Horizontal and Vertical Profiles of In-Situ Cloud Properties Measured During Tropical Warm Pool International Cloud Experiment

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Introduction

In-situ measurements of ice particle sizes, shapes and numbers were made in fresh anvils, aging anvils and in generic cirrus during TWP-ICE. The vertical profiles and horizontal profiles performed by the Scaled Composites Proteus aircraft were made on 7 different days as illustrated in Table 1.

Table 1. Summary of flights conducted during TWP-ICE; *designates that spiral was conducted over Darwin, %spiral over ship; &designates constant altitude legs conducted in thin dissipating cirrus over ship at end of flight.

Date	Time (UTC)	Location	Situation
Jan. 25	0345 to 0700 UTC	(13.0, 130.0) to (12.19, 131.25) at 12.5, 14 and 17 km	Horizontal legs through aging anvils in absence of active convection*
Jan. 27	0510 to 0926 UTC	(12.44, 130.39) to (12.40, 131.93) at 12, 13, 14 & 15 km	Horizontal E-W legs through aged cirrus of varying lifetimes*
Jan. 29	0530 to 0945 UTC	(12.40, 130.89) to (15.5, 131.0) and shorter NE-SW lines at 11, 12, 13 & 15 km	Transition of anvil cirrus to more generic cirrus; N-S legs to look at cirrus bands of varying age (1-4 hours)*
Feb. 2	0130 to 0700 UTC	From 14 to 8 km at (11.55, 131.36) & at (11.43, 131.53)	Spirals through fresh/aged anvils behind convective line over Tiwi Islands*,&

Table 1. (contd)			
Feb. 6	0530 to 0830 UTC	From 11 to 15 km at (11.2, 130.8)	Spiral in fresh anvil over Tiwi Island
Feb. 10	0600 to 1030 UTC	EW line from 11 to 16 km (11.75, 130.0) to (11.75, 131.0)	Sampling Hector anvil over Tiwi Islands
Feb. 12	0530 to 1000 UTC	NE-SW line at 12, 13 &14 km (12.3, 130.8) to (12.8, 130.4)	Sampling fresh in-land anvil SW of Darwin*,%

Instrumentation

The Proteus was equipped with the ARM UAV suite of microphysical probes for TWP-ICE which includes the instruments listed in Table 2. Not all of the probes worked on all of the flights.

Table 2. In-situ microphysical probes from ARM UAV payload installed on Proteus for TWP-ICE measuring size distributions (SDs), ice water content (IWC), total water content (TWC) and extinction coefficient (β_e).

Instrument	Size Range	Parameters	Description
Cloud Particle Imager (CPI)	10 μm to ~ 1 mm	2.3 μm res images, SDs	Small sample volume
Cloud Aerosol Spectrometer (CAS)	0.35 to 50 μm	SDs	Forward scattering probe: enhanced small crystals?
Cloud Droplet Probe (CDP)	1 to 50 μm	SDs	Forward scattering probe: open path
Cloud Imaging Probe (CIP)	100 μm to 1.6 mm	SDs; two-d images	Shadowing of photodiodes
Counterflow virtual impactor (CVI)	Bulk measurement from >~ 5 μm	IWC	Evaporator probe
Nevzorov Probe	Bulk measurement	LWC, TWC	Hot wire probe
Cloud Integrating Nephelometer (CIN)	Bulk measurement	$\beta_{e,}$, asymmetry parameter	Light scattered by cloud particles

Horizontal Profiles

On several days the Proteus measured how the microphysical properties of cirrus bands varied according to band age or according to distance away from the convective tower or its remnants. Several such legs show how the properties vary with height and time after tower formation. Figures 1, 2 and 3 below show how the cirrus properties varied on a N-S line flown at 11 km on January 29, where younger cirrus was typically at the southern end of the band.

