Year-5 Report

University of Wisconsin, Space Science and Engineering Center
Scanning High-resolution Interferometer Sounder (S-HIS) Participation in HS3

NASA Grant NNX10AV08G

Hank Revercomb, Principal Investigator
Joe Taylor, Project Manager

Report Author: Joe Taylor

27 July 2015

HS3 Year-5 Final Report
University of Wisconsin, Space Science and Engineering Center
Hank Revercomb, PI

Introduction

This is the Year 5 report for the time period 9/1/2014 - 8/31/2015 of NASA Grant NNX10AV08G to the University of Wisconsin (UW) Space Science and Engineering Center for Scanning High-resolution Interferometer Sounder (S-HIS) instrument participation in the NASA EV-1 Hurricane and Severe Storms Sentinel (HS3) project with the goal of enhancing our understanding of the processes that underlie hurricane intensity change in the Atlantic Ocean basin. Primary activities this year include:

(1) Support of S-HIS for flights conducted in the reporting period (range, transit, and science) and subsequent data analyses;
(2) Pre-campaign and post-campaign testing of S-HIS performance;
(3) Ongoing development and optimization of architecture and software to implement real-time, near real-time, and long term data handling, processing, and display for long duration Global Hawk flights;
(4) Further development and implementation of improved temperature, water vapor, and cloud retrieval capabilities; and
(5) Support HS3 Science Team teleconferences and the Science Team Meeting May 5 – 7, 2015.

This report consists of a brief summary of each of these activities.

1. Support S-HIS for HS3 range, transit, and science flights and subsequent data analyses

The UW S-HIS team supported instrument integration onto NASA Global Hawk AV-6, as well as range, transit and science flight operations. Activities formally within this reporting period include:

(1) Science flight support:
- 2014-09-02: Tropical Storm Dolly
- 2014-09-05: Invest 90, Pouch 27
- 2014-09-11: Tropical Storm Edouard
- 2014-09-14: Hurricane Edouard
- 2014-09-16: Hurricane Edouard
- 2014-09-18: Tropical Storm Edouard
- 2014-09-22: MDR flight #1 (SAL)
- 2014-09-28: MDR flight #2 (Pouch 41, Pouch 42, SAL)
- 2014-09-30: NOAA G-IV intercomparison over the Gulf of Mexico

(2) Transit flight support:
- 2014-09-30: Transit flight from NASA Wallops Flight Facility (WFF) to NASA AFRC (combined transit and science flight)

(3) De-integration of S-HIS from AV-6 at NASA AFRC

Activities completed in the 2014 HS3 flight season, but formally within the prior reporting period include:

(1) Integration of S-HIS onto AV-6 at NASA AFRC, including support of the range flight conducted on 2014-08-06.
(2) Transit flight support:
   - 2014-08-26: Transit flight from NASA AFRC to NASA WFF
(3) Science flight support:
   - 2014-08-26: Combined transit / science flight
   - 2014-08-28: Hurricane Cristobal

The S-HIS instrument successfully collected high quality data from takeoff to landing for the range test flight. The AFRC to WFF transit flight was completed 2014-08-26, with return transit from WFF to AFRC on 2014-09-30. Transit flights were supported by the UW S-HIS team at the AFRC and WFF sites. The S-HIS instrument successfully collected high quality data for the full duration of both flights.

The UW S-HIS team supported the HS3 mission and science flights of the NASA AV-6 Global Hawk from the NASA Wallops Flight Facility 2014-07-28 through 2014-08-07 and 2014-08-19 through 2014-10-01. The S-HIS instrument successfully collected high quality data from takeoff to landing for all science flights, with the exception of planned instrument power cycles 45 – 60 minutes prior to science waypoint 1 during the 2014-08-28, 2014-09-05, 2014-09-11, 2014-09-14, 2014-09-16, and 2014-09-22 flights. The power cycle was implemented to address concerns with S-HIS Stirling Cooler behavior, and resulted in no loss of science data.

Final products and Matlab readers for the data products were delivered via the SSEC ftp server. New users are required to register with an email address for contact information such that a distribution list can be easily maintained for product announcements and updates. A web link to the S-HIS HS3 data product distribution is included at the ESPO HS3 webpage:

http://espo.nasa.gov/missions/hs3/data_products.

The direct link is:

http://download.ssec.wisc.edu/sys/login/form/hs3_shis.

The S-HIS team has been coordinating with the GHRC DAAC to ensure the S-HIS data products are compliant with file format standards. Once final reprocessing of the complete S-HIS HS3 dataset is completed, it will be submitted to the GHRC DAAC complete with quick-look images.

Representative examples of S-HIS retrieval and brightness temperature products are provided in Figure 1 through Figure 5.

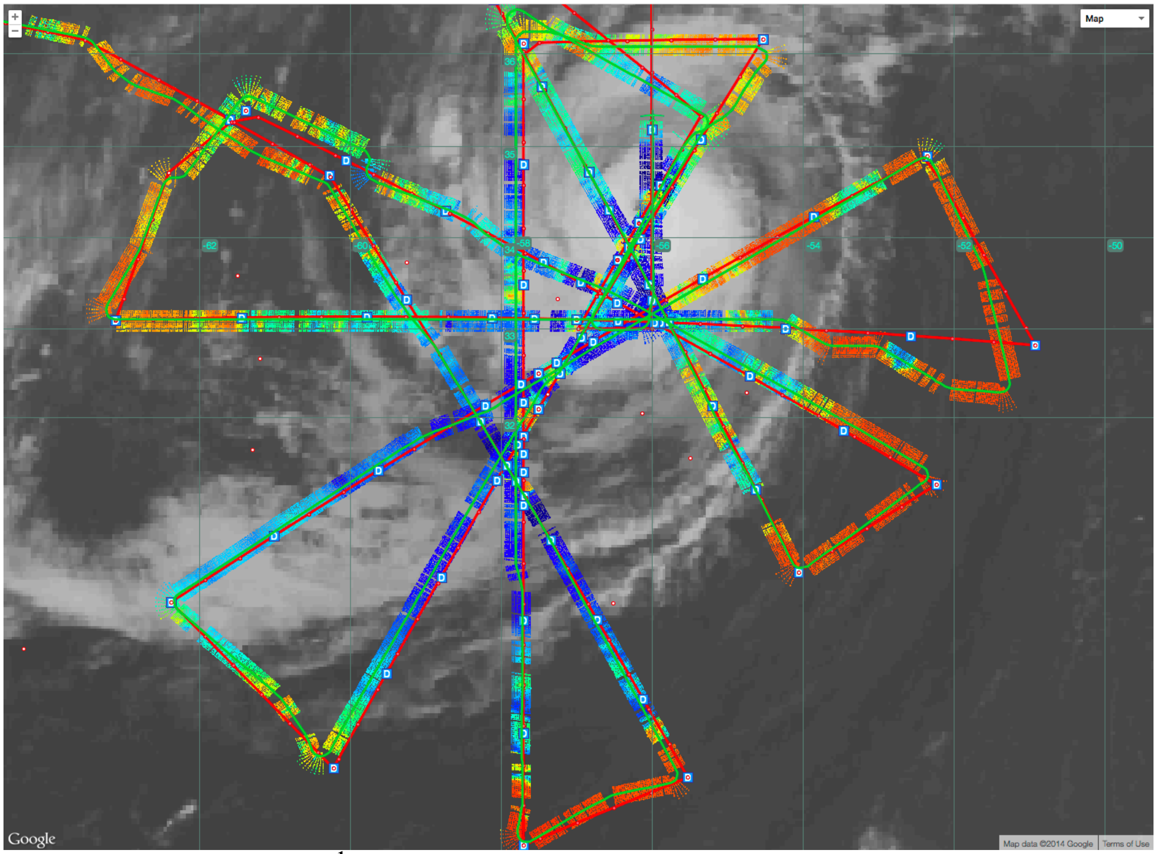

Figure 1: S-HIS 895-900 cm^{-1} Brightness Temperature image overlaid on GOES IR in MTS showing multiple overpasses of the eye of Hurricane Edouard (2014-09-16).

