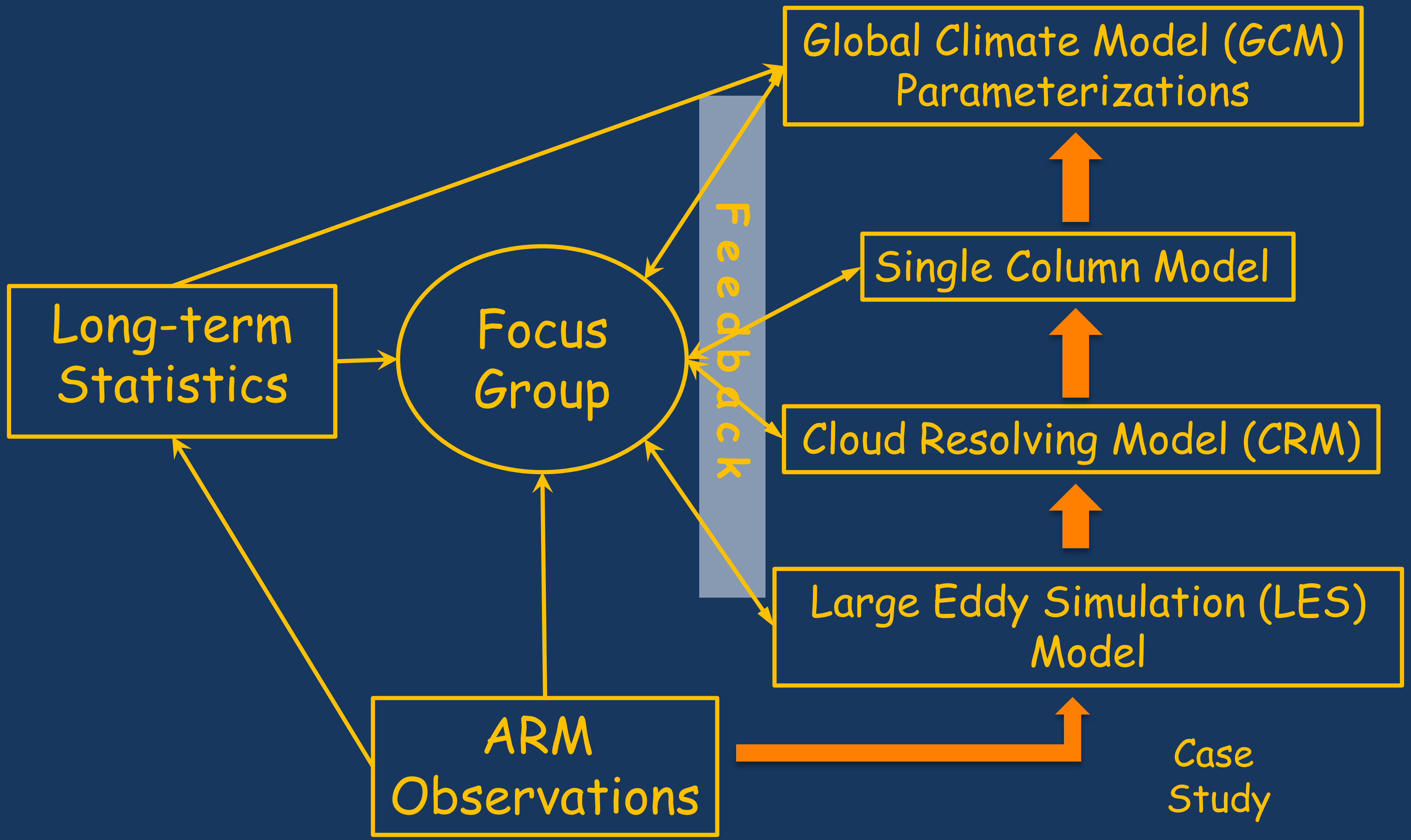
Vertical Velocity Focus Group

Jennifer Comstock[1] and Virendra P. Ghate[2]
1. PNNL; 2. Rutgers University

* Input from many PIs

ASR Science


Global Climate Model (GCM) Parameterizations
Single Column Model
Cloud Resolving Model (CRM)
Large Eddy Simulation (LES) Model
Long-term Statistics
Focus Group
Feedback
ARM Observations
Case Study

ASR Science Objective

"ASR will pursue multiple research fronts towards better understanding of vertical velocity, it's relation to buoyancy forces, and the associated dynamical-microphysical interactions"

- ASR Science Plan, 2010

Vertical Velocity Focus Group

- Formed in 2007

- Goals
  - Improve understanding of linkages between cloud micro-physics and dynamics.
  - Provide observational targets (VAP) to evaluate LES, CRM and aspects of GCM parameterizations.

Outline

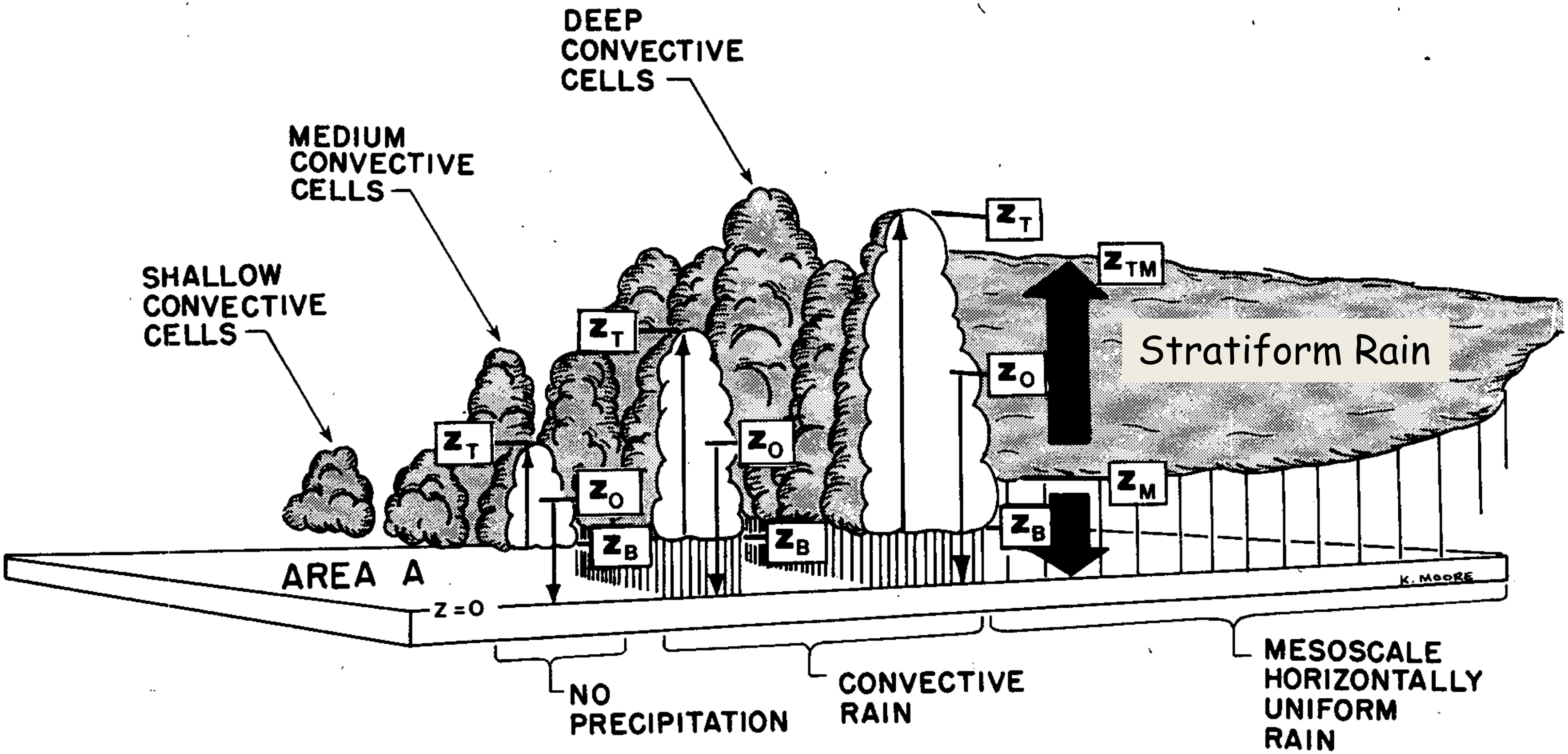
- Scientific motivation and associated VAPs
  - Deep Convective Clouds
  - Boundary layer/low Clouds
  - Cirrus Clouds
- Future work
  - Other science needs

Datasets

- Datasets used to develop statistics for model development, evaluation, and process understanding

Doppler Lidar

Deep Convective Clouds



Houze et al. (1980)

Parcel Model for Vertical Velocity

$$\frac{1}{2}\frac{dw^2}{dz} = a(B - D) - b\lambda w^2$$

Thermodynamic Buoyancy

Hydrometeor Drag

Entrainment

From LES of deep convection: $w(z) \approx c * B(z)$.

Using $w(z)$ and $D(z)$ from radar, we can retrieve $B(z)$ and λ, the fractional rate of entrainment.

