Ice Crystal Sice Retrievals using High Spectral Resolution Lidar and Millimeter Wave Radar Data

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The University of Wisconsin Arctic High Spectral Resolution Lidar (AHSRL) and the NOAA 8.6 mm radar (MMCR) are collecting data in the high Arctic at Eureka, Canada (79.94 N, 85.56W). The have been deployed as part of the NOAA SEARCH program since August of 2005. The AHSRL provides measurements of the backscatter cross section, extinction cross section, and depolarization that are robustly calibrated by reference to molecular scattering. In addition, the AHSRL receiver accepts light from a very small angular field-of-view (45 microradian) limiting errors caused by multiply scattered photons. These factors make AHSRL data uniquely suited for use in lidar-radar particle size retrievals. This paper presents examples of lidar-radar particle size retrievals, compares derived precipitation estimates with conventional meteorological measurements and looks at the use of fall velocities to provide particle shape information.

Our size retrieval follows that of Donovan and Lammeren (JGR, V106, D21, p 27425). The lidar and radar backscatter cross sections are used to derive:

$$D_{eff\ prime} = \left(\frac{9}{\Pi}\frac{\langle Volume^2\rangle}{\langle Area\rangle}\right)^{1/4}$$ where < > denotes an averages over the particle size distribution.

$$D_{eff\ prime} \sim \left(\frac{\text{Radar backscatter cross section}}{\text{Lidar scattering cross section}}\right)^{1/4}$$

We can use either the lidar backscatter cross section or the directly measured extinction cross section in this retrieval. Typically, we use the backscatter cross section and an assumed value of the backscatter phase function (.035) to compute the lidar scattering cross section. The AHSRL backscatter cross section measurement is not affected by multiple scattering errors and it is less affected by measurement noise.

$D_{eff\ prime}$ is easily measured with little potential error due to a prior assumptions. However, determination of liquid water content, and number density require measurements of the effective diameter:

$$D_{eff} = \frac{3}{2}\frac{\langle Volume\rangle}{\langle Area\rangle}$$

In regions where the lidar measures depolarizations of less than 3% we assume that the scattering particles are spherical. In this case we assume a modified gamma distribution of particle sizes, N(D):

$$N(D)=aD^{\alpha}\exp(-bD^{\gamma})$$

Given assumed values for the dispersion parameters α and γ, The measured lidar cross section and the computed $D_{eff\ prime}$ values are used to solve for the values of a and b. N(D) is then used to compute the relationship between $\langle Volume^2\rangle$ and $\langle Volume\rangle$ allowing us to convert from $d_{eff\ prime}$ to d_{eff}.

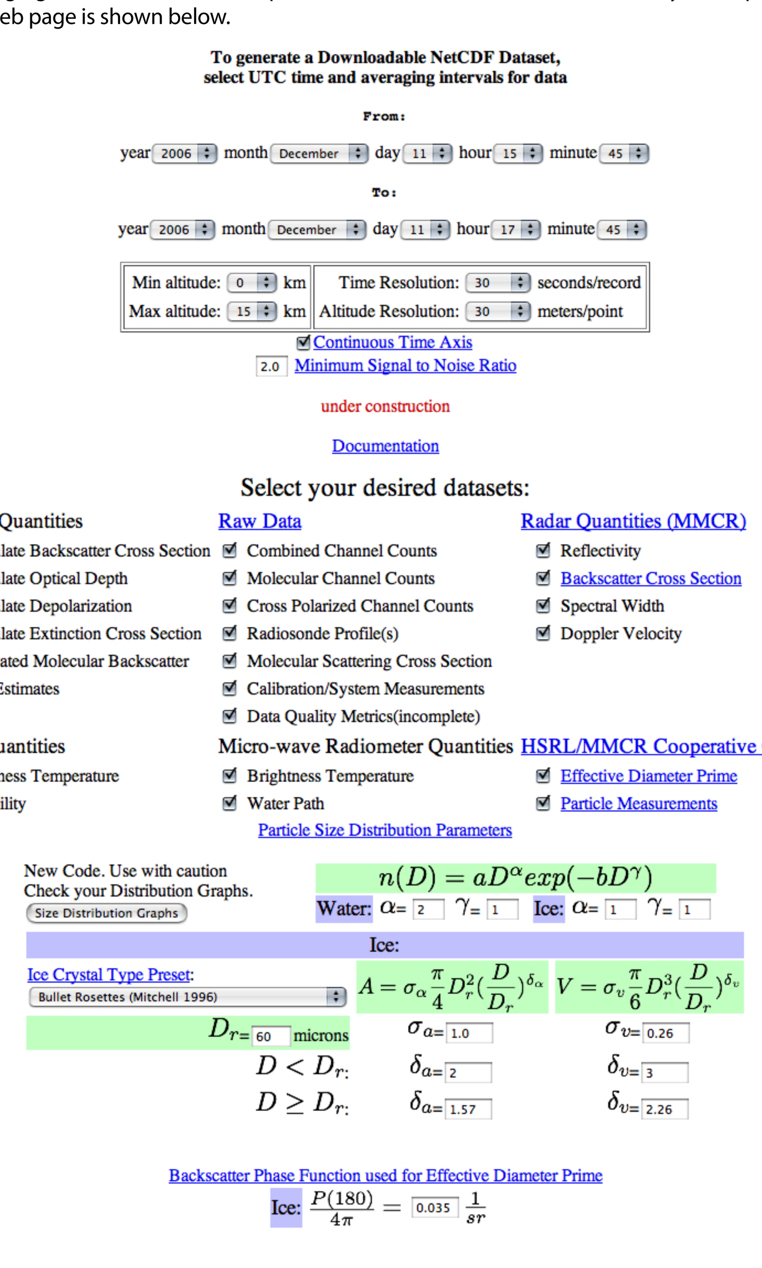
In the case of ice particles the conversion of $D_{eff\ prime}$ to D_{eff} is made more difficult by the wide variety of crystal shapes present in cirrus clouds and falling snow. When the measured lidar depolarization is greater than 3% we assume the particles are ice crystals. We allow the assumption of separate dispersion parameters for the gamma distribution of ice crystal sizes. In addition we assume power law relationships describing the projected area and volume of crystal as a function of the crystal diameter measured along longest axis of the particle. This approach is described by a number of authors including Mitchell (JAS, V 53, 1996, p 1710). Rewriting Mitchell's power law relationships slightly in order to make the coefficients non-dimensional:

