Potential Impacts of Radio Frequency Interference of precipitation retrievals from space – from an IPWG perspective

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International Precipitation Working Group (IPWG)

- IPWG is a permanent Working Group of the Coordination Group for Meteorological Satellites (CGMS).
- The IPWG builds upon the expertise of scientists currently involved in precipitation measurements from satellites with emphasis on derivation of products. The IPWG was established to foster the:

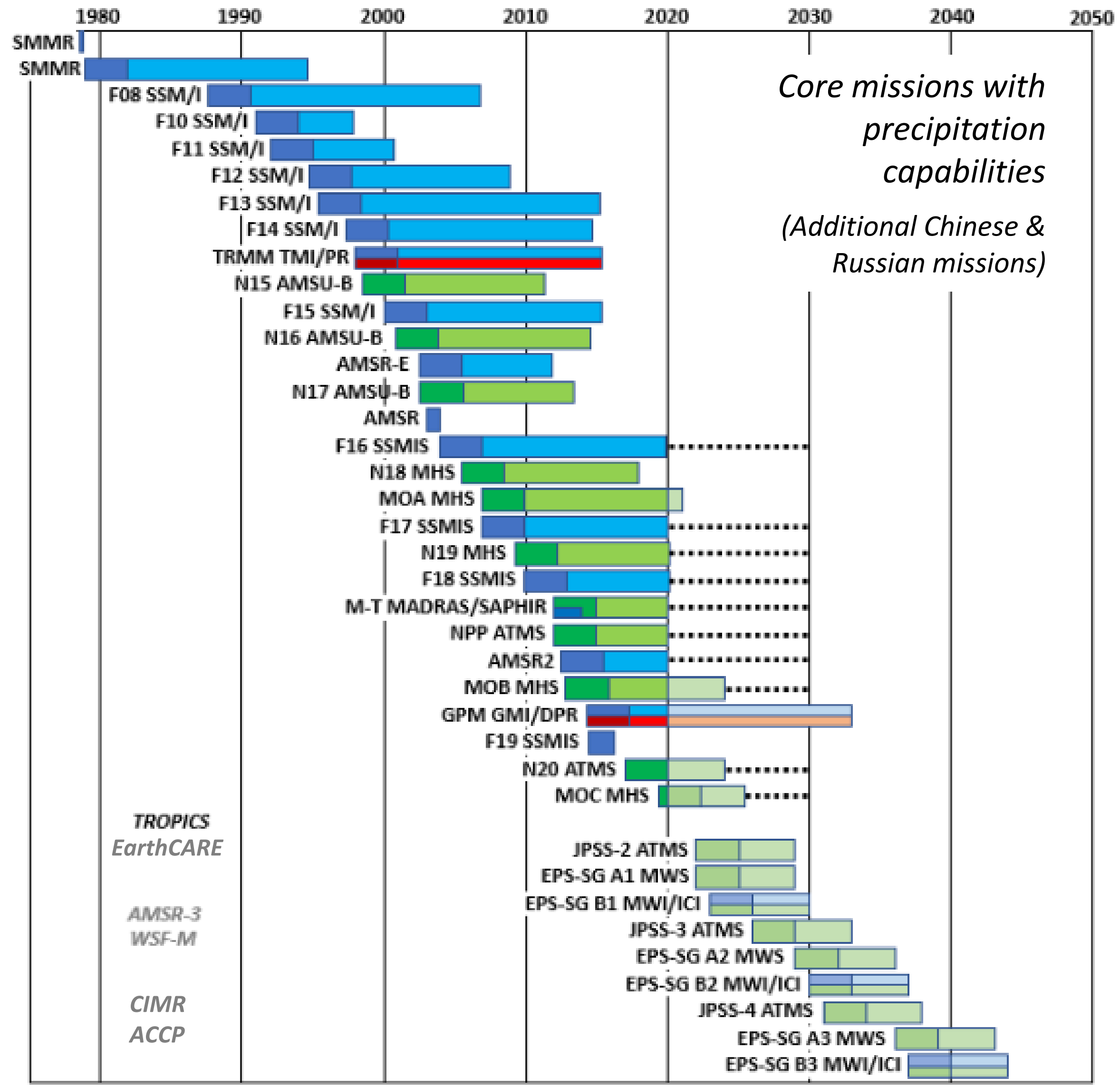
i. Development of better precipitation measurements, and improvement of their utilization;
ii. Improvement of scientific understanding;
iii. Development of international partnerships.

Formed in 2001, IPWG currently has 480 members from 52 countries and 5 international organisations.

Biennial meetings with student training sessions (2020 held virtually, 2022 Fort Collins).

