HIRDLS

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HIGH RESOLUTION DYNAMICS LIMB SOUNDER

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Excerpts from Tom Eden's paper on calibration. Conversion algorithm used for on-orbit calibration.

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Purpose of this Document:

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Derivation of HIRDLS Original On-orbit Conversion Algorithm

The HIRDLS flight instrument measures channel radiance L (in units of W m^{-2} sr^{-1}) emitted by the atmosphere, averaged over the spectral and instantaneous fields of view for a given HIRDLS channel:

$$L(V) = \int F(V, n)\, L_{mc}(17, n)\, dQ\, dV \quad (1)$$

Here, *F(V,n)* is the HIRDLS averaging function, which depends on the wavenumber *V* of the differential bandwidth *du*, and the unit vector n, which defines the direction at the entrance pupil of the differential solid angle $d\phi$. $L_{mc}(17, n)$ is the incident spectral radiance at the pupil of HIRDLS, with the same independent variables as those of *F(V,* n). Effects from polarization are presumed to be inconsequential for a HIRDLS channel radiance measurement, and therefore are not included in (1). Certainly, the blackbody targets used in this calibration exercise were not polarized, while on-orbit spectral radiance measurements of the atmosphere, for the most part, are not polarized.

During calibration, a large blackbody cavity was used as a full field-of-view atmospheric target for characterizing the radiometric response of the HIRDLS flight instrument. The blackbody provided incident radiation that was spatially and spectrally uniform. This point is important because it allows for *F(V,n)* in (1) to be factorized into components which describe the instrument spectral and geometric responses:

$$F(V, n) = F_{fov}(n)\, F_{spec}(V) \quad (2)$$

Here the field-of-view function, $F_{Fov}(n)$, and the spectral response function, $F_{spec}(V)$, are separately normalized to unity. The approximation in (2) allows for a separate determination of each of these functions during calibration. The absolute scaling of *F(V,n)* then represents the radiometric response. During calibration, this scaling was achieved by using a full field-of-view blackbody, which provided a spatially uniform radiance target that could be imaged over the entire focal plane. Introducing the approximation in (2), the channel radiance (or measured flux) *L* can be represented as:

$$L = \int F_{spec}(V)\, B(V, T)\, dV \quad (3)$$

Here, *B(V, T)* is the Planck function at temperature T. In orbit, the HIRDLS flight instrument must convert channel signals into radiances, while also having the capability of performing an on-orbit radiometric calibration, hence, being a self-calibrating instrument. To achieve these goals, an inflight calibrator (IFC) was used to provide a spatially uniform, thermally stable warm blackbody target. Effectively, a view to the IFC at a temperature *T* provides a measured flux L_{ifc}, which comes from (3), and an associated digitized signal S_{ifc}. The conversion of any atmospheric channel signal S to radiance L can thus be accomplished the following way:

$$L = L_{ifc} \frac{S}{S_{ifc}} \quad (4)$$

It should be noted at this time that during calibration, a thermometric test between the IFC and the warm atmospheric blackbody (HBB) was performed, where the results showed that when $T_{ifc} = T_{hbb}$, then $S_{ifc} = S_{hbb}$, to within the radiometric noise of each channel. Equation 4 is not yet complete for two main reasons. First, for low or moderate count levels, (4) is a good representation of the measured flux; however, as will be observed later, larger signal levels up to a value of 2^{16} (= 65536) counts, reveals a small non-linearity in the behavior of L for each channel. Because this non-linearity was predicted to be small (< 3%), a reasonable approximation for L is then:

$$L = L_{ifc} \frac{S\,(1 + kS)}{S_{ifc}\,(1 + kS_{ifc})} \quad (5)$$

Here, k is the measured detector non-linearity (in units of $counts^{-1}$), and was solely determined from this calibration. The second point originates from the notion that the signal in HIRDLS is a *chopped* signal, and that the "true" radiance as perceived by the instrument is the difference between the atmospheric-view and the space-view (S_o) signals. Taking this point into account, the radiometric conversion equation is now given fully as:

$$L = L_{ifc} \frac{(S - S_o)\,(1 + k\,(S - S_o))}{(S_{ifc} - S_o)\,(1 + k\,(S_{ifc} - S_o))} \quad (6)$$

When $S = S_o$ in (6), the low radiance (L_o) point in the two-point radiometric calibration algorithm is known. Thus, under the planned operating conditions the only quantity that would be needed from the pre-launch calibration would be the non-linearity parameter k. Table 1 enumerates parameter *k* for all 21 HIRDLS channels.

