Observational Needs for Studying Convective Transition Processes

Angela Rowe and Zhe Feng
ASR STM Breakout Session 5
16 March 2017
Vienna, VA

Motivation

- ASR-sponsored workshop (Feb 2016) : "The Treatment of Convection in the Next Generation Climate Models: Challenges and Opportunities"
  - "To develop *short- and long-term strategies* to accurately represent convection in these models and to identify opportunities for the ASR program to effectively *leverage DOE's unique capabilities*, high performance computing resources and ARM observational facilities, to this end."
- **This breakout session will summarize this workshop discussion and provide a venue to discuss additional needs within the community to increase our understanding of transitional convective processes.**

Basic understanding of cloud processes

- Key to better represent convection in climate models
  - Boundary layer evolution
  - Properties and variability of updrafts/downdrafts
  - Microphysical feedbacks
  - Aggregation of convection
  - Mesoscale circulation/relationship with environment
  - Stochastic processes

- Parameterization: Must represent the sub-grid states, processes and **transitions**, and their interactions

Understanding convective transitions

- Boundary layer variability and development of **shallow cumulus** clouds
  - Internal instabilities (e.g., BL rolls, open cells)
  - Role of vertical wind shear
  - Land-use heterogeneity, topography, thermodynamic instability
  - Cold pools (production, initiating/prolonging convection)

Understanding convective transitions

- Transition to **deep convection**
  - Moist, deep, buoyantly unstable air
  - Interaction via cold pools, further clustering
  - Role of land-surface conditions and their fluxes/ gradients
  - Characteristics of updrafts
    - **Co-variability** of width, intensity, and internal turbulent characteristics of drafts
    - Interactions with the environment
    - Interactions with microphysical processes

Understanding convective transitions

- Upscale growth to **MCS**s
  - How does the initial group of convective cells that grow into an MCS originate (e.g., self-aggregation over oceans, but what about over land)?
  - Interaction with vertical wind shear
  - Cold pools (depth, speed, lifetime, strength, updrafts)

- **Which environmental conditions and internal feedback processes control these transitions?**

Observational Needs

- **<u>Short-term</u>** strategies
  - Creating **merged products** from existing integrated datasets targeting specific science questions
  - **Adaptive operations** to fully sample convective transitions

Presentation Outline

- Mid-latitude Continental
  - **David Mechem** (2 slides/5 min): Multisensor observations of shallow and precipitating cumulus during MC3E
- Green Ocean
  - **Mike Jensen/Yolande Serra** (2 slides/5 min): Shallow-to-deep transition and modulation by environment during GoAMAZON
- Tropical Oceanic
  - **Daehyun Kim** (2 slides/5 min): Convective organization and cold pools during AMIE
- Merged Data Products
  - **Zhe Feng** (2 slides/5 min): Dynamics/microphysics interactions
- Adaptive radar measurements at SGP
  - **Joe Hardin/Adam Varble** (4 slides/10 min): Motivation and feasibility

Presentation Questions

- How do the **existing data products** from the field campaign/site address the science needs related to convective transitions?
  - Which convective transition(s) does your study address?
  - Which data products were especially helpful?
- What **additional (merged) data products** could be created from existing data to address your science question(s)?
- What **additional observations** do you wish were/could be collected to address remaining science questions?

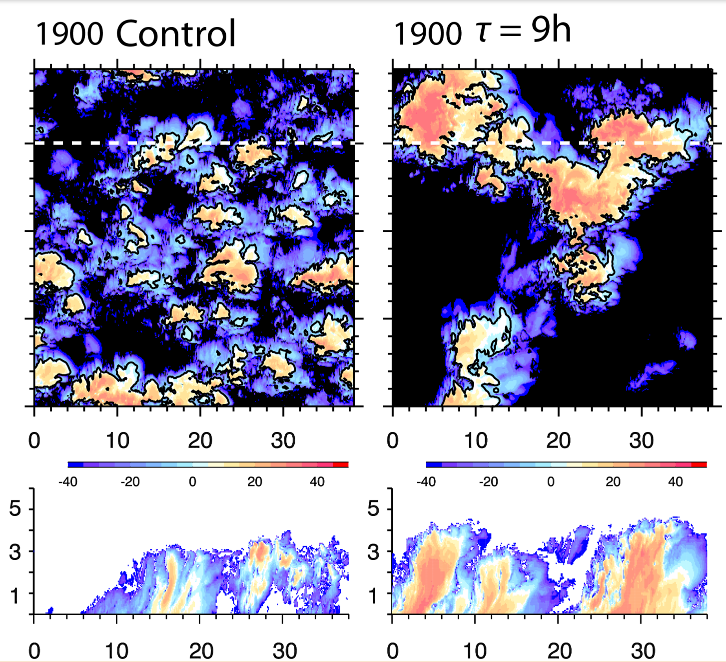
Modeling and Observational Evaluation of a Precipitating Continental Cumulus Event Observed During the MC3E Field Campaign

David B. Mechem, Scott E. Giangrande, Carly S. Wittman,
Paloma Borque, Tami Toto, and Pavlos Kollias

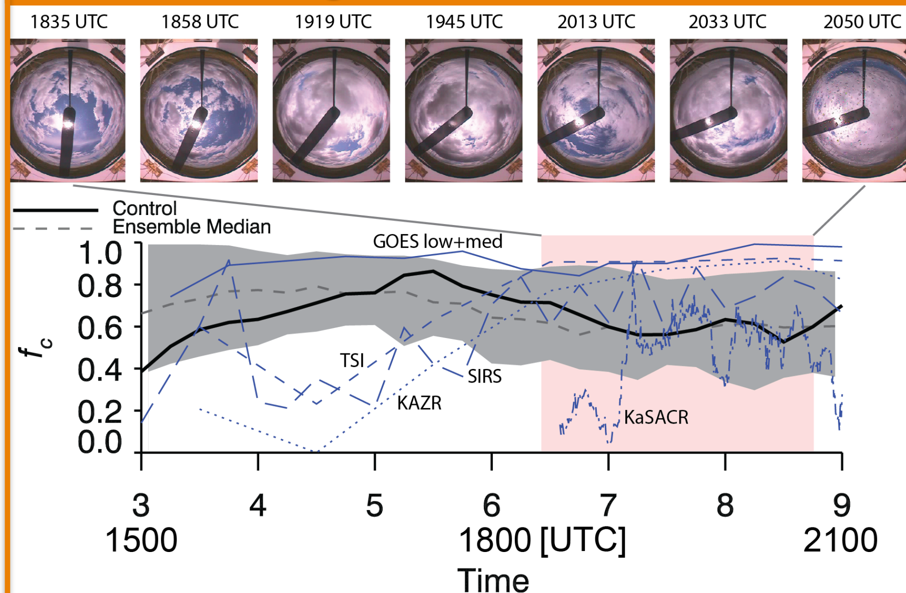
Science Questions:

- How sensitive is cloud evolutionary behavior to details in meteorological forcing?
- What are the best paths to compare macroscale cloud properties between models and observations?

