# The CrIS NASA L1B Product and Project
# L1B – IMG – CHIRP


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and the CrIS NASA L1B Team

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UMBC AN HONORS UNIVERSITY IN MARYLAND

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*05 Oct 2022*

# Outline

- Introduction
- CrIS L1B
  - Unique attributes
  - Algorithm
  - Calibration parameters and traceability
  - Radiometric uncertainty
  - FSR and NSR product differences
- IMG
- CHIRP and RTA
- Summary

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# The CrIS NASA L1B Project and Product

- A low-cost, small team, PI led effort, tasked with efficiently producing extremely accurate, transparent, and traceable multi-sensor continuity radiance products needed for long-term trending of key climate variables
- Funded by NASA to develop calibration software to generate a climate quality CrIS L1B mission data record (SNPP, JPSS-1/NOAA-20 through JPSS-4/NOAA-23) to continue or improve on EOS-like data records
- The CrIS L1B team continues to support efforts relating to creating climate quality products from five CrIS sensors: two in orbit, one to be launched in November, one just completed ground testing, and one to undergo ground testing this upcoming year
- This climate quality radiance dataset enables all follow-on NASA Sounder science and product generation, including for example the atmospheric sounding products, trace gas products, various climate process and trending studies

# The CrIS NASA L1B Project and Product

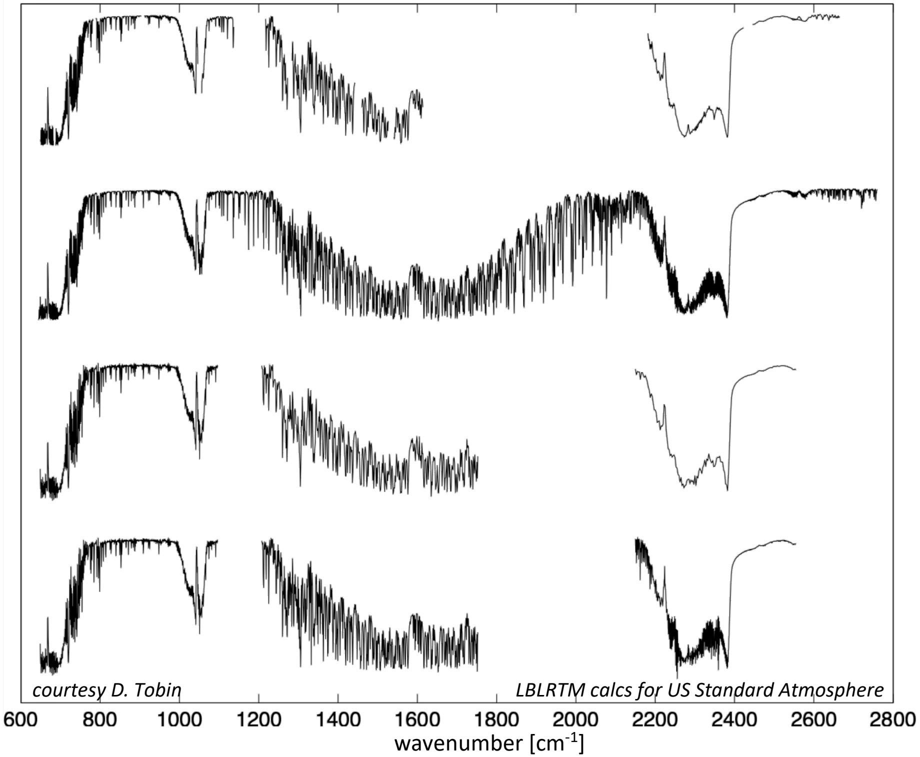
- Joint effort at University of Wisconsin – Madison and University of Maryland Baltimore County
- PIs: Joe Taylor and Larrabee Strow
- Current Focus and Products:
  - CrIS L1B (*Version 3*)
  - CrIS/VIIRS IMG software and datasets (*Version 2*): provide a subset of Visible Infrared Imaging Radiometer Suite (VIIRS) products that are co-located to the CrIS footprint
  - Climate Hyperspectral Infrared Product (CHIRP) for the AIRS and CrIS sounders (*Version 1*). The CHIRP product converts the parent instrument's radiances to a common Spectral Response Function (SRF) and removes inter-satellite biases, providing a consistent inter-satellite radiance record
  - CrIS RTA

*Product Generation and Distribution via Sounder SIPS, Atmosphere SIPS (IMG), and GES-DISC*

# The CrIS Sensors

- CrIS is an infrared Fourier Transform Spectrometer (FTS)
- An FTS measures an interferogram as a function of optical path difference
- The spectrum and the interferogram are simply related via the Fourier Transform
- CrIS spectral coverage is split into 3 spectral bands (LW, MW, and SW)
- Each spectral band uses a 3 x 3 detector array to provide ~14 km fields of view at nadir from an 833 km orbit
- 27 detectors, 2223 spectral channels at 0.625cm$^{-1}$ sampling, 14 km footprint at nadir

- Compact, large aperture, athermalized design
- Fully wedged / tilted with excellent image quality
- Pupil imaging system
- PV MCT detectors
- 4-stage passive cooler

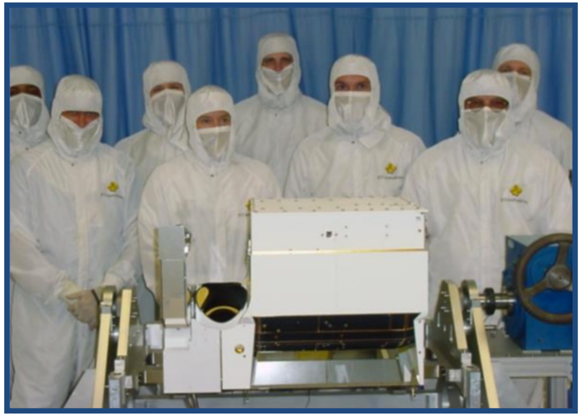


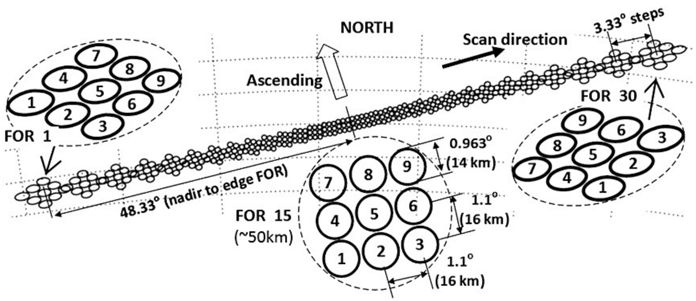

AIRS
L1B: > 1200
Resolving Power
9 FOV/50km square

IASI
L1C: ±2 cm OPD
Gausian apodized
4 FOV/50km square

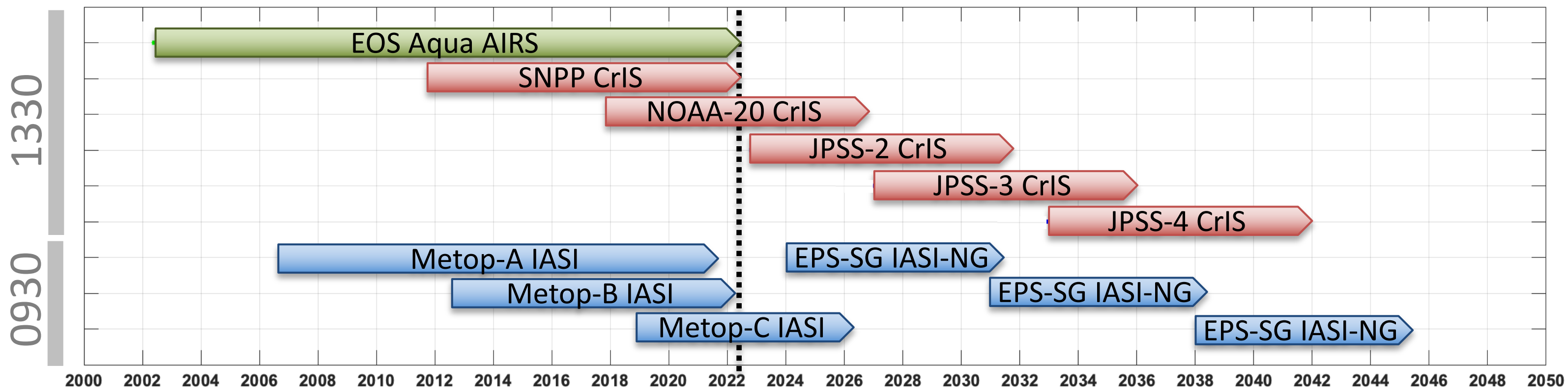
CrIS NSR
±0.8, 0.4, 0.2 cm
OPD unapodized
9 FOV/50km square

