Monday – 35 mins

Session T1: Satellite precipitation observations

Introduction of precipitation-related satellite missions

Joe Turk (JPL/Caltech) and Chris Kidd (UMD/ESSIC & NASA/GSFC)

Why measure precipitation?

Water is

- a fundamental component of the Earth's energy and water cycle, redistributing energy through evaporation and condensation across the Earth's surface and atmosphere.
- essential to life on Earth - the only planet we know of that has abundant, usable water.
- critical to social and economic well being - too much or too little can be disastrous.
- increasingly important politically - water resources transcends national boundaries.

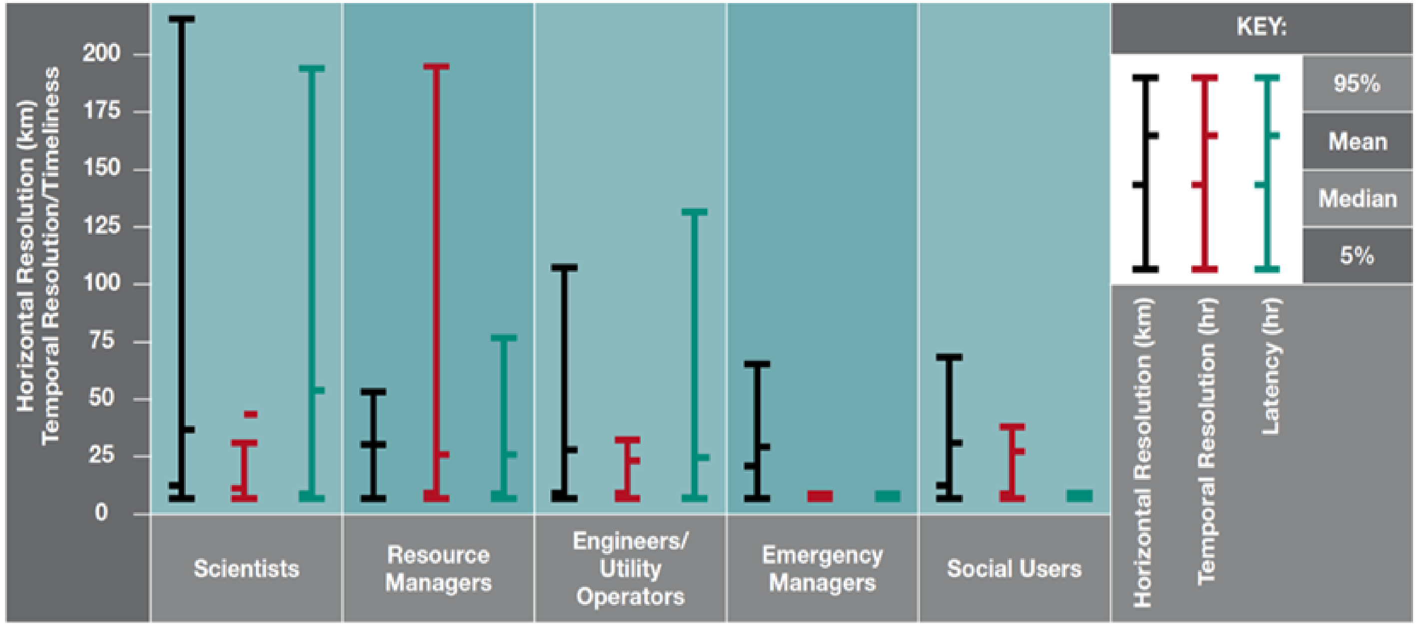
Measuring precipitation, its accuracies and errors is extremely problematic:

- dependent upon the characteristics of the precipitation, observational capability of the instrument, interpretation of the measurements/observations and, perceived versus real requirements.
- conventional measurements made (primarily) by observations/reports, rain/snow gauge and weather radar do provide global coverage.

Precipitation user requirements

Wide range of users - wide range of requirements:

- Spatial resolutions: 300 m to 50 km;
- Temporal scales: 18 mins to 15 days;
- Latency (acquisition): 6 mins to 24 hours.

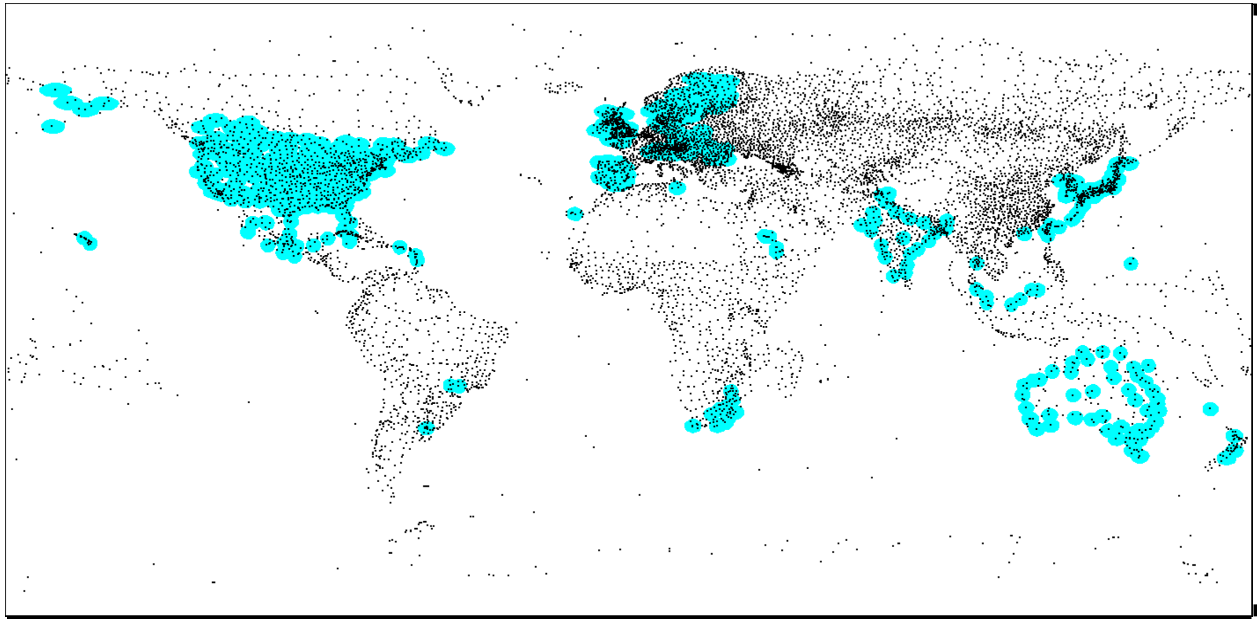


GEO (2010), Fig. 2

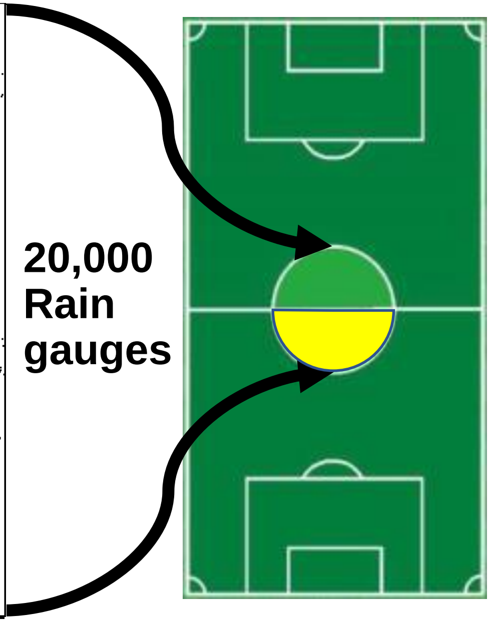
There is no 'one-size fits all'

Conventional Observations

Sevruk & Klaman identified 50 types of daily, manually-read gauges worldwide



Radar duplicates rain-gauge coverage



While gauges and radar are a critical part of measuring precipitation, satellites can provide *consistent*, *regular* observations, with *global coverage* and *real-time* delivery of data

Why satellites?

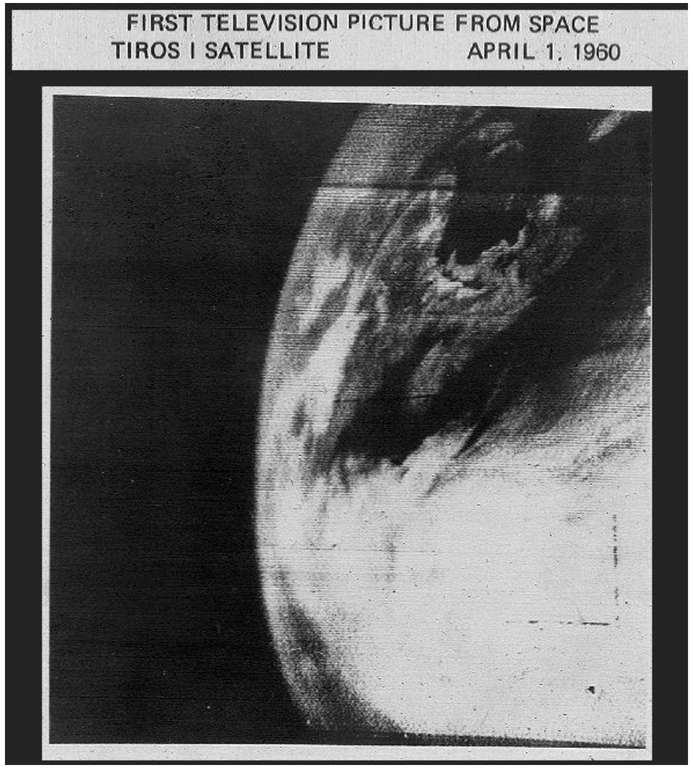
Satellites offer an unparalleled view of the Earth.

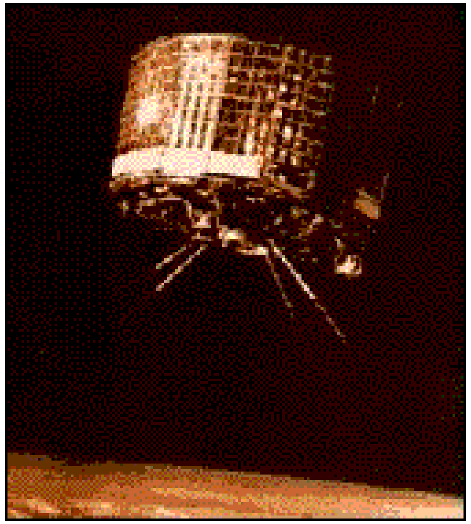
They provide:

- regular and consistent observations;
- cover large, often inaccessible, areas, and;
- a complete picture of the Earth System.

