SC–HIR–018L

HIRDLS

HIGH RESOLUTION DYNAMICS LIMB SOUNDER

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Contents / Description / Summary:

This document describes the requirements that the High Resolution Dynamics Limb Sounder (HIRDLS) instrument must meet in order to satisfy the scientific goals of the HIRDLS Program.

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Purpose (20 characters maximum): specify requirements

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DOCUMENT REVISIONS

Substantive Revisions of This Document, Relative to the Previous Version

Section Number	Section Heading	Comments
1.5	Definitions	added the definition of the ECIRCF
1.6	Referenced Documents	added SP–HIR–154
2	INVESTIGATION AND INSTRUMENT REQUIREMENTS	added "INVESTIGATION AND" to the heading; divided the section into two parts entitled "INVESTIGATION REQUIREMENTS" and "INSTRUMENT REQUIREMENTS"
2.1.2	Orbit	changed "4°" to "5° or less"
2.1.3	Orbital Position Knowledge	rewrote the requirement
2.1.4	Spacecraft Attitude Stability	removed the TBV; rewrote the requirement
2.2.1	Global Mode	added "with a maximum coarseness"; changed "4°" to "5°"
2.2.2	Alternative Global Mode	added "maximum"; changed "400 km" to "500 km"
2.2.3	Medium Resolution Mode	added "nominal"
2.2.4	High Resolution Mode	added "nominal"
2.4.1	Spectral Response	changed the specifications of the spectral channels (and the format of their presentation) in Table 1
2.4.3	Out-of-Band Response	removed the TBV; clarified the requirement; changed "2.1" to "4.2" for the radiometric noise of HNO_3 in Table 3
2.4.4	Out-of-Band Response Knowledge	removed the TBV; clarified the requirement
2.5.1	Radiometric Accuracy	removed the TBV; rewrote the requirement
2.5.2	In-Flight Radiometric Calibration	removed the four TBVs from the minimum space view values in Table 2
2.5.9	Radiometric Sampling Uniformity	clarified the requirement
2.6.2	Out-of-Field Response	removed the TBV; rewrote the requirement to parallel § 2.4.3
2.6.2.1	Out-of-Field Response Knowledge	added the requirement to parallel § 2.4.4

Substantive Revisions of This Document, Relative to the Previous Version (continued)

Section Number	Section Heading	Comments
2.6.3.1	Vertical Spatial Response Knowledge for a Channel	removed the TBV; changed “2 arcseconds” and “7 arcseconds” to “10 µrad” and “33 µrad”
2.6.3.2	Vertical Spatial Response Knowledge for a Channel Pair	rewrote the requirement
2.7.1	Altitude Scan Range	removed the TBV; clarified the requirement
2.7.3	Altitude Scan Rate Uniformity	removed the requirement
2.7.5.1	Relative Altitude Angle Knowledge within a Scan	removed the parenthetical comment from the end of the systematic error requirement; clarified the random error requirement; converted arcseconds to microradians
2.7.5.2	Relative Altitude Angle Knowledge between Scans	converted arcseconds to microradians
2.8.2.1	Azimuth Step Size Flexibility	changed “4°” to “5°”
2.8.3.1	Absolute Azimuth Angle Knowledge	changed “0.1°” to “0.15°”
2.10.4	Spacecraft and Orbital Data	clarified the requirement

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1 INTRODUCTION

1.1 Purpose of This Document

This document presents the current version of the requirements for the High Resolution Dynamics Limb Sounder (HIRDLS), to insure that its performance will meet the scientific goals of the experiment, as presented in the Science Requirements Document (SRD, SC–HIR–012B). These requirements are intended to be the first step in the instrument specification. All of the critical performance requirements that are needed to achieve the desired scientific results are presented. Unless stated otherwise, the requirements may be met after the application of agreed-upon calibration or correction factors.

Trade-offs between better performance in one parameter versus poorer performance in another will be clarified during the course of the instrument specification. The Science Team will evaluate these trade-offs in terms of their impact on the scientific return of the experiment, and they will update the requirements as needed. Some of the requirements may prove to be quite demanding, leading to concerns about technical difficulties, with consequent implications for schedule and cost. All such issues must be brought to the attention of the Principal Investigators as soon as possible, so that the costs and risks can be weighed against the scientific benefits of meeting the requirement at issue.

