The Airborne Hyperspectral Microwave Sounder CoSMIR-H

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PBL Community Meeting
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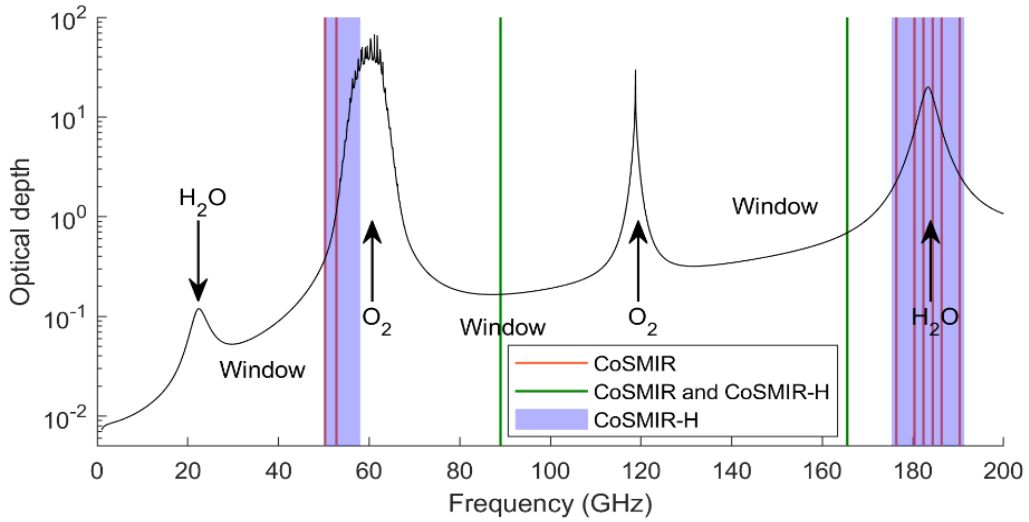
CoSMIR-H DSI Proposal

Through the NASA ESTO Decadal Survey Incubation (DSI-21) program, we modified the existing CoSMIR 50/52 and 183 GHz channels with new hyperspectral receivers using PMCC ASIC spectrometers to achieve three main objectives:

1) Enable hyperspectral measurements from an airborne platform at 50-58 GHz and 175-191 GHz
2) Demonstrate the capability of hyperspectral microwave sounding for improved measurement of the PBL thermodynamic (temperature and water vapor) vertical structure
3) Provide a viable pathway to space by advancing the field of digital spectroscopy for microwave radiometers



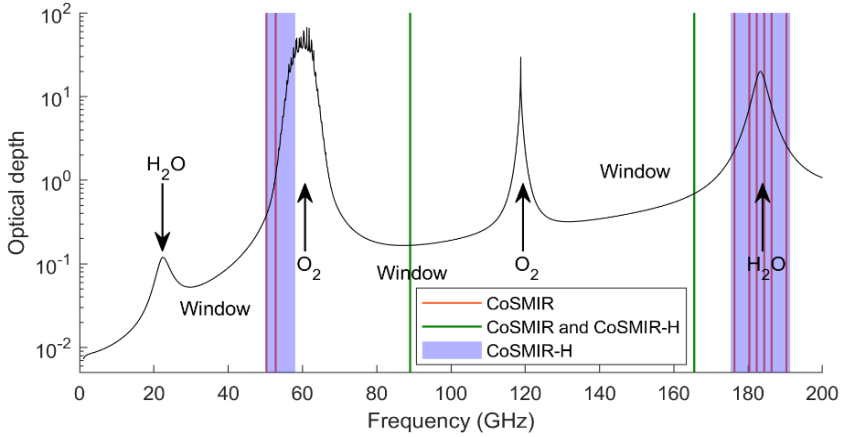
ATMS	CoSMIR-H
23.8	--
31.4	--
50-58 (13 channels)	50-58 (~2k channels)
88.2	89v/h
165.5	165.3v/h
183±7-183±1 (5 channels)	175-191 (~4k channels)

CoSMIR-H Status Overview

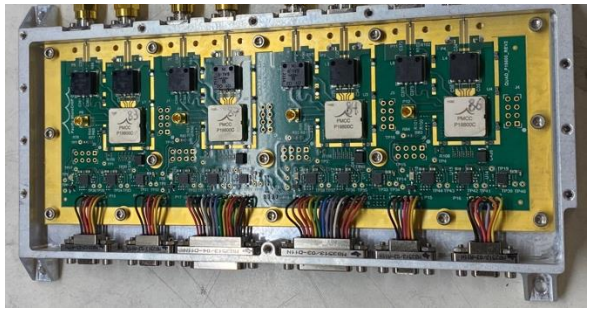
- Started development in Oct 2022 with a plan to have a fully-functioning instrument by mid-2024 to do engineering check flights on the NASA ER-2 high-altitude aircraft
  - Completed five flights in July 2024
- Received additional funds through NOAA Joint Ventures Partnership program to fly CoSMIR-H in a larger campaign in 2024
  - Completed ten flights in WH^2yMSIE in Oct-Nov 2024
- Issues noticed during the check flights allowed us to optimize CoSMIR-H performance prior to flying again in WH^2yMSIE by having a couple months in between flights
- Calibration/Validation ongoing
  - Level 1 dataset is publicly available on our WH^2yMSIE data archive
- Retrieval algorithm development ongoing
  - Last major milestone for the DSI project
  - Determine optimal bandwidths and center frequencies needed for retrievals

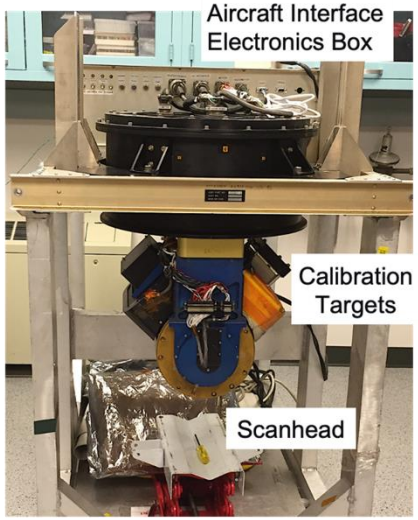
CoSMIR → CoSMIR-Hyperspectral

Modified the CoSMIR 50-GHz and 183-GHz receivers to achieve full spectrum (4 MHz resolution) observations at 50-58 GHz (O_2) and 175-191 GHz (H_2O) using six PMCC ASIC spectrometers

