GOES HYPERSPECTRAL ENVIRONMENTAL SUITE (HES)

PERFORMANCE AND OPERATION REQUIREMENTS DOCUMENT (PORD)

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GOES
HYPERSPECTRAL ENVIRONMENTAL SUITE

PERFORMANCE AND
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Table of Contents

LIST OF FIGURES

LIST OF TABLES

1 SCOPE

1.1 IDENTIFICATION

This Sensor Performance and Operations Requirements document sets forth the performance requirements for the NOAA Hyperspectral Environmental Suite (HES).

1.2 DOCUMENT OVERVIEW

This document contains all performance requirements for the sensor except those labeled “TBD”, “TBS”, and “TBR”. The term “TBD”, meaning "to be determined" applied to a missing requirement means that the contractor should determine the missing requirement in coordination with the government. The term “TBS”, meaning "to be specified", indicates that the government will supply the missing information in the course of the contract. The term “TBR”, meaning "to be reviewed" implies that the requirement is subject to review for appropriateness by the contractor or the government. The government may change “TBR” requirements in the course of the contract.

1.2.1 Requirement Weighting Factors

The requirements stated in this specification are not of equal importance or weight. The following two paragraphs define the weighting factors incorporated in this specification.

- **Shall** designates the most important weighting level, which is *mandatory*. Any deviations from these contractually imposed mandatory requirements require the approval of the contracting officer.
- Should designates an intermediate weighting that indicates the requirements requested by the government are not mandatory. These are goal requirements that would greatly enhance the utility of the data if they were met. Unless required by other contract provisions, noncompliance with the should requirements does not require approval of the contracting officer, but requires documented technical substantiation.

1.2.2 Conflicts

In the event of conflict between the referenced documents and the contents of this document, the contents of this requirements document **shall** be the superseding requirements.

In the event of a conflict involving the external interface requirements, or in the event of any other unresolved conflict, the NASA contracting officer **shall** determine the order of precedence.

1.2.3 Detector and Pixel Definition

Throughout this document, the term 'detector sample' refers to a physical detector and its output after the A/D converter. The term 'pixel' applies to data samples after processing, including calibration and navigation.

1.2.4 Requirements Applicability

All requirements **shall** apply over the entire life of the HES.
All requirements in this document apply to data after any ground processing except as indicated in the Radiometric Accuracy and Precision sections within this document.

1.2.5 Units of Measure

For all documents, the contractor **shall** use the International System of Units (SI) for all measurement units in accordance with IEEE/ASTM SI-10. The contractor may include English units in parenthesis for clarification.
Large angles, greater than 1.0 milliradian, **shall** be in decimal degrees.
Small angles, equal to or less than 1.0 milliradian, **shall** be in microradians (μrad).

1.3 MISSION OVERVIEW

A main goal of GOES-R is to maintain continuity of GOES service to users and user agencies and to upgrade services. The weather and environmental monitoring instruments of GOES-R include at least the Advanced Baseline Sounder (ABI) and the Hyperspectral Environmental Suite, designated HES in this document. The HES is ***any combination of instrument or instruments that meet the requirements of the tasks described in this document***. It is anticipated that the instrument(s) meeting the disk

sounding (DS) and severe weather/mesoscale (SW/M) tasks of this document will be either a dispersive spectrometer or an interferometric spectrometer.

The HES suite will provide data to the HES Ground System, designated as HES-GS in this document, via the spacecraft communication system. The HES-GS will be procured by the government but may implement algorithms developed by the vendor to satisfy HES performance requirements. The required algorithms are discussed in the SOW. It is also the task of the vendors to determine INR requirements and to develop an INR budget that meets the requirements.

Specific tasks are broken down as follows.

1.3.1 Threshold Tasks

These tasks **shall** be performed (see 1.3.2 below).
The HES threshold tasks are to provide disk sounding (DS), severe weather/mesoscale sounding (SW/M), and shelf and coastal waters imaging (CW). These tasks provide the following information:

a) (DS,SW/M)Provide vertical moisture and temperature information, and other environmental data that will be used by NOAA and other public and private agencies to produce routine meteorological analyses and forecasts.
b) (SW/M)Provide environmental data that can be used to expand knowledge of mesoscale and synoptic scale storm development and provide data that may be used to help in forecasting severe weather events.
c) (DS,SW/M)Provide data that may be used to extend knowledge and understanding of the atmosphere and its processes (e.g., by viewing the evolution and motion of storms and other atmospheric phenomena) in order to improve short/long-term weather forecasts.
d) (CW)Provide information about ocean current, ocean color, optical properties, and sea surface temperatures.
e) (DS,SW/M,CW) Contingency mode in the event of a GOES-R ABI failure.

1.3.2 Goal Tasks

These tasks should be performed (see 1.2.1 below).
The HES goal tasks are to provide open ocean imaging, land imaging, and a backup to the ABI at GOES O image quality. These tasks provide the following information.

a) Open Ocean (OO) Provide information about ocean current, off shore ocean color, offshore optical properties, and offshore sea surface winds.
b) Land (L) Provide information about snow cover and the vegetative index.
c) (DS,SW/M,CW) Backup mode in the event of a GOES-R ABI failure yielding images at GOES O image quality.

2 APPLICABLE DOCUMENTS

The following documents provide background and context for this HES RFP specification. They are now or will soon be available on the HES document web site http://goes1.gsfc.nasa.gov/HES_docs.htm or from the GOES HES project library at NASA/GSFC by contacting the GSFC GOES Program Office at (301)-286-1384.

Reference documents may be found at the GOES-R website, along with relevant technical and scientific background information. The GIRD and the UUID also contain relevant information.

3 INSTRUMENT REQUIREMENTS

3.1 General

3.1.1 HES Overview and Description

The HES instrument(s) are designed to sense emitted thermal energy and reflected solar energy from sampled areas of the Earth's surface and atmosphere. These data are used to compute vertical profiles of temperature and moisture, surface and cloud-top temperatures, and winds, along with information about the earth surface and oceans. The HES, in conjunction with data from an imaging instrument, is part of a 3-axis stabilized, geostationary satellite system that collects weather and environmental data to aid in the prediction of weather and climate monitoring. The HES data, depending on the task, provide moderate to high spatial resolution, high spectral, temporal and radiometric resolution to accurately monitor rapidly changing environmental conditions including coastal waters and rapidly changing weather. Figure 3.1.1 shows the notional interfaces among the HES, spacecraft and ground system.

Figure 3.1.1 Notional Interfaces

The requirements in this document pertain to the HES 'system', which may include scanner, optics, detectors, signal processing electronics and software, and ground processing. The HES vendor is not responsible for the whole HES-GS, but certain

specifications may require some level of ground processing after collection but before data distribution, i.e. calibration and navigation.

3.1.2 Top level functions

The HES performs the following functions:

- scene IR spectroscopy
- imaging
- radiometric calibration of spectroscopic and imaged data
- star sensing, if required to meet navigation requirements.
- on-orbit monitoring of calibration sources and instrument response changes
- acquisition of sensor health and status data
- generation of sensor, calibration, monitoring, health and status data streams
- reception and execution of command and control data

3.1.3 HES Modes

The HES **shall** accept solar illumination from any angle for all Modes except the Off Mode for indefinite durations without permanent damage.
Either loss of spacecraft attitude knowledge, an inappropriate HES pointing command, or failure of the HES or its pointing system or Attitude Control System (ACS) anomaly could potentially cause the HES to scan through or point at the Sun for an extended period of time.
All HES Modes and their functions **shall** be documented in the Interface Control Document (ICD).
The HES **shall** include ground commands to individually enable and disable each autonomous function of the HES.
The HES **shall** initiate all commanded mode transitions in no more than 10 seconds after receipt of command, except for transitions to Safe Hold Mode.
Transitions to Safe Hold Mode, whether commanded or autonomous **shall** require no more than 1 second to initiate.
Transitions to Safe Hold Mode, whether commanded or autonomous, **shall** require no more than 60 seconds to complete.

Potential HES Modes and their functional characteristics are summarized in Table 3.1.1. This table is for information only. The specific requirements are stated in the subsequent paragraphs. Although the HES may be commanded to certain modes, each element of the mode may be independently commanded:

Table 3.1.1 Table of HES Modes

Mode	Off Mode	Normal Operations Mode			Outgas Mode	Safe Hold Mode
Functional Characteristic	On-Orbit Storage & Launch	Normal Operations	Idle State	Instrument Diagnostic State	Outgas	Safe Hold
Main Instrument Power from S/C	Off	On	On	On	On	On
Health & Safety Telemetry	Yes	Yes	Yes	Yes	Yes	Yes
Survival Heaters	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled
Operational Heaters	Disabled	Enabled	Enabled	Enabled	Enabled	Disabled
Outgas Heaters	Disabled	Disabled	Disabled	Disabled	Enabled	Disabled
Scan Mirror Parked	Yes	No	Yes	No	No	Yes
Sun Protection	Passive	Active	Active	Active	Active	Passive
Imaging Capabilities	No	Yes	No	Yes	<3 um only	No
Star Sense	No	Yes	No	Yes	Yes	No
Calibration	No	Yes	No	Yes	<3 um only	No
Upload New Software	No	Yes	Yes	Yes	Yes	No
Special Telemetry for Trouble Shooting	No	No	No	Yes	No	No
Store & Download Complete Instrument State	No	No	No	Yes	No	Yes

3.1.3.1 Off Mode

The HES **shall** implement an Off Mode. During Off Mode, the HES survival heaters **shall** be enabled and only draw power if their heater set points are reached. The HES components associated with HES health and safety telemetry to the spacecraft data **shall** be provided to the spacecraft. The scan mirror, if present, **shall** be parked at commandable gimbal angles that are stored in the HES's reprogramable nonvolatile memory. The HES **shall** be in the Off Mode during Launch. Launch is the period of time between lift off and the separation of the GOES-R series satellite from the launch vehicle. The duration of launch is expected to be less than 2 hours long. The HES **shall** be in the Off Mode during transfer orbit. Transfer orbit is the sequence of events that transpires to establish the GOES-R series satellite on-station after the GOES-R series

satellite has separated from the launch vehicle. The HES **shall** be in the Off Mode during on-orbit storage.

3.1.3.2 Normal Operational Mode

The HES **shall** implement a Normal Operational Mode upon ground command.
In this mode, the HES **shall** be in a fully functional configuration and capable of all requirements presented in section 3.2.

3.1.3.2.1 Idle State

In the Idle State, the HES **shall** be in a fully functional configuration with the exception that moving mirrors (if any) are not scanning.
In the Idle State, the scan mirrors (if present) **shall** be parked at commandable gimbal angles that are stored in the HES's reprogram able nonvolatile memory.

3.1.3.2.2 Commanded Reset

The HES **shall** be interruptible by a reset command that ceases current operations and causes the HES to enter the Idle State.

3.1.3.2.3 Instrument Diagnostic State

The HES **shall** implement an Instrument Diagnostic State.
In the Instrument Diagnostic State, the HES **shall** be in a fully functional configuration.
Furthermore, in this state, the HES **shall**, as a minimum, have the following capabilities.

- Increase the sampling rate of selected critical telemetry points for anomaly investigation.
- Acquire data while scanning with TDI (if used) inhibited or enabled.
- In those cases where TDI data is digitally processed off the focal plane in the HES, be capable of sending the individual measurements for ground assessment.
- Be capable of sending data from any subset of detectors.
- Be capable of sending the same data, both compressed and uncompressed to allow ground evaluation of the impact of compression on the data.
- For those channels, where low order bits from the A/D converter are not sent to the spacecraft, be capable of sending all of the data.

In all of the above requirements, the data channels to be sent to the spacecraft will be selected to stay within the allocated data rate. The acquisition of this data will be done in a manner that does not require any design modification of the focal planes and their readout systems from their nominal design.

The following section is under review by the HES PORD Team

3.1.3.3 Contingency Mode of Operations

In the event that an Advanced Baseline Imager (ABI) fails in orbit, and can no longer produce critical image products, HES may be tasked to provide backup imaging, albeit with degraded capability compared to ABI.

The HES **shall** implement a Contingency Mode of Operations upon ground command.
In this mode, the HES **shall** be in a fully functional configuration and capable of all requirements presented in section (TBS).

3.1.3.4 Outgas Mode

The HES **shall** implement an Outgas Mode. Initial outgas will occur after the GOES-R series satellite has successfully reached its on-station orbit and the solar array has successfully deployed.
This mode **shall** be utilized to outgas and evaporate contaminants from HES hardware to prevent contamination from jeopardizing HES performance.
During the Outgas Mode, the HES **shall** be in a fully functional configuration and be capable of meeting all requirements for channels < 3 um.

3.1.3.5 Safe Mode

The HES **shall** implement a Safe Mode.
In the Safe Mode, health, status, and critical instrument temperature data will be collected and transmitted by the spacecraft.

In the Safe Mode, the scan mirror, if present, **shall** be parked at commandable gimbal angles that are stored in the HES's reprogrammable nonvolatile memory.
In the Safe Mode, the HES power bus will be on. However, all HES components not required for health, status, and critical instrument parameter monitoring **shall** be turned off. Survival heaters **shall** be enabled and draw power if their heater set points are reached.

3.1.3.6 Entrance into and Exit from Safe Mode

The HES **shall** enter into Safe Mode autonomously or upon command in the event the spacecraft enters an anomalous configuration or orientation as determined by the spacecraft computer or the ground system.

The return to Normal Operational Mode **shall** require ground intervention.

3.1.4 Operational Concept

3.1.4.1 Launch Operations

3.1.4.1.1 Pre Launch

The satellite, including the HES, will be transported to the launch site where final vehicle preparations and checkout will be accomplished. Final pre-launch system verification tests will be accomplished at the launch site.

3.1.4.1.2 Launch and Injection

During launch the HES **shall** be in Launch Mode in order to provide protection from the launch environment or to comply with other specified requirements. During orbit raising and after insertion into its operational orbit, appropriate deployments will be initiated by command. Spacecraft telemetry transmission to ground monitoring stations will be used to the extent practicable during the injection phase.

3.1.4.2 On-orbit Operations

The HES **shall** fly aboard a 3-axis stabilized, geostationary spacecraft with orbital constraints in the HES GIRD/UIID. Regular operations **shall** consist of star sensing, if required, and acquiring data from: 1) selectable ground sources (e.g., to perform the DS, SW/M and CW tasks), 2) non-routine variable size and source areas, and 3) calibrations. The HES **shall** interrupt current operations by command and start the acquisition of a new image, after an image coordinate upload, within 30 (TBR) seconds.

3.1.4.3 Zones of Reduced Data Quality

3.1.4.3.1 Operational Zone

The HES **shall** meet all of its operational requirements for all detector elements greater than the THRESHOLD limits in the Table 3.1.2 from the center of the uneclipsed sun. The HES should meet all of its operational requirements for all pixels greater than the GOAL limits in Table 3.1.2 from the center of the uneclipsed sun. Thorough analysis and innovative designs are encouraged to minimize the outer limit. See Figure 3.1.2 for a pictorial description for both sections 3.1.4.3.1 and 3.1.4.3.2.

Table 3.1.2 THRESHOLD and GOAL Operational Zones

Channel	**Outer Limit (THRESHOLD)**	**Outer Limit (GOAL)**
Emitted IR bands (650-2720 cm^{-1})	10° (TBR)	5° (TBR)
Reflected Solar (0.4-3.0 um)	10° (TBR)	5° (TBR)
Low light	10° (TBR)	5° (TBR)

3.1.4.3.2 Restricted Zone

The HES **shall** meet all requirements, except the NEDN and On-Orbit calibration and accuracy sections, for all detector elements between the Threshold limit in Table 3.1.3 and the Threshold limit of Table 3.1.2, measured from the center of the uneclipsed sun. The HES should meet all requirements, except the NEDN and On-Orbit calibration and accuracy sections, for all detector elements between the Goal limit in Table 3.1.3 and the Goal limit of Table 3.1.2, measured from the center of the uneclipsed sun.

Table 3.1.3 THRESHOLD and GOAL Restricted Zones

Channel	Outer Limit (THRESHOLD)	Outer Limit (GOAL)
Emitted IR bands (650-2720 cm^{-1})	3° (TBR)	2° (TBR)
Reflected Solar (0.4-3.0 um)	3° (TBR)	2° (TBR)
Low light (visible)	3° (TBR)	2° (TBR)

Reflected solar (<3 um) Signal-to-Noise Ratio (SNR), INR, and calibration accuracy and Low Light requirements, except for star sensing, are not applicable over the coverage area whenever any point on the coverage area falls within the Zone of Reduced Data Quality.

In place of the NEDN, dynamic range, and On-Orbit calibration and accuracy sections, the HES **shall** meet the following requirements:

- NEDN < 2x normal specification.
- The performance of the detector elements in the reflective solar bands for all tasks **shall** have performance degradation of less than TBD.
- Detectors **shall** not saturate.
- The calibration performance **shall** not degrade by more than TBD (THRESHOLD) and 0.5 K (Goal).

3.1.4.3.3 Scanning across the sun

Ground operations will not routinely scan any detector of the HES closer than 1.4 (TBR) degrees from the center of the sun.

Figure 3.1.2 Pictorial of A. THRESHOLD (shall) and B. GOAL (<u>should</u>) operational and restricted zones

3.1.4.4 Reserved

3.1.4.5 Eclipse

During eclipse, the HES **shall** continuously operate and **shall** meet all requirements except navigation. See section 3.2.8.3.1 for the relaxation of navigation.

3.1.4.6 Flexible and Efficient Scan Pattern

The HES **shall** be designed such that the Earth-scanning patterns are fully re-programmable on-orbit. The command information listed below will be uploaded concurrently with earlier operations and activated by a single command. The complexity of the required commanding **shall** be minimized to change coverage and reduce the impact of the sun on data loss. Some examples of possible approaches may include, but are not limited to:

- Conversion of latitude and longitude to HES scan coordinate.
- Command the Scanning mode.
- Command the corner locations of the frame when applicable.
- Command a scan line that is not orthogonal to N/S or E/W (to image a storm front).
- Commands to minimize the impact of the sun on Data Quality and Quantity.
- Split the Full Earth into 3 segments, two are the normal E-W width and one segment has a reduced E-W width, on the East or West side, to minimize the impact of the sun (applies to the DS task).
- Abort a scan and begin a new scan within 30 (TBD) seconds.

For the purposes of this requirement document, a frame is a collection of observations that together form a spatially contiguous data set that might be analyzed to characterize the radiation from the earth-atmosphere system. The spatial extent of a frame is described by the coverage region specifications in section (3.2.4).

3.1.4.7 Operations After Maneuvers

3.1.4.7.1 Yaw Flip

If required for meeting instrument envelope and radiometric performance requirements, the GOES spacecraft may be rotated 180° twice per year, within ±4 (TBR) days of the sun crossing the plane of the orbit, so that the solar loading on the instrument radiative coolers is reduced. The rotation will be performed any time during the 8 (TBR) day window and will be carried out such that neither the sun nor Earth illuminates the cooler during the maneuver. The maneuver is expected to last less than 1 (TBR) hours. The net effect reverses the sign of the roll and pitch axis while maintaining yaw pointing at nadir. The HES **shall** meet INR requirements (3.2.4) within 1 day after the yaw flip.

3.1.4.7.2 Stationkeeping

The HES **shall** meet all radiometric, coverage, and INR requirements within 60 minutes (TBR) after the spacecraft interface has returned to being within specification following spacecraft North-South stationkeeping maneuvers. Compliance with this requirement is contingent upon the maneuver being conducted while the sun is not illuminating the ABI aperture and passive cooler and that adequate orbit information is available and that any contaminants from the spacecraft are negligible.

3.1.4.7.3 Post Storage Activation

The HES **shall** meet all requirements within 5 days of HES turn on after post storage activation for a HES with passively cooled detectors and 3 days for a HES with actively cooled detectors.

3.1.4.8 Infrared Detector Operating Temperatures

Any HES instruments requiring cooling **shall** minimize the degradation in radiometric quality of IR data resulting from reductions in cooler capacity and/or increasing parasitic heat loads on the IR detectors. The contractor **shall** develop a contingency plan to operate the IR detectors above their baseline operational temperatures, and **shall** provide all onboard temperature controls and perform all pre-flight calibration required to maximize the radiometric quality of the IR data when operating the detectors above their baseline temperatures. The detector operation temperatures **shall** be selectable by command. The control temperature selection **shall** be selectable in 1K increments to +10K/-5K (TBD) of the nominal operational temperature. The tolerance on the control temperatures accuracy **shall** be to 1K. The HES is not required to meet the NEdN/NEdT specifications when the detectors are operated above their nominal temperature.

3.1.4.9 Solar Illumination Self-Protection

Recovery time to full performance should be less than TBD hours and **shall** be less than 48 hours.

3.1.5 Space Environment

The HES **shall** provide radiation protection by means of local shielding to assure meeting required performance of all parts in the instrument modules for the lifetime (section 3.1.7) of the instrument. The satellite radiation environment is defined in the GIRD.

The HES **shall** be designed to prevent latch-ups and minimize the occurrence of single event upsets and unintentional commands due to cosmic rays. No damage to the instrument **shall** result from any single event upset or unintentional command.

The optical systems and surface coatings of the HES instrument(s) **shall** be designed to provide the required performance over the life of the sensors. The coating(s) selected for the scan mirror(s), if present, and optics **shall** have demonstrated (by flight or ground testing) long life performance in the combined solar input plus orbital particle environment.

3.1.6 Data Compression

Data compression of HES data, derived from all tasks, **shall** be selectable between lossless compression (~2:1) and lossy compression (~4:1, or possibly higher). The acceptable criteria are TBD. Such user selectibility will enable user comparison and evaluation of the suitability of lossy compression schemes.

3.1.7 Lifetime

The HES **shall** have a 10-year instrument on time after a maximum of 5 years on orbit storage and after a maximum of 5 years of ground storage. The mean mission duration (MMD), namely the integrated area under the reliability versus time curve for the instrument shall be 8.4 years with a reliability of 0.6.

3.2 NORMAL OPERATIONAL MODE SENSOR REQUIREMENTS

3.2.1 Scope

It is emphasized again that there are three threshold tasks in the normal mode of operations that are outlined in section 1.3: two hyperspectral sounding tasks (DS and SW/M), and one hyper- or multi- spectral imaging task (CW). The sensor requirements presented below pertain to these tasks. Sensor requirements for the goal tasks are addressed in appendix A. When appropriate, a single requirement is specified and applied to all tasks. Task specific requirements are uniquely identified in each section, i.e. the ground sample distance requirement is unique to each task. Often the DS and SW/M task requirements are grouped together and identified as "sounding" requirements. Finally, there are some requirements that only apply to a single task, and they are appropriately identified.

As previously stated, the measurement requirements for the HES could be met with a single integrated sensor or with multiple sensors, each dedicated to a task. This section of the document attempts to present requirements that allow design flexibility in that regard. It is also recognized that there are several ways to collect spectral data. The government has decided not to discriminate against one method over another. As such, the requirements in this section are written so that no particular architecture is preferred. This causes some difficulty when trying to specify unambiguous requirements. Apparent ambiguities arise from the fact that the attributes of the collected data depend (to some extent) on the collection method, i.e. whether a dispersive or multiplexing spectrometer is used. An effort was made to avoid ambiguous requirements; therefore it was necessary to make certain basic assumptions in order to assimilate a reasonably bound set of sensor requirements. Some of the relevant assumptions are described in sections (2.10.2) 2.A and (2.10.2) 3.B.2.g of the MRD. *These assumptions are referenced for insight only, and do not mandate particular design features*.

