Utilisation of the passive microwave for geophysical retrievals

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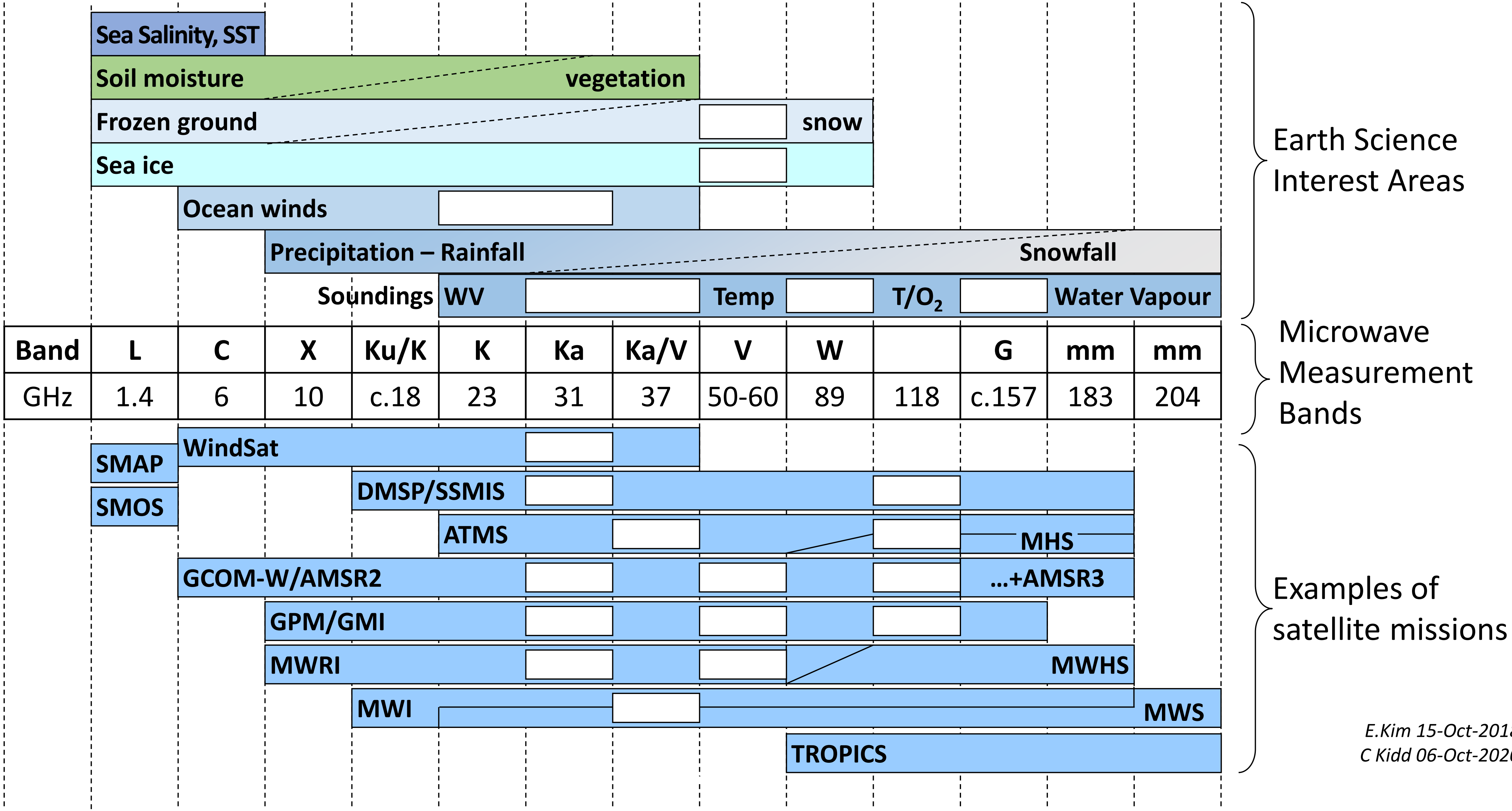
Introduction

- Passive microwave observations of the Earth have been available since the 1960’s, with long-term data availability since the 1970’s.
- They provide all-weather observations which relate to geophysical properties of the surface and atmosphere.
- Frequencies from ca.10-50 GHz provide the ‘core’ channels for Earth observation, complemented by other frequencies.

This talk will cover:

- Background to mid-frequency passive microwave observations
- Examples of geophysical retrievals
- Retrieving precipitation, including channel selection

Passive Microwave Science, Bands, & Satellite Sensors



E.Kim 15-Oct-2018
C Kidd 06-Oct-2020

Mid-frequency Passive Microwave channels and uses

Frequency	Active/Passive	Purpose	Use/Sensors
10.6-10.7 GHz	Passive	Window	Low frequency passive microwave channels used for soil moisture, snow/ice and over ocean liquid precipitation (e.g. AMSR-2, GMI)
13.256-13.8 GHz	Active	Scatterometer Altimeter Precip. Radar	Numerous narrow-band channels used for scatteromters (e.g. SCAT, Rapidscat) and altimeters (e.g. OSCAT, Poseiden), together with precipitation radars (PR, DPR, Rainradar).
18.0/18.7 GHz 19.35 GHz	Passive	Window	Low-mid passive microwave channels used for for soil moisture, snow/ice and over ocean liquid precipitation (e.g. AMSR-2, GMI)
21.0 GHz 22.235 GHz 23.8 GHz	Passive	Water vapour	Water vapour channel used in conjunction with other passive microwave channels for geophysical retrievals and correction of altimeter data.
31.4 GHz	Passive	Window	Mid passive microwave channels used for snow/ice and ocean/land precipitation retrievals (e.g. AMSU-A, MWS[e], ATMS)
34.0 GHz	Passive	Window	Mid passive microwave channel used in support of altimeter measurements (e.g. AMR)
35.5 GHz 35.75 GHz	Active	Altimeter Precip.Radar	Altimeter and Ka-band precipitation radar (e.g. KaRIN, DPR)
36.5-37.0 GHz	Passive	Window	Mid passive microwave channels used for snow/ice and ocean/land precipitation retrievals (e.g. AMSR-2, GMI) and in support of Altimeter measurements (e.g. MWR).
42.0/48.0 GHz	Passive	Window	Passive microwave channels for geophysical retrievals (e.g. MTVZA-GY)

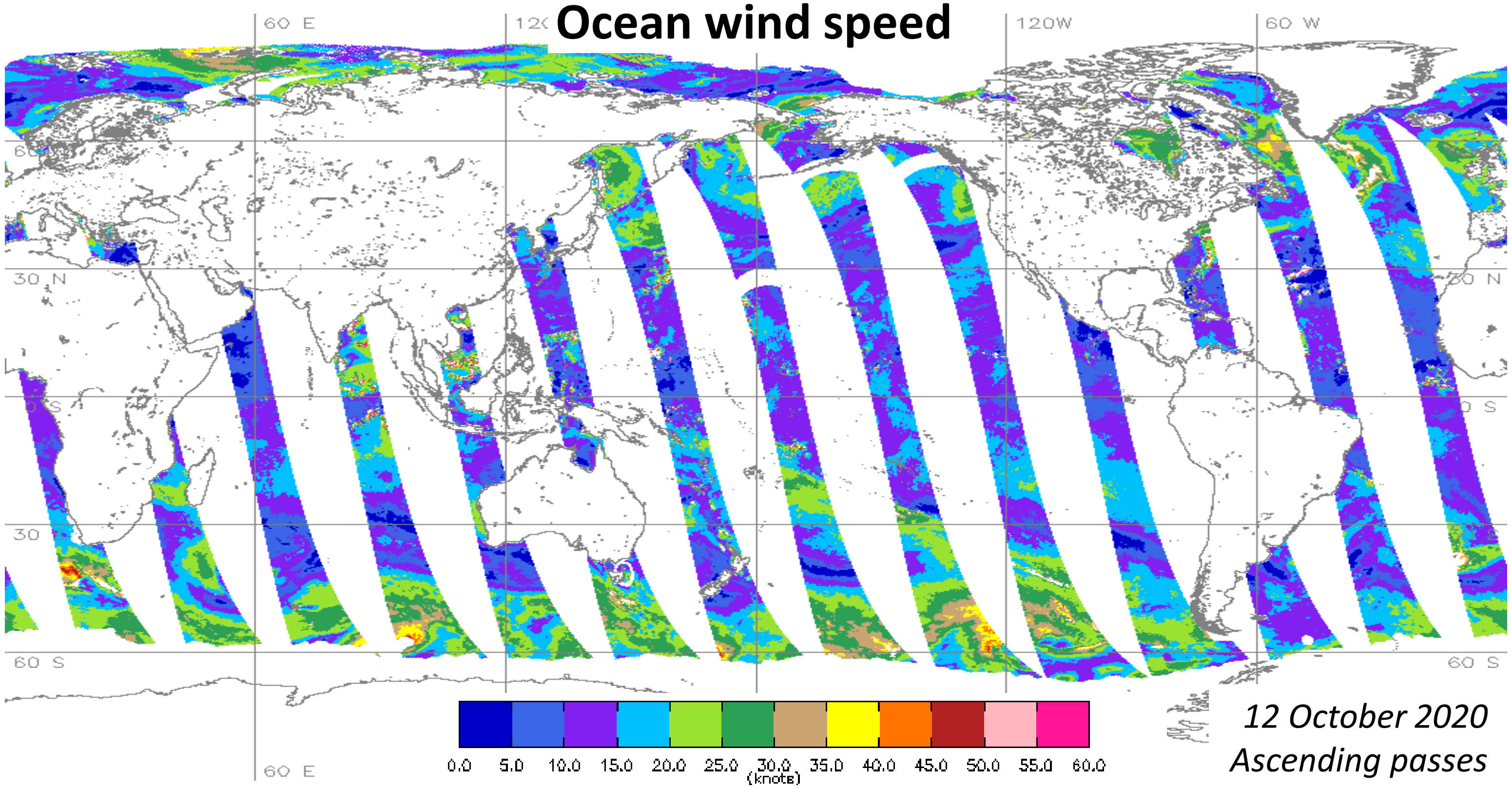
Sensor categories

Satellite-based sensors utilising passive microwave frequencies for Earth Observation:

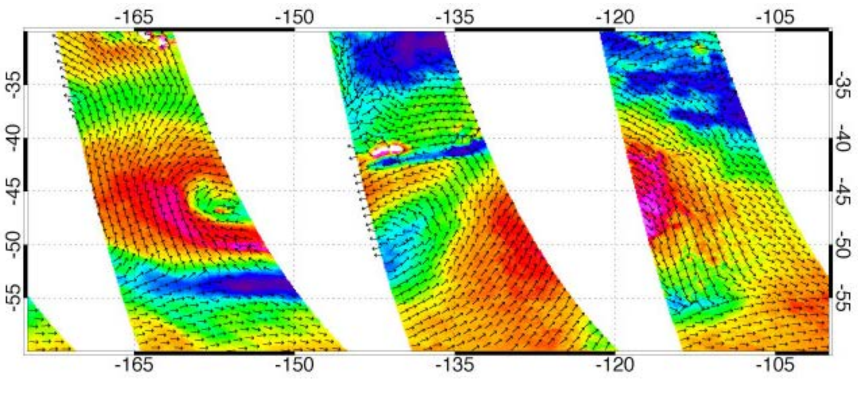
- ***Imaging instruments***: radiometers using primarily window channels to observe (primarily) the Earth surface, with a wide swath with mapping capabilities, typically conically-scanning;
- ***Sounding instruments***: radiometers focusing upon the atmospheric absorption bands (e.g. WV, O_2) for observing atmospheric parameters with a wide swath, typically cross-track scanning;
- ***Active instruments***: primarily nadir-viewing or narrow-swath altimeters or scatterometers for surface parameters, but also precipitation/cloud radars to provide vertical information;
- ***Single beam instruments****:* radiometers used in support of the altimeters and scatterometers.

Ocean Products

Ocean wind speed



12 October 2020
Ascending passes



WindSat Wind Field 2006.02.09

Other products include soil moisture, sea surface temperature, land surface temperature, and vegetation mass.

