SC-HIR-1511A

HIRDLS

High Resolution Dynamics Limb Sounder
Earth Observing System (EOS)

Data Description and Quality
Version 003
(HIRDLS Version 2.04.09)

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1.0 Introduction

As the following sections describe, the entrance aperture of the High Resolution Dynamics Limb Sounder (HIRDLS) was largely obscured by a piece of plastic material that came loose during launch. This resulted in a loss of signal from the atmosphere, and the addition of extraneous signals from the plastic blockage material. Because of the position of the blockage, coverage of Antarctica was lost, as well as loss of the higher longitudinal resolution expected, although latitudinal resolution has been increased.

The HIRDLS team has been working since the discovery of this anomaly to understand the nature of the blockage and, to develop four major correction algorithms to make the resulting radiances as close as possible to those originally expected. Corrections for some channels, and therefore the products retrieved from them, have been successful earlier than others, which has led to this initial group of retrieved data products. This document provides a description of the first fully-released version of data for the entire mission, which includes retrieved temperature, ozone, and nitric acid, as well as cloud top pressure.

Work is ongoing to improve the radiances, and therefore the retrievals, for these channels, as well as for those channels whose products are not included in this release.

These data are scientifically important, but it is recognized that they will be improved in future versions. Some of the known problems with the data are described below, but these are almost surely not the only ones. This work is ongoing, and further improvements are being developed and implemented. The HIRDLS team is releasing these data for scientific use and validation, with the expectation that those who look at the data will provide feedback on deficiencies that need to be addressed in future versions, as well as strengths of the data. This document will be updated as additional data products are released, and as other changes dictate.

We strongly suggest that anyone wishing to work with the data contact the HIRDLS team. In the first instance, this should be one of the Principal Investigators (PI's):

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2.0 The HIRDLS Experiment

2.1 The Experiment as Designed

HIRDLS is an infrared limb-scanning radiometer designed to sound the upper troposphere, stratosphere, and mesosphere to determine temperature; the concentrations of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC11, CFC12, ClONO2, and aerosols; and the locations of polar stratospheric clouds and cloud tops. The goals were to provide sounding observations with horizontal and vertical resolution superior to that previously obtained; to observe the lower stratosphere with improved sensitivity and accuracy; and to improve understanding of atmospheric processes through data analysis, diagnostics, and use of two- and three-dimensional models.

HIRDLS performs limb scans in the vertical, measuring infrared emissions in 21 channels ranging from 6.12 to 17.76 μm. Four channels measure the emission by CO_2. Taking advantage of the known mixing ratio of CO_2, the transmittance is calculated, and the equation of radiative transfer is inverted to determine the vertical distribution of the Planck black body function, from which the temperature is derived as a function of pressure. Once the temperature profile has been established, it is used to determine the Planck function profile for the trace gas channels. The measured radiance and the Planck function profile are then used to determine the transmittance of each trace species and its mixing ratio distribution.

The overall science goals of HIRDLS were to observe the global distributions of temperature, 10 trace species and particulates from the upper troposphere into the mesosphere at high vertical and horizontal resolution. Observations of the lower stratosphere are improved through the use of special narrow and more transparent spectral channels.

2.2 The Launch-induced Anomaly

2.2.1 History and Present Status

HIRDLS was launched on the EOS Aura spacecraft on 15 July 2004. All steps in the initial activation were nominal until the initialization of the scanner on 30 July 2004 indicated more drag than anticipated, and a subsequent health test of the scan mechanism indicated that the damping of the elevation mechanism was ~ 20% greater than on the ground. After the cooler was turned on and the detectors reached their operating temperature (~62 K), initial scans showed radiances much larger and more uniform than atmospheric radiances, except for a region of lower signals at the most negative azimuths. The HIRDLS team immediately identified this as indicating a probable blockage of a large part of the optical aperture.

Tests confirmed that the blockage emits a large, nearly uniform radiance, and covers all of the aperture except a small region 47° from the orbital plane on the side away from the sun.
A number of scan mirror and door maneuvers were conducted in an attempt to dislodge the obstruction, now believed to be a piece of plastic film that was installed to maintain the cleanliness of the optics. None of these maneuvers were successful in improving HIRDLS' view of Earth's atmosphere.

However, these studies and subsequent operations of the instrument have shown that, except for the blockage, HIRDLS is performing extremely well as a stable, accurate and low noise radiometer. These qualities have allowed the HIRDLS team to develop methods for extracting the atmospheric radiance from the unwanted blockage radiance and to retrieve a significant portion of the original science objectives.

2.2.2 Impact of Loss of Azimuth Scan Capability

In its present configuration, HIRDLS can view past the blockage only at the extreme anti-sun edge of the aperture. Vertical scans are made at a single azimuth angle of 47° line of sight (LOS) from the orbital plane, on the side away from the sun. (This differs from the original design, in which HIRDLS would have made vertical scans at several azimuth angles, providing orbit-to-orbit coverage with a spacing of ~ 400-500 km in latitude in longitude.) The inability to make vertical scans at a range of azimuths is a definite loss in data gathering, but not a major loss of scientific capability for many of the mission goals. Some of the impacts of the inability to observe at different azimuth angles are:

Changes in coverage

The single-azimuth coverage is plotted in Fig. 2.1, which shows that coverage only extends to 65°S, thus missing all of Antarctica and the S. Polar cap. In the Northern Hemisphere (N.H.) it reaches 82° N in mid-latitudes, the descending orbit views nearly the same orbit at midnight as the ascending orbit at 3:00pm 9 orbits or 15 hours later.

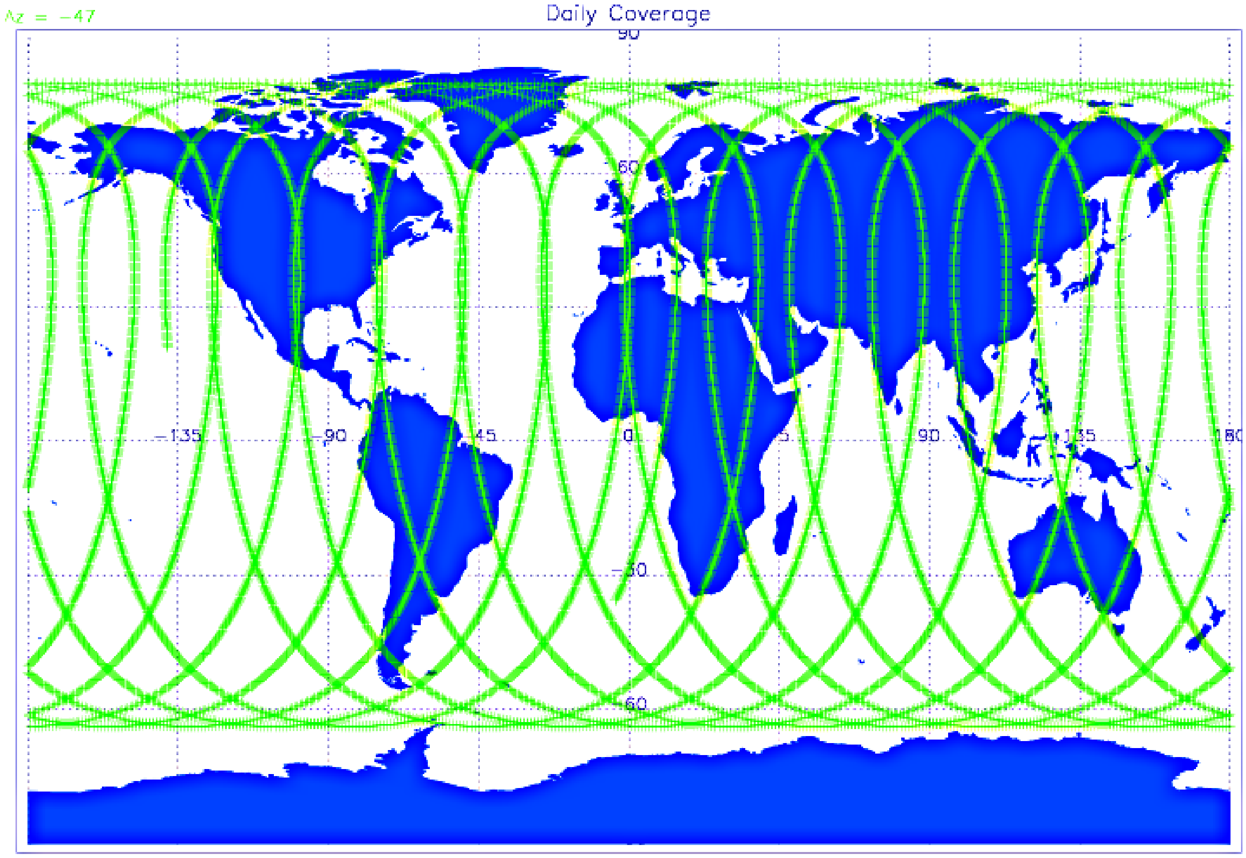

Figure 2.1 HIRDLS Daily Coverage

Inability to View the Same Air Mass as MLS, TES or OMI Within 15 Minutes

The HIRDLS scan track is compared with the MLS scan track in Fig. 2.2. HIRDLS views nearly the same volume as MLS at night (descending part of orbit, left part of figure), but on successive orbits; thus HIRDLS views the same volume 84 minutes earlier than MLS (one orbit, or 99 minutes, minus the 15 minutes that separates MLS views ahead of the S/C and HIRDLS measurements behind the S/C). In the daytime (ascending part of orbit, right side of plot), HIRDLS observations fall 17° to the east of the MLS track in the same orbit, or 8° to the west of the MLS track in the previous orbit. Especially in the daytime, this difference impacts making comparisons, the planning of correlative measurements, and the opportunities to do combined science. However, comparisons and science can easily be done at night where desired.

A corollary feature is that, in the daytime, HIRDLS and MLS combined observe more longitude at a given latitude, which will improve the spatial resolution. At night, together they look at the same volume 84 minutes apart, increasing the temporal resolution.

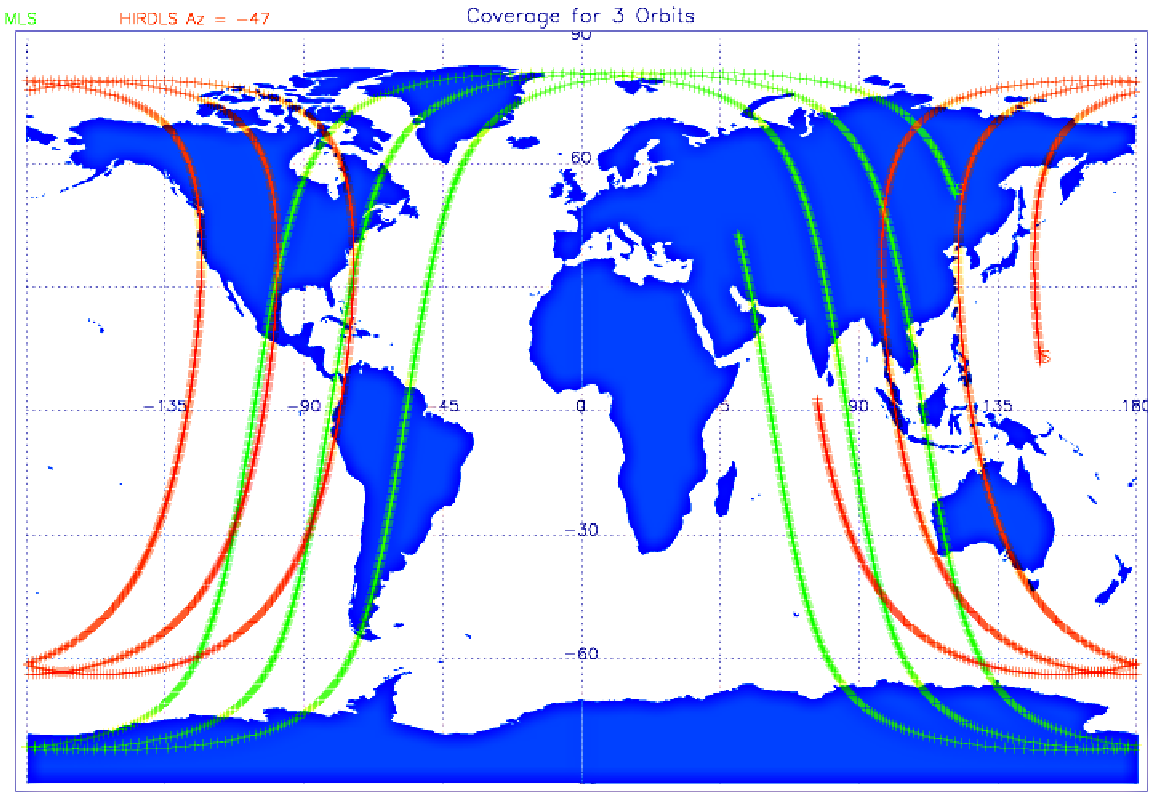

Figure 2.2. Comparison of 3 orbits of HIRDLS (red) measurement locations to MLS (green). HIRDLS is measuring the atmosphere at one azimuth angle (i.e., -47° from the orbit plane). The day and night portion of the orbits are on the right and left side of the figure respectively. During the day part of the orbit, HIRDLS is trailing MLS by one orbit (99-minutes). During the night part of the orbit, the coincidence is much better and HIRDLS is leading MLS by one orbit.