With these instrument assumptions, and to first order, the achievable radiometric performance of the HES depends only on the ground sample rate (GSR) requirement. In this document, the GSR and radiometric performance (NEdN and SNR in section 3.2.7.2) are considered the most fundamental performance requirements. The operational implementation of HES however, will utilize a variety of coverage areas and spatial sampling implementations. Ideally, the HES would arbitrarily trade coverage area, coverage time, and spatial resolution per frame, while maintaining GSR and radiometric performance. For the purpose of presenting a well-defined sensor to potential contractors, the government has decided to envelope these operationally variable parameters based on the envisioned typical tasks, i.e. CW, DS, and SW/M. The threshold coverage area capabilities are presented in section 3.2.4. The threshold coverage time capabilities for each coverage region are presented in section 3.2.6.1. The threshold sampling capabilities are presented in section 3.2.5.

3.2.2 Spectral Requirements

3.2.2.1 Number of Spectral Bands

Overview: The number of spectral bands describes how many spectral regions are covered in the sensor(s). The requirement does not dictate the number of unique detector elements or focal planes or optical paths within the sensor. It is acceptable to design the sensor such that multiple bands are imaged onto a single detector or focal plane, e.g. the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) combines the SWIR and MWIR bands into a single SW/MW-IR band (see bands 2 and 3 below). Conversely, separating bands and imaging onto multiple focal planes is also an acceptable approach. The bands are consecutively numbered below. This enumeration defines the HES band number referenced throughout the rest of this document. For more information, see section (2.10.2) 3.B.2.g of the MRD.

As a THRESHOLD, the sounding task sensor(s) **shall** have four (4) spectral band observations:

1. A Long-Wave infrared (LWIR) band primarily for temperature sounding, skin surface temperature, and tracers employing ozone.
2. A Mid-Wave infrared (MWIR) band primarily for water vapor sounding.
3. A Short-Wave infrared (SWIR) band primarily for sounding the mid to lower troposphere, surface skin temperature, and detection of thin cirrus.
4. A Visible (Reflected Solar) band primarily for cloud clearing.

As a GOAL, the sounding task sensor(s) SWIR band (HES band 3) should also provide information for enhanced retrieval performance in the troposphere as well as improved atmospheric soundings in the presence of clouds.

As a THRESHOLD, the CW task sensor **shall** have one (1) spectral band:

5. A Reflected solar < 1 μm band for coastal ocean color and other measurements outlined in the MRD.

As a GOAL, the CW task sensor should also include two (2) additional bands:

6. Reflected solar > 1 μm band for measuring cloud properties.
7. A LWIR band for sea surface temperature measurements co-located with the color measurement.

3.2.2.2 Spectral Range

Overview: Since sounders measure the absorption features of atmospheric constituents to retrieve temperature and water vapor profiles, is not possible to specify a unique set of spectral channels to meet retrieval requirements. There are several possible channel sets that can be used with the appropriate models to produce acceptable profiles. Refer to the MRD for more details. The optimal channel set then depends on the type of sensor used to acquire the data, the noise characteristics and the specific algorithms used to process the radiances into profiles. As a result, the THRESHOLD requirements for the sounding

sensor(s) are presented in a way that allows flexibility in the water vapor sounding region where heritage sensors have operated or are planned in two distinct spectral regions within the MWIR band. Two options are presented for the MWIR band. Also included in the table is a band continuity requirement. It mandates either contiguous or non-contiguous spectral sampling within each band. Note that although contiguous bands are mandated for some, there are acceptable limits for missing channels. These limits are presented in the spectral band breaks section 3.2.2.7 and spectral operability section 3.2.7.2.1.

As a THRESHOLD, the sounding task sensor(s) band **shall** conform to the band limits and continuity presented in Table 3.2.1. Either MWIR spectral band option presented in the table is acceptable. It is also acceptable to split the MWIR spectral range between the two contiguous options, provided the water vapor vertical profile derived from the absorption feature is sufficiently covered, as described in the MRD, section (2.10.2) 3.B.2.g.

Table 3.2.1 Sounding sensor(s) THRESHOLD bands.

Band	HES Band Number	Spectral Range (cm^{-1})	Spectral Range (um)	Band Continuity
LWIR	1	650 – 1200	15.38 - 8.33	Contiguous
MWIR (option 1)	2	1650 – 2150	6.06 - 4.65	Contiguous
MWIR (option 2)	2	1210 – 1740	8.26 - 5.74	Contiguous
SWIR	3	2150 – 2250	4.65 - 4.44	Contiguous
VIS	4	NA	0.52 - 0.70	Contiguous

As a GOAL, the sounding task sensor(s) SWIR contiguous spectral range (HES band 3) should be 2150 – 2720 cm^{-1} (4.65 – 3.68 um). This will allow the improvements listed in MRD section (2.10.2) 3.B.2.g.

As a THRESHOLD, the CW task sensor spectral range (HES band 5) **shall** conform to the values and continuity presented in Table 3.2.2. Specific channels, and the resolution of each, are designated in section 3.2.2.3.

Table 3.2.2 CW task sensor THRESHOLD band.

Band	HES Band Number	Spectral Range (um)	Band Continuity
Reflected solar < 1 um	5	0.4 – 1.0	Non-contiguous

As a GOAL, the CW task sensor band limits should conform to the values and continuity presented in Table 3.2.3. Specific channels, and the resolution of each, are designated in section 3.2.2.3 for the LWIR band 7.

Table 3.2.3 CW task sensor GOAL bands.

Band	HES Band Number	Spectral Range (cm^{-1})	Spectral Range (um)	Band Continuity
Reflected solar < 1 um	5	NA	0.40 - 1.0	Contiguous
Reflected solar > 1 um	6	NA	1.0 - 2.285	Contiguous
LWIR	7	813 - 893	11.2 - 12.3	Non-Contiguous

3.2.2.3 Spectral Channels, Resolution, and Resolving Power

The following section is under review by the HES PORD Team

Overview: A channel is defined as a spectral band sub-element. A set of channels defines a band. The spectral width of each channel defines the spectral resolution, $\Delta\lambda$ (um) or $\Delta\nu$ (wavenumbers). The spectral resolution is defined as the full-width-half max of the line-shape function for filter and dispersive implementations ($\Delta\lambda$ μm), or the distance between the first minima of the line-shape function (a Sinc function) for a multiplexing implementation ($\Delta\nu$ cm^{-1}).

Contiguous bands are specified in terms of the effective instrument spectral resolving power ($\Re$) for all points within the band limits:

$$\Re \equiv \frac{\lambda}{\Delta\lambda} = \frac{\nu}{\Delta\nu},$$

Equation 3.2.1

where λ is the wavelength in a dispersive system and ν is the wavenumber in a multiplexing system. The instrument spectral resolving power is specified at discrete points within each band. As defined here, $\Re$ is a property of the instrument, i.e. not the

dispersive element alone in a grating implementation. The specification for in-between channels is found by linear interpolation.

Non-contiguous bands are specified in terms of the individual channel centers and the full-width-half max resolution ($\Delta\lambda$ μm) for each.

As a THRESHOLD, the sounding task sensor(s) LWIR band (HES band 1) resolving power **shall** be greater than or equal to the THRESHOLD values plotted in Figure 3.2.1 (solid line). As a GOAL, it <u>should</u> be greater than or equal to the GOAL values (dashed line). Values for key wavelengths are quantified in Table 3.2.4.

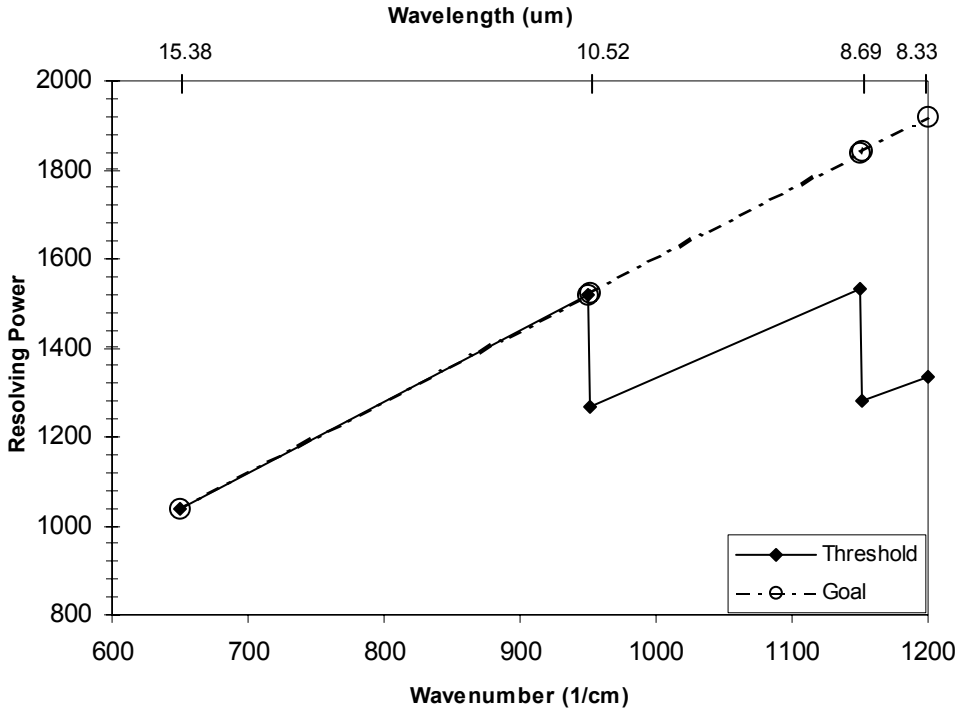

Figure 3.2.1 Plot of sounding sensor(s) LWIR band spectral resolving power requirement.

Table 3.2.4 Sounding sensor(s) LWIR band spectral resolving power requirement.

Wavenumber (cm^{-1})	Wavelength (um)	THRESHOLD	GOAL
650	15.38	1040	1040
950	10.53	1520	1520
951	10.52	1268	1522

1150	8.70	1533	1840
1151	8.69	1279	1842
1200	8.33	1333	1920

As a THRESHOLD, the sounding task sensor(s) MWIR band (HES band 2) resolving power **shall** be greater than or equal to the THRESHOLD values plotted in Figure 3.2.2 (solid line). As a GOAL, it should be greater than or equal to the GOAL values (dashed line). Values for key wavelengths are quantified in Table 3.2.5.

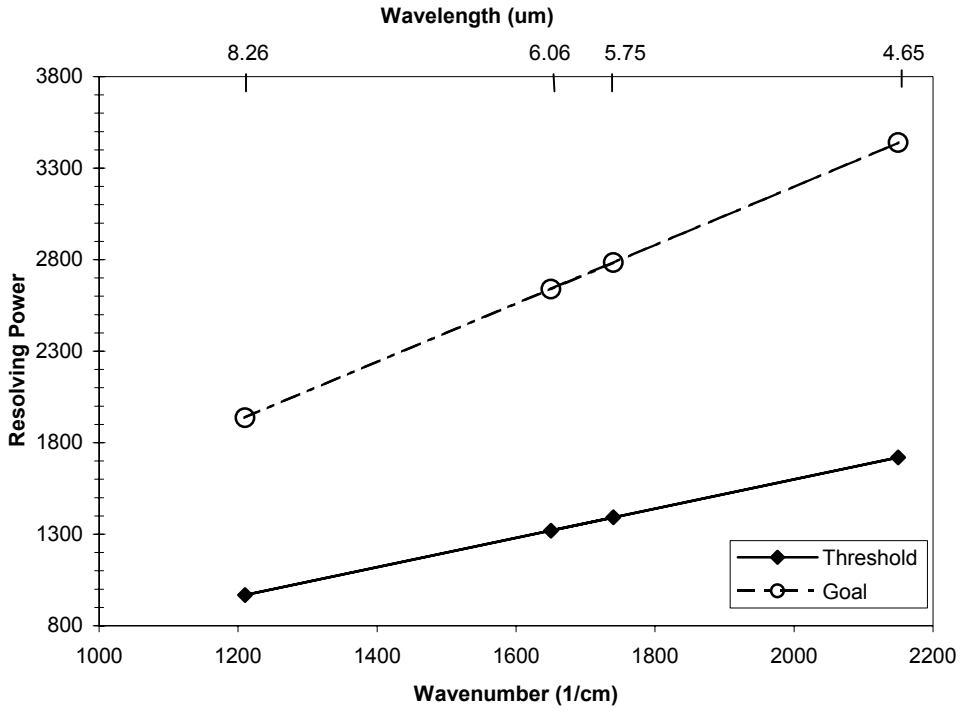

Figure 3.2.2 Plot of sounding sensor(s) MWIR band spectral resolving power requirement.

Table 3.2.5 Sounding sensor(s) MWIR band spectral resolving power requirement.

Wavenumber (cm^{-1})	Wavelength (um)	THRESHOLD	GOAL
1650	6.06	1320	2640
2150	4.65	1720	3440
1210	8.26	968	1936
1740	5.75	1392	2784

As a THRESHOLD, the sounding task sensor(s) SWIR band (HES band 3) resolving power **shall** be greater than or equal to the THRESHOLD values plotted in Figure 3.2.3 (solid line). As a GOAL, it should be greater than or equal to the GOAL values (dashed line). Values for key wavelengths are quantified in Table 3.2.6.

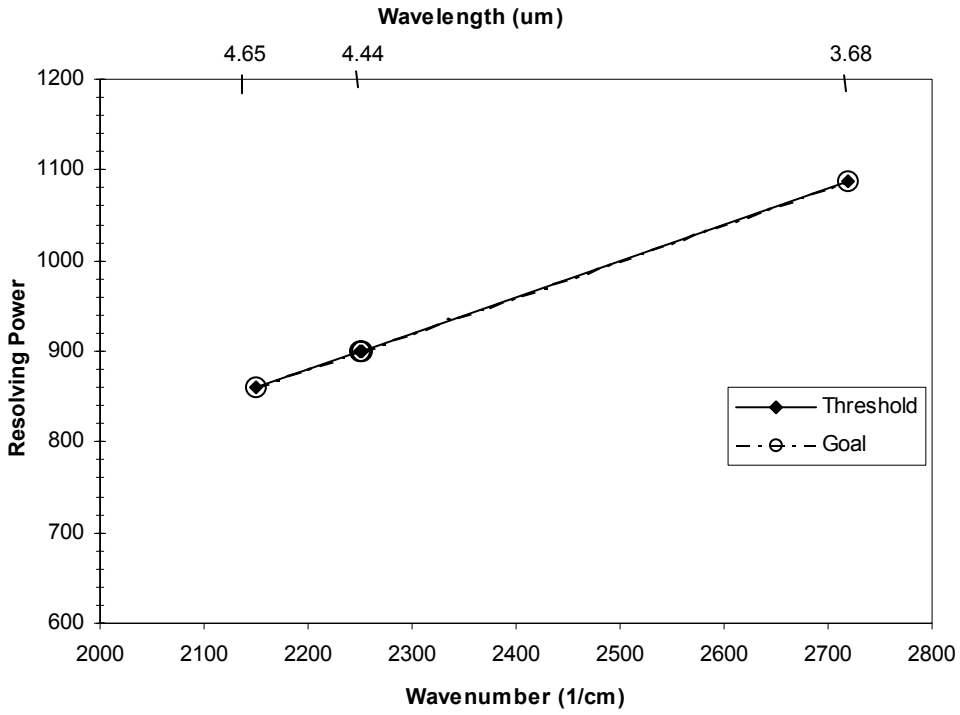

Figure 3.2.3 Plot of sounding sensor(s) SWIR band spectral resolving power requirement.

Table 3.2.6 Sounding sensor(s) SWIR band spectral resolving power requirement.

Wavenumber (cm^{-1})	Wavelength (um)	THRESHOLD	GOAL
2150	4.65	860	860
2250	4.44	900	900
2720	3.68	1088	1088

As a THRESHOLD, the sounding task sensor(s) Reflected Solar band (HES band 4) spectral resolution **shall** be less than (finer) or equal to 0.18 um.

As a THRESHOLD, the CW task sensor Reflected solar < 1 μm band (HES band 5) channel center and spectral resolution **shall** conform to the values presented in Table 3.2.7.

Table 3.2.7 CW sensor THRESHOLD spectral resolution.

Channel Center (um)	Resolution (um)
0.412	0.02
0.443	0.02
0.477	0.02
0.490	0.02
0.510	0.02
0.530	0.02
0.550	0.02
0.645	0.02
0.667	0.02
0.678	0.02
0.750	0.02 (TBR)
0.763	0.02
0.865	0.04
0.905	0.02

As a GOAL, the CW task sensor(s) spectral resolution and number of channels should conform to the values presented in Table 3.2.8. The non-contiguous LWIR band (HES band 7) channels are listed separately with band centers identified.

Table 3.2.8 CW sensor GOAL spectral resolution.

Band	HES Band Number	Channel Center (cm^{-1})	Channel Center(s) (um)	Spectral Resolution (cm^{-1})	Spectral Resolution (um)
Reflected Solar < 1 um	5	NA	NA	NA	0.02, 0.04
Reflected Solar > 1 um	6	NA	1.38, 1.61, 2.26	NA	0.3, 0.6, 0.5
LWIR	7	893	11.2	64	0.8
LWIR	7	813	12.3	66	1.0

3.2.2.3.1 On-Board Spectral Compression

Each HES sensor **shall** downlink the THRESHOLD channel set upon ground command, excluding channels missing due to planned band breaks (see section 3.2.2.7).

3.2.2.4 Instrument Line Shape, Spectral Response Envelope

(TBD)

3.2.2.5 Spectral Purity

The following section is under review by the HES PORD Team

The radiance contribution from any error in spectral width or any signal contribution from outside the spectral resolution element of interest **shall** be less than 28% (TBR) of the total signal in the spectral resolution element, when a blackbody (TBR) source is used.

3.2.2.6 Spectral knowledge and Stability

The following section is under review by the HES PORD Team

Knowledge of spectral stability of the line center of 1 part in 10^5 (TBR) over TBS time at the specified wavenumbers and wavelengths is required.

3.2.2.7 Spectral Band Breaks

The following section is under review by the HES PORD Team

Overview: This section presents the limits on planned spectral band breaks due to the need to separate a band into multiple optical paths to simplify the overall design. It is anticipated that band breaks will result in the loss of usable spectral channel data in the region surrounding the break. Unlike inoperable spectral channels (see section 3.2.7.2.1), which are due to random unforeseen or uncontrollable circumstances in the sensor due to,

e.g., detector or electronics outages, missing channels from band breaks will always be present in all pixels. The requirements below present planned band break specifications in terms of the number of missing channels allowed in a break and the number of breaks allowed in each band spectral sub-region.

The government **shall** approve all planned band breaks.

The sounding sensor(s) spectral band breaks **shall** conform to the THRESHOLD limits presented in a Table 3.2.9. Figure 3.2.4 shows a graphical representation of the sub-regions for the sounding task sensor(s).

Table 3.2.9 Spectral band breaks THRESHOLD requirements.

Band	Sub-Region	Spectral Range (cm^{-1})	Band Break Limits	
			Channels	Groups
LWIR [Band-1]	1	650-665	<10	< 2
	2	665-672	NONE	-
	3	672-722	NONE	-
	4	722-1016	< 35	< 5
	5	1016-1046	< 20	< 2
	6	1046-1200	< 35	< 2
MWIR (option 1) [Band-2]	NA	1650-2150	< 35	< 5
MWIR (option 2) [Band-2]	NA	1210-1740	< 35	< 6
SWIR [Band-3]	1	2150-2250	NONE	-
	2	2250-2380	< 35	< 2
	3	2380-2390	NONE	-
	4	2390-2720	< 35	< 2

The sounding sensor(s) spectral band breaks **shall** conform to the GOAL limits presented in Table 3.2.10. Figure 3.2.4 shows a graphical representation of the sub-regions for the sounding task sensor(s).

Table 3.2.10 Spectral band breaks GOAL requirements.

Band	Sub-Region	Spectral Range (cm^{-1})	Band Break Limits	
			Channels	Groups
LWIR [Band-1]	1	650-665	<10	< 2
	2	665-672	NONE	-
	3	672-722	NONE	-
	4	722-1016	< 35	< 5
	5	1016-1046	NONE	-
	6	1046-1200	< 35	< 2
MWIR (option 1) [Band-2]	NA	1650-2150	< 35	< 5
MWIR (option 2) [Band-2]	NA	1210-1740	< 35	< 6
SWIR [Band-3]	1	2150-2250	NONE	-
	2	2250-2380	< 35	< 2
	3	2380-2390	NONE	-
	4	2390-2720	< 35	< 2

The CW-task sensor contiguous band implementation (a GOAL requirement) **shall** have fewer than two (2) band breaks.

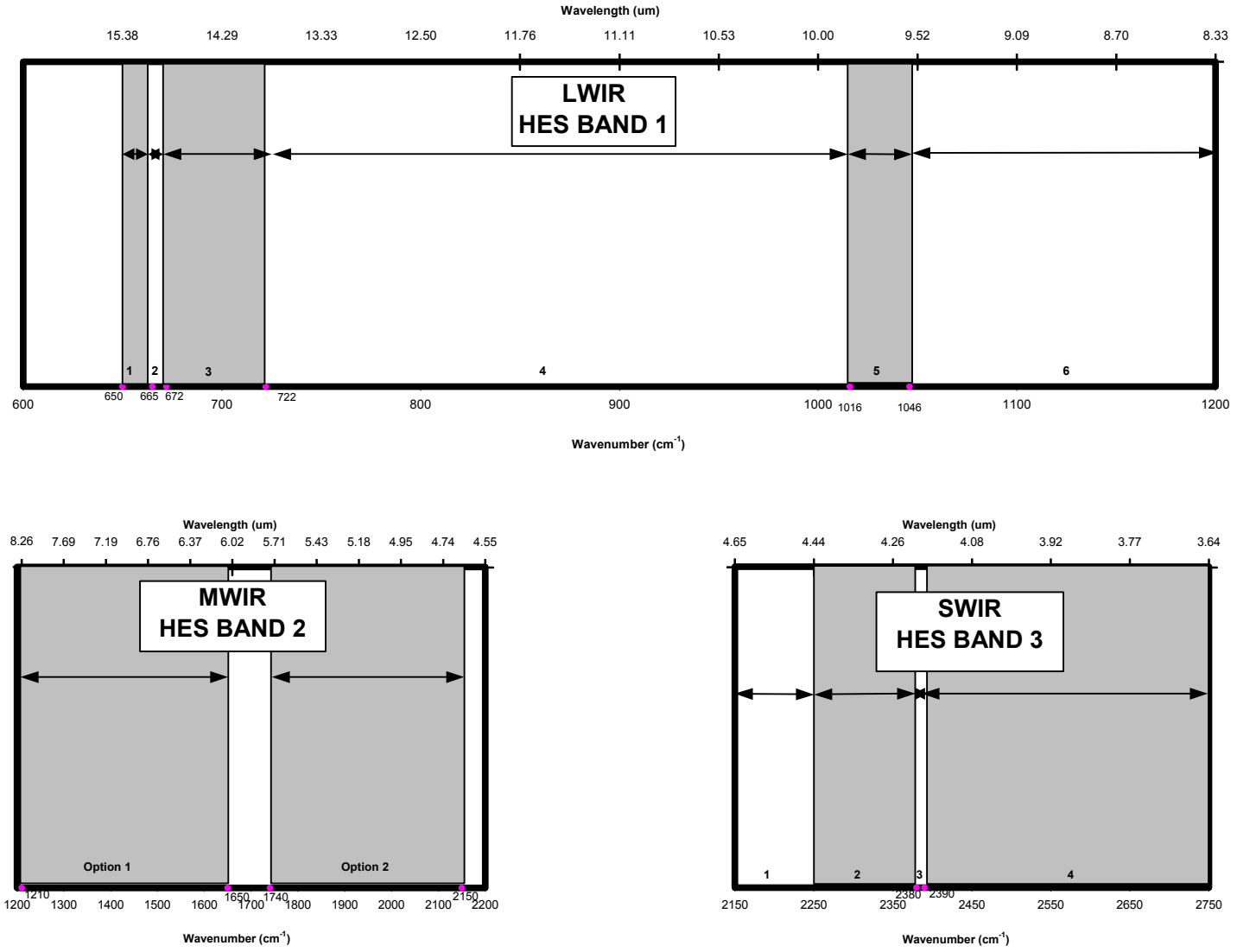

Figure 3.2.4 Graphical representation of sounding band sub-regions

3.2.3 Scan Requirements

3.2.3.1 Ground Sample Rate

Overview: The ground sample rate (GSR) mandates the number of calibrated and navigated full-spectrum pixels that must be collected per unit time. Note the GSR requirements presented below is the processed rate, and *not* the raw spatial sample collection rate, which is higher because of inefficiencies due to image rotation, slew time, and other overhead.

