Utilizing the PLOWS dataset to derive vertical motions in banded structures

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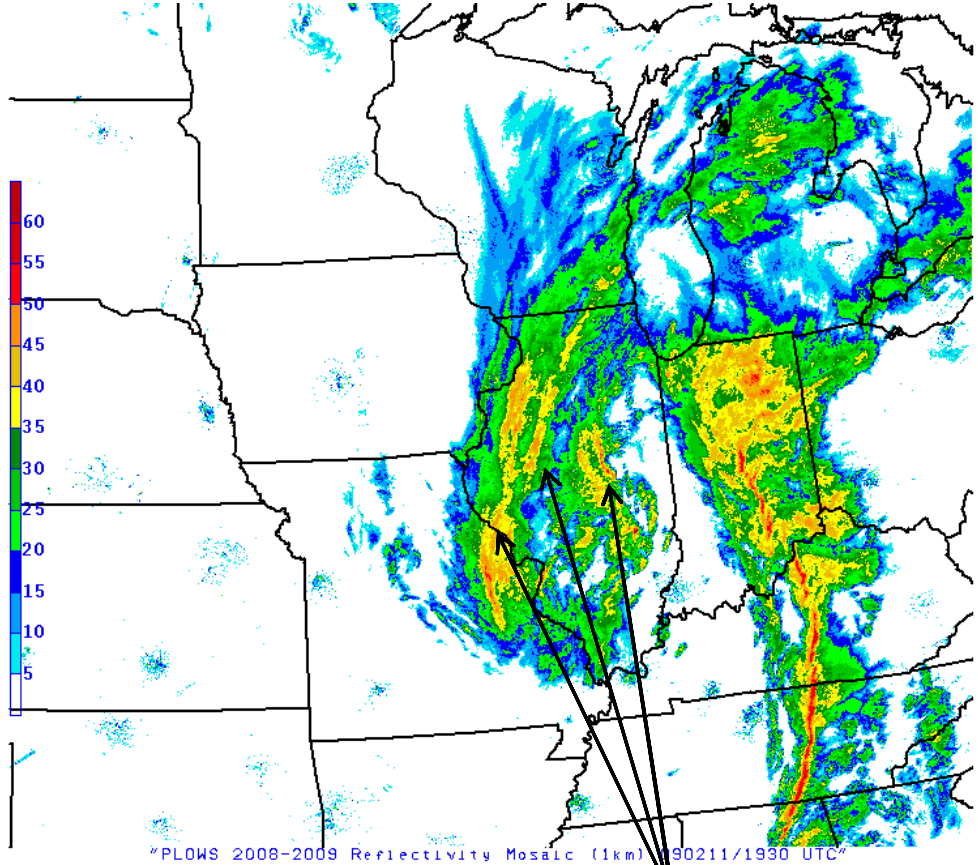
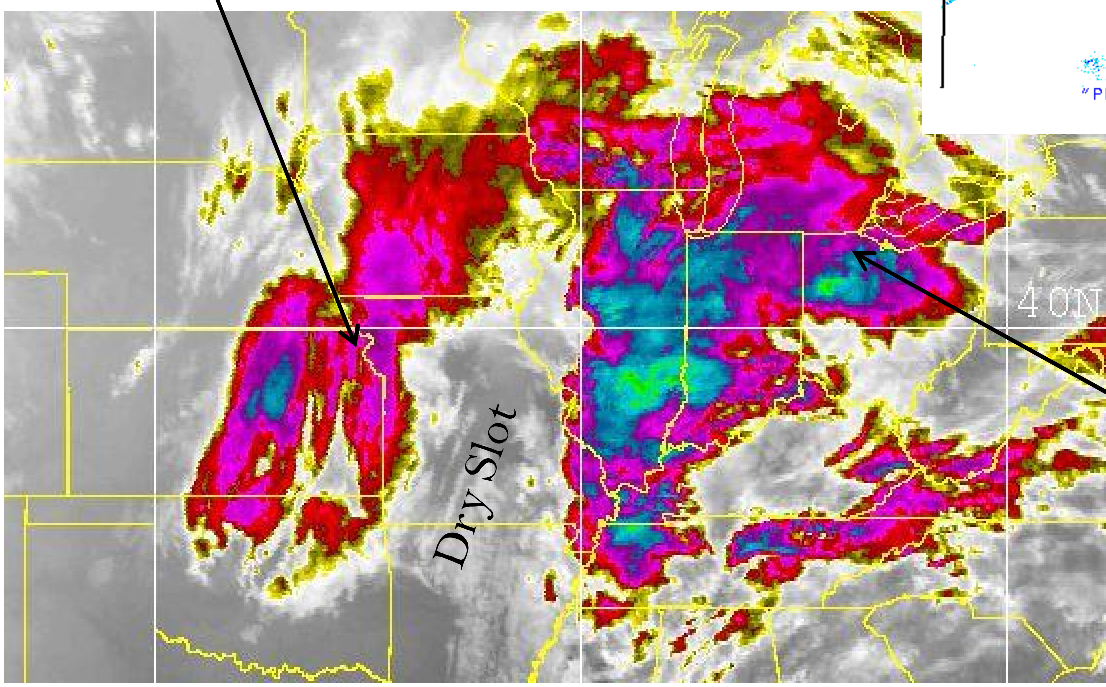
One of the scientific objectives of PLOWS is to understand the causes of the banded structures observed within the warm frontal shield and in the wraparound region of cyclones.