WindSat

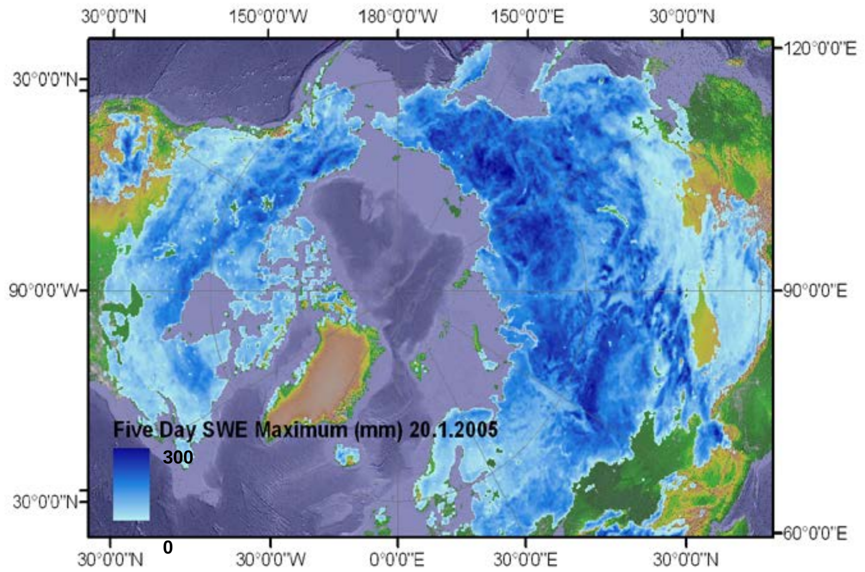
Freq.	Polarisation	Notes
6.8	V,H	Used to correct for SST
10.7	V,H ±45,L,R	
18.7	V,H ±45,L,R	
23.8	V,H	Used to correct for WV
37.0	V,H ±45,L,R	

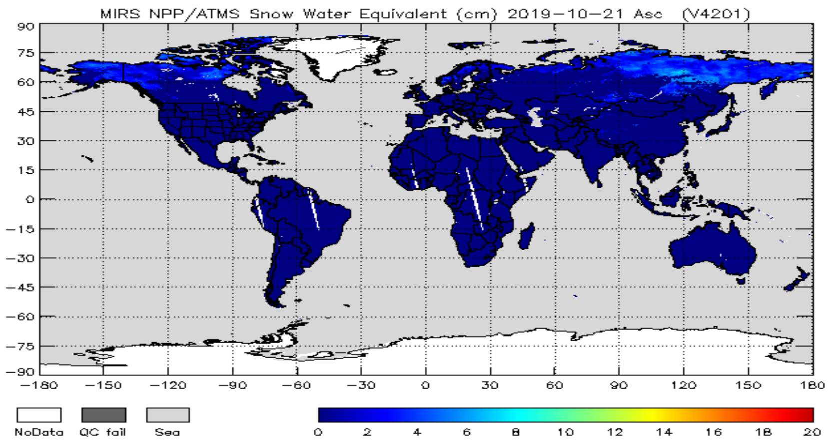
Snow cover extent and characteristics

PMW essential for snow depth & snow water equivalent products (seasonal snow on land):

- only truly global technique (although poor over mountainous & forested areas); existing + planned PMW satellites provide global coverage ~daily
- Initially developed in 1980s, still routinely used for civil & military operational products (US & int'l)

- *dry snow scatters*: more SWE → more volume scattering → colder TBs (extinction of TB from underlying soil); *wet snow emits*: no longer a function of SWE, TB approaches 273K blackbody
- Freqs ≤ 10 GHz tend to not be sensitive enough to volume scattering for global typical SWE amounts (<60cm, or ~ 1.8m depth)
- Freqs > 37 GHz saturates for SWE > 50 cm, too sensitive to surface scattering (not a function of SWE), and atmospheric conditions
- Optimum freqs for most snow conditions: 18 & 37 GHz; TB difference reduces dependence on other factors such as grain size; 10 GHz can assist with deep snow; 89 GHz is used to mask out very thin snow





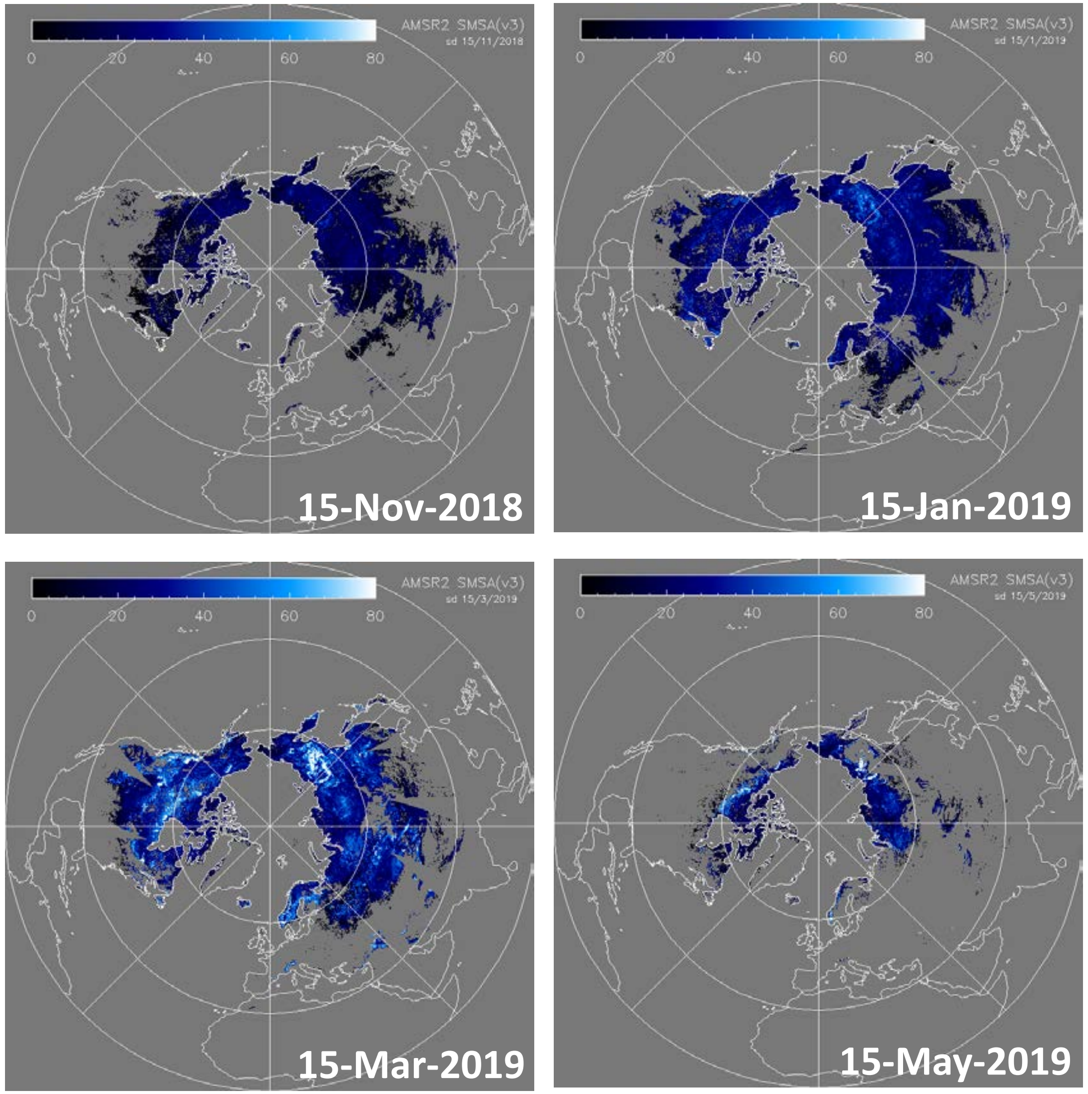
E.Kim 10/13/20

Snow cover products

AMSR-2 based retrievals

Model-based sequential daily multi-channel approach – each channel responds differently to the characteristics of snow on the surface

- AMSR2 Tbs (10, 18, 22, 36, 89 GHz)
- Static ancillary data
  - Land Ocean Ice Mask (MODIS LC)
  - Forest transmissivity map (Li *et al.,* 2018)
  - DEM Global – mountains (UNEP definition)
  - Water fraction (global water bodies)
- DMRT-ML (QCA-CP) radiative transfer model



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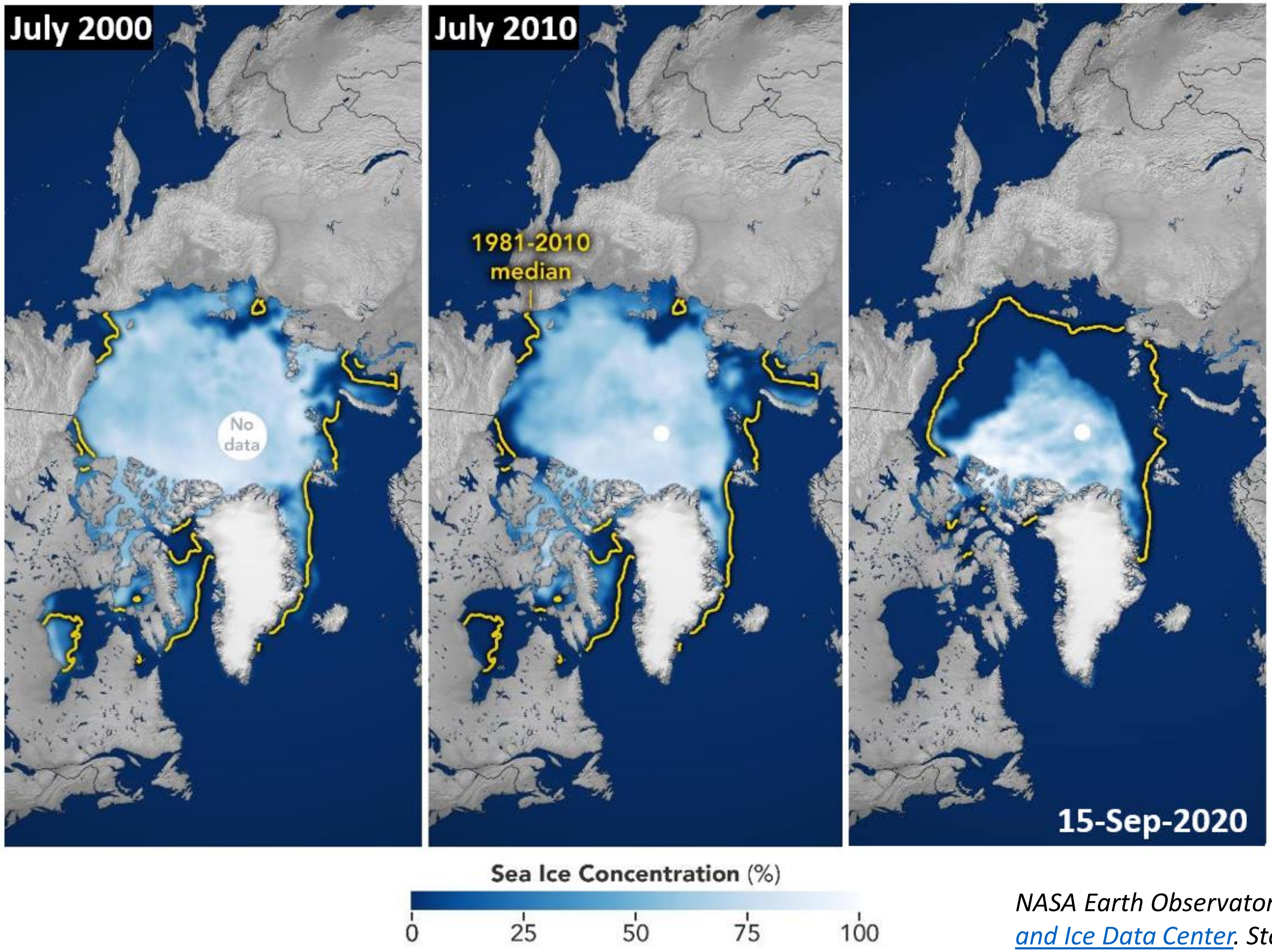
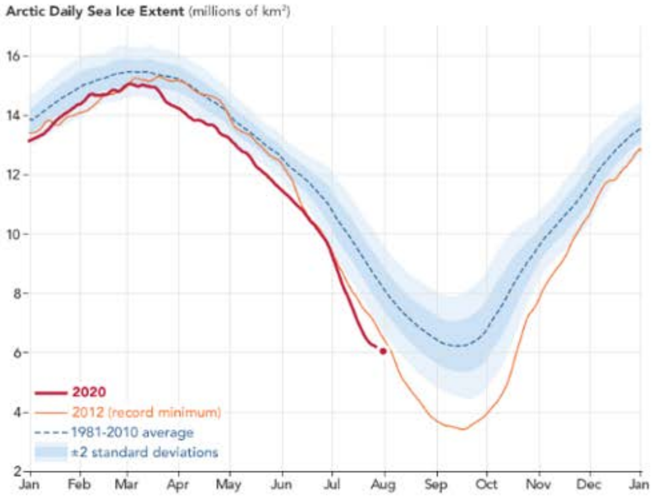
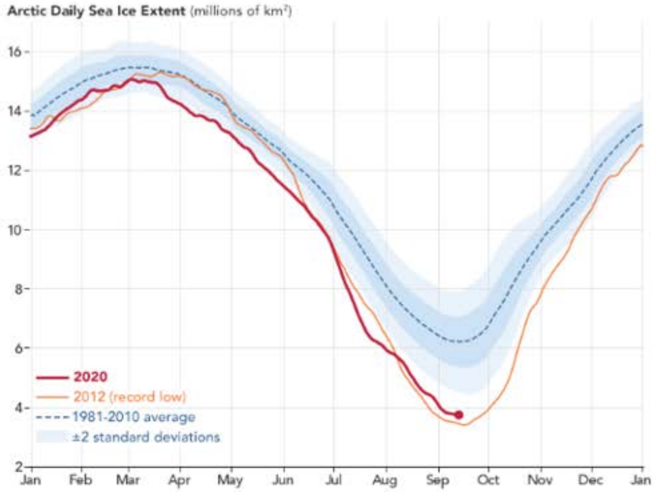
Monitoring sea ice extent







