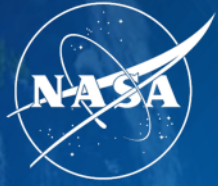


National Aeronautics and
Space Administration



NASA Earth

Hydrosphere Meeting 2026

Precipitation

State of the Science

**Claire Pettersen, Simon Pfreundschuh, Sarah
Ringerud, Courtney Schumacher, Jackson Tan**

Contributions from Andrea Portier, Patrick Gatlin, Chris Kidd, Toshi Matsui, Dan Cecil, Rachael Kroodsma, Chip Helms, and many others

Precipitation Observation from Space

NOVEMBER 1961

MONTHLY WEATHER REVIEW

447

ANOTHER VIEW FROM TIROS I OF A SEVERE WEATHER SITUATION MAY 16, 1960¹

LINWOOD F. WHITNEY, JR.

U.S. Weather Bureau, Washington, D.C.

(Manuscript received April 25, 1961; revised August 25, 1961)

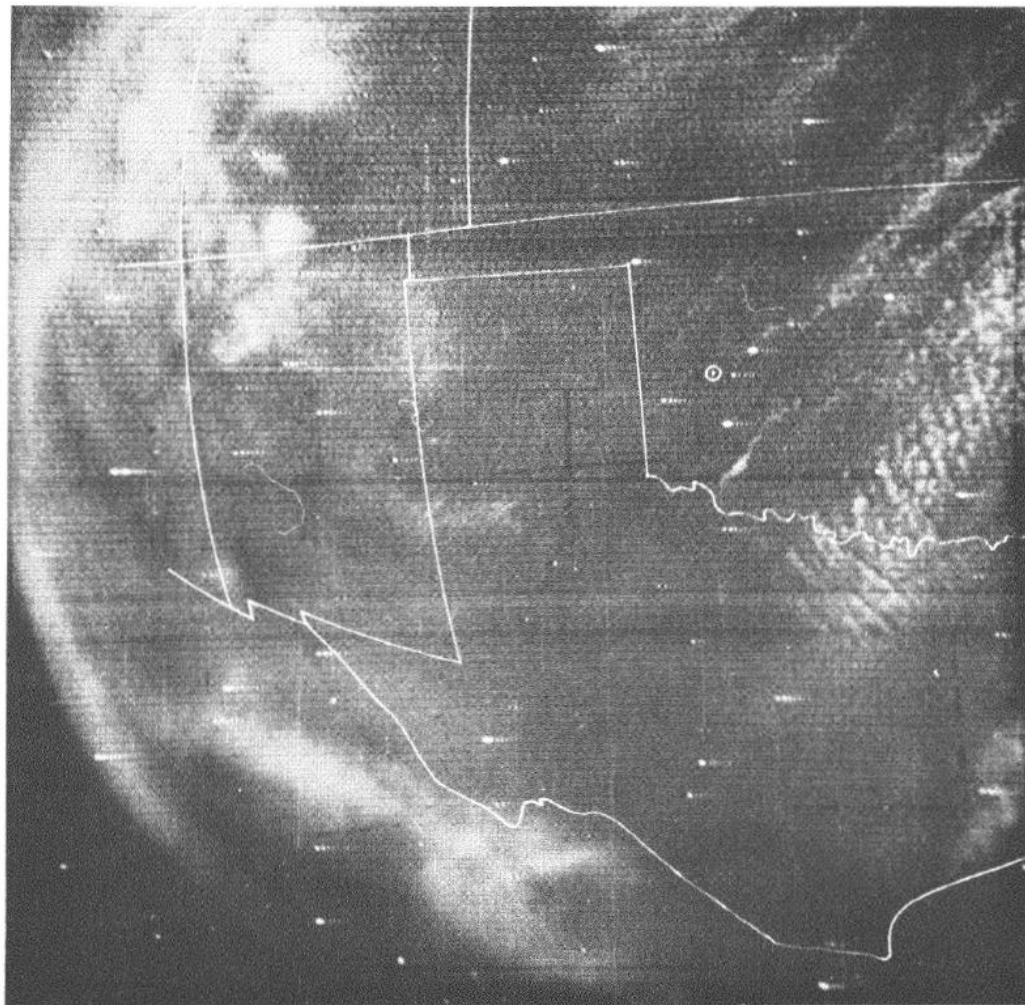
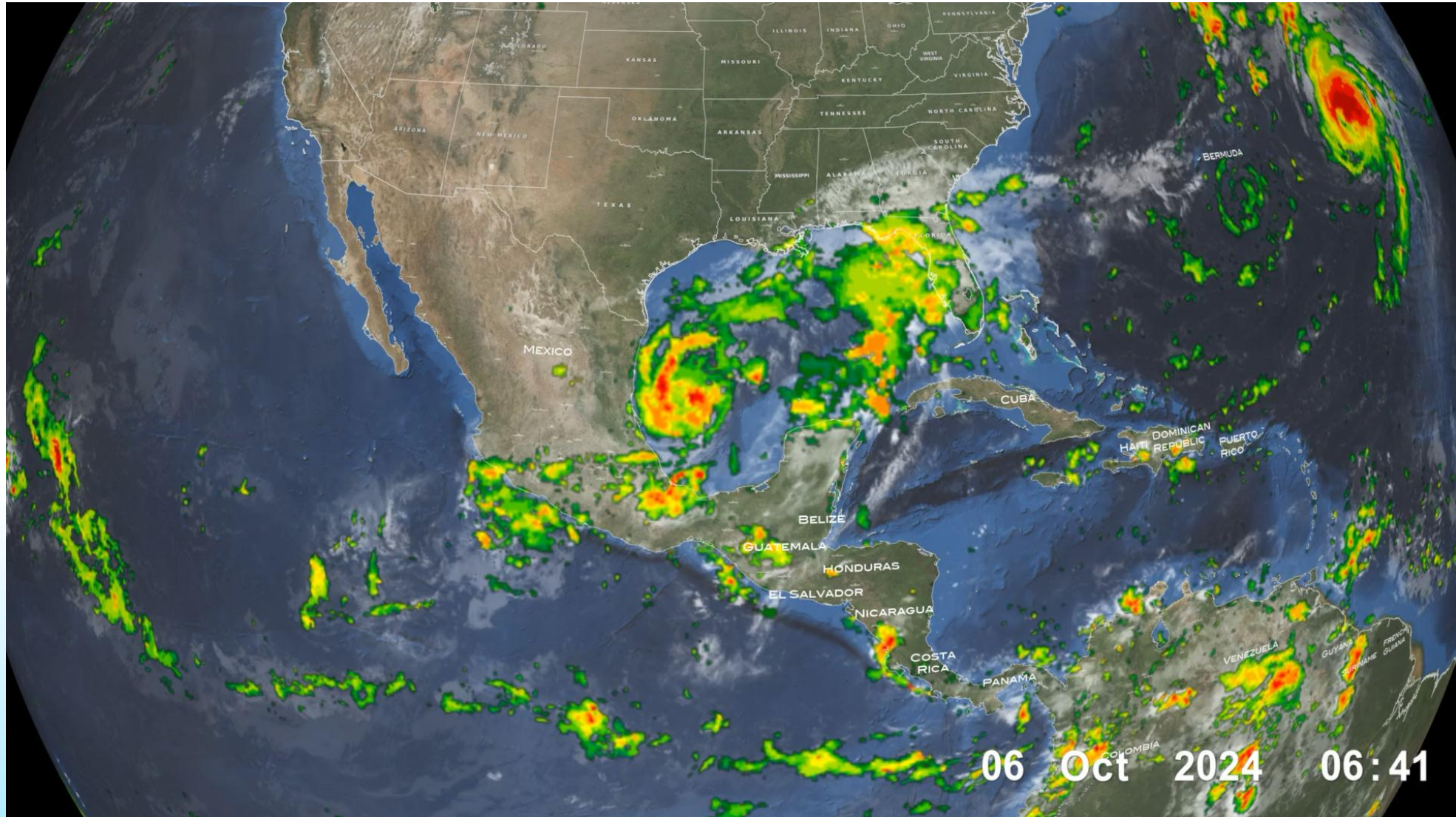


FIGURE 1 —Gridded photograph of frame 4 from the TIROS I pass 659, May 16, 1960, 2100 GMT. Cloud streets are seen at the right in the picture.

Precipitation Observation from Space



Precipitation Observation from Space





ENABLING APPLICATIONS FOR SOCIETAL BENEFIT

ENVIRONMENTAL MANAGEMENT

- Resource monitoring
- Land management & assessment

ECOLOGICAL MANAGEMENT

- Ecosystem monitoring
- Habitat assessment

ENERGY & UTILITIES

- Renewable forecasting
- Hydropower planning
- Grid resilience
- Energy demand

INSURANCE & FINANCE

- Risk assessment
- Portfolio risk
- Loss modeling
- Parametric insurance

DISASTER MONITORING & EMERGENCY RESPONSE

- Situational awareness
- Flood estimation
- Rapid response and aid

WEATHER FORECASTING & NWP

- Model initialization
- Forecast verification
- Precipitation assimilation
- Extreme-event monitoring

CLIMATE MODELING

- Model validation
- Bias correction

WATER RESOURCES & HYDROLOGY

- Rainfall estimation
- Drought monitoring
- Flood forecasting
- Water availability

AGRICULTURE & FOOD SECURITY

- Early warning of crop yield
- Irrigation system planning
- Water resource management

PUBLIC HEALTH

- Disease risk mapping
- Vector habitat
- Outbreak forecasting
- Waterborne disease

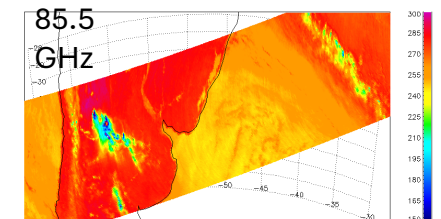
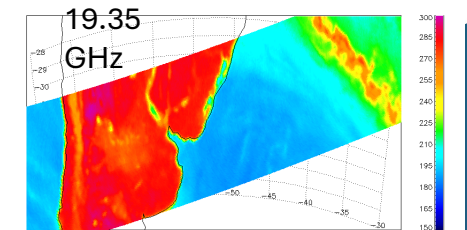
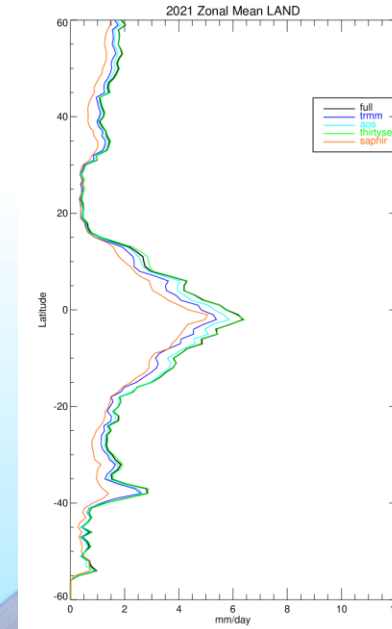
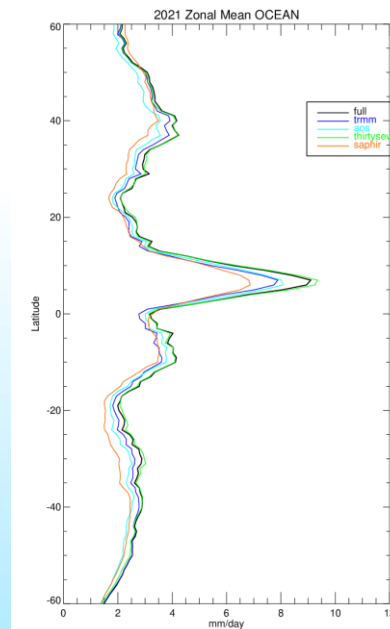
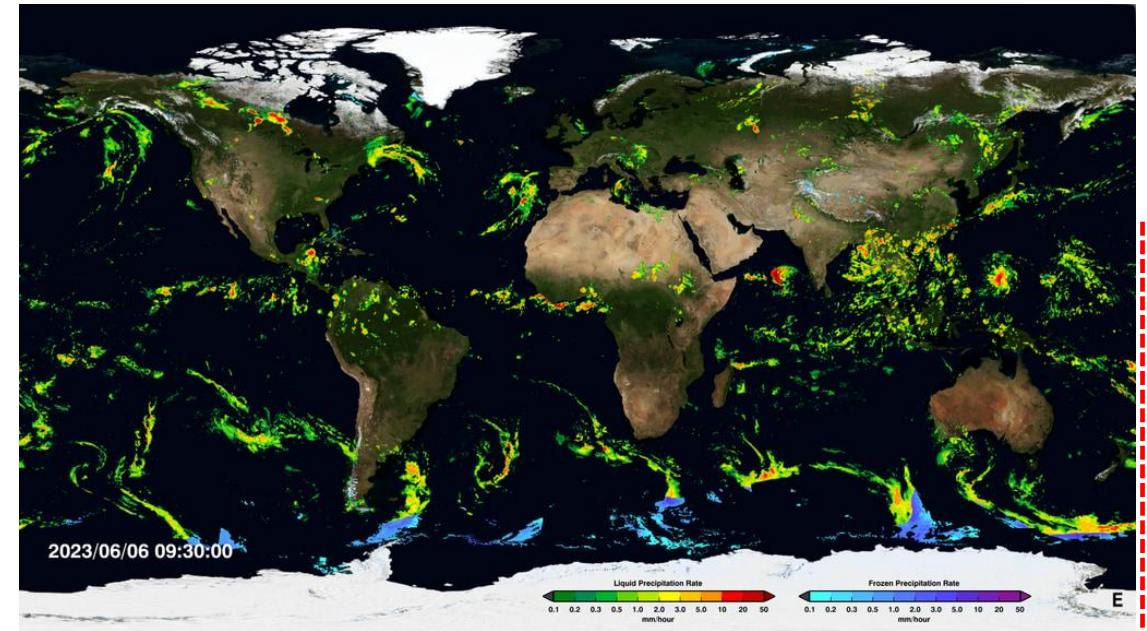
EARTH INTELLIGENCE SERVICES

- Risk monitoring
- Predictive analytics
- Decision support



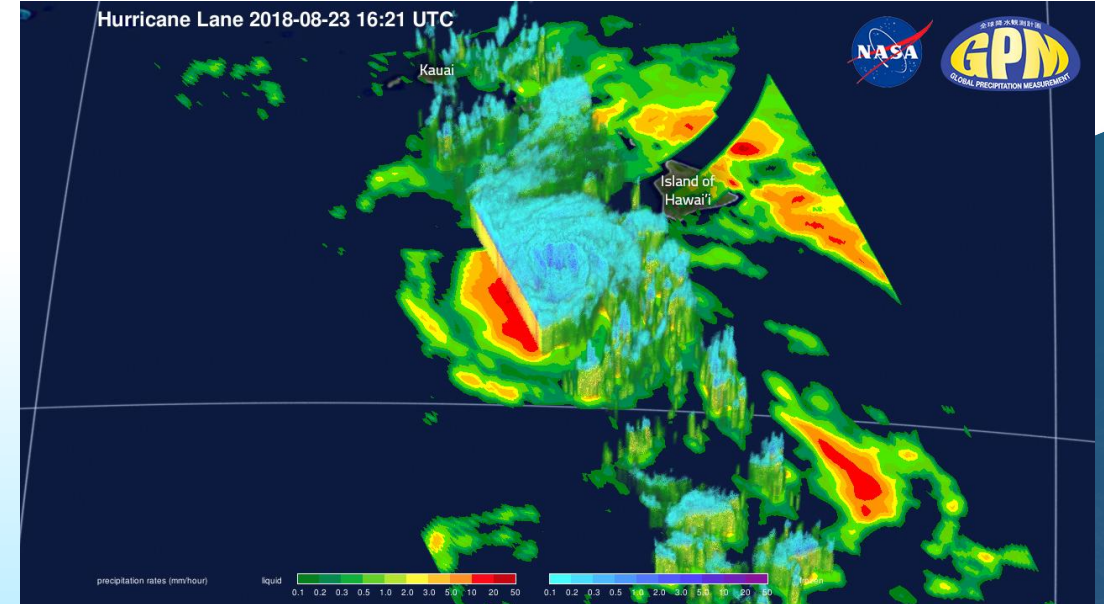
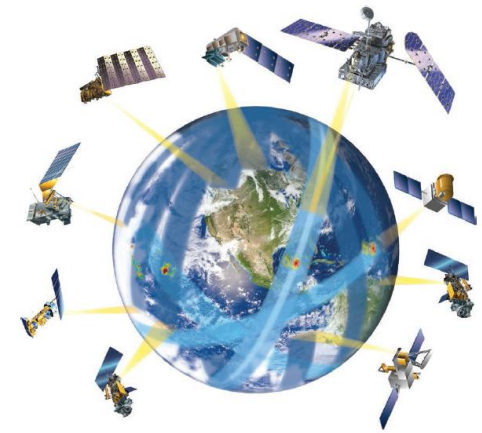
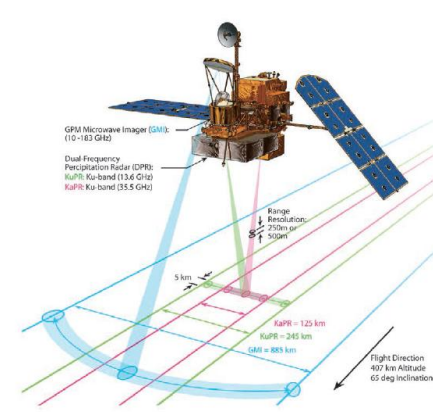
Necessary Ingredients for Multi-Satellite Product

- Sensors with appropriate information content
 - Frequency, resolution
- Passive microwave observations form the backbone of the global product
- Sampling/configuration of constellation members
- Calibration
 - Hardware + software
 - GPM: XCAL & L1C
 - IMERG calibrates using 2BCMB
- Processing system
 - PPS



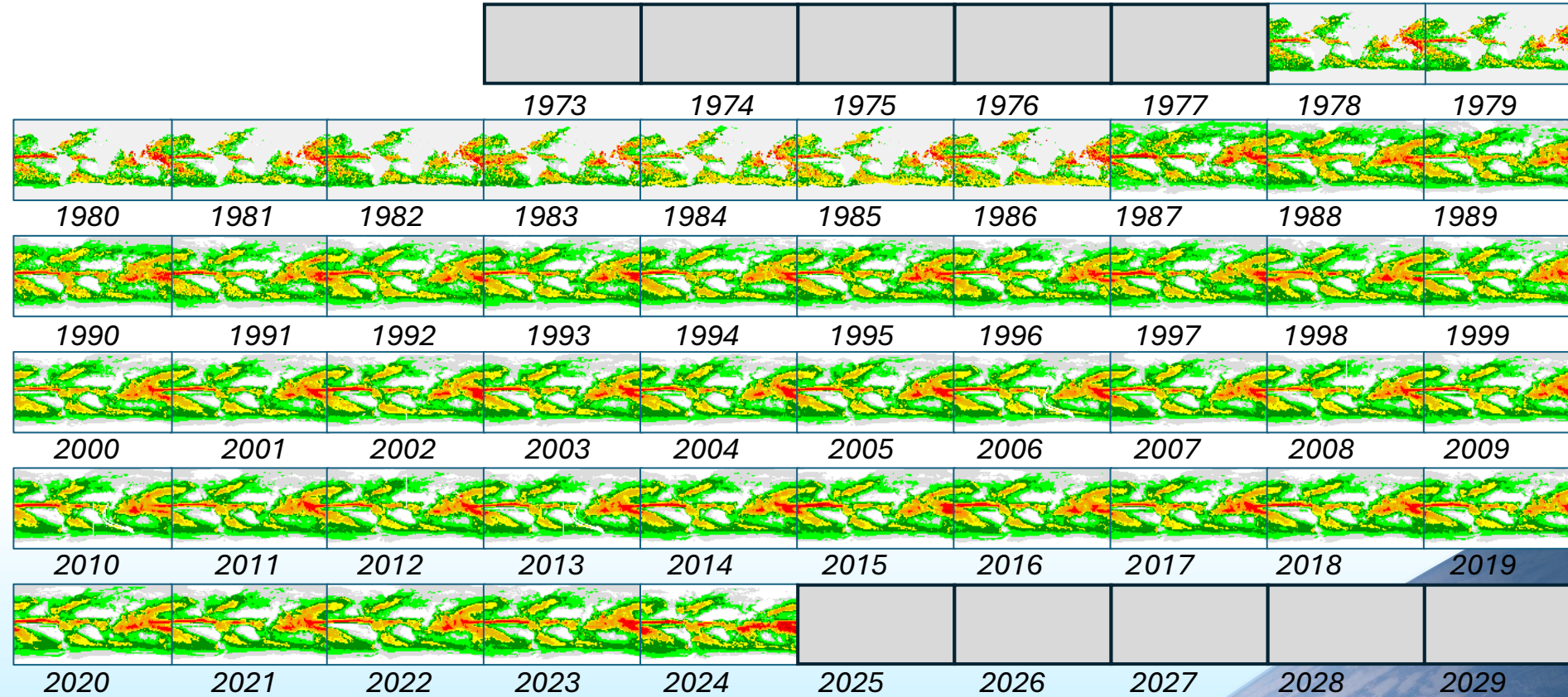
Current Methodology

- GPM Algorithm Flow
 - Combined retrieval
 - Active + Passive optimal solution for GPM core observatory (CO) in areas with active signal
 - Transfer Standard
 - Passive Constellation Retrievals
 - GPROF operational algorithm
 - Database constructed from CMB retrievals Constrained Bayesian (V8 transitions to ML)
 - IMERG
 - Integrated product every 30 min
 - Constellation+IR+gauges
 - Products intercalibrated to Combined retrievals
 - Precipitation Processing System (PPS)



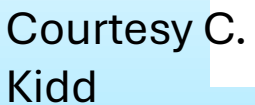
Data Record

47 years of PMW precipitation products on the NASA GES-DISC (C. Kidd)



