2 CALIBRATION AND VALIDATION SITES & FINDINGS

2.1 Introduction

Three of the sites (Lake Frome, Uardry and Lake Argyle) were designated specifically as Calibration and Validation sites. In the selection of these sites, the emphasis was on (where possible) uniform land covers, stable conditions, logistical support and associated continuously recording instrumentation and prior field campaigns. The Coleambally site, discussed previously for its significant agricultural time series and applications, also provided a valuable site for geometric studies and sensor inter-comparisons. The studies carried out here were made possible by the well-surveyed field boundaries and roads and the large uniform fields that cover the site.

Lake Frome is a large salt lake (playa) in the north of South Australia. It has a high visible region reflectance (about 70% when dry) with little fall-off in the blue end of the signature. It is ideal for VNIR instruments. Unfortunately, the year of intensive effort (2001) was a wet year and the lake surface had too much associated moisture for the SWIR region (which has high water absorption) to provide effective calibration for an instrument with the SNR of Hyperion. However, Lake Frome provided a very important support function for TRW in the early phase of the Checkout that occurred in the Northern Hemisphere winter. The lake has been imaged in more recent times following a drying period and is being used to study calibration stability and VNIR “smile”.

Uardry (near Hay in NSW and close to the Coleambally site) is a prairie site that has been used for AVHRR and MODIS calibration and validation as well as surface radiation balance (SRB) studies. It is located at 14°24’S and 145°18’E. The site is maintained by Fred Prata, Bob Cechet and Graham Rutter of CSIRO. As well as EO-1, data was available for the site from DATM and HyMap scanners, various satellites (AATSR, MODIS, ASTER), tower based surface radiation balance (SRB) and meteorological data and site BRDF measurements. The site was also used in the early checkout period to refine the initial TRW calibrations.

Lake Argyle is an extensive man-made lake in northern Australia. It was planned to provide a dark target to complement Lake Frome and which could be used in the winter period in Australia for calibration. There is an AeroNet CIMEL (maintained by CSIRO) located there and a field campaign was carried out. Studies of the darker end of the calibration for Hyperion have been carried out but reporting has not yet been finalised. There were extensive water quality data and water reflectance obtained and we have therefore provided a report on the completed analysis of Lake Argyle as an inland water body.
2.2 Lake Frome

Locating Sites on (the Salt) Lake Frome in northern South Australia

Site Information:

Site P/Co-Investigator(s): Dean Graetz, Susan Campbell, Edward King, Jenny Lovell David Jupp (CSIRO EOC), Jay Pearlman, Pamela Barry & Peter Jarecke (TRW Inc)
Site Name: Lake Frome
Type of measurement: Surface reflectance
Measurement devices: ASD FR (400-2500 nm)
Dates of acquisition: December 17-20, 2000
Latitude: 30º 51’ S
Longitude: 139º 45’ E
Elevation: sea level
Surface type: Salt Lake
General atmospheric conditions: Clear
Other satellite data: Landsat ETM+, ALI, AVHRR
Comments: Meteorological data were recorded during the field campaign and Hyperion overpasses on December 20, 2000 and January 5, 2001.
Contact email: Susan.Campbell@csiro.au

Report prepared by: Susan Campbell & David L B Jupp
CSIRO EOC
2.2.1 Introduction

CSIRO EOC carried out a field validation campaign between December 17 and 20, 2000 at Lake Frome (see Figure 2.2.1 & Figure 2.2.2) in coordination with an early Hyperion data collect on December 20, 2000. This day was less than perfect so images were also collected on January 5 and 21, 2001 and used in its place. Landsat 7 ETM+ and Advanced Land Imager (ALI) data were also collected at the same time for analysis and comparison. The objective of the field mission was to validate and evaluate the Hyperion and other EO-1 sensors in the early check-out period. Since the northern hemisphere was in the depths of winter in December 2000 it was necessary to find and use suitable sites in the southern hemisphere.

Lake Frome was judged to be an ideal site as the Hyperion ground track aligns with a well-established and persistent salt track well away from edge effects and where the surface is uniform and flat. In the period leading up to the EO-1 mission the Lake had been dry for an extended period and Landsat images showed it to be extremely bright in the visible region to the extent that the Hi-gain mode was purposely only activated when the Landsat track was south of Lake Frome.

![Figure 2.2.1: Landsat Image of Lake Frome – a salt lake in northern South Australia.](image)

Vicarious calibration, in which ground measured data are used to assess the calibration of space data, provides a unique opportunity to investigate the characteristics of the instrument from a position that is user and end-use oriented. However, because of the variability of atmospheric and environmental conditions, the process has to involve extensive ground truth and careful coordination with spacecraft mission operations to coordinate the time of data collection of the spacecraft with the ground truth measurements. It also demands the
collection of sufficient ground information to characterise the site and the atmosphere at the
time of the acquisition. The desired result is a direct comparison of the top of atmosphere
(TOA) measurements made by the instrument with the TOA predictions based on the
independently measured ground spectral reflectance measurements and propagation through a
predicted atmosphere using a radiative transfer model that incorporates ground based
ancillary atmospheric data (such as visibility and water vapour).

The purpose of the first visit to Lake Frome in December 2000 was to model the TOA
radiances from the field measurements of surface reflectance at the time of Hyperion
overpass and the ancillary data. The data were acquired soon after the launch of Hyperion as
part of the early and vital check-out of the instrument by the instrument team and were
provided in an un-calibrated form to maximise the independence of the evaluation. In the end,
the TOA radiances were estimated by the CSIRO team for the January 5\textsuperscript{th} 2001 overpass
assuming surface reflectance was stable and persistent but the mission served its purpose well
and played a significant part in making Hyperion data ready by the end of the check-out
period for provision to the NASA Science Validation Team.

The Lake Frome site data were also used to check for sensor uniformity (both for sensor
calibration in-equalities and scene dependent effects) and to test the accuracy of geo-locating
the Hyperion image with the physical sites where the measurements were made. Descriptions
of these tests and the uniformity of the sites over regions comparable with the ground sample
distance (GSD, approximately 30 m for Hyperion) of the instrument during the campaign can
be found in the paper by Campbell \textit{et al.} (2001).
This report describes the early ground truth campaign and the resulting comparison between the predicted and measured TOA radiances. As stated above, these studies were carried out soon after EO-1 launch and provided valuable support to the instrument checkout and validation prior to the release of data in early 2001. It was, in fact, the first vicarious calibration test for Hyperion post-launch and provided very welcome confirmation of excellent calibration performance from the sensor. Lake Frome is also providing an excellent site to support on-going work to characterise the cross-track “smile” effect due to its having a section of the complete Hyperion swath within a relatively uniform area of salt and a very good characterisation of the reflectance of the salt surface based on (at this time) two major field campaigns to the Lake.