Two complementary observing systems:

- Low Earth Orbits ca.800 km
- Geostationary orbits ca.35,000 km





TIROS-1
1st April 1960

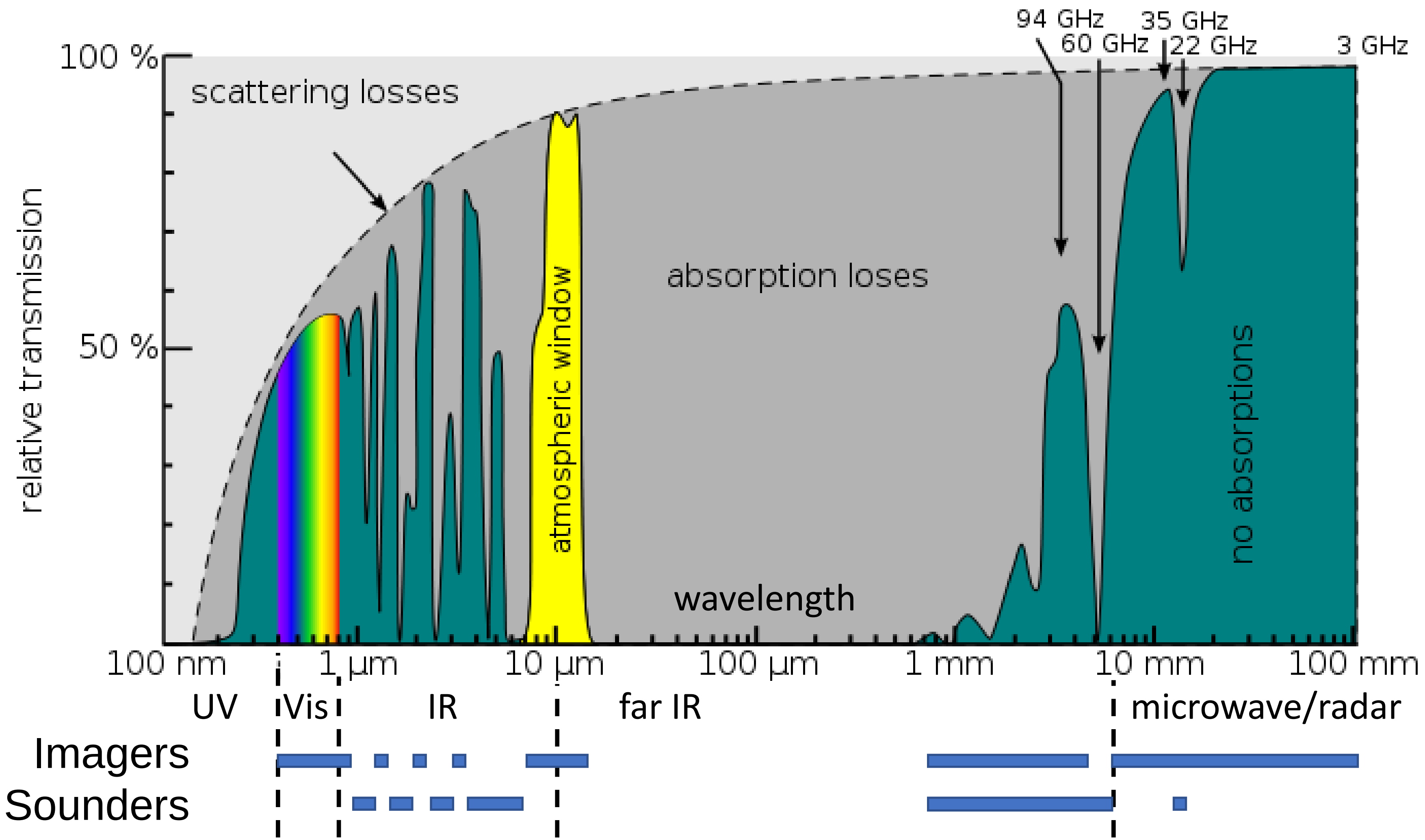
42” x 19” 270lbs
9200 solar cells
Operated for 78 days

TIROS-9 Global Mosaic

450 photos taken on 13th February 1965
Operated for 1,238 days
Early images were photographs, mosaiced together

Modern-day observations provided by multi-satellite, multi-sensor systems

The Electromagnetic Spectrum



Observations for precipitation exploit particular parts of the spectrum:

- Visible (reflection)
- Infrared (emissions)
- Microwave (passive=emissions)

Different regions of the spectrum exhibit different radiative characteristics

Observing precipitation from satellites

Visible (including near IR)

- Reflectance, cloud top properties (size, phase)

Infrared

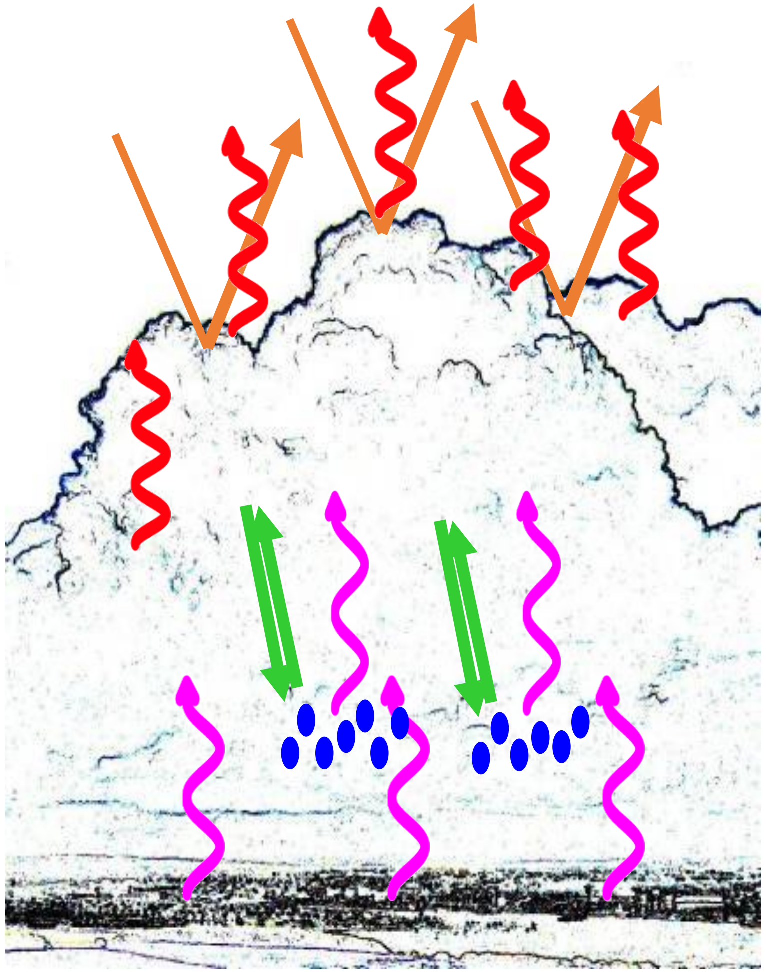
- Thermal emission – cloud top temperatures → height

Passive Microwave

- Natural emissions from surface and precipitation *(emission and scattering)*

Active Microwave

- Backscatter from precipitation particles



Visible (0.4-0.8μm)
- cloud delineation, cloud top properties, ~1 km

Infrared (thermal 10-12 μm)
- cloud top temperatures/ properties. ~2 km

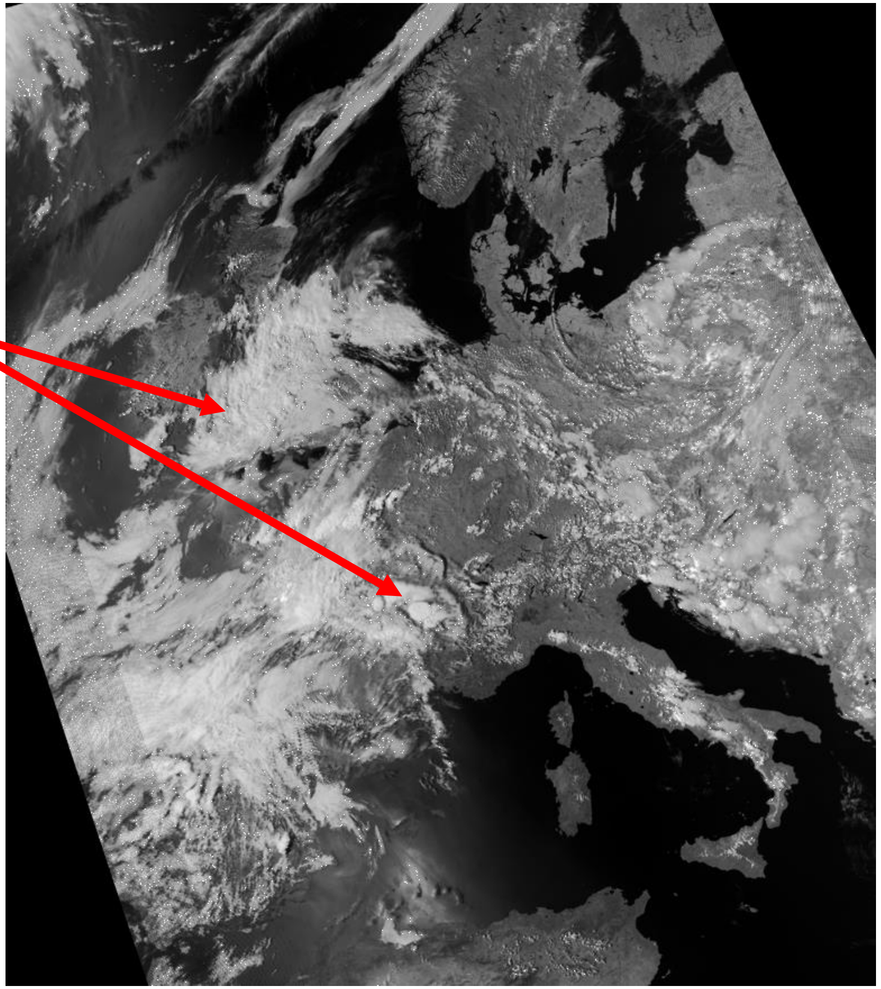
Passive microwave ~6–190 GHz
- imagers – emission/scattering, ~5-70 km frequency dependent
- sounders – absorption/emission 15+km frequency/scan dependent

