Observations of aerosol and cloud properties: ice microphysics

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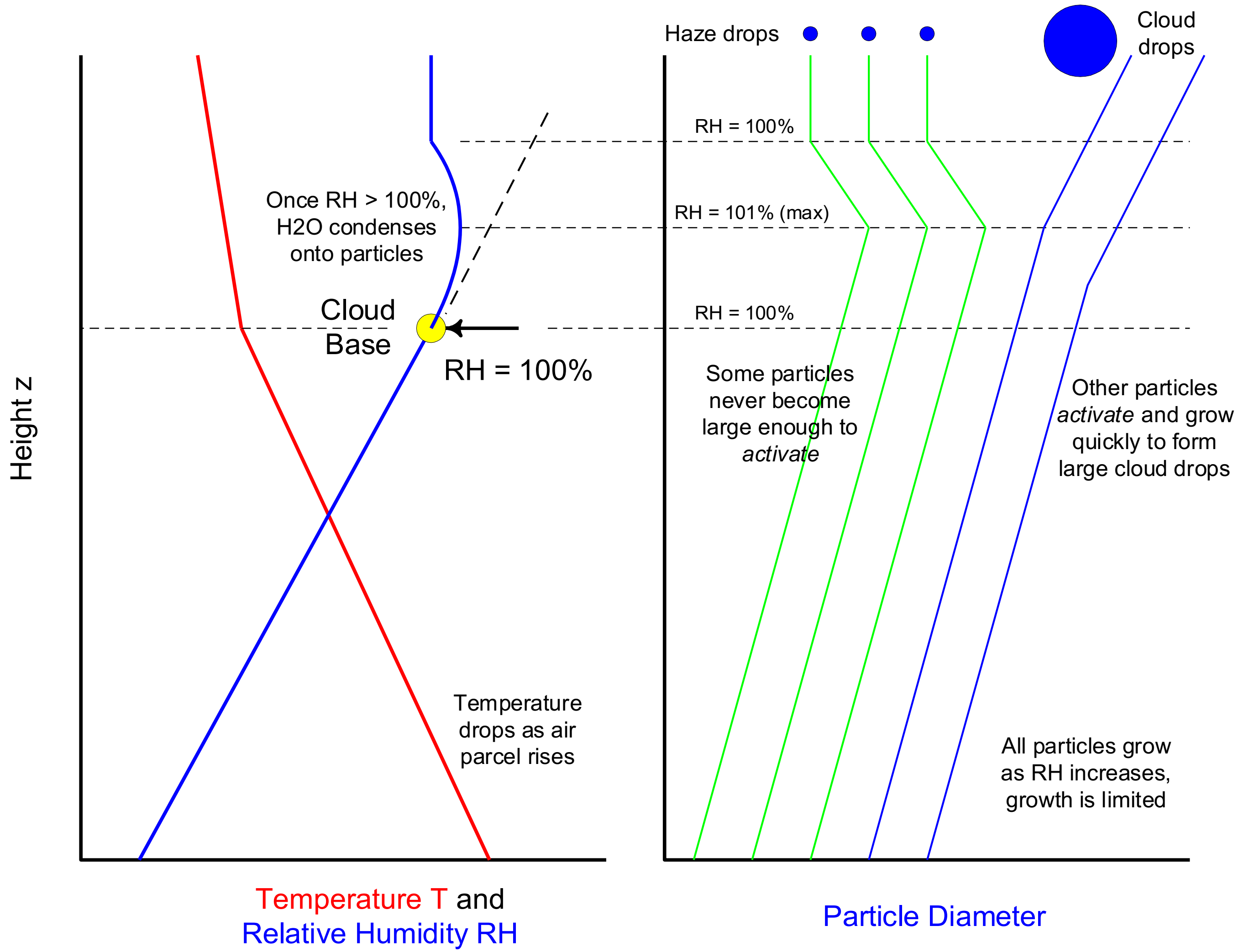
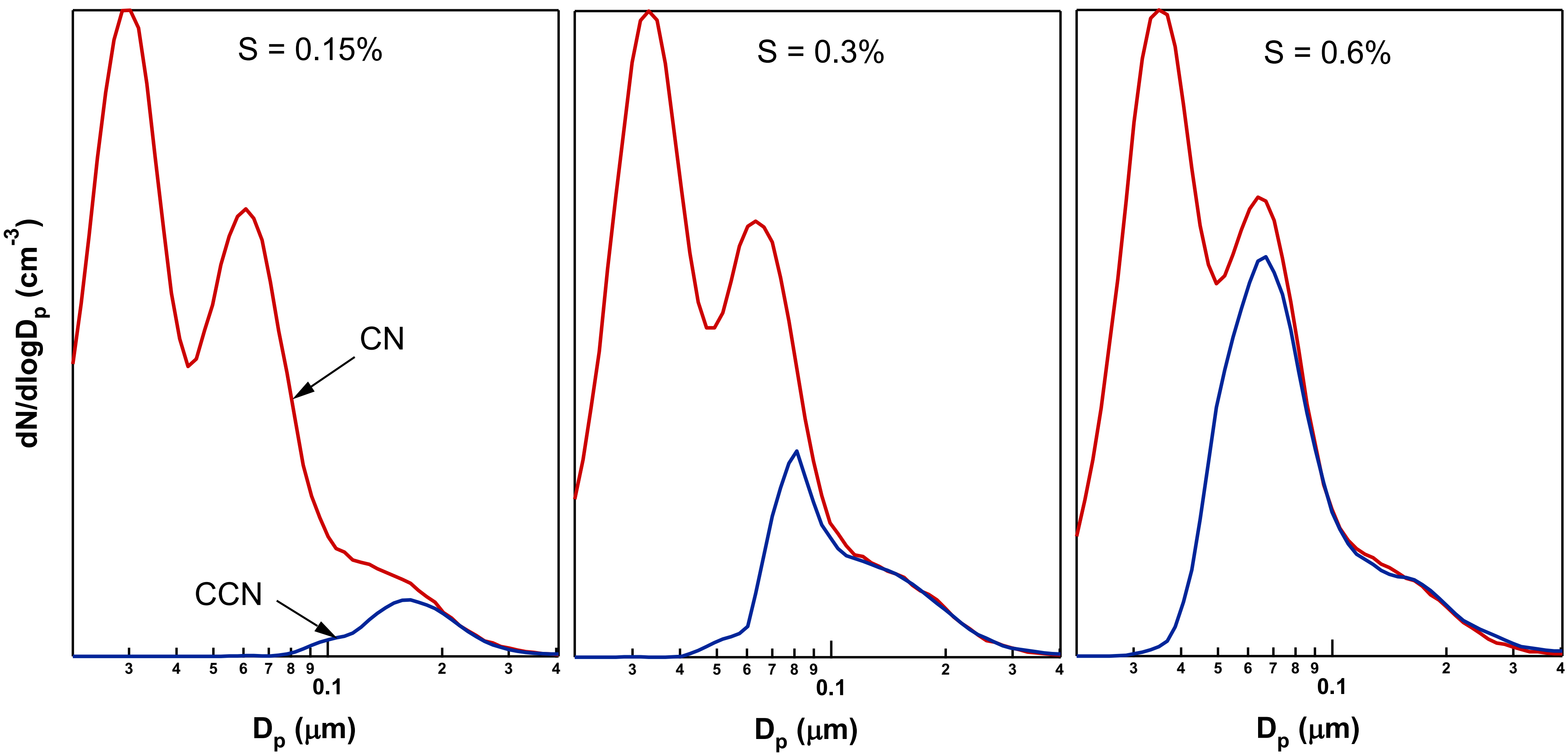
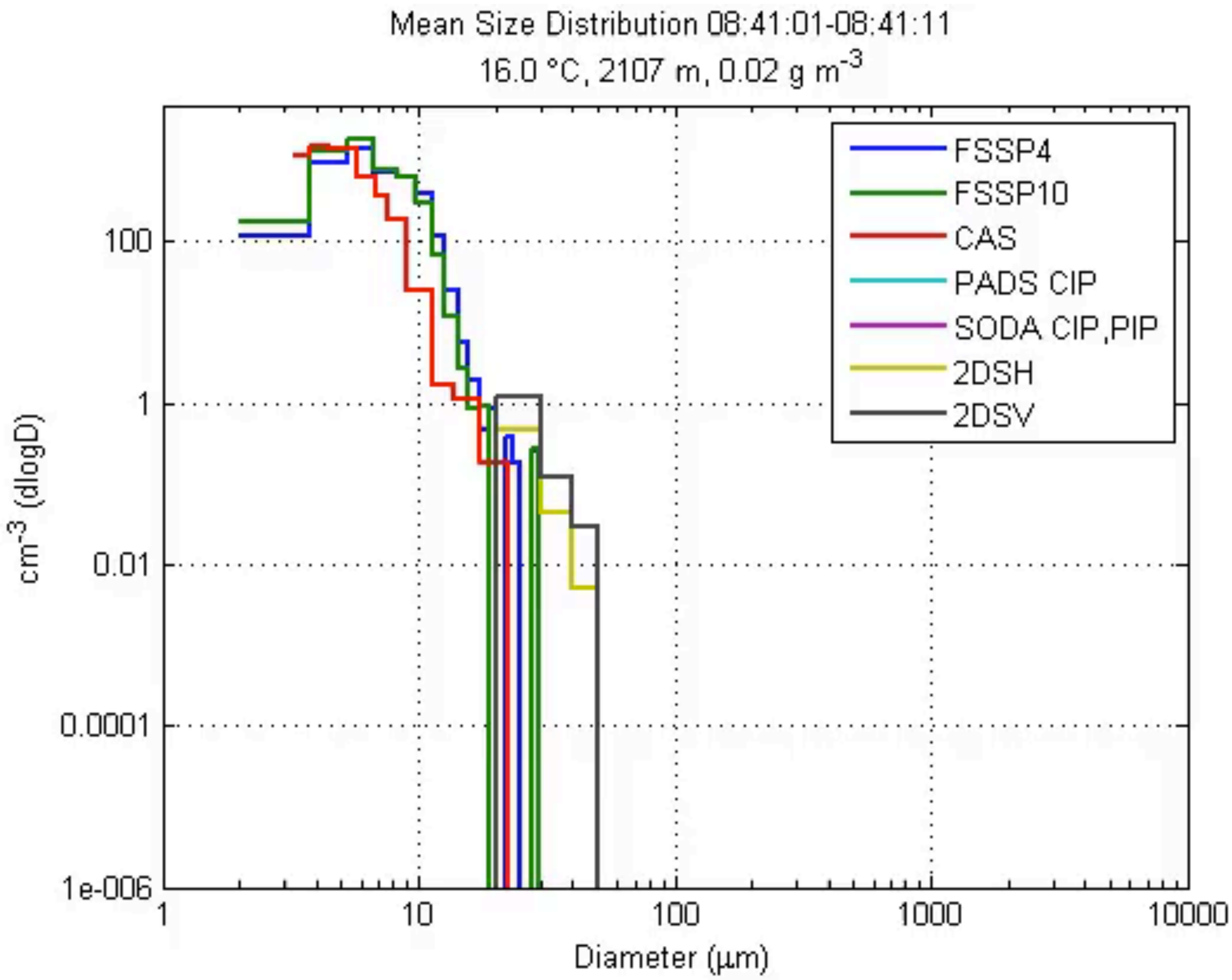
Droplet Measurement Technologies

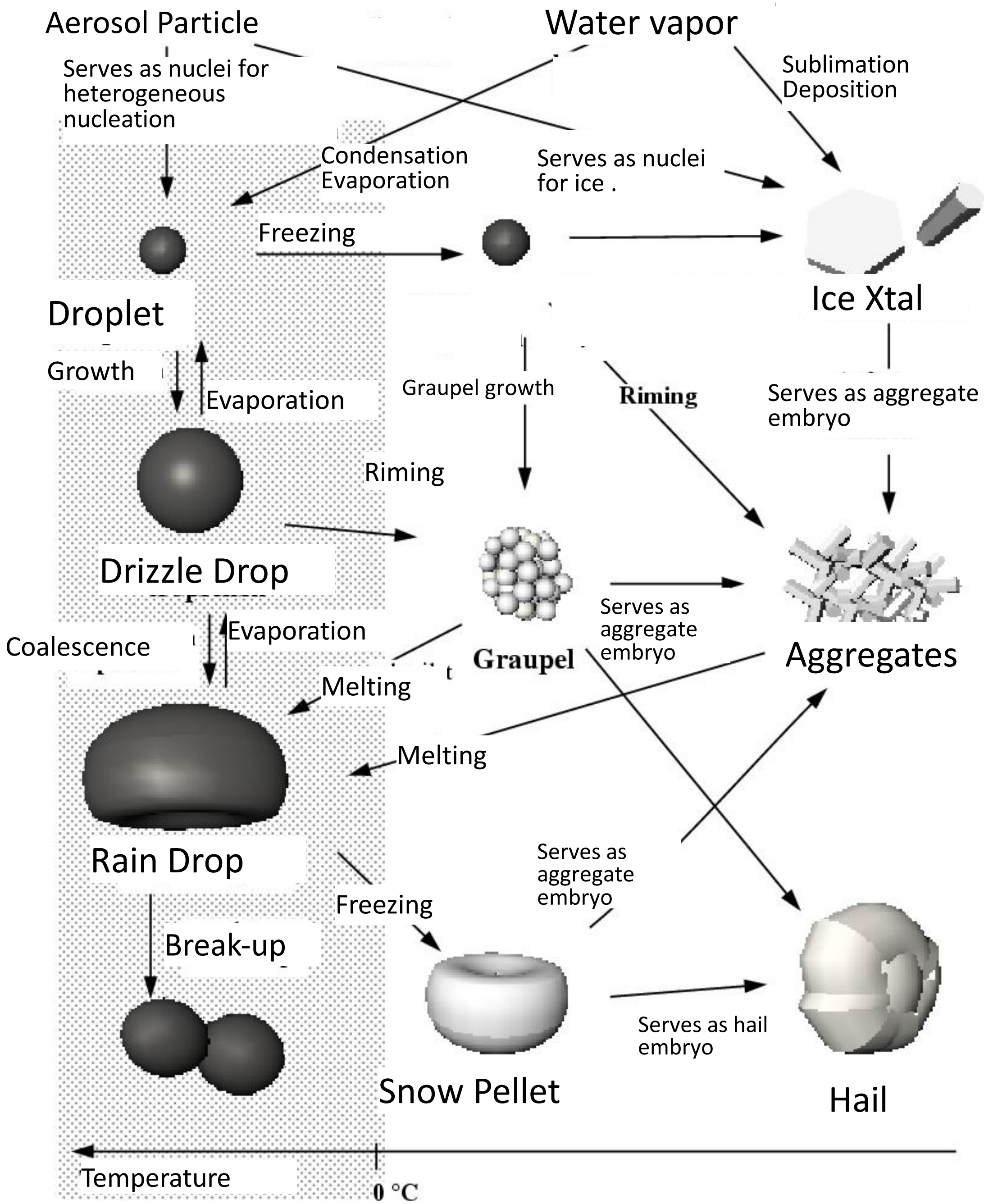
Cloud droplet activation



Example aerosol and CCN data from forest site




Mean Size Distribution 08:41:01-08:41:11
16.0 °C, 2107 m, 0.02 g m-3
FSSP4
FSSP10
CAS
PADS CIP
SODA CIP,PIP
2DSH
2DSV
100
1
0.01
0.0001
1e-006
cm-3 (dlogD)
1
10
100
1000
10000
Diameter (µm)



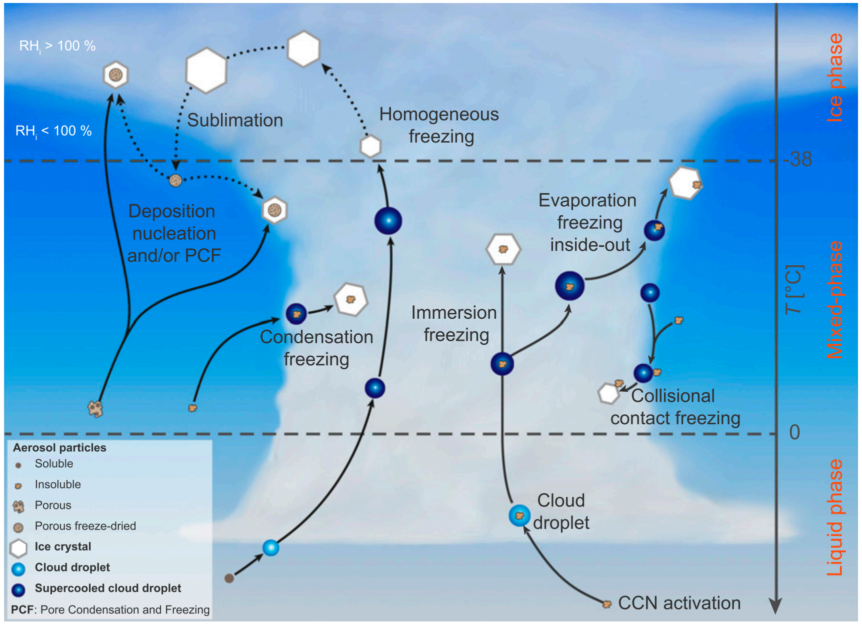
This diagram summarizes the possible pathways to the formation of precipitation.

A microphysical model must take each of these pathways into account.

