Hyperspectral Microwave Sounder Airborne Capability at 50 and 183 GHz for CoSMIR-H

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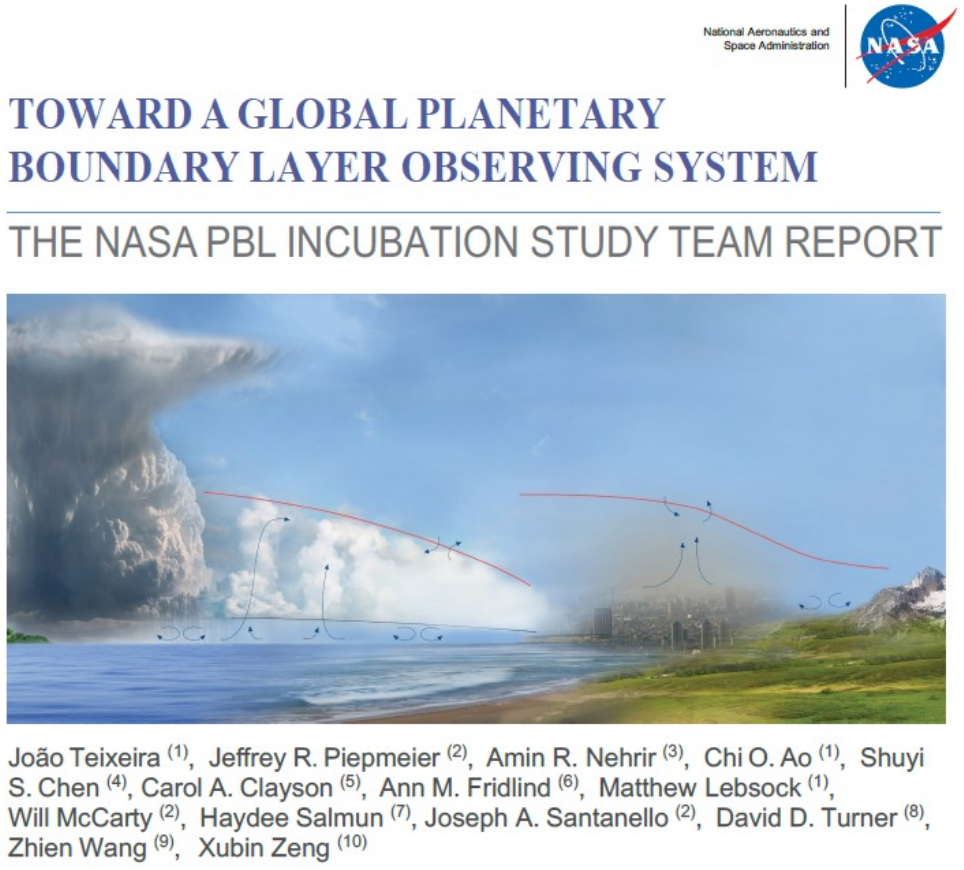
Introduction



https://science.nasa.gov/earth-science/decadal-pbl

Motivation:
PBL Study Team Report lists hyperspectral microwave (HMW) sensors as one of the ***"Essential Components"*** of a future global PBL observing system, to provide ***"accurate PBL and free tropospheric three-dimensional (3D) temperature and water vapor structure context"***.

Objective:
Build an airborne HMW sensor and collect observations to demonstrate capability of HMW sounding, especially in the PBL. Enhance the airborne CoSMIR instrument with hyperspectral receivers (renamed CoSMIR-H) by utilizing ASIC spectrometers to give full spectrum coverage at 50-58 GHz and 175-191 GHz and conduct test flights to collect data.

What is Hyperspectral Microwave?

Sampling of Papers: 2010-2015

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 49, NO. 1, JANUARY 2011

Hyperspectral Microwave Atmospheric Sounding

William J. Blackwell, *Senior Member, IEEE*, Laura J. Bickmeier, R. Vincent Leslie, Michael L. Pieper, Jenna E. Samra, Chinnawat Surussavadee, *Member, IEEE*, and Carolyn A. Upham

Benefits of a Hyperspectral Microwave Sensor

Applications in Environmental Monitoring and Weather Forecasting

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Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2015JD023331

Key Points:
- A hyperspectral MW instrument could improve temperature & humidity retrieval compared to MetOp-SG
- The main impact from HYMS comes from higher resolution in the O_2 band

Microwave hyperspectral measurements for temperature and humidity atmospheric profiling from satellite: The clear-sky case

