Inter-Comparison of COSMIC-2 Radio Occultation with ATMS Microwave and CrIS Infrared Sounding Measurements using the Community Radiative-Transfer Model

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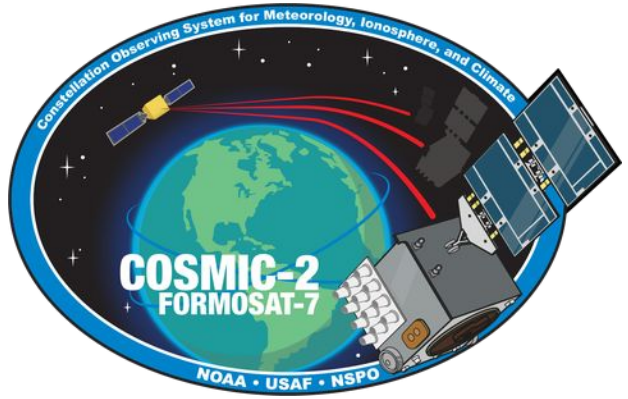
Motivation and Outline

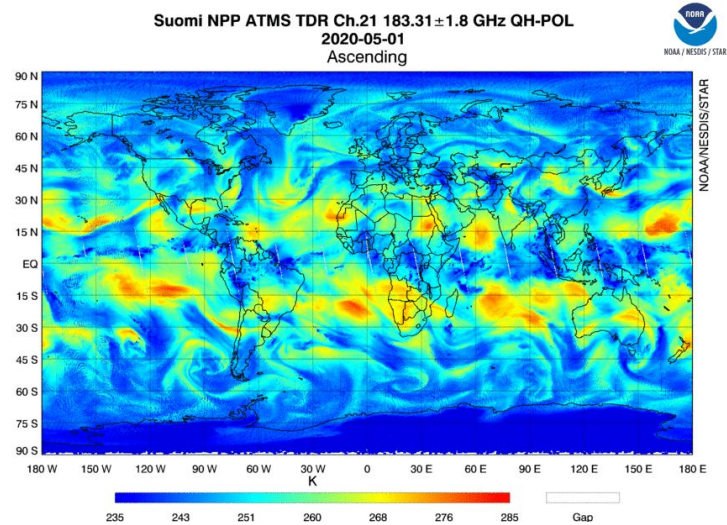
- Motivations
  - Are COSMIC-2 RO data consistent with IR/MW data calibrated/validated/monitored at NOAA/NESDIS/STAR?
  - How to use RO/COSMIC-2 data to calibrate/validate MW and IR data?
  - Impacts of variation in 1DVAR processing algorithms on RO temperature and water vapor retrieval biases.
  - Impacts of COSMIC-2 RO data on ECMWF Reanalysis data through O-B bias trending analysis.
- Introduction of Microwave (Advanced Technology Microwave Sounder (ATMS)) and Infrared (Cross-Track Infrared Sounder (CrIS)) sounding sensors, and Community Radiative Transfer Model (CRTM) Simulation setup.
- Evaluation of COSMIC-2 Wet Temperature and Humidity Data Products (WETPrf and WETPrf2) from UCAR through inter-comparison with IR/MW sensor measurements.
- Conclusions

COSMIC-2, ATMS and CrIS

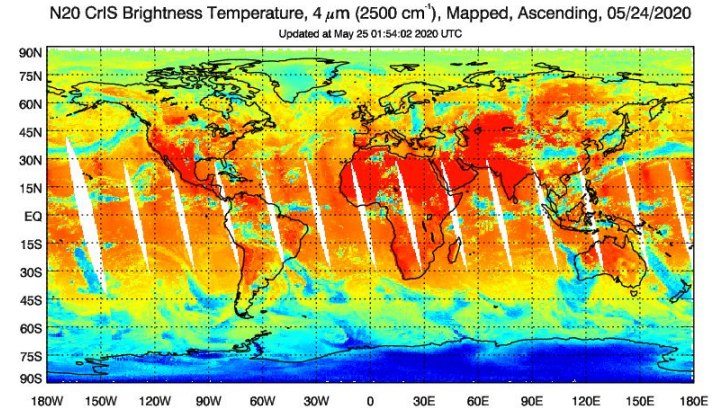
- COSMIC-2 Radio Occultation (RO) Sensor
  - Launched on on June 25, 2019 as COSMIC-1 follow on.
  - Six small satellite-constellation; 24-degree inclination LEO;
  - Tri-GNSS Radio-occultation System (TGRS) payload; GNSS: GPS and GLONASS
  - Enhanced RO signal quality and deeper penetration depth
  - On March 16, 2020, data became available for atmospheric and climate studies and NWP applications .
- Advanced Technology Microwave Sounder (ATMS)
  - A cross-track scanner, 22 channels in bands from 23 GHz through 183 GHz.
  - Provide sounding observations for retrieving profiles of atmospheric temperature and moisture for NWS as well for climate monitoring purposes.
- Cross-Track Infrared Sounder (CrIS)
  - A Fourier transform spectrometer; Soundings of the atmosphere with 2211 spectral channels, over three wavelength ranges: LWIR (9.14-15.38 µm), MWIR (5.71-8.26 µm) and SWIR (3.92-4.64 µm).
  - Provide more accurate, detailed atmospheric temperature and moisture observations for weather and climate applications.
- Both ATMS and CrIS are onboard NPP and NOAA-20, and will be on the follow-on JPSS missions. Both are calibrated/Validated and monitored at NOAA/NESDIS/STAR.



