Precipitation measurements for hydrological applications

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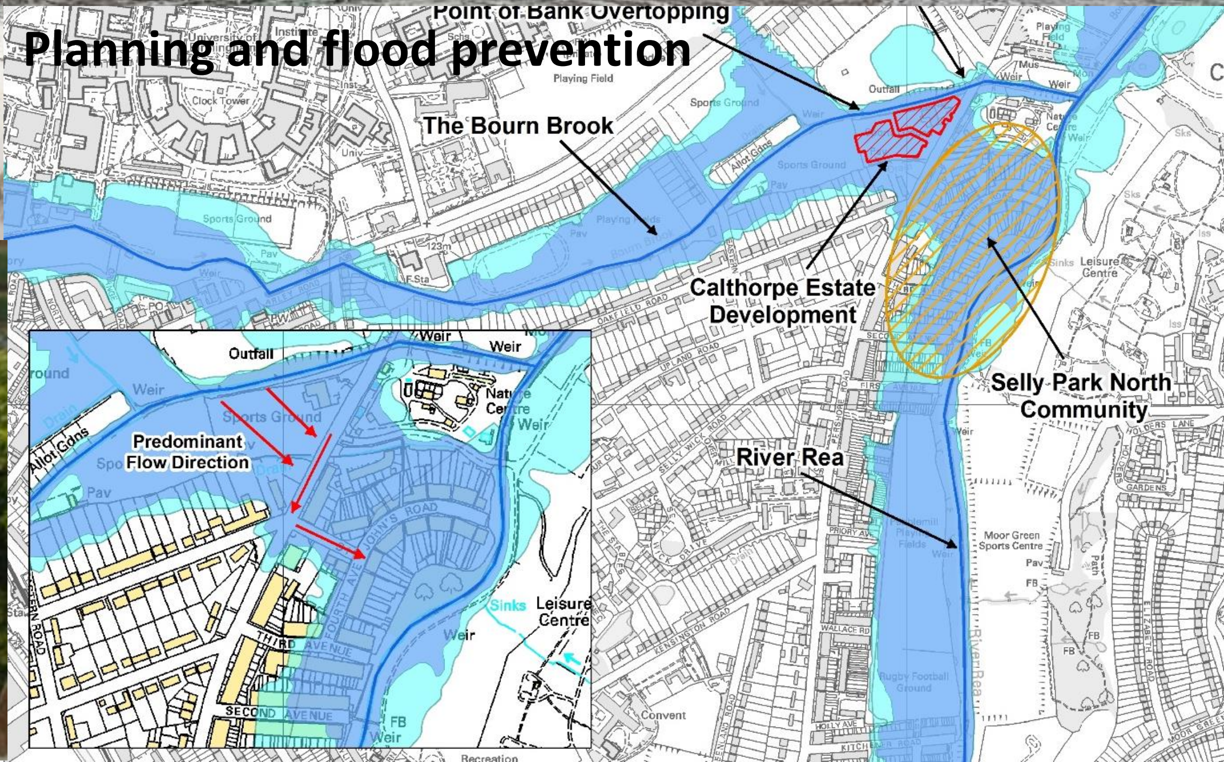
Precipitation

- is ultimately the source of all of our fresh water – it governs our society and the environment, and is a critical resource, but one that causes natural disasters through drought and floods;
- forms a critical part of the Earth's water and energy cycle (evaporation-transportation-deposition), but the atmospheric water content is small: input/output >> atmosphere storage leading to short-term cycling;
- is challenging to measure, due to the vagaries of its temporal and spatial occurrence – it is itself, an extreme event – and is very much dependent upon scale, both 3-dimensionally and temporally;
- users have different expectations of the measurements: meteorologists, hydrologists, water resources, civil defence, etc.


Hydrology – river flow


Infrastructure impacts


Pluvial events


Planning and flood prevention
Point of Bank Overtopping
The Bourn Brook
Calthorpe Estate Development
Selly Park North Community
River Rea
Outfall
Weir
Predominant Flow Direction
Leisure Centre

Measuring Precipitation

Key to accurate measurements are the:

- **<u>Observational capability</u>** - ability of a sensor to observe precipitation (*wavelength/frequency*, temporal and spatial resolution, sensitivity)
- **<u>Retrieval capability</u>** - ability of a scheme to 'convert' observations into precipitation estimates (*empirical through physical relationships*)

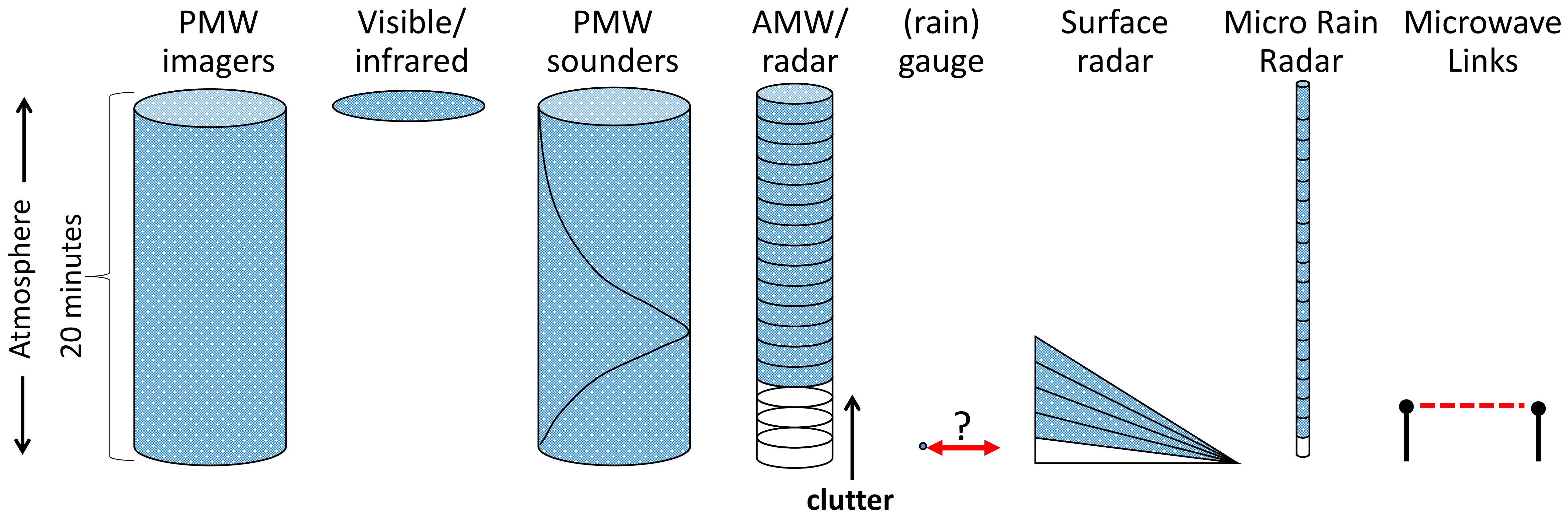
Measurements made by **rain/snow gauges, surface radar, satellite observations** have their own individual characteristics, advantages and disadvantages.

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, 0.2 mm or 1/100”) and data logger
	Distrometers	Instantaneous	Point	Individual drop measurements
	Micro rain radar	Instantaneous	Point	Vertical profiles up to 256 levels/10 s sampling
	Weather radar	Instantaneous	Radial	Radial measurements of dBZ converted to a Cartesian grid
	Microwave links	Instantaneous	Linear	Line of sight measurements along length of link
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 dependent
	Active Microwave (radar)	Instantaneous	5 km	c.80 vertical levels; Limited intermittent sampling (LEO)

Note the different spatial and temporal sampling of each sensor.