1978

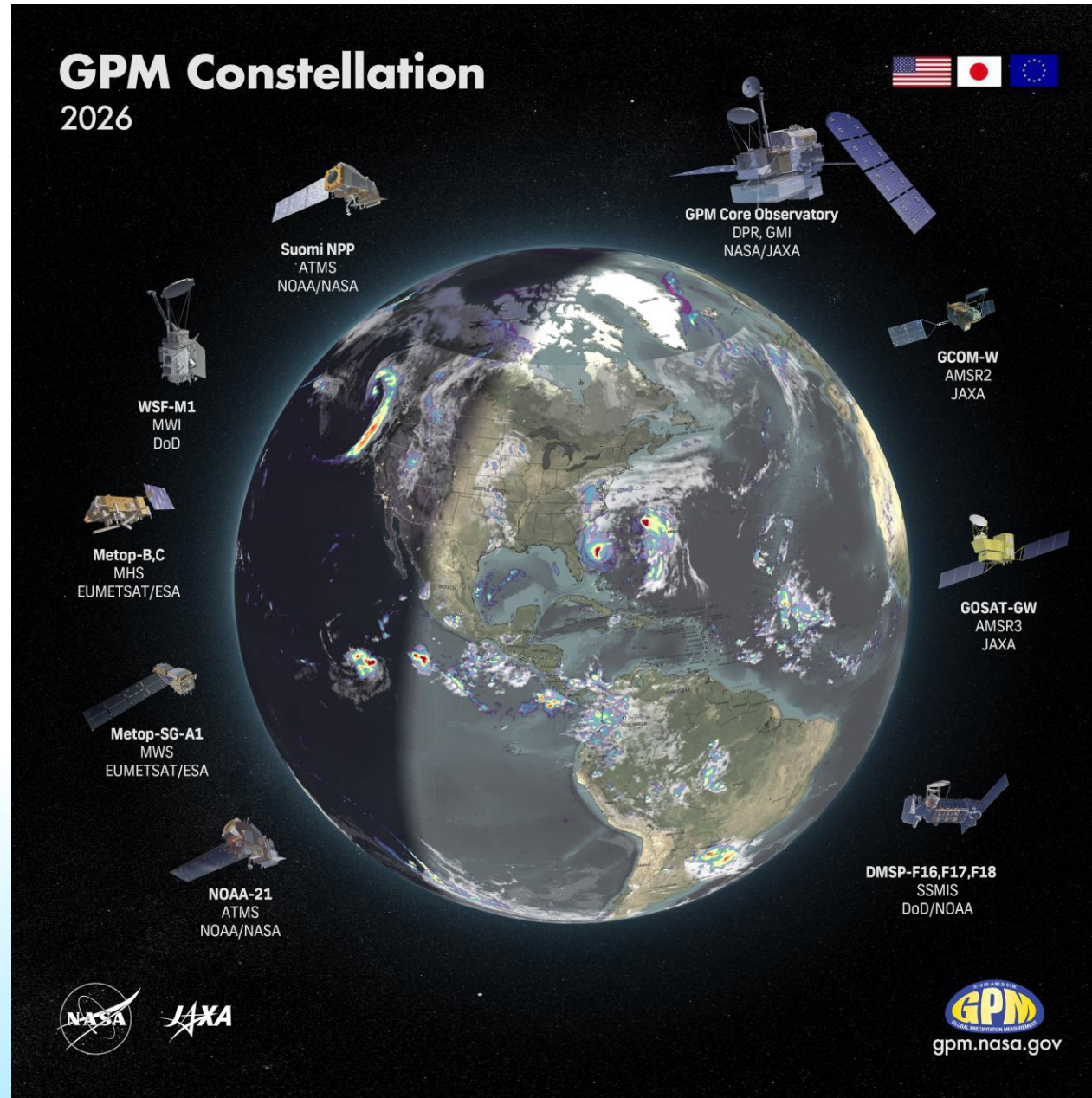
Nimbus-7



Constellation

Science:
Spaceborne W-band

CloudSat
EarthCARE
Falcon Radar (future)



Current fuel
projections show
core satellite
lifetime to
May 2034

Precipitation Airborne Campaigns*



MC3E: Convective systems over the southern plains
Apr-Jun 2011



GCPEX: Snowfall near southern Canada
Jan-Feb 2012



IPHEX: Orographic and complex terrain in the southern Appalachians
May-Jun 2014



OLYMPEX/RADEX: Orographic precipitation in the Northwest U.S.
Nov-Dec 2015



IMPACTS: Snowstorms along the East Coast (and Midwest)
Jan-Feb 2020, 2022, 2023

*Only recent airborne campaigns shown with a primary objective of measuring precipitation

NASA's operational airborne precipitation resources*

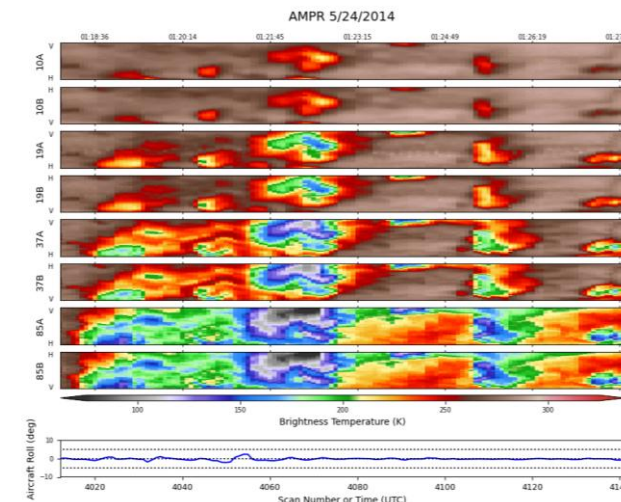
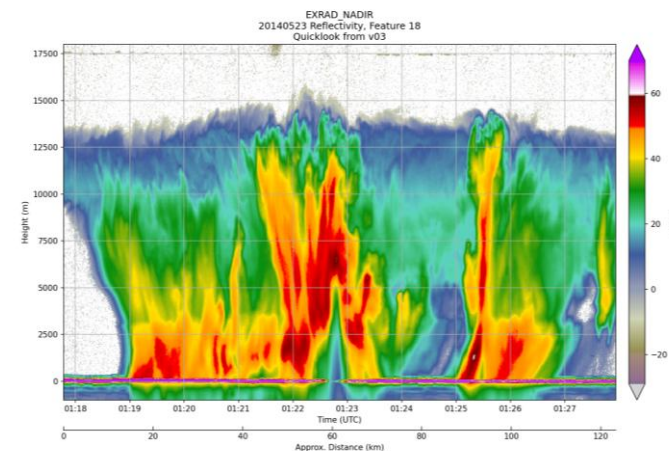
Radars

- **EXRAD:** X-band (GSFC)
- **HIWRAP:** Ku/Ka-band (GSFC)
- **CRS:** W-band (GSFC)
- **APR-3:** Ku/Ka/W-band (JPL)
- **CloudCube:** Ka/W/G-band (JPL)

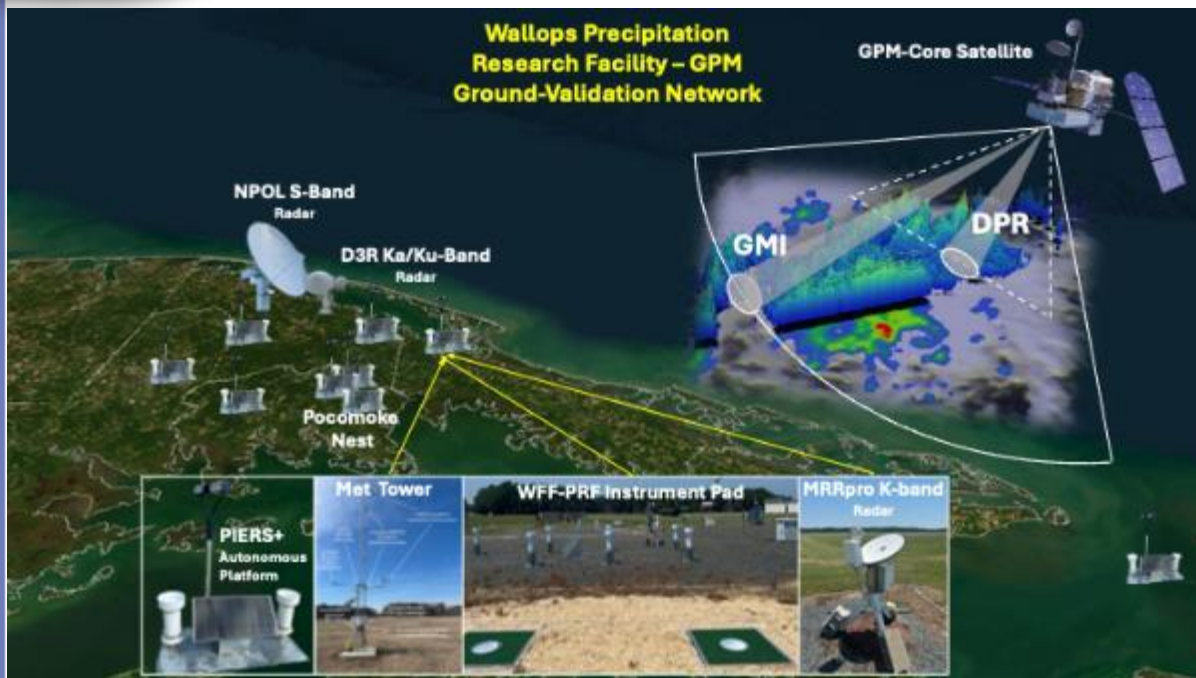
Passive Microwave

- **AMPR:** 10-85 GHz (MSFC)
- **HAMSR:** 50-183 GHz (JPL)
- **CoSMIR-H:** 50-183 GHz (GSFC)
- **CoSSIR:** 170-684 GHz (GSFC)

*Not including in-situ cloud instruments



EXRAD (top) and AMPR (bottom) during IPHEX



<https://wallops-prf.gsfc.nasa.gov>



<https://earth.gsfc.nasa.gov/climate/instruments/achieve>

- **NPOL:** S-band, Dual-pol, Doppler, Scanning
- **D3R:** Ku-/Ka-band, Dual-pol, Doppler, Scanning
- **MRRPro:** K-band, Doppler, Vertically Pointing
- **ACHIEVE:** Multi-sensor platform for cloud & precipitation
- **Disdrometers:** 2DVD, PIP, Parsivel²
- **Precipitation Gauges:** Dual-tipping bucket, Pluvio²
- **Validation Network:** Existing operational & research weather radar networks matched with GPM core satellite overpasses



GPM Validation Network Radars



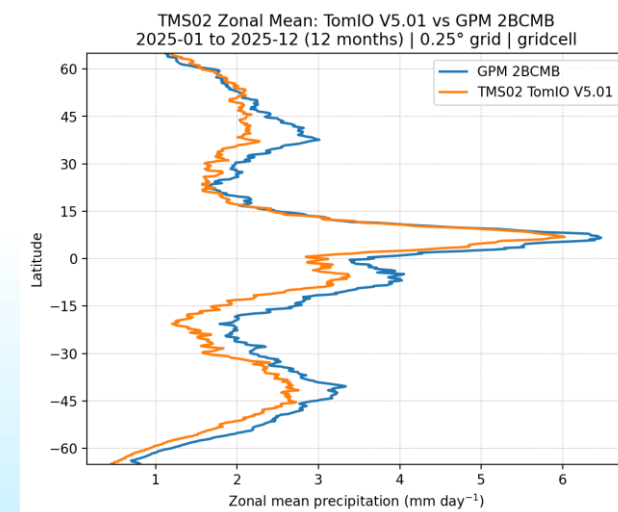
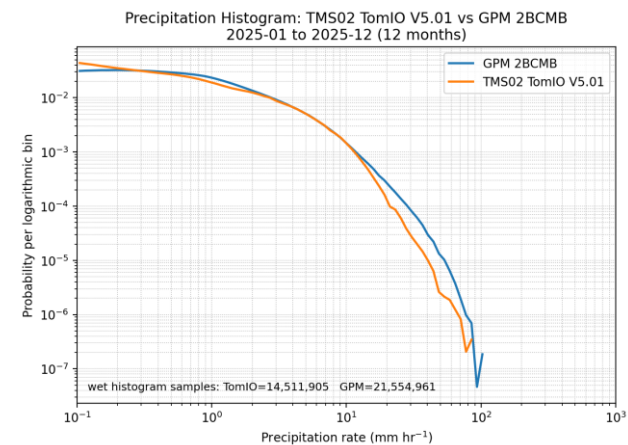
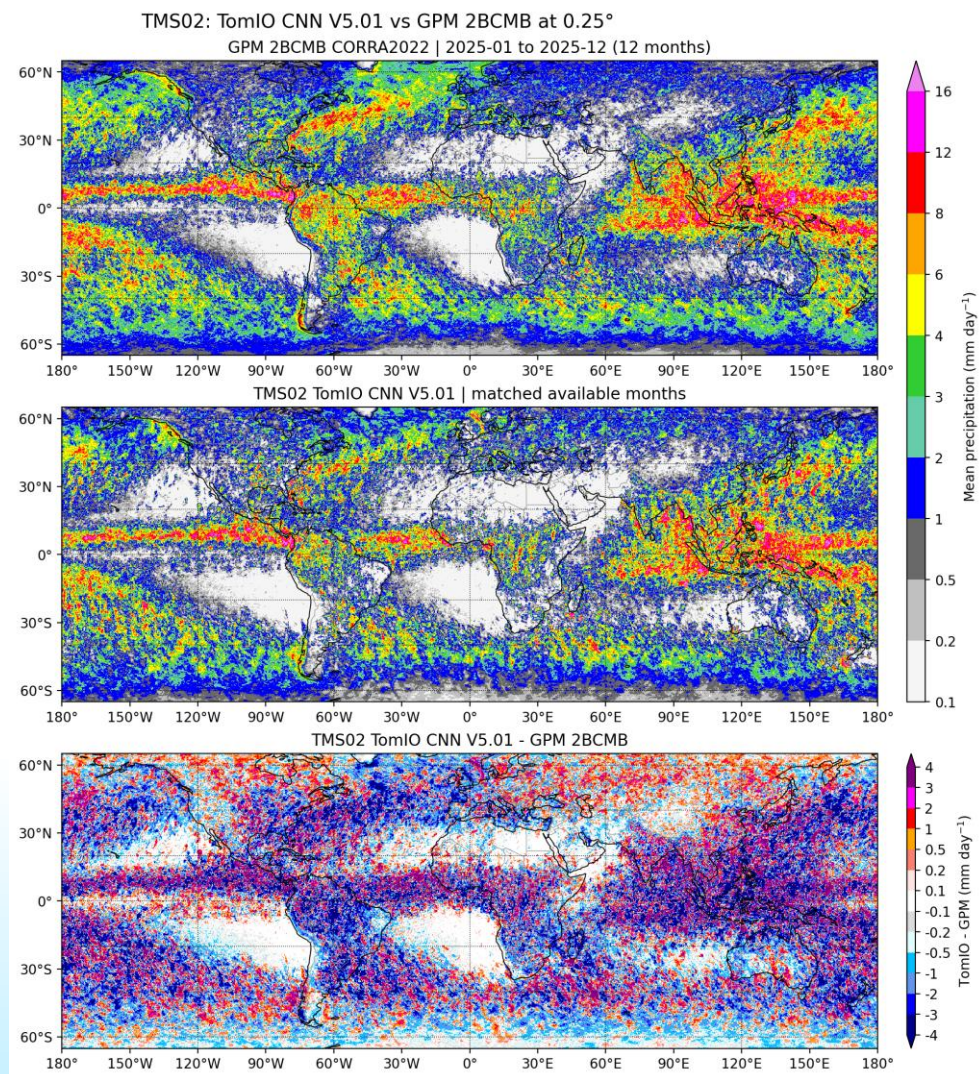
118 ground-based radars
(GR): March 2014-present

<https://gpm-gv.gsfc.nasa.gov/>

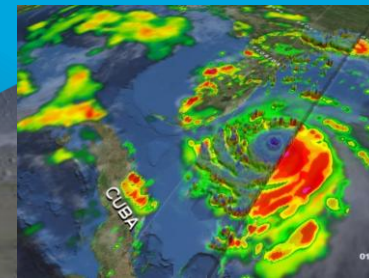
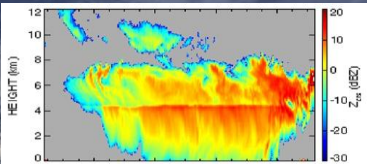
Smallsats TROPICS



Tomorrow.io



FALCON Precipitation-Related Missions



INCUS

PI: Sue van den Heever, CSU

Objective: Precipitation and convective mass flux

Approach: Relate temporal variations in reflectivity to vertical mass flux using time-differenced measurements

Instruments: 3 Ka-band radars separated by 30 and 90 sec, TEMPEST-like MW radiometer

Mission specs: 38° inclined orbit, launch in 2027

FALCON Radar

PS: Matt Lebsock, JPL

Objective: Cloud profiling and dynamics

Approach: Cloud radar measurements of reflectivity and Doppler velocity

Instruments: W-band radar, DPCA approach

Mission specs: Sun-sync. orbit, launch March 2029

PMM

PS: Scott Braun, GSFC

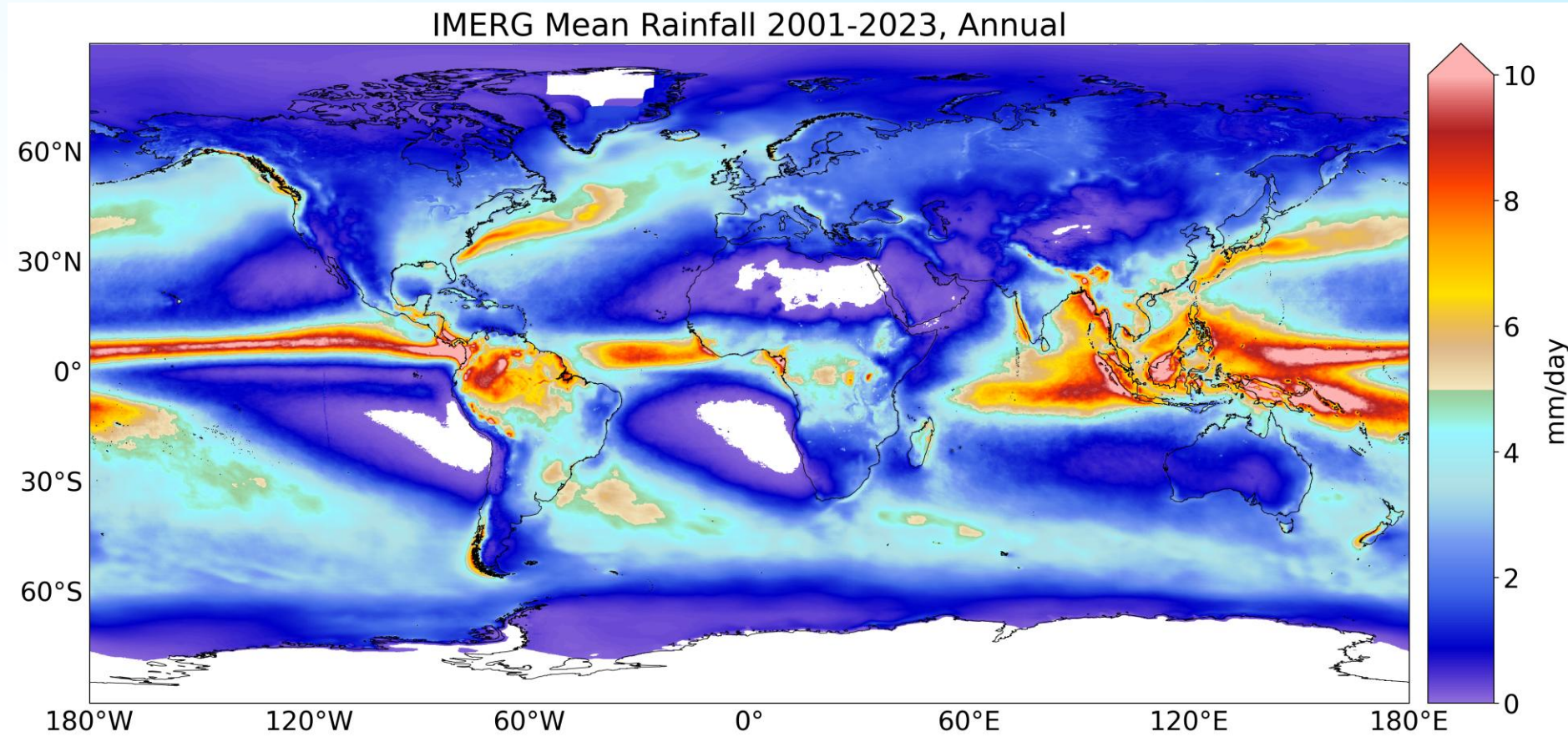
Objective: Precipitation, convective dynamics

Approach: Precip. radar measurements of reflectivity, Doppler velocity, time-differenced radiometers

Instruments: Ku-band radar, DPCA approach, tandem MW radiometers

Mission specs: 55° inclined orbit, launch in March 2030

Global Rainfall

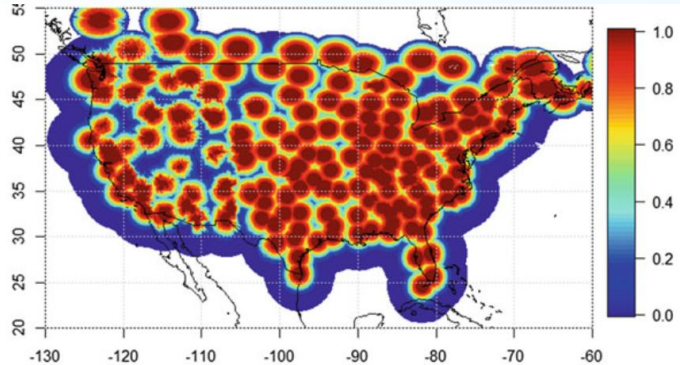


Why does rain occur where and when it does and what dictates how much rain is produced?

I will be focusing on the variability of rain in the tropics and warm season midlatitudes with an emphasis on advancements made possible by NASA program of record.

