Earth Science Research and Resources at NASA/UAH

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- Overview of organizations
- Airborne and Satellite Instruments
- Cooperative Research Topics and Example Applications*

  Satellite remote sensing of land, ocean surface, atmosphere, R20

  ***Hydrometeor size distribution measurement capabilities- point to global**

  Synergies in cloud modeling

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Collaboration of multidisciplinary teams from universities, government, and private sectors in order to conduct / communicate cutting edge space research and education in support of NASA missions. For Earth / atmospheric science, brings together

- 25 NASA civil service, 20 computer scientists and support staff (misc. contractors)
- 60 research scientist (UAH, USRA, others), 10 faculty, >60 graduate students
- 20 NWS forecasters

195 personnel supporting weather /disaster related activities

Earth System Science Center and Department of Atmospheric Science at the University of Alabama in Huntsville

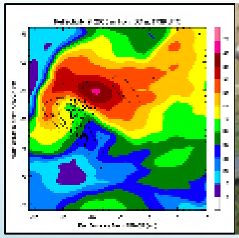
http://www.uah.edu/essc

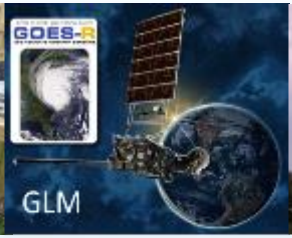
http://www.uah.edu/atmos

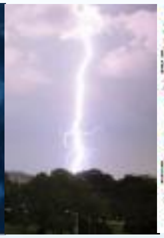
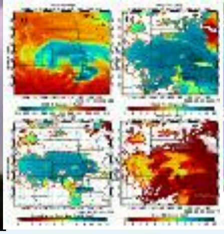
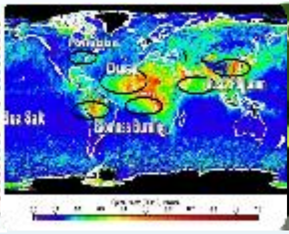
Integrated earth-atmosphere research, undergraduate and graduate education

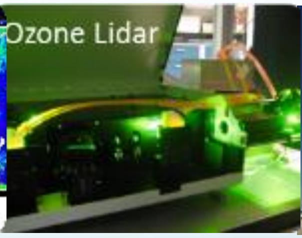
60+ Researchers, 15 Full Time Faculty Members, 1 Joint Faculty Appointment with Political Science, 1 Research Faculty Member, 1 Full Time Lecturer, 15+ Affiliate Graduate and Adjunct Faculty Members

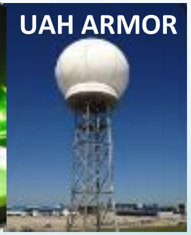
Climatology, Land-Atmosphere-Ecosphere Systems, GIS, Satellite Remote Sensing, Severe Weather, Cloud Processes, Lightning and Atmospheric Electricity, Radar Meteorology, Meteorological Instruments, Atmospheric Modeling and Data Assimilation, Space Archaeology, Public Policy, Atmospheric Chemistry and Aerosols









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SWIRLL

Severe Weather Institute and Radar & Lightning Laboratory

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Research Education Outreach

Tour Tuesday 3:30 PM at UAH SWIRL

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NASA MSFC Earth Science Branch

~ 25 civil servants (management, technical, engineers), 80 Contractors (UAH, USRA, Jacobs, ENSCO, Post-Docs…)

Our Mission

Integrating unique space-borne observations, data, and models, we

- ***advance understanding*** of the Earth's weather and its energy and water cycles,
- ***develop scientific and technical solutions*** to challenging coupled Earth-atmosphere systems problems, and
- ***transition research*** to applications that enable decision support ***for societal benefit.***

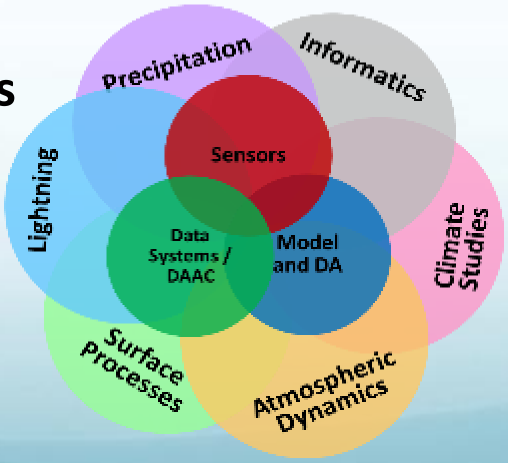
Our Vision

Expand our role as Agency ***leaders and innovators*** of Earth science discovery and focused technology development for capacity-building and societal benefit.

Scientific and Technical Expertise

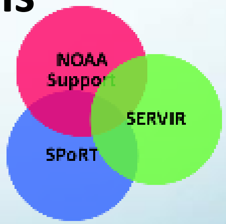
Thematic Research Emphasis

Lightning
Precipitation
Data Informatics
Climate Studies
Atmospheric Dynamics
Surface Processes



Enabled Programs

SERVIR
SPoRT
NOAA Support



Hardware Development

LIS, ISS LIS
AMPR, HIRad, FEGS

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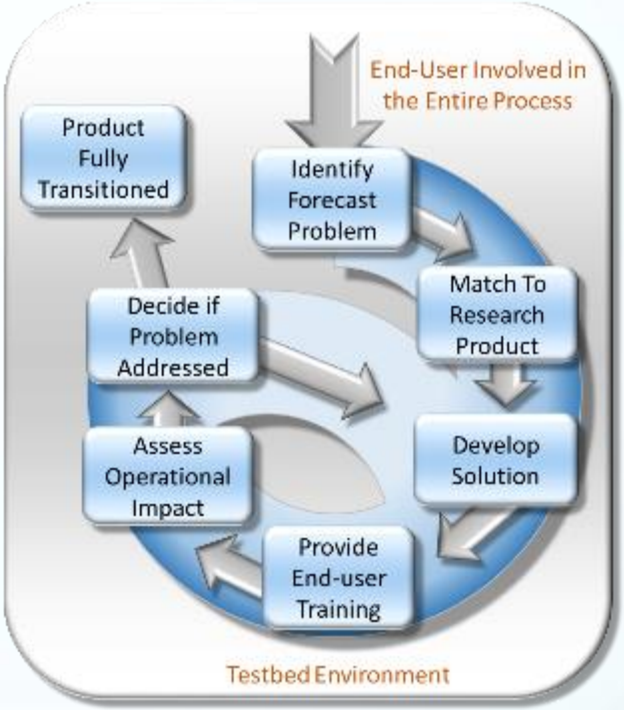
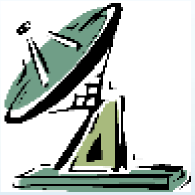
Short-term Prediction Research and Transition (SPoRT)

- **SPoRT is focused on transitioning unique NASA and NOAA observations and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale**
- **Established research-to-operations and operations-to-research paradigm that solves specific forecast problems, develops applications-focused training, and integrates data into end-user decision support systems**





Data downlinked from satellite

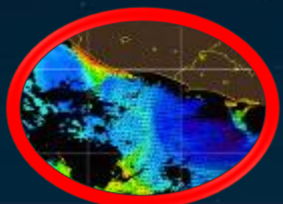
Data obtained by SPoRT; value-added products generated

Product disseminated to end-user formatted for their decision support system

End-user makes operational decisions using SPoRT products

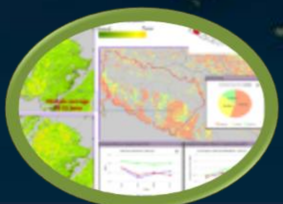
http://weather.msfc.nasa.gov/sport/
https://nasasport.wordpress.com/
@NASA_SPoRT

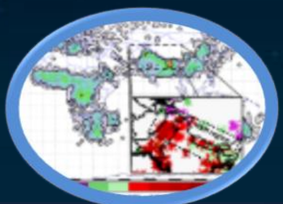
SERVIR is a joint development initiative of NASA and USAID, working in partnership with leading regional organizations around the globe, to help developing countries use information provided by Earth observing satellites and geospatial technologies to address Food Security, Water and Disasters, Weather and Climate, and Land Use/Land Cover Change.


Preventing seafood poisoning by mapping harmful microalgae


Helping herders and farmers by detecting ephemeral water bodies


Conserving forests by mapping land cover and land use change


Supporting food security by monitoring agricultural drought


Protecting lives by monitoring and forecasting intense thunderstorms

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Technology Develoment/Application
Lightning Imaging Sensor (LIS) on ISS

Mission

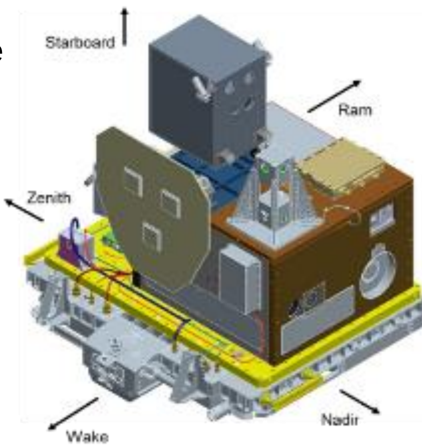
- TRMM and GOES-16 GLM development associated; fly a flight-spare LIS on ISS to take advantage of *high inclination, real time data.*

Measurement

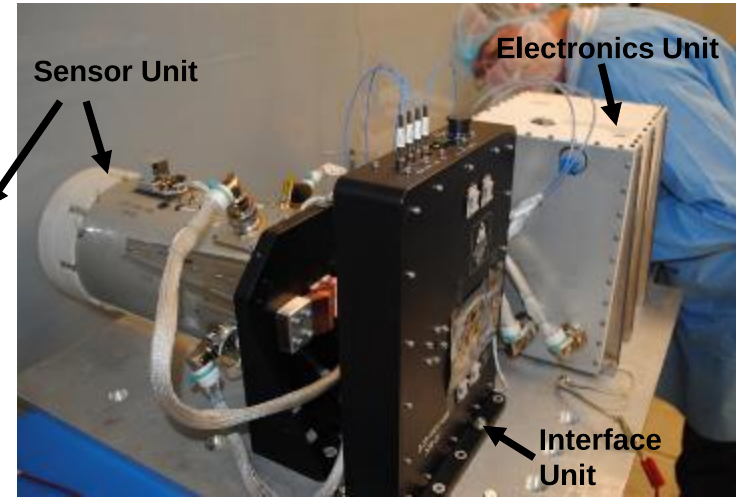
- Global lightning (*amount, rate, radiant energy*) with high detection efficiency

Need and Benefit

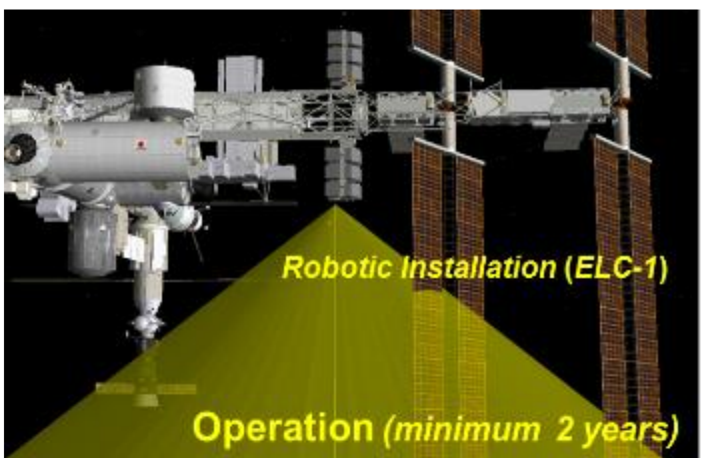
- Lightning coupled to many geophysical processes and a wide range of disciplines (e.g., *weather, climate, atmospheric chemistry, lightning physics*).
- ISS LIS extends TRMM heritage LIS, expands latitudinal coverage, provides real time data to operational users, cross-validates GOES GLM

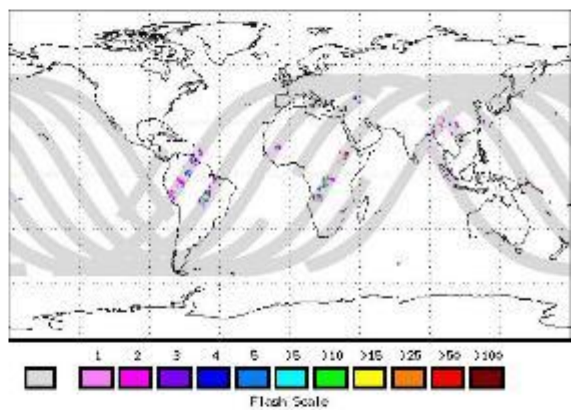


LIS is flown as a hosted payload on the Space Test Program STP-H5 mission

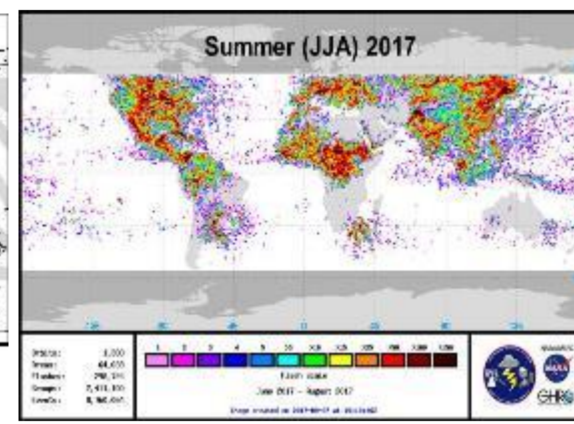


LIS being prepared for integration on STP-H5 payload (February 17, 2015)





