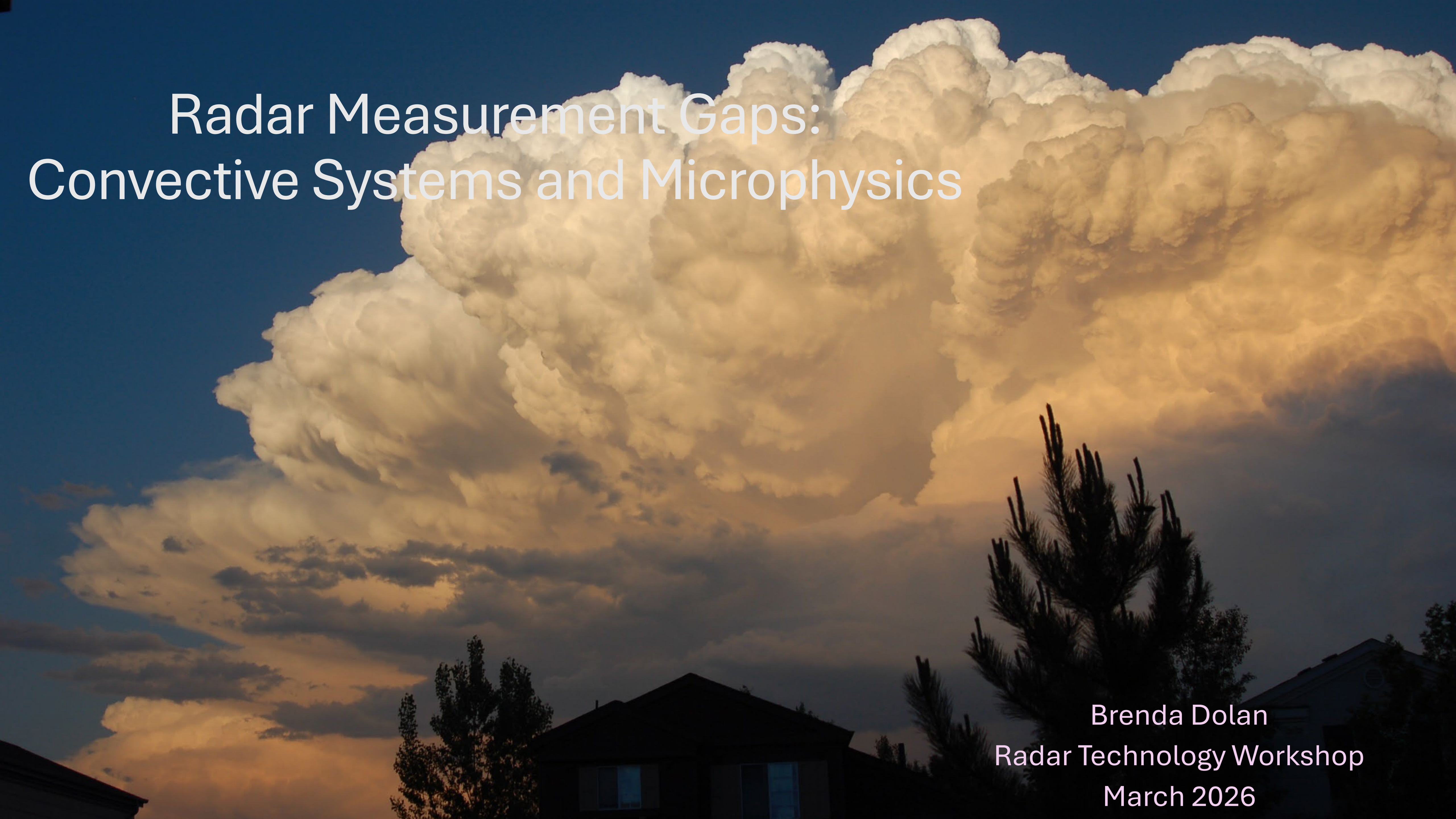


Radar Measurement Gaps: Convective Systems and Microphysics

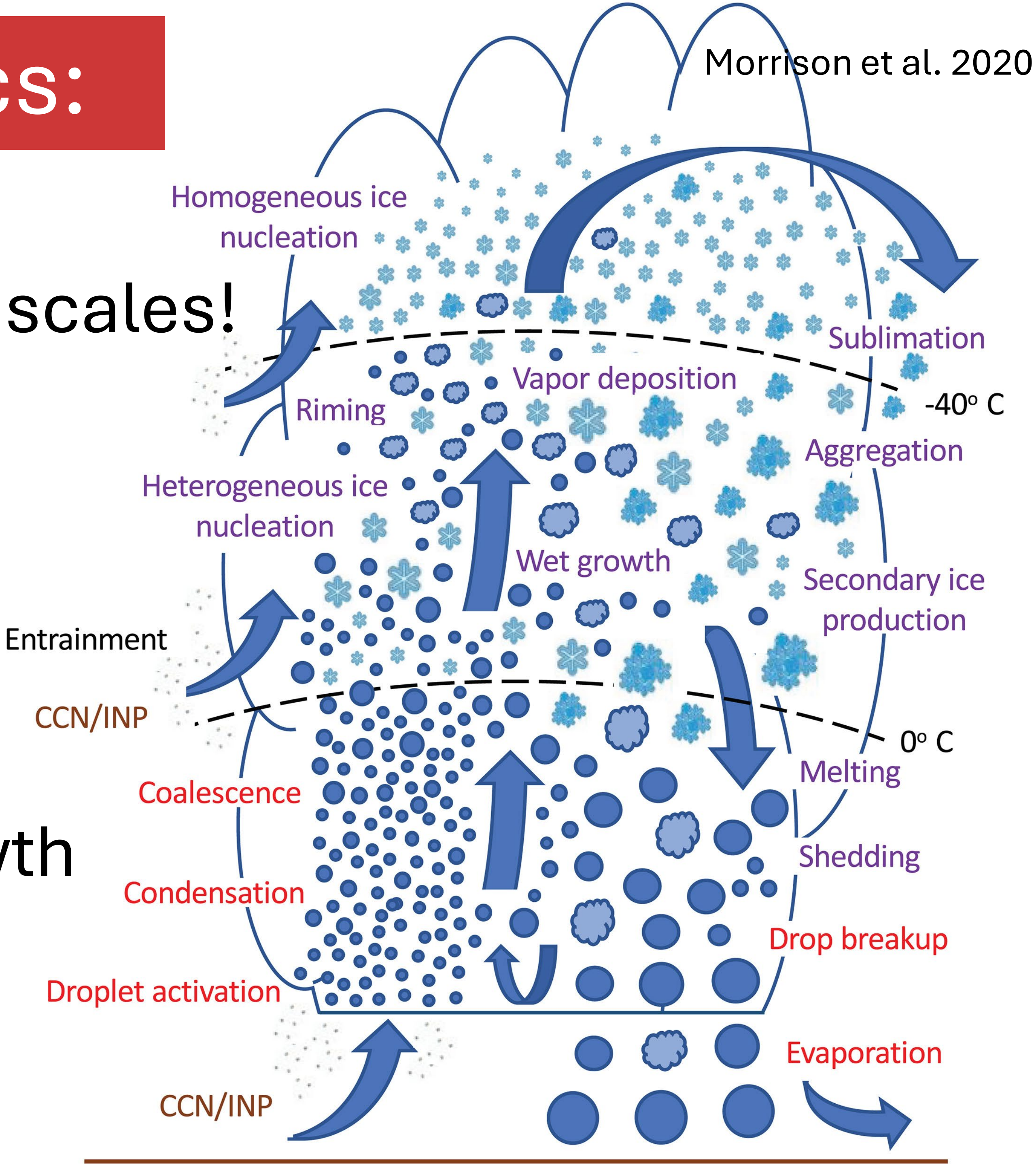
Brenda Dolan
Radar Technology Workshop
March 2026

Convective Microphysics:

Morrison et al. 2020

Challenge: Complexity across scales!

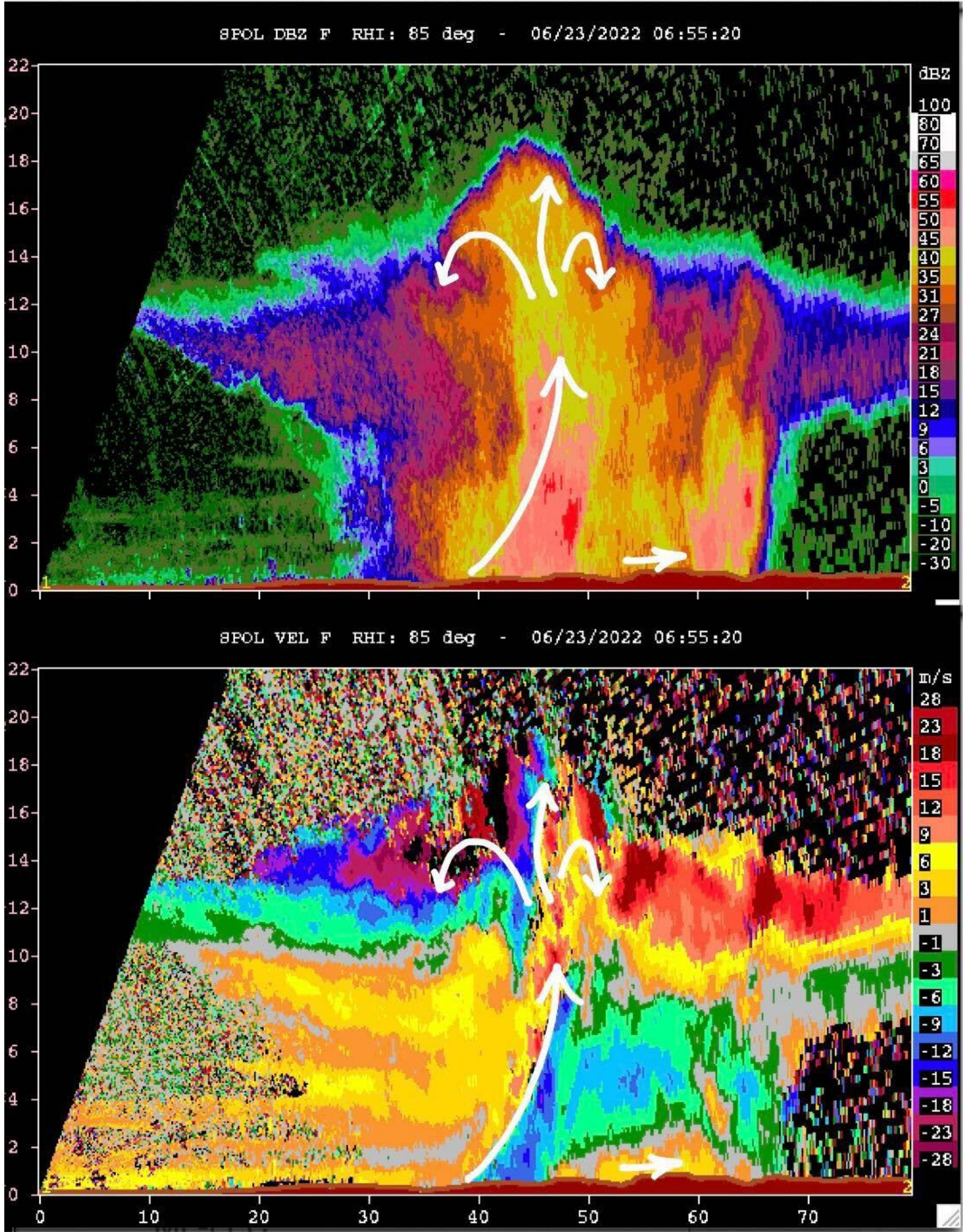
- Individual particles
  - Shape, size, density
- Distributions
  - Number, shape, diversity
- Cloud-scale
  - Collisions, removal, growth