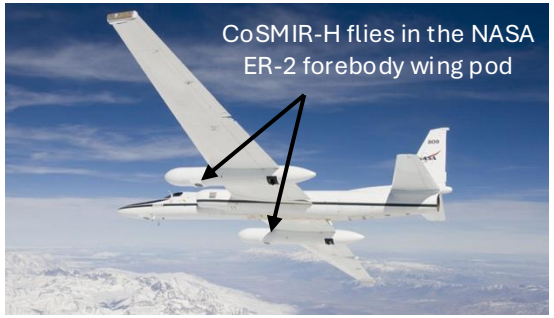


Quad-ASIC board for CoSMIR-H



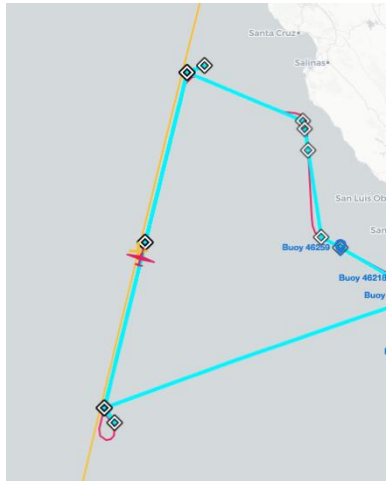


- New receivers
  - 50-GHz and 183-GHz major updates with ASIC spectrometers
- Same mechanical structure
  - Calibration targets and elevation/azimuth axes
- Data System
  - Major updates to handle large data volume
  - CoSMIR-H is ~3 MB/s vs 1.8 kB/s for CoSMIR
- Software
  - New ground processing software
  - Retrieval algorithms for hyperspectral channel set

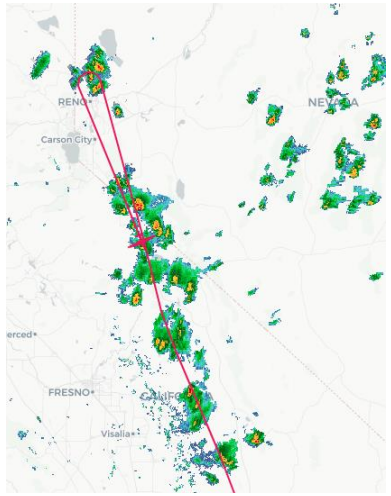


CoSMIR-H Engineering Check Flights

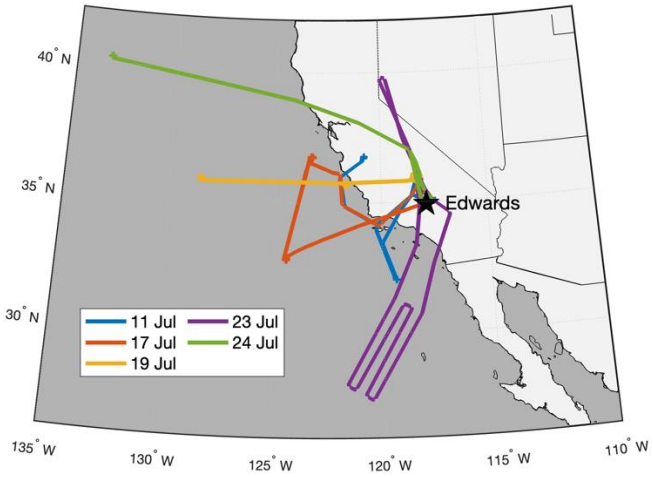
- Successful engineering check flights on the ER-2 in July 2024
  - CoSMIR-H and MBARS flew together
    - MBARS: Microwave Barometric Radar, PI: Matt Walker-McLinden
  - Five total flights, ~19 hours of observations
- Preparations for the WH^{2}yMSIE campaign
  - Issues noticed during the check flights allowed us to further optimize CoSMIR-H prior to flying again in WH^{2}yMSIE



