Investigation of Ice Cloud Microphysical Properties of DCSs Using Aircraft in Situ Measurements

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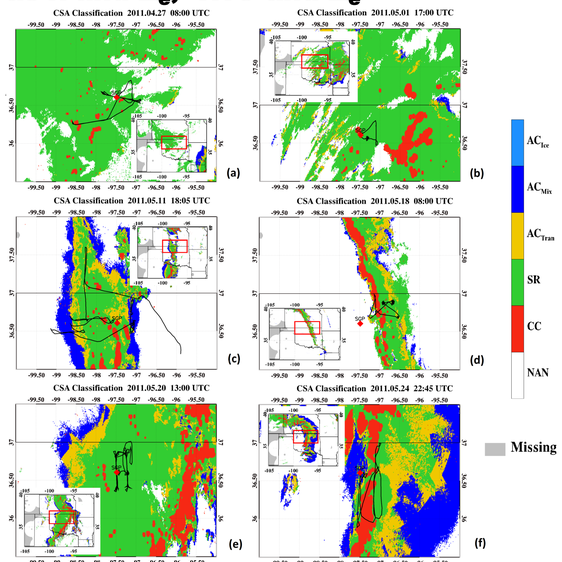
Data and results available for ARM/ASR

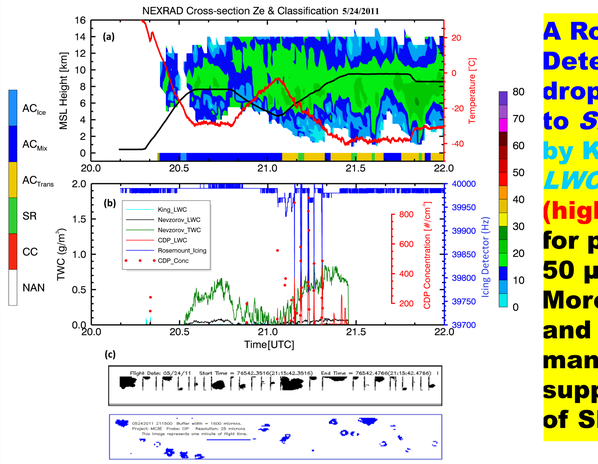
1. Correction of NEVZOROV TWC probe in IWC measurements
2. Gamma fitted ($N=N_0D^{\mu}e^{-\lambda D}$) parameters observed Particle Size Distribution (PSD)
3. Best-estimated ice cloud microphysical properties: IWC, Dm, Nc.
4. New empirical relationships for remote sensing, such as λ and Z_e, IWC and Z_e



6 selected DCS cases
04/27/2011
05/01/2011
05/11/2011
05/18/2011
05/20/2011
05/24/2011

Correction of NEVZOROV IWC measurement

Step 1. Using multi-sensor measurements to determine ice phase of a DCS

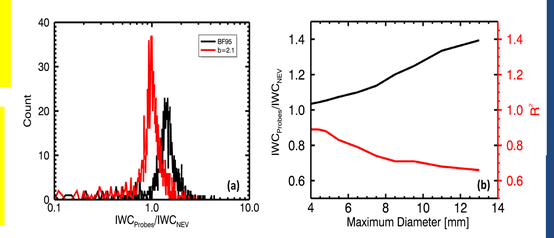


A Rosemount Icing Detector (RID, a sudden drop in frequency due to *SLWC* occurrence), by King Probe (high *LWC*), and CDP probe (high *LWC*), accounting for particles with *D* < 50 μm.
More than 16,000 2DC and CIP images were manually examined to support the detection of SLWC

