REVIEW OF ASPECTS ASSOCIATED WITH THE CHRIS CALIBRATION

Mike Cutter
Sira Technology Ltd, South Hill, Chislehurst, Kent, BR7 5EH, England.
E-mail: Mike.Cutter@sira.co.uk

ABSTRACT

Following almost two years of CHRIS in-orbit operations, this paper reviews the procedure for calibration of the CHRIS instrument to assess whether changes could be implemented to improve the radiometric calibration. In particular the paper addresses: first, the variation of the dark signal data acquired over the period of the mission, from October 2001 to March 2004, secondly, the use of the generic dark-field data sets for correcting analogue electronic offsets and, thirdly, the influence of the platform temperature variations on instrument response and hence radiometric calibration.

1 INTRODUCTION

Sira Technology Ltd developed the Compact High Resolution Imaging Spectrometer (CHRIS). This instrument has been designed principally to provide remote sensing data for land applications and aerosol measurements; it is also used for coastal zone monitoring, although this was not a design driver. It is the main instrument payload on the European Space Agency (ESA) small satellite platform PROBA (Project for On-Board Autonomy). At perigee, CHRIS provides a ground sampling distance of 17m, over typical image areas 13km square. It has a spectral range from 400nm to 1050nm, at spectral resolution <11nm. The instrument provides sets of images of selected target areas, at different pointing angles, forming up to 5 images of each target in a single overpass.

The small platform offers limited scope for on-board calibration facilities. Consequently, calibration is provided by a mixture of on-ground and in-orbit measurements.

On-ground measurements included:

- full aperture radiometric calibration,
- stray light calibration,
- spatial resolution,
- spectral and spatial registration assessment,
- wavelength characterisation (with respect to temperature),
- linearity and saturation, and
- noise measurements.

In-flight measurements include:

- DC offset measurements,
- relative gain measurements,
- wavelength calibration,
- response calibration using sunlight,
- linearity and saturation, and
- noise measurements.

Vicarious calibration for response has also been undertaken by some PIs.

Data for absolute response measurement is gathered in flight by use of a solar calibration device (SCD). This device comprises a small reflecting prism, with one lens surface, which is located at the outer end of the instrument external baffle. When the platform is over the Antarctic region, on the dark side of the terminator, with the telescope pointing to nadir, the SCD receives direct sunlight. The platform is manoeuvred so that the device reflects sunlight into the field of the instrument, with spread provided by the lens power. The SCD fills the field of the instrument at a nominal radiance equivalent to albedo 0.25 in direct sunlight. The SCD is not moved; it is fixed in the main instrument aperture area, but occupies (and samples) only a small fraction of the instrument aperture area. The field of the device for receiving sunlight is limited to 2° x 4°. This field is fully sampled, in pre-flight calibration and in orbit, to check for non-uniformities in transmission of the device and instrument optics: this provides a check for local particulate contamination that would invalidate results.

Wavelength calibration is checked in flight using atmosphere absorption features, particularly the atmospheric oxygen absorption band at 762nm.

Aspects associated with the calibration procedure are reviewed in this paper. The main purpose of the review is to assess whether changes need to be implemented in the calibration procedure or instrument configuration.

2 CALIBRATION PROCESS

Each image acquired by CHRIS includes raw image data and DC offset data. Components of DC offset include electronic offsets, dark signal and "smear" generated during CCD frame transfer. Full-frame dark field data is acquired using images of dark Earth, with

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the platform in eclipse. The current process of correcting CHRIS images involves subtracting dark signal and other offsets, and dividing the result by response data acquired from pre-launch measurements.

Adjustments are made at various stages during the processing to take account of the gain, integration time and number of CCD rows in each spectral band.

3 DARK SIGNAL VARIATIONS

As indicated above, one aspect of the calibration process is the measurement of the DC offsets and in particular the offset generated by CCD dark signal. The magnitude of the dark charge will typically increase with time due to space radiation. This variation in dark charge through the mission life was investigated to assess the impact on the calibration performance.

A number of dark charge measurements were made through the in-orbit mission life as well as during pre-launch tests. These measurements were compared using a selection of imaging CCD pixels assigned to wavelengths ranging from 400 to 1050nm.