$$Area = \sigma_a \frac{\pi}{4} D_r^2 \left(\frac{D}{D_r}\right)^{\delta_a}$$

$$Volume = \sigma_v \frac{\pi}{6} D_r^3 \left(\frac{D}{D_r}\right)^{\delta_v}$$

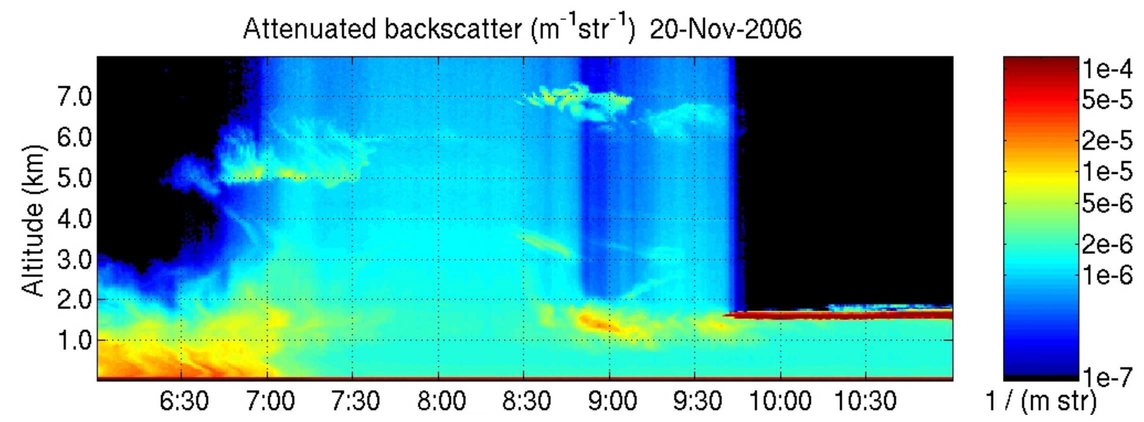
Where σ_v is the fraction of the volume of the sphere with a diameter of D_r that is filled with ice and σ_a is the fraction of the projected area of sphere with diameter D_r that is covered by ice. The coefficients δ_a and δ_v can be specified separately for particles smaller than and larger than the reference diameter D_r.

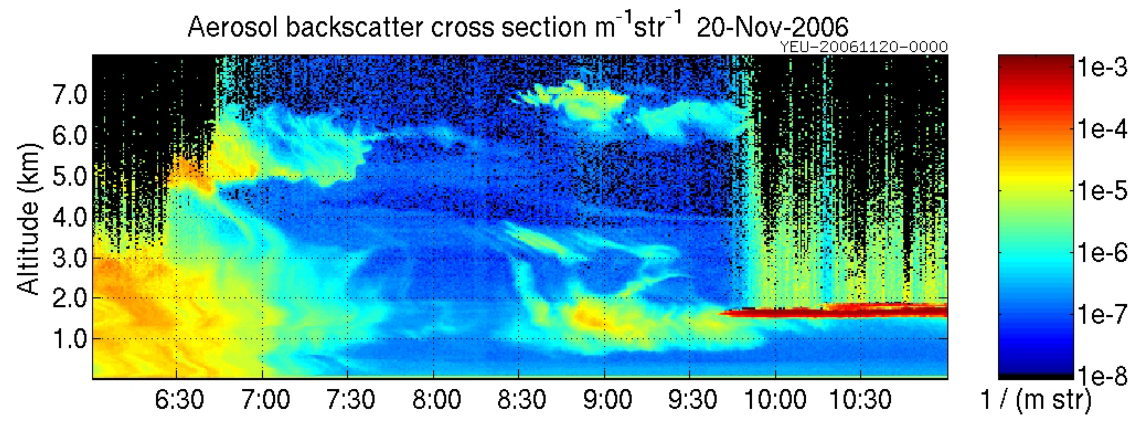
The particle size retrieval has been incorporated into our web page 'http://lidar.ssec.wisc.edu' and can be applied to any of the lidar and radar data collected in nearly continuous operation at Eureka, Canada since August of 2005. All data is presented in the form of netCDF files which can be downloaded by anyone interested in this data. The user can specify the time and altitude interval, the time and altitude averaging and all of the assumed parameters needed for size, number density and liquid water retrievals. A reproduction of the web page is shown below.

