Initial Validation of the Hyperspectral Microwave Sensor (HyMS)

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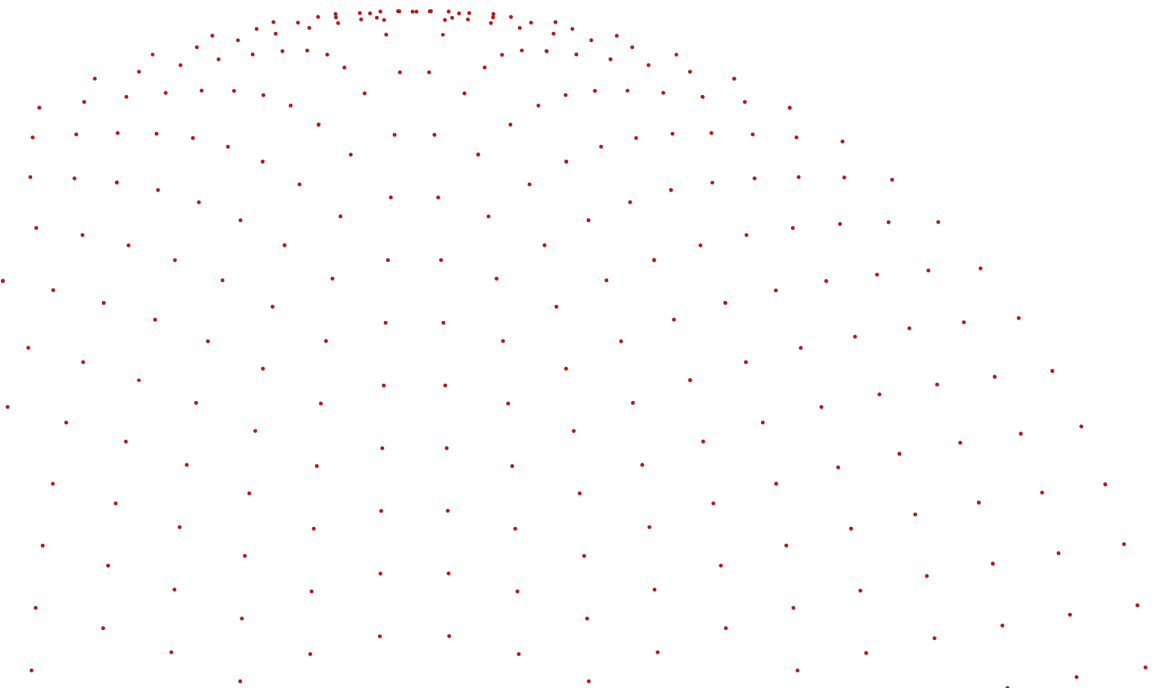
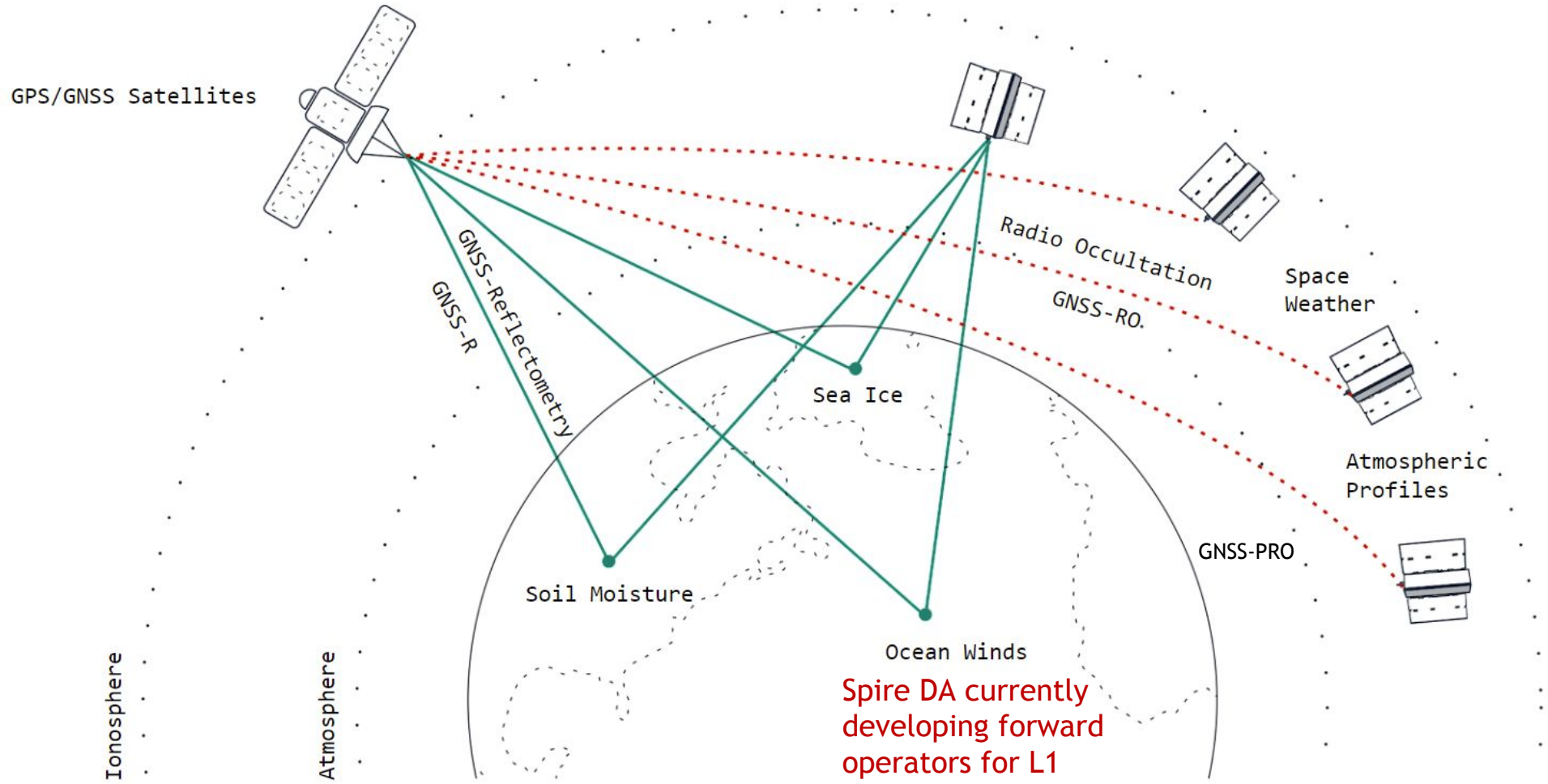
AGENDA