MetOp-B Overpass



Convection Observations

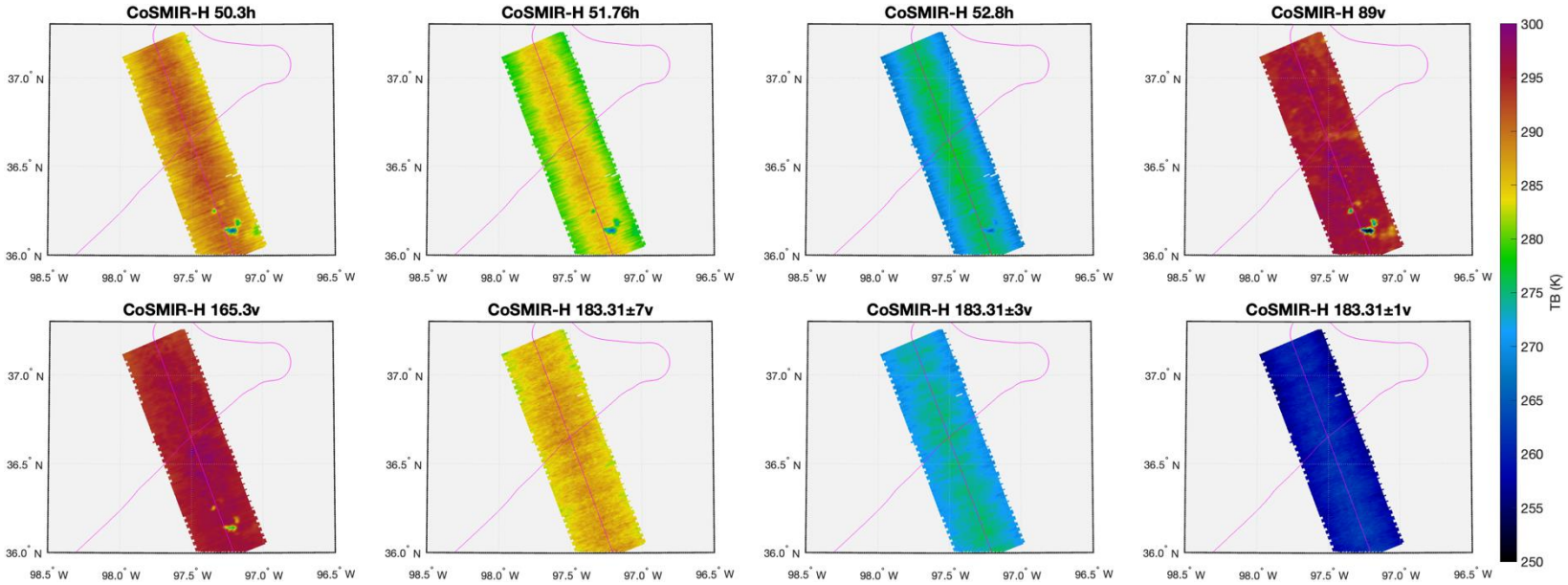


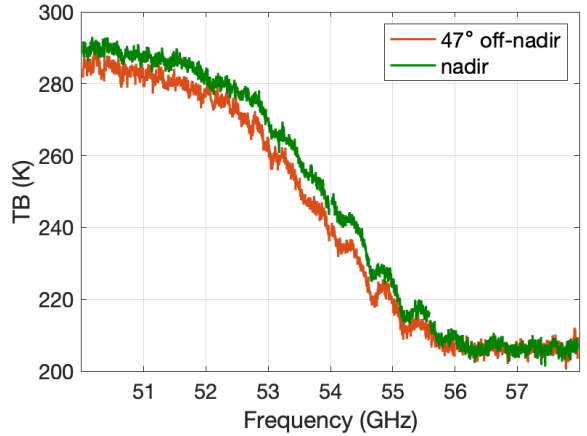
Flight Tracks

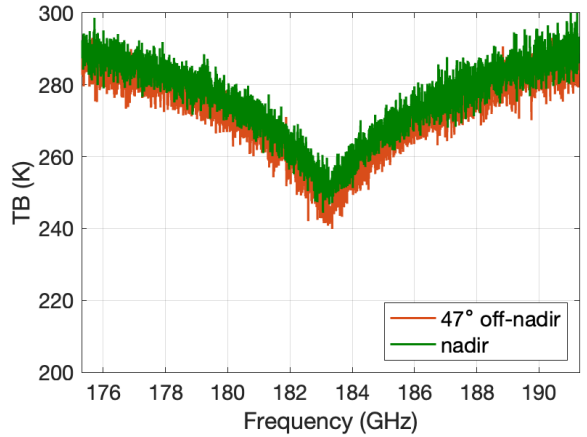
(Top) CoSMIR-H and MBARS teams perform instrument check outs prior to first flight. (Bottom) ER-2 lands at Edwards AFB after a flight. (Credit: NASA AFRC)

WH²yMSIE Observation Highlights

Clear sky over ARM SGP site (Oklahoma, USA): 22 Oct



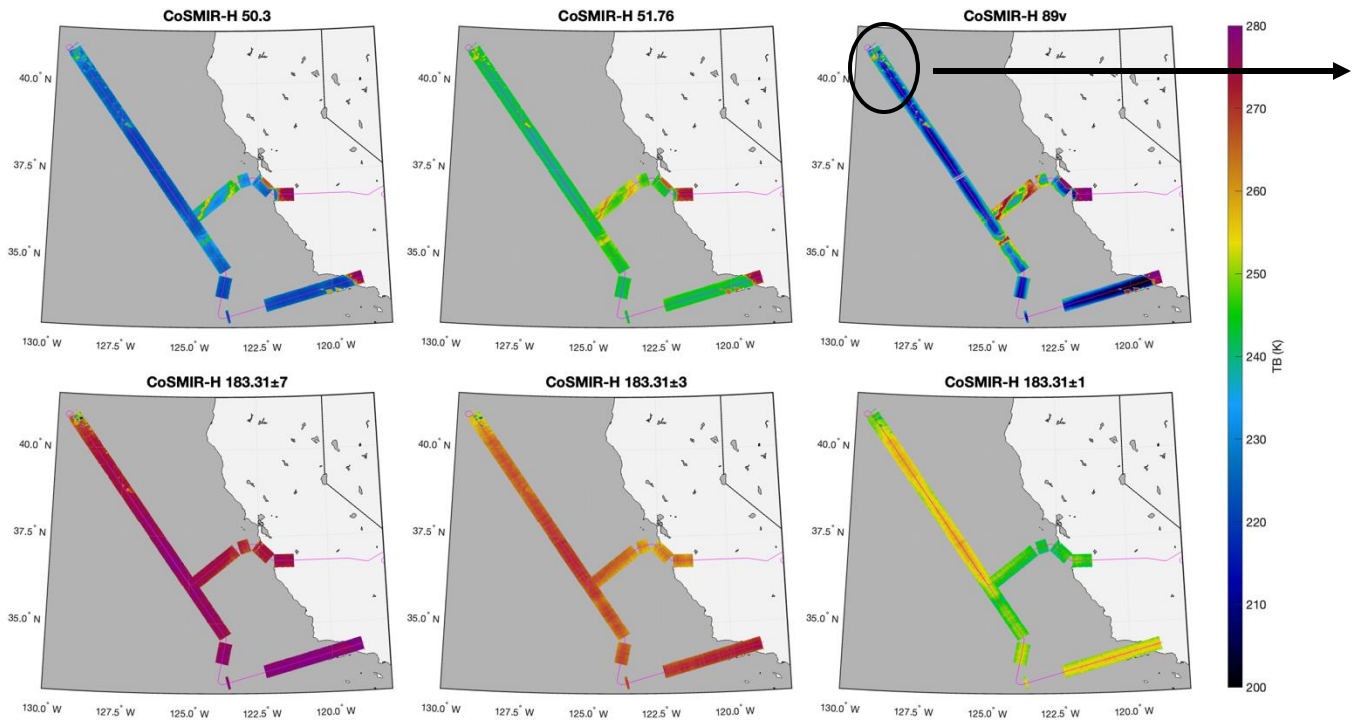




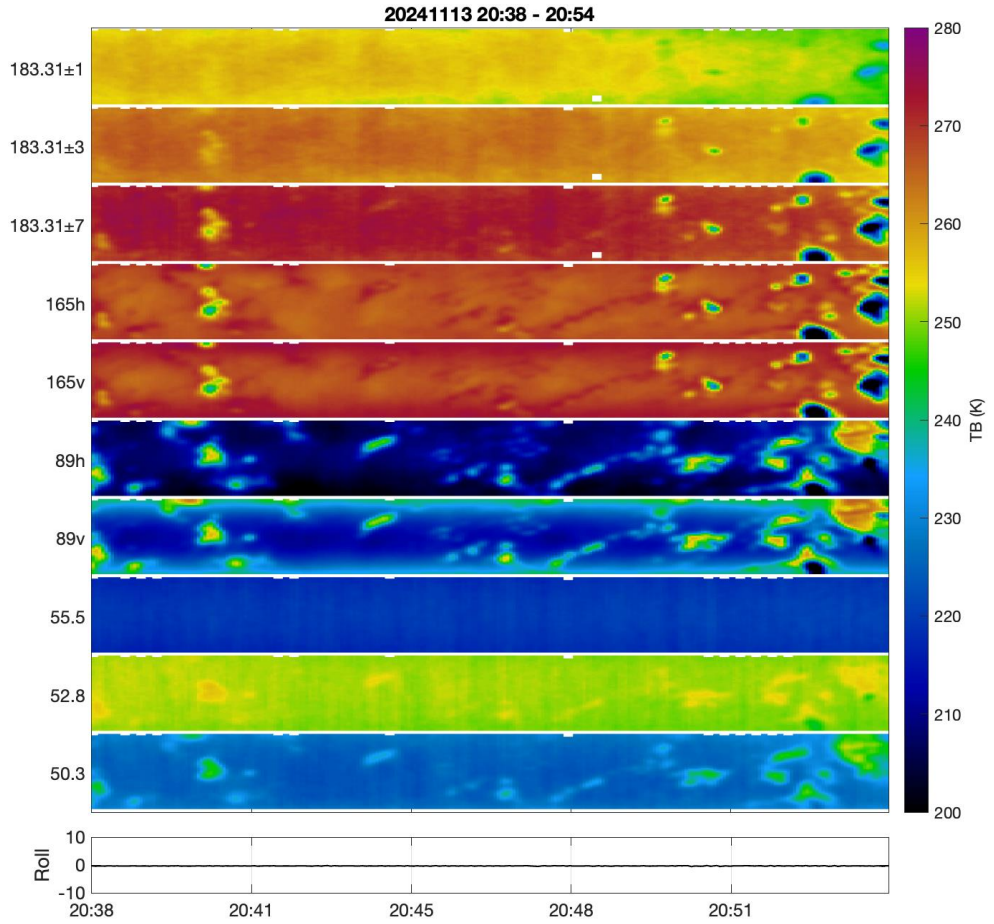
(Top) Selected band-averaged (ATMS-equivalent) channel observations. SGP central facility site where the pink lines intersect (aircraft ground track).
(Right) TB as a function of frequency at SGP overpass

WH²yMSIE Observation Highlights

Atmospheric River: 13 Nov



CoSMIR-H selected channels for the 11/13 atmospheric river flight. Precipitation can be seen in the 50/89 GHz channels and ice scattering in the 183 GHz channels on the north side of the leg.

