Investigation of warm rain during HIWC-2022 TCu runs

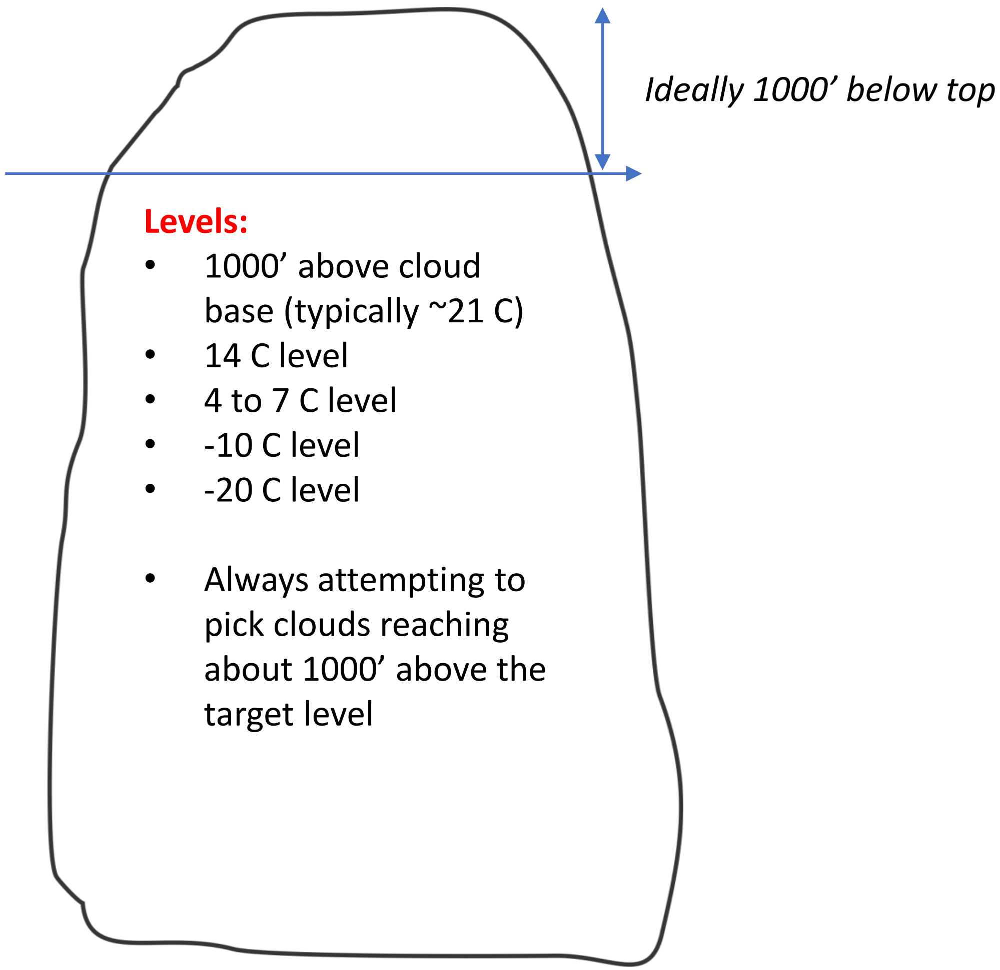
Prepared by J. W. Strapp

For HIWC-2022 Boulder workshop, 29-30 Nov. 2023

Objective

- quantify the amount of warm rain in HIWC-2022 clouds by computing the PSDs and rainfall rates
- Is the warm rain significant enough to potentially deplete TWC rising in the cloud?

Reminder of Inventory



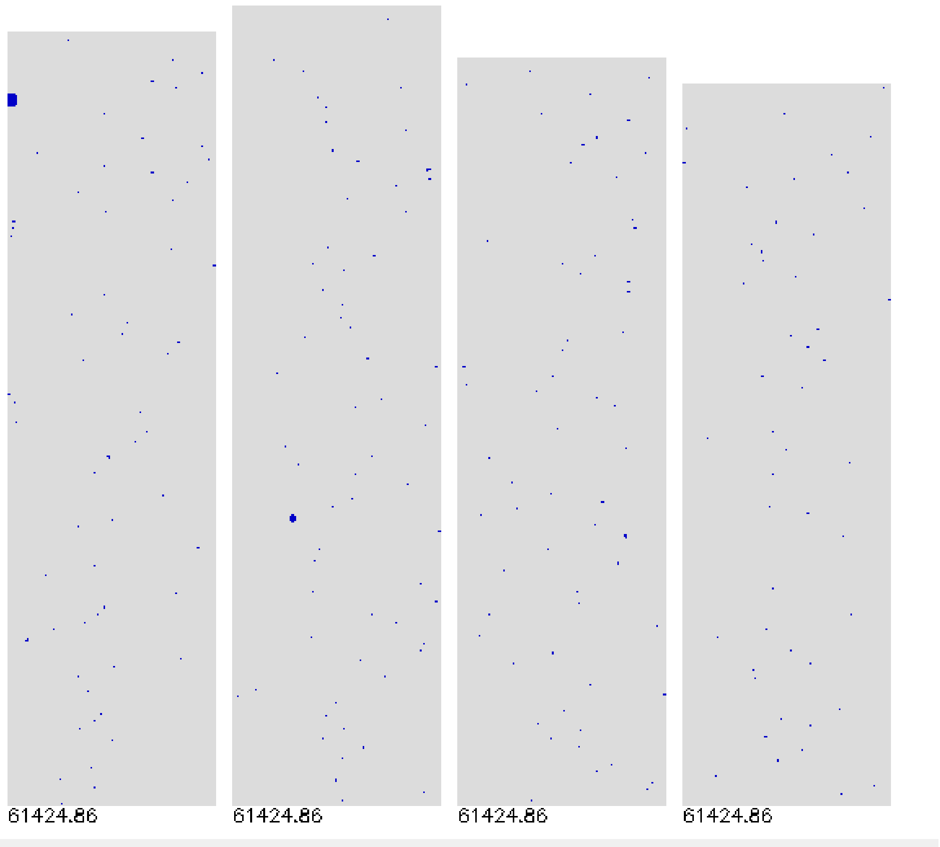
Inventory of HIWC-2022 TCu runs

		Above-Base ~ +21 C		Below FZ1 ~ +14 C		Below FZ2 ~+4 to +7 C		Above FZ1 ~ -9 C		Above FZ2 ~ -19 C	
Flight	date	good runs	SATav	nruns	SATav	good runs	SATav	nruns	SATav	good runs	SATav
3	8-Jul-22	0	23.7								
4	10-Jul-22	5	22.7					4	-8.5	0	-19.1
5	14-Jul-22	3	23.0								
6	16-Jul-22										
7	18-Jul-22										
8	22-Jul-22	2	20.6								
9	24-Jul-22	4	20.9			2	4.7	5	-9.4	4	-18.1
10	26-Jul-22	0	20.9	5	13.7	4	4.1	5	-9.6	6	-19.8
11	27-Jul-22	3	21.3			5	7.0	5	-8.0		
12	**30-Jul-22**	**5**	21.6	**3**	14.5			**5**	-9.9	3	-18.4
	totals	**22**		**8**		**11**		**25**		**13**	
	Total runs	78									

Case study 30-Jul-2022, cloud base run

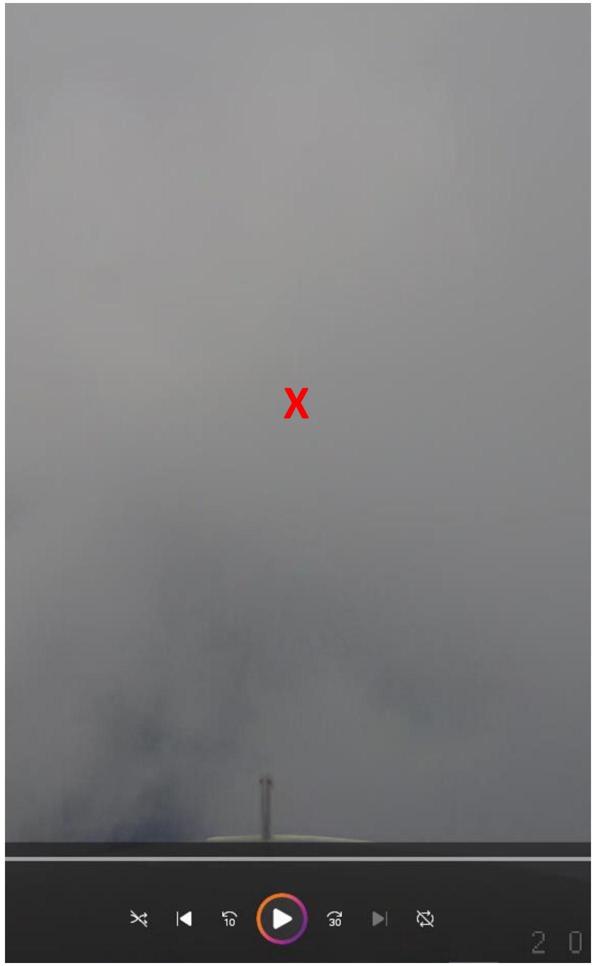
Case study 30-Jul-2022, Cloud base (highest CDPmax of 715 cm^{-3})

2D-S V



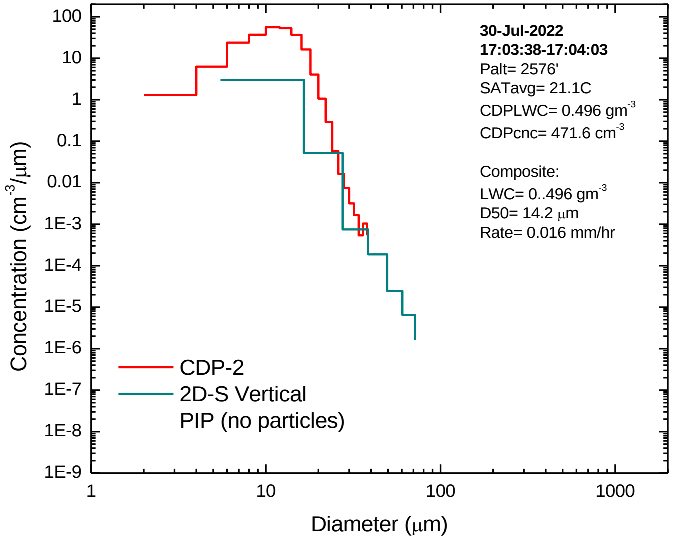
PIP

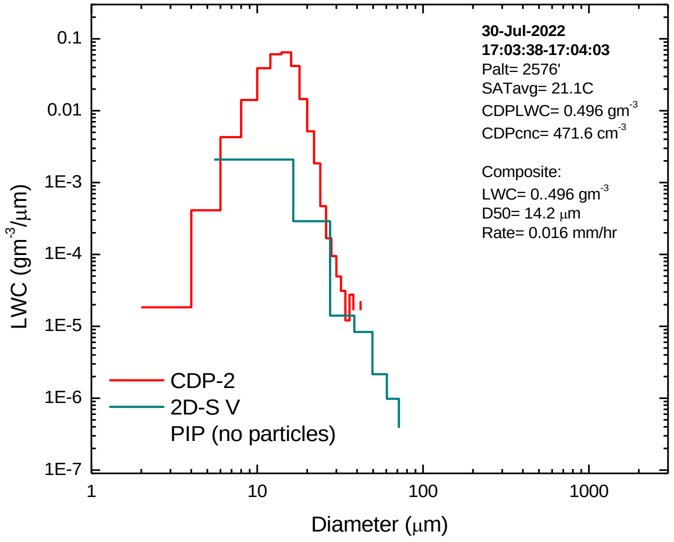
NO PIP IMAGES
DIODE VOLTAGES OK

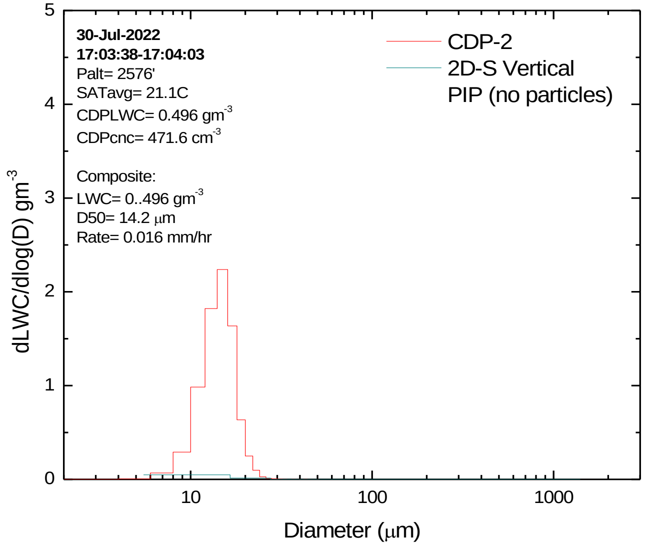


17:03:38-17:04:03

Case study 30-Jul-2022, Cloud base

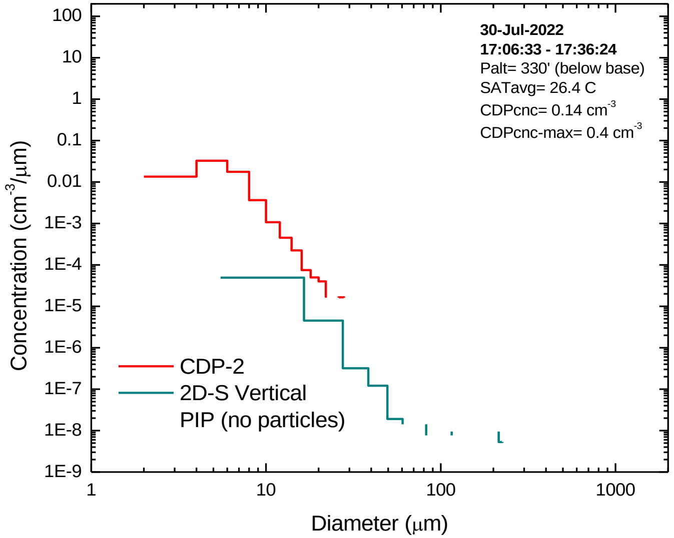






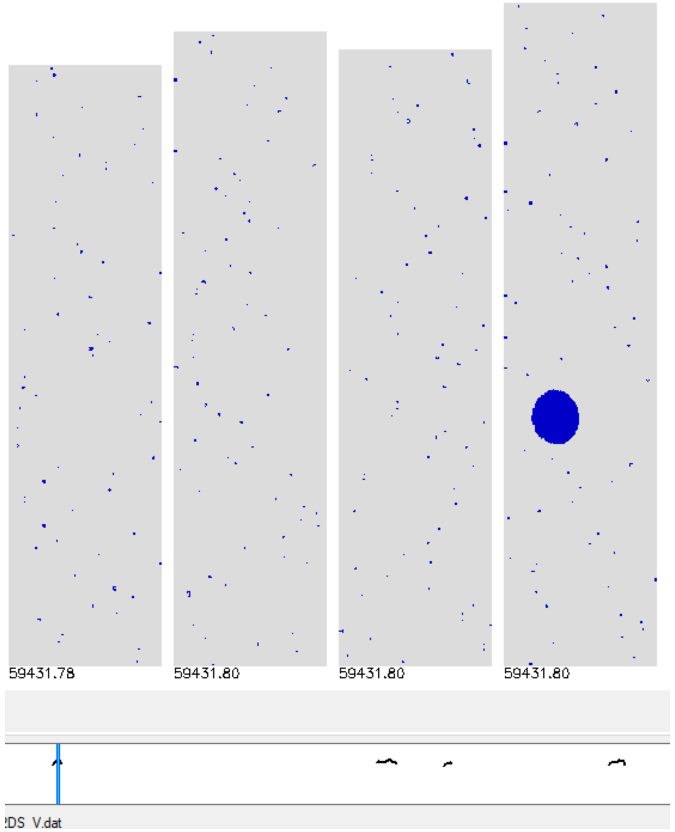
- Coalescence embryos to ~77 μm
- Negligible LWC above 50 μm
- Rainfall rate ~= 0.016 mm/hr
- PSD TWCav = 0.50 gm^{-3}
- ICDTWCav = 0.59 gm^{-3}
- IKP TWC not accurate (background WV = ~ 13 gm^{-3})

BELOW BASE



Case study 30-Jul-2022, +14.6 C

2D-S V



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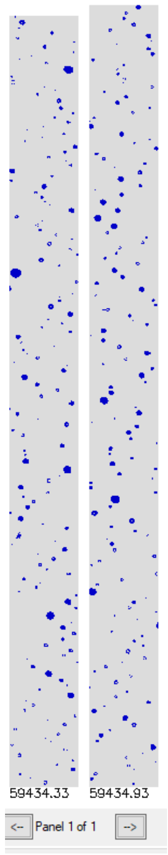
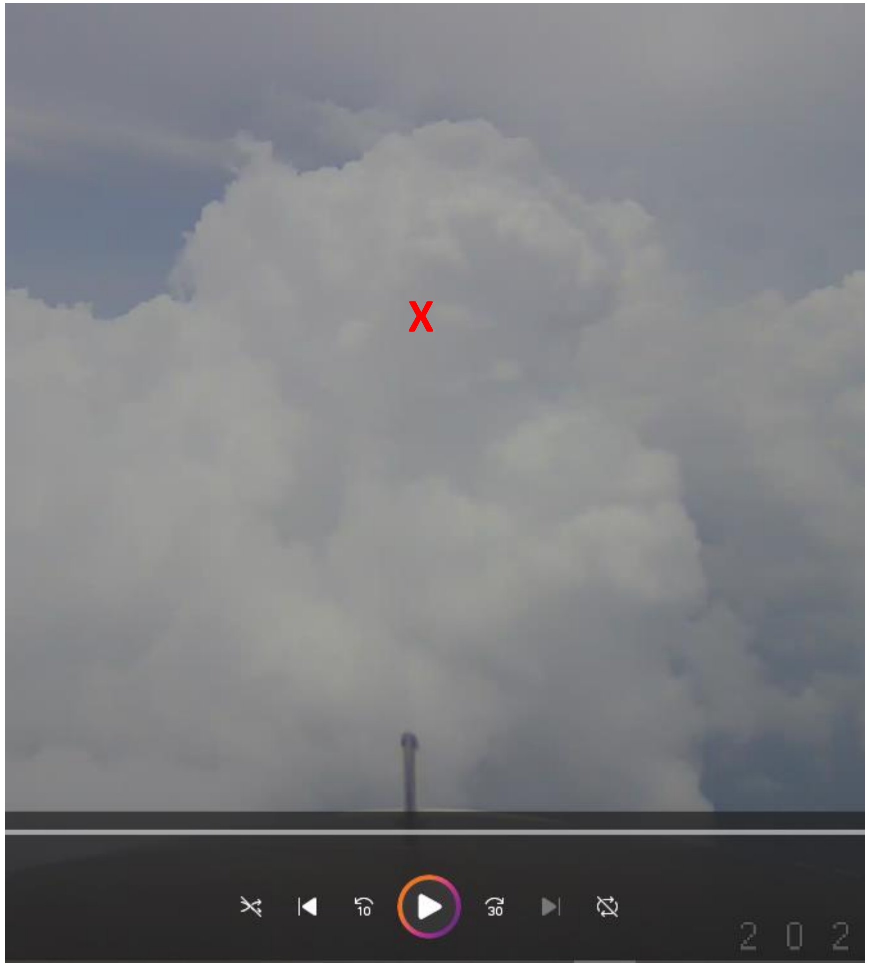
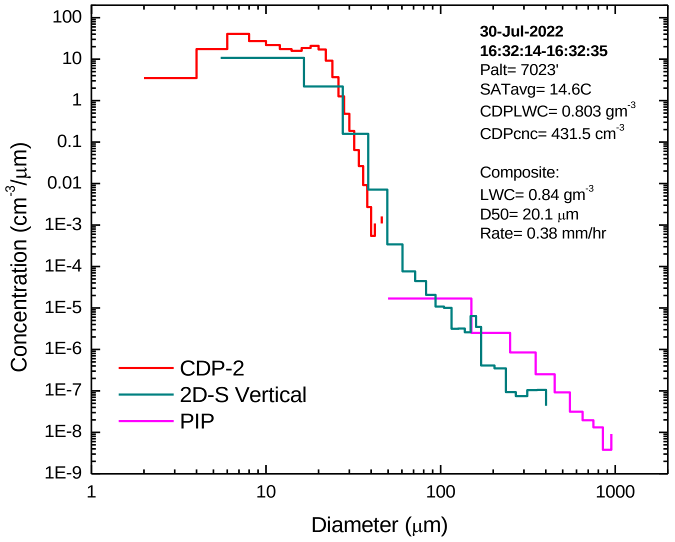
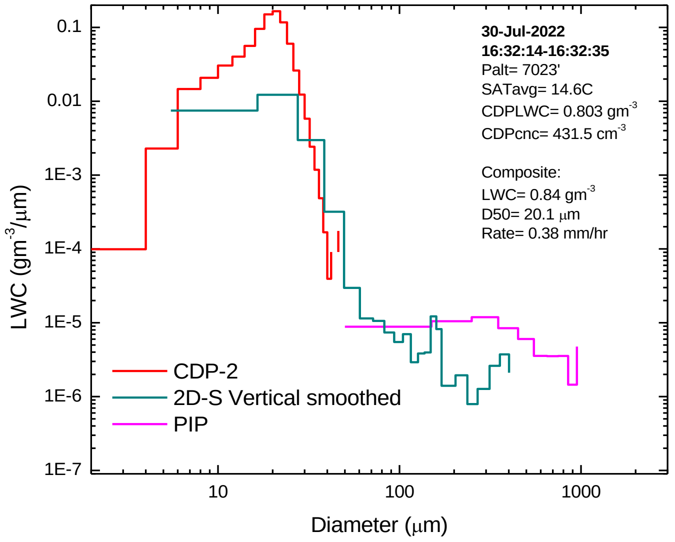
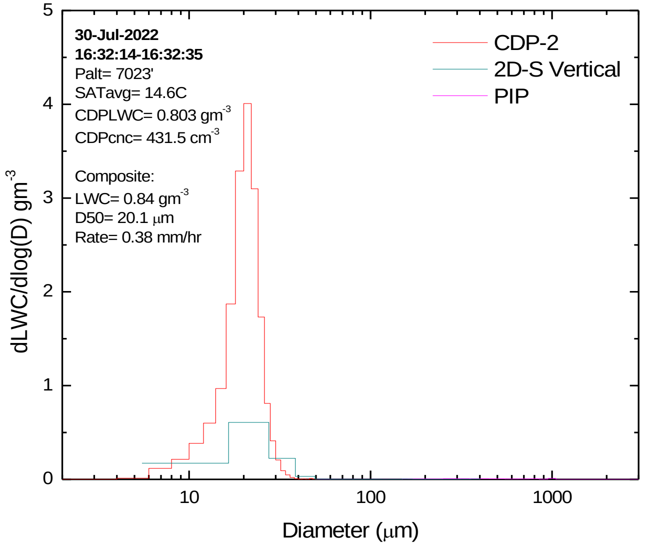