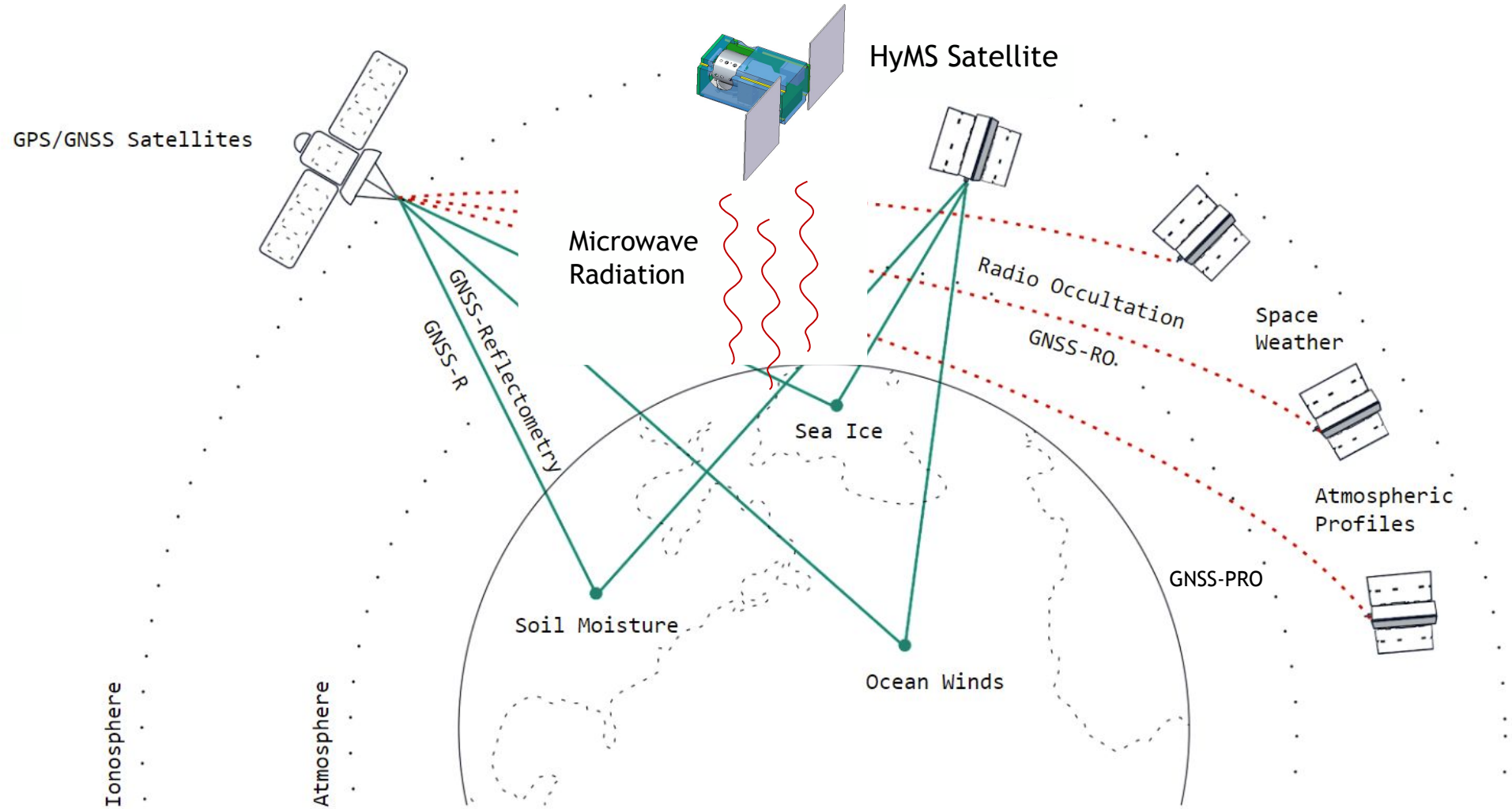
- Spire Observing System
- Hyperspectral Microwave Sensor Details
- Development and Benefits
- Airborne Results

Spire's Current Observing System

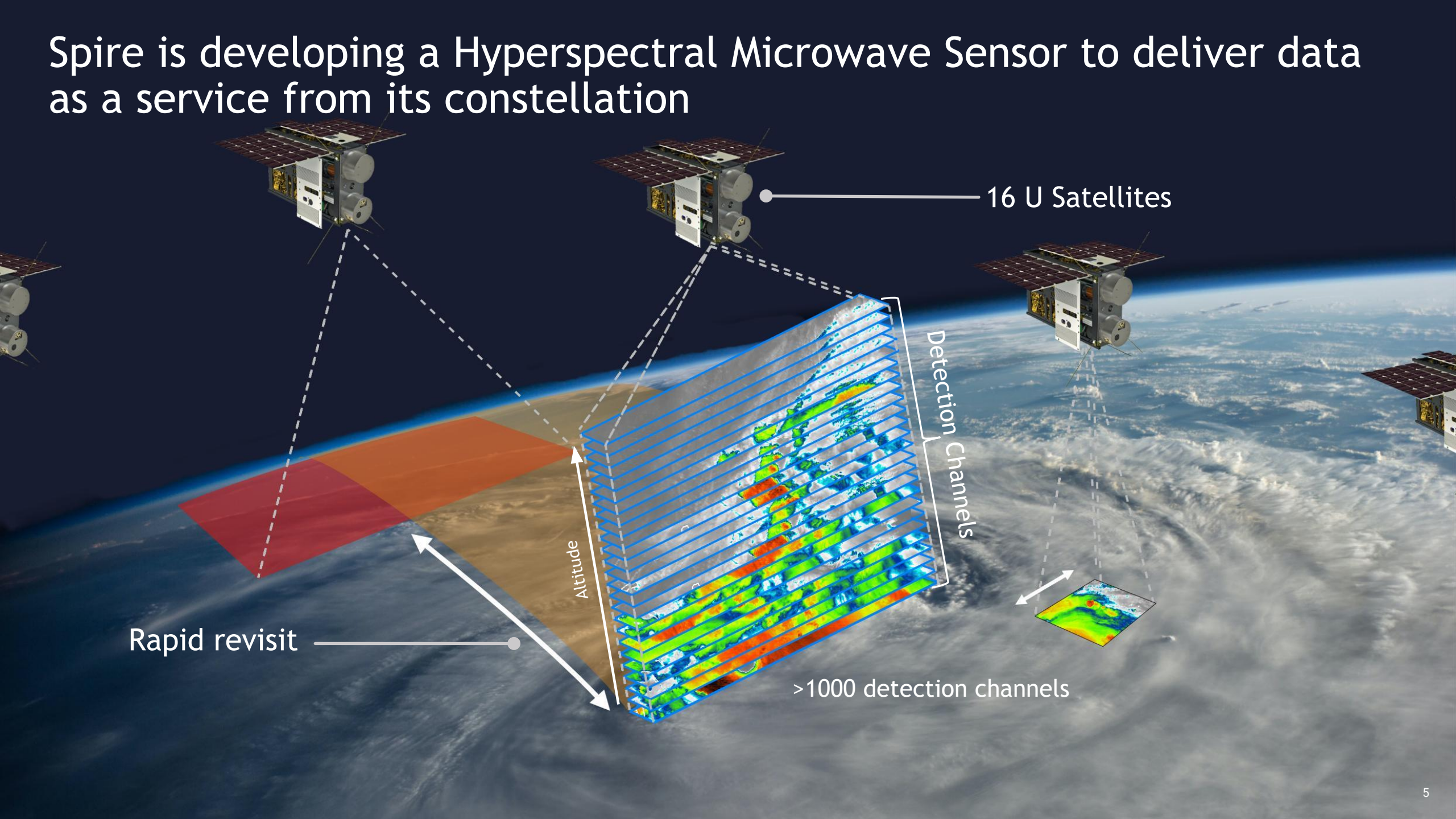


Spire DA currently developing forward operators for L1 GNSS-R Winds

Spire's Future Observing System

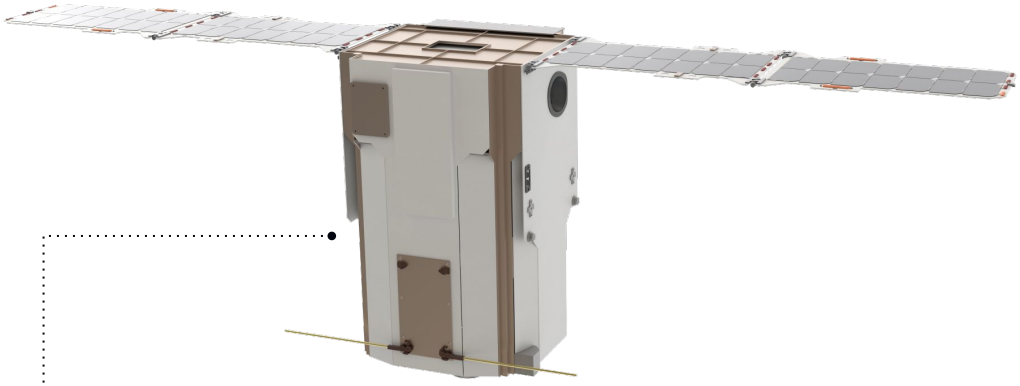


Spire is developing a Hyperspectral Microwave Sensor to deliver data as a service from its constellation



