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HIRDLS

HIGH RESOLUTION DYNAMICS LIMB SOUNDER

Originators: John C. Gille, Brian R. Johnson

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Oxford University
Department of Atmospheric, Oceanic, and Planetary Physics
Parks Road
Oxford OX1 3PU, United Kingdom

University of Colorado at Boulder
Center for Limb Atmospheric Sounding
3300 Mitchell Lane, Suite 250
Boulder, Colorado 80301–2296
United States of America

1.0 INTRODUCTION

This plan describes the activities to be carried out by the HIRDLS science team in support of the HIRDLS data validation effort. These activities include preparatory tasks in the pre-launch period as well as post-launch interaction with various instrument and investigation groups. The goal of the validation effort is to determine the accuracy and precision of the various HIRDLS science data, and consequently the appropriateness of their use in future scientific investigations.

1.1 Science Objectives

HIRDLS is an extremely capable and versatile instrument, with the ability to make accurate and precise measurements of the temperature, trace species and aerosols from the mid-troposphere (under clear conditions) to the mesopause (8–80 km) and above. It will provide data that are relevant to a large number of scientific questions and investigations, some of which have probably not yet been identified.

At this time, seven primary objectives have been identified as representative of important areas in which HIRDLS can make critical contributions to the study of global change. They are related to the priorities of the US National Plan for the Study of Global Change as stated in the Committee on Earth Sciences (CES) Report of May 1989. Here they are briefly stated; they are discussed in greater detail in the HIRDLS Science Requirements Document (SC-HIR-012).

1. To understand the fluxes of mass and chemical constituents (including greenhouse gases and aerosols) that affect the dynamics and composition of the troposphere, stratosphere, mesosphere, and thermosphere and link these regions together. These fluxes must be determined down to smaller scales than previously observed.
2. To understand the chemical processing, transport, and small-scale irreversible mixing of trace constituents in the middle atmosphere, including the chemical and dynamical processes responsible for creating the Antarctic (and perhaps Arctic) ozone holes.
3. To understand the momentum, energy, and potential vorticity balances of the middle atmosphere, by extending observations to smaller horizontal and vertical scales than has previously been possible. These small-scale processes are believed to be fundamentally important to the determination of some large-scale characteristics and are thought to cause irreversible chemical mixing.
4. To obtain climatologies of upper tropospheric, stratospheric, and mesospheric quantities, in particular, profiles of temperature, ozone, several radiatively active gases, aerosol, gravity wave activity, and cloud top heights. Seasonal, interannual, and long-term trends will be obtainable because of the five-year measurement sequence that will be provided by each EOS instrument, combined with pre-EOS measurements and future EOS observations.
5. To provide data to validate and improve numerical models of the atmosphere, in order to gain confidence in their ability to predict climate change. These simulations are critically dependent on the treatment of horizontal and vertical scales that are much finer than those currently observed.
6. To improve tropospheric temperature and water vapor profiles and cloud top height data that are used for climate and weather forecasting, by combining high vertical resolution limb data with data from operational nadir sounders such as AIRS and AMSU. This will yield valuable data from the tropopause region and the lower stratosphere, information that would not otherwise be available.
7. To improve the understanding of tropospheric chemistry through the use of temperature and constituent retrievals that extend into the upper troposphere, under favorable conditions. The combination of these

observations with observations from other EOS instruments, and with chemical models, will yield information about the oxidation capacity of the atmosphere.

1.2 Measurement Objectives

To accomplish the objectives stated in section 1.1, the constituents listed in Table 1.2.1 will be measured in addition to measuring the temperature and the geopotential height gradient. These are the key elements that are needed to understand the chemistry and dynamics of the upper troposphere, stratosphere, and mesosphere, including the roles of planetary and gravity waves in transporting and mixing radiatively and chemically active species that are important to climate change. Note that the geopotential height is measured by HIRDLS but this is difficult to calibrate exactly over long periods. The height gradient is actually the quantity of interest in determining wind fields and this requires only high precision of the height measurement between adjacent profiles.

Table 1.2.1—Constituents Measured by HIRDLS

Formula	Name	Altitude Range (km)
O_3	ozone	8–80
H_2O	water vapor	8–65
CH_4	methane	8–60
N_2O	nitrous oxide	8–30
HNO_3	nitric acid	10–40
NO_2	nitrogen dioxide	10–55
N_2O_5	nitrogen pentoxide	15–45
$CFCl_3$	CFC 11	8–30
CF_2Cl_2	CFC 12	8–30
$ClONO_2$	chlorine nitrate	20–40
aerosol	aerosol extinction	8-22, or above

The required precisions and absolute accuracies of the measurements are listed in Table 1.2.2. The vertical ranges listed in Table 1.2.1 are for the regions in which the expected precision is better than 10%, but at least 5% precision is expected over most of the range for all constituents and better than 1% for many of them (e.g., ozone).