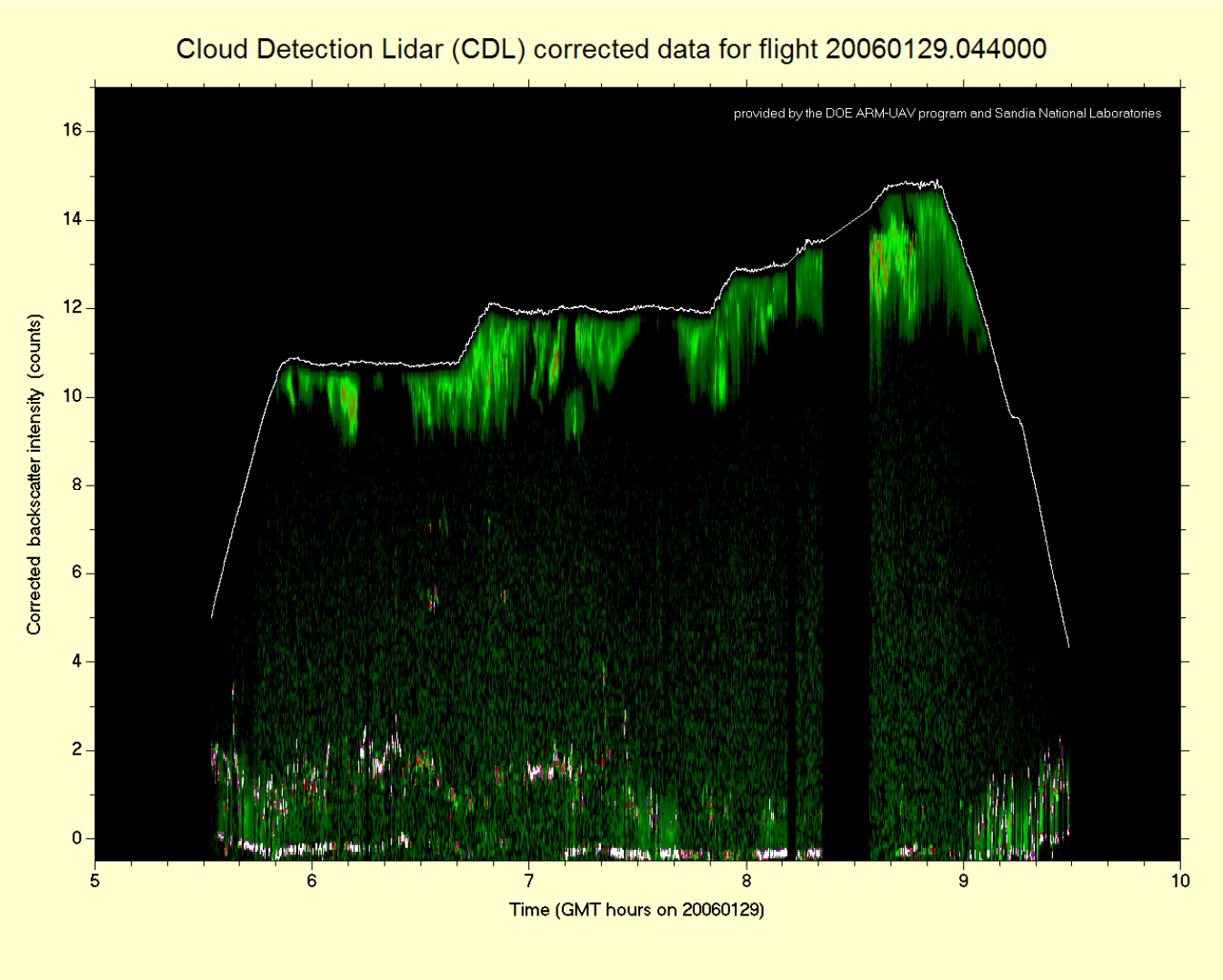

Figure 1. Uncorrected backscatter measured by ARM UAV lidar January 29; red arrows illustrate start and end of N-S line highlighted below to examine aging of cirrus bands.