The GSR requirement **shall** be achieved for each operational task, in any data collection mode. The requirement varies by band.

The HES GSR **shall** be greater than or equal to the THRESHOLD values presented in Table 3.2.11. It should be greater than or equal to the GOAL values.

Table 3.2.11 HES THRESHOLD and GOAL GSR

HES Band Number	Band/Task	GSR THRESHOLD (Hz)	GSR GOAL
1	LWIR-DS	195	TBS
1	LWIR-SW/M	240	TBS
2	MWIR-DS	195	TBS
2	MWIR- SW/M	240	TBS
3	SWIR- SW/M	195	TBS
3	SWIR- DS	240	TBS
4	VIS-DS	19,500	TBS
4	VIS-SW/M	3,840	TBS
5	Reflected Solar < 1 um: CW	7,400 (TBR)	TBS
6	Reflected Solar > 1 um: CW	464 (TBR)	TBS
7	LWIR: CW	170 (TBR)	TBS

We anticipate the raw GSR will be about the same for either the DS or SW/M sounding task due to differences in scan efficiency for each associated primary scan modes.

3.2.3.2 Scan Direction

The dominant direction of instrument "scan" **shall** be in the East-West directions for the DS, SW/M, OO, and L tasks. There is no dominant direction of scan for the CW task. To accommodate a possible seasonal Yaw flip, “scanning” and stepping **shall** be possible in North to South, South to North, West to East, and East to West directions. Ground sample data acquisition should begin with the northern most coordinate and proceed south.

3.2.3.3 Scan Flexibility

The HES sensor(s) **shall** scan an area of arbitrary size anywhere within the full disk when commanded (described in section 3.2.4.1). This ranges from mesoscale areas through the size of the full disk. The scan area and geographic location should be selectable from one scan to the next. More details of specific coverage regions are presented in section 3.2.4.

3.2.3.4 Scan Efficiency

3.2.3.4.1 Within Frame Scan Efficiency

Overview: The within frame scan efficiency is a metric describing the fraction of time spent collecting Earth scene measurements in one complete frame. The coverage regions presented in section 3.2.4 define a frame. Frame scans are inherently inefficient for a variety of reasons. It is expected that large area frame collection will be less efficient than small area frame collection.

All of the following events **shall** be considered when computing the scan efficiency within a frame.

a) Scan the required region. The coverage region is defined for each task in section 3.2.4.
b) Scan mirror (if present) steps, settles, and slews.
c) Spatially over-sample the scene to correct for image rotation and any other scan artifacts, in order to meet THRESHOLD sampling requirements presented in section 3.2.5.
d) Acquire the required space look and/or calibration target data needed to meet the radiometric requirements.
e) Necessary operations to switch between tasks if one sensor is used for multiple tasks.
f) Operations to meet navigation requirements.

There are no requirements on within frame scan efficiency. The expected minimum values are values below for each task to provide insight.

Table 3.2.12 Minimum expected within frame scan efficiency.

HES Task	Within Frame Scan Efficiency
DS	0.65
SW/M	0.95
CW	0.95

3.2.3.4.2 Overall Task Efficiency

Overview: TBD

As a THRESHOLD the sounding task sensor(s) **shall** continuously perform either a DS scan *or* a SW/M scan.

The time to switch between HES sounding tasks **shall** be 25 (TBR) seconds or less. (Under review)

As a GOAL, the sounding task sensor(s) should be capable of continuously and concurrently performing both a DS scan *and* a SW/M scan.

As a THRESHOLD, the CW task sensor(s) **shall** continuously perform CW scans.

3.2.4 Coverage Area Requirements

Overview: The requirements below define the geographical regions to be covered in any particular scan mode. A complete scan of a region defines a frame of data. Each HES task has different requirements for coverage with respect to geographical region. Each task has a primary geographical scan region, but is required to perform scans of other regions for operational flexibility or back-up functionality. The dimensional bounds are specified for each region as well as the size and number of acceptable gaps in coverage. A gap is defined as the centroid-to-centroid distance between adjacent pixels on the ground, excluding the effects of non-responsive detector samples. In this context, adjacent pixels do not include the diagonal pixels of a square grid. As a reference, the area (km^2) for each region is presented in Table 3.2.13. This area is referenced to a disk that is tangent to the earth's surface at the SSP.

Table 3.2.13 HES geographical regions coverage area

Coverage Region	Coverage Area (km^2)
Full Disk	10^8 (TBR)
62-degree LZA	$7.0x10^7$ (TBR)
CONUS	$1.5x10^7$ (TBR)
Mesoscale	1,000,000 (TBR)
Coastal Waters	$2.4x10^6$ (TBR)

Any and all area scans **shall** be selectable and flexible, i.e. meet the requirements presented in section 3.1.4.6

3.2.4.1 Full Disk Region

Overview: The full disk region is defined as a 17.76-degree diameter circle centered at nadir, as seen from each satellite. It is realized that acceptable soundings may not be retrieved over the entire full disk region. The full desk region is not a primary scan mode for any of the HES THRESHOLD tasks. Figure 3.2.5 shows the approximate full disk coverage regions as seen from east and west satellite positions.

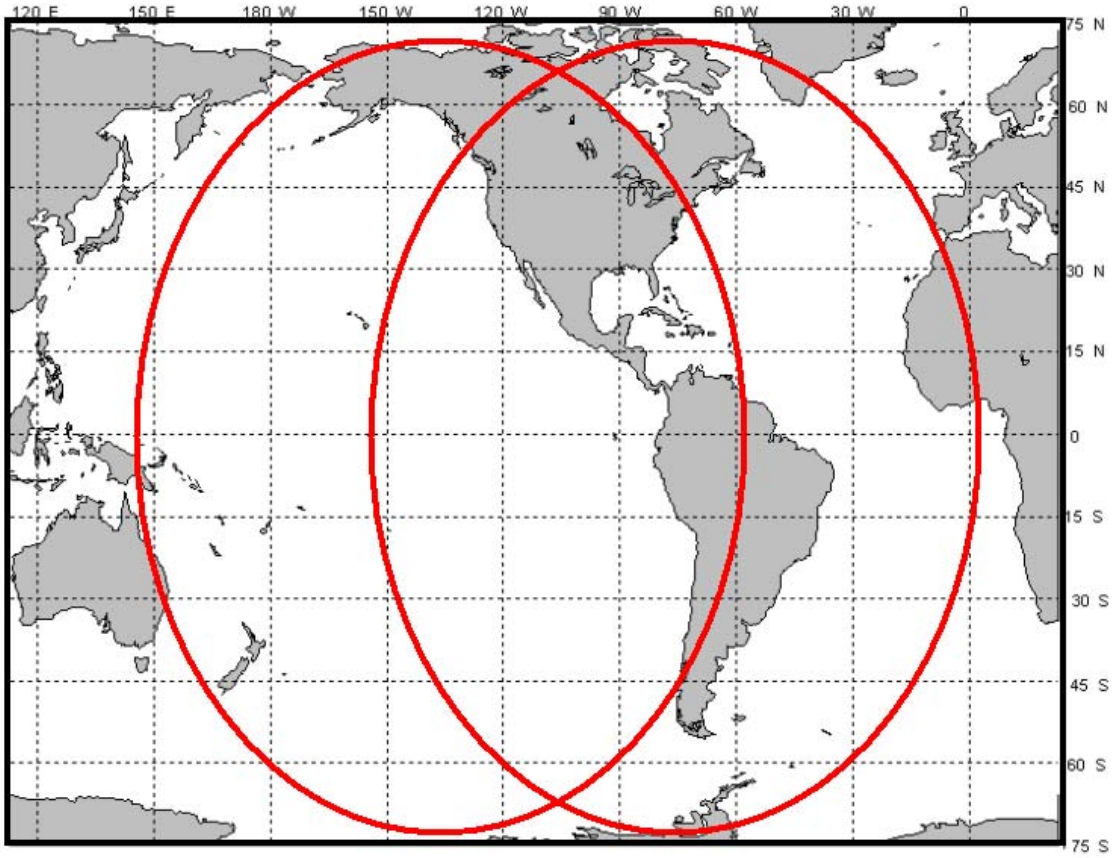

Figure 3.2.5 Approximate full disk coverage regions as seen from east and west satellite positions.

As a THRESHOLD, the HES sensor(s) **shall** perform full disk scans when commanded.

As a GOAL (TBR), the centroid-to-centroid distance between adjacent samples should be no larger than the same dimension at SSP when scanning the full disk region, eliminating gaps between samples.

3.2.4.2 62-degree LZA Region

Overview: This region is defined as the 62-degrees local zenith angle (LZA) minus half of the region of overlap that occurs between the east and west satellites. The area is shown graphically for the east and west satellites in Figure 3.2.6. Acceptable soundings can be retrieved over the entire region when the satellite is positioned over the equator. The 62-degree LZA region is the primary scan mode for the DS task sensor.

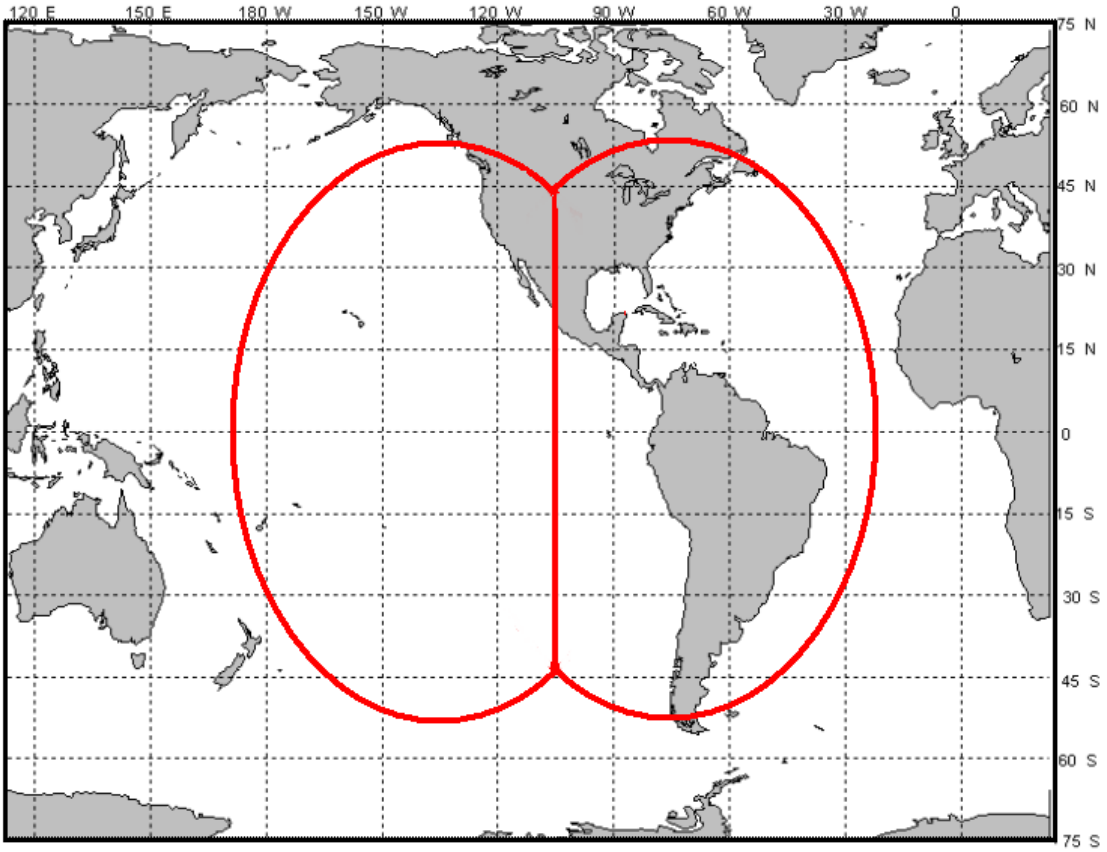

Figure 3.2.6 Approximate 62-degree LZA coverage regions as seen from east and west satellite positions.

As a THRESHOLD, the HES sounder task sensor(s) **shall** perform 62-degree LZA scans when commanded.

As a THRESHOLD for the DS task sensor, the centroid-to-centroid distance between adjacent samples **shall** be no larger than the same dimension at SSP when scanning the 62-degree LZA region, eliminating gaps between samples.

As a GOAL for the SW/M task sensor, the centroid-to-centroid distance between adjacent samples should be no larger than the same dimension at SSP when scanning the 62-degree LZA region, eliminating gaps between samples.

3.2.4.3 CONUS Region

Overview: The CONUS (CONtinental United States) region is defined for HES as a rectangle, approximately 3000-km by 5000-km. The approximate geographic area for the east satellite is 25N-50N latitude (TBR) and 50-105W longitude (TBR). The

approximate geographic area for the west satellite is 25N-50N latitude (TBR) and 105W-160W longitude (TBR). Acceptable soundings can be retrieved over the portion of the region falling within 62-dregree LZA when the satellite is positioned over the equator. Between the east and west satellites, sounding coverage of nearly the entire CONUS region is possible. The CONUS region is not a primary scan mode for any of the HES THRESHOLD tasks, however it is an important region and may be utilized often operationally.

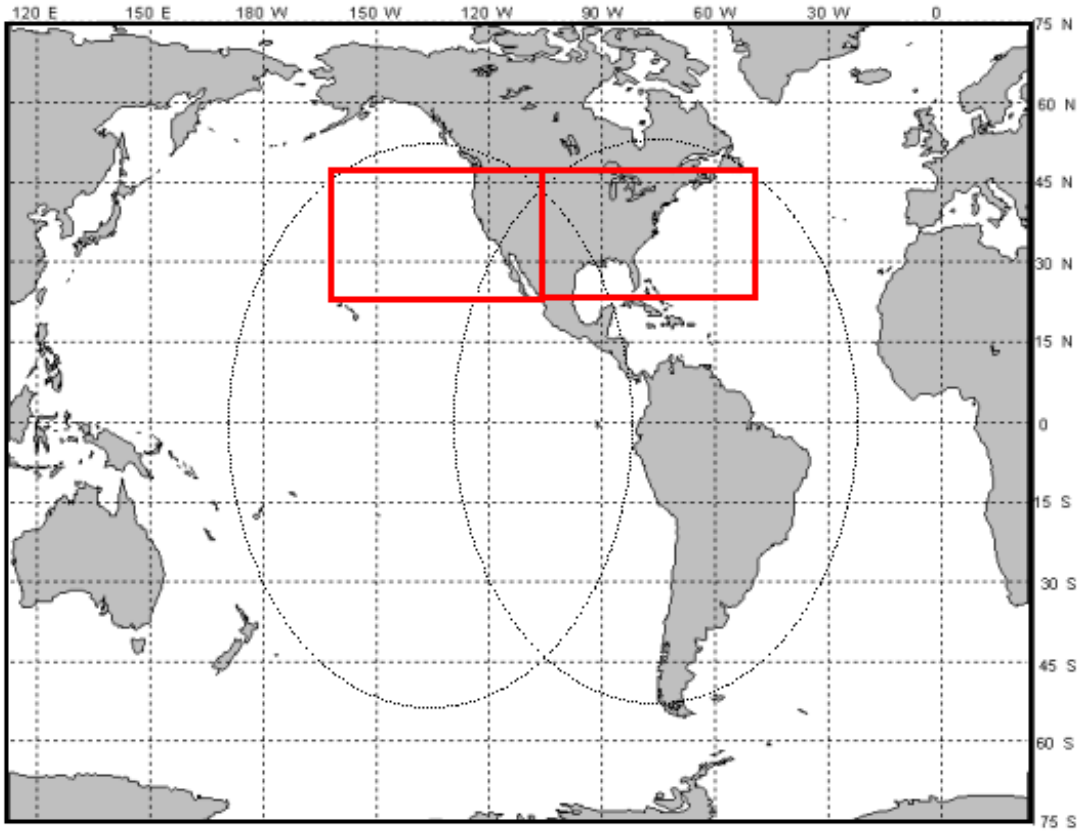

Figure 3.2.7 Approximate CONUS coverage regions as seen from east and west satellite positions, shown with 62-degree LZA limits.

As a THRESHOLD, the HES sensor(s) **shall** perform CONUS sized scans when commanded.

As a THRESHOLD, the sounding task sensor(s) **shall** not have any gaps in coverage exceeding the ground sample distance (TBR) presented in section 3.2.5.2, when scanning the CONUS region.

3.2.4.4 Mesoscale Region

Overview: A mesoscale region is defined as a rectangular region of arbitrary size up to the equivalent of a 1.6-degree by 1.6-degree (~1000-km by 1000-km) nadir-viewed area. The coverage rate applies to the 1000-km by 1000km region. A mesoscale region can be defined anywhere within the full disk with the understanding that acceptable soundings may only be retrieved over the 62-degree LZA region (with the satellite positioned over the equator). Figure 3.2.8 shows several mesoscale regions from each satellite within the full disk envelope. The mesoscale region is the primary scan mode for the SW/M task sensor.

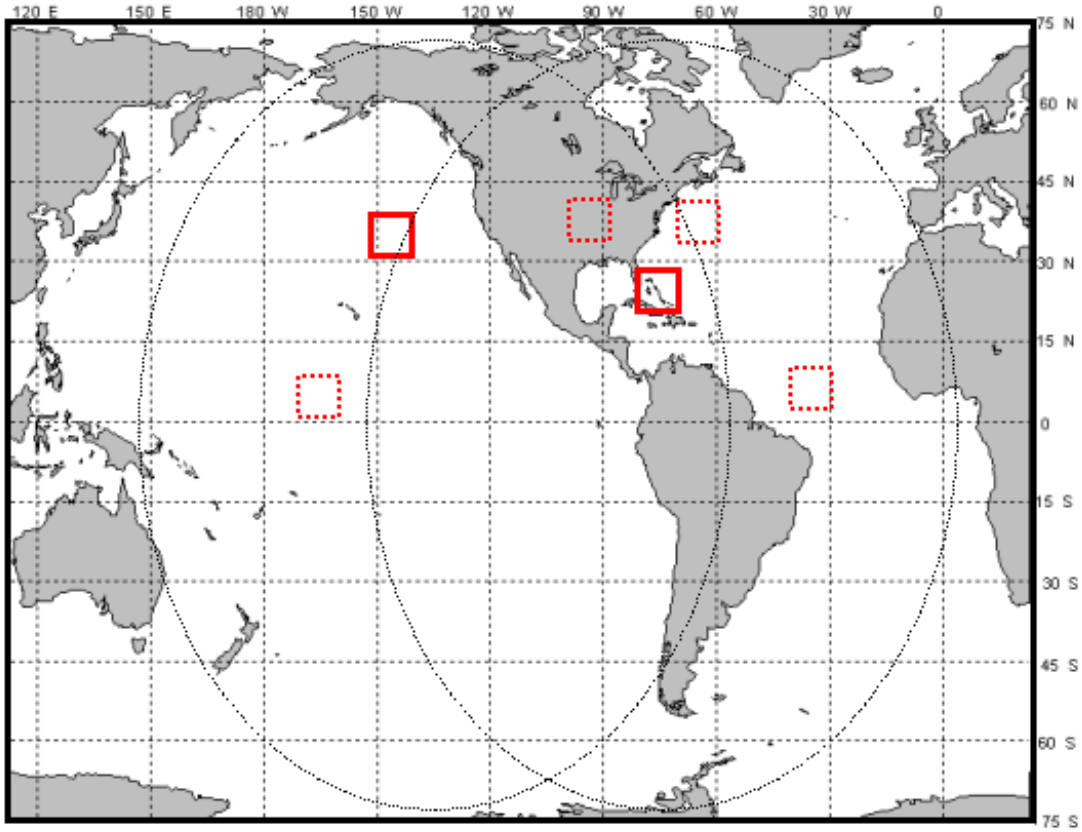

Figure 3.2.8Mesoscale coverage regions (one east and one west), shown with full disk limits.

As a THRESHOLD, the HES sensor(s) **shall** perform mesoscale scans when commanded.

As a THRESHOLD, the sounding task sensor(s) **shall** not have any gaps in coverage exceeding the ground sample distance (TBR) presented in section 3.2.5.2, when scanning a mesoscale region.

3.2.4.5 Coastal Waters Region

Overview: The coastal waters region addresses the US navigable waterways. For the coasts, this is defined as ocean waters within 400 km from the shore along the length of the US coast (east and gulf coast: ~6000 km, US west coast ~2100 km). The coastal waters region is the primary scan mode for the CW task sensor however, the sensor may also be used to image lakes, rivers, and estuaries. Also note that the coverage area requirements of the CW task sensor are driven by the need for a single sensor to scan the east and gulf coasts. Figure 3.2.9 shows the approximate coverage region for the east, gulf, and west coast of the United States.

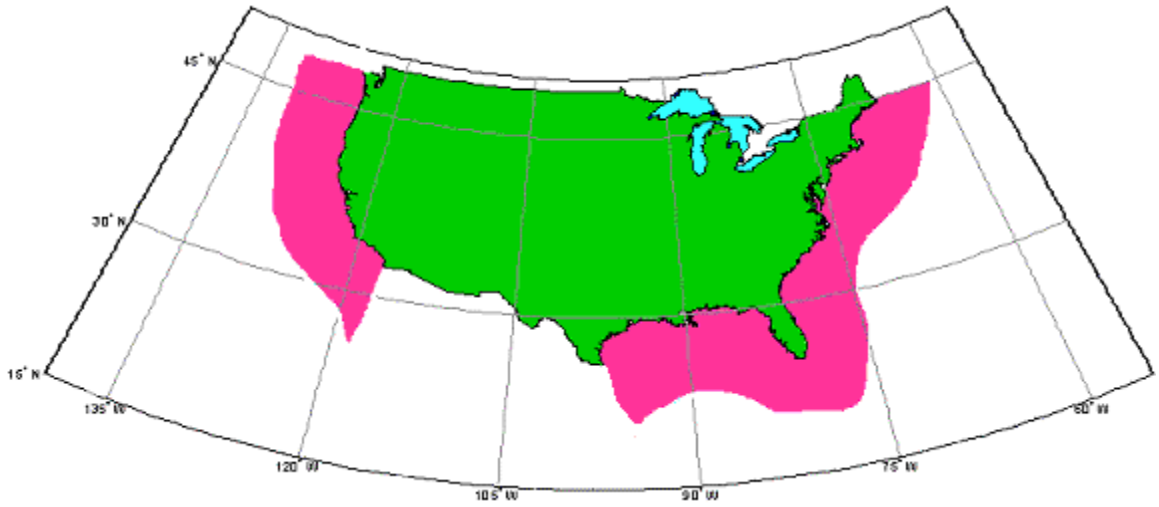

Figure 3.2.9 Approximate east and west coastal waters coverage regions (shaded pink).

As a THRESHOLD, the HES CW task sensor **shall** perform coastal water scans when commanded.