Some compensating effects

With the azimuthal limitation, the profiles will have closer latitudinal separation (~100 km), facilitating gravity wave studies. It has also been suggested that transects through tropopause folds might be improved by continuous views at one azimuth.

Since HIRDLS views a long way off the orbital track, as seen above, it measures at a different local time from MLS, TES and OMI. At the northern and southern extremes it means that HIRDLS will get data at a significantly different local time from the other instruments, which could help constrain data assimilation models.

3.0 Revised Operational Scan Patterns

The limited angle at which HIRDLS can see the atmosphere necessitates a revision to previously planned scan patterns. Scans of the atmosphere are done in the region in which the view of the atmosphere is the clearest, at -23.5° azimuth shaft angle, or -47° LOS from the orbital plane (on the side away from the sun).

Science Modes

Scan Table 30 (21 January 2005-28 April 2005) Initial scan used more rapid vertical scan speed, which generated larger amplitude oscillations in the signals. This scan also made vertical scans at an LOS azimuth angle of -44.8°, which were found to be inferior to those at -47°.

Scan Table 13: (28 April 2005- 24 April 2006). Upper and lower limits of scans vary around the orbit, following Earth's oblateness. This was discovered to cause different types of oscillations to be seen in the signals, complicating attempts to remove these artifacts.

Scan Table 22: (25 April 2006 to 3 May 2006) Similar to ST 23, but with lower space-ward limit on the scans.

Scan Table 23: (Used since 4 May 2006) It makes slower vertical scans; 27 vertical up and down scans of ~ 15.5 sec. duration each, followed by a 1-2 second space view before the next 27 scans. To facilitate removal of the oscillations, the space-ward and earth-ward limits of the scans are at fixed elevation scan angles.

4.0 Method for Processing HIRDLS Data

The modified science scans described in Sec. 3 and the need to account for blockage of the scene and radiance from the blockage require substantial modifications to the operational data processing. A diagram of the flow of data in the HIRDLS processing is shown in Figure 4.1.

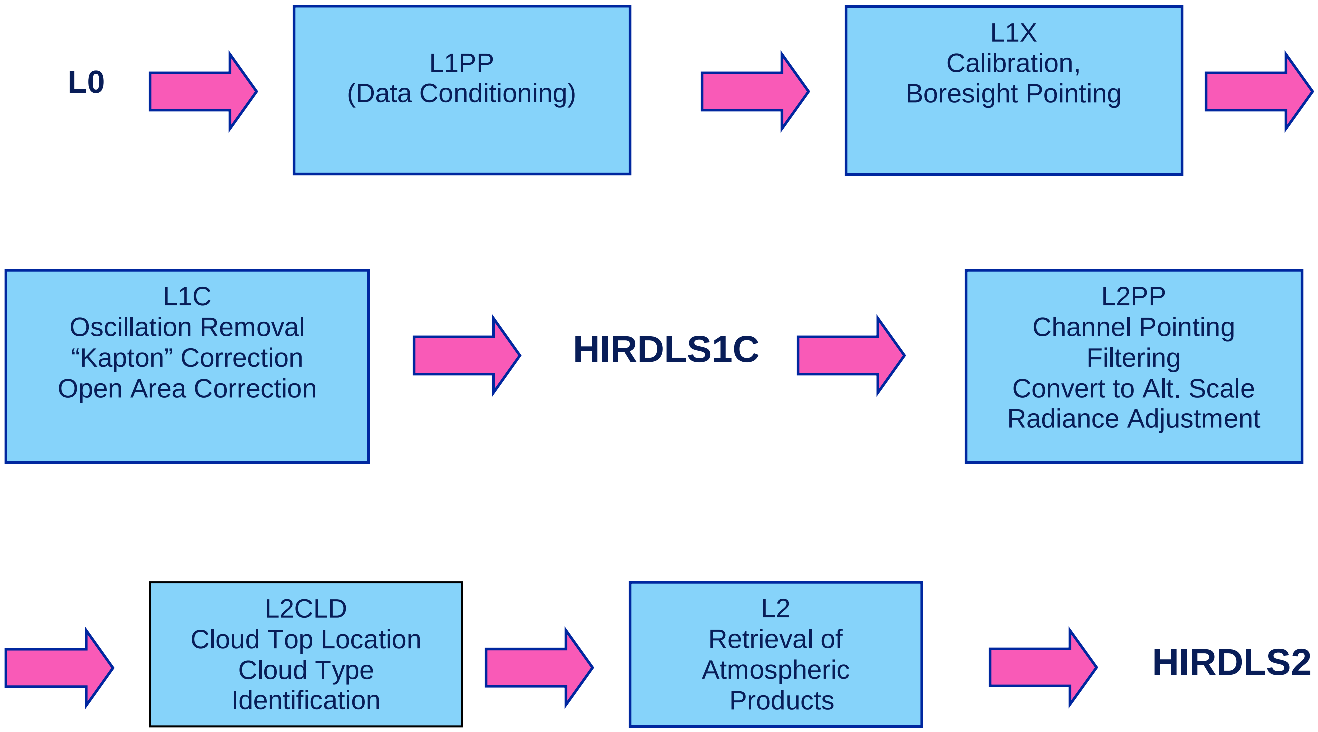

Figure 4.1 HIRDLS Processing Flow

4.1 L0-1 Process (L1PP, L1X, L1C)

In the L0-1 suite of processor, L1PP corrects an occasional problem with the time in L0 data (raw data counts). L1X carries out the modified calibration, and geolocation, while L1C applies the 3 main correction algorithms to remove the effect of the blockage. Overall, the L0-1 processor creates a time series of calibrated radiances blocked into profiles as well as housekeeping data necessary to the further data processing.

4.2 L2 Pre-processor (L2PP)

The L2PP process takes the time series of radiance profiles from L1, separates it into individual geolocated vertical scans, determines the vertical registration in altitude, and performs low-pass filtering to condition the radiances for retrieval by the L1-2 software.

4.3 L2 Cloud Detection (L2CLD)

The L2CLD routine screens for clouds based on detection of radiance perturbations from the average clear sky case. Cloud tops are located and identified.

4.4 L1-2 Processor (L2)

The L2 step accepts the conditioned radiance data from the L2CLD, and performs the retrievals through a series of iterations. This code is designed to be flexible in handling combinations of radiance channels to retrieve the HIRDLS target species in a user-defined sequence. One of the major features is the use of ancillary GMAO data to determine temperature gradients along the line of sight, which are incorporated to yield an improved retrieval. This processor is described in the L1-2 ATBD.

5.0 HIRDLS Standard Products

5.1 Temperature

Species:	Temperature
Data Field Name	Temperature
Useful Range:	400 – 1hPa
Vertical Resolution	1.2 Km
Contact:	John Gille
Email:	gille@ucar.edu
Validation paper	Gille *et al*., The High Resolution Dynamics Limb Sounder (HIRDLS): Experiment Overview, Results and Validation of Initial Temperature Data – First results, in review, *J. Geophys. Res*., 2008

Systematic Biases

HIRDLS temperatures have been compared to several data sets in an effort to determine the extent and magnitude of any biases. The results shown here summarize results described by Gille et al. (2008). An important comparison is between radiosondes and nearby HIRDLS temperatures. Fig. 5.1.1 shows comparisons among high resolution radiosonde profiles and 2 nearby HIRDLS retrievals at St. Helena (15.9°S in the Atlantic) and Gibralter. The differences in space and time are given. Points to note, in addition to the good agreement, are the way the HIRDLS retrievals follow the small scale vertical structure in the radiosonde data, and HIRDLS' apparent small warm bias at the tropical tropopause. Statistics of such comparisons at Gibralter, a representative site, are shown in Figure 5.1.2. The green line indicates that HIRDLS is between 1-2 K warmer than the sondes from 100 to above 10 hPa, but becoming as much as 2K cooler down to ~ 400 hPa. The red and blue dotted lines are discussed below. Separate analyses show HIRDLS is sensitive to temperature variations with wavelengths as small as 2 km

A comparison with the more extensive ECMWF global analyses are shown in Figure 5.1.3. From this we see that HIRDLS V003 temperatures are between 1-2K warmer than ECMWF temperatures from 100 to 6 hPa. Above and below these levels HIRDLS temperatures become lower, and overall are within ± 2K from 400-1 hPa.

Temperature precision

One definition of precision is that it is the standard deviation (s.d.) of repeated measurements of the same quantity. Following this, one approach to determining the precision of HIRDLS temperatures is to compare repeated views of the same atmosphere, and derive an estimate of the noise from the statistics of their differences. At 80°N and 63°S, successive scan tracks pass over the same points on the Earths' surface one orbit (99 minutes) apart.

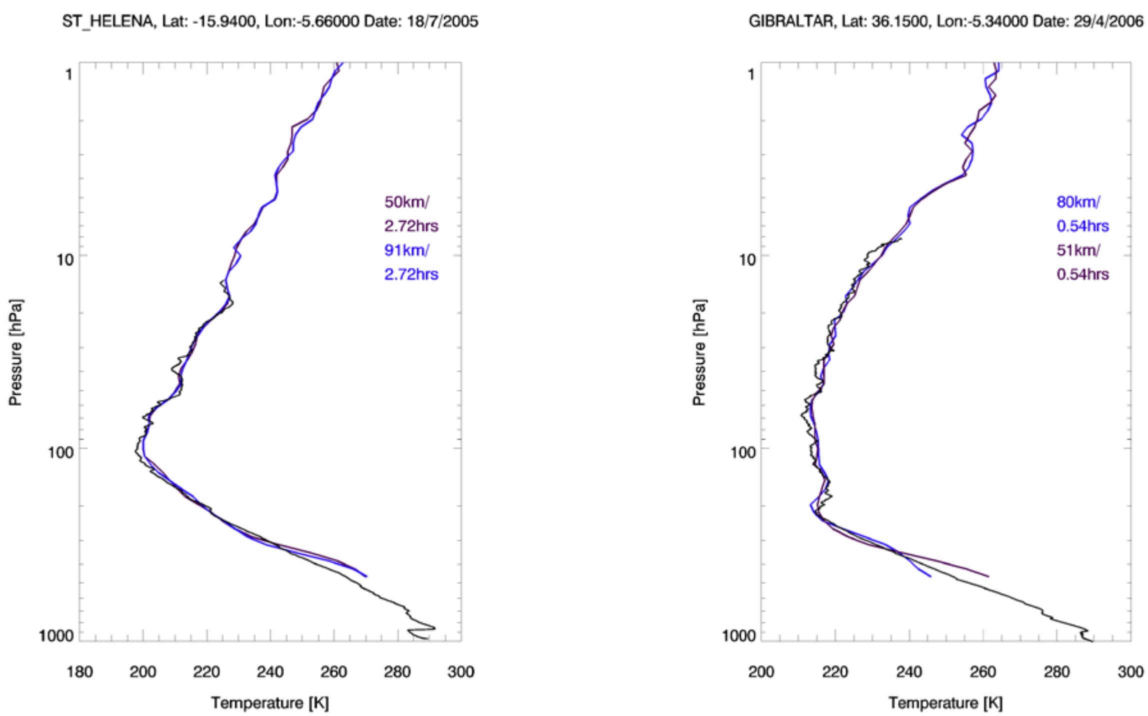

Figure 5.1.1. Temperature comparisons between radiosonde profiles at St. Helena (left) and Gibralter. Black lines are high resolution radiosondes, blue and magenta are two nearby HIRDLS retrievals. Differences in distances and times are shown.

Results of this type of analysis are shown in Figure 5.1.4 for 63S for 3 days each season. The pairs of HIRDLS profiles are separated on average by 33 km. The short dashed line shows the precision derived from the differences between the 2 paired HIRDLS profiles after removing the small meteorological changes shown by changes in the GMAO data (RMS value ≤ 0.1K up to 40 km, increasing to 0.8K at 58 km) for December. The thick solid line shows the precision calculated from the parameters in the retrieval code. The agreement between the predicted and observed

precision at the minimum near 20 km, ~ 0.6 K, is reasonably good for this summer season, when a minimum of small-scale dynamical activity is expected. The curves are similar in shape, although the empirical curve increase more rapidly with altitude, presumably because it includes the effects of small-scale motions (e.g. gravity waves) with rapid time scales that have changed in the 99 minute interval between observations. Northern Hemisphere summer values at 80°N are very similar. The larger values of the paired precisions, especially at high altitudes during southern winter and spring, when small scale motions should be larger, support this interpretation.