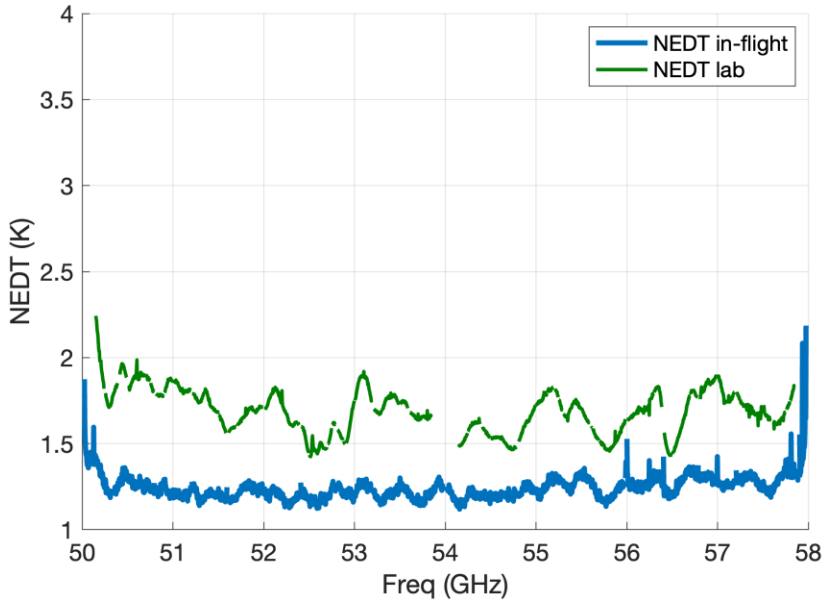


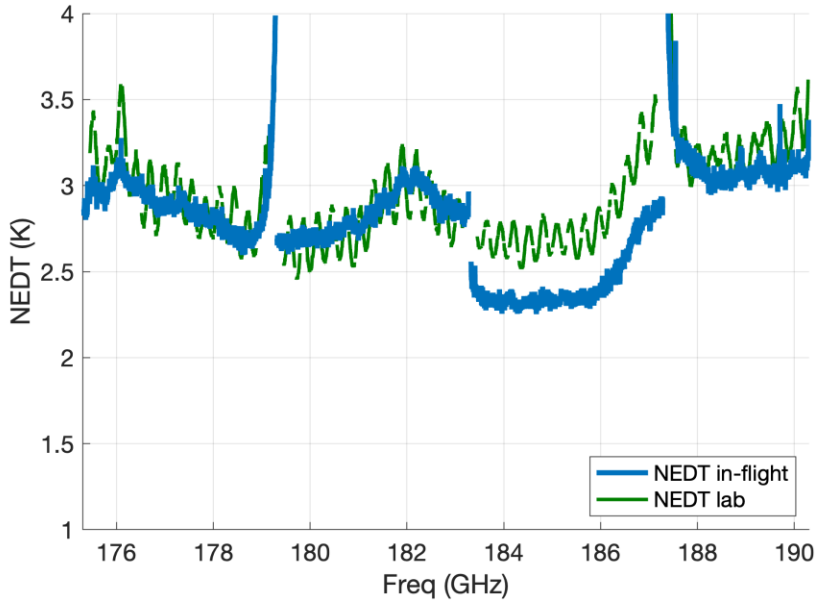
50-GHz and 183-GHz channels are created by averaging the 4-MHz bins into ATMS-equivalent bandwidths

Noise Performance

- Laboratory measurements of the receiver noise temperature (T_R) as a function of frequency were made prior to WH^{2}yMSIE using the onboard hot target and an LN_2 target
- NEDT is estimated from these measurements and is compared with in-flight NEDT calculations for 70 ms integration time (τ) and 4 MHz bandwidth (B)
- **The in-flight NEDT shows very good results within what is expected**

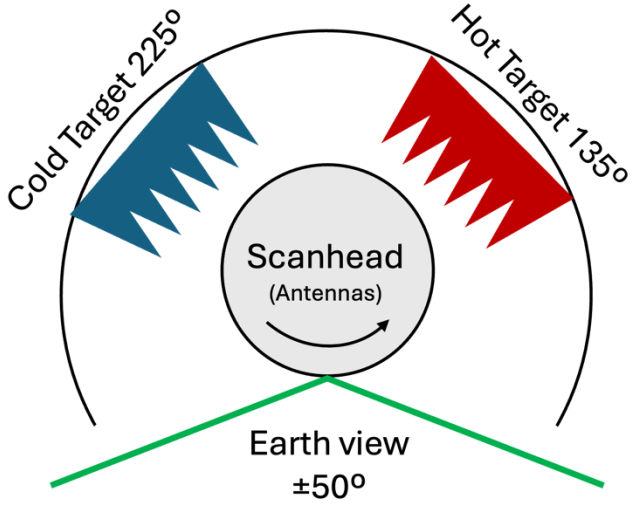
$$NEDT = \frac{T_A + T_R}{\sqrt{B\tau}}$$