Active microwave 13/35/94 GHz vertical profiles, ~ 1-5 km/250m

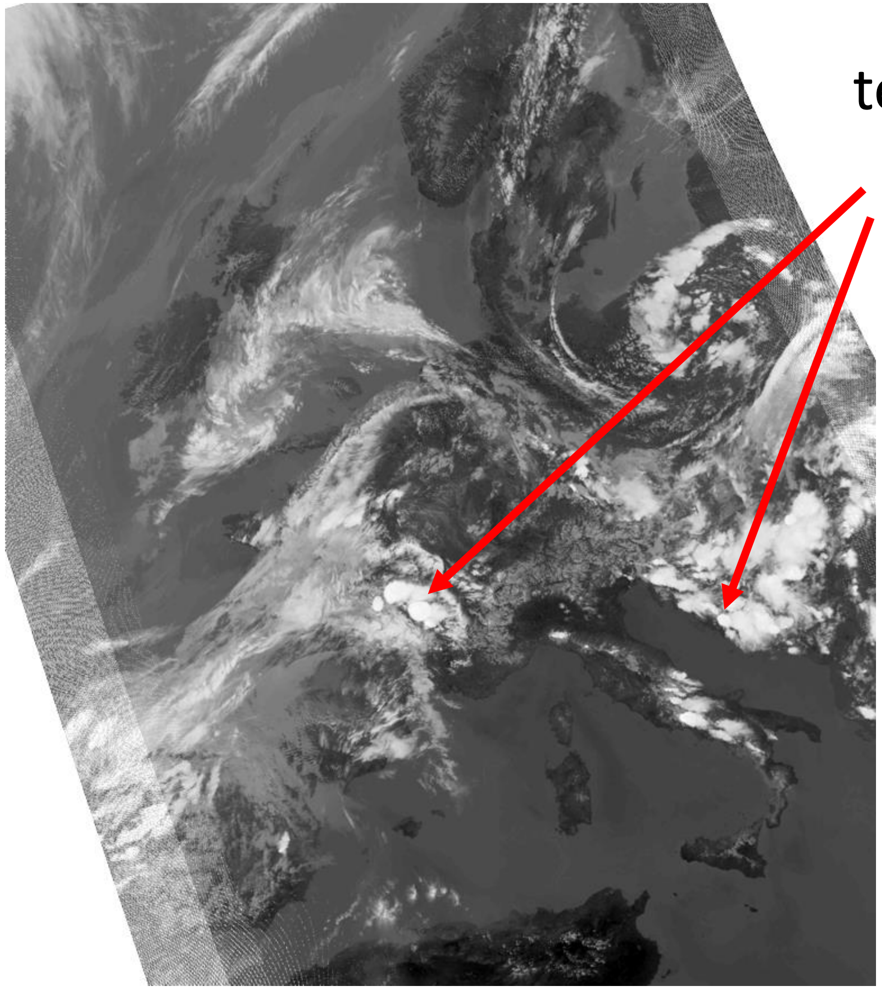
Microwave observations provide the most direct measurements

Visible/Infrared Imagery

Delineation of clouds



Channel 2, visible



cloud top temperatures

identifying cold/deep clouds

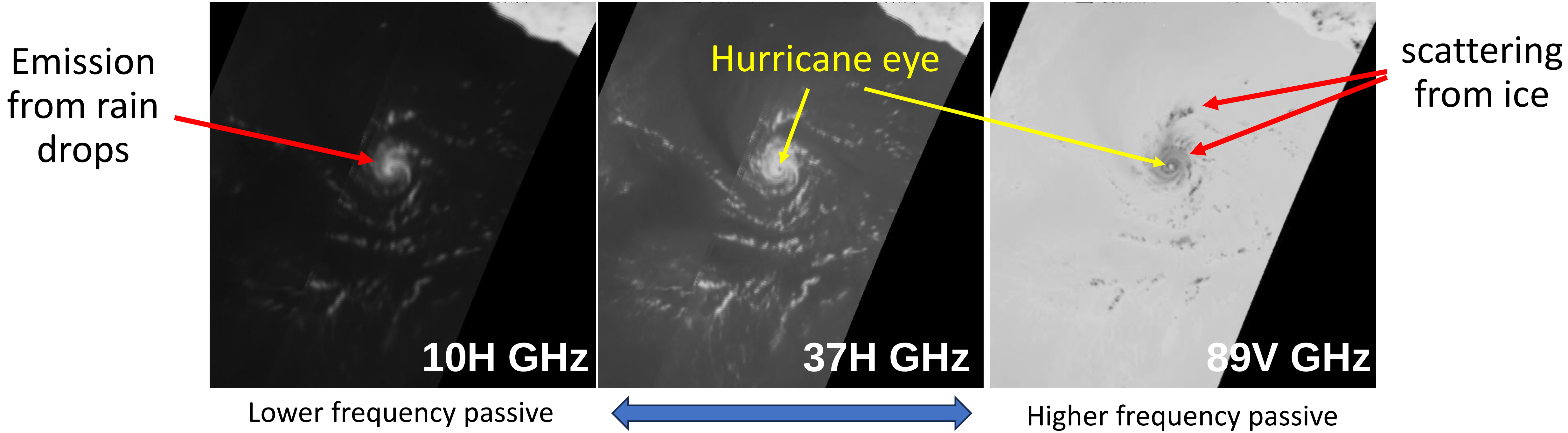
Channel 4, Thermal Infrared *correct/inverted greyscale*

AVHRR 2018-05-25

Passive microwave Imagery

Hurricane Amanda

First eastern Pacific hurricane of 2014 season
Category 4 storm
Captured by GMI on 24 May 2014 at 23:30Z

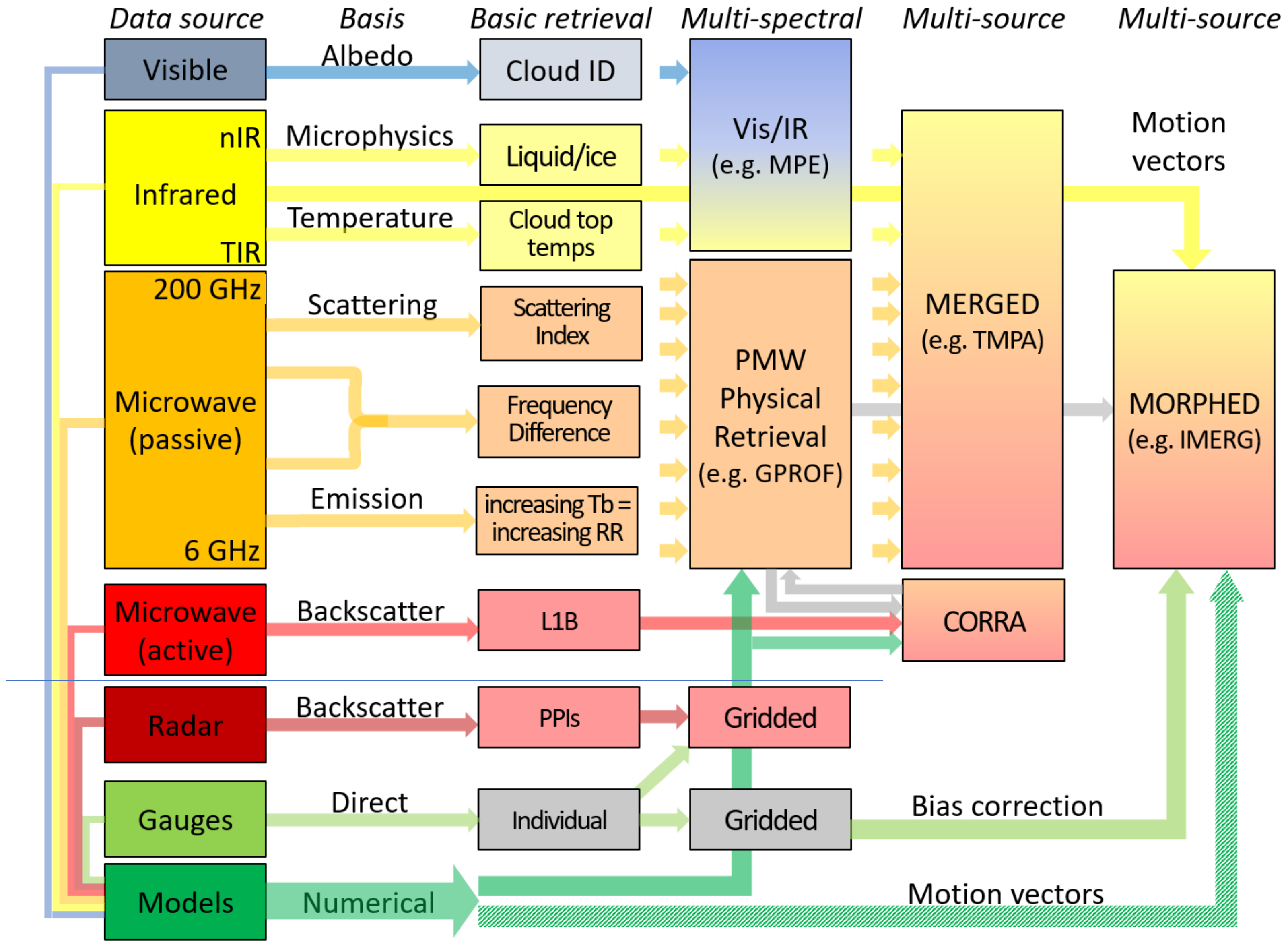


Lower frequency passive microwave responds to emissions from liquid hydrometeors

Transition zone: responds to liquid/ice hydrometeors from thick/deep cloud

Higher frequency passive microwave responds to scattering of the upwelling radiation by ice hydrometeors

Satellite precipitation estimation



Satellite estimates of precipitation encompass a wide range of frequencies together with auxiliary data.

Retrieval of precipitation from satellite observations is complex since the range of precipitation properties and characteristics is large (cloud, rainfall, snowfall, hail).

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

Satellite systems

Satellites form a very broad and dynamic “*system of systems*” but maybe grouped by:

Orbital type:

- Geostationary satellites (GEO)
- Low Earth Orbiting Satellites (LEO)

Frequency/wavelength of observation

- Visible/infrared *(typically grouped together)*
- Passive microwave
- Active microwave (i.e. radar)

