IPWG Cubesat/Smallsat WG

11th Workshop of the International Precipitation Working Group
Tokyo, Japan 15-18 July 2024

What are we trying to measure?

- Precipitation (rain and snow) at the surface (and through the atmosphere).
- Precipitation is spatially and temporally highly variable, and that variability is highly variable.
- Temporal and spatial scales are intrinsically embedded within the retrieval ability of any sensor/scheme.
- At-surface requires observations that are sensitive to near-surface precipitation (vis/IR not direct, HF MW ice, LF liquid)
- Instantaneous PMW retrievals are generally very good, as are long-term (monthly/annual) accumulations
- Gaps between observations and (sub-)daily accumulations are weaknesses.
- It is necessary to provide sufficient sampling to capture the variability.

Why Cubesats/smallsats?

Precipitation is highly variable, both spatially and temporally.

- Instantaneous PMW retrievals are generally very good, as are long-term (monthly/annual) accumulations
- Gaps between observations and (sub-)daily accumulations are weaknesses.
- It is necessary to provide sufficient sampling to capture the variability.
- Need to provide more observations *within cost limitations*.

Considerations:

- Data quality/calibration: *small Tb differences impacts precip/no-precip boundary more than higher intensities*
- Data characteristics and continuity: *do changes in the observations (frequency, resolution, etc) affect long-term precipitation records: are these commensurate with what is needed to be measured?*
- Data delivery: *data latency & consistency of delivery*

Recent satellite launches

30 June 2021: ***TROPICS-01 (pathfinder*** **-** *near polar orbit)*

January 2022: ***TEMPEST-H8 and COWVR*** begin science operations from ISS.

08 May 2023: ***TROPICS-03/07*** *(low inclination orbit)*

26 May 2023: ***TROPICS-05/06*** *(low inclination orbit)*

14 April 2023 and 12 June 2023: Tomorrow-R1 and Tomorrow-R2*: Ka precipitation radar (non-scanning)*

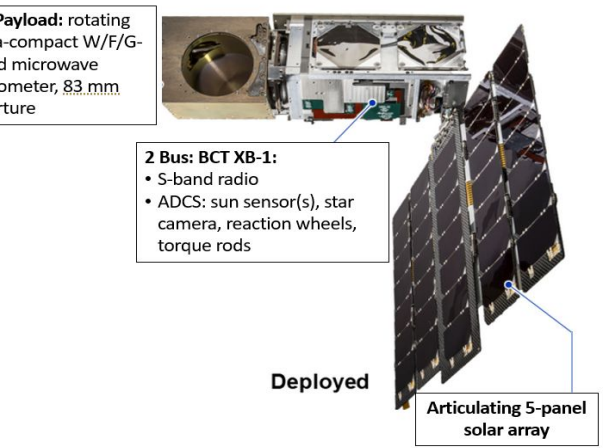
TROPICS Millimeter-wave Sounder (TMS)

30 June 2021: TROPICS-01 (pathfinder - *near polar orbit)*

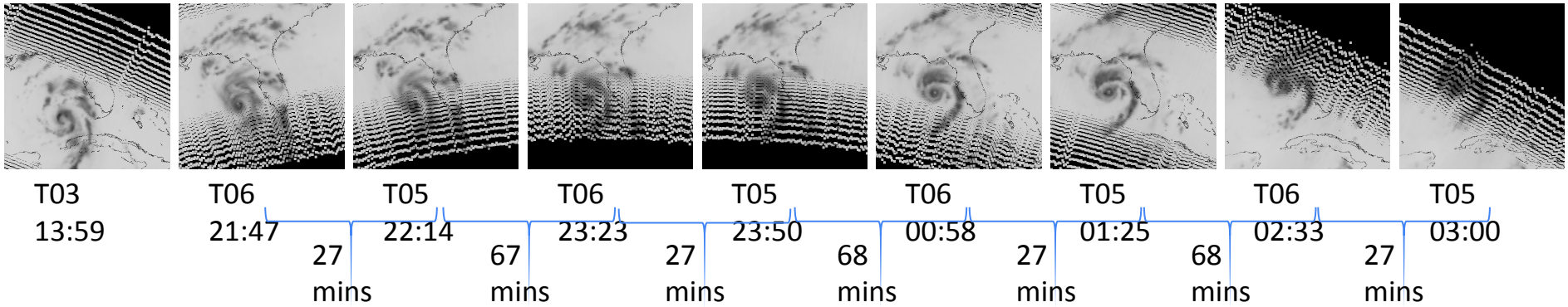
08 May 2023: *TROPICS-03/07*
(low inclination orbit)