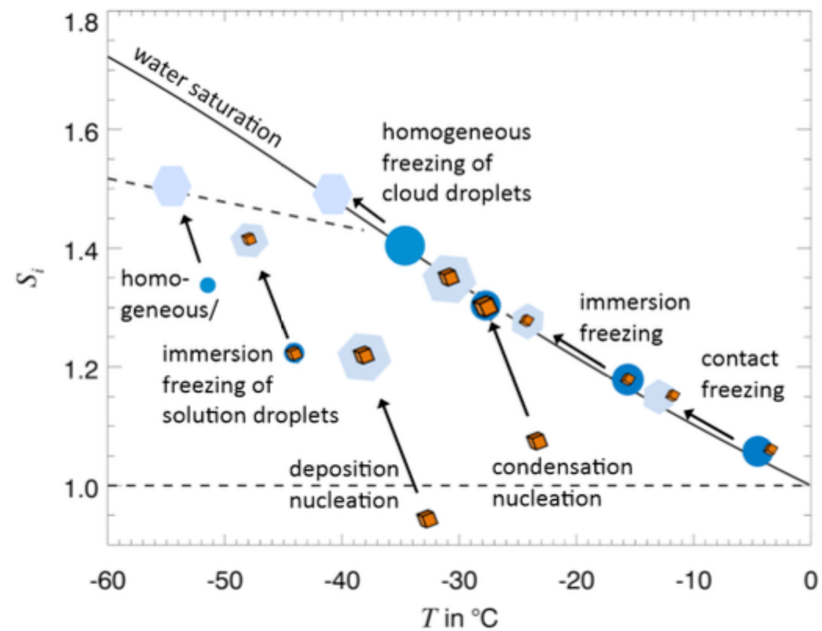
Each arrow belongs to a process requiring individual numerical treatment/subroutine for the model simulation

Figure courtesy of S. Borrmann

Modes of ice formation in clouds



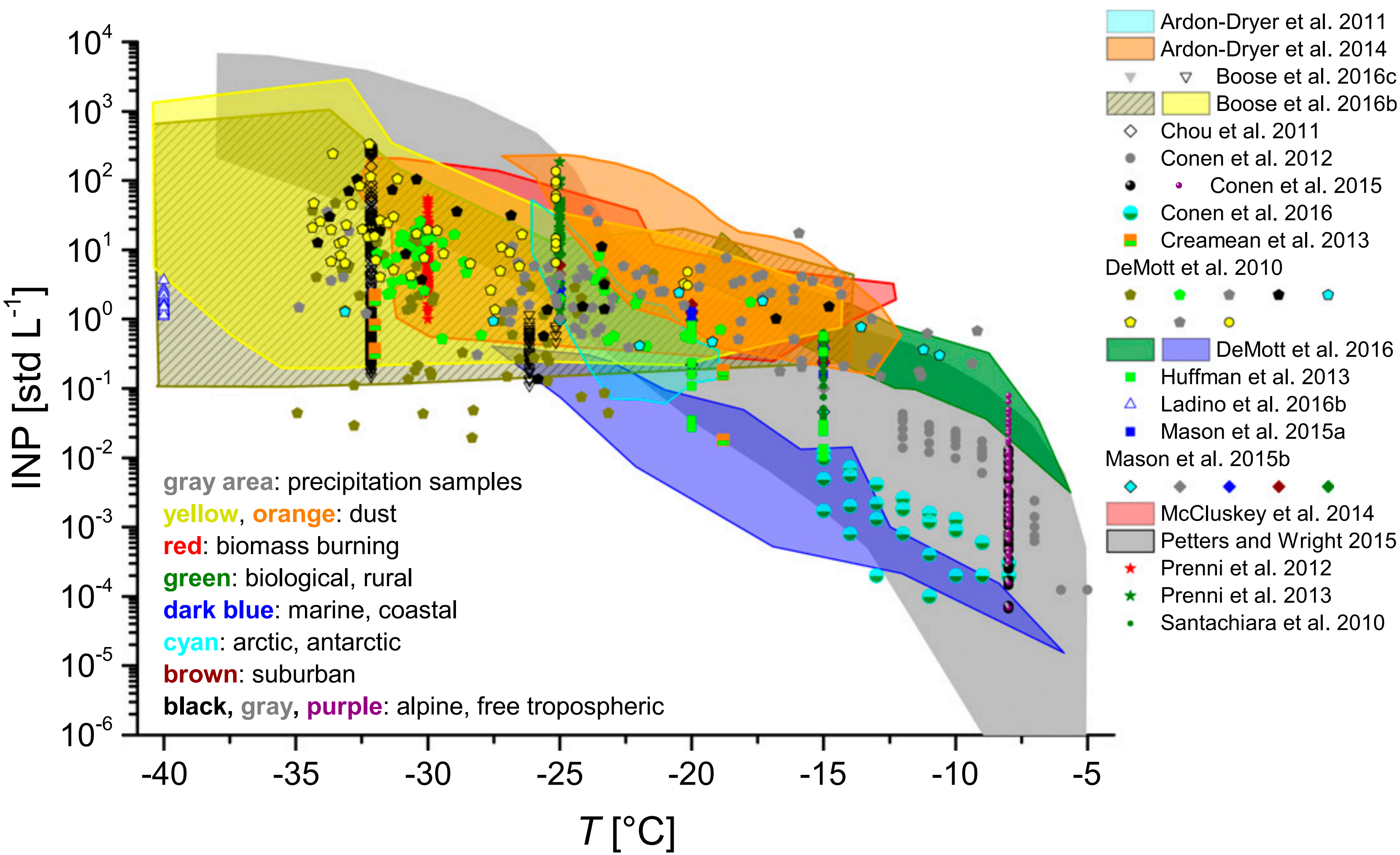
Kanji et al. 2017



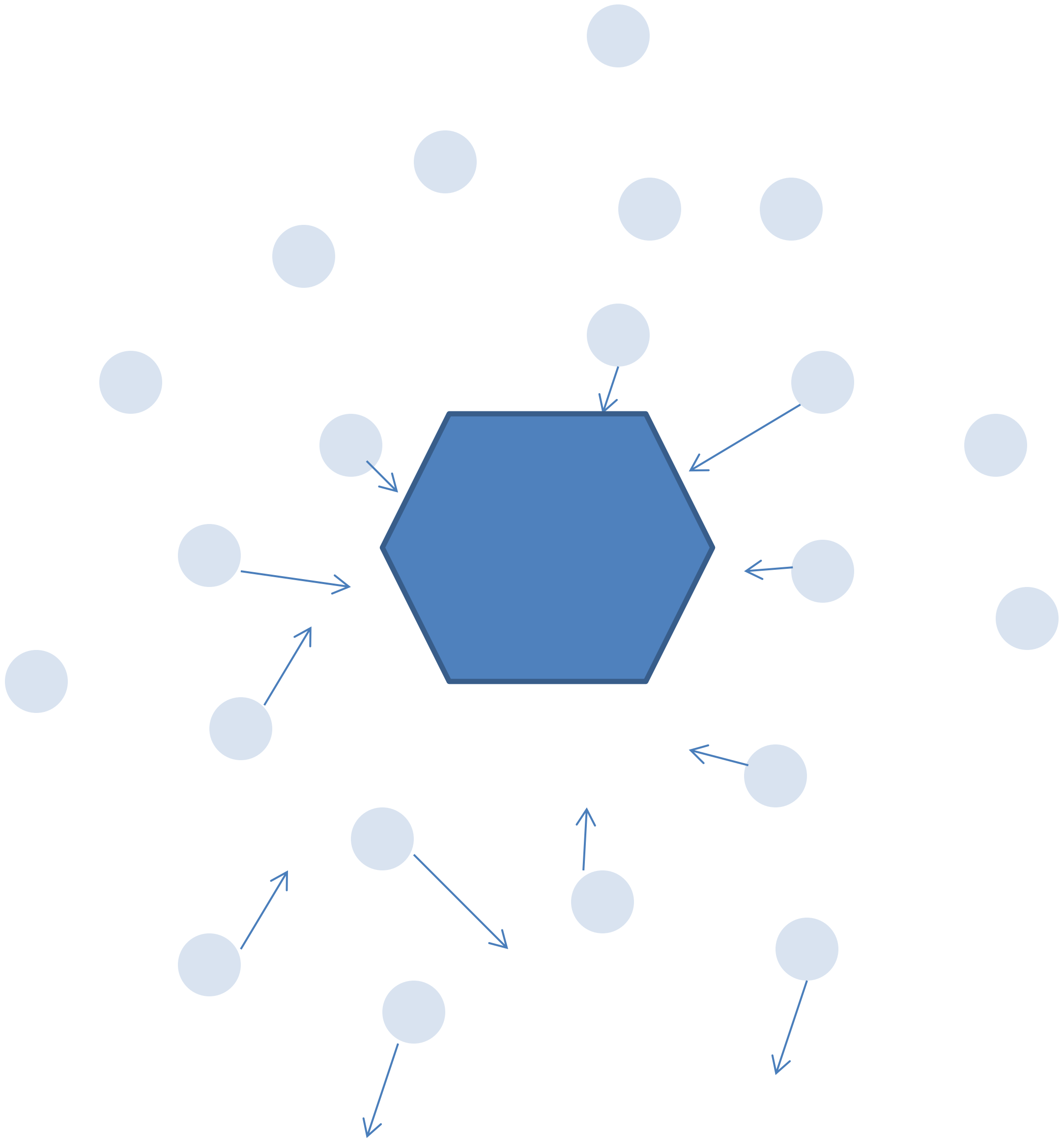
Hoose and Mohler 2012

- The importance of ice crystals in clouds for our climate is manifold: Their presence, number and shape influences the optical properties of clouds, the formation of precipitation and their lifetime. All of these aspects have an impact on the radiation balance and therefore on climate.

INP concentrations (Kanji et al. 2017)



Growth of IN by deposition



$$\frac{dM}{dt} = \frac{CGS}{\varepsilon}$$

C = shape factor

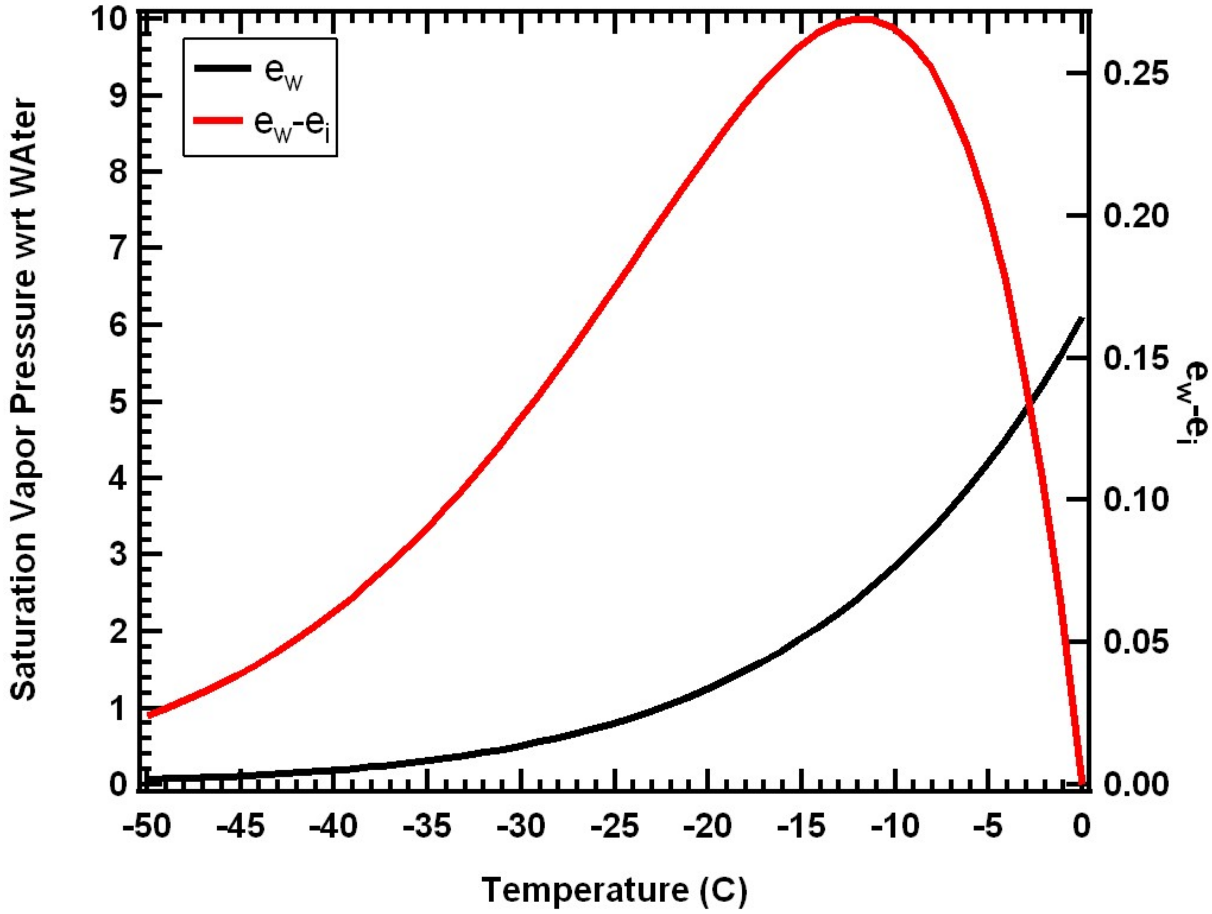
G~Diffusion coefficient

$S = e - e_s / e_s$

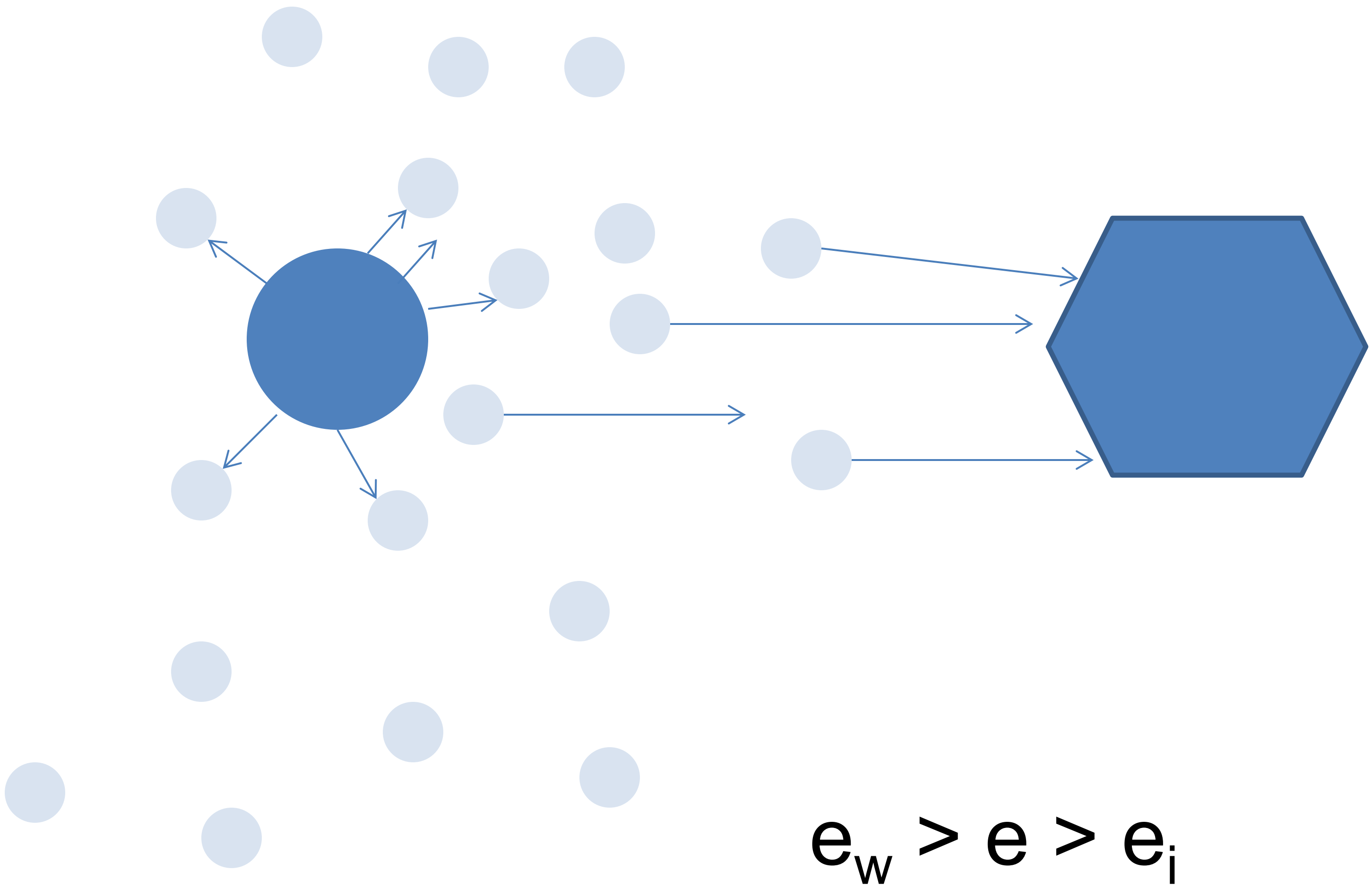
ε = permittivity of free space

Wegener – Bergeron – Findeisen process

The saturation vapor pressure for water, e_w, is always greater than that for ice, e_i. When the vapor pressure, e, in a cloud environment colder than freezing is $e_w > e > e_i$ then water droplets will evaporate and ice crystals will grow.



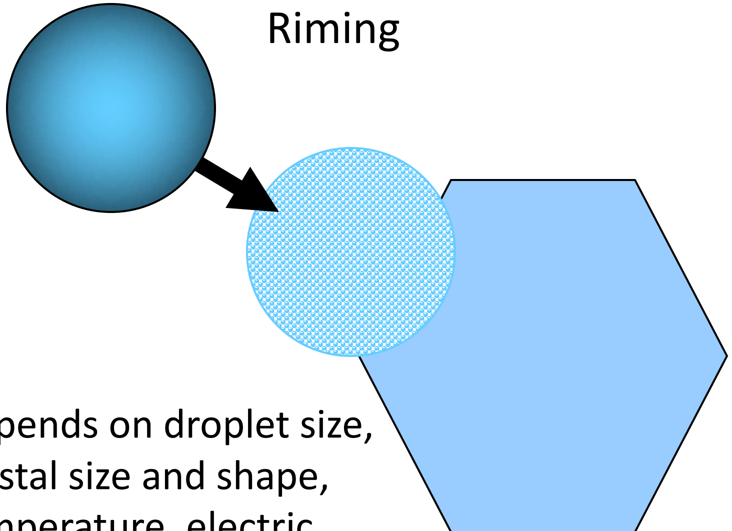
Wegener – Bergeron – Findeisen process



$$e_w > e > e_i$$

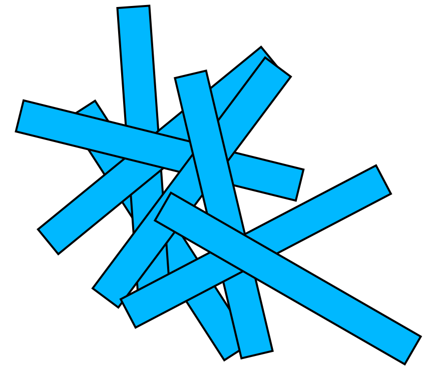
Growth of IN by aggregation, riming and multiplication

Riming



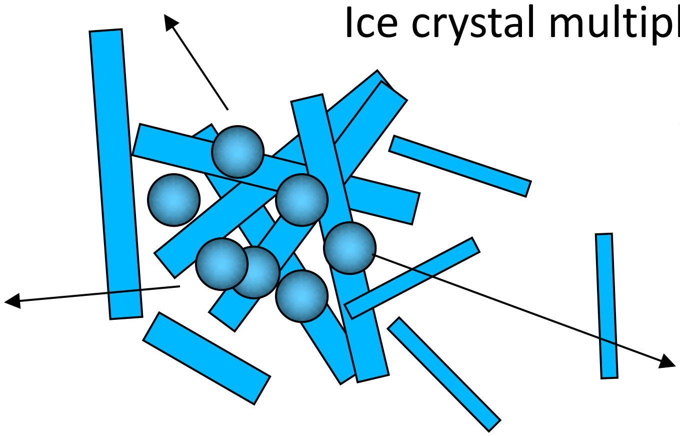
Depends on droplet size, crystal size and shape, temperature, electric charge, etc.