NASA Earth Observatory images by Joshua Stevens, using data from the National Snow and Ice Data Center. Story by Kathryn Hansen, and includes reporting by Kate Ramsayer.

https://earthobservatory.nasa.gov/images/147306/arctic-sea-ice-reaches-second-lowest-extent

Precipitation retrievals

- *Why is precipitation important?* It is vital to understanding the Earth System and for societal benefits: we depend upon fresh water.
- *Why use satellites (and why not use models)?* Satellites provide global coverage (rain gauges essentially land-only), and models do not, so far, capture the subtleties of precipitation (e.g. diurnal cycle).
- *Why not use visible/infrared from geostationary?* GEO observations provide frequent and regular observations, these are of the cloud tops, not of the precipitation falling from the clouds.
- *Why use the passive microwave?* PMW observations respond more directly to the hydrometeors within the atmosphere, allowing more direct measurements of surface precipitation to be made.

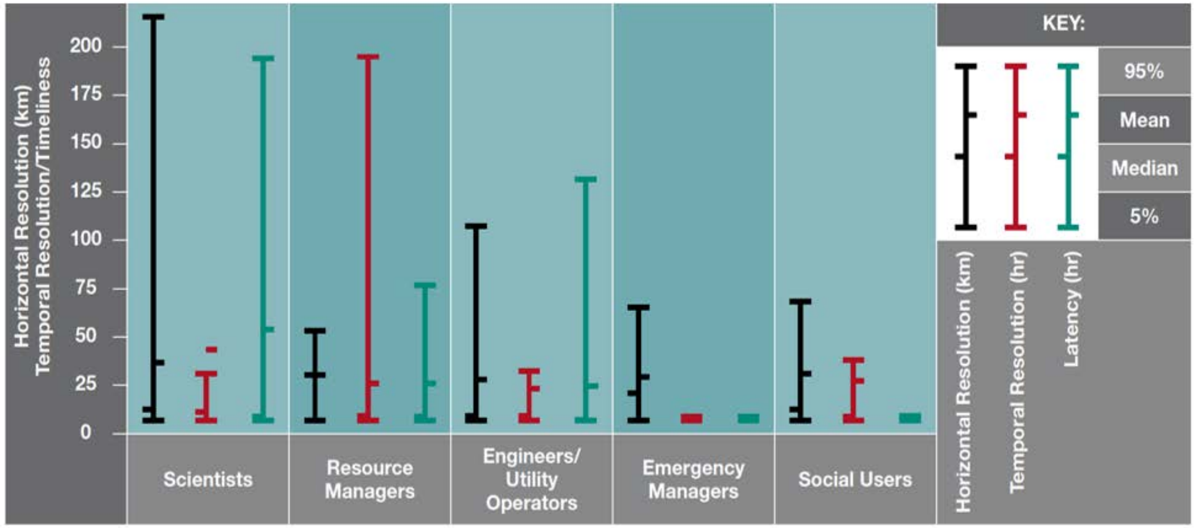
Addressing user requirements

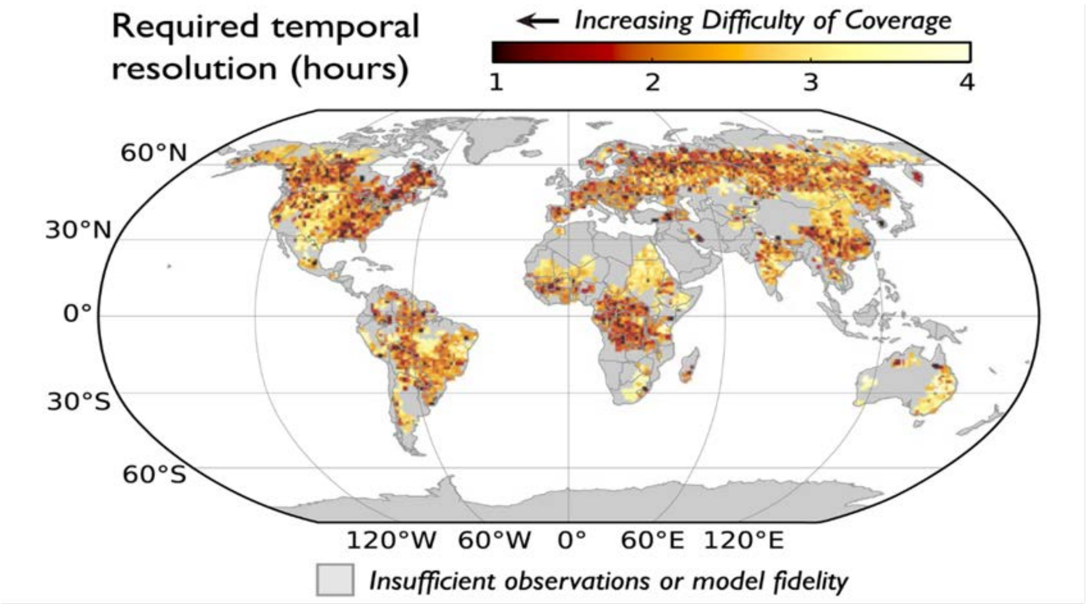
GEO Task US-09-01a: *Precipitation Data Characteristics and User Types*

- Spatial resolutions from 5-cm to 1000-km (median c.0.63 to 5-km)
- Temporal resolutions from 1-min to 30-days (median c.15-min to 1-hour)
- Latency from 1-min to 60-days (median c.1-min to 30-mins)

Crucially – **large range of requirements for a large range of users** – whose requirements are not necessary the same across user domains.

User requirements (GEO 2020, Fig 2)