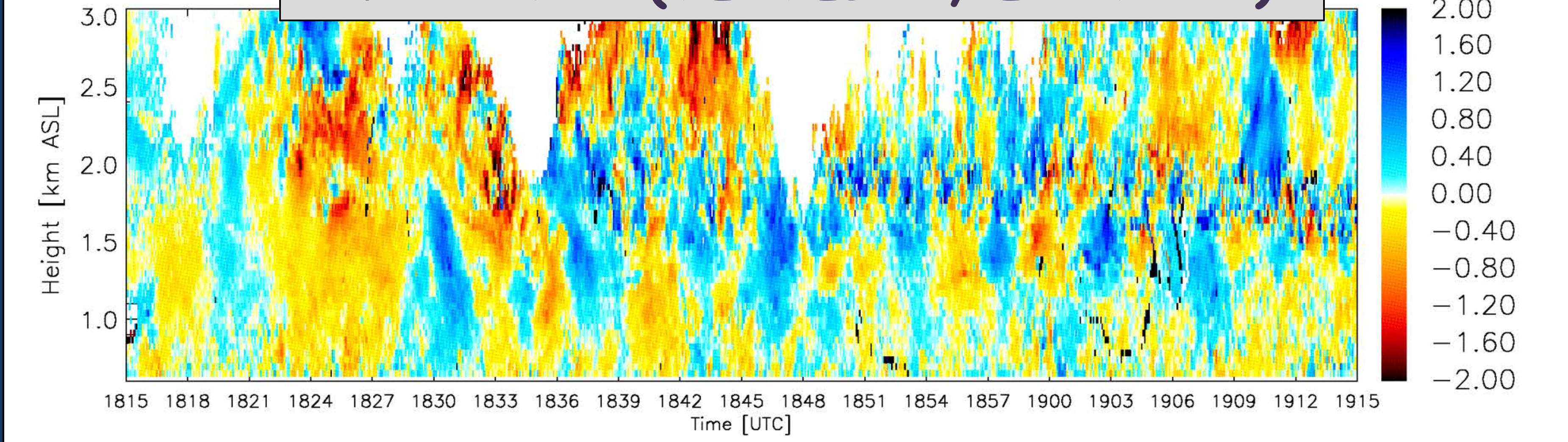
- How does vertical velocity vary in height, space, time and strength?
- How do these variations correlate with microphysical properties?

Steven Krueger

Vertical Velocity in Stratiform Rain

https://www.arm.gov/data/eval/72

WACR VAP (VERVELSR, Evaluation)



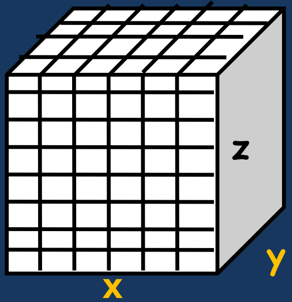
- **Vertical Velocity** in Stratiform Rain conditions with accuracy to within 10 cm/s
- Novel spectra processing helps overcome partial W-band attenuation in rain.
- VAP Data Available **NOW**: Niamey (June to September, 2006); SGP (May 2007).

M. Dunn, M. Jensen, S. Giangrande

Giangrande et al. (2010) JTECH (AMS)
Giangrande et al. (2012) JAMC (AMS)

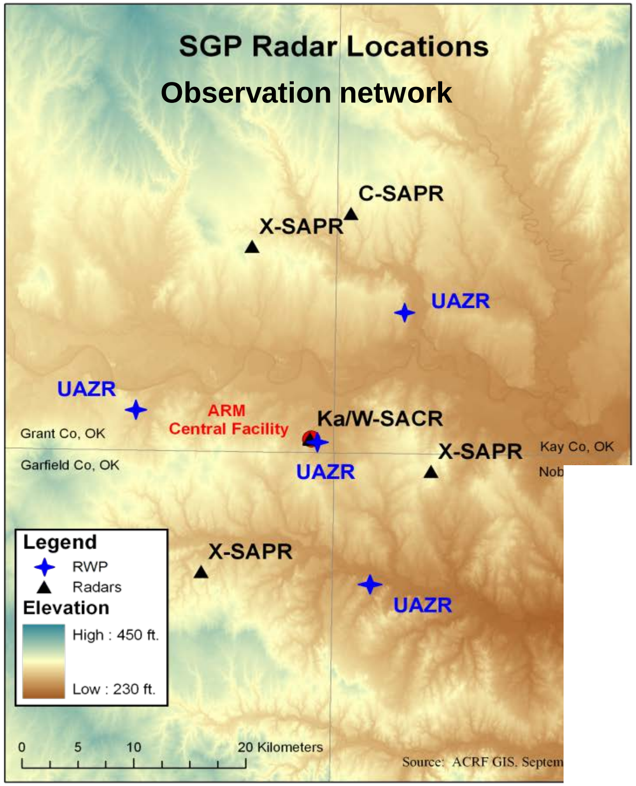
ConVV – Convective Vertical Velocity (ARM Evaluation Product)
Midlatitude Continental Convective Clouds Experiment (MC3E)

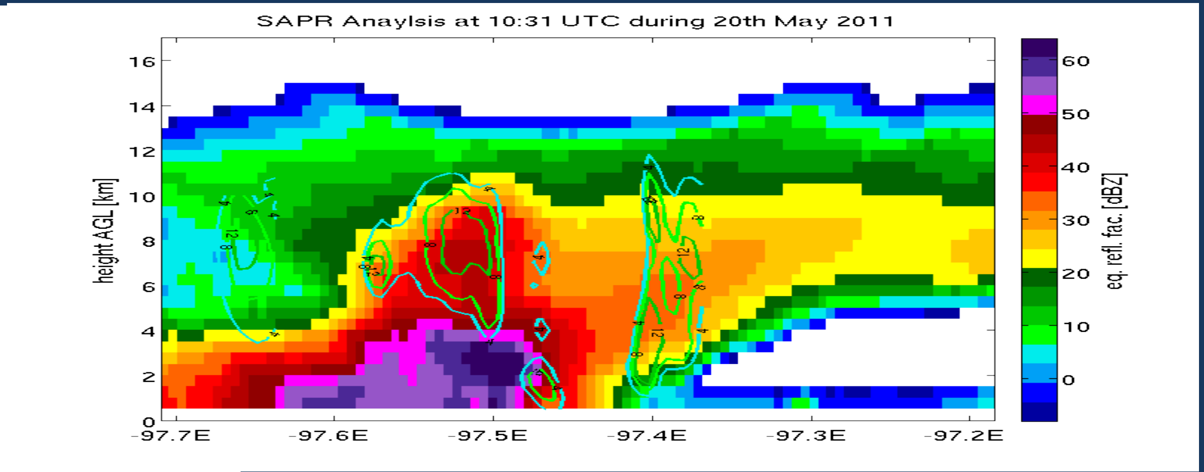
ARM scanning precipitation radar observations assimilated in 3D-VAR algorithm to produce analysis of three Cartesian wind components (**U**,**V**,**W**).

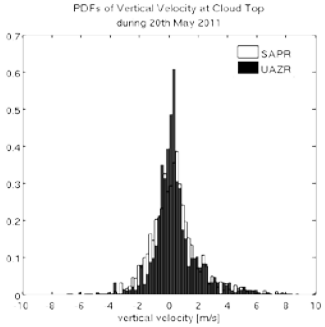


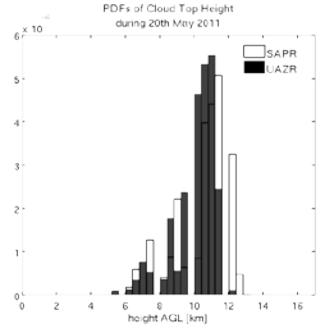
Analyses currently available:
1. 25th April 2011 (8-11 UTC)
2. 20th May 2011 (6-11 UTC)
3. 23rd May 2011 (21-23 UTC)

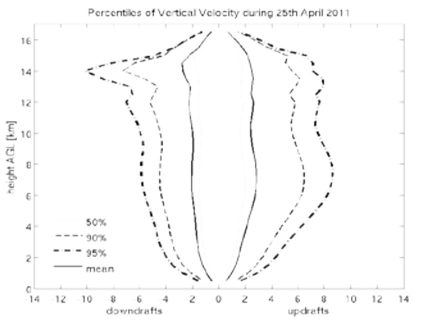
Current model parameters:
- 100 x 100 x 17 km domain
- 500 x 500 x 500 m resolution











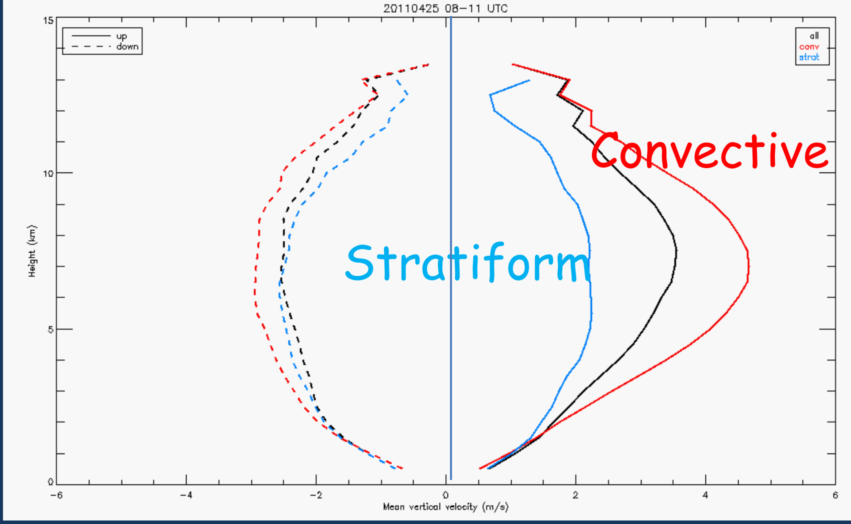
North, K. W., S. Collis, S. E. Giangrande, and P. Kollias, 2013: Vertical Velocity Retrievals in Convective Clouds using the ARM Heterogeneous Radar Network at SGP during MC3E. *in preparation*

