Relationships between Radar Reflectivity and Vertical Velocity Fluctuations in Convective Clouds

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Introduction

- Dynamical and microphysical processes are known to be related
- Validation/development of cumulus and microphysical parameterizations require data describing the statistical characteristics of vertical velocity
    - Key areas of uncertainty include the relationship between vertical velocity variability and mass flux/microphysical processes.
- Radar reflectivity can be used as a proxy for the microphysical characteristics of convection

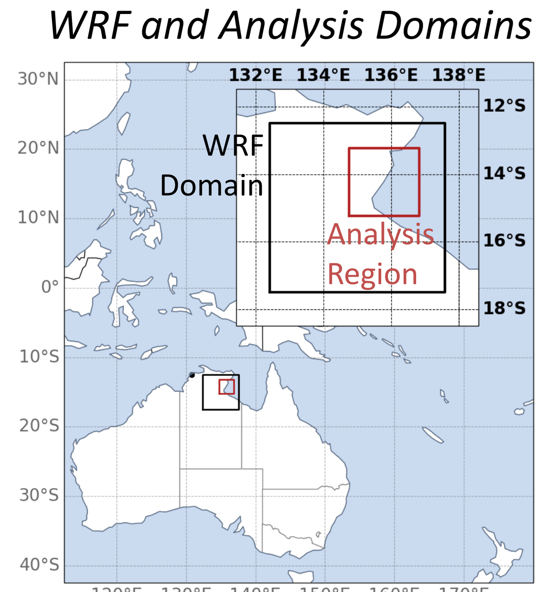
Objectives

- Explore whether vertical velocity variability can be characterized by substituting reflectivity into basic conservation equations
- Increase our ability to characterize vertical velocity and mass flux in convection

WRF Simulation

Time	18 -20 Jan 2006
Horizontal Resolution	500 m
Vertical Levels	100
Output Interval	1 min
Longwave / Shortwave Radiation Scheme	RRTMG
Microphysics Scheme	Thompson
Land Surface Scheme	Unified Noah
Surface Layer Scheme	Eta Similarity

WRF and Analysis Domains

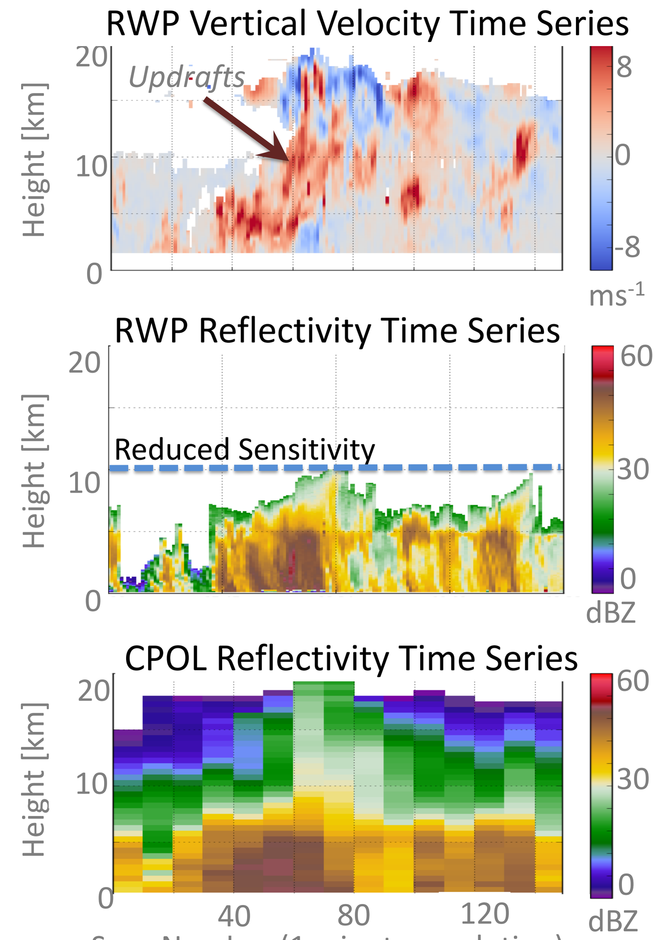


- Analysis conducted at 9 UTC 18 Jan 2006 for convective cores [Powell et al. 2016] in mixed phase regions (6-11 km)