Precipitation Bands

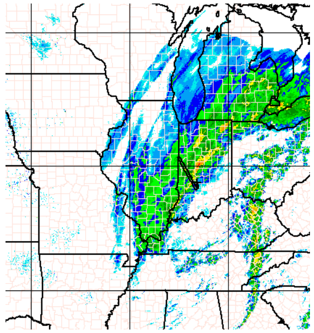
Wraparound Region



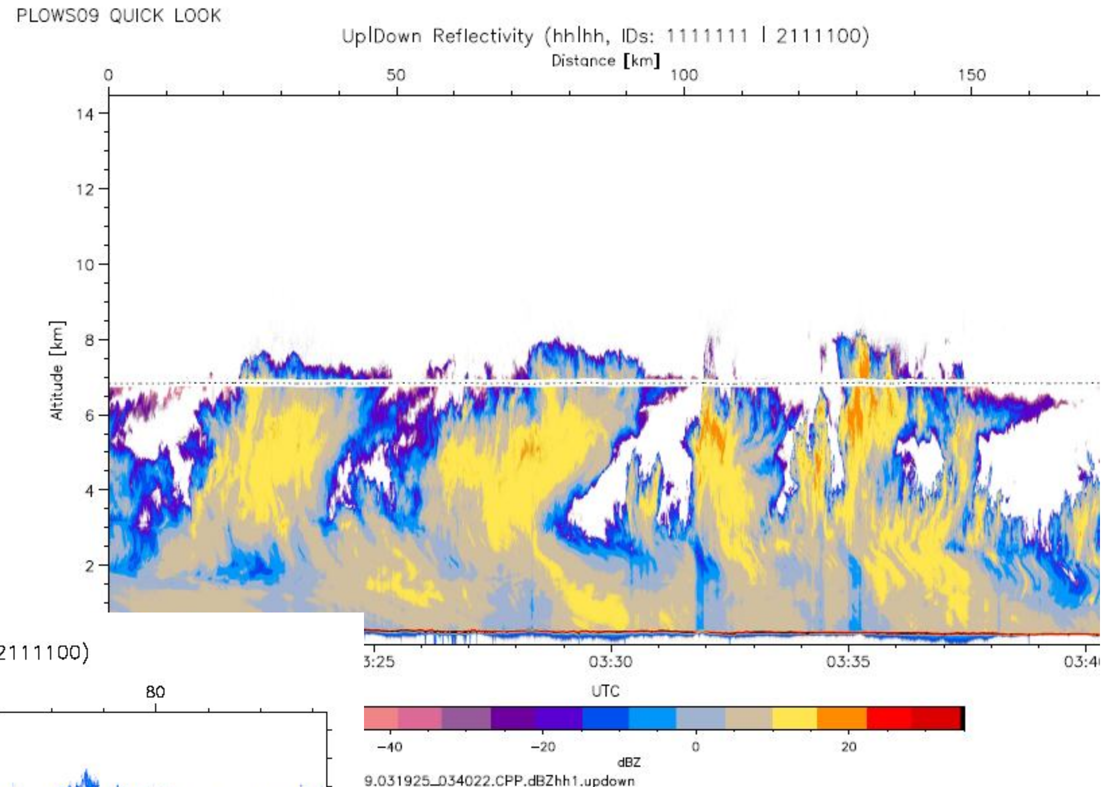
Warm Frontal Shield

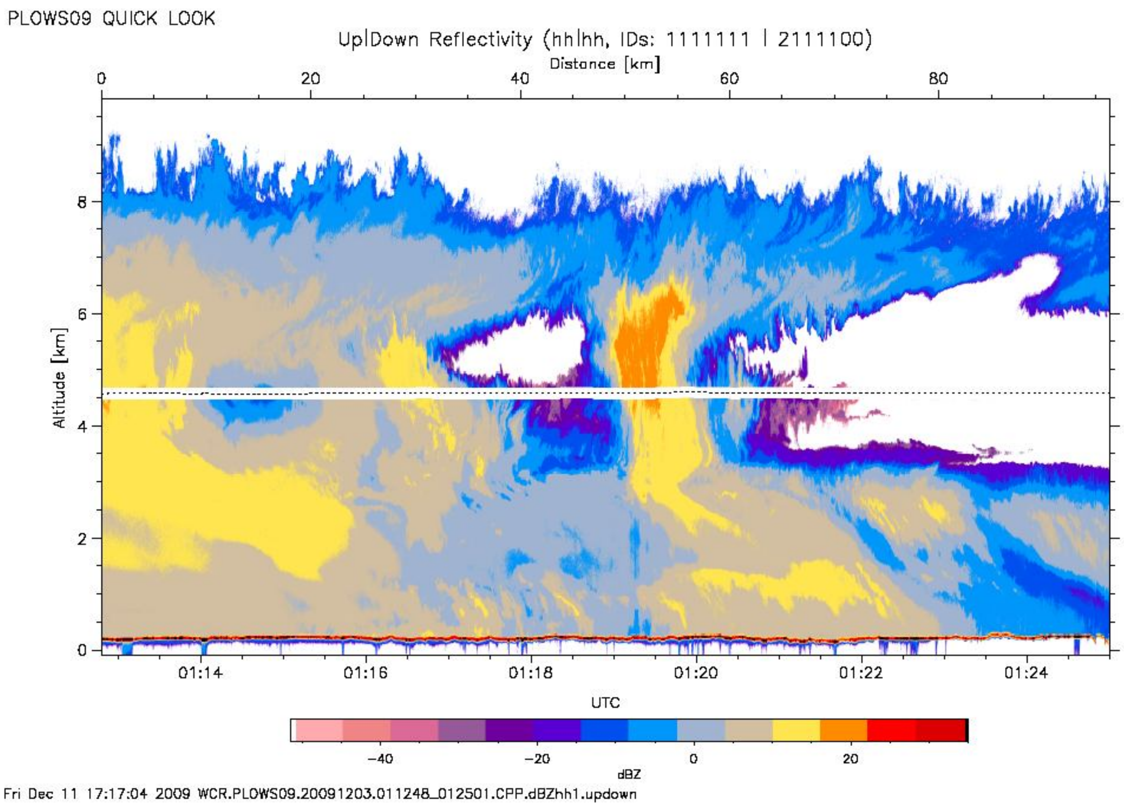
Dynamical Mechanisms

- The predominate explanation for these banded structures in the literature is the release of conditional symmetric instability (CSI), a slantwise instability
- Our working hypothesis is that the bands are produced by the release of potential instability near the cloud top as dry air ascends over moist air, creating a vertical instability due to the different lapse rates for dry and ice-saturated air

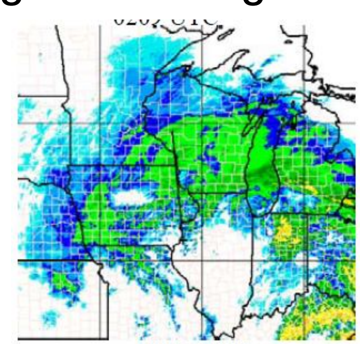


Below: Wyoming Cloud Radar reflectivity-flight occurred Dec 03, 2009. Radar returns appear to contain upright (vertical) convective structures.



