Vertical Velocity Analyses Using ARM's Heterogeneous Scanning Radar Network at SGP

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Motivation

The Atmospheric Radiation Measurement (ARM) program is currently addressing *4* broad research topics: aerosol life cycle, **cloud life cycle**, cloud-aerosol interactions, and radiative processes.

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The study of cloud life cycle during the various stages of evolution provides **observational targets** for modelers.

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Doppler velocities observed from scanning precipitation radars are both highly reliable and they provide a necessary constraint for **vertical velocity** retrievals.

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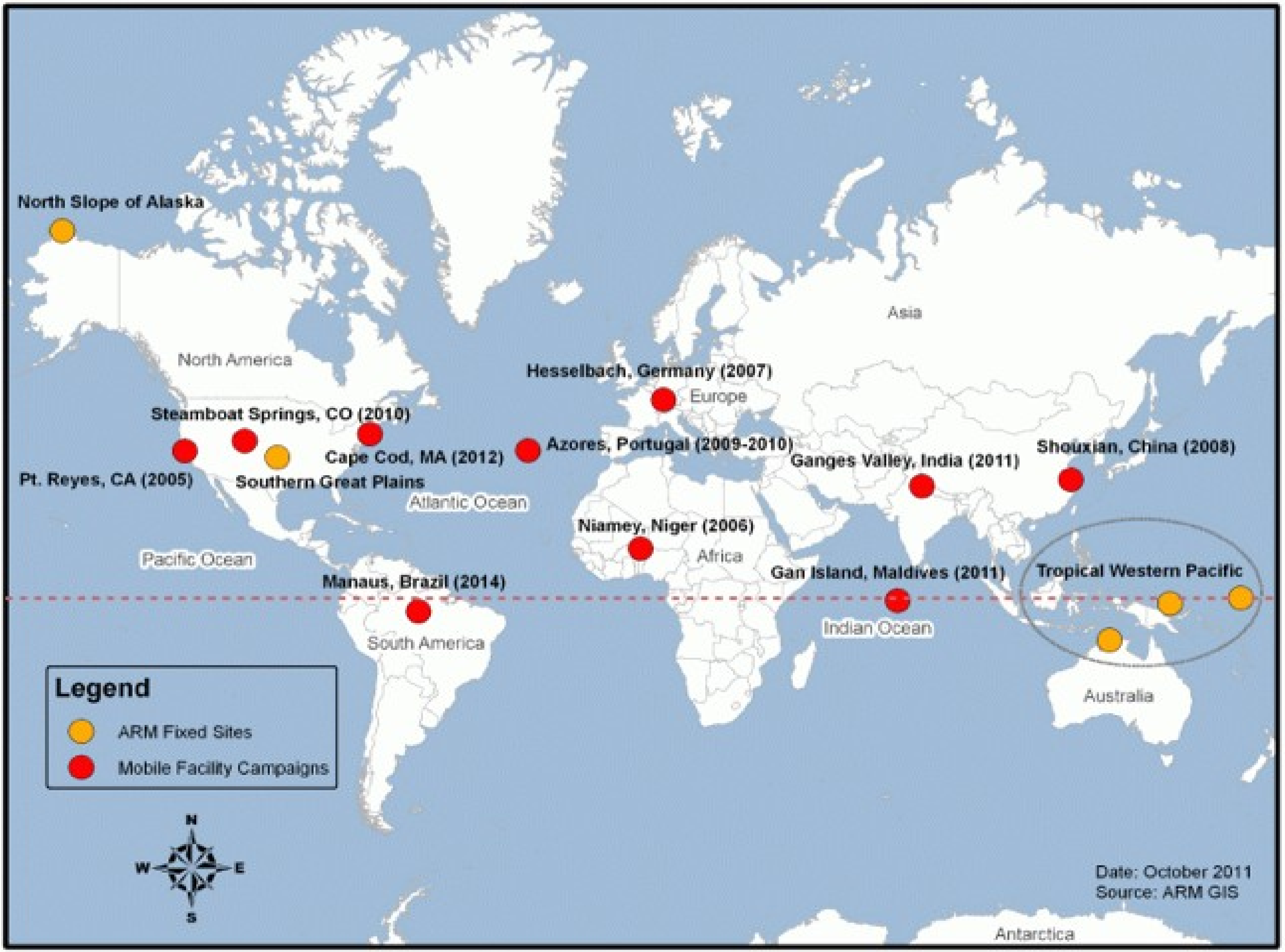
These vertical velocities are the *observational* target we supply to modelers in order to evaluate their **model parameterizations**, with the end goal of improving the model.

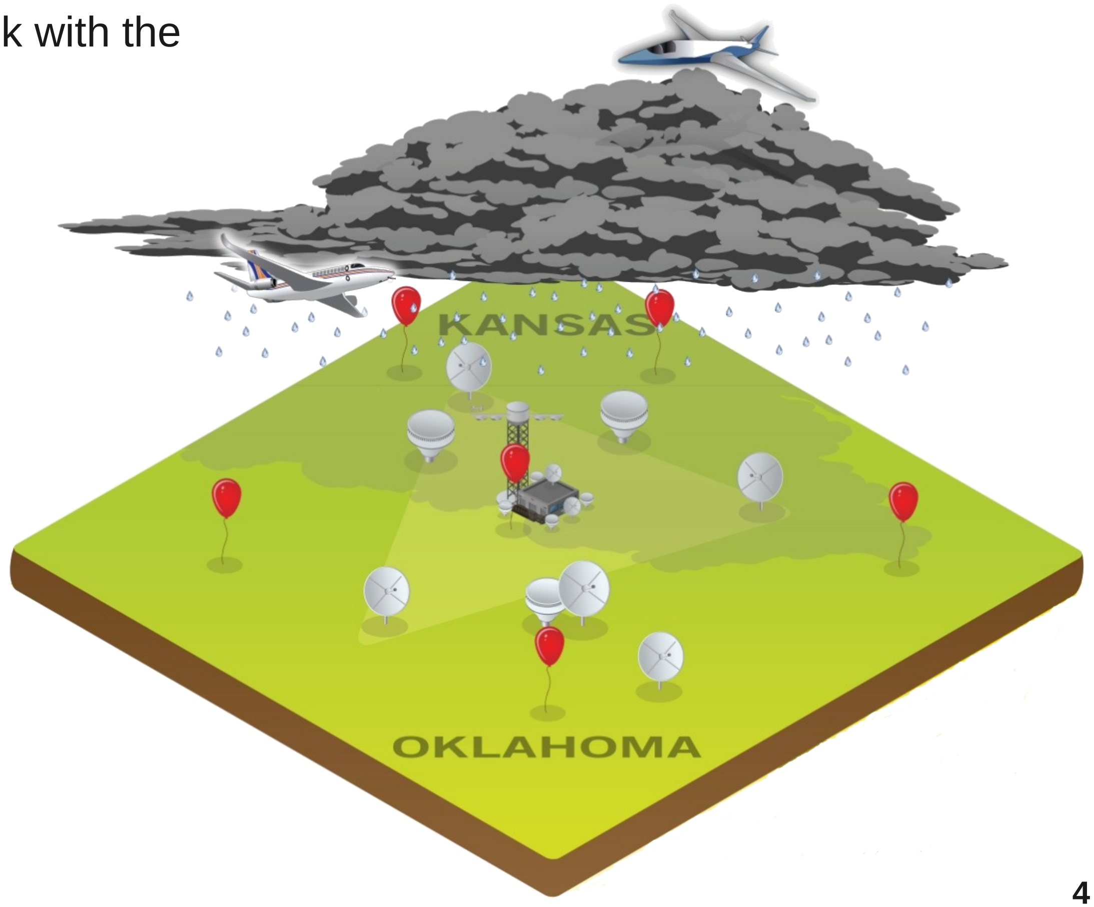
ARM Facilities

Three preliminary locations – Southern Great Plains (**SGP**), Tropical Western Pacific (TWP), and North Slope of Alaska (NSA) – represent the broad range of climate conditions around the world.



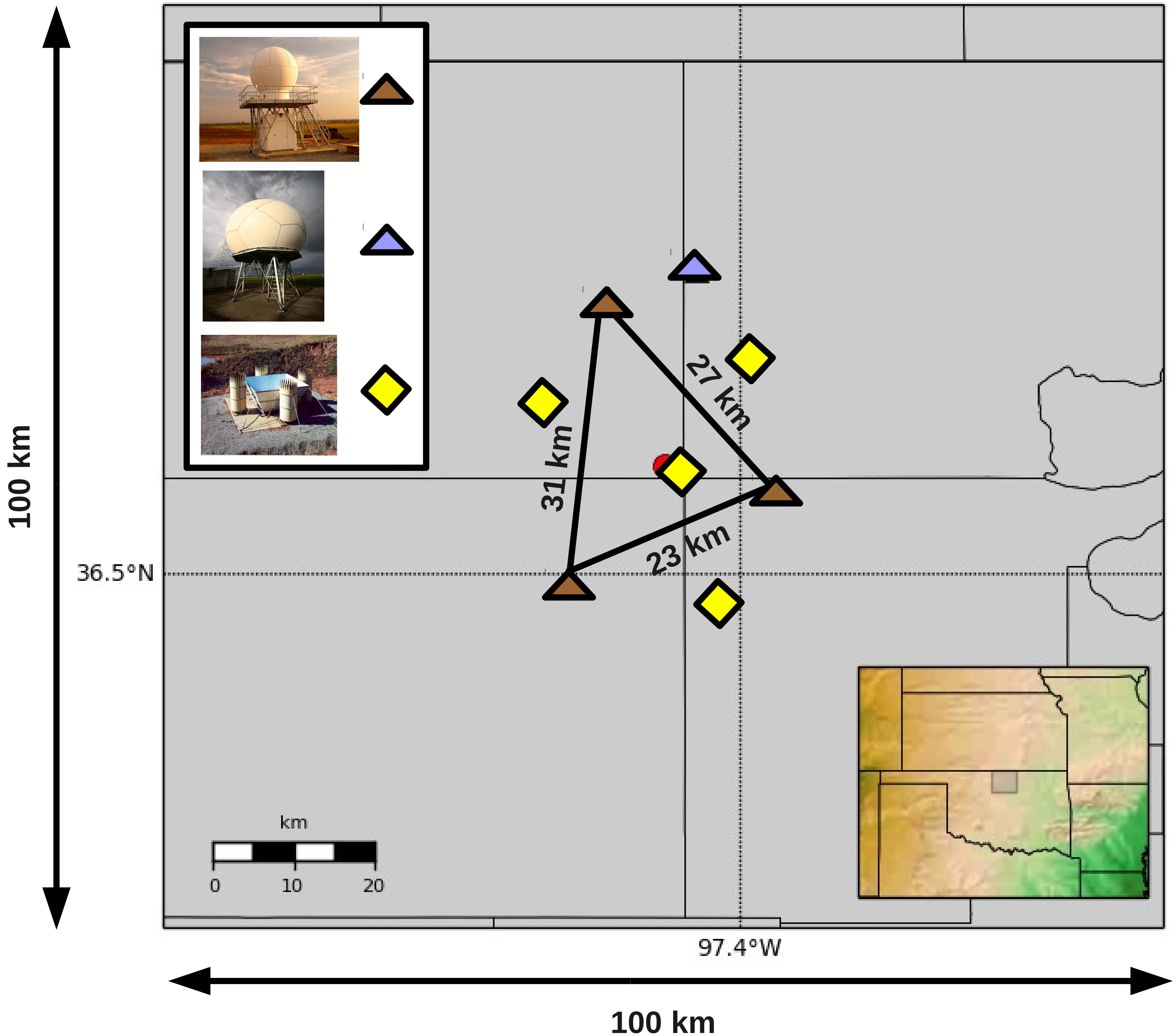
- Joint field program involving **NASA**'s GPM program and DOE's **ARM** program.
- The IOP was focused around ARM's SGP site , and ran between April-June 2011.
- Included a new multi-scale observing strategy with the participation of a network of distributed sensors (both active and passive).
- Main goal for these sensors was to document, in 3-D, **precipitation**, **clouds**, **winds**, and thermodynamic fields in an attempt to provide a holistic view of **convective clouds** and their feedback with the environment.
- **First use** of ARM's precipitation radar network at SGP.

Unprecedented observing capabilities implies a greater responsibility to develop synthesis data products suitable for model studies and evaluation



Radars at SGP

***SAPR** = Scanning ARM Precipitation Radar*
***UAZR** = UHF ARM Zenith-pointing Radar*

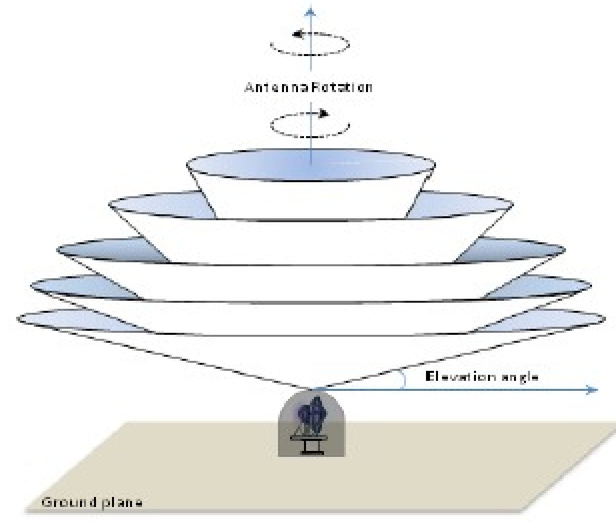


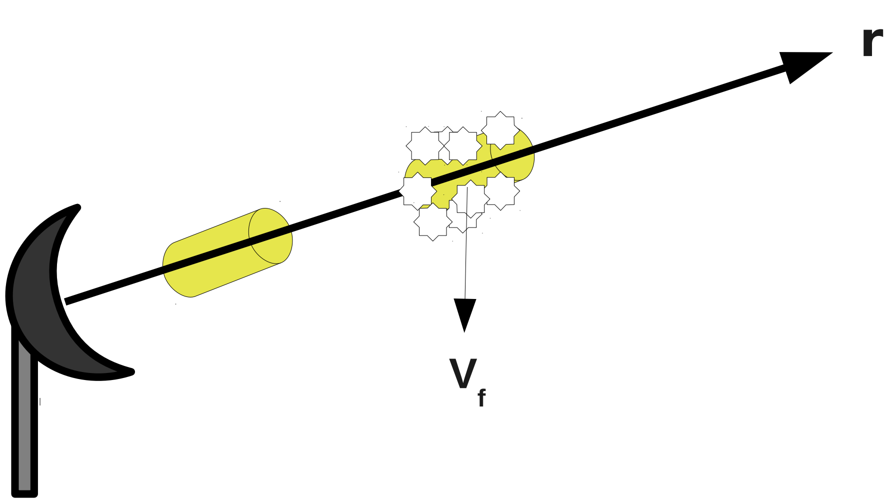
- **3** X-bands, **1** C-band, and **4** UHF-bands.
- X-band = **3.2 cm**
- C-band = **5.4 cm**
- UHF-band = **32.8 cm**
- C-band provides coverage throughout entire domain.
- X-bands have a max range of 40 km.
- Zenith-pointing UHFs provide a source for vertical velocity comparisons.

