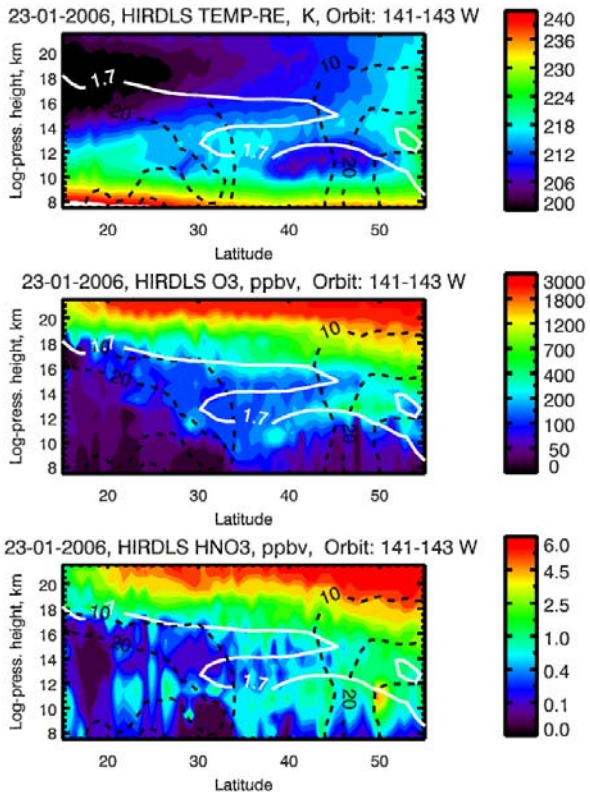
HIRDLS

High Resolution Dynamics Limb Sounder
Earth Observing System (EOS)
Data Description and Quality

Version 5 (V5)
(HIRDLS Version 5.00.00)
April 2010



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Cover Page:

Top Panel: Temperature; showing a double tropopause between 38° - 48° N.

Center Panel: Ozone; mixing ratio, showing a thin layer of air with low ozone extending poleword from the UT into the LS near 14 Km altitude. Its extension follows a region of low scaled potential vorticity (Ertel PV scaled by potential temperature).

Bottom Panel: Nitric acid; mixing ratio, also showing thin layer of UT air with low nitric acid extending into the LS near 14 Km altitude. It also follows the region of low PV.

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Minimum Information That Every HIRDLS Data User Needs to Know

M.1 Acquiring & Reading HIRDLS Level 2 Data

HIRDLS Level 2 data is available from several worldwide data repositories. In the United States, HIRDLS data can be downloaded from the Goddard Earth Sciences Data and Information Services Center (GES DISC). (http://disc.sci.gsfc.nasa.gov/data-holdings). HIRDLS data is also available in the United Kingdom and Europe from the British Atmospheric Data Centre (BADC) (http://badc.nerc.ac.uk/browse/badc/hirdls). In both institutions, several versions of HIRDLS data are available and care should be taken to make sure that V5 data is requested.

HIRDLS Level 2 (L2) data is stored in the HDF-EOS5 format 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. A HIRDLS developed IDL routine "get_aura" is also available upon request for those users who wish to use IDL to access the HIRDLS data.
[1]http://www.eos.ucar.edu/hirdls/HDFEOS_Aura_File_Format_Guidelines.pdf

Warning for IDL users: Due to internal changes within the HDF5 library used to create V5 data, IDL must be upgraded to 7.1 in order to read the HIRDLS V5 data.

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 for all products that HIRDLS measures. The HIRDLS data are a set of values of temperature or mixing ratio on a set of 24 pressure levels per decade of pressure, uniformly distributed in log pressure. 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 Table 1 for the exact names). 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 V5. CloudTopPressure does not have Precision, NormChiSq or Quality fields. For V5 data, the fields for products other than those listed in Table 1 are filled with missing values (-999.0) since the radiance correction algorithms for these products are not mature yet.

There are two time fields in the HIRDLS data file, Time and SecondsInDay. Time is stored in TAI time (seconds since the epoch of 00.00 UTC 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.

M.2 Data That Should Be Used With Caution

Data points for which the majority of the information comes from the a priori have their precision fields set negative and the user should decide whether data are suitable for scientific studies. (See http://www.agu.org/journals/jd/jd0920/2009JDD11937/ for details on quantitative a priori contributions to the errors. In addition, one may consult the web page http://www.eos.ucar.edu/hirdls/data for details on negative precision.)

M.3 Known Problems

A few cloud tops are not detected, resulting in retrievals at low altitudes of cloud-contaminated radiances. This can result in retrieved temperatures being too warm, and positive or negative spikes in species retrievals.

While not expected, there may be some residual differences between up and down scans. Critical features should be checked to ensure they appear in scans in both directions.

Table 1 below details the useful vertical range, estimated accuracy, and the HIRDLS team contact for each product in this version. The vertical range and accuracy entries generally summarize complex variations, and the listed references, or the web page http://www.eos.ucar.edu/hirdls/, should be consulted before any use of the data. Additional products may be available in future versions.

Table 1: Information concerning V5 HIRDLS standard products.

Product	Field Name	Useful Range	Estimated Accuracy	Contact Name	Contact Email
Temperature	Temperature	400 - .04 hPa	± 2 K	John Gille	gille@ucar.edu
O_3	O3	260 – 0.5 hPa	† 3-10% 10-100% UTLS	Bruno Nardi	nardi@ucar.edu
HNO_3	HNO3	161 - 10hPa	† 10 to > 30%	Douglas Kinnison	dkin@ucar.edu
Cloud top pressure	CloudTopPressure	422 - 10 hPa	± 20%	Steven Massie	massie@ucar.edu
12.1 Micron Extinction	12.1 Micron Extinction	215 – 20 hPa		Steven Massie	massie@ucar.edu
CFC11	CFC11	287.3 - 26.1 hPa		Michael Coffey	coffey@ucar.edu
CFC 12	CFC12	287.3 - 10.0 hPa		Michael Coffey	coffey@ucar.edu
GPH	GPH	400 - .04 hPa	2%	Lesley Smith	LSmith@ucar.edu
HDF5, HDF-EOS5	Library installation			GSFC DAAC	Help-disc@listserv.gsfc.nasa.gov
HDF-EOS5	Reading HIRDLS data			Cheryl Craig	cacraig@ucar.edu

† Varies with latitude and altitude. See Nardi et al. (2008), Kinnison et al. (2008)

Note that the following references refer to the V3 data, but the descriptions of the data and the methods of evaluation are still applicable. In addition, one may consult the web page http://www.eos.ucar.edu/hirdls/

Gille et al., (2008), The High Resolution Dynamics Limb Sounder (HIRDLS): Experiment Overview, Results and Validation of Initial Temperature Data, *Journal of Geophysical Research*; doi:10.1029/2007JD008824, 2008.

Kinnison et al., (2008), Global Observations of HNO3 from the High Resolution Dynamics Limb Sounder (HIRDLS) – First Results, *Journal of Geophysical Research*; doi:10.1029/2007JD008814, 2008.

Massie et al., (2007), Validation of HIRDLS Observations PSC's and Subvisible Cirrus, *Journal of Geophysical Research*; doi:10.1029/2007JD008788, 2007.

Nardi et al., (2008), Validation of HIRDLS Ozone Measurements, *Journal of Geophysical Research*; doi:10.1029/2007JD008837, 2008.

End of Minimum Information Section

Table of Contents

1.0 Overview

1.1 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 partial blocking of the 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 and the higher longitudinal resolution expected are precluded, 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, are more advanced than for others. This had let us to release the current group of retrieved data products. This document provides a description of the third fully-released version of data for the entire mission, which includes retrieved temperature, ozone, nitric acid, chlorofluorocarbons (CFC) 11 and 12, geopotential height and aerosol extinction, as well as cloud top pressure.

Work is ongoing to improve the radiances, and 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.

The minimum information needed by a HIRDLS data user is presented in Section M (Minimum Information That Every HIRDLS Data User Needs to Know) at the front of this document. 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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j.barnett@physics.ox.ac.uk

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 mixing ratios of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC11, CFC12, ClONO2, Geopotential Height (GPH), 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. The retrieval can be thought of as operating in the following way. Four channels measure the emission by CO_2. Taking advantage of the known (and increasing) 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 measurement goals of HIRDLS were to observe the global distributions of temperature, the 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 (~61 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 was 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 all of the desired species, although not all of them are of sufficient quality to be released at this time. This will allow HIRDLS to meet a significant fraction of the original science objectives.

At this time data are available from 21 January 2005 until 2 January 2008, although occasional days are missing when spacecraft maneuvers took place. In future, the usable portions of these days will be processed. In addition, some data from January – March 2008 may eventually be available. HIRDLS stopped acquiring data after 17 March 2008 when the chopper experienced an anomaly. Efforts are now underway to restore it to operation.

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 and 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:

<u>Changes in coverage</u>

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 of the N. Hemisphere, the descending orbit views nearly the same orbit at midnight as the ascending orbit at 3:00pm, 9 orbits or 15 hours later.

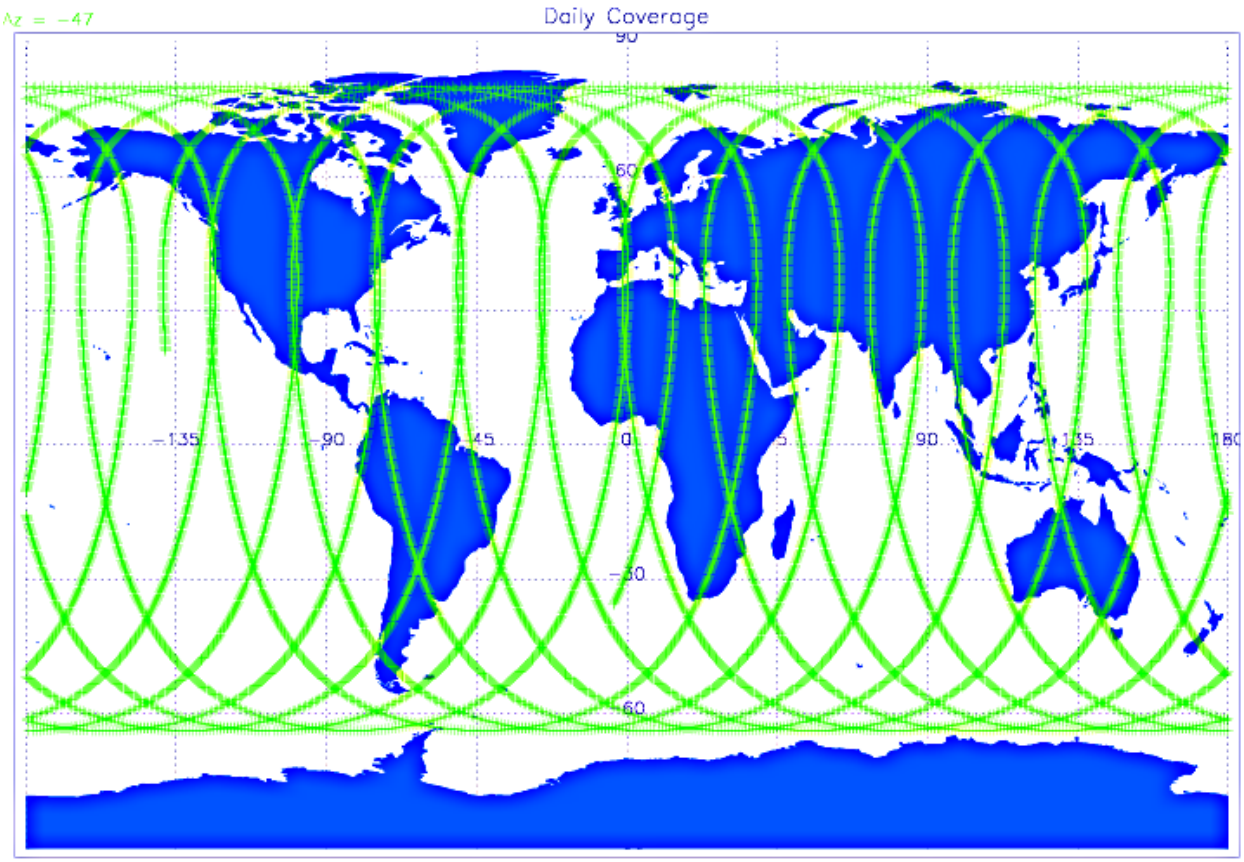

Figure 2.1 HIRDLS Daily Coverage

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

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 side of figure), but one orbit earlier. Thus HIRDLS views the same volume 84 minutes earlier than MLS (one orbit, or 99 minutes, minus the 15 minutes that separate 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.

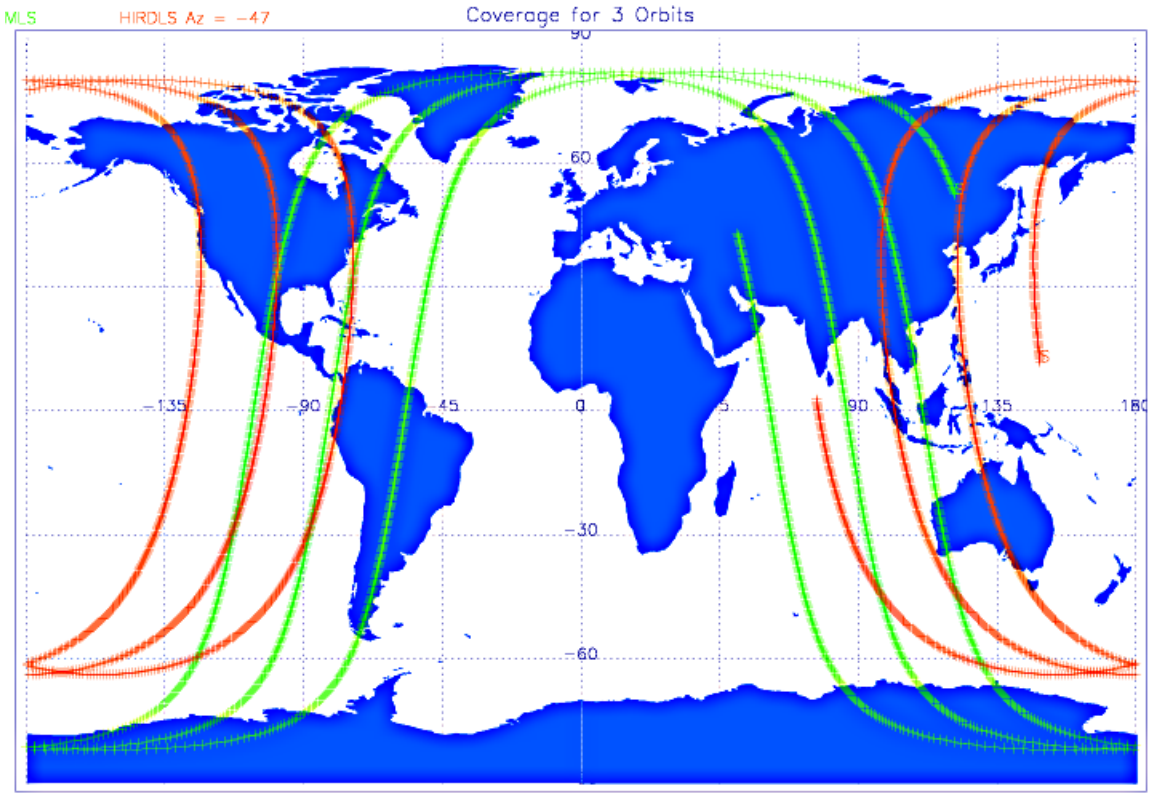

Figure 2.2. Comparison of 3 orbits of HIRDLS (red) measurement locations to MLS (green). HIRDLS is measuring the atmosphere at one azimuth angle (i.e., -47° from the orbit plane). The day and night portion of the orbits are on the right and left side of the figure respectively. During the day part of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

Some compensating effects

With the azimuthal limitation, the profiles will have closer latitudinal separation (corresponding to ~100 km along track spacing), facilitating gravity wave studies. Transects through tropospheric intrusions into the lower stratosphere and tropopause folds are 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 Scan Modes

Scan Table (ST) 30 (21 January 2005-28 April 2005). This initial scan used a more rapid vertical scan speed, which generated larger amplitude spurious oscillations in the signals. Because of the difficulty in completely removing these, data from this period are not as good as later data obtained with the other scan tables. 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 pairs of vertical up and down scans of ~ 15.5 sec. duration each, followed by a 1-2 second space view before the next 27 scan pairs. 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.

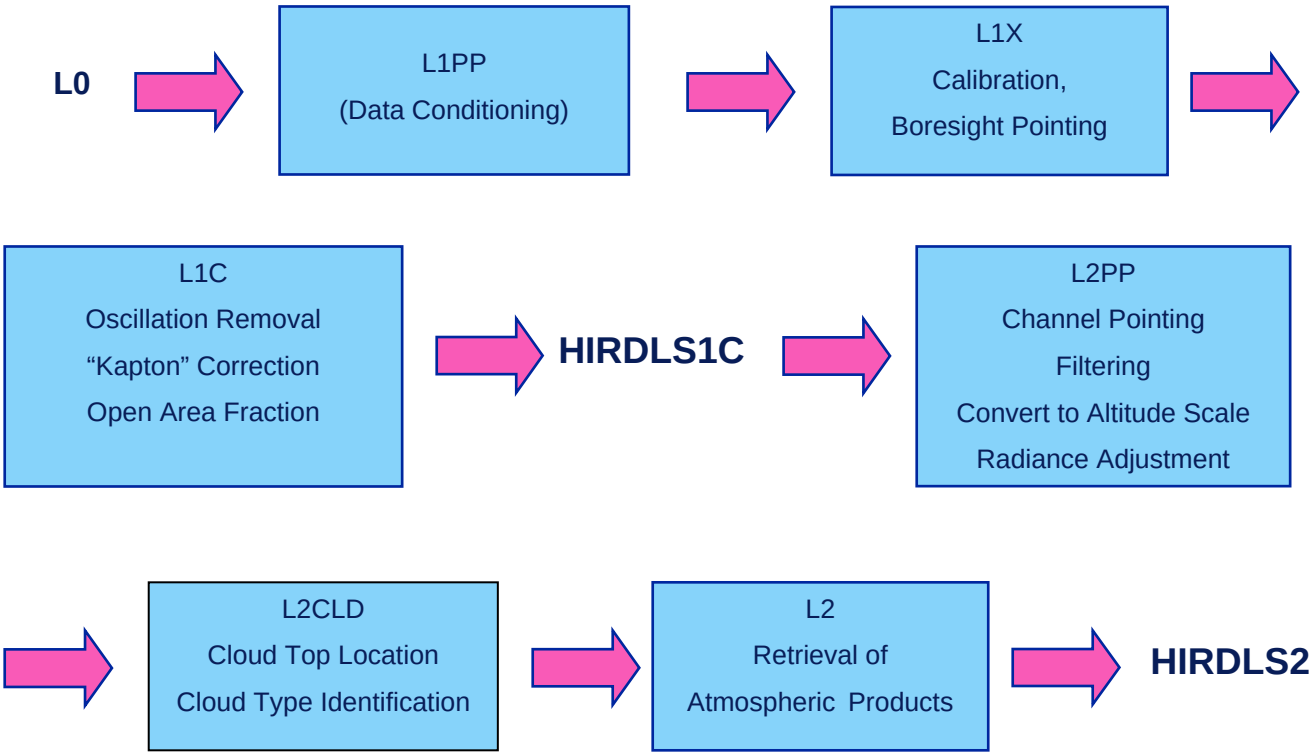

Figure 4.1 HIRDLS Processing Flow

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

In the L0-1 suite of processor, the Level 1 Pre-processor (L1PP) corrects an occasional problem with the time in Level 0 (L0) data (raw data counts). Level 1 Excellorator (L1X) carries out the modified calibration, and geolocation, whileLevel 1 Corrector (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 in channels 6 and 12. 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 Algorithm Theoretical Basis Document (ATBD). GMAO version 5.01 data were used through January 2, 2008, after which version 5.1 data were used.