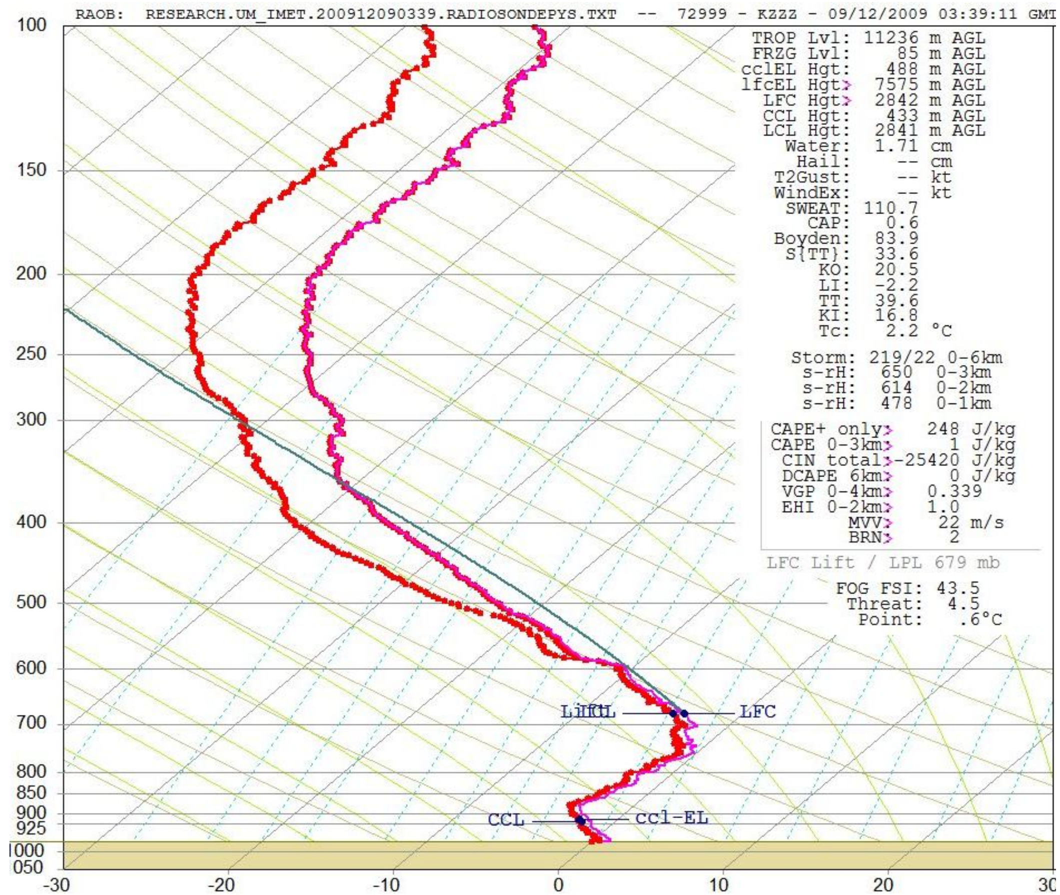


Above: WCR reflectivity from Dec 9, 2009. Convective structures again are evident throughout the flight path.



Dynamical Mechanisms

- By determining the magnitude of vertical motions from remote sensors in conjunction with in situ and sounding analyses, we can directly determine the dynamic forcing for the bands.
  - The sounding at right shows elevated potential instability (with respect to moist [liquid] ascent) during IOP 10



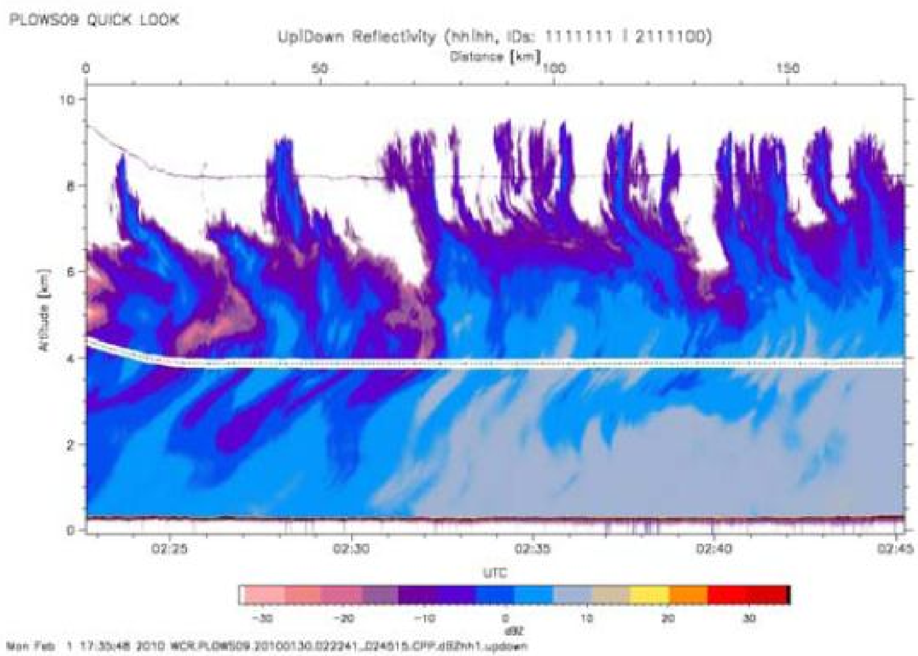
Dec 9, 2009 UMO sounding at 0339 UTC

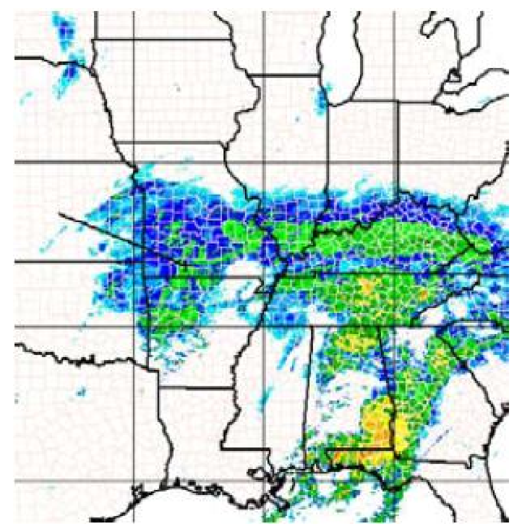
Conditional Symmetric Instability:

- Under inviscid conditions vertical motions due to a release of CSI have been theoretically shown to be limited to about 1 ms^{-1}
  - With frictional forces and entrainment considered, the maximum value of vertical motion should be about 0.25 ms^{-1}
  - Vertical motions of these magnitudes are within the noise with PLOWS remote sensors, and are therefore undetectable

Potential Instability:

- The magnitude of vertical motions are limited only by the CAPE generated by ice-saturated ascent of a moist layer capped by a dry layer





