HIRDLS

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HIGH RESOLUTION DYNAMICS LIMB SOUNDER

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EOS

High Resolution Dynamics Limb Sounder

Level-2
Algorithm Theoretical Basis Document

Updates to version 2 (dated Oct. 1999)

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Introduction

This document provides updates to some aspects of the HIRDLS retrieval algorithm that have changed since launch of the instrument on-board NASA's EOS Aura spacecraft on July 15, 2004. As described in Gille et al. [2008] and the HIRDLS v7 data quality document (DQD, available at http://www.eos.ucar.edu/hirdls), HIRDLS suffered an aperture blockage during launch, when (most likely) a piece of plastic insulating material separated from inside the instrument frame and covered most of the scan mirror. As a result, only a very small fraction of the optical aperture has been open for acquiring radiances from the atmosphere. These radiances are contaminated by the large signal from the insulating material when the optical beam arrives at the detectors. The acquired radiances are (partially) corrected for the blockage radiance by the HIRDLS level-1 correction processor (L1-C) before they are input to the level-2 (L2) processor [DQD, Gille et al., 2008].

The changes to the retrieval algorithm that were necessitated by the aperture blockage are: retrieval scheme, line-of-sight gradient correction, and use of forward models. In addition, although not impacted by the aperture anomaly, source and use of ancillary data as well as aerosol correction (i.e., method of determining aerosol extinction as a contaminant) have also changed since launch. In the following, sections 1-4 update these aspects of the retrieval algorithm for v7 data and eferences are provided in Section 5.

1. Retrieval Scheme and Ancillary Data

Before launch, various retrieval schemes were investigated to optimize accuracy and processing performance. These schemes included simultaneous retrieval of all products in one step, multi-step retrievals with feedback of a retrieved gas profile as a contaminant to subsequent retrievals of other products, and applying line-of-sight gradient correction (see Section 2) for both temperature and gas inversions.

In the current operational processing, retrieval of the complete suite of products is performed in sequential steps, beginning with temperature and pressure (T/P). This is followed by retrievals of H_2O, O_3, NO_2, the group of N_2O, N_2O_5, $ClONO_2$, CH_4, the group of CFC-11, HNO_3, CFC-12, and aerosol extinction at 17.4, 12.1, 10.8, 8.3, and 7.1 µm (mid-band wavelengths of channels 1, 6, 9, 13, and 19, respectively). Gas and extinction retrievals are performed based on the retrieved T/P from the first step.

In version 7 of HIRDLS data (as with all released versions since launch) two forward models, FM1 and FM2 are used (see details in section 4). FM1 is based on Curtis-Godson (CG) and Emissivity-Growth (EG) approximations. It yields radiance accuracy of 1-10%, depending on channel and tangent height, relative to line-by line calculations based on GENLN-3 [Edwards, 1992]. FM2, which was developed to achieve the high accuracy and performance requirements imposed by the pre-launch instrument design specifications, yields radiance accuracies of 0.5-1.0 % relative to GENLN-3. However, because of the contamination of the observed radiances with the blockage signal, the retrievals based on FM2 alone are too noisy to take direct advantage of FM2's high accuracy in one pass. For this reason, the retrievals are performed in two passes through the iteration loop. In the first pass, all products are retrieved using FM1. In the second pass, T/P, H_2O, and O_3 from the first pass are applied as initial guess to obtain more accurate results for these products. Because of lower signal-to-noise ratios for the other products, FM2 does not appreciably improve their retrievals (see section 4) and hence they are only retrieved with FM1.

Temperature and pressure retrievals are performed jointly using Global Modeling and Assimilation Office (GMAO) Goddard Earth Observing System (GEOS) [see http://gmao.gsfc.nasa.gov] data for a priori and LOS gradient correction (see section 2). GEOS-5 version 5.1.0 analyses data are used for HIRDLS v7 retrievals. The a priori profiles for T/P are constructed by co-locating the GEOS data to HIRDLS tangent points.

Retrievals of gas mixing ratios are performed using "climatology" data for initial guess and a priori. This dataset is constructed by co-locating to HIRDLS tangent points monthly zonal mean gas mixing ratios from the NCAR 3-D chemical transport model, WACCM (Whole Atmosphere Community Climate Model). The contaminant dataset is constructed from daily zonal mean WACCM data along with Aura MLS v3.3 data for N_2O, H_2O, O_3, and HNO_3.