Case study 30-Jul-2022, +14.6 C



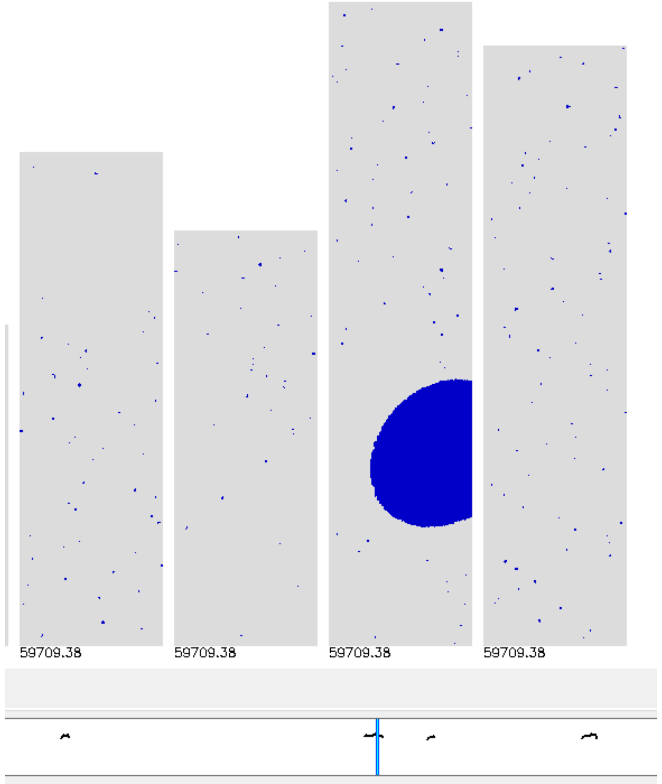


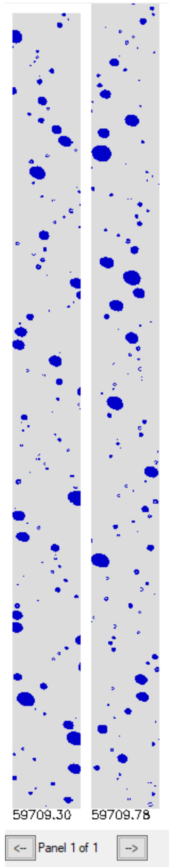


- Spectrum tail developing
- Only about 0.04 gm-3 above 50 µm
- Rainfall rate ~= 0.38 mm/hr
- PSD TWCav = 0.84 gm^{-3}
- ICDTWCav= 1.01 gm^{-3}
- IKP TWC not accurate (background WV = ~ 13 gm^{-3})

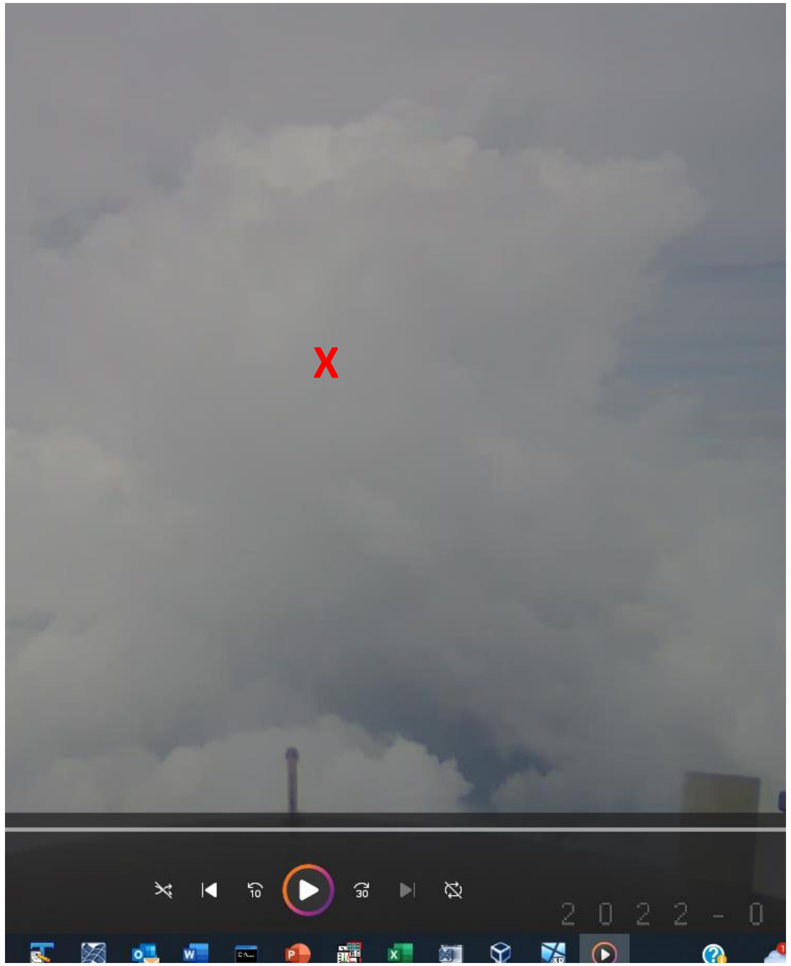
Case study 30-Jul-2022, +14.6 C (2nd example)

2D-S V



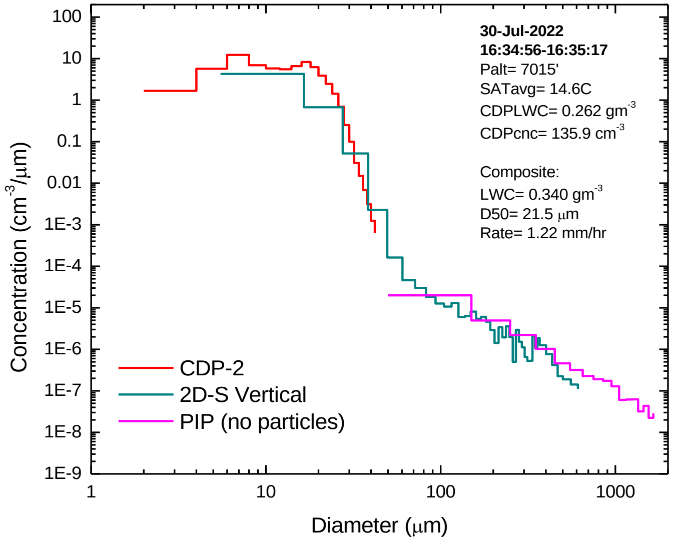


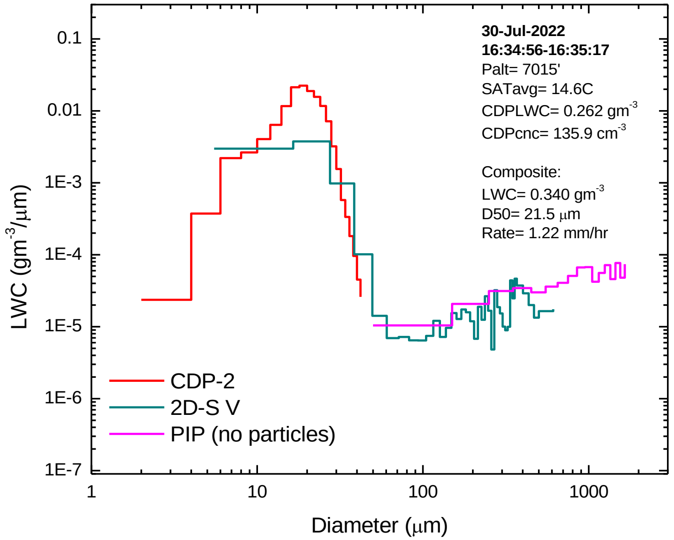
PIP

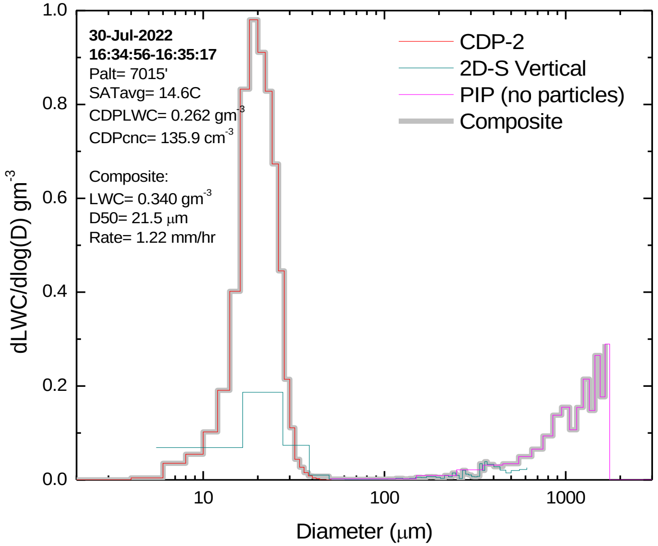


16:34:56-16:35:17

Case study 30-Jul-2022, +14.6 C (2nd example)



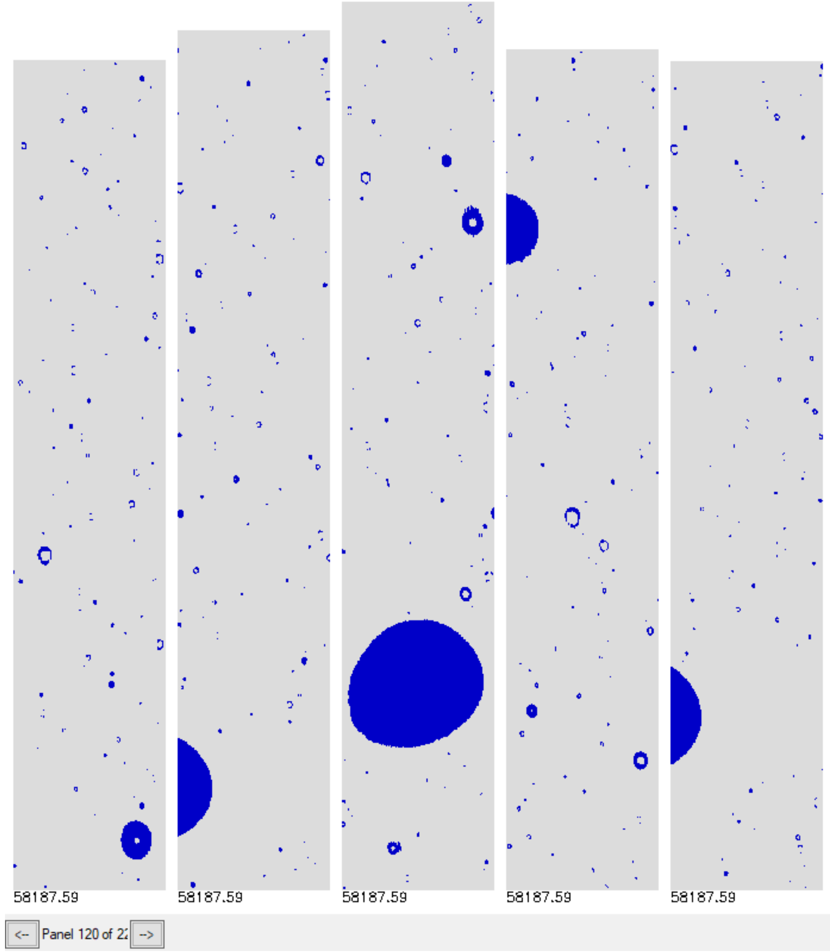




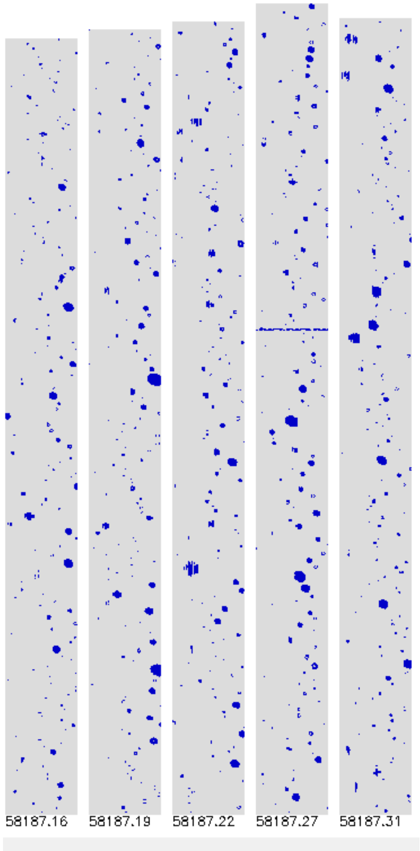
- Messy looking cloud, could be collapsing top
- Spectrum tail developing, more than previous example
- Strange PIP cutoff at 1.7 mm
- About 0.18 gm-3 above 50 µm
- Rainfall rate ~= 1.22 mm/hr
- PSDTWCav= 0.34 gm^{-3}
- ICDTWCav = 0.37 gm^{-3}
- IKP TWC not accurate (background WV = ~ 12 gm^{-3})

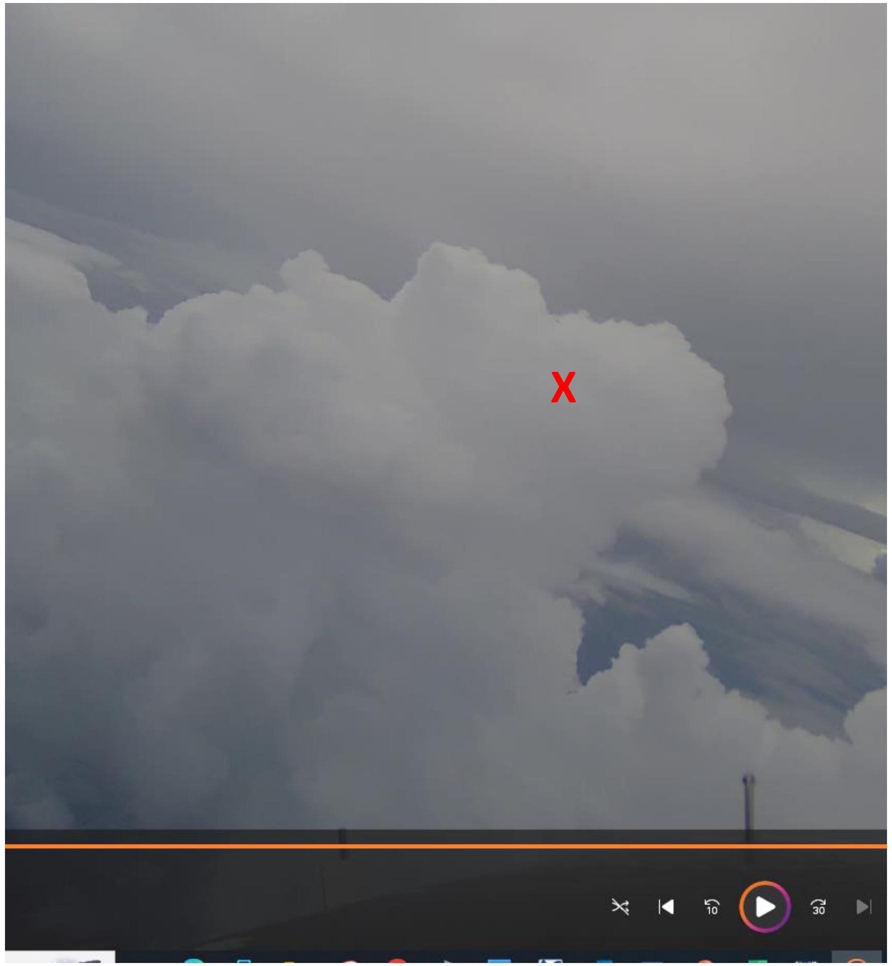
Case study 30-Jul-2022, -9.0 C

2D-S V



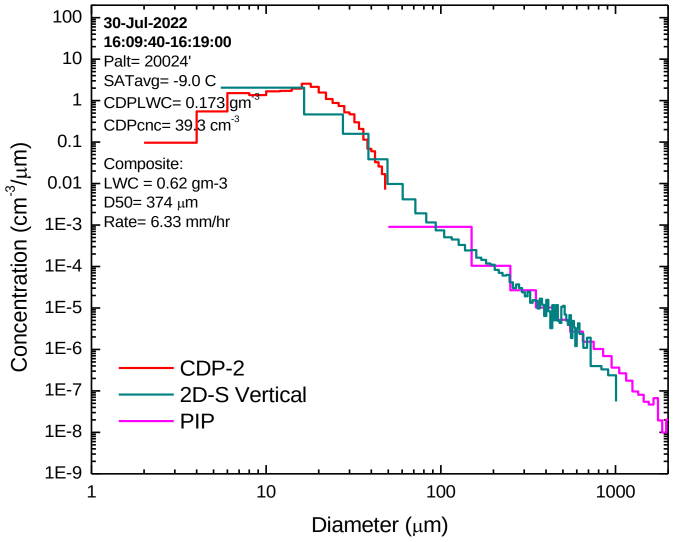
PIP
(some poor data)