However, as was mentioned earlier, a detrimental blockage problem occurred during launch, which precluded any use of the on-board IPC for calibration purposes. Furthermore, an unobstructed view outside the instrument to attain a useful So was also impossible. Discussion about the blockage problem, its adverse affect on two critical scan-mirror view planes, and why it was necessary to replace the original calibration conversion algorithm (6) with an alternative approach will be presented below.

Channel	*k*	*G*	ε_{CM}	ε_{CH}
1	3.748e-8	5.1057e-5	0.0109	0.0182
2	4.527e-7	4.2801e-5	0.0109	0.0164
3	8.253 e-7	6.8616e-5	0.0109	0.0149
4	6.749 e-7	6.6753e-5	0.0110	0.0140
5	6.718 e-7	7.4500e-5	0.0110	0.0136
6	2.989 e-7	4.9818e-5	0.0115	0.0099
7	5.196 e-7	5.2129e-5	0.0115	0.0111
8	1.556 e-6	1.1402e-5	0.0114	0.0086
9	4.491 e-7	4.6018e-5	0.0116	0.0070
10	6.385 e-7	3.7341e-5	0.0117	0.0054
11	8.846 e-7	6.1680e-5	0.0117	0.0053
12	5.503 e-7	3.0953e-5	0.0119	0.0051
13	8.598 e-7	2.4334e-5	0.0120	0.0048
14	1.125 e-7	3.3064e-5	0.0120	0.0050
15	5.719 e-7	2.4676e-5	0.0121	0.0052
16	6.378 e-7	2.1001e-5	0.0121	0.0057
17	1.074 e-6	3.4070e-5	0.0120	0.0101
18	2.972 e-7	3.4730e-5	0.0122	0.0163
19	1.939 e-7	1.0360e-5	0.0123	0.0164
20	4.395 e-7	5.8477e-5	0.0123	0.0171
21	2.819 e-7	2.1008e-5	0.0125	0.0179

Table 1. Radiometric Calibration Parameters

Modified HIRDLS Radiometric Calibration Algorithm to Account for Blockage

During launch, HIRDLS experienced a debilitating event, conceivably caused by a rupture of an unvented piece of inner fore-optics cavity sheathing made of a fairly rigid, lightweight material called Kapton (developed by DuPont). The resulting configuration of this ruptured material adversely affected two critical optical view planes accessed by the scan mirror:

1) ***The atmospheric view plane.*** The view outside the instrument is completely obstructed, except for a small opening (nominally 5-20% open area depending on channel and scan-mirror elevation angle) at extreme anti-sunward scan-mirror azimuth angles (*i.e.*, a line-of-sight angle

-47° from the plane containing the negative spacecraft velocity vector). Effectively, any view outside the instrument has an infrared emission and possible reflective components from this material. Furthermore, the scan mirror does not have a clear view of deep space, which is needed in the conversion algorithm.

2) ***The calibration view plane.*** This view is mostly obscured as well, *i.e.*, the scan mirror does not have an unobstructed view of the on-board in-flight calibrator (IFC) blackbody, rendering it useless for in-flight calibration purposes.

In the procedure adopted to handle this situation, the raw radiometric observations are first calibrated using the following procedure. These calibrated radiances are then corrected for the effects of the Kapton blockage, as described in a later section.

It was pointed out previously that the normally a radiometer views a warm IFC target and cold space, in order to determine the Space View Offset, S_0, and the radiometric gain. Since this was not possible for HIRDLS, we first describe how we calculated S_0, and then the Gain G directly.

MODELING OF THE IN-ORBIT SPACE-VIEW SIGNAL

Because of the obstructed view through the HIRDLS exit aperture, a clear view to space is prohibited. The need to establish a usable space-view signal S_0 is necessary in (6), where a channel signal in counts is converted to a radiance (in units of W m^{-2} sr^{-1}). To successfully produce a reasonable orbital space-view signal, both in-orbit and calibration data must be utilized.