ARM archive:
http://iop.archive.arm.gov/arm-iop/0eval-data/north/convv/

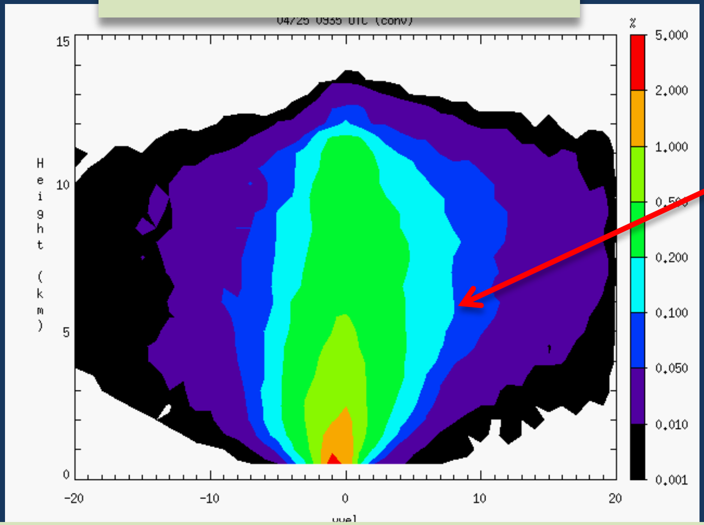
MC3E Case-Study

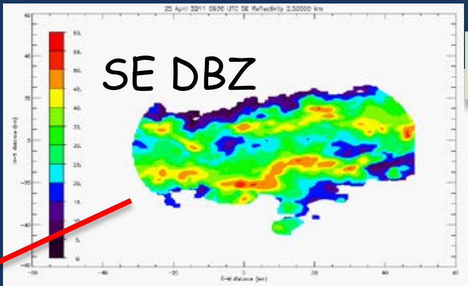
S. Rutledge, B. Dolan, A. Rowe and A. Matthews

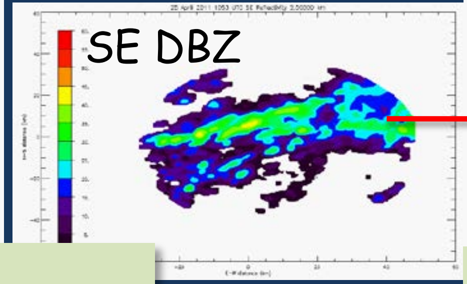
- Hand unfolded velocities
- Dual-Doppler analysis between SE and SW X-band radars
- Separated convective and stratiform using Yuter & Houze methodology



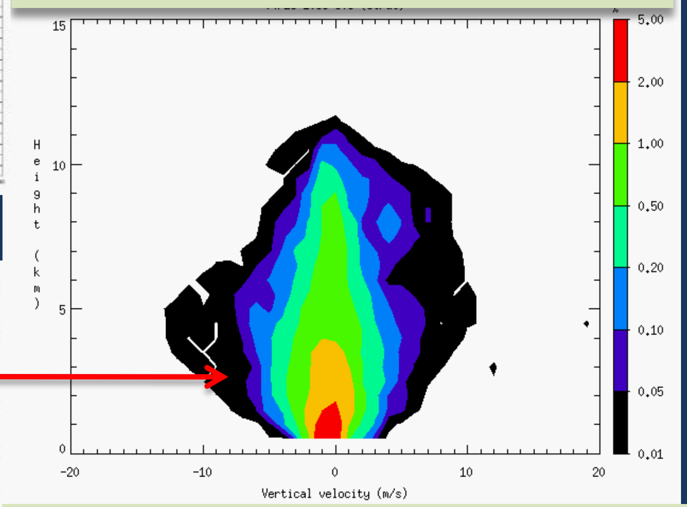
Convective







Stratiform / Convective mix

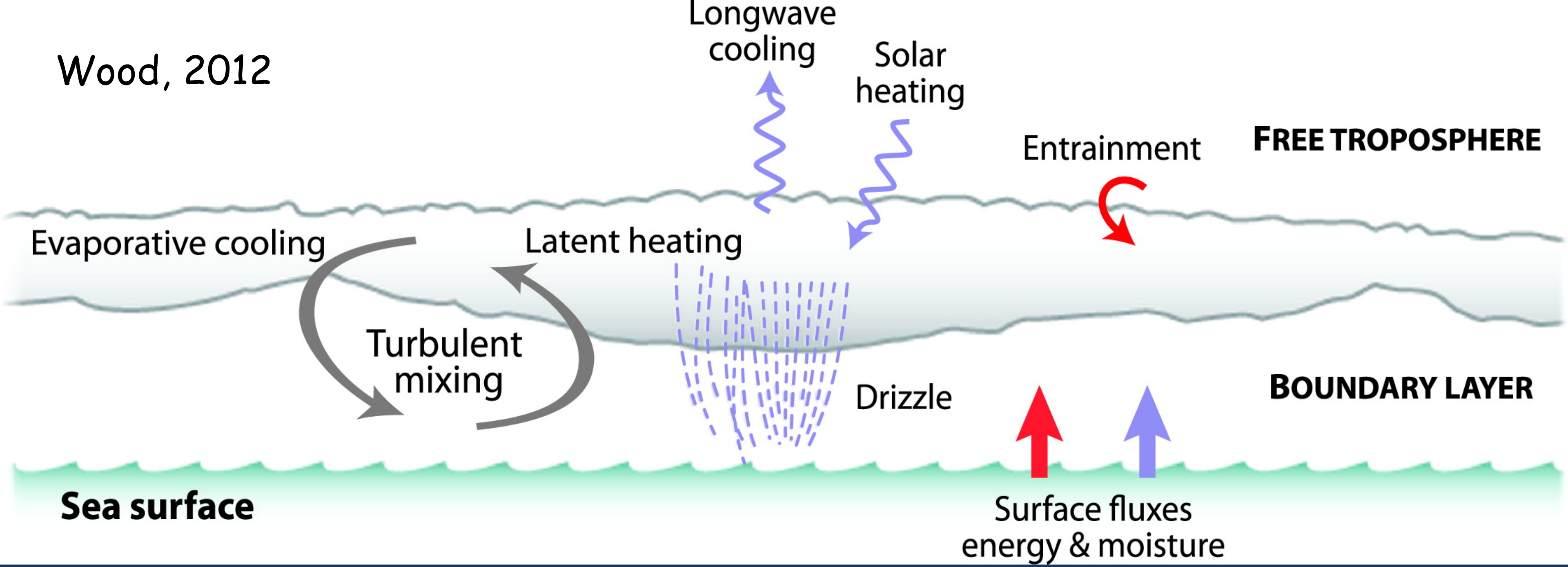


CFAD of vertical velocity
- Occurrences of w > |10| m s^{-1}; broad distribution

CFAD of vertical velocity
-Weak w < |5| m s^{-1}; narrow distribution

Low Clouds

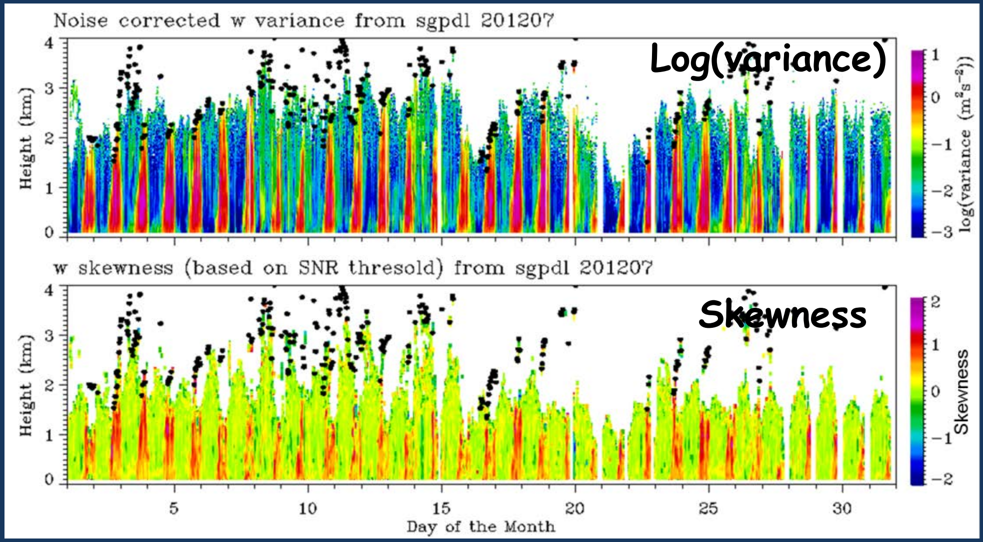
Wood, 2012



- What relationships between various microphysical and dynamical factors determine the low cloud precipitation onset?
  - Vertical velocity statistics classified by Liquid Water Path
- What is the relationship between cumulus mass-flux and the cloud fraction?
  - Especially for broken shallow cumuli

The Doppler lidar Boundary-Layer Turbulence Statistics (BLTS) VAP

- The ARM Doppler Lidars (DLs) provide height and time resolved measurements of vertical velocity and attenuated aerosol backscatter in the lower troposphere



- The BLTS VAP contains…
  - DL-derived quantities
    - Profiles of vertical velocity statistics
    - Profiles of horizontal winds
    - Cloud properties
      - Cloud base height (CBH)
      - Cloud fraction
      - *Cloud base vertical velocity*
  - Quantities derived from other instruments
    - Surface fluxes (ECOR) and met
    - Presence/absence of surface precipitation; LWP
    - CBH from ceilometer
  - Daily files, 30-minute average, 30m vertical resolution