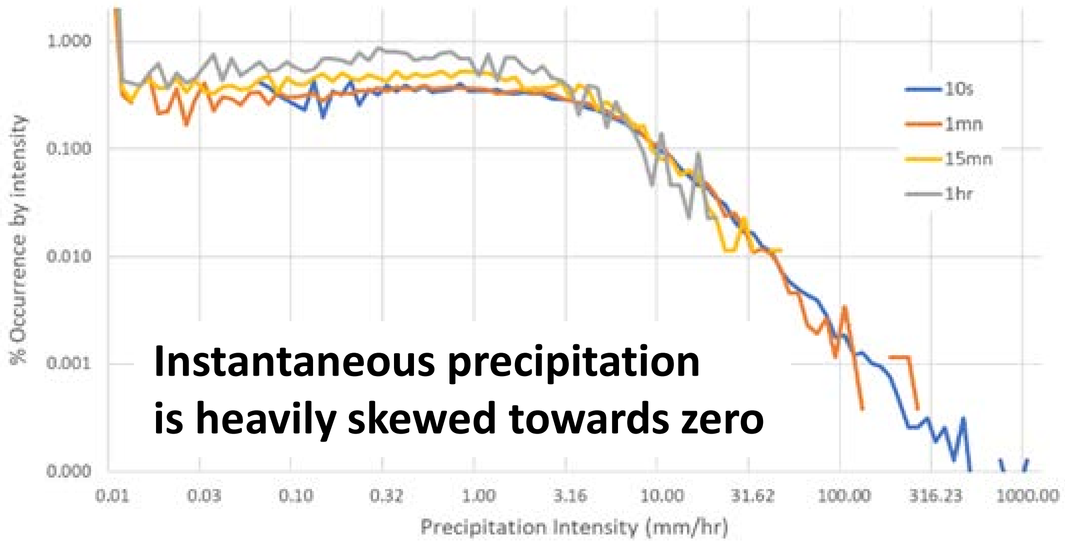
Reed et al. (2015), Fig. 1

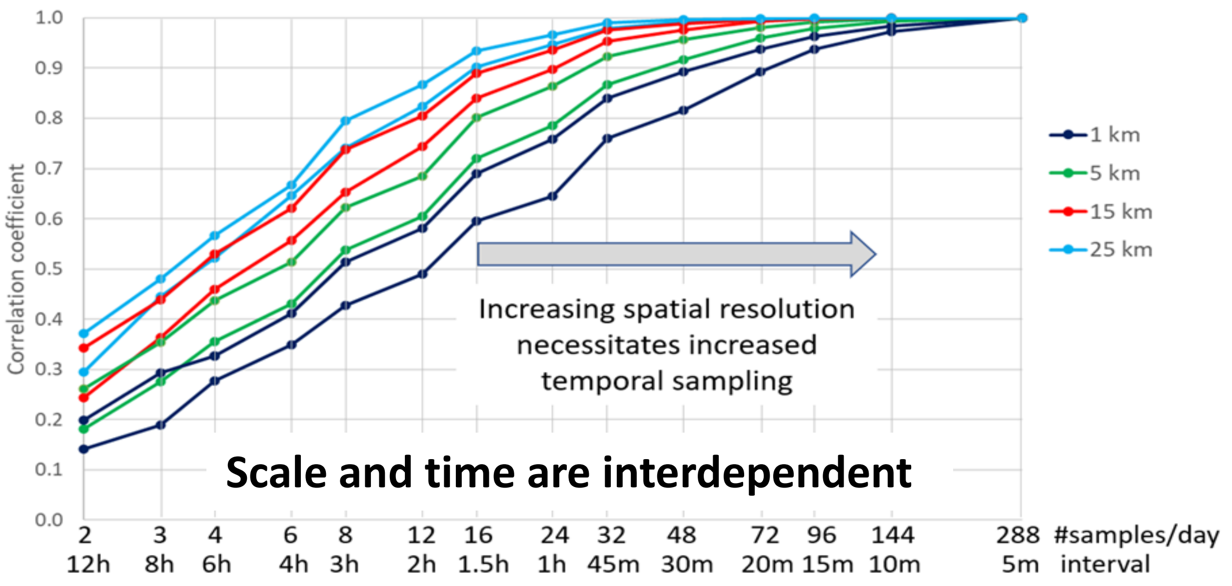
Understanding Precipitation

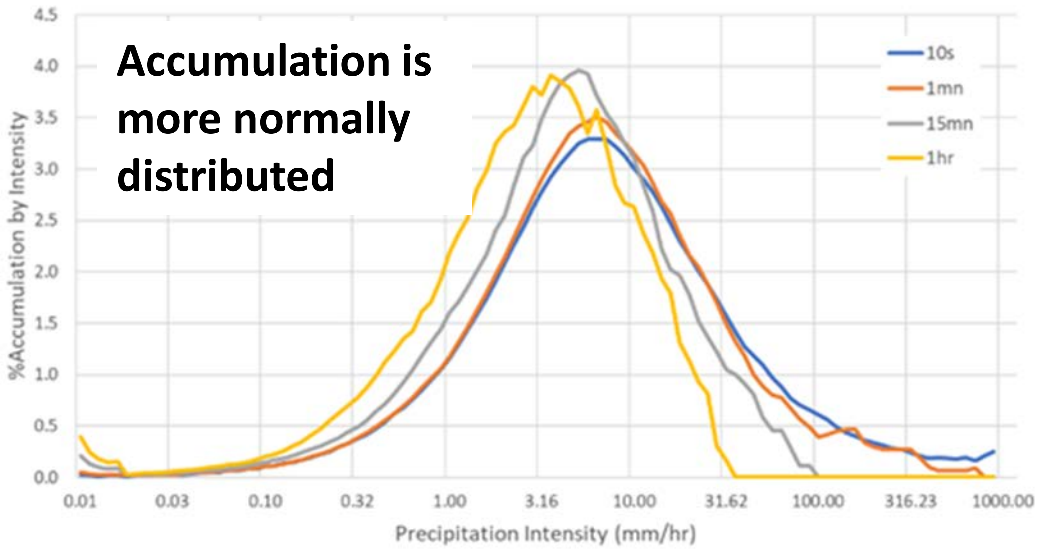
Fundamental to any type of measurement is an understanding of the properties and characteristics of what is being measured.

Precipitation – both rain and snow:

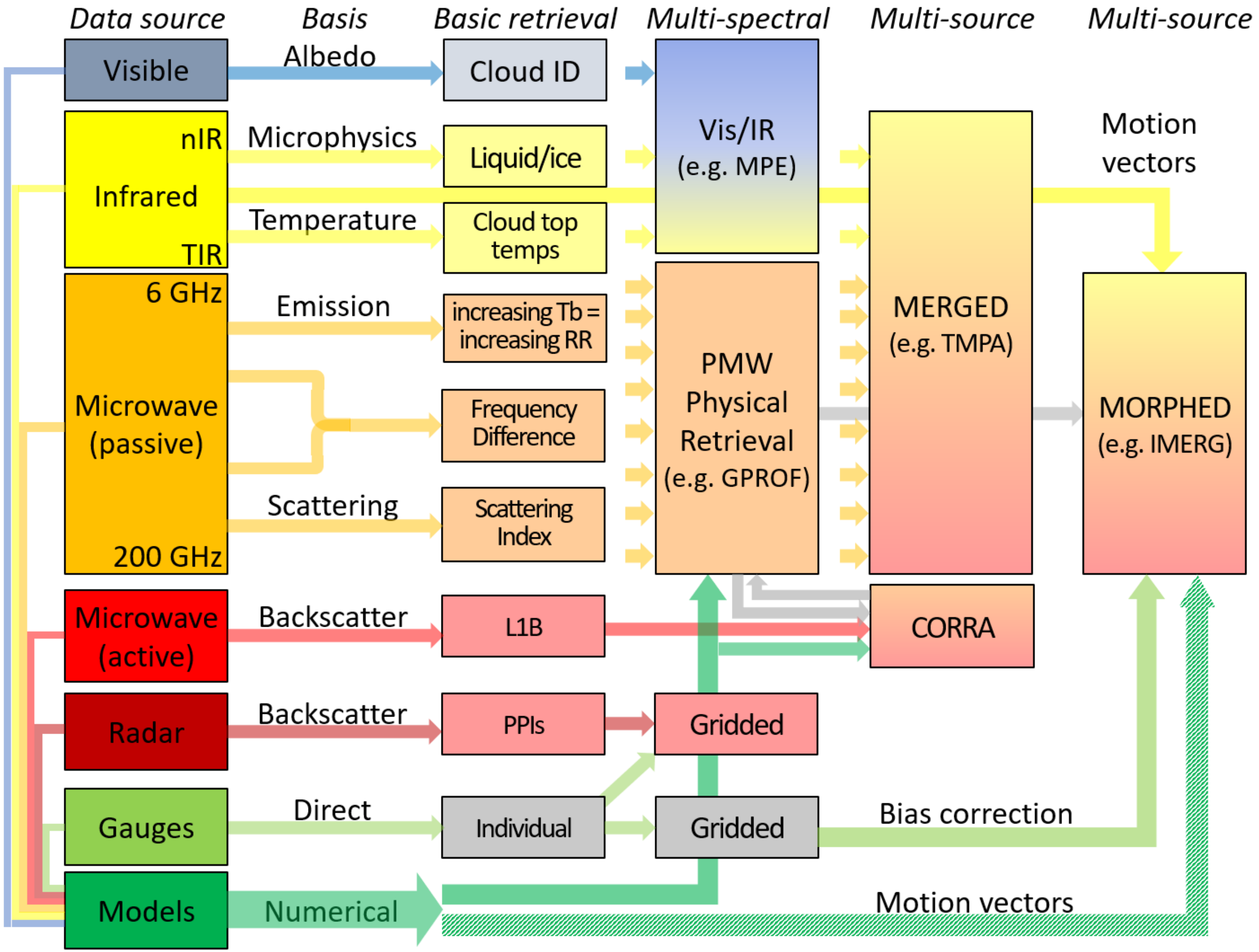
- is highly variable in time and space;
- has intensities heavily skewed towards zero;
- has characteristics that vary by location.







Satellite precipitation estimation



Retrieval precipitation from satellite observations is complex:

Very variable over time and space – good sampling is essential;

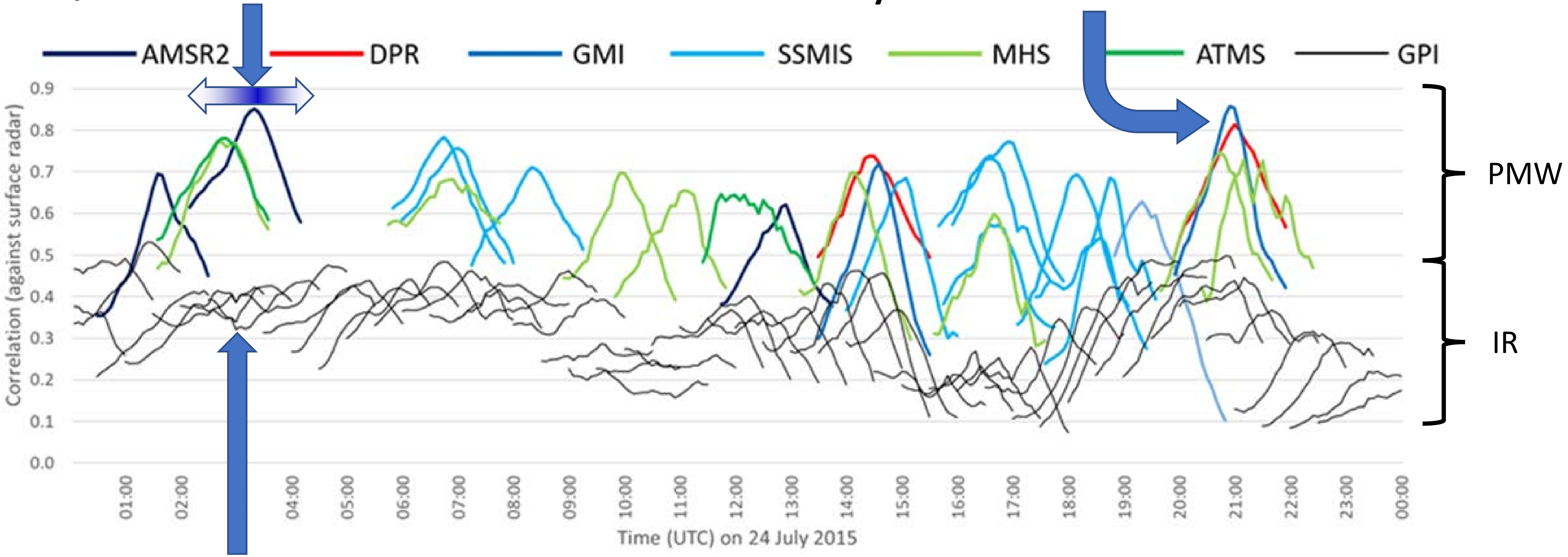
Range of precipitation properties and characteristics is large (cloud, rainfall, snowfall, hail).

Requires a multi-spectral, multi-satellite, multi-sensor approach

Temporal sampling of precipitation

Satellite:surface correlations peak at time of observation

correlations decline markedly away from time of observation



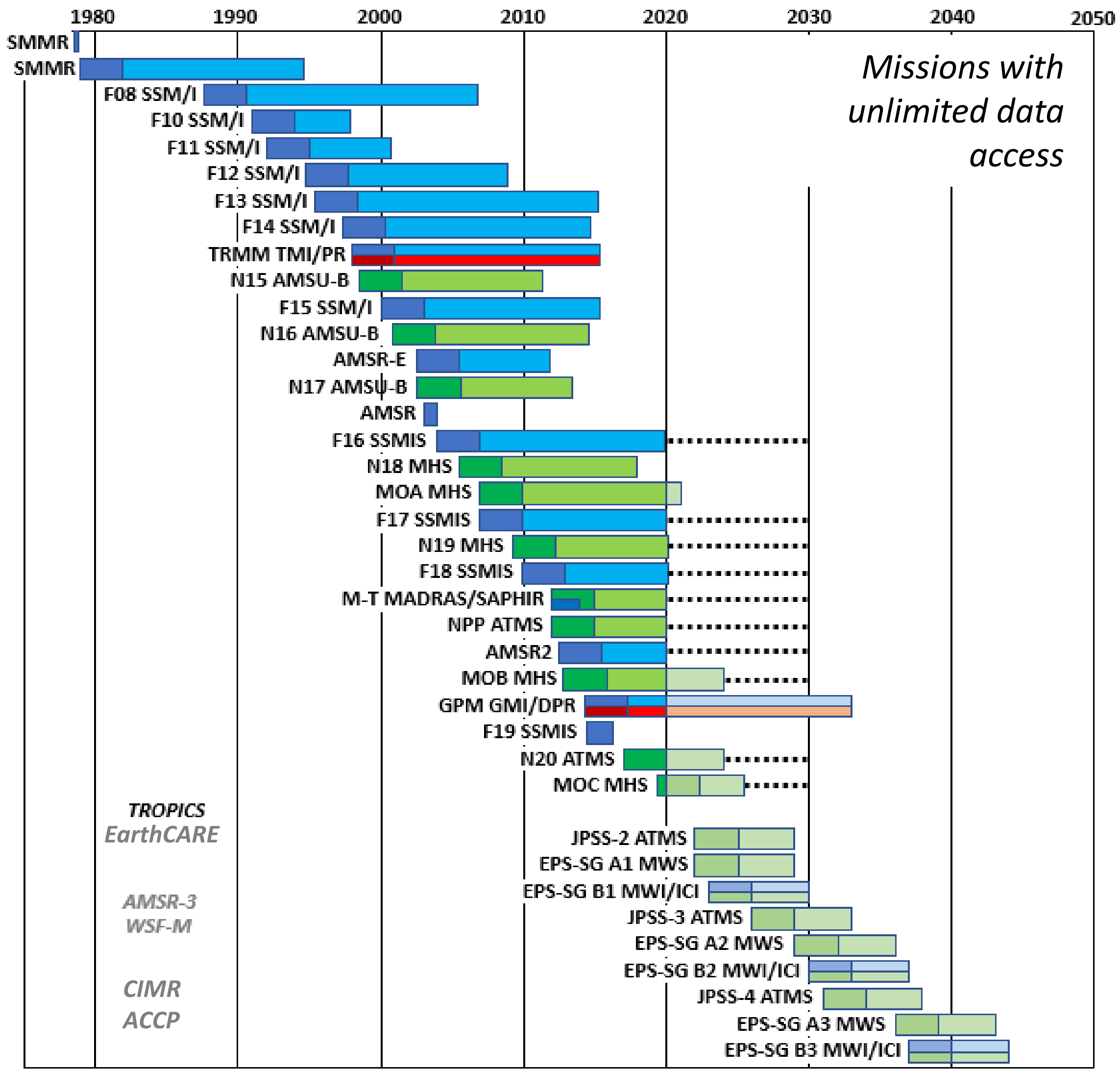
IR-only retrievals never match those of the PMW