Radar Basics

- Precipitation radars typically scan in a Plan Position Indicator (**PPI**) mode.
- For convective days during MC3E, the SAPRs were run in **convective mode**.
- Min/max elevation scanned was **0.5º** and **50º** respectively.
- Heartbeat of **6 min**.
- Maximum unambiguous velocity (Nyquist) of **17 m s^{-1}.**

PPI mode





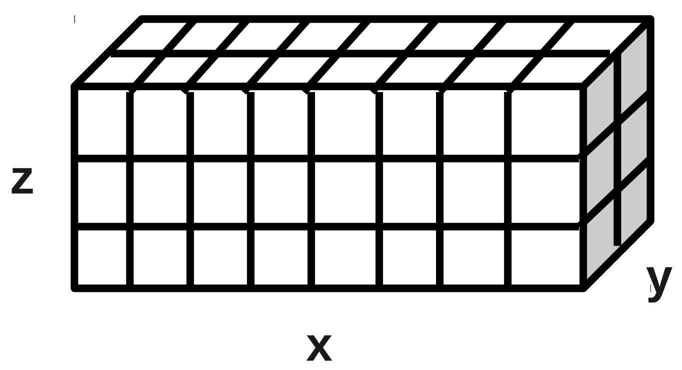
- **Doppler theory** tells us the velocity of the medium by measuring the phase shift between **two pulses**.
- Radars scanning in PPI mode will measure the **radial** component of this medium.

Methodology

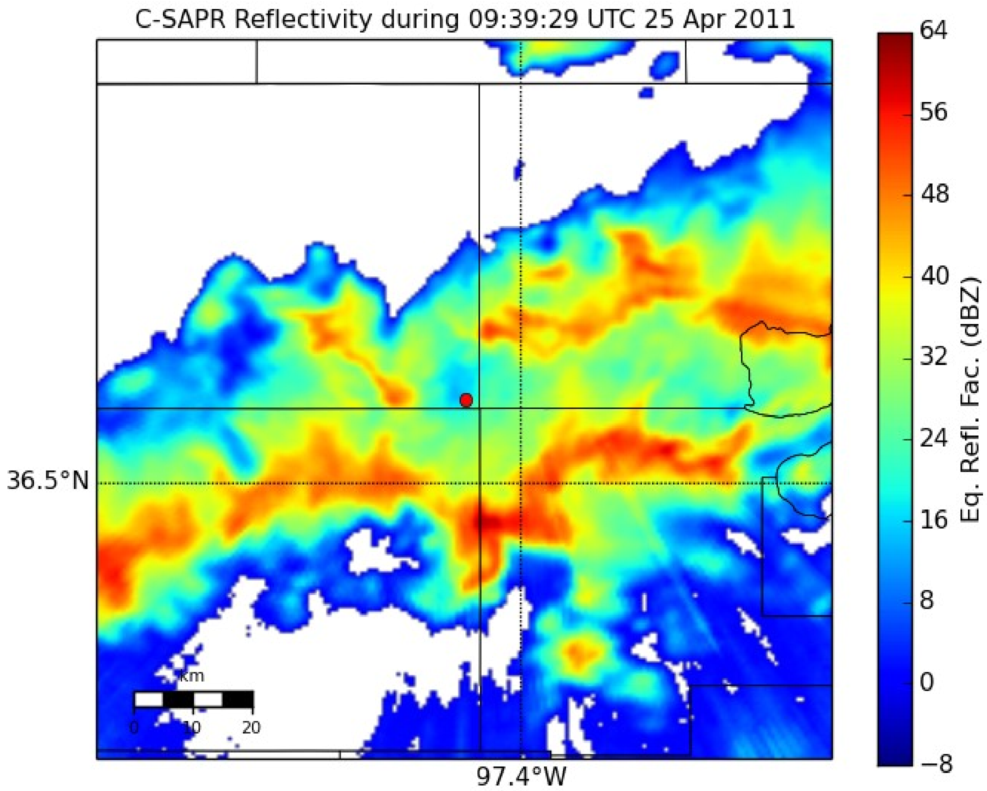
SAPR observations	Notes
Reflectivity	Fall speed estimation Steiner echo classification
Doppler (radial) velocity	Assimilated to retrieve (**u**, **v**, and **w**)
Differential reflectivity	Quality control: ground clutter
Differential phase	Quality control: signal attenuation correction
Copolar correlation coefficient	Quality control: ground clutter
Coherent power	Quality control: second-trip echoes

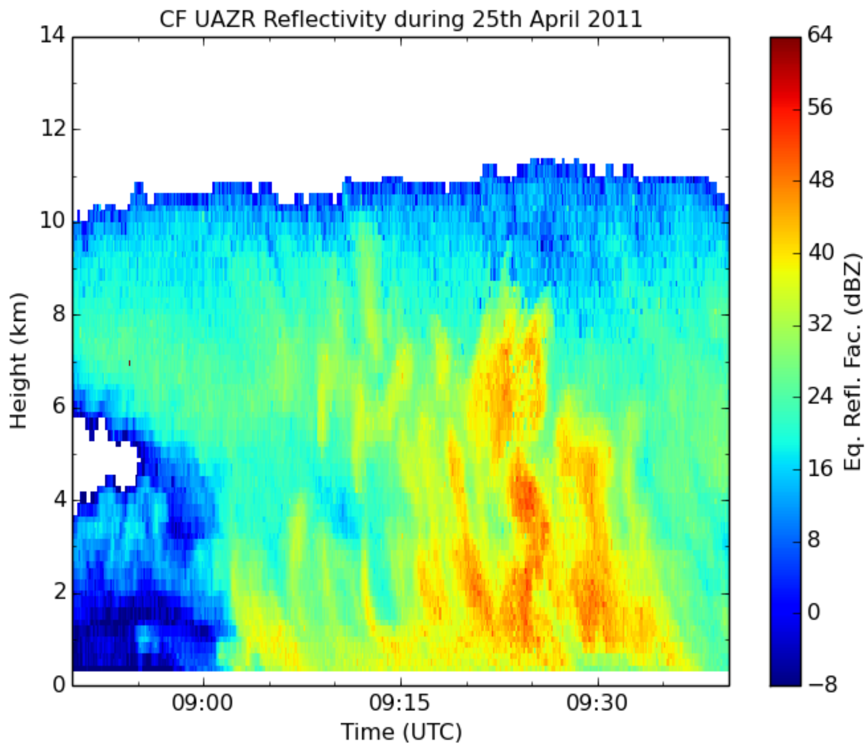
- SAPR observations in antenna coordinates are interpolated to a uniform Cartesian grid.
- Analysis domain covers **100 x 100 x 17 km** in **x**, **y**, and **z** respectively, each with a resolution of **500 m**.
- The retrieval technique uses a 3D-VAR approach consisting of radial velocity observations, anelastic continuity, and a noise-reduction term.

Analysis domain



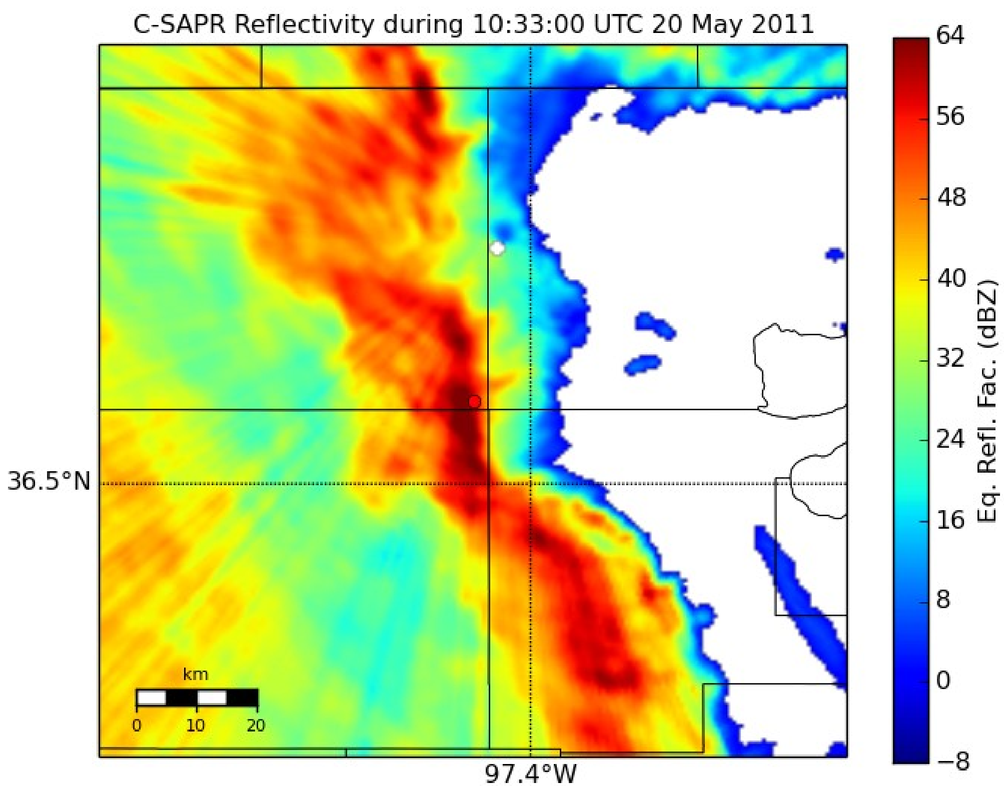
Dataset

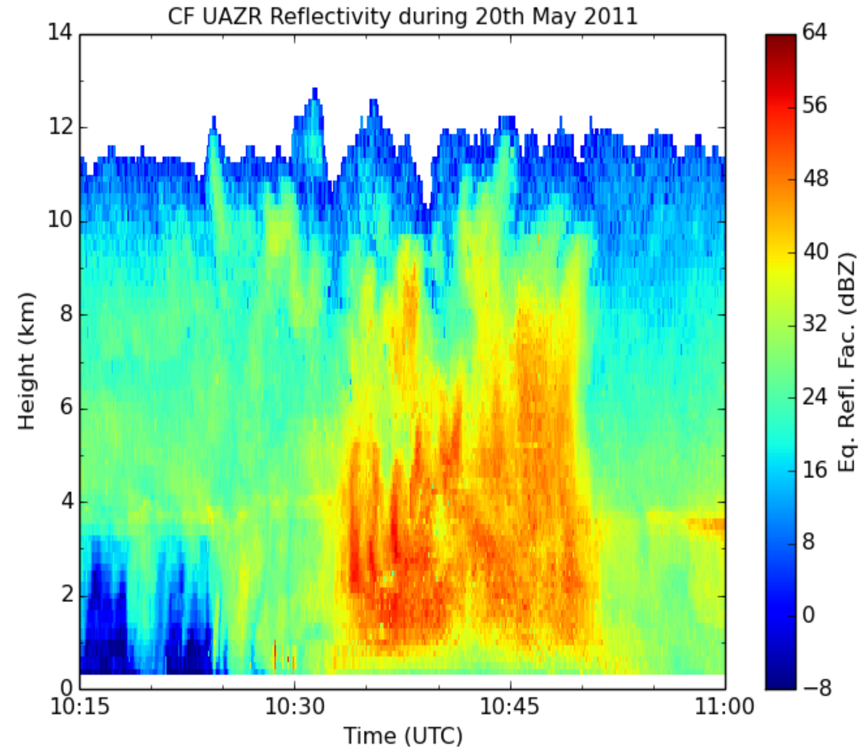




- First well-coordinated aircraft-ground precipitation operation during MC3E.
- Convective cells developed along an elevated front, aided by mid to upper level ascent associated with an upper level trough.
- Convective cells were relatively shallow in depth.
- (**u**, **v**, **w**) analyses were produced between 8 and 11 UTC, for a total of 32 retrievals.