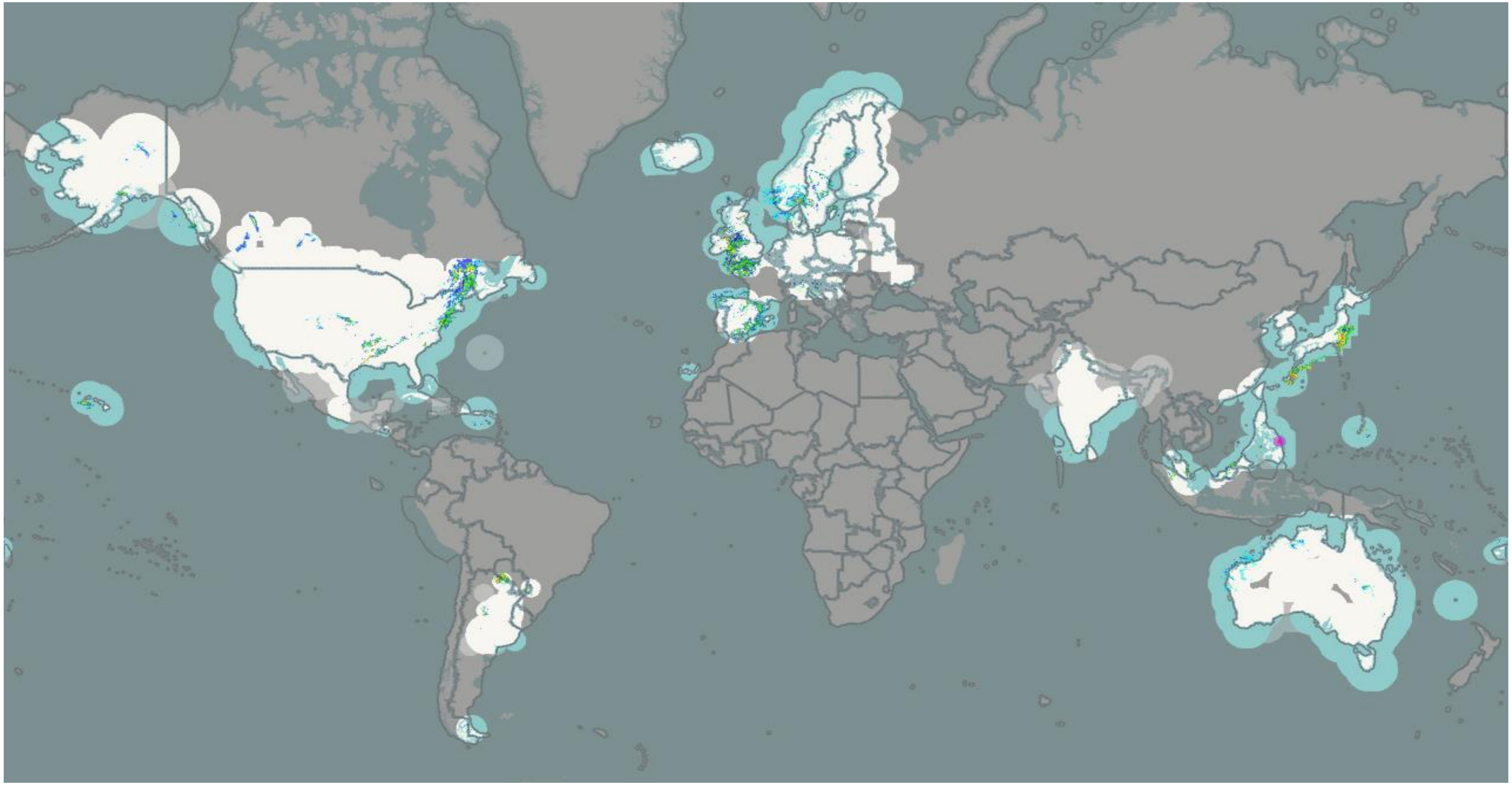
Surface & Satellite Observing Systems



Different systems observe things differently – spatially, temporally and physically

Weather Radars (WMO database)

Weather Radars (real time) *rain-alarm.com*



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Satellite observations

Visible/infrared observations are historically the mainstay of precipitation estimates, despite poor cloud-top to surface rainfall relationships. Geosationary Infrared still plays an important role – resolution and sampling.

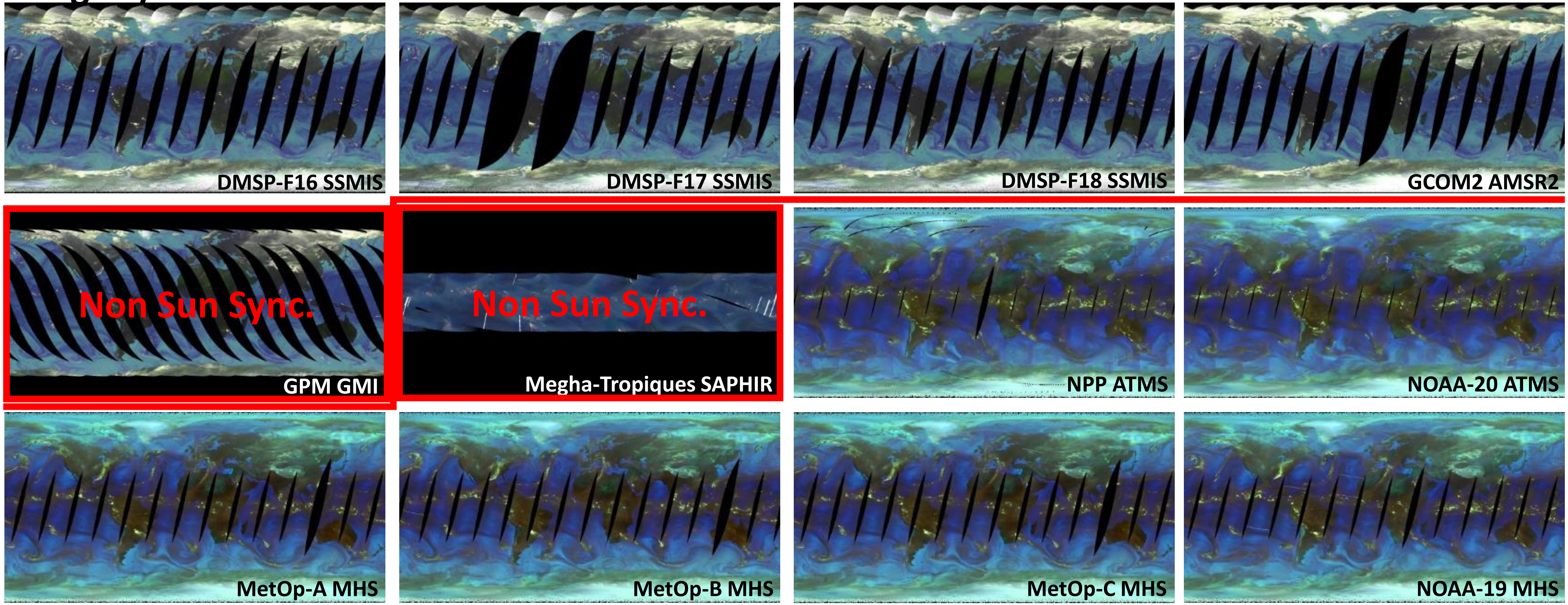
Passive microwave observations (1978/1987 onwards) provide more direct measures of precipitation. Since 2014 the Global Precipitation Measurement mission coordinates am international constellation of partner satellites:

The constellation includes 12 PMW +1 AMW sensors:

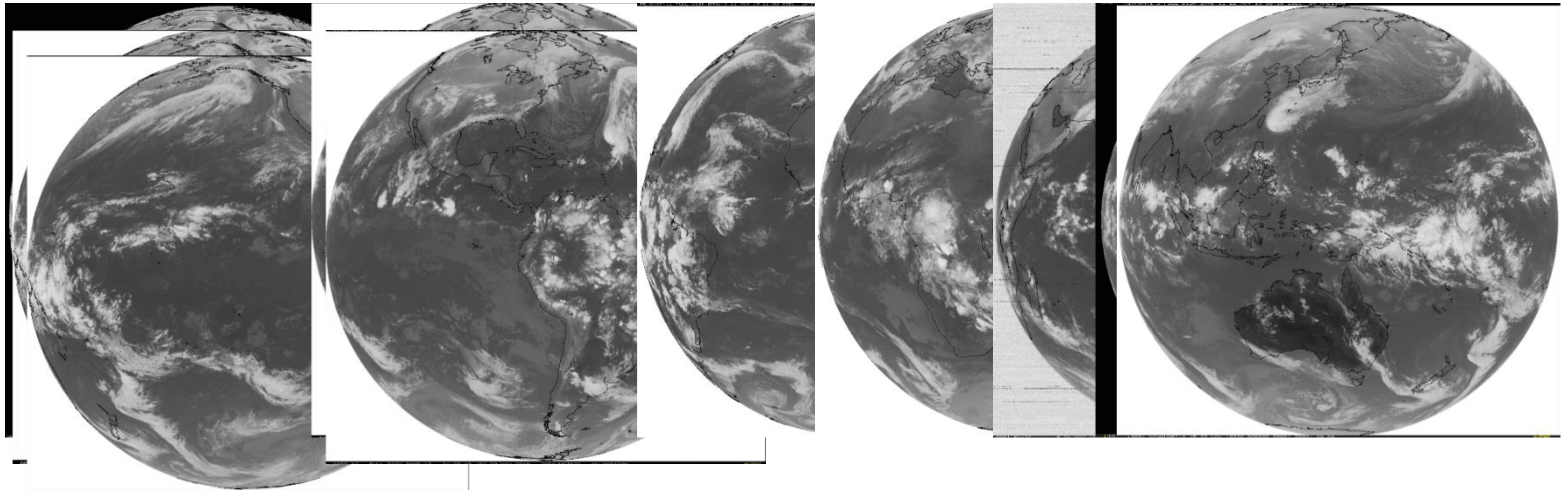
- GMI – 1x GPM Microwave Imager plus DPR Dual-frequency Precipitation Radar;
- AMSR2 – 1x Advanced Microwave Scanning Radiometer-2;
- SSMIS – 3x Special Sensor Microwave Imager/Sounder;
- MHS – 4x Microwave Humidity Sounder;
- ATMS – 2x Advanced Technology Microwave Sounder, and;
- *SAPHIR – 1x Sondeur Atmosphérique du Profil d'Humidité Intertropicale par Radiométrie*

GPM Constellation (01 Nov 2018 descending)