Observational Data

- Darwin, Australia
- 2005-06 & 2006-07 wet seasons
- Dual-frequency radar wind profiler (RWP)
    - Reflectivity
    - Vertical velocity [Williams 2012]
- CPOL Radar (Scanning C-band) [Keenan et al. 1998]
    - Reflectivity
    - Hydrometeor types [Keenan 2003; May and Keenan 2005]
- Data synchronized to 1 minute resolution over profiler

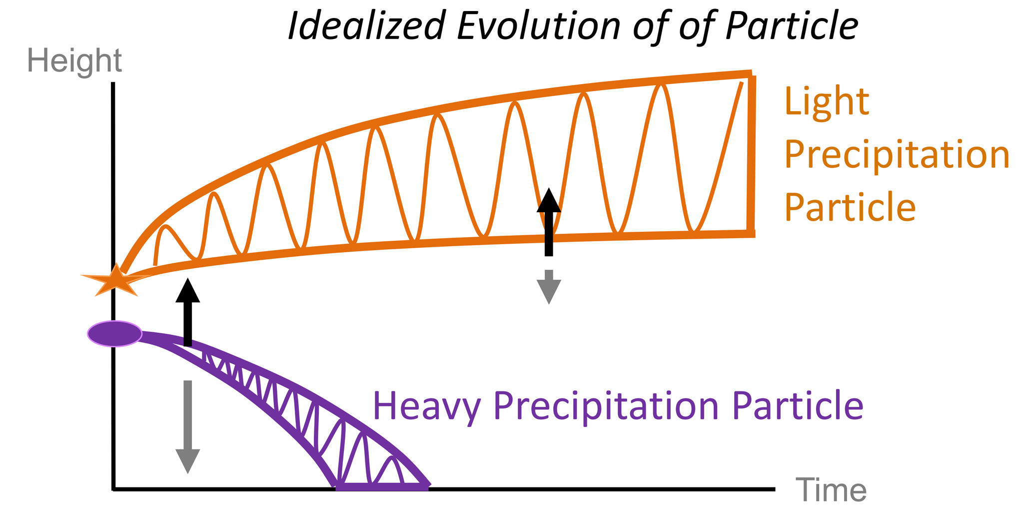
23 January 2006 1710-1930 UTC



Kinetic Theory (Diffusion + Drift)