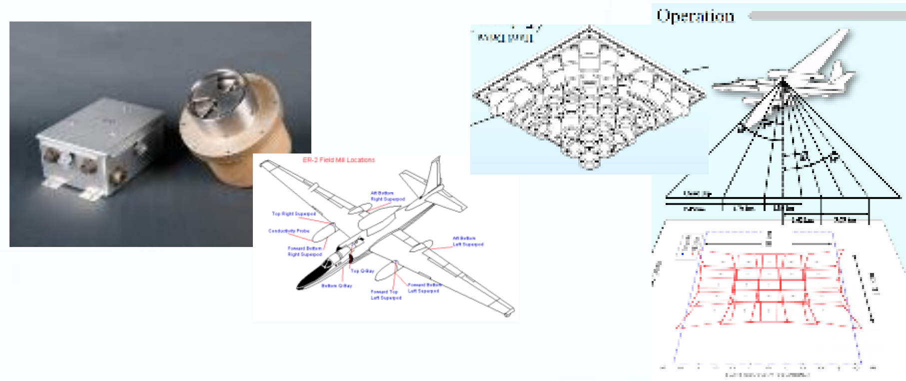
LIS near real time lightning data produced every two minutes



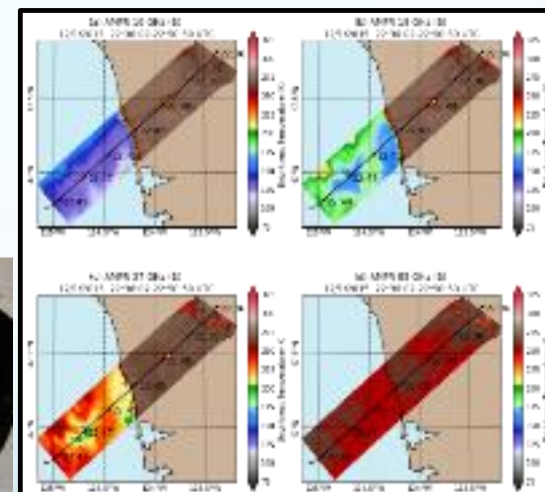
LIS global lightning detections during Summer 2017

Airborne Remote Sensing Technology and Science

- Fly's Eye GLM Simulator (FEGS) Radiometer, array to map total lightning properties. Lightning Instrument Package (LIP): Electric field, conductivity, total lightning. Aircraft: ER-2- Global Hawk;

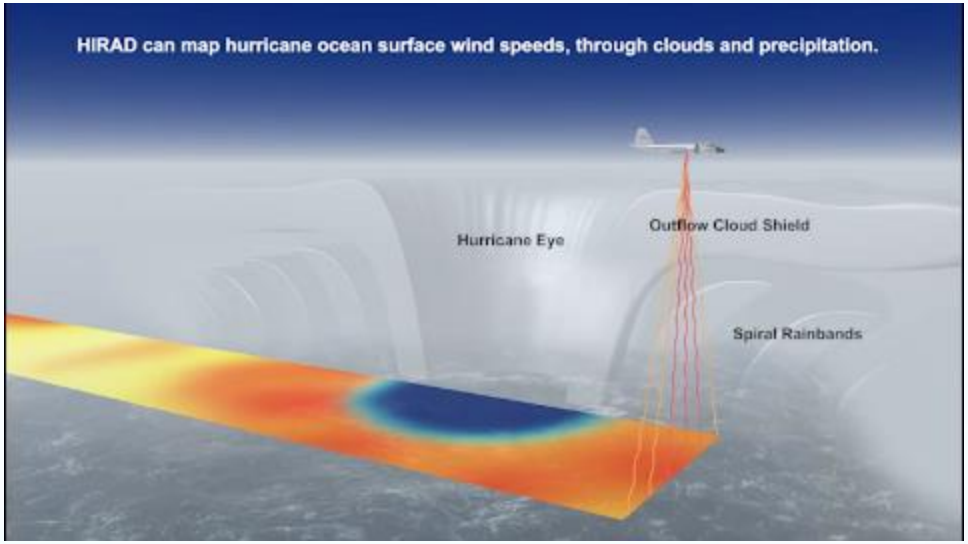


- AMPR: Advanced Microwave Precipitation Radiometer: Cross-track scanning microwave radiometer. Frequencies - 10.7, 19.35, 37.1, 85.5 GHz, dual-polarization. Surface, clouds and precipitation remote sensing. Aircraft ER-2, DC-8, P-3



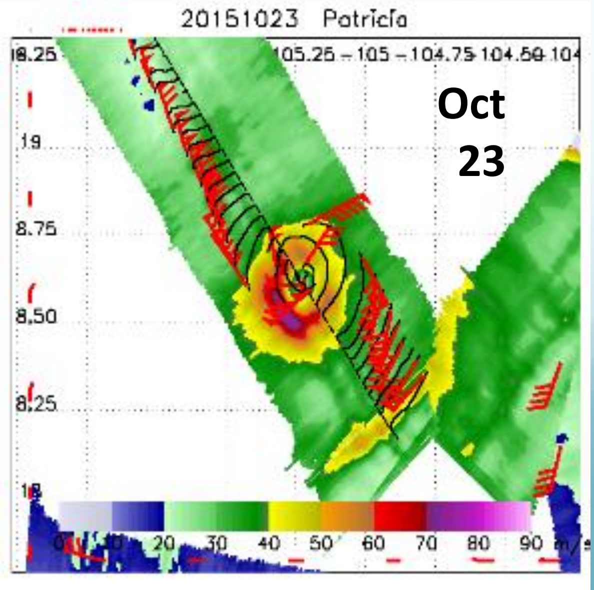
HIRAD (Hurricane Imaging Radiometer)

- **Objectives:**
  - Map surface wind speed *over wide swath* (~50 km, for aircraft > FL600) in hurricanes
  - Provide research data for understanding hurricane structure, intensity change
  - Improve predictions, decision support
- **Technical Approach:**
  - Multi-frequency C-band radiometer
  - Stronger wind -> more foam -> warmer brightness temperatures
  - Minimum detectable wind speed ~ 15 m s^{-1})
- **History**
  - Leveraged technology from UMich, LaRC
  - MSFC internal and NOAA investments (2006-2010)
  - Several field efforts on NASA aircraft (WB-57, Global Hawk)
- **Future Goals:**
  - Upgrade to add wind direction
  - More robust 2nd-generation instrument(s)
  - Facility instrument on multiple aircraft for both research & operations

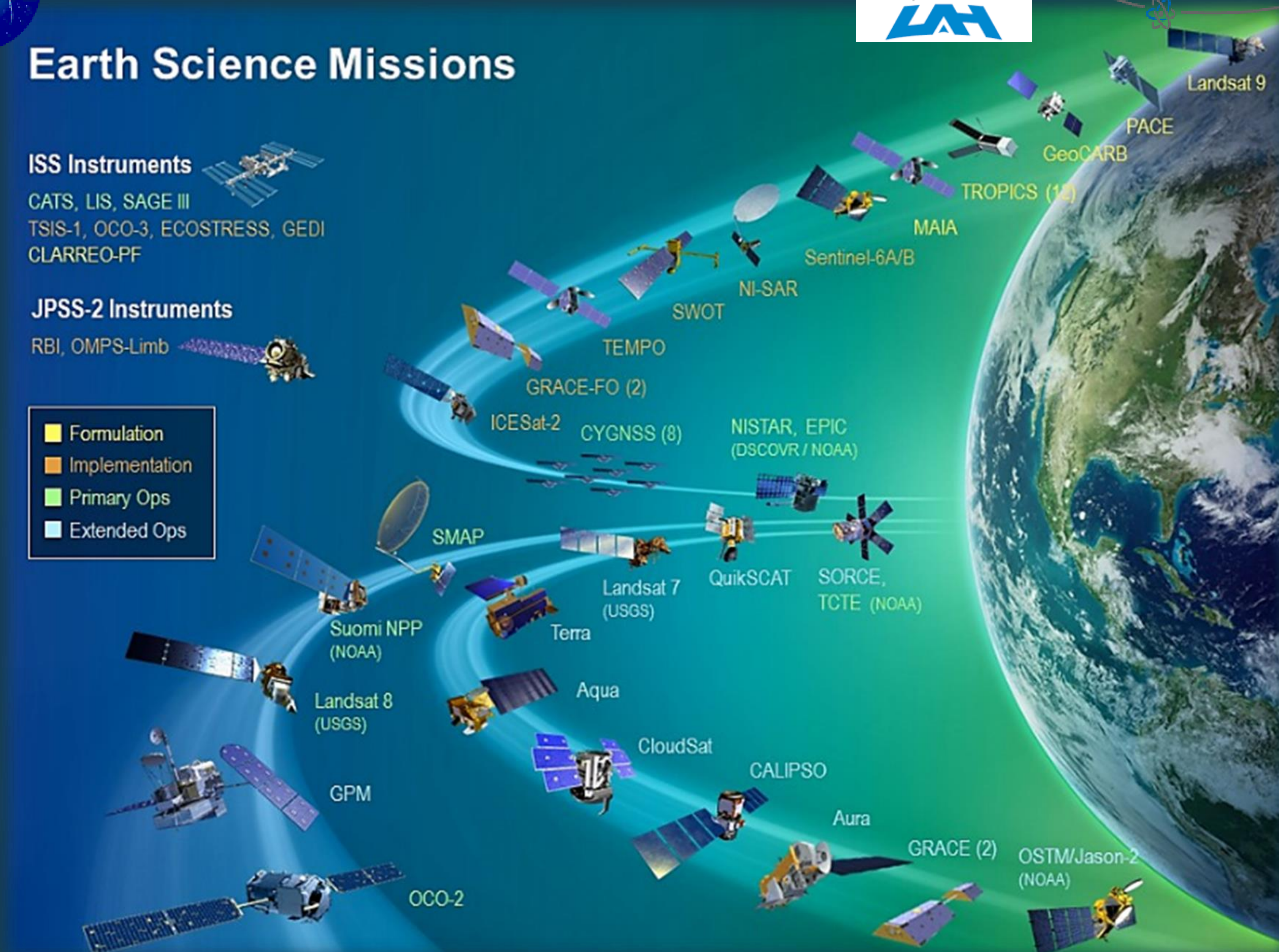


Hurricane Patricia (2015) at Cat 5 intensity, with dropsonde wind barbs overlaid.

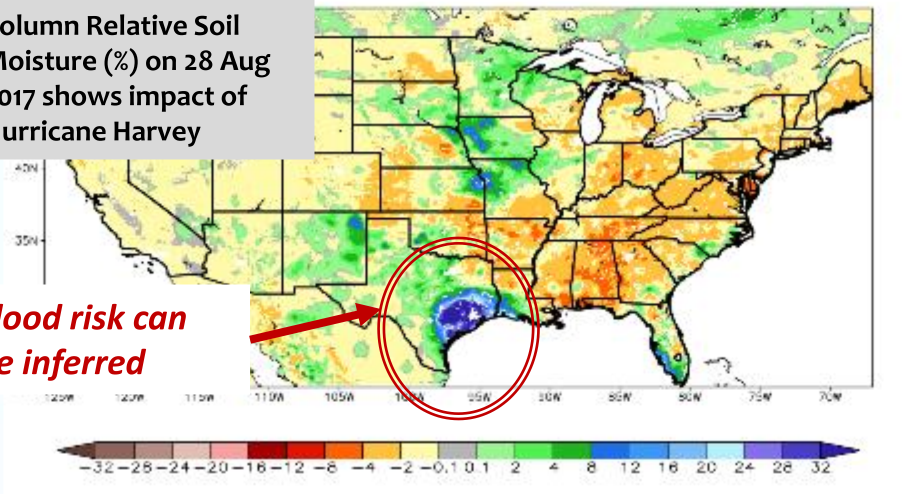
For a small storm like Patricia, one aircraft pass maps the entire eyewall.