From December 4-18, 2007, there were problems with the spacecraft data system, resulting in some corrupted data products. Subsequently the input data were reconstructed by the NASA ground data system, and reprocessed in the HIRDLS SIPS. We are not aware of any resulting undetected problems at this time, but users should scrutinize these data carefully.

5.0 HIRDLS Standard Products

Comments common to all products:

Vertical range:
The radiance of limb viewing instruments generally decreases as altitude increases, since there are fewer emitting molecules along the path through the atmosphere. The level where the signal to noise ratio (S/N) becomes of order 1 generally sets the upper limit of useful retrievals. Gases with smaller mixing ratios at all levels, will in general have lower top altitudes.

For those gases whose distribution has a layer structure in the stratosphere, the fall to low mixing ratios at and below the troposphere may also lead to low S/N, and no useful retrievals at low altitudes. For species with mixing ratios that fall with altitude, the lower boundary will be reached either when a cloud intercepts the ray path from the tangent point to the detector, or where the channels become optically thick, so that no radiance reaches the detector from the geometric tangent level.

Vertical Resolution:
The vertical resolution is shown by the full-width at half-maximum (FWHM) of the averaging kernels. These are presented for the different products in paired panels, with the averaging kernels on the left, and the FWHM on the right. Typically these are very close to 1 km over the range of interest.

The left panel also shows the sum of the averaging kernel values at a given tangent altitude. Values ≈ 1 indicate that all of the information is coming from the measured radiances, with little affect of the a priori values. Because of the low noise of the HIRDLS measurements, this is usually the case over the ranges of interest.

Precision:
There are 2 measures of precision of the HIRDLS products. The L2 retrieval, which uses the Rodgers Maximum A-Posteriori Likelihood method, calculates an expected uncertainty of the retrievals based on the uncertainties of the input parameters (See Khosravi et al., 2009a, b). These are referred to here as the predicted uncertainties.

As described in section 1.3, the predicted precision values are flagged as negative when most of the information in the retrieval comes from the a priori. Details regarding negative precision and an example of how to assess the a priori's contribution to the retrievals are given in the web page
http://www.agu.org/journals/jd/jd0920/2009JDD11937/.

We also estimate the precision from the variability of the retrieved products; this is referred to as the measured precision. These values are derived from an analysis of the variability in a set of multiple consecutive adjacent scans. The precision is estimated as the standard deviation of 12 consecutive profiles taken in a ~3 minute window over about 1100 km, roughly equivalent to 10 degrees latitude. The set of values at each

pressure level is de-trended with a linear least squares fit in order to remove any effect introduced by mean gradient with latitude. This usually has a negligible effect in the tropics, where geophysical variability is generally expected to be at a minimum. In other cases we have looked at all data in a day, and taken the mean of the 10 smallest values. The standard deviation necessarily still includes some level of geophysical variability and is therefore an upper limit to the precision. The actual precision will be ≤ the standard deviation given here.

Accuracy:

Because of the aperture blockage, it is not possible to do a first principles estimate of accuracy by the propagation of calibration and other errors. We have taken the approach of comparing the HIRDLS products with results from conventional methods, or well validated satellite data sets. These are the results presented here.

Reference:

Khosravi, R., et al. (2009a), Overview and characterization of retrievals of temperature, pressure, and atmospheric constituents from the High Resolution Dynamics Limb Sounder (HIRDLS) measurements, J. Geophys. Res., 114, D20304, doi:10.1029/2009JD011937.

Khosravi, R., et al. (2009b), Correction to ‘‘Overview and characterization of retrievals of temperature, pressure, and atmospheric constituents from High Resolution Dynamics Limb Sounder (HIRDLS) measurements,’’ J. Geophys. Res., 114, D23399, doi:10.1029/2009JD013507.

5.1 Temperature

Species:	Temperature
Data Field Name	Temperature
Useful Range:	400 – 0.4 hPa
Vertical Resolution	1 Km
Contact:	John Gille
Email:	gille@ucar.edu
Validation paper	Gille, J., et al. (2008), High Resolution Dynamics Limb Sounder: Experiment overview, recovery, and validation of initial temperature data, J. Geophys. Res., 113, D16S43, doi:10.1029/2007JD008824.

Resolution:

The vertical resolution is determined from the full-width at half maximum of the averaging kernels. These are shown for each altitude level by the green lines in the left panel of Figure 5.1.1. The blue line in the right panel shows the half-widths explicitly, indicating the vertical resolution is ~1 km from 13-60 km.

The red line in the left panel indicates the fraction of the information that comes from the HIRDLS measurements; values of 1 mean that there is negligible influence from the a priori.

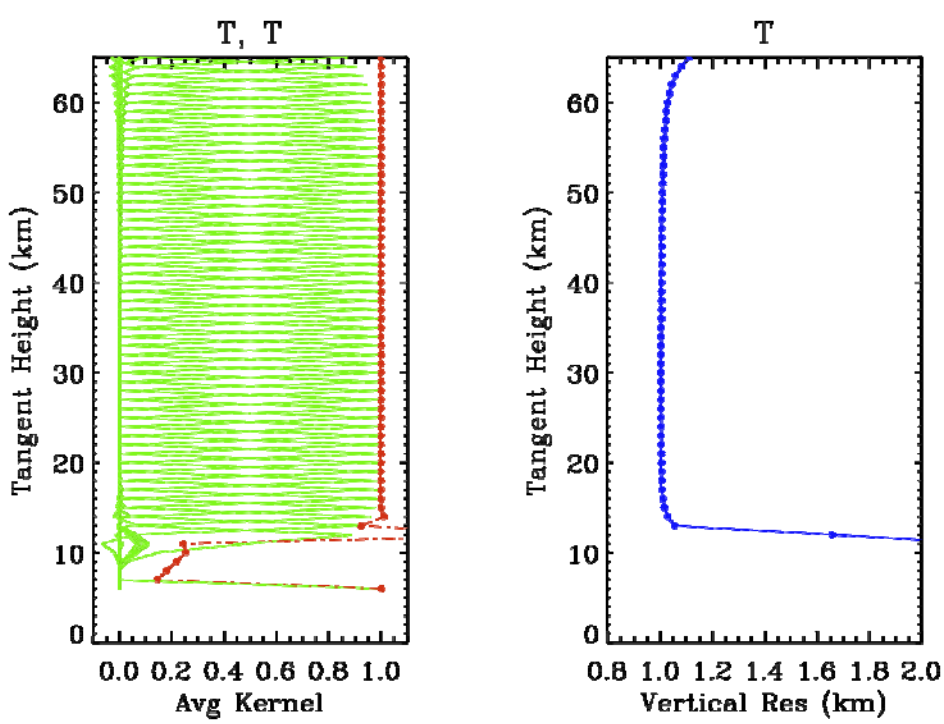

Figure 5.1.1. Averaging kernels (left) and vertical resolution (right) as a function of altitude for HIRDLS temperature profiles.

The averaging kernels were calculated for 15 January at 45°N with a cloud top altitude of 8 km. The rapid drop of the averaging kernel maxima, increase in the half widths, and increase in the fraction of information at altitudes below about 13 km results from relaxation to the a priori. This is the GEOS5 temperature for the day for which the data are retrieved. Thus, the retrieval relaxes seamlessly to temperatures that are accurate in the lower atmosphere. Since the GEOS5 resolution is ~1 km in this altitude range, the resolution of the combined retrieval should not be degraded.

Another indication of the resolution comes from comparison with the results from the radio-occultation temperature profiles obtained by the FORMOSAT-3/COSMIC constellation of 6 GPS receivers launched on 14 April 2006. These enable temperatures up to the mid-stratosphere to be retrieved with vertical resolution of about 1 km (C. Rocken, private communication). With 1000-3000 such temperature profiles being measured per day at quasi-random locations, a number of coincidences within 0.75° great circle distance and 500 sec can be found with which to undertake comparisons of the two data types, including the fine vertical structure which tends to vary on a short time scale. In this study, each COSMIC profile was paired with the 1 or 2 HIRDLS profiles that fit the criteria for closeness in space and time. If there were 2, the HIRDLS profiles were averaged together. Where there were COSMIC profiles very close together in space and time, a HIRDLS profile might be used more than once in different comparisons. In addition, the GMAO data were included as an indication of the absence of short vertical scales in the operational meteorological analyses.

For this evaluation, data from 11 July 2006 to 31 October 2007 were used. To isolate the small scales, a parabolic fit was subtracted from all 3 types of profiles over the range 2.2-5.7 scale heights, and the residual profiles then apodized. (The pressure scale height is ln 1013/p, so this corresponds to a range of 112-3.4 hPa. Since the scale height is approximately 7 km, this corresponds to an altitude range of ~24 km).

When the apodized profiles are Fourier transformed, the spectra, plotted as amplitudes vs spatial frequency, are as shown in Figure 5.1.2. Here all 1217 COSMIC profiles are included, irrespective of difference of viewing directions between HIRDLS and COSMIC. As expected, the spectra all have their largest amplitudes at the lowest frequencies. The COSMIC and HIRDLS spectra are very similar for frequencies up to 12 cycles per 24 km, or a 2 km wavelength, and beyond, although the amplitudes become quite small. Clearly these small-scale motions are not contained in the GMAO analyses.

This establishes that HIRDLS is capable of resolving vertical variations in the atmosphere with scales down to ~2 km wavelengths, or 1 km features.

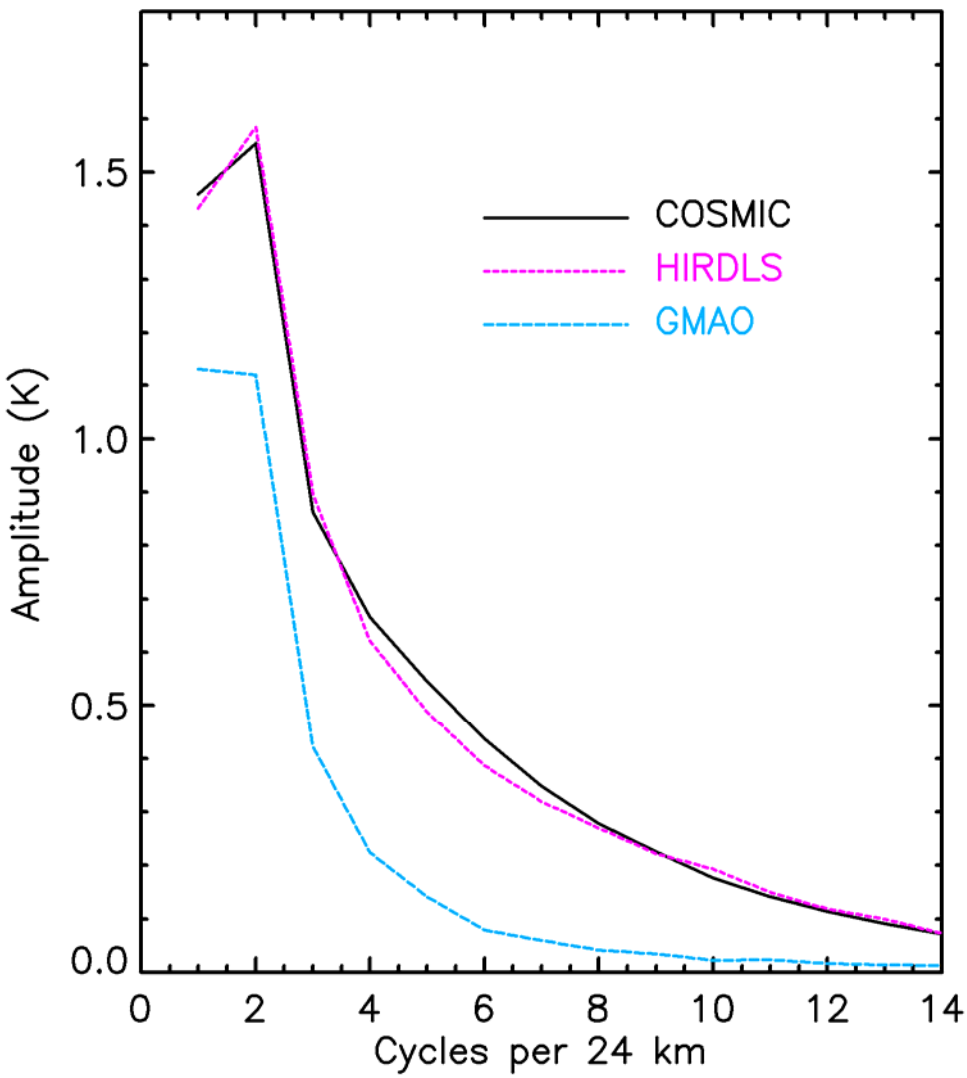

Figure 5.1.2. Comparison of amplitudes versus small scale wavelengths among HIRDLS, COSMIC and GMAO. HIRDLS and COSMIC recover vertical scales down to and beyond 12 cycles per 24 km, or 2 km wavelengths.

Precision:

The precision of the temperature data was calculated as described in Sec. 5.0. The results are displayed in Figure 5.1.3. At pressures > 400 hPa the precision is that of the GMAO data that are essentially those of the a priori data there. For pressures < 100 hPa the precision is that of the retrievals, with negligible influence from the a priori. As noted above, the method of estimating the precision may necessarily include some atmospheric variability, so is an upper limit to HIRDLS retrieval precision. This may contribute to some of the increase with altitude where the effect of small-scale waves motions, especially gravity waves, may be included.

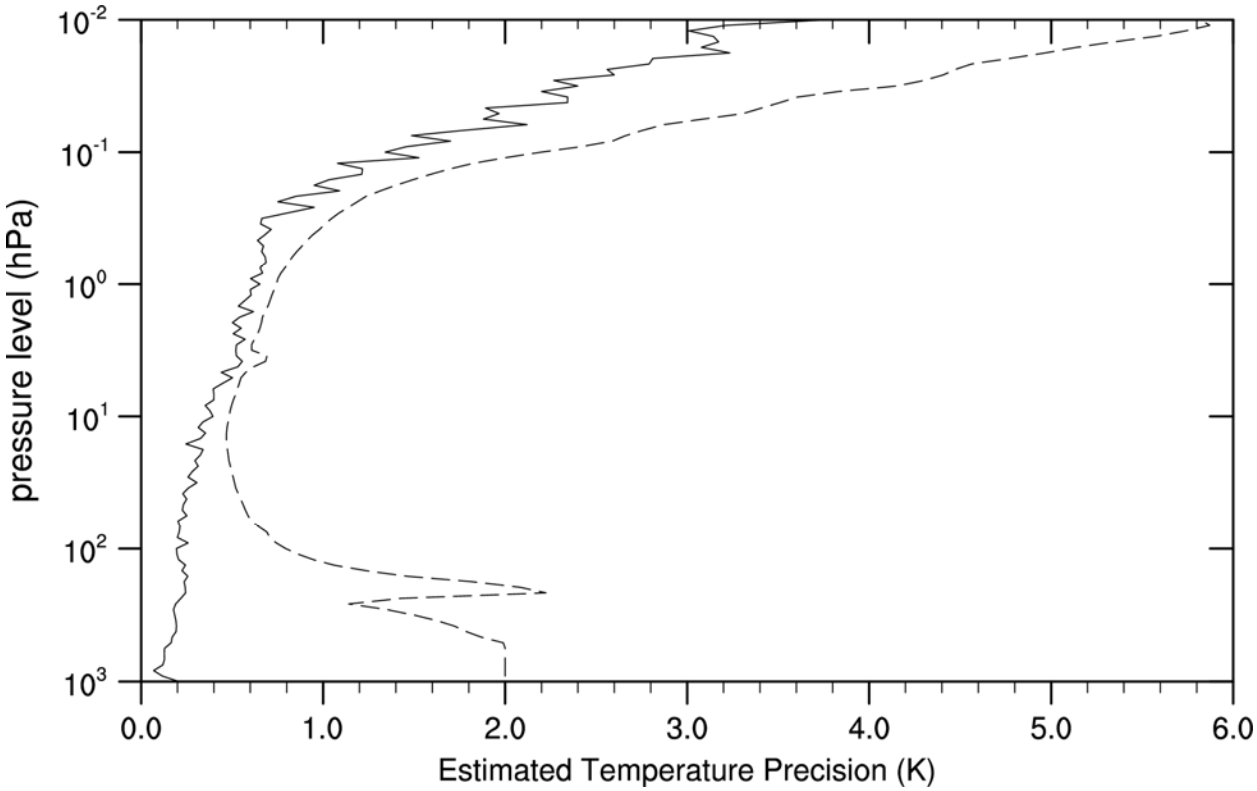

Figure 5.1.3. Estimated precision of HIRDLS V5 Temperature retrievals (solid line), compared with precision predicted by the retrieval algorithm (dashed line).

Certainly above 0.1 hPa reduced S/N plays a major role, and relaxation to the a priori keeps the precision from being even larger.

The random error predicted by the retrieval algorithm may be overestimated because we believe the uncertainty of the forward radiative transfer model may be less than the values we have used.

Accuracy (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 update results of comparisons described by Gille et al. (2008) for V3, An important comparison is between radiosondes and nearby HIRDLS temperatures. Fig. 5.1.4 shows comparisons among high-resolution radiosonde profiles and 2 nearby HIRDLS retrievals at St. Helena 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, as discussed above. Note in particular that 1 of the Gilbralter retrievals follows the sharp kink at the lower tropopause exactly, and both follow the double tropopause structure.

