Validating and ***Improving*** Simulated Deep Convective Vertical Velocities

Past Work and Future Directions

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A lot of collaborators and inspiration that will be mentioned throughout the talk

ARM/ASR PI Meeting

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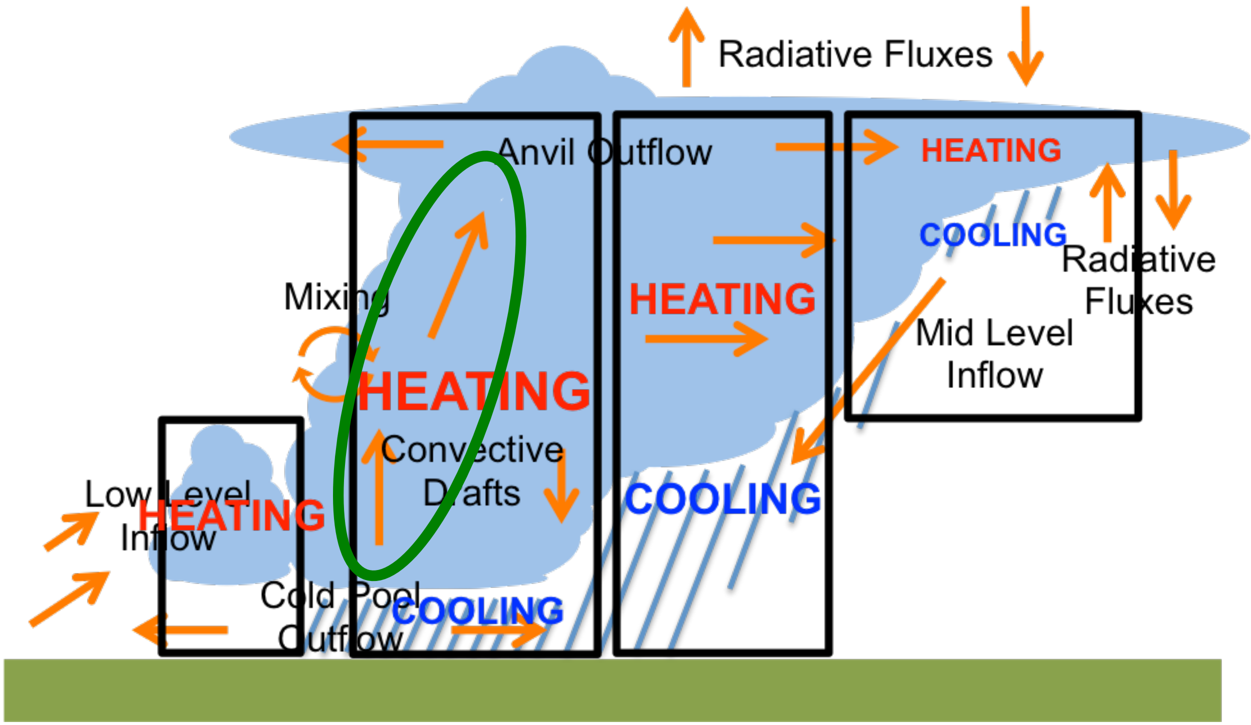
Why do we care about convective vertical velocities?

Fundamental control on microphysical processes (thus cloud and precipitation characteristics) and redistribution of heat, moisture, momentum, aerosols, and hydrometeors

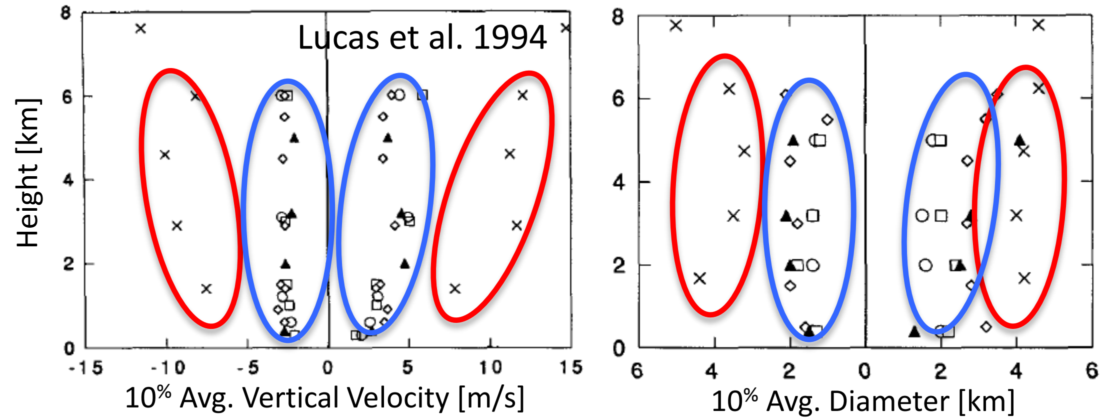


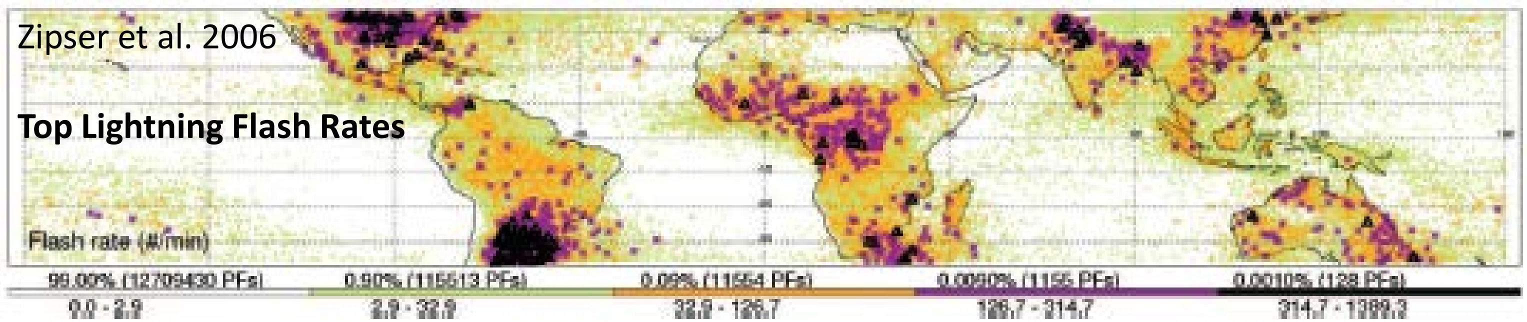
Modelers request vertical velocity and condensate measurements

Vertical velocity depends on a number of components that interact in complex ways, so **moving from model validation to improvement is not straightforward**

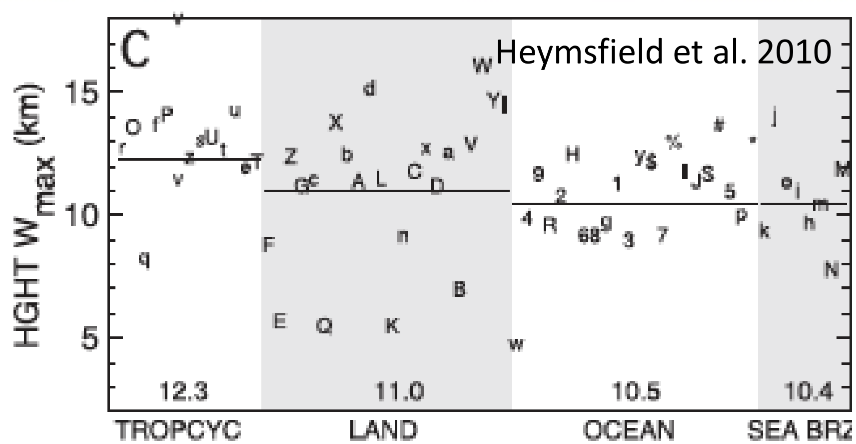
Convective vertical velocity values and scales