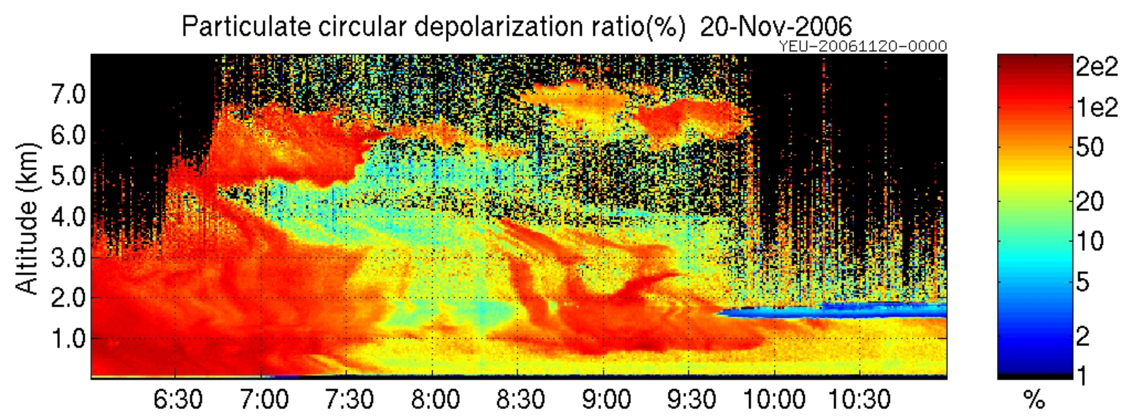

To generate a Downloadable NetCDF Dataset, select UTC time and averaging intervals for data
From:
year 2006 month December day 11 hour 15 minute 45
To:
year 2006 month December day 11 hour 17 minute 45
Min altitude: 0 km | Time Resolution: 30 seconds/record
Max altitude: 15 km | Altitude Resolution: 30 meters/point
Continuous Time Axis
2.0 Minimum Signal to Noise Ratio
under construction
Documentation
Select your desired datasets:

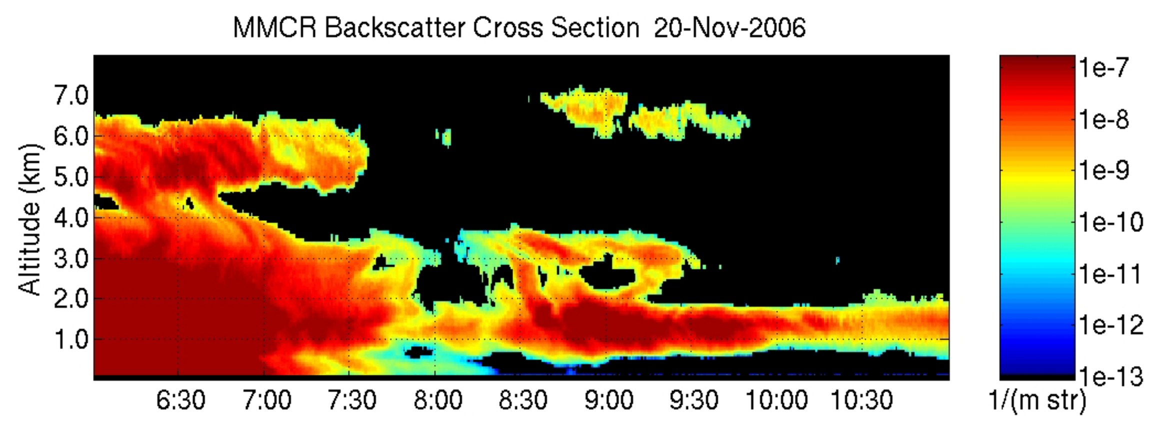
Derived Quantities	Raw Data	Radar Quantities (MMCR)
Particulate Backscatter Cross Section	Combined Channel Counts	Reflectivity
Particulate Optical Depth	Molecular Channel Counts	Backscatter Cross Section
Particulate Depolarization	Cross Polarized Channel Counts	Spectral Width
Particulate Extinction Cross Section	Radiosonde Profile(s)	Doppler Velocity
Attenuated Molecular Backscatter	Molecular Scattering Cross Section	
Error Estimates	Calibration/System Measurements	
	Data Quality Metrics(incomplete)	
AERI Quantities	**Micro-wave Radiometer Quantities**	**HSRL/MMCR Cooperative Quantities**
Brightness Temperature	Brightness Temperature	Effective Diameter Prime
Variability	Water Path	Particle Measurements

