Fundamentals of Satellite Precipitation Estimation

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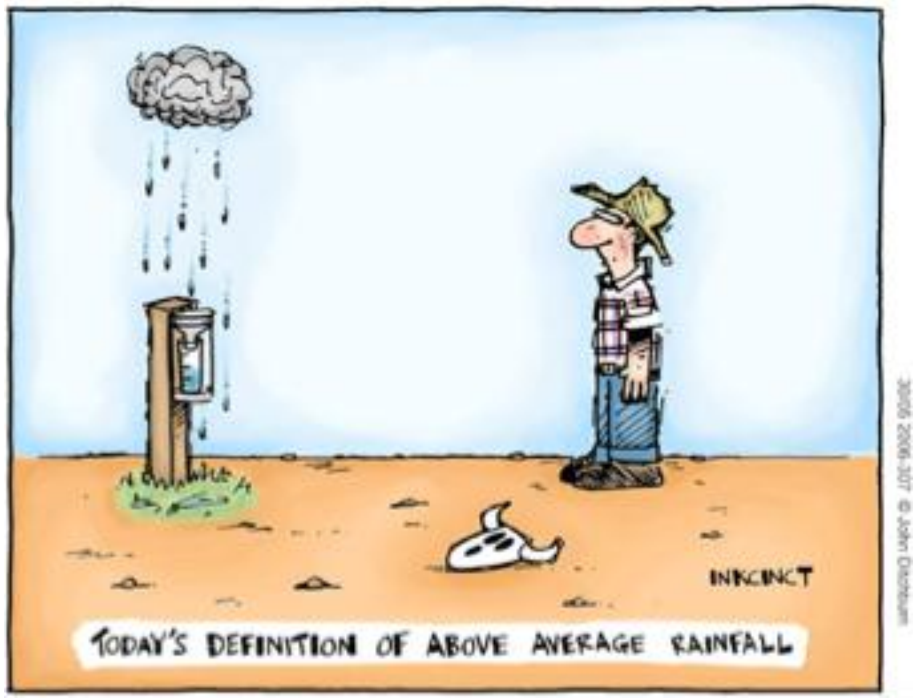
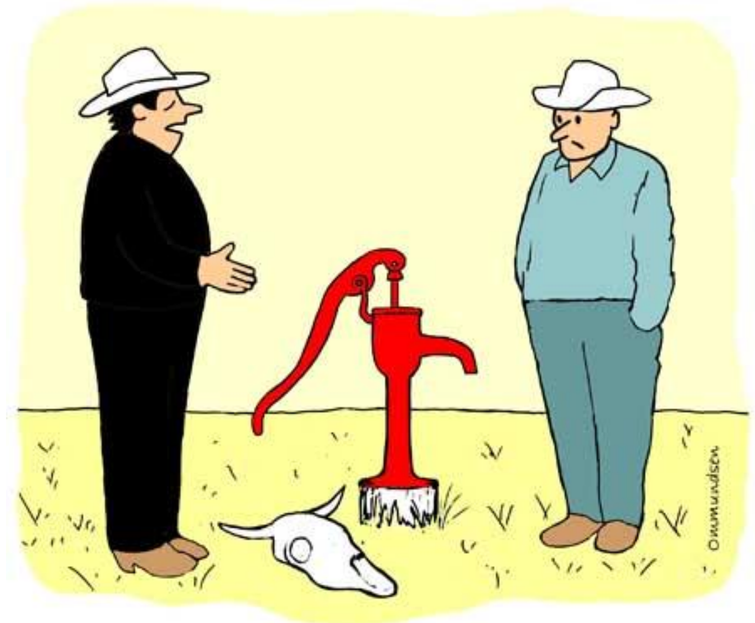
NASA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE
JAXA
Japan Aerospace Exploration Agency
EUMETSAT
esa
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
CSIRO
ECMWF
CONAE
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
EUROPEAN GEOSCIENCES UNION
est. 2002
arpa
agenzia regionale prevenzione e ambiente dell'emilia-romagna
PROTEZIONE CIVILE NAZIONALE
ČHMÚ
IPWG
International Precipitation Working Group
CGMS
WMO
FAO
FIAT PANIS
UNEP

Precipitation…what are we talking about?



...meteorology



"It ain't nothing that a century of rainfall won't fix."

...hydrology

Is it humour or not?

©John Hambrock.

...climate

©King Features Syndicate.

...common sense...

Rainfall Requirements Depend Upon the Application

- Monthly average rainfall, global ($\pm 60^{o}$ latitude), pentad-type (e.g. 2.5-degree boxes), over land/ocean (Climatic shifts? Desertification?)

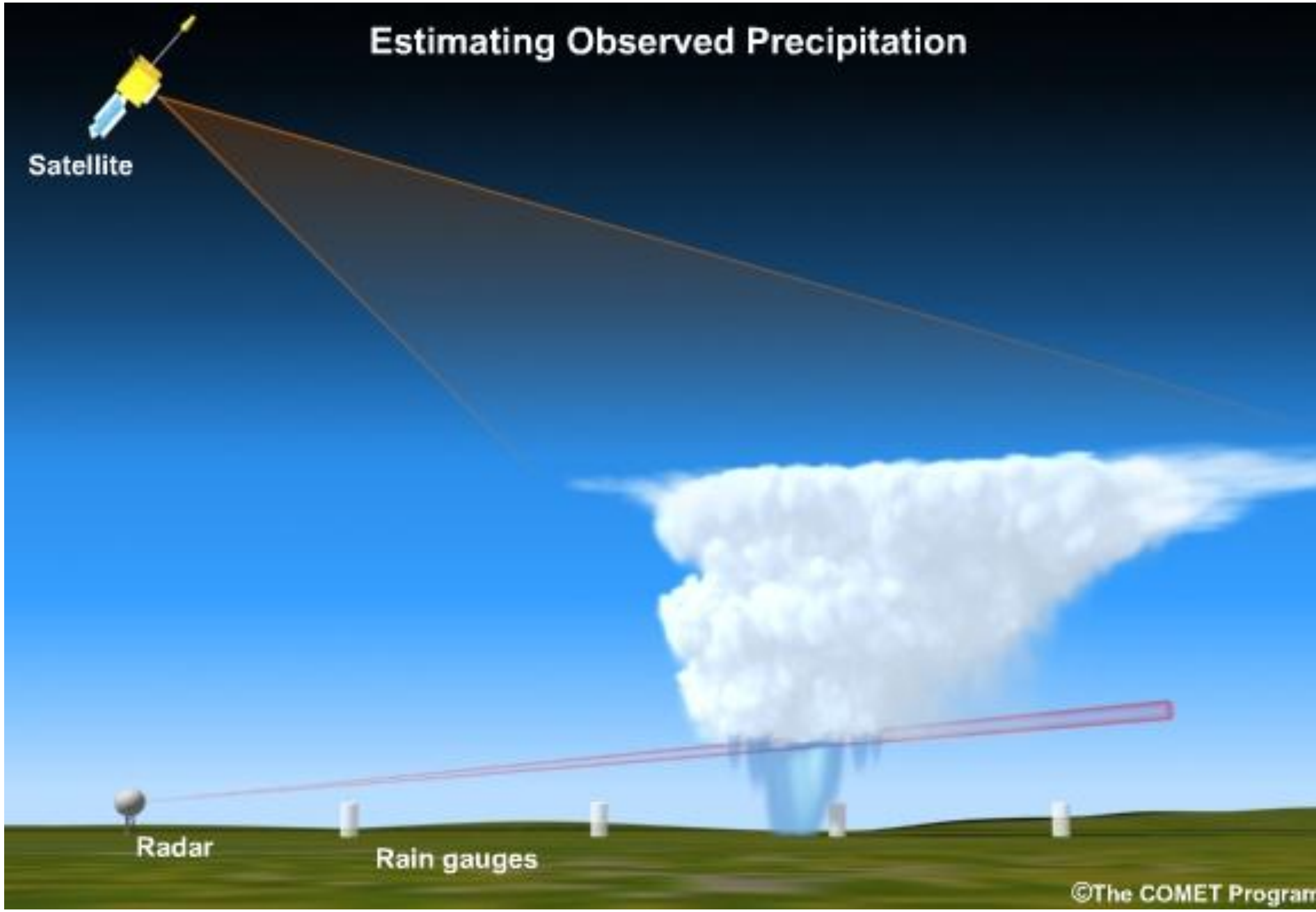
- Daily accumulated rainfall and snowpack, many stations over a watershed (When do I release water from a reservoir? Allocate water distribution?)

- "Single point forecasts" (Will it rain on my wedding day? e.g., mid-afternoon of September 14, 2014 at location 36.84451N and 121.53481W)

- "Realtime" global or regional analysis of rainrate at the best possible horizontal resolution (hydrological models)

- 5-minute updates of point rainfall inside an area (e.g., 10^5 km^2) during the lifetime of a thunderstorm or landfalling hurricane away from coastal radars (Should coastal or low-lying areas be evacuated? Temporarily relocate naval fleet to safe harbor?)

- Any indications that this winter is associated with El Niño conditions? (An energy company, a tree removal company, emergency services)


Estimating Observed Precipitation
Satellite
Radar
Rain gauges
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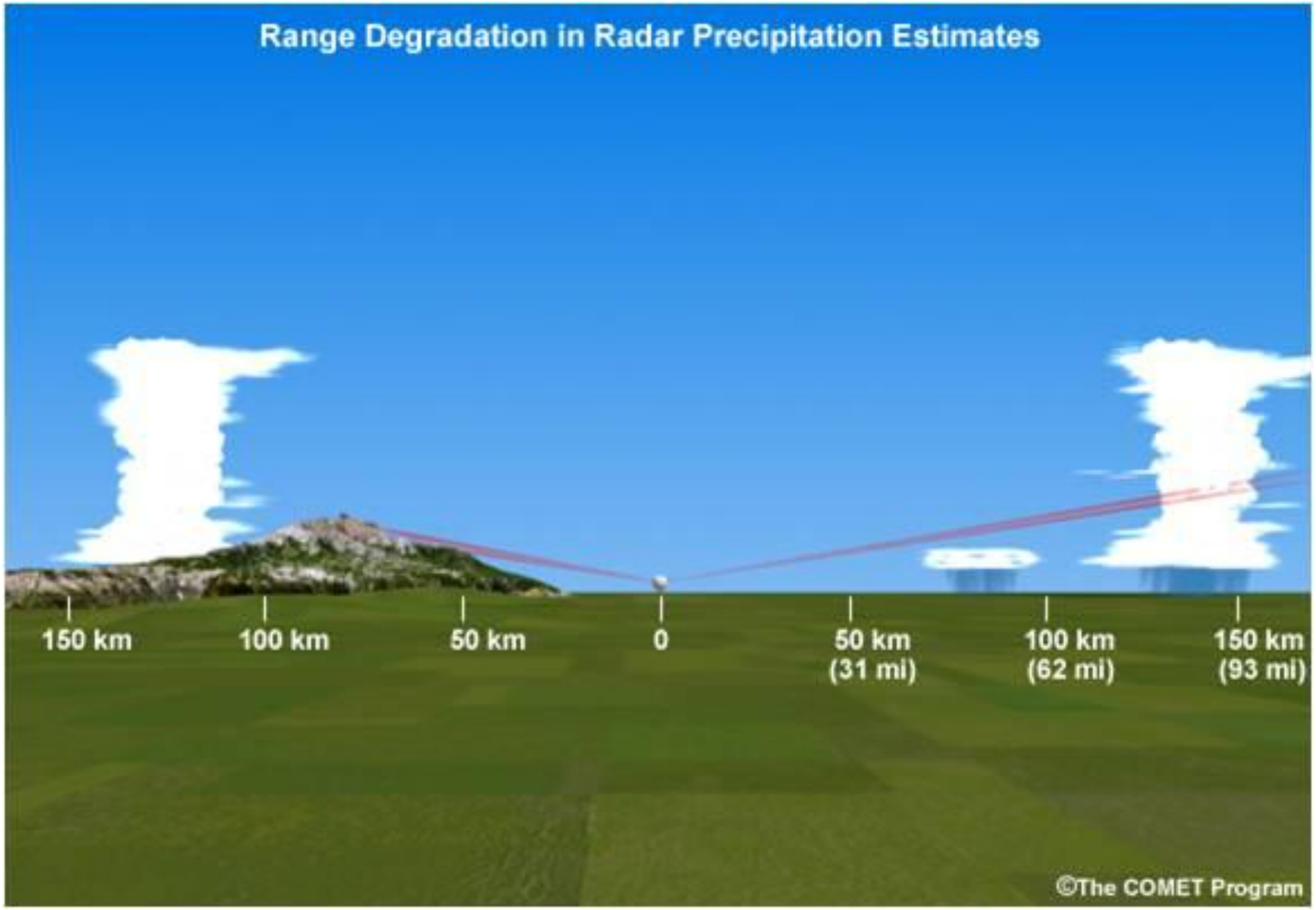
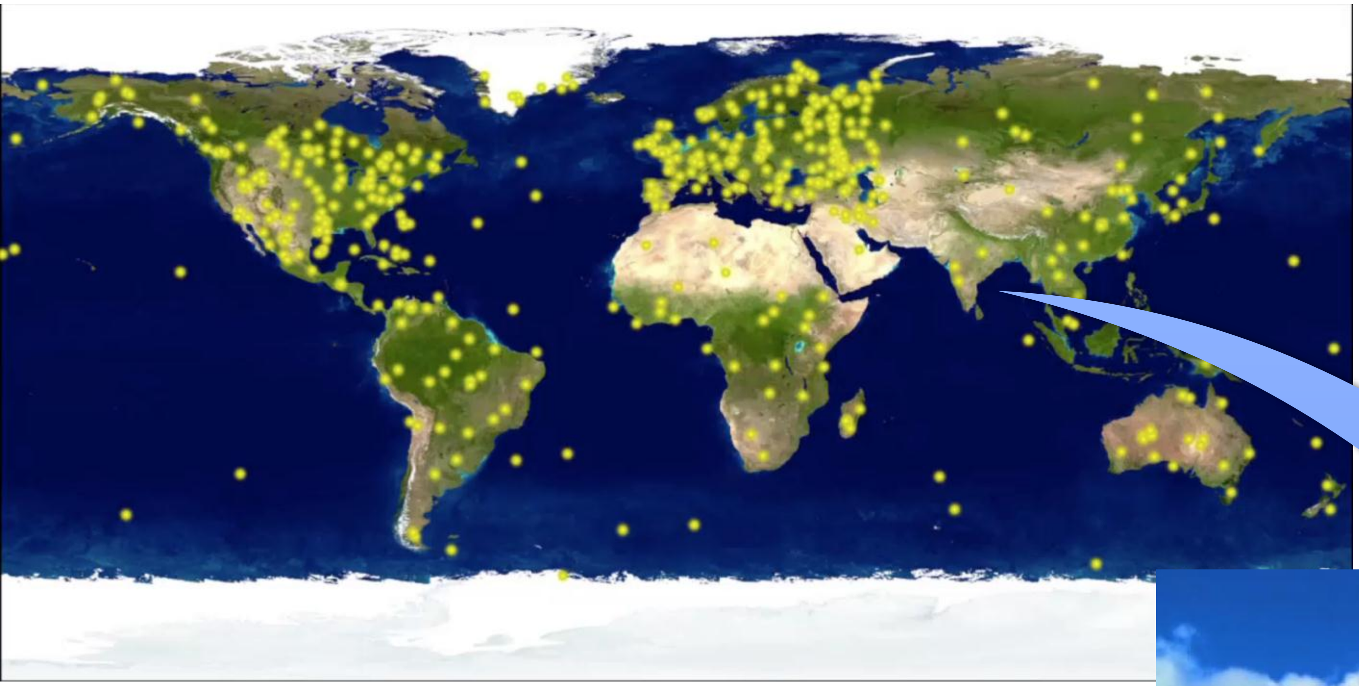
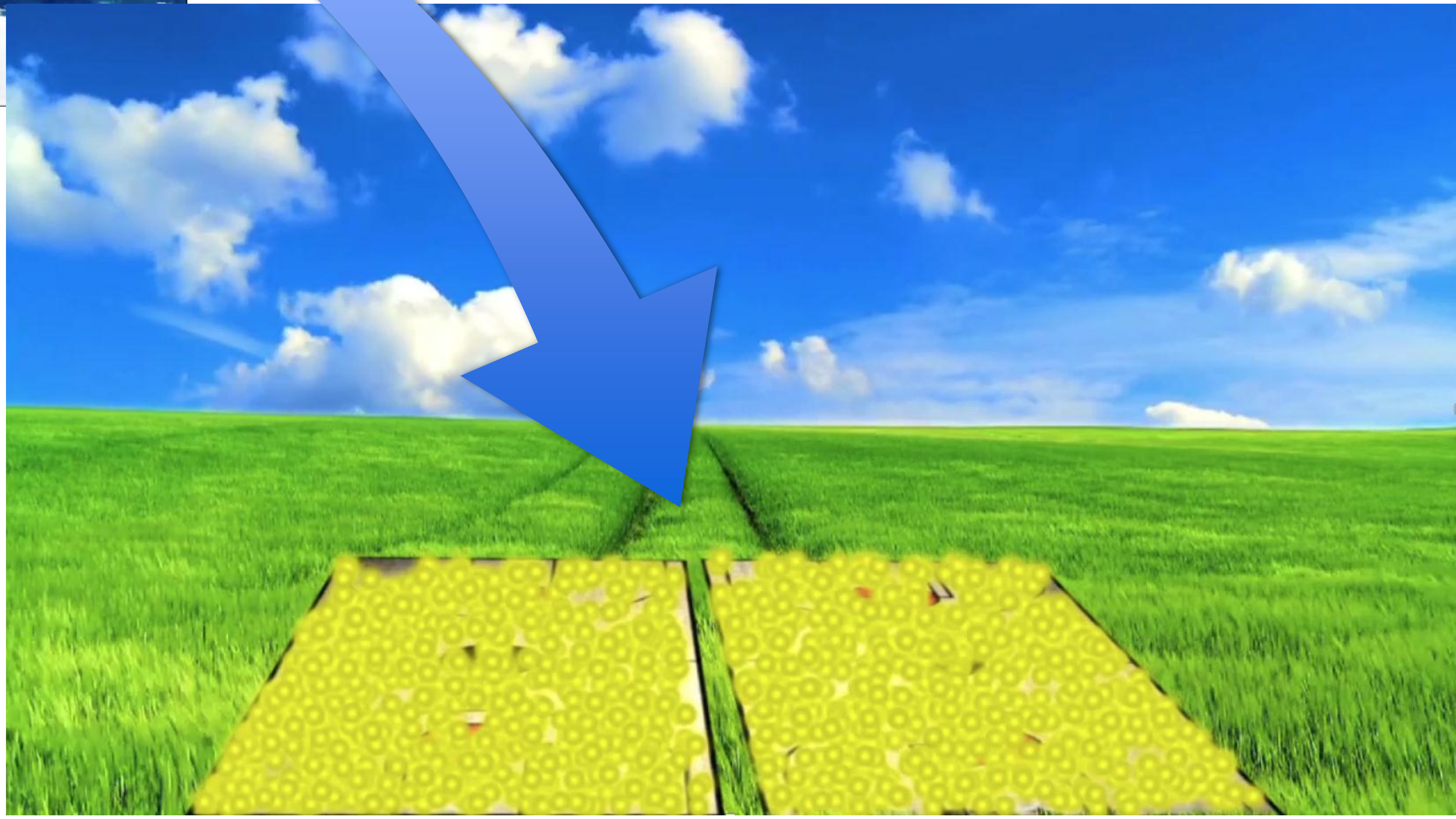
Is the radar the perfect instrument for precipitation?



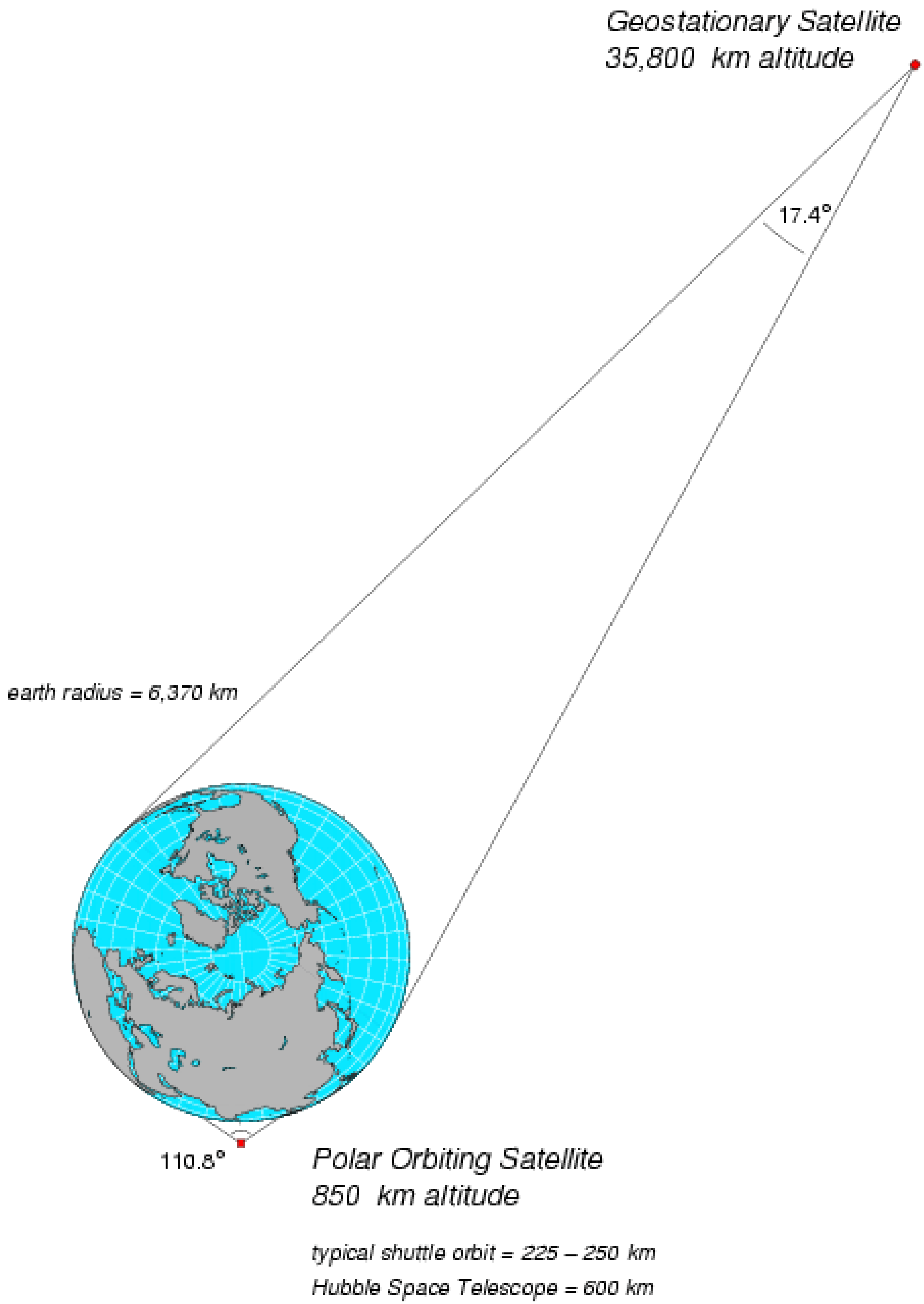
Density of rain gauges



Taking all of the rain gauges combined would equal about the surface area of two basketball courts!



Satellites, orbits,….



Two Main Orbits for Earth Orbiting Weather Satellites

Geostationary (GEO)
As the satellite orbits, the Earth appears in a fixed position (relative to an observer on the satellite)

Low Earth-Orbiting (LEO)
Earth rotates under the satellite as the satellite orbits. Satellites are much closer to Earth.

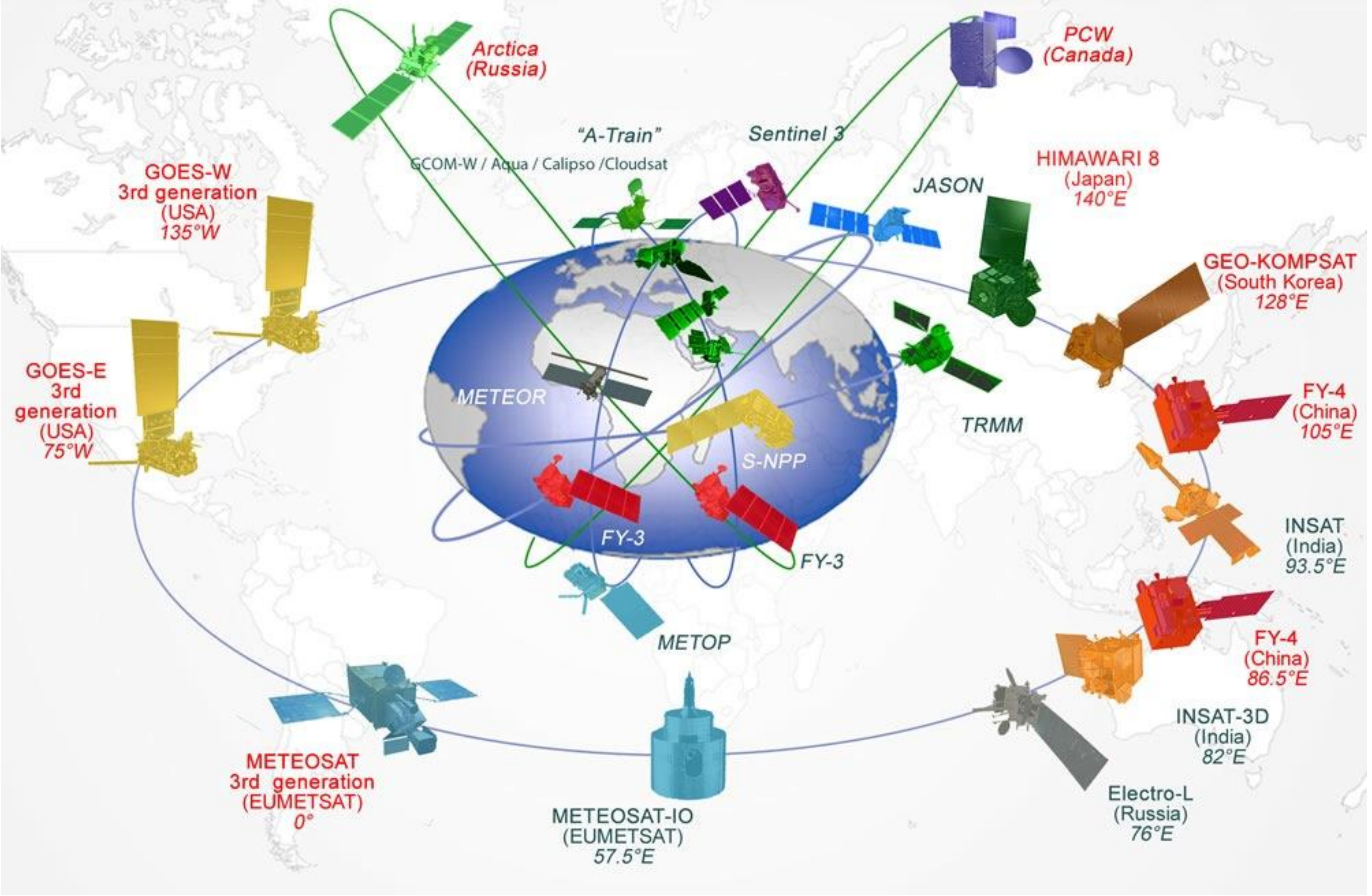
LEO orbit characteristics

1. Global coverage with 2 daily overpasses over the same area at very high spatial resolution (1 m – 50 km).
2. Great variety of sensors on the same platform, both passive (radiometers) and active (radar, lidar).
3. Frequent monitoring of polar regions (once per orbit).
4. Heliosynchronous satellites guarantee an overpass at the same local time.

