Calibration Activities for CHRIS−PROBA

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Introduction

CHRIS was designed to be inexpensive, compact and light. This means that only a relatively small part of this experimental mission is given over to on−board calibration, and that ground based activities will be an important feature of our calibration plans.

Dark Fields

The detector array registers counts even when there is no exposure to light. The level at which this happens depends on temperature, among other things, and so varies continually. A so−called “dark field” needs to be acquired as close as possible to the time an image is acquired, so that the appropriate correction may be made to the detector counts. The instrument needs to be looking at a dark target, of course, which means taking data when the satellite is on the dark side of the earth. The best times are on the half –orbit before or after the image is acquired. It is necessary to acquire these data in the appropriate configuration, but it is not necessary to capture an entire image set of data: a much smaller amount can be used, but it must be enough so that noise spikes due to, for example, cosmic rays can be identified and eliminated. A sensible margin would be for 100 lines to be taken, which allows for good characterisation of the dark signal and electronic noise, while still amounting to just a small overhead in terms of memory.

Wavelength Calibration

It is possible that as a result of perturbations during launch, there may be some slight change in the relative positions of some elements in the optical path. As a consequence of this the relationship between detector row number and wavelength, established before launch, may be affected. It is also possible that there will be changes as a result of thermal variations on board. The aim of the wavelength calibration activity is to quantify the detector−wavelength relationship as a function of temperature. The main effort will take place during the commissioning phase, although some continuing analysis will be undertaken on suitable images throughout the mission.

Our preliminary studies have worked on the assumption that the main effect of any perturbation is the physical displacement of the detector system parallel to the λ−direction. Our approach has been to use the O_2 absorption feature at 762nm to estimate the amount of movement suffered. The problem with using prominent water vapour features is that the precise shape of any such feature changes slightly for atmospheres with the same amount of precipitable water; it depends on the complete profile of water vapour concentration with atmospheric pressure and temperature.

We decided to simplify matters by using a spectrally ‘bland’ surface target such as the ocean surface so that the spectral ‘fingerprint’ of the atmosphere alone could be used in the spectral calibration.

Absolute Calibration

A small, light experimental calibration device has been designed into the system. This samples only a small part of the optical aperture, but it can be used to check for variations in spectral sensitivity at the finest spectral level. The current plan is to record all detector rows in solar calibration, which may make it less important to measure many bands in vicarious calibration. Because the aperture is only partially sampled, and because it is good practice in any case, there will be at least one dedicated campaign of vicarious calibration.

Vicarious Calibration

It is possible that the transmissions of the optics may change from their pre−launch calibrated values by several percent (D. Lobb, pers.comm.). Most effects are expected to be smooth, but not uniform, over the spectrum. It is possible that there may be some detector to detector changes, caused by debris being deposited during launch on the entrance slit or detectors.

As a check on whether any gross changes have occurred, there will be a vicarious calibration exercise taken soon after launch. This will involve capturing a 5−image string of data over a suitable calibration site, and comparing the radiances against values predicted by radiative transfer models. These models need to know the surface reflectance properties, and certain atmospheric parameters. Even under the best conditions, there is typically a 5−10% error in predicting the Top−of−Atmosphere (TOA) radiance values through radiative transfer (RT) modelling using ground based measurements, so that no change to the on−board calibration would be effected unless the discrepancies seen are very large and cannot be accounted for by, for example, out−of−field scattering by clouds, etc.

Vicarious calibration of an instrument such as AVHRR or Landsat TM is made easier by the very limited number of detectors involved. With the CHRIS, each across–track pixel has its own set of detectors and it is not feasible to generate, on the ground, the surface reflectance measurements that would be needed to calibrate every detector element. A possibility is to use an aircraft−based scanning instrument, such as AVIRIS, to provide across track values of reflectance, although this introduces problems of its own. A more practical approach is to validate a small area of the total field, validating a given set of detectors, and relying on the uniformity of the site to infer the soundness or otherwise of remaining pixels.