SNPP ATMS



N20 CrIS

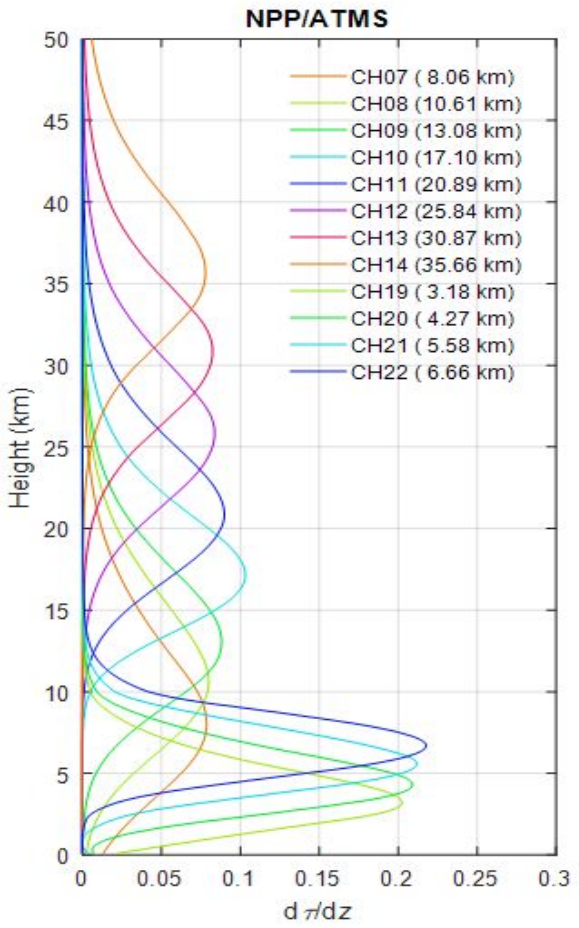


NPP-ATMS Sounding Channels of Interest

8km – 35 Km

Below 6.66 km

ATMS		
Ch	GHz	Pol
1	23.8	QV
2	31.4	QV
3	50.3	QH
4	51.76	QH
5	52.8	QH
6	53.596 ± 0.115	QH
7	54.4	QH
8	54.94	QH
9	55.5	QH
10	fo = 57.29	QH
11	fo ± 0.3222 ± 0.217	QH
12	fo ± 0.3222 ± 0.048	QH
13	fo ± 0.3222 ± 0.022	QH
14	fo ± 0.3222 ± 0.010	QH
15	fo ± 0.3222 ± 0.0045	QH
16	88.2	QV
17	165.5	QH
18	183.31 ± 7	QH
19	183.31 ± 4.5	QH
20	183.31 ± 3	QH
21	183.31 ± 1.8	QH
22	183.31 ± 1	QH



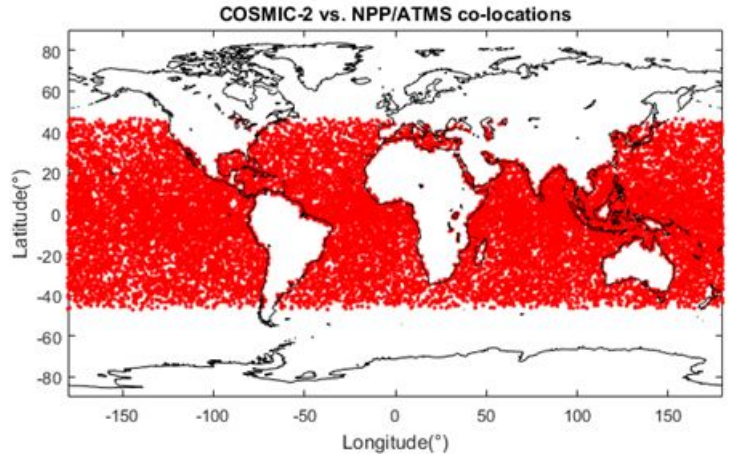
- This study focused on ATMS sounding channels:
  - CH07-CH14 (sounding peak height: 8 km to 35 km)
  - CH19-CH22 (sounding peak height: 3.18 km to 6.66 km ; Moisture sounding channel)

CRTM Simulation Setup for MW Sensor Inter- comparison

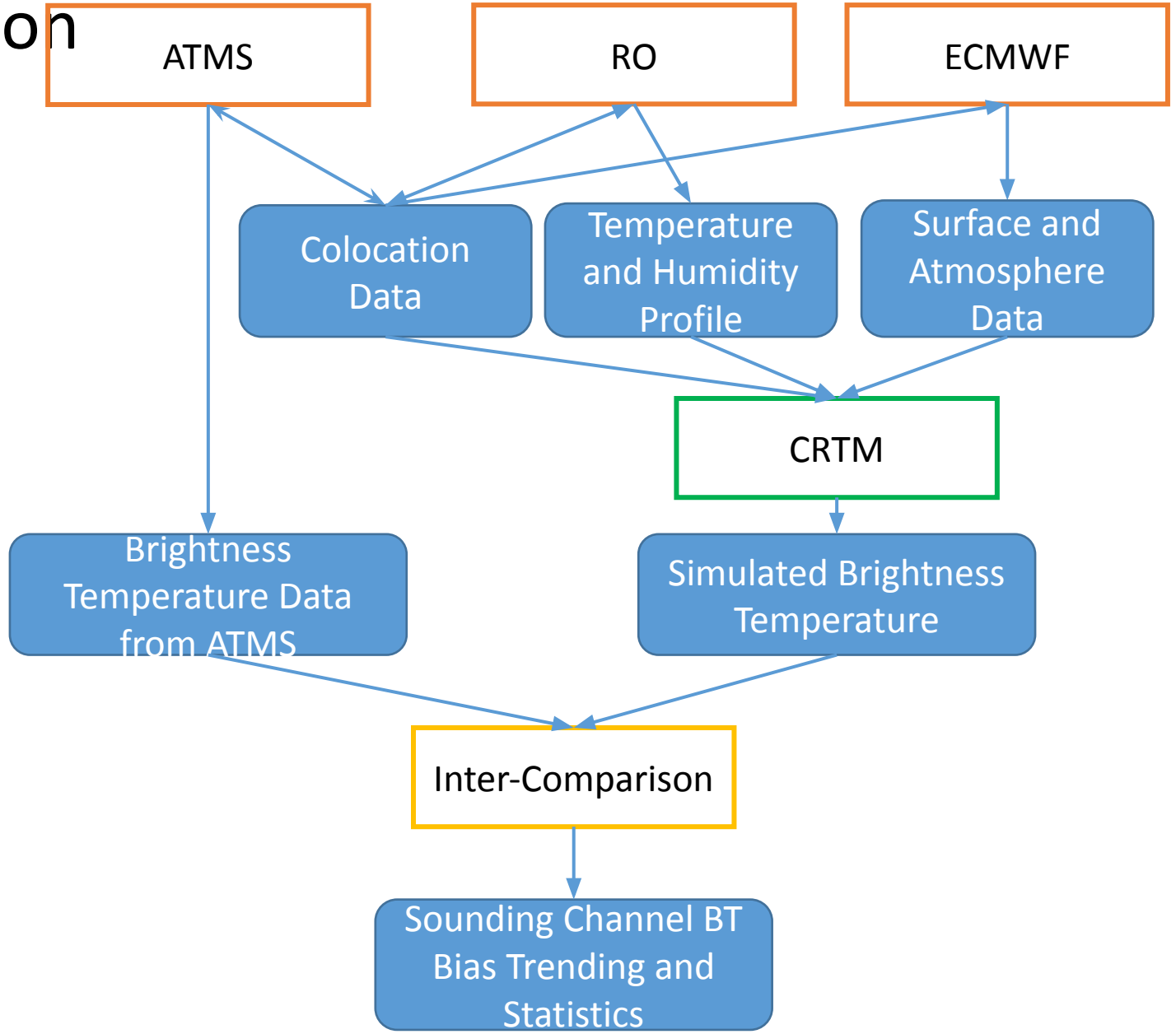
CRTM Input Parameters

Category	Variable	Data source
Atmosphere	Level and layer pressure temperature	RO or ECMWF
	Specific humidity	RO or ECMWF
	Ozone mass mixing ratio	ECMWF
Surface	Water type	1 (sea water)
	Skin temperature	ECMWF
	Wind speed	ECMWF
	Wind direction	ECMWF