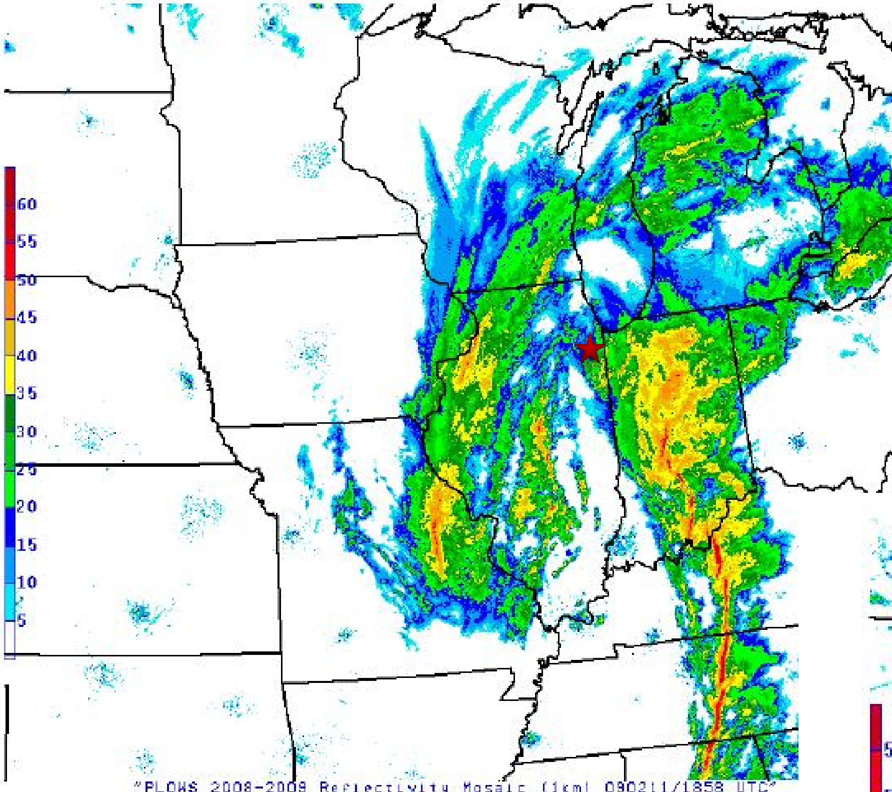
Determining Vertical Motion from Profiler Data

- This approach, the lower bound method (Atlas, 1973), utilizes 915 MHz wind profiler Doppler spectra to derive vertical velocities
- The profiler measures the mean total fall speed of the ensemble of particles within the resolution volume.
  - What we want to measure is the vertical air motion in the resolution volume

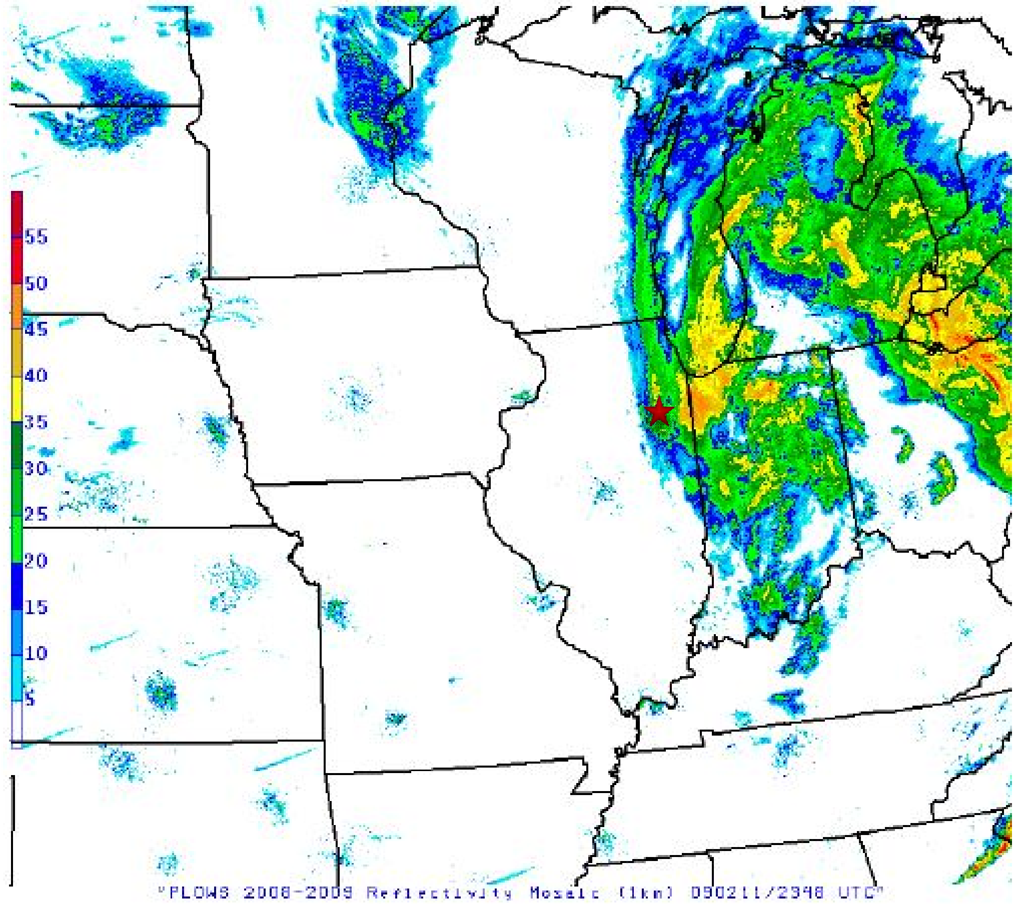
Test Case

- Currently, the lower bound method algorithm is being developed with the data from IOP 1, the best case from the first year.
- IOP 1 had the Mizzou rawinsonde team along with the MIPS profiler.

