The JPSS CrIS Instrument and the Evolution of Space-Based Infrared Sounders

Ronald Glumb, Lawrence Suwinski, Steven Wells, Anna Glumb, Rebecca Malloy and Marie Colton

Harris Space and Intelligence Systems, Fort Wayne, Indiana, USA

AMS Annual Meeting, January 2018

HARRIS® TECHNOLOGY TO CONNECT, INFORM AND PROTECT™

Topics

Infrared sounder evolution since the 1970s

Cross-track Infrared Sounder (CrIS) on Suomi National Polar-orbiting Partnership (SNPP)

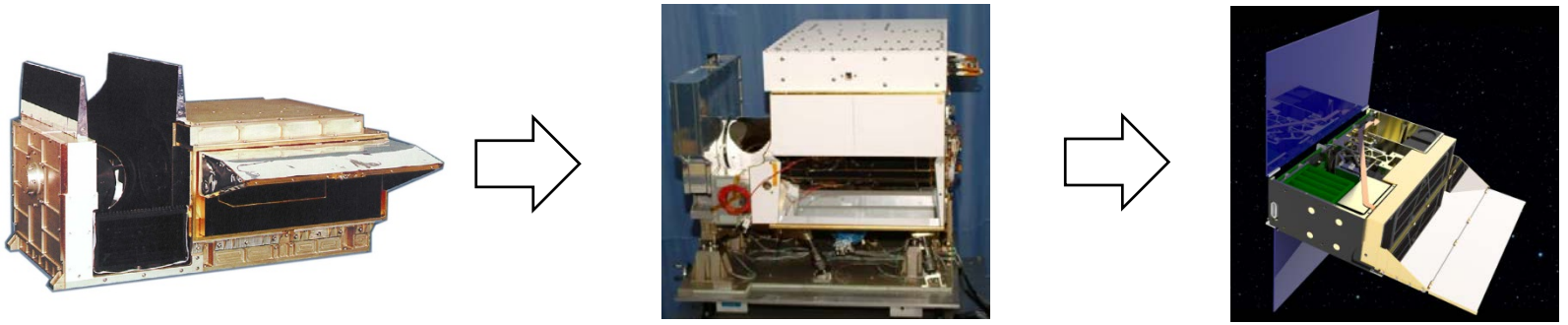
CrIS on Joint Polar Satellite System-1 (JPSS-1)

- Improvements over CrIS SNPP
- Measured performance during ground test
- On-orbit status

Production status of CrIS instruments for JPSS-2 through JPSS-4

New technologies for future infrared sounders

The expanding usage of infrared sounding data



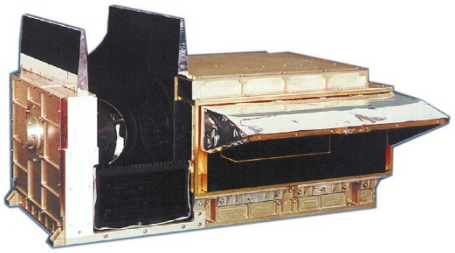
Filter Wheel Sounders (1970s to Present)

First generation of sounders used multiple spectral filters in a rapidly spinning wheel

- ~20 filters spanning Visible through Long Wave Infrared (LWIR)
- Technical challenges overcome
  - Lifetime of filter wheel mechanism
  - Very fast readout of detectors to achieve reasonable spatial coverage
  - Achieving adequate Signal-to-Noise (SNR) with short integration time per band

NOAA/NASA explored hyperspectral versions of both instruments during the 1990s

- "HIRS Hybrid" and "GOES High-resolution Interferometric Sounder"
- Both were interferometer-based
- Neither reached flight status



High-resolution Infrared Radiation Sounder (HIRS)

- 20 channels
- 10 km spatial resolution
- First Launch: 1972
- 12 units flown

High-resolution Infra-Red Sounder (HIRS)

- 19 channels
- 8 km spatial resolution
- 8 units flown

First Hyperspectral Sounders: AIRS and IASI

Atmospheric Infrared Sounder (AIRS): 2002-Present

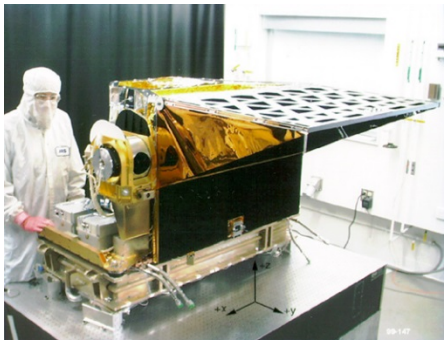
- World's first hyperspectral sounder
- Validated the improvement in sounding quality due to large number of channels
- Dispersive spectrometer, active cooling
- Still operating well past required mission life

Infrared Atmospheric Sounding Interferometer (IASI):

- Contiguous spectral range (no gaps)
- Finer spectral resolution enables trace gas detection
- Interferometric spectrometer, active cooling

Both instruments are relatively large with considerable power consumption

- Design goal for CrIS: smaller size and power



AIRS

- 2378 channels
- 13.5 km spatial resolution
- Launched in 2002

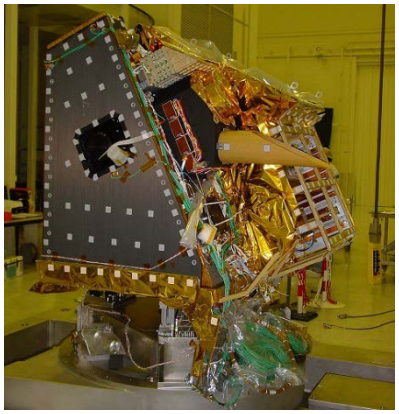
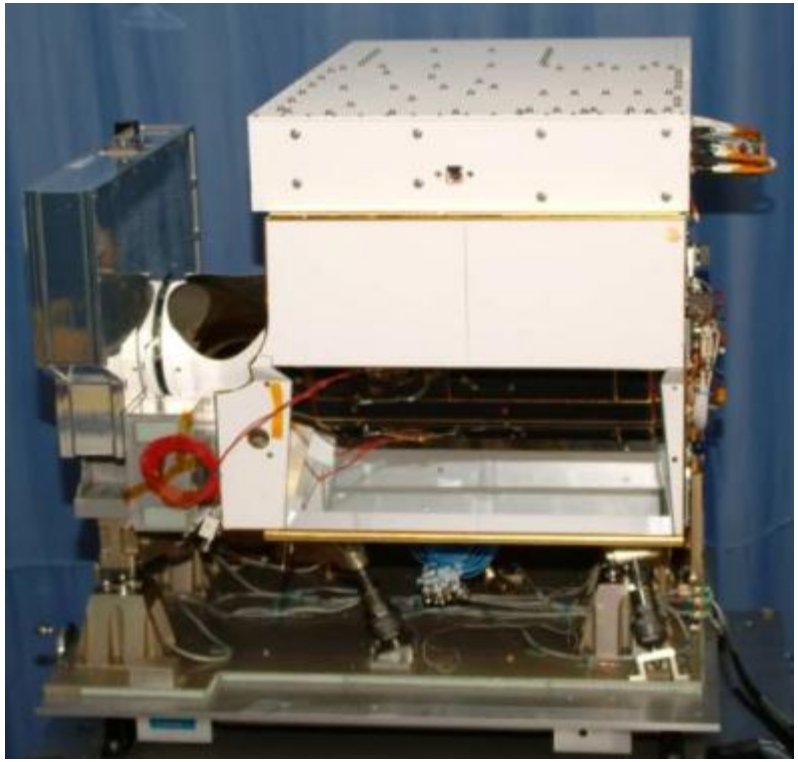


