UW Scanning High-resolution Interferometer Sounder

S-HIS Radiance Data Users' Guide

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JKT / RKG / ROK / DCT / JG / HER
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Introduction and prerequisites

The purpose of this guide is to provide a useful starting point for end-users with a background knowledge of passive infrared atmospheric radiometry who wish to perform quantitative analyses using radiances derived from Scanning High-resolution Interferometer Sounder (S-HIS) observations.

S-HIS is an airborne infrared sounding instrument built and maintained by the Space Science & Engineering Center at the University of Wisconsin - Madison. It is based around a highly customized commercially sourced Michelson interferometer, combined with data acquisition systems, digital signal processors, data storage and software automation to make a robust, autonomous aircraft interferometer-sounder which has flown on a variety of research aircraft since 1998. 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 radiance data is distributed in NetCDF3-classic files in a convention derived from DOE ARM instrumentation. These files can be read using analysis software that supports NetCDF3, NetCDF4, or HDF4 (if compiled with NetCDF support) libraries. Future file formats may require NetCDF3 with 64-bit offsets, or NetCDF4 (which in turn requires HDF5) in order to address file size limitations and/or performance.

Technical specifications

Absolute radiance accuracy	0.2 K (k=3) for scenes > 250 K
Cross-track field-of-view	-45º to +45º about nadir on GlobalHawk, 14 views
Observation time per spectrum	0.5s
Nadir ground footprint @ 20km	2km (0.100 radian iFOV)

Naming convention

Data is delivered with simple ISO UTC time-codes embedded in the filenames to ease identification of time ranges of interest. Time codes are derived from instrument local time, which may differ from aircraft navigation stream time by several seconds.

`SHIS_rdrAAAAAAAATAAAAAAendBBBBBBBBTBBBBBBsdrCCCCCCCCTCCCCCC_rad.nc`
e.g.
`SHIS_rdr20121006T125528end20121006T155533sdr20121108T032308_rad.nc`
This is the primary output product.

`SHIS_rdrAAAAAAAATAAAAAAendBBBBBBBBTBBBBBBsdrCCCCCCCCTCCCCCC_rad_pcfilt.nc`
The _pcfilt suffix indicates radiances which have been noise-filtered using principal component techniques but should otherwise have identical structure.

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.

`AAAAAAAATAAAAAA` denotes the UTC start-time of the raw instrument data files in ISO format.
`BBBBBBBBTBBBBBB` denotes the UTC end-time of the raw instrument data files in ISO format.
`CCCCCCCCTCCCCCC` denotes the UTC start-time of the radiance calibration data processing.

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

Characteristics of the dataset

Typically, Scanning HIS generates data in an "ASHE" scan-line pattern - 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.

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.

IEEE NaNs or NetCDF missing-value sentinels may be present to signal missing data, as in the case of differing navigation data being provided dependent upon aircraft.

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.

Content of the data files

A structural overview of a NetCDF file can be obtained with the NetCDF utility “ncdump -h”. Highlighted below are the most-often-used variables. Note that variables in the file have attributes including units and longname (explanation). See Appendices for a complete listing.

wavenumber(wavenumber)
radiance(time, wavenumber)

This variable joins the shortwave (SW), midwave (MW), and longwave (LW) radiances into a single array varying in time, with a separate one-dimensional variable for the regularly-spaced standard instrument wavenumber scale. Only the real component of the complex radiances are included, as imaginary components are primarily of use as diagnostic quantities. As of this writing, removal of radiances based on imaginary-part QC scores is not yet done. Note that radiance is adequately stored as single-precision floating point while wavenumber values require double-precision.

FOVangle(time)

Cross-track observation angle in degrees relative to aircraft nadir, with negative values indicating left-of-track (portside).

base_time

time_offset(time)

When added together, these represent UNIX epoch seconds of the observation. This is a corrected time derived by offsetting the instrument time based on its correspondence to the aircraft navigation stream time.