Reflectivity Calculation from Model Simulation of Precipitating Congestus



Imagery from TSI (top) and Cloud Fraction from LES and a Range of Observational Estimates

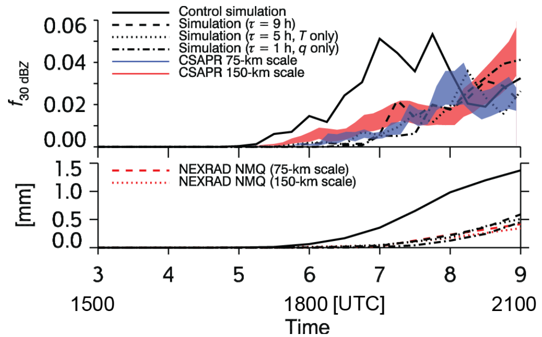


Key Accomplishment:

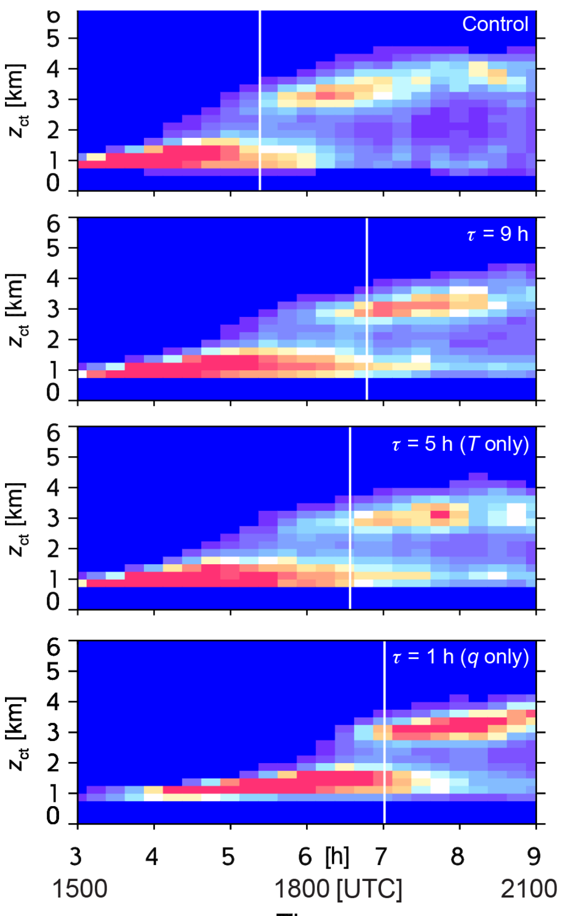
Multi-dimensional cloud measurements from ARM radars demonstrate several advantages for simulations using time-varying forcing.

Mechem, D. B., et al., 2015: Insights from modeling and observational evaluation of a precipitating continental cumulus event observed during the MC3E field campaign. *J. Geophys. Res.*, doi:10.1002/2014JD022255.

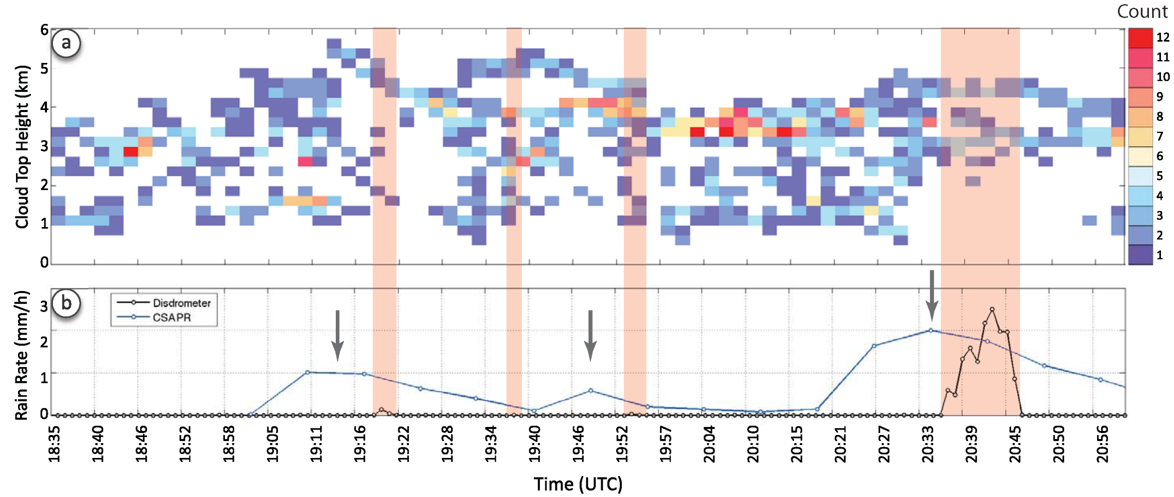
Bulk precipitation statistics



Time evolution of cloud-top PDFs from LES



Time evolution of cloud-top PDFs from the SACR



Key points:

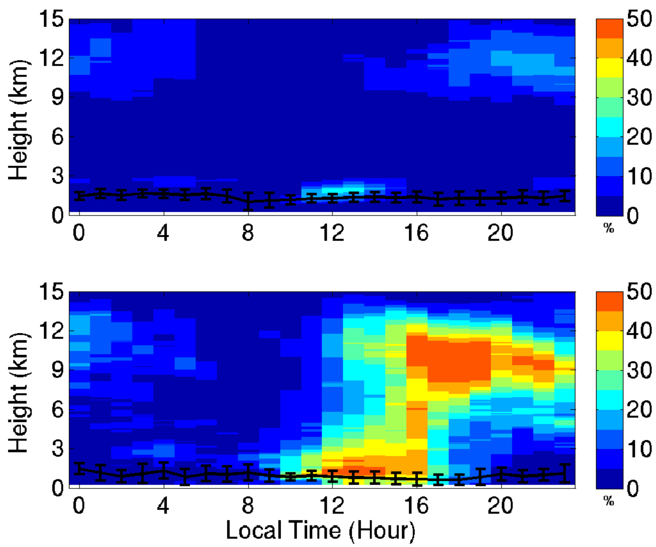
Cloud fraction/cover is is difficult to constrain observationally and provides very little diagnostic guidance to identify model pathologies

Area-mean behavior is the first step in evaluating models, but simulations with similar 'bulk' measures may have substantially behavior underlying them

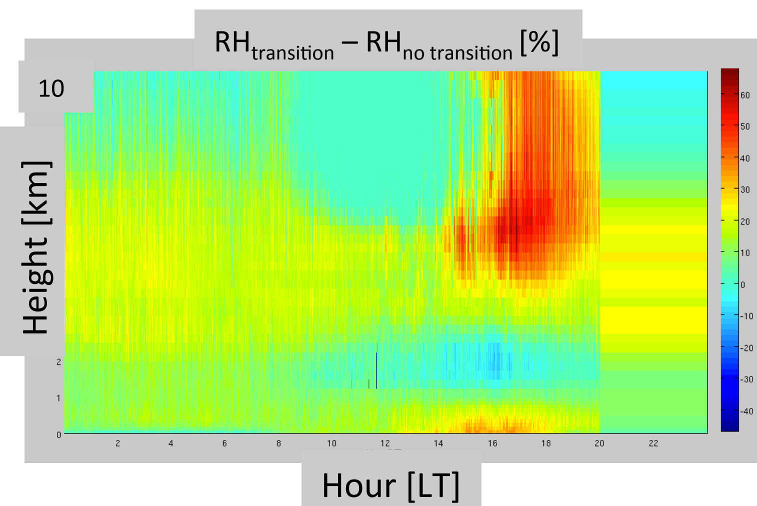
Need to constrain models with higher-order statistical information such as cloud-top height distribution, distribution of cell-sizes, and cell evolution. Need spatial and temporal information to capture behavior over cell lifetimes

AMF Observations of Shallow2Deep Transitions During GoAmazon

Mike Jensen



- Defined "Transition" Days and "Non-Transition" Days using WACR and disdrometer observations
- Composite observations of relevant environmental parameters including:
  - Surface Fluxes - Sfc. Thermodynamics
  - State Profiles - PWV, LWP
- Transitions to deep clouds occur on days with pre-sunrise cloudiness and larger mid-level humidity.



