Global Hydrology Resource Center

# Data User Guide

# *Hurricane and Severe Storm Sentinel (HS3) Scanning High-Resolution Interferometer Sounder (S-HIS)*

## Introduction

The Hurricane and Severe Storm Sentinel (HS3) Scanning High-Resolution Interferometer Sounder (S-HIS) measures emitted thermal radiances that are used to obtain temperature and water vapor profiles of the Earth's atmosphere in clear-sky conditions. Due to the S-HIS scanning capability, the instrument provides 2 km resolution (at nadir) across a 40 km wide ground swath when flown at an altitude of 20 km onboard the NASA Global Hawk unmanned aircraft. S-HIS data were collected during the 5-week HS3 field campaign study periods in the 2012 to 2014 Atlantic hurricane seasons.

**Notice:**
S-HIS data are subject to periodic improvements in accuracy as instrument calibration software is improved. If you use these data, please preserve the dataset timestamp information as reference in all slides and publications.

## Citation

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## Keywords:

*GHRC, NASA, HS3, S-HIS, hurricane, spectrometer, atmospheric temperature, radiance, water vapor*

## Campaign

The Hurricane and Severe Storm Sentinel (HS3) was a five-year NASA field campaign mission targeted to investigate the processes that underlie hurricane formation and

intensity change, including assessing the relative roles of the large-scale environment and the storm-scale internal processes. To achieve these goals, three 5-week campaigns were carried out during 2012 - 2014 which consisted of 21 flight missions over nine storms, two undeveloped systems, and several Saharan air layer outbreaks. The HS3 campaign utilized two Global Hawks, one with instruments geared toward measurement of the environment and the other with instruments suited to inner-core structure and processes. The environmental payload included the scanning High-resolution Interferometer Sounder (S-HIS) and the AVAPS dropsonde system; the over-storm payload included the HIWRAP conically scanning Doppler radar, the HIRAD multi-frequency interferometric radiometer, and the HAMSR microwave sounder. Information about instrument flights made during each campaign year are summarized in Table 2 of the HS3 2016 BAMS paper. More information about the HS3 campaign can be found at https://ghrc.nsstc.nasa.gov/home/projects/hs3.

## Instrument Description

S-HIS is an airborne infrared sounding instrument (high spectral resolution Fourier Transform Spectrometer) that provides upwelling infrared radiance spectra. It was built by the Space Science & Engineering Center at the University of Wisconsin - Madison using a customized, commercially-sourced Michelson plane mirror interferometer combined with a scene mirror module, telescope, aft optics, detector module with mechanical cooler, laser metrology, calibration blackbodies, digital signal processors, data storage and software automation. The S-HIS has flown on a variety of research aircraft since 1998, including the NASA Global Hawk for HS3. It is descended from the UW High-resolution Interferometer Sounder (HIS), and is in the same family of instruments as the ground-based UW Atmospheric Emitted Radiance Interferometer (AERI), and the satellite-based Cross-track Infrared Sounder (CrIS), among others.

S-HIS measures emitted thermal radiances between 3.3 to 18 microns, which are used to produce sounding data with 2 km resolution (at nadir) across a 40 kilometer wide ground swath when flown at a an altitude of 20 km. Earth and internal calibration bodies are viewed by rotation of the scan mirror, which scans from -45º to +45º about nadir on the Global Hawk, producing 14 views and several calibration views per scan. Imaging is accomplished by cross-track scanning at a speed of 4 cm/s and the maximum optical path difference is ±1.037 cm, resulting in the collection of an interferogram with spectral resolution of 0.48 1/cm (FWHM = 0.58 1/cm) every ~0.5 seconds. . The optical design provides useful signal-to-noise performance from a single spectral 0.5 s observation. The instrument noise levels are sufficiently low to allow cloud and surface properties to be derived from each individual field of view. Principal Component Analysis is used to reduce noise levels and improve data quality. The instrument is calibrated every 20-30 seconds by viewing onboard blackbody references. The calibrated thermal radiances are then used to obtain temperature and water vapor profiles of the Earth's atmosphere in clear-sky conditions, emissivity, cloud top temperatures, sea surface temperatures, and trace gas total column amounts. More information on the S-HIS interferometer can be found at http://deluge.ssec.wisc.edu/~shis/.

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## Data Characteristics

The S-HIS measures emitted thermal radiances that are used to obtain temperature and water vapor profiles of the Earth's atmosphere in clear-sky conditions. Data for S-HIS is processed in approximately 5-hour 'sections' on arbitrary boundaries in order to balance file size, calibration accuracy, and output yield with performance.