2.2.2 Lake Frome ground truth data collection

Lake Frome is located in the north east of South Australia (Figure 2.2.2(a)) and is a large, normally dry salt lake (playa). The centre of the playa is approximately at 30°51’S and 139°45’E. The mission was well supported by atmospheric measurements from the CIMEL site at Tinga Tingana and the ABoM radiosonde site at Woomera. Both of these locations are marked on Figure 2.2.2(a). It also has excellent supporting logistics at the Arkaroola resort which is close to the Lake access.

The Lake is very bright when dry with visible region reflectance being over 70%. However, moisture decreases the SWIR reflectance very significantly and this will be addressed later in this report. Figure 2.2.2(b) is an image of the January 5th 2001 Hyperion acquisition over the Lake Frome area showing the field sites. The sites fall on a path along the centre region of the Hyperion swath.

Figure 2.2.3: Lack of “hotspot” halo around aircraft shadow indicates flat smooth but diffuse texture. However, there is a pattern of “mottles” to take into account.
The Lake was judged to have good surface homogeneity and texture and was hard enough for Quad-bikes to access the central area and carry people and equipment out to the sites. The environment was harsh and great care was taken to avoid possible problems for staff out on the Lake. The surface texture was also good from a radiative point of view. An aerial survey showed it to be primarily smooth as indicated by lack of a distinct “hotspot” halo around the aircraft shadow (Figure 2.2.3) but it did have a pattern of small circular features (called “mottles” during the field survey) that were assessed carefully at each site.

Meteorological data were collected during the mission using a portable weather station and a Yankee Environmental Systems multi-frequency shadow-band radiometer (MFR) operating at the lakeshore. Data were also acquired for every acquisition of the EO-1 data from Bureau of Meteorology radiosondes launched from Woomera (250 km west of Lake Frome, see Figure 2.2.2(a)) and the CIMEL sun photometer located at another CSIRO field site at Tinga Tingana 150 km to the north of the lake.

2.2.2.1 Reflectance Measurements

Spectral reflectance measurements were made with an Analytical Spectral Devices (ASD) Field Spec spectroradiometer at a range of ground sites as shown in Figure 2.2.4. A GER spectroradiometer was also used but its data were not judged to be as good as the ASD.

![Figure 2.2.4: Field work at Lake Frome illustrating high surface reflectance and site homogeneity (The field record later won a photo competition prize!).](image)

The measurements during the first field mission were made over specified ground blocks to account for spatial variation and the mean signatures were established. The measurements were referenced to a standard Spectralon panel. However, since field staff had to carry and operate the ASD the design was fairly limited. At a second (later) field mission, a more extensive methodology was developed using an ASD mounted on a quad-bike and
establishing reflectance in a grid at each site. This more advanced methodology was later also used at the Coleambally site.

A brief description of some of the sites that were measured during the first field mission is included in Table 4.2.1. Sites 018, 020, 022 and 024 were used for the initial comparison with Hyperion measurements on behalf of TRW. The “Island” soil site and the wetter Site 8 are included here for comparison.

<table>
<thead>
<tr>
<th>Site</th>
<th>Surface Description</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>018</td>
<td>Uniform Salt</td>
<td>-30.80</td>
<td>139.68</td>
</tr>
<tr>
<td>020</td>
<td>Uniform Salt</td>
<td>-30.83</td>
<td>139.67</td>
</tr>
<tr>
<td>022</td>
<td>Mixed Salt and Mottle</td>
<td>-30.87</td>
<td>139.66</td>
</tr>
<tr>
<td>024</td>
<td>Uniform Salt</td>
<td>-30.90</td>
<td>139.65</td>
</tr>
<tr>
<td>008</td>
<td>Salt Graded to Ooze</td>
<td>-30.63</td>
<td>139.73</td>
</tr>
<tr>
<td>Island</td>
<td>Soil</td>
<td>-30.80</td>
<td>139.71</td>
</tr>
</tbody>
</table>

During the first field mission, because the ASD was carried by field personnel, the sites were only sampled using a central cluster of points that was augmented by local transects of about 100m to characterise the spatial (co-)variance and to produce an effective mean site signature at the scale of the Hyperion GSD. However, the initial measurements showed such high uniformity at each site and this design was judged adequate for the purposes of the first mission. Salt and mud samples at the sites from both at and below the surface and also in nearby wetter areas were also collected for laboratory characterisation.

![Lake Frome Spectra](image)

**Figure 2.2.5**: ASD Spectra recorded at field sites shown in Figure 2.2.2(b). Spectra have been linearly interpolated over regions of strong atmospheric water vapour absorption

Figure 2.2.5 shows some mean reflectance spectra for the main calibration field sites as well as Site 8 and the “Island” soil site. These spectra have been linearly interpolated across the main water absorption bands as the ASD spectra are very noisy in these regions. The form of the spectrum is very similar at all the salt sites. Variation is mostly related to the thickness of the salt crust (a thin crust allows the underlying mud to influence the spectrum – mostly at the
blue end) and the amount of liquid water present in the salt matrix. The liquid water is indicated by a clear “water” absorption effect in the data. As discussed later, the pure dry salt matrix is spectrally flat and nearly “white”.

The soil signature was taken on the loess islands around the Lake. The soil is fine textured and quite dark in the visible. However, its reflectance in the SWIR is very high and it would provide an excellent base for SWIR assessment. If Lake Frome is used in the future a parallel “track” of soil sites will be set up and monitored in addition to the salt track.

The full extent of the spatial variation of the surface and its components is being studied in on-going work using a range of data available for Lake Frome including Hyperion, ALI, HyMap airborne hyperspectral and Landsat ETM data. One outcome has been from an initial study of the effects of wetting on the salt signatures. Figure 2.2.6 shows a sequence of signatures (normalised to a panel but not corrected for panel conditions) ranging from “dry” (dried in a microwave oven) to wet (saturated).

The microwave was not sufficient to drive off the bound water but it is clear that more extensive drying would result in a base dry salt signature that is very bright and spectrally flat. Although the work is still preliminary, it has suggested that the amount of water may be determined spectrally through well-chosen ratios and then used to obtain the absolute reflectance from the wetting series without the need for fieldwork. Certainly, a Principal Components Analysis shows that the sequence of data has two “dimensions” of base salt and water effects. This idea, which depends on the main central area at Lake Frome maintaining its “purity”, is being assessed against a time series of Frome images.

Figure 2.2.6: A sequence of salt samples with different level of wetting showing the two-component spectral variation. Work is continuing to assess its use for time series calibration.
2.2.2.2 Navigation Accuracy Assessment

The utility of the field measurements is crucially dependent on their accurate location (and relocation) on the Lake and in the image data. The GPS readings taken at all sample positions provided an accurate base of geo-located data and so it was necessary to also establish accurate image geo-location.