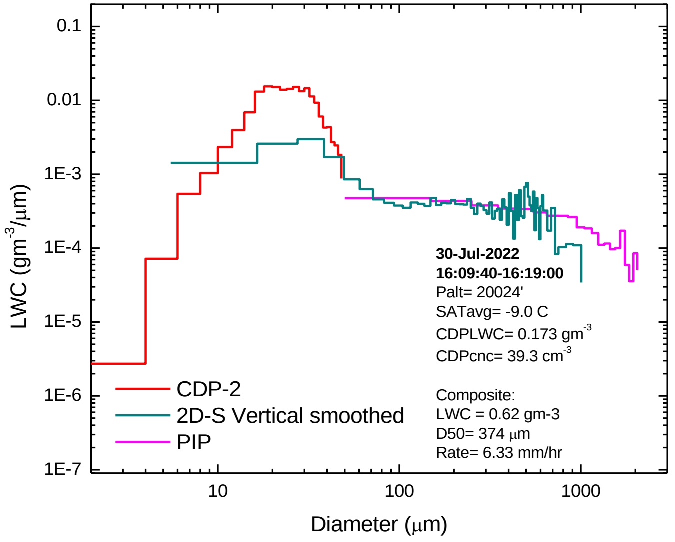


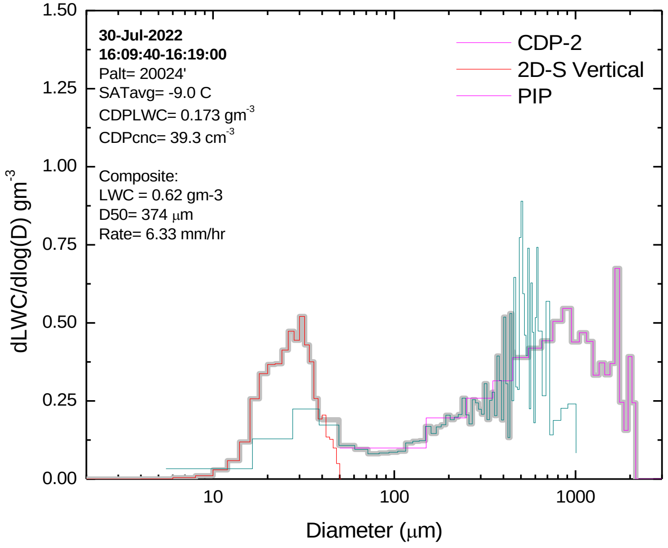


16:09:40-16:09:54

Case study 30-Jul-2022, -9.0 C



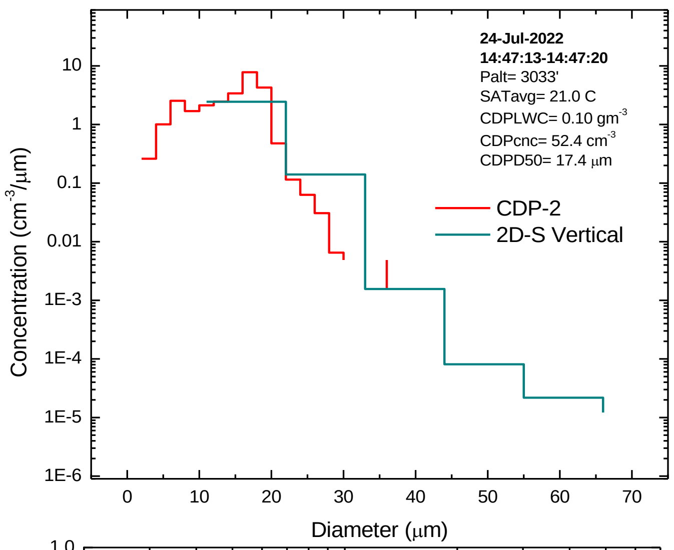


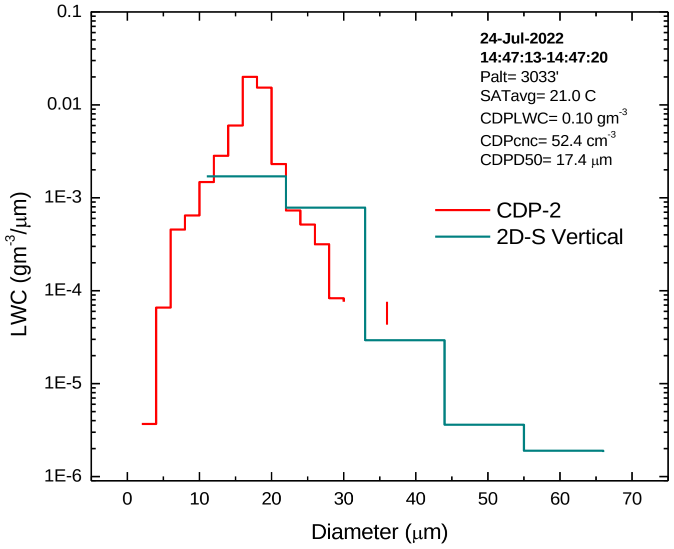


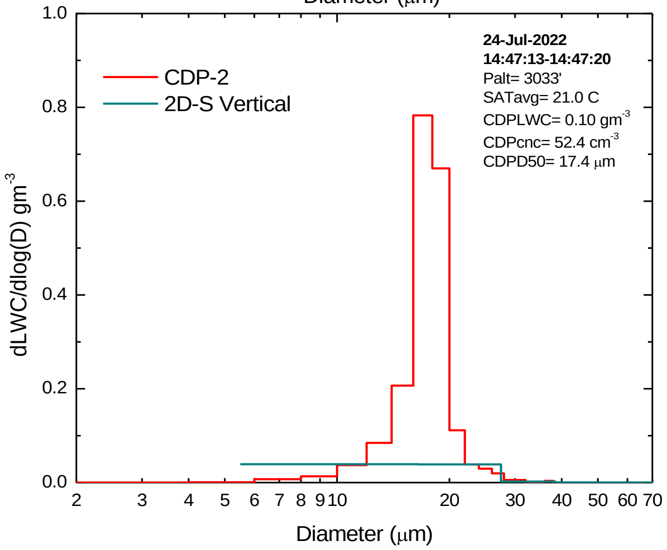
- Most of LWC now in tail of spectrum
- About 0.4 gm-3 above 50 µm
- Rainfall rate ~= 6.3 mm/hr
- PSD TWCav = 0.62 gm^{-3}
- ICDTWCav= 0.39 gm^{-3}
- IKP TWCav= 0.73 gm^{-3}

24-Jul-2022: low aerosol case

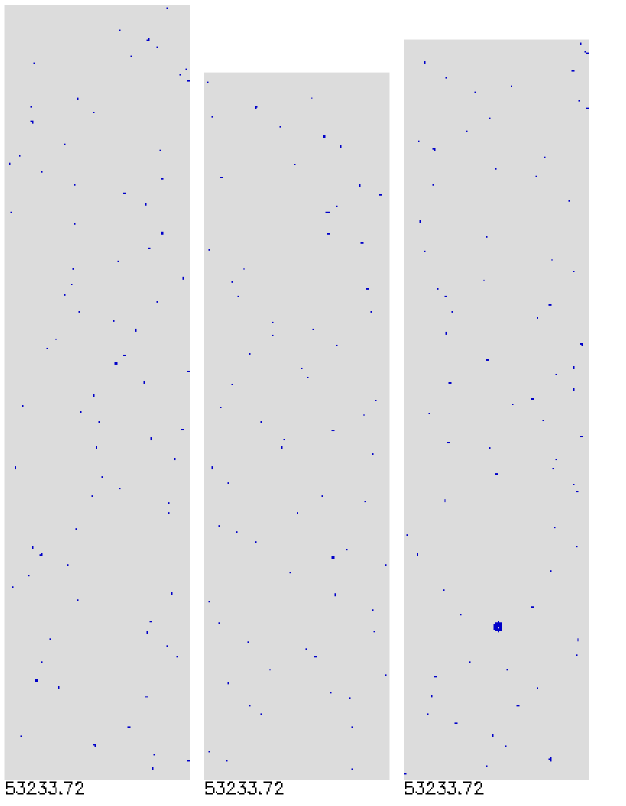
Case study 24-Jul-2022, cloud base (21 C)





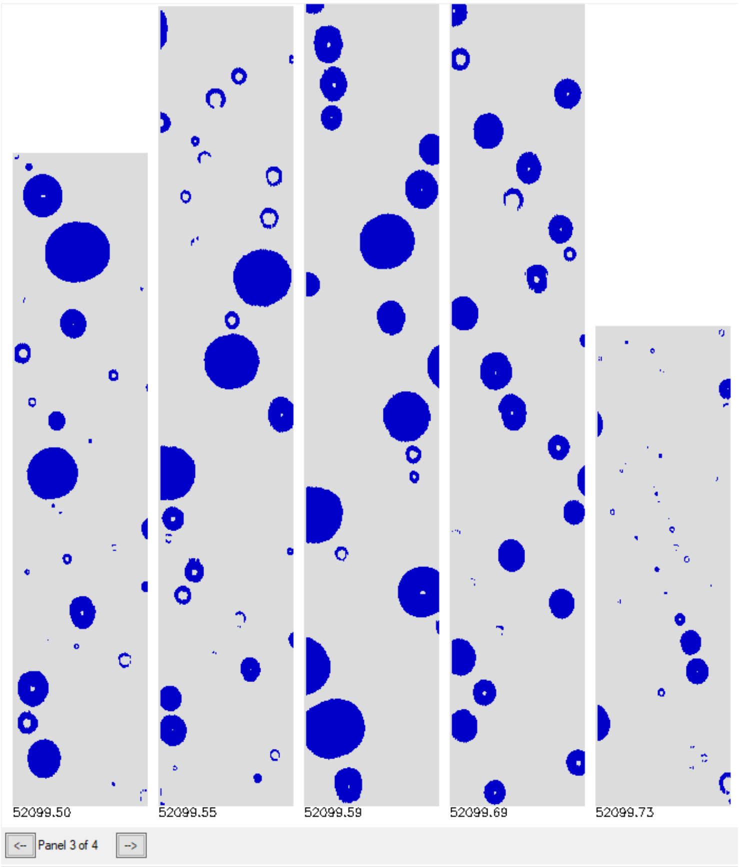


- Coalescence embryos to at least ~ 66 μm
- Negligible LWC > 50 μm (4.1e-5 gm^{-3})
- CDPLWCav= 0.10 gm^{-3}
- ICDTWCav= 0.15 gm^{-3}
- IKP TWC not accurate (background WV = ~ 20 gm^{-3})

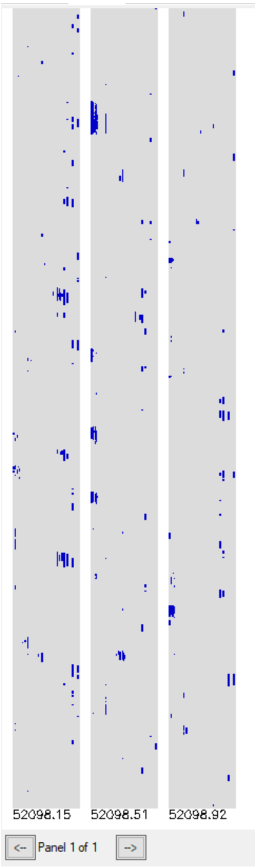


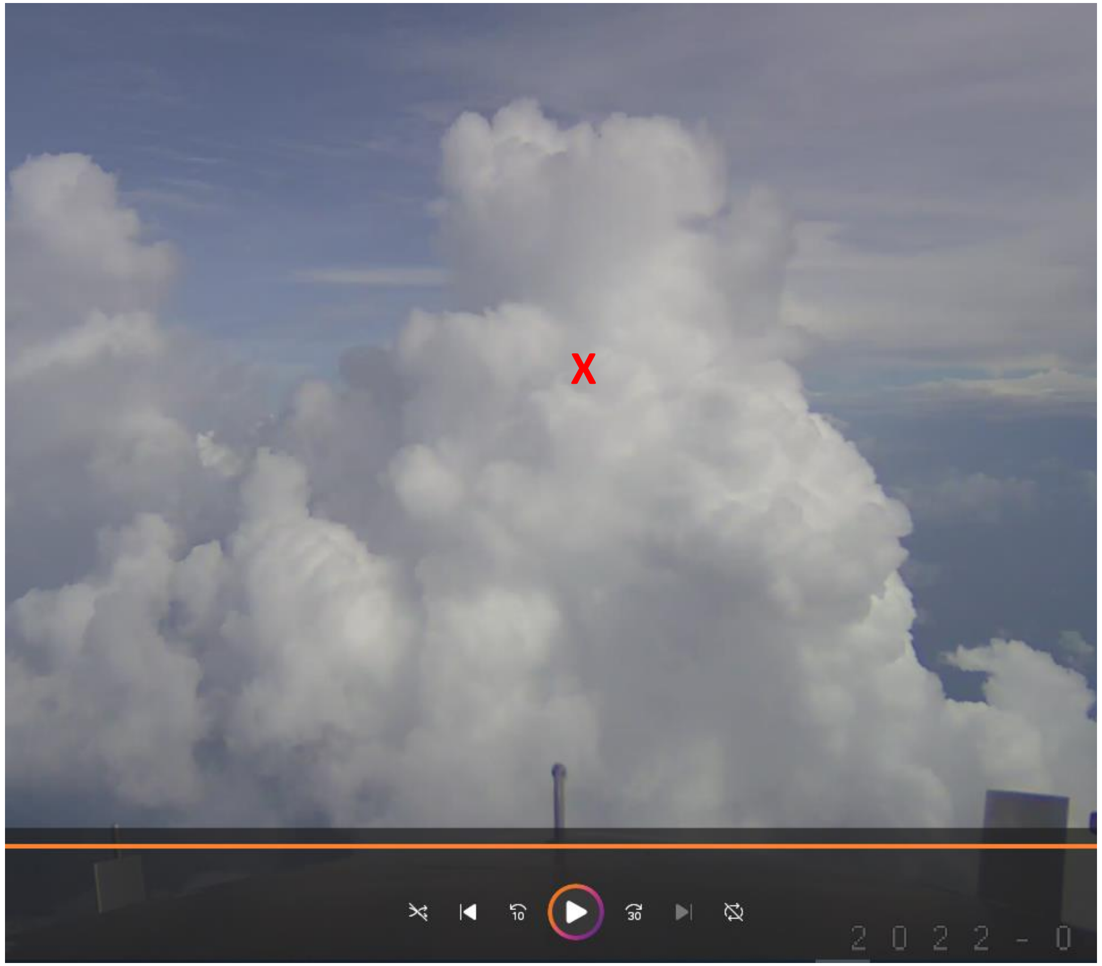
Case study 24-Jul-2022, +4.7 C

2D-S V



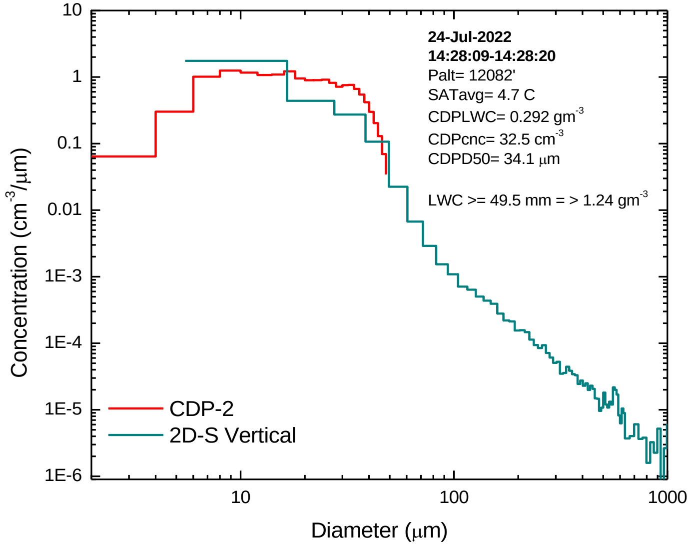
PIP
(low ref. voltages)
Not used

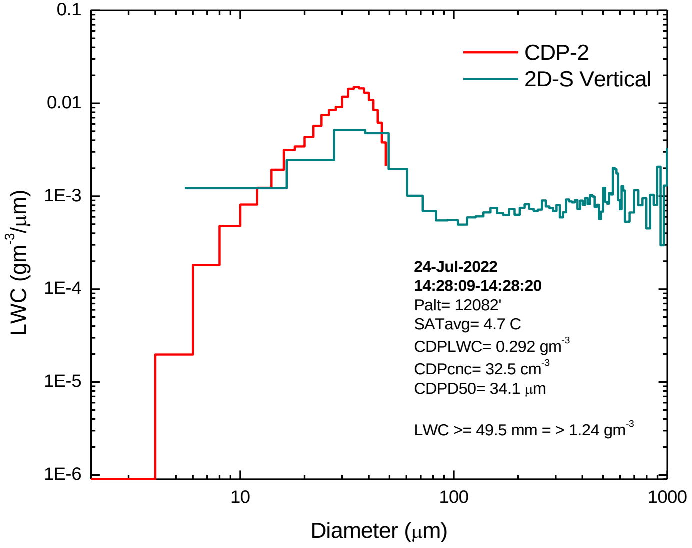


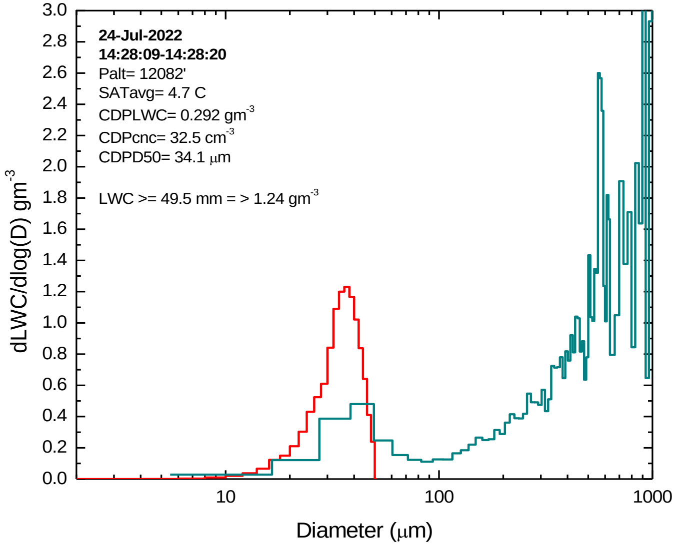


14:28:09-14:28:20

Case study 24-Jul-2022, +4.7 C



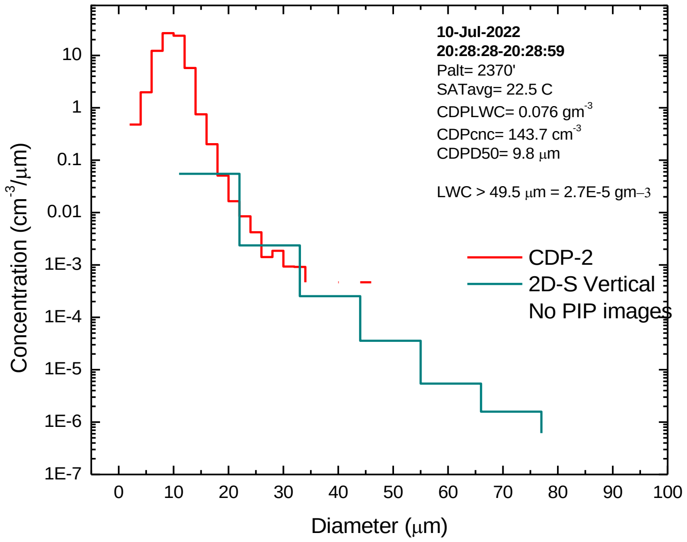


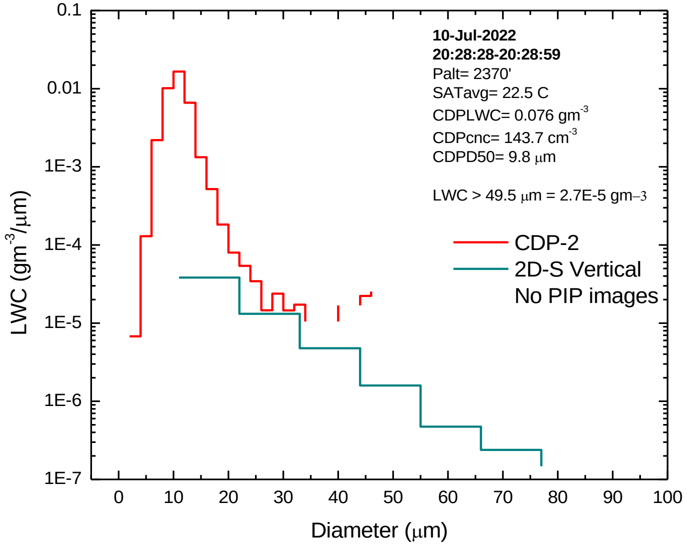


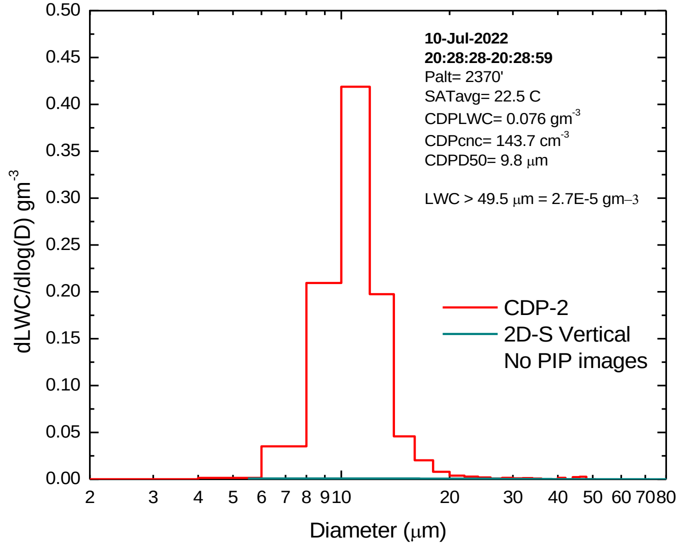
- Most of LWC now in tail of spectrum
- PIP spectra not available
- 2D-S LWC is not closing the spectrum
- At least 1.24 gm^{-3} above 50 µm
- Rainfall rate > 16 mm/hr (excluding PIP)
- PSDTWCav > 1.24 gm^{-3}
- ICDTWCav = 0.72 gm^{-3}
- IKPTWCav = 1.94 gm^{-3} (~7 gm^{-3} backgound)

10-Jul-2022: low aerosol case

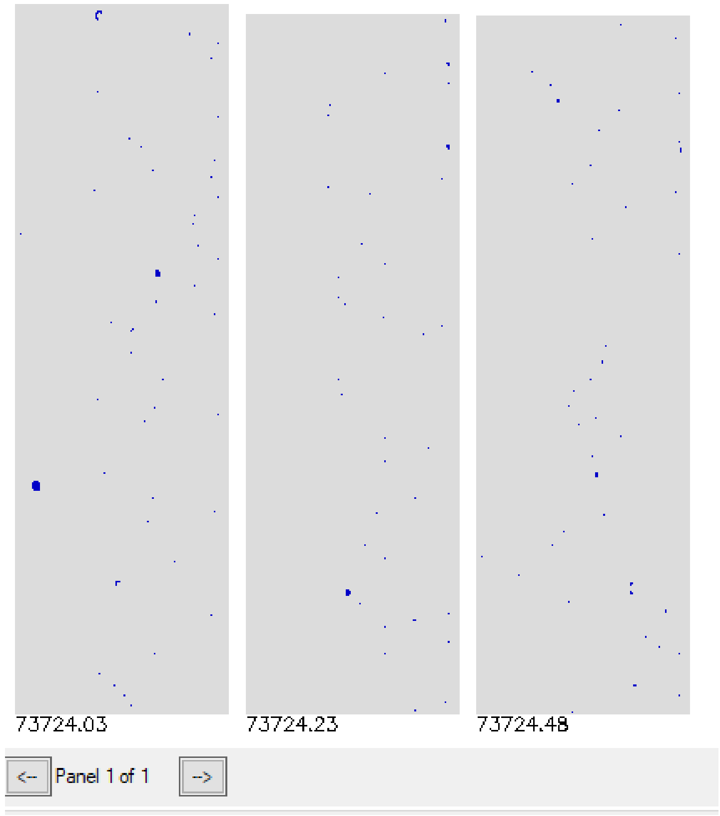
Case study 10-Jul-2022, cloud base (22.0 C)