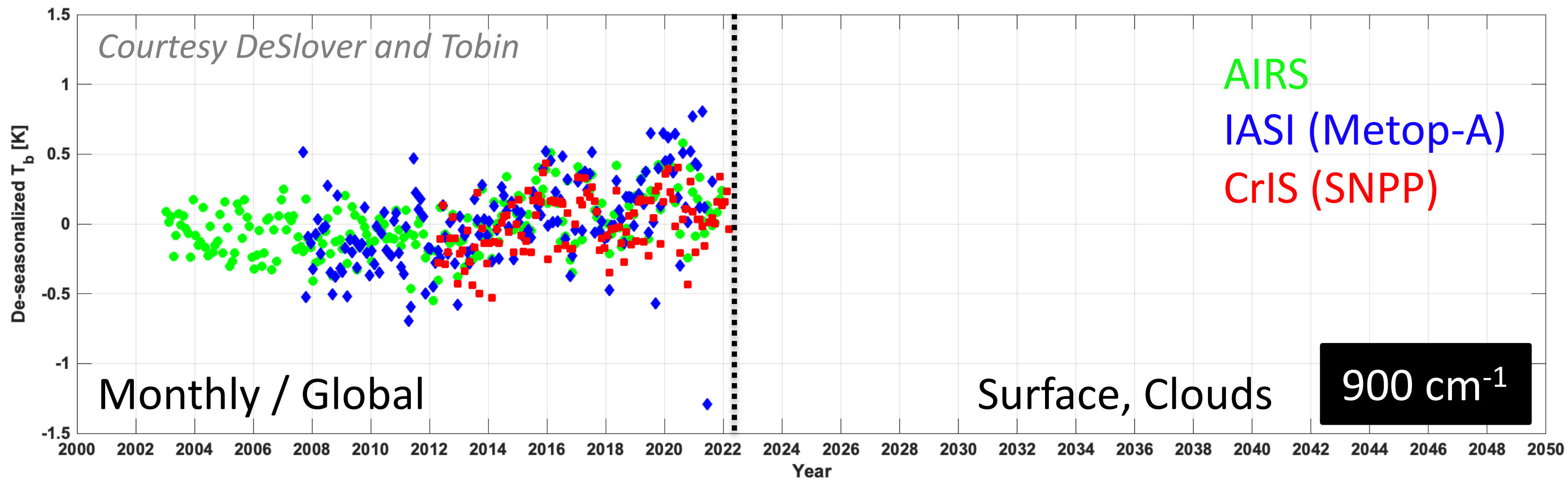
CrIS FSR
±0.8 cm OPD
unapodized
9 FOV/50 km square





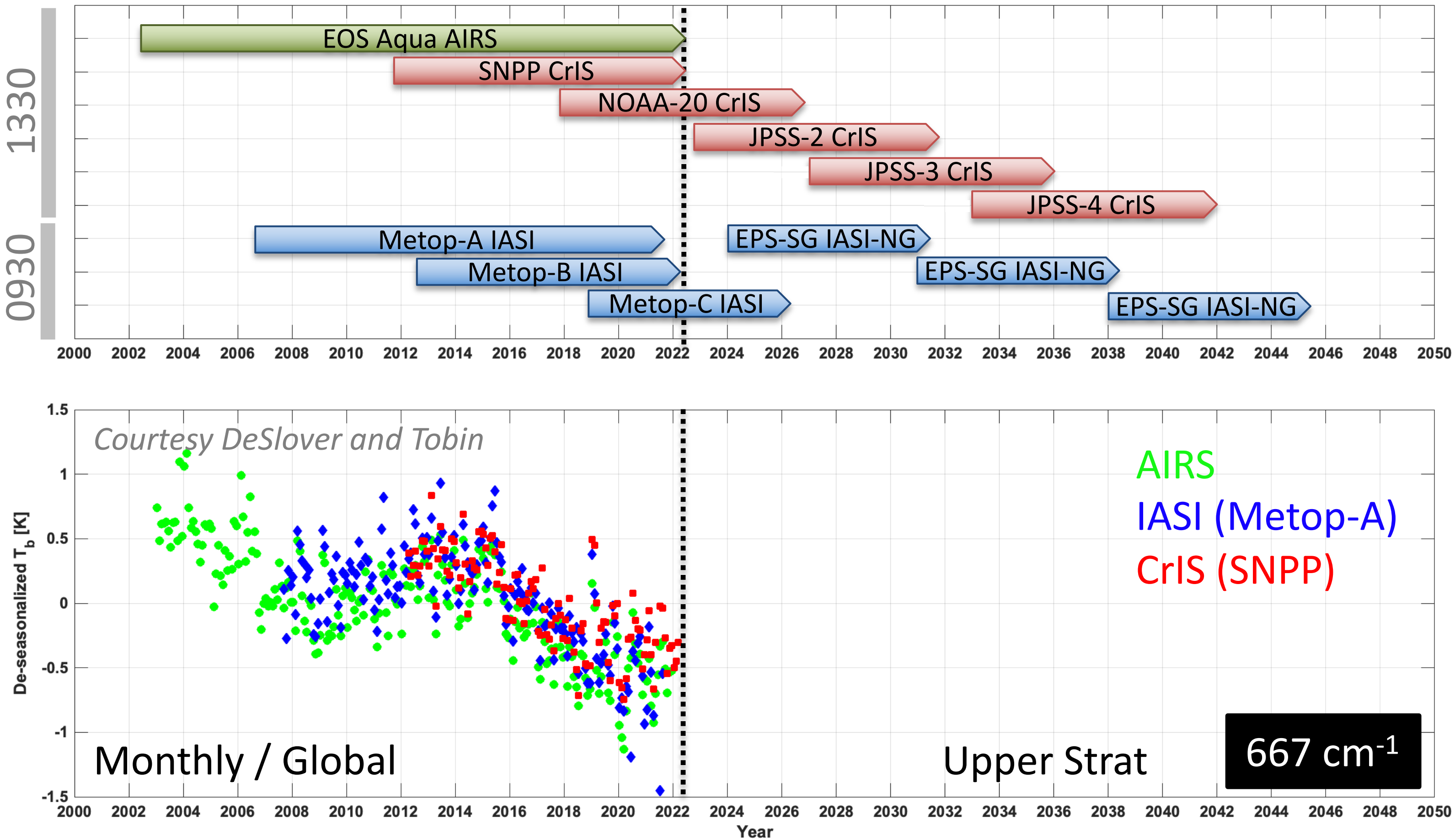
# Multi-sensor Hyperspectral Infrared Climate Data Record