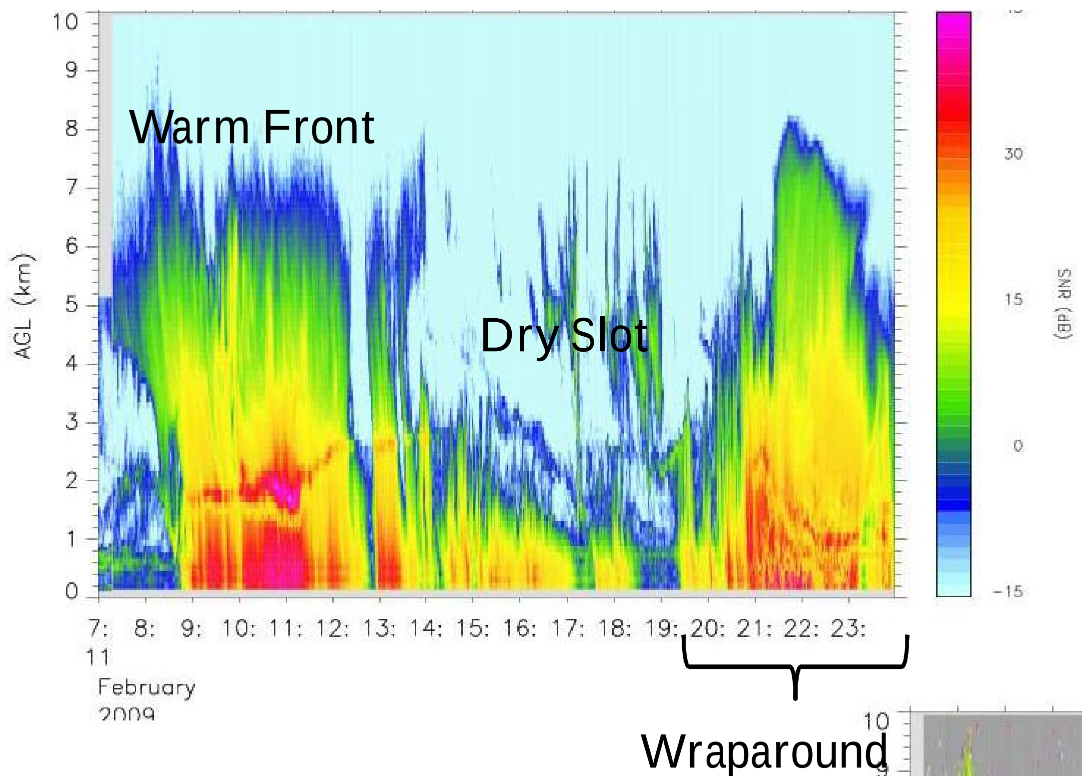
IOP 1

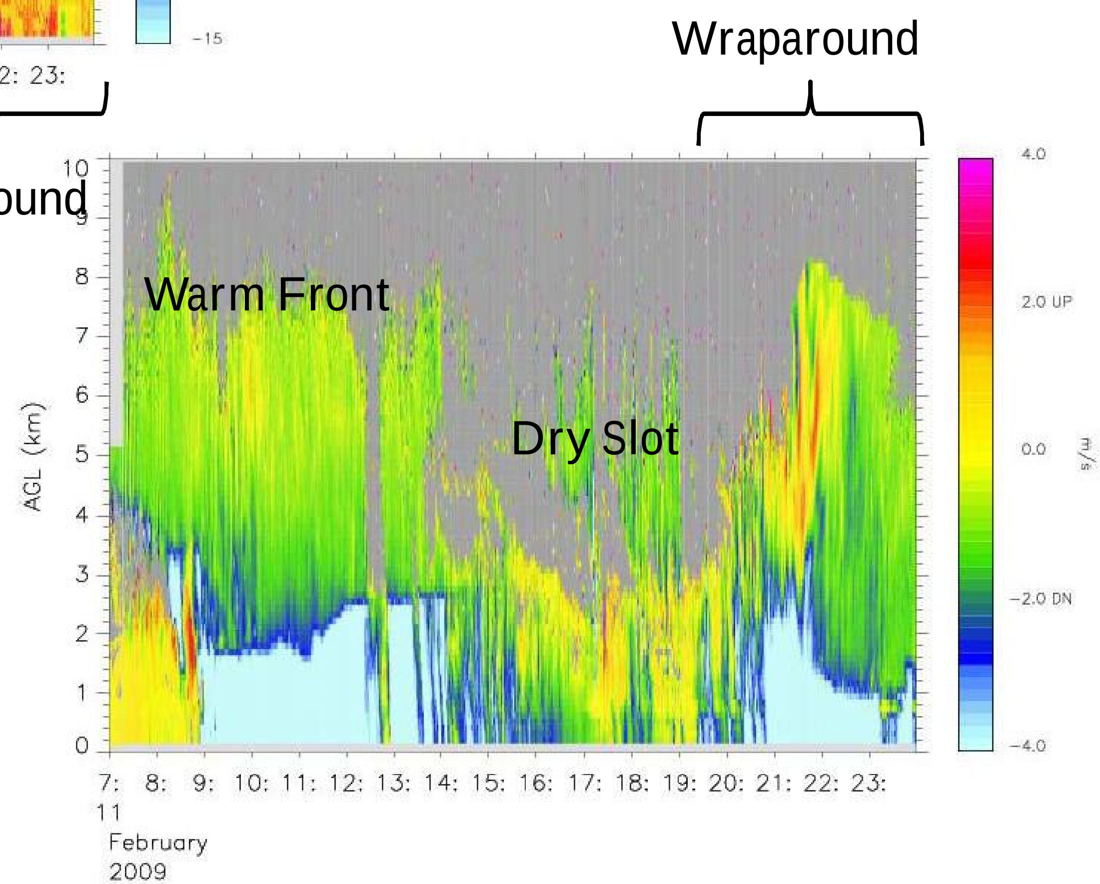


NEXRAD composites for 1858 UTC (top) and 2348 UTC (bottom) on Feb. 11, 2009. The red star is indicating the location of the ground equipment.



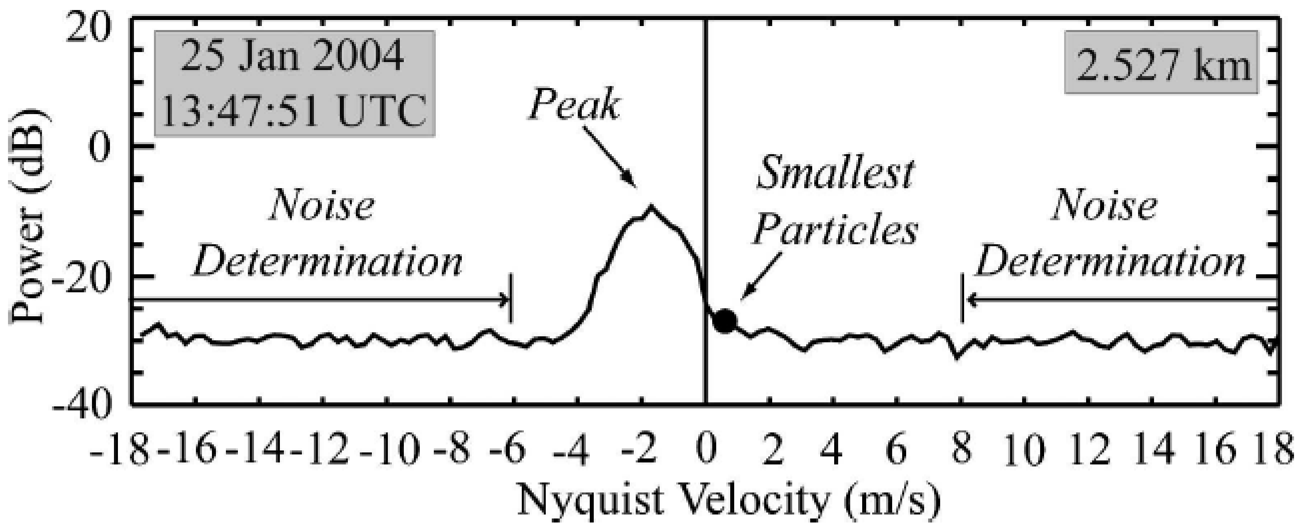
IOP 1





MIPS profiler SNR (top) and radial velocity (bottom) from IOP 1. Especially noteworthy is the area on the edge of the wraparound region that shows positive radial velocity measurements.

