Evaluation of Hyperion Performance at Lake Frome, Australia

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Introduction

A ground truth campaign was carried out by the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) between December 17 and 20, 2000, at Lake Frome (Figure 1) in coordination with a Hyperion overpass on December 20. The day was not ideal so additional images were collected on January 5 and 21, 2001, to use in place of the December 20 image. Lake Frome is an ideal calibration site as the Hyperion ground track aligns with a well-established and persistent salt track. Landsat 7 Enhanced Thematic Imager Plus (ETM+) and Advanced Land Imager (ALI) data collections also occurred.

Figure 1. Field work at Lake Frome.

Vicarious calibration techniques were used for this study. Vicarious calibration provides a unique opportunity to investigate the characteristics of the instrument from a direction that is user oriented. The process involves extensive ground truth and coordination with spacecraft mission operations to coordinate the time of data collection from the spacecraft with ground truth measurements. The result is a direct comparison of top of atmosphere (TOA) measurements made by the instrument with TOA predication based on the independently measured ground spectral reflectance measurements and propagation through a predicted atmosphere.

Using a simple but convenient model available to the group, at-sensor radiances from the Lake Frome sites at the time of the overpass were estimated by the CSIRO team for January 5.

This summary reviews the ground truth campaign and presents the results of the on-orbit agreement in the predicted and measured TOA radiances with reference to a cross-comparison with the solar calibration results.

Lake Frome Ground Truth Data Collection

Lake Frome is located in the northeast of South Australia (Figure 2a) and is a large, normally dry salt lake (playa). The center of the playa is approximately at latitude 30°51'S and longitude 139°45'E. The lake is very bright when dry with visible region reflectance being over 70%. However, moisture decreases the shortwave infrared (SWIR) reflectance very significantly. Figure 2b is an image of the Hyperion pass over the Lake Frome area with the field sites indicated. Note that the sites fall on a path along the center of the Hyperion swath. The data collected as part of the Lake Frome vicarious calibration effort include spectral, navigation, and atmospheric data.

Figure 2a. Location of Lake Frome in northeast South Australia.

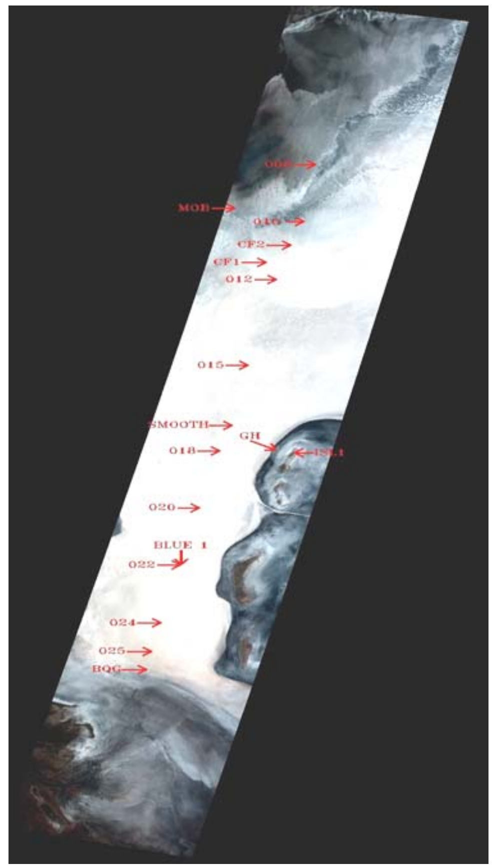

Figure 2b. Lake Frome image taken by Hyperion on the January 5, 2001 overpass. Field sites are identified.

Reflectance Measurements

Spectral reflectance measurements were made with an ASD Field Spec imaging spectrometer for a range of ground sites. The measurements 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. Table1 lists some of the sites that were measured; sites 018, 020, 022, and 024 were used for the comparison with Hyperion measurements.

Table 1. Sites characterized for comparison with Hyperion.

Site	Surface Description	Latitude	Longitude
018	Uniform Salt	-30.80	139.68
020	Uniform Salt	-30.83	139.67
022	Mixed Salt and Mottle	-30.87	139.66
024	Uniform Salt	-30.90	139.65
008	Salt Graded to Ooze	-30.63	139.73
Island	Soil	-30.80	139.71

The sites were sampled in a central cluster of points and along local transects of about 100 meters to characterize the spatial variance and produce a mean site signature at the scale of Hyperion. Salt and mud samples were also collected for laboratory characterization.

Figure 3 shows mean reflectance spectra for the field sites. These spectra have been linearly interpolated over 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) and the amount of liquid water present in the salt matrix. However, the full extent of the spatial variation and its components is being studied using a range of data available for Lake Frome including Hyperion, Hymap airborne hyperspectral data, and Landsat ETM+ data.