GEO orbit characteristics

1. High resolution spatial sampling of the observed area (≈1 km).
2. Quasi-real-time sampling (15-30 min) allows for a continuous monitoring of rapidly evolving events.
3. Imagery is distorted with increasing latitude.
4. The technology for active sensor is not available at present while microwave passive radiometers are foreseen in a few years.

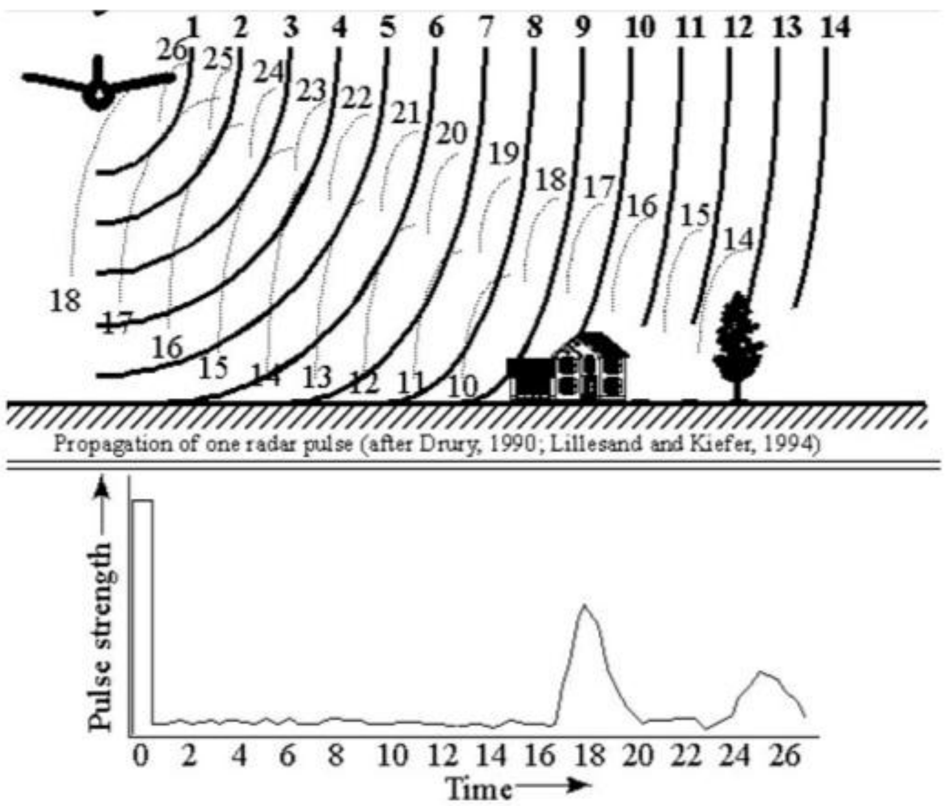
Operational environmental satellites



Remote Sensing Fundamentals

Active Remote Sensing

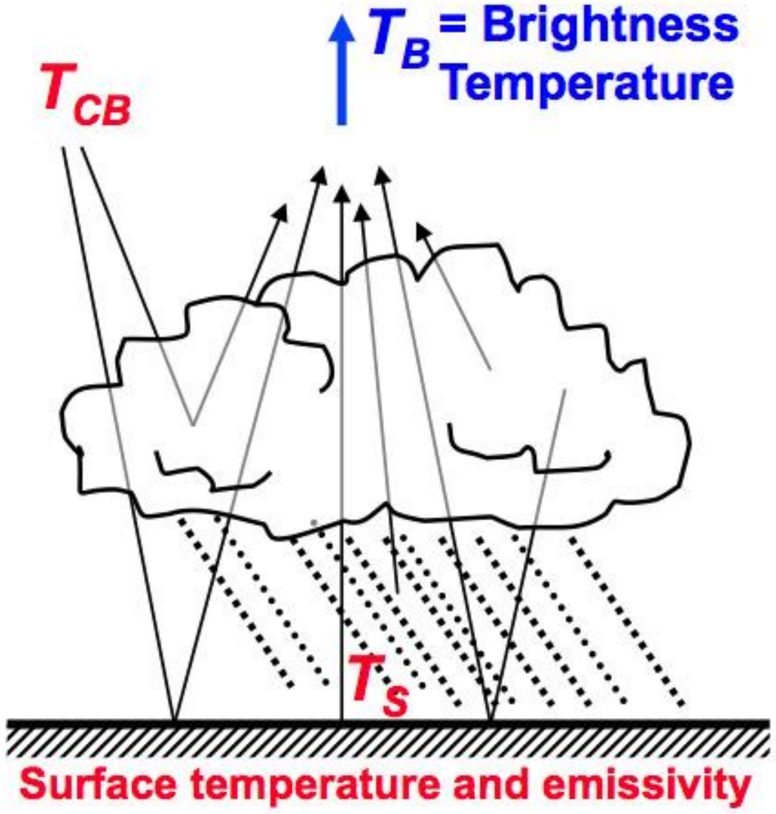
Source: Instrument pulse,
Needs power to operate



Propagation of one radar pulse (after Drury, 1990; Lillesand and Kiefer, 1994)

Passive Remote Sensing

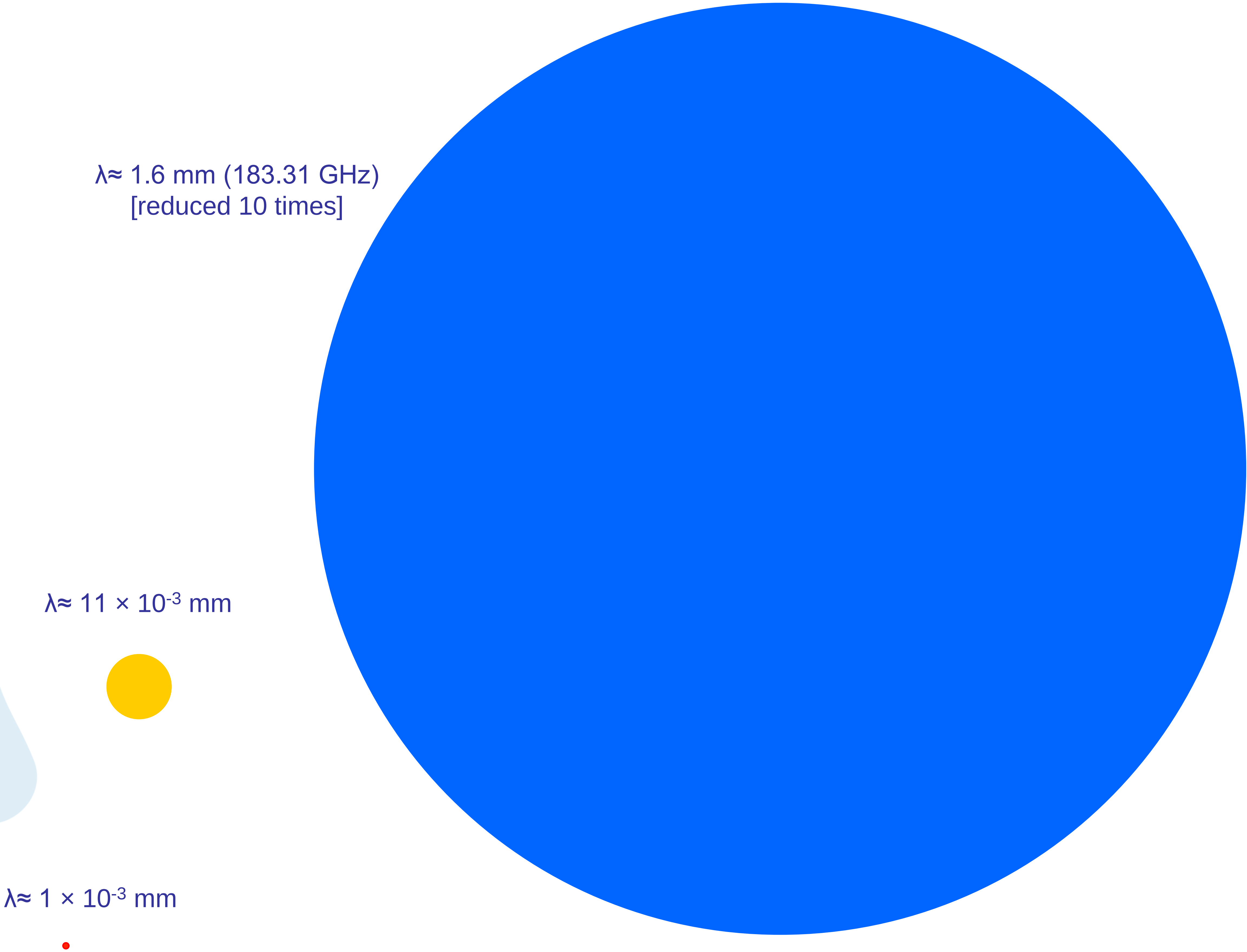
Sources: surface emission,
cosmic background,
rain emission



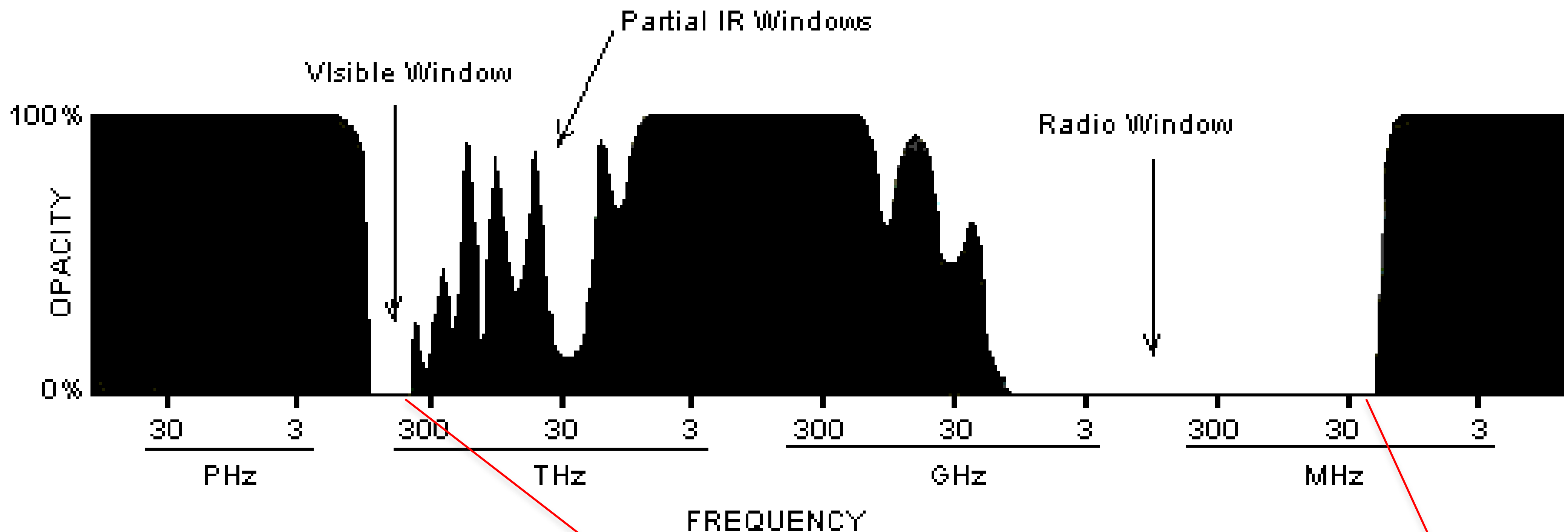
Passive

Active

From visible (VIS) to microwave (MW)



ATMOSPHERIC WINDOWS IN THE ELECTROMAGNETIC SPECTRUM



Traditional	*f range(GHz)*
L	1 - 2
S	2 - 4
C	4 - 8
X	8 - 12
Ku	12 -18
K	18 - 27
Ka	27 - 40
V	40 - 75
W	75 - 110
mm	110 - 300
sub-mm	> 300

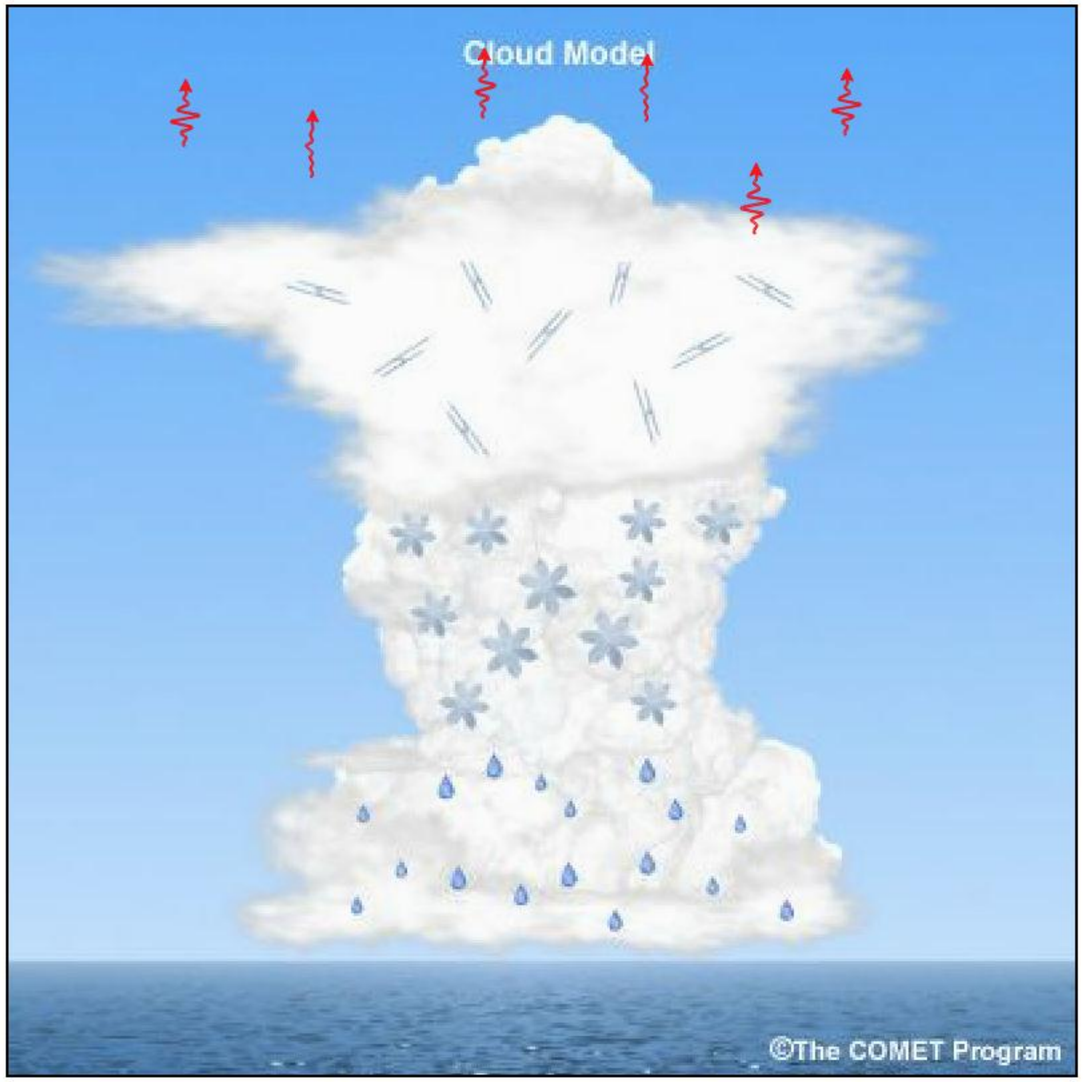
New	*f range(GHz)*
D	1 - 2
E	2 - 3
F	3 - 4
G	4 - 6
H	6 - 8
I	8 - 10
J	10 - 20
K	20 - 40
L	40 - 60
M	60 - 110

- 300 MHz – 30 GHz
- 30 GHz – 300 GHz (millimetric)
- > 300 GHz (centimetric)

actual

future

MICROWAVE RADIO BANDS

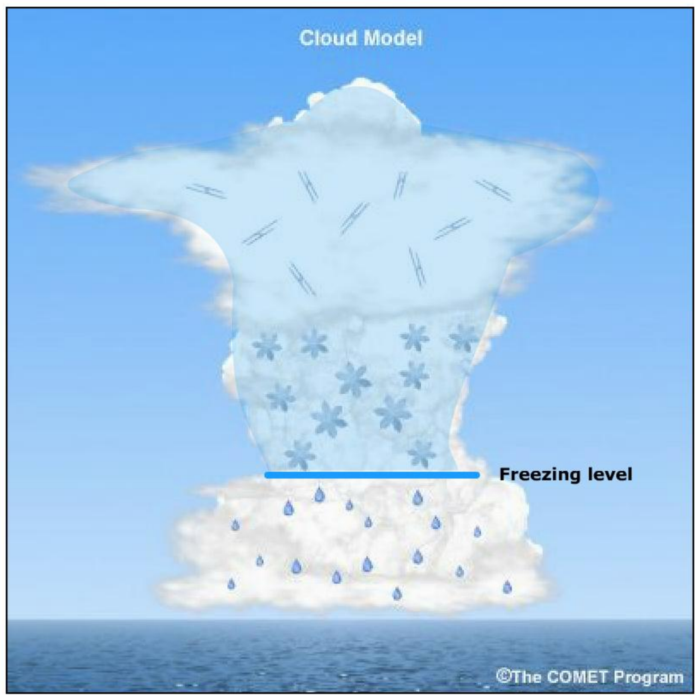


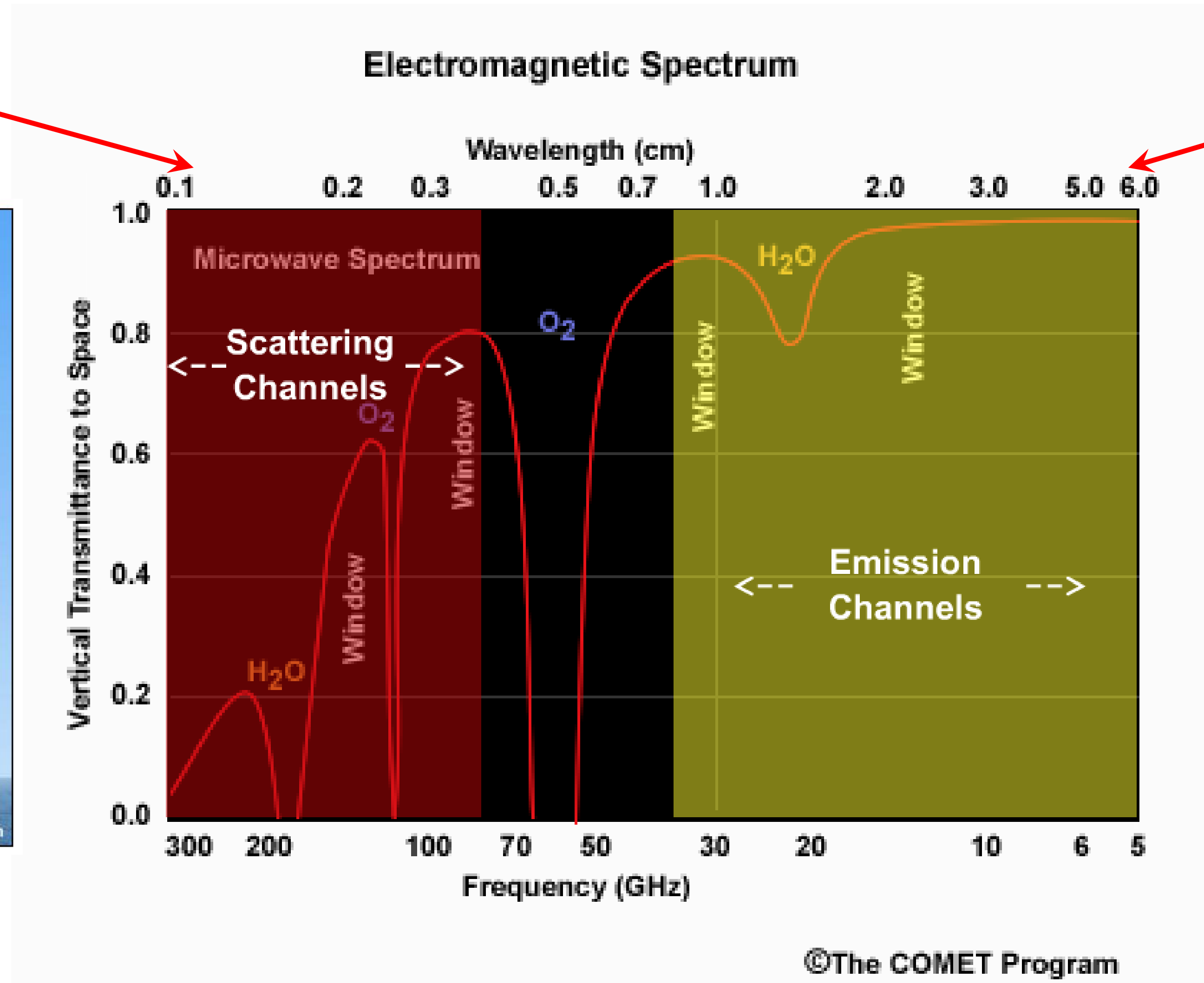
Infrared channels

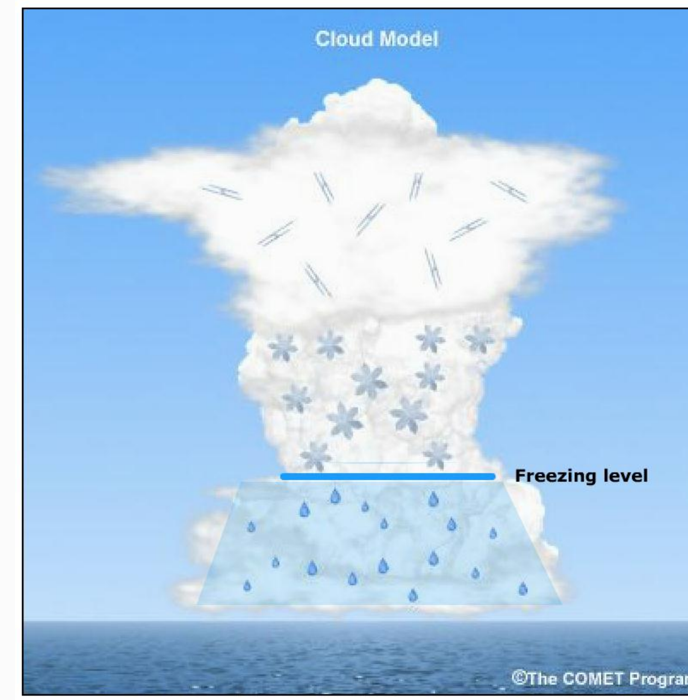
Infrared instruments sense energy emitted from cloud tops. IR-based cloud-top temperatures can be used to approximate precipitation rates, but no information comes from the layers below the cloud top.