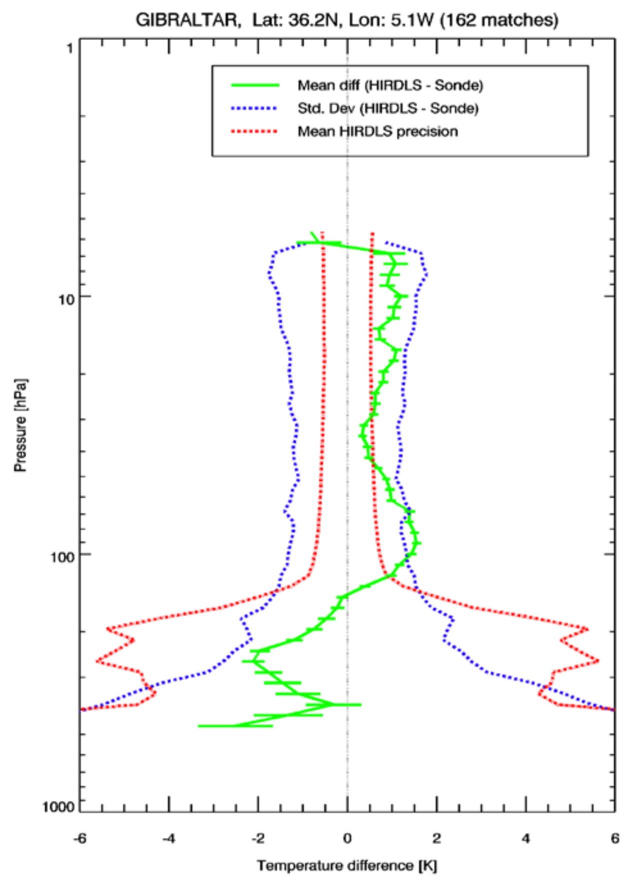

Figure 5.1.2. Statistics of HIRDLS minus sonde differences for Gibralter. Green line shows mean differences, blue dots show ± 1 standard deviation of the differences, while red dots show ± 1 standard deviation predicted by retrieval algorithm.

The s.d.'s of GMAO and HIRDLS retrieved temperatures for 3 days in July 2006 are also shown, indicated by the thin solid and dotted lines respectively. The HIRDLS and GMAO variations are similar up to about 40 km, above which the GEOS5 data show larger variations, perhaps reflecting a lack of observational data at those levels. This shows the magnitude of the meteorological variations. These curves show that the noise on the HIRDLS temperatures is much less than the atmospheric variation, making clear that HIRDLS is able to track the meteorological variations to this kind of fidelity.

These values were indicated by the red dotted lines in Figure 5.1.2, where they were seen to be smaller than the blue dotted lines. Inclusion of the stated precision of the radiosondes does not explain the differences. It is believed that most of the difference comes from differences in time and space between the radiosondes and the HIRDLS profiles, as well as effects of gradients along the HIRDLS line of sight which are not completely corrected. On the other hand, the differences between the ECMWF and HIRDLS data are also larger than the quadrature sum of HIRDLS and ECMWF precisions, although the latter are interpolated in time and space to the HIRDLS locations. In this case, the errors of the interpolations, and the coarser vertical resolution, as well as gradient effects, are apparently the source of the differences.

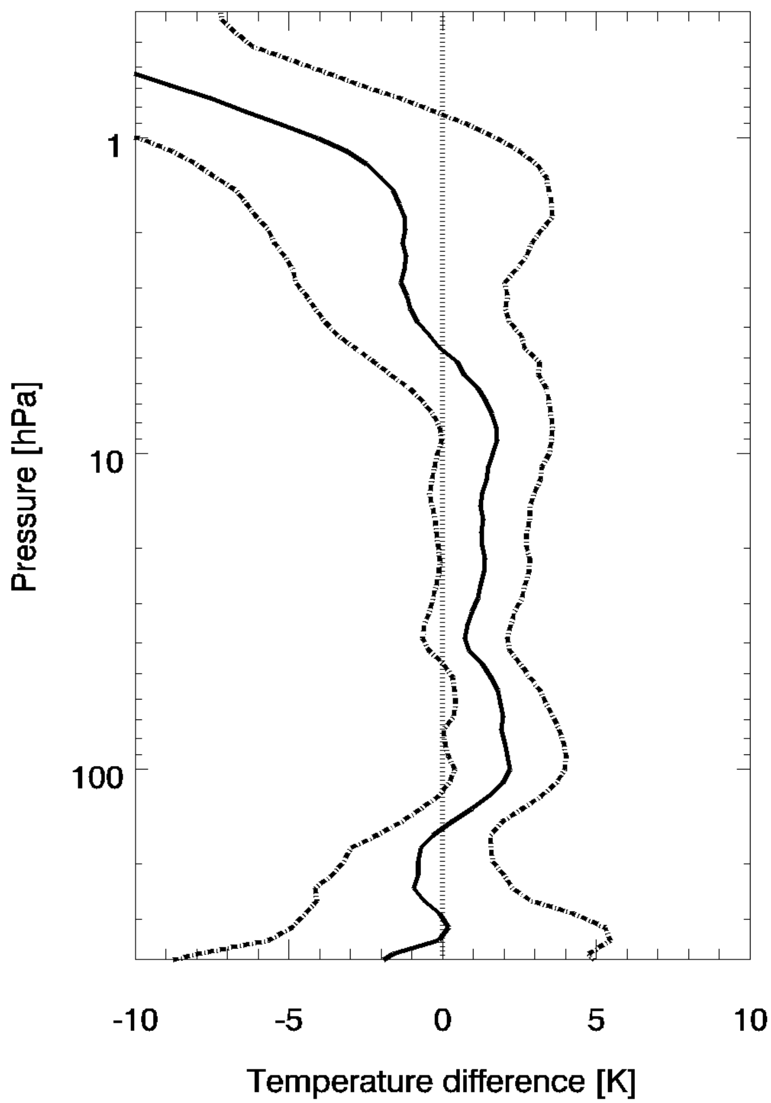

Figure 5.1.3 Results of comparison of HIRDLS temperatures with analyzed ECMWF temperatures interpolated to HIRDLS measurement locations over the full latitude range of HIRDLS observations. HIRDLS minus ECMWF differences ± 1 standard deviation of the differences.

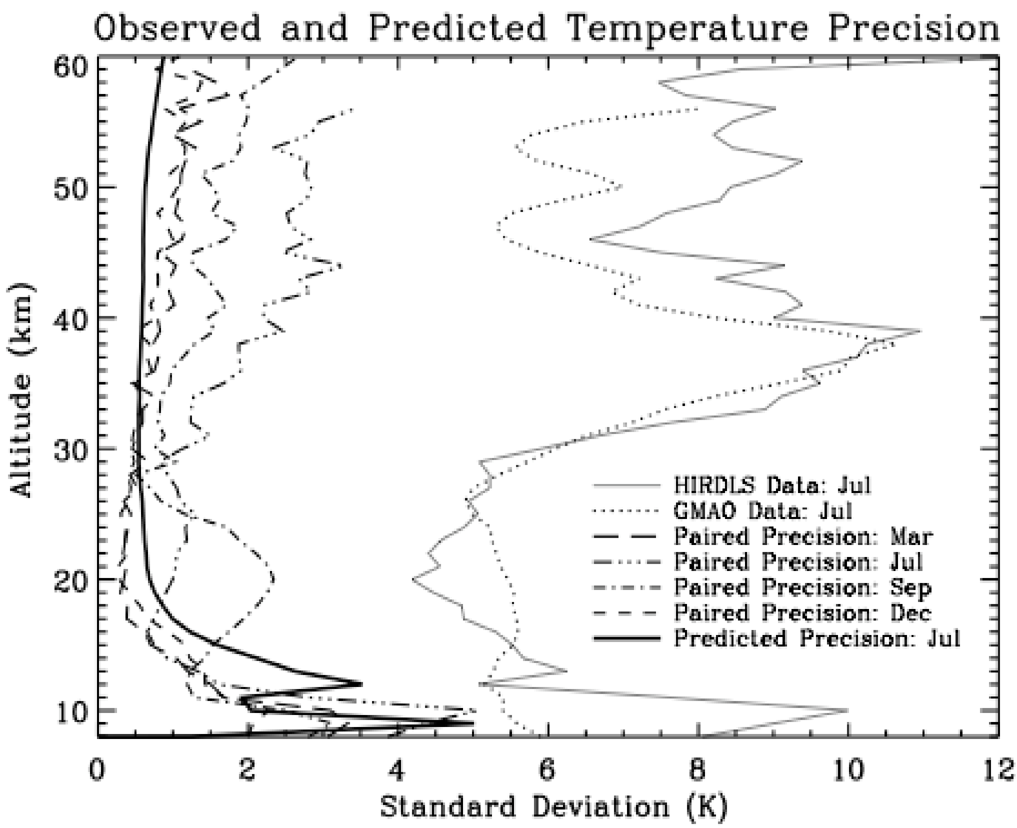

Figure 5.1.4. Empirically determined precision for HIRDLS determined from differences of paired profiles (dashed line) at latitude cross-over points at 63°S for 3 days each in in March, July, September and December, compared to total precision calculated by the retrieval code (solid line). The standard deviations of the GMAO and HIRDLS data for July are also shown. The similarity between the shapes of the summer curve and the predicted values gives us confidence that the predicted values are a reasonable indication the true repeatability of HIRDLS temperatures.

5.2 Ozone

Species	Ozone (O3)
Data Field Name:	O3
Useful Range:	1hPa – 100+ hPa
Vertical Resolution:	1.2 - 2 km
Contact:	Bruno Nardi,
Email:	nardi@ucar.edu
Validation Paper:	Nardi *et al*., Initial Validation of Ozone Measurements from the High Resolution Dynamic Limb Sounder (HIRDLS), *J. Geophys. Res*., in press 2008.

Early Results and Validation

Validation and Accuracy

Comparisons with ground based, balloon-borne and satellite correlative measurements indicate that HIRDLS ozone shows good accuracy between 1 hPa - 100 hPa with accuracy of 5% to 10% between 1 hPa - 20 hPa (Figures **5.2.1-5**). Comparisons with ground-based lidar indicate agreement as good as <5% in this region.

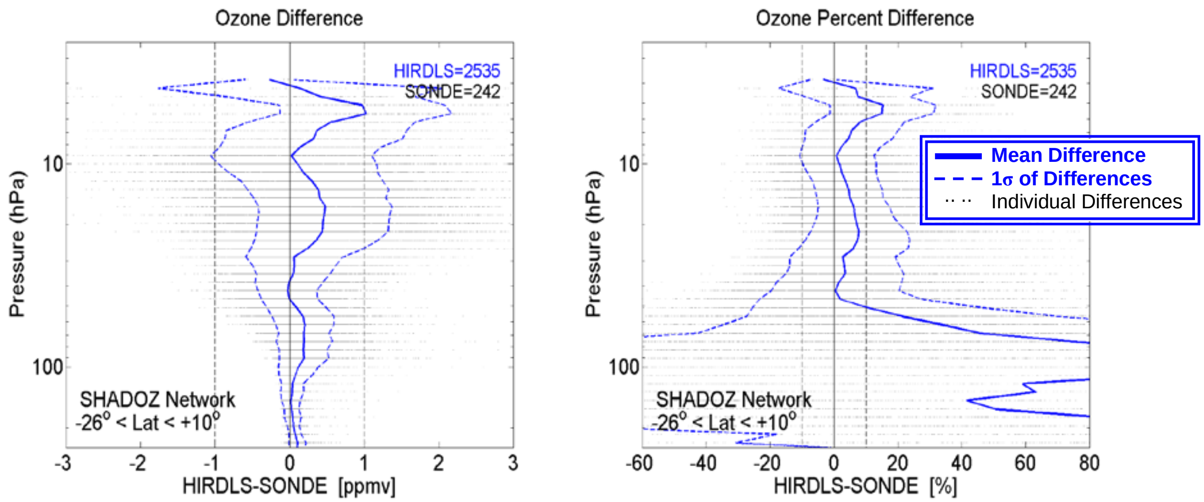

Figure 5.2.1. Ozone difference between 97 SHADOZ Network (low latitude) ozonesonde profiles and 1042 coincident HIRDLS profiles, in terms of mixing ratio, left and in terms of percent (of sonde values), right. Shown are the mean difference (solid blue), the standard deviation (dashed blue) and the individual differences (black dots) from which these are derived.