Co-location of COSMIC-2 with NPP/ATMS



- Time difference: 120 minutes; Distance difference: 150 km;
- Nadir view over ocean
- All RO data are WETPrf2/WETPrf from UCAR



Three sets of input data used in CRTM simulation

Data Set Name	Provided by	Time Coverage	Note
UCAR COSMIC-2 WETPrf	UCAR	2019/10/01 to 2019/10/31 (1 Month)	Bias Evaluation
UCAR COSMIC-2 WETPrf2	UCAR	2019/10/01 to 2020/05/31 (8 Months)	Bias and Trending
ECMWF (Background)	ECMWF	2019/10/01 to 2020/05/31 (8 Months)	O-B bias trending

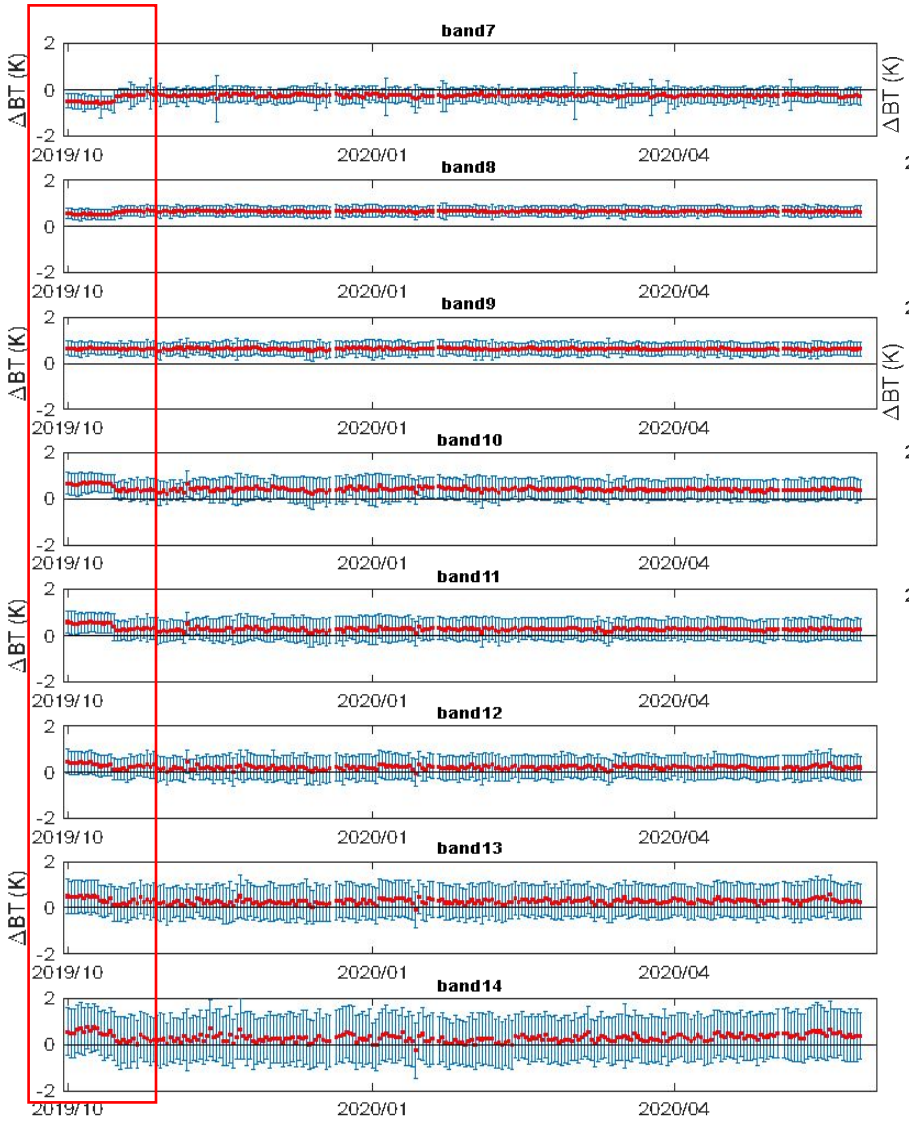
	UCAR WETPrf 1DVAR	UCAR NRT WETPrf2 1DVAR
Observation Error	Extreme condition	Statistical
Background Error	Empirical	Consistent with Observation Err.
Background Error Correlation	Univariate	Multivariate
Error Covariance Matrix Resolution and Construction	Low/Mid/Latitude; Seasonal Runtime	Lat/Lon (10^ox10^o); Monthly Precomputed on fixed levels
Observation Operator	Refractivity	Variational Abel Transform
Initialization Model as priori	ECMWF	Global Forecasting System (GFS)

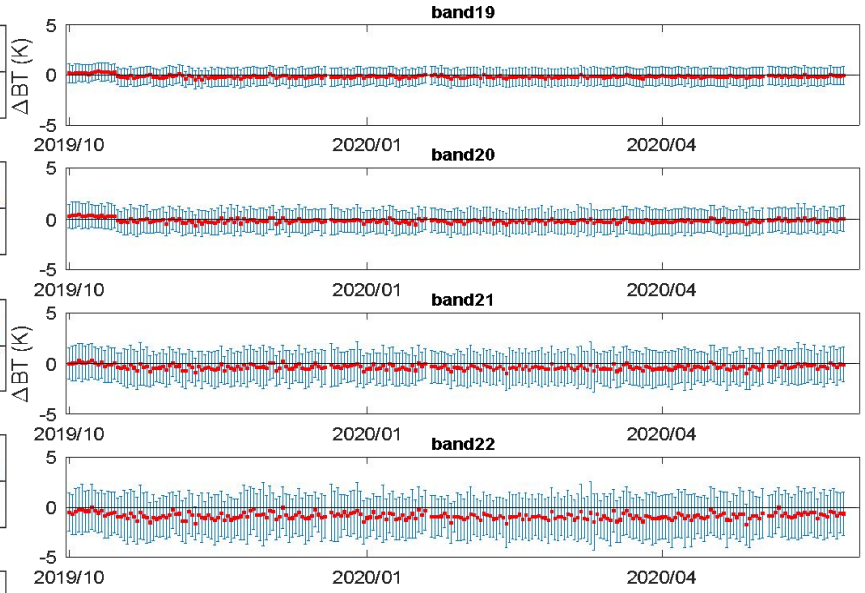
RO 1DVAR retrieval algorithm difference can cause retrieved Temperature and Humidity profiles to be different.

