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David Etheridge, Zoe Loh, Ivan Schroder, Henry Berko, Tehani Kuske, Colin Allison, Rebecca Gregory, Darren Spencer, Ray Langenfelds, Steve Zegelin, Mark Hibberd and Andrew Feitz



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David Etheridge¹, Zoe Loh¹, Ivan Schroder², Henry Berko², Tehani Kuske², Colin Allison¹, Rebecca Gregory¹, Darren Spencer¹, Ray Langenfelds¹, Steve Zegelin³, Mark Hibberd¹ and Andrew Feitz².



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Geoscience Australia



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Introduction

The Arcturus greenhouse gas (GHG) monitoring station began operation in July 2010 50 km southeast of Emerald, Queensland. The station was 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 in a geological carbon dioxide capture and storage (CCS) region. The primary purpose of the station was to establish 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 CO₂ storage project (see for example Leuning et al., 2008 and Etheridge et al., 2011), 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.

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 (Berko et al., 2012). During early 2010, the ZeroGen CCS project had an active exploration program for geological storage and the atmospheric station was therefore eventually located approximately 8 km 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 Central Highlands and the GHG signals are likely to be influenced by cropping, pasture, cattle production, and gas and coal activities. The site is secure, can be accessed via an existing road, is not often subject to flooding, and has easy access to electricity supply.

The station comprises a modified air conditioned shipping container equipped with gas monitoring instruments, meteorological sensors and a 10 metre fibre-glass mast with air inlets (Berko et al., 2012). Wavelength scanned cavity ring down spectroscopy (WS-CRDS) was adopted for gas measurements. Two Picarro gas analysers (wavelength scanned cavity ring down spectrometers) continuously monitor greenhouse gases and CO₂ isotopes. One unit measures isotopic ratios of carbon in CO₂ (¹²C and ¹³C) and water vapour while the other measures the concentrations of CH₄, CO₂ and water vapour. Atmospheric composition is also occasionally measured on air samples collected with flask sampling equipment. An automated weather station measures wind speed, wind direction, temperature, humidity and rainfall. A solar powered eddy covariance flux tower was also installed at the site, some 250 m south of the main station. The flux tower comprises a LI-7500A LI-COR open-path eddy covariance gas instrument that measures atmospheric CO₂ and H₂O. Wind speed and direction are measured in 3 dimensions 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 PC running GoToMyPC software can access and control the PC in the container via the internet over the NextG network.

In June 2010, on the basis of a pre-feasibility study of the ZeroGen project, it was found that the geology of the north Denison Trough was not viable for large scale CO₂ storage (Greig, 2012). This meant that Arcturus was no longer providing atmospheric baseline measurements for an active geological storage region. Nevertheless, the stakeholders agreed that there is a clear benefit to continuing the project as there was no alternative onshore exploration program in Australia, and many of the project objectives could still be realised. This includes 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 (Wilson, 2013). Preliminary results demonstrate that significant methane anomalies are being detected that can be attributed to coal mine emissions in the area. The station also generates data that could be used for the purposes of estimating regional and national greenhouse gas budgets (Ziehn et al., submitted).

Citation notice

Calibrated, averaged concentration data should be considered an interim product. CMAR may update records to improve quality, internal consistency or alignment to a calibration scale as new or improved information becomes available. The water vapour correction and in particular the calibration requirements of the Picarro cavity ring down instrument for CO₂ isotopes are under active investigation by CMAR staff, the instrument manufacturers and other users of the instruments (Allison et al., submitted).

Please contact the relevant staff member (as listed for each variable in the tables below) via telephone or e-mail addresses if any clarification of the meaning or limitations of the data is required. If users wish to send us preprints of any publications using the data, we would be happy to check that the data are being used within their limitations.

It is recommended that in addition to the required attribution for use of this data, that the version of the data (as specified by release date) be explicitly stated (e.g. Data supplied by CSIRO and Geoscience Australia (2014) version 31.03.2014.).

Central repository for atmospheric data from Arcturus

Most composition data reside both on CMAR's servers (gl-as, dagage1) and on the local PC belonging to the staff member responsible for work-up of that data stream. Flask data can be accessed through the GASLAB database (Squall: <http://squall-as/gaslab/index.php>). Access is presently available on request to the relevant CSIRO staff member.

