Airborne Demonstration of Next-Gen Imaging Infrared Sounder Capabilities and Algorithms

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Introduction

Airborne instrumentation and measurements are a valuable resource for development, test, and demonstration of next-generation technology and algorithms. The Scanning High-resolution Interferometer Sounder (S-HIS) has demonstrated state-of-the-art performance and excellent robustness and reliability over 20-years of operation on 35 missions around the globe, and has earned recognition as an infrared calibration reference standard for satellite calibration validation.

The current S-HIS measurement capability provides highly accurate spectrally resolved infrared radiances with relatively small spatial footprints at high spectral resolution and contiguous spatial coverage. These measurement qualities can be leveraged for algorithm development and testing for next-generation LEO and GEO high spectral resolution imaging infrared sounders. The S-HIS measurements can also be used with SRF convolution for spectral band assessment for the next generation IR imagers. Co-located measurements from other instruments in the payload are often useful for product assessment.

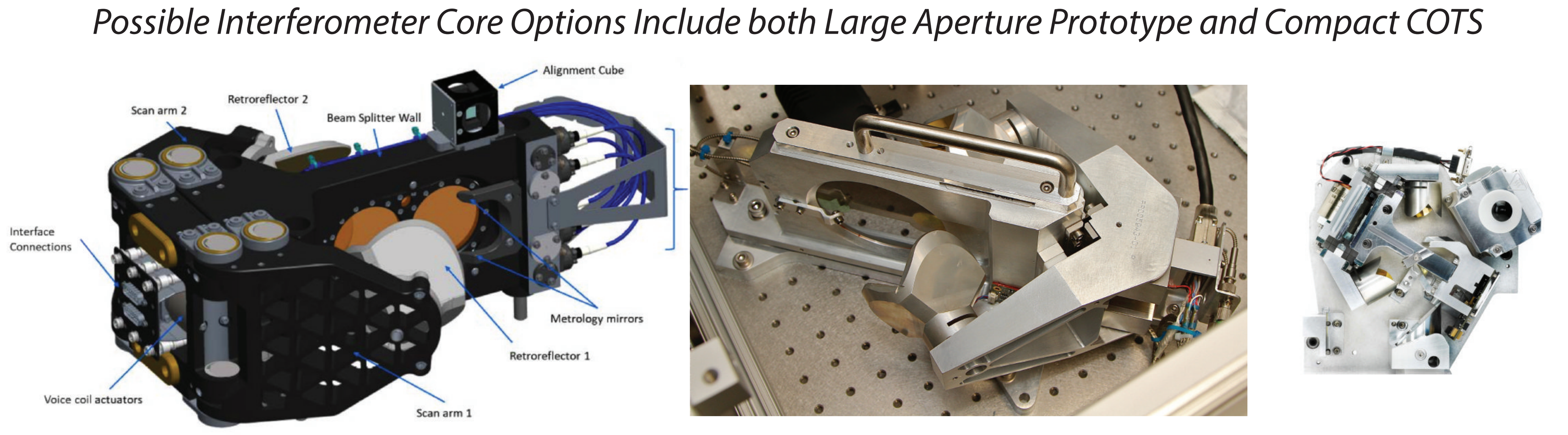
Furthermore, the UW-SSEC is conducting a study to (1) define what is required to maintain the current capability of the S-HIS into the future, (2) identify enhanced capabilities enabled by new technologies and guided by science community consensus on key questions posed by NASA and and NOAA, and (3) identify sources of funding and a consistent development approach for various upgrade scenarios.