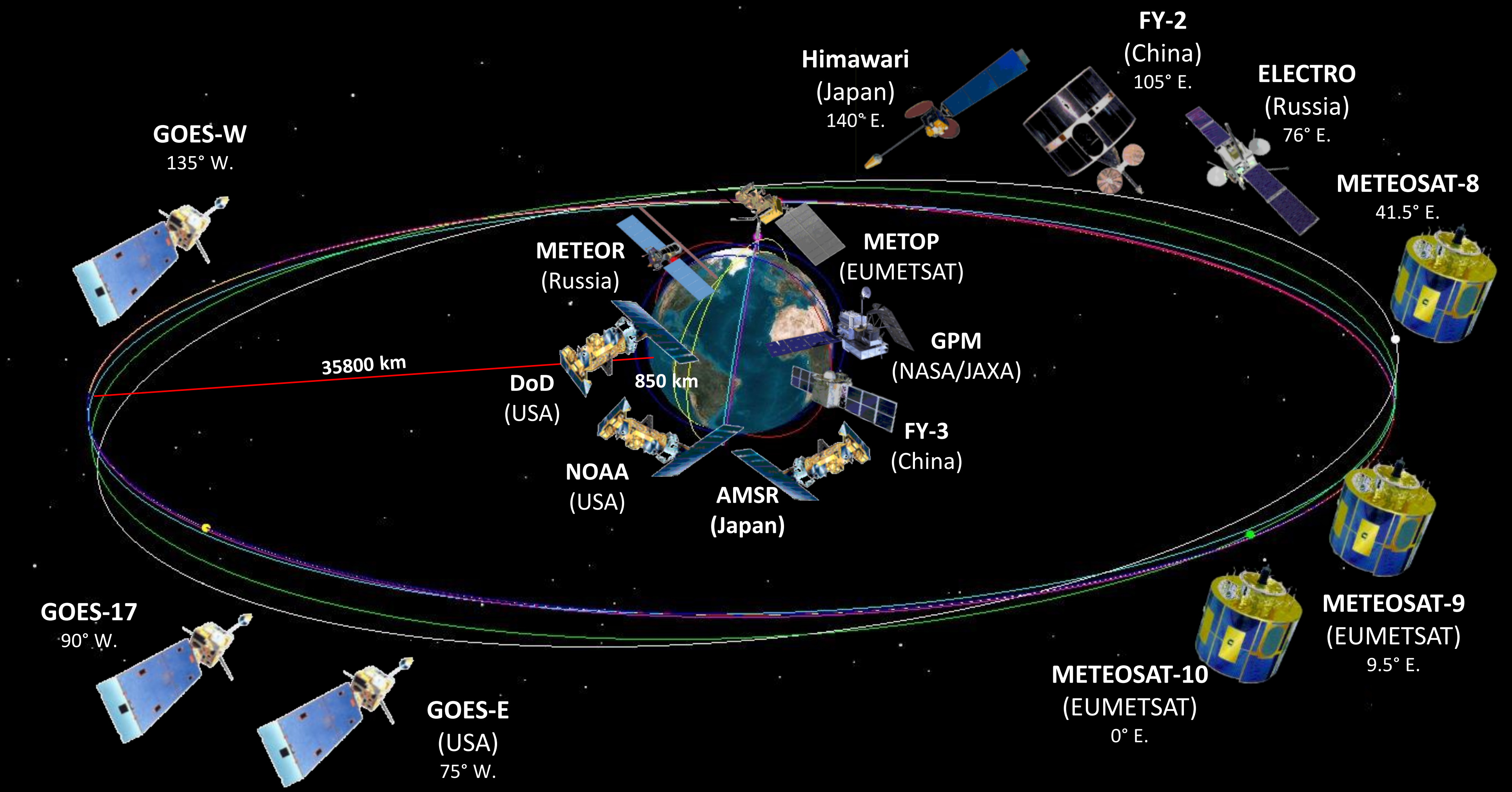
Type of sensor

- Imaging or sounding *(some sensors share same frequencies for both)*
- Conically-scanning or cross-track scanning

By applications

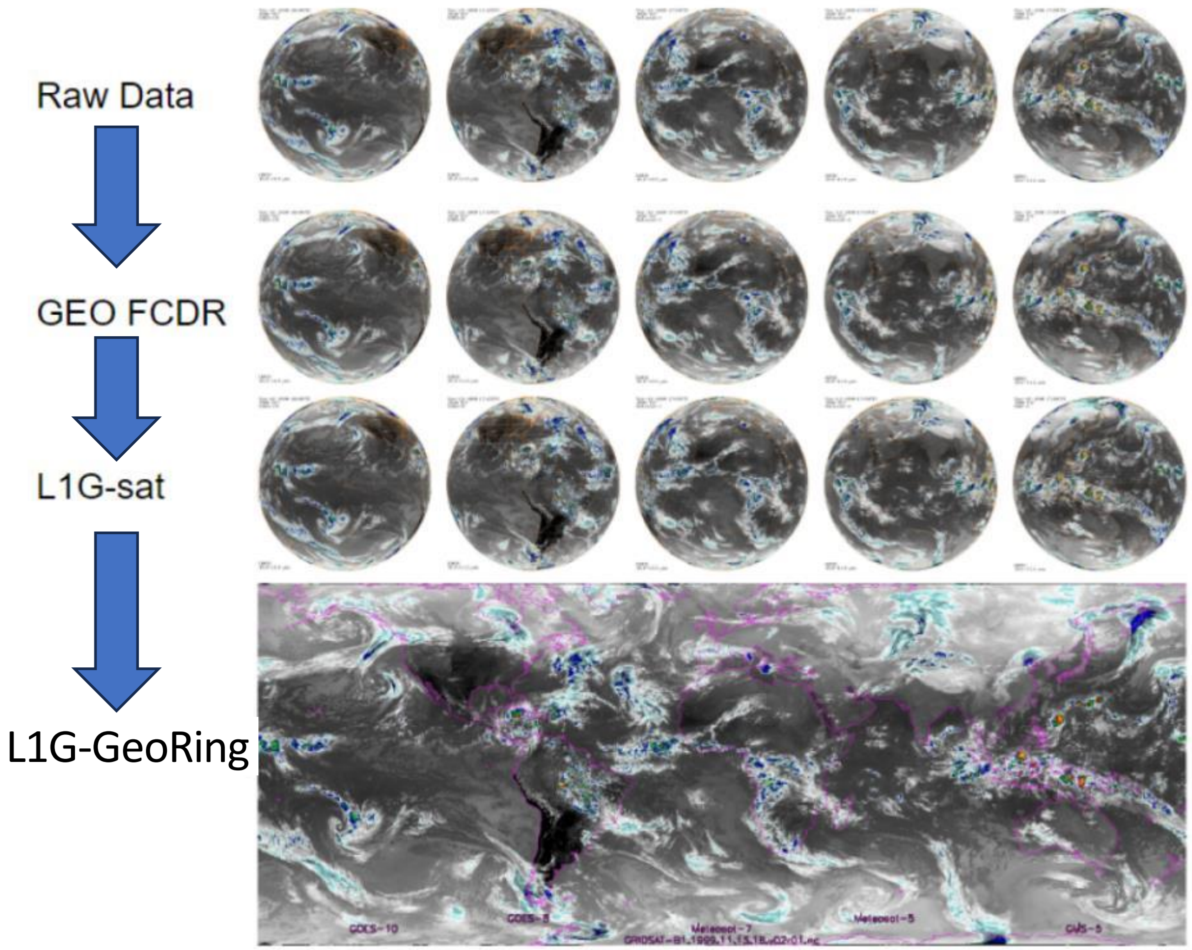
- Cloud (radar), radio occultation (limb sounding), etc.

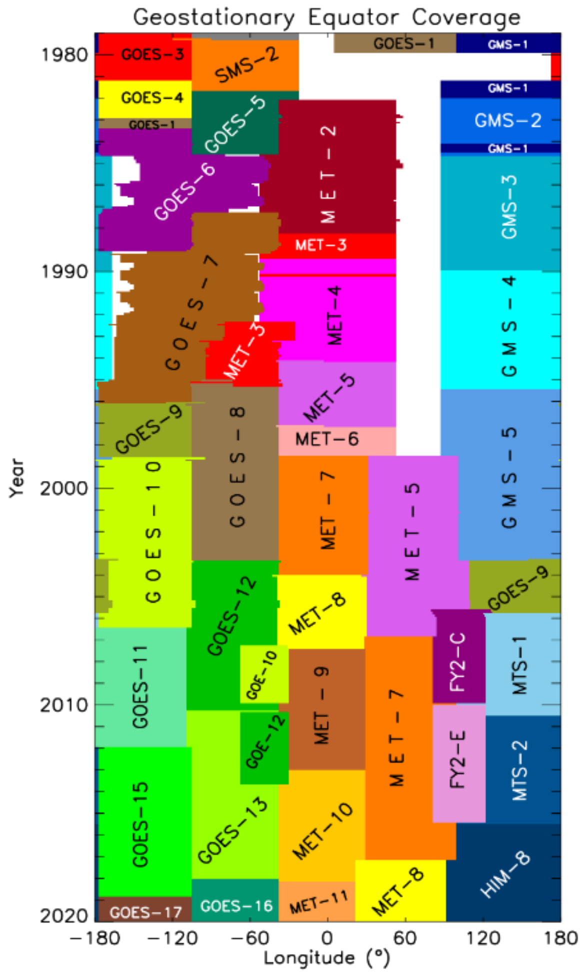
EARTH OBSERVATION SATELLITE SYSTEM (Met)



Low Earth Orbiting systems and Geostationary systems

Geostationary observations

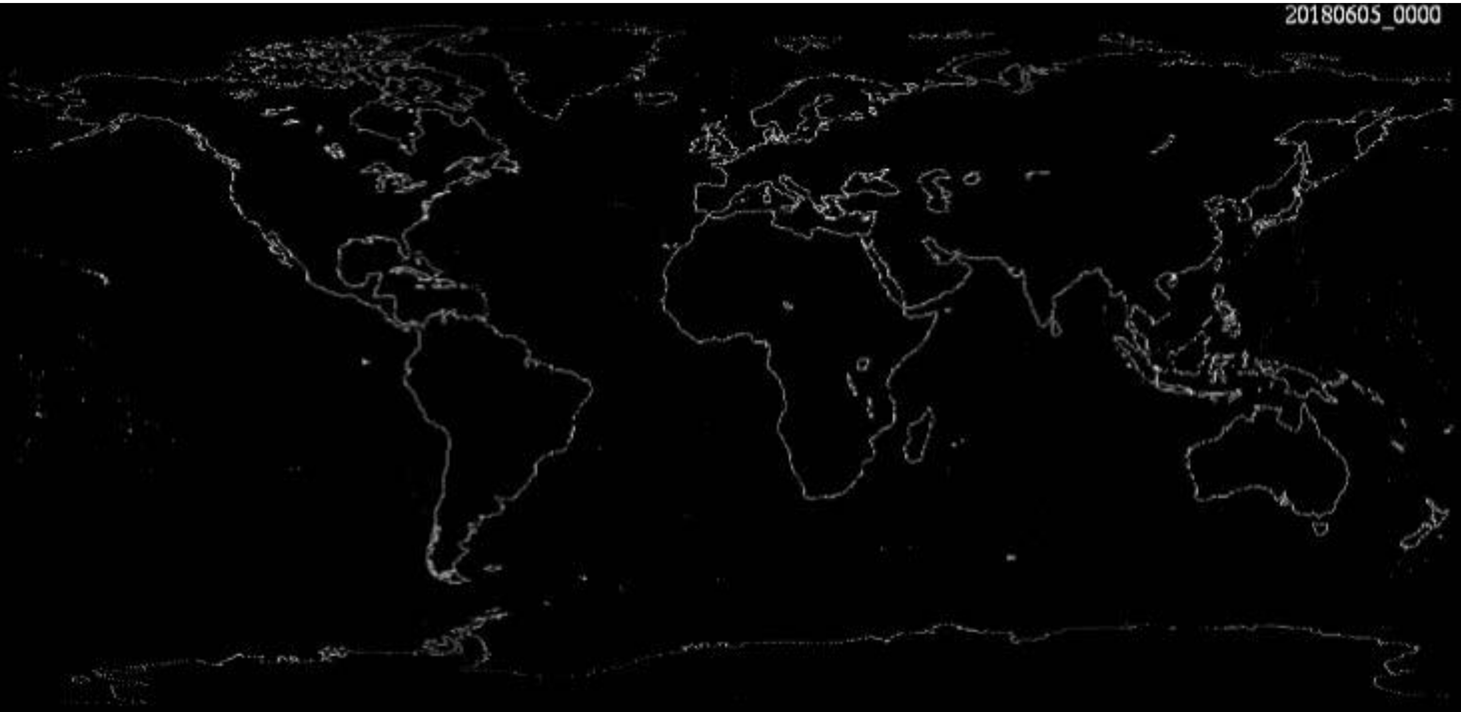




- Geostationary observations in the Vis/WV/IR available since early 1980's
- (easily) available combined products – for IR at least – from 2000 onwards (e.g. CPC Global-IR 4km)
- 30-min baseline temporal resolution
- New effort to provide multi-spectral data through GEO-Ring project for whole GEO-period.