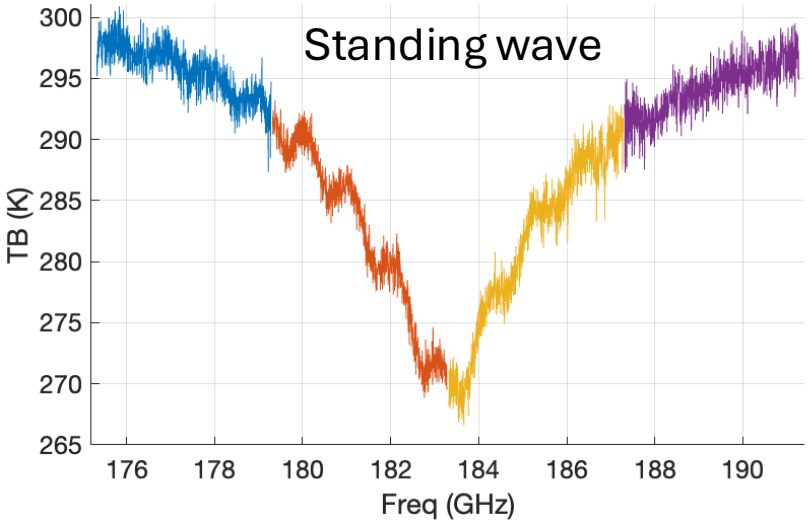


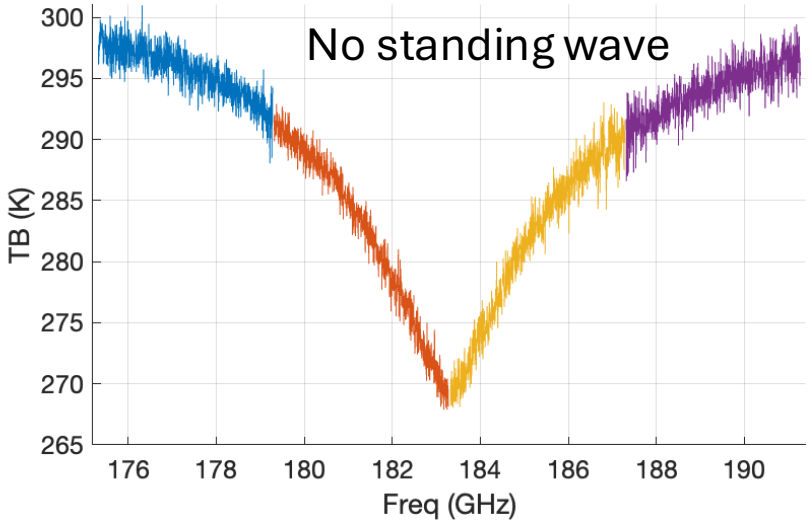
Challenge: Standing Waves

- The default scanning pattern for CoSMIR-H was to stop and stare at the two calibration targets
  - Standing wave noticed when staring directly at targets
- Changing the scan to slowly spin past the target and not using the middle target view removed this wave
- **Hyperspectral measurements allowed us to diagnose this issue**



Earth TB spectrum using cal target data from direct view (left) showing standing wave compared with offset view (right). Colors indicate different ASIC chips.

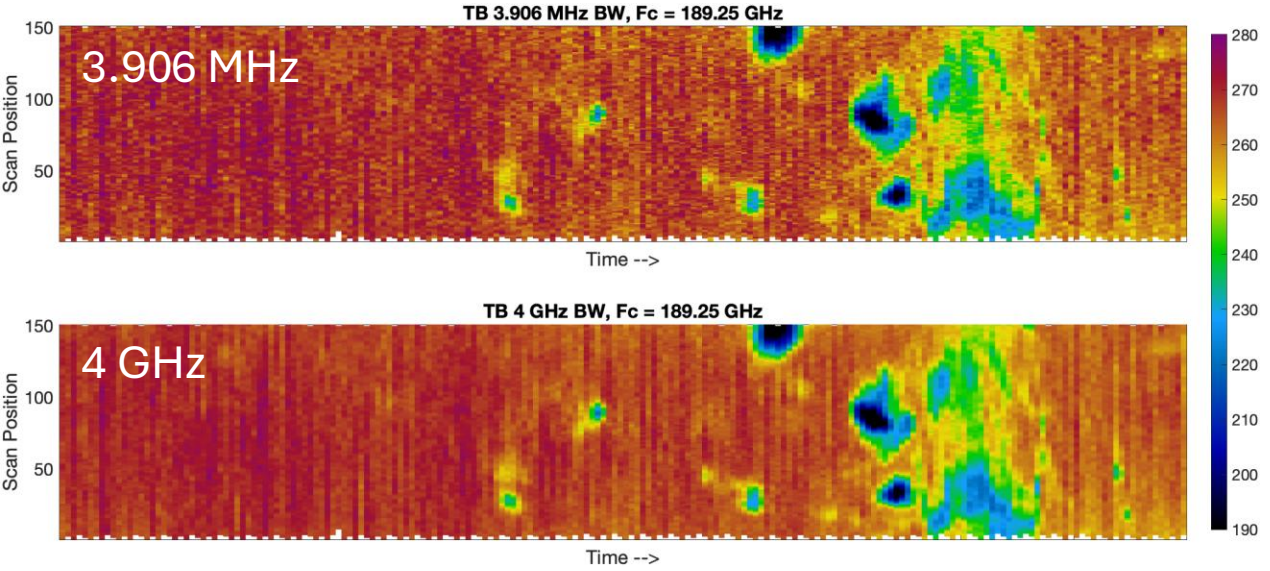




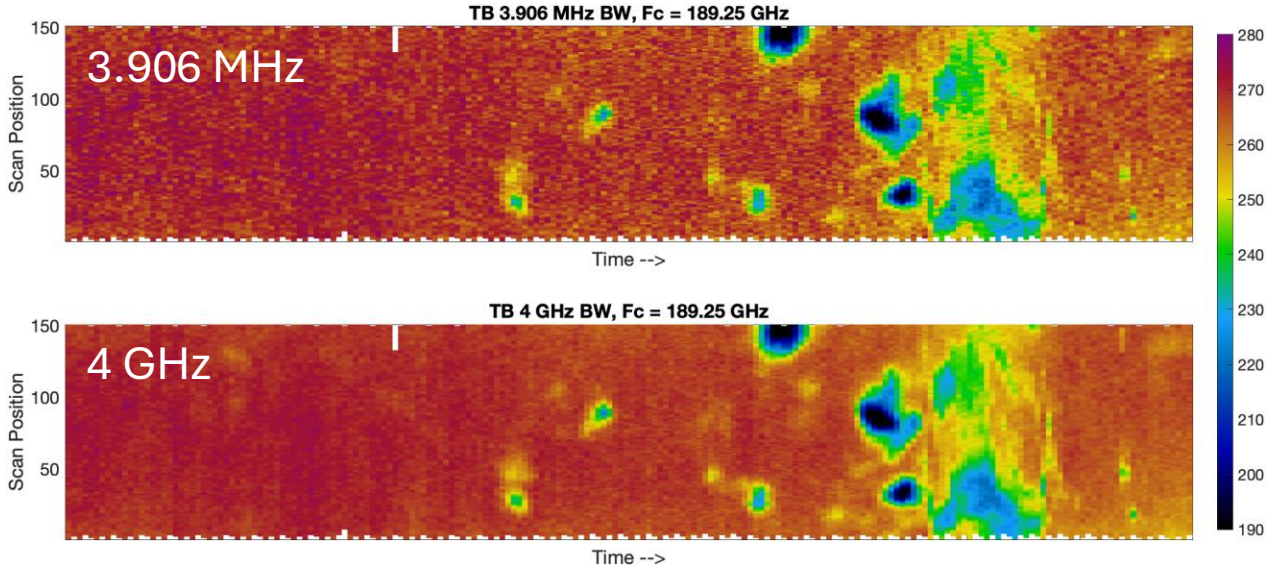
Challenge: 1/f Noise

- Significant striping (i.e. flicker or 1/f noise) was noticed in the 183-GHz hyperspectral channels
- Correction was developed and applied for the first data release, but we are continuing to investigate other methods to remove the noise
- Conducting laboratory measurements to better characterize and mitigate the noise for future measurements

