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SUOMI NPP/JPSS CROSS-TRACK INFRARED SOUNDER (CRIS): CALIBRATION VALIDATION WITH THE AIRCRAFT BASED SCANNING HIGH-RESOLUTION INTERFEROMETER SOUNDER (S-HIS)

Joe K. Taylor *, H.E. Revercomb, D. C. Tobin, R. O. Knuteson, F.A. Best, P.J. Gero, R. K. Garcia, N. C. Ciganovich, M. W. Werner, D. D. LaPorte, D. Deslover, and L. Borg

Space Science and Engineering Center, University of Wisconsin-Madison, Madison, Wisconsin

1. INTRODUCTION

To better accommodate climate change monitoring and improved weather forecasting, there is an established need for higher accuracy and more refined error characterization of radiance measurements from space and the corresponding geophysical products. This need has led to emphasizing direct tests of in-orbit performance. Calibration validation typically involves collecting high quality reference data from airborne and/or ground-based instruments during the satellite overpass, and a detailed comparison between the satellite-based radiance measurements and the corresponding high quality reference data.

The detailed comparison between the satellite-based radiance measurements and the corresponding measurements made from a high-altitude aircraft must account for instrument noise and scene variations, as well as differences in instrument observation altitudes, view angles, spatial footprints, and spectral response. For the calibration validation process to be both accurate and repeatable, it is very important that the reference data instrument be extremely well characterized and understood, carefully maintained, and accurately calibrated. The Scanning High-resolution Interferometer Sounder (S-HIS) meets and exceeds these requirements and has proven to do so on multiple airborne platforms, each with significantly different instrument operating environments.

The first aircraft calibration validation campaign for the Suomi NPP instrument suite was scheduled for November 2012 with a primary objective of providing detailed validation of CrIS radiance observations and meteorological products. This campaign has been delayed until May 2013. However, on 6 October 2012, the S-HIS (onboard the NASA Global Hawk for the NASA HS3 campaign) completed a single under-flight of Suomi NPP. The preliminary results of that flight are presented here. The Scanning-High resolution Interferometer Sounder (S-HIS), the NPOESS Atmospheric Sounder Testbed-Interferometer (NAST-I), and the NPOESS Atmospheric Sounder Testbed-Microwave Spectrometer (NAST-M) will fly on the high altitude NASA ER-2 aircraft during the May 2013 Suomi NPP airborne calibration validation campaign.

This paper will include (1) overviews of the S-HIS and CrIS instruments, (2) a summary of the radiance calibration validation approach and accuracy of the S-HIS data, and (3) a preliminary assessment of the CrIS spectral radiance observations for the October 6 flight.

2. THE CROSS-TRACK INFRARED SOUNDER (CRIS)

The Cross-track Infrared Sounder (CrIS) on Suomi NPP, launched 28 October 2011, is designed to give scientists more refined information about Earth's atmosphere and improve weather forecasts and our understanding of climate. CrIS is an infrared Fourier transform spectrometer with 1305 spectral channels, and produces high-resolution, three-dimensional temperature, pressure, and moisture profiles. These profiles will be used to enhance weather forecasting models and they will facilitate improvements to both short and long-term weather forecasting.

The CrIS optical system was designed to provide an optimum combination of optical performance and compact packaging [1, 2]. Its key subsystems include a step and settle two-axis scene selection module with image motion compensation capability, a full-aperture internal calibration source, a large-aperture Michelson interferometer, a three-element all

* *Corresponding author address:* Joe K. Taylor, Univ. of Wisconsin-Madison, Space Science and Engineering Center, 1225 West Dayton Street, Madison, WI 53706; e-mail: joe.taylor@ssec.wisc.edu.

reflective telescope, a cooled aft optics module, a multiple-stage passive cooler, and an attached electronics assembly.

The interferometer uses a flat-mirror Michelson configuration equipped with a dynamic alignment system to minimize misalignments within the interferometer and has a maximum optical path difference of ±0.8 cm. Each of the three spectral bands (longwave, midwave, and shortwave) uses 3 x 3 detector arrays to provide 14 km iFOVs from 833 km altitude.