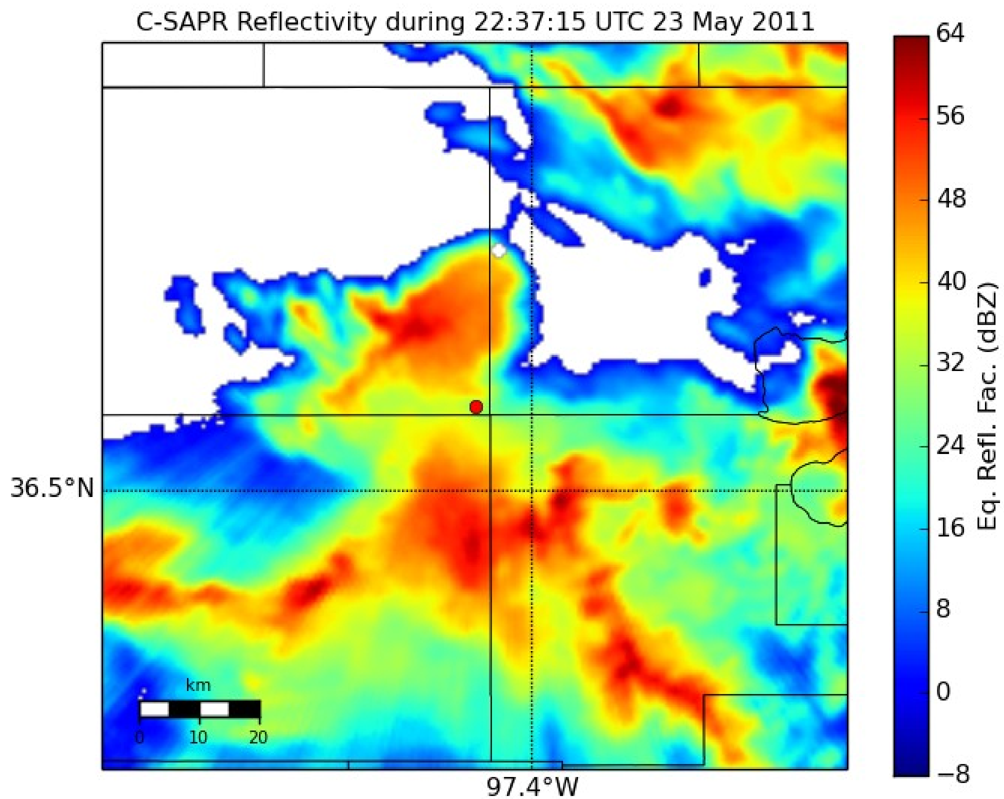
Dataset

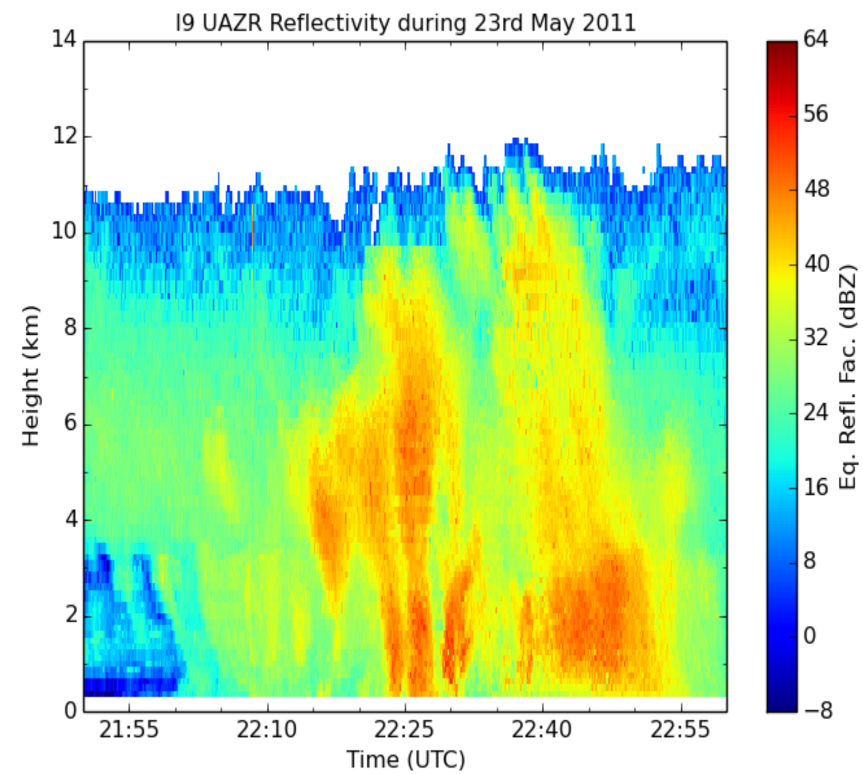




- Several surface-driven discrete convective cells were observed near the beginning of the event.
- Towards the end of the event, a squall line/MCS system with a classic trailing stratiform region was observed.
- (**u**, **v**, **w**) analyses were produced between 6 and 11 UTC, for a total of 39 retrievals.

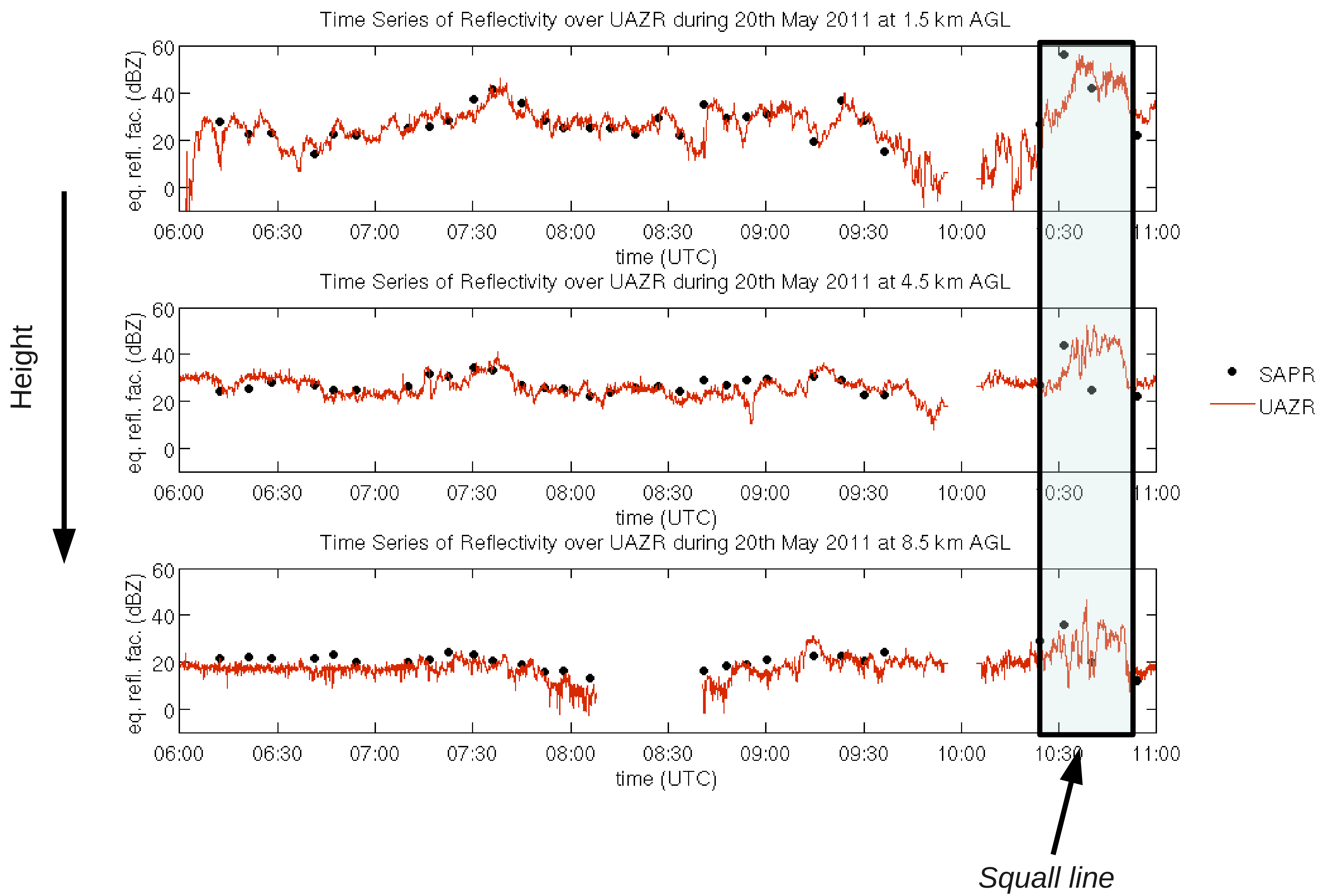
Dataset



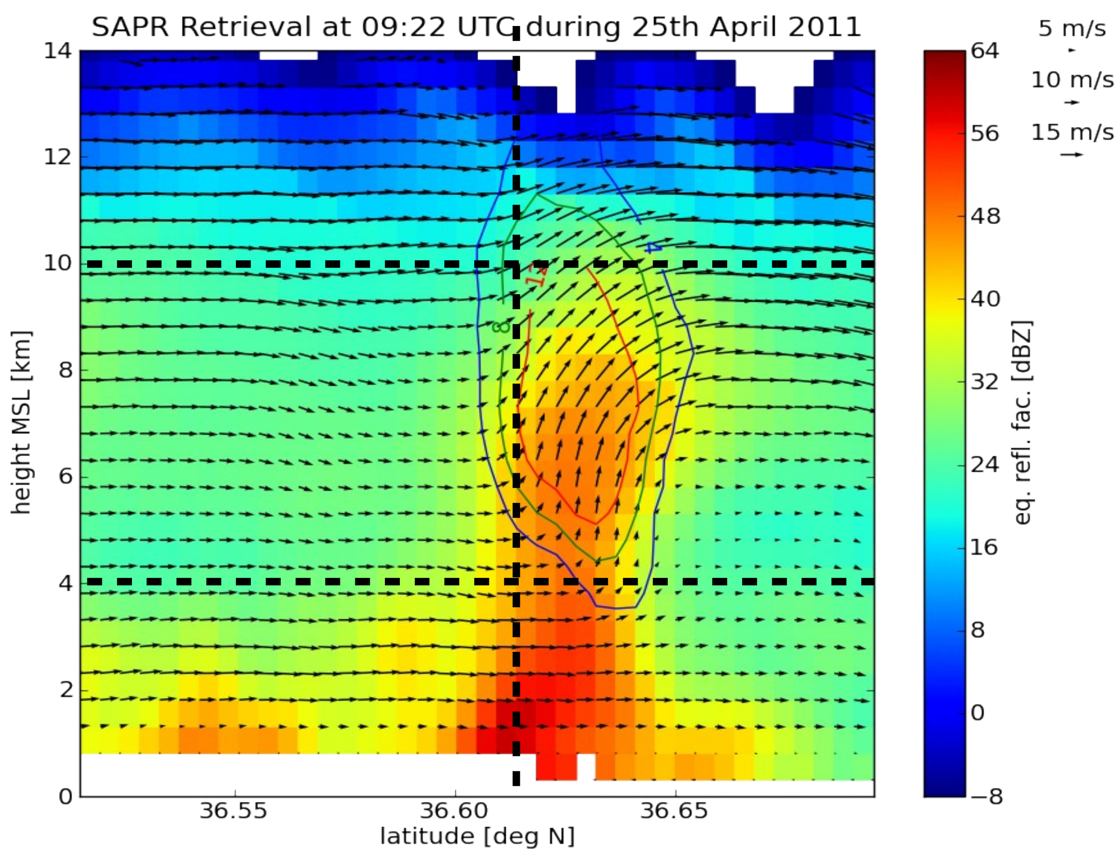


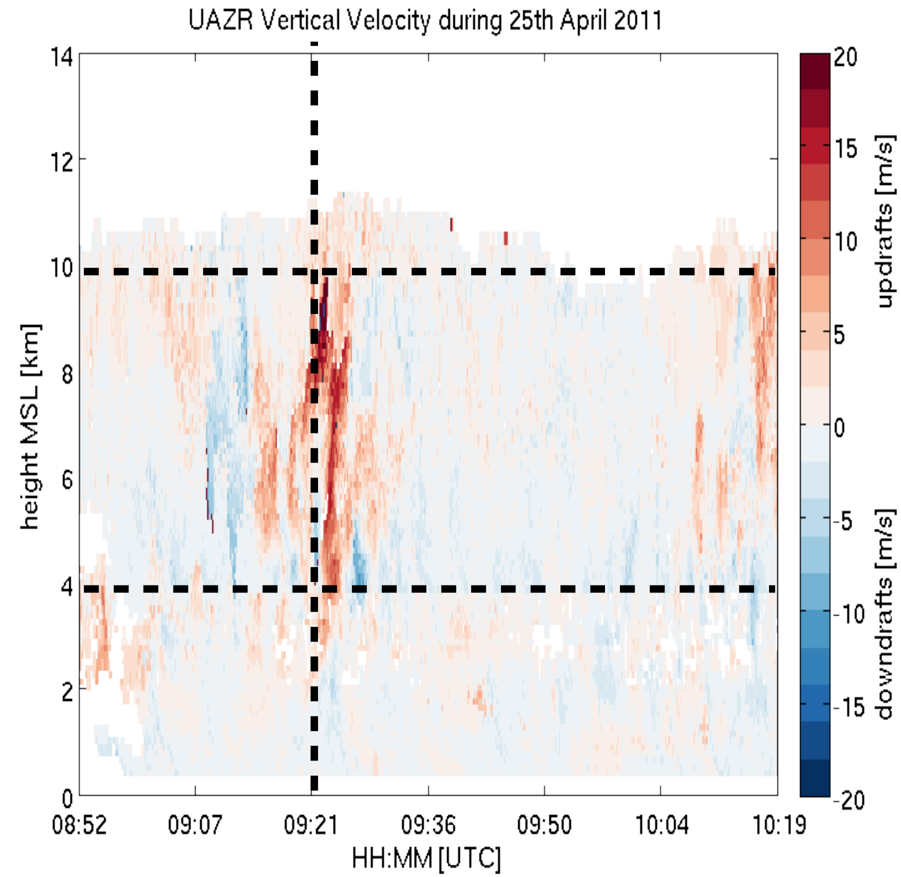
- Environmental forcing coupled with strong daytime heating led to significant instability.
- The addition of deep-layer shear led to multiple supercell thunderstorms, one of which passed just north of the C-SAPR and produced a tornado.
- This was one of the most dynamically-driven, environmentally well-forced events during MC3E.
- (**u**, **v**, **w**) analyses were produced between 21 and 23 UTC, for a total of 16 retrievals.