Which data products were especially helpful?

- WACR-ARSCL, MWRP

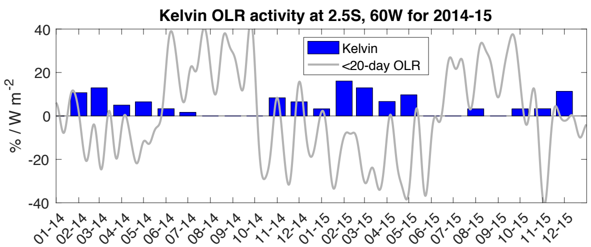
What merged products would be useful?

- Feng's combined RWP-ARSCL product
- Improved thermodynamic profiling (CAPE/CIN)
- VARANAL (sounding network)

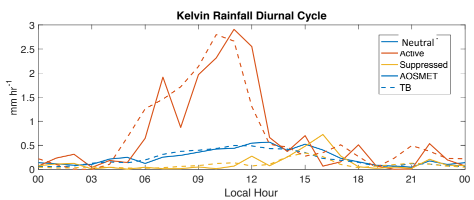
Useful additional observations?

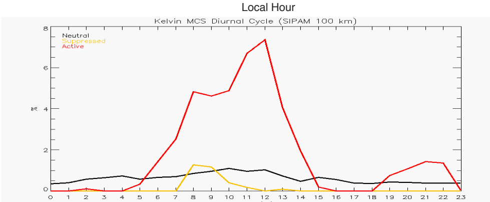
- Spatial information, especially surface fluxes and thermodynamic profiles

Understanding The Role of Large-scale Forcing in Supporting The Shallow-to-Deep Transition in The Central Amazon (Yolande Serra)

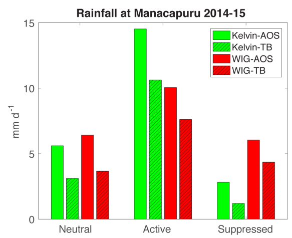


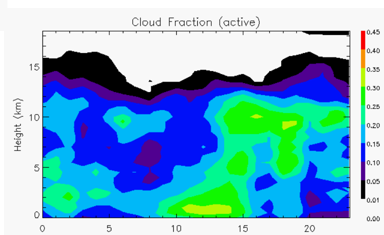
Kelvin Wave Modulated Diurnal Cycle



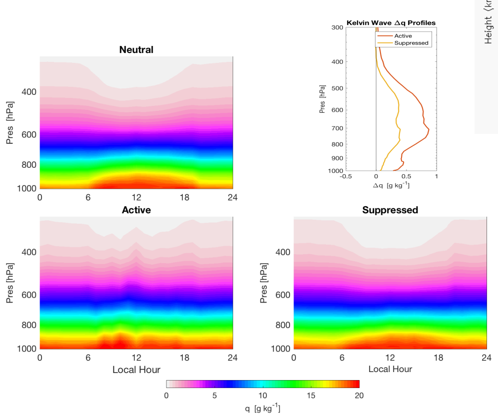


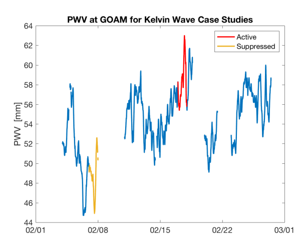
Kelvin Wave Modulated Rainfall, Cld fr & PWV





Kelvin Wave Modulated MWRP q





- Kelvin wave activity observed over AMF region in 2014-15.
- Composite observations by wave phase for relevant environmental parameters including:
  - q profiles (MWRP)
  - PWV (MWR, GPS network)
  - SIPAM radar features
  - WACR cloud fraction

Opportunity for synthesized data sets?

- GPS PWV and MWRP q profiles
- Trajectories of tracers that we can also examine in PWV from GPS network

How does the large-scale forcing modify the STD transition?

- Modified tropospheric humidity
- Increased MCS activity in active phase
- Impact on localized rainfall at AMF site

Next steps for improving STD in models?

- Understanding the forcing conditions associated with STD transition may be useful in diagnosing model errors

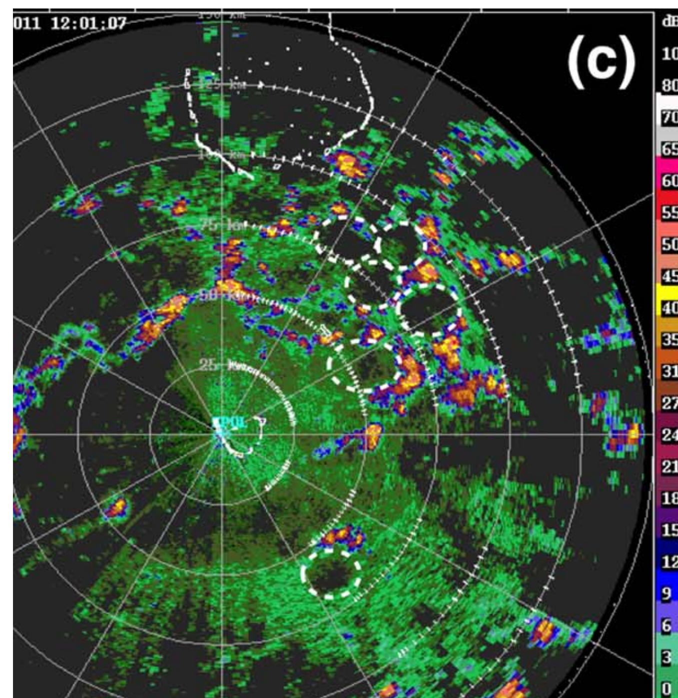
Diagnosis of convective organization and cold pools using ARM datasets and evaluation of a unified convection parameterization (UNICON) – Kim, Rowe, and Park

Project objectives

- Diagnose convective organization and cold pool processes over the SGP (MC3E) and central Indian Ocean (AMIE) using the ARM field campaign observations combined with related field campaign datasets (DYNAMO) and high-resolution CRM simulations driven by ARM observations.
- Evaluate processes related to convective organization and cold pools that are explicitly parameterized in a unified convection scheme (UNICON).