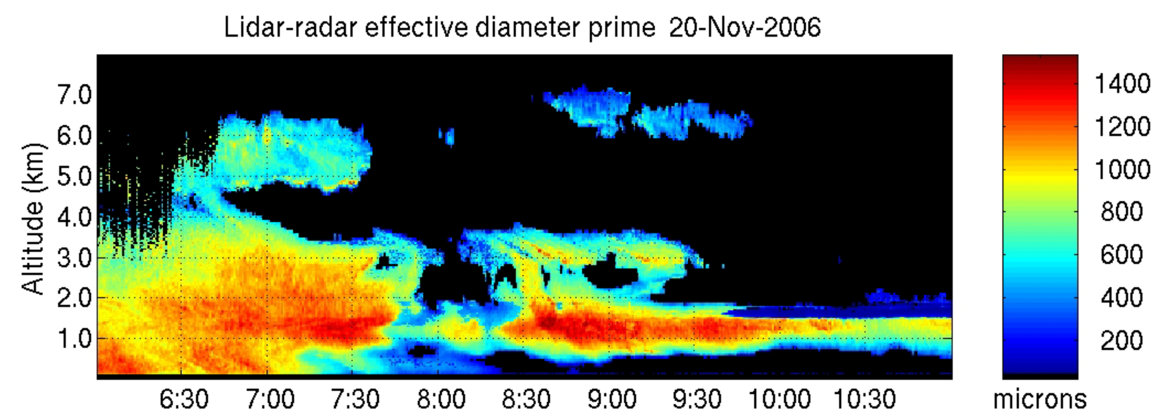
Particle Size Distribution Parameters
New Code. Use with caution
Check your Distribution Graphs.
Size Distribution Graphs
$n(D) = aD^{\alpha}exp(-bD^{\gamma})$
Water: α= 2 γ= 1 Ice: α= 1 γ= 1
Ice:
Ice Crystal Type Preset:
Bullet Rosettes (Mitchell 1996)
$A = \sigma_a \frac{\pi}{4} D_r^2 (\frac{D}{D_r})^{\delta_a}$ $V = \sigma_v \frac{\pi}{6} D_r^3 (\frac{D}{D_r})^{\delta_v}$
D_r= 60 microns σ_a= 1.0 σ_v= 0.26
$D < D_r$: δ_a= 2 δ_v= 3
$D \geq D_r$: δ_a= 1.57 δ_v= 2.26
Backscatter Phase Function used for Effective Diameter Prime
Ice: $\frac{P(180)}{4\pi}$ = 0.035 $\frac{1}{sr}$
BETA Submit *BETA*

