Science and the Path from Here to There

Walter A. Petersen, Chief
Science Research and Projects Division, NASA, Marshall Space Flight Center

“A good reason to stick around and get your Ph.D. at CSU is that you never know where that Ph.D. is going to take you…….but usually it’s somewhere exciting!”

Prof. Bill Gray, ca. ~1995

MSFC Science Research and Projects Division : Research Spanning the Universe

Astrophysics: ***Origins and Physics of the Cosmos***

- Black Holes, Neutron Stars, Nebula, and Pulsars in the X-ray
- X-ray grazing incidence optics
- Gamma-ray bursts, time-domain/multi-Messenger
- High-energy particles and sources

Science Test and Technology Development: ***Enabling the next generation science missions***

- X-ray and Cryogenic Test Facility (XRCF)
- Stray light test facility
- Normal Incidence optics (UVOFIR) mirror technology development

Science Project management

- Management of science flight missions, instruments, and supporting projects.
- Pre-formulation project management in proposal phases
- Transform to Open Science (TOPS) Project Office

Heliophysics: ***Understanding the Sun and its impact on the solar system.***

- Solar Transition Region and Magnetic Atmosphere
- Thermal Plasma/Plasmasphere Modeling, Analysis, and Instrument Development
- Space Weather: Ionospheric disturbances, R2O/O2R

Planetary Science: ***Science of the Moon, Mars and beyond***

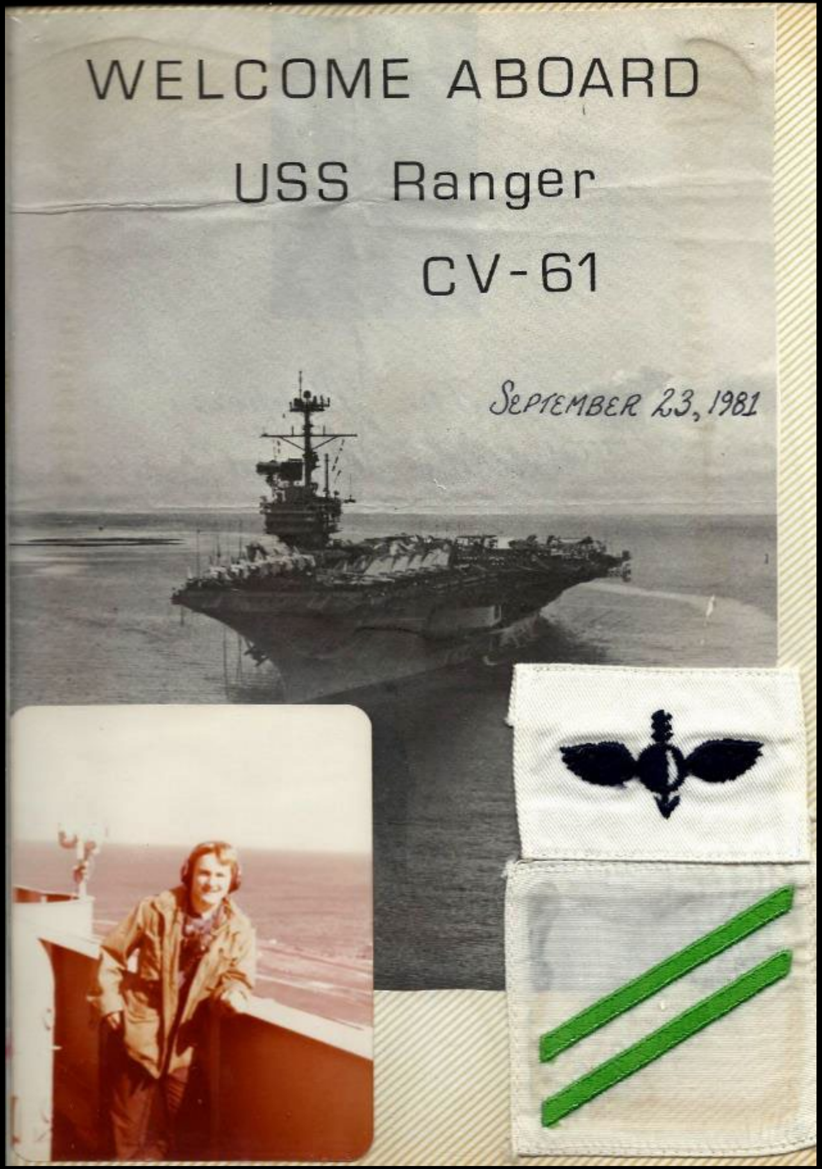
- Lidar Planetary Terrain Mapping and Navigation
- Planetary Surfaces and Interiors
- Science Integration with Human Exploration Capabilities

Earth Science: ***Understanding Earth - Improving life on Earth***

- Weather, Energy and Water Cycle, Surface Processes, Atmospheric Modeling
- Lightning physics and remote sensing
- Research transition to operations (SERVIR, SPoRT, Disasters)
- Data Science, Informatics, Advanced Concepts (IMPACT, SNWG, VEDA, CSDA)

We all started somewhere…….

Find ways to pursue an interest…….

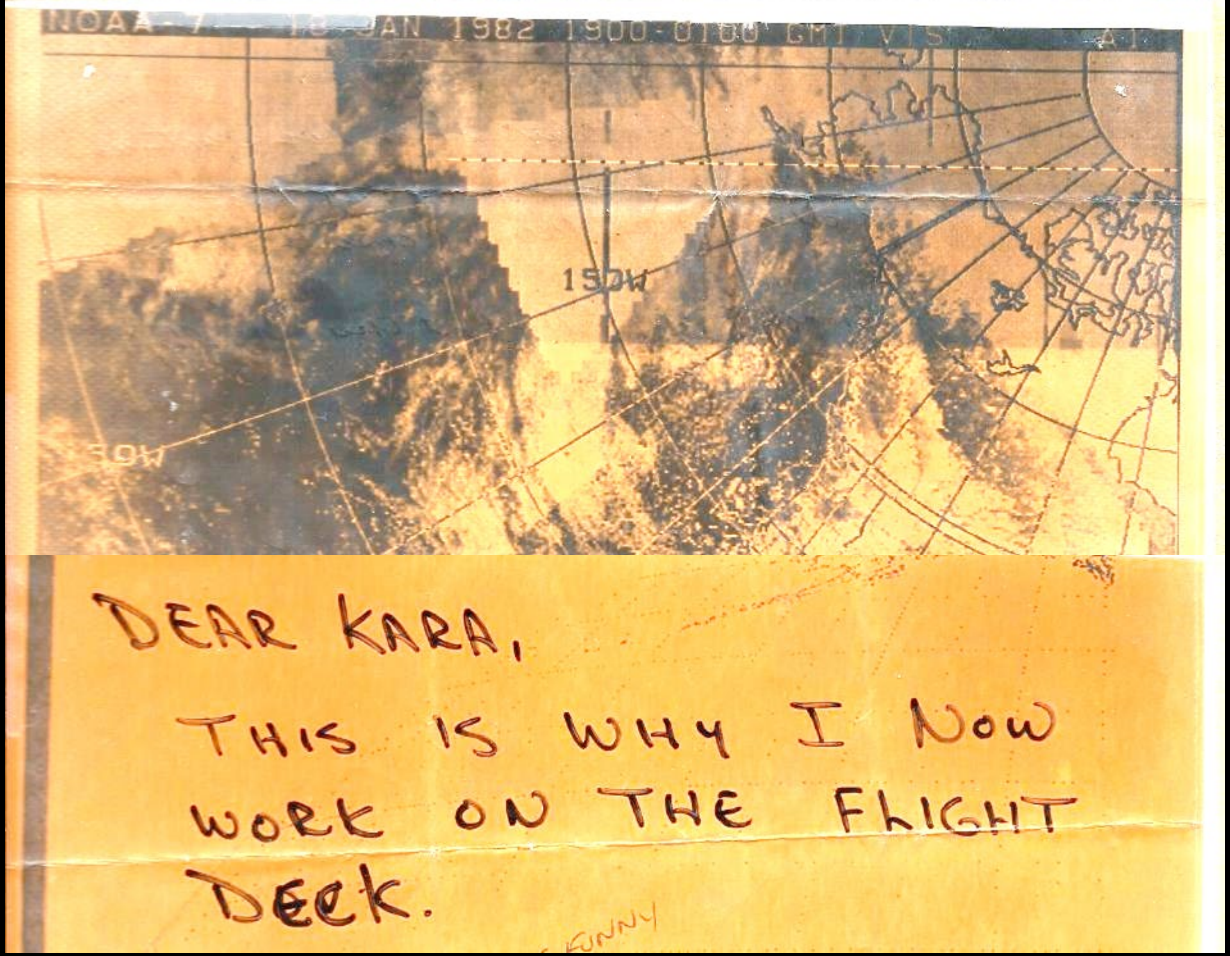


WELCOME ABOARD

USS Ranger

CV-61

September 23, 1981



DEAR KARA,
THIS IS WHY I NOW WORK ON THE FLIGHT DECK.

FUNNY

…..be properly motivated to continue learning………

Early science motivation ………….

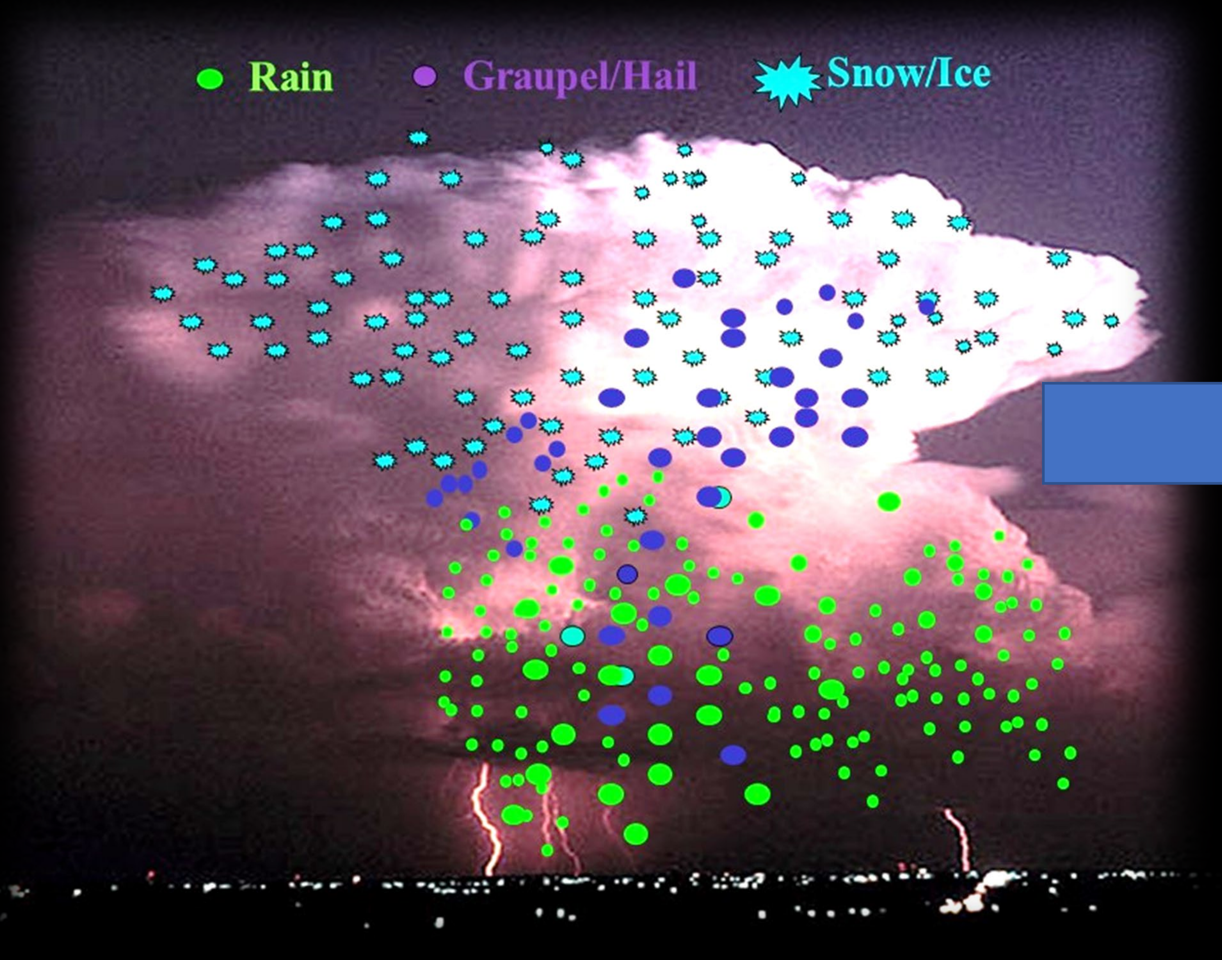
Military and Civil weather observations (Met-Tech.) vocational background………..

Undergrad Math/Physics……And an influential article by Earle Williams in 1988…….

"Although it has been known for two centuries that lightning is a form of electricity, the exact microphysical processes responsible for the charging of storm clouds remain in dispute"

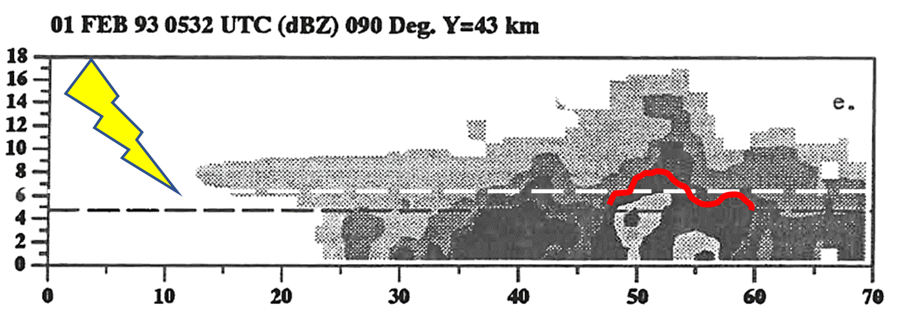
(Williams, E.R., 1988: The Electrification of Thunderstorms, Scientific American, 259, 88-99)

The CSU "Experience": Study of Cloud Electrification and Precipitation Process Variability Using Field Observations from Land and Sea, and Global Satellite Observations