Based on Fokker – Planck Equation

Idealized Evolution of of Particle

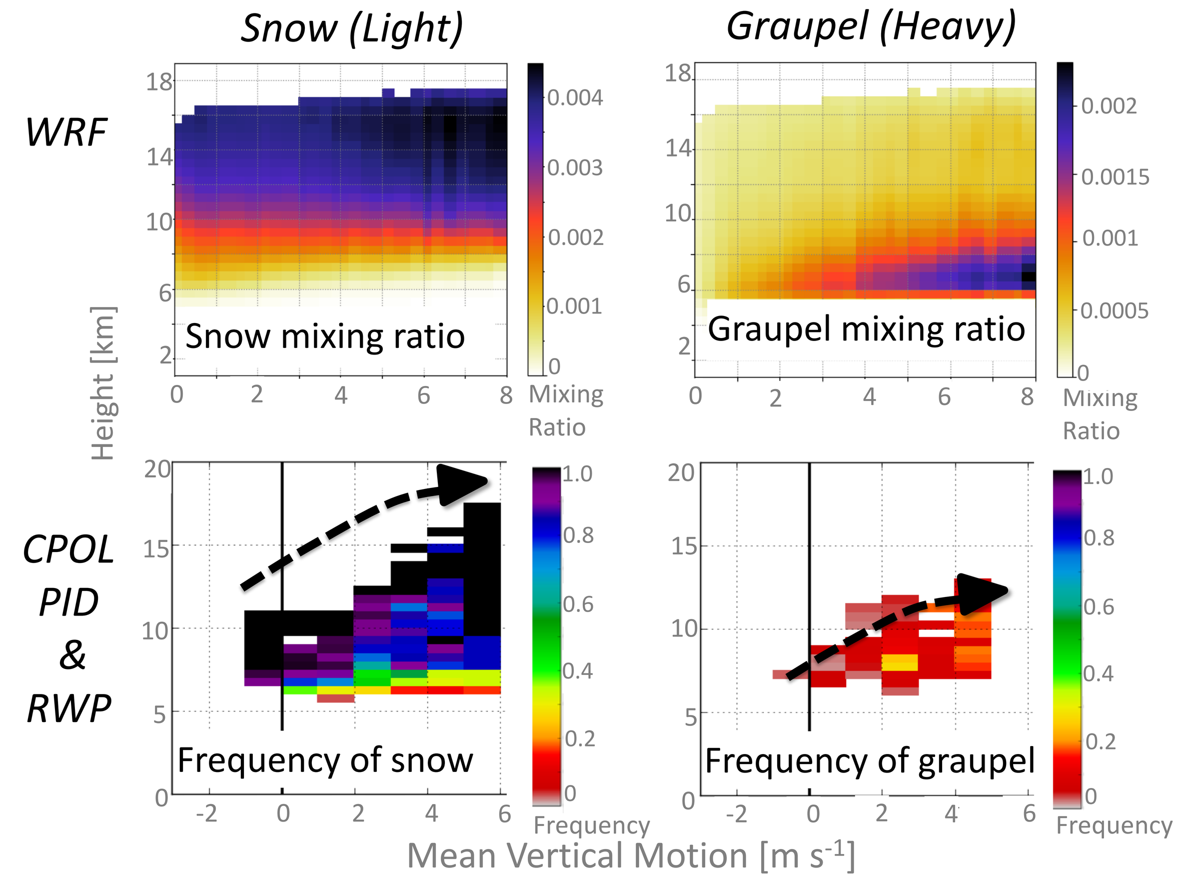


$$\frac{\partial P(x,t)}{\partial t} = -\frac{\partial [v(x)P(x,t)]}{\partial x} + D\frac{\partial^2 P(x,t)}{\partial x^2}$$

Change in distribution *(Reflectivity Profile)* = **Drift** *(Gravitational Balance)* + **Diffusion** *(Variability of Vertical Motion)*

Drift

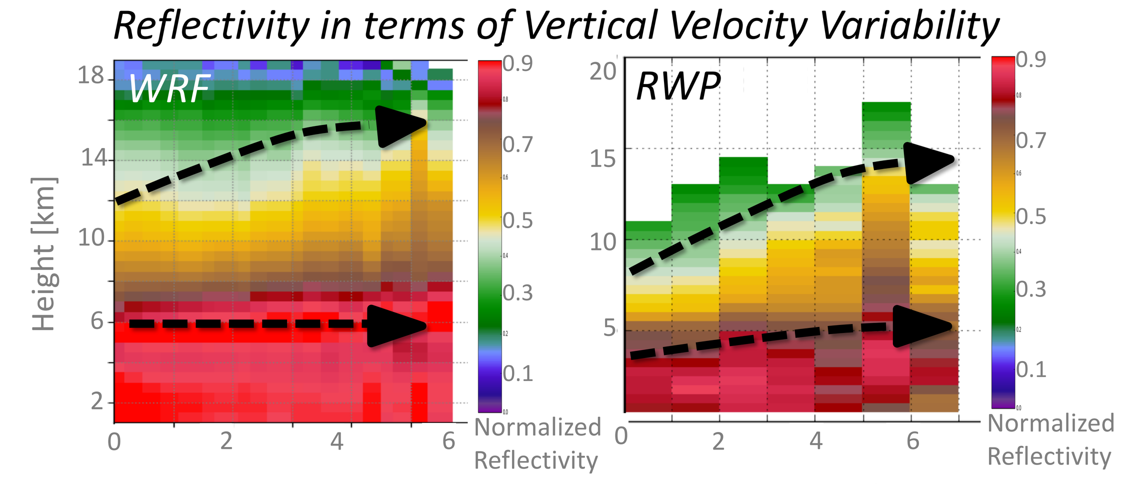
Microphysical Distribution in terms of Mean Vertical Velocity



