Assessment of Current Sounding Capabilities on Small Sats/Cube Sats

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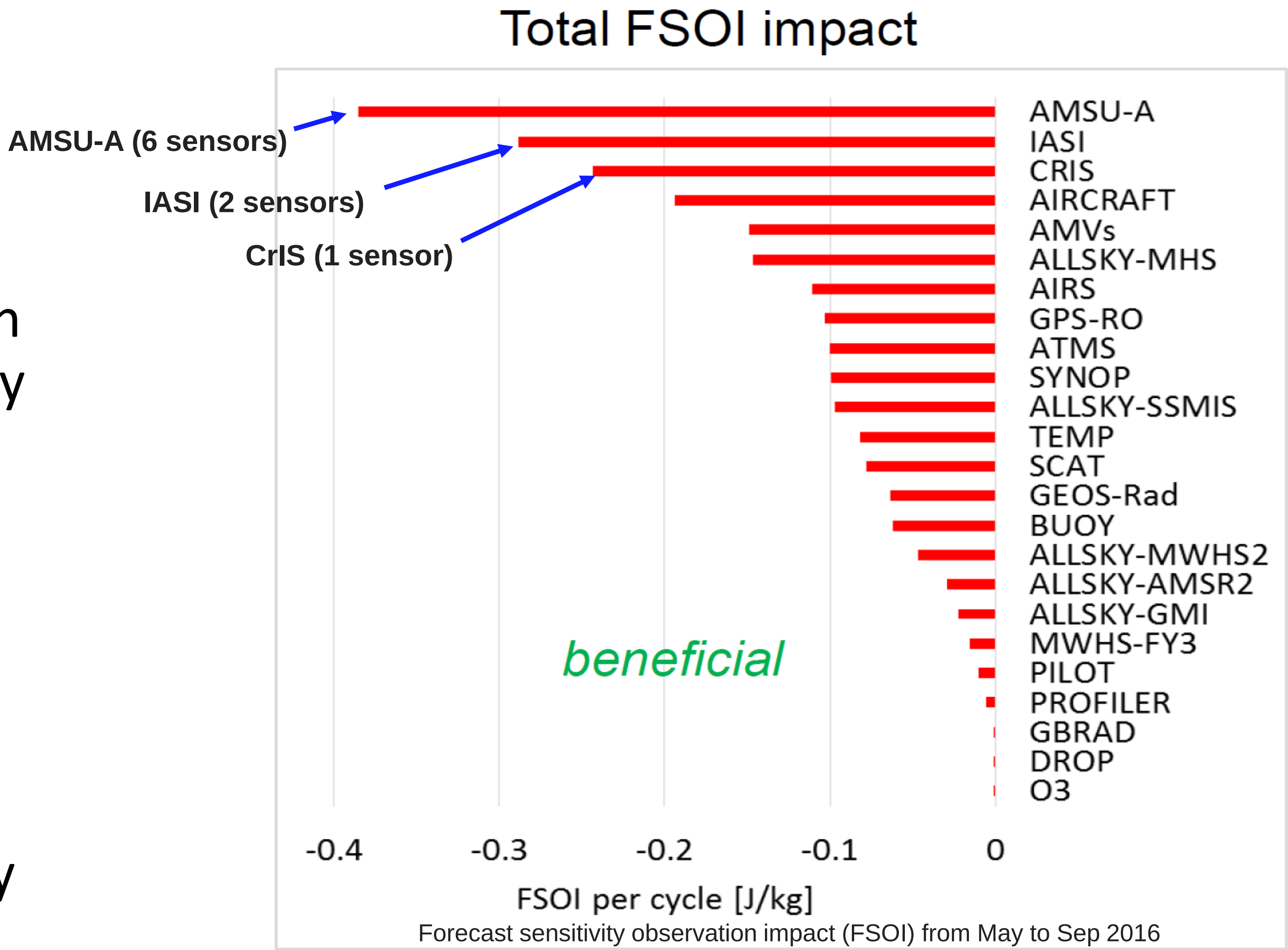
Outline

- Background
- A framework for assessing Smallsat sounding instrument performance
- Integrated calibration/validation system using operational systems as backbone for smallsat
- Example using the TEMPEST-D data as proxy
- Study of onboard processing for hyperspectral sounders to reduce downlink data volume

Background: Impact of Major Observing Systems on Reducing 24-h Forecast Errors

- Legacy Microwave, infrared sounders, and GNSS-RO are on top of the list with high impact scores
- Forecast Sensitivity Observation Impact (FSOI) Assessments may vary from study to study
- Smallsat programs focusing on these technologies have high priorities
- A number of smallsat microwave and infared sounding missions are currently being developed



Forecast sensitivity observation impact (FSOI) from May to Sep 2016

Sources: Lupu, 2019, ECMWF Data Assimilation Course;
6th Workshop on the Impact of Various Observing Systems on NWP (WMO, 2016).

Evolution of Microwave and Infrared Sounders

- Past, present, and future instruments

MSU AMSU ATMS Smallsat Metop-SG/MWS LEO SounderSat Future

HIRS AIRS IASI CrIS Smallsat IASI-NG LEO SounderSat Future

GOES Sounder ABI Sounding Channels MTG/IRS GeoXO Future

Smallsat Background

- Proliferation of small satellite missions in recent years for weather applications, from Radio Occultation, Microwave, to Infrared.
- Smallsat constellations have distinct advantages: agile, cheaper, faster, smaller, compared to legacy systems which takes decades to develop.
- However, smallsats also have disadvantages for operational weather forecast, including short lifespan, lack of consistency, stability, calibration/validation, and data quality assurance.
- Two major areas of study in transitioning smallsat from research to operations to assess its full utility for NOAA’s Satellite Observing System Architecture (NSOSA):
  - Data quality assurance through calibration/validation
    - Develop a framework for integrated calibration and validation of multi-sensor
    - Accommodate diverse sensor types with large data volume, and address challenge in cross-calibration of SmallSat sensors for applications in data assimilation for weather forecasting.
  - Direct radiance assimilation into NWP (such as GFS)

Smallsat Studies at NOAA/STAR

- Developed a framework of Integrated Calibration/Validation System (ICVS) for Smallsat MW, RO, and IR sensors
- Implemented well-established satellite instrument Calibration/Validation techniques for SmallSat
  - Radiometric bias evaluation
  - Geolocation accuracy evaluation
  - Spectral calibration
- Evaluated available SmallSat data using the system developed for demonstration

Methodology and Data

Using current operational systems as backbone to evaluate smallsat data

- ➢ Microwave – ATMS/AMSU
- ➢ Infrared – CrIS/IASI
- ➢ Radio Occultation – COSMIC2/Metop/KOMPSAT5