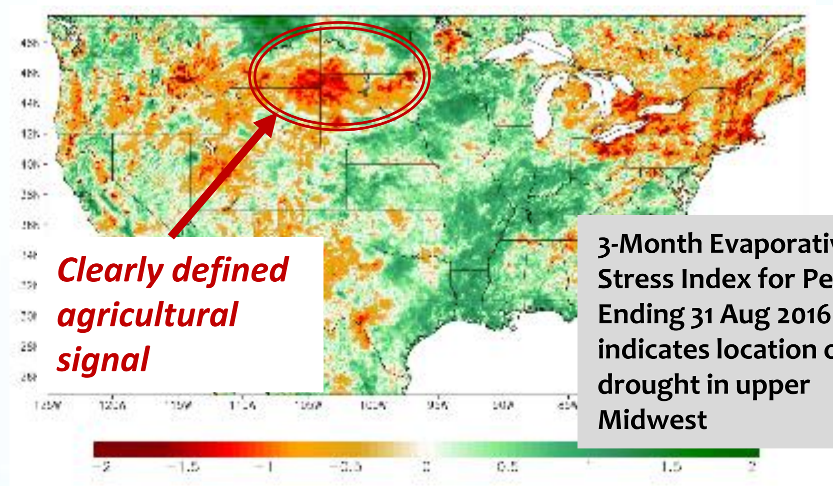
Research


Earth Science Missions
ISS Instruments
CATS, LIS, SAGE III
TSIS-1, OCO-3, ECOSTRESS, GEDI
CLARREO-PF
JPSS-2 Instruments
RBI, OMPS-Limb
Formulation
Implementation
Primary Ops
Extended Ops
Landsat 9
PACE
GeoCARB
TROPICS (12)
MAIA
Sentinel-6A/B
NI-SAR
SWOT
TEMPO
GRACE-FO (2)
ICESat-2
CYGNSS (8)
NISTAR, EPIC
(DSCOVR / NOAA)
SMAP
Landsat 7
(USGS)
QuikSCAT
SORCE,
TCTE (NOAA)
Suomi NPP
(NOAA)
Terra
Landsat 8
(USGS)
Aqua
CloudSat
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason-2
(NOAA)
OCO-2

Land Surface State: Flood & Drought

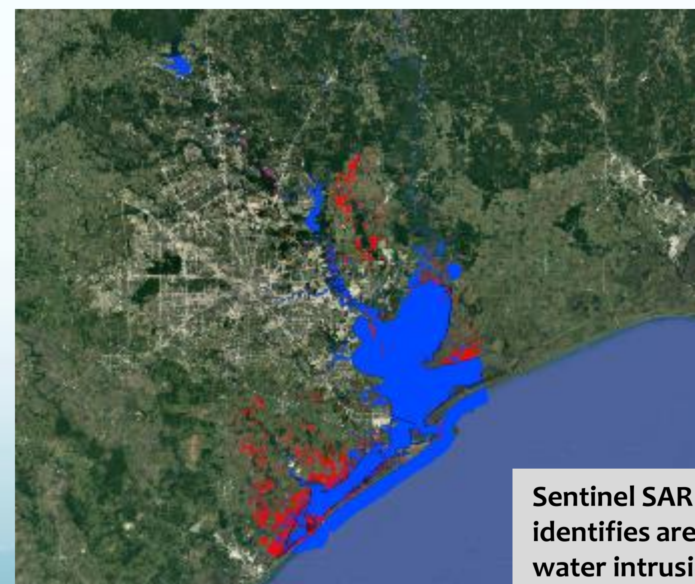


1-Week Difference in Column Relative Soil Moisture (%) on 28 Aug 2017 shows impact of Hurricane Harvey



3-Month Evaporative Stress Index for Period Ending 31 Aug 2016 indicates location of drought in upper Midwest

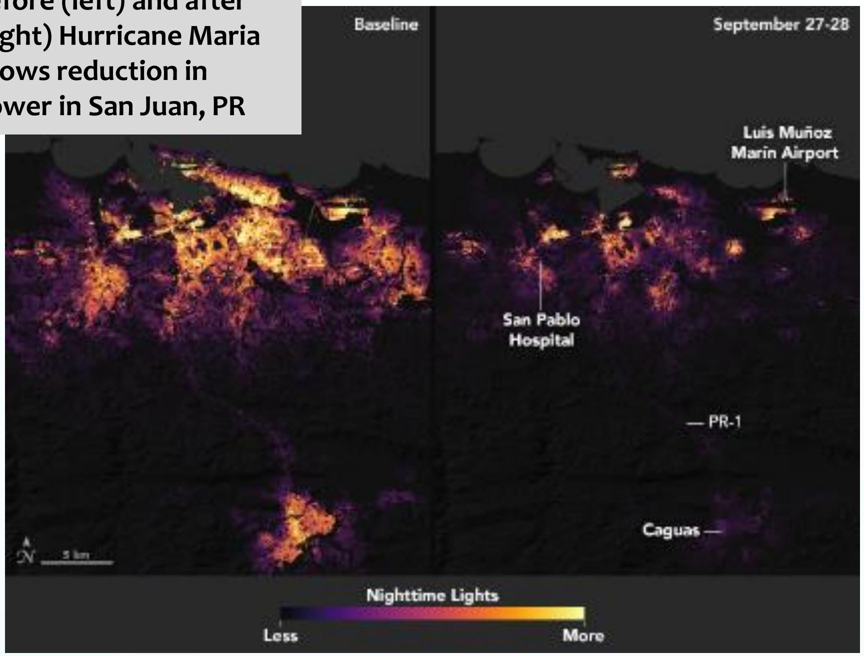
- Land surface (LIS; SMAP) to improve short-term weather, flood potential, and agricultural forecasts (top)
- Use Synthetic Aperture Radar (SAR) to see through clouds to observe flood extent at high spatial resolution (right)

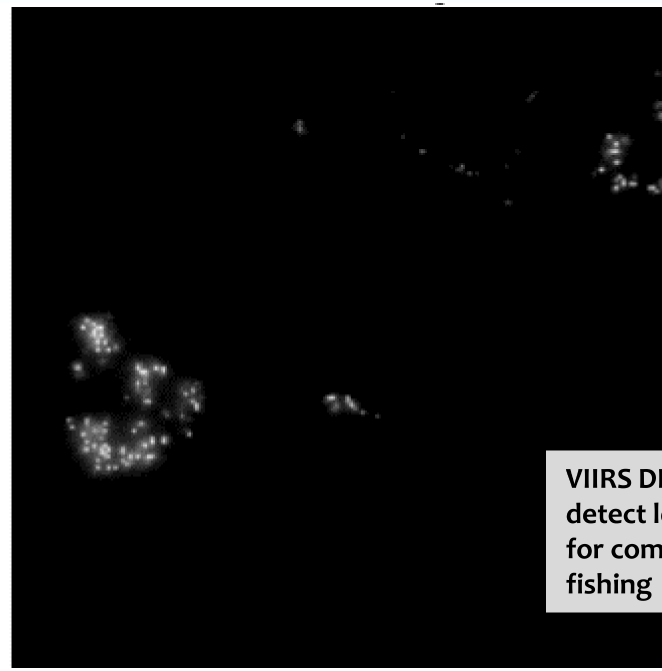


Sentinel SAR data identifies areas of flood water intrusion

VIIRS Day Night Band

VIIRS DNB comparison before (left) and after (right) Hurricane Maria shows reduction in power in San Juan, PR





VIIRS DNB is able to detect location of boats for combating illegal fishing

- **Visible Infrared Imaging Radiometer Suite (VIIRS) has a low light sensor that can detect moonlight-reflected clouds at night and lights on the ground in low-moonlight conditions**
- **SPoRT has developed a number of real-time products that can be used for detecting power outage related to disasters (left) or for detecting small-scale light sources (right) to track human migration**

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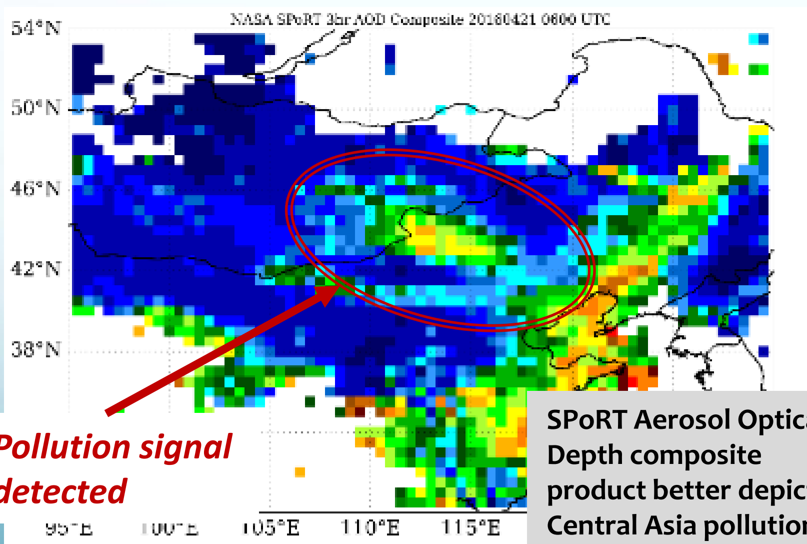
Atmosphere: Dust & Aerosols

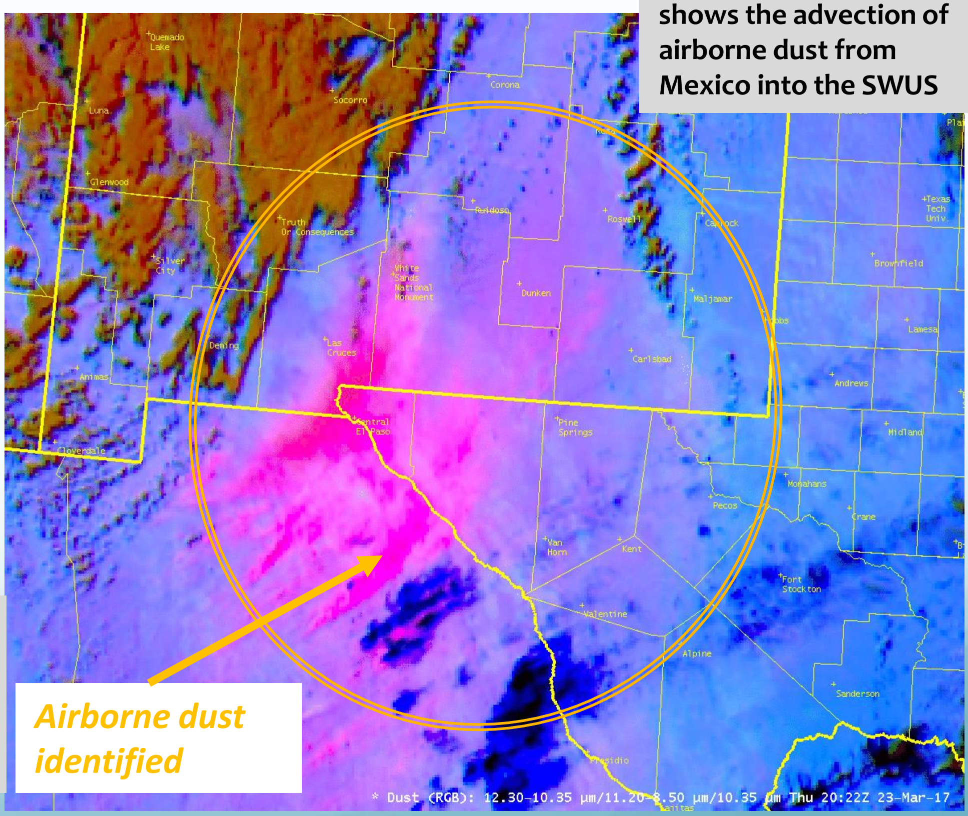
- **SPoRT has developed a real-time global aerosol optical depth (AOD) composite product (left) for detecting pollution and dust for studying their impact on cloud and precipitation development**
- **Multispectral imagery (Dust RGB; right) identifies airborne dust (magenta) that may be difficult to identify in single-channel imagery**



Pollution signal detected

SPoRT Aerosol Optical Depth composite product better depicts Central Asia pollution than model

Dust RGB from GOES-16 shows the advection of airborne dust from Mexico into the SWUS

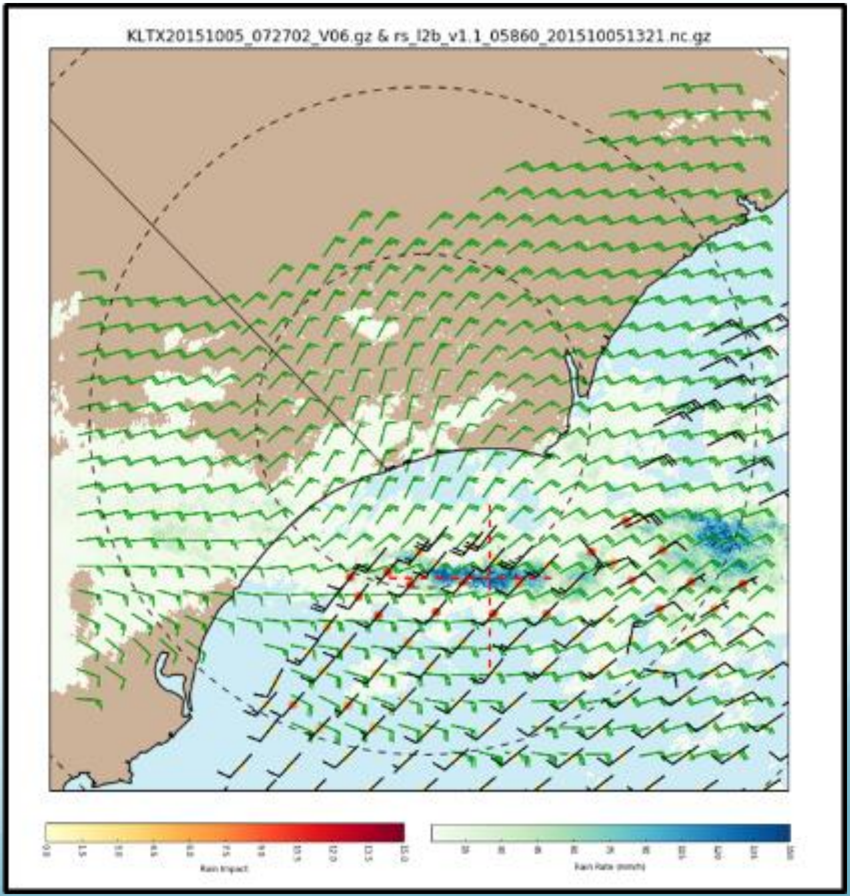


Airborne dust identified

Ocean Surface Vector Winds

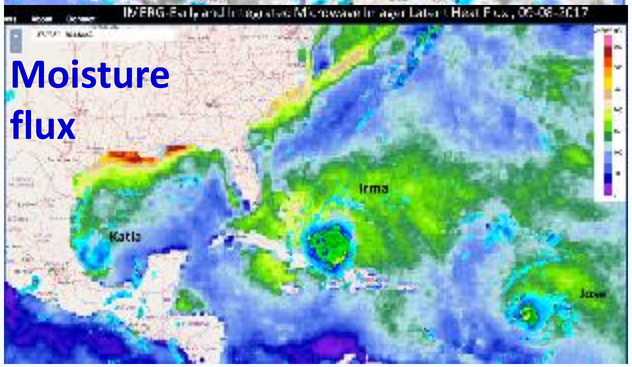
- **Objectives:**
  - Integrate ground and satellite radar estimates of precipitation with satellite-based wind retrievals to resolve mesoscale low-level flow field.
- **Technical Approach:**
  - Coastal/Island radars, GPM satellite, scatterometer, GPS-reflectometry (CYGNSS mission)
- **Future Goals:**
  - Statistical analysis of key mesoscale wind features organizing a wide spectrum of convective storms
  - Model data assimilation experiments to improve prediction of convection

Coastal radar rainfall and single-Doppler winds (green) combined with RapidScat winds (black). The radar fills in low-level wind information where satellite is sparse (heavy rain and coastal regions). Together they show convergence line fueling heavy rain.