Photo Courtesy of Alcatel

IASI

- 8461 channels
- 12 km spatial resolution
- 2 units in orbit

CrIS: Designed for Compact Size, Optimum LWIR NEdN, and Superb Calibration



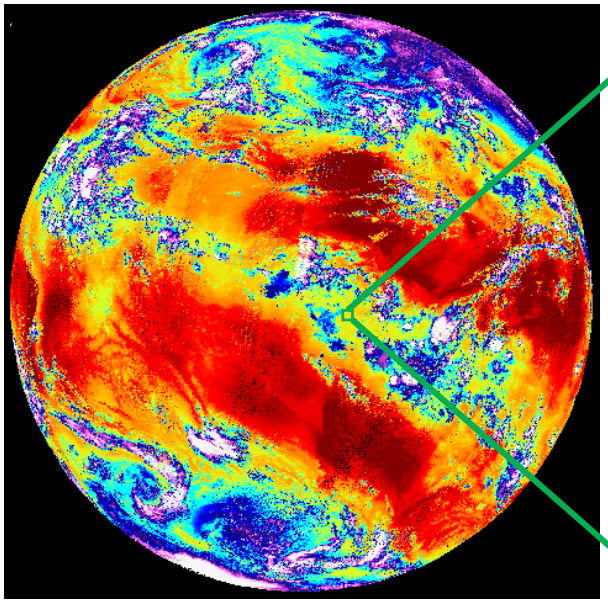
Band	Wavelength Range (cm^{-1})	(μm)	Sampling (cm^{-1})	No. Chan.
SWIR	2155-2550	4.64-3.92	0.625	633
MWIR	1210-1750	8.26-5.71	0.625	865
LWIR	650-1095	15.38-9.14	0.625	713

Total Channels = 2211

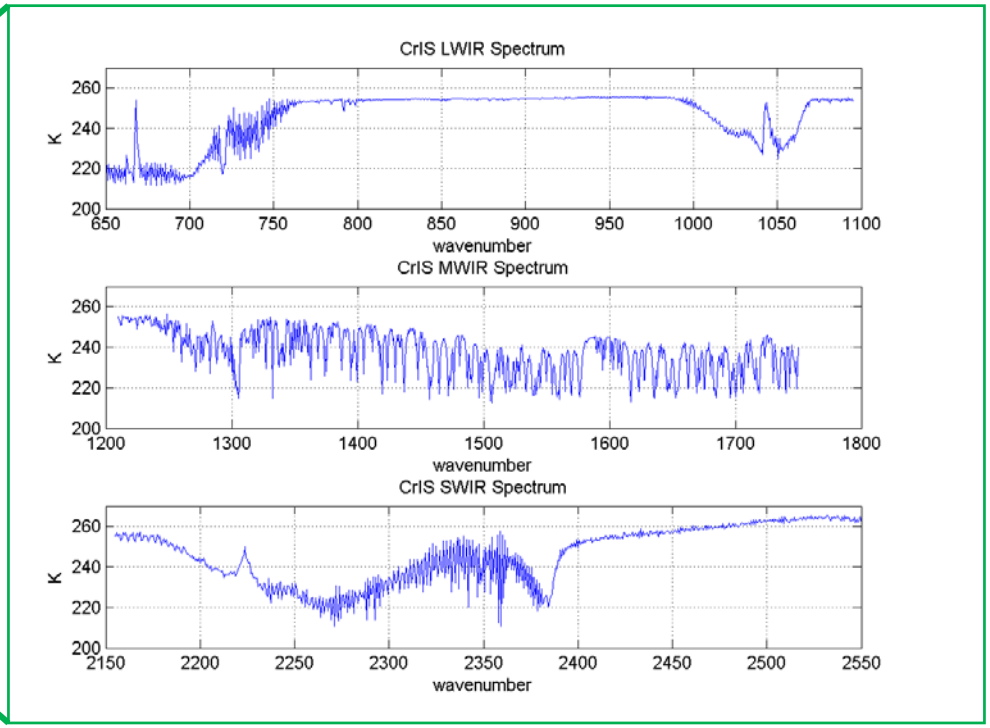
- Innovative CrIS Features
  - Passive detector cooling to minimize power consumption
  - Compact packaging for small size and mass
  - Low noise levels (NEdN) enabled by 8cm aperture and low-noise FPAs / electronics
  - Extremely stable radiometric response, enabled by low-drift electronics and optical stability
  - Precise radiometric calibration enabled by high-quality calibration target and frequent calibration looks
  - Spectral accuracy maintained using onboard neon calibration sources