Filipe Aires[1,2,3], Catherine Prigent[1,2], Emiliano Orlandi[4], Mathias Milz[5], Patrick Eriksson[6], Susanne Crewell[4], Chung-Chi Lin[7], and Ville Kangas[7]

RMetS
Royal Meteorological Society

Information content on temperature and water vapour from a hyper-spectral microwave sensor

J.-F. Mahfouf,[a*] C. Birman,[a] F. Aires,[b,c] C. Prigent,[c] E. Orlandi[d] and M. Milz[e]

NOAA BAA 2022

BROAD AGENCY ANNOUNCEMENT: Demonstrating the Hyperspectral Microwave Sensor (HyMS) and Assessing the Benefits for NOAA/NESDIS

WE2.R18: Hyperspectral Microwave Sounder Science and Technology

Wed, 19 Jul, 10:15 - 11:30 Pacific Time (UTC -7)

IGARSS 2023 Special Session

Location: Room 18
Session Type: Oral
Session Co-Chairs: Jeffrey Piepmeier, NASA and William Blackwell, MIT Lincoln Laboratory
Track: Community-Contributed Sessions

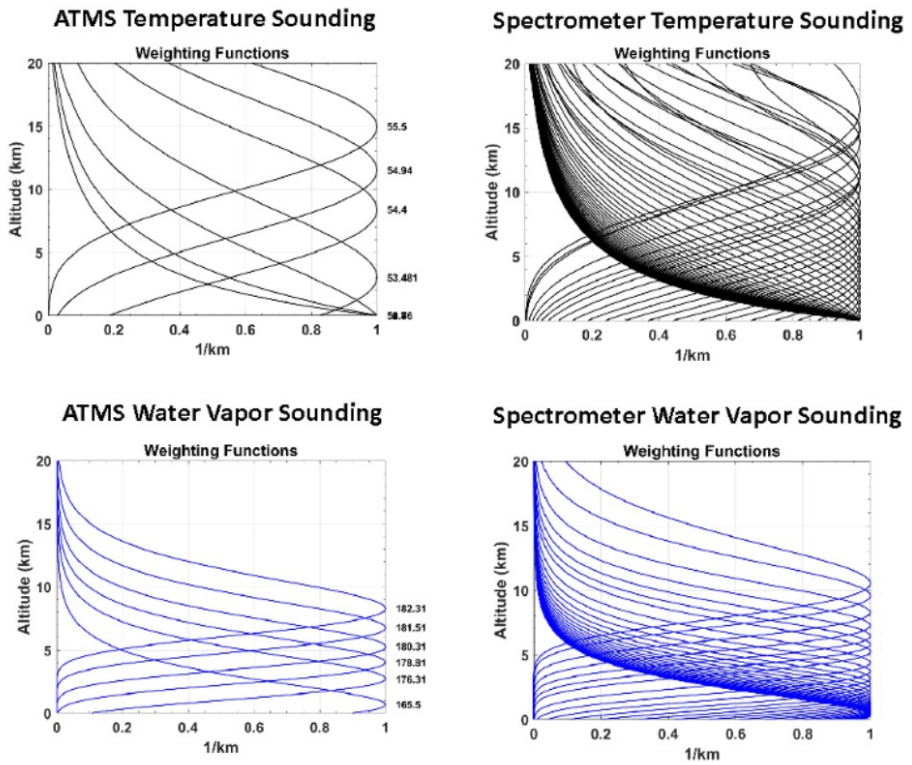
How many channels are needed to be considered "hyperspectral"?

- Infrared Atmospheric Sounding Interferometer (IASI) = 8461 channels
- Microwave = >100 channels

Current Microwave Sounding Standard

ATMS	TMS	CoSMIR-H
23.8	--	--
31.4	--	--
50-58 (13 channels)	--	50-58 (thousands)
88.2	91.655	89v/h
--	114-118 (7 channels)	--
165.5	--	165v/h
183±7-183±1 (5 channels)	184-190 (3 channels)	175-191 (thousands)
--	204.8	--

CoSMIR-H will have 4-MHz spectral resolution for both 50-GHz and 183-GHz ranges.