Significantly vary depending on environmental conditions (stability and wind profiles, forcing mechanisms)





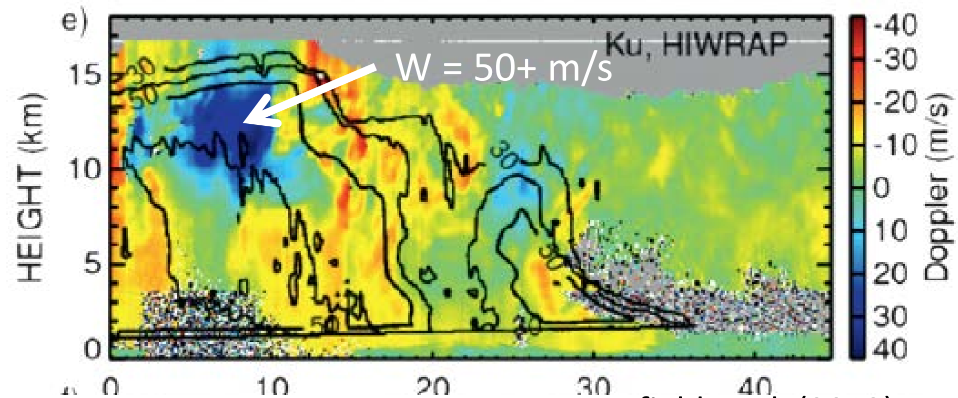
Statistically peaks in the upper troposphere because vertical velocity is a function of integrated buoyancy (acceleration)



Available observations and retrievals

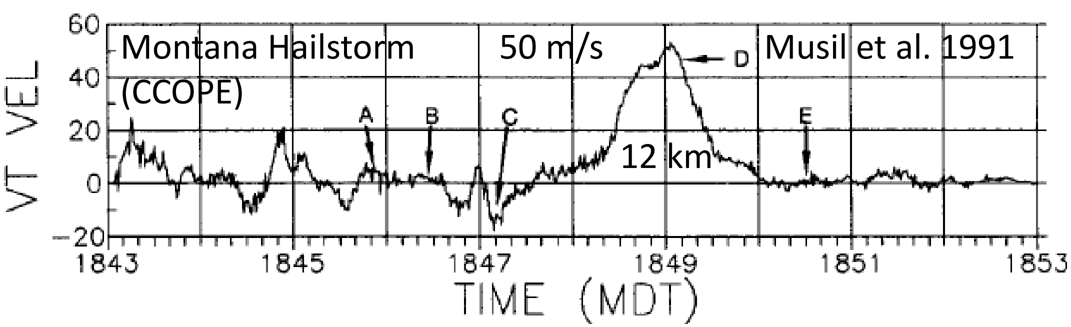
Remote Sensing

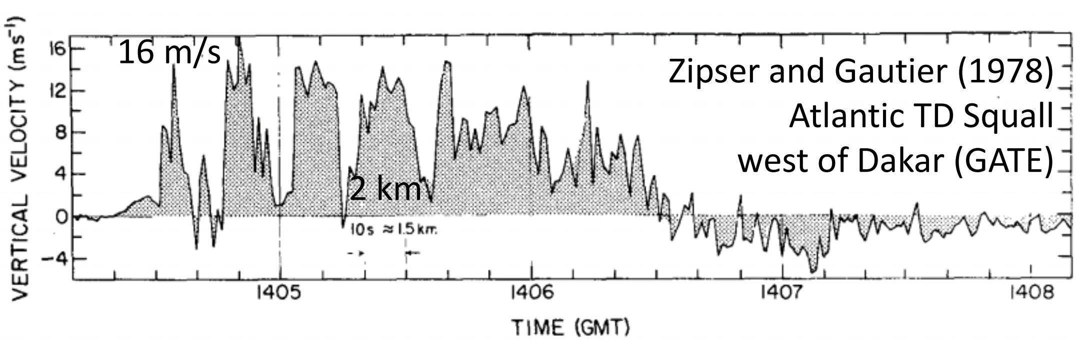
Vertical profiling – good time resolution and detail, lacks context, difficult to build significant sample size

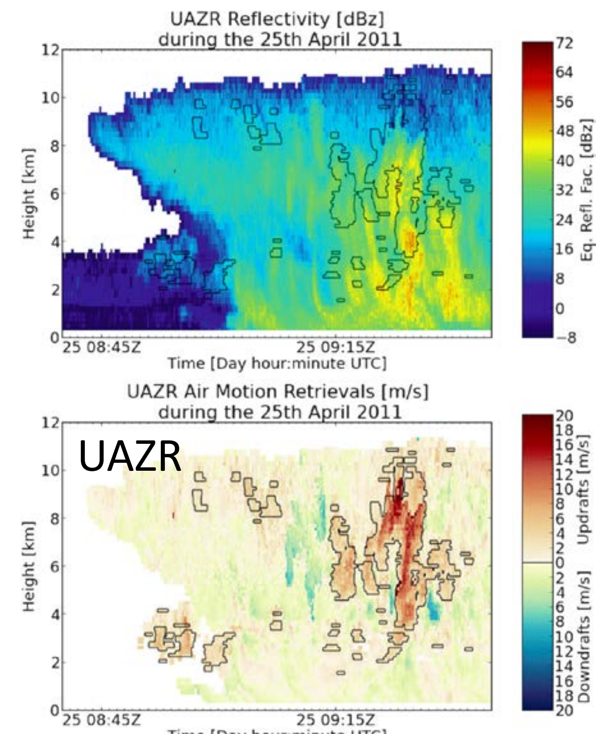


Heymsfield et al. (2013)

In Situ: Aircraft motion







Giangrande et al. (2013)

Available observations and retrievals

<u>Remote Sensing</u>

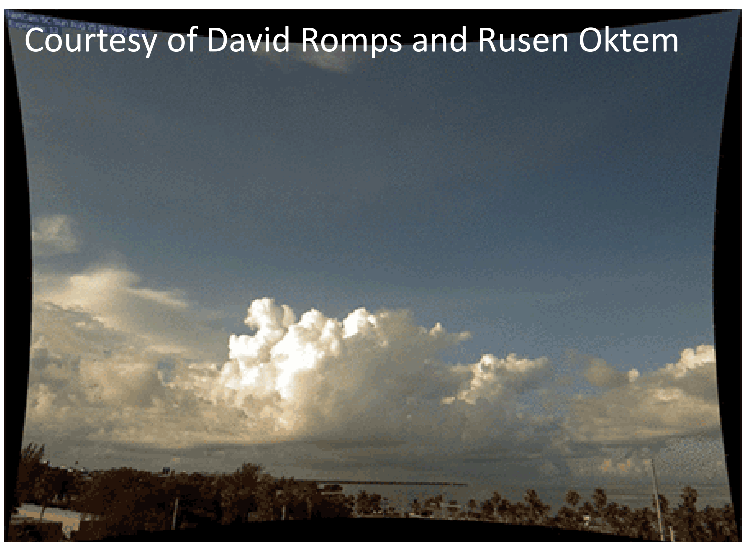
Multi-Doppler retrievals – larger sample size with context, less resolution, complex algorithm