Meteorological data are held on GA's server (\\nas\\energy\\ccs\\Atmospheric monitoring facility\\Arcturus site\\Met_Data\\archived), and accessible by request to the relevant GA staff member.

The raw and processed eddy covariance data (covariances, met data and soil data) are held on GA's server (\\nas\\energy\\ccs\\Atmospheric monitoring facility\\Arcturus site\\Eddy covariance tower\\Fully_Processed_Data), and accessible by request to the relevant GA staff member. The raw data are also held on CSIRO's server (fsact01-cdc\\csiro\\cmar\\Enterprise1\\flux\\arcturus). Processed eddy covariance data are also publically accessible from the OzFlux Data Portal (accessible from <http://www.tern.org.au>).

Calibration scales for concentration measurements

CMAR's GASLAB has a multi-decade history of maintaining close links with a number of global atmospheric trace gas sampling networks. These include the National Oceanographic and Atmospheric Administration's (NOAA, USA) global sampling network; the Advanced Global Atmospheric Gases Experiment (AGAGE), and the World Meteorological Organization's Global Atmosphere Watch (WMO GAW) program.

In order to merge data with these global networks, laboratories are required to maintain their measurements on internationally recognised mole fraction scales. These scales are typically defined by a set of primary standards, produced either manometrically or gravimetrically and held at a nominated central calibration facility. Participating laboratories hold one or more suites of their own calibration standards that are measured and defined against the scale in the central calibration laboratory. Linkage to a given international scale may be maintained in a number of ways, including regular exchanges of high-pressure cylinder standards and more frequent flask-air-sharing comparisons.

1 METADATA: Ambient atmospheric composition – in situ measurements

Atmospheric composition is measured by two Picarro gas analysers located within the shipping container, which sample continuously from aspirated inlets at 10 m on the fibre-glass mast.

All composition data is logged onto the Picarro instruments and written to daily files, which are compressed and copied to the Arcturus PC workstation. These daily files are downloaded from the workstation via the internet weekly to CSIRO, where quality control and processing of the data is performed, producing average minute and hourly summary files.

The analysers automatically measure their reference standard daily. Calibration runs, which are initiated remotely every 4-6 weeks, comprise repeatedly measuring each of the calibration standards (as a set of pyramids; low, ambient, high, reference, high, ambient, low), to tie measurements back to internationally recognised mole fraction scales.

1.1 CO₂

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Picarro continuous wave cavity ring down spectrometer. The initial unit, Picarro G1301 Analyser (CFADS63), was replaced by a Picarro G2301 Analyser (CFADS2324) on 22 Oct 2013.
Period of record	July 2010 – June 2014
Frequency of measurement/ effective averaging time	Continuous measurement with data averaged to minute and hourly means.
Forms of data	Raw output and diagnostics. Quality controlled, corrected for water vapour, calibrated, minute and hourly means.
Corrections	Water vapour correction for volumetric dilution and spectroscopic pressure broadening as per Chen et al., 2010.
Calibration scale	Linked to the WMOx2007 CO ₂ mole fraction scale. Maintained by a reference standard measured for 30 minutes every day and three calibration standards measured several times each month.
Accuracy	Better than ± 0.1 ppm
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of record	CSIRO: \\gl-as\Picarro\CFADS63\arcturus and \\dagage1\arcturus-picarro\DataLog_User Hour and minute averages (calibrated): \\gl-as\GOLD\Data\Arcturus and \\dagage1\arcturus-picarro\export
Other locations	External CSIRO back-up

Organisation and primary contact	CSIRO Marine and Atmospheric Research Zoe Loh zoe.loh@csiro.au 03 9239 4518
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1.2 CH₄

