Aerosol Particles from Cirrus Anvils and Cloud Bases: TEM results

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1 Introduction

Aerosol particles work as CCN and IN, affecting cloud formation. Efficiency as CCN and IN depends on their **compositions**, **sizes**, **crystal structures**, and **mixing states**. Individual particle analysis using TEM is uniquely suited for obtaining such information. The combination of imaging, selected-area electron diffraction (SAED), and energy dispersive X-ray spectrometry (EDS) enables detailed characterization of individual aerosol particles.

We are studying aerosol particles collected from cloud anvils and bases as well as outside of the clouds. Characterization using TEM and comparison between different kinds of aerosol samples provides insights regarding formation and processing of particles inside clouds.

Ca-sulfate particles
- Elongated grains or rods
- Commonly coexist with sea salt

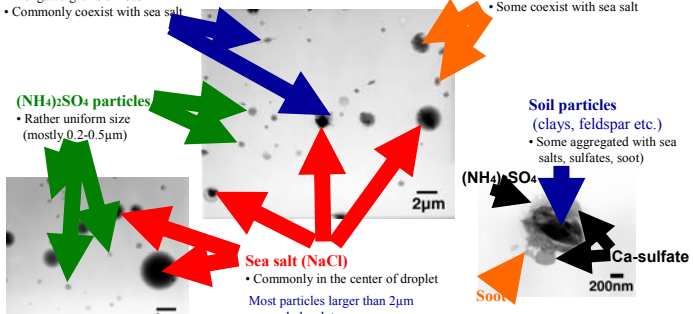
Na-sulfate particles
- Round or rectangular grains
- Some coexist with sea salt

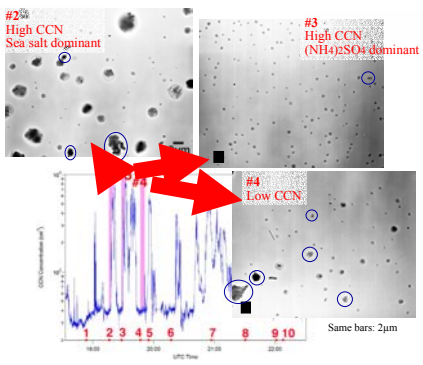
$(NH_4)_2SO_4$ particles
- Rather uniform size (mostly 0.2-0.5μm)

Soil particles
(clays, feldspar etc.)
- Some aggregated with sea salts, sulfates, soot)

Sea salt (NaCl)
- Commonly in the center of droplet

Most particles larger than 2μm are such droplets



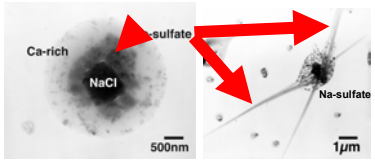


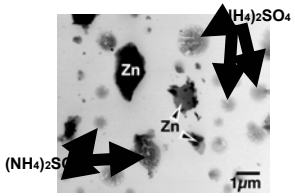
Variations of aerosol compositions

Proportions of sea salt, sulfates, soil particles, and soot differ considerably among samples.

Example: July 28th samples
Based on the CCN-counter data, both grids #2 and #3 collected abundant CCN. But the particle compositions differ. Sea salt particles predominate on grid #2, while $(NH_4)_2SO_4$ particles predominate on grid #3. On grid #4, sampled when the CCN concentration was low, soil and $CaSO_4$ particles occur in higher proportion than on grids #2 and #3.

Water droplets
Most droplets enclosing sea salt are rich in Ca, Na, Cl and S.
Ca- and Na-sulfate particles commonly occur in such droplets.





Relationship to aerosols from anvils?
Two of the Twin Otter samples contain unusually abundant metal-rich particles similar to those in the anvil samples. The relationship is currently unknown.