1.2 Necessity of Infrared Limb Scanning

The HIRDLS instrument is being designed to examine the role of the upper troposphere, stratosphere, and mesosphere in global atmospheric change. This requires measurements of the temperature and a large number of trace species, with global coverage, day and night (including the polar night). Consequently, the instrument must measure atmospheric emission, rather than absorption. Furthermore, since the atmospheric quantities must be determined with high vertical resolution, the atmosphere must be observed at the limb, with a narrow field of view (FOV). High vertical resolution also dictates the use of limb scanning, rather than limb staring, because the high spatial frequency features in the atmosphere can be measured by oversampling. Low noise is another critical requirement for high vertical resolution, because the high spatial frequency features must be measured with a signal-to-noise ratio (S/N) that is greater than unity. Otherwise, the desired vertical resolution of 1 km is unachievable. These requirements motivate the choice of infrared (IR) observations. In addition, there are easily measurable IR emission features, the technology is well developed, and there is a large amount of experience in this field.

1.3 Baseline Configuration

It is necessary to have a general concept for the HIRDLS instrument, in order to develop the instrument requirements. This assumed baseline configuration is presented in this section, with the understanding that it is not an instrument description or specification.

The HIRDLS instrument will be a multichannel limb-scanning IR radiometer for high resolution monitoring of upper tropospheric, stratospheric, and mesospheric temperature, trace chemicals, and geopotential height gradients. These are the key elements that are needed to understand the chemistry and dynamics of those regions, including the roles of planetary and gravity waves in transporting and mixing radiatively and chemically active species that are important to climate change. 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 principal novel characteristics of the HIRDLS instrument are:

- the improved horizontal resolution,
- the improved vertical resolution,
- the improved ability to sound the tropopause region, and
- the ability to sound a large number of trace species with a range of chemical lifetimes.

1.4 Principles of Infrared Limb Scanning

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. This document spells out the requirements that meet this need.

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 being critical pieces of scientific information.

1.5 Definitions

Earth-Centered Inertial Reference Coordinate Frame (ECIRCF)

The ECIRCF is a right-handed Cartesian coordinate system with the origin at the center of mass of the earth and the positive *Z* axis directed toward the north pole of the earth, along the predicted rotation axis of the earth at midnight on 2000–01–01. The positive *X* axis is directed toward the vernal equinox at the same time and date, and the *Y* axis is determined by the right-hand rule. The orbital position requirements in this document are specified relative to the ECIRCF. Further information about the ECI and related coordinate systems is available in the Technical Paper from Hughes Applied Information Systems entitled "Theoretical Basis of the SDP Toolkit Geolocation Package for the ECS Project" (445–TP–002–002).

Spacecraft Reference Coordinate Frame (SRCF)

The SRCF is a right-handed Cartesian coordinate system with the origin at the center of mass of the spacecraft (S/C) and the positive *z* axis directed toward the center of mass of the earth. The *x* axis lies along the line of intersection between the plane perpendicular to the *z* axis and the instantaneous orbital plane of the S/C, with the positive *x* axis directed approximately parallel to the velocity vector of the S/C. The *y* axis is determined by the right-hand rule. All of the pointing requirements in this document are specified relative to the SRCF, unless stated otherwise.

1.6 Referenced Documents

SC–HIR–012B	Science Requirements Document
SP–HIR–090A	Fiducial Atmospheric Radiance Profiles
SP–HIR–154	Out-of-Band Spectral Blocking Requirements

2 INVESTIGATION AND INSTRUMENT REQUIREMENTS

INVESTIGATION REQUIREMENTS

2.1 Orbital Platform Requirements

2.1.1 Platform

The instrument must be flown on an earth-oriented S/C with three-axis stabilization.

2.1.2 Orbit

The platform for the instrument must have a sun-synchronous near-circular polar orbit. The daytime equator-crossing time should be within 4.5 h of local noon. (However, because of expected technical constraints, it should not be closer than 1.5 h to local noon.) During both the northbound and southbound halves of the orbit, the instrument must be able to measure atmospheric radiance profiles with a longitudinal spacing of 5° or less, for all latitudes and seasons. The acceptable range for the mean orbital height is (600 to 1100) km; however, the instrument should be designed for the expected range of (650 to 850) km. This orbital height above the geoid should vary by at most ± 20 km around an orbit, but a larger variation can be accommodated if necessary. To the extent possible, the instrument requirements are expressed in ways that are independent of the platform and its orbit. Where necessary (or for illustrative purposes), a nominal orbital height of 705 km and an orbital period of 98.9 min are assumed.