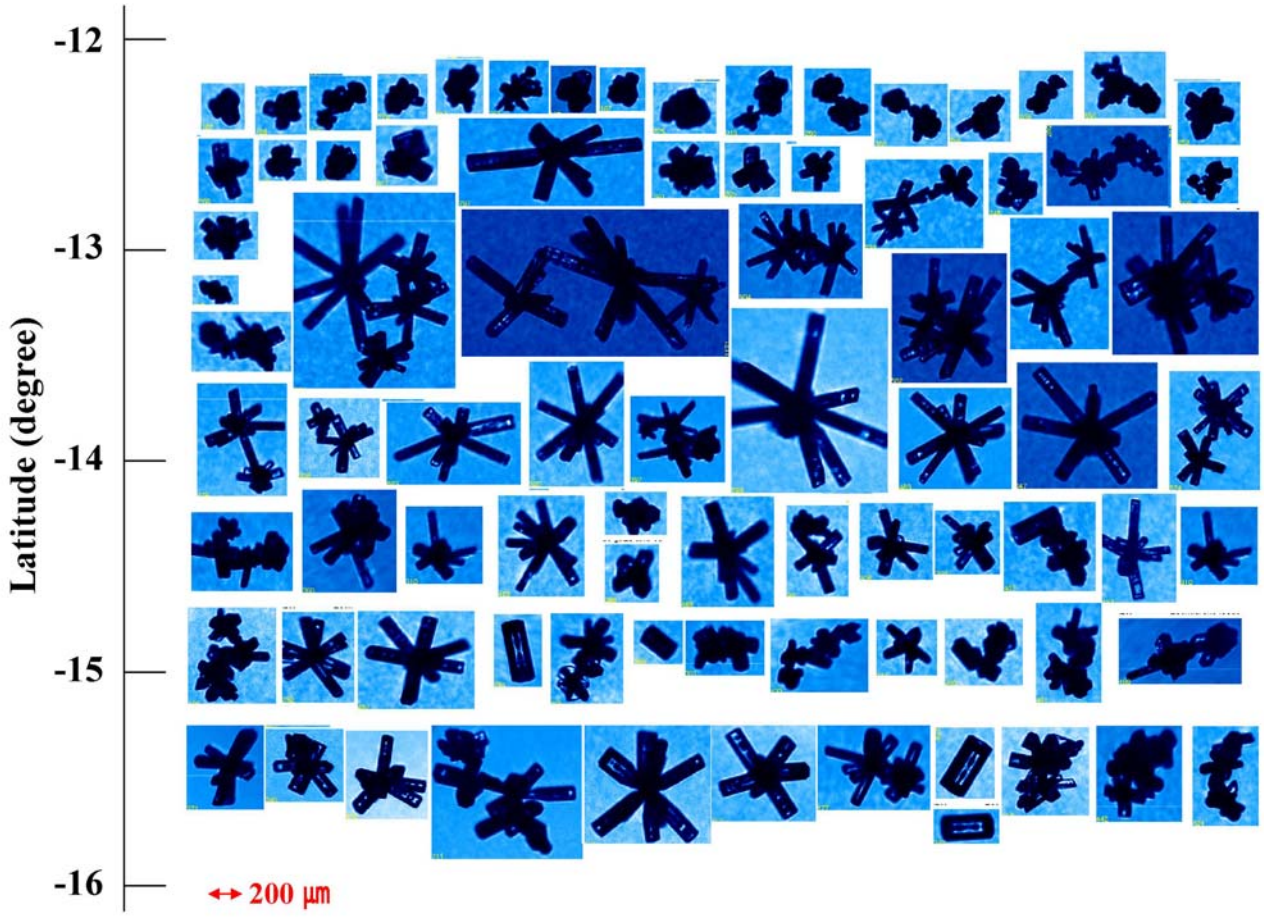

Figure 2. Selected CPI images on N-S run highlighted in Figure 1 as function of latitude; dominance of bullet rosettes and aggregates of bullet rosettes is seen.