Aggregation



Depends on, crystal size and shape, temperature, electric charge, etc.

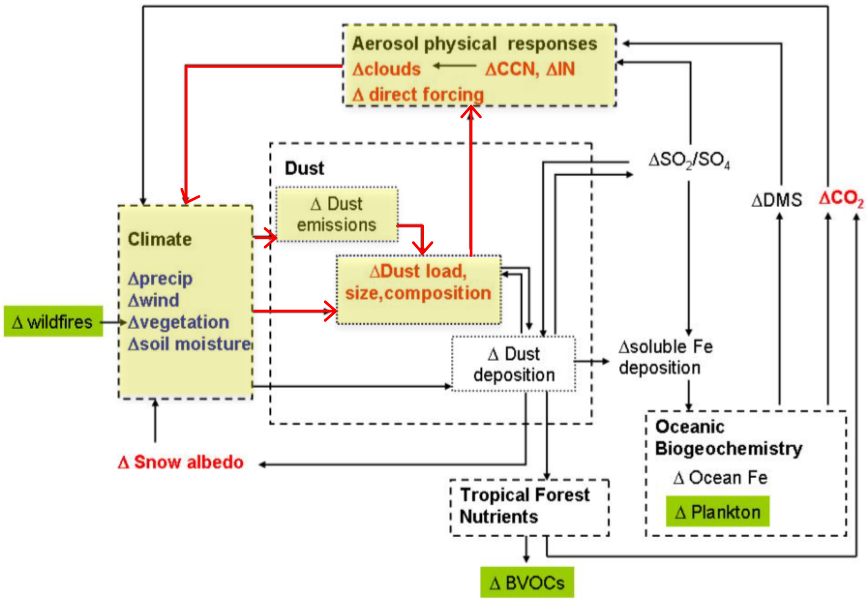
Ice crystal multiplication



Very little known about this mechanism for producing ice crystals.

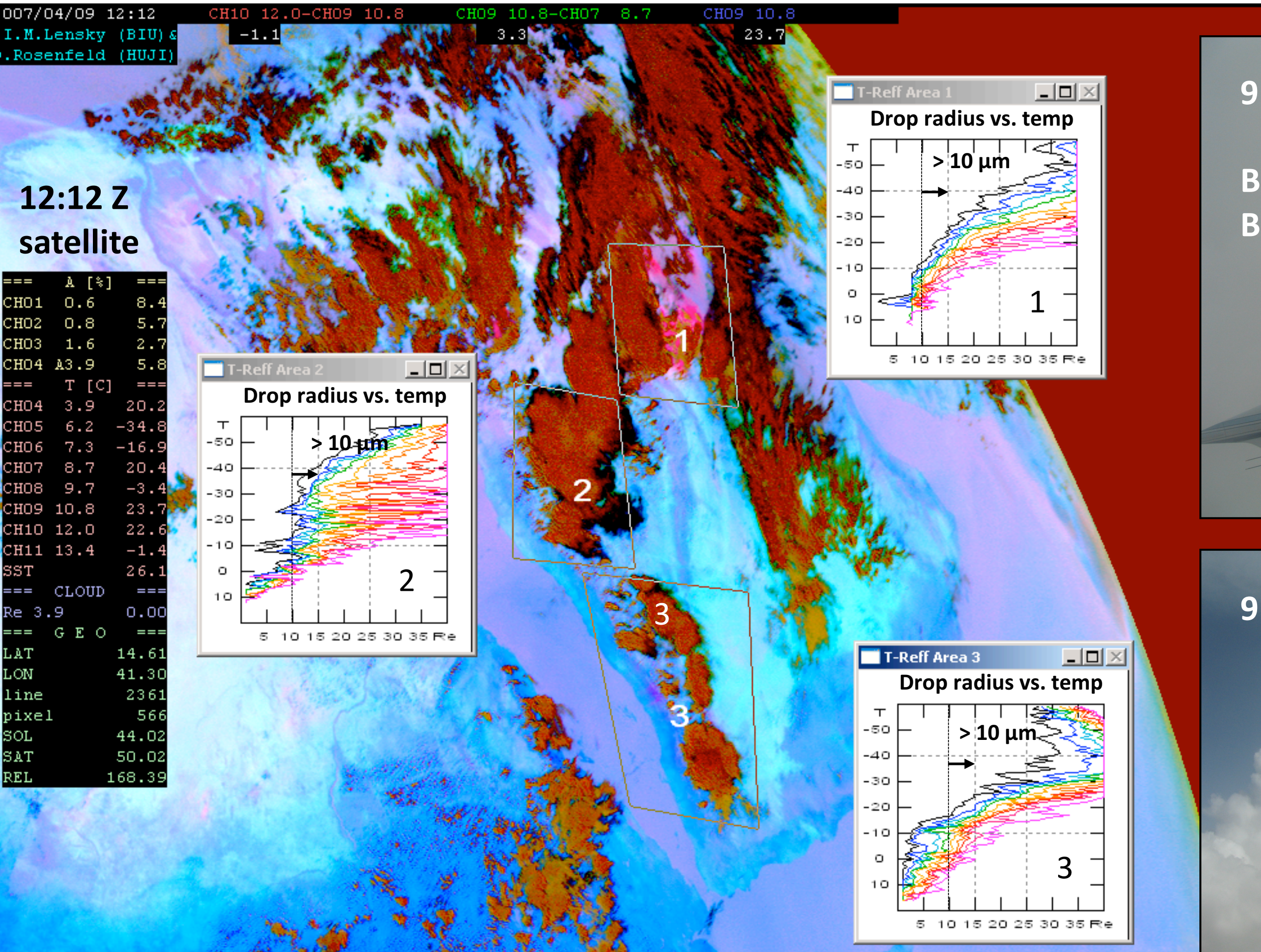
'Hallett-Mossop' and droplet splintering are the only processes that have been replicated in the laboratory

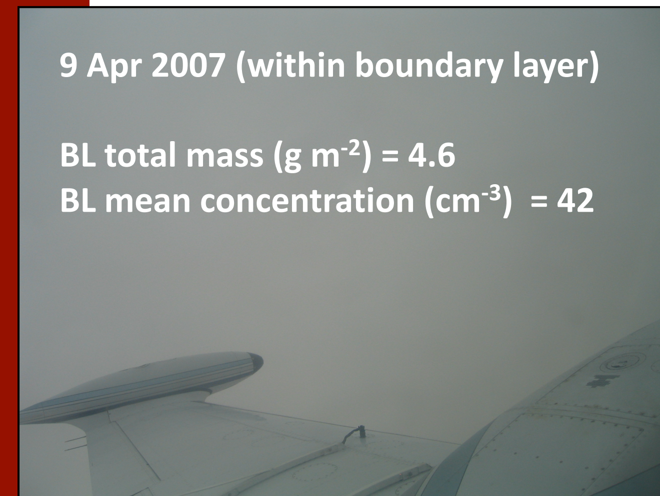
Impact of dust aerosol on climate through aerosol-cloud interactions



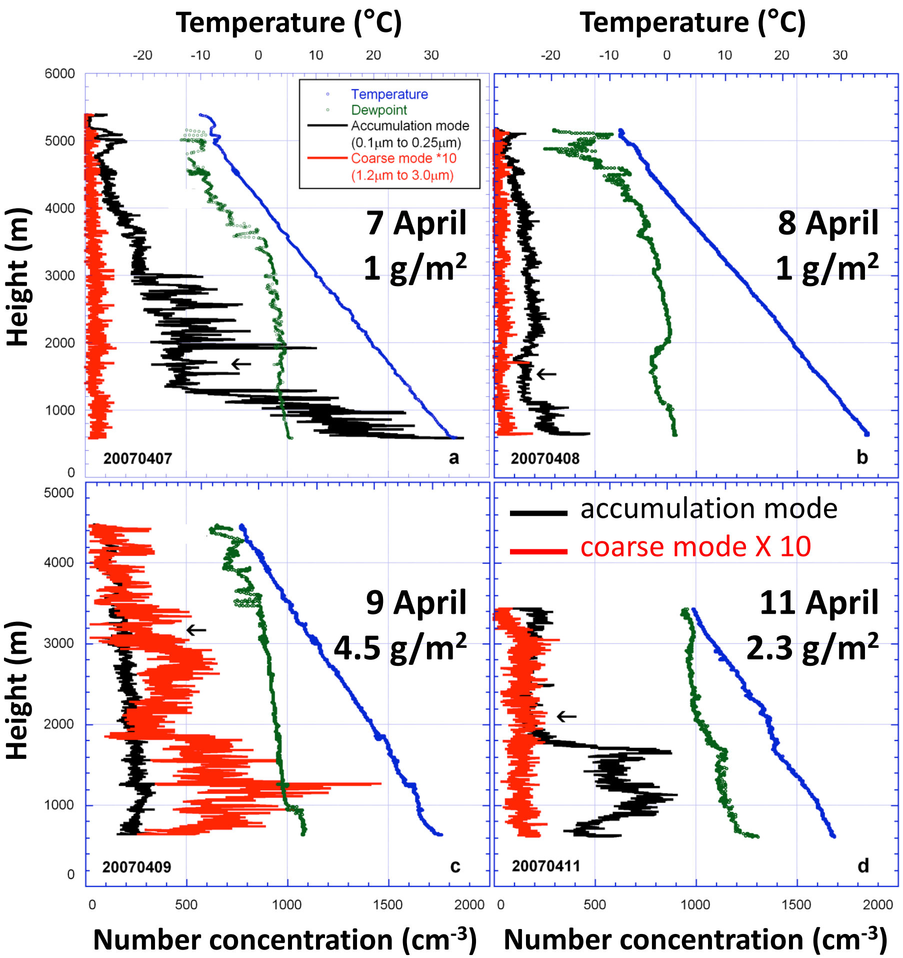
From "A review of natural aerosol interactions in the Earth system" by Carslaw et al., 2011.

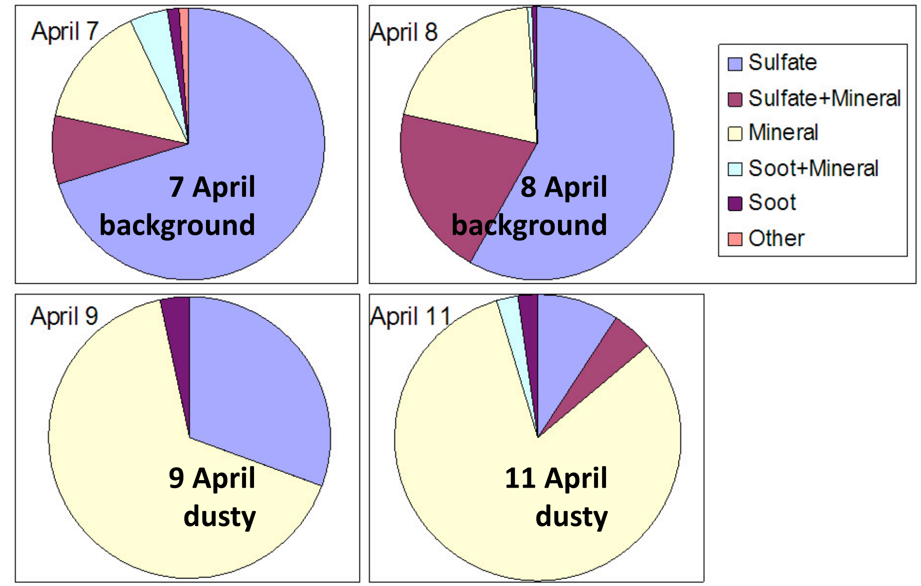
Aerosol-cloud interactions in Central Region
(9 April 2007 ‘haboob’ case)

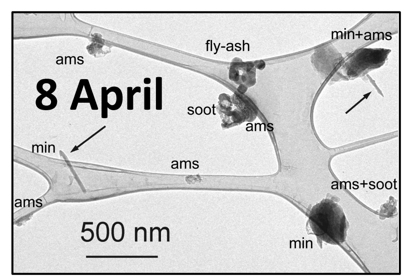




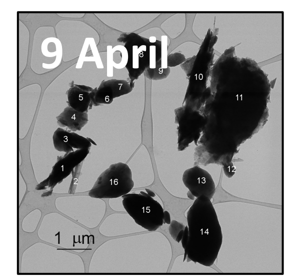
Aerosol properties





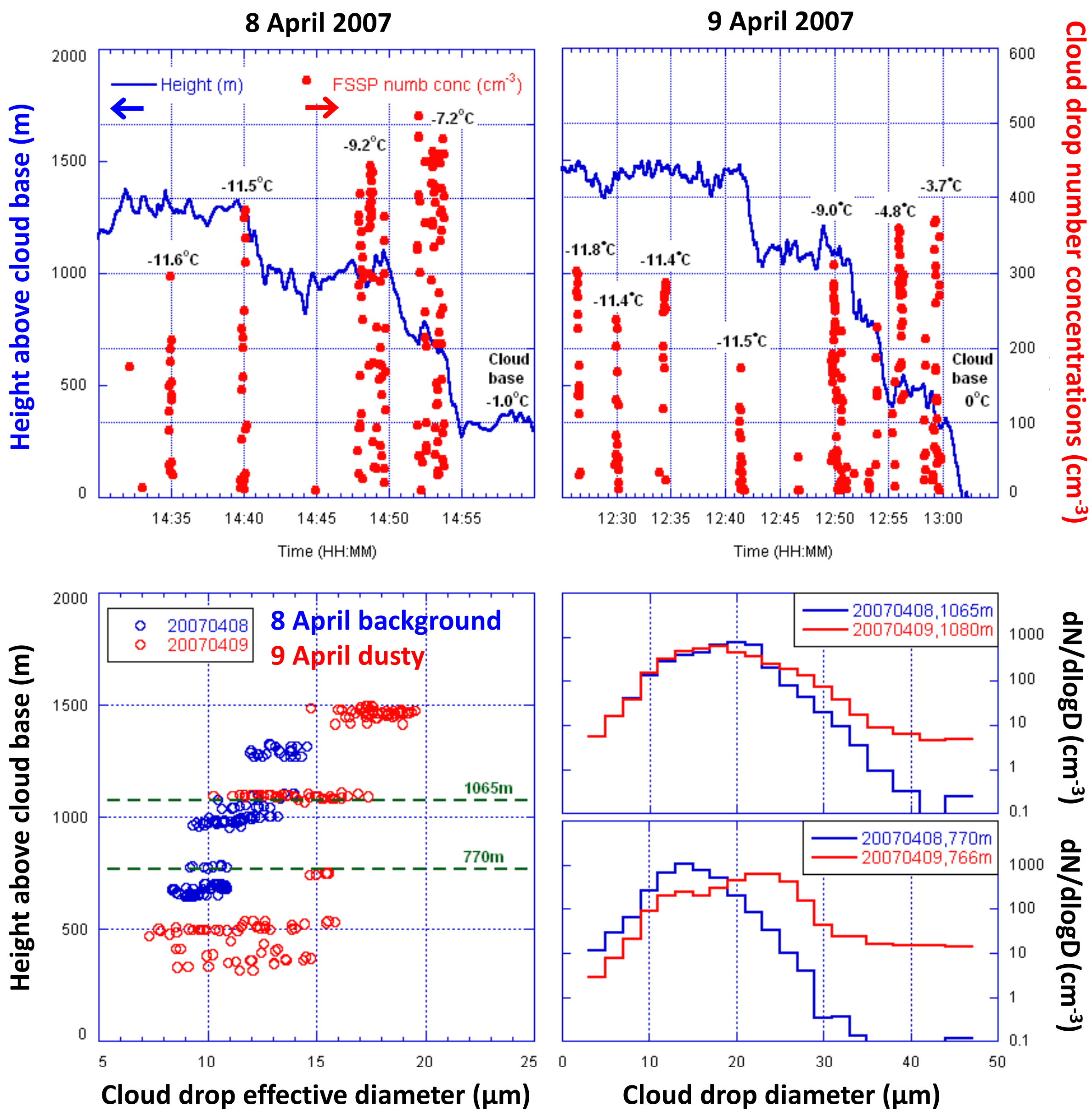


Internal mixtures of mineral particles with combustion-derived pollution particles (Δ CCN).



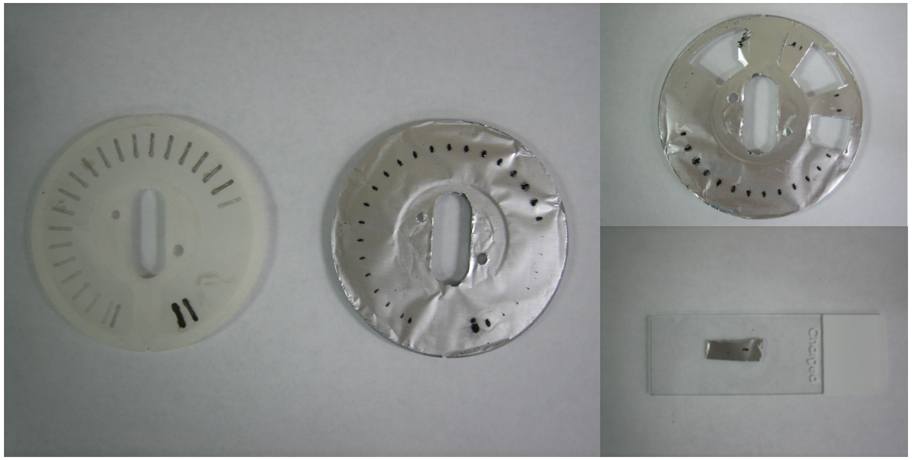
Aggregates of several silicate particles (Δ GCCN).

