Year-2 Report

University of Wisconsin, Space Science and Engineering Center
Scanning-HIS Participation in HS3

NASA Grant NNX10AV08G

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HS3 Year-2 Final Report
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Introduction

This is the Year 2 report for the time period 9/1/2011 - 8/31/2012 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 included (1) Support S-HIS for HS3 demonstration flights (from NASA Dryden, 9 and 14 September 2011) and subsequent data analyses; (2) Follow-up optimization of S-HIS interface to Global Hawk zone 25 thermal environment; (3) Laboratory verification of S-HIS reference blackbody temperature calibration and pre-campaign testing of S-HIS performance and; (4) Establish architecture and implement software to improve real-time, near real-time, and long term data handling, processing, and display for long duration Global Hawk flights; (5) Development and implementation of improved temperature, water vapor, and cloud retrieval capabilities; (6) Support HS3 Science Team telecons and the Science Team Meeting 7-8 May 2012.

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

1. Support S-HIS for HS3 demonstration flights and subsequent data analyses

During the month of September 2011, the UW S-HIS team supported flight operations of the NASA AV-6 Global Hawk from the NASA Dryden flight facility in Southern California. Two long test flights were conducted with an instrument complement that included the hyperspectral infrared Scanning HIS sensor, the microwave HAMSR sensor, and dropsondes from the AVAPS system. Two flights were successfully conducted; a Pacific flight on 9 September 2011 which made a North/South transition along longitude 155W near Hawaii and a flight on 14 September 2011 from Dryden to the Gulf of Mexico for a dropsonde comparison with the NOAA G-4 aircraft. The S-HIS instrument successfully collected high quality data from take-off to landing for both flights, however the engineering data from the flight indicated that the instrument electronics and calibration blackbody were operating at or near the upper range of acceptable limits. This problem was identified as due to inadequate cooling in the instrument bay of the Global Hawk. Subsequently this problem has been successfully resolved by routing air intake from the front of the aircraft into the S-HIS instrument bay.

The following figures summarize the results of the S-HIS from the 9 Sept 2011 Pacific flight presented at the May 2012 science team meeting. These figures illustrate the vertical resolving capability of the hyperspectral IR retrievals from the aircraft down to opaque cloud top. The performance in these test flights meets all the HS3 requirements for a successful mission.

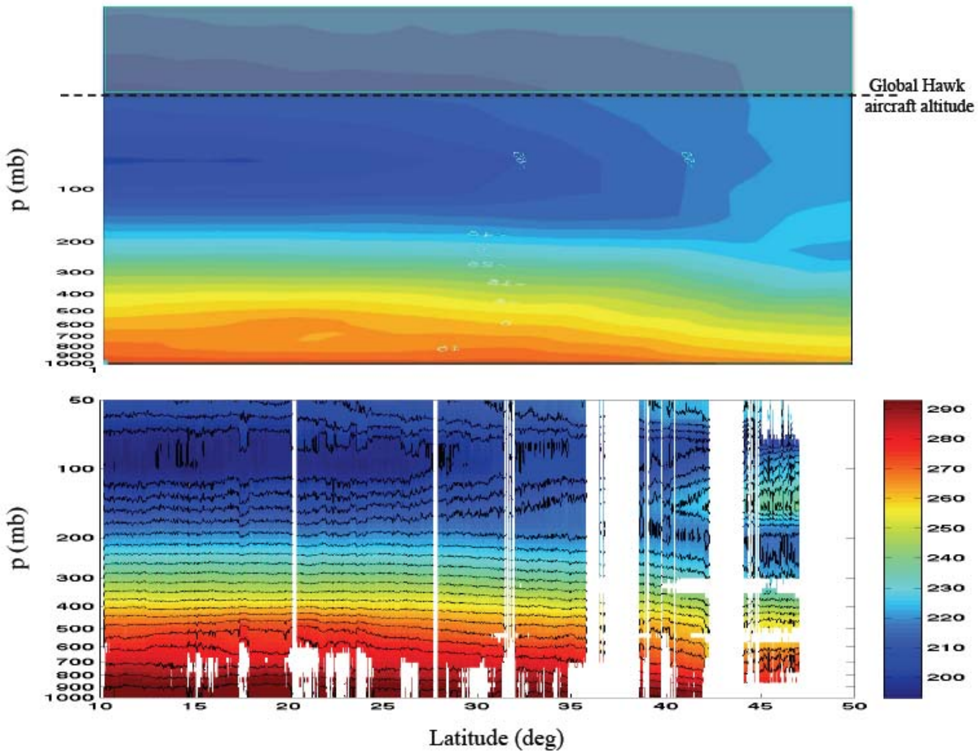

Figure 1: Vertical cross-section of GDAS NWP model (upper) and SHIS retrieval (lower) of atmospheric air temperature along longitude 155W on 9 September 2011 near Hawaii. The polar jet maximum is clearly defined in the S-HIS retrievals of temperature.

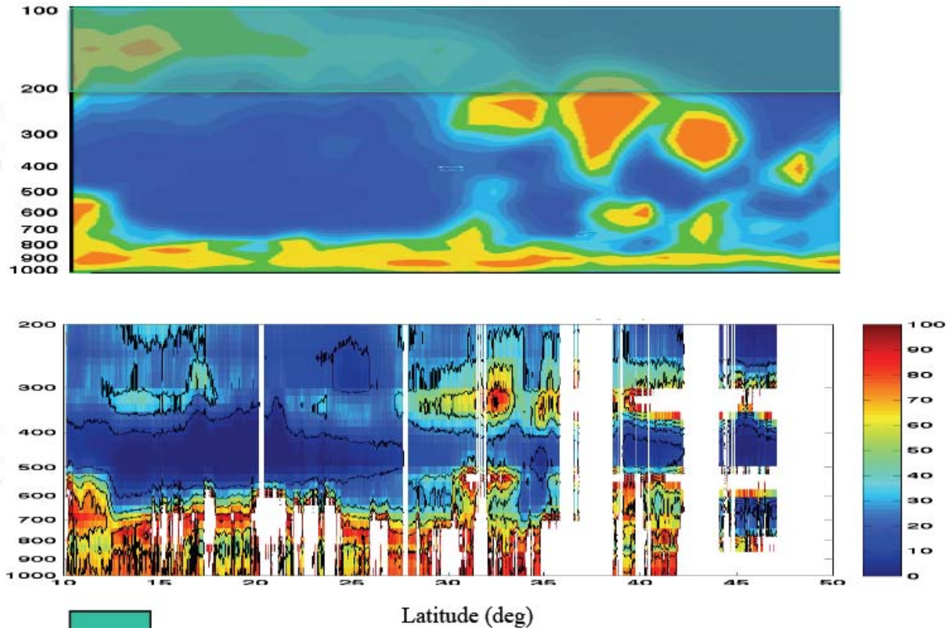

Figure 2: Vertical cross-section of GDAS NWP model (upper) and SHIS retrieval (lower) of atmospheric water vapor relative humidity along longitude 155W on 9 September 2011 in the Pacific passing near Hawaii. The S-HIS moisture layers illustrate the higher vertical resolution of the hyperspectral IR observations.