CrIS Sensor Features

- Large 8 cm Clear Aperture
- Three Spectral Bands
- 3x3 FOVs at 14 km Diameter
- Photovoltaic Detectors in All 3 Bands
- 4-Stage Passive Detector Cooler
- Plane-Mirror Interferometer With DA
- Internal Spectral Calibration
- Deep-Cavity Internal Calibration Target
- Modular Construction

Physical Requirements	
Volume	80 x 47 x 56 cm
Mass	< 98 kg
Power	< 95 W
Data Rate	< 1.5 Mbps

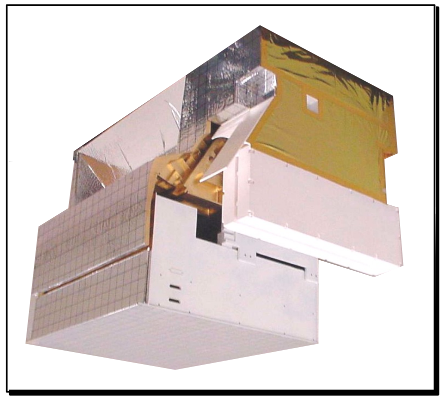


Figure 1: The Cross-track Infrared Sounder (CrIS) [3].

3. THE SCANNING HIGH-RESOLUTION INTERFEROMETER SOUNDER (S-HIS)

The S-HIS (Figure 2) is an advanced version of the HIS NASA ER-2 instrument. The S-HIS was initially designed to fly on an unmanned aircraft vehicle (UAV) with limited payload capacity. This drove it to be small, lightweight, and modular, with low power consumption. It was developed between 1996 and 1998 at the University of Wisconsin (UW) Space Science and Engineering Center (SSEC) with the combined support of the US DOE, NASA, and the NPOESS Integrated Program Office. Its design and calibration techniques have matured from experience with the HIS and with the ground based Atmospheric Emitted Radiance Interferometer (AERI) instruments developed for the DOE Atmospheric Radiation Measurement (ARM) program. The nadir-only spatial sampling of the original HIS has been replaced by programmable cross-track coverage with similar sized footprints. The S-HIS is also smaller, more robust, and easier to operate. Since 1998, the S-HIS has flown in several field campaigns and has proven to be very dependable and effective and highly accurate. It has flown on the NASA ER-2, the NASA DC-8, the Scaled Composites Proteus, the NASA WB-57, and most recently, the NASA Global Hawk. On the Proteus and WB-57 aircraft, an upward (zenith) view is available, providing a means for further calibration verification analysis and upper atmosphere studies.

The S-HIS employs a customized commercial dynamically aligned plane-mirror interferometer (DA5 from Bomem Inc., Quebec, Canada). The Michelson mirror is voice coil driven with a support mechanism that was designed and built at UW-SSEC to make use of a linear bearing approach to minimize vibration-induced tilt errors. The spectral characteristics of the measurements are very well known and stable because of the use of a HeNe laser to control optical delay sampling. A 1/4-wave quadrature system is used to assure that no samples are dropped or miscounted. The laser is also used to maintain alignment via the dynamic alignment (DA) servo. Any residual misalignments are measured as a diagnostic and used for operational tilt correction during data processing.

To achieve the required noise performance, the spectral coverage is divided into three bands with separate detectors for each band (two photoconductive HgCdTe and one InSb). Together, the three detector bands provide continuous spectral coverage from 3.3 to 16.7 μm at 0.5 cm^{-1} resolution, with overlap between the adjacent bands that is useful for instrument diagnostics. Due to the initial design constraints on size, the S-HIS instrument uses a novel detector configuration with the shortwave detector positioned in front of the side-by-side longwave and midwave detectors that share the available aperture. The bands use a common field stop, ensuring accurate spatial co-alignment. This arrangement allows cooling to be provided by a single mechanical cooler and eliminates the need for dichroic beamsplitters. The cooler is a 0.6 W, split-cycle Stirling cooler from Litton.

The flight calibration assembly consists of a 45° scene mirror, two calibration sources, the scene mirror motor, and front-end hex structure. The S-HIS 45° scene mirror allows the instrument to image using cross-track scanning. It executes a sequence consisting of multiple views of the earth, a zenith view (when available), and the two calibration sources, one at ambient and another controlled to a fixed temperature (typically 305 K in flight). The S-HIS calibration techniques achieve the high radiometric accuracy needed for atmospheric state retrieval, spectroscopic applications and calibration validation activities.