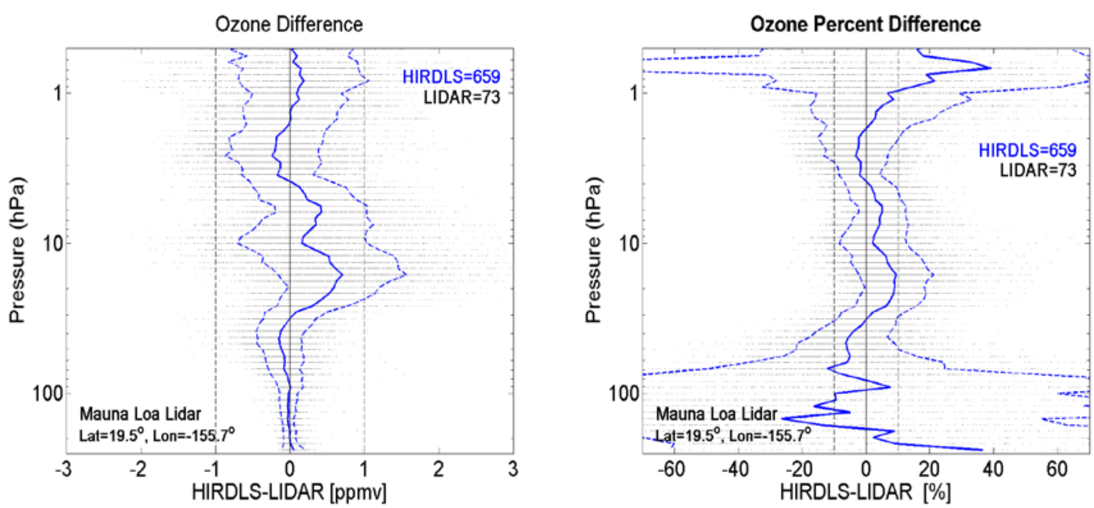

Figure 5.2.2. Ozone difference between 73 MLO lidar profiles and the 659 coincident HIRDLS profiles, in terms of mixing ratio, left, and percent (of sonde values), right.

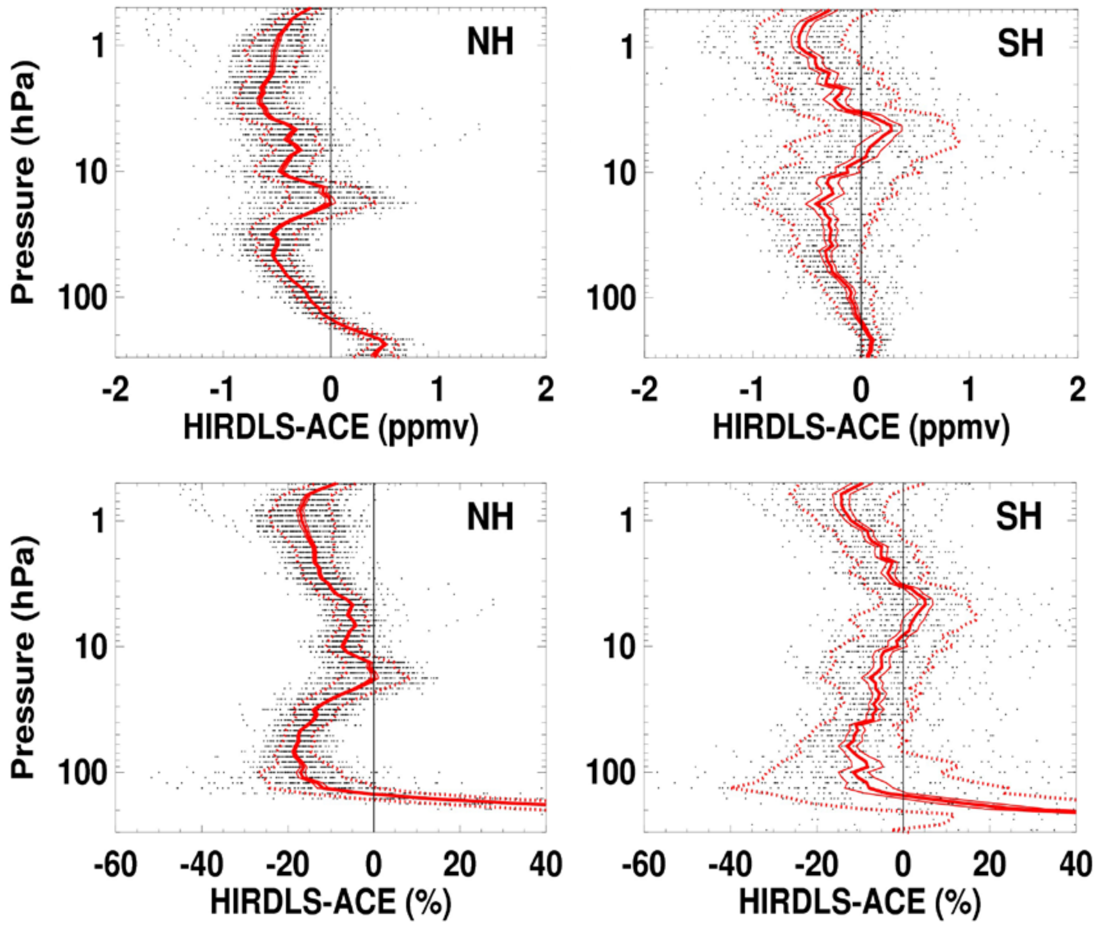

Figure 5.2.3. ACE satellite solar occultation comparisons since May 2006 show agreement to within ~10% (bottom) between 3 - 25 hPa in the Northern Hemisphere (left) and between 1 - 100 hPa in the Southern Hemisphere (right), with HIRDLS biased generally low .

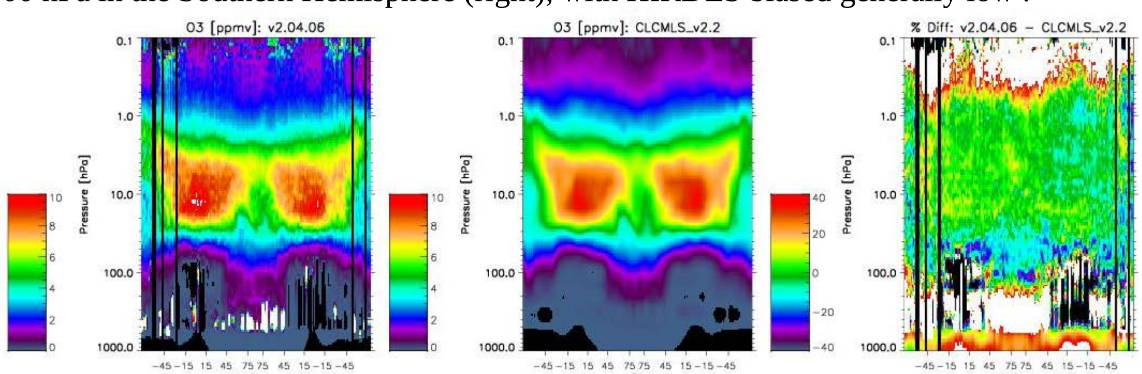

Figure 5.2.4. A single orbit curtain plot comparison with MLS (Left: HIRDLS; Middle: MLS; Right: Difference) indicates HIRDLS is tends to be 10% lower earthward of ~30 hPa and is

generally 10% high above ~1hPa and rapidly increases. HIRDLS ozone tends to be slightly lower than MLS, especially in the (night-time) descending node (RHS of panels).

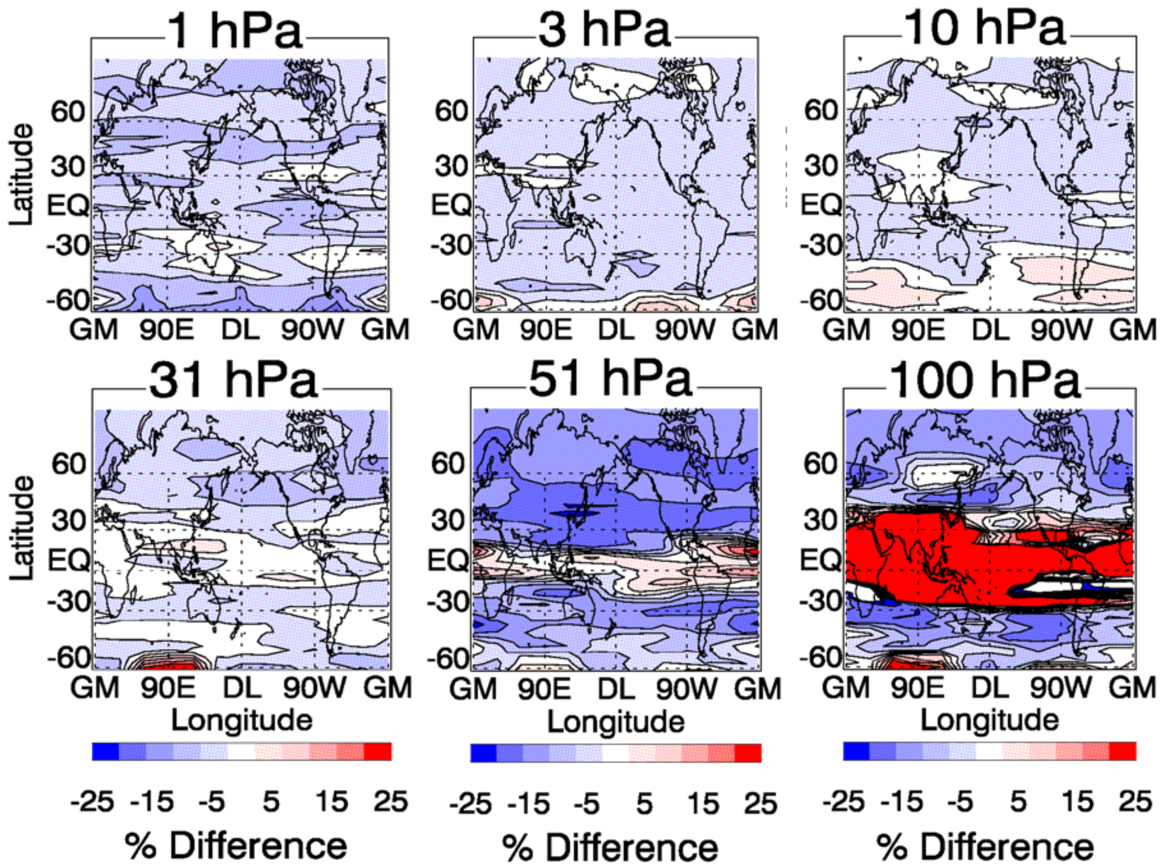

Figure 5.2.5. Mercator representations of the ozone percent difference between HIRDLS and collocated MLS (v2.2) for 2006-July-15, at pressure levels, 1 hPa, 3 hPa, 10 hPa, 31 hPa, 51 hPa and 100 hPa, as indicated over each sub-plot. The ozone fields for this day are relatively quiescent. Clearly illustrated in this and the previous figure is that in the tropics earthward of ~60 hPa HIRDLS ozone tends to be very high with respect to MLS. This is probably related to the presence of high cloud-tops.

Vertical Resolution

Comparisons with ozonesondes and lidar give strong indication that HIRDLS is capable of resolving fine vertical ozone features (1.2 km to 2 km) in region 1hPa to >100+hPa. Numerous coincident profiles with better than 500 km coincidence show similar layered features. Figure **5.2.6** shows comparisons with ozonesonde and lidar profiles.

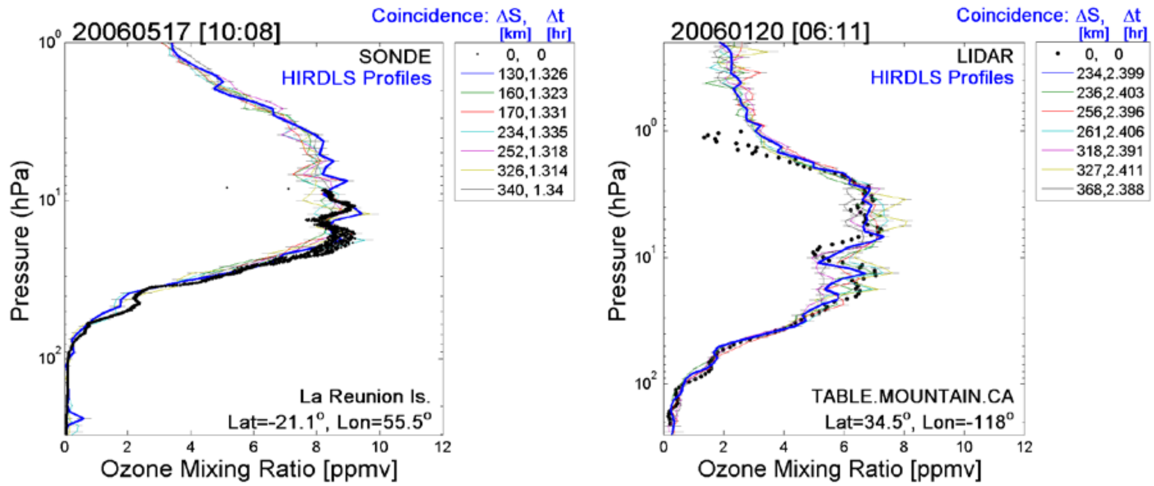

Figure 5.2.6 Comparisons of HIRDLS profiles with: ozonesonde profile from La Reunion Island (left), and with MLO lidar profiles (right).