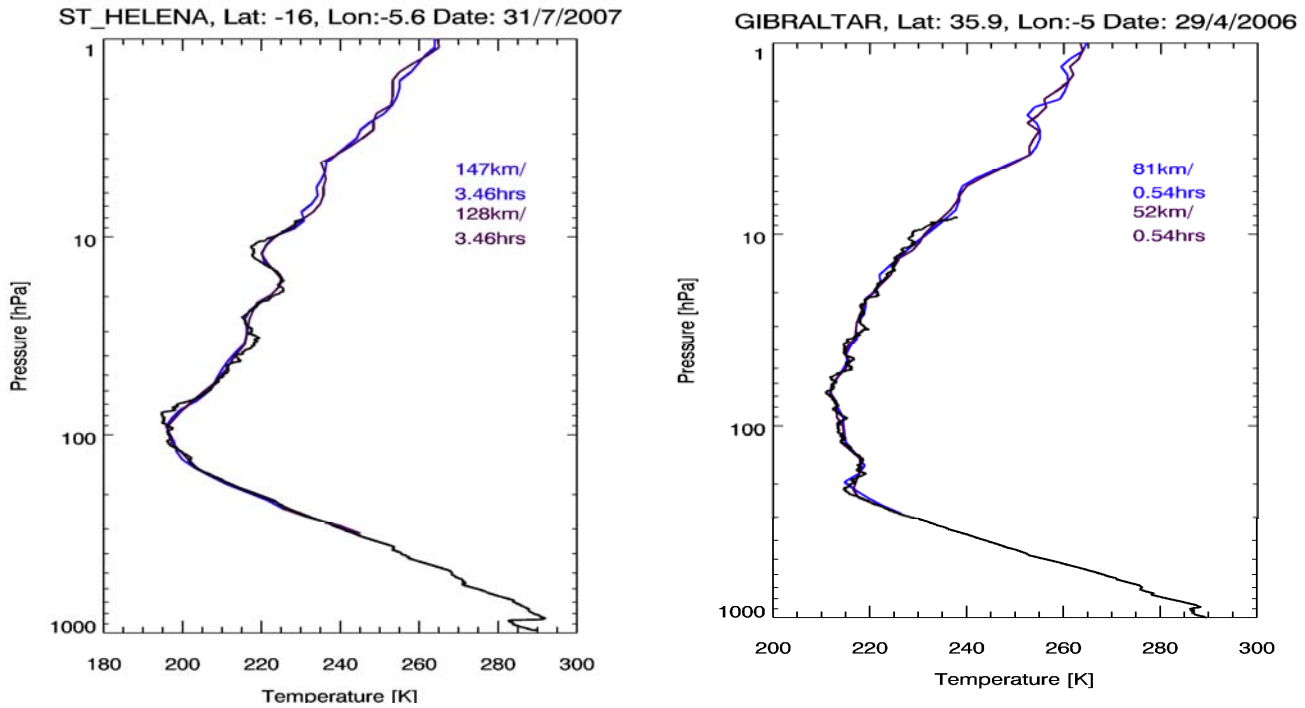

Figure 5.1.4. Temperature comparisons between radiosonde profiles at St. Helena (left) and Gibralter. Black lines are high-resolution radiosondes, blue and magenta are two nearby HIRDLS retrievals. Differences in distances and times are given.

Statistics of such comparisons at Gibralter, a representative site, are shown in Figure 5.1.5. The green line indicates that HIRDLS is within 0.5K of the sondes from ~ 300hPa to above 10 hPa, with larger differences below 300 hPa. The blue dotted lines are the standard deviation (s.d.) of the differences of HIRDLS minus sondes, while the red dotted lines are ± the precision value calculated in the retrieval code. 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 possible effects of gradients along the HIRDLS line of sight which are not completely corrected. Differences in vertical resolution may also enter, although HIRDLS is sensitive to temperature variations with wavelengths as small as 2 km as pointed out above and in Gille et al., 2008.

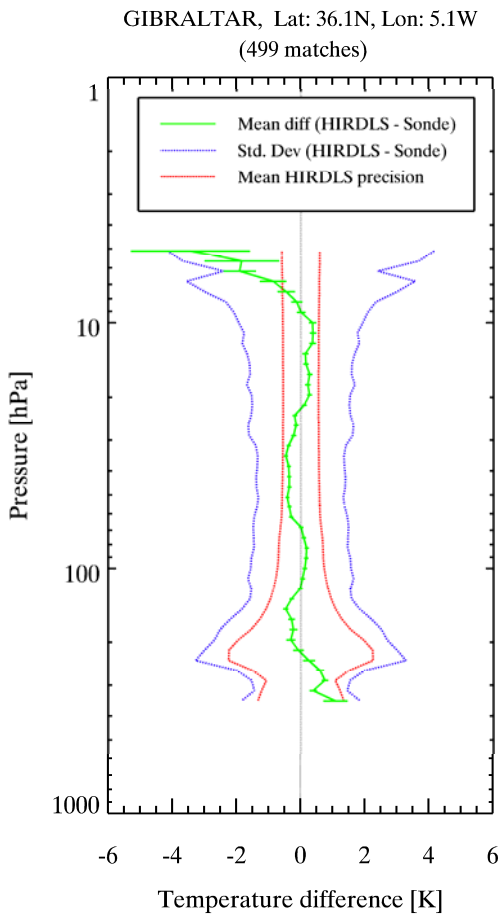

Figure 5.1.5. Statistics of HIRDLS minus sonde differences for Gibralter. Green line shows mean differences, blue dots show ± 1 standard deviation of the differences, while red dots show ± 1 standard deviation predicted by retrieval algorithm.

A comparison between HIRDLS and ECMWF assimilated data over the HIRDLS latitude range for November 2007 is shown in Figure 5.1.6. (Note that the ECMWF assimilation model has changed over the time of the HIRDLS mission; this incorporates the last version that overlaps HIRDLS data.) This comparison extends the validation comparisons above radiosonde altitudes, and shows differences as a function of latitude. From this we see that HIRDLS V5 temperatures are within 1K of ECMWF temperatures from 400 to 1 hP, becoming lower above that level, with little latitudinal structure. These are regarded as good results. The retrieval extends up to 0.1 hPa, with increasing uncertainty above 0.3 hPa.

Comparison with lidar temperature profiles from Mauna Loa and Table Mountain also indicate that the temperature is ~ 2K low from 4 – 1 hPa, becoming as much as 6K low by 0.3 hPa. Although there may be biases in the values, variations at the upper altitudes seem to reflect atmospheric variations.

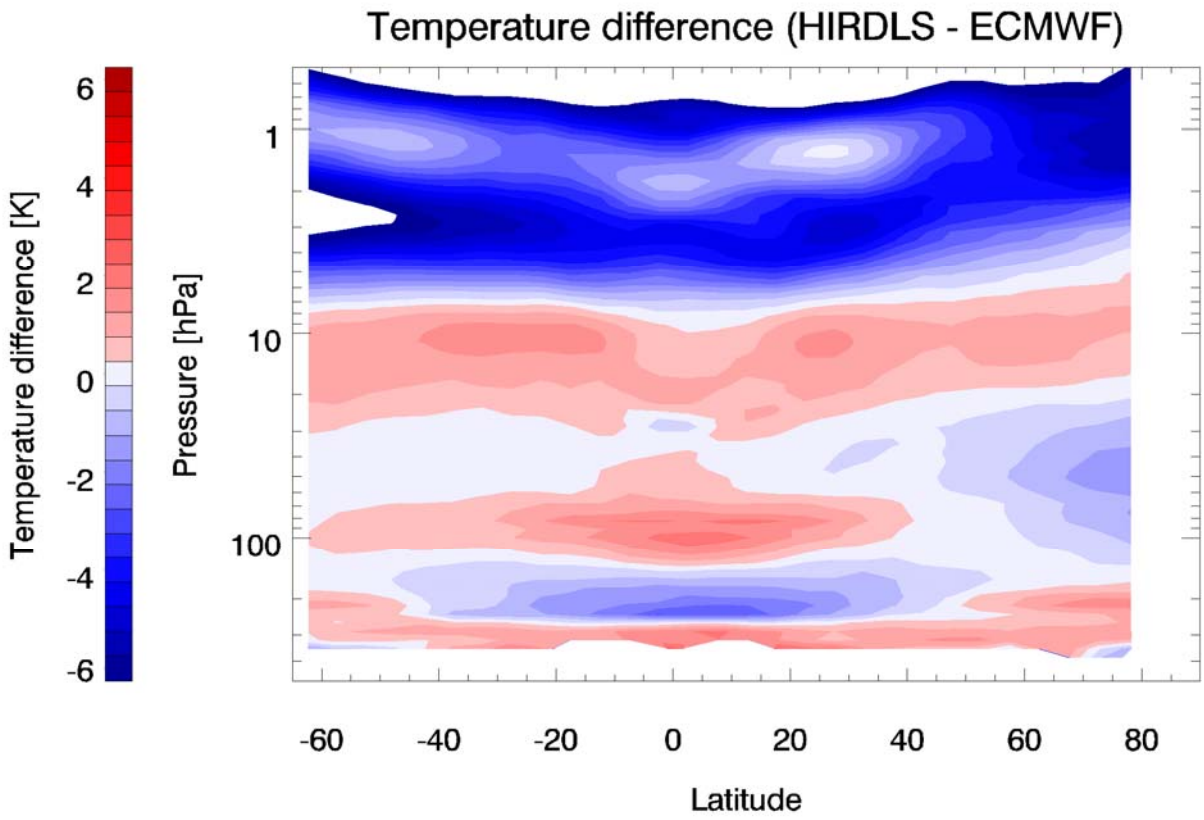

Figure 5.1.6 Results of comparison of HIRDLS temperatures with analyzed ECMWF temperatures interpolated to HIRDLS measurement locations over the full latitude range of HIRDLS observations.

Conclusion

The HIRDLS temperatures have 1 km vertical resolution, a precision of ≤ 0.5K and are accurate to ≤ 1K from the 3-400 hPa to 7 hPa, becoming cooler above that level. In the upper stratosphere and lower mesosphere HIRDLS temperatures are cooler than lidar temperatures and ECMWF .

5.2 Ozone (O3)

Name of Product: O3 (ozone)
Useful Range: 260 hPa - 0.5hPa
Vertical Resolution ~1 km
Contact: Bruno Nardi
Email: nardi@ucar.edu
Validation Paper: Nardi, B., et al. (2008), Initial validation of ozone measurements from the High Resolution Dynamics Limb Sounder, *J. Geophys. Res.*, 113, D16S36, doi:10.1029/2007JD008837.

Vertical Resolution

The vertical resolution is given most directly by the averaging kernels shown in figure 5.2.1. The resolution is 1km down to 12 km or ~200hPa. The resolution increases to about 2 km by 10 km (~260 hPa) and below.

It should be noted that although the useful range is specified only to 260 hPa, some comparisons with ozonesondes show good agreement at greater pressures (up to 400 hPa), especially at high latitudes. However this is not consistently the case, which may be due to strong a priori influence in many cases, and the accuracy is not easily verified statistically there. For these reasons data a p>260 hPa are not officially include in the useful range.

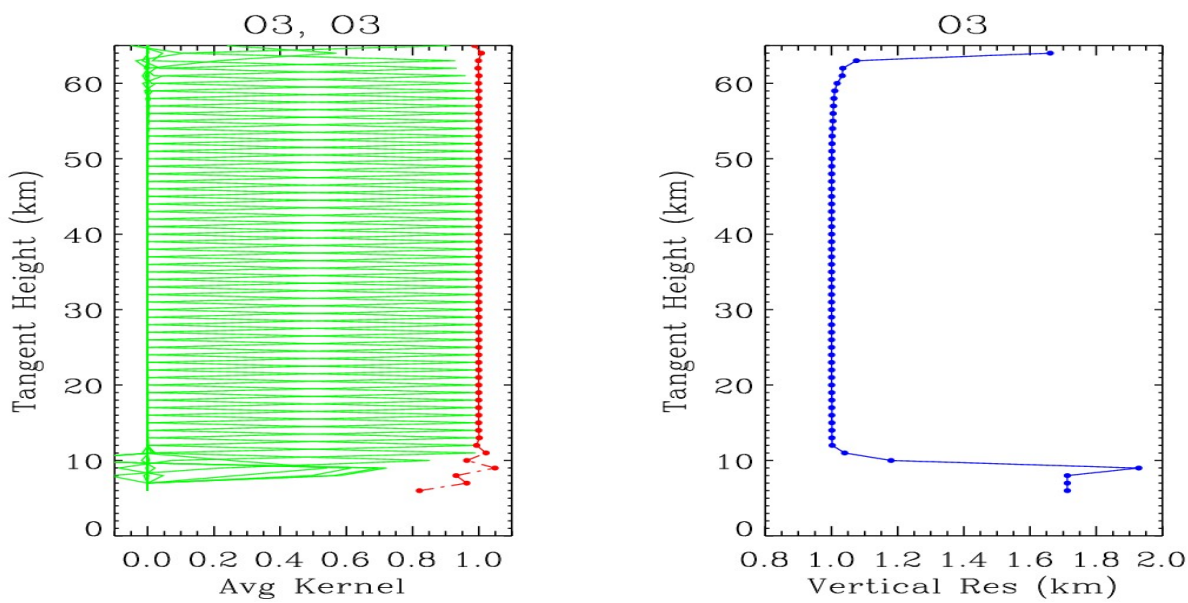

Figure 5.2.1. Averaging kernels for HIRDLS ozone.

Comparisons with ozonesondes during the NH mid- and high latitude spring, where ozone layers (~1 km) in the upper troposphere lower stratosphere (UTLS) region are widespread, show clearly that HIRDLS is capable of resolving these fine vertical ozone

features. See figure 5.2.2. This can be confirmed statistically by calculating the HIRDLS-sonde ozone difference for all cases on the one hand and for only those cases with strong layers on the other. If the presence of thin ozone layers with high vertical gradients poses a higher difficulty to resolve then one would expect either the mean difference, or the standard deviation of the differences to have larger values for the layer-only case in regions where those layers are present. This is not the case, as seen in figure 5.2.3, and it can therefore be inferred that the ozone layers are resolved with similar accuracy as the slowly varying ozone profiles.

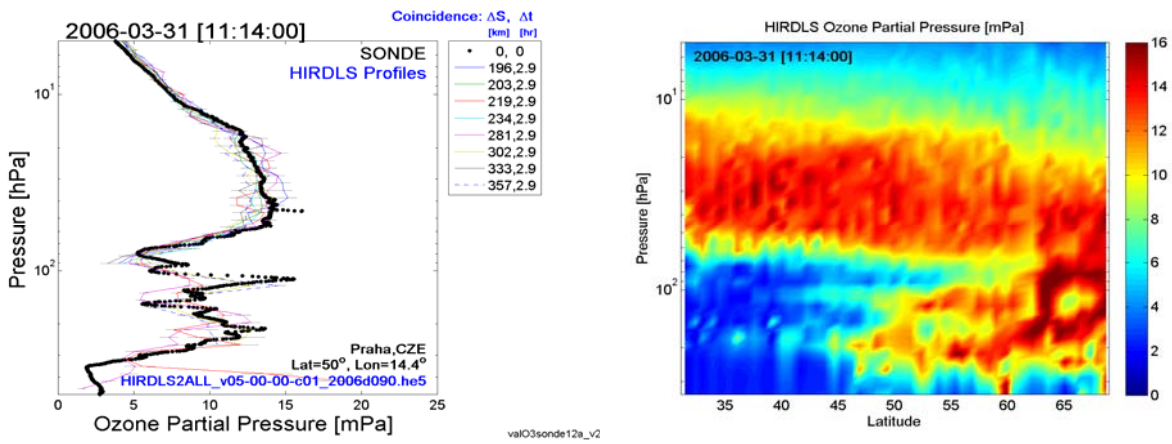

Figure 5.2.2. Shown is a double layered ozone filament in the NH spring UTLS, extending down to 300 hPa (left). The comparison between an ozonesonde and the closest eight coincident HIRDLS profiles (200-350 km, 3 hours), indicates that the vertical features are measured by HIRDLS.

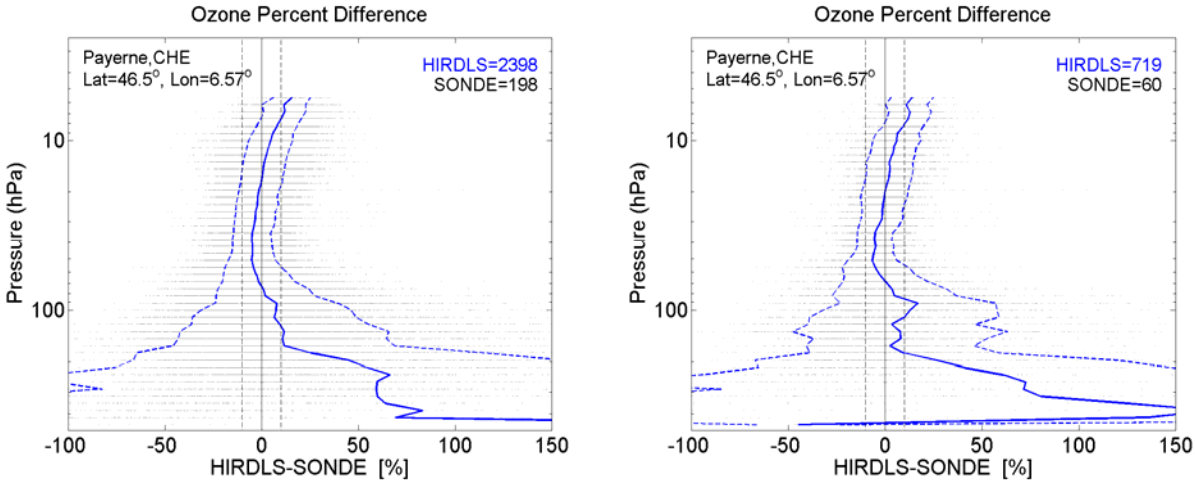

Figure 5.2.3. On the left hand side is plot of the mean percent difference between sonde and HIRDLS ozone profiles for all coincident profiles from years 2005, 2006 and 2007 combined, for the WOUDC site, Payerne (46.5N). On the right hand side is a similar mean percent difference for the same site, but which includes only the coincident profiles in which strong lamina were present. The fact that neither the mean difference nor the standard deviation of differences is higher for the laminae-only case (right) is a strong indication that HIRDLS is measuring the thin laminae with close to the same accuracy as the profiles with little vertical structure.

Precision

The determination of the measured precision is described in Section 5.0. Ozone precision is 100-300 ppbv, approximately 1-4%, between 1-100 hPa, with the largest values occurring at 5-20 hPa. Between 100-260 hPa precision is typically 50-100 ppbv or less, which is 5-15% at high latitudes, about 25% at mid-latitudes, and 100% or greater in the tropics where ozone concentrations are relatively small in the upper troposphere. Between 0.5-1 hPa ozone precision is also 100-300 ppbv, or approximately 4-10%.

Figure 5.2.4 shows precision estimates (standard deviation, blue lines) for latitude bands centered at 0 deg, 48 deg N and 78 deg N respectively. The ozone precision values contained in the HIRDLS L2 data files (O3Precision, black dashed lines) are plotted for comparison.