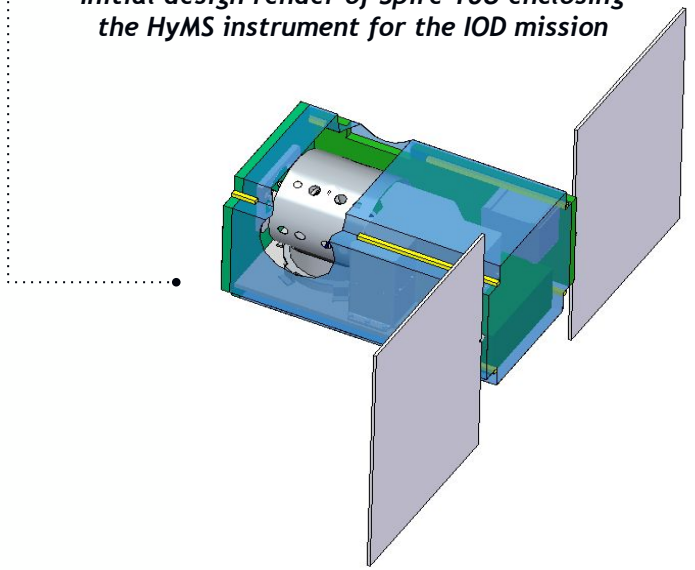
In-Orbit Demonstration of the HyMS:

- Integrate instrument into Spire 16U LEMUR spacecraft
- Sample oxygen and water vapor bands from space
- Demonstrate free-flying instrument performance in orbit
- Assess and understand data collected from HyMS



Standard Spire 16U satellite bus

Initial design render of Spire 16U enclosing the HyMS instrument for the IOD mission



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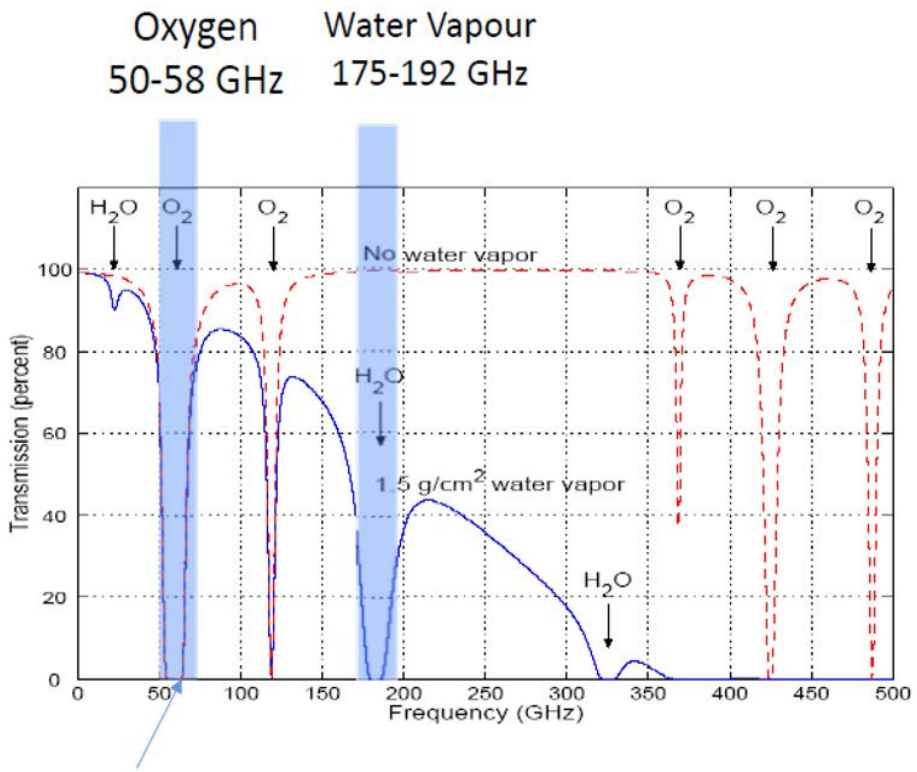
Band Selection and Spectral Resolution



Two key molecular species:

- Atmospheric oxygen (50-58 GHz)
- Atmospheric water vapor (175-192 GHz)

Spectral Resolution

- 5 MHz for oxygen band
- 40 MHz for water vapor band
- 4 GHz for 89 GHz

Window channel for calibration

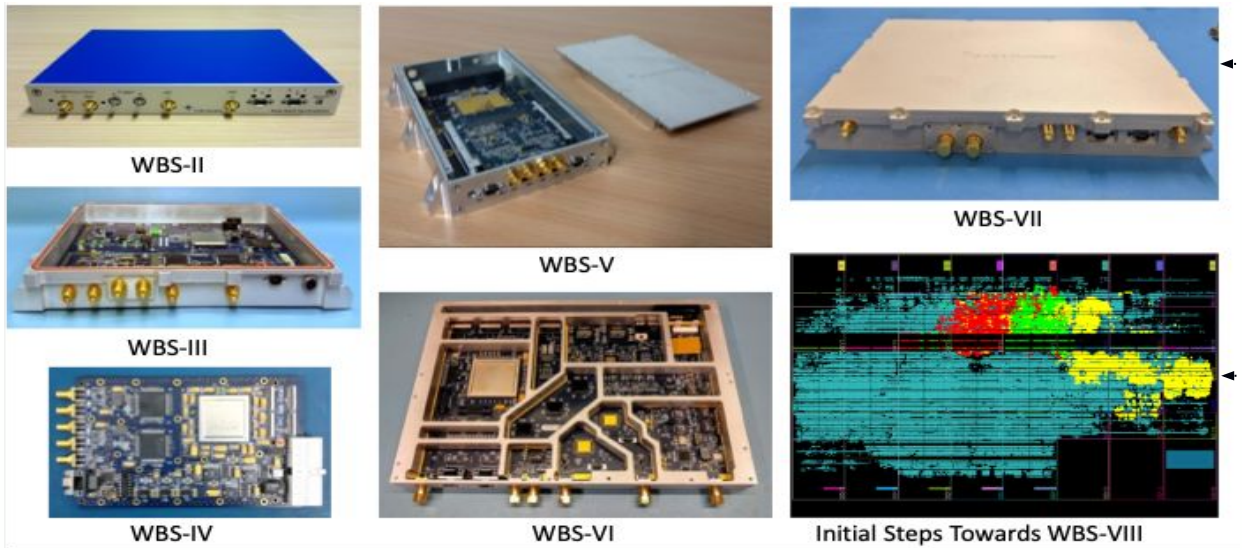
- 89 GHz

Sensor Details

Cross-track Scanner Specifications	
Estimated orbital altitude	500 km (low-Earth orbit)
Scan period	2.55 seconds
Instrument field of view	33 km at 54 GHz
	23 km at 89 GHz
	18 km at 183 GHz
Earth scan angle	+/- 45 degrees
Swath width	1000 km
Calibration	Two-point using onboard hot calibration target and cold space view

HyMS Payload - Spectrometer

- Spire and partner STAR-Dundee developing new version Wide Band Spectrometer (WBS) - WBS-VIII
  - Adapted to fit inside 16U satellite form factor
  - Include spectrometer with four (8) channels at 2 GHz each for flexibility in concurrent band selection and processing, 16 GHz total instantaneous bandwidth
  - 1.22 MHz raw resolution for each spectrometer band, 5 MHz averaged sampling



HyMS Sensor Details: Meets & Exceeds MWS Requirements

Centre Freq (GHz)	Preselected BW (MHz)	Antenna Loss (dB)	Trec (K)	Tsys (K)	NEΔT (K)			Raw NEΔT (K)	Raw NEΔT (K) Total	MWS Req'mt	MWS Pred'n
					frontend	cal noise	Th ΔG/G	Total	20% margin		
54	12	0.3	200	235	0.90	0.32	0.04	0.96	1.15	2	1.6
54	5	0.3	200	235	0.99	0.35	0.04	1.49	1.78		
54	100	0.3	200	235	0.99	0.35	0.04	0.34	0.4		
89	3000	0.3	450	502	0.09	0.03	0.06	0.11	0.14	0.25	0.15
89	4000	0.3	450	502	0.08	0.03	0.06	0.1	0.12		
89	4000	0.3	450	502	0.08	0.03	0.06	0.1	0.12		
183	500	0.1	670	692	0.27	0.09	0.08	0.29	0.35	0.75	0.6
183	40	0.1	670	692	0.29	0.10	0.08	0.1	1.12		
183	400	0.1	670	692	0.29	0.10	0.08	0.32	0.39		

Scene Temperature	280	K
Cold Cal Temp	3	K
Hot Cal Temp	300	K
Tau Scene	32	ms
Tau Cold cal	54	ms
Tau hot cal	54	ms
Tau Cal Effective	216	ms
Cal Average Factor	4	
ΔG/ΔT	0.04	dB/°C
ΔT/Δt	0.003	°C/s
Intercal period	?	s
Δgrx	1.50E-04	