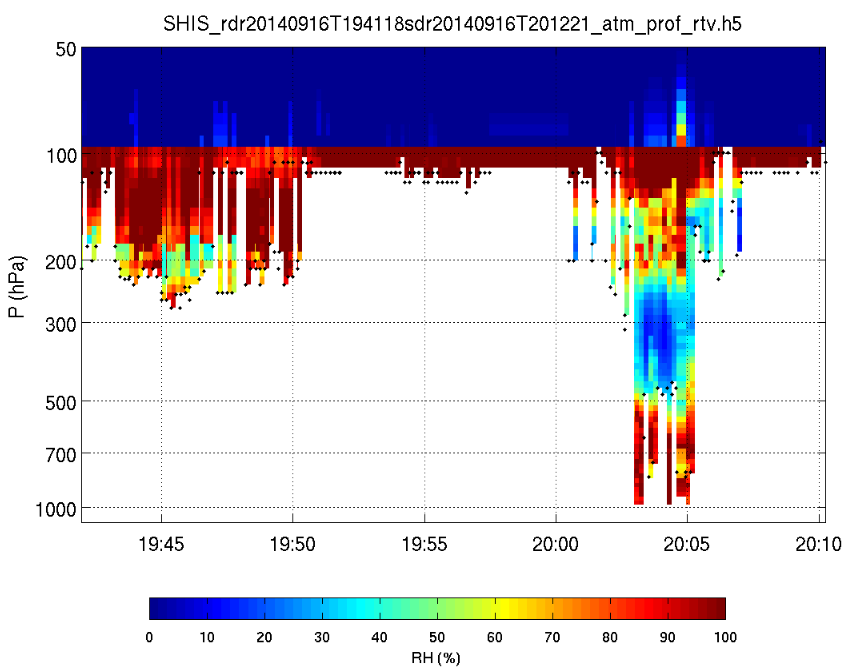

Figure 2: S-HIS relative humidity profile retrieval during the third eye transect of Hurricane Edouard (2014-09-16).

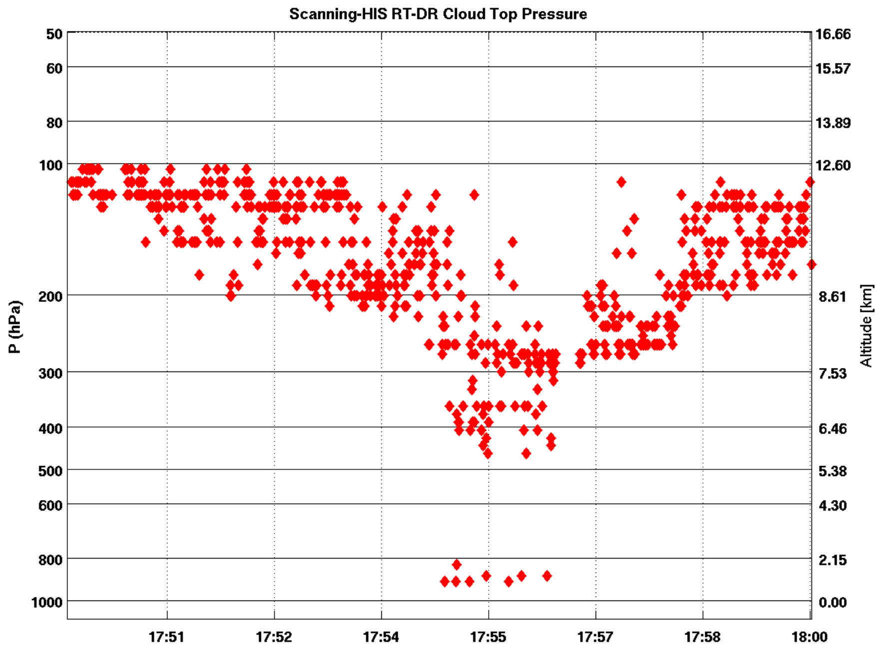

Figure 3: 10 minute history of S-HIS retrieved CTP during the second eye transect of Hurricane Edouard (2014-09-16).

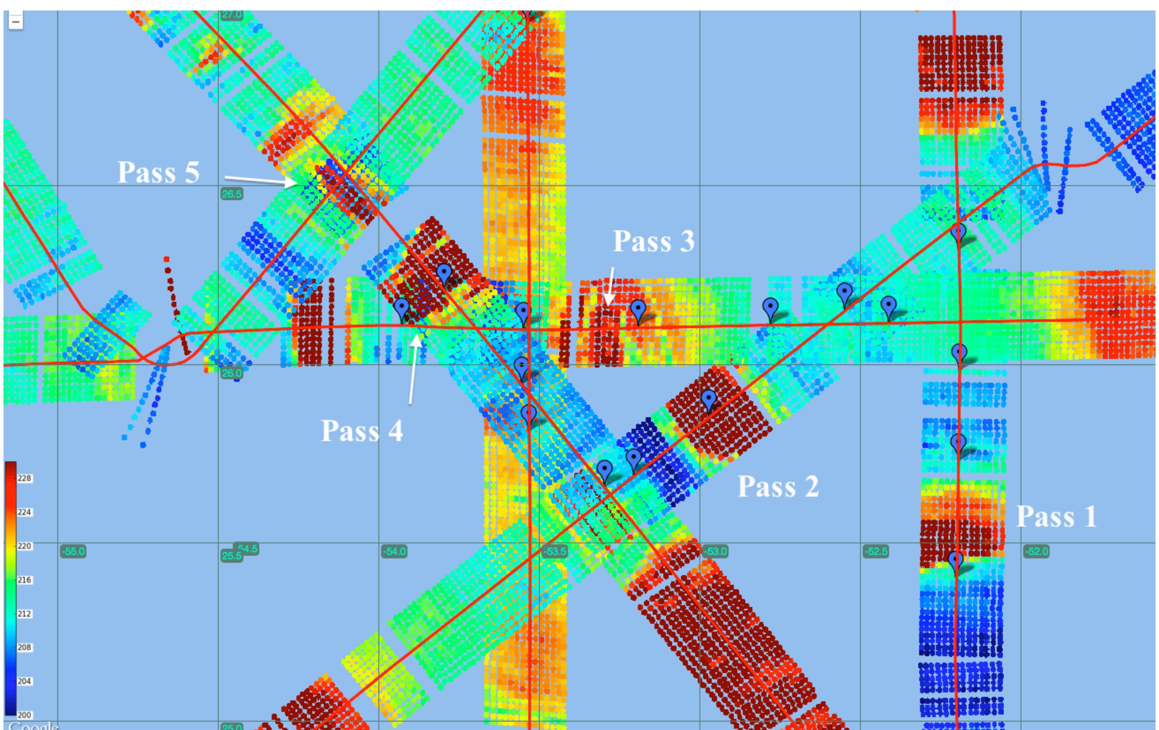

Figure 4: S-HIS 895-900 cm^{-1} Brightness Temperature image in MTS showing multiple overpasses of the eye of Hurricane Edouard (2014-09-14).