2.1.3 Orbital Position Knowledge

The error in the knowledge of the distance from the center of mass of the earth must be at most 5 m (1σ), at all times. The error in the knowledge of the angular velocity of the S/C about the center of mass of the earth must be at most 0.12 $\mu rad \cdot min^{-1}$ (1σ), at all times. Relative to the ECIRCF (see § 1.5), the error in the knowledge of the orbital position across the orbital track must be at most 1 km, at all times.

2.1.4 Spacecraft Attitude Stability

The error in the knowledge of the rotational rate of the S/C around the pitch and roll axes of the SRCF (see § 1.5) must be at most 4.8 $\mu rad \cdot s^{-1}$, to allow the instrument to collect usable scientific data without the aid of a gyroscope.

INSTRUMENT REQUIREMENTS

2.2 Scientific Operational Mode Requirements

The instrument must have a choice of operational modes for collecting scientific data, and it must be possible to select and control these modes from the ground. The modal parameters that must be selectable from the ground are: the upper and lower limits of the altitude scan, the azimuth angle, the scan rate, and the channels to be sampled. The first mode described below is the principal, general one; the others are examples of special research modes.

2.2.1 Global Mode

This is the normal mode for collecting scientific data. The limb scans are performed on a nominal global grid with a maximum coarseness of 5° longitude by 5° latitude. This is also the default mode.

2.2.2 Alternative Global Mode

This mode also observes the atmosphere on a nominal global grid; however, the maximum grid size is 500 km in both longitude and latitude.

2.2.3 Medium Resolution Mode

This mode produces a nominal resolution of 2° in both longitude and latitude, within 4° longitudinal strips that cover the globe. The vertical scan rate is the same as, or faster than, that for the global mode.

2.2.4 High Resolution Mode

This mode is the same as the previous mode, but with a higher resolution. Within 2° longitudinal strips, the nominal resolution is 1° in both longitude and latitude.

2.2.5 Orbital Period Mode

This mode allows the atmospheric locations that correspond to extreme azimuth angles in one orbit to also be observable from adjacent orbits.

2.2.6 Gravity Wave Mode

This mode yields the highest vertical resolution of the six modes, by scanning at the slowest rate that is specified in section 2.7.2.1.

2.3 Lifetime Requirements

2.3.1 Moved to Section 2.3.2

2.3.2 Reliability

The instrument must be designed to have an 85 % probability of operating within specifications during five years in orbit.

2.4 Spectral Channel Requirements

2.4.1 Spectral Response

The desired 50 % points of the spectral response curves for the twenty-one channels of the instrument are shown in Table 1. The minimum and maximum permissible values for both of the 50 % response points are also listed in Table 1.

2.4.2 Spectral Response Knowledge

The relative spectral response of a channel is given by $S(\tilde{\nu}) / S_{\max}$, where $S(\tilde{\nu})$ is the spectral response at a wave number $\tilde{\nu}$, and $S_{\max}$ is the maximum spectral response for that channel. The wave number at which the response is measured must be known with an accuracy of 0.2 cm^{-1} (1σ). For frequencies between the 1 % points of the relative spectral response function, the error in the knowledge of the relative spectral response to unpolarized radiation must be at most 1 %. The spectral resolution for this knowledge must be at most 1 cm^{-1}, with three samples per resolution element. Between either 1 % point and the corresponding 0.2 % point, the error in the knowledge of the relative spectral response must not be greater than 100 %. Compliance with these requirements should be determined by both measurement and analysis, and the requirements must be maintained over the operational lifetime of the instrument in orbit.

2.4.3 Out-of-Band Response

The out-of-band response of a channel is defined as the integrated response outside of the points where the relative spectral response is 0.2 %. While viewing the atmosphere over the sounding ranges that are listed in Table 2, or while viewing the in-flight calibration (IFC) blackbody, the out-of-band response must be at most the greater of: (1) 1 % of the total integrated response or (2) 200 % of the radiometric noise that is specified in Table 3. The requirement of 0.5 % of the total integrated response in section 2.4.4 takes precedence over the 1 % requirement in this section. Therefore, the 1 % requirement can be relaxed, as long as the 0.5 % requirement is still met. These requirements must be maintained over the operational lifetime of the instrument in orbit. The HIRDLS document SP–HIR–154 specifies the atmospheric scene radiances that must be used to demonstrate compliance with this requirement.