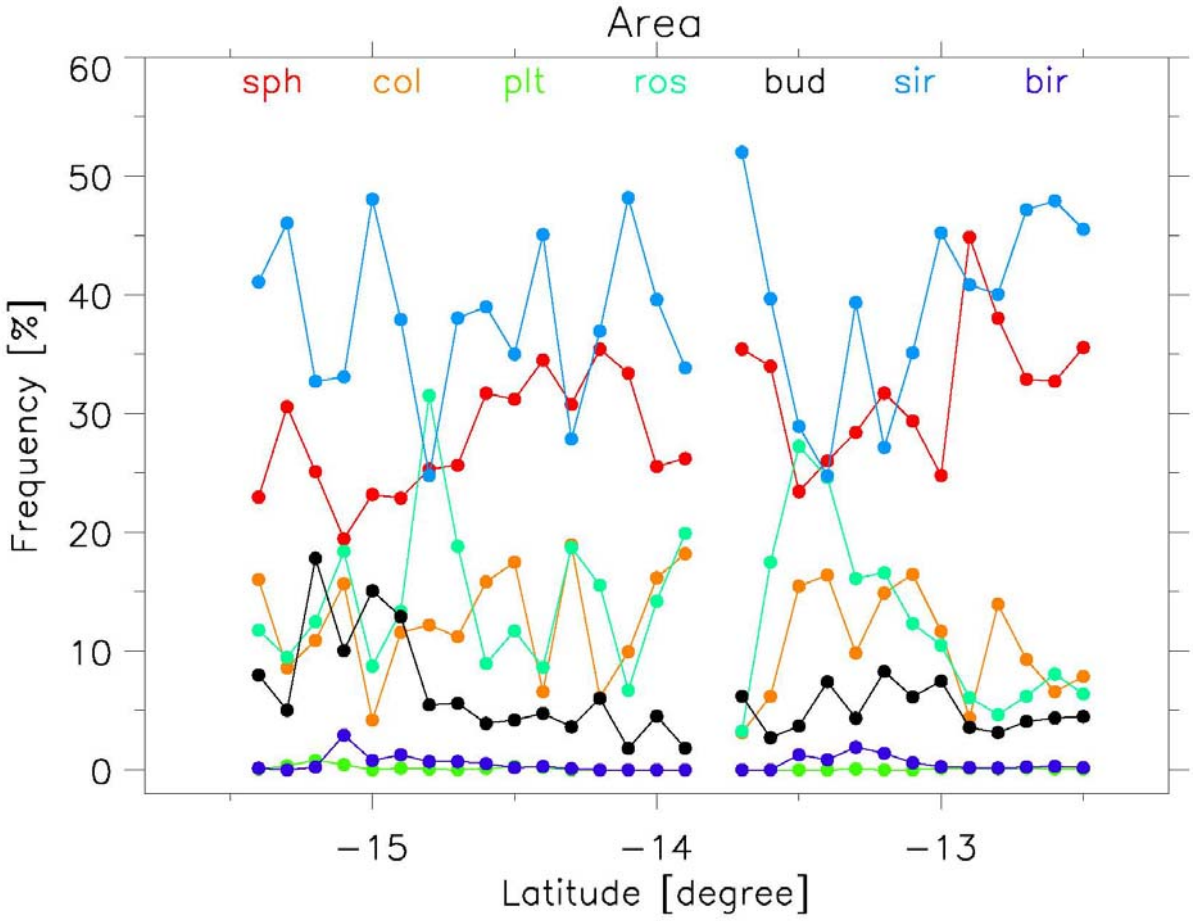

Figure 3. Contribution of different habit classes to projected area for N-S leg on January 29; quasi-spheres (sph) and small irregular (sir) particles contributions mainly due to particles smaller than 100 μm; bullet rosettes (ros) dominate the larger particles.

Vertical Profiles

In addition to the horizontal profiles discussed in Section 3, the Proteus also made several vertical profiles through cirrus during TWP-ICE. These vertical profiles were typically made by flying spiral ascents or descents through cirrus. One particularly interesting case was flown on February 2 where the Proteus flew several spirals through an anvil generated off of the Tiwi Islands. These profiles allow an investigation of how the properties of the anvil change with its age.