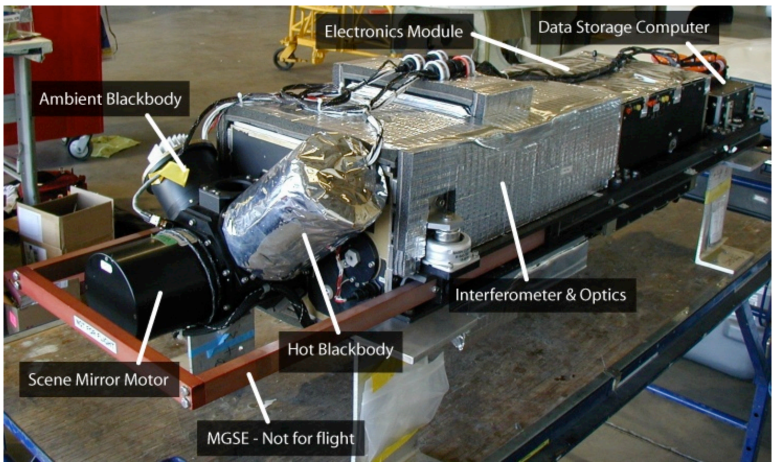


Figure 2: The Scanning High-resolution Interferometer Scanner (S-HIS); Proteus integration, Scaled Composites, July 2004.

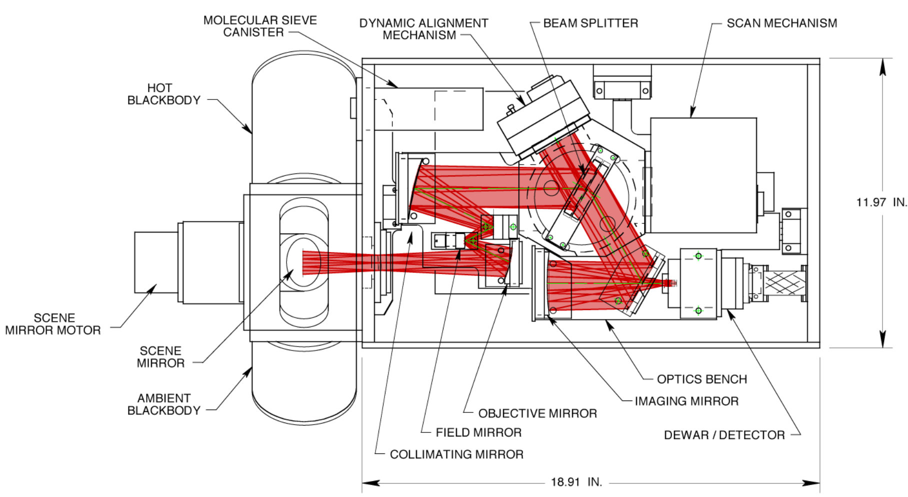


Figure 3: Diagram of the S-HIS interferometer module and flight calibrator assembly viewed from the nadir perspective. The Zemax prescribed IR beams are shown, and have been omitted from the figure between the beamsplitter and the Michelson mirror.

For a wide range of scene temperatures, the calibration uncertainty (k = 3) estimate for S-HIS is less than 0.2 K [4, 5], as illustrated in Figure 4.

UW-SSEC experience with the S-HIS has led to a more complete understanding of issues with absolute calibration. Tests with the NIST Transfer Radiometer (TXR) solidly confirm the calibration uncertainty estimates. To verify the S-HIS calibration accuracy and provide direct NIST traceability of the S-HIS radiance observations, laboratory tests of the S-HIS and the NIST Transfer Radiometer (TXR) were conducted using a thermal chamber to simulate flight temperatures for the S-HIS instrument. Two basic tests were conducted: (1) comparison of radiances measured by the Scanning HIS to those from the TXR, and (2) measurement of the reflectivity of a UW-SSEC blackbody by using the TXR as a stable detector [6 – 10].

The radiance comparison involved the S-HIS and the TXR each observing a highly stable (and accurate) Atmospheric Emitted Radiance Interferometer (AERI) blackbody over a wide range of temperatures (227 to 290 K). The test results showed mean agreement between (1) predicted AERI blackbody radiance and the S-HIS NIST TXR Channel 2 equivalent spectral band of 60 ± 90 mK, (2) predicted AERI blackbody radiance and NIST TXR channel 2 (10 µm) of -22 mK, (3) NIST TXR channel 2 and the S-HIS band equivalent of less than 40 mK, (4) predicted AERI BB radiance and the S-HIS NIST TXR channel 1 (5 µm) equivalent of 40±85 mK. Unfortunately, the NIST TXR uncertainty analysis for the tests, and final calibration of the NIST TXR 5 µm channel remain uncompleted. Results are shown in Figure 5.

