Estimating precipitation from surface and satellite systems: managing expectations

Chris Kidd

University of Maryland/Earth System Interdisciplinary Center and NASA/Goddard Space Flight Center

GPCP AIP-3 Shinfield Park c.1993

Outline

- What is precipitation?
- Satellite sensing of precipitation
- Surface observations of precipitation
- Precipitation retrieval schemes
- Validation of precipitation estimates
- Inter-comparison of precipitation estimates
- Latest inter-comparisons: GPM constellation

What is precipitation?

Precipitation is usually defined as the liquid (or equivalent) falling on a unit area over time from the atmosphere

Gauge measurements usually include surface-generated liquid, such as dew, frost and condensation

- Precipitation varies greatly temporally and spatially; the variability is regionally dependent *(e.g. 'hydrological climax')*

- Different users have different expectations; moisture budgets, water resources, civil defence, etc.

Satellite Sensing of Precipitation

Observational capability - ability of a sensor to observe precipitation

- wavelength/frequency
- resolution (usually horizontal/spatial)
- sensitivity

Retrieval capability - ability of a scheme to 'convert' observations into precipitation estimates

- simple empirical observation-rainrate relationships
- multi-channel/multi-sensor retrievals
- radiative transfer-based relationships
- *Complexity not necessarily better*

Observation Capability

Frequency/wavelength:

- Visible/infrared
  - cloud delineation, cloud top properties
  - resolutions typically ~1 km (5 m – 4 km)
- Passive microwave imagers/sounders
  - ~6–190 GHz
  - imagers=transparent, sounders=opaque
  - resolutions ~5–70 km, frequency/scan dependent
- Active microwave
  - 13, 35, 94 GHz
  - resolutions ~ 1-5 km

Retrieval capability

- Sensitivity of channel(s) to phenomenon requiring to be measured
- Availability of multiple channels
- Provision of external information

- Data availability (observations, sensors…)
- Latency (observation→delivery)
- Application (hydrology, meteorology, severe storms…)
- Complexity (computing/data resources)

Surface Observations of Precipitation

Rain/snow gauges

- point-based spatial sampling
- temporal or quantised sampling

Types: drop counters; accumulation gauges; size/design

Weather radar

- spatial/volume sampling
- instantaneous observations

Types: scanning, vertically-pointing; measurement frequency

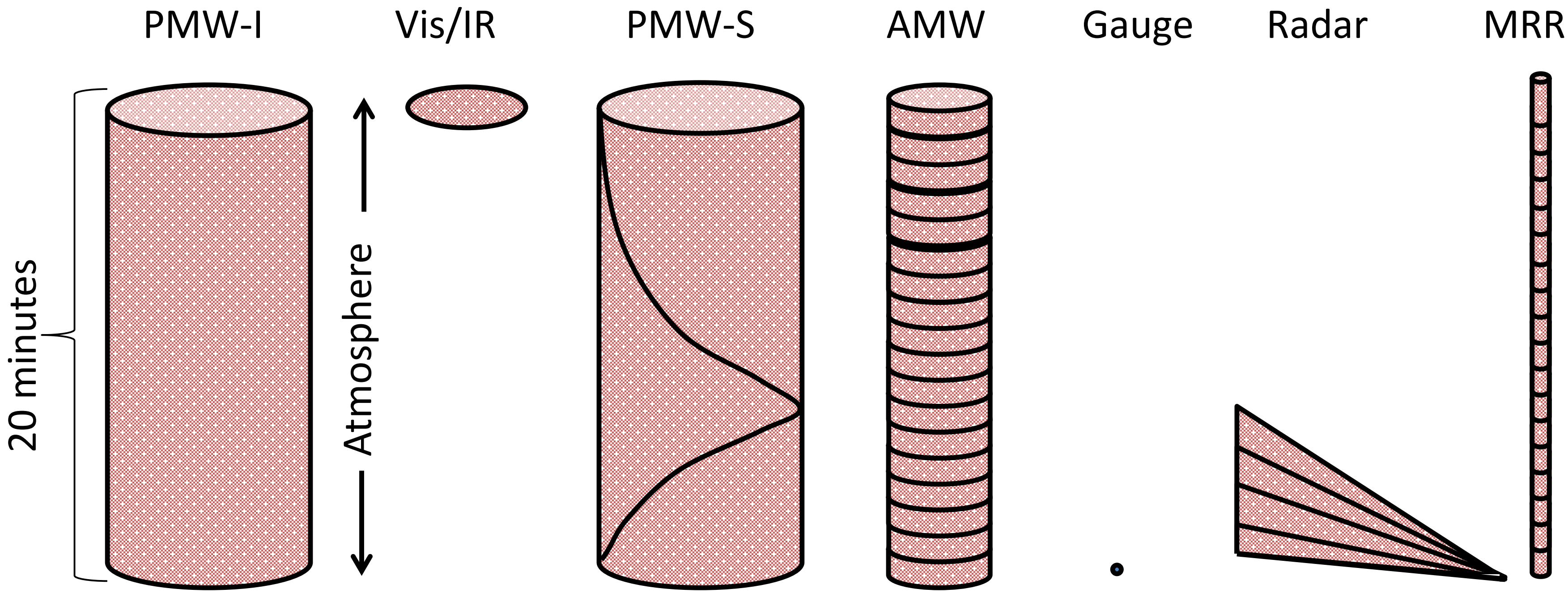
Microwave links

'line of sight' observations, ~15 minute samples

Surface & Satellite Observing Systems

	Instrument	Temporal	Spatial	Notes
Surface	Gauges: accumulation	Variable	Point	Temporal scale dependent upon observation frequency
	Gauges: Tipping Bucket	Quantised	Point	Quantisation of bucket (0.1 or 0.2 mm or 1/100”) and data logger
	Distrometers	Instantaneous	Point	Individual drop measurements
	Micro rain radar	Instantaneous	Point	30 vertical levels
	Weather radar	Instantaneous	Radial	Radial measurements of dBZ converted to a Cartesian grid
Satellite	Visible imagery	Instantaneous	1-4 km	Intermittent (LEO) 15 min sampling (GEO)
	Infrared imagery	Instantaneous	1-4 km	Intermittent (LEO) 15 min sampling (GEO)
	Passive Microwave Imagers	Column	5-25 km	Intermittent sampling (LEO) Resolution = frequency dependent
	Passive Microwave Sounders	Column	16-48 km	Intermittent sampling (LEO) Resolution = frequency/scan position depen.
	Active Microwave (radar)	Instantaneous	5 km	80 vertical levels; Intermittent sampling (LEO)

Surface & Satellite Observing Systems



Different systems observe things differently – spatially, temporally and physically

Validation of precipitation products

Different measuring techniques will inevitably provide different measures:

- Gauges – ‘surface’ precipitation
- Radar – backscatter from precipitation-sized particles
- Satellites – cloud tops, columnar or column-weighted

Observations/measurements will differ in quality:

- Accuracy of measurement
- ‘Noise’ (e.g. anaprop, blockage, RFI, etc)
- Mechanical and technical issues
- Quality control procedures

Statistics

Lies, damn lies, and statistics

- Fundamental time/space relationship impacts upon statistical performance
- User requirements (e.g. instantaneous, climatological…)
- Proper match-ups – temporally and spatially - critical in achieving good statistical measures

Common statistical metrics

- Bias
  Estimated - Observed
- Ratio
  Estimated/observed
- RMSE
  sqrt(estimates-observed)^2
- Correlation
  e.g. Pearsons

- Rainrate dependent
- Retrievals should have zero bias w.r.t. calibration data
- Superfluous in bias-correction techniques

- Rainrate dependent
- Somewhat superfluous in bias-correction techniques

- Affected by spatial patterns and dynamic range of rainrates; instantaneous different to daily/monthly