Typically, S-HIS generates data in an "ASHE" scan-line pattern - that is, Ambient reference blackbody views, Sky view (on aircraft having an uplooking port), Hot reference blackbody views, and Earth views at a variety of FOV angles between -45º and 45º. Reference blackbody views are not present in the output NetCDF data files. Each set of three (longwave, midwave, shortwave) interferograms takes ~0.51s to acquire, and is radiometrically calibrated in a localized "calibration window" of blackbody spectra. Alternating spectra are Forward sweeps of the scan mirror with Backward sweeps. A typical scan mirror sequence will have an odd number of views such that alternating scan lines have alternating forward-backward patterns. Scan-lines often have 14 downlooking Earth views, at least one of which is within 2 degrees of nadir; however, scan pattern can vary from flight to flight. Calibrated data is normalized to a standard wavenumber scale, and sweep-direction artifacts - if there are any - are removed. Filters have been applied to eliminate calibration blackbody views, areas of questionable calibration value (system stabilization or out-of-lock), and areas where the aircraft is not in straight and level flight. Engineering data, including aircraft navigation and ground footprints, are included.

Table 1: Data Characteristics

| Characteristic | Description |
|---|---|
| Platform | Global Hawk UAV |
| Instrument | Scanning High-Resolution Interferometer Sounder (S-HIS) |
| Projection | n/a |
| Spatial Coverage | N: 49.34 , S: 10.79, E: 0.00, W: -129.05 (Atlantic Ocean) |
| Spatial Resolution | 2 km at nadir when flown at 20 km altitude |
| Temporal Coverage | Start date: November 12, 2015 Stop date: December 19, 2015 |
| Temporal Resolution | ~1 hour |
| Sampling Frequency | 0.5 seconds |
| Parameters | Thermal radiance, atmospheric temperature profiles, |

| | |
|---|---|
| | atmospheric water vapor profiles in clear-sky conditions, emissivity, cloud top temperatures, sea surface temperatures, and trace gas total column amounts. |
| Version | 1 |
| Processing Level | 1A and 2 |

## File Naming Convention

The Hurricane and Severe Storm Sentinel (HS3) Scanning High-Resolution Interferometer Sounder (S-HIS) dataset consists of four types of product files. These data files are named with the following conventions:

**Data files:** SHIS_rdr<start_time>end<end_time>sdr<sdr_time>_<product_type>.nc

Table 2: File naming convention variables

| Variable | Description |
|---|---|
| <start_time> | UTC start time of raw instrument data files in ISO format<br>YYYYMMDDThhmmss<br>Where,<br>YYYY: Four-digit year<br>MM: Two-digit month<br>DD: Two-digit day<br>hh: Two-digit hour in UTC<br>mm: Two-digit minute in UTC<br>ss: Two-digit seconds in UTC |
| <end_time> | UTC end-time of the raw instrument data files in ISO format<br>YYYYMMDDThhmmss<br>Where,<br>YYYY: Four-digit year<br>MM: Two-digit month<br>DD: Two-digit day<br>hh: Two-digit hour in UTC<br>mm: Two-digit minute in UTC<br>ss: Two-digit seconds in UTC |
| <sdr_time> | UTC start-time of the radiance calibration data processing<br>YYYYMMDDThhmmss<br>Where,<br>YYYY: Four-digit year<br>MM: Two-digit month<br>DD: Two-digit day<br>hh: Two-digit hour in UTC<br>mm: Two-digit minute in UTC<br>ss: Two-digit seconds in UTC |
| <product type> | rad: radiances<br>rad_pcfilt: noise-filtered radiances |

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|---|---|
| | atm_prof_rtv: dual regression retrieval record<br>atm_prof_rtv_avg: “nearest neighbor” retrievals are filtered and averaged |
| .nc | netCDF-4 format |

## Data Format and Parameters

The Hurricane and Severe Storm Sentinel (HS3) Scanning High-Resolution Interferometer Sounder (S-HIS) data have a level 1A (rad files and rad_pcfilt files) and level 2 (atm_prof_rtv and atm_prof_rtv_avg files) data processing level and are in netCDF-4 format. MIssing values are -9999.0 or IEEE NaN values, unless stated otherwise. ISO UTC time-codes are embedded in the filenames to allow for easy identification of desired time ranges. Time codes are derived from instrument local time, which may differ from aircraft navigation stream time by several seconds.