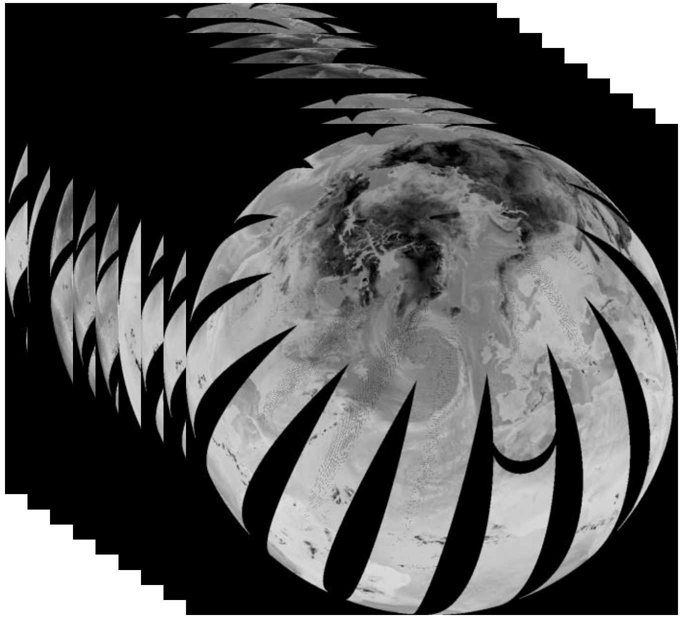
Imagers/conical



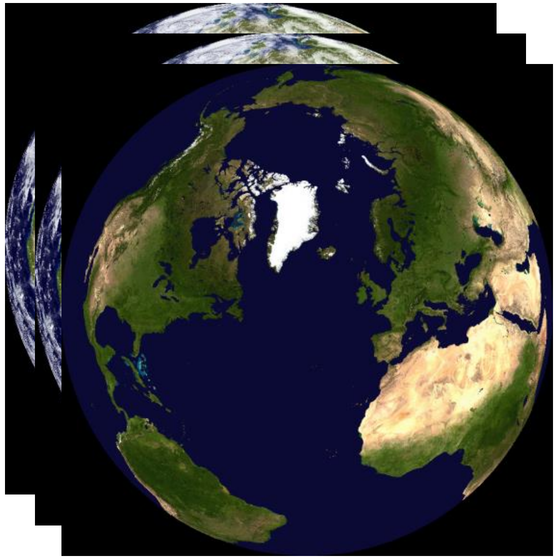
Sounders/cross-track



GOES-W (3) GOES-E (2) MSG/EU MSG/IODC FY-2G Himawari COMS-1

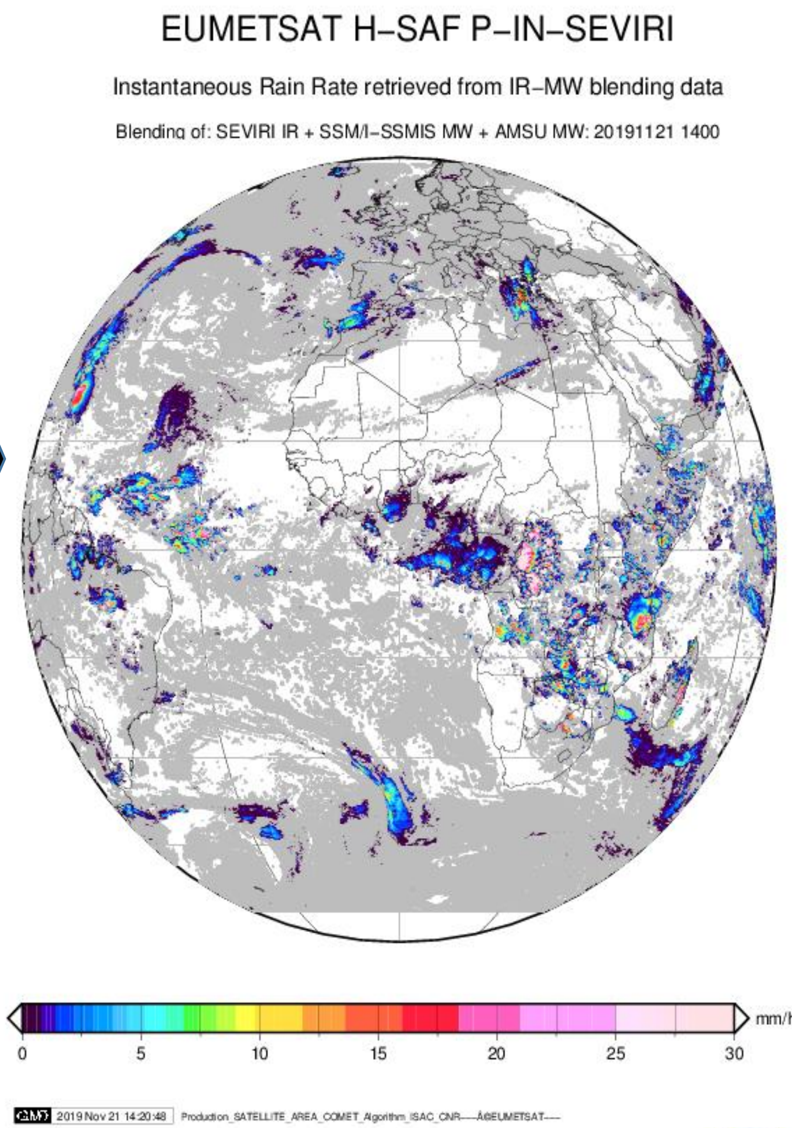


LEO passive microwave sensors



Ancillary data

turning these into….



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Operational retrieval schemes (single, passive microwave)

NASA Goddard PROFiling (GPROF) scheme:

- *physically-based Bayesian retrievals;*
- database of 400M GMI-DPR matchups, used as the basis for all sensors in the constellation through modelling of frequencies/resolutions;
- *Retrievals constrained by surface type (& snow cover) and model information (TPW/T2m)*

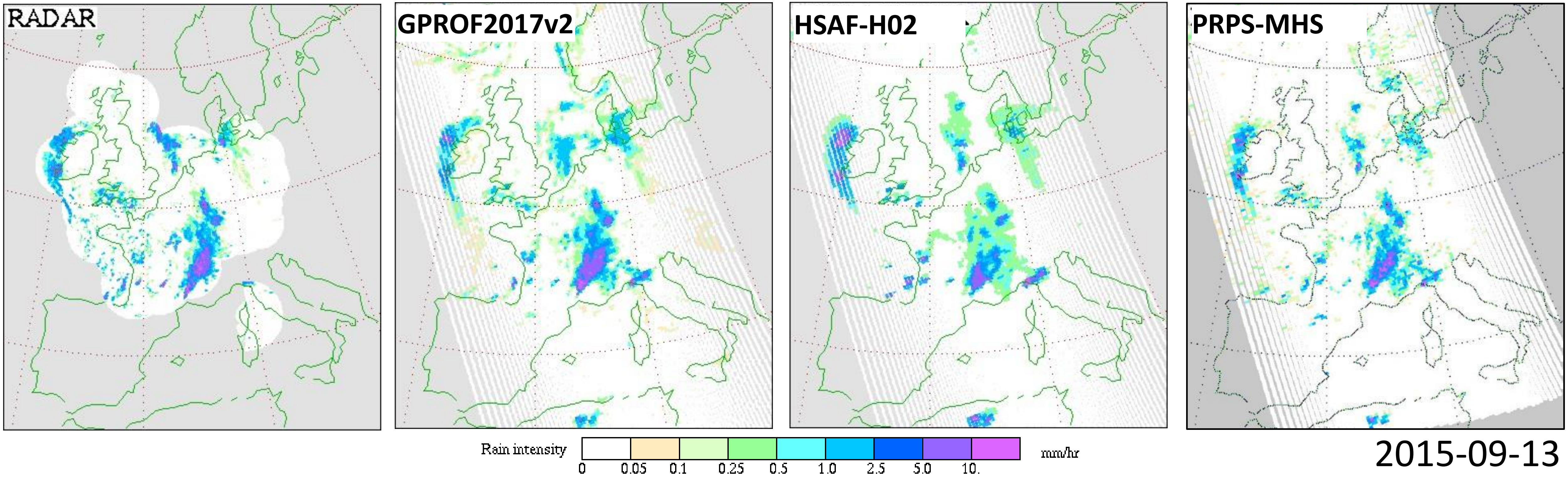
EUMETSAT HSAF – H01 and H02 schemes:

- model-generated Cloud Dynamics Radiation Database to establish Tb-RR relationships;
- different schemes for Imagers (H01 - Bayesian) and Sounders (H02 – neural networks)

Precipitation Retrieval and Profiling Scheme (PRPS):

- *Primarily developed for passive microwave sounders (SAPHIR, MHS, ATMS, AMSU-B);*
- database sensor-DPR matchups, typically < 40M entries;
- *SAPHIR retrievals constrained by model information (TPW/T2m) (as per GPROF).*

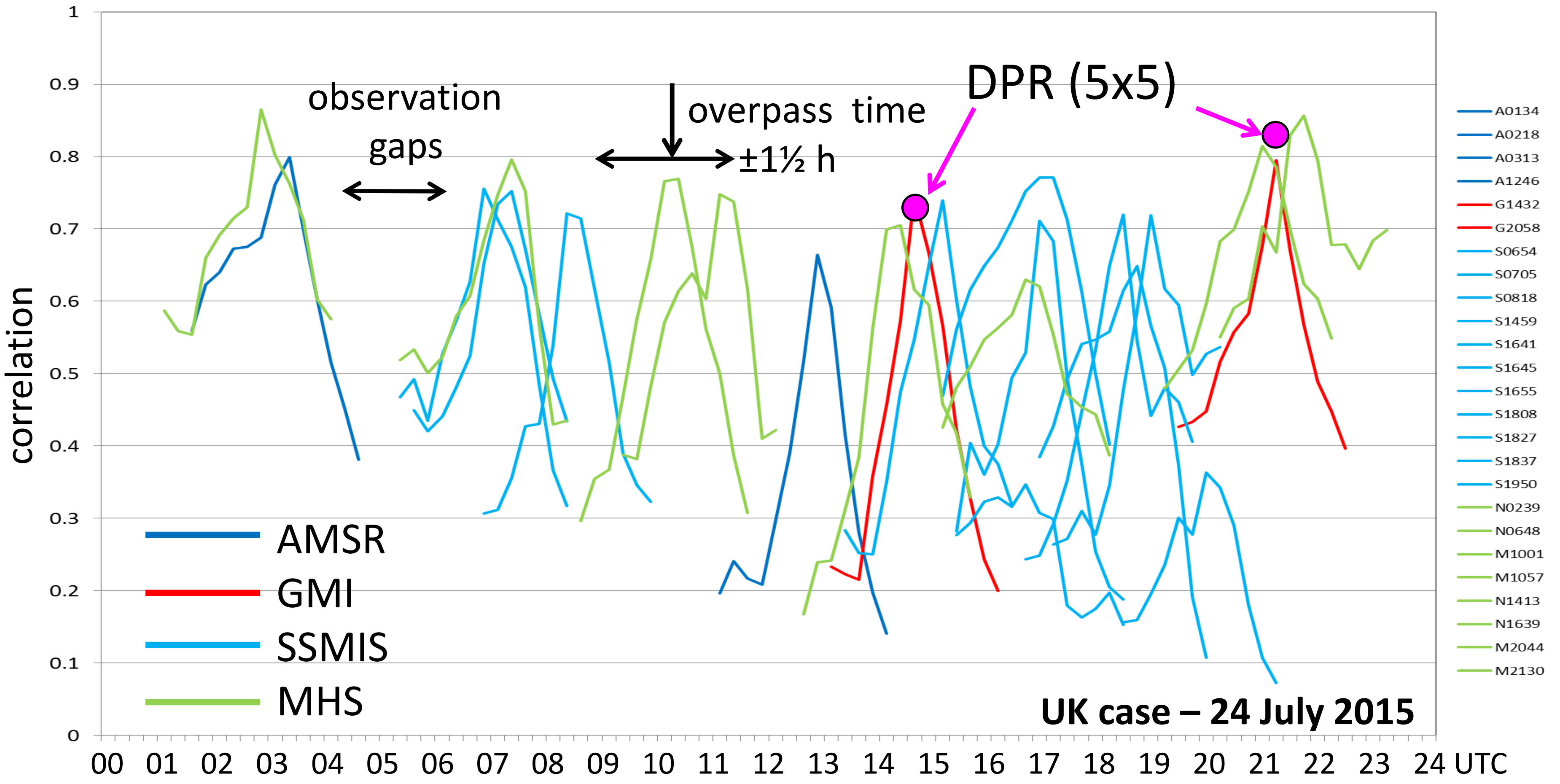
Precipitation from passive microwave sounding instruments