Scales: < mm to m to km
sec to minutes

Convective Dynamics:

- Challenge: Measuring motion
  - Vertical velocity
  - Entrainment
  - Initiation
  - Organization

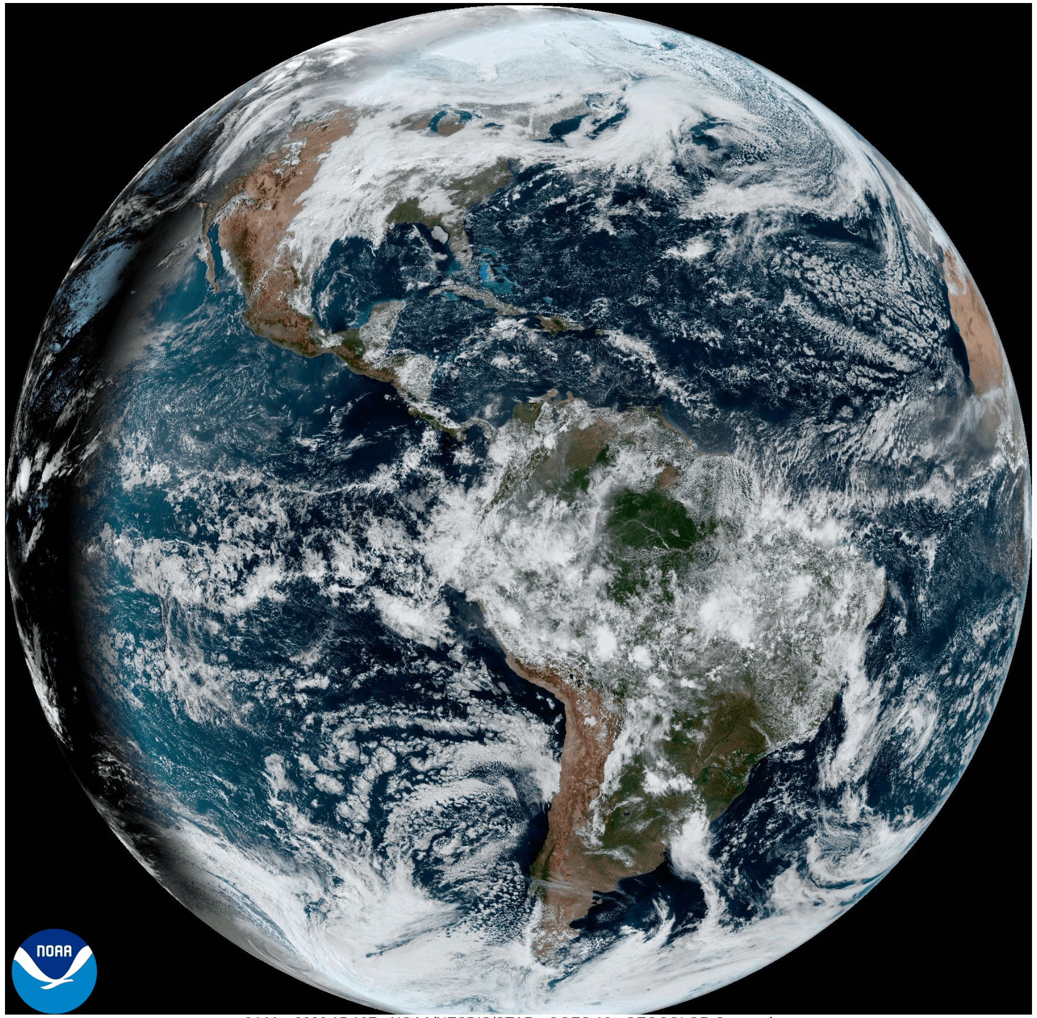


Scales: m to km<
minutes

Global Convection

- When, where, how frequent, and why (environments) across the planet

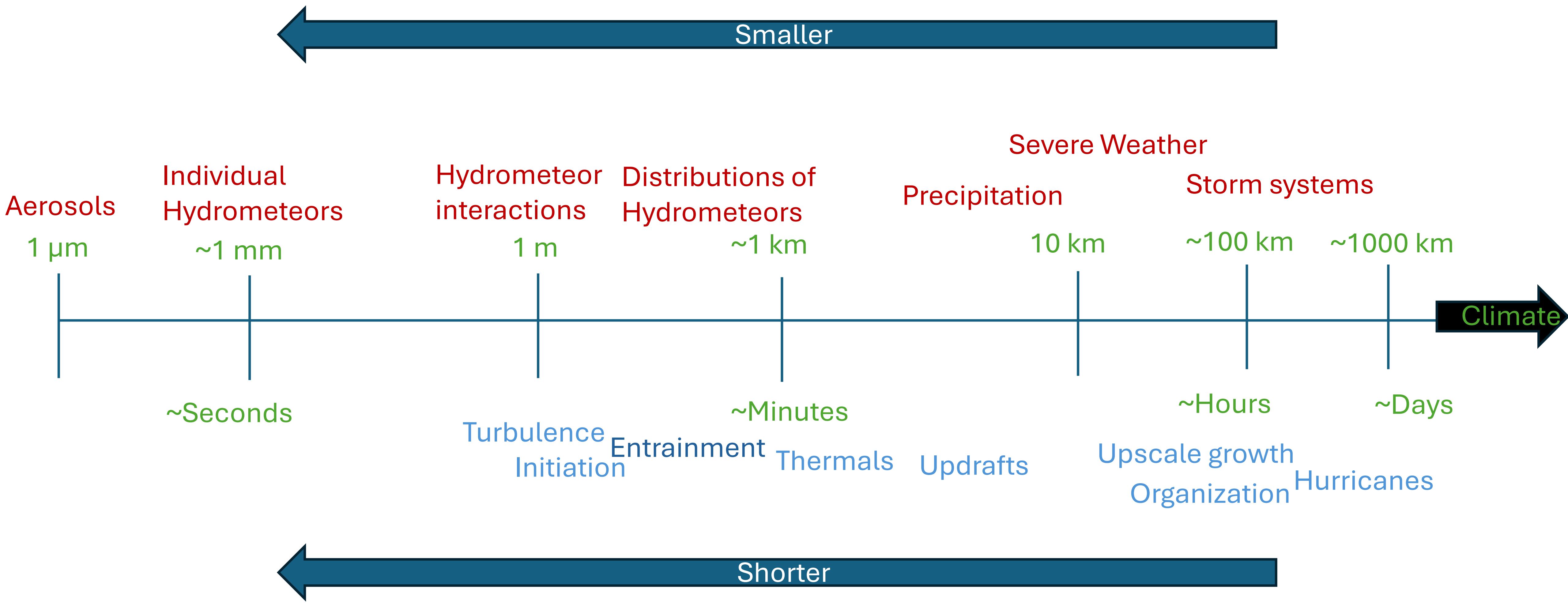
- Organization
- Environment
- Climate Sensitivity



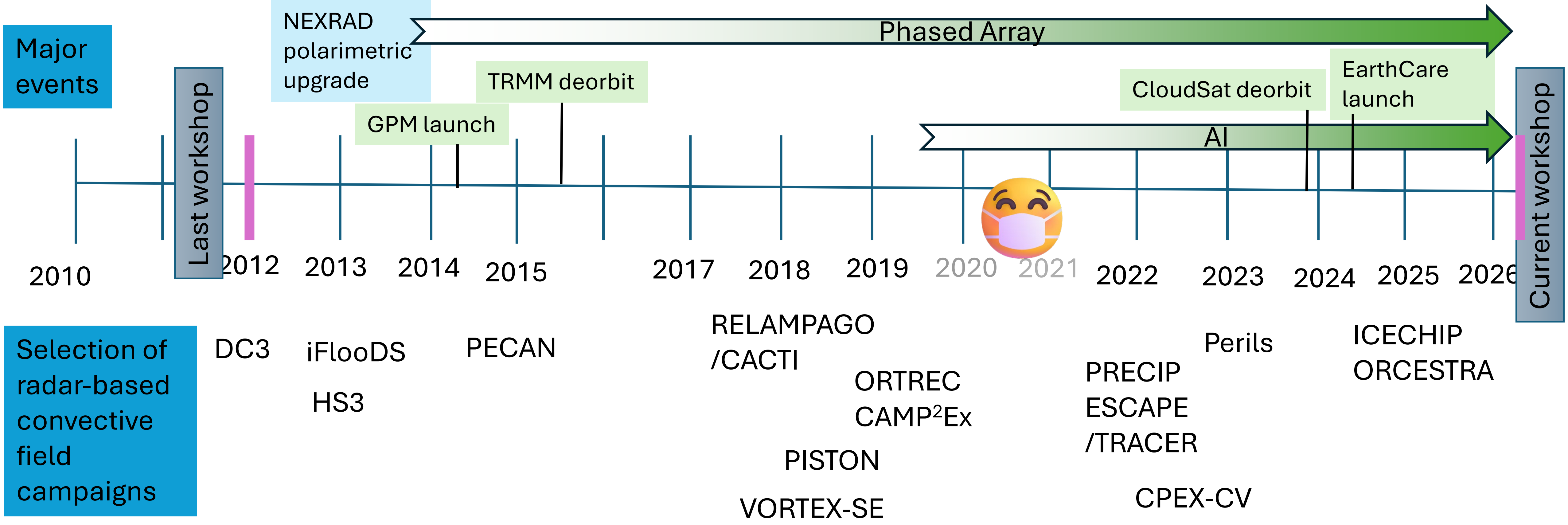
04 Mar 2026 15:10Z - NOAA/NESDIS/STAR - GOES-19 - GEOCOLOR Composite

Scales: 1000 km<
hours
climate scale

Scales of convection



Where are we now?



Radar technology and observations have underpinned great strides in convective understanding, from cloud microphysics and dynamics to precipitation to model representations

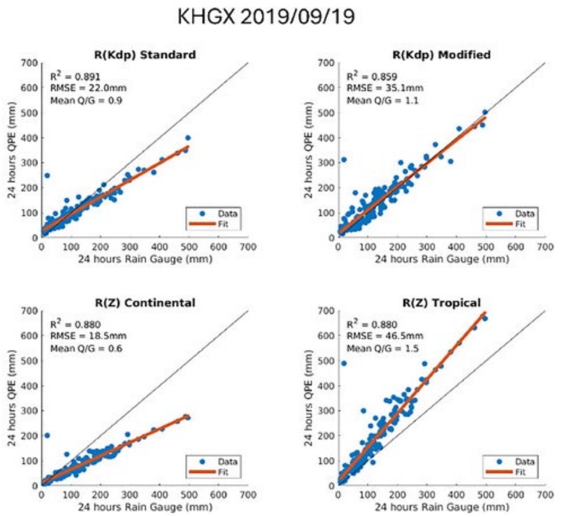
Open source and the advancement of community tools has greatly improved our ability to analyze the troves of data generated by polarimetric, Doppler, and phased-array radars.

