat and Bowen basins were identified as key early mover regions by the site selection consultation group. The Surat Basin has the potential to be a major CO_2 storage hub but exploration at the time of the meeting was limited compared to the Bowen Basin. In addition, CO_2 storage exploration permits had not at that time been released in the Surat Basin compared to the Bowen Basin. The consultation group agreed that the Bowen Basin was a key target in terms of a potential early mover but noted that the Surat is likely to be a more significant storage site over the longer term.

The Stakeholder Consultative Group discussed the other criteria but noted that, particularly for the logistics criteria, many of these were detailed site issues and not relevant for basin selection. The complications of an inland site with multiple anthropogenic sources and similar ecosystem carbon-13 isotope signals was discussed in some detail and the project team emphasised that a site in the Bowen Basin would be challenging to monitor and operate because of ecosystem influences. In terms of atmospheric modelling criteria only, the project team ranked the Cooper Basin as number 1; followed by Surat, Galilee and Bowen (in that order).

2.4 FINAL SITE LOCATION

Based on the guidance provided by the Stakeholder Consultative Group, it was decided to proceed with an atmospheric monitoring site in the Denison Trough (Bowen Basin) and scope out a second backup site in the Surat Basin. Exploration drilling for the Zerogen CO_2 storage project in the Bowen Basin at the time was well underway and in October 2009 a CO_2 injectivity test was conducted at the southern end of Zerogen's CO_2 greenhouse gas storage exploration permit. The prevailing wind direction in the region is from the south-east and hence an 'upwind' site was preferred for a baseline. A suitable location was found approximately 8km east of Zerogen's ZG11 well (refer to ZeroGen figure in Appendix B). The site was characterised by the following:

- flat terrain
- away from major point source greenhouse gas emissions

- straddled cropland and pasture
- above the floodplain
- a cooperative landowner
- a nearby powerline
- a formed road
- some 3G network signal
- away from through traffic

Power and physical security were identified as key risks that needed to be minimised through careful site selection. Installation of a new powerline to an optimally located site would have required a lead time of several years – far longer than the project duration. Hence, it was critical to tap into the existing electricity network. The project negotiated early installation of a new transformer at a nearby powerpole with the local electricity supplier, which required 4 months in total. Locating the instrumentation and tower away from vehicle thoroughfares was preferred in order to minimise the chance of vandalism. The final site was located at the end of formed road that terminated on the landowner's property. A licence agreement was signed with the landowner that detailed the researchers' and landowner's responsibilities regarding access and use of the site and a yearly site licence fee was agreed with the landowner.

Figure 1: *Location map of Arcturus*

It became clear during a scoping study for a second site in the Surat Basin, that, in the absence of greenhouse gas storage exploration permit areas, the uncertainty for selecting a site was too large to make a meaningful site selection. The storage area based on a high level geological assessment is hundreds of square kilometres (Bradshaw et al, 2009) and it was highly probable that early installation could be incorrectly located. At the time of writing this report, greenhouse gas storage exploration permits had not been released for the Surat Basin.

Despite the high level of exploration activity for the Zerogen project, there was a significant risk that the project would not proceed beyond the exploration phase. This came to fruition in June 2010, when on the basis of apprasial drilling, it was found that the geology of the northern Denison Trough was not viable for large scale CO_2 storage. Arcturus had been installed and tested only 1 month prior to this decision. This meant that Arcturus was no longer providing atmospheric baseline measurements for a potential storage region. Nevertheless, the project continued to receive support as there was no alternative onshore exploration program in Australia and many of the project objectives could still be realised. This included field-testing and evaluating a new generation of greenhouse gas monitoring technology in remote environments; understanding a complex greenhouse gas baseline; and developing methods for leak detection. The station would also generate data that could be used for developing procedures that will assist in the planning and implementation of a national atmospheric monitoring network and provide data for the purposes of estimating regional and national greenhouse gas budgets.

Geological formations and landowner properties in the Denison Trough region are typically named after stars and the locality where the station is located is called Arcturus (constellation Boötes; fourth brightest star in the sky). A unique Global Atmospheric Watch Station Information System (GAWSIS) global atmospheric station identifier was chosen incorporating Arcturus and Australia, ARA. The World Meteorological Organization (WMO) has accepted Arcturus as a regional GAW station.

3 Instrumentation

3.1 HIGH PRECISION GREENHOUSE GAS INSTRUMENTS

Continuous *in situ* atmospheric composition measurements are made by a pair of continuous wave cavity ring down spectrometers manufactured by Picarro Inc. (Sunnyvale, CA, USA) (Figure 2). One of these instruments, CFADS63, (model G1301) measures concentrations of CO_2, CH_4 and H_2O. The second instrument, CBDS36 (model G1101i) measures $^{12}CO_2/^{13}CO_2$ and H_2O. Both instruments have optical cells (35 cc volume) that operate at sub-ambient pressure (140 Torr) and slightly elevated temperature (45 °C). The instruments actively maintain the pressure within the cell to within 0.02% by adjusting the gas flow rate. CFADS63 draws approximately 300mL/min through its cell; CBDS36 draws around 100mL/min. CFADS63 is specified to provide a 5 second measurement precision of better than 0.2 ppm for CO_2 and 1 ppb for CH_4. CBDS36 is specified to provide precision of 0.3‰ on a 5 minute average measurement. However, Picarro later noted that the performance of their G1101i instruments was below specification due to a number of spectroscopic interferences and artefacts (see http://www.picarro.com/resources/whitepapers). The CBDS36 was returned to the Picarro USA factory late in 2011 and rebuilt to specifications of the newer G2000i analyser platform.

Figure 2: *High precision greenhouse gas monitoring instruments (Picarro CFADS63 and CBDS36), blowers, valves, reference tanks and the original uninterrupted power supply (UPS) units installed in container at Arcturus*

Two aspirated air intakes (R.M. Young aspirated radiation shield, model 43502) fixed at heights of 5 and 10 m (Figure 3) were located on the fibreglass mast. An equal length of 3/8” diameter Synflex tubing (composed of high density polyethylene around aluminium internally coated with an ethylene copolymer) capped with mesh at the intake, runs from each aspirated intake into the module where it is purged by a blower (Elmo Rietschle Gas-Ring Vacuum Pump/Compressor G-Series, type: 2BH10 02-_AA53). A TSI thermal mass flowmeter (Series 4000/4100) on the outlet of one of the blower monitors the rate of purge of the line, which is around 18.5 L/min.

Figure 3: *Mast and air intakes at 5m and 10m height.*

Stainless steel Swagelok T-unions, located upstream of the blower, allow each instrument to draw an appropriate flow of ambient air from the intake lines, via 1/16” external diameter, 0.75 mm internal diameter stainless steel tubing connected to port 8 of a VICI Valco valve: (1/16” 0.75mm port 8 position SD valve with microelectric actuator (part # EMTCSD8MWE)). The outlet of each valve connects directly into one of the instruments. Four of the remaining ports on each valve are connected permanently to a high pressure cylinder via a two stage Tescom gas regulator (with metal-metal seals part # 64-3460KA412-006). One of these is the reference cylinder, having ambient concentrations of all relevant species, measured daily; the remaining three form a calibration suite (with CO_2 from 366 to 453 ppm and CH_4 from 1640 to 1827 ppb) that is measured approximately monthly. A schematic of the configuration used for high precision composition measurements and calibration is given in Figure 4.

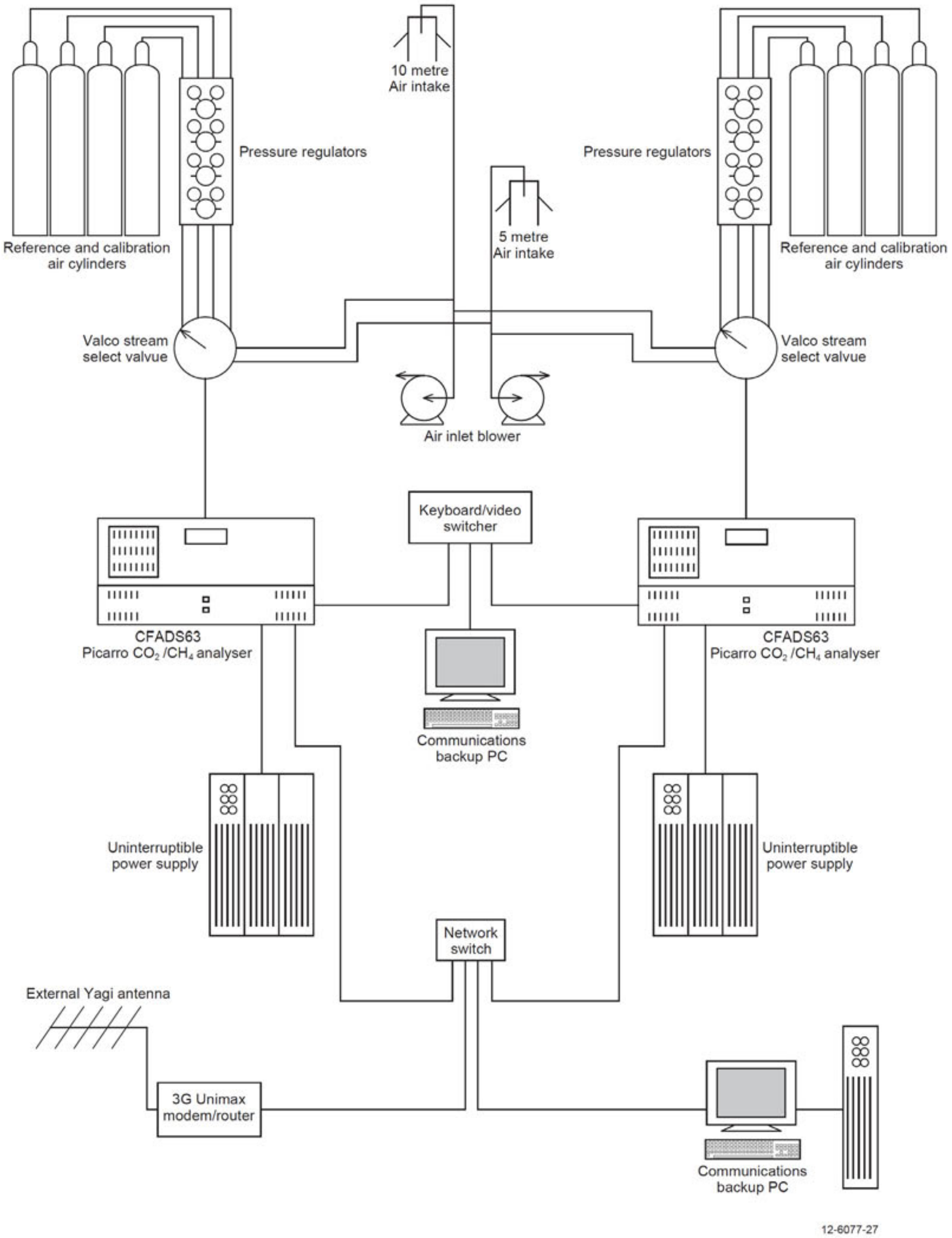


Figure 4: *Schematic of the configuration for the Picarro composition analysers*

3.2 METEOROLOGICAL INSTRUMENTS

A Campbell Scientific (CS) weather station is used to collect meteorological data at the site (Figure 5). Wind, temperature and relative humidity (RH) sensors are located on a cross arm which is installed at a height of 10m on the fibre-glass mast, next to the container (Figure 5a). The R.M. Young Wind Sentry set (model 03001), comprising a cup anemometer and a wind vane, is located at one end of the cross arm and a Vaisala temperature and RH probe (HMP50), mounted in a Gill radiation shield, is located at the other end of the cross arm. The wind vane was oriented to true north after correcting for the magnetic declination angle for the location.


(a) (b)

Figure 5: *a) Temperature and relative humidity sensors mounted in a Gill radiation shield on cross arm (left) and RM Young Wind sentry set (right) (mast in lowered position); b) solar panel for weather station, top mounted pyranometer, dish for wireless connection to EC tower and Yagi Antenna for internet communication*

Rainfall is measured with a Hydrological Services 12 tipping bucket rain gauge (CS701) which is located on the roof of the container; a LICOR4 silicon pyranometer (LI-200SX), also mounted on the roof, is used to measure solar radiation. Barometric pressure is measured with a Vaisala barometer (PTB110) installed in an environmental enclosure cabinet (ENC 14/16) which is mounted inside the container. Internal temperature and relative humidity are measured with the HMP155 sensor located in the container to independently monitor and log temperature inside the container in the event of a power failure. The enclosure contains a CR1000 data logger to which all the sensors are connected, and is powered by a 12 V power supply battery fitted with a 5 amp regulator. The battery is charged constantly by a DC power supply powered by the mains electricity supply, or an externally mounted 12V solar panel (SX10M) in case of power failure. A CS295 data view display on the front of the Enclosure cabinet enables viewing of real time data.

The CR1000 data logger logs 15 mins, 60 mins and 24 hour data, transferred daily via a serial connection to the PC workstation at the station, using the Logger Net software. Meteorological data can be viewed with the Logger Net software or downloaded when the PC is accessed remotely via the Internet.

3.3 EDDY COVARIANCE TOWER INSTRUMENTATION

Turbulent fluxes of *in situ* CO_2, CH_4 and H_2O within the atmospheric boundary layer are measured using Eddy Covariance (EC) instrumentation (Figure 6). Gas sensor measurements are coupled with 3D wind measurements to calculate a flux of gas towards (negative flux) or away from (positive flux) the land surface. The LI-7500A, manufactured by LI-COR Biosciences, uses non-dispersive infrared detection to measure CO_2 and H_2O in the atmosphere with precision accuracies of 0.11 ppm and 4.7 ppm respectively. The LI-7700, also manufactured by LI-COR Biosciences, uses wavelength modulation spectroscopy to measure CH_4 in the atmosphere with a precision of 5 ppb. Both sensors are open-path eddy covariance gas analysers and are particularly suitable for remote gas flux studies. 3D wind speed and direction is measured using a CSAT3 sonic anemometer (Campbell Scientific Inc) which transmits and receives an ultrasonic signal to sense wind speeds and directions, and measures the speed of sound through an air volume to measure air density (e.g. temperature and humidity).

(a) (b)

(c)

Figure 6: *(a) Open path CH4 sensor; (b) Open path CO2 sensor; (c) Sonic anemometer (far left), CO2 sensor, CH4 sensor, radiometer (far right), temperature and humidity in radiation shields*

Several other variables are measured which feed into the overall flux calculation equations. These include long and shortwave radiation (CNR4; Kipp and Zonen 4 component radiometer), wind speed and direction (CSAT3 and Windsonic4; Gill 2D sonic anemometer), temperature and humidity (HMP45; Vaisala temperature and relative humidity probe). Soil property measurement are also required and include soil temperature (TCAV; Campbell type E thermocouple averaging soil temperature probes), soil heat flux (CN3; Middleton soil heat flux plates), and soil moisture (CS616; Campbell water content reflectometer) (Figure 7). This site is powered by two 80W solar panels which charge batteries to power the flux tower.

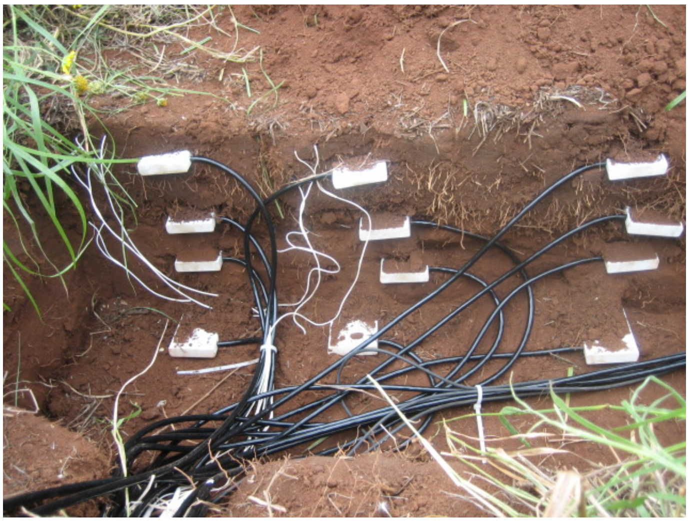


Figure 7: *Soil moisture and temperature probes before burial*

4 Atmospheric station installation

4.1 CONTAINER FIT-OUT AT GEOSCIENCE AUSTRALIA

A modified shipping container (6m x 2.4m) was purchased from ANL Container Hire and Sales Pty Ltd, who had modified it to specifications provided by GA and CMAR (Figure 8; see Appendix J). In addition, the vendor was requested to install data/telephone outlets; earth leakage; solar vent; panic bar linked to the external handle and lock; and to paint the container a white colour.

Figure 8: *Container after modifications including installation of double glazed windows; spotlight, security bar and insulated metal shutters*

The modified 6m container arrived at GA workshops in Canberra in April 2010 for further fitting and instrument installation/testing. Further modifications were made to the container including installing a spotlight, double glazing on the window, security bar/lock and insulating the metal shutters; temporary electricity connection was also provided. A 39RU instrument rack, manufactured by Server Racks Australia (SRA), was assembled in the container to hold the Picarros and UPSs (Figure 9a). Additional fittings in the container and on the mast were required: installation of a regulator rack (to hold 8 gas cylinder regulators) on the container wall (Figure 9b); shelves to hold the pumps; fitting the inlet aspirators and a cross bar (to hold the wind sensors) on the mast.

(a) (b)

Figure 9: *(a) Instrument rack to hold Picarros and UPSs; (b) Gas cylinder rack and gas regulator rack*

The pre-tested Picarro instruments, pumps and accessories were shipped to GA from CMAR in Aspendale in early May 2010. A full installation and testing of the monitoring instrumentation was conducted at GA before deployment to Arcturus. This included the two Picarro instruments (CFADS63 (CO_2/CH_4) and CBDS36 (CO_2 isotopes)), two UPSs, a computer screen monitor and keyboard, and other accessories on the instrument rack. A PC workstation was installed on the workbench of the container. Other items such as two Valco valves and pumps were also installed in the container. The regulators on the rack were fitted with 1/16” stainless steel tubing to connect the high pressure gas cylinders and the valves servicing the analysers.

A computer monitor and keyboard (also located on the rack) were used to control the CPU of the Picarros enabling communication to either by toggling between them using the appropriate keys (Scroll Lock, Scroll Lock, Up arrow) on the attached keyboard. An eight port VICI Valco valve controlled gas flow to each of the Picarros and two pumps connected to Synflex tubing were used for aspirating the 10 m and 5 m inlets (that were later installed on the mast). The Picarros were tested and ran successfully overnight.

Eight 29.5L aluminium Luxfer high pressure gas cylinders were prepared as on-site calibration and reference standards. These were shipped from Aspendale to GA to enable onsite calibration of the Picarros and further testing of the system before deployment. The calibration tanks provide the basis for monthly field calibration of the instruments and daily reference checks (via remote access).

Each tank was connected to a high pressure cylinder regulator mounted on the rack, and each of these were connected to one of the Valco valves via 1/16” stainless steel tubing. The valves could then be switched remotely to introduce ambient air from heights of 5 or 10 m and any of the reference and three calibration gases assigned to each Picarro.

The communications for remote access to the instruments were also tested before deployment. This involved installation of a Maxon UNIMAX router/modem fitted with a Telstra NextG mobile phone SIM card (on a 6GB per month broadband plan) and connected to an external Yagi antenna. A multi-port D-Link Network switch was used in the LAN. Communication was effected as follows: the UNIMAX modem was connected to the Ethernet port of the PC workstation and also to one of the Ethernet ports of the D-Link LAN switch; and the Picarros were each connected to the other ports on the D-Link by Ethernet cables. PCAnywhere software, installed on the workstation, enabled communication with, and control of, the Picarro’s software from the PC workstation. Any authorised remote PC running GoToMyPC software, with Citrix, could access and control the PC in the Container via the Internet over the NextG network. To build in some redundancy, GoToMyPC was later added directly to CBDS36 as an additional entry point to the remote system.


(a) (b)

Figure 10: (a) Testing the tiltable 10m fibre-glass mast; (b) original pulley block and cleat mechanism for raising and lowering the mast (later replaced with a winch)

A 10 m tiltable fibre-glass mast was ordered from Advanced Composite Technologies Co. (ADCOMP) (Figure 10a). Further machining was required including adding a counterweight at the base of the mast, adding cross arms for the air intake aspirators, and fitting it to a galvanised fabricated metal stand. The mast was originally equipped with a multi pulley block and cleat system for lowering and raising (Figure 10b) but this was later replaced with a winch. A sketch of the site layout showing the positions of the shed and mast (raised & lowered) was agreed upon (see Appendix K).

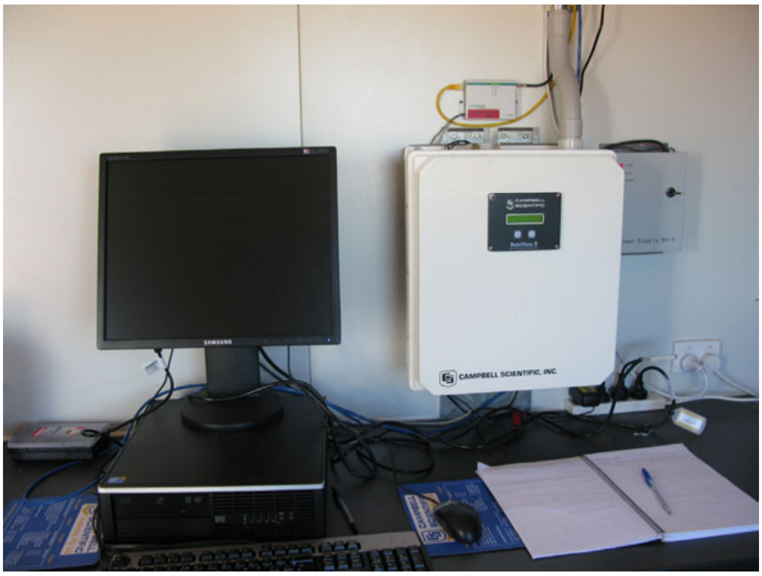


Figure 11: Environmental enclosure cabinet for the weather station mounted on the wall in the container next to the supervisor PC

A Campbell Scientific weather station enclosure was installed in the container (Figure 11). The enclosure had a CR1000 data logger that was connected to various meteorological sensors located on the mast and on the roof of the container. Campbell Scientific LoggerNet software was installed on the PC Workstation which was connected directly, via a dedicated serial port, to the CR1000 logger to automatically download meteorological data to the PC. Longer sensor cables were required since most of the sensors were placed on the cross bar atop the 10m mast. A lightning arrestor box was also installed.

After the successful conclusion of testing, the instruments inside the container were dismantled, packed into boxes and secured in the container prior to the container being shipped by road using a crane truck from Canberra to the Arcturus site.