2.4.4 Out-of-Band Response Knowledge

Over the atmospheric sounding range, or while viewing the IFC blackbody, the error in the out-of-band response knowledge must be at most the greater of: (1) 0.5 % of the total integrated response or (2) 100 % of the specified radiometric noise.

2.4.5 Focal Plane Layout

2.4.5.1 Rows of the Focal Plane Array

The channels each have a specific altitude range over which they are useful, as listed in Table 2. The layout should reflect this fact (in order to minimize the altitude scan range), by placing the low altitude channels in the lower rows of the focal plane array and the high altitude channels in the upper rows.

2.4.5.2 Columns of the Focal Plane Array

Some of the channels are designed to work together, because considerable information can be derived by using the signals in combination. These channels should be adjacent to each other in a column. The relevant channel pairs are:

- the N_2O, aerosol channel (#1) and the low altitude CO_2 channel (#2),
- aerosol channel number 6 and the $CFCl_3$ channel (#7), and
- the low altitude H_2O channel (#18) and aerosol channel number 19.

Ideally, channels that are combined in the retrieval algorithm to form a common product should be placed in the same column. This is probably not always possible. However, it is very important that the CO_2 channels should be in the same column, since they are used to retrieve the temperature and pressure.

The series of channels numbered 13 to 17 constitutes a coupled group for which spatial closeness in the focal plane is also advantageous.

Table 1—Spectral Channels

Channel		Lower 50 % Response Point [cm^{-1}]			Upper 50 % Response Point [cm^{-1}]		
Number	Species	Minimum	Desired	Maximum	Minimum	Desired	Maximum
1	N_2O, aerosol	561.50	563.00	565.50	586.25	588.00	588.25
2	CO_2	598.50	600.00	602.50	613.75	615.00	615.75
3	CO_2	607.00	610.00	613.00	637.50	640.00	641.50
4	CO_2	623.00	626.00	629.00	657.00	660.00	663.00
5	CO_2	652.00	655.00	658.00	677.00	680.00	683.00
6	aerosol	819.20	821.00	823.80	832.60	836.00	837.40
7	$CFCl_3$	832.60	835.00	837.40	849.60	853.00	854.40
8	HNO_3	859.00	860.00	864.00	901.00	905.00	906.00
9	CF_2Cl_2	913.40	915.00	918.60	928.90	933.00	934.10
10	O_3	988.20	990.00	993.80	1006.20	1010.00	1011.80
11	O_3	1008.10	1011.00	1013.90	1043.60	1048.00	1049.40
12	O_3	1116.80	1120.00	1123.20	1135.30	1140.00	1141.70
13	aerosol	1198.60	1200.00	1205.40	1216.60	1220.00	1223.40
14	N_2O_5	1227.50	1229.00	1231.50	1258.75	1260.00	1260.75
15	N_2O	1255.25	1256.00	1257.25	1280.75	1282.00	1282.75
16	$ClONO_2$	1277.25	1278.00	1279.25	1297.75	1299.00	1299.75
17	CH_4	1321.70	1324.00	1329.30	1363.70	1369.00	1371.30
18	H_2O	1383.00	1385.00	1391.00	1431.00	1435.00	1439.00
19	aerosol	1401.25	1402.00	1403.25	1414.75	1416.00	1416.75
20	H_2O	1417.90	1422.00	1426.10	1537.70	1542.00	1546.30
21	NO_2	1581.00	1582.00	1590.00	1625.90	1634.00	1635.10

Table 2—Critical Atmospheric Tangent Heights

Channel Number	Species	Atmospheric Sounding Range* [km]	Minimum Space View [km]
1	N_2O, aerosol	8 to 70	75
2	CO_2	8 to 40	95
3	CO_2	8 to 60	125
4	CO_2	15 to 60	140
5	CO_2	30 to 105	150
6	aerosol	8 to 55	65
7	$CFCl_3$	8 to 50	60
8	HNO_3	8 to 70	65
9	CF_2Cl_2	8 to 50	65
10	O_3	8 to 55	100
11	O_3	30 to 85	105
12	O_3	8 to 55	80
13	aerosol	8 to 55	65
14	N_2O_5	8 to 60	70
15	N_2O	8 to 70	75
16	$ClONO_2$	8 to 70	75
17	CH_4	8 to 80	75
18	H_2O	8 to 40	75
19	aerosol	8 to 55	65
20	H_2O	15 to 85	75
21	NO_2	8 to 70	70

* These ranges represent the tangent heights over which useful retrievals will be possible, plus an additional 15 km at the upper boundary, which is required for the retrieval process.