Precipitation

Small scale

QPE – lower RMSE, better QPF

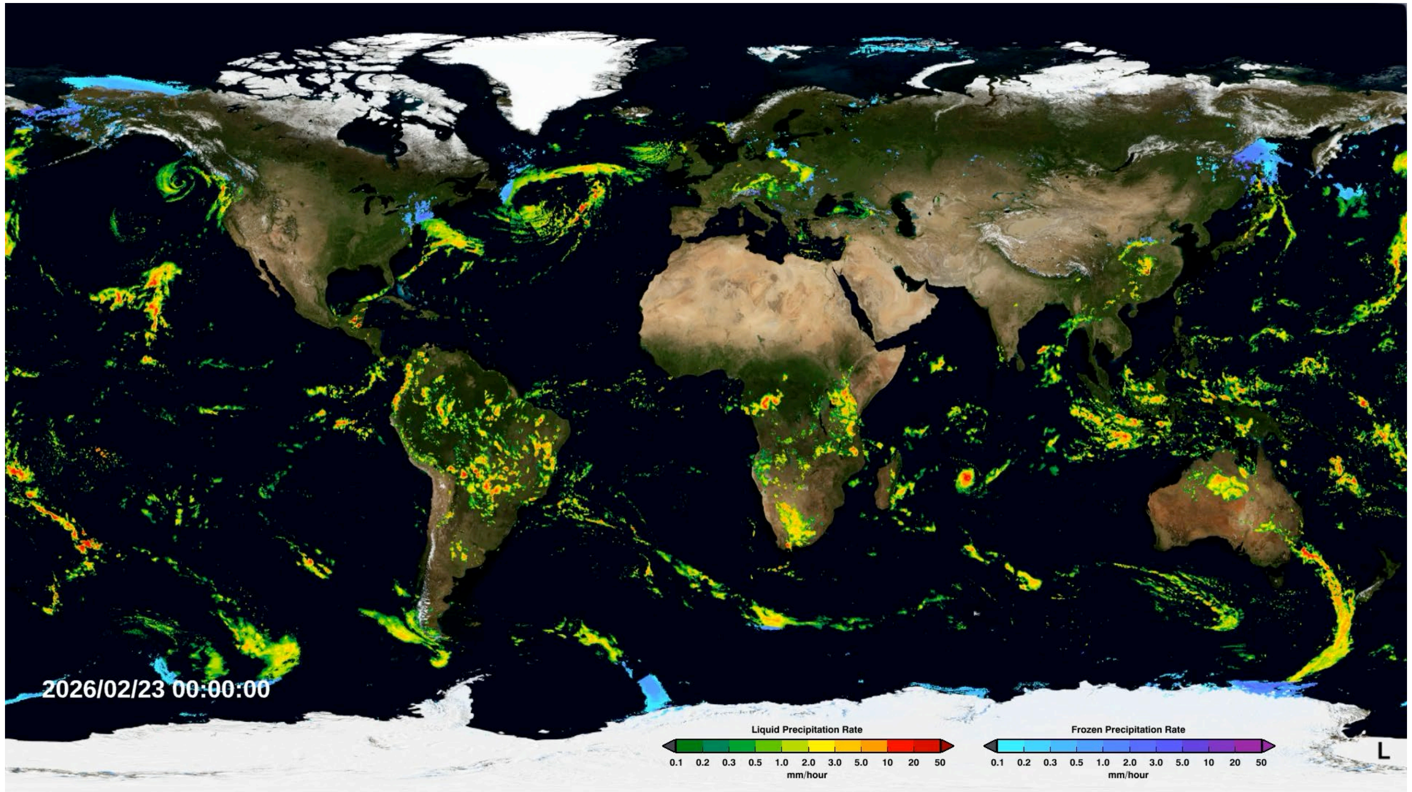
- Polarimetric radar estimation
    - R(A), R(Kdp), R(Zdr)



Ryzhkov et al. 2025

Large scale

Global distribution of rainfall on 30 min time scale!
Satellites /IMERG



We have made great strides in terms of QPE

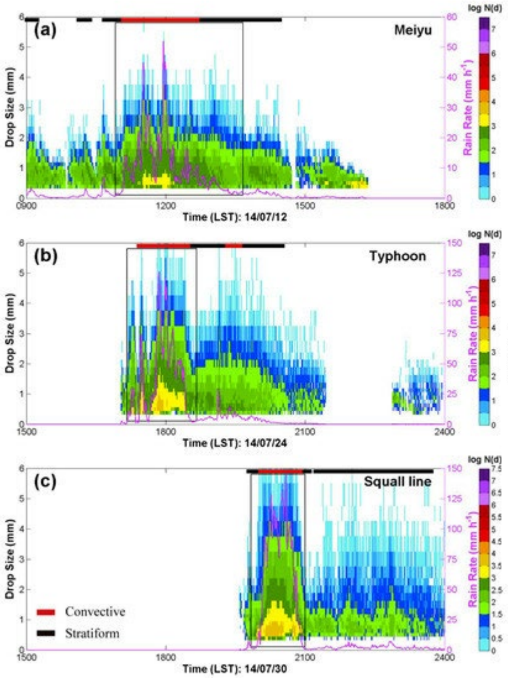
Gap: Understanding generation of heavy rainfall, long term climate trends

Precipitation: Heavy Rainfall

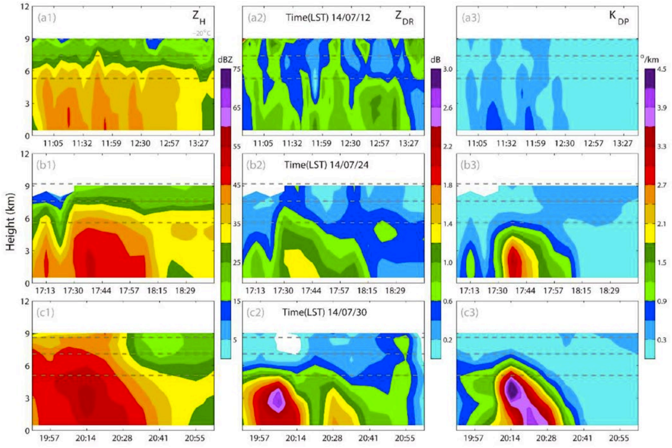
Small scale

Microphysical generation mechanisms of heavy rain

- Orographic enhancement
- Efficient collision-coalescence



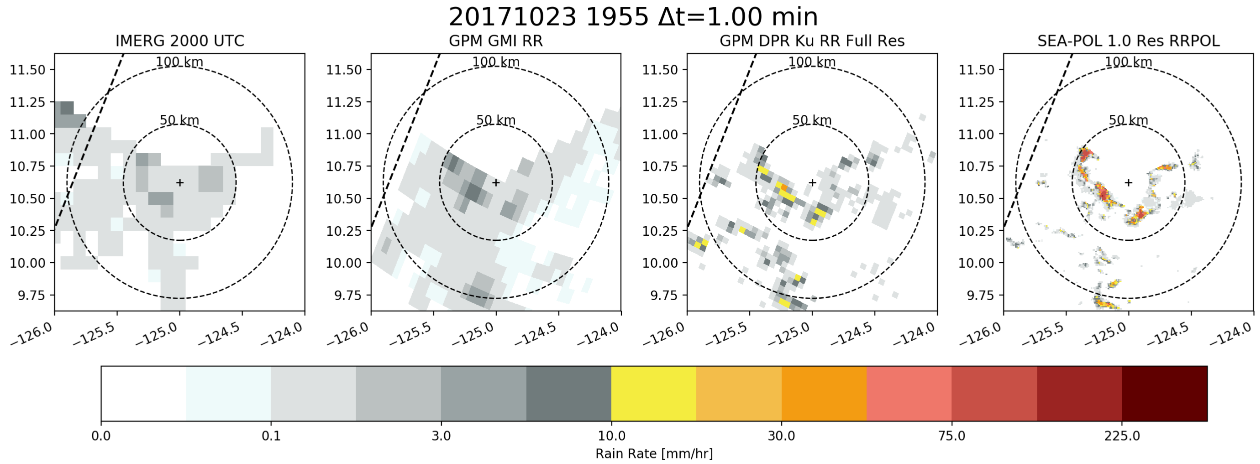
Chen et al. 2019



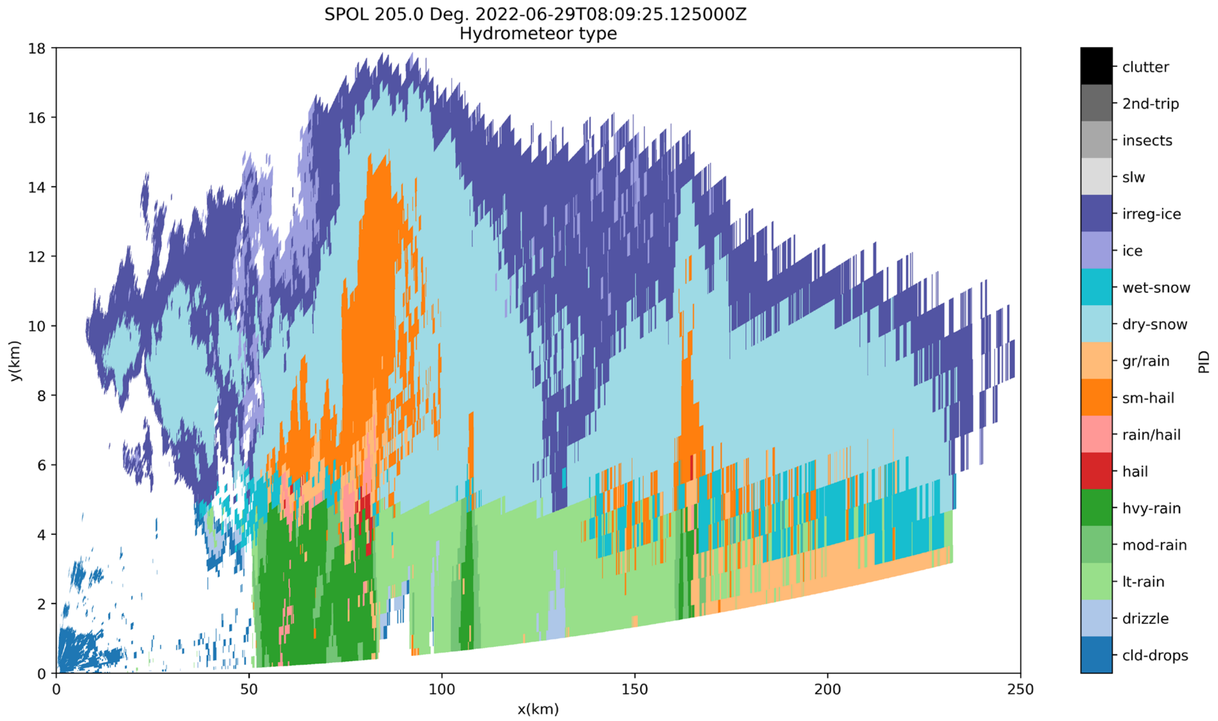
Large scale

- Blind zones from satellites
- Subfootprint variability -> scales of intensity
- Blockage in orographic regions
- Heavy attenuation in short wavelengths

IMERG GPM GMI GPM DPR Sea-Pol



Cloud Microphysics



Bulk microphysics --- classifying radar volumes into bulk particles, rough mixtures, C/S, non-meteorological echo