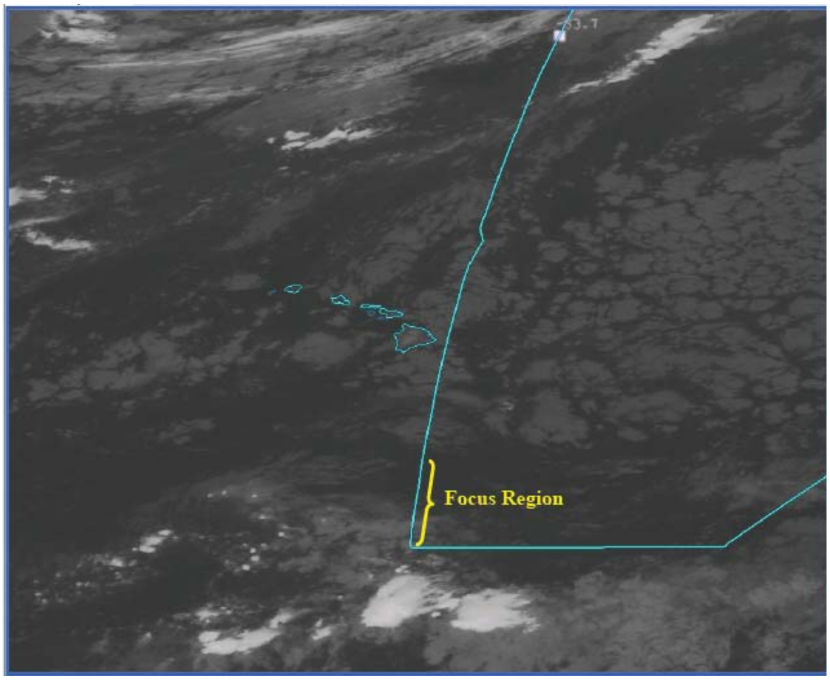

Figure 3: Global Hawk flight track for 09 September 2011 along longitude 155W. The focus region indicated marks the transition from sub-tropical to tropical air masses.

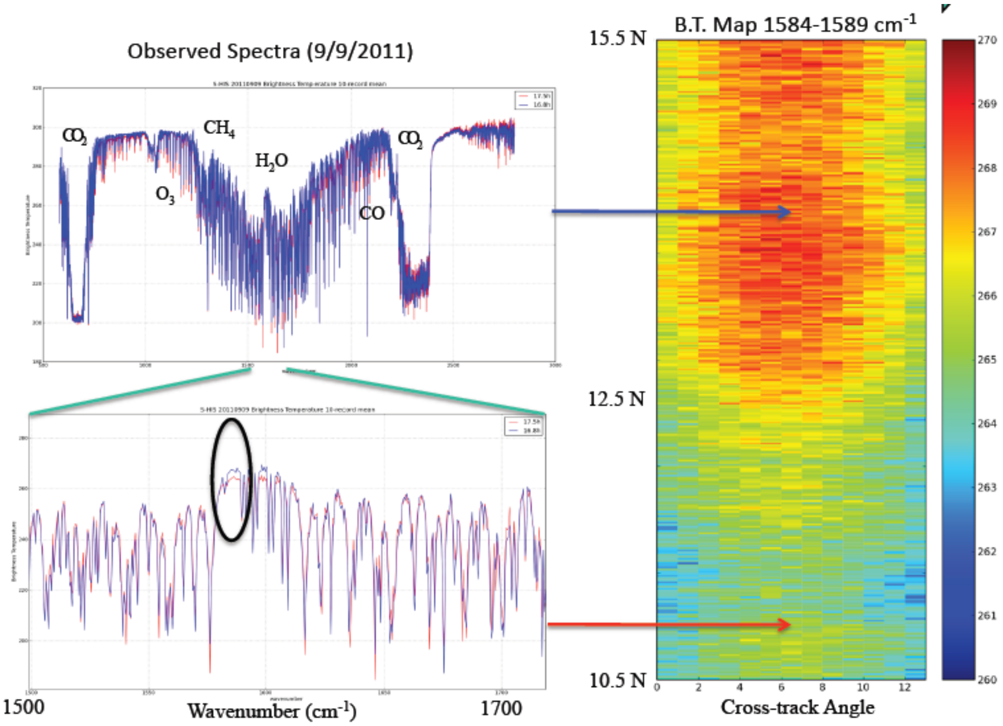

Figure 4: The transition between the subtropical and tropical air masses within the focus region is illustrated by observed brightness temperatures. The brightness temperature image is created using narrow spectral channels in the center of the 6.5 micron water vapor band and clearly shows a transition from dry (warm) to moist (cold).