Doppler Spectrum



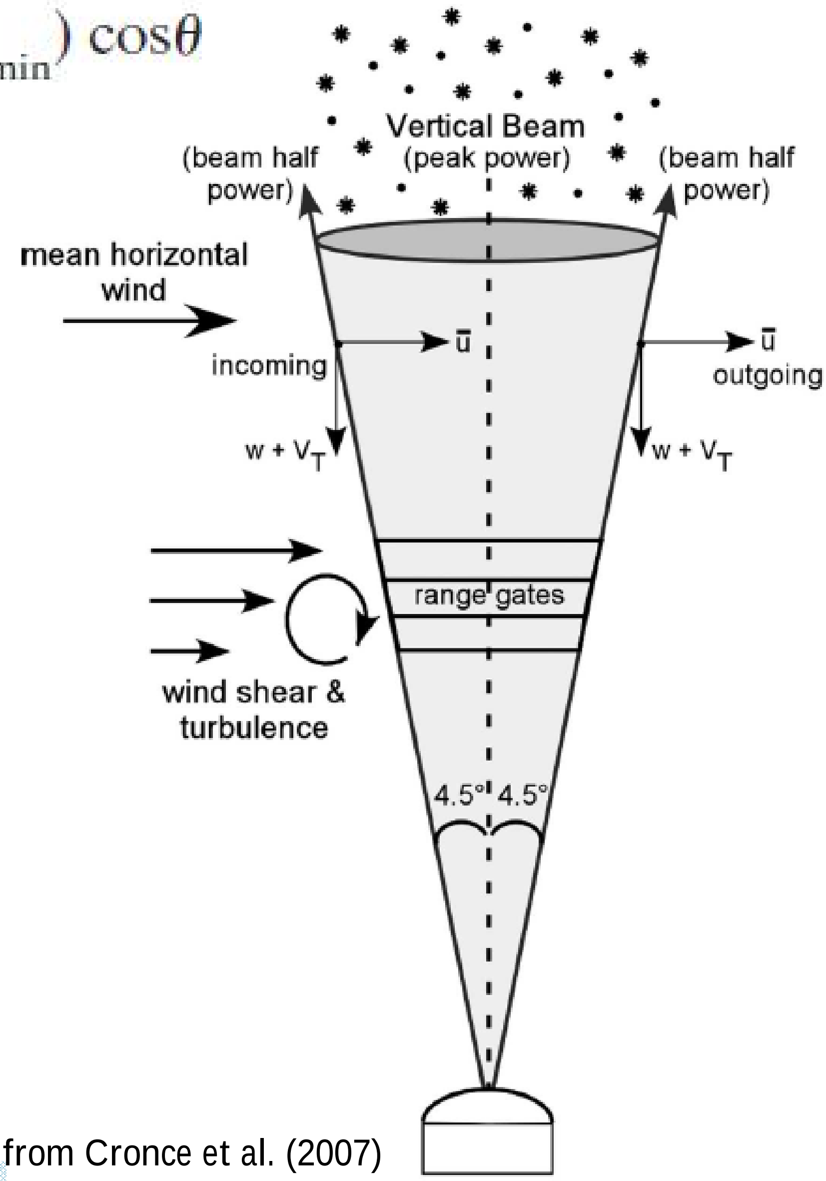
from Cronce et al. (2007)

- "Peak" in the spectrum represents the modal total fall velocity of the particles
- The part of the spectrum just above the noise on the right hand side represents the contribution to the signal from the motions along the beam direction of the smallest detectable particles in the resolution volume
- In PLOWS, these particles are all ice

Contributions to the Radial Velocity

$$V = (\overline{u} + u')\sin\theta + (w + w' + V_{T_{min}})\cos\theta$$

- The spectrum of velocities in the Doppler spectra include:
  - The vertical velocity of the air (w)
  - Particle terminal velocities (V_T)
  - Mean horizontal wind due to a finite beamwidth ($\overline{u}$)
  - Turbulent air motions due to wind shear (u’, w’)



from Cronce et al. (2007)

Equation for radial velocity:

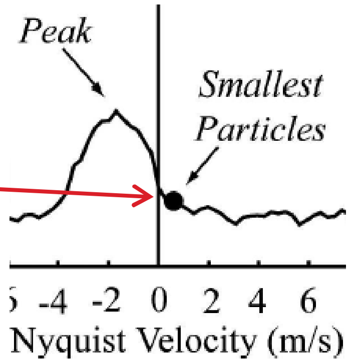
$$V = (\overline{u} + u')\sin\theta + (w + w' + V_{T_{\min}})\cos\theta$$

Inverting equation to find w:

$$w = \frac{V - (\overline{u} + u')\sin\theta}{\cos\theta} - V_{T_{\min}} - w'.$$

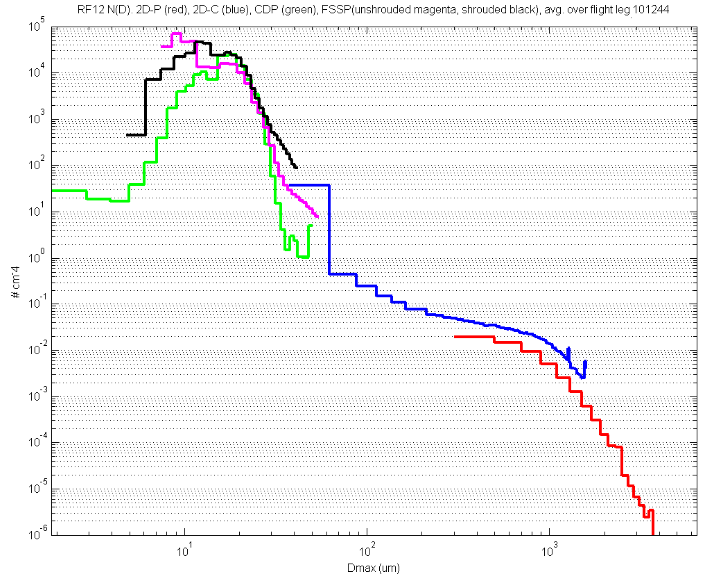
To use this equation we need to know:

- V (First measured velocity above the noise threshold at the right side of the Doppler spectrum)
- V_T (The terminal velocity of the smallest ice particles detectable by the profiler)
- $\overline{u}$ (The mean horizontal wind speed at the level of the range gate where the Doppler spectrum is measured)
- u' (The turbulent component of the horizontal wind at the range gate where the Doppler spectrum is measured)
- w' (The turbulent component of the vertical wind at the range gate where the Doppler spectrum is measured)
- θ (The maximum angle from which a contribution to the Doppler velocity from the horizontal wind is obtained)