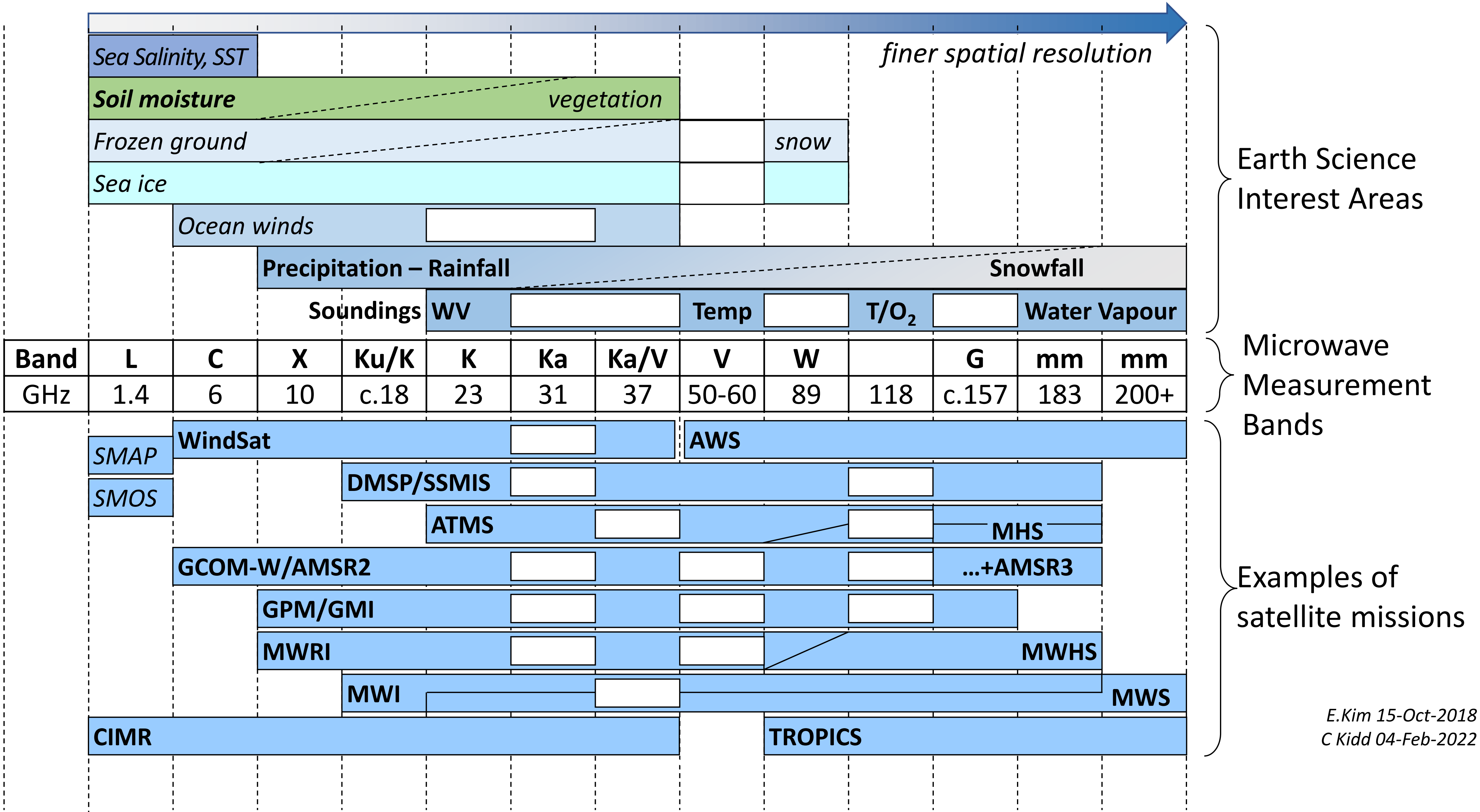
IPWG-9, Yonsei University, Seoul, 2018

Introduction – historical context



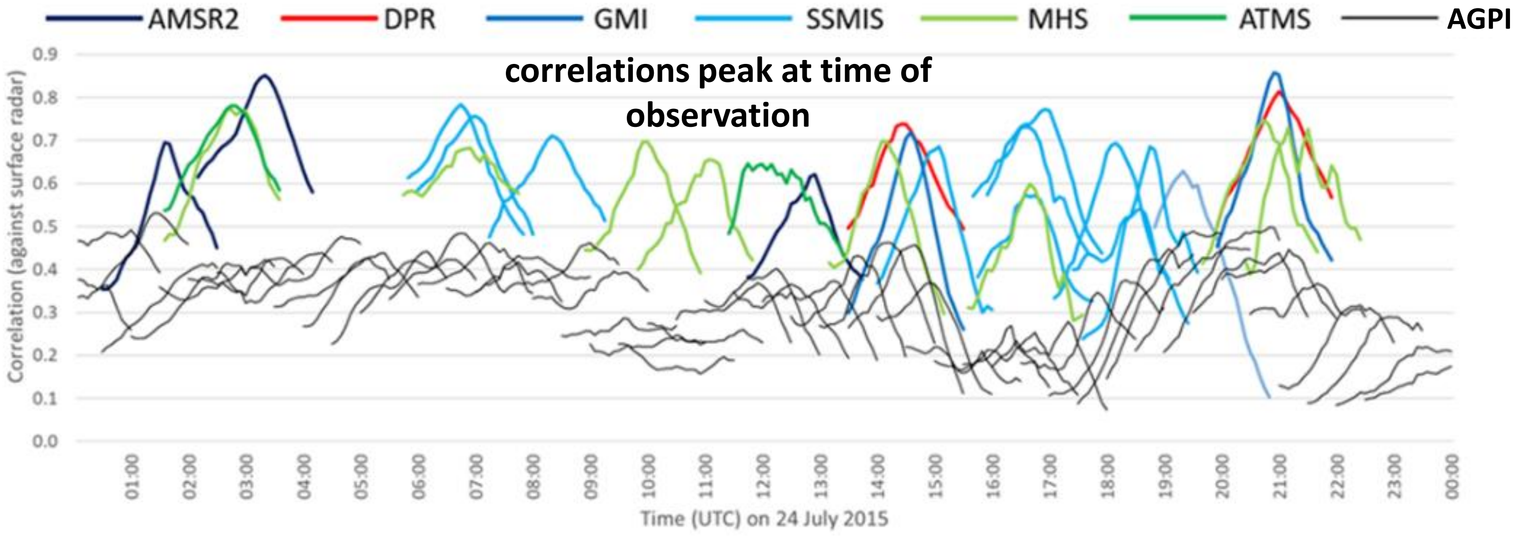
- ***Passive microwave sensors*** operating since the 1960's, with long-term data availability since the late 1970's.
- ***All-weather observations*** of geophysical properties of the surface and atmosphere.
- ***Imaging instruments***: primarily window channels with wide swath for mapping capabilities, typically conically-scanning;
- ***Sounding instruments***: focusing upon the atmospheric absorption bands (e.g. WV, O_2) with a wide swath, typically cross-track scanning;
- ***Active instruments***: nadir-viewing or narrow-swath, altimeters, scatterometers or precipitation/cloud radars for vertical information;
- ***Single beam radiometers*** used in support of the altimeters and scatterometers.

Passive Microwave Science, Bands, & Satellite Sensors



Why Passive Microwave for Precipitation Retrievals?

- *Precipitation is* vital to understanding the Earth System and for society.
- *Satellites* provide global coverage (rain gauges are essentially land-only).
- *Visible/infrared* GEO observations provide frequent and regular observations of the cloud tops, not the precipitation beneath the clouds.
- *Microwave observations* respond more directly to hydrometeors within the atmosphere, allowing more direct measurements of precipitation.



Passive microwave retrievals are significantly better than IR-based retrievals

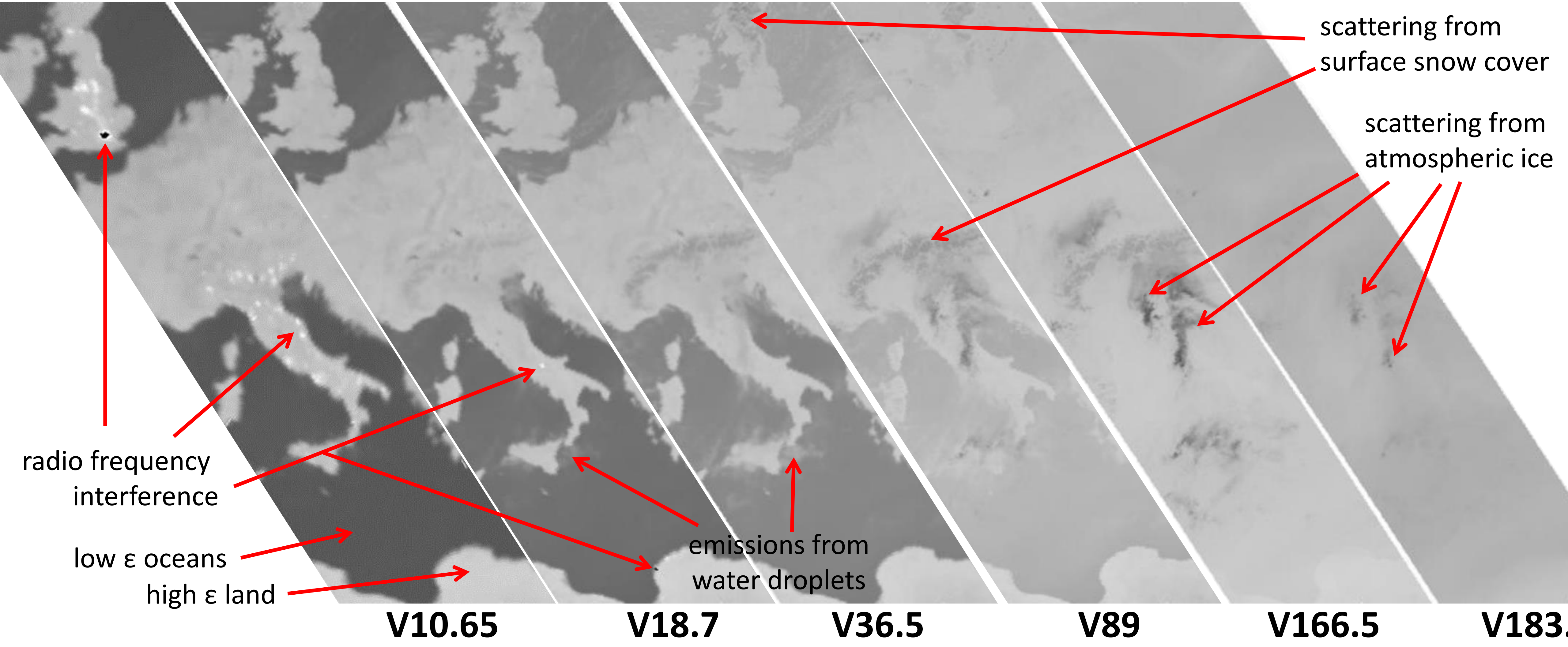
Passive Microwave sensor characteristics for precipitation

Sensor	SSMIS	AMSR2	TMI	GMI	MHS	SAPHIR	ATMS
Satellite	DMSP-F16, F17, F18, F19	GCOMW1	TRMM	GPM	NOAA18,19, MetOp-A, B	Megha-Tropiques	NPP
Type	Conical	Conical	Conical	Conical	Cross-track	Cross-track	Cross-track
frequencies	-	6.925/7.3VH	-	-	-	-	-
	-	10.65VH	10.65VH	10.65VH	-	-	-
	19.35VH	18.70VH	18.70VH	18.70VH	-	-	-
	22.235V	23.80VH	23.80VH	23.80V	-	-	23.8
	37.0VH	36.5VH	36.5VH	36.5VH	-	-	31.4
	50.3-63.3VH	-	-	-	-	-	50-3-57.3
	91.65VH	89.0VH	89.0VH	89.0VH	89V	-	87-91
	150H	-	-	165.6VH	157V	-	164-167
	183.31H	-	-	183.31V(2)	183.31H (2)	183.31H(6)	183.31(5)
	-	-	-		190.31V	-	-
Sampling resolution	12.79 km XT 12.59 km AT	4.65 km XT 4.28 km AT	4.74 km XT 13.10km AT	5.13 km XT 13.19 km AT	16.87 km XT 17.62 km AT	6.73 km XT 9.86 km AT	16.06 km XT 17.74 km AT
Retrieval resolution	50 x 40 km	19x11 km	26 x 21 km	16 x 10 km	15.88 x 15.88 km	10 x 10 km	16 x 16 km