Categorical statistics

Based upon RR/NRR/RNR/NRNR counts

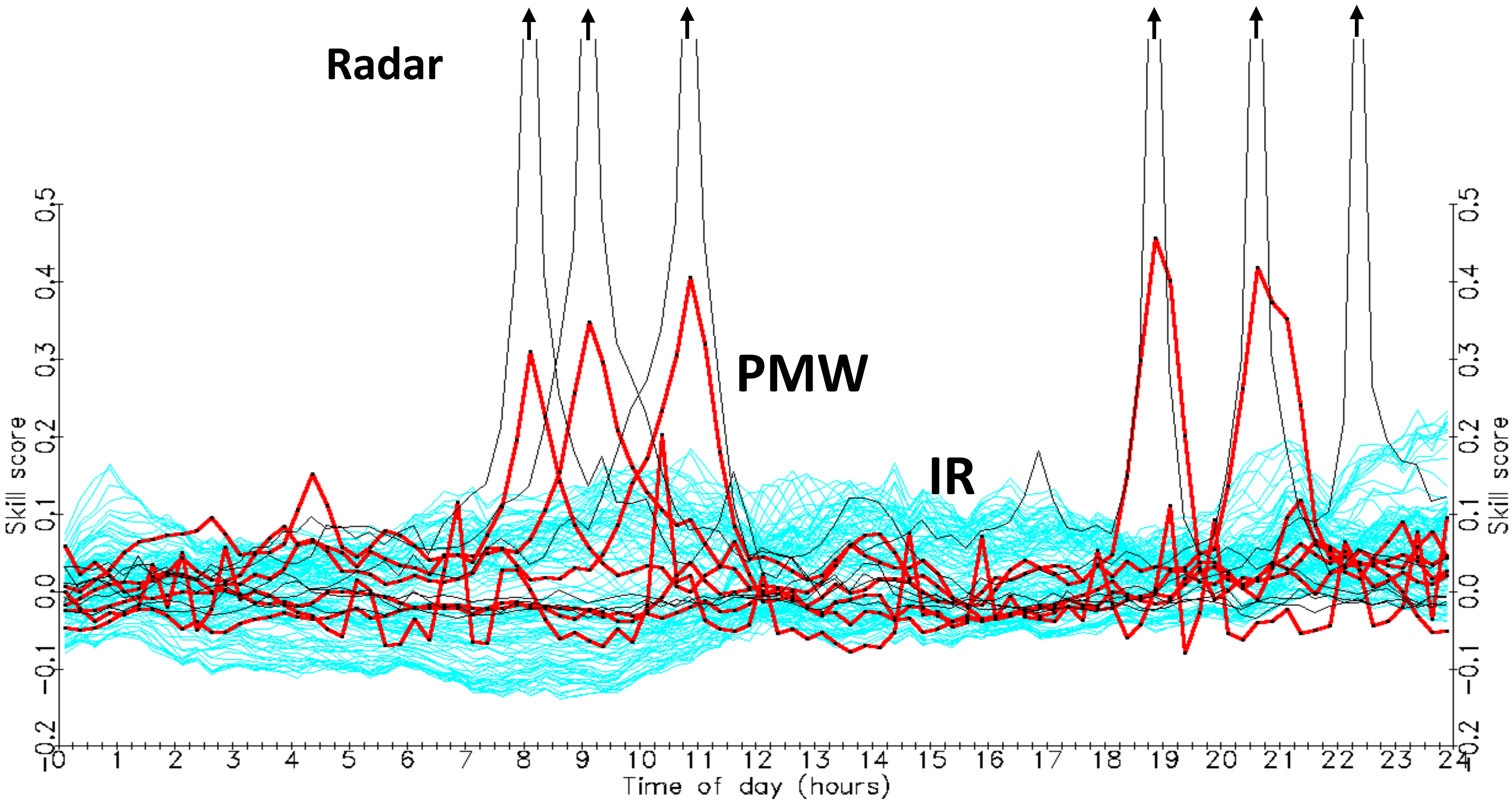
- **Probability of Detection (POD)**
- **False Alarm Ratio (Rate) (FAR)**

  Both affected by rain occurrence, form (area) of precipitation, geolocation issues
- **Skill Score (SS)**

  variable thresholds can be used to determine intensity skill scores; but same issues as POD/FAR
- **Heidke Skill Score (HSS)**

  Similar to SS – but splits intensity into categories – either fixed groups, or dynamic by numbers in each group.

Time skill scores of rain retrievals



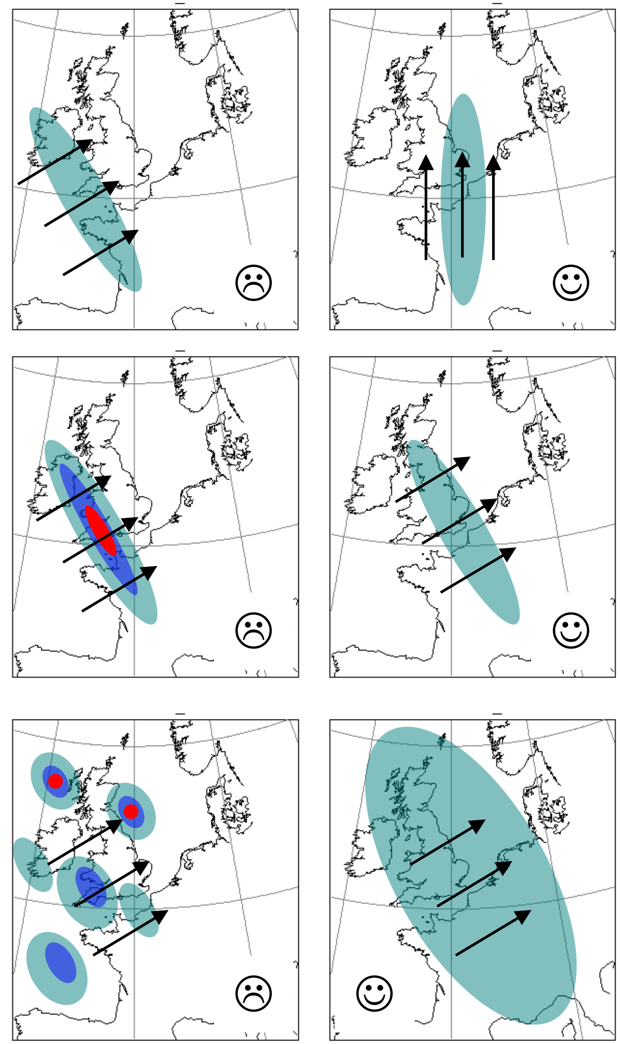
Statistical scores very dependent upon coincidence of observations

Statistics: *regime dependency*

Movement:
Is the movement perpendicular or along the rain band?

Intensity
What is the range of values within the rain area?

Size/variability
What is the size and variability of the rain area(s)?

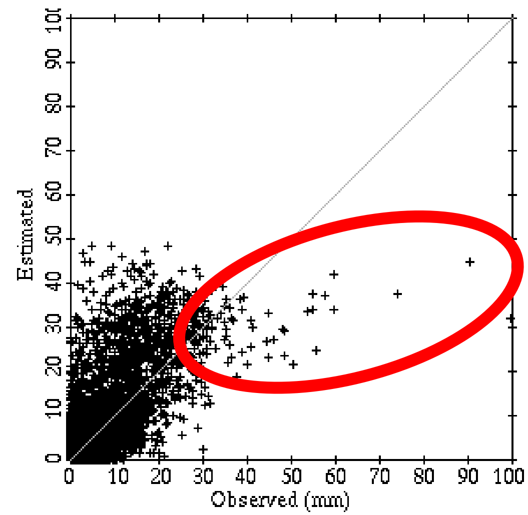


Statistical success has as much to do with meteorology as the algorithms ability…

Cross-comparison of satellite/surface

Spatial mapping of radar errors through comparison with satellite data sets

Not so much the ‘agreements’, but the disagreements



Through the generation of a contingency table of rain/no-rain and subsequent spatial mapping, errors can be identified.