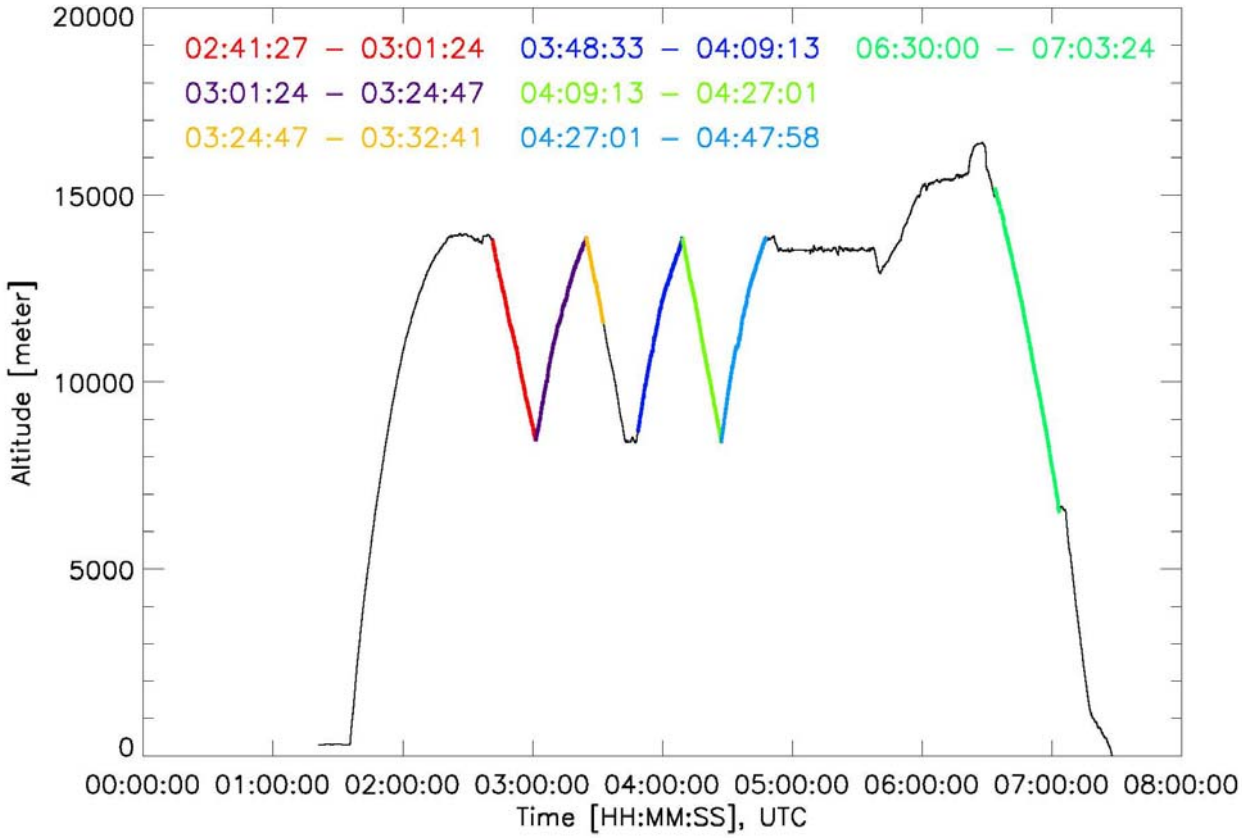

Figure 4. Profile for February 2 flight, where several ascents/descents flown through fresh anvil generated off Tiwi Islands.