26 May 2023: *TROPICS-05/06*
(low inclination orbit)

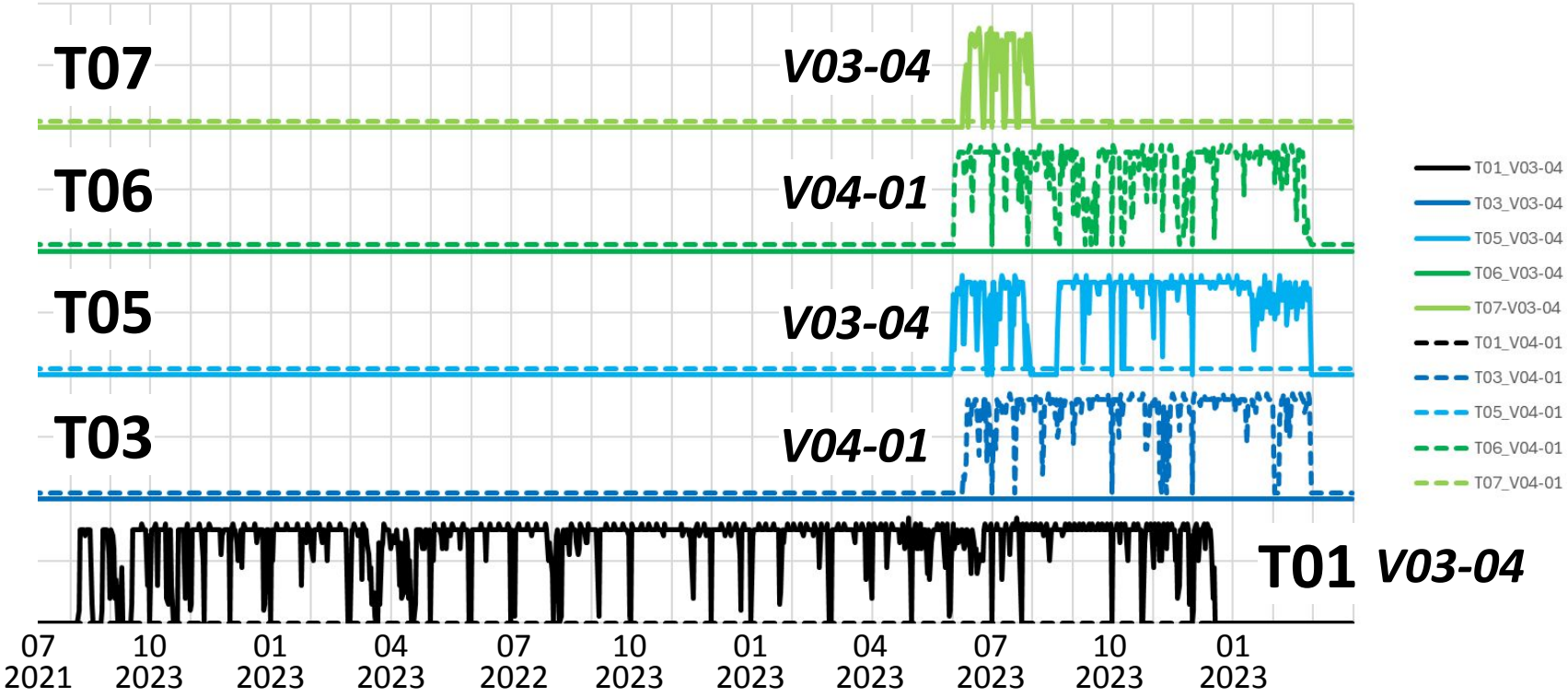
TMS Channel	Central frequency	ATMS Channel	MHS Channel	*MWHS-2 Channel*
1	91.655±1.4 GHz	88.2 GHz	89.0 GHz	*89.0 GHz*
2	114.50 GHz	-	-	*118.75±5.0*
3	115.95 GHz	-	-	*118.75±3.0*
4	116.65 GHz	-	-	*118.75±2.5*
5	117.25 GHz	-	-	*118.75±1.1*
6	117.80 GHz	-	-	*118.75±0.8*
7	118.24 GHz	-	-	*118.75±0.3*
8	118.58 GHz	-	-	*118.75±0.2*
9	184.41 GHz	183.31±1.0	183.31±1.0	*183±1.0*
10	186.51 GHz	183.31±3.0	183.31±3.0	*183±3.0*
11	190.31 GHz	183.31±7.0	190.31	*183±7.0*
12	204.8 GHz	-	-	-



TROPICS 205 GHz imagery of Hurricane Idalia, 29/30 August 2023



TROPICS data availability – Level 1B

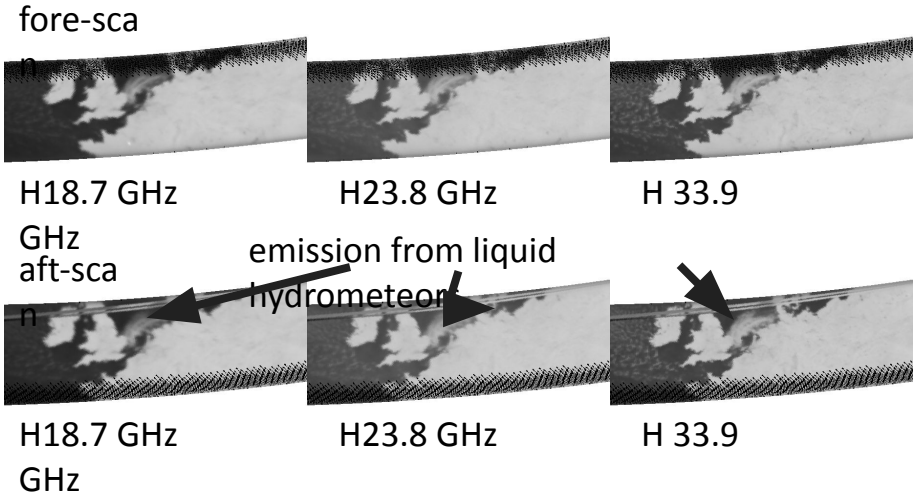


International Space Station STP-H8 mission

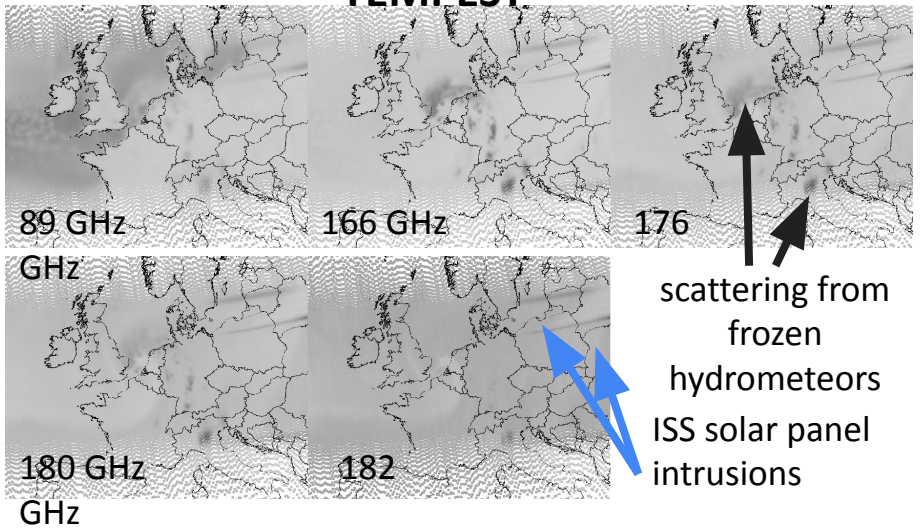
Two instruments *attached to the International Space Station (ISS)*:

- **Compact Ocean Wind Vector Radiometer (COWVR)** - fore/aft conical imaging at three frequencies (18.7, 23.8, and 33.9 GHz) with six (full) polarizations for each frequency.
- **Temporal Experiment for Storms and Tropical Systems (TEMPEST)** - cross-track scanning at five frequencies (89, 166, 176, 180, and 182 GHz).