Surface \ Satellite	R	NR
R	R:R	R:NR
NR	NR:R	NR:NR

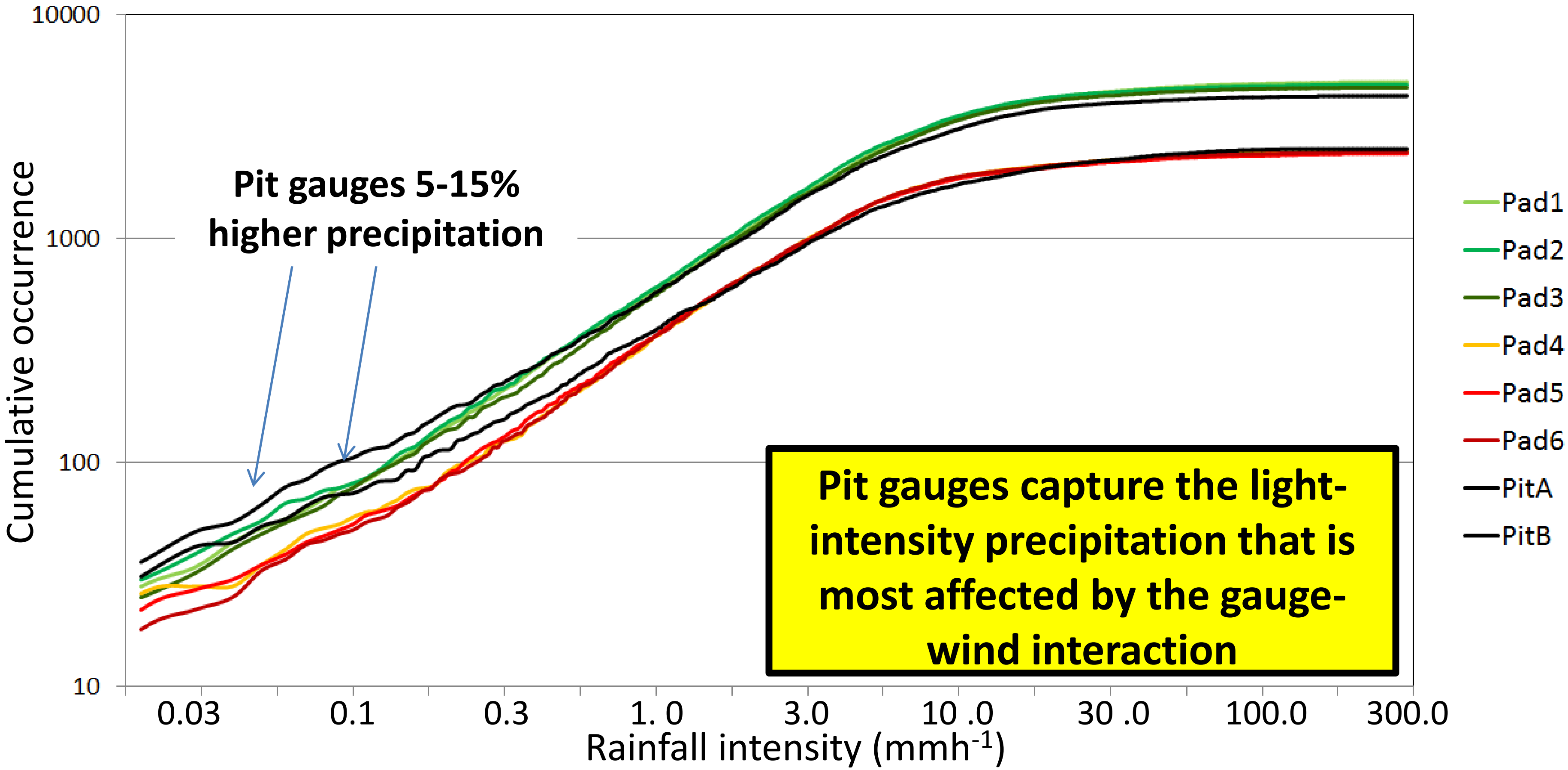
‘Improving’ results

- Spatial and temporal averaging greatly improves statistical performance (care needed in comparing different products)
- Temporal and spatial matching are essential to ensure similar quantities are being observed (e.g. column ≠ instantaneous measure)

Careful quality control of all data sets:

- Satellite products – surface background issues…
- Gauges – measurement at the ‘surface’…
- Radar – anaprop, beam blockage, beam elevation…

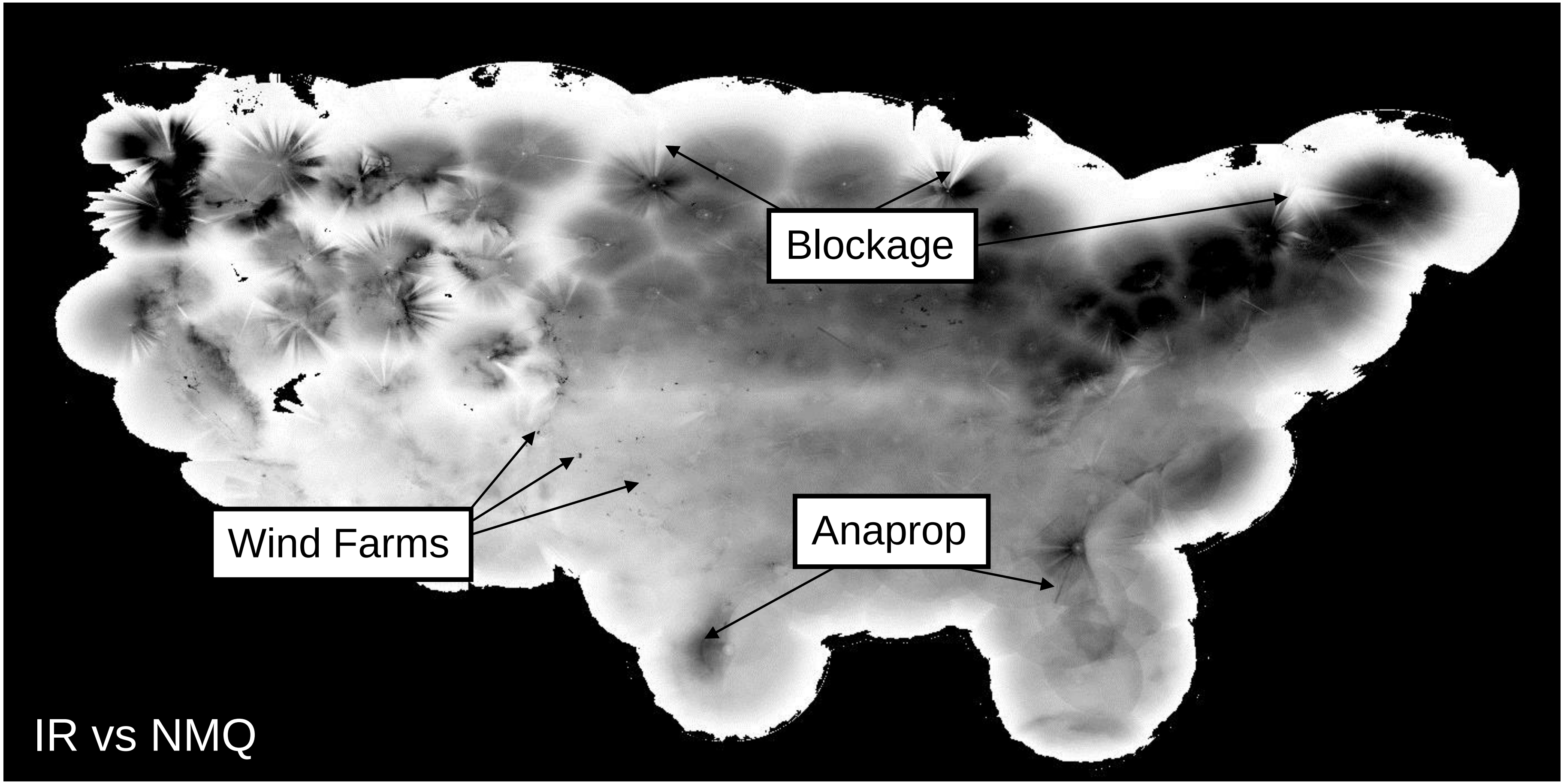
'Pad' vs 'Pit': Wallops gauges



Pit gauges capture the light-intensity precipitation that is most affected by the gauge-wind interaction

if you want to measure *surface precipitation*, it needs to be *measured at the surface*!