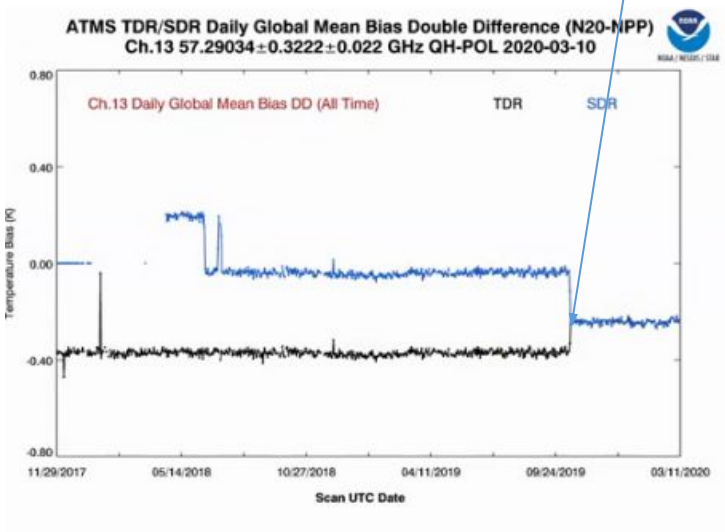
Wee, 2018, 2019

COSMIC-2 (WetPrf2) vs. NPP ATMS BT Bias Trending

SNPP/ATMS Calibration Update



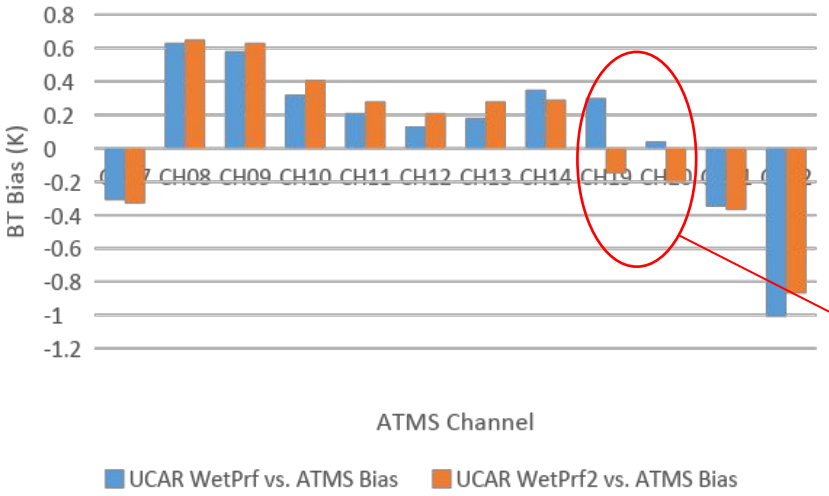




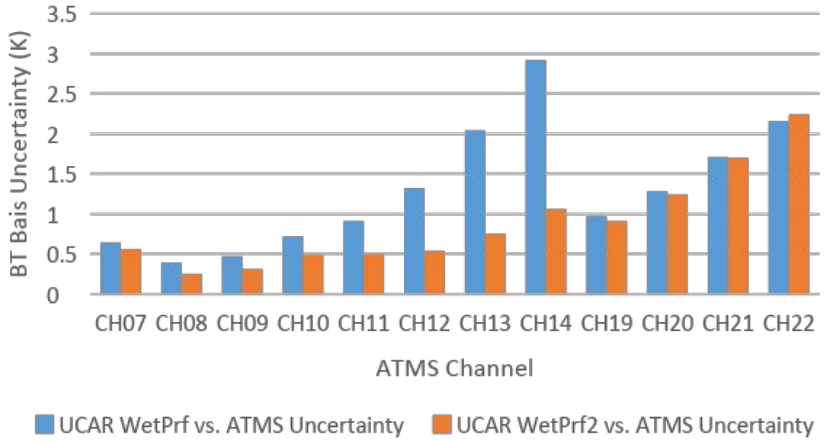
- Major calibration updates on Oct. 15, 2019 for SNPP ATMS: antenna reflector emission correction algorithm update and antenna pattern correction coefficients update
- The bias trending shows that COSMIC-2 data captured the calibration update of SNPP ATMS on Oct. 15, 2020 very well.
- Able to evaluate the ATMS bias variations before and after the calibration update.
- Maintain long term stability consistency between COSMIC-2 and ATMS after Oct. 15, 2019 for all ATMS channels of interest.