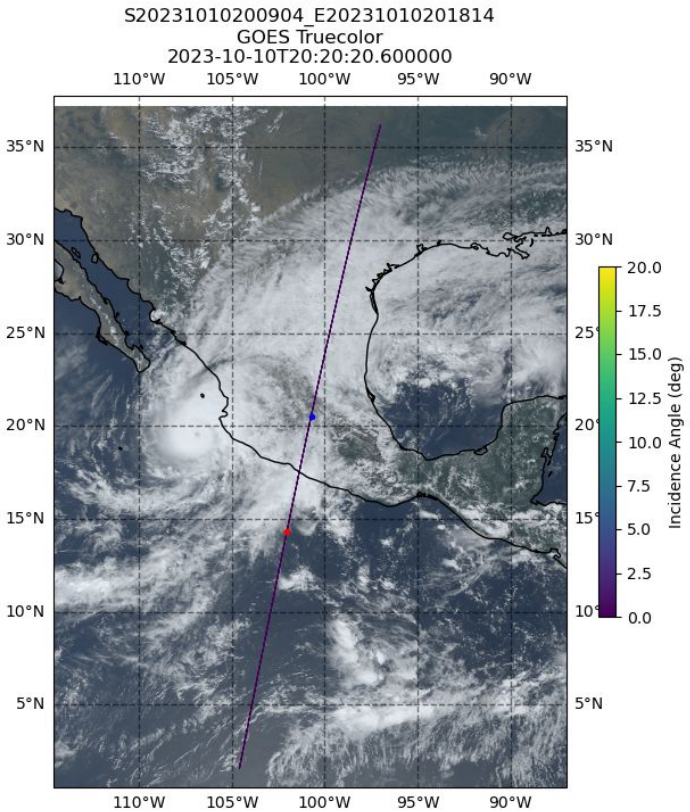
COWVR

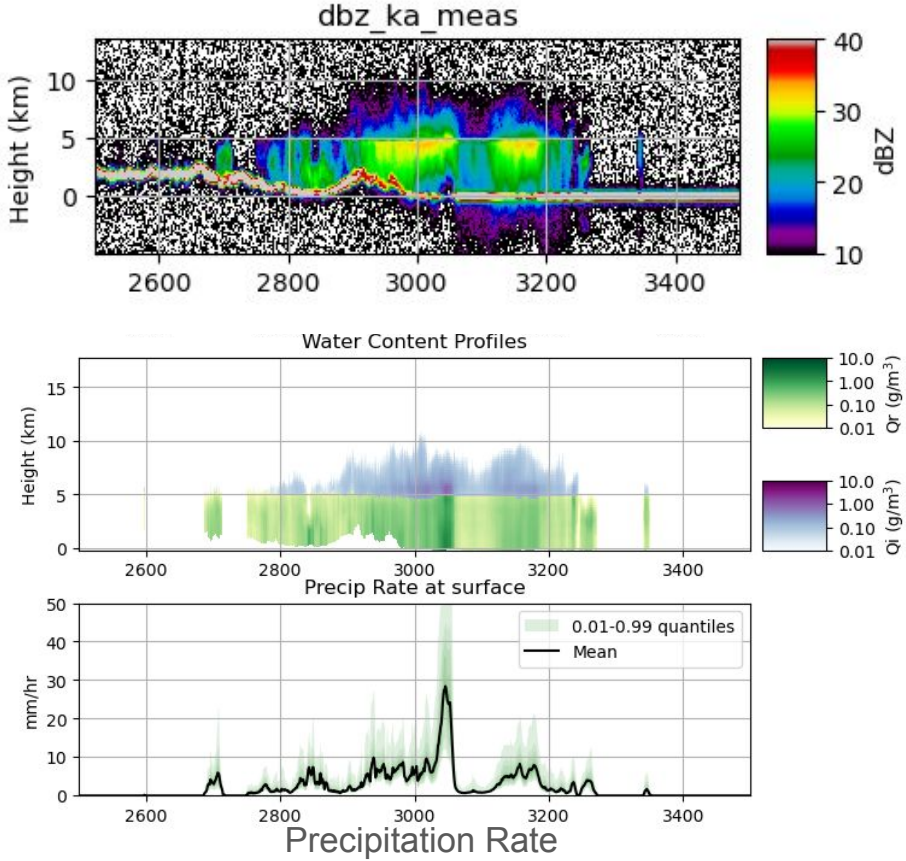


TEMPEST

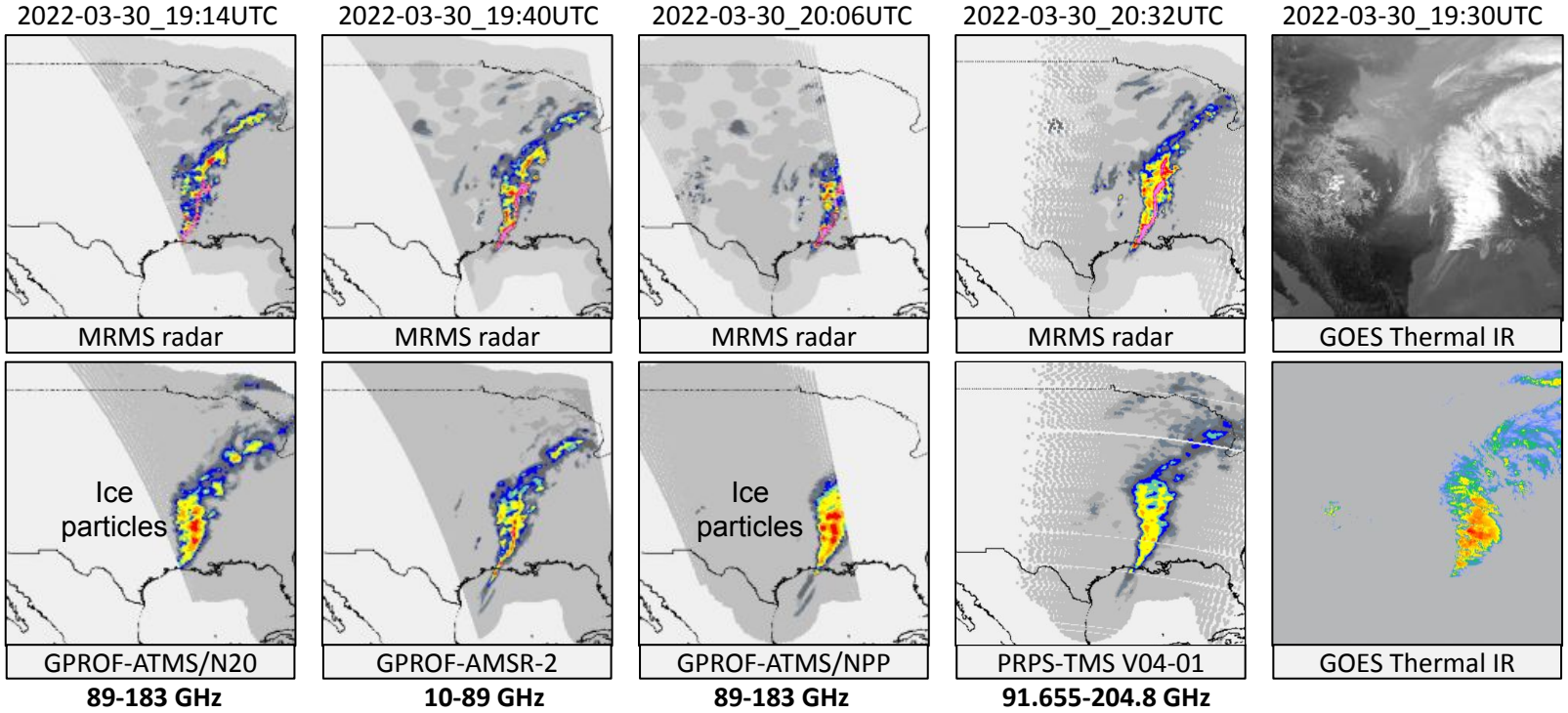


Tomorrow-R1/R2 Pathfinder Radars

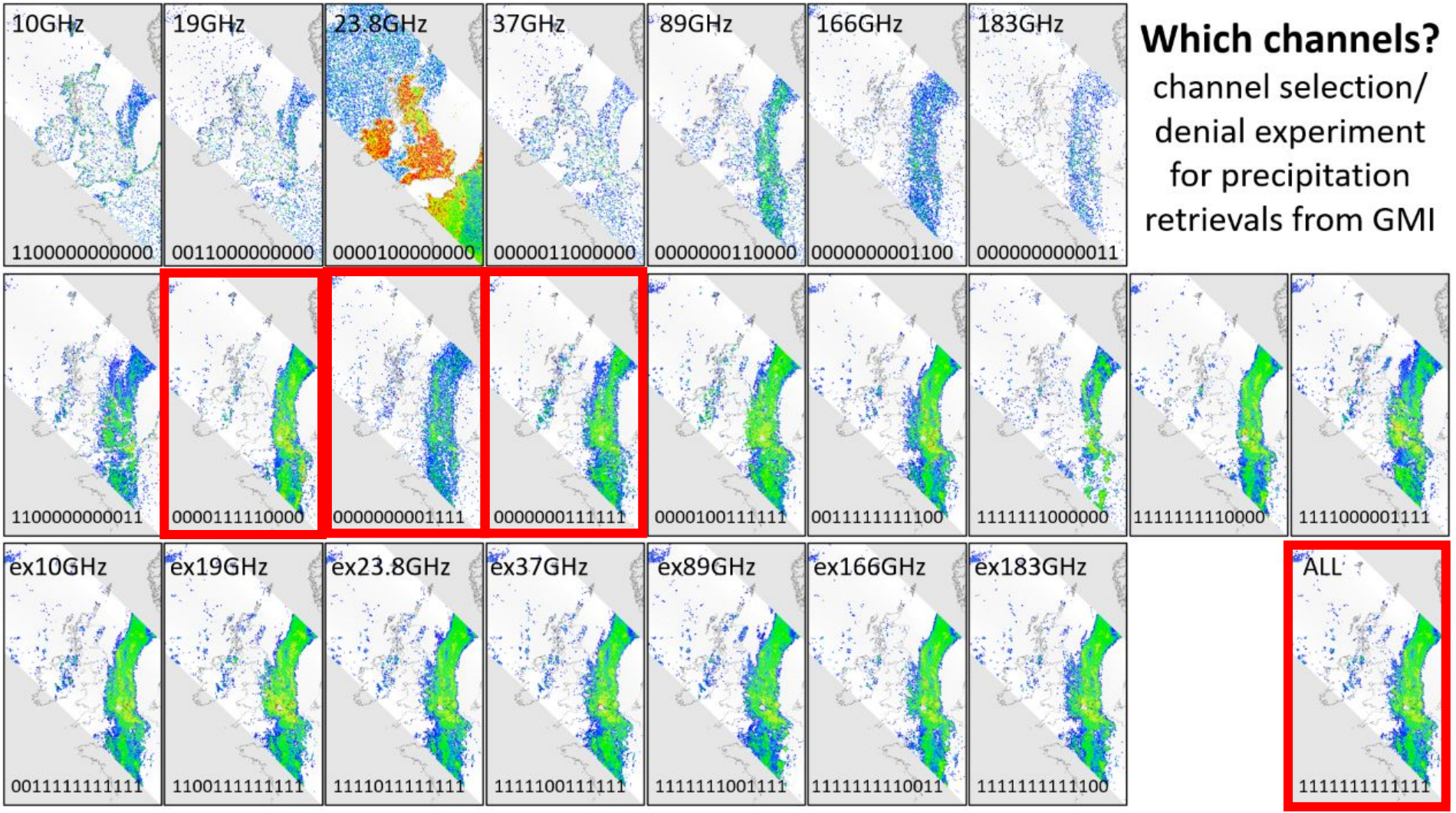




What is being measured? imager vs sounder precipitation



High-frequency PMW retrievals tend to be more similar to the cloud-top Thermal IR


10GHz
19GHz
23.8GHz
37GHz
89GHz
166GHz
183GHz
1100000000000
0011000000000
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0000000110000
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ex166GHz
ex183GHz
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ALL
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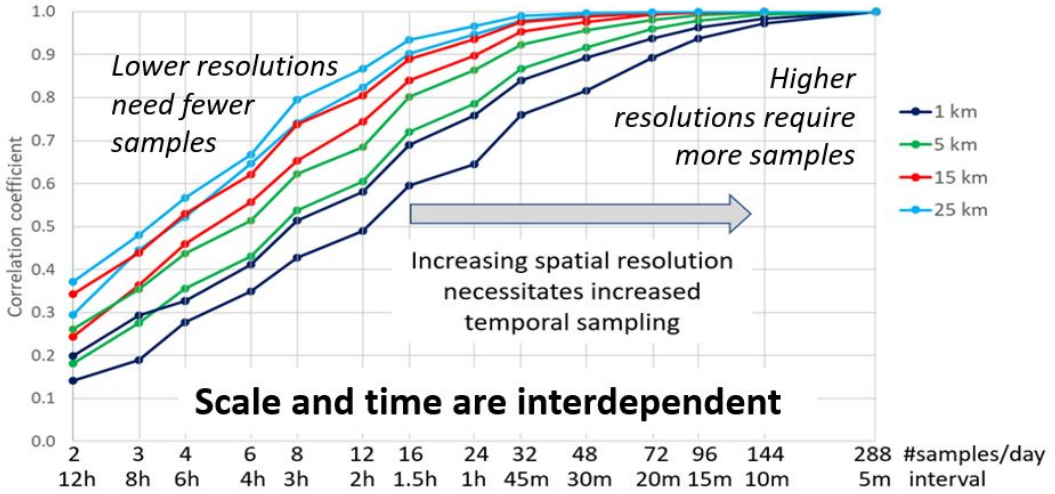