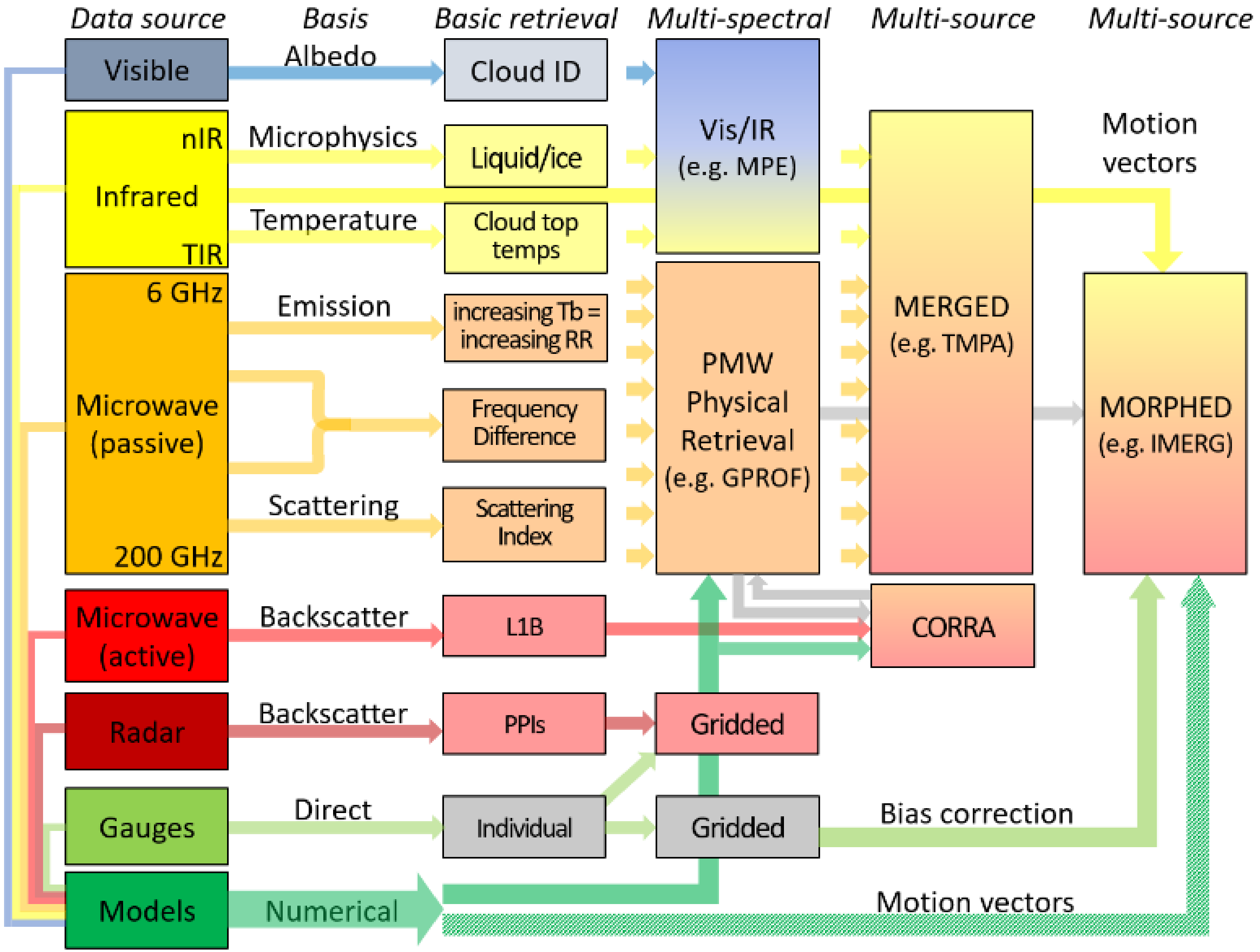
emission

scattering

Typical Passive Microwave channels (GMI)



Satellite precipitation estimation – food chain



Precipitation is very variable over time and space.

Good sampling necessitates multi-sensor, multi-satellite observations.

A range of precipitation properties and characteristics can be retrieved (cloud, rainfall, snowfall, hail).

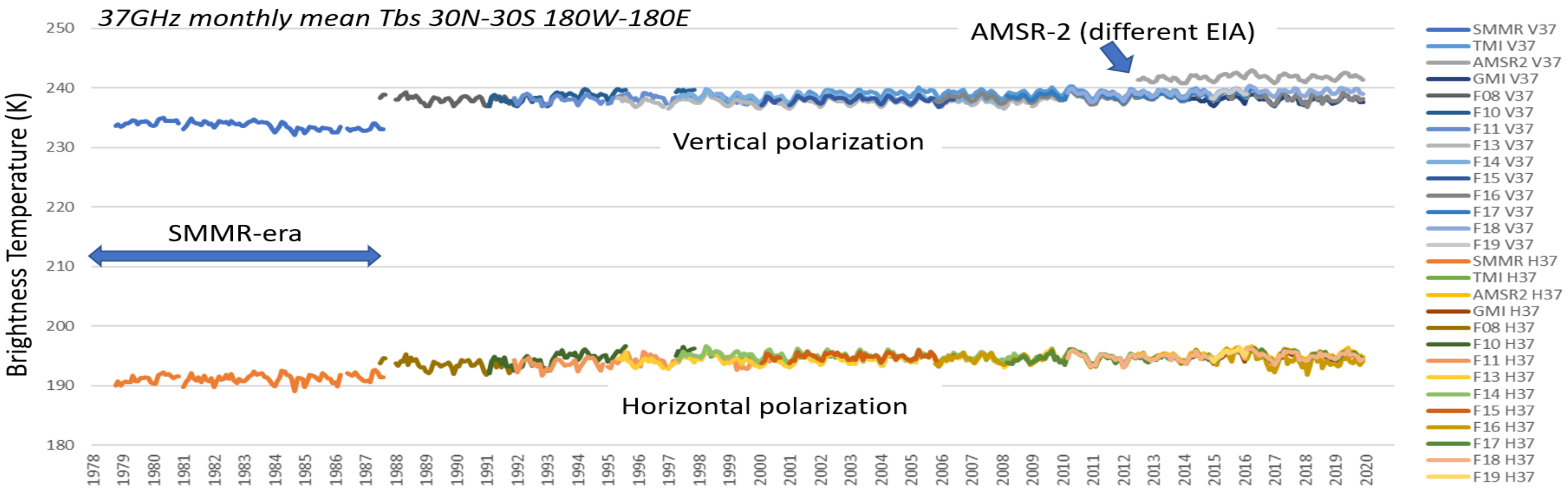
Impacts of RFI on PMW retrievals affects the estimates from combined schemes.

Climate Data Records - Brightness Temperatures

Satellite data records for the passive microwave span 40+ years.

Variations arise from orbits drifting across time of day, Earth Incidence Angles (EIA) and slight differences in frequencies. (*SMMR did not have any robust calibration*).

Calibration within a few $^{1}/_{10}$'s K – necessary to meet the exacting requirements of climate-scale applications and studies: Long term stability is crucial



Observing precipitation: RFI issues

Surface RFI - primarily at 6.7 GHz and 10 GHz

- 6.7 GHz: surface emissions – linked population density.
- 10.67 GHz: low-power (mW) motion detection systems (within ITC regulations)
- 18.7 GHz: some broadcast bands (usually satellite-ground), occasionally associated with ship-based radars. Possible communication links at 18 GHz.

Satellite Broadcast RFI – primarily 18.7 GHz

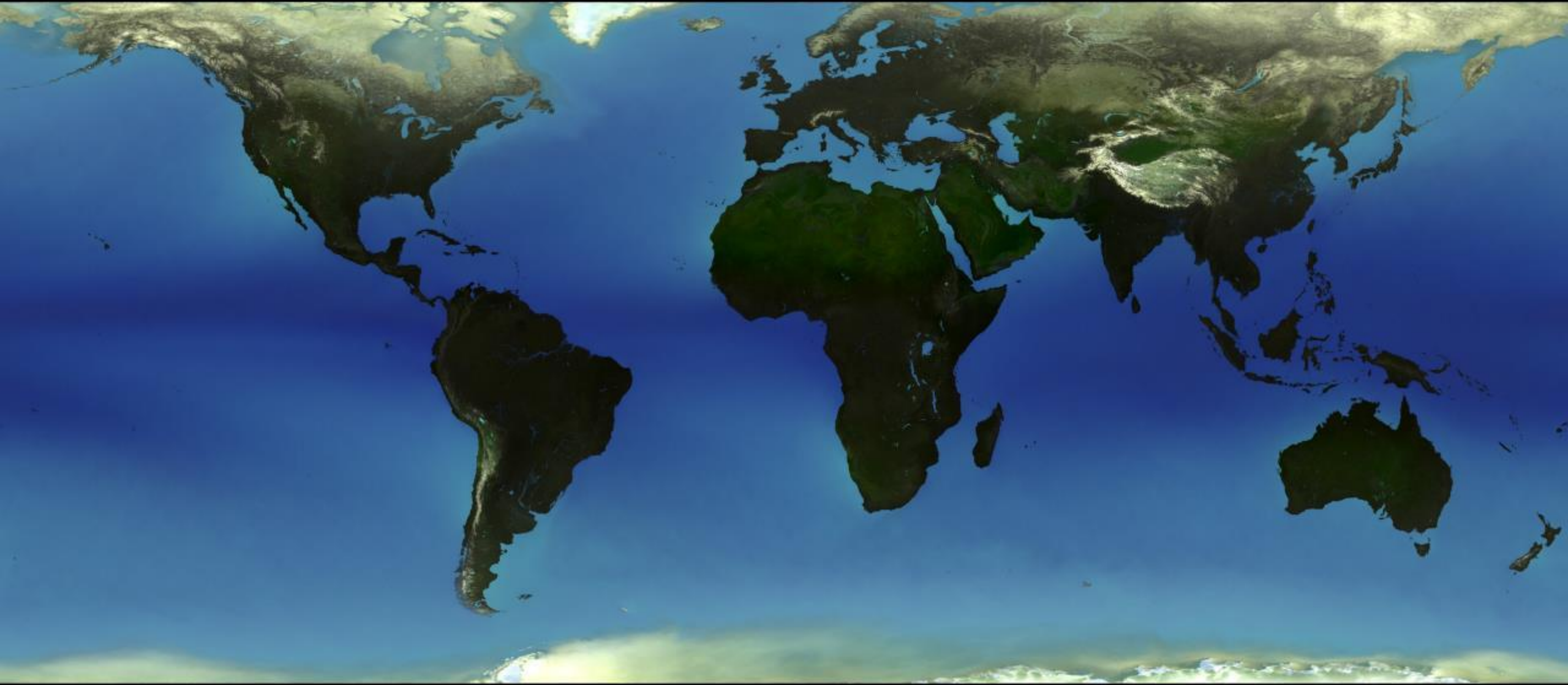
- High reflectance over ice (ice structure), more variable over water surfaces (wave characteristics) and more subtle over land surfaces.
- Possible to calculate satellite-surface-satellite path to identify possible RFI.