S-HIS: Next Generation Capabilities

Enhancement of the S-HIS capabilities can be enabled by upgrading the instrument with new technologies such as (but not limited to):

- An independent On-board Absolute Radiance Standard. This technology has been developed for the UW-SSEC Absolute Radiance Interferometer and an airborne version for the S-HIS would allow for traceability to absolute references via end-to-end calibration verification in-flight, as well as improved detector nonlinearity characterization and correction, and reduced radiometric uncertainty.
- Improved spatial resolution via the integration of a detector array and conversion of the instrument to an imaging FTS. The next generation LEO and GEO sounders will move to improved spatial resolution and will benefit from technology and algorithm demonstration. Additionally, improved S-HIS spatial resolution will enable a wider breadth of research and applications.
- Improved spectral coverage and/or improved spectral resolution. Spectral coverage beyond our current spectral limits and/or finer spectral resolution would allow additional research opportunities and applications.
- A bore-sighted sub-pixel imager (infrared microbolometer FPA). A bore-sighted high spatial resolution infrared imager would provide additional scene information within the FTS footprint at a relatively low cost.
- Enhanced on-board processing to facilitate the imaging FTS and sub-pixel imager capabilities.
- Upgraded instrument electronics based on small-sat technology to further increase reliability and reduce instrument power and size.

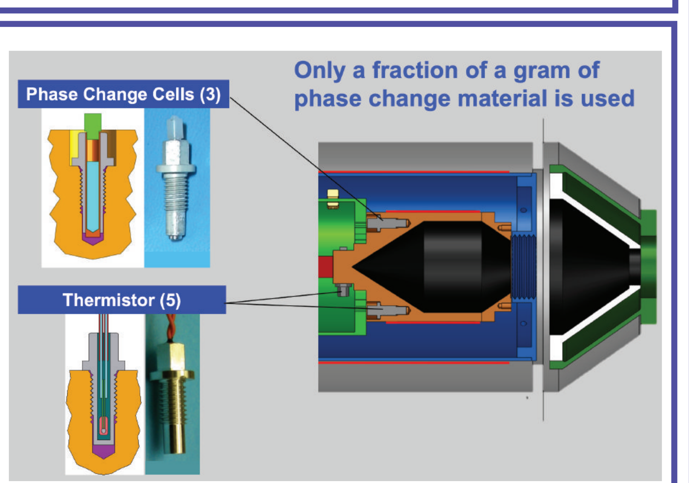
Possible Interferometer Core Options Include both Large Aperture Prototype and Compact COTS



Sub-pixel Imager: FLIR Boson IR Microbolometer Core

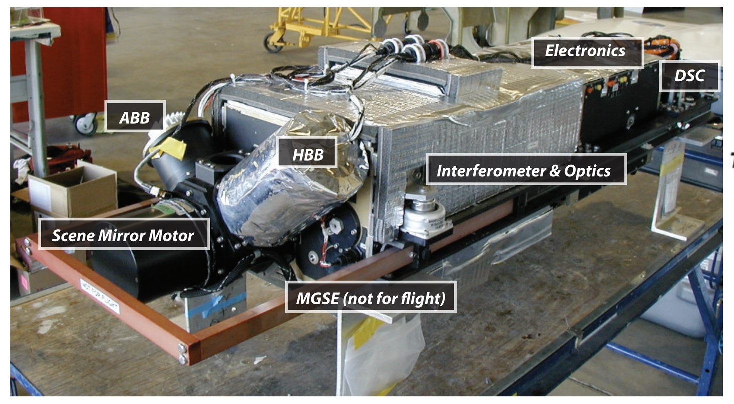
Absolute Radiance Standard developed for ARI

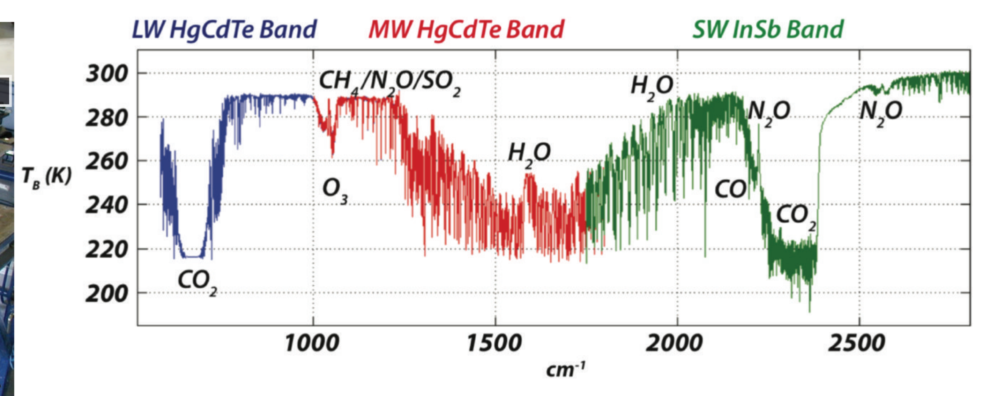
Scale to S-HIS Aperture and modify design for airborne application