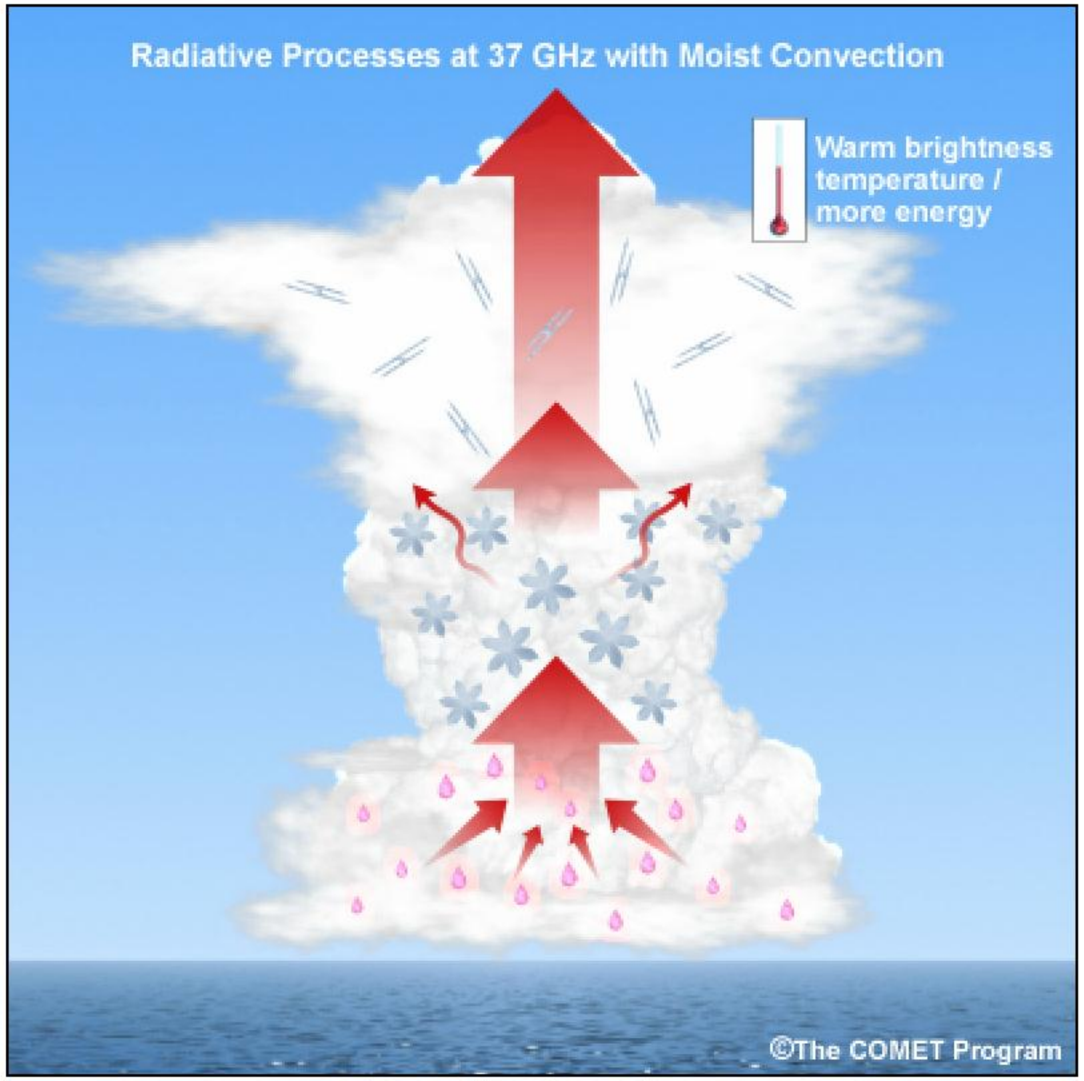
Higher-frequency channels
Emission from
small raindrops, and scattering
and attenuation by precipitation-sized ice hydrometeors

Lower-frequency channels
Emission from
medium-to-large-sized raindrops



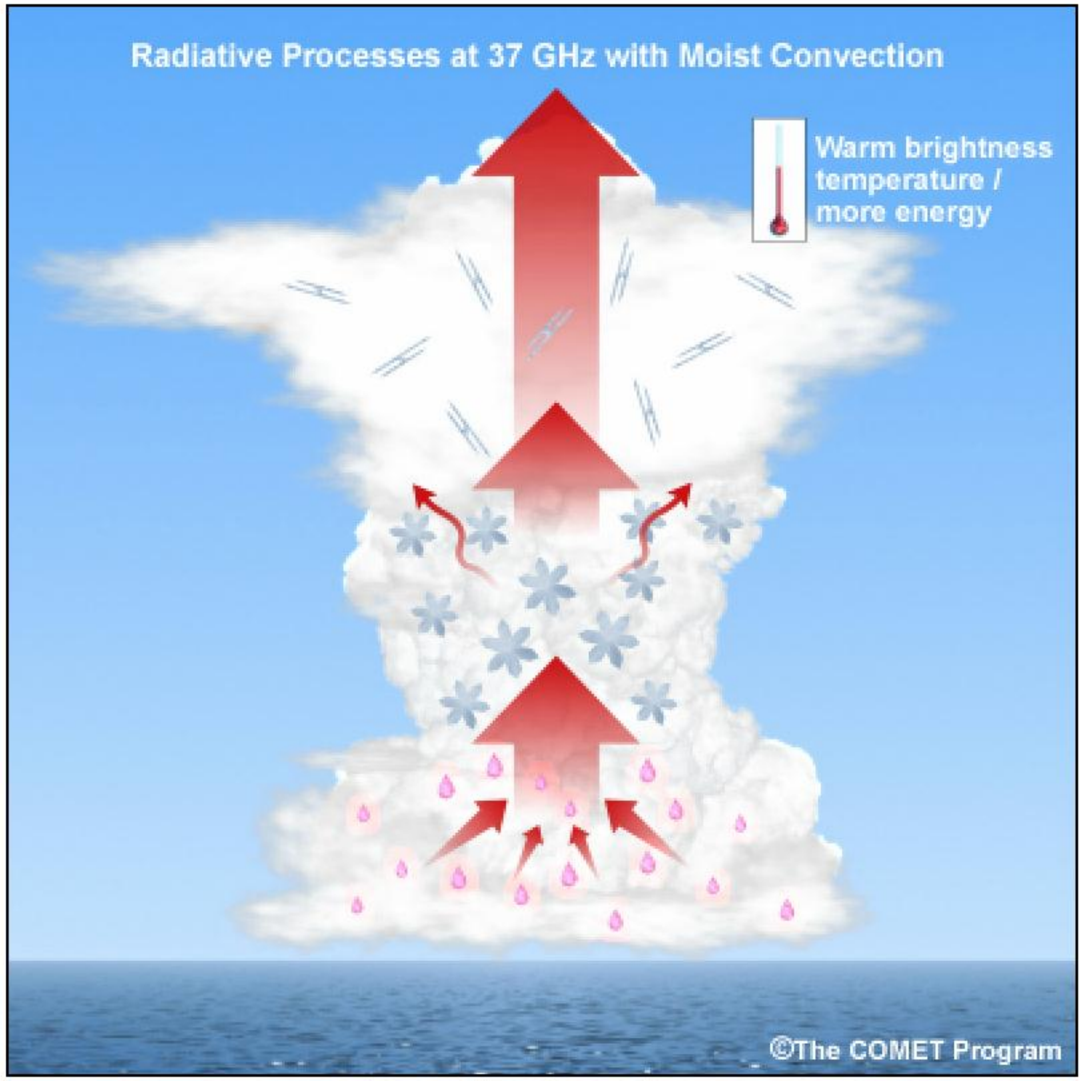


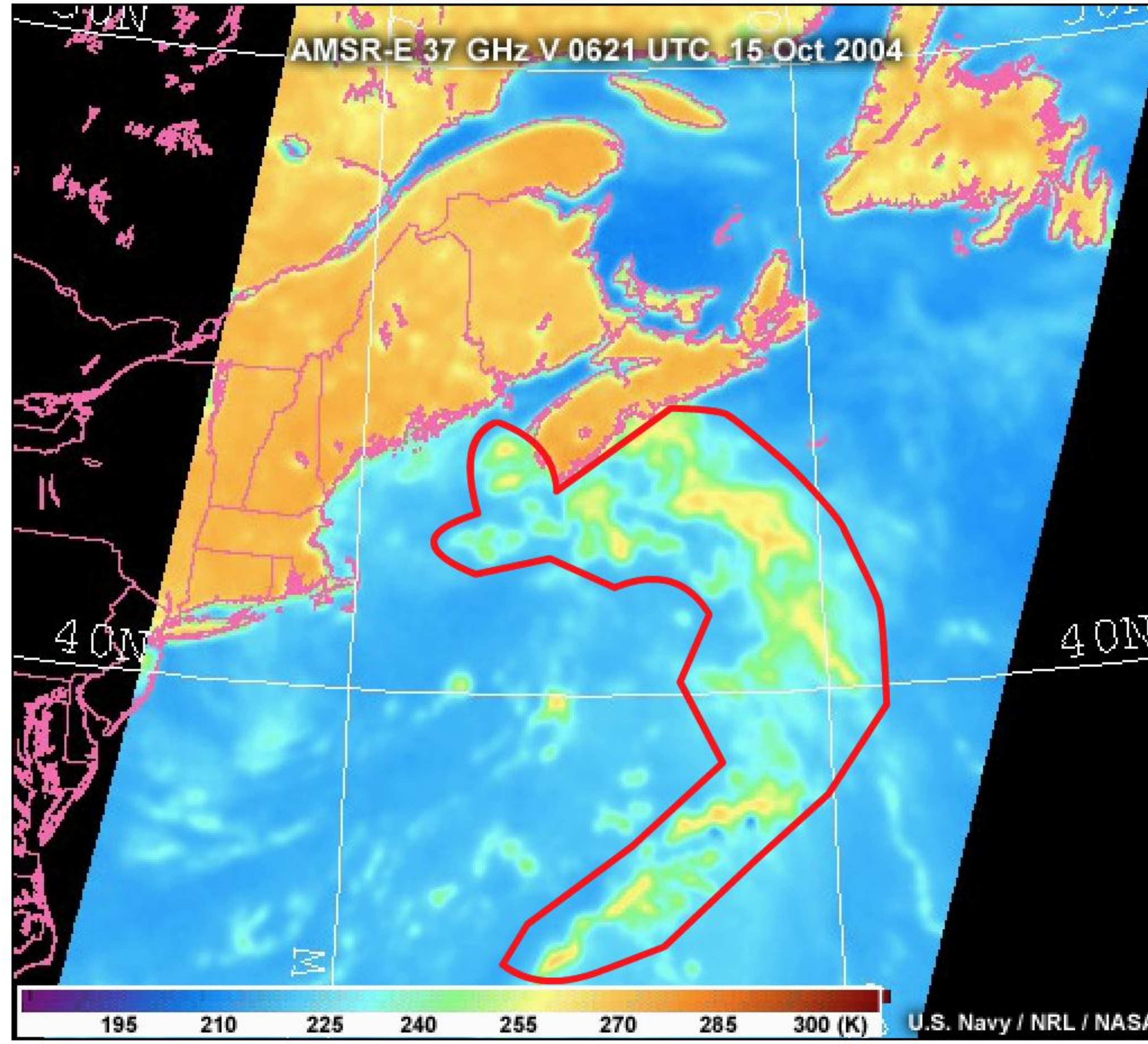




Low-frequency channels

Low-frequency channels sense energy from the surface that is then increased by emissions from cloud water and rain drops.





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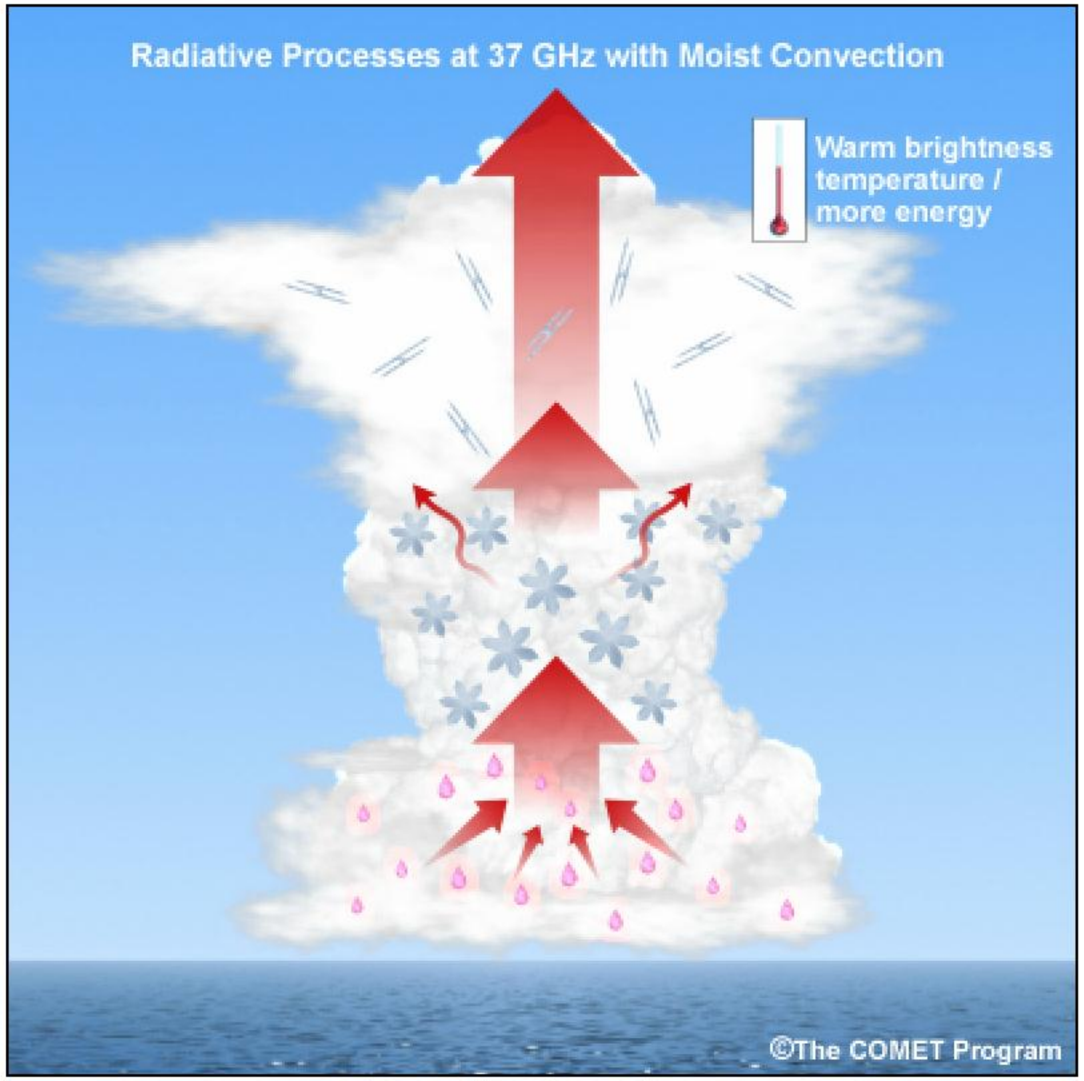

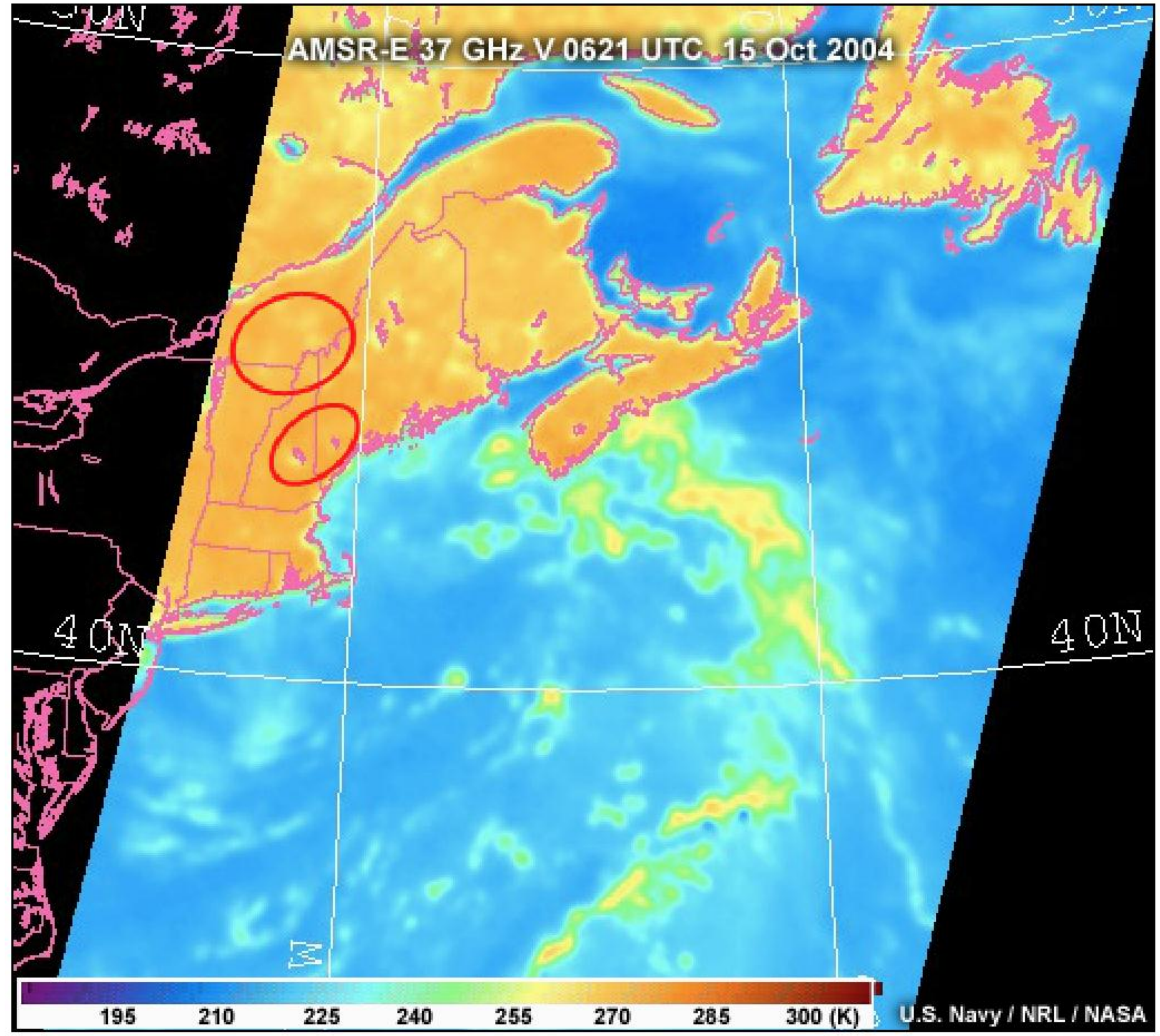

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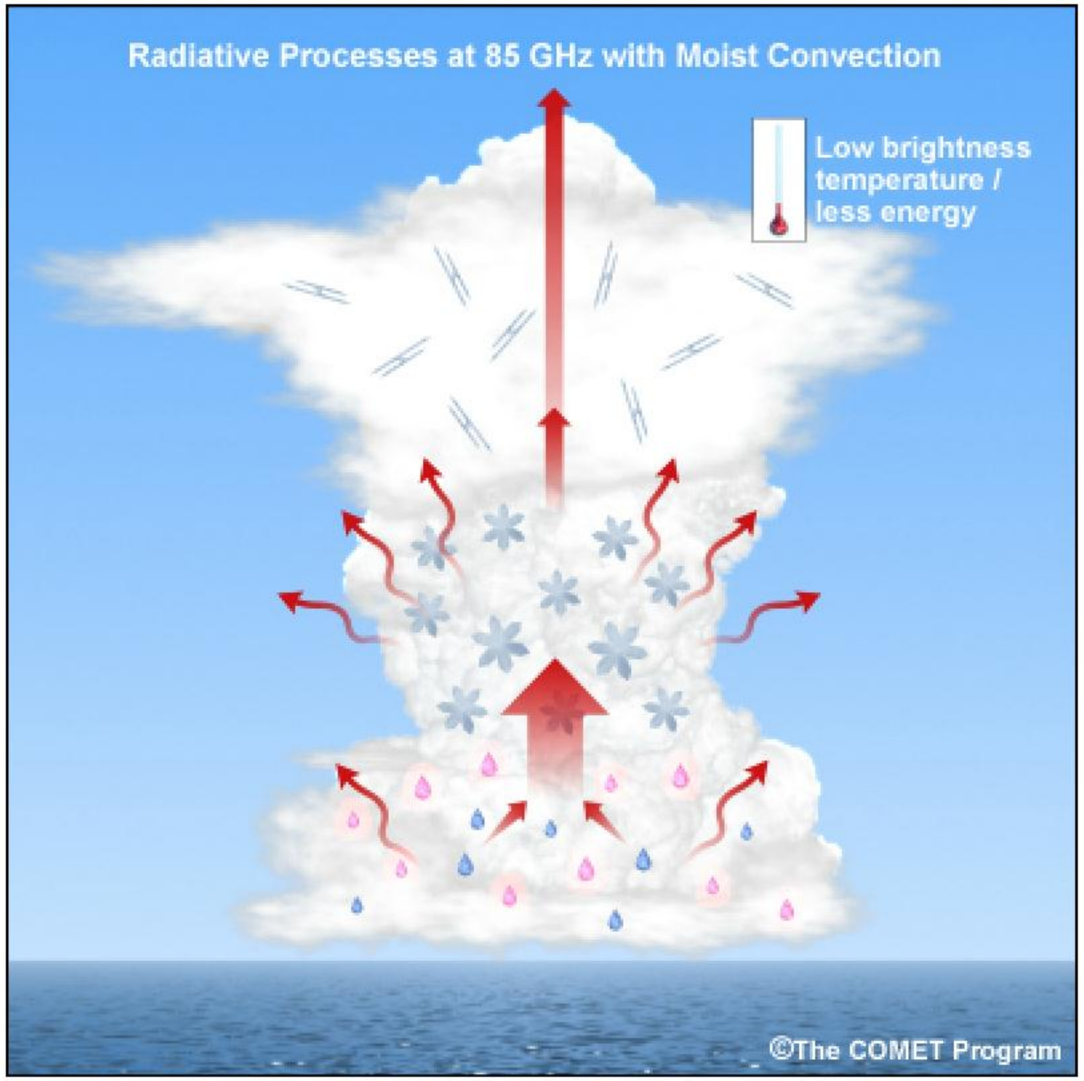
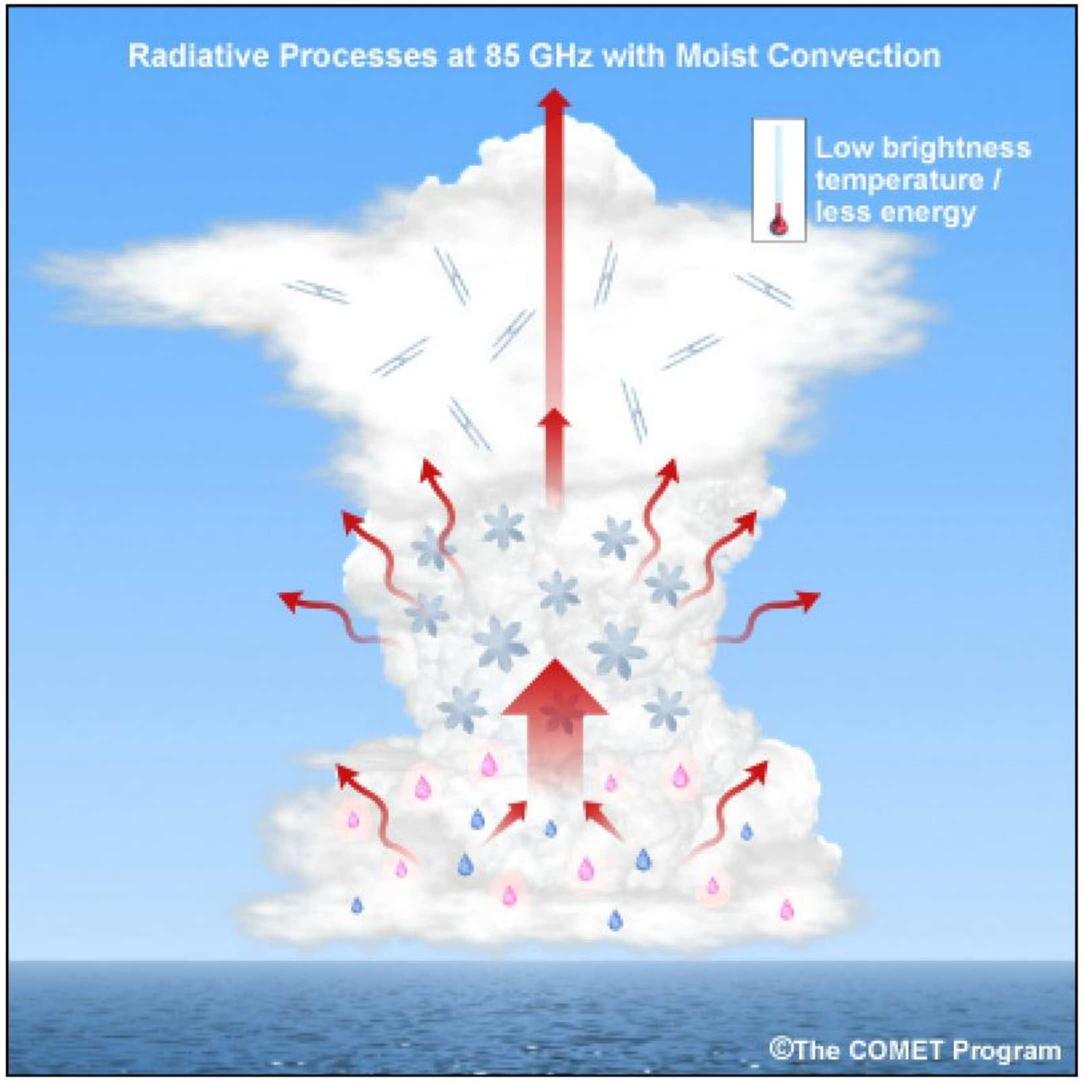
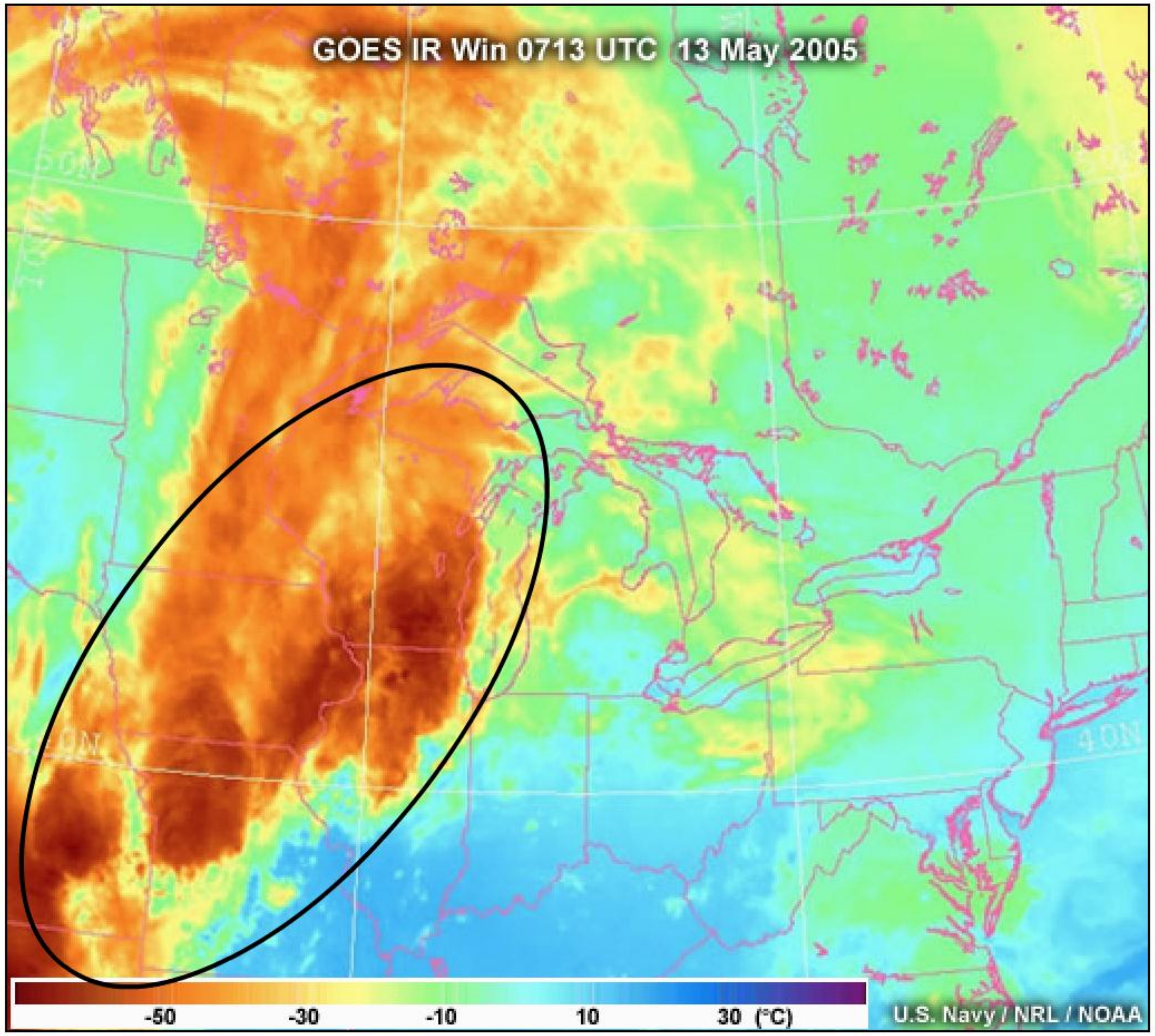


High-frequency channels

Higher-frequency channels are sensitive to Scattering and attenuation of energy by rain and ice hydrometeors, and emission from small raindrops.
Precipitation-size ice particles act to cool the observed Brightness temperatures.