Table 1.2.2—Measurement Requirements

Parameter	Precision	Absolute Accuracy
temperature	0.4 K below 50 km	1 K below 50 km
	1 K above 50 km	2 K above 50 km
constituents	1–5%	5–10%
aerosol extinction	1-5%	5-25%
height gradient	20 m / 500 km	N/A

1.3 Instrument Description

The HIRDLS instrument will be a multi-channel limb-scanning IR radiometer for high resolution monitoring of upper tropospheric, stratospheric, and mesospheric temperature, trace chemicals, and geopotential height gradients. The instrument will have a better vertical resolution than previous limb sounders, because of its smaller FOV; and the horizontal spacing between the profiles will be much closer, since the instrument will be able to scan azimuthally. A gyroscope package will measure the motion of the optical bench along three axes. This will allow pressure level determinations at different locations to be related to one other, and it will make the deduction of the gradients of geopotential surfaces possible. The instrument will have flexible on-board computational capabilities, and its actions will be controllable and programmable from the ground. Filters will be used to select radiation from narrow wavelength regions, chosen to optimize chemical identification and to facilitate the determination of, and the correction for, aerosol emission. Consequently, the measurements will be valid down to lower levels (viz., 8 km or less) than with previous limb sounders.

The fundamental measurement in IR limb scanning is the radiance as a function of the relative position of the line of sight (LOS) of the radiometer as it is scanned across the limb. Thus, it is critical to measure the radiances accurately and precisely, in well-defined spectral intervals, and to know their relative positions accurately and precisely.

During the data reduction, the measured vertical profiles of the radiance emitted by CO_2 (which has a known distribution in the atmosphere) are inverted to determine the temperature of the atmosphere as a function of the atmospheric pressure (i.e., the altitude). Subsequently, these temperature profiles are combined with the measured vertical profiles of the radiance emitted by other gases, to determine their vertical distributions. Finally, regional and global maps of the temperature and the trace gas concentrations are constructed from the profiles. These maps are valuable aids for making wise policy decisions about important environmental issues such as global warming, as well as critical pieces of scientific information.

1.4 Mission

HIRDLS is scheduled to fly onboard the CHEM-1 spacecraft planned for launch into a sun-synchronous near-circular polar orbit during the fourth quarter of 2002. A nominal orbital height of 705 km and an orbital period of 98.9 minutes are assumed. These orbit characteristics combined with the HIRDLS measurement technique provides global coverage, day and night including polar night, of temperature and constituent measurements. The expected operational lifetime for the CHEM-1 mission will be five years, with a goal of six years. As currently planned, the instrument compliment will be HIRDLS, TES, MLS and perhaps an ozone measuring instrument. The goal of the CHEM-1 mission is to measure atmospheric chemical composition, tropospheric-stratospheric exchange of energy and chemical species, and chemical-climate interactions.

1.5 Science Data Products

The basic geophysical data products of the HIRDLS instrument will be vertical profiles of atmospheric temperature, the geopotential height gradient, and the mixing ratios of the constituents (with the exception of aerosol) that are listed in Table 1.2.1. For aerosols, the basic geophysical product will be vertical profiles of spectral extinction. Higher level aerosol products will include profiles of aerosol amount and surface area density. The basic geophysical quantities will be gridded horizontally. The direct geopotential measurement by the HIRDLS instrument, after pointing corrections have been applied, will give an accurate representation of the variation of geopotential heights between soundings, but it will require periodic correction based on satellite data or ground processing with tropospheric analyses, in order to produce consistent global geopotential fields. Wind fields will be derived from the temperature and geopotential fields by using either nonlinear balance approximations or assimilation techniques. Higher order derived quantities, such as potential vorticity, will be calculated from the basic data products. All of the above fields will be made available to other investigators.

2.0 VALIDATION APPROACH

2.1 Overview

It is impossible to establish the quality of remotely sensed satellite data as a simple add-on at the end of the process by comparing them to measurements by a different instrument or technique. As a minimum, the second measurement often has a different sampling volume, the measurement may differ in time and location, and there will be different systematic errors that may be masked by large random errors. However, the major problem is that such comparisons are made at a small number of locations and times, while confidence is needed that the data are valid over all observing conditions. The goal of accurate determinations under all conditions needs to be designed into the experiment, not only in the hardware, but also in the plans to checked instrument performance and calibration in orbit, and into the process by which the geophysical data are retrieved from the measurements.