Notes:

Averaging factor from footprint calculations not included

Based on MWS requirement for 12MHz spectral resolution, 3000 MHz spectral resolution and 400 MHz spectral resolution

Spectral averaging can be done on ground depending on user requirements

Key

	Comparison to MWS Bandwidth
	Illustrative figures of averaged bandwidth for 183 (400 MHz) and 50GHz (100MHz)
	Figures for sampling bandwidth on IOD, lowest possible sample rate

- NEDT figures shown are based on varying spectral resolutions
- Predicted sensitivity of HyMS is equivalent to the MWS requirements and predictions
- Spectral averaging can be done on ground to enhance NEDT depending on user requirement

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HyMS Drivers

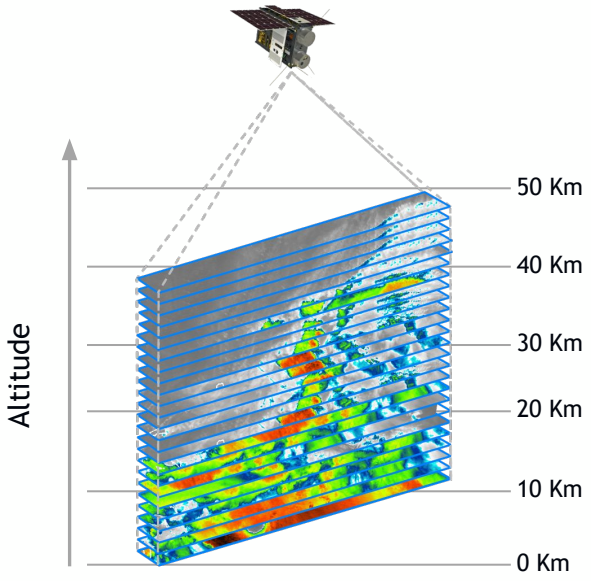
Hyperspectral Microwave Sensor (HyMS) vs. Microwave Sensors

HyMS

<35 kg Dedicated Platform

>1000 Channels

Updated every 3-5 Years



Drivers

1 Retrieval Accuracy [1,2,3,4]

2 RFI Noise Mitigation [4]

3 Vertical Resolution [1,2,3,4]

4 Hydrometeor Characterization [5]

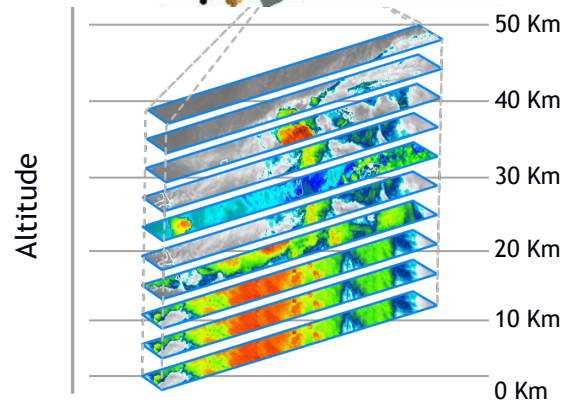
5 Spectroscopic parameters & physical modelling [1]

MetOP SG MWS Instrument

>4000 Kg Multi-sensor Platform

24 Channels

Updated every 20 Years



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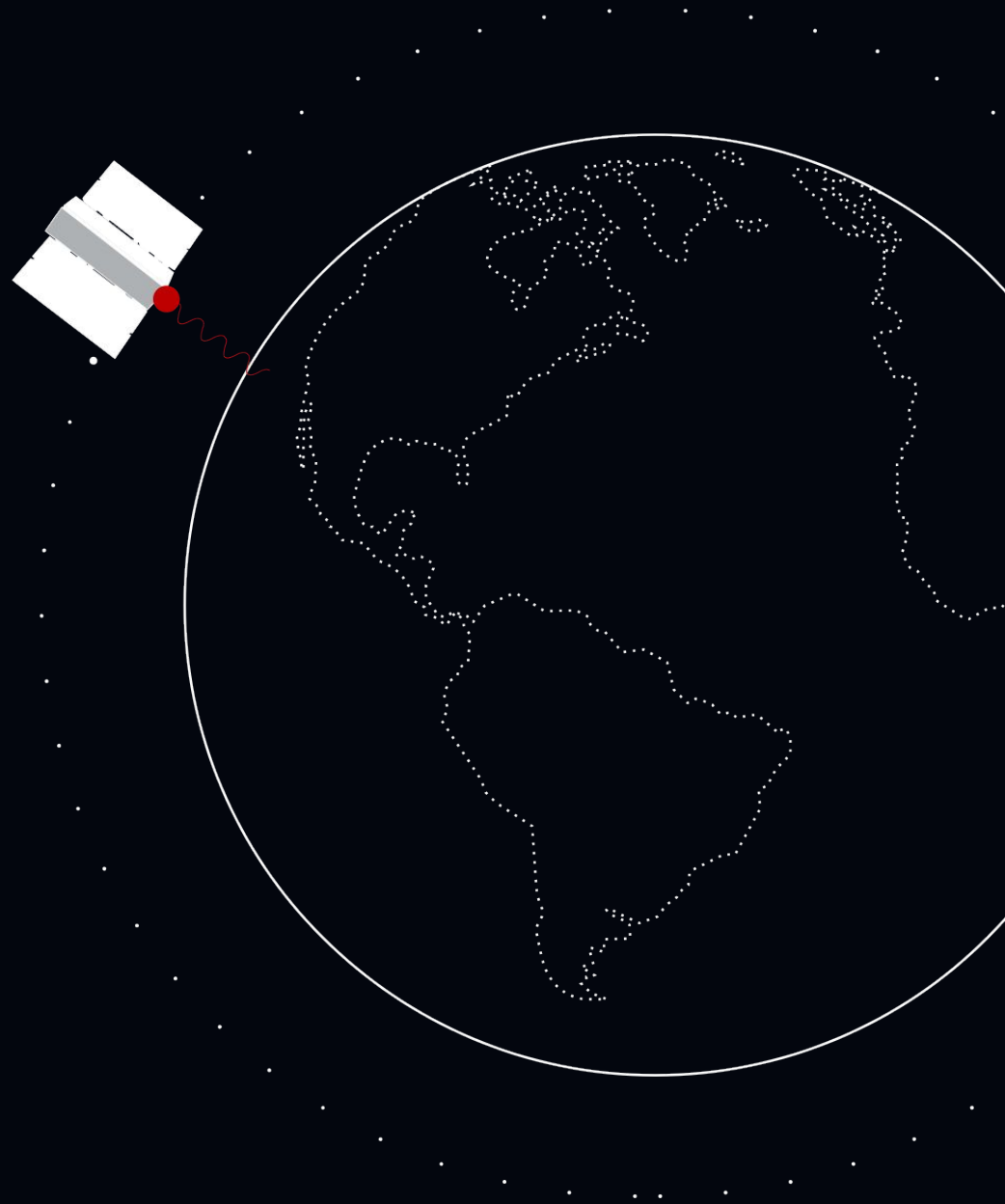
Airborne Demonstrator (SERMON)



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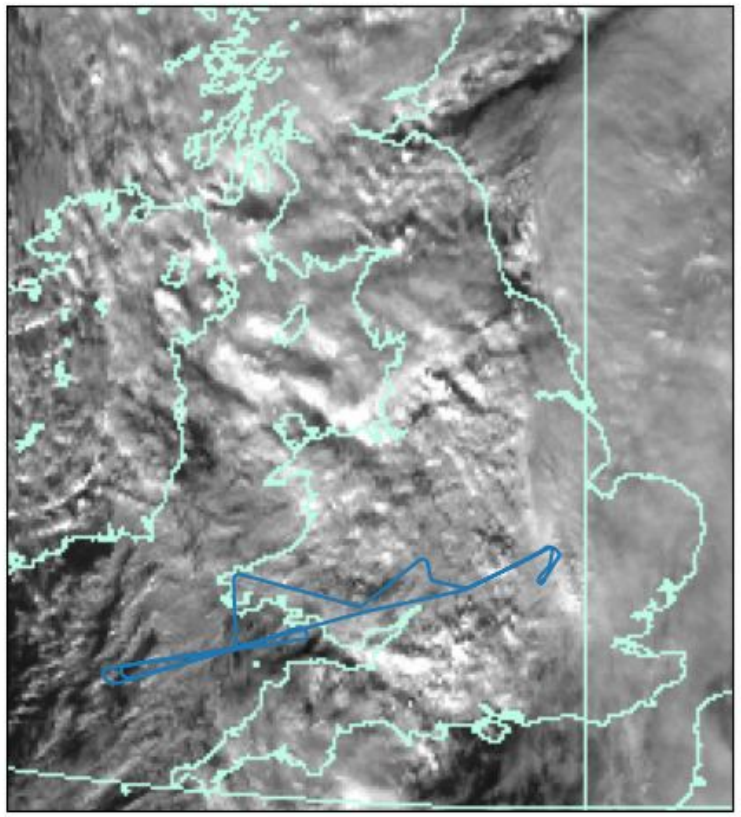
Airborne Demonstrator (SERMON)