Latitude(time)
Longitude(time)

Footprint latitude and longitude as calculated from aircraft attitude, location, height and FOVangle.

instrumentLatitude(time)
instrumentLongitude(time)
Altitude(time)

Aircraft latitude, longitude, and altitude (meters) at measurement time as reported by the aircraft navigational stream. Note that it is often the case that aircraft data updates at 1 second intervals while the instrument data is produced at ~0.5s intervals. Furthermore, there is potential delay between the aircraft acquiring navigational and attitude data, and passing it on to instruments onboard. This is believed to principally be a problem on older configurations using RS-232 (or equivalent) serial delivery of navigational data.

aircraftTime(time)

Fractional hours representing the most recently received time from the aircraft navigational stream.

segment(time)

Flight segment indices are monotonic arbitrary integers which increment when a sufficient discontinuity in the data is detected. In other words, all spectra having the same flight segment number can be expected to be contiguous, represent straight and level flight, and have favorable conditions for successful radiometric calibration. As currently implemented, segments are “rectangular” in that all FOVangles are present for each scan line. Data for a given segment number can be re-shaped to C cross-track spectra by N in-track scan-lines. C will be constant for a given flight.

scanDirection(time)

ASCII ‘F’ (70) or ‘B’ (66) representing forward or backward scan direction of the instrument.

Filtered radiance files

In addition to the original observed radiances, a separate file is provided which contains noise-filtered radiances. These are obtained from the original observed “noisy” radiances using dependent-set principal component analysis. The file contains “reconstructed” radiances using a subset of the original principal components, enough to reconstruct the signal. The net effect is the “noise filtered” S-HIS radiances have an effective uncorrelated noise level which is 5-10 times lower than the original dataset. References that describe the methodology used are given in the reference section.

Radiance QC

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.

HS3 2013

Implementation of a QC check using imaginary residuals has been integrated into the data processing, and questionable radiances are flagged and removed from the distributed dataset.

HS3 2012

For each netcdf radiance data file,

`SHIS_rdrAAAAAAAATAAAAAAendBBBBBBBBTBBBBBBsdrCCCCCCCCTCCCCCC_rad.nc`

there is a corresponding README file in the radiance_qc subdirectory:

README_shYYMMDD_`rdrAAAAAAAATAAAAAAendBBBBBBBBTBBBBBBsdrCCCCCCCCTCCCCCC`_SCICDFdistCheck.txt,

with information regarding the threshold value, and any netcdf radiance records that have been flagged with potential calibration issues.

References

Antonelli, P., Revercomb, H. E., Sromovsky, L. A., Smith, W. L., Knuteson, R. O., Tobin, D. C., and Best, F. A. (2004). A principal component noise filter for high spectral resolution infrared measurements. *Journal of geophysical research*, *109*(D23), D23102.

Revercomb, H. E., V. P. Walden, D. C. Tobin, J. Anderson, F. A. Best, N. C. Ciganovich, R. G. Dedecker et al. "Recent results from two new aircraft-based Fourier transform interferometers: The Scanning High-resolution Interferometer Sounder and the NPOESS Atmospheric Sounder

Testbed Interferometer." In 8th International Workshop on Atmospheric Science from Space using Fourier Transform Spectrometry (ASSFTS), Toulouse, France, pp. 16-18. 1998.

Revercomb, Henry E., David C. Tobin, Robert O. Knuteson, Fred A. Best, W. Smith, D. D. LaPorte, S. D. Ellington et al. "Highly accurate FTIR observations from the scanning HIS aircraft instrument." In Proc. SPIE, vol. 5655, pp. 41-53. 2004.

Taylor, J., Best, F., Ciganovich, N., Dutcher, S., Ellington, S., Garcia, R., ... & Werner, M. (2005, August). Performance of an infrared sounder on several airborne platforms: the scanning high resolution interferometer sounder (S-HIS). In *Optics & Photonics 2005* (pp. 588214-588214). International Society for Optics and Photonics.

Tobin, D. C., Antonelli, P., Revercomb, H. E., Dutcher, S., Turner, D. D., Taylor, J. K., ... & Vinson, K. (2007). Hyperspectral data noise characterization using principle component analysis: application to the atmospheric infrared sounder. *Journal of Applied Remote Sensing*, *1*(1), 013515-013515.

Tobin, D. C., et al. (2006), Radiometric and spectral validation of Atmospheric Infrared Sounder observations with the aircraft-based Scanning High-Resolution Interferometer Sounder, J. Geophys. Res., 111, D09S02, doi:10.1029/2005JD006094.

Release notes: HS3 2013

These upgrades have been completed for the HS3 2013 dataset. A re-release of HS3 2011 and 2012 will be done during Q1 2014.

Changes to radiance dataset production

Imaginary-part calibration residual checking has been added to the processing pipeline for HS3 2013, eliminating the need for having a separate record list delivered with the dataset.

Changes to dual-regression retrieved profile dataset production

Updated retrieval coefficients and improvements to the retrieval algorithm have improved the outcome, especially over land.