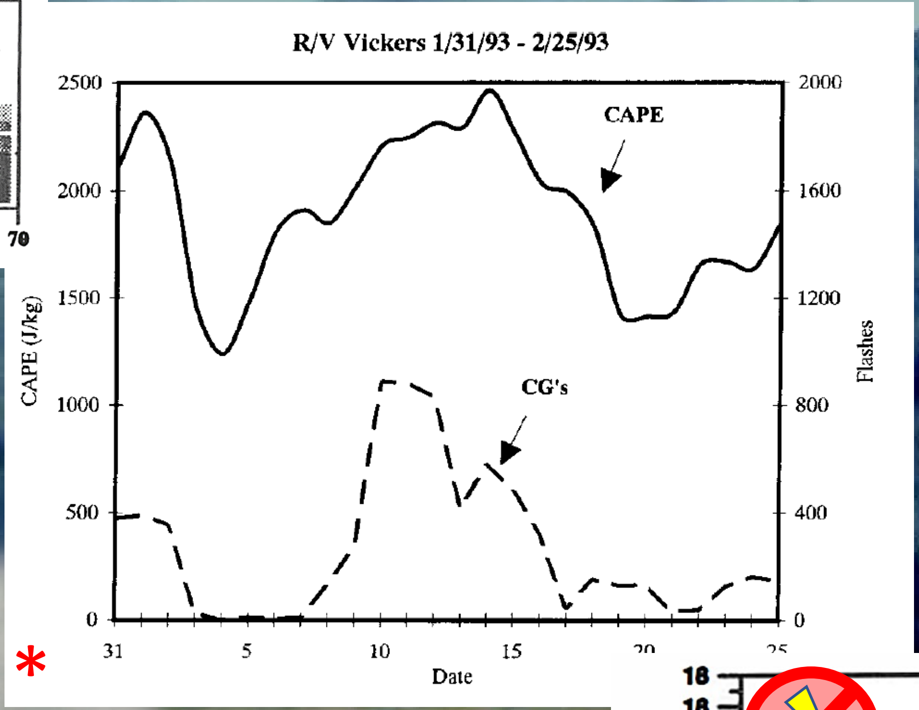
Foundational instrument and platform use

Electrified Convection over W. Pac. Warm-Pool
Convective Structure, Dynamics, and Environment Controls



Key component of Dissertation (1997) related papers:

Petersen et al., 1996, Petersen and Rutledge, 1998, Petersen et al., 1999



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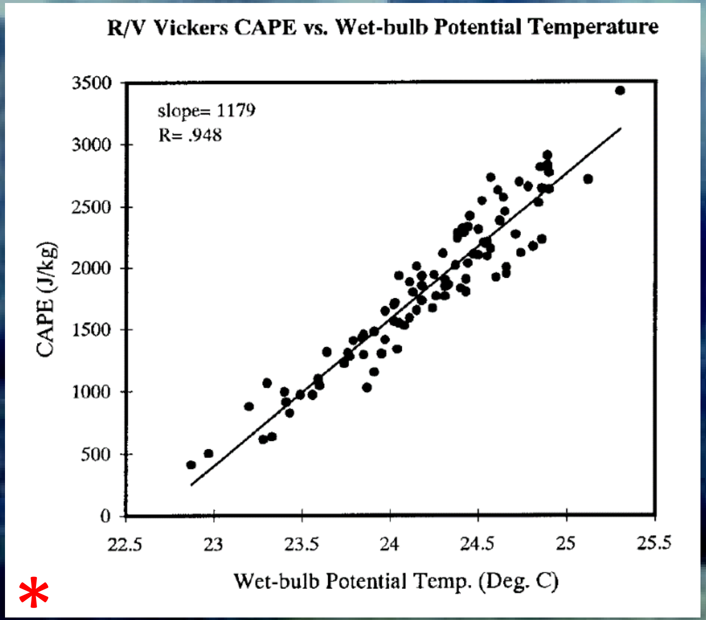

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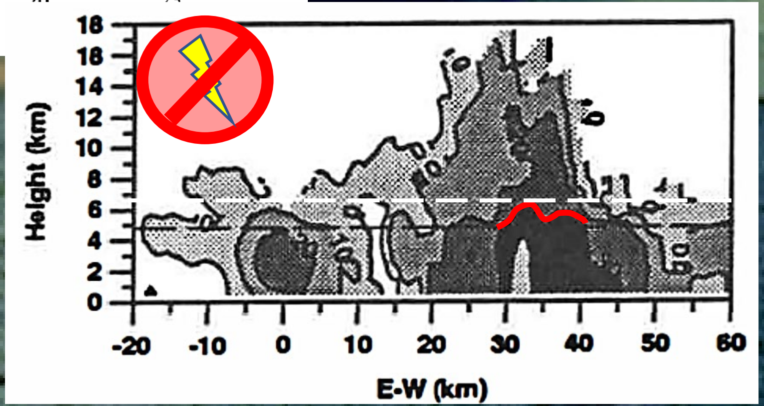
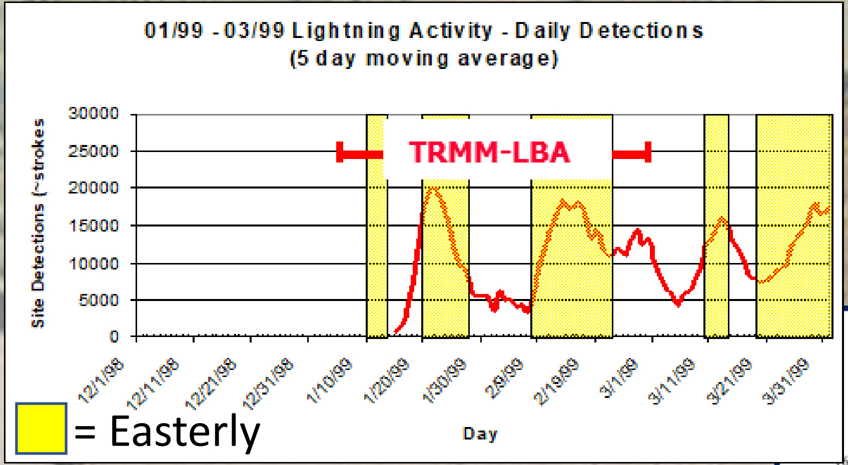
R/V J. Vickers with MIT C-band Radar



Petersen et al., 1996, Cloud to Ground lightning observations from TOGA COARE: Selected results and lightning location algorithms. Mon. Wea. Rev., 124, 602-620. DOI: https://doi.org/10.1175/1520-0477(1999)080<0191:MAROOT>2.0.CO;2

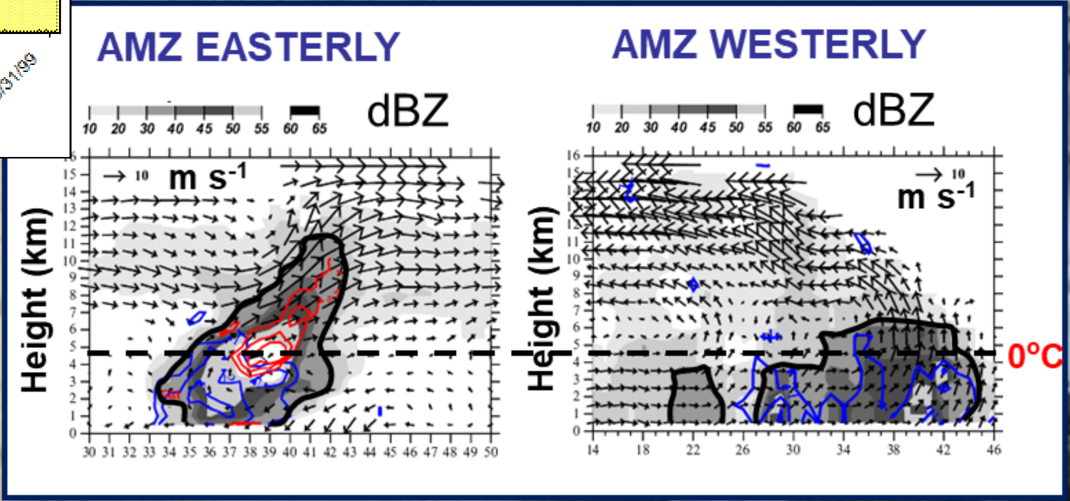
TRMM-LBA: Convection over the SW Amazon

- **Easterly and westerly regimes**



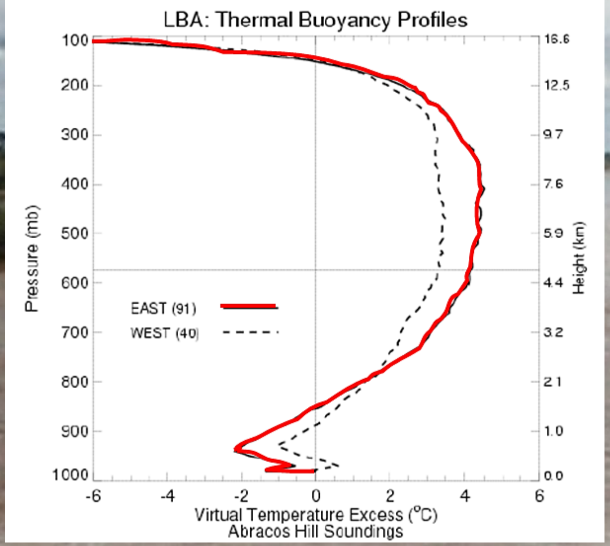
S-POL Radar

Research AC



- **Easterly- “break”-like, deep electrified convection, robust ice processes**
- **Westerly- monsoon-like, deep weaker electrified convection, reduced ice process**

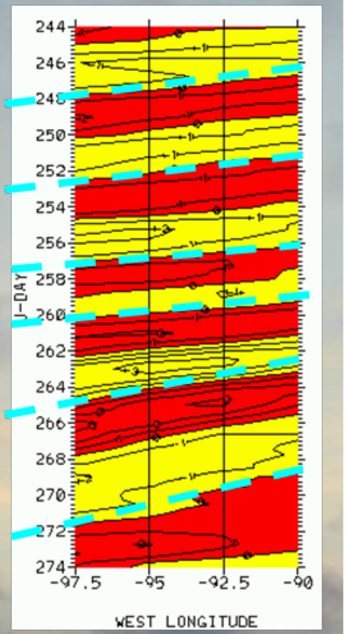
Synoptic modulation of the thermodynamic environment



Cf., Petersen et al., 2003, Cifelli et al., 2002, Stith et al., 2002, Silva Dias et al., 2007

EPIC 2001: Electrified Convection over East Pacific Warm-Pool Convective Structure, Dynamics, and Environment Controls