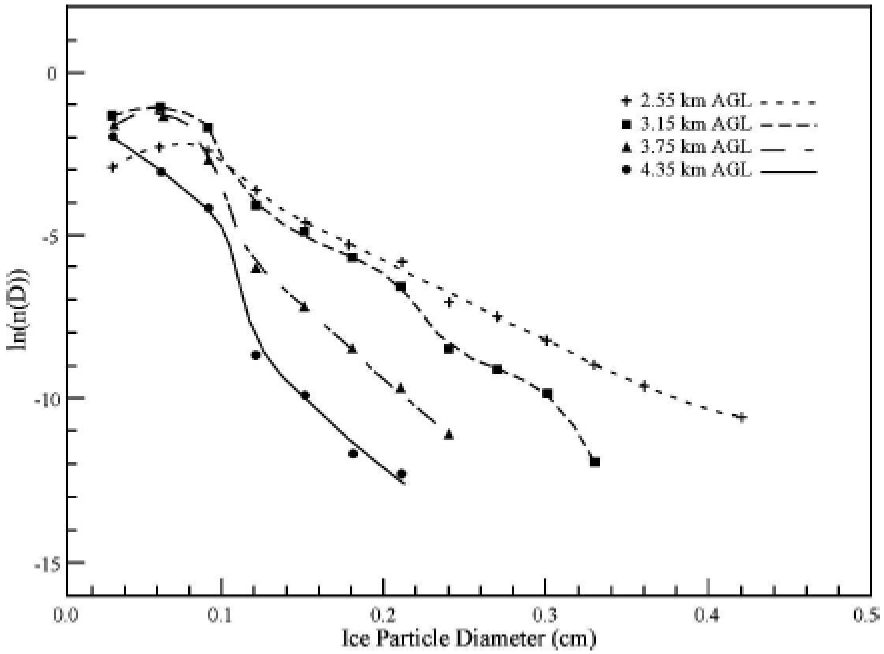


V_T (The terminal velocity of the smallest ice particles detectable by the profiler)

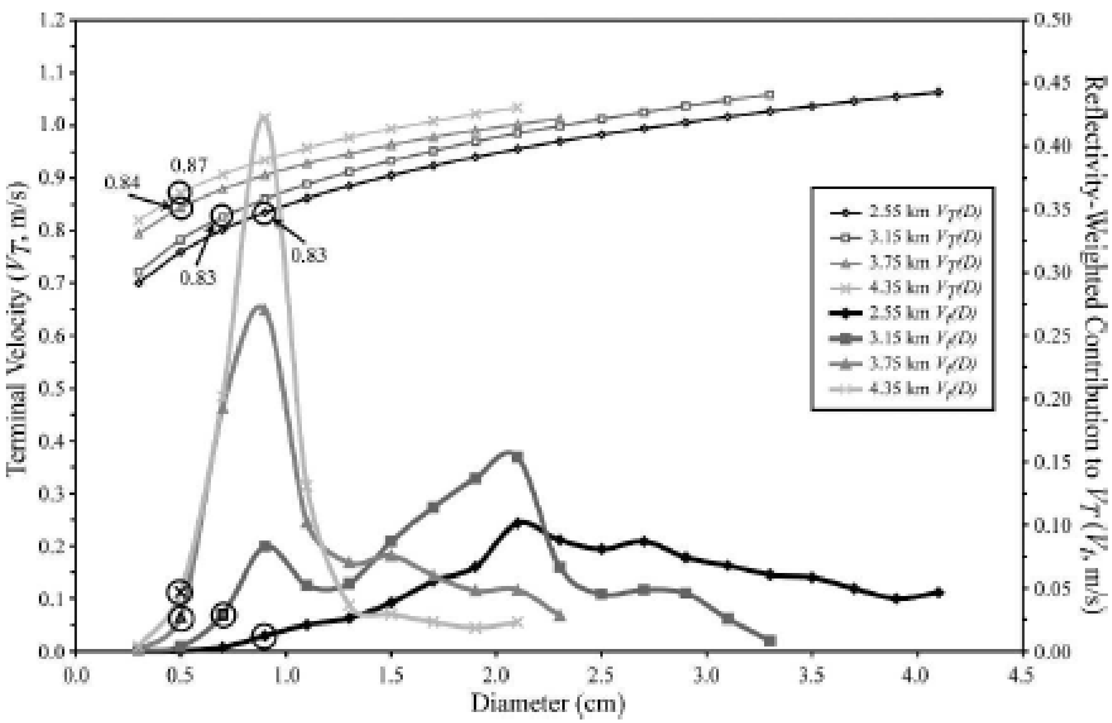
- Though small, the particles still have nonzero terminal velocities
- For PLOWS, we will be able to use the size distributions measured by the aircraft
- We can estimate the terminal velocity of these particles theoretically based on particle habits observed during PLOWS and habit-size/V_T relationships published in the literature



Above: Sample 10 sec size distribution from RF12 (courtesy David Plummer)



Example of determining V_T:

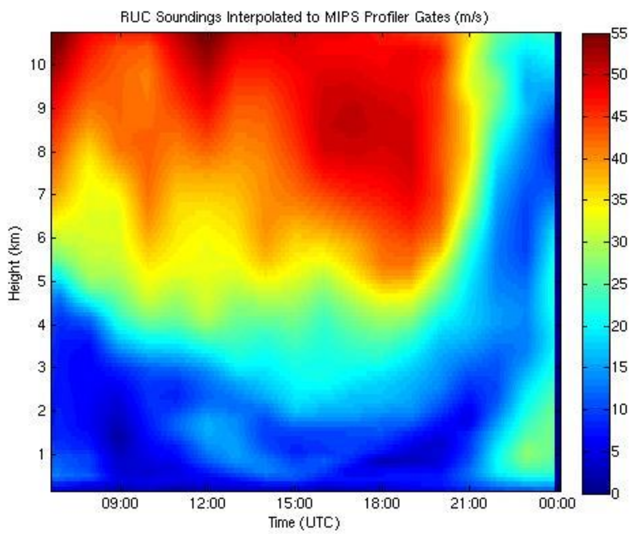


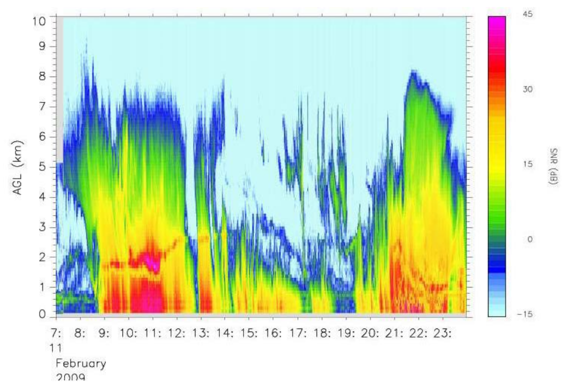
From Cronce et al (2007), using size spectra from Passarelli (1978)

