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In-situ observation and modelling of aggregation of snowfall

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Abstract. Different processes as aggregation and deposition are responsible for the growth of snowflakes. Especially aggregation leads to a shift in size distribution from smaller to larger snowflakes. The modelling of a data set, gained by optical instruments and X-band radar data during an insitu measurement campaign in March 2004, will be done by means of a shaft model that is bin-parameterized. Sensitivity studies regarding snow crystal types, riming degree, temperature or precipitation rate will be performed.

1 Introduction

Aggregation leads, especially in a temperature range of about $-6°$ to +1 °C (Fabry and Zawadsky, 1994), to a change in size distribution of snowflakes. Lawson et al., 1998 found, that the exposure of snowflakes to air-masses of temperatures close to 0 °C may even effect the growth of very large snowflakes by aggregation. This effect is reinforced in updraughts. To quantify the processes of aggregation, it is important to get representative field data. Lo and Passarelli (1982) performed aircraft measurements (advecting spiral descent) to collect data characterizing the evolution of snow-size spectra. They show, that deposition and aggregation are responsible for particle growth, playing different roles at different stages and break up acts as a limiting factor for growth. Based on the exponential approach of snow-size distribution derived from a veritable data set (Gunn and Marshall, 1958), discussions and modelling were led about aggregation efficiencies and processes (Passarelli, 1978; Leighton, 1980). Further factors affecting aggregation were presented from Othake (1970), such as temperature and snow crystal type. Applied on ground measurements, Harimaya et al. (2000) proclaim that the exponential size distribution of snowflakes is dependent on the snowfall intensity and formation mechanism, i.e. the slope of the size distribution becomes more gentle when snowflakes have low density and are not composed of rimed snow crystals.

Based on our extended in-situ measurements, we want to model the above mentioned processes and hopefully improve the understanding of the ongoing processes.

In March 2004, the Institute of Atmospheric and Climate Science (IAC) of the ETH Zürich was performing a field experiment in the region of Kleine Scheidegg/Jungfrau in the Swiss Alps. Two optical instruments that are capable to measure size properties of snowflakes were placed on two different altitudes on a roughly vertical profile. In case of aggregation during snowfall events, it should be possible to observe the change of snowflake size distribution (Barthazy, 1998). With transformations of size distribution data, the mass distribution is available (Schefold, 2004). To control the integrated mass distributions, the set up includes two balances next to the optical instruments that measure a continuous snow rate with a resolution of half a minute. Additionally, a vertically pointing X-band Doppler radar was used to compare radar patterns with the corresponding mass distributions.

The gained optical data set has been analyzed in combination with the balance data and the Doppler radar data. The modelling of the data-set will be done by means of a shaft model that is bin-parameterized. Sensitivity studies regarding snow crystal types, riming degree, temperature or precipitation rate will be performed.

2 Experimental Setup

The field experiment from March 2004 took place in the region of Kleine Scheidegg/Jungfrau in the Swiss Alps, Berner Oberland. Within one month time, we were able to measure 14 different cases. A case is defined as a phase of measurement of at least 90 min during a period of precipitation. These 14 cases cover 8 different weather situations with a total duration of 50 h and approximately 60 mm of total water equivalent. To reach a sufficient difference in altitude, the

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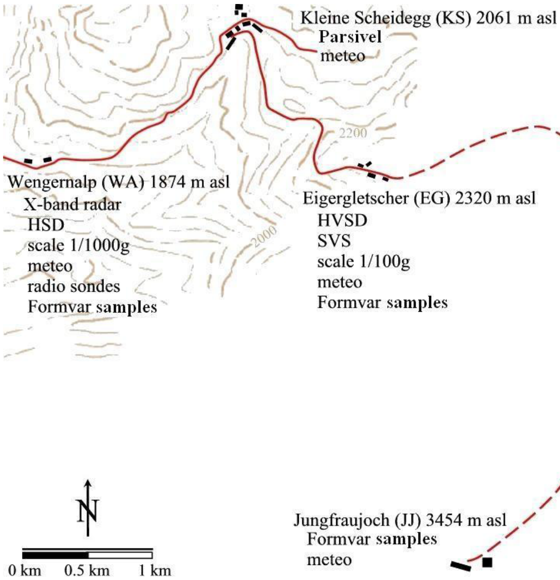

Fig. 1. Sketch of the setup during measurement campaign in the region of Kleine Scheidegg/Jungfraujoch in March 2004.