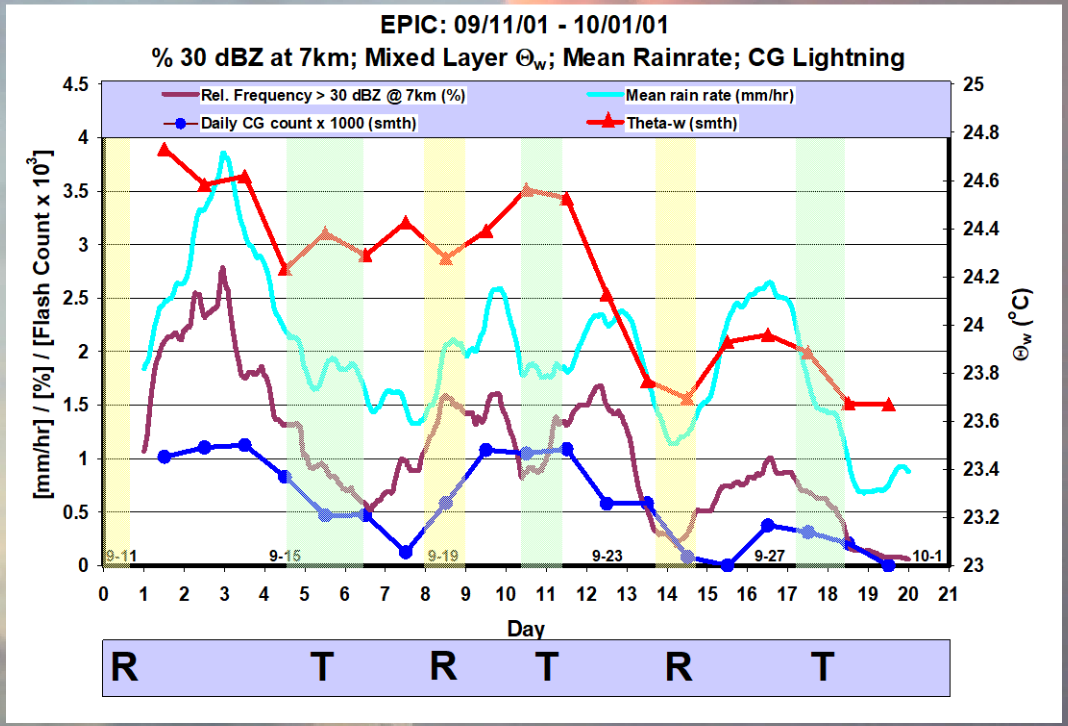
BP Filtered V-wind

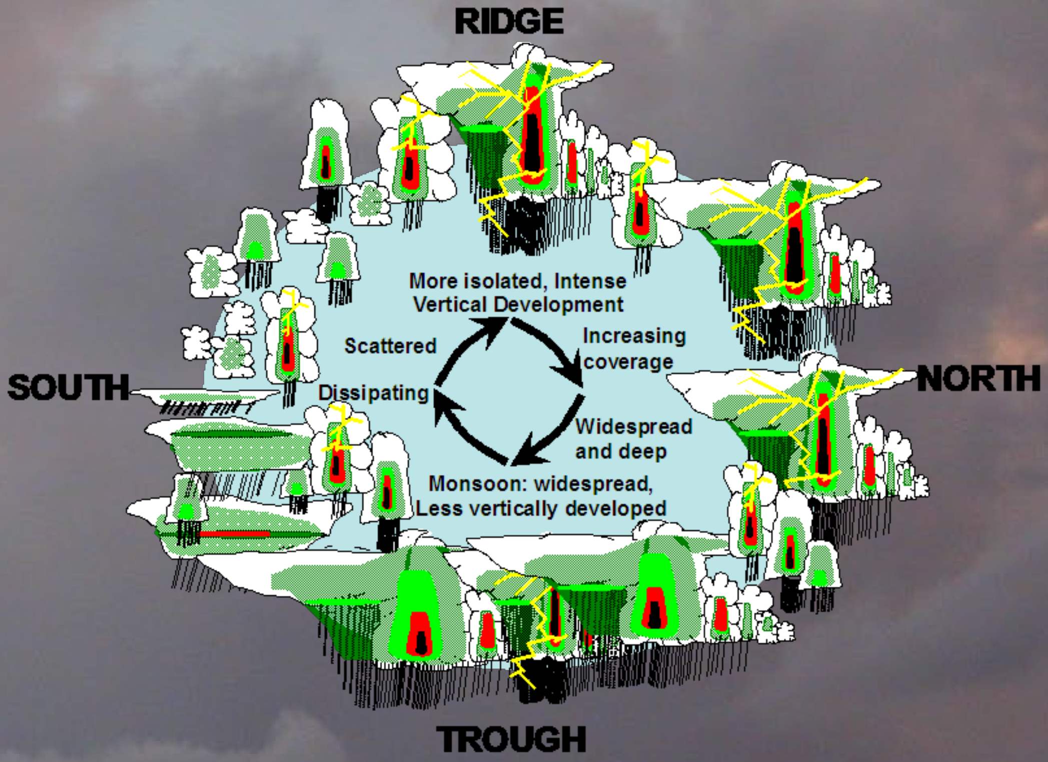


- - - = phase line

EPIC: 09/11/01 - 10/01/01

% 30 dBZ at 7km; Mixed Layer Θ_w; Mean Rainrate; CG Lightning



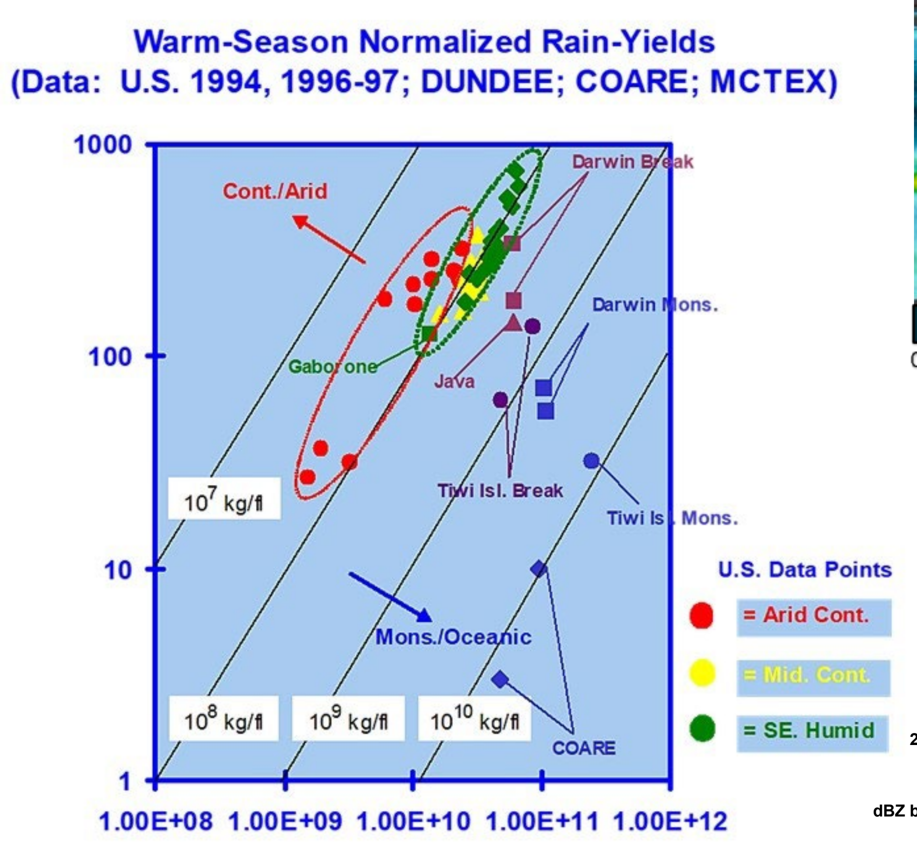


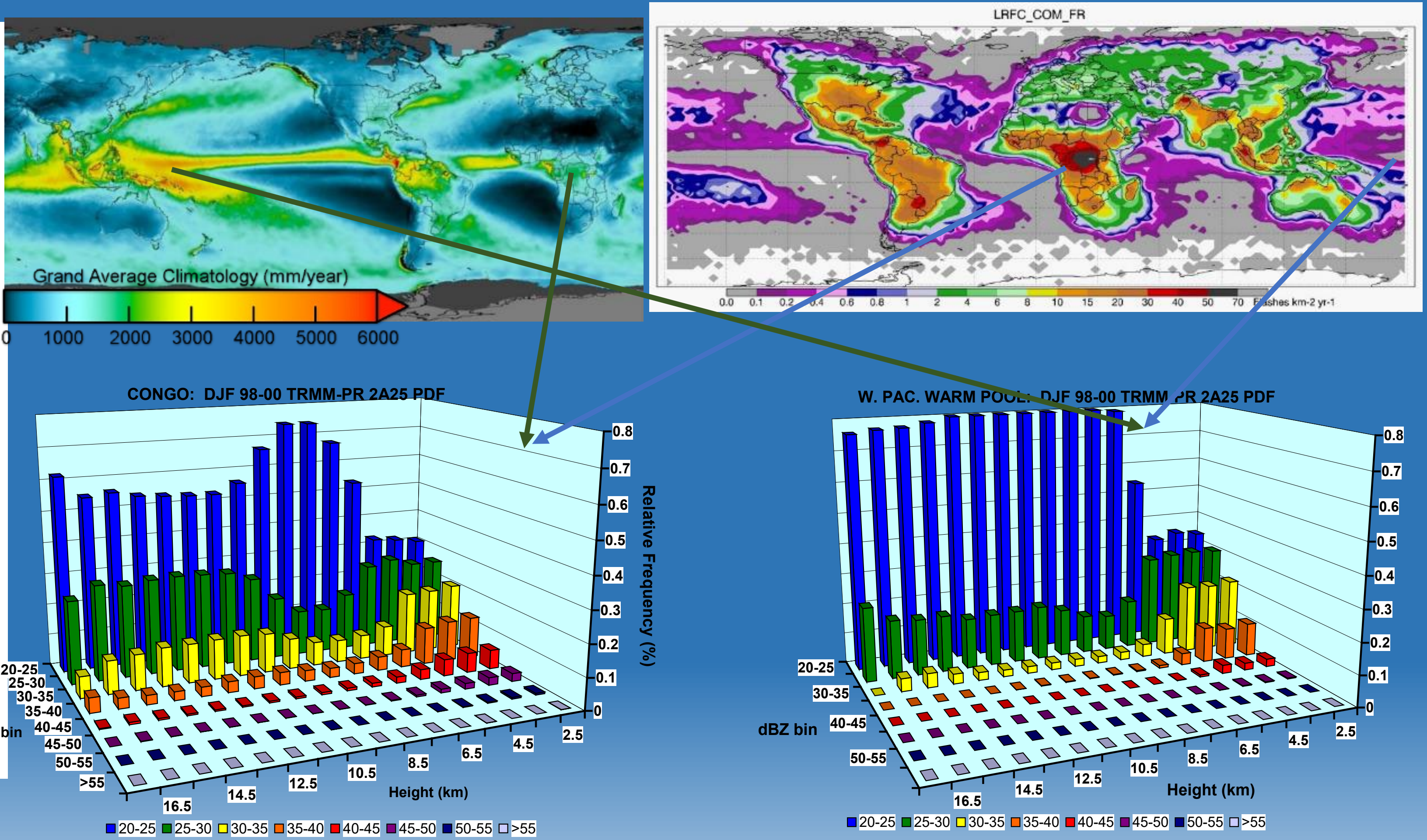
R/V Ron Brown
C-Band Radar + 6/day Soundings

See also Petersen et al., 2003, Raymond et al., 2004

- Later EPIC work spurred similar AEW studies via TRMM! cf. Lepert and Petersen 2010, Leppert et al. 2013a,b)

Global perspective: Convective precipitation regional process regimes?





Regional lightning and rainfall: Regime-varying warm vs. cold (ice) precipitation process can be discerned

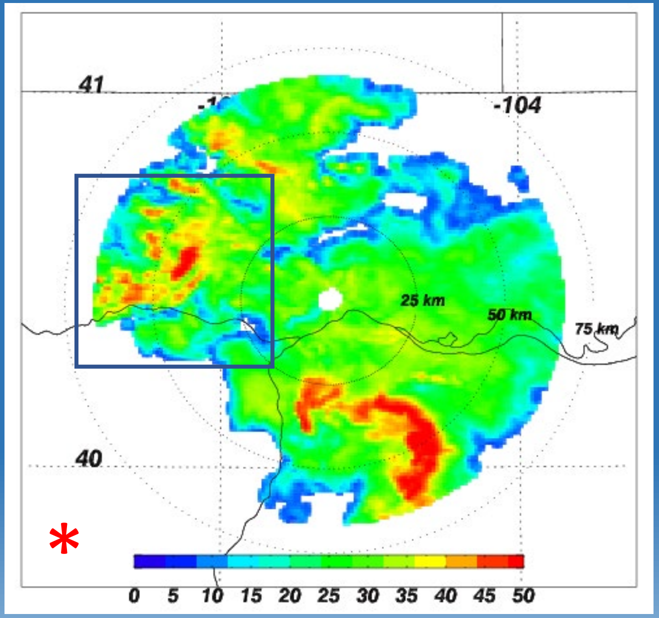
Also see:
Petersen, W. A., and Rutledge, S. A. (1998, 2001), Petersen et al., 2005, Boccippio et al. 2005)

A Local “Driving” Event: The Fort Collins Flash Flood of July 28, 1997

Opportunity: Polarimetric radar study of coupled cloud, precipitation, and electrical processes in the context of environment, precipitation, and lightning production for a tropical-looking (monsoon) storm over FCL!

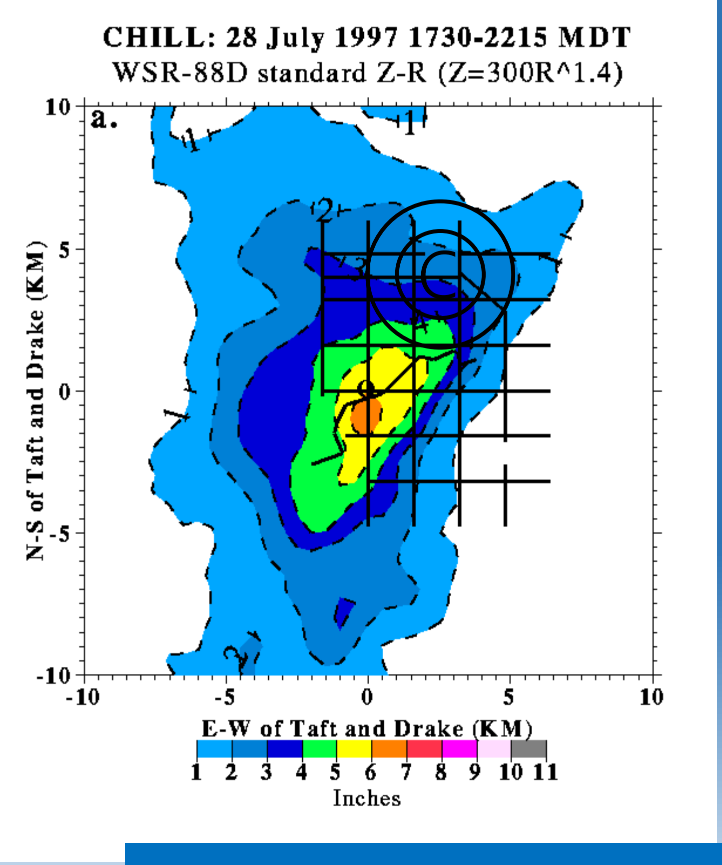
Small storm anchored to terrain- 10+ inches in 24 hours

CHILL 28 July 1997: 0208 UTC



Bow echo southwest- moist SE flow enhanced around its northern edge into FCL storm

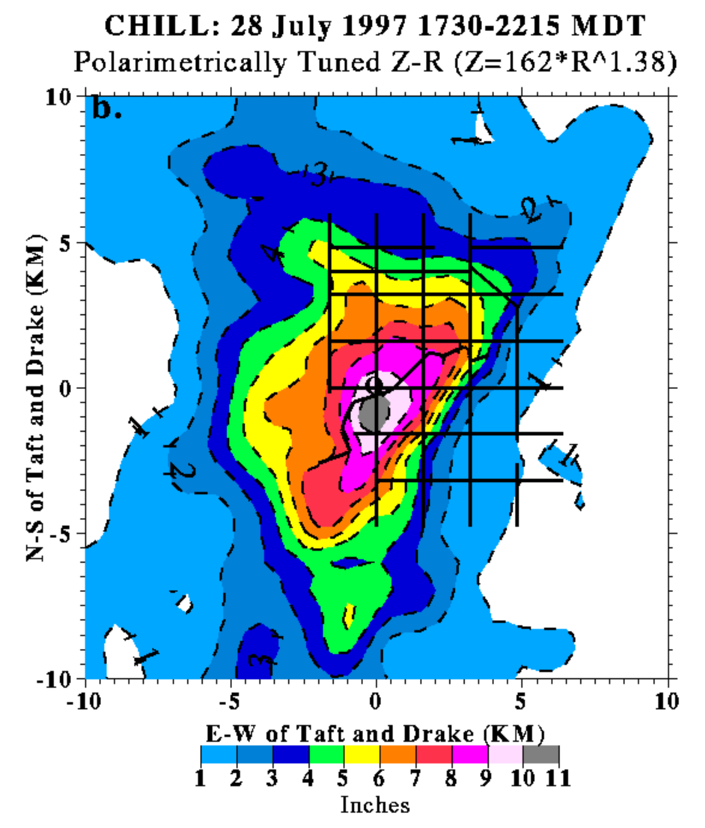
75-100% low-bias on 88D radar-estimated storm totals (Z-R)



CHILL: 28 July 1997 1730-2215 MDT

WSR-88D standard Z-R (Z=300R^1.4)

“Off the shelf” R(KDP,ZDR) and Pol-Tuned Z-R were much closer



CHILL: 28 July 1997 1730-2215 MDT

Polarimetrically Tuned Z-R (Z=162*R^1.38)

Power of internal consistency between polarimetric variables

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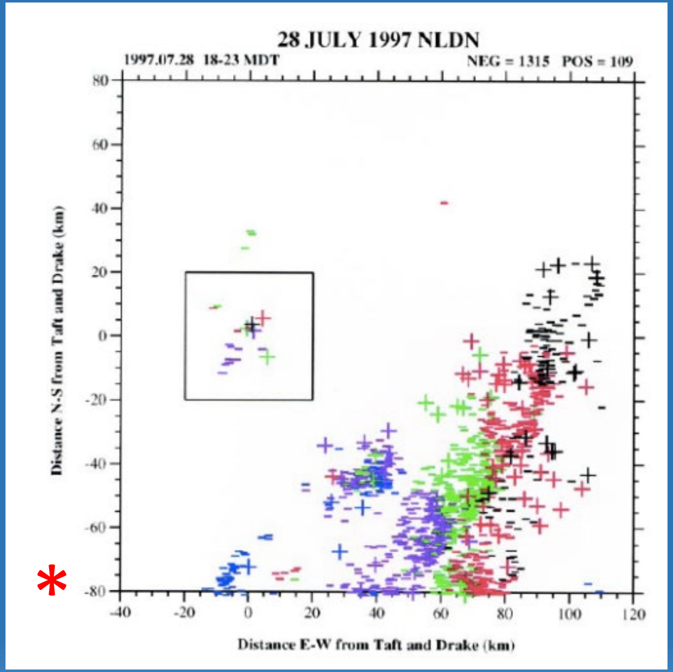
Petersen et al., 1999, Mesoscale and Radar Observations of the Fort Collins Flash Flood of 28 July 1997. DOI: https://doi.org/10.1175/1520-0477(1999)080<0191:MAROOT>2.0.CO;2

Process Physics Were Revealed by CHILL Operations

Relatively little lightning in FCL storms compared to bow echo system



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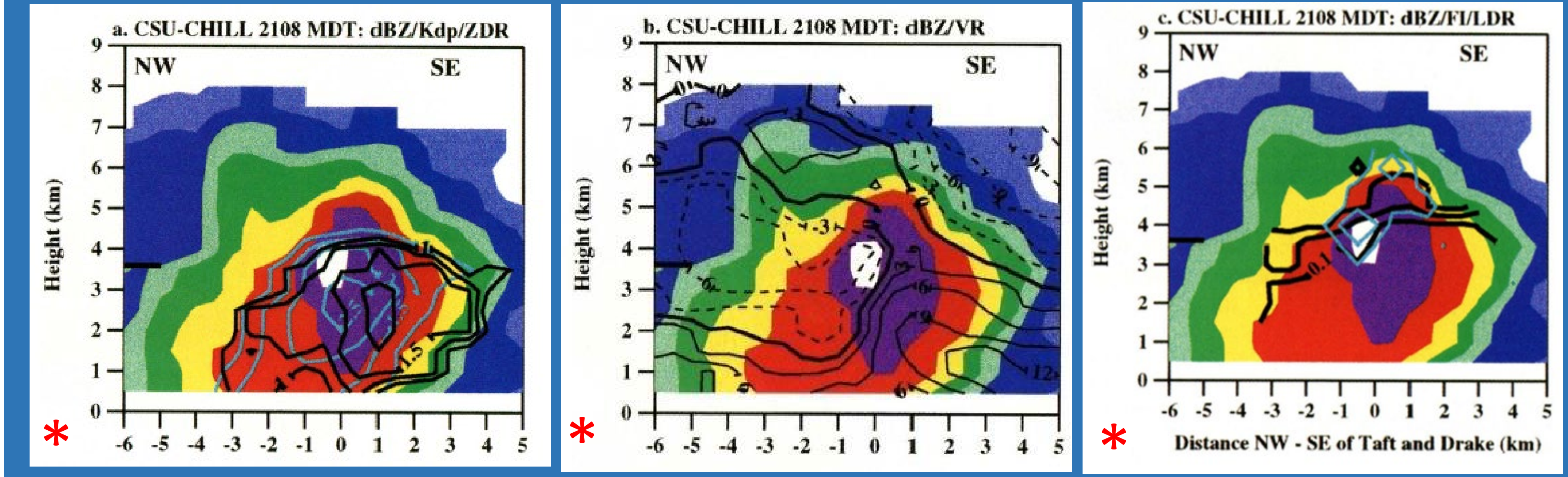
Pol variables elucidate process physics of an efficient, tropical monsoon-like rainfall process



* * *

Coalescence process, freezing, accretion, fall-out.......................but not deep enough into mixed phase to produce large amounts of lightning in most cells

Other Lesson I took to heart…….. “Research” platform(s) or not- Operate your Instruments!