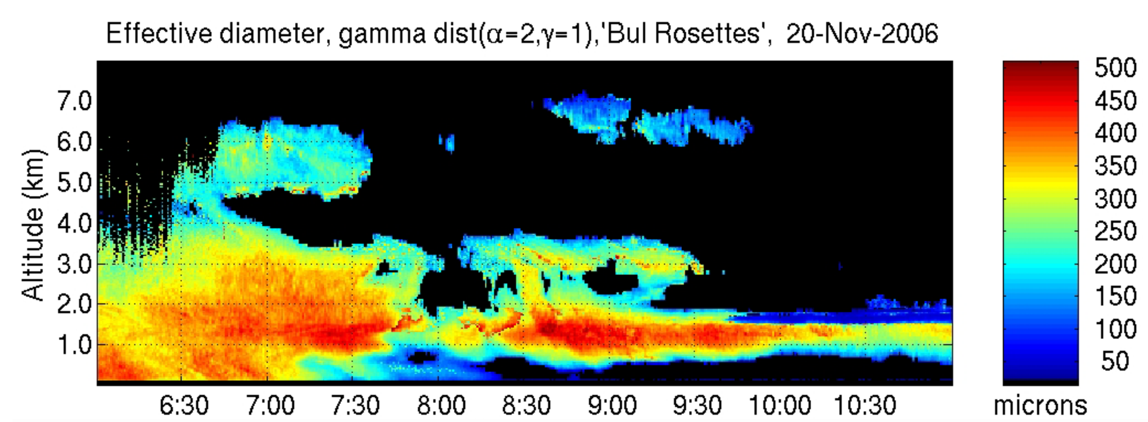


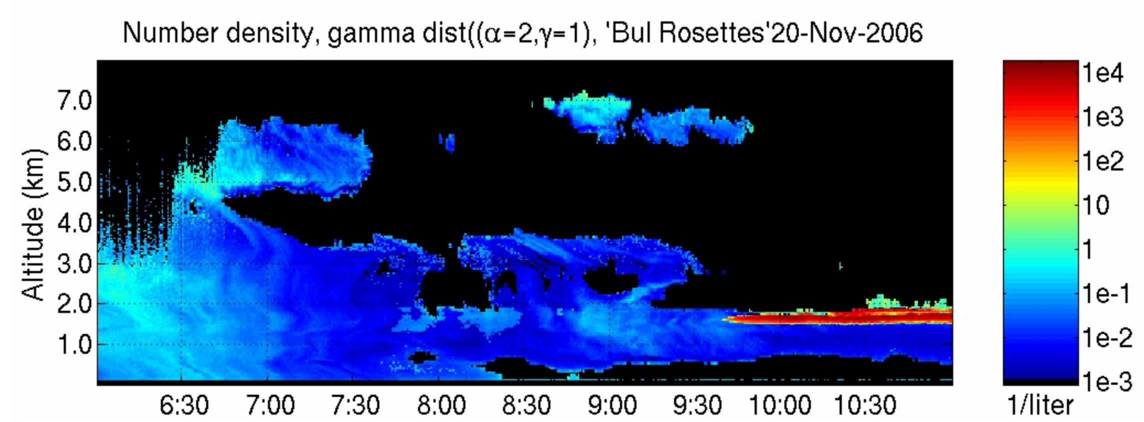


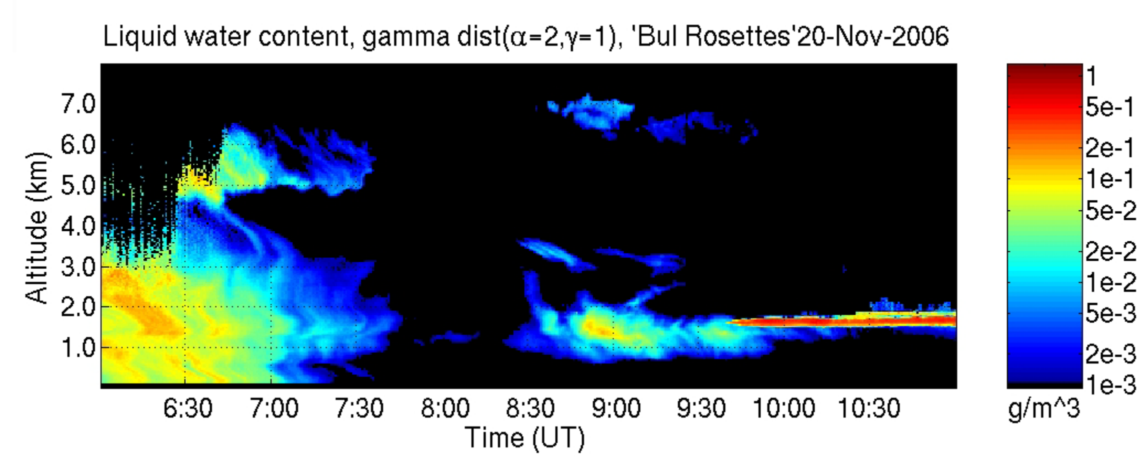






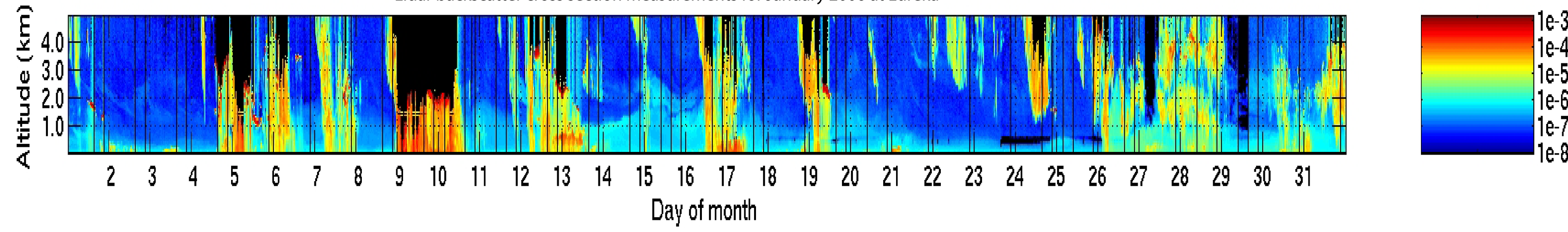




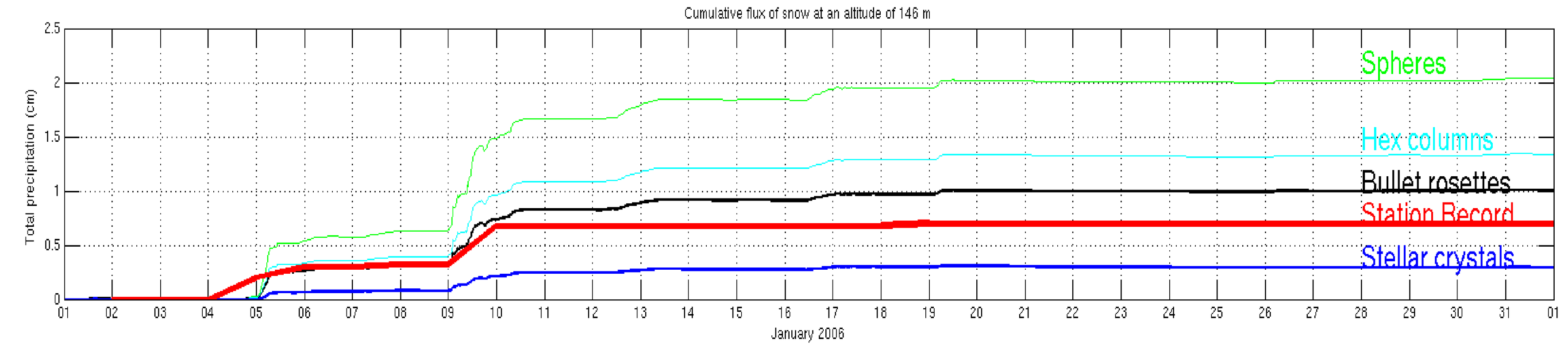


Derivations of D_{eff} and the lidar backscatter cross section can be used to derive water content. When this is combined with radar measurements of vertical velocity we can compute the downward flux of water. Here we compare this measurement made at an altitude of 150 meters with conventional measurements of precipitation recorded by the Eureka weather station.