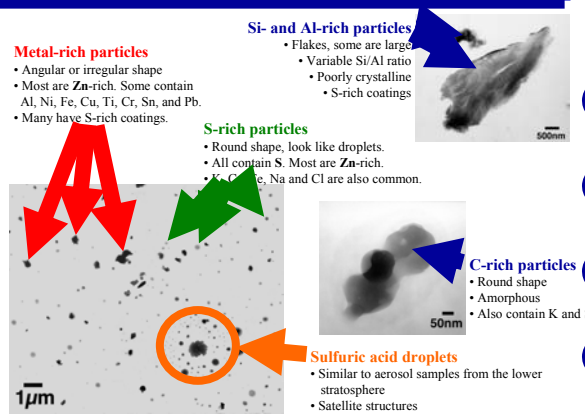
Metal-rich particles
- Angular or irregular shape
- Most are **Zn**-rich. Some contain Al, Ni, Fe, Cu, Ti, Cr, Sn, and Pb.
- Many have S-rich coatings.

Si- and Al-rich particles
- Flakes, some are large
- Variable Si/Al ratio
- Poorly crystalline
- S-rich coatings

S-rich particles
- Round shape, look like droplets.
- All contain **S**. Most are **Zn**-rich.
- K, Ca, Fe, Na and Cl are also common.

C-rich particles
- Round shape
- Amorphous
- Also contain K and S.

Sulfuric acid droplets
- Similar to aerosol samples from the lower stratosphere
- Satellite structures

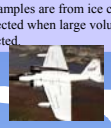


2 Aerosols from cirrus anvils
(Upper troposphere, 13-14km high)

We used CAPS/MASP and water-content data to determine which samples are from ice clouds. **Nine** samples were collected when large volumes of ice crystals were detected.

Flight	Grids
26-Jul	4 (of 7)
28-Jul	9 (of 14)
29-Jul	8 (of 13)
31-Jul	4 (of 13)
	25 (of 47)

Number of analyzed WB57F grids



3 Aerosols from cloud bases
(Lower troposphere, 1-3 km high)

We gave priority to the samples from July 28th flight.
We also analyzed several grids sampled when the relative humidity was high and large volumes of aerosol particles were detected.

Flight	Grids
3-Jul	3 (of 17)
16-Jul	3 (of 3)
18-Jul	2 (of 7)
21-Jul	1 (of 7)
23-Jul	1 (of 4)
26-Jul	2 (of 9)
28-Jul	10 (of 10)
	22 (of 84)

Number of analyzed TO grids

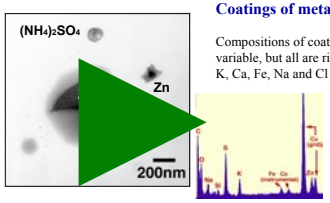
Sampling
Aerosol particles were directly deposited onto Cu TEM grids using single-stage multiple aerosol collection systems (MACS) on board the WB57F and Twin Otter aircraft.

4 Summary

- Samples from anvils contain abundant metal-rich (mostly Zn) particles. The amount is apparently related to the amount of ice crystals detected during sampling.
  …Artifacts resulting from ice crystals hitting the airplane?
- Aerosols at cloud bases consist mostly of sea salt and sulfate particles. Sea salt particles tend to acquire coatings of water and result in large particle sizes.
  …Sea salt would be removed from convecting air mass by precipitation.
- A direct link between aerosols from anvils and from cloud bases is not evident at this time.(The only type of particles common to both are the metal-rich ones but these may be artifacts).

Coatings of metal-rich particles
Compositions of coating materials are variable, but all are rich in **S**.
K, Ca, Fe, Na and Cl are common.

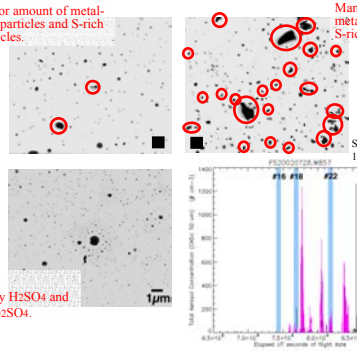
The compositions are similar to those of round S-rich particles.



#18
Minor amount of metal-rich particles and S-rich particles.

#22
Many and large metal-rich and S-rich particles.