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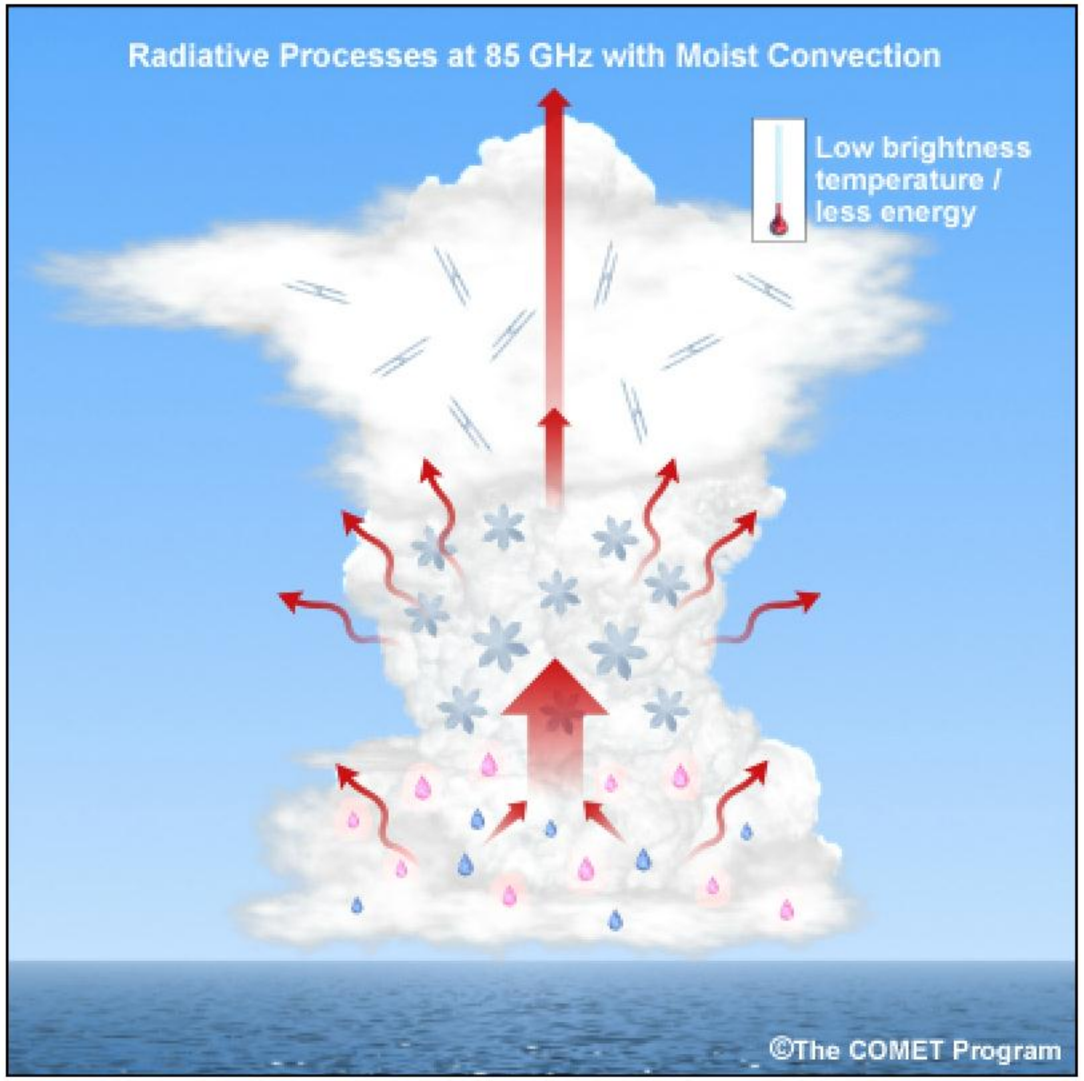

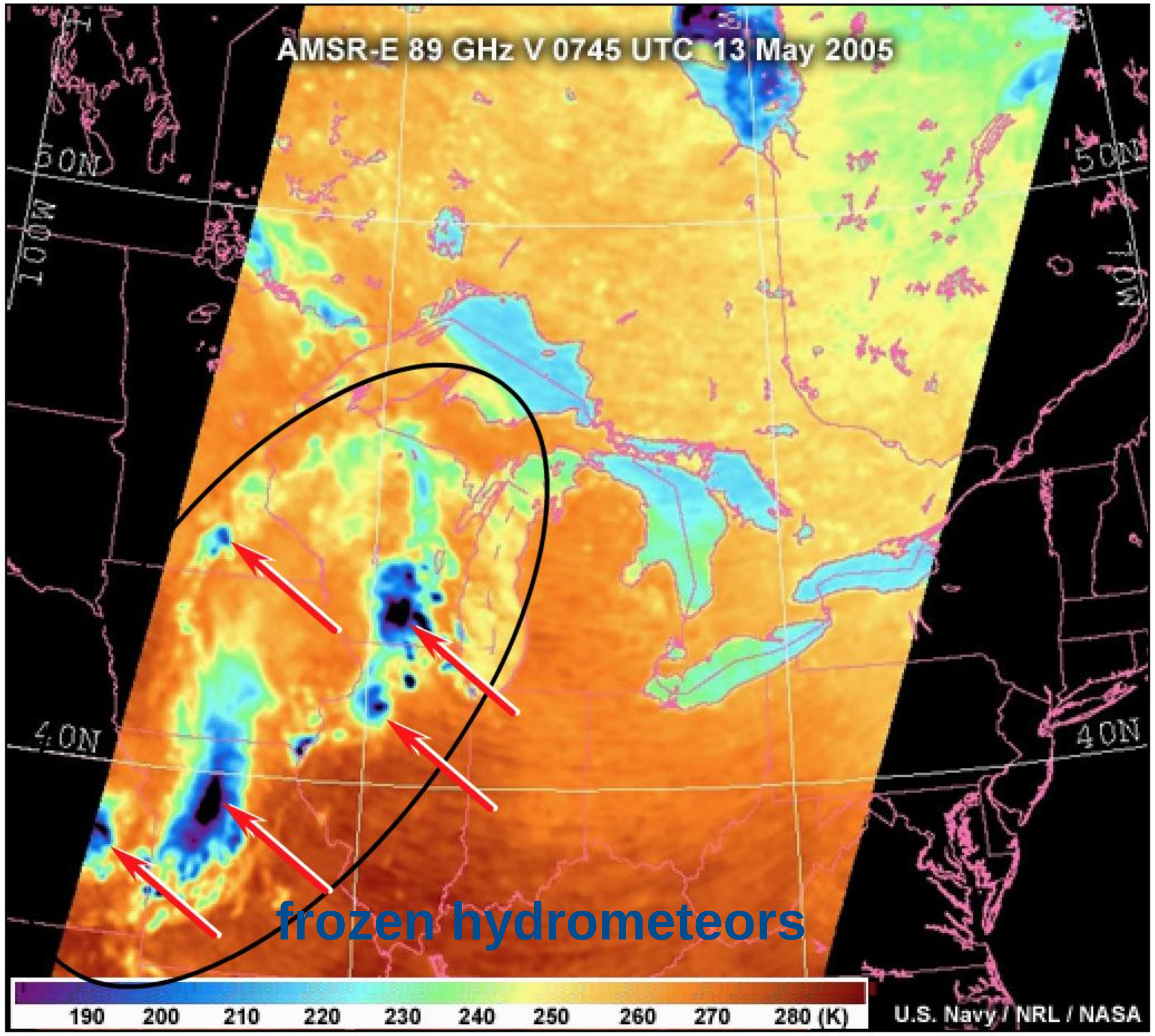

High-frequency channels

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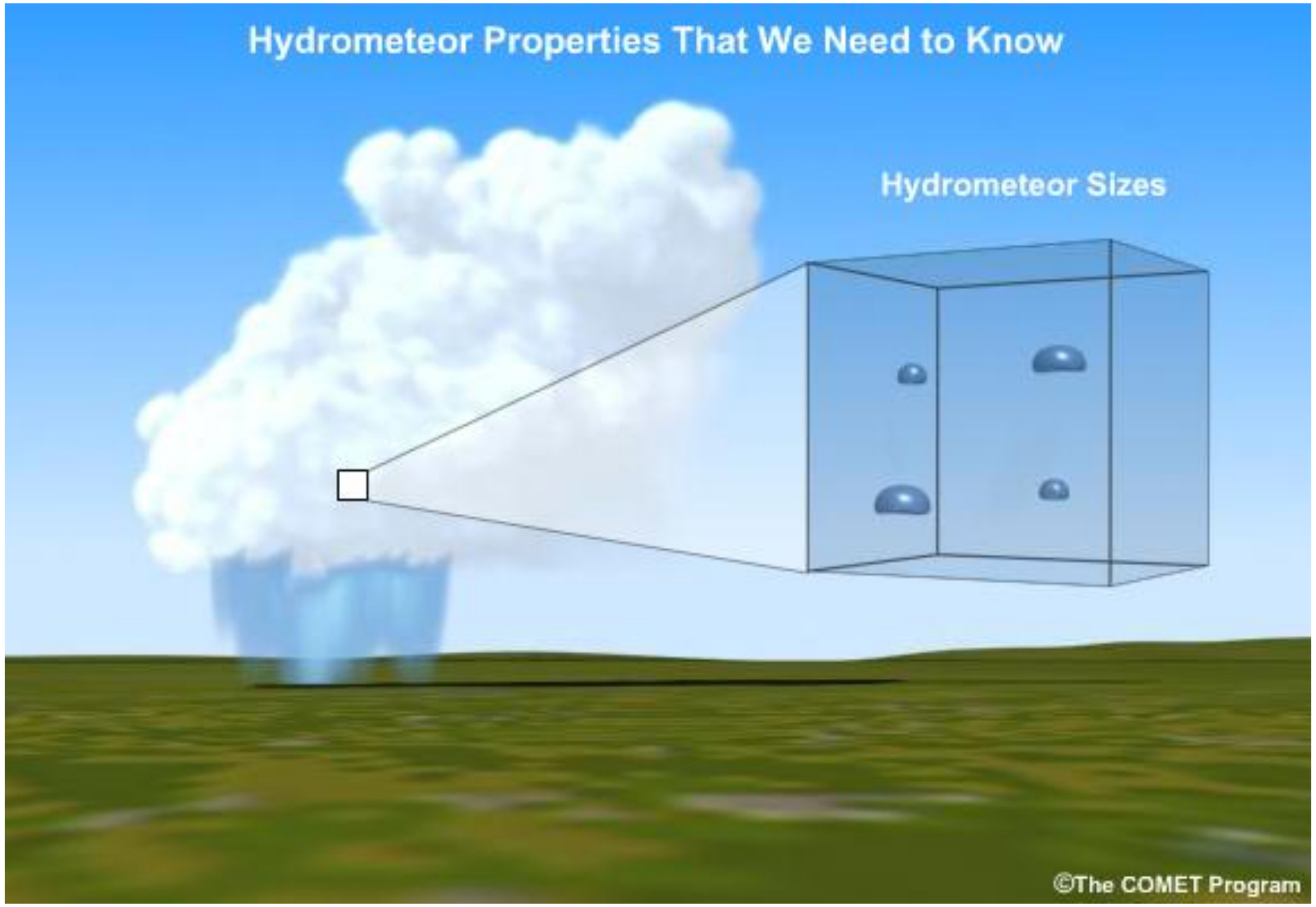
Precipitation-size ice particles act to cool the observed Brightness temperatures.

What do we need to know?


Hydrometeor Properties That We Need to Know
Hydrometeor Sizes
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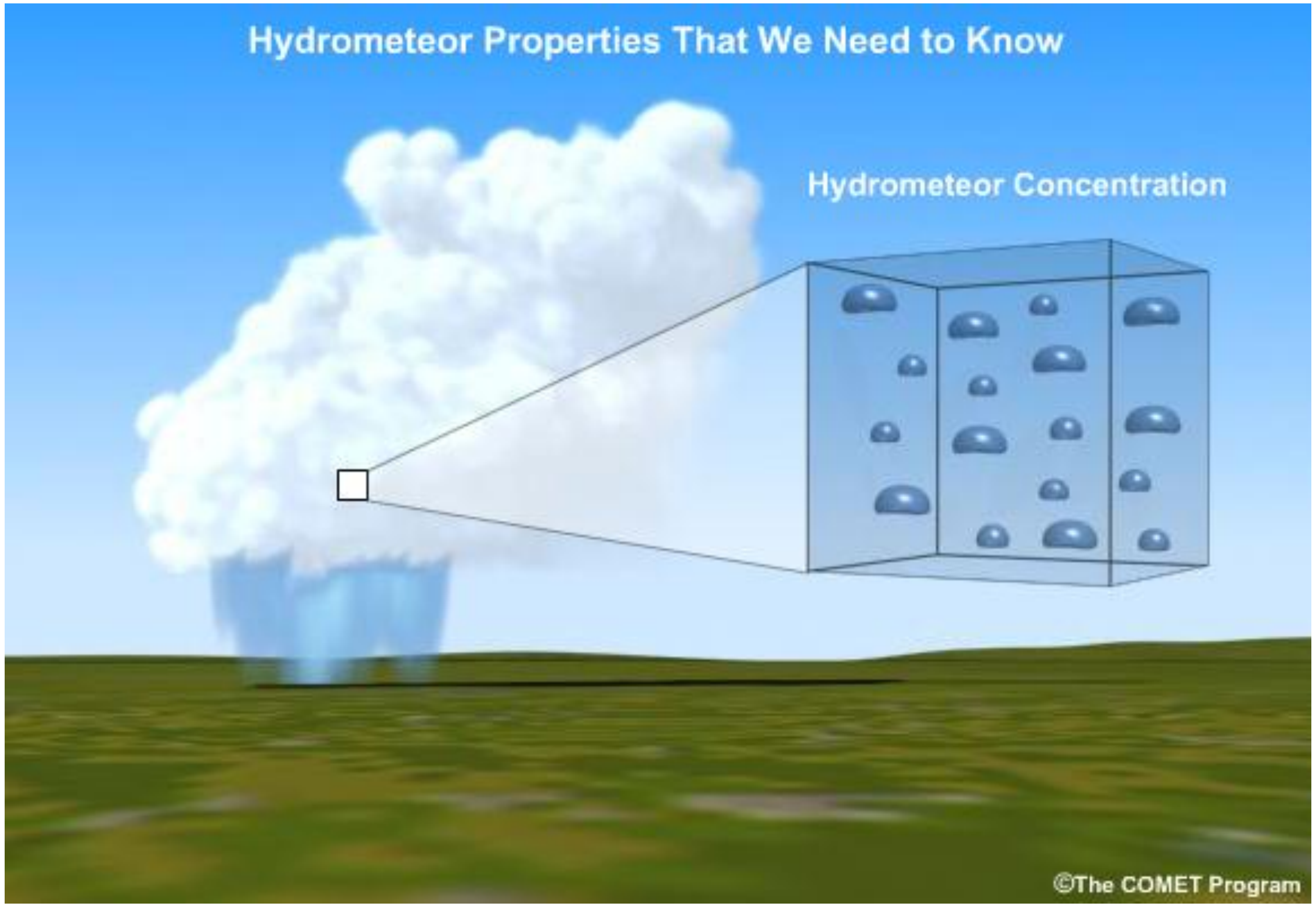
Hydrometeor Properties That We Need to Know
Hydrometeor Concentration
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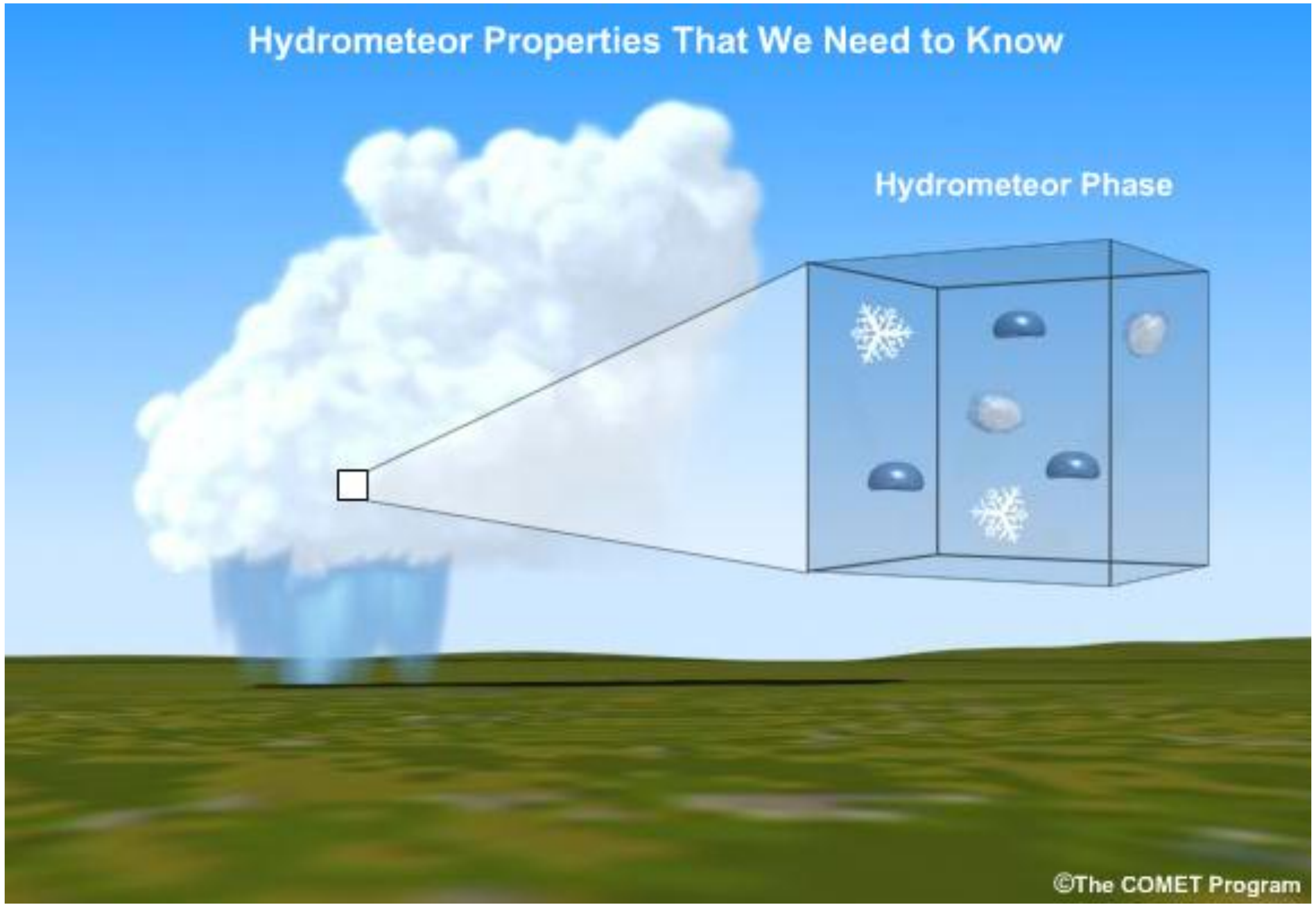
Hydrometeor Properties That We Need to Know
Hydrometeor Phase
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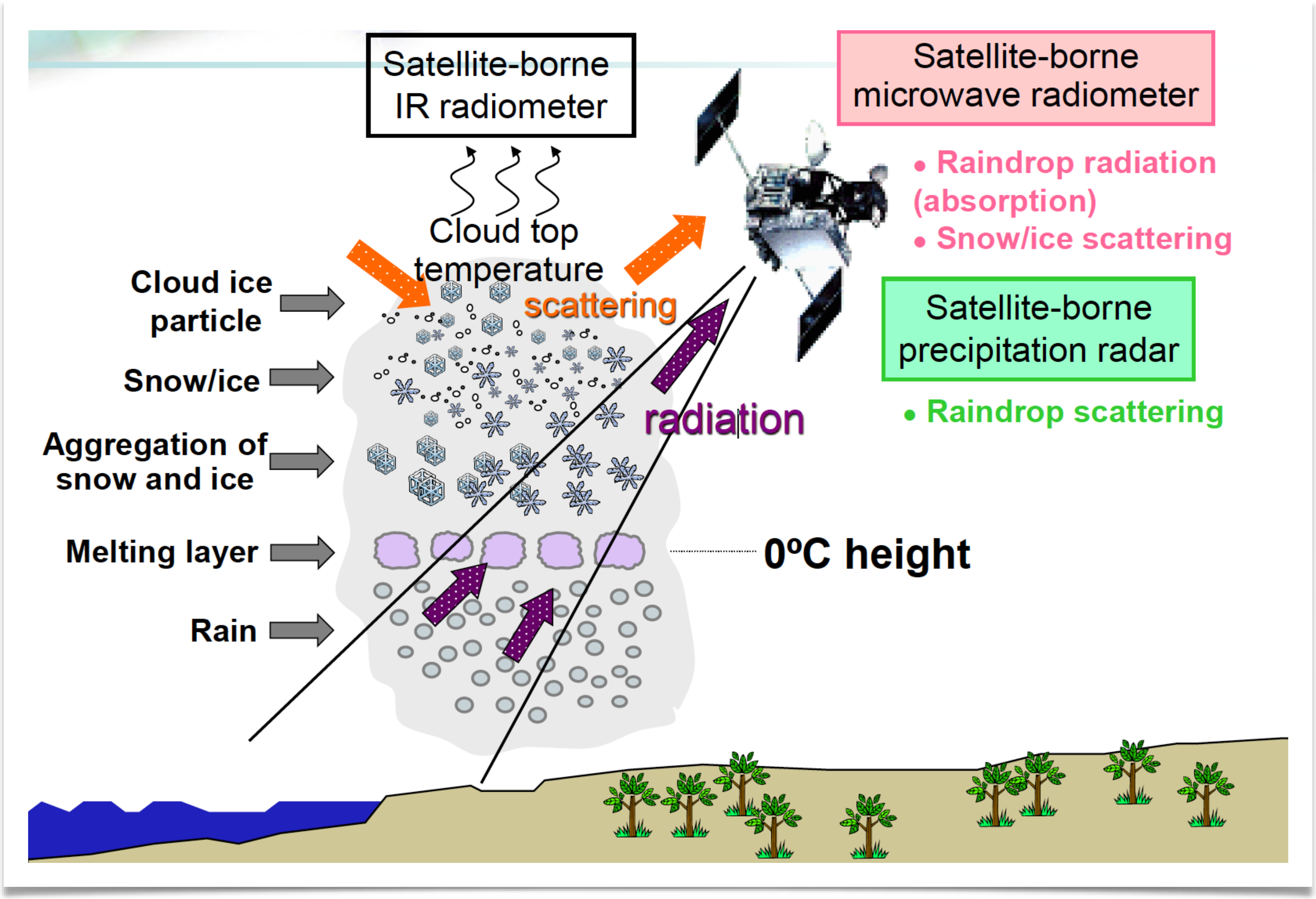
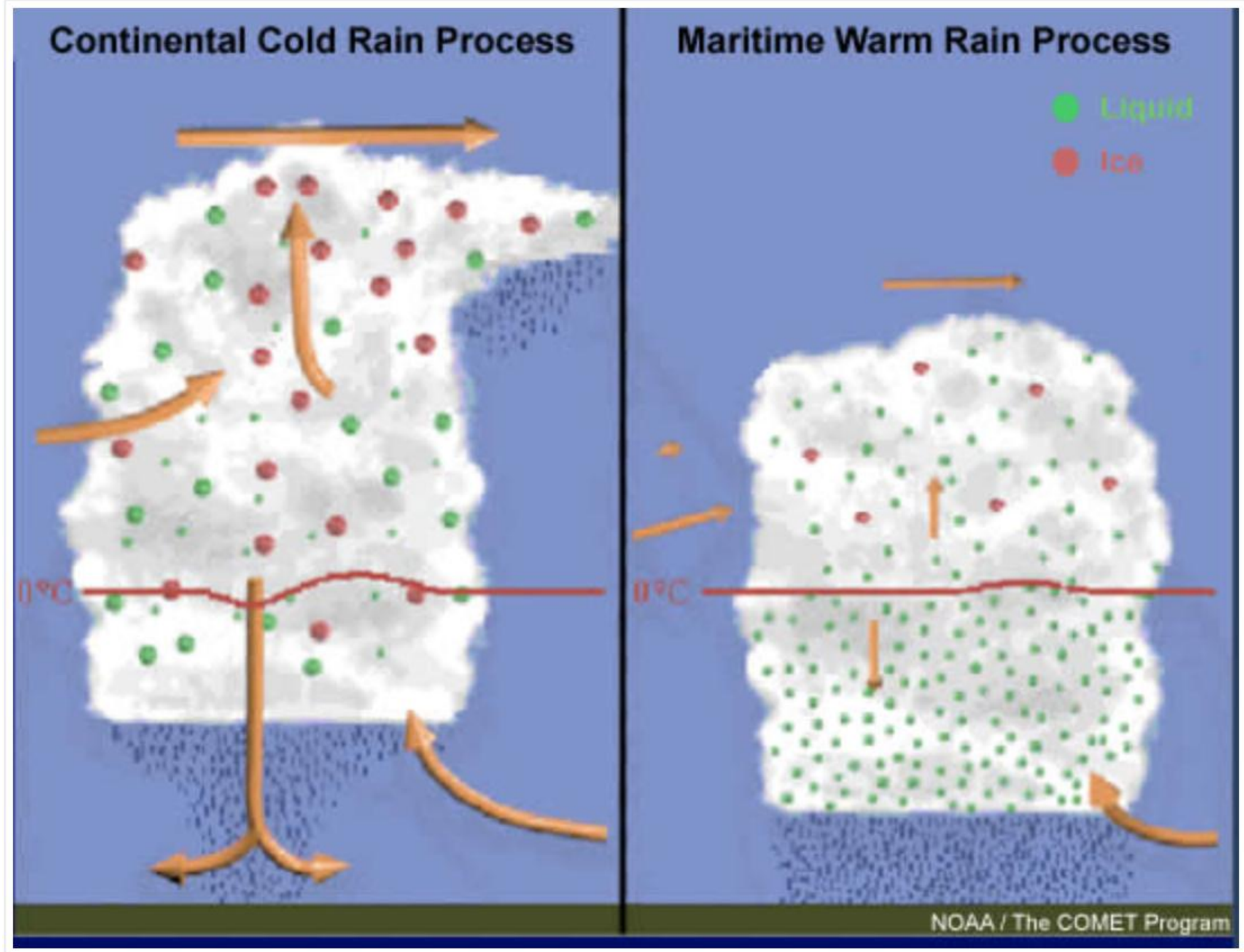