Bulk qualification of hydrometeor distributions and processes

	Z	Z_{DR}	K_{DP}	ρ_{hv}
Size sorting	↓	↑	↓	↔
Evaporation	↓	↔	↓	↔
Coalescence	↑	↑	↑	↓
Breakup	↓	↓	↓	↑
Freezing	↓	↓	↓	↓
Refreezing	↓	↑	↑	↓
Depositional growth of ice	↑	↑	↑	↓
Aggregation	↑	↓	↓	↑
Riming	↑	↓	↓	↑
Melting / wet growth of hail	↑	↑	↑	↓

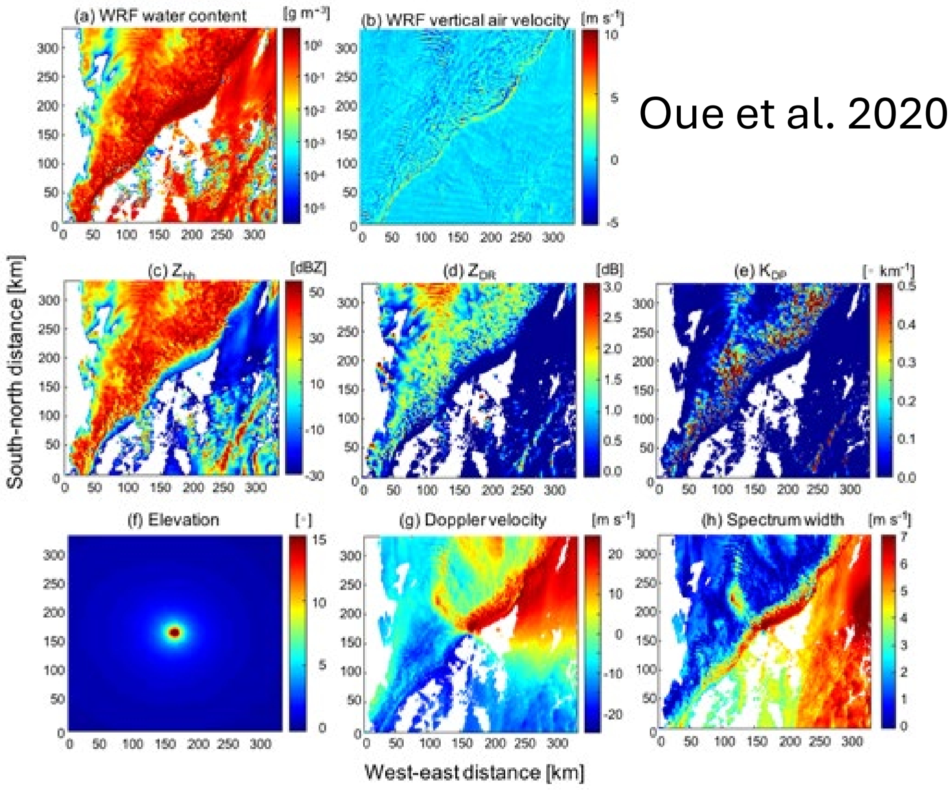
Kumjian 2012 and Ryzhkov and Zrnic 2019

Microphysical fingerprinting: Inferring processes acting in cloud from changes in polarimetric variables

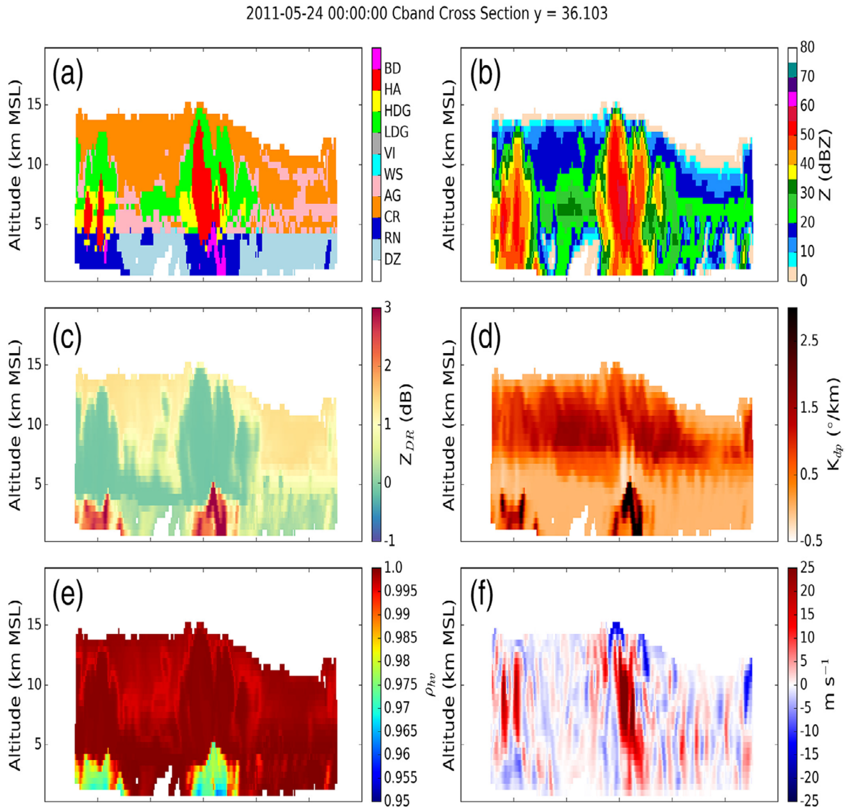
Gap: ***Quantification*** of number, type, characteristics, and process rates

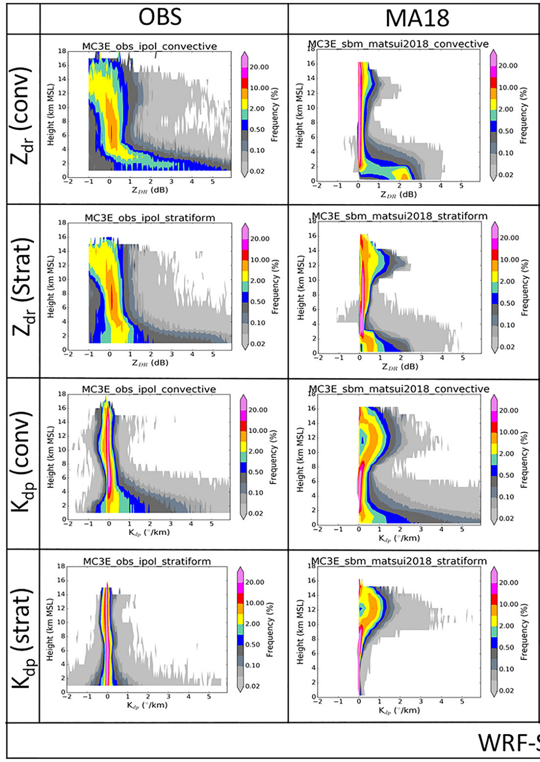
Cloud Microphysics and Models

Forward modeling of model simulations to radar space



Oue et al. 2020





Matsui et al. 2019

Linking models to observations through forward models in a way that benefits both parameterizations and radar retrievals

Gaps: Providing the predictands in the model (number, characteristics), ***ice and mixed phase***

Ice, Ice Baby….

- Inform models – parameterizations
- Process rates
- Remote sensing retrievals
- Precipitation generation
- Radiative impacts

How it started

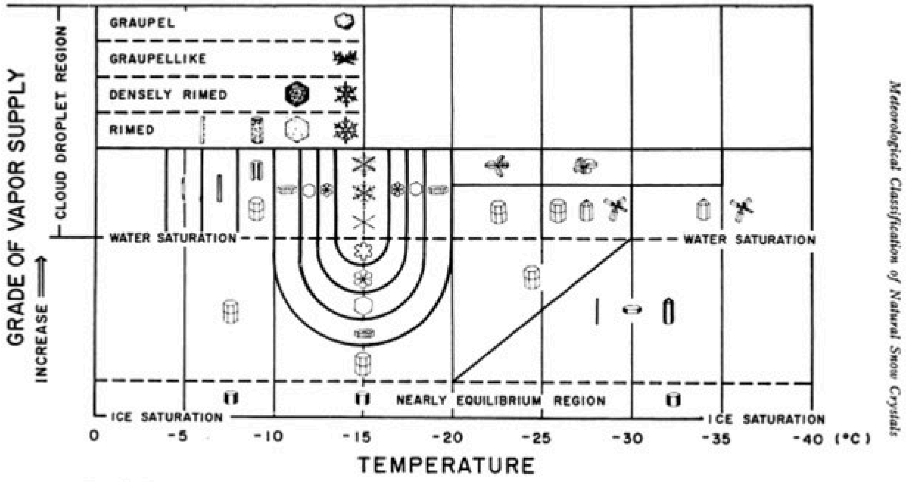
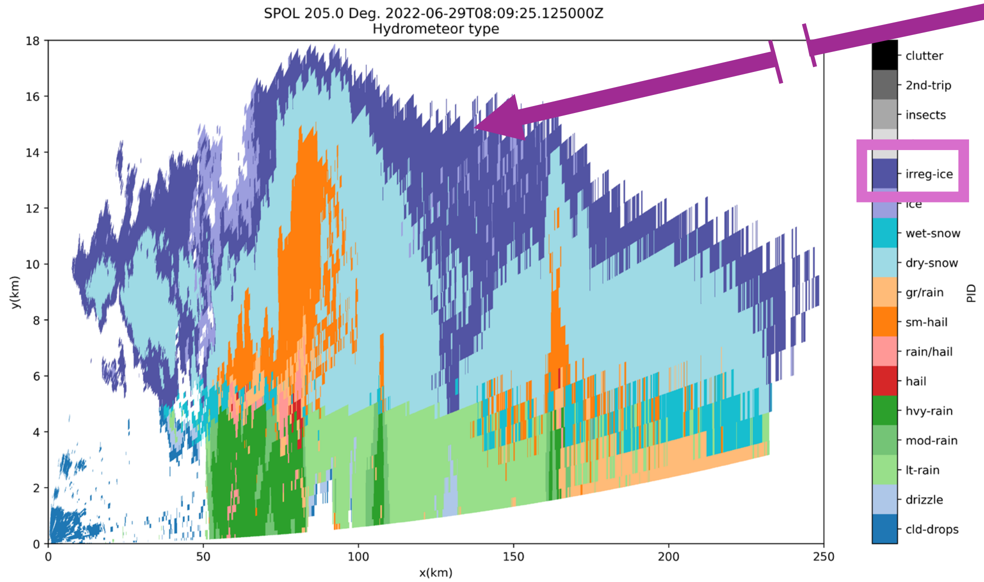
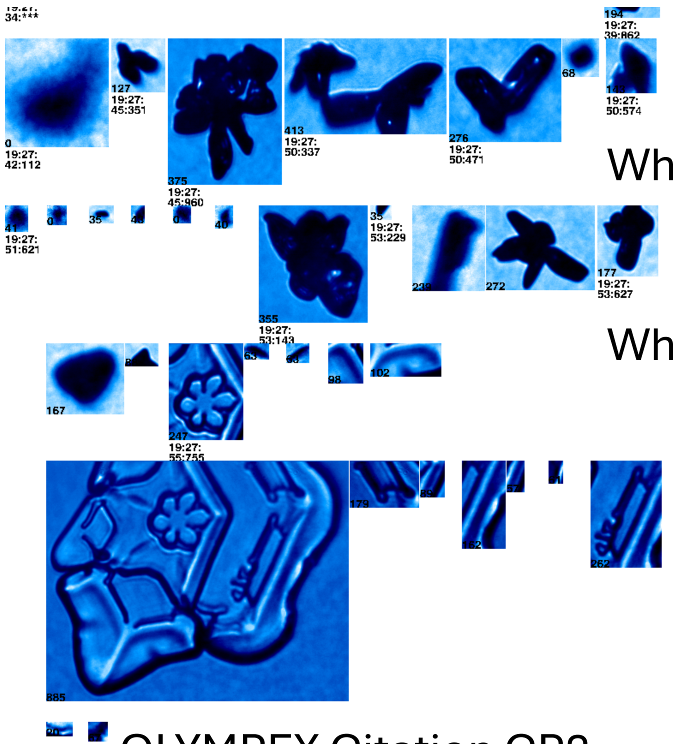


Fig. 2. Temperature and humidity conditions for the growth of natural snow crystals of various types

Magano and Lee, 1966



How it's going



What is the size distribution?