S-HIS: Current Capability and Existing Measurements

The Scanning High-resolution Interferometer Sounder (S-HIS) measures emitted thermal radiation at high spectral resolution between 3.5 and 17.3 microns (580 – 2850 cm^{-1}) at 0.5 cm^{-1} spectral sampling resolution with 0.100 radians angular field of view (2 km footprint from 20 km observing altitude) and imaging accomplished via cross-track scanning. Since 1998, the S-HIS has participated in 35 field campaigns on the NASA ER-2, DC-8, Proteus, WB-57, and Global Hawk airborne platforms. The S-HIS has proven to be extremely dependable with high calibration accuracy and consistent performance on all platforms. Applications of the S-HIS measurements have included radiances for evaluating radiative transfer models; temperature and water vapor retrievals; cloud radiative properties; cloud top retrievals; surface emissivity and temperature; trace gas retrievals; the characterization of the thermodynamic environment around hurricanes and tropical storms; the characterization of fire development, emission processes, plume evolution, and downwind impacts on air quality; and satellite calibration validation.





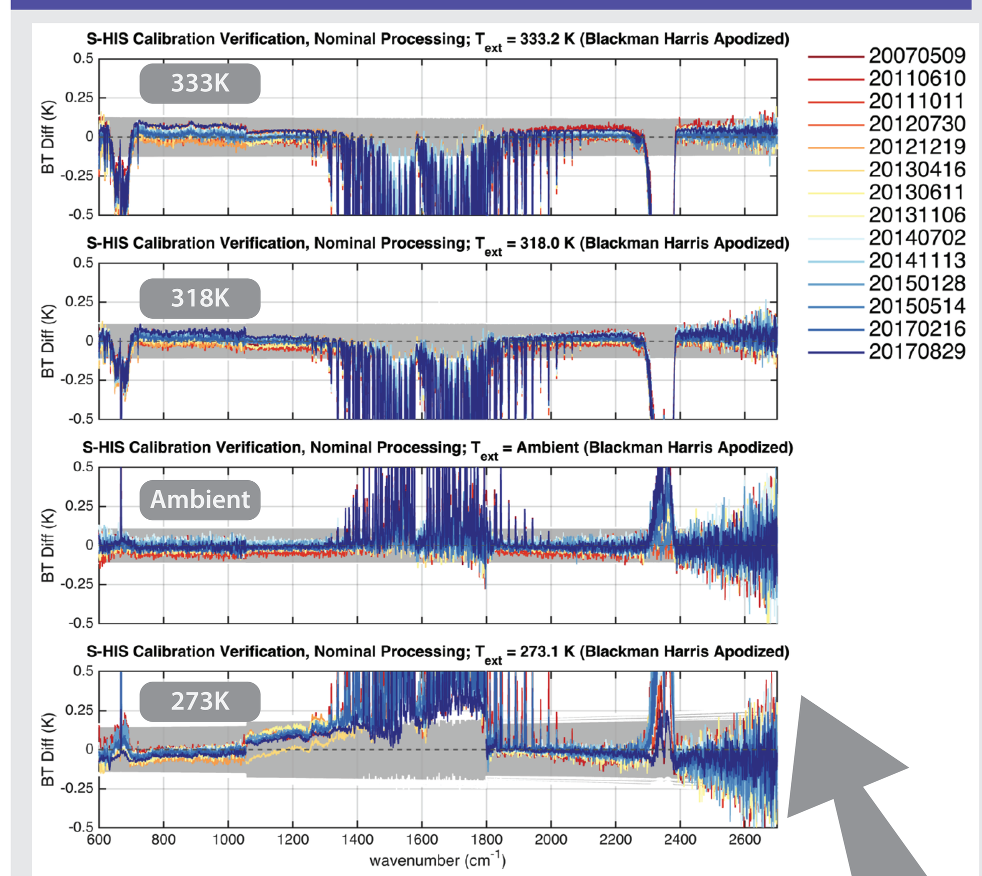
Sample upwelling S-HIS brightness temperature spectra.