Sufficient temporal sampling required to capture the variability of precipitation

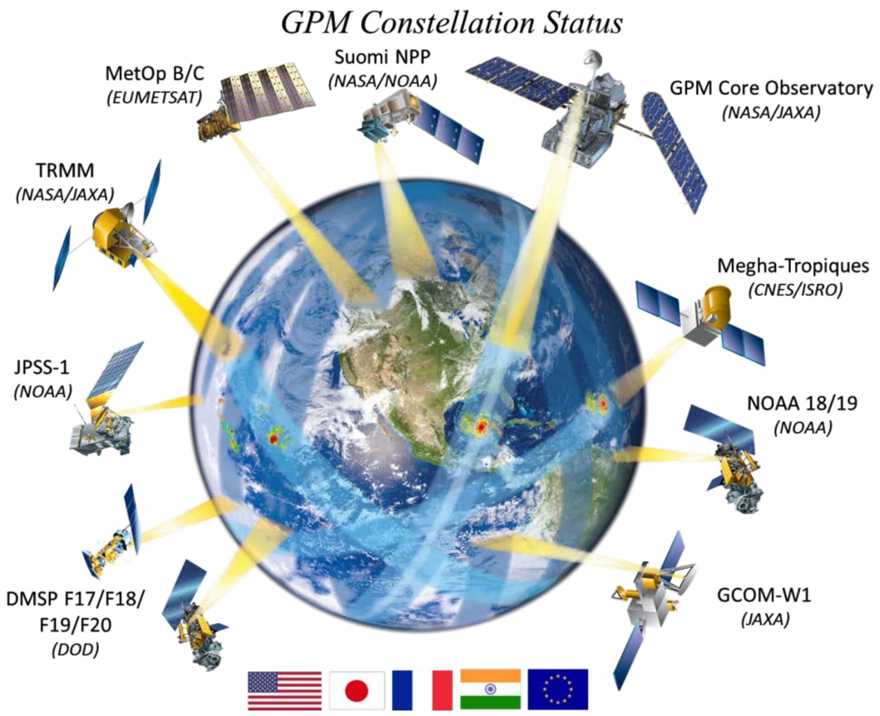
Satellite Precipitation Heritage

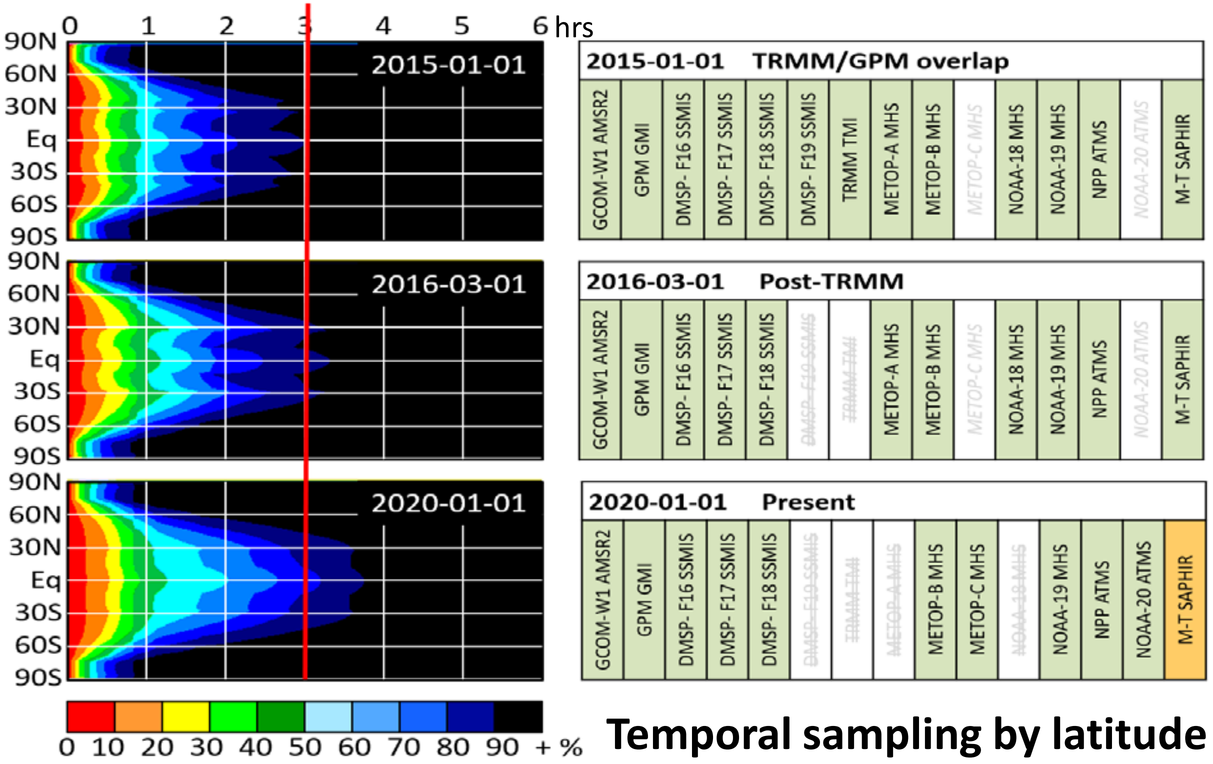
- First imaging meteorological satellite – TIROS-1 (1960)
- Relatively long history of precipitation-capable missions with ESMR-5/6 (1972/5), SMMR (1978), SSMI (1987)
- Only two precipitation-specific missions, TRMM (1997-2015) and GPM (2014-)

The precipitation science community has become very adept at adopting and utilizing a range of satellite observations to provide the necessary (temporal and spatial) products to meet user requirements.



GPM constellation: 2015-present





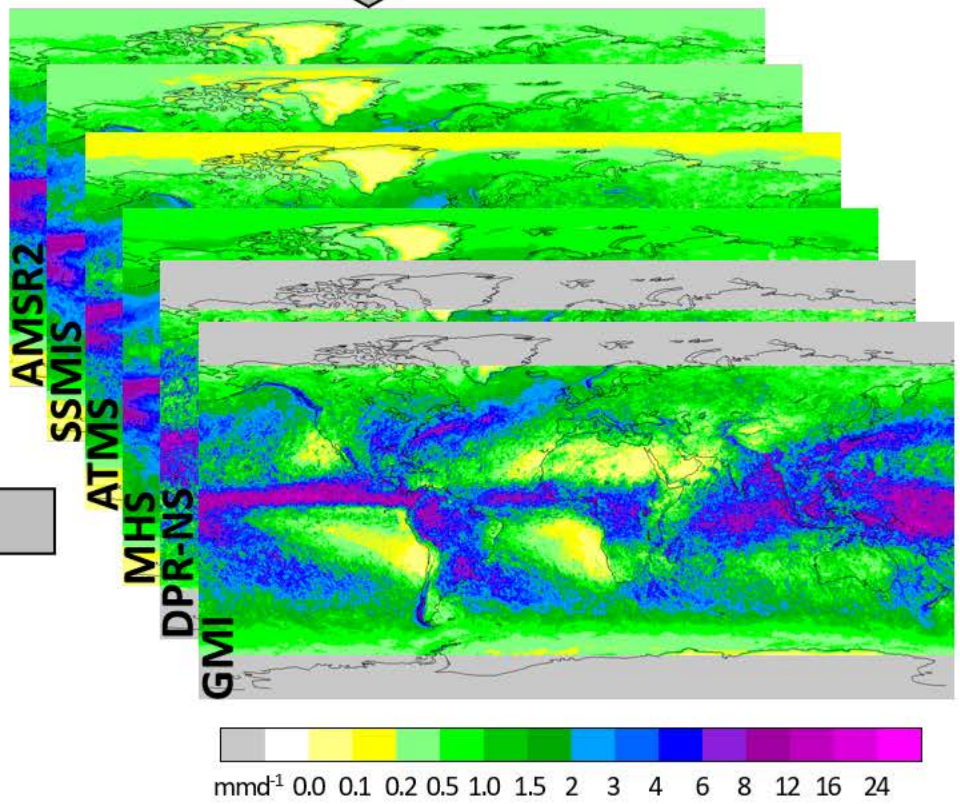
- GPM currently has about 12 precipitation-capable satellites, comprised of passive microwave imagers and sounders as well as a precipitation radar;
- Baseline sampling goal is 3-hourly 90% of the time, but has degraded over last 5 years;
- Combined with geostationary IR data allows 30-min, 10-km products to be generated.