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Picarro continuous wave cavity ring down spectrometer. The initial unit, Picarro G1301 Analyser (CFADS63), was replaced by a Picarro G2301 Analyser (CFADS2324) on 22 Oct 2013.
Period of record	July 2010 – June 2014
Frequency of measurement/ effective averaging time	Continuous measurement with data averaged to minute and hourly means.
Forms of data	Raw output and diagnostics Quality controlled, corrected for water vapour, calibrated, minute and hourly means.
Corrections	Water vapour correction for volumetric dilution and spectroscopic pressure broadening as per Chen et al., 2010.
Calibration scale	NOAA04 CH ₄ mole fraction scale (Dlugokencky et al., 2005). Maintained by a reference standard measured for 30 minutes every day and three calibration standards measured four times each month.
Accuracy	Better than ±1 ppb
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\Picarro\CFADS63\arcturus and \\dagage1\arcturus-picarro\DataLog_User Hour and minute averages (calibrated): \\gl-as\GOLD\Data\Arcturus and \\dagage1\arcturus-picarro\export
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research Zoe Loh zoe.loh@csiro.au 03 9239 4518

1.3 H₂O

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Picarro continuous wave cavity ring down spectrometer. The initial unit, Picarro G1301 Analyser (CFADS63), was replaced by a Picarro G2301 Analyser (CFADS2324) on 22 Oct 2013.
Period of record	July 2010 – June 2014

Frequency of measurement/ effective averaging time	Continuous measurement with data averaged to minute and hourly means.
Forms of data	Raw output and diagnostics Minute and hourly means
Corrections	Nil – these data are used to provide the volumetric dilution and spectroscopic pressure broadening correction to the CO ₂ and CH ₄ records.
Calibration scale	Uncalibrated. However, data from both instruments are cross-referenced to check for drift that might compromise the water vapour correction to the trace gas records.
Accuracy	±100 ppm
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\Picarro\CFADS63\arcturus and \\dagage1\arcturus-picarro\DataLog_User Hour and minute averages: \\gl-as\GOLD\Data\Arcturus and \\dagage1\arcturus-picarro\export
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research Zoe Loh zoe.loh@csiro.au 03 9239 4518

1.4 ¹²CO₂

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Picarro G1101-i Analyser (CBDS36) continuous wave cavity ring down spectrometer. It was returned to manufacturer for rebuild on 19 Jul 2011. Reinstalled at ARA as CFFDS36 on 17 Jul 2012.
Period of record	July 2010 – June 2014, with breaks given above
Frequency of measurement/ effective averaging time	Continuous measurement with data averaged to minute and hourly means.
Forms of data	Raw output and diagnostics Minute and hourly means
Corrections	Water vapour correction for volumetric dilution and spectroscopic pressure broadening as per Chen et al., 2010. Note that this instrument is under active investigation and highly subject to change (Allison et al., submitted).
Calibration scale	Linked to the WMOx2007 CO ₂ mole fraction scale. Maintained by a reference standard measured for 2 hours every day and three calibration standards (measured four times every month).
Accuracy	±0.5 ppm
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\Picarro\CFFDS36\Arcturus Hour averages: \\gl-as\GOLD\Data\Arcturus

Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research Zoe Loh zoe.loh@csiro.au 03 9239 4518

1.5 $^{13}\text{CO}_2$

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Picarro G1101-i Analyser (CBDS36) continuous wave cavity ring down spectrometer. It was returned to manufacturer for rebuild on 19 Jul 2011. Reinstalled at ARA as CFFDS36 on 17 Jul 2012.
Period of record	July 2010 – June 2014, with breaks given above
Frequency of measurement/ effective averaging time	Continuous measurement with data averaged to minute and hourly means.
Forms of data	Raw output and diagnostics Minute and hourly means
Corrections	Water vapour correction for volumetric dilution and spectroscopic pressure broadening as per Chen et al., 2010. Note that this instrument is under active investigation and highly subject to change (Allison et al, submitted).
Calibration scale	Linked to the WMOx2007 CO_2 mole fraction scale. Maintained by a reference standard measured for 2 hours every day and three calibration standards (measured four times every month).
Accuracy	± 0.02 ppm
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\Picarro\CFFDS36\Arcturus Hour averages: \\gl-as\GOLD\Data\Arcturus
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research Zoe Loh zoe.loh@csiro.au 03 9239 4518