Determining $\overline{u}$ (The mean horizontal wind speed at the level of the range gate where the Doppler spectrum is measured)

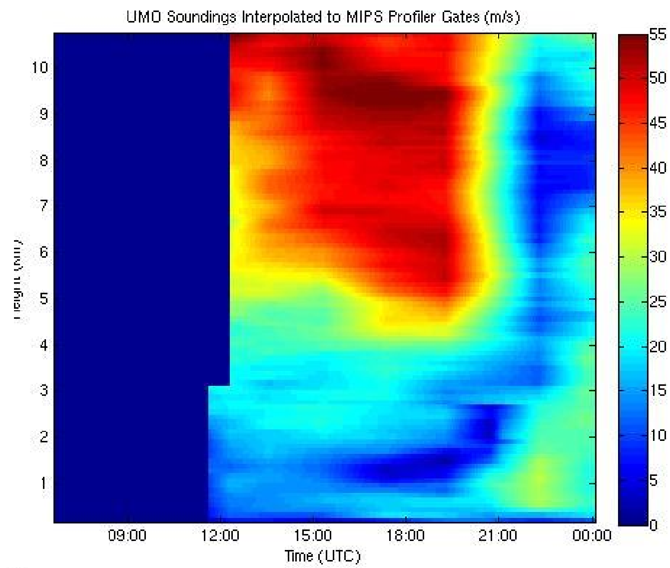
- To calculate the horizontal winds, we create a weighting function where the RUC analysis is used as a first guess.
- Then, the observed values from the rawinsondes and profilers are used where available to modify the RUC analysis to provide the best estimate of the wind field at the highest possible time resolution

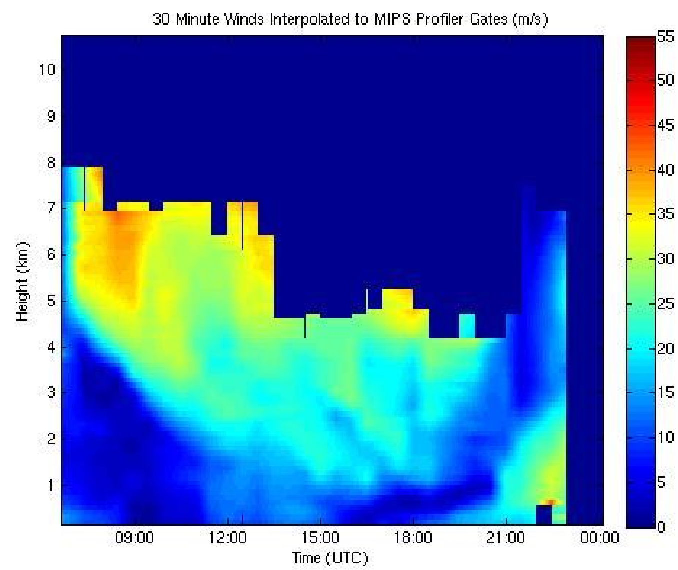
Determining $\overline{u}$ (The mean horizontal wind speed at the level of the range gate where the Doppler spectrum is measured)





IOP 1 MIPS SNR (above)





Analyzed winds interpolated in space and time to profiler gates for the RUC (top left), MIPS (bottom), and UMO Soundings (top right) for IOP1. Dark blue areas indicate missing data.

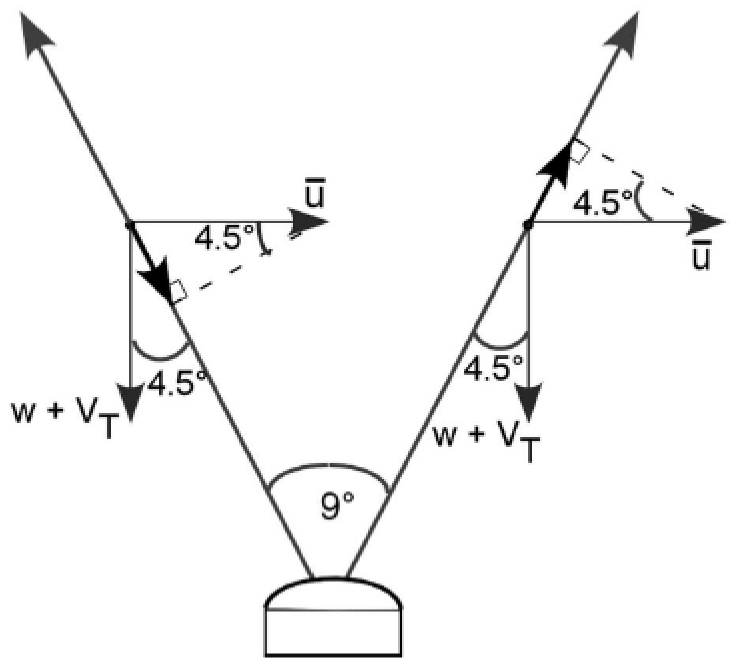
Determining u' and w' (The turbulent components of the horizontal and vertical winds at the range gate where the Doppler spectrum is measured)

$$u' = \frac{\partial u}{\partial z}\frac{\Delta z}{2}$$

Where du/dz is the vertical wind shear and Δz is the gate spacing

Assume $w' = u'$ (symmetric eddies)

Determining θ (The maximum angle from which a contribution to the Doppler velocity from the horizontal wind is obtained)



from Cronce et al. (2007)

Assume θ is the half-power beamwidth.

Error estimation for w:

$$\Delta w = [(\Delta V \sec\theta)^2 + (\Delta\theta V \sec\theta \tan\theta)^2 + (\Delta\overline{u} \tan\theta)^2$$
$$+ (\Delta\theta\overline{u} \sec^2\theta)^2 + (\Delta u' \tan\theta)^2 + (\Delta\theta u' \sec^2\theta)^2$$
$$+ (\Delta V_{T_{\min}})^2 + (\Delta w')^2]^{1/2}.$$

Processing the Whole Dataset

- After developing the processing code for IOP 1, all of the other IOPs will be processed in bulk
- Probability Density Functions for the vertical velocities in the wraparound region for the entire PLOWS dataset from each profiler and from the WCR and in situ data will be calculated.

Conclusions

- The lower bound method is being used on the data collected during PLOWS in order to calculate vertical air motions within the precipitation structures
  - The PLOWS dataset lends itself to this type of analysis due to the redundant profiling radars and sounding systems
- From these air motions and the in situ measurements taken during PLOWS, we should be able to address the type of instability responsible for the observed precipitation and cloud structures.