SAPR-UAZR Comparisons



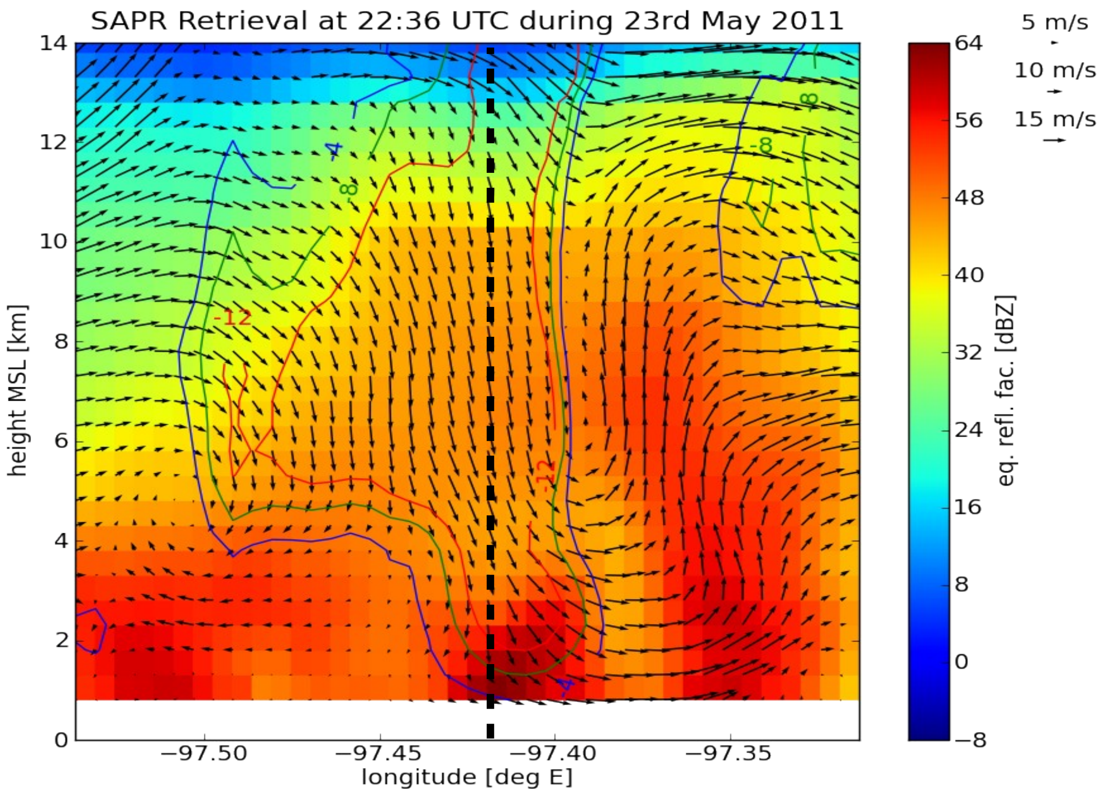
SAPR-UAZR Comparisons

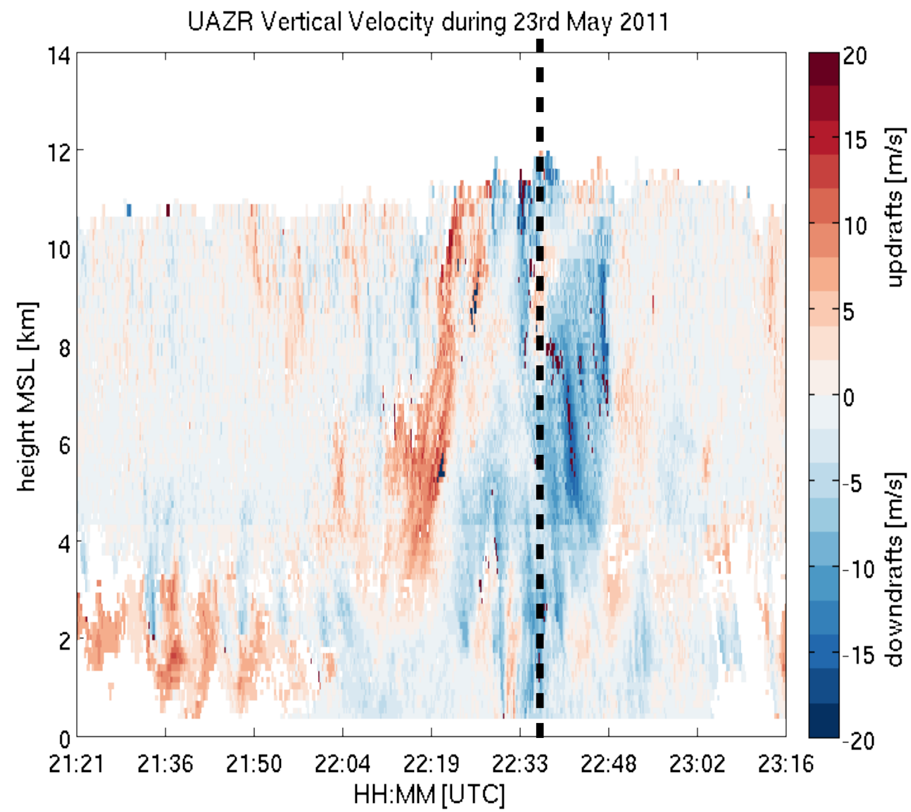




- Contours are 4 m s^{-1} (blue), 8 m s^{-1} (green), and 12 m s^{-1} (red).
- Elevated updrafts retrieved by both scanning and vertically-pointing techniques.
- Both techniques have the base of the updraft core near 4 km height.

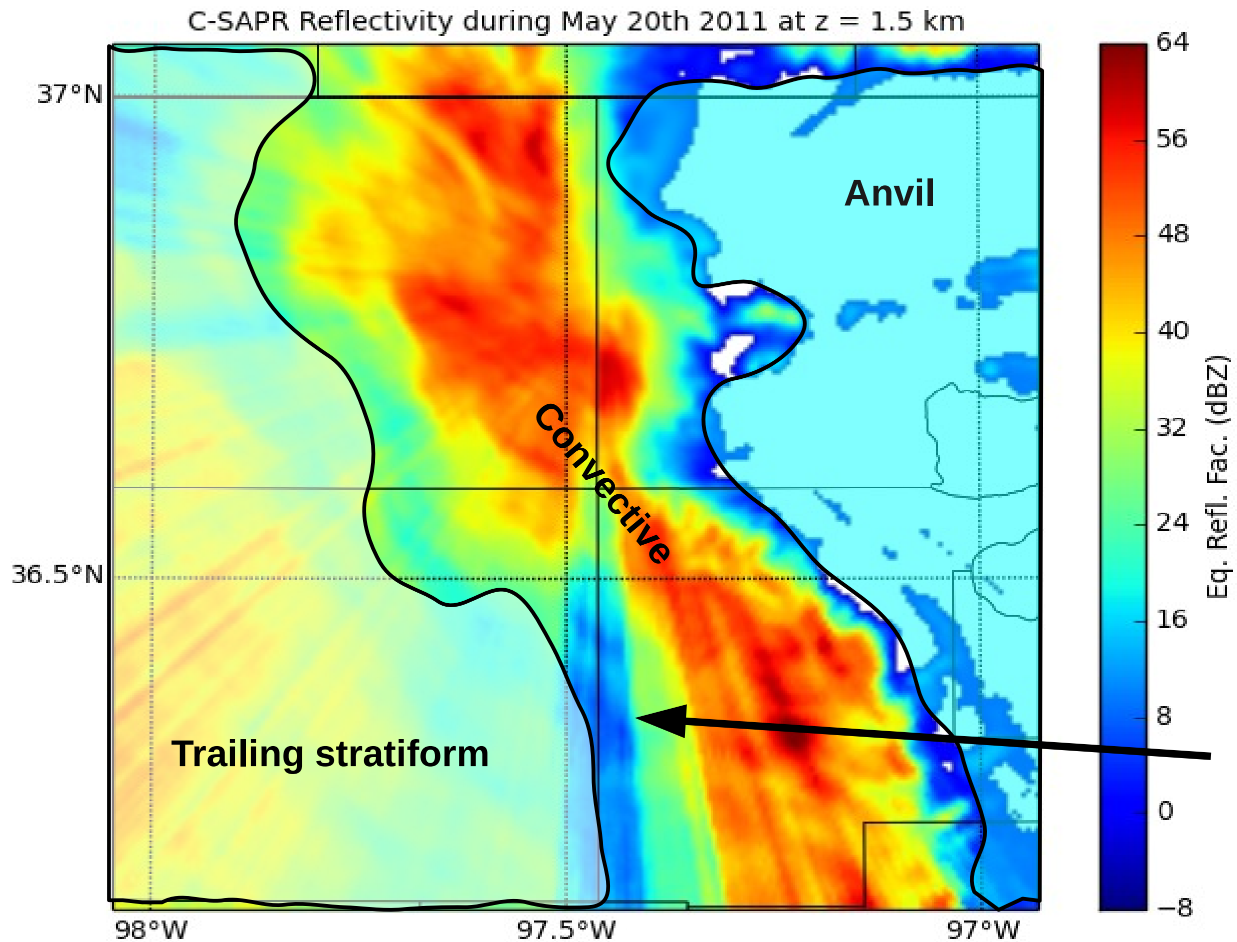
SAPR-UAZR Comparisons





- Contours are -4 m s^{-1} (blue), -8 m s^{-1} (green), and -12 m s^{-1} (red).
- UAZR retrievals have downdrafts extending throughout most of the column, including reaching the surface. SAPR retrievals behave similarly.
- Downdraft feature also consistent in time between two methods.

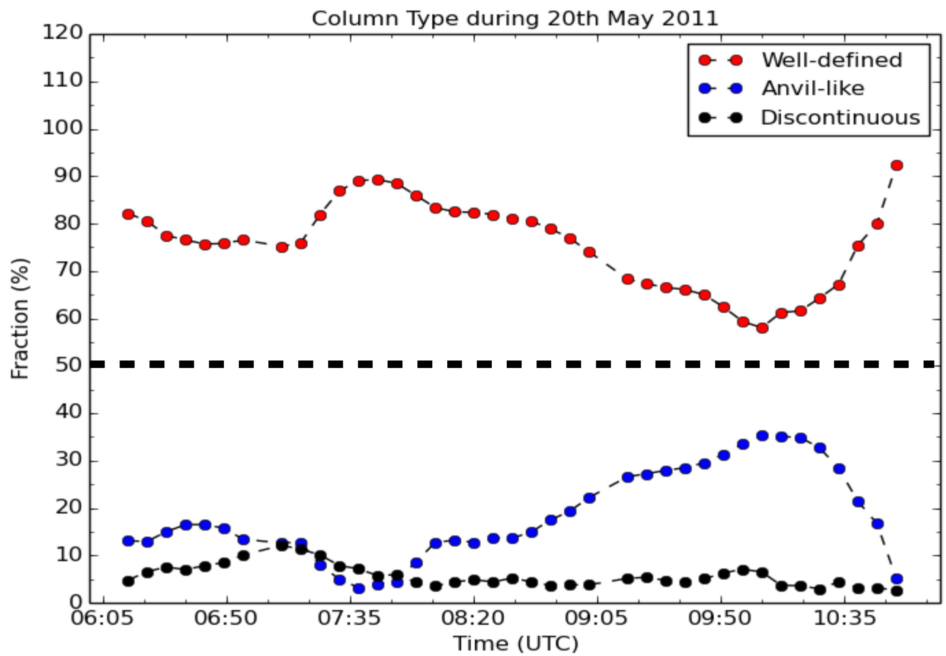
Echo Classification

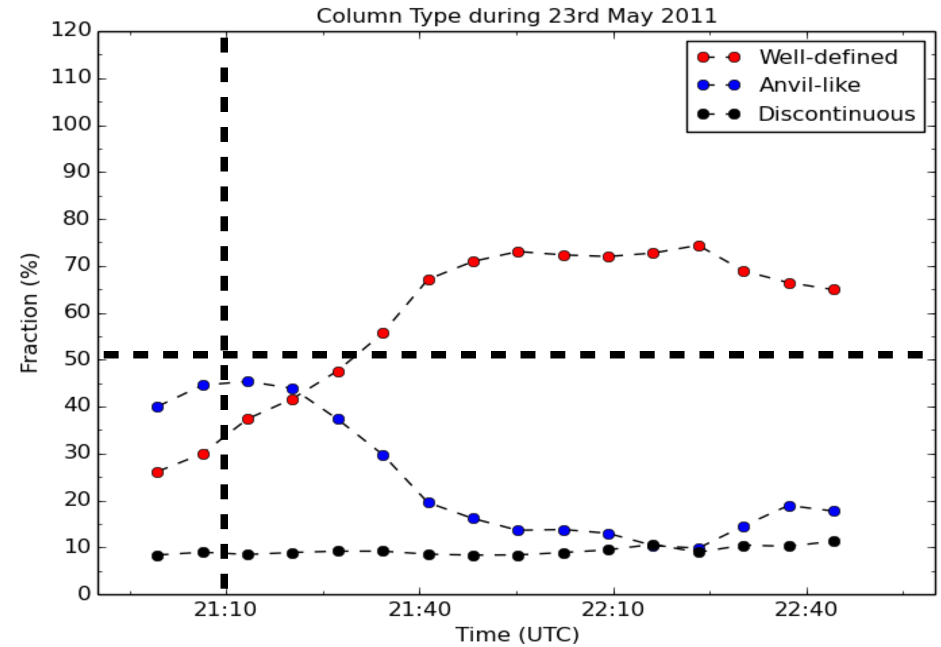


Poor attenuation correction

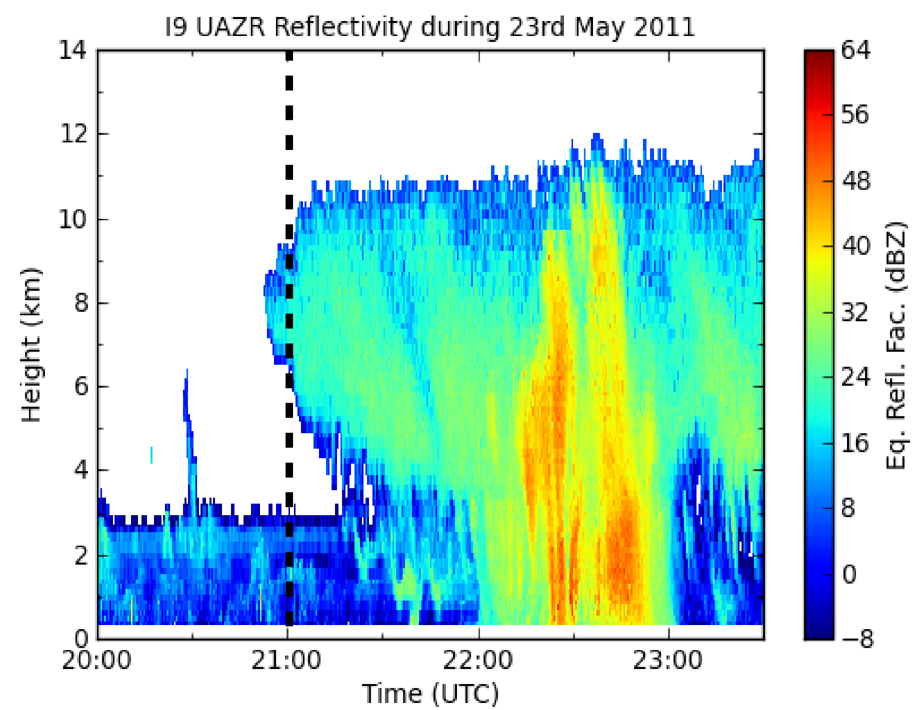
- We want to be able to accurately classify grid points as either **stratiform** or **convective**.
- Having reliable echo classifications provides another way to sub sample vertical velocities and compare with model output.
- We use a hybrid Steiner et al. (1995) algorithm to classify grid points.