During normal science data taking, in-orbit or on the ground, the space-view image plane provides views of cold space through the space-view aperture. Views of this image are reflected off the backside of the chopper (closed position), transmitted to the FPA, and are differenced with its scan- mirror accessible atmospheric component (chopper open) in the signal-processing unit. Of course, this space-view signal alone is not available to replace S_0 in (6), but it can provide useful information concerning S_0 with a scan mirror viewing a cold space-view blackbody, which was the case during the pre-launch radiometric calibration.

During calibration, a liquid nitrogen target was used at the space-view aperture, and a large external blackbody fixed at ~90 K was used as a space-view reference target accessed by the scan-mirror. For various experimental conditions, a usable in-orbit S_0 can be obtained by making use of scan-mirror views of this cold-space blackbody target during calibration.

A HIRDLS channel radiometric signal (in counts) is just the difference between the atmospheric and space-view image signals, and can be represented the following way:

$$S_o = E_o + G\left((\varepsilon_{SM} B_{SM} + \varepsilon_{M1} B_{M1}) - (\varepsilon_{CH} B_{CH} + \varepsilon_{SVA} B_{SVA})\right) \quad (7)$$

Here, ε is a mirror emissivity and B is a blackbody-equivalent measured flux for unlike components in each optical chain, where E_o is the electronic offset, G is the gain, and the subscripts "SM," "M1," "CH," and "SVA" refer to the scan mirror, M1 primary mirror, reflective backside of the chopper, and space-view aperture, respectively. Temperature sensors are located on, or near, each of these elements. If the mirror emissivities, gain, and electronic offset are known, then S_0 can be computed. Emissivities were not known for these elements, but measurements were performed on the full aperture, concave calibration mirror (CM) during pre-launch calibration [12]. To proceed, the following assumption was made:

$$\varepsilon_{SM} = \varepsilon_{M1} = \varepsilon_{SVA} \equiv \varepsilon_{CM}$$

This assumption seems reasonable because these surfaces are very similar to that of the CM, and therefore the emissivity of the CM can be substituted in for the respective emissivities in Equation 7. The chopper backside reflective surface, however, is not similar to that of the CM, and the surface's emissivity had to be derived from calibration data, noting that this is valid due to the launch-time blockage not affecting the chopper area. ε_{CH} was derived from four different calibration data sets, and the error in ε_{CH} was computed, via a typical 24-hour portion of in-orbit data, to be about the level of the radiometric noise. Table 1 also enumerates both ε_{CM} and ε_{CH} for all 21 HIRDLS channels.

HIRDLS DETECTOR GAIN STABILITY

Because of the blockage problem, HIRDLS was not able to perform an on-board determination of radiometric gain. Therefore, in-orbit radiometric conversion is done by utilizing (6), which requires knowledge of the detector gain G determined during calibration. As with any spaceborne cryogenic photoconductive detector system, there is a high probability for a long term, slow degradation of the channel gains while in orbit, whether it be from the detectors, electronics, or optical degradation (*e.g.*, mirror surfaces become less reflective). To a high degree, the channel gains have not changed noticeably since launch. Three reasons that support this statement are:

1) *Stable Cryogenic Cooler:* The cryogenic cooler has been operating near flawlessly since launch, and has kept the FPA cooled to (61.657 ± 0.001) K. This value is nearly identical to the average FPA temperature for the 61 K pre-launch calibration data point, which was 61.632 K. Incidentally, it was determined that the difference in FPA temperature between the in-orbit and pre-launch values provide a negligible change in gain for all channels.

2) *Time Series of HIRDLS Zonal Mean Radiances in the Tropics:* This quantity has been continuously monitored and appears to repeat from one year to the next.

3) *Similar HgCdTe Substrate Used in Aqua AIRS:* The HIRDLS photoconductive detector substrate material is of the same type and manufacturer that are currently being used in the Aqua AIRS instrument. The gains of the AIRS detectors have stayed constant to 0.25% over a five year period since launch.