Step 2. Determination of size threshold and exponent

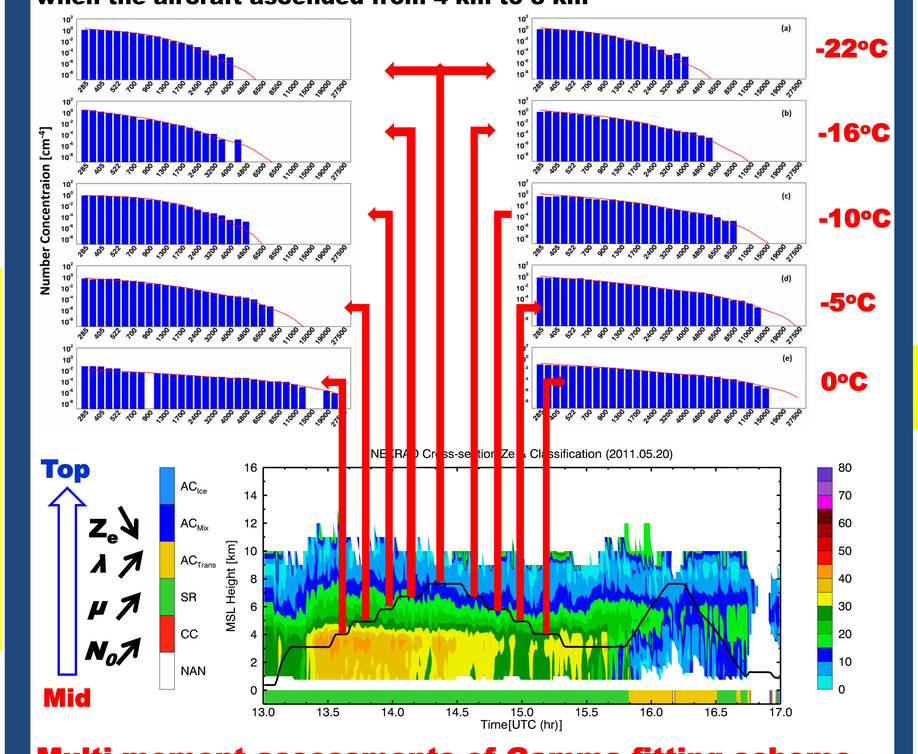
NEVZOROV deep cone is accurate when D < 4000 μm [Korolev, et al. 2013]

b=2.1 is the optimal exponent for mass-dimensional relationship [Heymsfield, et al. 2010]

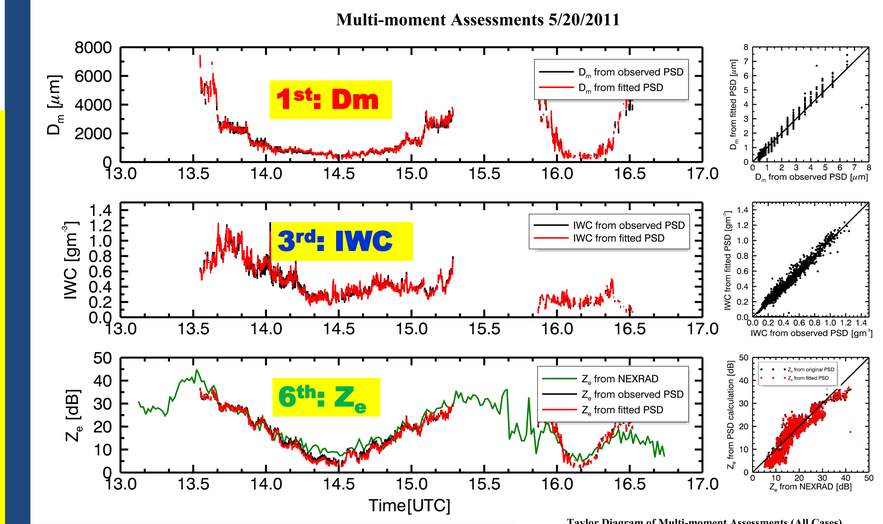


Gamma fitting to observed PSD

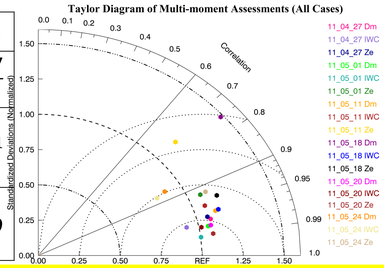
The maximum diameters decrease from 27,500 μm to 4,000 μm, whereas the total number concentrations increase about 100 times when the aircraft ascended from 4 km to 8 km



Multi-moment assessments of Gamma fitting scheme



Moments	Observed PSD	Gamma Para
1st: Dm	$\int_0^{D_m} n(D)aD^b = \frac{IWC}{2}$	$D_m = \frac{b+\mu+0.67}{\lambda}$
3rd: IWC	$IWC = \sum_{i=Dmin}^{i=Dmax} N_i \times 0.00365 \times D_i^{2.1}$	
6th: Z_e	$Z_e = \frac{\lambda'^4}{\pi^5\lvert K_w\rvert^2}\int_0^{\infty}\sigma(D)N(D)dD$	