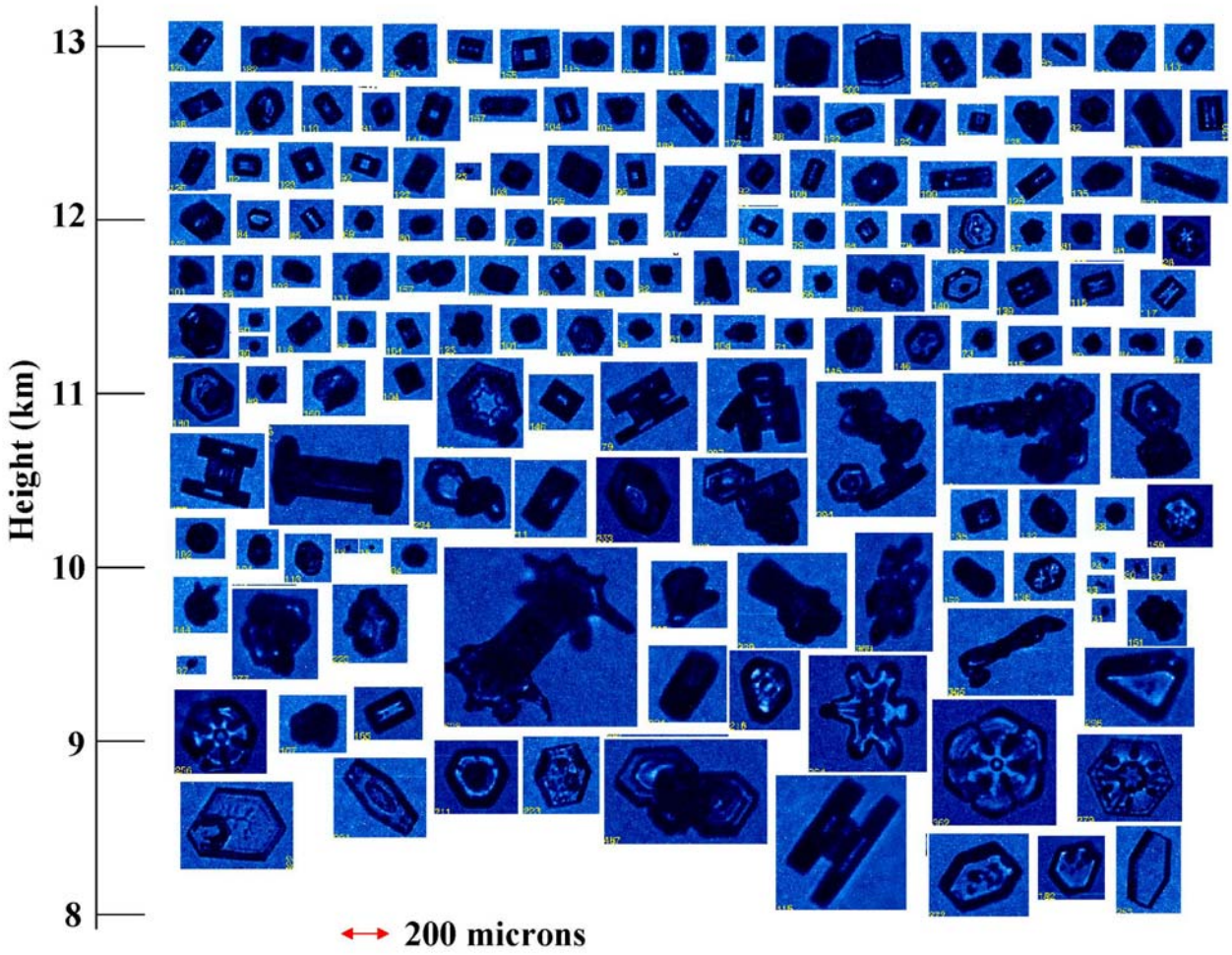

Figure 5. Vertical profile of CPI images collected during spiral indicated by red line in Figure 4. Notable is the absence of bullet rosettes compared to January 29 flight. These measurements were collected in fresher anvils compared to the January 29 case.