<u>Other techniques</u>

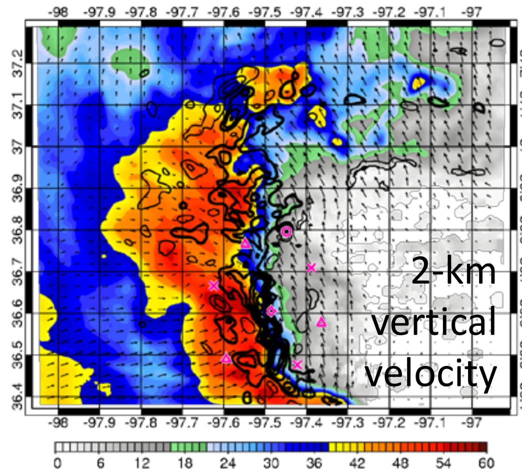
RHIs

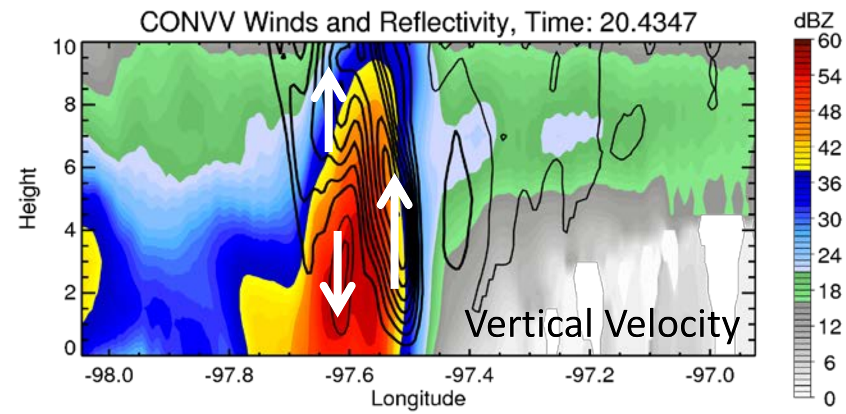
Combining RHIs/ sector PPIs with models/profilers

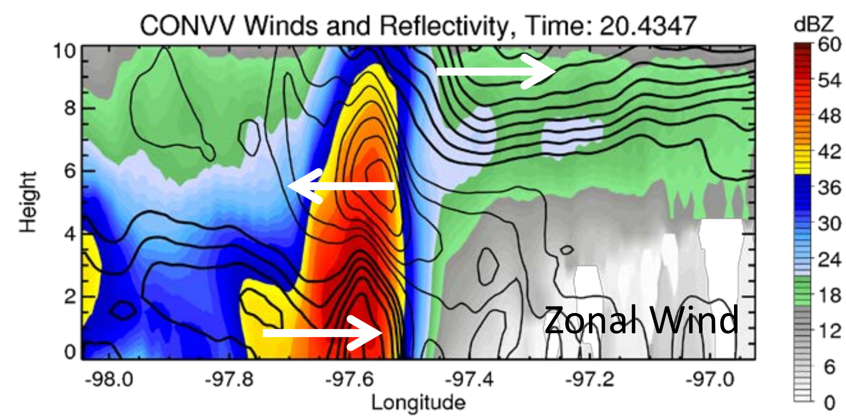
Stereo cameras



CONVV retrieval courtesy of Kirk North and Pavlos Kollias





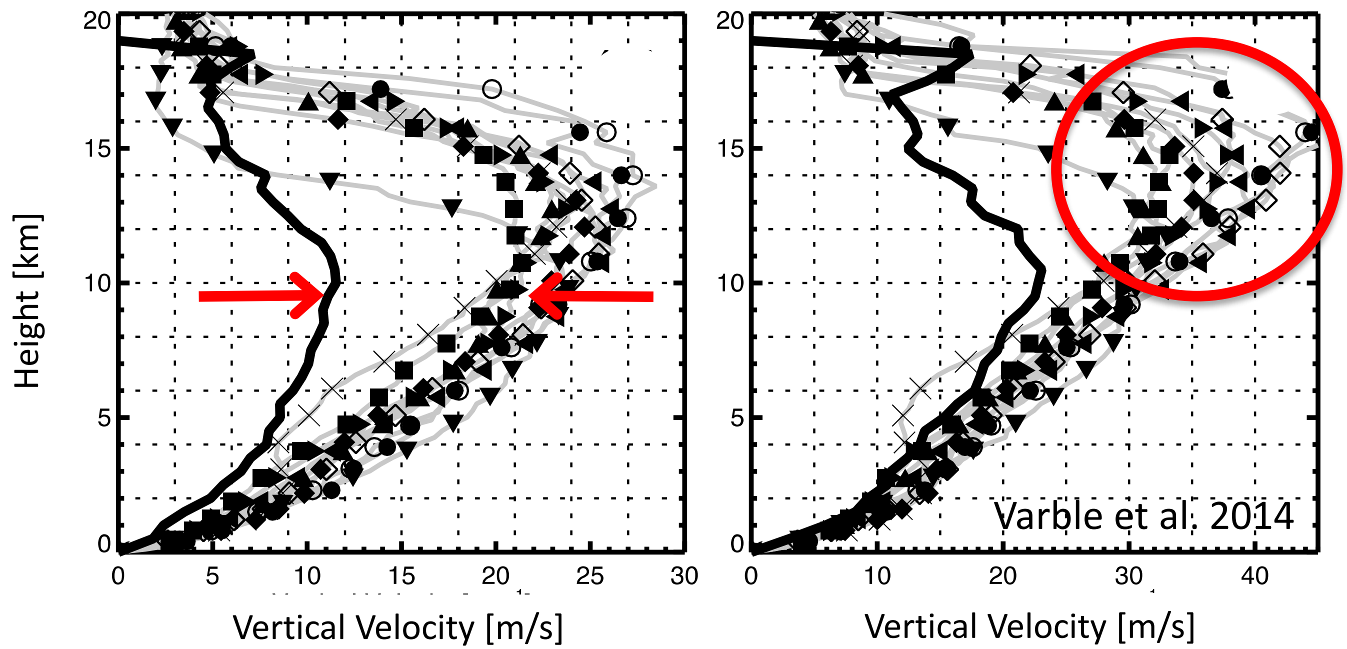


Model bias

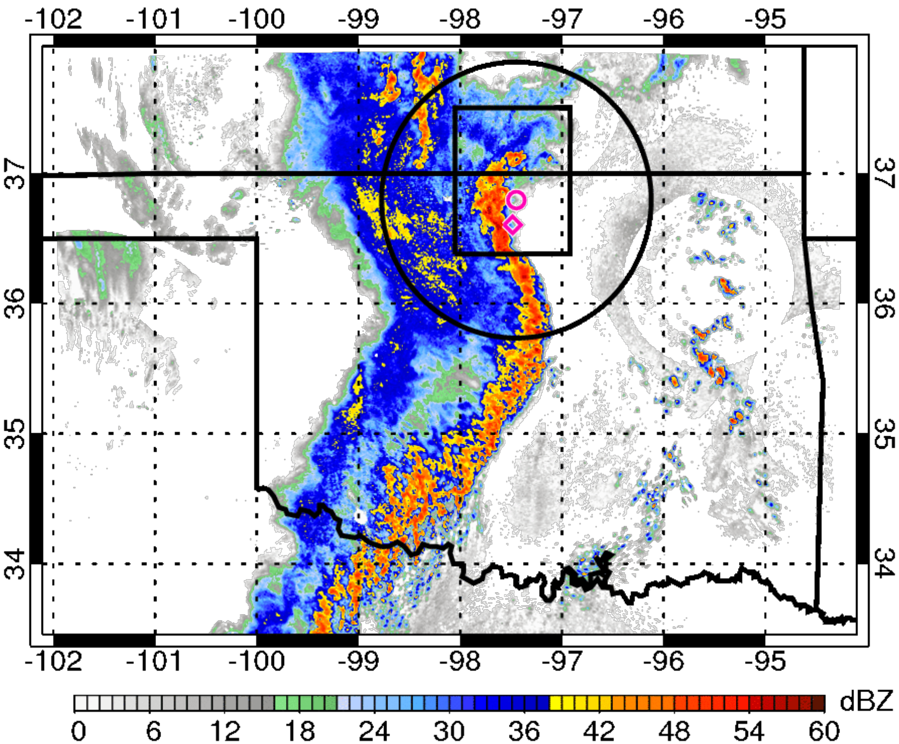
Models run at cloud-resolving scales overpredict peak vertical velocities, which are correlated with excessive rimed ice and detrainment too high in the troposphere

This impacts mesoscale precipitation evolution because of impacts on detrainment characteristics

TWP-ICE 50th and 90th Percentile Updraft Max. Vertical Velocity



Is the bias robust or representative?