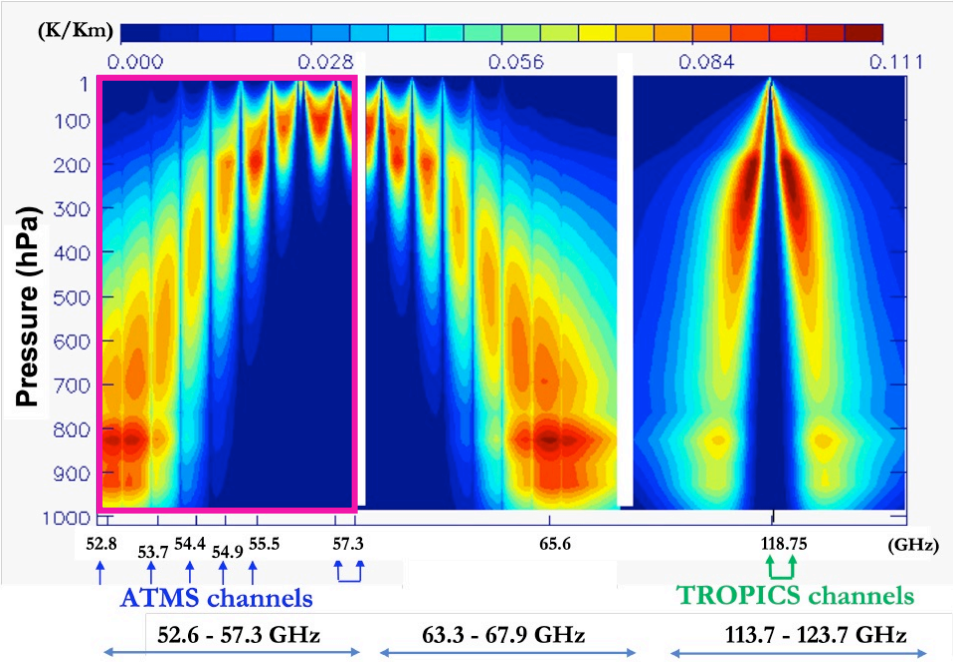


Teixeira, J., *et al.*, 2021: Toward a Global Planetary Boundary Layer Observing System: The NASA PBL Incubation Study Team Report, *NASA PBL Incubation Study Team*, 134 pp.

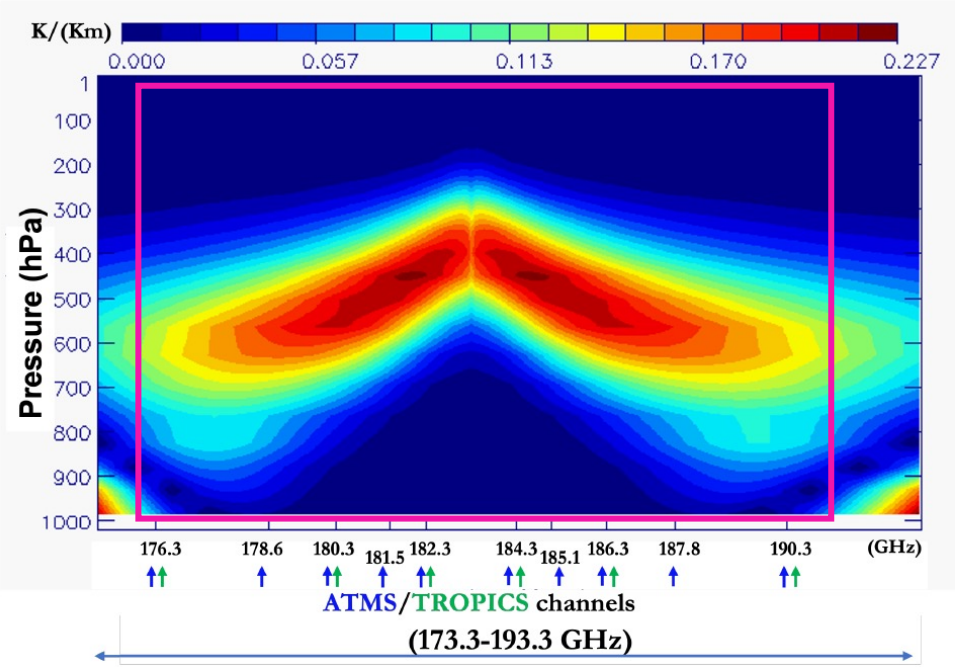
Hyperspectral Microwave Sounding Capability

CoSMIR-H covers a broad spectral range (pink box) to retrieve temperature and water vapor profiles, filling in gaps left by current spaceborne sounder capabilities.