Vis/IR GEO-observations are an integral part of global precipitation measurement primarily due to their temporal sampling and good spatial resolution

NPP AVHRR 2018-06-05



ascending

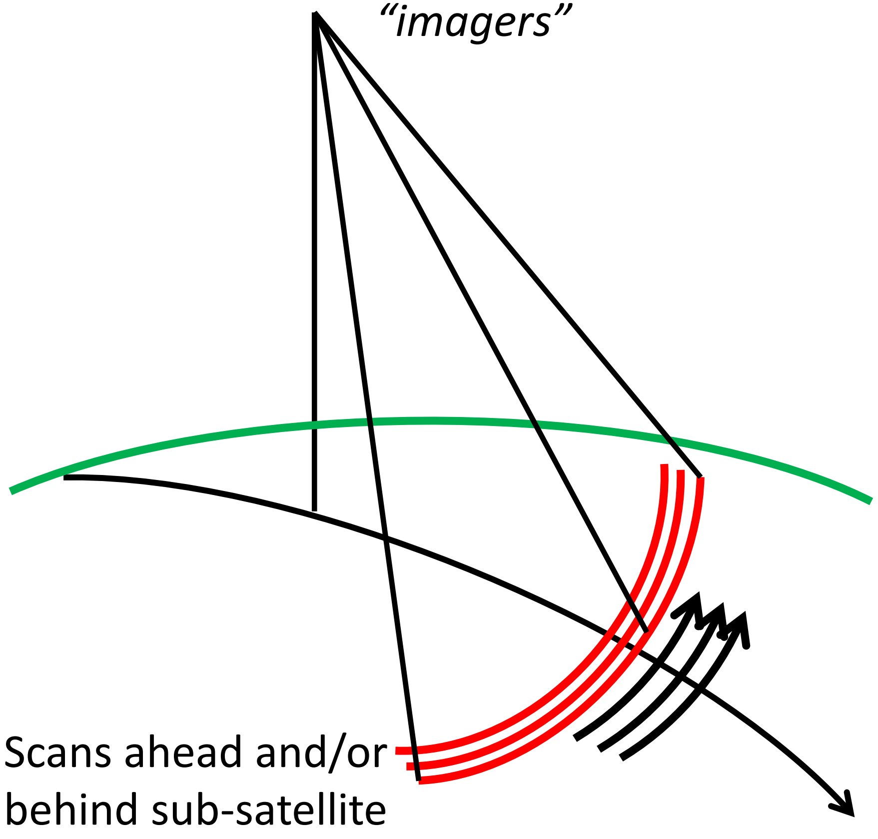
descending

Scan Geometry

E.g.
GMI
AMSR-2
SSMIS
WSF-M
COWVR

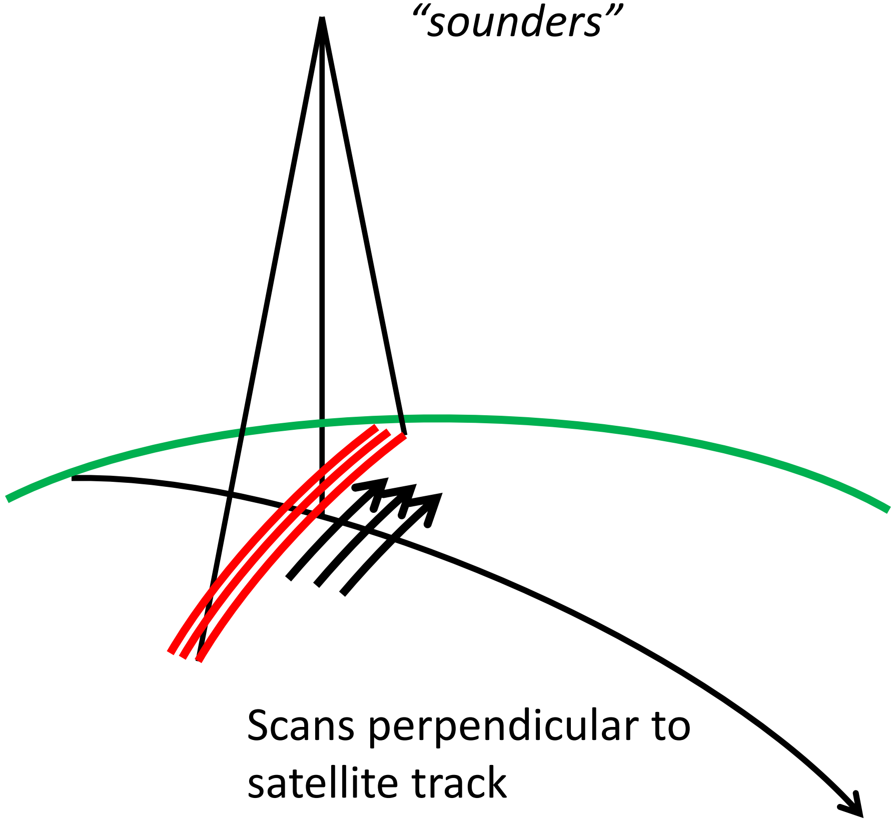
Conical

"imagers"



Cross-track

"sounders"



E.g.
MHS
ATMS
TMS
DPR
TEMPEST

GEO sensors are essentially cross-track sensors

consistent: variable:

polarisation, resolution, Earth-incidence angle, atmospheric path

Passive Microwave Characteristics

Radiation received by the satellite sensor relates to surface radiation and of atmospheric particles:

- atmospheric path length
- spatial resolution (partial beam filling)
- observational frequency

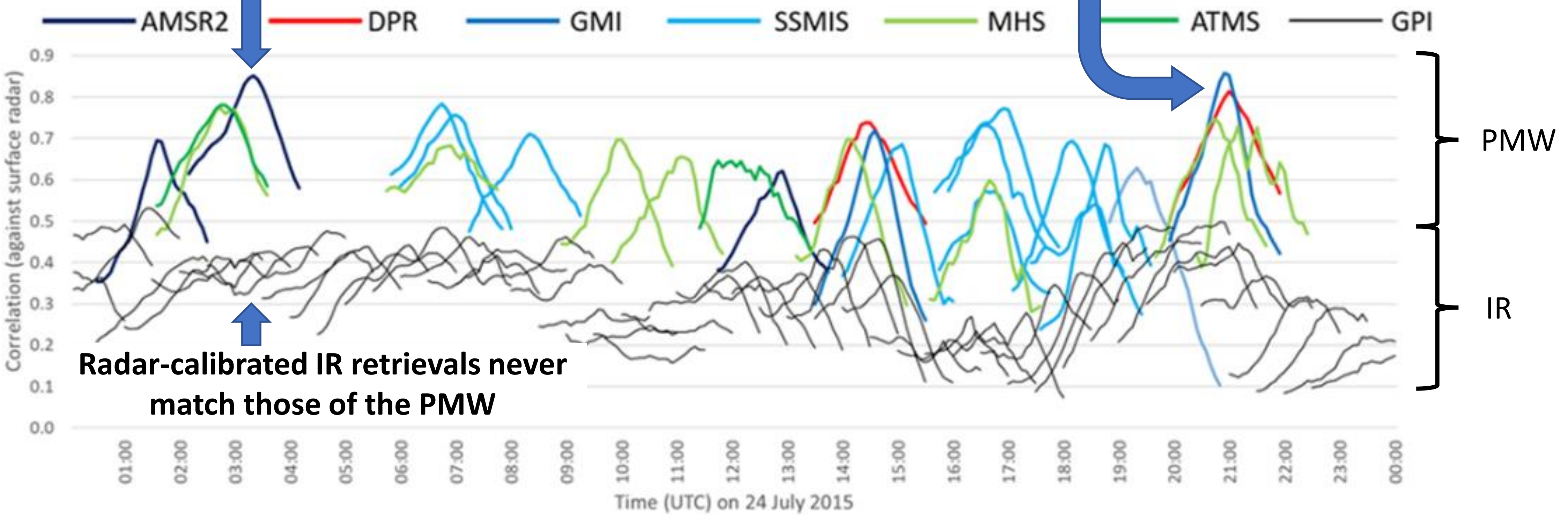
- Radiation is a product of the temperature and emissivity of the emitter – and termed ‘brightness temperatures’
- Different surfaces/particles will react differently across the frequency spectrum: a particle may contribute to emission at one frequency, but scatter at another
- Imaging sensors can measure the polarization (V or H)

Precipitation-sized particles that are sensed, not the cloud tops.

Why the reliance on passive microwave?

Satellite:surface correlations peak at time of observation

correlations decline markedly away from time of observation



Radar-calibrated IR retrievals never match those of the PMW

Instantaneous passive microwave retrievals are more direct than IR retrievals and are generally very good but temporal sampling greatly decreases their impact

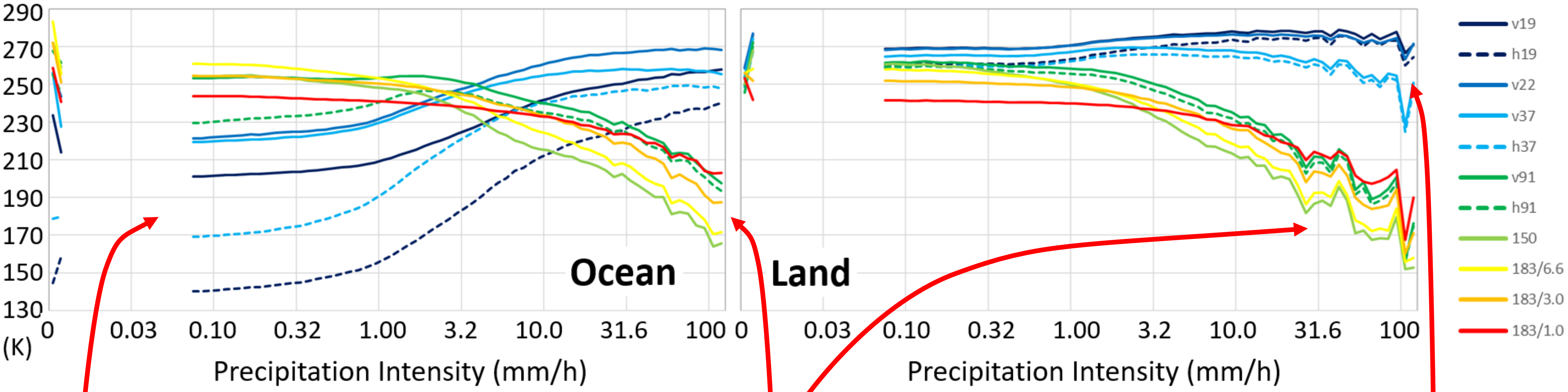
Tb-precipitation intensity relationship

Ocean:

LFs – increasing Tbs - emission from liquid precip.
HFs – scattering from ice – higher intensities

Land:

LFs – emission from liquid precipitation largely masked
HFs – scattering from ice hydrometeors at high intensities