1.6 $\delta^{13}\text{C}$ of CO_2

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Picarro G1101-i Analyser (CBDS36) continuous wave cavity ring down spectrometer. It was returned to manufacturer for rebuild on 19 Jul 2011. Reinstalled at ARA as CFFDS36 on 17 Jul 2012.
Period of record	July 2010 – June 2014, with breaks given above
Frequency of measurement/ effective averaging time	Continuous measurement with data averaged to minute and hourly means.
Forms of data	Raw output and diagnostics Minute and hourly means
Corrections	Water vapour correction for volumetric dilution and spectroscopic pressure broadening as per Chen et al., 2010. Note that this instrument is under active investigation and highly subject to change (Allison et al, submitted).
Calibration scale	Linked to the VPDB- CO_2 scale. Maintained by a reference standard measured for 2 hours every day and three calibration standards measured several times every month.
Accuracy	Estimated ± 0.5 ‰
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\Picarro\CFFDS36\Arcturus Hour averages: \\gl-as\GOLD\Data\Arcturus
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research Zoe Loh zoe.loh@csiro.au 03 9239 4518

2 METADATA: Ambient atmospheric composition – G050 (0.5 L glass) flask measurements

Air samples were collected through the 10 metre tower inlet, pressurised into 0.5 litre glass flasks using a CSIRO flask pump unit and drying (using magnesium perchlorate) and measured in CSIRO GASLAB in Aspendale, Victoria. Flask samples were typically filled in pairs. Being a manual process, samples were filled only during visits to the site, typically during well mixed daytime conditions. The flask sampling and measurements were consistent with the protocols of CSIRO's Greenhouse Gas Network (Francey et al., 2003).

2.1 CO₂

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Carle-3: gas chromatograph with flame ionisation detection after methanization of CO ₂ to CH ₄ .
Period of record	May 2010 – June 2014
Frequency of measurement/ effective averaging time	Flask samples, pre-dried, obtained in pairs, several times per year. Effective averaging time ~1 minute
Forms of data	Dry air mole fraction value
Corrections	Nil
Calibration scale	WMOx2007 CO ₂ mole fraction scale
Accuracy	±0.1 ppm
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\GOLD\Data\CSIRO\co2
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research Rebecca Gregory rebecca.gregory@csiro.au 03 9239 4656

2.2 CH₄

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Carle-3: gas chromatograph with flame ionisation detection.
Period of record	May 2010 – June 2014
Frequency of measurement/ effective averaging time	Flask samples, pre-dried, obtained in pairs, several times per year. Effective averaging time ~1 minute
Forms of data	Dry air mole fraction value
Corrections	Nil
Calibration scale	NOAA04 CH ₄ mole fraction scale
Accuracy	±2.4 ppb
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\GOLD\Data\CSIRO\ch4
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research Rebecca Gregory rebecca.gregory@csiro.au 03 9239 4656

2.3 CO

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	RGA3-1: gas chromatograph with a mercuric oxide reduction gas detector.
Period of record	May 2010 – June 2014
Frequency of measurement/ effective averaging time	Flask samples, pre-dried, obtained in pairs, several times per year. Effective averaging time ~1 minute
Forms of data	Dry air mole fraction value
Corrections	Nil
Calibration scale	Linked to NOAA's gravimetrically-derived CO mole fraction scale (Novelli et al., 1991) and augmented by CSIRO dilution standards for concentrations below 196 ppb.
Accuracy	± 1 ppb
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\GOLD\Data\CSIRO\co
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research Rebecca Gregory rebecca.gregory@csiro.au 03 9239 4656

2.4 H₂

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	RGA3-1: gas chromatograph with a mercuric oxide reduction gas detector.
Period of record	May 2010 – June 2014
Frequency of measurement/ effective averaging time	Flask samples, pre-dried, obtained in pairs, several times per year. Effective averaging time ~1 minute
Forms of data	Dry air mole fraction value
Corrections	Nil
Calibration scale	MPI 2009 (Max Planck Institute, Jena, Germany) H ₂ mole fraction scale
Accuracy	± 2 ppb
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\GOLD\Data\CSIRO\h2
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research Rebecca Gregory rebecca.gregory@csiro.au 03 9239 4656

2.5 N₂O

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Shimadzu-1: gas chromatograph with electron capture detection.
Period of record	May 2010 – June 2014
Frequency of measurement/ effective averaging time	Flask samples, pre-dried, obtained in pairs, several times per year. Effective averaging time ~ 1 minute
Forms of data	Dry air mole fraction value
Corrections	Nil
Calibration scale	NOAA 2006a N ₂ O mole fraction scale
Accuracy	± 0.3 ppb
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\GOLD\Data\CSIRO\n2o
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research Rebecca Gregory rebecca.gregory@csiro.au 03 9239 4656