Which channels?
channel selection/
denial experiment
for precipitation
retrievals from GMI

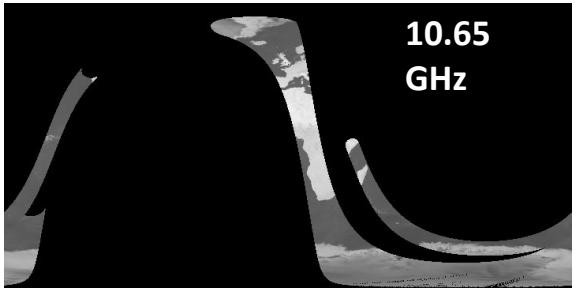
Spatial resolution

- Spatial resolution and temporal sampling characteristics of precipitation are directly related: i.e. increasing spatial resolution required increased temporal sampling.

- Accuracy of retrievals is related to the spatial resolution (coarser resolutions perform ‘better’
- Cubesats (TROPICS) have poorer spatial resolution – in part this explains ‘similar’ performance to finer resolution retrievals.
- **Resolutions need to be commensurate with what needs to be measured.**
- **Statistics should to be provided at a standard resolution**

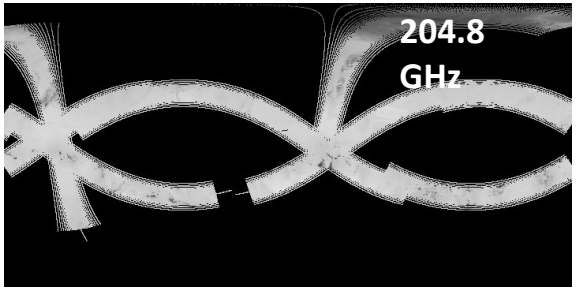


HF channels provide more PMW Observations



12:00 to 13:00 05-Jul-2023

Higher frequency channels (sensitive to ice) are better sampled than the lower frequency (liquid) channels



Can geostationary Vis/IR data be used to enhance resolution of Cubesat sounder precipitation retrievals?

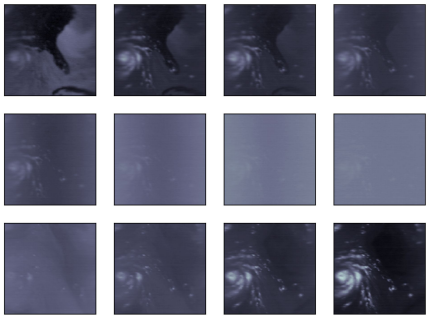
Why TROPICS?
The Tomorrow.io microwave sounder will be derived from the TROPICS Cubesat microwave sounder.

We used TROPICS Pathfinder observations to develop a training database for a convolutional neural network based on the HydroNN framework to explore the accuracy of precipitation retrievals from the forthcoming Tomorrow.io microwave sounders.