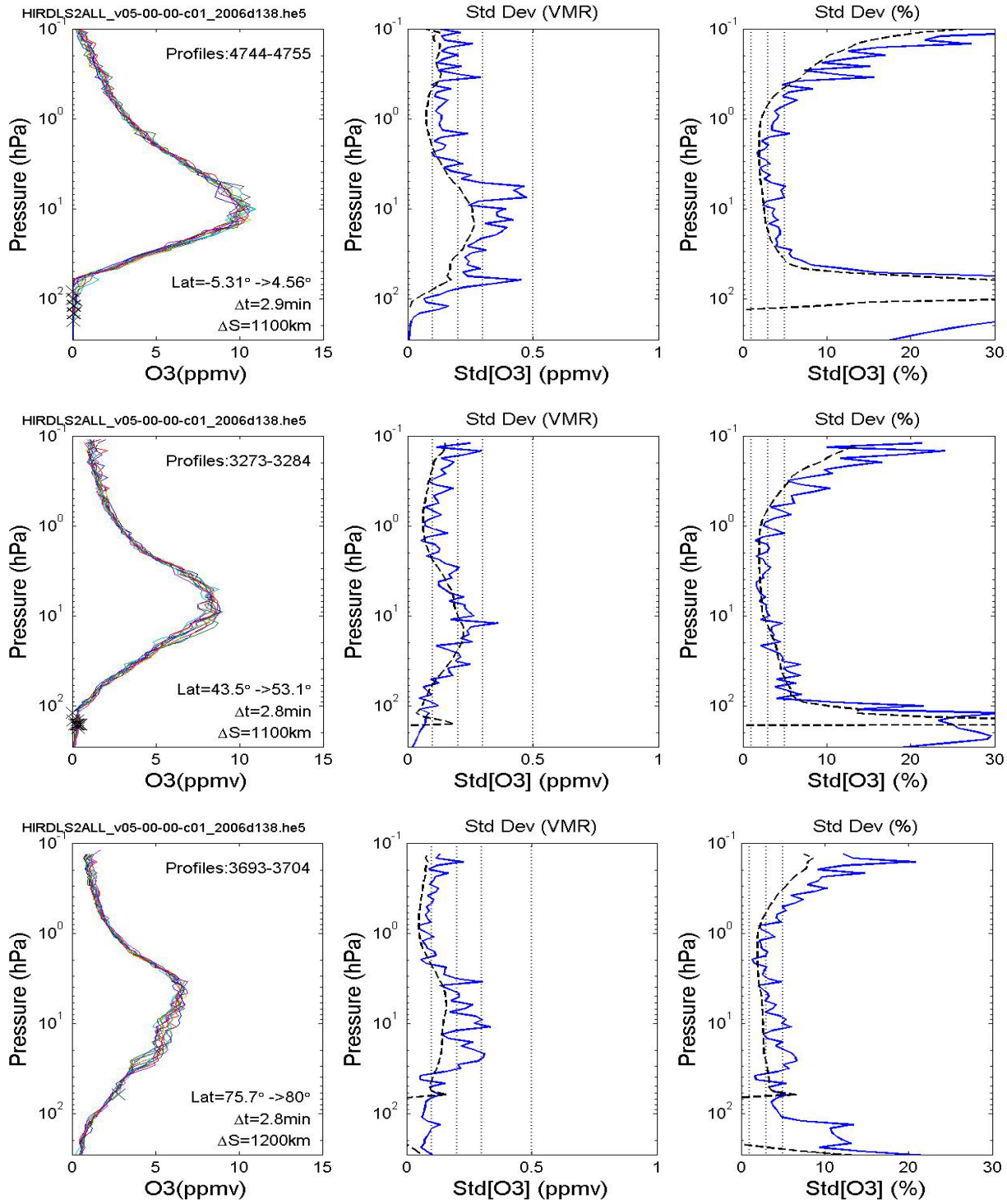

Figure 5.2.4. Precision high estimate as the standard deviation (blue lines)of 12 consecutive ozone profiles (left), and compared to the HIRDLS L2 precision parameter (black dashed lines). The three cases are for latitudes: 0 deg (top), 48 deg N (middle) and 78 deg N (bottom). Southern hemisphere values are similar.

Accuracy

High Latitudes: Comparisons with coincident ozonesonde measurements near 50 degrees N latitude and poleward indicate that HIRDLS V5 ozone between 10-50 hPa has a generally low bias of about 100-400 ppbv, approximately 1-10%. Between 50-260 hPa the bias typically increases with increasing pressure, from 200 ppbv low to 100 ppbv high, which corresponds to a bias of 10% or better at 100 hPa and above, and high bias of up to approximately 100% at 260 hPa. Known ozonesonde measurement inaccuracies of up to 10% and greater above 10 hPa precludes their use for determining HIRLDS accuracy in this region. See figure 5.2.5, top row.

These biases are in agreement with results of comparisons with satellite measurements of high latitude ozone made with ACE-FTS. ACE-FTS measurements also indicate a HIRDLS low bias of 5-20% between 10-0.5 hPa, the large value being at the top of the profile. Biases are similar in both hemispheres.

Mid Latitudes: At midlatitudes between 10-50 hPa there is typically a bias of +/-200 ppbv or less, 5% or better. Between 50-260 hPa the bias is slightly high with a magnitude <100ppbv, resulting in approximately a 50% high bias between 100-260 hPa. See figure 5.2.5, middle row.

Low Latitudes: Ozonesonde comparisons in the tropics indicate a high bias of 200-400 ppbv (5-10%) for p<30 hPa. Between 30-100 hPa there is a high bias of 100-400 ppbv (decreasing with increasing pressure) results in a 10-~150% high bias (increasing with increasing pressure). At 100-260 hPa the bias is <100ppbv, often 10s of ppbv, but due to the low ozone concentrations here it can result in 10-100+% bias. See figure 5.2.5, bottom row. It is not expected that ozone spikes linked to the presence of undetected clouds, a problem cited in earlier HIRDLS releases, contribute significantly to this high bias, but isolated instances of such spikes may be possible at both low and high latitudes.

Comparisons with the ground-based lidar at Table Mountain Facility (39°N) indicates agreement of 3% or better (<300 ppbv) between 2-70 hPa (figure 5.2.5, top row). The lower latitude Mauna Loa Observatory (20°N) comparisons yield a slightly higher HIRDLS bias as expected. See figure 5.2.6.

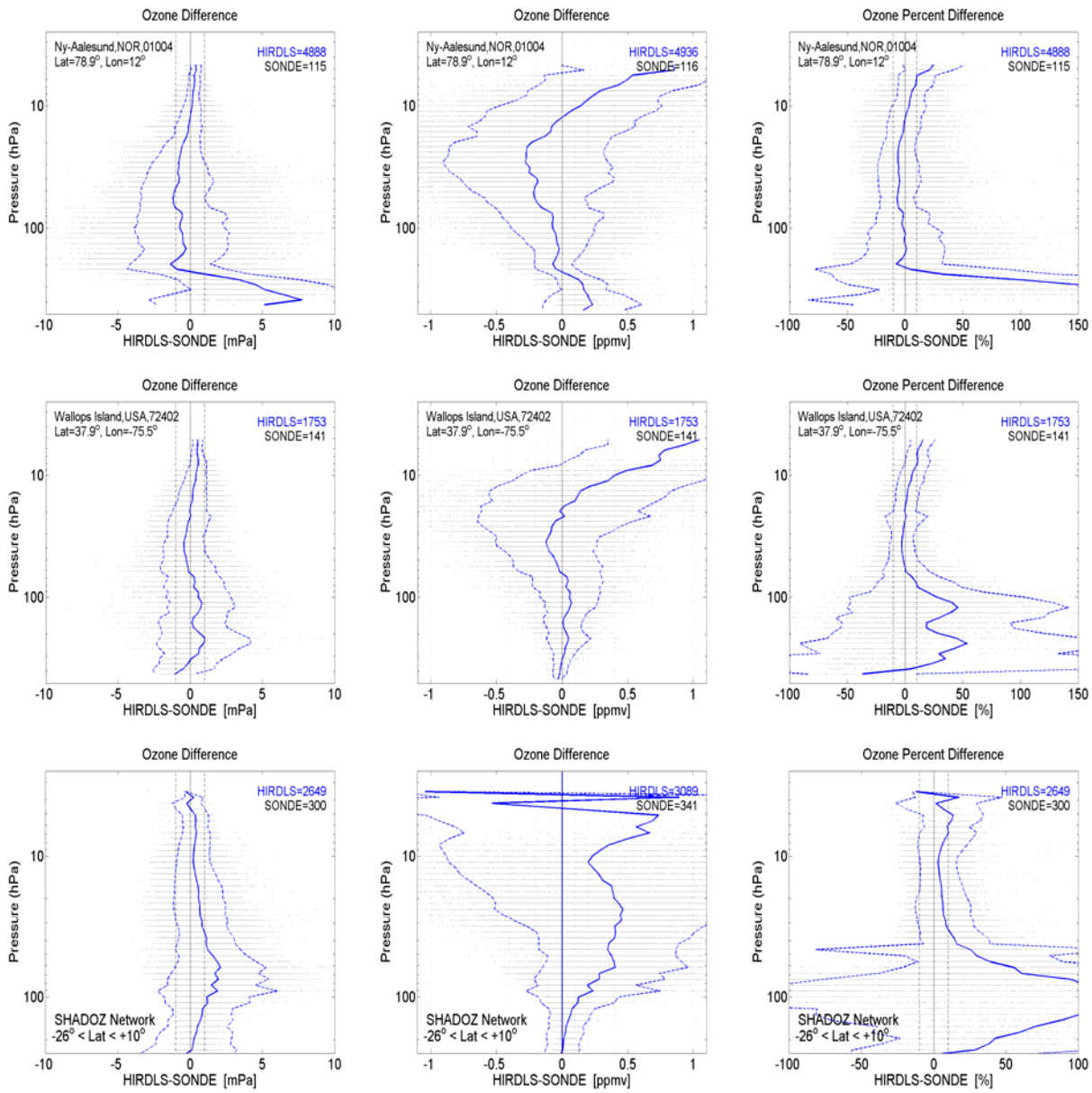

Figure 5.2.5. The mean ozone difference (solid blue lines) from comparisons with ozonesondes are shown for the high latitude station at Ny-Alesund (top row), for the mid-latitude station at Wallops Island (middle row) and for the low latitude SHADOZ Network (-26 º < Lat < 10º). From left to right the plots are in ozone units of partial pressure (mPa), volume mixing ratio (ppmv) and percentage difference. The dashed blue lines are the standard deviation of differences.

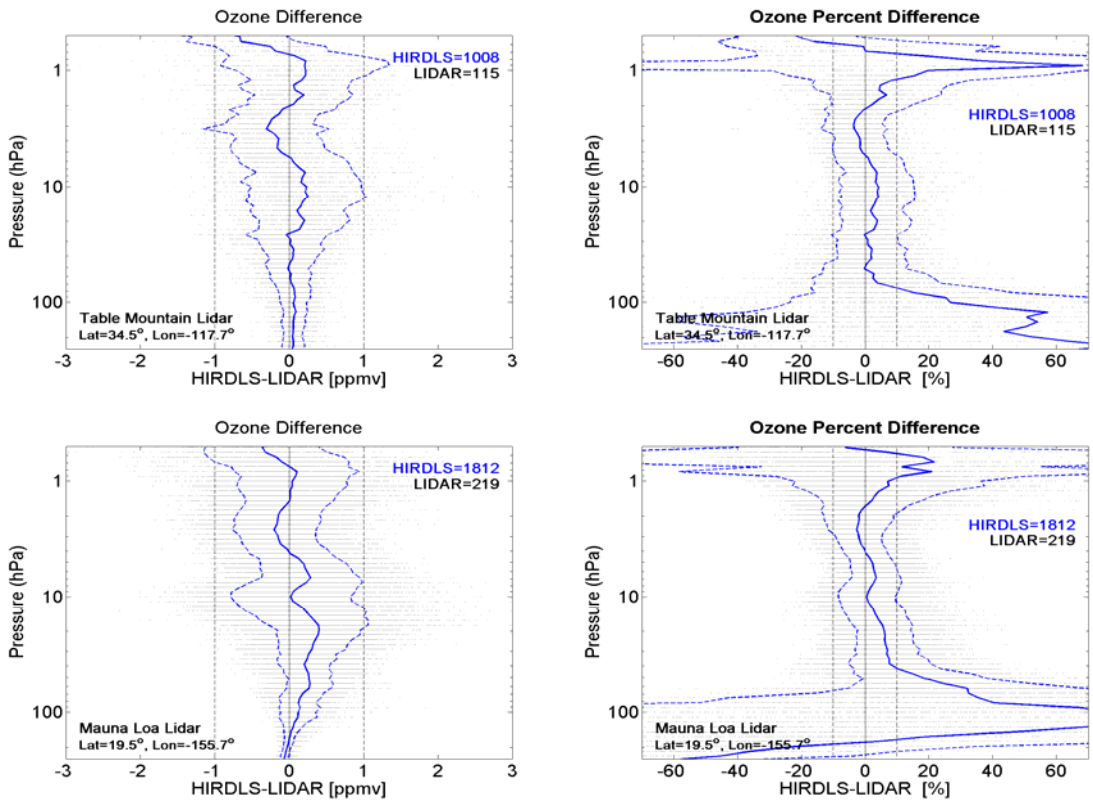

Figure 5.2.6. The mean ozone difference (solid blue lines) from comparisons with lidars are shown for the mid-latitude station at Table Mountain Facility (39°N, top row) and for the low latitude Mauna Loa Observatory (20°N, bottom row). Left plots are in ozone units of volume mixing ratio (ppmv); right side plots and percentage difference. The dashed blue lines are the standard deviation of differences.

Data Screening and Artifacts

The "CloudTopPressure" parameter indicates the pressure at which the cloud detection algorithm has identified a cloud for each profile. Where no cloud is detected the value is zero. At pressure levels earthward of a non-zero CloudTopPressure there is a strong a priori influence in the retrieved ozone. This is indicated by negative values of calculated total retrieval error ("O3Precision"), which specifically signifies that the retrieval error covariance is greater than half of the a priori error covariance, so most of the ozone information comes from the a priori.

Where it is not desired to use data that has a strong influence from the a priori source (GMAO), ozone values with corresponding O3Precision values that are negative should be screened out. A similar, but slightly more conservative approach can be taken by screening ozone data points at and earthward of the pressure level nearest and ABOVE the CloudTopPressure. The reason that the CloudTopPressure may not correspond to an exact point on the L2 pressure grid is that it is determined earlier in the data processing stream, where a finer pressure grid is still in place.

In certain isolated cases, ozone spikes with unrealistically high ozone values may still exist. The source of these spikes is as yet not fully understood, but they may be related to undetected thin clouds, such as PSCs. This is being investigated. In such cases one may apply a "gradient filter" by removing points at, and earthward of, the level where the ozone vertical-gradient threshold of >1.9 ppmv/p-level is reached. Great care should be used in employing such a filter, especially in the NH winter and spring mid- and high latitudes, where ozone laminae with high vertical gradient are known to be very prevalent, especially earthward of 50 hPa. Use of this filter may remove these real features and should not be used in this region and period.

5.3 Nitric Acid (HNO3)

Species:	Nitric Acid (HNO_3)
Data Field Name:	HNO_3
Useful Range:	161 hPa – 10 hPa
Vertical Resolution:	~ 1 km
Contact:	Douglas E. Kinnison
Email:	dkin@ucar.edu
Validation Paper	Kinnison, D. E.**, et** al., (> 20 co-authors), Global observations of HNO_3 from the High Resolution Dynamics Limb Sounder (HIRDLS), *J. Geophys. Res.*, 113, D16S44, doi:10.1029/2007JD008814, 2008.

General Comments:

HIRDLS HNO_3 data are generally good over the full 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. The upper limit is determined by the falling signal to noise (S/N) with altitude, while the lower limit is determined by very low mixing ratios in the troposphere.

Vertical Resolution:
The HIRDLS HNO_3 vertical resolution is approximately 1 km, but does vary with altitude and latitude, as shown in Figure 5.3.1. Because of the low HNO_3 mixing ratios in the upper tropical atmosphere, the resolution degrades above 35 km altitude, although, because the red line remains near 1, the information is still coming from the measurements, with only minimum contributions from the a priori estimates.

Precision
Again, the predicted precision is derived by the HIRDLS level-2 retrieval algorithm. The measured precision is obtained by examining HIRDLS variations between adjacent scans in regions in which there is small natural variability. The components of the estimated precision (forward model, measurement, and a priori errors) are shown for low, middle and high latitudes 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) for the reasons mentioned above under general comments. The HIRDLS HNO_3 at pressures <10 hPa (altitudes >32 km) is characterized by large uncertainties and should be used with caution. The individual profile "measured" precision is between 0.1-0.5 ppbv (Figure 5.3.3), slightly less than the theoretical value. Because the HNO_3 mixing ratio can vary significantly with latitude and altitude, the percentage error in HNO_3 will also vary, with lowest values (in high latitudes) only a few percent, but can be much larger if the HNO_3 abundance is low.

Accuracy:

The accuracy is again estimated through comparison with other global data sets. Global results, when compared with the HNO_3 observations from version 2.2 of the EOS Aura Microwave Limb Sounder (MLS), show 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 ± 10% relative to Aura MLS in the mid-to-high latitudes and biased 50% high in the tropical stratosphere. 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. In Figure 5.3.6, HIRDLS HNO_3 is also compared with the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS). Here, all coincidences used data between 60°-80°N and 40°-63°S. Coincidence criteria were taken within 2-hours in time and 500 km distance. There were a total of 2138 coincidences between 5 February 2005 and 19 August 2007. Note: only HIRDLS profiles with relative precision between 0 and 0.3 were included. In these, high latitude comparisons, the HIRDLS HNO_3 data are biased 0 ± 10%, depending on altitude. This is an improvement over HIRDLS V4.

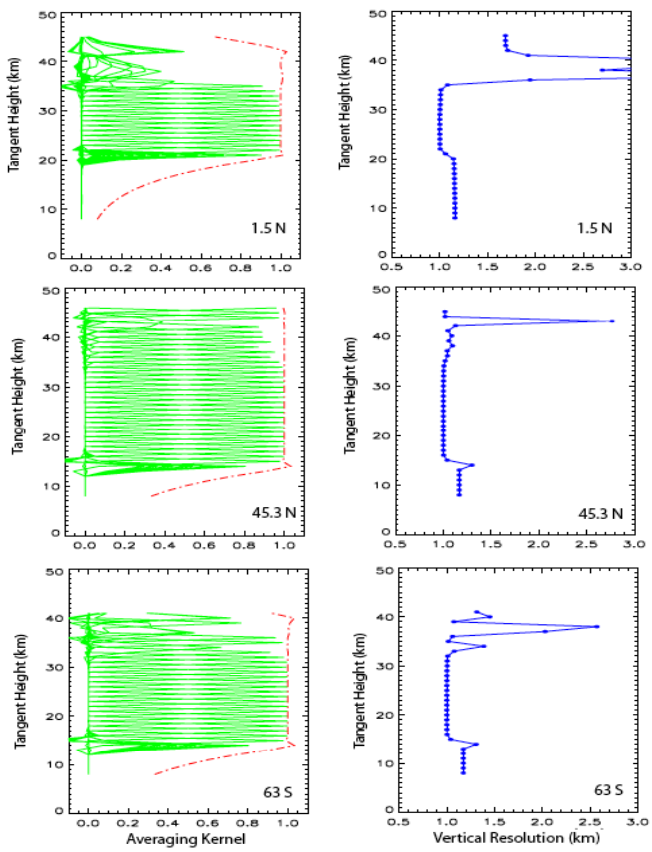

Figure 5.3.1: HIRDLS HNO_3 averaging kernels and full width half maximum (FWHM) vertical resolution profiles are shown on 21 June 2006 at 1.5°N, 45.3°N, and 63°S. The left column shows the averaging kernels (green lines) and the integrated area under each kernel (red line). Where values of unity indicate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

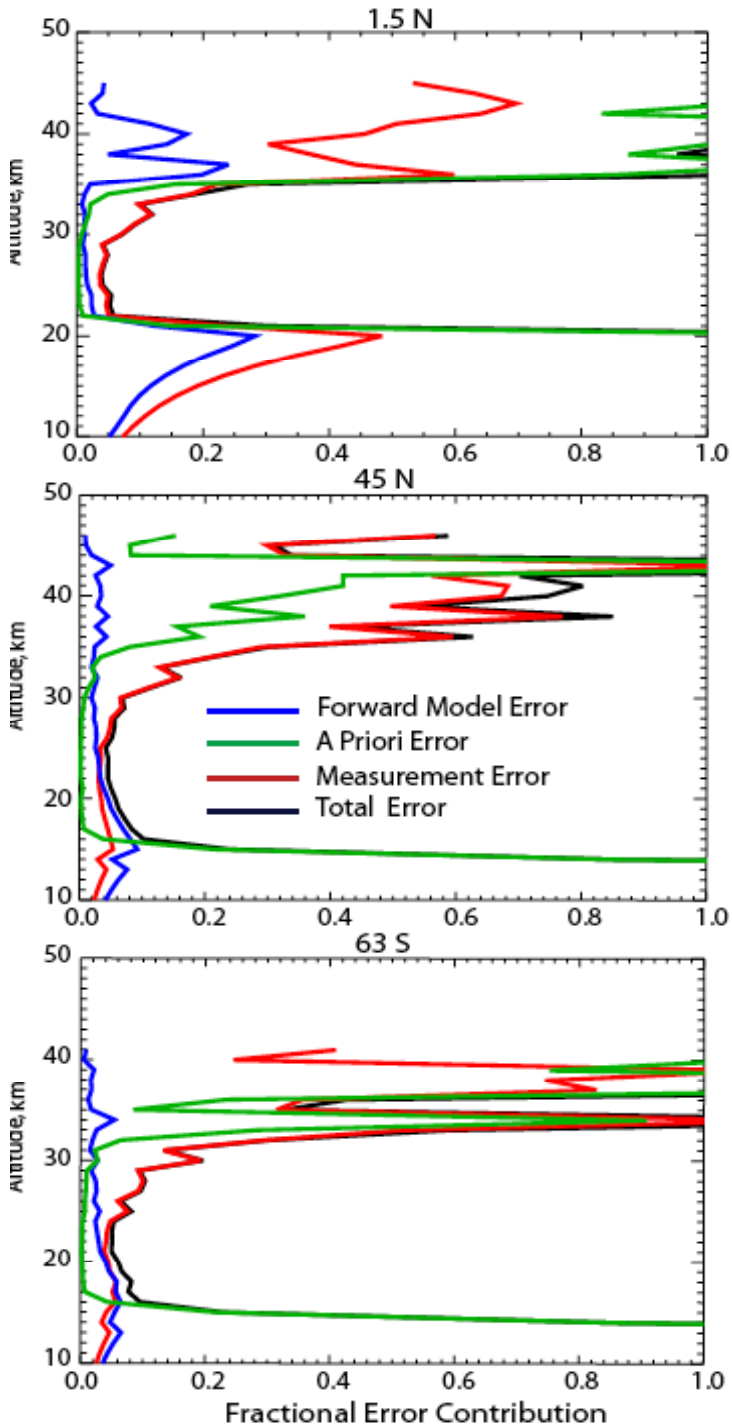

Figure 5.3.2: Shown is the HIRDLS HNO_3 "theoretical precision" displayed as the fractional error contribution (i.e. 0.2 = 20% error) for 21 June 2006. The top, middle, and lower panels are for latitudes 1.5°N, 45.3°N and 63°S respectively (same regions as Figure 5.3.1). The forward model error (blue line), the a priori error (green line), and the measurement error (red line), along with the total retrieval error (black line) are shown.