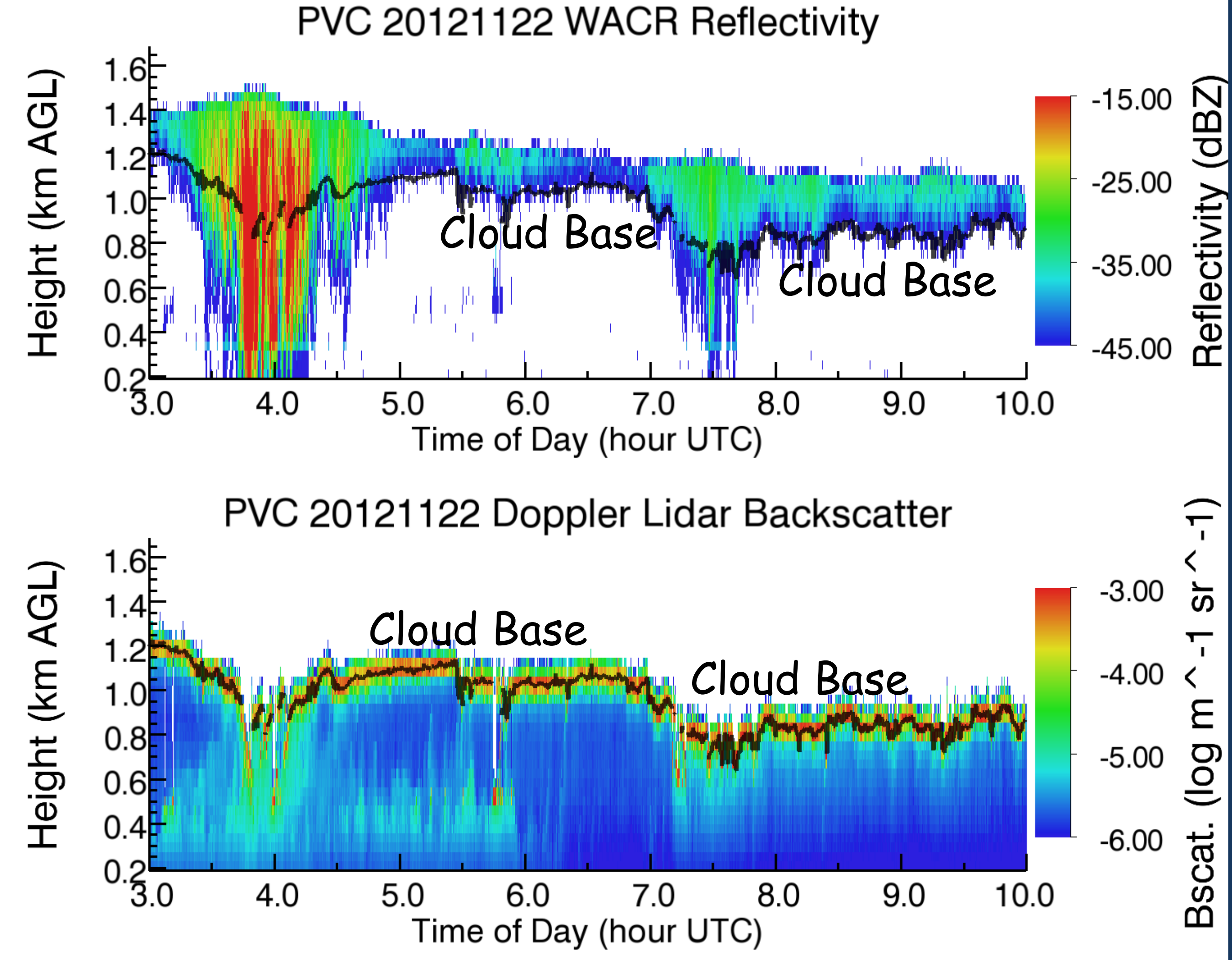
- DL Current Deployments
  - SGP
  - AMF#1
  - TWP-Darwin
- DL Planned Deployments
  - Graciosa, Azores
  - NSA-Oliktok Point

Rob Newsom, PNNL

Warm Cloud Vertical Air Velocity Best Estimate

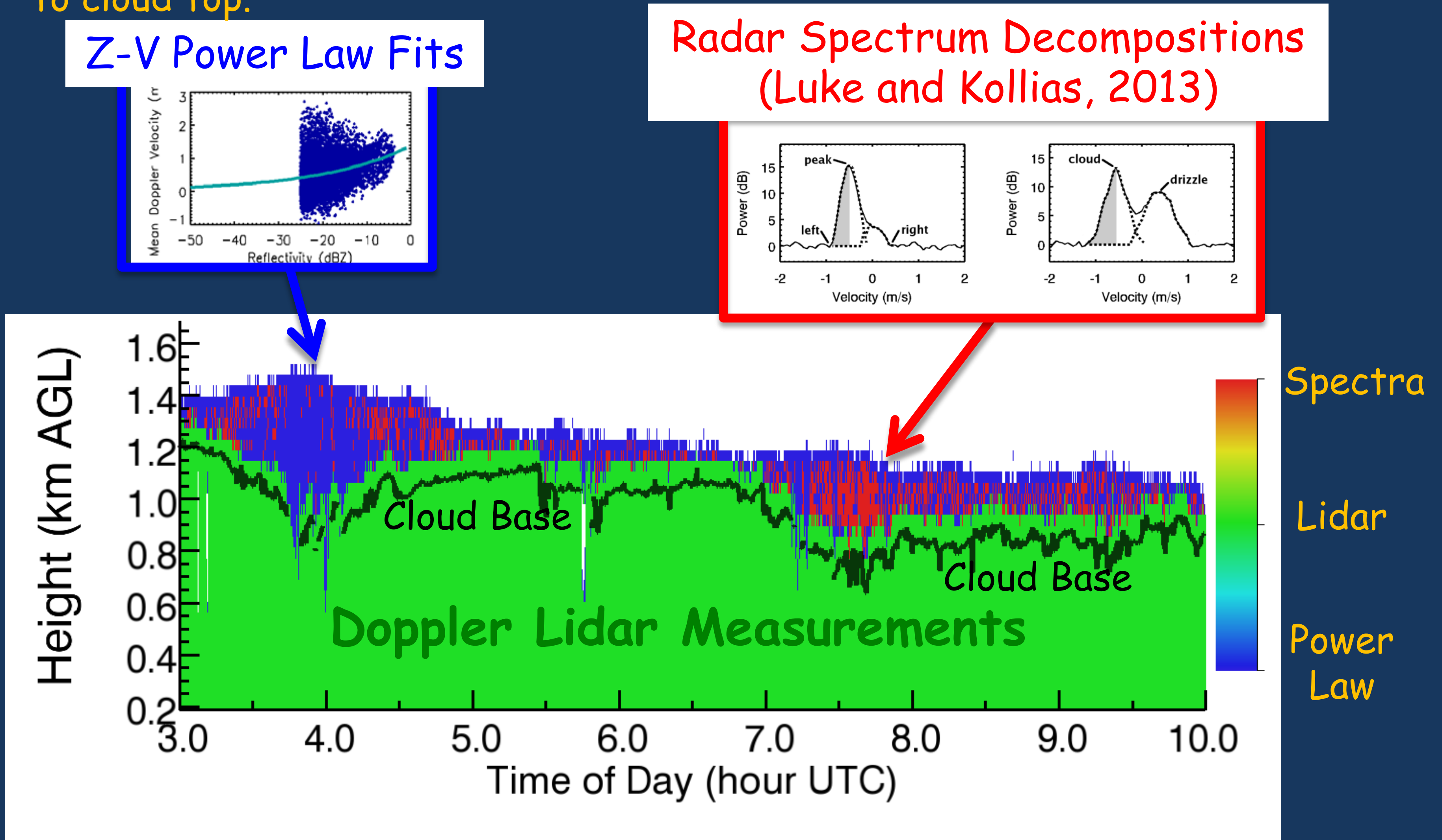
Edward Luke and Pavlos Kollias

- Uses complimentary measurements of cloud radar and lidar.
- Retrieves vertical velocity under ***precipitating and non-precipitating*** conditions.