What about mixtures?

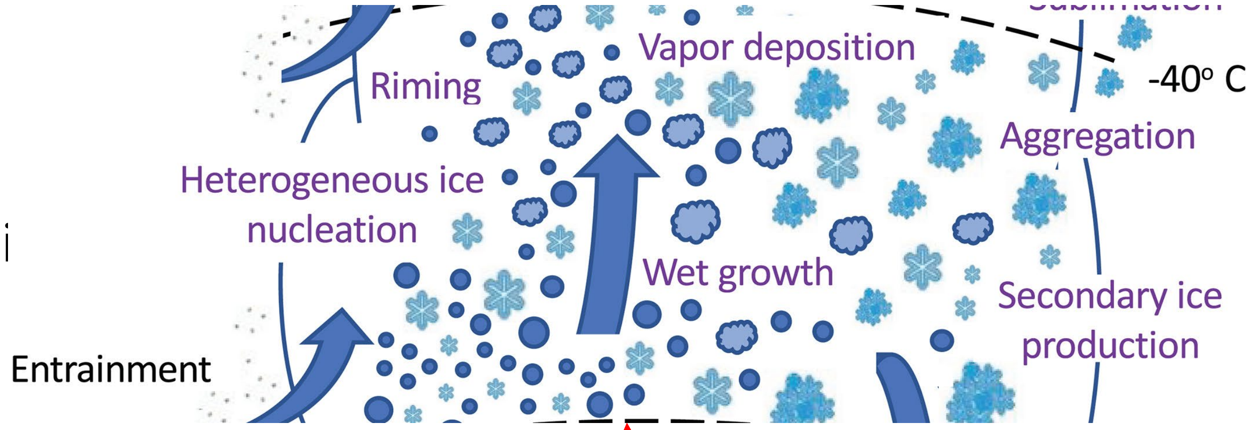
What are the densities?

What are the scattering characteristics?

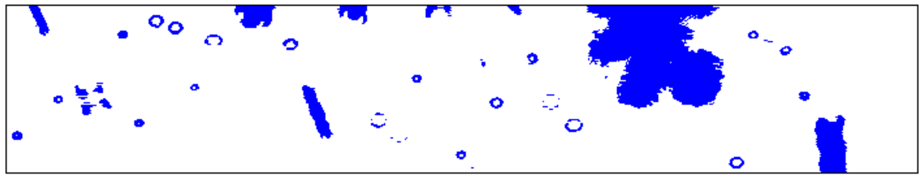
OLYMPEX Citation CP2

Mixed Phase

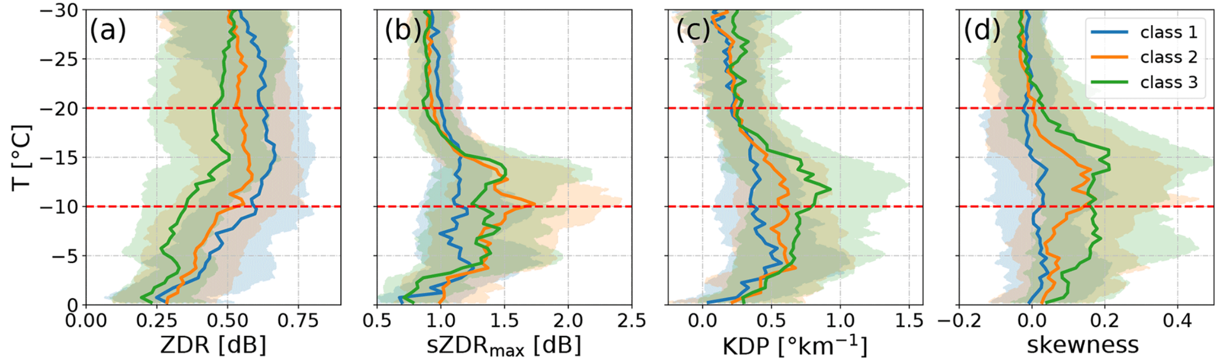
- Many processes
  - Important for modeling physics, precipitati estimation, and forecasting
- Super-cooled liquid water amount
  - Attenuation, riming, aircraft icing, electrification
  - Hail growth
    - Impact on size and concentration falling at surface
- Mixtures, melt fraction
- Challenging to validate



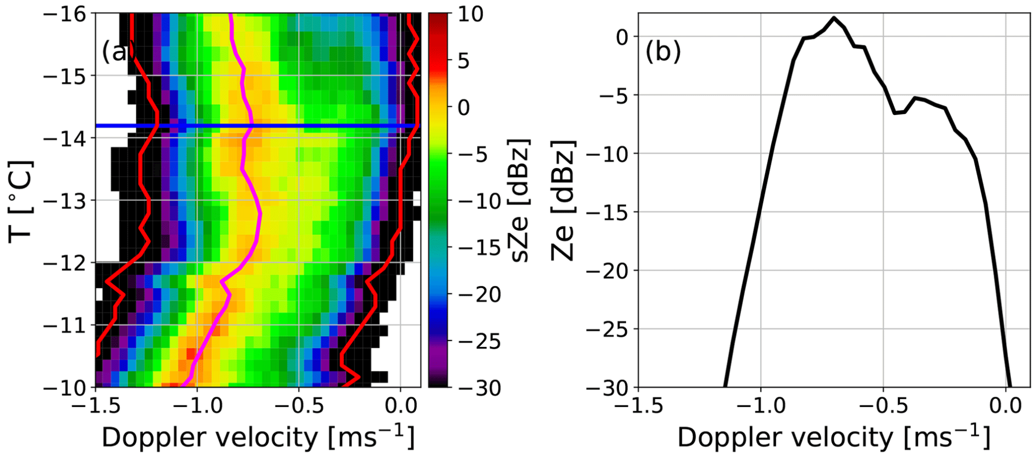
This may be one radar pulse volume!



OLYMPEX Citation 2DS

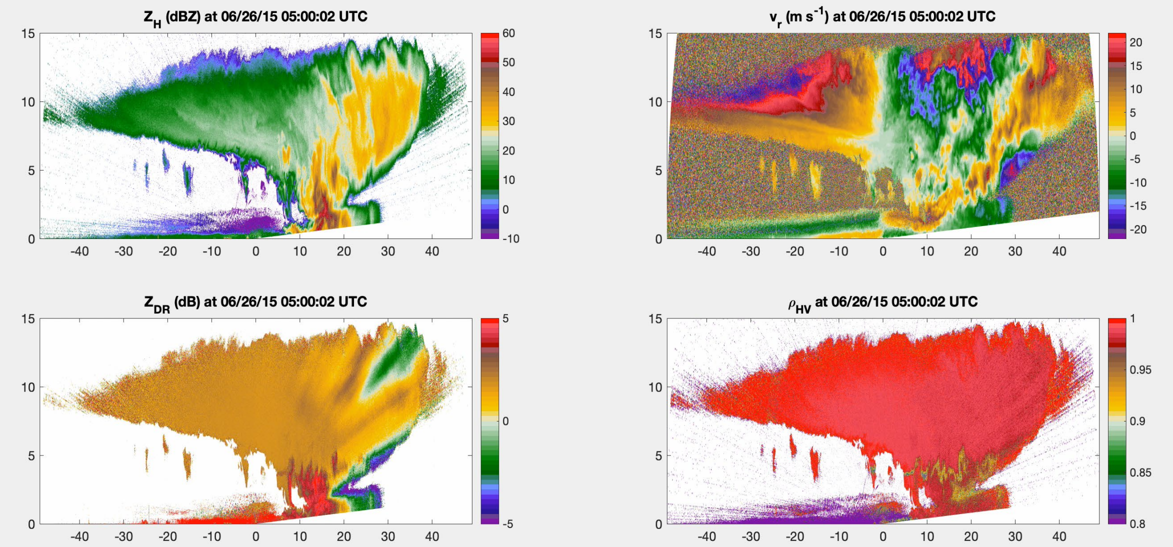


Terzi et al. 2022



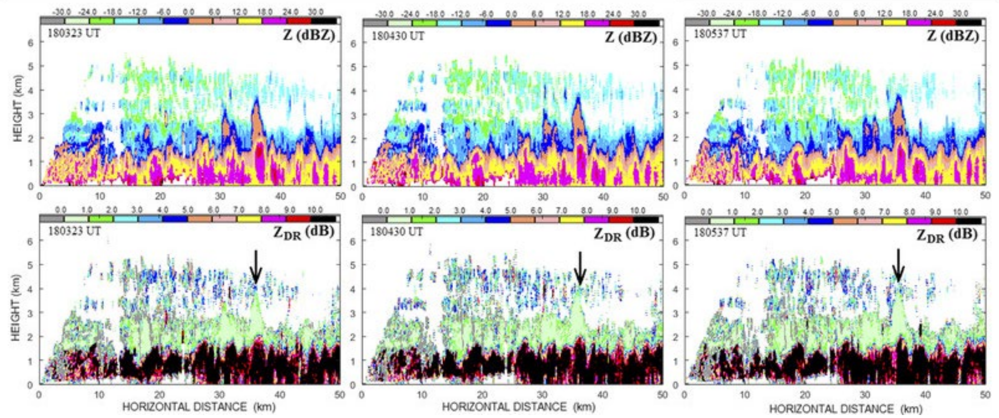
Convective Dynamics

- Characteristics of updrafts / downdrafts



Courtesy D. Bodine and H. Bluestein, OU

Melnikov and Zrnic 2017

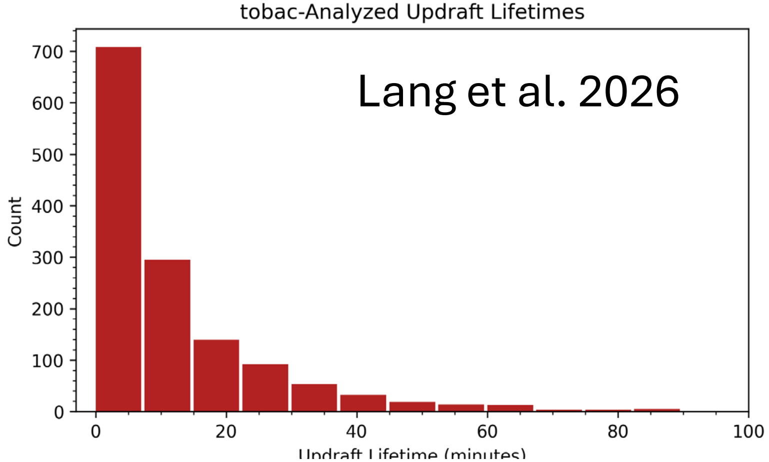


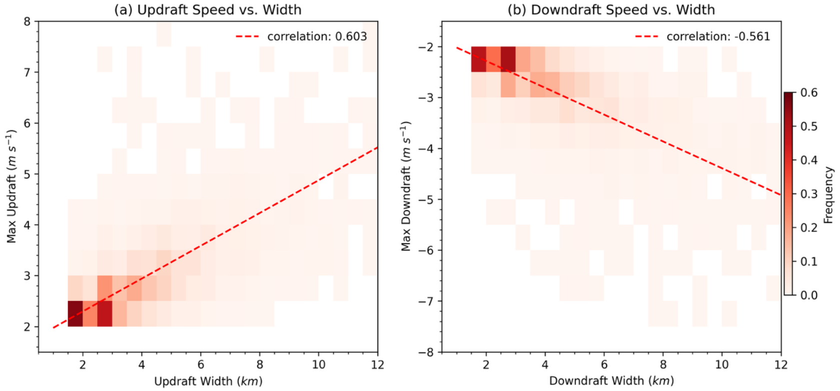
Agile radars and fast updates are closer to convective scales – learning about thermal structures and growth