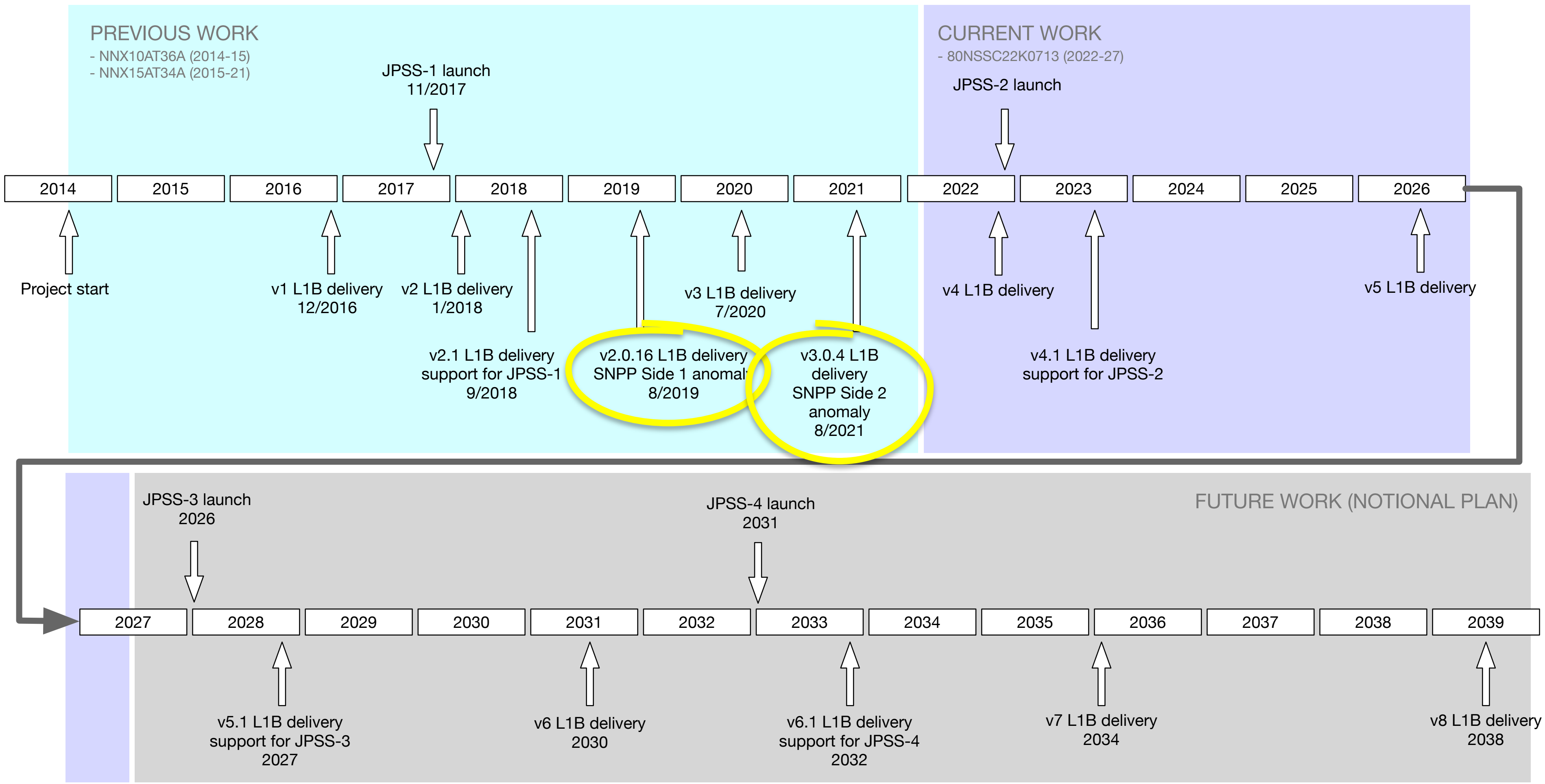

*The trends from AIRS, IASI, and CrIS in overlapping time periods are very similar*

# Multi-sensor Hyperspectral Infrared Climate Data Record




*The trends from AIRS, IASI, and CrIS in overlapping time periods are very similar*

# CrIS NASA L1B Timeline



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# CrIS NASA L1B: Unique Attributes

- The CrIS NASA L1b processing and NOAA SDR (IDPS ) processing are designed for two different applications
- The NOAA SDR product was designed to support operational weather forecasting
- The NASA L1B product priority is long term climate records:
  - homogeneous radiance product across multiple sensors, including inter-satellite calibration efforts with rigorous radiometric uncertainty estimates for all observations
  - "operational science" code: transparent and accessible code base produced by a small PI led team of engineers, scientists, and programmers in a high-level language that is easily understandable by current and future users
  - long-term monitoring and validation of the CrIS L1B data record and maintenance and refinement of the L1B software by the same algorithm and software development team
  - support reprocessing of the full mission datasets with a consistent calibration algorithm and optimal calibration coefficients and parameters (the mission datasets have been reprocessed several times already),
  - software and re-processing is under NASA control

# CrIS NASA L1B: Unique Attributes

- The underlying calibration equation and theory for CrIS NASA L1b Version 3 processing and current IDPS (NOAA SDR) processing are similar but may diverge, as needed, for future releases
  - CrIS NASA L1B Version 3 includes correction of the Doppler shift due to the Earth's rotation. The CrIS NASA L1B Version 4 will include full Doppler correction (Earth rotation and satellite velocity). The NOAA SDR product does not include Doppler correction.
  - Ongoing efforts to assess and mitigate any remaining "spectral ringing" in the L1B product have been made and will continue, which simplifies the use of data across multiple CrIS sensors.

| | NOAA SDR | NASA L1B |
|---|---|---|
| Granule size | 31.997 sec | 6 min |
| File type | HDF5 | NetCDF4 |
| Geolocation | in a separate file | included in the same file |
| Terrain-corrected Geo? | no | yes (corrected and uncorrected geo available) |
| Doppler correction? | no | yes |
| Includes data for RU tool? | no, but output from NASA RU tool is applicable | yes |
| Wavenumbers included? | no | yes |
| Missing data representation | multiple values in -999.x range | single value near data max or min (NetCDF4 fill value) |

# CrIS L1B Calibration Algorithm

- CrIS uses a physical calibration with clearly defined traceability and uncertainty assessment for all calibration parameters *(No nonphysical correction parameters)*
- Key components of the algorithm: FFT, nonlinearity correction, radiometric calibration, spectral calibration (including self-apodization correction), polarization correction
- Radiometric calibration: Complex calibration method (Revercomb, 1988)
  - A simple two-point calibration (Internal Calibration Target and Deep Space View) is applied to the Earth scene spectra after all spectra have been corrected for any nonlinear response
  - Efficiently accounts for differences in phase between instrument self-emission and input radiance (no need for a traditional phase correction)
- Full calibration is applied to **complex** spectra (producing real and imaginary components for the output)
  - Imaginary part of calibrated radiance is a powerful calibration diagnostic

# CrIS L1B Calibration Algorithm

- Spectral calibration: an onboard neon source is used for spectral calibration, and instrument self-apodization correction via inverse self apodization operator (Genest and Tremblay, 1999; Desbiens et al., 2006).
  - Self-apodization is caused by the expected mixing of signals with a continuous range of OPD scales that arises from the range of field angles passing through the interferometer
  - This effect is defined very accurately by sensor geometry and can be rigorously corrected
  - The sensor geometry is determined in TVAC and confirmed and monitored for any changes on-orbit
  - Corrects all spectra in each 3x3 array (corner, side, and center FOVs) to look like they were collected on the central optic axis
  - CrIS spectral calibration and SA correction provide a consistent sampling and ILS across all CrIS sensors and FOVs
- NEdN Estimate: Full calibration (without Doppler or polarization correction) is used to produce an NEdN estimate for every granule.

# Radiometric Calibration: Key Calibration Parameters and Traceability

*Traceability is critical for a climate data record*

Detector Nonlinearity: quadratic nonlinearity coefficient and DC Level

$a_2$ and $V_{DC}$

- Pre-launch Out-of-band harmonic analyses
- Pre-launch ECT views at six temperatures
- Post-launch Out-of-band harmonic analyses
- Post-launch FOV-to-FOV analyses

ICT (Internal Calibration Target): ICT temperature and emissivity

$T_{ICT}$ and $e_{ICT}$

- Pre-launch PRT calibrations
- Pre-launch emissivity characterization
- Pre-launch $L_{ICT}$ verification using TVAC External Calibration Target (ECT) with $T_{ECT} = T_{ICT}$

Polarization: combined scene mirror and sensor polarization and sensor polarization angle

- Optical design analyses and component level measurements
- Post-launch pitch maneuver data