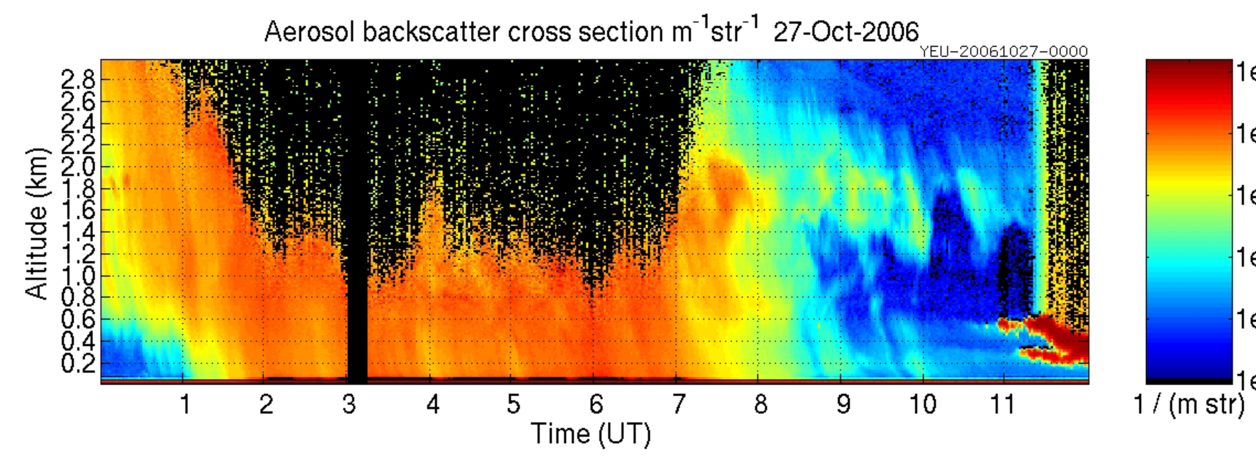
Lidar backscatter cross section measurements for January 2006 at Eureka

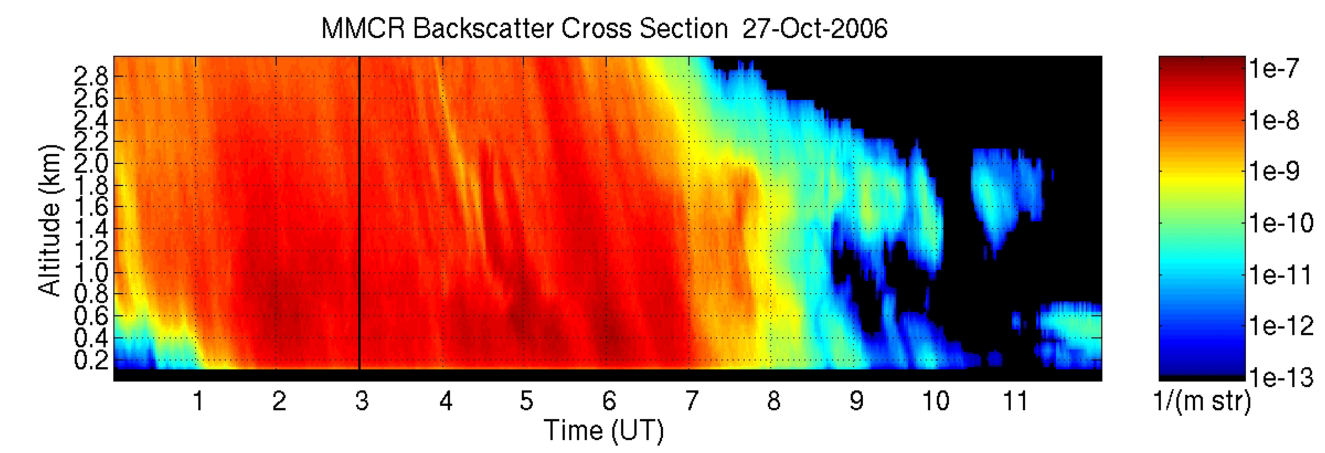


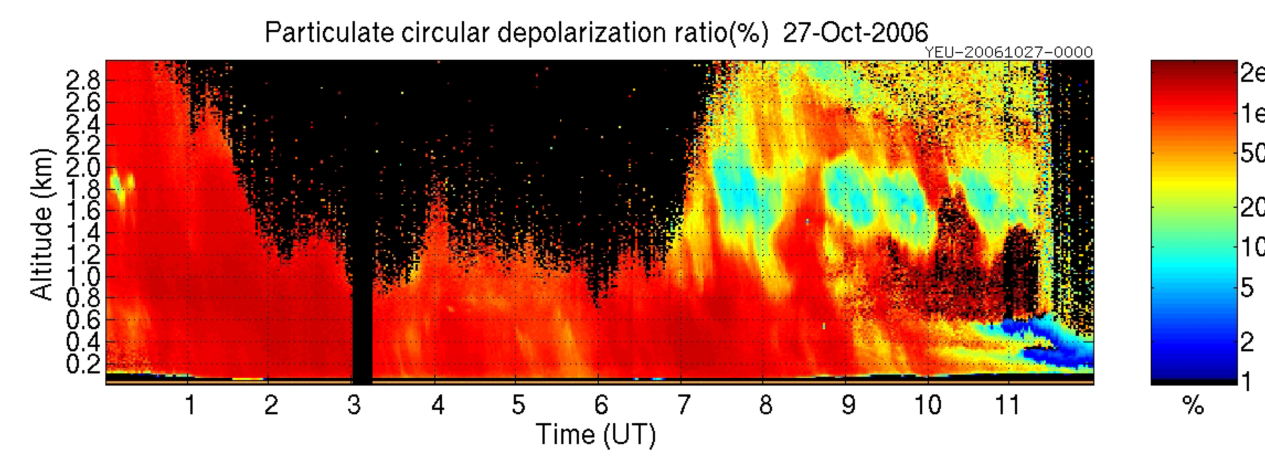
A comparison between Eureka weather station measurements of cumulative precipitation (red) and cumulative precipitation computed from the lidar-radar derived water content and the radar Doppler velocity for January 2006 at Eureka. This shows the sensitivity to the assumed particle shape