*

Petersen et al., 1999, Mesoscale and Radar Observations of the Fort Collins Flash Flood of 28 July 1997. Bull. Amer. Meteor. Soc., 76, 319-328. DOI: https://doi.org/10.1175/1520-0477(1999)080<0191:MAROOT>2.0.CO;2

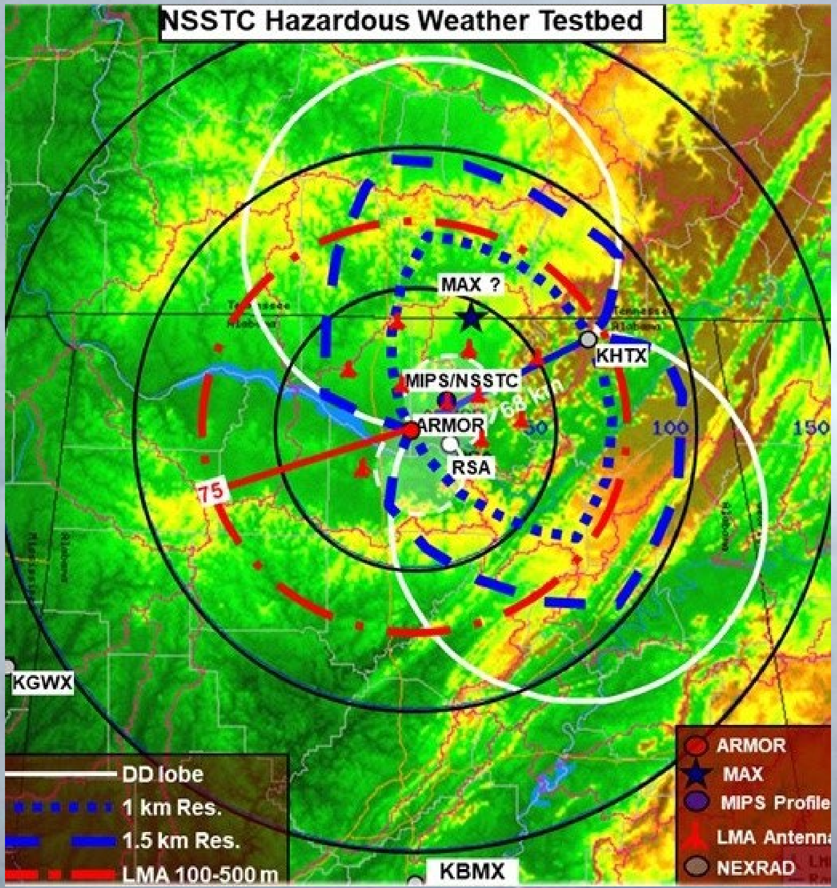
Front Range Radar Legacy in Alabama
Building a Storm and Precipitation Study Network

UAH/WHNT ARMOR Radar

- C-band *dual-polarimetric* Doppler radar
  - SIGMET (RVP/RCP), Baron Services
- Unique Collaboration:

  UAH + WHNT-19 (TV) + NASA MSFC
- Operations (public situational awareness via WHNT); Warning decision support NWS HUN (gap filling); KSC Range ops analogue
- Research: Precipitation, Convection, Lightning, PBL (UAH, NASA MSFC)
- TVA Rain mapping- Hydrologic Operations
- Numerous tornado events captured
- GPM physical validation exploration tool

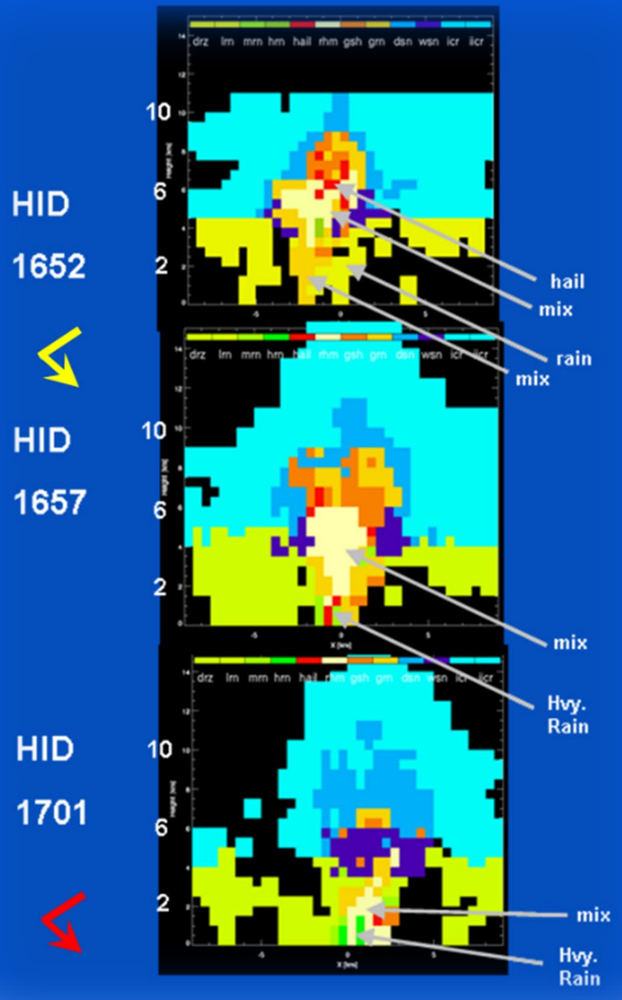
Expands to UAH SWIRL Facility



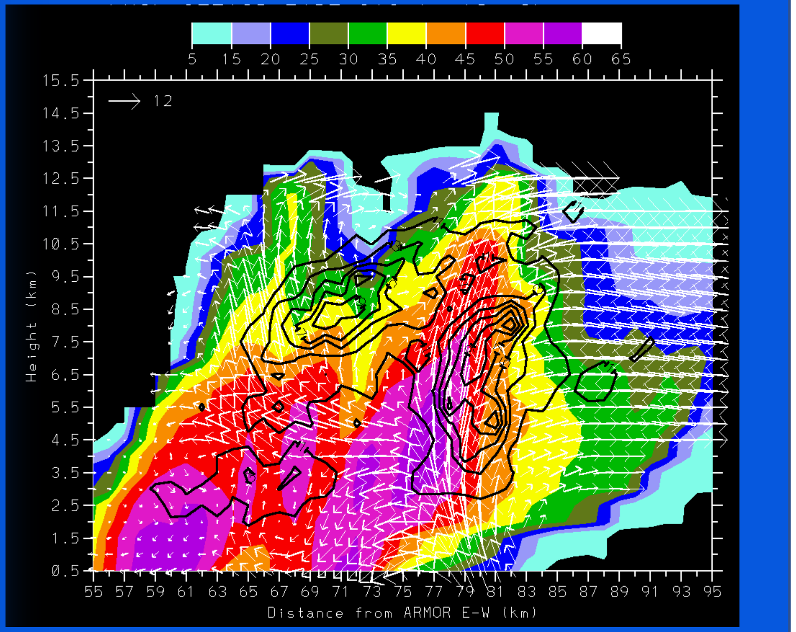
Multi-Radar Studies of Storm Updraft, Microphysics and Lightning

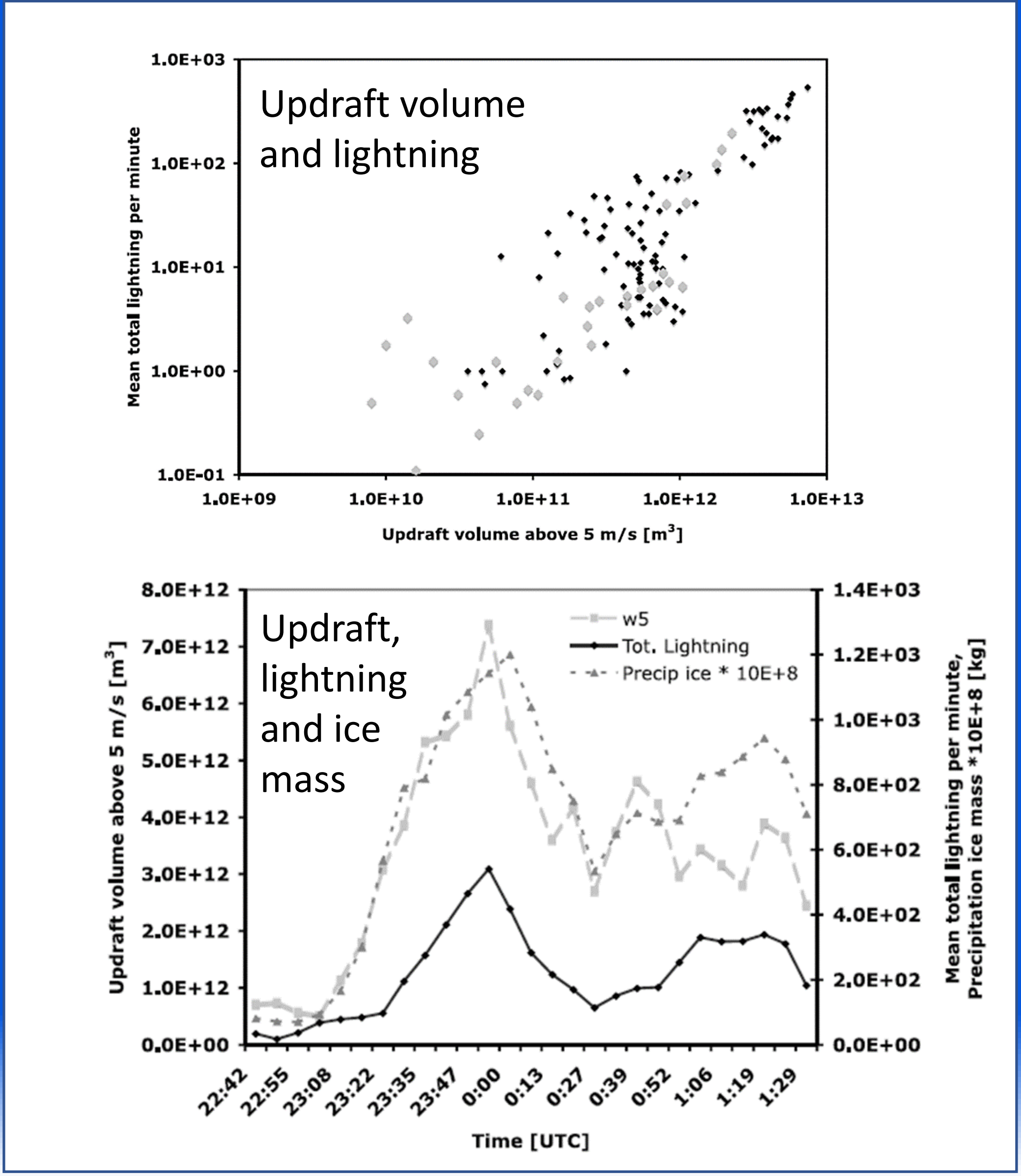
Deierling and Petersen (2008)

ARMOR radar + NA LMA network, STEPS2001 Storms



Updraft controls precipitation process and electrification





Updraft volume and lightning

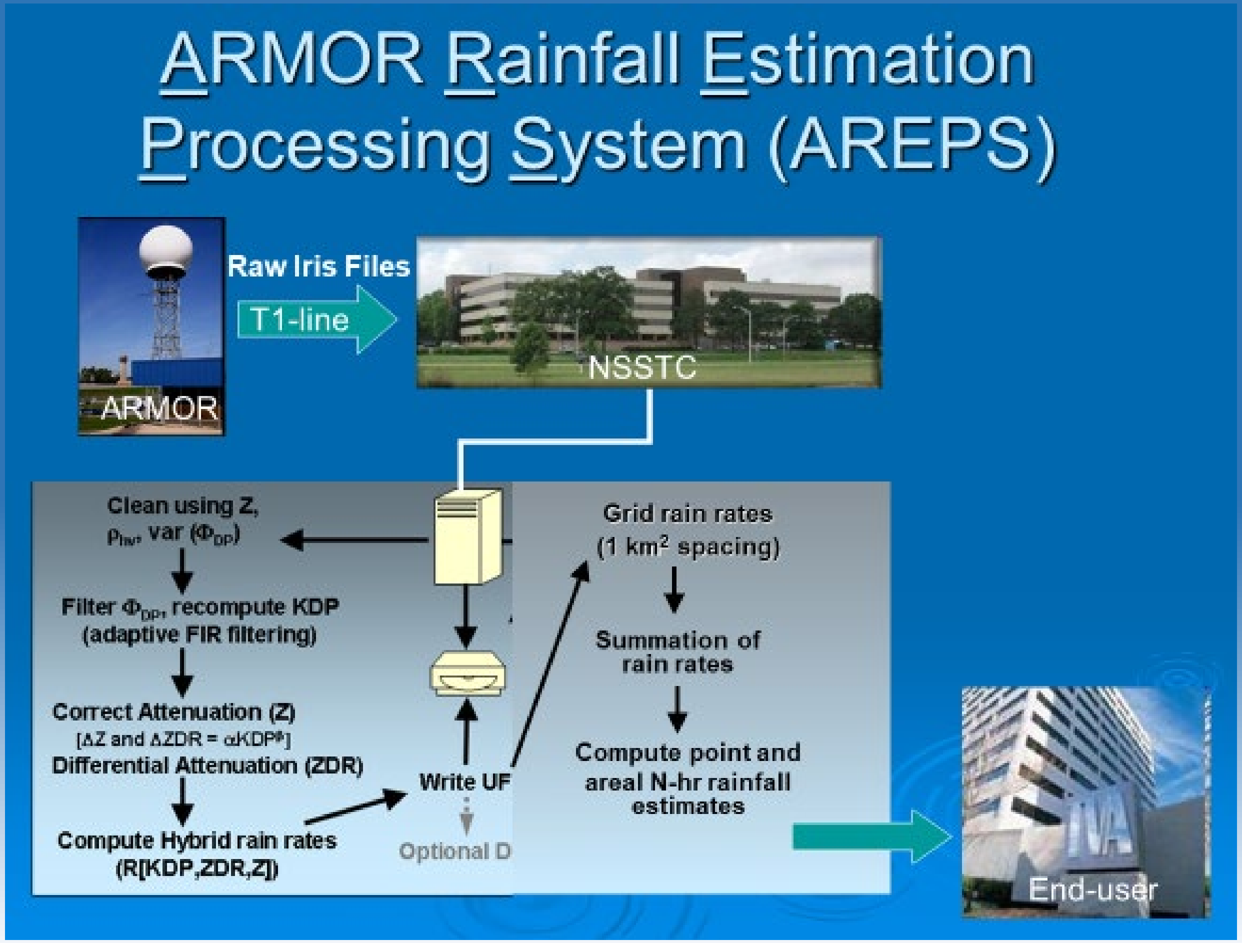
Updraft, lightning and ice mass

Deierling, W., and Petersen, W. A. (2008), Total lightning activity as an indicator of updraft characteristics, *J. Geophys. Res.*, 113, D16210, doi:10.1029/2007JD009598.