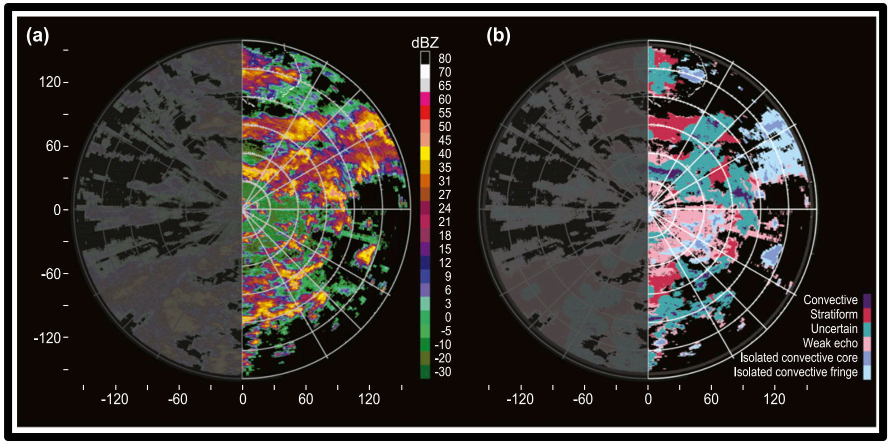
Data product that has been (and will be) useful

- (raw) Scanning precipitation radar
  - Contiguous convective echoes (CCEs)
  - Cold pools identification and tracking
- (raw) Surface met observations from ship and AMF + radar
  - cold pool properties (temperature and humidity perturbations)
- (product) ARM AMIE-Gan large scale forcing dataset
  - SCM simulations (UNICON)
  - high-resolution WRF simulations



New data product needed

- convective-stratiform classification algorithm applied to reflectivity maps
- size distribution of CCEs (indicative of size distribution of CCUs)
- cold pools fraction (LES? radar?)
    - LASSO: no plan to extend the current framework to precipitating events (we could/should make suggestions?)



New observations needed (specifics, including temporal and spatial resolution)

- Surface met + flux measurements + scanning precipitation radar
- Downdrafts from vertically pointing radar? (vertically pointing radar wind profiler +lidar+cloud radar+scanning precipitation radar, e.g. GoAmazon)
- Cold pool properties from drones (Sue)

Dynamics-Microphysics Interactions

Zhe Feng, Samson Hagos, Hannah Barnes

Example of Merging Existing Data Products:

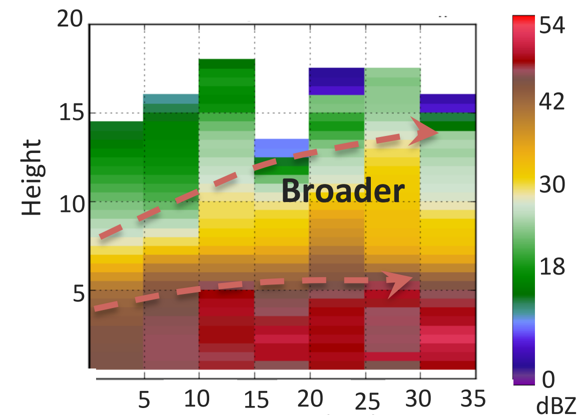
Science Question:

- Characterize the relationship between vertical velocity fluctuations and the vertical distribution of hydrometeors

Darwin Data:

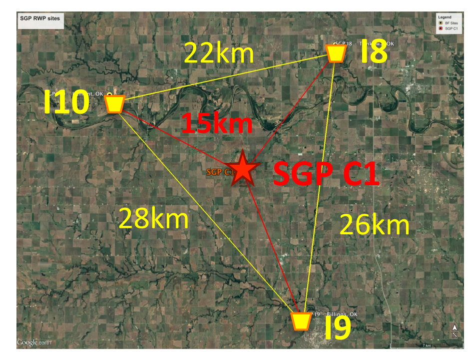
1) CPOL dual-polarimetric scanning C-band radar
2) Dual-frequency in-cloud vertical velocity retrieval (Williams et al., 2012)

Relationship between Vertical Velocity Variance and Reflectivity Profile



Merged Data Products Needs:

- Increased availability of vertical velocity and hydrometeor data
- Merged scanning radar & profiler data at ARM sites



Desired Additional Observations:

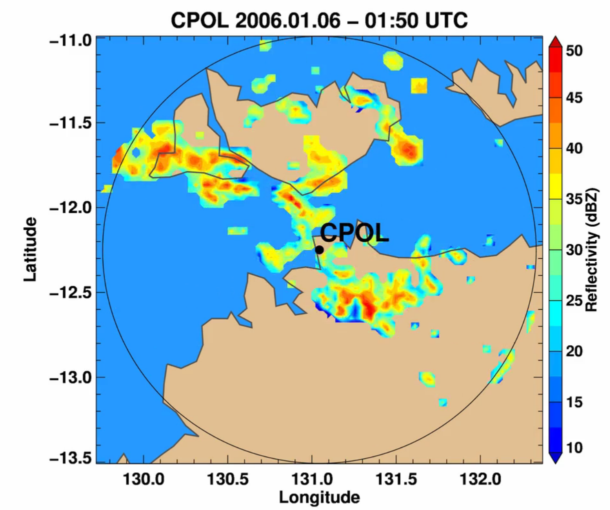
- Observe Lagrangian change of vertical velocity and microphysics profiles
  - Additional profiler networks (example: SGP)

Example of Gridded Precipitation Radar Data Products:
Science Question:

- How do convective clouds across size spectrum interact and collectively shape the state and evolution of the cloud populations?

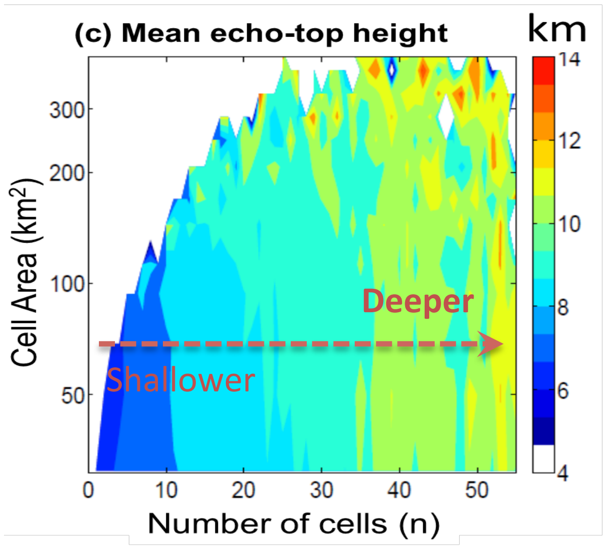
Darwin Data:

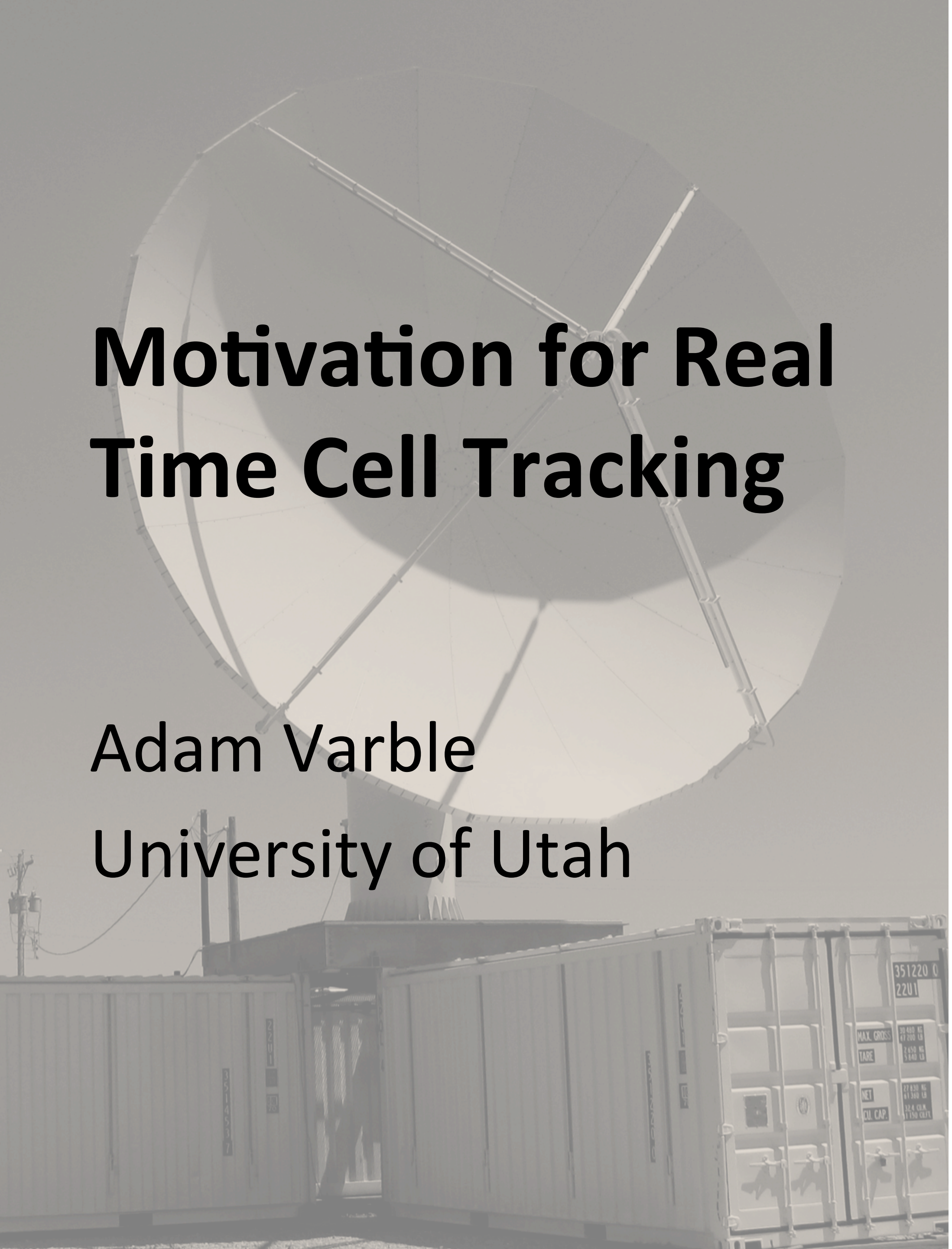
- Characterize convective cell features (e.g. size, depth, intensity) from CPOL radar data



Merged Data Products Needs:

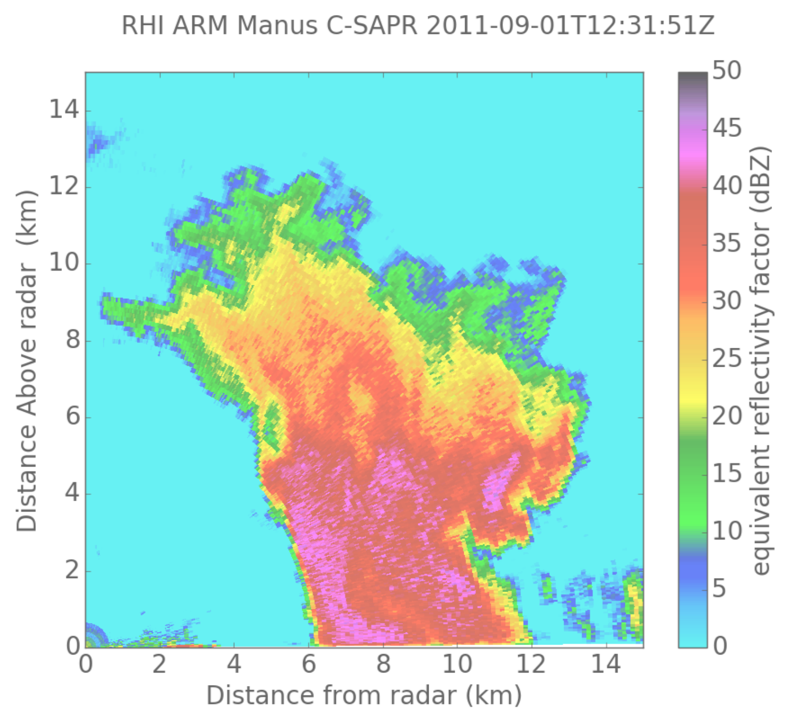
- Increased availability of gridded precipitation radar data for all ARM sites
- Implement convective feature identification to add values to the data product