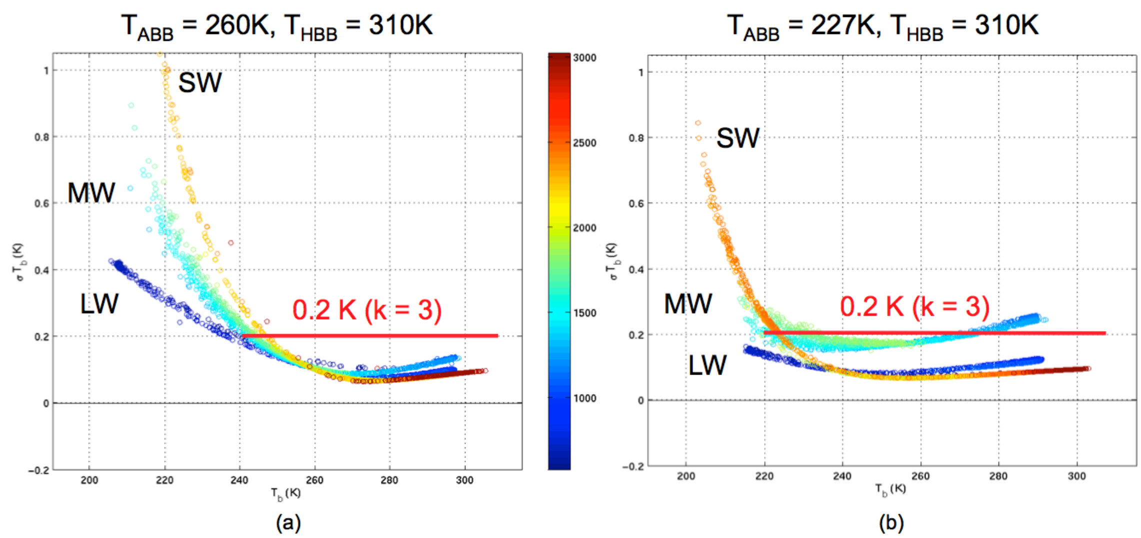
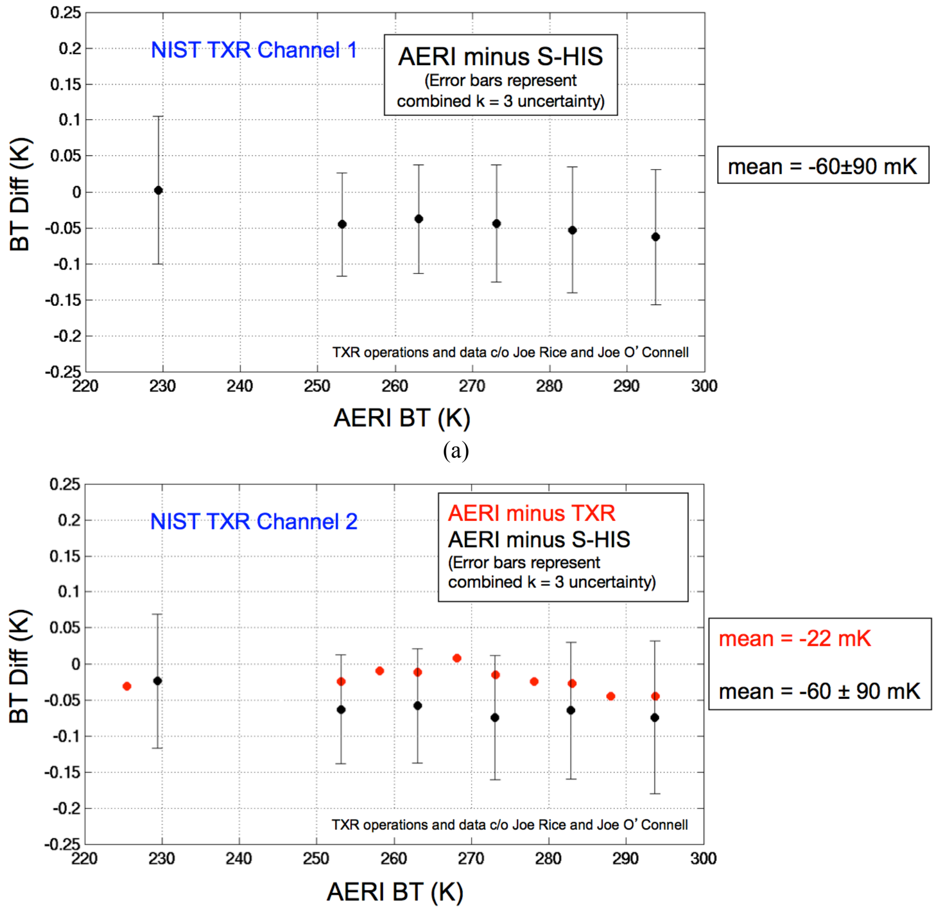