UCAR COSMIC-2 WETPrf &WETPrf2 vs. ATMS: Bias and Uncertainty Analysis

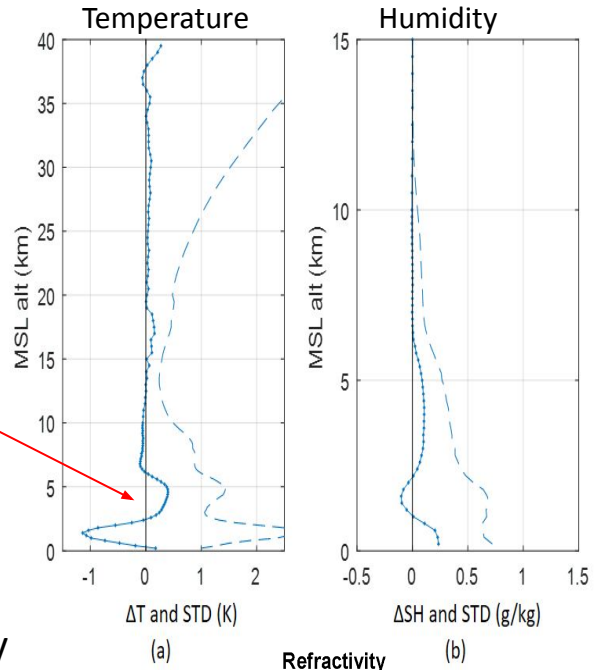
COSMIC-2 WETPrf &WETPrf2 vs. ATMS: Bias

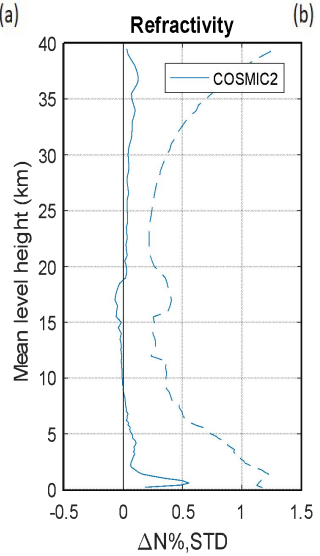


COSMIC-2 WETPrf &WETPrf2 vs. ATMS: Uncertainty



WETPrf2 vs. WETPrf

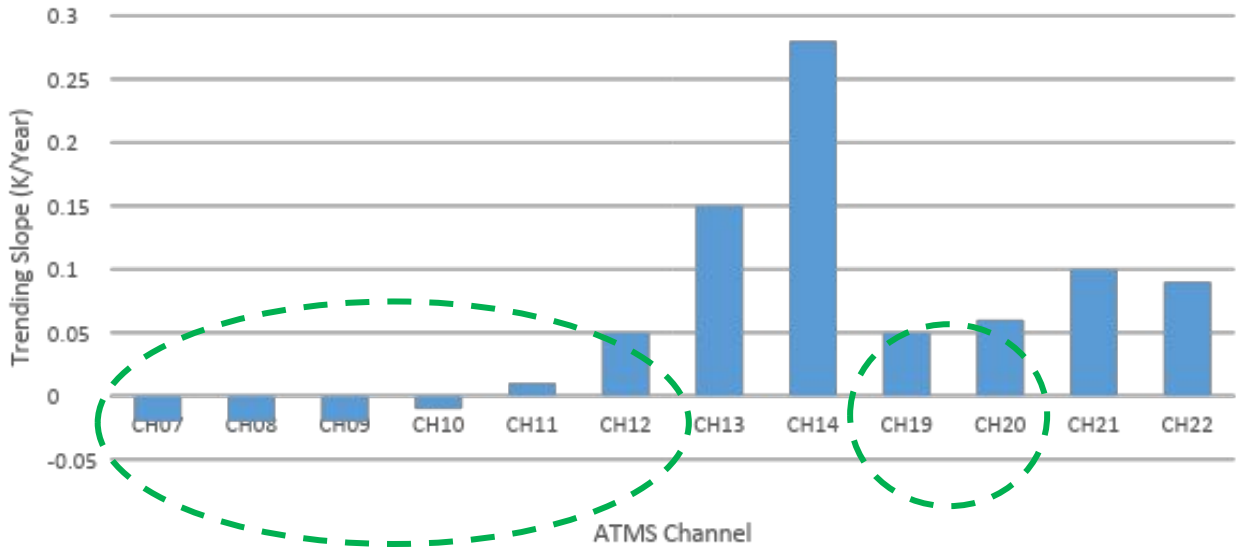




- Difference in RO 1DVAR retrieval algorithms cause difference in retrieved Temperature and Humidity profiles which can be identified in COSMIC-2 vs. ATMS comparison.
- WETPrf2 vs. ATMS biases are mostly within 0.4K for CH10-14 and CH19-20.
- Overall consistency in bias between WETPrf and WETPrf2 for most of channels except CH19 and CH20.
- Large reduction in bias uncertainty with WETPrf2 in comparison with WEtPrf. Most significant reductions occur at ATMS CH08-CH14. Can be due to the weighting difference of priori model.
- Larger BT bias uncertainty in ATMS humidity sounding channels (CH19-CH22).

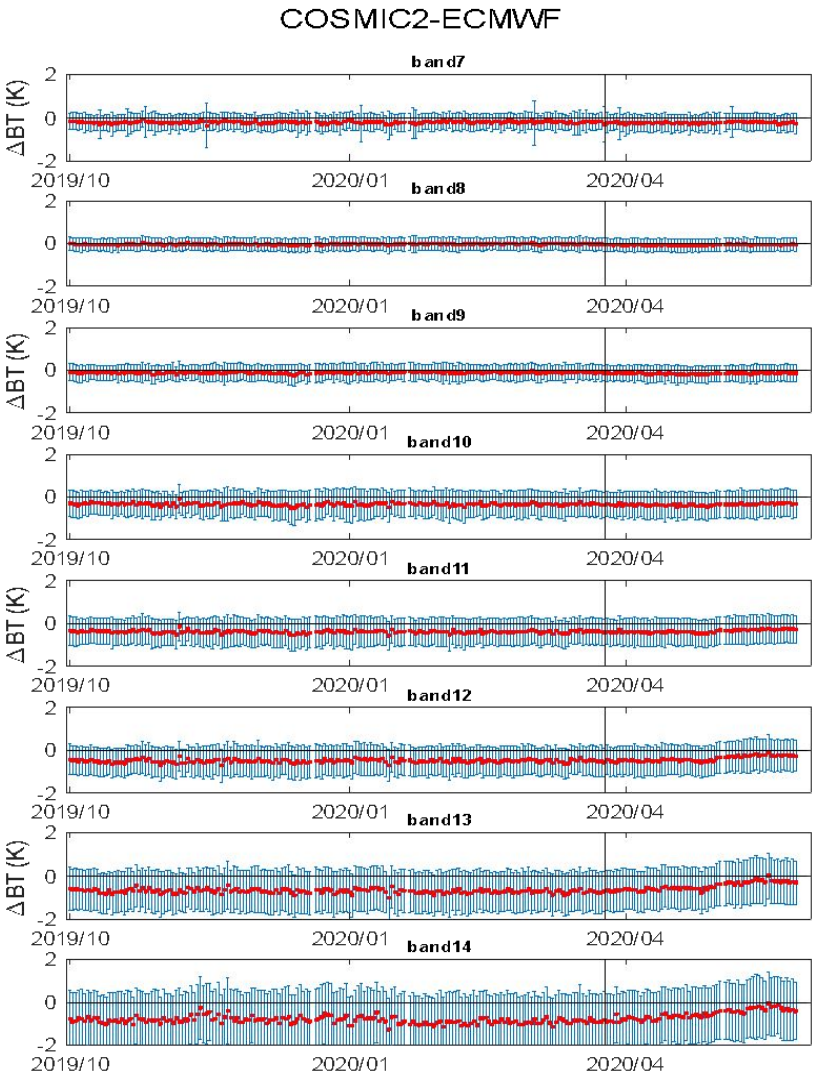
Stability Analysis: UCAR WETPrf2 vs. ATMS Trending