As a THRESHOLD, the CW task sensor **shall** not have gaps in coverage (TBR) exceeding (TBD), when scanning the coastal waters region.

3.2.5 Spatial Sampling Requirements

3.2.5.1 Field of Regard

Overview: The field of regard is defined as an angular diameter through which the instrument can detect any instrument-external source of interest. The diameter is centered at the sub-satellite point and the angle is measured at the instrument. This field of regard is unvignetted. For HES, these sources include at least space, which is used for

instrument background subtraction when appropriate, and emission from the earth's atmosphere and surface.

The unvignetted Field of Regard (FOR) **shall** be large enough to accommodate the calibration and navigation needs (section 3.2.8) of the HES tasks being addressed by the instrument.

3.2.5.2 Ground Sample Distance and Angle

Overview: The centroid-to-centroid distance between adjacent spatial samples on the Earth's surface, as measured at the sub-satellite point, defines the ground sample distance (GSD). The associated ground sample angle (GSA) is constant for all scan position and satellite altitude geometry. Often, in the document, the GSD is referenced with the caveat that the actual GSD is calculated from the GSA. A two-dimensional pixel is defined by the GSD in the East/West and North/South dimensions, therefore a single GSD quantity is specified for each task and each band required for the task.

The DS task sensor **shall** produce pixels no larger than the THRESHOLD GSD and GSA values presented in Table 3.2.14. It should produce pixels as small as the GOAL values.

Table 3.2.14 DS task sensor THRESHOLD and GOAL GSD and GSA capabilities

Band	HES Band Number	GSD (km)	GSA (microradians)	GSD (km)	GSA (microradians)
		THRESHOLD		GOAL	
LWIR	1	10	280	2	56
MWIR	2	10	280	2	56
SWIR	3	10	280	2	56
VIS	4	1	28.0	0.5	14

The SW/M task sensor **shall** produce pixels no larger than the THRESHOLD GSD and GSA values presented in Table 3.2.15. It should produce pixels as small as the GOAL values.

Table 3.2.15 SW/M task sensor THRESHOLD and GOAL GSD capabilities

Band	HES Band Number	GSD (km)	GSA (microradians)	GSD (km)	GSA (microradians)
		THRESHOLD		GOAL	
LWIR	1	4	111	2	56
MWIR	2	4	111	2	56
SWIR	3	4	111	2	56
VIS	4	1	28	0.5	14

The CW task sensor **shall** produce pixels no larger than the THRESHOLD GSD and GSA values presented in Table 3.2.16. It should produce pixels as small as the GOAL values.

Table 3.2.16 CW task sensor THRESHOLD and GOAL GSD capabilities

Band	HES Band Number	GSD (km)	GSA (microradians)	GSD (km)	GSA (microradians)
		THRESHOLD		GOAL	
Reflected Solar < 1 um	5	0.3 (TBR)	8.3 (TBR)	0.15 (TBR)	4.2 (TBR)
Reflected Solar > 1 um	6	1.2 (TBR)	33 (TBR)	0.9 (TBR)	25 (TBR)
LWIR	7	2	56	1	28

3.2.5.3 Pixel Spatial Binning

Any design achieving less than the THRESHOLD GSD (finer resolution), for any task, **shall** perform on-board spatial pixel binning when commanded, such that the effective GSD is equal to the THRESHOLD value ± 25% *and* all other THRESHOLD requirements are satisfied. (TBR)

3.2.5.4 Detector Sample Ground Footprint

Overview: This section presents the detailed requirements of the imaged detector elements on the ground. The requirements with regard to detector sample ground

footprint vary depending on task and band and on whether the function is imaging or sounding. Contiguous spatial sampling *is* mandated from the CW task sensors and Reflected Solar band of the sounding task sensors, but *is not* mandated from the IR bands of the sounding task sensors. The former bands are subject to MTF requirements (section 3.2.5.4.4), while the latter bands are subject to *ensquared energy* requirements (section 3.2.5.4.3). As such the requirements below are presented by task and separated by band when appropriate.

3.2.5.4.1 Geometric Shape

There is no requirement on the geometric shape of the footprint as long as all other THRESHOLD spatial sampling requirements are satisfied (TBR).

3.2.5.4.2 Uniformity

As a THRESHOLD, the two-dimensional spatial response uniformity within each HES detector element **shall** be known to better than TBD% of the average response by measurement. The measurement resolution <u>should</u> be TBD.

As a GOAL, the two-dimensional spatial response uniformity within each HES detector element <u>should</u> be known to better than 5% (TBD) of the average response by measurement. The measurement resolution <u>should</u> be TBD.

3.2.5.4.3 Detector/Optics Ensquared Energy

Overview: The detector/optics ensquared energy (DOEE) is a unitless figure of merit, which is the ratio of the energy *measured by* a detector from its corresponding ground sample area (defined by the GSD, not the detector active-area footprint) to the energy *measured by* the detector from the entire large and uniform scene. The DOEE can be understood in terms of the scene-spread function (SSF), which is the convolution of the polychromatic system point-spread function (PSF) with the detector spatial response function (SRF); however the detector spatial response function <u>must</u> be measured in order to fully characterize all of the optical and electrical cross-talking that is present in real detectors. This adds to the wings of the detector spatial response and degrades the DOEE:

$$\mathrm{DOEE} := \frac{\int_{-\frac{\mathrm{GSD}}{2}}^{\frac{\mathrm{GSD}}{2}} \int_{-\frac{\mathrm{GSD}}{2}}^{\frac{\mathrm{GSD}}{2}} \mathrm{SSF}\, dx\, dy}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \mathrm{SSF}\, dx\, dy}.$$

Equation 3.2.2

Figure 3.2.10 is a 1-D graphical representation of the above equation.

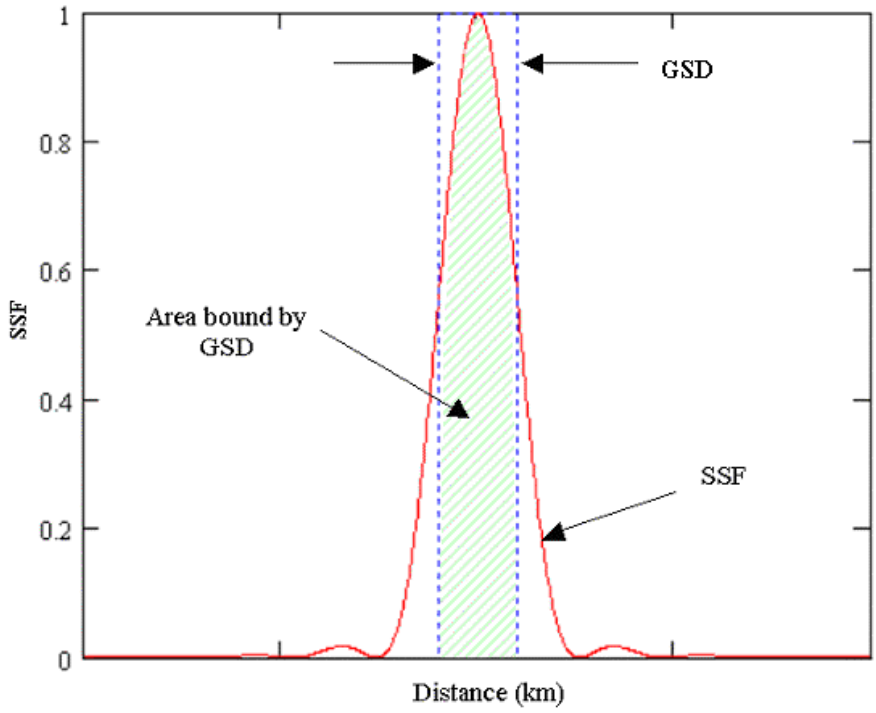

Figure 3.2.10 1-D graphical representation of Equation 3.2.2

As a standard, the DOEE is always referenced to the THRESHOLD GSD capability requirement for each task. The DOEE requirements below are presented by band. The requirement applies to all channels within each specified band.

The DS task sensor (10 km THRESHOLD GSD capability) DOEE **shall** be greater than or equal to the THRESHOLD requirements presented in Table 3.2.17. It should be greater than or equal to the GOAL requirements. The Reflected Solar band (HES band 4) is not subject to this requirement.

Table 3.2.17 DS task sensor THRESHOLD and GOAL DOEE requirements

Band	HES Band Number	DOEE (%) THRESHOLD	DOEE (%) GOAL
LWIR	1	90 (TBS)	93
MWIR	2	90 (TBS)	93
SWIR	3	90 (TBS)	93

The SW/M task sensor (4 km THRESHOLD GSD capability) DOEE **shall** be greater than or equal to the THRESHOLD requirements presented in Table 3.2.18. It should be greater than or equal to the GOAL requirements. The Reflected Solar band (HES band 4) is not subject to this requirement.

Table 3.2.18 SW/M task sensor THRESHOLD and GOAL DOEE requirements

Band	HES Band Number	DOEE (%) THRESHOLD	DOEE (%) GOAL
LWIR	1	64	90
MWIR	2	64	90
SWIR	3	64	90

3.2.5.4.4 Modulation Transfer Function

Overview: The spatial resolution of the HES imaging bands is defined by the system modulation transfer function (MTF). The sensor(s) **shall** meet the requirements below in both East/West and North/South directions after any ground processing including spacecraft jitter as detailed in the HES IRD.

As a THRESHOLD, the sounding task sensor(s) Reflected Solar band (HES band 4) **shall** meet the MTF requirements listed in Table 3.2.19. The values are consistent with 1.0 km resolution in this band.

Table 3.2.19 Sounding task sensor(s) Reflected Solar band MTF requirement

Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)	
8.0	4500	0.85 (TBR)
4.0	9000	0.73 (TBR)
2.666	13500	0.53 (TBR)
2.0	18000	0.32 (TBR)

As a THRESHOLD, the CW task sensor Reflected Solar band (HES band 5) **shall** meet the MTF requirements listed in Table 3.2.20. The values are consistent with 0.3 km resolution in this band. (TBR)

Table 3.2.20 CW task sensor Reflected Solar < 1 um band MTF requirement

Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)	
2.4	15000	0.90 (TBR)
1.2	30000	0.73 (TBR)
0.8	45000	0.53 (TBR)
0.6	60000	0.32 (TBR)

As a THRESHOLD, the CW task sensor NIR band (HES band 6) **shall** meet the MTF requirements listed in Table 3.2.21. The values are consistent with 1.2 km resolution in this band. (TBR)

Table 3.2.21 CW task sensor Reflected Solar > 1 um band MTF requirement

Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)	
9.6	3750	0.90 (TBR)
4.8	7500	0.73 (TBR)
3.2	11250	0.53 (TBR)
2.4	15000	0.32 (TBR)

As a THRESHOLD, the CW task sensor LWIR band (HES band 6) **shall** meet the MTF requirements listed in Table 3.2.22. The values are consistent with 2 km resolution in this band. (TBR)

Table 3.2.22 CW task sensor LWIR band MTF requirement

Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)	
16.0	2250	0.84
8.0	4500	0.62
5.33	6750	0.39
4.0	9000	0.22

3.2.5.5 Band-to-Band Registration

The following section is under review by the HES PORD Team

Overview: Band-to-band registration error, or co-registration, is the difference in pointing between spectral bands for any given pixel in the same frame. Where the pointing is defined by the RMS centroid location calculated from each channel within a band. Since the sounding process involves the combination of data from each of the individual spectral bands, it is vital that the energy detected in each spectral channel from the sounding task sensor(s) emanate from the same column of air as closely as possible. In a similar fashion, the CW task sensor will require the same geographic coverage of the various spectral bands because products involving multiple bands will be formed. This becomes especially important in regions of strong gradients. The requirements below specify how well the HES bands must be registered to each other. It is anticipated that in practice the co-registration will be determined from array image overlap. In that case, only knowledge of the co-registration at the corners of each array is actually required to determine shift and the rotation for all pixels. The requirements only apply to bands within a single sensor, i.e. if the sounding task is split between two sensors, band registration between the sensors is not required. Co-registration requirements within the same band imply channel-to-channel registration. This is relevant in a non-contiguous spectral band, and split-band sensor implementation. Co-registration between bands having different GSD is defined by centroiding a grid of the finer pixels to determine a "mean" pixel equal in extent to the coarser pixel.

NOTE: If meeting these requirements is considered a significant cost driver, the contractors should spell out expected cost versus co-registration.

As a THRESHOLD, the centroid band-to-band registration error between bands in the sounding task sensor(s) **shall** not exceed the values presented in Table 3.2.23. Values for emissive bands (HES bands 1-3) are written in terms of a percentage of the ground sample angle (GSA). Values for the reflective band (HES bands 4) are written as an absolute angle.

Table 3.2.23 Sounding task sensor(s) co-registration THRESHOLD requirements

	LWIR	MWIR	SWIR	Reflected Solar
LWIR	0.25 GSA (TBR)	0.25 GSA (TBR)	0.25 GSA (TBR)	70 urad (TBR)
MWIR	0.25 GSA (TBR)	0.25 GSA (TBR)	0.25 GSA (TBR)	70 urad (TBR)
SWIR	0.25 GSA (TBR)	0.25 GSA (TBR)	0.25 GSA (TBR)	70 urad (TBR)
VIS	70 urad (TBR)	70 urad (TBR)	70 urad (TBR)	70 urad (TBR)

As a GOAL, the centroid co-registration errors between bands in the sounding task sensor(s) should not exceed the values presented in
Table 3.2.24.

Table 3.2.24 Sounding task sensor(s) co-registration GOAL requirements

	LWIR	MWIR	SWIR	Reflected Solar
LWIR	0.10 GSA	0.10 GSA	0.10 GSA	28 urad
MWIR	0.10 GSA	0.10 GSA	0.10 GSA	28 urad
SWIR	0.10 GSA	0.10 GSA	0.10 GSA	28 urad
VIS	28 urad	28 urad	28 urad	28 urad

As a THRESHOLD, the centroid co-registration errors between bands in the CW task sensor **shall** not exceed the values presented in Table 3.2.25. Values are written as an absolute angle.

Table 3.2.25 CW task sensor co-registration THRESHOLD requirements

	Reflected Solar < 1 um	Reflected Solar > 1 um	LWIR
Reflected Solar < 1 um	9 urad (TBR)	9 urad (TBR)	14 urad (TBR)
Reflected Solar > 1 um	9 urad (TBR)	9 urad (TBR)	14 urad (TBR)
LWIR	14 urad (TBR)	14 urad (TBR)	14 urad (TBR)

As a GOAL, the centroid co-registration errors between bands in the CW task sensor should not exceed the values presented in Table 3.2.26. Values are written as an absolute angle.

Table 3.2.26 CW task sensor co-registration GOAL requirements

	Reflected Solar < 1 um	Reflected Solar > 1 um	LWIR
Reflected Solar < 1 um	7 urad	7 urad	7 urad
Reflected Solar > 1 um	7 urad	7 urad	7 urad
LWIR	7 urad	7 urad	7 urad

3.2.6 Temporal Requirements

3.2.6.1 Coverage Time

Overview: The coverage time for each region is defined as the time to produce a complete frame of data. It is specified for each of the primary scan regions for each sensor task. All of the following **shall** be performed within the coverage time:

a) Scan the required region. The coverage region is defined for each task in section 3.2.4.
b) Scan mirror (if present) steps, settles, and slews.
c) Spatially over-sample the scene to correct for image rotation and any other scan artifacts, in order to meet THRESHOLD sampling requirements presented in section 3.2.5.
d) Acquire the required space look and/or calibration target data needed to meet the radiometric requirements.
e) Necessary operations to switch between tasks if one sensor is used for multiple tasks.
f) Operations to meet navigation requirements.

As a THRESHOLD the DS task sensor **shall** scan the 62-degree LZA region in 1 hour when commanded.

As a GOAL, the DS task sensor should scan the 62-degree LZA region in (TDB) when commanded.

As a THRESHOLD the SW/M task sensor **shall** scan the mesoscale region in 4.4 minutes when commanded.

As a GOAL the SW/M task sensor should scan the mesoscale region in (TDB) when commanded.

As a THRESHOLD the CW task sensor **shall** scan the coastal waters region in 1 hour when commanded.

As a GOAL the CW task sensor should scan the coastal waters region in 20 minutes (TBR) when commanded.

For example, the tables below show the maximum expected scan time for each task and for each coverage region. The primary scan mode for each task, for which the coverage time capability is specified, is highlighted with **bold** text.

Table 3.2.27 Expected scan times for the DS task sensor emissive bands (HES bands 1-3).

Coverage Region	Coverage Area (km^2)	GSR (Hz)	GSD (km)	Coverage Time
Full Disk	1.00E+08	195	10	1 hr 32.6 min
62-degree LZA	**7.00E+07**	**195**	**10**	**0 hr 59.8 min**
CONUS	1.50E+07	195	10	0 hr 9.3 min
Mesoscale	1.00E+06	195	10	0 hr 0.7 min
Coastal Waters	2.40E+06	195	10	0 hr 1.4 min

Table 3.2.28 Expected scan times for the SW/M task sensor emissive bands (HES bands 1-3).

Coverage Region	Coverage Area (km^2)	GSR (Hz)	GSD (km)	Coverage Time
Full Disk	1.00E+08	240	4	9 hr 38.7 min
62-degree LZA	7.60E+07	240	4	6 hr 46.0 min
CONUS	1.50E+07	240	4	0 hr 57.9 min
Mesoscale	**1.00E+06**	240	**4**	**0 hr 4.3 min**
Coastal Waters	2.40E+06	240	4	0 hr 8.8 min

Table 3.2.29 Expected scan times for the CW task sensor Reflected Solar band (HES band 5)

Coverage Region	Coverage Area (km^2)	GSR (Hz)	GSD (km)	Coverage Time
Full Disk	1.00E+08	7400	0.3	65 hr 56.9 min
62-degree LZA	7.60E+07	7400	0.3	46 hr 16.0 min
CONUS	1.50E+07	7400	0.3	6 hr 35.7 min
Mesoscale	1.00E+06	7400	0.3	0 hr 29.7 min
Coastal Waters	**2.40E+06**	7400	**0.3**	**0 hr 60.0 min**

3.2.6.2 Spectral Bands Simultaneity

As a THRESHOLD, data from spectral bands 1-4 of HES obtained from any specific point on the Earth **shall** be coincident within 10 seconds.

As a GOAL, data from spectral bands 1-4 of HES obtained from any specific point on the Earth **shall** be coincident within 10 seconds.

As a THRESHOLD, data from spectral bands 5-7 of HES obtained from any specific point on the Earth **shall** be coincident within 15 seconds.

As a GOAL, data from spectral bands 5-7 of HES obtained from any specific point on the Earth **shall** be coincident within 10 seconds.

3.2.6.3 Adjacent Pixels Simultaneity

Overview: Temporal simultaneity is important for the purpose of creating images, or using retrieval information in weather prediction models. The requirements below present the maximum time between Earth measurements for adjacent pixels. When a sensor rasters a detector footprint (or array of detector footprints) across a scene to create a complete frame, these requirements determine the maximum swath length. The requirements are presented for each HES task and for each geographical coverage region.

The time between collection of adjacent pixels within a single HES data frame **shall** be less than or equal to the THRESHOLD values presented in Table 3.2.30. It should be less than or equal to the GOAL values.

Table 3.2.30 THRESHOLD and GOAL pixel simultaneity requirements

Sounding Task Sensor(s)				CW Task Sensor	
Coverage Region	**Pixel Simultaneity THRESHOLD**	**Pixel Simultaneity GOAL**		**Pixel Simultaneity THRESHOLD**	**Pixel Simultaneity GOAL**
Full Disk	TBD	TBD		TBD	TBD
62-degree LZA	6 min	3 min		TBD	TBD
CONUS	3 min	2 min		TBD	TBD
Mesoscale	3 min	TBD		TBD	TBD
Coastal Waters	TBD	TBD		15 min (TBR)	TBD

3.2.6.4 Time Tagging

The data **shall** be time identified so that the time any detector sample in the data was acquired can be determined to within 0.1 seconds relative to the spacecraft provided clock information. The spacecraft clock is synchronized to UT to better than 0.1 seconds.

3.2.7 Radiometric Performance Requirements

3.2.7.1 Dynamic Range

The HES emissive bands (HES band 1 – 3, and 7) **shall** have sufficient dynamic range to view cold space and without saturation of any detector element during any possible combination of the following operational conditions:

- viewing the Earth surface at the temperature of 330 K at the sub-satellite point (SSP) (TBD) through a clear standard atmosphere (radiance values to be supplied by the government);

- solar intrusion heats the fore optical elements and baffles to their maximum operational temperatures;
- viewing any internal blackbody calibration source operating at its maximum operational temperature;
- with the IR detectors operating TBD K above their baseline temperatures (refer to section 3.1.4.8).

HES band 5 (reflected solar <1 um) in the CW task only **shall** have sufficient dynamic range for measurements between 0 and 10 (TBR) % above the supplied spectrum (see appendix) without saturation of any detector element.

HES band 6 (reflected solar > 1um) shall have sufficient dynamic range for measurements between 0 to 100% albedo solar spectrum without saturation of any detector element.

3.2.7.2 Measurement Precision (SNR, NEdN, and NEdT)

Overview: The noise performance requirements are defined at the aperture of the system by the noise-equivalent radiance difference (NEdN) for emissive bands (HES bands 1 – 3, and 7) and signal to noise ratio (SNR) for reflective bands (HES bands 4-6). The measurement precision is a fundamental performance metric for the HES. The noise radiance is defined as the standard deviation (1 sigma) of the calibrated radiance in each spectral channel over many measurements while viewing the same scene. The signal radiance in each case is defined as the radiance arriving from the top of the atmosphere (TOA). The NEdT at a given wavelength is defined by dividing the NEdN at that wavelength by the derivative with respect to temperature of the Planck blackbody radiance function, evaluated at 250 K at the same wavelength. The NEdN and NEdT, or SNR is defined at several key channels within a band. The requirement for channels between those identified can be found by linear interpolation.

The requirements apply for any possible clear air Earth scene spectral radiance; see section (2.10.2) 3.B.2.m of the MRD and Appendix B of this document for representatives of the extremes in radiance. The requirements only apply to channels present in the sensor, i.e. optional and GOAL channels not provided in the design are not subject to these requirements.

It is recognized that for some large focal plane array implementations there could be a significant spread in performance across the array due to the statistical nature of the detection device. The performance distribution maps to the spectral dimension in a dispersive implementation, and the spatial dimension in a multiplexing implementation. Specifications setting the bounds to the performance distribution in the spectral dimension are presented in section 3.2.7.2.1. Specifications setting the bounds to the performance distribution in the spatial dimension are presented in section 3.2.7.2.2.

As a THRESHOLD, the sounding task sensor(s) LWIR band (HES band 1) NEdN **shall** be less than or equal to the values plotted in Figure 3.2.11. NEdT values are calculated using 250 K as the reference temperature and plotted in Figure 3.2.12. Values for key wavelengths are quantified in Table 3.2.31.