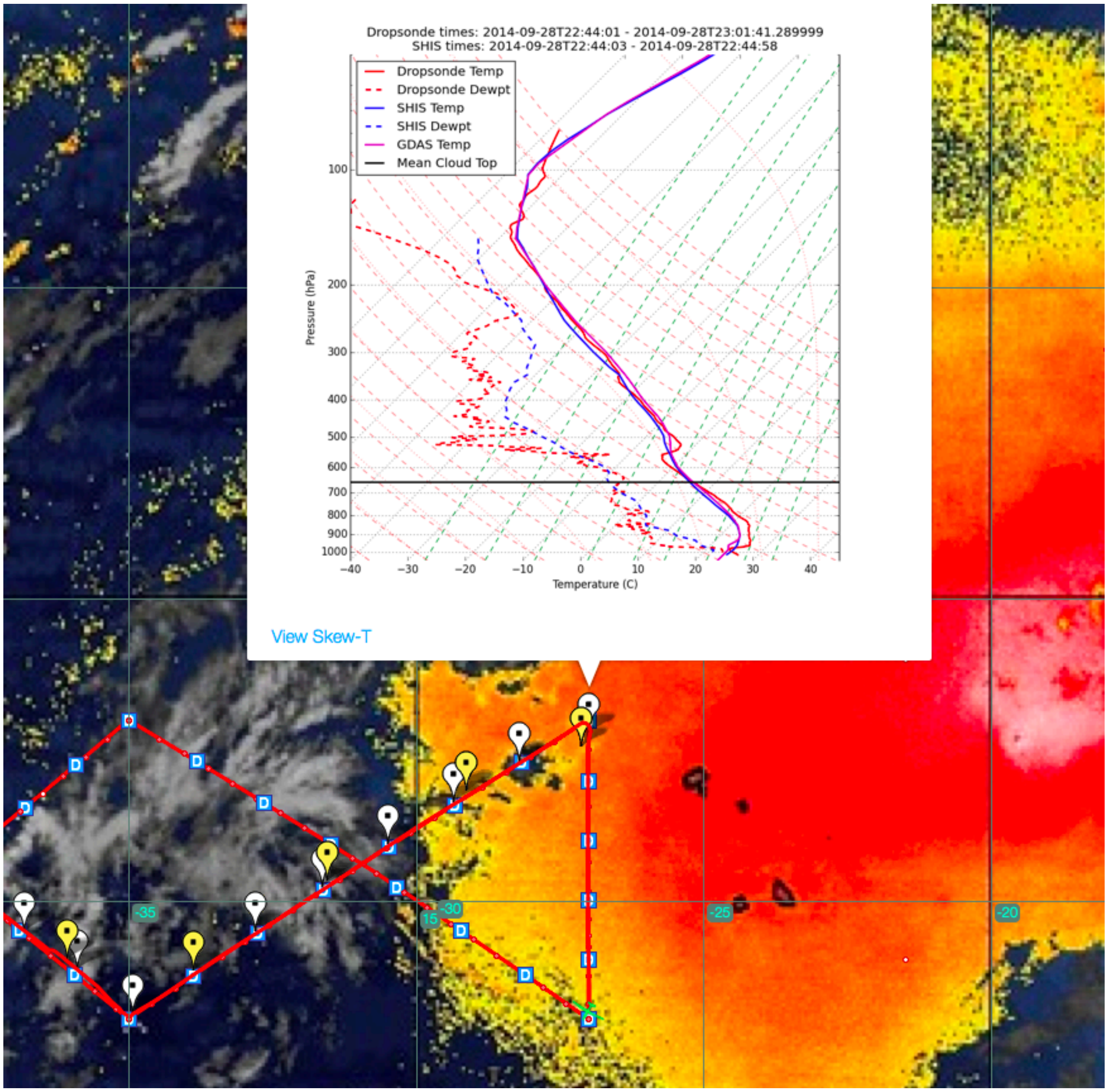

Figure 5: S-HIS and AVAPS skew-T comparison plot for 2244 UTC (2014-09-28). This sounding was noted in the #HS3 room to be a classic ENATL SAL sounding with a dry slot from ~955-550 mbar, and 20-30% RH at 600-900 mbar.

2. Pre-campaign and post-campaign testing of S-HIS performance

There are four major phases of S-HIS radiometric calibration:

1. Pre-Integration at Subsystem Level
2. Pre-Deployment Calibration Verification
3. Post-Deployment Calibration Verification
4. Instrument Calibration During Flight Using On-Board Calibration Blackbodies

Step one is typically completed on the order of every 5 years and was completed in 2012 (details provided in year-2 report). Steps 2 and 3 are completed pre and post mission, respectively, and step 4 describes the in-flight calibration scheme.

2.1. Pre-Integration at Subsystem Level

The S-HIS thermistor readout electronics are calibrated using a series of 6 fixed resistance standards, that are each calibrated to an accuracy of better than 5 mK (3-sigma) equivalent temperature, using a Fluke 8508A DMM. The S-HIS On-Board Calibration Blackbody thermistors are calibrated at 10 temperatures over the range from -60 °C to 60 °C. These tests are done in a controlled isothermal environment using a NIST traceable temperature probe that is calibrated at Hart Scientific to an accuracy of 5 mK (3-sigma). Following these tests the On-Board Calibration Blackbodies and Readout Electronics are integrated to the S-HIS Instrument.

Results from the blackbody calibration conducted in the spring of 2012 show insignificant change in the key temperature ranges used from the last major blackbody calibration (2004) – less than 25 mK change for the ABB, and less than 5 mK for the HBB. It is noteworthy that the duration between tests (2004 and 2012) in this case exceeds the preferred 5-year interval between tests, but the results confirm insignificant change in blackbody thermometry in this 8-year period.

The overall blackbody temperature uncertainty budget is 53 mK (3-sigma), compared with the requirement of 100 mK. This uncertainty budget reflects the current state of the art for the S-HIS blackbody temperature calibration and captures the best methods, procedures, and techniques developed at UW-SSEC for blackbody calibration. Details of the blackbody calibration are included in the 2012 report.

2.2. Pre-Deployment Calibration Verification

Prior to each field campaign end-to-end calibration verification is performed using a variable temperature blackbody in the zenith view and an ice-bath blackbody in the nadir view. Similar to the post-campaign tests, the radiances measured by the S-HIS instrument are compared to those calculated for the verification blackbodies, using the measured cavity temperature, knowledge of the emissivity, and measurements of the background temperature.

All tests showed agreement within the established calibration and validation uncertainty (3-sigma). The pre-deployment test was completed in the prior reporting period, but the results are included in Figure 7 for reference.

A description and photographs of the end-to-end calibration verification process are included in Step 4 below.

2.3. Post-Deployment Calibration Verification

Following the field campaign end-to-end calibration verification is performed. End-to-end calibration verification is conducted using a variable temperature blackbody in the zenith view and an ice-bath blackbody in the nadir view (Figure 6). Radiances measured by the S-HIS instrument are compared to those calculated for the verification blackbodies, based on the measured cavity temperature, knowledge of the emissivity, and measurements of the background temperature.