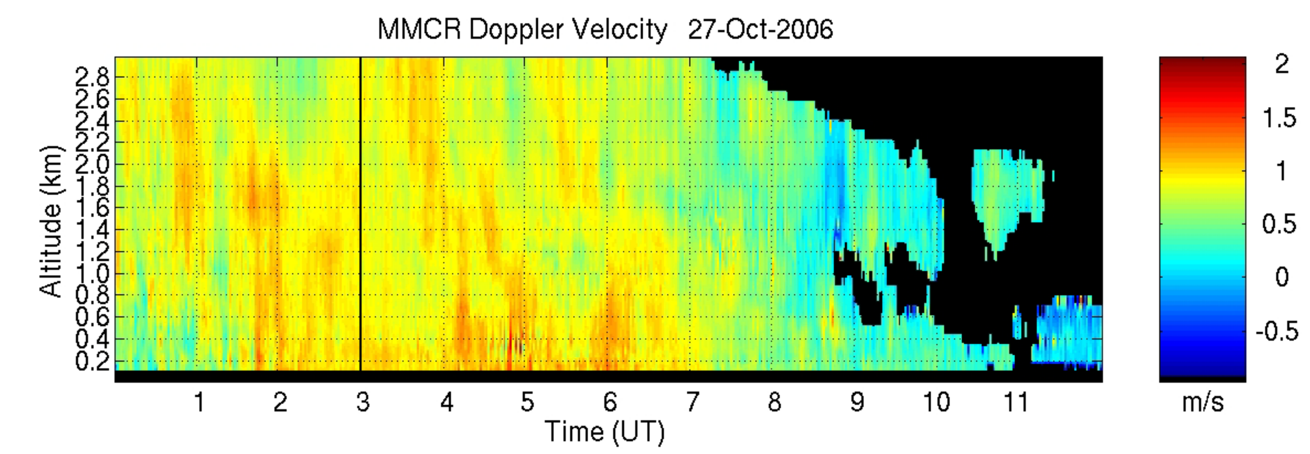


Can we use radar measured fall velocities as a function of the lidar-radar derived particle size to provide additional information on ice crystal shape? A look at data from 27-Oct-2006.