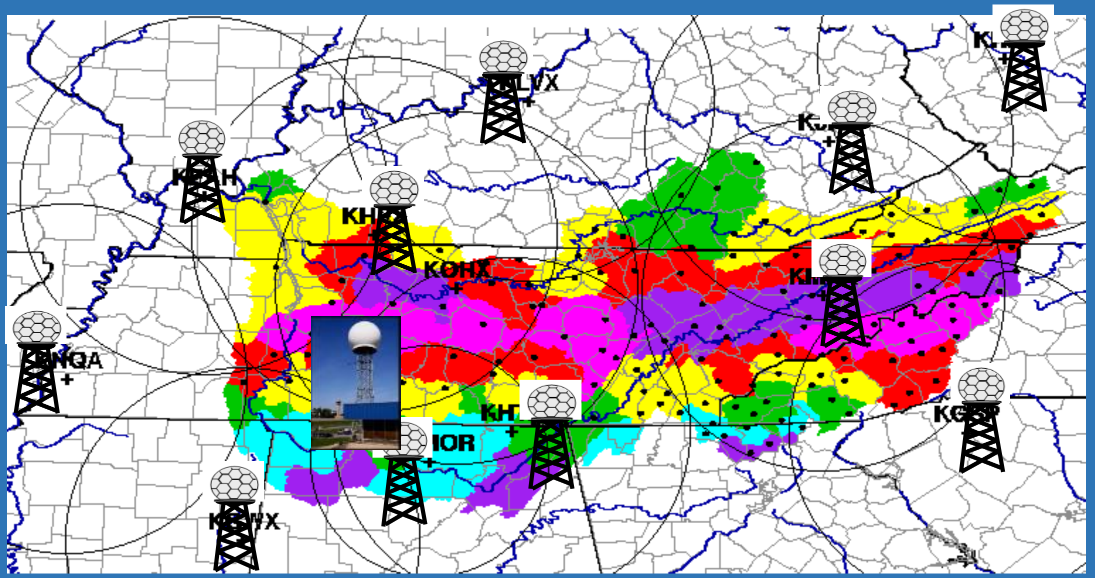
ARMOR: Exploring Rain Mapping Application with TVA

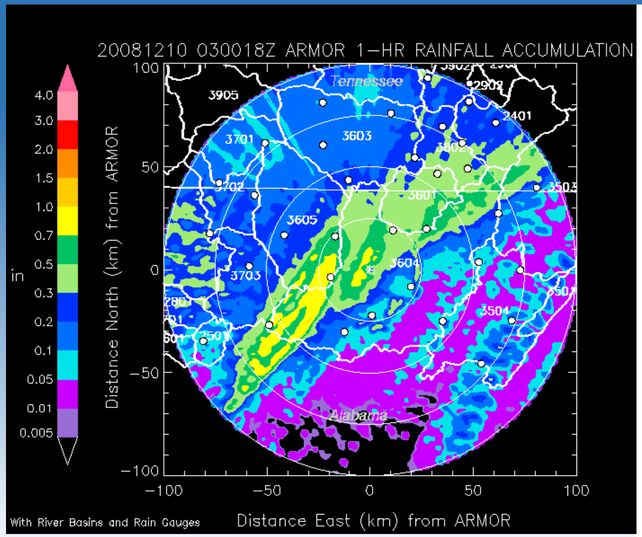
Objective:

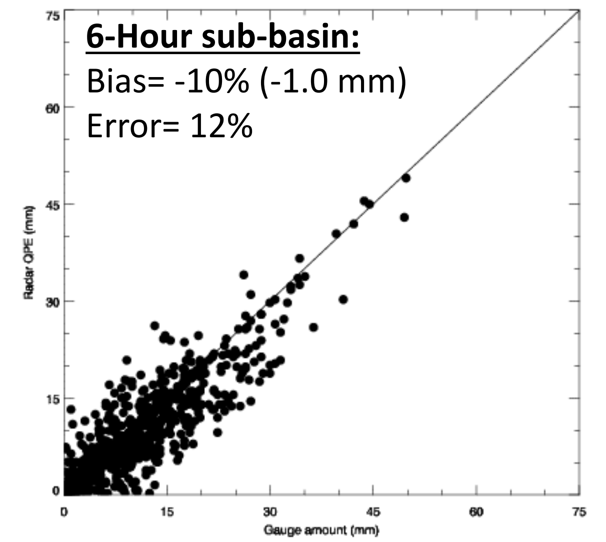
Demonstrate/implement improved rainfall estimation for water management and reduce gauge ops cost



ARMOR Rainfall Estimation Processing System (AREPS)

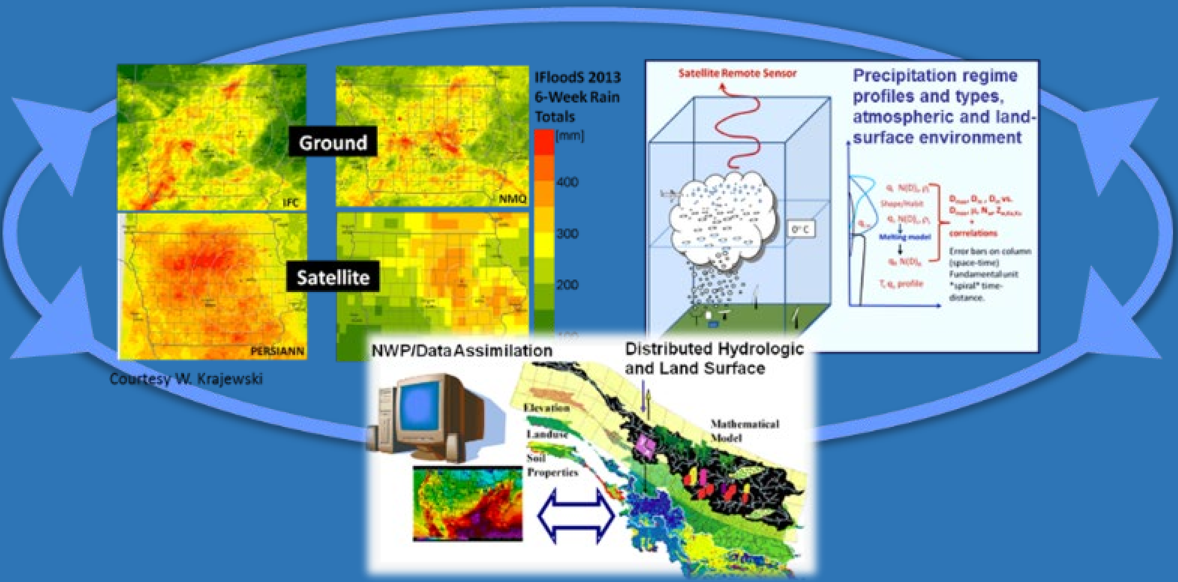






6-Hour sub-basin:
Bias= -10% (-1.0 mm)
Error= 12%

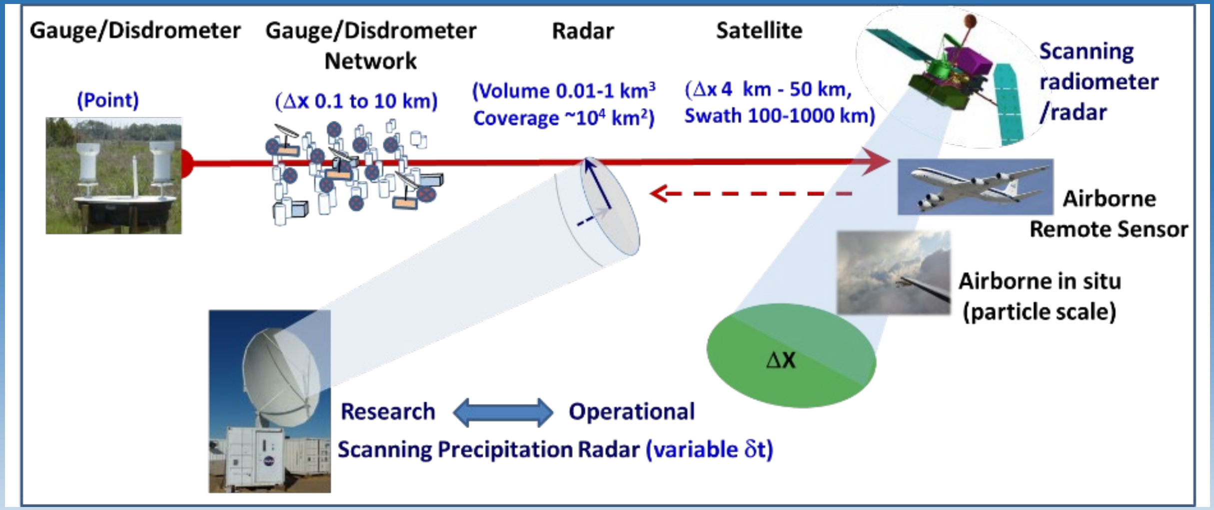
10+ Years of GPM Ground Validation



Courtesy W. Krajewski

General Approaches

- **Direct:** National network statistical GV- convergence of estimates between ground and space
  - E.g., MRMS, Validation Network (VN)
- **Physical:** Process physics and algorithm consistency
  - Field Campaigns (periodic and extended)
- **Integrated:** Impact/utility with uncertainties



Multi-Platform Bridging of Scales

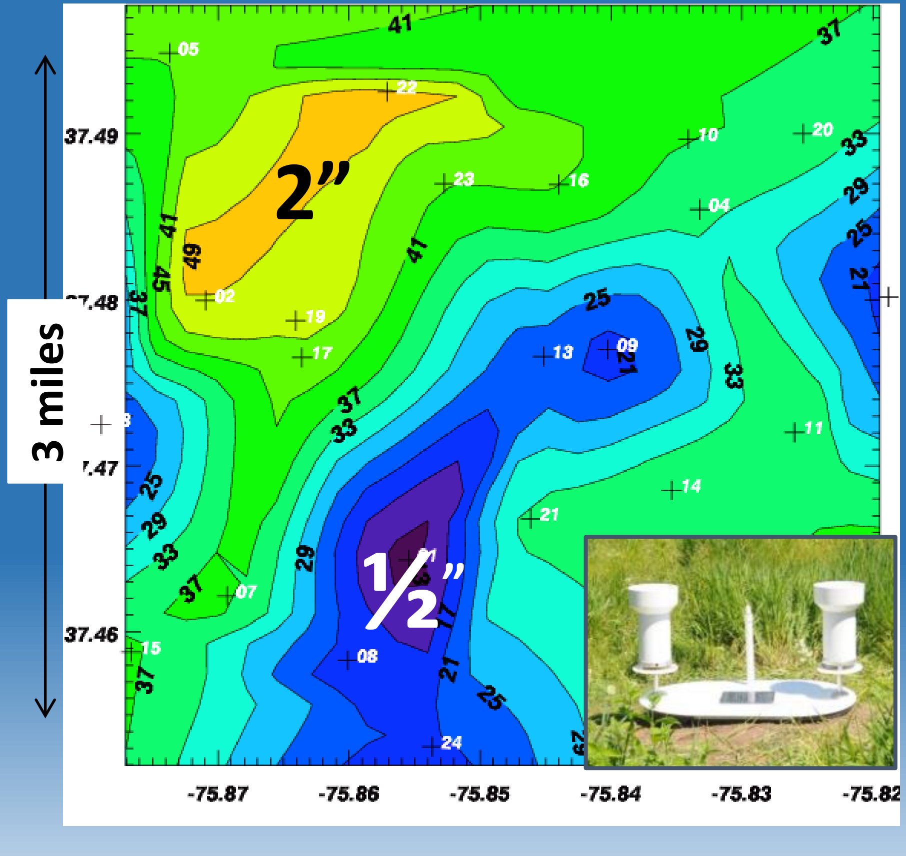
- Telescoping reference from point to footprint to regional scales- validate the validation and validate GPM
- Ground/airborne radar/radiometer process to remote sensing scale "translator"

In the end aren't we just validating rainfall?...Just use rain gauges?

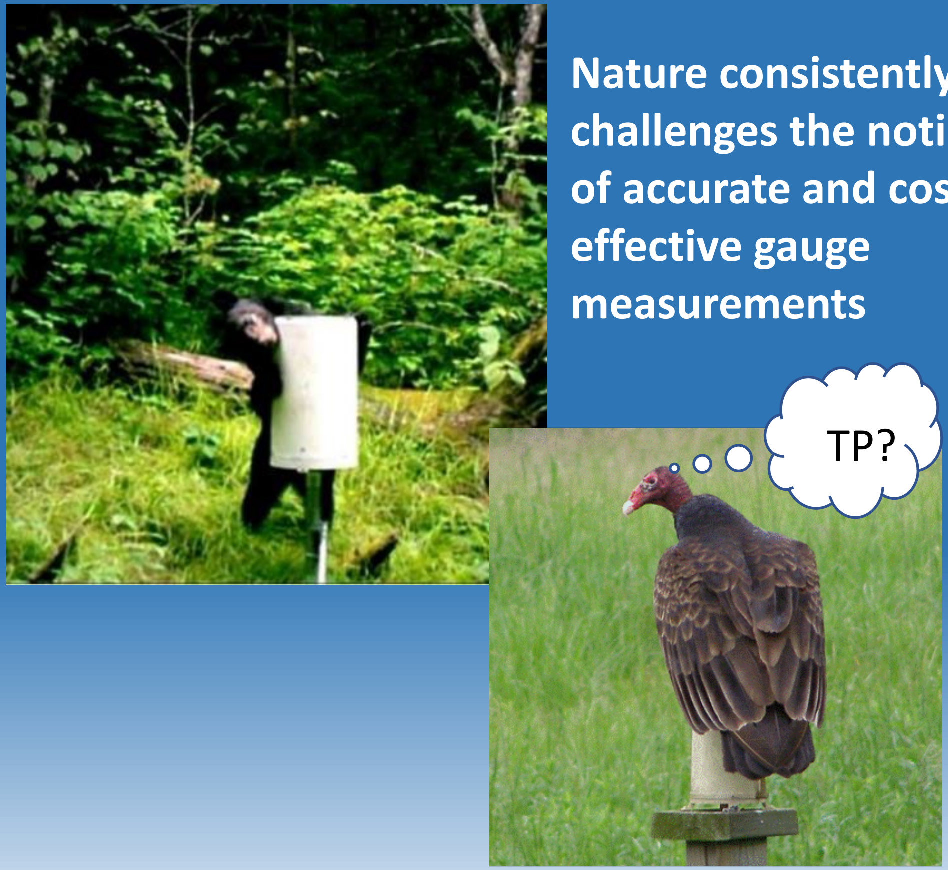
How Many Rain Gauges for an Accurate Estimate of FOV *Daily* Rainfall (e.g., box ~ 5 – 25 km on a side)?

