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Calculation and Interpretation of Cloud Peak Supersaturations at the High Alpine Site Jungfraujoch

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1. Introduction

Aerosols influence radiative forcing directly through scattering and absorption of solar and infrared radiation in the atmosphere but also indirectly by modifying the properties of clouds. However, climate models still suffer from large uncertainties inferred by aerosols. An important aerosol parameter is the critical supersaturation (supersaturation where the particle forms a cloud droplet), which is dependent on its dry size and chemical composition. The highest supersaturation that a particle in a cloud has experienced is the so-called peak supersaturation (SS_p). To date, no measurement device is available that is able to measure this value within a cloud. Thus, the cloud peak supersaturation has to be retrieved indirectly from other parameters. During summer 2010 a Cloud and Aerosol Characterization experiment (CLACE2010) has been conducted at the high alpine research station Jungfraujoch (3580 m a.s.l., Switzerland).

2. Theory

The relationship between equilibrium *RH* and the size of a solution droplet can be described by the Köhler equation. If the κ water activity parameterization is used (Petters and Kreidenweis, 2007), the equation takes the following form:

$$RH = \frac{D^3 - D_0^3}{D^3 - (1-\kappa)D_0^3} \cdot \exp\left(\frac{4M_w\sigma_{sol}}{RT\rho_w D}\right)$$

Equation 1

where D and D_0 are the droplet and the corresponding dry diameter. M_w shows the molar mass of water, σ_{sol} is the surface tension of the solute, R is the ideal gas constant, T the surrounding temperature and ρ_w is the density of the water. The κ parameter is the semi-empirical hygroscopicity parameter, which takes values between 0 (non-hygroscopic but wettable) and ~1.3 (most hygroscopic salts) for atmospheric aerosols. The maximum of Eq. 1 is the critical saturation ratio which can be searched numerically if κ is known.

3. Methods

Aerosols were sampled with two different inlets. The total inlet collected hydrometeors and interstitial (non-activated) aerosol particles; the interstitial inlet collected only the interstitial aerosol particles (up to a size of 2 µm). Two scanning mobility particle sizers (SMPS) were connected to these inlets to measure the respective aerosol size distributions simultaneously. The diameter where 50% of the particles are activated as cloud droplets is called activation diameter, D_{50}. The ambient activation diameter $D_{50,amb}$ can be retrieved from the difference of the total and interstitial number size distributions. To determine SS_p one has to link $D_{50,amb}$ with measurements of supersaturation dependent CCN activity. This has been done through the κ parameter (in order to be able to correct for the temperature effects) using the activation diameter climatology from Jurányi et al., 2007. Since D_{50} for a given SS remained nearly constant over the whole 17 months measurement period, the assumption of extrapolating the results of the climatology study at another time seems to be reasonable.

4. Results

The calculated SS_p values covered a wide range between 0.12 % and 2.12 % during the campaign (from June 19 to August 13). While air masses coming from the north (270° < horizontal wind direction <90°) showed values in a quite wide range, SS_p related to air masses coming from the south (130° < horizontal wind direction < 230°) was rather constant around 0.16 %. This can be most likely explained by the difference in the topography between south and north of the Jungfraujoch. While the south side of the Jungfraujoch has a rather smooth topography (Aletsch glacier), resulting in relatively low updraft velocities, the north side is characterized by steep rock walls, with more turbulent wind conditions and high updraft velocities. This result is in quite good agreement with the findings of Verheggen et al., 2007. Since air masses coming from the south are more polluted, the available water vapor could be distributed faster to the particles and thus SS_p remains on a low level. The median values of the total particle concentration for south and north during CLACE2010 are $N_{tot,south}$=771 cm^{-3} and $N_{tot,north}$=279 cm^{-3}.

Another possibility could be that from south only advection clouds are possible and thus SS_p is low due to expected small updraft velocity w. This issue will be investigated in detail during further measurement campaigns (i.e. summer 2011).

5. Conclusions and Outlook

It has been found that effective peak supersaturations at the Jungfraujoch have a mean value of 0.56 % and a median value of 0.46 %. Considering origin of air parcels during cloud events, when air is coming from south, median SS_p value of ~0.16 % was found. Air parcels coming from the north show a wider and higher range of calculated SS_p values. When distinguishing between convective and advective clouds it was observed that the former type corresponds well to increases in updraft velocity and SS_p. With data from the Windprofiler and the Lidar the separation between these two cloud types may improve. Further knowledge on the location of the activation of aerosols could be gained with these devices. It is expected that aerosols in convective clouds activated just before reaching the Jungfraujoch but aerosols within advection clouds can activate already at lower altitudes.

6. Acknowledgements

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7. References

Z. Jurányi *et al.*, A 17 month climatology of the cloud condensation nuclei number concentration at the high alpine site Jungfraujoch, *J. Geophys. Res.* **116**(2007), p. D10204.

M.D. Petters and S.M. Kreidenweis, A single parameter representation of hygroscopic growth and cloud condensation nucleus activity, *Atmospheric Chemistry and Physics* **7**(2007), pp. 1961-1971.