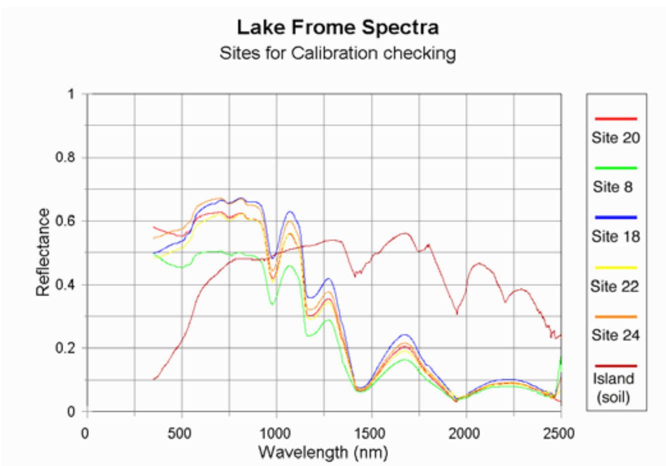

Figure 3. ASD spectra recorded at field sites shown in Figure 2b. Spectra have been linearly interpolated over regions of strong atmospheric water vapor absorption.

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 from Bureau of Meteorology radiosondes launched from Woomera (250 km west of Lake Frome) and a CIMEL sun photometer located at Tinga Tingana, another CSIRO field site 150 km north of the lake.

Navigation Measurements

The utility of the field measurements is crucially dependent on their accurate location (and re-location) on the lake and in the image data. The GPS readings provided a very accurate base of geo-located data and so it was necessary to establish accurate image geo-location. A set of ground control points (GCPs) was identified in the image of Hyperion band 22 (568 nm) and an accurately geo-rectified Landsat ETM+ image (acquired on January 21, 2001). Analysis of the data fits based on predictive error showed that a bi-linear transformation was best. This allowed for x, y shifts, separate changes of scale in x and y, skew and rotation plus an xy interaction term. The statistical significance of the x-y interaction term showed that there was a projective geometry in the Hyperion image on the surface. This is likely to be even more significant in other cases since Lake Frome was imaged at near nadir view. The main characteristics of the geometry can be summarized in Table 2.

Table 2. Hyperion geometric characteristics.

Pixel-X	30.646 m
Pixel-Y	30.528 m
Rotation	-12.38°
Skew	0.006°

EO-1 has a specific yaw to compensate for the Earth rotation skew,which seems to be very effective. The pixel shape is very close to square. The predictive error for the visible and near infrared (VNIR) sensor was 15 meters in x and 20 meters in y. This close registration and the uniformity of much of the Lake Frome site meant that the spectra of pixels relating to the ground sites could be identified with considerable confidence.

The GCPs were also identified in band 94 of the Hyperion image (1084 nm) to test the alignment of the two spectrometers. The data were again well fitted by a bi-linear transformation. An offset of approximately one pixel in x and a fraction of a pixel in y was 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 seemed to be due to a slight misalignment in the two arrays and may be significant in areas with highly spatially variable spectra.

Atmospheric Models

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) from which estimates of aerosol optical depths and water vapor can be determined. The second was the Woomera meteorological station, which provides daily radiosondes that were used to obtain lapse rates for the pressure, temperature, and water vapor profiles. These measurements were combined with historical atmospheric knowledge of the region. A simple radiative transfer model was used for the initial investigation since the necessary outputs were easy to obtain and the model could be optimized to the field data.

Top of the Atmosphere Radiance Comparison

As the mission started, CSIRO worked to provide feedback on the Hyperion calibration. Using the atmospheric model, Lake Frome data, and Level 1 uncalibrated data, the following initial estimate (Figure 4) of the calibration was obtained and then compared with the current curve provided by TRW (the developer of Hyperion).

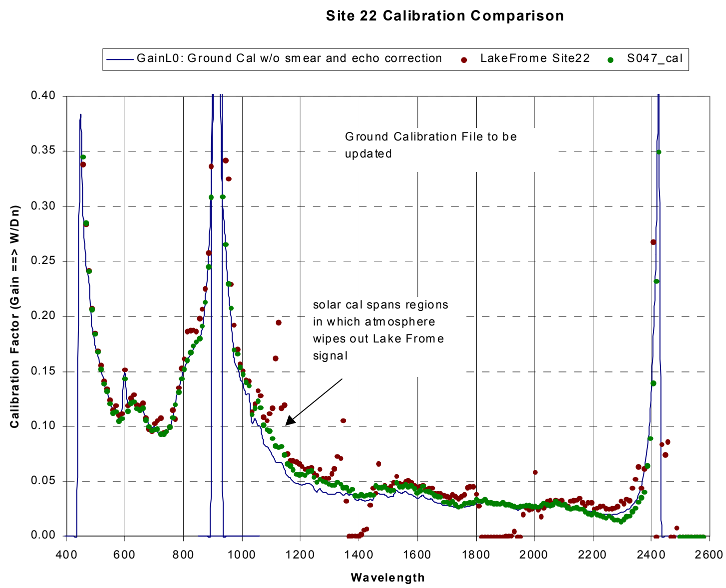

Figure 4. Initial early comparison of calibrations using Lake Frome data.