S-HIS field deployment map, 1998 to present. Green circles indicate aircraft integration locations. (1) CAMEX, DC-8, 1998; (2) AirMISR 98, ER-2, 1998; (3) WINTEX, ER-2, 1999; (4) KWAJEX, DC-8, 1999; (5) WISC-2000, ER-2, 2000; (6) SAFARI 2000, ER-2, 2000; (7) AFWEX, DC-8, 2000; (8) TX-2001, ER-2, 2001; (9) CLAMS, ER-2, 2001; (10) IHOP, ER-2, 2002; (11) SMEX 2002, DC-8, 2002; (12) ARM UAV-SGP, Proteus, 2002; (13) TX-2002, ER-2, 2002; (14) Pacific THORpex, ER-2, 2003; (15) Atlantic THORpex, ER-2, 2003; (16) Tahoe 2004, ER-2, 2004; (17) INTEX Proteus, Proteus, 2004; (18) ADRIEX Proteus, Proteus, 2004; (19) EAQUATE, Proteus, 2004; (20) M-PACE, Proteus, 2004; (21) AVE-OCT04, WB-57, 2004, (22) AVE-JUN05, WB-57, 2005; (23) CR- AVE, WB-57, 2006; (24) Tahoe 2006, ER-2, 2006; (25) JAVIEX, WB-57, 2007; (26) TC-4, ER-2, 2007; (27) Railroad Valley, ER-2, 2011; (28) HS3, Global Hawk, 2011; (29) HS3, Global Hawk, 2012; (30) SNAP2013, ER-2, 2013 (31) HS3, Global Hawk, 2013; (32) HS3, Global Hawk, 2014 (33) SNAP2015, ER-2, 2015; (34) GOES-16 PLT, ER-2, 2017; (35) FIREX-AQ, ER-2, 2019. Map imagery courtesy of NASA Visible Earth, http://visibleearth.nasa.gov.

Calibration, Calibration Verification, and Traceability

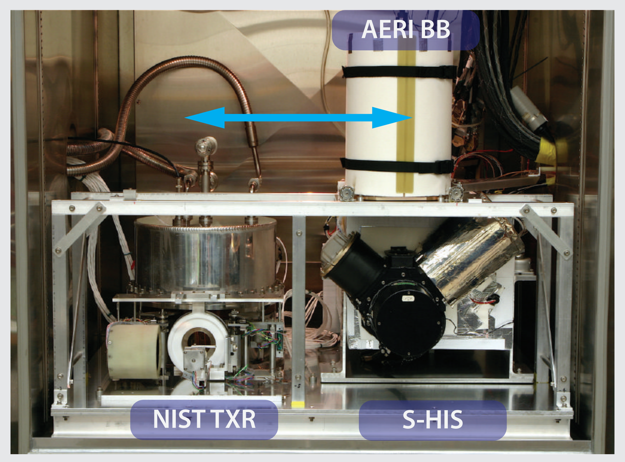
- Pre-integration **calibration of on-board blackbody references** at subsystem level
- **Pre and post deployment end-to-end calibration verification**
- Periodic **end-to-end radiance evaluations under flight like conditions with NIST transfer sensors**.
- Instrument calibration during flight using **two on-board calibration blackbodies**