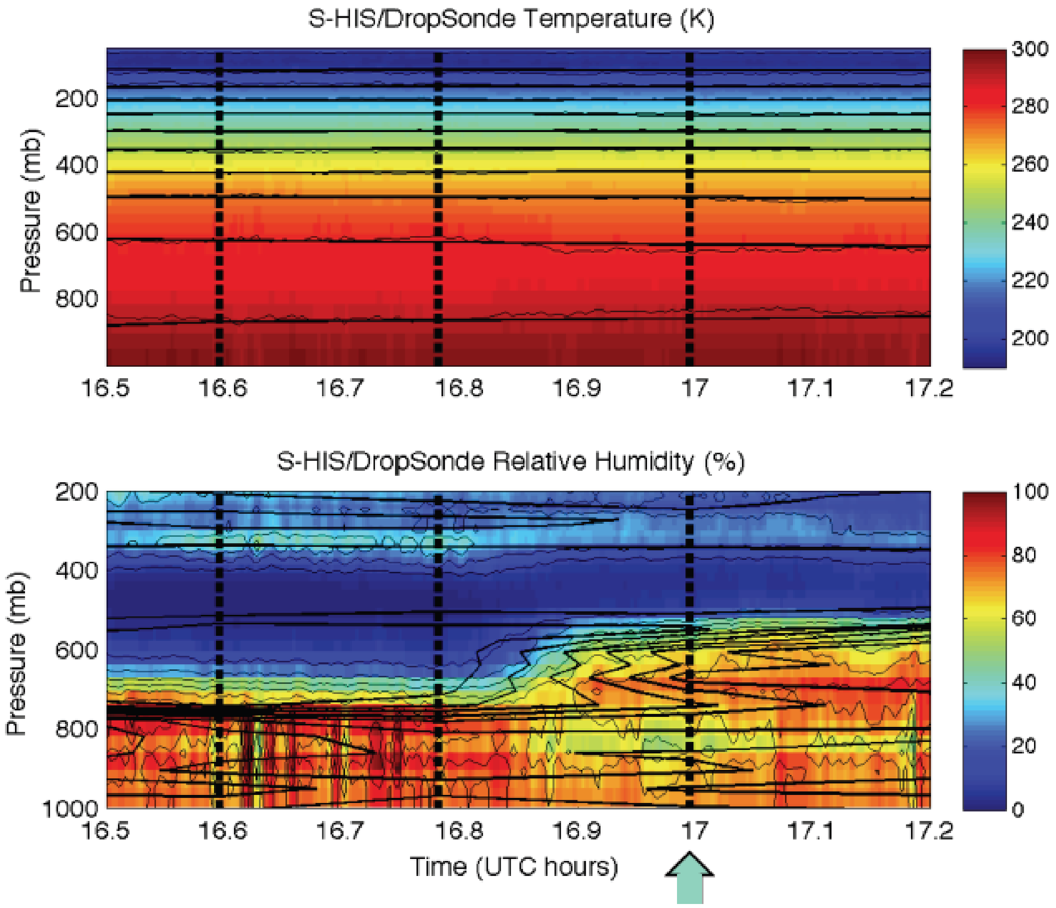

Figure 5: S-HIS retrievals of temperature and water vapor across the transition from sub-tropical to tropical air masses on 09 Sept 2011 in the Pacific Ocean south of Hawaii. The water vapor relative humidity cross section indicates an abrupt change in the height of the moist depth of the atmosphere. The solid black lines are contours created from the dropsonde profiles launched at times shown by the vertical dashed lines.

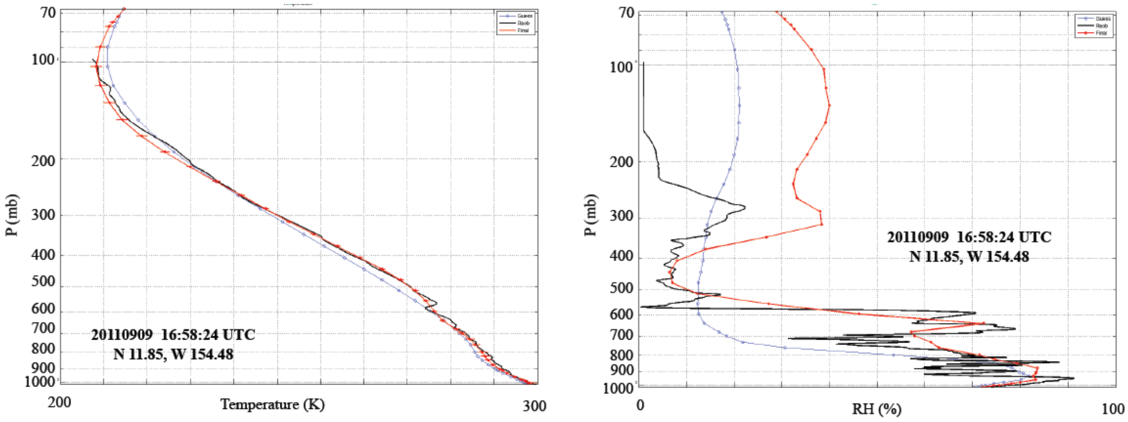

Figure 6: Comparison of the S-HIS retrieval (red) to a coincident AVAPS dropsonde from the Global Hawk in the moist region indicated in the previous figure. Good agreement is found below 400 mb but the sonde is clearly too dry above about 300 mb. Also shown (blue) is a tropical climatology profile.

2. Optimization of S-HIS interface to Global Hawk zone 25 thermal environment

The typical flight environment for the S-HIS is in a wing pod exposed to outside ambient pressure and temperature. There are plans on the Global Hawk to provide such a pod for S-HIS, but this will not be implemented until next year's flights. Until that time S-HIS will be flying in the Global Hawk Zone 25. Last year's flights showed temperatures in this location were warmer that desired – close to the operational limit for some key subsystems. For the series of flights this year (2012) the S-HIS team worked with NASA Dryden to plumb outside air through the zone 25 through a 3" diameter tube. There are 5 different flexible heat straps that couple key areas on the S-HIS instrument to heat exchangers that are thermally coupled to the flow stream. These areas are the ambient blackbody, the Stirling cooler expander and compressor (interferometer box), the electronics box, and the data storage computer box. Each of the unique thermal straps were designed and fabricated by UW SSEC. Table-1 shows key information for each strap and the anticipated flight temperatures that will result from the implementation of the new thermal scheme. The expected performance is based on an ambient instrument environment of -11 °C (based on experience from the 2011 flights), and an effective cooling air tube temperature of -50 °C.

Table 1. Key Thermal Strap Information with Predicted Performance

	ER-2 Source Temp (C)	ER-2 Enclosure Temp (C)	GH Source Temp (C)	GH Enclosure Temp (C)	Power Input (W)	Strap Length (in)	Number of strap wires	Strap wire gage	Wire Area (kcmil)	Strap Thermal R (K/W)	Strap Conducted Power (W)	Predicted GH Source Temp (C)	Predicted GH Enclosure Temp (C)
ABB	-48		-8.8	-8	0	2.5	3	6	26.3	4.2	0.5	-47	--
Compressor	-22	--	12	--	11.5	5	5	4	41.7	3.2	17	-1	--
Expander	-15	--	15	--	5.8	7.1	5	6	26.3	7.1	6.9	4	--
Electronics	0	-16	23	12	52	1.94	5	6	26.3	1.9	26	12	1
Computer	21	12	37	27	52	17.5	6	4	41.7	9.2	6.6	33	23

*Note predicted temps are based on GH pod temp of -11 C and cooling tube air temp of -50 C

Figures 7 and 8 illustrate the new heat straps and their connection to a tube with internal heat exchangers. The left end of the tube is connected to a new forward inlet port of the Global Hawk (zone 25), and the right end to a new outlet port.