Methodology

- ✓ Global comparisons of observations
- ✓ Simultaneous Nadir Overpass (SNO) methodology
- ✓ Comparison between observation and model calculations (O-B)
- ✓ Model calculation with radio occultation profile as input

Datasets used in the study

- TEMPEST-D SmallSat MW data
- COSMIC2 data
- Proxy data for infrared/microwave sounders

Smallsat Roadmap to Operational Use in NWP

Vendor

- Smallsat development, launch, early orbit checkout
- Data acquisition
- Experimentation

Early assessments

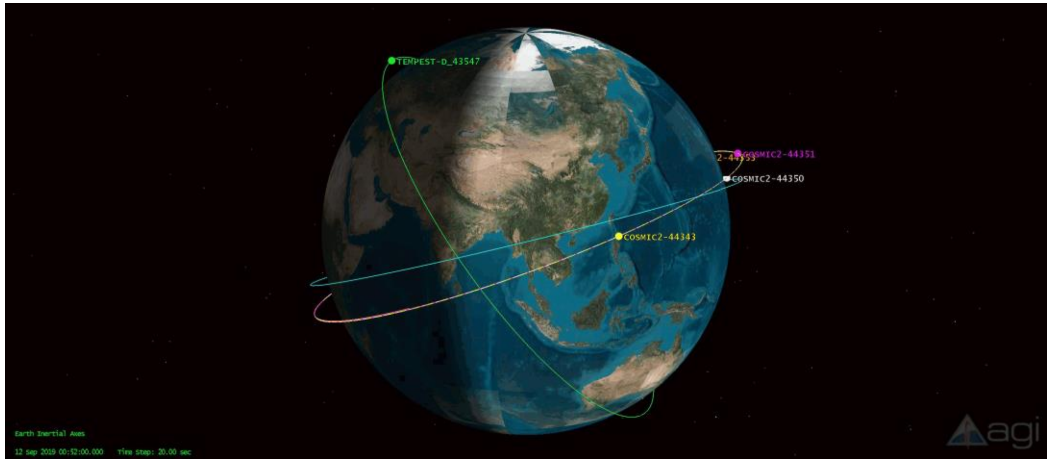
- Data quality assessment suitability for NWP (radiometric bias, noise, geolocation accuracy, spectral calibration, latency etc.)
- Data assimilation experiments & transition to operations
- Impact studies

Operational use

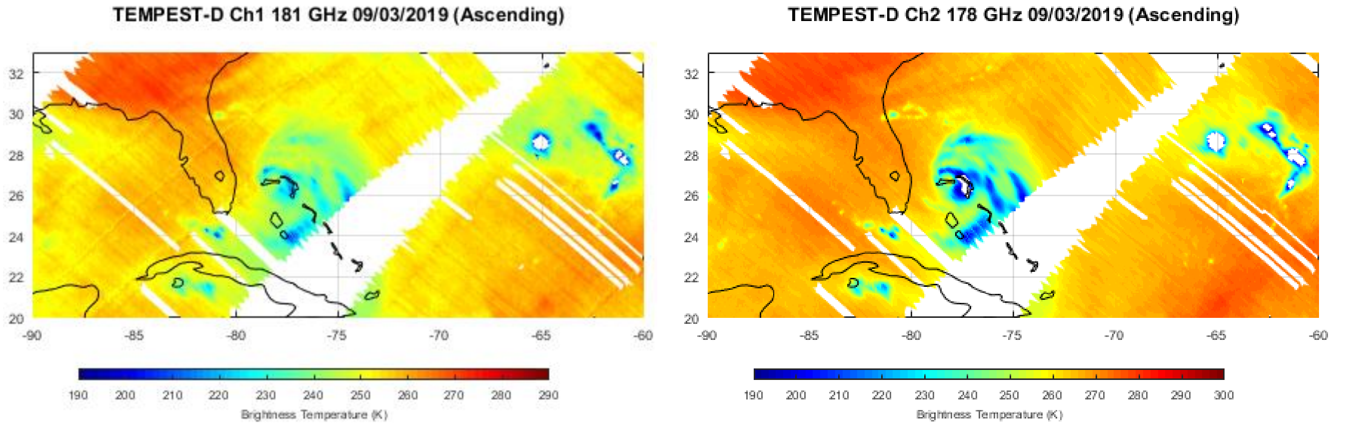
- Data acquisition
- Data management
- Data quality assurance
- Impact scores