2.5 Radiometric Requirements

2.5.1 Radiometric Accuracy

The systematic error in the knowledge of the radiances must be at most the greater of: (1) 0.5 % of the radiance for spectral channels 2 to 5 and 1 % for the other channels or (2) 100 % of the radiometric noise that is specified in Table 3.

2.5.2 In-Flight Radiometric Calibration

The in-flight radiometric accuracy will be established by using the space view at the top of an altitude scan and by viewing a known-temperature IFC blackbody through the entire optical system. The minimum tangent height for a good space view in each channel is given in Table 2.

2.5.3 Radiometric Noise

The radiometric noise in each channel must be less than or equal to the radiometric noise value specified in Table 3. These values assume an effective measurement bandwidth of 7.5 Hz, which is the nominal bandwidth for the global mode.

Table 3—Radiometric Parameters

Channel Number	Species	Radiometric Noise* [10^{-4} W·m^{-2}·sr^{-1}]	Maximum Expected Atmospheric Radiance [W·m^{-2}·sr^{-1}]	Radiance of a 300 K Blackbody [W·m^{-2}·sr^{-1}]
1	N_2O, aerosol	12	2.328	3.897
2	CO_2	6.3	0.9052	2.337
3	CO_2	5.9	1.658	4.656
4	CO_2	6.0	1.997	5.248
5	CO_2	4.3	1.775	3.819
6	aerosol	1.9	2.268	1.980
7	$CFCl_3$	2.0	2.597	2.328
8	HNO_3	4.2	6.265	5.514
9	CF_2Cl_2	2.0	2.307	2.070
10	O_3	1.5	1.417	2.017
11	O_3	2.4	1.230	3.531
12	O_3	0.96	1.380	1.555
13	aerosol	1.1	0.9657	1.299
14	N_2O_5	1.1	0.8515	1.856
15	N_2O	1.1	0.3474	1.467
16	$ClONO_2$	1.1	0.2055	1.129
17	CH_4	1.2	0.5231	2.091
18	H_2O	1.2	0.5404	1.967
19	aerosol	1.3	0.1881	0.5517
20	H_2O	1.6	0.7407	3.901
21	NO_2	1.1	0.2041	1.173

* These values assume an effective measurement bandwidth of 7.5 Hz, which is the nominal bandwidth for the global mode.

2.5.4 Radiometric Digitization Error

The RMS digitization error (i.e., $\Delta / \sqrt{12}$, where Δ is the digitization step size) must be at most 50 % of the radiometric noise that is specified in Table 3.

2.5.5 Radiometric Digitization Step Size Uniformity

The radiometric signals must be digitized with a resolution of one part in 2^{16}, and the step size must be uniform to within $\Delta / 2$.

2.5.6 Radiometric Dynamic Range

The instrument must be capable of measuring radiances up to 1.25 times the maximum expected atmospheric radiances listed in Table 3. (For the sake of convenience, Table 3 also gives the radiance of a 300 K blackbody, for each spectral channel.)

2.5.7 Moved to Section 2.6.2

2.5.8 Radiometric Sampling Rate

In the global mode, the limb radiance must be measured five times per FOV. In other modes the sample spacing and the number of channels sampled will be selected so that the data rate is not greater than the global mode data rate.

2.5.9 Radiometric Sampling Uniformity

The spacing between the LOS positions of adjacent radiance samples that are taken during a uniform segment of an altitude scan (see § 2.7.2.2) must not deviate from the mean spacing by more than 25 %.

2.5.10 Radiometric Signal Processing

2.5.10.1 Spatial Resolution and Noise Rejection

In the global mode, the signal-processing system must pass signals with atmospheric spatial frequencies of (0 to 1) km^{-1}. Over the spatial frequency range of (0 to 0.5) km^{-1}, the gain and the attenuation of the signal must be constant to within 0.1 dB; for (0.5 to 1) km^{-1}, they must be constant to within 0.5 dB. Any noise signals that might be aliased into the signal band by the sampling process must be attenuated by at least 20 dB, for all operational modes.