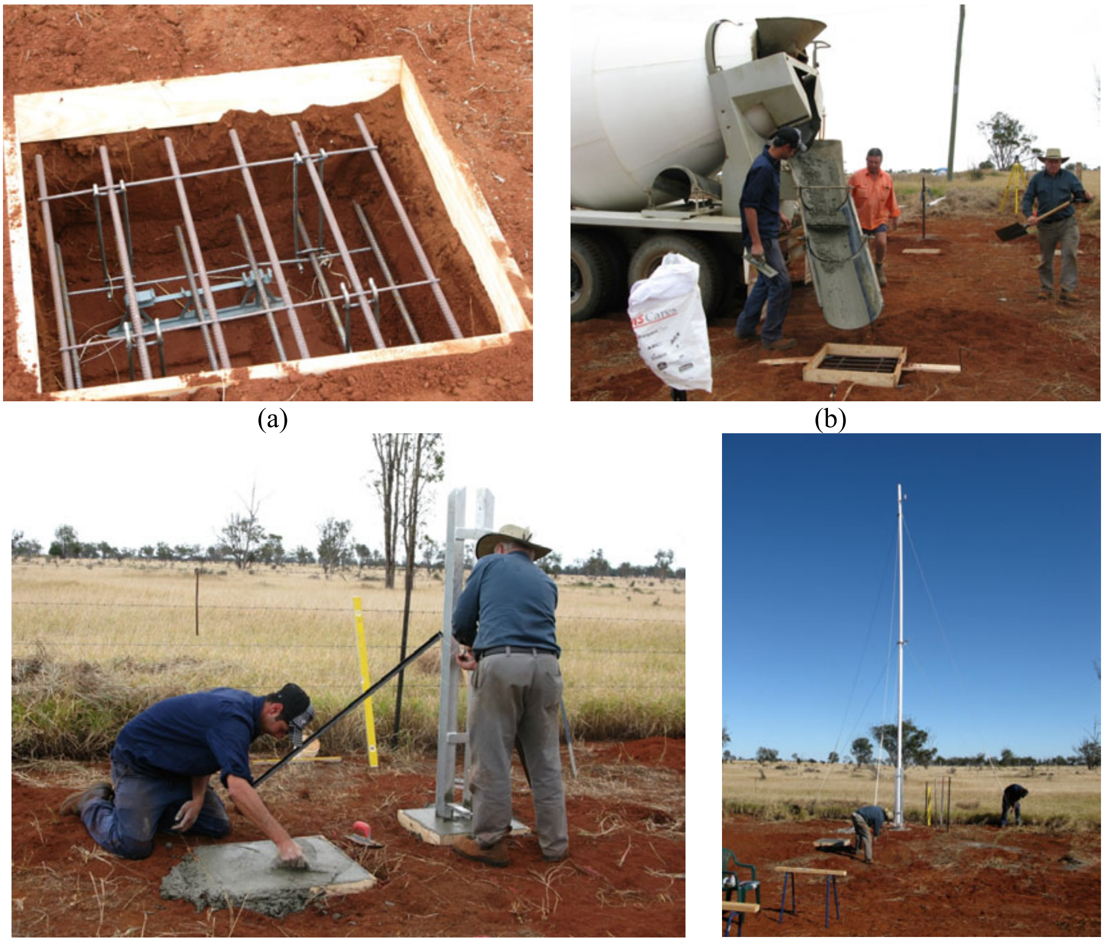
4.2 ARCTURUS SITE PREPARATION

A forward party travelled to the site in late May 2010 to prepare for the arrival of the shipping container and instrumentation. A vehicle was used to transport the 10m fibre-glass mast (dismantled into two sections), guy lines and anchors, galvanised metal stand, petrol electric generator, and various tools and equipment from Canberra to the site. At the site, the vegetation was cleared and mapped out with the aid of a surveyor's level, as per the schematic in Appendix K, showing the locations for building the concrete pads on which the container would be placed (Figure 12). The position for installing the mast was also marked out.


(a) (b)

Figure 12: *(a) Mapping out the location of the container showing a surveyor's level; (b) positions of cement pads*

A bobcat operator with an 350mm auger drill dug four holes to be used for building the concrete pads, and a fifth hole for installing the mast stand (1m deep). The holes for the concrete pads were widened with a shovel to the required dimensions to fit metal support frames to be placed in each hole (400 x 400 x 500mm deep). The depths of the holes were checked with the surveyor's level to ensure that the concrete pads would be level when built. Each of the holes for the concrete pads was fitted with a metal support frame and wooden boards; the latter were used to support the metal frame and to keep the cement in place and at the correct height when it was poured. The heights of the wooden boards were established precisely with the aid of the surveyor's level. A cement truck arrived at the site and the holes were filled with concrete and levelled. The galvanised metal stand for the mast was placed in its hole and cemented into place. After the concrete had set, the wooden boards supporting the concrete pads were removed and the area surrounding the pads levelled with soil. Anchor points for the 4 guy-lines were installed into 1m deep augered holes, and consisted of stainless rods connected to a 200mm square plate, which were then backfilled with soil.



(a) (b)

(c) (d)

Figure 13: *(a) A hole fitted with metal support frame and wooden planks for the concrete pads; (b) cement truck delivering concrete; c) levelling concrete pad and securing the metal stand for the mast; (d) securing guy-wires to anchor points*

The station is installed in an area classified by the Bureau of Meteorology as an area with a high probability of lightning strikes during the summer. Protective measures were determined to be essential especially as the high occurrence of lightning strikes was confirmed by anecdotal evidence from the local farmers. Protection from lightning strikes on the power lines coming into the container is provided by a Critec TSGSRF140 single phase bypass and surge reduction filter. Protection from lightning strikes on electronic equipment mounted on the mast is provided by a Critec ISODC air terminal and isolated down conductor system. An earth mat installed comprised about forty meters of copper wire with eight one and a half metre earth stakes in the ground, joining the electrical supply earth at one end of the container, and the mast lightning arrester at the other, as per the Australian Standard for lightning protection AS/NZS 1768:2007 (Figure 14). Part of the earth-leakage wire (about 20 m) was buried in a 0.5m deep trench that had been dug to the front of the site. Copper plated steel rods were attached to the buried wire at intervals of 1.5 m and completely sunk into the ground. More trenches were dug at the sides of the site to bury the remainder of the earth leakage wire and enable attachment to the mast on one side and lightning arrestor box on the other.


(a) (b) (c) (d)

Figure 14: *Installing the earth mat. (a) Bobcat used to drill holes and dig trench; (b) burying earth leakage wires; (c) hammering in 1.5m long copper coated steel rods; mast lightening arrestor connected to earth mat (note pulley block replaced with winch)*

A mast and pulley system was initially attached to the concreted stand and the pulley tested by raising and lowering the mast according to a developed safe operating procedure (Figure 10b). Nevertheless, raising and lowering the mast using this technique was difficult and remained a safety risk to staff. Sections of the barbed wire fence close to the mast were covered with conduit pipe to prevent injury to staff operating the pulley system. The mast and pulley system was later replaced with a hand winch (Figure 29).

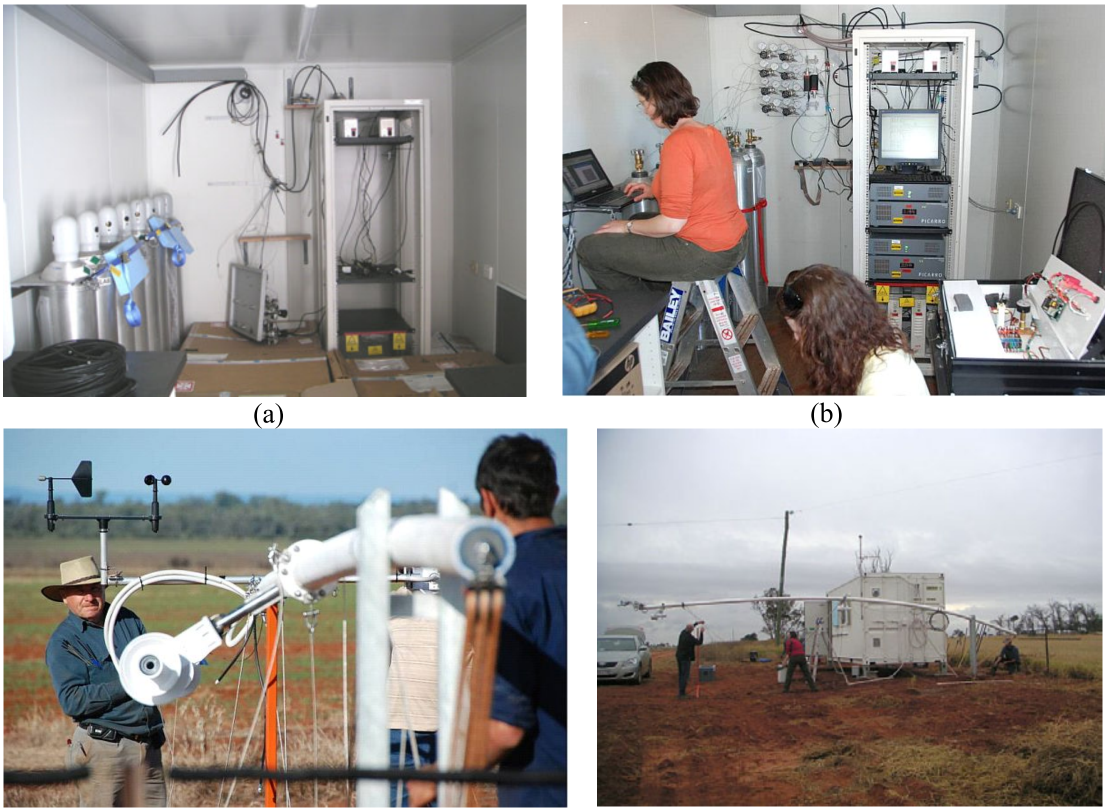
4.3 CONTAINER FIT-OUT AT ARCTURUS

The container arrived at the site on a crane truck the morning after site preparation had concluded in late May 2010. The crane was used to lift and position the container on the metal supports that had been placed on the concrete pads (Figure 15a). When the container had been squarely positioned on the supports, the metal supports were bolted onto the concrete pads and their tops clamped into slots in the bottom of the container (Figure 15b).


(a) (b)

Figure 15: *(a) Crane truck lifting container to position on footings; (b) securing the container footings to concrete pads*

After the truck had departed, the petrol generator was connected to the container to provide electricity to run all the equipment, including the air conditioner. Then the container's door was opened carefully to examine its contents. All equipment transported in the container appeared to be intact, with the exception of the regulator rack which was hanging loosely by one screw to the wall. It was obvious from the position of the rack that it must have been swinging and possibly hitting the regulators on it and attached tubing to the sides of the container during transit. Further examination revealed that the regulator rack had sheared off the wall, destroying several lines of 1/16" tubing and deforming some fittings on the regulators themselves. The fall of the regulator rack was broken largely by the Picarro box sitting beneath the rack however some of the weight of the rack was being supported by a Valco valve cable. Fortunately there were no problems driving the Valco valve either from the manual actuator or through the Picarro instruments themselves.



(a) (b)

(c) (d)

Figure 16: *(a) Sheared off regulator rack and damaged tubing (b) setting up equipment in container; (c) installing intake aspirators and cabling; (d) raising the 10m fibreglass mast*

Initial damage was assessed and arrangements were made to ship spares to Emerald. The regulator rack was remounted on the wall and any damaged tubing replaced.

The following few days involved re-assembling equipment to the same state that they were before being shipped from GA. Activities included:

- Installing Picarros, UPSs etc on the instrument rack;
- Assembling the PC workstation;
- Enabling connection to the Picarros and PC via Ethernet cables;
- Connecting the UNIMAX modem to the PC to provide access to the internet;
- Replacing the faulty regulator connections and broken stainless steel tubing;
- Connecting the stainless steel tubing to the calibration gas cylinders
- Connecting Picarros to inlet lines;
- Installing pumps and Valco valves; and
- Re-installing the Yagi antenna and orienting it towards the telecommunication tower at Fernlees (~32km west of the site).

Overnight leak checking revealed that three regulators had failed to hold pressure. One of these (Tescom2-L10) was because the regulator had not been backed-off. A second overnight test of this regulator determined that it was not leaking. Regulators Tescom2-F14 and F18 had low side leaks at the pressure gauges. These were located and fixed by increased tightening. Further overnight testing of these regulators confirmed that they were no longer leaking.

The replacement parts arrived at the depot and were collected the following morning allowing for overnight calibration of the Picarros.

Other activities accomplished that day included:

- Collection of flask samples (G050-A55 & G050-A56);
- Installation of two aspirated inlets on the mast at 5 and 10 m above ground level to service both the CFADS63 (CO2/CH4 Picarro) and CBDS36 (CO2 isotopes Picarro).
- Attached the power supply cables to the aspirators;
- Connected the Synflex inlet tubing from each of the pumps to the inlet aspirators on the mast;
- Attached Campbell Scientific meteorological instrumentation (windvane, anemometer and temperature/relative humidity sensors (enclosed in the radiation shield) on the cross bar at the top the mast and attached sensor cables;
- Aligned wind vane to true north (plus/minus approximately 3 degrees);
- Threaded all tubing and cables through the interior of the fibre-glass mast before exiting to the container through a conduit pipe; and
- Installed the solar radiation sensor on the antenna pole and the tipping bucket rain gauge on the roof of the container.

More activities were completed during the following days including:

- Running the calibration tanks on Picarros during the daylight hours;
- Modifications to the mast and intake lines including ‘bird-proofing’ the mast and associated tubing & cables (using electrical wire conduit and cable ties);
- Pop-riveting the ‘excess’ 5m of tubing from the 5m inlet to the wall inside the container to ensure no low points for liquid water to pool; and
- Purchasing more items for the station including fire extinguisher, brooms, brushes, bin, trolley, ladder, floor mats, a wooden palette and cement blocks to be used as steps.

Flask samples G050-A57 and G050-A58 were filled. The line from the 10 m intake was also configured to service the flask pump unit. A CSIRO standard pump unit (black “suitcase” style with KNF diaphragm pump and magnesium perchlorate drying tower) was used, while the new “Sherpa” unit was being delivered and configured.

Overnight tests were successfully conducted on switching between levels on CFADS63 (30mins each hour for 10 & 5 m levels). A step was constructed at the entrance to the container, using cement blocks, for improved access. Data was downloaded from both instruments and they were shut-down in preparation for the generator being turned off. As a final test of the integrity of the regulators, all eight were left pressurised.

The facility was left awaiting power connection and instrument start up during the next visit. Electricity was connected to the station on 7 July 2010.

5 Eddy Covariance tower installation

5.1 INITIAL INSTRUMENT SETUP AT GEOSCIENCE AUSTRALIA

The purpose of the eddy covariance flux tower is to gain flux measurements of CO_2 and CH_4 (greenhouse gases) in the area of the atmospheric monitoring site to help quantify possible sources of these gases and gain a general understanding of the annual flux budget for the area. Due to the large size of the CH_4 sensor, the instrument must be deployed at least 5 metres above the land surface to ensure no boundary layer interference with wind eddies (Burba and Anderson, 2010).

A “One Man Tower” from the “Super Midi” range was purchased from Australian Enterprise Industrial in Queensland and delivered to GA. This is a 5.5 metre tall square lattice tower with an adjustable pulley lever system to wind the instrument arm up and down as required. A heavy duty lightning rod was wired to the tower to ensure power surges and instrument failure is avoided during storms. All field instruments were ordered by CSIRO (Black Mountain) staff and delivered to GA. The LI-COR gas analysers (Greenhouse Gas Analyzer Systems Package 1) were purchased from John Morris Scientific Pty Ltd. All other instruments, sensors and data loggers were purchased from Campbell Scientific Inc.

The tower was first erected outside at GA and mounting arms and brackets on which the instruments were to be mounted were custom manufactured. These were all made adjustable to ensure instrument positioning could be modified if required. The orientation and position that instruments are mounted is very site specific. In order to minimise errors and avoid data loss, the sensor separation (the distance between the gas analysers and the sonic anemometer) was minimised and the orientation of the gas analysers adjusted to avoid water droplets collecting on the window surfaces. The sonic anemometer was positioned to face the predominant wind direction (SSE) in order to get the most useable dataset. Radiation sensors were mounted on the same mounting arm as the gas sensors but at opposite ends to help ensure measurements are as representative of the land surface as possible with minimal interference from other sensors and tower reflections.

All instruments were wired to the CR3000 data logger according to wiring charts listed in Appendix L. The data logger program was provided by CSIRO and initially did not include the LI-7700 sensor. The program was loaded to the logger using the LoggerNet software (Campbell Scientific), which is used to access the site, both remotely and during site visits, via the computer’s RS-232 port. This allows the user to view data in real time as tables or graphs and allows the user to send or retrieve the data and updated logger programs to the logger or laptop. Both gas analysers can also be accessed using a laptop and Ethernet cables connected directly to the respective gas analyser interface boxes. These come with software that allows the user to view data in real time and to change certain settings in the instruments (i.e. set cleaning commands for the LI-7700 CH_4 sensor).

Figure 17: *EC equipment and tower tested at Geoscience Australia before deployment*

Instruments were run over a 24 hour period to ensure all were measuring correctly. The CO_2/H_2O sensor was calibrated using a dew point generator according to calibration instructions in the instrument manual. The soil sensors were also connected and tested, although they were not tested in a soil environment.

A Unimax modem was also installed in the logger housing so remote access is possible. This was wired to the logger so data can be transferred via a network and an aerial was attached to the top of the tower to get maximum reception. A MaxWan account was acquired with Telstra and SIM cards inserted and recorded for both the logger box modem and the computer modem used to access the site. Initially remote access was not possible as the SIM cards were not appropriate for the Telstra data plan and this could not be updated remotely on the LoggerNet software (see section on Post installation teething problems). It was important to ensure all the IP addresses and port numbers associated with each account and modem are entered into the remote access (device configuration) of LoggerNet correctly.

Testing of the instruments and programming proved successful and everything was packed securely back into boxes or carry cases to be transported to Arcturus..

5.2 EC SITE PREPARATION

The tower, instruments and all equipment required to install the EC site were transported to the Arcturus site using a GA vehicle in April 2011. Another GA staff member arrived in Emerald on the same day the two GA staff members arrived having driven from Canberra. A concrete truck was also organised in advance to arrive 2 days after the setup began to lay the foundations for the tower and the solar panel installation.

To begin, a location for the flux tower site was selected, far enough away from wind turbulence interference from the baseline container, or tall trees (Figure 18). A site was selected along the farm access road approximately 250 metres south of the container site. The most ideal orientation for the site was identified to ensure instruments faced in the predominant wind direction (SSE).

Figure 18: *Location of EC tower some 250m south of the monitoring station*

The site was cleared of grass so the digging of foundations could begin. Two concrete base platforms were constructed; one for the instrument tower, the other for the solar panels and battery boxes. For the tower, a one metre square hole was dug (1 metre deep). Three trenches leading out in 3 different directions were also dug (>0.4m deep). These trenches were to: 1) lay a power cable to connect the instrument tower to the solar panel and battery station; 2) lay cables to the soil sensors (soil temperature, moisture and heat flux), and; 3) lay an earthing cable for the lightning rod attached to the tower (Figure 19).

Wooden framing was constructed for the pouring of the concrete foundations. Plastic piping and steel rod reinforcing was placed into the foundation holes prior to concreting. This meant wiring could run down the inside of the tower, into the pipes and out into the relevant trench (i.e. power, soil sensors or earthing cable).

(a) (b)

(c) (d)

Figure 19: *(a) Wooden frame for solar panel base; (b) frame for tower with conduits for power and earth leakage; (c) tower base (foreground) and solar panel base (rear); (d) conduit for power from solar panels to tower*

The first trench (running roughly north) was a 0.4m deep trench that housed a plastic pipe that ran along the entire trench connecting the solar panel and battery station with the instrument tower. The pipe forms a conduit for the power cables from the power source to the instruments. The second trench (running roughly east) was approximately 0.6m deep for the first 2 metres, then 0.4m deep for running the earthing wire for lightning protection. The third trench (running roughly south) was a 0.4m trench to run the soil sensor wires from the tower to the sensor locations underground (see instrument deployment section).

The concrete truck arrived near the end of the second day of site preparation to pour the foundations for the tower and the solar panel and battery station (Figure 20). The pole on which the solar panels are mounted was concreted into place. The foundations were smoothed out and left to dry. The following day brought rain and meant access to the site was not possible. This gave the concrete more time to set before erecting the tower and solar panels.

(a) (b)

Figure 20: *(a) Concreted stand for solar panels; (b) concreted base for 5.5m tall tower (foreground)*

The following day, while the concrete dried, the lightning protection and solar panels were installed. This required running out the earthing cable for lightning protection and mounting the solar panels, battery boxes and installing the batteries and power/switch board (Figure 21). The earthing cable (thick copper wiring) was run down the correct pipe from the base of the instrument tower into the trench heading east, and then buried. The solar panels were also mounted on a custom built bracket and mounted on its platform and pole. The battery/electrical boxes were also firmly secured to the concrete base and batteries installed (including the power/switch board) – one box housed the batteries, the other housed the power/switch board.

(a) (b)

(c) (d)

Figure 21: *(a) Earthing cable; (b) mounting the solar panels and battery boxes; (c) battery box; (d) power/switchboard for solar energy system*

Tower and instrument deployment

The next day the concrete base of the tower was dry enough to erect the tower and begin instrument deployment. The base of the tower was bolted to the concrete platform and securely fastened so the second half of the tower could be erected on top of the first section of the tower. The pulley lever system was attached as well as the adjustable, flexible casing to hold instrument cables running from the logger and instrument boxes to the instruments themselves. The lightning protector rod was attached to the top of the tower and connected to the heavy duty cabling connected that then run underground (Figure 22). The datalogger box and its components were then mounted to the tower at chest height (Figure 23a). Ideally, it should be mounted so a laptop can be placed on top to be used. The LI-COR interface boxes (including the LI7700 washer box) and the CSAT3 box were mounted to the adjustable section of the tower, together with the instrument arms (Figure 23a, c and d). As instruments were mounted, their orientation was noted and sensor separation distances measured and minimised while still ensuring all other error sources were minimised (see Burba and Anderson, 2010).

(a) (b)

(c) (d)

Figure 22: *(a) Securing the bottom section of the tower to the concrete base; (b) attaching the lightning rod and cable to the top section of the tower; (c) top tower section secured to base tower section; (d) attaching mounting arms and equipment to the moveable frame*

(a) (b)

(c) (d)

Figure 23: *(a) Moveable platform hosting instruments and sensors in down position with logger and communication enclosure at chest height; (b) winch for raising and lower the platform on the EC tower; (c) flexible casing for instrument cables connects instruments on the moveable frame to the data loggers at the base of the tower; (d) EC tower (ex CH4 sensor) and solar panel*

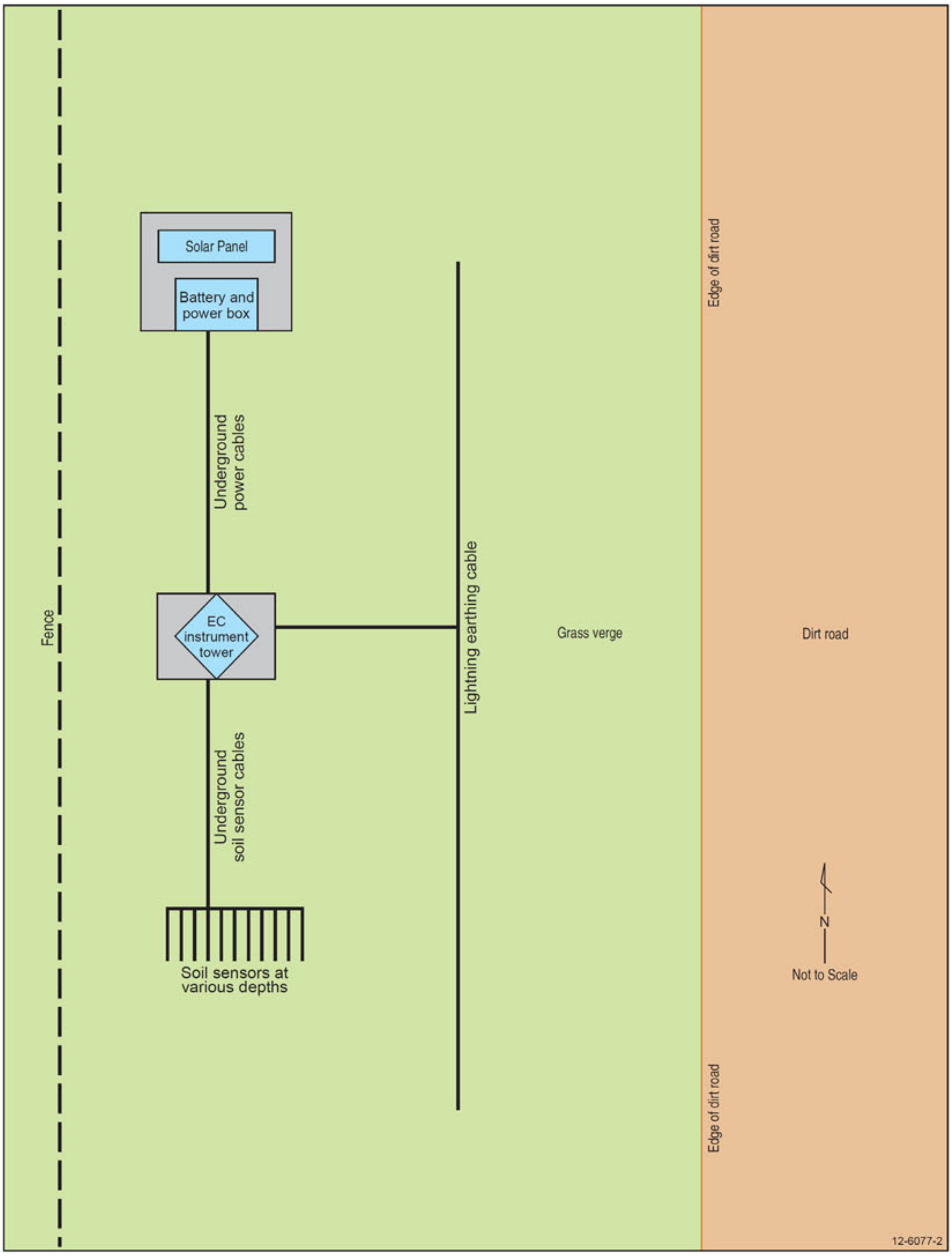


Figure 24: *Schematic of the EC tower, solar panels, lightning earth cables and soil sensor layout*

The soil climate sensors were installed in the soil in order to provide data for energy and water balance calculations. The location was selected based on several attributes: the most representative soil of the measurement footprint, undisturbed area and close enough to tower for cables to reach. A site approximately 6 metres to the south of the tower was selected. A pit 1.25m in length, 0.3m deep and approximately 0.5m wide was dug, trying to maintain the top grass layer and the soil structure as best as possible. All soil climate sensors were inserted into the south facing wall of the soil pit according to Figure 25. In total there were 16 soil moisture probes, 3 soil heat flux plates and 4 soil temperature probes (4 thermocouples per probe).