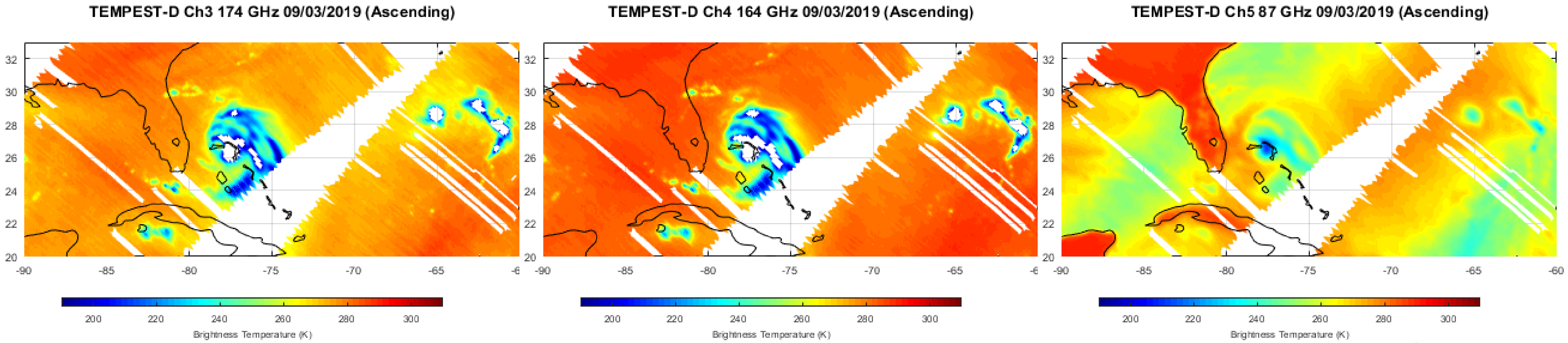
Research → Operations

Example 1: TEMPEST-D MW Sensor Performance and Data Quality Assessment



Hurricane Dorian observed by 5 channels of TEMPEST-D



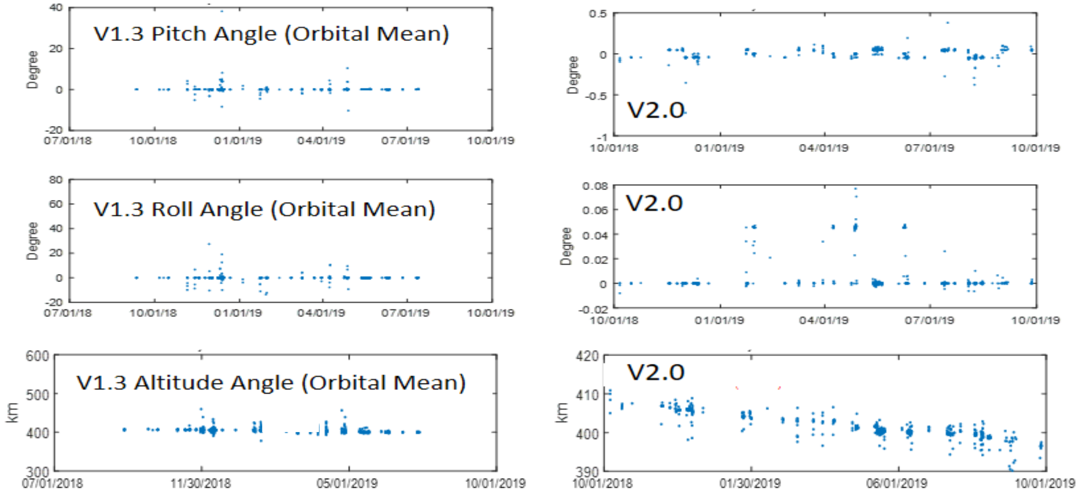


- TEMPEST-D
  - Launched: May 21, 2018
  - # of Channels: five (87-181 GHz)
  - Size: 6U
  - Line dropouts due to transmission bandwidth limit

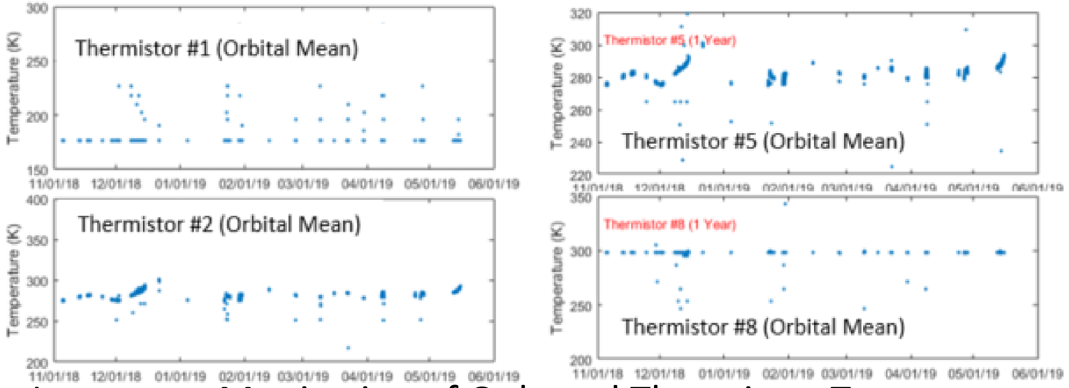
Overall TEMPEST-D is very successful

Integrated Cal/Val System (ICVS) for TEMPEST-D MW Sensor Performance Monitoring

- Daily and long term monitoring of the TEMPEST-D SmallSat made available online, including parameters such as:
  - Spacecraft position/attitude, instrument health, daily channel imagery, geolocation matching, and sensor radiometric performance
- Provided timely feedback to the TEMPEST-D science team on instrument performance and data quality evaluation for five processing releases
  - Using the SmallSat ICVS framework and tools, feedback provided within 24-48 hours through reanalysis of 6-10 months of historical TEMPEST-D datasets.
- Supported CRTM coefficient development to enable TEMPEST-D calculations
  - Essential step for data assimilation, product retrievals, and forward calculations.



Monitoring TEMPEST-D Attitude Data Quality Improvements with Processing Software Update



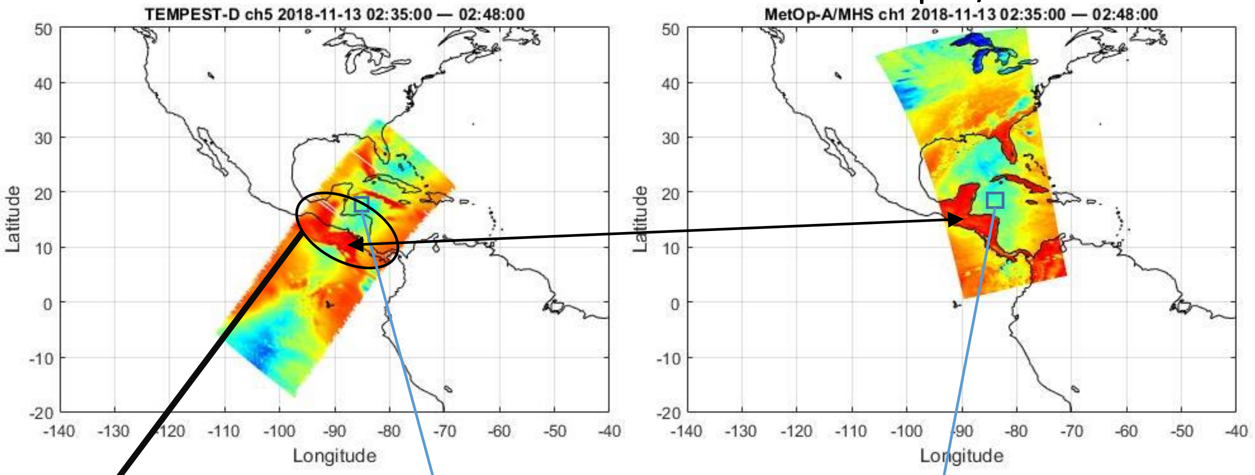
Long term Monitoring of Onboard Thermistor Temperature

Developed framework to evaluate and monitor smallsat/TEMPEST-D instrument performance and data quality