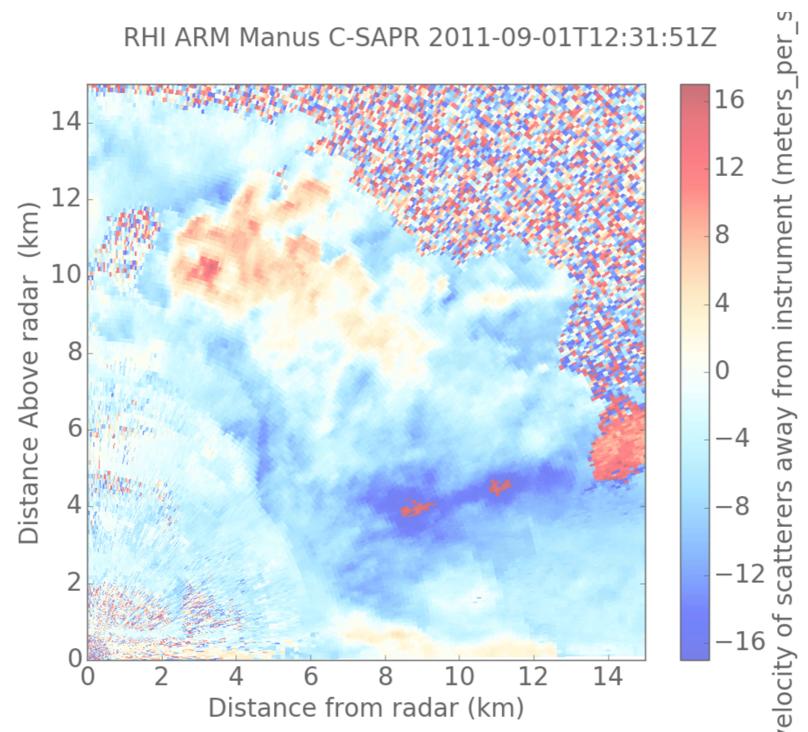




Motivation for Real Time Cell Tracking

Adam Varble
University of Utah



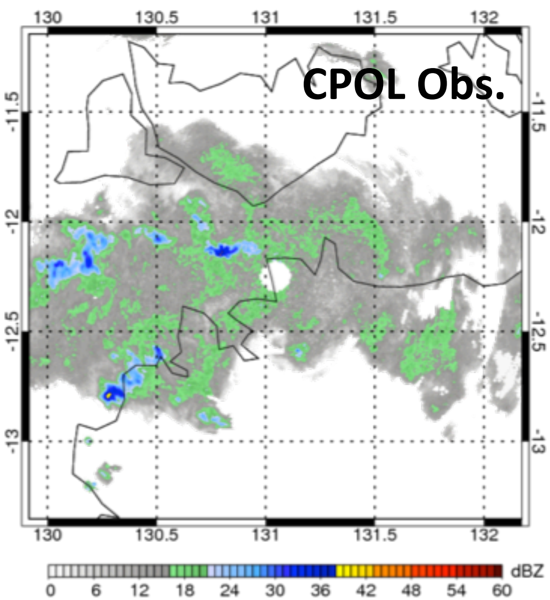


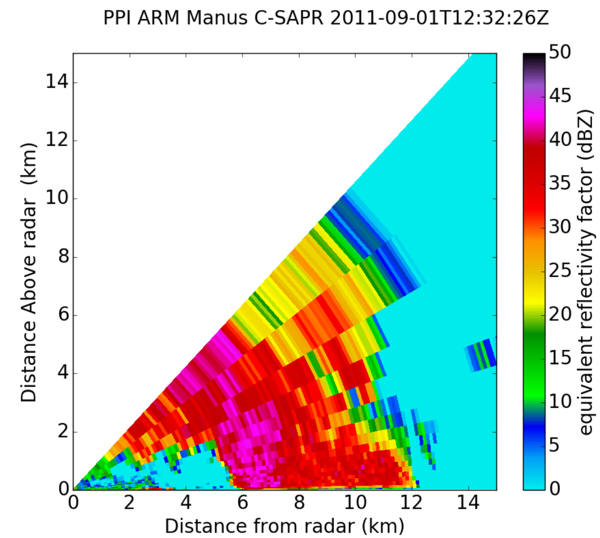
What do surveillance scans give us?

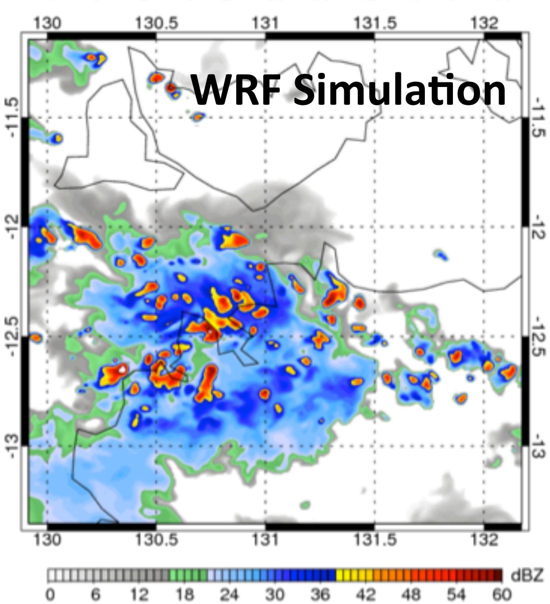
Climatological cloud and precipitation properties over a mesoscale region and mesoscale precipitation event evolution

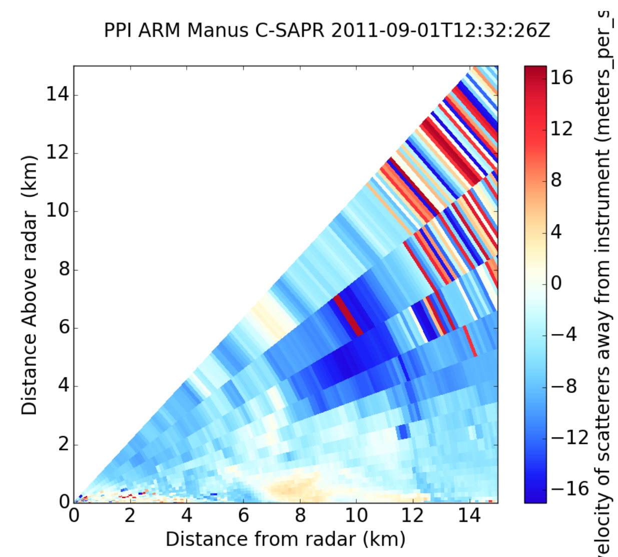
But Oklahoma is well characterized by NEXRAD, and model convective system precipitation biases are well known (causes are not)

Advantage of SAPRs over NEXRAD is higher resolution near SGP and ability to scan in creative ways targeting dynamic and microphysical processes and interactions

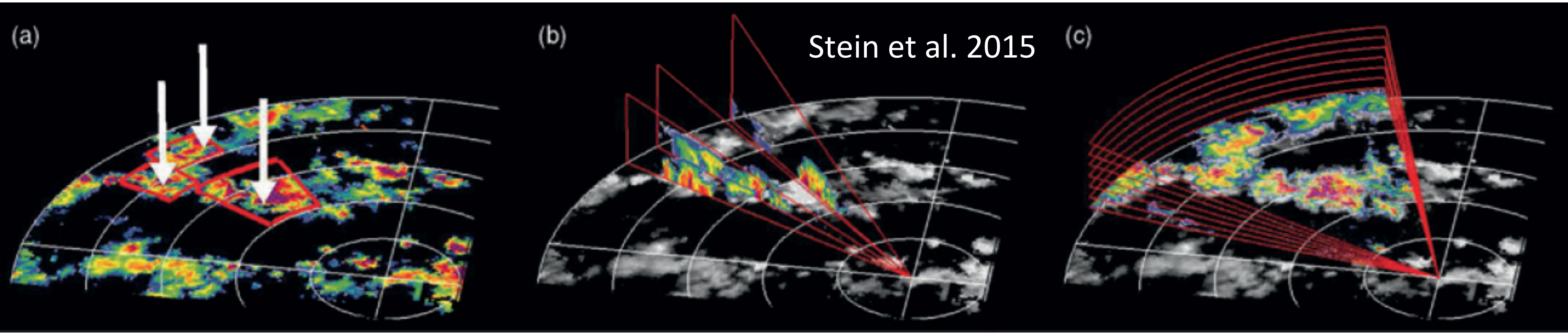








This calls for cell tracking



Stein et al. 2014 highlight "adaptive" scanning with Chilbolton during DYMECS, but "agile" scanning in a similar manner is also possible

Can use peaks in dBZ, KDP, etc.