Precision

The variability of the ozone data is plotted on in equivalent latitude- potential temperature bins for NH and SH summer in figure **5.2.7**. This variability includes both the atmospheric variability and the random error of the HIRDLS data. The atmospheric variability is a minimum In the summer seasons, so that the variability shown in the high latitude summer is an upper bound to the HIRDLS precision. This is estimated to be 5-10% between 1 and 50 hPa (500-2000K in potential temperature.

Data Caveats

The data are most reliable over the pressure range 1 to > 100 hPa at latitudes poleward of ± 30 degrees, and from 1 to 51 hPa at low latitudes (-30° < lat < 30°).

For p >100 hPa: HIRDLS ozone may be useable sometimes, to several hundred hPa, particularly at mid-latitude and in the absence of local cloud features. Vertical features may be captured, but systematic bias is unknown due to lack of statistics; HIRDLS ozone here is expected to be low in the absence of clouds, and very high where high clouds are present.

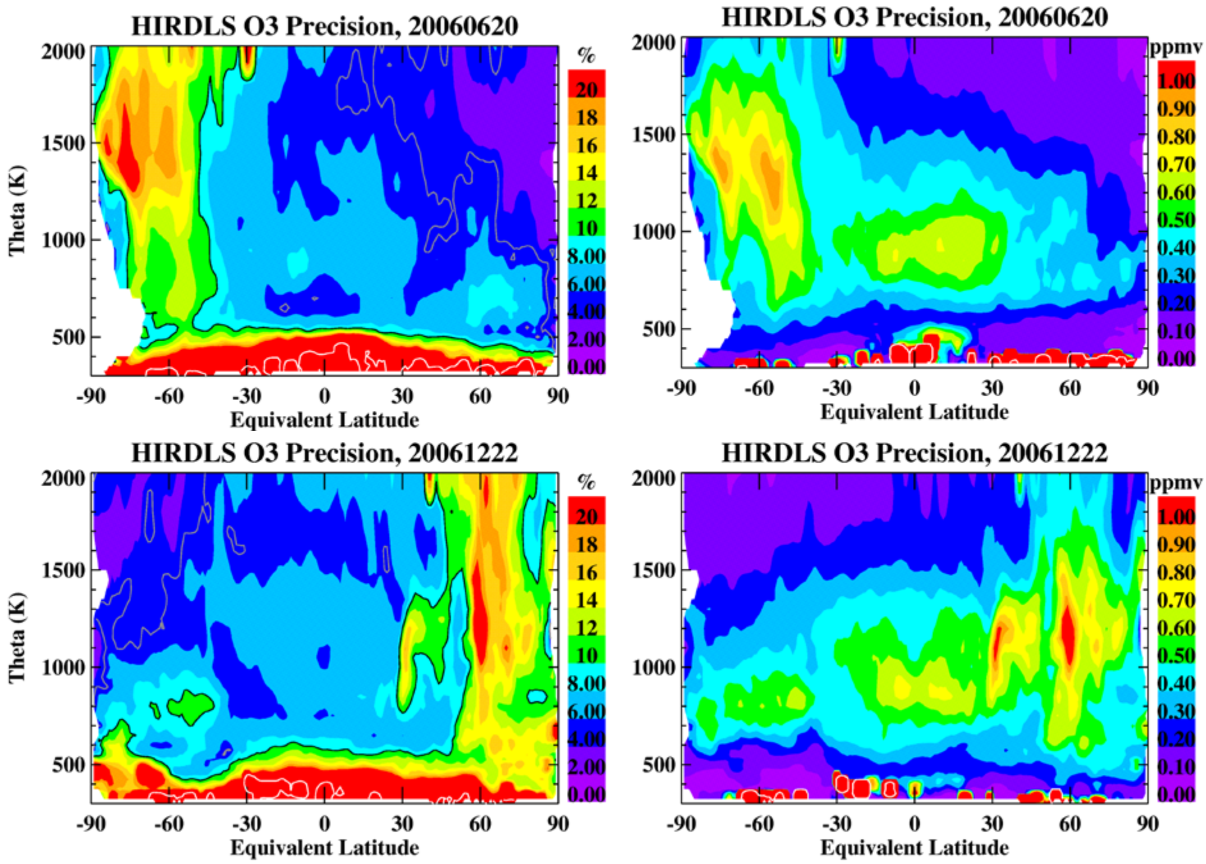

Figure 5.2.7. An estimate of the HIRDLS ozone precision based on ozone variability in equivalent latitude bins. High precision estimates at winter-hemisphere high latitudes (LHS of top plots; RHS of bottom plots) are indicative of large atmospheric variability rather than of an actual deterioration of HIRDLS precision.

Precision: Negative values of calculated retrieval total error ("O3Precision") indicate a >50% contribution to the error from a priori, and thus a strong *a priori* influence in the result. Ozone values containing negative precision should not be used, or used only with caution.

Clouds: Any profile for which the 'CloudTopPressure' parameter is a non-zero number should be used with caution. Ozone values may be severely effected by the presence of clouds at pressures greater than or equal to the 'CloudTopPressure', and possibly also at lower pressures. Ozone corrupted by clouds appear as ozone spikes which can be variable in magnitude and thickness. These are especially prevalent at pressure > ~60 hPa at low latitudes (-30<Lat<30).

Artifacts

Lower Stratosphere: HIRDLS ozone has a systematic generally low bias, between roughly 30 hPa to 100 hPa, with values of up to 10%. The region of roughly positive 5% HIRDLS bias exists in a limited pressure range within 10-30 hPa at nearly all latitudes; this is observed by comparisons with sondes (SHADOZ, WAVES), lidars (MLO, TMF) and satellites (ACE, MLS).

Upper Troposphere / Lower Stratosphere: Two of the three ozone channels, 10 and 12, are very sensitive to clouds in the upper troposphere / lower stratosphere. Even when the cloud algorithm is turned on, spikes are present in some of the ozone profiles, primarily between 80-200 hPa but also at pressures as low as 60 hPa; these are probably related to the presence of clouds detected at these or greater pressure levels. This is particularly true of low latitude profiles.

Priorities for future data improvements are the reduction of the systematic low bias of ozone at pressures greater than ~50 hPa, and improvement of removal of the cloud effect, especially at low latitudes.

5.3 Nitric Acid

Species:	Nitric Acid (HNO_3)
Data Field Name:	HNO_3
Useful Range:	161 hPa – 10 hPa
Vertical Resolution:	~ 1 km
Contact:	Douglas E. Kinnison, NCAR-HIRDLS
Email:	dkin@ucar.edu
Validation Paper	Kinnison *et al*., Global observations of HNO_3 from the High Resolution Dynamics Limb Sounder (HIRDLS) – First results, *J. Geophys. Res*., in press 2008.

Early Results and Validation:

HIRDLS HNO_3 data are generally good between 28 April 2005 to the present over the latitude range of 64ºS to 80ºN and pressure range ~100 hPa to 10 hPa, with some profiles, depending on latitude, having useful information between 100 hPa to 161 hPa. HIRDLS observations before 28 April 2005 are marginal in quality and not recommended for science applications. The HIRDLS HNO_3 vertical resolution is approximately 1 km, but does vary with altitude and latitude (Figure 5.3.1). The HIRDLS HNO_3 precision was estimated in two ways. The first approach examined the precision as derived by the HIRDLS level-2 retrieval algorithm. We called this the "theoretical" precision. The second approach derived the precision by examining HIRDLS HNO_3 data in regions of low atmospheric variability. We call this the "measured" precision. The components of the theoretical precision (forward model, measurement, and *a priori* errors) are shown in Figure 5.3.2. This figure shows that for the 100 hPa - 10 hPa (18 - 32 km) region, the contribution of the *a priori* is minimal. However, in the deep tropics, the altitude region where the *a priori* contribution is minimal is smaller (~40 hPa - 10 hPa; ~22 km - 32 km). The HIRDLS HNO_3 at pressures <10 hPa (>32 km) is characterized by large uncertainties and should be used with caution. The individual profile "measured" precision is between 10 - 15%, but can be much larger if the HNO_3 abundance is low or outside the ~100 hPa to 10 hPa range (Figure 5.3.3). Global results are compared with the HNO_3 observations from version 2.2 of the EOS Aura Microwave Limb Sounder (MLS) and it is found that large-scale features are consistent between the two instruments (Figures 5.3.4 and Figures 5.3.5). HIRDLS HNO_3 is biased 0-20% low relative to Aura MLS in the mid-to-high latitudes and biased 50% high in the tropical stratosphere (Figure 5.3.6). More work will be needed to see whether this high bias in the tropics is an issue with the HIRDLS or Aura MLS HNO_3 observations. HIRDLS HNO_3 is also compared with Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) (Figures

5.3.7 and 5.3.8). In these, high latitude comparisons, the HIRDLS HNO_3 data are biased 10-30% low, depending on altitude.

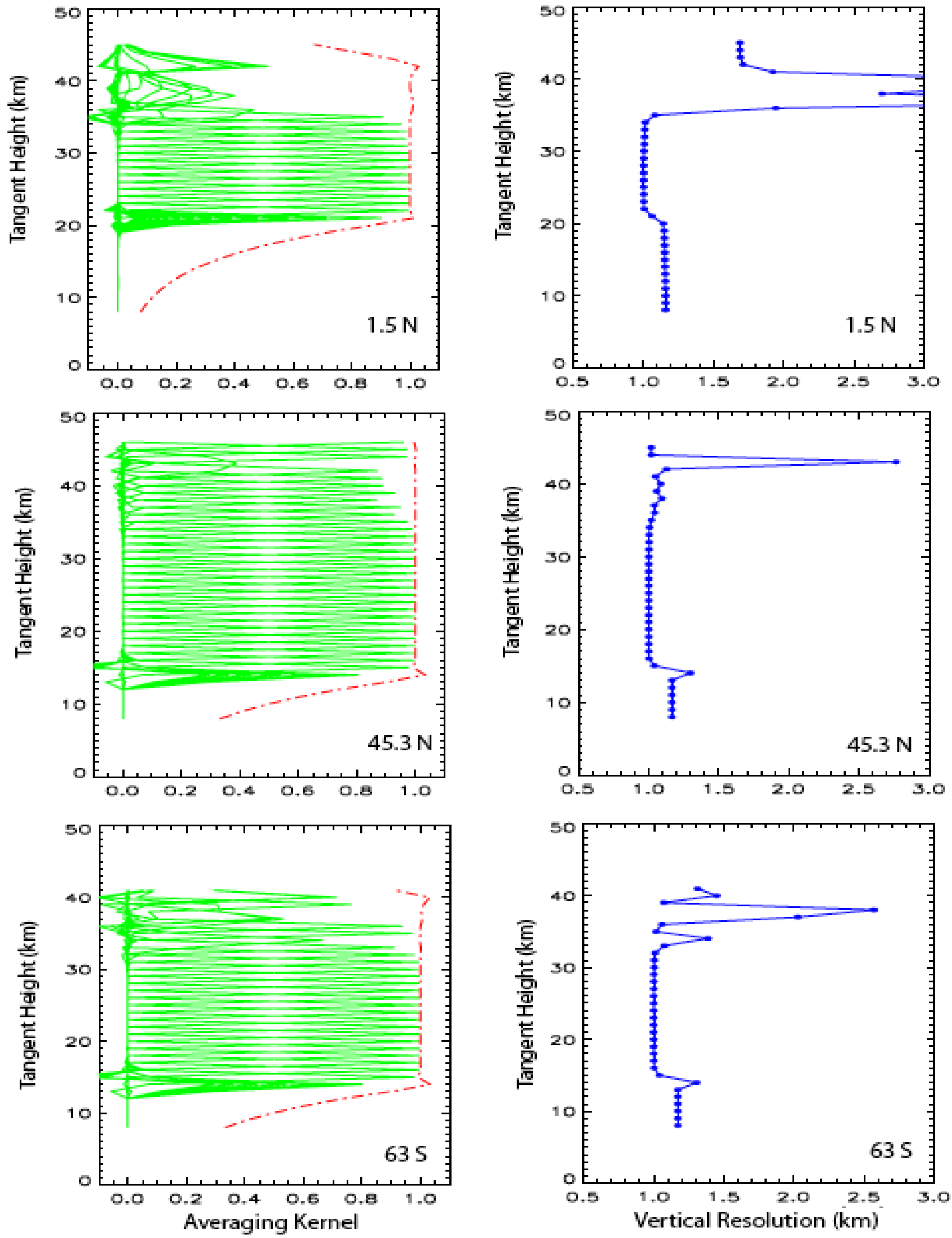

Figure 5.3.1: HIRDLS HNO_3 averaging kernels and full width half maximum (FWHM) vertical resolution profiles are shown on 21 June 2006 at 1.5°N, 45.3°N, and 63°S. The left column shows the averaging kernels (green lines) and the integrated area under each kernel (red line). Where values of unity indicate that all of the information for that vertical region is coming from

the measurements and not the *a priori* estimate. The right column represents the vertical resolution as derived from the FWHM of each kernel (blue line).