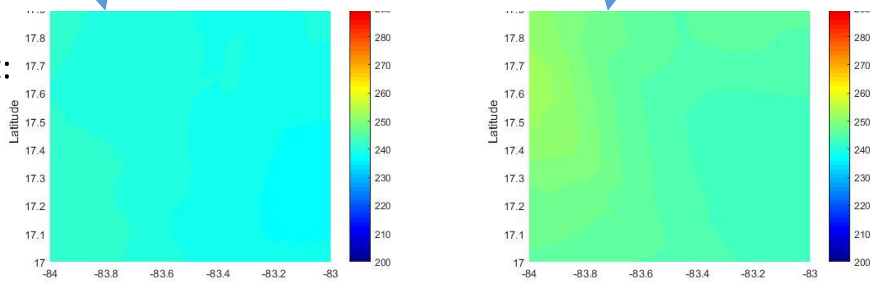
Assessing the Geolocation Accuracy

TEMPEST-D V1.3 vs. MetOp-A at SNO

TEMPEST-D V 1.3 | MetOp-A/MHS

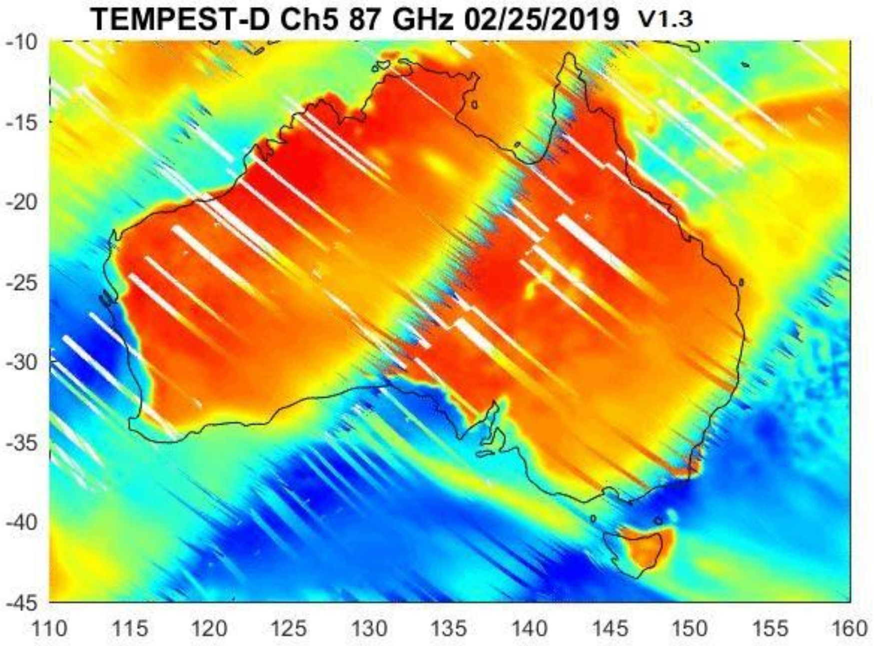


Estimated geolocation shift:
E-W: ~200 km
S-N: ~200 km

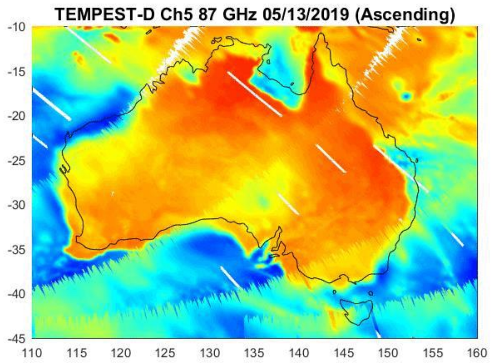


TEMPESt-D V1.3 vs. MetOp-A	TEMPEST-D V1.3 CH 5 (87 GHz)	MetOp-B/MHS CH 1 (89 GHz)	Difference
SNO day	2018-11-13	2018-11-13	
SNO time	02:39:11	02:44:30	319 seconds
Coordinates	17.35, -83.61	17.27, -83.55	10.16 km
TB (k)	239.83	245.25	-5.42 (too large)

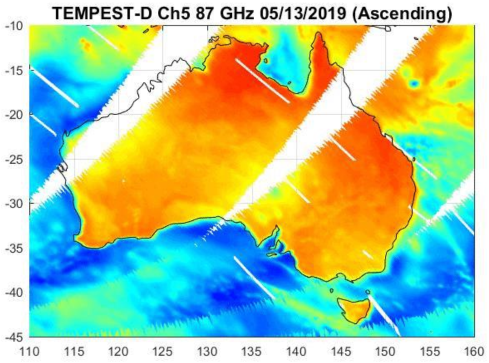
Improved Geolocation Accuracy



TEMPEST-D 87 GHz (May to July, 2019)



V 1.4



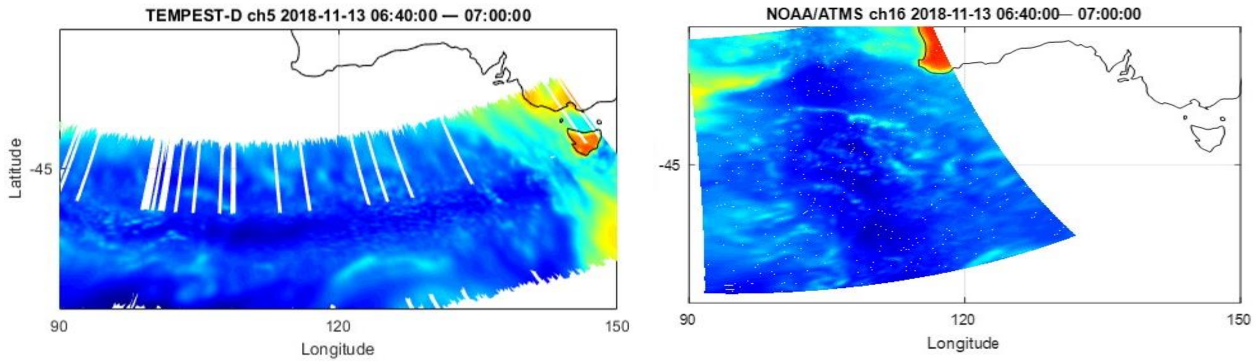
V 2.0

Working closely with the TEMPEST-D team to improve data quality

Radiometric Bias Evaluation of TEMPEST-D with four Legacy Sensors (SNO method)

- Four reference sensors:
  - NPP/ATMS, NOAA-20/ATMS, MetOp-A/MHS, MetOp-B/MHS
- SNO criteria:
  - Time and Distance Difference: 10 minutes and 20 km
  - BT homogeneity: standard deviation < 1 k
  - Viewing angle: nadir
  - Anomaly Rejection: Difference > 5 k

Example of SNO between TEMPEST-D and ATMS

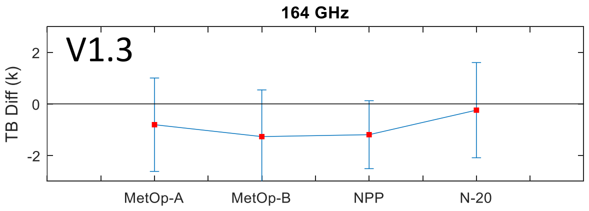


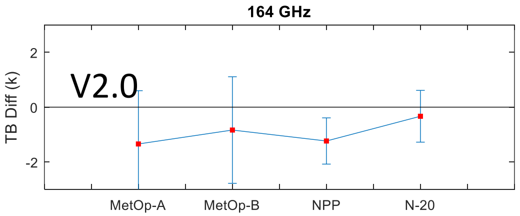
164 GHz channel

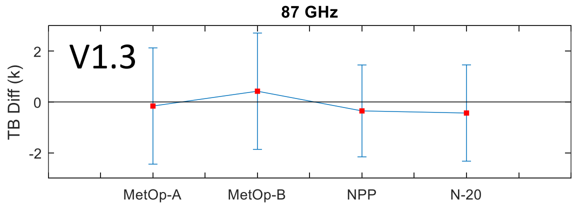
Reference sensor Channel (GHz)		V1.3 Qualified SNOs	V1.3 ΔBT	V2.0 Qualified SNOs	V2.0 ΔBT
MetOp-A/MHS	157	30	-0.81±1.81	47	-1.34± 1.94
MetOp-B/MHS	157	37	-1.27±1.92	72	-0.84± 1.82
NPP/ATMS	165.5	43	-1.20±1.32	85	-1.24± 0.84
NOAA-20/ATMS	165.5	34	-0.24±1.85	86	-0.33± 0.94