Original



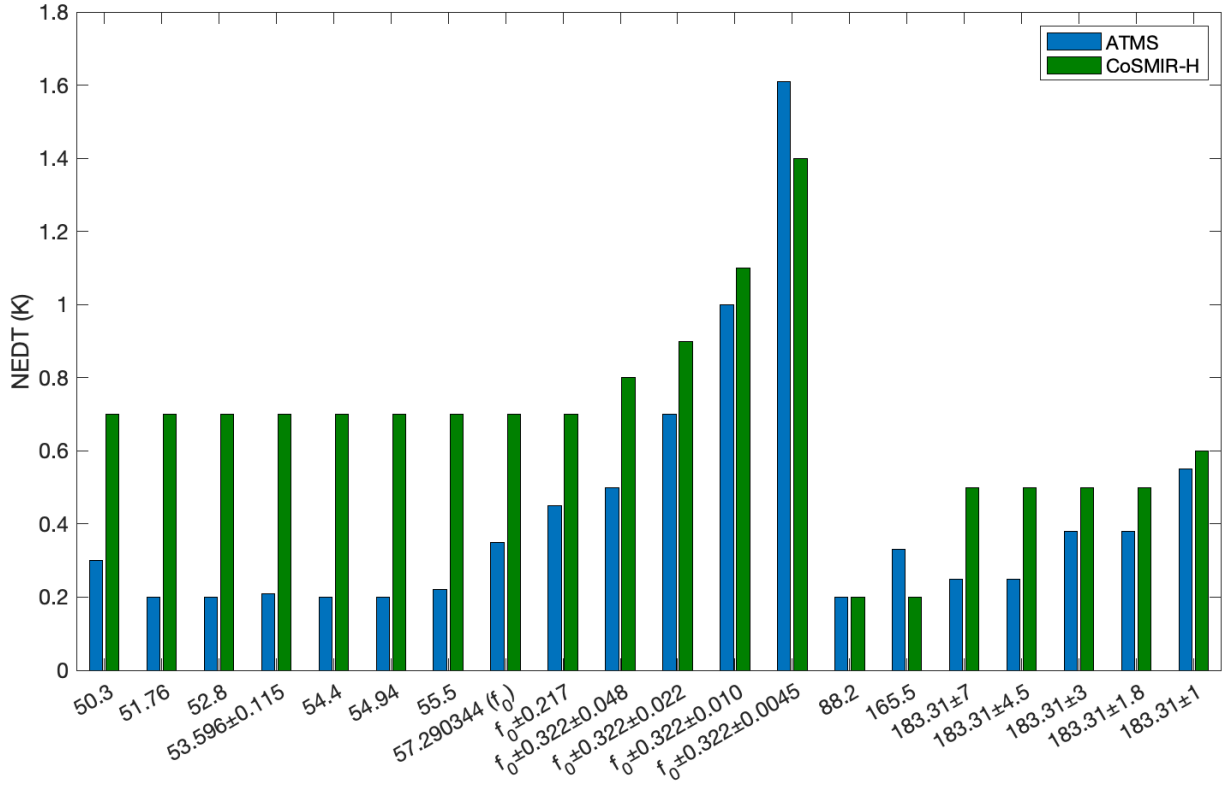
Corrected



1/f noise correction significantly reduces the TB striping while maintaining the fine geophysical features.

NEDT Estimate for BW Averaging

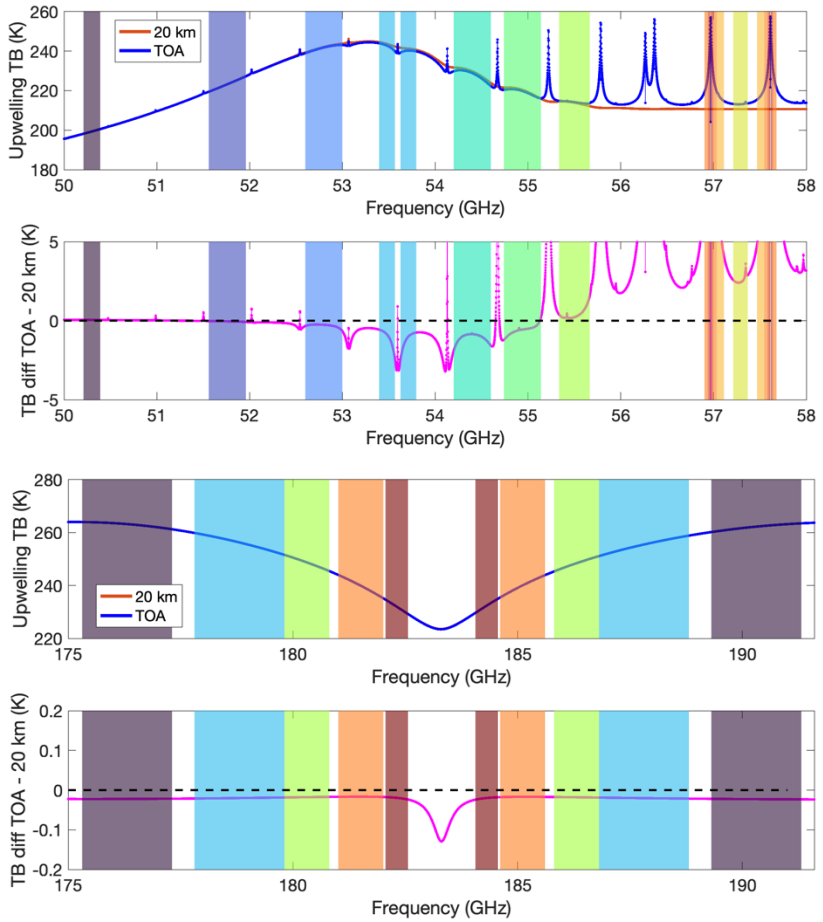
- Currently working on calculating NEDT as a function of bandwidth averaging
- Estimates shown here comparing with NOAA21 ATMS
  - CoSMIR-H 70 ms integration time
  - 183-GHz comparable, 50-GHz channels show significant difference
- Complication is how to use the cal targets to calculate NEDT when there is significant 1/f noise