Ocean Real-Time Surface Meteorology and Energy Fluxes from Space

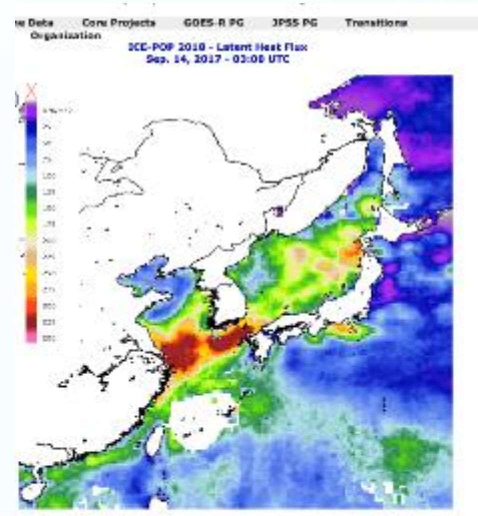
Near-real-time *global ocean surface meteorology* and heat flux estimates (25 km, hourly resolution) from GPM satellite constellation *passive microwave imagers*



Applications

Topical cyclone and other synoptic disturbances

Coastal storm systems: E.g., over Korean Peninsula ocean provides moisture flux to air transiting Sea of Japan; subsequent mountain interaction produces heavy snow.



Atmosphere

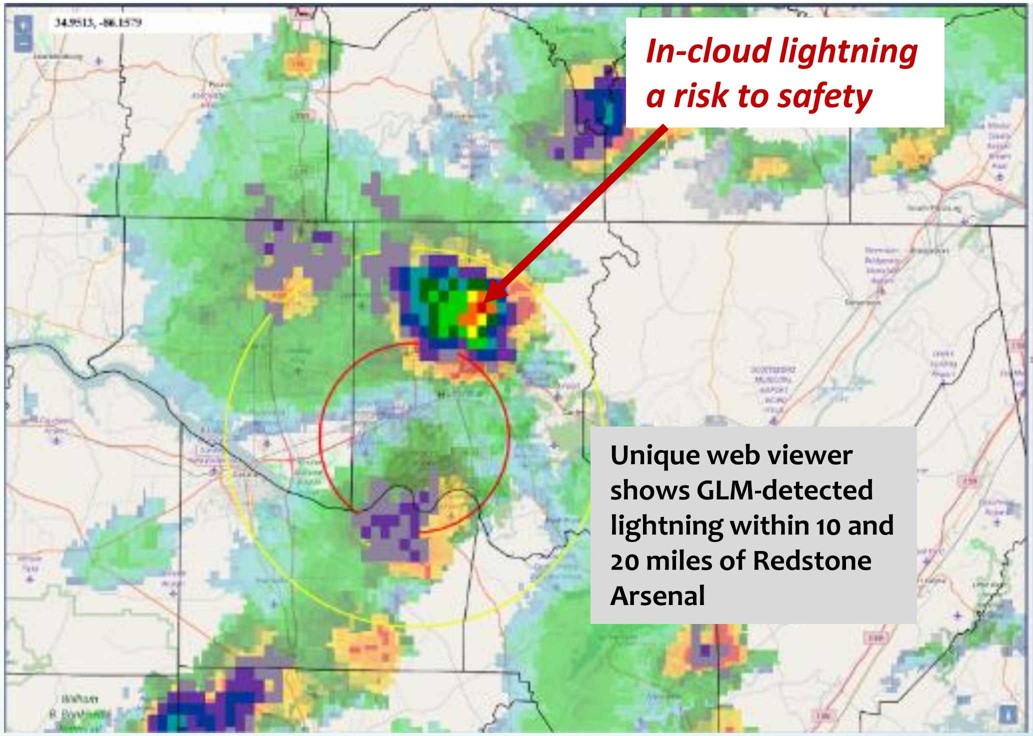
- Short-term weather forecasts can potentially be improved through use of near-real-time estimates of surface meteorology and atmosphere-ocean exchanges of heat and moisture
  - Hurricane Forecasting, Winter-weather forecasting / Air-mass modification via surface fluxes

Ocean (discussion with NRL-Stennis- potential applications with NFLUX product)

- Ocean models are forced by near-surface temperature, humidity, and wind fields
- Can be used to improve model forecasts and/or develop bias-corrected forcing

Atmosphere: Thunderstorms and Lightning

- **Transition unique total lightning data from VHF ground-based Lightning Mapping Array (LMA) and space-based GOES-16/S Geostationary Lightning Mapper (GLM) for severe weather and lightning safety applications**
- **Europeans and Japanese planning similar GLM-like lightning sensors in early 2020s with coverage in areas of international interest**
- **SPoRT expertise develops value-added products**



Precipitation Science

ESSC
Earth System Science Center

UAHuntsville
ATMOSPHERIC SCIENCE

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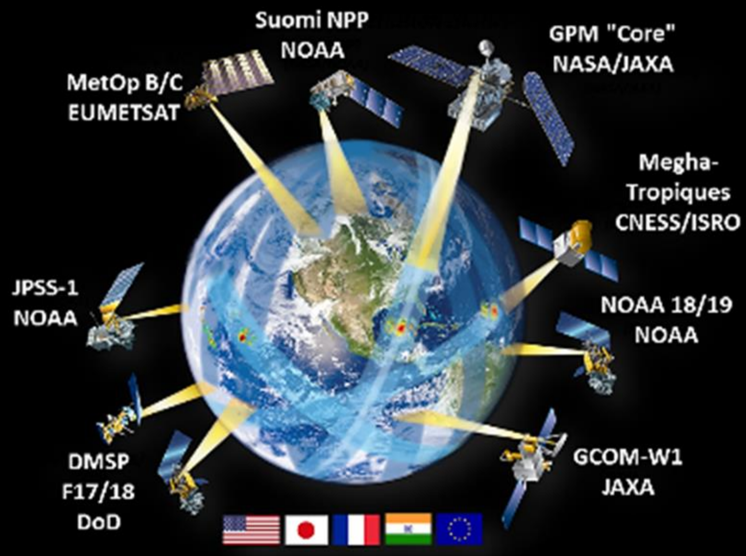
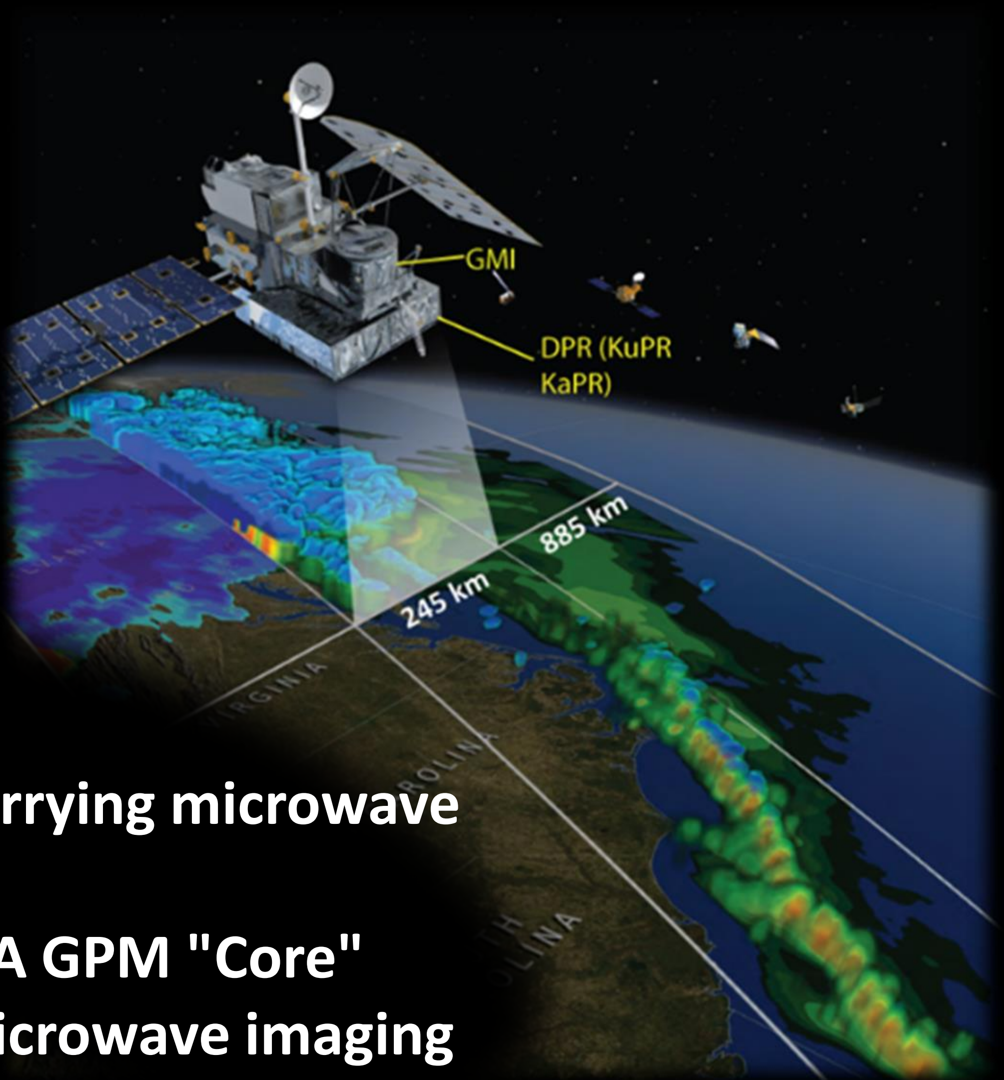




- **International constellationcarrying microwave radiometers**
- **Referenced to the NASA-JAXA GPM "Core" satellite carrying the GPM microwave imaging radiometer (GMI) and the Dual-frequency Precipitation Radar (DPR)**

The Drop Size Distribution (DSD): Fundamental to remote sensing of precipitation physics


publicly accessible pinterest.com

Your brain on "DSD"………

Common representation (Normalized Gamma Distribution)

$$N(D) = N_w \, f(\mu, D_m) \, \exp[-(\mu+4)D/D_m]$$

μ (shape parameter; *fixed at 3* for GPM algorithms)
D_m= mass-weighted mean diameter
N_w= normalized intercept (measure of drop concentration)

Level 1 Science Requirement

- **GPM Core observatory radar estimation of the Drop Size Distribution (DSD)- specifically, *D_m to within +/- 0.5 mm*. [note- no N_w requirement]**

Measuring DSD Properties: Disdrometer Capabilities

We collect and process high resolution liquid/frozen hydrometeor size distribution measurements/datasets to support a variety of precipitation science applications

Instruments

Autonomous Parsivel² Units (APU)

Two-dimensional Video Disdrometers (2DVD)

Meteorological Particle Spectrometer (MPS)

Precipitation Imaging Package (PIP)

Micro-Rain Radars (MRR)

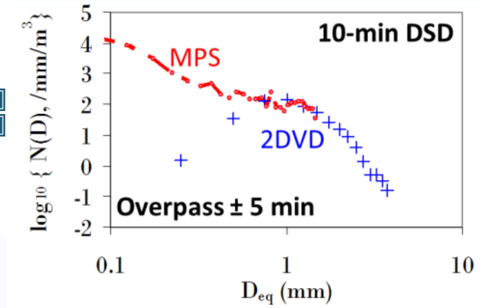
Global Field Deployments

Applications:

- Satellite and multi-parameter radar-based precipitation retrievals (e.g. NASA-GPM)
- Flight environments and sensors requirements/research (e.g., AMRDEC)
- Severe storm dynamics (e.g., UAH-SWIRL, VORTEX-SE)
- Cloud-modeling (model microphysical parameterizations; multi agency/institution)