A set of ground control points (GCPs) was identified in both the image of Hyperion Band 22 (568 nm) and an accurately geo-rectified Landsat ETM+ image (acquired on January 21, 2001) in its (green) Band 3. Analysis of the data fit by different orders of polynomial was based on predictive error and showed that a bi-linear transformation was adequate and possibly best among various orders of model. This model allows for shifts in x and y, separate changes of scale in x and y, image skew, rotation and an x-y interaction term. The statistical significance of the x-y interaction term may indicate that there was a projective geometrical effect in the Hyperion image at the surface. This is likely to have greater significance at other sites since Lake Frome was imaged at near nadir view.

The main characteristics of the pixel geometry as determined from this model is summarised in Table 4.2.2.

<table>
<thead>
<tr>
<th>TABLE 4.2.2 Hyperion Geometric Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel-X</td>
</tr>
<tr>
<td>Pixel-Y</td>
</tr>
<tr>
<td>Rotation</td>
</tr>
<tr>
<td>Skew</td>
</tr>
</tbody>
</table>

EO-1 has a specific yaw to compensate for the Earth rotation skew. It seems to have been very effective. The pixel shape was also very close to square in this model. The predictive error for the VNIR sensor was 15 metres in x and 20 metres in y. This close registration and the uniformity of much of the Lake Frome site therefore means we can identify the spectra of pixels relating to the ground sites with considerable confidence.

The GCPs were also independently identified in band 94 of the Hyperion image (1084 nm) to test the alignment of the VNIR and SWIR spectrometers that make up the Hyperion instrument. These share the same focal plane but have different read-out properties. Based on predictive errors, the data for each spectrometer were again well modelled by a bi-linear transformation. However, offsets of approximately one pixel in x and a fraction of a pixel in y were noted between the VNIR and SWIR sensors. The magnitude of the offset varied between about 1.0 and 1.2 pixels across the 256-element array. This finding, in fact, confirmed what the TRW checkout team had suspected from pre-launch testing and this and other studies eventually resulted in a standard correction being implemented for the different geometries of the VNIR and SWIR in the later Level 1B release of the Hyperion data.

2.2.2.3 Atmospheric Modelling

Two sources of measured atmospheric data were available. One was CIMEL data taken at Tinga Tingana (a site established in 1998 in central Australia to study aerosols) that could be used to provide estimates of aerosol optical depths and water vapour at that site. The other was the Woomera meteorological station, which is located about 200 km west of the lake (see
Figure 2.2.2(a)) and provides daily radiosondes. The radiosonde data were used to obtain lapse rates for the pressure, temperature and water vapour profiles. These measurements were modified where necessary by using the historical atmospheric statistics for the region to provide stable lapse rates that should be applicable at Lake Frome. A general idea of the total column ozone was available from the GOME satellite data.

The CIMEL data were used to infer integrated atmospheric properties such as the angstrom coefficient of the extinction. The most important parameters of the local visibility and total column water vapour at Lake Frome were not, however, easy to establish for the acquisitions taken later than the field work. Comparisons between the total column water vapour as measured by the MFR at Lake Frome, the value that best predicted the LICOR irradiance data, the Woomera Radiosonde and the CIMEL total water vapour estimate at Tinga Tingana at the time of the field work seemed to show the Lake Frome site tended to have a greater water vapour loading than the others. This relationship was used in the estimation of TOA radiance.

2.2.2.4 Top of the atmosphere radiance comparison

As the EO-1 mission started, CSIRO worked to provide timely feedback on the Hyperion calibration. The Lake Frome data were used with an atmospheric model to compare the estimated at-sensor radiance with un-calibrated Level 1 data. A simple radiative transfer model was used for the initial investigation since the necessary outputs were easy to obtain and it was able to be optimised to the field data that was taken. The estimate (Figure 2.2.7) of the “calibration” (ratio of the estimated radiance to the raw counts) was obtained and compared with the then current curve provided by TRW.

![Figure 2.2.7: Early comparison of TRW and vicarious calibration using Lake Frome data](image)

This graph, which provided very welcome confirmation of the post-launch quality of the instrument and its functioning in a working situation, is now largely historical as TRW and CSIRO then proceeded to make considerable efforts to refine the study and look at reasons for the residual discrepancies as well as to undertake many other types of comparisons. However, the basic result that Hyperion was working within a close range of good calibration post-launch provided a major outcome from the Lake Frome mission.
Site 20 showed the best overall agreement between the TOA radiances calculated from ground truth and the Hyperion measurements. Figure 2.2.8(a) shows the spectral radiance curves. The agreement is best in the visible and near IR.

**Figure 2.2.8 (a).** Spectral radiance comparisons over the VNIR and SWIR spectral response region of Hyperion. (b) VNIR spectral radiance comparison from Site 20.

As shown in the expanded wavelength scale in Figure 2.2.8(b), the mean difference is less than 1.5 % ± 0.5 % from 450 to 900 nm. The CSIRO TOA radiances are 16 % higher than that measured by Hyperion in the SWIR for site 020. The largest differences occur at 715, 760 and 810 nm and in these cases are most likely related to atmospheric correction effects at the spectral features shown in Figure 2.2.7. Otherwise, the general difference ratio ranges from 2 to 10 % throughout the spectral region. In the SWIR, sites 018, 020, and 024 indicate that the TOA model predictions are generally 10 to 25 % higher while site 022 data are lower as shown in Figure 2.2.8. The gaps are where water absorption bands affect the data. Corrections for BRDF effects based on view angle and the Standard Spectron panel SWIR performance would improve the validity of these comparisons.

**Figure 2.2.9:** Coefficient of variation in the Hyperion image around Site 20 (blue dots) plus similar estimates based on the field spectra (brown lines).
A basic limitation on the data in this case was the wetter than normal state of the Lake. This led to the SWIR region being very dark and the data in the SWIR – both from the satellite and at the ground surface – being quite noisy. Figure 2.2.9 shows the coefficient of variation in a neighbourhood of Site 20 from the image and indicates that the coefficient of variation is affected by the instrument sensitivity and SNR but also has an intrinsic behaviour related to the base salt reflectance combined with the solar irradiance. The similar data from the field measurements indicates the base relationship is intrinsic and not instrumental. It would have been better if more sites on the very bright SWIR soil areas (see Figure 2.2.5) that surround Lake Frome had also been measured.

2.2.3 Conclusions from the campaigns

The Lake Frome field campaign in December 2000 was the first time the lake had been visited for a ground based spectral measurement effort. Despite the extreme nature of the environment it was highly successful. A second mission to the lake was made in September 2001 but due to the wet year experienced in 2001 the data were valuable to characterise the Lake but the overpass was not a success for calibration and validation. The lake surface has, however, now been well characterised and the range of target sites has been extended for future EO-1 data collection. Data from the Lake Frome site are available as part of the EO-1 mission and can be found at http://www.eoc.csiro.au under Hyperspectral/Australian Science Validation Team/Data Collections. The site provides an excellent base with which to cross-compare Landsat ETM, ALI and Hyperion and compare their performance with that of other polar orbiting satellites of varying resolution and scale, such as AVHRR, MODIS, ATSR2 and SPOT Vegetation. In recent times a series of images has been acquired following a drying period. These will be processed for testing calibration stability.