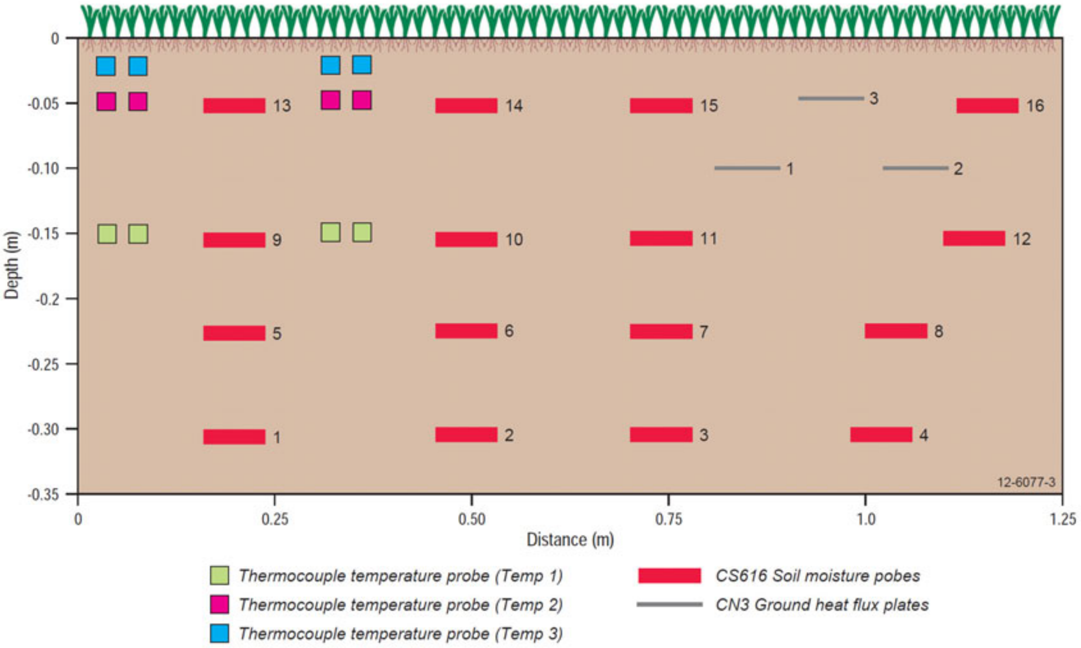


Figure 25: *Soil moisture and temperature probes before burial; (b) schematic of soil moisture probes, temperature probes and ground heat flux plates at EC tower*

The final stage of the installation was wiring all the instruments to the data logger. It was important to keep the wires as tidy as possible so mistakes could be easily fixed and ensure the wires were securely fastened. Some of the wires were a little short which made wiring difficult. The wiring charts can be found in Appendix L.

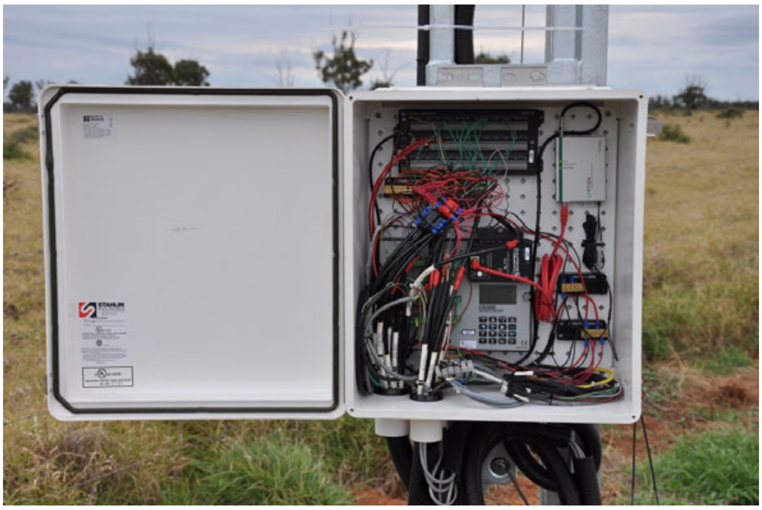


Figure 26: *Wiring for EC tower*

6 Post Installation Teething Problems

6.1 PROBLEMS IDENTIFIED DURING INSTALLATION

Despite tightening the connections to the regulators, which were damaged during transit and changing the tubing/fitting, some of the lines from the calibration cylinders were still leaking and had to be isolated; hence not all the calibration gases could be used.

Both Picarros were observed to have a lot of dust in the external foam filters sitting in front of the cooling fans after just 3 days operation. These filters require regular checking and a dust-buster for the container was purchased.

Raising and lowering the mast was difficult with the pulley system.

The 12V battery supplying power to the Campbell Scientific logger was also used to power up the UNIMAX modem; unfortunately the latter draws a lot of current during communication, and the power supply used to charge the battery could not match the required amperage.

Communication from the site, even using the Telstra NextG network (which has better coverage than other networks in that region) was intermittent at times.

6.2 FURTHER VISITS/ACTIVITIES AFTER INSTALLATION

6.2.1 Electricity connection

A local electrician was contracted to install a meter box on the shed at the Arcturus site, as required by the electricity company. The electrician was also requested to install a switch on the meter box to enable connection to a secondary power source such as a generator. GA opened an account with Ergon Energy for supply of electricity. Ergon Energy informed GA that the transformer had been installed on the electric pole at the site, but they could not supply electricity since a propriety switch was not in stock. On 30 June 2010, Ergon Energy informed GA staff that electricity was connected to the site.

6.2.2 Powering-up the Container

GA staff arrived at the Arcturus site on 6 July 2010 and observed that although an electric cable was connected from the transformer to a meter box on the container, there was no electricity to the container. A local electrician was organised the following day to inspect the shed as required by Ergon Energy. The local electrician switched on power to the container on 7 July 2010 after examining the electrical connections to the container, including the earthing.

On the 7 July 2010, all instruments in the container were turned on and CMAR staff provided instructions over the phone on powering up the Picarros and setting the gas cylinder regulators to the required pressures. The CFADS63 (CO_2/CH_4 Picarro) produced an erratic signal, but the signal from CBDS36 (CO_2 isotopes Picarro) was acceptable. A new DC power supply for the UNIMAX modem was installed, as the latter demanded a lot of power during communication. In addition, a solar panel that came with the Campbell Scientific Weather Station to charge the 12V battery during brown-outs was installed. Unfortunately communications to the site was erratic on that day.

Two flasks samples were collected the following day. When staff left the site the CFADS63 (CO_2/CH_4 Picarro) was still producing erratic signals, although it had improved from the previous day. The analyser eventually stabilised after a few days.

6.2.3 Brown-outs at the site and installation of new UPSs

There were several instances of brown/black outs at the site over the July - November 2010 period where the two UPS attached to the Picarro were unable to maintain adequate power supply. These UPSs were replaced with more powerful systems that could maintain the power supply for up to 4 hours. APC (American Power Conversion) Smart-UPS SURT1000XLI augmented with two battery packs (part # SURT48XLBP) providing dual wave conversion and approximately four hours of back-up power were installed on each Picarro instrument. The new systems can log and clean the quality of the power to the units, which appears highly variable (see Figure 27).

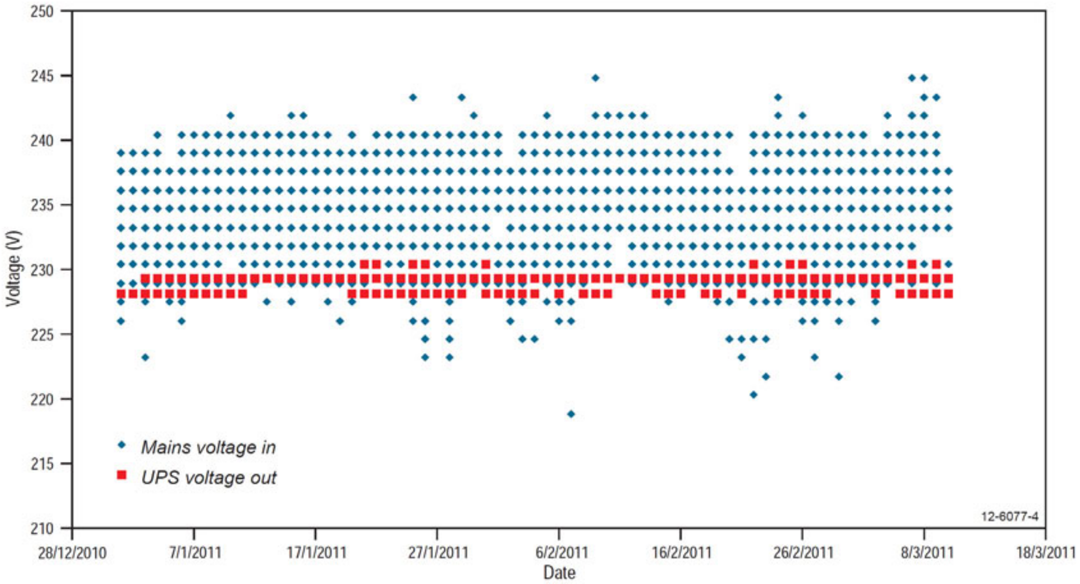


Figure 27: *Sample log of mains voltage supply to Arcturus from one of the new UPSs. The oscillations in mains voltage and the frequent excursions below 220V are likely to have been responsible for frequent interruptions to the analysers prior to the introduction of the new UPSs*

6.2.4 Brown-outs at the site and installation of second air-conditioner

While the installation of the new UPSs ensured that the Picarros performed more reliably, this in turn created a new problem. The air-conditioner installed for the container did not reliably self-start after a brown-out or power outages but the Picarros did. This led to a rapid build up of heat in the insulated shipping container and operating temperatures exceeding that suitable for computers (Figure 28). A more powerful and reliable second air-conditioner was hard-wired into the container to address this problem and was used as the master air-conditioner.

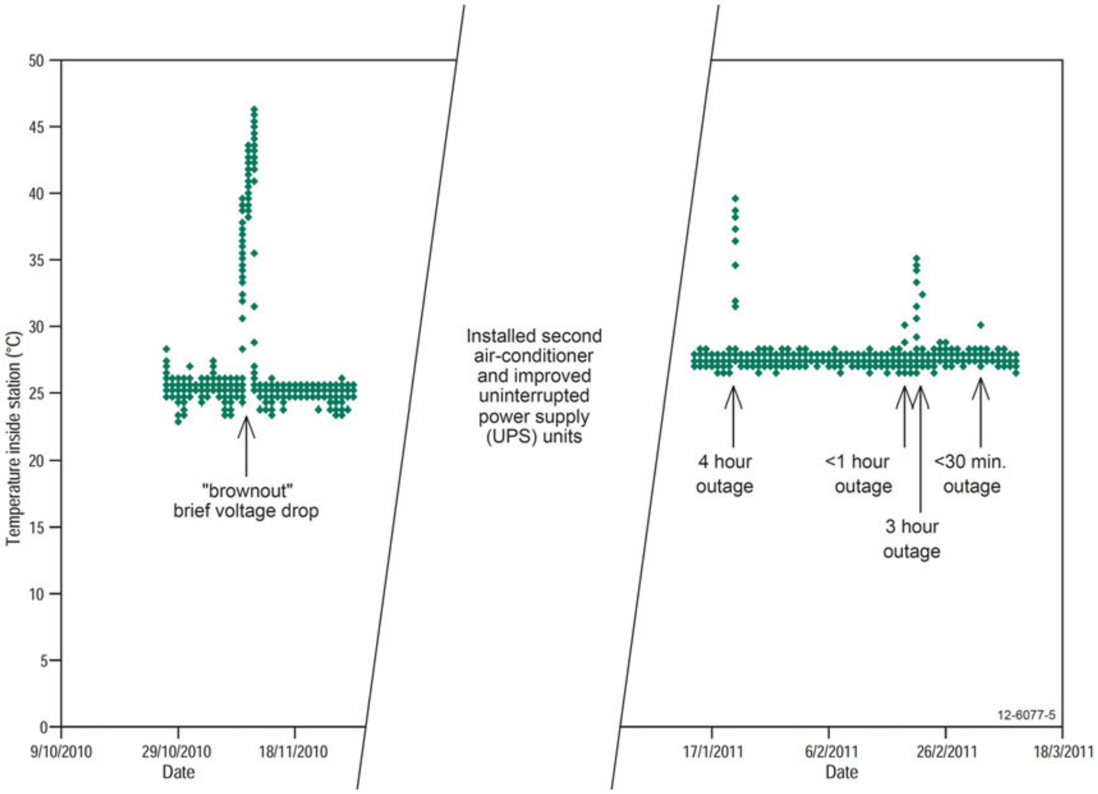


Figure 28: *Example of rapid increases in temperature after the air-conditioner failed to self-start following a power outage. The air-conditioner had to be manually restarted. After installation of the second air-conditioner and new UPS units, temperature reached 40˚C after 4 hour outage and quickly recovered to normal operating temperature after self-starting*

6.2.5 Replacement of the pulley system for the mast with a winch

It was identified that raising and lowering the mast presented a significant operational and safety risk to staff at the site. While raising and lowering the mast had been improved with a multi-pulley block and cleat system, it still required significant strength to do this in a controlled manner as per the standard operating procedures. Two people were required and it is essential to keep clear of the area in which the mast could fall. It was originally anticipated that the mast would not need to be lowered often; however, it was identified that the pulley system would need to be replaced with a winch. The pulley system of the mast was replaced with a handwinch, additional counterweights and a stabiliser bar and strength lines (Figure 29).

(a) (b)

(c) (d)

Figure 29: (a) Addition of winch to replace pulley block and cleat system for raising and lowering the mast; (b) additional counterweights bolted to end of mast to make lowering and raising the mast easier; (c) addition of stabilising bar and strength; (d) raising the mast using the winch

6.2.6 Communication drop-outs

During the initial months of operation, communication with the station was intermittent or very slow. The antenna was re-orientated towards an alternative tower and a request was lodged with the telecommunication provider, Telstra, to improve mobile signal for the station. Telstra technicians undertook capacity extension at the nearby tower. Communication is now much improved.

6.2.7 Leaky air-conditioner

During a site visit it was observed that the air conditioner had leaked water and had drenched the PC workstation, which was located on the bench beneath the air conditioner. This occurred when leaving the door to the container open during a hot, humid day. Despite attempting to dry out the PC, it could not be saved. It was packed up and freighted to CMAR (Aspendale, Vic) and replaced during a later site visit. An air conditioner repairer was contacted to examine the reverse cycle air-conditioning unit in the container. It transpired that the air conditioner drainage line had not been correctly installed and this was repaired.

6.2.8 Remote access to the EC tower

Remote access using LoggerNet was not initially possible due to a delay with acquiring a SIM card with the appropriate data plan. Before heading back out to the site to finalise the communications, all potentially relevant information was compiled including all relevant IP addresses associated with each modem, SIM card and mobile data account used for accessing the site via NextG. It was also important to note and confirm which ports and coms were assigned to the IP addresses and the logger and LoggerNet. This was to ensure all the IP addresses and port numbers associated with each account and modem are entered into the remote access (device configuration) of LoggerNet correctly. During a subsequent site visit, the laptop was directly connected to the logger and the modem alternatively to ensure configuration between the three devices matched and successful remote access was achieved.

6.2.9 Wiring at EC tower

During a subsequent site visit in June 2011 it became apparent that the wiring was not to a high standard and some data had been lost due to wires coming loose from the wiring board. Unfortunately all LI-7500A data had been lost since initial site setup (April 2011) and 2 months worth of data had been lost. This problem would have been spotted earlier if remote access to the data had been possible. During this second site visit, the wiring was tidied and more securely fastened.

6.2.10 Logging problems with the CH_4 sensor

The LI-7700 methane sensor was installed together with all other EC equipment. The instrument appeared to be functioning correctly when monitored using the LI-7700 software using a direct connection via the instrument box. The sensor was not, however, tested prior installation because updates to the logger software program were required and had not been finalised.

7 Cost

A summary of contract services and items purchased for both the monitoring station and EC tower are shown in Tables 3 and 4 below. Costs include post installation modifications, including new UPSs, replacement computer and second air-conditioner for the station. Costs do not include staffing or travel costs.

Table 3: Summary of expenditure for fit-out and installation of the baseline monitoring station

CAPITAL COST	COST	NOTES
Electricity connection & supply	$5,408	
Site preparation	$1,960	
Container, fitout and installation	$40,886	Includes cost of container
2 Picarro instruments	$115,000	
Gas monitoring ancillary equipment	$41,260	Includes UPSs and regulators
Flask sampling equipment	$23,200	
Communications	$3,921	
Fibre-glass mast & fittings & winch	$3,209	
Miscellaneous	$1,878	Mostly hardware
Weather station	$10,131	
TOTAL CAPITAL COST - STATION	**$246,853**	

ANNUAL OPERATING COSTS	COST	Excluding staff time and travel costs for calibration/ maintenance, sample analysis, provision of gases, data calibration and management – a major cost component
Annual licence fee for access to land	$5,200	
Electricity charges annual	$1,400	
NextG Broadband Internet annual plan (6GB)	$1,000	
GoToMyPC annual subscription	$420	
Freight	$1,200	
Replacement reference cylinders	$1440	
Consumables/minor repairs	$3,000	
TOTAL	**$13,660**	

Table 4: Summary of expenditure for installation of the EC tower

CAPITAL COST	COST	NOTES
Tower and solar power		
Tower and winch system	$2,146	5.5m tall tower
Site preparation	$714	Including delivered concrete
Lightning protector equipment	$1,294	
Fabricated mounting arms, electrical and brackets	$1,163	
Solar panels, charge controller and batteries	$2,636	
EC equipment		
GHG Package 1	$82,285	Includes LI-7700, LI-7500A and interface units
CSAT3 3-D sonic anemometer	$12,260	
CR3000 data logger and base	$4,460	
Kipp and Zonen net radiometer	$11,600	
Vaisala temperature and RH probe	$998	
Gill 2-D sonic wind sensor	$3,160	
3 averaging soil thermocouple	$1,020	
16 water content reflectometer	$4,160	
Fibreglass data logger box	$620	
Sensor cross arm	$150	
Mounting poles/pipes (combined)	$265	
10 plate gill radiation shield	$310	
Channel relay multiplexer	$980	
Digital cellphone kit NextG	$1,000	
Custom CS program	$1,500	
LoggerNet program	$780	
TOTAL CAPITAL	**$133,501**	

8 Communications, data management and calibration

8.1 COMPOSITION INSTRUMENTATION

Control of the analysers and data retrieval occurs via the Telstra-3G Network. The remote access software, GoToMyPC is installed on the ‘supervisor’ PC at Arcturus. From the supervisor PC, pc-Anywhere software allows the user to access each of the instruments.

Several times per week, a CMAR staff member logs on to the instruments to check that they are operating and address any problems that may have occurred. The analysers have been programmed to measure their reference standard daily (to track instrument drift), but this can be altered manually if the need arises. Initiation of a calibration run, comprising the repeated measurement of each of the calibration standards (as a set of pyramids; low, ambient, high, reference, high, ambient, low) occurs manually, typically once a month. Details of the calibration and reference standards are given in Table 5 below. The measurement of these standards allows the data to be tied back to internationally recognised mole fraction scales, maintained at CMAR’s GASLAB in Aspendale through a set of primary standards and rigorous intercomparison activities with other laboratories (in particular NOAA’s Earth Systems Research Laboratory, Boulder, Colorado) worldwide that make atmospheric trace gas measurements on these scales.

A schematic outline of data handling is shown in Figure 30. The analysers operate continuously, generating daily data files containing 45 and 63 parameters respectively for CFADS63 and CBDS36. Each day, these (large) files are automatically compressed and copied to the local ‘supervisor’ PC. Currently on a weekly basis (soon to become an automated daily task) the compressed files are transferred via wireless network to CMAR’s server, gl-as, located at Aspendale.

Every month the raw data are processed in a number of steps. Firstly, because the instruments are sampling wet air, a water vapour correction (Chen et al. 2009) is applied to the reported CO_2 and CH_4 concentrations to transform the data into standard dry air mole fractions and to account for pressure broadening induced by H_2O absorption lines lying close to the measured CO_2 and CH_4 lines. Secondly, the dry air mole fraction data are then transformed onto the appropriate mole fraction scale by application of the calibrated factors obtained by measurement of the calibration standards.

Finally, the calibrated data are then reduced to minute and hourly averages and the number of ancillary parameters are reduced from 45 and 63 to 8 and 10 for CFADS63 and CBDS36, respectively. These calibrated, averaged data files are placed back on the server.

It is worth noting that while drift and calibration performance of each of the analysers is being tracked, automatic correction for instrument drift is not currently implemented. We are in the process of operationalising a database to perform this function. Consequently, the calibrated, averaged data currently reported should be considered an interim product. Moreover, once drift and calibration corrections are automatically implemented, the data should still be considered provisional as they may be updated by CMAR to improve quality, internal consistency or alignment to a calibration scale as new or improved information becomes available. This is particularly important to note for these instruments, which are a new technology that the atmospheric measurement community are still developing. The water vapour correction and, in particular the calibration requirements of the CO_2 isotopes instrument, are under active investigation by both the instrument manufacturers and users of the instruments.

Table 5: Reference and calibrations standards attached to each analyser. CO_2 mole fraction is reported on the WMO 2007x CO_2 scale, CH_4 mole fraction is reported on the NOAA04 CH_4 scale and $\delta^{13}CO_2$ is reported on the VPDB-CO_2 scale.