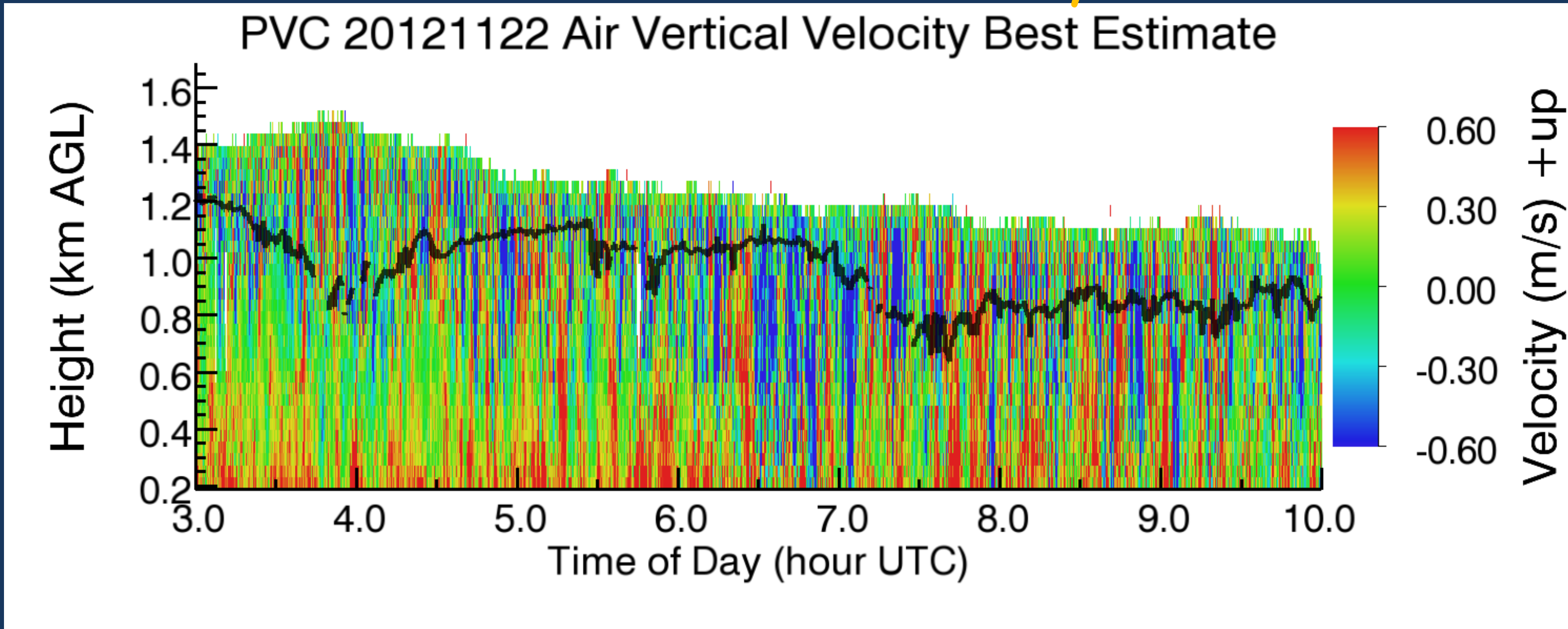


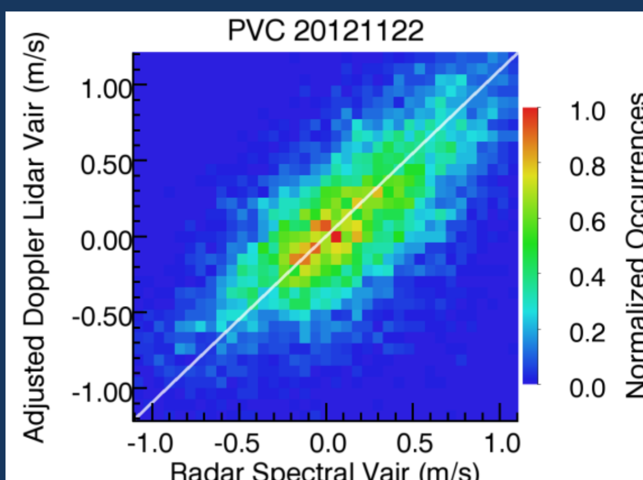
Warm Cloud Vertical Air Velocity Best Estimate

Radar Doppler spectrum decompositions (Luke and Kollias, 2013) combined with radar Z-V power law fits and Doppler lidar measurements provide seamless, high resolution vertical air velocity retrievals from the ground to cloud top.



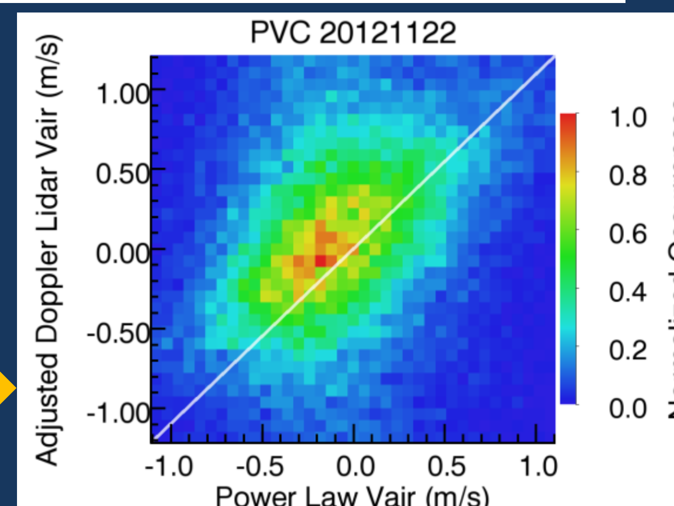
Warm Cloud Vertical Air Velocity Best Estimate





Doppler Lidar
Vs
Radar spectra

Doppler Lidar
Vs
Power-law



Synergistic retrievals of vertical air velocity in warm stratiform clouds: Luke, E.P. and P. Kollias, *Geophys. Res. Let.*, manuscript in preparation

Cirrus Clouds

Cirrus Clouds

- What factors control the ice crystal size distribution in cirrus clouds?
  - Dynamics
  - Thermodynamics
  - Aerosol/ice nuclei

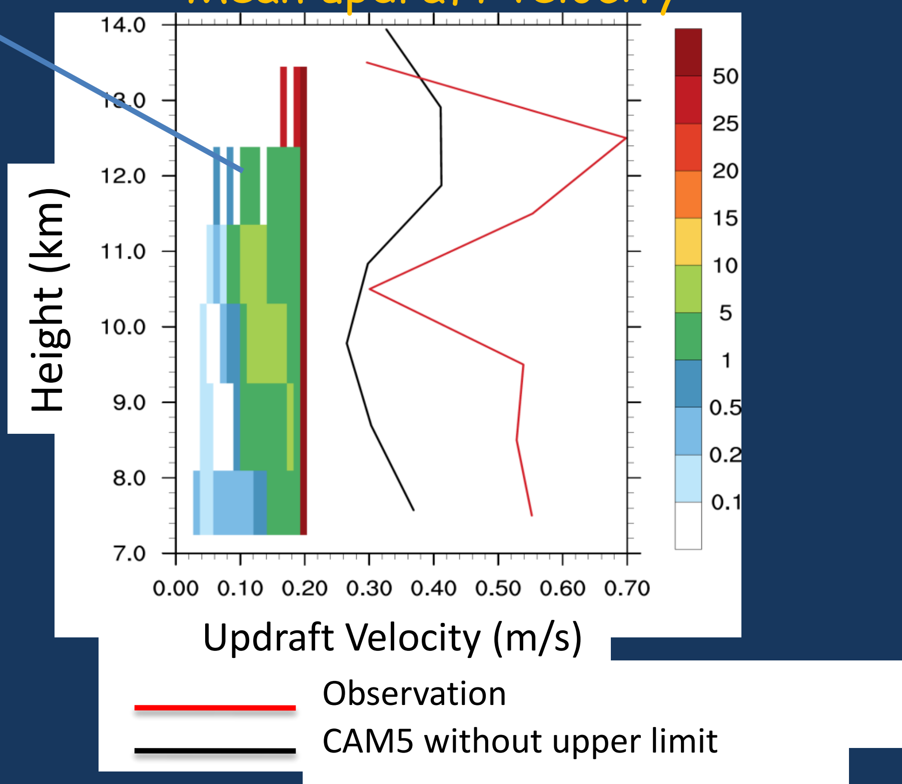
Vertical updrafts play a key role in regulating the thermodynamic conditions in ice nucleation regions. Representing these sub-grid meso-scale motions in large-scale models is one key to improving the simulation of upper tropospheric clouds.

Using SPARTICUS vertical velocity measurements for GCM model evaluation/improvement (K. Zhang et al.)

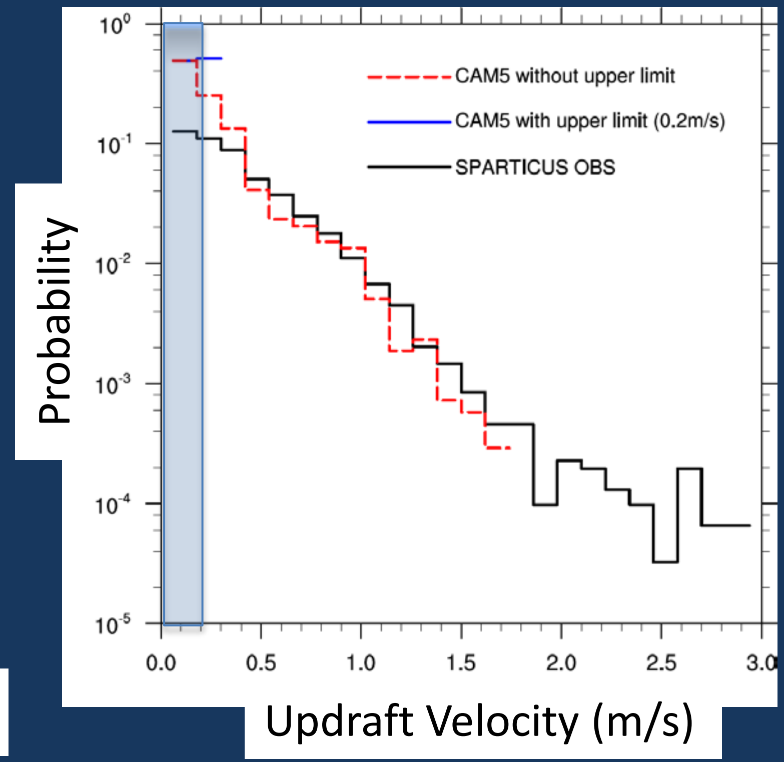
- **Mean updraft velocity and standard deviation** → provide constraints for ice cloud parameterization in GCM
- **Relationship between w, RH_{ice}, and N_{ice}** → useful for investigating the competition between homogeneous and heterogeneous ice nucleation