While some site spectra in the first exercise provided a very accurate match with the Hyperion data, at others there were variations between the Hyperion data and site measurements that may have a range of causes. Among these is the surface BRDF which it was intended that we measure but is still not completely determined. The HyMap data will provide more insight into this factor. Visual assessment as in Figure 2.2.3 indicates the BRDF of the lake is likely to be stable and able to be characterised. The combination of field and laboratory measurements allowed TRW to quickly confirm that their calibrations were generally within about 5-10% in the VNIR and perhaps similar in the SWIR. The low reflectance of the Lake Frome salt in the SWIR prevented precise conclusions in that region. The wetter-than-normal conditions in the first year of the EO-1 mission contributed to the low environmental SNR in the SWIR region.

On the basis of this work, TRW used the solar calibration to improve uniformity and absolute corrections so that the Level 1 products that were released were of high quality when the data were first delivered to members of the SVT. In the first year of the campaign, results from a range of sites and using a number of sensors were used to define a major correction to the overall calibration. This was implemented in late 2001 to bring Hyperion into alignment with standard choices of solar constant, Landsat ETM and ALI. However, the absolute calibration is certainly still being discussed.
2.2.4 Acknowledgements

Staff from TRW Inc. provided data, responsive help and were a wonderful group to work with. NASA provided access to the Hyperion data, CSIRO Land & Water supported field campaigns with their ASD and staff support including the important role of Guy Byrne in the missions, the CSIRO EOC funded the field missions, the Australian Bureau of Meteorology provided extra radiosonde data for Woomera and the Arkaroola resort provided great interest, help beyond normal hosting and their wonderful surroundings (Figure 2.2.10).

![Figure 2.2.10: The road to Arkaroola Resort – Flinders Ranges, northern South Australia](image)

2.2.5 References


2.3 Uardry

Field Crew at the Uardry site near Hay, taken from the 15m tower

Site P/Co-Investigator(s): Fred Prata
Site Name: Uardry (near Hay, New South Wales).
Type of measurement: Short- and long-wave radiation, albedo, surface temperature, aerosol optical depth, surface meteorology
Measurement devices: Pyranometers (5), pyrgeometers (3), infrared radiometers (4), shadowband radiometer (1), surface meteorological instruments, portable radiosonde, 15 m observation tower.
Dates of acquisition: Continuous.
Latitude: 34.392 S
Longitude: 145.304 E
Elevation: 110 m
Surface type: Mitchell grass and bare soil (red cracking clay)
General atmospheric conditions: Generally clean atmosphere, optical depth (500 nm) < 0.1, low rainfall (<350 mm annually). No industrial pollution sources, occasional smoke from stubble burning and large distant bushfires.
Other satellite data: Cal/val site for MODIS/ASTER, ATSR-2/AATSR, GLI (NASDA)
Comments: Instruments in continuous operation since 1993. Well-characterised field site with copious data available. Good uniformity at scales from 10 m to 10 km.
Contact email: Fred.Prata@csiro.au
2.3.1 Introduction and Objectives

On January 9, 2001, EO-1 passed over the Uardry field site, near Hay in NSW, Australia. Hyperion was programmed to acquire an image around 10 AEST (11 am local summer time and close to 00 UT on the boundary between January 8 and January 9) and one minute after the Landsat-7 overpass. The uncorrected Hyperion data for the site are shown in Figure 2.3.1.

![Figure 2.3.1 Early check-out phase of EO-1 mission - Hyperion Image of the Uardry site – January 9 2001 (Uncorrected data).](image)

A team of scientists from CSIRO visited the Uardry site to undertake a careful calibration and validation study and acquired the following data:

- A set of ground-based spectral reflectance measurements at the site;
- Aerosol optical depth information;
- Atmospheric temperature and moisture profiles (radiosonde);
- Radiation data;
- Visual and digital camera measurements of the clear sky;
- Landsat and MODIS data were also collected for this exercise.

The aim of the data collection was to provide important vicarious calibration and validation information for the early check-out period of operation of the Hyperion mission. This activity, and others at Lake Frome and Mt Fitton in South Australia (reported separately) provided vital information at a time when the northern hemisphere was in the depths of winter. A template for the scientific rationale and methodology supporting the field work may be found in the published paper by Prata and Grant (1998).
2.3.2 The Uardry field site

Uardry (34.392 S, 145.304 E, 110m) is a large sheep station situated on the largest plain (prairie) in Australia—the Hay plain. The climate is temperate with most rain falling in the winter months from June to October, but with quite low rainfall totals of around 300 mm annually. The landcover consists primarily of perennial Mitchell grass used for sheep and cattle grazing. The soil is a red-coloured cracking clay. There are few trees and no industry within 200 km of the field site. Skies are generally clean—aerosols arise mainly from smoke particles from bush fires and burning-off episodes, but there are occasional periods of wind blown dust from inland desert sources. The site has been used as a cal/val target for many space and air-borne sensors and has been operational for about 10 years. Time series data of surface radiative fluxes and meteorological parameters such as air temperature, wind speed and humidity are routinely collected both from ground level instrumentation and from levels on a 15m tower that has been constructed at the site. More details of the field site may be found in Prata (1994).

2.3.3 Instrumentation

Instruments are permanently deployed at the field site and collect data in an autonomous fashion. The site uses a distributed network of field instruments to acquire radiation measurements from the surface and sky. The principle measurements pertain to the thermal infrared region, but shortwave (broadband, hemispheric) data from upward- and downward-looking pyranometers are also acquired. The data are relayed to a central computer and stored on disk for later processing. Site visits to download the data and to make routine instrument checks are carried out at roughly 1–2 month intervals.

Table 2.3-1 Instruments and measurements made at Uardry field site on 9 January, 2001.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measurement</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCD Spectrometer</td>
<td>Reflectance</td>
<td>%</td>
</tr>
<tr>
<td>MFRSR</td>
<td>Aerosol optical depth</td>
<td></td>
</tr>
<tr>
<td>Pyranometers</td>
<td>Solar irradiance</td>
<td>W m^{-2}</td>
</tr>
<tr>
<td>Pyrgeometers</td>
<td>Thermal irradiance</td>
<td>W m^{-2}</td>
</tr>
<tr>
<td>Radiosonde</td>
<td>Temperature profile</td>
<td>K</td>
</tr>
<tr>
<td>Radiosonde</td>
<td>Relative humidity</td>
<td>%</td>
</tr>
<tr>
<td>GPS</td>
<td>Latitude &amp; Longitude</td>
<td>S, E</td>
</tr>
<tr>
<td>Radiometers</td>
<td>Surface radiometric temperature</td>
<td>K</td>
</tr>
</tbody>
</table>

In addition to the routine suite of measurements made at Uardry, a portable radiosonde unit was used for this mission to measure atmospheric profiles of temperature and moisture and a CCD spectrometer was deployed to collect spectral reflectance data. A computer controlled GPS unit was used to log the positions of the reflectance measurements. Table 2.3-1 lists the instruments and measurements made during the field experiment.