An atmospheric remote sensing experiment such as HIRDLS begins with the atmosphere, from which radiation emerges, determined by the state of the atmosphere, and governed by the laws of radiative transfer. The instrument then measures the emerging radiation in engineering units, such as counts or volts (Level 0 data). We must first convert these measurements into calibrated, located radiances (Level 1 data). We then attempt to recover the state of the atmosphere from these by inverting the laws of radiative transfer. Ideally, when we have done this, we will recover atmospheric parameters that are identical to those in the original atmosphere. The process of creating data of high and known quality clearly begins with understanding the measurement and radiative transfer processes as well as possible.

Thus, our initial requirement is to understand the measurement process and its uncertainties, as it is impossible to get good, reliable final products if the intermediate measurements are inaccurate or inconsistent. Validation begins with a thorough test and calibration program, in which all instrument parameters that affect the measurement , and their dependencies on instrument conditions, are determined in the laboratory before launch, and a detailed instrument model is verified and brought into consistency with these observations. Validation continues with development and implementation of a plan to verify the measurement process in orbit, through in-flight determination of all instrument properties that affect the measurement process, or analysis that confirms that these will not change from pre-launch conditions. In addition, the best measurements of some quantities, such as off-axis scatter, can be done better from orbit than on the ground.

In parallel, we must understand the retrieval process and its uncertainties. Again, the characteristics of the retrieval process can be studied before launch by the calculation and retrieval of simulated data, and the analysis of the retrieval process, which can show the sensitivity to various types of measurement error, and show the expected resolution, precision and accuracy of the final products.

Subsequently, our goal should be to verify that these predictions are correct, and, if not, to understand why, and bring our understanding into agreement with the data. Thus, there are several steps that must be taken;

1) Pre-launch testing and calibration (This is described in other HIRDLS documents);
2) Pre-launch testing and analysis of the retrieval algorithms (to be described in the ATBD's);
3) On orbit evaluation of instrument performance and consistency, including comparison of observed signals with ones calculated for climatological conditions ;
4) Evaluation of initial retrievals for plausibility compared to climatological values, and spatial and temporal consistency;
5) Estimation of retrieval precision;

Only when the HIRDLS data pass these tests will it make sense to put much effort into comparison with other data. Here we propose two principles:

1.) Comparison, wherever possible, with data from MLS and TES, on the same spacecraft, and looking at the same atmosphere at close to the same times. These have the advantages that they allow comparisons at all latitudes and longitudes;
2.) Validation of quantities with the largest signals, in regions with high signal to noise ratios first.

Thus, temperature, ozone and water vapor in the stratosphere and mesosphere will allow an early search for any anomalies in instrument or retrievals. Since these may affect the retrievals of species with smaller signals, this is also a necessary precursor step.

The major effort of the Science Team will be on data validation during at least the first 1.5 years after launch. It is during this time that HIRDLS will have its greatest need for correlative observations. Validation will be continued on a lower level during the remaining years to identify any trends in the results that may be due to instrumental effects.

Specific activities associated with the validation of various data products are described below. It should be understood that, where possible, several of these may take place in parallel in order to provide the broadest possible perspective.

2.2 Measures of Success

A data product can be considered as validated when it has been demonstrated to represent the real atmosphere to within a well quantified uncertainty and over a stated range of atmospheric and observational conditions. Associated with this is the requirement that any anomalies initially found in the data be either traceable to algorithm, instrument, physical, or spacecraft causes or identified as real geophysical phenomena.

It is important that end-users understand the nature and any limitations of the HIRDLS observations, especially with regard to derived products. The comparison of HIRDLS measured parameters with observations from a variety of measurement systems will aid in characterizing the differences, in understanding the reasons for them, and to help users of the data to understand how these differences will affect derived quantities.

3.0 PRE-LAUNCH VALIDATION ACTIVITIES

3.1 Prototype Algorithm Development

An important component of HIRDLS data validation is the validation of data processing algorithms used to infer geophysical parameters from calibrated radiance data. Pre-launch algorithm development will include the development of algorithms for inverting calibrated radiances to produce profiles of temperature and of the concentrations of trace species and aerosols, and the characterization of uncertainties resulting from parametrizations and operational implementation. The relationship between HIRDLS measurables and geophysical parameters will be documented in the HIRDLS Algorithm Theoretical Basis Document (ATBD). The retrieval algorithm and estimates of its uncertainties will be refined during post-launch activities based on comparisons with climatological and correlative data.

3.2 Development of Instrument Model

During pre-launch calibration and testing, the spectral, spatial, and absolute radiometric response of each of the HIRDLS 21 spectral channels will be carefully characterized over a range of operating conditions and over the entire field of regard. These data are a required input to the data processing algorithms. In addition, calibration and test data will be used to develop an instrument model to be used in end-to-end simulations of the measurement and retrieval process to test and validate the data processing procedures. Using the end-to-end simulations, an objective analysis can be used to determine the expected on-orbit instrument performance and the magnitude of expected errors in retrieved quantities to be compared with post-launch analyses.