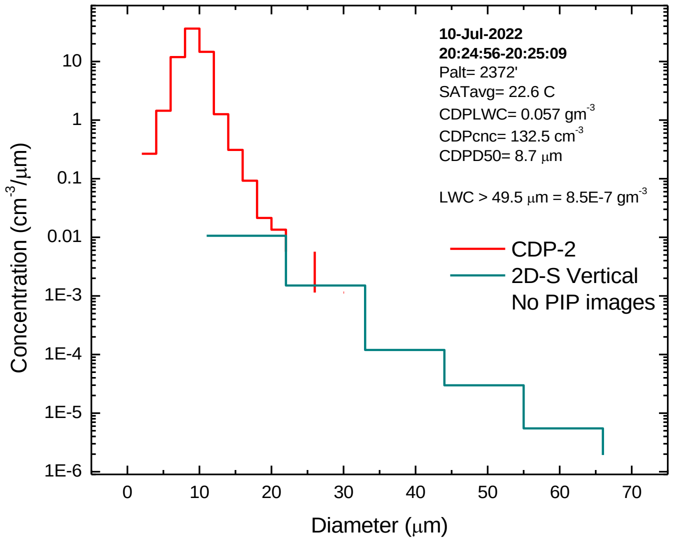


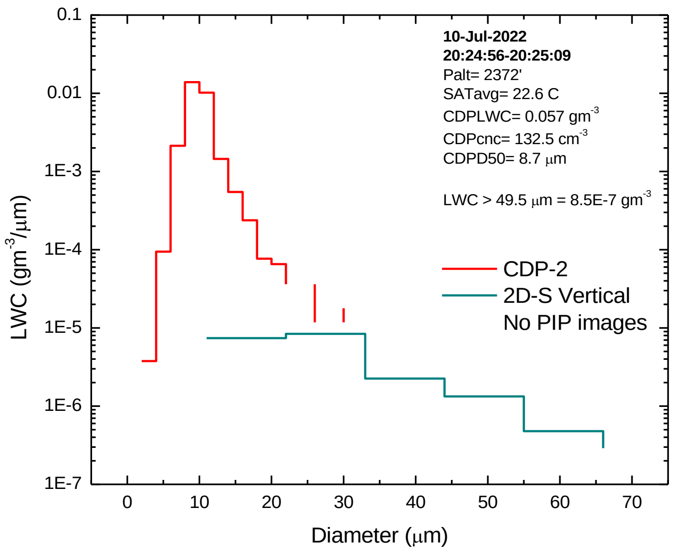


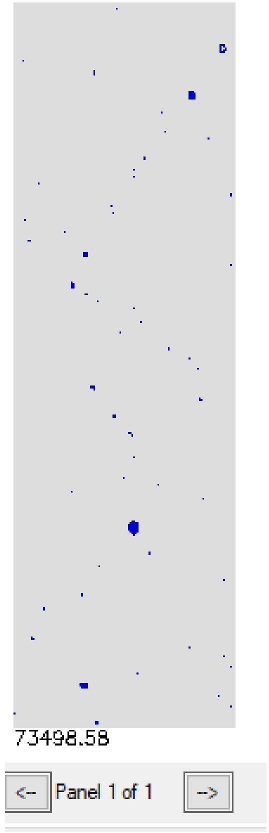
- Coalescence embryos to ~77 µm
- Negligible LWC above 50 µm
- CDPLWCav = 0.08 gm^{-3}
- ICDTWCav= 0.09 gm^{-3}
- PSDTWCav = 0.08 gm^{-3}
- IKP TWC not accurate (background WV = ~ 19 gm^{-3})

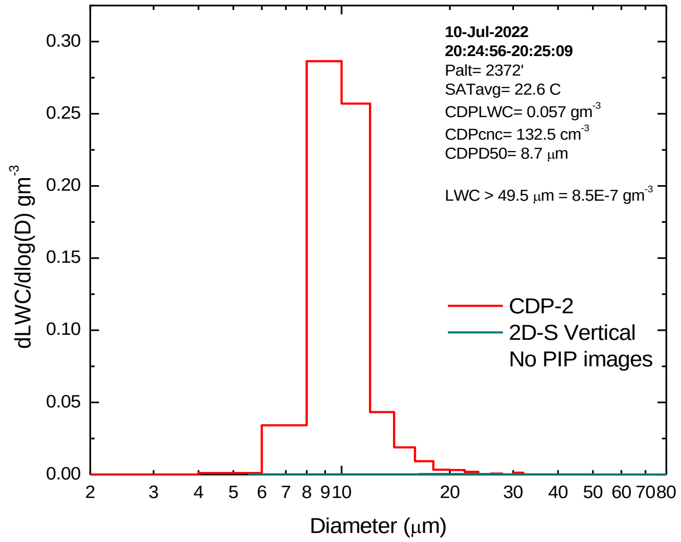


Case study 10-Jul-2022, cloud base (22.0 C)





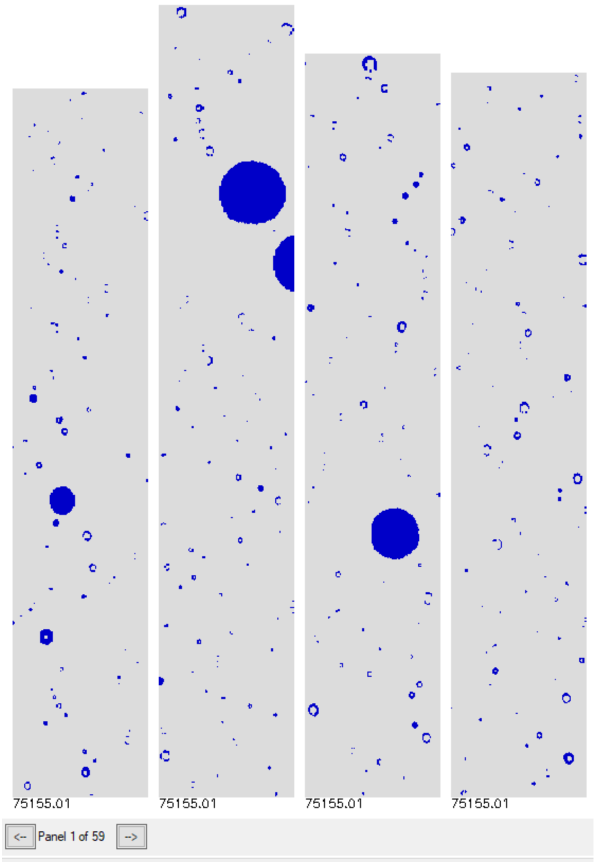




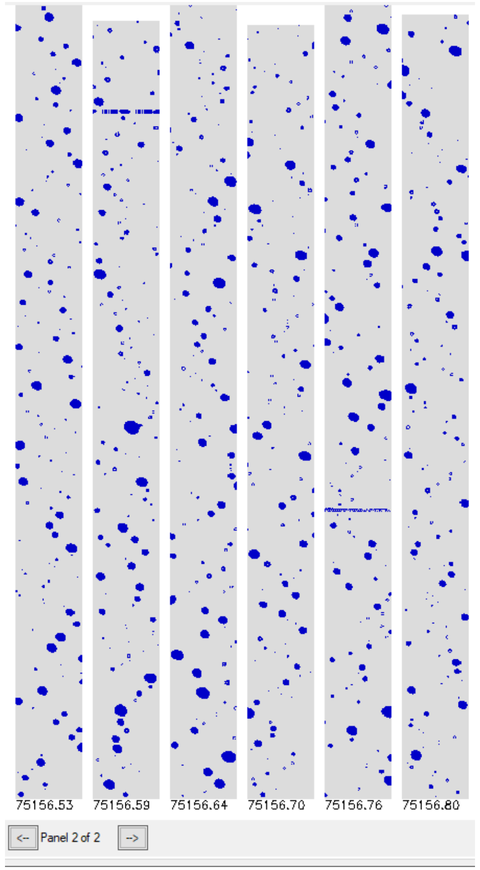
- Coalescence embryos to ~66 µm
- Negligible LWC above 50 µm
- CDPLWCav = 0.06 gm^{-3}
- PSDTWCav = 0.06 gm^{-3}
- ICDTWCav = 0.07 gm^{-3}
- IKP TWC not accurate (background WV = ~ 19 gm^{-3})

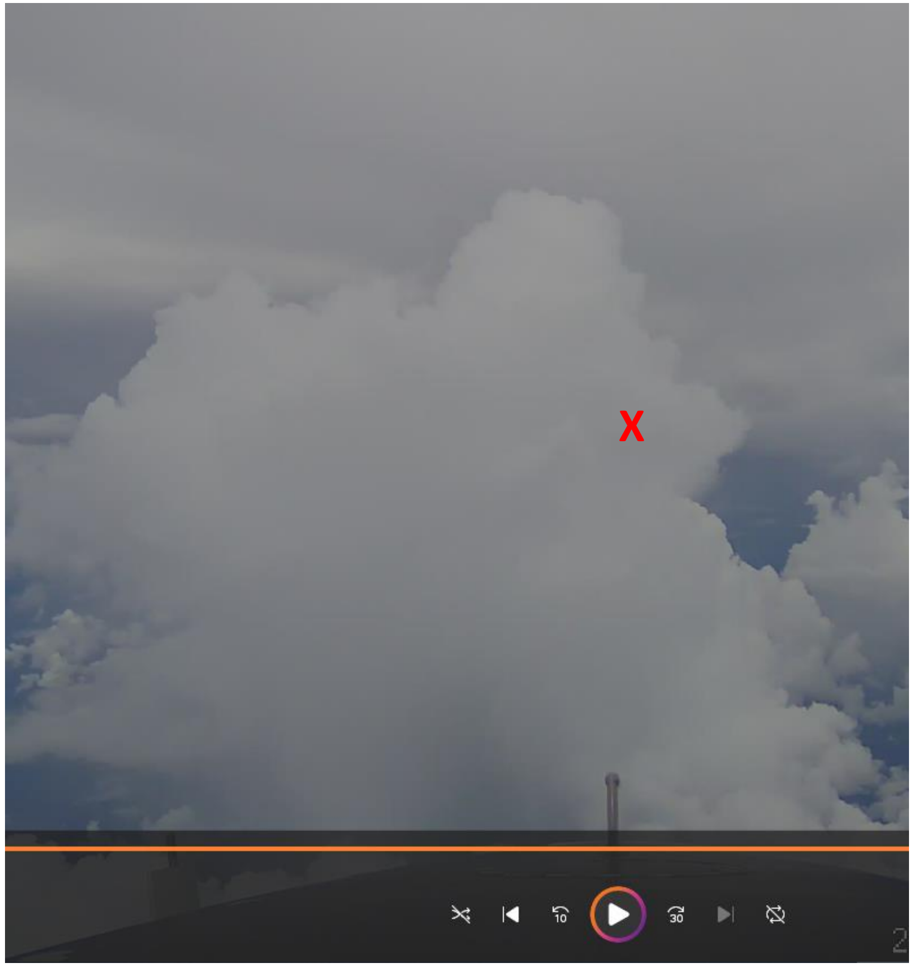
Case study 10-Jul-2022, -9.0 C

2D-S V



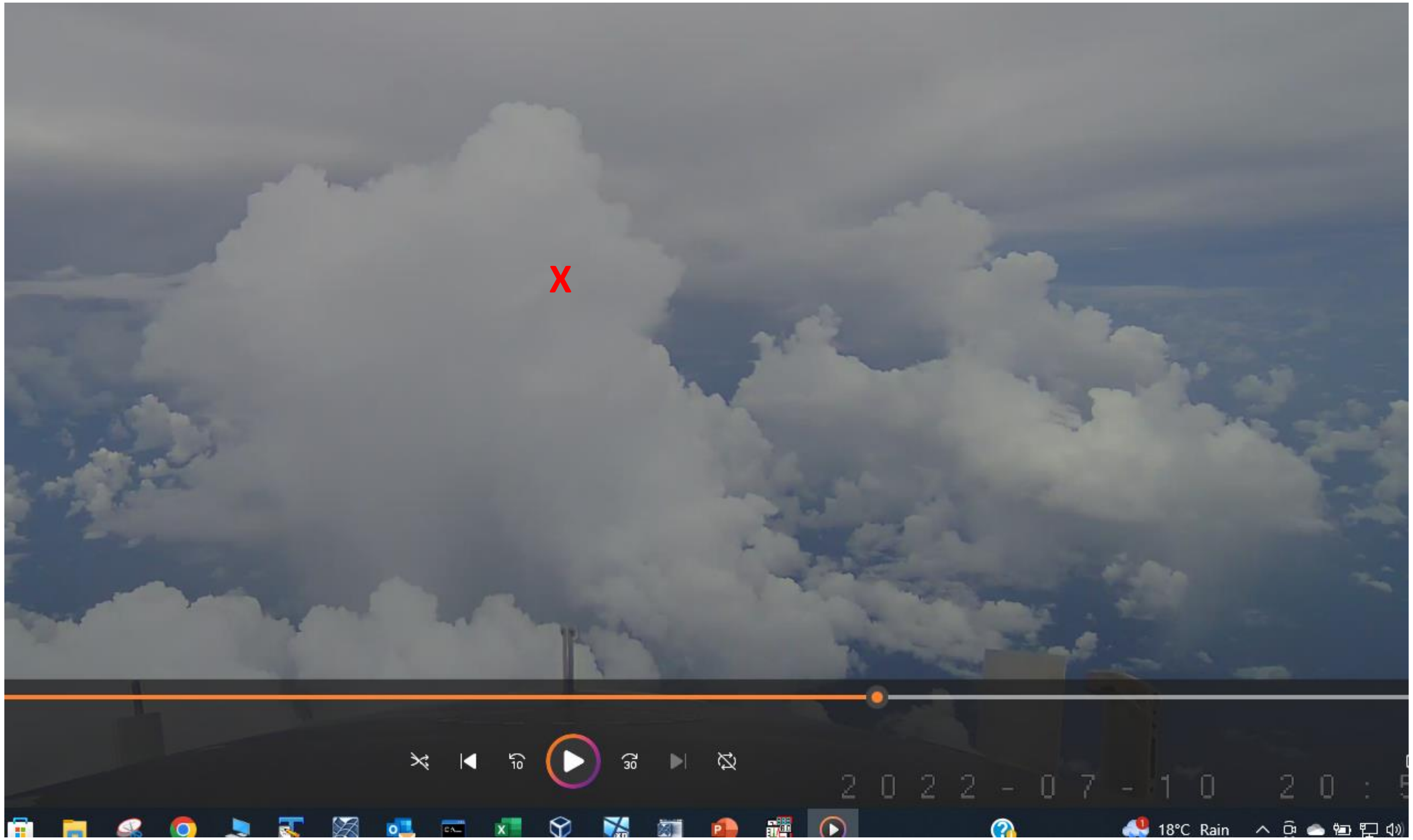
PIP
(some poor data)





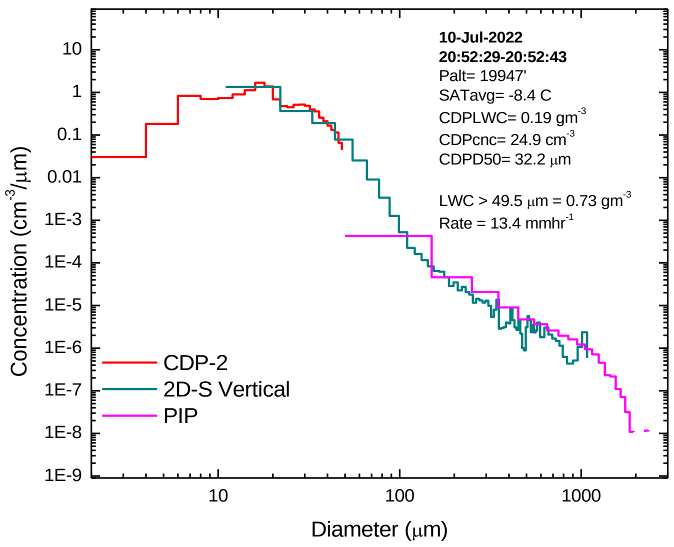
20:52:29-20:52:43

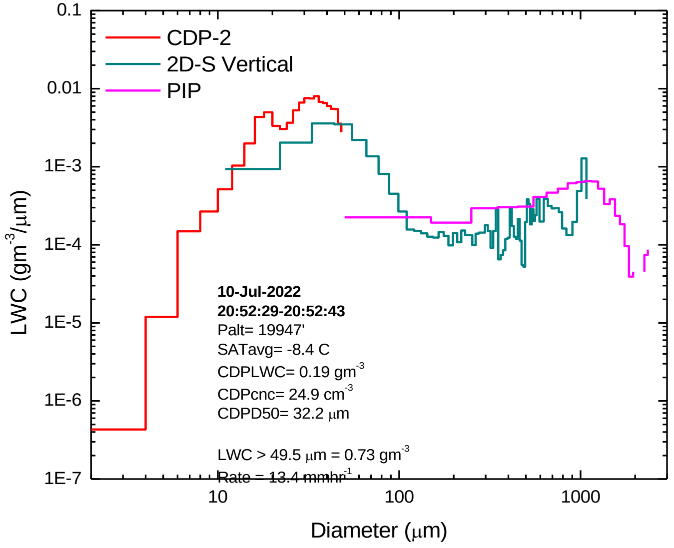
Case study 10-Jul-2022, -9.0 C, possible rain below base ?

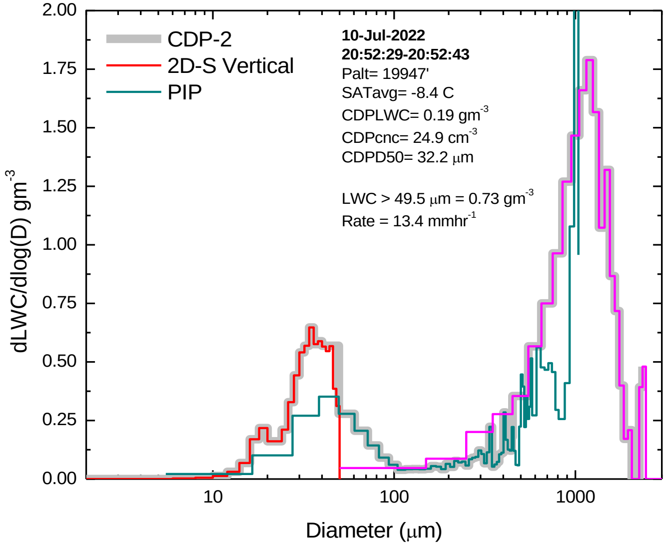


20:52:29-20:52:43

Case study 10-Jul-2022, -8.4 C







- Most of LWC now in tail of spectrum
- About 0.73 gm^{-3} above 50 μm
- Rainfall rate = 13.4 mm/hr
- PSDTWCav = 0.93 gm^{-3}
- ICDTWCav = 0.34 gm^{-3}
- IKPTWCav = 1.08 gm^{-3} (BWV = ~2.5 gm^{-3})

Case study 10-Jul-2022, -9.0 C: rough calculation of balance of fluxes

Assume:

- Cloud is 6100 m tall
- Average updraft velocity is 10 ms^{-1}
- Average TWC through depth is 1 gm^{-3}

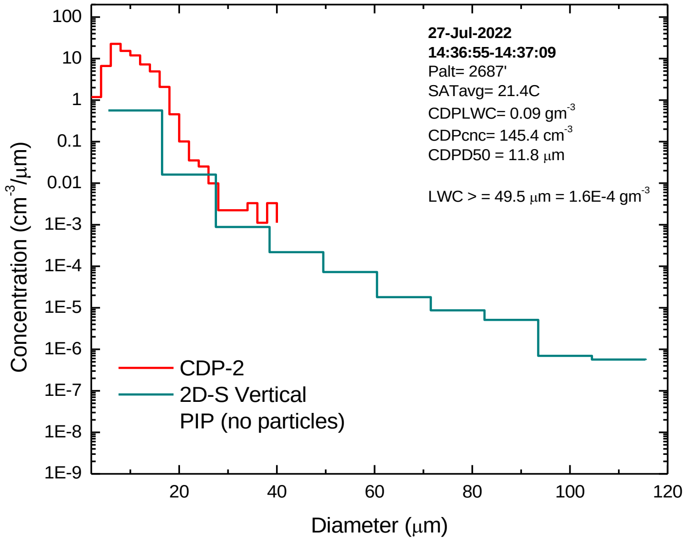
Calculations

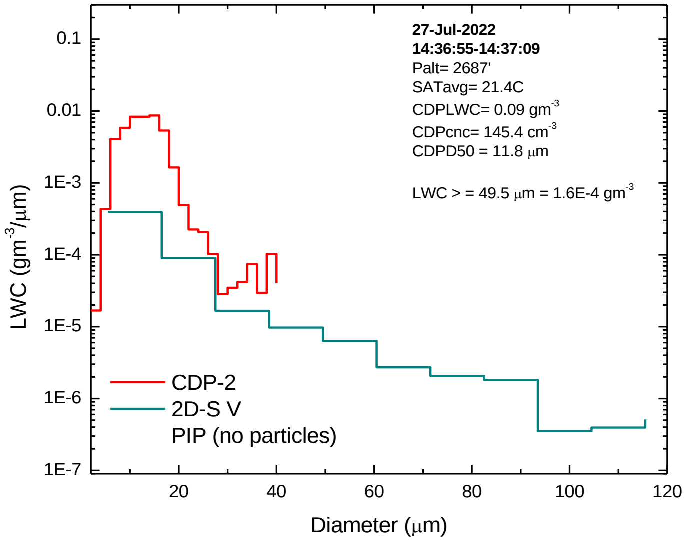
- Integrated water content of cloud is 6.1 mm
- Integrated adiabatic condensation is about 78 mm/hr
- Depletion due to entrainment unknown (50%?)