Gaps: **Initiation**, lifecycle, mass flux, entrainment rates

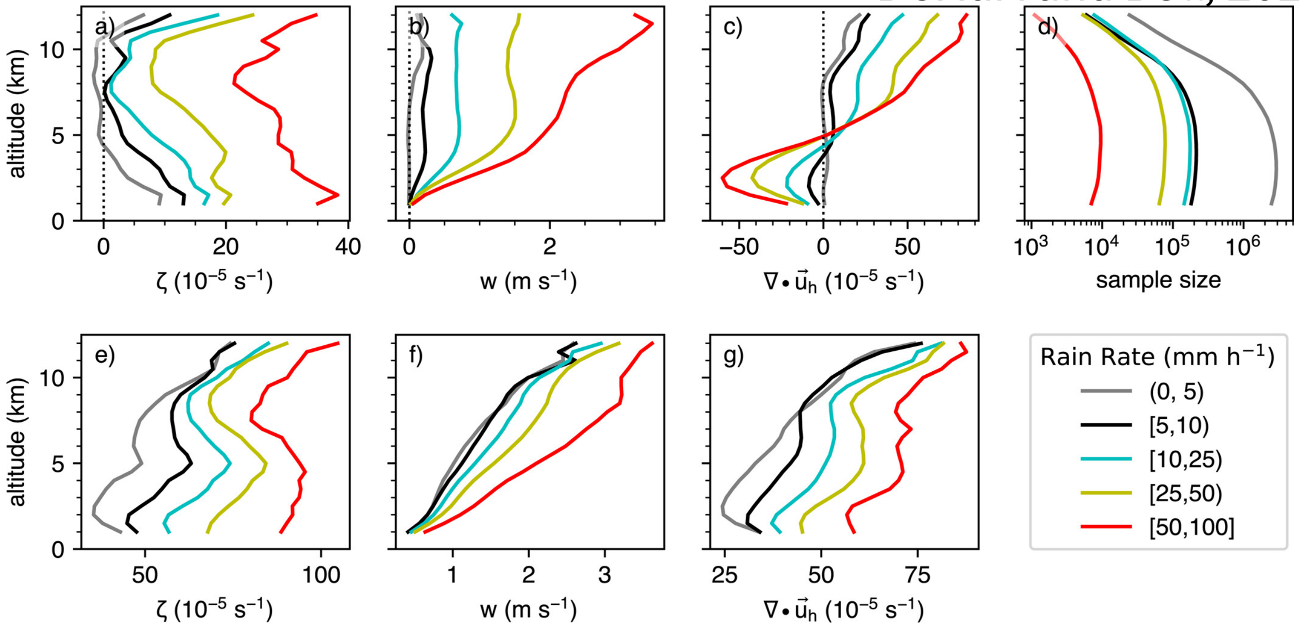
Convective Dynamics: Vertical Velocities

- Doppler retrievals





DeHart and Bell, 2025



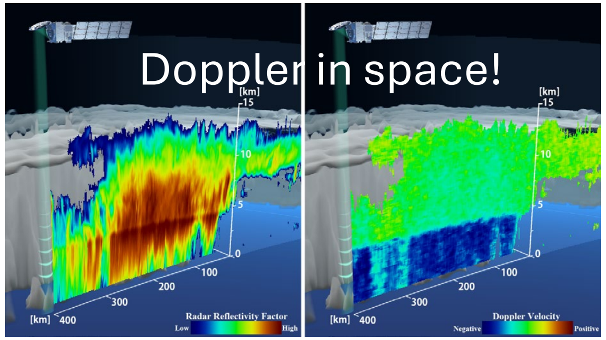
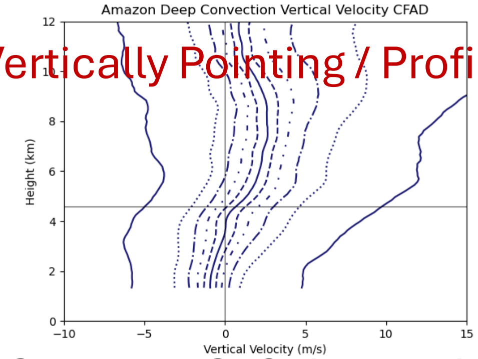


Image credit: JAXA/NICT/ESA

Vertically Pointing / Profilers

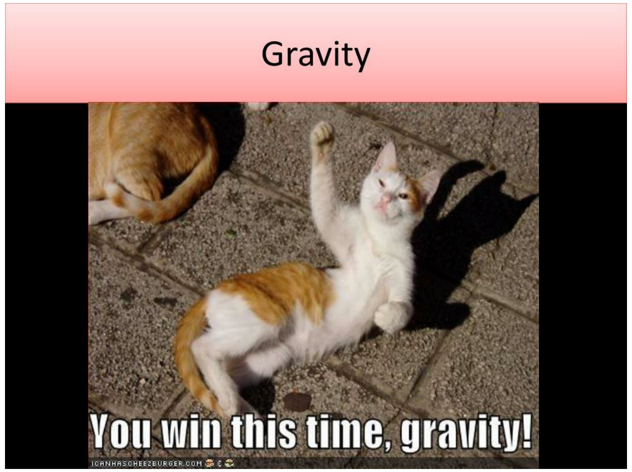


Courtesy C. Schumacher

Community tools for multi-Doppler and tracking provide multi-day systematic and statistical evaluation of motions and characterizations of updraft scales

Gaps: **Fall speeds**

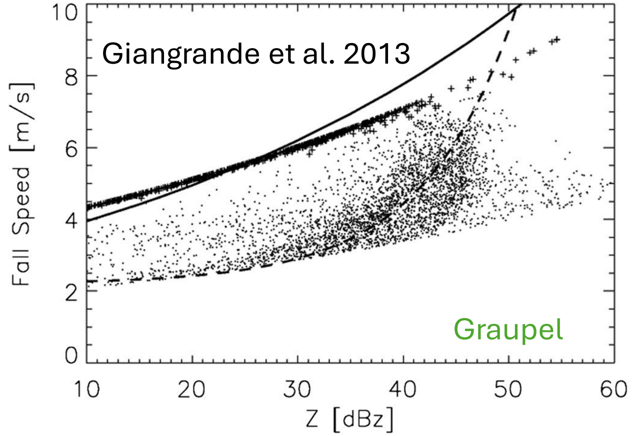
Vertical Velocities – Fall Speeds



All Doppler velocity measurements of precipitation-sized hydrometeors include contributions from the particle fall speeds

- Estimation usually relies on Z-v_t relationships
- Especially challenging in convection

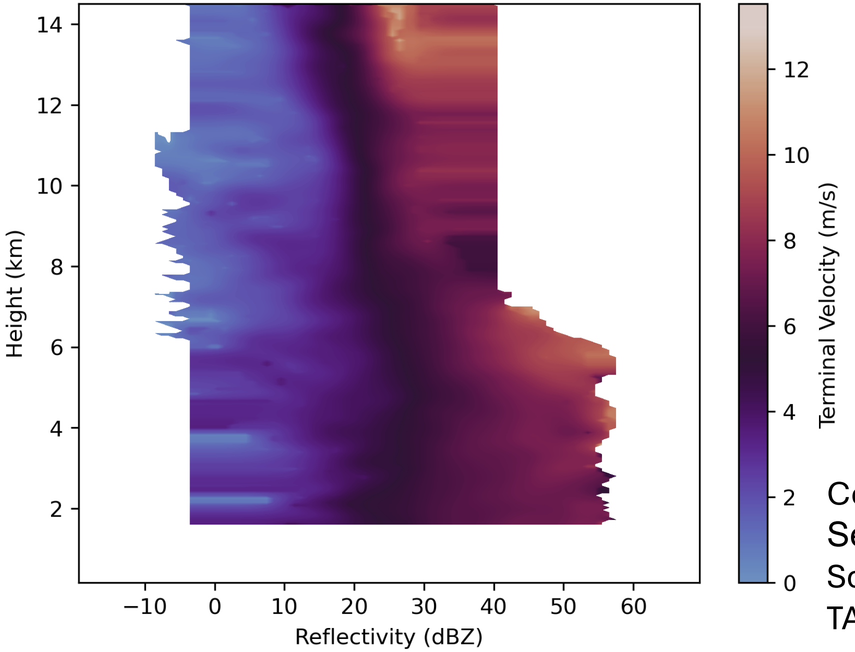
Example: Graupel



Graupel fall speed vs. reflectivity for different densities

And that's assuming a uniform volume of graupel!

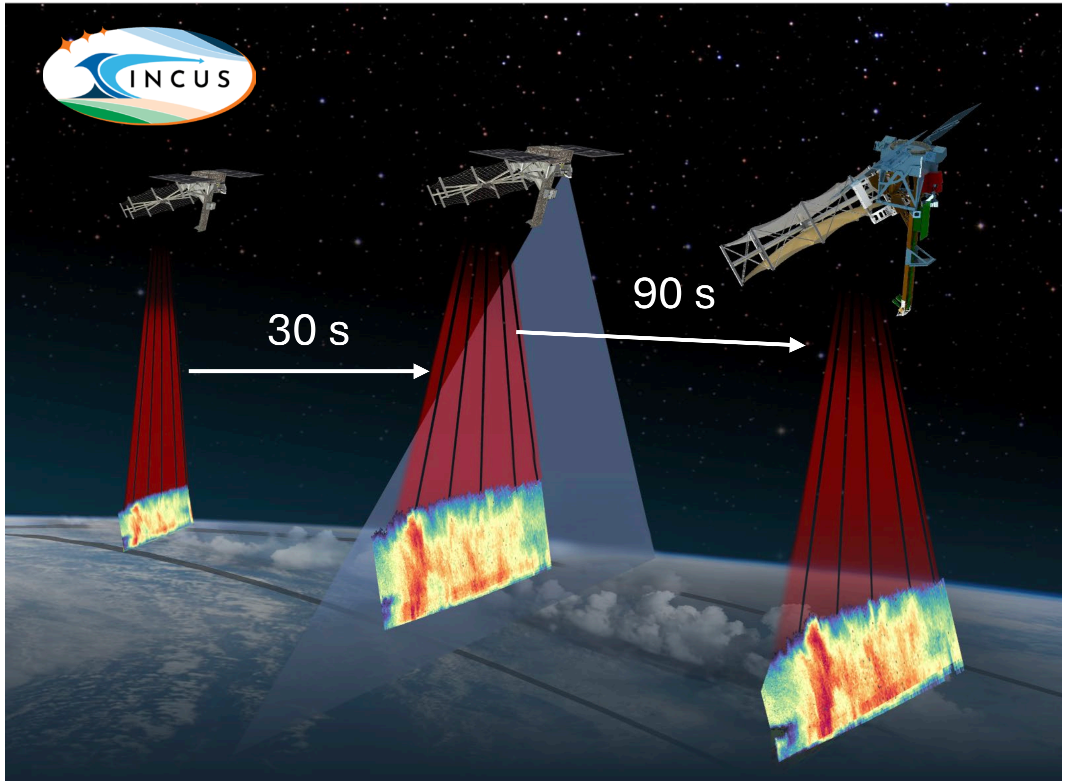
Terminal velocity LUT derived from Darwin 50 MHz + 920/1290 MHz applied to Amazon RWP instead of using assumed fall speed relations