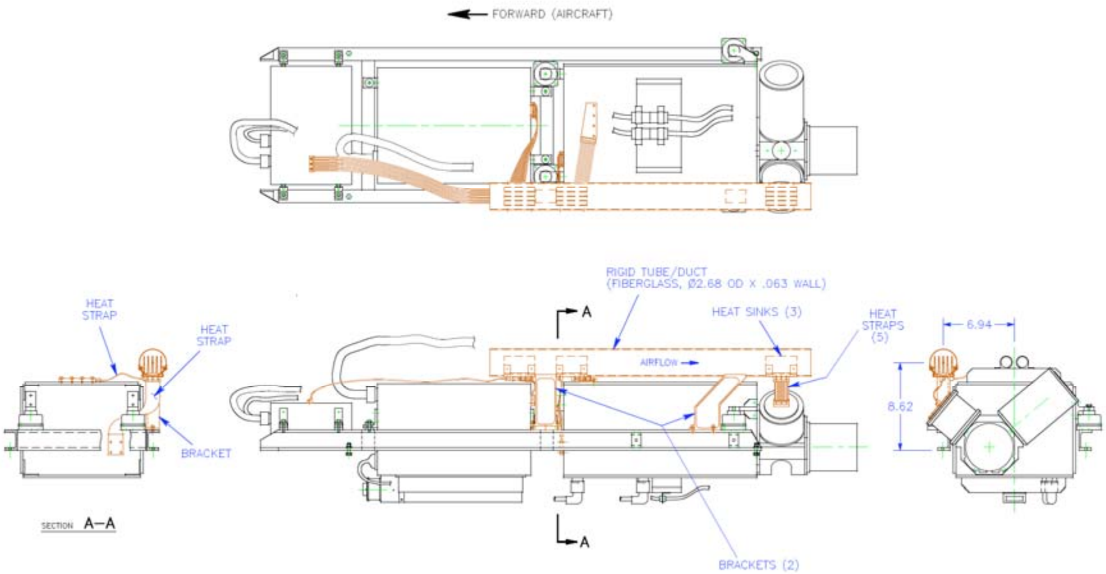

Figure 7: The new flexible heat straps that are connected to heat exchanges within a tube where outside air is forced will help reduce key temperatures in the S-HIS. The end-views at lower left and right show the heat exchangers mounted inside the flow tube.

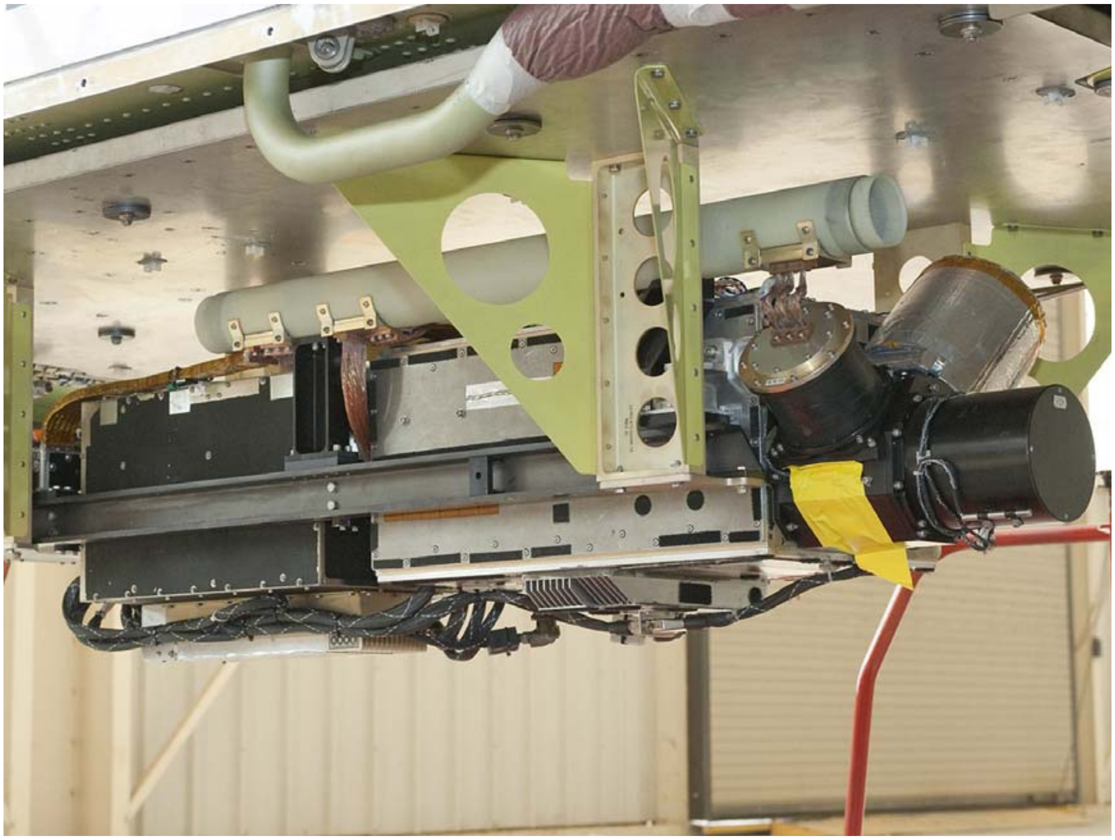

Figure 8: The Scanning HIS integrated to the Global Hawk with the heat straps (4 of 5 are visible) in place and connected to the rigid segment of the outside air flow tube.

3. Laboratory verification of S-HIS reference blackbody temperature calibration and Pre-campaign testing of S-HIS performance

There are four major phases of S-HIS radiometric calibration, outlined below. Steps one and two have been completed for the 2012 field campaign. Step 3 describes the in-flight calibration scheme, and step 4 describes the activities to be conducted after the campaign is completed.

1) Pre-Integration at Subsystem Level

The Scanning-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 Scanning-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 Scanning-HIS Instrument.

Results from the blackbody calibration conducted in the spring of 2012 are shown in Figure 9 compared with the results from the last major blackbody calibration (2001).