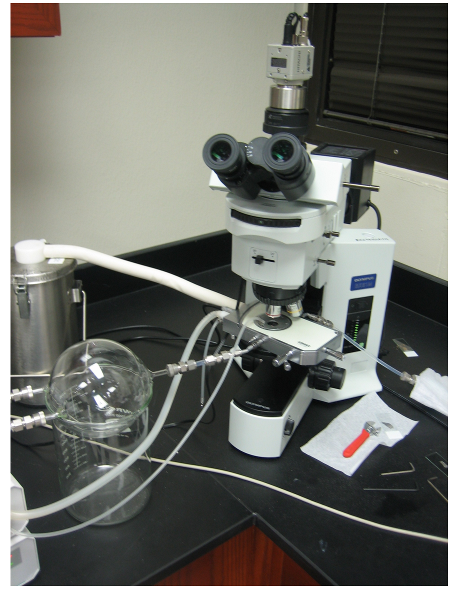
Cloud microphysical properties: near cloud base

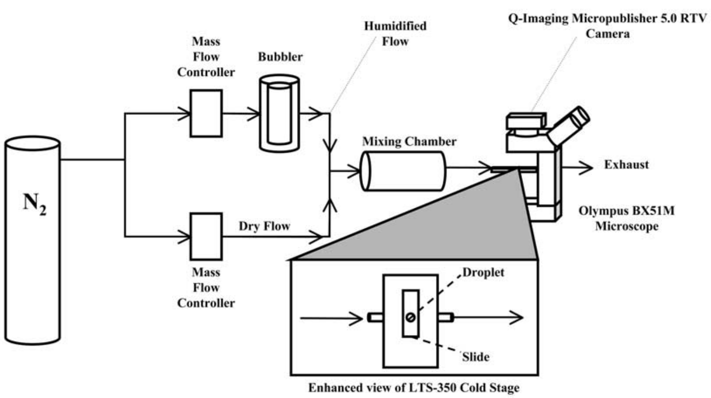


Conventional IN measurements using substrates

DROPLET MEASUREMENT TECHNOLOGIES

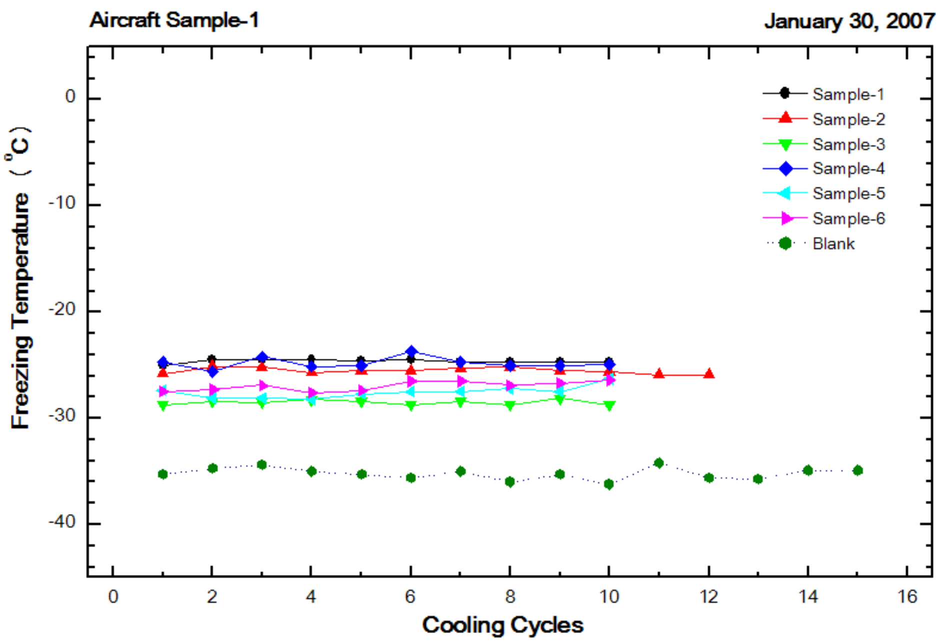


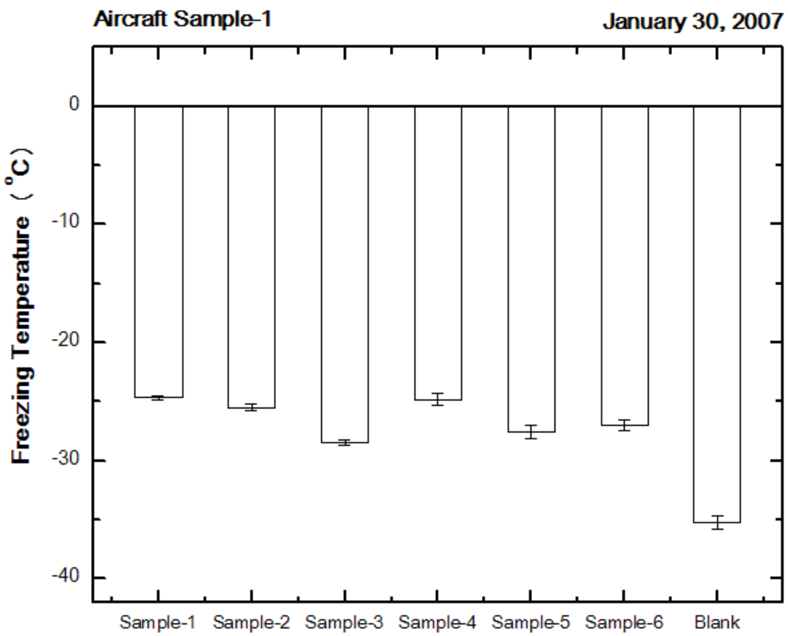




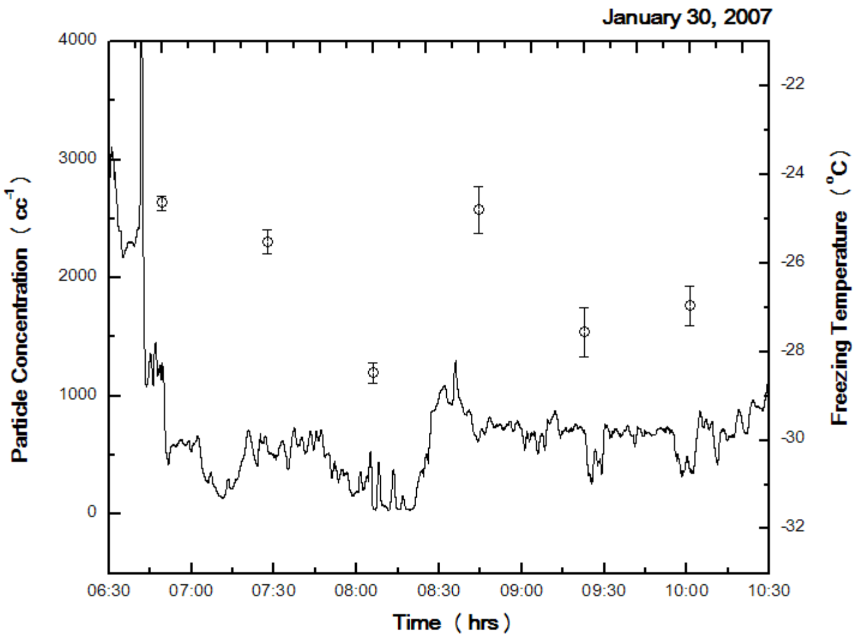
- Using ice nucleation microscope apparatus, we can observe immersion, contact, and deposition freezing events and identify the freezing temperatures of ice nuclei as a function of nuclei composition and freezing mechanism.
- Substrates can introduce biases, bulk measurement and slow.

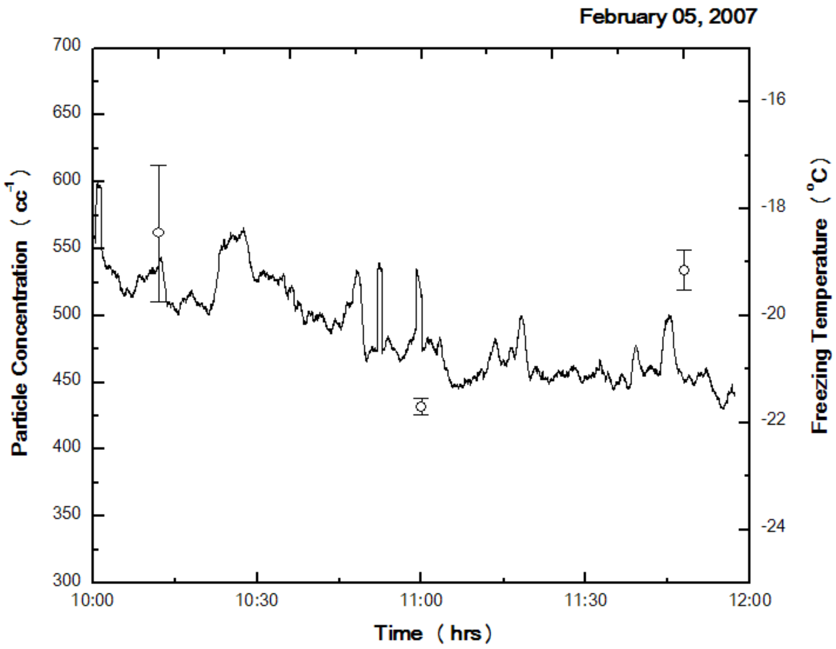
Freezing temperatures of Jan 30 samples





Example IN sampling time resolution



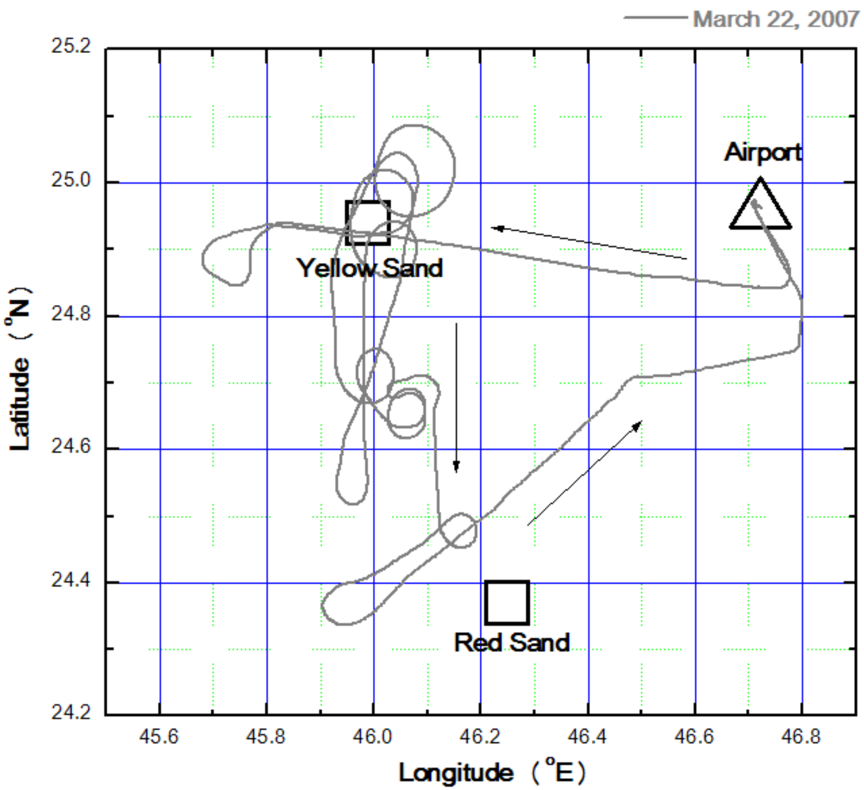


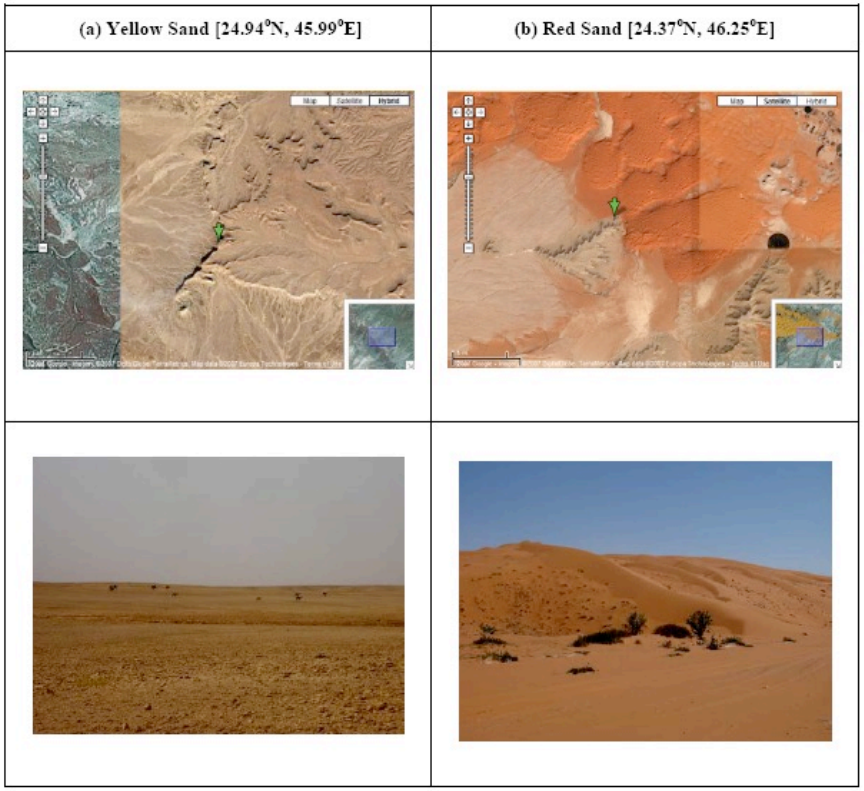
IN analysis summary

Table 10.1: Freezing temperatures of the Streaker samples analyzed for the entire study period

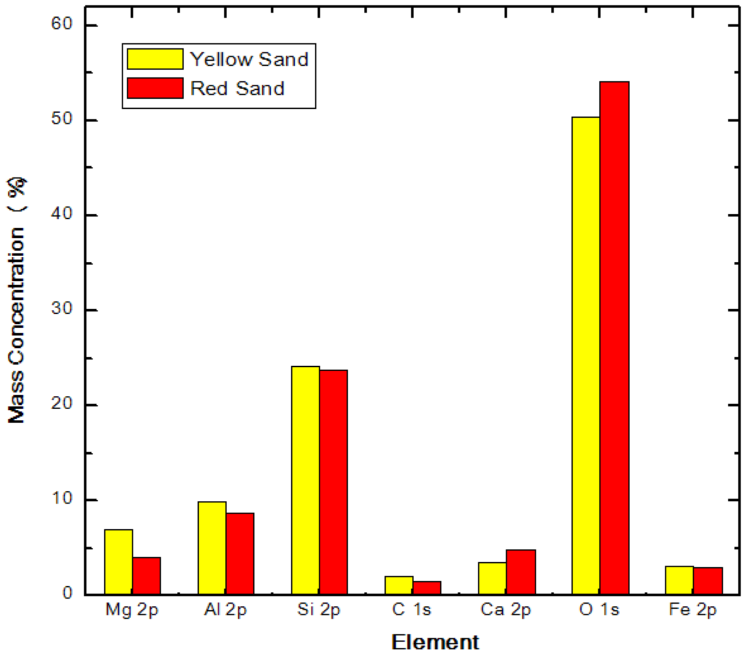
Sl.	Date	Sample	Freezing Temperatures (°C)		
			Sample		Field Blank
			Mean ± S.D	Range	
1.	Jan. 30, 2007	Aircraft Sample-1 (Coarse)	-26.3 ± 1.6	-28.5 to -24.6	-35.2
2.	Feb. 01, 2007	Aircraft Sample-2 (Coarse)	-31.8 ± 2.3	-33.7 to -27.7	-34.5
3.	Feb. 01, 2007	Aircraft Sample-2 (Fine)	-35.3 ± 3.6	-40.0 to -31.6	-39.2
4.	Feb. 05, 2007	Ground Test-1 (Coarse)	-19.8 ± 1.7	-21.7 to -18.5	-35.6
5.	Feb. 27, 2007	Ground Test-2 (Coarse)	-30.6 ± 3.3	-34.2 to -26.1	-33.8
6.	Mar. 19, 2007	Aircraft Sample-3 (Coarse)	-30.9 ± 2.0	-33.1 to -28.2	-32.8
7.	Mar. 22, 2007	Aircraft Sample-4 (Coarse)	-29.3 ± 3.4	-33.4 to -23.9	-32.0
8.	Mar. 26, 2007	Aircraft Sample-5 (Coarse)	-28.4 ± 2.6	-31.1 to -23.5	-31.5
9.	Apr. 01, 2007	Aircraft Sample-6 (Coarse)	-27.9 ± 1.1	-30.0 to -26.9	-27.8
10.	Apr. 01, 2007	Aircraft Sample-6 (Fine)	-31.0 ± 1.9	-33.2 to -28.1	-35.5
11.	Apr. 03, 2007	Aircraft Sample-7 (Coarse)	-28.3 ± 2.2	-32.1 to -26.2	-34.9
12.	Apr. 03, 2007	Aircraft Sample-7 (Fine)	-28.5 ± 2.1	-31.2 to -25.4	-30.6
13.	Apr. 07, 2007	Aircraft Sample-8 (Coarse)	-28.8 ± 1.8	-31.3 to -26.3	-31.6
14.	Apr. 07, 2007	Aircraft Sample-8 (Fine)	-29.3 ± 4.2	-33.0 to -20.7	-34.5

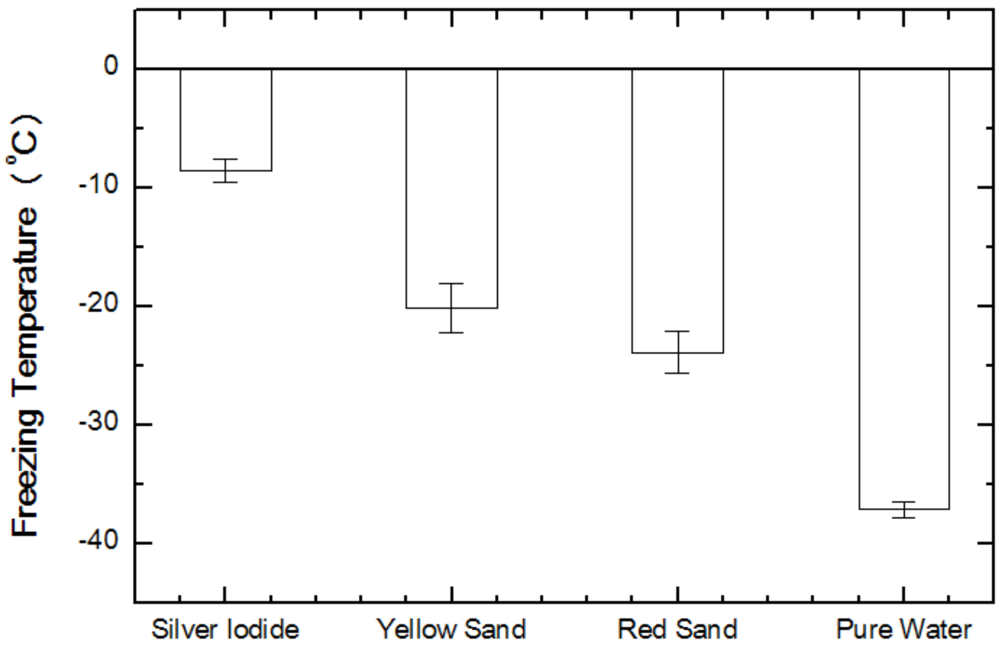
Collection of “representative” dust samples