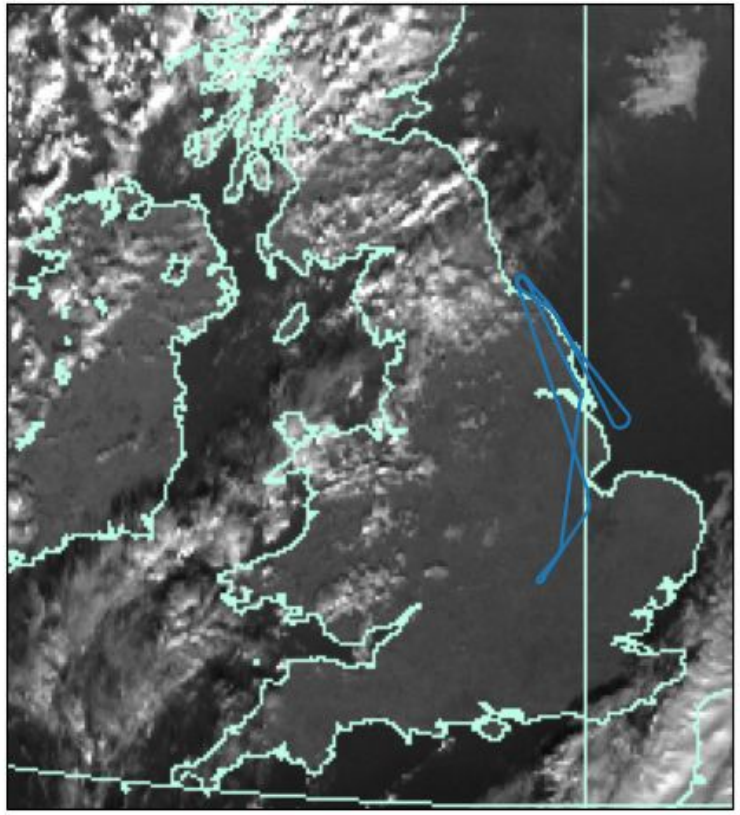
- The SERMON instrument (airborne version of HyMS) can be installed on an FAAM aircraft, in either a zenith or nadir configuration.
- Two flights were completed, operated by the UK MetOffice:

  19 Dec, 2022 (Zenith View)

  20 Dec, 2022 (Nadir View)

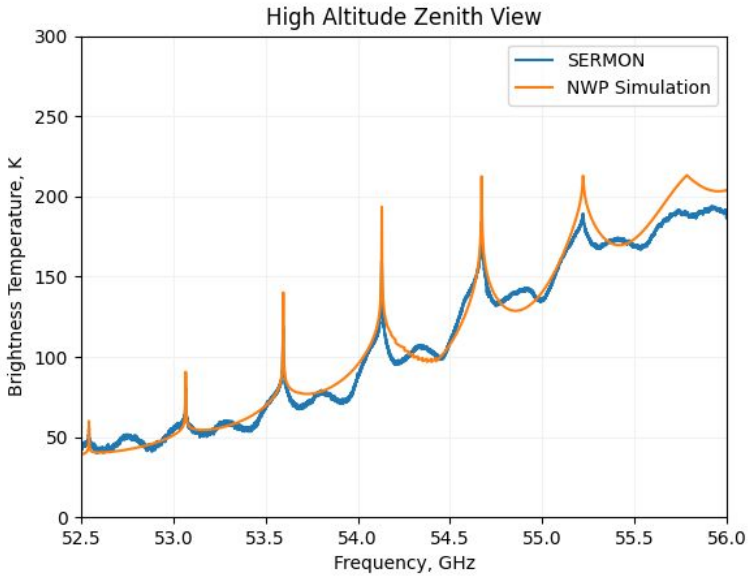


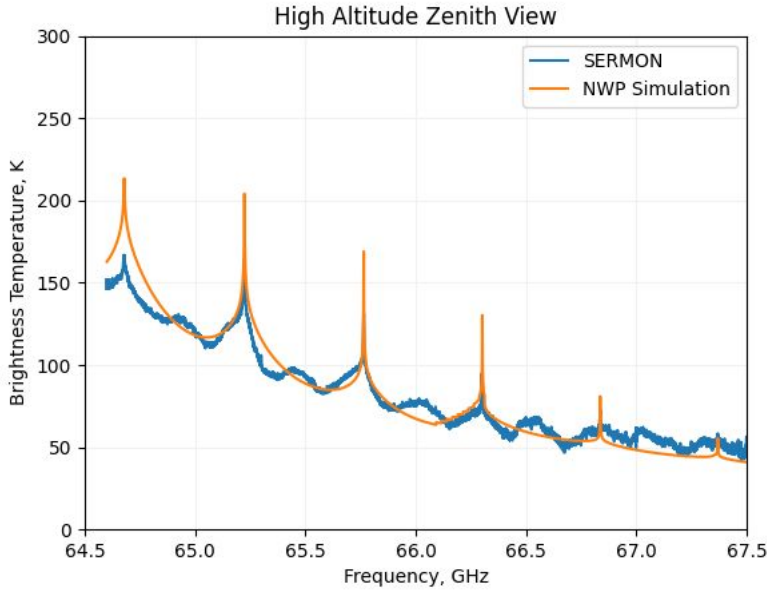
Zenith view flight path

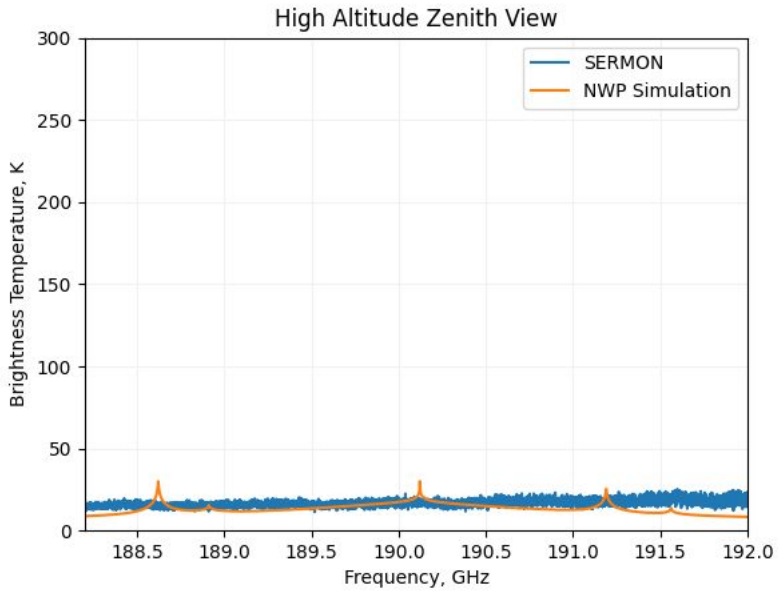


Nadir view flight path

Calibrated Brightness Temperature - High Altitude

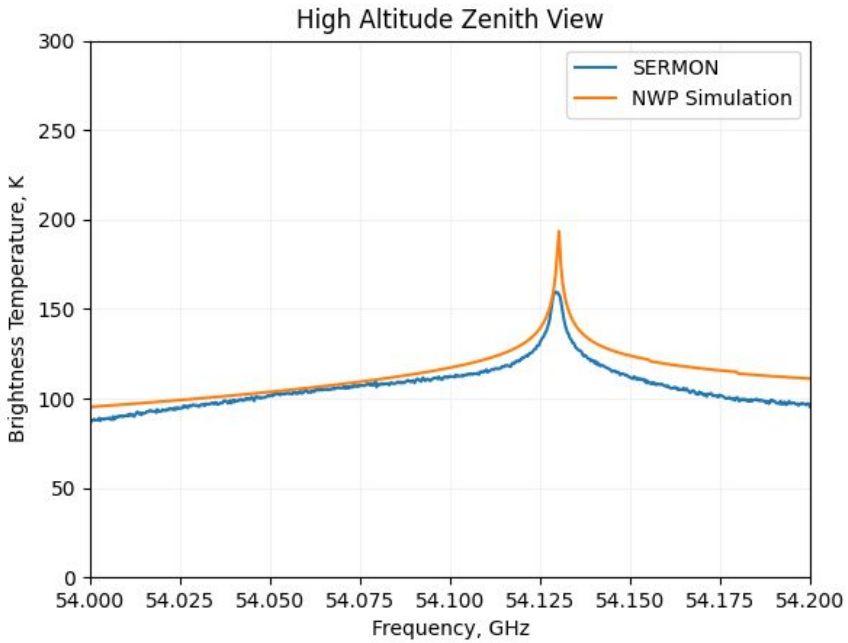


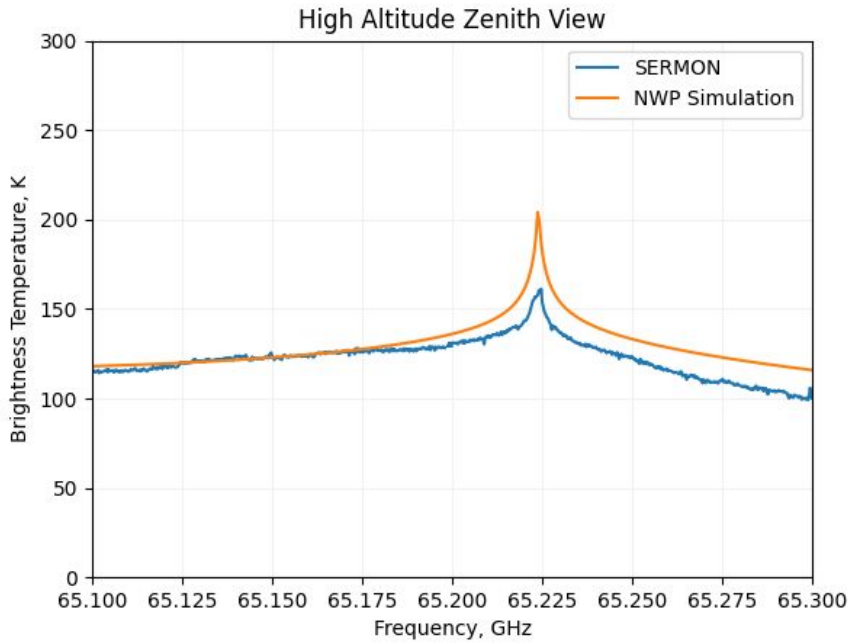




- High altitude (9.1km) measurements averaged over a 5 minute period, **in zenith pointing view.**
- Simulations use profiles above the aircraft from GFS forecast model and CAMS data
- SERMON measurements follow approximately the expected shape, some ripple on calibrated brightness temperature

Zoom on previous plot





- SERMON captures sharp spectral features at correct frequency
- Peak has smaller magnitude and is less sharp than simulation

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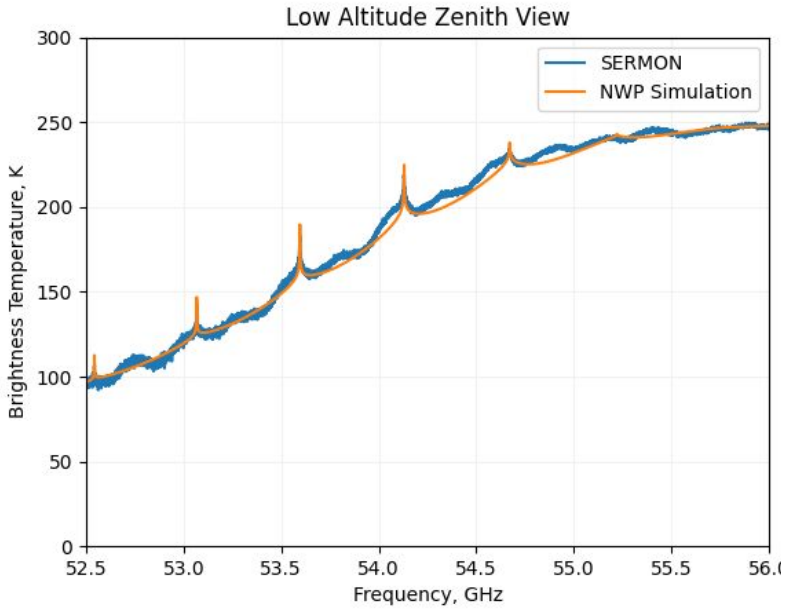
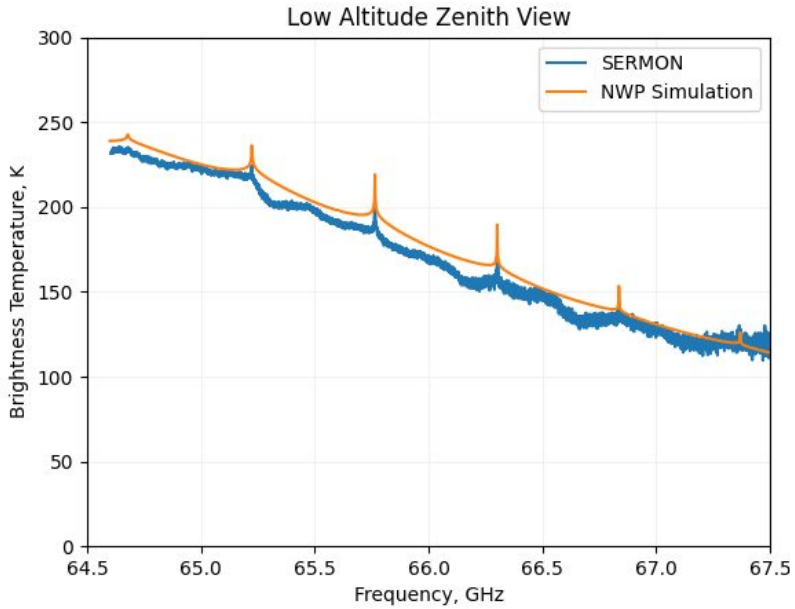
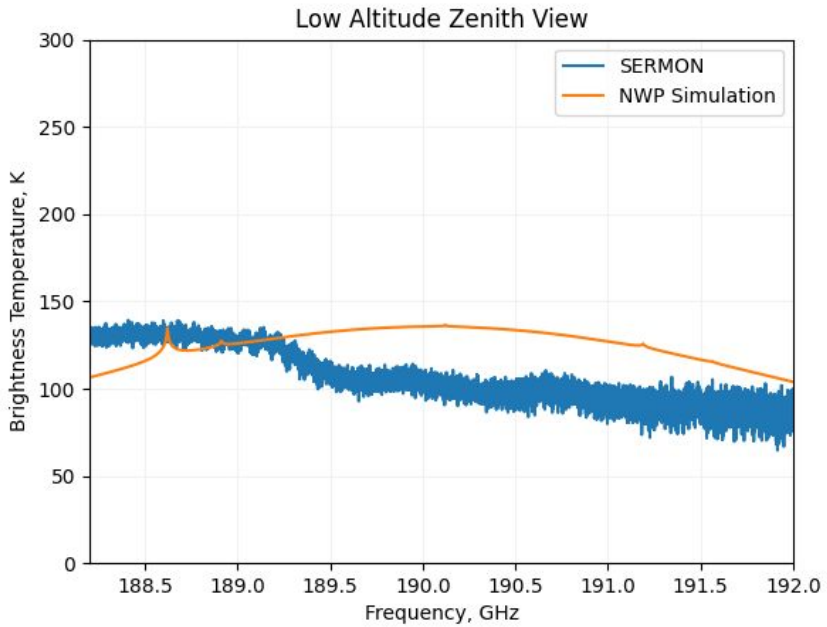
Calibrated Brightness Temperature - Low Altitude