2. Line-of-Sight Gradient Correction

HIRDLS was originally designed to perform vertical scans at several azimuth angles across the orbital track, providing orbit-to-orbit coverage in latitude and longitude. This across-track capability would have allowed using retrieved fields to correct for line-of-sight (LOS) gradients by making two passes through the retrieval algorithm. In the first pass, the atmosphere would he considered homogeneous along the LOS while retrieving the state vectors along the longitudes across track. The gradients along the line-of-sight would then be computed based on the retrieved fields and used in the second pass through the retrieval with LOS gradient correction turned on.

However, a major impact of the blockage on the instrument's operation has been that HIRDLS can view the atmosphere only at the extreme anti-sun edge of the aperture; i.e., at a single azimuth angle of 47^o line-of-sight from the orbital plane (see the DQD for details). As a result, no radiance scan can be obtained at the longitudes across track. Therefore, in the current scheme, LOS gradient correction is performed only for temperature, using GMAO/GEOS data co-located to points along the LOS. Temperature gradients are then calculated and applied in the forward model to retrieve T/P profiles, which are passed to the subsequent trace gas retrievals, where LOS temperature gradients are again applied to calculate transmittances accurately.

3. Aerosol Correction

A major enhancement to the HIRDLS L2 in version 7 processing is a new method of determining (background) aerosol extinction as contaminants, which in previous versions had been specified to SAGE-II data mapped to the spectral passband of each channel. The shortcoming of this dataset was that it was invariant with latitude and underestimated aerosol extinction in the tropical upper troposphere. This resulted in large radiances calculated by the forward model in some channels, thereby producing pockets of anomalously high amounts ("hot spots") of some gaseous products such as CFC11, and CFC12.

In v7, aerosol extinction in channel 6, which is centered at 12.1 µm and is the clearest HIRDLS aerosol channel, is retrieved simultaneously with the main product (s) (except for temperature and ozone, which were deemed better using the previous method). During the iteration process, the retrieved channel 6 extinction at each tangent height is scaled by a spectral model to the passband (s) of the channel (s) involved in retrieving the trace gas (es) in a given retrieval block. The scaled extinctions are then passed to the forward model for calculation of radiances.

Application of the new method has removed, to a large extent, the hot spots in CFC11 and CFC12 in the tropical UTLS, the noise in the upper altitude regions of these products as well as in HNO_3, and has resulted in smoother retrievals (e.g., NO_2 and N_2O_5; see the DQD). These improvements can be seen in the curtain plots in Figure 1, which compares retrievals of CFC11, CFC12, and HNO_3 in v6 and v7.