2015-09-13
20:34UTC

- Passive microwave sounding instruments – not necessarily ideal for precipitation;
- Techniques provide ‘reasonable’ estimates w.r.t. surface radar product;
- Subtle differences between the retrieval techniques – but all potentially useful!

Temporal correlation times: Satellite vs surface



Satellite estimates are generally very good – <u>at the time of observation.</u>

How to fill in the observation gaps?

Multi-channel/multi-sensor techniques

Rationale: to make best use of all precipitation-capable observations

- Passive microwave calibrated infrared retrievals, updated at various temporal/spatial resolutions, e.g. AGPI, PERSIANN etc.
- Use of IR-derived (or model) motion vectors to advect precipitation between the passive microwave overpasses.

Techniques include:

- IMERG (NASA)
- GSMaP (JAXA)
- CMORPH (NOAA)

All use passive microwave retrievals as ‘true’, advected by IR data or models by forward/backward propagation with/without Kalman filter.

IMERG precipitation products (0.1°x0.1°/30min)

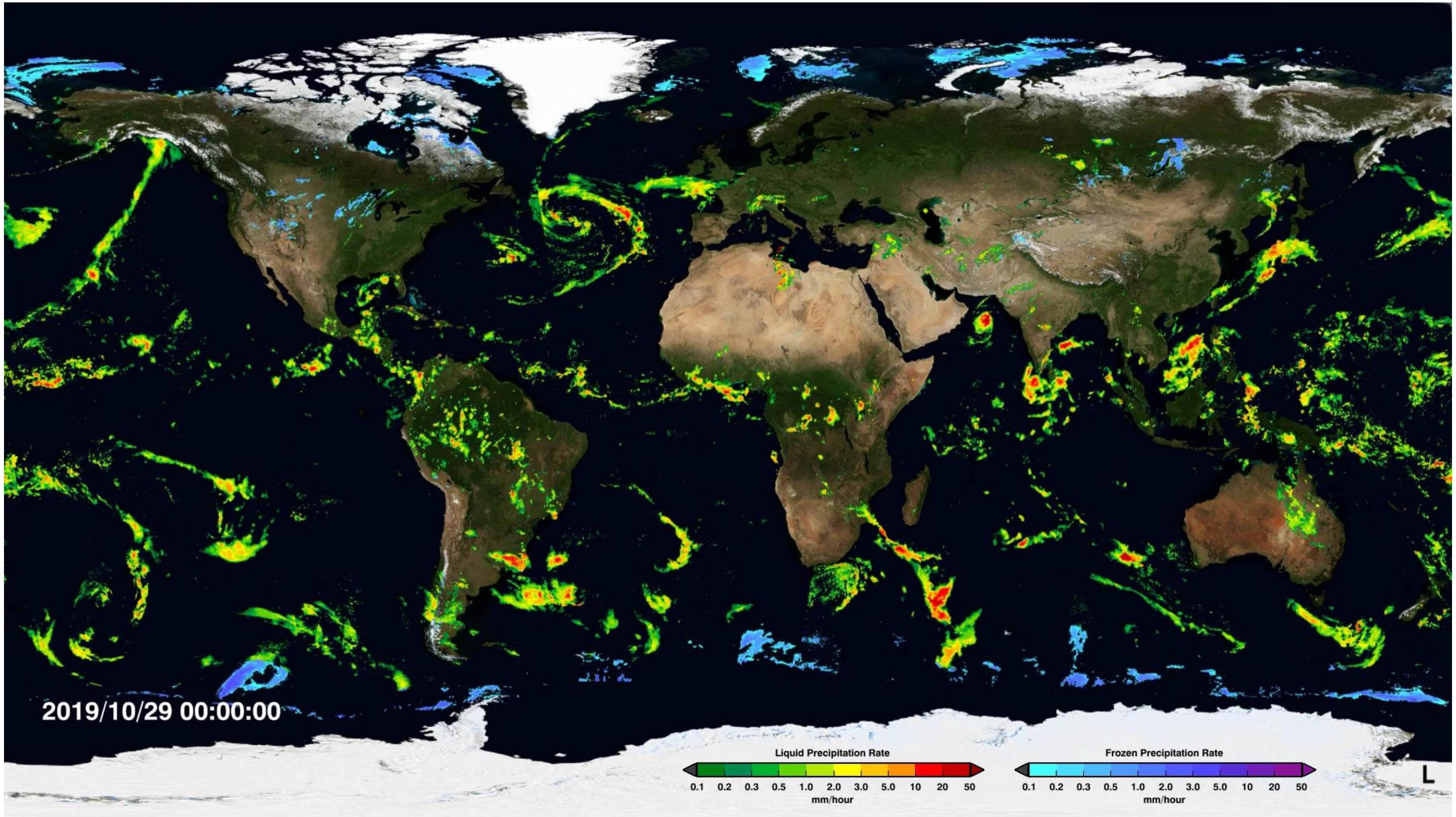
IMERG (V06B)

Early (4 hrs)

Late (18 hrs)

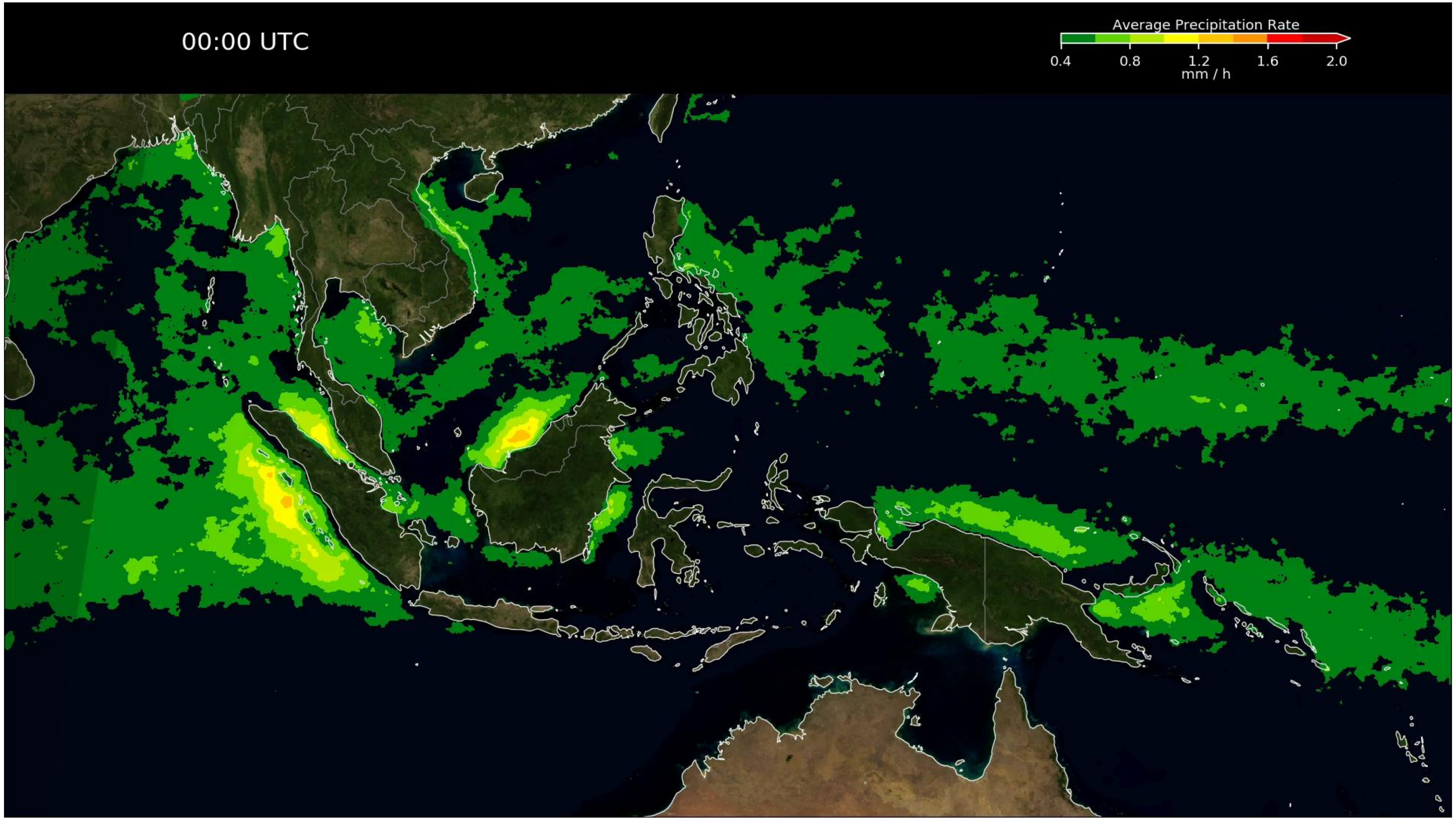
Final (c.3 months)