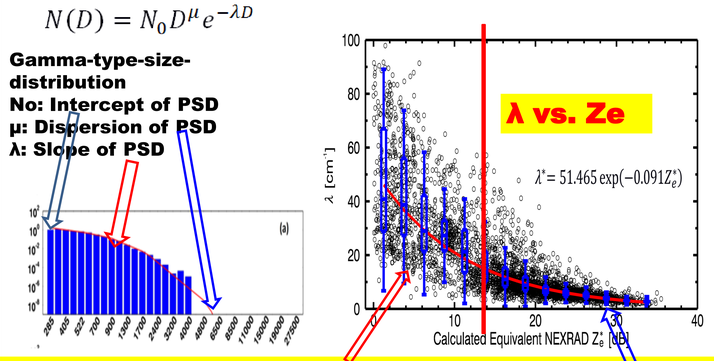


σ-D (σ=sD^t) relationships for different ice crystal habits were tested to calculate Z_e. Finally bullet-rosette showed the best performance and consistency in parameterization was achieved based on data provided by two separate research groups (Hong: s=1.02×10⁻⁹, t=4.6; Liu: s=1.66×10⁻⁹, t=4.6. D in mm)

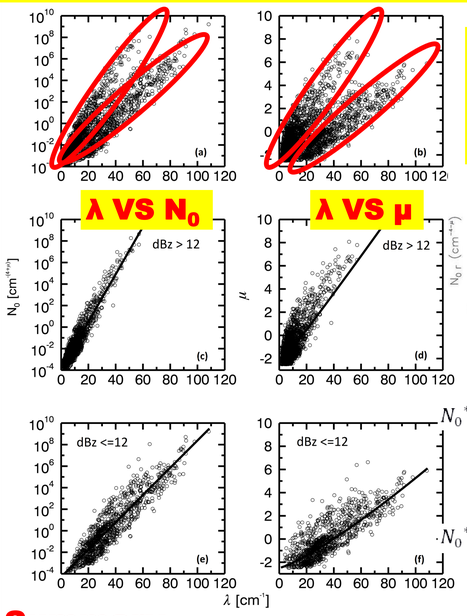
Empirical relationships between λ and Z_e, N_0 and λ, μ and λ, IWC and Z_e

$$N(D) = N_0 D^{\mu} e^{-\lambda D}$$

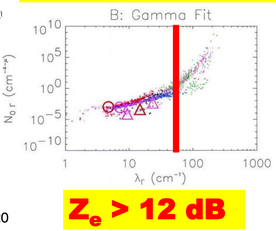
Gamma-type-size-distribution
No: Intercept of PSD
μ: Dispersion of PSD
λ: Slope of PSD



At upper layers of a DCS (0-12 dB), λ values vary from 50% to 200%. Around middle layers of a DCS (above 20 dB), the variation in λ is very small (within 10%).



Both λ-N_0 and λ-μ plots showed two trends with Z_e=12 dB as separation criterion, similar to [*Heymsfield et al.* 2002]



Z_e > 12 dB

$$N_0^* = 1.187 \times 10^{-4} \exp(0.508\lambda)$$
$$\mu^* = (0.131\lambda^{1.042}) - 2.5$$

Z_e ≤ 12 dB

$$N_0^* = 5.131 \times 10^{-5} \exp(0.292\lambda)$$
$$\mu^* = (0.028\lambda^{1.225}) - 2.5$$

Summary

1) Multi-sensor detection has been adopted to eliminate the super-cooled liquid water (SLW) in the ice dominated cloud layers of DCSs
2) Based on the conclusions of *Heymsfield et al.* [2010] and *Korolev et al.* [2013], the MC3E mass-dimensional relationship was developed: a=0.00365, b=2.1.
3) Gamma fitting to observed PSDs was carried out, and the accuracy of fitted parameters is guaranteed by multi-moment assessments (1st: D_m, 3rd: IWC, 6th: Z_e).
4) Empirical relationships were established for λ-Z_e, N_0-λ, and μ- λ. The transition happened at 12 dB indicates changes in microphysical processes, which has been noticed by *Heymsfield et al.* [2002], *McFarquhar et al.* [2007] and *Smith et al.* [2009].

Future Work: Better parameterizations taking into account the large variability in different habits to calculate Z_e.

Reference: Wang J., X. Dong, and B. Xi (2015), Investigation of Ice Cloud Microphysical Properties of DCSs Using Aircraft in Situ Measurements, J. Geophys. Res., under revision

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