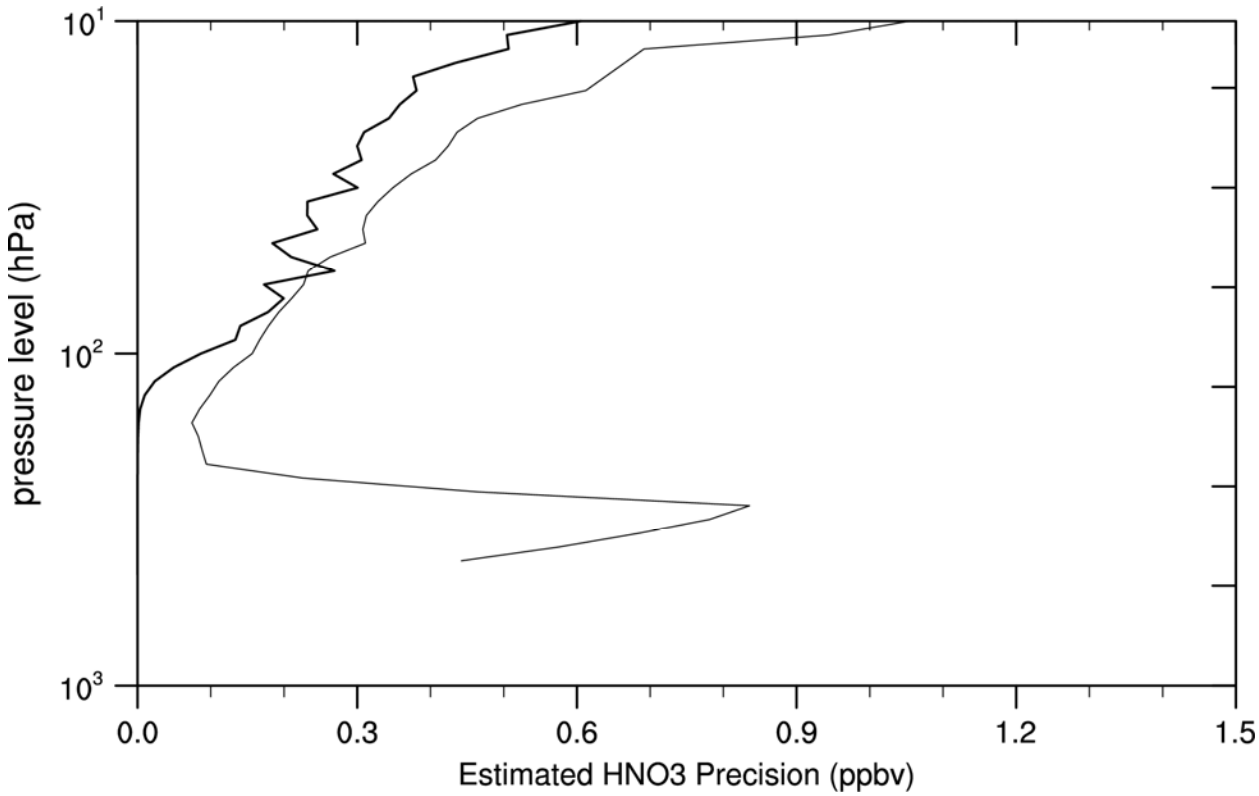

Figure 5.3.3: "Measured" HNO_3 precision, estimated from sets of 12 consecutive profiles in undisturbed regions (thick line), compared to the theoretical precision (thin line). The method is described in Section 5.0. The agreement generally supports the values produced by the retrieval software.

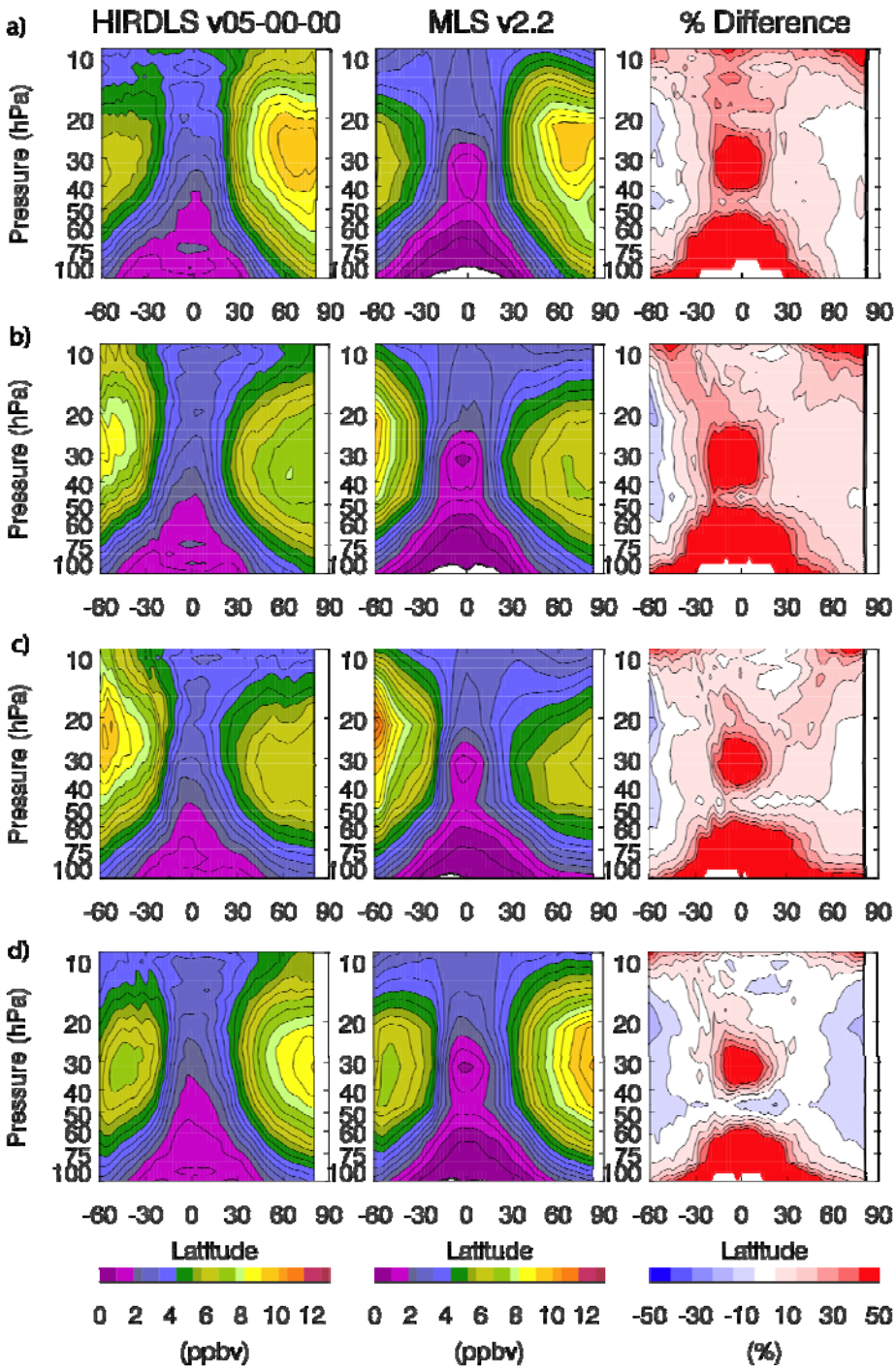

Figure 5.3.4. Latitude-height cross sections are shown for HIRDLS and MLS HNO_3 (ppbv). The two left columns are absolute abundances of HNO_3. The right column is percentage difference of (HIRDLS – MLS / MLS). The zero percentage difference contour line is the transition from white to blue. The rows depict the zonal mean average for the given month for the entire HIRDLS mission. Row a) contains 101 days for the month of January. Row b) is 83 days for the month of April. Row c) contains 90 days for the month of July. Row d) contains 91 days for the month of October.

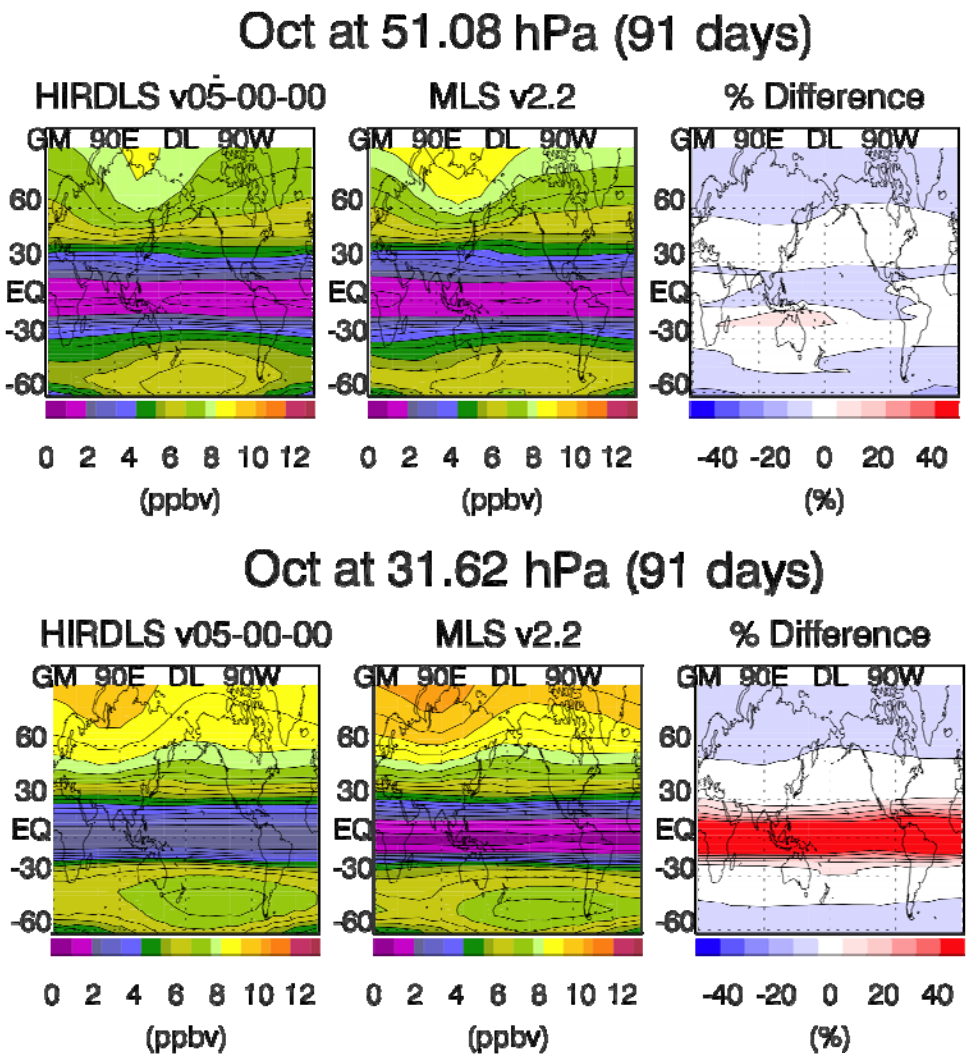

Figure 5.3.5. Longitude-latitude cross sections of HIRDLS and MLS HNO_3 (ppbv) for October. The rows depict the average for the given month for the entire HIRDLS mission. The top and bottom rows are for 51.1 hPa and 31.6 hPa respectively. The percentage difference of (HIRDLS – MLS / MLS) is also shown.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

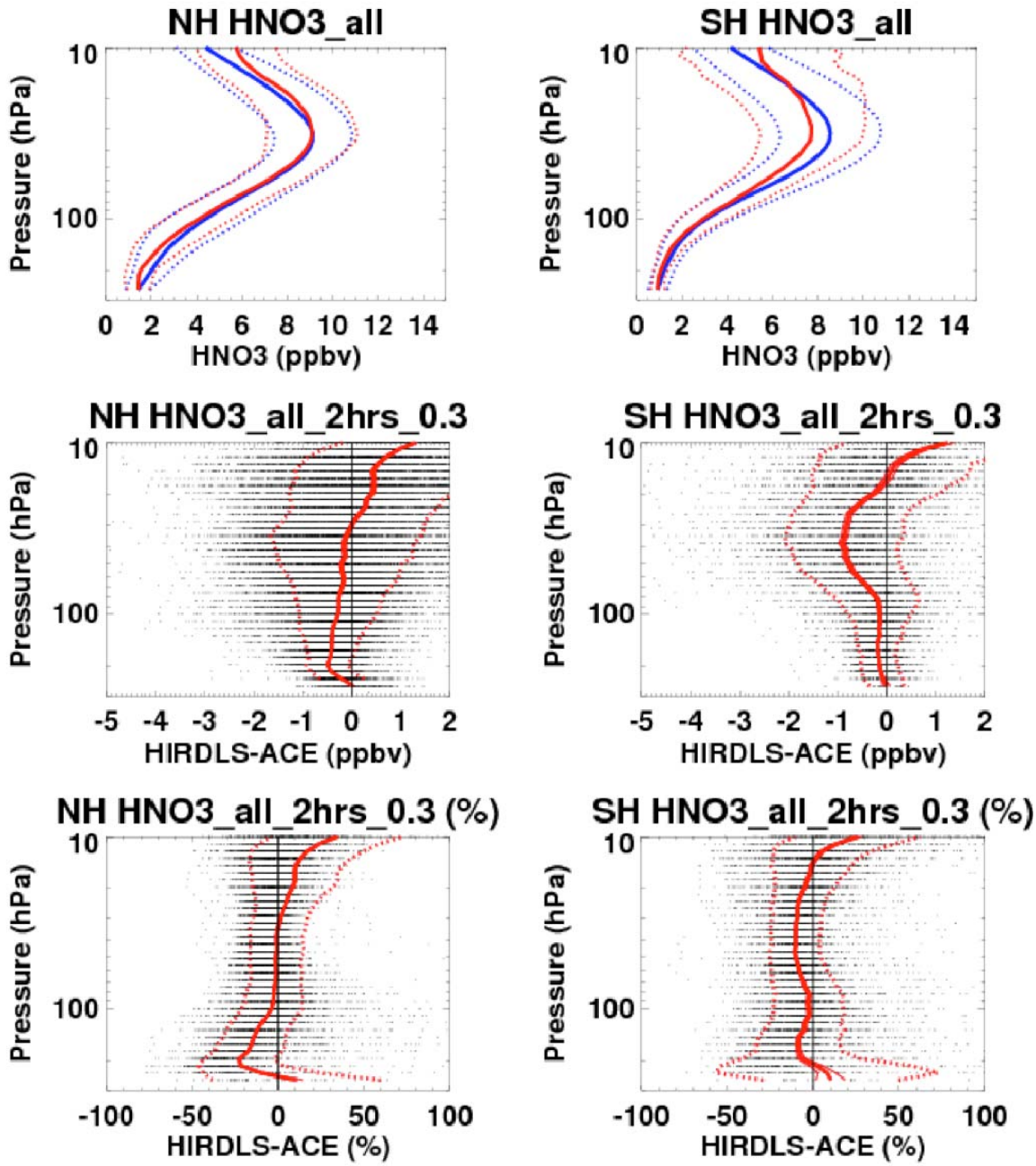

Figure 5.3.6. Profile differences of HIRDLS and ACE-FTS measurements. Comparisons shown here were between 13 February 2005 and 19 August 2007. Coincident HIRDLS profiles were averaged together and then subtracted from a single ACE-FTS profile. The top row shows the absolute profiles (ppbv) for HIRDLS and ACE-FTS. The solid blue and red lines are the average profiles for ACE-FTS and HIRDLS respectively. The dotted blue and red lines are the uncertainty (±1-σ) in the mean for ACE-FTS and HIRDLS respectively. The middle row shows the absolute difference of (HIRDLS – ACE-FTS). The bottom row shows percentage differences (HIRDLS-ACE-FTS/ACE-FTS). The mean (solid red) and standard deviation (dashed red) of the differences for all coincidences are shown. The individual differences from which the mean and standard deviation 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).

5.4 CFC11, CFC 12

Species:	CFC11 ($CFCl_3$) CFC12 (CF_2Cl_2)
Data Field Name:	CFC11 CFC12
Useful Range:	CFC11 287.3 hPa - 26.1 hPa CFC12 287.3 hpa - 10.0 hPa
Screening Criteria:	Use with caution: Data with negative precisions Data with cloud flag ≠ 0 - data should not be used CFC 11 data above surface value (approx. 250pptv) CFC 12 data above surface value (approx. 540pptv)
Vertical Resolution:	~1 km
Contact:	Michael Coffey
Email:	coffey@ucar.edu

General Comments:

This section will describe HIRDLS observations of CFC11 ($CFCl_3$) and CFC12 (CF_2Cl_2). These human-made gases have common sources, distributions and chemistry in the atmosphere and will be discussed together here. HIRDLS CFC measurements are generally useful between latitudes of 65 S to 82 N and within pressure ranges of 26.1 – 287.3 hPa (about 10 to 25 km) for CFC11 and 10.0 – 287.3 hPa (about 10 to 31 km) for CFC12. Observations should only be used for dates after 28 April 2005 when an appropriate scan pattern was in use by HIRDLS (see section 3.0).