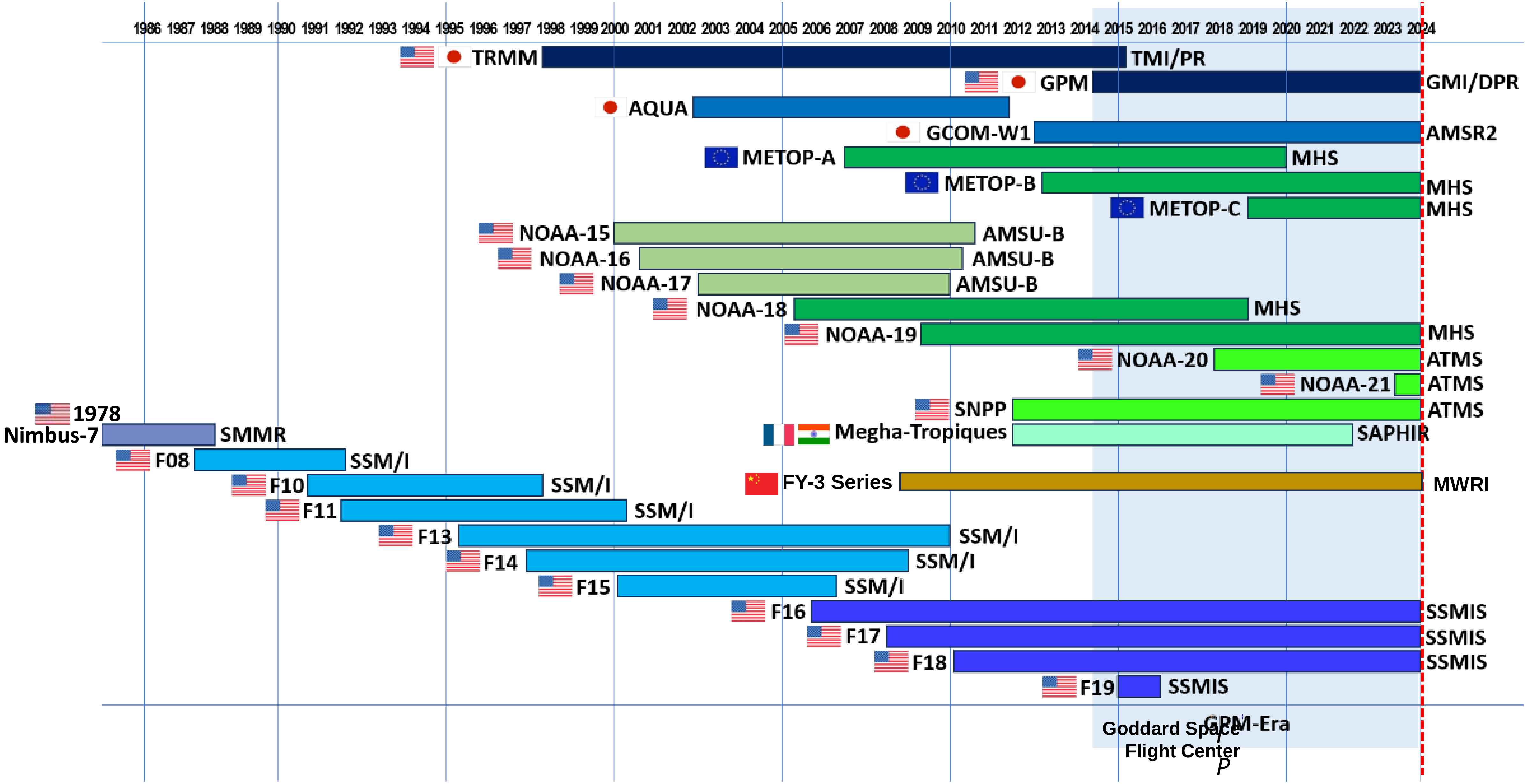


Increasing Tbs with increasing precipitation intensity due to emission from liquid hydrometeors

Decreasing Tbs resulting from increased scattering caused by ice particles

Slight increases in Tbs with precipitation intensity at 19 GHz, some tail off at 37 GHz due to scattering

Evolution of satellite precipitation observations



I
P
W
G

Mapping Global Precipitation

Why do we need more than just one satellite/sensor?

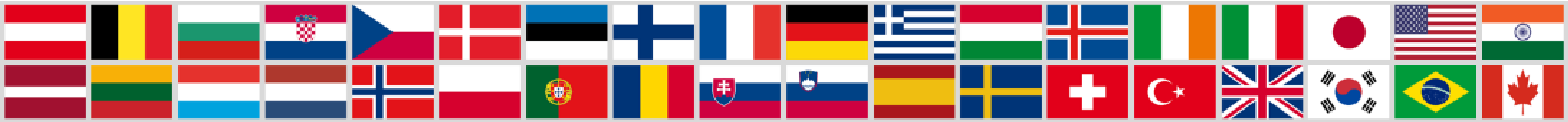
Precipitation varies greatly in time and space – often over just a few miles/km or a few minutes.

The single sensors can provide high-quality measurements, but it cannot measure global precipitation alone

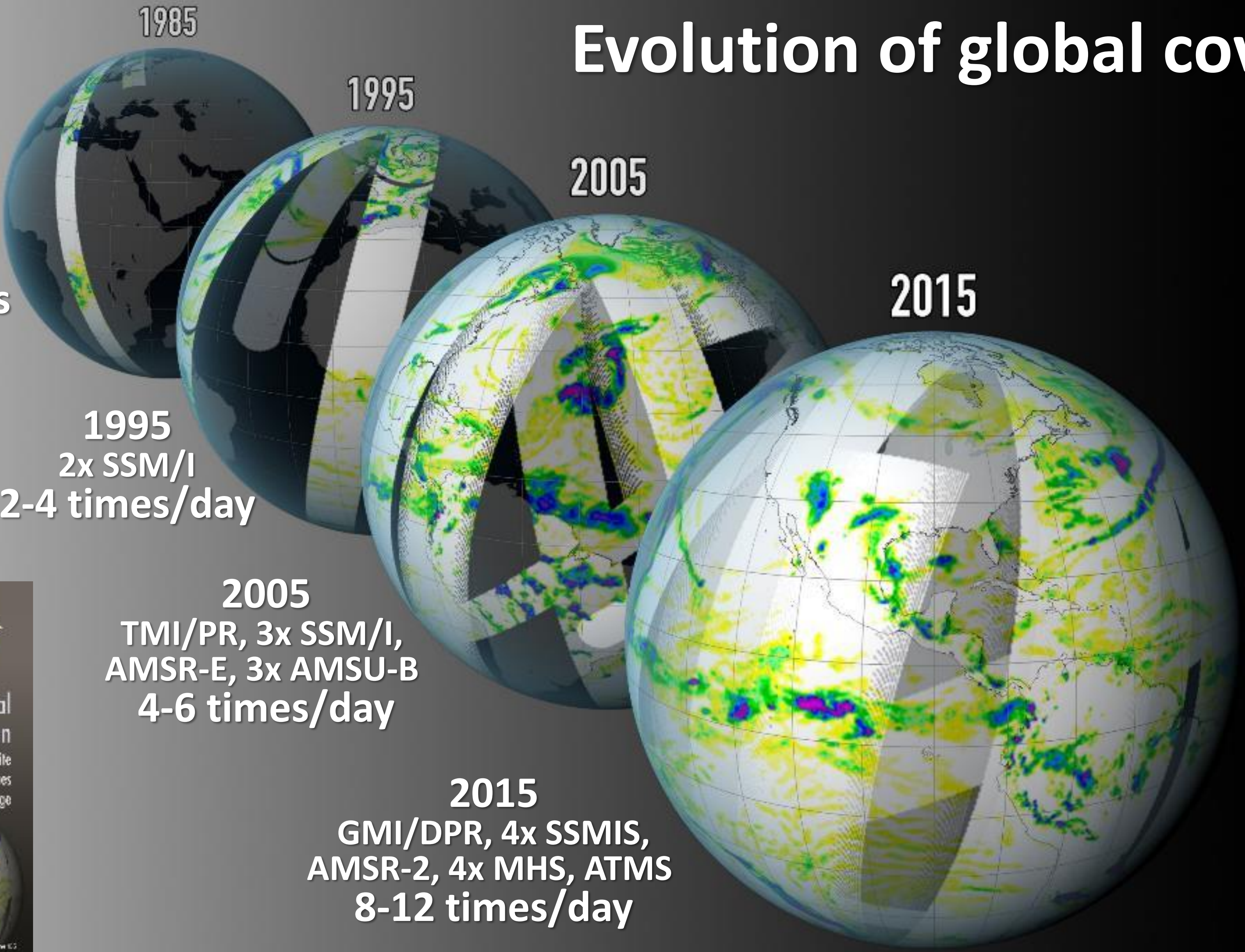
GPM-Core and international partner missions

Agencies and organisations – both national and international – with precipitation-capable missions make their data available.

United States (NASA, NOAA, DoD), Japan, 30 member states of EUMETSAT and India have been or are involved with GPM, and many more counties contributing to the GPM ground validation.