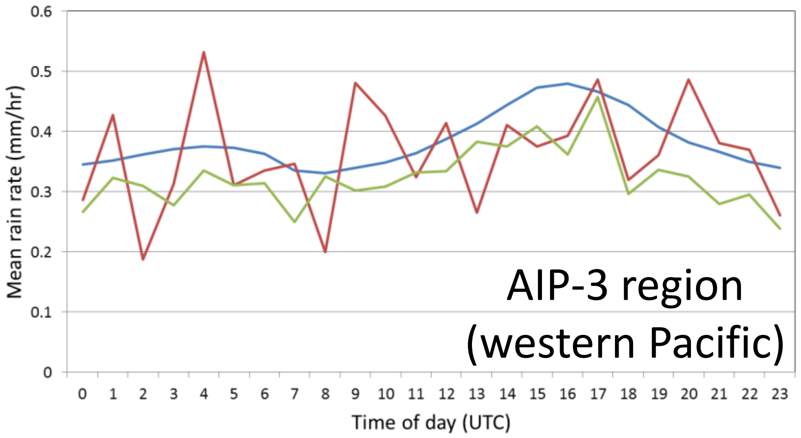
- new source for morphing vectors
- higher-latitude coverage
- extension back to 2000 (and eventually 1998)
- improved Quality Index

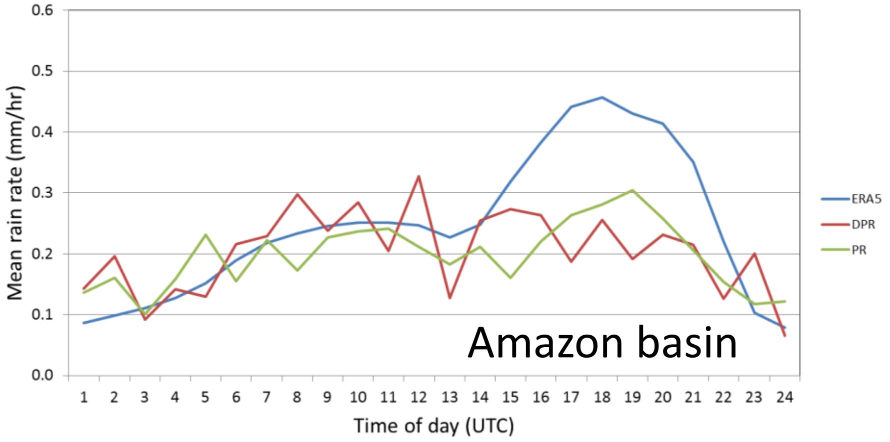


IMERG – diurnal cycle, Maritime continent

Average September-November for 2001 to 2018, Late Run
- day/night shading
- Blue Marble land
- smoothed in space and time
  - even 18 years of seasonal data still has lumps



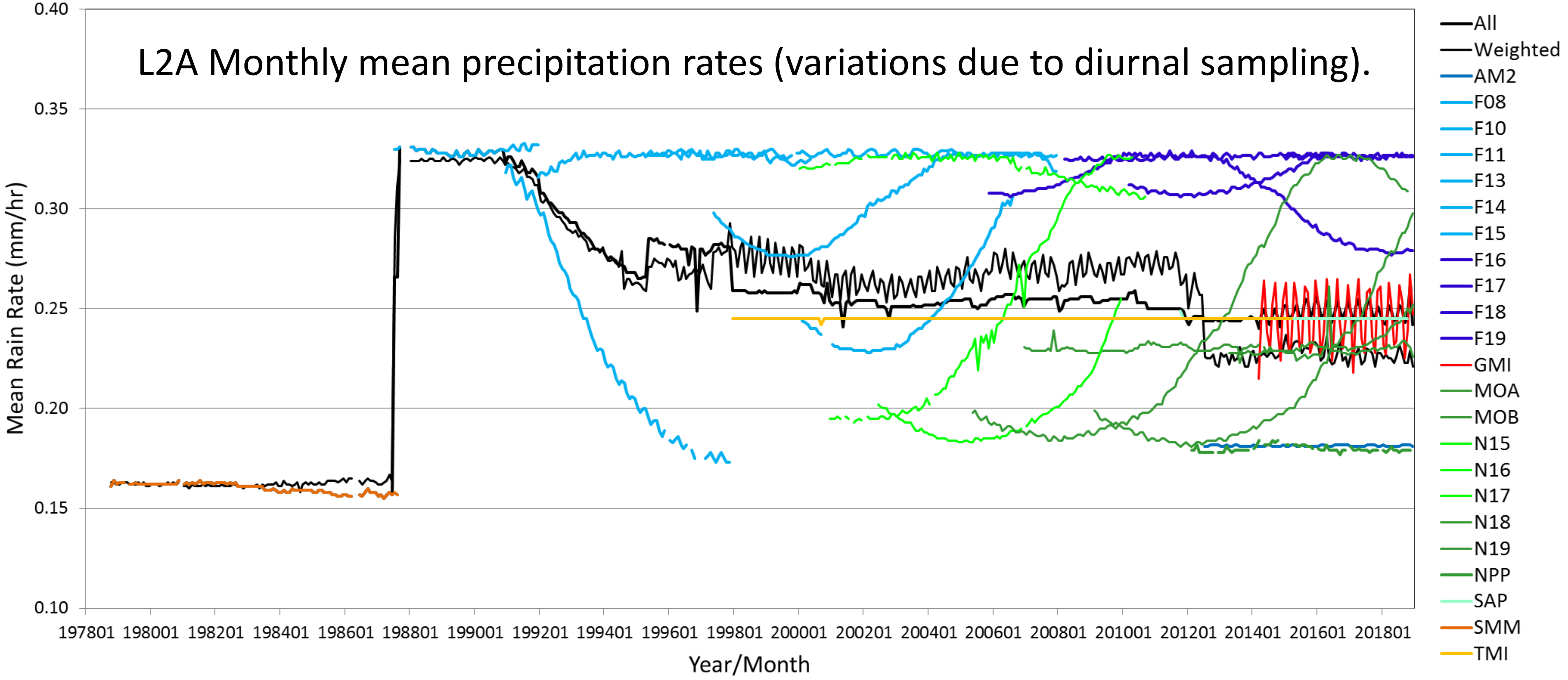




Diurnal sampling and long term records

ERA5, GPM DPR and TRMM PR all agree over AIP-3 region, not over the Amazon.

Since many of the LEO satellites drift over time, their sampling of the diurnal cycle changes over time.



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International Precipitation Working Group: Ground Validation

#2) Establish standards for validation and independent verification of precipitation measurements

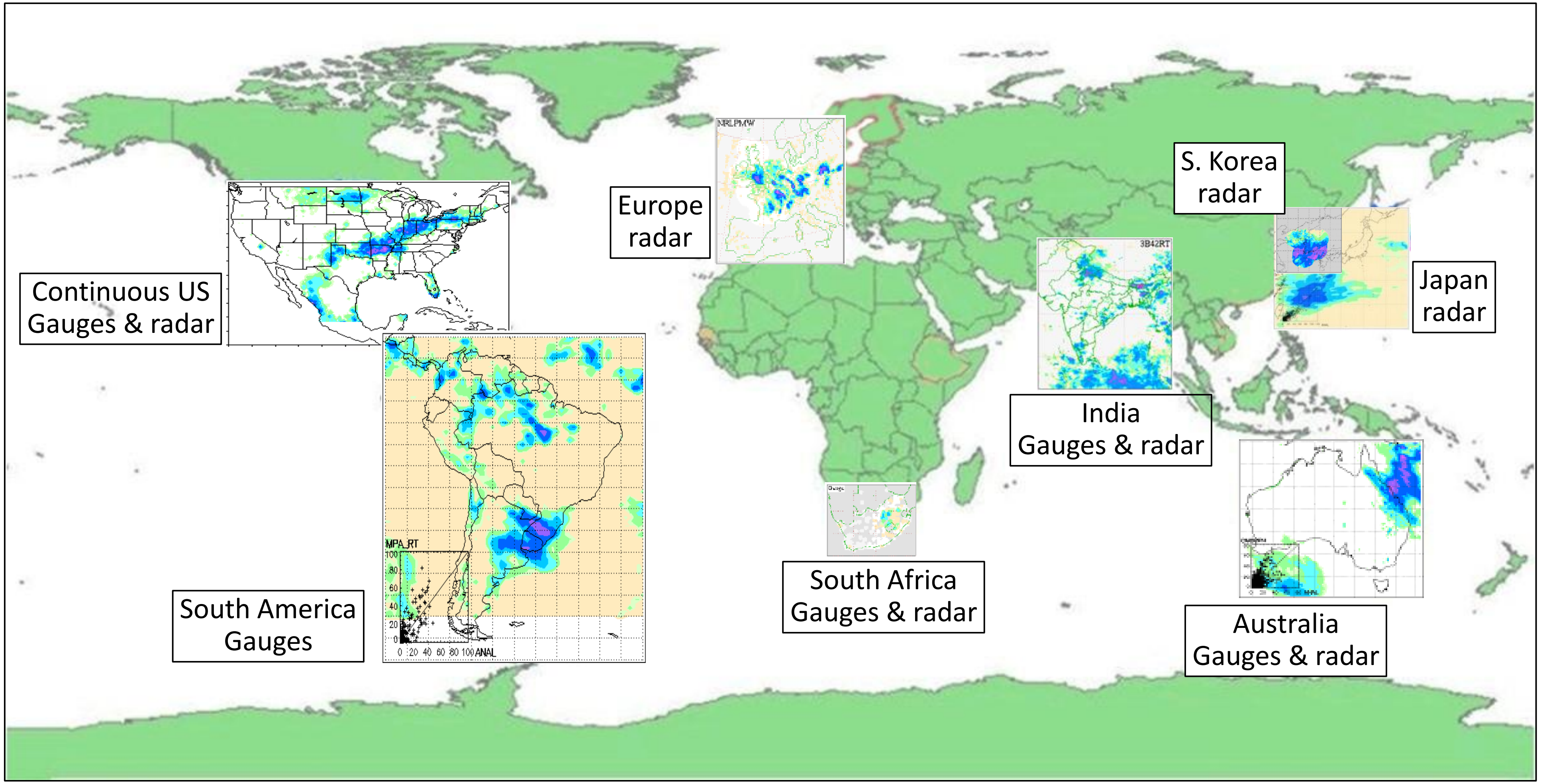
#3) Foster the exchange of data on inter-comparisons of operational precipitation measurements from satellites