Observe Rain spatial variability (with consistent *accuracy*) with the GPM Dense Gauge Network

25 dual-gauge platforms , 5 km x 5 km grid   5/30/2013 Event: Daily rain accumulation



Variability-
Huge point to point maximum difference



Nature consistently challenges the notion of accurate and cost effective gauge measurements

Multiple and significant implications for validation approach!

Need radar…..CSU ATS/EE influences NASA Meteorological Radar Technology

2009 - 2012

NASA NPOL ca. 2000/2002

- Innovative container based, new lightweight deployable, telescoping mesh antenna approach
- Unfortunately, antenna had poor polarimetric performance and marked issues when it got wet!

NASA NPOL 2013 [Deployed in Iowa during IFloodS]

- Research grade dual-pol radar overhaul
- One of 2 transportable S-band/DP research radars in the world
- Used at WFF supersite and in every U.S. GPM Field campaign

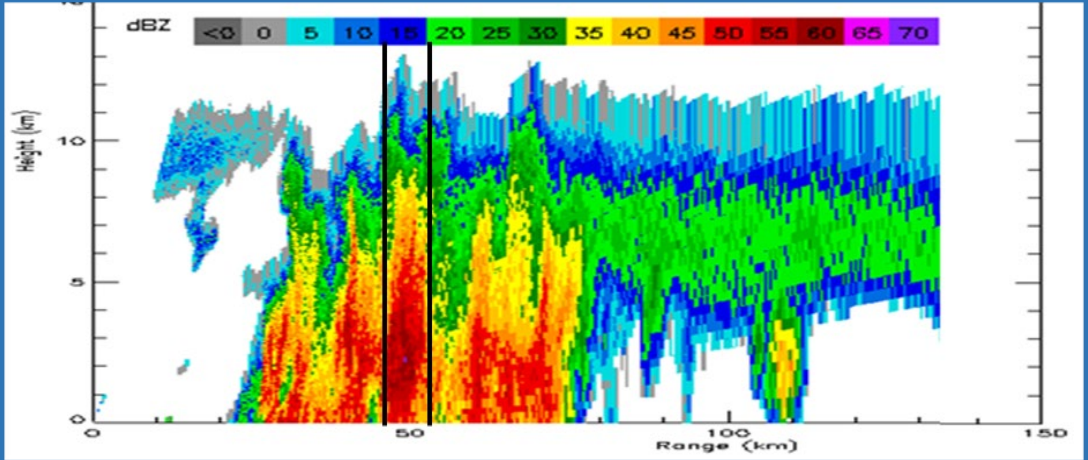
NASA D3R

- Ka/Ku band Doppler and Polarimetric- state of the art wave form generation and processing

NPOL fundamental to quantifying horizontal and vertical variability

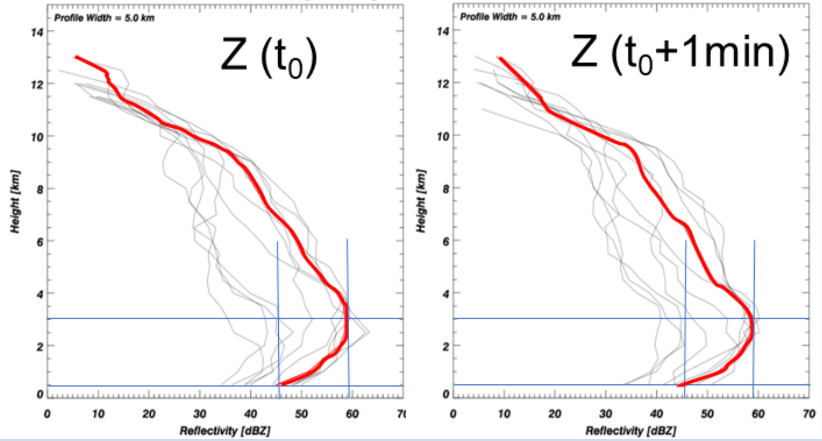
- **E.g., How much radar reflectivity (Z_e), DSD spatial/temporal *profile variability* is there within a 5 km Pixel?**

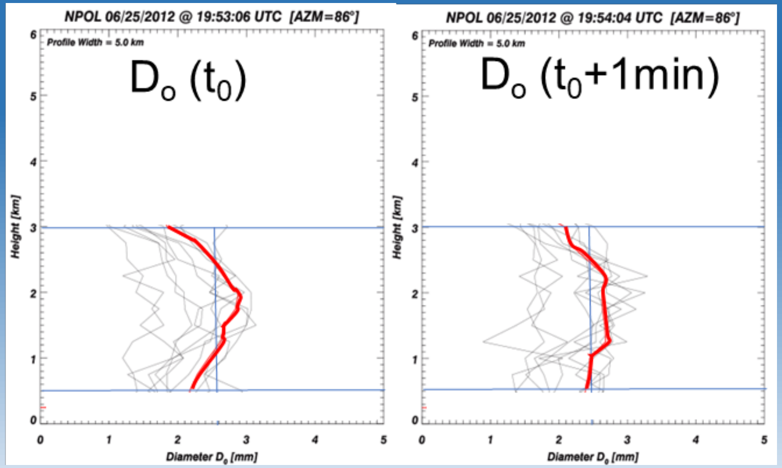
25 June 2012
NPOL Radar Wallops



Use Range-Height sampling (RHIs) and polarimetry to profile the DSD in individual columns within a 5 km "FOV"

- **Sub-FOV Z_e *and D_0 (median volume diameter) profile changes evident…and coupled to horizontal variability!***





Assemble, Build, Operate GV Infrastructure

Radars: Domain 4-D precip structure, DSD, rates

NPOL Radar: S-band transportable, dual-pol, scanning

D3R radar: Dual-frequency (KA-KU), dual-polarimetric, Doppler radar.

T-REX radar: X-band dual-pol, transportable

TOGA C-band land/ship deployable Doppler radar

4 Metek Micro Rain Radars (K-band), vertically pointing

Disdrometers/Gauges: DSD, particle imager, rain rate and rain/snow water

6 2D Video Disdrometers

30 Parsivel-2 laser disdrometer

8 Joss Waldvogel

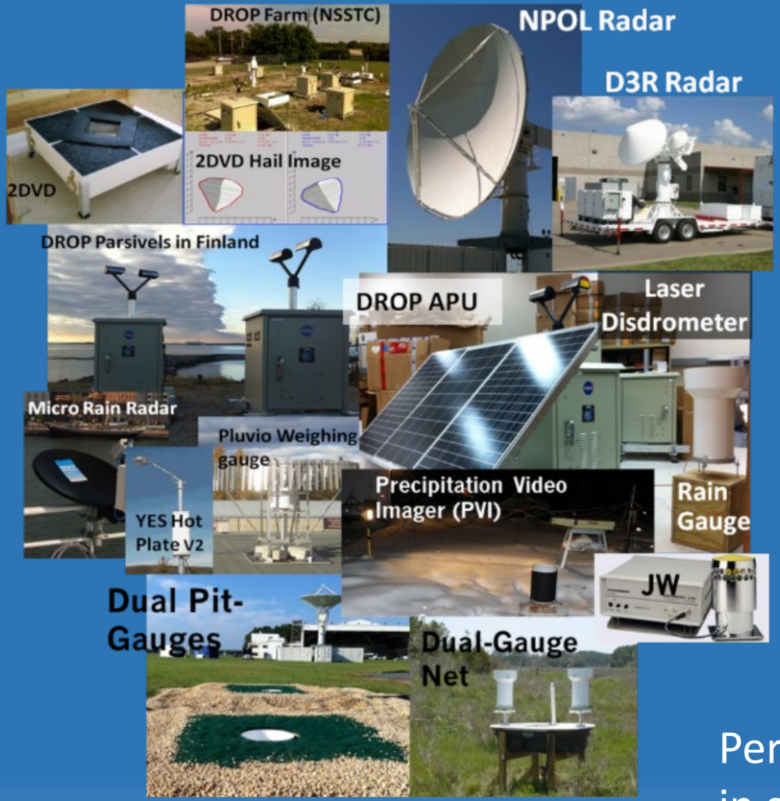
9 Precipitation Imager Packages (PIP)

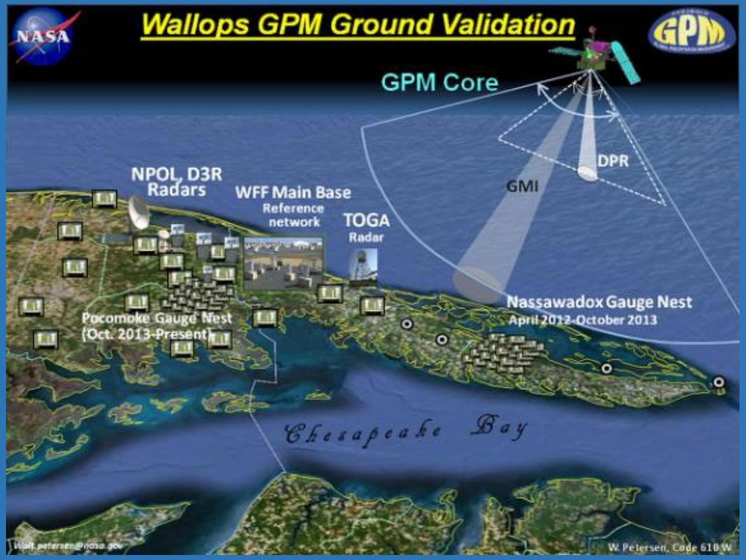
100+ Met One TB rain gauges

50 dual-gauge dense network + Pit

7 Hot plate sensors – Snow

9 OTT Pluvio$_2$ gauges – Snow

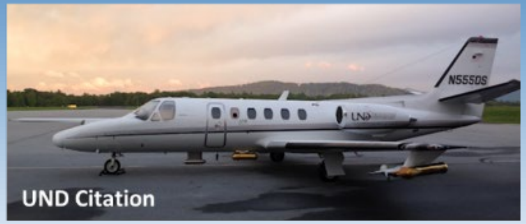




Periodic Airborne: Field Campaign Aircraft, in situ probes, active and passive remote sensors (radars, radiometers)


NASA DC-8

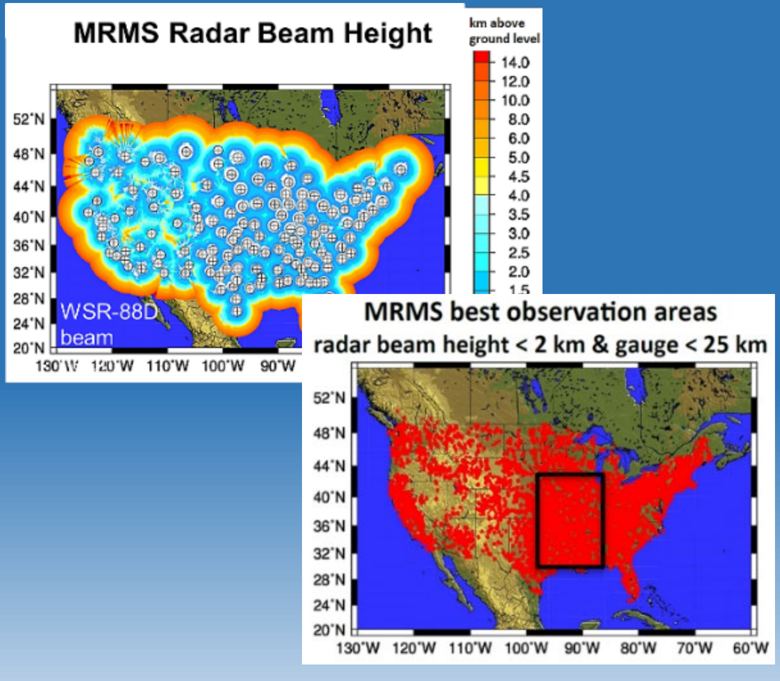

NASA ER-2


UND Citation

3 Core “Data” Components

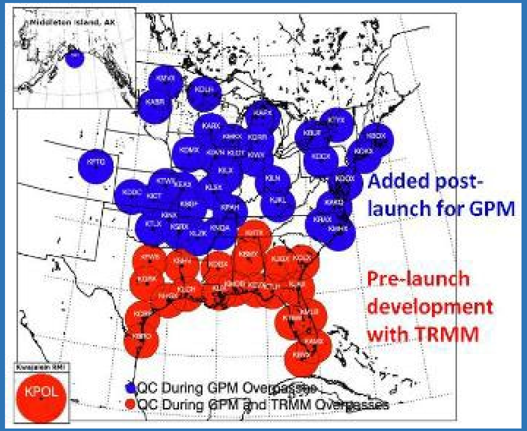
1) NOAA Multi-Radar Multi-Sensor (MRMS) Precipitation Rates

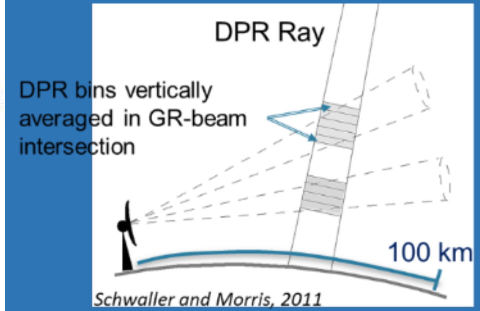
- Gauge bias-corrected radar estimates of precip ***rate and type***
- 0.01^{o} / 2 minute resolution
- Quality-constrained "reference" subsets created