Validation: TB Comparison with ATMS

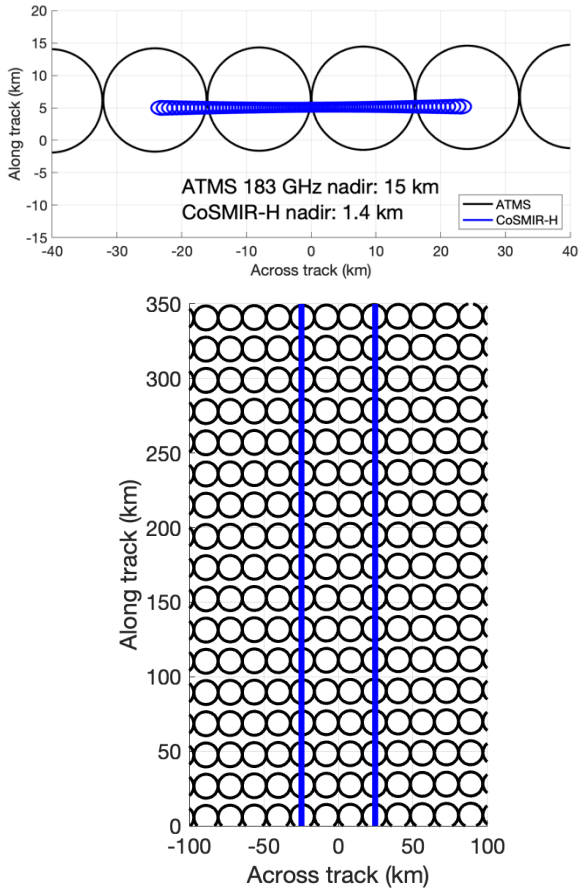
- Two primary WH²yMSIE underflights
  - Ocean clear-sky
  - ~30-minute aircraft flight track along NOAA21 satellite track
- One ‘underflight of opportunity’
  - NOAA21 intersected over-land flight track ~30 min after the ER-2
- CoSMIR-H 4-MHz frequency bins averaged to approximate ATMS channel bands using NOAA21 spectral response functions

Upwelling TB comparison: TOA vs 20 km



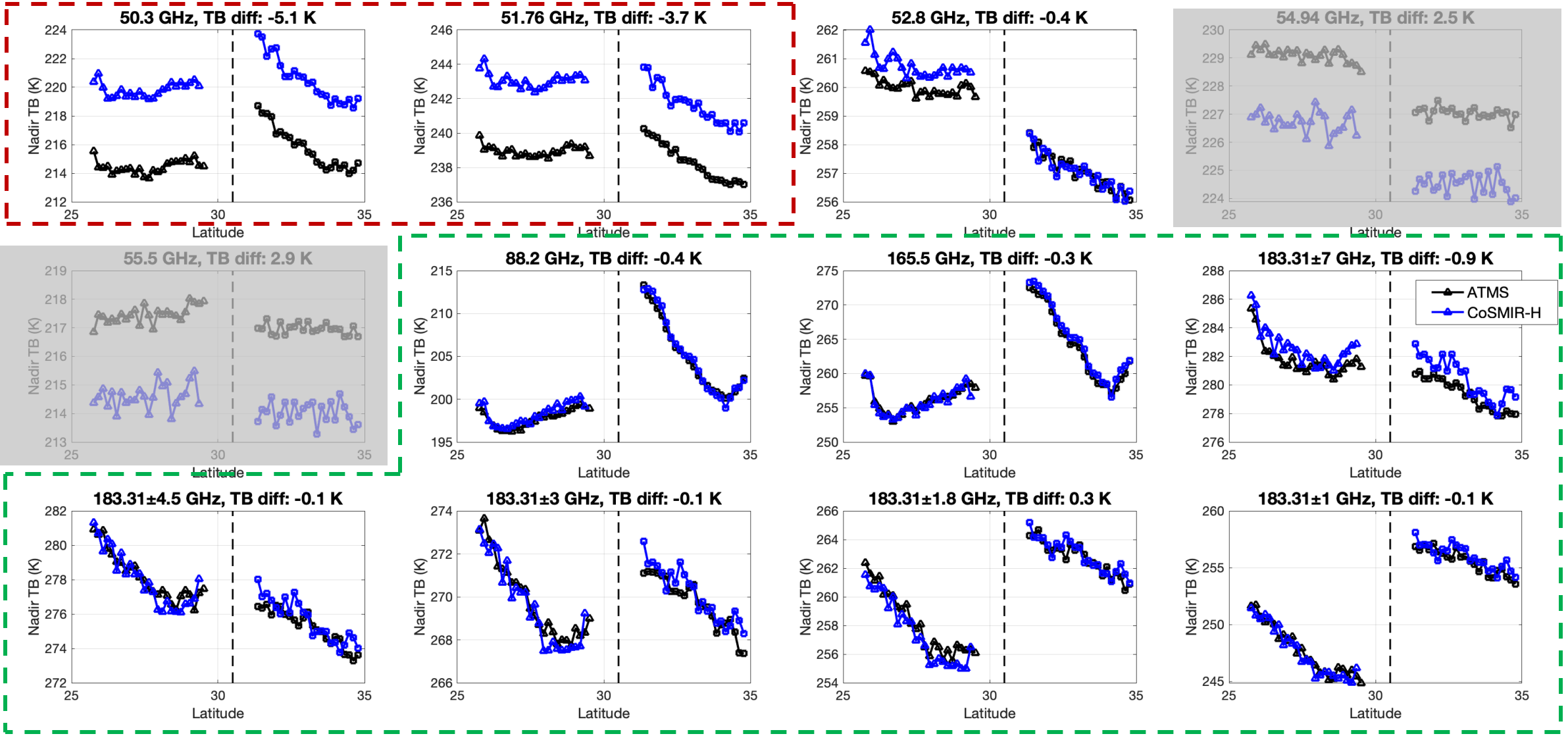
Stratospheric O_2 sounding channels show significant differences from ATMS but the differences in the H_2O sounding channels should be negligible.

Footprint/swath comparison



ATMS underflights over homogeneous scenes to compare observations

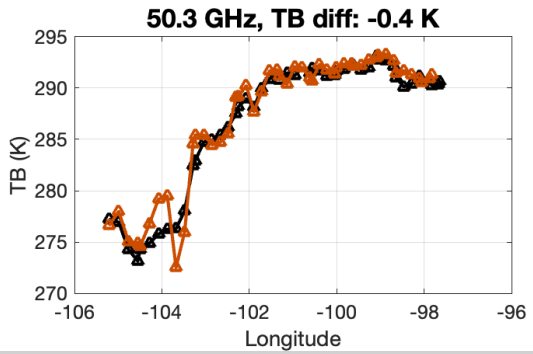
Ocean Clear-Sky: 23 Oct and 07 Nov

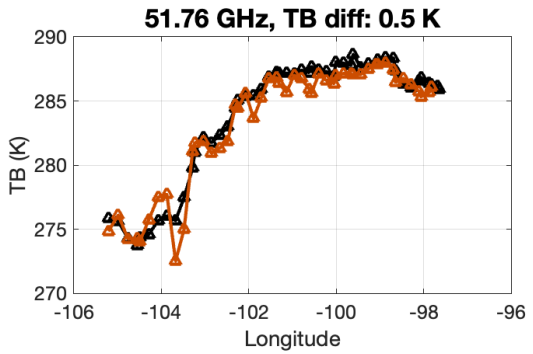


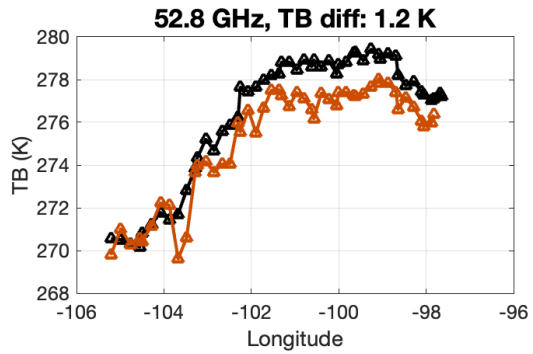
89, 165, and 183-GHz shows very good agreement