The platform temperature changes through the year, affecting the operating temperature of the detector. The dark charge data was scaled to a nominal temperature of 5°C using the following formula:

$$\text{Dark charge} = A.T^{\mathbf{1.5}}.e^{(-E/2kT)}$$

$$\text{where } E = 1.1557-(7.021^{-4}.T^{2})/(1108+T)$$

T is in Kelvin and $k = 8.62^{-5}$ eV/K

The dark files used were:

File	Date	Temp. °C
Pre-flight	July 1999	20.0
2B4B	September 1st 2002	0.2
2B8B	September 1st 2003	3.2
2B8C	October 3rd 2003	4.4
2B8D	November 3rd 2003	5.6
2B8E	December 2nd 2003	6.6
2B8F	January 8th 2004	6.1
2B90	February 2nd 2004	8.5
2B91	March 4th 2004	4.5

Table 1 Dark File Data

Figure 1 shows the corrected dark charge histogram.

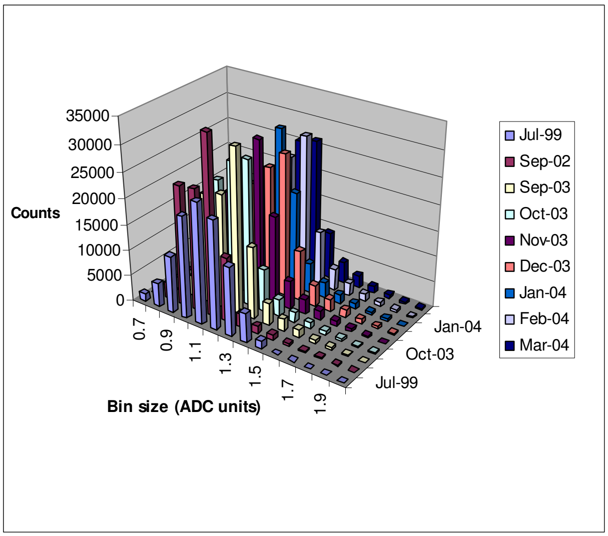

Figure 1 Dark Charge Histogram

In general the dark charge is small and does not change dramatically with time, although it is possible to detect a trend towards signals in higher bins and a slight broadening of the dark-signal spectrum. Typical useful signals are in the range 200 to 1000 ADC counts. Changes in dark signal – typically in the order 0.1 ADC count – are thus not likely to introduce significant calibration errors.

4 ANALOGUE OFFSET ERRORS

Analogue offsets are present on all recorded pixels. These can be removed in the image processing procedure by subtracting the pixel data from a "specific" dark image data set. A "specific" dark image data set is a dark image, acquired in dark scene conditions, with the same spectral, spatial and gain configuration as the bright image that is being corrected. The dark image would typically be acquired in the eclipse period of the orbit.

In practice the use of specific dark image data for offset correction is quite cumbersome for the CHRIS operations for two reasons. First, the configuration gain is optimised with respect to target latitude to maximise the signal to noise ratio, leading to 46 different configurations for the 2004 Science Plan. Secondly, only one dark image can be acquired in a single download session and in practice we would wish to repeat the acquisition of dark image data each month. In practice acquisition of the 46 specific dark images would take several days and is not the preferred approach.

To minimise the number of configurations that need to be used, a "generic" dark image data set is acquired and used together with the average bright image offset data that is recorded at each end of a CCD row.

The "generic" dark image data is acquired by recording a dark image of all the bands that are within the total spectrum of interest, i.e. 400 to 1050nm, plus the smear band. This is in practice about 242 bands. This data can then be used to construct any band combination required to correct the dark signal offsets in the bright images.

The use of the generic dark image approach is convenient for the CHRIS operation. However, it provides the correct offset only if the offsets are constant across the CCD and in practice this is not the case and a small variation is expected. Assuming the analogue levels across the CCD stay within the offset pixel levels recorded at the ends of each recorded CCD row, which is probably a reasonable assumption, then the maximum offset error is half the difference between the averages of the offset levels recorded at the ends of each row.

Examples of the levels of maximum bias errors, as a proportion the scene signal, are shown in the figure below. In most cases the level of errors are probably acceptable, although mode 1 and 2 errors are higher than those of the other modes.