Temperature sounding



Water vapor sounding



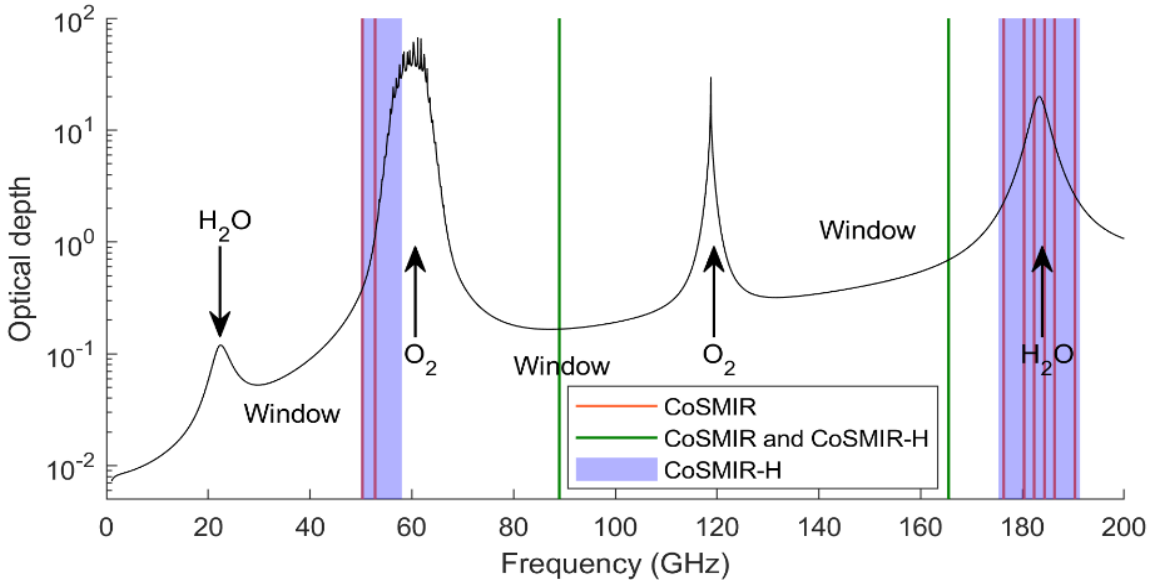
Gambacorta, A., et al., "Advancing Atmospheric Thermodynamic Sounding from Space using Hyperspectral Microwave Measurements," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, 2023.

CoSMIR-H DSI Proposal

Modify the current CoSMIR 50/52 and 183 GHz channels with new hyperspectral receivers (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

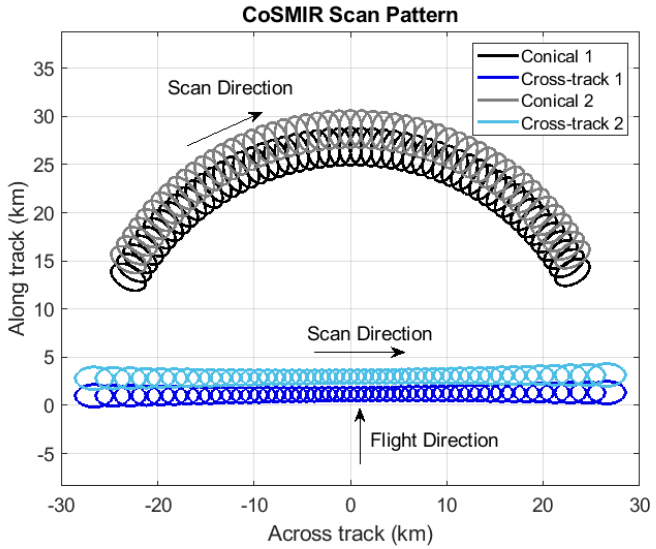
Fc (GHz)	BW (MHz)	Number of Channels	Pol	NEDT (K)
50.0-58.0	100	80	H	0.2
	10	800		0.6
89.0	2,000	--	V/H	0.14/0.13
165.5	2,000	--	V/H	0.18/0.16
175.31-191.31	400	40	H	0.3
	40	400		0.8