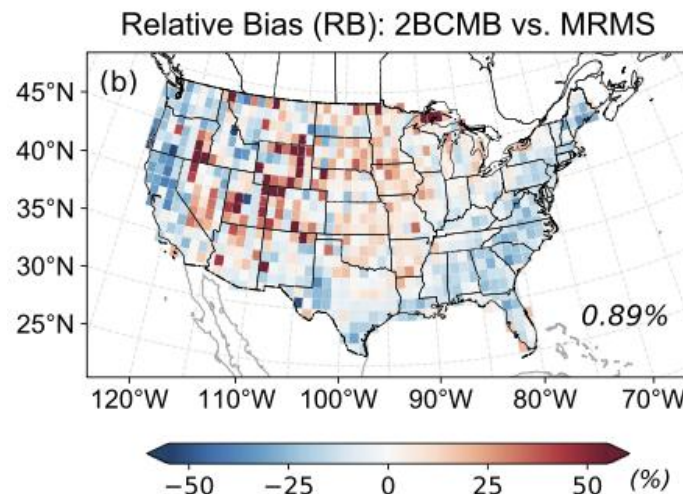
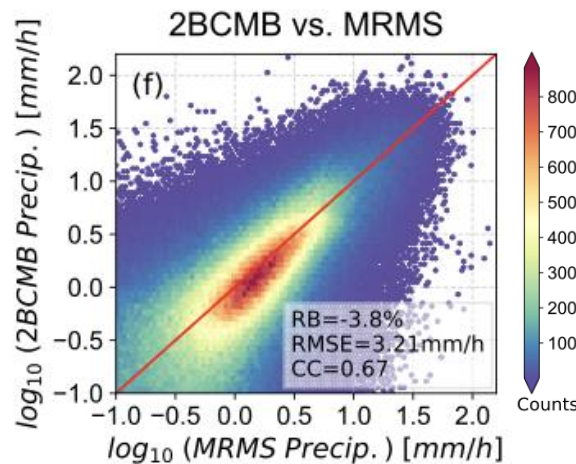
Precipitation Validation

MRMS radar quality index



Guilloteau and Foufoula-Georgiou, 2020

- MRMS is high-fidelity network of ground radars over North America (GPM Virtual Network extends to other regions)
- Example: DPR-GMI combined algorithm (2BCMB, V6) performs well over CONUS, with some regional differences



Li et al., IEEE, 2023

Advancement

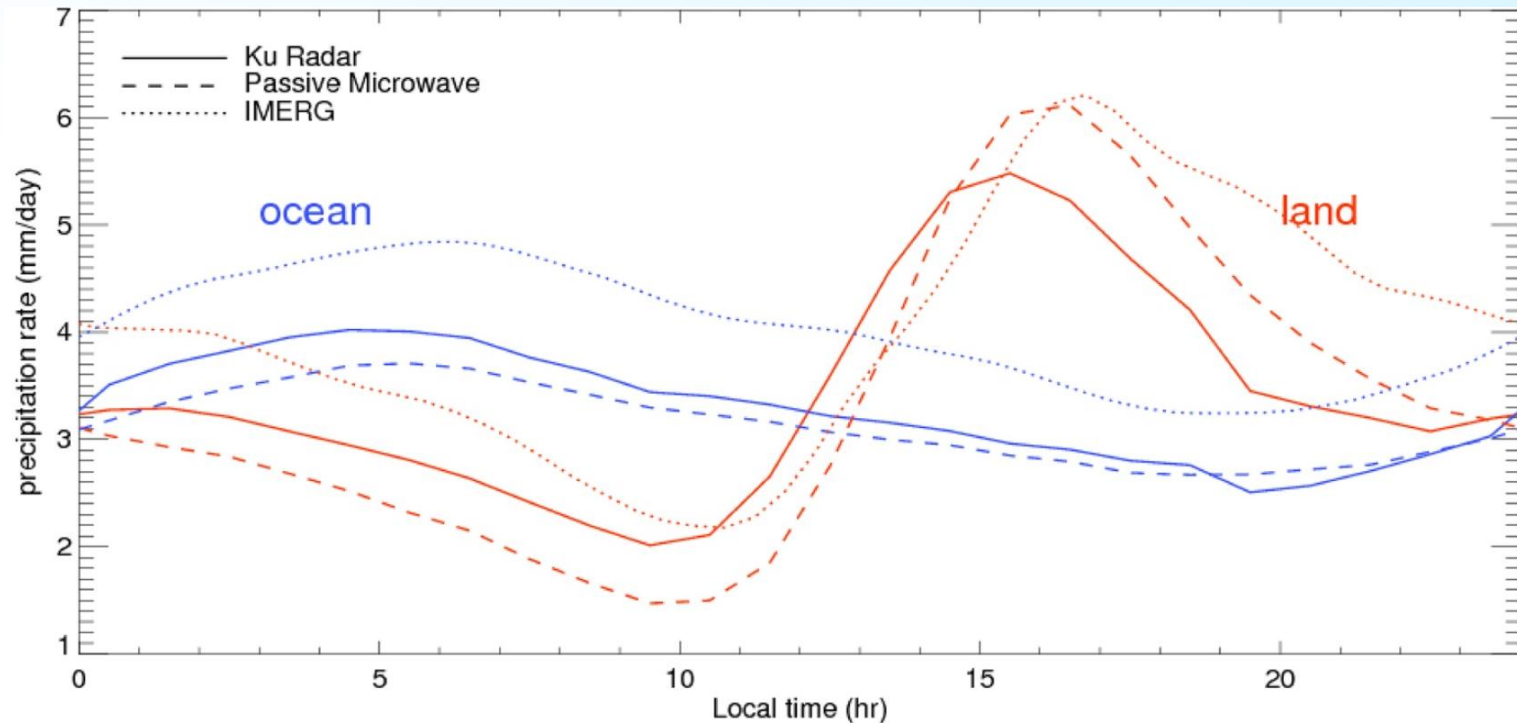
- *Ground validation sites have provided stringent assessment of uncertainty and biases in satellite-based precipitation products*
- Building public trust, Earth Science to Action

Challenges

- Validation over ocean and other data sparse regions
- Pathways to feedback into algorithm development

Diurnal Cycle

Mean precipitation rate 20°N-S, V6



Hayden and Liu, *JGR*, 2021

- TRMM/GPM radars and passive MW radiometers have inclined orbit that allow statistical sampling of diurnal cycle
- Example: Land has strong afternoon/evening peak, ocean has weak morning peak

Advancement

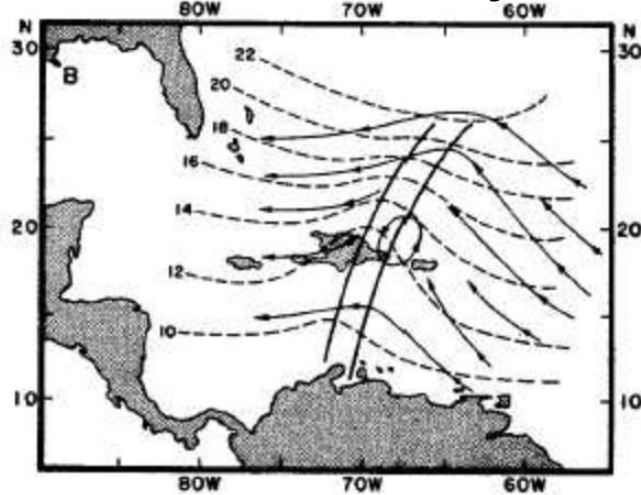
- *Characterization of diurnal cycle of rainfall globally*
- Target for model improvement since models struggle with the diurnal cycle, esp. over land

Challenges

- Timing and magnitude of diurnal cycle is instrument dependent
- Describing environmental drivers of diurnal cycle

Subseasonal to Seasonal Variations

Schematic of easterly wave



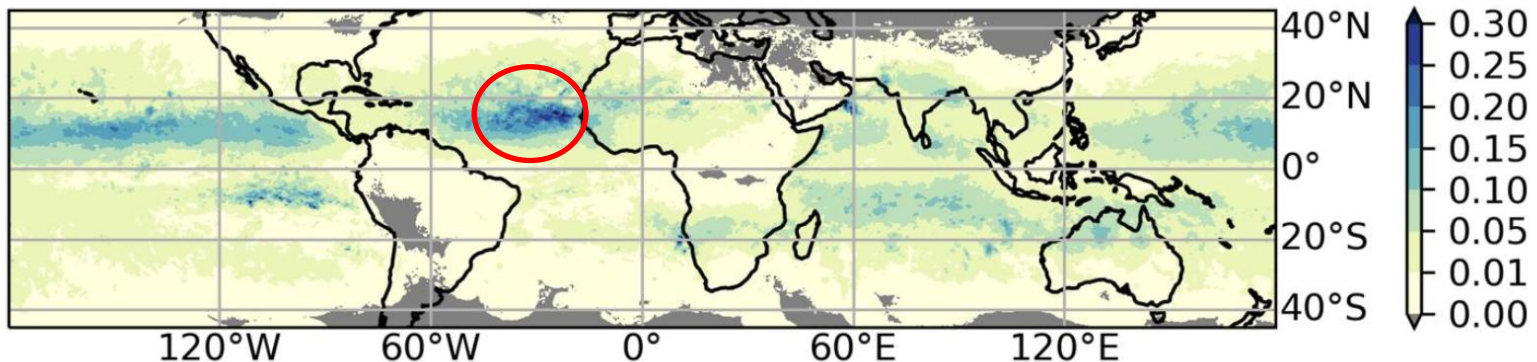
Carlson and Lee, 1978

- Large-scale circulation features (often identified with reanalysis) can dictate week to months precipitation variability
- Example: Easterly waves identified by MERRA-2 account for up to 30% of regional rainfall based on IMERG

Advancement

- *Circulation/precipitation coupling for a wide range of subseasonal to seasonal phenomena: easterly waves, convectively-coupled equatorial waves, the MJO, and monsoons*

Fraction of precipitation associated with easterly waves at 850 hPa



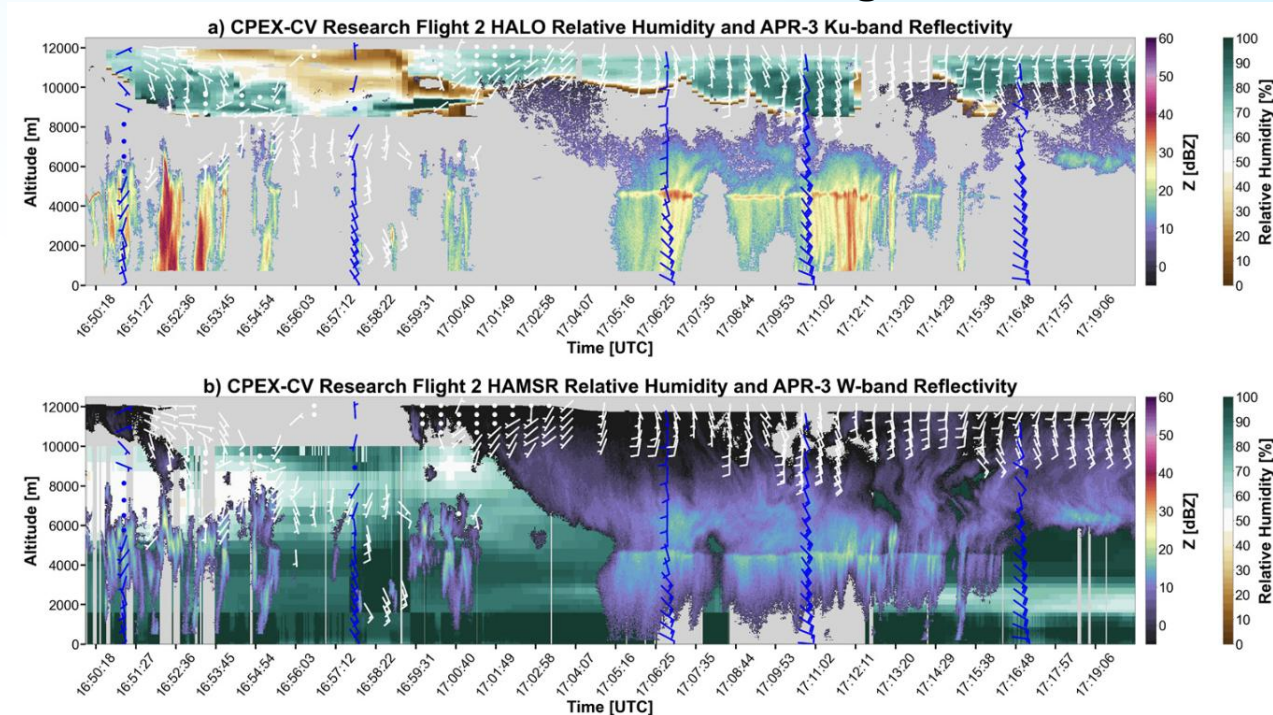
Hollis et al., *JGR*, 2024

Challenges

- Obtaining coincident (or physically consistent in the case of reanalysis) environmental conditions during precipitation events

Suborbital

CPEX-CV Research Flight 2



Nowottnick et al., **BAMS**, 2024

- CPEX-CV took place out of Cape Verde in September 2022 to study coupling of atmospheric dynamics, marine boundary layer properties, convection, and the Saharan air layer
- Example: DC-8 took coincident measurements of convective structure with near-storm environment in African easterly wave

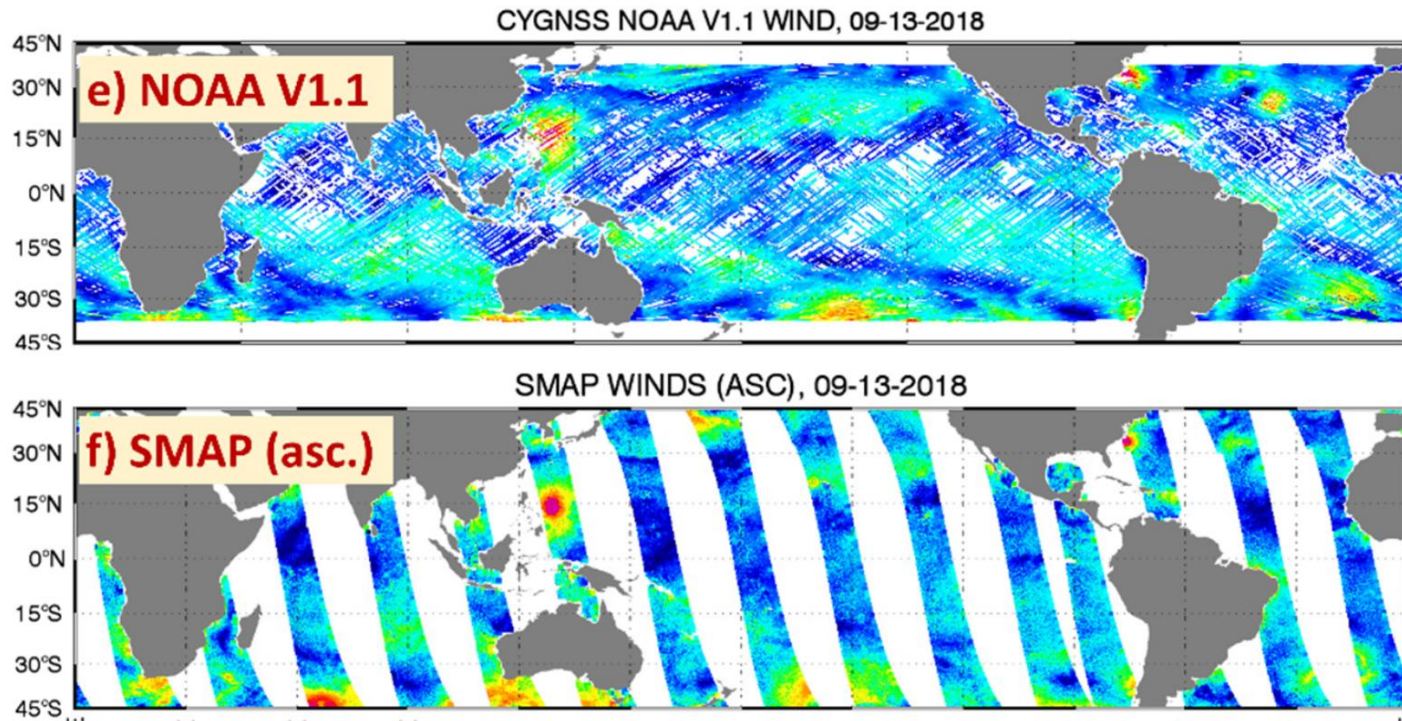
Advancement

- *Suborbital observations have provided detailed studies of processes not observable from space*
- Validation of spaceborne sensor observations and retrievals
- Technology development for future spaceborne missions

Challenges

- Representativeness

Tropical Cyclones



Ricciardulli et al., *Remote Sensing*, 2021

Advancement

- *CYGNSS tested proof of concept for added information by frequent revisits of TC surface interactions, especially during rapid intensification*
- Surface fluxes in low and moderate wind speeds have provided insight on air-sea interactions for weather phenomena like the MJO and atmospheric rivers

Challenges

- Less than ideal performance in high-wind situations

- CYGNSS is constellation of eight micro-satellites to measure wind speeds over Earth's oceans using L-band surface reflectometry and GNSS
- Goal to monitor and predict rapid changes in TC intensity

Figure 1 displays four panels (A, B, AA, BB) showing upper-air maps of the tropical Western Pacific region, overlaid with a grid of latitude and longitude lines. The maps illustrate wind vectors, cloud clusters, and various meteorological labels.

- Panel A (top right):** Shows a large cloud cluster labeled 'A' with a legend for wind speed (0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100, 100-110, 110-120, 120-130, 130-140, 140-150, 150-160, 160-170, 170-180, 180-190, 190-200, 200-210, 210-220, 220-230, 230-240, 240-250, 250-260, 260-270, 270-280, 280-290, 290-300, 300-310, 310-320, 320-330, 330-340, 340-350, 350-360, 360-370, 370-380, 380-390, 390-400, 400-410, 410-420, 420-430, 430-440, 440-450, 450-460, 460-470, 470-480, 480-490, 490-500, 500-510, 510-520, 520-530, 530-540, 540-550, 550-560, 560-570, 570-580, 580-590, 590-600, 600-610, 610-620, 620-630, 630-640, 640-650, 650-660, 660-670, 670-680, 680-690, 690-700, 700-710, 710-720, 720-730, 730-740, 740-750, 750-760, 760-770, 770-780, 780-790, 790-800, 800-810, 810-820, 820-830, 830-840, 840-850, 850-860, 860-870, 870-880, 880-890, 890-900, 900-910, 910-920, 920-930, 930-940, 940-950, 950-960, 960-970, 970-980, 980-990, 990-1000, 1000-1010, 1010-1020, 1020-1030, 1030-1040, 1040-1050, 1050-1060, 1060-1070, 1070-1080, 1080-1090, 1090-1100, 1100-1110, 1110-1120, 1120-1130, 1130-1140, 1140-1150, 1150-1160, 1160-1170, 1170-1180, 1180-1190, 1190-1200, 1200-1210, 1210-1220, 1220-1230, 1230-1240, 1240-1250, 1250-1260, 1260-1270, 1270-1280, 1280-1290, 1290-1300, 1300-1310, 1310-1320, 1320-1330, 1330-1340, 1340-1350, 1350-1360, 1360-1370, 1370-1380, 1380-1390, 1390-1400, 1400-1410, 1410-1420, 1420-1430, 1430-1440, 1440-1450, 1450-1460, 1460-1470, 1470-1480, 1480-1490, 1490-1500, 1500-1510, 1510-1520, 1520-1530, 1530-1540, 1540-1550, 1550-1560, 1560-1570, 1570-1580, 1580-1590, 1590-1600, 1600-1610, 1610-1620, 1620-1630, 1630-1640, 1640-1650, 1650-1660, 1660-1670, 1670-1680, 1680-1690, 1690-1700, 1700-1710, 1710-1720, 1720-1730, 1730-1740, 1740-1750, 1750-1760, 1760-1770, 1770-1780, 1780-1790, 1790-1800, 1800-1810, 1810-1820, 1820-1830, 1830-1840, 1840-1850, 1850-1860, 1860-1870, 1870-1880, 1880-1890, 1890-1900, 1900-1910, 1910-1920, 1920-1930, 1930-1940, 1940-1950, 1950-1960, 1960-1970, 1970-1980, 1980-1990, 1990-2000, 2000-2010, 2010-2020, 2020-2030, 2030-2040, 2040-2050, 2050-2060, 2060-2070, 2070-2080, 2080-2090, 2090-2100, 2100-2110, 2110-2120, 2120-2130, 2130-2140, 2140-2150, 2150-2160, 2160-2170, 2170-2180, 2180-2190, 2190-2200, 2200-2210, 2210-2220, 2220-2230, 2230-2240, 2240-2250, 2250-2260, 2260-2270, 2270-2280, 2280-2290, 2290-2300, 2300-2310, 2310-2320, 2320-2330, 2330-2340, 2340-2350, 2350-2360, 2360-2370, 2370-2380, 2380-2390, 2390-2400, 2400-2410, 2410-2420, 2420-2430, 2430-2440, 2440-2450, 2450-2460, 2460-2470, 2470-2480, 2480-2490, 2490-2500, 2500-2510, 2510-2520, 2520-2530, 2530-2540, 2540-2550, 2550-2560, 2560-2570, 2570-2580, 2580-2590, 2590-2600, 2600-2610, 2610-2620, 2620-2630, 2630-2640, 2640-2650, 2650-2660, 2660-2670, 2670-2680, 2680-2690, 2690-2700, 2700-2710, 2710-2720, 2720-2730, 2730-2740, 2740-2750, 2750-2760, 2760-2770, 2770-2780, 2780-2790, 2790-2800, 2800-2810, 2810-2820, 2820-2830, 2830-2840, 2840-2850, 2850-2860, 2860-2870, 2870-2880, 2880-2890, 2890-2900, 2900-2910, 2910-2920, 2920-2930, 2930-2940, 2940-2950, 2950-2960, 2960-2970, 2970-2980, 2980-2990, 2990-3000, 3000-3010, 3010-3020, 3020-3030, 3030-3040, 3040-3050, 3050-3060, 3060-3070, 3070-3080, 3080-3090, 3090-3100, 3100-3110, 3110-3120, 3120-3130, 3130-3140, 3140-3150, 3150-3160, 3160-3170, 3170-3180, 3180-3190, 3190-3200, 3200-3210, 3210-3220, 3220-3230, 3230-3240, 3240-3250, 3250-3260, 3260-3270, 3270-3280, 3280-3290, 3290-3300, 3300-3310, 3310-3320, 3320-3330, 3330-3340, 3340-3350, 3350-3360, 3360-3370, 3370-3380, 3380-3390, 3390-3400, 3400-3410, 3410-3420, 3420-3430, 3430-3440, 3440-3450, 3450-3460, 3460-3470, 3470-3480, 3480-3490, 3490-3500, 3500-3510, 3510-3520, 3520-3530, 3530-3540, 3540-3550, 3550-3560, 3560-3570, 3570-3580, 3580-3590, 3590-3600, 3600-3610, 3610-3620, 3620-3630, 3630-3640, 3640-3650, 3650-3660, 3660-3670, 3670-3680, 3680-3690, 3690-3700, 3700-3710, 3710-3720, 3720-3730, 3

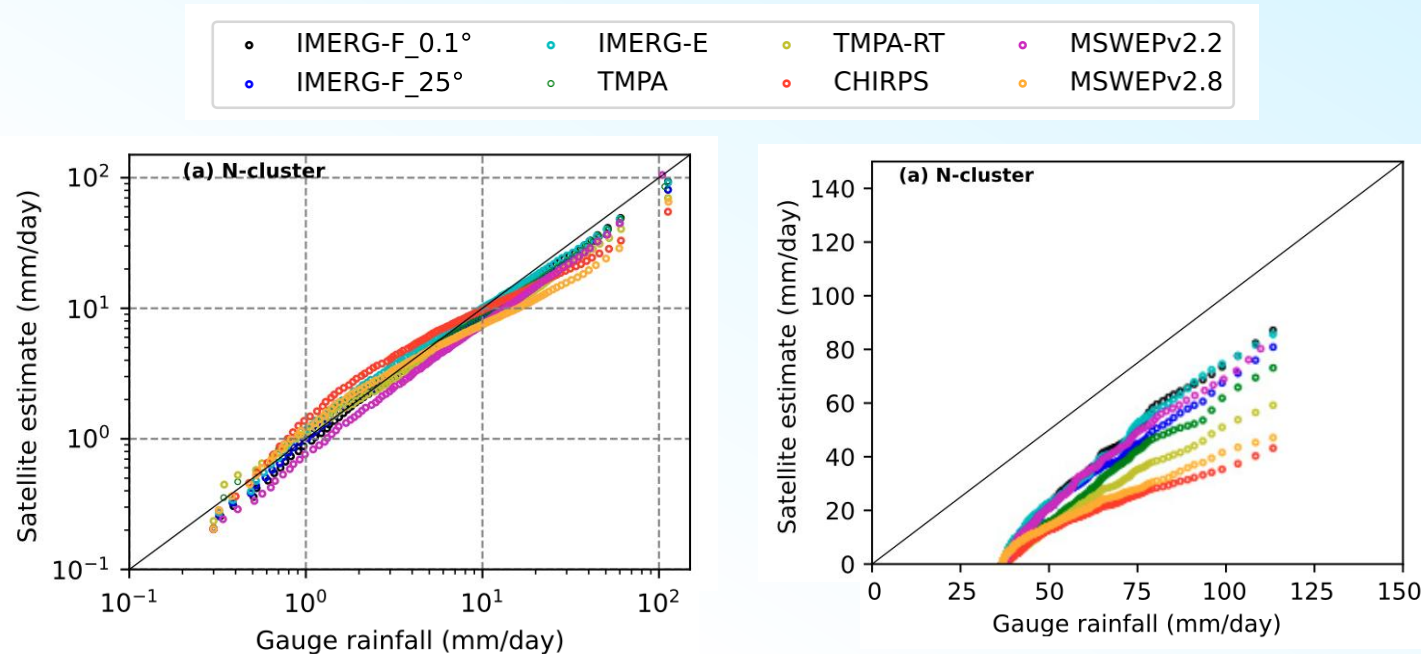
- TROPICS is constellation of five low-cost MW sounders operating ~92 GHz (sensitive to ice scattering)
- Provides rapid-refresh of 3D temperature and humidity and cloud ice and precipitation horizontal structure