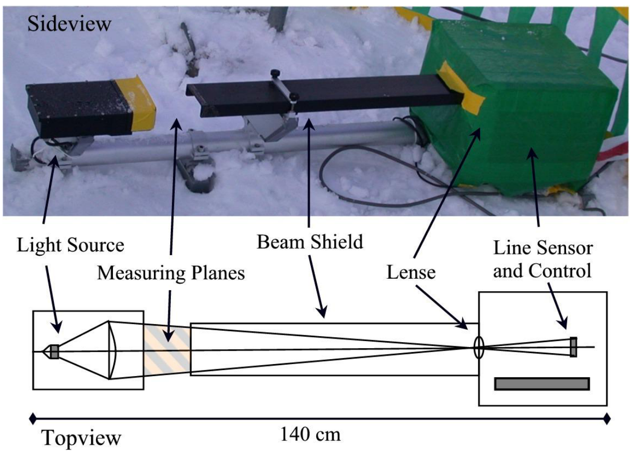

Fig. 2. Side- and top view of HVSD on its platform at Eigergletscher.

four stations were chosen as platforms for the instrumental setup (see Fig. 1). The difference in altitude between WA and EG, the main stations of the project, amounts roughly to 450 m. This is assumed to be enough to measure a shift from smaller to larger snowflakes, growing on their way down during snowfall events when aggregation is occurring. Especially in March, climatic conditions are ideal to come up on temperatures between +1 ° and −6 °C during precipitation at the chosen sites. A critical dimension is the horizontal distance between measuring stations, e.g. about 3 km between WA and EG. In unfavorable cases, precipitation cells are not that extended to be measured at all stations simultaneously, either because of inhomogeneous precipitation systems or because of topographical effects, as the measurement took place in the inner Alps with their complex orography.

Table 1.

Jungfraujoch	JJ	3454 m asl
Eigergletscher	EG	2325 m asl
Kleine Scheidegg	KS	2061 m asl
Wengernalp	WA	1874 m asl

The sampling of the optical data was performed by four optical instruments. At EG the HVSD (Hydrometeor Velocity and Size Detector, see Fig. 2) was placed, which detects the shadow of objects, passing the two measuring planes defined by the geometry of light source and LCD detector (Barthazy et al., 2004). Thus, dimension data and fall velocities can be logged. Received results are number fluxes, which can be used to compute size distributions. A method to transfer number fluxes into mass fluxes is introduced in Schefold (2004). The instrument at WA is a HSD (Hydrometeor Size Detector) comparable to the HVSD but without two measuring planes. Therefore, no fall velocities can be measured and mass fluxes can only be obtained by further assumptions. The third optical device, the PARSIVEL (IMK, University of Karlsruhe, Germany), was placed on KS. It measures the size distribution of passing hydrometeors with a one-minute resolution by scanning the change of intensity from a light beam. Furthermore, at EG a SVS (Snow Video Spectrometer, NCAR Boulder, Colorado) was positioned. This instrument records on video the image of snowflakes and their melted drop equivalent, received by melting the flakes. Because the relation between drop diameter and drop mass is known experimentally, the SVS yields information about the mass of the snowflakes with their specific diameter.

To have snow rate data with an increased resolution in time compared to heated tipping buckets, two laboratory scales with a sampling resolution of 1 mg and 10 mg respectively were run at WA and EG. The scales were placed in plastic boxes with defined tubed openings (50 mm radius) and recorded each second the actual weight value. To smoothen the influence of air movement, snow rate resolution was set to 30 s. The accumulated snow mass over a specific time period can later act as a validation parameter for the aggregation model.

At WA, a vertically pointing X-band Doppler Radar (3.2 cm) was deployed and reflectivity as well as Doppler velocity of precipitation are available with a resolution of 2 seconds for the lowest 4 to 5 km of the atmosphere. Radar data are used to control precipitation patterns. Cell like precipitations are not analyzed since the horizontal distance between the HVSD and the HSD amounts up to 3 km and physical processes cannot be compared directly.