3.3 Radiance Simulations

A quick and effective check of instrument behavior is the comparison of observed radiances with simulated radiances based on climatological values for atmospheric parameters. This provides an early detection of possible discrepancies in instrument characterization, calibration or spectroscopic parameters. From climatology, one knows the expected distributions and variances of temperature and mixing ratio for several stratospheric species; in particular CO_2, O_3, H_2O, HNO_3, NO_2. Expected ranges of radiance will be calculated based on the climatology. One can then determine if the range of observed radiances lies outside these climatological bounds. The areas of violation may point to cases for which the instrument is misperforming, or point to spatial regions for which atmospheric contaminants are present (e.g. clouds). Atmospheric climatologies of mean, extreme, and variances of observed atmospheric quantities will be compiled for use in instrument validation studies immediately after launch.

3.4 Development of Tools and Methods to Expedite Post-launch Validation

Many of the studies described in the Validation plan will make extensive use of non-HIRDLS data such as correlative measurements, climatology, model data and other CHEM-1 instrument data. They will also frequently require CHEM-1 spacecraft ephemeris data and other non-atmospheric information. It will be desirable to find a standard format or interface for this data to facilitate its use in combination with the primary HIRDLS data. Many of the analyses needed for validation share common requirements for calculation and display, for which software utilities will be developed. For example, these will include,

- data management utilities to allow the convenient manipulation and comparison of multiple data sets such as instrument vs. instrument, instrument vs. model, and instrument vs. correlative measurements.
- utilities to compare data sets using, e.g., difference maps, variance plots, and other statistical properties.
- display utilities to plot latitude-longitude maps, latitude-pressure cross-sections, time-height cross sections and other time series, profiles of temperature and other quantities vs. height, along-track cross-sections, and other common graphics.
- a facility to assemble and manage large, out-of-core data sets for long term statistical comparisons.
- routines to calculate derived products such as chemical ratios and chemical abundances, geostrophic winds, eddy heat and momentum fluxes, and potential vorticity.

4.0 POST-LAUNCH VALIDATION ACTIVITIES

4.1 Strategy

The purpose of the post-launch validation activities is to gather the necessary information to provide meaningful estimates of the uncertainties associated with the HIRDLS science data products. In order to begin the validation process, the on-orbit characteristics of the HIRDLS instrument must be well understood. This will be accomplished by analysis of the raw instrument counts, referred to as Level 0 data, and engineering data. The first level of processed data, the calibrated and geo-located radiance profiles (Level 1) will be validated in a variety of ways to assure that the observed radiances are correct to the best of our understanding.

Each Level-1 through Level-3 data product will have with it an associated estimate of its uncertainty and the range of conditions over which this estimate is valid.

4.1.1 Level 0 (raw instrument counts)

The operation of the instrument under orbital conditions will be assessed by studying a variety of operational parameters. The stability of the outputs from the in-flight calibration sequence will be checked against pre-launch and orbital values throughout the HIRDLS mission. The history of temperature variations will be well characterized. A useful diagnostic is a plot of the orbit-by-orbit variations of the operational parameters. Examination of these graphical displays will look for discontinuous jumps in parameters, and quantify the variance in parameter values.

In particular, a small amount radiation from within and external to HIRDLS that is originally off-axis will be scattered into the HIRDLS fields of view. Contamination on the scan mirror and primary mirror are expected to be major causes of this scattered radiation. This scattered radiation will eventually dominate at some height in each channel. HIRDLS algorithms will correct for this, based on empirical models of angular variation of the scatter and its amount.

Determination of the angular model and scattering amount requires making use of observations when the field of view is directed above the measurable atmosphere, and vertical scans can be made at a number of azimuth angles. However, this allows only a small part of the total angular range to be included, and does not permit separation of the effects of internal and external sources. Determination of the angular model and scatter amount requires occasional movement of the external source (i.e. earthshine) out of the field of regard, allowing the angular distribution of scattered instrument radiation to be isolated and measured.

This will require that the HIRDLS boresight be pitched up ~ 5° (TBV) in 20 minutes, which will allow vertical scans at several azimuth angles, for every 0.25° movement of the external source. With a return in 10 minutes (TBV), this results in a total time for the maneuver of 30 minutes. The initial maneuver should take place after about 1 month of instrument operation, and on the order of 1-2 times per year (TBV), depending on the rate at which the scatter (and mirror contamination) increases.