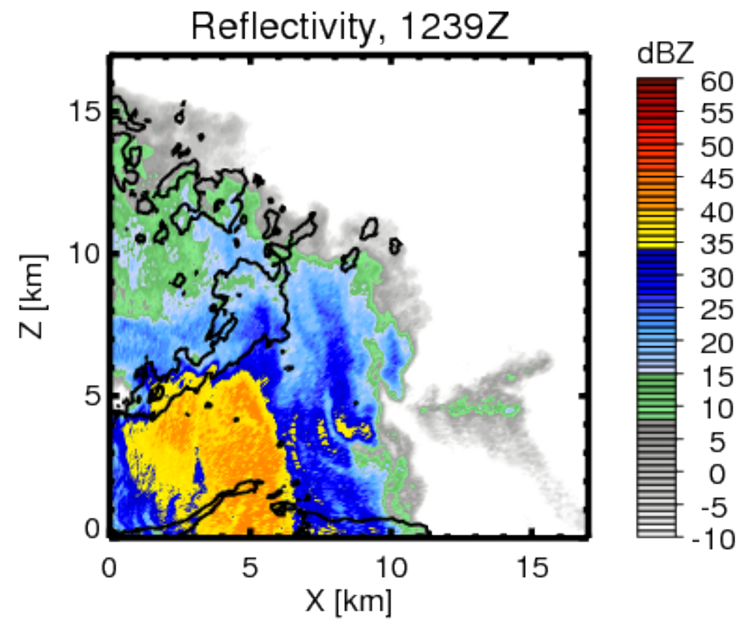
But there is difficulty early in the life cycle when no echo is present at low levels – how can we follow a cell before maturity?

With sector PPIs or RHIs covering the cell, repeat scans frequently, but how frequently is necessary? How are scan rates limited?

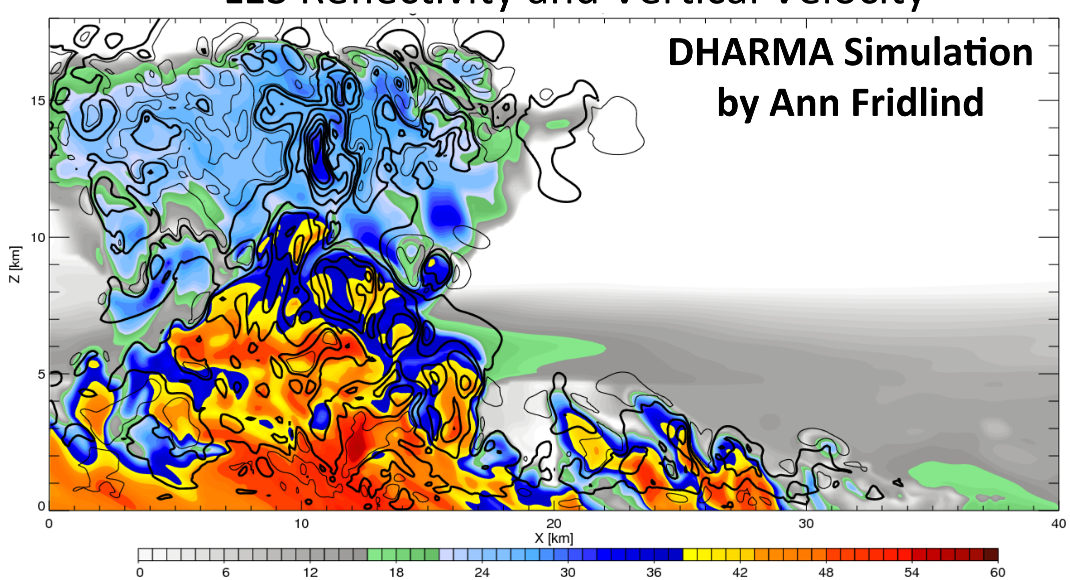
Focus within close range (e.g., 30 km) of radar to increase Nyquist velocity, sensitivity, and resolution

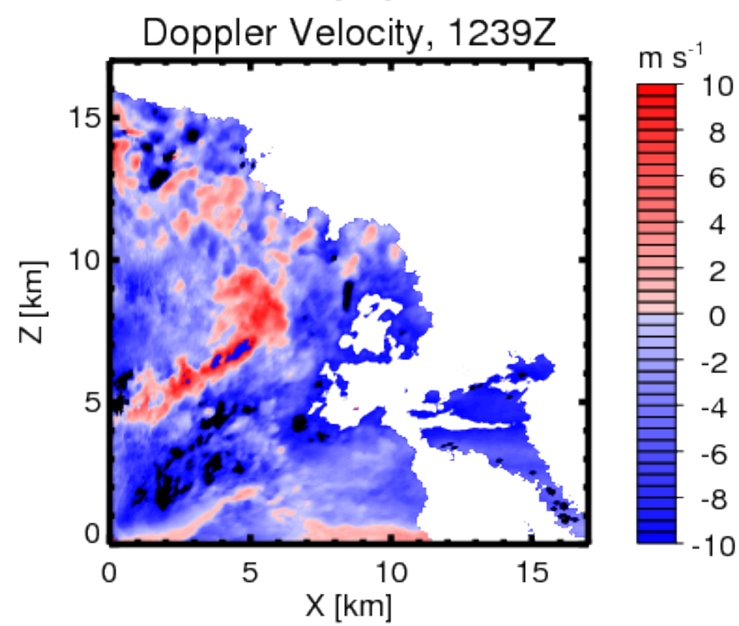
Examples of what can be done

1. Spatial scales of convective drafts and hydrometeor growth and sedimentation
2. Lag correlation of draft dynamics with hydrometeor properties and inferred microphysical processes causing accelerations
3. Using a radar simulator, model output can be scanned using the same cell tracking method and validated at a process level



LES Reflectivity and Vertical Velocity





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Agile/Adaptive Scanning Capabilities of ARM SGP Radars

JOSEPH C HARDIN, NITIN BHARADWAJ, ANDREI LINDENMAIER, BRAD ISOM, ALYSSA MATTHEWS

PNNL Radar Engineering and Operations

DOE ARM/ASR PI Meeting 2017

U.S. DEPARTMENT OF ENERGY

ARM CLIMATE RESEARCH FACILITY

- There are currently two parallel but related requests floating around ARM/ASR related to “adaptive” scanning.

- Half the group means **adaptive** scanning
  - Automated tracking of storms and updates of scan strategies with no human in the loop.
- The other half means **agile** scanning
  - Humans quickly adjusting scanning strategy.

- Neither approach is new, but each presents challenges.

SGP Radar Readiness & Capabilities

- XSAPRs finish their upgrades in April 2017
  - Andrei Lindenmaier has completely overhauled of many subsystems to improve operation.
- CSAPR1 is currently down, requires engineering work to fix.
- CSAPR2 is at SGP and starts its engineering evaluation beginning of 2018; pack up for CACTI starts ~May
- SGP KAZR is currently operational
- SGP SACR starts active work April 2017.

- All radars can be controlled remotely.
- XSAPR – Scanning, Agile Scan Capable
  - 50km range, dual-pol
- CSAPR – Scanning, Agile Scan capable.
  - ~115km range, dual-pol
- SACR – Scanning, Agile scan capable
  - ~25km range, dual-pol
- KAZR – Limited reconfigurability, Vertically pointing only
- CSAPR2 – Scanning, Agile Scan capable
  - At SGP for engineering evaluation.