Freezing temperatures of dust samples





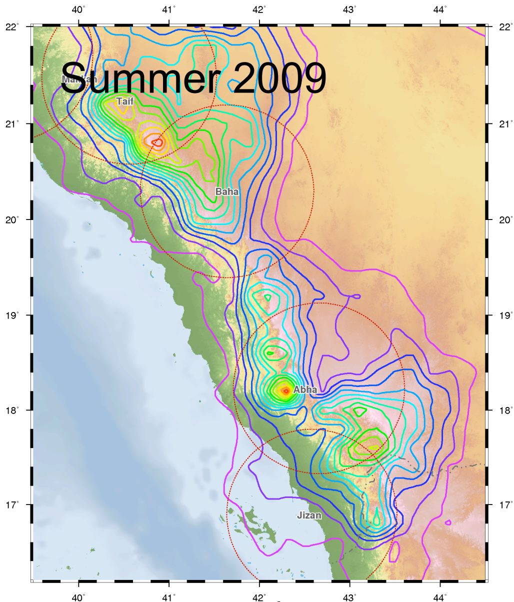
Conclusions for Central Region

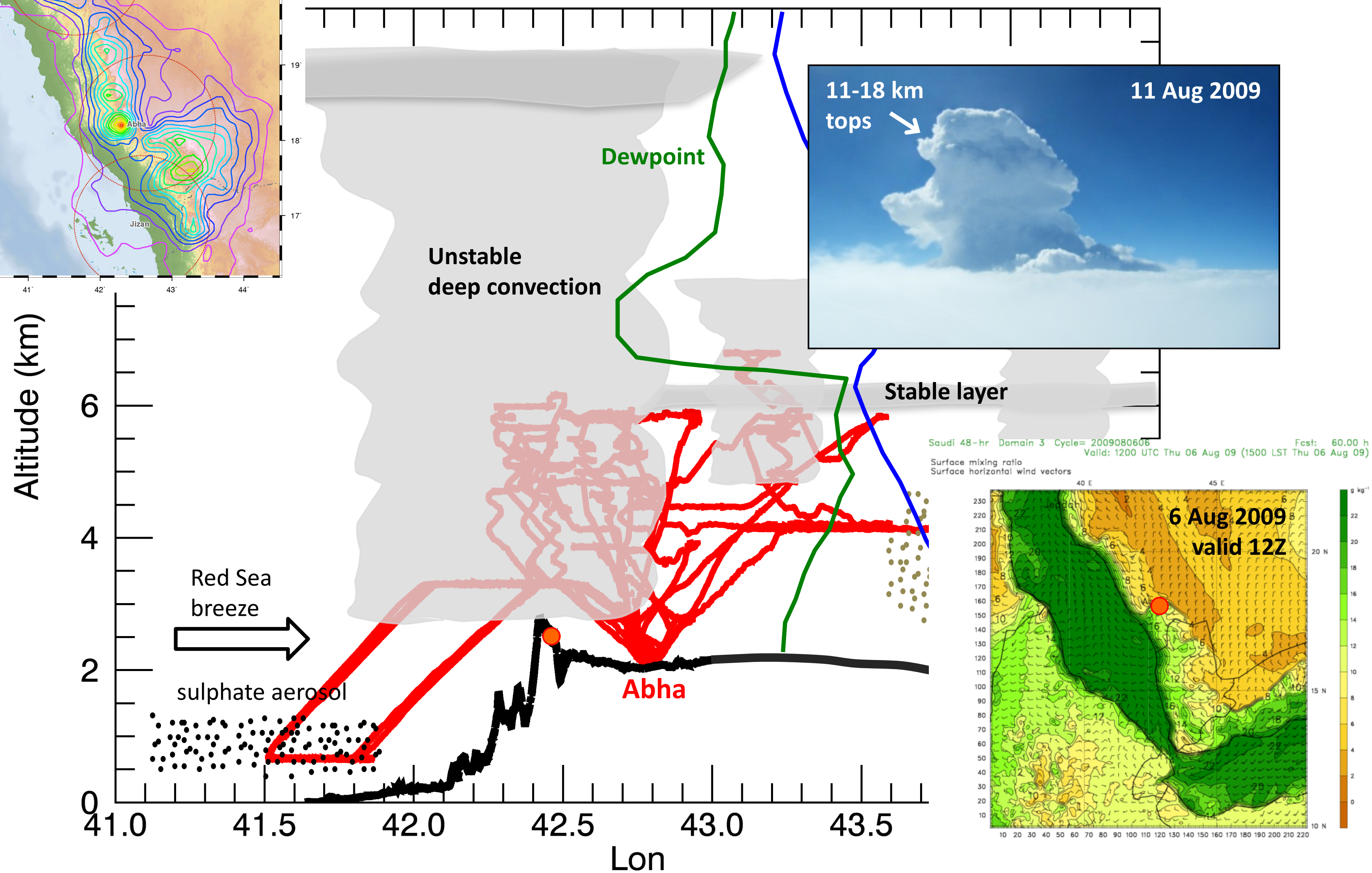
- **Under dusty conditions, the coarse fraction consisted of unreacted mineral grains. A significant mineral component also occurred in the submicron fraction. Dust contributes to the concetration of the accumulation mode, cloud condensation nuclei and giant cloud condensation nuclei.**

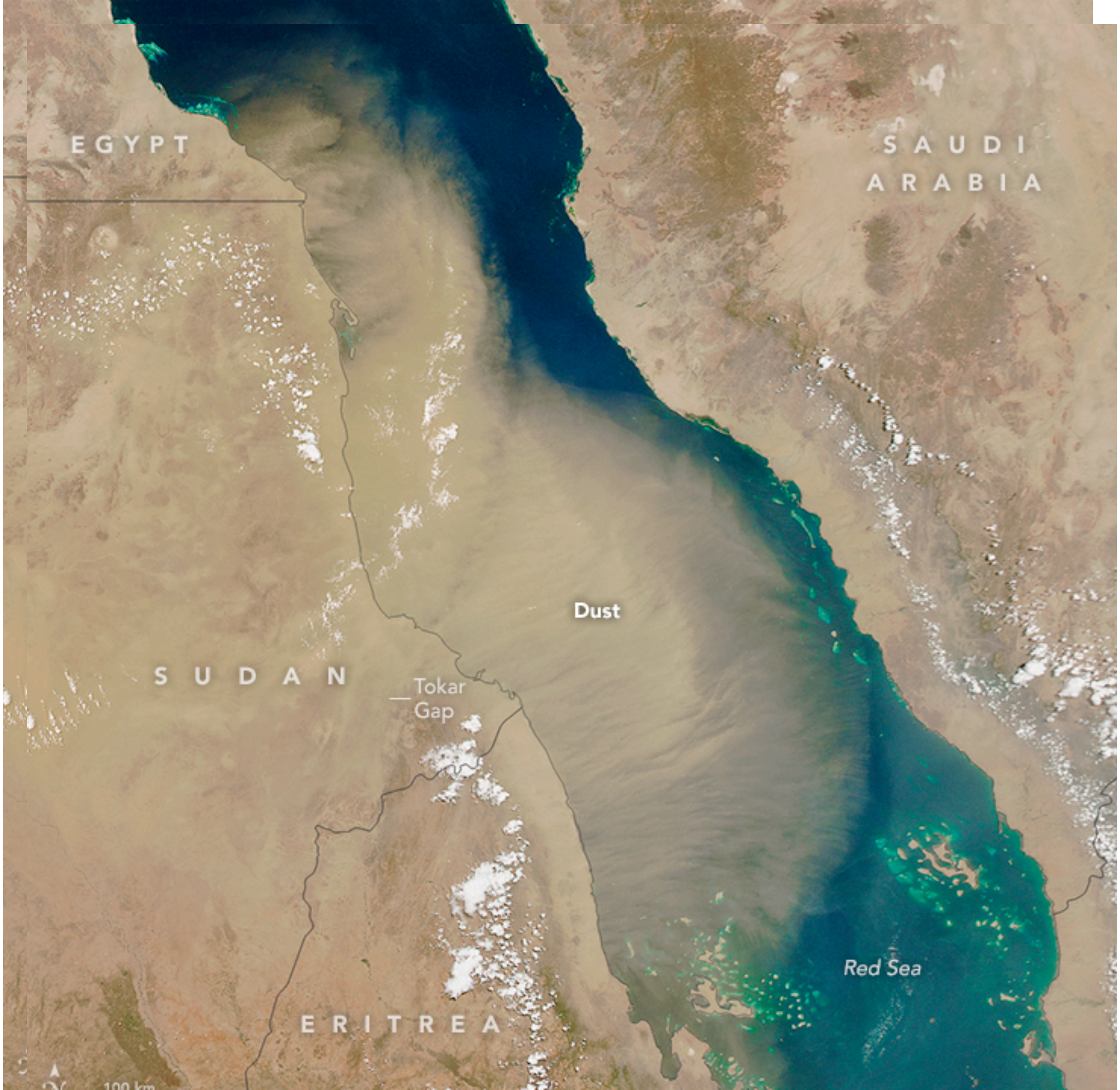
- **When local pollution sources affected the air mass, the dominant particle type was ammonium sulfate, and roughly half the mineral particles were internally mixed with ammonium sulfate and soot. These also contribute to the cloud condensation nuclei but their effect on drop size distribution depends on particle size and cloud supersaturation.**

- **A relationship is apparent between the physical and chemical properties of the aerosol particles and cloud-droplet properties. Under regional background conditions, the droplets had a narrower size distribution and were smaller near the base of the cloud than under dusty conditions. Less numerous and larger droplets in the cloud formed above the dusty boundary layer and favor the formation of warm rain. Supermicron dust particles enhance drop diameters while suppressing the concentration of cloud drops.**

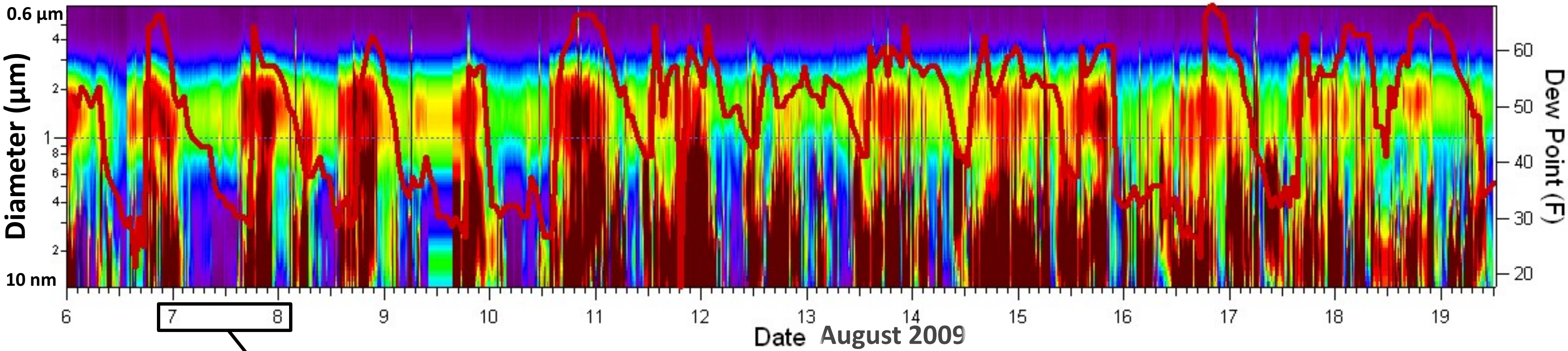
Aerosol-cloud interactions in Southwest Region

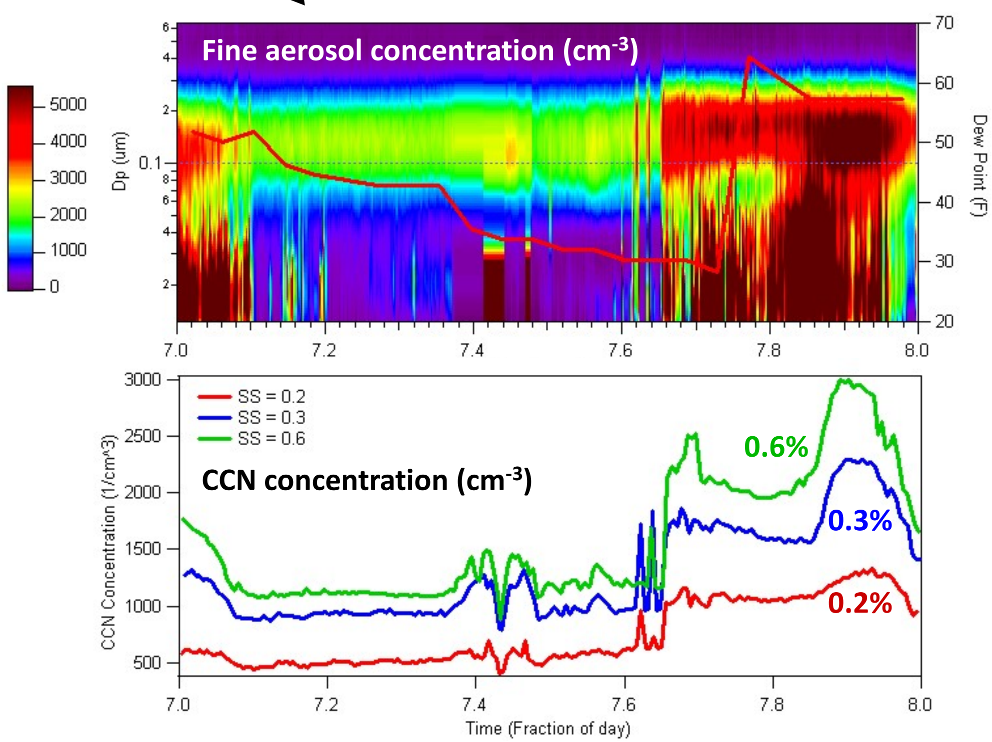


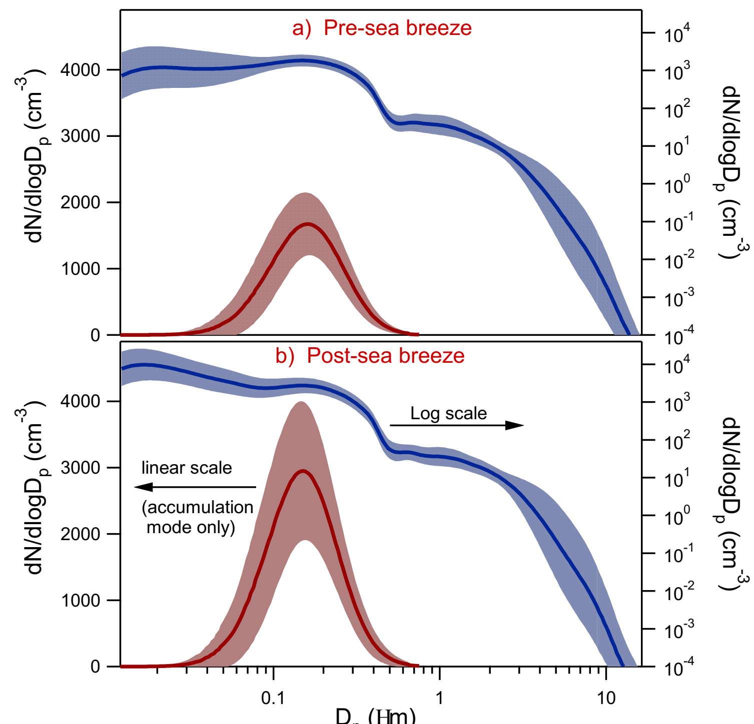



EGYPT
SAUDI ARABIA
Dust
SUDAN
Tokar Gap
Red Sea
ERITREA

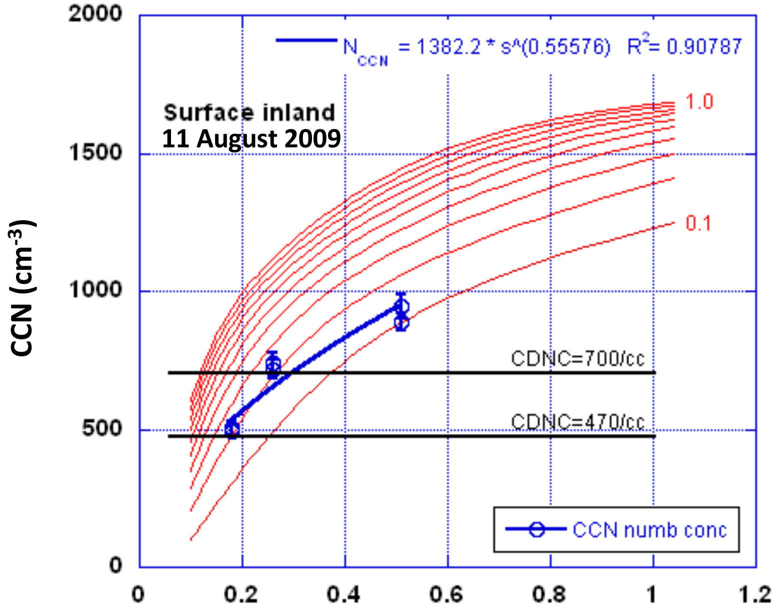
Aerosol properties at surface site top of Asir escarpment