The variable temperature blackbody used for S-HIS calibration validation has its heritage rooted in the Atmospheric Emitted Radiance Interferometer (AERI) instrument. These blackbodies have had their emissivity measured at NIST using three methods: the Complete hemispherical infrared laser-based reflectometer (CHILR); the Thermal infrared transfer radiometer (TXR); and the Advanced Infrared Radiometry and Imaging Facility (AIRI). The ice-bath blackbody is geometrically similar to the AERI Blackbody, and is coated with the same paint.

The S-HIS instrument has undergone a side-by-side radiance intercomparison test with the NIST TXR, using an AERI blackbody as a transfer standard. The mean difference at 10 microns between these instruments was 38 mK - well less than the propagated 3-sigma uncertainties.

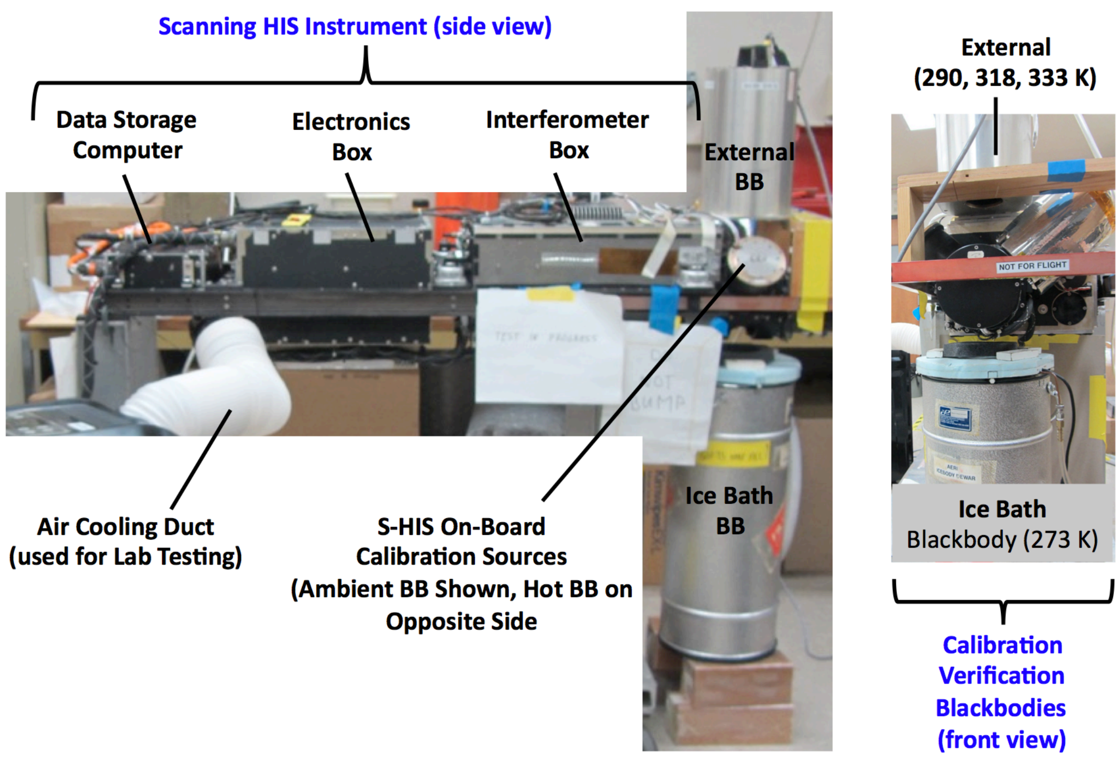

Figure 6: S-HIS radiometric calibration verification configuration.

The results from the S-HIS end-to-end calibration verification conducted after the 2014 HS3 field deployment are discussed below. The test configuration is shown in Figure 6.

After instrument and source set-up and stabilization were completed and verified, 30 minute datasets were collected at three external blackbody temperatures (Ambient, 318K, 333K). The external blackbody temperature was allowed to stabilize before each data collection, and ice-bath blackbody data was collected for the duration of the test (approximately 135 minutes). Ambient, 318K, 333K, and ice-bath blackbody tests showed agreement within the established calibration and validation uncertainty (3-sigma). Results are shown in Figure 8. While the results are within the established uncertainties, the mid-wave band result for the ice-bath blackbody is not ideal. This behavior is consistent with historical results for ice-bath blackbody tests conducted in the laboratory environment. The nonlinearity correction parameters for the long-wave and mid-wave band are optimized for flight conditions, and the mid-wave result is likely due to non-optimal nonlinearity correction in the laboratory thermal environment.

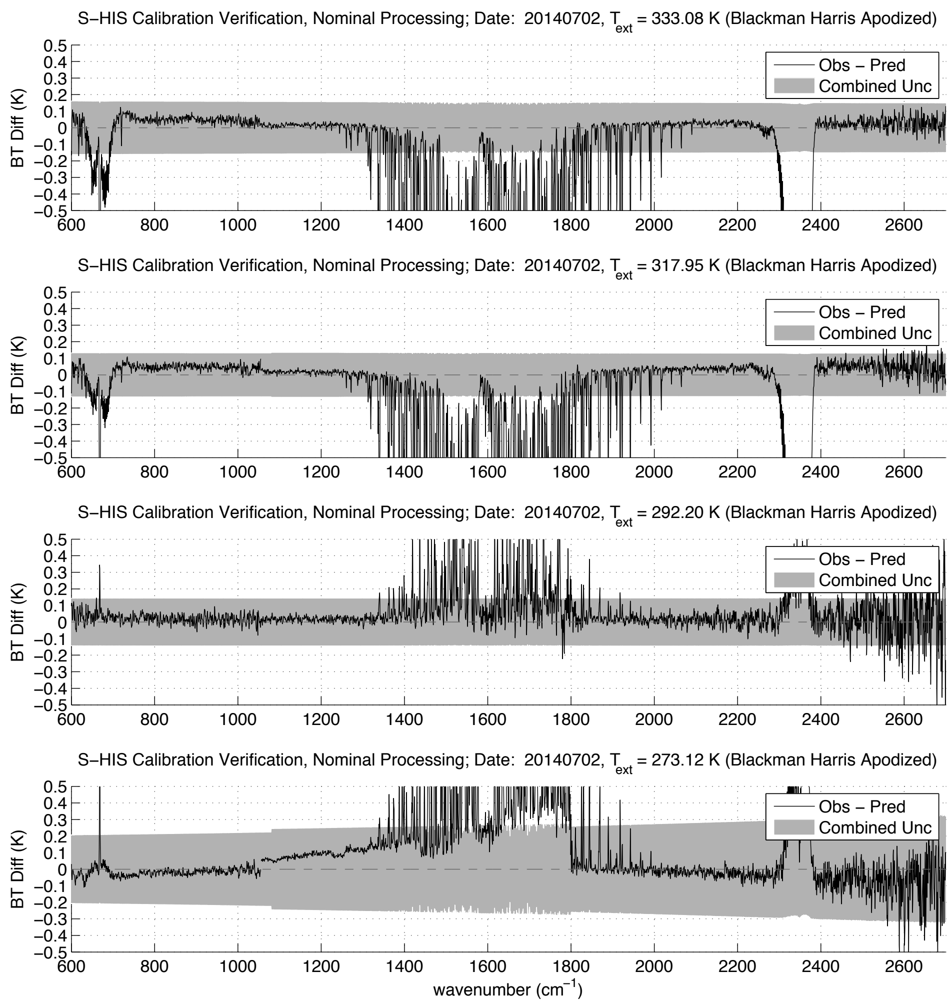

Figure 7: Pre-deployment radiometric calibration verification brightness temperature residuals (measured – predicted difference, with combined uncertainty). The 4 panels represent different external blackbody temperatures, top to bottom: 333.08K, 317.95K, 292.20K (ambient), and 273.12K (ice bath blackbody). Atmospheric absorption and emission are not included in the predicted brightness temperatures (no line by line radiative transfer model utilized). All uncertainties are 3-sigma.