- Provide regional-scale validation of precipitation products using common graphical, descriptive and statistical analysis of daily, 0.25° resolution products;
- Precipitation products made available for comparisons at local 'validation' centres (thus avoiding exchange of 'sensitive' surface data sets);
- carried out on a '<u>best effort</u>' basis - <u>very reliant</u> upon the contributors (or lack of – modellers included!).

http://www.isac.cnr.it/~ipwg/

IPWG Inter-comparison regions

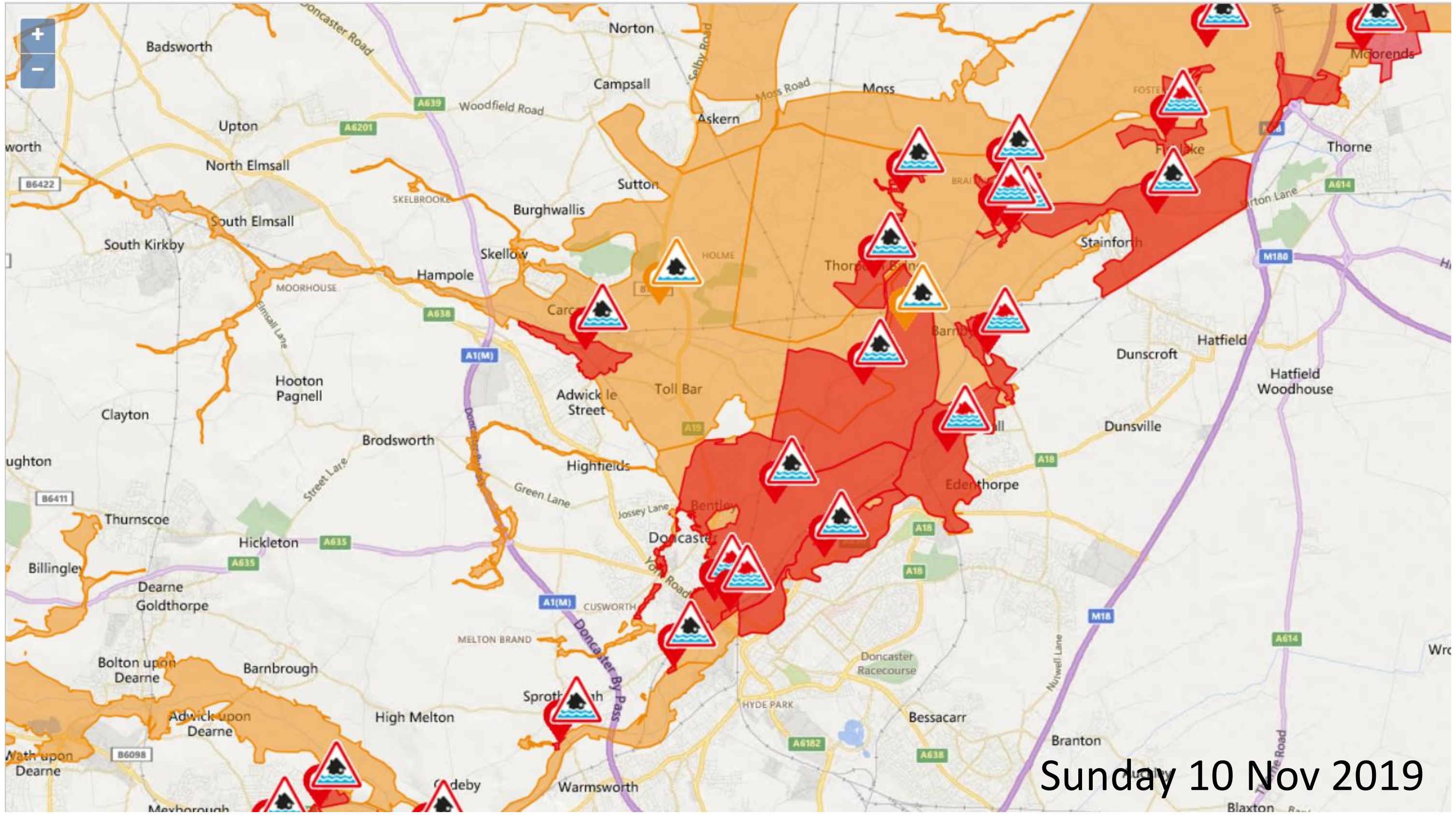
Near real-time inter-comparison of model & satellite estimates vs radar/gauge