CAM5 with upper limit

Mean updraft velocity



Frequency distribution

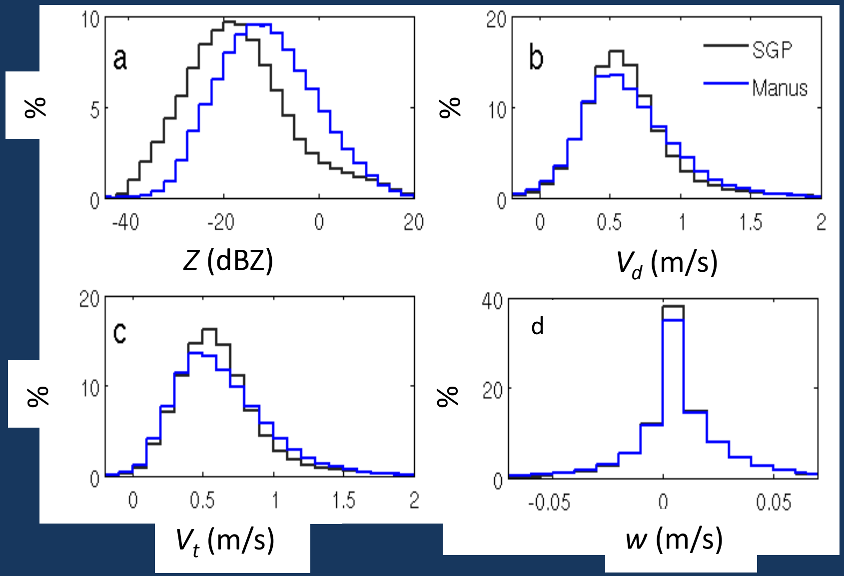


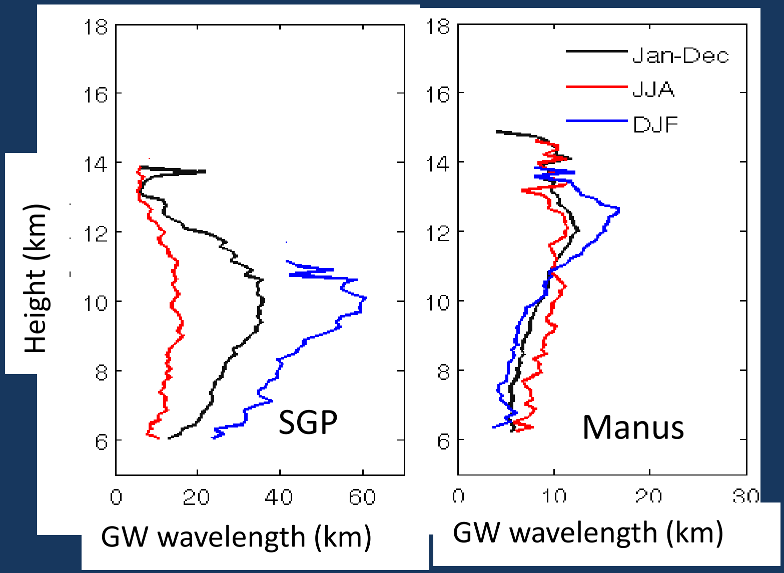
Climatology of ice cloud dynamics using profiling ARM Doppler radar
(H. Kalesse & P. Kollias, 2013, accepted by J. Clim.)

- SGP: 14 yrs (1997 – 2010) - 26700h (24% of MMCR operating time)
- TWP-Manus: 11 yrs (1999 – 2010) - 25900h (44% of MMCR operating time)

1. Decomposition of Doppler velocities (V_d) into reflectivity-weighted particle terminal fall velocity (V_t) and vertical air motion (w) for finite time spans ($V_d = aZ^b$)
2. Use w to detect gravity-waves (GW) via wavelet analysis and determine cirrus cloud turbulence (ε) via FFT

Climatology of Z, V_d, V_t, w, cloud depth, ε etc. in absence/presence of GW





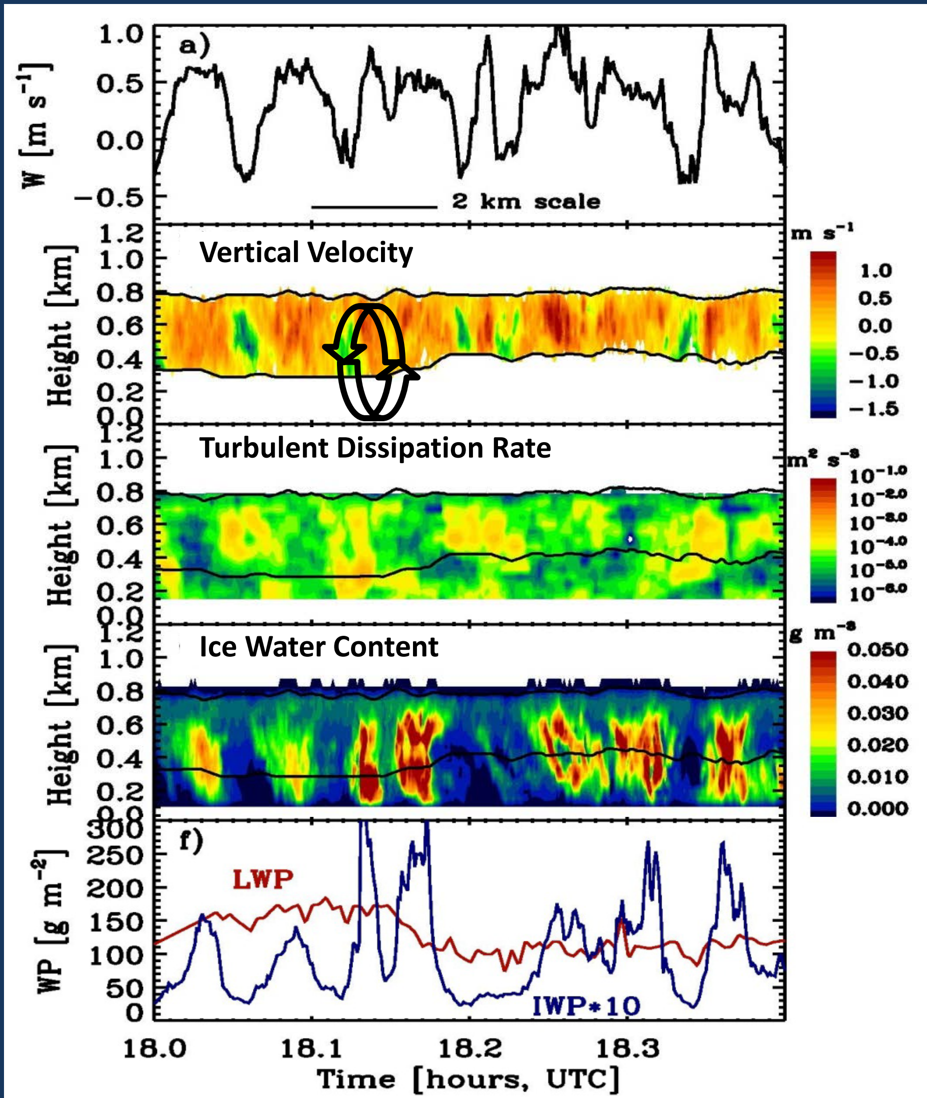
- Availability: daily netcdf of ice cloud dynamics will be made available at ARM archive (so far generated for SPARTICUS (Jan-Jun 2010): http://meteo.mcgill.ca/~heike/sparticus*.tar.gz)

Summary

Cloud Type	Products
Boundary Layer	• Boundary Layer Turbulence Statistics (Rob Newsom, PNNL) • Warm Cloud Vertical Air Velocity (Ed Luke, BNL)
Deep Convective Clouds	• Vertical Velocity in Stratiform Rain (Maureen Dunn, BNL) • Convective Vertical Velocity (Kirk North, McGill University)
Cirrus	• Ice Cloud Dynamics at SGP and Manus (Heike Kalesse, McGill University)

Future Direction
&
Other Scientific Needs

Vertical Motions in Arctic Mixed-Phase Clouds



High resolution W retrievals reveal relationship between 1-2 km eddies and cloud microphysics.

Cloud-driven, vertical air motions play a critical role in the life cycle of Arctic mixed-phase stratiform clouds by:

- Producing cloud water in the presence of a continual ice precipitation sink, contributing to cloud persistence;
- Influencing ice production and thus phase partitioning and precipitation;
- Driving entrainment and vertical mixing of moisture, aerosols, etc.;
- Sometimes providing a dynamical linkage between cloud and surface.

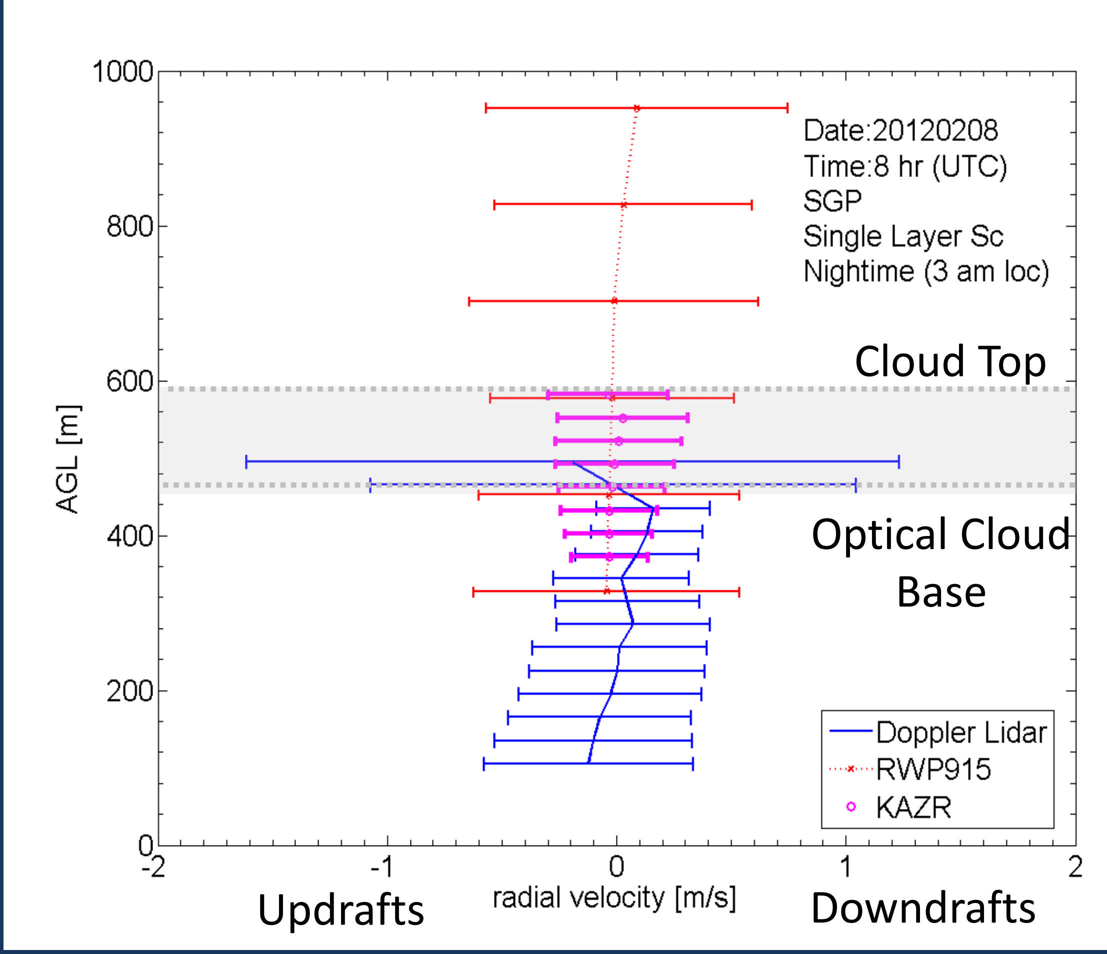
In Barrow, we only have part of the picture!