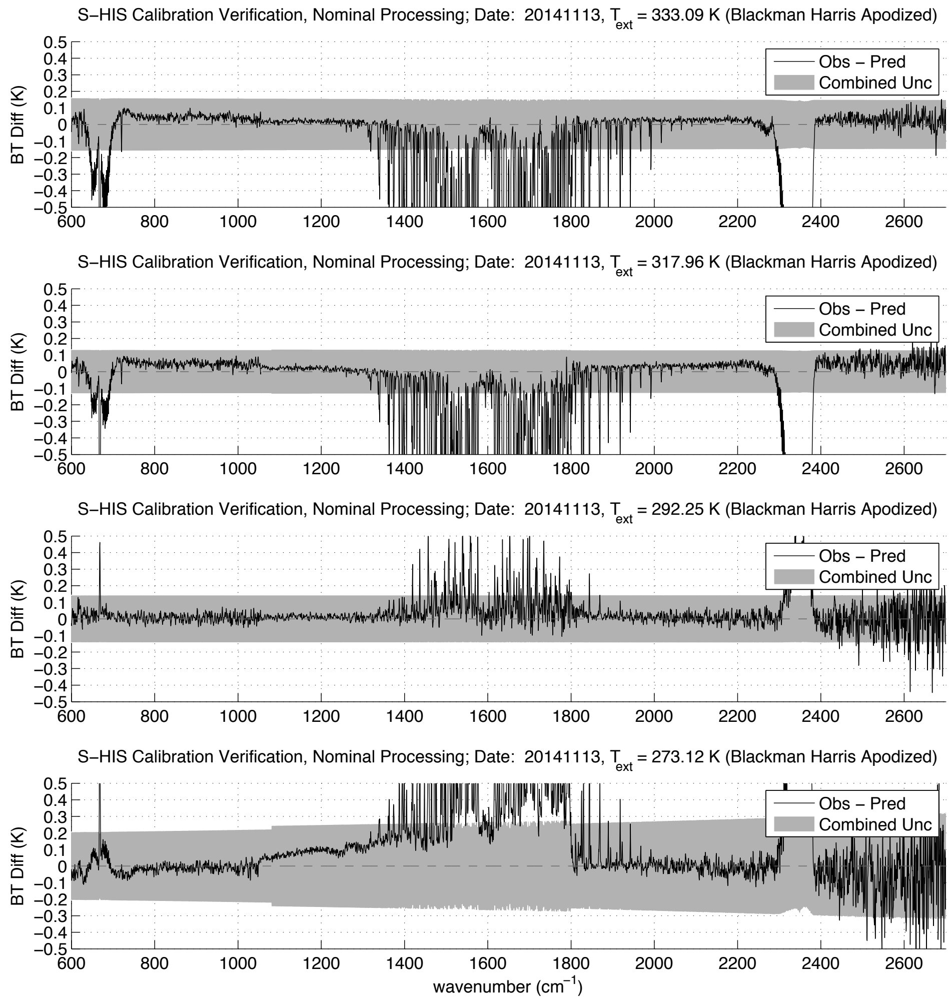

Figure 8: Post-deployment radiometric calibration verification brightness temperature residuals (measured – predicted difference, with combined uncertainty). The 4 panels represent different external blackbody temperatures, top to bottom: 333.09K, 317.96K, 292.25K (ambient), and 273.12K (ice bath blackbody). Atmospheric absorption and emission are not included in the predicted brightness temperatures (no line by line radiative transfer model utilized). All uncertainties are 3-sigma.

2.4. Instrument Calibration During Flight Using On-Board Calibration Blackbodies

During flight, the S-HIS earth scene radiance measurements are calibrated several times a minute using its two On-Board Calibration Blackbodies: the Ambient Blackbody runs at the pod ambient temperature (between -25 and -55°C, depending on the local ambient environment); and the Hot Blackbody runs at 27°C.

3. Ongoing development and optimization of architecture and software to implement real-time, near real-time, and long term data handling, processing, and display for long duration Global Hawk flights.

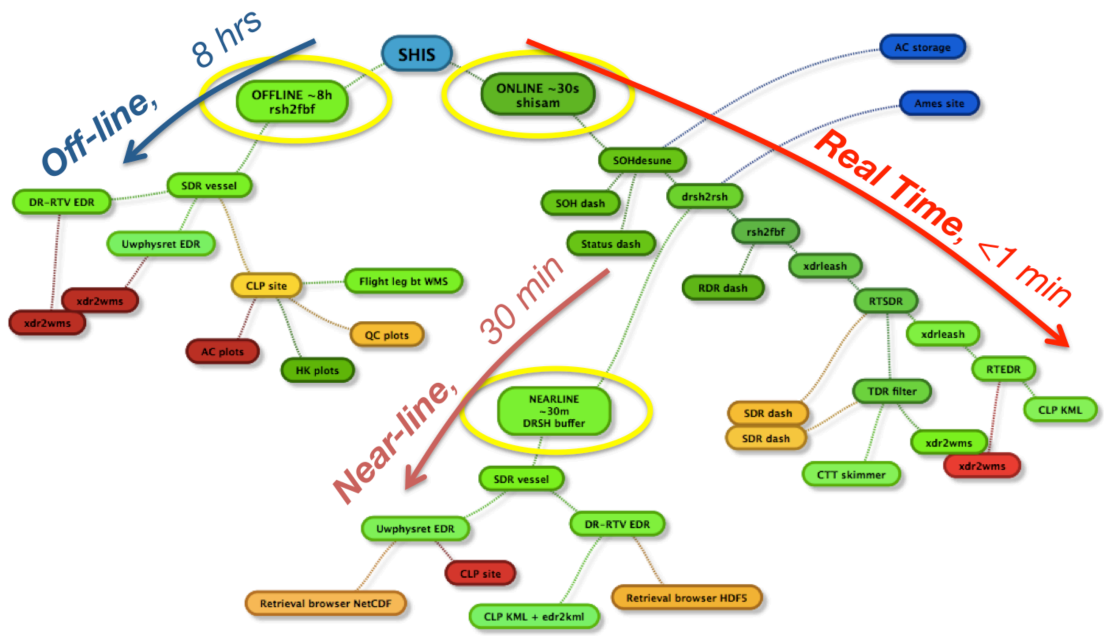

Figure 9: S-HIS HS3 data processing paths.

S-HIS offers three levels of data products, raw data records (RDR), scientific data records (SDR), and environmental data records (EDR). Raw data records are provided directly from the instrument and include housekeeping temperatures and measurements, blackbody temperatures, and raw observed interferograms. Through radiometric calibration using reference blackbody spectra, RDRs are used to create calibrated absolute radiance spectra SDRs that can in turn be represented as brightness temperature spectra. Through a second, longer, software processing step, SDRs are used to create EDR atmospheric profiles. The SDR and EDR data are operationally produced and distributed.

There are three S-HIS HS3 data processing paths: (1) Offline batch post processing, (2) near-line processing (30 minute latency), and (3) real-time processing (~45 second latency). These data processing paths are illustrated in Figure 9 and are summarized in the following sub-sections.