Invalid sections do not have output files

Sections in which no spectra were produced that passed QC, for instance during cooler and blackbody startup, ascent and descent, do not have NetCDF or HDF5 product files.

Errata: HS3 2011-2012

This section addresses known areas for improvement in the HS3-2012 dataset release Feb 2013. These notes do not apply to HS3 2013.

Some sections missing

Data processing errors have prevented some flight sections from processing completely, primarily at start-of-flight when calibration is invalid due to warm detector or insufficient separation of reference blackbody sources. Future releases will address this.

Imaginary Radiance Residual QC Check

Implementation of a QC check using imaginary residuals has not been integrated into routine data processing. A listing of known-bad radiance records can be found in the radiance_qc/ README text files. A future data release is likely to remove radiance records/footprints based on this test.

Turn regions missing

Turn regions are currently filtered from flight segments though they may include good data. It may be desirable to export these spectra with a zero segment indicator, since this would reduce the data loss when GlobalHawk is in a loitering pattern.

Appendix: NetCDF File Format Description

```
netcdf SHIS_rdr20120828T144334end20120828T191342sdr20121103T035535_rad {
dimensions:
  wavenumber = 4607 ;
  time = UNLIMITED ; // (1722 currently)

variables:
  float radiance(time, wavenumber) ;
         radiance:precision = "1.0E-4 " ;
         radiance:range_of_values = "min_rad_val, max_rad_val" ;
         radiance:source = "RAD" ;
         radiance:longname = "radiance Spectrum" ;
         radiance:units = "mW/(m2.sr.cm-1)" ;
         radiance:shortname = "radiance" ;
         radiance:missing_value = -9999.f ;
         radiance:type = "float" ;
```

```
        radiance:fbf_filename = "RAD.real4.4607" ;
    long base_time ;
        base_time:format = "seconds since 1970-1-1 00:00:00" ;
        base_time:longname = "Base time in Epoch" ;
        base_time:units = "seconds" ;
        base_time:shortname = "base_time" ;
        base_time:type = "int" ;
        base_time:fbf_filename = "base_time.int4" ;
        base_time:string = "14-MAR-2003,22:14:20 GMT" ;
    float Altitude(time) ;
        Altitude:precision = "1.0 " ;
        Altitude:range_of_values = "0.0 60000.0 " ;
        Altitude:longname = "Observation Altitude" ;
        Altitude:units = "meters" ;
        Altitude:shortname = "Altitude" ;
        Altitude:missing_value = -9999.f ;
        Altitude:type = "float" ;
        Altitude:fbf_filename = "Altitude.real4" ;
    float Latitude(time) ;
        Latitude:precision = "0.01 " ;
        Latitude:range_of_values = "-90.0 90.0 " ;
        Latitude:longname = "Observation latitude  (surface-projected)" ;
        Latitude:units = "degrees_north" ;
        Latitude:shortname = "Latitude" ;
        Latitude:missing_value = -9999.f ;
        Latitude:type = "float" ;
        Latitude:fbf_filename = "Latitude.real4" ;
    float FOVangle(time) ;
        FOVangle:precision = "0.1 " ;
        FOVangle:range_of_values = "start_angle, end_angle" ;
        FOVangle:longname = "Angle from nadir, negative left of track" ;
        FOVangle:units = "degrees" ;
        FOVangle:shortname = "FOVangle" ;
        FOVangle:missing_value = -9999.f ;
        FOVangle:type = "float" ;
        FOVangle:fbf_filename = "FOVangle.real4" ;
    long segments(time) ;
        segments:precision = "0 " ;
        segments:range_of_values = "1, 100+" ;
        segments:longname = "integer value that represents what flight segment this
is part of" ;
        segments:units = "int" ;
        segments:shortname = "segments" ;
        segments:missing_value = -9999 ;
        segments:type = "int" ;
        segments:fbf_filename = "segments.int4" ;
    float HBB_NESR(wavenumber) ;
        HBB_NESR:precision = "1.0E-4 " ;
```

```