- Higher vertical velocity magnitudes:
    - Suspends more mass
    - Lofts hydrometeors higher

Diffusion

Reflectivity in terms of Vertical Velocity Variability



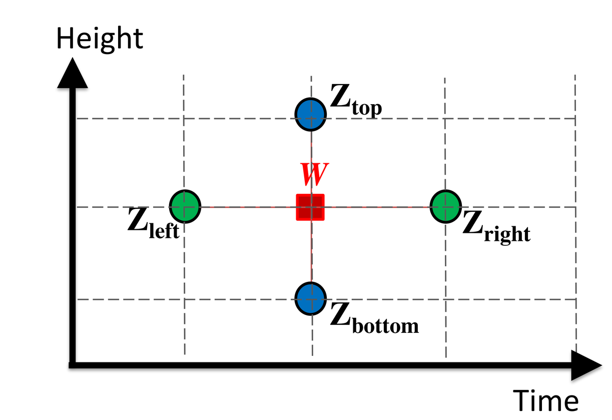
- Each profile normalized by maximum reflectivity
- Large vertical velocity variability associated with broad reflectivity distribution

Estimating Vertical Velocity

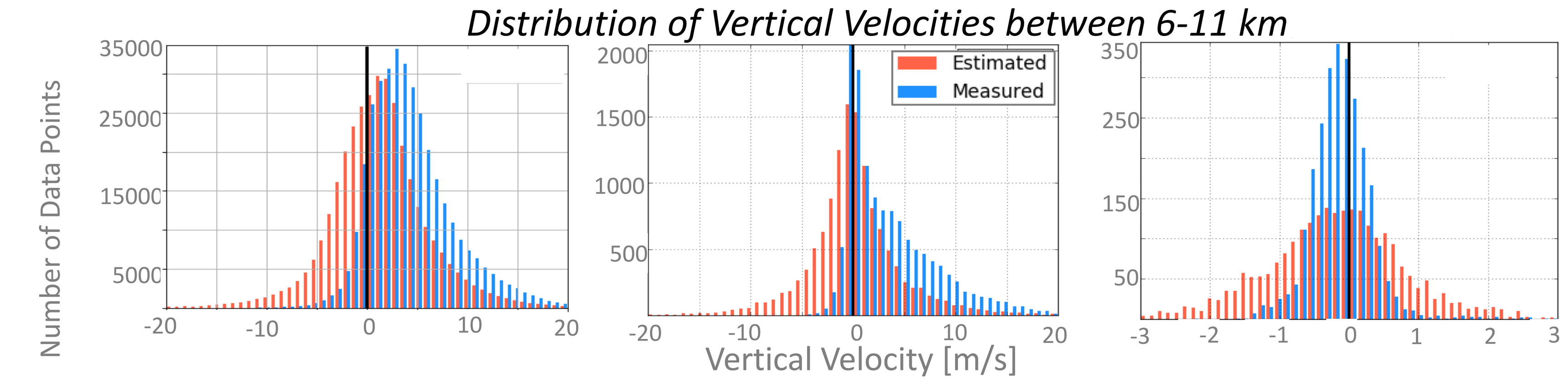
- Based on conservation of moisture and mass
- Reflectivity is used as a proxy for moisture and mass
- WRF based estimates assume no sources/sinks
- Profiler based estimates assume no sources/sinks and no horizontal advection
- Estimates exclude small vertical reflectivity derivatives

$$\frac{\partial Z_e}{\partial t} + \underbrace{\vec{U}\frac{\partial Z_e}{\partial \vec{x}}}_{\text{Horizontal Advection}} + \underbrace{W\frac{\partial Z_e}{\partial z}}_{\text{Vertical Transport}} = \underbrace{\cancel{\text{Source}}}_{\text{Unknown}}$$