	UNIVERSAL ANALYSIS NUMBER	TANK ID	CO_2 (PPM)	CH_4 (PPB)	$\delta^{13}CO_2$ (‰)
CFADS63 reference	20100776	CA08019	383.60	1730.1	-8.265
CFADS63 low	20100777	CC324355	366.07	1640.4	-8.448
CFADS63 ambient	20100780	CC324543	385.29	1731.4	-8.310
CFADS63 high	20101778	CA08041	452.83	1827.4	-8.038
CBDS36 reference	20100783	CC324491	384.55	1729.0	-8.281
CBDS36 low	20100782	CC324555	365.25	1720.8	-7.649
CBDS36 ambient	20101784	CC324533	384.89	1729.9	-8.287
CBDS36 high	20100781	CC324524	421.09	1728.8	-10.684

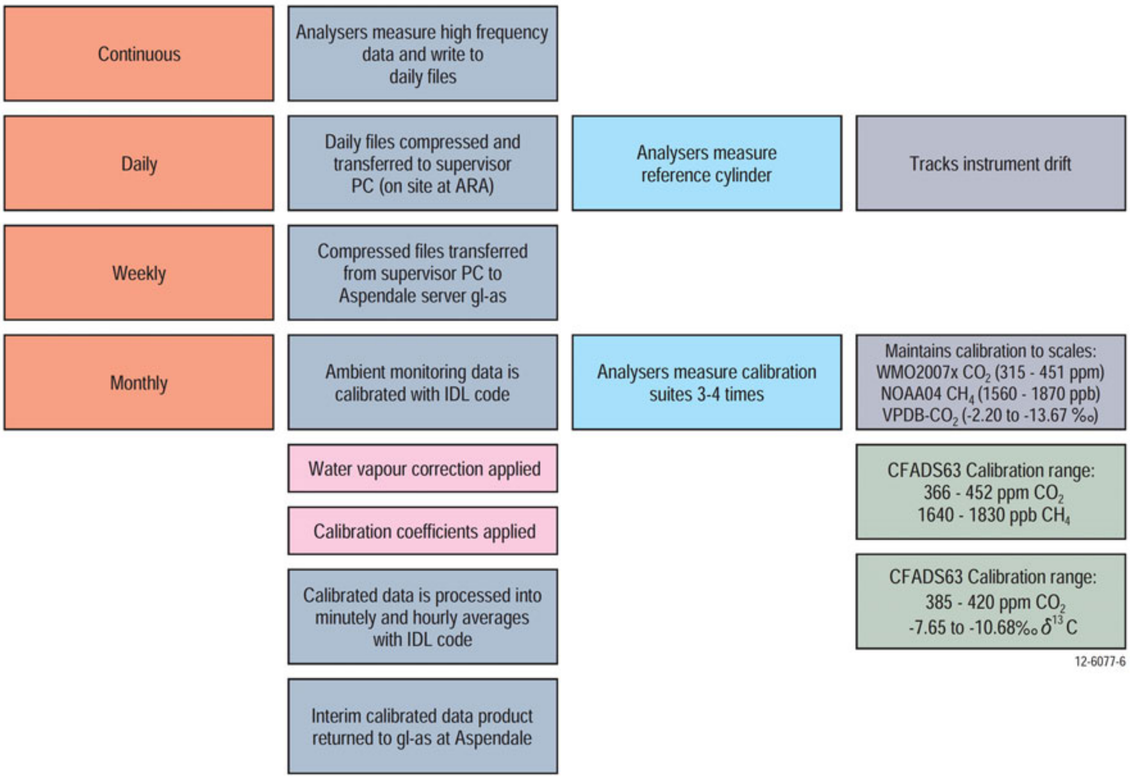


Figure 30: *Schematic representation of the concentration data acquisition, calibration and stewardship protocols*

8.2 EC INSTRUMENTATION

Communication with the EC tower is possible using LoggerNet and a MaxWan account that communicates with the modem in the data logger box. Data can be transferred to and from the data logger to the laptop on which LoggerNet is configured to match the site. Only the half hourly averaged data can be downloaded in this manner as the 10Hz data is too large for remote access download. The tables that are downloaded on a weekly basis via remote access are:

- Emerald_CR3000_RemoteAccess_slow_core.dat
- Emerald_CR3000_RemoteAccess_slow_flux.dat
- Emerald_CR3000_RemoteAccess_slow_met.dat
- Emerald_CR3000_RemoteAccess_slow_rad.dat

The 10Hz data (approximately 20MB per day) was originally stored on the data logger and downloaded manually each site visit. During the site visits, the data was downloaded via LoggerNet using a direct connection to the data logger and all the 10Hz data was deleted off the 2 GB flash card. The capacity of the flash card was no more than 8 weeks worth of data.

A wireless network has been subsequently established in December 2011 between the EC tower and the main station. It consists of a wireless access point in the container with high-gain directional external antenna and a wireless bridge located in the logger box at the mast, which links the CR3000 and both LICOR sensors directly to the container wired network. The Unimax modem/router at the tower provides DHCP service for mast instruments, datalogger, and wireless network hardware, as well as a backup communication pathway. The new Wi-Fi network allows real-time access to the CR3000 data streams (10Hz time series data from the anemometer and CO_2 and CH_4 sensors can be copied to a PC in the container). The 2GB data storage module on the CR3000 data logger is now a data backup device.

Ultimately, EC data has four levels of processing, however only the first three levels are required for TERN (Terrestrial Ecosystems Research Network; www.tern.org.au). Python scripts and training were provided to Tehani Kuske (GA) by Ray Leuning from CSIRO, James Cleverly from UNSW and Peter Isaac from Monash University. These processing methods are applied to the 30min ASCII data files retrieved directly from the site.

Level 1: (Control File) Calls all 30min averaged data files (covars, met, soil and radn) and their metadata and does preliminary quality checks on the data, including range checks, diurnal checks and applies dates and/or times which should be excluded (due to instrument failure or site maintenance shutdown).

Level 2: (Processing and corrections using results from Level 1 processing) All data corrections are applied during Level 2 processing including linear corrections for Ah7500 and Cc7500, coordinate rotation corrections, frequency and sensor separation corrections, WPL corrections and calculated fluxes.

Level 3: Data from Level 2 is then QC’ed again (similar to the Level 1 procedure) and a new CDF file is created and ready for upload to the OzFlux/TERN network site.

Level 4: Gapfilling Procedures: usually applied to rainfall and other meteorology and fluxes using data from other sensors or alternative sites nearby.

Data is currently processed to Level 3 for upload to the OzFlux/TERN website (www.tern.org.au)

9 Lessons learned

The installation of the Arcturus baseline monitoring station took some 16 months in total, from project conception and the first stakeholder meeting to deployment and powering up the station in July 2010. This included 8 months for the stakeholder consultation process and formalising the agreement between CSIRO and GA. An additional 3-4 months to the stakeholder consultation process was required for selecting the site and negotiating a site access agreement with the landowner.

Risks to the project were identified early, monitored regularly and minimised where possible. The key risks to the project were identified as follows:

Delays in obtaining site approvals: the stakeholder consultation and landowner negotiation process could potentially drag out and impact on the major project milestone of collection of one year's worth of data (between July 2010 – June 2011); 9 months was originally allowed for this process, which took 12 months in total;
Delays in obtaining equipment: delivery of the Picarro instruments had a lead time of 6-9 months; actual delivery time was 5 months;
Delay in power connection: once a site has been identified, installation of a transformer and connection to a power supply in a remote area could take up to 12 months; actual power connection time was 7 months after negotiation to a high priority connection;
Loss or damage to field equipment: vandalism or fire could seriously delay the project due to long lead time for replacement equipment;
Insufficient funding: significant additional costs would be incurred if a powerline to the site or large solar/wind remote power system was required (>$100k).

The risks were minimised through good site selection (e.g. near an existing powerline; away from thoroughfares; above flood plains) and by starting the ordering and stakeholder consultation process early. Despite the well executed site selection at the local level, the broader context for the station changed with ZeroGen project not continuing beyond its exploration phase. It raises the issue of the risks involved with the early deployment of baseline monitoring equipment during the assessment stage of a geological storage project. Nevertheless, the station has been designed so that it can be easily relocated if necessary.

It is important to collect sufficient atmospheric baseline data before CO_2 injection to understand the local ecological and large regional point source emissions and their contribution to the CO_2 baseline. In the order of 2-3 years worth of data is ideal. Given a realistic lead time of 12 months for the construction and deployment of an atmospheric station similar to Arcturus, it is recommended that the process for the installation of an atmospheric monitoring station begin shortly after the final investment decision (FID) is made. This would provide sufficient time before plant operation (scoped to be 4 years for the ZeroGen project). There will be significant emissions associated with construction of the plant, which would limit the suitability of certain wind sectors for baseline measurements, but provided the atmospheric station is nominally 'upwind' of the plant, useful baseline CO_2 data from ecological sources, in particular, could be collected.

The Picarro instruments performed well and restarted reliably despite multiple brownouts and blackouts. Temperature management inside the container turned out to be a key operational issue and required additional redundancy (two air-conditioners) and independent temperature monitoring inside the container via a sensor connected to the solar powered weather station, which could be accessed remotely and independently of the main station.

The present project was arguably executed too early for baseline monitoring for the ZeroGen Project, although its primary purpose was to address broader atmospheric monitoring issues like field-testing of new technology and development of atmospheric monitoring methods for CCS projects. Also, it has emerged that the Arcturus station could be useful in estimating the emissions of methane from coal mining activities in the area. These topics are the subject of an accompanying report due for release in late 2012.

10 Acknowledgements

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Appendices

APPENDIX A: DESCRIPTION OF SITE SELECTION CRITERIA

The following sections provide a summary of the selection criteria for evaluating a preferred atmospheric monitoring site.

1. Likelihood and size of future CO_2 storage in the region

Offshore GHG storage acreage areas were released in March 2009 by the Australian Government in: Gippsland Basin, Torquay Sub-Basin, Otway Basin, Vlaming Sub-basin and Petrel Sub-Basin (RET, 2009). In addition, proponents have expressed interest in onshore CO_2 storage sites at Moomba, in the Cooper Basin (Santos, 2009); in the Surat (Wandoan Power, 2009); and in the Denison Trough (Tarr, 2009).

The size of acreage released or estimated storage capacity and the likelihood that storage would occur should be priority considerations for selecting an appropriate site for GHG monitoring. Sites in which storage is likely to first occur should be given even higher priority for monitoring. Table 6 below lists available information on the potential storage capacity and likelihood of storage commencing for short-listed atmospheric monitoring sites.

Table 6: Summary of basin storage capacity estimates (P50), likelihood of storage and earliest start date for storage in basin for three short-listed atmospheric monitoring sites (RET, 2009)

EXAMPLE MONITORING SITE	BASIN	BASIN STORAGE CAPACITY ESTIMATE P50 (GT)	LIKELIHOOD/EXTENT/DATE OF STORAGE
Surat	Surat	10.3	unknown
Fernlees	Denison	3	exploration stage, storage planned for 2015
Moomba	Cooper	7.9	postponed

2. Suitability of the location in providing baseline atmospheric information for monitoring of CO_2 storage and other GHG sources

Fetch and Flux Footprint

The “fetch” is defined as the distance upstream of a measurement site, receptor site, or region of meteorological interest that is relatively uniform. A measurement site in the centre of large fetches with uniform distribution of wind from all directions will reduce errors in concentration measurements and flux measurements (if required). When measuring the impact of potential emissions from a source such as a GHG storage site, it is preferable for the source to be located upwind in the direction of the prevailing winds, in addition to being within the fetch. Estimated fetches for all the sites would need to meet the minimum requirement for a measurement height of 10 metres; hence all the sites could be given equal rankings for this criterion.

The ‘footprint’ is specified as the relative contribution from each element of the upwind surface area source to the measured concentration or vertical flux (Schuepp et al. 1990). This is an important criterion for onshore sites, which may require additional eddy covariance flux measurements to interpret significant ecological contributions to CO_2 measurements. A measurement site in the centre of large fetches with uniform distribution of wind from all directions will reduce errors in flux measurements, and a large percentage of measured flux footprint would lie within the fetch. At a canopy height of 12 m the minimum required upwind fetch over water is 3 km; over grass it is 1.5

km, and over trees it is 0.32 km (ASCE 1996). The fetch for each site is estimated by examining the uniformity of its environs.

Current and Future land use:
The three short-listed atmospheric monitoring sites can be prioritised according to land use such as heritage, tourism, commercial or private or agricultural use, which have the potential to impact on future monitoring activities at the site.

Proximity to a BoM weather station:
Example sites close to BoM Automatic Weather Stations (AWS), which have historical and high quality 1-hour average meteorological data, should be given higher priority. Meteorological data from the BoM AWS will be used to model the impact of potential sources at the site.

Wind climatology/ prevailing winds
Munger and Loescher (2004) recommend that a measurement tower should be sited so as to maximize the time with winds blowing from a representative land cover type, and with the longest possible upwind fetch.

Wind rose data was used to establish whether prevailing winds were blowing from preferred directions at the sites.

Table 7: Summary of location parameters that could influence site selection

SITE	FETCH km	MINIMUM REQUIRED FETCH km	LAND USE TYPE	DISTANCE OF NEAREST BOM METEOROLOGICAL STATION TO SITE BOM_AWS	km	WIND CLIMATOLOGY
Surat	15	0.3	Private	ROMA	75	TBA
Fernlees	3	0.3	Private	EMERALD AIRPORT	33	TBA
Moomba	5	0.3	Commercial	MOOMBA AIRPORT	*80	TBA

*Based on distance from Dullingari site

3. Natural and anthropogenic GHG sources that could affect the detection of new GHG signals

Ecosystem emissions
CO_2 fluxes from the local and regional ecosystem can have a significant impact on the background CO_2 variations and therefore the ability to detect and quantify other sources. Sites with sparse vegetation should therefore be preferred. Scoring for this ecosystem emissions criterion can be based on forest cover obtained from Landsat satellite data (DCC 2004) and mapping of vegetation type (BRS, 2004). Some of the forest cover data are available at a species level for selected areas (e.g. State Land and Tree Survey).

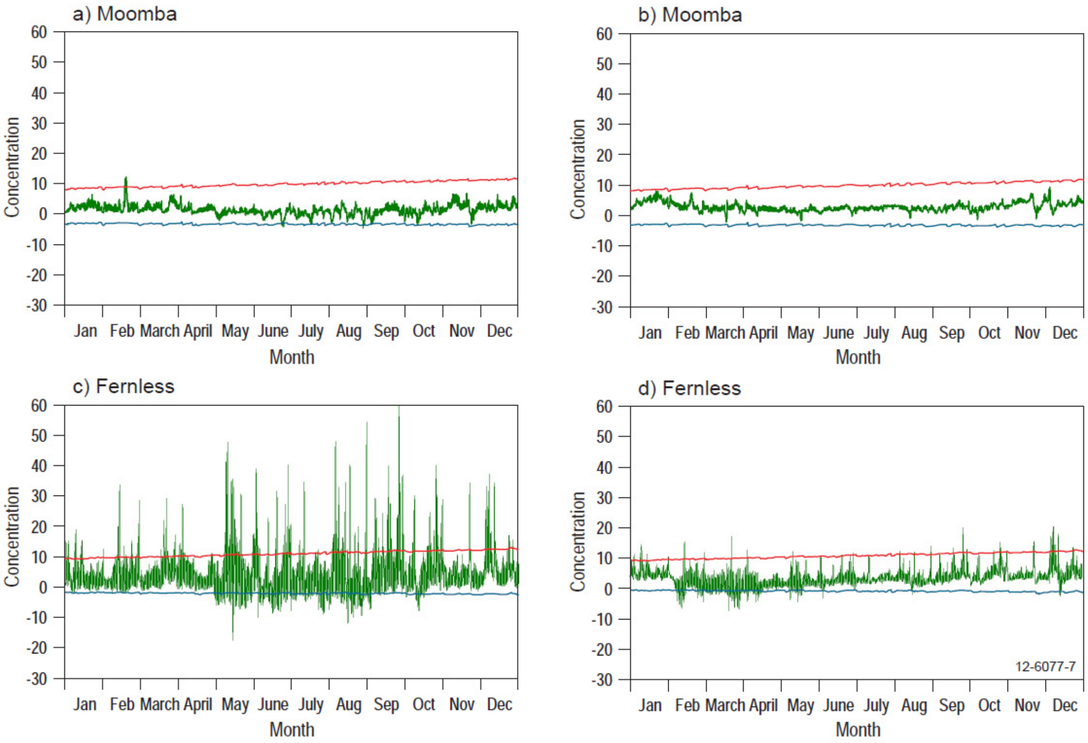


Figure 31: *Comparison of the regional atmospheric model simulations of CO2 variations for Moomba (SA) and Fernlees (Qld) sites. Simulations are over a year (2003) and consider terrestrial biosphere fluxes (green), ocean fluxes (blue) and global fossil fuel emissions (red), using the CSIRO CCAM model and fluxes from Law et al. (2008). Two different biosphere models are used (CASA model left column, SiB model right column). Model horizontal resolution is 200 km and concentrations are for 40 metre height. The results are for the nearest model grid point to the site. Simulations for other sites (including the CO2CRC Otway site) can be found in Appendix G*

The ecosystem contribution to the local CO_2 variations can also be simulated by atmospheric models coupled with terrestrial ecosystem models. Figure 31 shows the predicted CO_2 variations over a year at the model grid point nearest to the locations in Table 5, using the CCAM global atmospheric model and large scale fluxes described by Law et al (2008). The effects of the terrestrial ecosystem fluxes, the ocean fluxes and global fossil fuel emissions are given as concentration differences from the mean background. The ecosystem fluxes are derived from process models and gridded vegetation cover and type. The ecosystem dominates the local CO_2 variations at each site. Sites with sparse vegetation and coastal sites have smaller ecosystem variations. Fossil fuel combustion causes only small variations in these simulations as the main sources are far away from the modelled grid point. When selected for winds only from the ocean sector, coastal CO_2 records display almost no ecosystem influence.

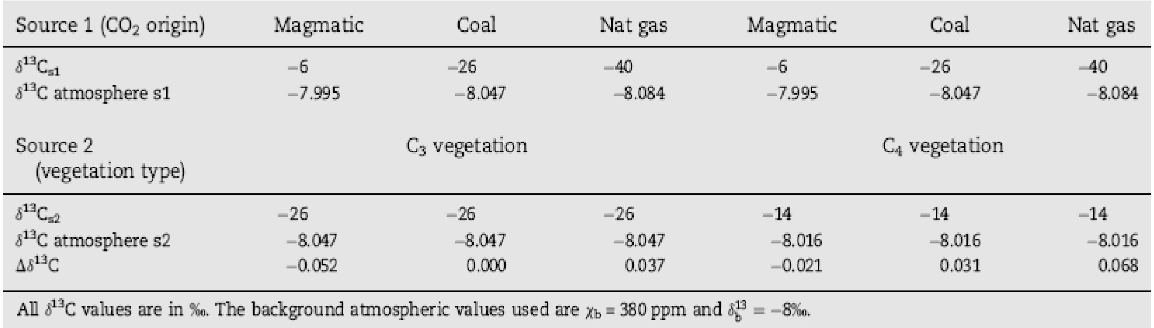
Source discrimination from background ecosystem (woodlands, shrublands, plantations, grasslands, arid region, etc)

One of the main challenges in atmospheric monitoring of geological storage of CO_2 is to discriminate leaked CO_2 from the large and variable background. This can be met by quantifying the ecosystem and anthropogenic fluxes by measurement or modelling (Luhar et al., 2009) or by using naturally-accompanying or injected tracers (Loh et al., 2009; Etheridge et al., 2011) .

The type of photosynthetic pathway dominant in the local ecosystem (C_3 or C_4) can affect the degree to which the source emissions such as from GHG storage can be differentiated from background CO_2 variations, using measurements of the stable carbon isotope, ^{13}C, in CO_2 (Etheridge et al., 2005)

As a tracer, $^{13}CO_2$ has the advantage of being naturally occurring and therefore does not require introduction to the injected fluid. Continuous measurement technology suitable for field deployment is improving and air samples can be collected and measured in laboratories. Measurements of $^{13}CO_2$ can be used to trace CO_2 from different types of fossil sources in backgrounds of C_3 and C_4 ecologies (Leuning et al. 2008). Some combinations of source and background enable $^{13}CO_2$ to act as a useful tracer (see Table 8 below). Sites with such combinations (i.e. coal and C4 vegetation) should be rated highly. C3 is widespread in trees, shrubs and cool region grasses, while C4 photosynthesis is dominant in tropical and savannah grasses.

Table 8: Calculations of the change in the $\delta^{13}C$ of atmospheric CO_2 per 1ppm CO_2 mole fraction increase ($\Delta\delta^{13}C$), resulting from a storage leak (source 1, from three types of carbon origin; $\delta^{13}C_{s1}$) or from terrestrial ecosystem emissions (source 2, from two dominant vegetation types; $\delta^{13}C_{s2}$) (Leuning et al., 2008)



Source 1 (CO_2 origin)	Magmatic	Coal	Nat gas	Magmatic	Coal	Nat gas
$\delta^{13}C_{s1}$	−6	−26	−40	−6	−26	−40
$\delta^{13}C$ atmosphere s1	−7.995	−8.047	−8.084	−7.995	−8.047	−8.084
Source 2 (vegetation type)		C_3 vegetation			C_4 vegetation	
$\delta^{13}C_{s2}$	−26	−26	−26	−14	−14	−14
$\delta^{13}C$ atmosphere s2	−8.047	−8.047	−8.047	−8.016	−8.016	−8.016
$\Delta\delta^{13}C$	−0.052	0.000	0.037	−0.021	0.031	0.068

All $\delta^{13}C$ values are in ‰. The background atmospheric values used are $\chi_b = 380$ ppm and $\delta_b^{13} = -8$‰.

Information on land use area and vegetation for the proposed monitoring sites can be obtained from the Bureau of Rural Sciences (BRS, 2004). Most of the sites are located in areas of native forests and woodlands, native shrublands and heathlands, desert, or native grasslands and minimally modified pastures. There are only very limited built-up areas in the vicinity of any of the sites.

Impact of anthropogenic CO_2 sources:

Sites impacted heavily by GHG emissions from anthropogenic sources such as motor vehicles from a nearby highway, residential areas, industries or bush fires should be avoided, since high CO_2 emissions from these sources will reduce the detection of GHG in the canopies. Carbon monoxide (CO) and oxides of nitrogen (NOx) emissions data from the 2007-2008 National Pollutant Inventory (DEWHA, 2009) can be used as indicators of emissions from combustion sources to score the potential impacts of anthropogenic GHG emissions on the sites.

Fossil fuel CO_2 emissions are also included in the CCAM model simulations (Figure 31 and Appendix G). The spatial emissions are from the EDGAR database (Olivier and Berdowski, 2001). These have 1x1 degree spatial resolution and may not include small local sources that could cause significant signals if close enough and during suitable meteorological conditions. Differences between site fossil fuel simulations thus stem mainly from proximity to major population centres and industry.

Opportunity to provide regional GHG data from presently data sparse region

A study by CSIRO predicts that an additional atmospheric monitoring station located in central or northwest Australia would provide data that could significantly strengthen current continental carbon flux modelling, as compared with one located in the southeast or southwest coastal regions (Law et al., 2004). The potential contribution of the sites to strengthening continental flux modelling can be scored based on the results of the CSIRO model. Based on this analysis, measurements at Arcturus would provide a 12% reduction in uncertainty in the Australian continental emissions.

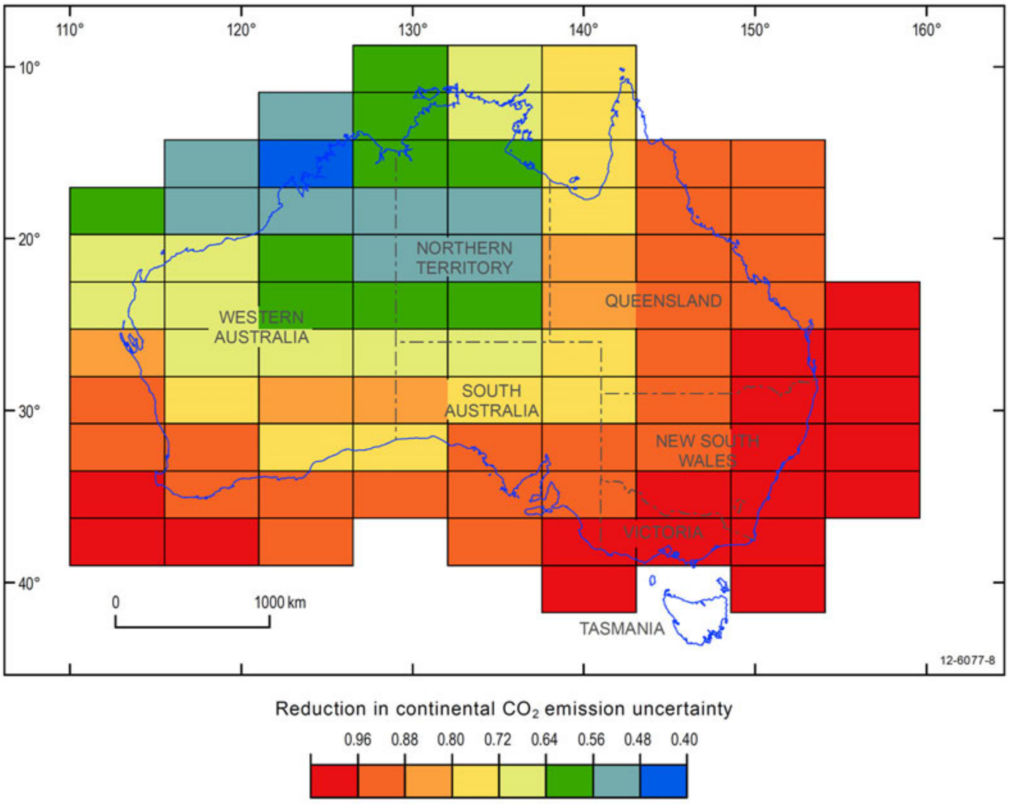


Figure 32: *Reduction in the uncertainty of Australian continental CO_2 emissions from the inclusion of an additional continuous atmospheric CO_2 monitoring site into a chosen grid point (colour scale represents ratio of uncertainty of the new network to existing network) (From Law et al., 2004)*

4. Availability of Infrastructure

Power supply

Solar panels are often used to power equipment located in remote locations, however, it is estimated that the total amount of power required for the GA-CMAR atmospheric monitoring station design is about 2.7kW, which may be met with solar panels augmented with a power generator and storage batteries. This would add substantial costs, and more importantly, data might be compromised by exhaust emissions from the power generator. Much of this power requirement is for air conditioning, which may not be necessary for cool southern coastal sites.