Column Type

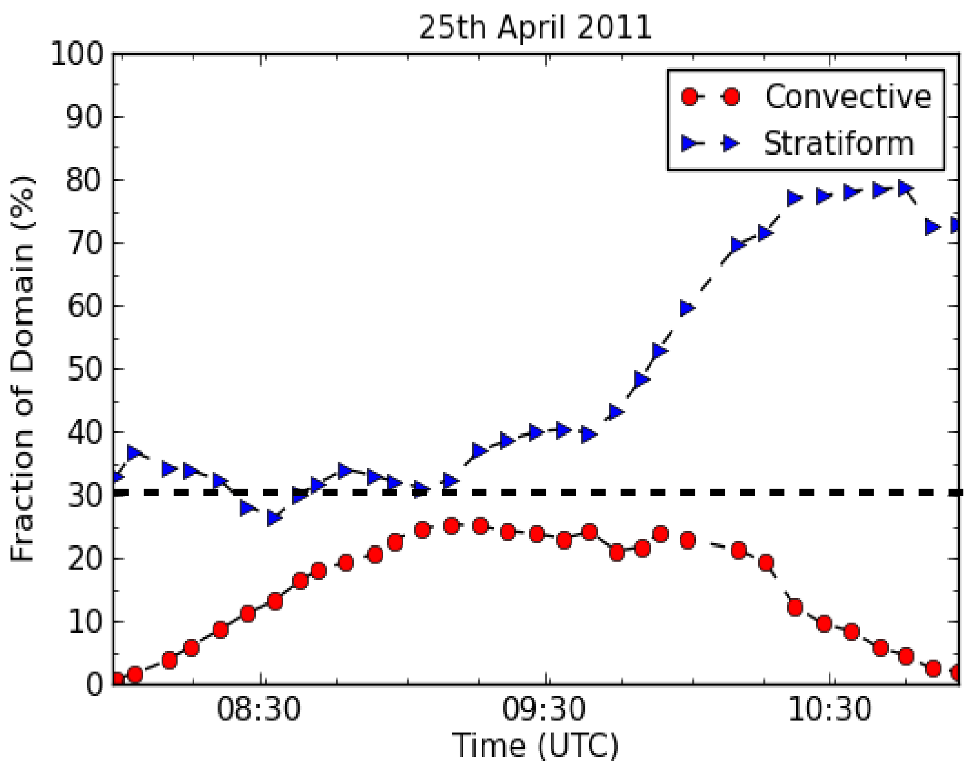


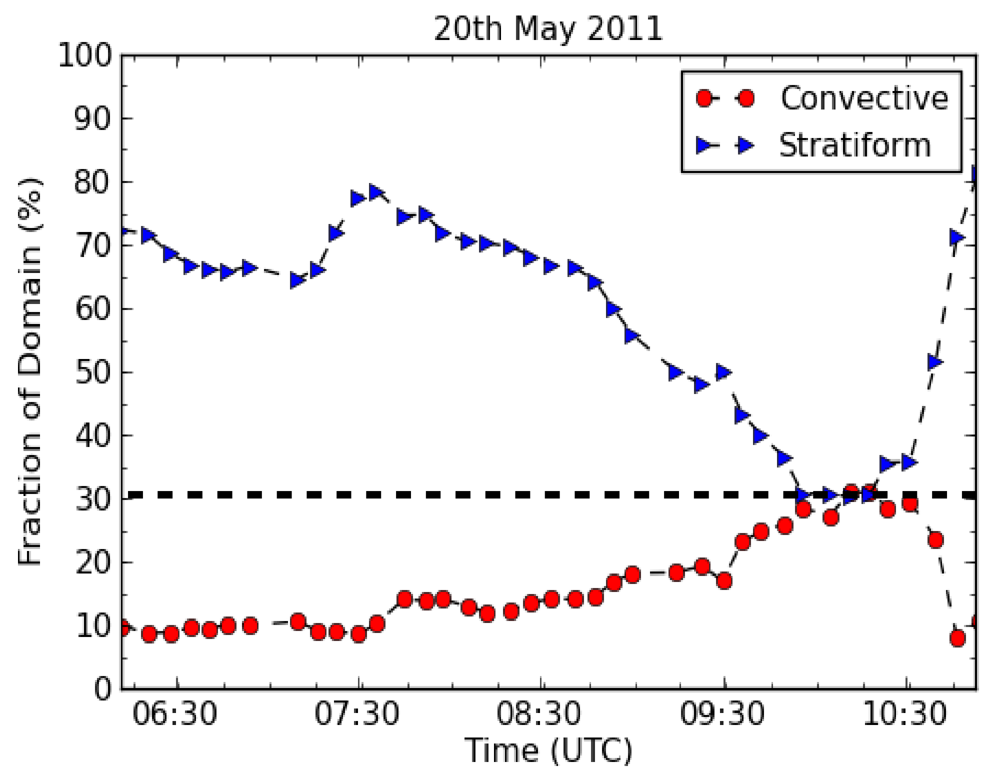


- **Greater than 50%** of the columns are usually **well-defined**.
- This information is beneficial to our echo classification efforts. **Discontinuous** columns can automatically be ignored, and **anvil-like** columns can automatically be set to stratiform or ignored.



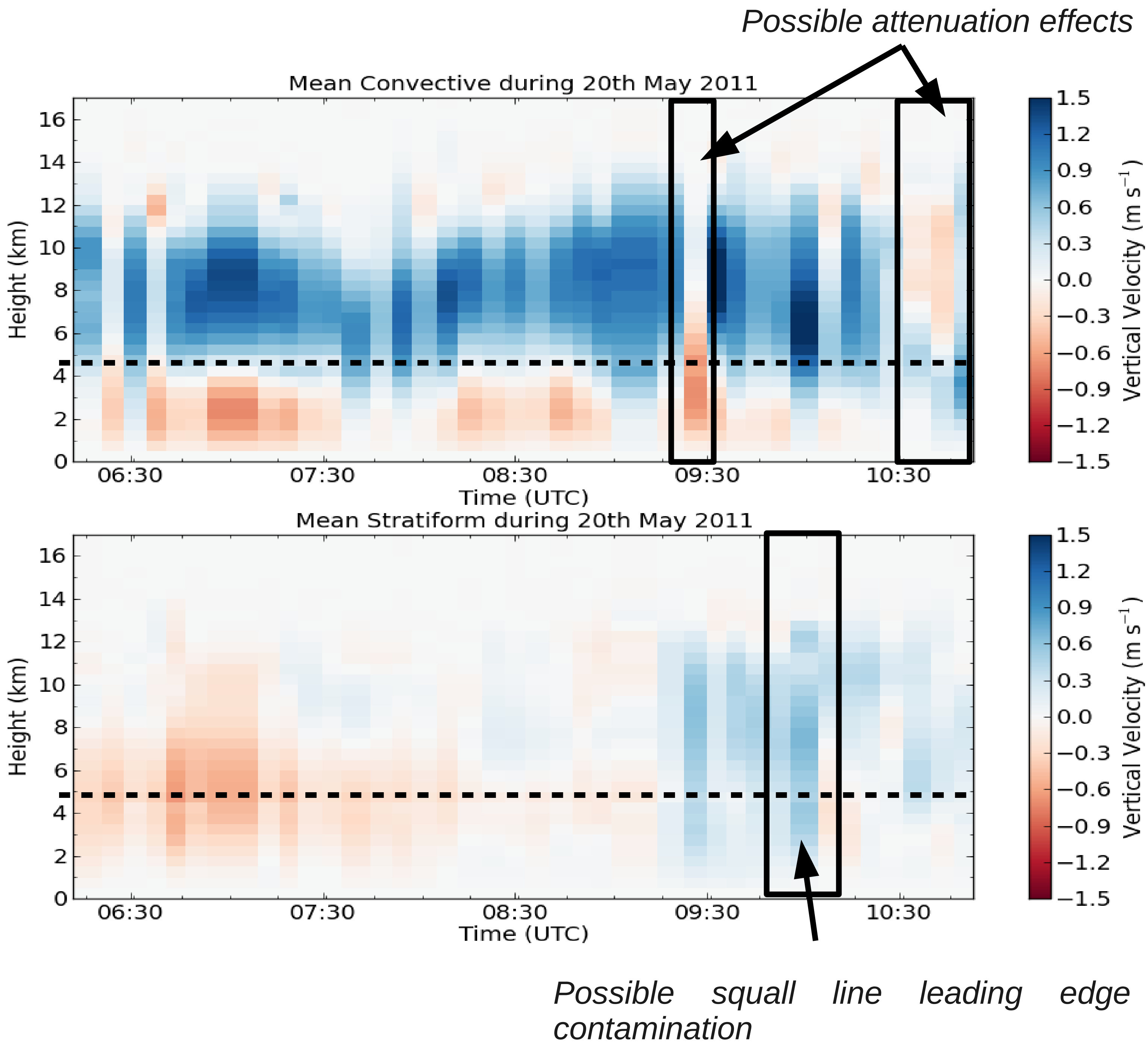
Convective vs Stratiform



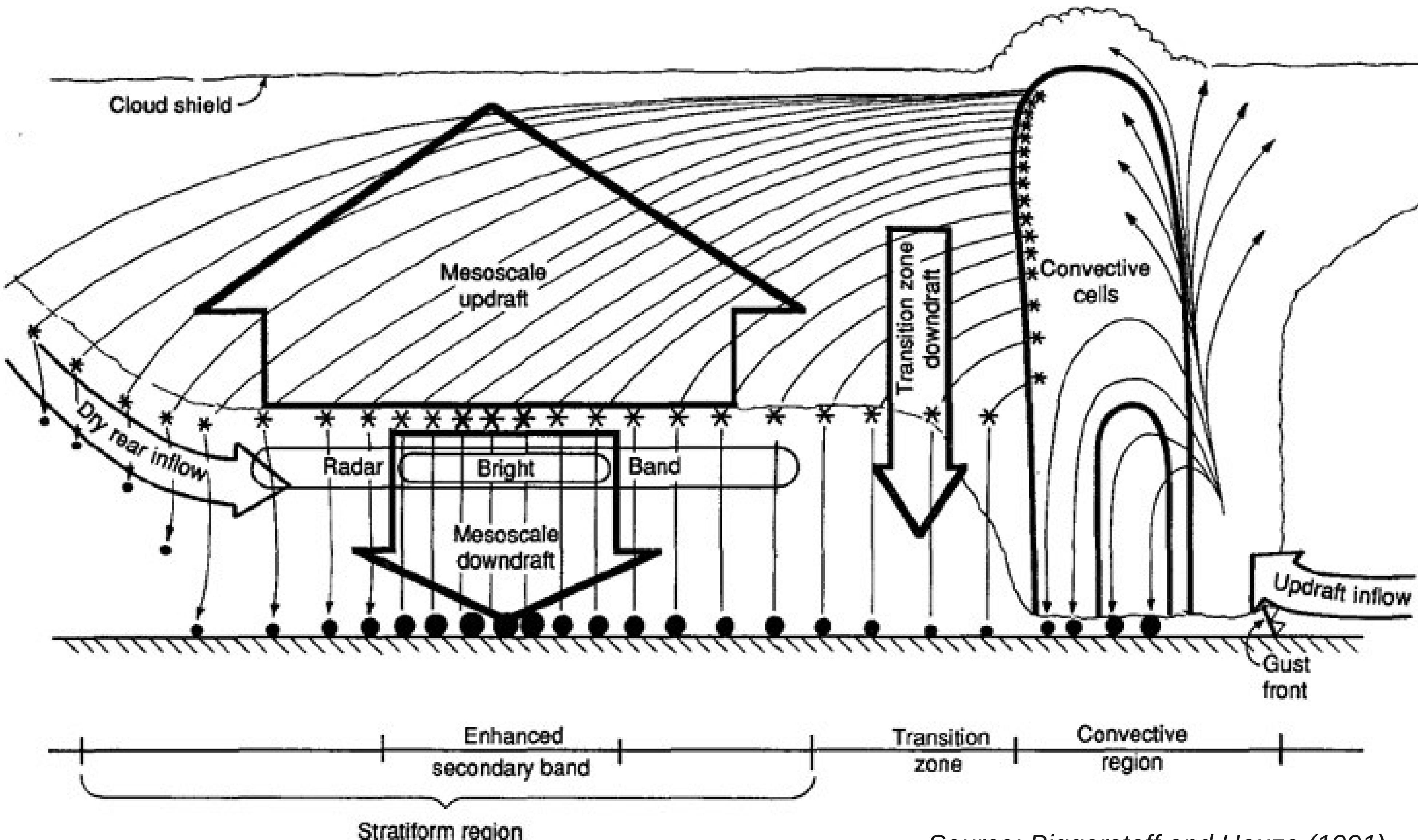


- **Convection** rarely exceeds **30%** of domain coverage.
- We are **confident** that the areas we classify as convective *are* convective.
- Sources of miss-classification using a *hydrometeor-based* approach include **attenuation effects**, **brightband contamination**, and **transition regions**.