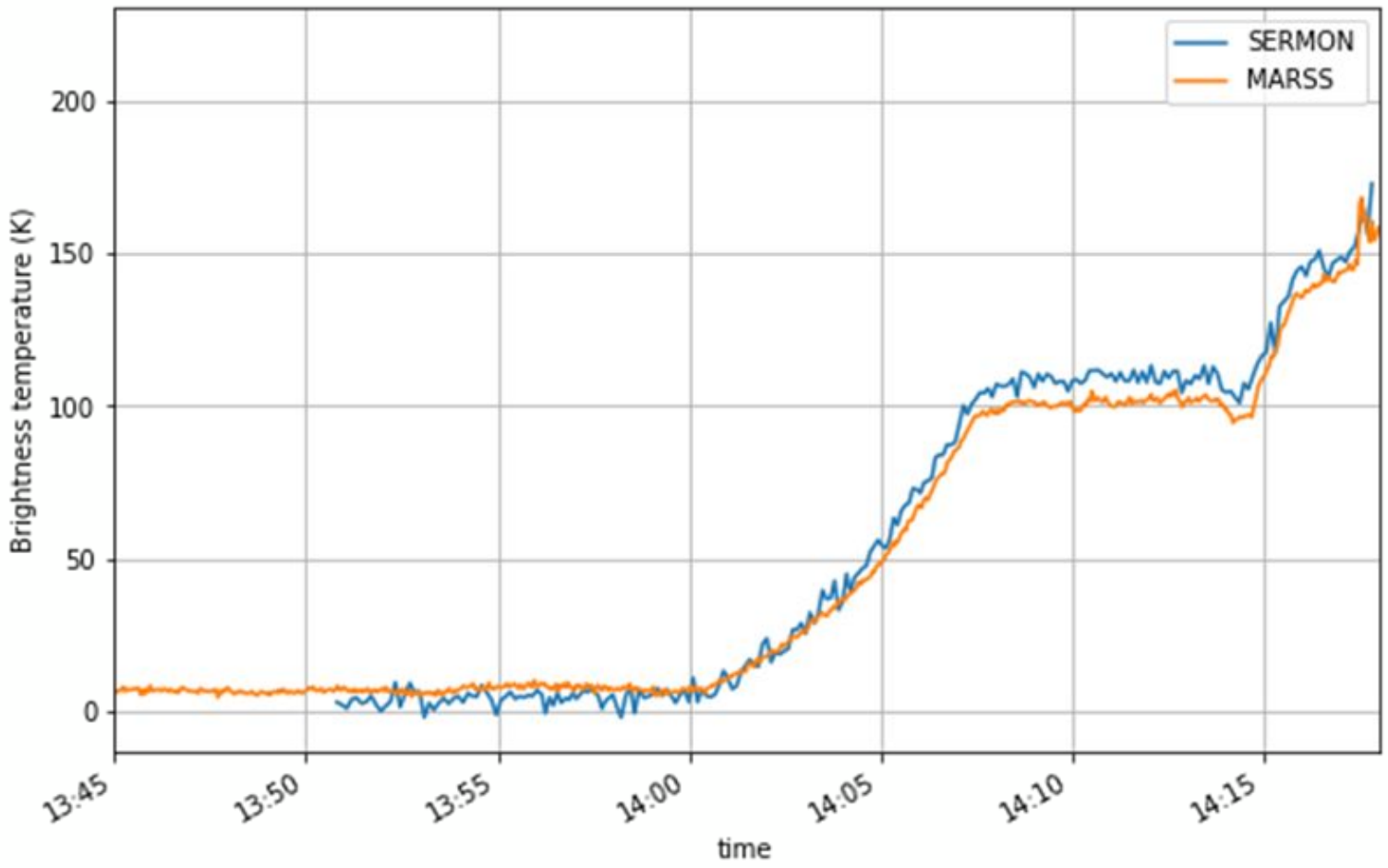




- Low altitude (3.8km) measurements averaged over a 5 minute period, **in zenith pointing view.**
- Simulations use profiles above the aircraft from GFS forecast model and CAMS data
- SERMON measurements follow approximately the expected shape, some ripple on calibrated brightness temperature

Direct Comparison with MARSS

- MARSS is another microwave sensor that flew on the airborne demonstrator
- SERMON 183GHz data were integrated over the MARSS channel bandwidth (189.31 – 191.31 GHz)
- Data shown covers final high-altitude run, descent, low-altitude run and initial return



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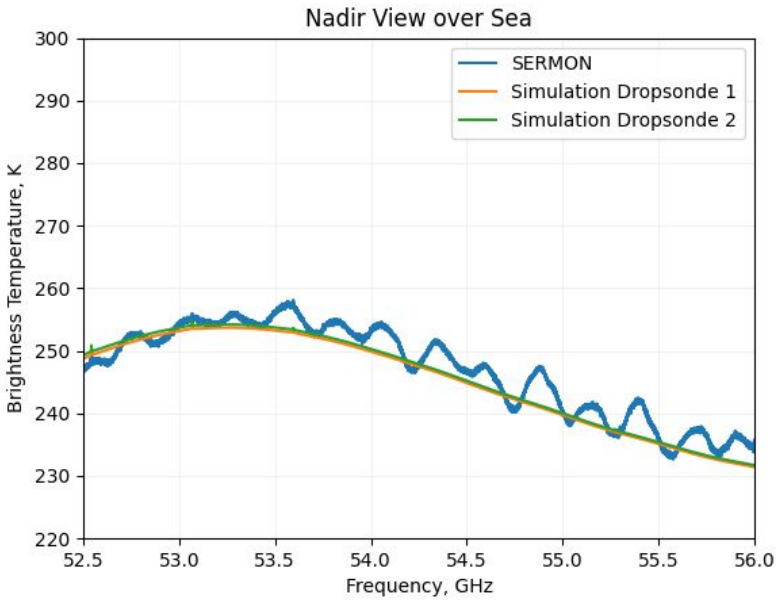
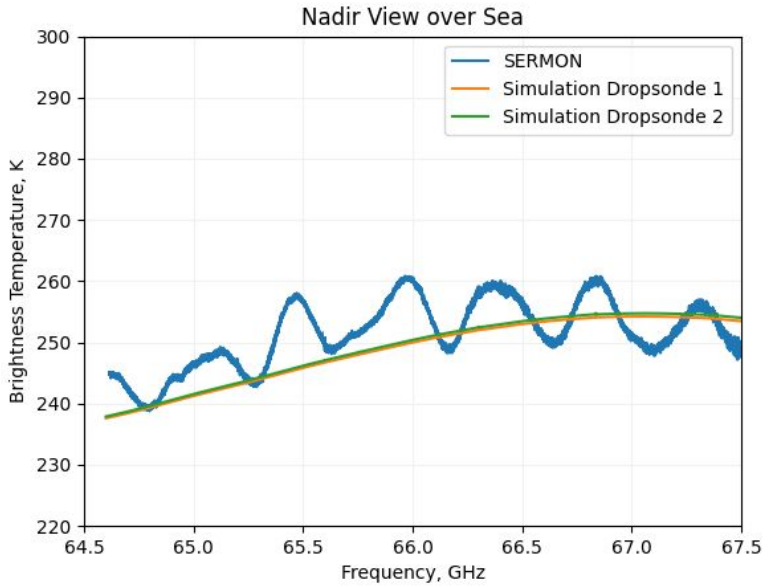
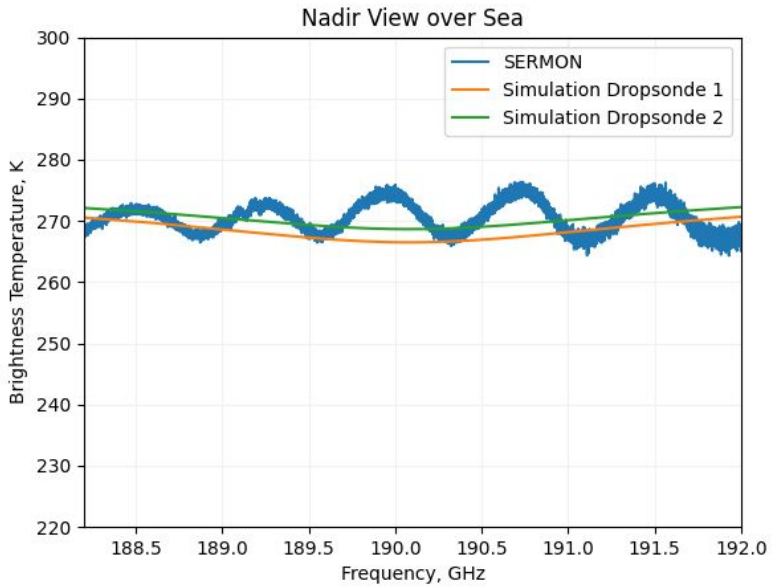
Calibrated Brightness Temperature-Sea