In situ measurements and retrievals are limited to one piece of case studies

But retrievals that are available are more consistent with each other than models

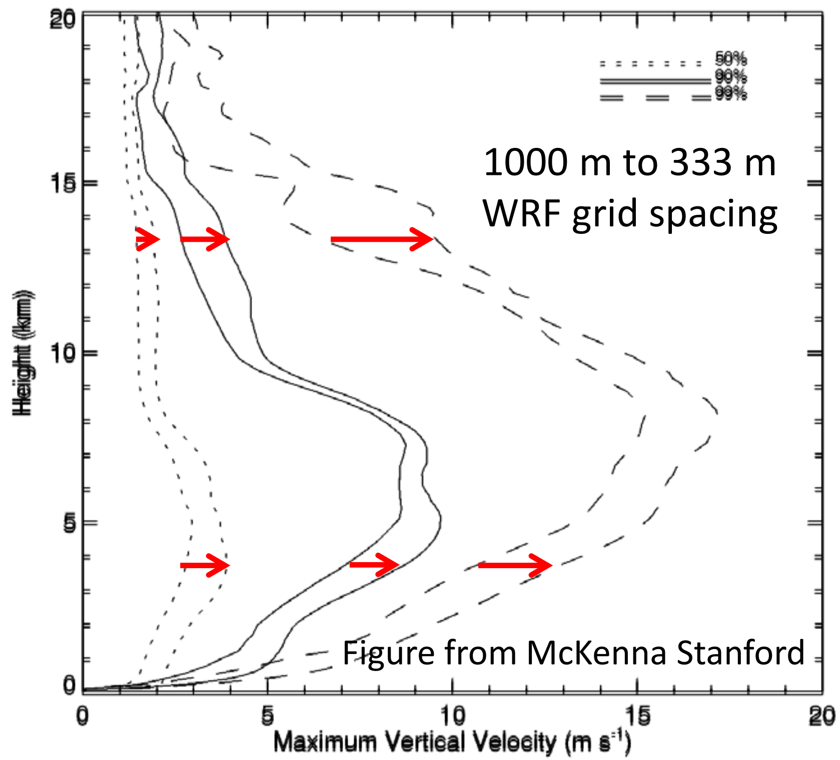
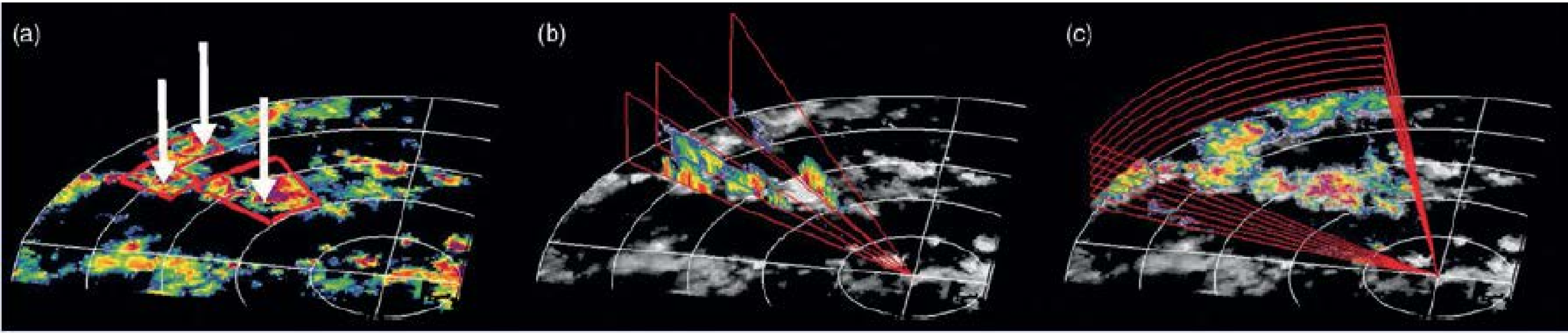


Figure from McKenna Stanford

Retrieval uncertainty and resolution are poorly characterized, which is problematic because comparisons with models are not necessarily apples-to-apples

How can we improve validation?

1. Extend retrievals to semi-operational
2. Characterize radar retrieval resolutions, uncertainties, and biases
3. Obtain more in situ measurements
4. Use multi-wavelength radar RHI and sector PPI high frequency scans together to target dynamical-microphysical interactive processes in individual, evolving convective features



Stein et al. 2015

Validation must lead to model improvement, but how?

For convection-resolving models, **tuning vertical velocity is not an option**.

Convective vertical velocity depends upon acceleration, which depends on:

(1) **draft structure** through vertical pressure gradients and *mixing*

(2) **the local surrounding environment** through buoyancy

(3) **microphysics** through latent heating and condensate *loading* (buoyancy)

These are all potential sources for model bias.
Measurements are needed to constrain each of them if model biases are to be reduced in a physically realistic way limiting ad hoc model tuning.

But convective vertical velocity also impacts (1-3).
If any of (1-3) are different from observations, then cloud and precipitation structure will evolve differently than observed.

For any one event, this is expected since many processes are stochastic on timescales of hours, especially given limited environmental measurements. Therefore, we really want to **prevent a bias that causes a shift in the PDF of solutions for a given large-scale environment**.