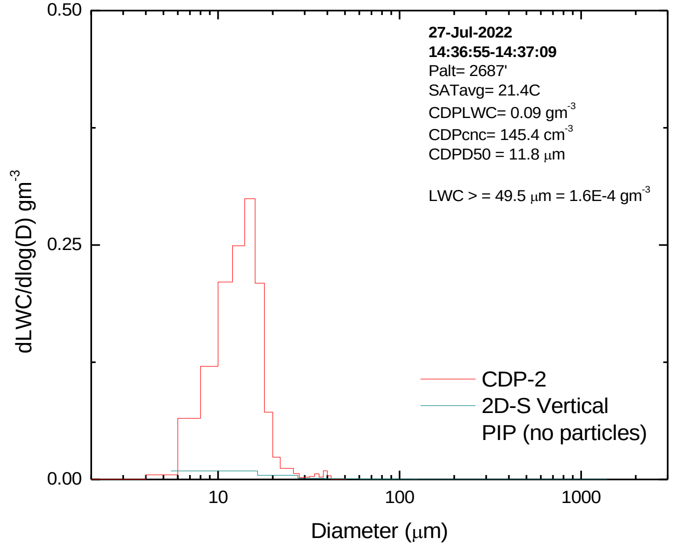
- Depletion due to precipitation 13 mm/hr is not insignificant

27-Jul-2022: possible medium aerosol case

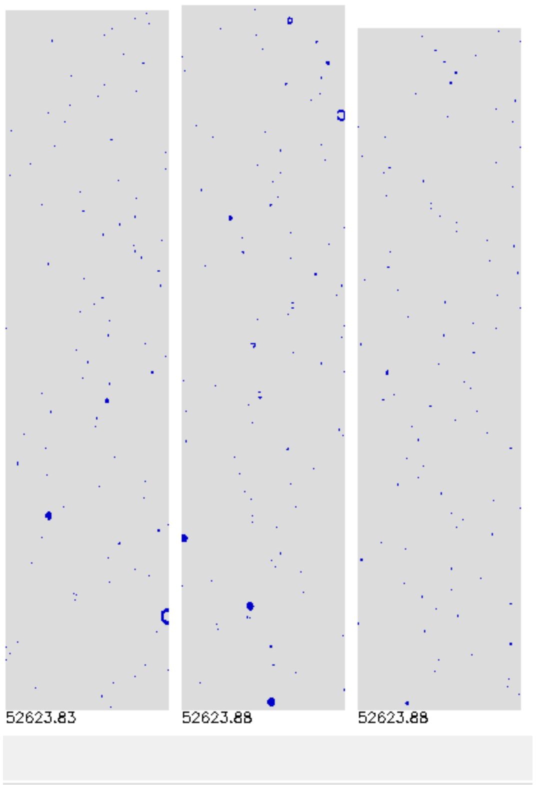
Case study 27-Jul-2022, cloud base





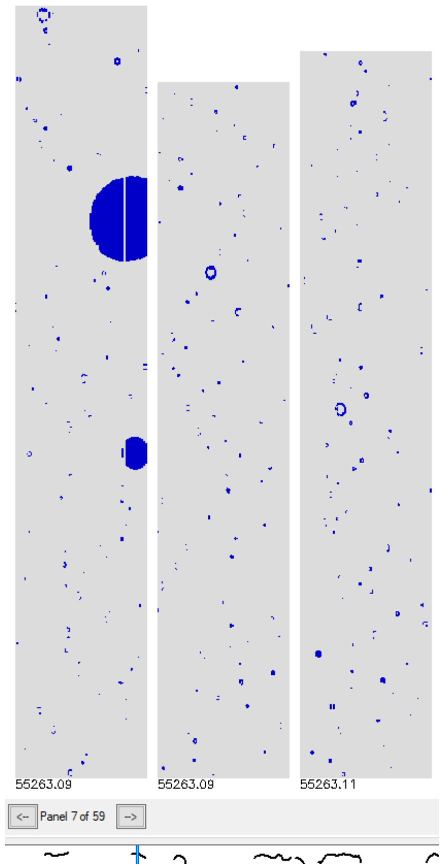


- Coalescence embryos to > 100 μm
- Negligible LWC above 50 μm
- PSDTWCav = 0.09 gm^{-3}
- ICDTWCav = 0.10 gm^{-3}
- IKP TWC not accurate (background WV = ~ 17 gm^{-3})

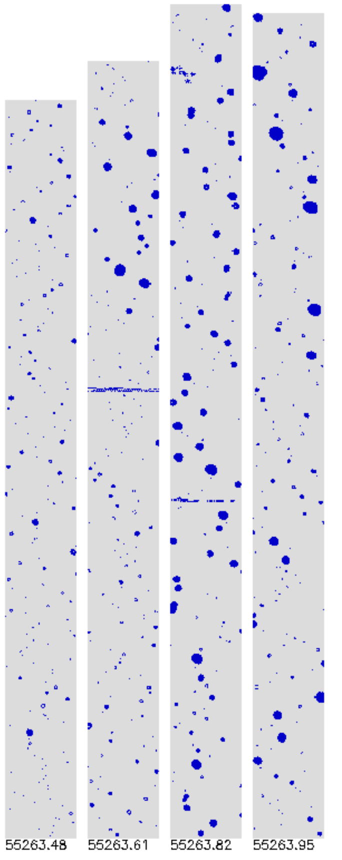


Case study 27-Jul-2022, +7.4 C

2D-S V

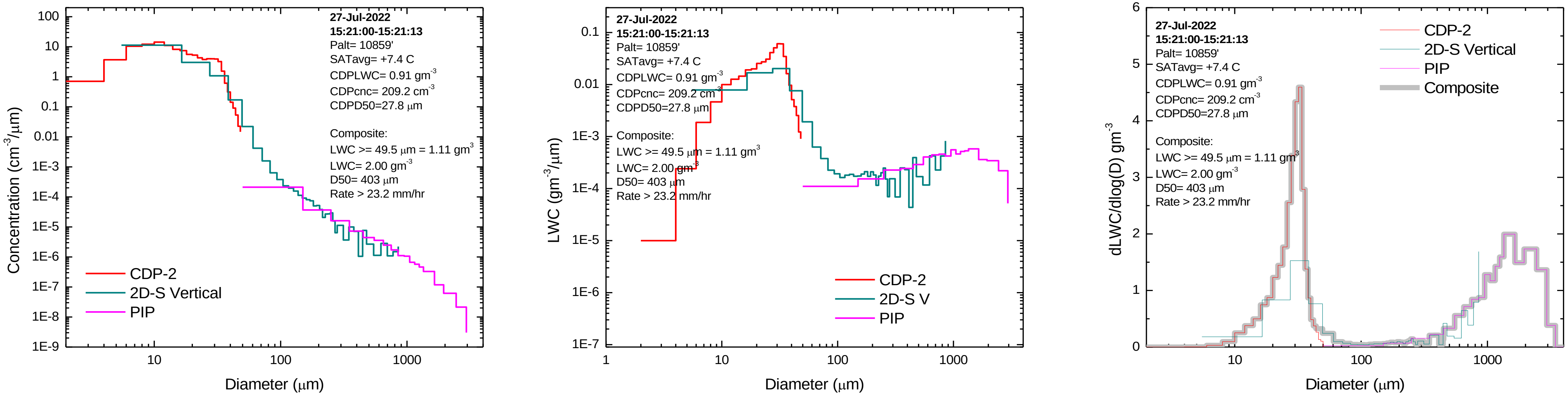


PIP
(some poor data)



15:21:00 – 15:21:13

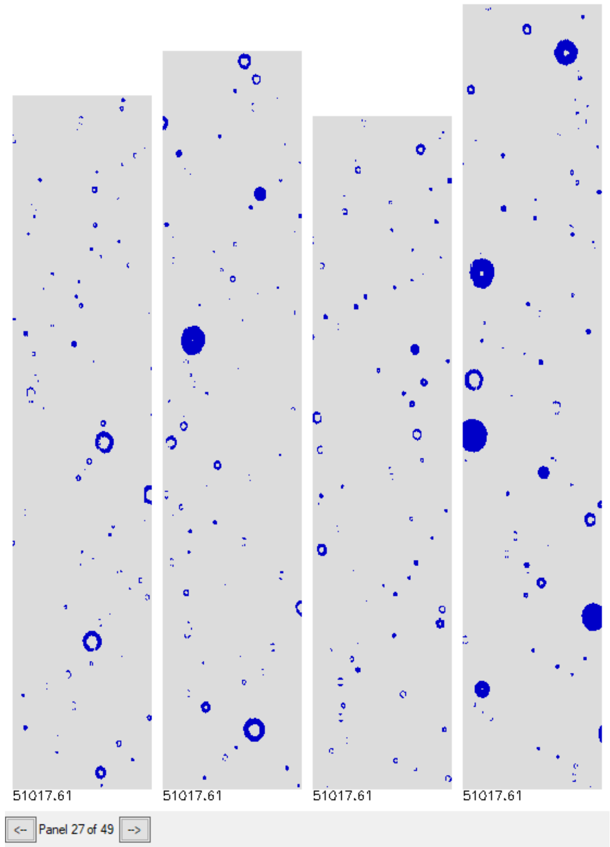
Case study 27-Jul-2022, +7.4 C



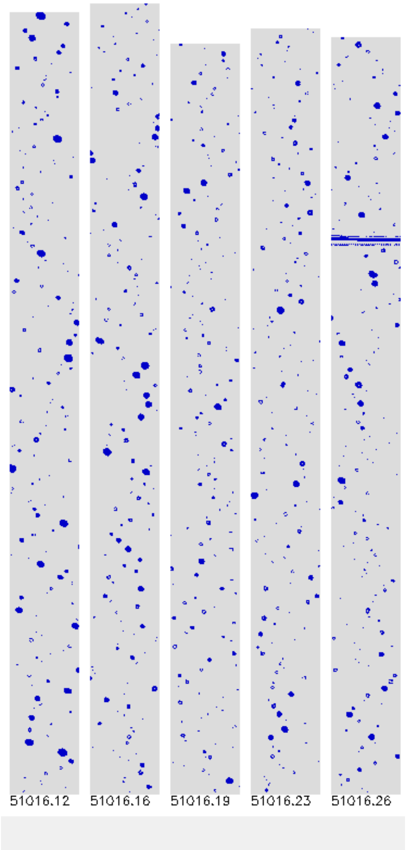
- More than 50% of LWC now in tail of spectrum
- Rainfall rate = 23.2 mm/hr
- PSDTWCav = 2.00 gm^{-3}
- ICDTWCav = 1.08 gm^{-3}
- IKPTWCav = 3.24 gm^{-3} (DLH says subsaturated, ~ 80%, if use water sat, IKPTWCav = 1.79 gm^{-3}

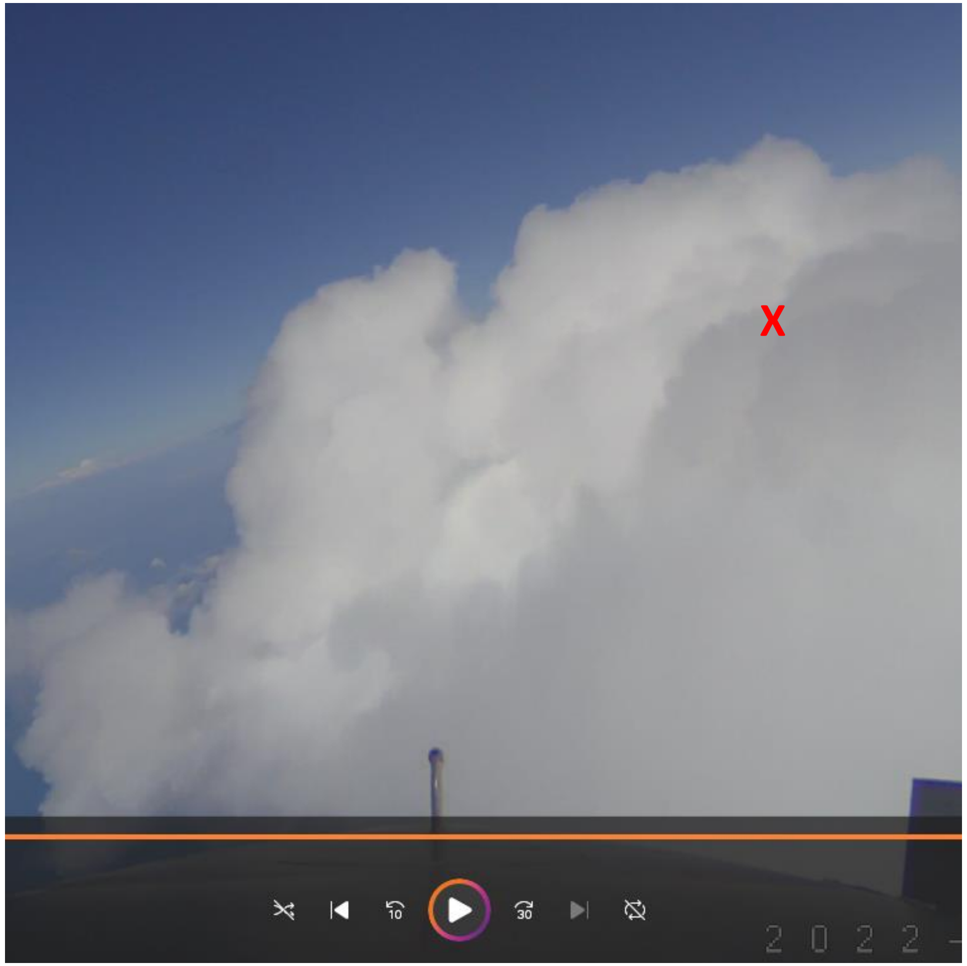
Case study 27-Jul-2022, -8.6 C

2D-S V



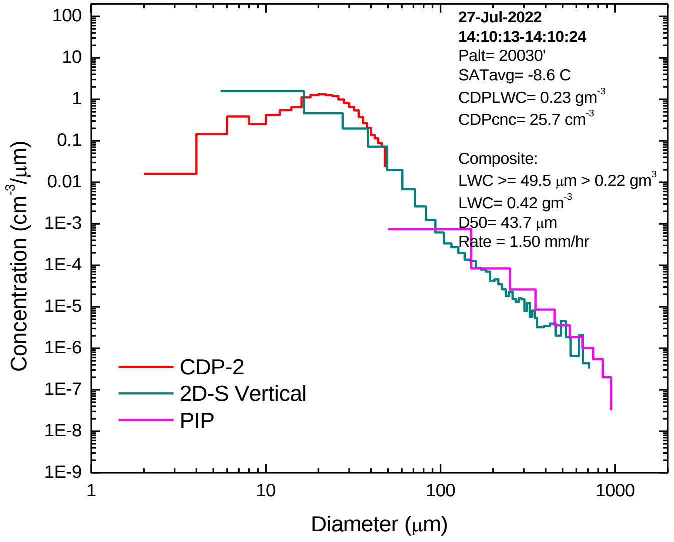
PIP
(some poor data)

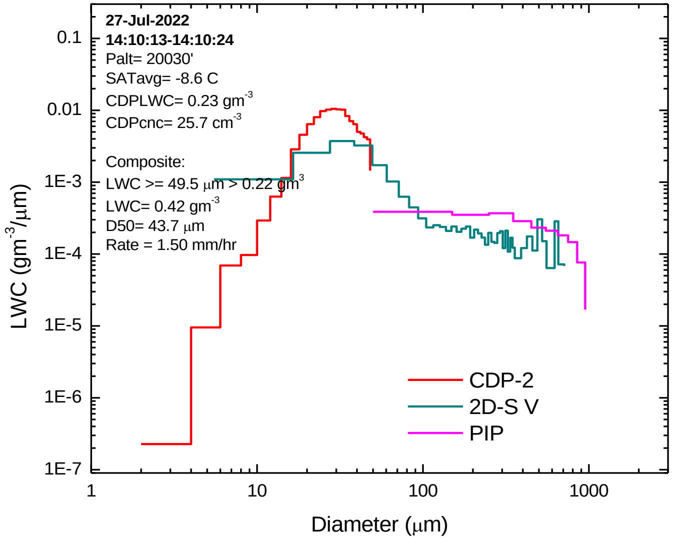


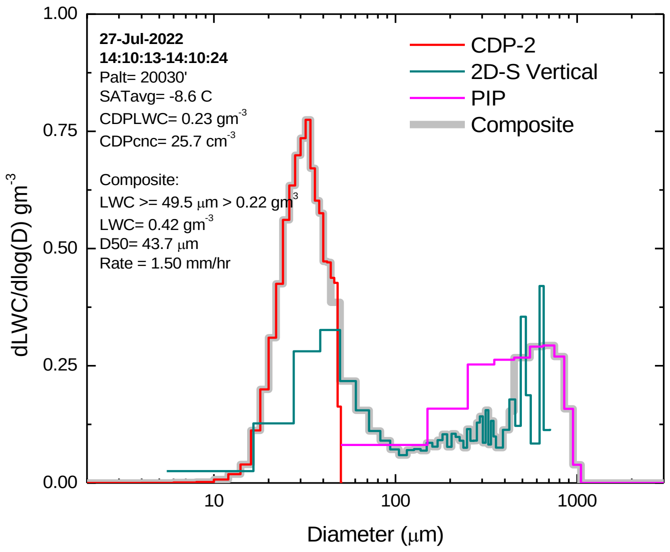


14:10:13-14:10:24

Case study 27-Jul-2022, -8.6 C





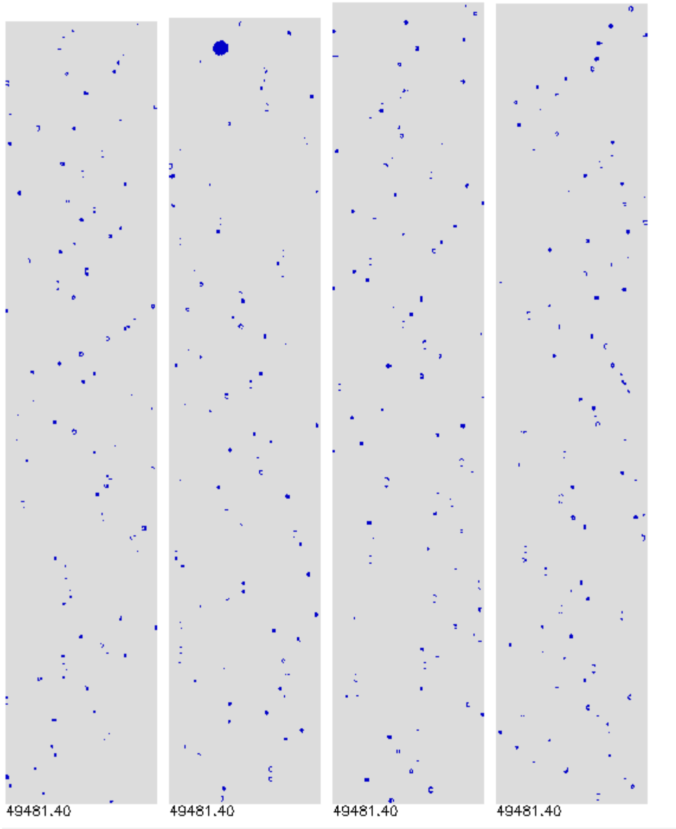


- About half of the LWC in tail of spectrum, LWC ≥ 49.5 μm = 0.22 gm^{-3}
- Composite rainfall rate ~ 1.50 mm/hr
- PSDTWCav = 0.42 gm^{-3}
- ICDTWCav = 0.34 gm^{-3}
- IKPTWCav = 0.49 gm^{-3} (BWV ~ 2.0 gm^{-3})