Mass	Power	Volume
146 kg	105 W	~0.4 m^3

The Extraordinary Data Content of Hyperspectral Sounders

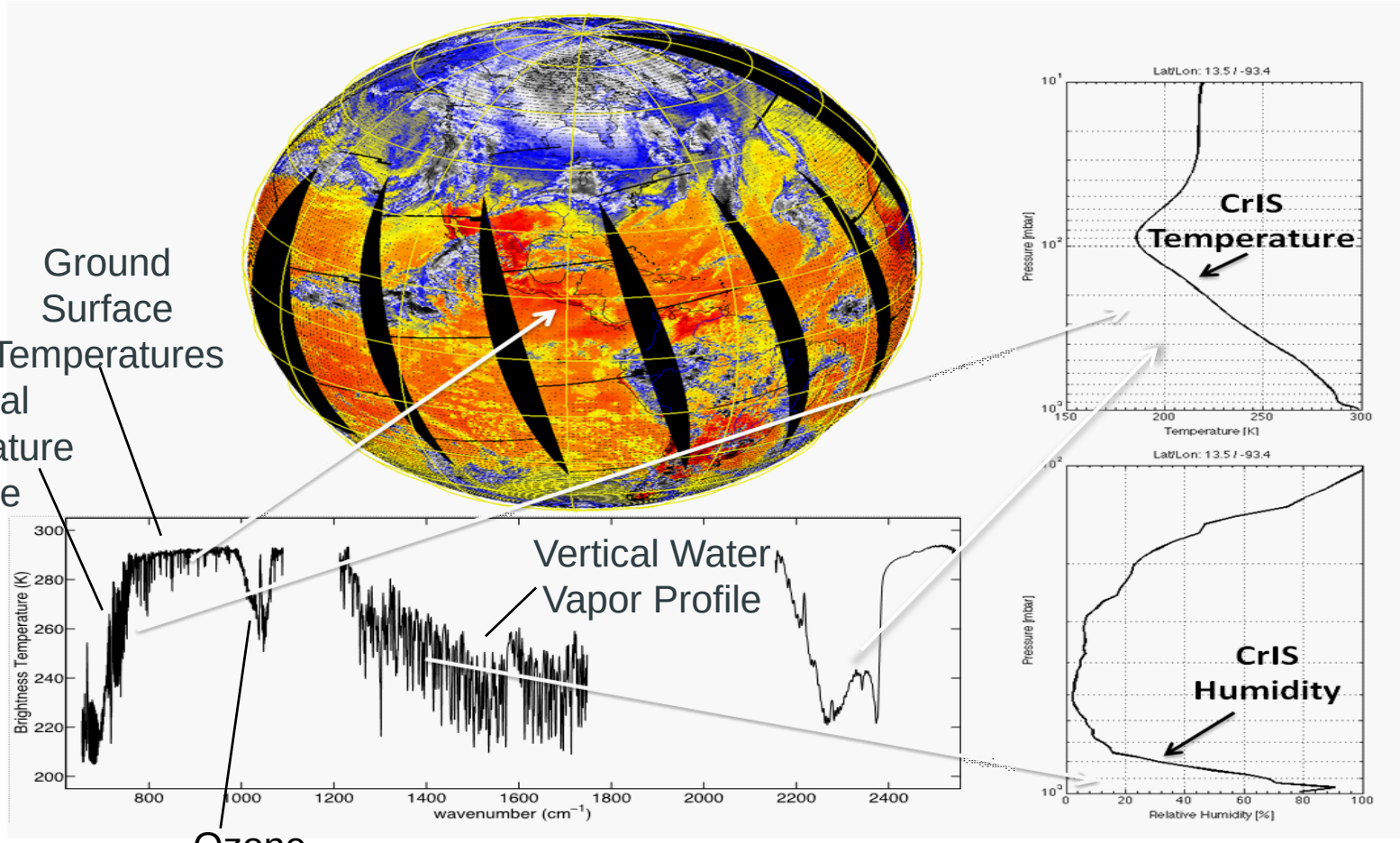


Ensemble of CrIS Data Collected During a Typical 2-Day Period in May 2012



Each Pixel Contains Over 2000 Spectral Channels Across 3 Bands

CrIS Data Products Provide Critical Inputs to Global Weather Predictions



CrIS SNPP Status: Launched in 2011

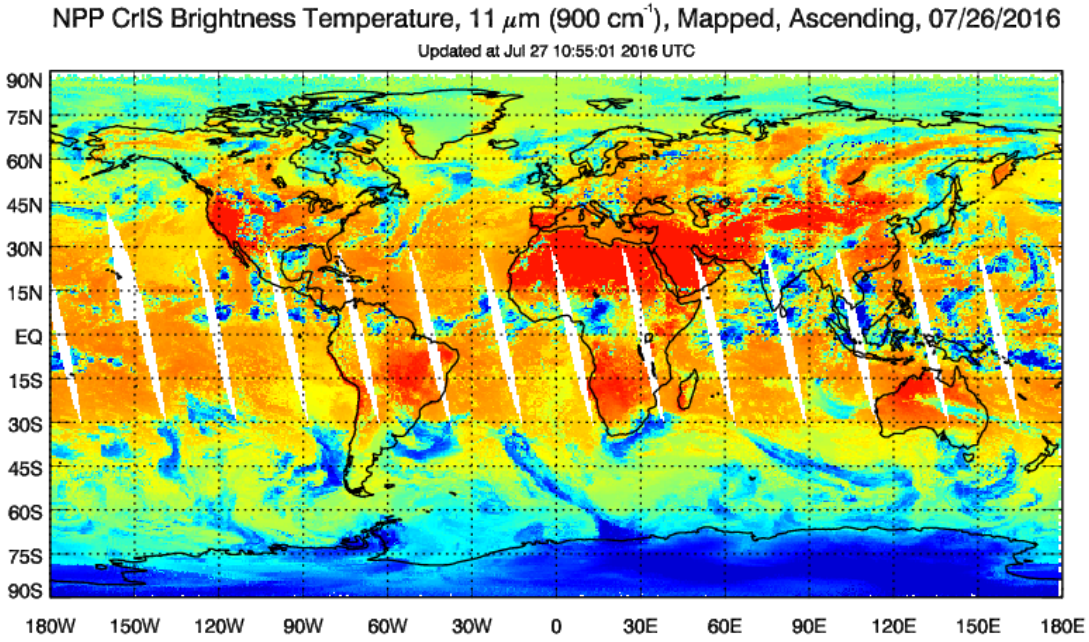
Over 6 years in orbit

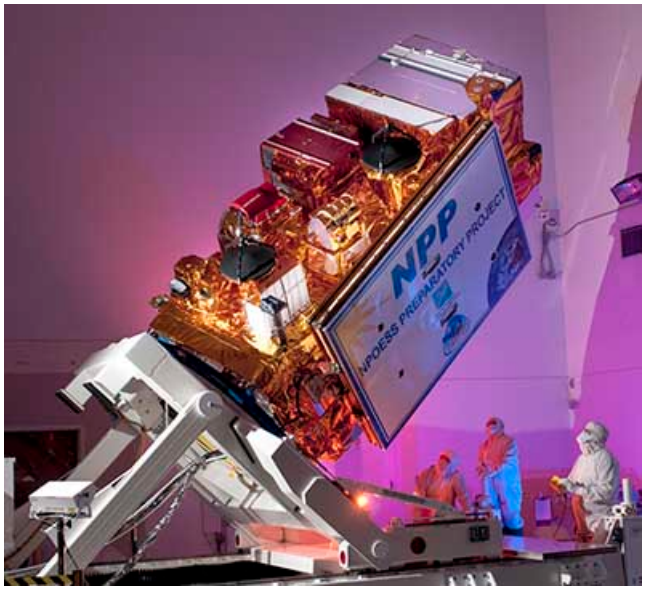
- Approaching required lifetime of 7 years

Excellent radiometric performance

- Very stable throughout mission life

Full spectral resolution test mode became baseline after launch





CrIS Continues to Provide Critical Inputs to Global Weather Forecast Models

Improvements for CrIS JPSS-1

Improved Internal Calibration Target

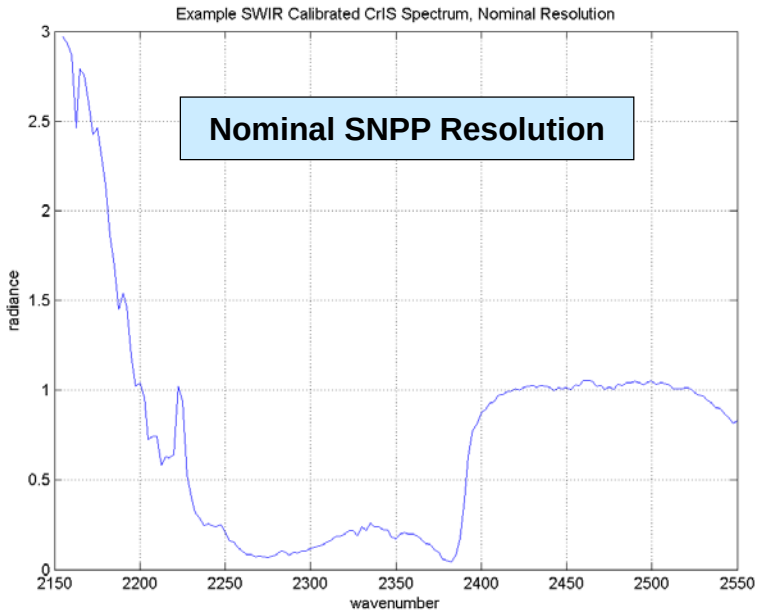
- Higher emissivity, more tightly calibrated temperature sensors