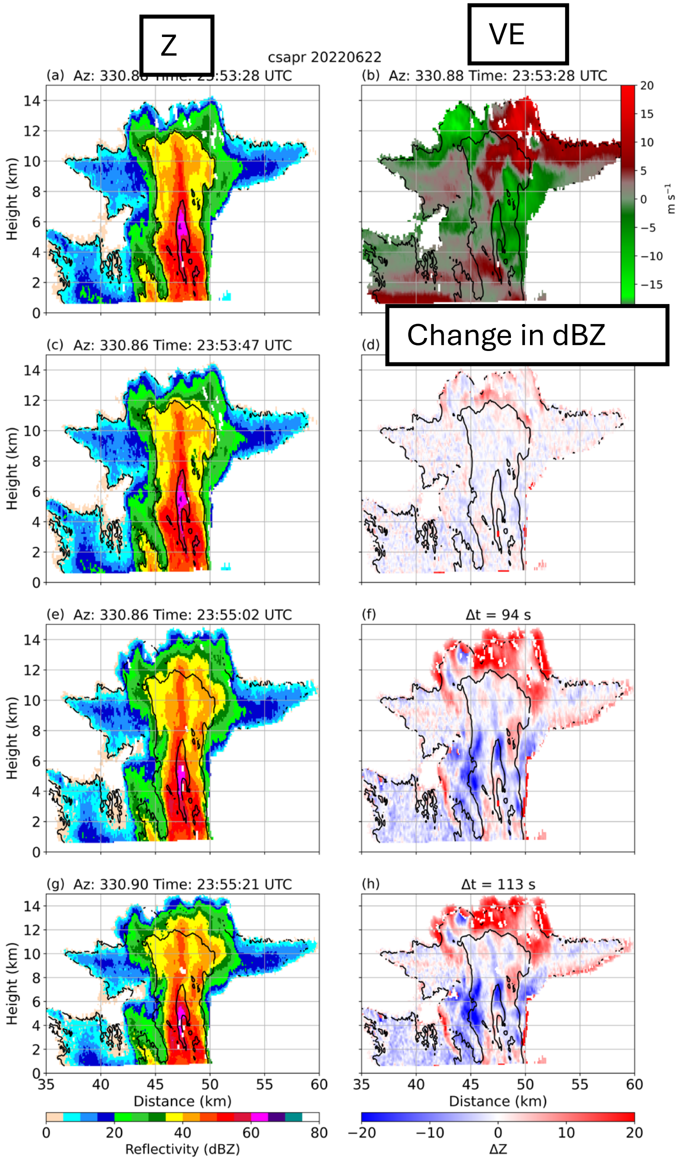


Courtesy A. Sebok and C. Schumacher TAMU

Vertical Velocities:

Snapshots of reflectivity over short time periods minimize the contribution from particle fall speeds





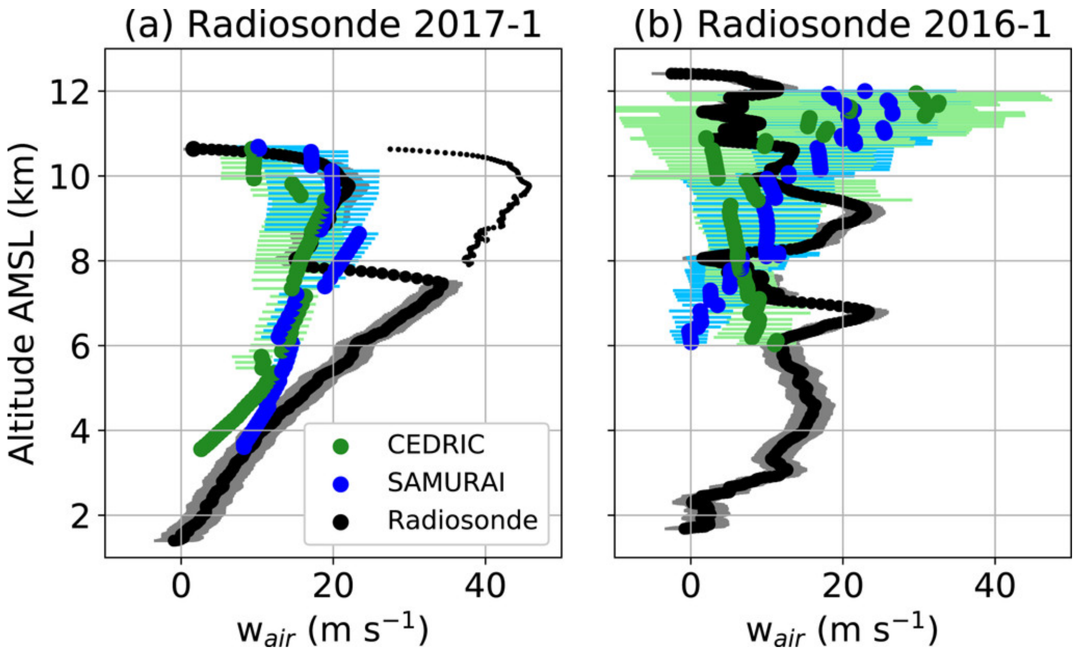
19 s

94 s

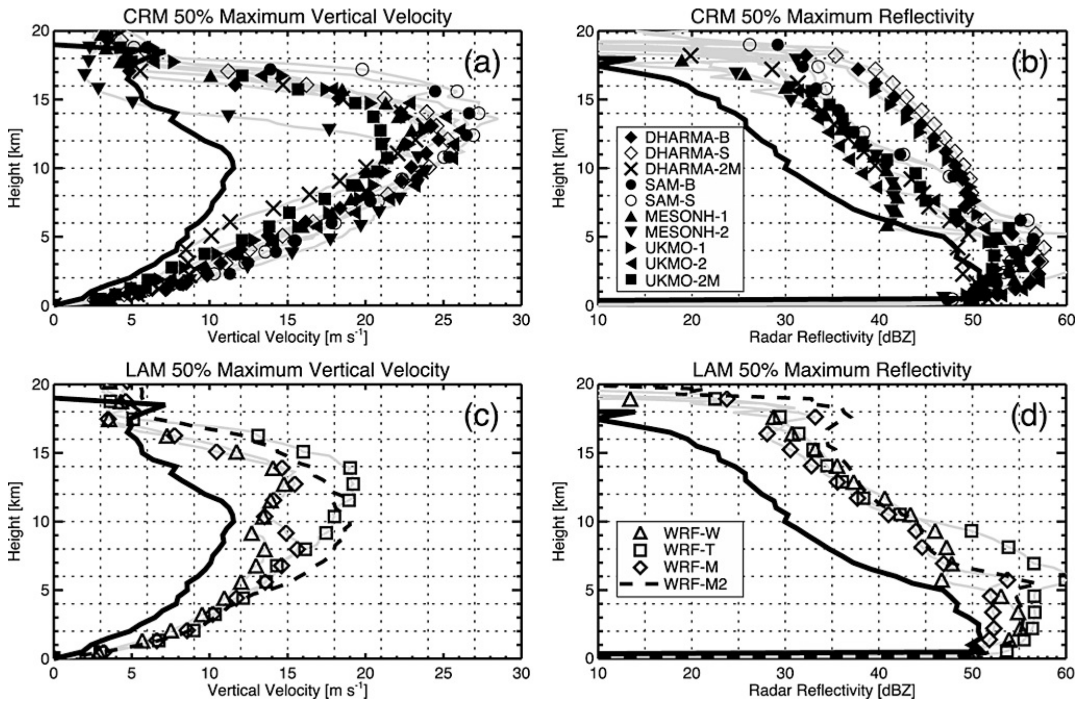
113 s

Dolan et al. 2023

Vertical Velocities - Uncertainties



Marinescu et al. 2020



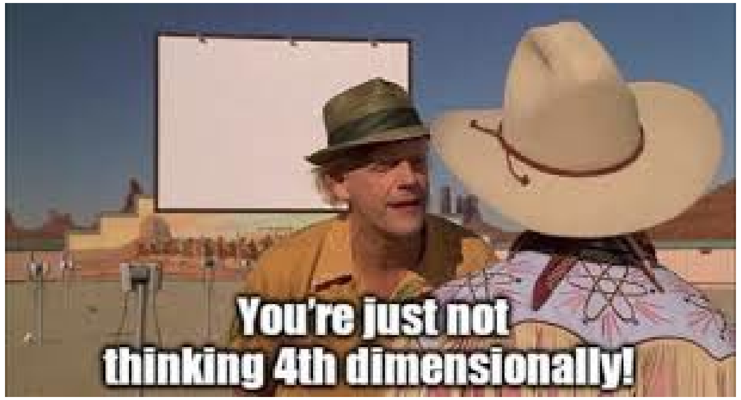
Varble et al. 2014

What are the uncertainties in different retrieval/measurement methods, and how does that vary across spatial and temporal scales?

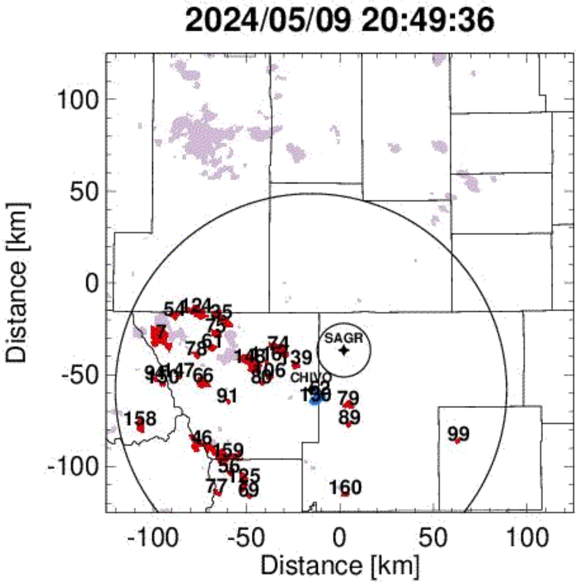
- Key parameter sought by modelers
- Important for mass flux, severe weather, global circulation