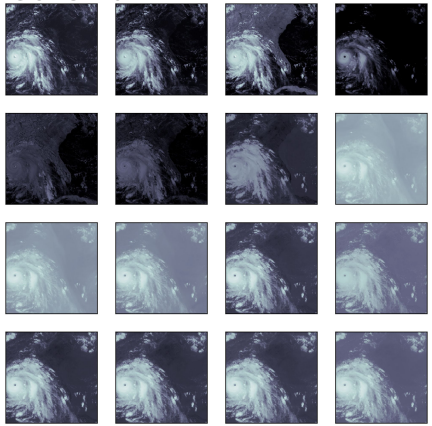
Key question: **Given the improvement in geostationary precipitation retrievals aided by machine learning, how much value do microwave sounders add?**

We wanted to perform a fair assessment using the same retrieval method, training data, and reference data.

TROPICS channels



GOES-16 channels



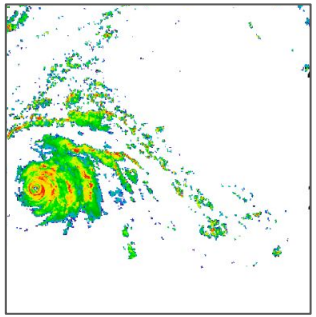
Training Data

- TROPICS Pathfinder (3 mo./~1000 scenes)
- MRMS Precipitation Rate (filtered by RQI)
- GOES-16

Model Configurations

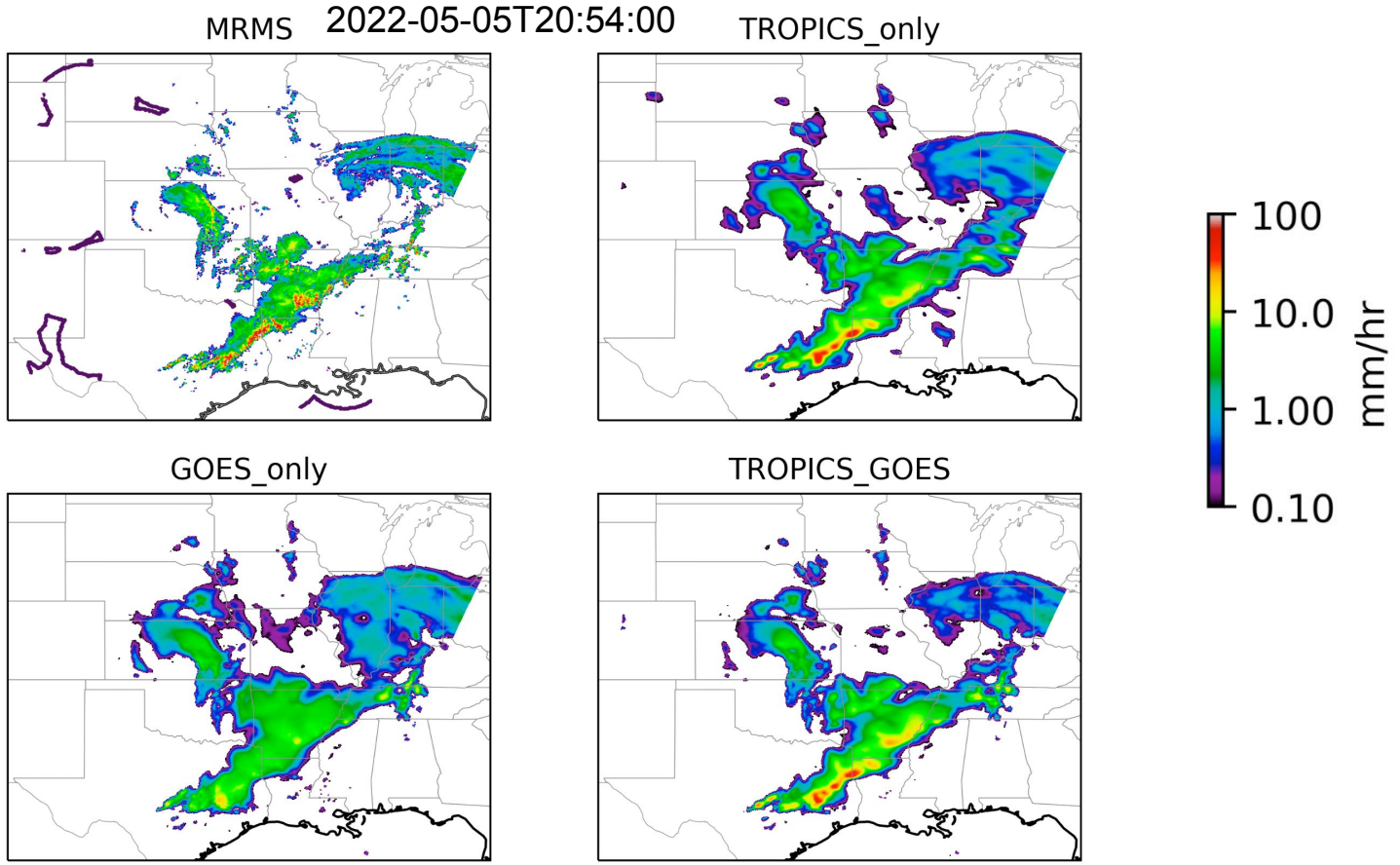
- TROPICS-only
- GOES-16-only
- TROPICS+GOES-16

MRMS Precipitation



Can geostationary Vis/IR data be used to enhance resolution of Cubesat sounder precipitation retrievals?

GOES retrieval can't detect most intense precipitation. TROPICS and TROPICS + GOES accurately identify convective regions.



Can geostationary Vis/IR data be used to enhance resolution of Cubesat sounder precipitation retrievals?