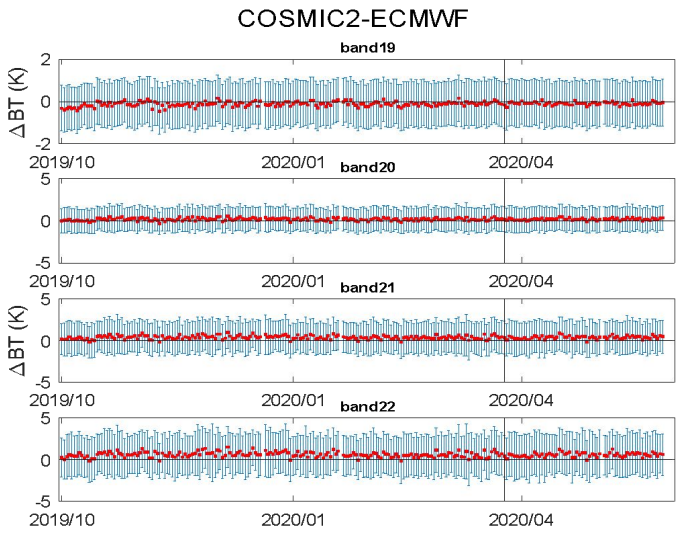
ATMS Channel	Peak Sounding Height (km)	UCAR-WetPrf2 Slope (K/year)
CH07	8.06	-0.02±0.03
CH08	10.61	-0.02±0.02
CH09	13.08	-0.02±0.02
CH10	17.10	-0.01±0.05
CH11	20.89	0.01±0.04
CH12	25.84	0.05±0.05
CH13	30.87	0.15±0.07
CH14	35.66	0.28±0.10
CH19	3.18	0.05±0.07
CH20	4.27	0.06±0.11
CH21	5.58	0.10±0.16
CH22	6.66	0.09±0.23



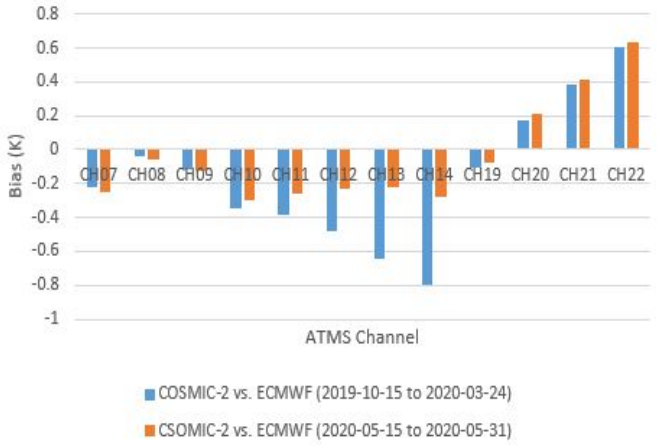
- Long term trending of biases (K/year) between simulated BT from 8-month COSMIC-2 UCAR WETPrf2 data and SNPP ATMS measurements.
- The stability between modeled BT from COSMIC-2 and ATMS BT are consistent with yearly drift of BT bias < 0.06 K/year for ATMS CH7-CH12 and CH19-CH20.
- The yearly drift of BT bias for the remaining ATMS channels (CH 13-14,CH21-22) are less than 0.3 K/year.
- Improvements in stability characteristics are expected as long term data accumulates.

O-B Bias Trending between COSMIC-2 and ECMWF via ATMS





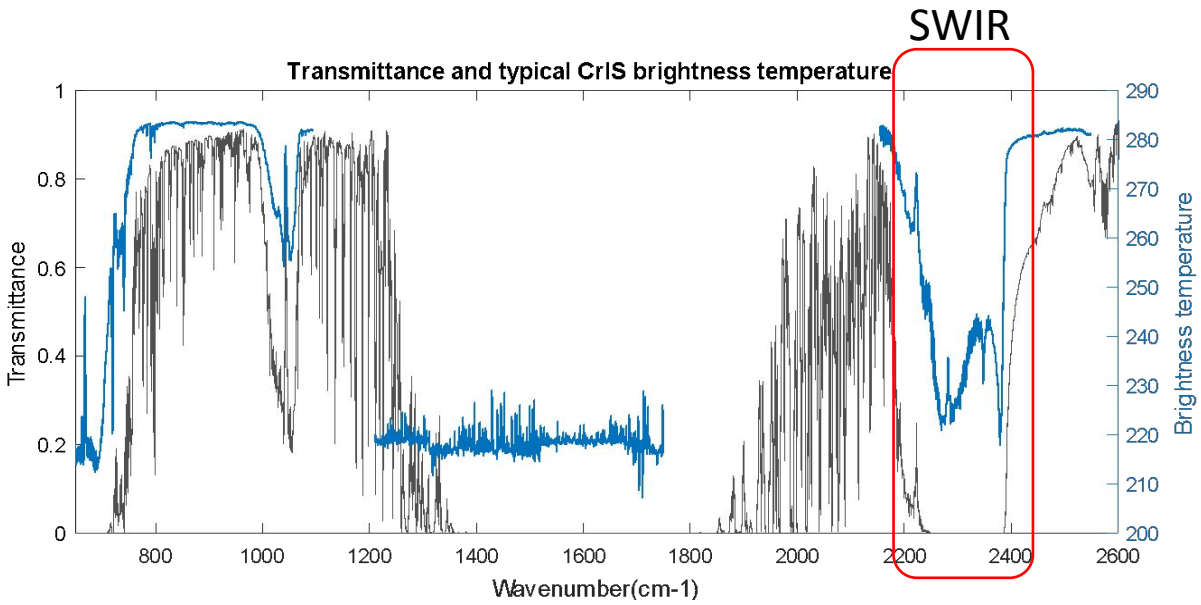
O-B Biases before and after Assimilation of COSMIC-2 data into ECMWF



- O-B BT bias trend between COMSIC-2 and ECMWF for ATMS channels are derived through double difference.
- ECMWF started assimilating GNSS RO measurements from the COSMIC-2 mission on 25 March 2020 (Healy, 2020).
- Trending up of O-B BT bias over the last two month after March 25, 2020. At the end of May, 2020, the O-B bias trending is stabilized.
- Significant reduction in absolute O-B BT biases for ATMS CH10 to CH14 can be clearly identified after the assimilation of COSMIC-2 data into ECMWF on Mar. 25, 2020.
- The O-B biases for ATMS CH07-CH14 , CH19, and CH20 are all within 0.3K at the end of May, 2020.