Resolution:

Vertical resolution of the CFC observations is described by the vertical averaging kernel and is shown in Figure 5.4.1. There is some variation in the vertical resolution with latitude but that variation is small within the useful pressure range. As may be seen in Figure 5.4.1 the vertical resolution for both CFC11 and CFC12, over the useful pressure range, is 1.0-1.2 km. The horizontal resolution of the observations is approximately 100 km along an orbit track with an orbital separation of about 24 degrees of longitude (about 2000 km at 40N), (see section 2.2.2).

Precision:

Average precision of the zonal mean for CFC11 and CFC12 is shown in Figure 5.4.2 for the useful pressure region. The precision estimated from 12 sequential profiles in undisturbed regions (See Sec. 5.0), shown by the thick line, indicates precisions of 0.01-0.02 ppbv for both CFC11 and CFC12, in agreement with the values calculated by the retrieval program. The agreement of these values supports the calculated estimates over

the useful range, and indicates that the uncertainty is generally only a few percent over much of the useful range.

Accuracy:

Comparisons are made with other global observations of CFC11 and CFC12. It should be noted that data outside of the useful range has been eliminated from the publicly released data.

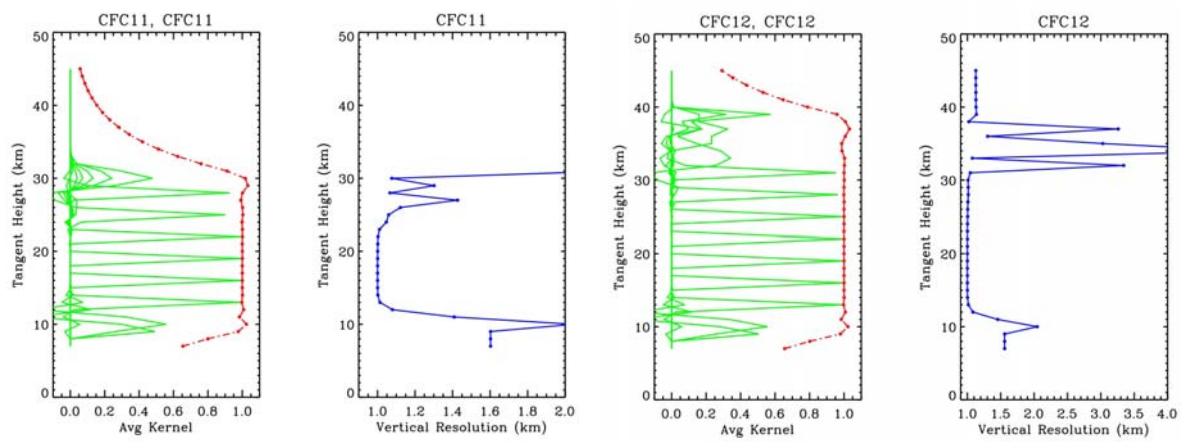

Figure 5.4.1: HIRDLS CFC11 and CFC12 averaging kernels and vertical resolution profiles (full width half maximum, FWHM) for 45.6 N on 15 January 2007. The left column shows averaging kernels (green lines) and the integrated area under each kernel (red line). Values of unity indicate that all of the signal for that vertical region comes from the measurement and not from a priori information. The right column shows the vertical resolution versus tangent height as derived from the FWHM of each kernel (blue line).

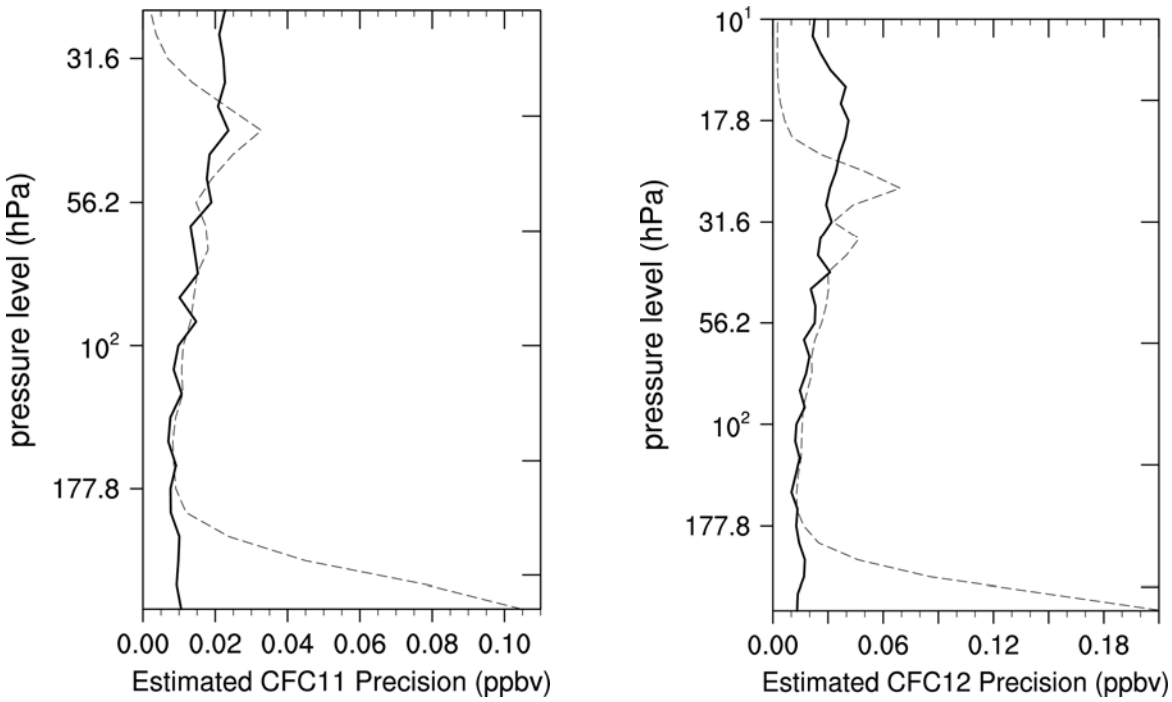

Figure 5.4.2. The "measured" precision (thick line), estimated from sequences of 12 consecutive profiles in undisturbed regions (see Section 5.00), compared with the precision estimated from the retrieval program, for CFC11 (a) and CFC12 (b).

Accuracy

Figure 5.4.3 shows an altitude versus latitude cross-section of CFC11 and CFC12 for 11 May 2006. All longitudes are averaged for the plots. The lifetimes of CFC11 and CFC12 in the atmosphere are relatively long (approximately 50 and 100 years respectively). Thus we may expect that the tropospheric amounts of the CFCs to be fairly uniform with the same magnitude as the surface value. Surface observations of CFCs have been made by NOAA [Elkins et al., 1994] for many years and show a slowly varying concentration with time. CFC11 surface values, from stations at latitudes from 71N to 90S, in 2006 ranged from 248 to 252 pptv; for CFC12, for the same stations and times, surface amounts were 530-540 pptv. As may be seen in Figure 5.4.3 the tropospheric amounts retrieved by HIRDLS are similar to those measured from the NOAA surface stations. There is a regularly observed excess of CFC11, of about 30%, in the upper tropical troposphere that cannot be explained at this time.

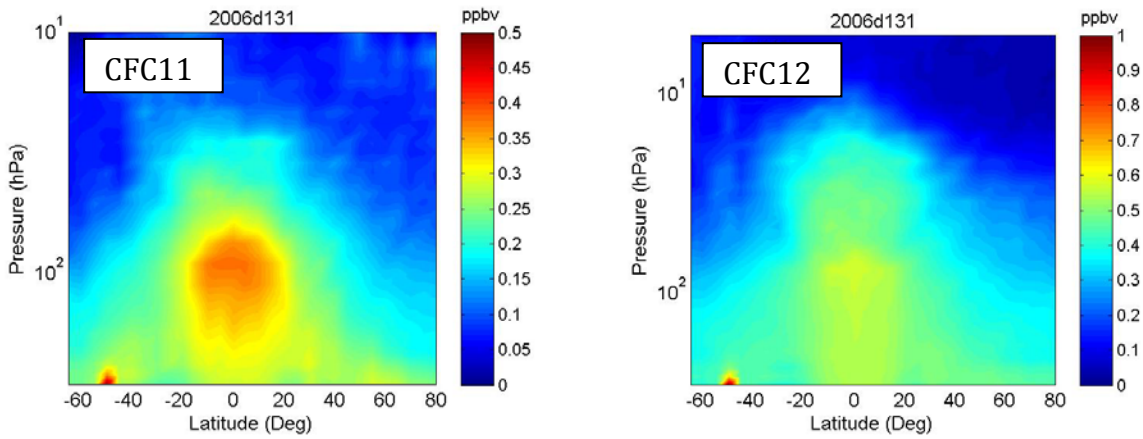

Figure 5.4.3: Latitude-pressure cross-section of CFC11 and CFC12 on 11 May 2006. Note the different color scales of the plots. The high region near 50S in the CFC11 and CFC12 plots is probably the effect of high cloud on the retrieval process.

Figure 5.4.4 shows the CFC11 and CFC12 vertical mixing ratio profiles from HIRDLS and results from a number of satellite and balloon-borne instruments. The satellite results are reported in Hoffmann et al, 2008, the latest results being from the space-borne MIPAS instrument on Envisat for 2002-2004. Care must be taken in comparing the older satellite observations with HIRDLS since both CFC11 and CFC12 show a clear temporal change. CFC11 surface mixing ratio increased steadily until about 1995 and has shown about a 1% per year decrease since then. The CFC12 amount, with a longer lifetime, leveled off around 1995

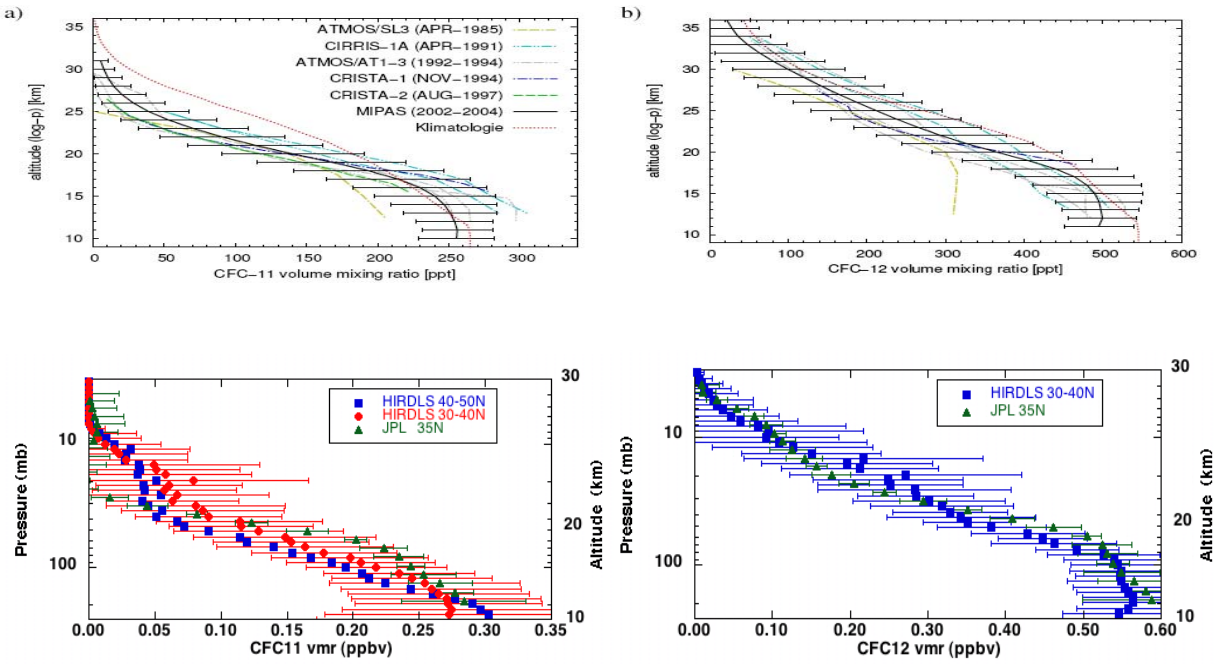

Figure 5.4.4: Vertical profiles of CFC11 and CFC12 from a number of satellite and balloon experiments (ATMOS, CIRRIS, CRISTA, MIPAS, JPL MkIV) and from HIRDLS. Observations are all from northern hemisphere mid-latitudes.

Two recent satellite-borne experiments report measurements of CFC11 and CFC12. The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) instrument aboard Envisat (launched in March, 2002) and the Atmospheric Chemistry Experiment (ACE) aboard SciSat (launched in August, 2003). Figure 5.4.6 shows altitude versus latitude plots of HIRDLS and MIPAS for one day in 2007. Reasonable agreement is seen in the CFC11 and CFC12 distributions. The high inclination (74 degree) orbit of ACE tends to concentrate coincident observations between HIRDLS and ACE in latitudes near 60 degrees (see Figure 5.3.7). Figure 5.4.7 shows all northern hemisphere HIRDLS and ACE CFC11 profiles within 2 hours and 500 km of each other and for which the measurement precision was between 0.0 and 0.3. Good agreement is found between HIRDLS and the more extensively validated ACE CFC11 observations [Mahieu et al., 2008]. No good coincidences were found between HIRDLS and ACE for CFC12.

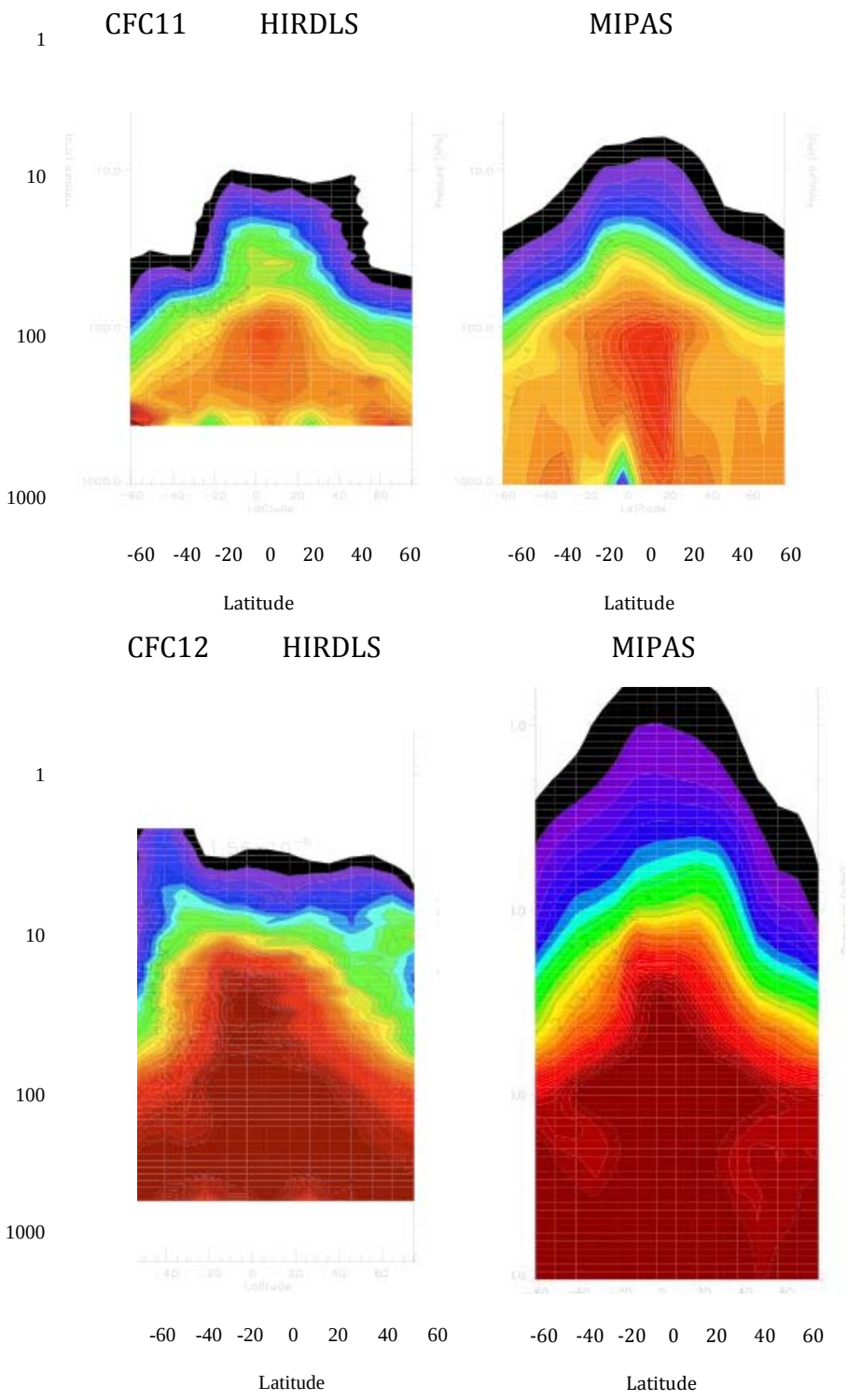

Figure 5.4.5: Altitude-latitude cross-sections of CFC11 and CFC12 as measured on the same day (2007d287) by HIRDLS and MIPAS.

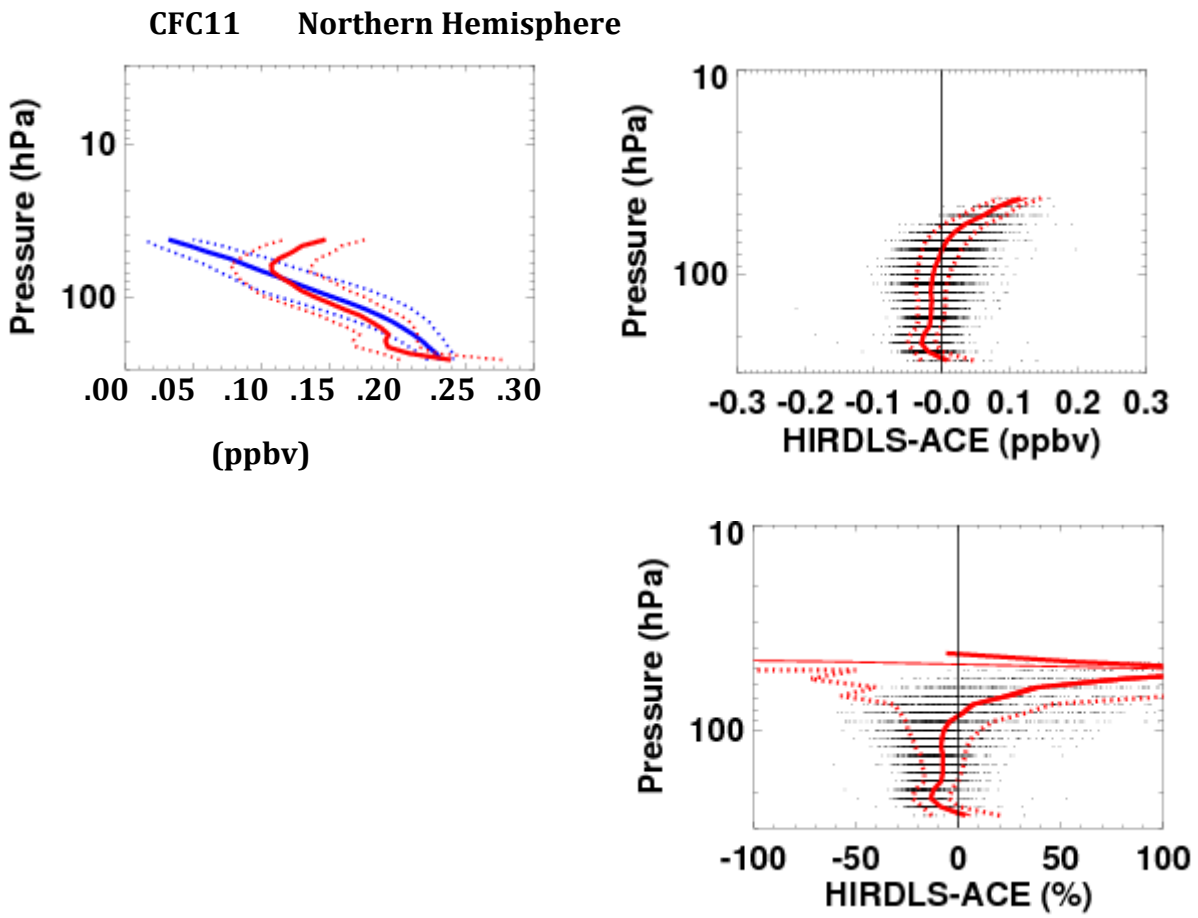

Figure 5.4.6 (Top left) Northern hemisphere average CFC11 vertical profile from HIRDLS (red) and ACE (blue) with one sigma standard deviations shown. (Top right) HIRDLS-ACE difference for coincident observations within 2 hours and 500 km. (Bottom right). Difference profile shown as a percentage of the HIRDLS observation.