Future RFI encroachment – ca.24 GHz & 37 GHz

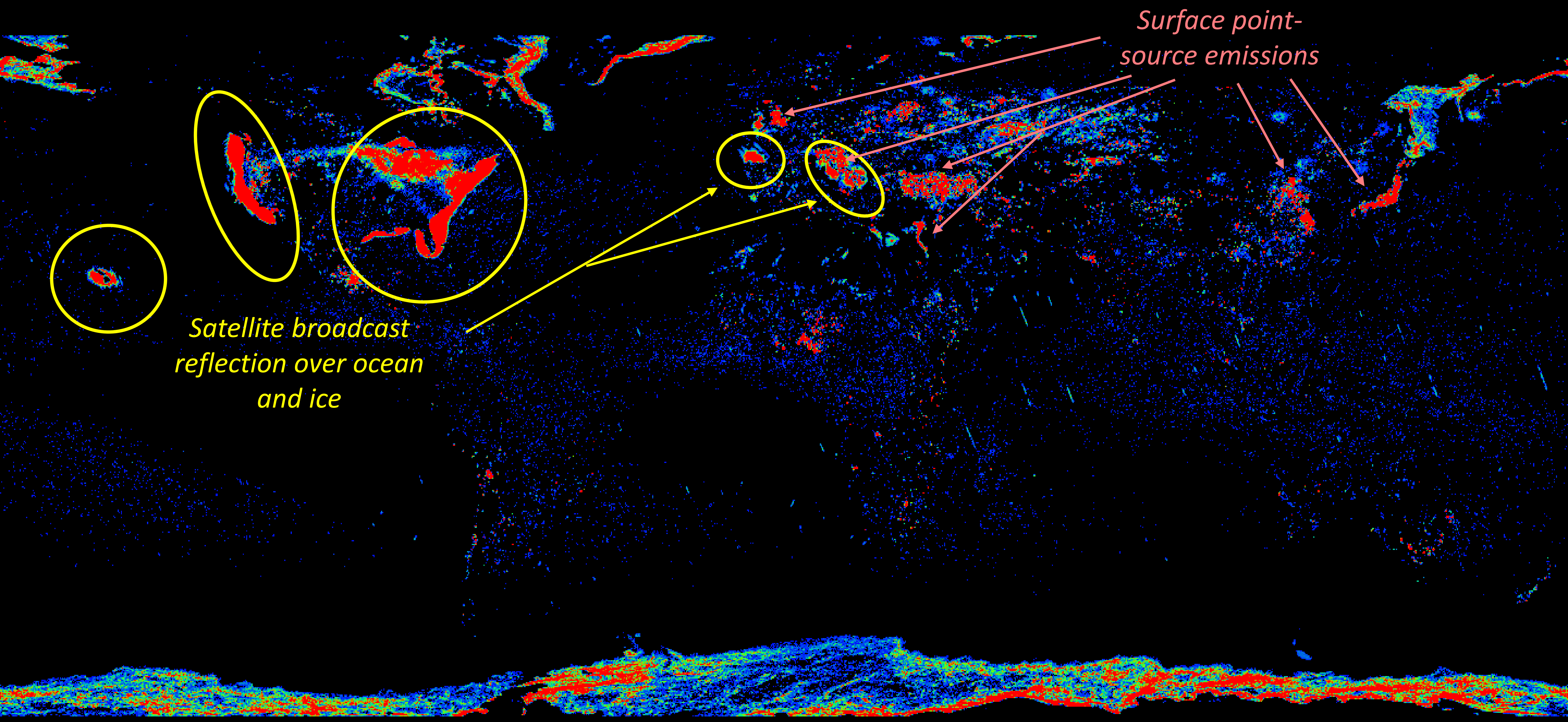
- WV channels around 24 GHz and 37 GHz window channels likely to be affected.

Obvious RFI is easy – subtle RFI is difficult.

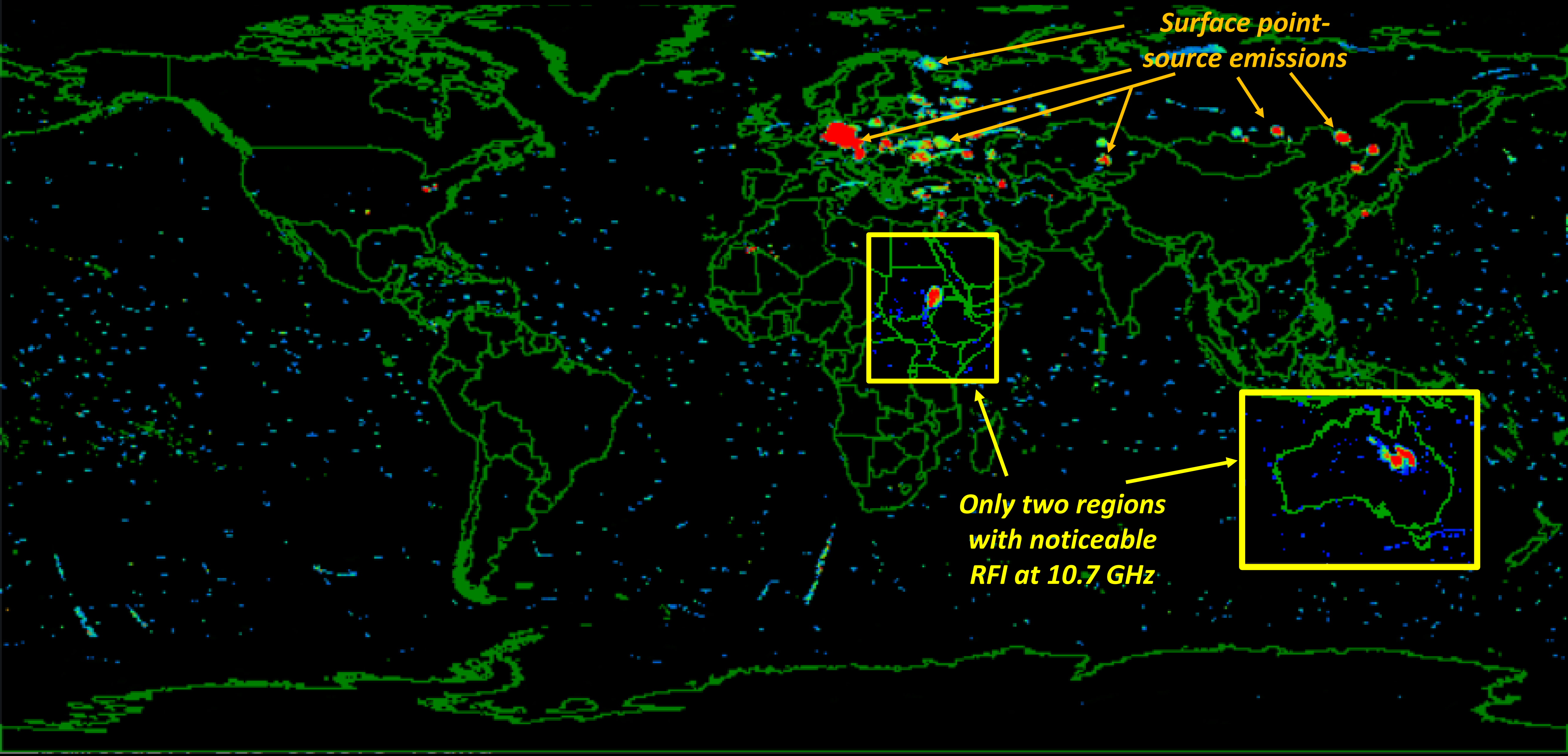
Multi-year false colour composite (GMI 2014-2020)



RFI-identified or out-of-bounds data – 2021 *(NASA PPS L1C GMI 10.7 GHz)*



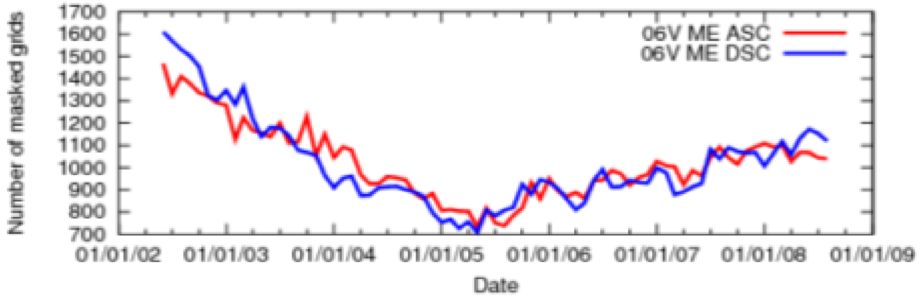
Out-of-bounds data – 1979 *SMMR 6.63 GHz L1B data*