2.6 $\delta^{13}\text{C}$ of CO_2

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Finnigan MAT252 stable isotope ratio mass spectrometer.
Period of record	May 2010 – June 2014
Frequency of measurement/ effective averaging time	Flask samples, pre-dried, obtained in pairs, several times per year. Effective averaging time ~1 minute
Forms of data	Delta (difference) measurement of the ratio of $^{13}\text{C}^{16}\text{O}_2/^{12}\text{C}^{16}\text{O}_2$ in sample from the ratio in the international reference material.
Corrections	Isobaric interference from N_2O
Calibration scale	The international VPDB- CO_2 scale, via a precisely maintained internal scale designated CSIRO2005: CO_2 -in-air (Allison and Francey, 2007; Coplen, 1995).
Accuracy	$\pm 0.03 \text{ ‰}$
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\GOLD\Data\CSIRO\co2c13
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research David Etheridge david.etheridge@csiro.au 03 9239 4590

2.7 $\delta^{18}\text{O}$ of CO_2

Location	Arcturus station 23.85872° S, 148.4746° E, 175 masl inlet at 10 m above ground level.
Instrument	Finnigan MAT252 stable isotope ratio mass spectrometer.
Period of record	May 2010 – June 2014
Frequency of measurement/ effective averaging time	Flask samples, pre-dried, obtained in pairs, several times per year. Effective averaging time ~1 minute
Forms of data	Delta (difference) measurement of the ratio of $^{12}\text{C}^{16}\text{O}^{18}\text{O}/^{12}\text{C}^{16}\text{O}^{16}\text{O}$ in sample from the ratio in the international reference material.
Corrections	Isobaric interference from N_2O
Calibration scale	The international VPDB- CO_2 scale, via a precisely maintained internal scale designated CSIRO2005: CO_2 -in-air (Allison and Francey, 2007; Coplen, 1995).
Accuracy	$\pm 0.05 \text{ ‰}$
Network	Australian Greenhouse Gas monitoring network, WMO GAW (site code ARA)
Primary data storage of calibrated record	CSIRO: \\gl-as\GOLD\Data\CSIRO\co2o18
Other locations	External CSIRO back-up
Organisation and primary contact	CSIRO Marine and Atmospheric Research David Etheridge david.etheridge@csiro.au 03 9239 4590

3 METADATA: Meteorological data

All data from the instruments located on the fibre-glass mast and on the rooftop of the station are logged onto a Campbell Scientific Instruments (CSI) logger (CR1000) located in the Arcturus station. Data are transferred daily, automatically, from the CR1000 logger to the Arcturus PC workstation. Periodically, 15-minutes, 24-hour and 60-minutes average data are downloaded from the workstation via the Internet to GA, where quality control and filtering of the data are performed.

Processed and filtered data are placed on GA's server, \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Met_Data\archived in the following files:

"CR1000_Min15" and "CR1000_Daily24" have 15-minutes and 24-hour data respectively from 07/07/2010 to 03/06/2011

"ARA_Met_CR1000_Min15"; "ARA_Met_CR1000_Min60" and "ARA_Met_CR1000_Daily24" have 15-minutes, 60-minutes and 24-hour data respectively from 03/06/2011 to 21/03/2014

3.1 Wind Speed

Location	Fibre-glass mast 23.85872°S, 148.4746°E, 175 masl, 10 m above ground level.
Instrument	RM Young Wind Sentry cup anemometer
Period of record	July 2010 – June 2014
Frequency of measurement/ effective averaging time	Measurements taken every minute. Used to prepare 15 minute, hourly and daily averages.
Forms of data	Raw data, quality controlled
Corrections	Nil
Calibration scale	N/A
Accuracy	±0.5 ms ⁻¹
Network	N/A
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Met_Data\archived
Other locations	Arcturus Station PC
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

3.2 Wind Direction

Location	Fibre-glass mast 23.85872°S, 148.4746°E, 175 masl, 10 m above ground level.
Instrument	RM Young Wind Sentry wind vane
Period of record	July 2010 – June 2014
Frequency of measurement/ effective averaging time	Measurements taken every minute. Used to prepare 15 minute, hourly and daily averages.
Forms of data	Raw data, quality controlled
Corrections	Nil
Calibration scale	N/A
Accuracy	±5°
Network	N/A
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Met_Data\archived
Other locations	Arcturus Station PC
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