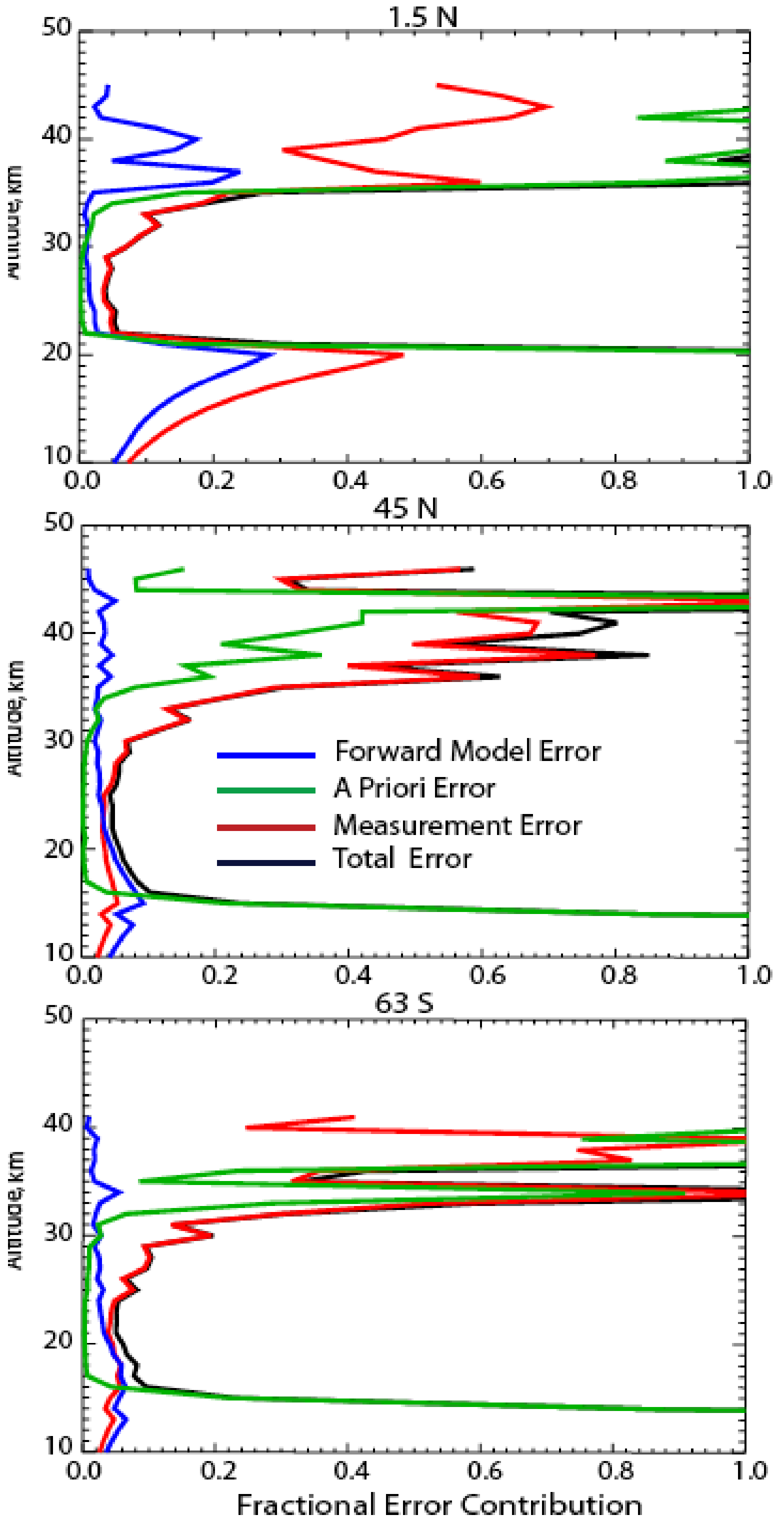

Figure 5.3.2: Shown is the HIRDLS HNO_3 "theoretical precision" displayed as the fractional error contribution for 21 June 2006. The top, middle, and lower panels are for latitudes 1.5°N, 45.3°N and 63°S respectively (same regions as Figure 5.3.1). The forward model error (blue line), the *a priori* error (green line), and the measurement error (red line), along with the total retrieval error (black line) are shown.

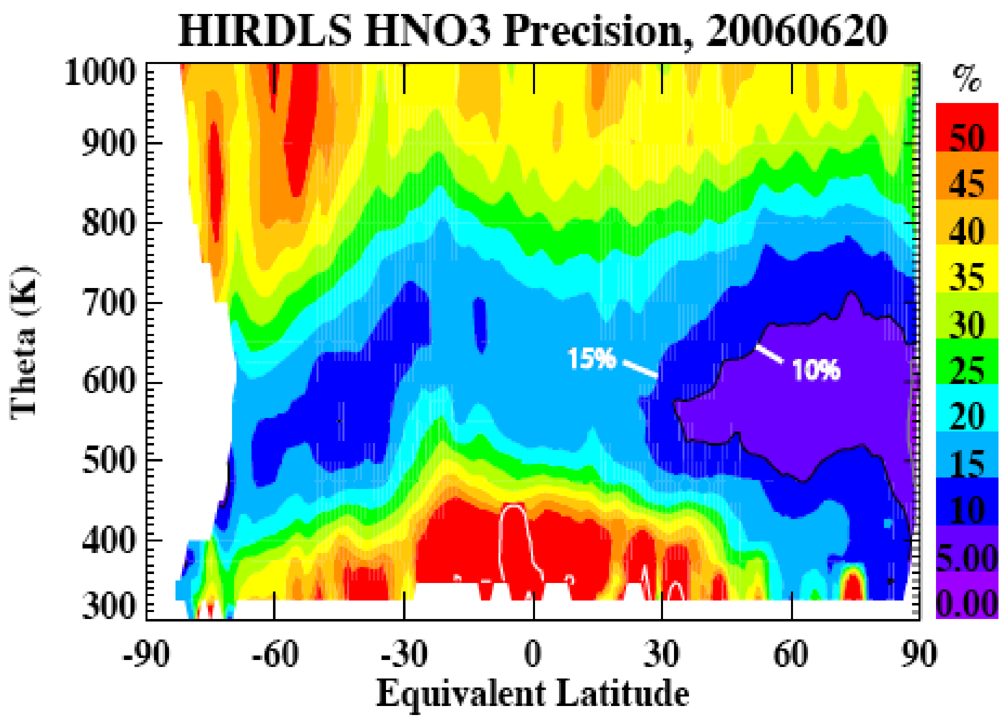

Figure 5.3.3: Shown is the standard deviation of HIRDLS HNO_3 retrievals in a potential temperature and equivalent latitude coordinate system. Results are given for 20 June 2006. Standard deviation units are given in terms of percentage of HNO_3 mixing ratio. The black lines highlight the 10% contour. In this figure we call this estimate of the precision the "measured precision". To examine the observed variability, 24-hours of HIRDLS HNO_3 were interpolated onto a potential temperature grid and then assembled into 4° equivalent latitude bins centered on 1° increments (essentially 4° wide box-car smoothing in equivalent latitude). The equivalent latitude was derived from Met Office potential vorticity data. In addition, in order to compare air parcels with similar insolation, an additional criterion was imposed. This criterion limits measurements to within 5 degrees of the average geographic latitude in each equivalent latitude bin. The potential temperature range is from 300 to 1000 K or approximately 10 to 35 km. The minimum observed standard deviation is approximately 10 % in this figure. This occurs in the summer hemisphere, where atmospheric variability is known to be a minimum and HNO_3 is abundant (typically >4 ppbv). The theoretical precision (not shown) from the HIRDLS level-2 processor approaches 5% in this region. This figure supports the derivation of the theoretical

precision obtained from the level-2 retrieval. Based on this analysis, the theoretical precision may be an underestimate of the true precision, but the error would be on the order of 5% in regions of relatively high abundance of HNO_3.

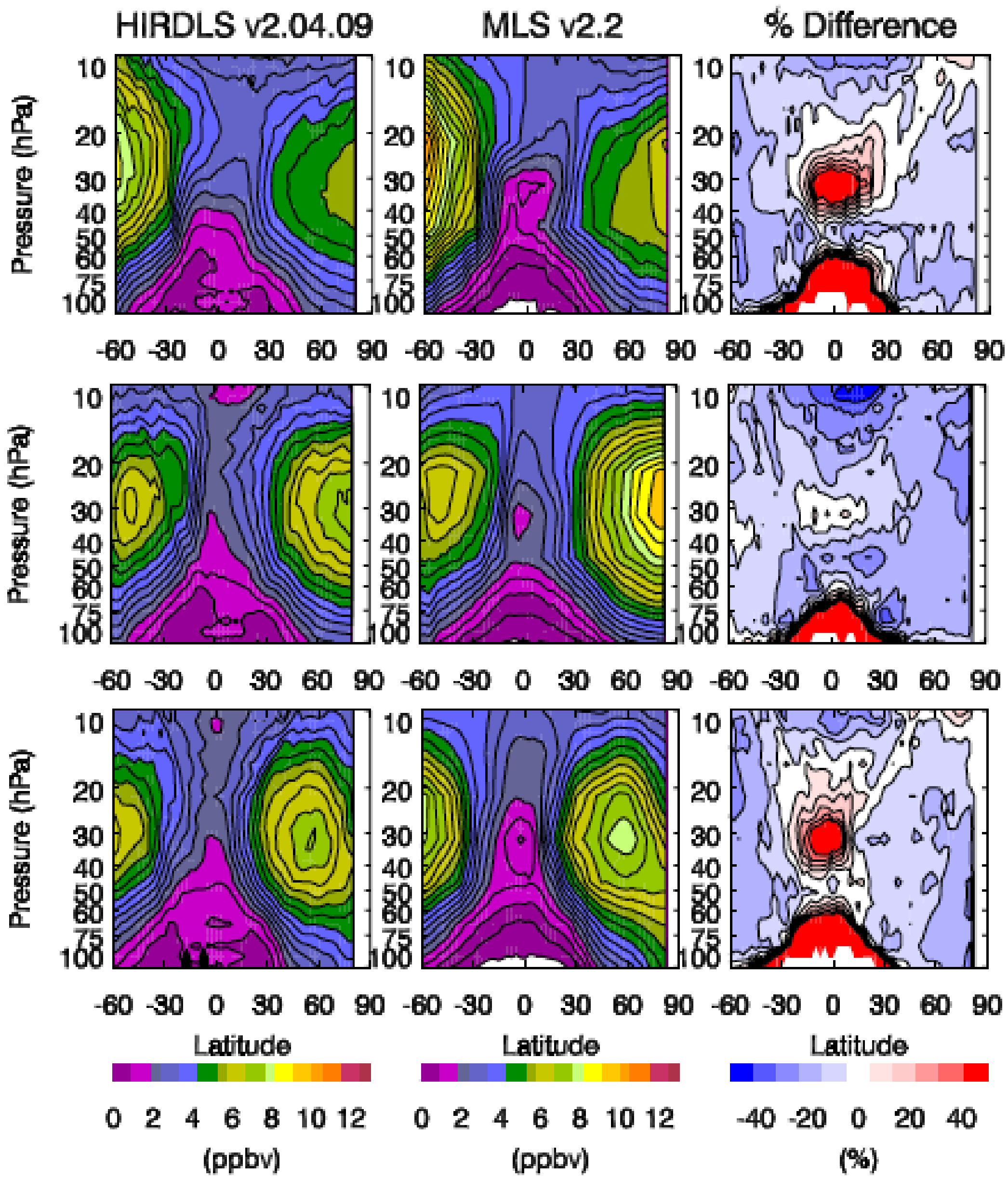

Figure 5.3.4. Latitude-height cross sections are shown for HIRDLS and MLS HNO_3 (ppbv). The top panel is a zonal mean average of four days (in May 2006). The middle panel is a zonal mean average of eight days (in October 2006). The bottom panel is a zonal mean average of 27 days (in March 2007). The percentage difference of (HIRDLS – MLS / MLS) is also shown. The zero percentage difference contour line is the transition from white to blue.