Fortunately most of the example sites nominated have power hence there will be no need for solar power. Point Hicks, however, is remote and uses a power generator. Although there are plans to augment the power supply at Point Hicks with solar cells, these are long term plans that may not coincide with the project plans for this project.

Powered sites are a distinct advantage for instrument operation and should be given priority.

Support staff

It would be a powerful advantage to have access to support staff that work or live near the site, to perform simple tasks such as resetting modems or basic operations of monitoring equipment.

Accessibility for operations, showcasing

Easy access to the site for operators is essential. Many of the sites will be remote and will need four-wheel drive vehicles. Access will be required year round (every 2 months for calibration) and hence it is critical that the risk of extended road closure after rain is minimised.

Cost

A major expense for running a site will be the costs of travel and accommodation for staff to calibrate and maintain instruments. However, the difference is only a few hundred dollars per trip for the various short-listed monitoring sites. An important consideration will be the cost of deploying flux measuring instruments and towers at inland sites if these are found necessary to interpret the greenhouse gas concentration measurements. Inland baseline monitoring sites are likely to require additional measurements of terrestrial CO_2 fluxes to quantify the large and variable contribution from the local ecosystem. This might require eddy covariance flux tower(s) and possibly a network of soil flux measurements, combined with modelling of the ecosystem fluxes and other CO_2 sources. Alternatively, an elevated inlet (such as from a tower taller than the default 10 m mast) might be sufficient.

Security

Security at the short-listed monitoring sites is very important and remote sites will be vulnerable to security risks, which could result in the loss of equipment from theft or vandalism. The sheds will be fitted with padlocks and lock boxes and a video camera could be installed on the mast. Sites with live-in caretakers, such as Point Hicks, would be preferred.

Telecommunications

Most of the short-listed monitoring sites have access to the Telstra Next G network to enable remote data download. However, sites with land lines should be given higher priority since it would be less expensive and more reliable to observe real time data.

Towers

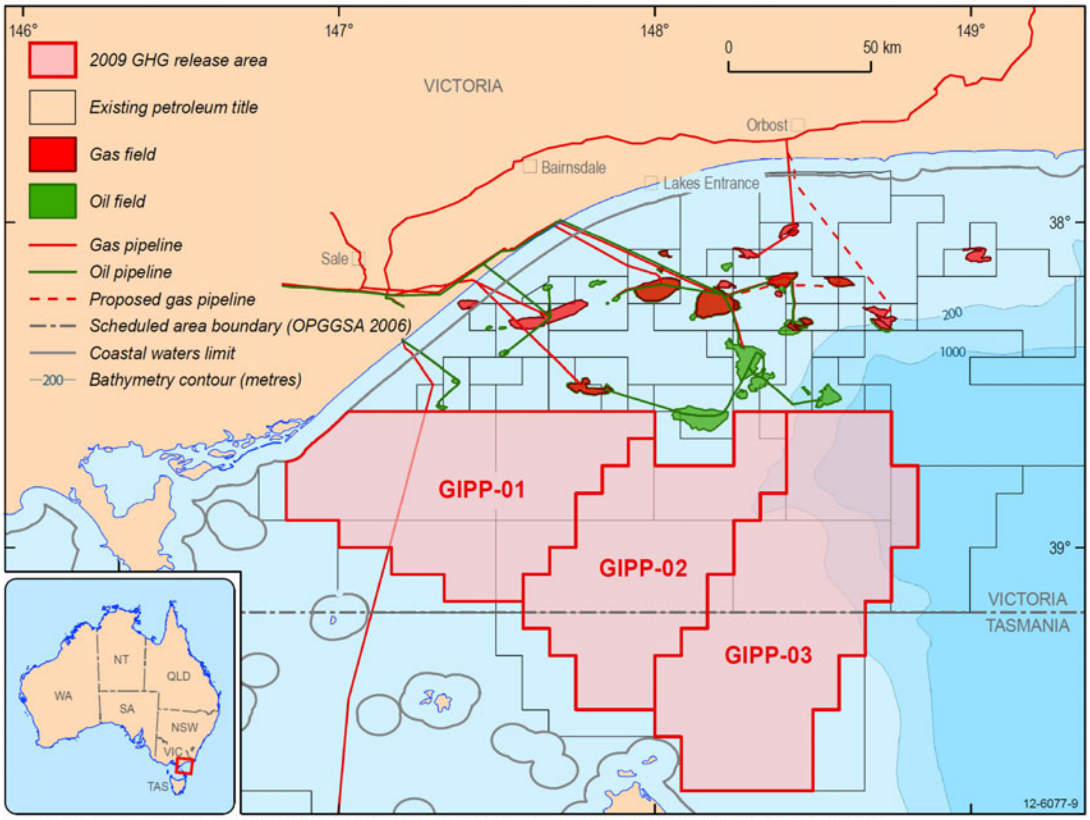
Several of the short-listed monitoring sites have high towers (40 – 120 m) owned by third parties, and within distances of 10 km, however, there is no guarantee that access to the towers will be granted. The availability of tall towers especially at inland sites can be ranked using information from maps provided by the National Geographic Information Group, Geoscience Australia.

Table 9: Telecommunications and tower heights for the short-listed monitoring sites

	POWER SUPPLY	SUPPORT STAFF	ACCESS	ADDITIONAL COSTS	SECURITY AT SITE	PHONE	*TALLEST TOWER HEIGHT
SITE	TYPE	AVAILABLE	EXTENT	ACTIVITY		TYPE	m
Surat	Mains	No	Medium	Flux Monitoring	Low	Landline	70 @ 8 km
Fernlees	Mains	No	Medium	Flux monitoring	Low	Landline	90 @ site
Moomba	Mains	Yes	Low	Flux Monitoring	Good	Landline	100 @ 23 km

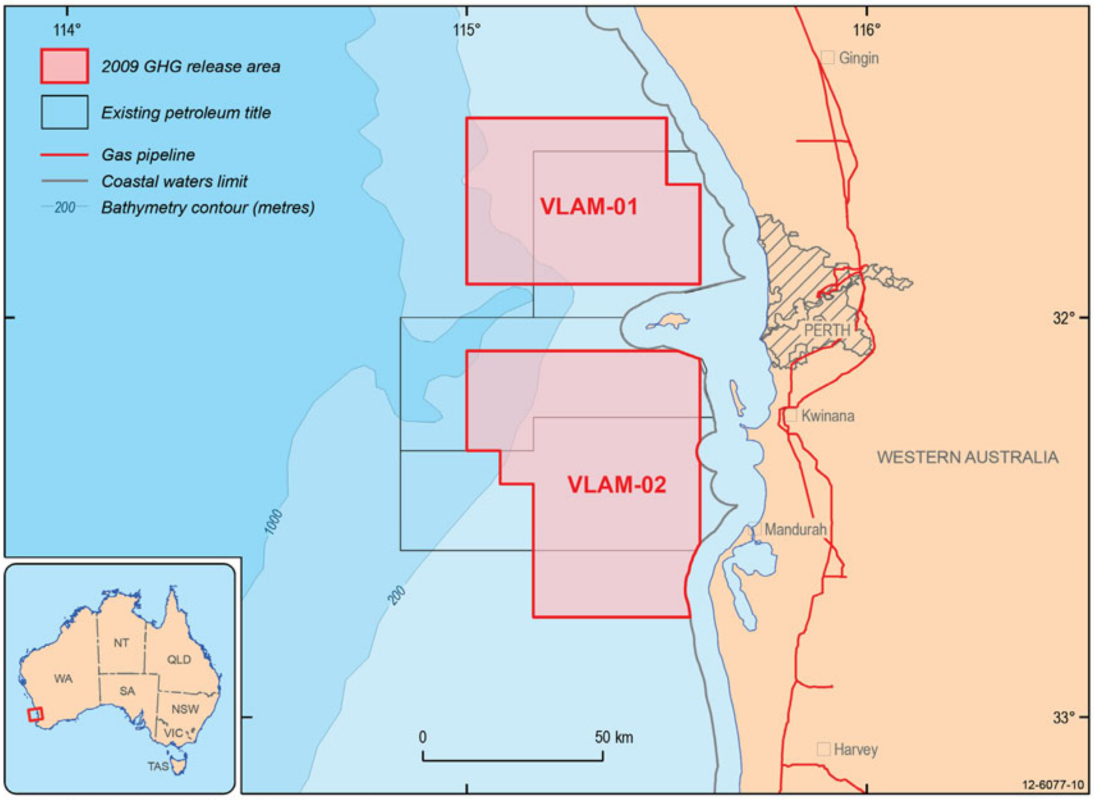
APPENDIX B: POTENTIAL GREENHOUSE GAS STORAGE SITES

Potential Offshore GHG Storage Sites (RET, 2009)



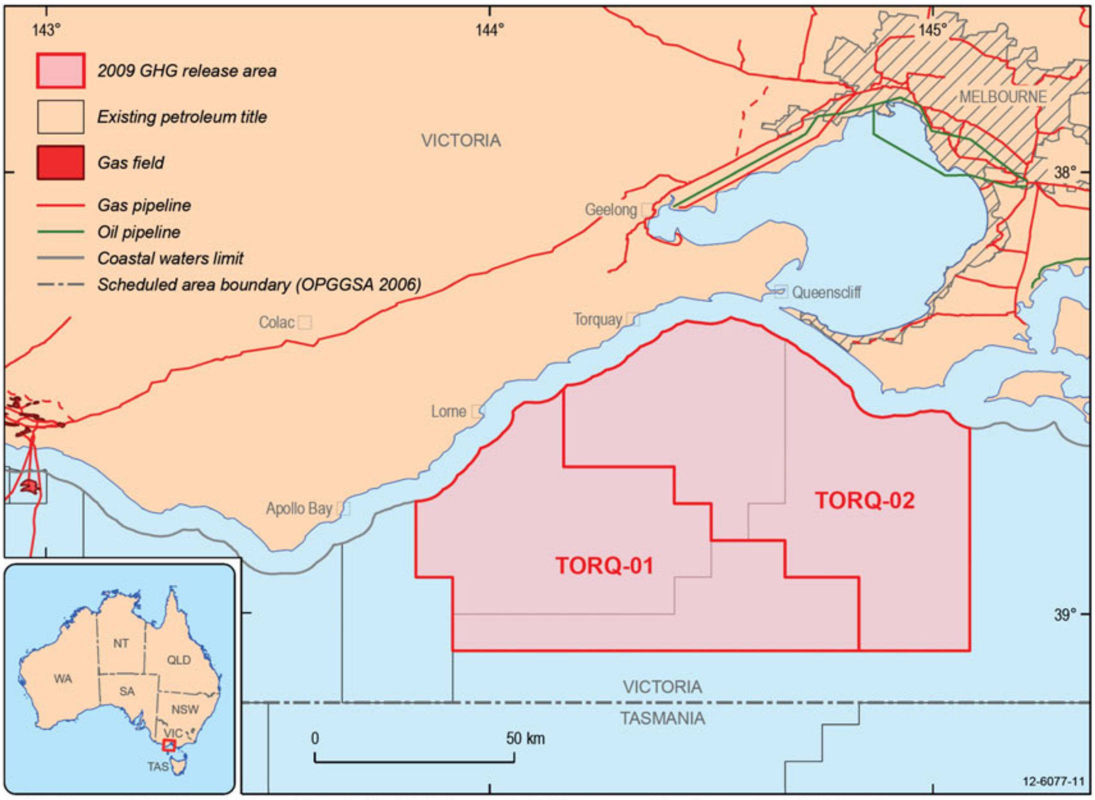
Field outlines supplied by Encom Petroleum Information Pty Ltd. Field outlines in GPinfo are sourced from the operators of the fields only.
Outlines are updated at irregular intervals but with at least one major update per year.
The Coastal Waters shown on this map are indicative only.
A precise determination of the Coastal Waters will be determined at the time of issue and included in the permit boundary as a Metes and Bounds determination.

Figure 33: *GHG storage acreage release area: Gippsland Basin*



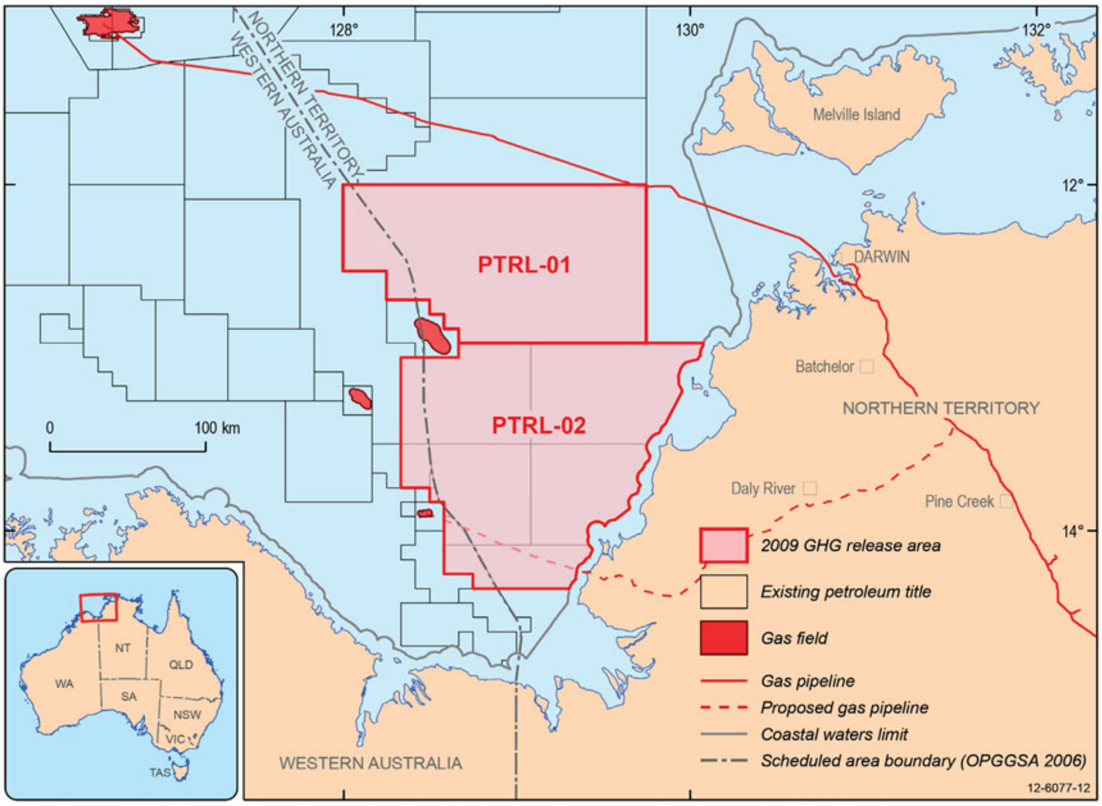
The Coastal Waters shown on this map are indicative only.
A precise determination of the Coastal Waters will be determined at the time of issue and included in the permit boundary as a Metes and Bounds determination.

Figure 34: *GHG storage acreage release area: Vlaming Sub-basin*



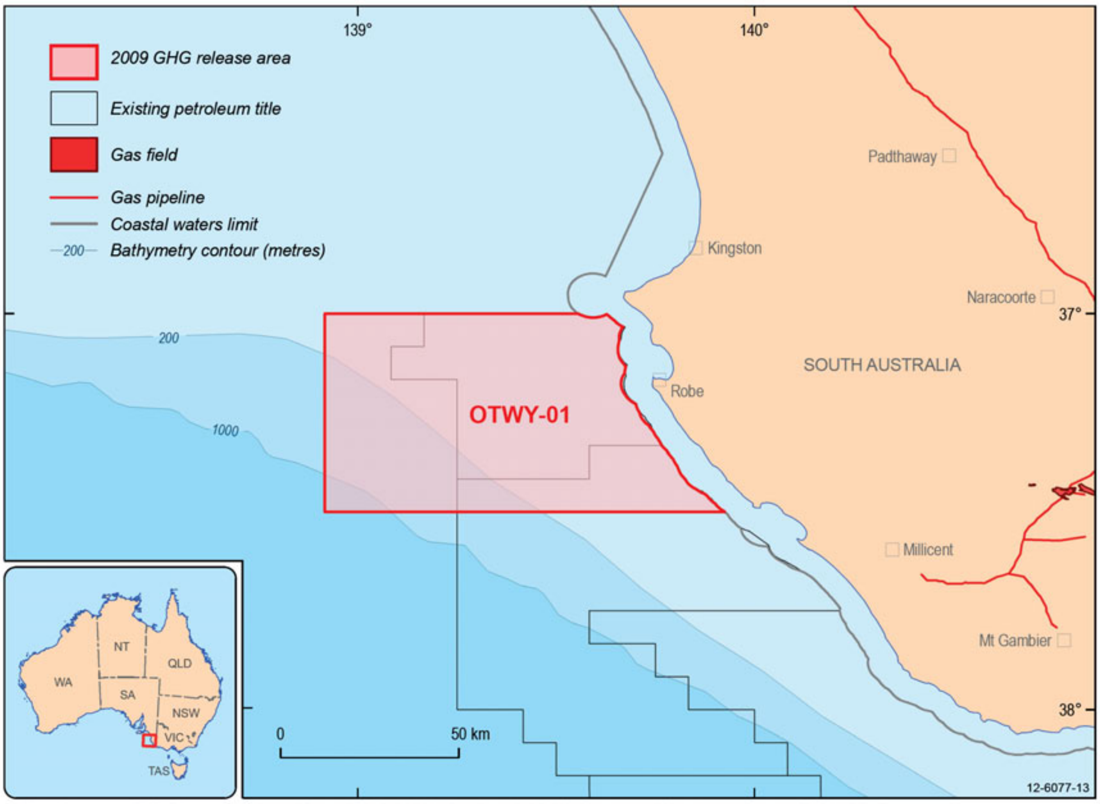
Field outlines supplied by Encom Petroleum Information Pty Ltd. Field outlines in GPinfo are sourced from the operators of the fields only.
Outlines are updated at irregular intervals but with at least one major update per year.
The Coastal Waters shown on this map are indicative only.
A precise determination of the Coastal Waters will be determined at the time of issue and included in the permit boundary as a Metes and Bounds determination.

Figure 35: *GHG storage acreage release area: Torquay Sub-basin*



Field outlines supplied by Encom Petroleum Information Pty Ltd. Field outlines in GPinfo are sourced from the operators of the fields only.
Outlines are updated at irregular intervals but with at least one major update per year.
The Coastal Waters shown on this map are indicative only.
A precise determination of the Coastal Waters will be determined at the time of issue and included in the permit boundary as a Metes and Bounds determination.

Figure 36: *GHG storage acreage release area: Petrel Sub-basin*



Field outlines supplied by Encom Petroleum Information Pty Ltd. Field outlines in GPinfo are sourced from the operators of the fields only.
Outlines are updated at irregular intervals but with at least one major update per year.
The Coastal Waters shown on this map are indicative only.
A precise determination of the Coastal Waters will be determined at the time of issue and included in the permit boundary as a Metes and Bounds determination.

Figure 37: *GHG storage acreage release area: Otway Basin*

Potential Onshore Storage Sites

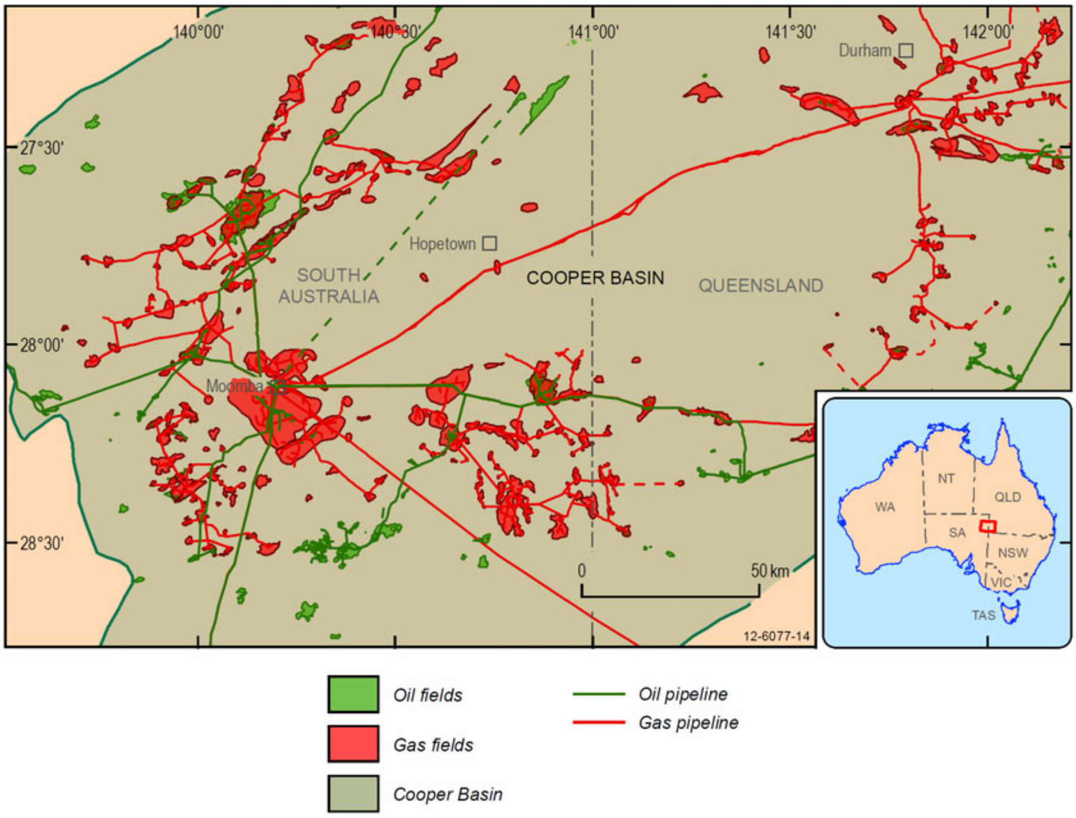


Figure 38: *Potential onshore GHG storage area at Moomba in the Cooper Basin identified by Santos (2009)*

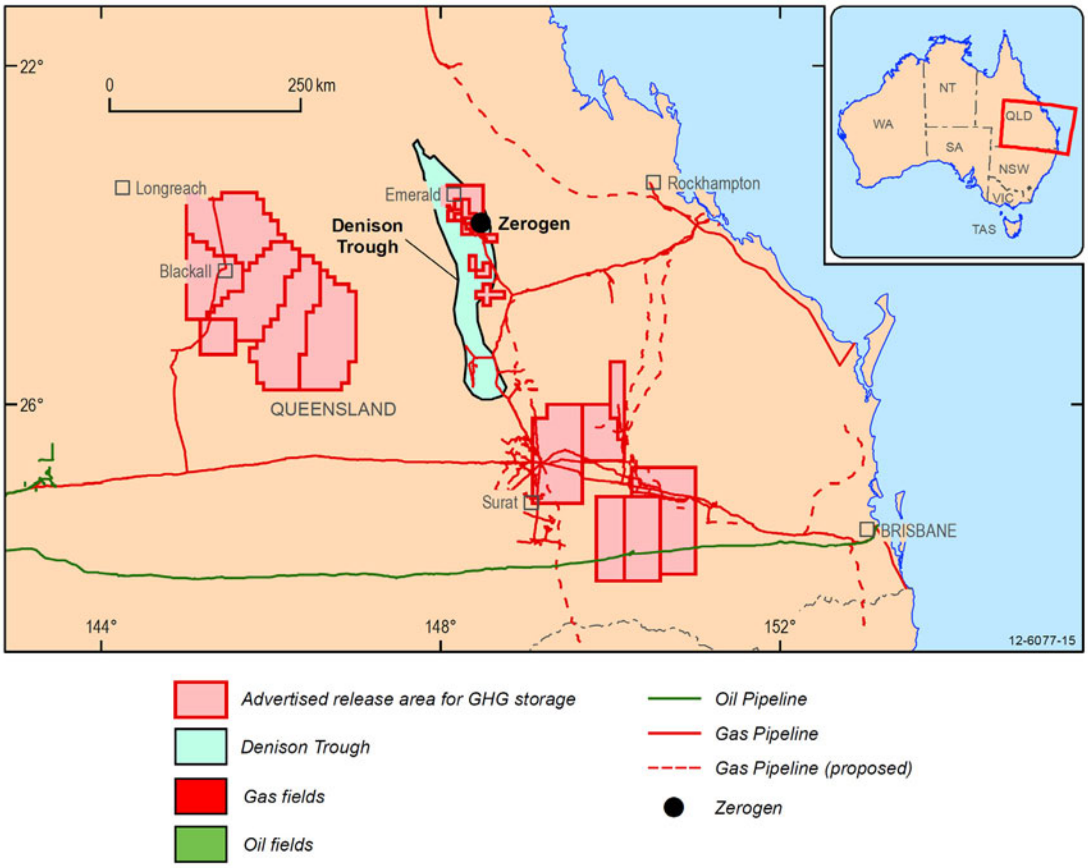


Figure 39: *Potential onshore GHG storage area in the Denison Trough identified by ZeroGen (Tarr, 2009). Release areas for GHG storage advertised by the Queensland Government are also included*