2.5.10.2 Digital Filter

A programmable digital filter is required for each channel, so that the performance of the signal-processing system can be optimized in orbit, for each mode of operation. This filter will also allow the sensitivity to drifts or changes in component values to be minimized.

Some of the operational modes will require a higher sampling rate than that of the global mode. (No modes with a lower sampling rate are envisaged.) Therefore, a subset of the twenty-one channels will be sampled in those modes. The digital part of the signal-processing system must be sufficiently programmable to allow a subset of channels to be sampled at a rate that meets the requirements of section 2.5.10.1, without exceeding the maximum specified data output rate. It must also be possible to sample a subset of channels at least five times per FOV, for any scan rate that is required by section 2.7.2.1.

2.5.10.3 Filter Characteristic Knowledge

For spatial frequencies of (0 to 1) km^{-1}, the error in the knowledge of the filter characteristic for the gain/frequency must be at most 0.01 dB (i.e., 0.2 %). This level of knowledge must be maintained over the operational lifetime of the instrument in orbit.

2.5.11 Radiometric Intercalibration

It must be possible to compare the calibration of the HIRDLS instrument with that of other EOS instruments by, for example: (1) the use of a roving black target or reference radiometer at the HIRDLS calibration facility or (2) a comparison in vacuum at the facility of the S/C contractor.

2.6 Optical Requirements

2.6.1 Field of View

For the end-to-end vertical instrument response function of each channel (i.e., the response to a line source that is tangent to the limb of the earth), the design goal is a function with a full width at half maximum (FWHM) of 1 km, when measured at the limb. The acceptable range for the

FWHM is (0.9 to 1.05) km. The integrated vertical response between the half-maximum points must be at least 80 % of the total integrated response. Define the center of the vertical FOV as the midpoint between the half-maximum points, and let Δz be the distance (in kilometres at the limb) from this center. For $\Delta z \le 0.75$, the integrated response must be at least $(100 - 0.4\lambda)$ % of the total, where λ is the central wavelength (in micrometres) of the channel; for $1 \le \Delta z \le 4$, the integrated response must be at least $(100 - 0.25\lambda / \Delta z^{1.15})$ % of the total; and for $\Delta z > 4$, the vertical response function is governed by the Out-of-Field Response requirement in section 2.6.2. The FWHM of the horizontal FOV must be less than 72 km. The FOV specifications of a channel only apply to altitude angles within the atmospheric sounding range of that channel, and they only apply at an azimuth angle of zero. At other azimuth angles, the vertical response must not broaden more than that resulting from image rotation.

2.6.2 Out-of-Field Response

The out-of-field response of a channel is defined as the integrated response (including optical cross talk) to scene radiance that originated from points in the FOV with $\Delta z > 4$ (see § 2.6.1). Over the atmospheric sounding range, or while viewing the IFC blackbody, the out-of-field response must be at most the greater of: (1) 1 % of the total integrated response or (2) 200 % of the radiometric noise that is specified in Table 3. The requirement of 0.4 % of the total integrated response in section 2.6.2.1 takes precedence over the 1 % requirement in this section. Therefore, the 1 % requirement can be relaxed, as long as the 0.4 % requirement is still met. These requirements must be maintained over the operational lifetime of the instrument in orbit. The HIRDLS document SP–HIR–090A specifies the atmospheric scene radiances that must be used to demonstrate compliance with this requirement.

2.6.2.1 Out-of-Field Response Knowledge

Over the atmospheric sounding range, or while viewing the IFC blackbody, the error in the out-of-field response knowledge must be at most the greater of: (1) 0.4 % of the total integrated response or (2) 100 % of the specified radiometric noise.

2.6.3 Vertical Spatial Response Knowledge

2.6.3.1 Vertical Spatial Response Knowledge for a Channel

The vertical spatial response (VSR) of a channel is the horizontally integrated response of that channel to radiation, within its FOV, that has passed through the entire optical system. The relative VSR is given by $F(z) / F_{max}$, where $F(z)$ is the VSR at a relative vertical position z, and F_{max} is the maximum VSR within the FOV. The relative position at which the response is measured must be known with an accuracy of 10 µrad (i.e., 30 m at the limb). For positions between the 1 % points of the relative VSR function, the error in the knowledge of the relative VSR must be at most 1 %. The spatial resolution for this knowledge must be at most 33 µrad (i.e., 100 m at the limb), with three samples per resolution element. Between either 1 % point and the corresponding 0.2 % point, the error in the knowledge of the relative VSR must not be greater than 100 %. Compliance with these requirements should be determined by both measurement and analysis, and the requirements must be maintained over the operational lifetime of the instrument in orbit.