Convective vs. Stratiform



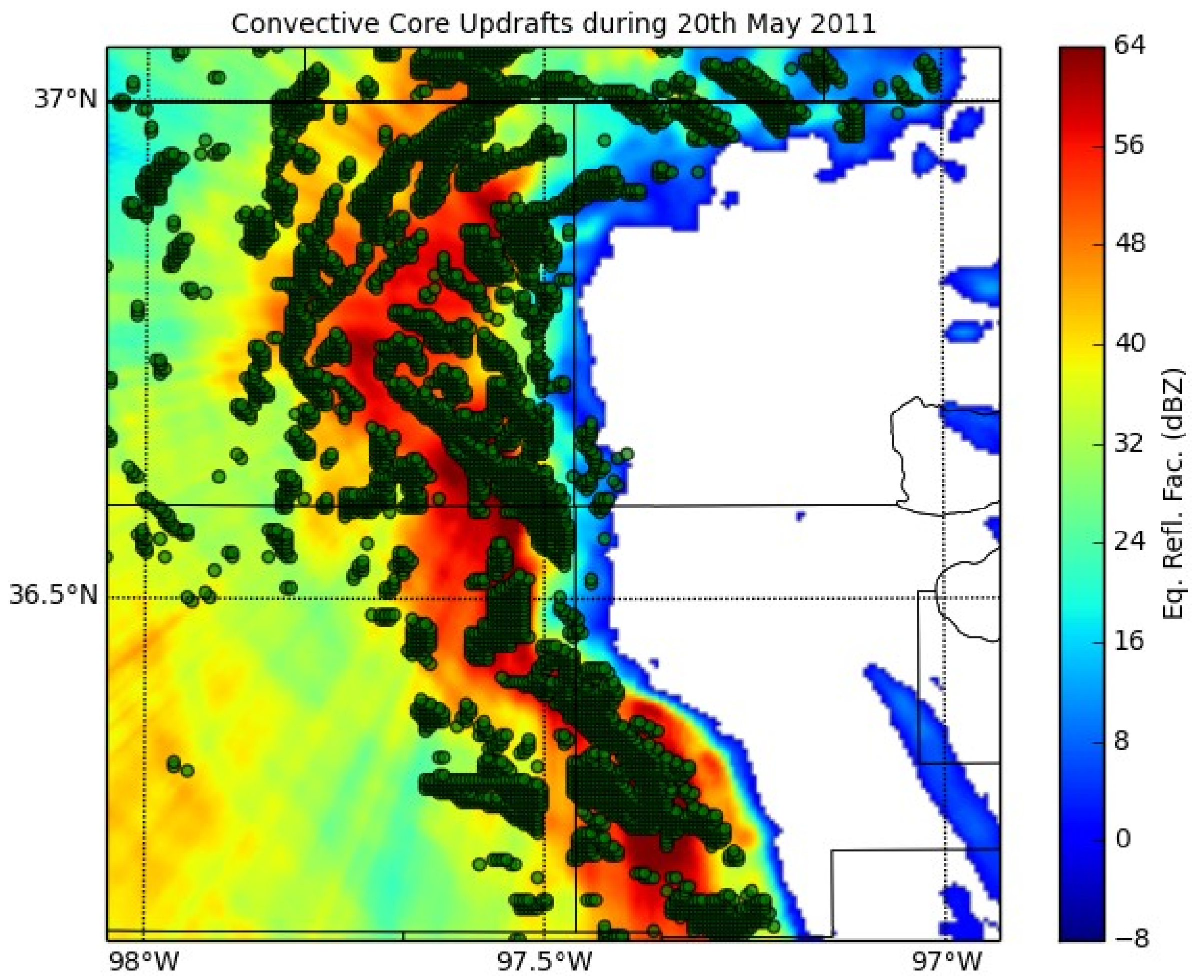
Ideal Squall Line Features



Source: Biggerstaff and Houze (1991)

Deep Convective Cores

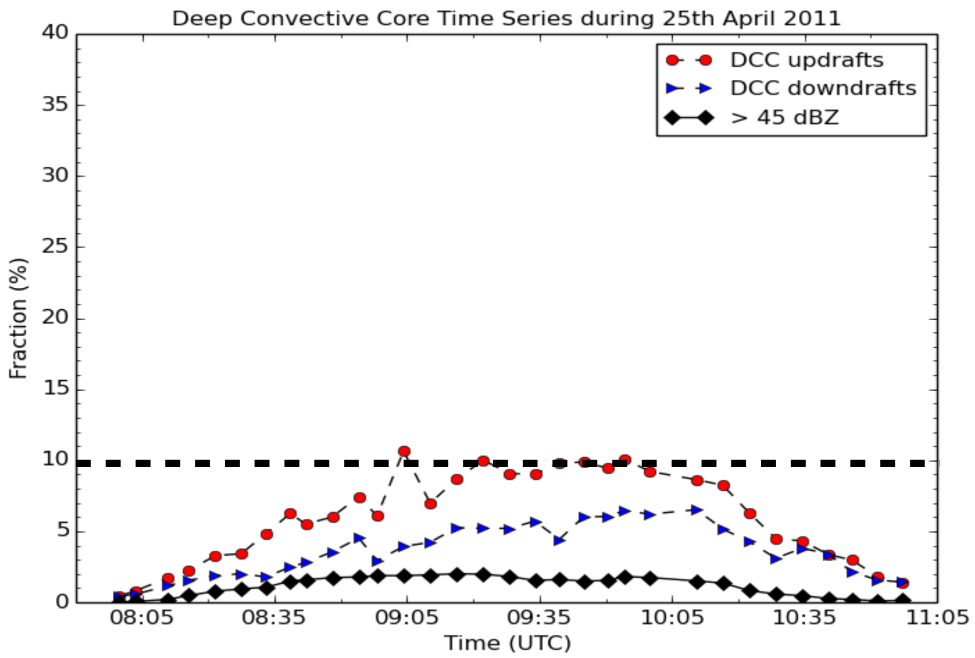
Deep convective **updraft** cores are defined as **any** column which has sustained w > 1.5 m s^{-1} over 5 km depth. Deep convective **downdraft** cores are defined as **any** column which has sustained w < -1.5 m s^{-1} over 5 km depth.

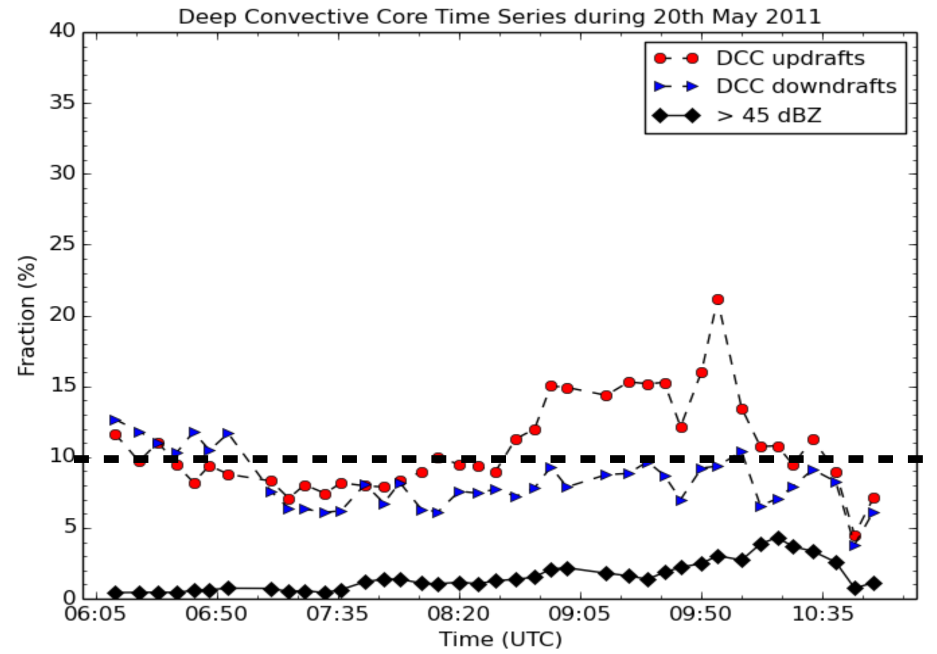


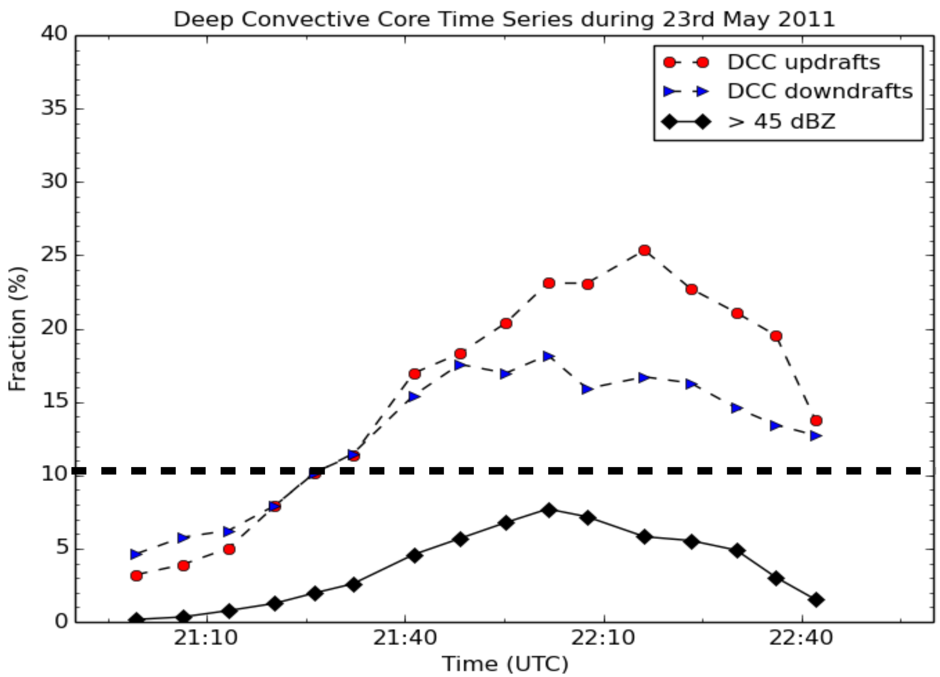
Squall line moving west-east through analysis domain.

- This definition has been adopted in modeling studies (e.g. Wu et al., 2009), as well as observational studies (e.g. Collis et al., 2013).
- Since it is by definition column-based, the entire column becomes a single entity.
- With this definition, a single column could be both a DCC updraft and a DCC downdraft.

Deep Convective Cores





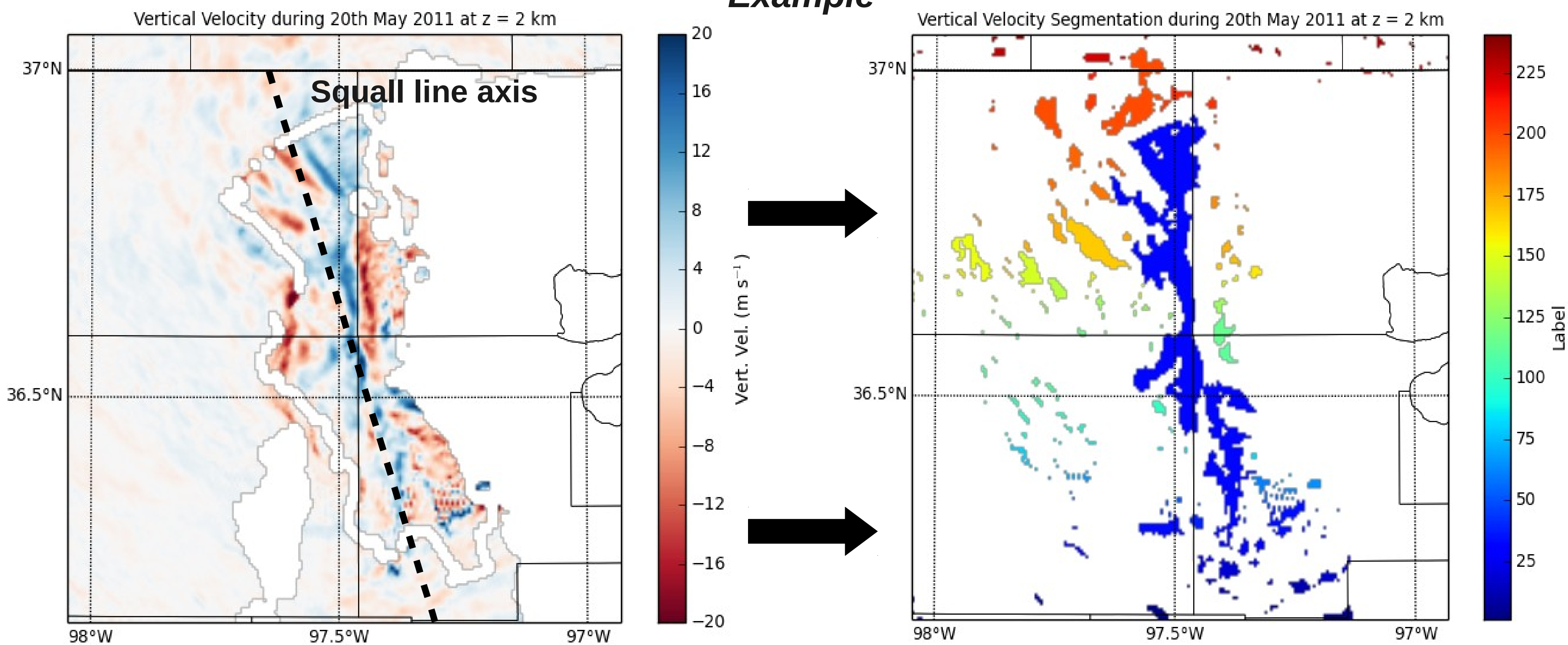


- Downdraft cores represent a **smaller fraction** of DCCs.
- Higher DCC fractions on May 20th and 23rd compared to April 25th.
- May 23rd was undoubtedly the **most intense** out of the 3 events.
- We get some sense of the robustness of our analysis from the temporal continuity of these DCCs.