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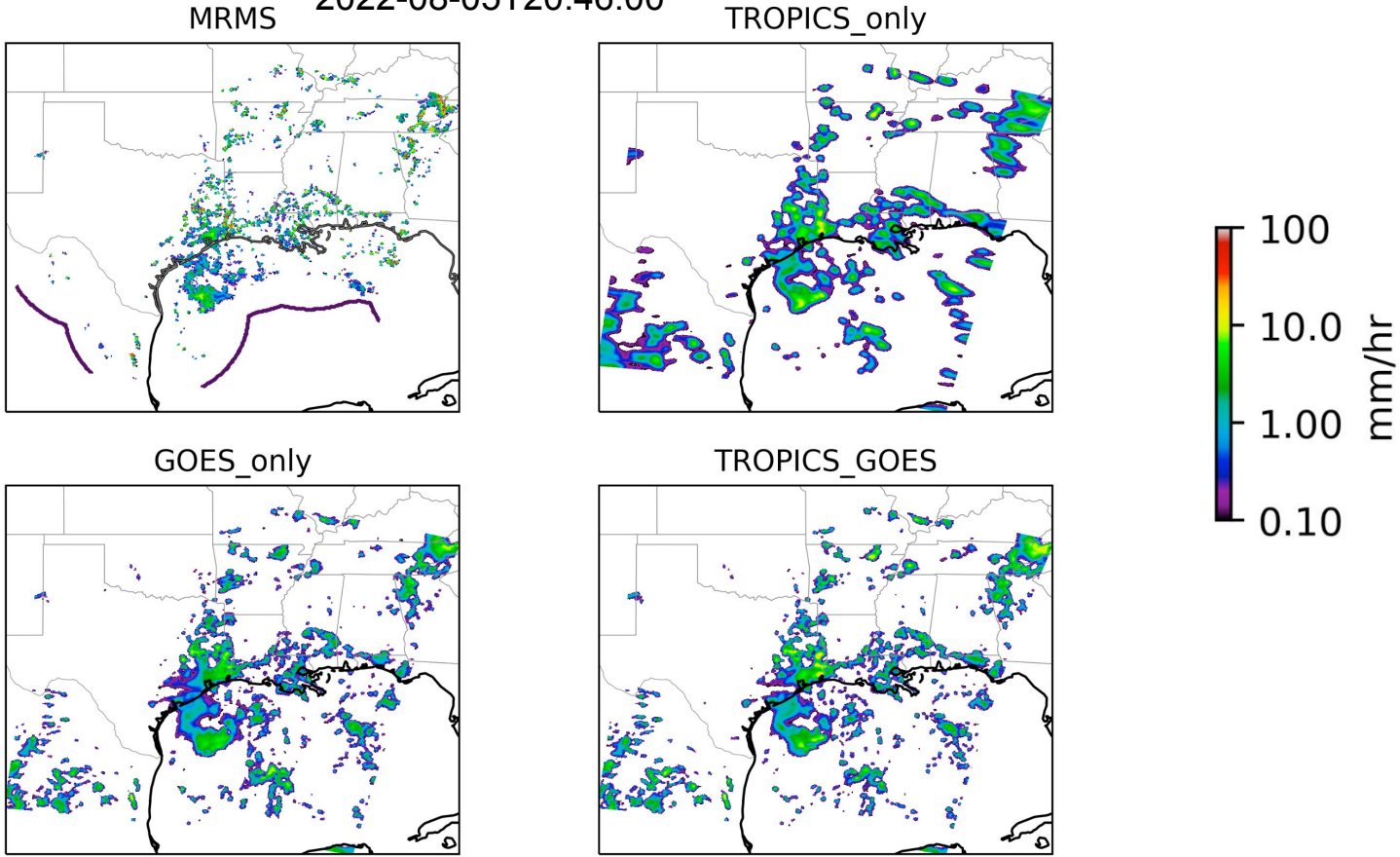
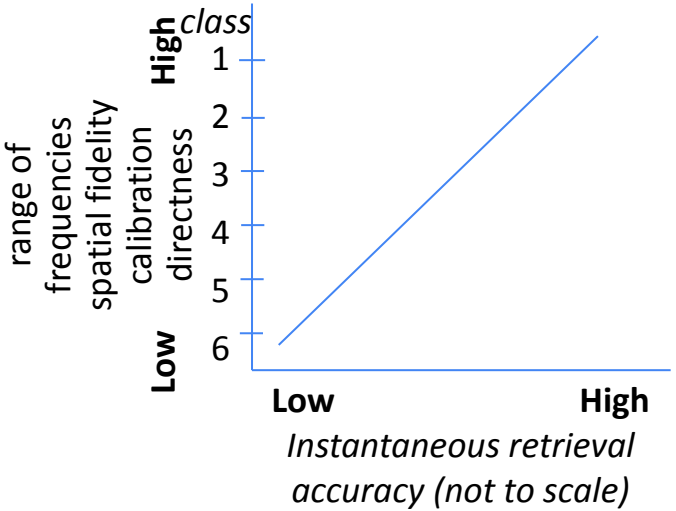
TROPICS retrieval can't detect small, isolated cells. GOES and TROPICS + GOES sense smaller storms.





Simplifying spaceborne systems increases the complexity of processing the data received, interpreting the observations made, and potentially negatively impacting the resulting geophysical retrievals.

Diverse observations add additional degrees of complexity, particularly if observations are sampled at > 1/*e* of the temporal/spatial variability of precipitation (ca. 15 mins @ 25 km, or 5 mins @ 5 km).

class	Sensor examples	freq (GHz) or wavelength	scan style	cal/val results	retrieval directness	co-located footprints	spatial resolution	temporal interval
1	GMI/AMSR	10-183	Conical	excellent	very good	good	good	poor
2	SSMIS, WSF-M	18-183/10-89	Conical	very good	good	good	good	poor
3	ATMS, MHS	23-183/89-183	X-track	excellent	good/poor	excellent	good-poor	poor
4	small/cubesats	89-204	X-track	varies	poor	good/poor	poor	good*
5	IR sensors	3 - 14 µm	*X-track*	very good	poor	excellent	excellent	excellent
6	Visible sensors	0.6 - 0.9 µm	*X-track*	very good	poor	excellent	excellent	good*