Some of the information in the following section about sites is taken from the document “Validation Plan for MODIS Level 1 At−Sensor Radiance”, by Kurt Thome of the University of Arizona.

Sites

The calibration site needs to be level, homogeneous, preferably bright and preferably be sitting beneath a simple atmosphere. Un−level surfaces have uneven illumination, which would have to be accurately modelled. Very heterogeneous sites give rise to uncertainties through environmental radiance, that is, light which has been reflected form parts of the surface outside the IFOV of the instrument. If it is from an area of different brightness, it is almost impossible to model properly; if the surface is fairly uniform, the effect can be modelled within the RT code. The brighter the surface is, the less error will accrue from uncertainties in the calculation of atmospheric path radiance. We would prefer a dry atmosphere with little aerosol loading in order to minimise the uncertainties in atmospheric transmission.

Suitable sites are provided by high altitude salt lakes, and a number of these are used for vicarious calibration of the TERRA instruments MODIS and MISR. It is proposed to use one of these, Railroad Valley Nevada, for the calibration of CHRIS. The surface is level, homogeneous and its reflectance characteristics (albedo ~0.5) are well studied; the amount of cloud cover is usually small. The only problem is likely to arise if the calibration has to take place in the winter or early spring, as the moisture in the playa increases, which decreases the reflectance generally, and makes the surface more heterogeneous. Physical access may also be hampered under these conditions.

Alternative sites have been proposed: Amburla and Tinga Tingana, both in Australia, are permanently instrumented sites which the Australians use for validation activities. Tinga has very low aerosol loading, is almost always cloud−free, and is on the core list of sites. It is intended that perform validation calculations will be performed at Tinga for each acquisition.

Measurements – Ground Based

On the day of overpass, ground−based measurements will be taken of surface reflectance, and of atmospheric properties. Ideally, we would like the full BRDF at high spectral resolution at several points on the site. This is impractical, and an acceptable substitute would consist of a fairly full sampling of the directional ground leaving radiance, such as would be given by the PARABOLA instrument.. Unfortunately, PARABOLA measures radiance in only a small number of wavelengths. On the other hand, the surface at Railroad Valley is reported to be nearly Lambertian, and it may be enough just to characterise, parametrically, the small non−Lambertian effect. This may be feasible with a radiometer mounted on an A−Frame. Full spectral measurements of reflectance will be taken with a spectroradiometer, probably a GER 1500[1], at a large number of locations to establish the uniformity of the surface. This may take the form of a long transect, with surface measurements made every ten paces over a 1km or so; however, the effort involved in this should not be underestimated, especially as a reflectance panel needs to be taken on the transect and levelled at each measurement point. There should be several such transects, preferably between known points which could be identified in the image. A combination of the two instruments, PARABOLA to give information on directional isotropy, and the GER for detailed spectral information, would be useful.

Ideally, atmospheric measurements will be taken with a sun photometer, so that aerosol properties can be estimated form a study of the solar aureole, and surface irradiance at high spectral resolution with a shadowband spectroradiometer. The surface irradiance measurements give atmospheric transmission (direct beam) and the diffuse component helps to constrain the radiative transfer calculations.

For geometric rectification of the images, and to locate point measurements within individual pixels, surface features with known will need to be identified and their locations obtained with GPS. This is an activity that can be carried out on non−overpass days. (It is likely, in fact, that this information already exists).

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[1] We only need to cover the range 400−1050, and the GER 1500 is considerably lighter and easier to deploy than instruments that cover the full optical range. The main requirement is that the instrument have a high spectral resolution, so that the CHRIS bands can be simulated with reasonable accuracy.

Measurements − Satellite

A full set of five images is required, as this gives five radiance values instead of just the one at nadir, and will help to check the consistency of the aerosol data and the RT code use din the effort.