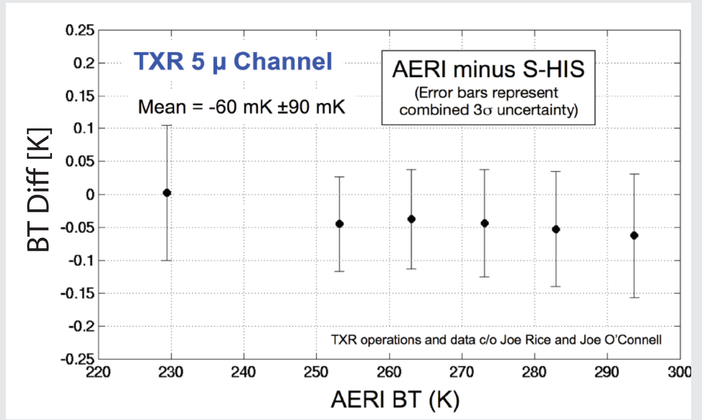
Pre and post deployment End-to-end Cal Verification 2007 - 2018

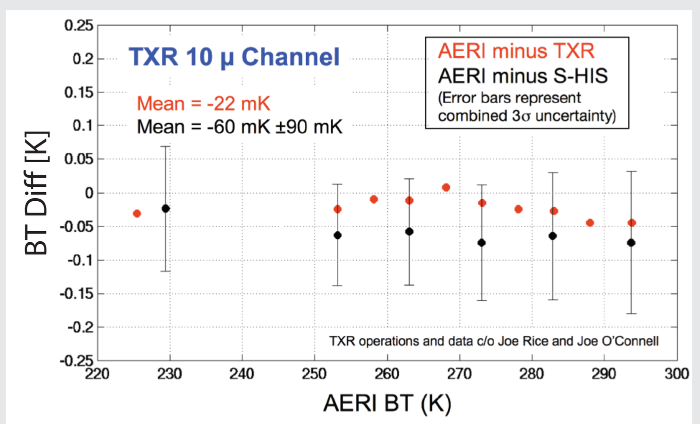


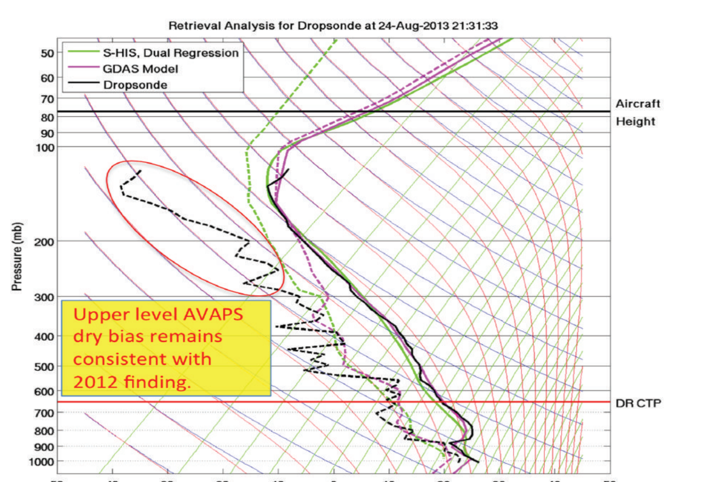
- Data acquired for external blackbody temperatures of ambient, 318K, 333K, and Ice Bath Blackbody
- Atmospheric emission/absorption not included in predicted BT (i.e. no LBLRTM)
- S-HIS NLC is optimized for 'flight' detector and instrument temperatures, not for laboratory temperatures
- 2013-04-16: Stirling cooler failing during testing and detector temperature increased to ~85K during calibration verification; primary impact is on MW nonlinearity (note the outlier spectra for Ice Bath blackbody.