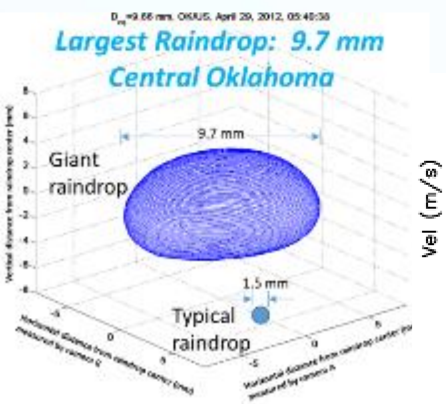
Example Measurements

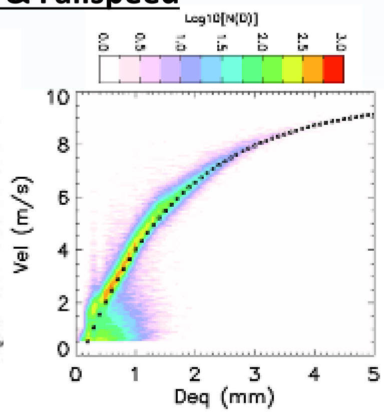
A More Complete Depiction of the Raindrop Size Distribution

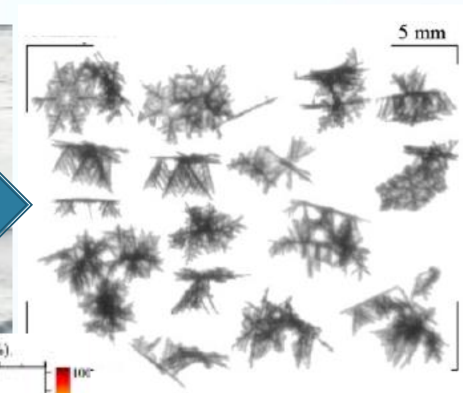


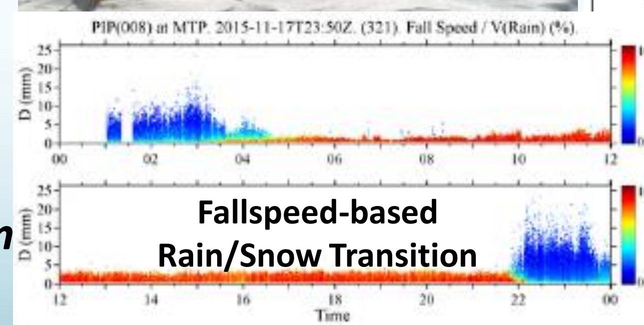
- Disdrometer limitations can mask the "truth"
- Small drops more prevalent than often specified in drop size distribution models

<u>**Particle Size, *Shape* & Fallspeed**</u>









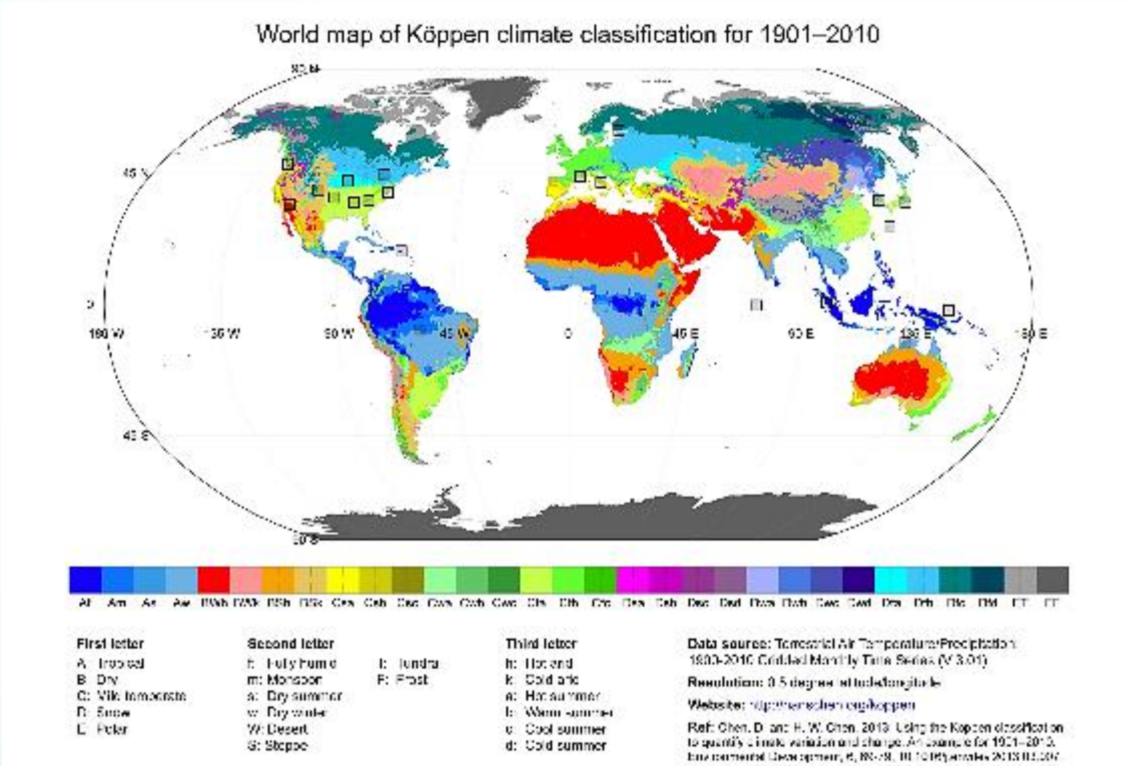
<u>**Complex Snowflakes**</u>

Scattering computation and water equivalent sensitivities

→ Implications for accurate remote-sensing involving a precipitation medium

Liquid, freezing, frozen!

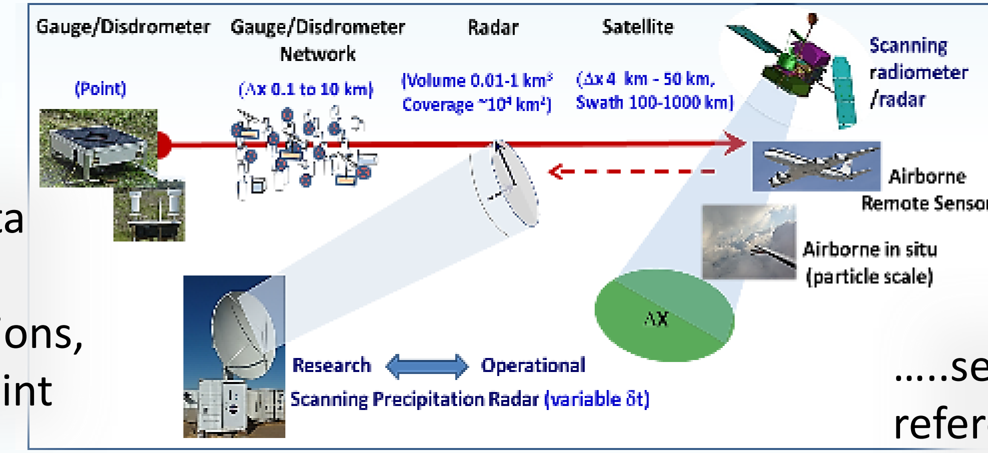
2DVD DSD Datasets Collected Around the Globe



- 20 different locations (more if APU collections included)
- 8+ of 31 climates
- ~9,500 hours of rain observations
- Primarily via NASA's GPM precipitation science satellite validation activities
- Highly accurate measurements of raindrop (also snow) size, shape and fallspeed

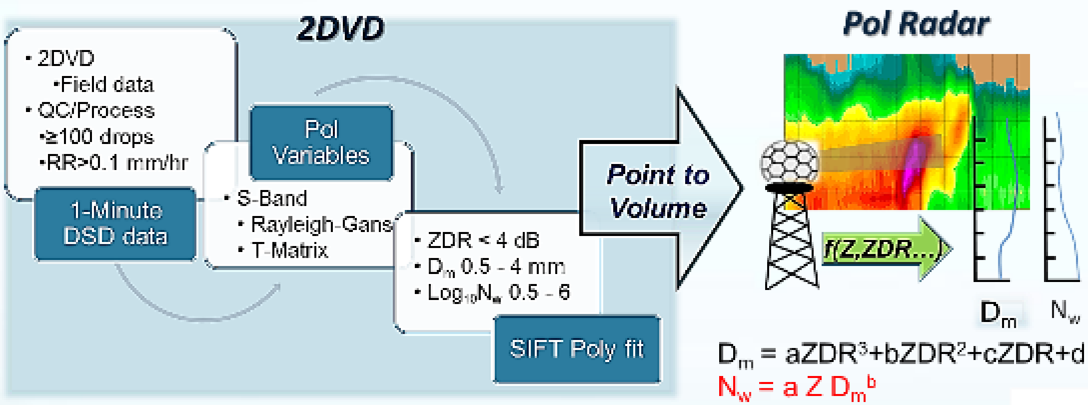
A treasure trove of highly detailed information about naturally occurring precipitation that can be used to constrain theoretical models.

Translating the DSD: Upscaling from Point to Global

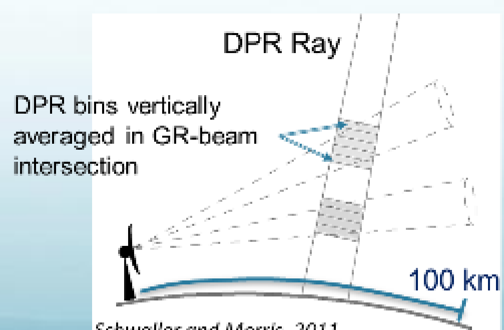


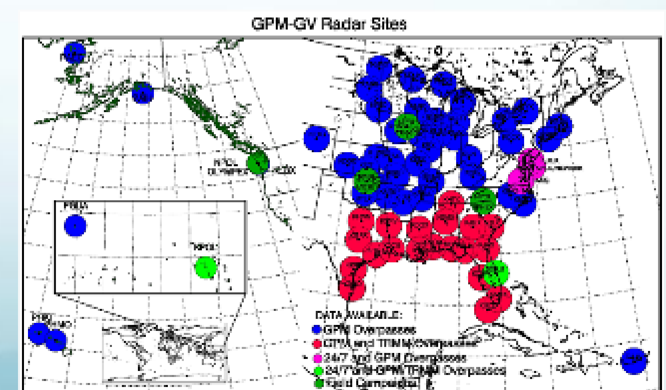
2D Video disdrometer data collected at numerous locations, regimes, and point scales……

…..serves to reference volume scanning multi-parameter radar retrievals from pulse-volumes to regional domains…..

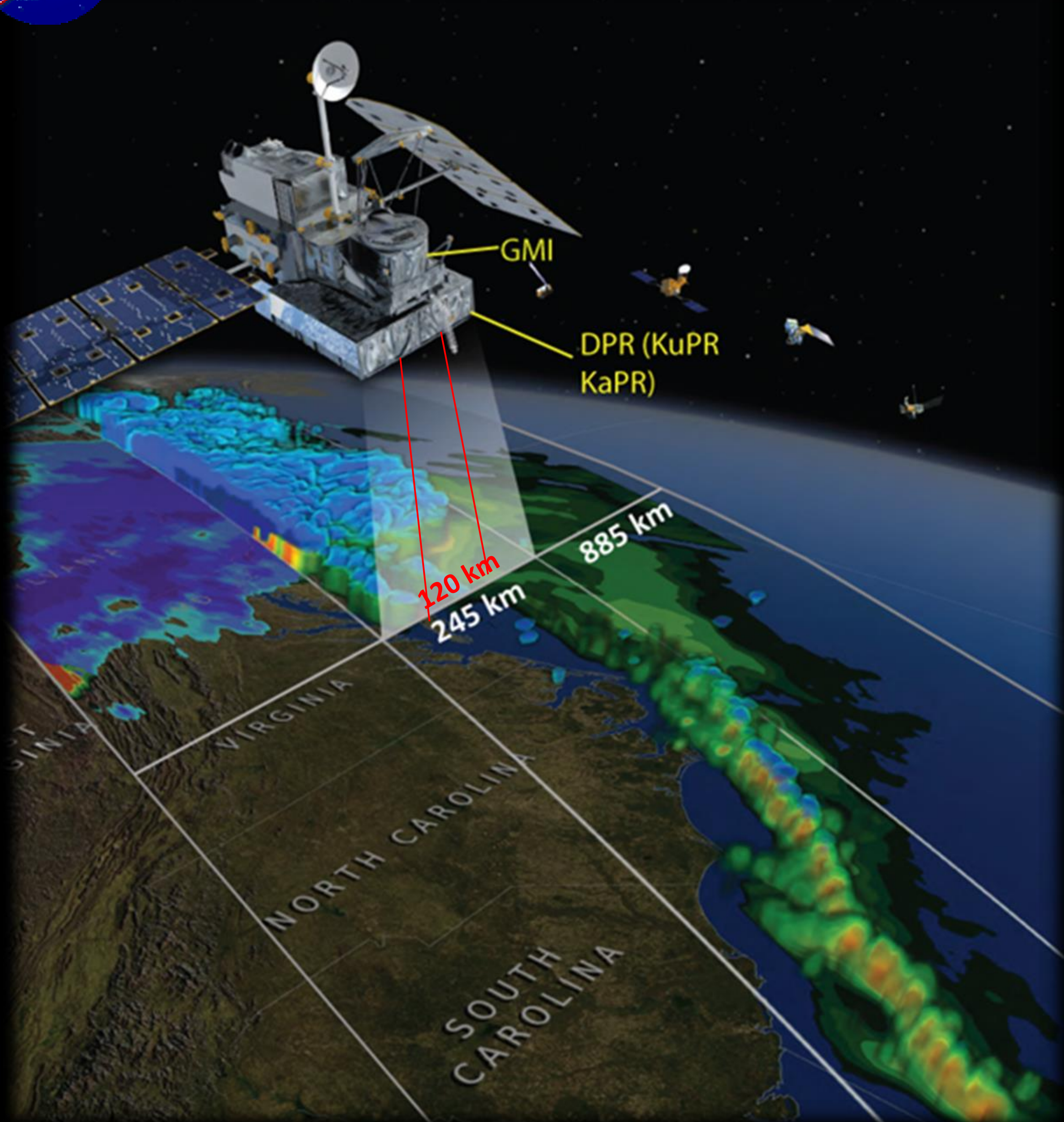


…….subsequently matched to GPM satellite footprint and continental scales …….