- Vertical pointing Doppler cloud radars provide in-cloud vertical motions;
- *Doppler lidar is needed* to get motions below cloud and make atmosphere-cloud linkages.

Matt Shupe

Vertical Velocity Measurement Inter-comparisons

- Doppler Lidar
  - Tracking Aerosols
- Cloud Radar
  - Tracking cloud drops
- Wind Profiler
  - Changes in temp. and humidity

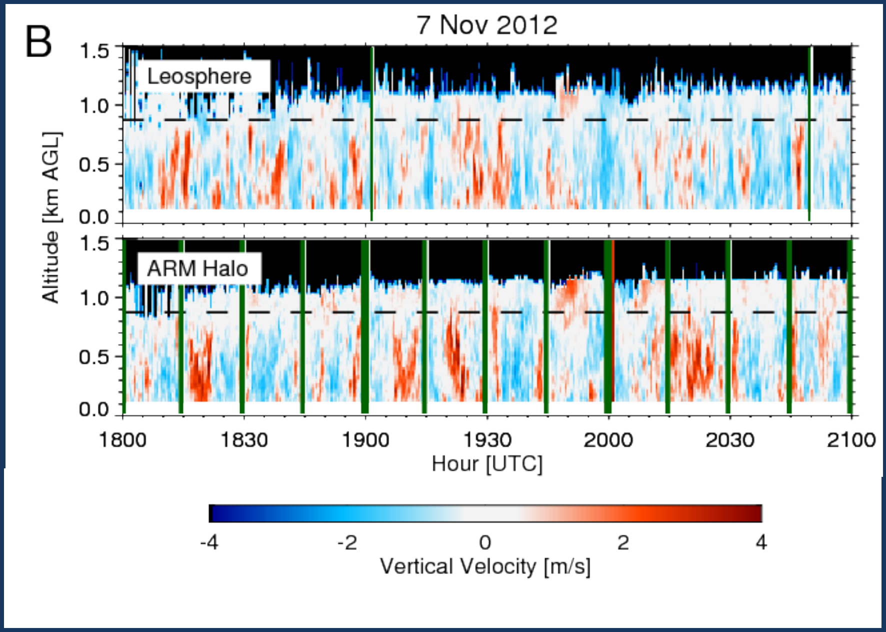


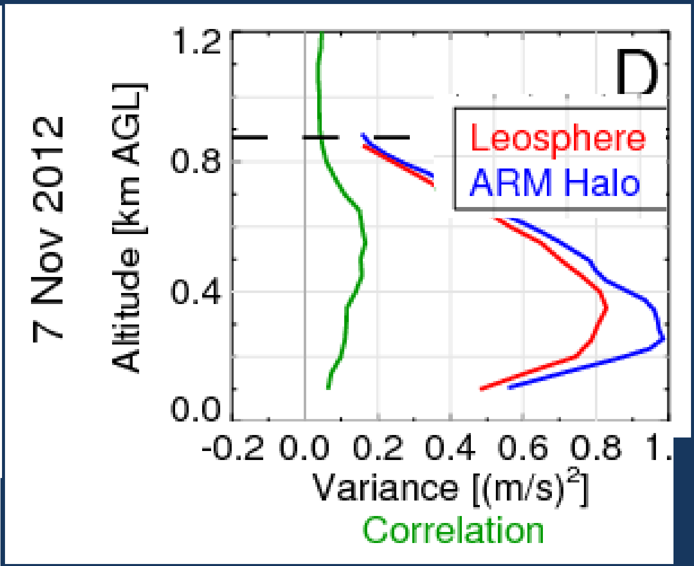
- What is the best estimate for modeling purposes?
- What is the best instrument for set of atmospheric conditions?

Mark Miller

Horizontal Differences in Turbulence

- Deployed two additional Doppler lidars to SGP CF during Lower Atmosphere Boundary Layer Experiment (LABLE)
- Analyzing vertical velocity structure, variance, and correlation between lidar systems in CBL based upon wind direction (i.e., fetch) relative to the lidar orientation





- See poster by Turner et al. on Tuesday, Room 1, #185

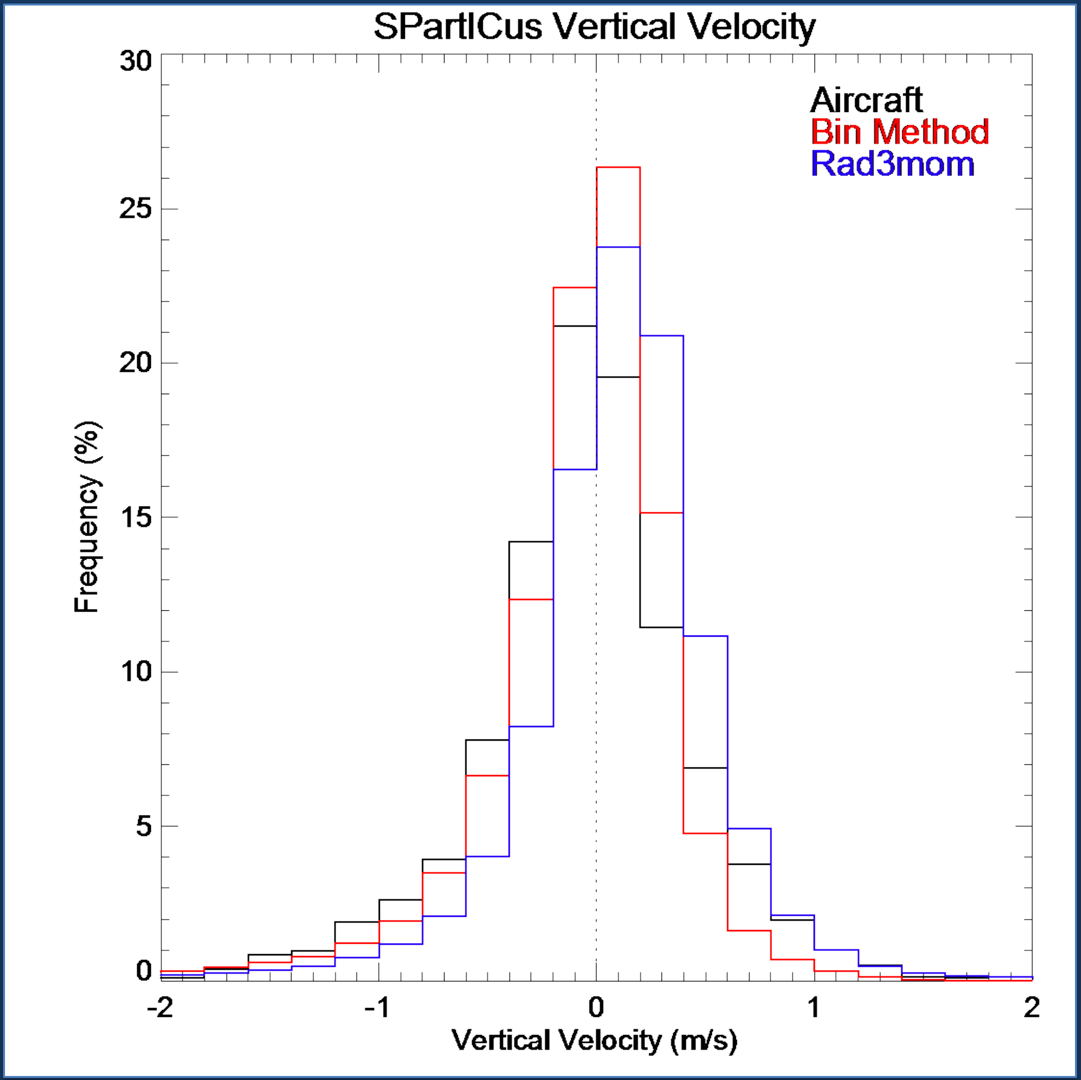

A visualization of a Giga-LES cloud system using SHDOM, a 3D radiative transfer method.
THANKS

Joint PDFs

Retrieval Algorithm Development

Using Aircraft Measurements to Evaluate Radar Retrievals

Good agreement between aircraft and radar retrievals provides basis for developing long-term statistics from ground based measurements



J. Comstock and M. Deng

VERtical VELocity in Stratiform Rain (VERVELSR)

M. Dunn, M. Jensen, S. Giangrande

- Exploits Mie scattering at 94 GHz.
- Vertical Velocity in Stratiform Rain conditions with accuracy to within 10 cm/s.
- Novel spectra processing helps overcome partial W-band attenuation in rain.
- Available Data: Niamey (June to September, 2006); SGP (May 2007).