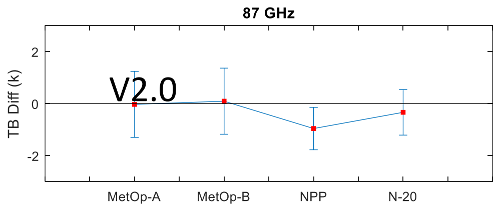
87 GHz channel

Reference sensor Channel (GHz)		V1.3 Qualified SNOs	V1.3 ΔBT	V2.0 Qualified SNOs	V2.0 ΔBT
MetOp-A/MHS	89	25	-0.16±2.29	67	-0.03± 1.27
MetOp-B/MHS	89	31	0.42±1.82	63	0.09± 1.37
NPP/ATMS	88.2	28	-0.44±1.98	51	-0.96± 0.82
NOAA-20/ATMS	88.2	24	-0.35±1.81	56	-0.34± 0.88









- Uncertainties of BT biases for 87 GHz channel are largely reduced in V2.0
- Confirmed radiometric consistency of TEMPEST-D V2.0 87 and 164 GHz channel data

Improved Radiometric Consistency with Reference instruments based on Feedback

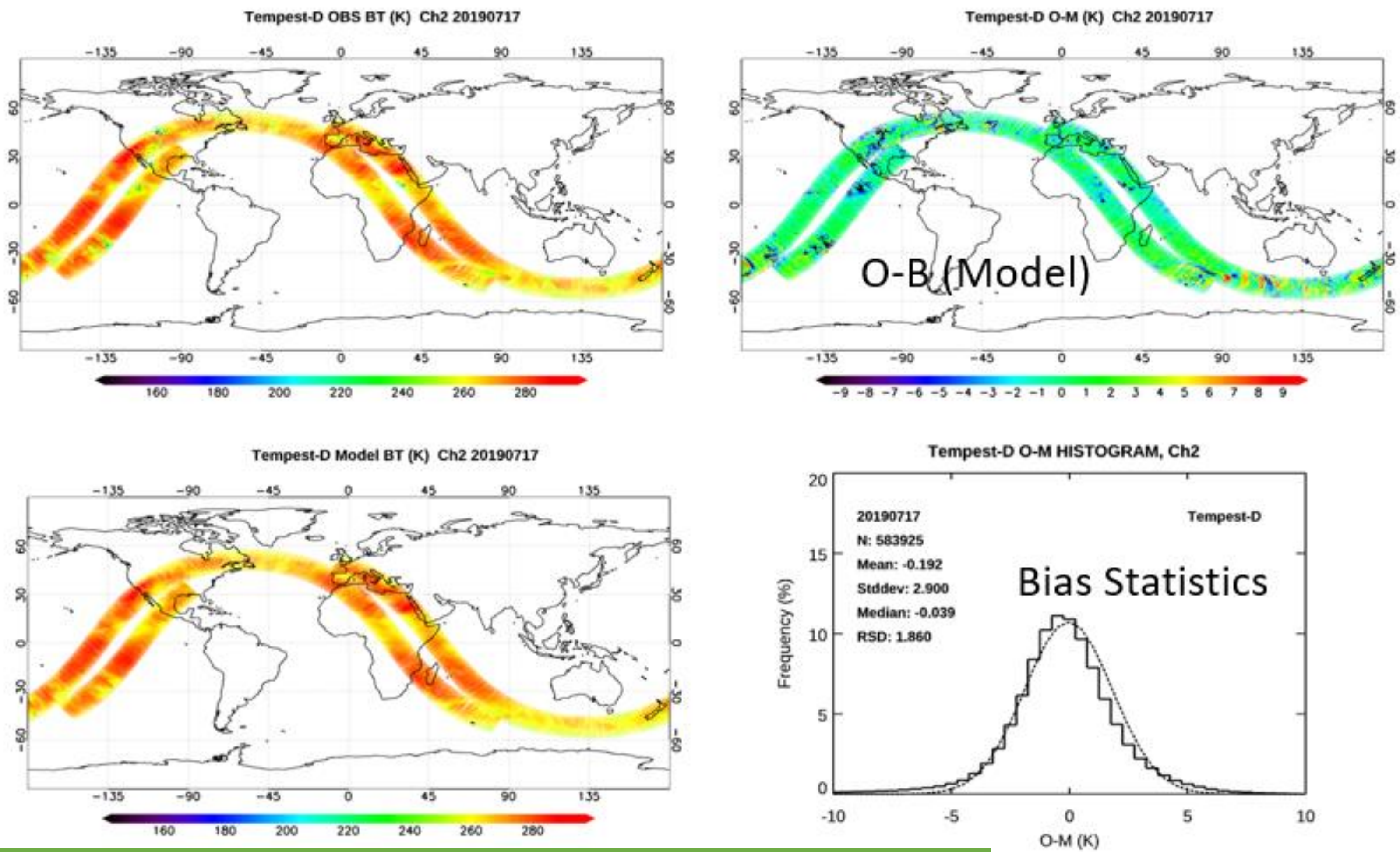
Ongoing Radiometric Bias Evaluation of TEMPEST-D with O-B (Model) Method

- Trending of radiometric biases of 5 channels of TEMPEST-D MW sensor with O-B (Model) is ongoing

- Both SNO-based and O-B-based bias trending of TEMPEST-D MW sensor for ocean or clear sky condition are being evaluated.

- Bias characteristics between TEMPEST-D and ATMS are currently being studied.