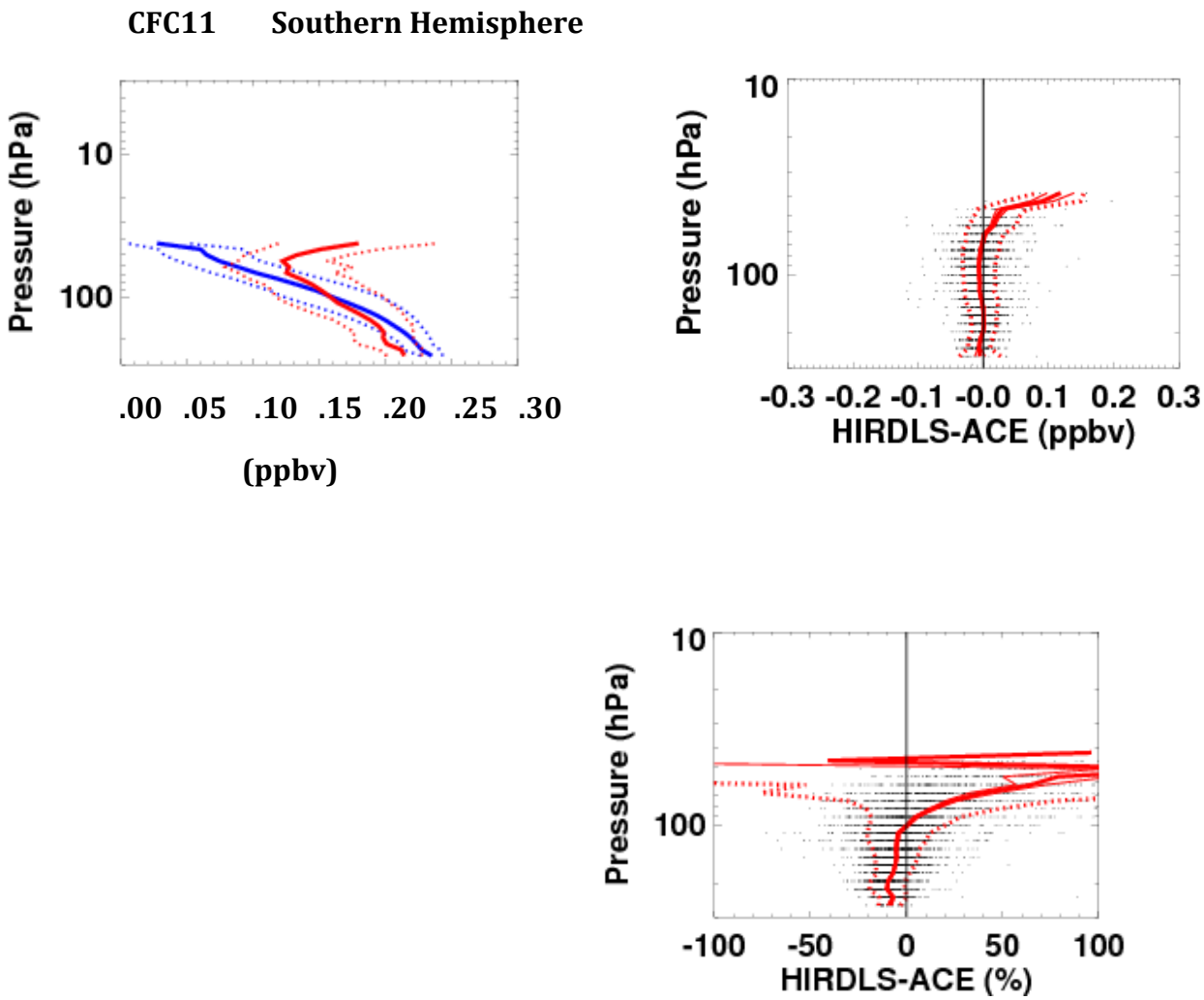

Figure 5.4.7: (Top left) Southern hemisphere average CFC11 vertical profile from HIRDLS (red) and ACE (blue) with one sigma standard deviations shown. (Top right) HIRDLS-ACE difference for coincident observations within 2 hours and 500 km. (Bottom right) Difference profile shown as a percentage of the HIRDLS observation.

References

Elkins, J.W., T.M. Thompson, J.H. Butler, R.C. Myers, A.D. Clarke, T.H. Swanson, D.J. Endres, A.M. Yashinaga, R.C. Schnell, M. Winey, B.G. Mendonca, M.V. Losleben, N.B.A. Trivett, D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter. 1994. "Global and hemispheric means of CFC-11 and CFC-12 from the NOAA/CMDL flask sampling program", pp. 28-40. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), Trends '93: A Compendium of Data on Global Change. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN, USA.

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Mahieu, E., P. Duchatelet, P. Demoulin, K. A. Walker, E. Dupuy, L. Froidevaux, C. Randall, V. Catoire, K. Strong, C. D. Boone, P. F. Bernath, J.-F. Blavier, T. Blumenstock, M. Coffey, M. De Mazi`ere, D. Griffith, J. Hannigan, F. Hase, N. Jones, K. W. Jucks, A. Kagawa, Y. Kasai, Y. Mebarki, S. Mikuteit, R. Nassar, J. Notholt, C. P. Rinsland, C. Robert, O. Schrems, C. Senten, D. Smale, J. Taylor, C. T´etard, G. C. Toon, T. Warneke, S. W. Wood, R. Zander, and C. Servais, Validation of ACE-FTS v2.2 measurements of HCl, HF, CCl3F and CCl2F2 using space-, balloon- and ground-based instrument observations, *Atmos. Chem. Phys. Discuss*., **8**, 3431–3495, 2008.

5.5 H2O*

5.6 CH4*

5.7 NO2*

5.8 N2O5*

5.9 ClONO2*

* To Be Supplied

5.10 Cloud Products

Data	Cloud Top Pressure, Cloud Flags
Data Field Names:	CloudTopPressure, 12.1MicronCloudAerosolFlag
Useful Range:	422-10 hPa
Screening Criteria:	Some false cloud positives are present, z > 20 km
Vertical Resolution:	1km
Contact:	Steven Massie
Email:	massie@ucar.edu
Validation Paper	Massie *et al.*, High Resolution Dynamics Limb Sounder observations of polar stratospheric clouds and subvisible cirrus, *J. Geophys. Res.*, *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 3.

Comparisons of clear sky and individual radiance profiles of the various cloud types are presented in Figure 5.10.1. 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 are removed from of 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.

Note that the HIRDLS focal plane has three columns of detectors. The 12 μm detector is in the middle column, while the three ozone detectors 10-12 are in the first column, and the

two columns are separated in distance by ~17 km. Situations arise in which the cloud top structure differs along the 17 km horizontal distance, i.e. a cloud top in the first column can be higher than that in the middle column. Subsequent to the methodology and discussions in Massie et al. (2007), the cloud detection routines now also determine cloud tops in the tropics in the transparent ozone channel 12. The cloud top altitude is assigned to be the higher of the channel 12 and channel 6 cloud top altitudes.

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 on the measurement altitude grid with 1 km vertical spacing. The cloud top pressure is determined before the temperature, mixing ratio, and extinction profiles are interpolated unto the standard output pressure grid.

There are some instances in which cloud flags falsely indicate the presence of clouds near and above 20 km altitude, especially at polar latitudes, outside of the seasons in which PSCs are expected to occur. These false identifications occur when radiances become very low in the 20 to 30 km altitude range.

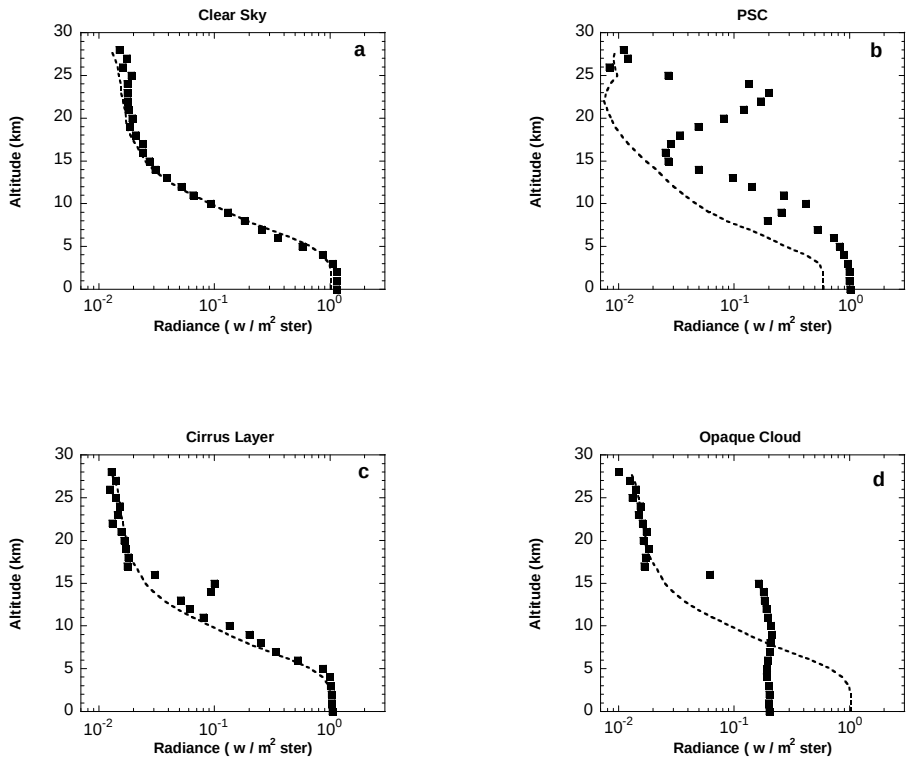

Figure 5.10.1. Four representative Channel 6 (12.1 µm) radiance (single squares) and clear sky average profiles (dotted curves) on January 27 2005, a) clear sky (15.57º N, 216.20º E), b) PSC (68.31º N, 343.41º E), c) tropical cirrus layer (4.32º N, 220.00º E), and d) opaque tropical cloud (16.79º S, 223.72º E) cases. Panels a, b, c, and d correspond to cloud flags equal to 0, 3, 2, and 4, respectively.

HALOE and V5 HIRDLS time averaged cloud top statistics are presented in Figure 5.10.2. The normalized distributions of HIRDLS cloud top pressure data in 2007 and HALOE data from 1998 to 2005 in Figure 5.10.2 for tropics and mid-latitudes have correlations of 0.64 and 0.89, respectively. The large differences in the number of observations of the HIRDLS and HALOE experiments are due to the fact that HALOE was an occultation experiment, while HIRDLS made observations every 5 seconds.

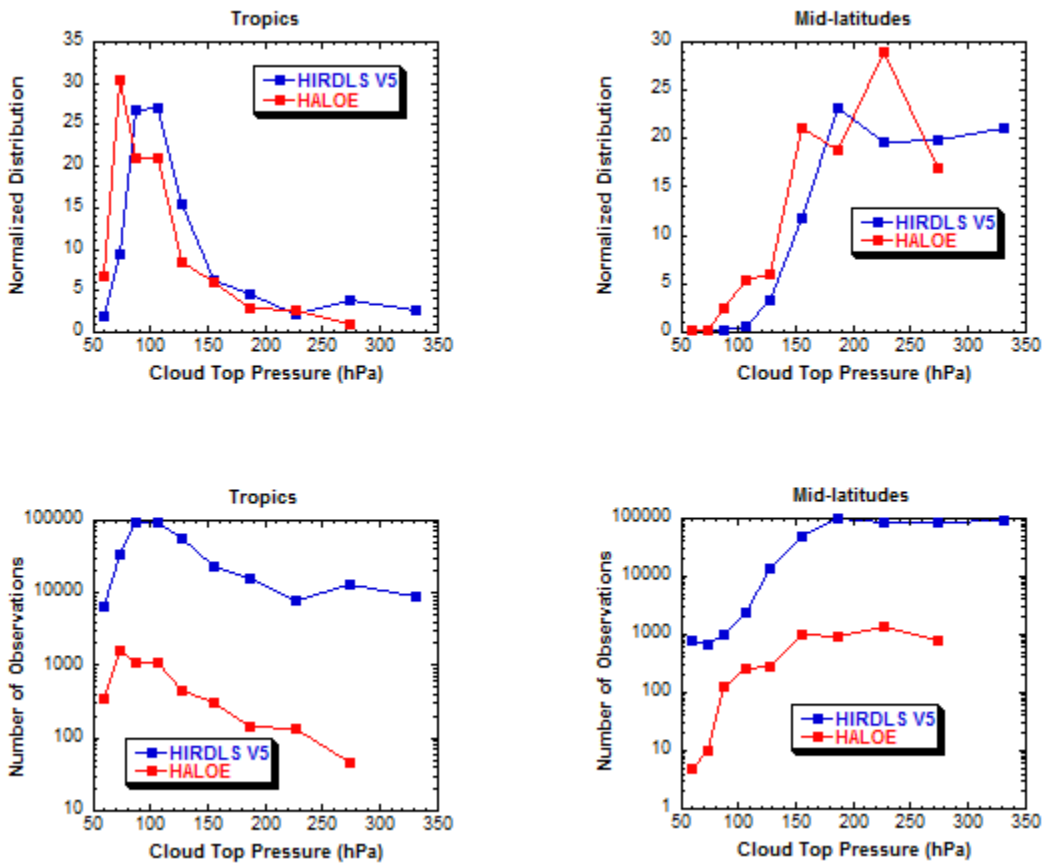

Figure 5.10.2 A comparison of V5 HIRDLS and HALOE cloud top pressure statistics for data in 2007 and HALOE data from 1998 through 2005.

Since the standard gas species retrievals terminate at the cloud top, the frequency of retrieval of gas species will decrease as pressures increase. The fraction of the time for which clouds are absent along HIRDLS limb paths in 2007 is presented in Figure 5.10.3. The latitudinal variation of the cloud free percent frequency is primarily influenced by the location of the tropopause. While the cloud free percent frequency is low at higher pressures, the number of cloud free profiles is still large at higher pressures due to the large number of profiles (~5500 per day) measured by the HIRDLS experiment.

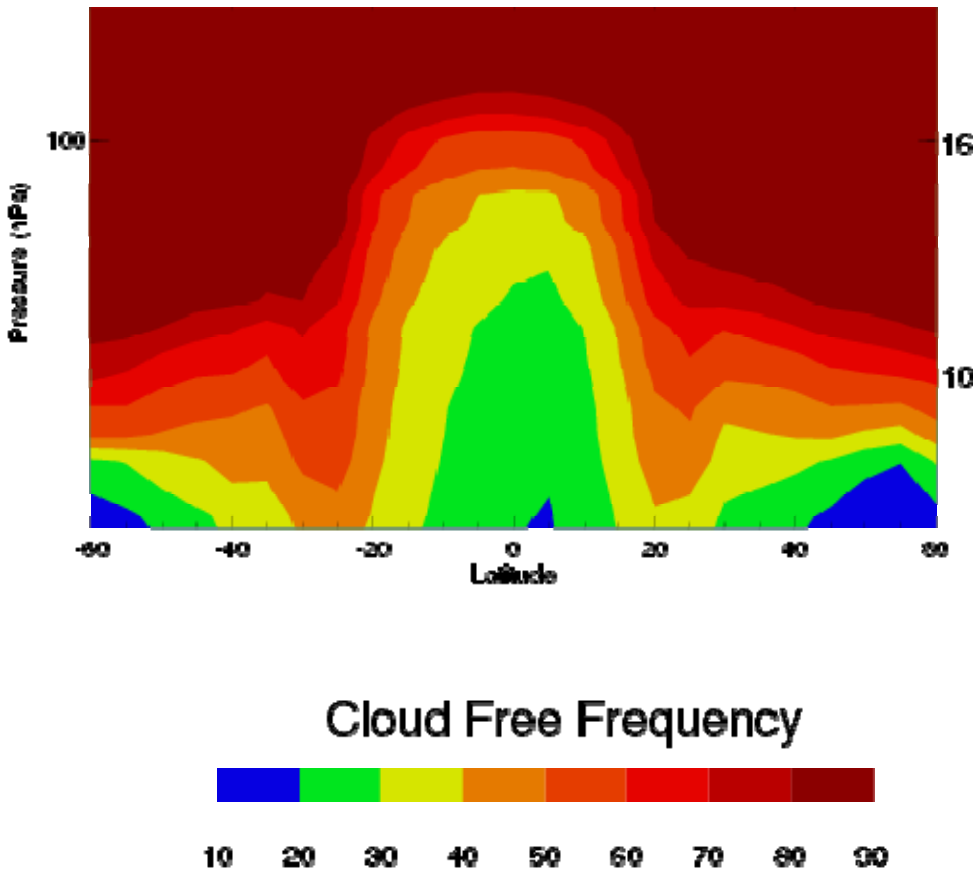

Figure 5.10.3. V5 cloud-free frequency in 2007. All pressures below the cloud top pressure of a single radiance profile are considered to be influenced by clouds. An approximate altitude scale in kilometers is given on the right hand side of the figure.

Figure 5.10.4 presents a comparison of V4 and V5 cloud frequency of occurrence in 2007 at 121 hPa for the four seasons. It is readily apparent that the two frequencies of occurrence are very similar for the two data versions. This figure was created by calculating at each pressure level the fraction of the time that extinction was between 9.0 x 10^{-4} km^{-1} and 1.0 x 10^{-2} km^{-1}, the extinction precision was less than the positive value of extinction, and when the cloud flag was nonzero.