$p_r p_t$ and $\alpha$

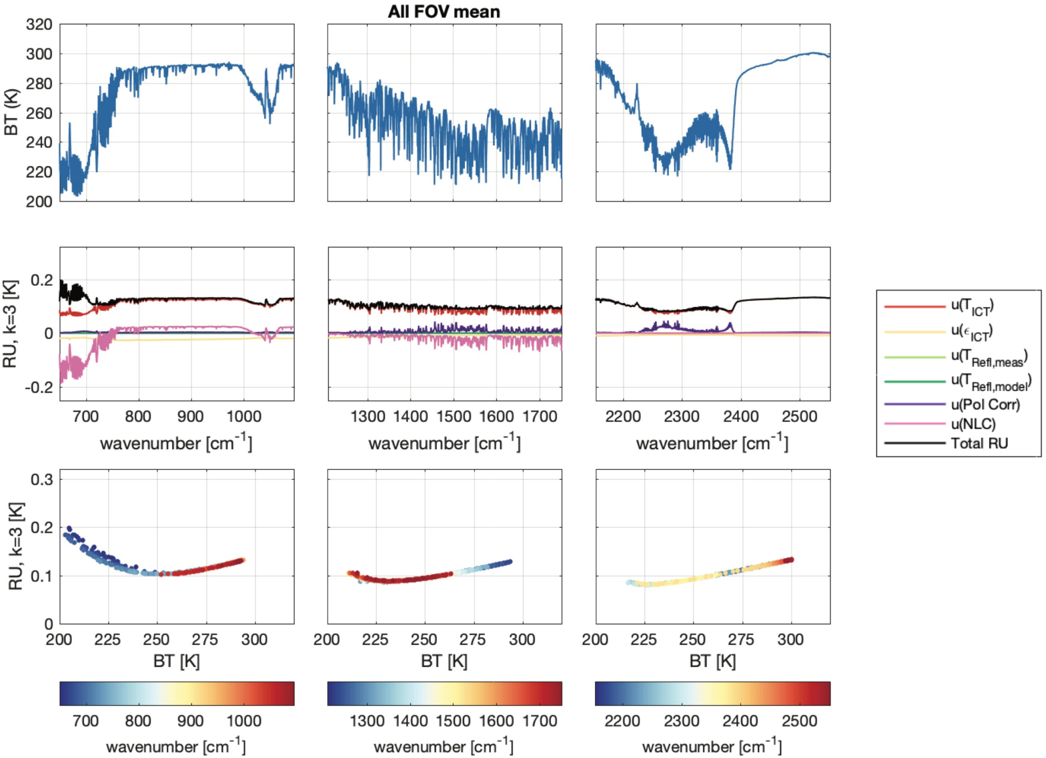
External Calibration Target (ECT) view TVAC data used to characterize the sensor radiometric nonlinearity and provide end-to-end calibration traceability to NIST via temperature sensor calibrations and NIST TXR measurements

# Radiometric Uncertainty and the Radiometric Uncertainty Tool

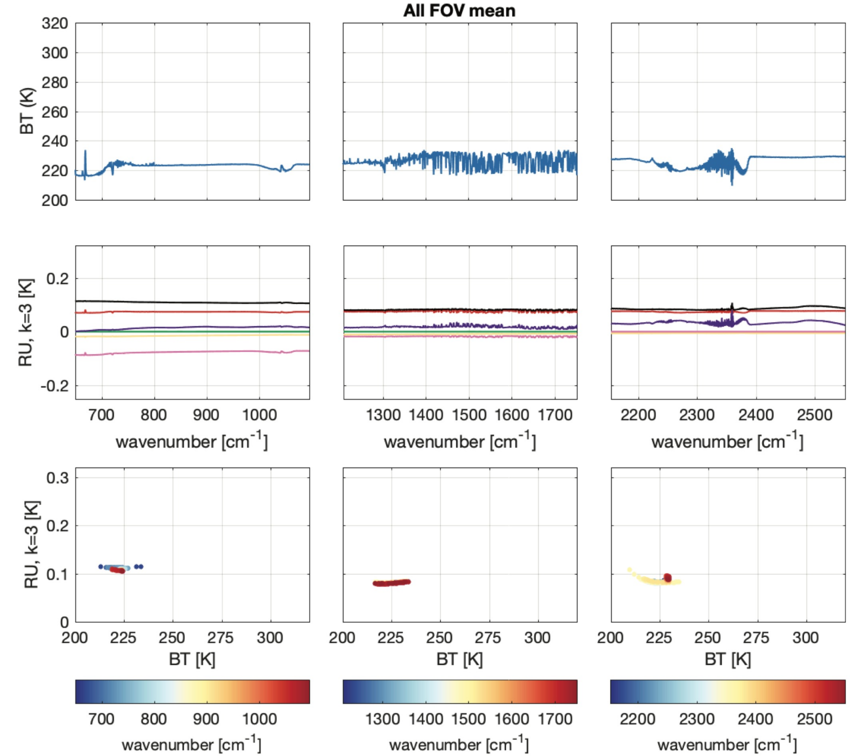
- A critical aspect of a reference sensor and climate quality measurement record is the documentation of and ability to calculate the uncertainty in the sensor measurements
- The radiometric uncertainty (RU) in the calibrated radiance can be determined via a perturbation analysis of the calibration equation
  - Equivalent to a differential error analysis described in the GUM (Guide to Uncertainty in Measurements)
- SNPP CrIS: Tobin, D., et al. (2013), Suomi-NPP CrIS radiometric calibration uncertainty, *J. Geophys. Res. Atmos.*, 118, 10,589–10,600, doi: 10.1002/jgrd.50809.
- The CrIS NASA L1B V3 product contains the information needed to accurately calculate the radiometric uncertainty for **any** CrIS NASA L1B calibrated radiance
- Radiometric Uncertainty Tool documentation, sample code, and static RU parameters are now available via the GES DISC L1b landing pages ('NASA Cross-track Infrared Sounder (CrIS) Level 1B Radiometric Uncertainty Description Document, v3')