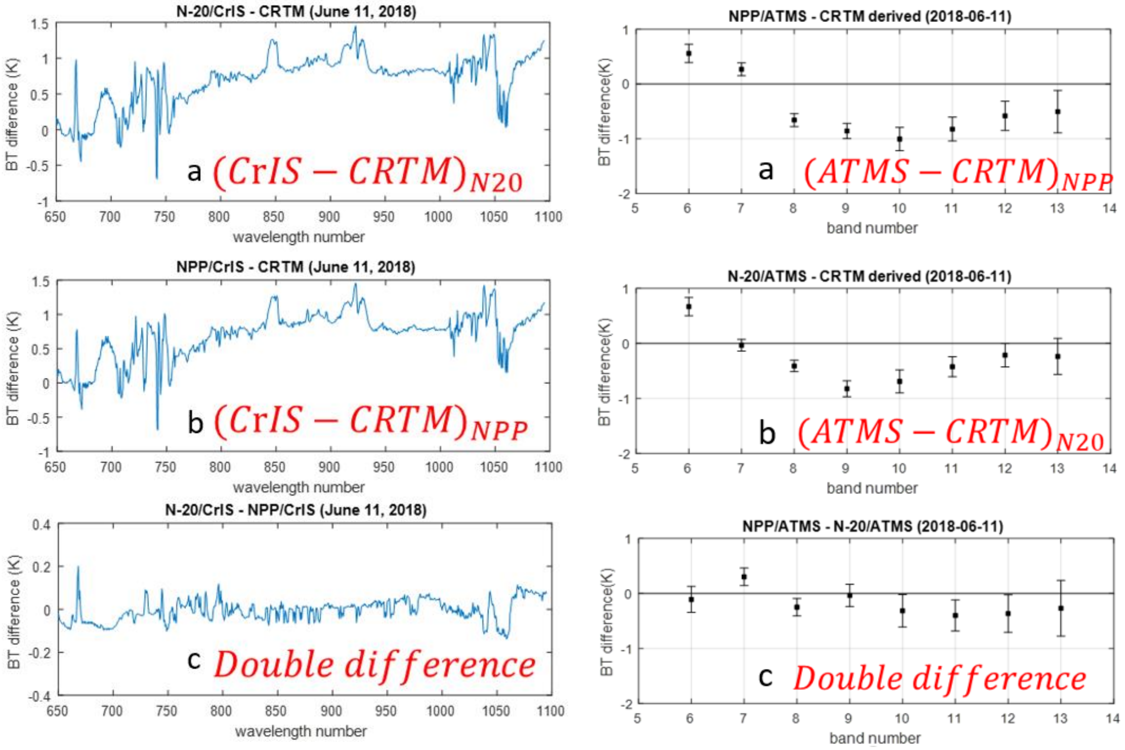
TEMPEST-D CH02 (178 GHz)



Radiative transfer model to account for channel frequency differences

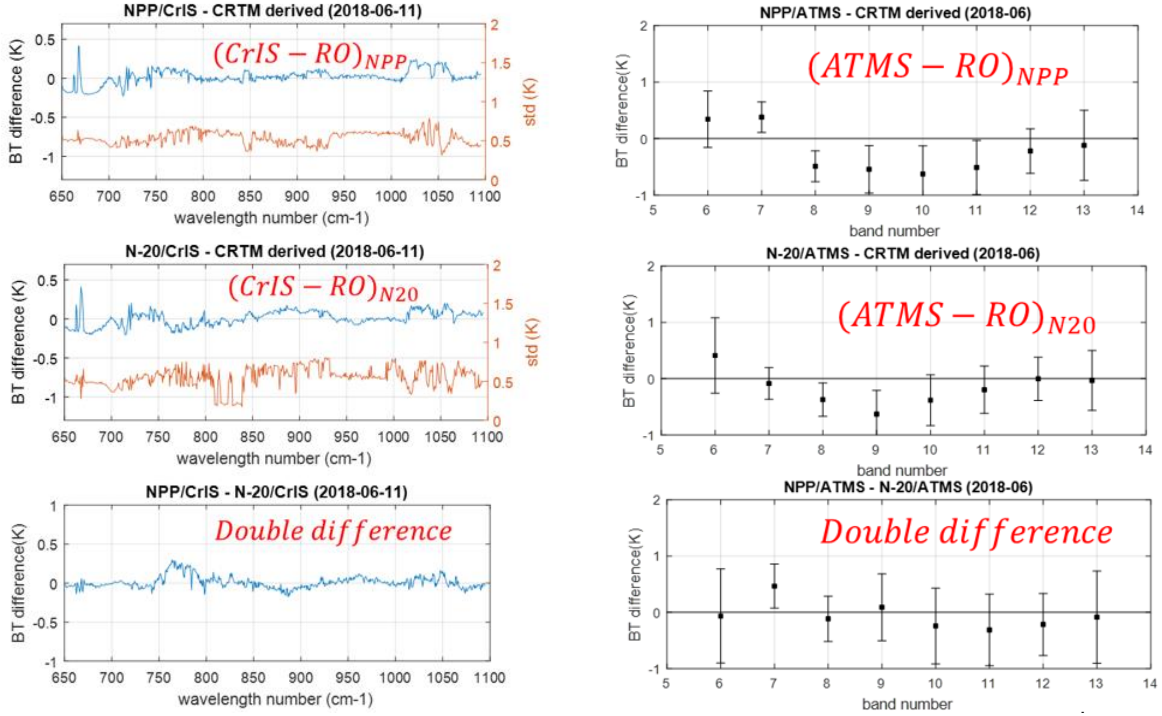
Example 3: Double Difference Analysis using CRTM

O-B (Model) Radiometric Bias Analysis



- Using NPP/NOAA-20 IR/MW sensors as proxy for SmallSat sensors
- Monitor O-B bias with CRTM-modeled BT profile from ECWMF reanalysis data