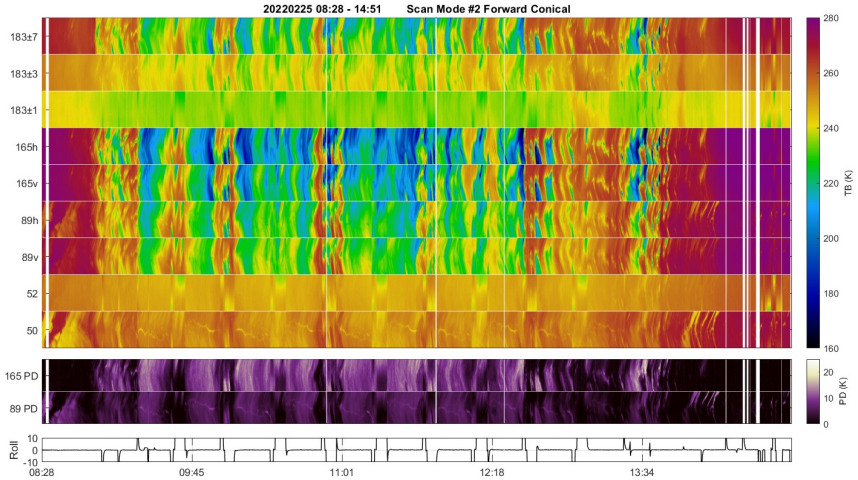


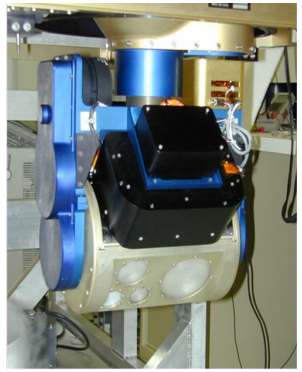
Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR)

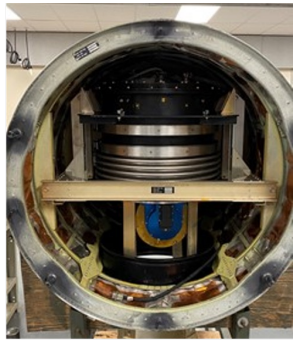
CoSMIR	GMI
50.3h	--
52.8h	--
89.0v/h	89.0v/h
165.5v/h	166v/h
183.31±1h	--
183.31±3h	183.31±3v
183.31±7h	183.31±7v

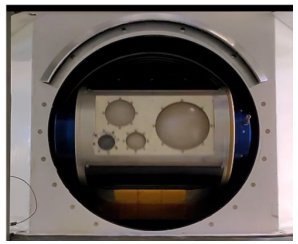
CoSMIR has the unique ability to scan in various modes: fore/aft conical and cross/along-track.