#16
Mostly H_2SO_4 and $(NH_4)_2SO_4$.



Sample#	CAPS/MASP data: Aerosol_Conc (# cm-3)	Aerosol_Vol (um3 cm-3)	Xtal_conc (# liter-1)	Altitude (km)	Particle type: Metal	S/-Al	C-rich	H_2SO_4
WB 0728-#17	1,671	0.386	3,861	13.2-16.2			◐	●
WB 0728-#18	58,681	14652.51	375,142	13.2-16.2	●		●	●
WB 0728-#19	84,387	11,525	107,210	16.1-16.2		◐	●	●
WB 0728-#20	47,719	57,839	179,611	4.8 - 6.6	●●●			
WB 0728-#12	2,475	0.553	5,387	17.7-18.0	◐	◐	●	●
WB 0728-#14	1,922	0.454	4,259	17.8-18.0	◐			●●
WB 0728-#16	11,608	2,568	22,231	16.2-16.3	◐	●	●	●●
WB 0728-#17	113,768	199420.495	45361.818	14.4-14.6		●		●
WB 0728-#18	251,777	275846.667	64403.437	13.6-13.8	●	●		●
WB 0728-#19	1234,455	3242660.708	7451.70.772	13.6-14.7	●●			
WB 0728-#20	414,858	679846.658	14214.5.791	14.0-14.3	●●	●		
WB 0728-#22	712,610	1554181.664	24864.1.945	13.6-14.3	●●●	●	●	●
WB 0728-#23	2,121	0.990	6,288	15.6-16.2	N	●	●	●
WB 0729-#12	1,572	0.218	3,072	13.7-13.8			●	●
WB 0728-#17	3,998	1.233	8,117	18.7-17.1	N	●●		N
WB 0729-#19	4,948	1.888	12,632	16.2-16.3	N	●●		●●
WB 0729-#19	8,788	3.209	29,989	13.7-16.3	N	●●		●
WB 0729-#20	21,439	7.527	45,248	13.7-13.8	N	●●	●	●
WB 0729-#21	14,573	724.541	203,488	13.7-13.8		●	●	
WB 0729-#22	942,330	147441.5,559	34861.0.597	13.1-13.8	●●	●●	●	●
WB 0729-#23	144,403	22257.68.718	53807.048	13.0-13.2	●●	●	●	
WB 0731-#15	4,571	0.715	7,758	18.8-18.0			●	
WB 0731-#16	2,469	0.284	4,017	18.9-18.4				
WB 0731-#17	2,341	0.308	4,464	18.5-18.3				
WB 0731-#20	10,212	20.605	25,812	18.3-18.1	●●			●●
WB 0731-#22	48,918,391	2480524.2	348024.347	18.1 - 18				

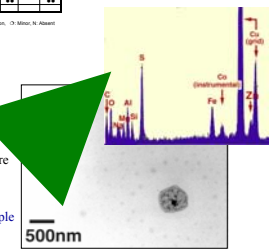
●●● :Especially abundant, ●● :Abundant, ● :Common, ◐ :Minor, N: Absent

Amount of metal-rich particles
Metal-rich particles are abundant only in the samples from ice clouds (green in the table).

Example: July 28th samples
Sampling periods of grids #16, #18, and #22 are shown as blue bands in the above graph. Number and volume of metal-rich particles (red circles) on grids increase in the order #16 < #18 < #22.
These values appear to correlate with ice concentrations.

Relationship to aerosols in the lower stratosphere?
Some sulfate particles in the samples from the lower stratosphere (blue in the above table) contain minor amounts of Zn and Fe.

WB 0728-#14 sample



5 Ongoing work

- Clarify origin of the metal-rich particles
  …Analysis of airplane material possible?
- Further systematic analyses necessary for better understanding of processing in clouds
  …Check with the data of other instruments
  …Analysis of more grids
  …More intense survey for each grid
- Further comparison of;
  pre- and post cloud processing
  particles at anvils and cloud bases
  particles from the upper troposphere and lower stratosphere