Application: Verifying GPM Radar-Retrieved Rain and DSD Data
Inner Dual-Frequency (MS) and Outer Single Frequency (NS) Swaths



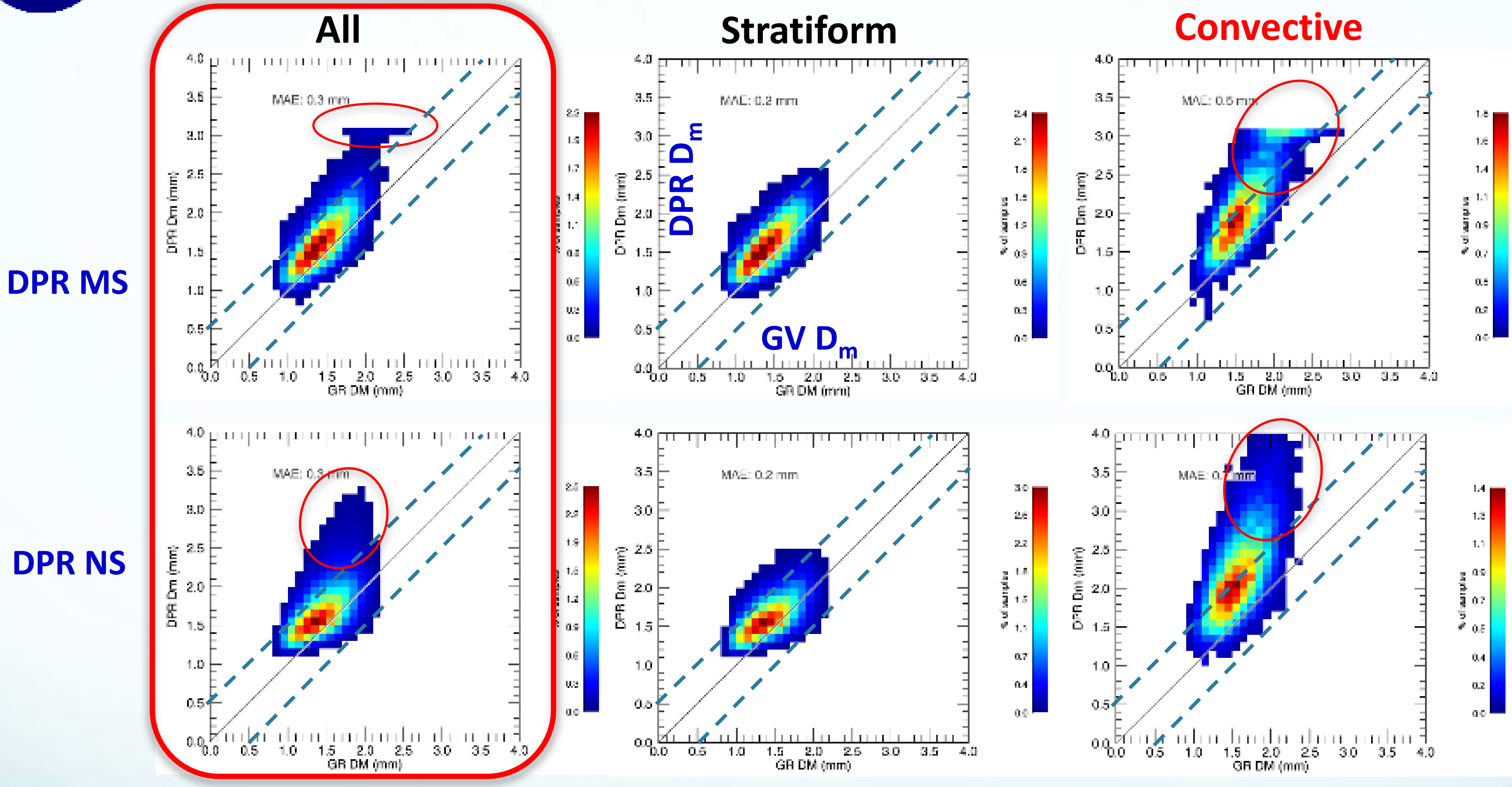
The rain rate estimate is ***driven by estimate of the Drop Size Distribution (DSD)***

Dual-frequency DSD and rain rate retrieval in MS swath- should be more accurate in light/moderate rain rates

Single-frequency retrievals in the NS swath

DPR data files combine dual and single frequency retrievals in the NS files……

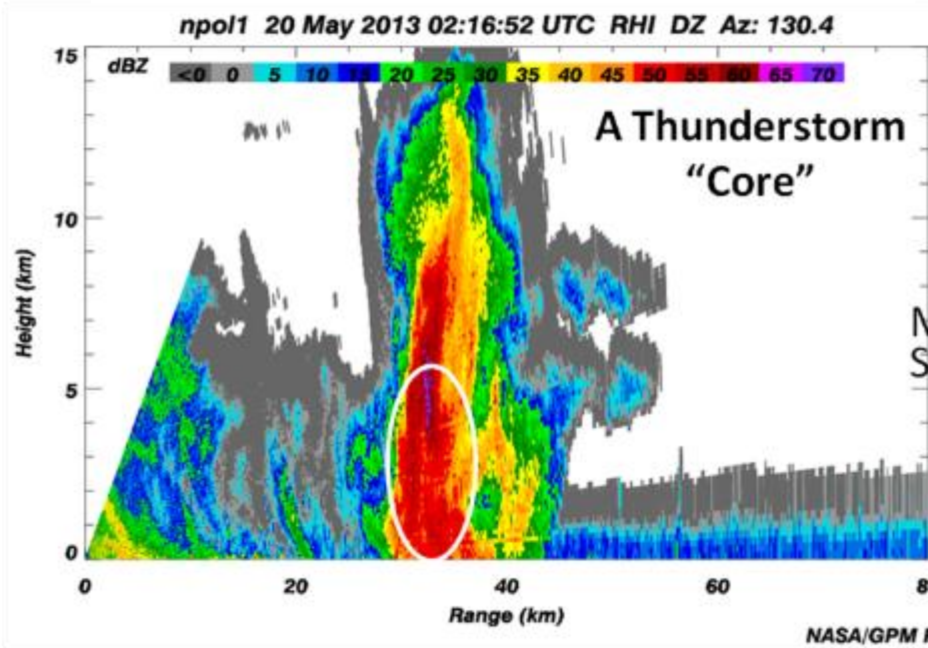
View from Ground-Validation (GV)
GPM DPR Mid (MS) and Outer (NS) Swath D_m vs. GV Radar D_m



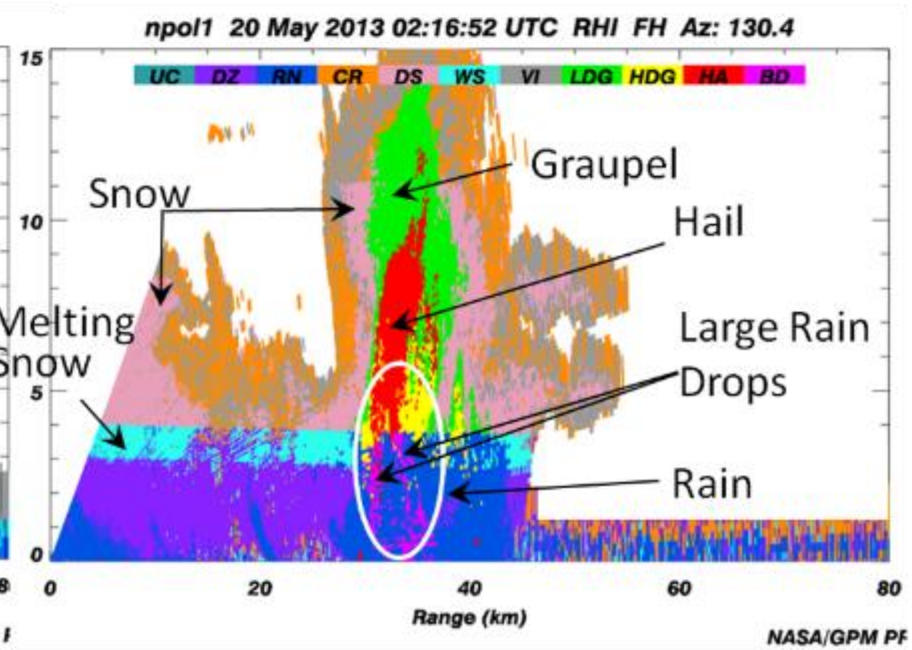
- **GPM Requirement: Core observatory radar estimation of the Drop Size Distribution (DSD)- specifically, *D_m to within +/- 0.5 mm***
- In stratiform precipitation, V5 DPR is about ~0.2 mm higher than GV
- 2ADPR Convective D_m bias is a problem (D_m ceiling at 3 mm in MS is an artifact), large positive deviation in NS creates an underestimation of rain rate……

Polarimetric Radar and Role of Ice Physics in Rain DSD
NPOL Cross-sections of Precip Microphysics