The CSIDAT-2 instrumentation (a system for continuously logging site parameters including albedo and components of the surface radiation balance) was also operating during the experiment. Table 2.3-2 lists the parameters and the locations where they were measured at Uardry.
Table 2.3-2 Routine data collected at the Uardry field site and their locations. $T_g$ is ground temperature, $T_a$ is air-temperature, RH is relative humidity, $U$ is wind speed, PAR is Photosynthetically Available Radiation, $I_s$ is shortwave irradiance, $I^s$ is shortwave exitance, $I_L$ is longwave irradiance, $I^L$ is longwave exitance, $P_S$ is surface pressure. Repeated parameters represent a cluster of measurements.

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Parameters</th>
<th>Longitude</th>
<th>Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>00 (Central)</td>
<td>$T_g$</td>
<td>145°18.28'E</td>
<td>34°23.50'S</td>
</tr>
<tr>
<td>00 (Central)</td>
<td>$T_a$ (2 m)</td>
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<td>34°23.50'S</td>
</tr>
<tr>
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<td>RH (2 m)</td>
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<td>34°23.50'S</td>
</tr>
<tr>
<td>00 (Central)</td>
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<td>145°18.28'E</td>
<td>34°23.50'S</td>
</tr>
<tr>
<td>00 (Central)</td>
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<td>34°23.50'S</td>
</tr>
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</tr>
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</tr>
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<td>PAR</td>
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<td>34°23.50'S</td>
</tr>
</tbody>
</table>

2.3.4 Data-sets

2.3.4.1 A note on time

For various reasons the data contained in this report use two different conventions for time. These are:

1. Universal time (UT) or Greenwich Mean Time (GMT). The GPS uses UT and the recorded spectra were tagged to this time using the GPS.

2. Local time (LT) or Australian Eastern Standard Time (AEST). AEST=UT+10 hours. Data from the CSIDAT-2 system and the digital camera use this time.

Note that Australian summer time was in force during the field work and this was the time used for synchronising the field work. Australian summer time=UT+11 hours.

2.3.4.2 Reflectance measurements

Reflectance measurements were made using a LasTek triple CCD spectrometer model S1000. The spectrometer and computer were mounted inside a vehicle and a specially constructed boom with fibre-optic mounting was used to position the fibres to view the surface at nadir from a height of about 2 m. The vehicle was driven across the field site, traversing from each of the satellite sites towards the central site and then two other legs were conducted along the dirt road and from the eastern most site (E500) to the northern most site (N500) along a near constant bearing of 290° to N. GPS readings were taken every 2 s and logged on a separate computer. The spectrometer was shaded and maintained at a near constant air temperature while taking the measurements.
The spectrometer operates over three separate intervals: 200–575 nm (the master channel), 360–850 nm (slave 01 channel), and 530–1000 nm (slave 02 channel). The spectral resolution of the measurements is between 0.5 and 1 nm, but subsequent processing of the data resamples the reflectances at 1 nm intervals starting from 350 nm and ending at 950 nm. Prior to and during the field measurements, it was noticed that slave 02 channel was rather noisy, particularly at longer wavelengths. The reason for this is unknown, but is under investigation.

In all, about 300 individual spectra were acquired. The pattern of measurements is shown in Figure 2.3.2. Each number identifies the corresponding spectrum file using the convention: s2_digit number.dat, e.g. s11.dat. All of the spectra are archived and available as listed in the Appendix.

Each sample spectrum was acquired with 10 ms integration time and 100 samples were averaged to provide the final spectrum. Thus each spectrum was acquired in about 1 s. Higher integration times tended to saturate the detector under these quite high solar illumination conditions, while lower values tended to be noisier. Every 4–6 data acquisitions, a white panel measurement was made by placing a flat plate covered with A3-size Reflex photocopy paper below the CCD mount. The Reflex plate was used in place of a Spectralon panel, which was unavailable for this experiment. The plate provided a measurement of the spectral solar irradiance within less than 5 minutes of the corresponding sample measurement and using the same illumination and viewing geometry. The Reflex plate was covered when not being used to prevent dirt damaging the surface. The plate had been used in a previous experiment (ACEX, see Prata and Grant, 1998) and its reflectance has been measured with respect to a spectralon panel.
The background image shown in Figure 2.3.2 is a Landsat-7 ETM+ image acquired around the same date as the Hyperion data acquisition, but one year earlier. This image was used as the basis for deciding which parts of the field site reflectance measurements should be made. Essentially at this time of year the vegetation has dried out and is yellow in colour. The height of the vegetation varied from 20 cm to as high as 60 cm in places. Bare soil was noticeable in places around the site, particularly at the eastern edge near the main road. Good representative spectra of the bare soil were obtained by acquiring a transect along the road. Figure 2.3.3 shows photographs of the grass and bare soil at the site.

![Figure 2.3.3](image1.png)  
(a) Photograph of a grass site at Uardry. (b) Photograph of the bare soil on the dirt road at Uardry.

### 2.3.4.3 Radiosonde measurements

Three radiosondes were launched at the site on 9 January at 0830 AEST, 1003 AEST and 1239 AEST. All three flights were successful. Conditions during launch were quite windy with a strong surface wind from WSW. This wind direction seemed to persist up to 850 mb before visual sighting of the balloon made it difficult to ascertain wind direction. The profiles show an inversion around 850–800 mb and some upper level dry regions. The total precipitable water calculated for each flight is 5.23 cm and 4.55 cm (0239 UT). This water vapour amount is quite high for the region and is due to the elevated surface inversion between 1 and 2.5 km above the ground. Despite the high water vapour content, there was no cloud formation.

### 2.3.4.4 Surface meteorological measurements

Data from the CSIDAT-2 system were downloaded and are provided in analysed files. The data-set consists of:

- Surface pressure (mb) at approximately 2 min intervals
- Air temperature (K) at 2 m at approximately 2 min intervals
- Relative humidity (%) at 2 m at approximately 2 min intervals
- Air temperature (K) at 15 m at approximately 2 min intervals
- Relative humidity (%) at 15 m at approximately 2 min intervals
- Surface (ground) radiometric temperature (K) at approximately 2 min intervals
2.3.4.5 Ancillary data

2.3.4.5.1 Sun’s position

Numerical values of the position of the sun at Uardry on 9 January 2001 from 0900 AEST to 1500 AEST are given in Table 2.3-3 every 2 minutes.