** with caveats*

Cubesat-GMI comparison

Parameter	TROPICS	GMI	
Frequencies	4	7	*Number of distinct frequencies*
Freq. diversity	92-205	10-183	*Lowest to highest frequencies*
Polarizations	none	V/H (most)	*GMI dual polarized at 10,19,37,91,166*
Resolution @ 91 GHz	50.7x50.7 km	3x5 km	
Resolution @ 183 GHz	26x26 km	3x5 km	
Lifetime	2.5 years	ca. 17 years	*TROPICS: based upon T01; GMI 10+years*
Latency	45 mins	5-10 mins	*Observation to availability*
Data availability	63.64%	96.51%	*Jul-Oct 2023: TROPICS T01/T03/T06 valid data; GMI valid data*
Samples/day	3.5 M	10.1 M	
Launch-1st data (days)	35/19/23/24/13	5	
Cost/observation	0.008c/obs	0.003c/obs	$20M TROPICS, $200M GMI (100% duty cycle)

Commercialisation…

- "*could be a good partner for us* " in the context of "*Life after GPM*"
- what are their plans for delivering free, open-access, wide-frequency range (10-183 GHz), good (spatial) resolution observations with low latency?
- Can commercial entities provide what we need (yet alone, what we want?).
- Are they prepared to 'finance' less-profitable (or loss-making) observations?
- How will they deal with the general 'free, open access data policies'?
- Data quality, availability (latency/uptime)?

Environmental consequences… (more satellites=more debris/burn-ups=SPF1000?)

(Inter)calibration needs for Cubesat/Smallsat constellations

Draft Recommendation 1: A sensor's calibration should be stable on the timescale between external reference opportunities

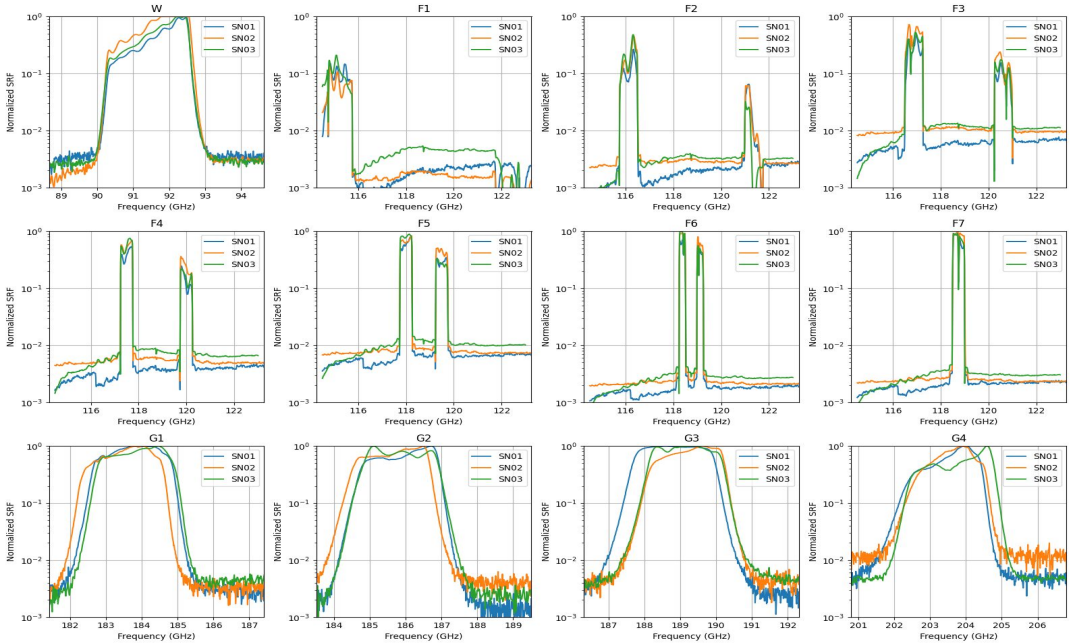
Draft Recommendation 2: Each constellation with multiple copies of a given sensor should have an intercalibrated product that, for level 2 algorithms, is indistinguishable for each satellite in the constellation. This entails:

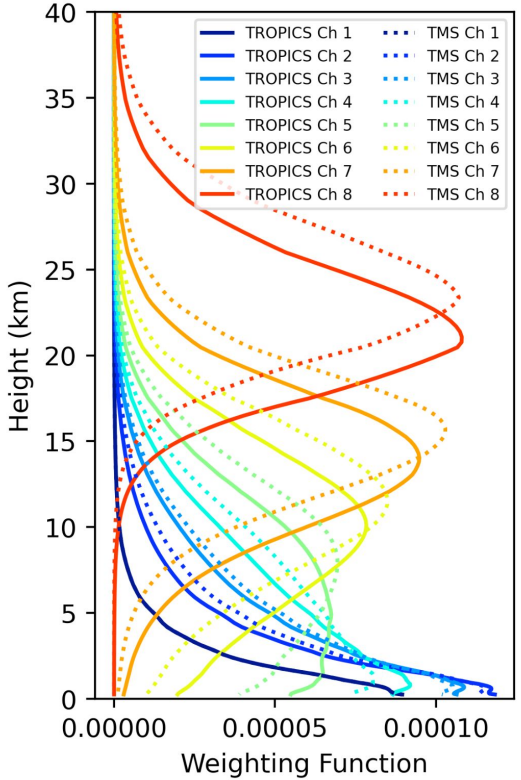
- Bias correction against an independent, well-calibrated reference
- Conversion of slightly differing passbands/incidence angles
- Regridding/Remapping to common geolocation

This could also be applied to large-sat sensor families (SSMIS, ATMS, MHS).

The benefit of this approach is that downstream algorithms do not need to be tailored for every sensor in a constellation.

TMS Instrument: Spectral Response and Weighting Functions





- W- and G- band channels are Direct Detect
- F-band channels processed with Digital IFP, which uses PMMC ASIC spectrometer re-combined to 7 channels