Evolution of global coverage

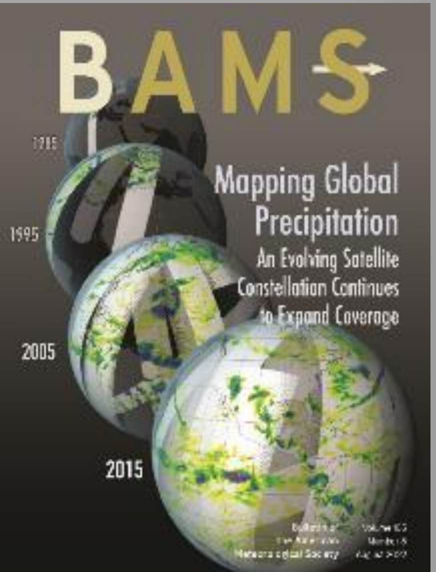


1985
SMMR
Twice/6 days

1995
2x SSM/I
2-4 times/day

2005
TMI/PR, 3x SSM/I,
AMSR-E, 3x AMSU-B
4-6 times/day

2015
GMI/DPR, 4x SSMIS,
AMSR-2, 4x MHS, ATMS
8-12 times/day

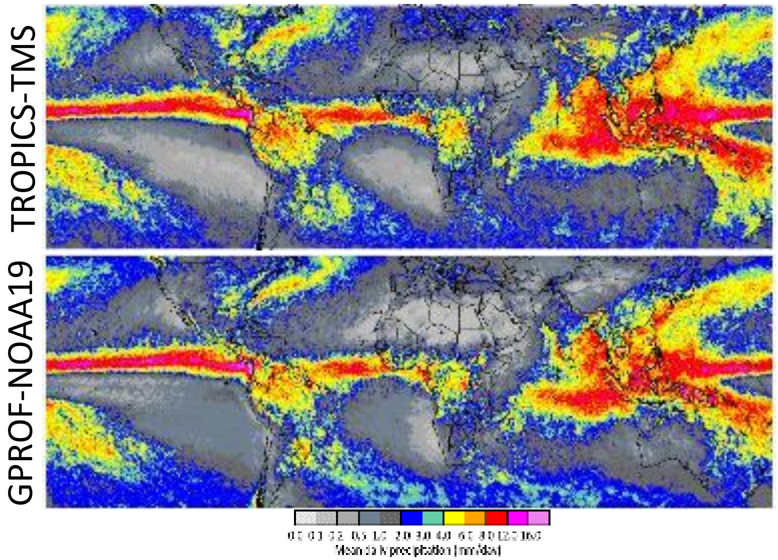


The rise of the cubesat/smallsats

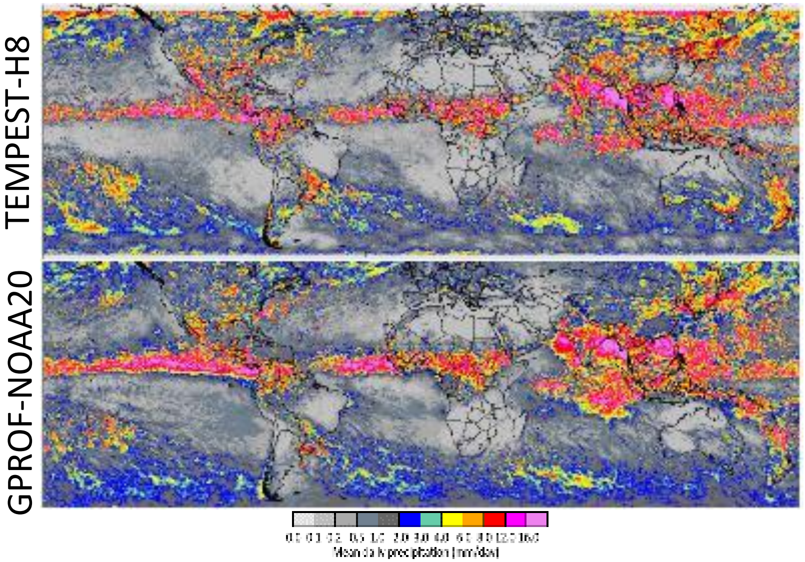
New technology has enabled smaller PMW sensors to be developed – as demonstrated by the TEMPEST and TROPICS-TMS sensors.

- Operating at frequencies from ca.89 to 183.31/204.8 GHz with resolutions similar to current PMW sounding instruments.
- Results to date are very encouraging, showing that basic retrievals are comparable with retrievals from current sensors.
- Results currently being fully evaluated (e.g. HF retrievals vs all-channel retrievals).

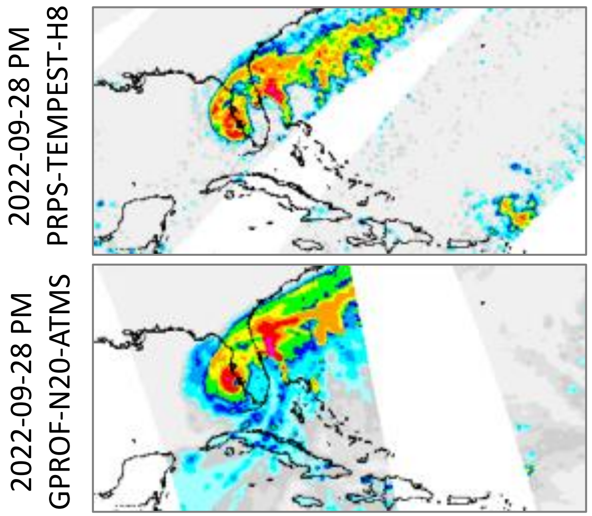
Mean annual precipitation (Aug'21-'22)



Monthly: August 2022



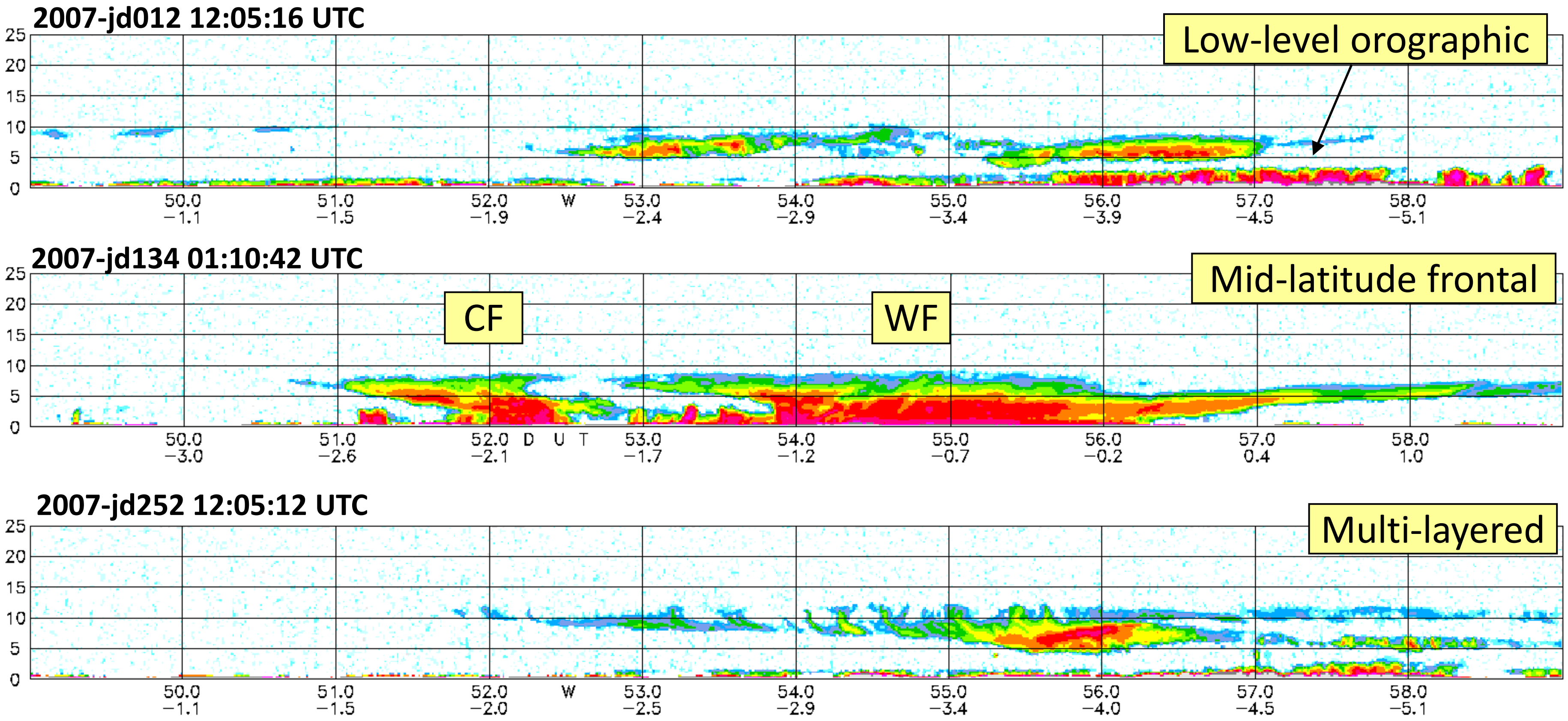
Hurricane Ian



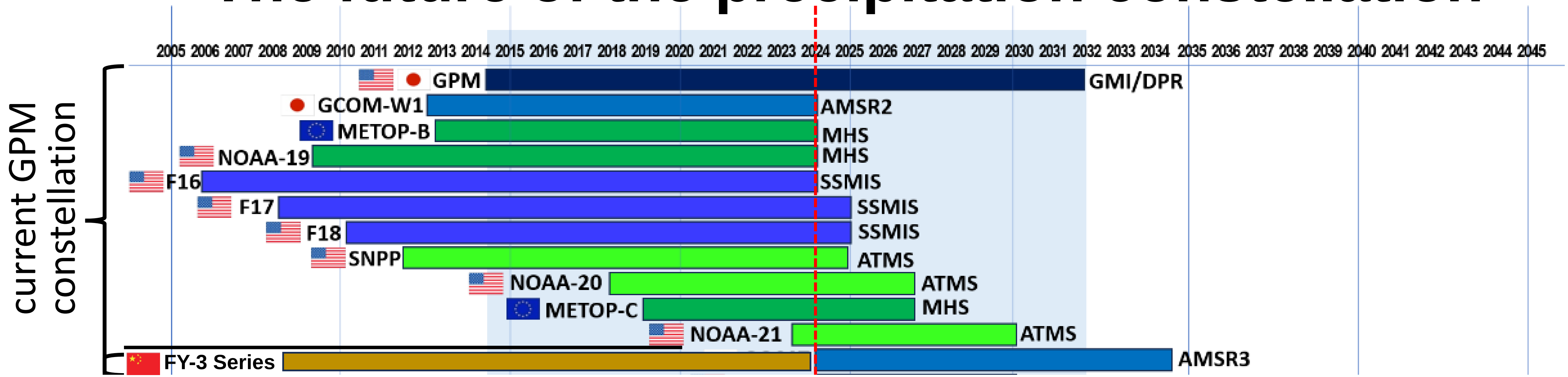
CloudSat CPR Profiles *(UK examples)*

CloudSat carries a Cloud Profiling Radar (CPR) operating at 94 GHz.

Although designed primarily for cloud studies, data/products from the CPR have proved invaluable for identifying and quantifying light rainfall and snowfall.