Satellite-borne
IR radiometer
Satellite-borne
microwave radiometer
• Raindrop radiation
(absorption)
• Snow/ice scattering
Satellite-borne
precipitation radar
• Raindrop scattering
Cloud top
temperature
scattering
radiation
Cloud ice
particle
Snow/ice
Aggregation of
snow and ice
Melting layer
Rain
0ºC height



In some situations, especially in maritime tropical environments, precipitation can be produced predominately via the warm rain process. Here, precipitation particles mainly grow in the liquid phase at altitudes where the temperature is greater than 0°C . By contrast, the very common cold rain process describes a situation in which precipitation particles grow mainly in the ice and snow phase and then melt on the way to the surface.

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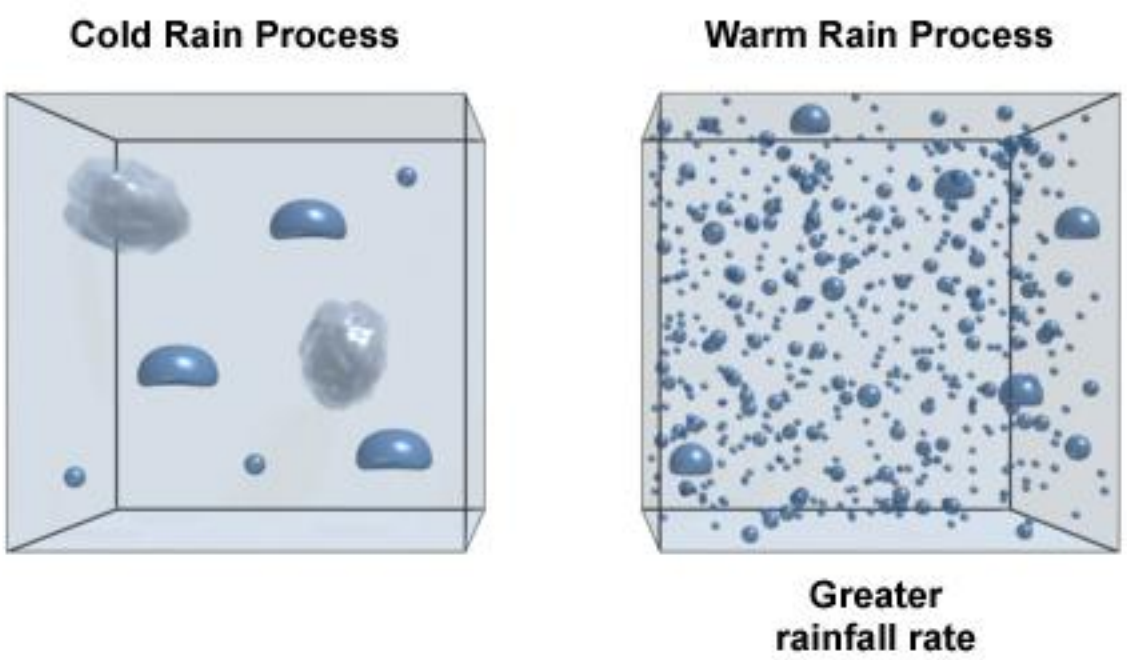
Hydrometeor Distributions with Equivalent Reflectivity but Different Rainfall Rates

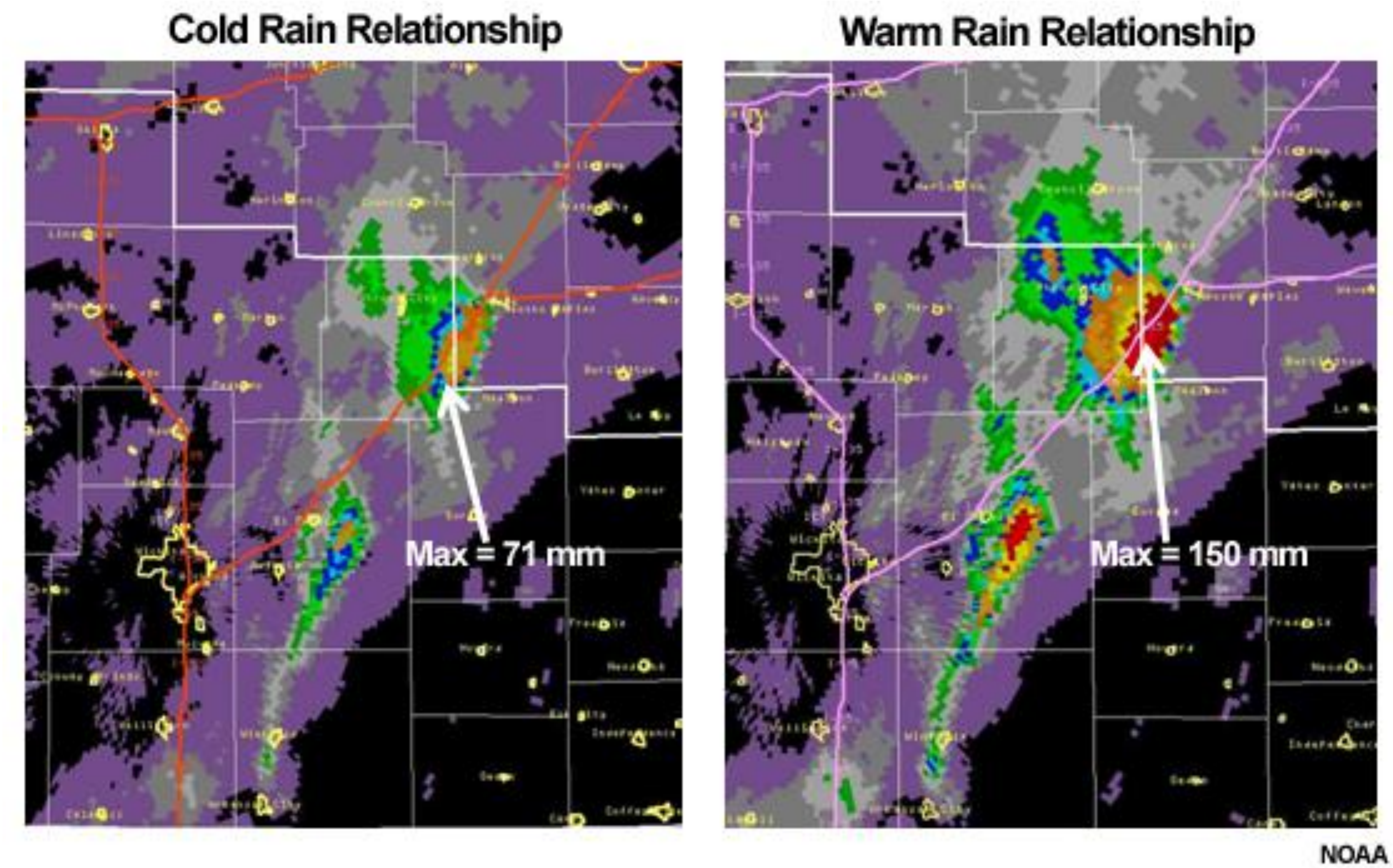


Reflectivity values are dependent on the number of precipitation particles present and the 6th power of the particle diameter. Rain rates are calculated from the reflectivity using a simple relationship that is based on empirically-derived estimates of the populations of each size of raindrop. During the warm rain processes, there are usually high concentrations of medium-to-small raindrops. By contrast, during cold rain processes, there tend to be lower concentrations of hydrometeors, and those hydrometeors can vary from small to very large.

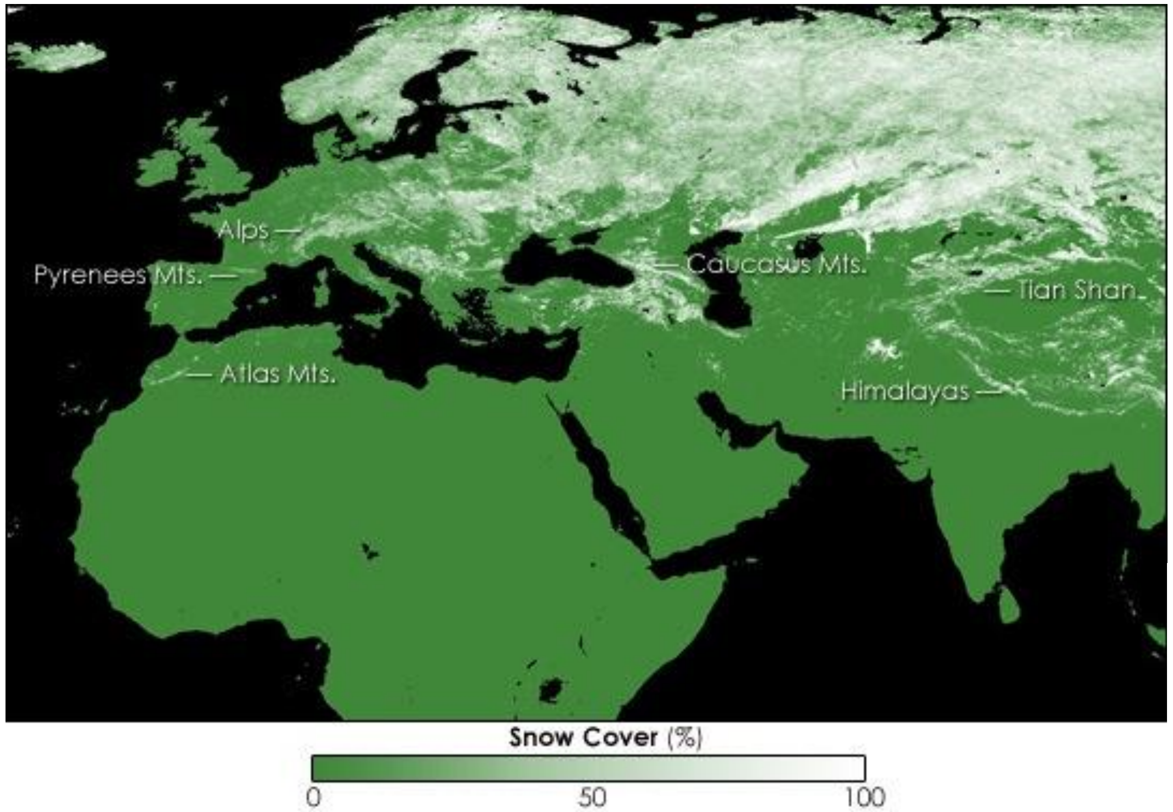
Reflectivity Factor - Rain Rate Relationships

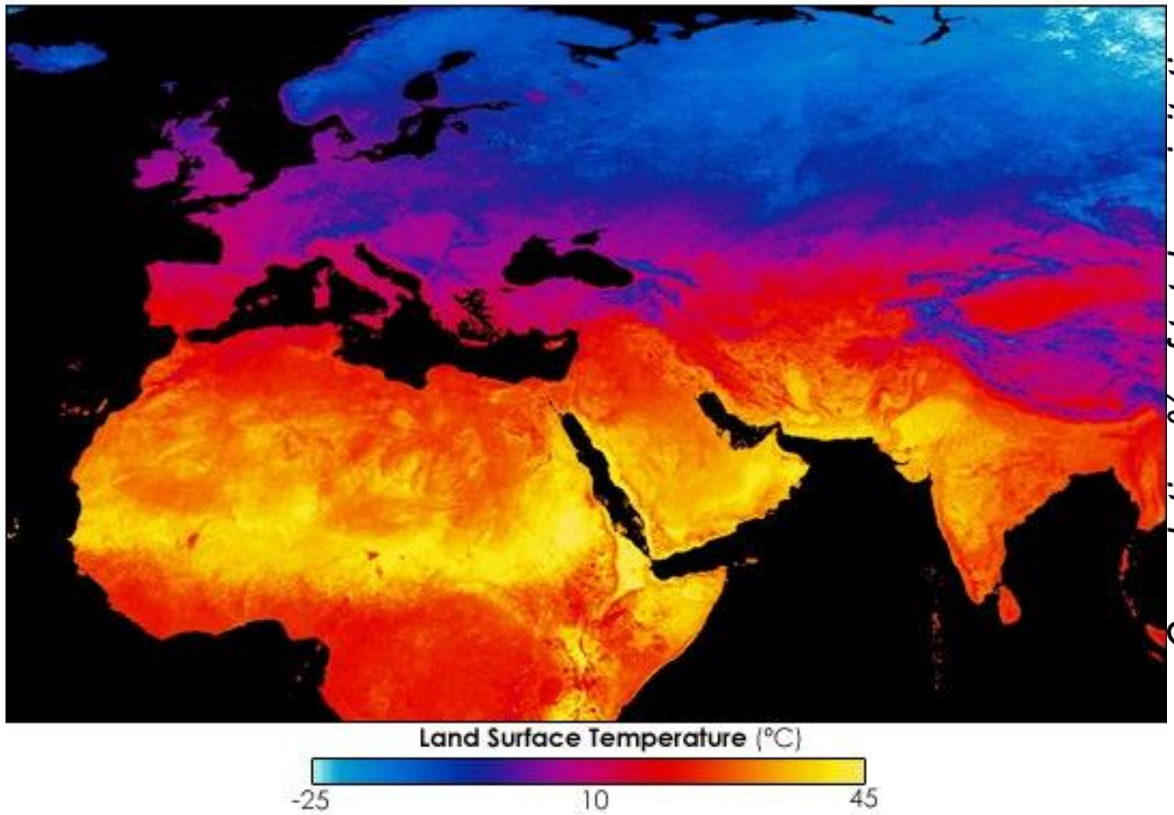
Reflectivity	Continental, Cold Rain $Z = 300 * R^{1.4}$	Maritime, Warm Rain $Z = 250 * R^{1.2}$
45 dBZ	27.9 mm hr^{-1}	56.5 mm hr^{-1}
50 dBZ	63.4 mm hr^{-1}	147.2 mm hr^{-1}
55 dBZ	144.2 mm hr^{-1}	384.6 mm hr^{-1}

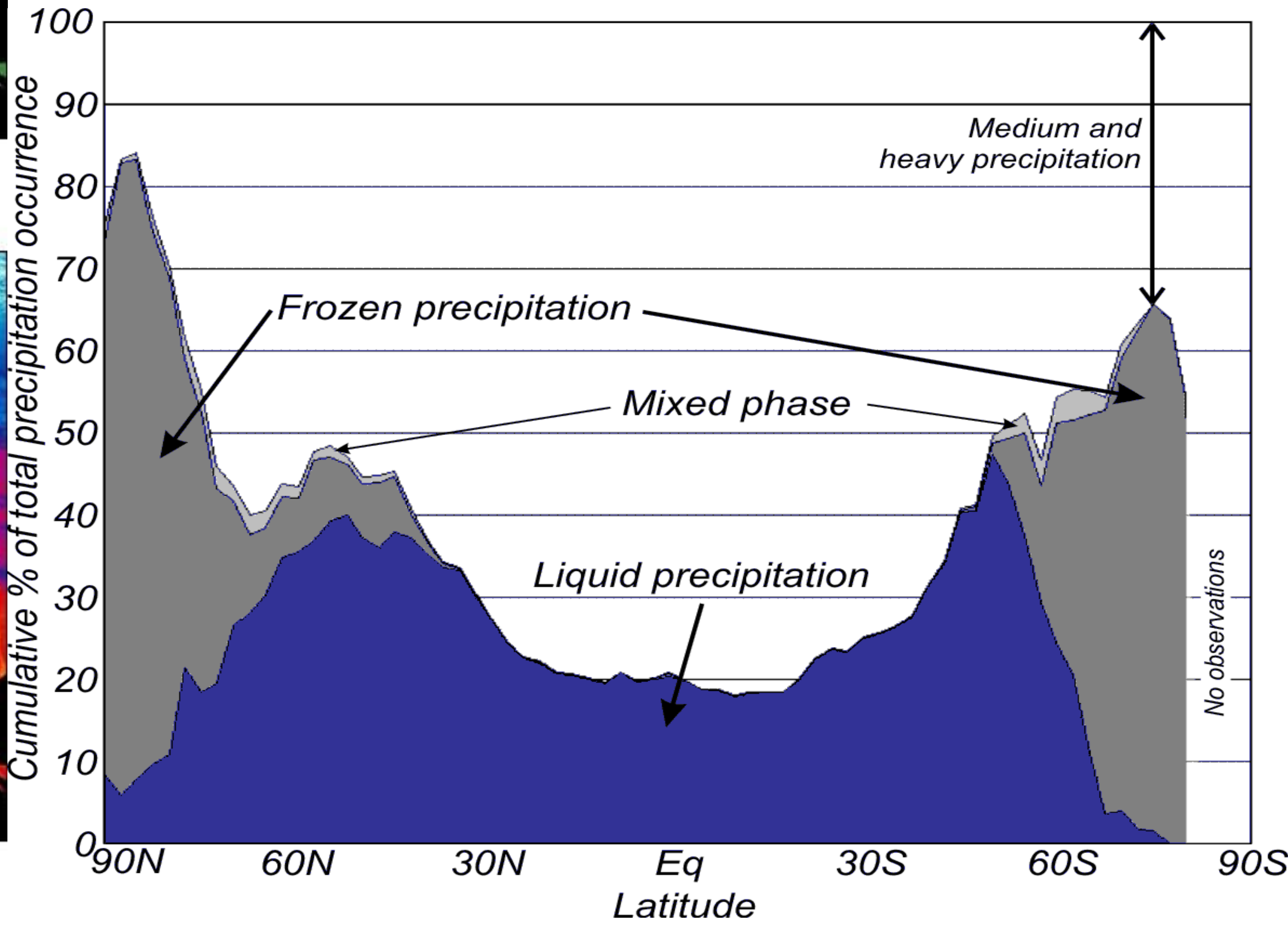
Is it the same precipitation episode?



How important is it to estimate snowfall?

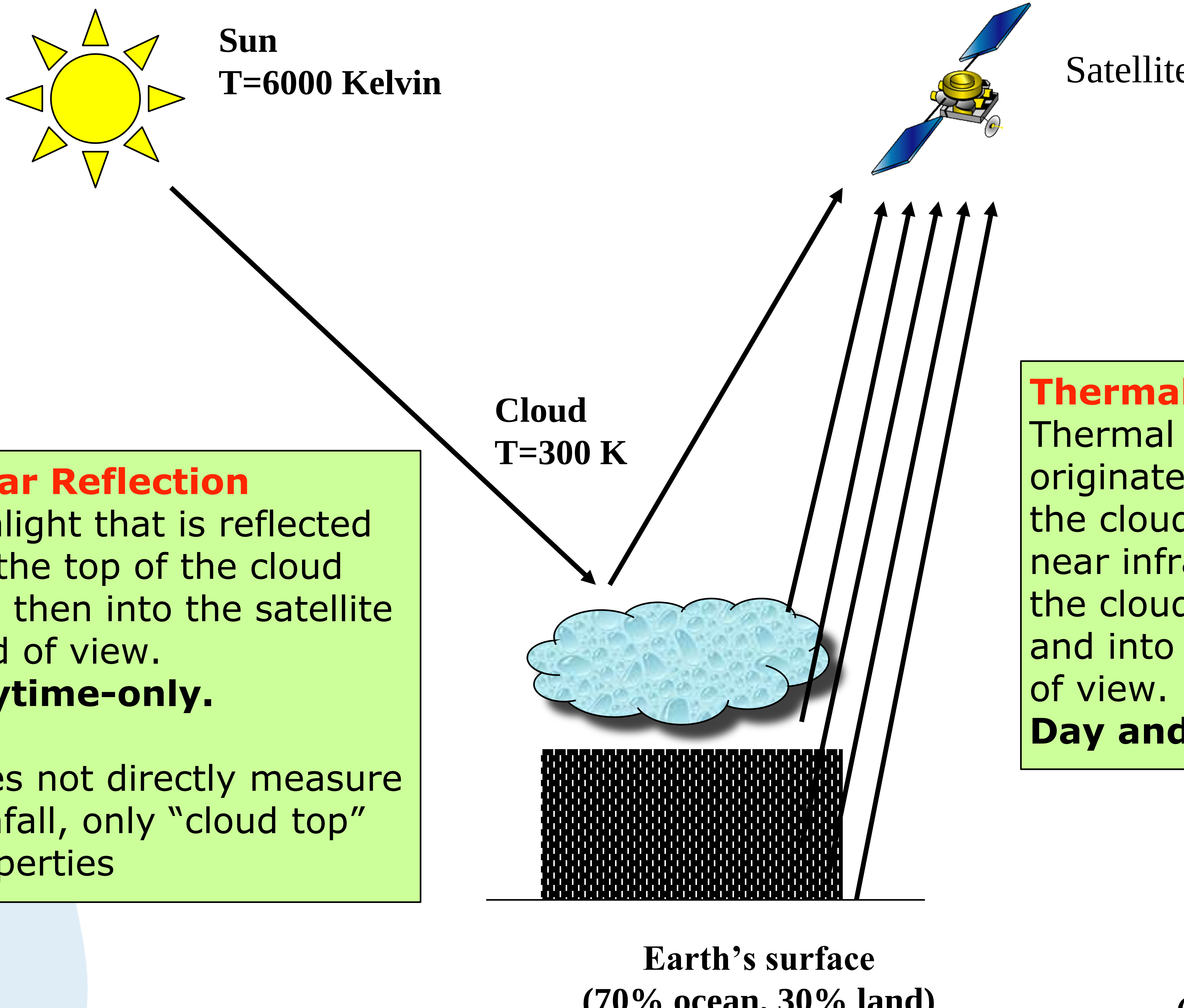






What are we observing and how?

Two Types of Satellite Measurements



Solar Reflection
Sunlight that is reflected off the top of the cloud and then into the satellite field of view.
Daytime-only.