- *Rapid sampling by TROPICS has led to significant positive impact on hurricane track forecasting and operational situational awareness*

- ## Challenges

- Lack of lower frequency channels that are sensitive to water emission
- Integration into IMERG

Precipitation Extremes



Ageet et al., *J Hydrometeorology*, 2022

- Increasing long records from spaceborne sensors allow determination of rainfall extremes
- Example: Multi-product comparison to gauges over Uganda show varying performance at highest daily rain rates

Advancement

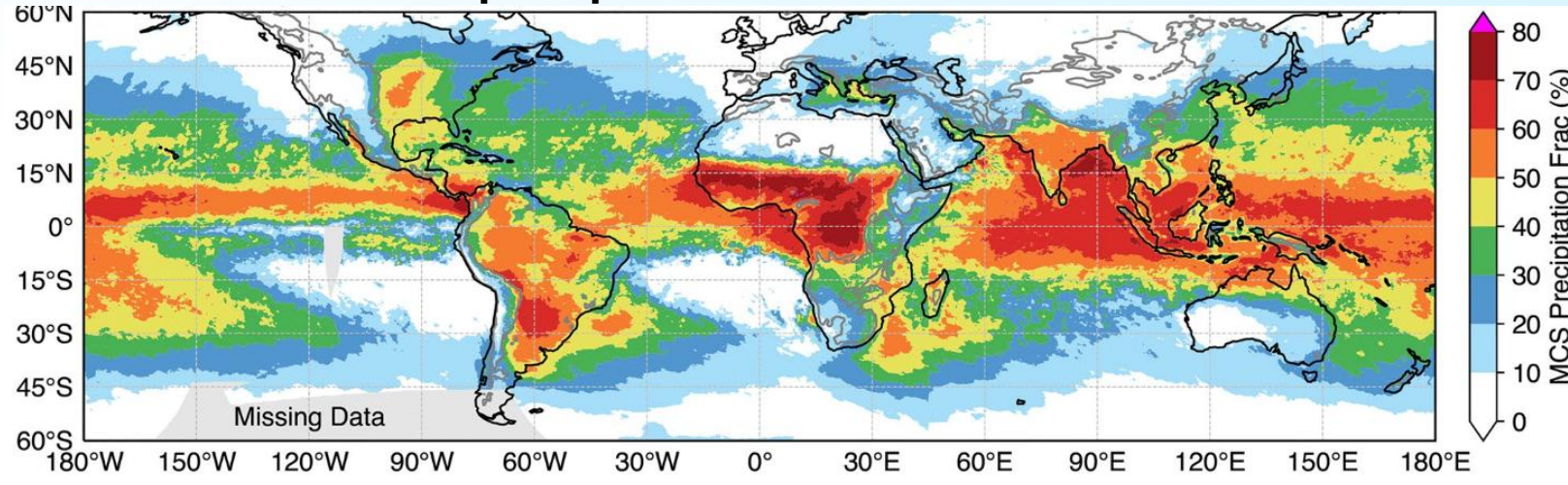
- Numerous regional studies of ability of IMERG and other satellite products to capture extreme rainfall
- Use in hydrological modeling

Challenges

- Satellites underestimate extreme rain rates
- Need to account for inhomogeneity in sensor timeline (including for use in trends)

Mesoscale Convective Systems (MCSs)

Fraction of precipitation associated with MCSs



Feng et al., *JGR*, 2021

Advancement

- *Quantification of the lifecycle of organized storms globally*
- Assessment basis for regional and global models

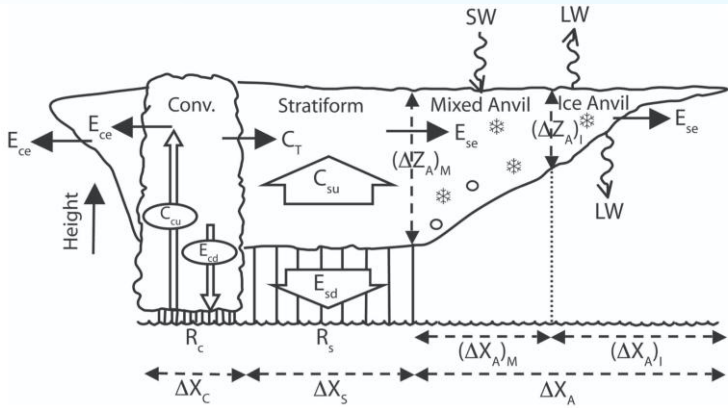
Challenges

- We still have many questions about how convection organizes

- MCSs are organized storms that have spatial scales > 100 km and last > 6 hours
- Example: Based on IMERG-tracked systems, MCSs are shown to be large rain producers, accounting for $> 50\%$ of rain across much of tropics and during warm season in the US

Convective/Stratiform Partition

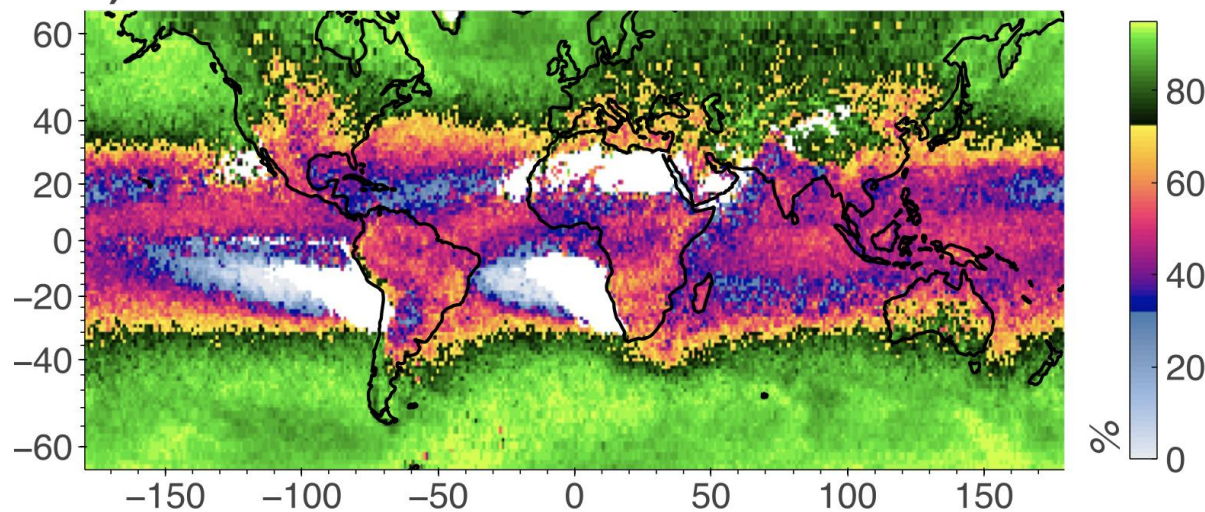
MCS water budget



- Convective and stratiform rain formed by distinct kinematics and microphysics
- Example: DPR shows lower latitudes are convectively driven, but convection back seat driver at higher latitudes

Frederick and Schumacher, *MWR*, 2008

Annual stratiform rain fraction



Schumacher and Funk, *GRL*, 2023

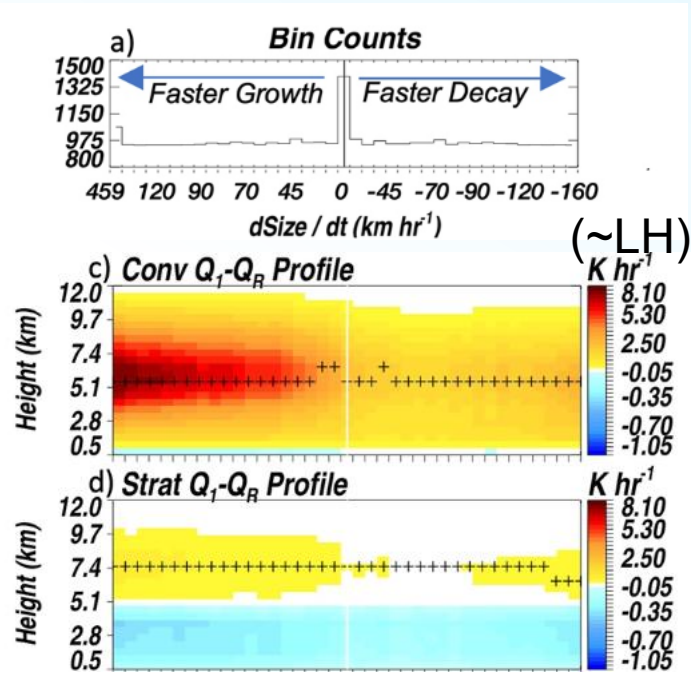
Advancement

- Characterization of storm types globally*
- Building block of latent heating estimates to link storms back to large-scale circulation

Challenges

- Haven't yet measured storm vertical motion from space
- Quantifying full water budget of MCSs, which requires observations of dynamics, microphysics, and environment

Models



$$\frac{dA}{dt} \approx A_{c, SRC} - \frac{1}{\rho} \frac{dM_c}{dz} - \frac{1}{\rho} \frac{dM_s}{dz} - \frac{A}{\tau}$$

A = cloud shield area

M_c = convective mass flux

M_s = stratiform mass flux

τ = decay timescale of A

Elsaesser et al., JGR, 2022

Advancement

- Observations from NASA program of record used to improve model representation of precipitation processes
- Validation of model precipitation globally

Challenges

- Finding common ground between model and observations in terms of parameters and time and space scales
- Pathways to feedback into model development

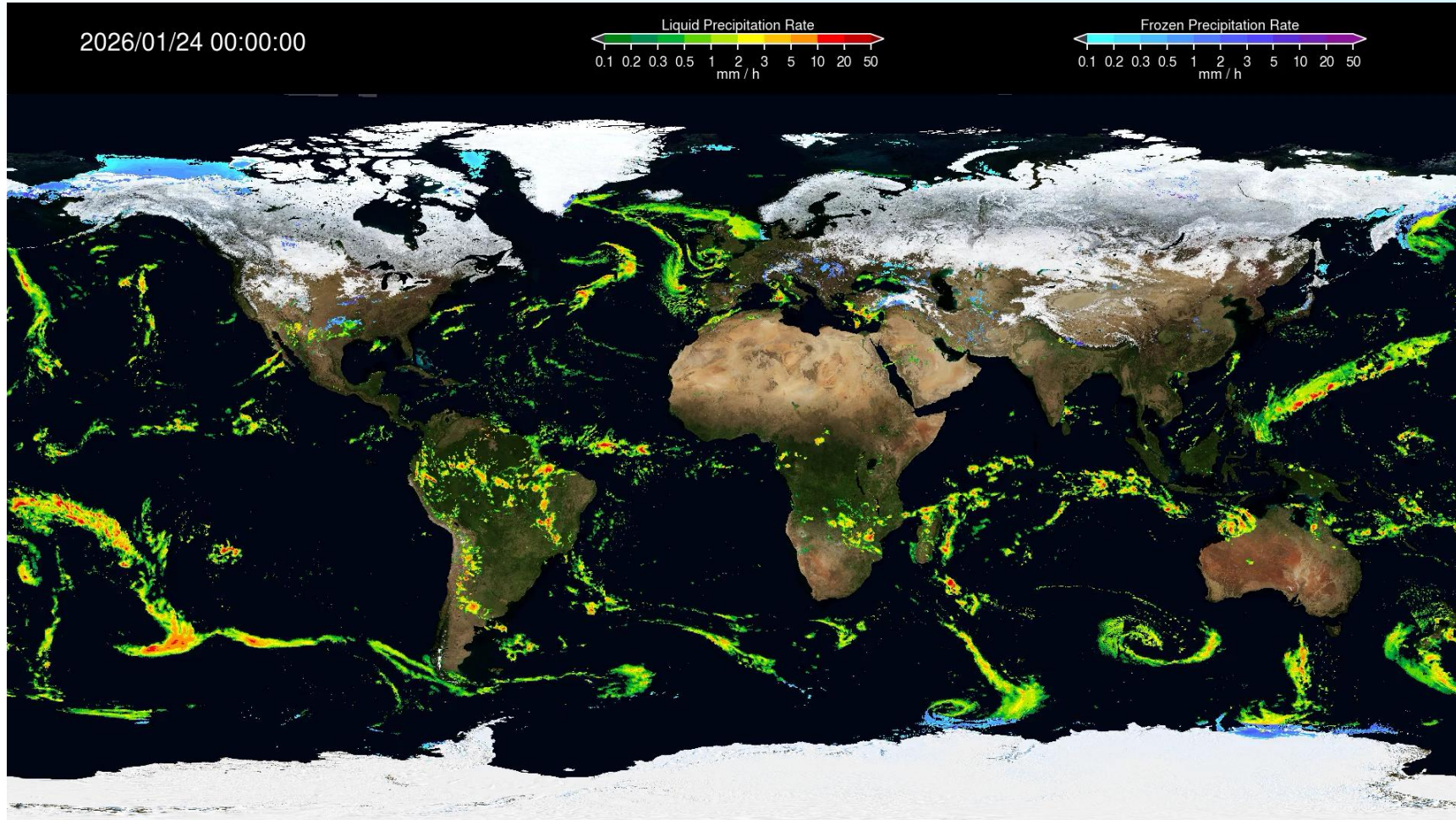
- Modeling the MCS lifecycle and its precipitation remains a significant challenge for models of all scales
- Example: A simple convective-source, slow-decay model to determine the cloud shield of MCSs was developed using satellite observational constraints

Winter Weather

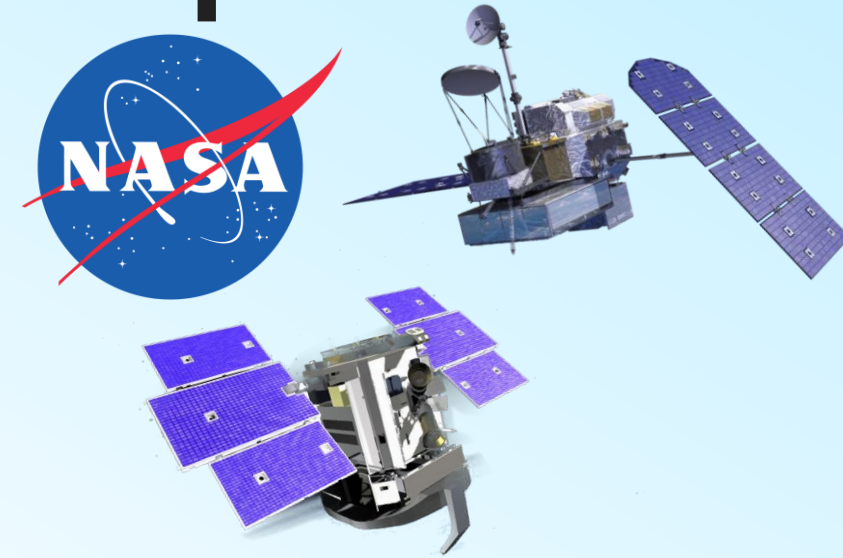
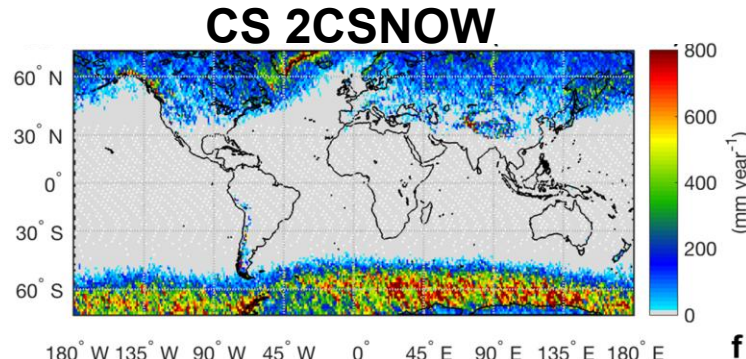
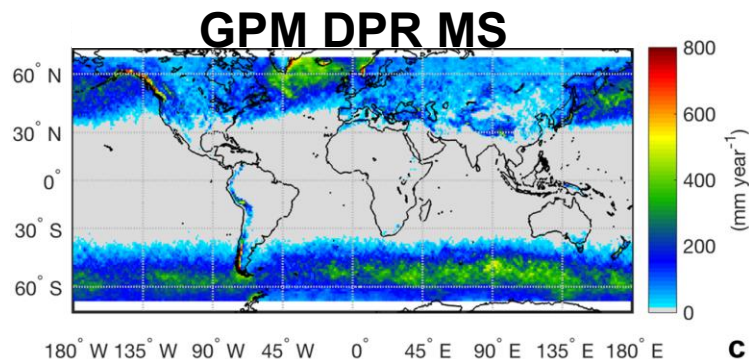
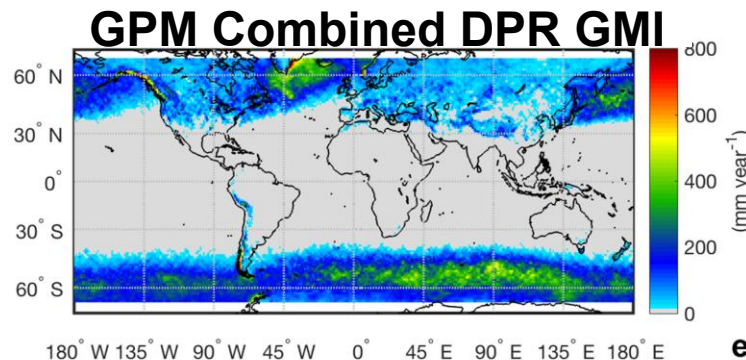
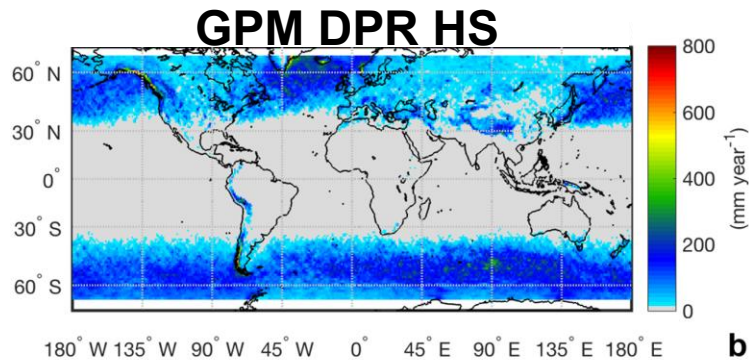
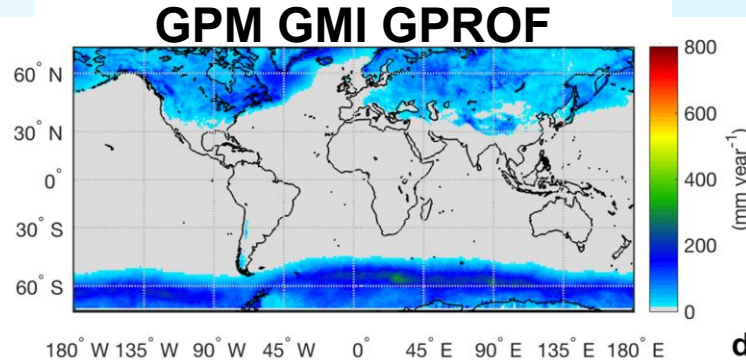
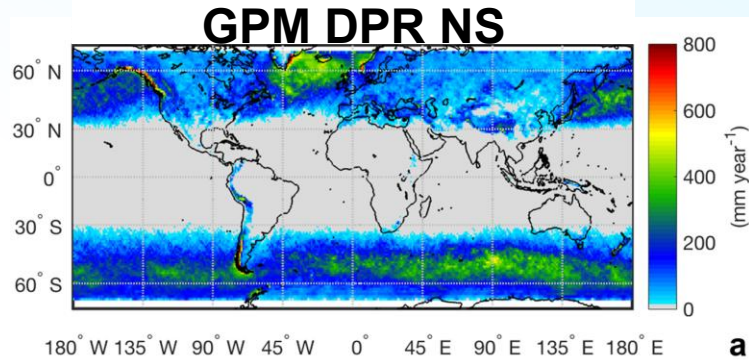
Global Snowfall

Winter Extremes

Microphysics



Global Snowfall from Space



NASA Global Snowfall from
2 satellites: CloudSat (**CS**)
and the Global Precipitation
Measurement (**GPM**) Mission

- Observations from many **diverse** instruments (*active and passive*)
- **Multiple** algorithms

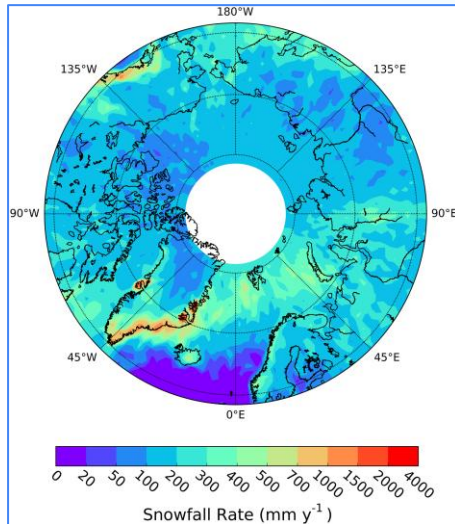


Skofronick-Jackson et al., JAMC, 2019

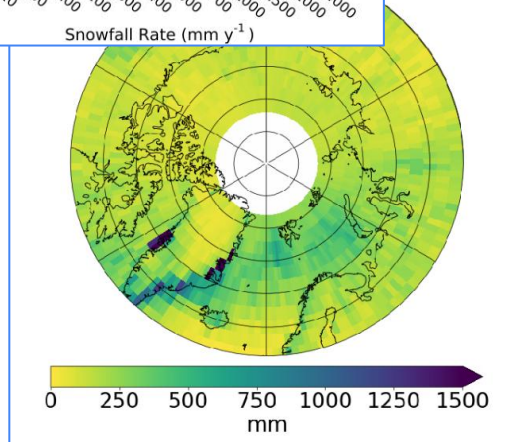
Global Snowfall from Space

NASA Satellites enabled understanding of key snow processes in **regions** that were **previously under- or unsampled**