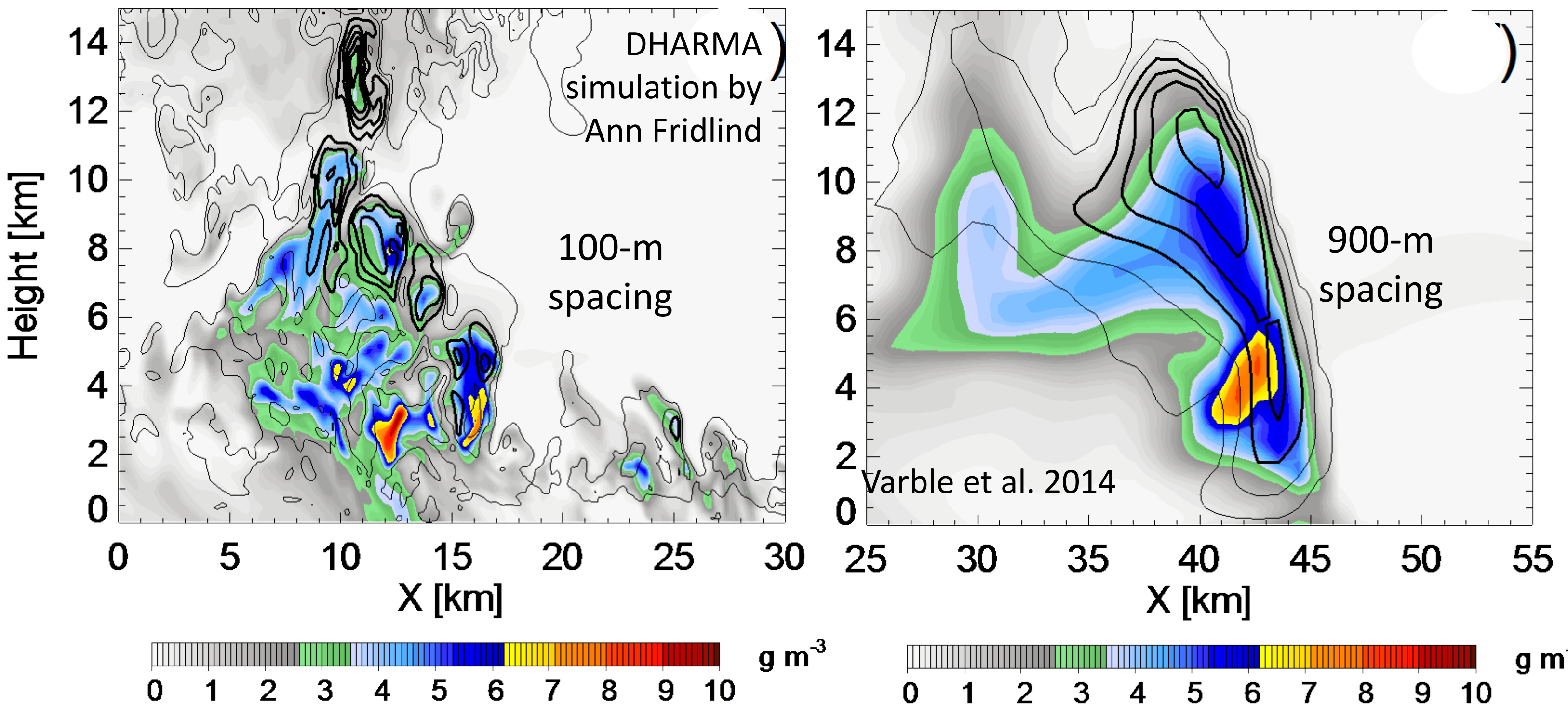
(1) Convective vertical velocity structure

Plume vs. shedding thermal mode depends on grid spacing

This impacts entrainment/dilution and vertical pressure gradients

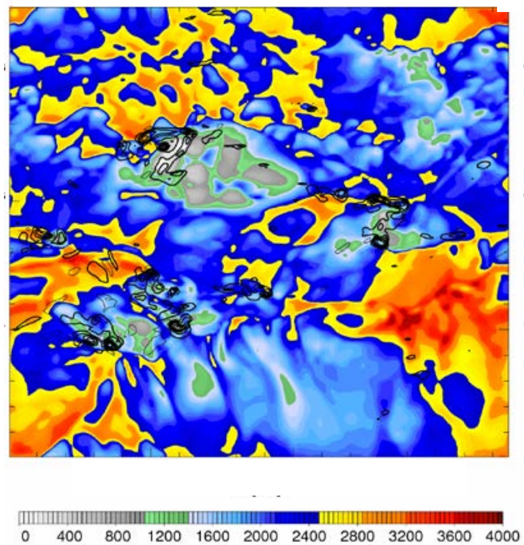
It also impacts hydrometeor sedimentation

TWP-ICE Condensate (filled) and Vertical Velocity (contoured)

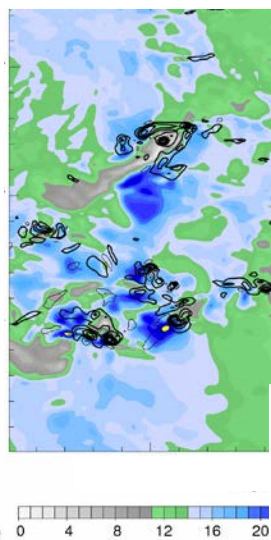


(2) Local surrounding environment

CRM Surface CAPE

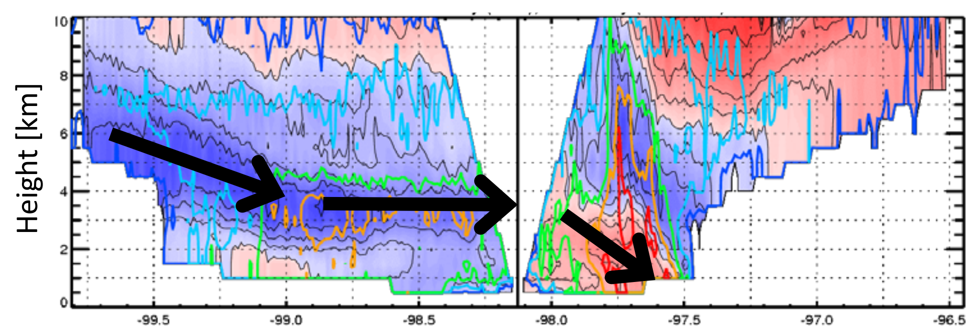


CRM 0-6 km Vertical Wind Shear

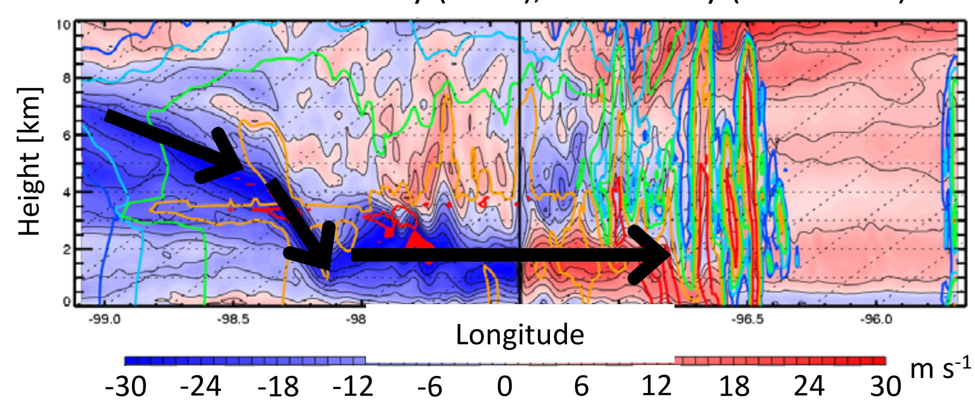


Convection responds to its local environment, which can be far different than the mean environment

KVNX Radial Velocity (filled), Reflectivity (contoured)



WRF Radial Velocity (filled), Reflectivity (contoured)

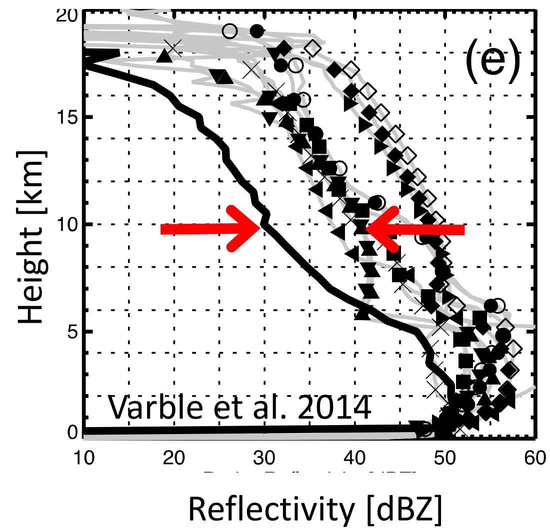


Mesoscale circulations respond to model errors (both large-scale environment and physics parameterizations) and can enhance them