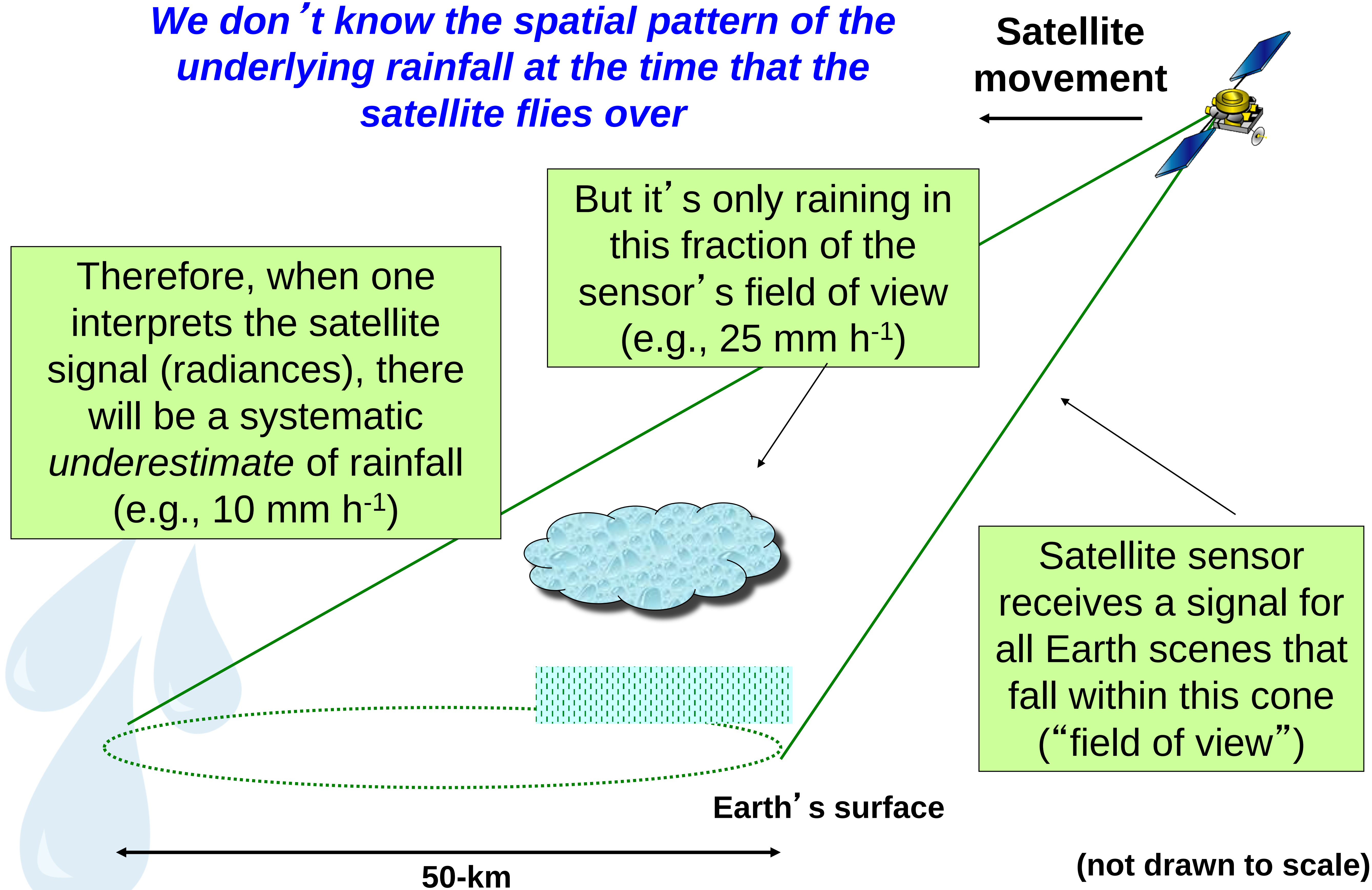
Does not directly measure rainfall, only "cloud top" properties

Thermal Emission
Thermal emission that originates near the top of the cloud (infrared to near infrared) or within the cloud (microwave) and into the satellite field of view.
Day and night.

(not drawn to scale)

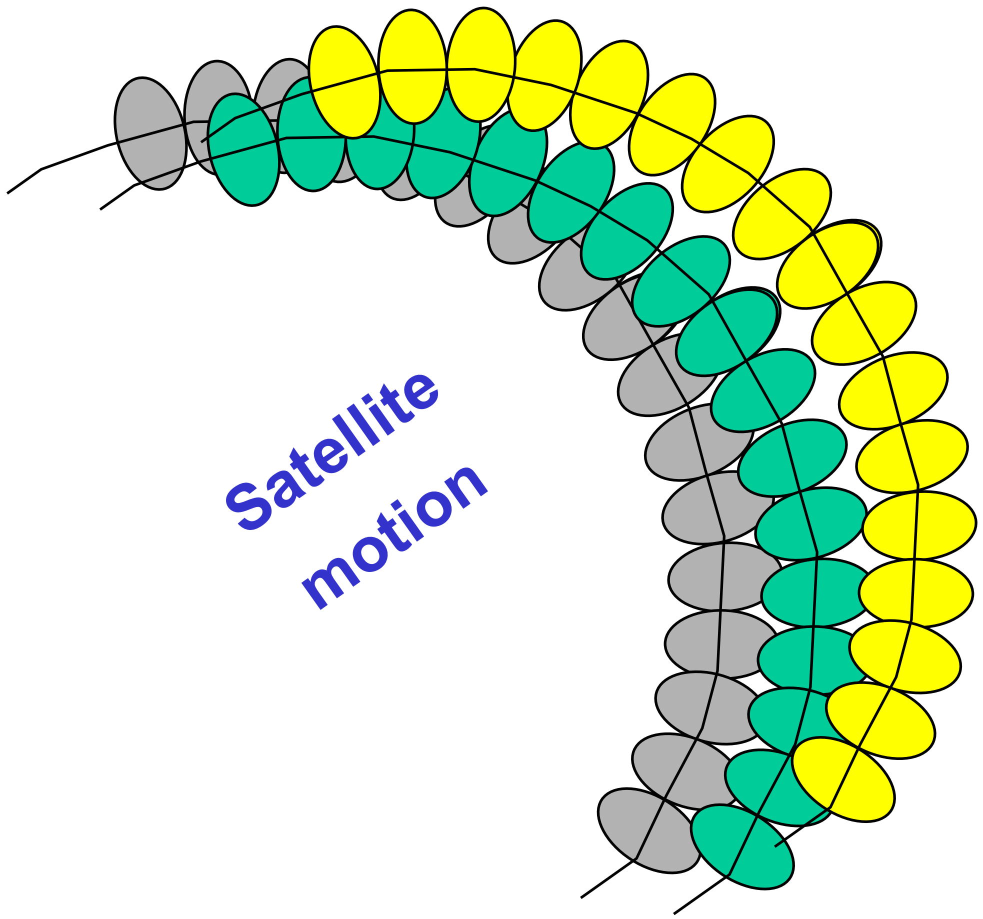
The Satellite “Beamfilling” Problem

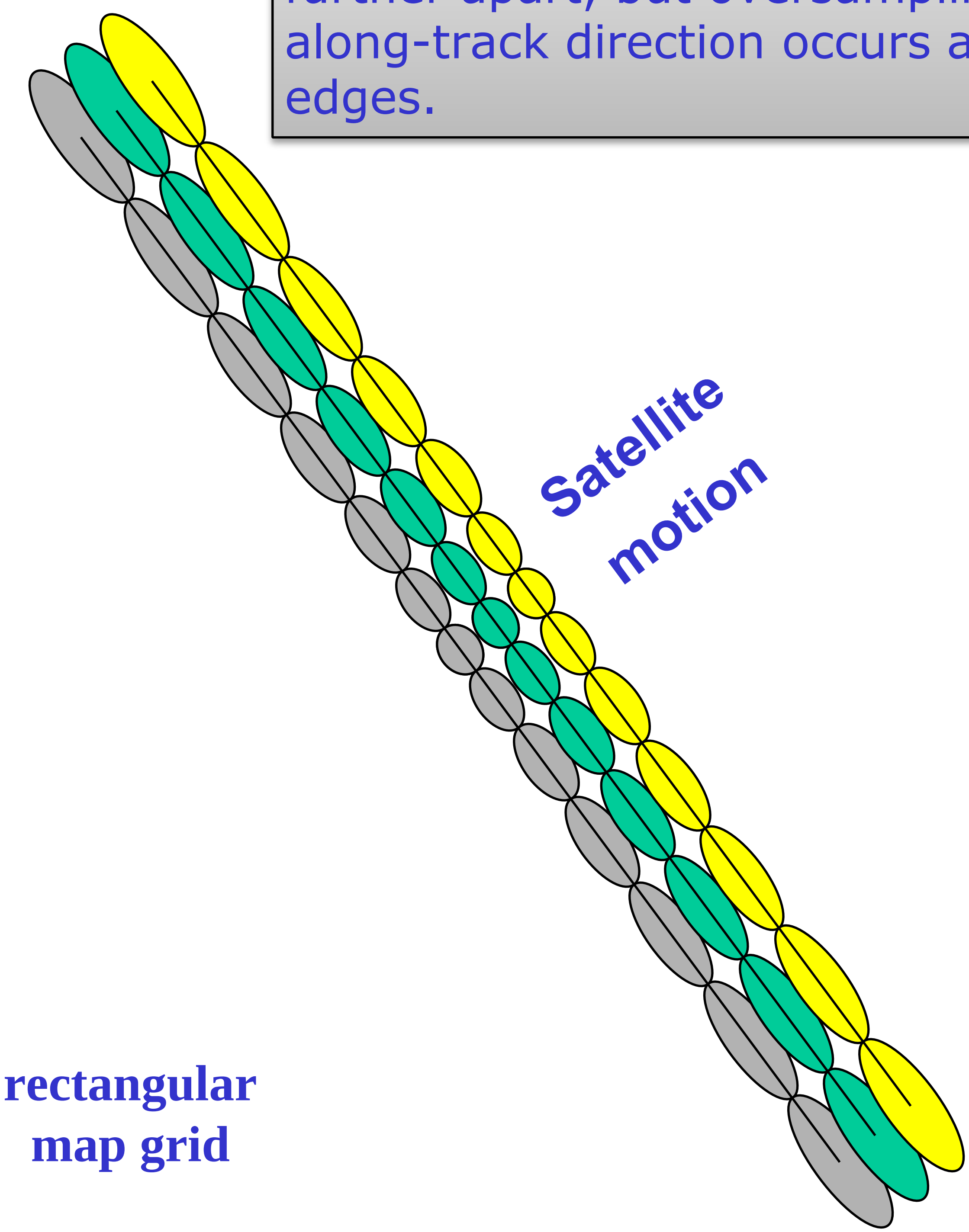
We don’t know the spatial pattern of the underlying rainfall at the time that the satellite flies over



Characteristics of the Satellite Sensor Scanning

Cross-track scanning (AMSU-B)
Pixels grow as viewing angle grows away from nadir. Pixels are spaced further apart, but oversampling in the along-track direction occurs at the edges.





Conical scanning (SSMIS, TMI, GMI)
Scan lines are segments of a cycloidal pattern. The along-track separation is the same everywhere, but the curvature causes over-sampling at the edges.

rectangular map grid

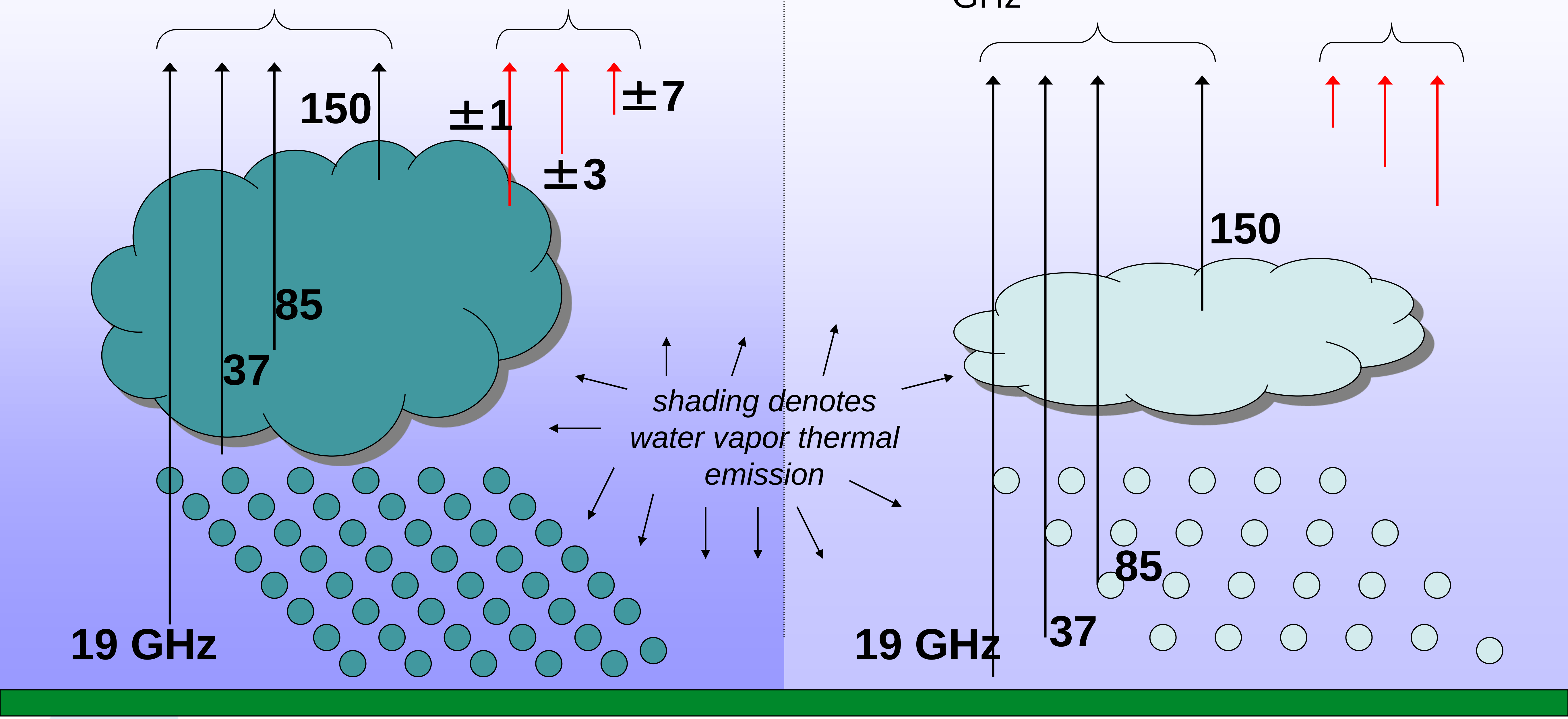
Using Imaging and Sounding Channels on SSMIS

19-85 GHz imaging channels are the most useful

183 GHz sounding channels less useful – water vapor and temperature variations less significant

Significant surface contribution between 19-85 GHz

Surface is usually opaque at 150 and 183 GHz – signals due to snow and drizzle



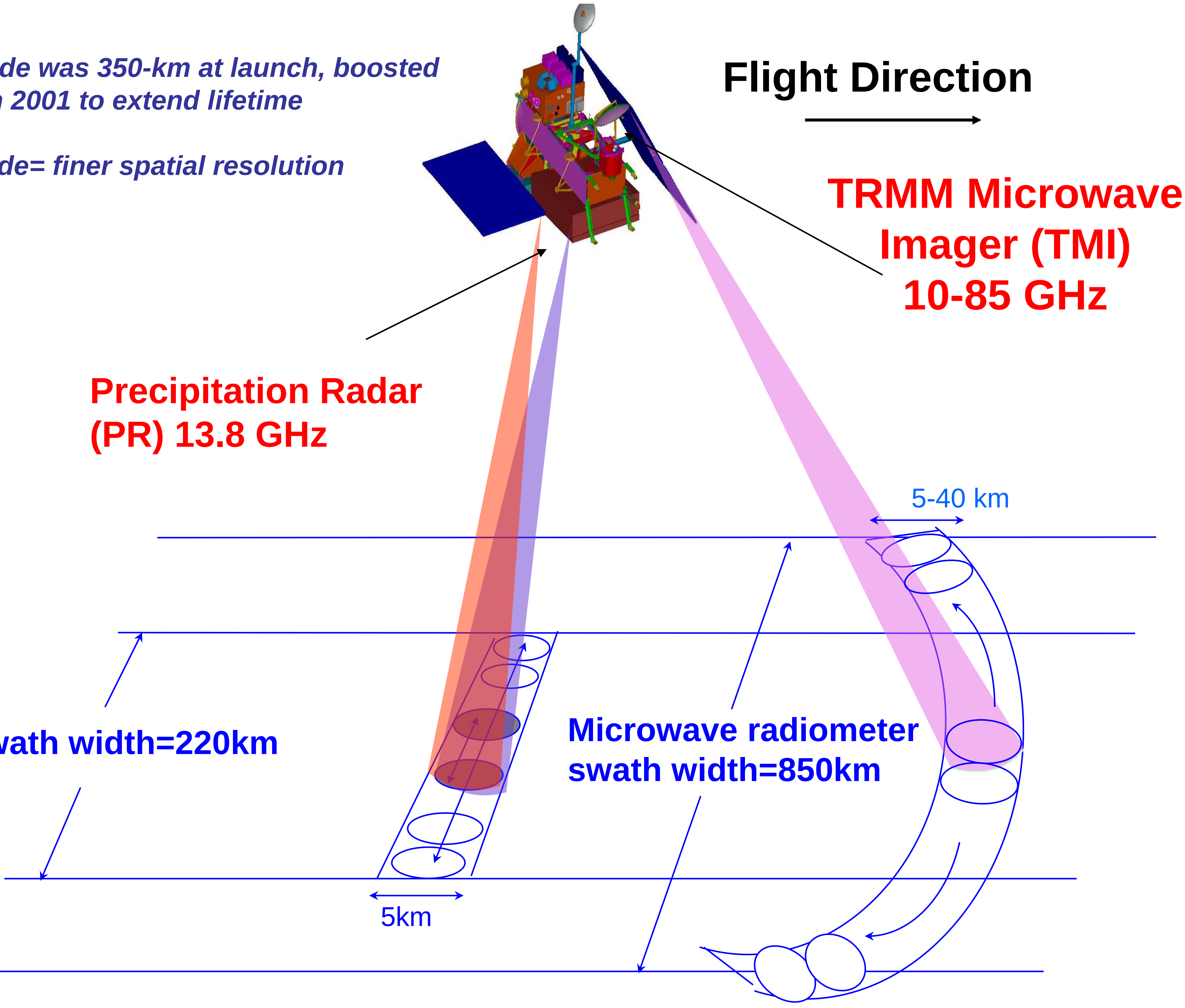
Tropical Rainfall
convective clouds with ice region above rain, warm ocean background

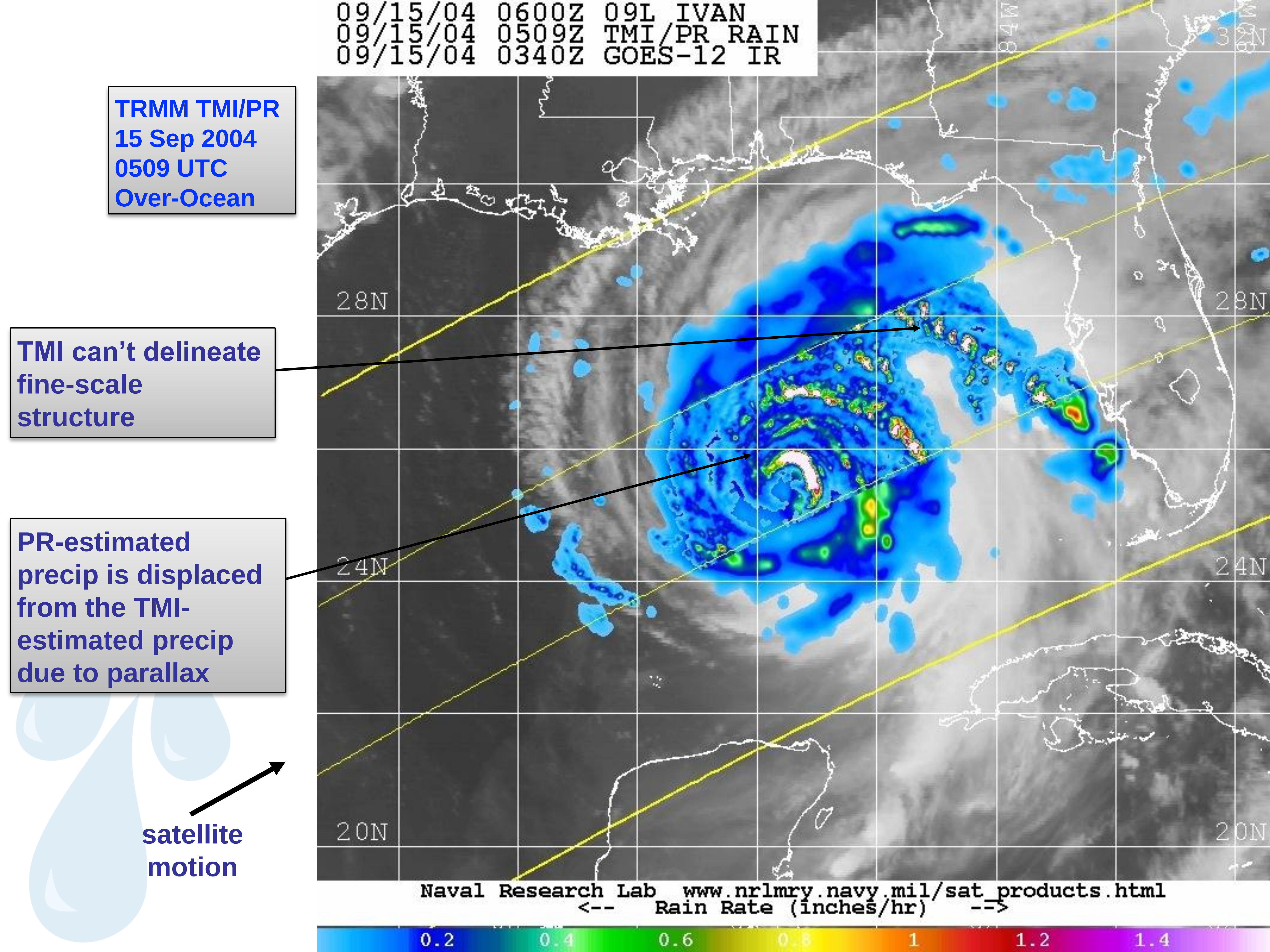
Higher Latitude Drizzle
Lower altitude clouds, mainly non-convective, cold ocean background

TRMM Satellite Sensors

TRMM altitude was 350-km at launch, boosted to 402-km in 2001 to extend lifetime

Lower altitude= finer spatial resolution



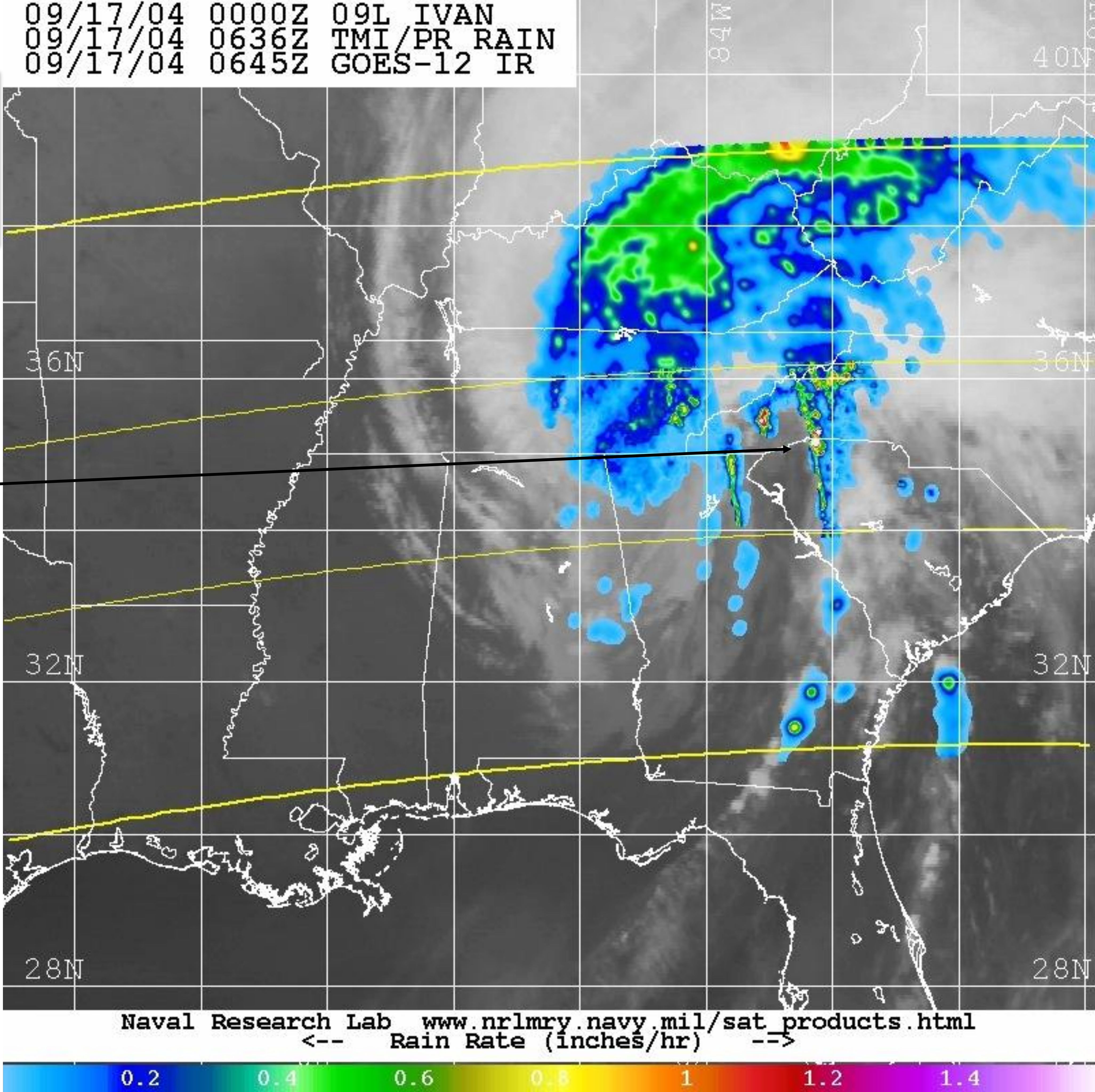


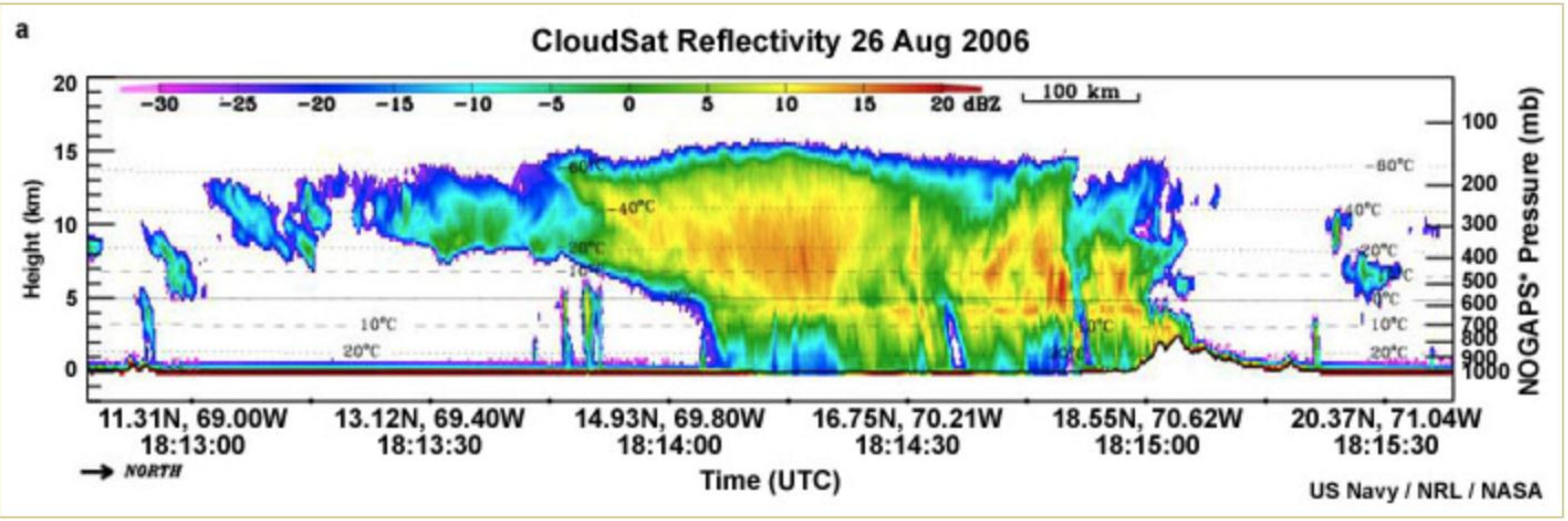
09/15/04 0600Z 09L IVAN
09/15/04 0509Z TMI/PR RAIN
09/15/04 0340Z GOES-12 IR
TRMM TMI/PR
15 Sep 2004
0509 UTC
Over-Ocean
TMI can't delineate fine-scale structure
PR-estimated precip is displaced from the TMI-estimated precip due to parallax
satellite motion
28N
24N
20N
Naval Research Lab www.nrlmry.navy.mil/sat_products.html
<-- Rain Rate (inches/hr) -->
0.2 0.4 0.6 0.8 1 1.2 1.4