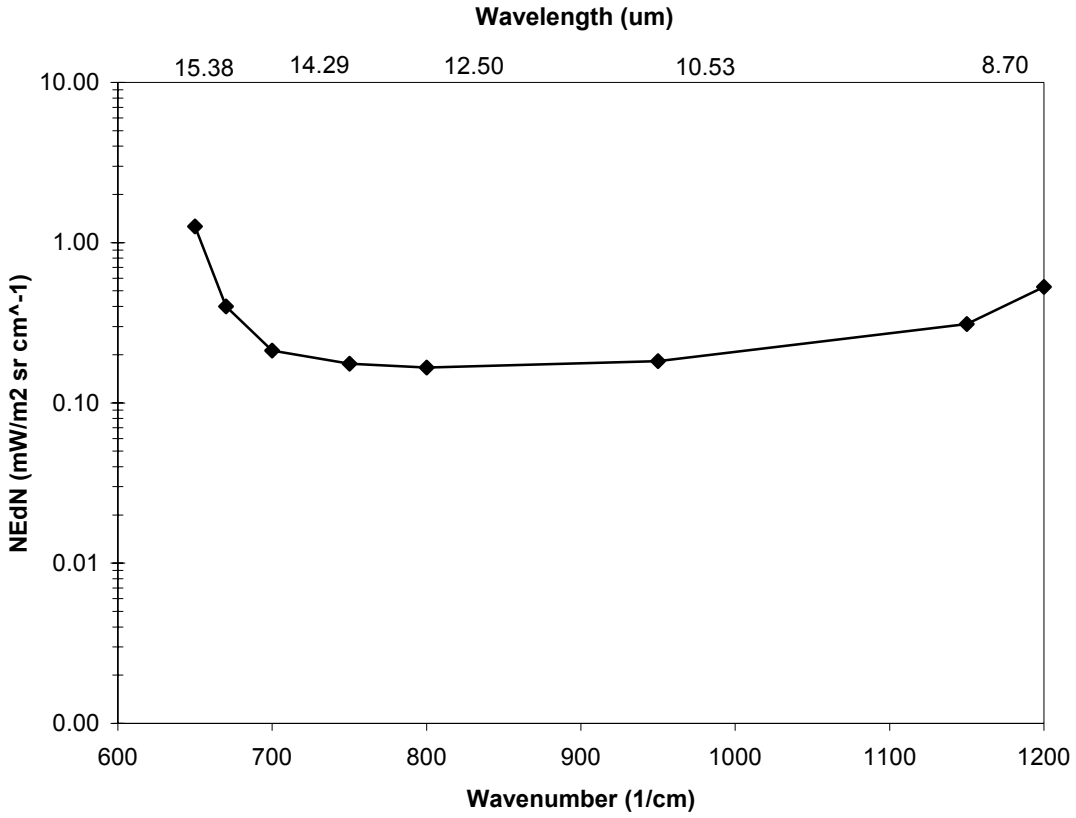

Figure 3.2.11 Plot of sounding sensor(s) LWIR NEdN requirement

Table 3.2.31 Sounding sensor(s) LWIR NEdN requirement

Wavenumber (cm^{-1})	Wavelength (um)	NEDN (mW/m^2 sr cm^{-1})	NedT @ 250K (K)
650	15.38	1.265	1.036
670	14.93	0.40	0.31
700	14.29	0.212	0.175
750	13.33	0.176	0.147
800	12.50	0.166	0.146
950	10.53	0.182	0.191
1150	8.70	0.310	0.483
1200	8.33	0.529	0.918

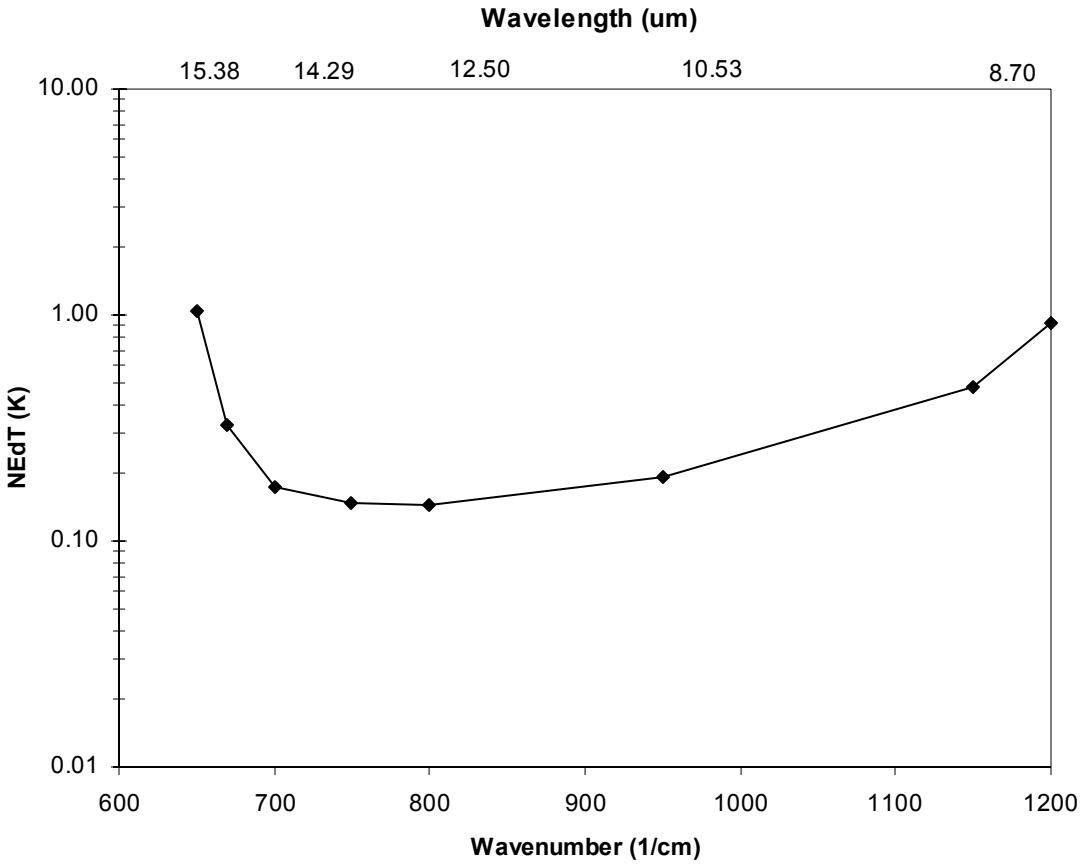

Figure 3.2.12 Plot of sounding sensor(s) LWIR NEdT @250K requirement

As a THRESHOLD, the sounding task sensor(s) MWIR band (HES band 2) NEdN **shall** be less than or equal to the values plotted in Figure 3.2.13. NEdT values are calculated using 250 K as the reference temperature and plotted in Figure 3.2.14. Values for key wavelengths are quantified in Table 3.2.32.

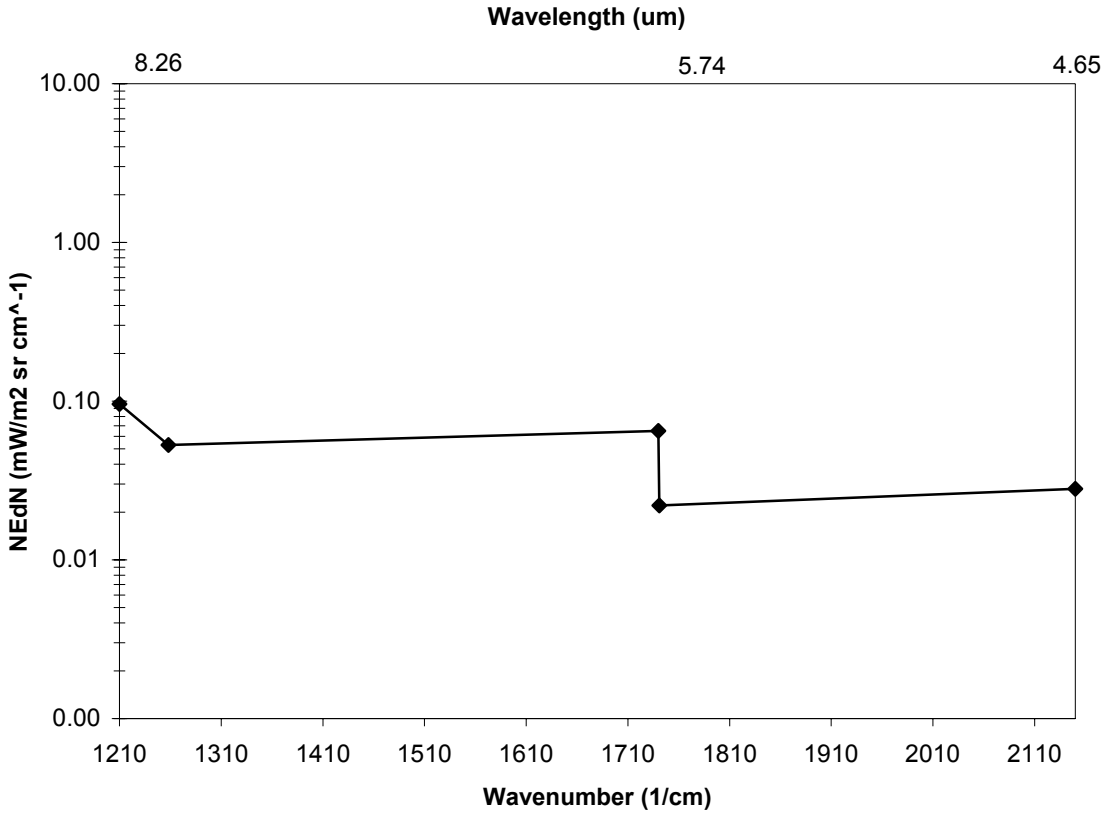

Figure 3.2.13 Plot of sounding sensor(s) MWIR NEdN requirement

Table 3.2.32 Sounding sensor(s) MWIR NEdN requirement

Wavenumber (cm^{-1})	Wavelength (um)	NEDN (mW/m^2 sr cm^{-1})	NedT @ 250K (K)
1210	8.26	0.096	0.24
1258	7.95	0.053	0.13
1650	6.06	0.092	0.605
2150	4.65	0.028	1.57

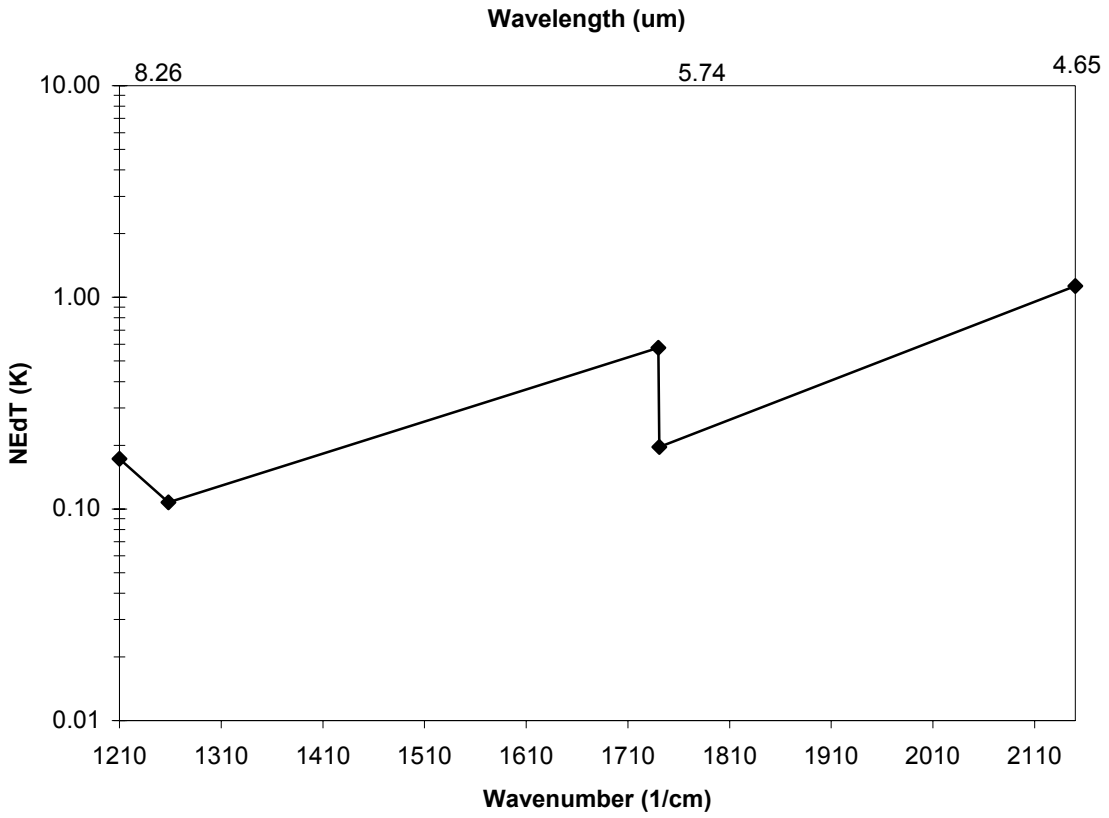

Figure 3.2.14 Plot of sounding sensor(s) MWIR NEdT @250K requirement

As a THRESHOLD, the sounding task sensor(s) SWIR band (HES band 3) NEdN **shall** be less than or equal to the values plotted in Figure 3.2.15 (solid line). Values are calculated using 250 K as the reference temperature and plotted in Figure 3.2.16. Values for key wavelengths are quantified in Table 3.2.33.

As a GOAL, the sounding task sensor(s) SWIR band (HES band 3) NEdN should be less than or equal to the values plotted in Figure 3.2.15 (dashed line). Values are calculated using 250 K as the reference temperature and plotted in Figure 3.2.16. Values for key wavelengths are quantified in Table 3.2.33.

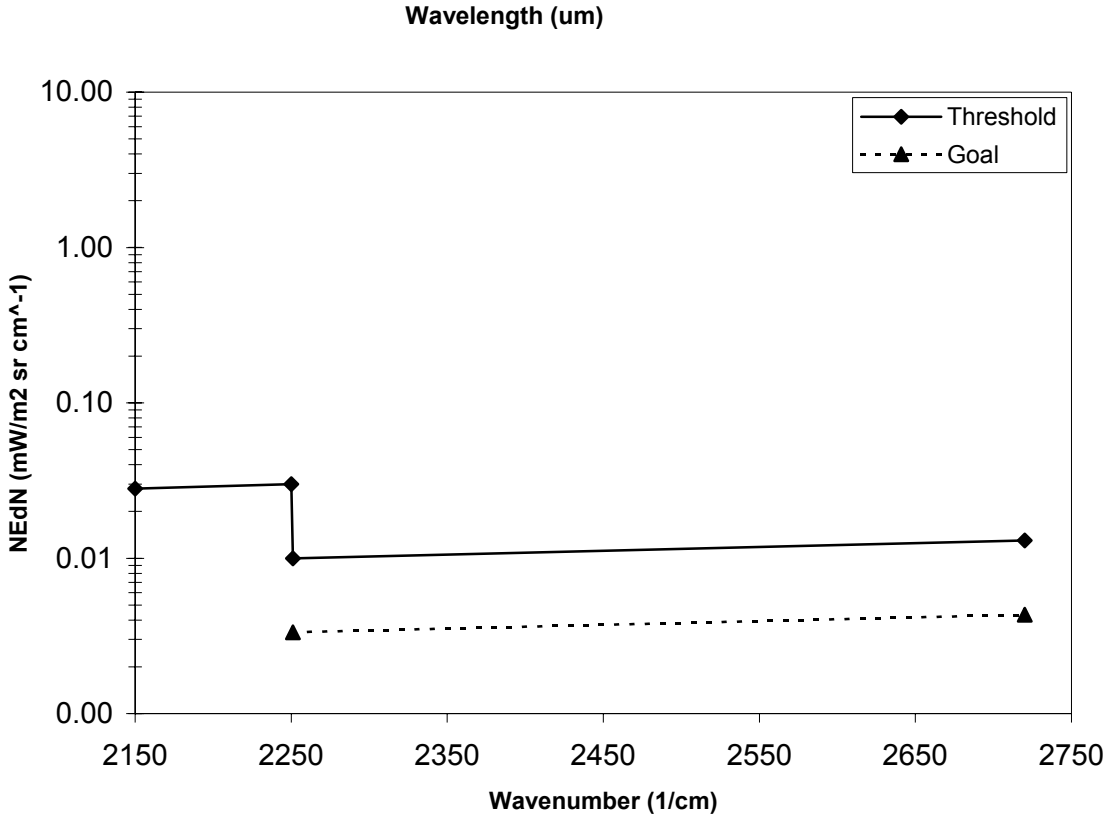

Figure 3.2.15 Plot of sounding sensor(s) SWIR NEdN requirement

Table 3.2.33 Sounding sensor(s) SWIR NEdN requirement

Wavenumber (cm^{-1})	Wavelength (um)	NEDN (mW/m^2 sr cm^{-1})		NedT @ 250K (K)	
		Threshold	Goal	Threshold	Goal
2150	4.65	0.028	NA	1.57	NA
2250	4.44	0.03	NA	2.57	NA
2251	4.44	0.010	0.003	0.6	0.2
2720	3.68	0.013	0.004	5.03	1.68

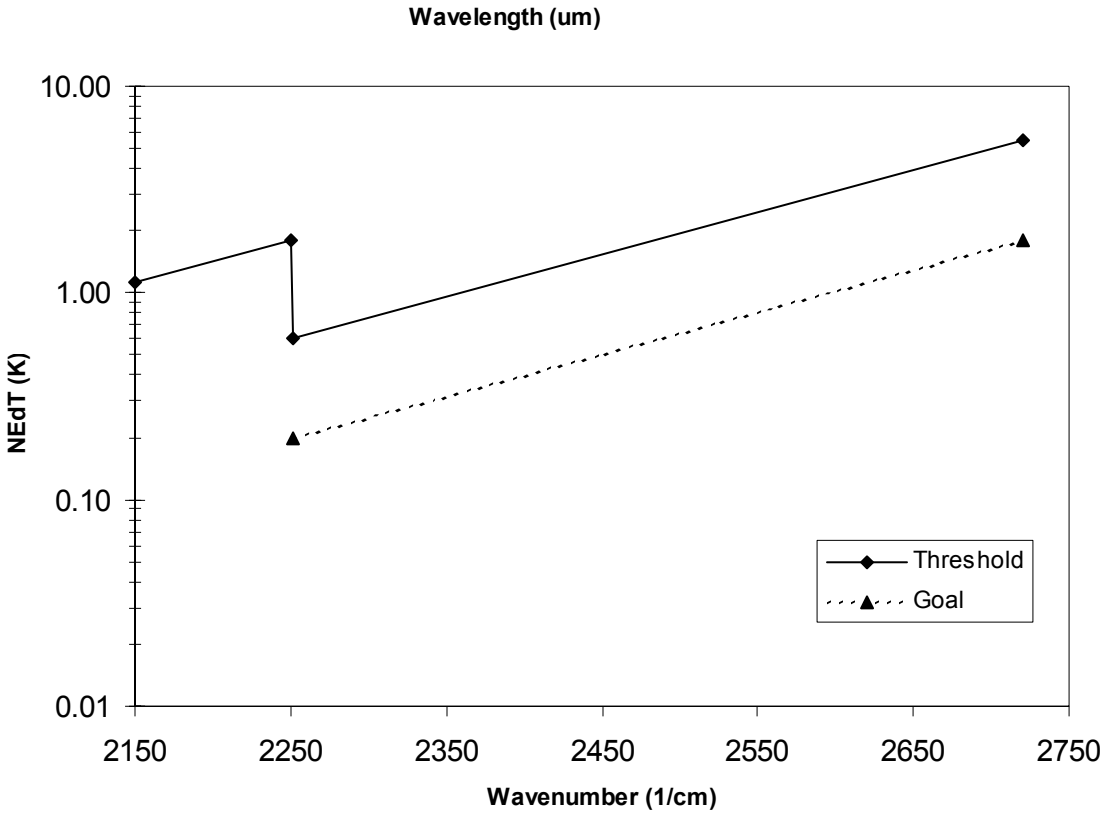

Figure 3.2.16 Plot of sounding sensor(s) SWIR NEdT @250K requirement

As a THRESHOLD, the sounding task sensor(s) Reflected Solar band (HES band 4) SNR **shall** be greater than or equal to 300 at 100% albedo with a low light capability having a signal to noise level greater than or equal to 10 (TBR) over a 2 km sample using 5% albedo; the signal level past sunset at the ground point of interest and extending as far as possible into night conditions will be lower than this specified level.

As a THRESHOLD, the CW task sensor Reflected solar bands (HES band 5 and 6) SNR **shall** be greater than or equal to the minimum values plotted in Figure 3.2.17 for the supplied radiances at the end of this document in Appendix B. As a GOAL, the CW task sensor Reflected solar bands (HES band 5 and 6) SNR should be greater than or equal to the values on the third column of Table 3.2.14. These SNR values will be updated by the government to reflect the radiances values listed in Appendix B. Values for key wavelengths are quantified in Table 3.2.34

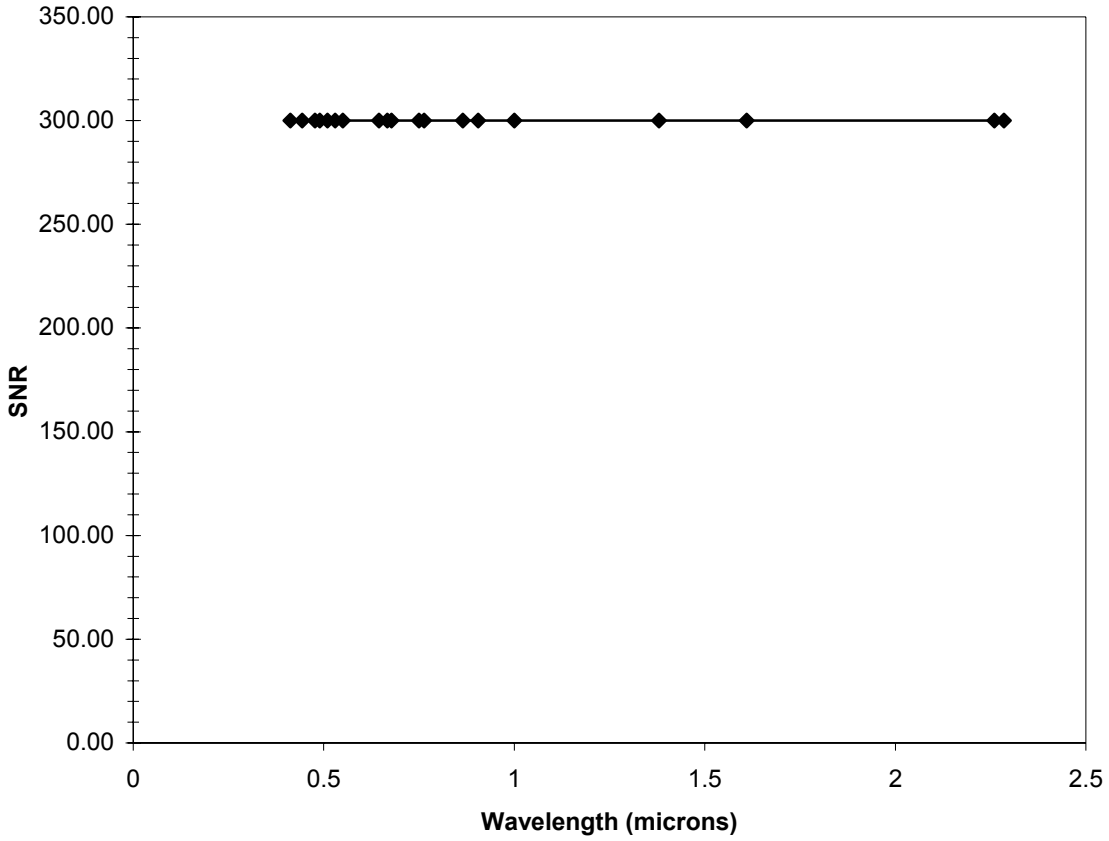

Figure 3.2.17 Plot of CW sensor Reflected Solar-NIR SNR requirement

Table 3.2.34 CW sensor Reflected Solar-NIR SNR requirement

Channel Center (um)	Minimum SNR (Threshold)	Minimum SNR (Goal)
0.412	300 (TBR)	600 (TBR)
0.443	300 (TBR)	600 (TBR)
0.477	300 (TBR)	600 (TBR)
0.490	300 (TBR)	600 (TBR)
0.510	300 (TBR)	600 (TBR)
0.530	300 (TBR)	600 (TBR)
0.550	300 (TBR)	600 (TBR)
0.645	300 (TBR)	600 (TBR)
0.667	300 (TBR)	600 (TBR)
0.678	300 (TBR)	600 (TBR)
0.750	300 (TBR)	600 (TBR)
0.763	300 (TBR)	600 (TBR)
0.865	300 (TBR)	600 (TBR)
0.905	300 (TBR)	600 (TBR)
1.0	300 (TBR)	600 (TBR)
1.38	300 (TBR)	600 (TBR)
1.61	300 (TBR)	600 (TBR)
2.26	300 (TBR)	600 (TBR)
2.285	300 (TBR)	600 (TBR)

As a THRESHOLD, the CW task sensor LWIR band (HES band 5 and 6) NEdN **shall** be less than or equal to the values in Table 3.2.35.