NIST TXR Comparison

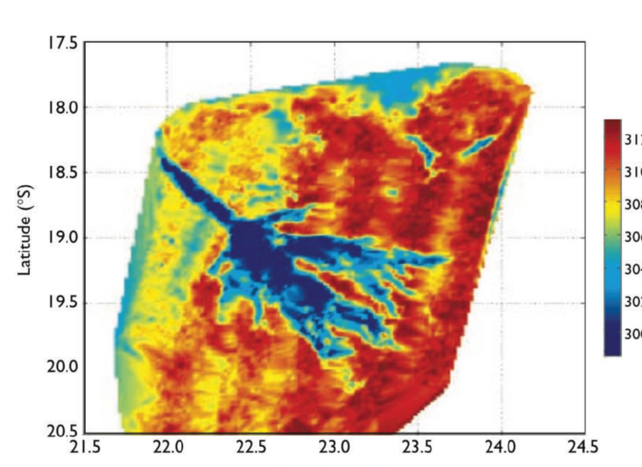




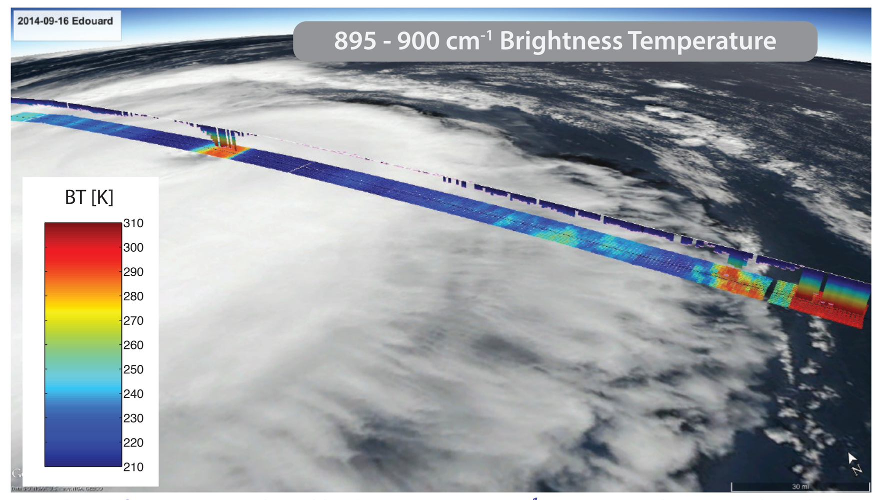




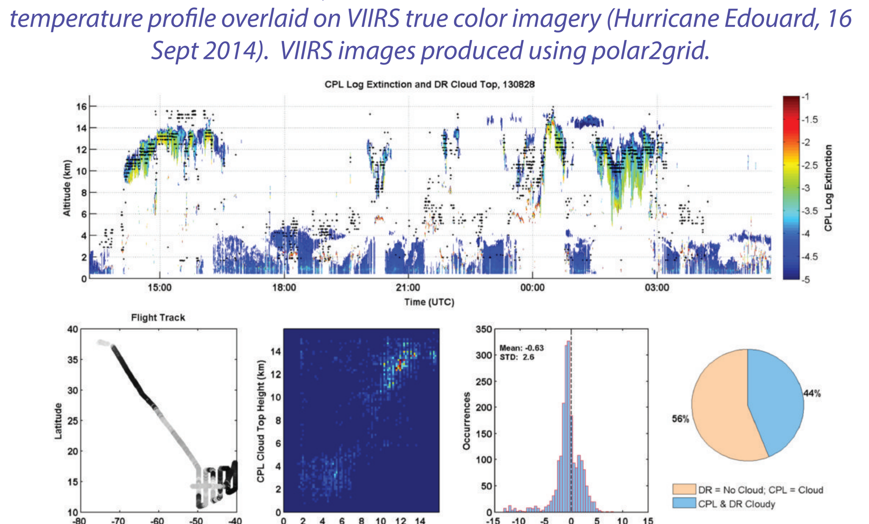
Example comparison of AVAPS Dropsonde and co-located S-HIS two-minute mean atmospheric state retrieval profiles. This example shows good retrieval despite upper level thin cirrus and lower level aerosol layers. AVAPS data since reprocessed and the upper level dry bias has been addressed.



BT Map of the Okavango Delta, Botswana at 10.2 micron, acquired by Scanning-HIS during six parallel flight lines over the Delta on 27 August 2000 [King 2003].