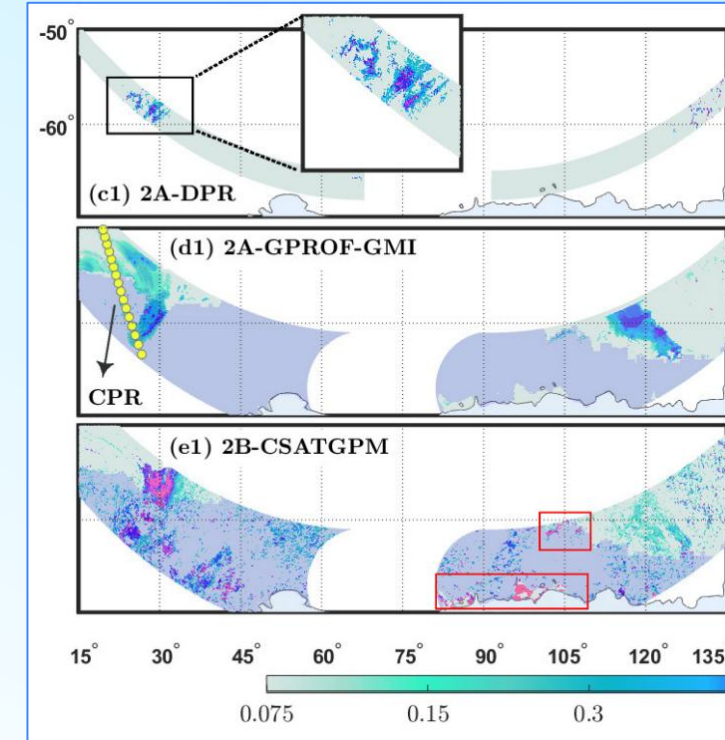
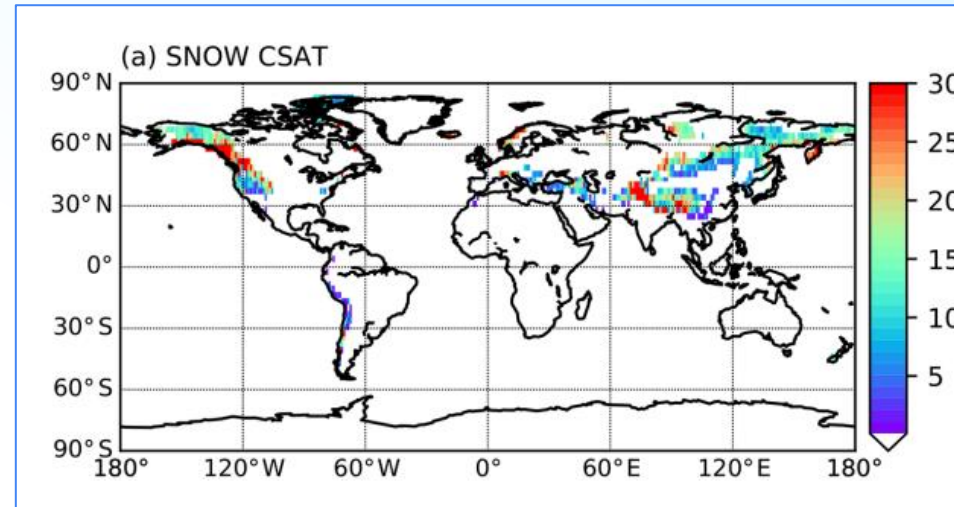
2007-2011



2007-2020



Global Mountain Ranges



Over sea ice and oceans

Limited
observations

Challenging for
models

Polar Regions

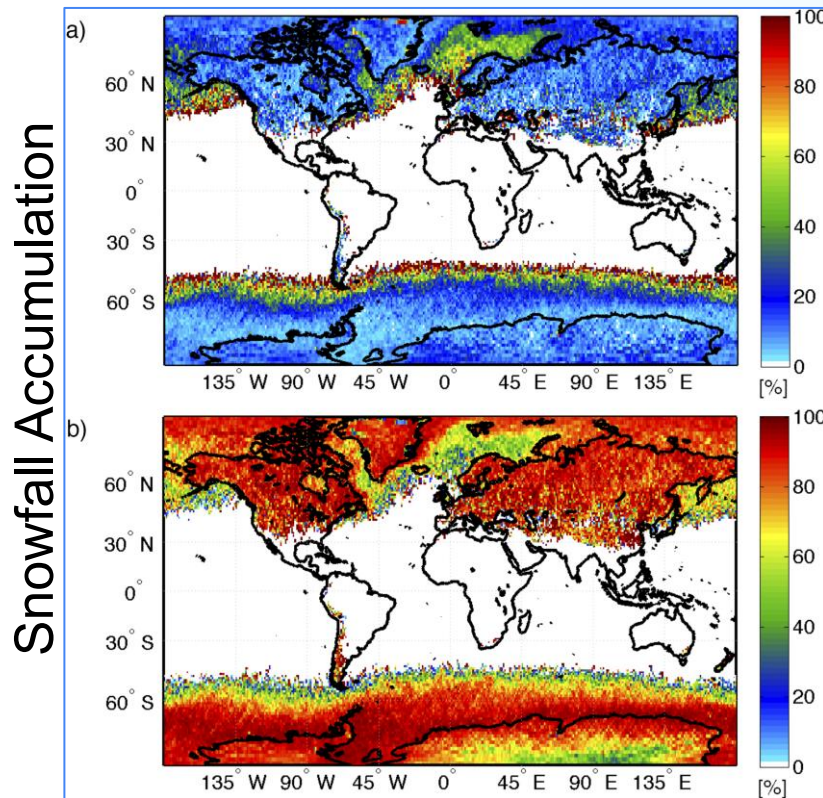
Edel et al., *J.Clim.*, 2020; L'Ecuyer et al., *ESS*, in review ; Daloz et al., *TC*, 2020; Vahedizade et al., *IEEE*, 2022

Global Snowfall from Space

NASA Satellite Observations supported investigation of **snow morphology** and further linked to **physical processes**

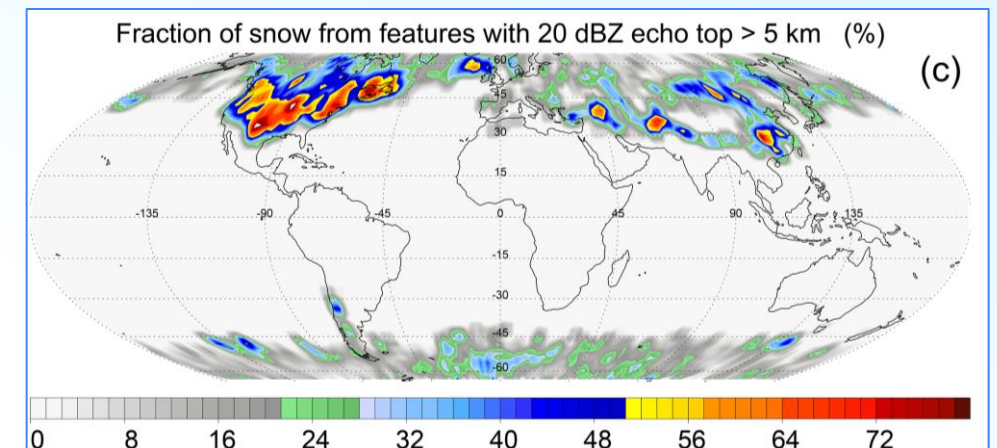
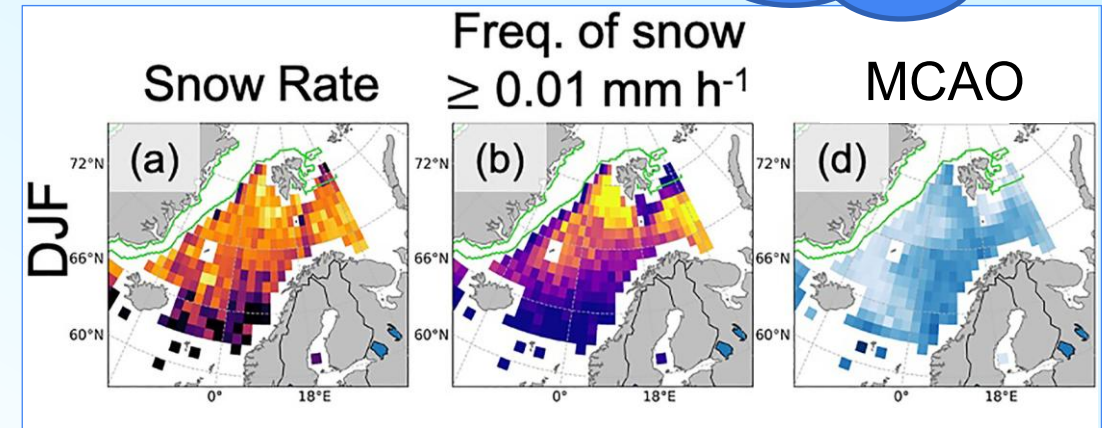
Modeling
“gray zone”

Shallow Cumuliform



Snowfall from
shallow
Marine Cold
Air Outbreaks
(MCAO)

Snowfall
from **deep**
and intense
systems



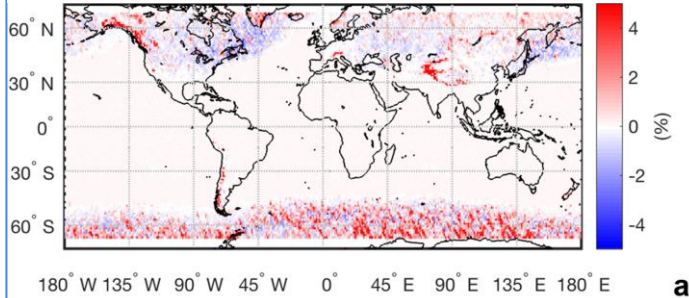
Deep Nimbostratus

Kulie et al., J. Hydro., 2016; Mateling et al., JGR:A, 2023; Adhikari et al., J. Clim., 2018

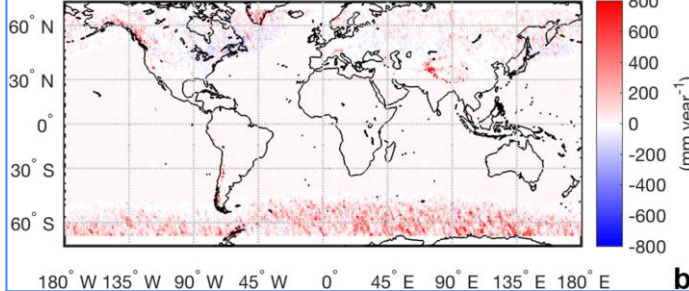
Global Snowfall from Space

NASA Satellites coupled with Suborbital and Ground Validation (GV) Assets enable near-surface improvements and advanced observational techniques

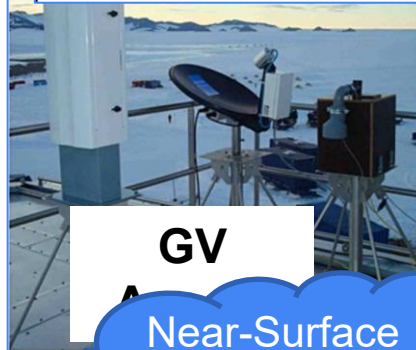
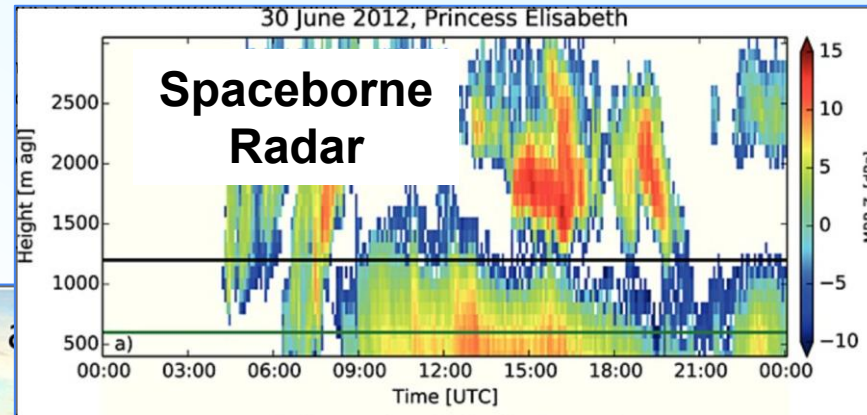
CS 2CSNOW and GPM DPR Δ Snowfall Occurrence



CS 2CSNOW and GPM DPR Δ Snowfall Amount



Cross Platform Evaluation



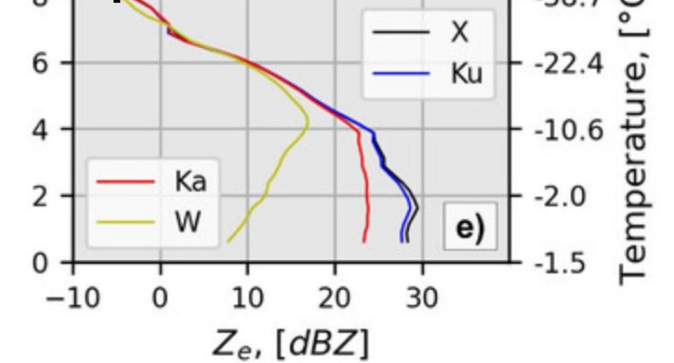
GV

Near-Surface
Improvement
Still Needed

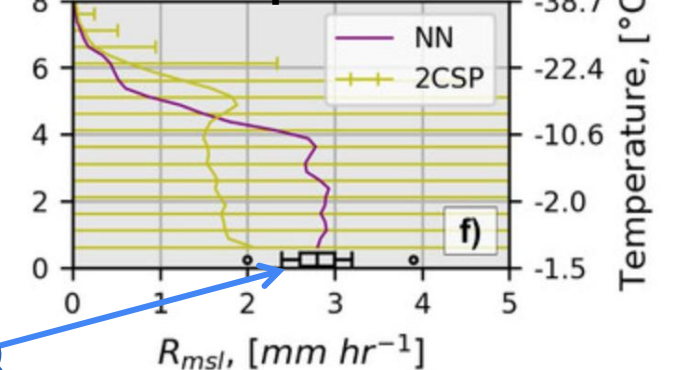
Quantifying
Near-Surface
Capabilities

Ground
Truth!

Spaceborne Radar



Precip. Rate



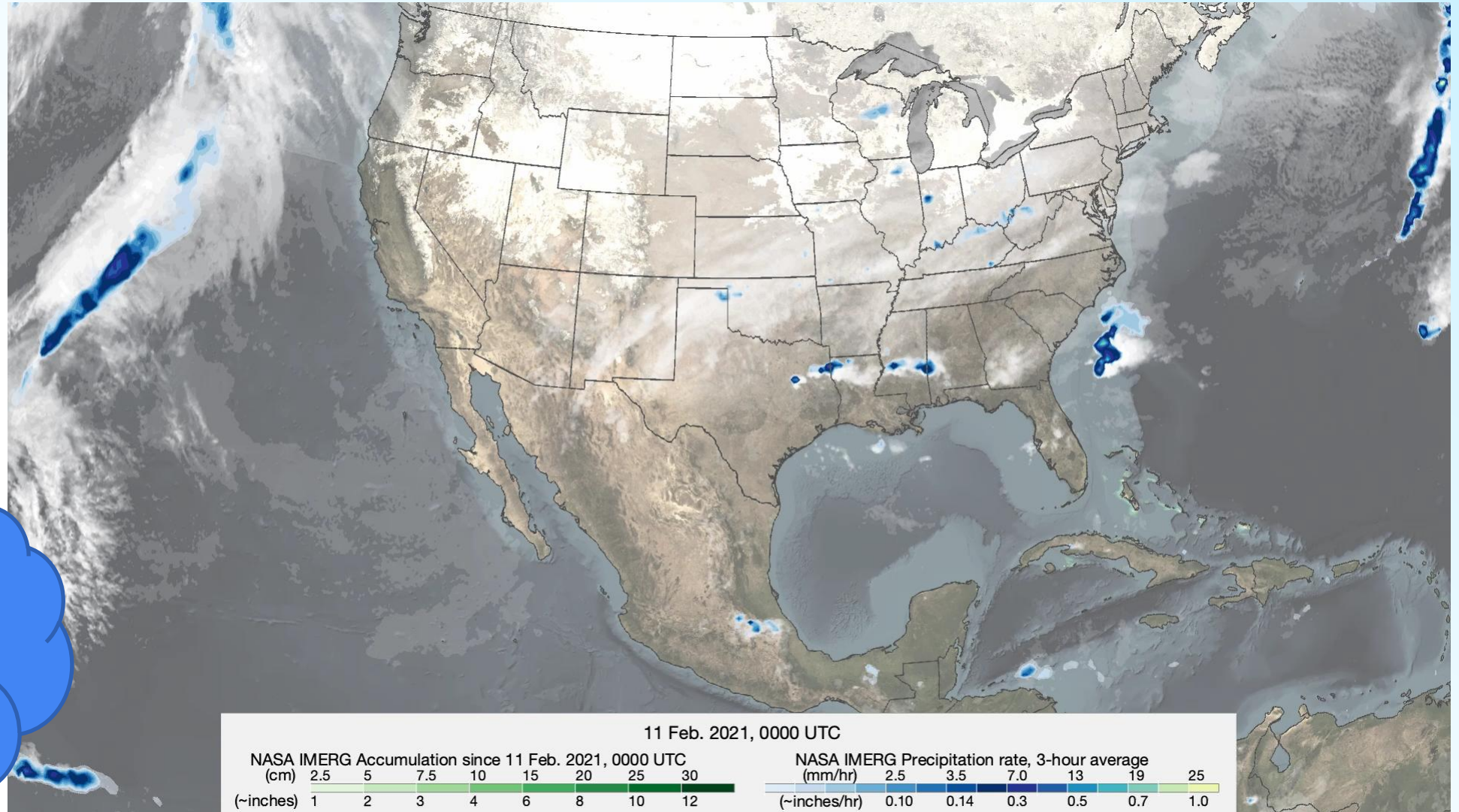
New ML tools for improved
precipitation rates

Winter Extremes

IMERG

**February
11 to 18
2021**

Total
accumulation
and
Precipitation
Rates

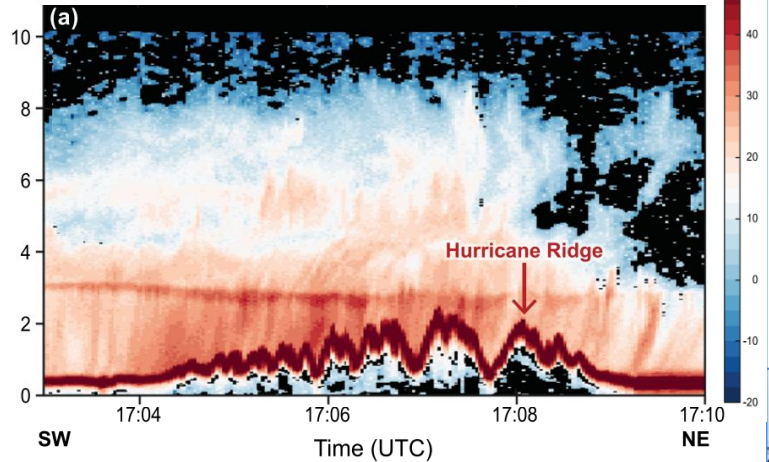


Winter Extremes

NASA Satellites and strategic Field Campaigns facilitate evaluation of precipitation extremes during **Atmospheric Rivers (AR)**

Coupling
Observations
with Reanalysis

P3 Ku Radar Observations

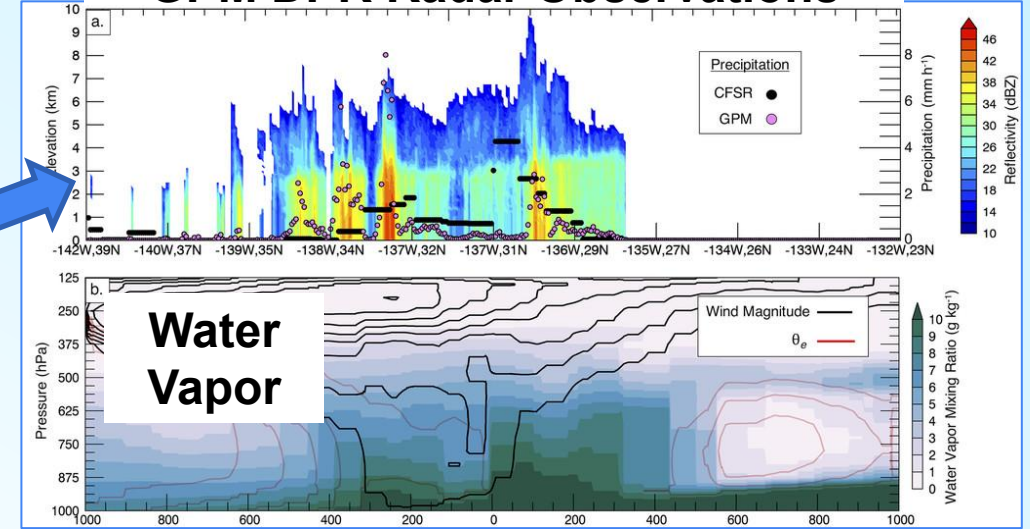


Extreme Rain
during winter AR

Deep precipitating
systems during
winter ARs

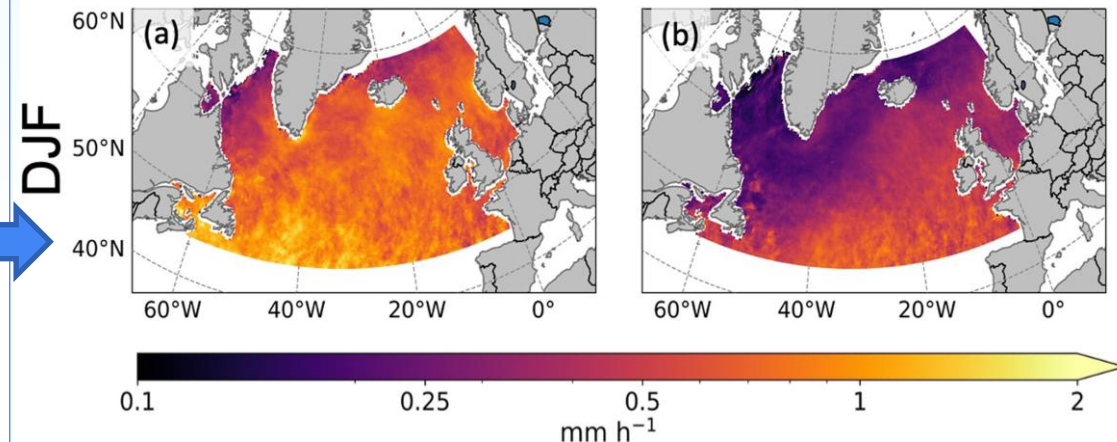
Increased
snowfall rates
during ARs

GPM DPR Radar Observations



AR

No AR



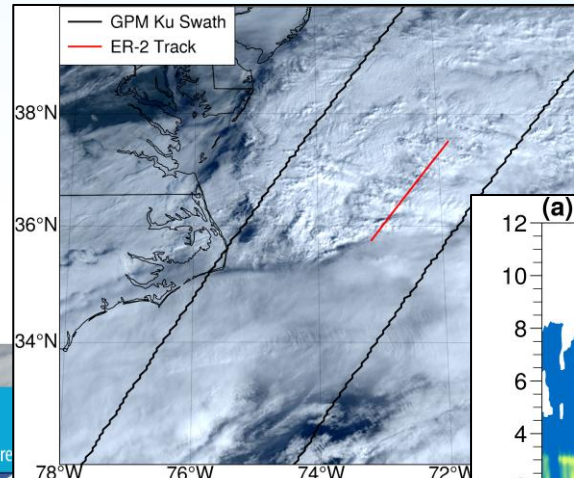
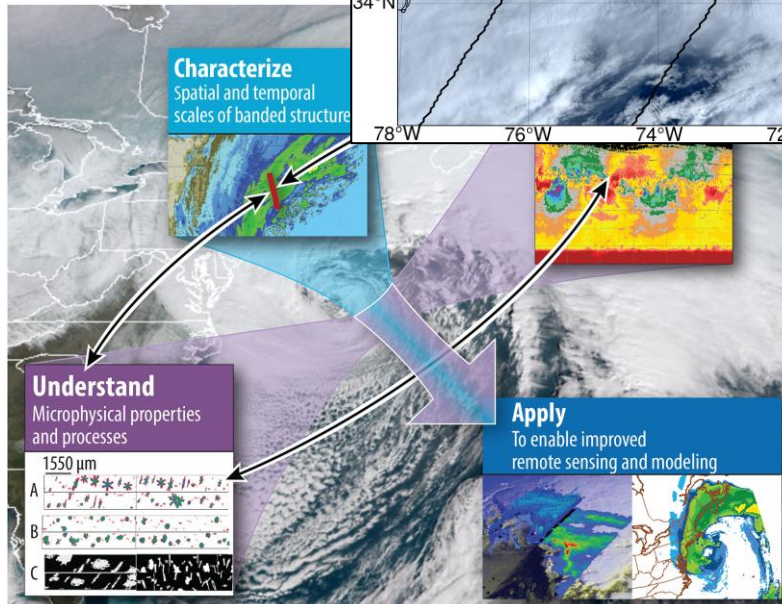
Winter Extremes

NASA Satellites and strategic Field Campaigns facilitate evaluation of precipitation extremes during Winter Snowstorms

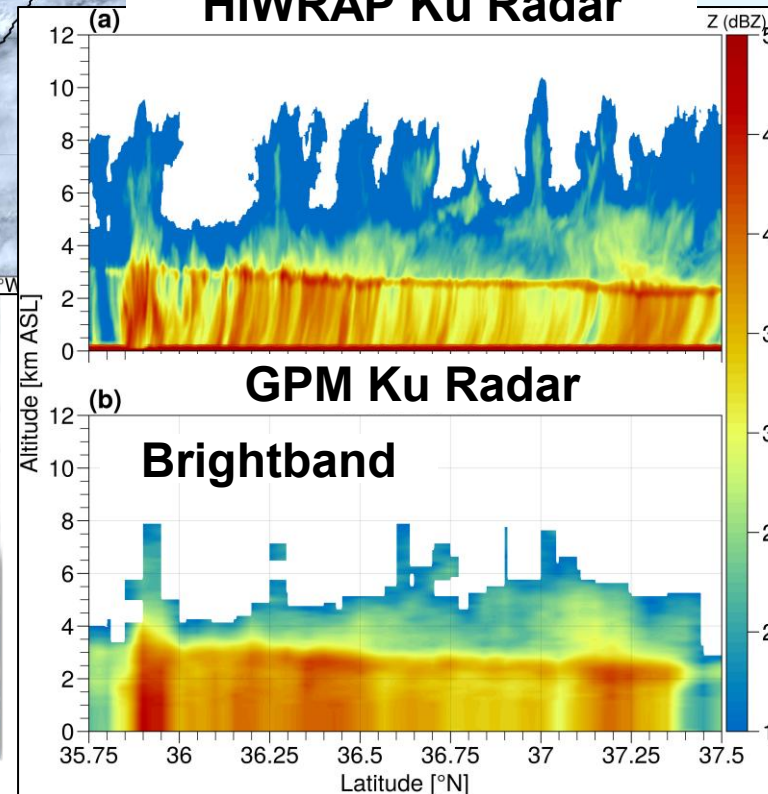
More than 70 publications on winter precipitation!!!