Off nadir images will be captured in the full swath, 36m configuration (63 bands). The nadir measurements will be somewhat unusual, as we want to use the opportunity to calibrate for each of a small number of standard configurations.. Instead of the 768 lines in a single configuration, we should take successive short images at each of the principal configurations. (This follows the acquisition plan that will be used for checking calibration drift, described below). Assuming that we can afford to take 1024 lines for the nadir image, and that there are 4 main configurations to be checked, I suggest that the nadir mage be composed thus:

lines 1−128 ,	lines 513−640	Conf. 1 (18m full swath: land)
lines 129−256,	lines 641−768	Conf. 2 (18m full swath: water)
lines 257−384,	lines 769−896	Conf. 3 (36m full swath)
lines 385−512,	lines 897−1024	Conf. 4 (18m half swath)

(As I understand things, the sub−images for the 36m mode will consist of 64 lines each, rather than 128). In switching from mode to mode a line is lost, but that has no real relevance here. For each across track sample, and for each wavelength channel save, we then have two separate sets of 128 (64) samples for analysis. The point of taking two sets of 128, separated by 3km or so, is to be able to test whether any trends seen across track are consistent with what’s on the ground, or are an artefact of the configuration. If such a trend is seen in both captures under one configuration, but is missing from those between, then we would infer that the trend was an artefact – we could not be quite so sure if only one run at each configuration were taken, and the switch happened to coincide with some true change at the ground.

It is hoped that this experiment will be repeated towards the end of the mission, and suitable images will be taken between these to check fore relative drifts in performance of the detectors.

Analysis

The surface reflectance measurements will be checked for consistency, and outliers discarded. The average reflection spectrum will then be computed, and together with the aerosol characteristics inferred from the sun photometer(s), will be used in the ESSC in−house RT Code. This will predict the at−sensor radiance as well as the surface irradiance. There are one or two parameters (anisotropy of the surface reflectance, etc.) that can be tuned so that the surface irradiance predicted by the model matches that measured at the surface. The TOA radiances are then calculated and compared with the satellite values. Perhaps the main uncertainty in the calculations is the aerosol phase function, to which the TOA radiances are sensitive, but the irradiance much less so. It would seem appropriate to estimate this sensitivity at the same time as doing the TOA radiance calculations. The radiances will be calculated for all viewing directions, although these will not have independent errors (an error in the aerosol optical depth will probably affect all views in the same sense) so the uncertainty is not reduced by as much as 5.

Other uses of the data

A number of tests will be carried out on the nadir data to check for consistency of the response of individual detectors. The procedure will be that described below for 'Detector Stability'

The uniformity of the surface should make these data suitable for checking the wavelength calibration. Given the simple atmosphere above the site, and its low water vapour content, we may be able to check for wavelength drift using the whole of the spectrum, and not just rely on the O_2 region.

Detector Stability

Catastrophic failure in any detector element will be obvious as data dropouts but the possibility exists that slow changes may occur in the sensitivity of individual detectors. This can be checked for provided a suitably uniform site is imaged, by comparing the relative response of the detectors. Here we take just the nadir view, but in all modes (just as for the main calibration acquisition). Each set of 128 along track samples is averaged (64 for the 36m mode) and compared to the average across the image. Effectively, we examine the across track profile of these average values, at each wavelength. Individual detector problems should be picked up easily this way. Things will be more problematic if small changes happen to groups of detectors in a correlated way; this will be difficult to separate from effects arising from slow changes in atmospheric or surface reflectance. For each across track sample we have a spectrum, of course, and this spectrum must be compatible with real atmospheric absorptions, and so on.

For this activity a single (nadir−only) image a month has been scheduled. Initially, plans were to make this the Libyan desert, which is used for vicarious calibration of AVHRR (through cross−calibration with ATSR2). However, it might be more sensible to continue to use the Railroad Valley site as a time series of images over a given site will help to identify long−term drifts (Dave Smith, RAL, pers.comm.) (although it might be stretching a point to regard the half dozen or so images collected this way as a long time series). There is the chance these acquisitions will overlap with other ongoing activities at RV of the University of Arizona and others. Apart from this site, the desert sites of Solar Village and Tinga Tingana, part of the aerosol programme, will make suitable additional sites for checking drifts.