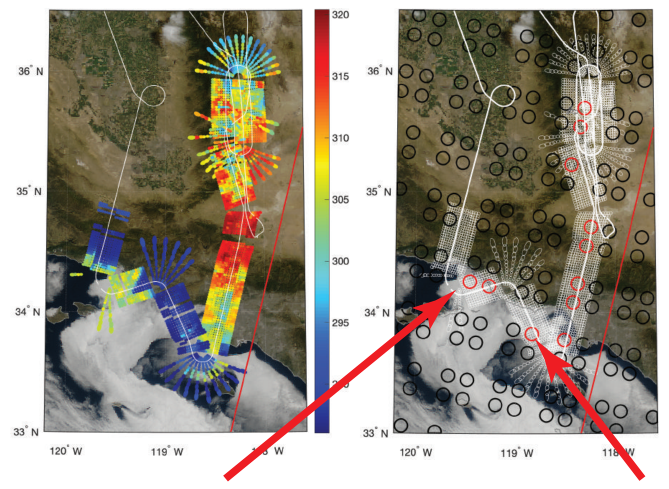
S-HIS footprints, colored by BT (895 - 900 cm^{-1} mean), and retrieved nadir temperature profile overlaid on VIIRS true color imagery (Hurricane Edouard, 16 Sept 2014). VIIRS images produced using polar2grid.



Example comparison of Cloud Physics Lidar (CPL) mean cloud top compared to S-HIS Dual Regression Retrieved Cloud Top Height product (2013-08-28 flight)

Recent S-HIS datasets are available on the UW-SSEC data distribution website, and historical datasets are available on request. HS3, GOES-PLT, and FIREX-AQ data are also available via the mission data archives. Preliminary Level 1b (geolocated radiances) and Level 2 (temperature, humidity, and trace gas profiles) products are typically available within a few hours of data download during a mission. When a high bandwidth downlink is available for the aircraft, the Level 1 and Level 2 products can also be processed using a real-time ground data processing system that is capable of delivering atmospheric profiles, radiance data, and engineering status to mission support scientists via a web browser in less than one minute from the time of observation.

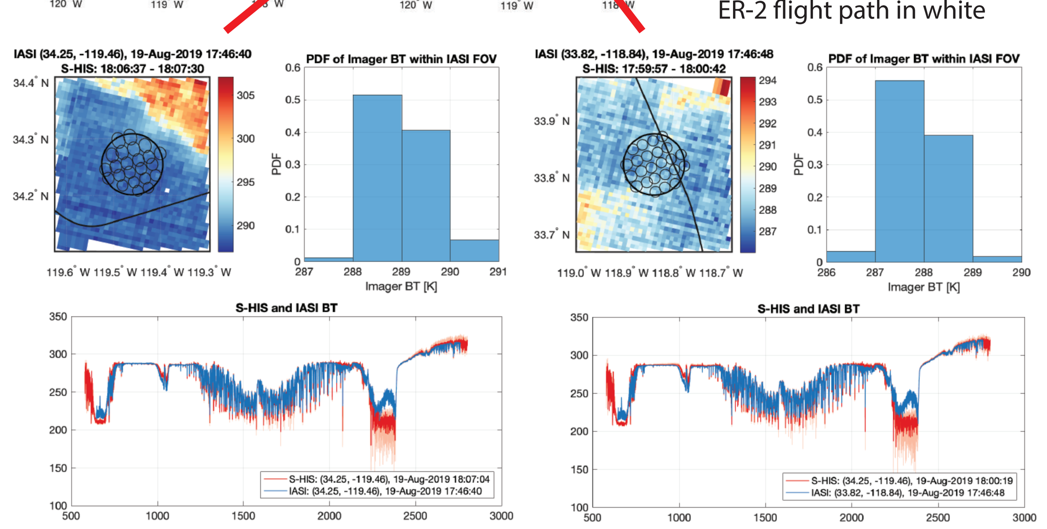
METOP-C Underflight Example (2019-08-19)



Near left:
S-HIS footprints (white outline)
IASI footprints (black outline)
Complete coverage of IASI footprints by S-HIS (red outline)

Far left:
895-895 cm^{-1} S-HIS BT
(17:20 – 18:15 UTC)

IASI Sub-sat line in red
ER-2 flight path in white



Low spatial variability within these IASI FOVs (IASI boresighted IR imager). GOES ABI data can be used to assess temporal stability between IASI and S-HIS time of observation for these FOVs

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