COSMIC-2 vs. CrIS Comparison: Selection of SWIR Band of CrIS

Spectral Transmittance and typical CrIS brightness temperature

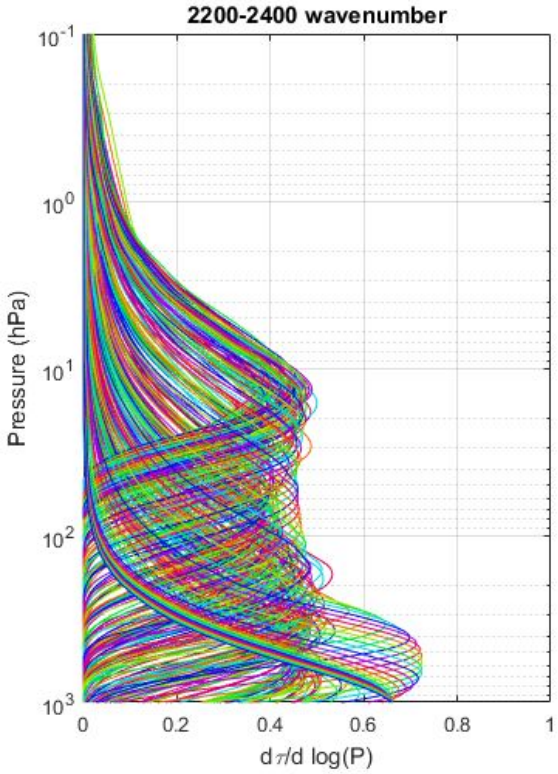


Sounding Channels analyzed in this study

2211 spectral channels, over three wavelength ranges: LWIR (9.14-15.38 µm), MWIR (5.71-8.26 µm) and SWIR (3.92-4.64 µm).

SWIR band of CrIS

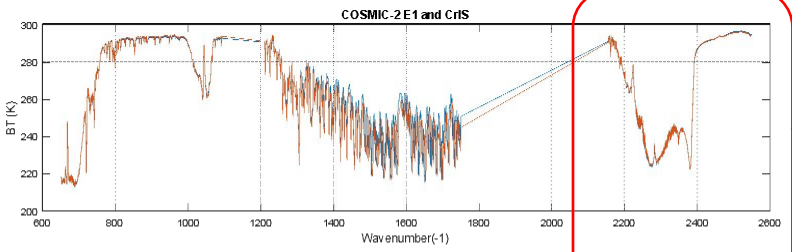
Weighting function



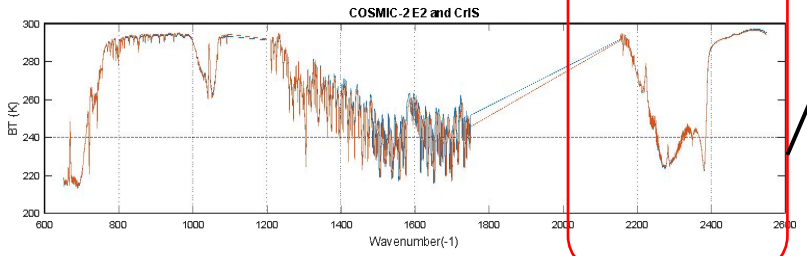
Precision Consistency among Six COSMIC-2 Satellites (WetPrf2)