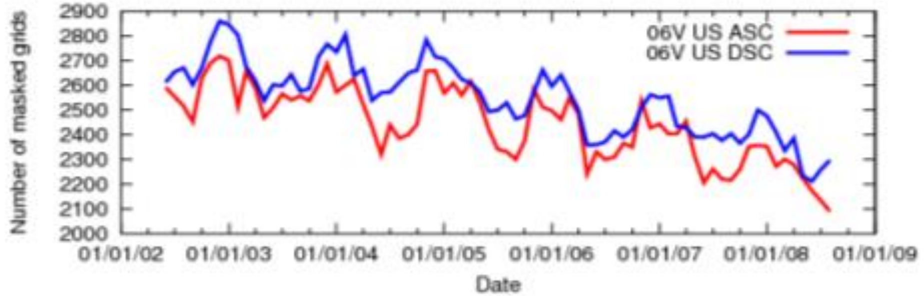


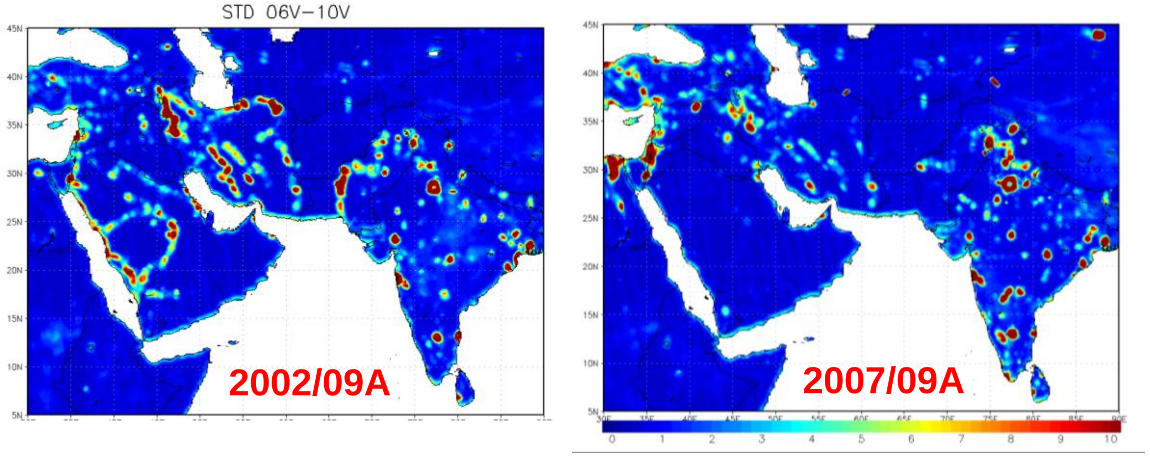
6.9 GHz

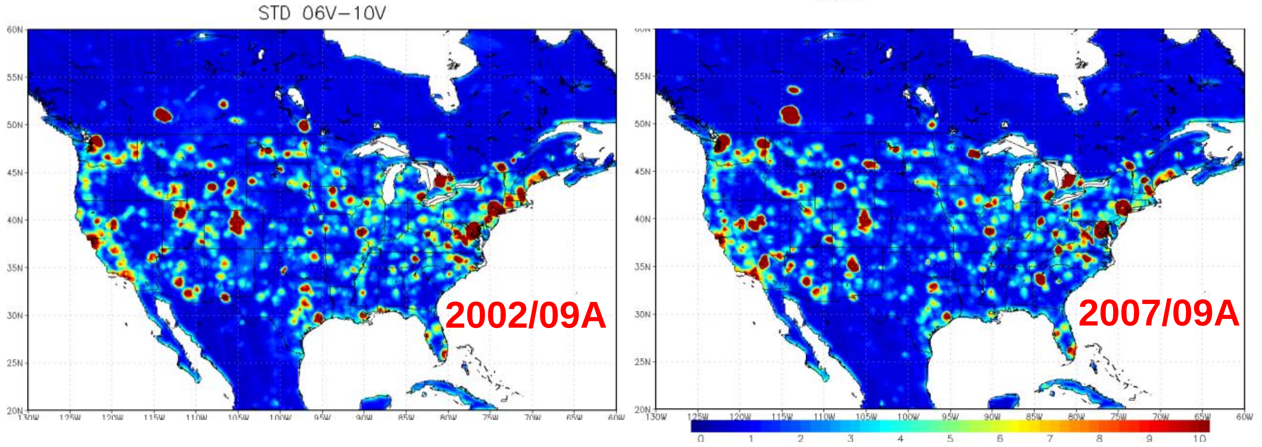
AMSR-E: over land

geophysical background

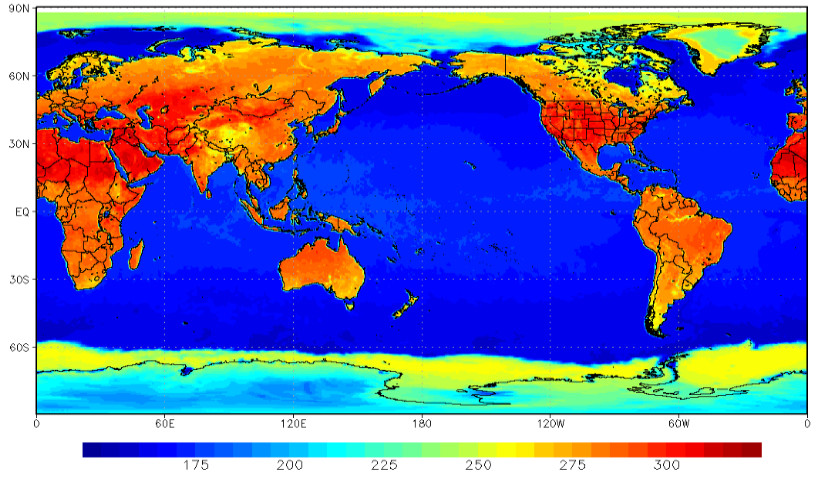




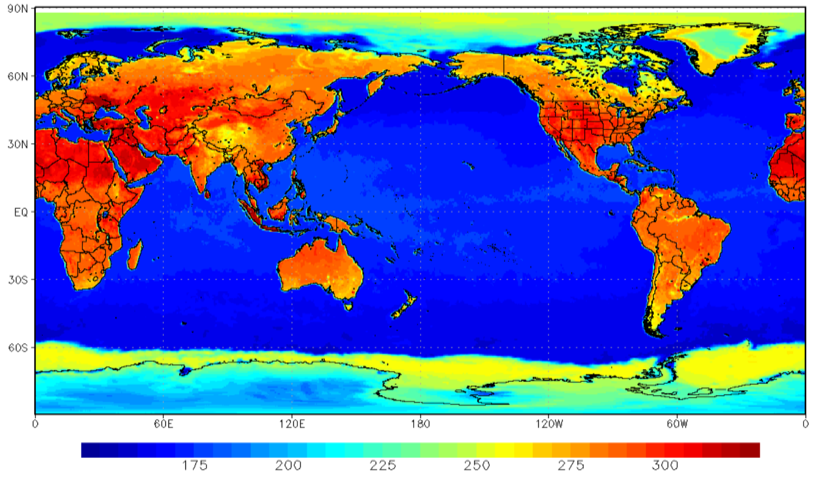




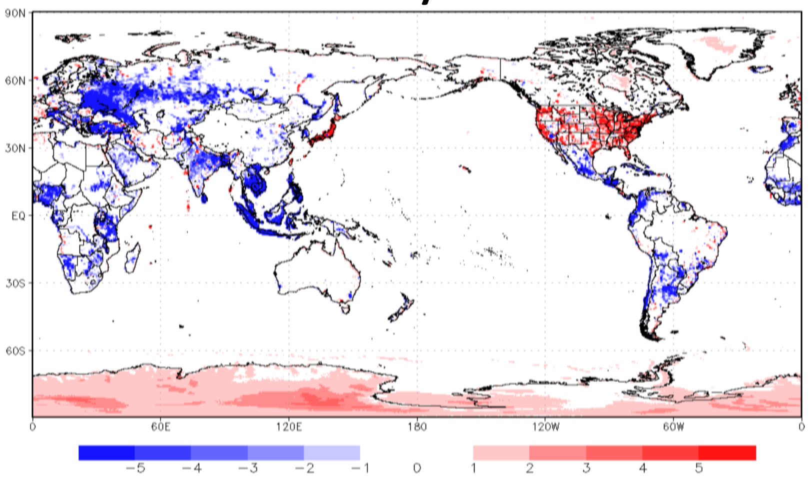
AMSR-2: introduced 7.3GHz channels in addition to 6.9GHz to better identify RFI



6.9GHz V-Pol. $TB_{6.9V}$ (July 11 – July 26, 2012)



7.3GHz V-Pol $TB_{7.3V}$ (July 11 – July 26, 2012)