2.6.3.2 Vertical Spatial Response Knowledge for a Channel Pair

For each pair of channels, the relative altitude angle between the centroids of the VSRs of the two channels must be known to an accuracy of 10 µrad (i.e., 30 m at the limb) for spectral channels 2 to 5 and 20 μrad for the other channels, over the operational lifetime of the instrument in orbit.

2.7 Altitude-Pointing and -Scanning Requirements

The altitude angle of a spectral channel is the angle between the LOS of the centroid of the vertical response of that channel and the (*x*,*y*) plane of the SRCF (see § 1.5).

2.7.1 Altitude Scan Range

The altitude scan range must be sufficiently large to allow each channel to view any location between the bottom of the atmospheric sounding range and 10 km above the minimum space view tangent height specified in Table 2, at all points along the S/C orbit.

2.7.2 Altitude Scan Flexibility

2.7.2.1 Altitude Scan Rate Flexibility

The scanner must be able to change the altitude angle of the instrument FOV at rates from $0.1°·s^{-1}$ to $1.0°·s^{-1}$ (inclusive), adjustable in increments of at most $0.01°·s^{-1}$.

2.7.2.2 Altitude Scan Range Flexibility

The instrument must be able to scan at a uniform angular rate over a segment of tangent heights as short as 5 km or as long as 140 km, and it must be able to perform a scan over the entire atmospheric sounding range as a sequence of up to four segments with different scan rates.

2.7.3 Removed

2.7.4 Moved to Section 2.7.1

2.7.5 Altitude Angle Knowledge

It is not necessary to know the absolute altitude angle; however, it is critical to know the relative angle between any two radiance measurements, where each measurement is located by its LOS.

2.7.5.1 Relative Altitude Angle Knowledge within a Scan

For a single altitude scan, the systematic error in the knowledge of the relative altitude angle θ for any two radiances that are measured with the same channel must be at most the greater of:
(1) $2.5 \times 10^{-3}\ \theta$ or (2) 1.7 μrad.

The random error in θ, within an effective bandwidth of 7.5 Hz, must be at most 4.8 μrad (1σ), with a design goal of 3.4 μrad (1σ). These values include the errors in the measurement of the LOS, and the measurement errors of the motions and vibrations of the S/C and the instrument.

2.7.5.2 Relative Altitude Angle Knowledge between Scans

The error in the knowledge of the relative altitude angle for two radiances that are measured by the same channel, but in adjacent altitude scans, must be at most 6.8 μrad (1σ). This applies whether the two adjacent altitude scans are in a single azimuth scan, in two azimuth scans that are sequential along the orbit, or in two azimuth scans at approximately the same latitude from successive orbits.

2.7.6 Moved to Section 2.7.5.2

2.8 Azimuth-Pointing and -Scanning Requirements

The azimuth angle of a spectral channel is the angle between the *x* axis of the SRCF (see § 1.5) and the projection of the LOS of the centroid of the horizontal response of that channel onto the (*x*,*y*) plane.

The scanner azimuth angle will normally be held constant during the atmospheric sounding portion of an altitude scan (see § 2.7.1).

2.8.1 Azimuth Scan Range

The azimuth scan range must extend as close to the direction of the sun as possible, on one side, and far enough on the other side to overlap one or more scan tracks from the adjacent orbit. A door/sunshade can be used to extend the scan range on the sun side.

2.8.2 Azimuth Scan Flexibility

2.8.2.1 Azimuth Step Size Flexibility

The primary factor that influences the step size of the azimuth scan is the desire for coverage of the entire surface of the earth at a resolution of 5° longitude by 5° latitude, in the global mode. (This implies that six altitude scans, the azimuth changes between them, any space view for IFC, and the return of the azimuth angle to the starting point for the next azimuth scan cycle must all be accomplished in the time it takes the tangent point to move 5° in latitude.) In all scientific operational modes, it must be possible to vary the azimuth step size with latitude. The smallest necessary step size for the azimuth angle is that corresponding to one-half of the horizontal FOV.