Inter-instrument (IR/MW vs. RO) Comparison through CRTM Modelling

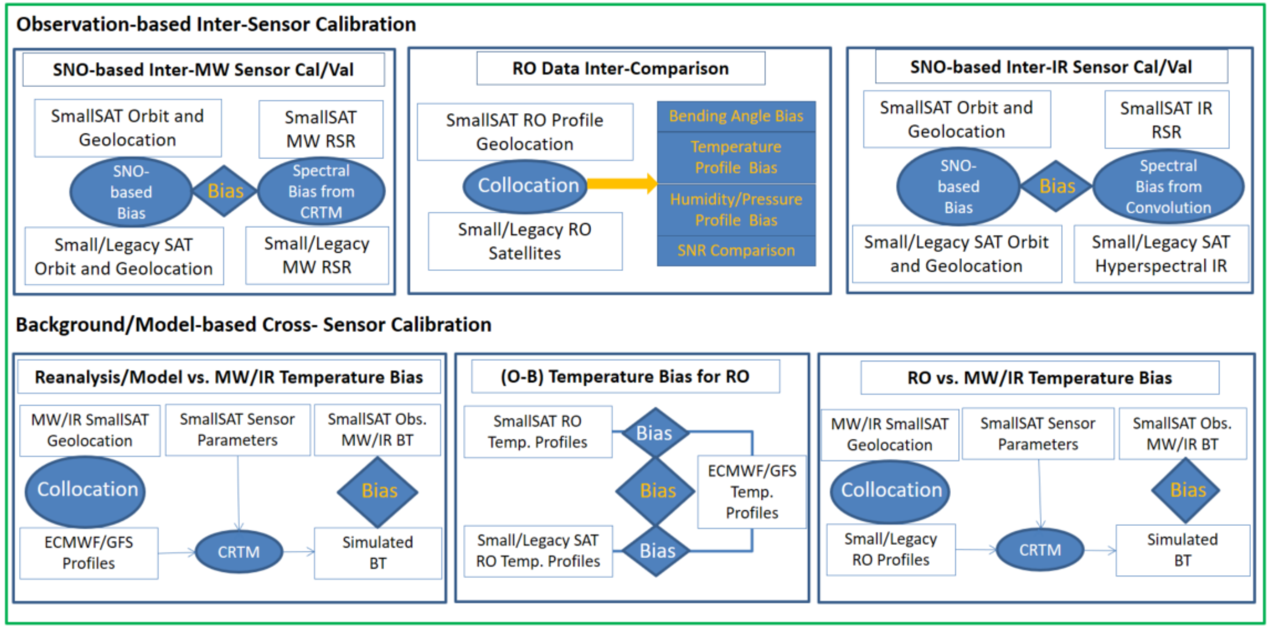


- Using NPP/NOAA-20 IR/MW as proxy SmallSat to monitor inter-instrument bias with CRTM-modeled BT profile from the RO data

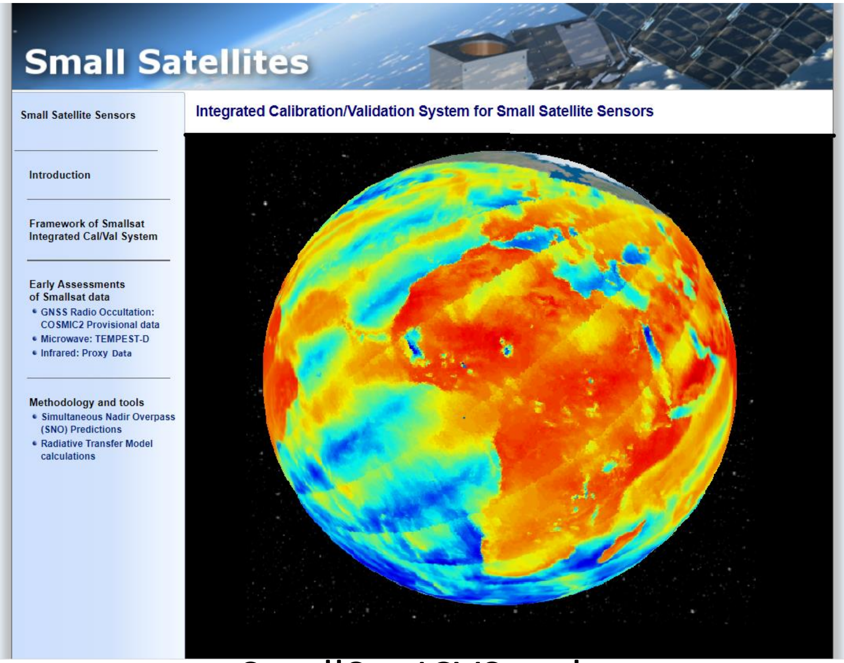
Radiative Transfer model for double difference analysis

ICVS Framework for SmallSats MW, RO, and IR Sensors

- An ICVS framework has been developed to enable rapid ingestion, calibration and validation of the data from different sources
  - Microwave (MW), Infrared (IR) and Radio Occultation (RO) sensors on SmallSats. All measure atmospheric profiles and related parameters which are potentially useful for weather forecasting
- Webpage "Integrated Cal/Val for Microwave/Infrared/Radio Occultation Small Satellite Sensors" is available at https://ncc.nesdis.noaa.gov/SmallSatellite/index.php.



SmallSat MW/IR/RO Sensor Cal/Val system



SmallSat ICVS webpage

A framework for Smallsat Cal/val has been developed

Hyperspectral IR Sounder onboard data processing for volume reduction

Advantages/Disadvantages of Utilizing More On-Board Processing

Advantages:

Data volume reduction. Option to mitigate downlink bandwidth limitations, if compression is not sufficient.

Disadvantages:

Inability to Reprocess/Recalibrate spectra:

- IASI-style processing scheme generates calibrated spectra on-board and downlinks the spectra only.
- If data is lost in the on-board processing, it is impossible to fully retrieve the data.

Reduced Hardware Robustness:

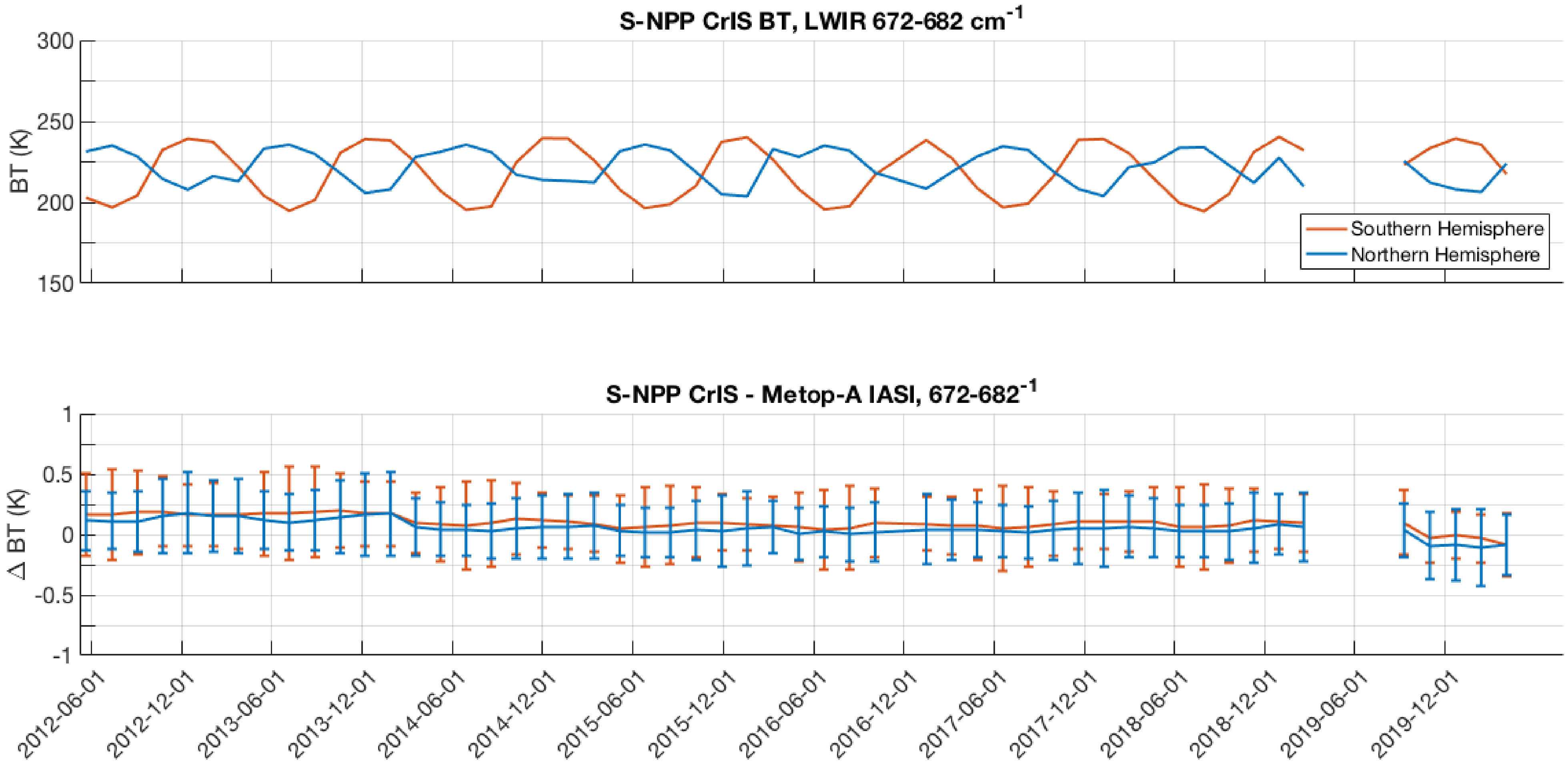
- On-board processing requires a large amount of memory that are vulnerable to high energy particles, e.g., Single Event Upset near SAA region.