Table 2.3-3 The Sun position at Uardry on 9 January 2001. The solar zenith angle is “zen” and the azimuth from North is “azim”. Angles are in degrees. Times are Australian Eastern Standard Time (AEST).

<table>
<thead>
<tr>
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<th>zen</th>
<th>azim</th>
<th>Time</th>
<th>zen</th>
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<td>28.99</td>
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<td>69.96</td>
<td>10:28</td>
<td>22.85</td>
<td>63.61</td>
</tr>
</tbody>
</table>

2.3.4.5.2 Total column ozone

Strong ozone absorption bands occur at wavelengths below 300 nm in the Hartley-Huggins bands and weaker absorption occurs within a broad band ranging from just above 400 nm to beyond 800 nm—the so-called Chappuis bands. Since most of the ozone lies above in the stratosphere, the Hartley-Huggins bands are responsible for removing most of the sunlight below 300 nm (the solar blind region). The Chappuis bands occur at the peak of solar spectrum and so are important for atmospheric correction of hyperspectral data.

Ozone profile data were not measured at the Uardry site and there are few ground-based ozone measurements made in Australia. There are satellites that can provide instantaneous total column ozone at regional spatial scales (100–300 km). GOME on board the ERS-2 satellite is a spectrometer designed to provide total column ozone and some profile information. For our purposes we have obtained the ‘fast delivery product’ from the web site operated by KNMI and sponsored by ESA. The URL is: http://www.knmi.nl/gome_fd/. The ozone amount given for 00 UT on 9 January 2001 at 34.3 S, 145.4 E is 275.8 DU. (Dobson units).
Figure 2.3.4 shows the total ozone derived from a global circulation model assimilating GOME radiances for 8 January (upper panel) and 9 January (lower panel), both at 12 UT. These maps suggest that at the scale of the GOME measurements, the ozone distribution was fairly uniform over Uardry between 8–9 January.

2.3.5 Results

2.3.5.1 Hyperion spectra comparison

The data used in this evaluation were provided directly by TRW and were in an early Level-1 stage of development of the processing chain and calibration of the arrays. The tests described here were focussed on the VNIR sensor and there was no extra pre-processing done to remove remaining image artifacts or other data noise. All comparisons were made directly with no local modifications to the data.
At the time of the exercise, investigations using a range of calibration sources (sun, moon, vicarious, on-board lamp) were being used for uniformity correction and absolute calibration improvements. These were subsequently available to the SVT in the Level 1A and higher Level products. A range of these effects can be seen in the Hyperion image at the beginning of this report (Figure 2.3.1).

The methodology used to analyse the Hyperion and other satellite data-sets follows that of Prata and Grant (1998). The ground-based spectra and atmospheric measurements are used in a detailed radiative transfer model (MODTRAN 3) to estimate the top-of-the-atmosphere radiances for each sensor. The modelling depends on the viewing geometry and input data, while the sensor data is crucially dependent on calibration as well as precise knowledge of its viewing parameters. Since the atmospheric conditions are benign, any intercomparison differences are largely due to errors in input data and/or imprecise knowledge of the sensor characteristics. The main result is shown in Figure 2.3.5.

Figure 2.3.5 Modelled top-of-the-atmosphere radiance and Hyperion measured radiances for (a) the spectral region 400-900 nm and (b) as a scatter plot of modelled vs. measured radiances.
Figure 2.3.6 Comparison of Hyperion spectra with individual ground-based spectra at the Uardry field site.

Figure 2.3.5 shows the Hyperion spectral measurements (400–900 nm) and the MODTRAN modelling estimates obtained from atmospheric data and the average of 15 ground-based spectra. The bias and standard deviation were found to be 0.17 and 2.3 W m$^{-2}$ sr$^{-1}$ m$^{-1}$, respectively. Figure 2.3.5 also shows a scatter plot of these results with a 1-1 line added. While these results are good, comparisons with individual spectra are not as good, but perhaps this is to be expected given the surface variability at the site and the different fields-of-view of the ground-based and space-based sensors. Figure 2.3.6 illustrates results for individual spectra.

2.3.5.2 MODIS and Landsat wide-band intercomparisons

Data from MODIS (250 m pixels) and Landsat 7 ETM+ were also used to compare with the field data. Figure 2.3.7(a) shows a comparison for a predominantly grass site and Figure 2.3.7(b) shows the result for a predominantly bare site.
Figure 2.3.7 (a) MODIS and Landsat 7 ETM+ wide-band measurements and modelled radiances at a grass site. (b) As for (a) but at a bare soil site.

For the grass site Landsat and MODIS overestimate the radiances in all bands, while for the bare soil site the results are more variable. The channels at around 600 nm appear to agree well for both sensors compared to the MODTRAN modelling for the grass site, while for the bare site Landsat 7 underestimates the radiances. The sample of measurements is not large enough to make firm conclusions about these sensors, but it appears that both MODIS and Landsat are within 3-6 % of the modelled at-sensor radiances.

2.3.5.3 Hyperion atmospheric correction

Given the good results obtained with the MODTRAN modelling for the Hyperion spectra between 400–900 nm, an attempt was made to perform an atmospheric correction of the data and then compare the reflectances directly with the ground-based spectra. The result for two surfaces (and Hyperion only for a water surface) is shown in Figure 2.3.8.
Figure 2.3.8 (a) Hyperion and ground-based reflectance measurements for two surfaces and Hyperion measurements over water. Hyperion data have been atmospherically corrected. (b) As for (a) but with a "dark" pixel subtraction procedure applied.

Again the comparison appears quite good, except below 500 nm where the Hyperion data appear to significantly underestimate the reflectance of both surfaces and in water vapour bands which indicate the atmospheric water vapour could have been modified for improved ground spectra. The problem below 500 nm could have been due to poor modelling but was certainly compounded by calibration errors on Hyperion.

[The blue-end (less than 500 nm) calibration was significantly improved for later data releases on the basis of check-out studies such as this one but it has remained an area of some concern in Hyperion data. Editor’s Comment.]
An apparent improvement can be made by performing a ‘dark’ pixel correction. This is done by subtracting out a constant reflectance based on the darkest pixel in the scene (in this case a river water pixel). The results of doing this correction are shown in Figure 2.3.8(b). Finally, a comparison of an atmospherically corrected and uncorrected Hyperion scene is given in Figure 2.3.9. The corrected image Figure 2.3.9(b) appears to be a little sharper, as might be expected.