        HBB_NESR:source = "HBB_total_noise" ;
        HBB_NESR:longname = "HBB NESR" ;
        HBB_NESR:units = "mW/(m2.sr.cm-1)" ;
        HBB_NESR:shortname = "HBB_NESR" ;
        HBB_NESR:missing_value = -9999.f ;
        HBB_NESR:type = "float" ;
        HBB_NESR:fbf_filename = "HBB_total_noise.real4.4607" ;
  float aircraftRoll(time) ;
        aircraftRoll:precision = "0.1 " ;
        aircraftRoll:range_of_values = "-90.0 90.0 " ;
        aircraftRoll:source = "Roll" ;
        aircraftRoll:longname = "Instrument aircraftRoll (0=level, positive
clockwise from behind)" ;
        aircraftRoll:units = "degrees" ;
        aircraftRoll:shortname = "aircraftRoll" ;
        aircraftRoll:missing_value = -9999.f ;
        aircraftRoll:type = "float" ;
        aircraftRoll:fbf_filename = "Roll.real4" ;
  float timeOfDay(time) ;
        timeOfDay:format = "hour.minute.second" ;
        timeOfDay:precision = "0.1 " ;
        timeOfDay:range_of_values = "start, end" ;
        timeOfDay:source = "timeHHMMSS" ;
        timeOfDay:longname = "Time since 0000UTC" ;
        timeOfDay:units = "" ;
        timeOfDay:shortname = "timeOfDay" ;
        timeOfDay:missing_value = -9999.f ;
        timeOfDay:type = "float" ;
        timeOfDay:fbf_filename = "timeHHMMSS.real4" ;
  float aircraftHeading(time) ;
        aircraftHeading:precision = "0.1 " ;
        aircraftHeading:range_of_values = "0.0 359.99 " ;
        aircraftHeading:source = "Heading" ;
        aircraftHeading:longname = "Direction of instrument travel (0=North,
90=East)" ;
        aircraftHeading:units = "degrees" ;
        aircraftHeading:shortname = "aircraftHeading" ;
        aircraftHeading:missing_value = -9999.f ;
        aircraftHeading:type = "float" ;
        aircraftHeading:fbf_filename = "Heading.real4" ;
  float refTimeDay(time) ;
        refTimeDay:precision = "1.0 " ;
        refTimeDay:longname = "Reference time, integer day-of-month" ;
        refTimeDay:units = "day" ;
        refTimeDay:shortname = "refTimeDay" ;
        refTimeDay:type = "float" ;
        refTimeDay:fbf_filename = "refTimeDay.real4" ;
  float aircraftPitch(time) ;
```

```
        aircraftPitch:precision = "0.1 " ;
        aircraftPitch:range_of_values = "-90.0 90.0 " ;
        aircraftPitch:source = "Pitch" ;
        aircraftPitch:longname = "Instrument aircraftPitch (0=level, positive
upward)" ;
        aircraftPitch:units = "degrees" ;
        aircraftPitch:shortname = "aircraftPitch" ;
        aircraftPitch:missing_value = -9999.f ;
        aircraftPitch:type = "float" ;
        aircraftPitch:fbf_filename = "Pitch.real4" ;
  float Longitude(time) ;
        Longitude:precision = "0.01 " ;
        Longitude:range_of_values = "-180.0 180.0 " ;
        Longitude:longname = "Observation longitude (surface-projected)" ;
        Longitude:units = "degrees_east" ;
        Longitude:shortname = "Longitude" ;
        Longitude:missing_value = -9999.f ;
        Longitude:type = "float" ;
        Longitude:fbf_filename = "Longitude.real4" ;
  float timeUTC(time) ;
        timeUTC:precision = "1.0E-6 " ;
        timeUTC:range_of_values = "start, end" ;
        timeUTC:source = "Time" ;
        timeUTC:longname = "Time since 0000UTC" ;
        timeUTC:units = "hours" ;
        timeUTC:shortname = "timeUTC" ;
        timeUTC:missing_value = -9999.f ;
        timeUTC:type = "float" ;
        timeUTC:fbf_filename = "Time.real4" ;
  float instrumentLongitude(time) ;
        instrumentLongitude:precision = "0.01 " ;
        instrumentLongitude:range_of_values = "-180.0 180.0 " ;
        instrumentLongitude:longname = "Longitude of nadir point" ;
        instrumentLongitude:units = "degrees_east" ;
        instrumentLongitude:shortname = "instrumentLongitude" ;
        instrumentLongitude:missing_value = -9999.f ;
        instrumentLongitude:type = "float" ;
        instrumentLongitude:fbf_filename = "instrumentLongitude.real4" ;
  float date(time) ;