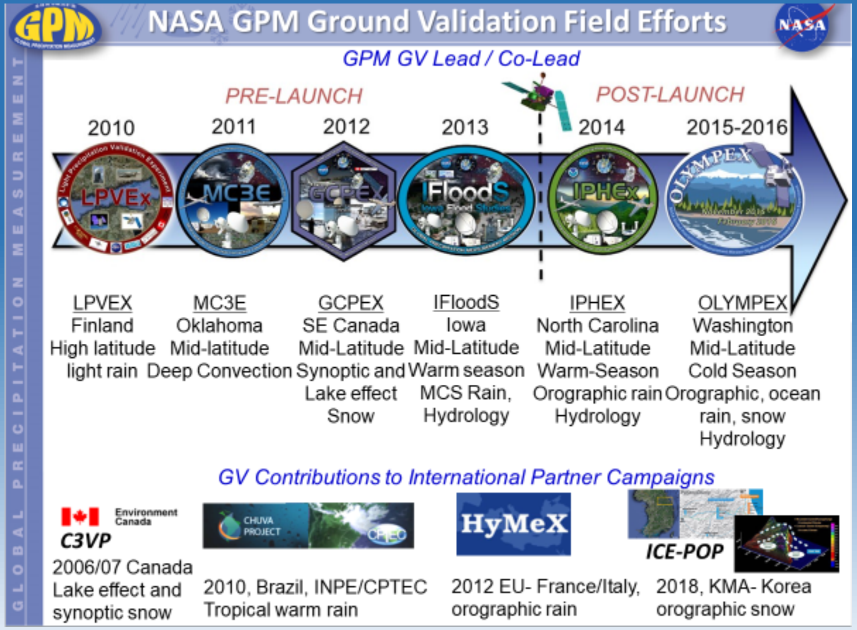
2) Validation Network

- QC'd 3-D radar volumes and variables geo-matched to DPR sample volumes and GMI footprints
- 65 US + numerous research and international radars





3) Global Field campaign and Extended Site observations



NASA GPM Ground Validation Field Efforts

GPM GV Lead / Co-Lead

PRE-LAUNCH | *POST-LAUNCH*

2010	2011	2012	2013	2014	2015-2016
LPVEX	MC3E	GCPEX	IFloodS	IPHEX	OLYMPEX
Finland High latitude light rain	Oklahoma Mid-latitude Deep Convection	SE Canada Mid-Latitude Synoptic and Lake effect Snow	Iowa Mid-Latitude Warm season MCS Rain, Hydrology	North Carolina Mid-Latitude Warm-Season Orographic rain Hydrology	Washington Mid-Latitude Cold Season Orographic, ocean rain, snow Hydrology

GV Contributions to International Partner Campaigns

C3VP	CHUVA PROJECT	HyMeX	ICE-POP
2006/07 Canada Lake effect and synoptic snow	2010, Brazil, INPE/CPTEC Tropical warm rain	2012 EU- France/Italy, orographic rain	2018, KMA- Korea orographic snow

GLOBAL PRECIPITATION MEASUREMENT

Did GV make (is it making) a difference?

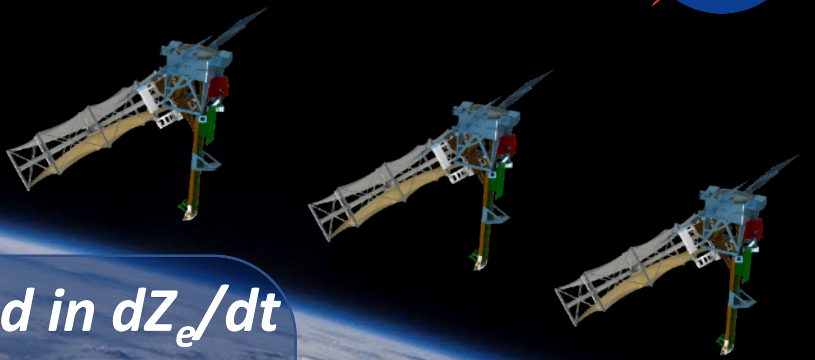
Yes

- Level 1 Requirements Verification
  - Rain Rate: GV WFF dense network, NPOL, GV-MRMS
  - Snow detection GV-MRMS, Finland Hyytiälä
  - DSD: GV Disdrometer infrastructure, NPOL, Validation Network (VN)
- Algorithms:
  - Multiple scattering and NUBF algorithms (e.g., Trigger)- MC3E, IPHEx field campaigns, larger VN datasets
  - Snow/ice retrievals and modeling (C3VP, MC3E, Hyytiälä, LPVEx, GCPEX)
  - Bright Band modeling and retrievals (LPVEx, OLYMPEX/RADEX)
  - DSD character (incl. NUBF), impacts and algorithm directions- Field campaigns and extended measurements: DPR, Combined algorithms
  - Near Surface estimation (sfc to first Clutter free bin)- OLYMEX/RADEX……
  - Models and associated instrument simulators: Field campaigns
  - IMERGE- MRMS, VN- and ongoing………….

….and new missions………….

INCUS

Ground Validation



Vertical transport of water & air in convection as manifested in dZ_e/dt

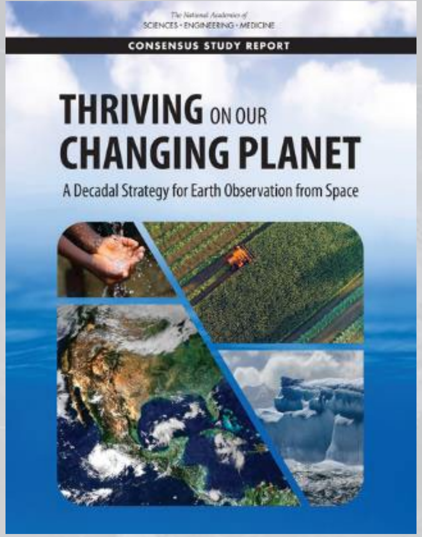
$$\frac{\Delta Z_e}{\Delta t} = -\overrightarrow{V}_{xy} \cdot \overrightarrow{\nabla}_{xy} Z_e - W_C \frac{\Delta Z_e}{\Delta z} + \text{Mic}\,(\alpha * W_C)$$

(Δ-t) Horizontal Advection Vertical Advection Microphysical conversions

GV Challenge: vertical profiles of convective hydrometeor properties and vertical air motion at 1 - 2 minute δt

Walt Petersen and Patrick Gatlin (MSFC) and Courtney Schumacher (TAMU)

Atmospheric Observing System (AOS) (Phase A)

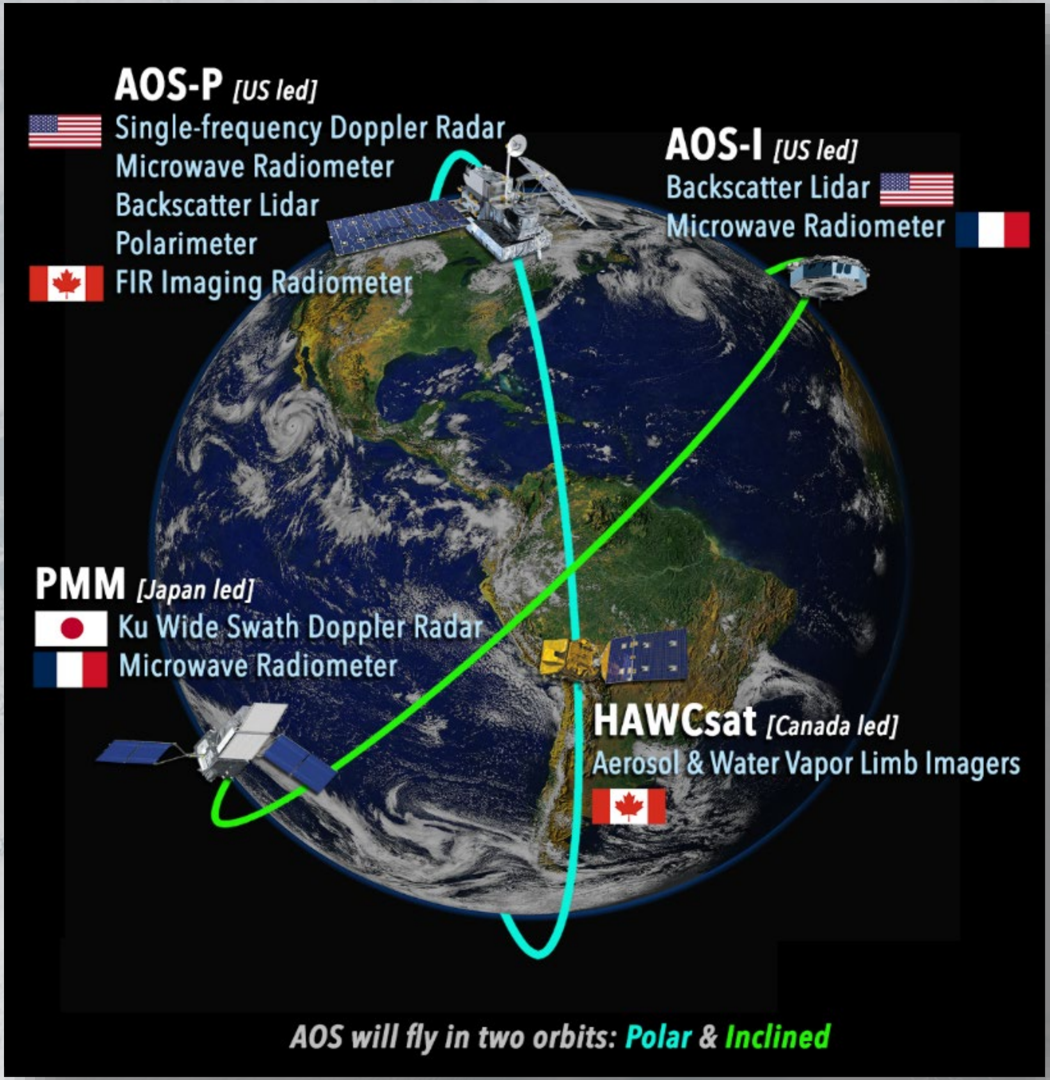


The National Academies of
SCIENCES · ENGINEERING · MEDICINE

CONSENSUS STUDY REPORT

THRIVING ON OUR CHANGING PLANET

A Decadal Strategy for Earth Observation from Space



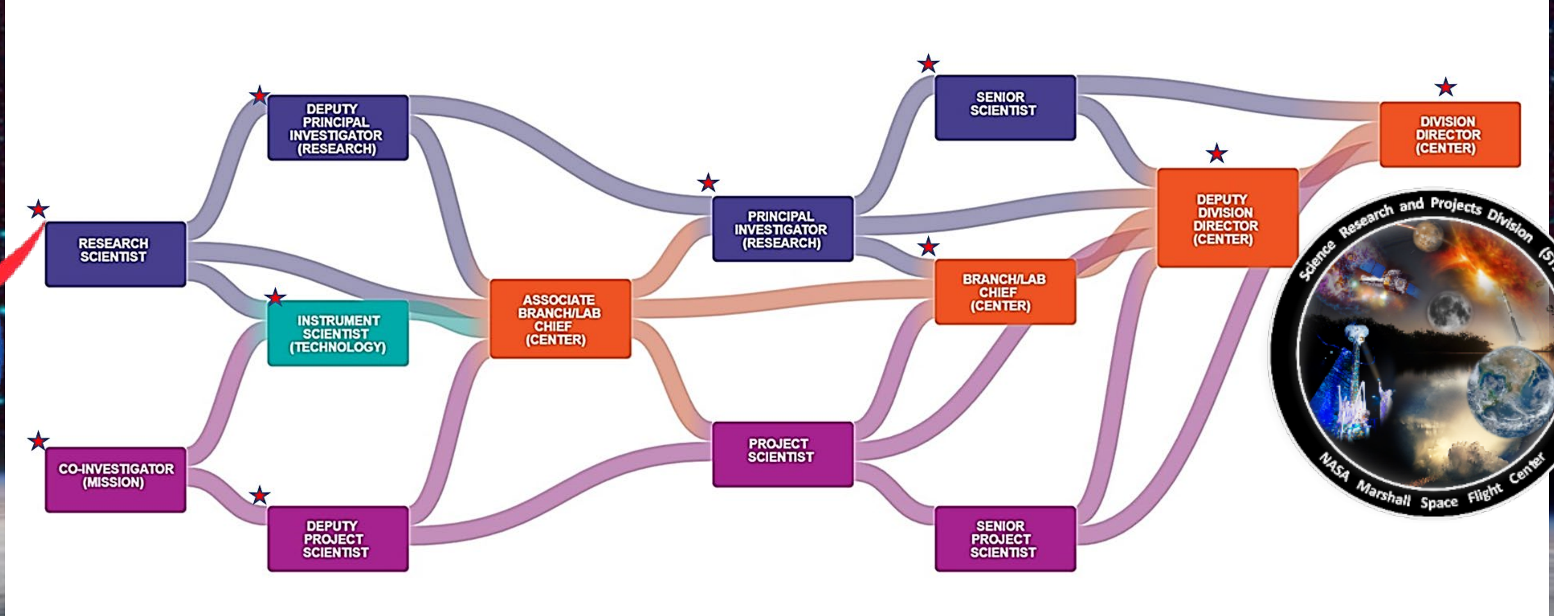
- AOS addresses two Decadal Survey Designated Observables: Convection, Clouds and Precipitation, and Aerosols
- Inclined (55°) orbit focuses on weather (sub-daily) time scales with emphasis on convection, high clouds, and aerosol/PBL evolution
- Polar, sun-sync orbit focused on improved measurements for climate processes
- **Ongoing Phase A architecture evaluation may alter final instrument complement and orbits.**
- Science-driven Sub-Orbital Program

- **Passed KDP-A January 2023. Working Phase-A trades considering KDP-A recommendations and budget constraints**

Pre-Decisional – AOS is in Phase A and NASA makes no commitments on the final design of the mission or instruments

Career Path Trajectory to “There”

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE



RESEARCH SCIENTIST

CO-INVESTIGATOR (MISSION)

DEPUTY PRINCIPAL INVESTIGATOR (RESEARCH)

INSTRUMENT SCIENTIST (TECHNOLOGY)

DEPUTY PROJECT SCIENTIST

ASSOCIATE BRANCH/LAB CHIEF (CENTER)

PRINCIPAL INVESTIGATOR (RESEARCH)

PROJECT SCIENTIST

SENIOR SCIENTIST

BRANCH/LAB CHIEF (CENTER)