3.3 Solar Radiation

Location	Station rooftop 23.85872°S, 148.4746°E, 175 masl, 3 m above ground level.
Instrument	Licor LI200x Pyranometer
Period of record	July 2010 – June 2014
Frequency of measurement/ effective averaging time	Measurements taken every minute. Used to prepare 15 minute, hourly and daily averages.
Forms of data	Raw data, quality controlled; total and average solar radiation
Corrections	Nil
Calibration scale	N/A
Accuracy	±3%
Network	N/A
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Met_Data\archived
Other locations	Arcturus Station PC
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

3.4 Relative Humidity

Location	Fibre-glass mast 23.85872°S, 148.4746°E, 175 masl, 10 m above ground level.
Instrument	Vaisala HMP50 temperature and relative humidity sensor
Period of record	July 2010 – June 2014
Frequency of measurement/ effective averaging time	Measurements taken every minute. Used to prepare 15 minute, hourly and daily averages.
Forms of data	Raw data, quality controlled
Corrections	Nil
Calibration scale	N/A
Accuracy	±5%
Network	N/A
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Met_Data\archived
Other locations	Arcturus Station PC
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

3.5 Temperature

Location	Fibre-glass mast 23.85872°S, 148.4746°E, 175 masl, 10 m above ground level.
Instrument	Vaisala HMP50 temperature and relative humidity sensor
Period of record	July 2010 – June 2014
Frequency of measurement/ effective averaging time	Measurements taken every minute. Used to prepare 15 minute, hourly and daily averages.
Forms of data	Raw data, quality controlled
Corrections	Nil
Calibration scale	N/A
Accuracy	±0.6°C
Network	N/A
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Met_Data\archived
Other locations	Arcturus Station PC
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

3.6 Pressure

Location	Inside station 23.85872°S, 148.4746°E, 175 masl.
Instrument	Vaisala barometer PTB110
Period of record	July 2010 – June 2014
Frequency of measurement/ effective averaging time	Measurements taken every minute. Used to prepare 15 minute, hourly and daily averages.
Forms of data	Raw data, quality controlled
Corrections	Nil
Calibration scale	N/A
Accuracy	±1.5 mbar
Network	N/A
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Met_Data\archived
Other locations	Arcturus Station PC
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

3.7 Rainfall

Location	Station rooftop 23.85872°S, 148.4746°E, 175 masl, 3 m above ground level.
Instrument	Hydrological Services tipping bucket rain gauge (TB4)
Period of record	July 2010 – June 2014
Frequency of measurement/ effective averaging time	Measurements taken every minute. Used to prepare 15 minute, hourly and daily averages.
Forms of data	Raw data, quality controlled; total and average rainfall
Corrections	Nil
Calibration scale	N/A
Accuracy	±2%
Network	N/A
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Met_Data\archived
Other locations	Arcturus Station PC
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4 METADATA: Flux data

All data from the flux tower instruments are stored on a Campbell Scientific CR3000 and transferred to a PC located in the Arcturus station via WiFi every half hour. At the end of each hour the fast data are processed to produce 30 minute averages and estimate fluxes of CO₂ and H₂O for the previous two half hour periods, using modified Campbell Scientific software. Processed data are saved within three worksheets (slow_flux, slow_met, slow_rad) and automatically transferred to a CSIRO FTP site on a daily basis via the internet where initial QC is done. Data are then fully processed from Level 1 to Level 3 (quality control, filtering and corrections) every few months by staff from GA.