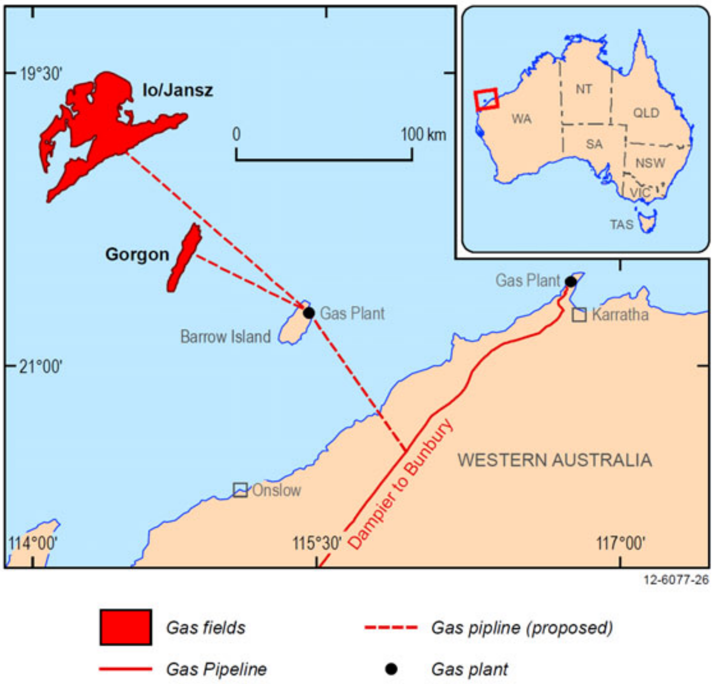
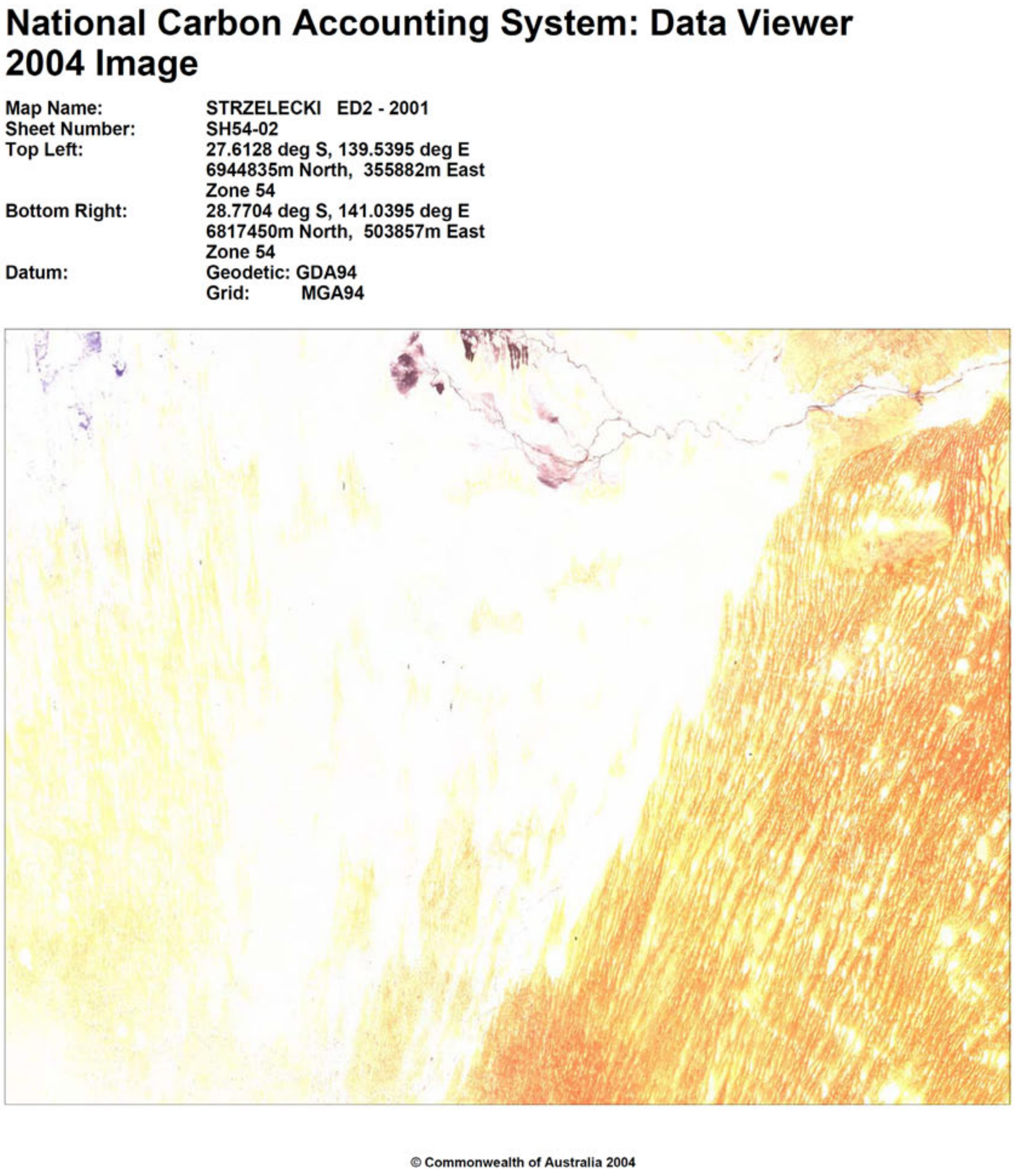


Figure 40: *Planned Onshore GHG storage area on Barrow Island as part of the Gorgon Project (Chevron Australia, 2012)*

APPENDIX C: LANDSAT VEGETATION COVER



National Carbon Accounting System: Data Viewer
2004 Image

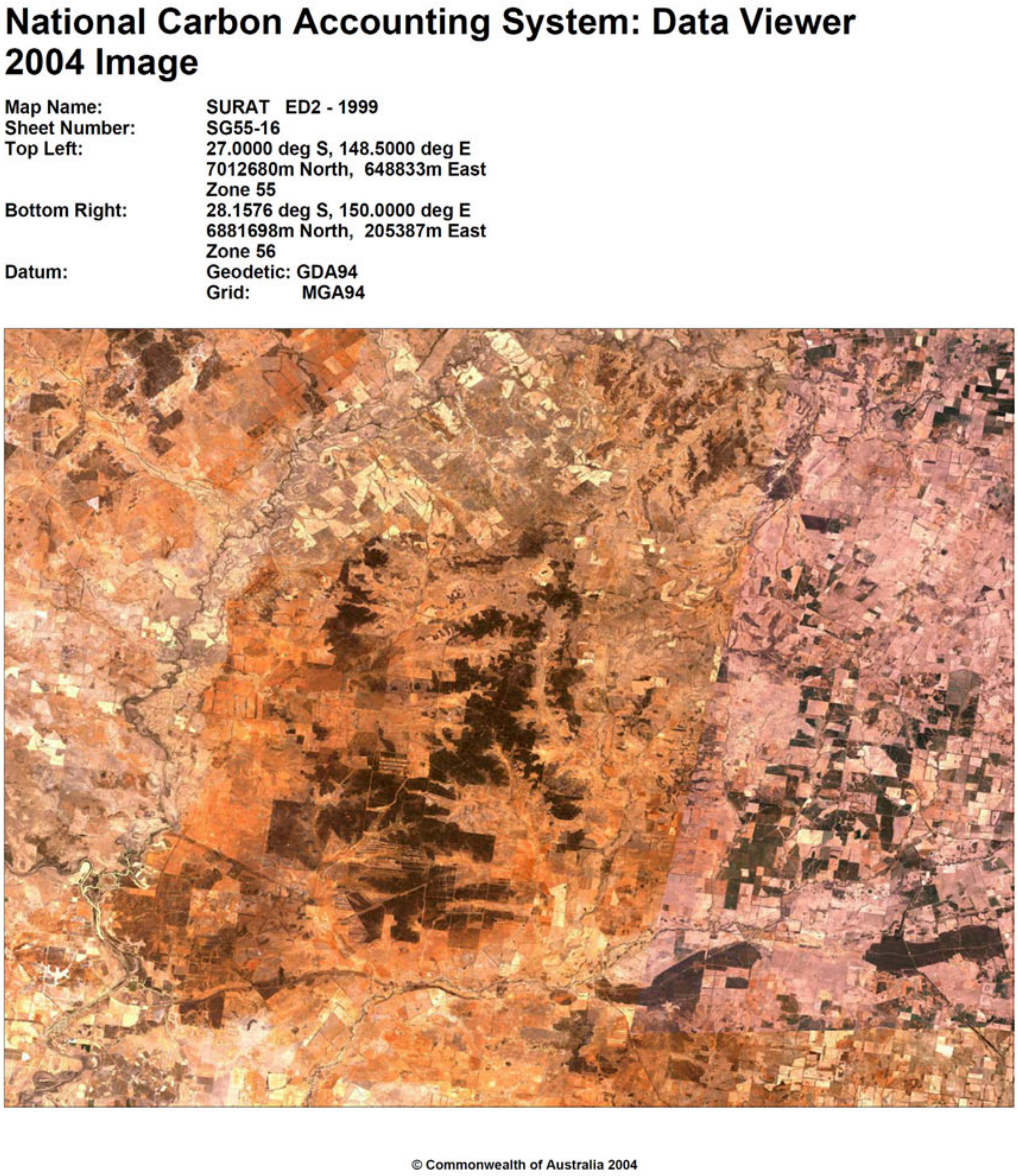
Map Name:	**STRZELECKI ED2 - 2001**
Sheet Number:	**SH54-02**
Top Left:	**27.6128 deg S, 139.5395 deg E** **6944835m North, 355882m East** **Zone 54**
Bottom Right:	**28.7704 deg S, 141.0395 deg E** **6817450m North, 503857m East** **Zone 54**
Datum:	**Geodetic: GDA94** **Grid: MGA94**

Figure 41: *Landsat vegetation cover for Moomba, Cooper Basin (DCC, 2004)*

National Carbon Accounting System: Data Viewer 2004 Image

Map Name:	EMERALD ED2 - 2001
Sheet Number:	SF55-15
Top Left:	23.2433 deg S, 147.4784 deg E 7429470m North, 548936m East Zone 55
Bottom Right:	24.4009 deg S, 148.9784 deg E 7299960m North, 700620m East Zone 55
Datum:	Geodetic: GDA94 Grid: MGA94

Figure 42: *Landsat vegetation cover for Fernlees, Denison Trough (DCC, 2004)*

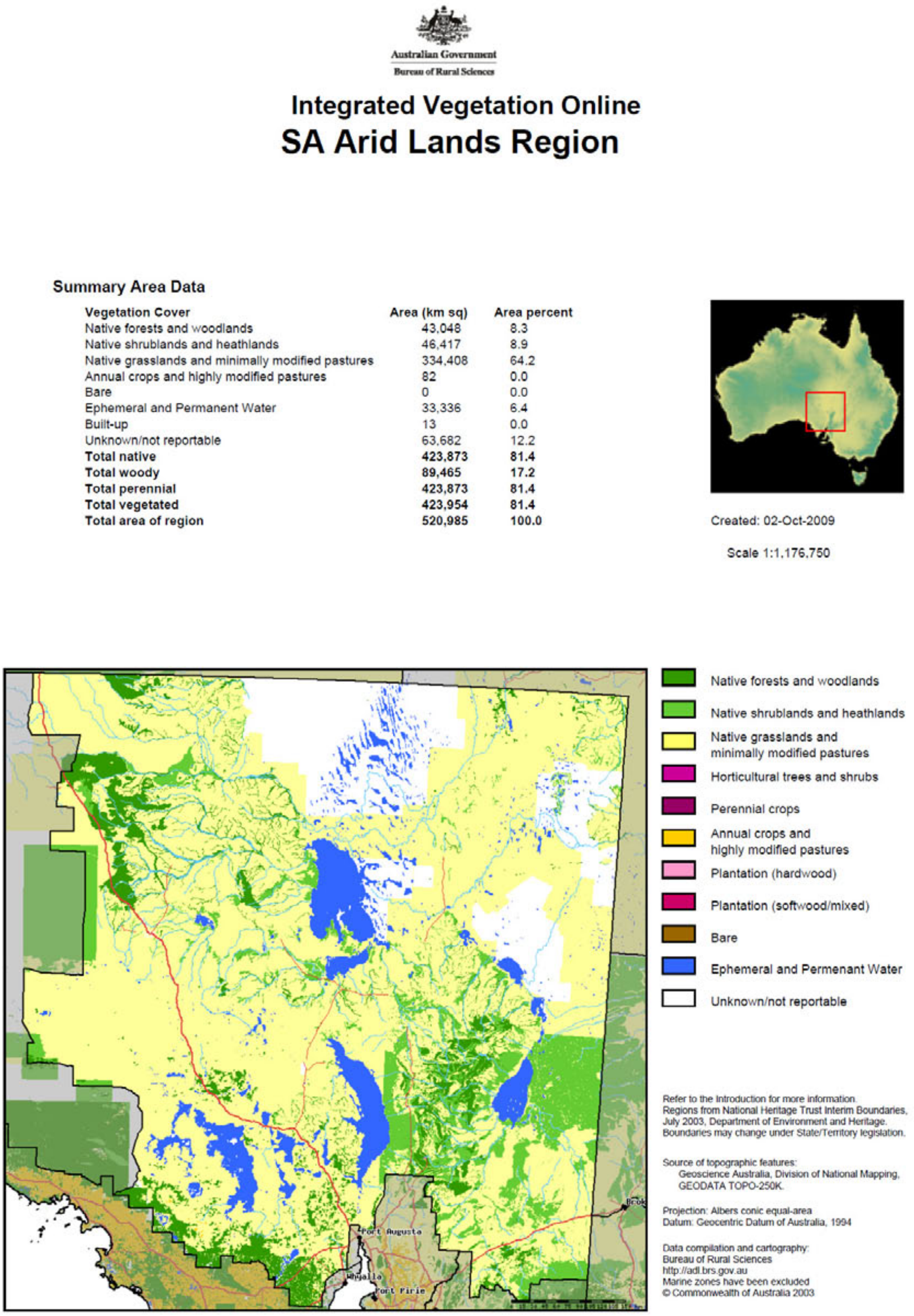


National Carbon Accounting System: Data Viewer
2004 Image

Map Name:	SURAT ED2 - 1999
Sheet Number:	SG55-16
Top Left:	27.0000 deg S, 148.5000 deg E 7012680m North, 648833m East Zone 55
Bottom Right:	28.1576 deg S, 150.0000 deg E 6881698m North, 205387m East Zone 56
Datum:	Geodetic: GDA94 Grid: MGA94

Figure 43: *Landsat vegetation cover for Surat, Surat Basin (DCC, 2004)*

APPENDIX D: VEGETATION TYPE



Australian Government
Bureau of Rural Sciences

Integrated Vegetation Online
SA Arid Lands Region

Summary Area Data

Vegetation Cover	Area (km sq)	Area percent
Native forests and woodlands	43,048	8.3
Native shrublands and heathlands	46,417	8.9
Native grasslands and minimally modified pastures	334,408	64.2
Annual crops and highly modified pastures	82	0.0
Bare	0	0.0
Ephemeral and Permanent Water	33,336	6.4
Built-up	13	0.0
Unknown/not reportable	63,682	12.2
Total native	**423,873**	**81.4**
Total woody	**89,465**	**17.2**
Total perennial	**423,873**	**81.4**
Total vegetated	**423,954**	**81.4**
Total area of region	**520,985**	**100.0**

Created: 02-Oct-2009

Scale 1:1,176,750

🟩 Native forests and woodlands
🟩 Native shrublands and heathlands
🟨 Native grasslands and minimally modified pastures
🟪 Horticultural trees and shrubs
🟪 Perennial crops
🟧 Annual crops and highly modified pastures
🟥 Plantation (hardwood)
🟥 Plantation (softwood/mixed)
🟫 Bare
🟦 Ephemeral and Permenant Water
⬜ Unknown/not reportable

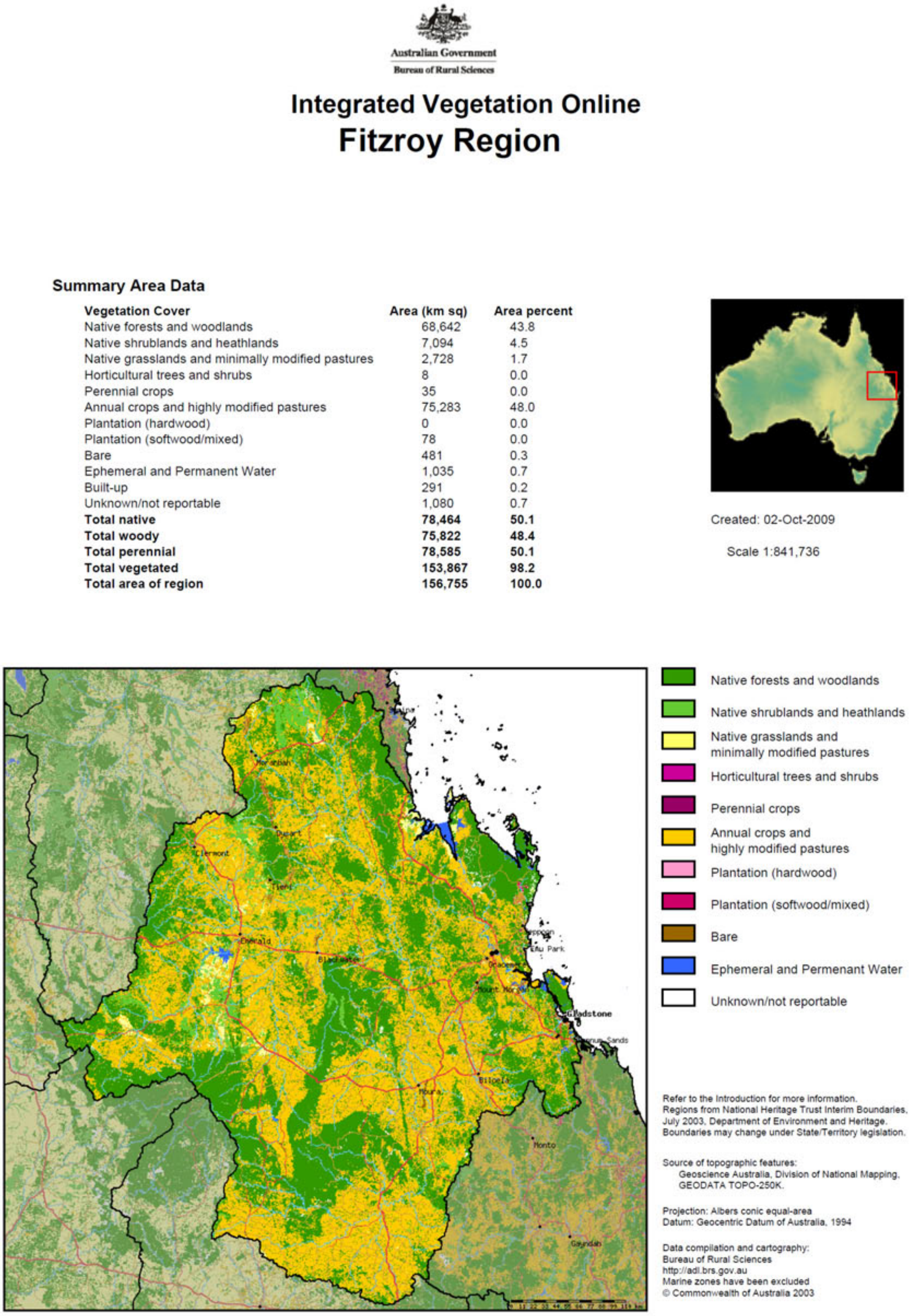
Refer to the Introduction for more information.
Regions from National Heritage Trust Interim Boundaries, July 2003, Department of Environment and Heritage.
Boundaries may change under State/Territory legislation.

Source of topographic features:
Geoscience Australia, Division of National Mapping, GEODATA TOPO-250K.