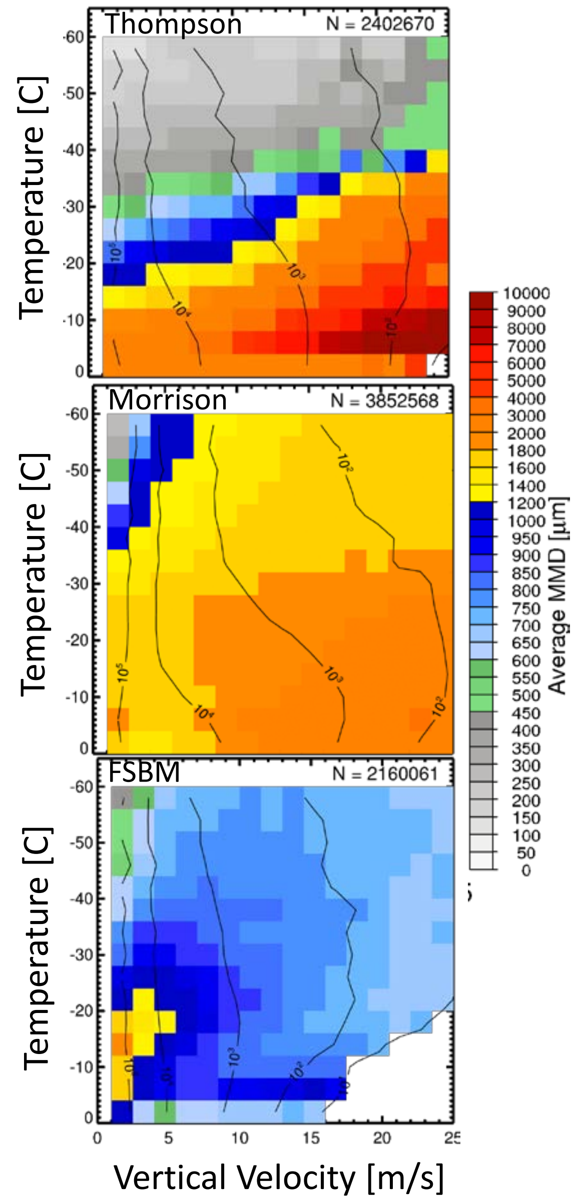
(3) Microphysics

Sizes and densities of hydrometeors impact the distribution of drag and supersaturation, and these critically depend on process parameterizations and assumed hydrometeor properties

TWP-ICE 50% and 90% Updraft Max. Reflectivity



Condensate MMD

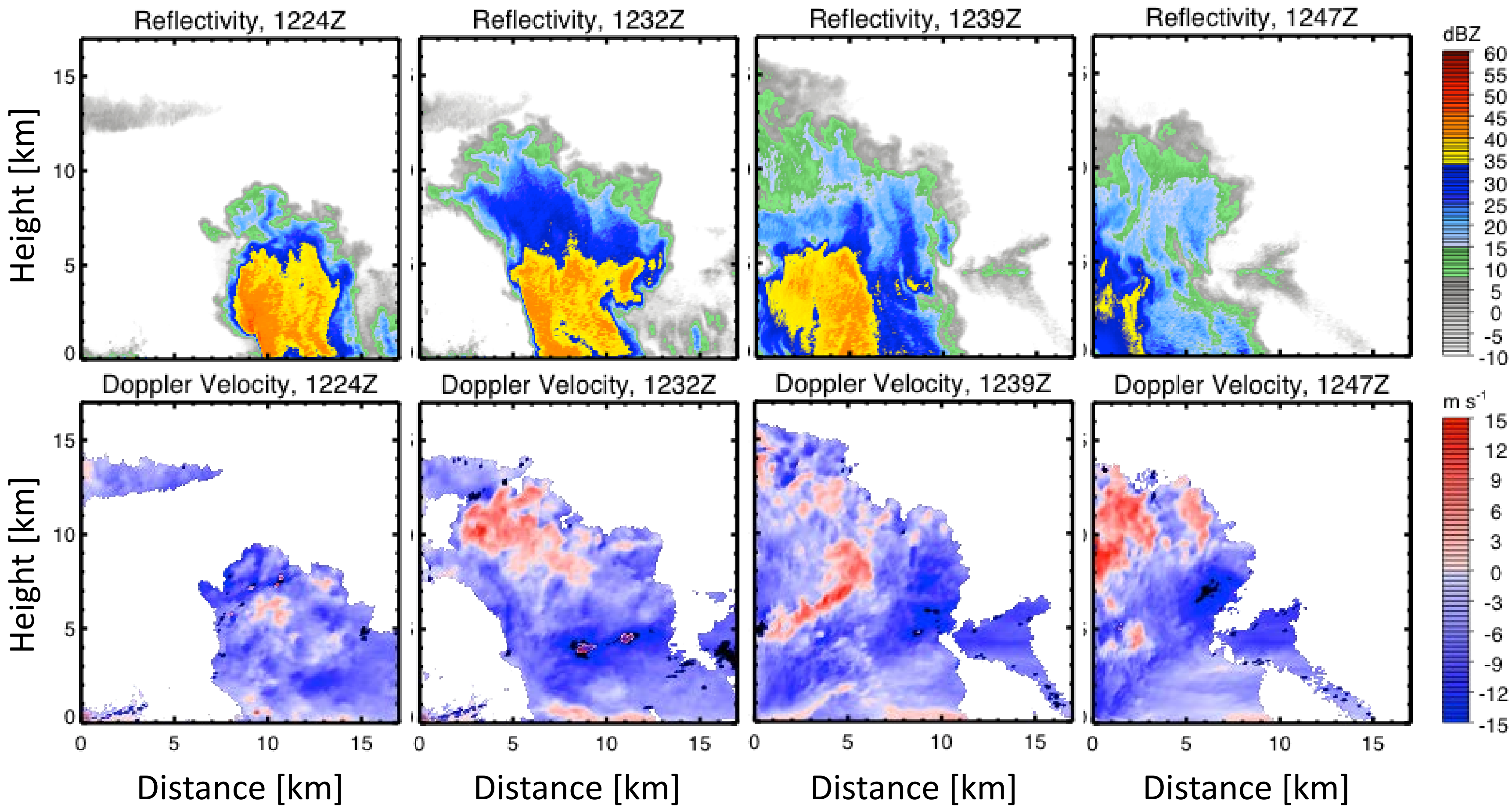


Different schemes give very different answers for the same simulated system, none that match observations

New schemes are moving away from particle types and deterministic properties

What can ARM measure?