# Radiometric Uncertainty Tool

## Example Tropical Ocean Scene: NOAA-20

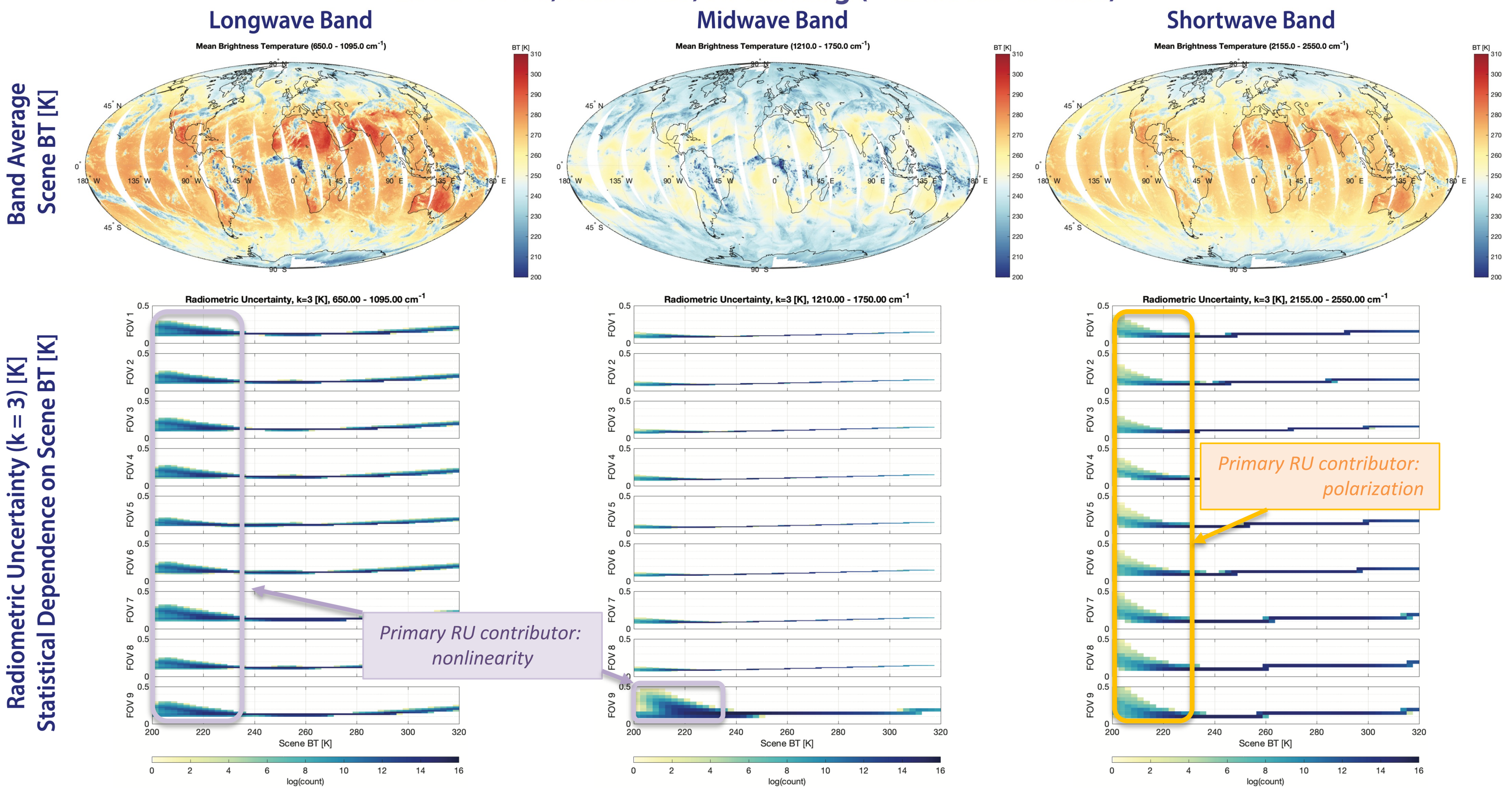



## Example Antarctic Scene: NOAA-20



# Radiometric Uncertainty Tool

## 2018-04-01, NOAA-20, Ascending (~12 hours of data)



# FSR and NSR

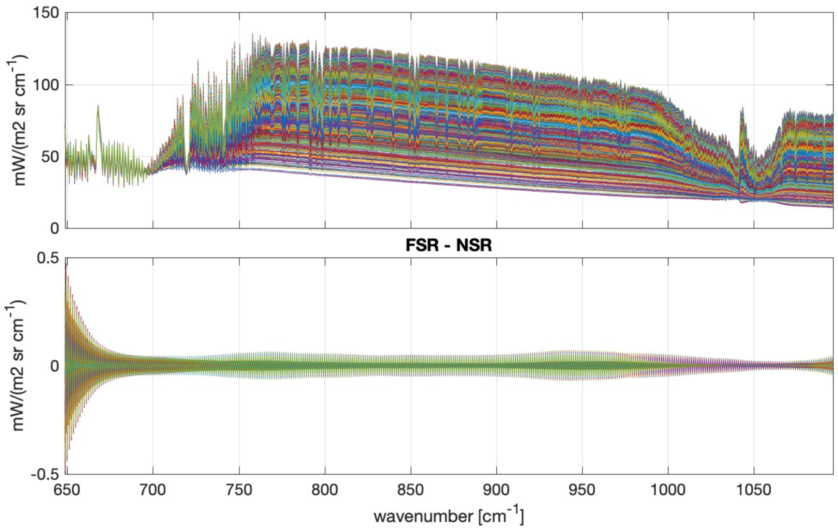
- The spectral resolution of SNPP CrIS was changed during the mission
- Initially the MW and SW bands were truncated onboard to 0.4 and 0.2 cm interferogram MOPD. This resulted in a product with spectral resolution of 0.625 $cm^{-1}$ in the LW band, and 1.25 $cm^{-1}$ MW band and 2.5 $cm^{-1}$ in the SW band (CrIS NSR)
- During the SNPP mission, the decision was made to downlink full resolution data in all three CrIS bands, supporting the production of a CrIS product with a spectral resolution of 0.625 $cm^{-1}$ in all bands (CrIS FSR)
- To support the two goals of providing the longest possible dataset and the highest resolution dataset, the SNPP CrIS L1B product is available at two spectral resolutions:
  - Normal Spectral Resolution (NSR), starting on April 19, 2012
  - Full Spectral Resolution (FSR), starting on November 2, 2015
- NOAA-20 has supported FSR product for the entire mission
- Current plan is to produce the NOAA-20 product only at FSR

# FSR and NSR

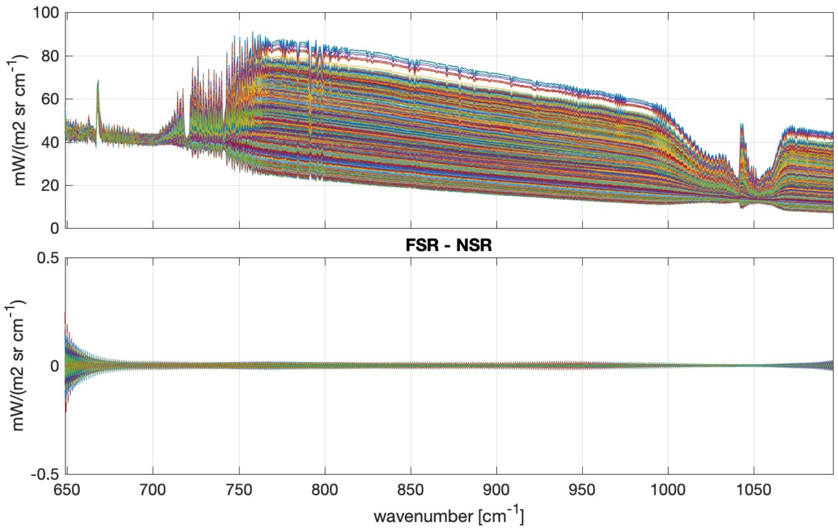
- To ensure a consistent NSR product through the life of the mission, the first step in the NSR product is to truncate the interferograms to the start of mission interferogram lengths
- This results in small “spectral ringing” differences in the unapodized SNPP CrIS LW NSR and FSR products
- We are currently working on a ringing removal technique

## Example FSR – NSR Difference (bottom panels)

### SNPP Tropical Granule




### SNPP Antarctic Granule



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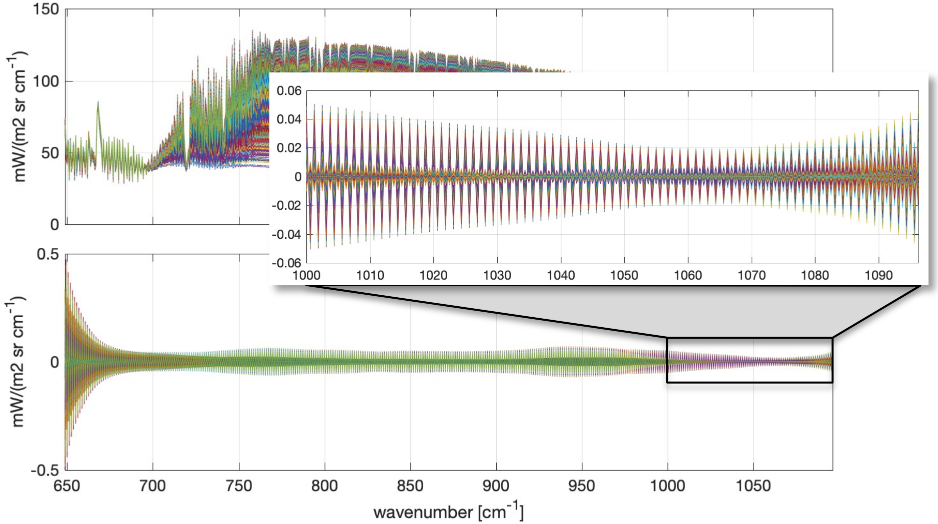
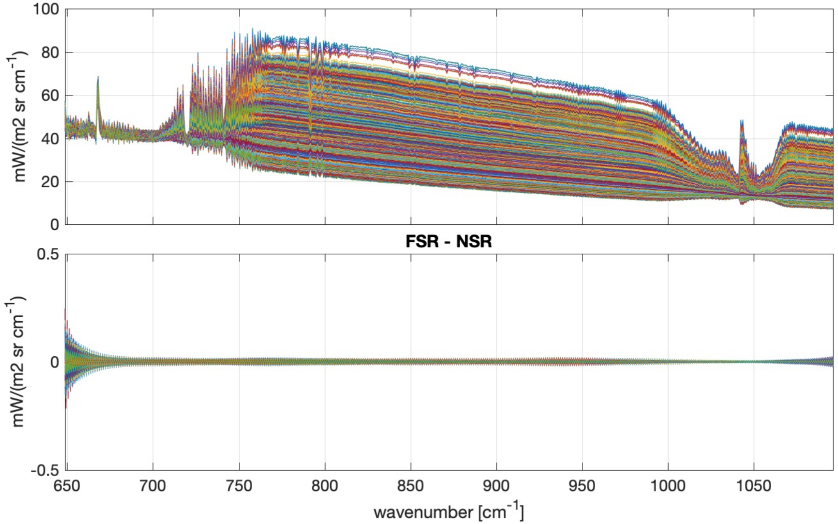



### SNPP Antarctic Granule



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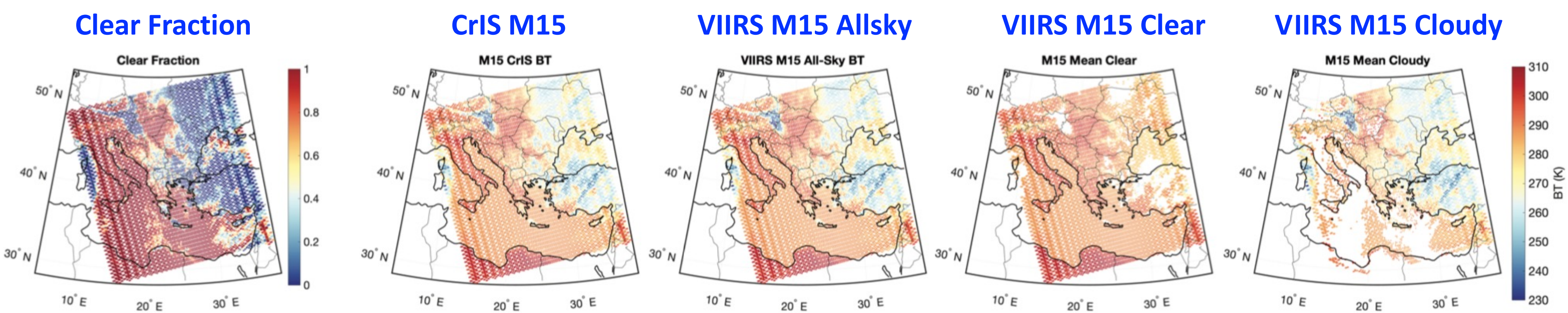
# VIIRS / CrIS IMG Product