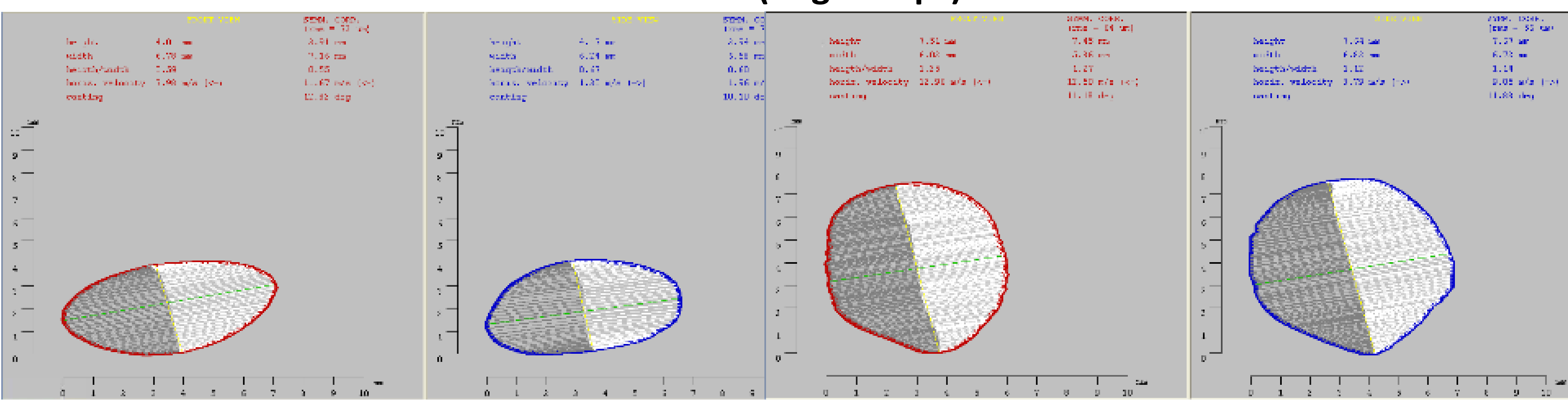
Radar Reflectivity



Diagnosed Precipitation Types



2D Video Disdrometer observes rain (large drops) and small hail mixture



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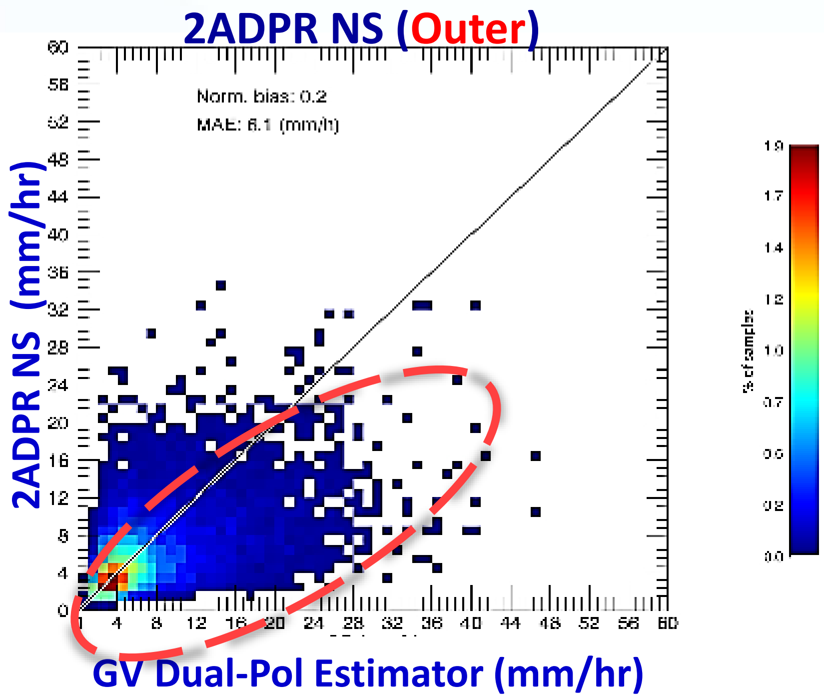
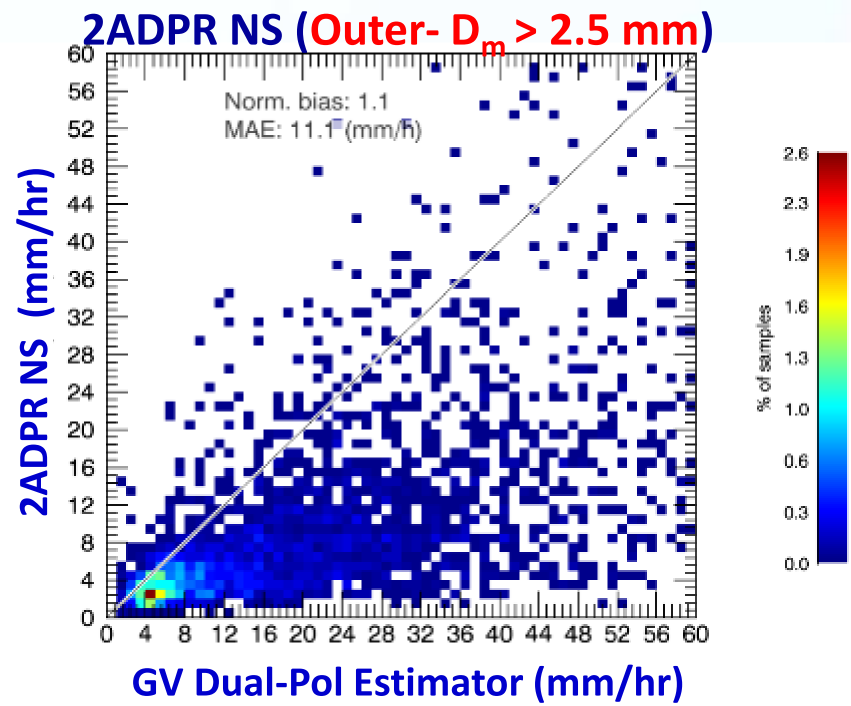
Why do we care?

DSDs impact rain rates and hence data products!

Marked low bias against GV rain rates due to DPR large drop estimates

Look for algorithm fixes in Version 6 (2018/19'ish)

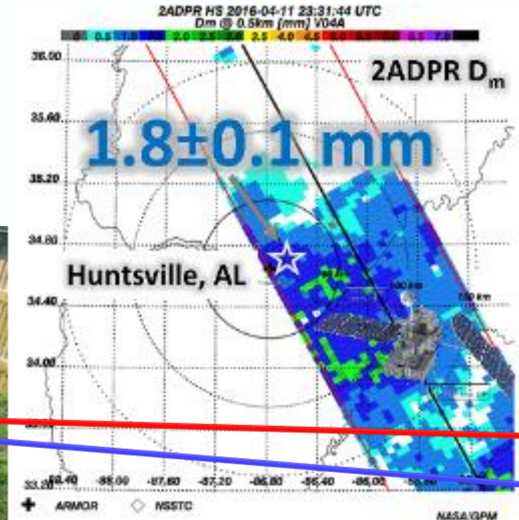




What About Light Rain and Small Drops?

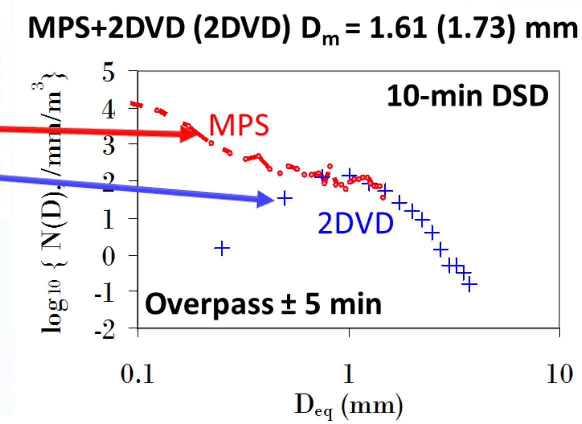
Do current DSD assumptions for GPM adequately represent the small rain drop sizes?

GPM dual-frequency precipitation radar (DPR) swath as it samples rain over Huntsville disdrometers



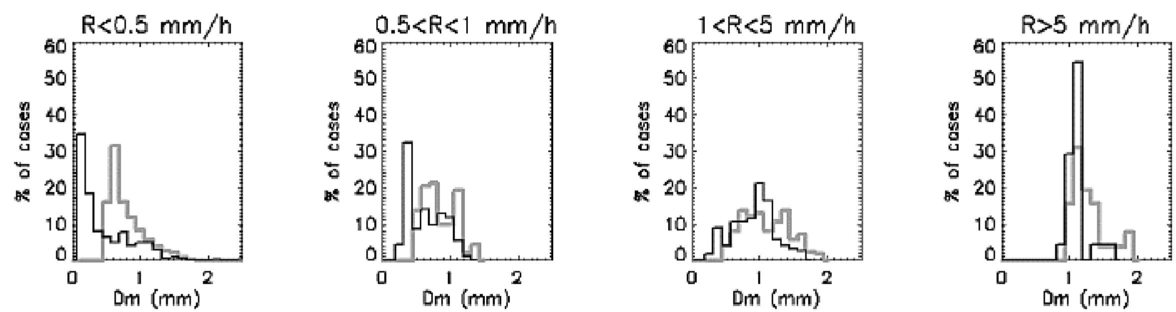
Right answer ….right reason**?**

DSD measured by GV



We do not properly represent the small-drop end (< 0.7 mm) of the drop size distribution-

Likely important for light rain estimation.



Reference: Thurai et al. 2017, JAMC

DoD Application(s): Sensor Development and Testing for Degraded Visual Environments (DVE)

DVE-Mitigation sensor development/testing require ***realistic*** environmental characterization

- *Scenario #1*: DVE-M needs a sensor capable of "seeing" through 95% of moderate rain.

  Question: What is moderate rain from a sensor perspective?

- *Scenario #2*: A vendor has a sensor that can "see" through rainfall intensities up to 10 mm/hour (0.5 inches/hour).

  Question: What needs to be produced in a test environment?

- **Problem**: To define requirements for DVE-M sensor development/testing we need to know the distribution of raindrops found in nature

Solution: Utilize global disdrometer database to categorize rainfall based on relevant metrics and define associated drop size distributions for each category

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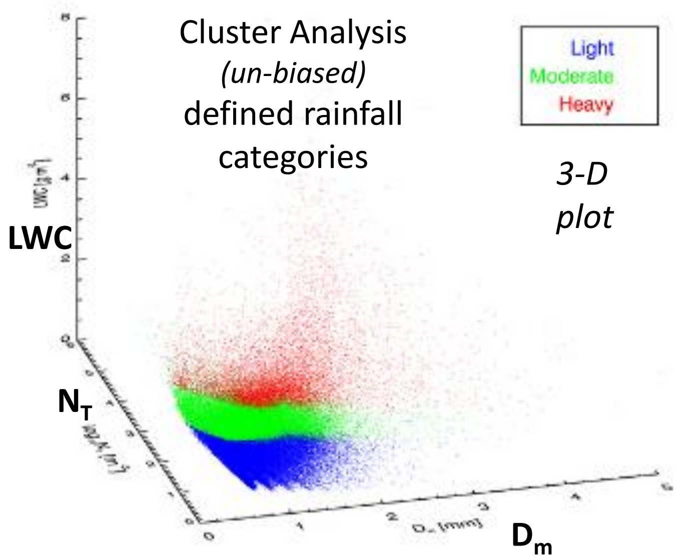
Defining rain from a sensor perspective: An Application of Precipitation Science to DVE-M

A taxonomy that defines naturally occurring rainfall characteristics was constructed from the raindrop size measurements contained in NASA's global 2DVD database



Rain Taxonomy Overview

Descriptive Rainfall Category	Defining Metric: Liquid Water Content [g m^{-3}]	Rainfall Intensity* [mm/hr]	Visibility [km]	Raindrop Diameter $\langle D_m \rangle \pm \sigma_{D_m}$ [mm]
Light	LWC < 0.09	R < 2.54	VIS > 9.6	0.9±0.3
Moderate	0.09 ≤ LWC < 0.4	2.54 ≤ R < 7.62	9.6 ≤ VIS < 2.6	1.1±0.4
Heavy	LWC ≥ 0.4	R ≥ 7.62	VIS ≤ 2.6	1.6±0.5

*Rain Intensity definitions are based on that given by the Federal Meteorological Handbook

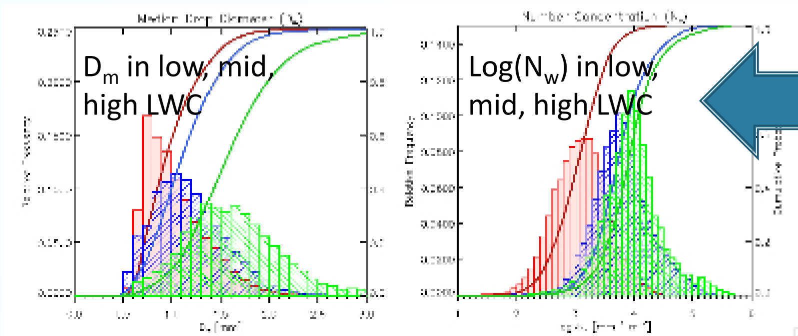
- These categories can be used for specifying sensor requirements

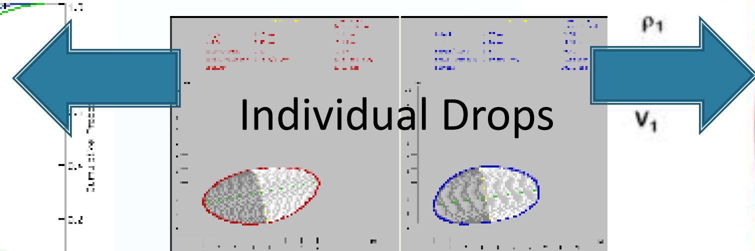
- Enables systems engineering process while providing familiar terminology for the *operational* end-users

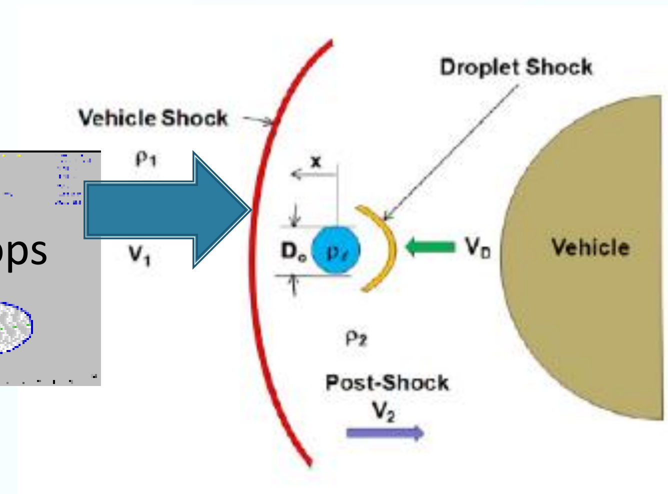
High Velocity Flight/Materials Interaction with Hydrometeors

"……withstand flight through natural adverse environments such as rain, ***accurate ground test protocols are required***……….work remains in order to develop material damage models of sufficient accuracy to estimate the true real-world performance of flight vehicles in adverse natural environments." (Moylan et al., 2013!)

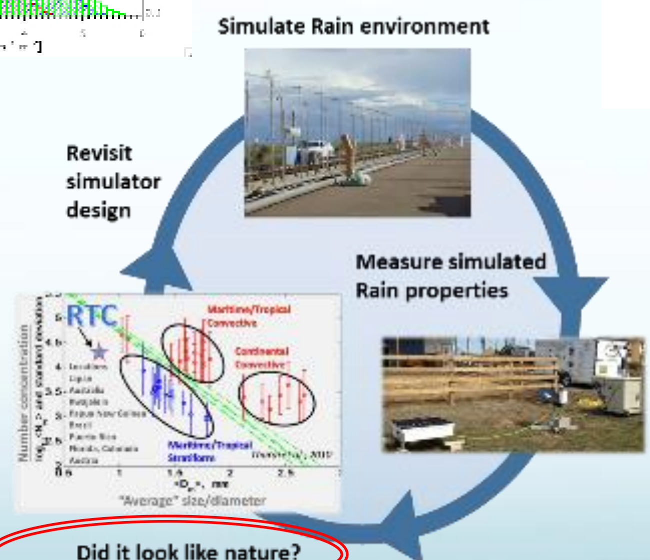
Bulk distribution behavior







Rain simulation and direct testing….