Radar artefacts



Thresholded IR data as a proxy for rain: radar over/under-estimation

User Impact

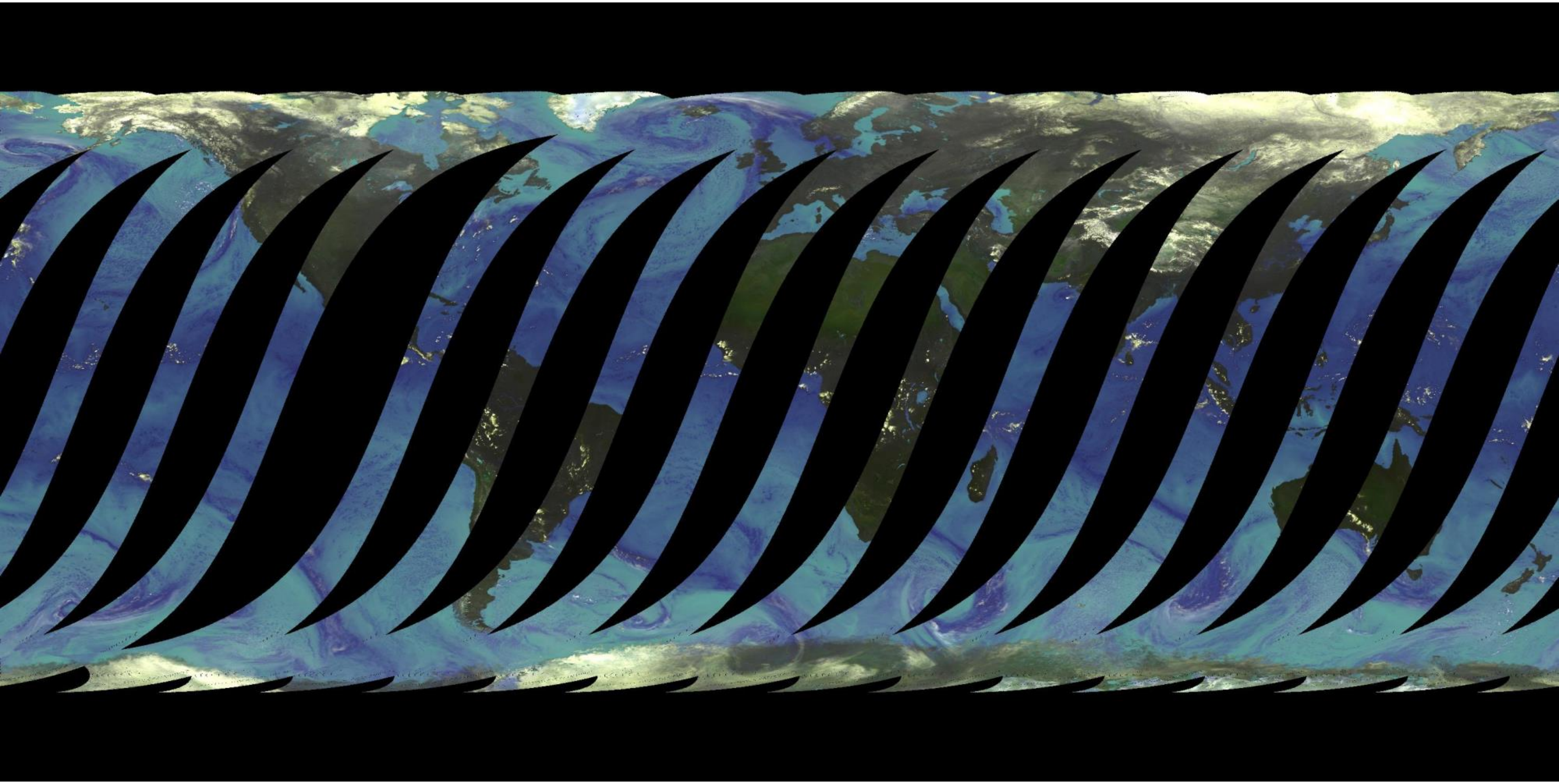
User requirements

- Often surface precipitation, vv atmospheric precipitation
- Latency vs accuracy
- Meteorology vs climatology
- Regional/global, surface type

E.g. hydrology:

- Amount falling within a given time *(sampling)*
- Basin morphology; shape, size, etc *(resolution)*
- Storm dynamics; inter-action of storm and basin characteristics (such as movement across a basin)

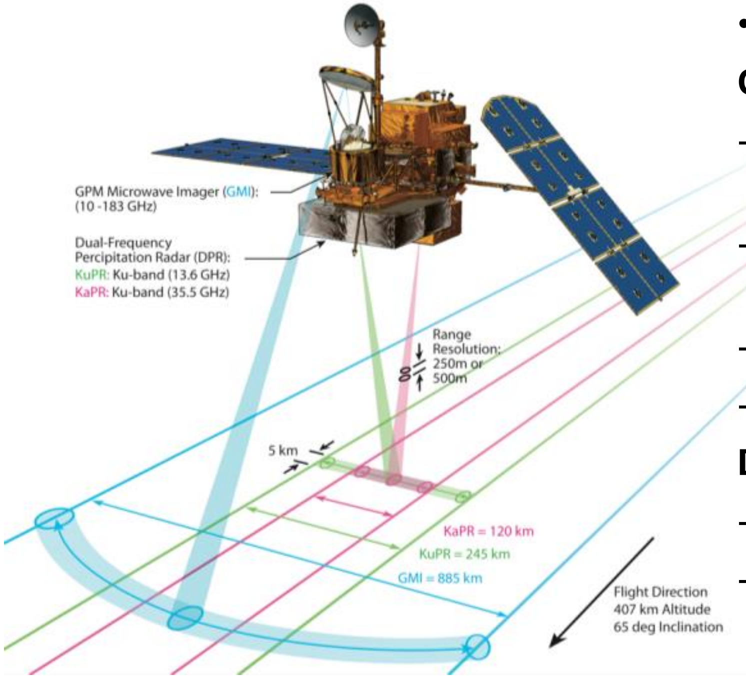
Latest results



31 October 2014

GPM extent 68N-68S vs *TRMM extent 38N-38S*

Core Observatory Geometry and Instruments



- Orbit: 407 km; 65 deg. inclination; 3-yr life, 5+ yr fuel

GPM Microwave Imager (GMI)

- passive microwave radiometer with hot and cold calibration, includes novel calibration engineering
- precipitation (rain and snow) intensity and distribution over wide swath (880 km)
- High spatial resolution (as fine as ~5 km footprints)
- 166 kg, 162 W, 34.9 kbs data,1.2 m ø reflector

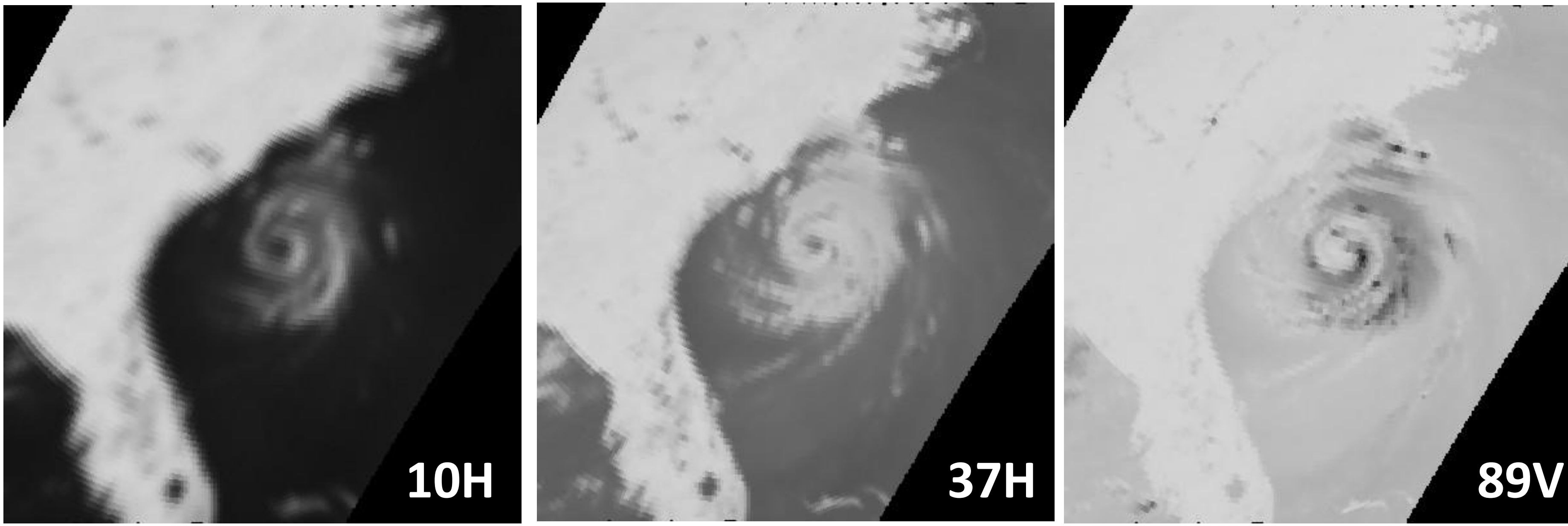
Dual-frequency Precipitation Radar (DPR)

- KuPR similar to TRMM, KaPR added for GPM
- 3D precipitation structure, particle size distribution (PSD), intensity and distribution
- High spatial resolution (5 km horizontal; 250 m vertical)

0.2-110 mmh^{-1} & snow

	KuPR	KaPR
Frequency	13.597, 13.603 GHz	35.547, 35.553 GHz
Min. detectable rainfall rate	0.5 mmh^{-1}	0.2 mmh^{-1}
Data Rate	< 109 kbps	< 81 kbps
Mass	< 472 kg	< 336 kg
Power Consumption	< 446 W	< 344 W
Size	2.5 × 2.4 × 0.6 m	1.2 × 1.4 × 0.7 m

GMI Frequencies	GMI Polarizations
10.65 GHz	V/H
18.7 GHz	V/H
23.8 GHz	V
36.5 GHz	V/H
89 GHz	V/H
166 GHz	V/H
183.31 GHz	Va/Vb (±3 & ±7)