B. Verheggen *et al.*, Aerosol partitioning between the interstitial and the condensed phase in mixed-phase clouds, *Journal of Geophysical Research-Atmospheres* **112**(2007).

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Introduction

Uncertainties from the contribution to the radiative forcing by aerosols are much higher than for the greenhouse gases. With improving knowledge about the indirect aerosol effect, more reliable climate projections can be provided.

Fig. 1: Research station at the high-alpine site JFJ

Measurements has been conducted at the high-alpine research station Jungfraujoch (JFJ, 3580 m asl), Switzerland under the Global Atmosphere Watch (GAW) program. The measurement campaign was focused on determining peak supersaturations (SS_p) with ambient N_{CCN} measurements. The campaign CLACE2010 (Cloud and Aerosol Characterization Experiment) was performed during three months in summer.

Instruments

- Two Scanning Mobility Particle sizers (SMPS): separate number size distribution measurement of all particles and of those that did not form cloud droplets
- Particle Volume Monitor (PVM): outdoor measurement of the liquid water content of the clouds
- A Rosemount Anemometer (provided by MeteoSwiss): outdoor measurement of the regional wind directions

Theory

Activation of Aerosol Particles in Warm Clouds

The supersaturation (SS) over a solution droplet is described by the Köhler theory. A particles critical SS (SS where the particle form a cloud droplet) is dependent on its size and chemical composition. The highest supersaturation that a particle in a cloud has experienced is the so-called peak SS (SS_p).

Activation Diameter (D_{50})

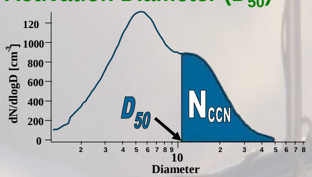

Fig. 2: Aerosol size distribution. assumption: Aerosol is internally mixed

- characteristic diameter
- particles larger than D_{50} will activate
- SS dependent
- can be calculated from the size distribution and the cloud condensation nuclei number concentration (N_{CCN})

Methods

17-month Climatology of CCNC

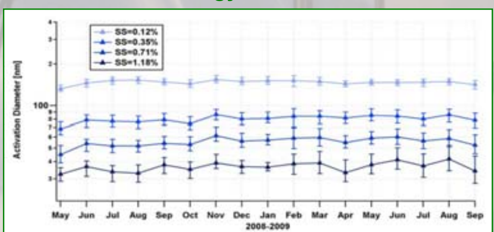

Fig. 3: D_{50} for four Supersaturations over 17 months retrieved from N_{CCN} measurements (Jurányi et al., 2011)

- constant D_{50} over 17 months

Results

Effective Peak Supersaturation (SS_p)

- SS_p values cover a wide range → no certain SS_p value characterizes the formation of clouds at the Jungfraujoch
- during the campaign mean SS_p value of 0.56% and median value of 0.46% during stable clouds periods
- the range of SS_p values during liquid clouds was between 0.12% and 2.12%

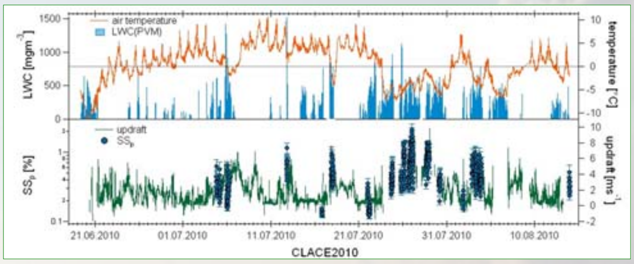

Fig. 4: Liquid water content (LWC) of clouds is shown with air temperature (upper panel). Calculated peak supersaturations (SS_p) only during liquid clouds are shown with updraft velocities (lower panel).

SS_p Dependence on Regional Wind Direction (dd)

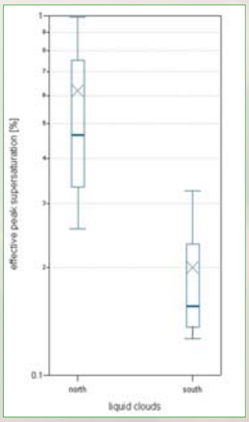

Fig. 5: SS_p values sorted according to the wind direction.

SS_p values when the air-mass comes from north (270°-90°) or south (130°-230°):

- higher SS_p values from north
- higher variability of the SS_p values from north
- SS_p values are fairly constant (~0.16%) when air comes from the south
- probable explanation: geographical situation of the Jungfraujoch (steep drop towards north, slow height decrease towards south)

Conclusion & Outlook

- A decrease in air temperature has been found for almost every cloud period measured during CLACE 2010
- SS_p values are in quite good agreement with results from earlier studies where laboratory measurements have been applied to outdoor conditions
- Lower SS_p values with a narrower range observed when air comes from south compared to air coming from north.

Outlook

- ongoing data analysis attempts to establish a link between the retrieved SS_p values and other parameters like temperature, updraft velocity and weather situation (i.e. cloud type)

References

Jurányi, Z., Gysel, M., Weingartner, E., Bukowiecki, N., Kammermann, L. and Baltensperger, U (2011) *J. Geophys. Res.*, submitted.

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