Figure 4: S-HIS calibration uncertainty estimates (k = 3) for flight conditions encountered on (a) 21 November 2002 on the ER-2 and (b) 16 November 2002 on the Proteus [11 – 12].



(b)

Figure 5: NIST TXR comparison results; (a) NIST TXR Channel 1 (5 μm) (b) NIST TXR Channel 2 (10 μm) [6 – 10].

4. CRIS CALIBRATION VALIDATION USING THE S-HIS

The ability to accurately validate infrared spectral radiances measured from space by direct comparison with airborne spectrometer radiances was first demonstrated using the S-HIS aircraft instrument flown under the Atmospheric Infrared Sounder (AIRS) sensor on the NASA Aqua spacecraft in 2002. Subsequent AIRS calibration validation under-flights were completed in 2004 and 2006, providing successful comparisons that span a range of conditions, including arctic and tropical atmospheres, daytime and nighttime, ocean and land surfaces [12, 13]. Similar comprehensive and successful calibration validation efforts have also been conducted with S-HIS for the MODIS sensors, the Tropospheric Emission Spectrometer (TES) [14, 15], and the MetOp Infrared Atmospheric Sounding Interferometer (IASI) [16 – 18]. These results show brightness temperature differences that often approach 0.1 K over much of the spectrum.

Figure 6: The S-HIS mounted in Zone 25 of the NASA Global Hawk for the NASA Hurricane and Severe Storm Sentinel (HS3) mission.

Selection of the CrIS and S-HIS footprints included in the comparison must take into consideration the spatial and temporal collocation of the two sets of observations, the spatial uniformity of the scene, and measurement noise reduction provided by co-adding individual fields of view for each sensor. While the scene was not spatially uniform at the temporal collocation of the two sensors for the 6 October 2012 flight, the southern leg of the validation flight leg prior to the temporal coincidence shows good spatial uniformity (Figure 7 and Figure 8). The use of spatially uniform scenes reduces potential differences due to collocation errors and also removes the need for exact representation of the S-HIS and CrIS footprints. It is necessary that the smaller S-HIS footprints be selected to provide as full coverage as possible of the selected CrIS footprints. Accordingly, many S-HIS footprints over a range of scan angles are required (Figure 8).

A comparison of the means of the selected spatially coincident CrIS and S-HIS spectra is shown in Figure 9 and Figure 10. The comparison presents the CrIS and S-HIS data reduced to the CrIS spectral resolution, but without accounting for view angle or altitude differences. As expected, in spectral regions where the satellite sensor is sensitive to significant contributions from above the aircraft altitude, large differences are observed. In the spectrally flat window regions the comparison shows very good agreement. The full double-difference method, detailed by Tobin [12], has not been completed at this time, but the preliminary calibration validation analysis indicates very good radiometric agreement between the CrIS and S-HIS sensors.