Table 3.2.35 CW sensor LWIR NEdN and NEdT @250K requirement

Channel Center (cm^{-1})	Channel Center (um)	NEdN (mW/m^2 sr cm^{-1})	NEdT @ 250 K (K)
893	11.2	0.12	0.1
813	12.3	0.12	0.1

3.2.7.2.1 Spectral Operability

Overview: The hyperspectral (contiguous bands) sensors in HES provide more channels than required by current models. In the absence of a low-noise spectral bin (i.e. a spectral band sub-element $\Delta\lambda$ or $\Delta\nu$), its threshold-compliant neighbor may be used in models to produce sufficient results. This section presents the bounds of acceptable spectral

operability for the HES. An operable spectral channel is defined as a single spectral band sub-element with noise equivalent radiance less than the stated measurement precision:

$$NEdN_i \leq NSF * NEdN_{Req} \text{ or } SNR_i \geq SNR_{Req}/NSF$$

Equation 3.2.3

where i designates the i^{th} spectral channel in a band, Req designates the THRESHOLD requirement, and NSF is a scale factor. Values for the scale factor will be supplied in the spatial operability section, to complete requirements in each dimension. The operability requirements are presented below as a percentage of the band total, i.e. a 90% operability requirement mandates that at least 90% of the channels must satisfy Equation 3.2.1, or fewer than 10% inoperable channels. There are however acceptable limits on the number of adjacent inoperable channels, or spectral inoperability clusters.

The sounding sensor(s) spectral operability and spectrally inoperable clusters **shall** conform to the THRESHOLD limits presented in Table 3.2.36. Clusters are specified in terms of number of adjacent pixels in a single grouping and total allowable number of groups in a sub-region. Figure 3.2.4 shows a graphical representation of each spectral region specified in the table.

Missing spectral channels due to intention band breaks within the defined spectral regions **shall** be considered inoperable pixels, however they **shall** not be considered clusters.

Table 3.2.36 Spectral operability THRESHOLD requirements.

Band	Sub-Region	Spectral Range (cm^{-1})	Operability	Inoperable Clusters	
				Channels	Groups
LWIR [Band-1]	1	650-665	≥ 50%	< 5	< 2
	2	665-672	≥ 50%	NONE	-
	3	672-722	≥ 50%	NONE	-
	4	722-1016	≥ 50%	< 5	< 40
	5	1016-1046	≥ 50%	< 5	< 4
	6	1046-1200	≥ 50%	< 5	< 19
MWIR [Band-2] (option 1)	NA	1650-2150	≥ 50%	< 20	< 10
MWIR [Band-2] (option 2)	NA	1210-1740	≥ 50%	< 20	< 10
SWIR [Band-3]	1	2150-2250	≥ 50%	< 5	< 4
	2	2250-2380	≥ 50%	< 5	< 5
	3	2380-2390	≥ 50%	< 2	1
	4	2390-2720	≥ 50%	< 5	< 13

The sounding sensor(s) spectral operability and spectral inoperability clusters should conform to the GOAL limits presented in Table 3.2.37.

Table 3.2.37 Spectral operability GOAL requirements.

Band	Sub-Region	Spectral Range (cm^{-1})	Operability	Inoperable Clusters	
				Channels	Groups
LWIR [Band-1]	1	650-665	≥90%	< 2	< 2
	2	665-672	≥90%	NONE	-
	3	672-722	≥90%	NONE	-
	4	722-1016	≥90%	< 2	< 40
	5	1016-1046	≥90%	< 2	< 4
	6	1046-1200	≥90%	< 2	< 19
MWIR [Band-2] (option 1)	NA	1650-2150	≥90%	< 5	< 10
MWIR [Band-2] (option 2)	NA	1210-1740	≥90%	< 5	< 10
SWIR [Band-3]	1	2150-2250	≥90%	< 2	< 4
	2	2250-2380	≥90%	< 2	< 5
	3	2380-2390	≥90%	< 2	1
	4	2390-2720	≥90%	< 2	< 13

The spectral operability requirements are only specified for contiguous bands. Non-contiguous band implementations **shall** have 100% operability.

CW-task sensor contiguous band implementations **shall** have 100% spectral operability.

3.2.7.2.2 Spatial Operability and Outages

Overview: This section bounds the noise performance for each pixel in a scan frame (as defined by the coverage region).

As a THRESHOLD, at least 50% of all pixels in a frame **shall** meet spectral operability requirements with the noise scale factor NSF = 1.

A pixel is considered *operable* if the THRESHOLD spectral operability requirements in section 3.2.7.2.1 are satisfied with the noise scale factor NSF = 2. A pixel is considered non-responsive, or an outage, when it is inoperable *and* the calibrated responsivity in each spectral channel is less than 10% (TBR) of the mean responsivity for the same channel across the entire focal plane array.

The spatial operability requirements below are specified per HES band. For designs that measure multiple bands with a single focal plane array, the less restrictive requirement **shall** apply.

As a THRESHOLD, the HES operability **shall** be greater than or equal to the values presented in Table 3.2.38.

As a THRESHOLD, the HES **shall** have fewer outages than the values presented in Table 3.2.38.

Table 3.2.38 HES THRESHOLD and GOAL pixel operability and outage requirements

HES Band Number	Band/Task	Operability THRESHOLD	Outages THRESHOLD
1	LWIR-Sounding	87 %	4%
2	MWIR-Sounding	97 %	1%
3	SWIR-Sounding	99% (TBR)	0% (TBR)
4*	Reflected Solar-DS	99.9%	0% (TBR)
4*	Reflected Solar-SW/M	99.9% (TBR)	0% (TBR)
5	Reflected Solar-CW	99.9% (TBR)	0% (TBR)
6	NIR/CW	87 % (TBR)	4% (TBR)

As a GOAL, the HES spatial operability should be 100% for all bands.

3.2.7.2.3 Inoperable Pixel Clusters

Overview: Any possible grouping of contiguous pixels (diagonals included) totaling (TBD%) of the frame total, with more than (TBD)% inoperable pixels.

As a THRESHOLD, there **shall** not be any inoperable pixel clusters in any HES data frames.

3.2.7.3 Radiometric Accuracy

3.2.7.3.1 Absolute Accuracy

Overview: The HES absolute radiometric accuracy is the unknown bias error in the measured radiance in each spectral channel, root-mean-squared with any random precision or repeatability component in a specific measurement period. It is specified in terms of a brightness temperature error at 300 K for emissive bands and percent of signal at 100% albedo for reflective bands.

As a THRESHOLD, the HES absolute accuracy **shall** be less than or equal to the values presented in Table 3.2.39. It should be less than or equal to the GOAL values.

Table 3.2.39 HES absolute accuracy THRESHOLD and GOAL requirements

HES Band Number	Band/Task	Abs. Accuracy (%) THRESHOLD	Abs. Accuracy (%) GOAL	Abs. Accuracy (K) THRESHOLD	Abs. Accuracy (K) GOAL
1	LWIR/Sounding	NA	NA	1	0.5
2	MWIR/Sounding	NA	NA	1	0.5
3	SWIR/Sounding	NA	NA	1	0.5
4	VIS	5	3 (TBD)	NA	NA
5	Reflected Solar < 1 um : CW	3	TBD	NA	NA
6	Reflected Solar < 1 um : CW	3	TBD	NA	NA
7	LWIR: CW	NA	NA	1	0.5

3.2.7.3.2 Relative Accuracy

Overview: The relative radiometric accuracy is defined as the unknown bias error *between two arbitrary radiance measurements*, root-mean-squared with any random precision or repeatability component in a specific measurement period. The relative accuracy error is defined as the root-mean-square (RMS) variation in signal level, for all measurements in an ensemble (e.g. all the pixels in a frame) illuminated by constant scene radiance. It is specified in terms of the NEdN for emissive bands and percent of signal at 100% albedo for reflective bands.

As a THRESHOLD, the HES relative accuracy **shall** be less than or equal to the values presented in Table 3.1.1. It should be less than or equal to the GOAL values. All values presented are 1-sigma, and apply to the following categories:

a) Swath to swath (where a swath is one traversal of the scan mirror, if present, in the east-west directions over the entire scene of interest).
b) Scan position to scan position (where scan position refers to a location of the target within a swath). (TBR)
c) Pixel to pixel.
d) Band to band.
e) Channel to channel.
f) Calibration to calibration.

Table 3.2.40 HES absolute accuracy THRESHOLD and GOAL requirements

HES Band Number	Band/Task	Rel. Accuracy (% Signal) THRESHOLD	Rel. Accuracy (% Signal) GOAL	Rel. Accuracy (% NEdN) THRESHOLD	Rel. Accuracy (% NEdN) GOAL
1	LWIR/Sounding	NA	NA	100	30 (TBR)
2	MWIR/Sounding	NA	NA	100	30 (TBR)
3	SWIR/Sounding	NA	NA	100	30 (TBR)
4	Reflected Solar/Sounding	0.2 TBR	TBS	NA	NA
5	Reflected Solar < 1 um : CW	0.2	TBS	NA	NA
6	Reflected Solar < 1 um : CW	0.2	TBS	NA	NA
7	LWIR: CW	NA	NA	100	30 (TBR)

The relative radiometric accuracy should be demonstrated by averaging a sufficiently large number of samples such that the residual temporal variation does not dominate the calculation.

3.2.7.3.3 Long-term Drift

The drift in absolute calibrated radiances for the CW task sensor reflective bands (HES bands 5 and 6) **shall** be less than 0.5 % over the instrument lifetime.

All calibration sources used **shall** be traceable to National Institute of Standards and Technology (NIST) standards.

3.2.7.3.4 Ground Calibration

The HES reflective bands (HES bands 4-6) **shall** be calibrated on the ground, pre-launch. The calibration **shall** be a full-system and full-aperture spectral response characterization, i.e. the clear aperture of every component in the optical train is subject to calibration.

3.2.7.3.5 On-Orbit Calibration

The HES **shall** have on-board spectral response calibration for the emissive bands (HES bands 1-3 and 7), i.e. the clear aperture of every component in the optical train is subject to calibration.

All emissive band calibrations **shall** be performed often enough to meet all accuracy requirements.

Calibration of the CW task sensor Reflected Solar and NIR bands (HES bands 4-6) **shall** be performed on-board during the life of the instrument to meet all accuracy requirements. Vicarious calibration can be used in place of a 100% albedo hardware calibrator if proved sufficient to meet accuracy requirements.

3.2.7.3.6 On-Orbit Electronic Calibration

A system for determining the linearity of the electronics and analog to digital converters **shall** be incorporated. The calibration signal input non-linearity **shall** be less then 0.1% (TBD) of full scene, and the amplitude **shall** be greater than the dynamic range of the channel. The calibration signal **shall** be inserted as close to the detector output signal as practical in the electronics chain.

3.2.7.3.7 Polarization Sensitivity

Overview: Polarization sensitivity is defined as the ratio of the difference between maximum and minimum output to the sum of the maximum and minimum output obtained when the plane of incoming 100% linearly polarized radiation is rotated through 180 degrees. All HES channels other than the visible cloud clearing channels of the DS and SW/M tasks with wavelengths <3 um **shall** have less than 3% (TBR) polarization sensitivity and they should have less than 1% (TBR) polarization sensitivity. The difference in polarization sensitivity between channels **shall** be less than 2% (TBR), and should be less than 1% (TBR). The uncertainty in the polarization sensitivity within a channel **shall** be less than 1% (TBR) and should be less than 0.5% (TBR). The polarization sensitivity requirements **shall** be met at all Earth-viewing angles throughout the life of the mission and the sensitivity requirements should be met over the entire field-of-regard.

3.2.7.3.8 Temperature Monitoring

Optical and structural elements that influence the radiometric response of emissive bands (HES bands 1-3 and 7) **shall** be temperature monitored and telemetered for calibration ground processing. Calibration corrections using the temperature data **shall** have an error ≤ 0.1 K precision (TBR) between calibrations.

3.2.7.4 System Linearity

The corrected system radiometric response non-linearity for each detector element **shall** be less than 1% RMS (TBD) over the full dynamic range to be stable enough to meet all radiometric performance requirements.

3.2.7.5 Stray Light Performance

Techniques, such as baffling, should be implemented on the HES to control stray light. The HES **shall** meet all performance and star sensing requirements in the presence of stray light when operating with the FOV within the operational zone defined in section 3.1.4.3.1. Performance bounds for operation in the restricted zone are presented in section 3.1.4.3.2. Star sensing requirements are presented in section 3.2.8.2.1.

3.2.7.6 Pixel to Pixel Cross-talk

Pixel to pixel cross-talk in the HES emissive bands (HES bands 1-3 and 7) will be low enough to meet ensquared energy requirements presented in section 3.2.5.4.3.

Pixel to pixel cross-talk in the HES reflective bands (HES bands 4-6) will be low enough to meet MTF requirements presented in section 3.2.5.4.4.

Any HES reflective band pixel (HES bands 4-6) located more than 5 (TBR) pixels away from a pixel containing a sun glint **shall** meet all performance requirements. A sun glint is defined as a signal of 200x (TBR) the 100% albedo level.

Any HES reflective band pixel (HES bands 4-6) located less than 3 (TBR) pixels away from a pixel containing a sun glint **shall** have a signal to noise ratio no less than half (TBR) that allowed in section 3.2.7.2.

Contributions to the total signal level from clouds may saturate the detectors but the saturation should be localized to within 2 (TBR) pixels from a nominal cloud edge described by a step function.

3.2.8 Image Navigation and Registration

3.2.8.1 INR Scope

Image navigation refers to the determination of the location of each image pixel relative to a fixed reference coordinate system. Image registration refers to maintaining the spatial relationship between pixels within image frames and between image frames.

Mission-level Image Navigation and Registration (INR) requirements apply to pixels and encompass the combined system performance of the HES, spacecraft and ground processing system.

3.2.8.2 INR Functions

This section defines several INR-related functions to be included in the HES and associated ground system.

3.2.8.2.1 Star Sensing

If star sensing is required to meet navigation requirements, the HES **shall** have an on-board star catalog provided by the HES vendor, which is loadable and modifiable from the ground, containing an identification (ID) number, right ascension, declination, proper motion, and instrument magnitude for each star.

If star sensing is required to meet navigation requirements, the HES **shall** autonomously acquire stars at a rate and accuracy required to meet INR requirements. In addition to autonomous star sensing, the HES **shall**, when commanded, acquire stars from an HES-GS list of target stars that will be within the nominal field of regard for the next 26 hours. The target star list will consist of star ID and viewing time windows in Universal Time Coordinated (UTC) for each star.

3.2.8.2.2 Pointing Compensation Profiles

The HES-GS may uplink pointing compensation data for certain predictable pointing errors, such as diurnal orbit errors, thermal distortion, and sensor misalignment. The maximum range of predictive compensation will be ± 1.0 degrees North/South and East/West.

The HES **shall** include the capability to compensate its scanning profile using the uplinked correction data. Characteristics of the correction profiles are TBD.

3.2.8.3 INR Performance Requirements

All INR requirements listed herein apply to the end-to-end system, taking all instrument, spacecraft, and ground processing effects into account. INR errors for any given pixel(s) can be determined through analysis and simulation, while on-orbit verification will require using landmarks in an image.

Unless otherwise specified, all INR requirements in this document are specified as North/South and East/West angles, in microradians, 3-sigma, and refer to all hours of operation. In addition, 3-sigma is interpreted as the arithmetic mean, plus or minus three times the square root of the variance for a population of 100 consecutive observations.
In this section, "image" or “frame” are synonymous, and refer any programmed scan area data set ranging from a full disk down through the mesoscale in pixel space, as opposed to detector sample space.
The ground sample distance (GSD) listed here is defined in section 3.2.5.2. The ground sample angle (GSA) is associated angular distance.

3.2.8.3.1 Navigation

Navigation error is the angular location knowledge error of pixels or features in an image.

The navigation error for each HES Task **shall** not exceed the threshold values in Table 3.2.41 for pixels on the Earth's disk, except during eclipse periods. The navigation error should not exceed the goal values in Table 3.2.41, except during eclipse.

For up to a four-hour period that includes an eclipse of the sun, the HES navigation error **shall** not exceed the "eclipse threshold" values in Table 3.2.41. The phasing of the four-hour relaxation relative to the eclipse may be design-specific and will be recommended by the HES contractor. The navigation error should not degrade for the entire day.

Table 3.2.41 - HES Navigation Requirements

HES Task	Threshold	Eclipse Threshold	Goal
DS	0.5 IR GSA	0.75 IR GSA	0.25 IR GSA
SW/M	0.5 IR GSA	0.75 IR GSA	0.25 IR GSA
CW	Max. of 1.0 (TBR) GSA or 9 urad	NA	Max. of 0.5 (TBR) GSA or 7 urad (TBR)

3.2.8.3.2 Frame to Frame Registration

Frame to frame registration error is the difference in navigation error for any given pixel in two consecutive images. Since images may be 60 minutes apart, these requirements apply over 60 minute periods. Frame to frame registration errors **shall** not exceed the threshold values in Table 3.2.42. Frame to frame registration error should not exceed the goal values in Table 3.2.42.

Table 3.2.42 - HES Frame-to-Frame Registration Requirements

HES Task	Threshold	Goal
DS	0.5 IR GSA	0.25 IR GSA
SW/M	0.5 IR GSA	0.25 IR GSA
CW	Max. of 1.0 (TBR) GSA or 9 urad	Max. of 0.5 (TBR) GSA or 7 urad (TBR)

3.2.8.3.3 Within Frame, Non-Adjacent Pixel Registration

Within-frame but non-adjacent registration error is the difference between the measured and nominal distance between any two non-adjacent pixels in an image. Within-frame but non-adjacent registration error **shall** not exceed the threshold values in Table 3.2.43. Within-frame but non-adjacent registration error should not exceed the goal values in Table 3.2.43

Table 3.2.43 - HES Within-Frame but Non-Adjacent Registration Requirements

HES Task	Threshold	Goal
DS	0.5 IR GSA	0.25 IR GSA
SW/M	0.5 IR GSA	0.25 IR GSA
CW	Max. of 1.0 (TBR) GSA or 9 urad	Max. of 1.0 (TBR) GSA or 7 urad (TBR)

3.2.8.3.4 Within Frame, Adjacent Pixel Registration

Within-frame and adjacent registration error is the difference between the measured and nominal distance between any two adjacent pixels in an image, including line to line and single integration image to single integration image. Within-frame and adjacent registration error **shall** not exceed the threshold values in Table 3.2.44. Within-frame and adjacent registration error should not exceed the goal values in Table 3.2.44.

Table 3.2.44 HES Within-Frame and Adjacent Registration Requirements

HES Task	Threshold	Goal
DS	0.5 IR GSA	0.25 IR GSA
SW/M	0.5 IR GSA	0.25 IR GSA
CW	Max. of 1.0 (TBR) GSA or 9 urad	Max. of 1.0 (TBR) GSA or 7 urad (TBR)

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APPENDICIES

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A OPEN OCEAN AND LAND GOAL REQUIREMENTS

Under review by the HES PORD Team

A.1 HES Goal Requirements Description and Overview

The goal tasks will be performed by the HES, located on satellite B in geostationary orbit. These goal tasks are open ocean (OO) imaging and land (L) imaging, both of these being performed at high (4 km or finer) spatial resolution.

Critical performance parameters for the OO and L tasks of the HES are the spectral coverage. This improved spectral coverage for the OO task will meet the needs of NOAA in ocean areas that have not been well covered spatially or spectrally by the current imager or sounder, due to lack of spectral coverage in the reflected solar spectrum. The land imager **minimal acceptable goal performance** requirement is be included as a goal task if either of the 1.61 and 0.865 um bands are not included in the ABI *The GOAL L task may not be required if the final choices for the bands of the ABI provide sufficient spectral and spatial coverage***.**

A.1.1 GOAL TASK SENSOR REQUIREMENTS

A.1.1.1 Scope

It is anticipated that the OO task and the L task will be met by one of three general classes of instruments: a multiple band radiometer, where the number of bands is nominally less than 10, a multiple band radiometer, where the number of bands is nominally greater than 10, or a dispersive spectrometer yielding higher spectral resolution at all wavelengths in the range producing more than 100 channels. Combinations of these instruments are not excluded. The measurement requirements for the HES goal tasks could be met with a single integrated sensor or with multiple sensors, each dedicated to a task.

A.1.1.2 Spectral Requirements

A.1.1.3 Number of Spectral Bands

Goal and threshold OO task requires the detection of scene radiance in the visible band. The threshold L task requires the detection scene radiance in the near-infrared bands and goal scene radiance detection in the visible band.

A.1.1.3.1 Spectral Range

As a threshold, the OO sensors **shall** have a spectral range of 0.4 - 1.0 um. As a goal, the OO sensors should have a spectral range of 0.4-1.0 um. The threshold spectral range of the L sensors **shall** cover the two bands 1.61 and 2.26 um, and the goal spectral range of the L sensors should cover the two bands 0.64 and 0.86 or 0.59 - 2.285 um.

These bands are provided, recognizing that only certain specific spectral lines are of interest. Table A 1 below summarizes bands necessary to complete the OO and L tasks.

Table A 1 OO and L Sensor Threshold and Goal Bands

Task and Priority	Band	Spectral Range (um)
OO Threshold	Reflected Solar < 1 um	0.4-1.0
OO Goal	Reflected Solar <1 um	0.4-1.0
L Threshold	Reflected Solar >1 um	1.61, 2.26
L Goal	Reflected solar < 1 um and > 1 um	0.64 and 0.86 or 0.59 - 2.285

A.1.1.3.2 OO and L Spectral Channels and Resolution

The THRESHOLD OO channel centers within the Reflected Solar band **minimal acceptable goal performance** matches the values in table 4.2.2. The GOAL OO channel centers with the Reflected Solar band ideal goal performance also match the values in Table A 2.

Table A 2 OO THRESHOLD & GOAL Channels Centers and Resolution

Wavelength (um)	Spectral Width (um)	Number Of Bins
0.4 –1.1 um or all of the bands listed below (GOAL)	0.02	35
0.412 (GOAL)	0.02	1
0.443 (THRESHOLD)	0.02	1
0.477 (GOAL)	0.02	1
0.490 (THRESHOLD)	0.02	1
0.510 (GOAL)	0.02	1
0.530 (THRESHOLD)	0.02	1
0.550 (THRESHOLD)	0.02	1
0.645 (THRESHOLD)	0.02	1
0.667 (THRESHOLD)	0.02	1
0.678 (GOAL)	0.02	1
0.750 (GOAL)	0.02	1
0.763 (GOAL)	0.02	1
0.865 (THRESHOLD)	0.04	1
0.905 (GOAL)	0.02	1

The THRESHOLD L channel centers within the NIR band **minimal acceptable goal performance** matches the values in table 4.2.3. The GOAL L channel centers with the Reflected Solar band ideal goal performance also match the values in Table A 3.