During the whole campaign, meteorological parameters like temperature and air pressure were recorded at all stations, while precipitation rate was only measured at WA and EG. Wind data are available for KS, EG and WA. While measurement cases took place, radio soundings were occasionally started at WA, in total 14. The sounding data should

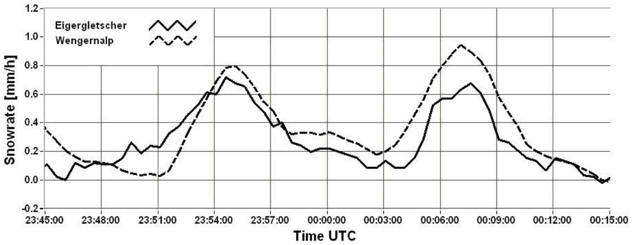

Fig. 3. Comparison of snow rate data at WA and EG with a resolution of 30 seconds. Case from 21 March 2004.

help to work out cases with ideal temperature gradients and stabile layered atmosphere.

To collect information about crystal type, aggregation and riming degree, at WA, EG and JJ Formvar probes (Schaefer, 1956) were taken. Formvar probes do not allow representative quantitative analysis but may draw a qualitative image of already mentioned parameters.

3 Data Analysis

To filter measurement phases, when aggregation of snowflakes might have occurred, the data set has been analyzed by three different approaches. First, the scale data were processed and periods with corresponding snow rates at WA and EG were identified (see Fig. 3. These periods might be of cases with homogenous and regionally spread precipitation.

A second step was the analysis of the meteorological data set, especially the temperature time series. As mentioned above, aggregation process is expected to be most efficient in the temperature range of −6 ° to +1 °C and therefore high priority was given to measurement periods showing this range of temperature. The comparison with radio sounding data, where available, shows roughly stable temperature gradients between measurement stations in all cases. Unfortunately, only one case was found to match the preferred temperature range. Mostly, temperatures were low and ranged between −8 ° and −12°C. A very efficient way to work out potential aggregation phases was the qualitative information of personal comments, made during measuring campaign.

Additionally, X-band radar data were studied to find precipitation events showing homogenous and/or strong signal (see Fig. 4). The increasing diameter of growing snowflakes (Fabry and Zawadzky, 1994) will most likely be indicated by strong radar reflectivity. Since only cases in a temperature range below freezing point were chosen, an increase in radar reflectivity caused by the change in dielectric constant during melting process can be excluded. Most cases show relatively shallow and weak radar signal.

4 First Results

Based on the results of the above mentioned screening of precipitation phases, optical data from HVSD and HSD were an-

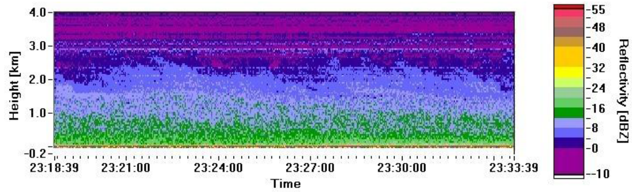

Fig. 4. X-band radar image of reflectivity during a period of reasonable snowfall at −7 °C, showing a homogenous reflectivity pattern . Case from 10 March 2004.

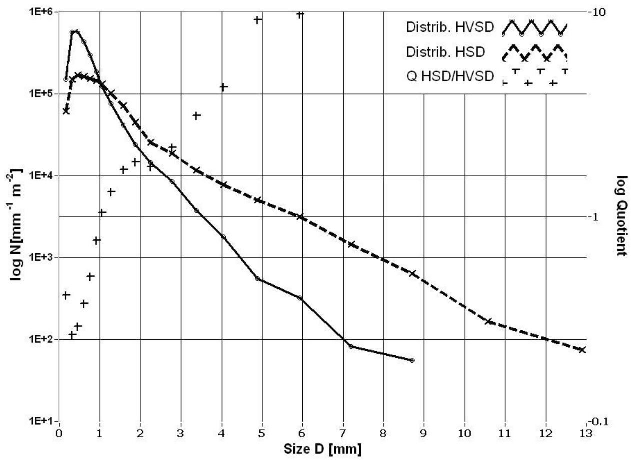

Fig. 5. Area standardised size distribution of snowflakes during 30 min, case from 21 March 2004. HSD was placed at lower station WA, HVSD at EG. A clear shift from smaller to larger particle classes is visible.

alyzed. During the measurement period of March 2004, we were able to catch at least a few cases, where the area standardised size distribution shows a shift from smaller to lager particle classes at a comparable mass flux shown by scales data, a clear proof of aggregation (see Fig. 5). Two cases are shown in the present extended abstract.