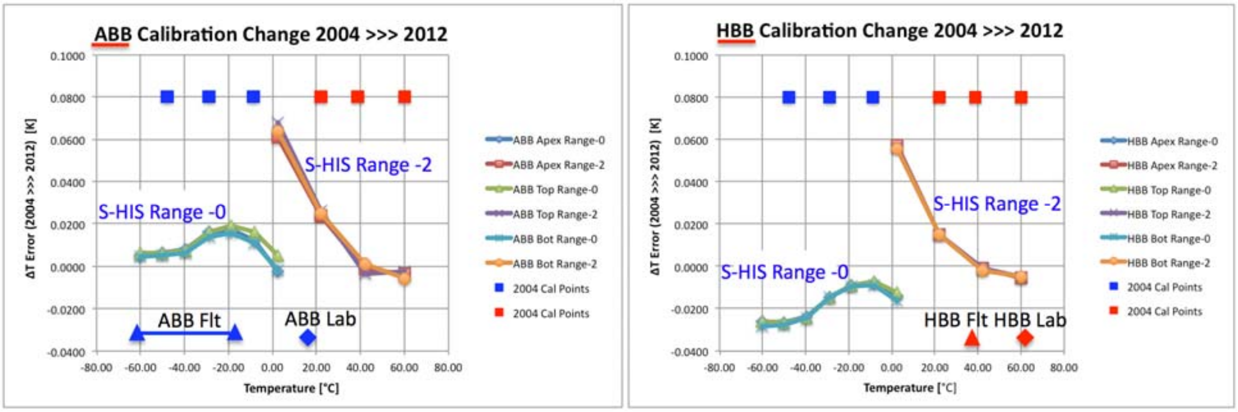

Figure 9: Blackbody calibration results compared with results from the last major calibration of 2004, show insignificant change in the key temperature ranges used – less than 25 mK change for the ABB, and less than 5 mK for the HBB.

The change in ABB calibration over the range it is used in S-HIS Current Range-0 and Range-2 is less than 25 mK, an excellent result. The large difference at 0 °C (Range-2) is most likely due to extrapolation error from the 2004 calibration where the lowest temperature used in the Range-2 calibration was at 21 °C.

The change in HBB calibration over the range it is used in S-HIS Current Range-2 is less than 5 mK, an excellent result. The large difference at 0 °C is most likely due to extrapolation error from the 2004 calibration where the lowest temperature used in the Range-2 calibration was at 21 °C.

Table 2 presents the overall blackbody temperature uncertainty budget, which totals 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.

Table 2. Blackbody Temperature Uncertainty Budget

Resistance	**Uncertainty**	**[mK] (3-sigma)**
Calibration Resistor Measurement Uncertainty (ΔT equiv)	0.5	Measured with UW-SSEC, Fluke 8508A
S-HIS Readout Electronics Measured Error (ΔT equiv)	10.0	Includes long-term stability - values represent readings in the "as-received" condition (8 years since last cal)
S-HIS Readout Electronics Temperture Error (ΔT equiv)	5.0	2 x (that measured with board from 24 to 36°C in lab), to account for mear vacuum
Self Heat Correction uncertainty (ΔT equiv)	3.3	30% of the correction
Subtotal (RSS)	**11.7**	
Thermistor		
Temperature Calibration Probe uncertainty	5.0	Custom made Thermometrics SP-60 Probe, read with Hart 2563 Thermistor Module. Probe with electronics calibrated end-to-end at Hart. Checked at TPW at SSEC and found to be within 2 ± 2 mK
Gradient between temp probe and cavity thermistors uncertainty	10.0	inludes gradients within the cavity and calibration plug; as well as includes probe stem error / wire lead heat leaks thermistor wire heat leaks
Calbiration Fit Equation Residuals	2.0	4-term Steinhart-Hart fitting equation
Long-term stability	10.0	Over the last 8 years, the HBB changed less than 5 mK, except where we know there was an exprapolation error from last time at 20C. The ABB is within 25 mK of last time; but this is within the old probe tolerance of 30 mK
Subtotal (RSS)	**15.1**	
Cavity Assembly, In-Use, Integrated to Instrument		
Cavity to thermistor gradient uncertainty	25.0	
Thermistor lead heat leak temperature bias uncertainty	25.0	Needs refiement
Paint gradient uncertainty	18.0	Full expeted gradient (needs refinement)
Monte-Carlo Ray Trace model uncertainty in determining Teff	30.0	
Subtotal (RSS)	**49.7**	
Total (RSS)	**53.3**	

2) Pre-Deployment Calibration Verification

An end-to-end calibration verification is performed using a variable temperate blackbody in the zenith view and an ice blackbody in the nadir view (Figure 10). Radiances measured by the Scanning 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 Scanning-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 Blackbody is geometrically similar to the AERI Blackbody, and is coated with the same paint.

The Scanning-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. These tests are expected to be repeated on the order of every 5 years.