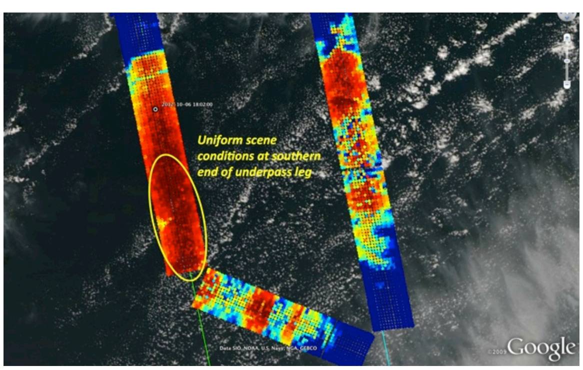


Figure 7: The southern end of the underpass leg shows uniform scene conditions. The S-HIS footprints are colored by 900 cm^{-1} Brightness Temperature and background image displays coincident NPP Visible/Infrared Imager/Radiometer Suite VIIRS imagery.

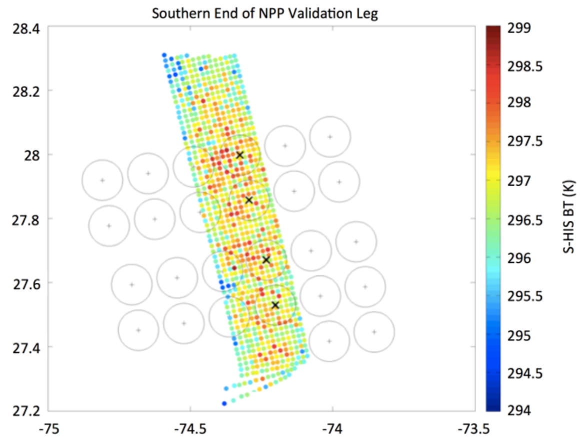


Figure 8: Approximate representations of CrIS (black) and S-HIS (colored by 900 cm^{-1} brightness temperature) footprints on 6 October 2012 at the southern end of the underpass leg.

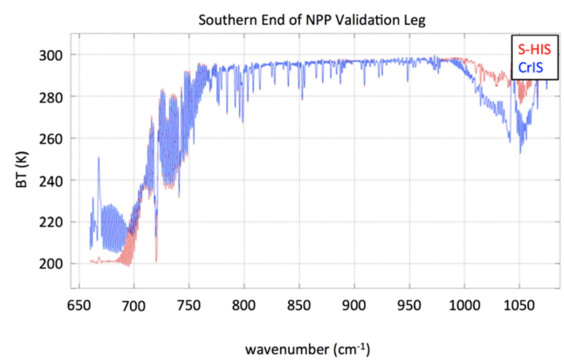


Figure 9: Comparison of mean S-HIS (red) and CrIS (blue) longwave brightness temperature spectra on 6 October 2012.

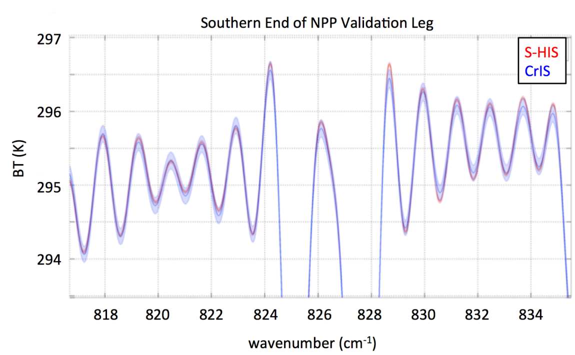


Figure 10: Comparison of mean S-HIS (red) and CrIS (blue) brightness temperature spectra (817 – 835 cm^{-1}) on 6 October 2012.

5. SUMMARY

The first aircraft calibration validation campaign for Suomi NPP was scheduled to be conducted in November 2012 with a primary objective of providing detailed validation of CrIS radiance observations and meteorological products. This campaign has been delayed until May 2013. However, on 6 October 2012, the S-HIS (onboard the NASA Global Hawk for the NASA HS3 campaign) completed a single under-flight of CrIS on Suomi NPP. The preliminary results of that flight have been presented here. While the atmospheric conditions were not ideal for a radiance validation at the temporal collocation point, the preliminary calibration validation analysis for the southern portion of the NPP validation leg indicates excellent radiometric agreement between the CrIS and S-HIS sensors.

During the May 2013 calibration validation campaign, the Scanning-High resolution Interferometer Sounder (S-HIS), the NPOESS Atmospheric Sounder Testbed-Interferometer (NAST-I), and the NPOESS Atmospheric Sounder Testbed-Microwave Spectrometer (NAST-M) will fly on the high altitude NASA ER-2 aircraft with multiple under-flights of Suomi NPP planned.

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