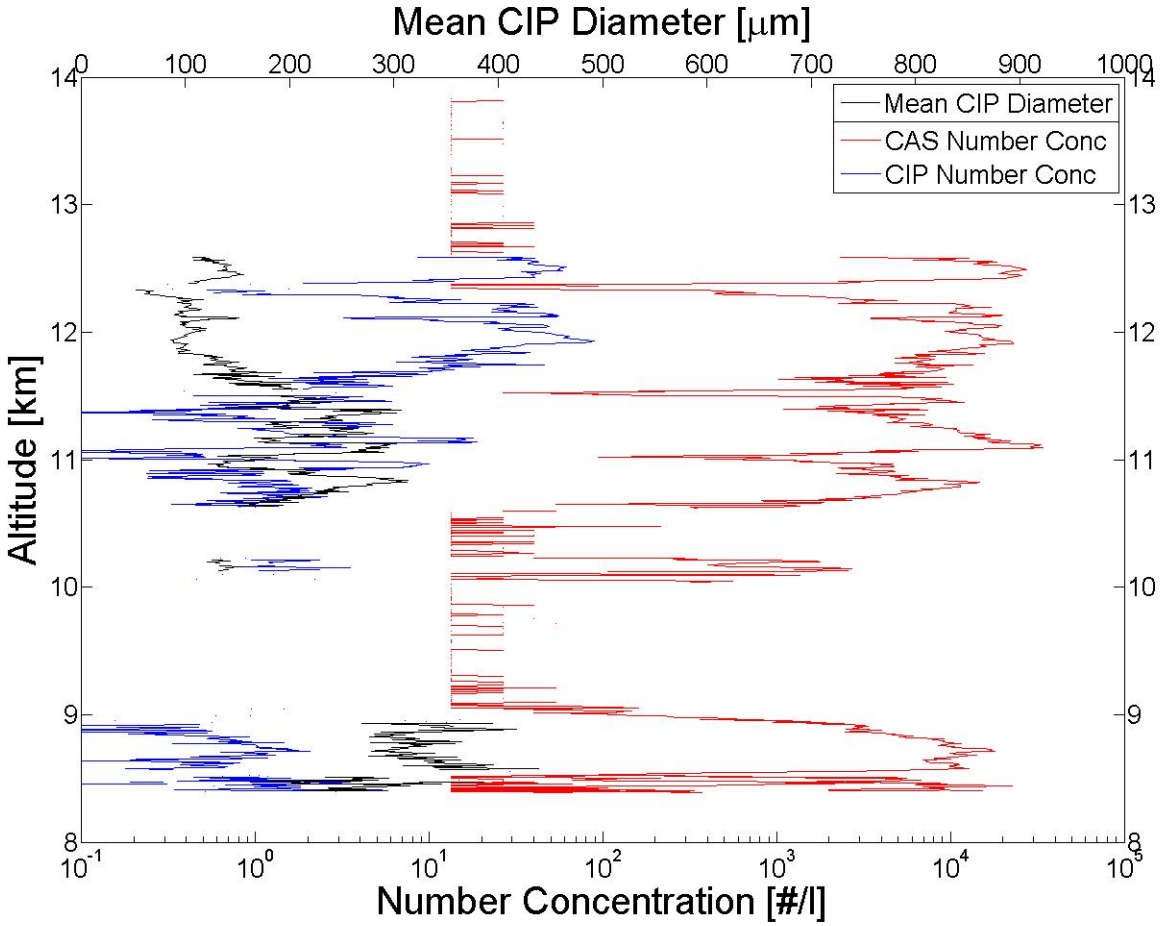

Figure 6. Total number concentration from CAS and CIP for spiral depicted in Figure 5. Decrease of large crystal concentration (CIP) and increase in mean particle size suggests aggregation is occurring. Note the large number of small crystals measured by CAS.