Table 3: Data Fields for all four types of product files

| Field Name | Description | Data Type | Unit |
|---|---|---|---|
| Aircraft_Altitude | Aircraft Altitude | float | km |
| aircraftExtPressure | Aircraft External Pressure | float | hPa |
| aircraftHeading | Direction of instrument travel:<br>0 = North<br>90 = East | float | degree |
| aircraftPitch | Instrument aircraft pitch:<br>0 = level<br>positive = upward | float | degree |
| aircraftRoll | Instrument aircraft roll:<br>0 = level<br>positive = clockwise from behind | float | degree |
| aircraftTime | Aircraft Time (fractional hours) | float | seconds since 2012-08-28 15:40:48 |
| Altitude | Observation altitude | float | m |
| barometricAltitude | Barometric Altitude | float | m |
| base_time | Base time in UNIX epoch seconds | int | Seconds since 1970-1-1 00:00:00 |
| CAPE | Convective Available Potential Energy | float | J/kg |
| Channel_Index | Indices of channels used in retrieval (out of full spectrum) | int | - |
| CldEmis | Effective Cloud Emissivity | float | - |
| Cmask | Cloud mask:<br>0 = clear<br>1 = cloud | int | - |
| CO2_Amount | Retrieved carbon dioxide (CO2) amount | float | 1e-6 |
| COT | Cloud Optical Thickness | float | - |

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|---|---|---|---|
| CTP | Cloud Top Pressure | float | hPa |
| CTT | Cloud Top Temperature | float | K |
| date | Date in format YY/MM/DD | float | counts |
| dateYYMMDD | Date in YYMMDD | float | - |
| Dewpnt | Dewpoint temperature profile | float | K |
| Flight_Segment | Flight Segment Numbers | int | - |
| FOVangle | Field of View Angle | float | degree |
| GDAS_RelHum | GDAS Relative Humidity Profile | float | % |
| GDAS_TAir | GDAS Temperature Profile | float | K |
| H2Ohigh | High-level precipitable water vapor: Vertically integrated water vapor from 300 hPa to 700 hPa | float | cm |
| H2Olow | Low-level precipitable water vapor: Vertically integrated water vapor from 900 hPa to surface | float | cm |
| H2Omid | Mid-level precipitable water vapor: vertically integrated water vapor from 700 hPa to 900 hPa | float | cm |
| H2OMMR | Retrieved humidity (water vapor mixing ratio) profile at 101 levels | float | g/kg |
| HBB_NESR | Total Noise | float | $mW/(m^2\ sr\ cm^{-1})$ |
| instrumentLatitude | Latitude of nadir point | float | °N |
| instrumentLongitude | Longitude of nadir point | float | °E |
| Latitude | Latitude | float | °N |
| Lifted_Index | Lifted Index (LI) stability index | float | °C |
| Longitude | Longitude | float | °E |
| O3VMR | Retrieved ozone profile at 101 levels | float | 1e-6 |
| Plevs | Atmospheric pressure levels: vertical coordinate axis (101 pressure levels) | float | hPa |
| Qflag1 | Reflects quality of input:<br>0 = successful<br>1 = no retrieval due to bad radiance<br>2 = no retrieval due to non-convergence of cloud class iteration | int | - |
| Qflag2 | Describes uncertainty associated with clear/cloudy decision:<br>0 = certain<br>1 = uncertain | int | - |
| Qflag3 | Temperature profile retrieval | int | - |

| | | | |
|---|---|---|---|
| | error with respect to GDAS temperature:<br>0 = very good<br>1 = good<br>2 = acceptable<br>3 = not acceptable | | |
| radiance | Radiance spectrum | float | $mW/(m^2\ sr\ cm^{-1})$ |
| refTimeDay | Reference time, integer day-of-month | float | day |
| refTimeMonth | Reference time, integer month | float | month |
| refTimeSec | Reference time, seconds from 00:00:00, not to exceed 86,400 | float | Seconds since 1970-1-1 00:00:00 |
| refTimeUsec | Reference time, microseconds and fractions of microseconds offset | float | microseconds |
| redTimeYear | Reference time, integer four-digit year | float | year |
| RelHum | Retrieved relative humidity at 101 levels | float | % |
| RtvWarmMeanCount | Number of records used in averaging retrieval values | long | - |
| sceneMirrorAngle | Scene mirror angle, relative to instrument zenith | float | degree |
| segments | Integer value that represents what flight segments this is part of | int | - |
| SkinWarmMeanCount | Number of records used in averaging for surface measurements | long | - |
| SurfEmis | Retrieved surface emissivity at full spectrum | float | - |
| SurfEmis_Wavenumbers | Wavenumbers at which emissivities are retrieved (full spectrum) | float | $cm^{-1}$ |
| SurfPres | GDAS surface pressure | float | hPa |
| TAir | Retrieved temperature profile at 101 levels | float | K |
| Time | Time | float | Seconds since 1970-01-01 00:00:00 |
| timeHHMMSS | Time in HHMMSS | float | - |
| time_offset | Time offset from base_time | double | Seconds since 2012-08-28 14:43:35 |
| timeOfDay | Time since 0000UTC | float | - |
| timeUTC | Time since 0000UTC | float | hours |
| totH2O | Total precipitable water vapor: | float | cm |