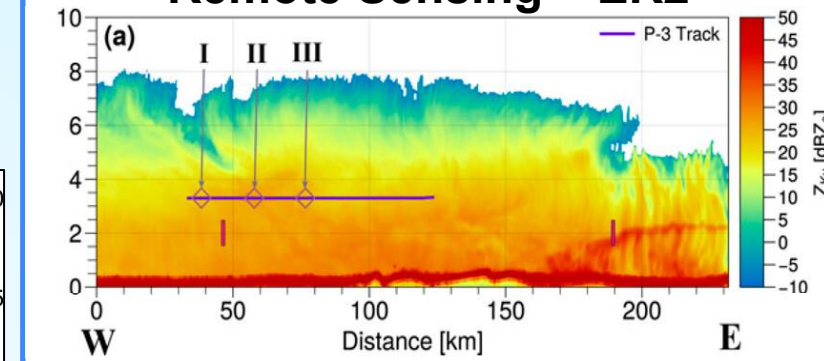
2020 - 2023



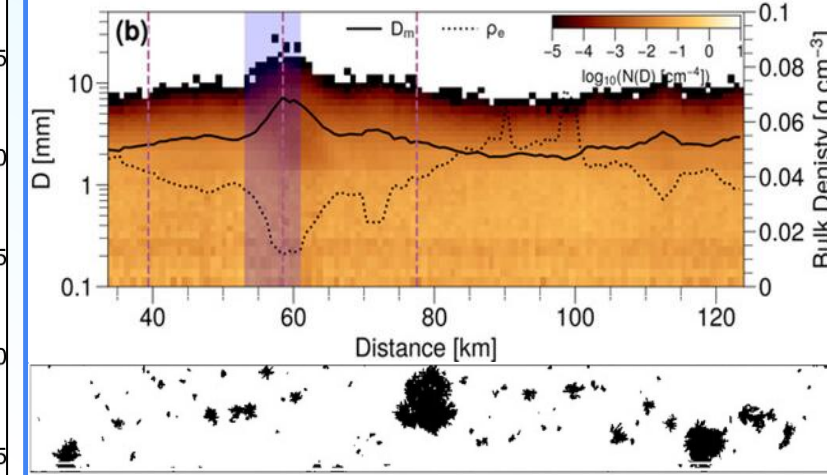
Airborne / Spaceborne Comparison
HIWRAP Ku Radar



Remote Sensing – ER2



In Situ – P3

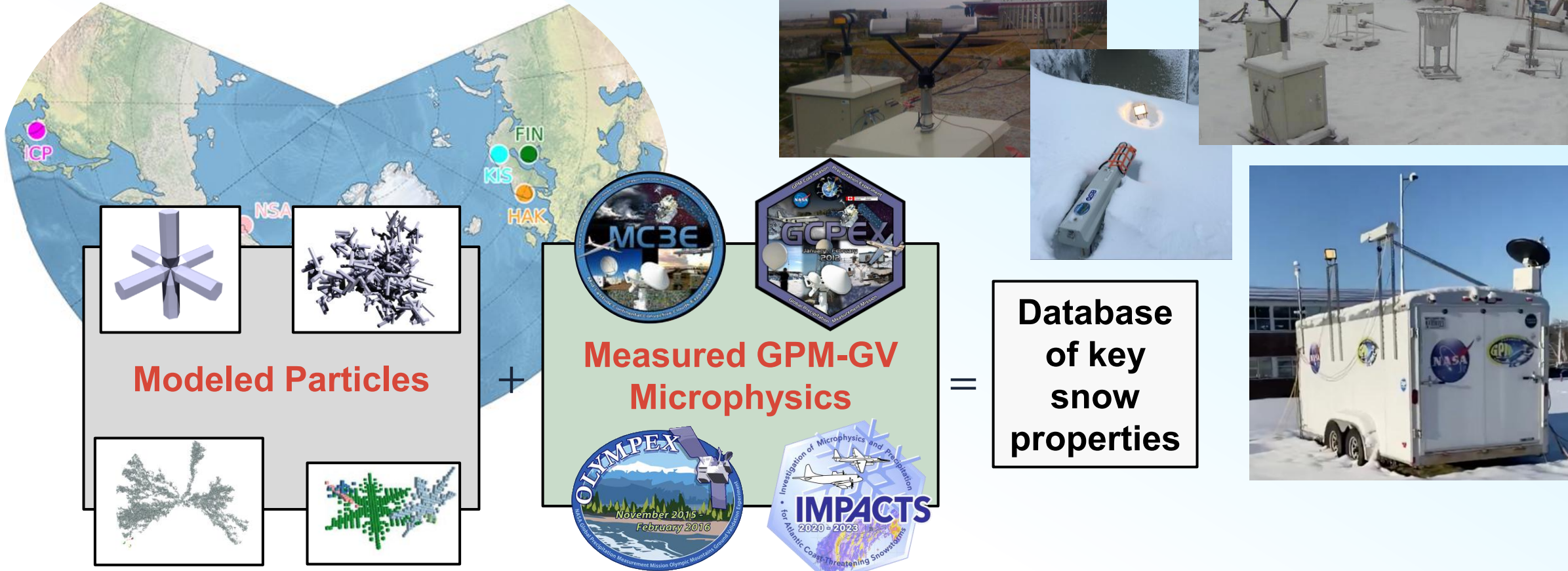


McMurdie et al., *MWR*, 2020; Finlon et al., *JAS*, 2022

Microphysical Processes

Disdrometers
Gauges
Radars

NASA has supported deployment of Ground Validation (GV) Assets globally for decades, supporting fundamental advances in understanding precipitation macro- and microphysics

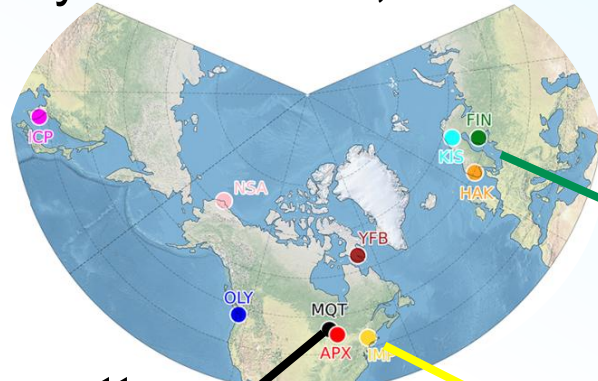


Kidd et al., **SPM**, 2020; King et al., **ESS**, 2024; Ringerud et al., **IEEE**, 2019; Liao and Meneghini, **RS**, 2022; Jensen et al., **BAMS**, 2016; Skofronick-Jackson, **BAMS**, 2015; Houze et al., **BAMS**, 2017; McMurdie et al., **MWR**, 2020

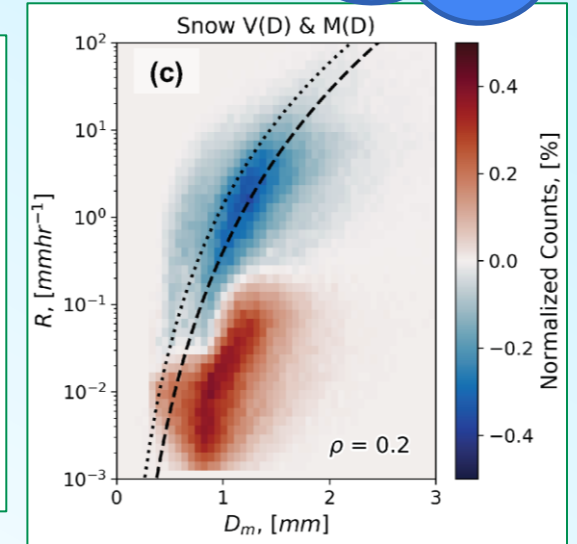
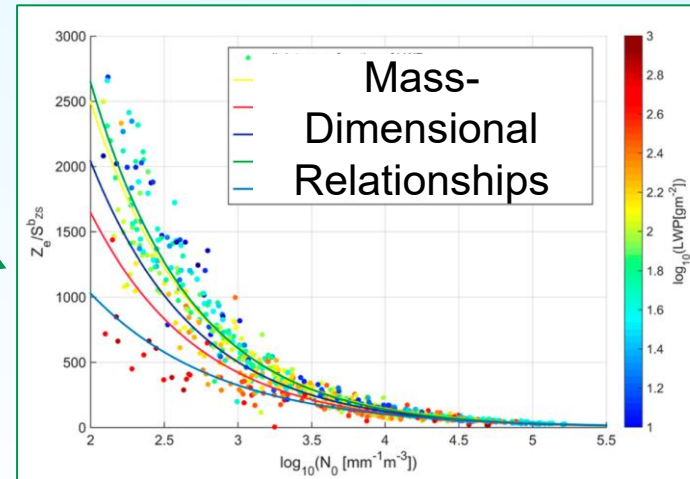
Microphysical Processes

NASA has supported deployment of Ground Validation (GV) Assets globally for decades, which have improved precipitation estimates

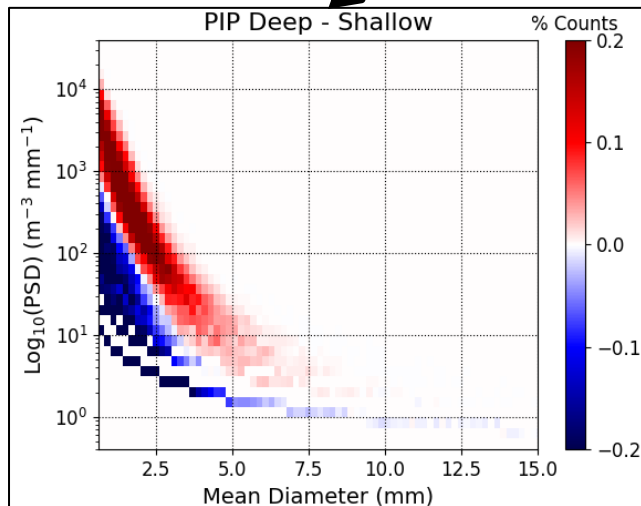
Statistics from Long-Term GV Sites



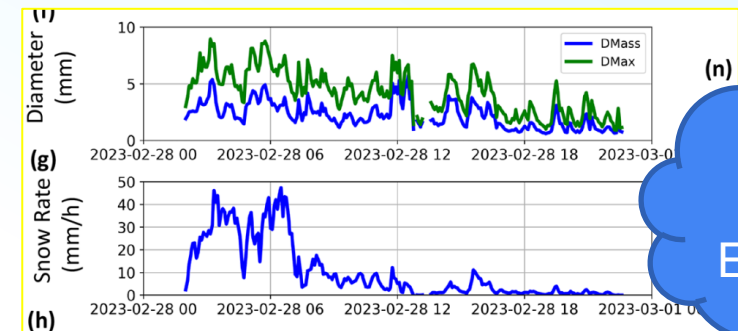
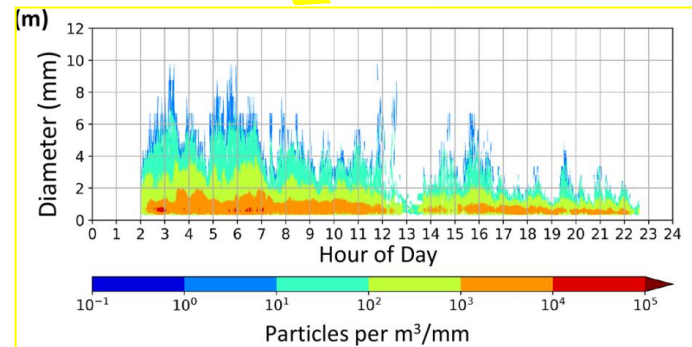
Finland



Marquette



UConn



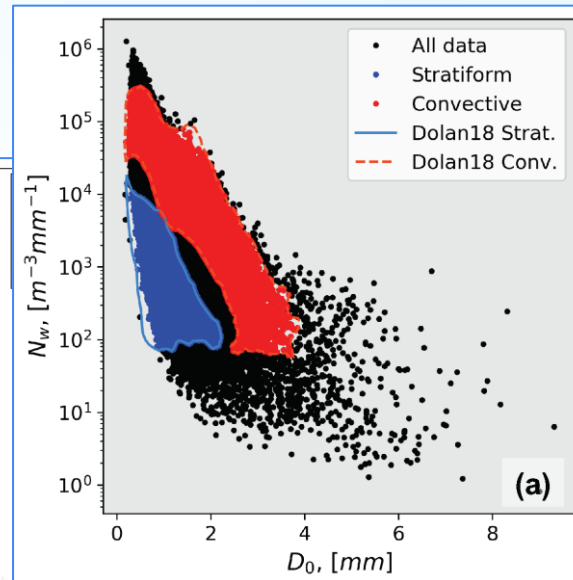
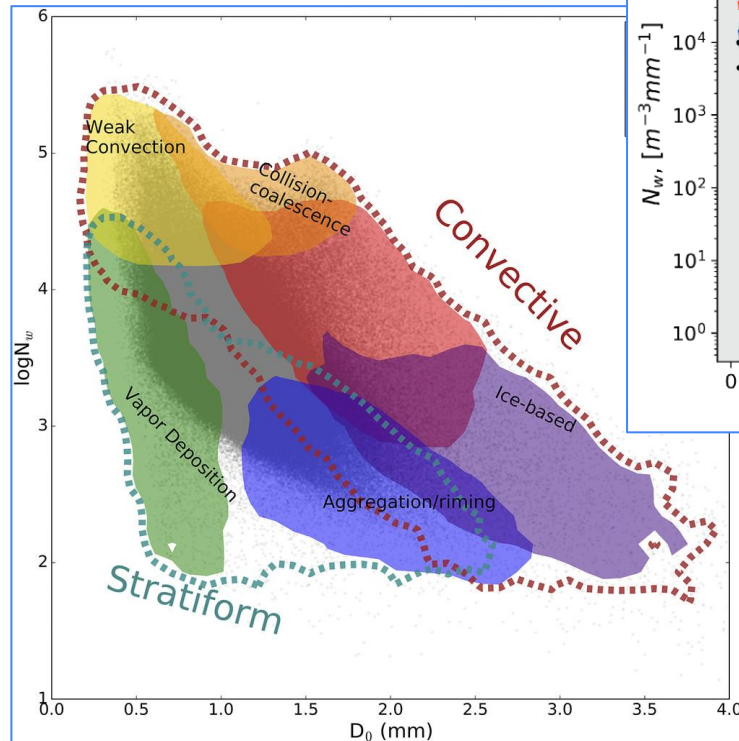
Better Snowfall Estimates!

Microphysical Processes

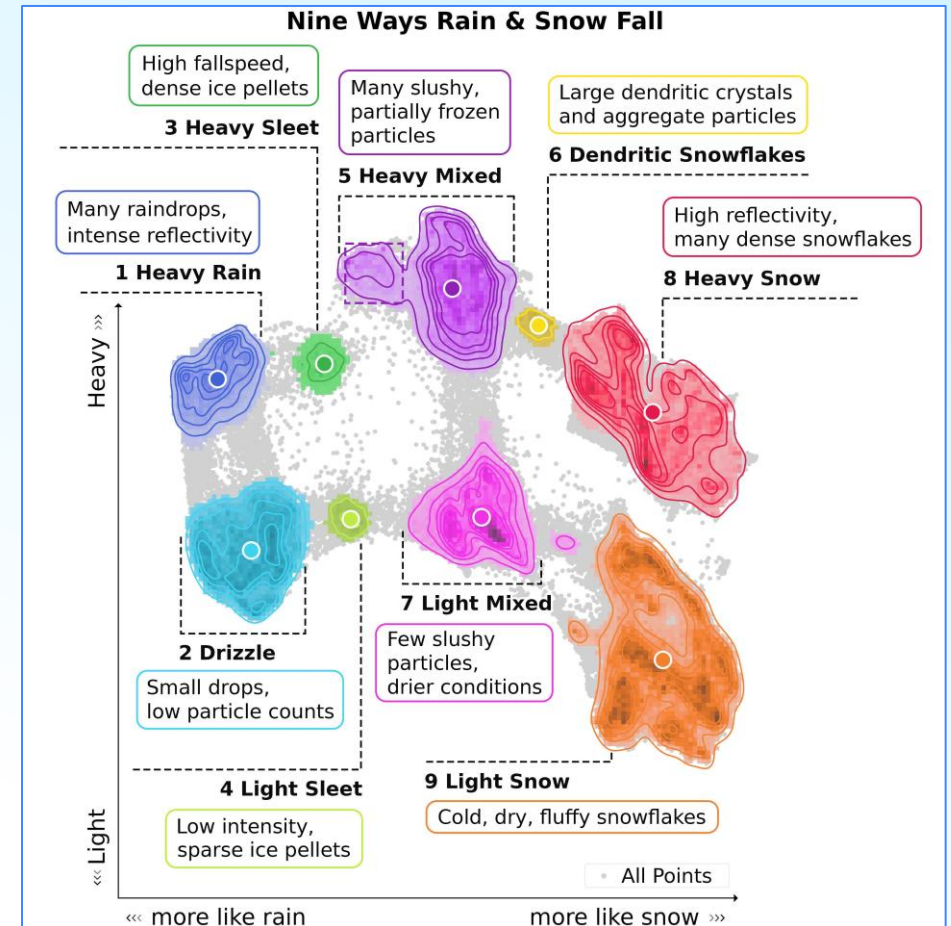
NASA has supported deployment of Ground Validation (GV) Assets globally for decades, which have enabled **evaluation of precipitation** as a function of **weather regimes**

Partition
Rain / Mixed / Snowfall
Regimes

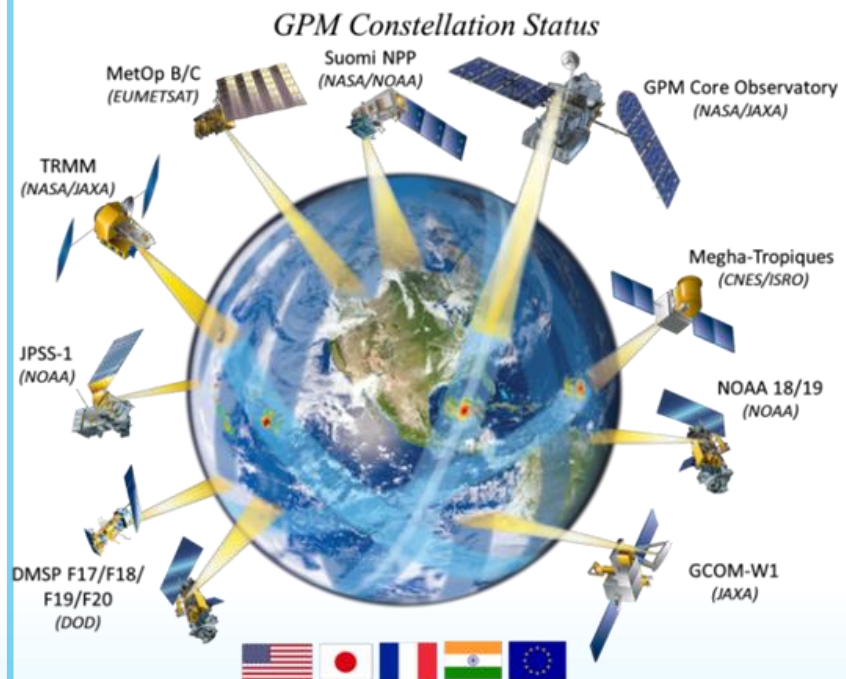
Rain Microphysics
by Environment



New Tools (ML) +
Global Observations
= Advancement



From Observations to Applications



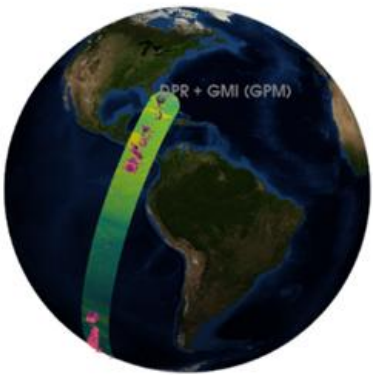
NASA Precipitation Products

IMERG
2BCMB
GPROF
...