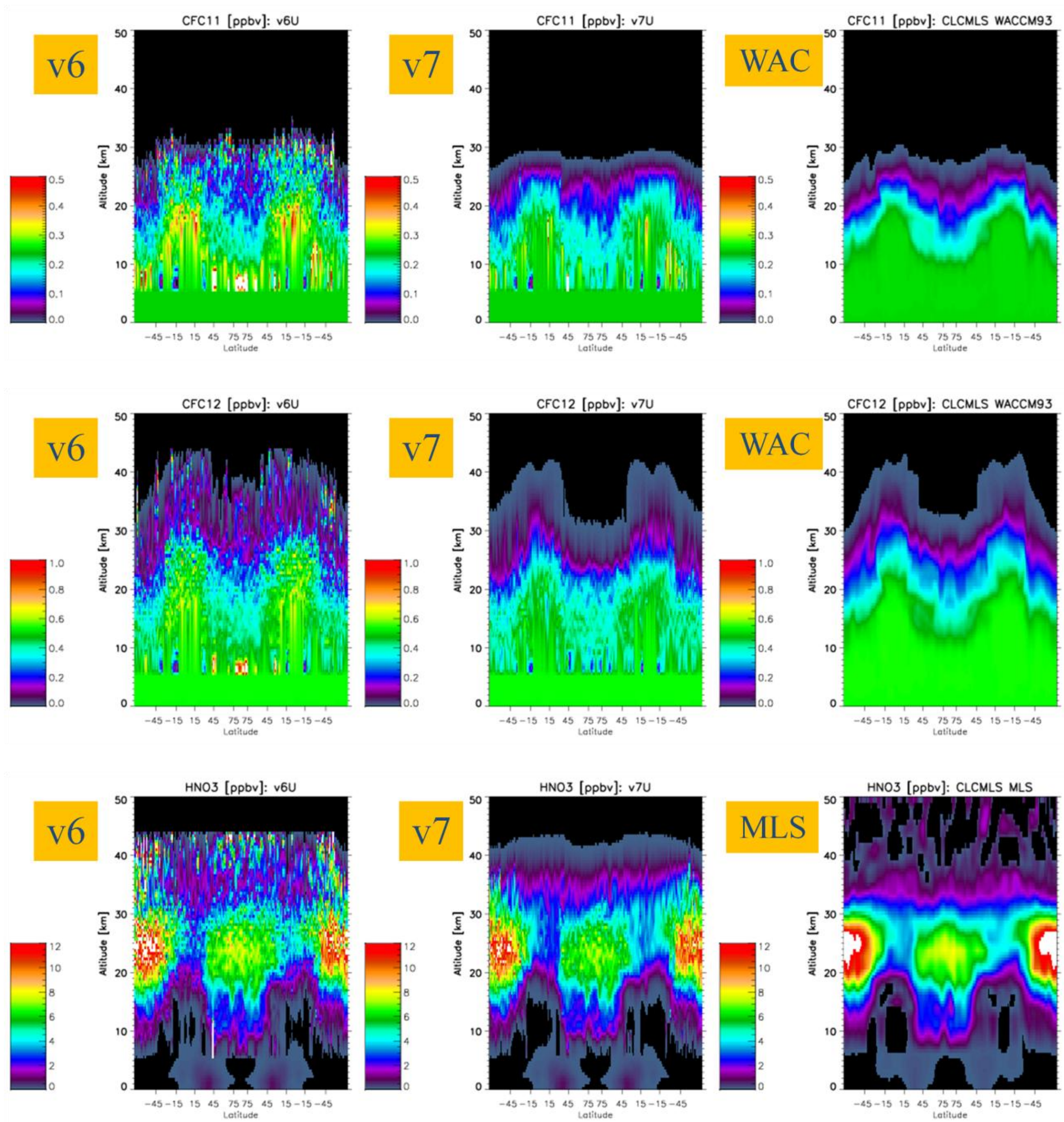

Figure 1. Altitude/Latitude cross sections of retrieved CFC11, CFC12, and HNO3 in versions 6 and 7 of HIRDLS data. These retrievals are compared with daily zonal mean data from the WACCM model (top two rows) and Aura MLS v3.3 co-located to HIRDLS tangent points.

4. Forward Model Hierarchy

We have developed a hierarchy of forward models specifically adapted to the somewhat disparate requirements of prototype algorithm development and operational processing. In the former case it is important to have models available which retain the essential physics of the measurement. In the latter case the speed of execution is a primary concern, which can only be achieved through highly parameterized calculations. This inevitably involves a competition between the conflicting demands of processing speed and accuracy. This challenge has been successfully addressed using the forward model hierarchy developed for HIRDLS and shown in Figure 2.