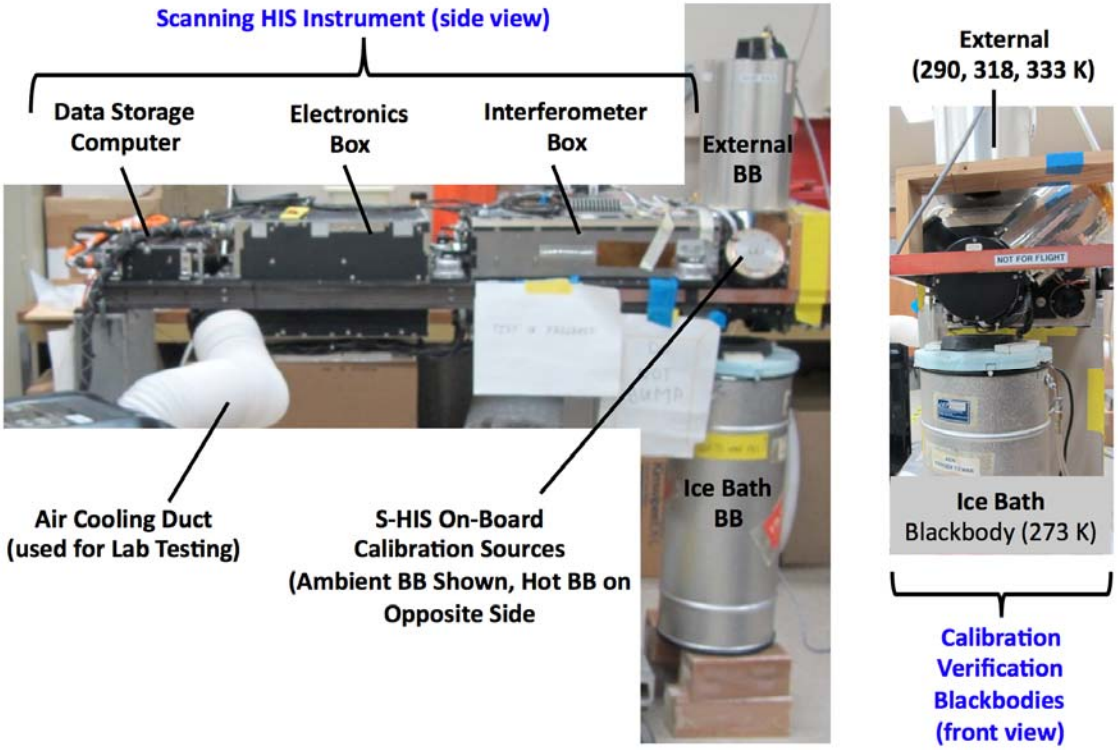

Figure 10: S-HIS radiometric calibration verification configuration.

The results from the S-HIS end-to-end calibration verification that was conducted immediately prior to the HS3 field deployment starting in August 2012, are discussed below. The test configuration is shown in Figure 10

After instrument and source set up and stabilization was 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). All tests showed agreement within the established instrument uncertainty of 0.2K (3-sigma). Note that the S-HIS nonlinearity correction is optimized for flight conditions. This will result in increased error for external targets at temperatures largely separated from the onboard calibration reference temperatures for tests conducted in the lab environment. This is evident in the ice bath blackbody result.

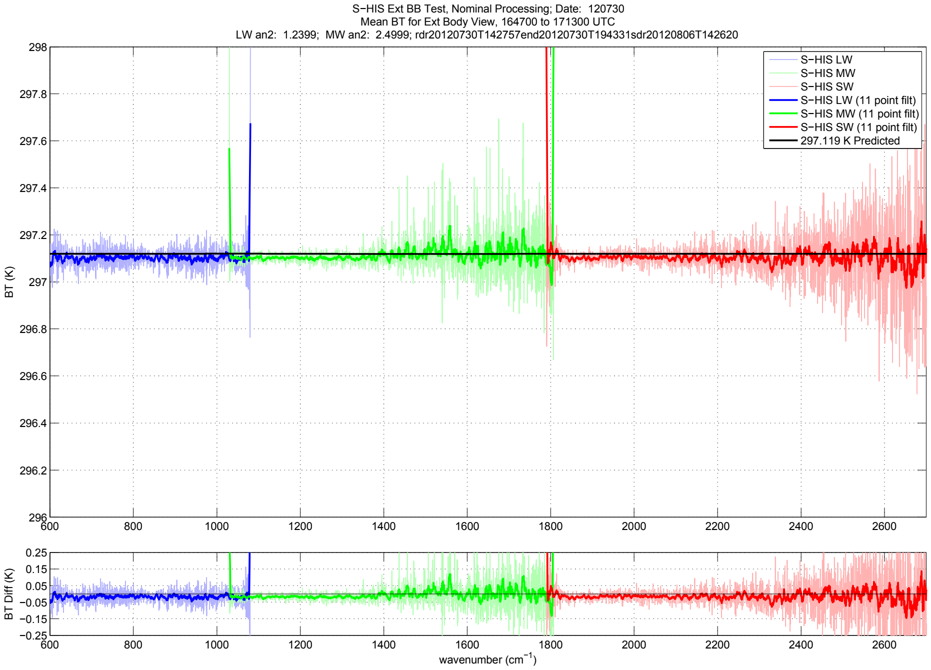

Figure 11: Radiometric calibration verification, external blackbody at ambient.

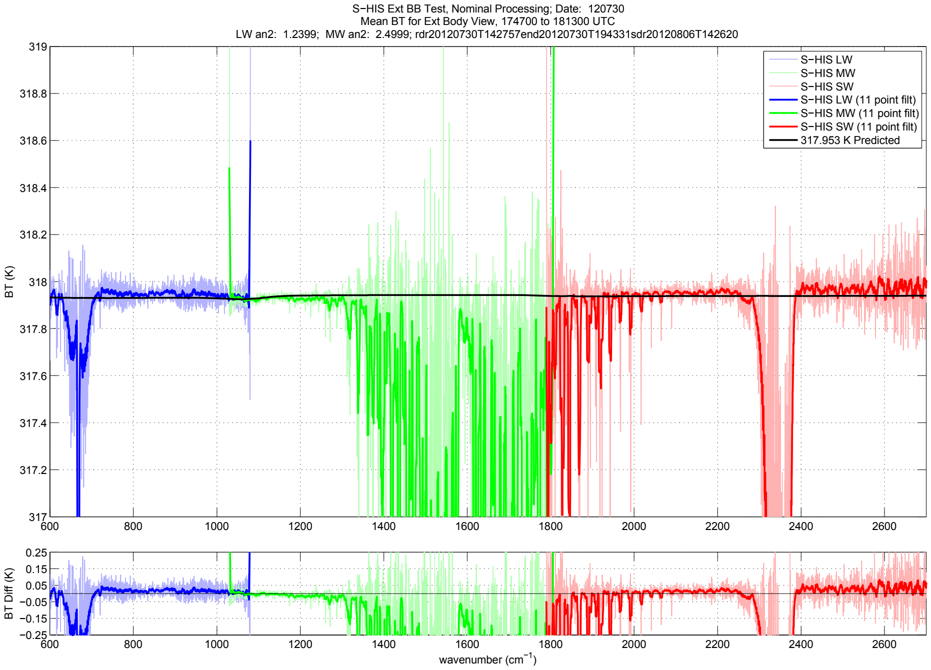

Figure 12: Radiometric calibration verification, external blackbody at 318K.