3.1. Post-processing of Radiance Calibration and Atmospheric Retrieval

Following each flight the UW team downloads the complete raw dataset collected onboard the S-HIS instrument and subsequently uploads the dataset to the SSEC at Wisconsin for post-processing. This post-processing consists of a sequence of batch scripts, which execute custom calibration software for the conversion of interferograms to radiances. A GH flight of 24 hours can be processed in about 4 hours of wall clock time on a dedicated computer at the UW-SSEC. The processing of raw data to radiances is fully tested and automated. Once the radiances are available, the UW team has custom software for the retrieval of temperature and water vapor profiles and cloud heights. Two independent retrieval algorithms have been developed, a Dual Regression (DR) algorithm that is a statistical eigenvector regression method, and provides retrievals under clear and cloudy conditions; and UWPhysRet that is a clear sky algorithm (see Section 5). The retrievals for temperature, water vapor retrieval, and clouds are compared with collocated dropsonde (AVAPS) and lidar (CPL) data. The DR retrieval algorithms is fully automated. Quick-look product images, comparison plots, and final data products were made available during this reporting period. Final products and Matlab readers for the data products are delivered via the SSEC ftp server. New users are required to register with an email address for contact information such that a distribution list can be easily maintained for product announcements and updates. A web link to the S-HIS HS3 data product distribution is included at the ESPO HS3 webpage:

http://espo.nasa.gov/missions/hs3/data_products.

The direct link to the data is:

http://download.ssec.wisc.edu/sys/login/form/hs3_shis.

The S-HIS team has been coordinating with the GHRC DAAC to ensure the S-HIS data products are compliant with file format standards. Once final reprocessing of the complete S-HIS HS3 dataset is completed, it will be submitted to the GHRC DAAC complete with quick-look images.

3.2. Real-time and Near-line Radiance Calibration and Atmospheric Retrieval

The S-HIS instrument data downlink methodology has evolved over time with the technology available and new aircraft platforms. Initially, S-HIS data was primarily retrieved from internal storage on the instrument after landing and processed post-flight. In some cases, a small amount of data was provided via status packets or state of health (SOH) packets. These packets hold a minimal amount of information to verify that the instrument is operating as expected and can't be used for high level scientific analysis. For lab or "fly-along" DC-8 airborne lab use, when direct connections to the instrument are possible and not bandwidth limited, a scientist uses a direct TCP network connection to subscribe to data in real-time.

The HS3 mission on the Global Hawk marks the first time that real-time S-HIS science data is downlinked, processed, and made available to scientists on the ground within 1 minute of observation. The ability to view real-time S-HIS observations allows scientists to quickly analyze the storm formation, and allows real-time mission planning, inclement flight weather avoidance as well as tracking the instrument state of health. Details of the real-time and near-line, data transport, radiance calibration, and atmospheric retrieval generation are provided in the Year-4 annual report.

The state of health of the S-HIS instrument is monitored in real-time in the PMOF at NASA WFF using graphical displays. Once data packets reach the processing machine in the PMOF, raw data record processing is performed and then displayed in a graphical user interface known as the S-HIS Dashboard. The Dashboard provides time series of temperatures and spectra for the last 200 measurements (approximately 100 seconds). It also displays the values of various instrument housekeeping sensors, and whether they are within their acceptable operating ranges. Further displays are available for Status and State-of-Health (SOH) packets (delivered via Iridium), for use in the case of a Ku communication outage or if the full datagram (DSRH) data is otherwise not available.

Furthermore, collaborating scientists can view the real-time downlinked S-HIS data products through the NASA Mission Tools Suite website or the SSEC S-HIS website during flight, from anywhere in the world. Data and images are provided to both of these services via processing on a server at the SSEC.

For each SDR record that is produced, the brightness temperature data is added to Web Map Service (WMS) layers, represented as GeoTIFF image fragments with metadata. WMS layers can be viewed in NASA Mission Tools or Google Earth to see geo-located real-time measurements made by S-HIS. Additionally, various quick-look images of the calibrated brightness temperatures and retrieved atmospheric profiles are produced at regular intervals in near real-time. The quick-looks are made available on the SSEC S-HIS website as geo-located PNG images and as dynamic KML markers that can be viewed in Mission Tools or Google Earth. KML markers are clickable icons on a map that open a separate window for viewing the quick-look images.

The algorithms used in the real-time calibrated radiance and Dual Regression retrieval processing are fast enough to produce values within seconds of reception. Near-line processing utilizes the full batch processing including quality control; applied to KU downlinked data separated into 30-minute data segments.

For the 2014 HS3 season, beginning with the 2014-09-12 flight, SHIS/AVAPS comparison skew-T plots were added to MTS. Initially, an average of S-HIS retrievals from data collected during the sonde drop was used in the comparison, with a simple outlier rejection applied to the S-HIS retrievals (Figure 10). By the 2014-09-22 flight a refined field of view averaging and selection algorithm was developed and applied to the S-HIS retrievals used in the AVAPS comparison plots. This resulted in improved temperature and dewpoint agreement between the two instruments. Two comparison plots from the 2014-09-22 flight are provided in Figure 11 and Figure 12. These profiles were taken east of a convective complex during the eastward track, with the later S-HIS retrieval average (Figure 12) more fully capturing the mid-level dry slot.

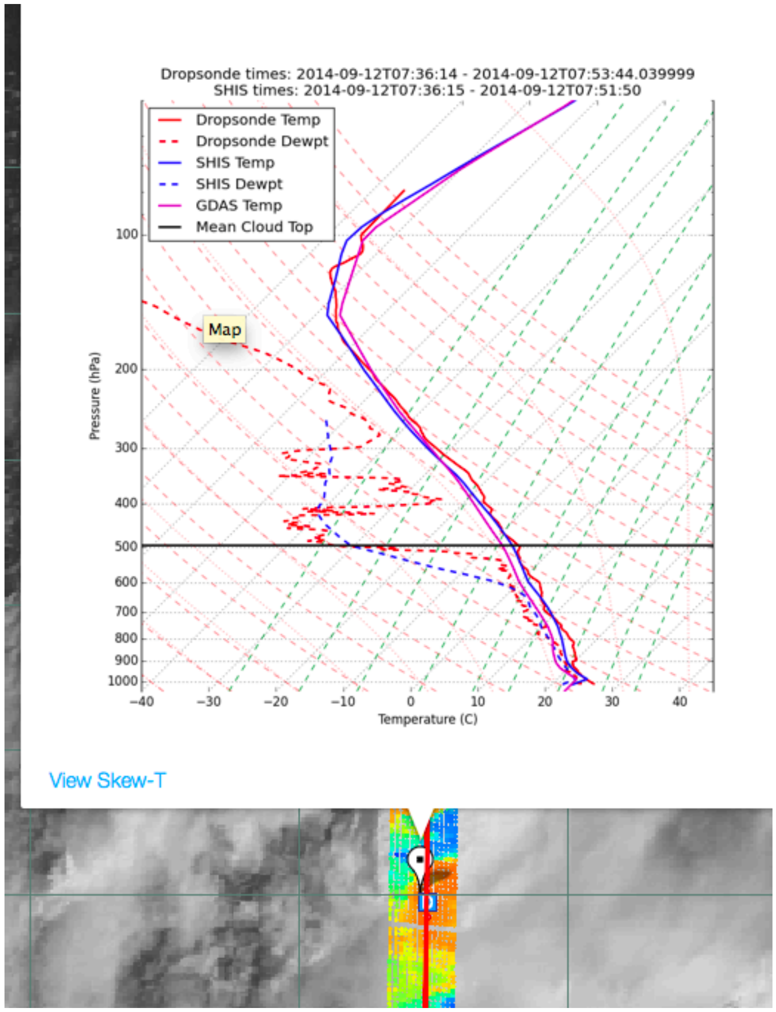

Figure 10: S-HIS / AVAPS comparison skew-T plot delivered via MTS (2014-09-12 flight, initial implementation).