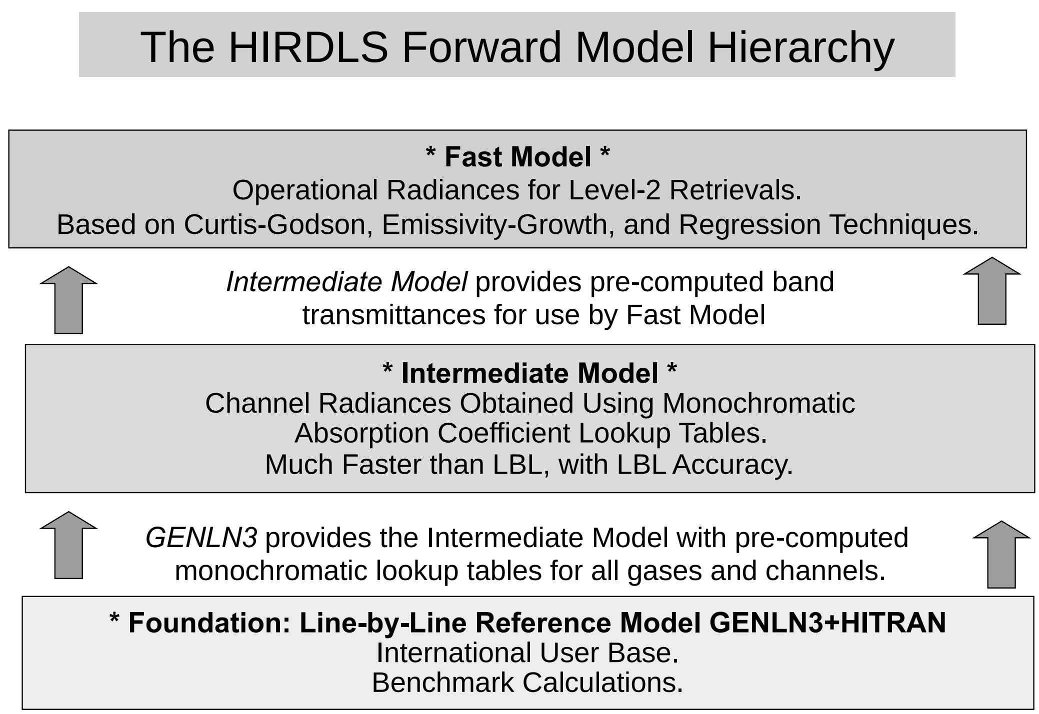

Figure 2: The HIRDLS forward model hierarchy

At its foundation are high-resolution line-by-line calculations obtained using GENLN3 and the HITRAN spectral database (the "Reference Model" [RM]). This yields reference calculations and benchmark tests with which faster algorithms were developed and assessed. The RM calculations have high precision but are too time-consuming for fast-model development work. Therefore, an "Intermediate Model" [IM] was developed which calculates HIRDLS channel radiances using pre-computed monochromatic absorption coefficient lookup tables obtained from the RM. By pre-computing the information in the tables, the IM is two to three orders of magnitude faster than the line-by-line RM while retaining comparable accuracy (differences between the RM and the

IM are typically a few hundredths of a percent). The IM calculations are framed in a manner that explicitly retains access to the underlying physics of the radiative transfer process, which is inevitably lost in a true fast model. This allowed the IM to be readily modified for additional studies. For example, these include the effect of adding or eliminating gas contaminants, changing passband filter shapes, and studying the influence of new line parameters. The following HIRDLS Technical Communications by *Halvorson* provide detailed information about the IM: TC-NCA-081B [“Amount Absorption Coefficient Data Files”]; TC-NCA-082A [“Spectral Response Data Files”]; TC-NCA-083A [“Curtis-Godson Transmittance Tables”]; TC-NCA-098 [“HIRDLS Limb Radiance Reference (HLR0) Model”]; TC-NCA-100 [“Generation of Forward Model Input Data Files”].

The HIRDLS “Fast Model” was efficiently developed using the rapid and accurate calculation framework provided by the IM. The Fast Model has two forms.

The first (“Fast Model #1”: FM1) calculates channel radiances using a weighted sum of line-of-sight band-averaged transmittances obtained with the Emissivity-Growth Approximation (EGA) and the Curtis-Godson Approximation (CGA). The EGA and CGA estimates for a given atmosphere are derived from pre-computed band-transmittance tables provided by the IM. The pre-computed weights (functions of channel and altitude) are determined empirically to maximize FM1 radiance agreement with the IM. A correction for use of the Independent Gas Approximation (IGA) is applied in FM1 as well. The IGA correction is pre-computed and based on the U.S. Standard Atmosphere. The accuracy of FM1 channel radiances is often in the 1-10% range but the overall precision, across a representative atmospheric ensemble, is insufficient to satisfy the HIRDLS forward model design requirements.

High radiance precision is obtained with Fast Model #2 (FM2) which takes transmittance estimates from the CGA and EGA and combines them with a statistical regression. FM2 also avoids the need for an IGA correction. Channel-dependent radiance accuracies obtained using FM2 for an eleven-member test ensemble are 0.5-1.0% or better, compared to reference radiances supplied by the IM, and satisfy the forward model design requirements. *Francis et al*. (2006) provides a detailed discussion of the forward model hierarchy, HIRDLS radiative transfer modeling, and global test results for FM1 and FM2. Part of the description given above is taken from this paper. HIRDLS Technical Communication TC-NCA-104 [“Database Generation for FM1 and FM2”] by *Francis* provides software information concerning the IGA correction and the regression coefficients.

Since the radiance from the optical path blockage is only partially removed by the L1C correction algorithm, the radiance noise in the corrected scan is elevated above the HIRDLS design standard for many soundings. In addition, the corrected scan may also contain large-scale structure of non-atmospheric origin that could lead to anomalies in the state vector during the iteration process. The FM2 regression is sensitive to these features because the regression is trained using blockage-free atmospheric states. In contrast, FM1, though less accurate, is less sensitive to these features because it does not involve a regression, only table-lookups. The operational retrieval algorithm takes advantage of these facts by carrying out initial retrieval iterations through a first pass using FM1, then refining the retrieved estimate by incorporating it as the first guess in a second pass using FM2. Both FM1 and FM2 play critical and complementary roles in the operational retrieval algorithm.

5. References

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