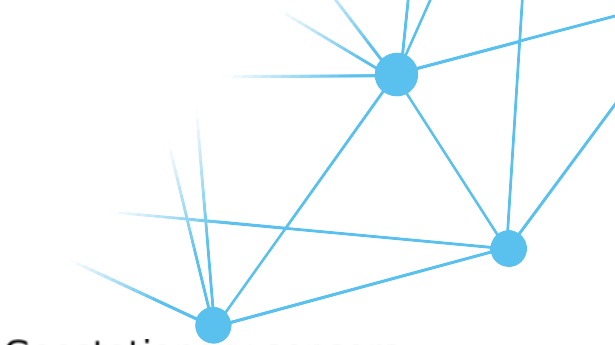
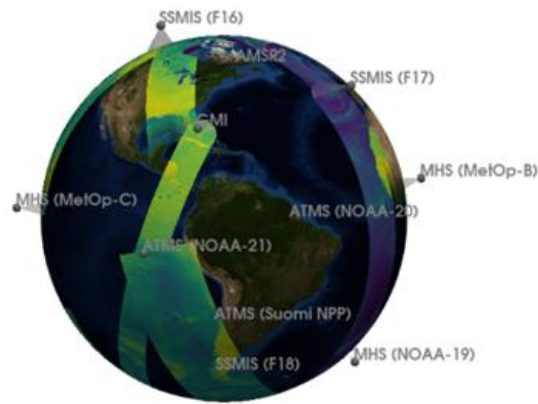


From GPM to IMERG

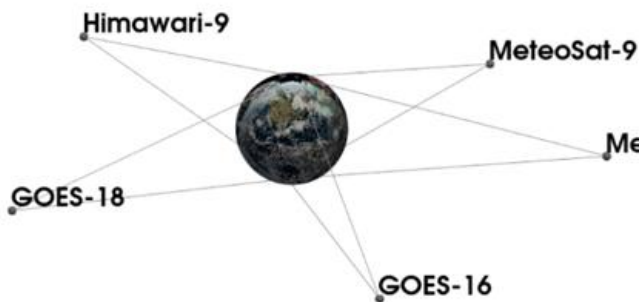
High-accuracy active observations



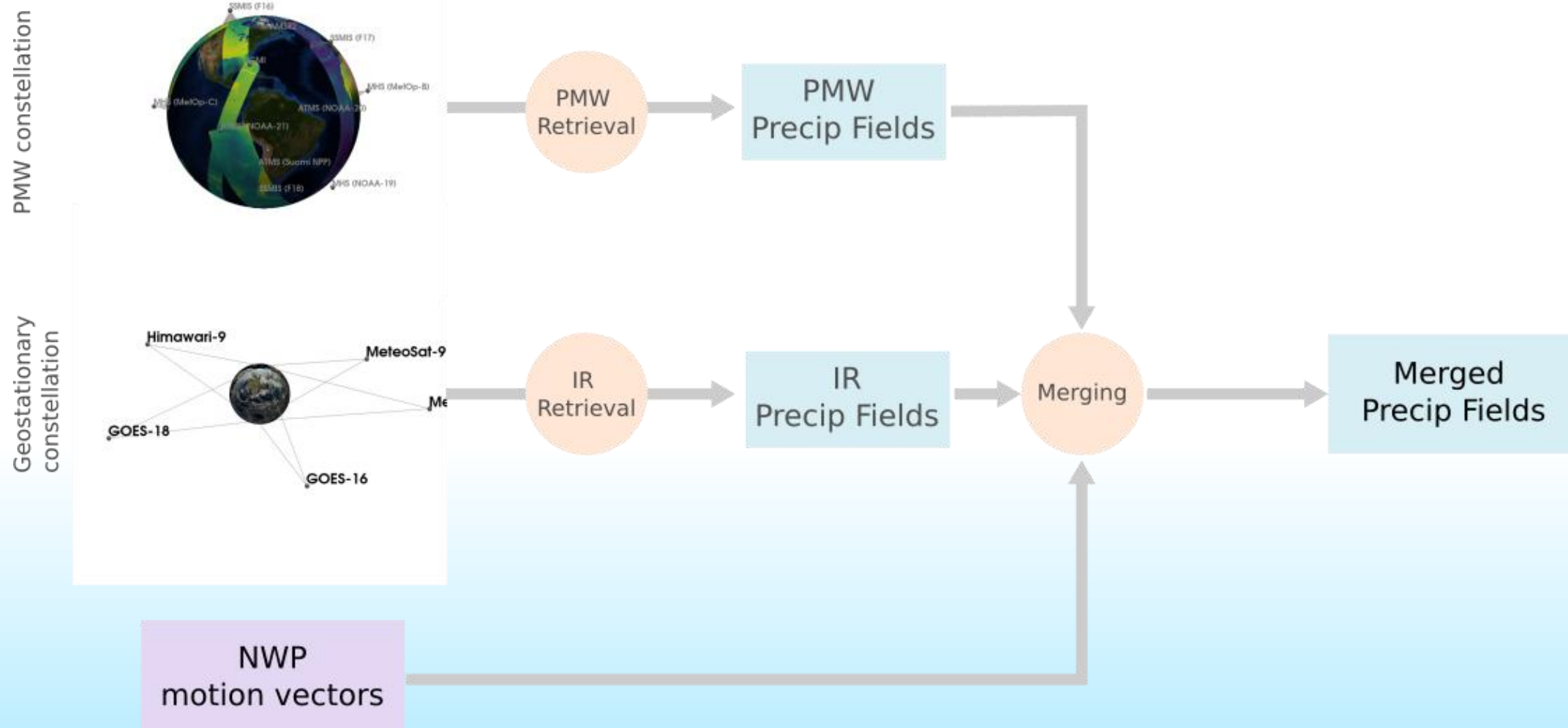
Constellation of passive microwave sensors



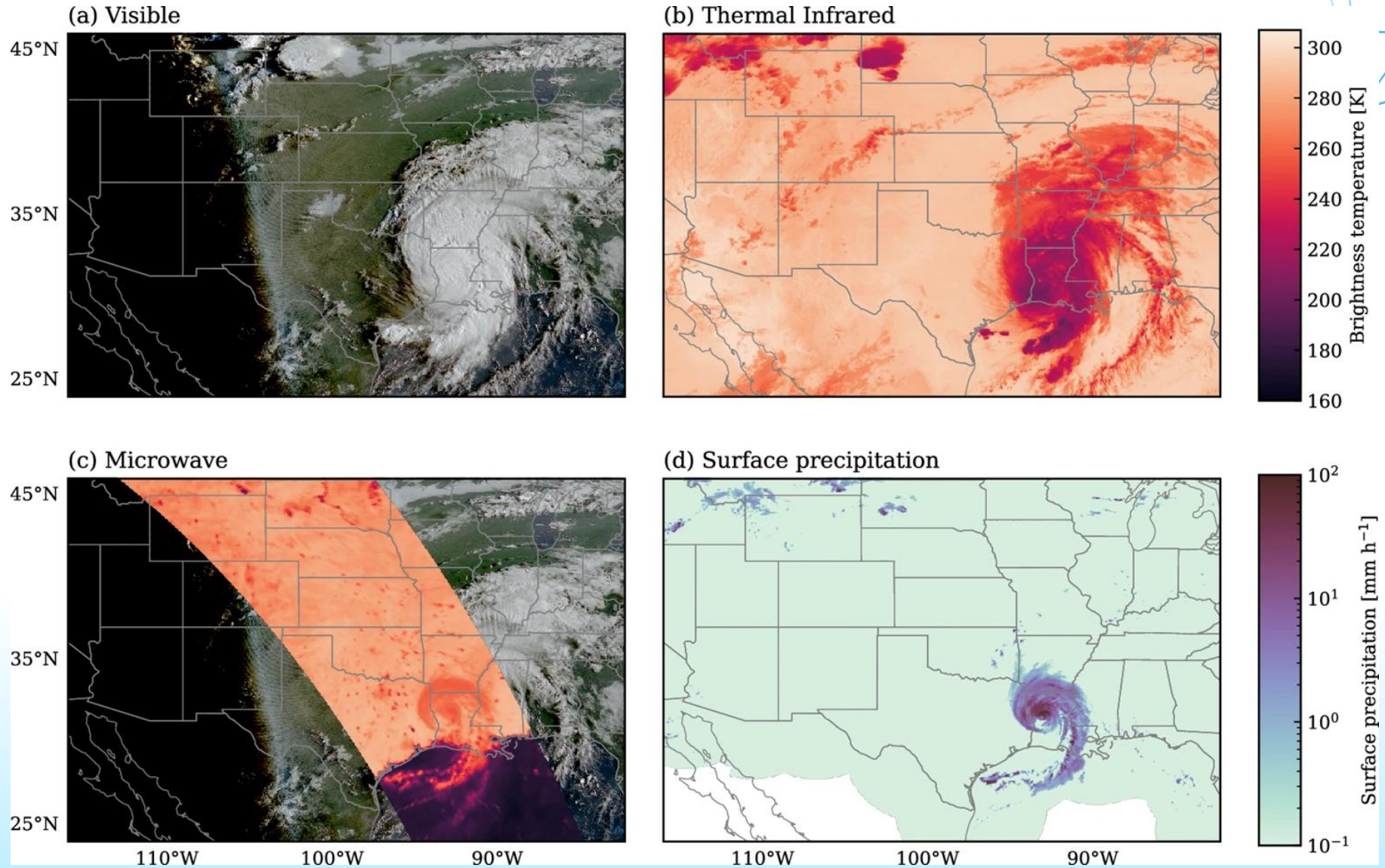
Geostationary sensors



From GPM to IMERG



Precipitation Retrieval: Challenges



Opportunities for AI: Leveraging Structural Information

Single Pixel

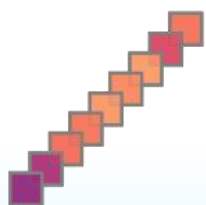
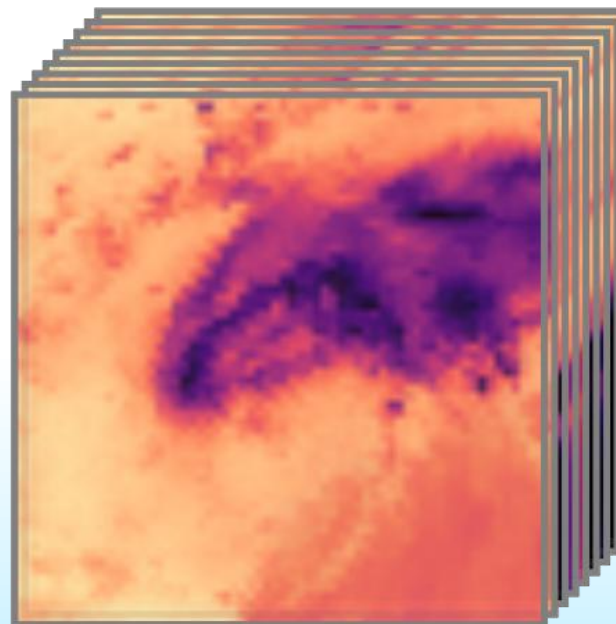


Image Patch

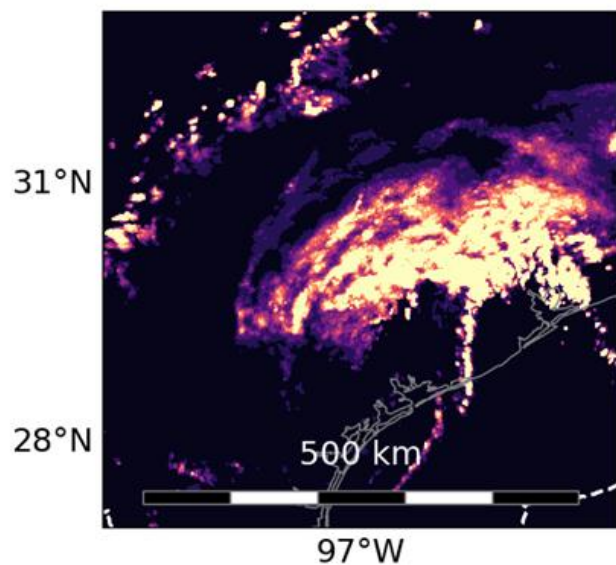


GPROF V08: Hurricane Harvey seen by GMI

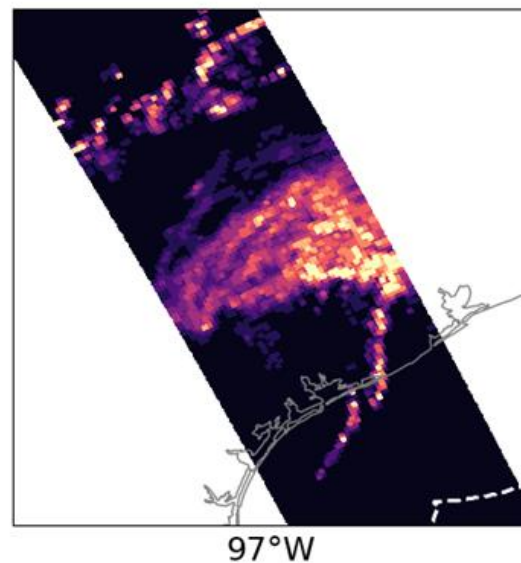


2017-08-27 21:21

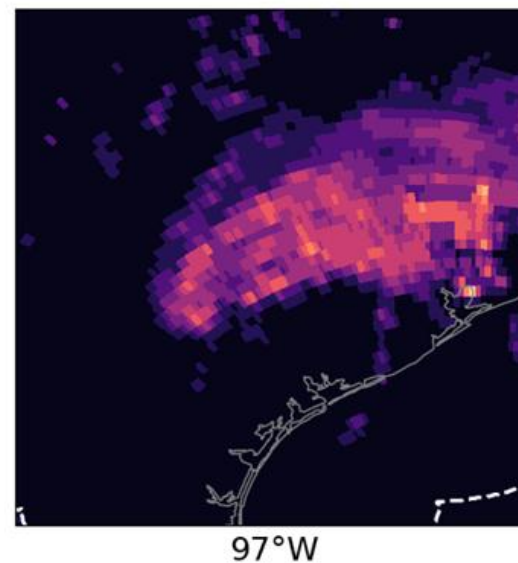
(a) MRMS



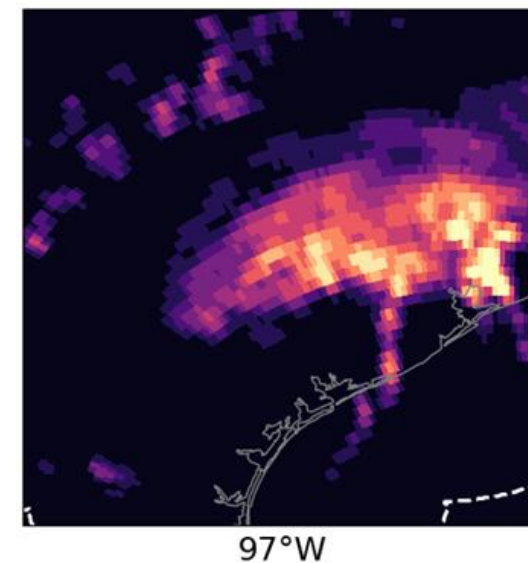
(b) 2BCMB



(b) GPROF V07

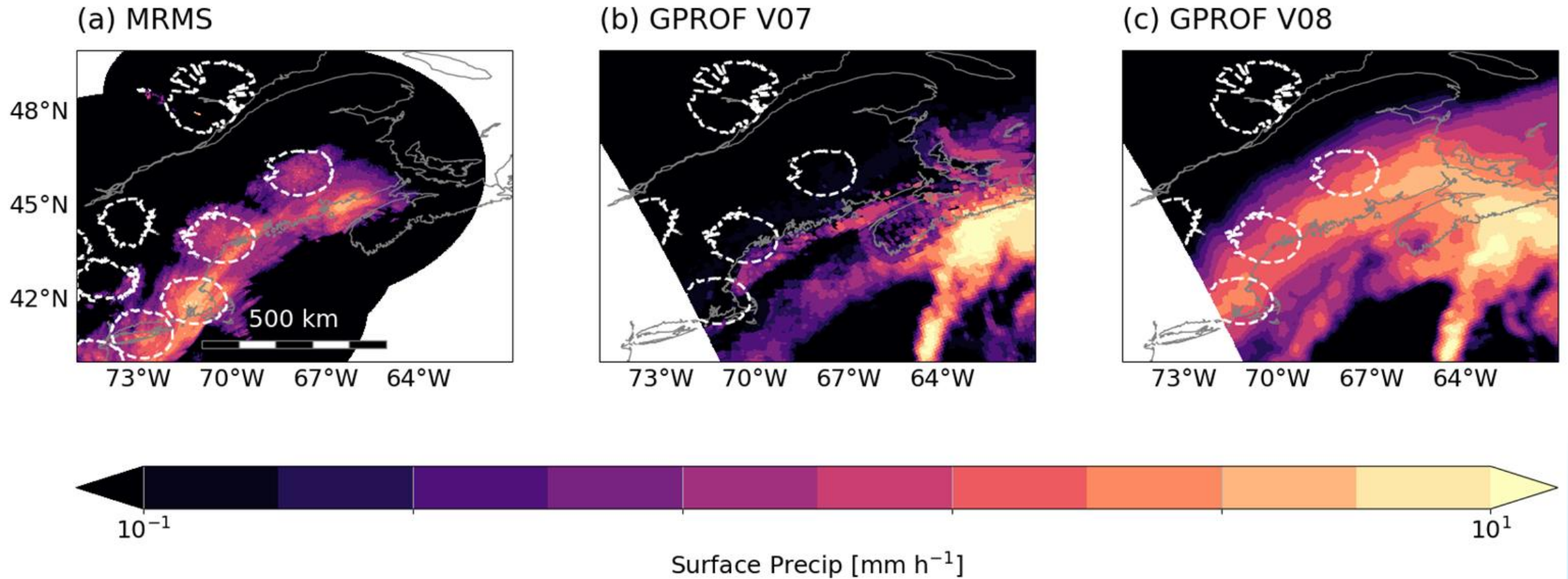


(c) GPROF V08



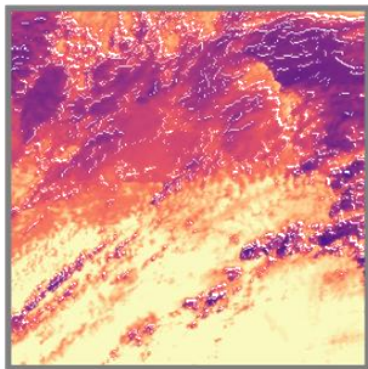
GPROF V08: Blizzard of 2022 seen by AMSR 2

2022-01-29 17:05

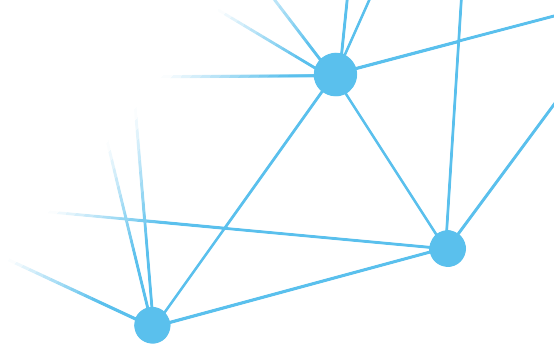
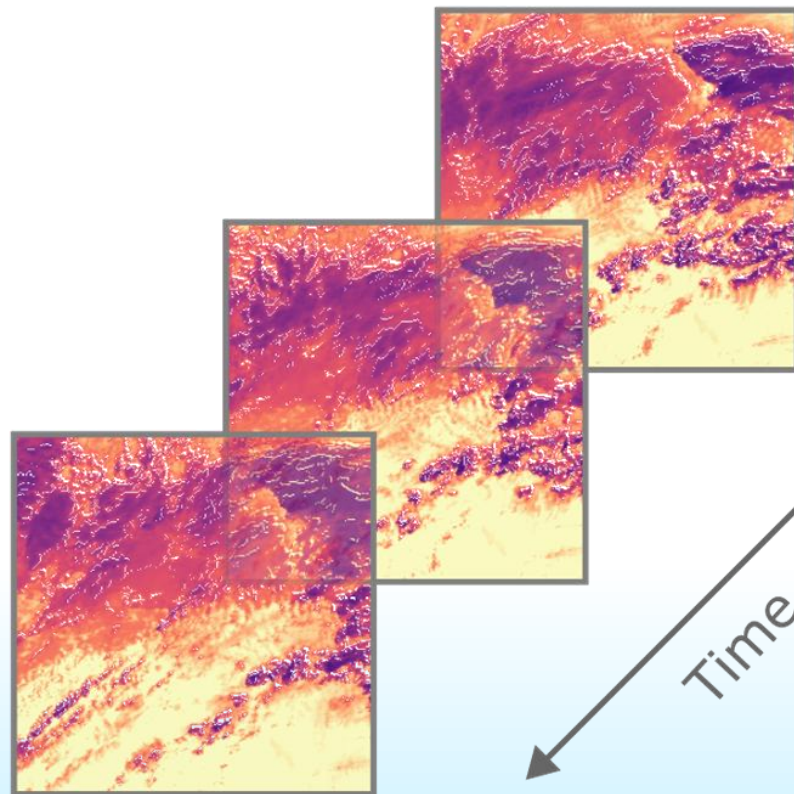