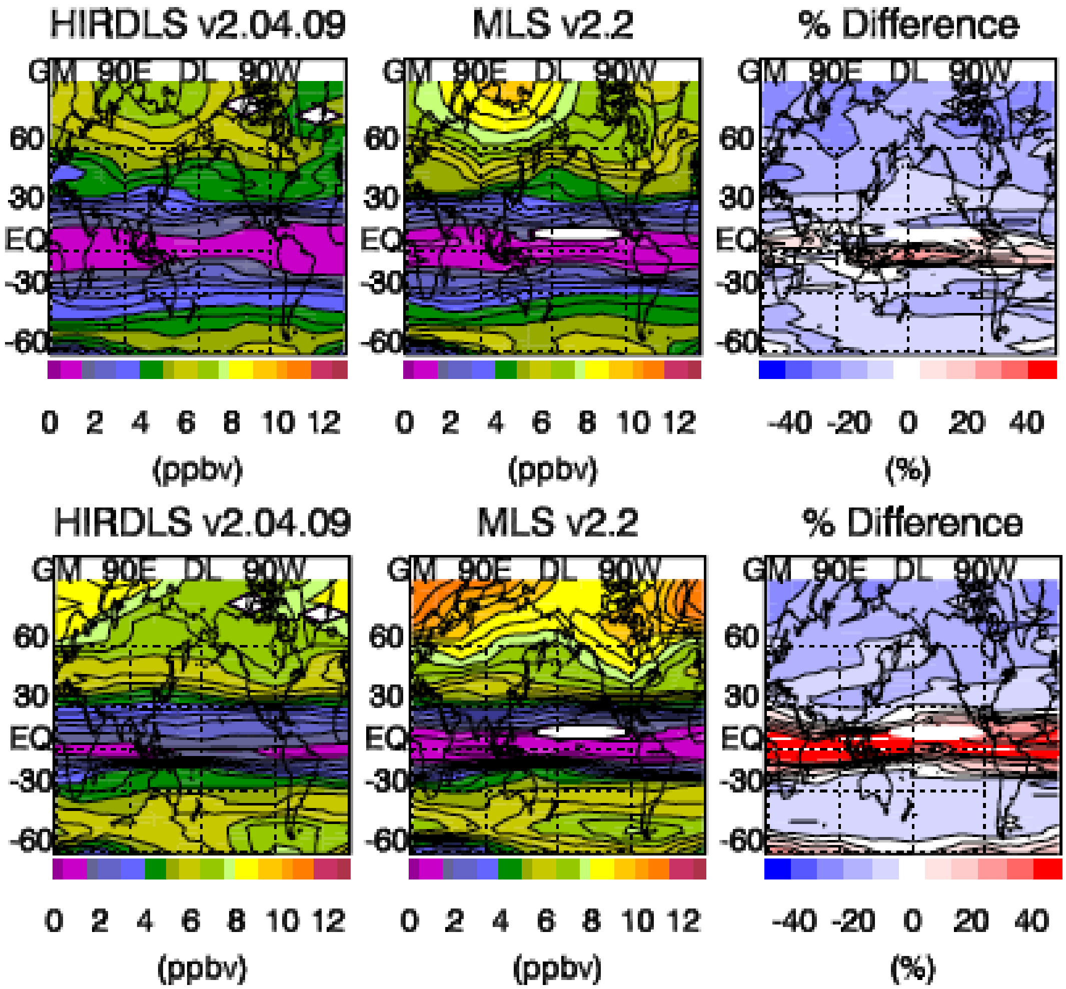

Figure 5.3.5. Longitude-latitude cross sections of HIRDLS and MLS HNO_3 (ppbv) on 28 October 2006. The top and bottom rows are for 51.1 hPa and 31.6 hPa respectively. The percentage difference of (HIRDLS – MLS / MLS) is also shown. The zero percentage difference contour line is the transition from white to blue.

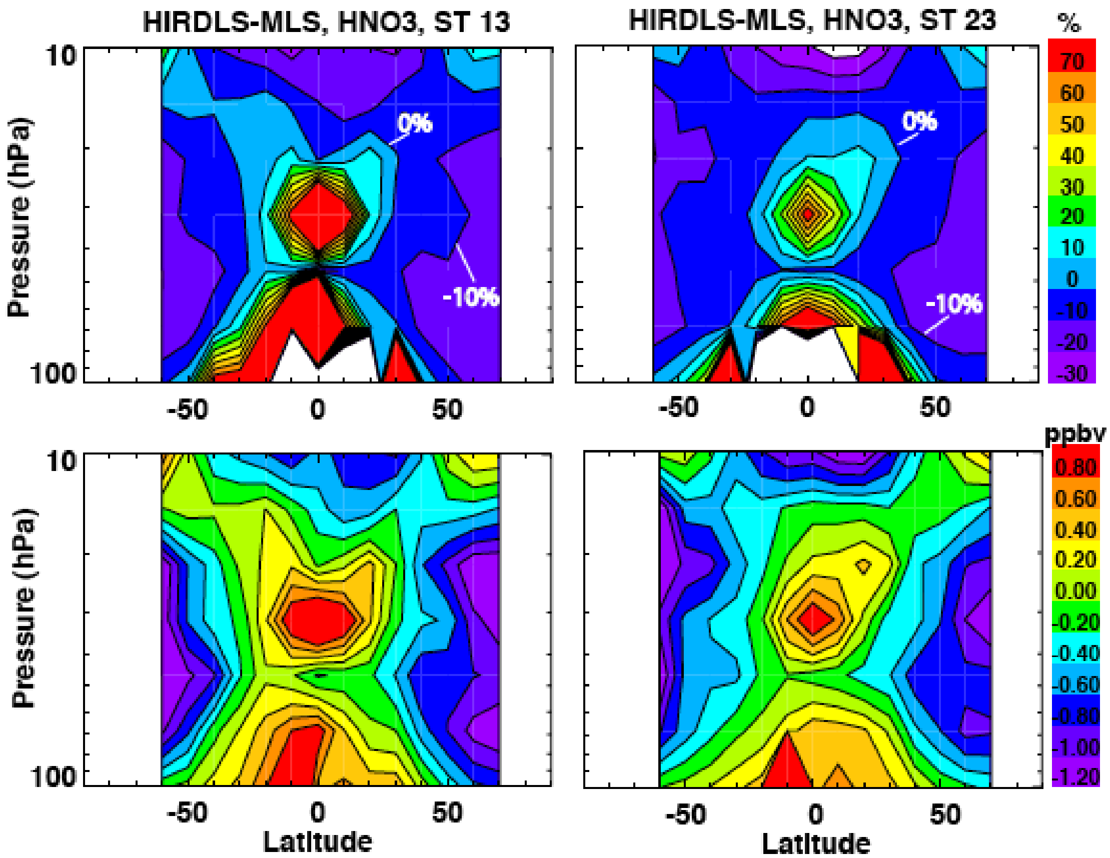

Figure 5.3.6. Latitude-height cross sections of HIRDLS-MLS coincidences for two different HIRDLS scan tables. The left column is for scan table 13; the right column is for scan table 23. There were 165,513 and 67,595 coincidences used to create the panels for scan tables 13 and 23 respectively. The top row shows the percentage difference of (HIRDLS – MLS / MLS). The bottom row shows the absolute differences in volume mixing ratio units (ppbv).

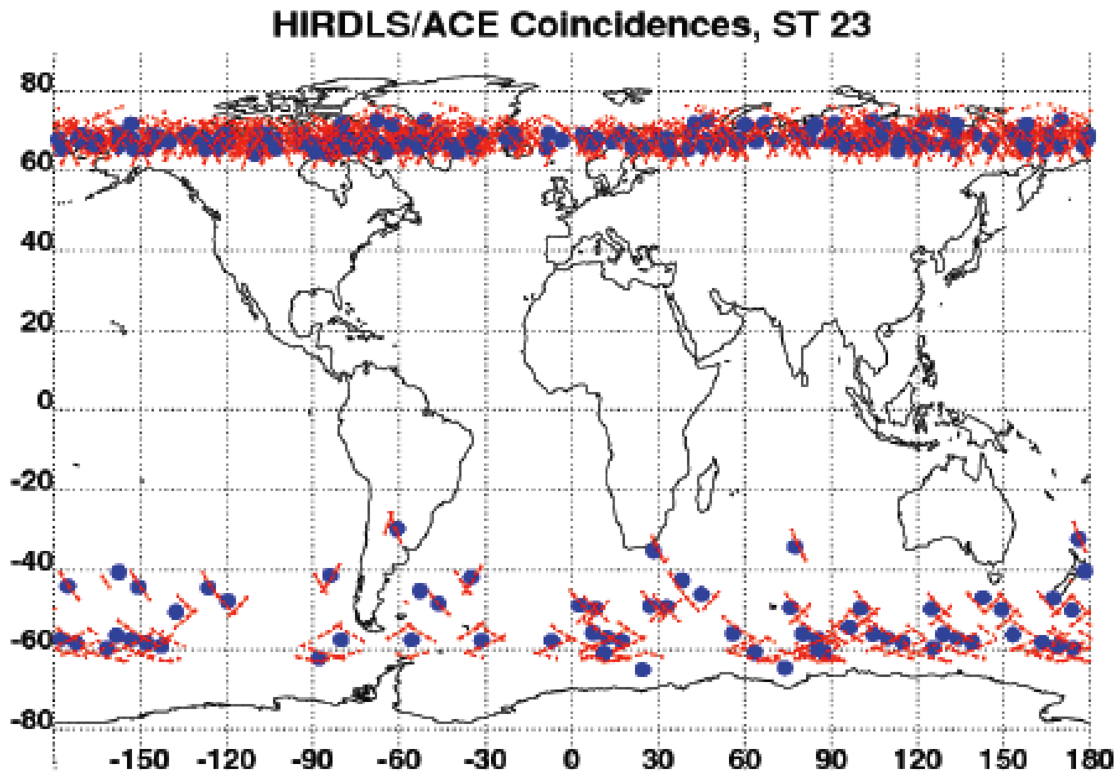

Figure 5.3.7. Latitude-longitude cross sections showing ACE-FTS HNO_3 measurement locations (blue) and HIRDLS HNO_3 measurement locations (red). Coincidences are defined as occurring within 2-hours in time and 500 km. The coincidences shown here are for scan table 23. There were a total of 150 coincidences between 19 May 2006 and 31 October 2006.

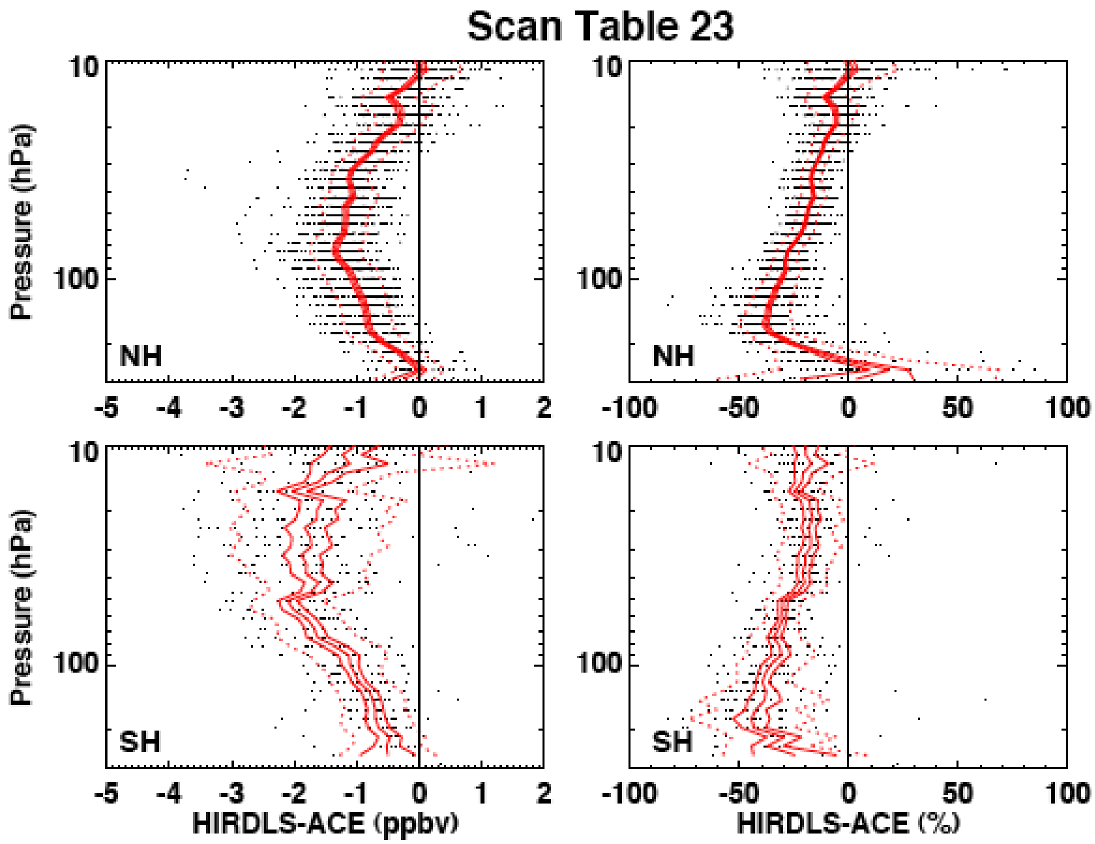

Figure 5.3.8. Profile differences of HIRDLS and ACE-FTS for the scan table 23 measurements. Comparisons shown here were between 19 May 2006 and 31 October 2006 (see Figure 5.3.5). Coincident HIRDLS profiles were averaged together and then subtracted from a single ACE-FTS profile. The top row shows the percentage difference of (HIRDLS – ACE-FTS / ACE-FTS). The bottom row shows absolute differences in volume mixing ratio (ppbv). The mean (solid red) and standard deviation (dashed red) of the differences for all coincidences are shown. The individual differences from which these are derived are the horizontally distributed layers of small black dots. The thin red lines bracketing the mean are the uncertainty in the mean (standard deviation divided by the square root of the number of points).