Table A 3 L THRESHOLD & GOAL Channels Centers and Resolution

Wavelength (um)	Bin Size (um)	Number Of Bins
0.64 (GOAL)	0.1	1
0.865 (TBR) (GOAL)	0.04	1
1.61 (THRESHOLD)	0.06	1
2.26 (THRESHOLD)	0.05	1

A.1.1.3.2.1 On-Board Spectral Binning

A.1.1.3.2.2 Instrument Line Shape, Spectral Response Envelope

A.1.1.3.2.3 Spectral Accuracy

A.1.1.3.3 Spectral Stability

A.1.1.3.4 Spectral Operability and Clusters

For both the OO and L tasks, an inoperable spectral channel is defined as a single spectral resolution element with signal to noise greater than two times the required measurement precision as shown below:

$$SNR_i = 0.5\ SNR_{Req}$$

Where I designates the I^{th} spectral channel in a band and Req designates the THRESHOLD requirements. In addition, any possible grouping of contiguous spectral channels totaling more than 0.5% (TBR) of the band total, with 50% or more spectral outages is defined as a cluster of spectrally inoperable channels.

The OO and L THRESHOLD spectral operability in all bands (Reflected Solar and NIR) **minimal acceptable goal performance** requirements are 100%.

A.1.1.4 Scan Requirements

A.1.1.5 Ground Sample Rate

The GSR for the OO and L tasks, listed in the tables below, **minimal acceptable goal performance** requirements are greater than or equal to the THRESHOLD values presented in Table A 4. GSR values ideal goal performance be greater than or equal to the GOAL.

Table A 4 OO and L THRESHOLD and GOAL GSR

TASK	GSR THRESHOLD	GSR GOAL
OO	**244**	**975**
L	**6433**	**102924**

A.1.1.5.1 Scan Direction

A.1.1.5.2 Scan Flexibility

The OO and L task sensor(s) **minimal acceptable goal performance** requirements are capable of providing arbitrary scan areas of open ocean and land respectively anywhere. The scan area and geographic location ideal goal performance be selectable from one scan to the next.

A.1.1.5.2.1 Within Frame Scan Efficiency

There are no requirements on within frame scan efficiency. However, it is expected that the scan efficiency values for the OO and L task sensors will be similar to the current class of instruments operating in the Reflected Solar or NIR (~3 um or less). Expected minimum values are shown in Table A 5 for each task to provide insight.

Table A 5 Minimum Expected Frame Scan Efficiency

HES Task	Within Frame Scan Efficiency
OO	0.95
L	0.95

A.1.1.5.2.2 Overall Task Efficiency

As a THRESHOLD, the OO and L sensor(s) **minimal acceptable goal performance** requirements are capable of continuously performing either an OO *or* an L scan.

As a GOAL, the OO and L sensor(s) ideal goal performance be capable of continuously and concurrently performing both an OO scan *and* an L scan.

A.1.1.6 Radiometric Performance Requirements

A.1.1.6.1 Dynamic Range

The OO and L task sensors operate in the reflective regime of the spectrum. Therefore, the OO and L reflective bands **minimal acceptable goal performance** have sufficient dynamic range for measurements between 0 and TBD % above the 100% albedo solar spectrum (radiance values to be supplied by the government) without saturation of any detector element.

A.1.1.6.2 Measurement Precision (SNR)

The noise performance requirements are defined at the aperture of the system by the signal to noise ratio (SNR) for the OO and L reflective bands. The measurement precision is a fundamental performance metric for the GOAL tasks of HES. The noise radiance is defined as the standard deviation (1sigma) of the calibrated radiance in each spectral channel over many measurements while viewing the same scene. The signal radiance, in each case, is defined as the radiance from the open ocean or the land that is transmitted through the atmosphere to the HES goal sensors.

As a THRESHOLD for SNR values, the SNR of the OO and L task sensors Reflected Solar and NIR bands and the THRESHOLD and GOAL channel centers **minimal acceptable goal performance** have SNR values greater than or equal to the values

plotted in

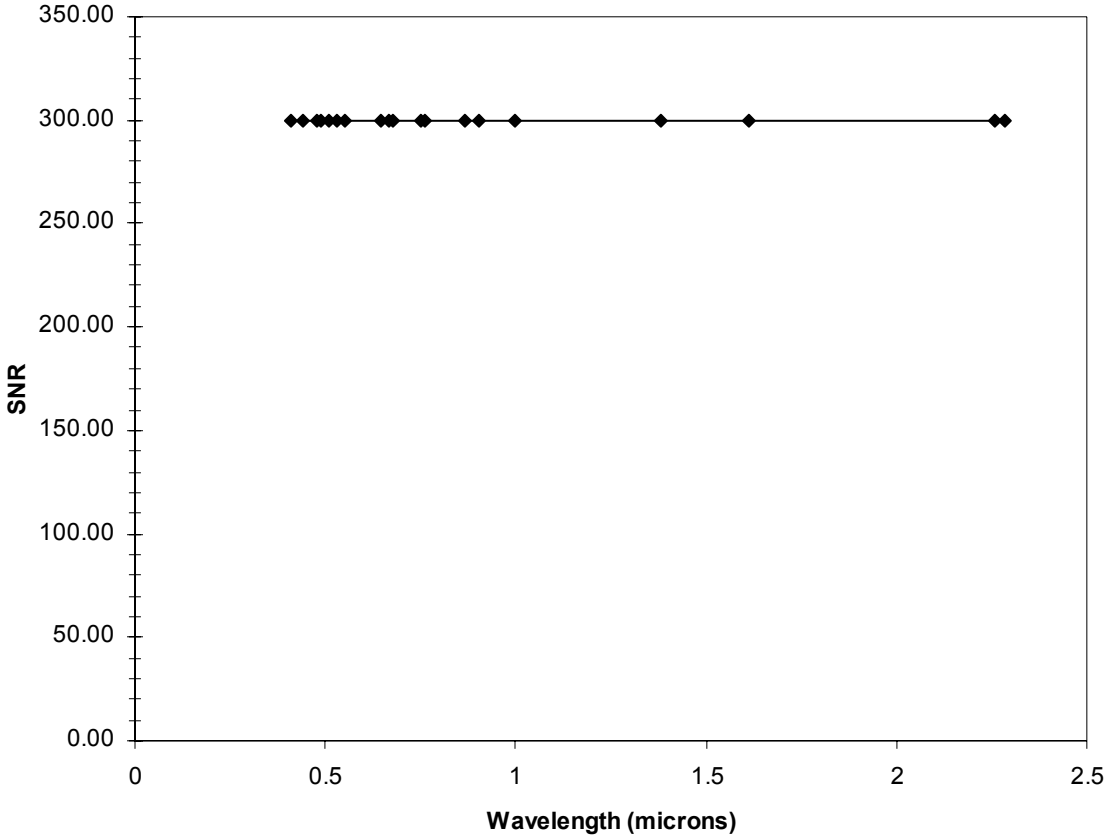

Figure A 1 for nominal water and land generated radiances. GOAL OO and L SNR values ideal goal performance be (TBD). The government will provide radiance values. THRESHOLD SNR values for key wavelengths are quantified in Table A 6 and Table A 7. Typical ocean radiances are less than 100 $W/m^2/um/sr$ and are provided in Appendix B to this document.

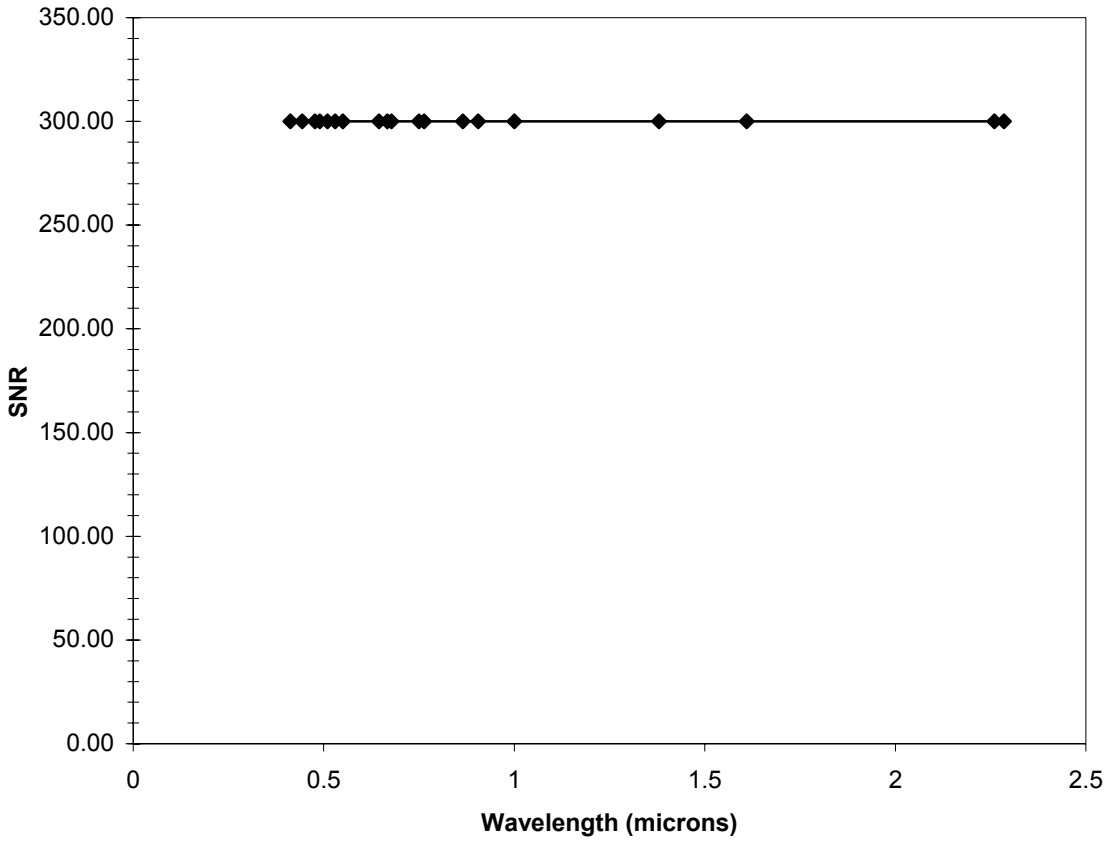

Figure A 1 Plot of OO and L sensor Reflected Solar-NIR SNR Requirements

Table A 6 OO Sensor Reflected Solar SNR Requirement

Channel Center (um)	**Minimum SNR**
0.412 (GOAL)	300 (TBR)
0.443 (THRESHOLD)	300 (TBR)
0.477 (GOAL)	300 (TBR)
0.490 (THRESHOLD)	300 (TBR)
0.510 (GOAL)	300 (TBR)
0.530 (THRESHOLD)	300 (TBR)
0.550 (THRESHOLD)	300 (TBR)
0.645 (THRESHOLD)	300 (TBR)
0.667 (THRESHOLD)	300 (TBR)
0.678 (GOAL)	300 (TBR)
0.750 (GOAL)	300 (TBR)
0.763 (GOAL)	300 (TBR)
0.865 (THRESHOLD)	300 (TBR)
0.905 (GOAL)	300 (TBR)

Table A 7 L Sensor Reflected Solar-SNR Requirement

Channel Center (um)	Minimum SNR
0.64 (GOAL)	300 (TBR)
0.865 (TBR) (GOAL)	300 (TBR)
1.61 (THRESHOLD)	300 (TBR)
2.26 (THRESHOLD)	300 (TBR)

A.1.1.6.3 Radiometric Accuracy

A.1.1.6.3.1 Absolute Accuracy

The absolute accuracy requirement is 3% of the 100% albedo calibrator with a pre-launch calibration traceable to a NIST standard.

A.1.1.6.3.2 Relative Accuracy

The relative accuracy error is defined as the root-mean-square (RMS) variation in signal level, for all measurements in an ensemble (e.g. all the pixels in a frame) illuminated by constant scene radiance. It is specified in terms of the percent of signal at 100% albedo for reflective bands. As a THRESHOLD, the HES relative accuracy **minimal acceptable goal performance** requirement is less than or equal to the values shown in Table A 8. The ideal goal performance requirement is less than or equal to the GOAL values.

Table A 8 HES GOAL Task Relative Accuracy Requirements

Band/Task	Rel. Accuracy (%) THRESHOLD	Rel. Accuracy (%) GOAL
Reflected Solar < 1 um: OO	1.0	TBS
Reflected Solar < 1 um: L	1.0	TBS
Reflected solar > 1 um: L	1.0	TBS

A.1.1.6.3.3 Long-Term Drift

The drift in absolute calibrated radiances for the OO and L task sensors reflective bands **minimal acceptable goal performance** requirement is less than 0.5 % over the instrument lifetime.

A.1.1.6.3.4 Ground Calibration

The OO and L reflective bands **minimal acceptable goal task performance** requirement is calibrated on the ground, pre-launch. The calibration **minimal acceptable goal performance** requirement is a full-system and full-aperture spectral response characterization, i.e. the clear aperture of every component in the optical train is subject to calibration.

The blackbody source, used for the onboard calibration, **minimal acceptable goal performance** requirement is traceable to National Institute of Standards and Technology (NIST) standards.

A.1.1.6.3.5 On-Orbit Calibration

Calibration of the OO and L task sensors Reflected Solar < 1 um and Reflected Solar > 1 um bands **minimal acceptable goal performance** requirement is performed on-board during the life of the instrument to meet all accuracy requirements. Vicarious calibration can be used in place of a 100% albedo hardware calibrator if proved sufficient to meet accuracy requirements.

A.1.1.6.3.6 On-Orbit Electronic Calibration

A system for determining the linearity of the electronics and analog to digital converters **minimal acceptable goal performance** requirement is incorporated. The calibration signal input non-linearity **minimal acceptable goal performance** requirement is less then 0.1% (TBD) of full scene, and the amplitude **minimal acceptable goal performance** requirement is greater than the dynamic range of the channel. The calibration signal **minimal acceptable goal performance** requirement is inserted as close to the detector output signal as practical in the electronics chain.

A.1.1.6.3.7 Polarization Sensitivity

Overview: Polarization sensitivity is defined as the ratio of the difference between maximum and minimum output to the sum of the maximum and minimum output obtained when the plane of incoming 100% linearly polarized radiation is rotated through 180 degrees. All HES channels other than the visible cloud clearing channels of the DS and SW/M tasks with wavelengths <3 um **shall** have less than 3% (TBR) polarization sensitivity and they should have less than 1% (TBR) polarization sensitivity. The difference in polarization sensitivity between channels **shall** be less than 2% (TBR), and should be less than 1% (TBR). The uncertainty in the polarization sensitivity within a

channel **shall** be less than 1% (TBR) and should be less than 0.5% (TBR). The polarization sensitivity requirements **shall** be met at all Earth-viewing angles throughout the life of the mission and the sensitivity requirements should be met over the entire field-of-regard.

A.1.1.6.4 System Linearity

The corrected system radiometric response non-linearity for each detector element **minimal acceptable goal performance** be less than 1% RMS (TBD) over the full dynamic range to be stable enough to meet all radiometric performance requirements. Stray Light Performance.

A.1.1.6.5 Stray Light Performance

Techniques, such as baffling, are required for ideal goal performance of the HES to control stray light. The HES **minimal acceptable goal performance** requirement meets all performance and star sensing requirements in the presence of stray light when operating with the FOV within the operational zone defined in section 3.1.4.3.1. Performance bounds for operation in the restricted zone are presented in section 3.1.4.3.2. Star sensing requirements are presented in section 3.2.8.2.1.

A.1.1.6.6 Pixel to Pixel Cross-talk

Pixel to pixel cross-talk in the OO and L reflective bands **minimal acceptable goal performance** requirement is low enough to meet MTF requirements presented in section A.1.1.8.3.3.

Any OO or L reflective band pixel located more than 5 (TBR) pixels away from a pixel containing a sun glint **minimal acceptable goal performance** requirement meets all performance requirements. A sun glint is defined as a signal of 200x (TBR) the 100% albedo level.

Any OO or L reflective band pixel located less than 3 (TBR) pixels away from a pixel containing a sun glint **minimal acceptable goal performance** requirement have a signal to noise ratio no less than half (TBR) that allowed in section A.1.1.6.2.

A.1.1.7 Coverage Requirements

Overview: The requirements below define the geographical regions to be covered in any particular scan mode. A complete scan of a region defines a frame of data. Each HES task has different requirements for coverage with respect to geographical region. Each task has a primary geographical scan region, but is required to perform scans of other regions for operational flexibility or back-up functionality. The dimensional bounds are specified for each region as well as the size and number of acceptable gaps in coverage. A gap is defined as the centroid-to-centroid distance between adjacent pixels on the ground, excluding the effects of non-responsive detector samples. In this context,

adjacent pixels do not include the diagonal pixels of a square grid. As a reference the area (km^2) for each region is presented in Table A 9 below.

Table A 9 OO and L geographical regions coverage area

Coverage Region	Coverage Area (km^2)
OO within 62-degree LZA	$1.2x10^7$ (TBR)
L within 62-degree LZA	$4.4x10^7$ (TBR)

A.1.1.7.1 62-degree LZA Region

Overview: This region is defined as the 62-degrees local zenith angle minus half of the region of overlap that occurs between the east and west satellites. The area is shown graphically for the east and west satellites in Figure A 2. Acceptable OO and L measurements can be made over corresponding regions of interest when the satellite is positioned over the equator. The 62-degree LZA region is the primary scan mode for both the OO and L task sensors.

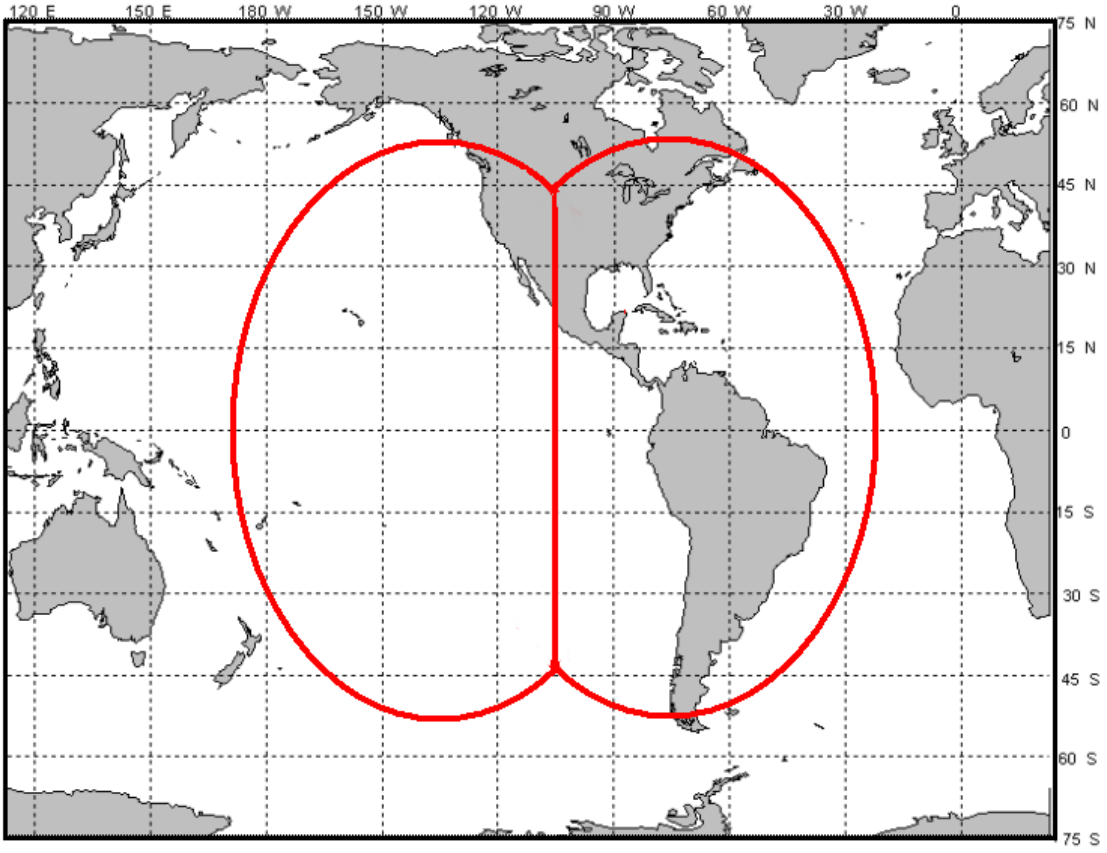

Figure A 2 Approximate 62-degree LZA coverage regions as seen from east and west satellite positions.

As a THRESHOLD, the OO and L task sensors **minimal acceptable goal performance** not have any gaps in coverage exceeding the ground sample distance (TBR) presented in section XXXX when scanning corresponding regions of interest in the 62-degree LZA region.

As a GOAL, the OO and L task sensors ideal goal performance not have any gaps in coverage exceeding (TBS) when scanning the corresponding regions of interest in the 62-degree LZA region.

A.1.1.8 Spatial Sampling Requirements

A.1.1.8.1 Field of Regard

Overview: The field of regard is defined as (TBS).

The HES's unvignetted Field of Regard (FOR) **minimal acceptable goal performance** requirement includes a circle of at least 20-degrees (TBR) in diameter with its center at the sub-satellite point. The FOR **minimal acceptable goal performance** requirement is large enough to allow every HES detector element to view space for instrument background subtraction when appropriate, and to view enough stars to support the navigation requirements in section A.1.1.10.3.1.

A.1.1.8.2 Ground Sample Distance and Angle

Overview: The centroid-to-centroid distance between adjacent spatial samples on the Earth's surface, as measured at the satellite sub point, defines the ground sample distance (GSD). The associated ground sample angle (GSA) is constant for all scan position and satellite altitude geometry. Often, in the document, the GSD is referenced with the caveat that the actual GSD is calculated from the GSA. A two-dimensional pixel is defined by the GSD in the East/West and North/South dimensions, therefore a single GSD quantity is specified for each task and each band required for the task.

The OO and L task sensors **minimal acceptable goal performance** requirement is capable of producing pixels no larger than the THRESHOLD GSD and GSA values presented in Table A 10. It ideal goal performance also be capable of producing pixels as small as the GOAL values.

Table A 10 OO and L task sensor THRESHOLD and GOAL GSD and GSA capabilities

Band	GSD (km)	GSA (microradians)	GSD (km)	GSA (microradians)
	THRESHOLD		GOAL	
OO	4	112	1	28
L	2	56	0.5	14

A.1.1.8.3 Pixel Spatial Binning

Any design achieving less than the THRESHOLD GSD, for any task, **minimal acceptable goal performance** requirement is capable of on-board spatial pixel binning such that the effective GSD is equal to the THRESHOLD value $\pm$ 25% *and* all other THRESHOLD requirements are satisfied. (TBR)

A.1.1.8.3.1 Detector Sample Ground Footprint

The OO and L reflective bands are subject to MTF requirements (section A.1.1.8.3.3).

A.1.1.8.3.2 Geometric Shape

There is no requirement on the geometric shape of the footprint as long as all other THRESHOLD spatial sampling requirements are satisfied. (TBR)

A.1.1.8.3.3 Modulation Transfer Function

Overview: The spatial resolution of the OO and L reflective bands is defined by the system modulation transfer function (MTF). The sensor(s) **minimal acceptable goal performance** meets the requirements below in both East/West and North/South directions after any ground processing including spacecraft jitter as detailed in the HES IRD.