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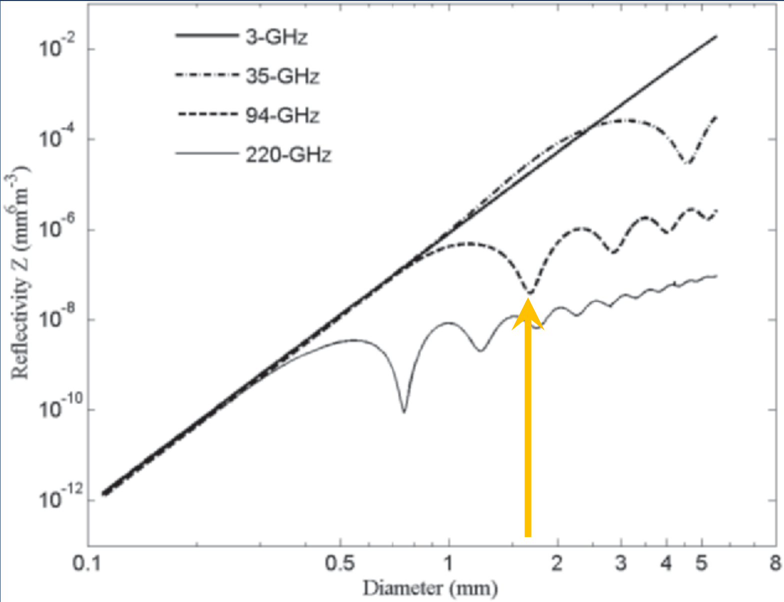

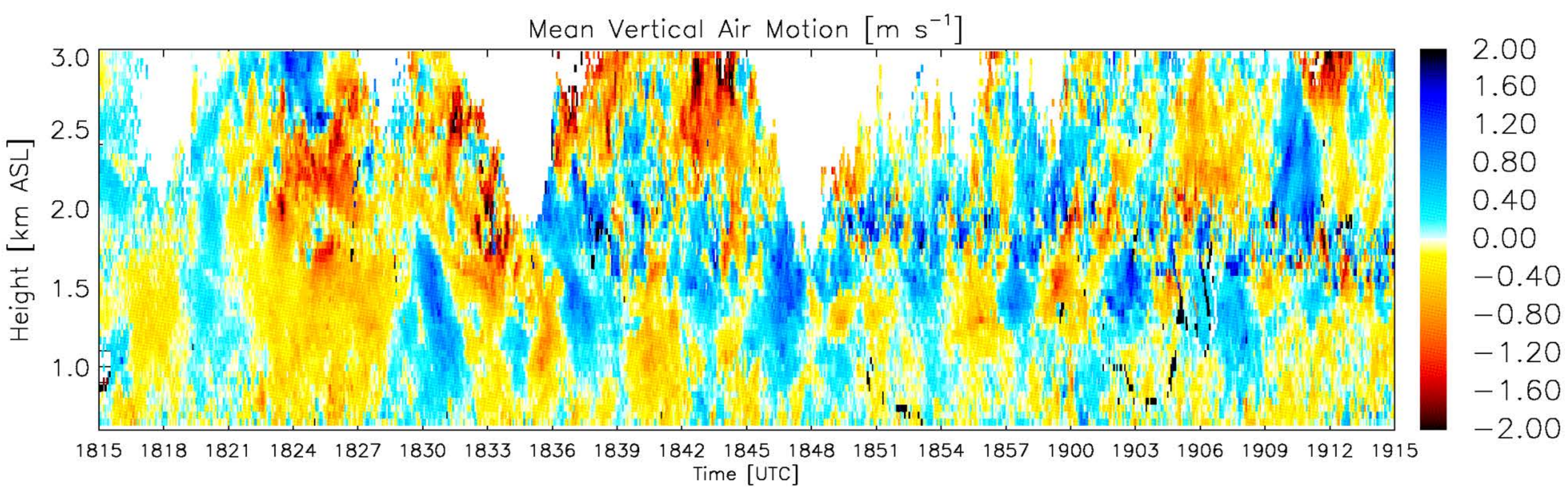

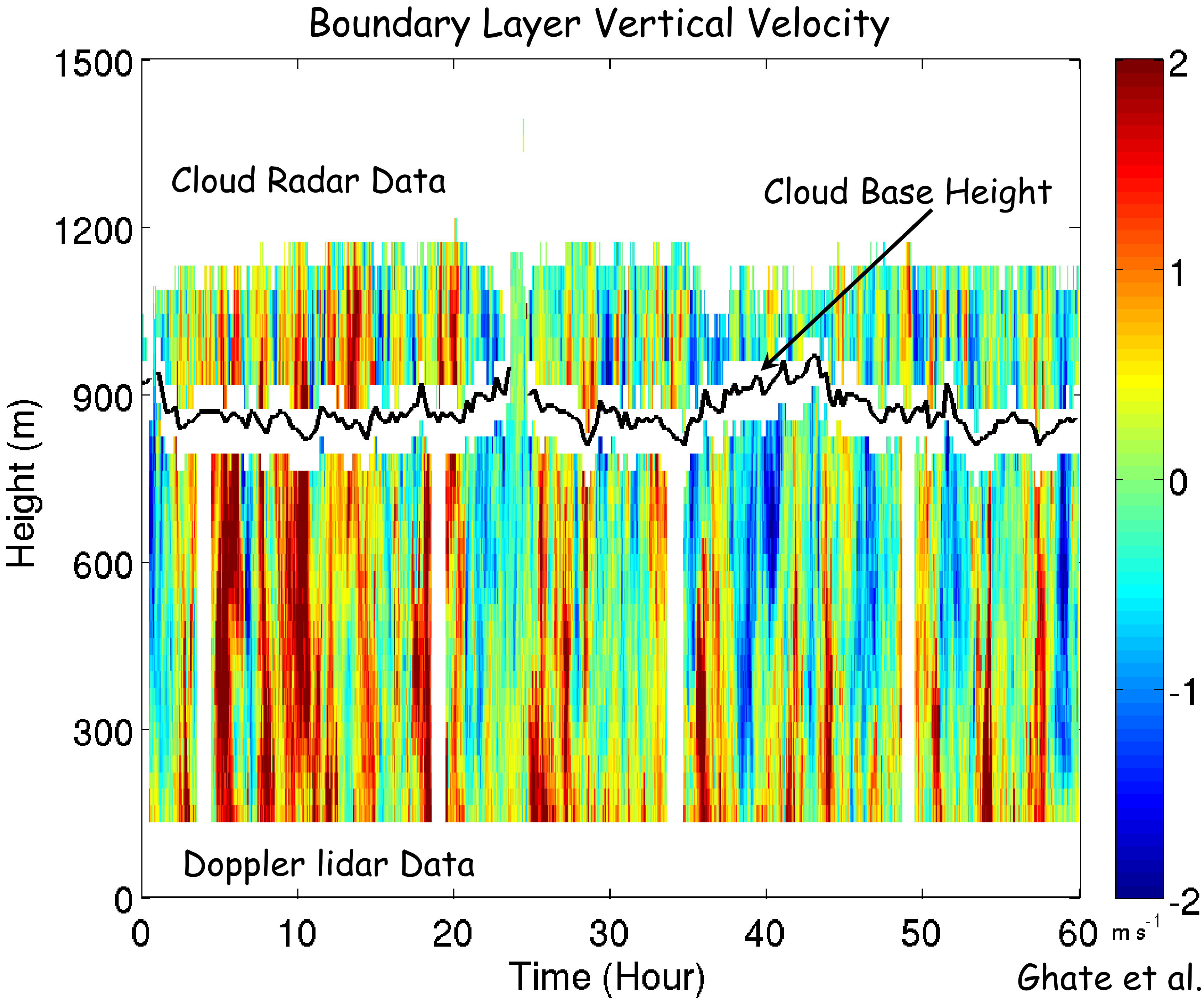

Ghate et al. 2013

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- **Mean updraft velocity and standard deviation** → provide constraints for ice cloud parameterization in GCM
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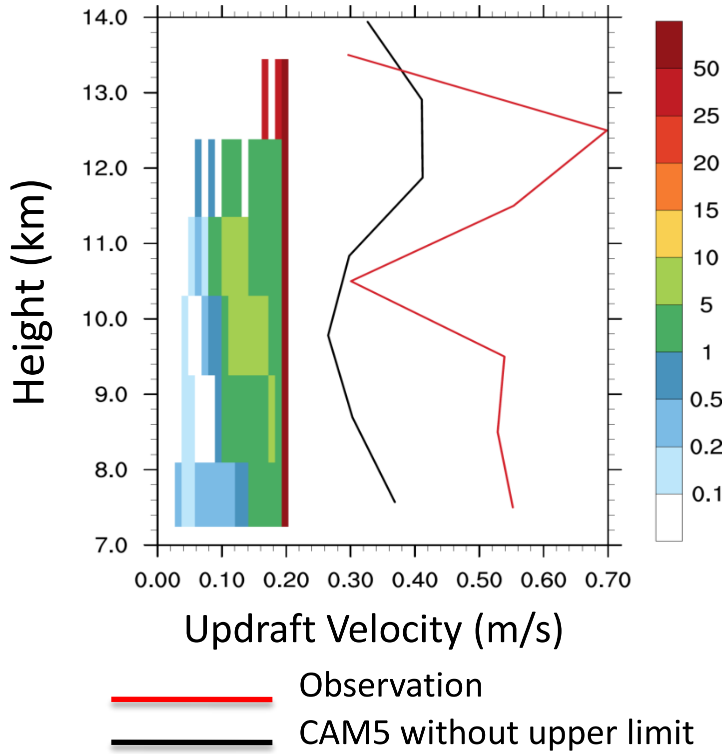
Mean updraft velocity



Frequency distribution