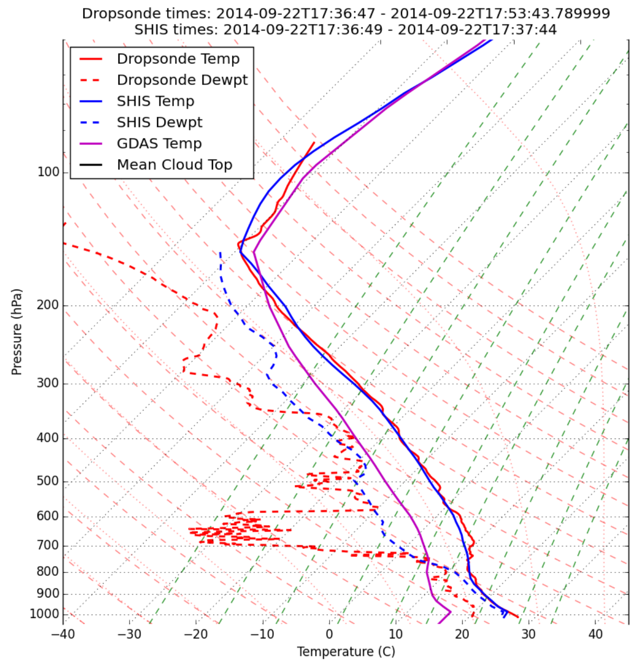

Figure 11: Example S-HIS / AVAPS comparison skew-T plot delivered via MTS for the 2014-09-22 flight. The S-HIS retrieval average does not resolve the mid-level dry slot for this sounding.

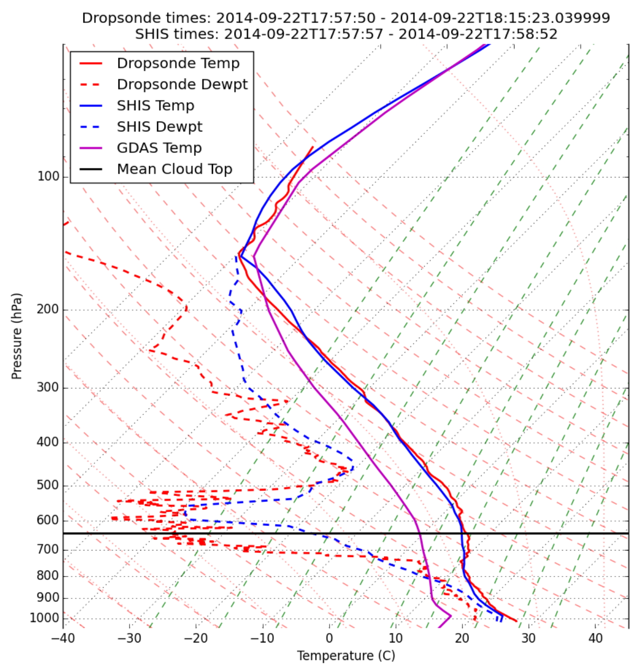

Figure 12: Example S-HIS / AVAPS comparison skew-T plot delivered via MTS for the 2014-09-22 flight. The S-HIS retrieval average more fully captures the mid-level dry slot in this case.

4. Optimization and implementation of improved temperature, water vapor, and cloud retrieval capabilities

4.1. S-HIS Dual Regression Retrieval

Development and optimization of the S-HIS Dual Regression Retrieval algorithm continued in 2014. All HS3 datasets (2011, 2012, 2013, 2014) will be reprocessed using the updated algorithm before final submission to the HS3 data repository. The largest Dual Regression Retrieval advancement completed during the 2014 reporting period was the implementation of a statistical bias correction. The Dual Regression retrieval method uses a statistical training data set, and imperfect skill due to lack of vertical resolution in radiances, leads to statistical bias. The statistical bias can be identified and corrected for by calculating model radiances from the forecast profile and performing the Dual Regression retrieval on the simulated radiances. The resulting retrieval error in the simulated retrieval is the statistical bias.

To provide atmospheric retrievals under all-sky conditions, the "Dual Regression" retrieval algorithm has been adapted for the S-HIS on the Global Hawk. This retrieval approach has been used previously for other high spectral resolution IR satellite sensors including AIRS, IASI, and CrIS, and provides retrievals of temperature and water vapor profiles, various cloud parameters, column ozone and carbon dioxide, and surface pressure and temperature (Smith et al. 2012). Primarily Drs. Elisabeth Weisz and William Smith performed this work, with coordination provided by Dr. David Tobin.

The S-HIS DR retrieved temperature and water vapor results are compared with collocated AVAPS profiles. Nadir S-HIS DR retrieved cloud top pressure and optical depth are also compared to collocated Cloud Physics Lidar (CPL) measurements for all flights. The analyses include:

- Two-minute means of S-HIS DR temperature and water vapor profiles are plotted on a skew-T diagram for each AVAPS dropsonde. An example from the 2013 season is provided in Figure 13;
- Daily mean, four-panel images representing S-HIS DR retrievals relative to AVAPS dropsondes are also created for each HS3 flight. An example four-panel image is provided in Figure 14;
- A radiative closure study to further characterize and confirm the observed AVAPS dry bias. An example of this comparison was presented at the 2015 HS3 Science Team Meeting and is also included in the Year-4 report.
- Nadir S-HIS DR retrieved cloud top pressure and optical depth are compared to collocated Cloud Physics Lidar (CPL) measurements for all flights, on both an individual flight, annual, and full-mission basis. An example of analysis results was included in the Year-4 report.

All comparisons for the full HS3 mission will be updated following the reprocessing of the S-HIS HS3 dataset in the following months.