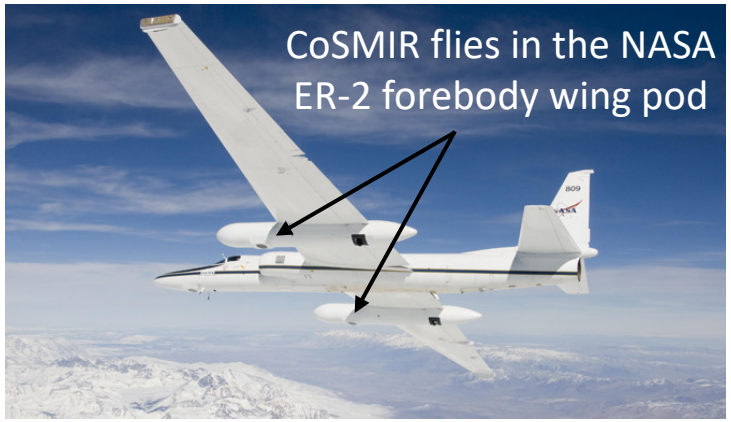






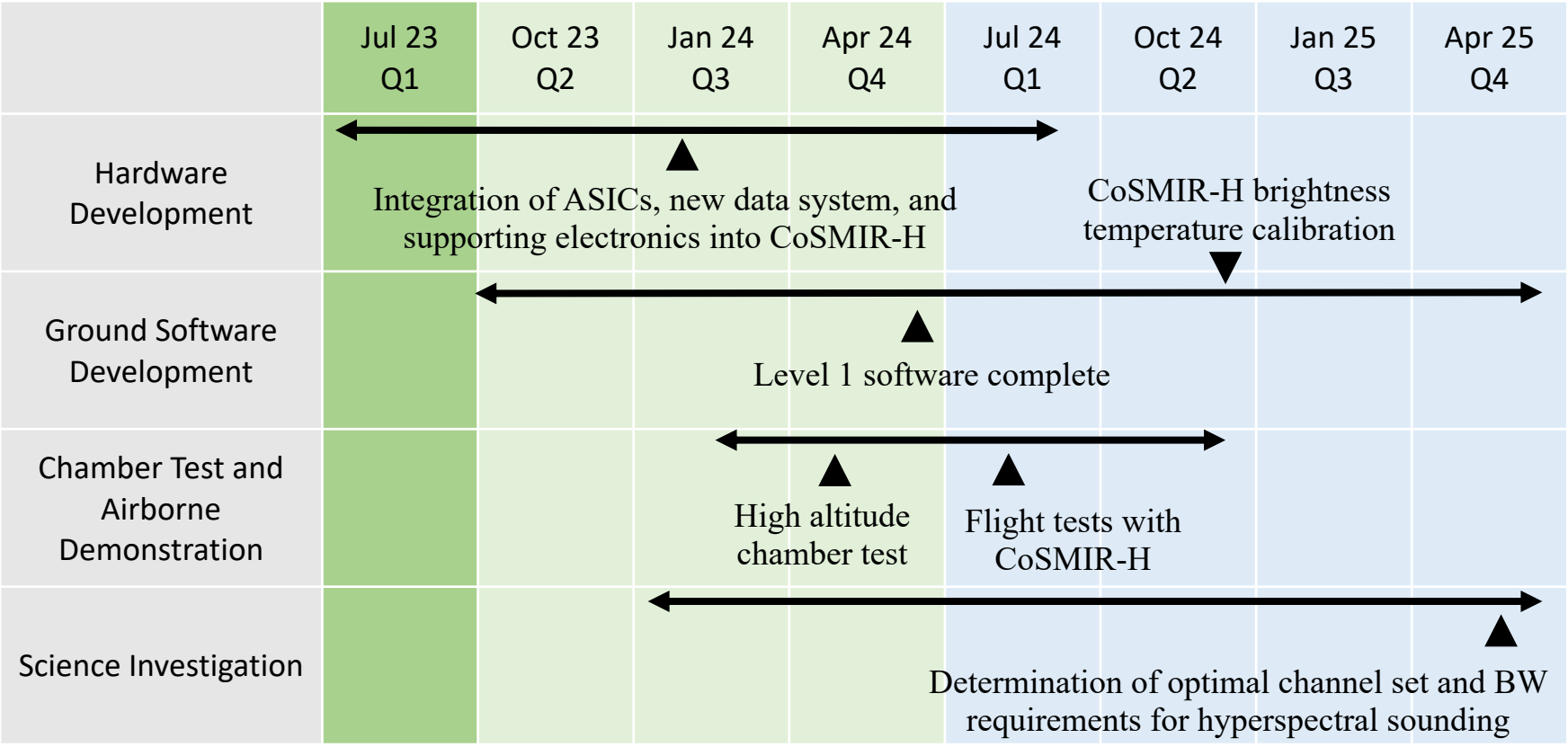


(Top left) CoSMIR mounted on the scan pedestal in the lab. **(Top/Bottom Right)** CoSMIR installed in the ER-2 forebody wing pod for IMPACTS.



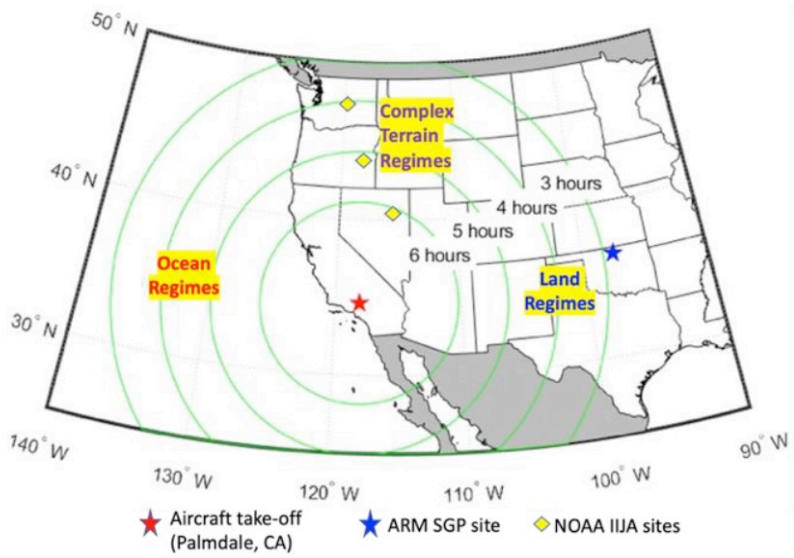
Three Year Schedule: June 2022-2025

First year of project focused on hardware development. We are on-schedule for CoSMIR-H test flights on the NASA ER-2 aircraft in July 2024.