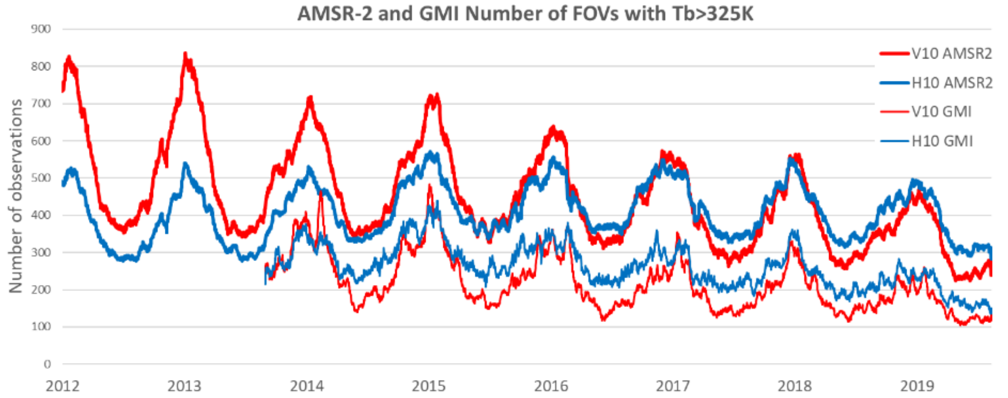


$TB_{6.9V}$-$TB_{7.3V}$

(Provided by JAXA)

10 GHz RFI

- Used for background characterization over land and **precipitation retrievals over oceans.**
- Significant, but decreasing impacts (GMI & AMSR2 sensors)



RFI Mitigation in AMSR3

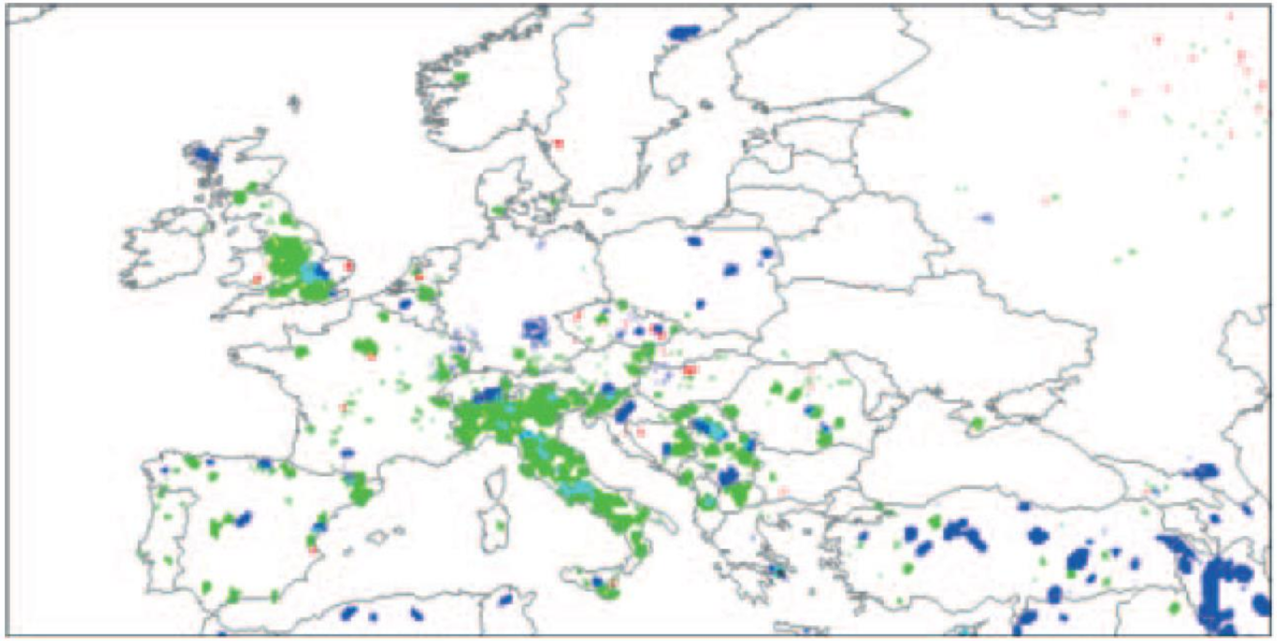
JAXA AMSR3 (launch in JFY2023) additional sensor characteristics to mitigate possible RFI impacts:

- **C-band**:
  - Keep both 6.9/7.3 GHz
- **X-band**:
  - New 10.25 GHz as in addition to 10.65 GHz with similar RFI detection as currently used in C-band
- **K-band**:
  - specification of 36 GHz passband is changed to 840 MHz to reduce the future risk of RFI from 5G mobile network.
  - At 23GHz a buffer band of 250 MHz and to improve the out-of-band frequencies.

Frequency [GHz]	Polari-zation	Bandwidth [MHz]	NEDT (1σ)	Beam width (spatial resolution)
6.925/7.3	H/V	350	<0.34 K	1.8° (34x58km)
10.25	**H/V**	**500**	**<0.34 K**	**1.2° (22x39km)**
10.65	H/V	100	<0.70 K	1.2° (22x39km)
18.7	H/V	200	<0.70 K	0.65° (12x21km)
23.8	H/V	400	<0.60 K	0.75° (14x24km)
36.42	**H/V**	**840**	**<0.70 K (TBD)**	**0.35° (7x11km)**
89.0 A/B	H/V	3000	<1.20 K	0.15° (3x5km)
165.5	V	4000	<1.50 K	0.23/0.30° (4x9km)
183.31±7	V	2000x2	<1.50 K	0.23/0.27° (4x8km)
183.31±3	V	2000x2	<1.50 K	0.23/0.27° (4x8km)

Red indicates differences from AMSR2 (Provided by JAXA)

Identifying RFI issues



Polarization difference anomalies associated with RFI over Europe, August 2004, AMSR-E.
(Red=18.7 GHz, Green=10.65 GHz and Blue=6.925 GHz.)

Kidd, 2006

Identifying RFI is crucial to provide ‘clean’ data for the retrieval of precipitation (and other geophysical parameters):

- NASA PPS –identification of extreme Tbs and thresholding;
- EUMETSAT H-SAF – remove extreme Tbs *(no GMI/AMSR2 products)*;
- JAXA – thresholding brightness temperatures/combinations.