The case from 21 March 2004 shown in Figs. 5 and 6, took place while a cold front was passing the region of Kleine Scheidegg/Jungfrau. The temperature was constantly falling after noon and reached values between −2 ° and −3°C at WA during night times. The snowfall rate was varying between 0 and 1 mm/h. At both stations, WA and EG, the snowfall rates behaved similar as can be seen in Fig. 3.

Looking at radar images of the above mentioned case, reflectivity pattern is inhomogeneous and shows several precipitation cells (see Fig. 6). A remarkable band of strong reflectivity is visible at WA during a representative period of the case. The strong reflectivity values of up to 36 dbZ let us assume, that aggregation process might be seen in this particular case. Even if radar image does not show a regular precipitation event, we assume, based on scale data (see Fig. 3, that this precipitation cell is extended enough to be measured at both stations.

A second case from 10 March 2004 showing a shift from smaller to larger particle size classes is plotted in Fig. 7. The

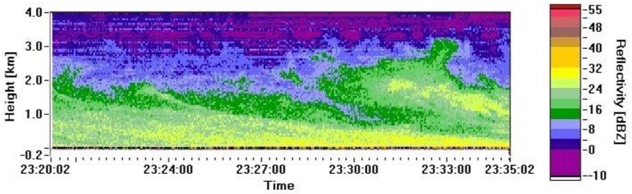

Fig. 6. X-band radar image of reflectivity during case from 21 March 2004. Air temperature is −2.5 °C and snowfall rate around 0.5 mm/h.

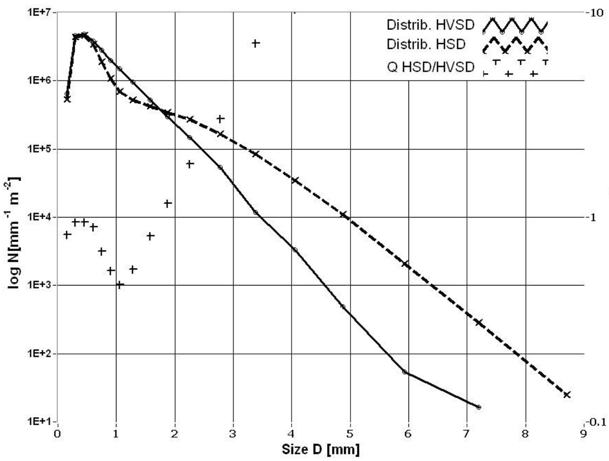

Fig. 7. Area standardised size distribution of snowflakes during 2 h, case from 10 March 2004. A shift from smaller to larger particle classes is visible at sizes larger than 0.7 mm. Air temperature is around −10 °C and snowfall rate at 1.2 mm/h.

dashed line, the data from HSD, follows the solid curve from HVSD at first four size classes and then clearly decreases more rapid than the HVSD curve, with a constant decrease, before showing a flattened gradient. Assuming that during measurement period homogeneous, constant and regionally spread precipitation occurred (see Fig. 4), snow crystals or small flakes with a diameter between 0.7 and 1.75 mm seem to build up larger flakes. Examining temperature ranges, it can be seen, that temperatures behave more or less constant around −9 ° at WA and −11.5 °C at EG respectively. This is far colder, than the earlier proclaimed -6 ° to +1 °C. This case will be topic of further analysis to validate this observation. Especially Formvar samples will be analyzed with attention to crystal types and riming degree.

5 Conclusions and Outlook

At least a hand full of cases seem to show aggregation and may be used for our aggregation-model. As mentioned earlier, there is still some work left to be done before coming to model aggregation processes based on the present data set.

The qualitative analysis of Formvar samples could be a further hint on aggregation and especially help to learn more about involved crystal types as aggregation seems to be type-dependent (Othake, 1970). Additionally, we want to process PARSIVEL data that should complete the optical data set by giving the size distribution at KS, the intermediate station. The evaluation of the influence of snowfall rate on size distribution will be critical as the spectra of varying snowfall rates during measurement campaign is narrow and ranges from close to 0 to 1.5 mm/h, scarcest up to around 2 mm/h.

Considering the fact that, unfortunately, never a case could be measured with a temperature range close to 0 °C, it is not astonishing we never measured snowflakes larger than about 16 mm. Nevertheless, by means of our set up, we were able to collect a valuable data set, even if horizontal distance is critical and vertical distance could be vaster to even see clearer shifts in size distributions.

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