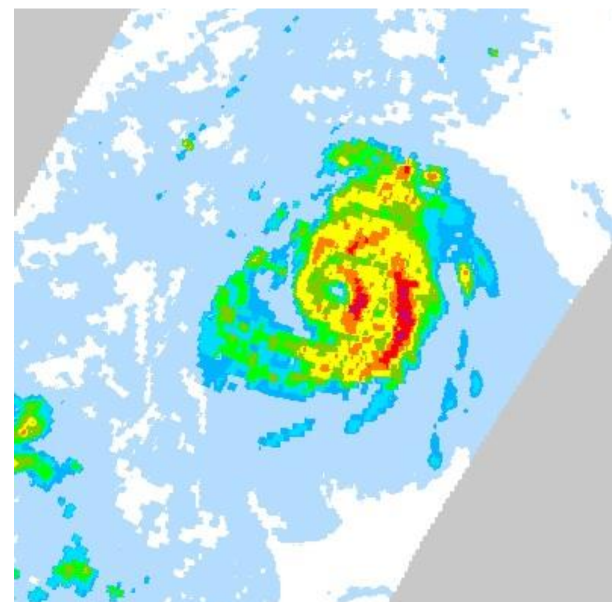
Hurricane Arthur

First Atlantic hurricane of 2014 season

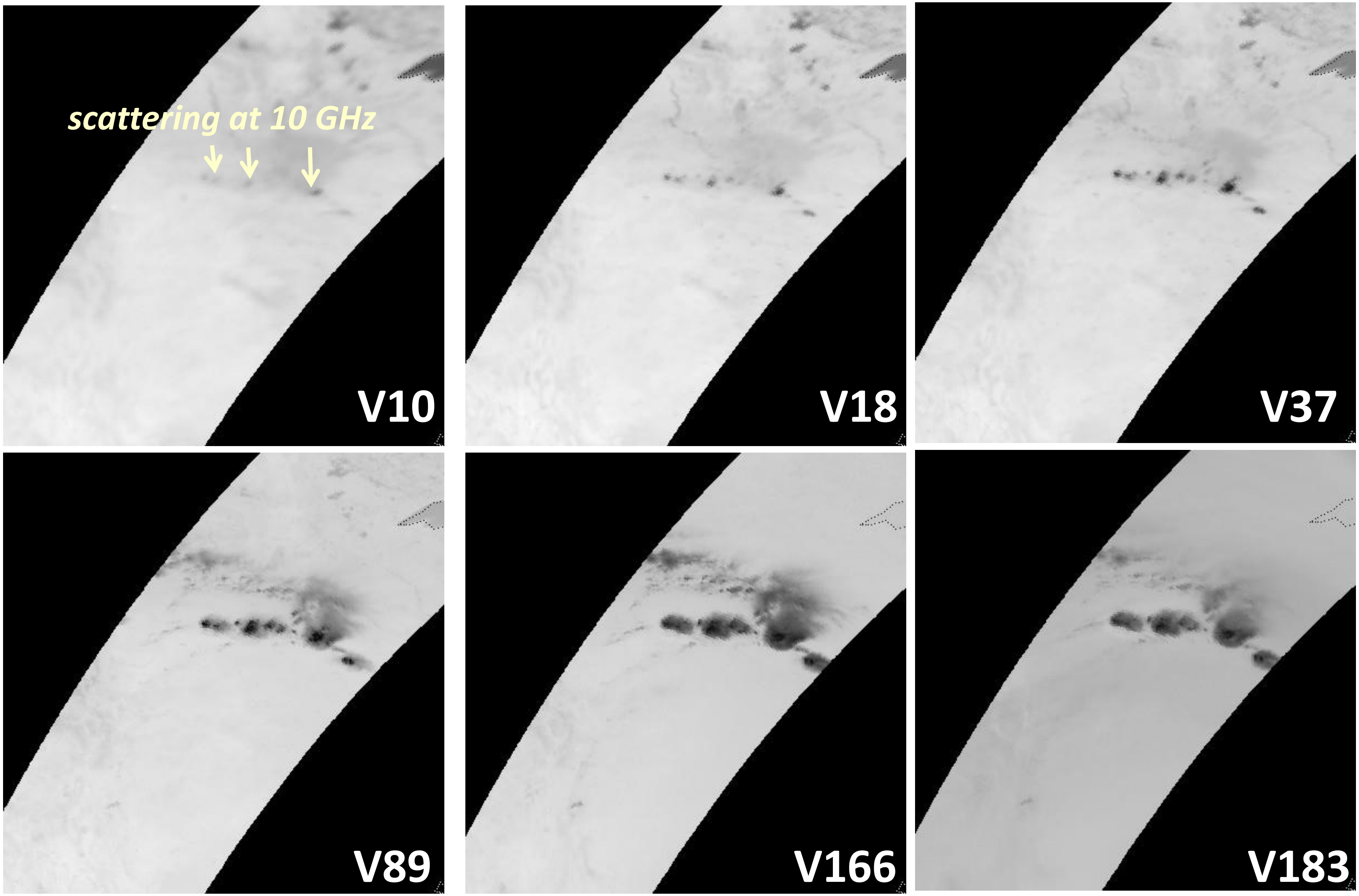
Category 2 storm

Captured by GMI on 3 July2014 at 11:38Z

GPROF2014 retrieval (right)



GMI – 20140603-S205848 Nebraska



Constellation sensors

Channel (GHz)	6-7	10	19	23	31-37	50-60	89-91	150-167	183-190
GMI		10.65 V&H	18.7 V&H	23.8 V	36.5 V&H		89.0 V&H	165.6 V&H	183.31 V (x2)
AMSR-2	6.925/7.3 V&H	10.65 V&H	18.7 V&H	23.8 V&H	36.5 V&H		89.0 V&H		
SSMIS *x3*			19.35 V&H	22.235 V	37.0 V&H	50.3-63.28 V&H	91.65 V&H	150 H	183.31 V (x2)
MADRAS			18.7 V&H	23.8 V	36.5 V&H		89.0 V&H	157 V&H	
MHS *x4*							89.0 V	157 V	183.31 (x2) 190.31
ATMS				23.8	31.4	50.3-55.5 (x7)	88.2	165.5	183.31 (x5)
SAPHIR									183.31 (x6)
GMI		26	15	12	11		6	6	6
AMSR-2	65/58	42	22	26	12		5		
SSMIS			59	59	36	22	14	14	14
MADRAS			40	40	40		10	6	
MHS							17n	17n	17n
ATMS				74n	74n	32n	16n	16n	16n
SAPHIR									10n