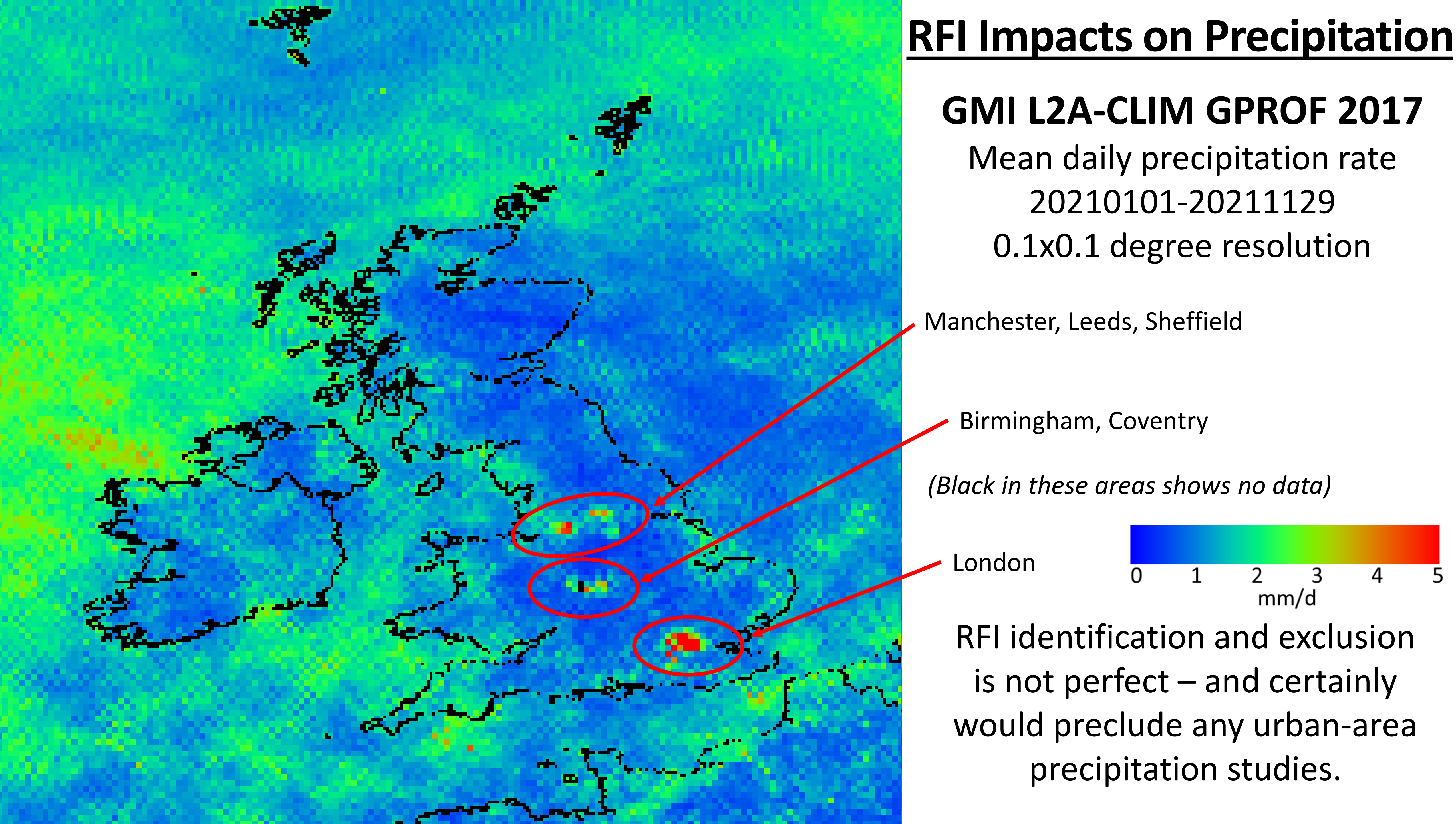
RFI Impacts on Precipitation

GMI L2A-CLIM GPROF 2017

Mean daily precipitation rate

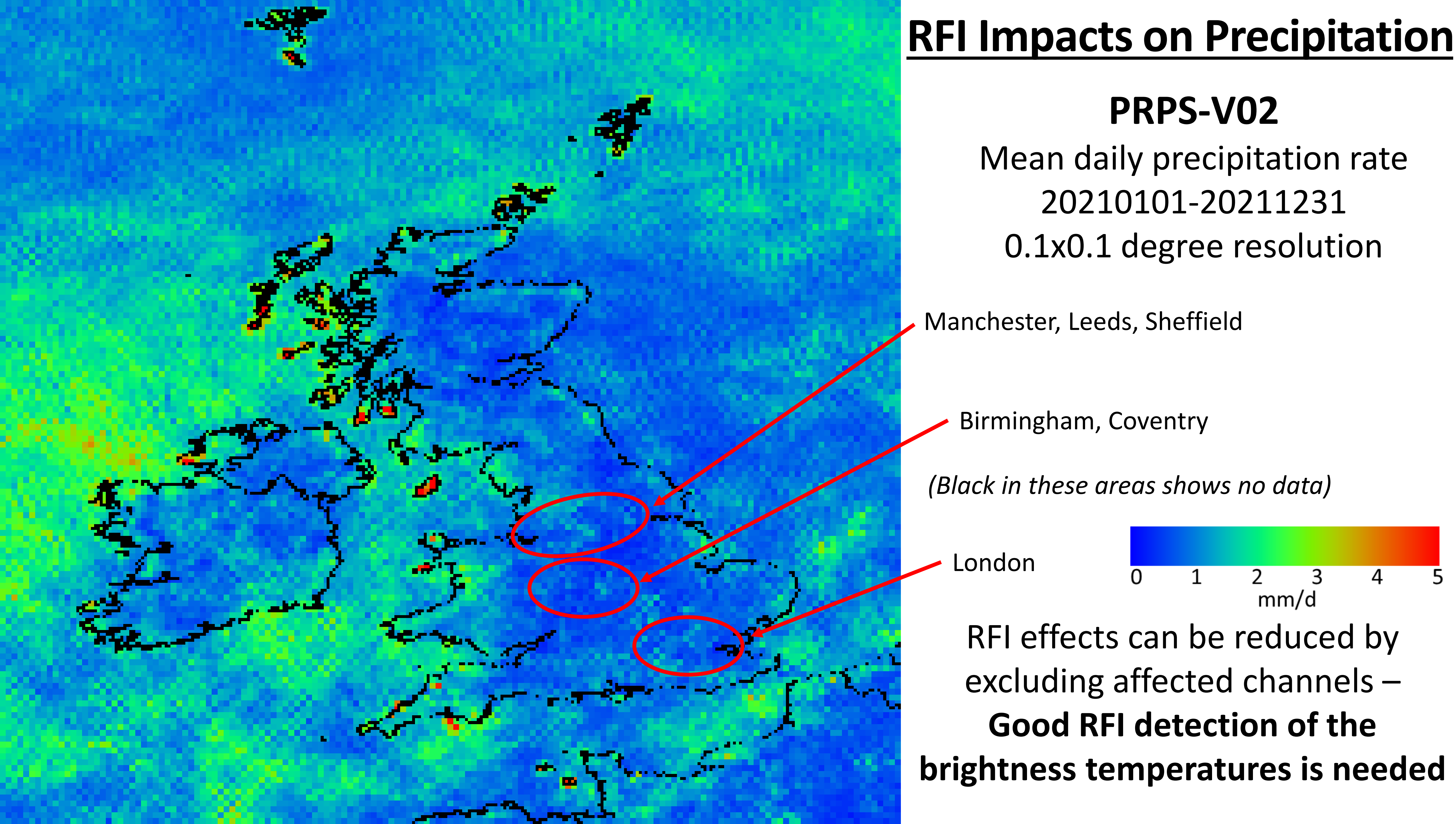
20210101-20211129

0.1x0.1 degree resolution



RFI identification and exclusion is not perfect – and certainly would preclude any urban-area precipitation studies.

RFI Impacts on Precipitation



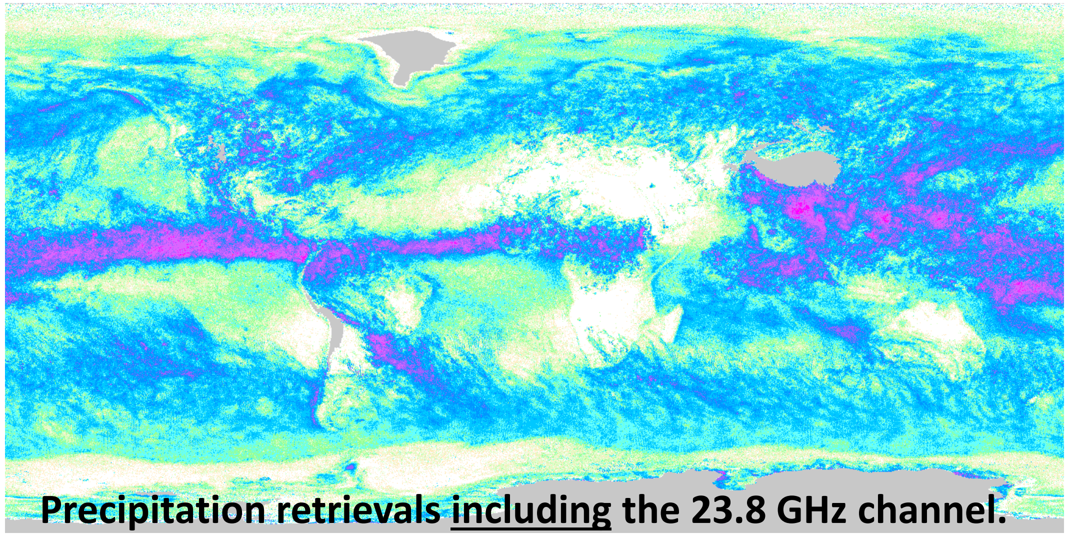
PRPS-V02

Mean daily precipitation rate
20210101-20211231
0.1x0.1 degree resolution

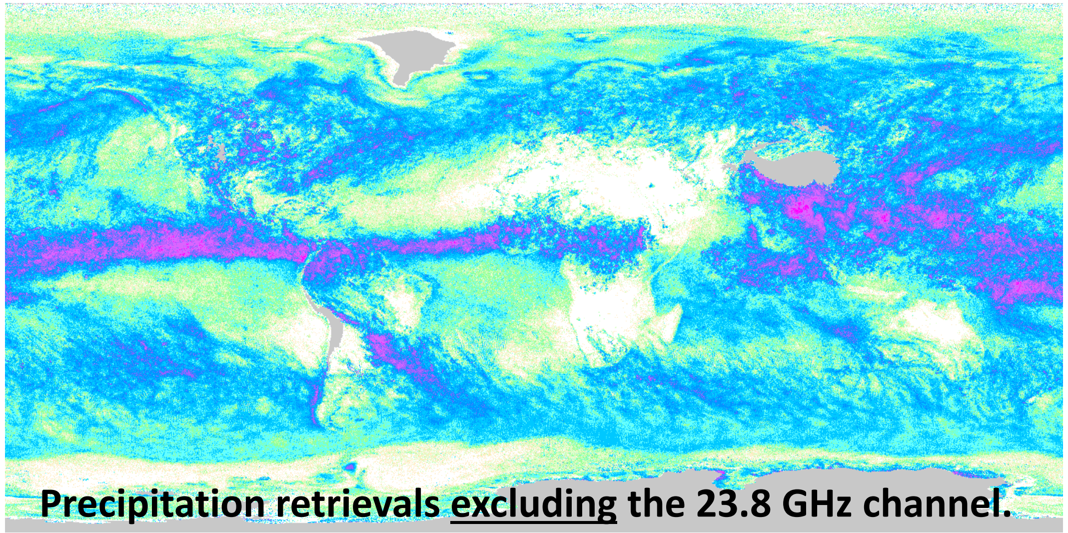
RFI effects can be reduced by excluding affected channels – **Good RFI detection of the brightness temperatures is needed**

Precipitation retrieval with/without the 23.8 GHz channel

NOAA NPP ATMS sensor July 2015



Precipitation retrievals including the 23.8 GHz channel.