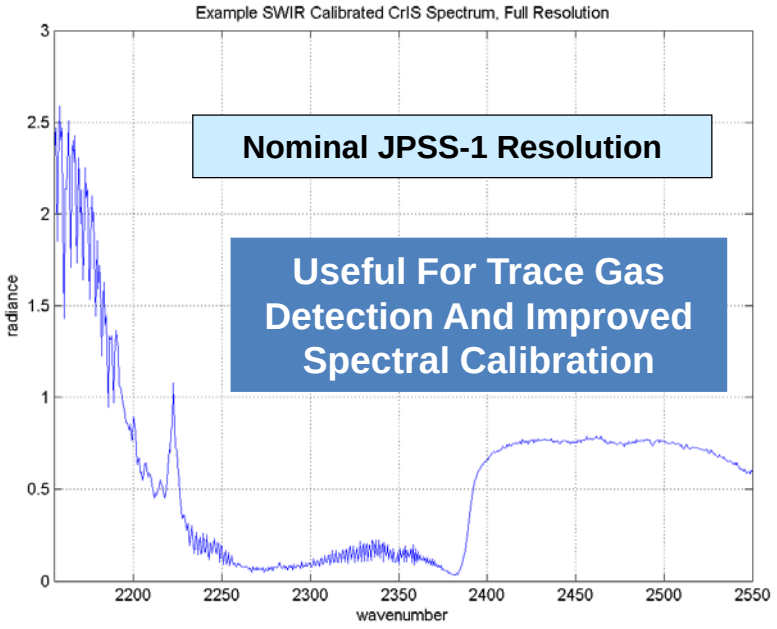
Several incremental improvements from SNPP lessons learned

- Structure, electronics boards, various modules

Full spectral resolution is now nominal mode

New Specular-Trap Internal Calibration Target





CrIS JPSS-1 Matches or Exceeds SNPP Performance

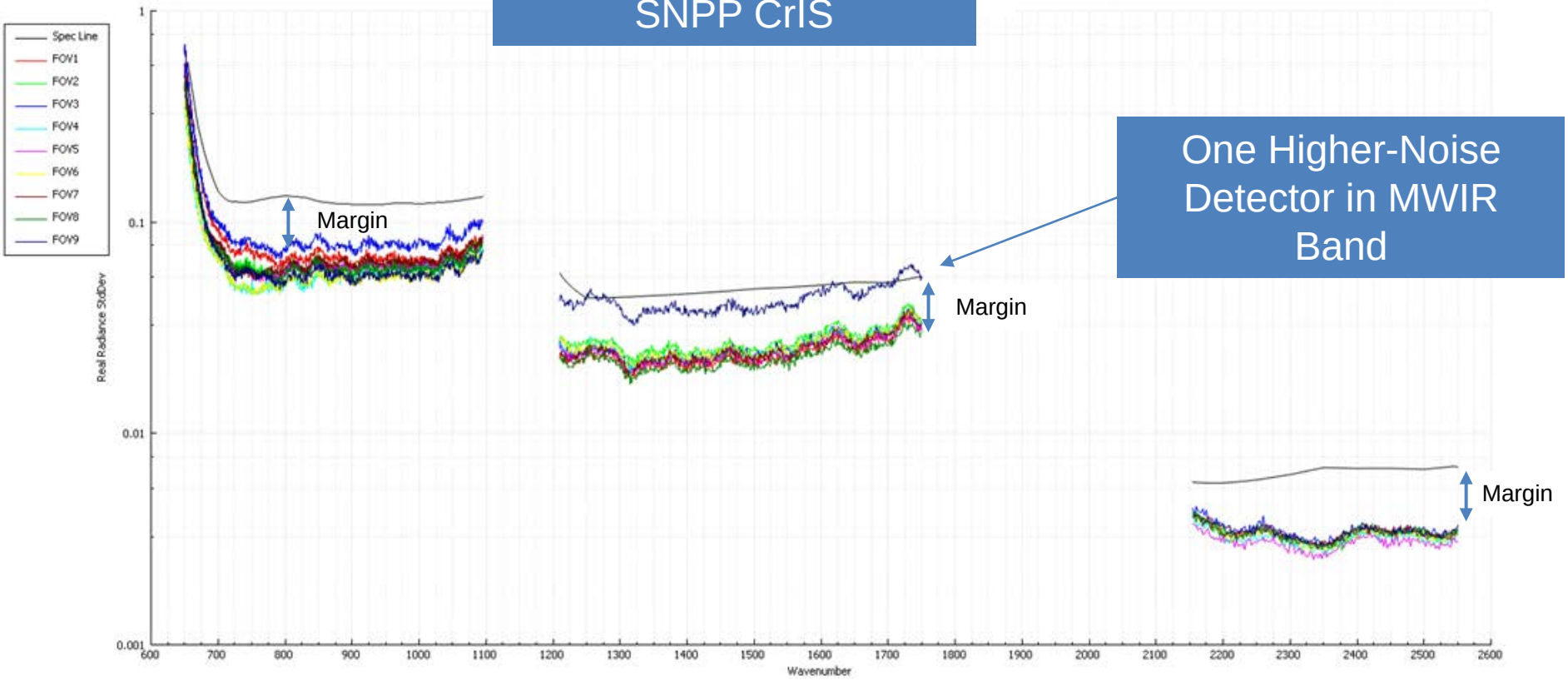
Four key performance parameters directly impact the quality of temperature and moisture soundings

- **Noise Equivalent Spectral Radiance (NEdN)**
- **Absolute Radiometric Uncertainty**
- **Radiometric Repeatability (short- and long-term stability)**
- **Spectral Stability**