- High altitude (9 km) measurements averaged over a 10 minute period, **in nadir pointing, cloud-free view, over sea.**
- Two dropsondes were released during this period
- SERMON measurements follow approximately the expected shape.
- Ripple on calibrated brightness temperatures in all bands (investigations ongoing)

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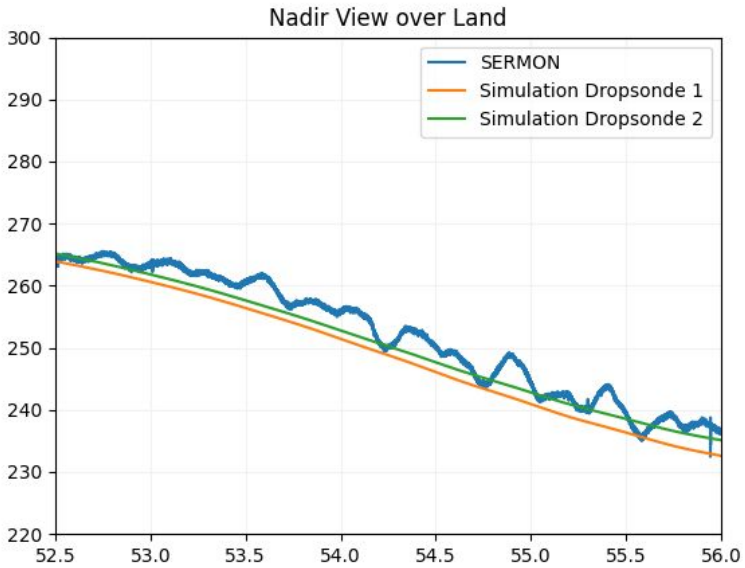
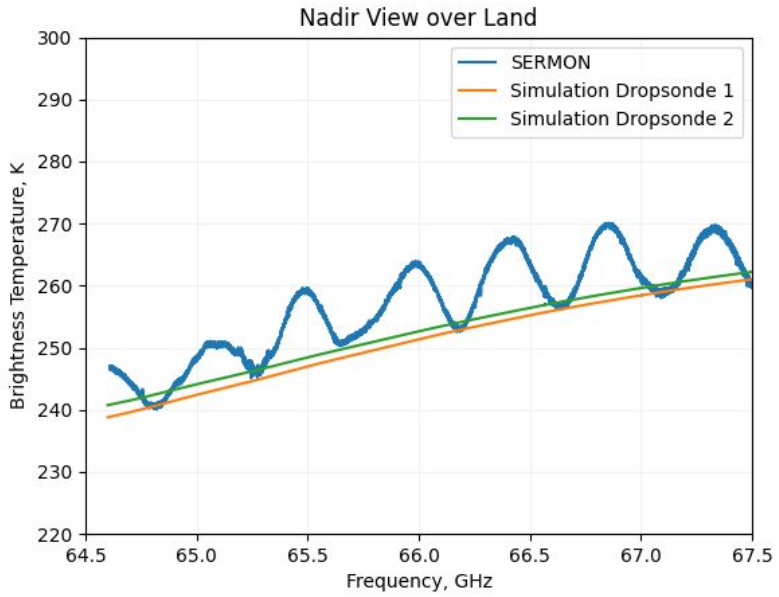
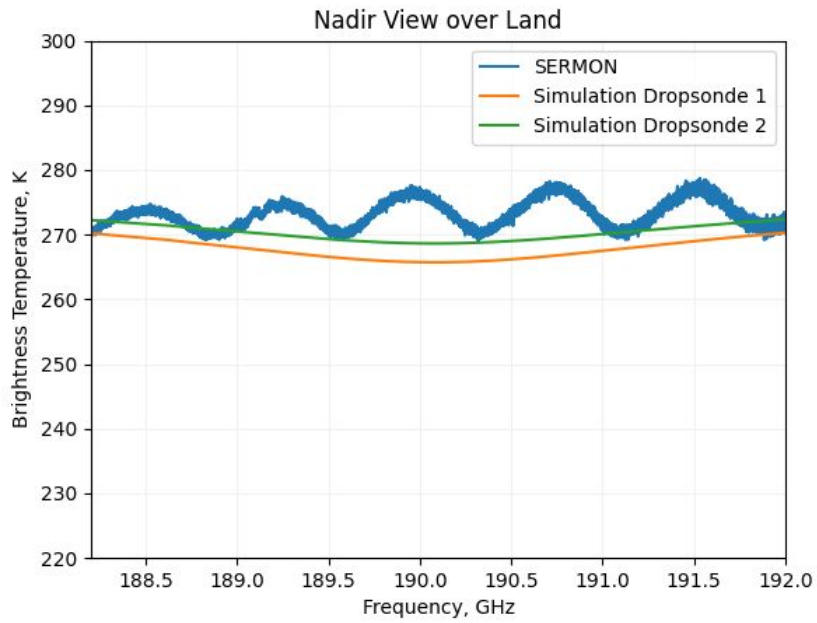
Calibrated Brightness Temperature-Land







- High altitude (9 km) measurements averaged over a 10 minute period, **in nadir pointing, cloud-free view, over land.**
- Two dropsondes were released during this period
- SERMON measurements follow approximately the expected shape.
- Ripple on calibrated brightness temperatures in all bands (investigations ongoing)

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Summary and Next Steps

- Spire is preparing to launch the HyMS instrument into space on a 16U satellite, and perform an in-orbit demonstration
- More airborne demonstrations may occur in the meantime, and further investigations on the anomalies through ground testing pointing in the zenith are on-going
- In preparation for the IOD, we will perform simulations of space-based HyMS data, study channel selection trade-offs, and prepare to do space-based retrievals.
- Spire will engage in case development with NOAA, who has a dedicated team supporting data and NWP assessment
- Spire will have continued engagement with ECMWF, Met Office, Eumetsat, and NOAA

Acknowledgement: LBL simulations were calculated with ARTS:

Buehler, S. A., J. Mendrok, P. Eriksson, A. Perrin, R. Larsson, and O. Lemke (2018),

ARTS, the atmospheric radiative transfer simulator — version 2.2, the planetary toolbox edition,

Geosci. Model Dev., 11(4), 1537–1556, doi:10.5194/gmd-11-1537-2018.

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References

- **[1]** Blackwell, William et al. (2011). Hyperspectral Microwave Atmospheric Sounding. Geoscience and Remote Sensing, IEEE Transactions on. 49. 128 - 142. 10.1109/TGRS.2010.2052260.
- **[2]** Boukabara, S.-A & Garrett, Kevin. (2011). Benefits of a hyperspectral microwave sensor. 1881-1884. 10.1109/ICSENS.2011.6127357.
- **[3]** Aires, F., Prigent, C., Orlandi, E., Milz, M., Eriksson, P., Crewell, S., Lin, C.-C., and Kangas, V. (2015), Microwave hyperspectral measurements for temperature and humidity atmospheric profiling from satellite: The clear-sky case, J. Geophys. Res. Atmos., 120, 11,334– 11,351
- **[4]** C. D. Kummerow et al., "Hyperspectral Microwave Sensors—Advantages and Limitations," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 15, pp. 764-775, 2022, doi: 10.1109/JSTARS.2021.3133382.
- **[5]** F. Aires et al. (2018) Towards more realistic hypothesis for information content analysis of cloudy/ precipitating situations - applications to a hyperspectral instrument in the microwave.