        date:source = "dateYYMMDD" ;
        date:precision = "1E0" ;
        date:label = "Date YY/MM/DD" ;
        date:long_name = "Date in format YY/MM/DD" ;
        date:units = "counts" ;
        date:shortname = "date" ;
        date:type = "float" ;
        date:fbf_filename = "dateYYMMDD.real4" ;
  float instrumentLatitude(time) ;
```

```
        instrumentLatitude:precision = "0.01 " ;
        instrumentLatitude:range_of_values = "-90.0 90.0 " ;
        instrumentLatitude:longname = "Latitude of nadir point" ;
        instrumentLatitude:units = "degrees_north" ;
        instrumentLatitude:shortname = "instrumentLatitude" ;
        instrumentLatitude:missing_value = -9999.f ;
        instrumentLatitude:type = "float" ;
        instrumentLatitude:fbf_filename = "instrumentLatitude.real4" ;
  float refTimeYear(time) ;
        refTimeYear:precision = "1.0 " ;
        refTimeYear:longname = "Reference time, integer four-digit year" ;
        refTimeYear:units = "year" ;
        refTimeYear:shortname = "refTimeYear" ;
        refTimeYear:type = "float" ;
        refTimeYear:fbf_filename = "refTimeYear.real4" ;
  float refTimeMonth(time) ;
        refTimeMonth:precision = "1.0 " ;
        refTimeMonth:longname = "Reference time, integer month" ;
        refTimeMonth:units = "month" ;
        refTimeMonth:shortname = "refTimeMonth" ;
        refTimeMonth:type = "float" ;
        refTimeMonth:fbf_filename = "refTimeMonth.real4" ;
  float refTimeSec(time) ;
        refTimeSec:precision = "1.0 " ;
        refTimeSec:longname = "Reference time, seconds from 00:00:00, not to exceed
86400" ;
        refTimeSec:units = "seconds" ;
        refTimeSec:shortname = "refTimeSec" ;
        refTimeSec:type = "float" ;
        refTimeSec:fbf_filename = "refTimeSec.real4" ;
  double wavenumber(wavenumber) ;
        wavenumber:precision = "1.0E-6 " ;
        wavenumber:range_of_values = "580.023101806641 2999.919982910 " ;
        wavenumber:source = "Wavenumber" ;
        wavenumber:longname = "Wavenumber in reciprocal centimeters" ;
        wavenumber:units = "cm-1" ;
        wavenumber:shortname = "wavenumber" ;
        wavenumber:missing_value = -9999. ;
        wavenumber:type = "double" ;
        wavenumber:fbf_filename = "Wavenumber.real8.4607" ;
  double time_offset(time) ;
        time_offset:longname = "Time offset from base_time" ;
        time_offset:units = "seconds" ;
        time_offset:fbf_filename = "time_offset.real8" ;
        time_offset:type = "double" ;
        time_offset:shortname = "time_offset" ;
  float sceneMirrorAngle(time) ;
        sceneMirrorAngle:precision = "0.1 " ;
```

```
        sceneMirrorAngle:range_of_values = "start_angle, end_angle" ;
        sceneMirrorAngle:longname = "Scene mirror angle, relative to instrument
zenith" ;
        sceneMirrorAngle:units = "degrees" ;
        sceneMirrorAngle:shortname = "sceneMirrorAngle" ;
        sceneMirrorAngle:missing_value = -9999.f ;
        sceneMirrorAngle:type = "float" ;
        sceneMirrorAngle:fbf_filename = "sceneMirrorAngle.real4" ;
  float refTimeUsec(time) ;
        refTimeUsec:precision = "1.0 " ;
        refTimeUsec:longname = "Reference time, microseconds and fractions of
microseconds offset" ;
        refTimeUsec:units = "microseconds" ;
        refTimeUsec:shortname = "refTimeUsec" ;
        refTimeUsec:type = "float" ;
        refTimeUsec:fbf_filename = "refTimeUsec.real4" ;

// global attributes:
        :fbf2cdf_filtered_by = "segments.int4" ;
        :Title = "SHIS band 1, unapodized radiance spectra, resampled to standard
wavenumber grid" ;
        :fbf2cdf_request_manifest = "config/shis_science.xml" ;
        :Comments = "SHIS unapodized earth-view radiance spectra" ;
        :FileHistory = "" ;
        :fbf2cdf_source_fbfdir = "." ;
        :CDL_Version = "$Id: shis_sci.cdl,v 1.1 2000/02/10 18:16:49 cvs Exp $" ;
        :fbf2cdf_cvsid = "$Id: fbf2cdf.py 3728 2012-10-03 23:05:25Z rayg $" ;
}
```

——EOF——