- A "value added" product, that provides VIIRS to CrIS footprint collocation information in small, easy to use files with common file granulation to the NASA VIIRS and CrIS L1b products
- Collocate CrIS FOVs with VIIRS Cloud Mask and Radiances/Reflectances
- For each CrIS and corresponding VIIRS L1B granule, CrIS/VIIRS collocation is performed, and the indices of VIIRS pixels within each CrIS footprint are written to an imager to sounder collocation file **(IMG_COL, 12-15 MB per file)**
- A corresponding **IMG file** is also produced, containing statistics of the VIIRS (MVCM) cloud mask and VIIRS radiances and reflectances that have been collocated within each CrIS footprint **(IMG, ~6 MB per file)**

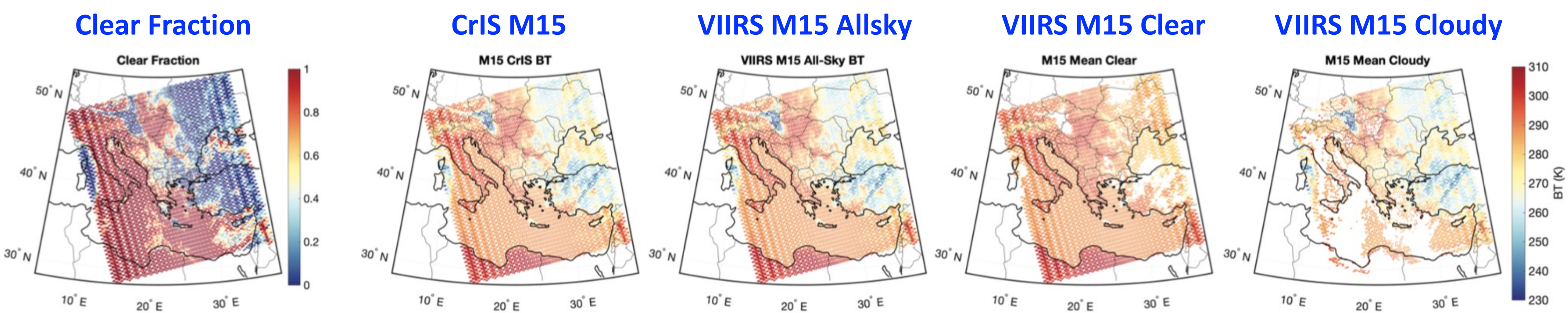



Example M15 IMG data, showing VIIRS Clear Sky BTs for clear and partially cloudy CrIS footprints

# VIIRS / CrIS IMG Product

- One-to-one relation to the {9 x 30 x 45} CrIS footprints in the L1b files
- Potential future work to create additional collocated fields or files, e.g.
  - VIIRS clouds heights, aerosols, etc
  - Surface temperature, re-analysis fields, carbon tracker, etc.
- Data processed at the Atmospheres and mission length products delivered to and available at GES-DISC
- Recent applications: Ammonia ”non-detects” paper, Evans et al. submitted.

*We are ready to expand the IMG product and apply it to AIRS/MODIS, but need the resources and support from NASA to move forward*