Two options for Agile scanning

- Predefined Scan Sets:
  - Set up different predefined scan strategies. Very fast switching between strategies. (Switch to scan set B)
- Predefined Scan Topology:
  - Scan configuration is predefined, but angles are changed based on evolution of storm.
  - Slightly slower depending on changes.
  - I.e. 10 stack RHI, rotate starting angles to track storm.

- Both approaches require science liason to make decisions during campaign, and availability of infrastructure to update scans.

Adaptive Scanning

- Adaptive scanning
  - Requires tying together data processing, scan tracking, and scan controller.
  - CASA for instance does this.

- Many benefits, I will only discuss drawbacks and roadblocks to implementation.

- Biggest roadblock is engineer development time.
  - Data is not processed in real-time right now.
  - Bypassing aspects of vendor systems.
  - Development of multiple scan controllers
  - Edge case testing

- If we take up adaptive scanning, we have to drop something else.
- The easy part is the storm tracking algorithm. Many already exist.

Current Plans for Agile/Adaptive Summer Campaign

- There are no current infrastructure plans to support an agile scanning summer field campaign.
- No one has formally proposed this field campaign to ARM as of yet.
- To make this happen:
  - Someone **MUST** propose an IOP or small field campaign formally to ARM.
  - If this is approved, then ARM re-allocates resources to support this effort.
  - Until then, radar engineering is not released to reallocate time to this.

Breakout Discussion Questions

- What additional merged products **are available from existing datasets**?
- What additional merged products **are needed from existing datasets**?
- What science questions (convective transitions) can be addressed via near-term **adaptive SGP operations**?
- What are the **long-term approaches** required to address these questions?

Data product needs

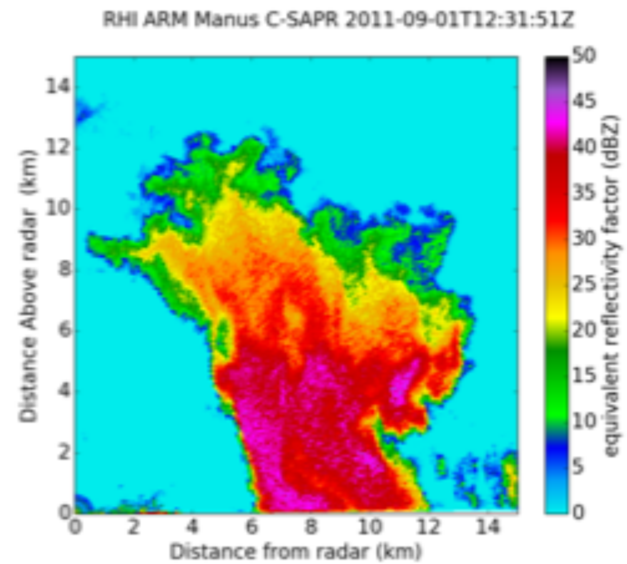
- **Concurrent observations** of microphysics, drafts, and environmental conditions in varying environments (land/ocean, tropical/midlatitude)
- Vertical profiles of environmental moisture across many timescales
  - GPS PWV (5-min all weather) and MWRP q profiles (attenuated by rainfall)
  - Trajectories of tracers (examine in PWV from GPS)
  - VARANAL (sounding network)
- Cloud and precipitation morphology and organization
  - Combined RWP-ARSCL product (Feng)
  - Gridded precipitation radar data for all ARM sites
  - Merged scanning radar and profiler data at ARM sites (satellite?)
  - Convective feature identification (tracking?) added to radar data products
  - Higher-order statistical information (e.g., distributions of cloud-top height, cell sizes, cell evolution)
- Coincident vertical velocity and hydrometeor data
- Cold pool properties
  - Horizontal gradients and vertical profiles of temperature and moisture
  - Automated identification for radar

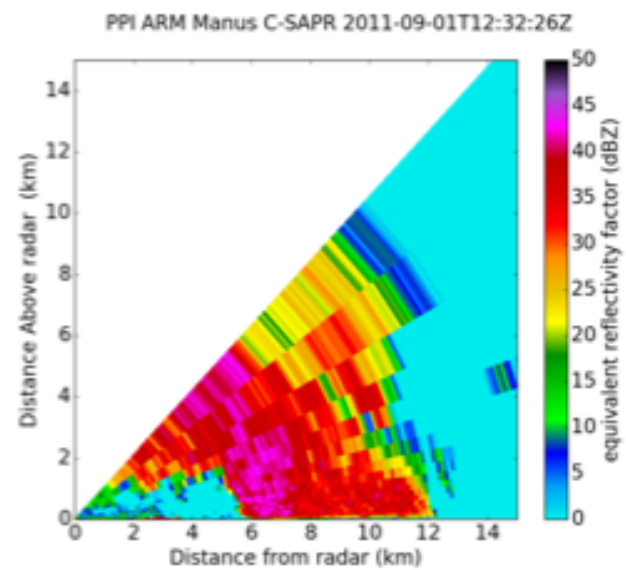
Additional Observations

- Better spatial information
  - Surface fluxes
  - Thermodynamic profiles
- High resolution measurements of evolving convective cells (Lagrangian change in covarying characteristics)
  - Temporal frequency to observe interactions between microphysics/drafts and overall behavior across cell lifetime
  - Additional profiler networks
  - **Agile/Adaptive scanning**

Motivation for radar cell-tracking studies of convective processes

- **Problem:** available observations (almost exclusively from radars) repeatedly demonstrate that weather and climate simulations of convective cells remain very poorly constrained
- **Motivation:** improve understanding and model representation of rapidly evolving processes and lag correlated microphysical and dynamical properties in convective cells (e.g., 5 m/s flows move ~2 km in 6-minute volume scan)
- **Approach:** observe the rapid evolution of convective cells at high spatial and temporal resolution, starting with isolated single cells
- **Proposal:** make it a priority to formulate and test automated real-time tracking and control algorithms for automated scanning polarimetric radars (e.g., C-SAPR and X-SAPR) suitable for ARM sites
- **Questions:** RHI or sector PPI approach? what is the optimal range of scan rates and elevation/azimuthal angles?





20-s RHI (top) and synthetic RHI from standard 6-min C-SAPR volumetric scan (bottom) of the same convective cell near Manus. *Source: Adam Varble/Univ. of Utah*

Publication in preparation: Van Lier-Walqui, M. and 24 co-authors: Use of polarimetric radar measurements to constrain simulated early convective updraft evolution: A pilot study using Lagrangian tracking in a region susceptible to aerosol influences on microphysical processes. *ACPD, to be submitted*

Observational Needs

- <u>**Short-term**</u> strategies
  - Creating **merged products** from existing integrated datasets targeting specific science questions
  - Forecast-based **adaptive operations** to fully sample convective transitions
- <u>**Long-term**</u> strategies
  - **Partnership** with other agencies
  - S-band radars
  - Simultaneous hydrometeor size distribution and vertical velocity observations via penetrating aircraft
  - Large-scale campaign over a tropical environment