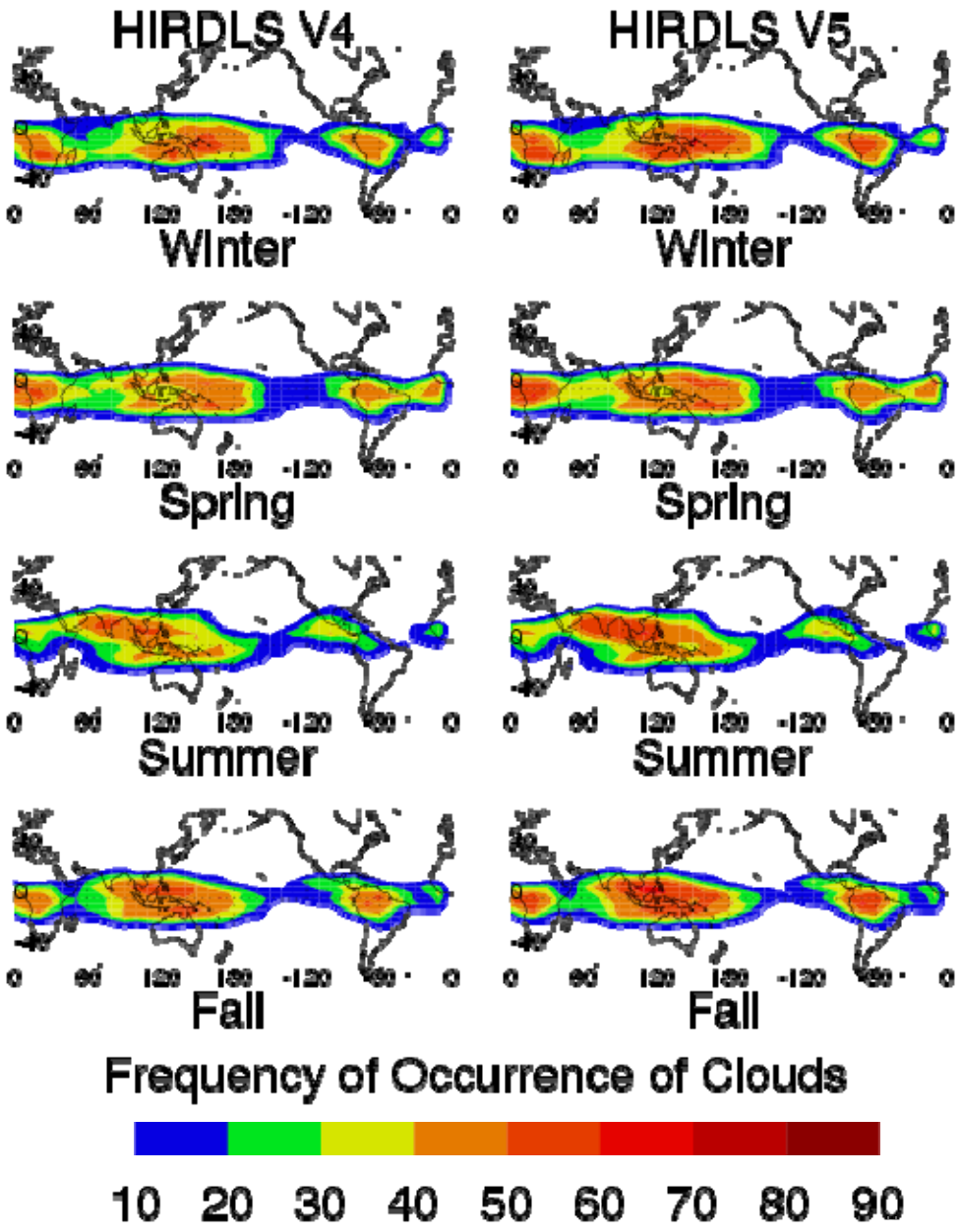

Figure 5.10.4. V4 and V5 cloud frequency of occurrence in 2007 for all cloud types for the four seasons at 121hPa.

5.11 12 Micron Aerosol Extinction

Data	12.1 Micron Extinction
Data Field Name:	12.1MicronExtinction
Useful Range:	215-20 hPa
Screening Criteria	Use extinction in a qualitative manner Use extinction between 10^{-5} to 10^{-2} km^{-1} Precision/data in 0 to 100% range Clouds are present if the extinction is greater than 9 x 10^{-4} km^{-1}
Vertical Resolution:	1km
Contact:	Steven Massie
Email:	massie@ucar.edu

Precision

Cloud and aerosol extinction and extinction precisions, in units of km^{-1}, at 12 μm are included in the "12.1MicronExtinction" and "12.1MicronExtinctionPrecision" data fields.

Extinction is archived for pressures between 20 to 215 hPa. Data above and below this range of pressure is flagged as -999 in the V4 and V5 data versions. It is recommended that extinction in the range of 10^{-5} to 10^{-2} km^{-1} be used when the precision is positive from 0 to 100%. Two week (or longer) zonal (hPa versus latitude) averages of extinction above the tropopause are recommended when examining the sulfate aerosol extinction in the stratosphere. Due to differences in the V4 and V5 radiance profiles, the V5 zonal averages of extinction become larger than the V4 zonal averages for pressures less than 40 hPa.

The 20 hPa pressure limit allows for inclusion of PSC observations in the archives and was also determined from comparisons of HIRDLS extinction profiles with correlative profiles. Mid-latitude HIRDLS extinction profiles at pressure levels less than 20 hPa increase in value, which is unrealistic. The high pressure limit of extinction (i.e. 215 hPa) was selected due to the fall off of extinction retrieval frequency (when the precision is less than the extinction) at pressures greater than 215 hPa in the tropics and mid-latitudes. Geospatial patterns of time averaged cloud extinction in latitude-longitude maps are coherent at pressures from 215 hPa up to the tropopause.

Since the 12 μm channel radiances are very low (which makes this "infrared window" especially good for detecting clouds), the absolute calibration of the radiances is still problematic. The extinction for the retrieved sulfate aerosol in the stratosphere is larger than correlative measurements (i.e. HALOE extinction zonal averages and University of Denver size distributions, converted to extinction profiles via Mie calculations) by a factor of ~2 for the V4 data, and more so for the V5 data at pressures less than 40 hPa. For this reason the data should be used in a qualitative manner, whereby the extinction data is used to indicate sulfate (low) extinction versus cloud extinction in a relative

manner. Cloud extinction at 12 μm is present when the extinction is greater than approximately 9 x 10^{-4} km^{-1} (i.e. the cloud extinction threshold determined previously by John Mergenthaler based upon analyses of the 12 μm extinctions of the CLAES experiment on the UARS platform) (Mergenthaler, J. L., A. E. Roche, J. B. Kumer, and G. A. Ely [1999], Cryogenic Limb Array EtaIon Spectrometer observations of tropical cirrus, *J. Geophys. Res*., *104*, No. D18, 22183-22194).

Figure 5.11.1 presents seasonal latitude-longitude graphs of V4 and V5 HIRDLS extinction for 2007 at 121 hPa. The extinction averages are similar to those obtained by previous solar occultation experiments, with maxima over the maritime continent, Africa, and South America. Monsoon dynamics influence the distribution of clouds over India during summer, while deep convection during winter produces high cloud frequencies over the maritime continent.

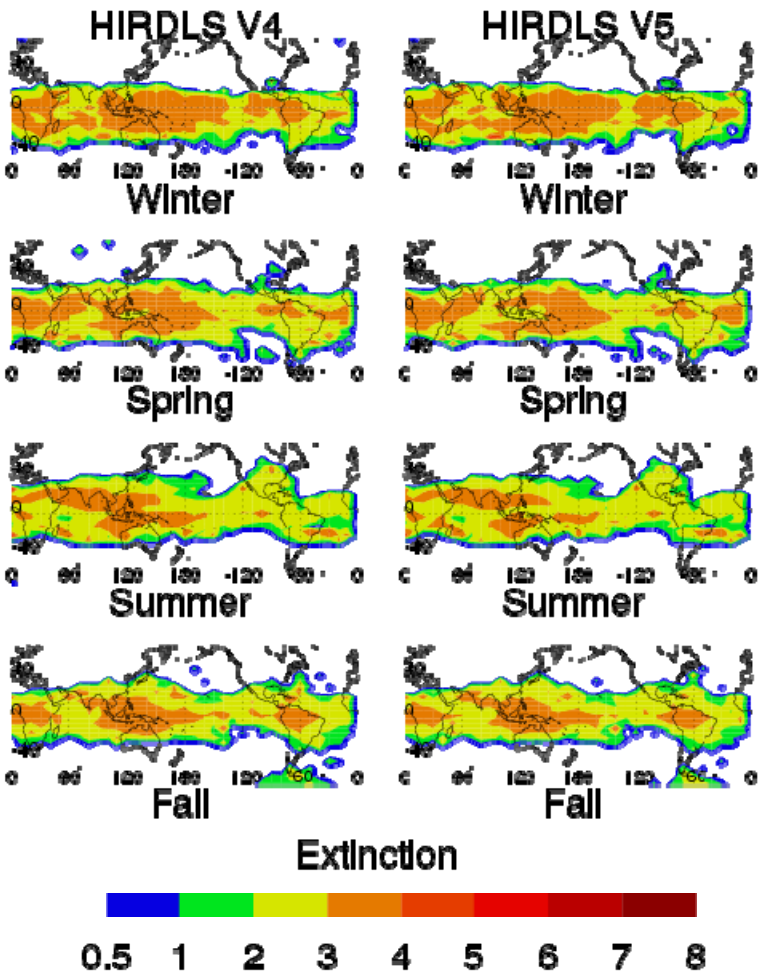

Figure 5.11.1. V4 and V5 HIRDLS seasonal extinction at 121 hPa during 2007. Extinction values are in units of 10^{-3} km^{-1}.

Reference: Massie, S. T. et al., HIRDLS Observations of PSCs and Subvisible Cirrus, 2007: J. Geophys. Res., doi:10.1029/2007JD008788.

5.12 Geopotential Height (GPH)

Species:	Geopotential Height (GPH).
Data Field Names:	GPH RawGPH
Useful (vertical) range:	400 – .04 hPa (same as Temperature).
Resolution:	Since GPH involves integrating over HIRDLS Temperatures. GPH is reported every pressure level, so a bit better than 1 km. See section 5.1.
Contact:	Lesley Smith
Email:	lsmith@ucar.edu

Precision: We estimate the precision of HIRDLS GPH by comparing views of the same atmosphere, and derive an estimate of the noise from the statistics of their differences. Here, we focus on adjacent GPH profiles in the tropics for equinoxes and solstices for years 2005-2007 and compute standard deviations of the differences of least-squares fit lines with data. Results of this type of analysis are shown in the figure, the line may be considered to be an observed precision.

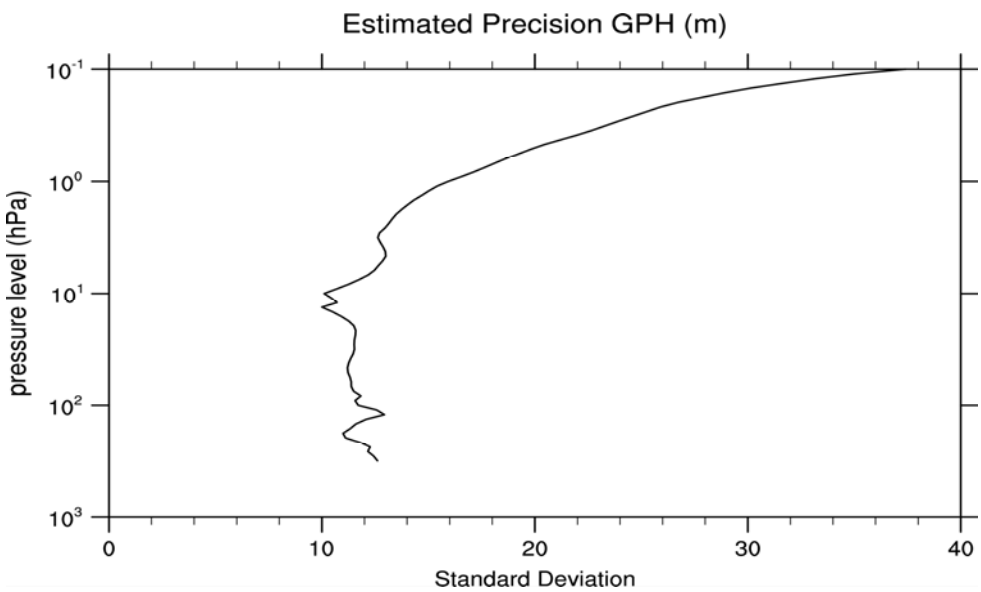

Figure 5.12.1: Estimated precision of HIRDLS GPH.

Accuracy: HIRDLS GPH's have been compared to several data sets in an effort to determine the extent and magnitude of any bias. In Figure 5.12.2 we see HIRDLS GPH binned by latitude, averaged over 2005-2007 minus ERA-Interim, NCEP/NCAR Reanalysis, MLS, and GMAO GPH data at sample pressure levels 10hPa and 100 hPa. HIRDLS clearly has systematic differences with the other fields, the reasons for which we do not know at this time.

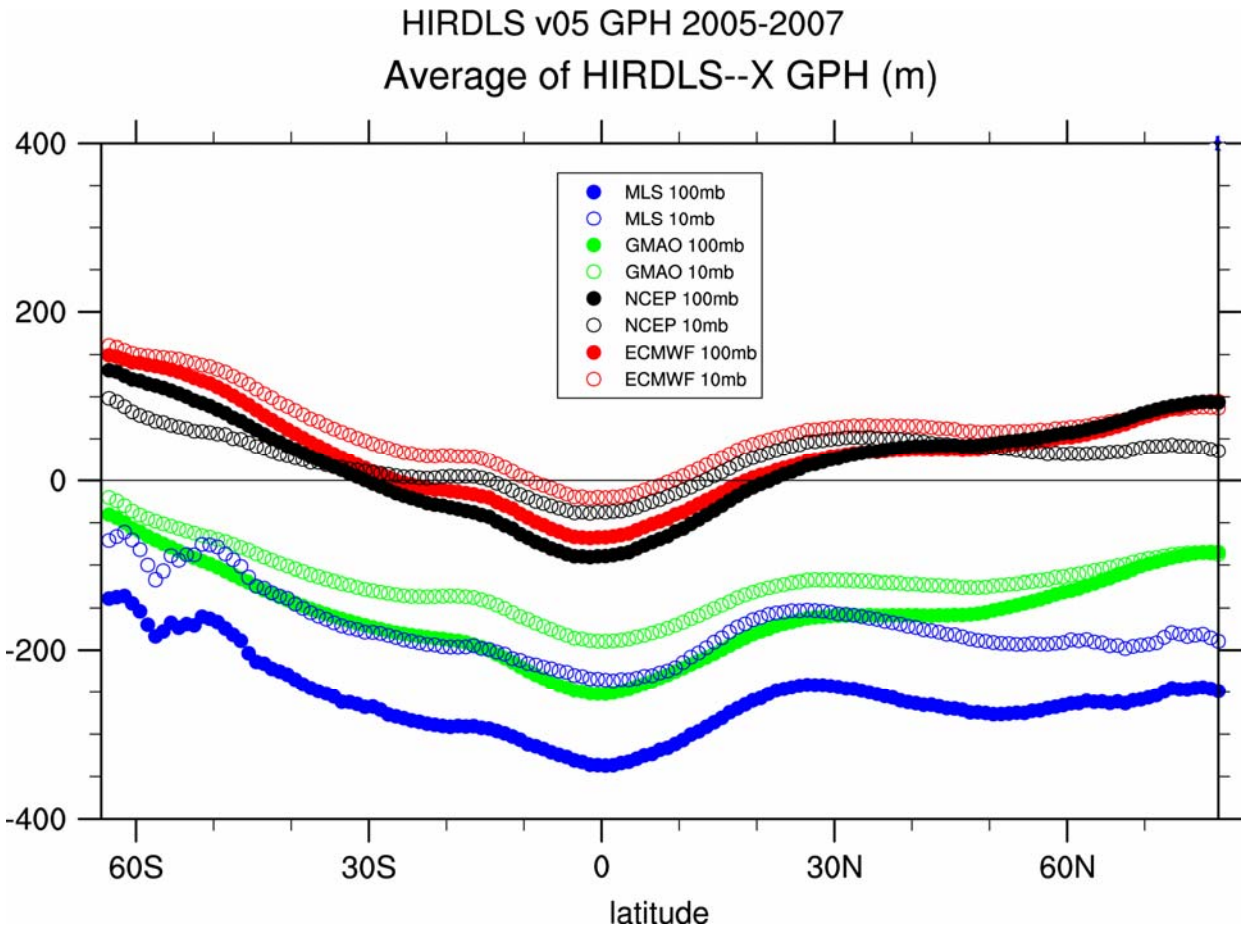

Figure 5.12.2 Differences between HIRDLS and several other calculations of GPH.

Future Improvements: We are investigating the slight low bias of HIRDLS GPH in the tropics (see accuracy statements above) and plan to resolve this issue.

6.0 Data File Structure and Content

Contact: Cheryl Craig
Email: cacraig@ucar.edu

Warning for IDL users: Due to internal changes within the HDF5 library used to create V5 data, IDL must be upgraded to 7.1 in order to read the HIRDLS V5 data.

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[2]. 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 are available for download via the HIRDLS web site, http://www.eos.ucar.edu/hirdls/data/access.shtml. The routines can also be supplied via email upon request.

With this release of the HIRDLS2 files, it is also possible to read the HIRDLS data via netCDF calls using the netCDF4.1 library. Even though the data was written with HDF-EOS5, the netCDF4.1 library can read the HIRDLS V5 files. Both the library and the HIRDLS data files must be these latest versions in order to use netCDF to read the data.

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 V5. 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 00.00 UTC 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.

[2]http://www.esdswg.org/spg/rfc/esds-rfc-009/ESDS-RFC-009.pdf/view

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.
2.04.19	004	Added new products: CFC11, CFC12, 12.1 micron aerosol extinction. Implemented updated open area fractions, improved cloud detection and out-of-field correction. Added correction for instrument-spacecraft alignment (equivalent to 2 km shift).
5.00.00	005	Includes packet checksum check; decreases tangent pt. altitude by 250 m; changes radiance scale factors and adds offsets; uses NoiseFac3 for radiance error spectrum, consistent with the latest Open Area Fraction (OAF) values (12/19/2008); incorporates 4/30/08 deoscillation Empirical Orthogonal Function (EOF) values; has +4-2 interpolation for el. angle tie-on; corrects C++ de-oscillator, adjusts alt. range that the boresight must cover to allow processing of ST30; corrects descaling/scaling of rad. errors; uses GEOS-5.1.0 for T radiance adjustment (v24), LOS gradient correction, and T a priori; corrects OrbAscFlag; adds capability to selectively adjust radiances by channels; adds OrbitNumber and SpacecraftDayFlag fields to HIRRADNC file; radiance adj. done on all channels except 7, 8, 9 (i.e., HNO3 and CFCs not adjusted); looks for clouds at lower altitude if too many negative radiances; uses toolkit 5.2.15; upgrades to Fortran compiler 10.1.015; releases GPH and potential temperature data as new products; includes option for using

GEOS O_3 and H_2O for a priori; adds OrbitNumber as a field in the output files; can now retrieve H_2O using channels 18 and 20 separately; capability to use 72-level GEOS data; applies geoid correction for GPH calculations; adds new Raw and Smoothed GPH calculations; includes capability to adjust input a priori errors at/below cloud tops or 10 km, whichever is higher; reduces T and O_3 a priori errors at these levels to 2k and 75%, respectively; radiance and retrieval ranges are now specified in altitude instead of pressure; T is retrieved to 120 km; number of diverged retrievals (dropouts) is substantially reduced, especially for T; improves lower mesospheric T retrievals;