### 2.3.6 Conclusions

A detailed field experiment at a grassland site in Australia has verified that the Hyperion sensor is operating within its specification over the wavelength region 400–900 nm. The bias and standard deviation of the top-of-the-atmosphere radiances within this spectral region are indistinguishable from the anticipated modelling and instrument errors. Good results were obtained through intercomparisons with MODIS and Landsat, suggesting that Hyperion is at least as well calibrated as these sensors. The modelling results suggested that below 480 nm there may be a problem with the Hyperion calibration. This was confirmed by other studies and the calibration (and dark correction) was improved by TRW before data were released to the SVT. However, as noted previously, it remains an area in Hyperion where there may still be improvements to be made. The relatively aerosol-free and cloudless atmosphere
(approaching a Rayleigh atmosphere) at the Australian field site does not challenge the efficacy of the modelling and so we suggest that these results provide an excellent benchmark for gauging Hyperion performance. A list of the data available from the field work and a means for obtaining the data are given in the Appendix.

### 2.3.7 References


### 2.3.8 Appendix: Available Data Sets for the Uardry experiment

All of the data acquired during this field experiment have been written to CD-ROM and can be acquired by email request to: fred.prata@csiro.au. The data are in ascii and are self-contained. The files are:

1. **Spectral data**

   There are 67 files of spectral reflectance data. Each file is in ASCII. The first line provides a time (UT) and location (latitude and longitude) from the GPS. There follows two columns of wavelength (nm) and reflectance (0–1) values starting at 350 nm and ending at 950 nm in 1 nm intervals.

2. **Solar radiation data**

   The solar radiation data measured from the tower at Uardry are contained in a single ascii file: *solar_data.dat*. There are four columns: Time (hours) Time (minutes) S S. The times are AEST and the irradiances (S is the surface-leaving flux density; S is the incoming solar flux density) are in W m⁻².

3. **Radiosonde profiles**

   Radiosonde data are in two ascii files: *us010109002.up, us010109003.up*. Each file consists of 7 columns of data. There is a line of text indicating time of launch, location and the number of records in the file. The columns: Time since start (seconds), Height (km),
Pressure (mb) Temperature (C), Vapour Pressure (mb), Relative Humidity (%) and Dew Point Temperature (C).

4. Surface meteorological data

These data are contained in two ascii files:

1. **met_data01.dat** contains time (hrs, min, sec), air temperature at 2 m (K, Ta) and surface temperature (K, Tg).
2. **met_data02.dat** contains time (hrs, min), relative humidity (%) at 2 m (RH2), air temperature (K) at 15 m (RH15), surface pressure (mb, Ps).
2.4 Lake Argyle

Site Information:

Site P/Co-Investigator(s): Edward King, Susan Campbell, Jenny Lovell, Dean Graetz, Tiit Kutser

Site Name: Lake Argyle
Type of measurement: Surface (water) reflectance
Measurement devices: ASD FR (400-2500 nm)
Type of measurement: In-water spectral profile
Measurement devices: HydroScat, HydroRad
Dates of acquisition: July 16-24, 2001
Latitude: 16º 17’S
Longitude: 128º 41’E
Elevation: 90 m
Surface type: Fresh water
General atmospheric conditions: Clear at Hyperion overpass, some cloud during reflectance measurements on preceding days
Other satellite data: Landsat, ALI, AVHRR
Comments:
Contact email: Edward.King@csiro.au

Report provided by: Edward King & Jenny Lovell
CSIRO EOC
2.4.1 Introduction & Objectives

Lake Argyle is a large (1000 square km) man-made lake in the Kimberley region of northern Australia. It has an associated agricultural region as well as tourism and recreation as uses. Its use as a dark target of satellite calibration has been suggested on a number of occasions and this was investigated for the purposes of the EO-1 mission as well as others of interest to the scientists who visited the area.

Lake Argyle provides a dark target in contrast to Lake Frome (bright target) and has a continuously reading CIMEL aerosol and atmosphere monitoring station in place (Figure 2.4.1) as well as a Nephelometer. Two simultaneous experiments were conducted during the period July 16 to 24, 2001. The objective of the first experiment was to compare the effectiveness of two algorithms for correcting for the influence of aerosols on AVHRR data. The aerosol loading over Lake Argyle in July varies on a daily basis with plumes and sheets of smoke from local and distant biomass burning moving SE-NW across the lake.

![Figure 2.4.1 CIMEL being serviced at Lake Argyle during field campaign](image)

The second objective was to measure the apparent optical properties of the lake, and to relate these to Hyperion data from an overpass on July 22. These results and some initial findings using Hyperion data are reported below. Surface radiance of the Lake was measured with a boat-mounted ASD spectroradiometer along six transects, including one aligned with the Hyperion strip. The ASD was mounted approximately 2 m above the water surface and a 1° foreoptic was used. Radiance measurements were made of water and sky consecutively at 30° from vertical along with reference measurements of a Spectralon panel so that reflectance could be measured free of sky reflections from the water surface. Three in-water instruments were also used to measure profiles and surface and bottom reflectance. The in-water measurements were made near the centre of the Hyperion scene at the time of the July 22 overpass. Water samples were taken for analysis of dissolved organic matter, chlorophyll and total suspended matter.
Figure 2.4.2: Average reflectance corrected for sky reflections along Transect 6 of Lake Argyle as support for Hyperion calibration and water modelling.

In addition to the spectral measurements, YES MFR shadow band radiometer, LiCor spectroradiometer (total and diffuse irradiance), Exotech radiometers, fish-eye sky camera and weather station (dry bulb air temperature, relative humidity, solar irradiance, wind speed and direction) instruments were operated on the lakeshore from July 16 to 24. The data from this site are still being processed but will be made available to investigators as they become available. The CIMEL data can be accessed via the AERONET web site.

2.4.2 Apparent optical properties of Lake Argyle

2.4.2.1 Introduction

Bio-optical measurements were carried out on Lake Argyle simultaneously with the Hyperion image acquisition on July 22, 2001 in three locations along the Hyperion track. Spectral downwelling irradiance and upwelling radiance just above the water surface and at depths down to 6-7 m were measured with a HydroRad-2. The backscattering coefficient of the water mass was estimated using a HydroScat-6 instrument. Concentrations of chlorophyll-a and other phytoplankton pigments were measured from the water samples using HPLC. The concentration of total suspended solids (TSS) as well as absorption by coloured dissolved organic matter (CDOM) phytoplankton and detritus were also measured from the water samples.

The concentration of chlorophyll-a varied between 2.26 and 3.13 µg/L between the three measurement stations. The pigment composition of the phytoplankton indicated that although levels were generally low, cyanobacteria were the dominating group of the algae present with some presence of diatoms, chlorophytes and cryptophytes. The amount of CDOM was also relatively stable in the lake. Absorption by CDOM at 380 nm varied between 0.819 and 0.885 m$^{-1}$. The biggest variation was found in the concentration of TSS. The concentration of suspended solids was relatively stable and between 1.8 and 2.2 mg/L in the central part of the lake, but rose to 4.6 mg/L in the shallower southern end of the lake. This may be due to re-
suspension through wind stirring in the shallow part of the lake or river discharge or both. The main inflow into the Lake Argyle is at the southern end.