4.1.2 Level 1 (geo-located and calibrated radiances)

The validation of the calibrated radiances allows an assessment of the consistency of the instrumental measurements and the forward radiance model used in the retrieval program. A plot of radiance at a given altitude versus altitude along the satellite track is a useful diagnostic of instrument performance and data product content. Inconsistent or erratic variations in the radiances may indicate problems in instrument or spacecraft ACS performance, or in data product creation. Several checks will be carried out, including checks for spatial and temporal consistency of observed radiances along the orbit, from orbit-to-orbit, from day-to-day, and from day-to-night for selected time periods and locations. Comparison of observed radiances with climatological calculations will be made to determine that the mean and variance of observed radiances over selected time periods fit within the mean and variance of modeled observed radiances based on climatologies with the purpose of early detection of possible discrepancies in instrument characterization or spectroscopic parameters. Comparison of observed radiances with values calculated from correlative measurements as inputs provide a more refined check on instrument characterization and forward radiance model parameters. Checks for the adequacy of the off-axis response will also be carried out.

4.1.3 Level 2 (profiles of geophysical quantities)

The validation of the retrieved profiles will generally follow the sequence of steps required to validate the radiances. The validation will include a detailed estimation of errors from all sources, examination for spatial and temporal consistency of the retrieved profiles, comparison of retrieved profiles with climatological data, and a comparison of retrieved profiles with simultaneous correlative measurements. A discussion of the types of correlative observations that could be used is given in section 4.6.

4.1.3.1 Sampling and Other Requirements

The spatial sampling requirements for the HIRDLS science data validation are determined by the limb-viewing geometry and by the commandable azimuth scan capability of HIRDLS. This flexible in pointing capability will allow for optimizing spatial coincidence of correlative measurements.

HIRDLS will require vertical profile measurements of temperature, the constituents in Table 1.2.1 and aerosols over an altitude range of 8- 80 km, with particular emphasis on the upper troposphere and lower stratospheric region. In this region, emphasis will be on comparison of HIRDLS data with aircraft measurements. The vertical resolution of correlative measurements must be consistent with HIRDLS 1-km vertical resolution. Horizontal resolution of correlative measurements should be consistent with HIRDLS azimuth scan, equivalent to about 5 degrees in latitude and longitude, typically, and to 1 degree depending upon the desired scan mode of HIRDLS.

4.1.3.2 Criteria for Coincidence

The criteria for spatial coincidence can be quite tight, because of HIRDLS flexible scanning capability. The desired spatial coincidence criteria for in-situ or remote correlative data should lie within a 50 km radius of a specific HIRDLS observation point, with an upper limit of 100 km considered adequate. For most constituents measured by HIRDLS, a temporal coincidence of 1 hour is desirable; 3-hours may be acceptable for species with lifetimes longer than 1 day. For some atmospheric constituents, the desired temporal and spatial coincidence may be difficult or impossible to achieve.

It is expected that coincidence with ground-based correlative measurements, in particular the Network for the Detection of Stratospheric Change (NDSC), to be within 50 km and 30 minutes of a HIRDLS limb observation given HIRDLS commandable pointing capability.

It may be possible to take advantage of trajectory analysis to extend the spatial and temporal coincidence criteria to include observations of the same air mass by HIRDLS and by correlative measurements for long-lived species, such as ozone, CH_4 and N_2O.

4.1.4 Level 3 (mapped data products)

Several checks upon the mapped products will be performed. The accuracy of representation of individual profiles will be checked against the mapped field by performing an RMS difference analysis between an ensemble of individual profiles and the mapped representation. The maps of HIRDLS temperature and ozone data will be compared with maps of the same quantities produced by NOAA operational satellites. The maps of the gradients of geopotential heights will be validated against analyses of conventional data over data rich areas like the continental US or Europe. Analyses of winds of smaller spatial scales may also be checked against local wind profile measurements.

Finally, HIRDLS maps will be checked against those of other EOS instruments, including AIRS/AMSU on the PM platform, and MLS and TES on the CHEM platform. (Note that comparison or joint use of the gridded data do not require that the instruments be on the same platform.)

4.2 Climatological Data Needs

Climatological data will be used where available in assisting in the validation of the HIRDLS parameters. It is intended to make use of various climatologies, notably those being compiled by the UARS program.

4.3 Comparison with Other CHEM-1 Measurements

A measure of the consistency of the HIRDLS parameters will be obtained by comparing the HIRDLS retrieved parameters with those in common from other CHEM-1 (e.g. TES and MLS) instruments at nearest coincidence. Each of these instruments use different techniques to obtain their measurements and therefore any agreement in measurements between HIRDLS and another CHEM instrument lend increased credibility to the estimated accuracy of a parameter. An attempt will be made to understand any differences, and to correlate variables with orbital or spacecraft events.