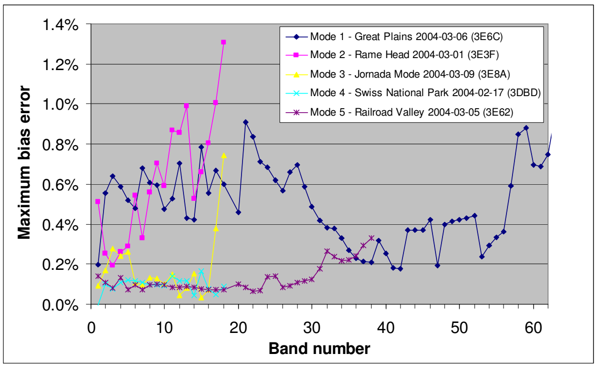

Figure 2 Maximum Bias Errors

. In practice the higher errors seen above are due to low scene signals. The mode 2 image over Rame Head – an area mainly of water giving low signals – resulting in the high bias error for band 18.

There are two options that could be considered for reducing bias errors generated by the variation in the analogue offsets. The first option is to increase the analogue gain levels, if not already at maximum level. The second option is to use specific dark image data for those modes that consistently have low signal levels, such as the modes used for coastal applications (i.e. mode 2). It should be noted that the current analogue gains have been selected to avoid saturation on clouds, for which an albedo of 1.1 is assumed as an upper limit. Most natural targets will have albedos lower than 0.7 and scenes over water will typically be much lower. There is some scope for increasing the gains, if saturation of cloud images is accepted, when clouds are present.

The preference out of the above two options is to increase the gains where possible, although some specific dark image data may be acquired as a fall back solution for mode 2 acquisitions.

5 WAVELENGTH CALIBRATION

5.1 PRE-LAUNCH MEASUREMENTS

CHRIS was calibrated for wavelength and wavelength variation with temperature using a monochromator operating at 10 wavelength groups (405, 446, 496, 546, 648, 746, 846, 910, 1020, 1060nm) and with CHRIS at 3 temperatures (13.3°C, 20.2°C, 28.8°C).

Analysis of this data indicated that the location of the spectrum incident on the CCD varied with temperature according to:

$$\Delta N = -0.103\Delta T \qquad (1)$$

where ΔN is the change in row number (for any selected wavelength) produced by a change of temperature ΔT. This shift with temperature is a consequence of the temperature dependent refractive index of the spectrometer prisms.

5.2 IN-ORBIT MEASUREMENTS

In orbit wavelength calibration measurements were made using the atmospheric oxygen absorption band at 762nm. Measurements were made over the ocean off the west coast of California.

The pre-launch calibration data from the SCD was measured at 23.5°C and this needed to be pixel shifted to compensate for a temperature-induced shift of 2.2 pixels. A first order comparison of the in-orbit SCD measurements with standard solar irradiance tables was undertaken by applying a temperature dependent pixel shift to the calibration data before correcting the in-orbit data. This gave a relatively close match as indicated in the Figure 3.

Measurements using the CHRIS solar calibration device (SCD), were intended principally to assess the CHRIS optical throughput. One particular surprise was that the spectrometer was able to resolve Fraunhofer structure on the SCD input near 430nm (probably the Fe and Ca lines). Having applied the pixel shift to the pre-launch SCD calibration data set, it was evident that there was a very close correspondence within 1nm of the standard and in-orbit irradiance data providing confidence in the wavelength calibration procedure.

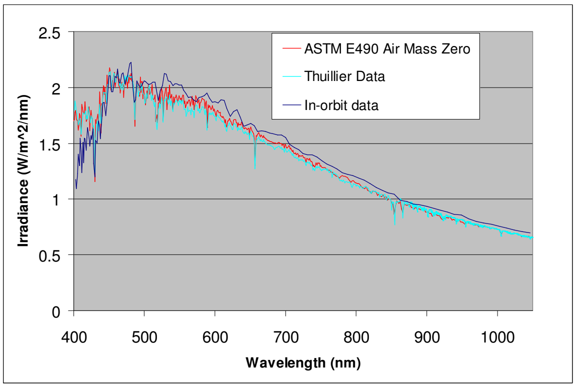

Figure 3 Comparison of in-orbit and standard solar data

5.3 IMAGE DATA CALIBRATION WRT TEMPERATURE

The temperature of the CHRIS instrument in-orbit varies due to seasonal variations and platform events. Temperature changes >8°C have been recorded, although within an imaging session the changes are <0.5°C.