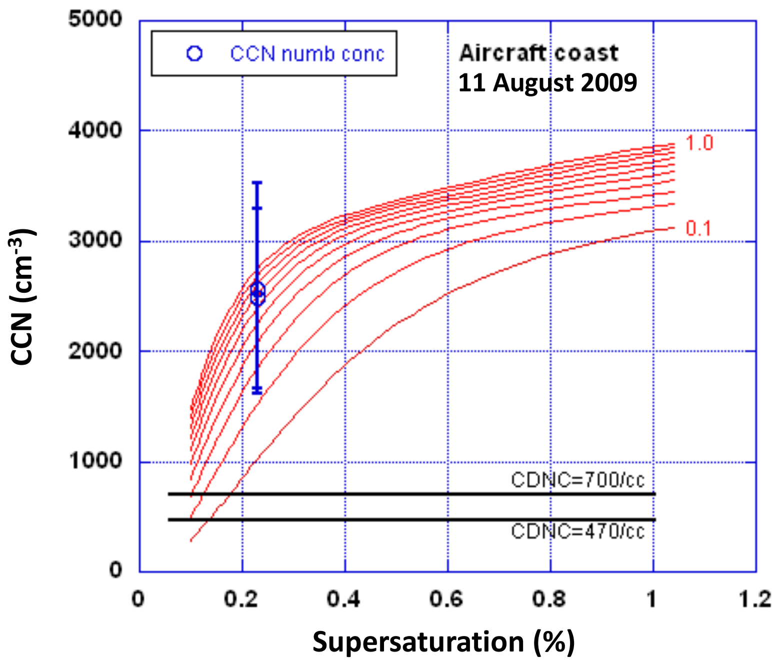


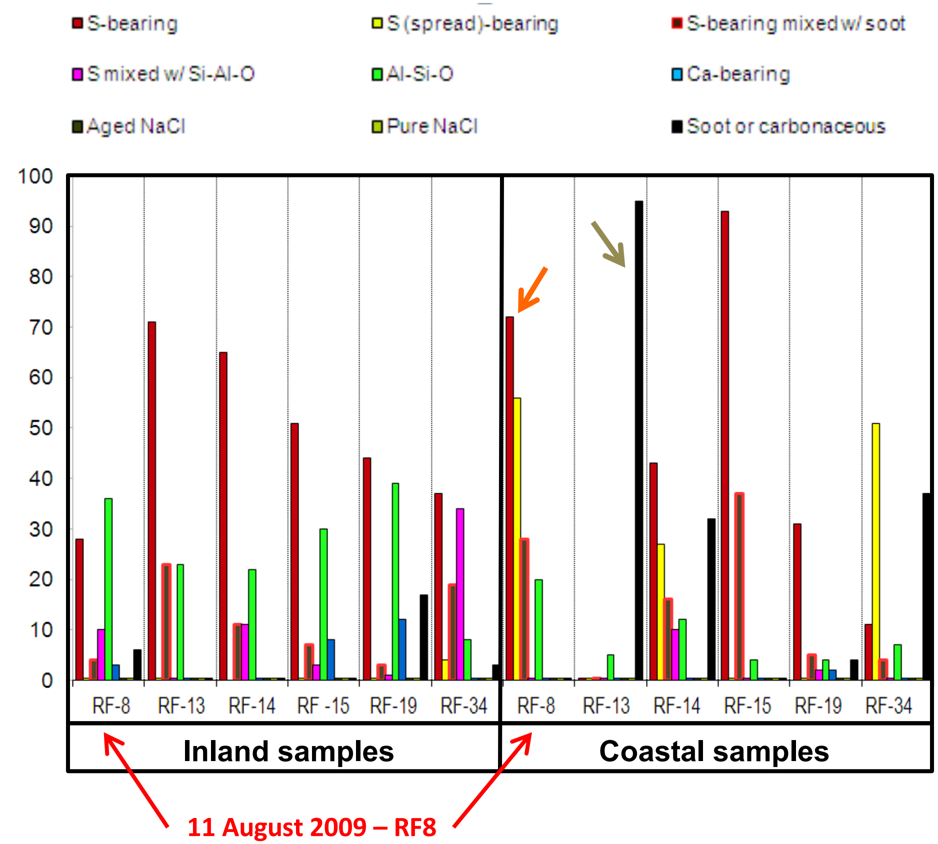




Aerosol physical and chemical properties (from aircraft)

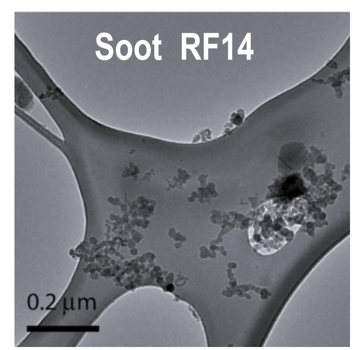




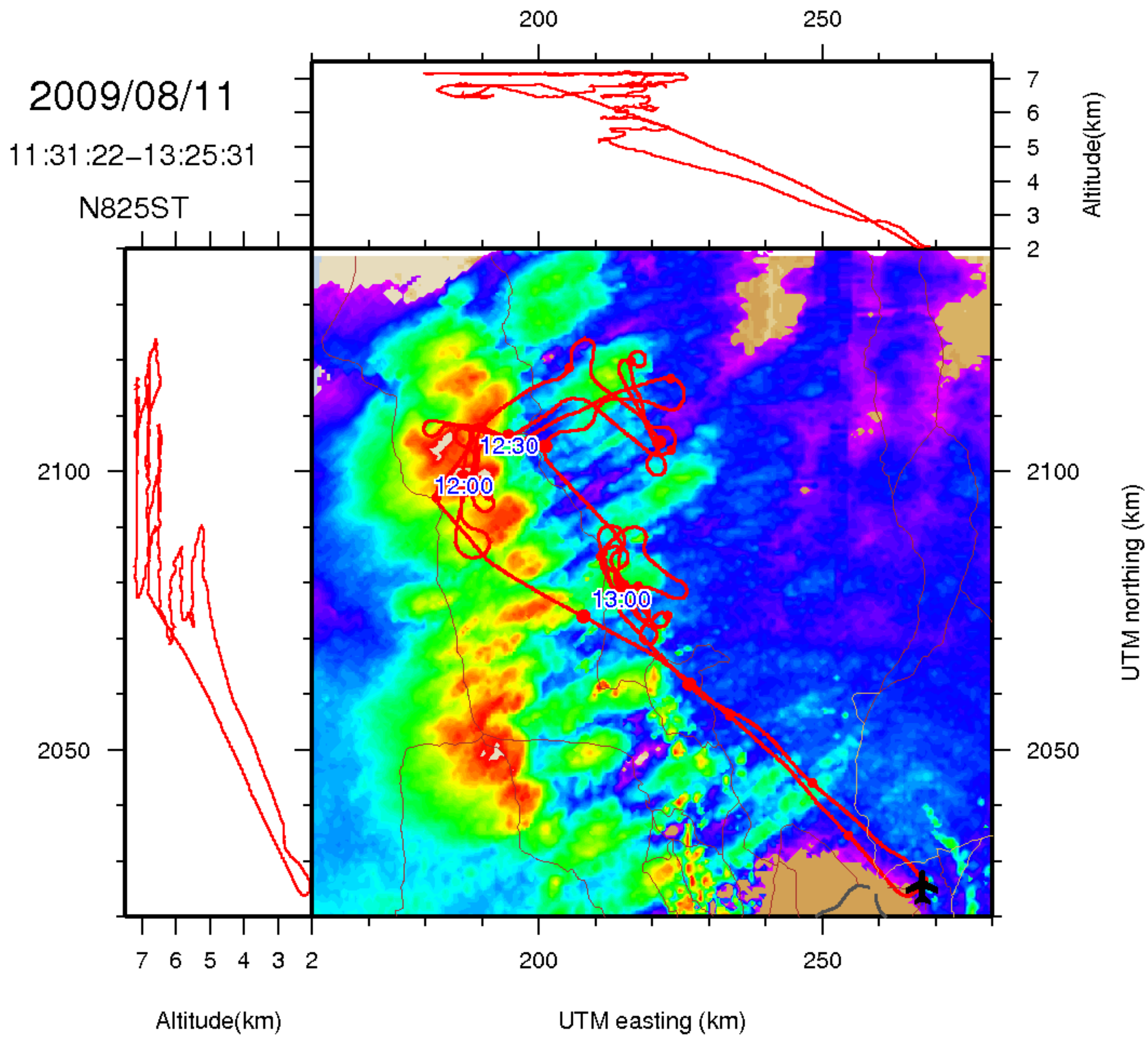


Coastal particles contain **sulfur-bearing** material that was not collected on inland samples. Coastal samples contain more soot and sulfate.

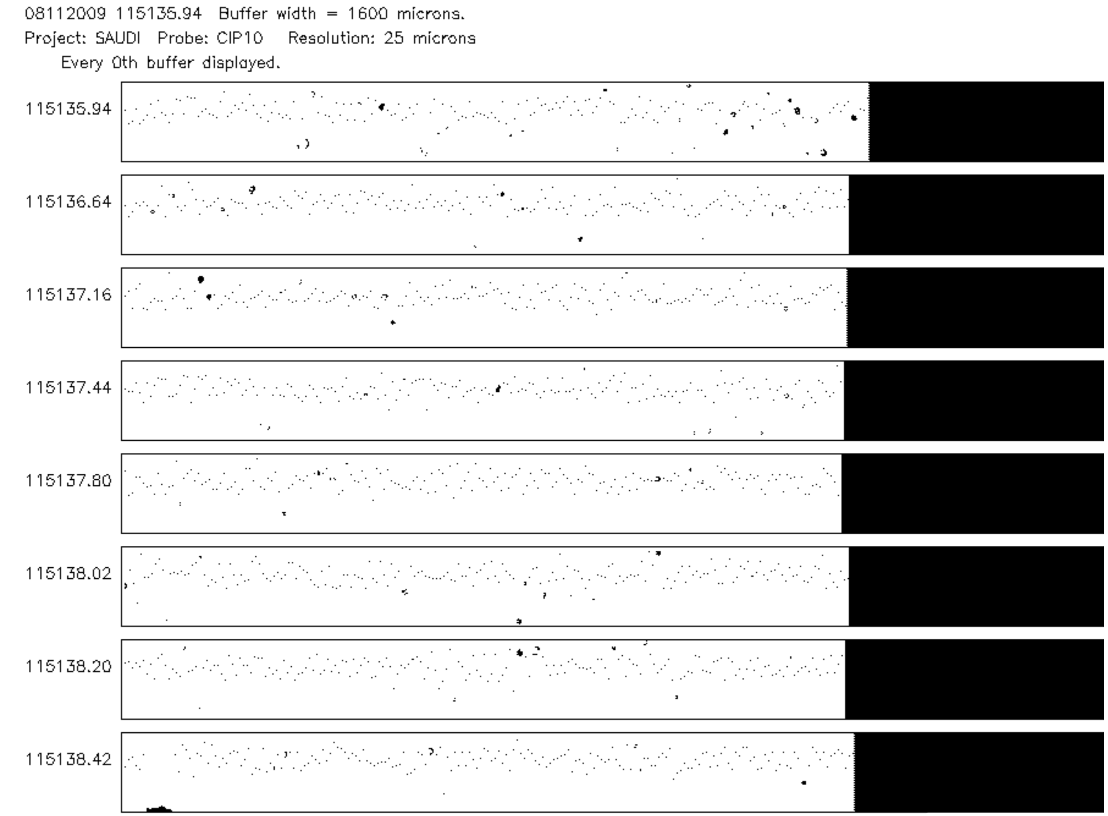
On some days (RF13, RF14 and RF34), the coastal samples contain high % of fine **carbonaceous** (combustion) particles.

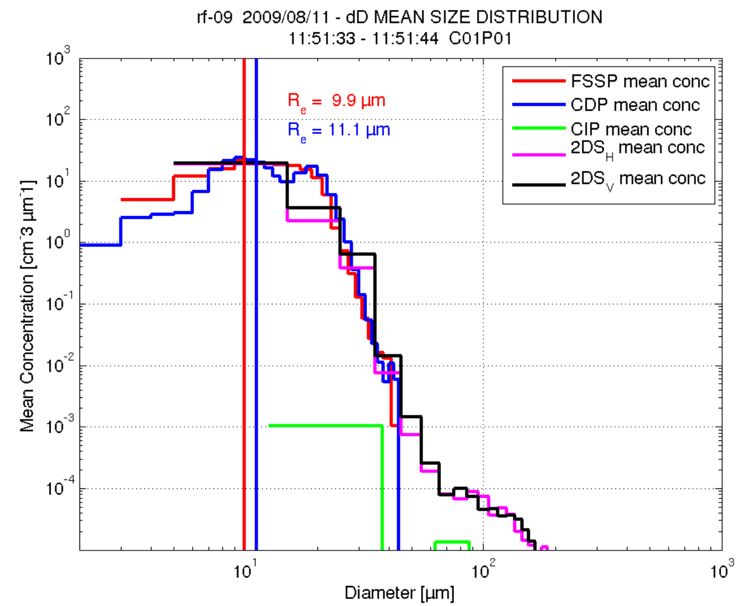


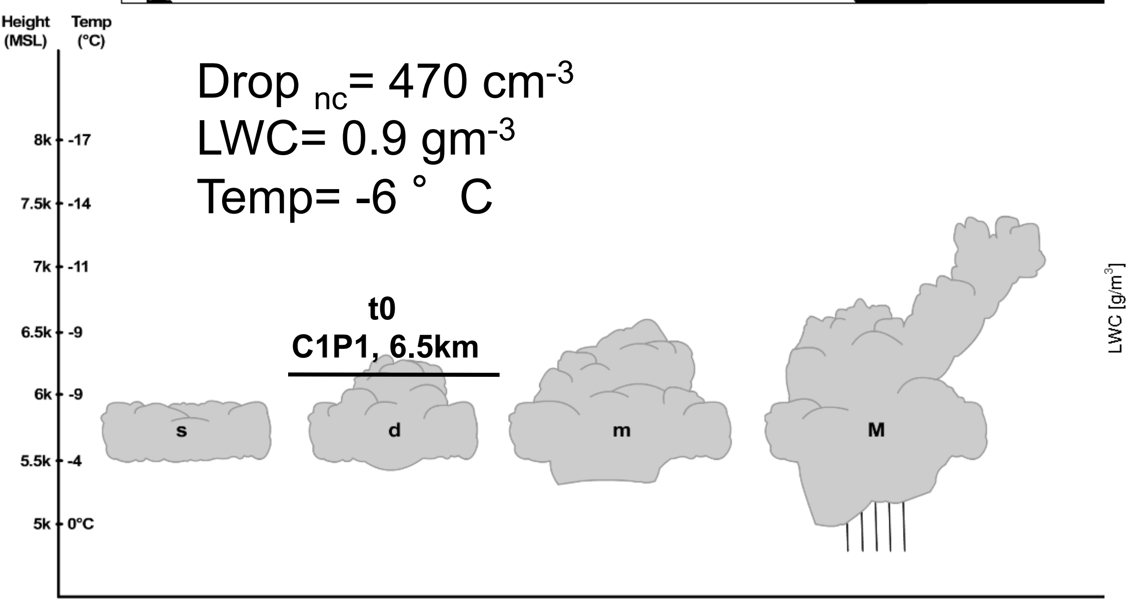
Cloud measurements on 11 August 2009 (RF9)