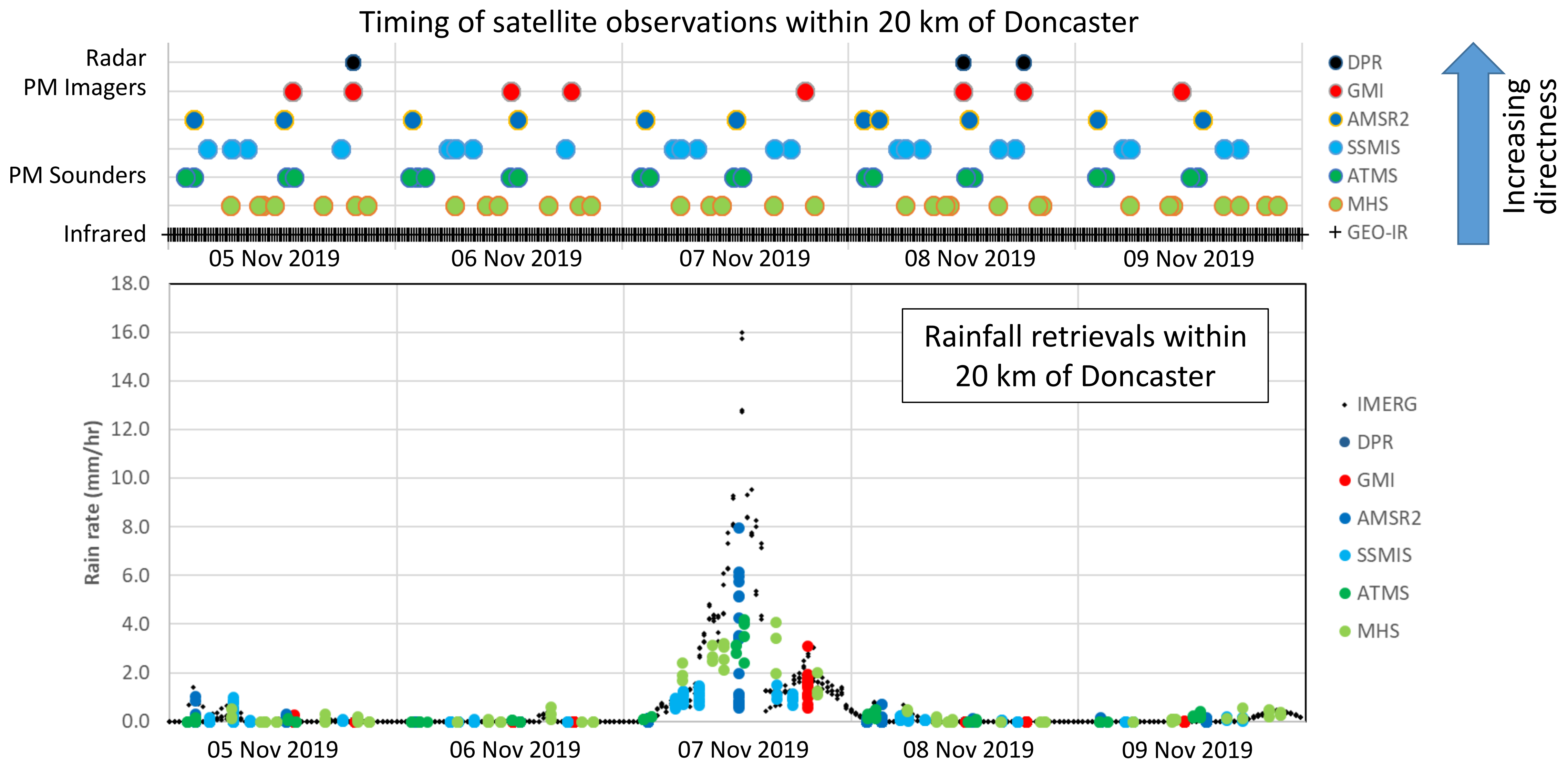
IPWG - http://www.isac.cnr.it/~ipwg/

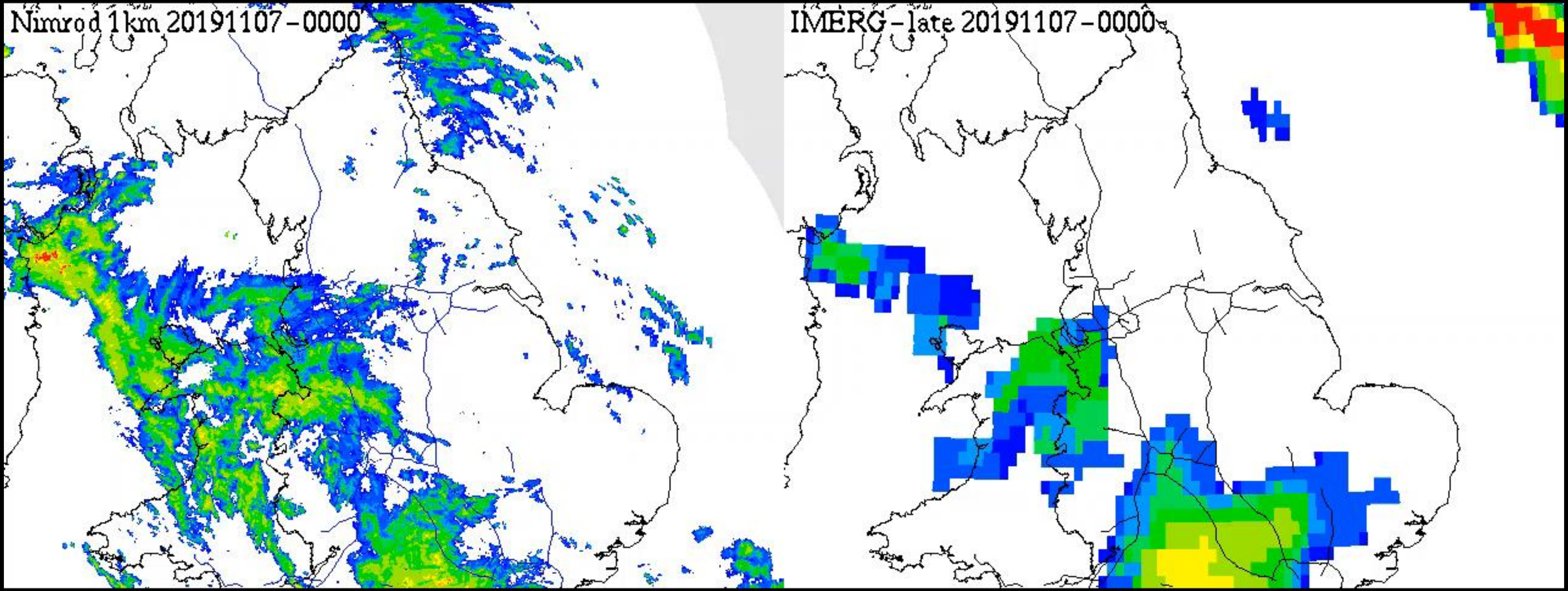
Yorkshire Floods: November 2019

A significant rainfall event took place on 7th November 2019 over South Yorkshire, leading to widespread flooding and disruption.



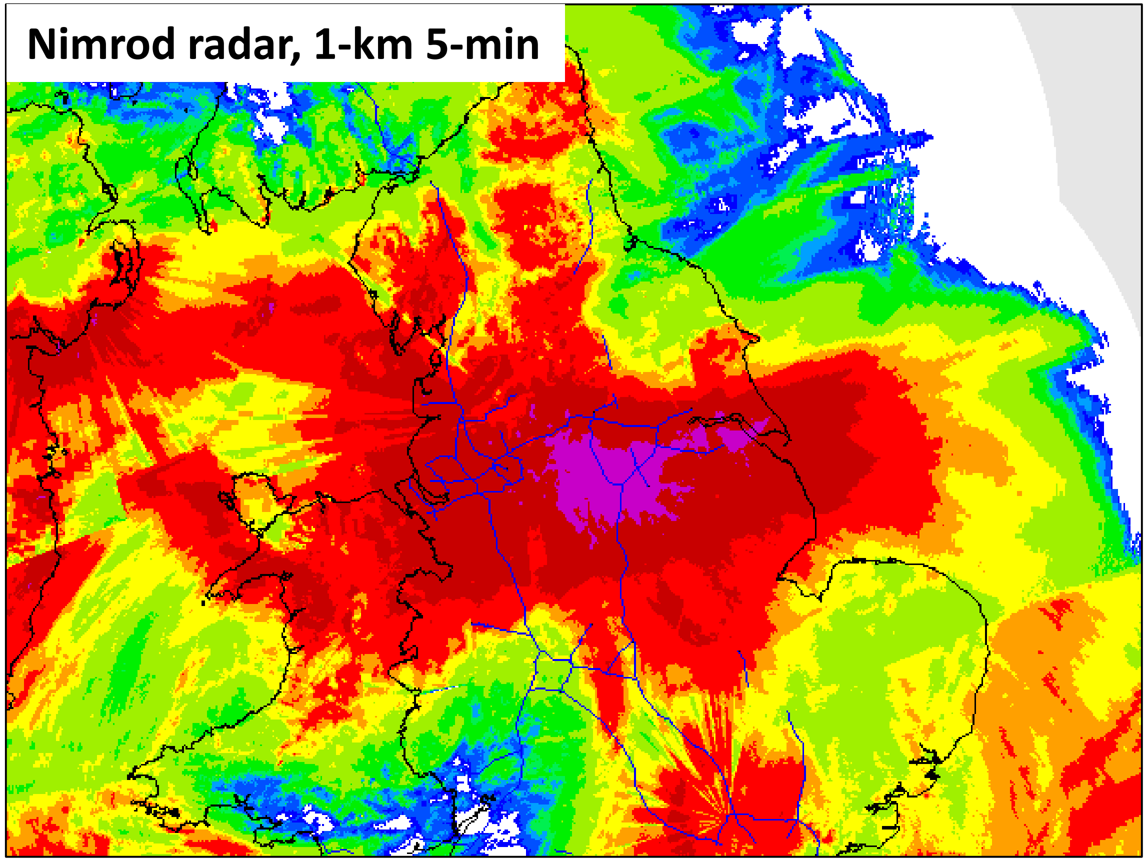
Yorkshire Floods: Satellite overpasses and sampling

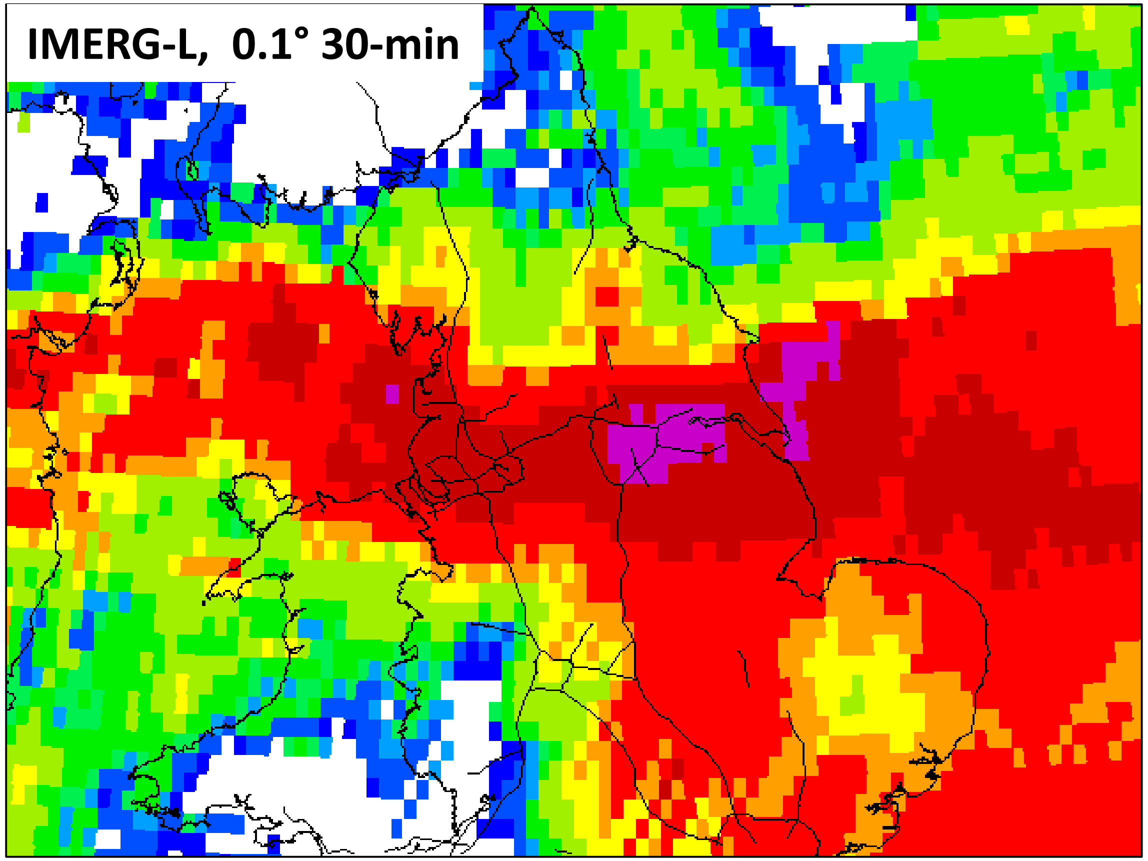



Nimrod 1km 20191107-0000
IMERG-late 20191107-0000

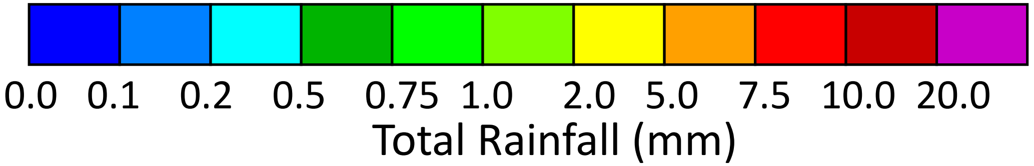
Yorkshire Floods: Radar vs satellite daily totals

7 November 2019





Some radar artefacts:
Radial effects;
Range effects…



Some missed precipitation?
Orography?
Light precipitation?