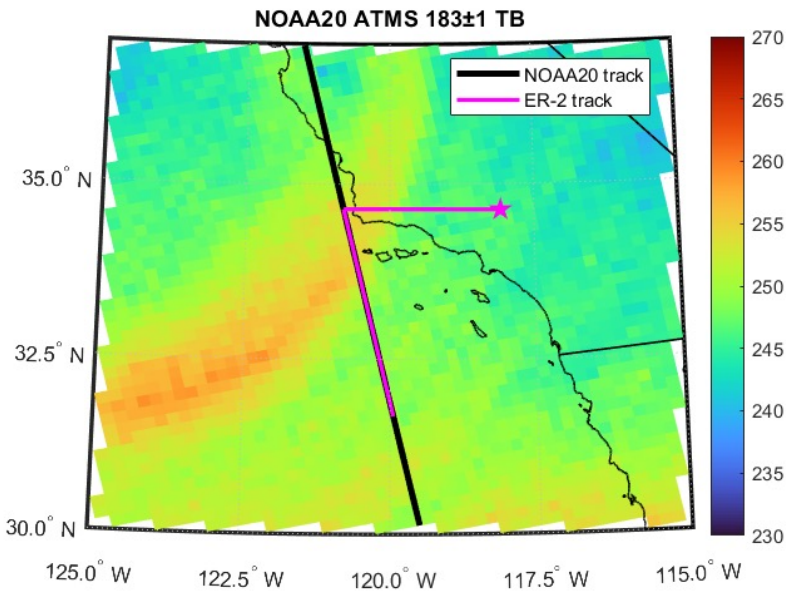


Check Flights and Campaign

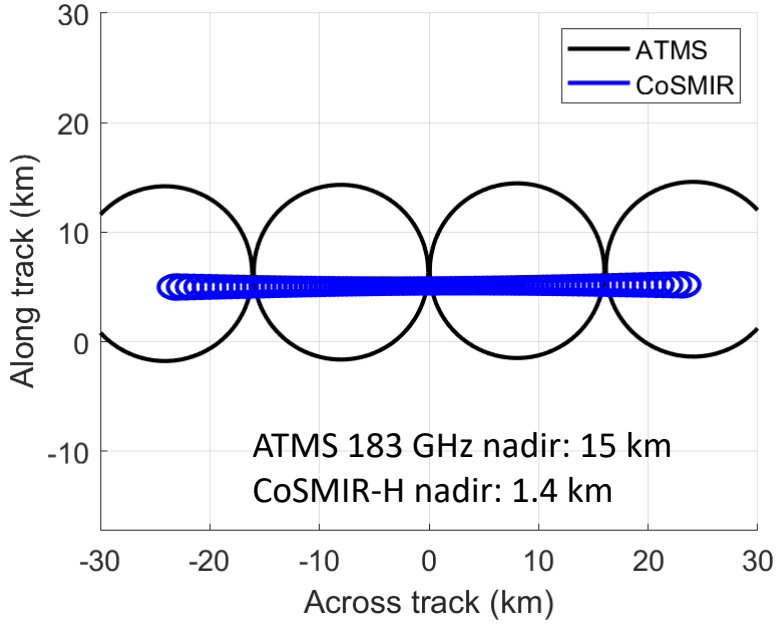
Range rings of the ER-2 (assuming an 8 hour flight)



Example ER-2 satellite underpass flight (~30 min overlap)



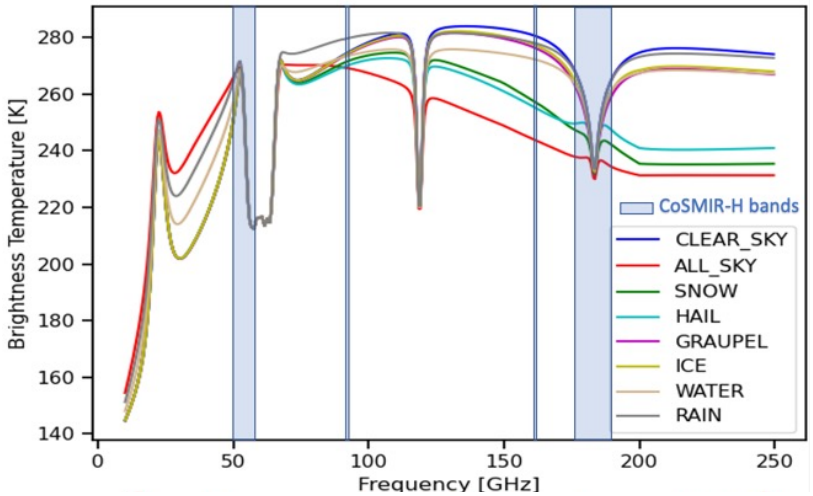
CoSMIR-H ground track compared with ATMS

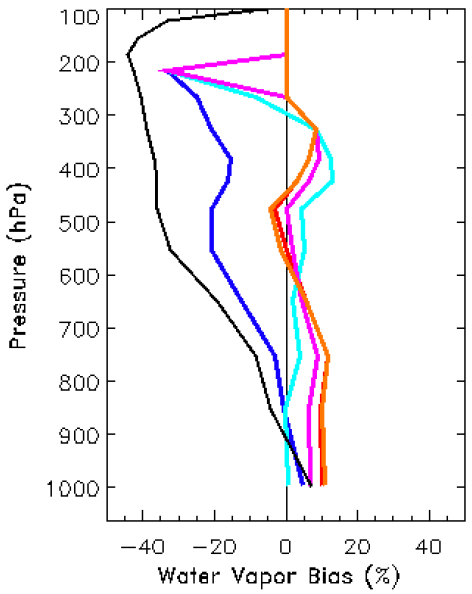


In addition to the engineering check flights funded under the DSI in July 2024, we have funds from NOAA to do a full 6-week campaign in Oct/Nov 2024 to collect a more robust HMW dataset over a variety of atmospheric and surface conditions.