Table A 11 OO task Reflected solar band MTF requirement for Threshold spatial resolution

Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)	
32.0	1125	0.90 (TBR)
16.0	2250	0.73 (TBR)
10.66	3375	0.53 (TBR)
8.0	4500	0.32 (TBR)

Table A 12 L task sensor Reflected solar band MTF requirement for Threshold spatial resolution

Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)	
16.0	2250	0.90 (TBR)
8.0	4500	0.73 (TBR)
5.33	6750	0.53 (TBR)
4.0	9000	0.32 (TBR)

A.1.1.8.4 Band-to-Band Registration

Overview: Band-to-band registration error, or co-registration, is the difference in pointing between spectral bands for any given pixel in the same frame. Where the pointing is defined by the RMS centroid location calculated from each channel within a band. Since OO and L imaging involves the combination of data from each of the individual spectral bands, it is vital that the energy detected in each spectral channel from these task sensor(s) emanate from the same geographic area as closely as possible. This becomes especially important in regions of strong gradients. The requirements below specify how well the HES bands must be registered to each other. It is anticipated that in practice the co-registration will be determined from array image overlap. In that case only knowledge of the co-registration at the corners of each array is actually required to determine shift and the rotation for all pixels. The requirements only apply to bands within a single sensor, i.e. if the sounding task is split between two sensors, band registration between the sensors in not required. Co-registration requirements within the same band imply channel-to-channel registration. This is relevant in a non-contiguous spectral band, and split-band sensor implementation. Co-registration between bands having different GSD is defined by centroiding a square grid of the finer pixels to determine a "mean" pixel equal in extent to the coarser pixel.

NOTE: If meeting these requirements is considered a significant cost driver, the contractors should spell out expected cost versus co-registration.

As a THRESHOLD, the centroid co-registration errors between bands in the OO and L task sensors **minimal acceptable goal performance** requirement does not exceed the values presented in Table A 13. Values are written as an absolute angle.

Table A 13 OO and L task sensor co-registration THRESHOLD requirements

	Reflected Solar < 1 um: OO	**Reflected Solar <1 um: L**	**Reflected Solar >1 um: L**
Reflected Solar < 1 um: OO	Max. of 0.25 GSA or 28 urad	N/A	N/A
Reflected Solar < 1 um: L	N/A	Max. of 0.25 GSA or 14 urad	Max. of 0.25 GSA or 14 urad
Reflected Solar < 1 um: L	N/A	Max. of 0.25 GSA or 14 urad	Max. of 0.25 GSA or 14 urad

As a GOAL, the centroid co-registration errors between bands in the OO and L task sensors ideal goal performance requirement is not exceed the values presented in Table A 14. Values are written as an absolute angle.

Table A 14 OO and L task sensor co-registration GOAL requirements

	Reflected Solar < 1 um: OO	**Reflected Solar <1 um: L**	**Reflected Solar >1 um: L**
Reflected Solar < 1 um: OO	Max. of 0.10 GSA or 11 urad	N/A	N/A
Reflected Solar < 1 um: L	N/A	Max. of 0.10 GSA or 7 urad	Max. of 0.10 GSA or 7 urad
Reflected Solar < 1 um: L	N/A	Max. of 0.10 GSA or 7 urad	Max. of 0.10 GSA or 7 urad

A.1.1.8.5 Pixel Operability and Outages

Overview: A pixel is considered *operable* if the THRESHOLD spectral operability requirements in section A.1.1.3.4 are satisfied. A pixel is considered non-responsive, or an outage, when it is inoperable *and* the calibrated responsivity in each spectral channel is less than 10% (TBR) of the mean responsivity for the same channel across the entire focal plane array.

The requirements below are specified per HES GOAL band. For designs that measure multiple bands with a single focal plane array, the less restrictive requirement **minimal acceptable goal performance** requirement applies.

As a THRESHOLD, the OO and L operability **minimal acceptable goal performance** requirements have greater than or equal to the values presented in Table A 15.

As a THRESHOLD, the OO and L **minimal acceptable goal performance** requirements have fewer outages than the values presented in Table A 15.

Table A 15 OO and L THRESHOLD pixel operability and outage requirements

Band/Task	Operability THRESHOLD	Outages THRESHOLD
Reflected Solar < 1 um: OO, L	99.9% (TBR)	0% (TBR)
Reflected Solar > 1 um: L	87 % (TBR)	4% (TBR)

As a GOAL, the HES operability ideal goal performance requirement is 100% for all bands.

A.1.1.9 Temporal Requirements

A.1.1.9.1 Coverage Time

Overview: The coverage time for each region is defined as the time to produce a complete frame of data. It is specified for each of the primary scan regions for each sensor task. All of the following **minimal acceptable goal performance** requirements are performed within the coverage time:

g) Scan the required region. The coverage region is defined for each task in section A.1.1.7.
h) Scan mirror (if present) steps, settles, and slews.
i) Spatially over-sample the scene to correct for image rotation and any other scan artifacts, in order to meet THRESHOLD sampling requirements presented in section A.1.1.8.
j) Acquire the required space look and/or calibration target data needed to meet the radiometric requirements.
k) Necessary operations to switch between tasks if one sensor is used for multiple tasks.
l) Perform necessary operations to meet navigation requirements.

As a THRESHOLD, the OO task sensor **minimal acceptable goal performance** requirement is capable of scanning the open ocean regions within the 62 degree LZA in 3 hour.

As a the GOAL the OO task sensor ideal goal performance be capable of scanning the open ocean regions within the 62 degree LZA in 3 hours hour.

As a THRESHOLD, the L task sensor **minimal acceptable goal performance** requirement is capable of scanning the land areas within the 62 degree LZA in 1 hour.

As a GOAL, the L task sensor ideal goal performance requirement is capable of scanning the land areas within the 62 degree LZA in 15 minutes.

For example, Table A 16 below shows the maximum expected scan time for each task and for each coverage region. Reasonable assumptions were made for within frame scan efficiency.

Table A 16 THRESHOLD scan times for the OO and L task sensors Reflected Solar bands

Coverage Region	Coverage Area (km^2)	GSR (Hz)	GSD (km)	Within Frame Scan Efficiency	Coverage Time
Open Ocean	1.20E+07	244	10.0	0.95	3 hr 0 min
Land	4.40E+07	6433	2.0	0.95	1 hr 00 min

A.1.1.9.2 Spectral Bands Simultaneity

As a THRESHOLD, data from all spectral bands for all bands of the OO task obtained from any specific point on the Earth **minimal acceptable goal performance** requirement is coincident within 30 seconds (TBR).

As a GOAL, data from all spectral bands for all bands of the OO task obtained from any specific point on the Earth ideal goal performance requirement is coincident within 20 seconds (TBR).

As a THRESHOLD, data from all spectral bands for all bands of the L task obtained from any specific point on the Earth **minimal acceptable goal performance** requirement is coincident within 10 seconds (TBR).

As a GOAL, data from all spectral bands for all bands of the L task obtained from any specific point on the Earth ideal goal performance requirement is coincident within 5 seconds (TBR).

A.1.1.9.3 Adjacent Pixels Simultaneity

Overview: Temporal simultaneity is important for the purpose of creating images, or using retrieval information in weather prediction models. The requirements below present the maximum time between Earth measurements for adjacent pixels. When a sensor rasters a detector footprint (or array of detector footprints) across a scene to create a complete frame, these requirements determine the maximum swath length. The requirements are presented for each HES task and for each geographical coverage region.

The time between collection of adjacent pixels within a single HES data frame **minimal acceptable goal performance** requirement is less than or equal to the THRESHOLD values presented in Table A 17. The ideal goal performance be less than or equal to the GOAL values.

Table A 17 THRESHOLD and GOAL pixel simultaneity requirements

OO task				**L task**	
Coverage Region	**Pixel Simultaneity THRESHOLD**	**Pixel Simultaneity GOAL**		**Pixel Simultaneity THRESHOLD**	**Pixel Simultaneity GOAL**
Open Ocean	30 sec (TBR)	20 sec (TBR)		(TBD)	(TBD)
Land	(TBD)	(TBD)		10 sec (TBR)	5 sec (TBR)

A.1.1.9.4 Time Tagging

The data **minimal acceptable goal performance** requirement is time identified so that the time any detector sample in the data was acquired can be determined to within 0.1 seconds relative to the spacecraft provided clock information. The spacecraft clock is synchronized to UT to better than 0.1 seconds.

Time relative to the Angular Displacement System **minimal acceptable goal performance** requirement is accurate to at least 100 microseconds.

A.1.1.10 Image Navigation and registration

A.1.1.10.1 INR Scope

Image navigation refers to the determination of the location of each image pixel relative to a fixed reference coordinate system. Image registration refers to maintaining the spatial relationship between pixels within image frames and between image frames.

Mission-level Image Navigation and Registration (INR) requirements apply to pixels and encompass the combined system performance of the HES, spacecraft and ground processing system.

The HES contractor is responsible for meeting the mission-level INR requirements specified in the PORD, given the spacecraft interface specifications contained in the IRD. In addition to flight hardware, the HES contractor is responsible for all ground processing algorithms required to meet mission-level INR requirements.

The HES contractor will develop INR error budgets and derive requirements for all hardware and processing elements related to INR

A.1.1.10.2 INR Functions

Overview: This section defines several INR-related functions to be included in the HES and associated ground system.

A.1.1.10.2.1 Star Sensing

If star sensing is required to meet navigation requirements, the following requirements apply:

The HES **minimal acceptable goal performance** requirement is an on-board star catalog provided by the HES vendor, which is loadable and modifiable from the ground, containing an identification (ID) number, right ascension, declination, proper motion, and instrument magnitude for each star.

The HES **minimal acceptable goal performance** requirement is capable of autonomously acquiring stars at a rate and accuracy required to meet INR requirements. In addition to autonomous star sensing, the HES **minimal acceptable goal performance** requirement is capable of being commanded to acquire stars from an HES-GS list of target stars that will be within the nominal field of regard for the next 26 hours. The target star list will consist of star ID and viewing time windows in Universal Time Coordinated (UTC) for each star.

A.1.1.10.2.2 Pointing Compensation Profiles

The HES-GS may uplink pointing compensation data for certain predictable pointing errors, such as diurnal orbit errors, thermal distortion, and sensor misalignment. The maximum range of predictive compensation will be ± 1.0 degrees North/South, East/West.

The HES **minimal acceptable goal performance** includes the capability to compensate its scanning profile with the uplinked correction data. Characteristics of the correction profiles are TBD.

A.1.1.10.3 INR Performance Requirements

All INR requirements listed herein apply to the end-to-end system, taking all instrument, spacecraft, and ground processing effects into account. INR errors for any given pixel(s) can be determined through analysis and simulation, while on-orbit verification will **minimal acceptable goal performance** require using landmarks in an image.

Unless otherwise specified, all INR requirements in this document are specified as North/South and East/West angles, in microradians, 3-sigma, and refer to all hours of operation. In addition, 3-sigma is interpreted as the arithmetic mean, plus or minus three times the square root of the variance for a population of 100 consecutive observations.

In this section, "image" or “frame” are synonymous, and refer any programmed scan area data set ranging from a full disk down through the mesoscale in pixel space, as opposed to detector sample space. The ground sample distance (GSD) listed here is defined in section A.1.1.8.2. The ground sample angle (GSA) is associated angular distance.

A.1.1.10.3.1 Navigation

Navigation error is the angular location error of pixels or features in an image.

The navigation error for each HES GOAL task **minimal acceptable goal performance** requirement does not exceed the threshold values in Table 4.2.18 for pixels on the Earth’s disk, except during eclipse periods. The navigation error ideal goal performance requirement does not exceed the goal values in Table 4.2.18, except during eclipse.

For up to a four-hour period that includes an eclipse of the sun, the HES navigation error **minimal acceptable goal performance** requirement does not exceed the “eclipse threshold” values in Table A 18. The phasing of the four-hour relaxation relative to the eclipse may be design-specific and will be recommended by the HES contractor. The navigation error ideal goal performance requirement does not degrade for the entire day.

Table A 18- HES Navigation Requirements

HES Task	Threshold	Eclipse Threshold	Goal
OO	0.5 IR GSA	0.75 IR GSA	0.25 IR GSA
L	0.5 IR GSA	0.75 IR GSA	0.25 IR GSA

A.1.1.10.3.2 Frame to Frame Registration

Frame to frame registration error is the difference in navigation error for any given pixel in two consecutive images. Since images may be 60 minutes apart, these requirements apply over 60 minute periods. Frame to frame registration errors **minimal acceptable goal performance** not exceed the threshold values in Table A 19. Frame to frame registration error ideal goal performance not exceed the goal values in Table A 19.

Table A 19– OO and L Frame-to-Frame Registration Requirements

HES Task	Threshold	Goal
OO	0.5 (TBR) GSA	0.25 (TBR) GSA
L	0.5 (TBR) GSA	0.25 (TBR) GSA

A.1.1.10.3.3 Within Frame but non-Adjacent Registration

Within-frame but non-adjacent registration error is the difference between the measured and nominal distance between any two non-adjacent pixels in an image. Within-frame but non-adjacent registration error **minimal acceptable goal performance** requirement is not to exceed the threshold values in Table A 20. Within-frame but non-adjacent registration error ideal goal performance requirement is not exceed the goal values in Table A 20.

Table A 20– OO and L Within-Frame but Non-Adjacent Registration Requirements

HES Task	Threshold	Goal
OO	0.5 (TBR) GSA	0.25 (TBR) GSA
L	0.5 (TBR) GSA	0.25 (TBR) GSA

A.1.1.10.3.4 Within Frame and Adjacent Registration

Within-frame and adjacent registration error is the difference between the measured and nominal distance between any two adjacent pixels in an image, including line to line and single integration image to single integration image. Within-frame and adjacent registration error **minimal acceptable goal performance** requirement is not to exceed the threshold values in Table A 21. Within-frame and adjacent registration error ideal goal performance requirement is not exceed the goal values in Table A 21.

Table A 21 HES Within-Frame and Adjacent Registration Requirements

HES Task	Threshold	Goal
OO	0.5 (TBR) GSA	0.25 (TBR) GSA
L	0.5 (TBR) GSA	0.25 (TBR) GSA

B RADIANCE VALUES

B.1 IR Radiance Values

Figure B 1. Radiance Values for sounding task sensor(s)

B.2 Initial Reflected Solar Radiance Values (TBD)

Figure B 2. Radiance Values for CW task sensor

C ACRONYMS AND ABBREVIATIONS

ABI	Advanced Baseline Imager
ACS	Attitude Control System
AJ	As Justified
AME	Angular Measurement Error
APE	Absolute Pointing Error
ASTM	
CCSDS	
CONUS	
CW	
DIS	
DOEE	Detector Optics Ensquared Energy
DS	Disk Sounding
FOR	Field of Regard
FOV	Field of View
GIFTS	Geostationary Imaging Fourier Transform Spectrometer
GIRD	
GOES	
GS	
GSA	Ground Sample Angle
GSD	Ground Sample Distance
GSFC	
GSR	Ground Sample Rate
HES	HYPERSPECTRAL ENVIRONMENTAL SUITE
ICD	Interface Control Document
ID	Identification
IEEE	
IFOV	Instantaneous Field of View
INR	Image Navigation and Registration
IR	
IRD	
ISO	
LWIR	
LZA	
MRD	More Details
MTF	Modulation Transfer Function
MW	
MWIR	
NA	
NAS	National Aerospace Standard
NASA	
NEdN	
NEdT	
NEN	
NER	Noise Equivalent Radiance
NESR	Noise Equivalent Spectral Radiance

NIR	
NIST	National Institute of Standards and Technology
NOAA	
OO	Open Ocean
PORD	
PSF	Point Spread Function
RFP	
RMS	Root Mean Square
SI	
SNR	Signal to Noise Ratio
SOW	
SRF	Spatial Response Function
SSF	Scene Spread Function
SSP	Sub Satellite Point
SW	
SWIR	
TBD	
TBR	
TBS	
TC	
TDB	
TDI	
TOA	Top of the Atmosphere
UIID	
US	
UT	
UTC	Universal Time Coordinated

D DEFINITIONS DOCUMENTATION

Absolute Radiometric Accuracy: The unknown bias error in the measured radiance in each spectral channel, root-mean-squared with any random precision or repeatability component in a specific measurement period.

Band: A set of spectral channels.

Channel: A spectral band sub-element.

Coastal Waters: Ocean waters of less than 2 km depth within 400 km from the shore along the length of the US coast (east and gulf coast: ~6000 km, US west coast ~2100 km).

CONUS (CONtinental United States): A rectangle, approximately 3000-km by 5000-km encompassing the entire geographic extent of the 48 contiguous United States.

Co-Registration: The difference in pointing measurement between spectral bands for any given pixel in the same frame. Also referred to as ***Band-to-Band registration error***.

Coverage Time: The time to produce a complete frame of data for each region.

Cross-Talk: The electrical and optical energy that is coupled into a detector from any other detector in the same array of detectors.

Detector: A device that converts electromagnetic radiation into an electrical signal. The reference to "detector data" corresponds to digital output following the analog-to-digital conversion.

Detector/Optics Ensquared Energy (DOEE): A unitless figure of merit, which is the ratio of the energy *measured by* a detector from it's corresponding ground sample area (defined by the GSD, not the footprint) to the energy *measured by* the detector from the entire large and uniform scene.

Field of Regard: The angular extent to which the field of view of the HES can be directed without obstruction.

Field of View (FOV): The angle subtended by the geometric projection of the entire detector array to the surface of the earth or the far-field angle subtended by the entire detector array.

Frame: A collection of observations that together form a spatially contiguous data set that might be analyzed to characterize the radiation from the earth-atmosphere system. A complete scan of a region defines

Full Disk Region: A 17.76-degree diameter circle centered at nadir, as seen from each satellite

Gap: The centroid-to-centroid distance between adjacent pixels on the ground, excluding the effects of non-responsive detector samples.

Goal:

Ground Footprint: detector sample

Ground Sample Distance (GSD): The centroid-to-centroid distance between adjacent spatial samples on the Earth's surface, as measured at the satellite sub point, defines the

Ground Sample Rate (GSR): Mandates the number of full-spectrum Earth spatial samples that must be collected per unit time.

Hyperspectral: (contiguous bands)

Image Navigation: Refers to the determination of the location of each image pixel relative to a fixed reference coordinate system.

Image Registration: Refers to maintaining the spatial relationship between pixels within image frames and between image frames.

Inoperable Spectral Channel: A single spectral resolution element with noise equivalent radiance greater than two times the required measurement precision.

Instantaneous Field of View (IFOV): The angle subtended by the geometric projection of a single detector to the surface of the earth or the far-field angle subtended by a single detector.

Launch: The period of time between lift off and the separation of the GOES-R series satellite from the launch vehicle.

LZA Region: The 62-degrees local zenith angle minus half of the region of overlap that occurs between the east and west satellites.

Mesoscale: A rectangular region of arbitrary size up to the equivalent of a 1.6-degree by 1.6-degree (~1000-km by 1000-km) nadir-viewed area. In general the minimum mesoscale region size will be 0.16-degree by 0.16-degree (~100-km by 100-km) nadir-viewed area (TBR).

Nadir: The point on the Earth intercepted by a line drawn from the centroid of the satellite to the center of the Earth.

Noise Radiance: The standard deviation (1 sigma) of the calibrated radiance in each spectral channel over many measurements while viewing the same scene.

Pixel: (Picture Element) The resultant data following processing of detector data (including calibration and navigation).

Pixel Binning: The combination of several pixels to form a single picture element (pixel).

Registration Error: There are two types of registration error:

1. Non-Adjacent Registration Error is the difference between the measured and nominal distance between any two non-adjacent pixels in an image.
2. Adjacent Registration Error is the difference between the measured and nominal distance between any two adjacent pixels in an image, including line-to-line and single integration image to single integration image.

Relative Radiometric Accuracy: The unknown bias error *between two arbitrary radiance measurements*, root-mean-squared with any random precision or repeatability component in a specific measurement period.

Scan Position: The location of the target within a swath

Signal Radiance: The radiance arriving from the top of the atmosphere (TOA).

Spectral Binning: The combination of several spectral channels/bands to form a single spectral channel/band.

Sub-Satellite Point (SSP):

Swath: One traversal of the scan mechanism in the east-west directions over the entire scene of interest.

TBD: Meaning "to be determined" is applied to a missing requirement. The missing requirement will be determined through the course of the contract execution.

TBR: Meaning "to be reviewed" implies that the requirement is subject to review for appropriateness by the contractor or the government. The government may change "TBR" requirements in the course of the contract.

TBS: Meaning "to be specified", indicates that the government will supply the missing information in the course of the contract.

Threshold: The minimum performance characteristic that is acceptable.

Transfer orbit: The sequence of events that transpires to establish the GOES-R series satellite on-station after the GOES-R series satellite has separated from the launch vehicle.

Within Frame Scan Efficiency: A metric describing the fraction of time spent collecting Earth scene measurements in one complete frame.

OTHER DEFINITIONS NOT FOUND IN THE HES PORD (BUT MAY BE USEFUL)

Line-of-sight: The center of the GIFTS instrument's primary visible imager/detectors FOV.

Line of Sight Angular Range: The angular range the pointing mirror can point the Line-of-sight.

Coverage: Refers to the equivalent area of the earth, centered at nadir, from which a set of data products is collected. It is defined as the area projected onto a plane through the center of the earth (TBR) over which the FOV is to be scanned.

Footprint: The geometric (two-dimensional) projection of either the entire detector focal plane array or a single pixel on to the surface of the Earth at nadir.

Local zenith: The vector normal to the surface of the Earth at a ground location. In other words, the local zenith lies along a radial vector extended from the center of the Earth through the surface of the Earth at a given ground location.

Zenith Angle: The angle measured from the local zenith to the line-of-sight to the spacecraft.

Boresight: The Line-of-sight at the center of the Line-of-sight angular range.

Solar Avoidance Zone: An annular area defined around the sun that will severely degrade HES performance. This is defined as a half-cone angle measured between the HES Line-of-sight and the un-eclipsed solar vector (center of the sun).

Solar Transition Zone: An annular area defined around the sun that will moderately degrade HES performance. This is defined as a half-cone angle measured between the HES Line-of-sight and the un-eclipsed solar vector (center of the sun).

Uneclipsed Solar Vector: The vector direction to the center of the sun from the HES line-of-site.

Radiance: A measure of the flux per unit area per unit solid angle. The units typically used for radiance are mW / ($m^2 \cdot sr$).

Spectral Radiance: A measure of radiance per unit of spectral bandwidth. The units typically used for spectral radiance is mW / ($m^2 \cdot sr \cdot \mu m$) or mW / ($m^2 \cdot sr \cdot cm^{-1}$)

Noise Equivalent Radiance (NER, NEN) [$mW/m^{2} \cdot sr \cdot$] or Noise Equivalent Spectral Radiance (NESR) [$mW/m^{2} \cdot sr \cdot cm^{-1}$]: A nominal way of describing noise and random errors in the measuring system. As used in these requirements, NER, NEN, or NESR include shot (photon) noise, and are specified at equivalent scene temperatures. The noise is projected from the system back to the scene radiance such that the overall effect can be compared with the true signal (that coming from the scene). Sources of noises typically include detector shot noise, thermal noise, and readout noise terms. Since these terms include shot noise, the effective scene temperature must be included.

Noise Equivalent Delta Temperature (NEdT) [K]: The NER in terms of temperature units. The NEdT is defined as NEN divided by the radiance derivative with respect to temperature. The NedT is a value, which depends on the temperature of the scene being observed.

Scene temperature: The effective temperature of the scene being viewed. This temperature differs from the radiance temperature of the surface due to emissivity, reflectance, and atmospheric attenuation of the radiation.

Absolute Pointing Error (APE): (Accuracy) The angular separation between the commanded direction and the instantaneous actual direction

Angular Measurement Error (AME): (Knowledge) The angular separation between the instantaneous actual direction and the