JPSS-1 NEdN Meets Specification With Margin

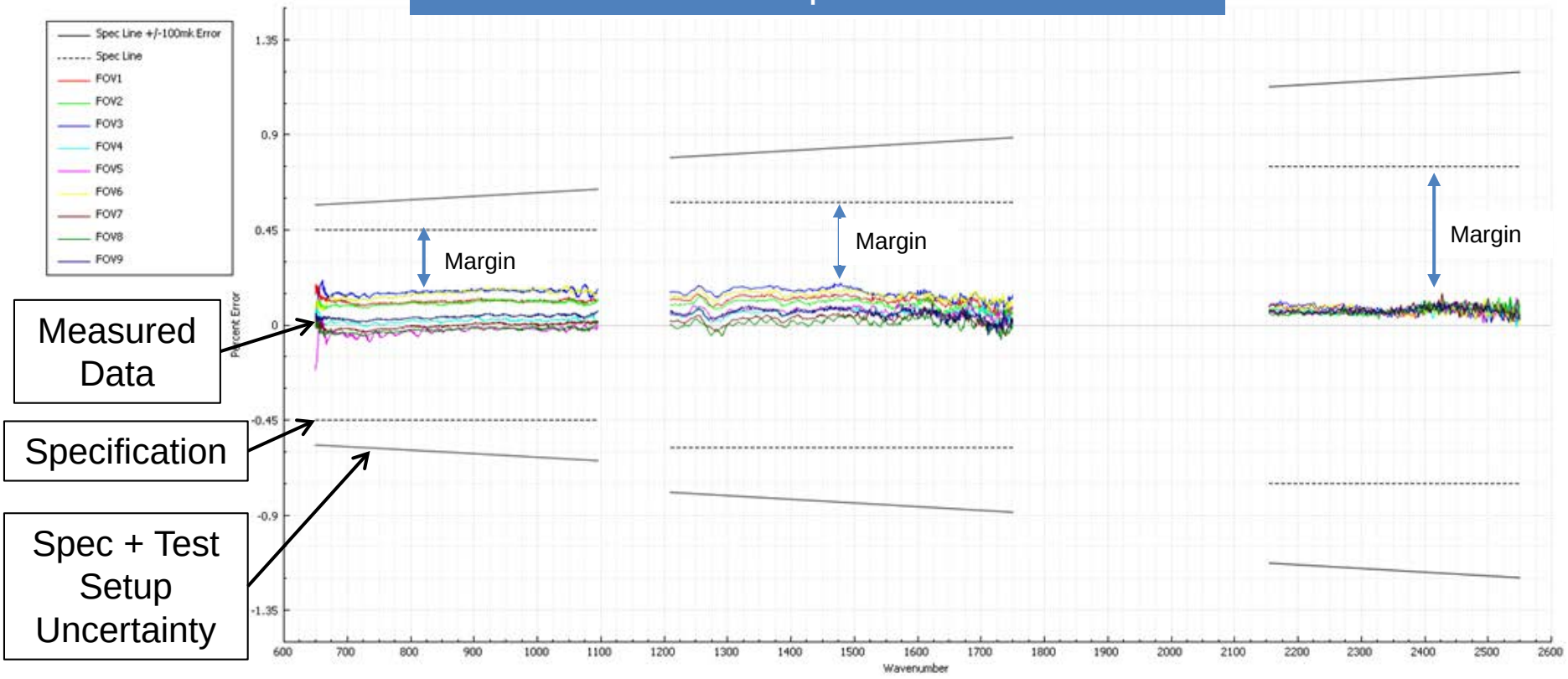
JPSS-1 NEdNs are Slightly Better Than SNPP CrIS