### 2.4.2.2 Image processing and classification

The image acquired on July 22, 2001 was cloud free (see Figure 2.4.3). Atmospheric correction to surface reflectance of a pre-processed and locally de-streaked image (as described in Datt et al., 2003) was performed using Modtran 4 with input visibility and water vapour information from the CIMEL instrument that was located at Lake Argyle at the time of the experiment. Attempts to use ACORN and FLAASH atmospheric correction packages were not successful due to the effects of the large body of water on their automatic algorithms. Special issues in the pre-processing that are needed for dark targets such as lakes were also an issue and will be discussed later.

A semi-analytical bio-optical model (Kutser et al., 2001) was used to study the variation seen in the Hyperion image and the results obtained by processing Hyperion data. The model simulations indicated that the variation in amount of phytoplankton observed in the field would not have a significant influence on water reflectance spectra. One of the reasons is the relatively strong absorption by CDOM in the shorter wavelengths that masks the influence of phytoplankton on the reflectance spectra. On the other hand, while the effect of CDOM on the signature is significant, the variation in the amount of CDOM observed in the field is too small to cause significant differences in the reflectance spectra across the lake.

Modelling results confirmed that the concentration of TSS is the dominating factor in the shape of the water spectrum in Lake Argyle as also indicated by the field spectra such as the transect 6 of Figure 2.4.2. In some places, the highest TSS values are very likely due to a component of lake bottom reflectance in the measured signal rather than a very high amount of re-suspended sediments in the water. However, it is difficult to estimate the extent of the influence of the lake bottom on the measured signal since we do not have reflectance spectra of the sediments present in the coastal areas of Lake Argyle.

A spectral library was created using the bio-optical model as a means to map the amount of TSS in Lake Argyle. The chlorophyll-a concentration was fixed at 2.8 µg/L, absorption by CDOM at 380 nm was fixed to 0.84 m$^{-1}$, and TSS concentrations of 1, 2, 4, 8, 16, 32, 64, and 128 mg/L were used. These spectra were used as templates with the Spectral Angle Mapper (SAM) classifier to allocate water areas to the different categories.

The classification results are shown on Figure 2.4.4 and Figure 2.4.5. The difference between the results is due to the greater level of pre-processing done for Figure 2.4.5 to account for the residual dark current artefacts that occur in water covered areas and clearly observed in Figure 2.4.4 (which had only standard pre-processing) as discussed below.
The classification results fit quite well with our field data. The direct comparison is shown in Table 2.4-1 for the three measuring stations - one in the shallow southern part of the lake and the other two in the central part of the lake.
Table 2.4-1: Comparison of TSS concentration estimated from the Hyperion image with that derived from water analysis.

<table>
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<th>Hyperion TSS estimate</th>
<th>TSS sample measured</th>
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<td>Centre, deep water</td>
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<tr>
<td>Centre, deep water</td>
<td>2 mg/L</td>
<td>2.2 mg/L</td>
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</table>

2.4.2.3 Special Pre-Processing of the Argyle Image

The effects that appeared in the classification shown in Figure 2.4.4 prompted a closer analysis of the noise structure over the water areas at Lake Argyle. The image had been subject to standard pre-processing to remove bad pixels, outliers and major “streaking” effects as described in Datt et al. (2003). However, over water targets this is not enough and the de-streaking could reduce the image quality unless great care was taken.

Figure 2.4.6 shows a subset of the image selected to investigate the effects. Figure 2.4.6 (a) is a colour balanced image to show the normal appearance and extent of the subset while in Figure 2.4.6 (b) the image has been heavily enhanced by histogram equalisation to show how a bright headland and a bright island have been “mirrored” as “ghosts” across the central pixel 128 of the 256 pixels of the image. The effect is quite small but degree of enhancement in this image is due both to the use of histogram equalisation and to the choice of bands (17, 18 and 52) on the two sides the central band 35 of the 70 band VNIR array in Hyperion.
Below this band the ghost increases the brightness of the water while above it the ghost reduces the water brightness.

Figure 2.4.7 shows the same subset with band selections for (a) of Bands 33, 34 and 35 enhanced by equalising within the “zoom” window near the centre of the image in the deep water and for (b) of Bands 36, 37 and 38 enhanced the same way.

The opposite effects of the ghost are seen here but there are also clear imbalances generally between two sides of the central pixel and across the divide at band 35. A number of these effects are seen in the initial classification shown in Figure 2.4.4.

Some reasons for these effects can be found in Pearlman et al. (2003). The VNIR array of Hyperion (the first 70 bands) is divided into four quadrants corresponding to Bands 1-35 and 36-70 and pixels 1-128 and 129-256. The noise and dark current properties of the quadrants are slightly different at a level that it was assumed was corrected by the dark current correction described in the reference. However, it is clear that over darker water areas where the signal and noise levels are not as well separated as they are in most land images that there is a residual imprint of this array structure that can affect image classification.

The residual imbalances across the image (between pixels 1-128 and 129-256) can also be affected and enhanced by image “smile” (Pearlman et al., 2003) and the best way to reduce the effect in the current case was to use the de-streaking tool used in the standard processing (Datt et al., 2003) to use an offset balancing so that the vertical column mean of pixels within a band where only water is covered become the same. While this may not be applicable where significant gradients exist in an image it has reduced the array effects to below the noise threshold affecting the classification. More work is to be done to find a general solution to this problem.
2.4.2.4 Conclusions

Provided the water areas of the image were also pre-processed to remove artefacts due to detector imbalance and residual dark current effects, the shape and magnitude of atmospherically corrected Hyperion spectra were reliable and fit well with the field data. It was difficult to estimate the suitability of Hyperion for mapping the amount of CDOM and phytoplankton in lakes since concentrations of those substances were low and relatively stable over the lake and the amount of CDOM masked the influence of phytoplankton on the water colour spectra. Variability in the amount of suspended solids was the dominating factor causing variance in Hyperion spectra. A map of the TSS obtained from the Hyperion image gave reliable estimations of TSS concentrations.

There are clearly significant residual dark current and other array effects that need to be corrected in water covered target areas. For example, the mirror or “ghosting” effect across the Hyperion image seen here is common in coastal and other water covered areas where high contrasts exist near the water. The mirror images of the bright targets (such as a peninsula or island) are seen in pseudo-true-colour image, classification results and in ratio images when the ratios are across the divide between bands 35 and 36. The edge between the “true image” and “mirror image” across the two sides of the VNIR array (first 128 pixels and the second 128 pixels) is clearly seen in clearer water (i.e. low reflectance) areas in the classification image of Figure 2.4.4. This effect has been significantly improved by the pre-processing described and work should be done in the future to establish the best ways to overcome them in general processing of water covered targets.

2.4.2.5 References