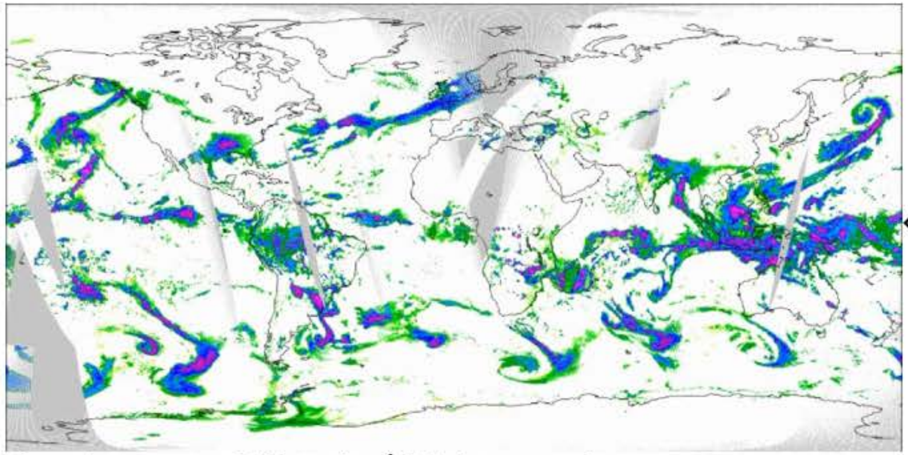
Measuring Global Precipitation

Exploiting multi-satellite, multi-sensor retrievals

Instantaneous snaphots of precipitation

Consistent retrieval scheme across all sensors



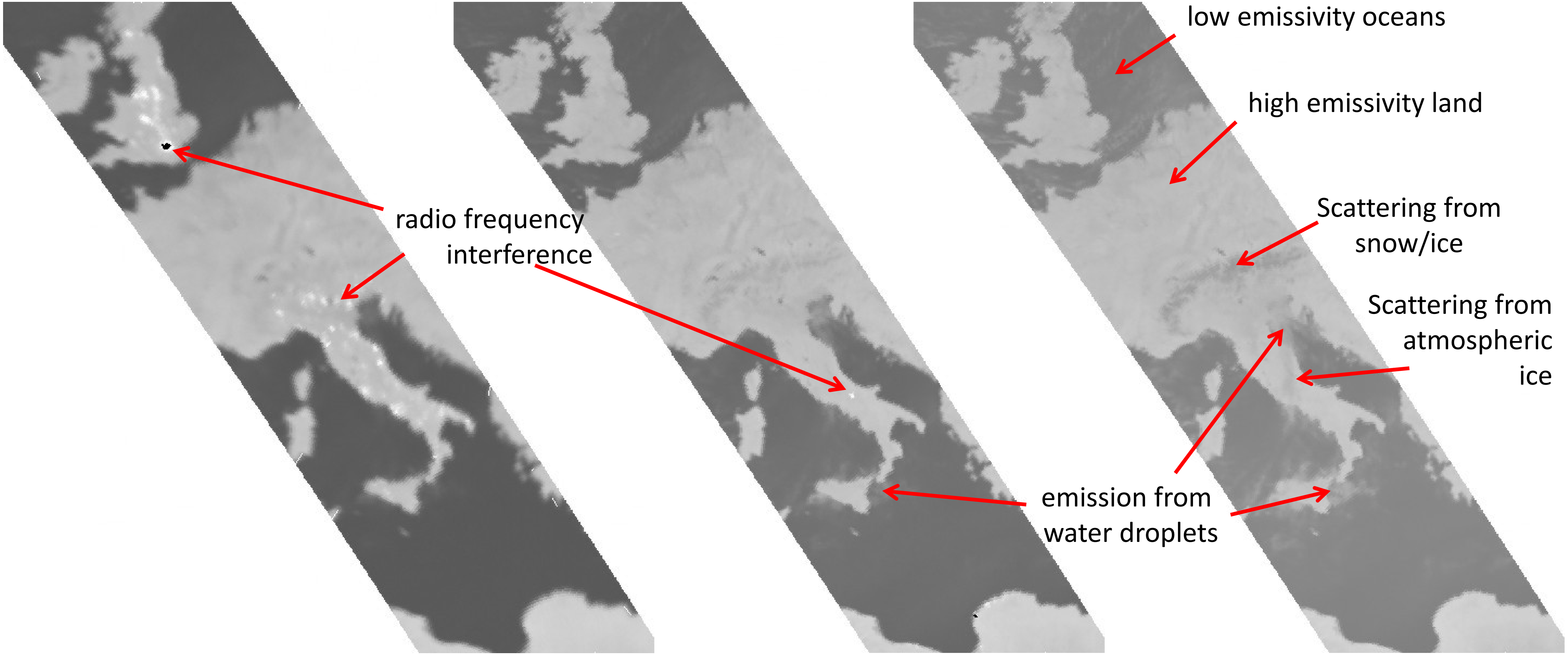


Products at 30-min/10-km or better

Passive Microwave sensor characteristics

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

Low frequency GMI channels – generally emission

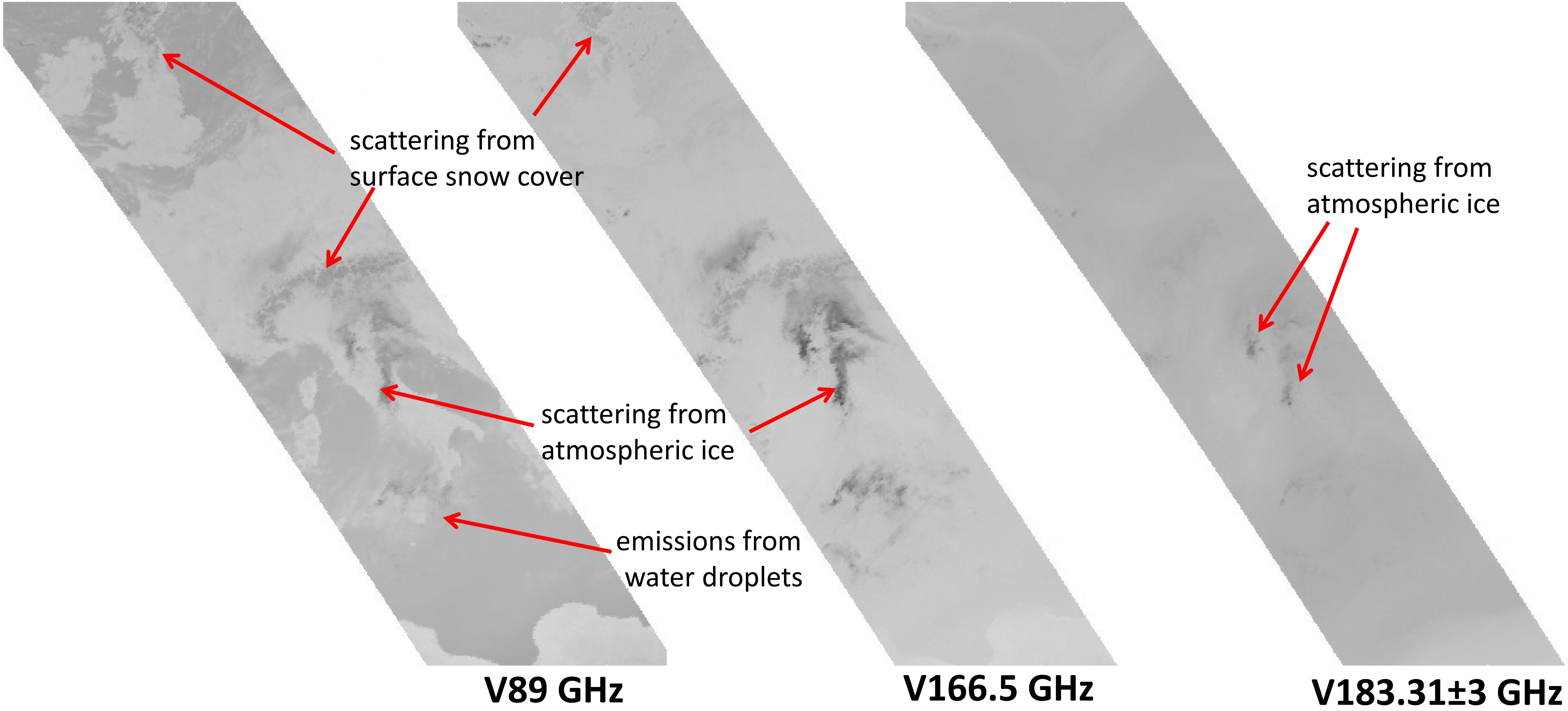


10.65 GHz

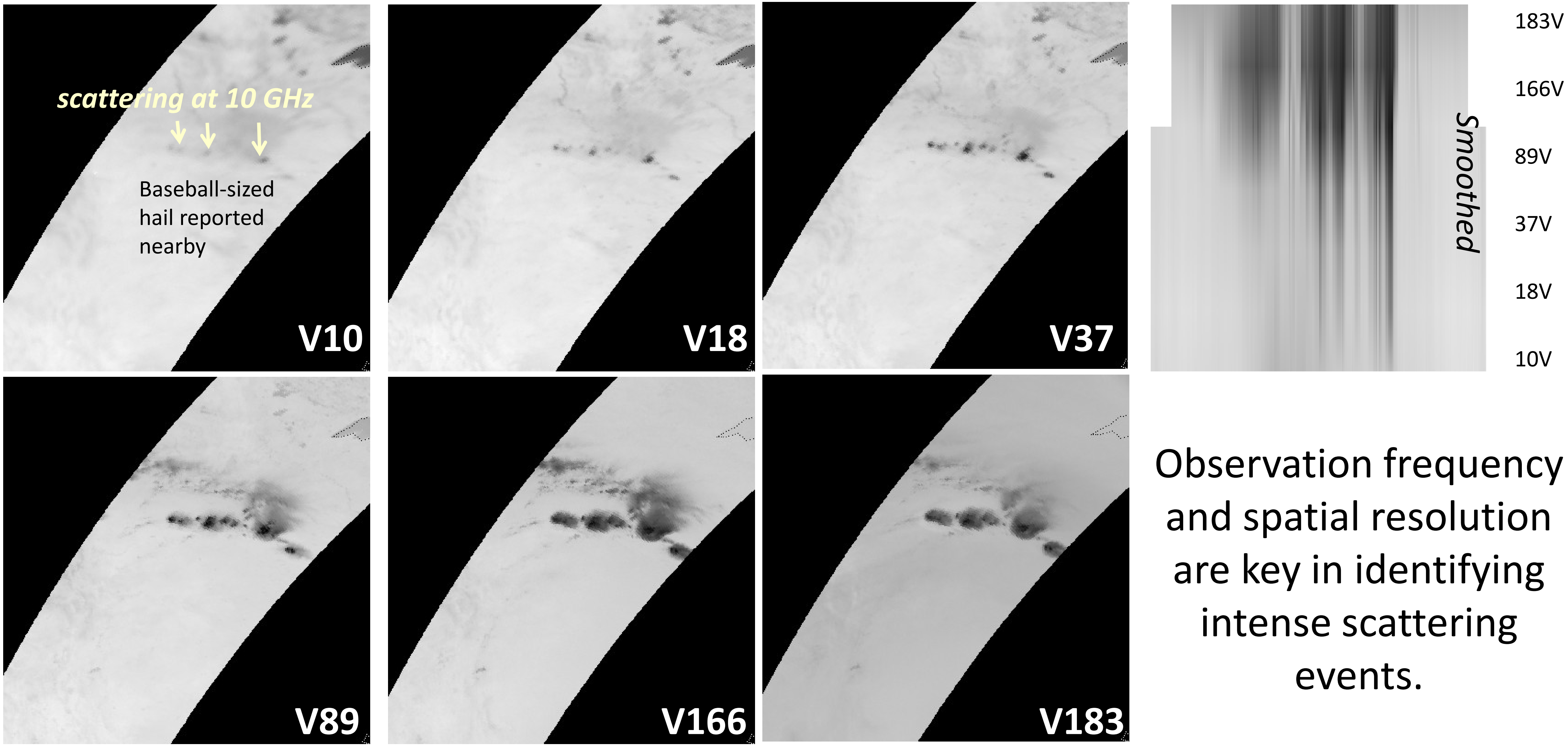
18.7 GHz

36.5 GHz

High frequency GMI channels – generally scattering



Low frequency scattering – GMI 20140603-S205848 Nebraska



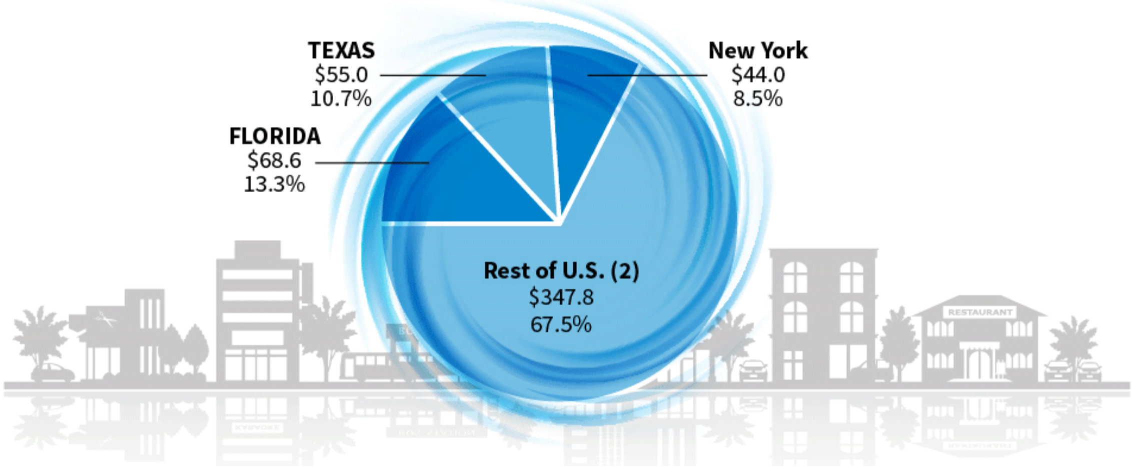
Observation frequency and spatial resolution are key in identifying intense scattering events.