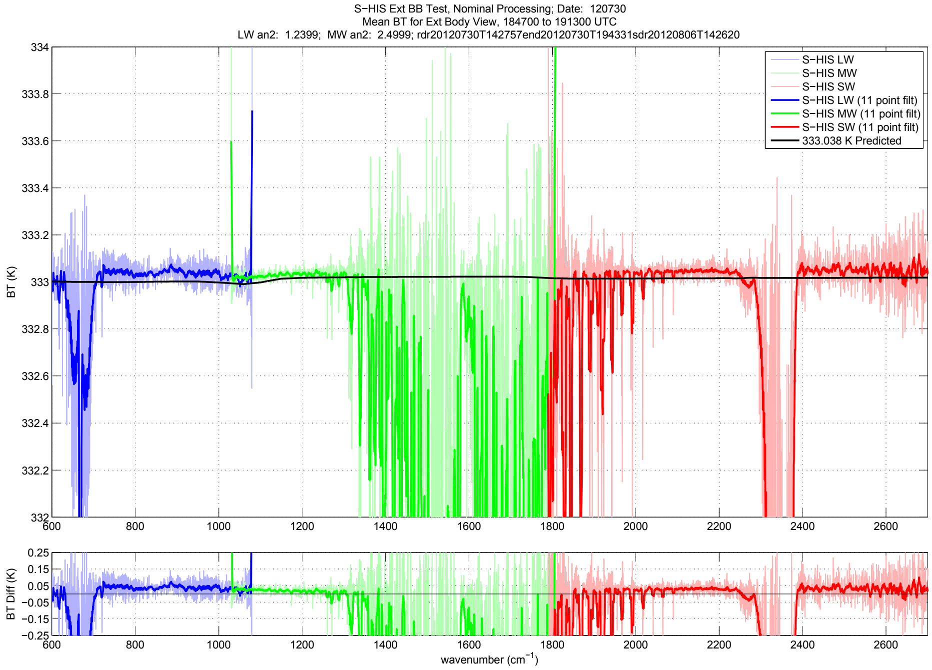

Figure 13: Radiometric calibration verification, external blackbody at 333K.

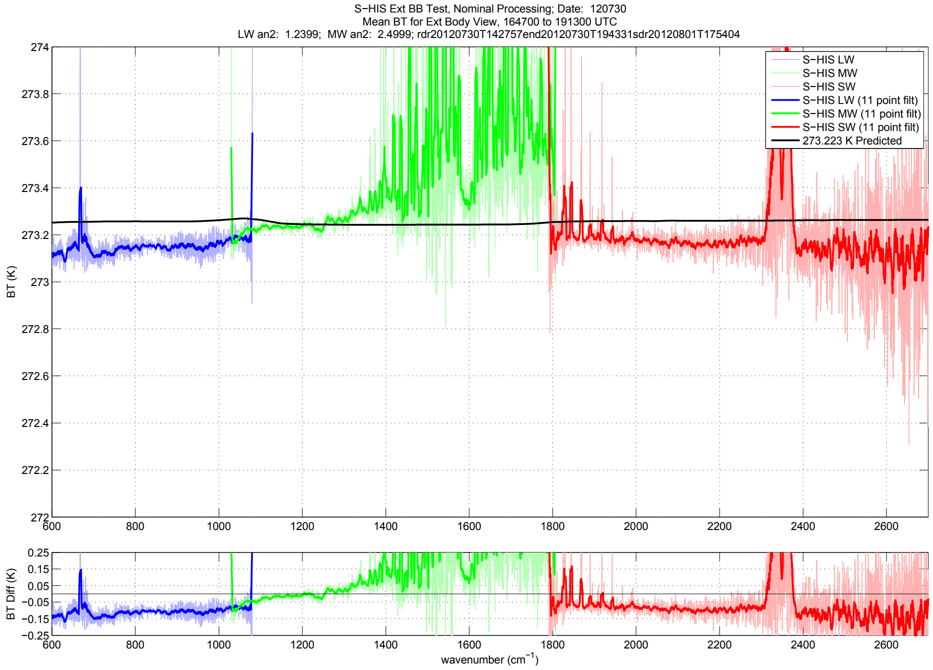

Figure 14: Radiometric calibration verification, ice bath blackbody. Note that the S-HIS nonlinearity correction is optimized for flight conditions. This results in increased error for external targets at temperatures largely separated from the onboard calibration reference temperatures for tests conducted in the lab environment. This is evident in the ice bath blackbody result.

If conditions and timing are sufficient during Pre-deployment, the Scanning-HIS also undergoes a side-by-side clear sky intercomparison using a well characterized and calibrated AERI instrument. These two radiance measurements are compared with each other and the radiance calculated from a locally launched radiosonde. This is not a required activity for pre-deployment calibration verification. For the 2012 HS3 pre-deployment, conditions and timing did not allow for a clear sky intercomparison with pre-deployment.

3) Instrument Calibration During Flight Using On-Board Calibration Blackbodies

During flight, the Scanning HIS earth scene radiance measurements are calibrated several times a minute using its two On-Board Calibration: 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.

4) Post-Deployment Calibration Verification

Following the field campaign an end-to-end calibration verification will be performed using a variable temperate blackbody in the zenith view and an ice blackbody in the nadir view. Similar to the pre-campaign tests, the radiances measured by the Scanning 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.

4. Establish architecture and implement software to improve real-time, near real-time, and long term data handling, processing, and display for long duration Global Hawk flights

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 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 Wisconsin. Once the radiances are available, the UW team has custom software for the retrieval of temperature and water vapor profiles. Two independent retrieval algorithms have been developed which are being run in parallel to produce a S-HIS best-estimate product. The processing of raw data to radiances is fully tested and automated. The algorithms for temperature and water vapor retrieval were tested using the dropsonde data during this performance period. The retrieval algorithms were not yet fully automated during this reporting period. Quicklook product images were under development during this time period.

2) Real-time Radiance Calibration and Atmospheric Retrieval

To provide real-time, in-flight calibration of the Scanning-HIS observations, the prototype Scanning-HIS calibration code was adapted to work with the real-time, in-flight stream of raw data. This is a Matlab application which reads in interferogram and other data from cyclical flat binary files, calibrates the data, and writes the calibrated spectra to cyclical flat binary files. The application (package shiscal_fbf_fifo.20120723.tar.gz) was demonstrated to work using a proxy stream of 128 record flat binary files on 23 July 2012 on the production machine “dreadnaught”, with latency of less than 10 ms.

The Matlab real-time application was further developed to include real-time Dual Regression retrievals (see Section 5 for more information). Following calibration of a user-defined number of calibrated spectra, the Matlab version of the Dual Regression code is called to perform the retrieval, and flat binary files of the retrieved quantities are produced. This package (shisrealtime.20120727.tar.gz) was developed using the July 2012 version of the Scanning-HIS Dual Regression retrieval and demonstrated to work on the production machine with latency of less than 30 seconds.