Fully processed and filtered data are placed on GA's server at: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data

4.1 Wind Speed and Direction

4.1.1 Primary 3D wind speed and direction

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, 6.7 m above ground level.
Instrument	Campbell Scientific CSAT3 3D sonic anemometer
L1 Output	Wind direction (WD_CSAT_Compass), wind speed (WS_CSAT), orthogonal wind components (Ux_CSAT, Uy_CSAT, Uz_CSAT) (slow_met)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages and fluxes.
Forms of data	30 minute data, quality controlled and filtered
Corrections	WD_CSAT_Compass: 2011-06-10 00:30 to 2012-09-18 22:00, adjusted clockwise 236° 2012-09-19 17:00 to 2012-09-24 22:00, adjusted clockwise 21° 2013-03-13 14:30 to 2013-03-18 10:00, adjusted clockwise 21°
Calibration scale	N/A
Accuracy	Wind speed < 30 ms ⁻¹ ; azimuth angles between ±170°. Offset Error: ux, uy: < ±8 cms ⁻¹ uz: < ±4 cms ⁻¹ Gain Error: Wind vector within ±5° of horizontal < ±2% Wind vector within ±10° of horizontal < ±3% Wind vector within ±20° of horizontal < ±6%
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data

Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.1.2 Secondary 2D wind speed and direction

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl 7.0 m above ground level.
Instrument	Gill WindSonic4 2D sonic anemometer
L1 Output	Wind direction (WD_WS4), wind speed (WS_WS4) (slow_met)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages.
Forms of data	30 minute data, quality controlled and filtered
Corrections	WD_WS4: 2011-06-10 00:30 to 2013-03-12 13:30, adjusted clockwise 177° 2013-03-12 14:00 to 2012-03-13 14:00 adjusted clockwise 7° 2013-03-13:14:30 to 2013-03-18 10:00 adjusted clockwise 177° 2013-03-18 10:30 to 2014-01-01 00:00 adjusted clockwise 7°
Calibration scale	N/A
Accuracy	Wind direction: $\pm 3^\circ$ with no dead band, Wind speed: $<60 \text{ ms}^{-1}$, $\pm 2\%$ at 12 ms^{-1}
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data on GA server
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.2 Temperature

4.2.1 Primary air temperature

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, 5.6 m above ground level.
Instrument	Vaisala HMP45 temperature and relative humidity probe
L1 Output	Air temperature (Ta) (slow_met)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages and fluxes.
Forms of data	30 minute data, quality controlled and filtered
Corrections	Nil
Calibration scale	N/A
Accuracy	± 0.3°C
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data on GA server
Other locations	Raw and 10 Hz files on CSIRO server (fsact01- cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.2.2 Virtual air temperature

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, 6.7 m above ground level.
Instrument	Campbell Scientific CSAT3 3D sonic anemometer
L1 Output	Virtual air temperature (Tv) (slow_met)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute fluxes
Forms of data	30 minute data, quality controlled and filtered
Corrections	Nil
Calibration scale	N/A
Accuracy	
Network	OzFlux

Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.2.3 Soil temperature

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, located at 2 cm, 5 cm and 15 cm below ground level.
Instrument	3x Campbell Scientific thermocouple temperature probe (TCAV)
L1 Output	Soil temperature (Ts_01 = 15 cm, Ts_02 = 5 cm, Ts_03 = 2 cm) (slow_met)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute CO ₂ and H ₂ O fluxes
Forms of data	30 minute data, quality controlled and filtered
Corrections	Nil
Calibration scale	N/A
Accuracy	± 0.3°C
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.3 Soil Heat Flux

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, located at 5 cm and 10 cm below ground level.
Instrument	3x Middleton CN3 thermopile heat flux plates
L1 Output	Ground heat flux (Fg_01 = 5 cm, Fg_02 = 10 cm, Fg_03 = 10 cm) (slow_flux)
Period of record	10 June 2011 – 31 December 2013

Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages
Forms of data	30 minute data, quality controlled and filtered
Corrections	Nil
Calibration scale	N/A
Accuracy	± 5%
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.4 Soil Moisture

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, located at 5 cm, 15 cm, 22.5 cm and 30 cm below ground level.
Instrument	16x Campbell Scientific CS616 water content reflectometer
Output	Volumetric water content (Sws_13-16 = 5 cm, Sws_09-12 = 15 cm, Sws_05-08 = 22.5 cm, Sws_01-04 = 30 cm) (slow_met)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages
Forms of data	30 minute data, quality controlled and filtered
Corrections	Nil
Calibration scale	N/A
Accuracy	± 2.5% Precision < 0.1%
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.5 CO₂ Concentration