4.4 Comparisons with Other Satellite Measurements

Inter-comparisons with instruments flying onboard other satellites will provide additional opportunities for correlative observations. Instruments being considered for validations studies are SAGE III, and ENVISAT-1 instruments GOMOS, MIPAS and SCIAMACHY. ENVISAT-1 is scheduled for launch in mid-1999, with a second launch planned for 2003.

SAGE III is a limb occultation instrument scheduled for launch onboard the Russian METEOR 3M spacecraft in 1998 with an expected lifetime of at least 3 years. Additional flights include an instrument onboard the International Space Station in 2002 and a "flight of opportunity" mission by 2005. SAGE III will provide useful correlative data in the upper troposphere and stratosphere, such as aerosol extinction profiles, and the concentration profiles of H_2O, NO_2, and O_3.

GOMOS is a stellar occultation instrument and will provide global observations of ozone, H_2O, NO_2 temperature and aerosols, as well as other species, using two bore-sighted telescopes, each with its own grating spectrometer. In the limb-viewing mode observations will be made over the altitude range from approximately 20 to 100 km with a vertical resolution of ~ 2-km.

MIPAS is a Fourier transform spectrometer for the measurement of high resolution gaseous emission spectra at the Earth's limb. It operates in the near to mid infrared where many of the atmospheric trace-gases playing a major role in atmospheric chemistry have important emission features. The objectives of MIPAS are simultaneous and global measurements of O_3, H_2O, CH_4, N_2O and HNO_3 and CFC's in the stratosphere, and climatology of temperature, CH_4, N_2O, O_3.

SCIAMACHY is an imaging spectrometer whose primary mission objective is to perform global measurements of trace gases in the troposphere and in the stratosphere. Of particular interest for HIRDLS will be observations of O_3, NO_2, N_2O, H_2O, and CH_4

4.5 Comparison with Aircraft Measurements

There are currently several instruments flying on airborne platforms that can provide correlative data for the HIRDLS instrument. The species, instruments, PIs and platforms are listed in Table 4.5.1. Given the predicted HIRDLS capabilities in the upper troposphere and lower stratosphere, it is most likely that correlative flights would be made with the NASA ER-2 and/or DC-8, which have flight ceilings of about 20 km and 12.5 km, respectively. Other platforms, such as the WB57F or C130 might also be possible in the future. These are not as heavily instrumented as the former two aircraft however. Instrumentation with sufficient accuracy and precision is available on both the ER-2 and DC-8 to validate nearly all of the observations made by HIRDLS below 20 km, including O3, H2O, CFCs-11 and -12, CH4, N2O, HNO3, NO2, and aerosols. It is not expected that HIRDLS will be able to retrieve N2O5 or ClONO2 at these altitudes.

Many of the logistical issues that must be considered in planning any satellite/ aircraft intercomparisons are simplified in this case because of HIRDLS' near-global coverage and regular sampling pattern, as well as it's flexibility in sampling schemes. The ER-2 has been based at numerous sites around the world, ranging from it's "home" at Moffett Field, CA to bases in Norway, Fiji, Australia, New Zealand, Chile, and Guam, as well as several sites within the continental United States. The main restrictions on flight center around weather conditions, particularly wind speeds, at take-off and landing. The DC-8 has a much wider range of acceptable conditions. Nominal flight durations are 2600 nautical miles for the ER-2 and 5700 nautical miles for the DC-8. These are probably sufficient to permit 1-2 coincidences per flight.