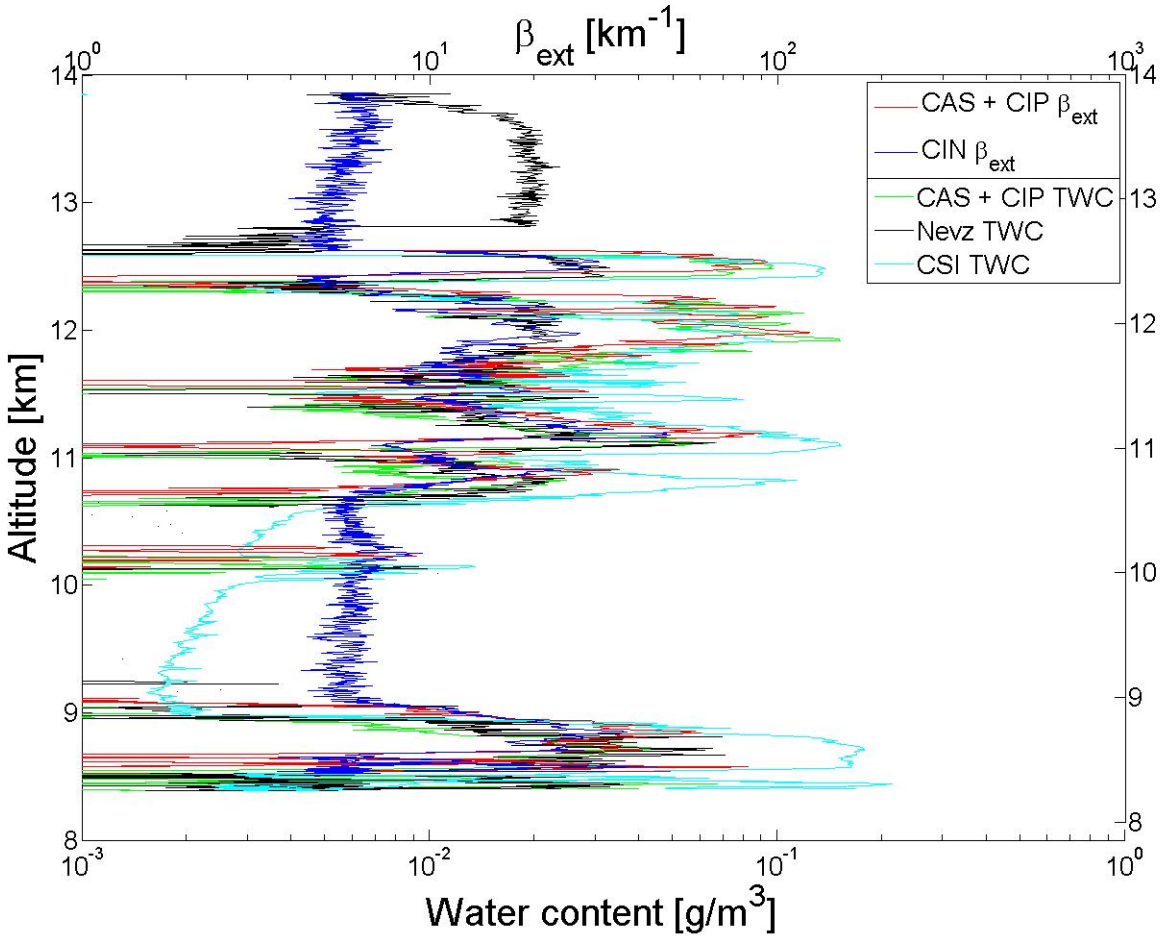

Figure 7. IWC measured by CSI and Nevzorov, β_e measured by CIN combined with IWC and β_e derived from the CAS and CIP SDs. These data can be used to show vertical structure of cloud; Nevzorov probe seems to underestimate IWC.

Conclusions

The TWP-ICE microphysical data collected by the Proteus offer a wealth of data to describe the properties of cirrus anvils at a variety of growth stages. In the coming years, these data will also be combined with modeling and remote studies during the TWP-ICE time periods to better understand the impacts of cirrus on radiative fluxes and to determine how the cirrus properties are related to the properties of the convection.

Acknowledgments

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