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, 6.7 m above ground level.
Instrument	Licor 7500A open path infrared gas analyser (Li7500A), replaced with the Licor 7500 (Li7500) open path infrared gas analyser from 13 December 2011 to 17 July 2012 and 12 March 2013 to 20 August 2013
L1 Output	CO ₂ concentration (Cc_7500) (slow_met)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages
Forms of data	30 minute data, quality controlled and filtered
Corrections	Nil
Calibration scale	Zero and Span calibrations
Accuracy	± 1% Zero drift: ± 0.3 ppm per °C Gain drift: ± 0.1% per °C at 370 ppm
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.6 CO₂ and H₂O Flux

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, 6.7 m above ground level.
Instruments	Licor 7500A open path infrared gas analyser (Li7500A), replaced with the Licor 7500 (Li7500) open path infrared gas analyser from 13 December 2011 to 17 July 2012 and 12 March 2013 to 20 August 2013. Campbell Scientific CSAT3 3D sonic anemometer
L1 Output	CO ₂ covariances (covUxCc, covUyCc, covUzCc), provisional CO ₂ flux (Fc) (slow_flux) H ₂ O covariances (covUxAh, covUyAh, covUzAh), provisional H ₂ O flux (Fe) (slow_flux)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages and fluxes.
Forms of data	30 minute data, quality controlled and filtered

Corrections	Sensor separation: CSAT3→Li7500 = 210 mm at 320°
Calibration scale	Zero and Span calibrations
Accuracy	N/A
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.7 H₂O

4.7.1 Primary absolute humidity and relative humidity

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, 5.6 m above ground level.
Instrument	Vaisala HMP45 temperature and relative humidity probe
Output	Absolute humidity (Ah_HMP), relative humidity (RH_HMP) (slow_met)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages
Forms of data	30 minute data, quality controlled and filtered
Corrections	Nil
Calibration scale	N/A
Accuracy	±2% RH (0 to 90% RH) ±3% RH (90 to 100% RH)
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.7.2 Secondary absolute humidity

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, 6.7 m above ground level.
Instrument	Licor 7500A open path infrared gas analyser (Li7500A), replaced with the Licor 7500 (Li7500) open path infrared gas analyser from 13 December 2011 to 17 July 2012 and 12 March 2013 to 20 August 2013.
Output	Absolute humidity (Ah_Li7500) (slow_met)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages.
Forms of data	30 minute data, quality controlled and filtered
Corrections	Nil
Calibration scale	Zero and Span calibrations
Accuracy	± 1% Zero drift: ± 0.05 mmol/mol per °C Gain drift: ± 0.3% per °C at 20 mmol/mol
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.8 Radiation

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, 6.7 m above ground level.
Instrument	Kipp & Zonen CNR4 net radiometer
Output	Net radiation (Fn), shortwave down radiation (Fsd), shortwave up radiation (Fsu), longwave down radiation (Fld), longwave up radiation (Flu (slow_rad)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages.
Forms of data	30 minute data, quality controlled and filtered
Corrections	Nil
Calibration scale	N/A
Accuracy	± 10%
Network	OzFlux

Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

4.9 Pressure

Location	Flux tower 23.85872°S, 148.4746°E, 175 masl, 6.7 m above ground level.
Instrument	Licor 7500A open path infrared gas analyser (Li7500A), replaced with the Licor 7500 (Li7500) open path infrared gas analyser from 13 December 2011 to 17 July 2012 and 12 March 2013 to 20 August 2013.
Output	Atmospheric pressure (ps_7500) (slow_met)
Period of record	10 June 2011 – 31 December 2013
Frequency of measurement/ effective averaging time	10 Hz, used to process 30 minute averages.
Forms of data	30 minute data, quality controlled and filtered
Corrections	Nil
Calibration scale	Zero and Span calibrations
Accuracy	± 1%
Network	OzFlux
Primary data storage of calibrated record	GA: \\nas\energy\ccs\Atmospheric monitoring facility\Arcturus site\Eddy covariance tower\Fully_Processed_Data
Other locations	Raw and 10 Hz files on CSIRO server (fsact01-cdc\csiro\cmar\Enterprise1\flux\arcturus). Backed up and processed at GA, Canberra.
Organisation and primary contact	Geoscience Australia Andrew Feitz andrew.feitz@ga.gov.au 02 6249 9781

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