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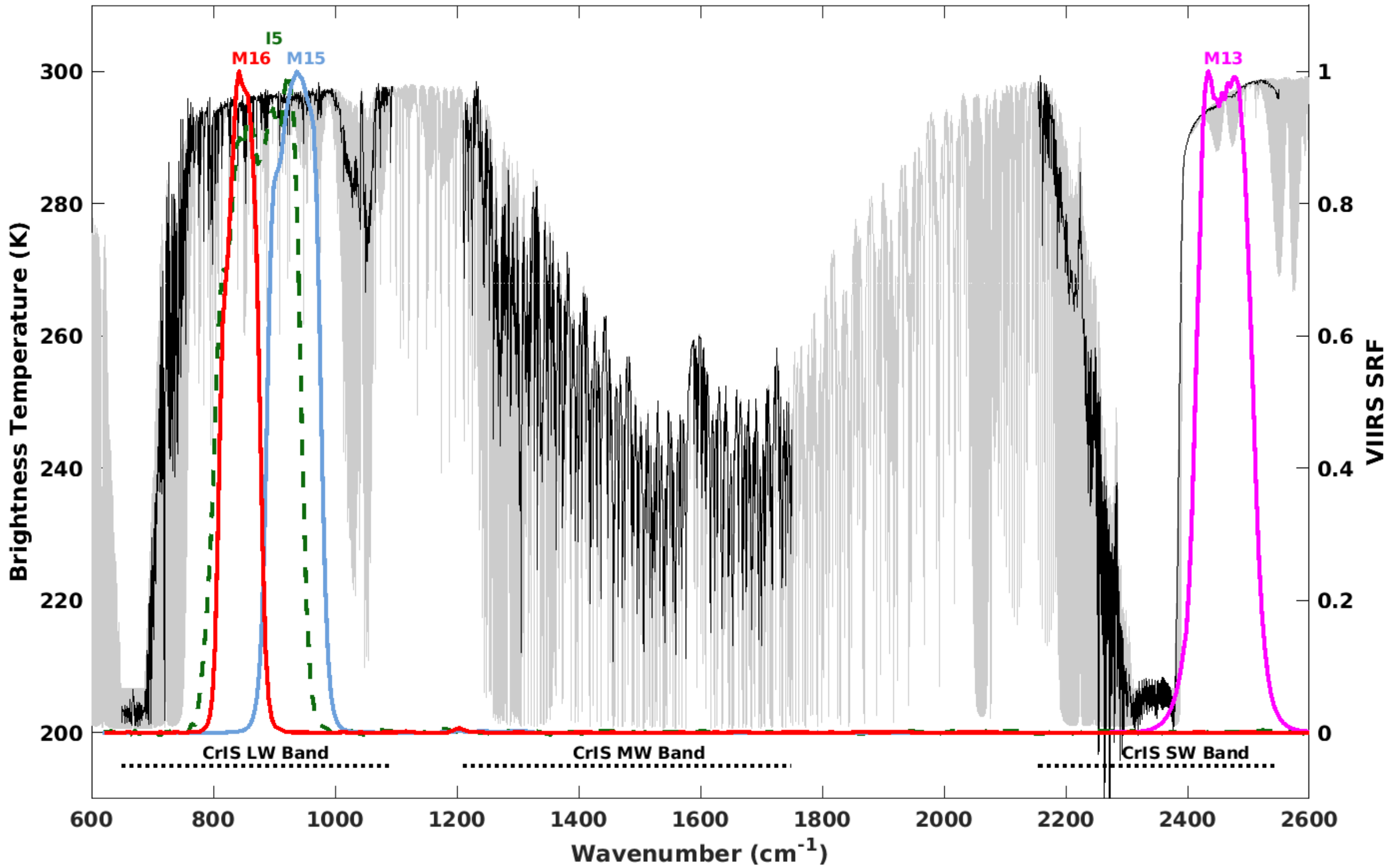
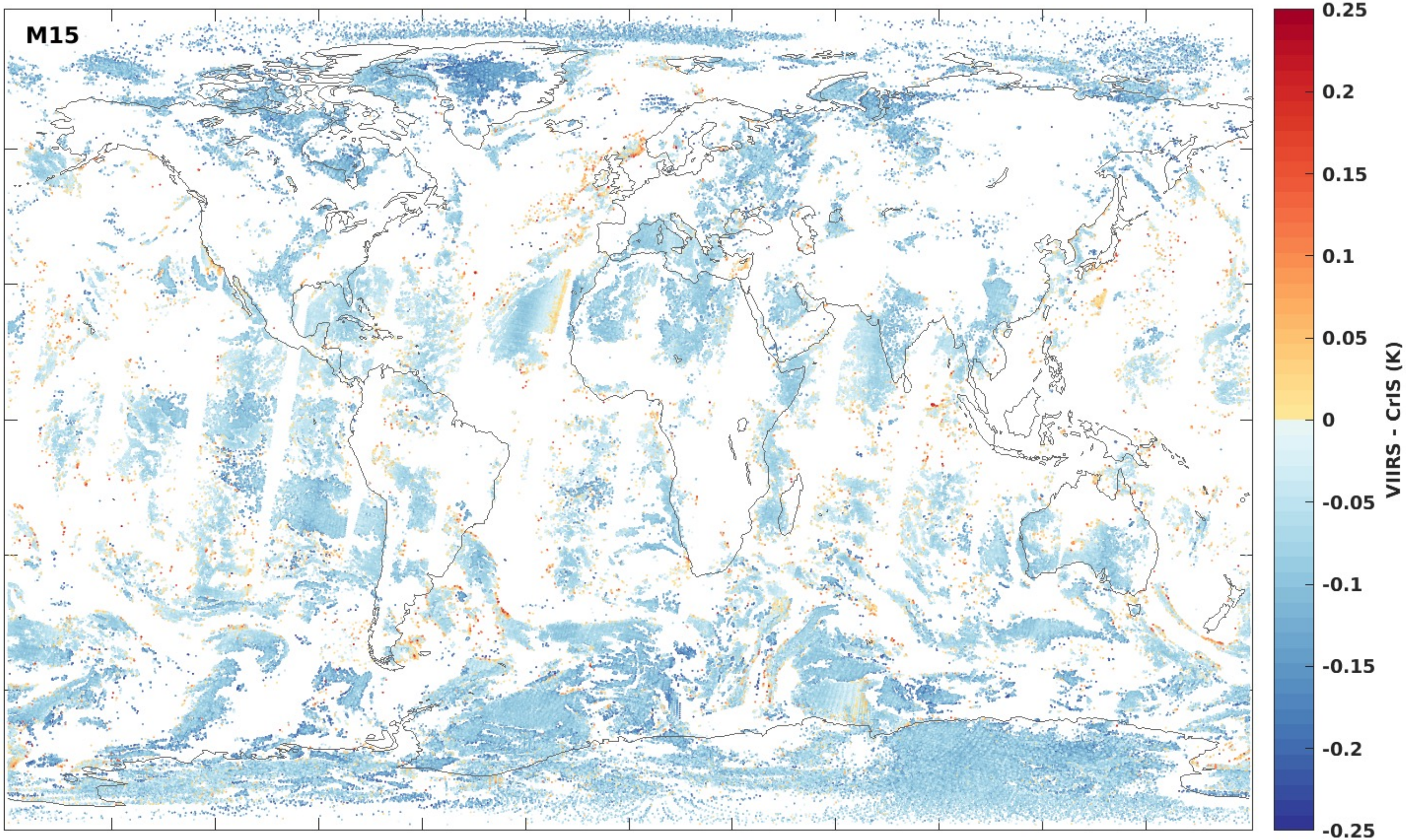
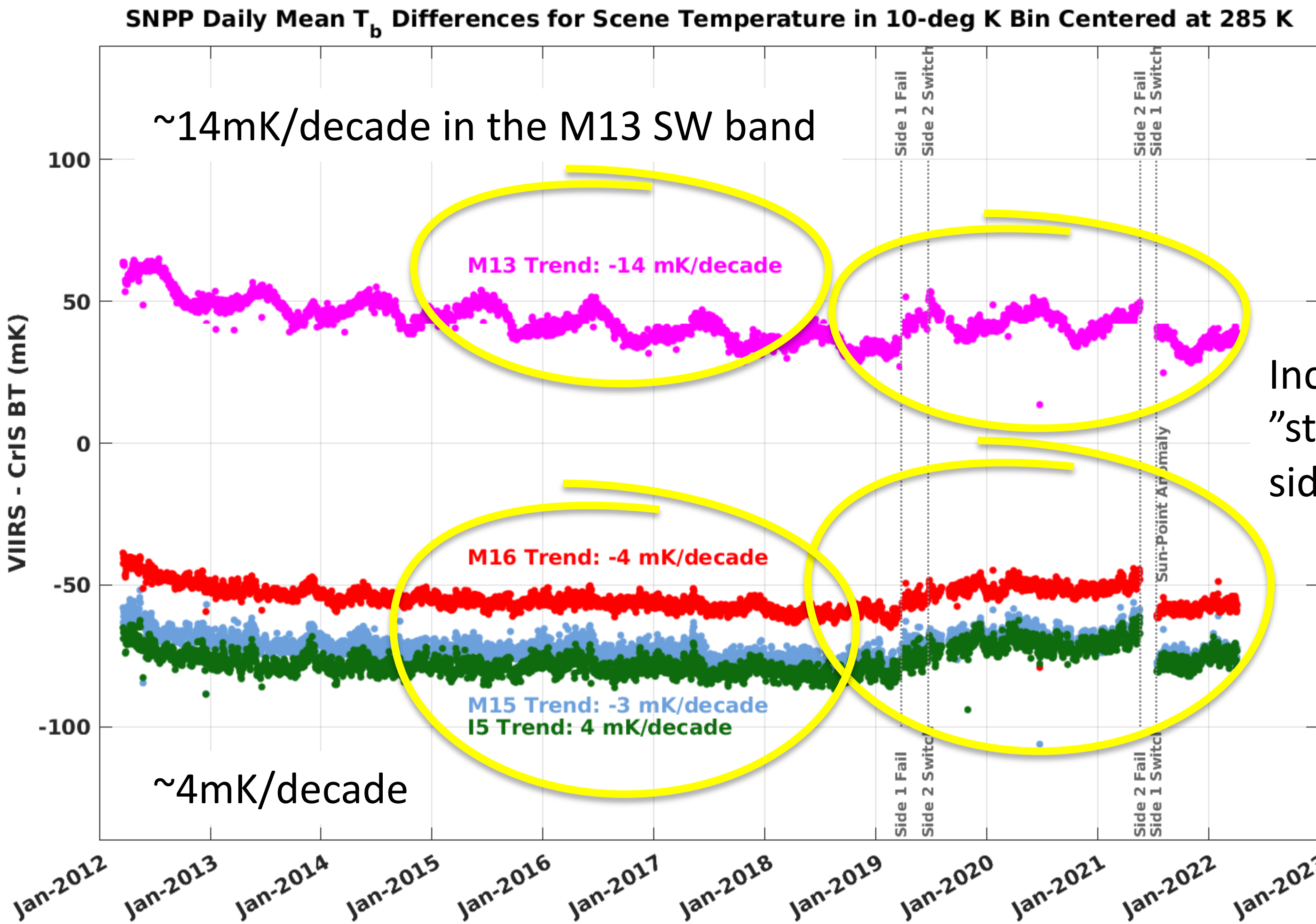
# VIIRS SRFs and CrIS Spectral Coverage



# Single Day Of VIIRS – CrIS (Uniform Scenes)



# Mission Length VIIRS – CrIS (SNPP)




Incredibly small "step" at CrIS side switches

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# Climate Hyperspectral Infrared Product (CHIRP)

## A New Approach for Climate Research

- Stay in radiance space "as long as possible”
  - Lowers uncertainty and effects of a-priori data
- Use appropriate sampling
  - Climate analysis can often be done with far lower sampling (avoid clouds for ex.)
- Time/space averaging can drastically lower compute and storage requirements
- "Retrievals" not always needed
  - Cloud trends
  - Events (fires, volcanic eruptions, extrema, dust)
- Requires homogeneous radiance record: "CHIRP". Same spectral and radiometric responses for AIRS and CrIS
- Atmospheric profile retrievals use radiance anomalies as input. With CHIRP this can cross instrument boundaries

# Climate Hyperspectral Infrared Product (CHIRP)

## CHIRP in the Cloud

- Save data into 64 x 72 = 4608 "Tiles". Each Tile is a series of "files" containing 16-days worth of data
- Allows (on an HPC filesystem) one to read in full mission, all scenes, in a single Tile in < 10 minutes
- Working to produce this product in the GES DISC cloud using zarr format for high-speed but simple cloud access to the scientific community
- ESDIS is just not oriented towards (a) "point" data like Level 1+2, and (b) has no concept of scientists doing data analysis in the cloud using their "normal" working environment (the unix/linux prompt)
- These problems should be easy to solve, but ESDIS is oriented to users of images and Level 3 data, not really what is needed in sounder science. We are presently "stuck"

# CrIS/CHIRP RTAs

- We continue to produce CrIS-NSR and CrIS-FSR RTAs that use same software as AIRS RTA
- Compatibility with AIRS RTA is extremely important for CLIMCAPS Level 2 algorithms
- Recent versions use the HITRAN 2020 line parameter database and improved continuum models (esp. in the 2400 $cm^{-1}$ sounding region).