One Higher-Noise Detector in MWIR Band

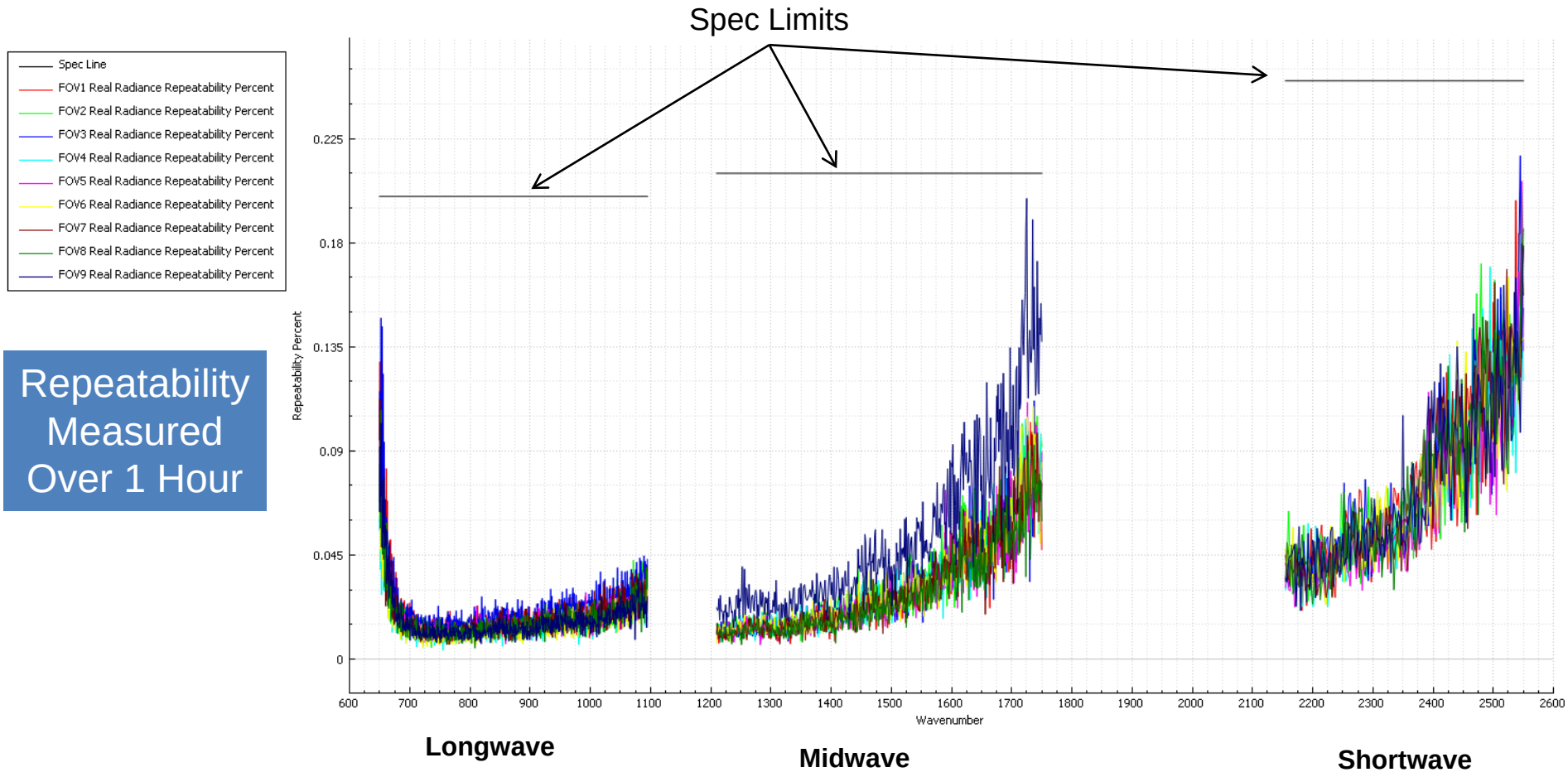


Calibration Accuracy Demonstrated During Testing

Absolute Accuracy <150mK, or >3X Better Than Requirements

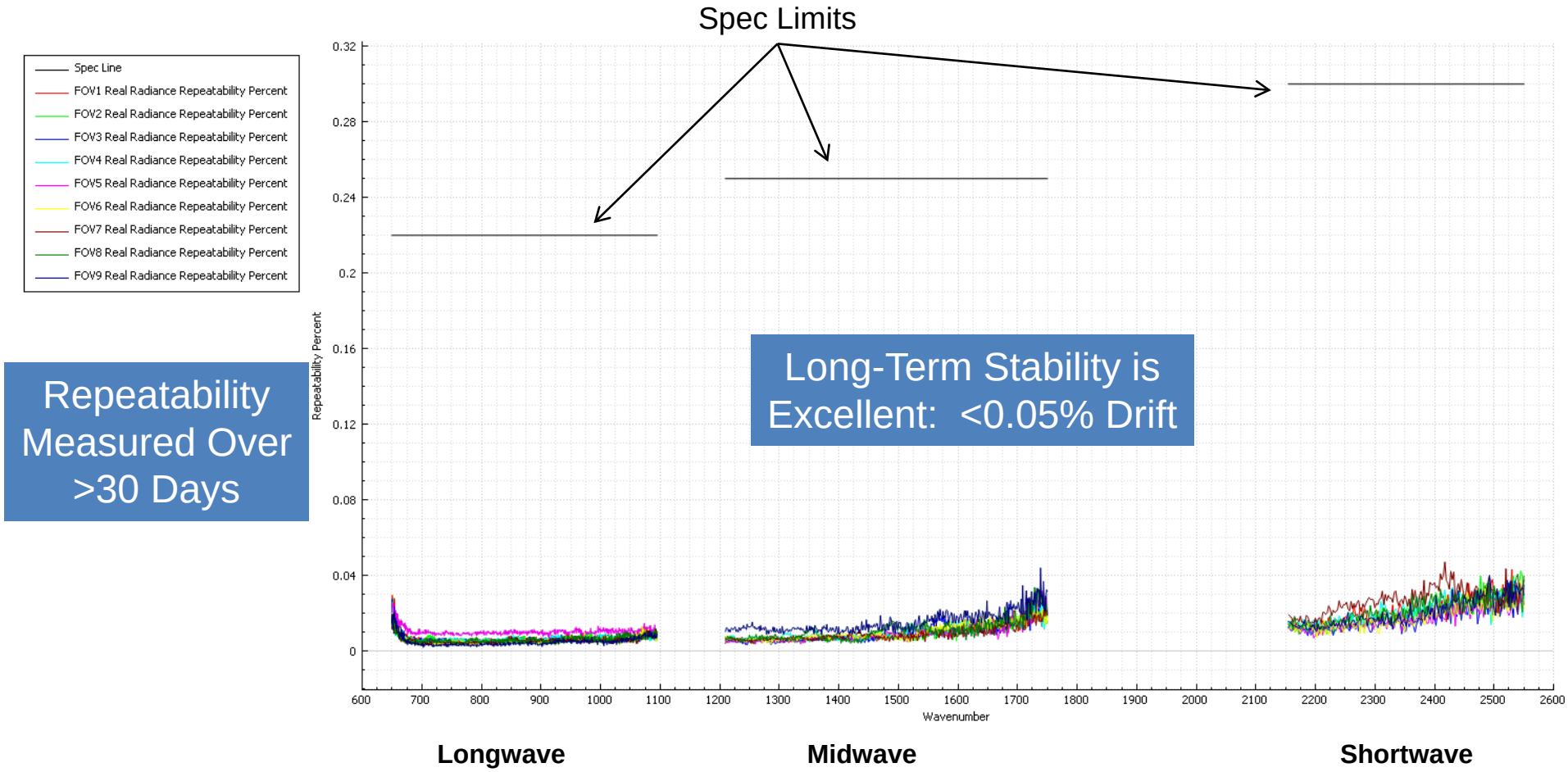


Short-Term Repeatability Well Within Spec Limits



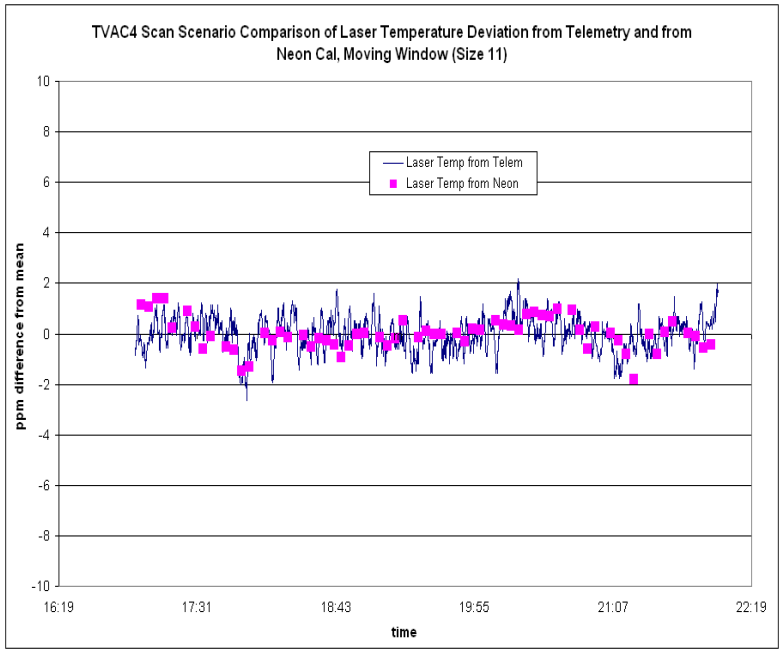
Repeatability Measured Over 1 Hour

Long-Term Repeatability is Outstanding

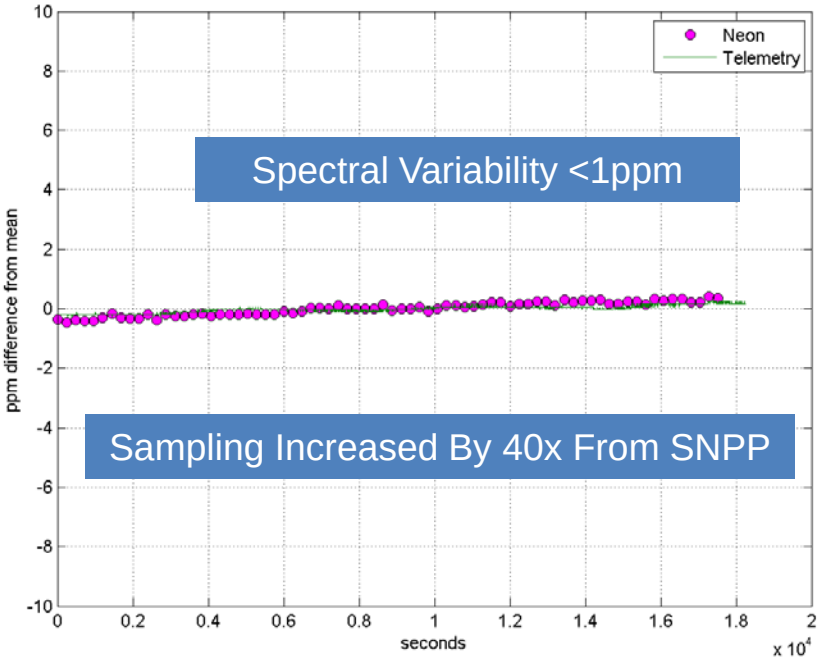


JPSS-1 Spectral Stability is Even Better Than SNPP

SNPP



J1



JPSS-1 Performance Improved by ~10x From SNPP;
Expected to Provide Improved Spectral Accuracy On-Orbit