Projection: Albers conic equal-area
Datum: Geocentric Datum of Australia, 1994

Data compilation and cartography:
Bureau of Rural Sciences
http://adl.brs.gov.au
Marine zones have been excluded

Figure 44: *Vegetation type near Moomba, Cooper Basin (BRS, 2004)*



Australian Government
Bureau of Rural Sciences

Integrated Vegetation Online
Fitzroy Region

Summary Area Data

Vegetation Cover	Area (km sq)	Area percent
Native forests and woodlands	68,642	43.8
Native shrublands and heathlands	7,094	4.5
Native grasslands and minimally modified pastures	2,728	1.7
Horticultural trees and shrubs	8	0.0
Perennial crops	35	0.0
Annual crops and highly modified pastures	75,283	48.0
Plantation (hardwood)	0	0.0
Plantation (softwood/mixed)	78	0.0
Bare	481	0.3
Ephemeral and Permanent Water	1,035	0.7
Built-up	291	0.2
Unknown/not reportable	1,080	0.7
Total native	**78,464**	**50.1**
Total woody	**75,822**	**48.4**
Total perennial	**78,585**	**50.1**
Total vegetated	**153,867**	**98.2**
Total area of region	**156,755**	**100.0**

Created: 02-Oct-2009

Scale 1:841,736

🟩	Native forests and woodlands
🟩	Native shrublands and heathlands
🟨	Native grasslands and minimally modified pastures
🟪	Horticultural trees and shrubs
🟪	Perennial crops
🟨	Annual crops and highly modified pastures
🟥	Plantation (hardwood)
🟥	Plantation (softwood/mixed)
🟫	Bare
🟦	Ephemeral and Permenant Water
⬜	Unknown/not reportable

Refer to the Introduction for more information.
Regions from National Heritage Trust Interim Boundaries, July 2003, Department of Environment and Heritage.
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Source of topographic features:
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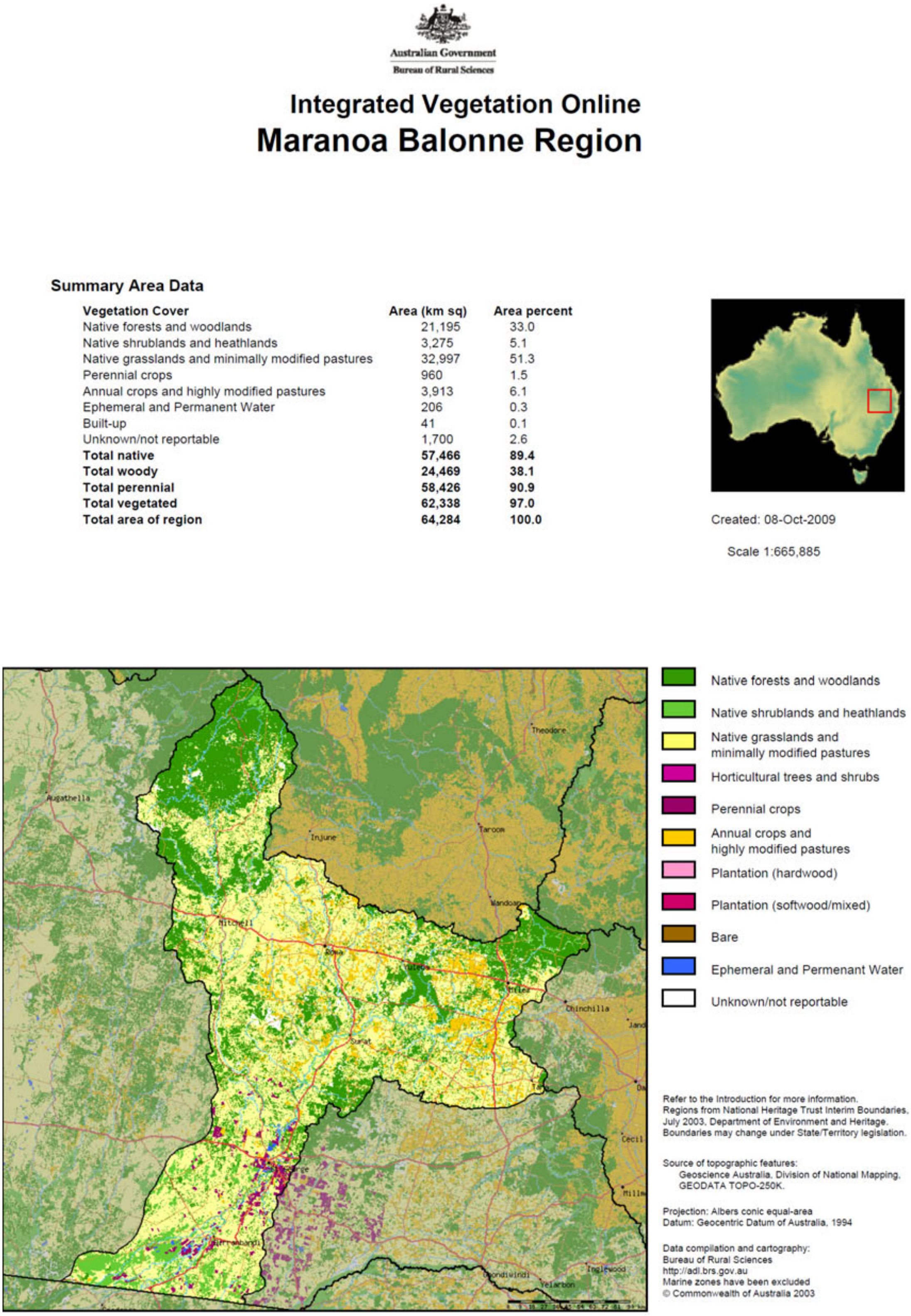
Projection: Albers conic equal-area
Datum: Geocentric Datum of Australia, 1994

Data compilation and cartography:
Bureau of Rural Sciences
http://adl.brs.gov.au
Marine zones have been excluded
© Commonwealth of Australia 2003

Figure 45: *Vegetation type near Fernlees, Denison Trough (BRS, 2004)*



Australian Government
Bureau of Rural Sciences

Integrated Vegetation Online
Maranoa Balonne Region

Summary Area Data

Vegetation Cover	Area (km sq)	Area percent
Native forests and woodlands	21,195	33.0
Native shrublands and heathlands	3,275	5.1
Native grasslands and minimally modified pastures	32,997	51.3
Perennial crops	960	1.5
Annual crops and highly modified pastures	3,913	6.1
Ephemeral and Permanent Water	206	0.3
Built-up	41	0.1
Unknown/not reportable	1,700	2.6
Total native	**57,466**	**89.4**
Total woody	**24,469**	**38.1**
Total perennial	**58,426**	**90.9**
Total vegetated	**62,338**	**97.0**
Total area of region	**64,284**	**100.0**

Created: 08-Oct-2009

Scale 1:665,885

- 🟩 Native forests and woodlands
- 🟩 Native shrublands and heathlands
- 🟨 Native grasslands and minimally modified pastures
- 🟪 Horticultural trees and shrubs
- 🟪 Perennial crops
- 🟧 Annual crops and highly modified pastures
- 🟥 Plantation (hardwood)
- 🟥 Plantation (softwood/mixed)
- 🟫 Bare
- 🟦 Ephemeral and Permanent Water
- ☐ Unknown/not reportable

Refer to the Introduction for more information.
Regions from National Heritage Trust Interim Boundaries, July 2003, Department of Environment and Heritage.
Boundaries may change under State/Territory legislation.

Source of topographic features:
Geoscience Australia, Division of National Mapping, GEODATA TOPO-250K.

Projection: Albers conic equal-area
Datum: Geocentric Datum of Australia, 1994

Data compilation and cartography:
Bureau of Rural Sciences
http://adl.brs.gov.au
Marine zones have been excluded

Figure 46: *Vegetation type near Surat, Surat Basin (BRS, 2004)*

APPENDIX E: COMBUSTION SOURCES IN AIRSHEDS

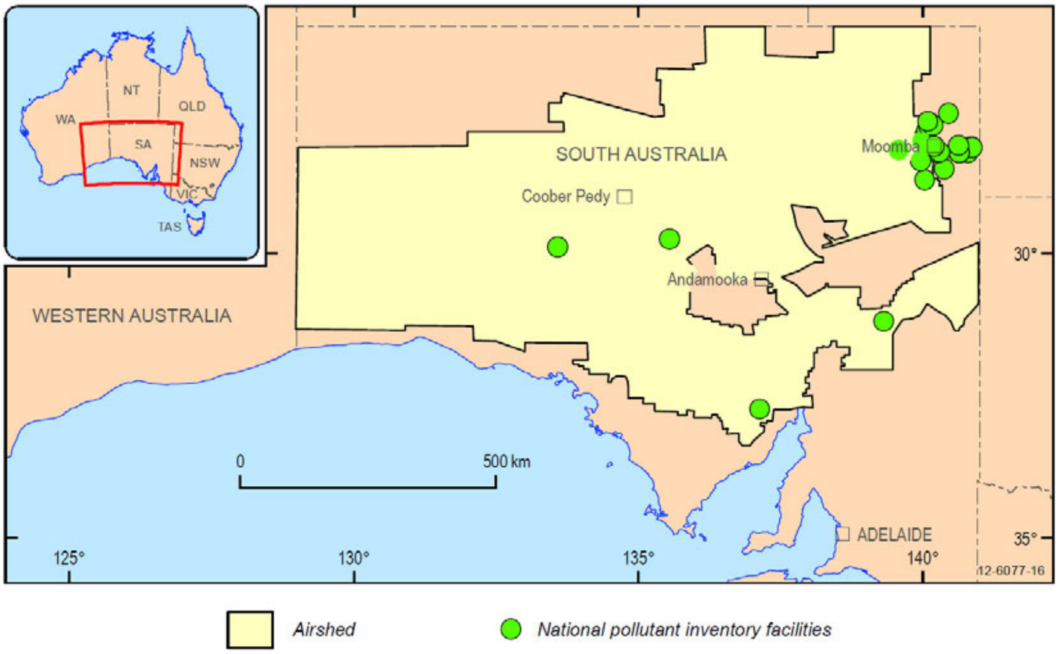


__Figure 47:__ Combustion Sources in Moomba (Cooper Basin) airshed (NPI: DCC, 2004)

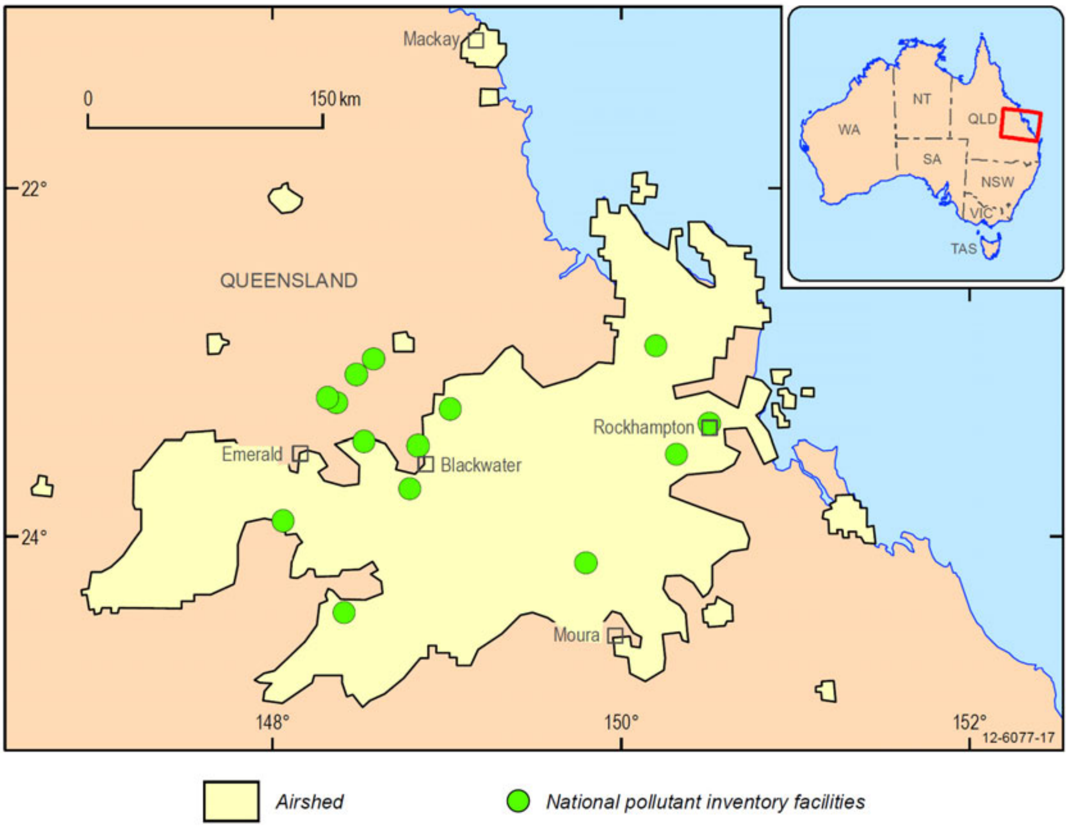


__Figure 48:__ Combustion Sources in Fernlees (Denison Trough) airshed (NPI: DCC, 2004)

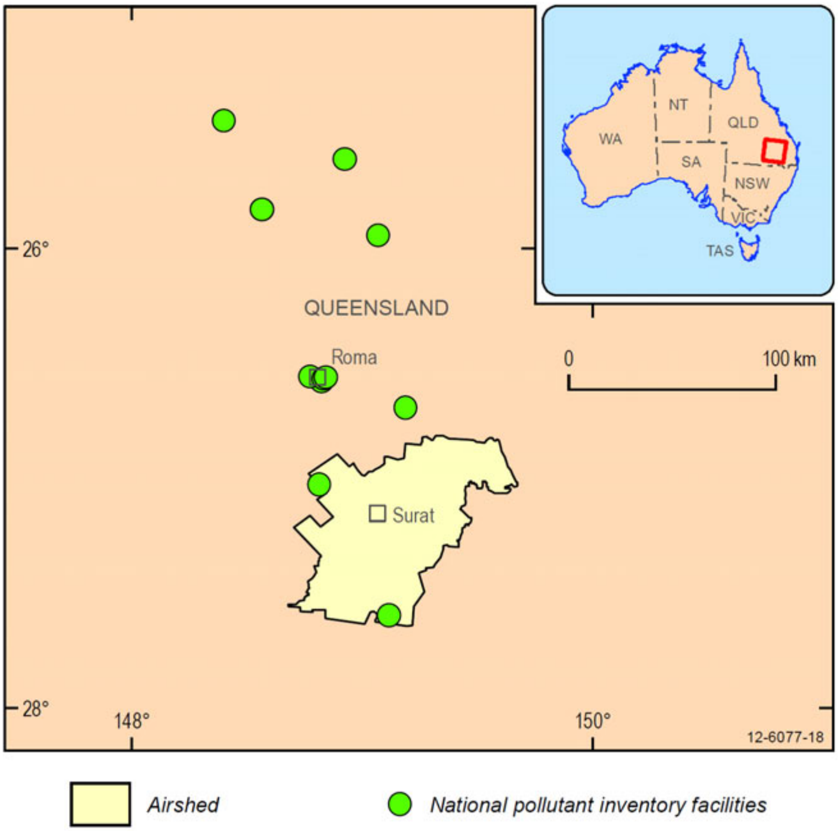


Figure 49: *Combustion Sources in Surat (Surat Basin) airshed (NPI: DCC, 2004)*

Appendix F: Location of tall towers

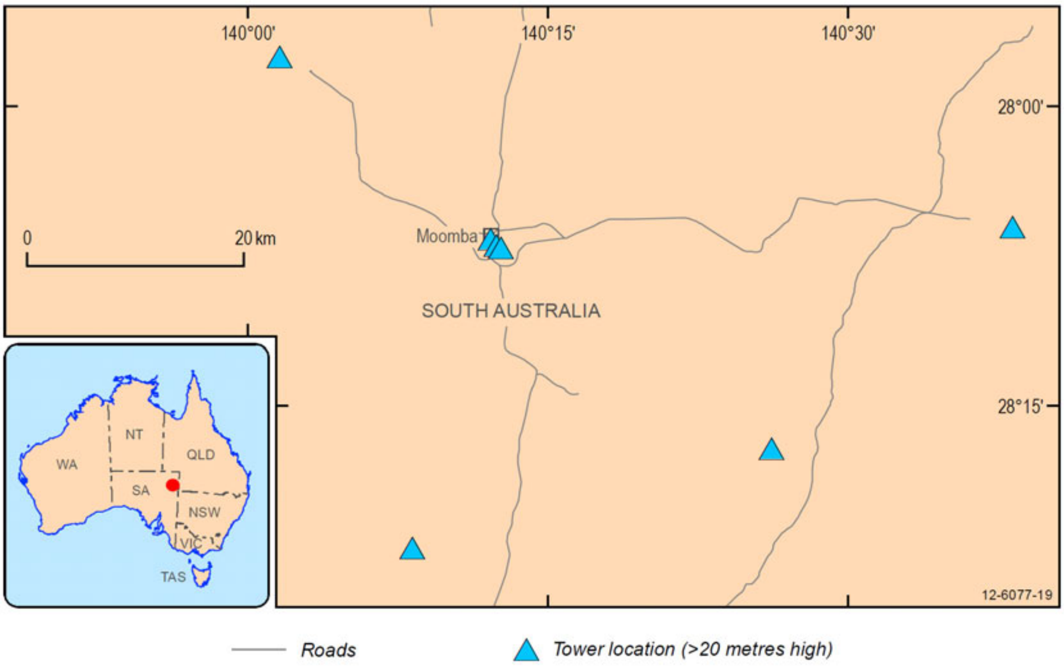


Figure 50: Location of towers (>20m in height) near Moomba, SA

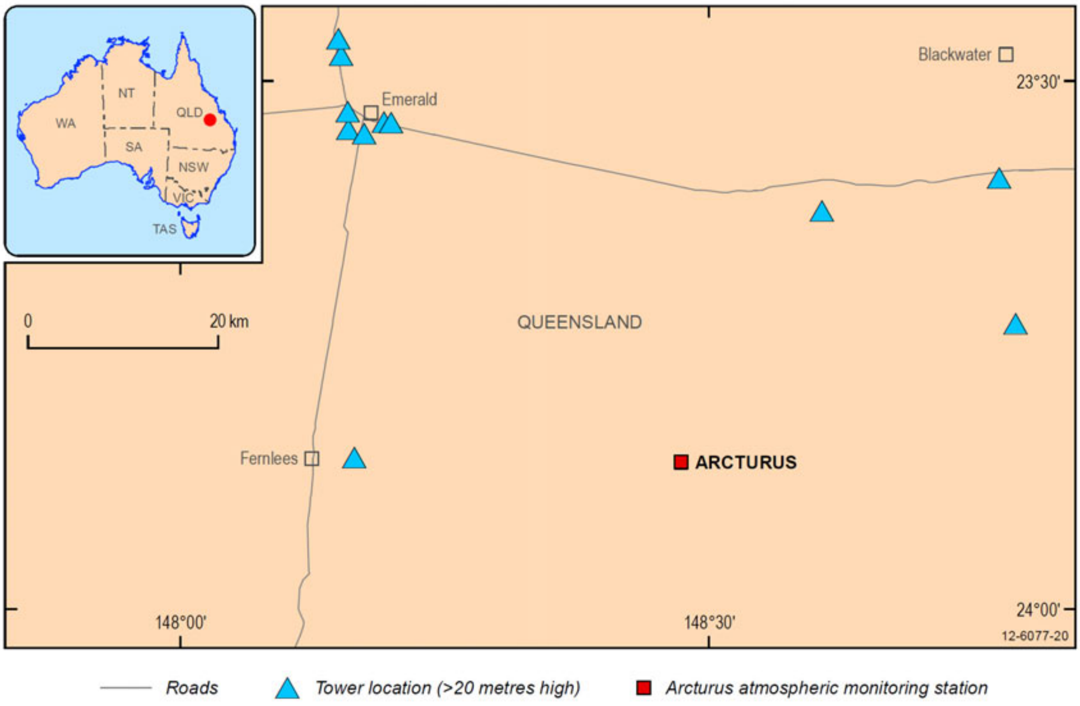


Figure 51: Location of towers (>20m in height) near Fernlees, Qld

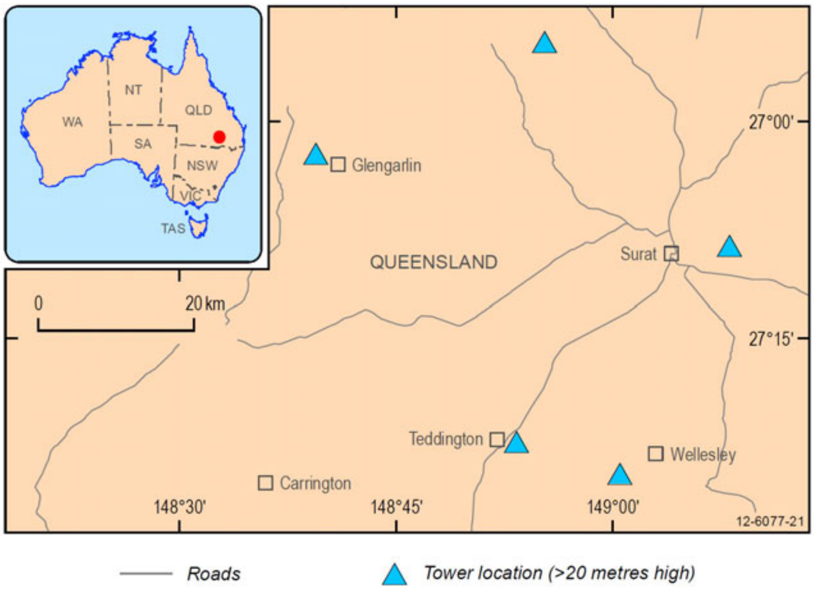


Figure 52: *Location of towers (>20m in height) near Surat, Qld*

APPENDIX G: REGIONAL ATMOSPHERIC MODEL SIMULATIONS

Comparison of the regional atmospheric model simulations of CO_2 variations for different example atmospheric monitoring sites. Simulations are over a year (2003) and consider terrestrial biosphere fluxes (green), ocean fluxes (blue) and fossil fuel emissions (red), using the CSIRO CCAM model and fluxes from Law et al (2008). Two different biosphere models are used (CASA model left column, SiB model right column). Model horizontal resolution is 200 km and concentrations are for 40 metre height. The results are for the nearest model grid point to the site. The Otway site is included for comparison.

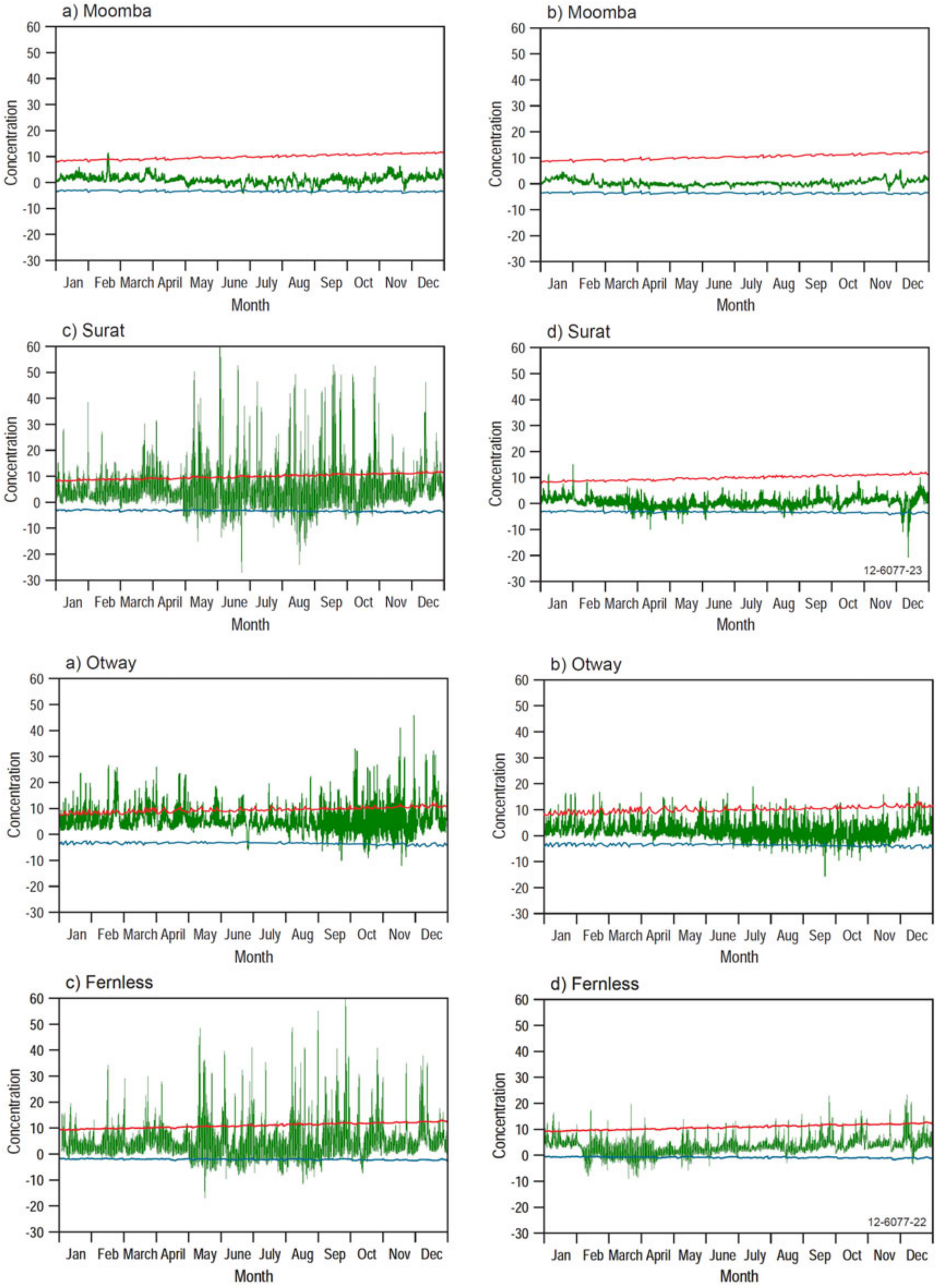


Figure 53: *Comparison of different regional atmospheric model simulations*

APPENDIX H: MAP OF ARCTURUS SITE

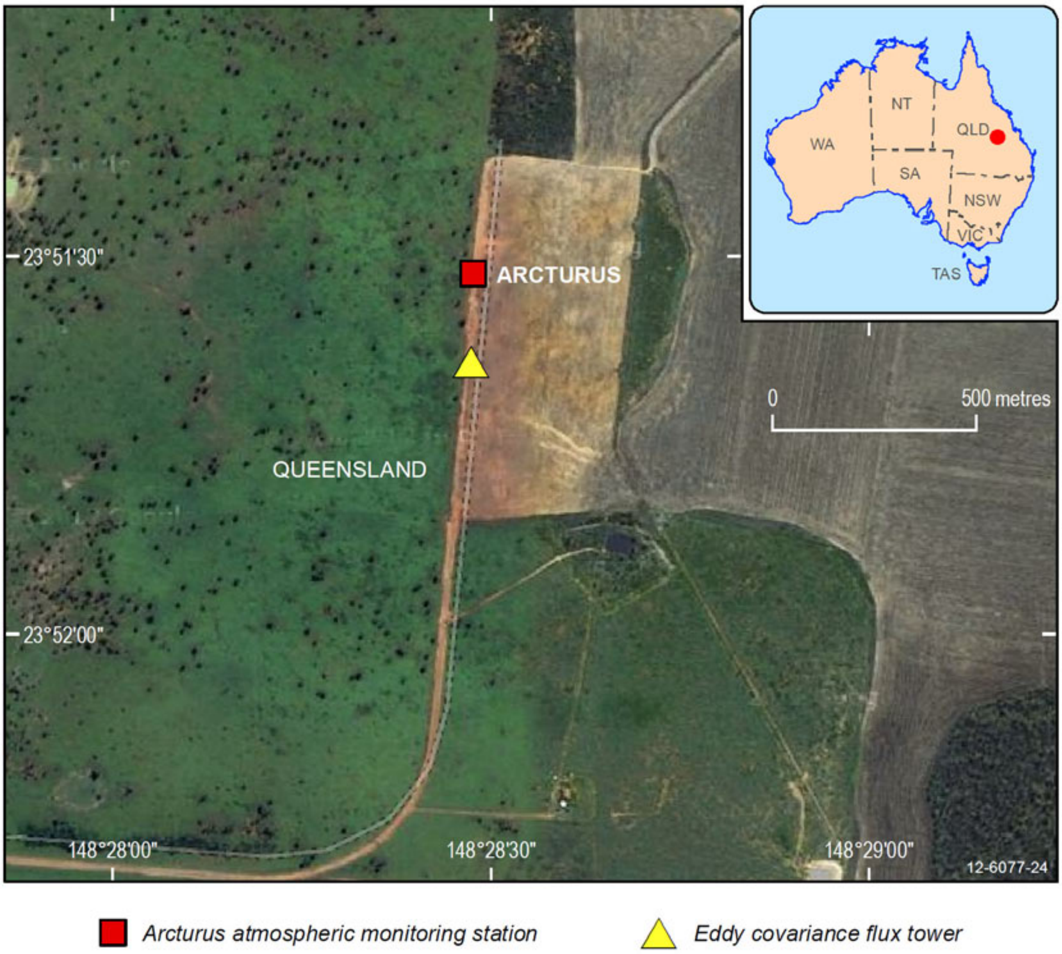


Figure 54: *Map of Arcturus Site*

Location information: GA-CSIRO baseline atmospheric monitoring facility, “Arcturus” ARA:

- “Starrain” property, Sullivan’s Road, Arcturus, Queensland
- Rural area – managed crops and grazing
- Facility container on an easement between cropping to the east and natural grass and bushland to the west
- 23 deg 51 min 31.4 sec south Latitude
- 148 deg 28 min 28.6 sec east Longitude
- 1.2 km from nearest dwelling, >40 km from towns, 500 km from coast
- 8 km from proposed CO_2 geological injection site

APPENDIX I: ROAD MAP NEAR ARCTURUS MONITORING STATION

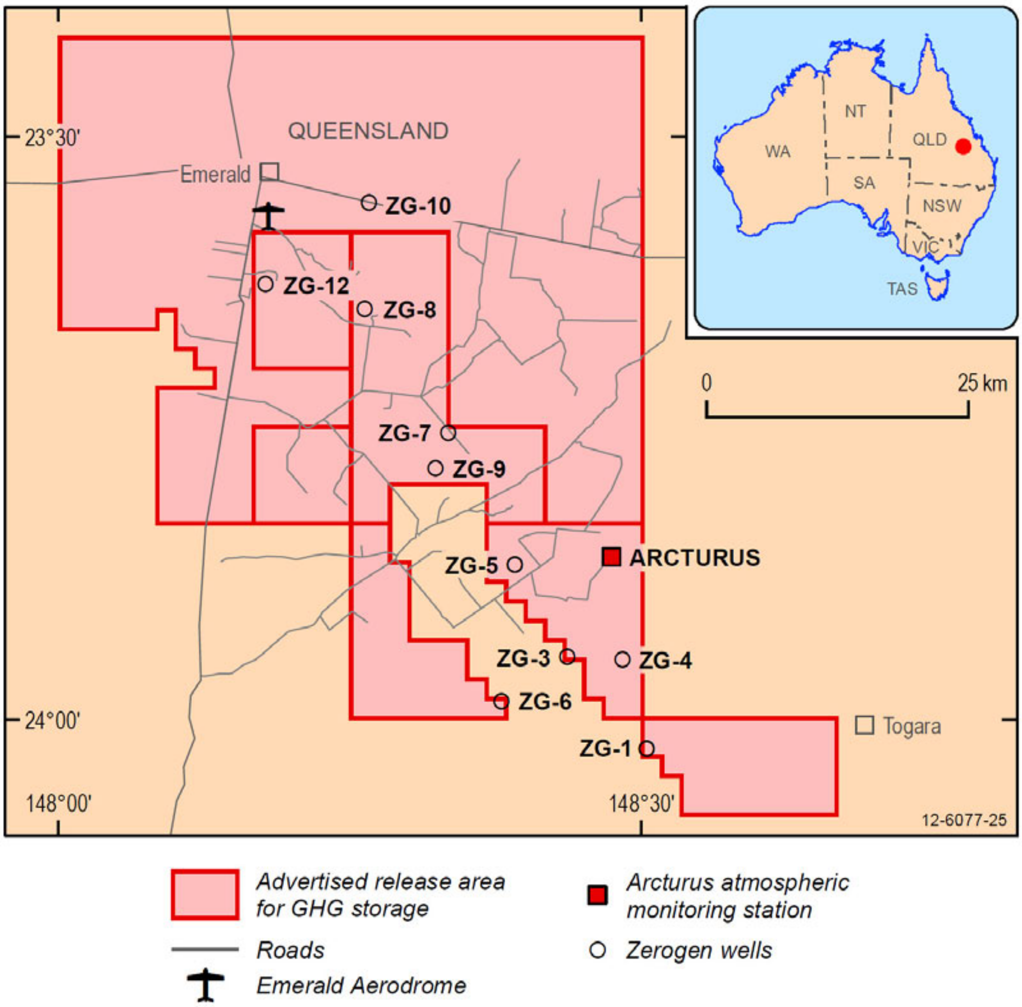


Figure 55: *Road map near Arcturus monitoring station*

Turn left from Emerald Aerodrome onto Gregory Highway
Continue on Gregory Highway and turn left at Glenorina Road for 18.6 km
Continue onto Milroy Downs Road after 23.5 km
Turn left at Wyntoon Road after 3.2 km
Turn left at Kilmore Access Road after 8.3 km (partly sealed road)
Turn right at Sullivans Road after 11.0 km (unsealed road)
Continue on Sullivans Road to Arcturus GHG monitoring site for 6.7 km (unsealed road)

The Arcturus site is at the end of Sullivans Rd.

Note the unsealed roads and many of the creek crossings are impassable after rainfall.

The nearest Telstra NextG Tower is at Fernlees (about 32 km West of the site)

APPENDIX J: SHIPPING CONTAINER SPECIFICATIONS

Shipping Container for Equipment Shelter (Amended Specifications)

Dimensions External
Length 6.05m (20')
Width 2.44m (8')
Height 2.59m (8' 6")
Modifications and Accessories
The vendor will modify the 20ft container and provide accessories according to the minimum specifications listed below and in the attached diagram. This container will be used as an Equipment Shelter to be deployed in a remote location in Central Queensland. It is important that the modified container is secure and safe enough to protect the scientific equipment located inside it against theft or damage.

Painting
The container should be painted with high-quality shipping container paint – white.

Insulation
Walls and roofs should be fully insulated and lined.
Wall cavity insulation minimum: glasswool, 70mm batt R1.5
Roof cavity insulation minimum: glasswool, 155mm batt R3.0
A tropical roof should be fitted to the container (optional).

Flooring
A Wooden floor is preferred.

Lights and Power
Adequate lighting: fluorescence tubes with diffusers and light switch
At least 3 Double 15 amp GPOs on each wall plus two above/on the bench.
1 x RCD circuit breaker
1 x phone + data inlets
15 amp caravan inlet
(Wired to SAA wiring rules AS3000 and fitted out with socket outlets, switches, lights and circuit breaker panel with earth leakage protection. All wiring concealed within wall and ceiling space.)

Door
Provide an Entrance door (~2043 x 846mm) with handle and knob entrance set; in addition the door should be secured with security bars/security padlocks/Lock box.
Heavy side doors must have Lock boxes and security padlocks.
All padlocks should be keyed alike if possible.

Window
Provide a Glass sliding window fitted with flyscreens and a lockable steel security cover (~1075 x 1155 mm).

Benches
Install a Laminated Workshop bench with shelves underneath (~2250 x 700mm)
Desk with drawers (~1000 x 500 mm)
Overhead cupboard (~300mm D x 1500mm W x 600mm H, Melamin)

Gas Cylinder Rack
Install a rack to hold 8 G-size gas bottles (225mm dia ea) upright against the wall; include chains with wall hooks or brackets to secure gas bottles.

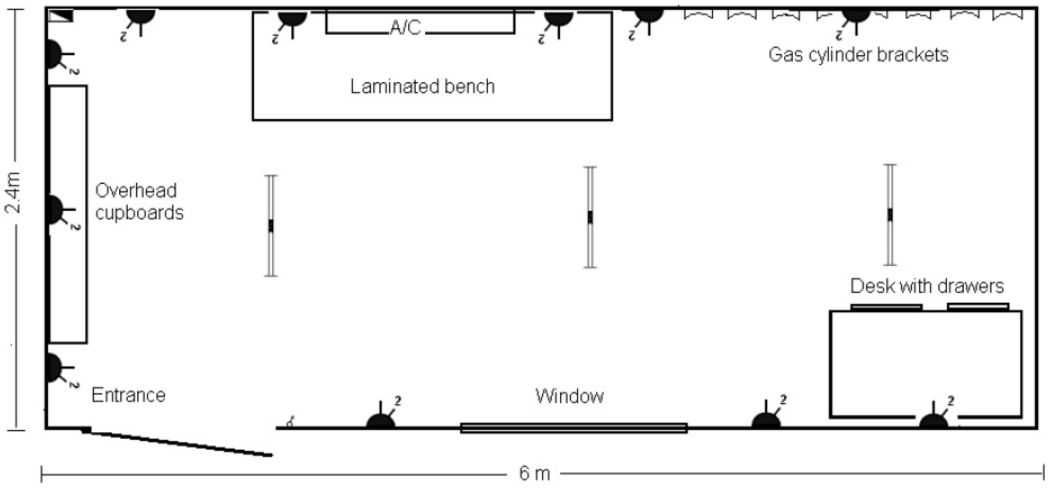
Air conditioning
Reverse cycle air conditioner capable of keeping the shed internal temperature in the range of 20 – 25 ^{o}C, in an area where outside temperature ranges from -5 – 45 ^{o}C. The air conditioner should be protected from the outside with a steel grating or similar.

Ventilation
Install Vents and/or a Whirly bird to aid air circulation in case the air conditioner fails.

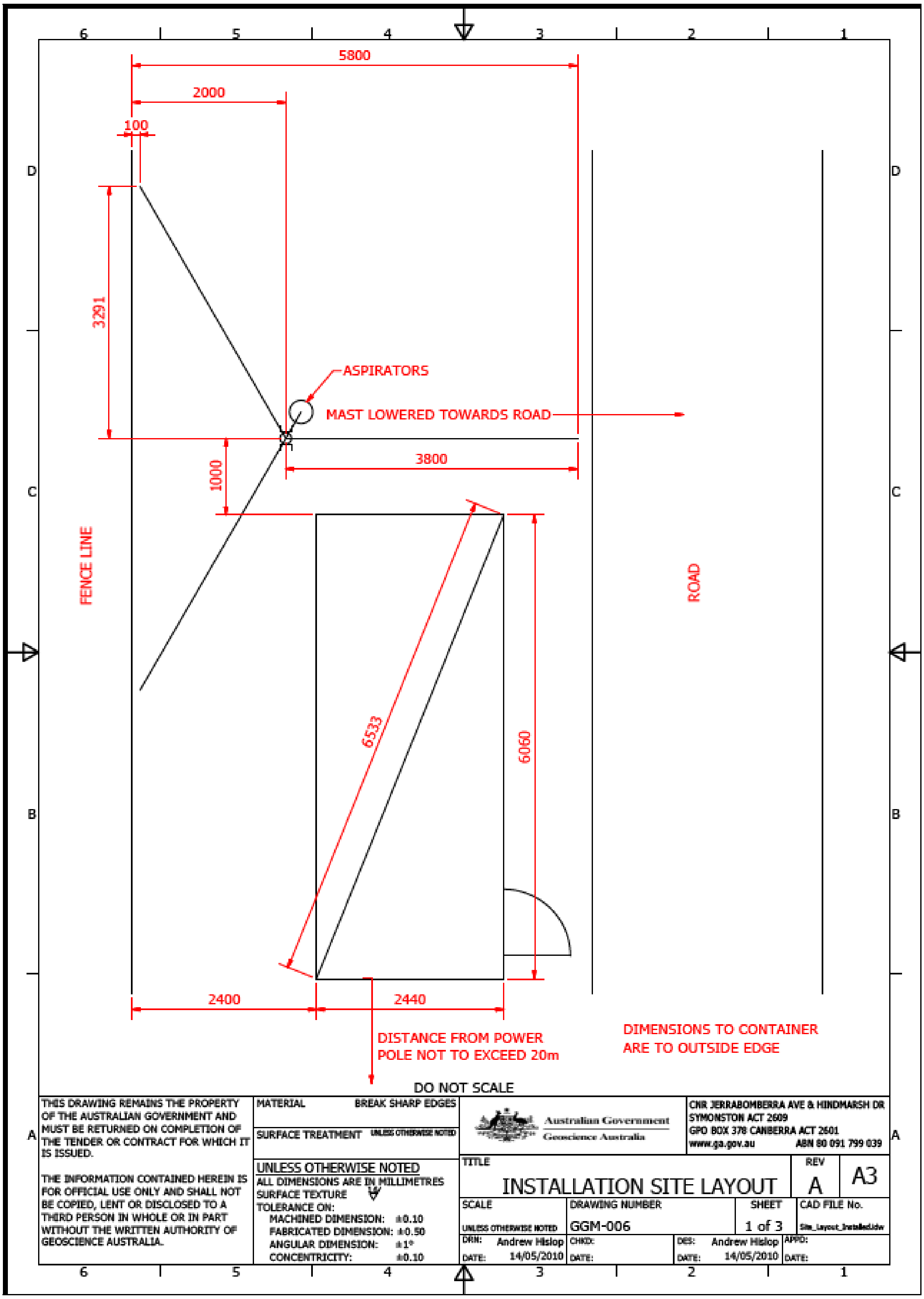
Certification
The container should meet legal and engineering requirements for transportation and an Engineering and Building Certificate(s) must be submitted.

Delivery
To Geoscience Australia, Hindmarsh Drive, Corner of Jerrabomberra Avenue, Symonston, ACT, 2609, by first week of February 2010.

Shed Layout


A/C
Laminated bench
Gas cylinder brackets
Overhead cupboards
Desk with drawers
Entrance
Window
2.4m
6 m
2

APPENDIX K: ARCTURUS SITE LAYOUT



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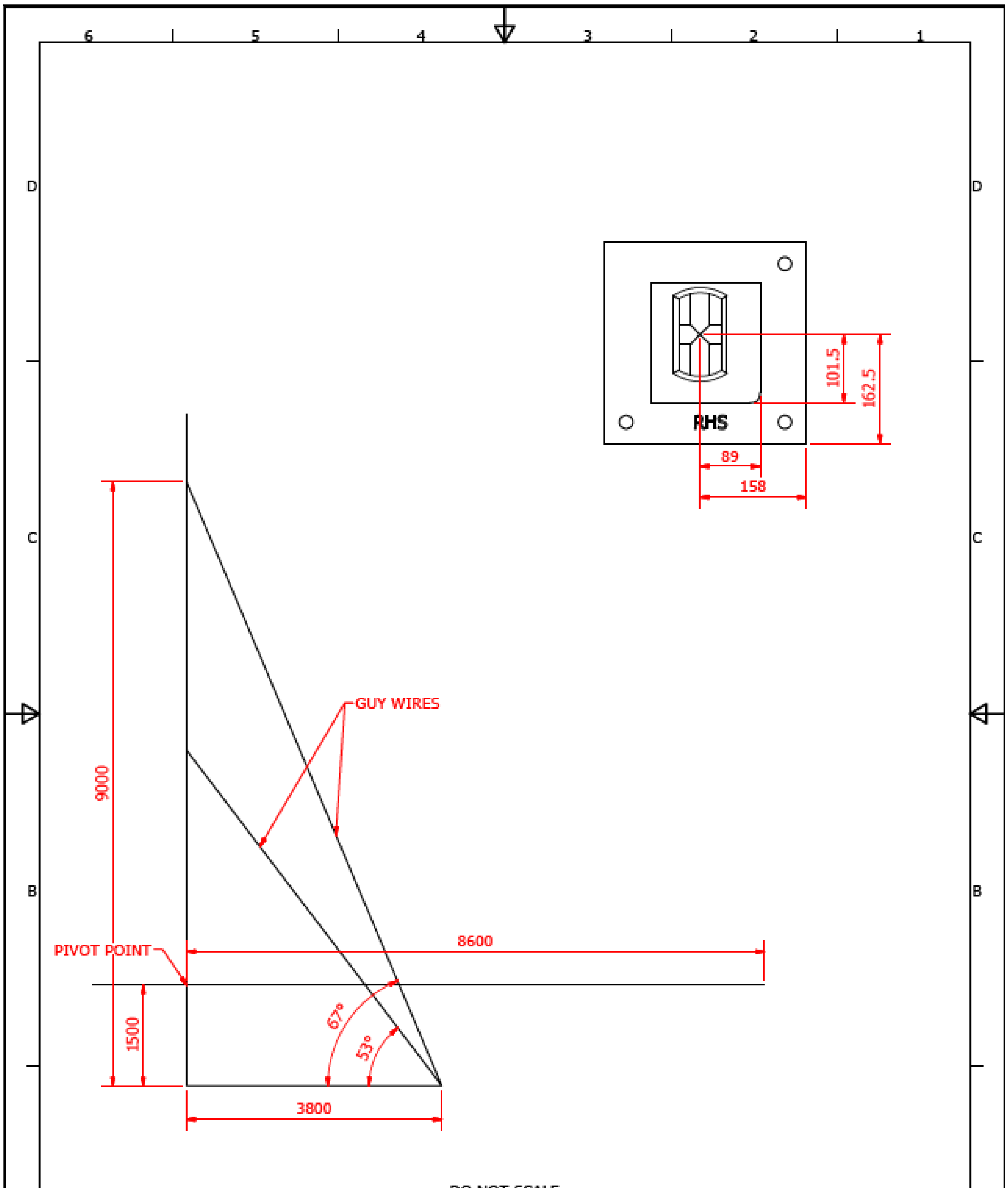
MATERIAL: BREAK SHARP EDGES
SURFACE TREATMENT: UNLESS OTHERWISE NOTED

UNLESS OTHERWISE NOTED
ALL DIMENSIONS ARE IN MILLIMETRES
SURFACE TEXTURE
TOLERANCE ON:
MACHINED DIMENSION: ±0.10
FABRICATED DIMENSION: ±0.50
ANGULAR DIMENSION: ±1°
CONCENTRICITY: ±0.10

CNR JERRABOMBERRA AVE & HINDMARSH DR
SYMONSTON ACT 2609
GPO BOX 378 CANBERRA ACT 2601
www.ga.gov.au ABN 80 091 799 039

TITLE: INSTALLATION SITE LAYOUT
REV: A
A3
SCALE: UNLESS OTHERWISE NOTED
DRAWING NUMBER: GGM-006
SHEET: 1 of 3
CAD FILE No.: Site_Layout_Installed.idw
DRN: Andrew Hislop DATE: 14/05/2010
CHKD: DATE:
DES: Andrew Hislop DATE: 14/05/2010
APPD: DATE:



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DES: Andrew Hislop
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APPD:
DATE:

APPENDIX L: WIRING DETAILS FOR EMERALD FLUX STATION (DECEMBER 2011)

CR3000 Panel - Analogue		Connector	Instrument
SE1	DIFF1✓	D1H (red)	CNR4 shortwave
SE2		D1L (blue)	(incoming)
⊥		(sensor shield)	
SE3	DIFF2✓	D2H (white)	CNR4 shortwave
SE4		D2L (black)	(reflected)
⊥			
SE5	DIFF3✓	D3H (grey)	CNR4 longwave
SE6		D3L (yellow)	(incoming)
⊥			
SE7	DIFF4✓	D4H (brown)	CNR4 longwave
SE8		D4L (green)	(reflected)
⊥			
SE9	DIFF5✓	D5H (green)	CNR4 PT100
SE10		D5L (yellow)	
⊥		(temperature shield)	
SE11	DIFF6		
SE12			
⊥			
SE13	DIFF7		
SE14			
⊥			
SE15	DIFF8✓	D8H (purple)	TCAV 1 soil T
SE16		D8L (red)	
⊥		(shield)	
SE17	DIFF9✓	D9H (white)	Soil heat flux 1
SE18		D9L (green)	
⊥		(shield)	
SE19	DIFF10✓	D10H (white)	Soil heat flux 2
SE20		D10L (green)	
⊥		(shield)	
SE21✓	DIFF11	SE21 (green)	CS616 1
SE22✓		SE22 (green)	CS616 2
⊥		(black & black)	
SE23✓	DIFF12	SE23 (yellow)	HMP45 T
SE24✓		SE24 (blue)	HMP45 RH
⊥		(purple & clear)	
SE25	DIFF13		
SE26			
⊥			
SE27✓	DIFF14	SE27 (COM Even H)	AM16/32
SE28✓		SE28 (COM Even L)	
⊥			

Notes:

Soil heat flux plate wiring colours not given – use information from specification sheet provided with plates.

CR3000 Panel – Control	**Connector**	**Instrument**
VX1		
VX2		
GND		
VX3		
VX4		
⏚		
CAO1		
CAO2		
⏚		
IX1	Excitation + (grey)	CNR4 PT100
IX2		
IX3		
IXR	Excitation – (brown)	CNR4 PT100
⏚		
P1		
⏚		
P2		
⏚		
P3		
⏚		
P4		
C1	(16 x orange)	CS616 measure
C2		
C3	(green)	Windsonic SDI
C4		
G	(16 x clear)	CS616 shield
C5		
C6		
C7		AM16/32 reset
C8		AM16/32 clock
G		AM16/32 gnd

Notes:

All 16 CS616 TDR probes are controlled via terminal C1 – use a terminal strip or similar to attach all orange cables to this port (and similar for gnd connection to ⏚ terminal).

The WindSonic uses the SDI-12 interface, using default port 0 (factory setting).

CR3000 Panel – Power	Connector	Instrument
5V	(orange)	HMP45 enable
G		
SW12-1		
SW12-2	(red)	Modem pwr
G	(black)	Modem GND
12V		
12V	(red)	AM16/32 pwr
G		

Notes:

Use the G terminals to attach ground cable from instruments. Do not attach power ground wires to analogue earth (⏚) connections!

CR3000 Panel – SDM	Connector	Instrument(s)
SDM-C1 (SDM Data)	(green CSAT) (blue Li7500A) (blue Li7700)	Li7500A, Li7700 & CSAT
SDM-C2 (SDM Clock)	(white CSAT) (white Li7500A) (white CSAT)	
SDM-C3 (SDM Enable)	(brown CSAT) (brown Li7500A) (brown Li7700)	
GND	(black CSAT) (black Li7500A) (black Li7700)	

Notes:

CSAT uses SDM #1
Li7500A uses SDM#7
Li7700 uses SDM#4

AM16/32 - Analogue		Connector	Instrument
1H	DIFF1✓	1H (purple)	TCAV 2 soil T
1L		1L (red)	
⏚			
2H	DIFF2✓	2H (purple)	TCAV 3 soil T
2L		2L (red)	
⏚			
3H	DIFF3✓	3H (signal +)	Soil heat flux 3
3L		3L (signal -)	
⏚		(shield)	
4H✓	DIFF4	4H (green)	CS616 3
4L✓		4L (green)	CS616 4
⏚			
5H✓	DIFF5	5H (green)	CS616 5
5L✓		5L (green)	CS616 6
⏚			
6H✓	DIFF6	6H (green)	CS616 7
6L✓		6L (green)	CS616 8
⏚			
7H✓	DIFF7	7H (green)	CS616 9
7L✓		7L (green)	CS616 10
⏚			
8H✓	DIFF8	8H (green)	CS616 11
8L✓		8L (green)	CS616 12
⏚		(shield)	
9H✓	DIFF9	9H (green)	CS616 13
9L✓		9L (green)	CS616 14
⏚		(shield)	
10H✓	DIFF10	10H (green)	CS616 15
10L✓		10L (green)	CS616 16
⏚		(shield)	

Notes:

Ensure AM16/32 Relay Multiplexer is set to 2x32 mode.