5. Development and implementation of improved temperature, water vapor, and cloud retrieval capabilities

1) Scanning-HIS Dual Regression Retrieval

To provide atmospheric retrievals under all-sky conditions, the “Dual Regression” retrieval algorithm has been adapted for the Scanning-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). This work was performed primarily by Drs. Elisabeth Weisz and William Smith, with coordination provided by Dr. David Tobin. The retrieval application was provided in both Fortran and Matlab. The Fortran version was provided with the intention of performing “batch” processing of the flight observations in near real-time and/or post-flight processing. The Matlab code has been incorporated into a real-time, in-flight application as described in Section 4. Two Fortran versions were provided, and demonstrated to work on the production machine “dreadnaught”. The first was provided in late July 2012 and assessed using Scanning-HIS flight data from May 2011. Figure 10 shows an assessment of the retrieval as compared to GDAS model fields for all-sky flight data collected in 9 September 2011. The performance of the all-sky Scanning-HIS Dual Regression retrieval is very similar to the performance obtained with CrIS, AIRS, and IASI. This is a major accomplishment for the Scanning-HIS HS3 effort.

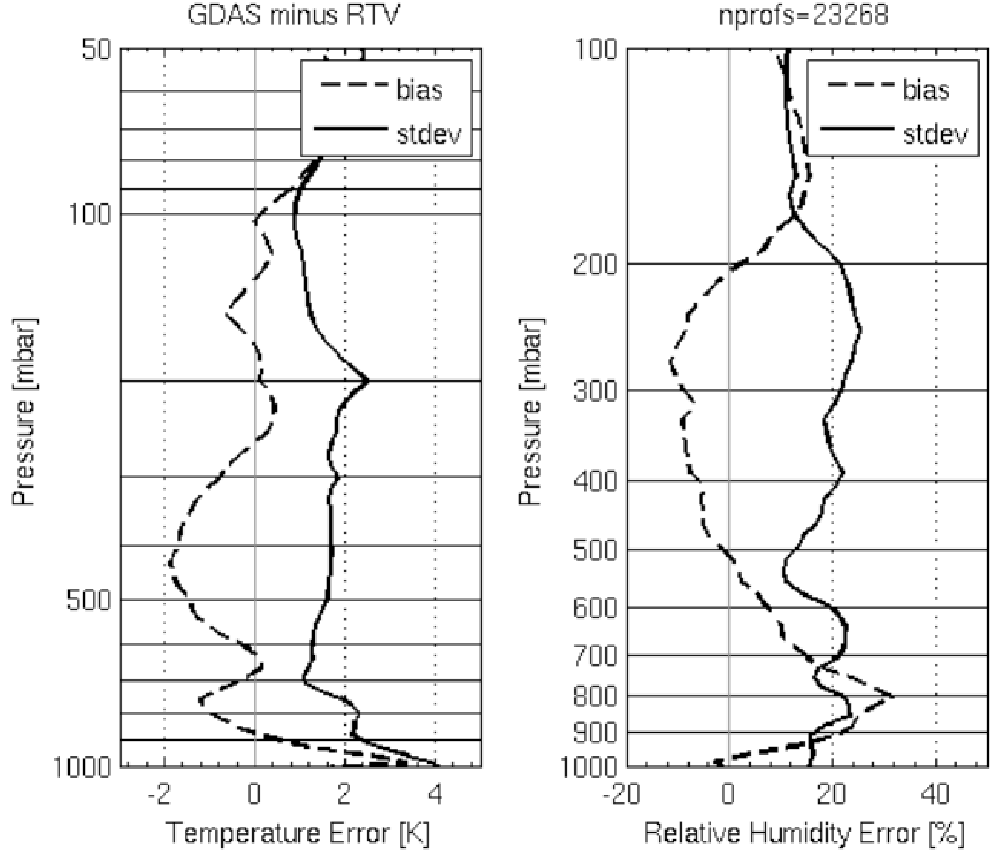

Figure 10. Bias and standard deviation of GDAS model fields minus Scanning-HIS Dual Regression retrievals for all valid observations from the 09 September 2011 flight data.

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.

2) UWPYSRET Physical Retrieval Algorithm

A research algorithm developed at the Uni. of Wisconsin for use with satellite data has been implemented for processing Scanning-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 uses the LBLRTM line-by-line model from AER, Inc. as the forward operator. A subsequent development will replace the LBLRTM model (which is very slow) with an optimal spectral sampling (OSS) fast model recently acquired by SSEC from AER, Inc.. This UWPHSRET methodology was used to produce the S-HIS nadir cross-sections presented at the May 2012 science team meeting. This method allows UW experts to carefully evaluate the diagnostic properties of the retrieval for selected case studies. This method also provides uncertainty estimates along with the estimate of profile temperature and water vapor values. The goal of the UW team is to use both retrieval methods to produce a best estimate of the atmospheric thermodynamic state.

6. Support of Science Team

The Scanning HIS group supported periodic Science Team telecons during the reporting period in addition to the Science Team meeting on 7-8 May 2012, where Joe Taylor presented the Scanning HIS capabilities and its performance on the Global Hawk demonstration flights and Dr. Robert Knuteson presented results of flight data analyses with comparisons of S-HIS retrievals to drop sonde and HAMSR measurements. These presentations are available on the HS3 home page at:
http://www.espo.nasa.gov/hs3/presentations.php

7. UW HS3 Year 2 Summary of Accomplishments

Year 2 activities by our University of Wisconsin Space Science and Engineering Center team supporting Scanning HIS have successfully laid the foundation for the first year of hurricane flights planned for early in Year 3 of the NASA HS3 project. Major accomplishments include

- Successful operation of the Scanning HIS on long duration Global Hawk flights has been demonstrated,
- Accurate radiance spectra from 9 and 14 September 2011 flights have been processed and temperature/water vapor profile products show reasonable agreement with dropsonde and HAMSR microwave results,
- Improvements to the aircraft thermal environment have been implemented to enhance calibration accuracy and reduce operational risks from high electronics temperatures,
- S-HIS calibration reference accuracy has been verified,
- Data handing and processing for real-time and near real-time processing are being significantly improved and will be ready for initial demonstration during upcoming hurricane flights,
- Improved retrieval capabilities are being implemented, including a physical retrieval for clear sky (UWPhysRet) and a dual regression capability for cloudy skies, and
- Active participation in the annual science team meeting and in team telecons.