CrIS JPSS-1 On-Orbit Status

JPSS-1 was successfully launched on November 18, 2017

CrIS successfully powered up in early December

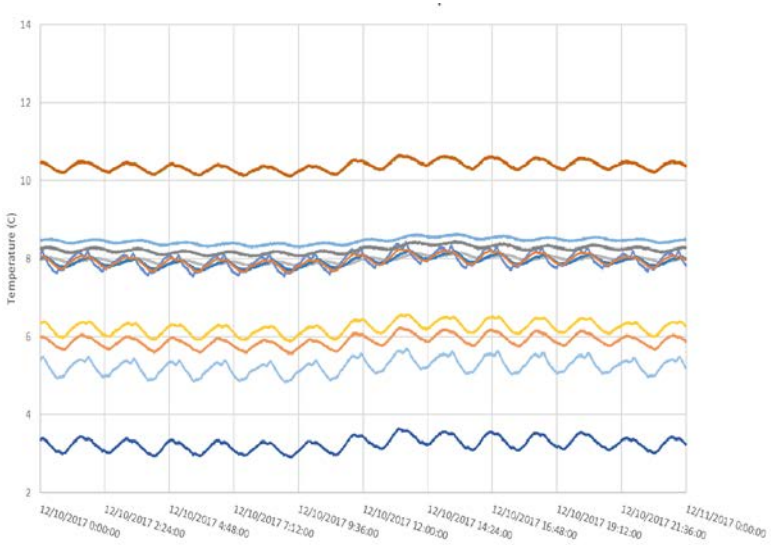
- Placed in outgas mode to ensure contaminants do not collect on passive cooler surfaces or cold detectors
- On-orbit telemetry shows as-expected temperature variations

Plan to reach CrIS operational status:

- L+45 (1/02/2018) Release Cooler Cover
- L+48 (1/05/2018) Power on Detectors
- ~L+90 (3/2018) Provisional Maturity
- ~L+270 (8/2018) Operational Maturity

JPPS-1 Launch

Satellite Deployment

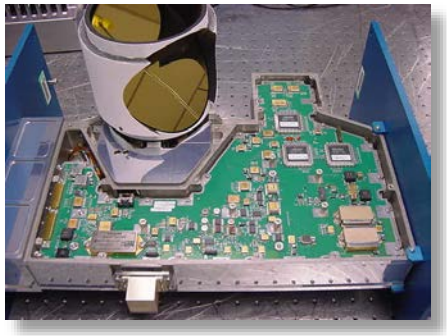


Temperatures Throughout the CrIS Instrument Show Small Temperature Variations in Sync With Orbital Period

CrIS JPSS-2 / JPSS-3 / JPSS-4 Status

CrIS for JPSS-2

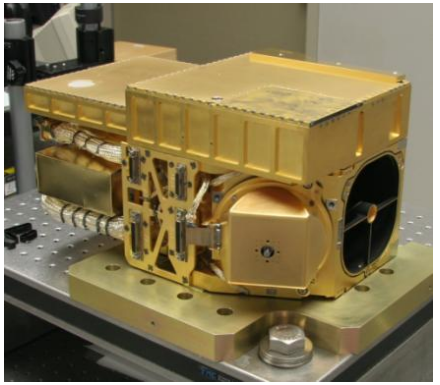
- Most modules complete and ready for integration
- Co-registration successfully completed
- Environmental testing begins later this year
- Delivery planned for 2019



CrIS Scanner Module for JPSS-2

CrIS for JPSS-3

- In Assembly: Aft Optics, Earth Shield, Detector Cooler, Scanner, Cal Target, Interferometer, Electronics, Frame
- In Manufacturing: Optical Bench, Telescope, Vibration Isolation System
- Delivery planned for 2020



CrIS Interferometer for JPSS-2

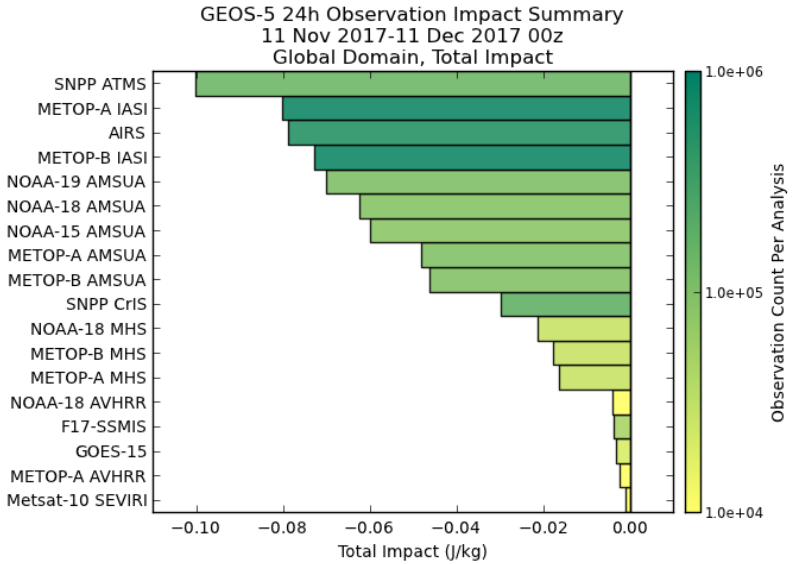
CrIS for JPSS-4

- 97% of parts on order
- Module builds are underway
- Delivery planned for 2021

Hyperspectral Sounder Data Utilization in Numerical Weather Prediction

Hyperspectral sounding data assimilation history is international research-to-operations success story

- Multi-spectral Soundings (1969 – 2012)
- Radiance assimilation techniques, ca. 1990s
- Establishment of multi-agency *Joint Center for Satellite Data Assimilation* to address backlog of data and accelerate utilization of new sensor data (ca. 2001-2002)
- Series of polar hyperspectral infrared sounders demonstrate significant forecast impact as most important measurement due to improved resolution
  - NASA AIRS (launch 2002, assimilation ca. 2003 - 2004)
  - EUMETSAT IASI (launches in 2006, 2011)
  - Suomi-NPP CrIS (launched in 2011
- Continuity of US polar operational hyperspectral sounding capability initiated with the second CrIS instrument launched on JPSS-1, 2017