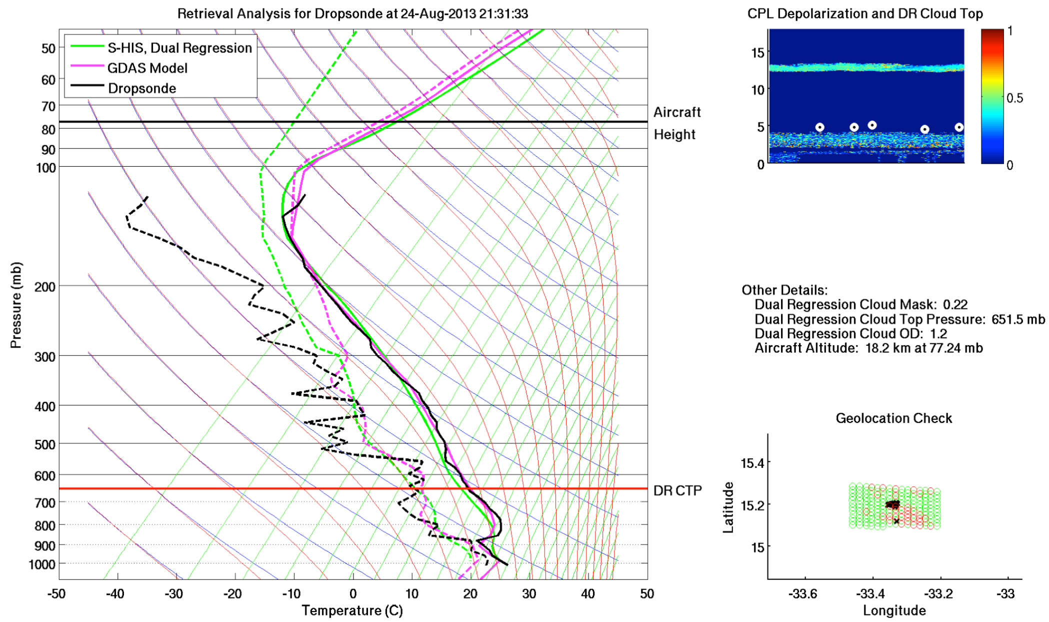

Figure 13: Sample DR Profile comparison to Dropsonde & GDAS; 24 August 2013. This example shows a good retrieval quality, despite upper level thin cirrus and lower level aerosol layers. The left panel shows a skew-T diagram that includes the dropsonde (black), S-HIS DR mean retrieval (green) and GDAS model (magenta) profiles; where dashed-lines represent dewpoint temperature and solid lines indicate temperature. The top right image shows the CPL depolarization for a two-minute window centered on the dropsonde time, used to illustrate the nadir cloud conditions for the given dropsonde. A geolocation sanity check is provided in the lower right. This image shows the S-HIS surface projected points (circles; green suggests no cloud while red specifies a positive cloud retrieval) and the dropsonde position during its descent (black x).

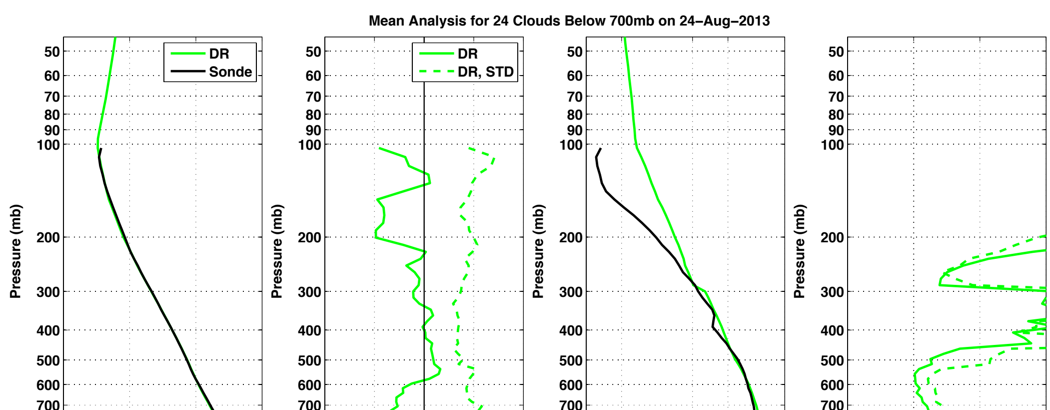

Figure 14: A daily-mean, four-panel image representing S-HIS DR retrievals relative to AVAPS dropsondes is created for each HS3 mission sortie. The dry bias of the dropsonde above 400 mb is a consistent feature. Data are compiled with respect to relative humidity (RH) and water mass mixing ratio (H2OMMR). Data are also filtered based on DR retrieved cloud top pressure limited to 700 mb. The first panel shows the mean daily temperature profile for each dropsonde (black) and corresponding two-minute mean S-HIS DR retrieval (green); panel 2 shows the difference from mean ($T_{DR} – T_{AVAPS}$) and its standard deviation; panel 3 shows the same as panel 1, but for relative humidity (note the significant dry bias in the dropsonde above 400 mb); and panel 4 shows the difference from mean for RH, along with its standard deviation ($RH_{DR} – RH_{AVAPS}$).

Smith, William L. Sr.; Weisz, Elisabeth; Kireev, Stanislav V.; Zhou, Daniel K.; Li, Zhenglong and Borbas, Eva E. ***Dual-regression retrieval algorithm for real-time processing of satellite ultraspectral radiances.*** *Journal of Applied Meteorology and Climatology, Volume 51, Issue 8, 2012, 1455–1476. Reprint #6809.*

4.2. UWPHYSRET Physical Retrieval Algorithm

A research algorithm developed at the University of Wisconsin for use with satellite data has been implemented for processing S-HIS data during the HS3 mission. This method is based on the Rodgers (2000) methodology of maximum a posteriori probability (MAP) estimation, also known colloquially as Optimal Estimation. The software package developed at the UW-SSEC is called UWPHYSRET. The initial implementation of this algorithm used the LBLRTM line-by-line model from AER, Inc. as the forward operator. This method is very slow, but allows the detailed properties of the retrieval to be accurately evaluated for selected clear case studies. During this reporting period, this retrieval scheme was modified to run much faster by using the OSS forward model that was tuned by AER to accurately agree with LBLRTM. It is now practical to explore a larger set of case studies. UWPHYSRET also provides uncertainty estimates along with the estimate of profile temperature and water vapor values.

5. Support of Science Team

The S-HIS group supported periodic Science Team telecons during the reporting period in addition to the Science Team meeting on Meeting May 5 – 7, 2014. Henry Revercomb (S-HIS Principal Investigator), Joe Taylor (S-HIS Project Manager and Instrument Engineer), Bill Smith (Researcher), and Dan Deslover (Researcher) attended the meeting. The following posters and talks were presented by the S-HIS team at the 2015 HS3 Science Team Meeting:

- (Presentation) S-HIS Instrument Overview, Joe Taylor et al;
- (Presentation) Atmospheric profiles from SHIS during the HS3 field campaigns - retrieval technique and results, Bill Smith et al;
- (Poster) Three-year analysis of S-HIS dual-regression retrievals using collocated AVAPS and CPL measurements, Dan Deslover et al;
- (Poster) Scanning High-resolution Interferometer Sounder (S-HIS) Radiometric Calibration and Performance During HS3, Joe Taylor et al.

6. UW HS3 Year 5 Summary of Accomplishments

Year 5 activities by our University of Wisconsin Space Science and Engineering Center team supporting S-HIS successfully provided real-time, and quality controlled radiance and retrieval products for the NASA HS3 mission hurricane flights. Final products have been made available for distribution. Major accomplishments include

- Successful operation of the S-HIS on long duration Global Hawk flights has been demonstrated, with greater than 99.8% up-time,
- Accurate radiance spectra from all science flights have been processed and temperature/water vapor profile products show reasonable agreement with dropsonde results,
- S-HIS calibration reference accuracy has been verified,
- Data handing and processing for real-time and near real-time processing were operational for all science flights, with products displayed in NASA MTS and via webpage quick-looks,
- Improved retrieval capabilities have been implemented, including a physical retrieval for clear sky (UWPhysRet) and a dual regression capability for clear and cloudy skies,
- Active participation in the annual science team meeting and in team telecons,
- Quick-look product images, comparison plots, and final data products were made available during this reporting period. Final products and Matlab readers for the data products were delivered via the SSEC ftp server. Prior datasets will be reprocessed using the 2015 data processing algorithms, and re-distributed and archived to the project data repository. A web link to the S-HIS HS3 data product distribution is included at the ESPO HS3 webpage.
    - ESPO link: http://espo.nasa.gov/missions/hs3/data_products
    - Direct link: http://download.ssec.wisc.edu/sys/login/form/hs3_shis