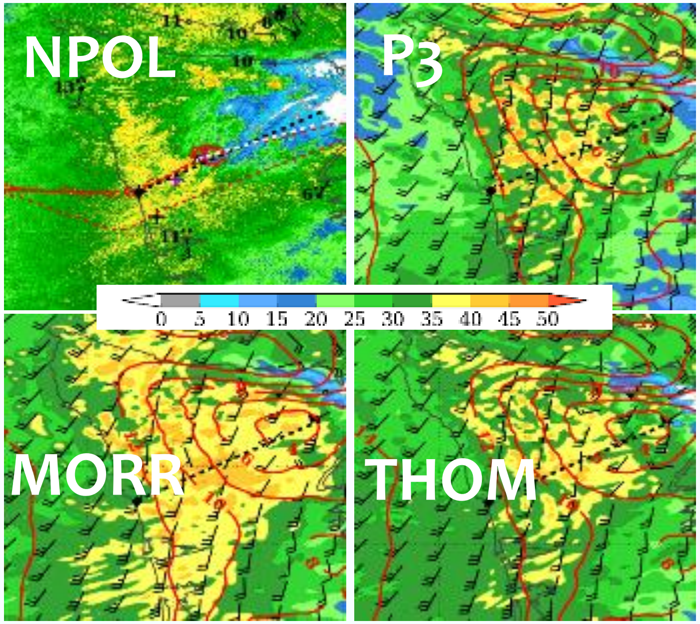


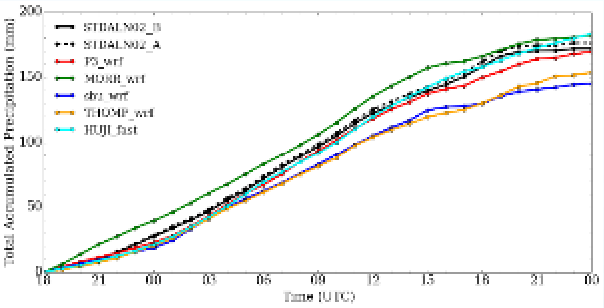
Modeling vehicle interaction…

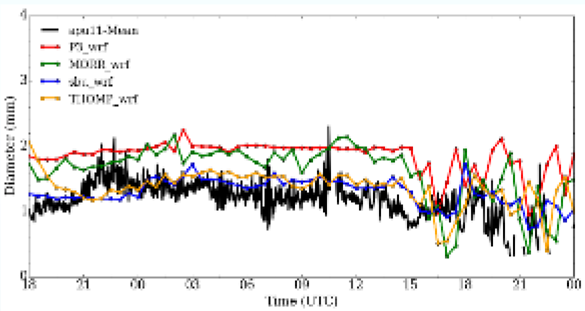
More extensive NASA DSD measurement data in multiple environments- ground, airborne and space-based provide new information to characterize "natural" hydrometeor behavior

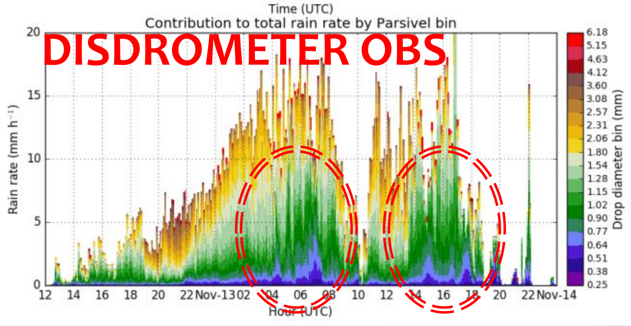
Hydrometeor Observations for Validating Cloud Models

- **Field radar and disdrometer data validates & refines cloud microphysical schemes in numerical models.**
- **Simulations show reasonable comparison to radar.**
- **Predicted Particle Properties (P3) scheme in closer agreement with obs, but raindrops too large.**
- **Rain drop sizes in Thompson scheme are similar to obs but the scheme under predicts precipitation.**

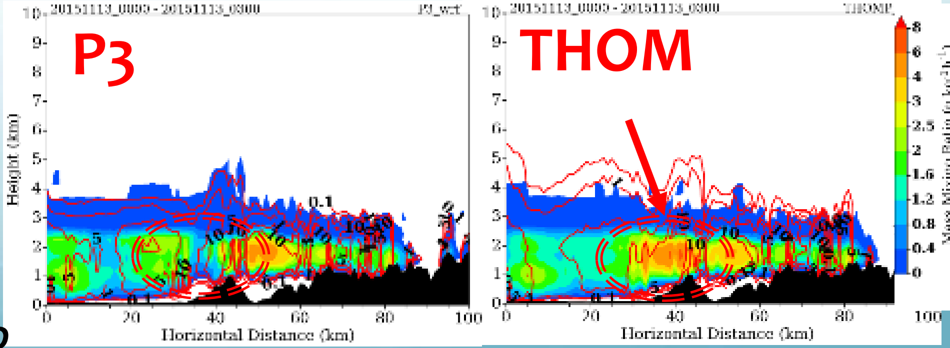






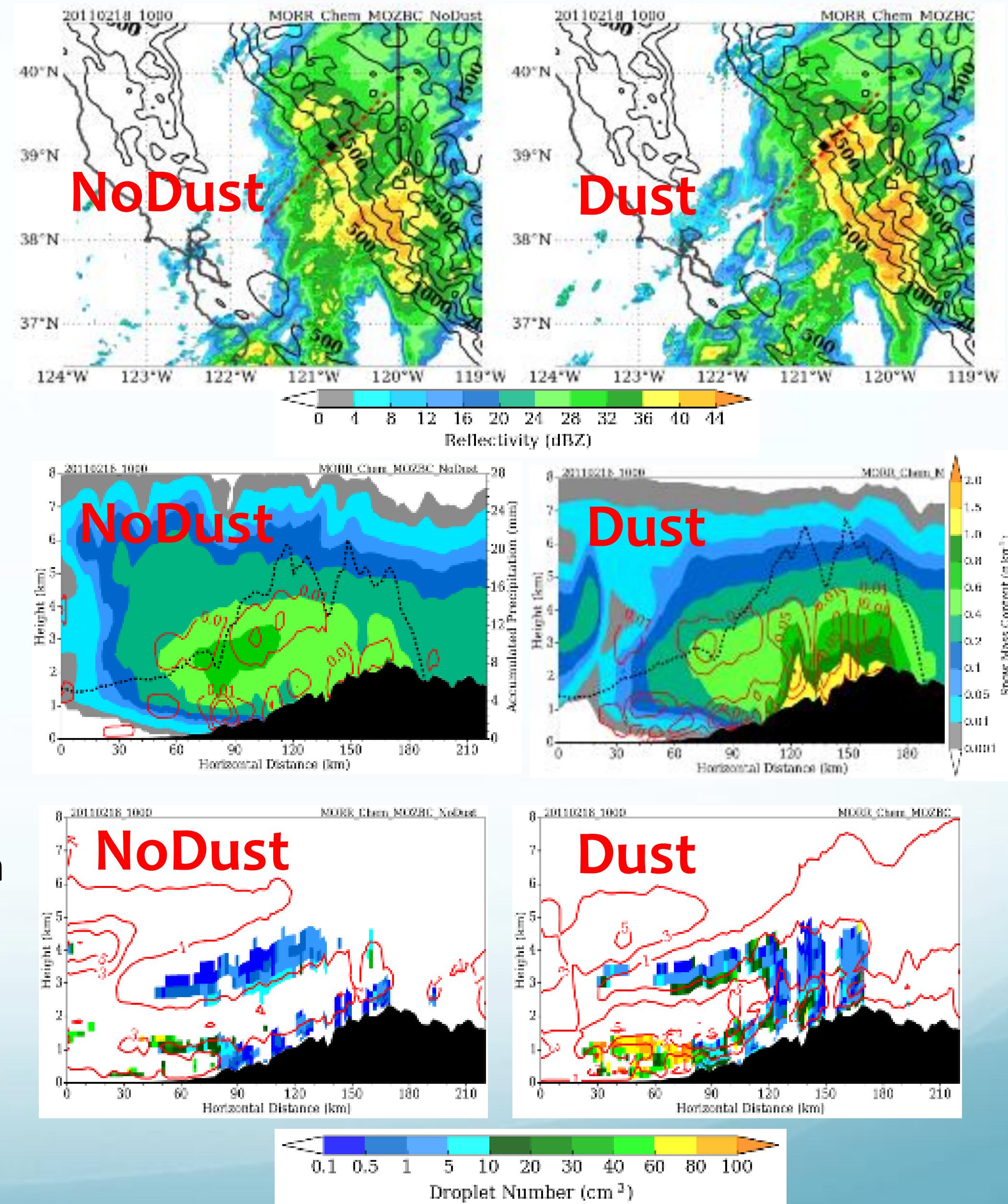


- **Warm rain processes along windward slopes in Thompson scheme leads to smaller rain drops**
- **Cold rain processes in P3 leads to larger rain droplets.**



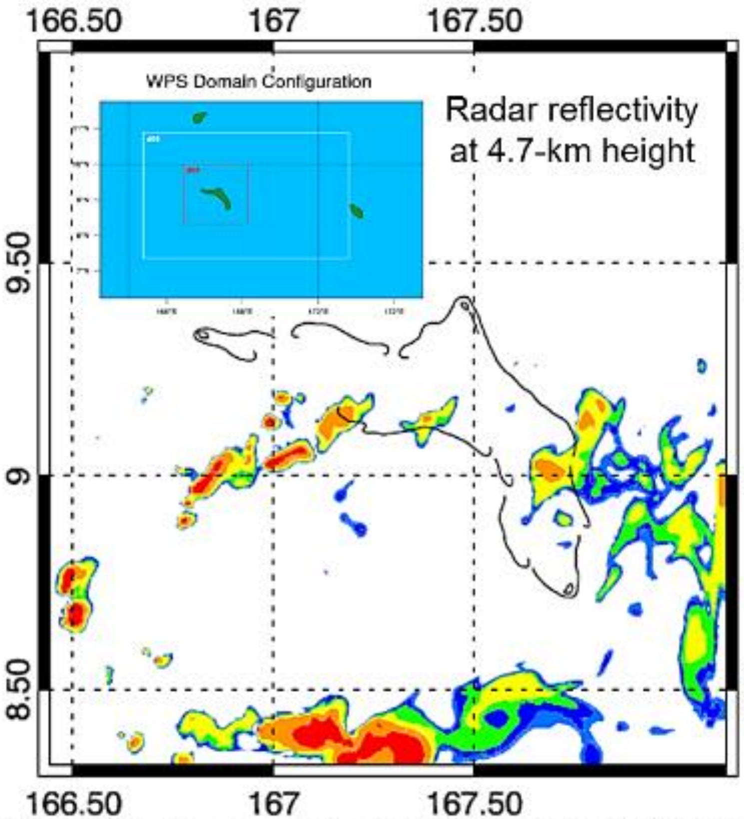
Modeling Aerosol-Cloud-Precipitation Effects

- **WRF-Chem for long-range (cross-Pacific) transported dust aerosols**
- **Control (CTL) and experimental (EXP) runs were identical, except dust included in EXP run.**
- **Snow mass and precipitation significantly larger across the higher terrain of the Sierra in the EXP run**
- **Efficient CCN activation of dust in the EXP run leads to an increase in cloud water, and consequently, precipitation in higher terrain.**
- **Future work needs to treat dust as IN instead of CCN**



Weather Research and Forecasting Modelling over Kwajalein Atoll

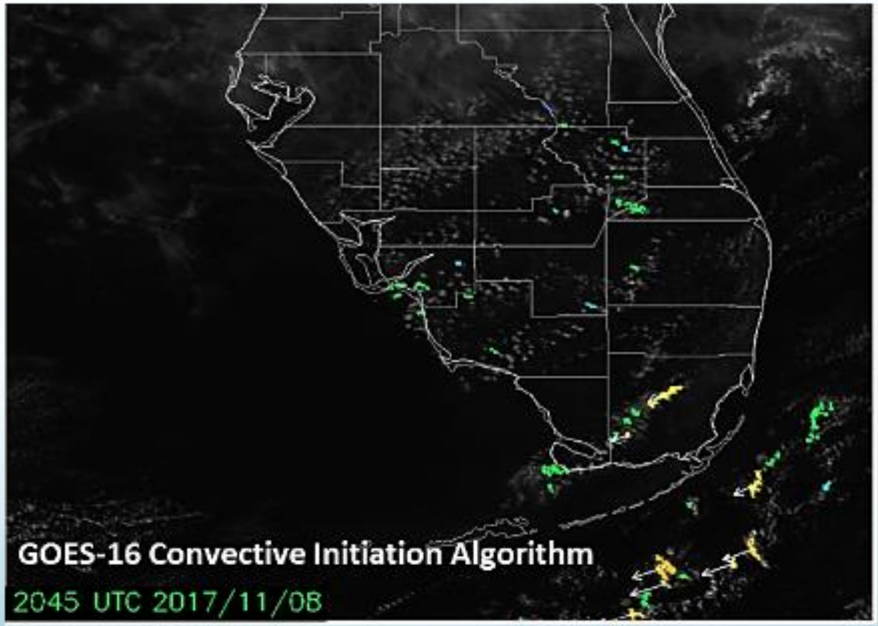
Convective Storm Prediction & Nowcasting



WRF 24-h Forecast at 0000 UTC 2014-12-04
WSM3 Microphysics & YSU PBL

In 2014-2015, developed a WRF modeling and 3DVAR radar data assimilation capability for CFDRC in support of defense operations over the Kwajalein Atoll.

Assisted CFDRC on development of radar and geostationary satellite based methods to estimate convective storm coverage and predict new convective storm development.



Prof. John R. Mecikalski, Dr. Xuanli Li
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Thanks!

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