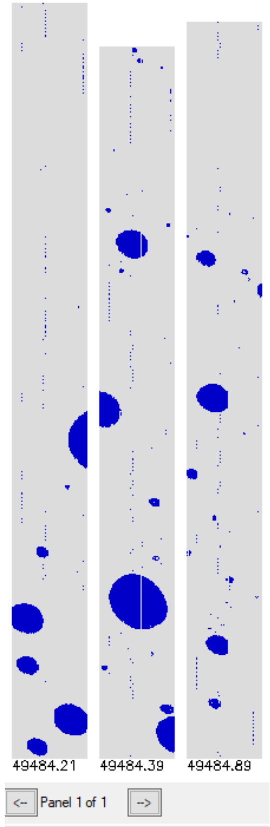
26-Jul-2022: low aerosol case

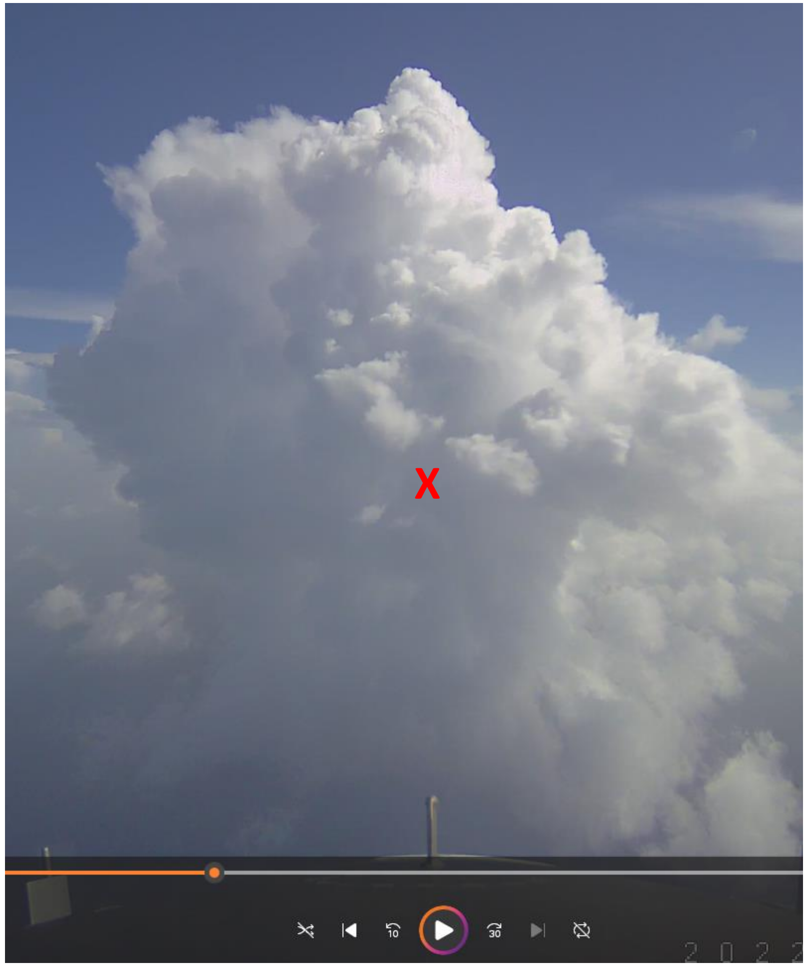
Case study 26-Jul-2022, +13.7 C

2D-S V



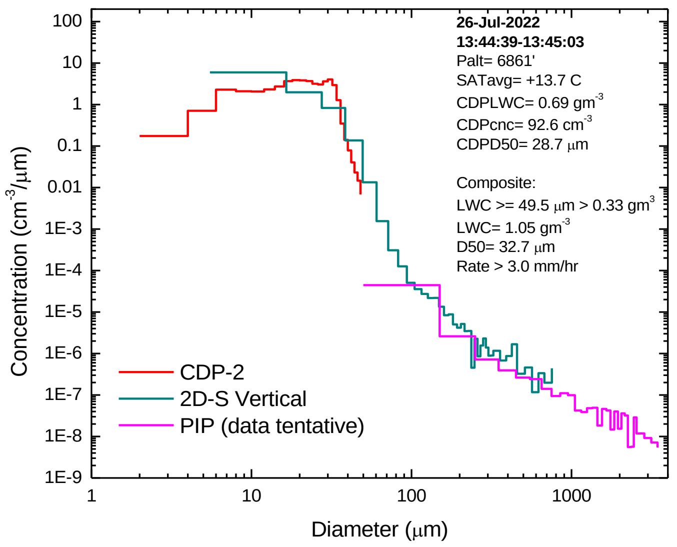
PIP
(poor data, but
very big drops)

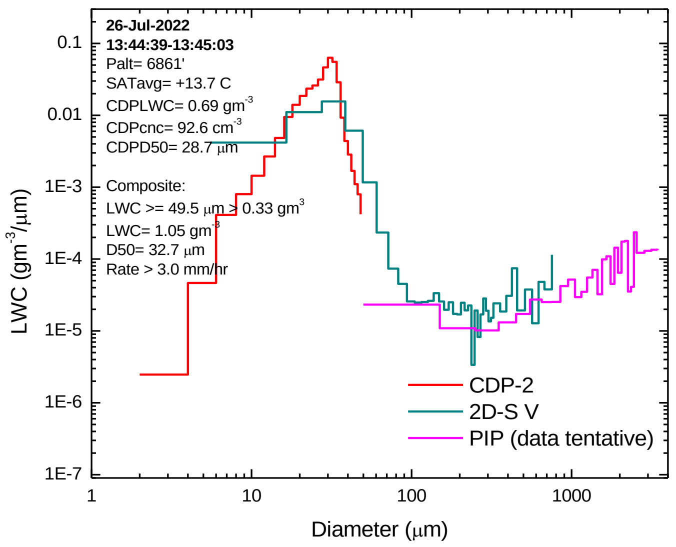


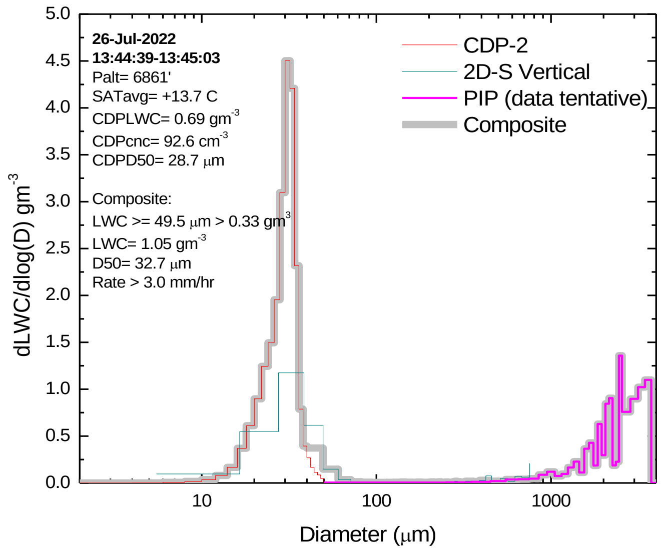


13:44:39-13:45:03

Case study 26-Jul-2022, +13.7 C



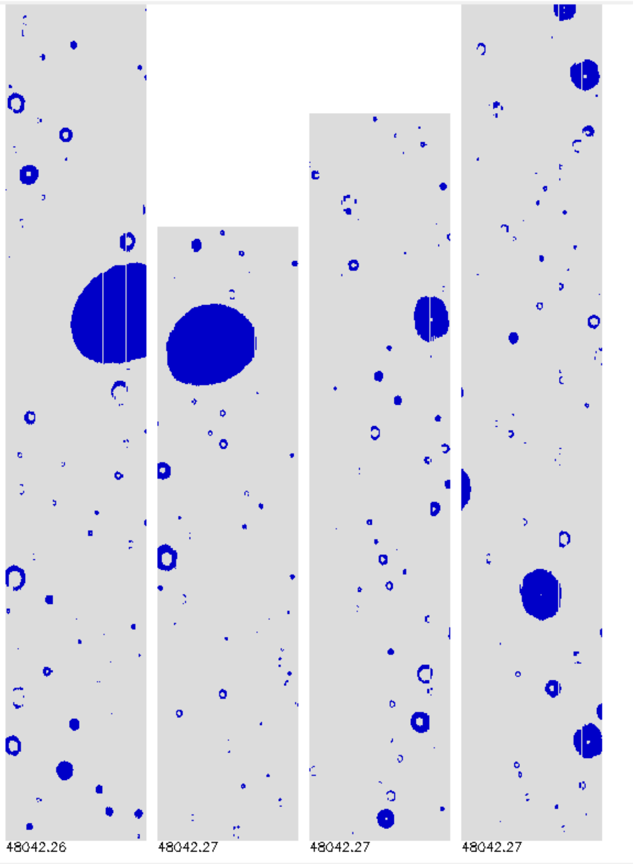




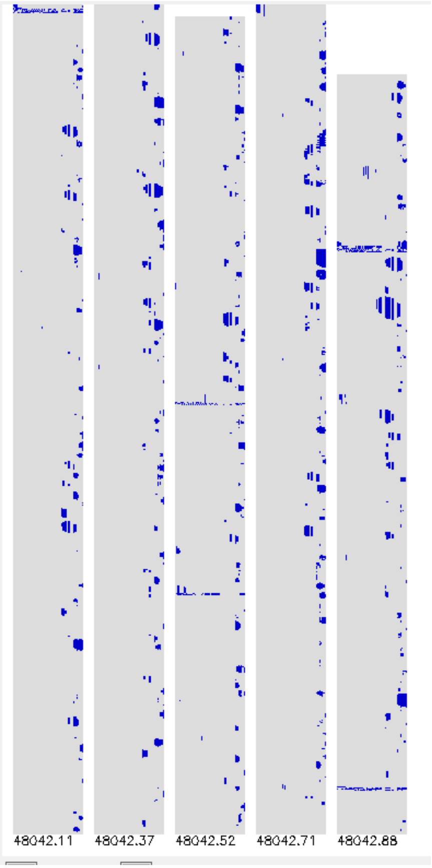
- LWC tail developing in spectrum, about 1/3 of LWC above 50 µm (0.33 gm^{-3})
- Very large drops (falling from above to bias coalescence distribution?, see sharp cutoff of distribution at 4 mm?)
- Rainfall rate ~ 3.0 mm/hr
- CDPLWC = 0.69 gm^{-3}
- PSDLWCav = 1.05 gm^{-3}
- ICDTWCav = 0.90 gm^{-3}
- IKPTWCav : DLH saturated, might be retrievable with careful second-by-second BWV removal (BWV ~ 12 gm^{-3})

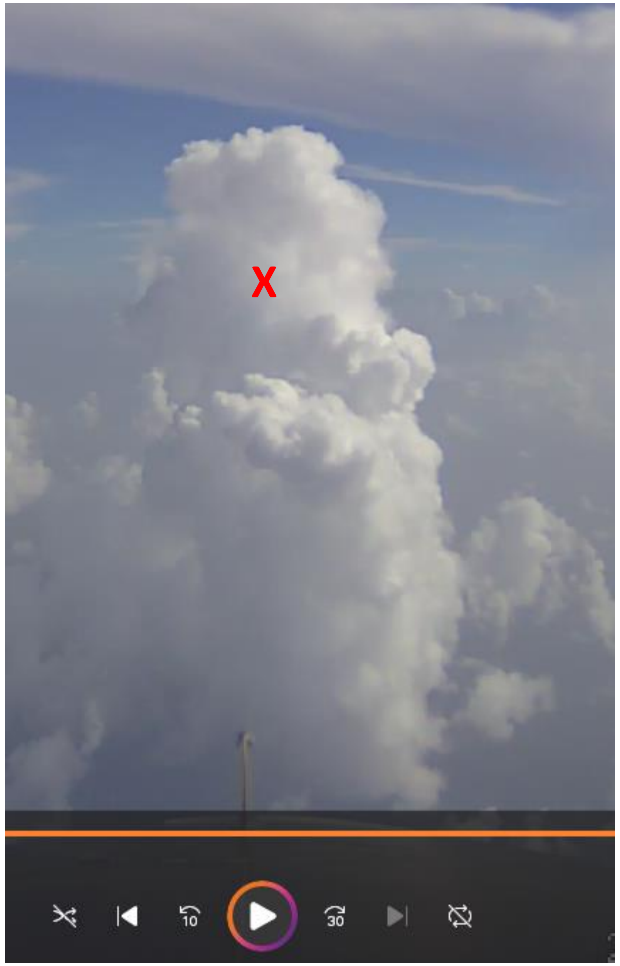
Case study 26-Jul-2022, +3.8 C

2D-S V



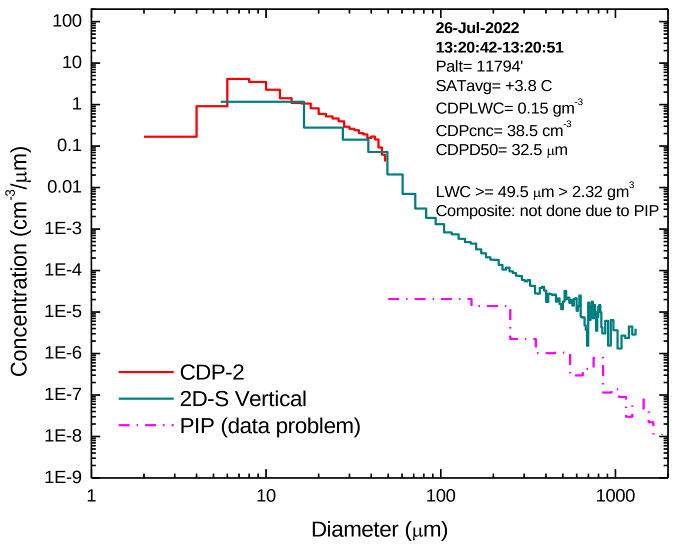
PIP
(poor data due to low reference voltages)

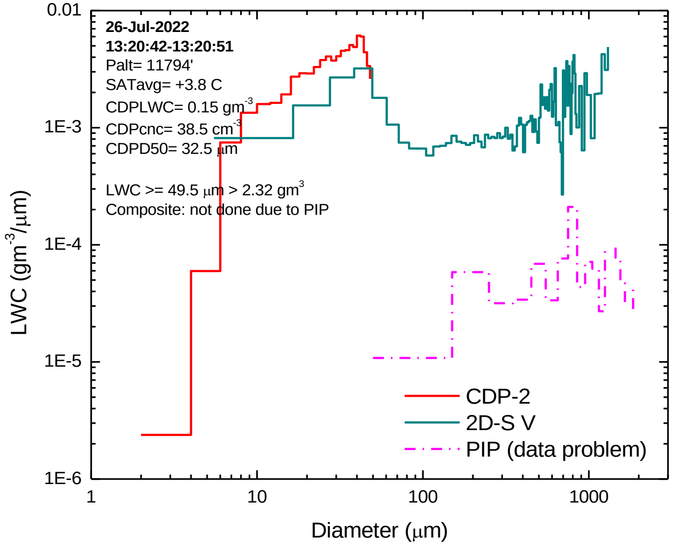


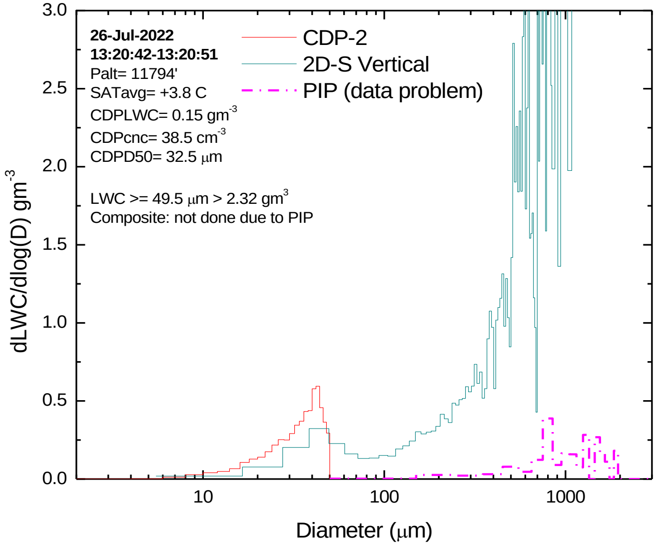


13:20:42-13:20:51

Case study 26-Jul-2022, +3.8 C



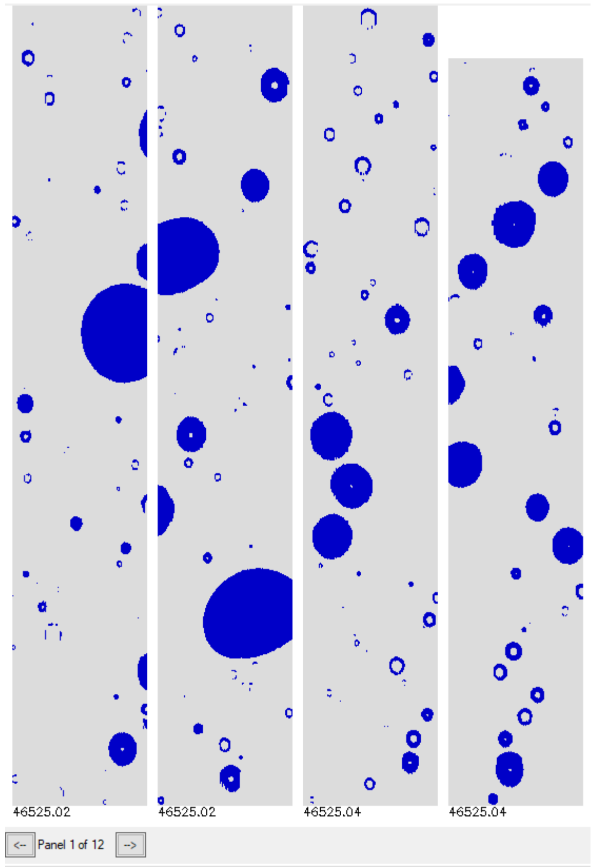




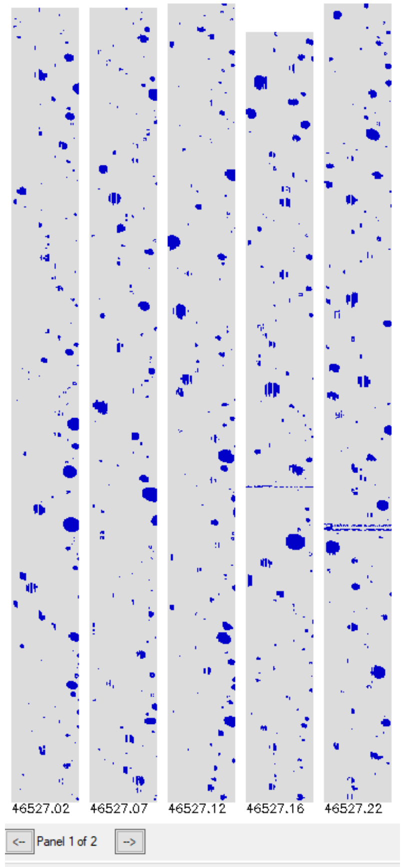
- Top may have been more than a couple of thousand feet above (i.e. more warm rain development above compared to other cases)
- Large amount of LWC now in tail of spectrum, at least 2.32 gm^{-3} above 50 µm
- Poor quality PIP data does not overlap well with 2D-S; lack of PIP data defeats closing tail
- Rainfall rate (2D-S) > 9.8 mm/hr
- PSDTWCav **>** 2.32 gm^{-3}
- ICDTWCav = 0.88 gm^{-3}
- IKPTWCav = 2.79 gm^{-3} (used water saturation ~ 6 gm^{-3}, DLH saturated)

Case study 26-Jul-2022, -9.8 C

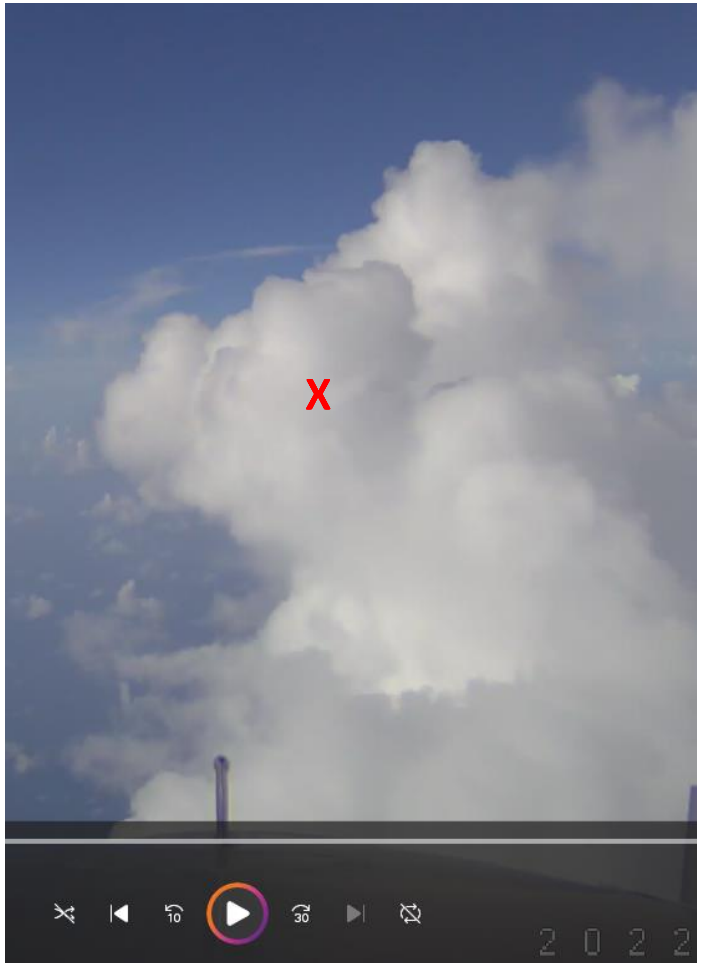
2D-S V



PIP
(poor data due to low reference voltages)