TRMM TMI/PR
17 Sep 2004
0636 UTC
Over-Land

TMI can't capture the heavy isolated rain events (the tail of the rainfall histogram, i.e. the "few big events") that the PR picks up

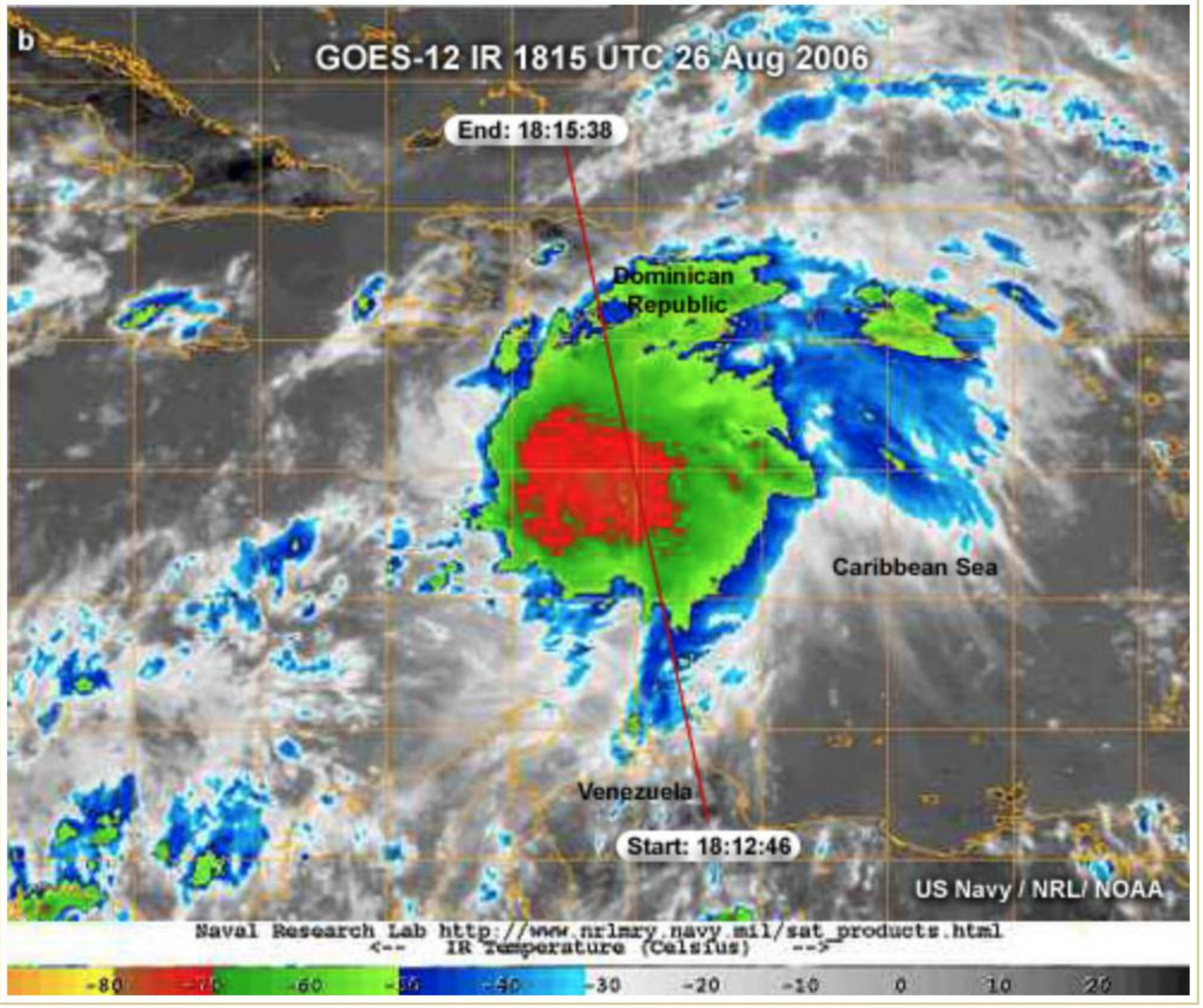
satellite motion



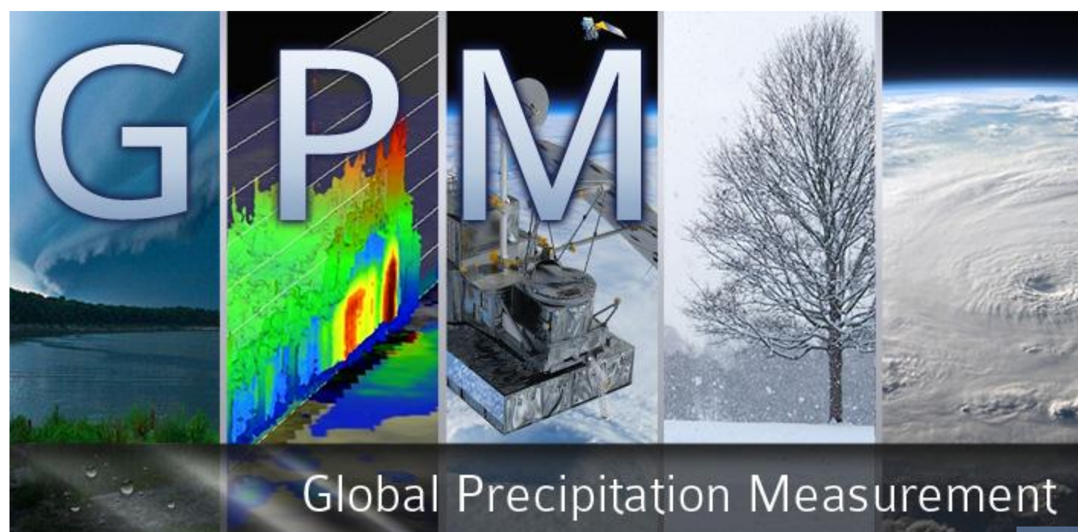


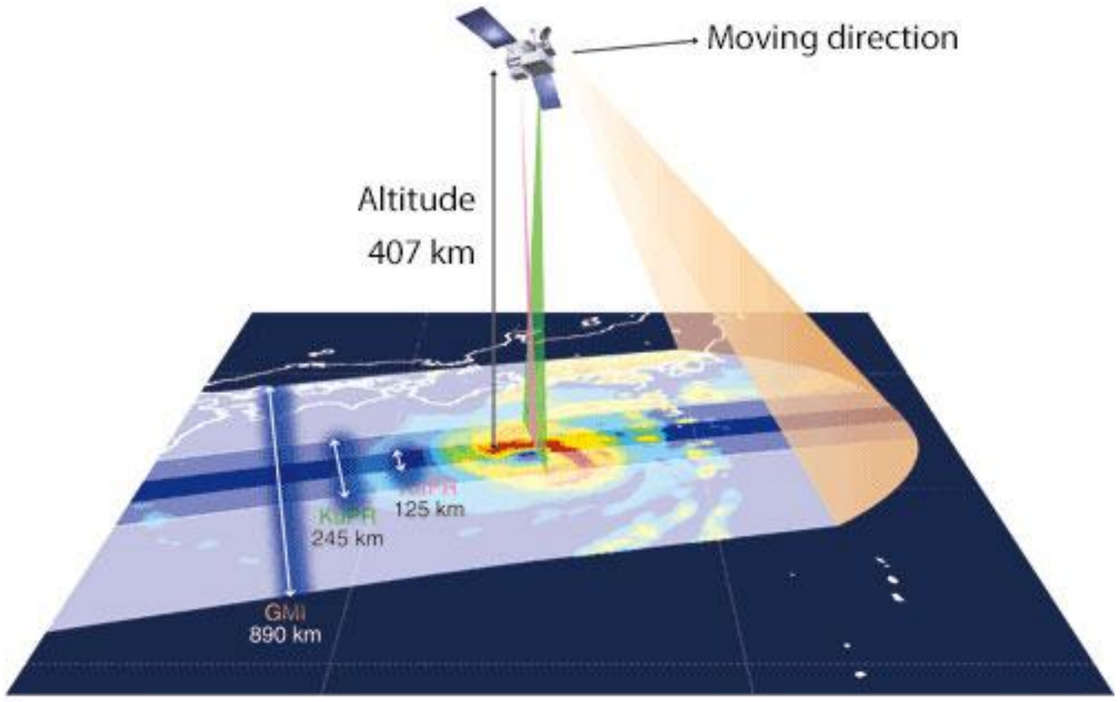
CloudSat profile through Tropical Storm Ernesto.

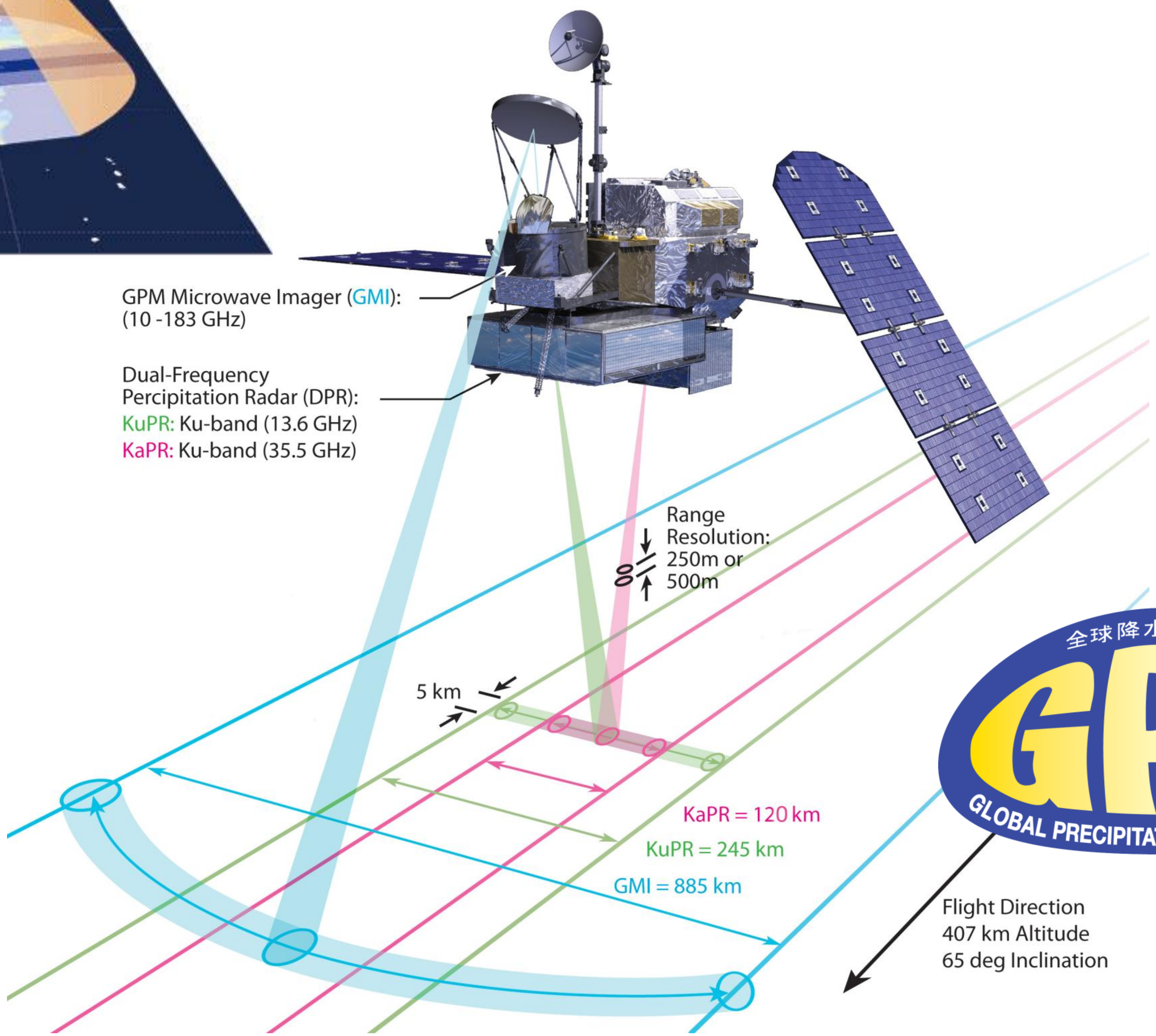
A broad area of high reflectivity extends south of the mountains of the Dominican Republic. Red and orange areas indicate the presence of large amounts of cloud water and/or ice while blue areas above indicate cloud ice. Wavy blue lines along the bottom of the cloud mass indicate intense rainfall. The top-down satellite-IR view misses two small thunderstorms beneath the cirrus anvil. The role of orographic lift in producing large amounts of cloud water is indicated by high reflectivity along the mountain peaks. At the same altitude over the ocean, reflectivity values are mostly lower.



The Global Precipitation Measurement GPM mission

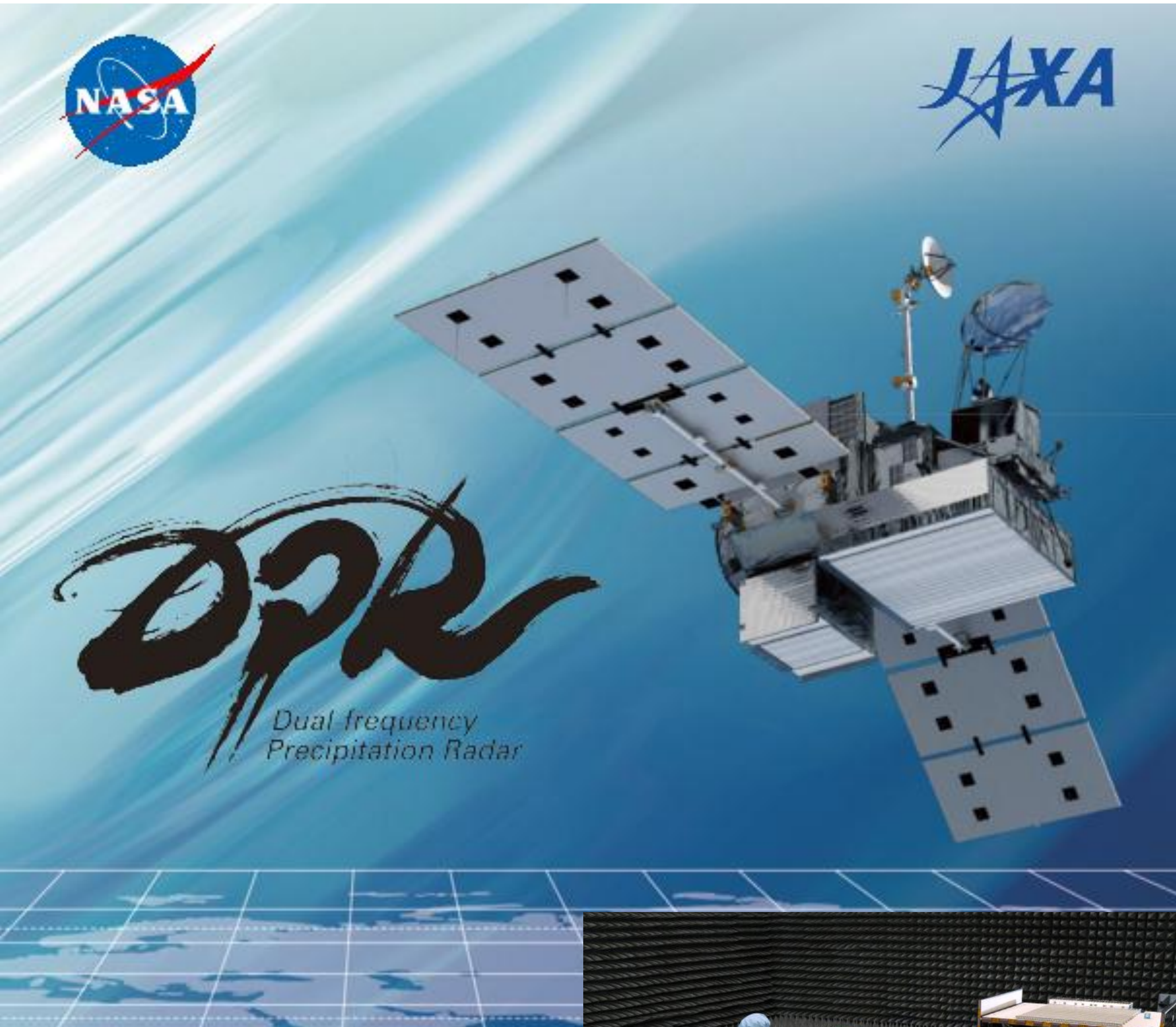


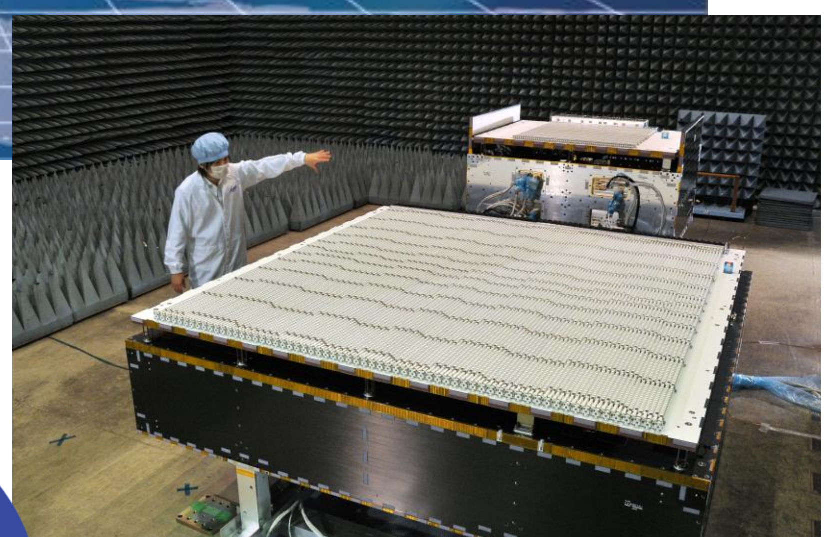




全球降水観測計画
GPM
GLOBAL PRECIPITATION MEASUREMENT

Dual-frequency Precipitation Radar (DPR)





GPM Microwave Imager (GMI)

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GPM
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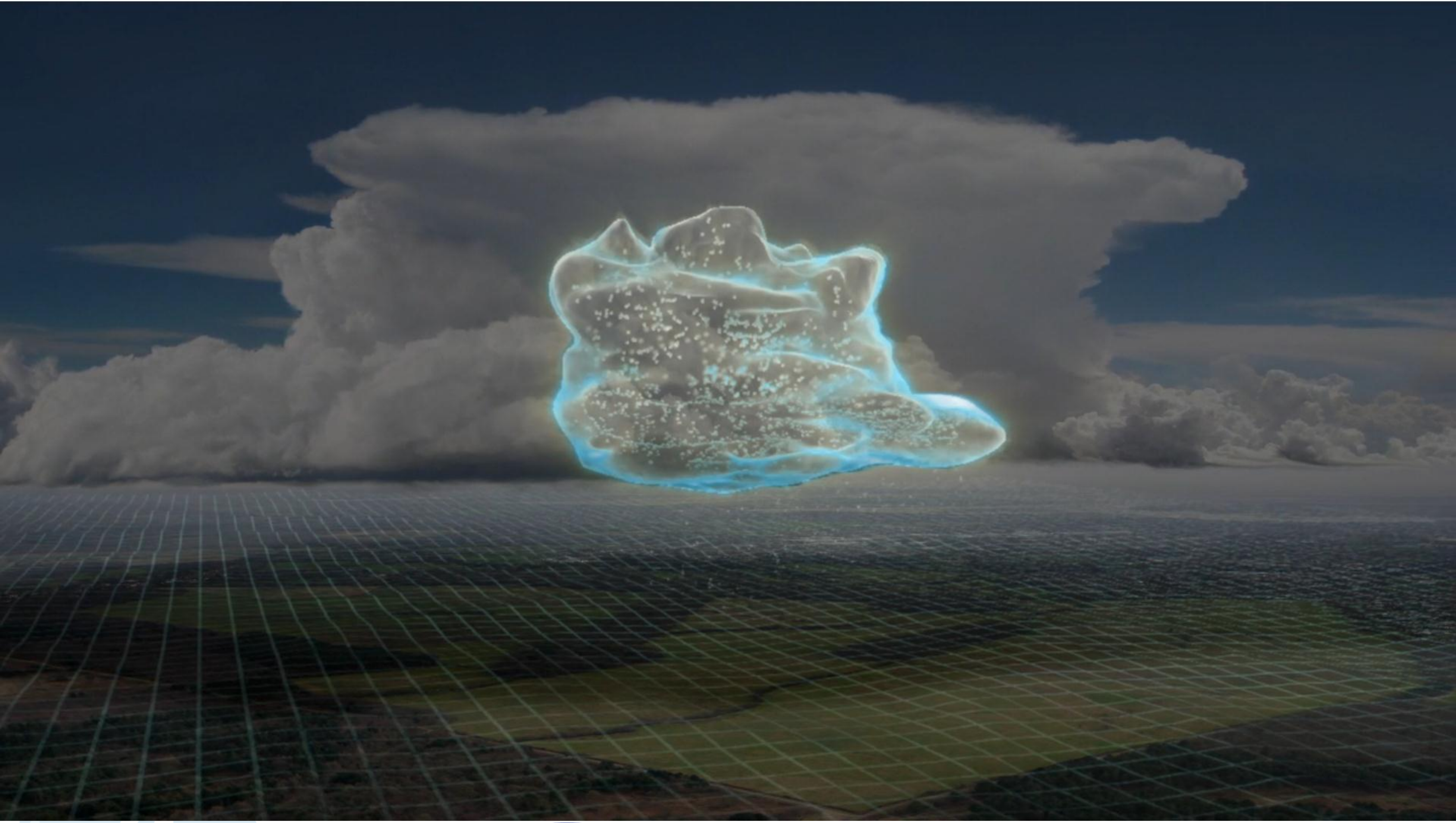