Revised Core Definition

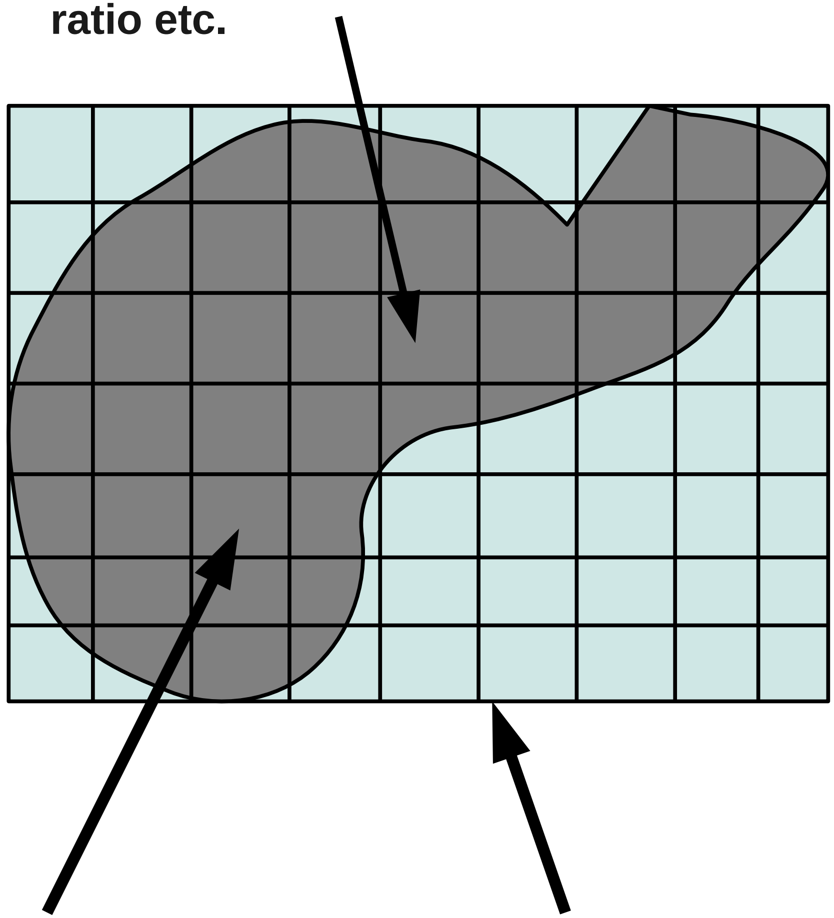
"Image segmentation is typically used to locate *objects* and *boundaries* (lines, curves, etc.) in images. More precisely, image segmentation is the process of assigning a label to every pixel in an image such that pixels with the same label share certain visual characteristics." - Wikipedia

Example



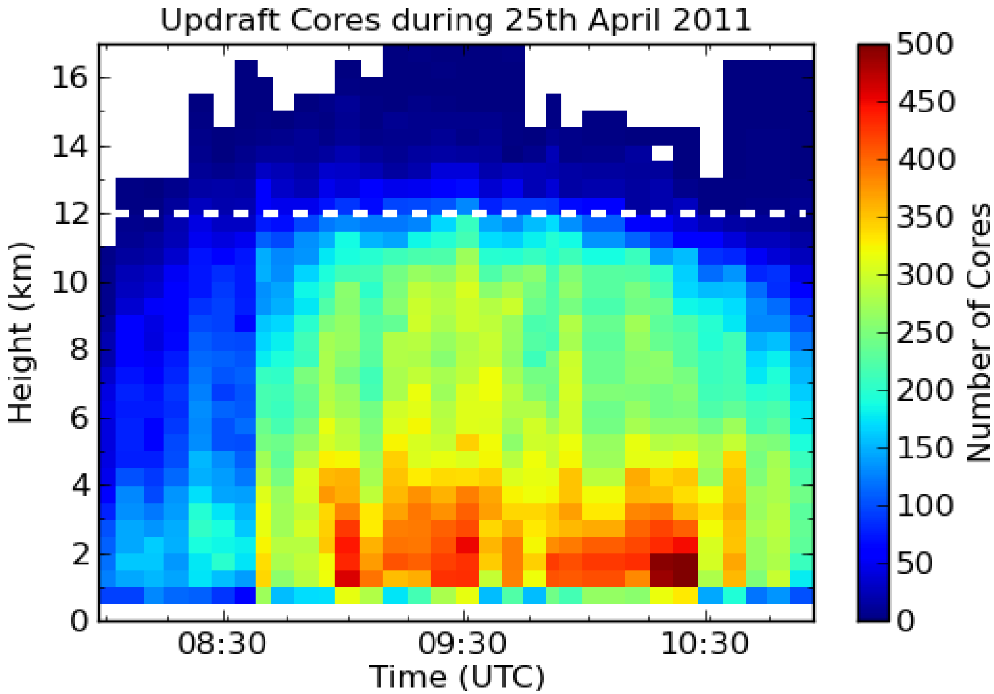
- Using a vertical velocity threshold of **1.5 m s^{-1}**, **241** distinct objects, or in this case, updraft cores, are found at a specific height.
- This process can be repeated for all heights, and core properties as a function of height computed.

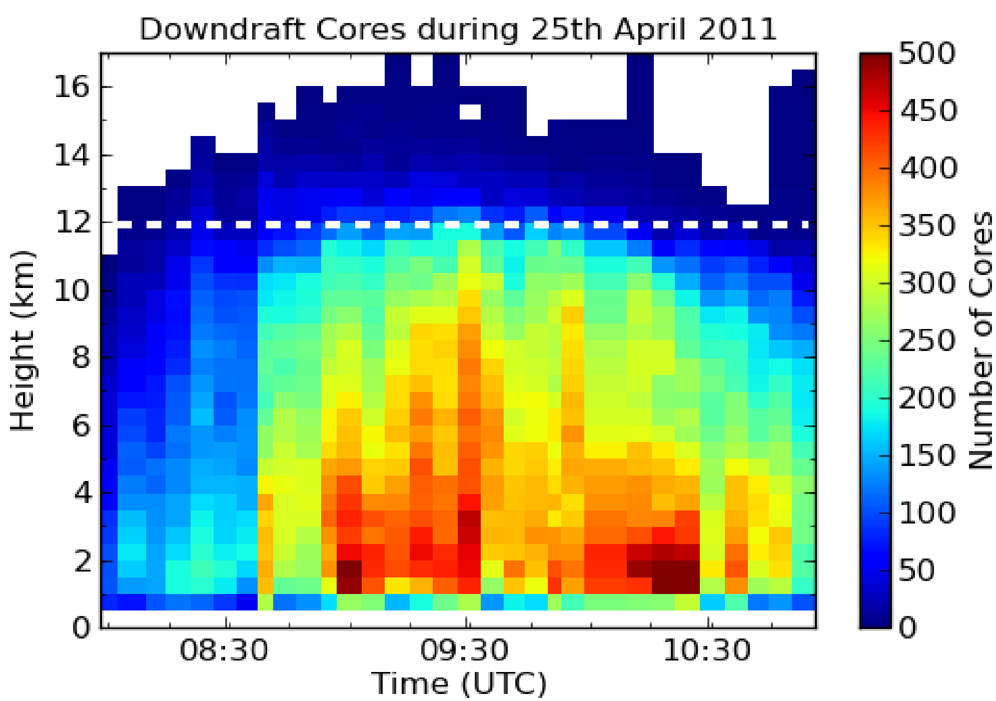
Revised Core Definition



- A core is defined as a **contiguous region** where vertical velocity is greater than **1.5 m s^{-1}** over at least **5 grid points**, or approximately **1 km^2** in area.
- This definition is much less restrictive than the DCC definition. It allows for cores to be defined in **2-D** and **3-D** space.
- Model-relevant variables, like **mass flux**, can now be computed since cores now have an area definition.
- We can calculate various statistics of the gray grid points.

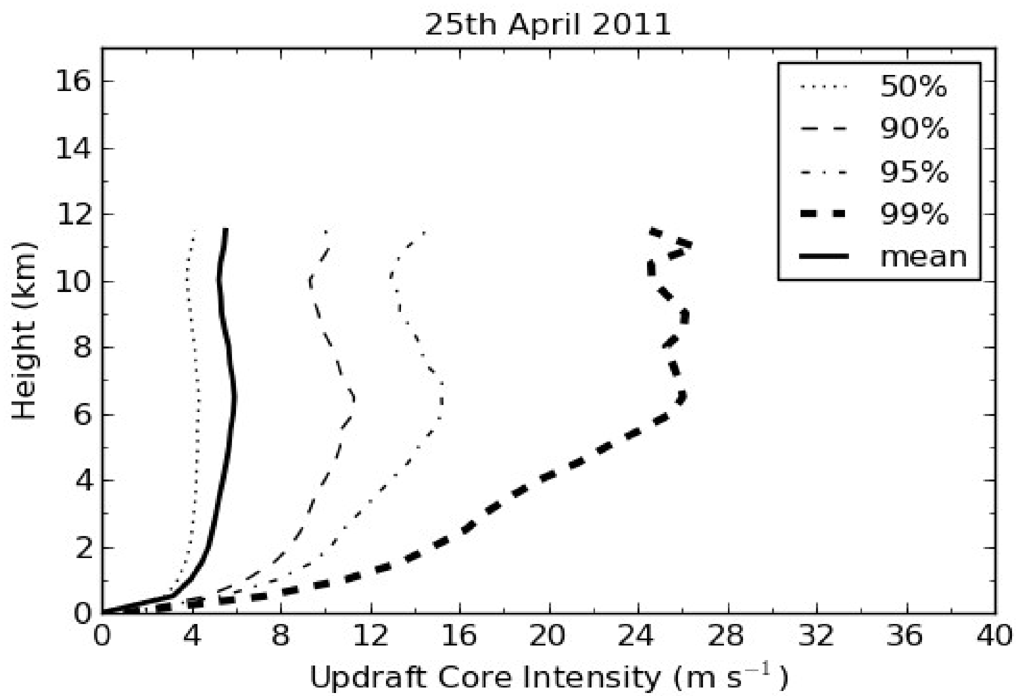
Number of Cores vs Height

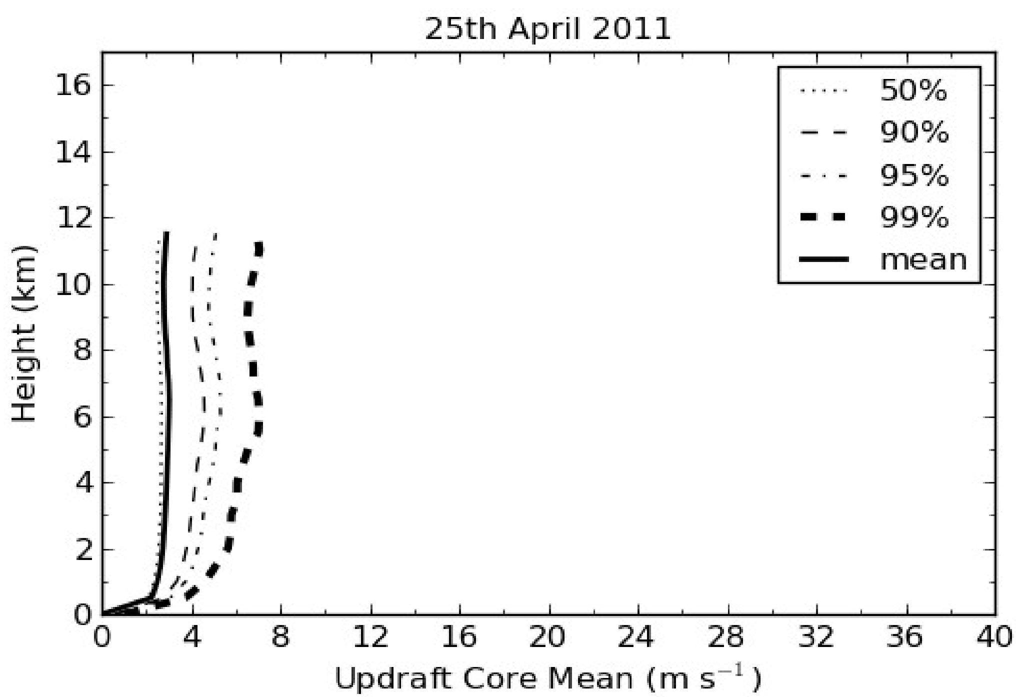




- The number of cores rapidly goes to zero near **12 km**.
- Stated another way, sample size goes to zero in the upper levels.
- There are typically more downdraft cores than updraft cores.
- The number of cores peaks around **6 km**.
- Is the number of cores decreasing after 6 km because cores are getting **bigger**?
- Highest number of cores at any time-height was around **540**. To put this in perspective, if each core was 2 km in diameter, **17%** of the analysis domain would be occupied by cores.