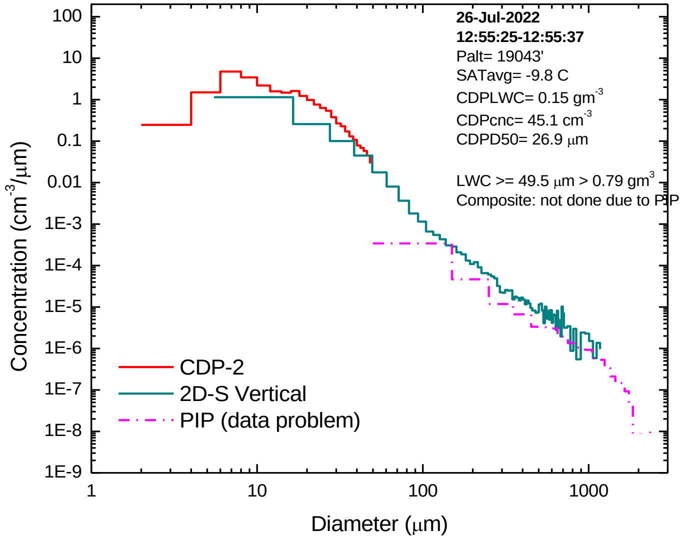


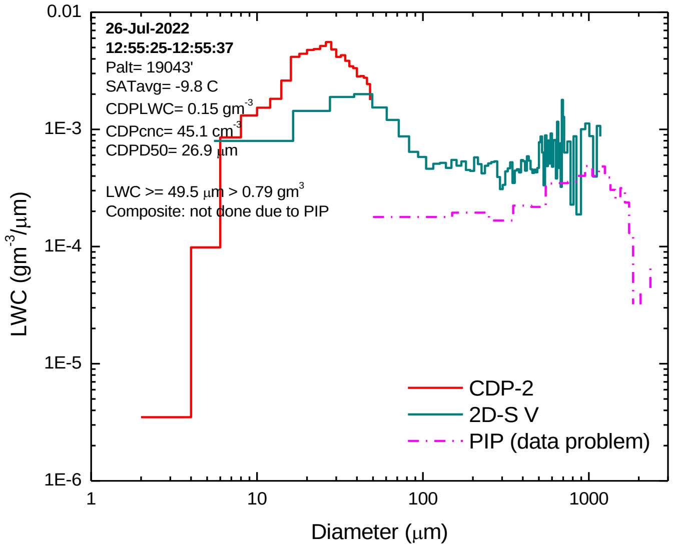
Did not go through cloud behind

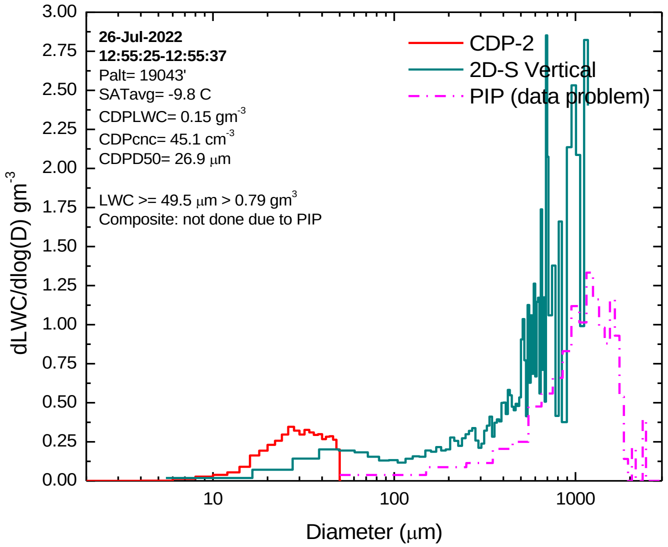


12:55:22-12:55:37

Case study 26-Jul-2022, -9.8 C







- Major fraction of LWC in tail of spectrum
- At least 0.79 gm^{-3} above 50 µm
- Poor PIP data does not overlap will with 2D-S
- Rainfall rate (excl. PIP) > 10.6 mm/hr
- PSDTWCav **>** 0.94 gm^{-3}
- ICDTWCav = 0.68 gm^{-3}
- IKPTWCac = 1.77 gm^{-3} (used water saturation ~ 2.4 gm^{-3}, DLH saturated)

Summary of TCu warm rain case Studies

		Cloud base		+14 C		+5 C		-9 C LWC only		Comments
Date 2022	**Aerosol**	**coal. embryos**	**Rrate mm/h**	**LWC, gm^{-3}/ % > 49.5 µm**	**Rrate mm/h**	**LWC, gm^{-3}/ % > 49.5 µm**	**Rrate mm/h**	**LWC, gm^{-3}/ % > 49.5 µm**	**Rrate mm/h**	
10-Jul	low	to 77 µm	negl.					0.93 78%	13.4	
24-Jul	low	to 66 µm	negl.			> 1.5 > 81%	> 16			Bad PIP data, est. from 2D-S
26-Jul	low	n/a	n/a	1.05 31%	3.0	> 2.5 > 94%	> 9.8	> 0.79 > 84%	> 10.6	Bad PIP data, est. from 2D-S
27-Jul	med	to 110 µm	negl.			2.0 55%	23.2	0.42 52%	1.50	
30-Jul	high	to 77 µm	negl.	0.34 23%	1.2			0.62 64%	6.3	

Summary of TCu warm rain case Studies

- Much time was spent trying to collect this TCu dataset. In retrospect, as a science study, a dedicated aircraft would have been appropriate to devote yet more time to the data collection. In addition, the following problems compromised the data collection.
- Problems:
  - DC-8 maintenance issues shortened some flights, where the TCu measurements were unable to be performed.
  - Some cloud tops could not be assessed from the DC-8 video due to obscuration from other clouds, and were not included as valid for warm rain evaluation.
  - Cloud at the desired altitude were not always available, limiting the variety of altitudes for a given case, along with the time available.
  - Problems with the PIP in some cases created difficulties in resolving the drop spectrum tail. Although not clear at the time, the 2D-S was often unable to resolve the tail by itself due to limited sample volume.

- In spite of the above, the following summary and conclusions are proposed.

Summary of TCu warm rain case Studies

- All cases studies displayed droplet coalescence embryos larger than 50 µm just above cloud base. 27-Jul-22 had embryos to at least 110 µm . There was no rain in shallow cloud base cloud measurements.

- All case studies showed development of a coalescence tail at +14 C and/or at altitudes above. In rough terms, warm rain developed from the base and increased to a maximum at the +5 C level.

- By +5 C, LWC in the tail of the spectrum dominated over the condensation mode. Rainfall rates were > 10 mm/h and as high as 23 mm/h

- In the 4 <u>liquid-only</u> cases at -9 C, similar results were observed to +5 C. Rainfall rates 1.5 – 13 mm/h.

- In the one high-aerosol case (30-Jul), cloud drop concentrations reached a 1-second maximum of 715 cm^{-3} at the base, and 790 cm^{-3} at +14 C. While warm rain was just starting at +14 C, at -9 C 64% of the LWC was ≥ 49.5 µm, and the rainfall rate was 6.3 mm/h.
    - It's only one case, but it may support the contention of others that high aerosol moved the onset of warm rain higher in the cloud

Conclusions

- The one important conclusion is that warm rain had developed to significant levels by the freezing level on all days.
  - The high aerosol and CDCs on 30-Jul do not appear to have shut down the warm rain process, as proposed in the HIWC-2022 hypothesis.
  - Perhaps the existence of giant aerosol, likely sea salt, counteracted any lessening effect of coalescence due to high anthropogenic aerosol concentrations.
- The limits of the dataset preclude <u>quantification</u> of any high aerosol effects on TWC that might have been present for the single high aerosol case.

What can be taken from Konwar and Braga similar studies?

Konwar (2010): Suppression of warm rain by aerosols in rain-shadow areas of India

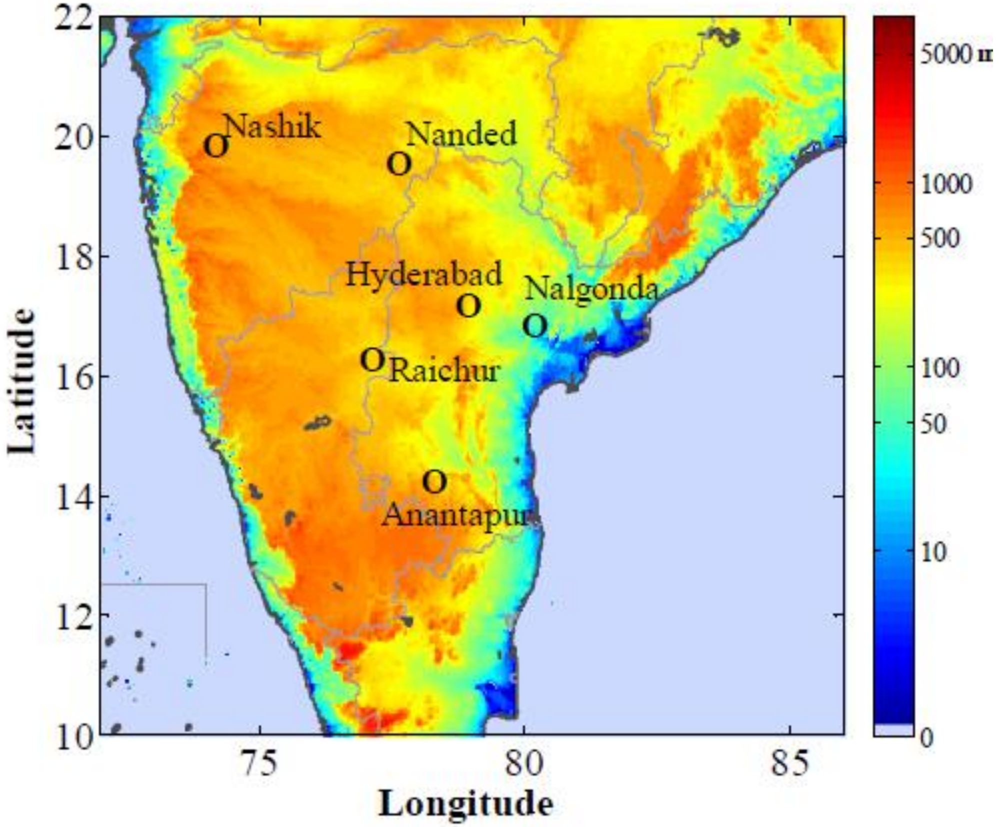


Table 1. Details of flight sorties, Aerosol and Cloud microphysical properties as measured by instrumented aircraft. Aerosol Optical Depth (AOD) from MODIS, Aerosol Index (AI) from TOMS and Convective Available Potential Energy (CAPE) obtained from radiosonde observations.

Date	Time of flight (UTC) Start	End	CAPE J/kg	AOD	AI	CDP cm^{-3}	CCN at 0.4% SS cm^{-3}	$CCN = aSS^b$ a	b
12/06/2009	07:04	09:55	1487	0.81	0.67	2062	3405	10 705	1.25
15/06/2009	08:12	10:10	221	0.40	1.28	948	1614	2849	0.62
16/06/2009	08:19	10:57	325	0.43	1.06	1379	2377	7405	1.24
21/06/2009	07:58	10:46	1523	0.64	0.81	1046	1669	4784	1.15
22/06/2009	07:53	10:46	439	0.15	1.12	388	657	1939	1.18
06/07/2009	07:46	10:44	1961	0.66	1.17	543	596	1856	1.24
16/09/2009	09:05	11:52	1070	0.47	0.75	1088	2989	18 681	2.00
23/09/2009	09:49	12:53	3138	0.52	0.64	1005	3858	9309	0.96
24/09/2009	09:21	12:40	2684	0.31	1.67	1076	2772	8884	1.27

- Nine flights, typically 5-10 cloud penetrations per flight
- Continental data that we do not have

Konwar (2010): Suppression of warm rain by aerosols in rain-shadow areas of India

- In lower aerosol concentrations, clouds developed warm rain early
- In high aerosol concentrations, warm rain development was slower and precipitation was suppressed in cloud that are not very deep, i.e., with tops less than at least 7 km.
  - Clouds had relatively cool bases ($T < \sim 15$ C) and therefore achieved lower adiabatic TWCs below the freezing level

Konwar (2012): Aerosol control on depth of warm rain in convective clouds

- 24 flights, presumably again with multiple cloud runs per flight (no details)
- 18 flights continental and/or coastal continental, 6 flight maritime over the Bay of Bengal and the Arabian Sea
- D* below is the height above cloud base that warm rain initiates; RLWC (d=50–1550 µm) > 0.01 g/m3 and re* > 12 mm

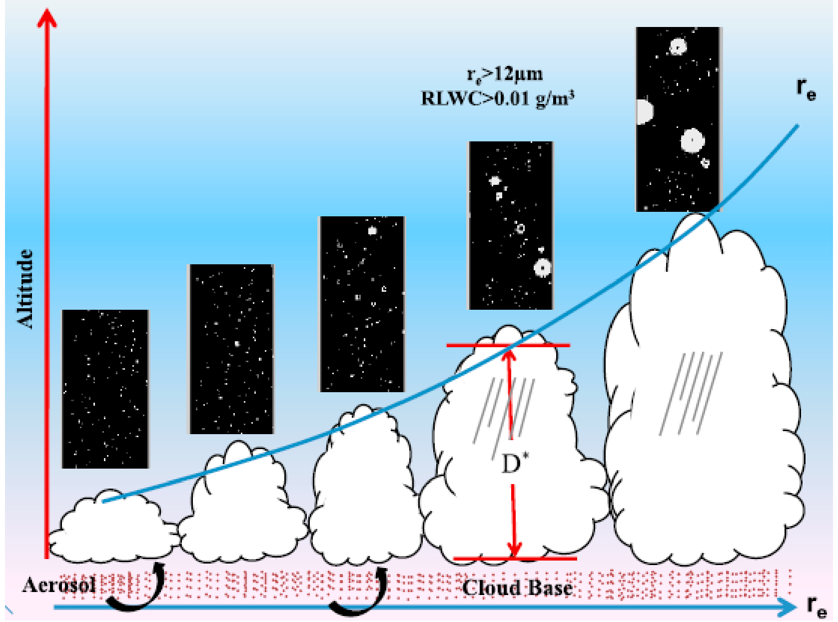
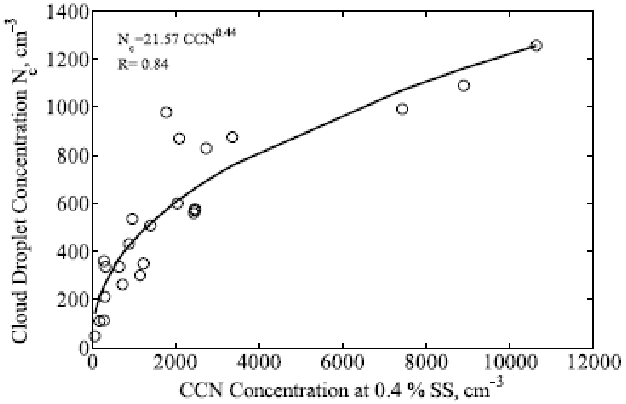


Figure 1. A schematic diagram for a developing convective cloud with images of in situ hydrometeors at cloud top that represent the microphysical processes. The effective radius (r_e) is shown conceptually by the blue line, r_e reaches 12 μm when precipitation is first seen at a cloud depth. When precipitation forms (RLWC > 0.01 g/m^3)the distance from cloud base to corresponding cloud depth is called the depth of warm rain, D*.



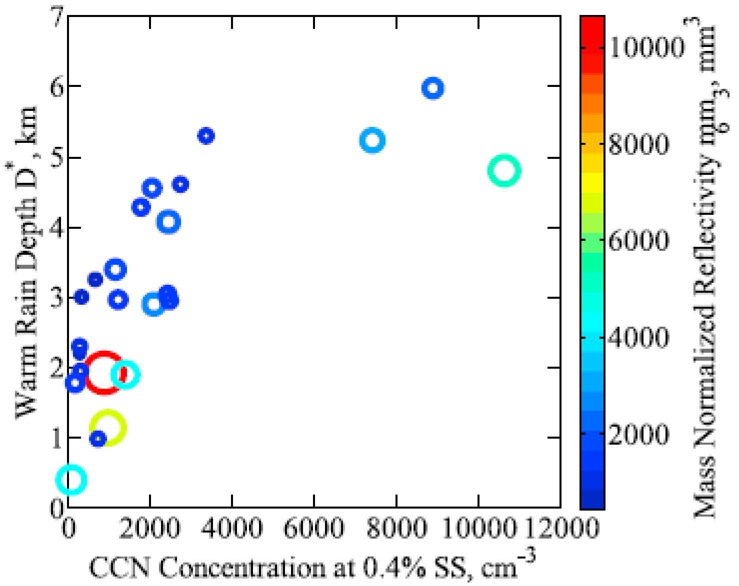


Figure 6. Interplay between CCN at SS = 0.4% and GCCN on the depth of warm rain. High CCN concentrations push the depth for warm rain higher (D*) while GCCNs (large Mass Normalized DSDs) induce smaller D*. For a given CCN, more GCCN (larger circle) show shallower depth for initiation of warm rain, D*.

Konwar (2012): Aerosol control on depth of warm rain in convective clouds

- Increasing concentrations of CCN push depth for warm rain to greater heights nonlinearly in the convective clouds. In extreme polluted cases D* exceeds 6 km.
- In the most pristine case found over BoB rain initiates at a very shallow cloud depth of 0.40 km.
- GCCN were found to decrease the depth for warm rain, counteracting the effect of small CCN.
  - Quite significant at high small CCN concentrations, not so much for pristine considitions

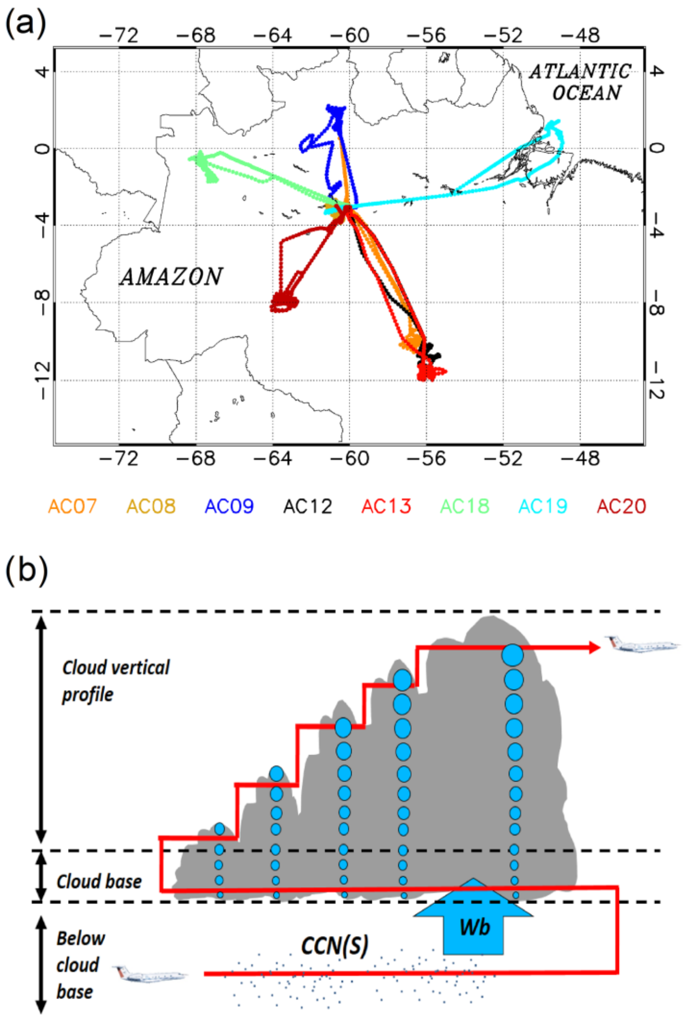
- With an increase in cloud water path (CWP) D* is found to decrease. (TWC effect again?)

Konwar (2012): Aerosol control on depth of warm rain in convective clouds

Our Measurements:

- We did not have any continental data. The Indian data shows that warm rain still exists over the continent, but can be cut off by high aerosol concentrations at least until depths where ice processes take over.
  - Could mean that we could expect higher TWC aloft in continental clouds versus maritime due to the CCN effect
- Our data established that warm rain was present and significant in our maritime clouds. There may be a hint of an suppressing effect for 30-July-2022.
  - The more general nature of the Konwar data seems to indicate that if high aerosol concentrations were present over the ocean, the suppression effect would also be active. The one caveat is that such maritime clouds would also be higher TWC than the Indian continental clouds due to much lower bases.