Space and time evolution are key to observing interactions between vertical velocity and factors that interact with it such as microphysics

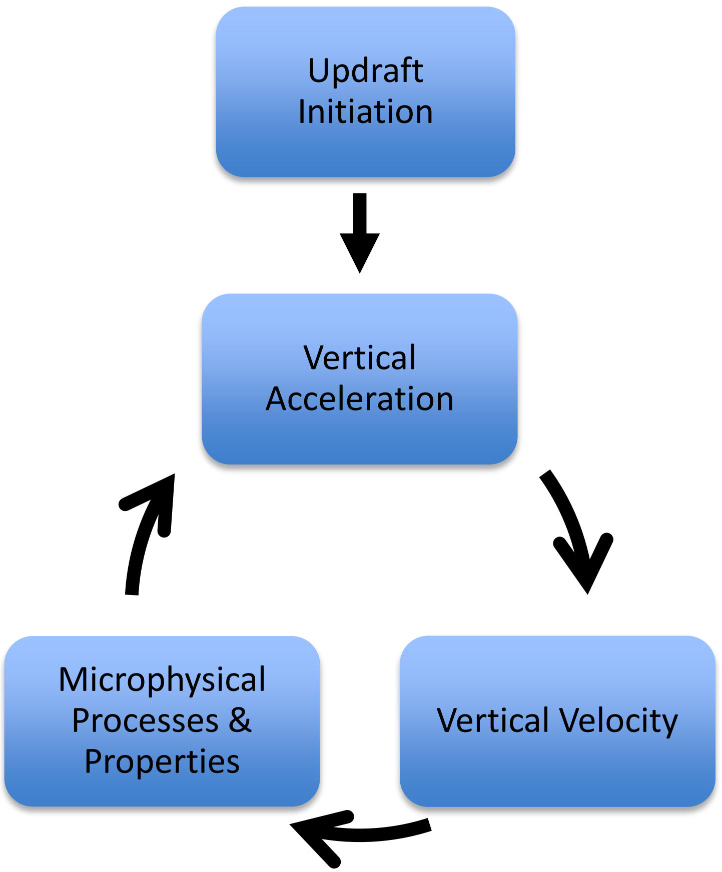


Cycling between vertical velocity and microphysics

Vertical velocity impacts microphysical processes, which then impact acceleration, thus cycling back to vertical velocity

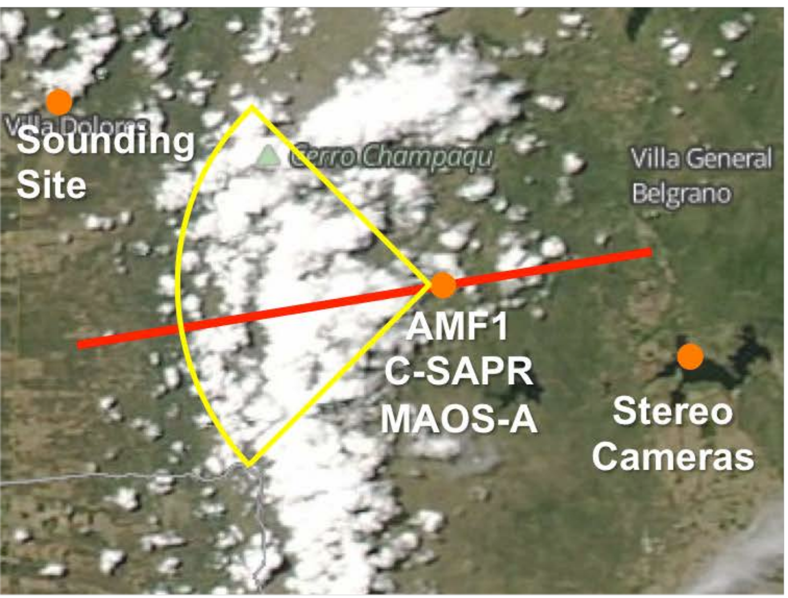
Acceleration needs to act over time to cause a significant change in vertical velocity and a microphysical process needs to act over time to cause a significant change in acceleration

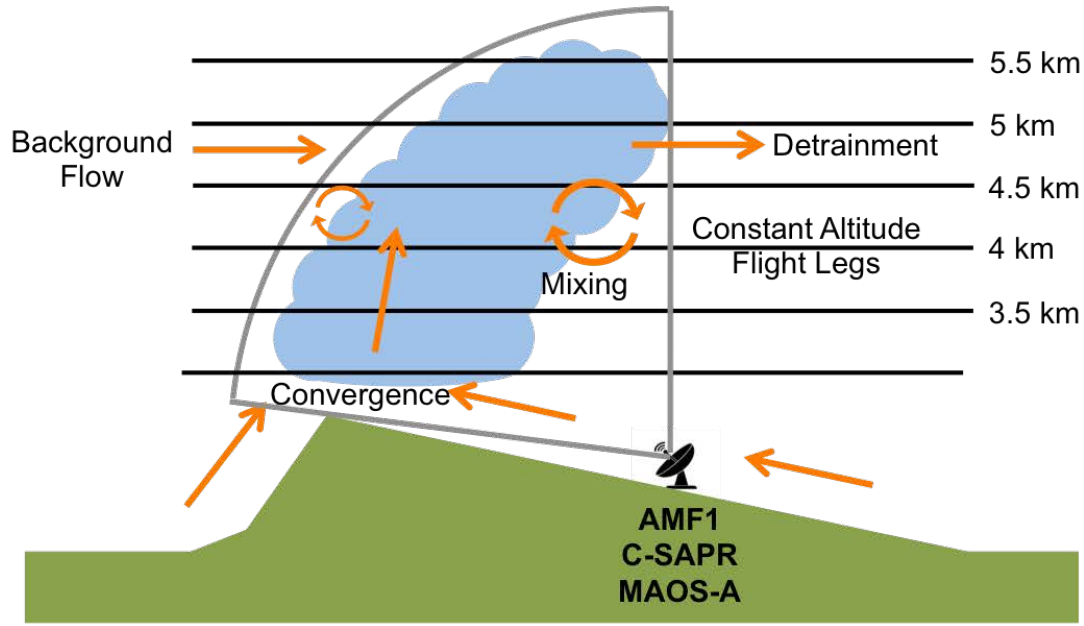
We need to measure this cycle with sufficient spatial and temporal sampling or model improvement will be severely limited!



Employing a new measurement strategy

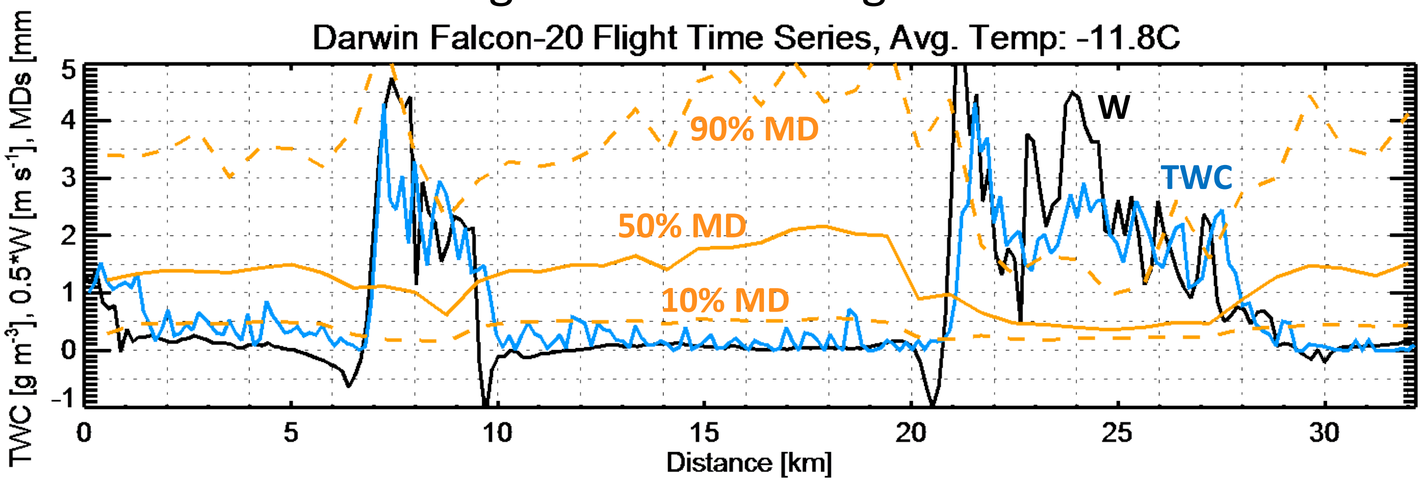
ARM will fund a field campaign called CACTI in central Argentina in 2018-19 that will attempt to constrain all relevant environmental factors to convective initiation and upscale growth while employing radar scan strategies that frequently sample individual convective clouds throughout their lifecycle