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H-SAF/HEPEX, ECMWF, Reading, UK, 25-29 Nov, 2019

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User considerations

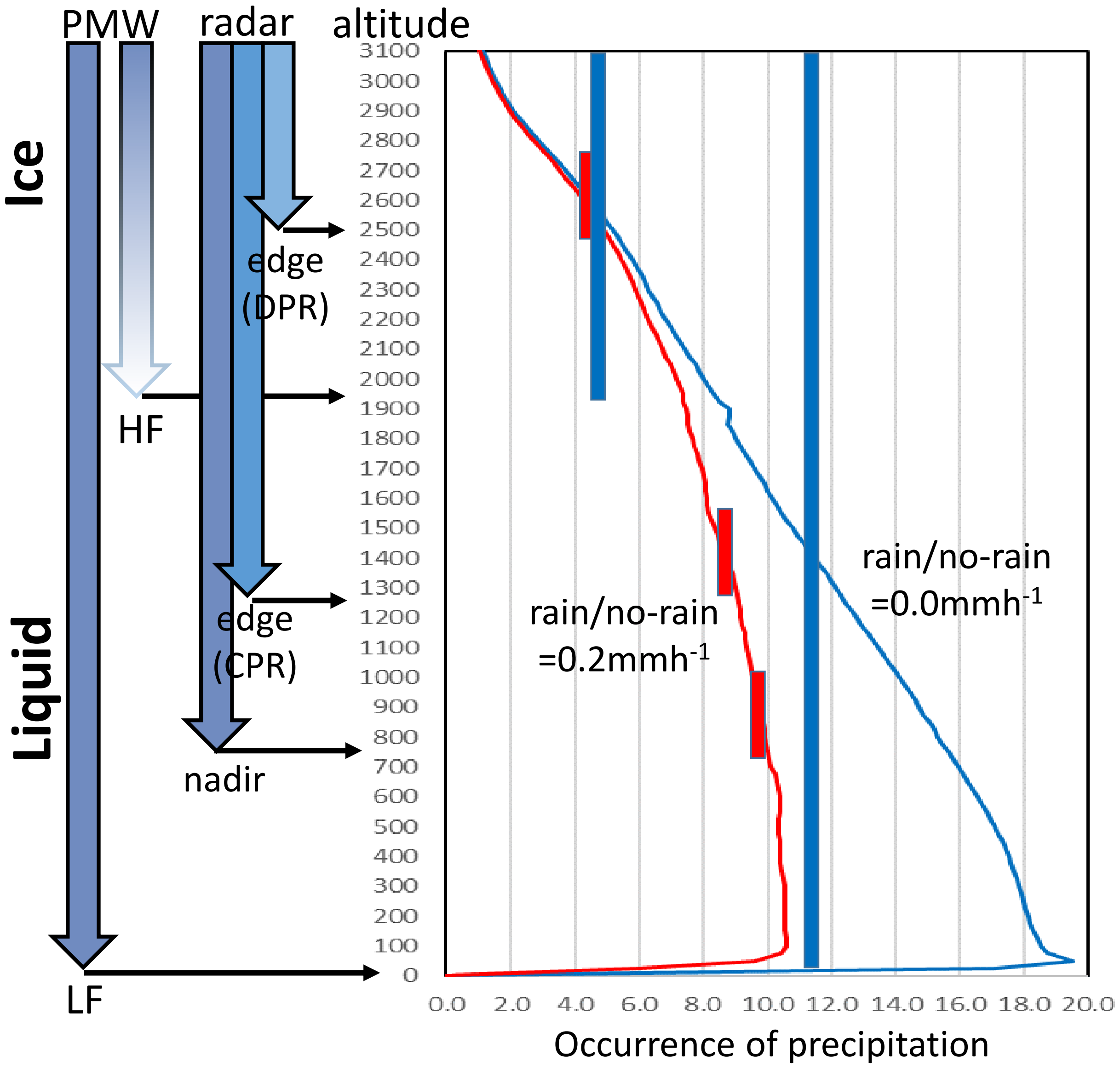
User requirements

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

E.g. hydrology:

- Amount falling over a certain area, within a given time *(sampling)*
- Basin morphology; shape, size, orography, etc *(resolution)*
- *Water management: regulated rivers and catchments (interference)*
- Storm dynamics; inter-action of storm and basin characteristics (such as movement across a basin)

What do we actually observe?

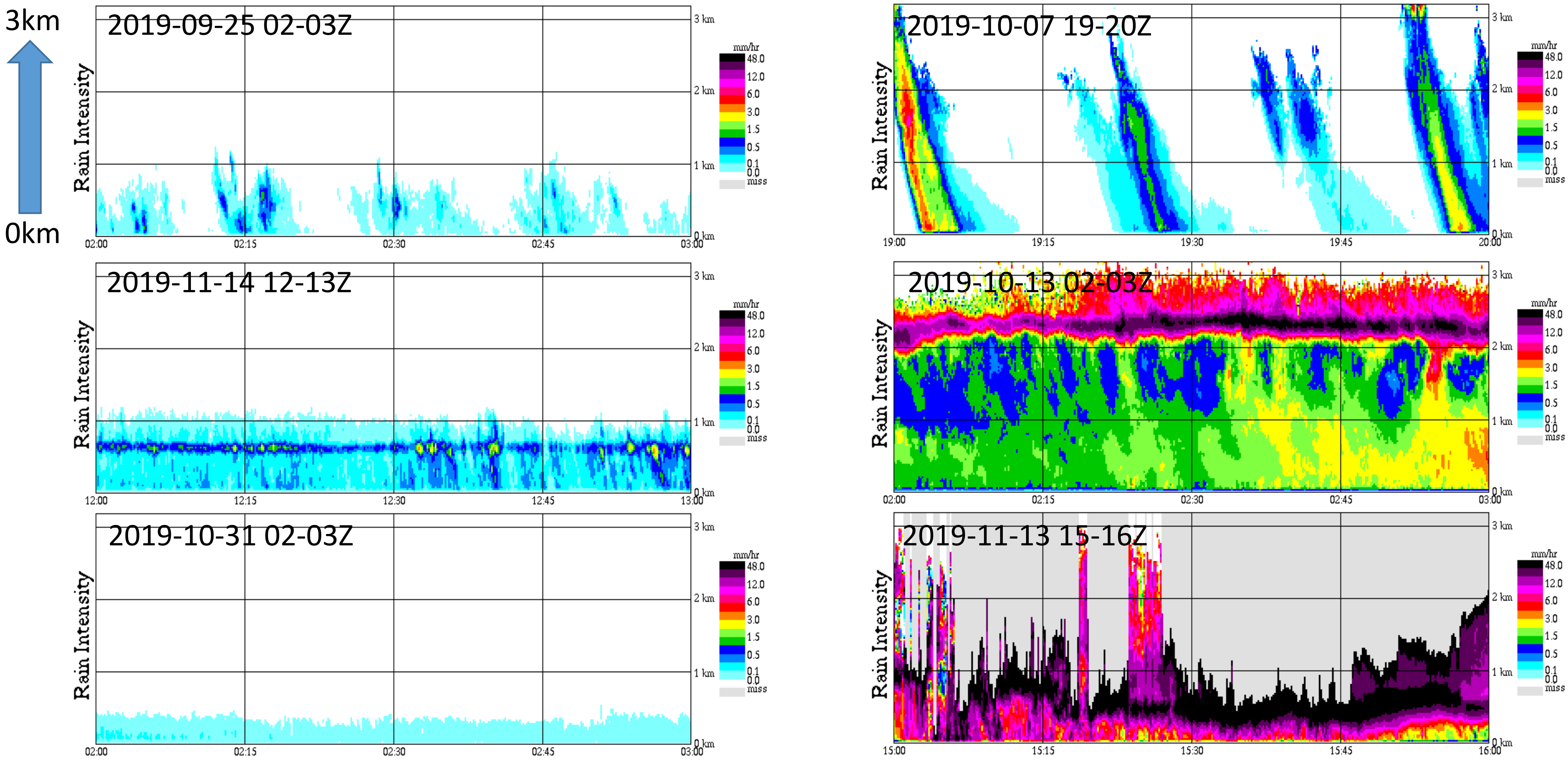


Typically spaceborne radars can only retrieve useful measurements to within c.750m of the surface – at nadir; off-nadir this is closer to 2500m. Passive microwave see an atmospheric column, although at high frequencies this is altitude-weighted.

Radars measure an instantaneous quantity with a rain/no-rain threshold of about 0.2 mm/hr, **passive microwave a time-integral** with a rain/no-rain threshold of (maybe?) 0.1 mm/hr.

There should be no expectation that measurements from different instruments will be similar

MRR-Pro profiles: Plymouth (UK)



Conclusions

- Range of satellite observations are available – used to augment surface data sets;
- Care needed to understand the capabilities – and limitations of each product;
- Often difficult to address the specific needs of the diverse range of user applications;
- Good reasons why different satellite estimates do not (and should not) match those at the surface;
- Ultimately temporal and spatial scales are critical in ensuring realistic precipitation products are delivered to the user community.