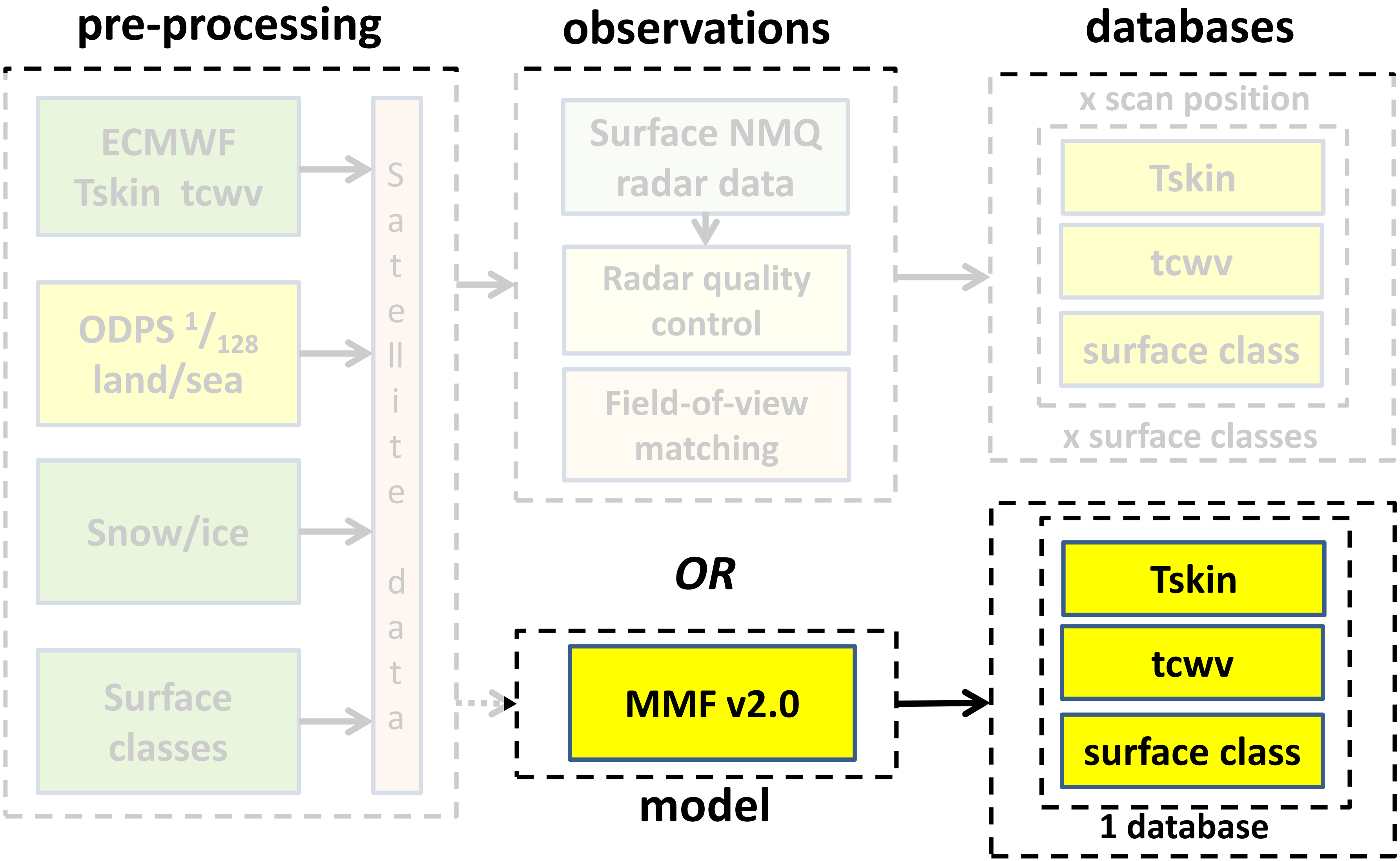
GPM constellation

MHS – MetOp/NOAA AMSR2 – GCOM-W SSMIS – DMSP
SAPHIR – MT GMI – GPM TMI - TRMM

GPROF retrieval scheme

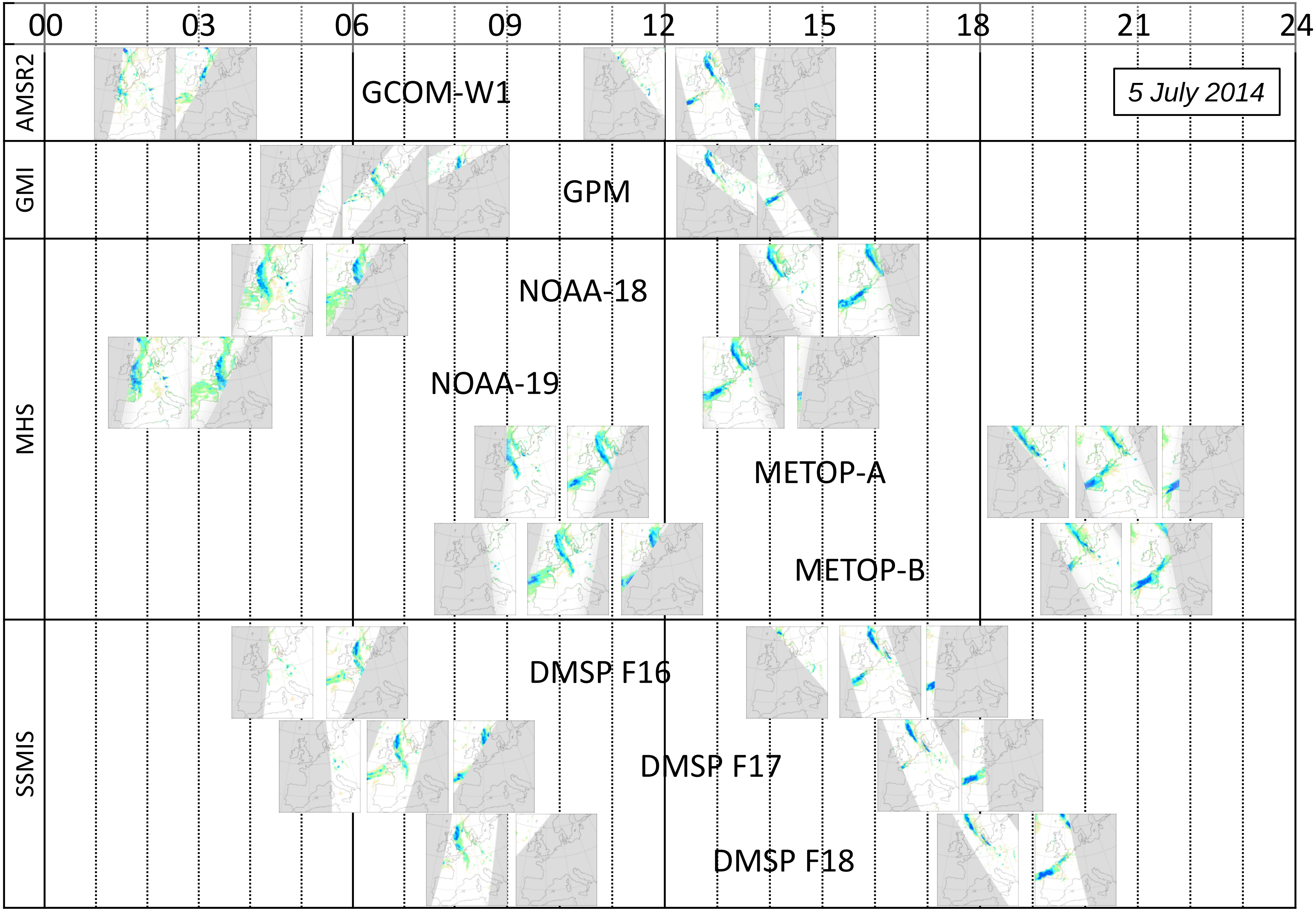
- GPROF (Goddard PROFiling) is a precipitation estimation scheme designed around a Bayesian retrieval using an a priori database from passive microwave observations.
- Retrievals constrained by model-generated surface temperature (T_{skin}) & total column water vapour (tcwv)
- Conical scanning radiometers (GMI, TMI, AMSR2, SSMIS) utilise an observational database, based upon surface/satellite and satellite observations include CloudSat, TRMM Precipitation Radar, US NMQ weather radar. Database divided into 15 surface types.
- Cross-track sensors (MHS, *ATMS, SAPHIR*) utilise a database generated by the MMF model, adjusted to GMI.