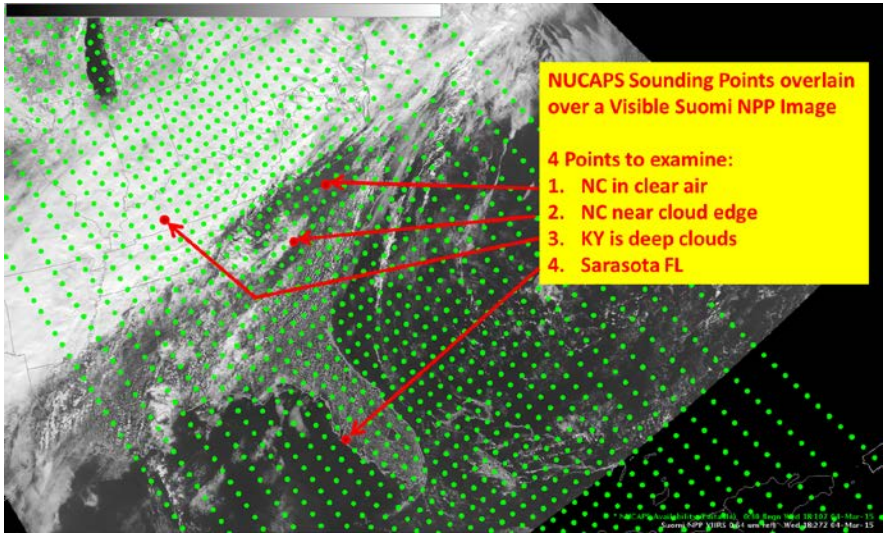


Sounder Data Analysis For Additional Applications

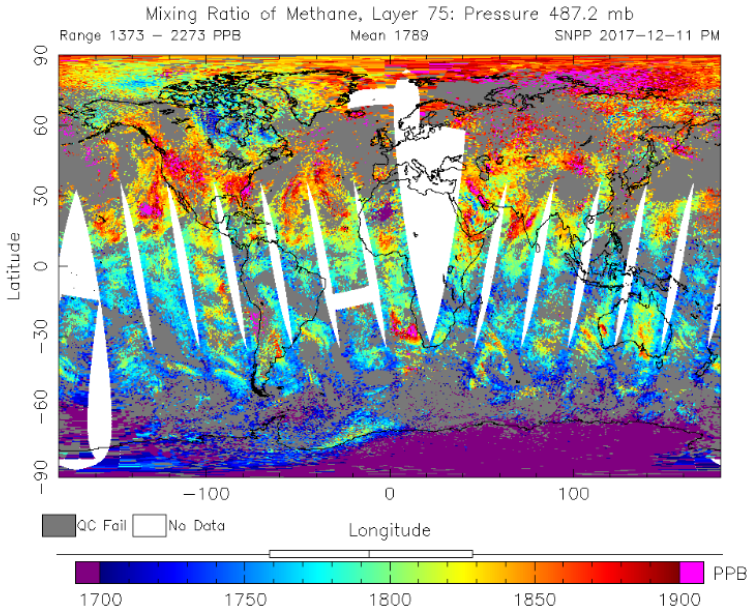
Environmental Data Products from hyperspectral sounders support new applications

- Temperature, water vapor, cloud fraction and cloud top pressure, ozone (O3), methane (CH4), carbon monoxide (CO), carbon dioxide (CO2), sulfur dioxide (SO2), nitrogen dioxide (N2O), and nitric acid (HNO3), and presence of dust and volcano emission

NOAA Unique Combined Atmospheric Processing System (NUCAPS) and distribution through AWIPS-II provides significantly more satellite-derived soundings to forecast offices in regions of interest for improving forecast guidance (B. Motta, NOAA/NWS)



- Constructing consistency among AIRS/IASI/CrIS for multi-decadal record of hyperspectral data will enable climate studies of atmospheric constituents



Hyperspectral Sounders and Data Utilization Continues to Evolve

Deploy smaller platforms to fill high-priority observing gaps

- Hypercube 3D Wind profiles

Extend to geostationary hyperspectral sounding capability for faster updates of horizontal and vertical water vapor and temperature structures

- 3-dimensional spatial and temporal continuity of observations needed for next significant improvements in short-term weather forecasting
- Geostationary Interferometric Infrared Sounder (GIIRS), China, 2016

Utilize more data from existing instruments

- Cloudy radiances
- Additional channels and new channel selection approaches
- Consideration of direct sounding assimilation
- Two operational US CrIS instruments separated by about one hour

Understand observing system impacts on Numerical Weather Prediction for next-generation instrument and constellation design

"Forecast sensitivity to observation" inter-comparison studies compare data assimilation systems at major weather centers and improve interpretation of hyperspectral sounding impact statistics

Likely Directions of Future IR Sounders

Better spatial resolution

- Fidelity of weather forecast models continue to improve
- Higher probability of cloud-free soundings
- Better mapping of trace gas sources and sinks

Better spectral resolution

- More utility for trace gas monitoring

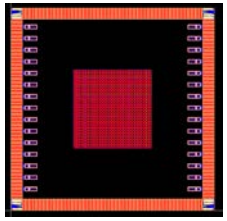
More frequent updates

- More frequent data model ingests possible
- Especially for finer-scale models

Lower Cost

Correlated: Lower cost enables more sounders which enables more frequent updates

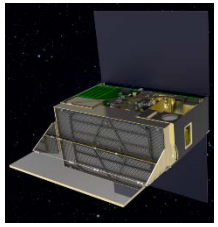
New Technologies to Enable Future IR Sounders



25x25 High-Speed IR FPA

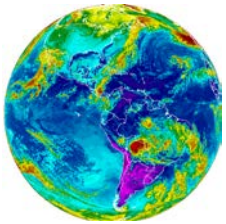
Extreme Onboard Processing

HyperCube Stratospheric Platform Test

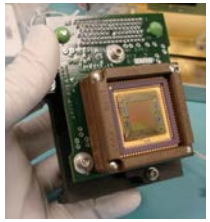


HyperCube Flight Demo (2020)

HarrisSat SmallSat Control Facility

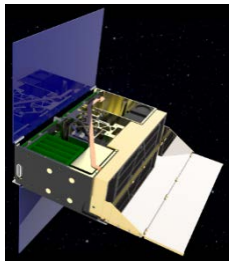


Hyperspectral Ground Processing

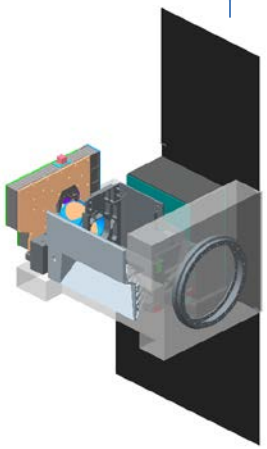


96x96 High-Speed FPAs

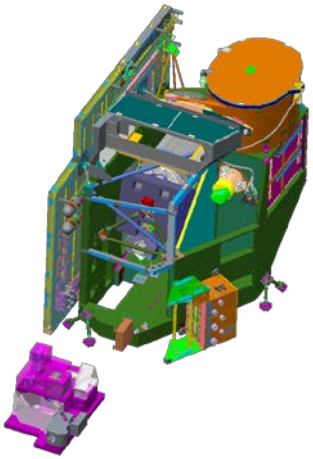
Interferometer Systems for GEO



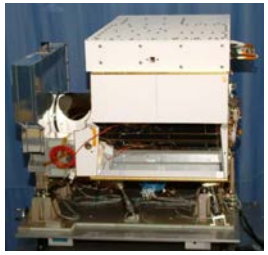
MWIR CubeSat Sounders in 6U CubeSats



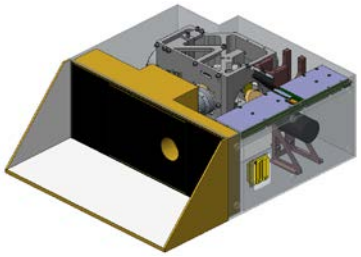
CrIS Free-Flyer in ESPA Ride Share



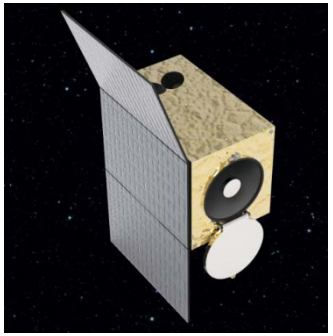
ABI-Based Hyperspectral Sounder in GEO (High Temporal)



CrIS With 2 km Spatial Resolution



LWIR CubeSat Sounders in 12U CubeSats



Large-Aperture Hyperspectral SmallSats

Summary

- **CrIS on JPSS-1 will continue to provide high-quality temperature and moisture soundings vital to weather forecasting**
- **CrIS JPSS-1 performance is as good or better than CrIS SNPP**
- **Three more CrIS instruments are in production**
- **New technologies are enabling improved IR sounders for the future**
  - Smaller instruments and platforms to fill high-priority observing gaps
  - Extend to geostationary hyperspectral sounding capability