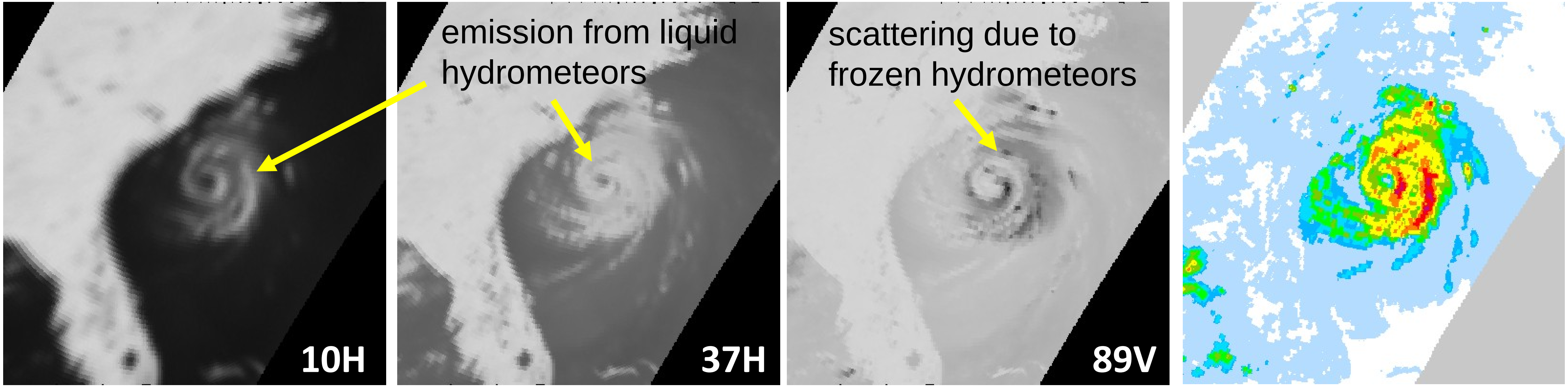
HURRICANES: Catastrophic Losses

Insured Losses, 1986-2015, Adjusted for Inflation

Total $515.4 billion

Source: Insurance Institute





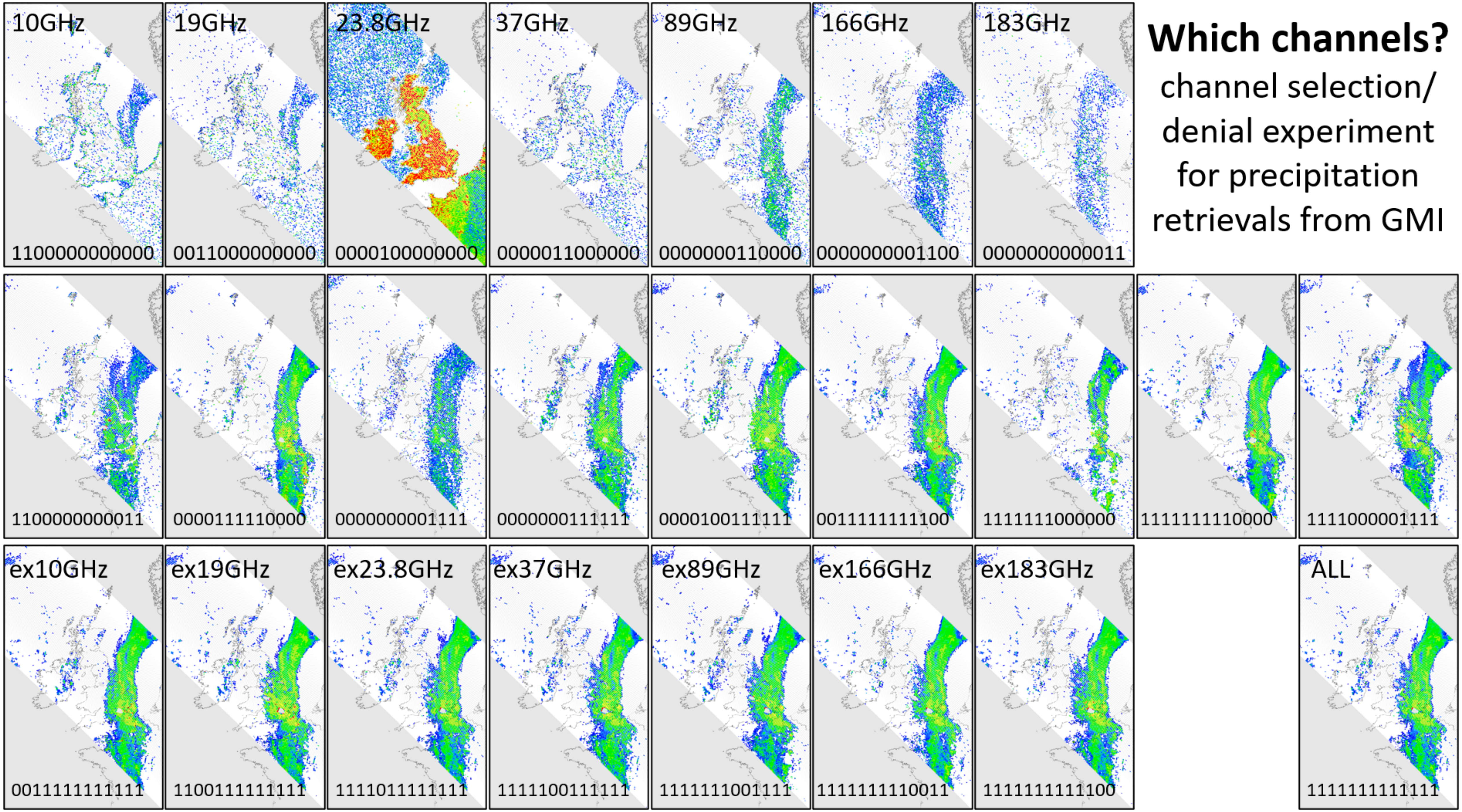
GMI 3 July2014 at 11:38Z

Hurricane Arthur Category 2 storm

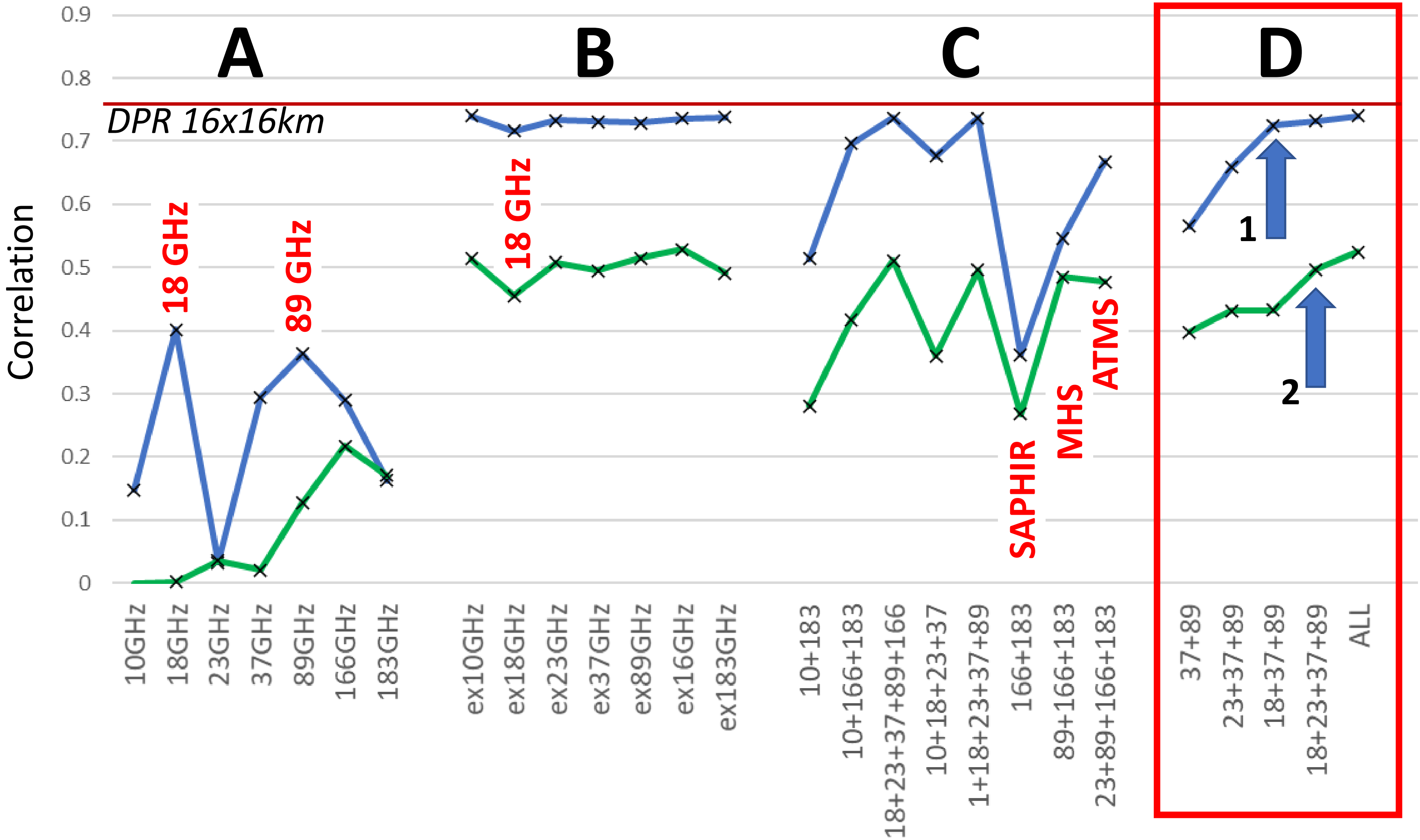
GPROF2014 retrieval

Which channels?

channel selection/ denial experiment for precipitation retrievals from GMI



Channel combination performance: Correlation



- Channel combinations of GMI observations
- GMI:DPR database
- Closest observation: database entry
- Validation against UK radar network

[1]*Over ocean* the 18+37+89 combination is nearly as good as all channels (10-183 GHz)
[2]*Over land* the addition of the 23 GHz channel improves the 18+37+89 combination.

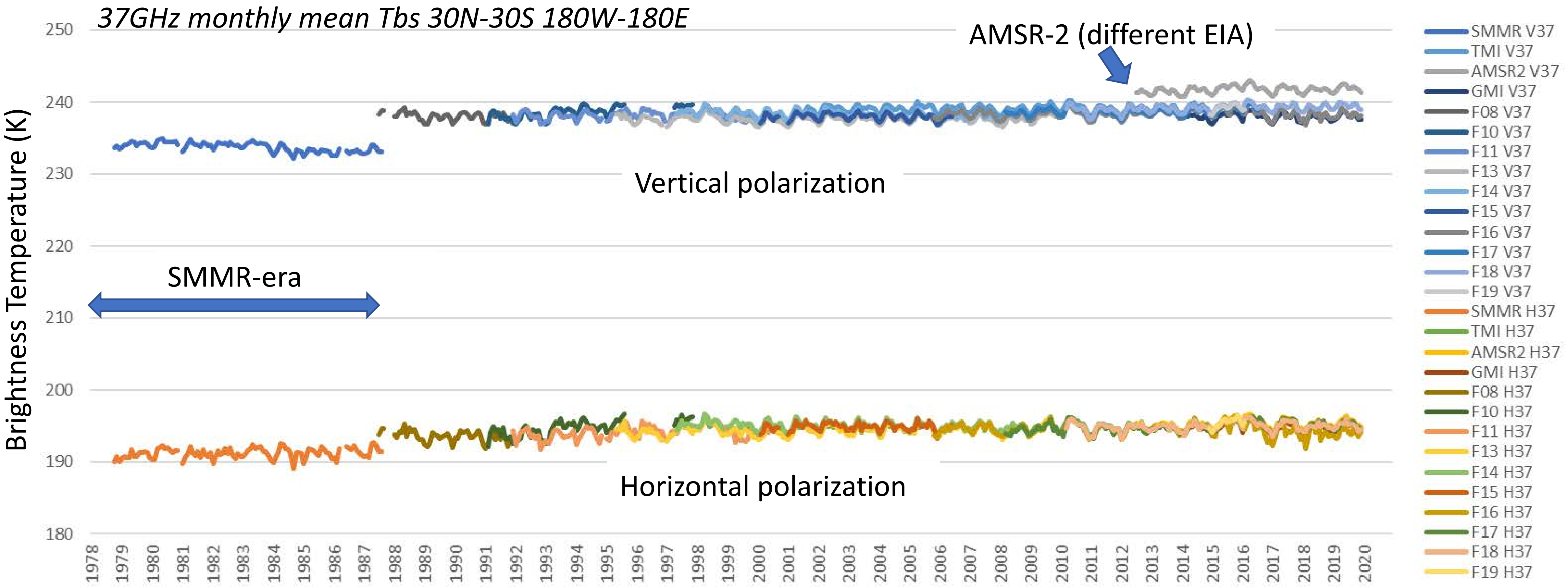
Brightness Temperature Data Records

Satellite data records for the passive microwave now span over 40 years. Satellite observations are now:

- delivered in very near real time (e.g. GPM, within 30 minutes of observation), for near real time retrieval of geophysical parameters for applications including emergency planning;
- processed for high-quality research-grade data for long-term ‘climate-scale’ retrievals for monitoring and assessing changes in the Earth System;
- provide an accuracy to within a few $^{1}/_{10}$’s K – necessary to meet the exacting requirements of climate-scale applications and studies.