Creating GPROF cross-track databases

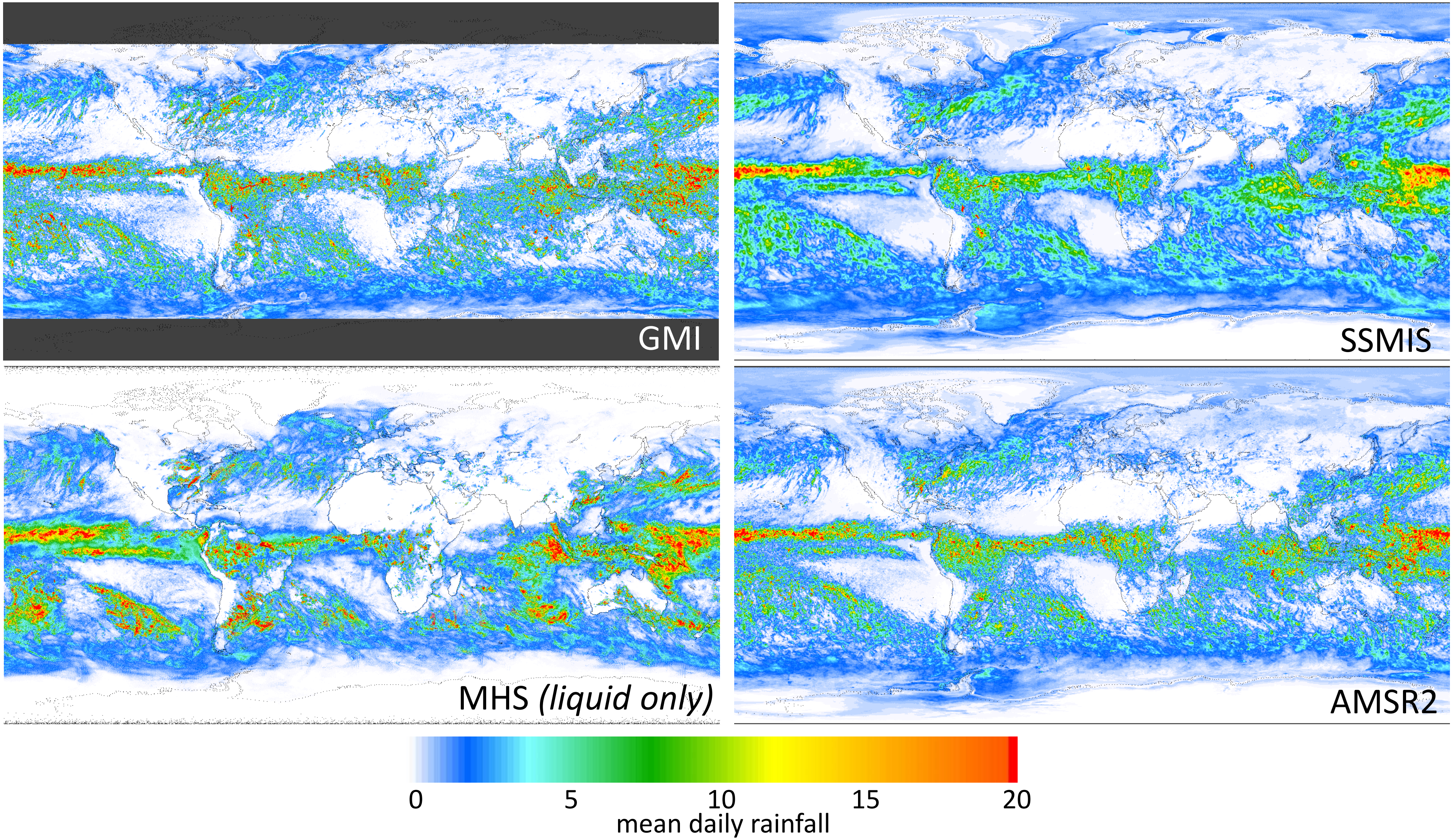


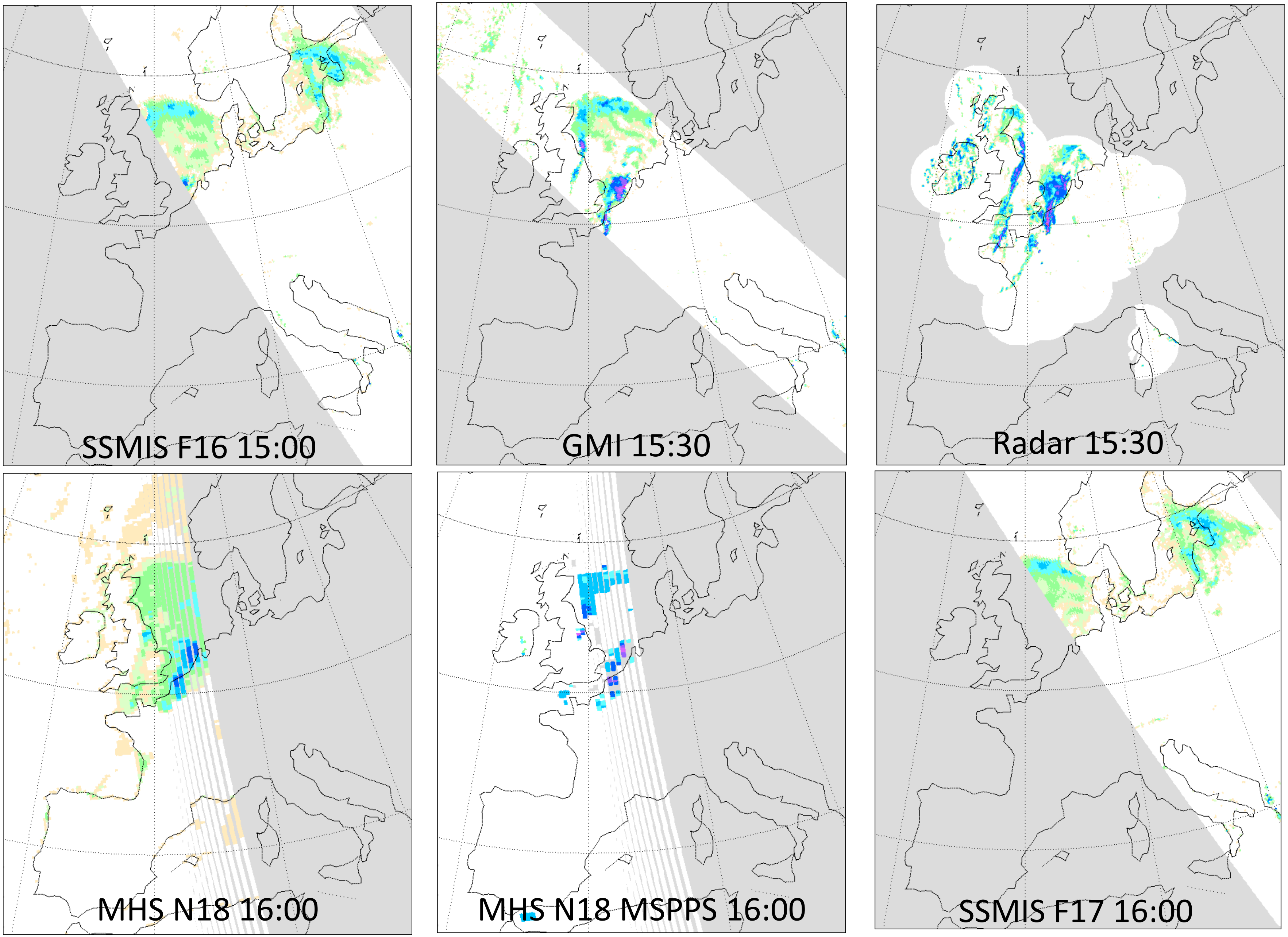
ODPS = Ocean Discipline Processing System