Table 4.5.1

Species	Instrument	PI	Platform
Ozone	UV photometer	Proffitt/Margitan (NOAA/JPL)	ER-2
	chemiluminescence	Ridley/Weinheimer (NCAR)	DC-8
	LIDAR	Browell (NASA Langley)	ER-2, DC-8
Water	TDL absorption	May (JPL)	ER-2, WB57
	"	Sachse (NASA Langley)	DC-8
	Lyman-alpha hygrometer	Kelly (NOAA)	ER-2
	"	Weinstock(Harvard)	ER-2
	LIDAR	Browell (NASA Langley)	ER-2
CFC-11	in situ GC/ECD	Elkins (NOAA)	ER-2
	grab sample	Atlas (NCAR)	ER-2
	"	Blake/Rowland (UCIrvine)	DC-8
CFC-12	same as above		
N2O	TDL absorption	Loewenstein (NASA Ames)	ER-2
	"	Webster (JPL)	ER-2
	"	Sachse (NASA Langley)	DC-8
	in situ GC/ECD	Elkins (NOAA)	ER-2
	grab sample	Atlas (NCAR)	ER-2
	"	Blake/Rowland (UCIrvine)	DC-8
CH4	TDL absorption	Webster (JPL)	ER-2
	"	Sachse (NASA Langley)	DC-8
	"	Kelly (NOAA)	WB57
	in situ GC/ECD	Elkins (NOAA)	ER-2
	LIDAR	Heaps (NASA Goddard)	C130
HNO3	TDL absorption	Podolske (NASA Ames)	DC-8
	CIMS	Viggiano (Phillips Lab)	DC-8
NO2	TDL absorption	Webster (JPL)	ER-2
	"	Podolske (NASA Ames)	DC-8
	photolysis/chemilum.	Fahey (NOAA)	ER-2
	"	Ridley/Weinheimer (NCAR)	DC-8
aerosol	CN counter	Wilson (UDenver)	ER-2
	"	Pueschel (NASA Ames)	DC-8
	FCAS	Wilson (UDenver)	ER-2
	FSSP	Pueschel (NASA Ames)	DC-8
	MASP	Gandrud (NCAR)	ER-2
	wire impactors	Pueschel (NASA Ames)	ER-2, DC-8
	LIDAR	Browell (NASA Langley)	DC-8

4.6 Specific Correlative Measurement Needs

The following notes the types of correlative measurements that may be of particular value to HIRDLS Data Validation. An important component of HIRDLS validation will be comparisons with multi-year observations from the Network for the Detection of Stratospheric Change (NDSC). These data are expected to be among the best validated measurements for comparison with HIRDLS measurements. Of particular use for a number of HIRDLS channels will be aerosol, temperature and ozone lidar measurements and FTIR measurements of O_3, HNO_3, $ClONO_2$, CH_4 and N_2O. Microwave measurements will provide profiles of H_2O and O_3well into the mesosphere. UV/visible spectrometers will yield the most useful results for NO_2. The combination of different instruments and the NDSC validation efforts will make these data a particularly useful correlative data set for HIRDLS validation.

4.6.1 Temperature

The HIRDLS temperature profiles will be compared to profiles from closely co-located radiosonde and lidar soundings and to satellite measurements from other EOS instruments, notably MLS and TES, instruments on non-US platforms, and operational sounders.

4.6.2 Dynamic Variables

Geopotential height fields derived from HIRDLS temperatures and conventional height data (with the aid of gyroscope information) will be used to calculate horizontal winds based on a balanced wind approximation (e.g., gradient wind). These winds will be compared with those provided by analyses of common data. In addition comparisons will be made with ground based wind measurements by radars and lidars, and rocket measured winds where available.

4.6.3 CFC 11 and CFC 12

During the EOS time frame, balloon experiments (followed by laboratory analysis of air samples) provide a means to measure CFC gas mixing ratios. Intercomparisons of retrievals of CFC 11 and CFC 12 with balloon measurements throughout the HIRDLS experiment will ensure confidence in the long term trends observed by the HIRDLS instrument. The CFC gas concentrations in the stratosphere are expected to be near a maximum during the HIRDLS mission. Several correlative measurements throughout the EOS time frame are desirable.

4.6.4 Ozone

During the EOS period, O_3 probably will be measured by several different techniques: ground based lidars including NDSC lidars, satellite instruments such as mentioned in section 4.4, and by balloon-borne instruments. Data validation will be carried out using these different techniques with special emphasis on comparisons with MLS and TES. As a check upon the size of the contaminant signal present in the O_3 HIRDLS channels, due to gases such as CO_2, a particularly useful data validation exercise will be to use a high resolution Michelson interferometer to assess the contaminant radiance level. For extreme conditions, ozone sondes will be very useful.

4.6.5 Aerosol

A primary concern with aerosol and clouds is their effects upon the infrared radiation; that is, how the aerosol contributes to the infrared opacity in a wavelength dependent manner. The wavelength dependence and the magnitude of the aerosol infrared opacity vary as a function of aerosol composition, space, and time. For example, aerosol particles from volcanic eruptions have extinction values which vary by a factor of 100 between periods shortly after the eruption and periods several years later. The wavelength dependence of the ambient aerosol extinction is also a function of pressure, temperature, and the H2O mixing ratio (these variables determine the H2SO4 content of the sulfuric acid droplets).

In the polar latitudes, Polar Stratospheric Clouds (PSCs) can produce extinctions substantially higher than the ambient aerosols. PSC compositions vary depending on the formation conditions. PSC particles can be composed of ternary solution droplets ($H_2SO_4/HNO_3/H_2O$), solid hydrates of nitric acid, mixed phases, and water ice particles. Based upon laboratory thin film studies, it is expected that the spectra for these particle types will differ.