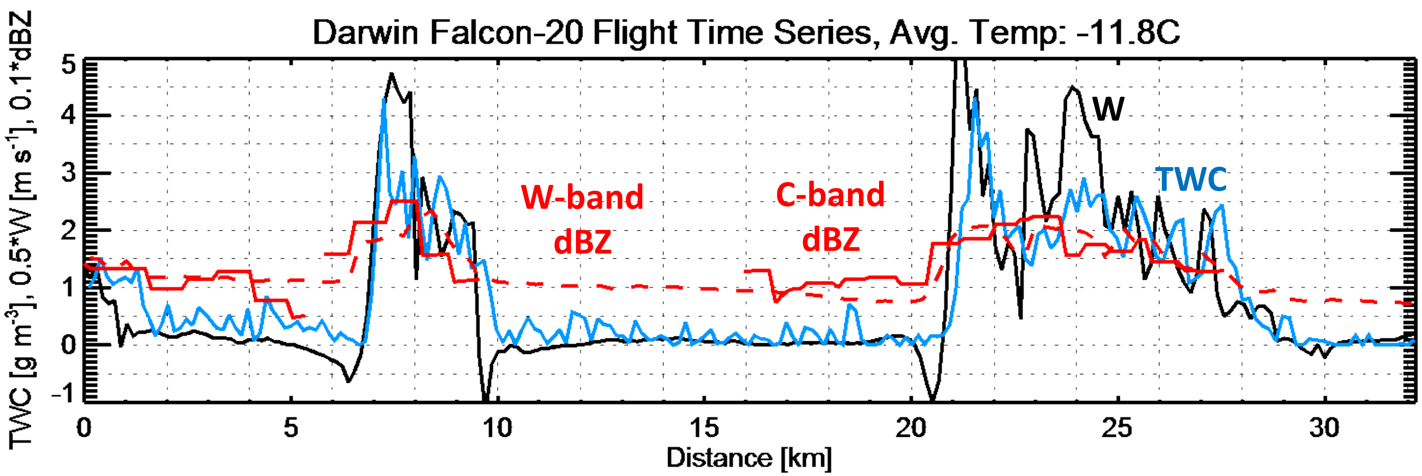




What isn't (currently) measured by ARM?

Aircraft measurements are critical for constraining hydrometeor properties, microphysical processes, and thermodynamics that are not quantifiable through remote sensing alone

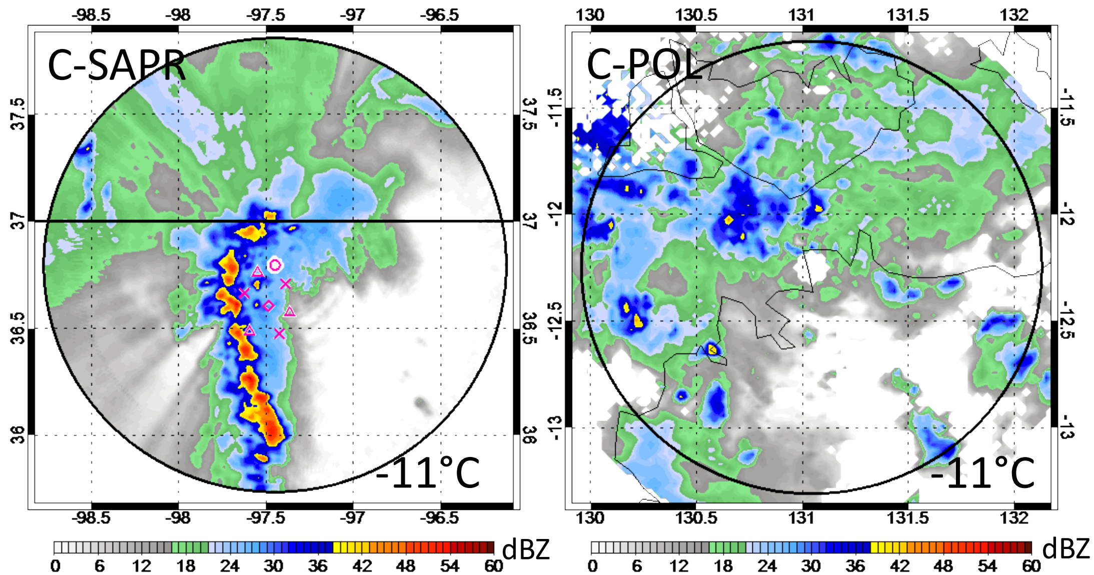




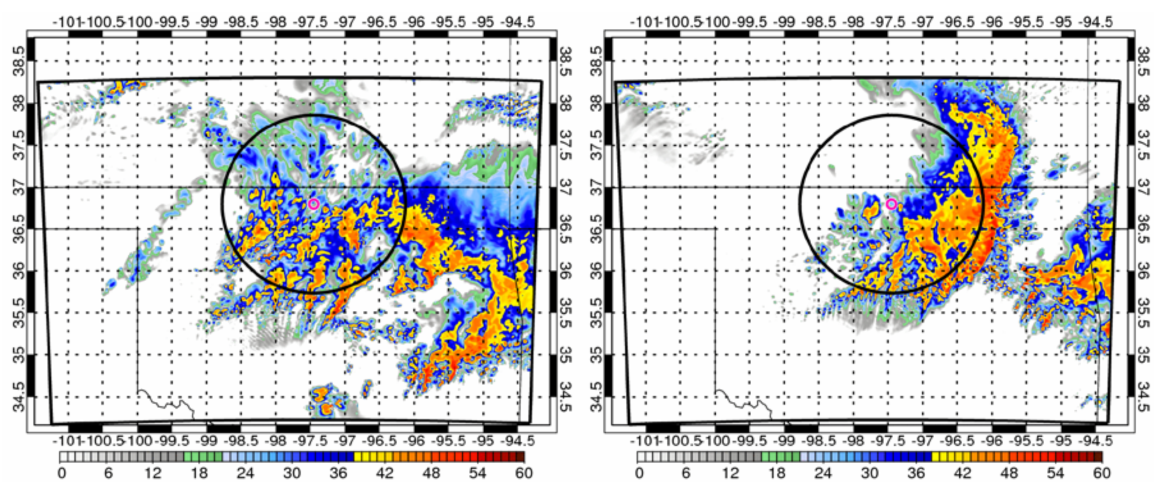
Data: W provided by SAFIRE, MSD by Delphine Leroy and Alfons Schwarzenboeck, TWC by Walter Strapp, dBZ by Julien Delanoë, Alain Protat, Rod Potts, and the BOM

Representative model-observation comparisons

Convective properties strongly vary based on environmental conditions, more so in observations than models, and models need to predict this variability



Models should not be expected to deterministically reproduce any one case study → ensembles and parameterization stochasticity



Summary

1. Cloud-resolving simulations overestimate updraft core vertical velocities, and it is not clear that decreasing grid spacing alone will solve this issue.
2. Several vertical velocity retrievals exist, but we need to move beyond case studies and better characterize retrieval resolution and uncertainty.
3. To move from validation to improvement requires measuring interactive cycling between vertical velocity and factors that impact it such as microphysics, which is something ARM is well positioned to do.
4. Even with radar scan strategies that target convective processes, in situ aircraft measurements are necessary, and models need to be tested across a wide variety of environmental regimes using ensembles and stochastic parameterizations.