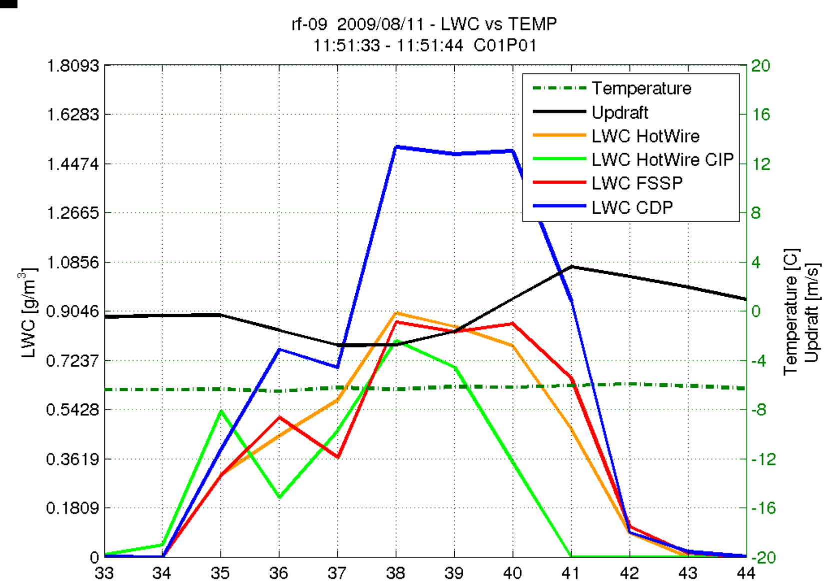


Lifecycle study C1P1

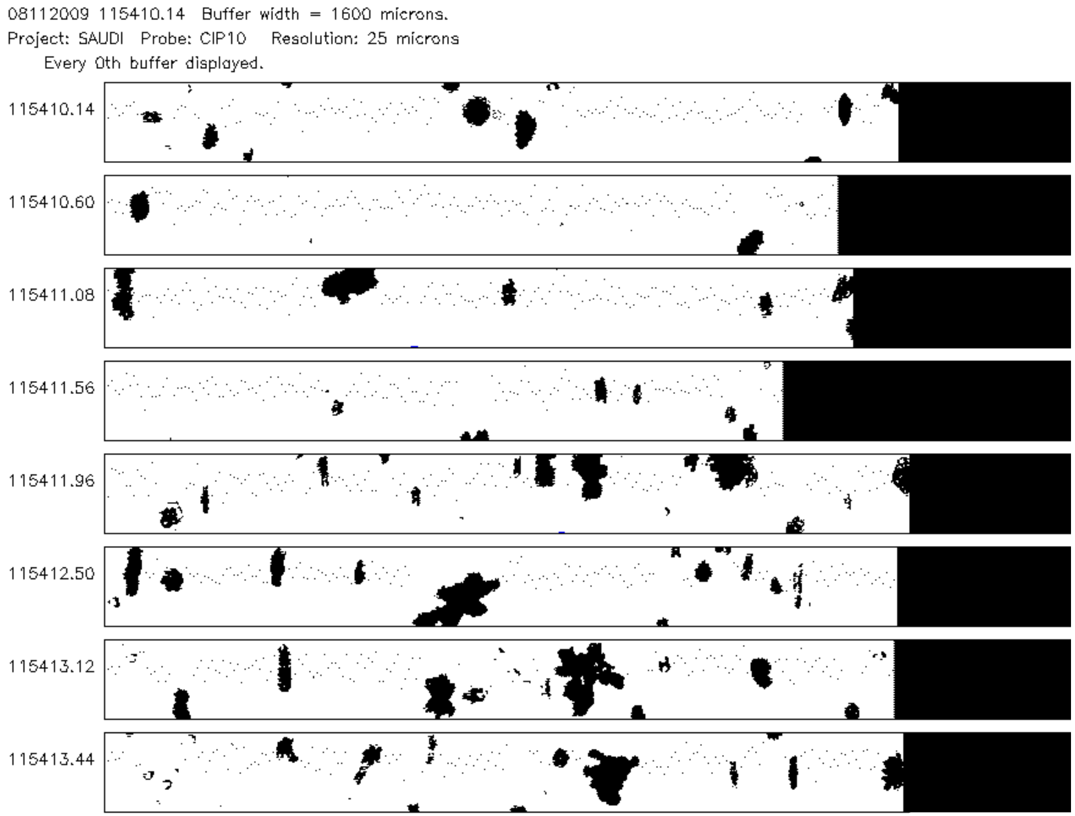


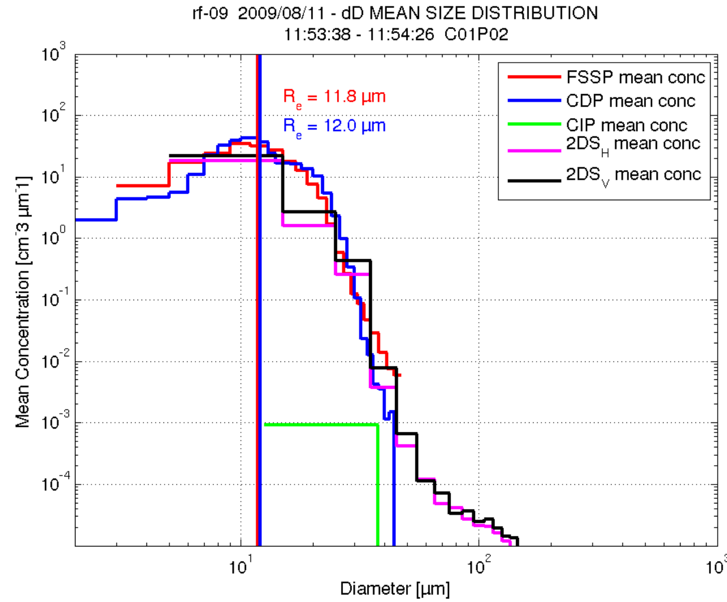


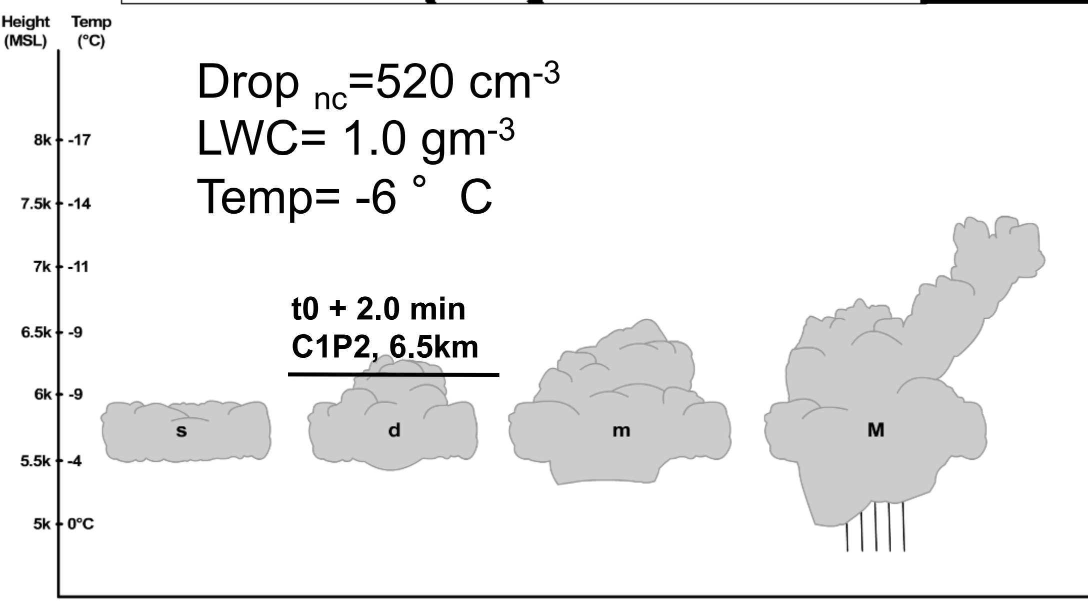


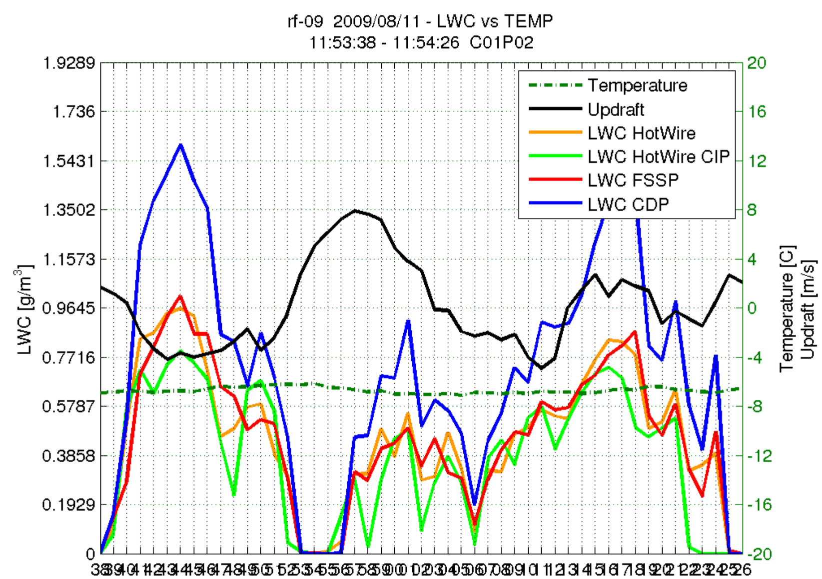


Lifecycle study C1P2

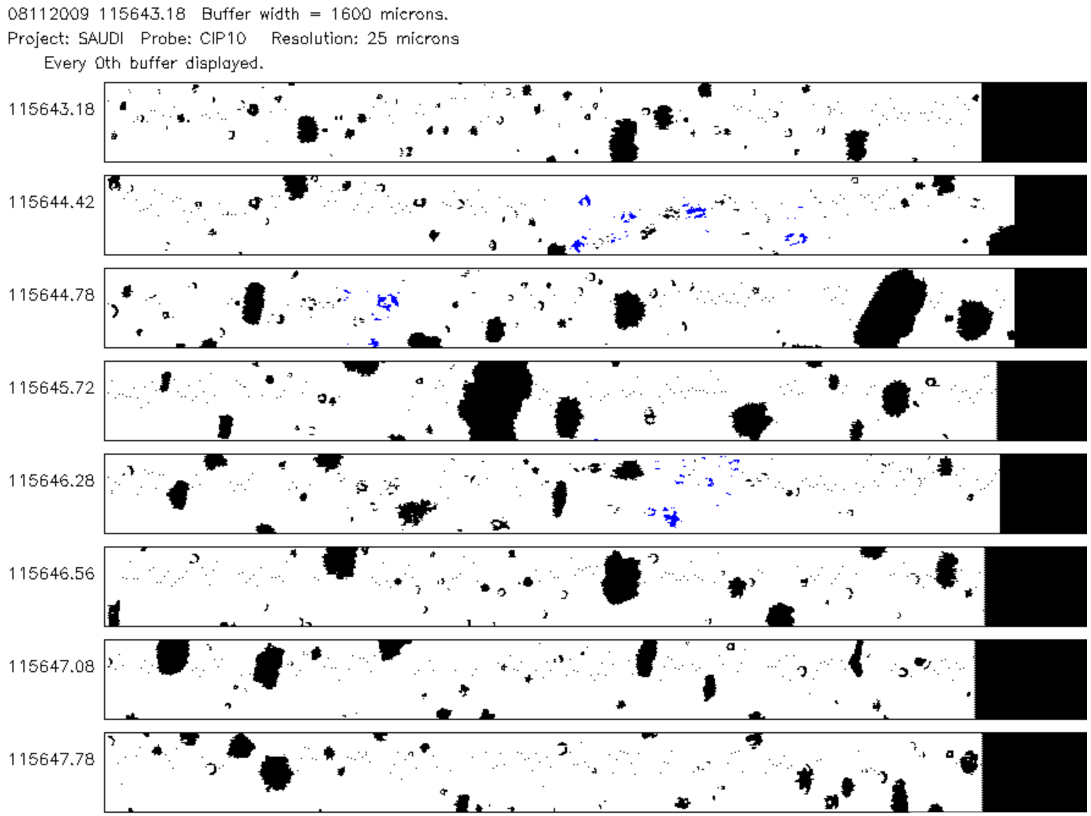


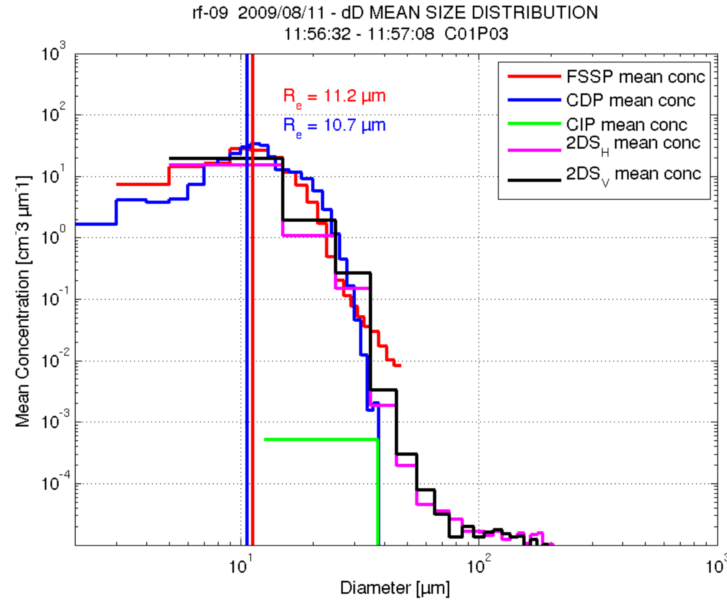


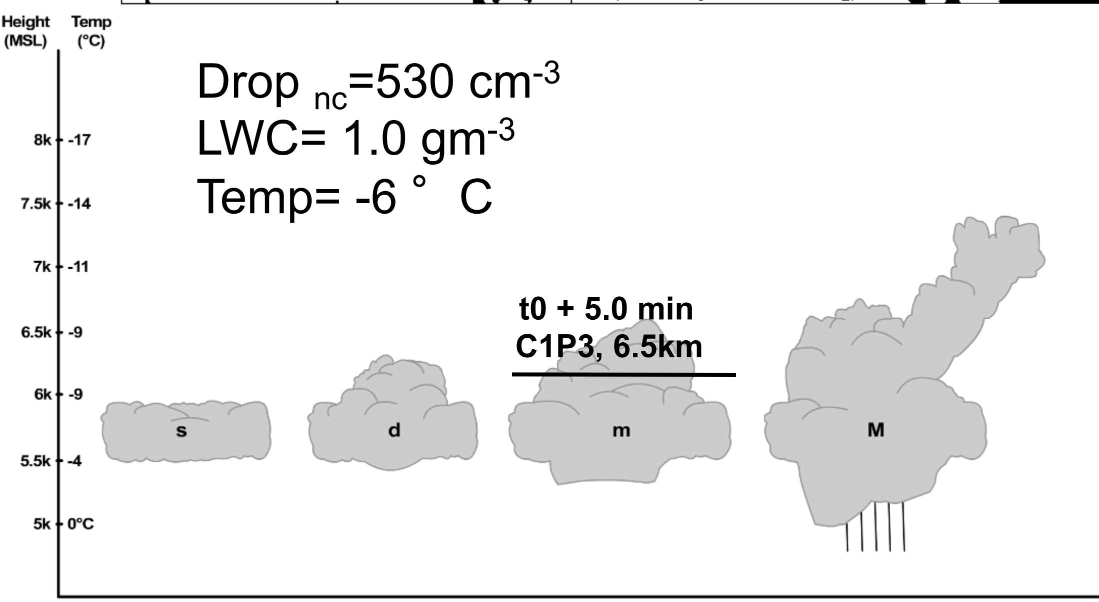


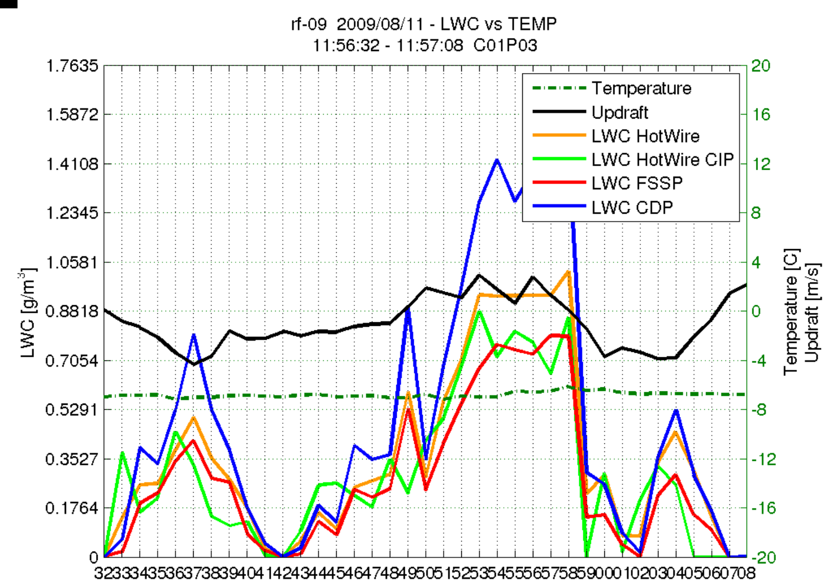


Lifecycle study C1P3

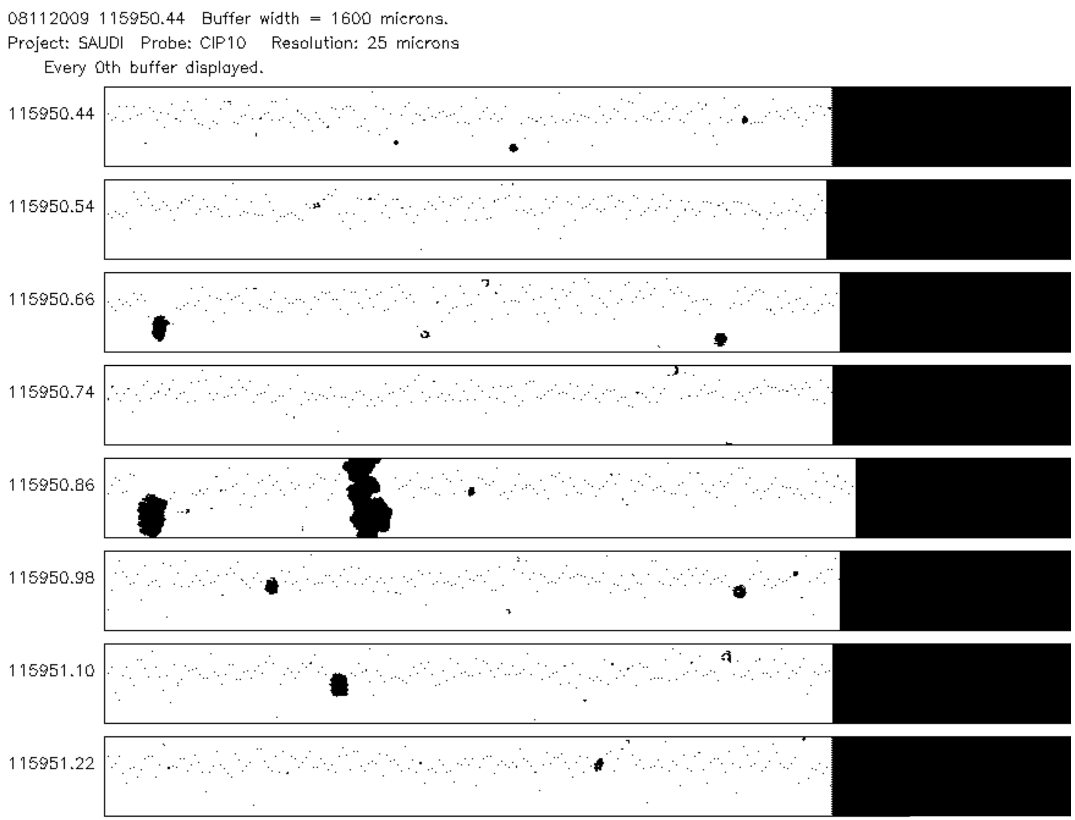


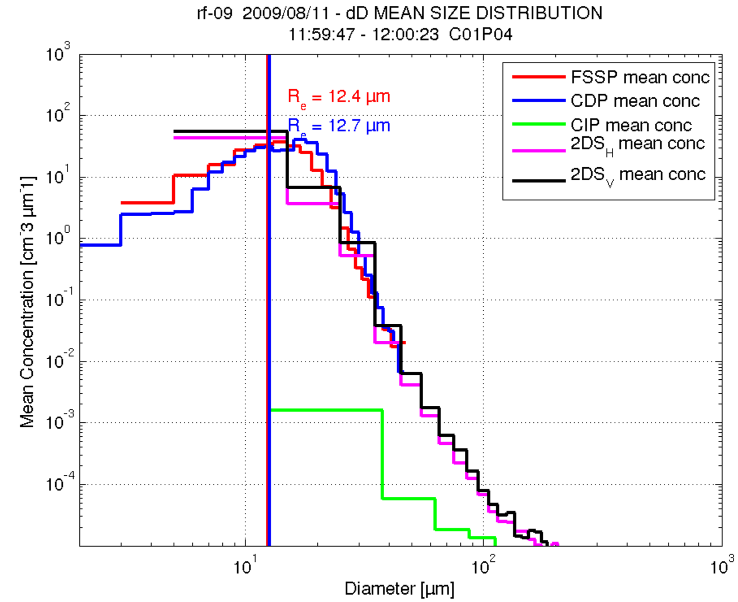




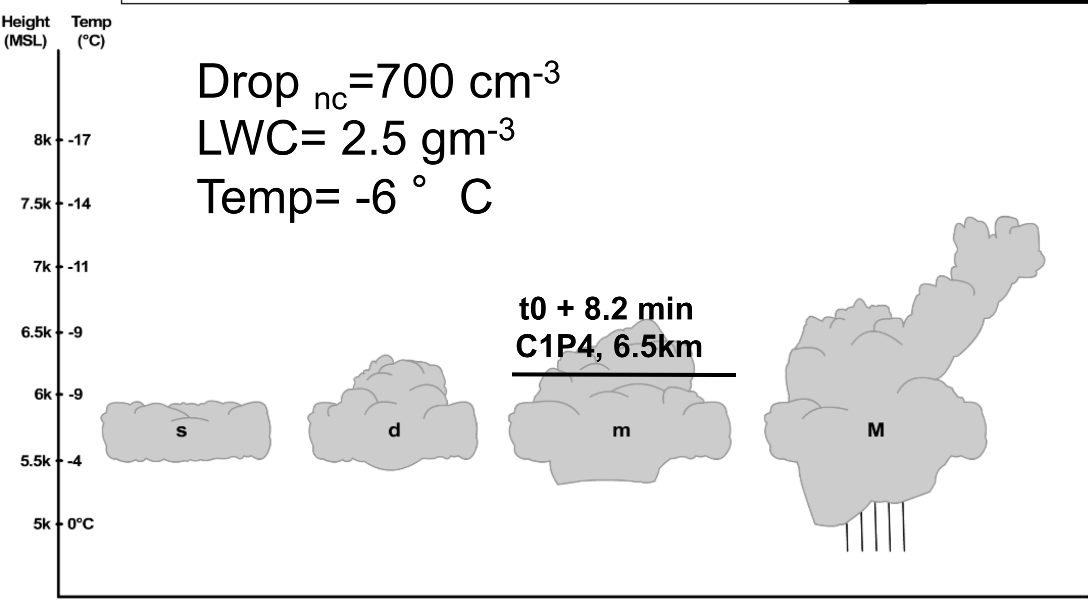


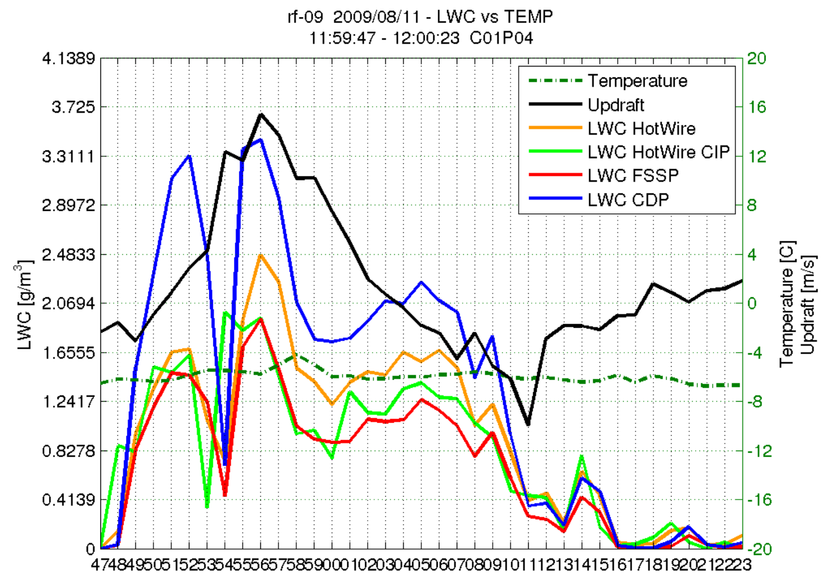
Lifecycle study C1P4



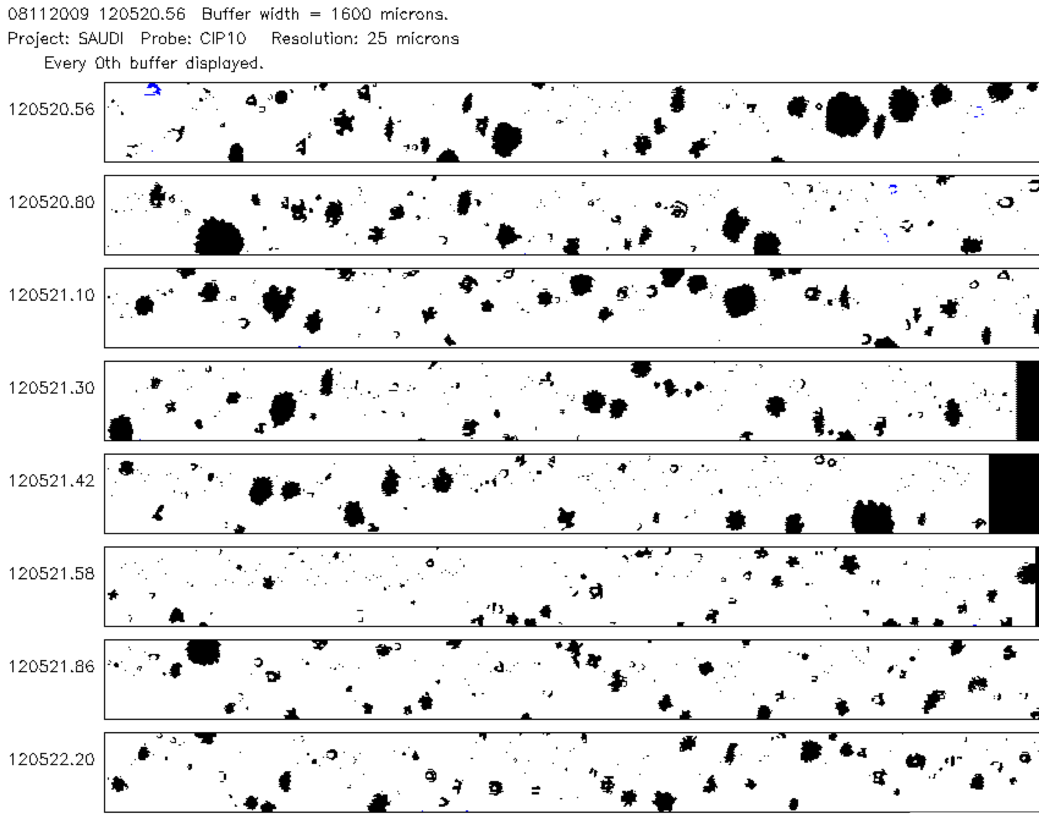


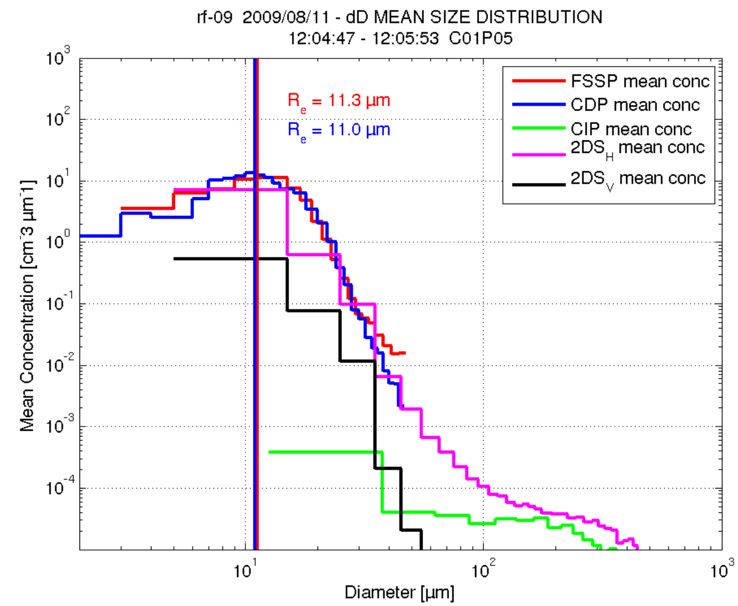
Drop $_{nc}$=700 cm^{-3}
LWC= 2.5 gm^{-3}
Temp= -6 ° C

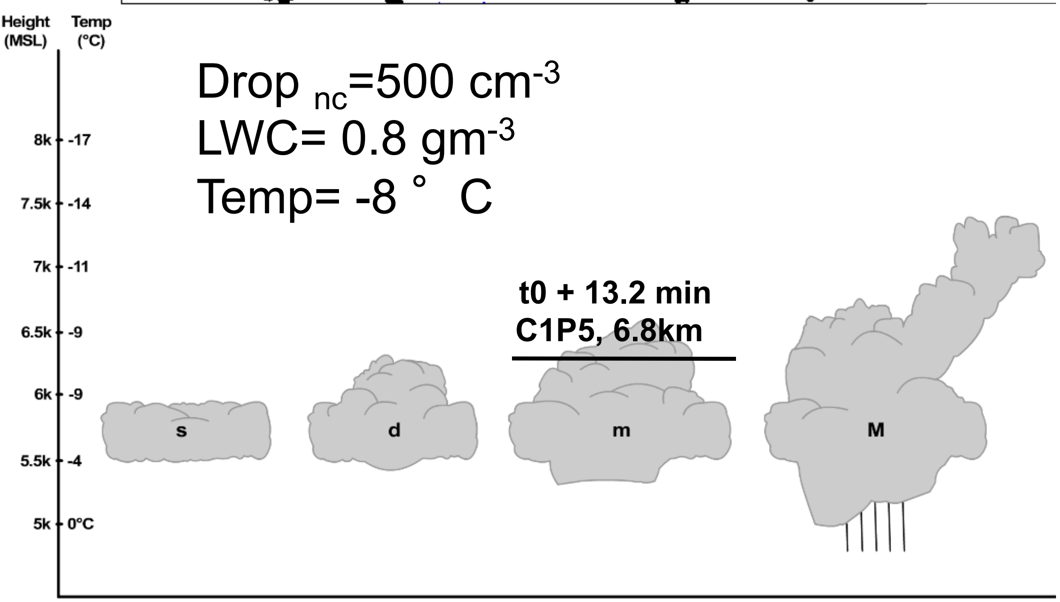


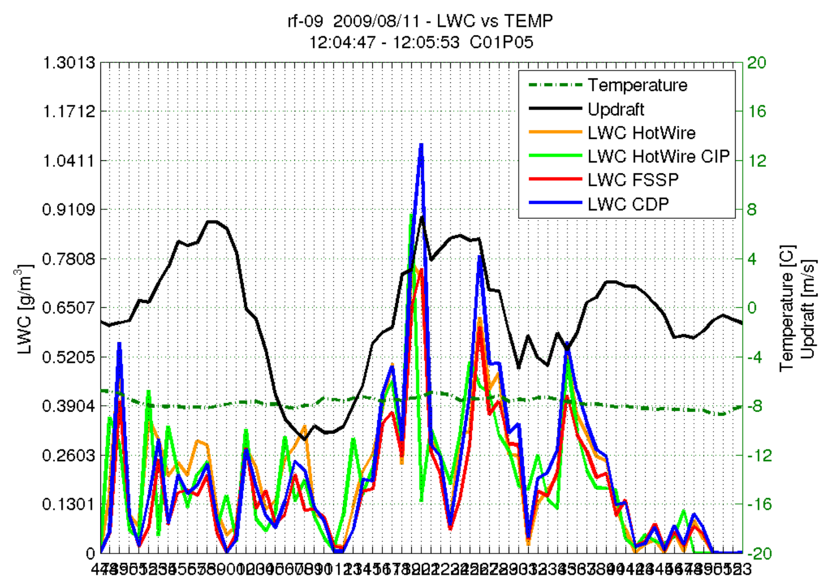


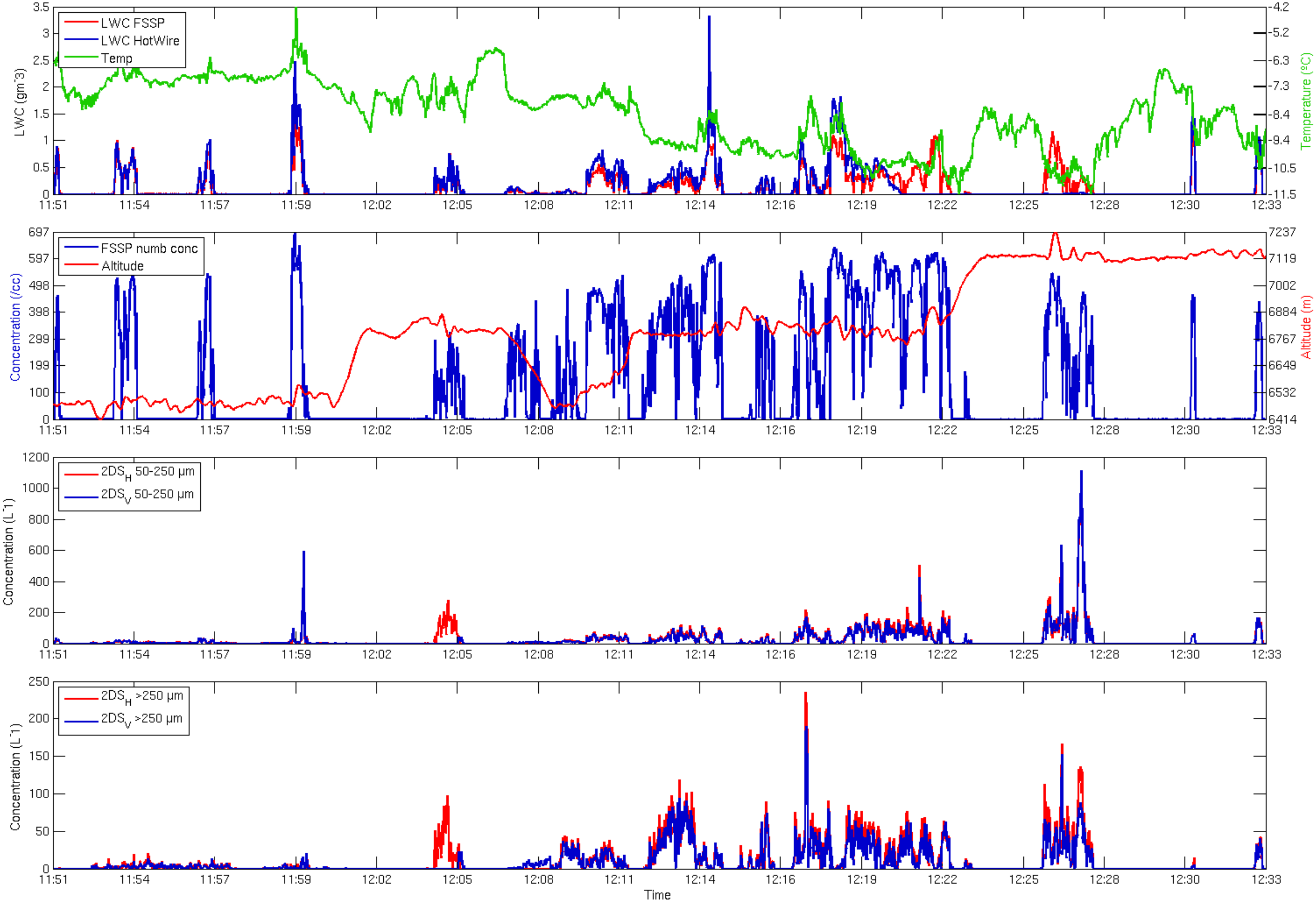
Lifecycle study C1P5







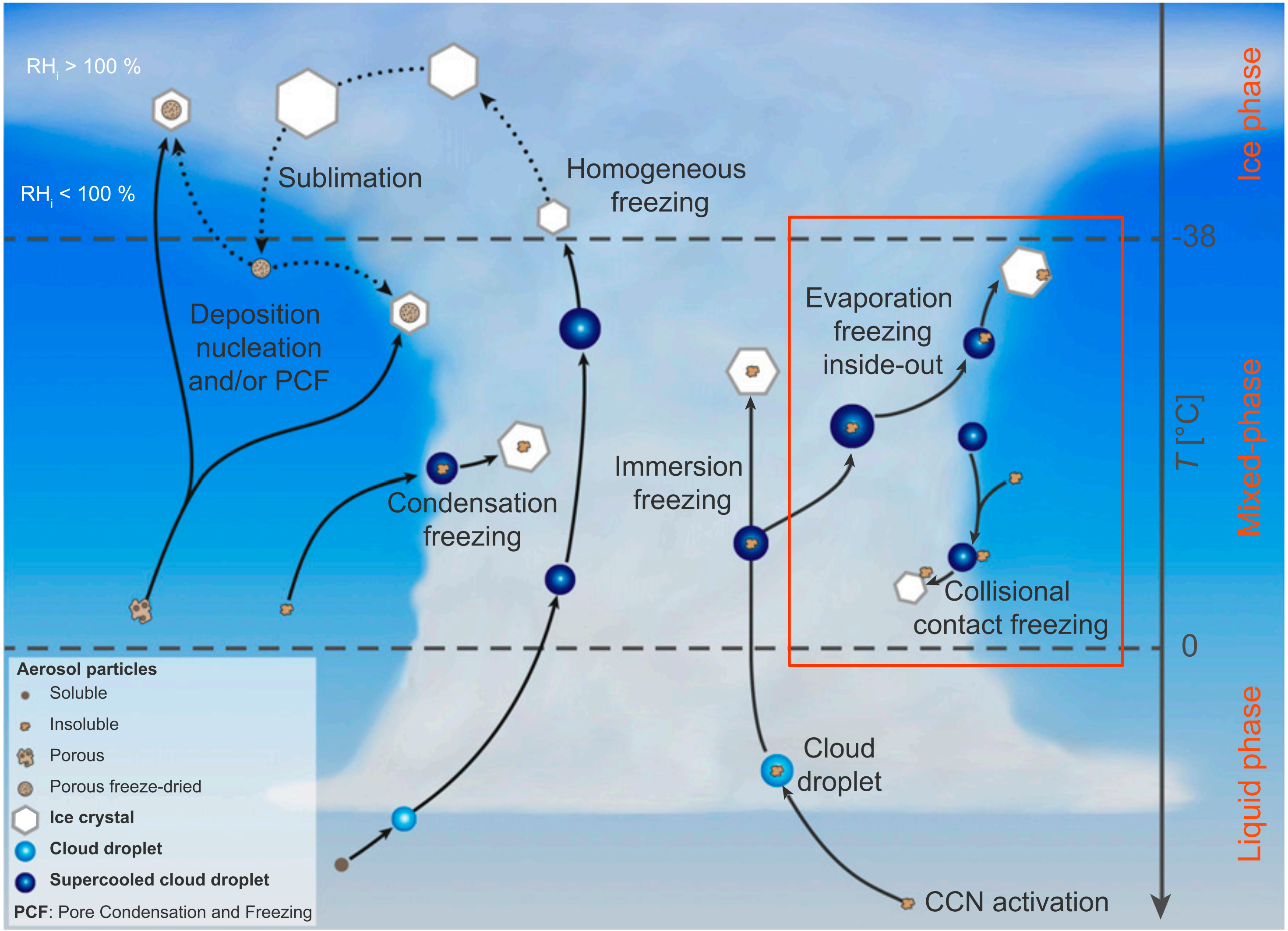



LWC FSSP
LWC HotWire
Temp
LWC (gm^3)
Temperature (ºC)
FSSP numb conc
Altitude
Concentration (/cc)
Altitude (m)
2DS_H 50-250 µm
2DS_V 50-250 µm
Concentration (L^-1)
2DS_H >250 µm
2DS_V >250 µm
Concentration (L^-1)
11:51
11:54
11:57
11:59
12:02
12:05
12:08
12:11
12:14
12:16
12:19
12:22
12:25
12:28
12:30
12:33
Time

Conclusions for Southwest Region

- The region is characterized by a highly stratified and deep aerosol boundary layer dominated by dust . In the southwest region, 10% of fine dust particles are coated while large dust particles are not.
- The inland ASD is characterized by a broad accumulation mode and high coarse mode. The size distribution appears to be aged and individual modes cannot be identified suggesting intermodal coagulation.
- Surface measurements indicate that coastal aerosol pushes inland during moist air intrusions increasing the aerosol numb conc. The coastal aerosol is more polluted, aged and contains more S-bearing material and soot. The increased accumulation mode aerosol increase CCN concentration over the Red Sea coast plains. Aerosol hygroscopicity remains unchanged.
- Calculations of CCN concentration can be related to particle chemistry speciation. Cloud droplet closure is not achieved due to lack of cloud base measurements close to complex terrain.
- Aircraft measurements of ‘smaller’ convective clouds are possible and give us the opportunity to study the lifecycle of convective bubbles pushing through the dry air inversion. These clouds form graupel quickly and the mechanism by which this graupel forms is still uncertain.

Modes of ice formation in clouds



Kanji et al. 2017