On-Board vs. Ground Processing

	More On-Board Processing	More Ground Processing
Instrument	**IASI/IASI-NG**	**CrIS/MTG-IRS**
On-Board Processing Inclusive	Pre-Processing, Spike Detection, Non-Linearity Correction, ZPD Determination FFT, Partial Radiometric Calibration, Spectral Band Merging	Pre-Processing, Filter & Decimation, Bit Trimming, Packet Encoding
Downlinked L0/L1a Data	Partially Calibrated Spectra	Decimated/Compressed Interferogram
Data Volume Reduction	✓ (x30)	✓ (x13.5)
Correction of Erroneous Calibration		✓ (More recovery capabilities)
Life-Cycle Reprocessing		✓ (Re-analysis, Climate Applications)
Simplicity of On-Board Electronics		✓ (More reliable system)
Hardware Robustness		✓ (More reliable/resilient system; side switch)

Which approach is better for smallsat? It depends?

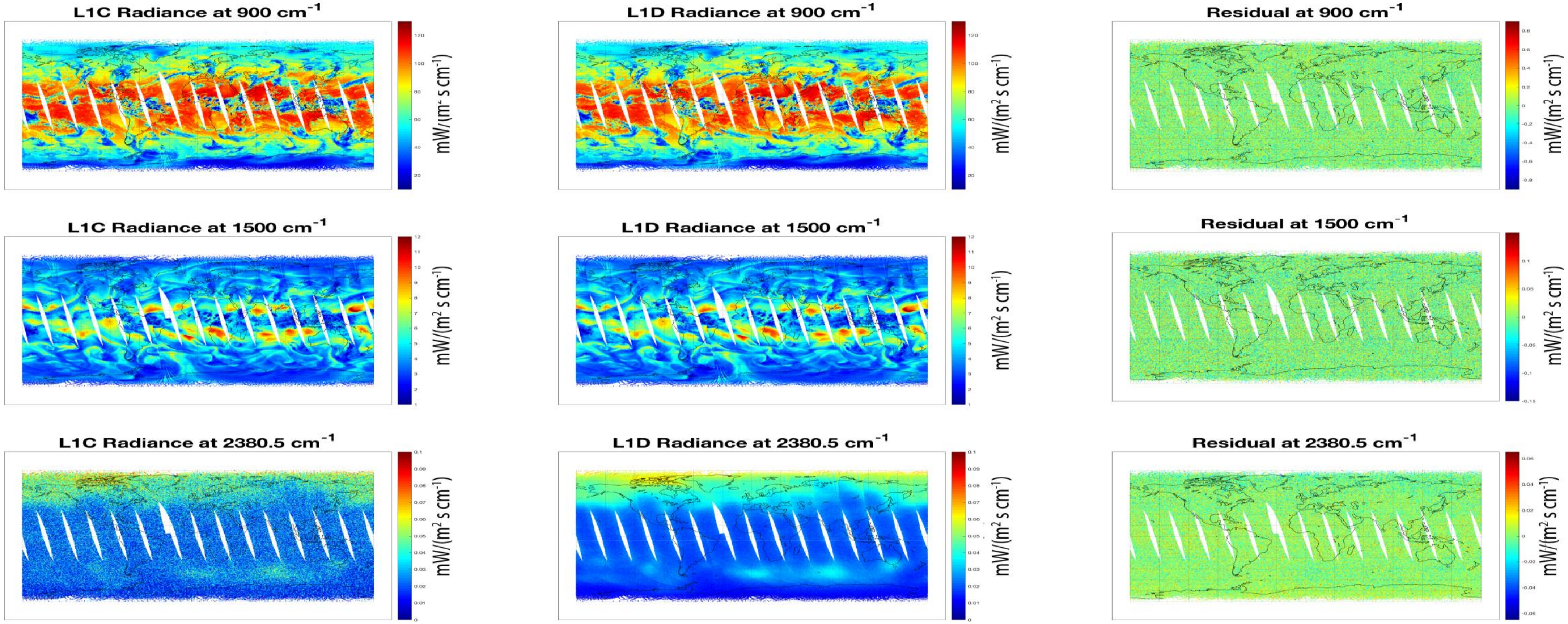
Trending of the CrIS and IASI Radiometric Comparison over a LWIR Spectral Region: 672-682cm^{-1}



Each point represents a three days average value

Excellent radiometric agreement between CrIS and IASI, serving as the backbone and reference standard for smallsat sounders.

Impact of Principal Component Compression (PCC)



Preliminary results show that the PCC (despite lossy) has little impact on radiances for most applications

Summary

- A new era is here for Smallsat observations in MW, IR, and RO with great potential for operational weather forecast
- Smallsat has unique advantages, but also has limitations
- Operational backbone systems can be used to evaluate the Smallsat data, to ensure their quality for operational use
- An integrated calibration/validation system has been prototyped to demonstrate the quality assurance for Smallsat to ensure the success of the program
- Onboard processing for IR sounder data volume reduction has pros and cons, depending on specific design and requirements. The end results are comparable for most applications.