2.8.2.2 Azimuth Scan Range Flexibility

In the global mode, the azimuth scan range, in terms of the azimuth angles at the S/C, will vary with latitude. The research modes also require a flexible scan range. The needed flexibility includes both the extent of the scans and the number and spacing of the azimuth angles at which altitude scans are made.

2.8.3 Azimuth Angle Knowledge

2.8.3.1 Absolute Azimuth Angle Knowledge

Over the entire atmospheric sounding range, the absolute azimuth angle must be known with an error of at most 0.15°.

2.8.3.2 Relative Azimuth Angle Knowledge

The error in the knowledge of the relative azimuth angle of each channel between two adjacent altitude scans must be at most 0.04°. This applies whether the two adjacent altitude scans are in a single azimuth scan, in two azimuth scans that are sequential along the orbit, or in two azimuth scans at approximately the same latitude from successive orbits.

2.8.4 Scanner Azimuth Angle Knowledge

The error in the knowledge of the absolute scanner azimuth angle must be at most 0.02°, over the operational lifetime of the instrument in orbit.

2.9 Instrument Control Requirements

2.9.1 Instrument Microprocessor

The instrument must be controlled by at least one instrument microprocessor (IMP) that can be programmed from the ground. The instrument operations described in sections 2.9.2 to 2.9.7 will be under the control of an IMP, but it must be possible to override or modify the preprogrammed sequences and settings at any time from the ground.

2.9.2 Door/Sunshade Control

An IMP must control the door/sunshade, preventing direct solar radiation from entering the front baffle, but allowing the LOS to approach the direction of the sun as closely as possible.

2.9.3 Altitude Scan Control

An IMP must be able to control the altitude scan range, rate, and vertical location, as a function of the orbital position, the time, or the radiance levels.

2.9.4 Azimuth Scan Control

An IMP must be able to control the number of altitude scans and their azimuth angles, as a function of the orbital position or the time.

2.9.5 Scan Synchronization Control

At present, there is no requirement to synchronize the scans with orbital events. If this ability is desired in the future, it may be accomplished through IMP control.

2.9.6 Electronic Filter Control

An IMP must be able to control the sampling rate and the characteristics of the digital filtering in the signal-processing chain.

2.9.7 Other Subsystem Control

An IMP must be able to control other subsystems that affect data collection, data quality, or the interpretation of the measurements.

2.10 Data Output Requirements

2.10.1 Scientific Data

The instrument must provide the following scientific data to the S/C, for transmission to the ground: all of the radiometer outputs and the data necessary to determine the LOS positions at which they were taken; also, the door angle and those temperatures and other parameters that are necessary to interpret the radiometer outputs. The scientific data must be taken continuously during the altitude and azimuth scans.

2.10.2 Moved to Section 2.5.10.1

2.10.3 Moved to Section 2.5.10.3

2.10.4 Spacecraft and Orbital Data

The data stream must be designed to allow for the incorporation of time and other selected S/C data. The following information is desired: orbital data, S/C attitude and attitude rate-of-change data, and the S/C event markers (e.g., ascending node and terminator crossings, attitude control operations, etc.).

It must be possible to ascertain the time of each radiance sample (and its corresponding LOS direction) to an accuracy that allows the time difference between any two samples to be determined with an accuracy of 200 μs or a relative accuracy of 2 $\mu s \cdot s^{-1}$, whichever is greater.

2.10.5 Engineering Data

The engineering data for the instrument (e.g., temperatures, voltages, motor currents, etc.) should be subcommutated within the scientific data stream.

ACRONYMS

ECI	earth-centered inertial
ECIRCF	Earth-Centered Inertial Reference Coordinate Frame
ECS	EOSDIS Core System
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
FOV	field of view
FWHM	full width at half maximum
HIRDLS	High Resolution Dynamics Limb Sounder
IFC	in-flight calibration
IMP	instrument microprocessor
IR	infrared
IRD	Instrument Requirements Document
LOS	line of sight
RMS	root mean square
S/C	spacecraft
S/N	signal-to-noise ratio
SDP	science data production
SRCF	Spacecraft Reference Coordinate Frame
SRD	Science Requirements Document
VSR	vertical spatial response