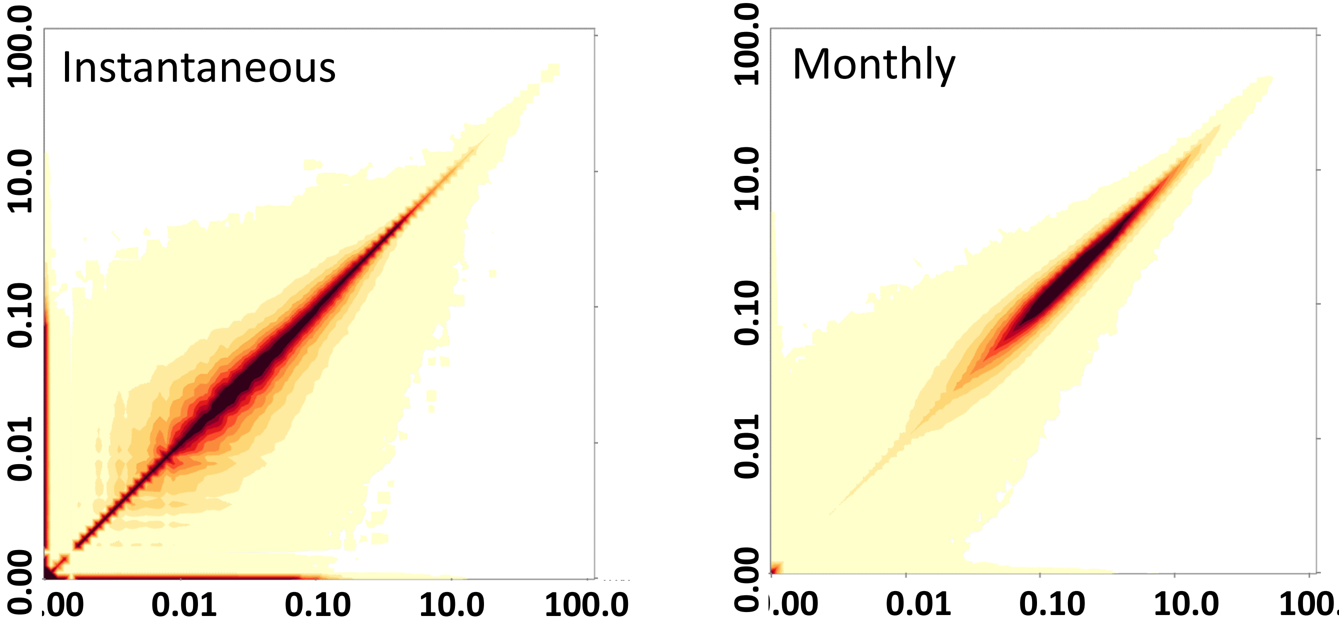


Precipitation retrievals excluding the 23.8 GHz channel.

Selling-off frequencies around 24 GHz has the potential to impact precipitation retrievals.

Monthly differences are often subtle but, excluding the 23.8 GHz on ATMS (for example) would be equivalent to an increase in noise resulting from a loss of about 37.5% of the number of observations.

Precipitation retrievals with/without the 23.8 GHz. (NOAA NPP ATMS, July 2015).



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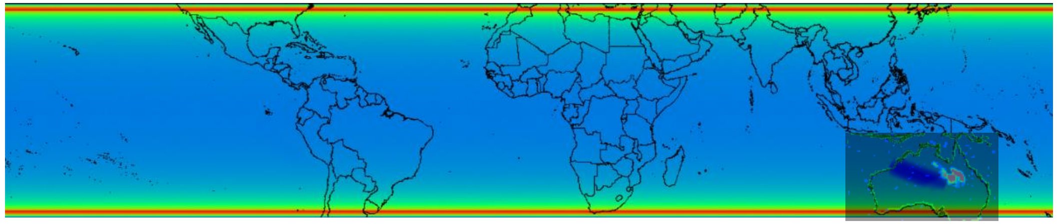
Goddard Space Flight Center

Precipitation Measurement – co-existance

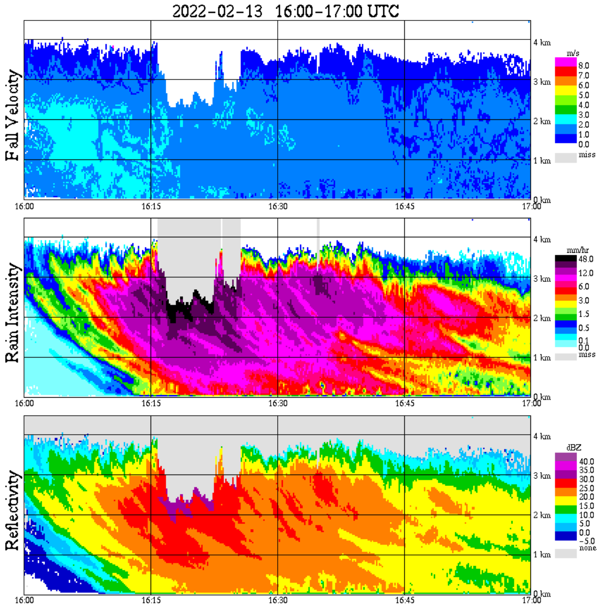
- Weather radars – X/C/S-band – carefully regulated
- Satellite precipitation radar – e.g. TRMM-PR/GPM-DPR
- Vertically pointing Micro Rain Radars (50mW, 24.1 GHz)
- Use of surface microwave links for precip measurement

Often reconfigured to avoid conflicts

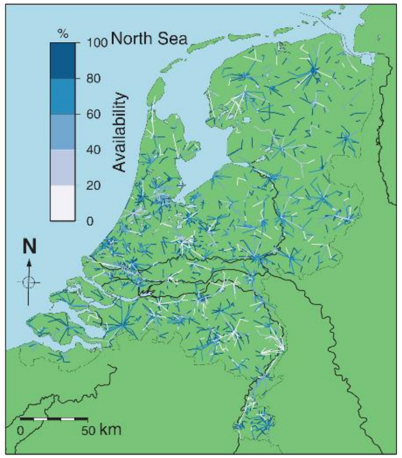
Distribution of global weather radars

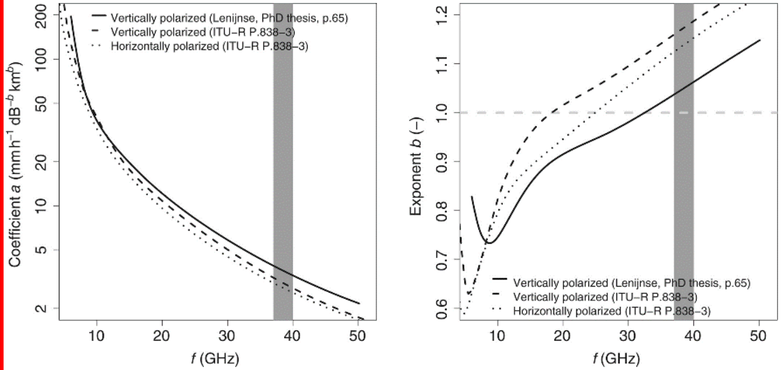


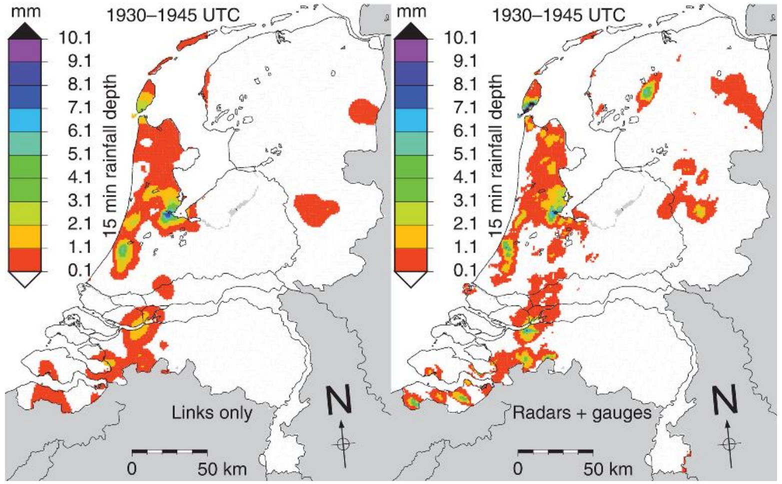
Number of observations made by TRMM PR (13.8 GHz)
(note 'hole' over Australia)



Surface MW links







Uijlenhoet, et al (2018), https://doi.org/10.1002/wat2.1289

RFI Conclusions

PMW observations are used for many geophysical observations, precipitation amongst them, but are subject to RFI impacts:

- 6.9 GHz & 10.7 GHz – emissions from surface-based sources.
- 18.7 GHz – mostly reflection from satellite broadcasts, but also surface.
- 23.8 & 37.0 GHz – possible future issues from surface communications.

Various approaches used to mitigate the effects:

- screening of Tbs through Tb thresholding or inter-channel comparison;
- extreme Tb detection;
- adaptive retrieval schemes to exclude RFI-contaminated channels;
- multi-channel RFI identification in future systems & use of AI.

The long planning, development time and longevity of satellite sensors means that their technology is often outdated during their operational lifetime.