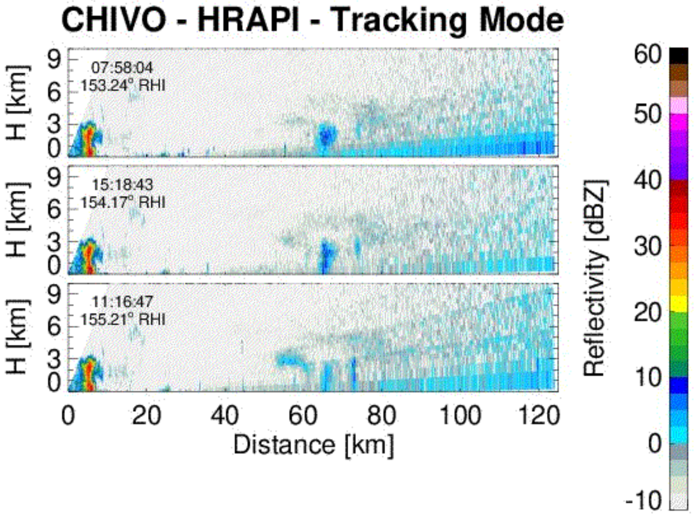
Process Rates

- What are the process rates (/efficiencies) and their variability?
  - Microphysics (breakup, collision-coalescence, aggregation)
  - Dynamics (entrainment, vorticity terms)
  - *Requires rapid scanning of same volumes for time derivatives*



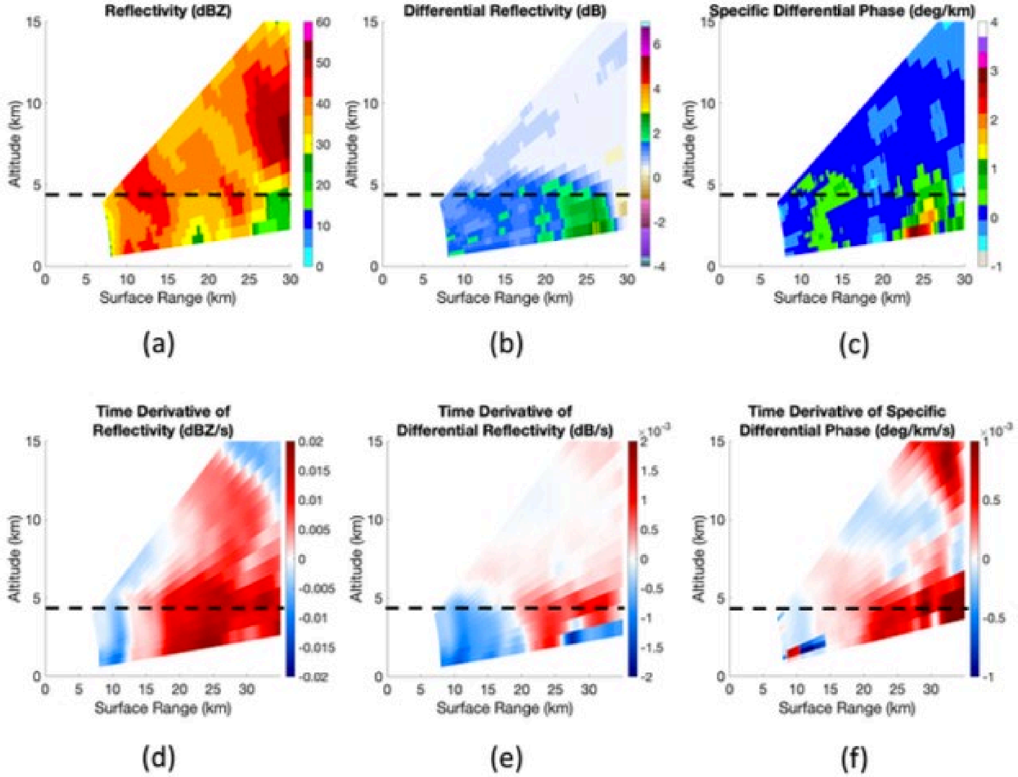
Adaptive tracking + scanning





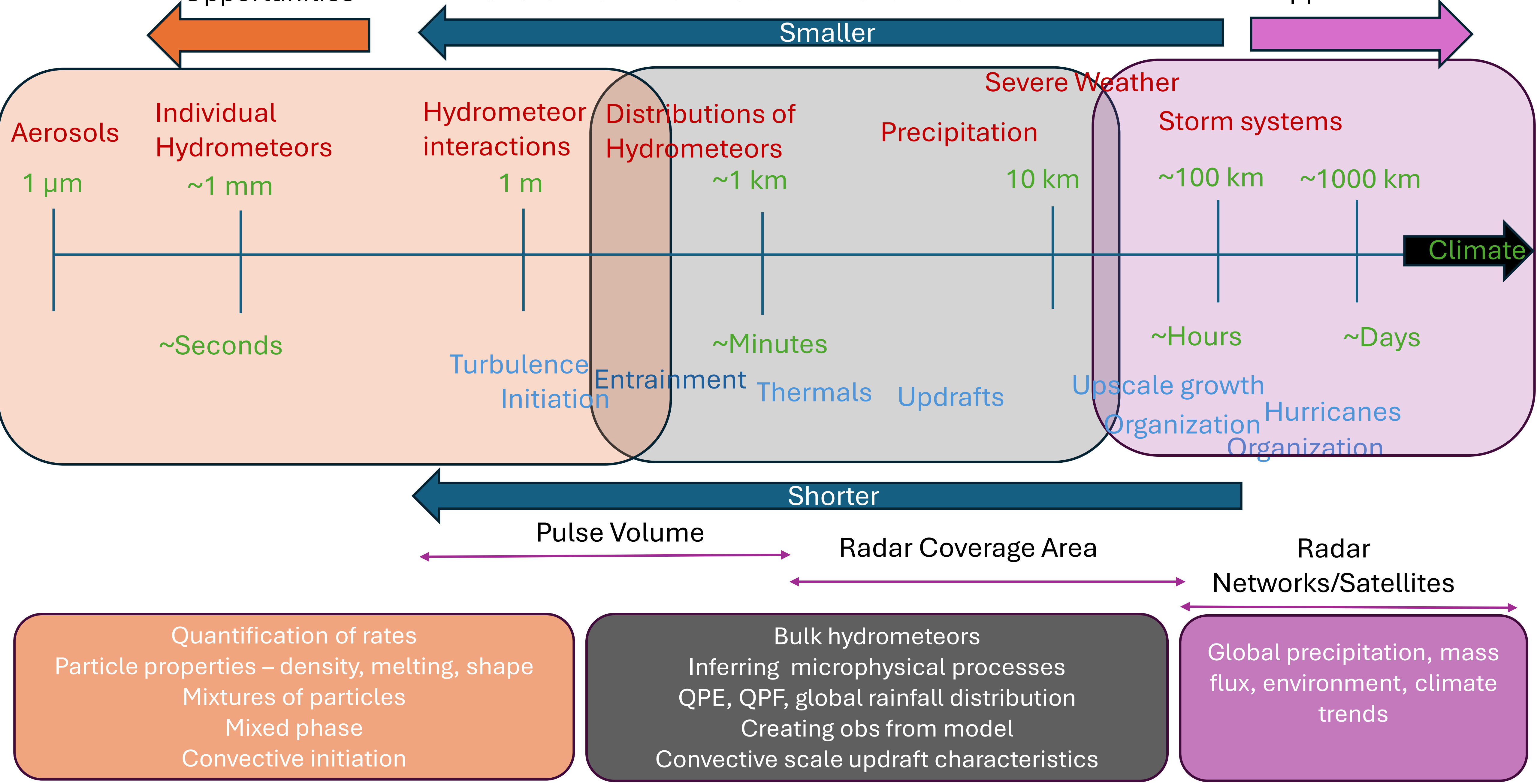
Multi-sensor Agile Adaptive Sampling (MAAS)
Lamer et al. 2023

PAR

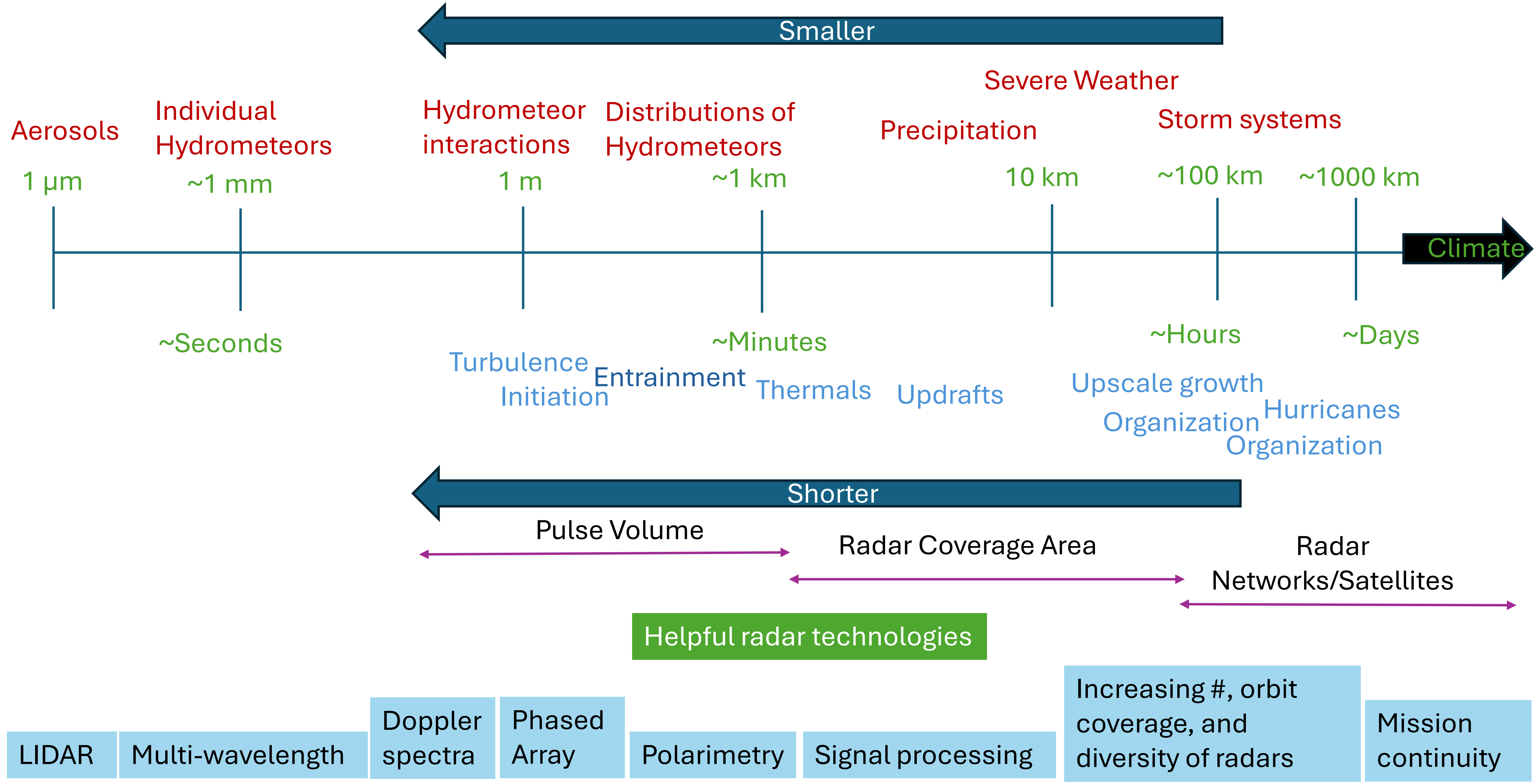


Matland-Dixon et al. 2026

Scales of convection



Scales of convection



In summary

- Radar technology, analysis tools, and computing power have pushed us forward in terms of understanding
  - bulk microphysics
  - updraft structures and statistics
  - improved precipitation estimates
  - forecasting severe weather
- To address outstanding questions in convection, future technology must be
  - smaller and *faster*
  - diverse and creative sampling strategies
  - Long term, global coverage of cloud processes for climate variability