GPROF-IR: From Images to Time Series

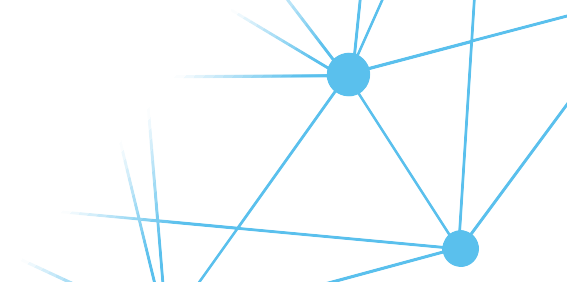
Single-Timestep
Geo IR



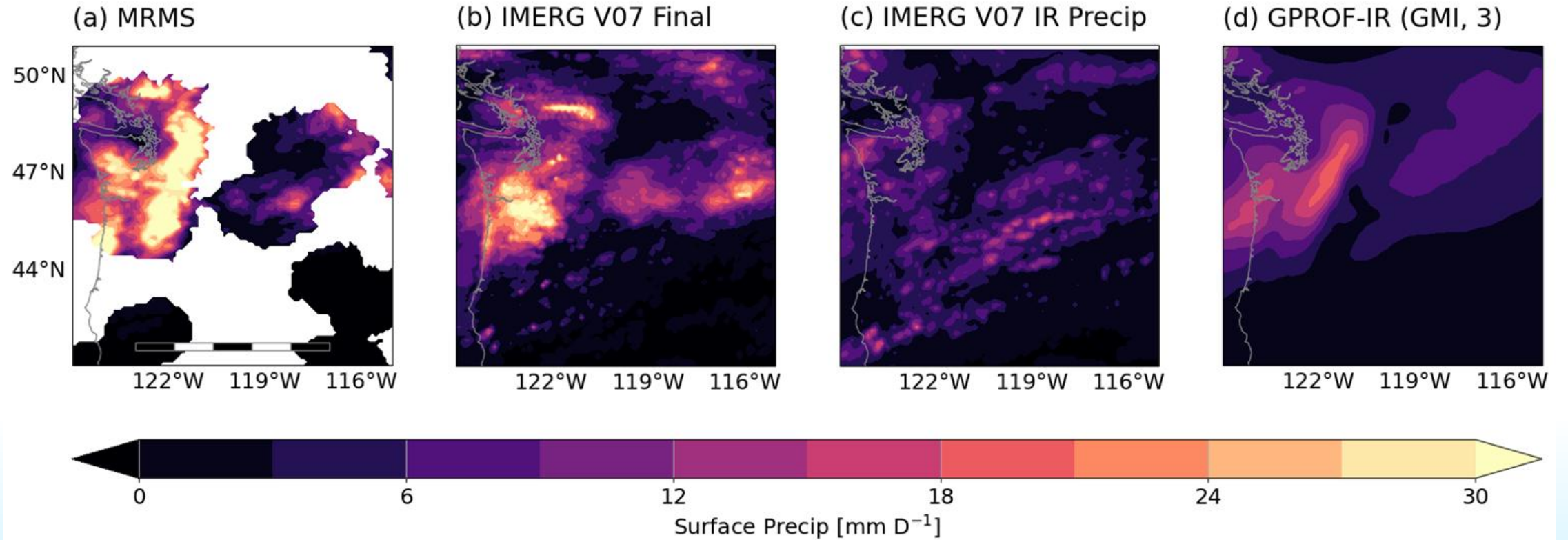
Multi-Timestep
Geo IR



GPROF-IR: June 2022 Atmospheric River

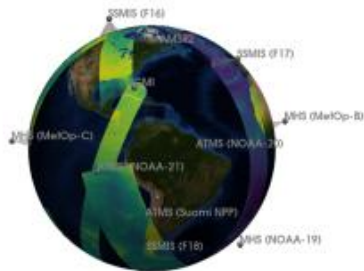


2022-06-10



Half Hourly Global Precipitation Estimates

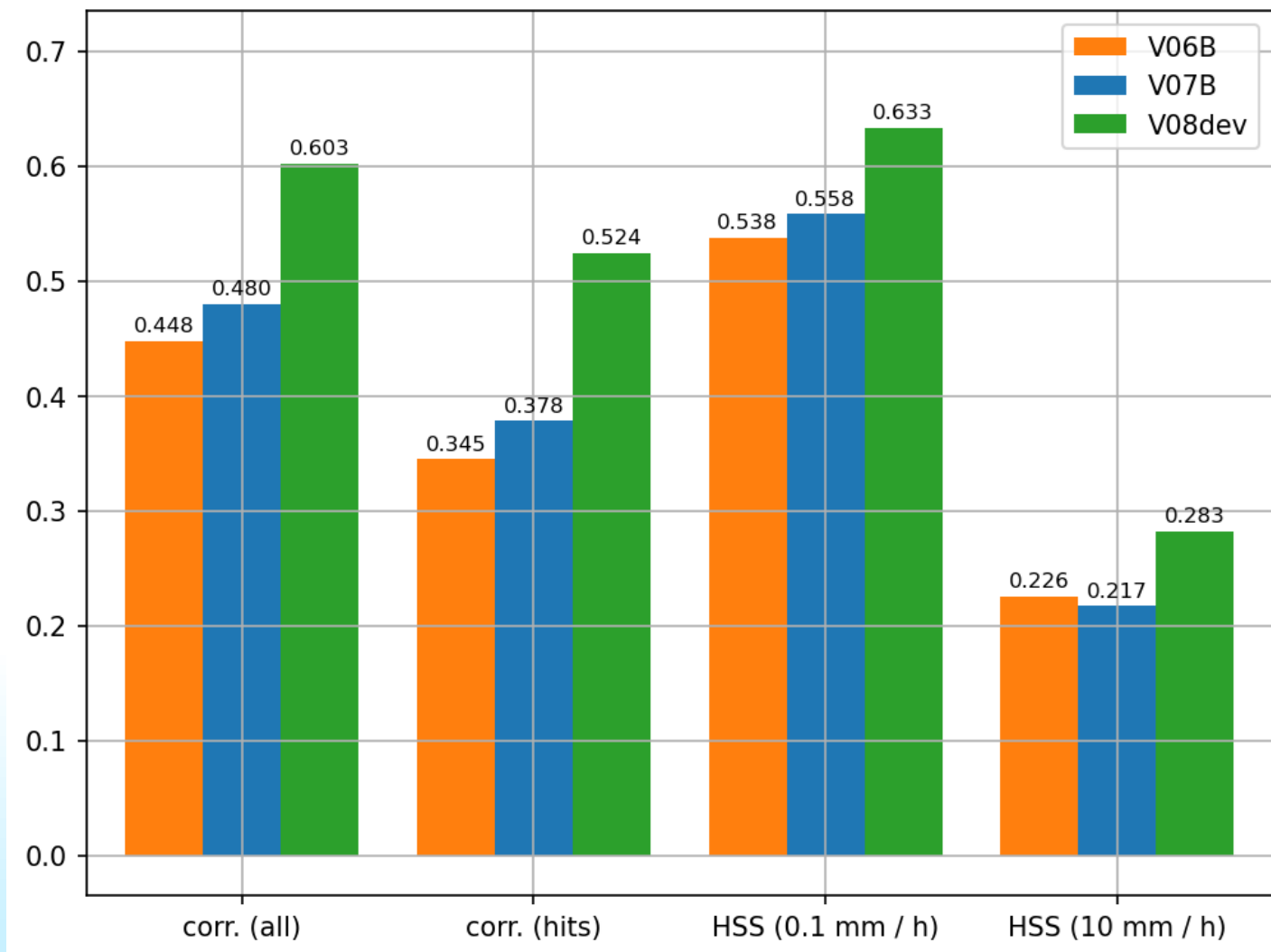
PMW constellation

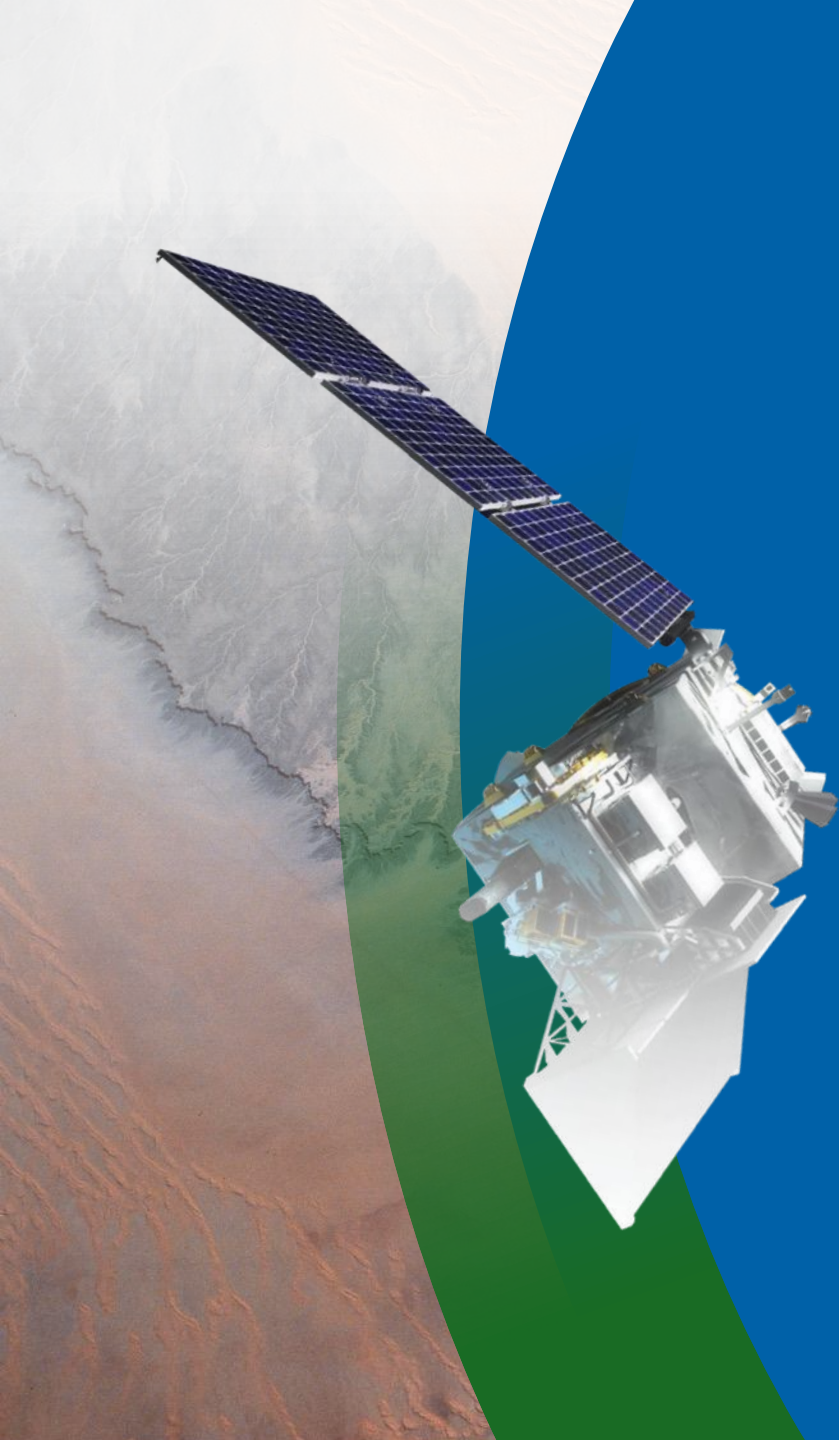
**GPROF V08**PMW
Precip FieldsGeostationary
constellation**GPROF-IR**IR
Precip FieldsNWP
motion vectors

Merging

Merged
Precip Fields

Impact on IMERG V08





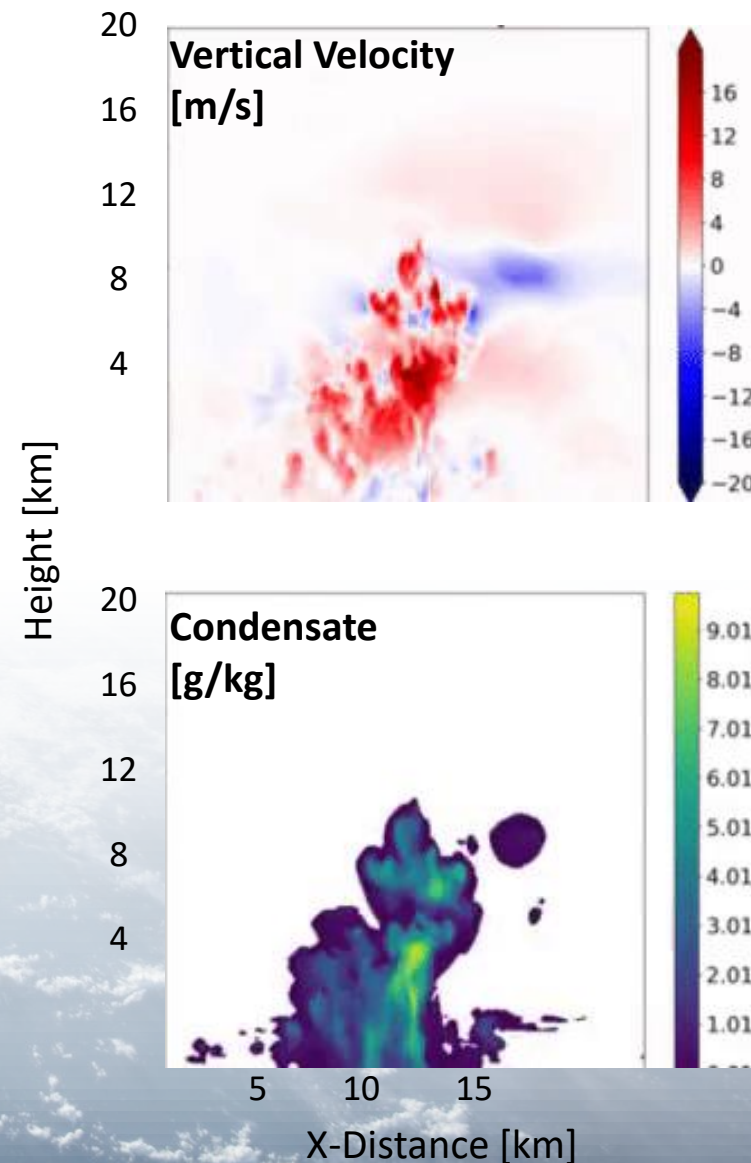
N A S A H y d r o s p h e r e -
P r e c i p i t a t i o n

Forward Looking Thoughts

A look ahead...

New observational **capabilities to exploit**:

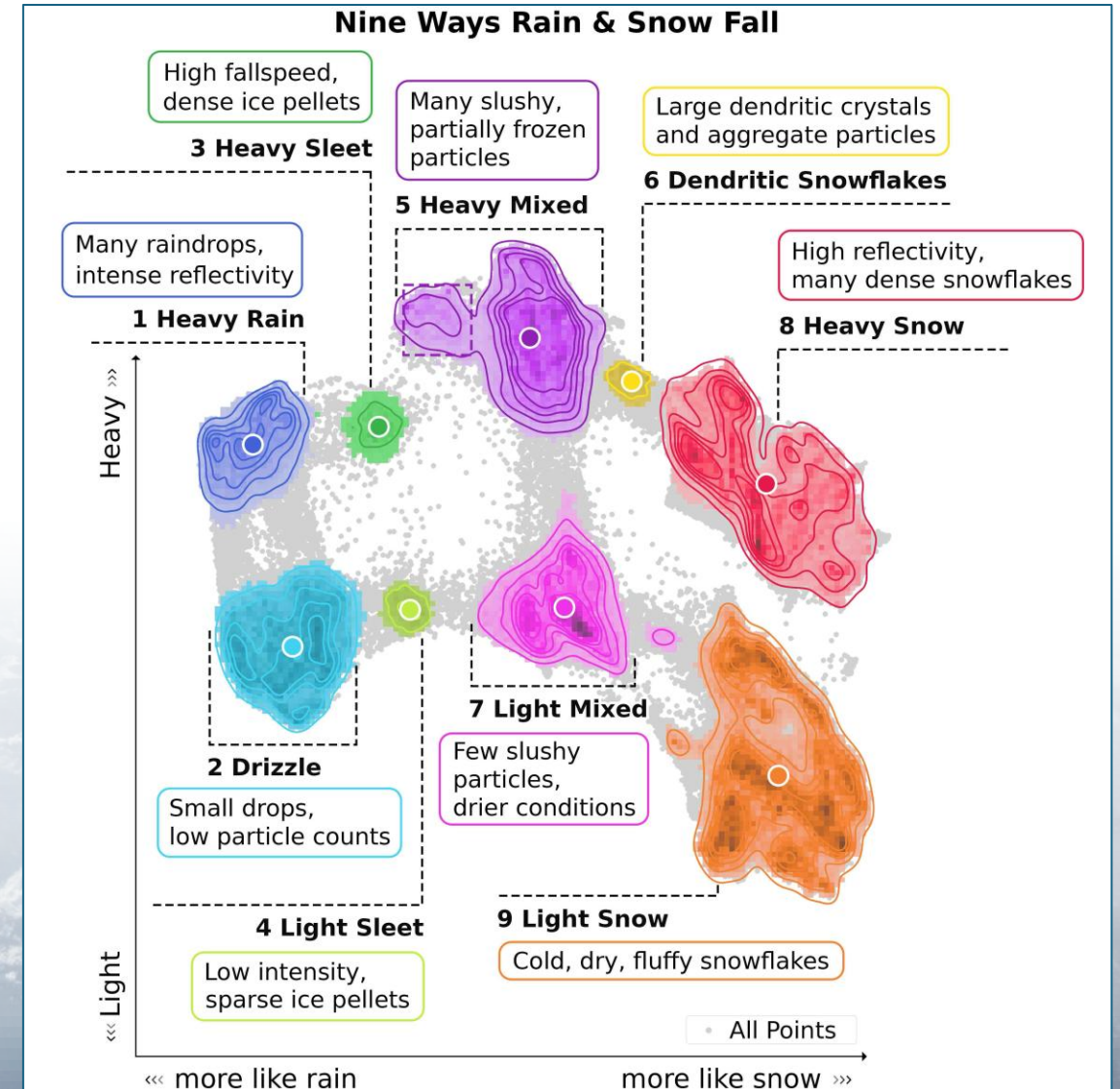
- Doppler capability from upcoming FALCON, INCUS, and PMM Radars plus cooperation with EarthCARE will help address longstanding science questions
 - Measure **kinematics** and **microphysics** together
 - Characterize **updrafts**, vertical **mass flux**
 - Improved phase determination leveraging vertical **Doppler velocity**



A look ahead...

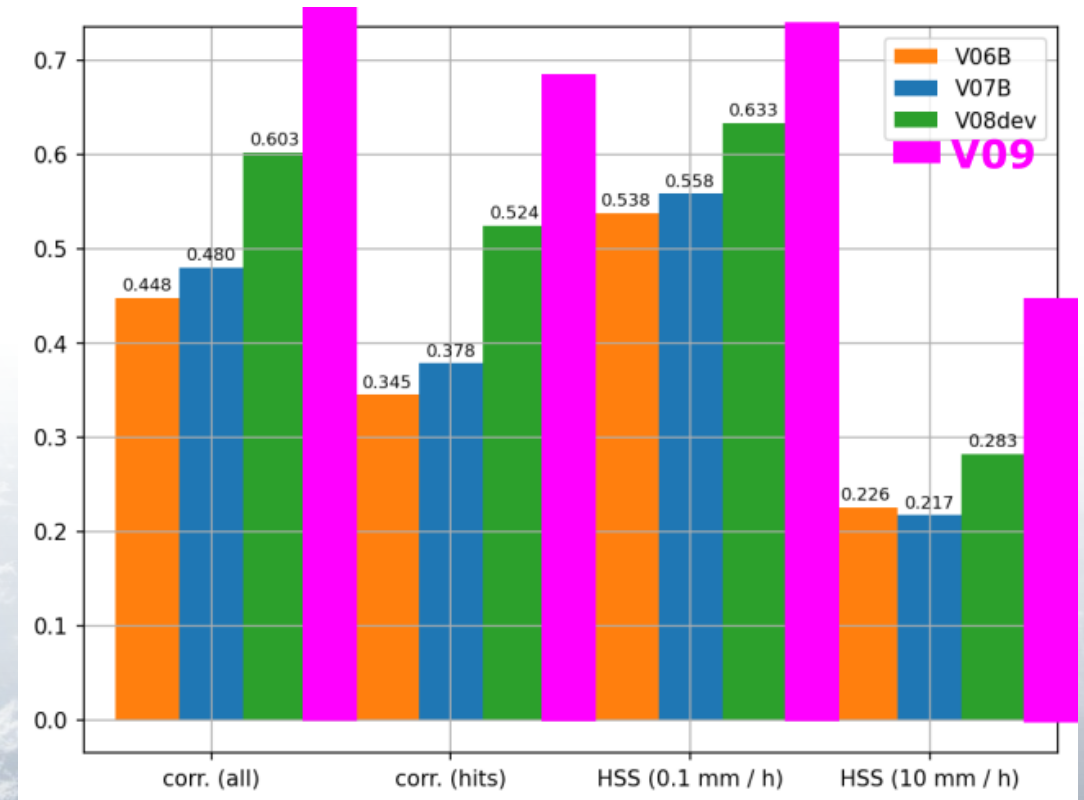
- So much to be done making full use of current NASA observations
 - Insights on **physical processes** to be gained using emerging AI/ML tools
 - Leverage **state-of-the-art** observations in training next generation of models
 - Better integration of **surface** and **suborbital** data

NASA observations are the **gold standard** for precipitation!



Algorithm and Product Continuity and Innovation

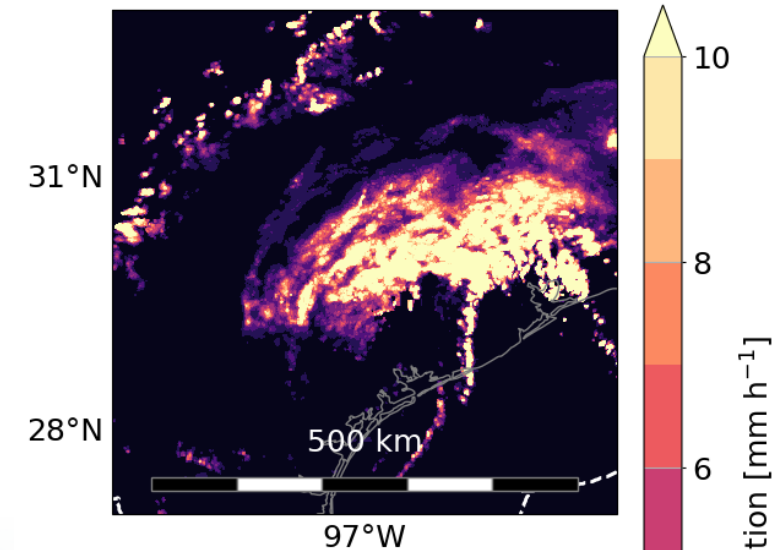
- **Research** and **applications** rely heavily on gridded data products
 - **Training Data for AIWP models**
- Improved data-fusion techniques may further improve the historical record
- NASA is **uniquely positioned** to evolve IMERG toward a long-term, high-resolution precipitation record that captures the **evolution of precipitation** across kilometer to synoptic scales



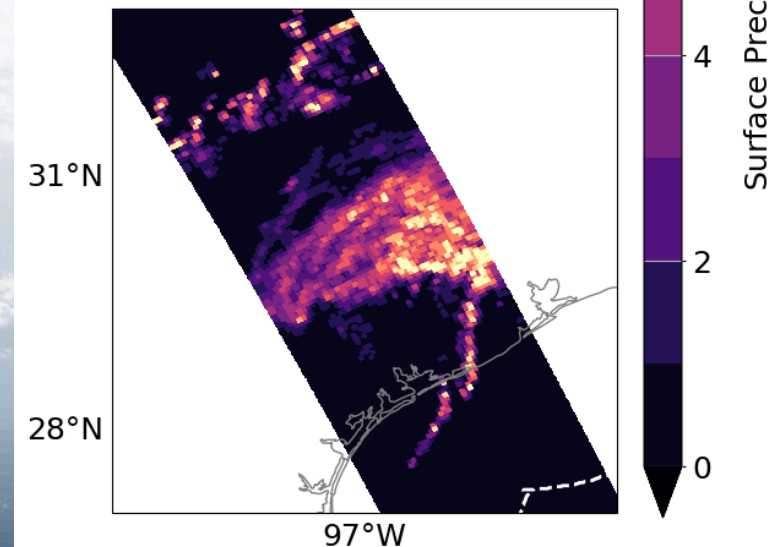
Algorithm and Product Continuity and Innovation

- AI/ML retrievals are only as good as reference data
 - NASA is *trusted source*
- Challenges remain
 - Intense convection/extremes
 - Spatiotemporal resolution
- Maintain periodic TRMM/GPM-class reference missions
- NASA's processing system needs to keep up with demands of upcoming multi-sensor AI techniques

(a) MRMS



(b) 2BCMB



Thinking Big!

- Integrated hydrosphere observation and modeling
- smallsat technology + FALCON + integrated science
- **Collocated** observations
 - L-band soil moisture and inundation
 - precipitation emission and scattering
 - warm rain and ice processes
 - water vapor
 - sub-mm ice processes
- Innovative observational capabilities + AI/ML + processing system