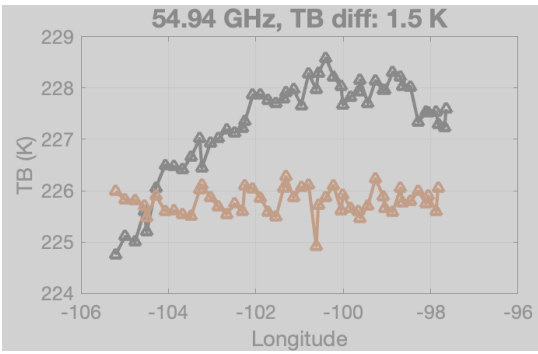
Low 50-GHz show significant bias

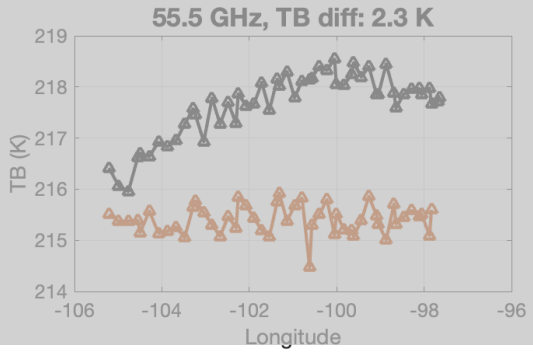
Land Overpass of Opportunity: 22 Oct

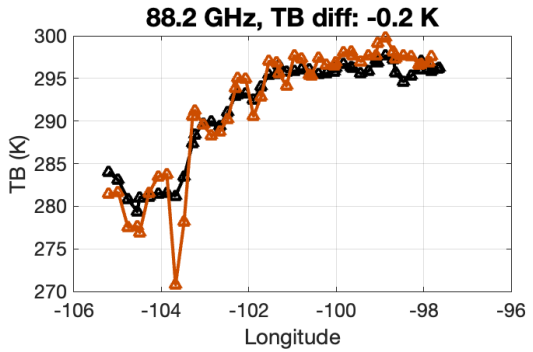


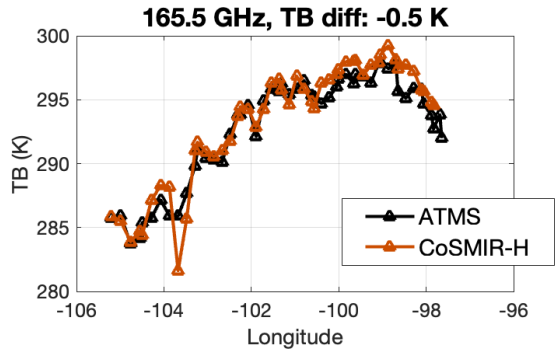


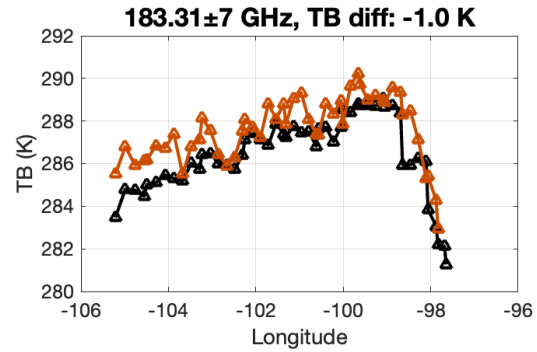


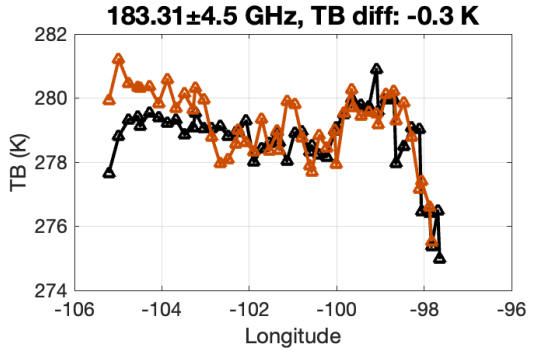


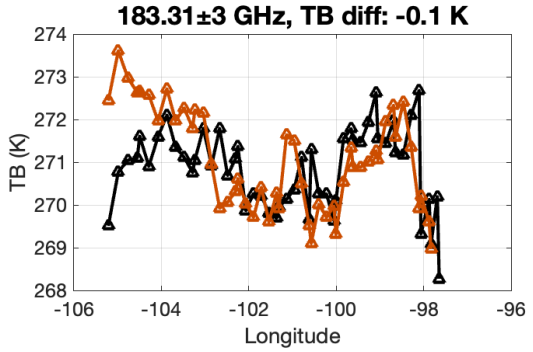


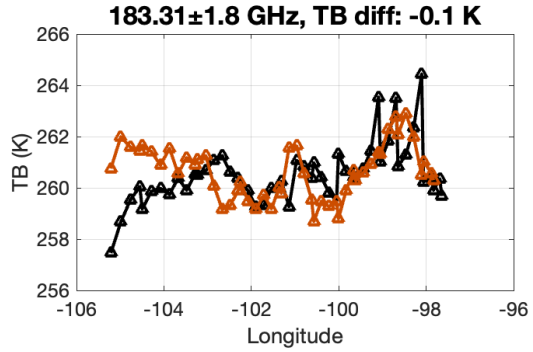


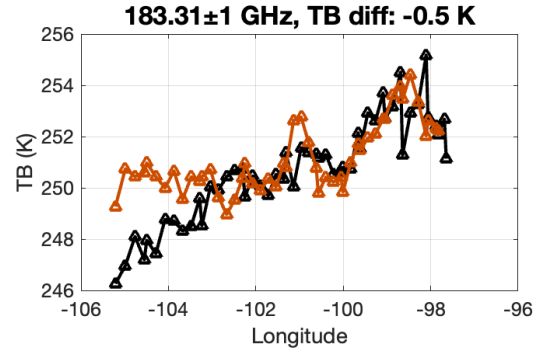












All channels show very good agreement (mid 50-GHz see different atmospheres)

Summary

- The airborne hyperspectral microwave sounder CoSMIR-H performed well during flights and collected a great dataset
- Level 1 calibrated brightness temperature dataset from WH^{2}yMSIE is available for download
- Thanks to NASA ESTO and NOAA's Joint Venture Partnerships program for funding this exciting project

Data download: **https://www-air.larc.nasa.gov/cgi-bin/ArcView/whymsie**

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