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|---|---|---|---|
| | vertically integrated water vapor from 100 hPa to surface | | |
| totO3 | Vertically integrated ozone | float | Dobson |
| TSurf | Retrieved surface skin temperature | float | K |
| wavenumber | Wavenumber in reciprocal centimeters | double | $cm^{-1}$ |

For a more detailed description of the data file variables, refer to the documentation at https://ghrc.nsstc.nasa.gov/pub/fieldCampaigns/hs3/S-HIS/doc/S-HIS_Radiance_Users_Guide.pdf

## Algorithm

A hyperspectral retrieval algorithm, based on the concept of 'Dual Regression' is used to process S-HIS radiances to retrieve surface and cloud parameters. The algorithm is a statistical eigenvector regression method that uses a large training dataset of globally representative atmospheric profiles, surface and cloud parameters with their associated simulated radiances. To simulate the cloudy radiances, a fast radiative transfer model developed in collaboration with Texas A & M University has been used. Parameters like total ozone, total precipitable water, precipitable water, lifted index and convective available potential energy are retrieved under clear sky conditions and under optically thin cloud and broken cloud conditions as long as cloud threshold conditions are satisfied. Note, the algorithm is applied to every SFOV. No cloud clearing is performed. The algorithm determines if a pixel can be considered clear or cloudy. Values below thick opaque clouds are replaced by fill values (i.e., -9999). Note that the retrievals below the surface are replaced with fill values. This information is important to know especially in regions of higher terrain. The input fields required by the algorithm are the L1 radiances and associated solar zenith angle products for the S-HIS, together with an estimate of the surface pressure, the skin temperature ,the atmospheric temperature profile, and the humidity profile (e.g. from NCEP GDAS). More details are provided in the PI documentation: University of Wisconsin-Madison (UW) S-HIS Dual-Regression Retrievals, V1.2 Data User's Guide, 2016-06-03 available at https://ghrc.nsstc.nasa.gov/pub/fieldCampaigns/hs3/S-HIS/doc/S-HIS_DualRegression_Retrievals_Users_Guide.pdf and the references Smith et al (2011) and Weicz et al (2007) and references within.

Stages of data processing currently include but are not limited to:

1. De-multiplexing of data packets into raw complex interferograms and engineering data.
2. Conversion to uncalibrated spectra.
3. "Tilt" correction for vibration-induced optical path jitter.
4. Nonlinearity correction to LW and MW bands.
5. Radiometric calibration reference window selection and characterization.
6. Radiometric calibration.
7. Forward-backward spectral correction.

8. Finite field-of-view correction.
9. Spectral resampling to from effective to reference wavenumber scale.
10. Band radiance merging with rolloffs (combining LW, MW, SW).
11. QC filtering and contiguous flight segment checks.
12. Principal Component Analysis noise filtering (optional).
13. Packaging from internal workspace format into netCDF files.

## Quality Assessment

A statistical bias correction is applied to the data. At a 50 km interval, simulated radiances are computed by applying PCRTM to the co-located GDAS profile; then a retrieval is performed on that simulated spectrum. The bias is then calculated from GDAS minus GDAS_retrieved (for temperature and humidity), and applied to the original retrieved profiles. The bias correction is integrated into the main dual regression retrieval algorithm.

At a 50 km intervals, simulated radiances are computed by applying the forward model of the retrieval algorithm to the co-located GDAS profile; then a retrieval is performed on that simulated spectrum. The bias is then calculated from GDAS minus GDAS_retrieved (for temperature and humidity), and applied to the original S-HIS retrieved profiles.

Examination of the imaginary part of the calibrated radiance is used to test for potential issues in the radiometric calibration for all radiances included in the netcdf distribution. Significant spectral signature in the imaginary part of the calibrated radiance indicates a potential problem with the radiometric calibration of that record. Comparison of a selected wavenumber band average, in each of the three S-HIS bands, versus an empirically determined threshold value is used to identify spectra with potential calibration issues.

S-HIS data are subject to periodic improvements in accuracy as instrument calibration software is improved. Please preserve the dataset timestamp information as reference in all slides and publications.

Comparisons have been made with AVAPS and CPL data flown coincidently with S-HIS during the HS3 project.

## Software

No software is required since these data are in netCDF-4 format; however, Panoply can be used to easily view the data.

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## Related Data

All other data collected during the HS3 field campaign are considered related datasets to this S-HIS dataset. Other HS3 data can be located using the GHRC HyDRO 2.0 search tool with the search term 'HS3'.

## Contact Information

To order these data or for further information, please contact:

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