The temperature variation of the CHRIS spectrometer produces two orthogonal shifts, first there is the shift of the slit across the CCD, which gives rise to banding seen in the images, and secondly, there is a shift of the spectrum along the CCD columns as indicated above.

The radiometric response curve for the CHRIS instrument can be considered to consist of two overlapping components. The first component is the 2-D map of pixel-to-pixel response of the CCD, which is relatively stable with temperature and time, although the dark charge will develop spikes due to proton damage. The second component is the “system response” of the optical system. This latter component is a 2-D function that shifts in two orthogonal directions due to the influence of temperature as indicated above. The ground calibration was undertaken at a different temperature to in-orbit measurements, therefore the associated pixel shifts need to be corrected. An ideal approach would be to separate out these two 2-D components, shift the system response function and recombine the two 2-D components before correcting the in-orbit data. In practice the process of separating the two components, shifting one, and recombining them is problematic. This is largely because the calibration data has low signal to noise at the two extremes of the spectrum, where the response of the system is low, resulting in significant noise artefacts in the separated data.

The preferred approach is to generate a 1-D function of the average spectral response across the CCD by averaging the data in the rows and applying a correction corresponding to the change in the response curve when the appropriate number of row shift is applied. The averaging process reduces the pixel-to-pixel response non-uniformity in the 1-D spectral response curve.

The average calibration curve of all CCD rows is shown in Figure 4.

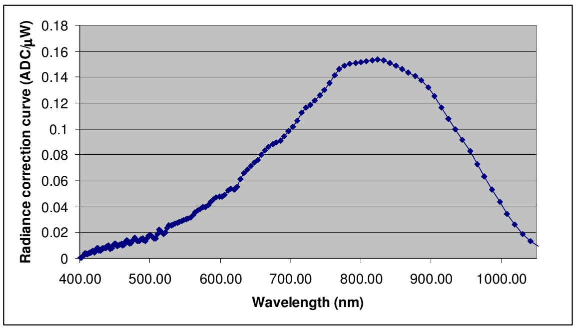

Figure 4 Average CHRIS response

An example of the correction coefficient is shown in the Figure 5.

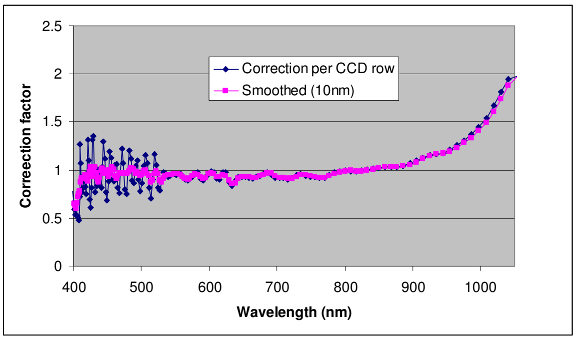

Figure 5 Sample correction curve

The blue curve indicates the row-by-row temperature correction factor, which at short wavelengths has high spectral resolution of the order of 2nm. In practice CHRIS is not used with such high resolution and thus the perturbations in the region between 400 and 500nm are smoothed, as indicated by the pink curve where the rows are integrated to represent bands of 10nm. The large temperature correction factor above 900nm is a consequence of the rapidly changing response function in this region.

It is planned to implement the temperature dependency into the software that is used to process images released to PIs, although some validation with ground data sets will be undertaken to improve confidence in the level of the precise temperature-induced pixel shifts.

6 CONCLUSIONS

This paper has reviewed the procedure for calibration of the CHRIS instrument, particularly addressing:

(a) the variation of the dark signal data acquired over the period of the mission,
(b) the use of the generic dark-field data for correcting analogue electronic offsets and,
(c) the influence of the CHRIS temperature variations on instrument radiometric calibration.

It is concluded, first, that the errors introduced by dark signal are small and can be neglected.

Secondly, the use of the generic dark image data for correcting analogue offsets is probably acceptable for most land applications, where the scene albedo is relatively high, but may be improved by increasing gain levels for coastal scenes, accepting that some images may experience saturation where clouds are present. Alternatively, in critical cases, specific dark image data can be used although it would be preferable to limit the number of acquired data sets.

Lastly, the temperature-induced pixel shifts do significantly affect radiometric calibration and this effect will need to be modelled within the image processing software.