Long term stability is crucial

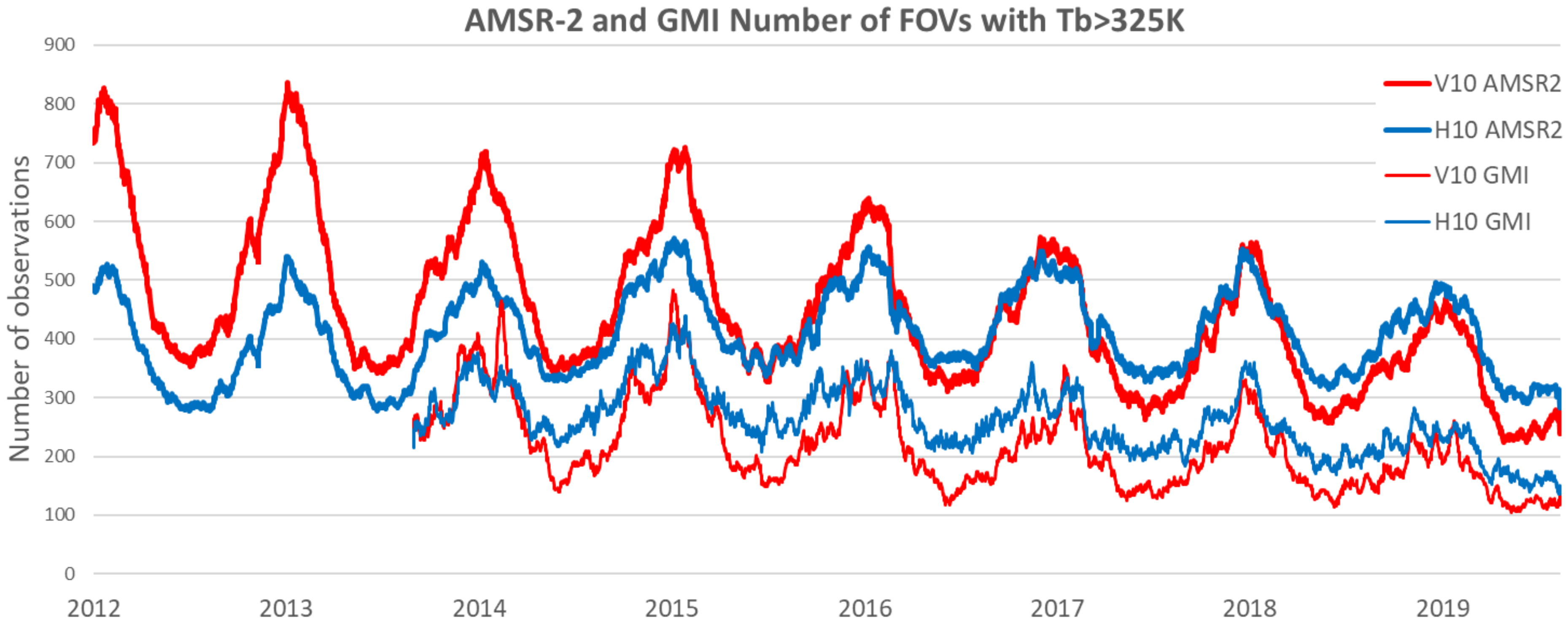
Brightness Temperature Climate Data Records



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

Passive Microwave Radio Frequency Interference

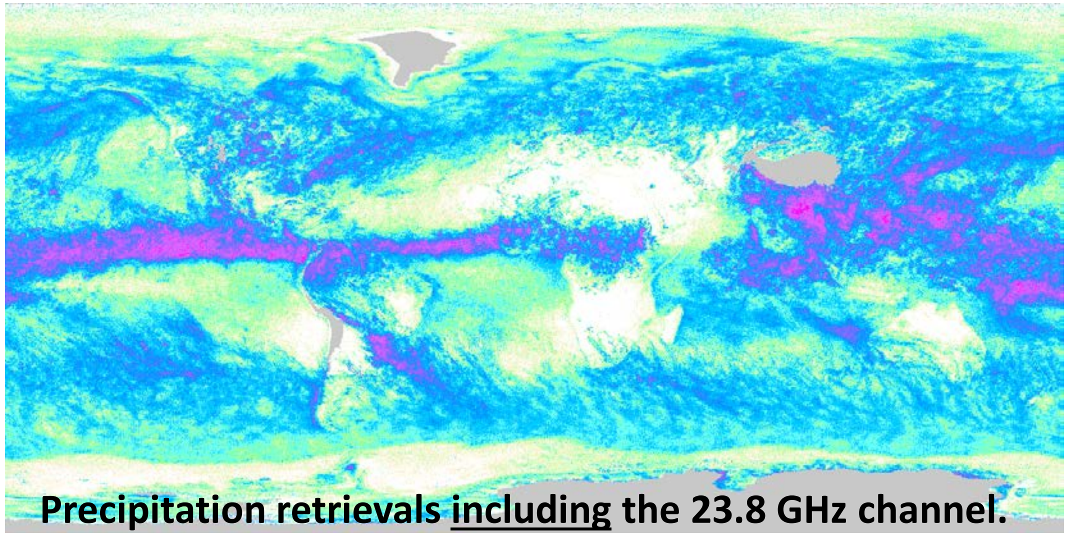
RFI has been a problem at the lower frequency channels of 6.9 and 10.65 GHz and is an increasing problem at 18.7 GHz: some are improving, some not. Both AMSR-2 and GMI are observing fewer Tbs>325K on a global scale.



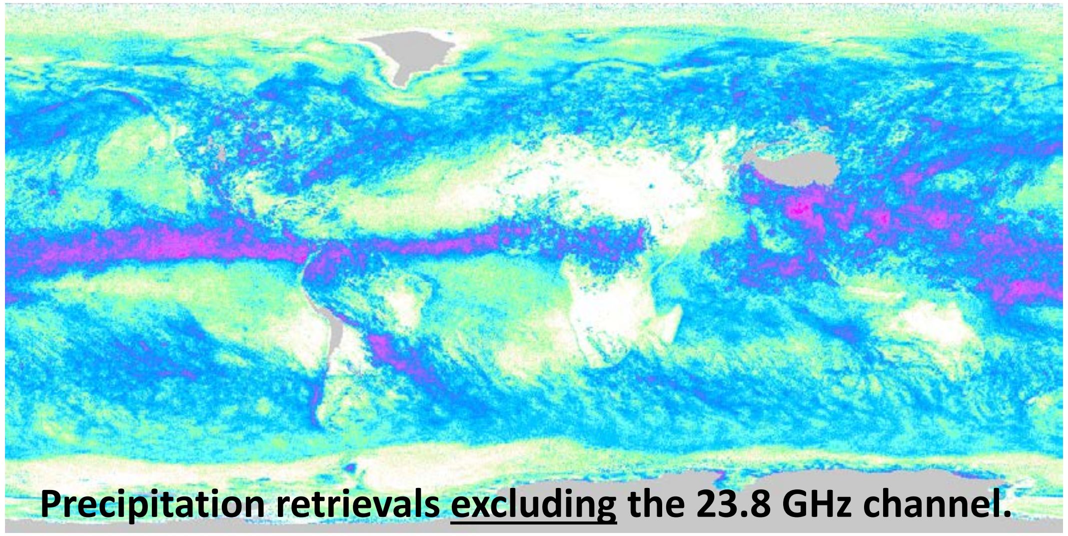
Addressing interference is crucial when dealing with climate-scale records.

Contributions by the 23.8 GHz channel to precipitation

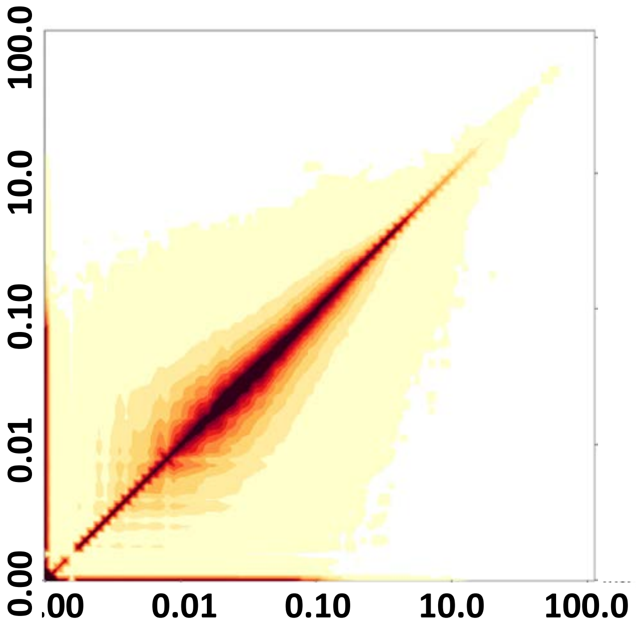
NOAA NPP ATMS sensor July 2015



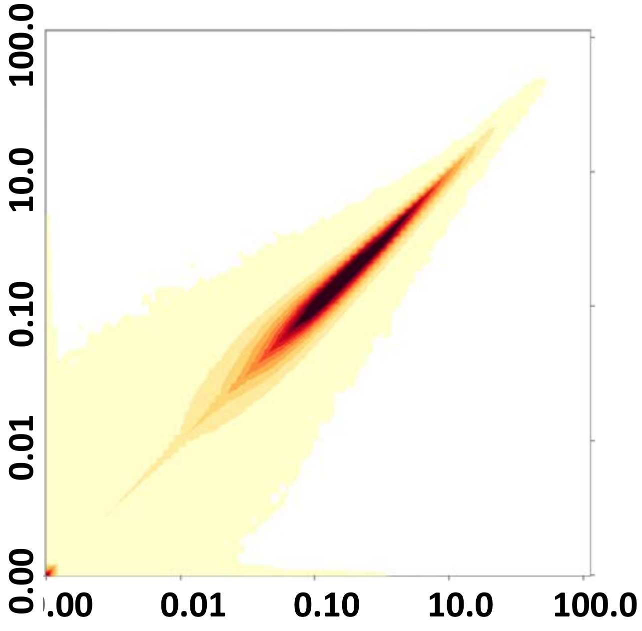
Precipitation retrievals including the 23.8 GHz channel.



Precipitation retrievals excluding the 23.8 GHz channel.



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



Monthly precipitation totals with/without the 23.8 GHz channel. (NOAA NPP ATMS, July 2015).

Differences are often subtle: 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. In the context of the GPM constellation, this would equate to a loss of more than 4 (out of 11) satellites.

Conclusions

Many geophysical variables can be retrieved from PMW observations:

- Sea ice extent, concentration and age; surface snow extent and type;
- Sea surface temperature, wind speed and direction;
- Precipitation, liquid water, clouds, water vapour;
- Soil moisture, vegetation, surface temperature.

Crucially,

- Retrieval schemes utilise all available channels – but rely heavily upon the 'core' mid-range frequencies;
- Multi-frequency observations are needed to provide robust retrievals;
- For climate-scale records accuracy is paramount, both in the original brightness temperature climate data record and in the retrieved products.