The future of the precipitation constellation



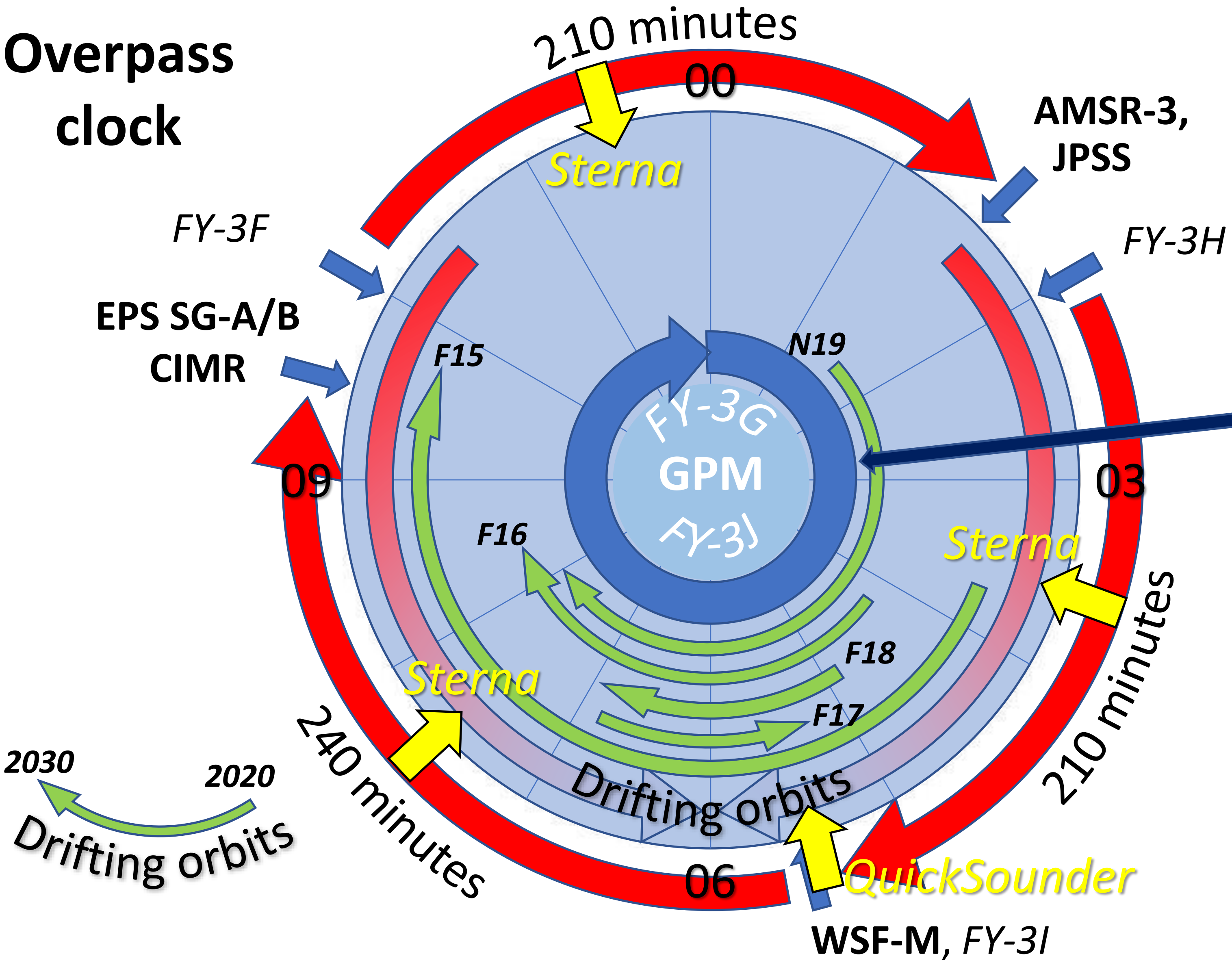
Updates and Recent launches

- GCOMW/AMSR2 12th anniversary, GPM/GMI-DPR 10th anniversary
- GPM – orbital boost, November 2023
- First precipitation radar deployment from commercial data provider, April 2023
- FY-3G Precipitation Radar, April 2023
- US DoD WSF-M1, launched 11 April 2024
- EarthCARE launched (Vandenberg, California), 28 May 2024.
- GOES-U, 25 June 2024

Future missions

- EUMETSAT Arctic Weather Satellite (AWS) July 2024
- JAXA GOSAT-GW with AMSR-3 in JFY2024
- EUMETSAT Polar System (EPS) Second Generation (SG) with MicroWave Sounder (MWS) and MicroWave Imager (MWI) and Ice Cloud Imager (ICI) and EPS-Sterna (in its Phase B).
- NOAA QuickSounder (2026), JPSS-4 (2027), JPSS-3 (2032), LEO Weather Satellites (LWS, 2030+), GeoXO (2032+)
- Atmosphere Observing System – International collaborative missions in a "Decoupled Architecture": *6 spacecraft and 4 launches, with JAXA PMM (precipitation radar) – precipitation processes.* (NASA/JAXA/…)
- ESA Copernicus Imaging Microwave Radiometer, CIMR. (2028+)

Future PMW radiometer constellation ca.2028-2030



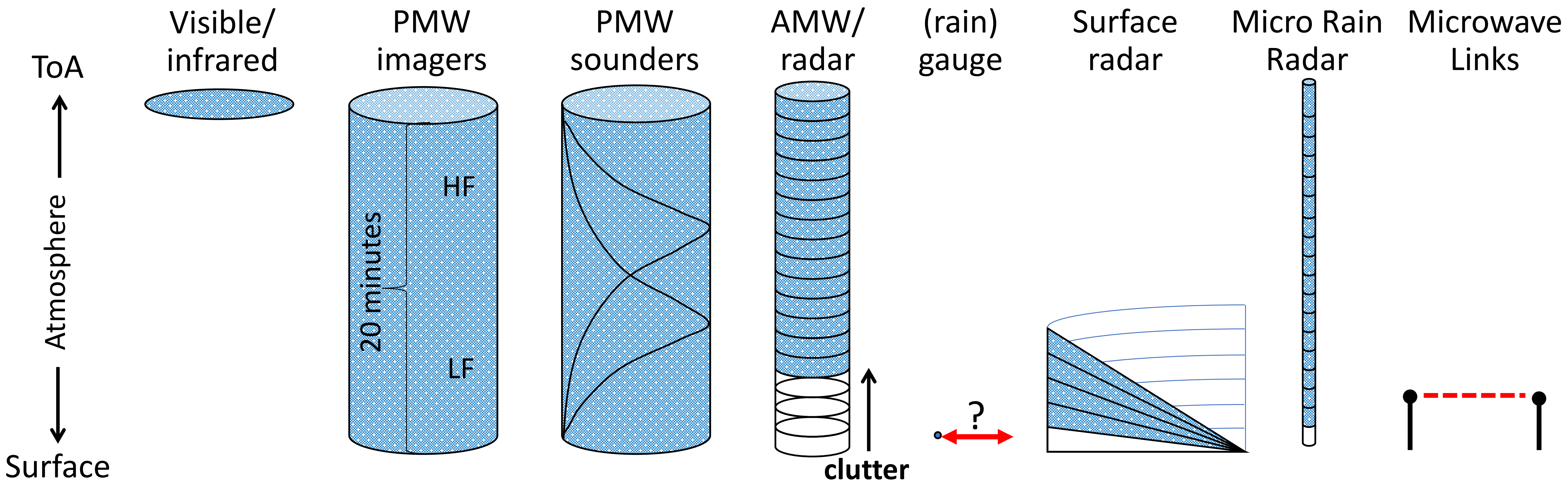
There are significant temporal gaps in coverage which could be filled with smallsats/cubesats.

A low-inclination 'calibrator' sensor(s) is critical for any constellation

Note: this assumes:

- no orbital drift (newer missions?)
- no continuation of current missions
- no Russian Meteor series

Final Notes #1: Observing precipitation



Different systems observe things differently – spatially, temporally and physically:
there are good, fundamental reasons why precipitation measurements should vary.

Final Notes #2: Vis/IR and microwave summary

Visible/IR relationships

Visible: Albedo, thickness

nIR: Particle size/type

thIR: Cloud top temperatures/height

Microwave relationships

Emission from hydrometeors over radiometrically '*cold*' backgrounds

Scattering by hydrometeors over radiometrically '*warm*' backgrounds

Visible/IR retrieval techniques

Thresholding of cloud-top temperatures (cold clouds=rain)

Cold cloud duration

Empirical calibration of thIR

Multi-spectral analysis

Neural Networks

Microwave techniques

Empirical techniques use surface/reference data for calibration

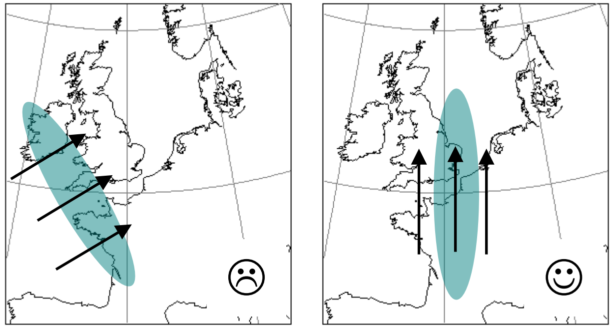
Physical techniques, Radiative Transfer Modelling of MW energy through the atmosphere (e.g. **Bayesian techniques** – *a priori* databases derived from Cloud Radiation Models).

Neural Networks

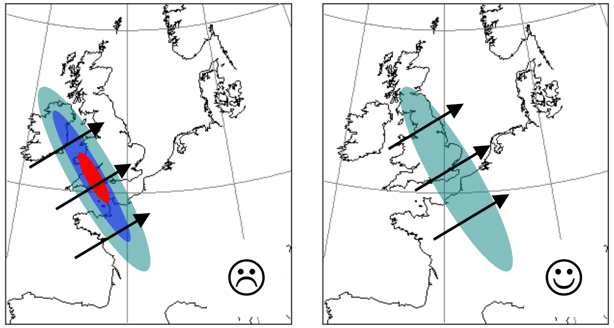
Final Notes #3: Validation of precipitation products

blame it on the weather!

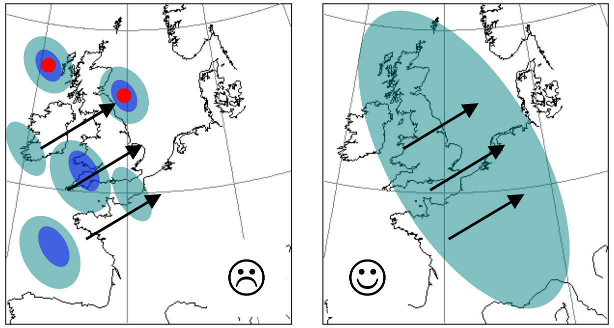
Movement:
Is the movement perpendicular or along the rain band?

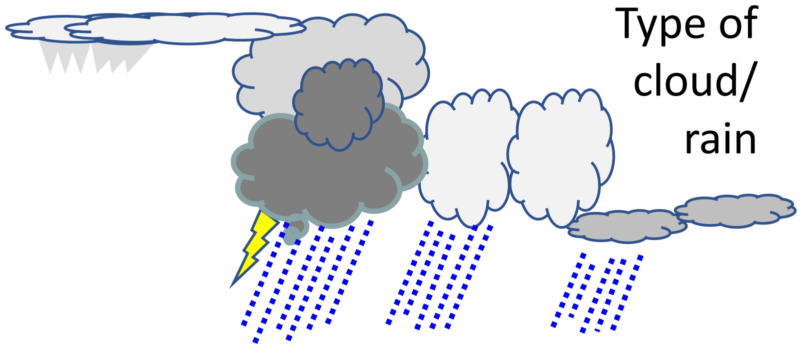


Intensity
What is the range of values within the rain area?

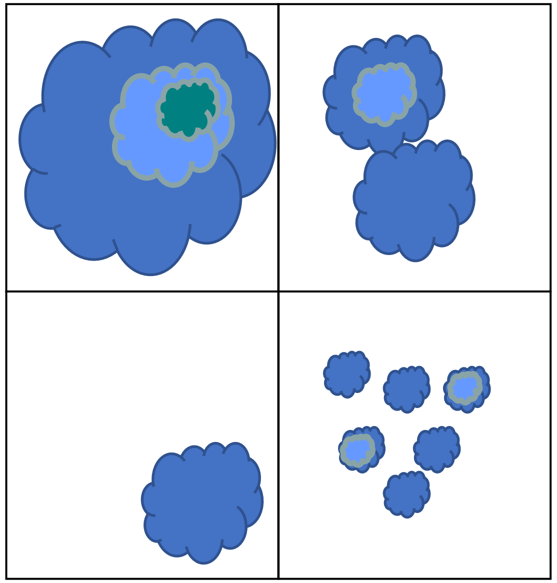


Size/variability
What is the size and variability of the rain area(s)?





Sensor field-of-view



Statistical success has as much to do with meteorology as the algorithm's ability…