全球降水観測計画

GPM

GLOBAL PRECIPITATION MEASUREMENT

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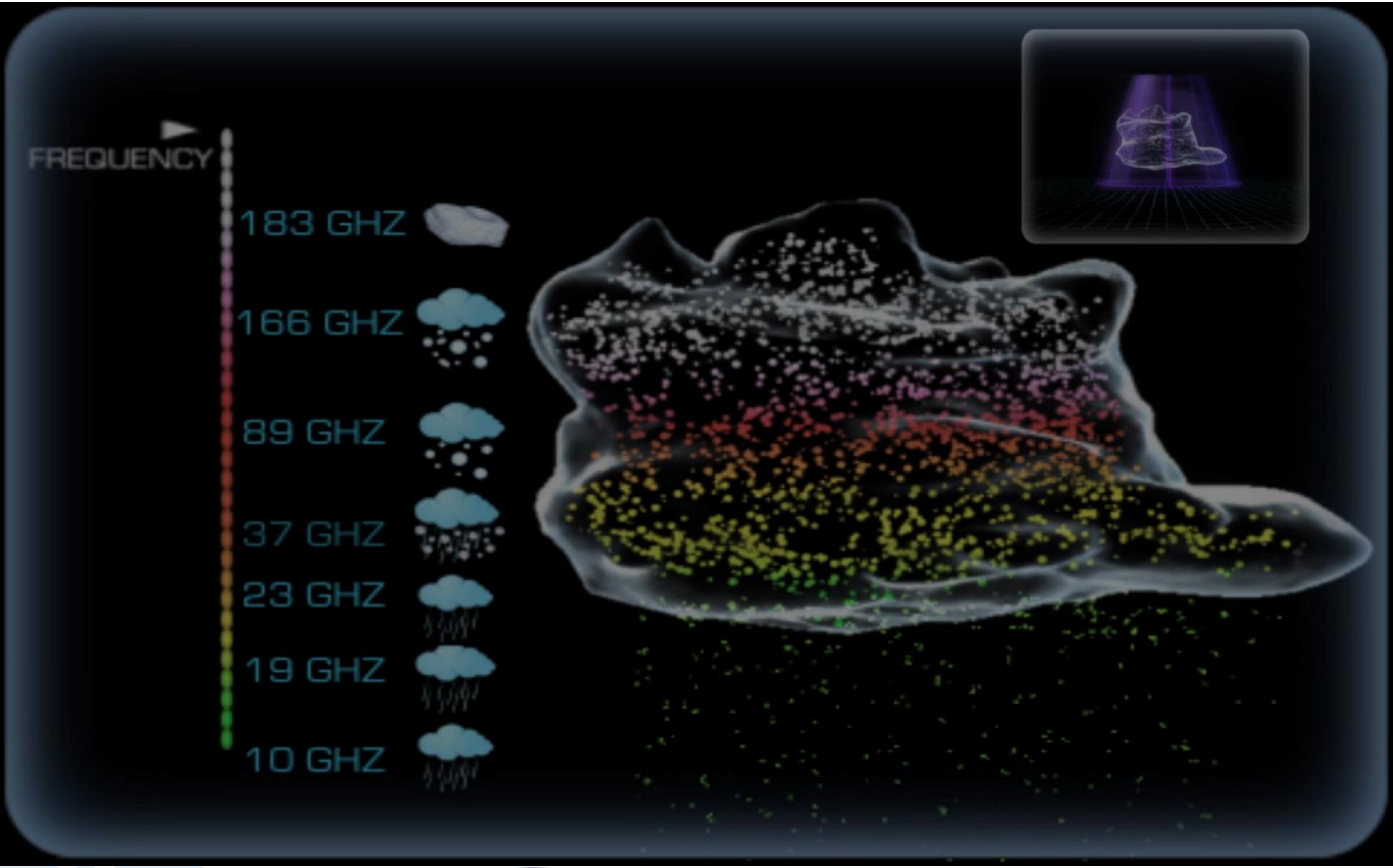
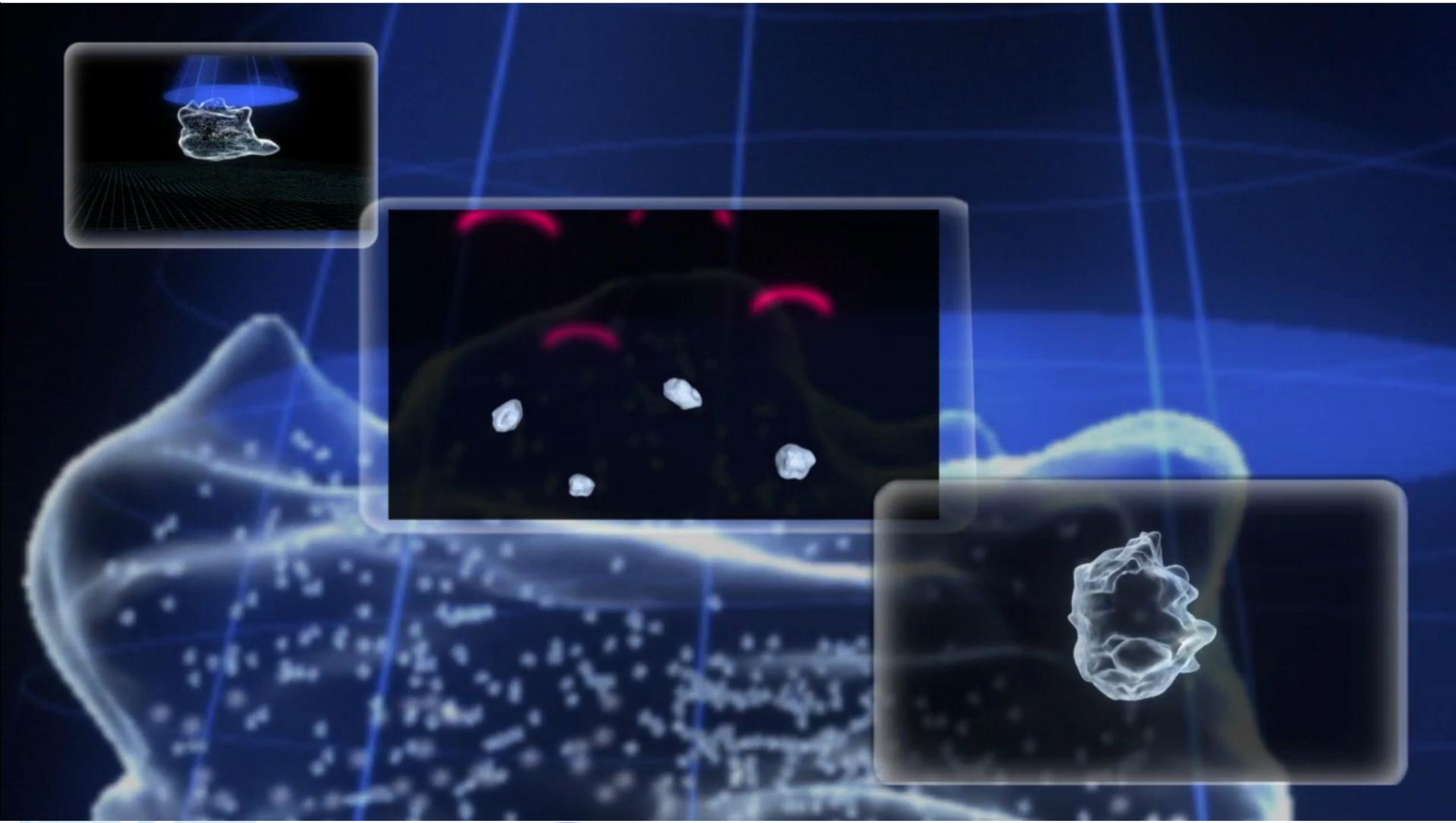


全球降水観測計画
GPM
GLOBAL PRECIPITATION MEASUREMENT


GPM
ACQUISITION MODE: RADAR-KU/KA
BAND



全球降水観測計画
GPM
GLOBAL PRECIPITATION MEASUREMENT

全球降水観測計画
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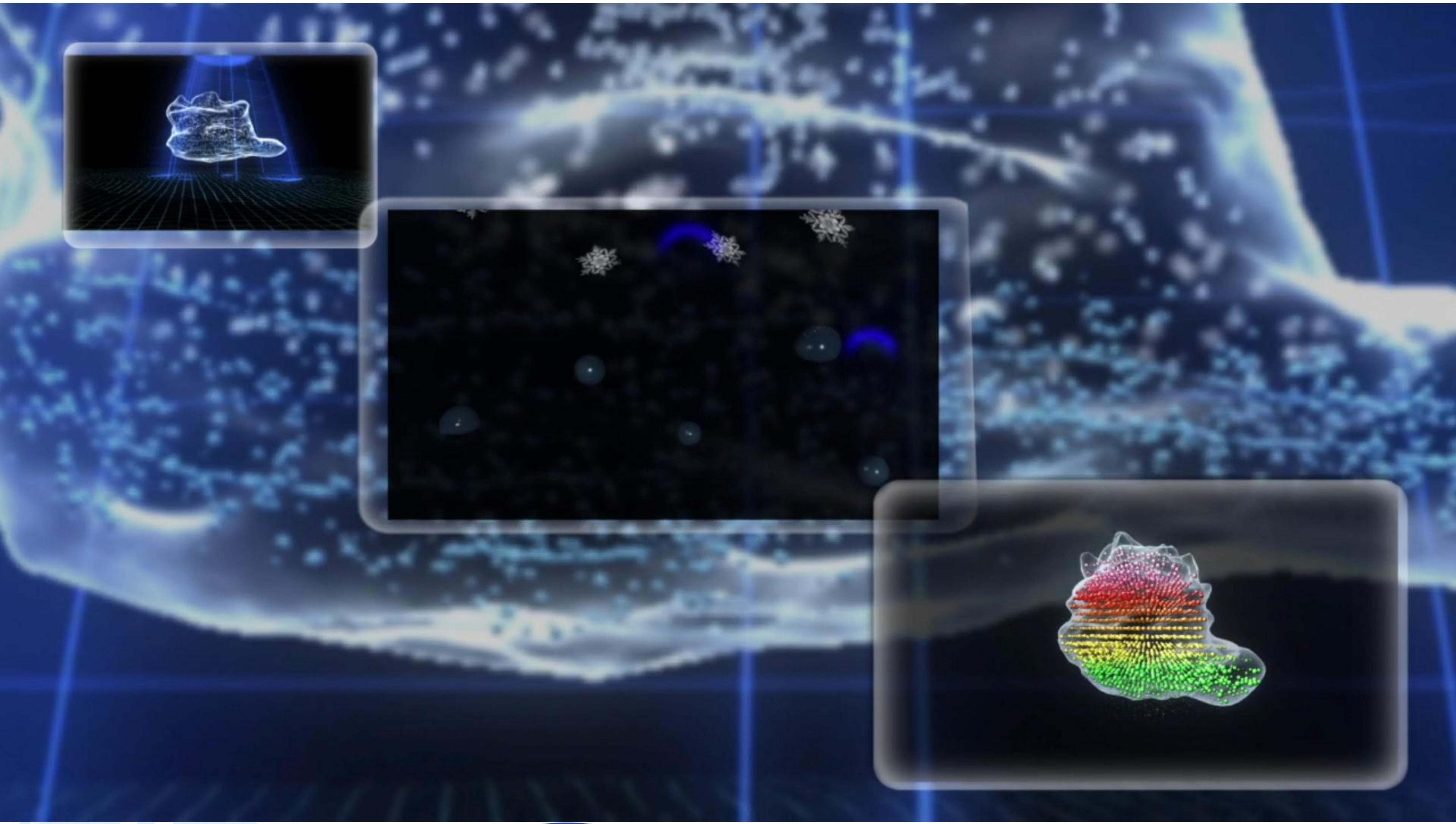

全球降水観測計画

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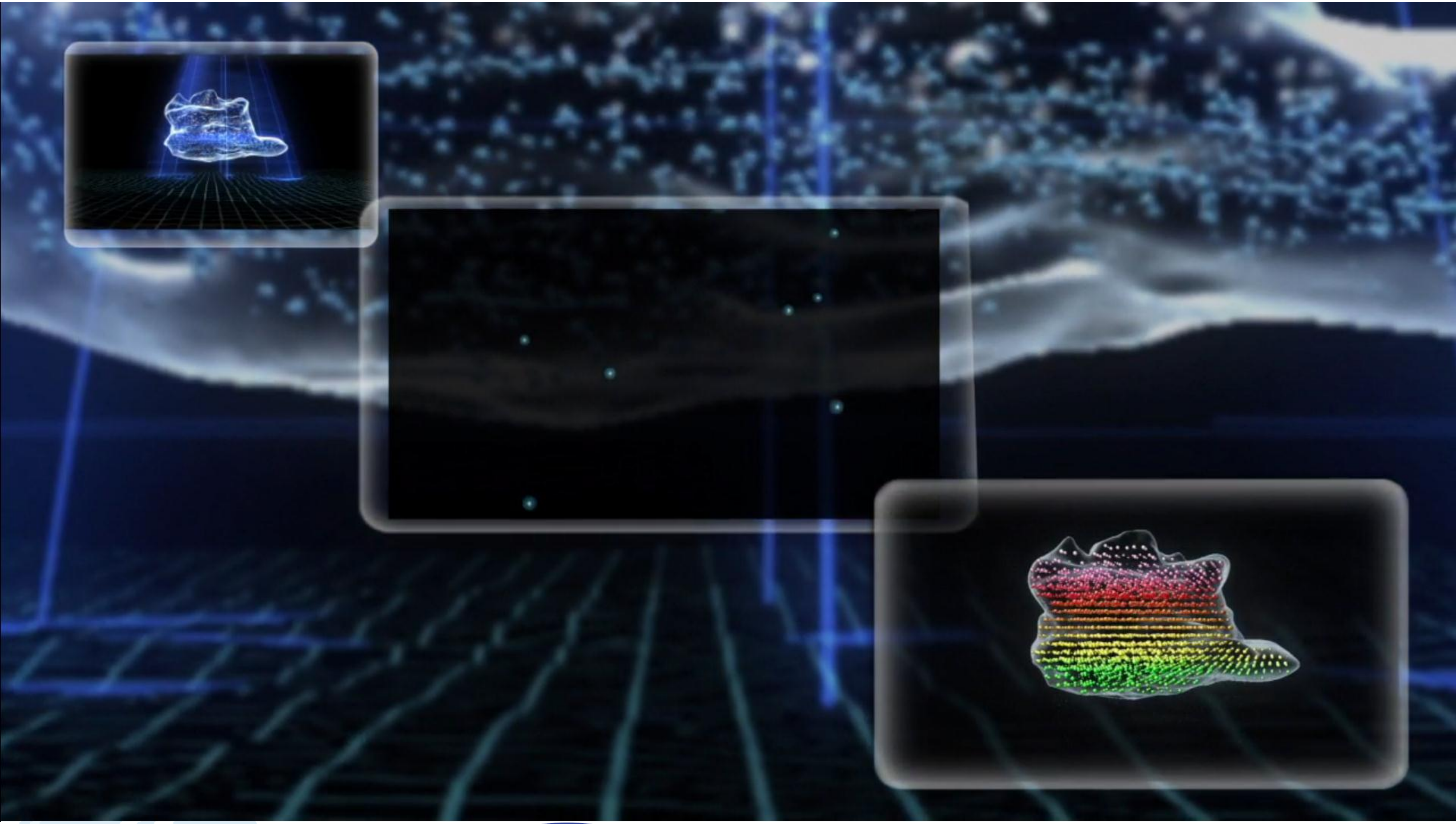
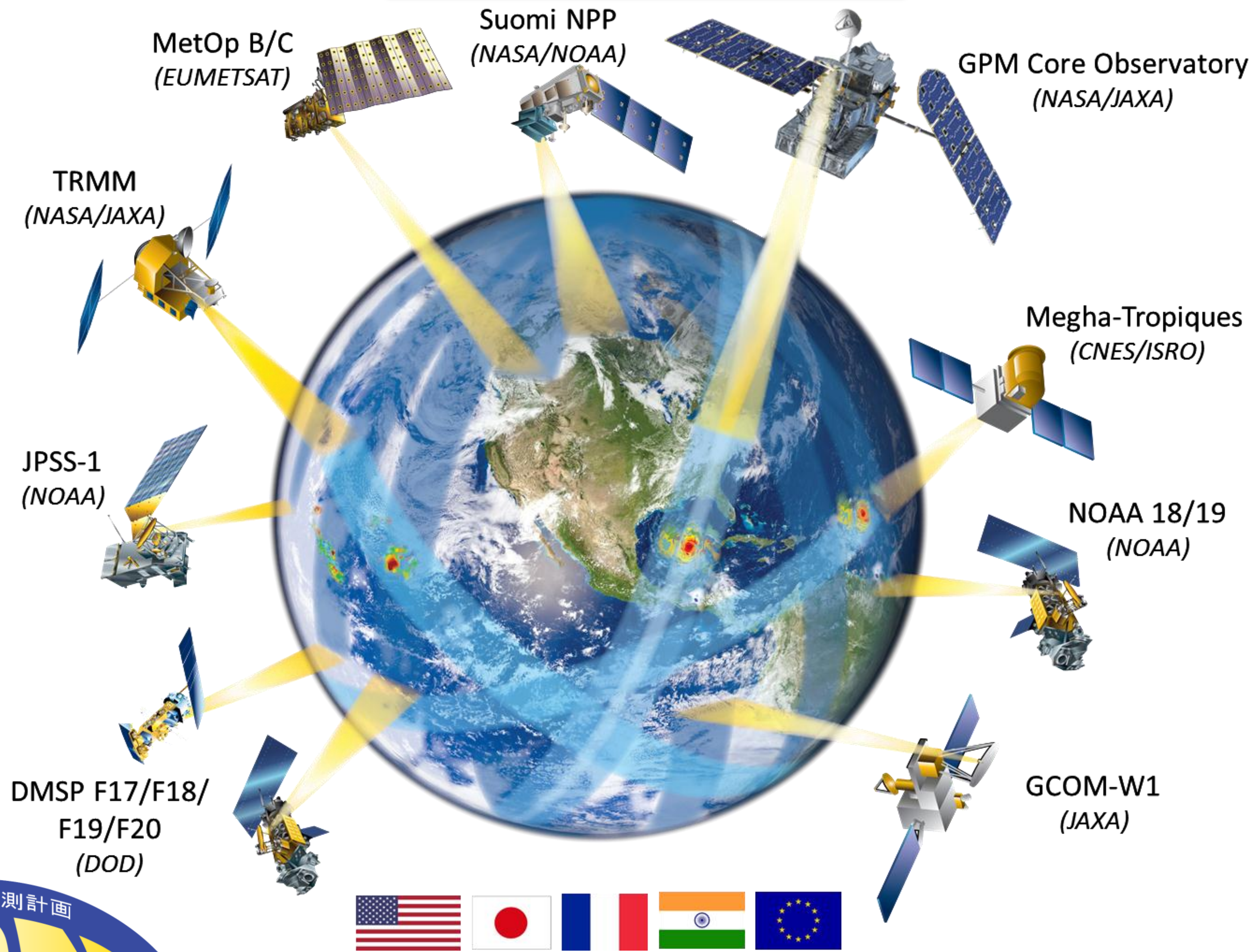
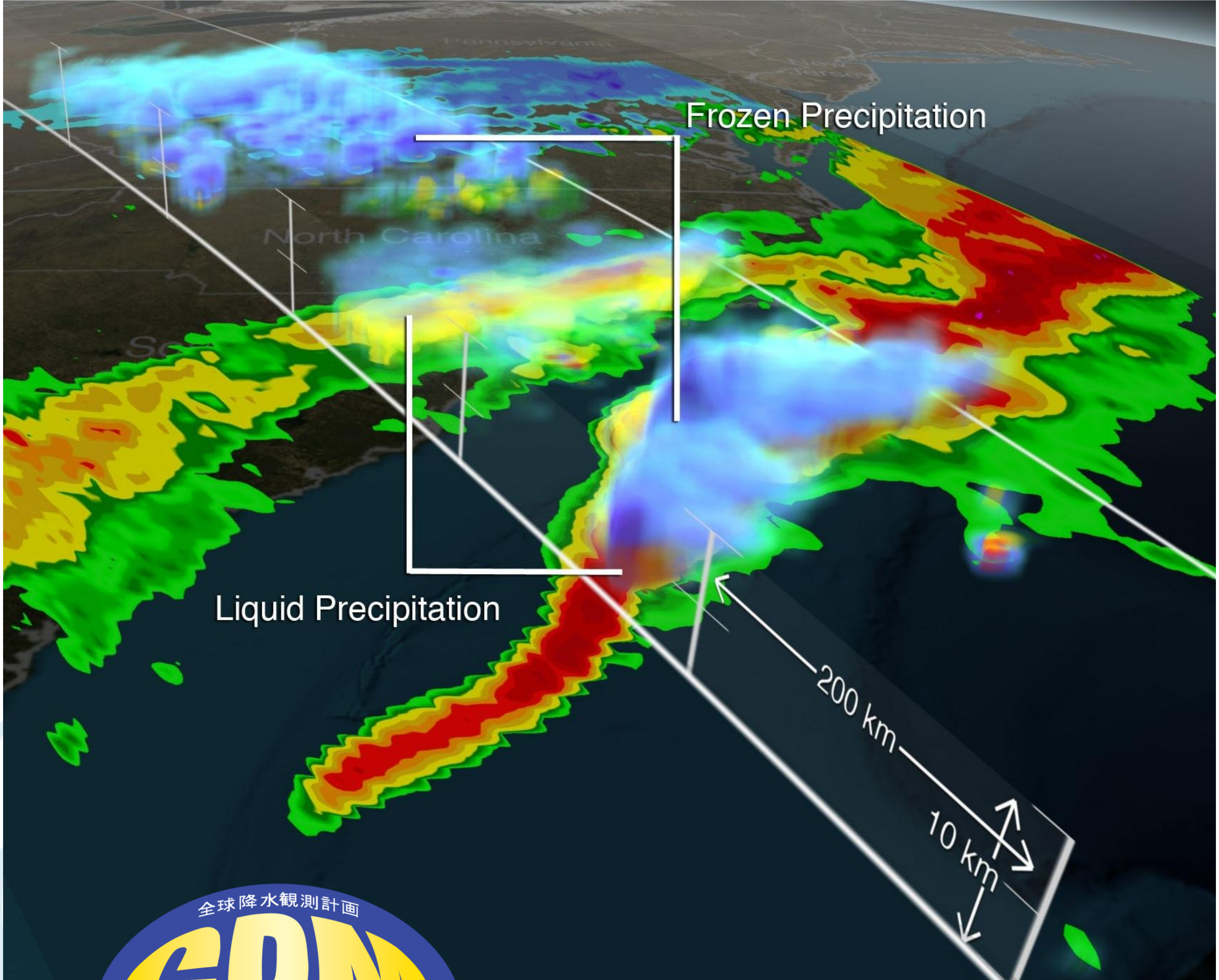
GLOBAL PRECIPITATION MEASUREMENT

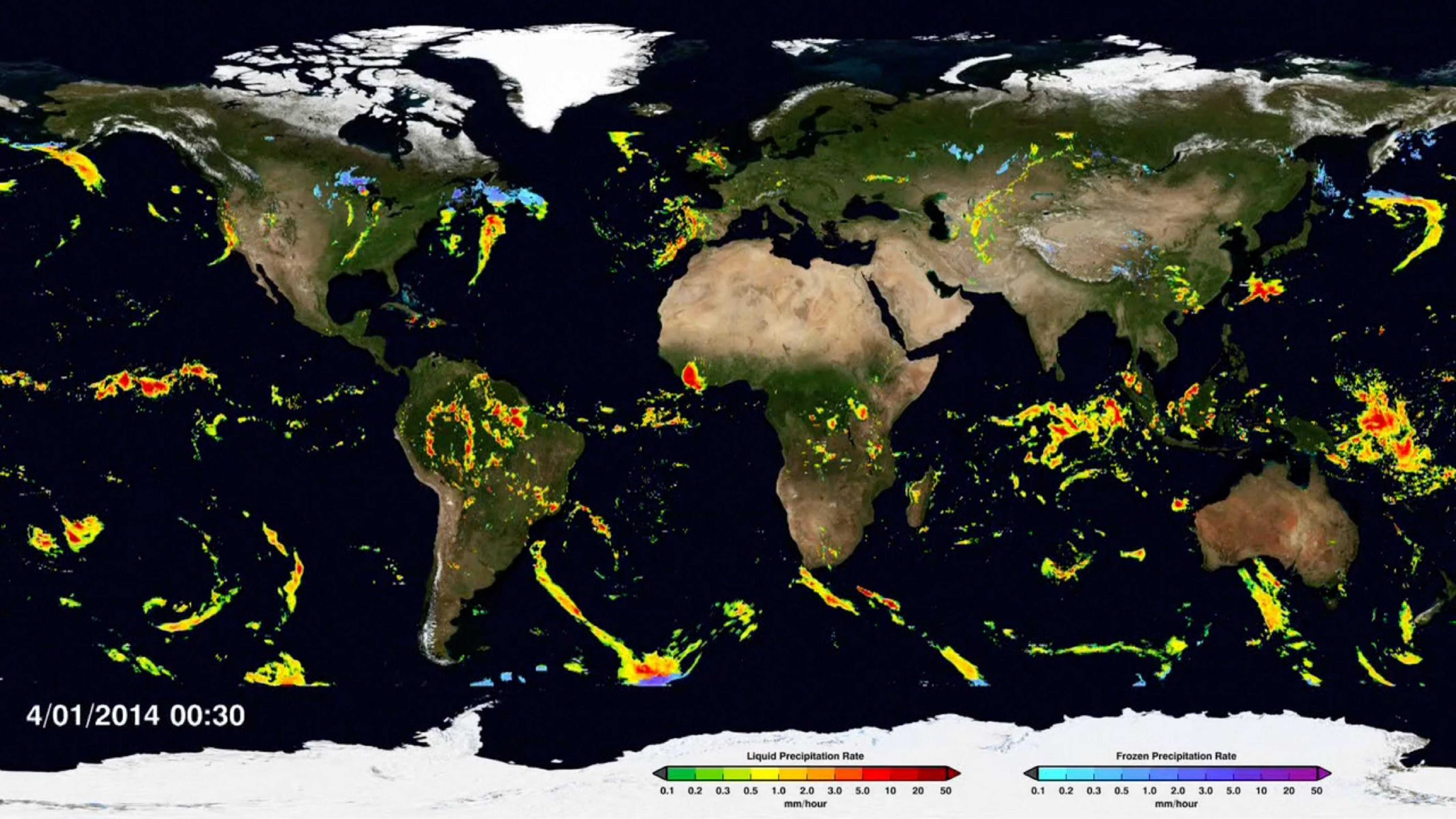


GPM constellation





One of the first storms observed by the NASA/JAXA GPM Core Observatory on March 17, 2014, in the eastern United States reveals a full range of precipitation, from rain to snow.



Global rainfall (yellow-red) and snowfall (blue) map from GPM, April-September 2014

全球降水観測計画 GPM GLOBAL PRECIPITATION MEASUREMENT

NASA

A one stop shop

IPWG
International Precipitation
Working Group

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

8th IPWG Workshop
Bologna, 3-7 October, 2016

That’s all folks!

Thank you