The above graph is largely historical as TRW and CSIRO proceeded to make considerable efforts to refine the study and look at reasons for the residual discrepancies. However, the basic finding was that Hyperion was working within a close range of good calibration post-launch.

In subsequent analysis, Site 20 showed the best overall agreement between the TOA radiances calculated from ground truth and the Hyperion measurements. Figure 5a shows the spectral radiance curves. The agreement was quite good in the VNIR range.

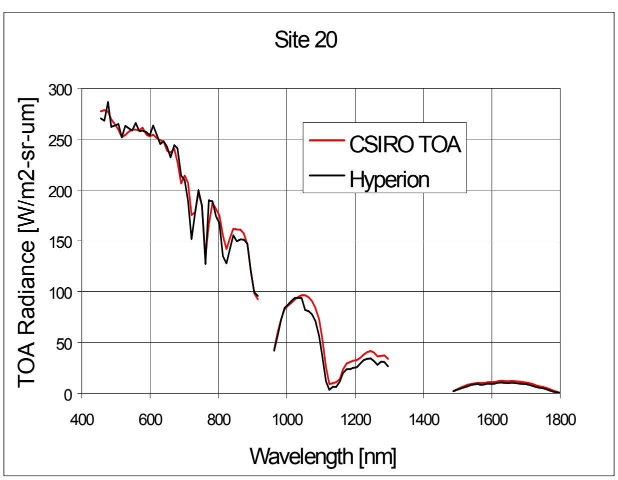

Figure 5a. Spectral radiance comparisons over the VNIR and SWIR spectral response region of Hyperion.

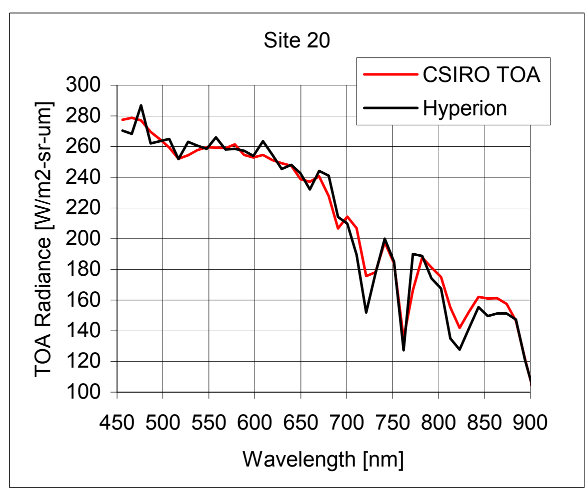

Figure 5b. VNIR spectral radiance comparison from Figure 2.

As shown in the expanded wavelength scale in Figure 5b, the mean difference was less than 1.5% $\pm$ 0.5% from 450 to 900 nm. The CSIRO TOA radiances were 16% higher than that measured by Hyperion in the SWIR for site 020. The largest differences occurred at 715, 760, and 810 nm and may have been related to atmospheric correction effects at the spectral features shown in Figure 3. Otherwise, the general difference ratio ranged from 2% to 10% throughout the spectral region.

In the SWIR, sites 018, 020, and 024 indicated that the TOA model predictions were generally 10% to 25% higher while site 022 data were lower. The gaps were where water absorption bands affected the data. Corrections for BRDF (bi-directional reflection distribution function) effects based on view angle and the Standard Spectralon panel SWIR performance would improve the validity of these comparisons.

Conclusions

The Lake Frome field campaign was the first time the lake had been visited for a ground-based spectral measurement effort. Given the extreme nature of the environment, it was highly successful. A revisit to the site and more intensive measurements are planned as well as an extension of the range of target sites for future EO-1 data collection. 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 satellite sensors of varying resolution and scale, such as the AVHRR (Advanced Very High Resolution Radiometer), the ATSR2 (Along Track Scanning Radiometer), and SPOT VGT (Systeme Pour l'observation de la Terre) Vegetation sensor.

While some site spectra 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 that the investigators intended to measure but is still not completely determined. The Hymap data will provide insight into this factor. Visual assessment indicates the BRDF of the lake is likely to be stable and able to be characterized.

The combination of field and laboratory measurements allowed TRW to confirm very quickly as the mission started that their calibrations were generally within about 5%-10% in the VNIR and perhaps similar in the SWIR. The dark reflectance in the SWIR prevented precise conclusions. The ground reflectance measurements and atmospheric correction leading to TOA radiances were consistent with the Hyperion solar calibration where the Sun was viewed by reflectance from a diffusely painted panel. The SWIR agreement was not as good as the direct Hyperion comparison with the absolute solar irradiance.

On the basis of this, TRW worked with the solar calibration to improve uniformity and absolute corrections so that the Level 1 products have been of high quality since the data were first delivered to members of the Science Validation Team. In the first year of the campaign, results from a range of sites were used and a major correction to the overall calibration made late in 2001. However, this can be seen as a refinement bringing Hyperion into alignment with standard choices of solar constant, with Landsat ETM+ and ALI, and provided an excellent product by the time the extended mission commenced.