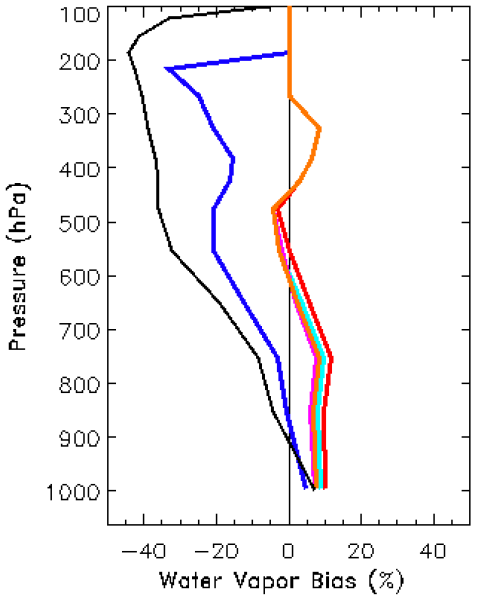
Science Investigation: 183 GHz Trade Studies

Where to place the 16-GHz band at the 183 GHz water vapor line? CoSMIR-H will have it centered at 183.31 GHz, but it is an interesting exercise to see how moving this band changes the water vapor profile retrieval.

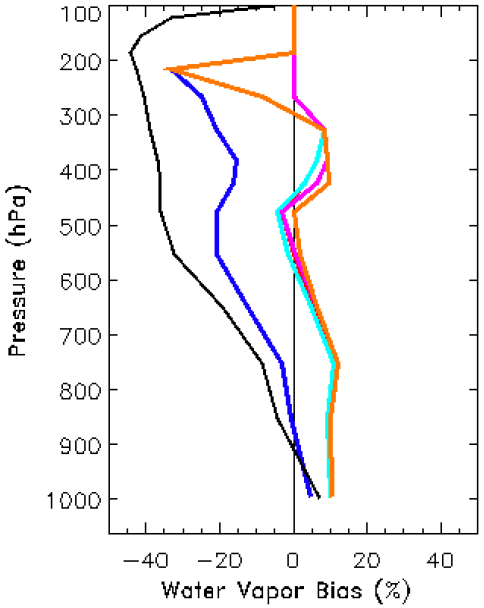




First Guess
ATMS
CoSMIR-H: 175.3 – 191.3
Test 1: 167.3 to 183.3
Test 2: 169.3 to 185.3
Test 3: 171.3 to 187.3



First Guess
ATMS
CoSMIR-H 175.3 – 191.3
Test 4: 173.3 to 189.3
Test 5: 175.3 to 191.3
Test 6: 177.3 to 193.3



First Guess
ATMS
CoSMIR-H: 175.3 – 191.3
Test 7: 179.3 to 195.3
Test 8: 181.3 to 197.3
Test 9: 183.3 to 199.3

Science Investigation: 183 GHz Trade Studies Results

- Proposed to place the 16-GHz hyperspectral band at 175.31-191.31
  - Covers the bands measured by current spaceborne sensors (e.g. ATMS)
- Wanted to see if we could get more sensitivity to the PBL by shifting to the left or right of the line center
- Trade studies show a slight improvement in PBL water vapor retrieval when shifted to the left
  - Comes at the expense of worse retrieval in the upper atmosphere
- Plan is to keep the band centered at 183.31 GHz
  - Better for radiative transfer validation and calibration comparison with ATMS

Summary

- We are developing an airborne hyperspectral microwave sensor with 4-MHz spectral resolution at 50-58 GHz and 175.31-191.31 GHz
  - Modifying the CoSMIR sensor with ASIC spectrometer receivers (CoSMIR-H)
  - Will give us thousands of channels to test the impact of HMW on temperature and water vapor profile retrievals
- CoSMIR-H is on schedule to do engineering check flights on the NASA ER-2 aircraft in July 2024
- We are excited to get CoSMIR-H data in-hand to assess the benefits of hyperspectral microwave observations