Algorithms will be developed to use HIRDLS observations to measure the wavelength dependence of the aerosol spectra, and to separate the gaseous and aerosol contributions from the total radiance. The HIRDLS aerosol observations will initially be compared to historical climatologies compiled from measurements by instruments such as the UARS HALOE, ISAMS and CLAES instruments, and the solar occultation SAGE and OAM instrument series, for an initial assessment of reasonableness and spatial distribution.

Subsequently, the HIRDLS observations can be tested by comparison with correlative measurements of aerosol and aerosol spectra. Examples of correlative measurements include ground-based Lidar, balloon dust-sonde measurements, and satellite measurements such as the SAGE series of solar occultation instruments. Such comparisons will normally require model-dependent calculations, utilizing assumptions of, e.g., size distributions or composition. For example, in-situ particle size distributions, as measured by balloon-borne instrumentation at mid-latitudes, can be used to calculate sulfate aerosol spectra. Coordination of EOS and the mid-latitude balloon launches can provide for the intercomparisons of HIRDLS derived sulfate extinction with in-situ observations.

Other EOS sensors (i.e. the TES experiment) will observe aerosol spectra for the limb viewing geometry, and will provide an important means for spectral intercomparison. A further test is provided by comparisons of the retrievals of the gas phase constituents with in-situ sampling and observations of constituents by the MLS instrument. Since MLS observes in the microwave, particles have a much smaller influence on the microwave emission. If the aerosol has been properly accounted for in the HIRDLS retrieval, then the HIRDLS gas phase mixing ratios will agree with those measured by the in-situ sampling and MLS instruments.

4.6.6 N_2O_5, $ClONO_2$, HNO_3, and NO_2

Data validation of N_2O_5, $ClONO_2$, HNO_3, and NO_2 will be performed by comparing HIRDLS retrievals with those obtained by ground based and perhaps balloon-borne instrumentation. Simultaneous comparisons of these gases with TES retrievals and HNO_3 with MLS will also be very important. Also, comparisons with MIPAS observation will be useful. Of particular interest is to assess the ability to measure the topside fall off in mixing ratio value for N_2O_5, $ClONO_2$, and HNO_3. The vertical resolution of the correlative measurement instrument must be made adequate for this task. Measurements should avoid latitudes where occasional sunrises or sunsets occur which show large temporal gradients. A correlative measurements experiment must be timed accordingly. Easier correlative measurement tasks are to measure the mixing ratios of N_2O_5, $ClONO_2$, and HNO_3 near the altitude of mixing ratio profile maxima.

4.6.7 N_2O, CH_4, and H_2O

An important data validation task is to assess how well HIRDLS can retrieve N_2O, CH_4, and H_2O, especially as one goes to lower altitudes (i.e., upper troposphere), and particularly for those cases in which clouds and aerosol are present. Simultaneous comparisons of these gases with TES retrievals, and with MLS results for N_2O and H_2O will be conducted. Accurate balloon or aircraft measurements of these gases during the EOS time frame will be needed to validate the HIRDLS and other CHEM observations.

5.0 IMPLEMENTATION OF DATA VALIDATION PLAN

HIRDLS science data product validation activities will be led by the Co-Principle Investigators, Dr. J.C. Gille at the University of Colorado and NCAR, and Dr. J.J. Barnett at Oxford University, and supported by other members of the HIRDLS Science Team and project personnel. It is expected that much of the post-launch validation effort will occur within the first 1 1/2 years after launch with continued examination and refinement of science data product uncertainties over the course of the 5 year mission. A comprehensive implementation plan including schedules and plans for archival of validation data will be developed as details of ground data system and data processing become available for the CHEM mission.

6.0 SUMMARY

The HIRDLS validation plan, to be conducted by the HIRDLS science team, includes preparatory tasks in the pre-launch period as well as post-launch interaction with various instrument and investigation groups. The goal of the validation effort is to determine the accuracy and precision of the various HIRDLS science data, and consequently the appropriateness of their use in future scientific investigations.

The key steps to be taken in this process will be;

1) Pre-launch testing and calibration (This is described in other HIRDLS documents);
2) Pre-launch testing and analysis of the retrieval algorithms (to be described in the ATBD's);
3) On orbit evaluation of instrument performance and consistency, including comparison of observed signals with ones calculated for climatological conditions ;
4) Evaluation of initial retrievals for plausibility compared to climatological values, and spatial and temporal consistency;
5) Estimation of retrieval precision;

The validation process described above will result in science data products with well quantified uncertainty over a stated range of atmospheric and observational conditions. In addition, any anomalies found in the data will be traceable to algorithm, instrument, physical, or spacecraft causes or identified as real geophysical phenomena.