GPM constellation, Western Europe

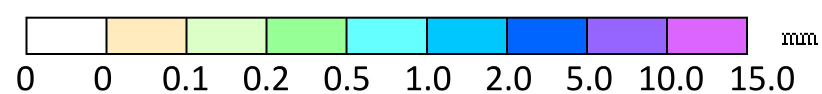


Global retrievals – April 2014

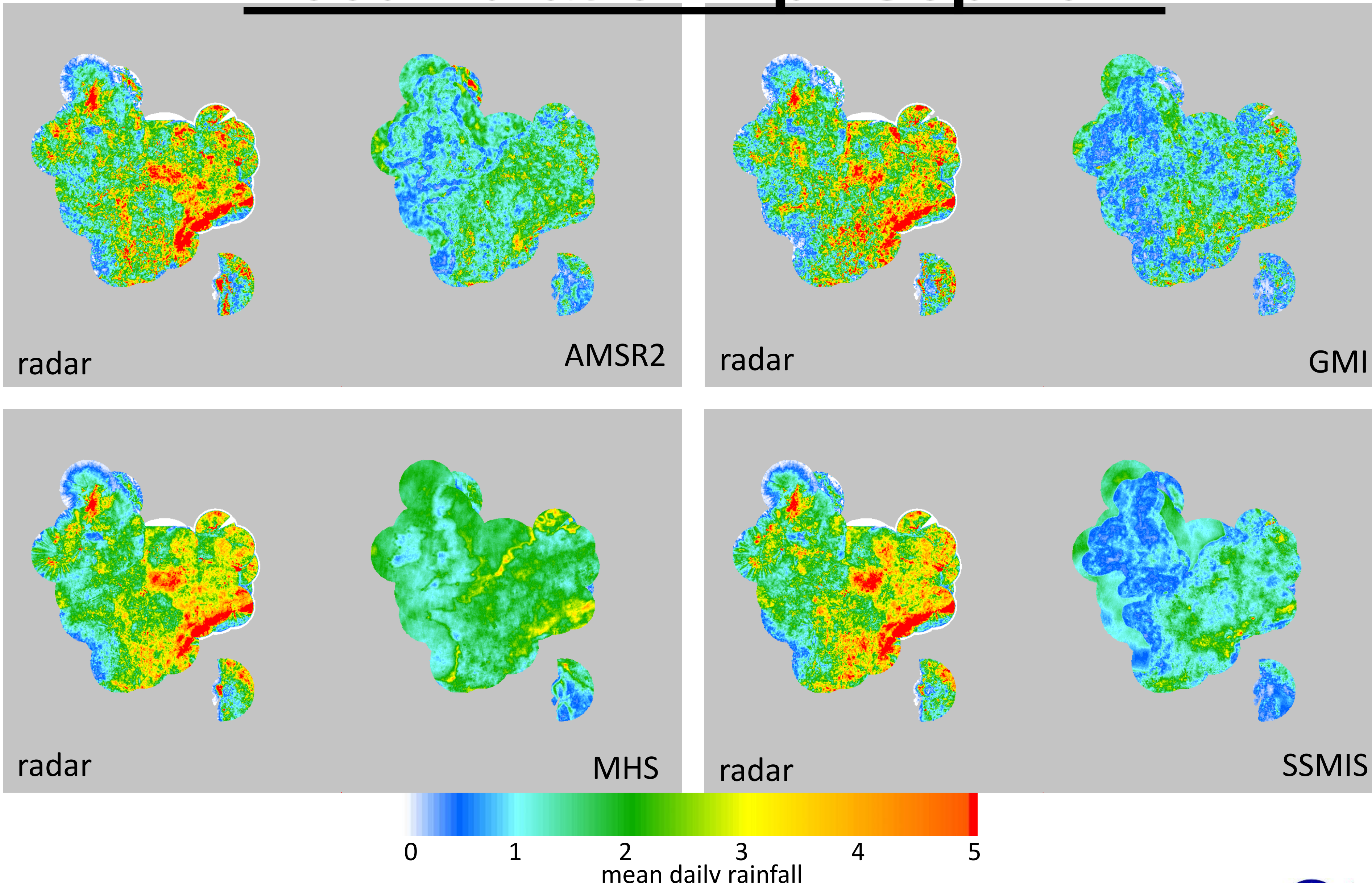




Precip retrievals 7 April 2014



Accumulation Apr-Sep 2014

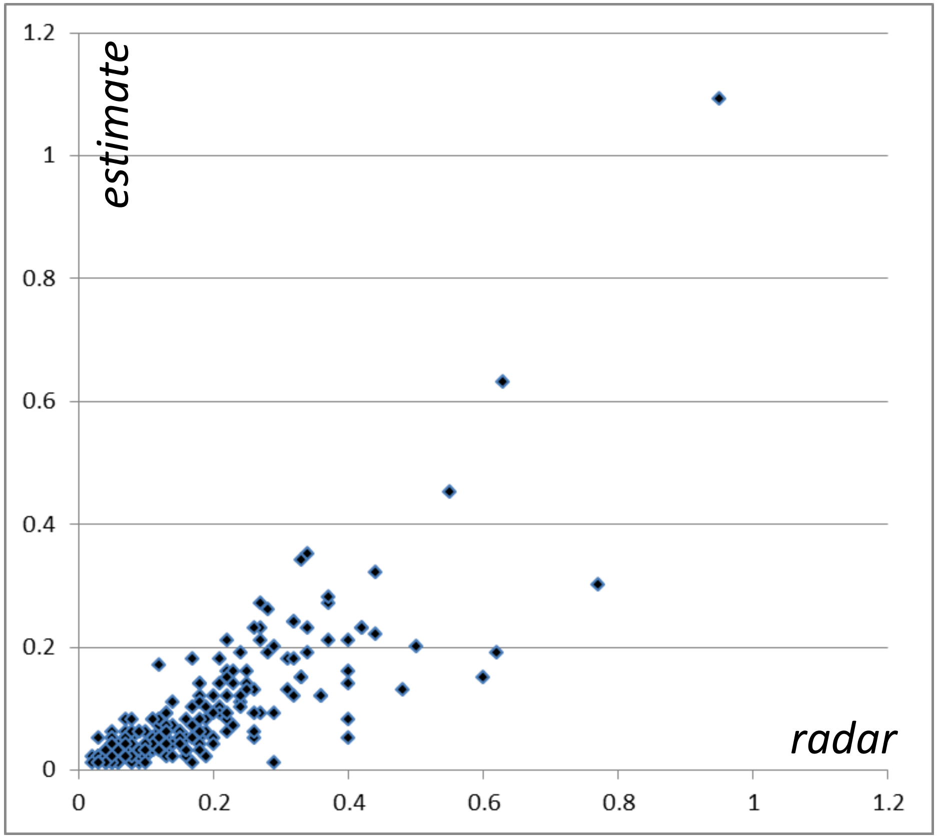


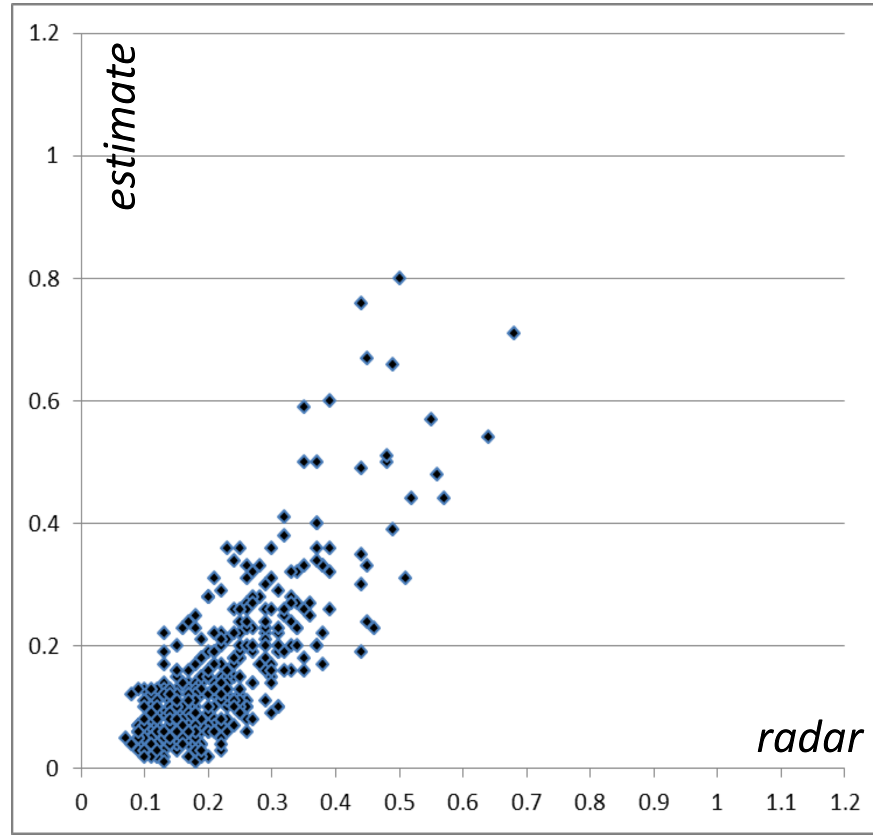
Correlation: Western Europe

Instantaneous (15-minute)

GMI			MHS nadir			MHS edge			SSMIS			AMSR		
5 km			15 km			15 km			15 km			15 km		
Only including those occasions with >100 radar cells with > 1 mm/hr														
Bin	*Frequency*	*%*	*Bin*	*Frequency*	*%*	*Bin*	*Frequency*	*%*	*Bin*	*Frequency*	*%*	*Bin*	*Frequency*	*%*
-1	0	*0.0*	-1	0	*0.0*	-1	0	*0.0*	-1	0	*0.0*	-1	0	*0.0*
-0.9	0	*0.0*	-0.9	0	*0.0*	-0.9	0	*0.0*	-0.9	0	*0.0*	-0.9	0	*0.0*
-0.8	0	*0.0*	-0.8	0	*0.0*	-0.8	0	*0.0*	-0.8	0	*0.0*	-0.8	0	*0.0*
-0.7	0	*0.0*	-0.7	0	*0.0*	-0.7	0	*0.0*	-0.7	0	*0.0*	-0.7	0	*0.0*
-0.6	0	*0.0*	-0.6	0	*0.0*	-0.6	0	*0.0*	-0.6	0	*0.0*	-0.6	0	*0.0*
-0.5	0	*0.0*	-0.5	0	*0.0*	-0.5	0	*0.0*	-0.5	0	*0.0*	-0.5	0	*0.0*
-0.4	0	*0.0*	-0.4	0	*0.0*	-0.4	0	*0.0*	-0.4	0	*0.0*	-0.4	0	*0.0*
-0.3	0	*0.0*	-0.3	0	*0.0*	-0.3	0	*0.0*	-0.3	0	*0.0*	-0.3	0	*0.0*
-0.2	0	*0.0*	-0.2	0	*0.0*	-0.2	0	*0.0*	-0.2	0	*0.0*	-0.2	0	*0.0*
-0.1	0	*0.0*	-0.1	0	*0.0*	-0.1	0	*0.0*	-0.1	0	*0.0*	-0.1	0	*0.0*
-1.4E-16	0	*0.0*	-1.4E-16	0	*0.0*	-1.4E-16	0	*0.0*	-1.4E-16	0	*0.0*	-1.4E-16	0	*0.0*
0.1	4	*1.6*	0.1	0	*0.0*	0.1	0	*0.0*	0.1	0	*0.0*	0.1	5	*1.4*
0.2	6	*2.4*	0.2	0	*0.0*	0.2	2	*1.0*	0.2	11	*1.4*	0.2	7	*2.0*
0.3	16	*6.5*	0.3	1	*0.6*	0.3	3	*1.4*	0.3	38	*4.9*	0.3	18	*5.2*
0.4	48	*19.4*	0.4	12	*7.2*	0.4	11	*5.3*	0.4	103	*13.3*	0.4	54	*15.5*
0.5	56	*22.6*	0.5	25	*15.1*	0.5	24	*11.6*	0.5	173	*22.4*	0.5	73	*20.9*
0.6	66	*26.6*	0.6	38	*22.9*	0.6	54	*26.1*	0.6	215	*27.8*	0.6	91	*26.1*
0.7	42	*16.9*	0.7	64	*38.6*	0.7	64	*30.9*	0.7	159	*20.6*	0.7	60	*17.2*
0.8	9	*3.6*	0.8	25	*15.1*	0.8	40	*19.3*	0.8	66	*8.5*	0.8	35	*10.0*
0.9	1	*0.4*	0.9	1	*0.6*	0.9	9	*4.3*	0.9	7	*0.9*	0.9	6	*1.7*
1	0	*0.0*	1	0	*0.0*	1	0	*0.0*	1	0	*0.0*	1	0	*0.0*
More	0	*248*	More	0	*166*	More	0	*207*	More	0	*772*	More	0	*349*

Mean rain rates per case





GMI

(Observational database)

Western Europe
Apr-Sep 2014

MHS

(MMF model database)

Conclusions

- Do not forget that precipitation is real – not just numbers
- "convergence" is not necessarily good – there are good fundamental reasons why measurements differ
- Careful quality control of data is critical
- Statistics need to used with caution – don't forget to look at plots of data (!)

- GPM data is flowing – all available online – together with constellation mission data
- Retrievals are looking good – latest MHS retrievals should be out very shortly