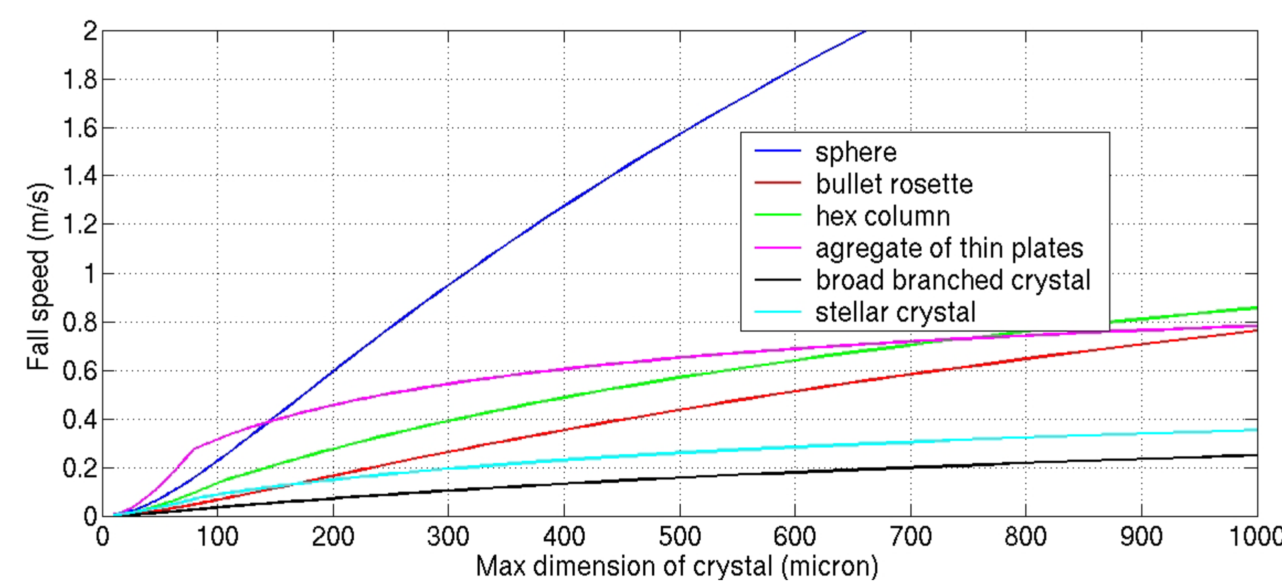




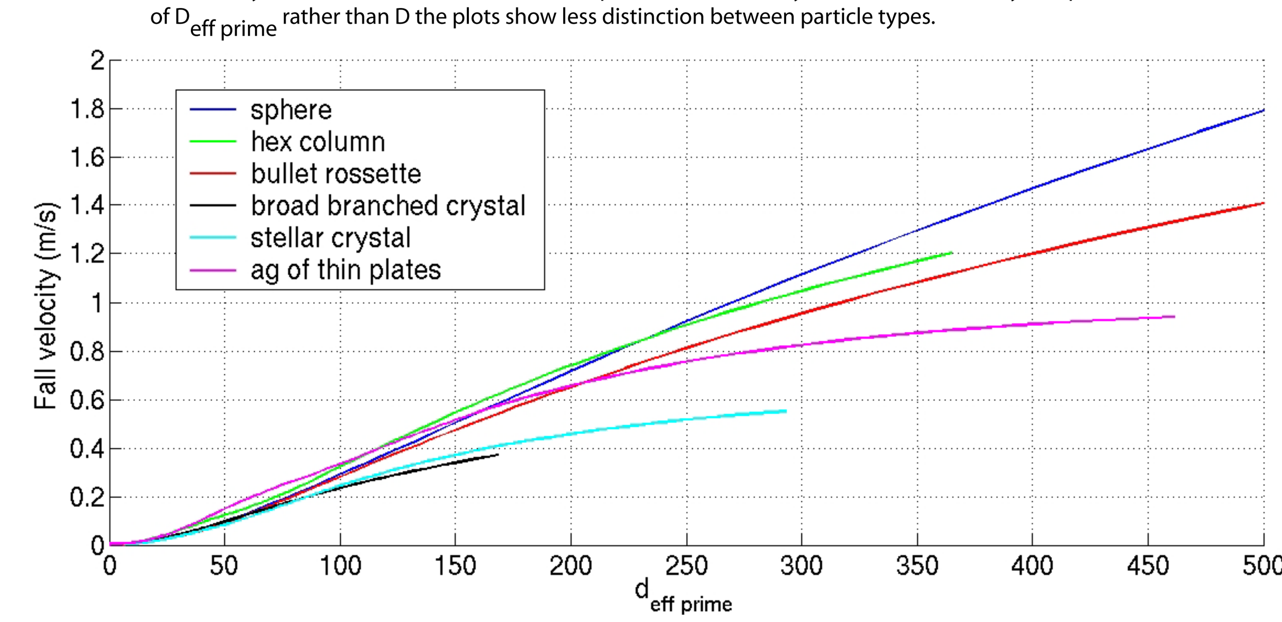




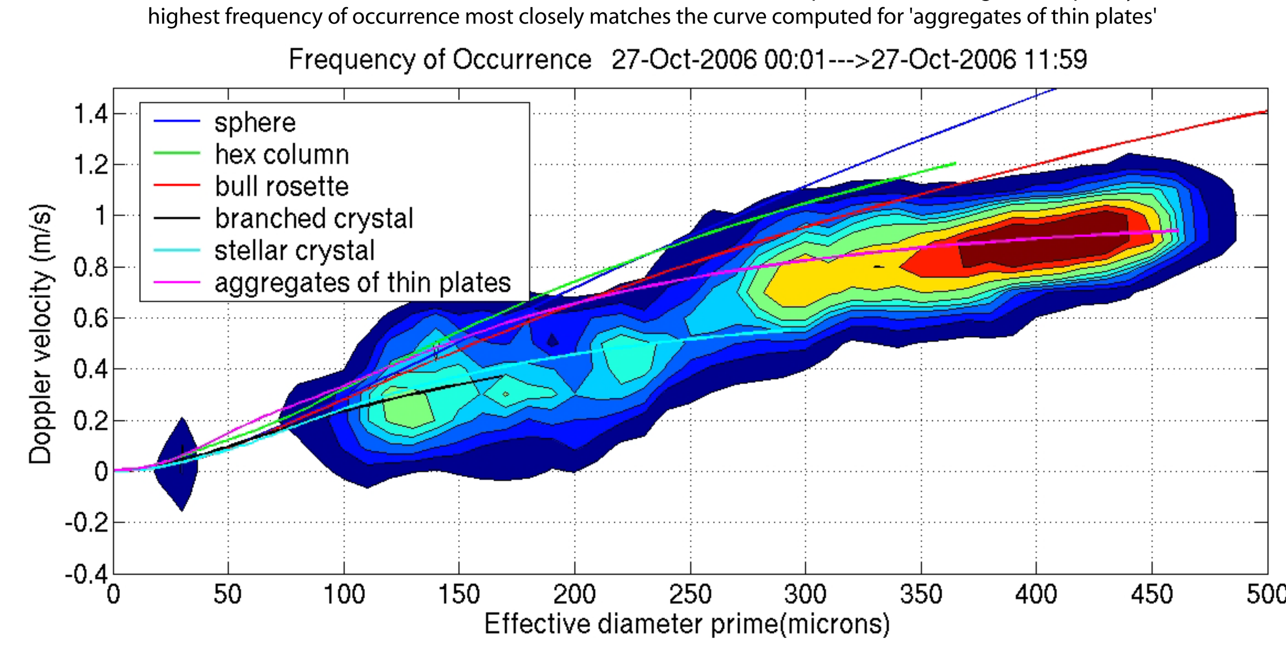
Fall velocity as a function of particle diameter with diameter defined along the longest axis.
Fall velocities computed following Mitchell and Heymsfield, JAS, V 62, 2005, p 1637.



Fall velocity as a function of effective diameter prime. Unfortunately, when the fall velocity is expressed in terms of $D_{eff\ prime}$ rather than D the plots show less distinction between particle types.



Doppler velocities as a function of effective diameter prime. Measurements represent 30 second time and 30 meter altitude averages. Contour levels are selected to enclose 90% of the points in the outside contour with 10% fewer points in each successive contour. Inner contour contains those 10% of the points with the highest frequency of occurrence. The highest frequency of occurrence most closely matches the curve computed for 'aggregates of thin plates'



Cumulative precipitation computed from the derived lidar-radar derived water content and the radar Doppler velocity measured at an altitude of 150 meters compared with station measurements of precipitation (red symbols).