COSMIC-2 E1 vs. NOAA-20 CrIS

SWIR

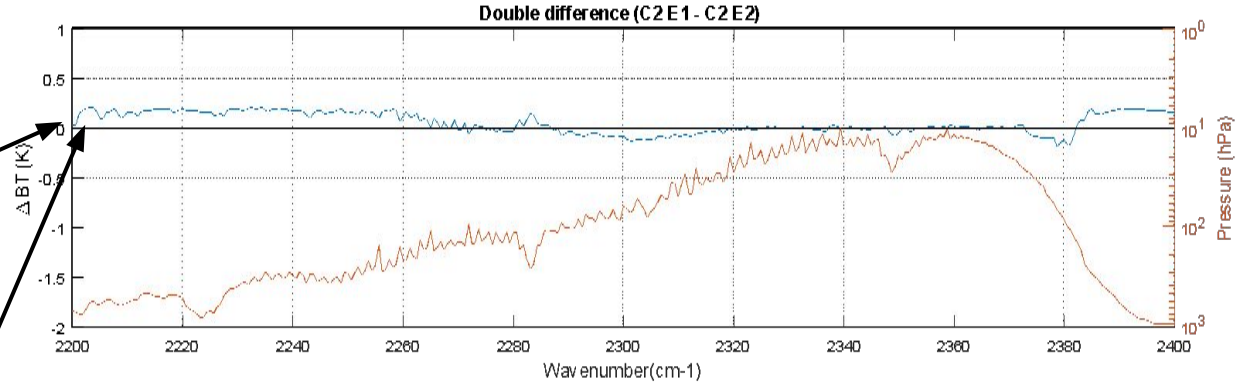


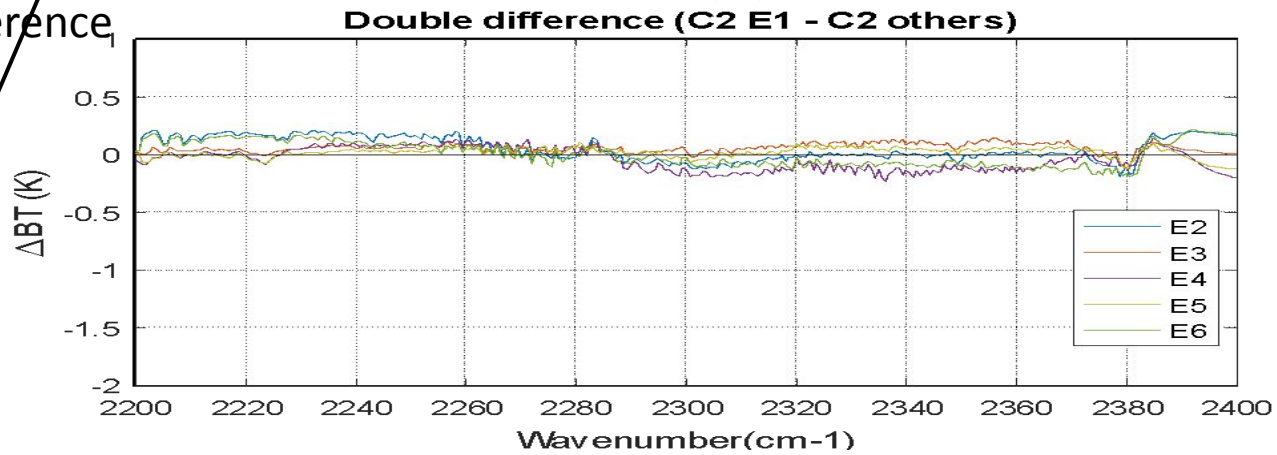
COSMIC-2 E2 vs. NOAA-20 CrIS



Double Difference

COSMIC-2 E1 vs. E2 via CrIS

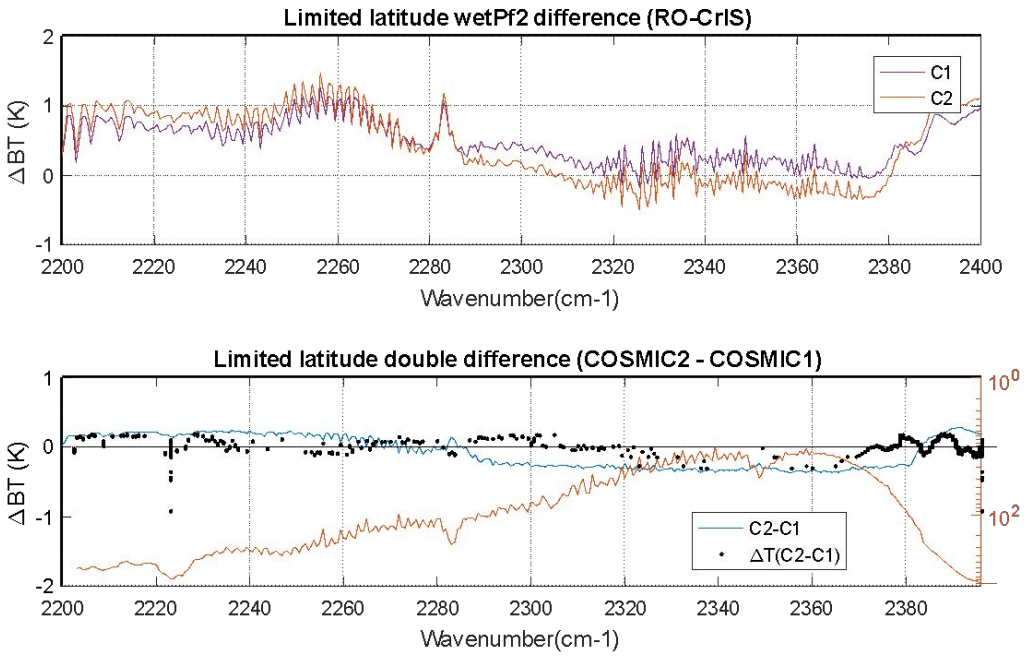




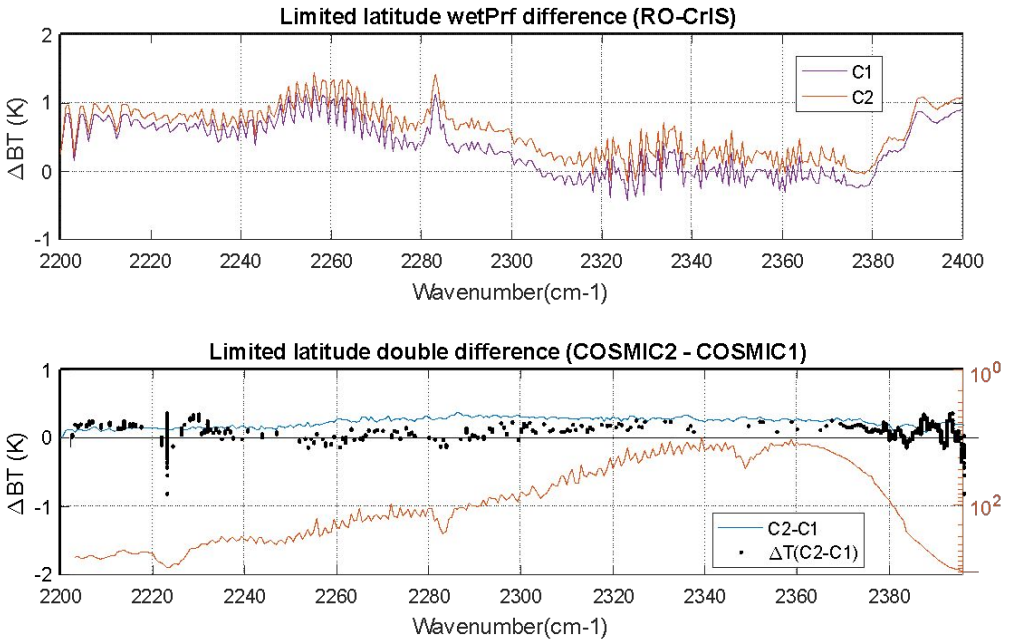
- Inter-RO bias is consistent within 0.15 K among six COSMIC-2 RO sensors over pressure range (~10-900 hPa)

Consistency between COSMIC-1 and COSMIC-2 via NOAA-20 CrIS: COSMIC-2 WetPrf vs. WetPrf2 (2019-10)

COSMIC-2 **WetPrf2** vs. COSMIC-1 WETPrf as Input to CRTM



COSMIC-2 **WetPrf** vs. COSMIC-1 WETPrf as Input to CRTM



- Spectral bias between COSMIC-1 and COSMIC-2 consistent within 0.3 K over pressure range (10-900 hPa)
- Consistent with co-location-based temperature comparison (black dots)
- Able to identify the difference between WetPrf2 and WetPrf through comparison with CrIS

Summary

- Evaluated bias and stability of COSMIC-2 Wet Temperature and Humidity data products (UCAR WETPrf and WETPrf2) through inter-comparison with IR and MW sensor measurements using CRTM simulation.
- The bias trending shows that COSMIC-2 data captured the major calibration update of SNPP ATMS on Oct. 15, 2020 very well.
- COSMIC-2 Wet Temperature and Humidity Data Products are in general consistent with ATMS measurements.
  - Large reduction in bias uncertainty with WETPrf2 w.r.t. WEtPrf.
  - Yearly drift of BT bias < 0.06 K/year for ATMS CH7-12 and CH19-20.
- Difference in RO 1DVAR retrieval algorithms can cause difference in RO-retrieved Temperature and Humidity profiles: confirmed in COSMIC-2 vs. ATMS and COSMIC-2 vs. CrIS comparisons.
- O-B Bias Trending between COSMIC-2 and ECMWF via ATMS captured the bias reduction after COSMIC-2 data were assimilated into ECMWF.
- Inter-RO bias analysis of COSMIC-2 using NOAA-20 CrIS as the reference
  - Spectral biases among six COSMIC-2 sensors are within 0.15 K
  - Spectral bias between COSMIC-1 and COSMIC-2 is mostly within 0.3 K.