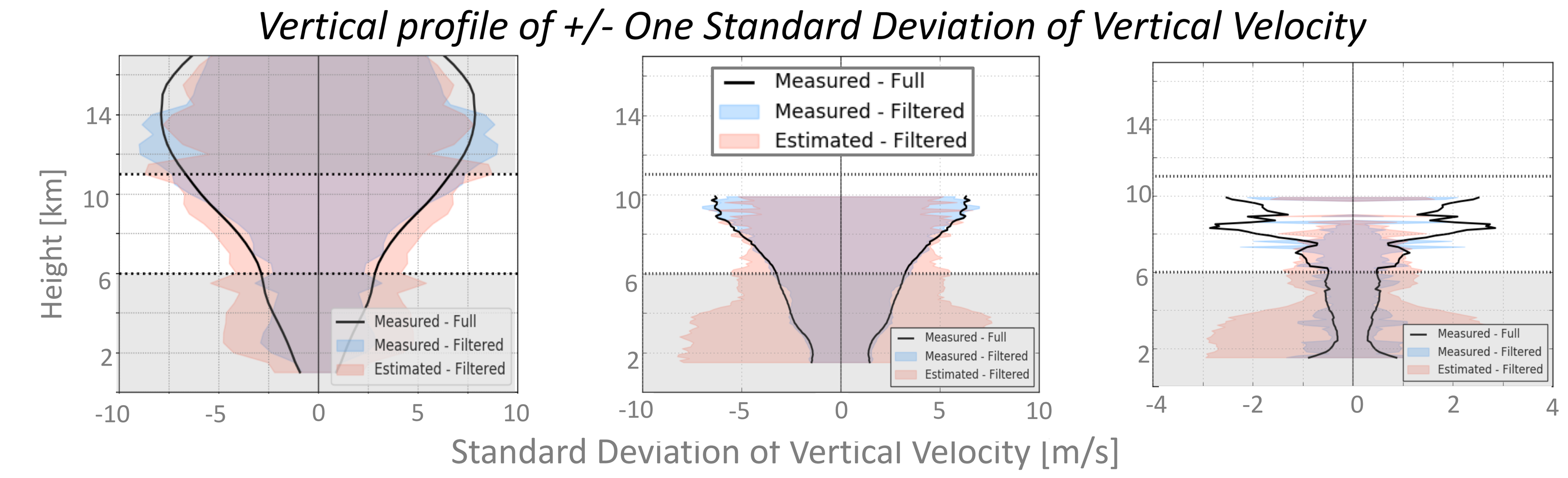
$$W = -\frac{\frac{\partial Z_e}{\partial t} + \vec{U}\frac{\partial Z_e}{\partial \vec{x}}}{\frac{\partial Z_e}{\partial z}}$$



Distribution of Vertical Velocities between 6-11 km



Vertical profile of +/- One Standard Deviation of Vertical Velocity



- The distribution of reflectivity can be used to describe a portion of the vertical velocity variability

Conclusions

- The statistical relationship between vertical velocity and hydrometeor distributions may be understood in terms of a kinetic theory based on:
    - *Drift* – Magnitude of vertical velocity determines the height and magnitude of the mass distribution
    - *Diffusion* – Vertical velocity variability influences the breadth of the hydrometeor distribution
- A portion of the vertical velocity variability in the mixed layer can be estimated by combining the conservation of moisture with the conservation of mass
    - Reflectivity with high spatial-temporal resolution can be used as a proxy for moisture and mass

Future Work

Our results motivate new observation strategies for scanning radars in order to improve our understanding of dynamical – microphysical interactions

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This research was supported by the U.S. DOE's ASR Program via the ICLASS SFA and the ARM Climate Research Facility.

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