Braga et al. 2017: Further evidence for CCN aerosol concentrations determining the height of warm rain and ice initiation in convective clouds over the Amazon basin



- Eight flights, 8-15 cloud penetrations per flight
- All continental except one coastal (AC19)
- Typically 100-300 m below cloud top
- Sample cloud clusters (like us)

- D13 is the depth above base at which re reached 13 μm in an adiabatic model,
- Dt is their observed depth above base for the initiation of warm rain (DWC> 0.01 gm^{-3}, d=75-250 μm)
- Na is predicted adiabatic cloud droplet concentration

- Analysed the effect of aerosol concentration on ice initiation as well

Flight	Cbh(m)/T (°C)	N_a (cm^{-3})	D_{13} (m)	D_{r-1} (m)	D_r (m)	T_r (°C)	D_{i-1} (m)	T_{i-1} (°C)	D_i (m)	T_i (°C)	NLS	W_{max} (m s^{-1})	Classification
AC07	1900/15	963 ± 236	4500 ± 1104	–	–	–	3631	−5.3	4537	−9.1	14	13.09	Very polluted
AC08	1100/20	920 ± 162	3900 ± 690	–	–	–	–	–	–	–	10	8.2	Very polluted
AC09	1200/19.5	566 ± 98	2400 ± 420	2300	3000	2.4	4570	−6.0	5217	−9.2	15	8.8	Polluted
AC12	2200/15.5	1546 ± 434	9000 ± 2540	–	–	–	–	–	–	–	12	18.9	Very polluted
AC13	2200/15.5	1080 ± 234	5500 ± 1194	–	–	–	4240	−9.0	4800	−14.1	12	9.2	Very polluted
AC18	1700/17	666 ± 114	2900 ± 512	3100	3800	−5.7	–	–	–	–	13	19.9	Polluted
AC19	600/22	276 ± 54	1000 ± 198	1150	1660	10	–	–	–	–	13	8.49	Clean
AC20	1900/16.5	987 ± 224	5000 ± 1130	–	–	–	–	–	–	–	8	16.6	Very polluted

Braga et al. 2017: Further evidence for CCN aerosol concentrations determining the height of warm rain and ice initiation in convective clouds over the Amazon basin

- Most pollution in Amazon Basin due to smoke from biomass burning
- Rain initiation occurred higher in polluted clouds
    - A supercooled levels in moderately polluted clouds
    - In very polluted conditions, suppressed completely

- Initiation of ice also delayed in more polluted conditions (suppression of Hallet and Mossop ice multiplication).
- Ice initiation by freezing raindrops when not suppressed (like ours??)

- Warm rain results are very similar to Indian study.

Braga et al. 2017: Further evidence for CCN aerosol concentrations determining the height of warm rain and ice initiation in convective clouds over the Amazon basin

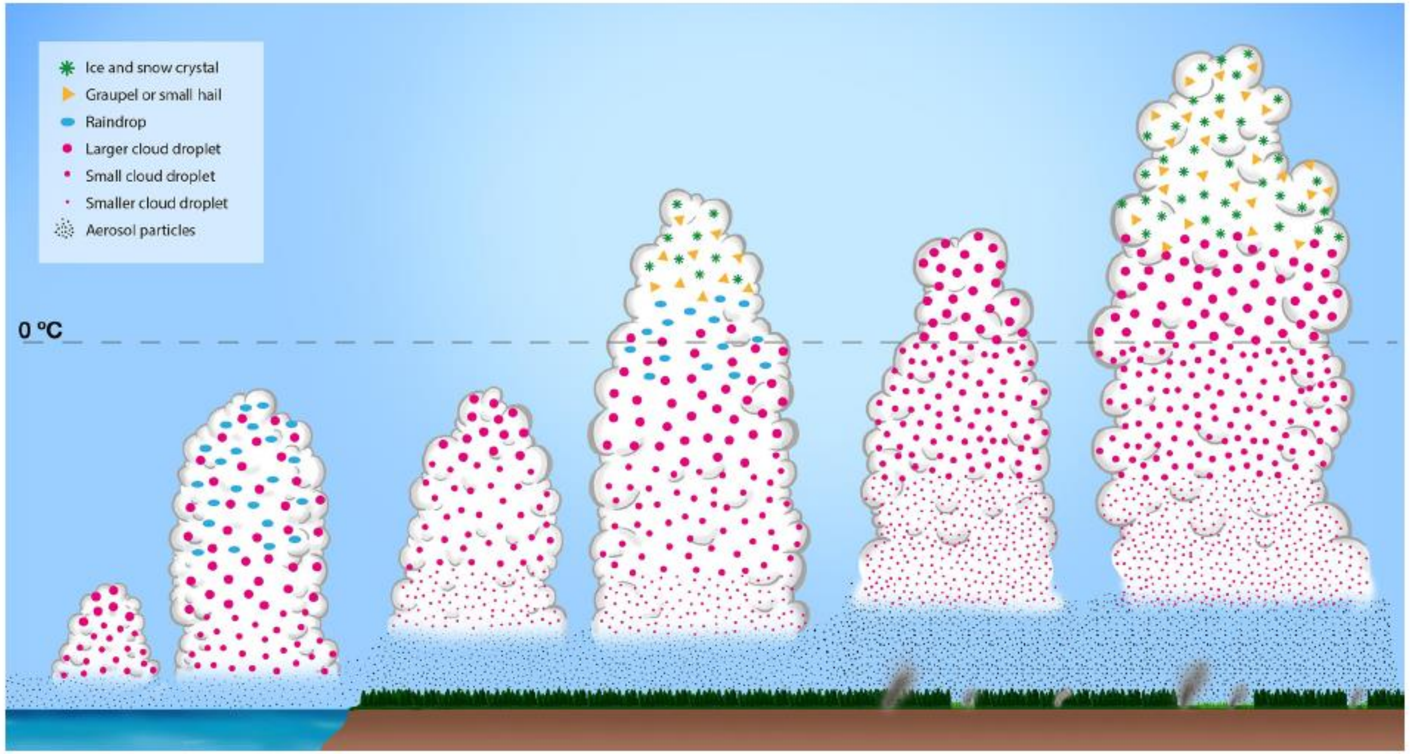


Figure 17. General characteristics of growing convective cumulus formed over the Amazon basin during the dry season. The heights of cloud base are higher over the continental Amazon due to the smaller relative humidity in comparison with the maritime region. Convective clouds formed over the Atlantic Ocean near the Brazilian coast have smaller cloud droplet concentrations (N_d) at cloud base due to the smaller concentration of aerosol and updraft speeds below cloud base. The initiation of warm rain (D_r) is observed at lower cloud depths (~ 2 km or ~ 10 °C) from collision and coalescence processes. When convective clouds are more continental, larger aerosol concentration and updrafts are observed below cloud base, leading to larger N_d nucleated at cloud base (as observed above forested and deforested regions). Over the forest D_r is observed near 0 °C, whilst for the deforestation arc region the collision and coalescence processes are totally suppressed and the formation of ice particles took place at higher altitudes in the clouds in very polluted conditions because the resulting smaller cloud droplets froze at colder temperatures compared to the larger drops in the less polluted cases.

Takeaways

- Both studies mainly document continental clouds
- Both studies show that the height at which drizzle forms above base is increased by increasing aerosol, and can be completely suppressed in the most polluted cases, at least until ice processes take over
- Indian study shows that GCCN somewhat counteract the high small CCN concentration effect. No observations from Brazil study in this regard.
- No cases of high pollution over the ocean, but
  - General nature of the results suggests that if high CCN concentrations existed over maritime areas, the same suppression effect could be active.
- The one caveat is the effect of the higher maritime TWCs caused by warm water and lower cloud bases
  - The continental cases in both the Indian and Brazil cases tended to be in drier atmospheres with colder cloud bases, and thus lower condensation rates

Adiabatic TWCs

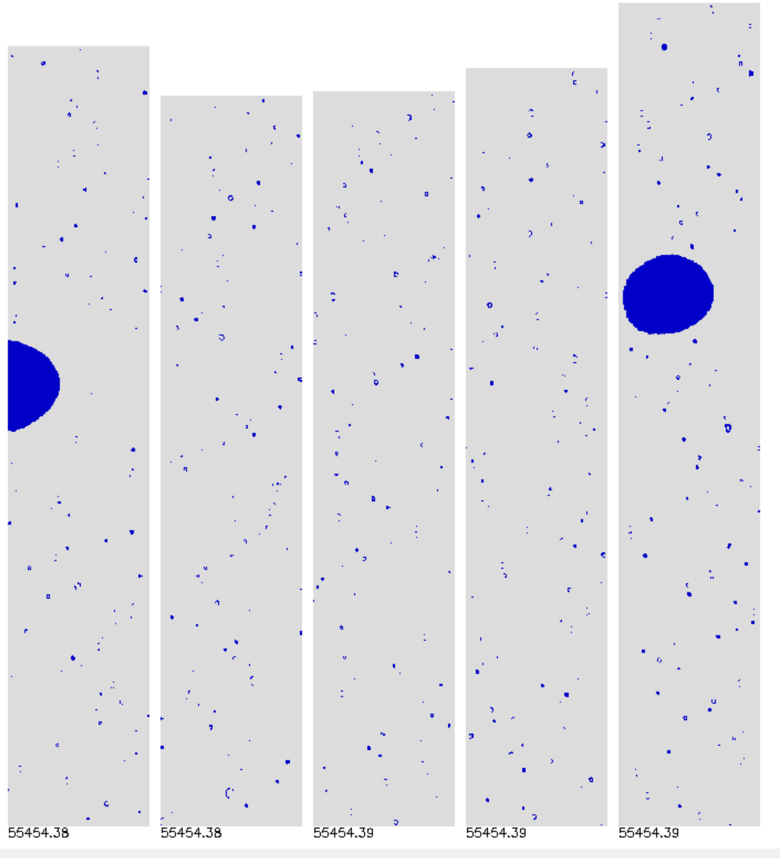
					Estimated Adiabatic Liquid Water Content (gm^{-3})								
Campaign	T_{surf}	Tdew $_{surf}$	RH_{surf}	W_{surf} g/kg	20 C	15 C	10 C	5 C	0 C	-15 C	-10 C	-15 C	-20 C
HIWC-2022	27	24	84	18.9	2.1	4.4	6.0	7.0	7.6	7.9	7.9	7.8	7.5
India/Brazil Dry Cont.	33	16	36	11.4	Below base	Below base	0.9	2.5	3.6	4.3	4.7	4.9	5.0
Brazil Wet Cont.	31	22	59	16.6	At base	2.5	4.3	5.5	6.2	6.7	6.9	6.9	6.7

End of Presentation

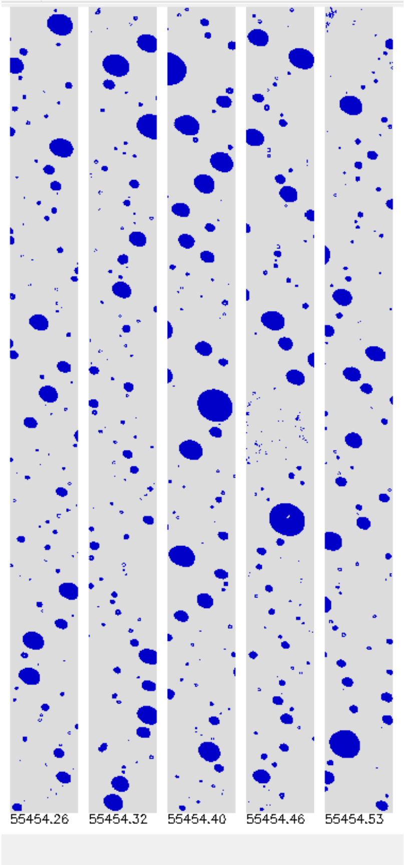
Extra slides

Case study 27-Jul-2022, +6.8 C

2D-S V

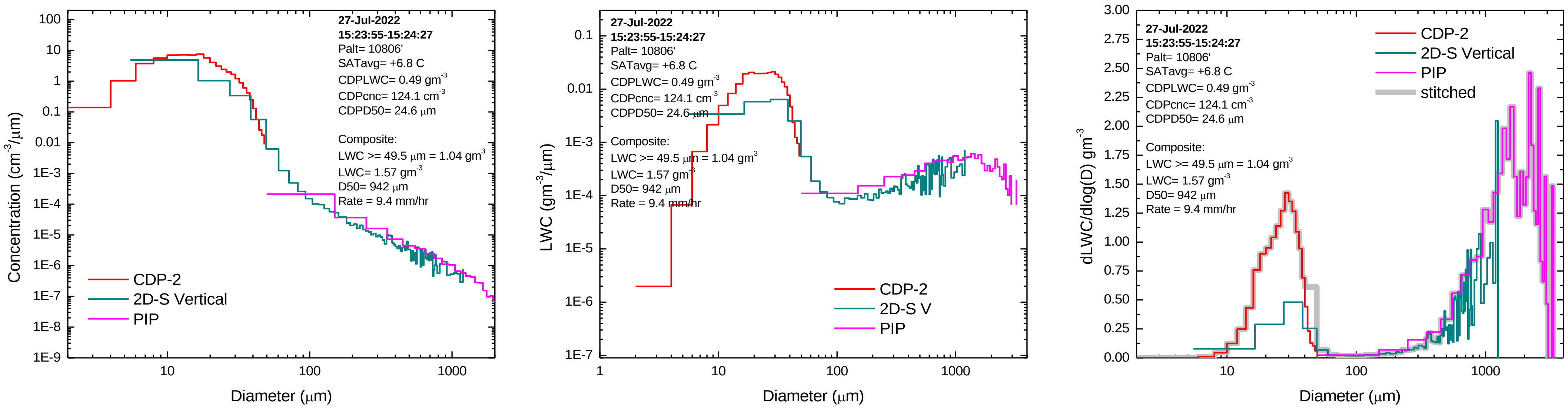


PIP



15:23:55-15:24:27

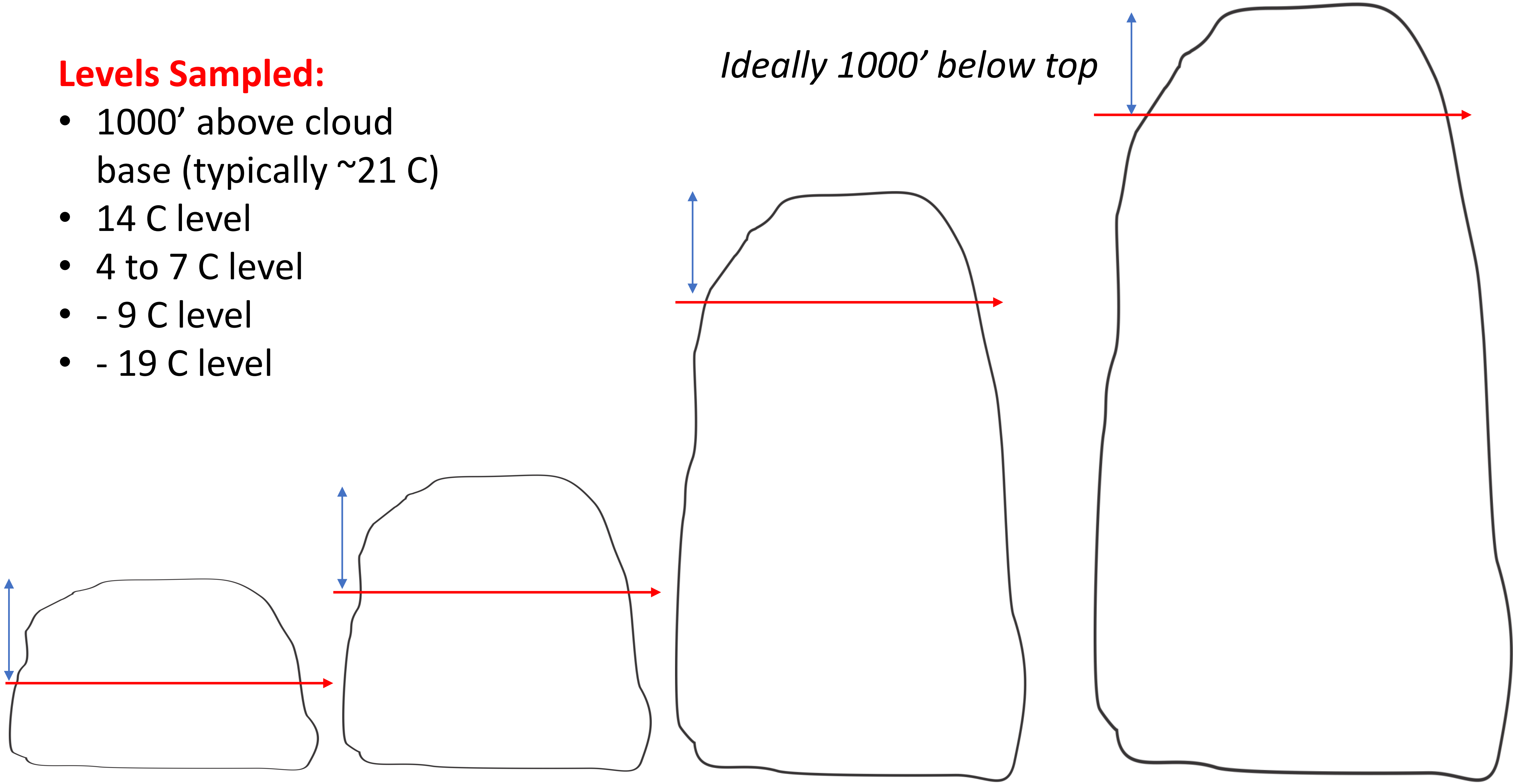
Case study 27-Jul-2022, +6.8 C



- Major fraction of LWC now in tail of spectrum; LWC > 50 µm about 2/3 of LWC
- Composite LWC = 1.57 gm^{-3} , Rainfall rate ~ 9.4 mm/hr

Levels Sampled:

- 1000’ above cloud base (typically ~21 C)
- 14 C level
- 4 to 7 C level
- - 9 C level
- - 19 C level



How TCu measurements fit into this.

- Convective cells are the building blocks of MCSs and transport condensate high into the atmosphere, ejecting ice into the surrounding anvil
- Examination of TCu data allows us to study the first order hypothesis before the system is mature, and before convective cells become influenced by complex interactions with the surrounding cloud
  - Also allows examination of cloud parcel evolution at different stages of parcel ascent.

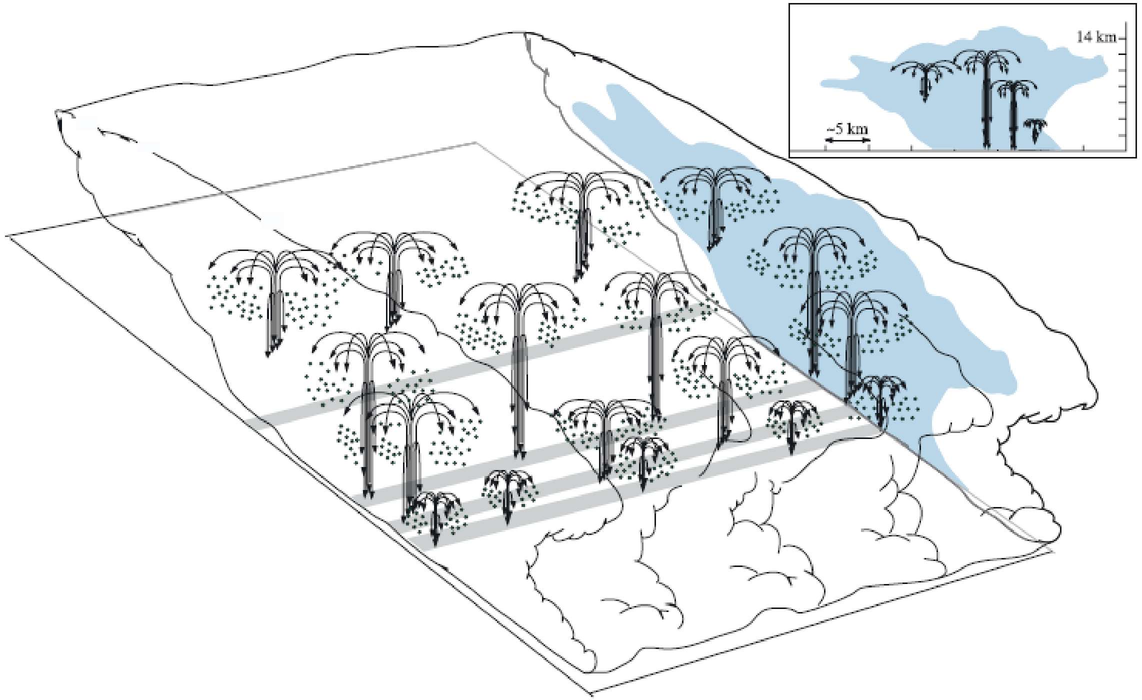


Figure 15. Conceptual model of an ensemble of particle fountains in a multicellular MCS. Shaded area represents radar reflectivity along a cross section perpendicular to the convective region. Cloud boundary is indicated by the scalloped outline. Inset shows approximate scales and arrangement of the largest particle fountains relative to the radar echo. From *Yuter and Houze* [1995b].