SENIOR PROJECT SCIENTIST

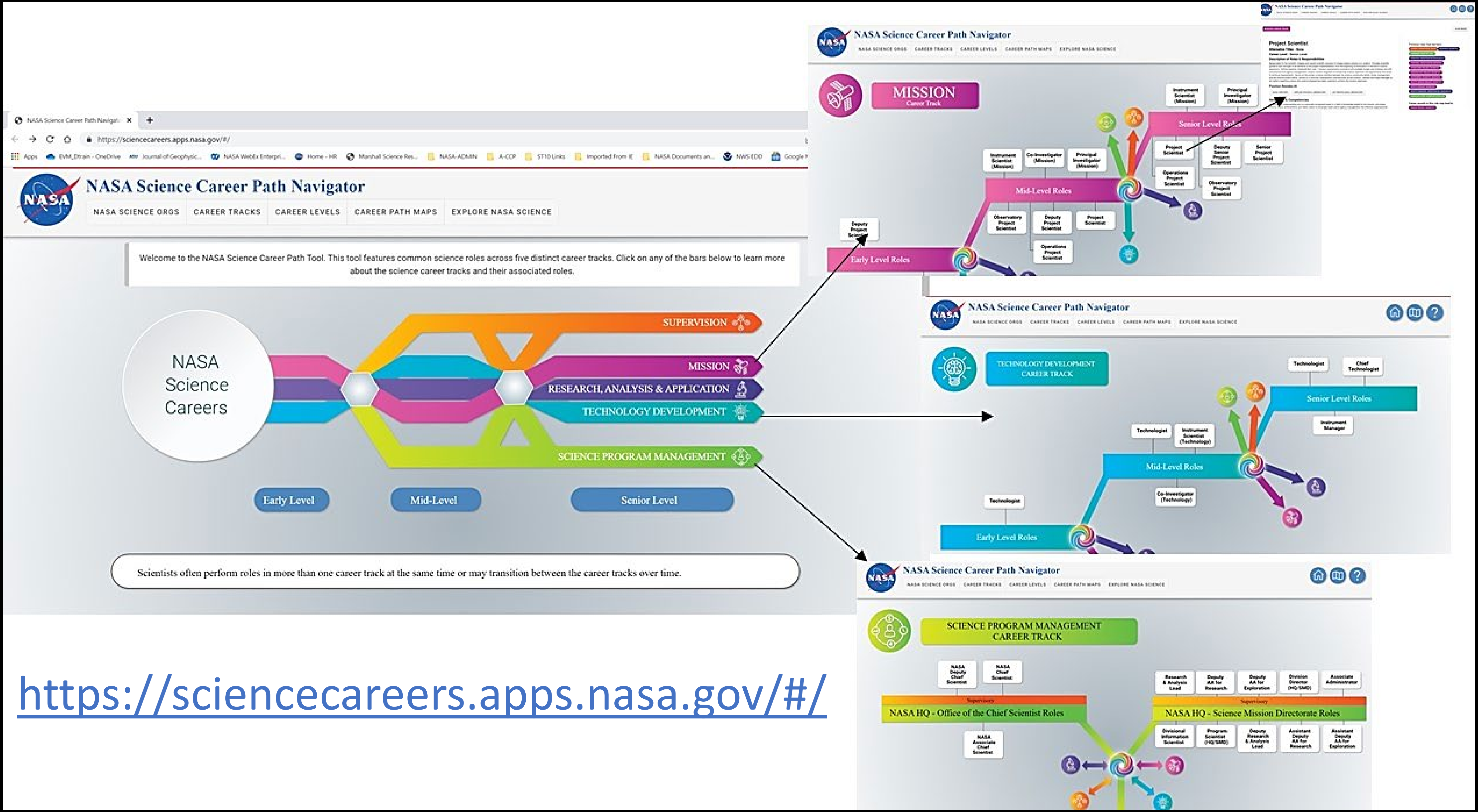
DEPUTY DIVISION DIRECTOR (CENTER)

DIVISION DIRECTOR (CENTER)

Science Research and Projects Division (ST10)

NASA Marshall Space Flight Center

More Broadly: “There” in NASA - Science Career Tracks



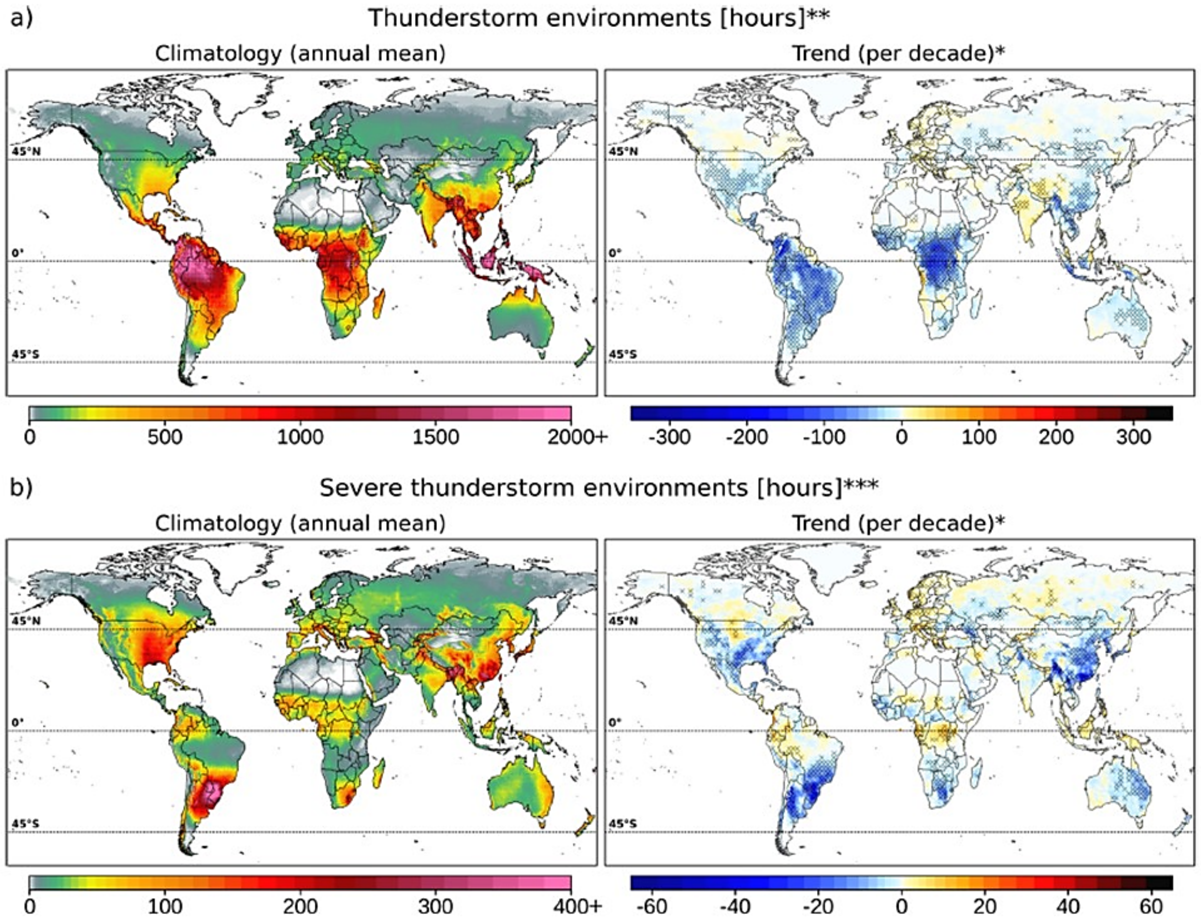
Welcome to the NASA Science Career Path Tool. This tool features common science roles across five distinct career tracks. Click on any of the bars below to learn more about the science career tracks and their associated roles.

Scientists often perform roles in more than one career track at the same time or may transition between the career tracks over time.

https://sciencecareers.apps.nasa.gov/#/

Backup

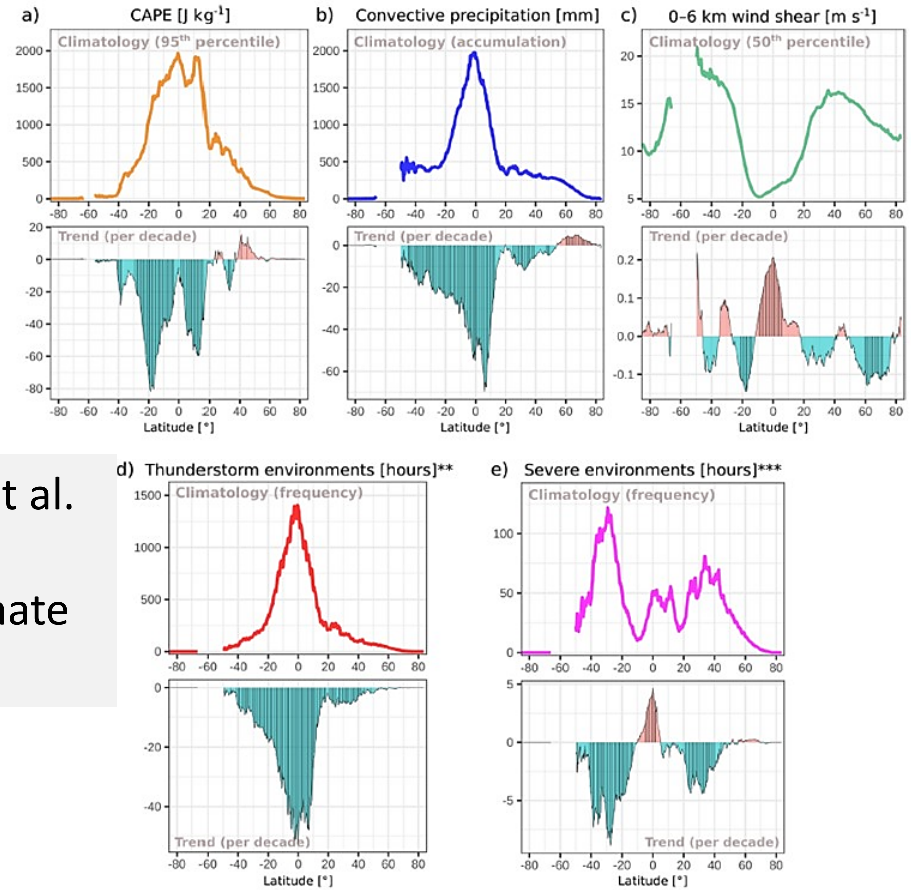
Context: Thunderstorms and Environments in Global Climate



* - 'x' marks denote statistically significant trend (p-value < 0.05)
** - Thunderstorm environment is considered when CAPE > 150 J kg^{-1} and CP > 0.25 mm h^{-1}
*** - Severe thunderstorm environment is considered when CAPE > 150 J kg^{-1}, 0-6 km wind shear > 12.5 m s^{-1} and CP > 0.25 mm h^{-1}

Fig. 2 ERA5 climatology and trends for thunderstorm and severe thunderstorm environments. As in Fig. 1 but with the application of a land-surface mask and showing the combined frequency proxy of (**a**) thunderstorm environments, and (**b**) severe thunderstorm environments.

Taszarek et al.
(2021)
ERA5 Climate
Study



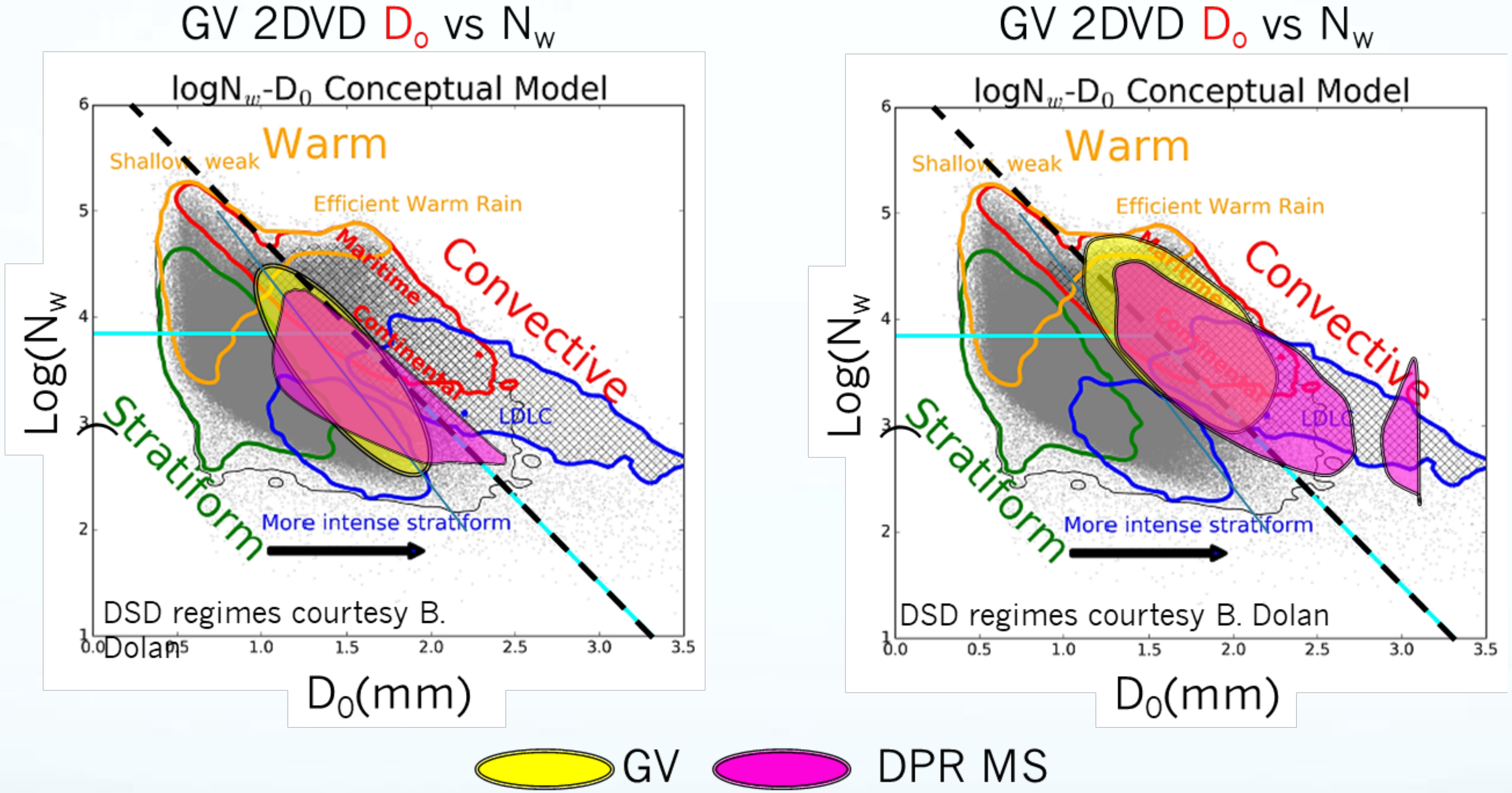
* - Vertical black lines indicate trend with p-value < 0.05
** - Thunderstorm environments is considered when CAPE > 150 J kg^{-1} and CP > 0.25 mm h^{-1}
*** - Severe thunderstorm environments is considered when CAPE > 150 J kg^{-1}, 0-6 km wind shear > 12.5 m s^{-1} and CP > 0.25 mm h^{-1}

Fig. 4 ERA5 zonal mean climatology and trends for CAPE, convective precipitation, vertical wind shear, thunderstorm and severe thunderstorm environments (land surface grids only). A 41-year (1979–2019) zonal mean climatology and trends for (**a**) 95th percentile of convective available potential energy (CAPE), (**b**) accumulated convective precipitation, (**c**) 50th percentile of 0–6 km vertical wind shear, (**d**) frequency of thunderstorm environments, and (**e**) frequency of severe thunderstorm environments. Only grids over the land surface are taken into account (at least 30 in any latitudinal band). Trend is computed using Sen's slope and value denote change per decade. Vertical solid lines indicate p-value below 0.05.

Thunderstorms are a fingerprint of climate change- observe the actual “fingerprint”?

Taszarek, M., Allen, J.T., Marchio, M. et al. Global climatology and trends in convective environments from ERA5 and rawinsonde data. npj Clim Atmos Sci 4, 35 (2021). https://doi.org/10.1038/s41612-021-00190-x;

DSD: V5 **DPR MS (inner) Convective** D_m and N_w



- DPR MS V5 fits GV sample space (Assuming $D_m \approx D_0$); behavior is somewhat similar to GPM GV Radar
- Shift to larger D_m and smaller N_w relative to GV; secondary mode at large D_m
- Combined algorithm (not shown) also generally "fits" GV - but with different N_w-D_m slope behavior in stratiform