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# Summary

- The CrIS sensors are producing extremely high-quality calibrated radiance data records and will extend the record through 2040 and potentially beyond
- The CrIS L1B team continues to support efforts relating to creating climate quality products from five CrIS sensors: two in orbit, one to be launched in November, one just completed ground testing, and one to undergo ground testing this upcoming year
- The CrIS NASA L1B project is responsible for providing the CrIS NASA L1B, IMG, CHIRP, and RTA products, and we are here to help investigators understand and use the data
- This climate quality radiance dataset enables all follow-on NASA Sounder science and product generation, including atmospheric sounding products, trace gas products, and various climate process and trending studies
- NASA support is critical for production of this multi-sensor climate quality radiance dataset and continuation of NASA Sounder Science activities through the JPSS series

Product contact info:

- CrIS L1B Team: cris.l1b.support@ssec.wisc.edu
- Sounder SIPS: sounder.sips@jpl.nasa.gov

*The L1B Version 3 Test Report is available at the L1B Product Landing Pages*

# Current Products

**CrIS L1B V3 products:**

S-NPP CrIS L1b NSR v3, SNPPCrISL1BNSR: https://doi.org/10.5067/OZZPDWENP2NC
S-NPP CrIS L1b FSR v3, SNPPCrISL1B: https://doi.org/10.5067/ZCRSHBM5HB23
JPSS-1 CrIS L1b FSR v3, SNDRJ1CrISL1B: https://doi.org/10.5067/LVEKYTNSRNKP

**IMG and IMG_COL v2 products:**

S-NPP CrIS IMG, SNDRSNCrISL1BIMG: https://doi.org/10.5067/NC505NHFIHCY
JPSS-1 CrIS IMG, SNDRJ1CrISL1BIMG: https://doi.org/10.5067/A7SVIO2AAD0E
S-NPP CrIS IMG_COL, SNDRSNCrISL1BIMGC: https://doi.org/10.5067/8ABZCV1TKE8D
JPSS-1 CrIS IMG_COL, SNDRJ1CrISL1BIMGC: https://doi.org/10.5067/51CRDMSIA1YJ

**CHIRP v1 products:**

Inter-instrument product, SNDR13CHRP1: https://doi.org/10.5067/WIG2N5C20MRJ
AIRS only, SNDR13CHRP1AQCal: https://doi.org/10.5067/G1DTUEAV5I18
S-NPP CrIS only, SNDR13CHRP1SNCal: https://doi.org/10.5067/BS76XFNJVRXL
JPSS-1 CrIS only, SNDR13CHRP1J1Cal: https://doi.org/10.5067/MK6ED0BPUBKJ

# Acknowledgements

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UMBC L1B Team: Larrabee Strow, Howard Motteler, Steven Buczkowski, Sergio DeSouza-Machado, Chris Hepplewhite

Jim Gleason, NASA HQ

The NOAA CrIS Cal Val Team, led by Flavio Iturbide

Dave Johnson, NASA LaRC

Sounder-SIPS and Atmosphere-SIPS Teams

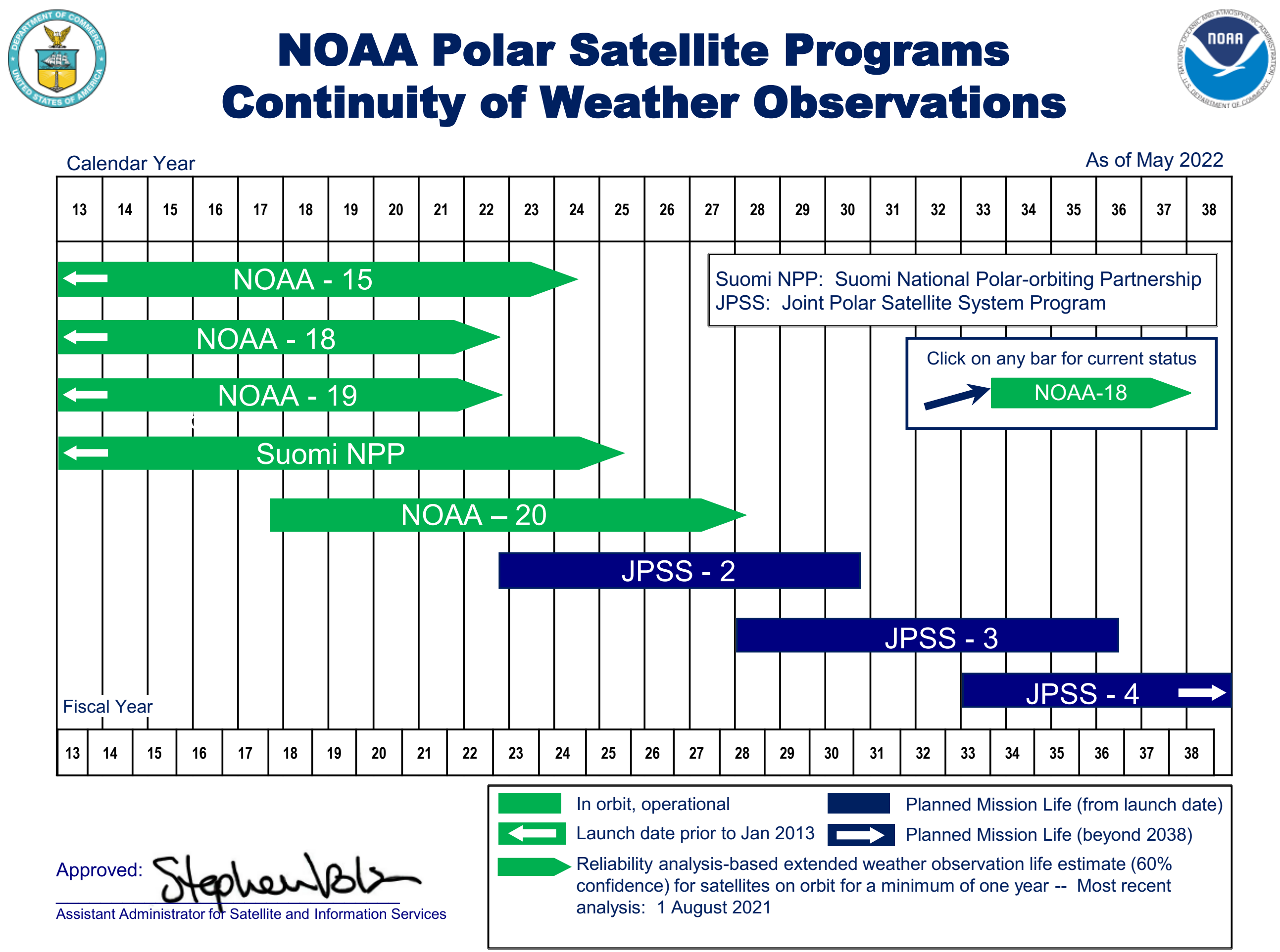
GES-DISC

The NASA Sounder Science Leads: Vivienne Payne, Larrabee Strow, Joao Teixeira

The NASA Sounder Science Team

# Extra Material

# NOAA Flyout Chart (As of May 2022)




*https://www.nesdis.noaa.gov/current-satellite-missions/currently-flying*

# Key Features of a Climate Data Record

## Climate Data Record (CDR)

"A time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change" (US National Research Council, 2004)

- **"Continuity"** of an Earth measurement exists when the **quality** of the measurement for a specific quantified Earth science objective is maintained over the required temporal and spatial domain set by the objective.
- **"Quality"** is characterized by the combined standard uncertainty, which includes instrument calibration uncertainty, repeatability, time and space sampling, and data systems and delivery for climate variables (algorithms, reprocessing, and availability).
- **"Consistency"** requires that instruments introduced to continue an existing CDR produce "backward compatible" measurements that allow continuation of the CDR without introducing discontinuities in the record.
- Since there is no "truth" available, ensuring that a data record satisfies the CDR criteria is challenging: multiple independent intercomparisons involving both satellite and surface/in-situ measurements are needed.

"Earth Radiation Balance", Norm Loeb, NASA LaRC; Climate and Radiation Monitoring - Mini-symposium, JPL Center for Climate Sciences

National Research Council. 2004. *Climate Data Records from Environmental Satellites: Interim Report*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10944.