Acknowledgements: The HIRDLS team would like to thank both the EOS Aura MLS science and the ACE science teams for making their data available for HIRDLS validation.

5.4 Cloud Products

Species	Cloud Top Pressure
Data Field Name:	CloudTopPressure
Useful Range:	422-10 hPa
Vertical Resolution:	1km
Contact:	Steven Massie
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Validation Paper	Massie *et al*., High Resolution Dynamics Limb Sounder observations of polar stratospheric clouds and subvisible cirrus, *J. Geophys. Res*., VOL. 112, D24S31, doi:10.1029/2007JD008788, 2007.

HIRDLS data files contain cloud flags and cloud top pressures. Details of the determination of cloud top pressures and cloud flags are discussed in Massie et al [2007].

Cloud flag data is contained in the "12.1MicronCloudAerosolFlag" data variable. Cloud flags are stated at each pressure level when pressures correspond to altitudes between 5 and 30 km altitude. Cloud flag values are 0 (no clouds), 1 (unknown cloud type), 2 (cirrus layer), 3 (extensive Polar Stratospheric Cloud), and 4 (opaque). If the cloud flag is nonzero, then this indicates that the radiance at that pressure is measurably different from the clear sky radiance profile. Note that the total number of PSCs is equal to the number of cloud flags with values of either 1 or 4.

Comparisons of clear sky and individual radiance profiles of the various cloud types are presented in Figure 5.4.1. Note that radiance perturbations are substantial for several cloud types, since gas opacity in HIRDLS Channel 6, the 12 µm "infrared window" channel, is very low. Any cloud opacity along the HIRDLS limb-view tangent ray path produces a substantial 12 µm radiance signal.

The cloud top pressure (i.e. the 'CloudTopPressure' variable in the archived data file) is determined in the following manner. For a single day's set of radiance profiles, the clear sky radiance profile for HIRDLS channel 6 is calculated by an iterative technique for several latitude bands. For the first iteration, the average profile, its standard deviation, and associated gradients from 5 to 30 km altitude, are calculated summing over all profiles. For the second iteration, profiles greater than the mean are removed from the ensemble average (based on the fact that a cloudy radiance profile deviates from the average curve). New standard deviations and associated gradients are recalculated. The iterative process continues for five iterations.

Once the clear sky radiance profile is calculated, we determine the altitude level at which cloud radiance perturbations are first noted. The cloud top pressure (in hPa) is the pressure derived by the operational retrieval that corresponds to the cloud top altitude. Since the v2.04.09 cloud top altitudes are on an altitude grid with one kilometer spacing, the cloud top pressure has a granularity reflective of the altitude grid spacing, e.g. for pressure level P, the cloud top pressure could be large by $\Delta P \sim P\ (\exp(1\ \text{km}/ 7\ \text{km}) - 1.0) \sim 0.15\ P$.

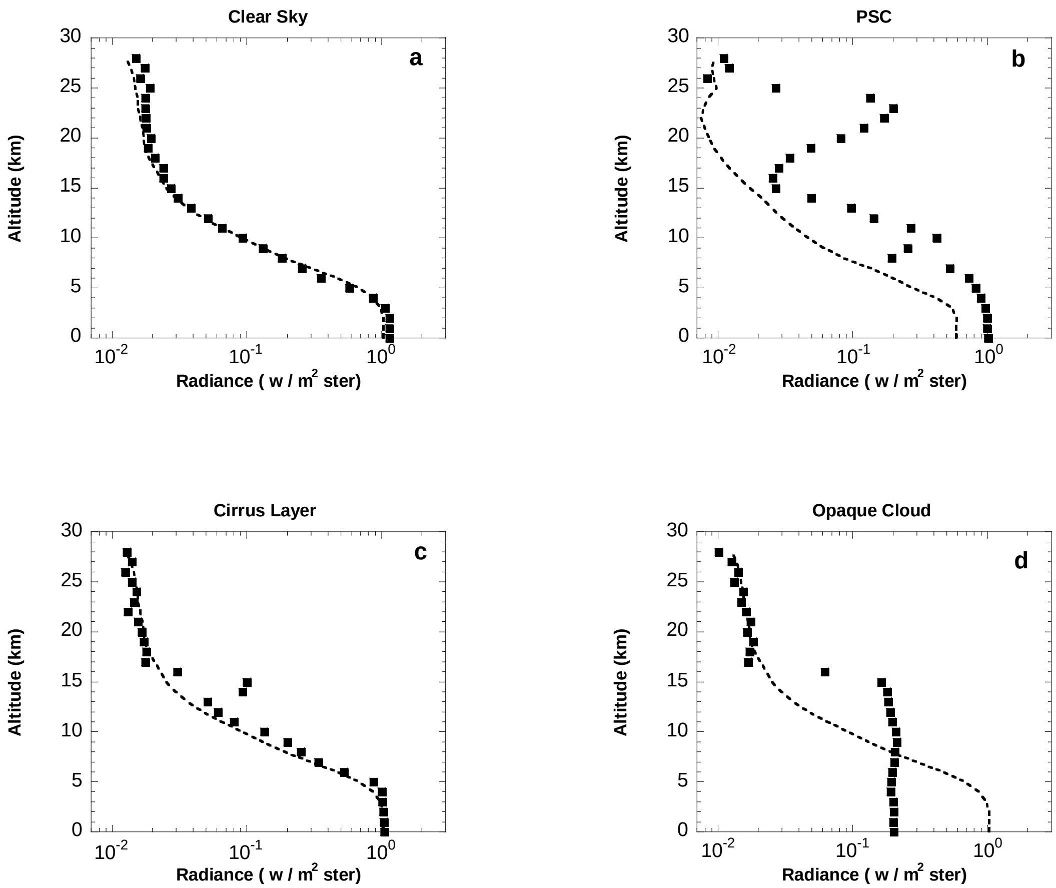

Figure 5.4.1. Four representative Channel 6 (12.1 µm) radiance (single squares) and clear sky average profiles (dotted curves) on January 27 2005, a) clear sky (15.57º N, 216.20º E), b) PSC (68.31º N, 343.41º E), c) tropical cirrus layer (4.32º N, 220.00º E), and d) opaque tropical cloud (16.79º S, 223.72º E) cases. Panels a, b, c, and d correspond to cloud flags equal to 0, 3, 2, and 4, respectively.

The distributions of time averaged cloud statistics, as determined by the HIRDLS cloud-detection algorithm, compare very well to distributions derived from correlative data. HALOE and HIRDLS time averaged cloud top pressures have a correlation coefficient of

0.87 and 0.93 in the tropics and mid-latitudes, respectively. SAGE III and HIRDLS cloud top pressure values in 2005 have a correlation coefficient of 0.85 when the distance between observations is less than 100 km and the time difference is less than six hours. HIRDLS cloud top pressures are 20% lower and 15% higher than SAGE III and HALOE cloud top pressures, respectively. Time series of the T < 195 K hemispherical area, on the 450 K potential temperature surface, and the total number of PSCs observed by the HIRDLS experiment in January and February 2005 have a correlation coefficient of 0.92. Finally, HALOE and HIRDLS normalized distributions of cloud counts, expressed as a function of outgoing longwave radiation (OLR), have a correlation coefficient of 0.99.

6.0 Data File Structure and Content

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Email: cacraig@ucar.edu

HIRDLS Level 2 data are stored in the HDF-EOS5 format and the fields are as described in the _HDF-EOS Aura File Format Guidelines_ document ^1 . These data files can be read via C/C++ or Fortran using either the HDF-EOS5 or HDF5 library. HIRDLS has developed both an IDL routine "get_aura" and a set of Fortran90 routines to access the HIRDLS Level 2 data. Both of these routines will be available for download via the HIRDLS web site, www.eos.ucar.edu/hirdls/, starting in 2008. The routines can also be supplied via email upon request.

Users should obtain the pre-compiled HDF5 library for their operating system, if possible, otherwise source code is also available (see http://hdf.ncsa.uiuc.edu). These are prerequisite in order to compile the HDF-EOS5 library (see http://www.hdfeos.org/). Both libraries are needed to fully access the Aura HIRDLS data files. For additional help contact the GES DISC at help-disc@listserv.gsfc.nasa.gov or telephone 301-614-5224.

Each HIRDLS Level 2 file contains one day's worth of data and contains all species that HIRDLS measures. A number of the fields are filled completely with missing values until correction algorithms are refined for these species. For users who require only a subset of the HIRDLS species, the Goddard DISC has the ability to subset data before distributing it to users. Contact the DISC directly for more information on this service.
Individual HIRDLS data values for a product are stored in fields labeled with the species name (see the appropriate section above for the exact Data Field Name). The estimated precision of each data point is a corresponding field named *Species*Precision (for instance, Temperature and TemperaturePrecision). Two additional fields for each species, *Species*NormChiSq and *Species*Quality, are both filled with missing for V003. CloudTopPressure does not have Precision, NormChiSq or Quality fields.

There are two time fields in the HIRDLS data file, *Time* and *SecondsInDay*. *Time* is stored in TAI time (seconds since the epoch of UTC 12 AM 1-1-1993). This time includes leap seconds and can cause problems with simplistic conversions. For this reason, HIRDLS is also storing *SecondsInDay* which is seconds since midnight of the data day. Leap seconds do not pose a problem when using this field. Note that the first data point may be negative which indicates a time stamp before midnight. This is the case for scans which span a day boundary.

[1]http://www.eos.ucar.edu/hirdls/HDFEOS_Aura_File_Format_Guidelines.pdf

7.0 Algorithm Changes

HIRDLS Version	DISC Version	Changes
2.00	001	[Baseline]
2.01		Modified to process Scan Table 22
2.02.07	002	Modified to process Scan Tables 30, 13, 22 and 23
2.04.09	003	Modified to include more precise geo-location, updated cloud detection, updated calibration constants, and bug fixes.

8.0 Acronyms

ACE	Atmospheric Chemistry Experiment
ACD-FTS	Atmospheric Chemistry Experiment Fourier Transform Spectrometer
ATBD	Algorithm Theoretical Basis Document
DISC	Data and Information Services Center
ECMWF	European Center for Medium range Weather Forcasting
EOS	Earth Observing System
FWHM	Full Width Half Maximum
GES DISC	Goddard Earth Sciences Data and Information Services Center
GMAO	Goddard Modeling and Assimilation Office
HALOE	Halogen Occultation Experiment
HDF5	Hierarchical Data Format Version 5
HDF-EOS5	HDF for EOS Version 5
HIRDLS	HIgh Resolution Dynamics Limb Sounder
HIRDLS1C	HIgh Resolution Dynamics Limb Sounder Level 1Data
IDL	Interactive Data Language
L0	Level 0
L0-1	Level 0-1
L1	Level 1
L1-2	Level 1-2
L1C	Level 1 Corrector
L1PP	Level 1 Pre-processor

L1X	Level 1 Excellorator
L2	Level 2
L2CLD	Level 2 Cloud Detector
L2PP	Level 2 Pre-processor
LOS	Line Of Sight
MLO	Mauna Loa Observatory
MLS	Microwave Limb Sounder
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
OMI	Ozone Monitoring Instrument
PIs	Principal Investigators
PSC's	Polar Stratospheric Clouds
RMS	Root Mean Square
SAGE III	Stratospheric Aerosol and Gas Experiment III
s.d.	Standard Deviation
SHADOZ	Southern Hemisphere ADditional OZonesondes
ST	Scan Table
TAI	International Atomic Time
TES	Tropospheric Emission Spectrometer
TMF	Table Mountain Facility
UK	United Kingdom
USA	United States of America
UTC	Coordinated Universal Time
WAVES	Water Vapor Validation Experiment Satellite/Sondes