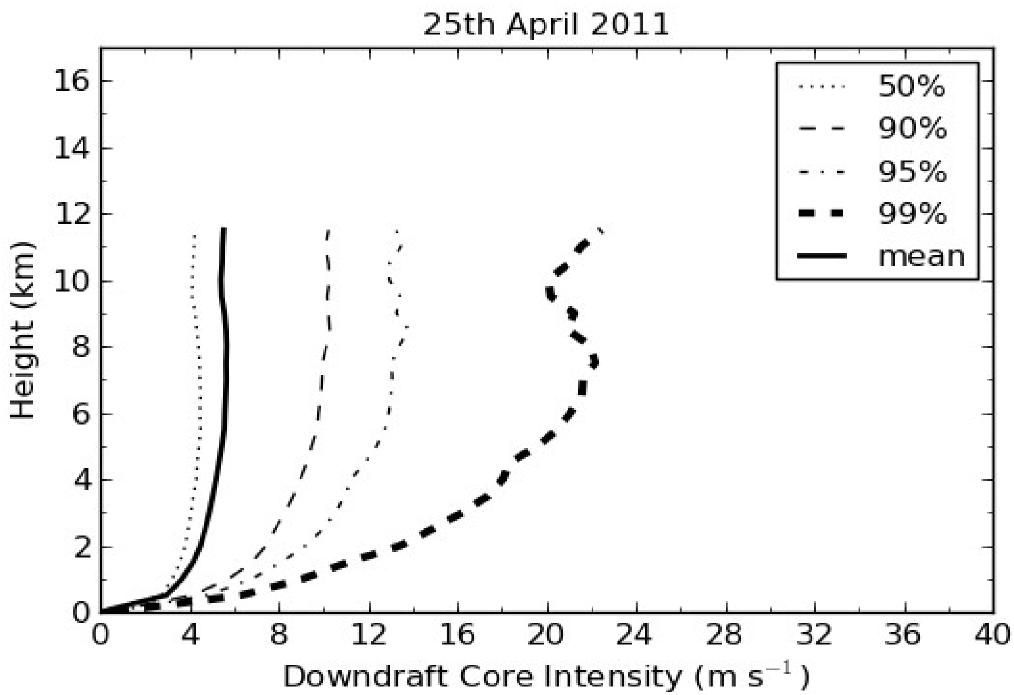
Updraft Core Velocity vs Height

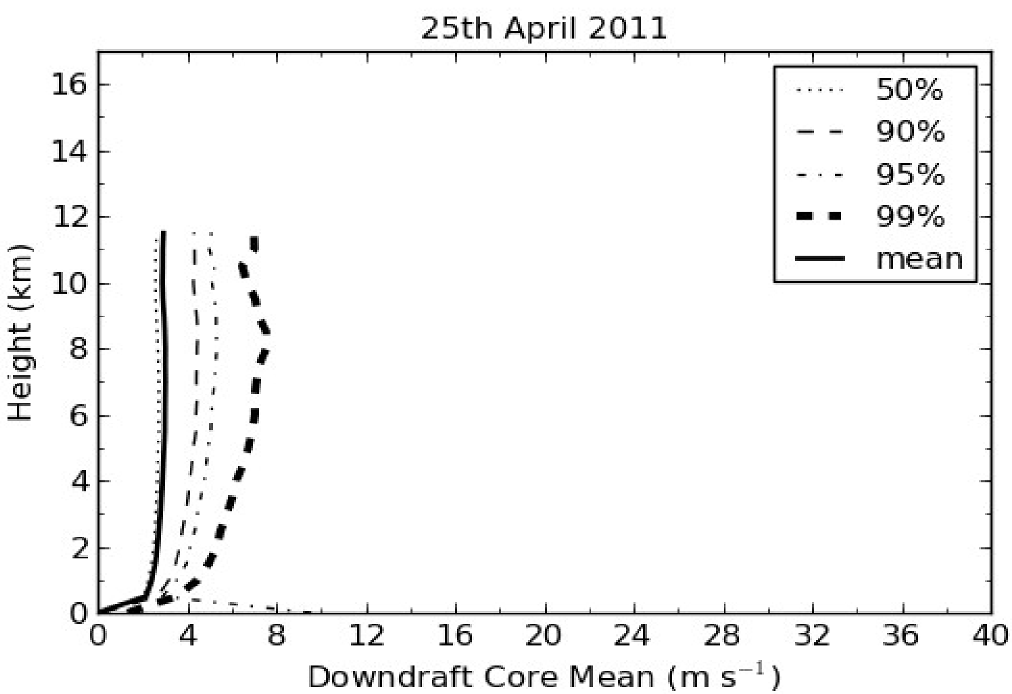




- Few updraft cores with intensity greater than **8 m s^{-1}**.
- Core intensity accelerates up to **7 km**.
- Few updraft cores with mean greater than **4 m s^{-1}**.
- Maximum retrieved updraft core intensity was 59 m s^{-1}.
- Maximum retrieved updraft core mean was 18 m s^{-1}.

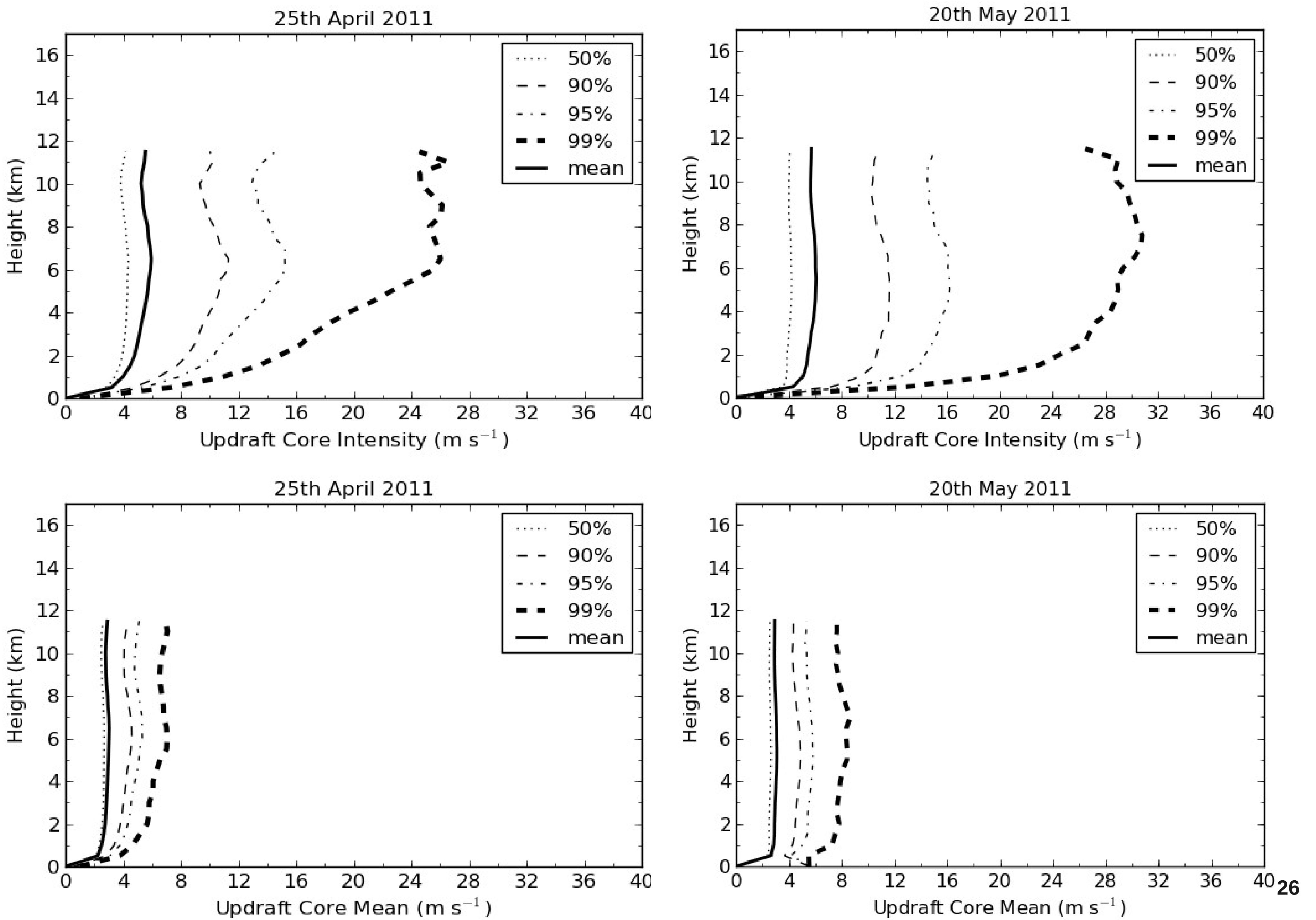
Downdraft Core Velocity vs Height



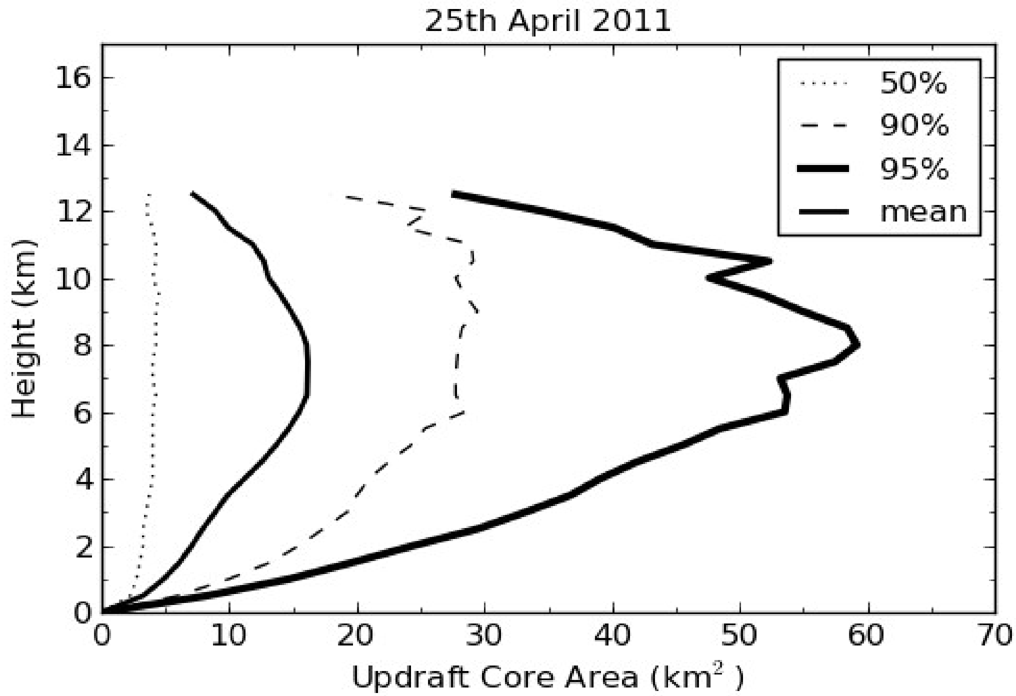


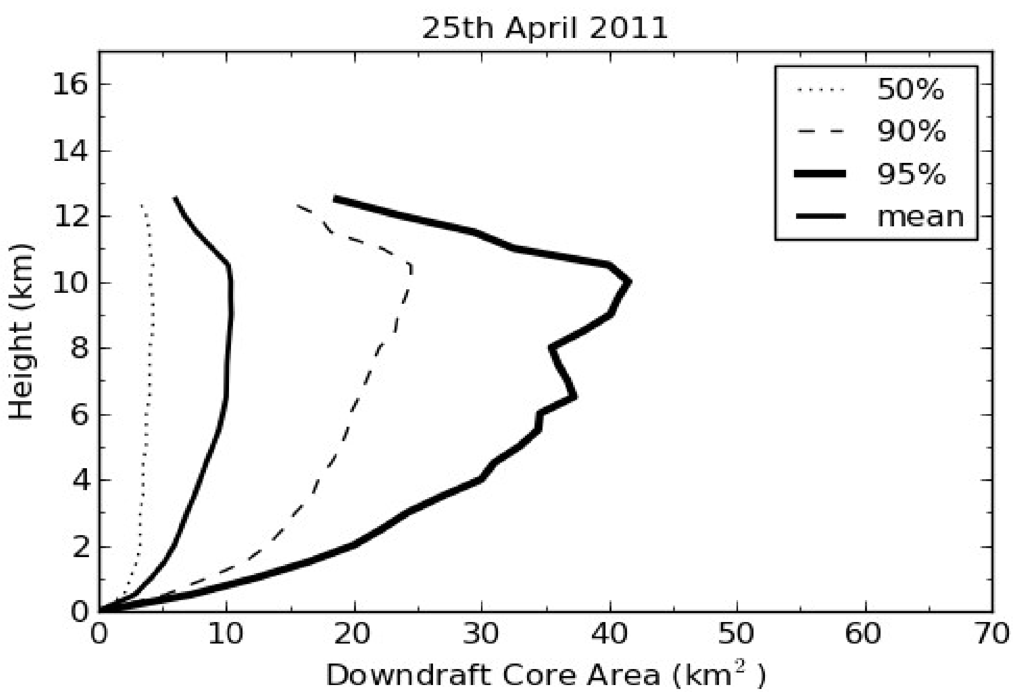
- Subtle differences between updraft and downdraft profiles.
- Maximum retrieved downdraft core intensity was 46 m s^{-1}.
- Maximum retrieved downdraft core mean was 23 m s^{-1}.

Updraft Core Velocity vs Height



Core Area vs Height





- Updraft cores are larger than downdraft cores.
- The **equivalent diameter** of a core covering 30 km^2 is **6 k**m.
- Lots of cores smaller than 5 km^2.
- Core size increases with height up to 10 km, then rapidly decreases.
- Updraft cores are typically thought to be **cone-shaped** in a vertical cross section, as they expand with height.

Summary and Future Work

- We looked at **convective/stratiform partitioning** and how we can relate that to convective cloud evolution.
- We looked at **two core definitions**, one a purely column-based definition and the other based on contiguous vertical velocity regions.
- Using the contiguous definition for cores, we are able to define core area as well as core mean vertical velocity => **core mass flux**.

Future Work

- **Core tracking!**
- Including advection and/or evolution correction within the retrieval.
- Include polarimetric data from the scanning radars into the echo classification scheme.
- And the rest I would like to leave to discussion. **Getting feedback from the modeling community on the types of metrics they believe are relevant from this observational target is key!**

References

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Thank you!