Properties of pure ice clouds in an alpine environment

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1. INTRODUCTION

Diamond dust is defined as small ice crystals which precipitate from a clear sky. This kind of precipitation is common for very cold places like Antarctica when temperatures are close to -40°C. Measurements of ice particle properties at the South Pole (2800 m asl) were performed by Hogan (1974) using Formvar replicas during summer at the southern hemisphere in 1973/74. The typical size of the "diamond dust" particles lies between 40 and 100 μm major axis length. A large data set of ice crystals at the South Pole Station was obtained by Lawson et al. (2006a) using the SPEC CPI instrument during February 2001. Another data set from 2002 includes measurements from a polar nephelometer in-line with the CPI. Lawson et al. determined the ice crystal habits from more than 700,000 particles which were observed during the first week of February 2001. Both instruments had a forced particle flow.

Two known common pathways to form ice crystals in a cloud-free layer of the lower troposphere are: (1) Large ice crystals precipitate from cirrus clouds above, evaporate partially and enter the measurement site. (2) The other process is deposition freezing due to local ice supersaturation either by adiabatic cooling in an updraught or by mixing near the top of an inversion layer. Another possible source of ice crystals in ground-based measurements is snow picked up by the wind. However, these particles often show an irregular habit (aggregate ice, rosette shapes, ice particles with round edges) and are therefore fairly easy to be distinguished from the "classic" diamond

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dust (i.e. pristine columns and plates).

This work contains the first results from ground-based measurements of diamond dust particles in an alpine environment using the SPEC 2D-S probe and a holographic probe on a mountain peak.

2. MEASUREMENT DESCRIPTION

The holographic cloud probe GipfelHolo was located close to the northern edge of the platform on Jungfraujoch. It is an open path instrument and can record up to 6 images per second at a resolution of $\sim$ 30 million pixels. Each of the square pixels is 5.5 μm wide. The sensor has a lateral area of 36×24 mm^2. The depth of the sample volume is determined by the distance between the two windows, in our case it is 350 mm. For holographic instruments, the sample volume is independent from the wind speed (here: 305 cm^3 per hologram). This allows a maximum volume sampling rate of 1830 cm^3 s^{-1}. During the case study discussed in this paper, we used a recording rate of 0.5 fps and therefore 152 cm^3 s^{-1}. The minimum particle size which can be detected with GipfelHolo is around 2 pixel (11 μm). The raw holograms are filtered and reconstructed numerically to obtain the particle in-focus images and the particle positions. All particles were then classified by their habit manually using four categories: short and long columns, plates, spheroids, and irregular particles.

The SPEC 2D-S (Stereo) probe, described in Lawson et al. (2006b), was operated on a platform roughly 5 m away from the location of GipfelHolo (instrument locations shown in Fig. 1). It has a sample area of 0.8 cm^2 which yields a volume sampling rate of 1200 cm^3 s^{-1} using aspiration with $\sim$ 15 m s^{-1} by a pump. Each of the images has a resolution of 10 μm but for classifying the particles as either ice or liquid water droplets, a minimum particle size of 60 μm is needed.

Temperature, relative humidity and wind speeds were obtained from the meteorological station of MeteoSwiss. The typical accuracy of the temperature measurement is around 0.3 °C and the typical accuracy of the humidity measurement is around 4 % (hysteresis effects close to water saturation not considered).

3. METEOROLOGICAL CONDITIONS During the time of this case study, an upper trough was present over central Europe and Switzerland lay at its western edge. At mid and upper levels, a moderate northwesterly flow was observed in this very cold airmass. Temperatures at the 500 hPa pressure level were as low as -40°C, at 700 hPa the temperature was $\sim$ -20°C, derived from analysis data of the GFS model. At the location of the instruments (pressure around 640 hPa) the temperature stayed between -25 and -26°C during the measurements. Wind speeds were fairly constant around 5 m s^{-1} from the north-northwest. Due to the steep incline of the north face of the Jungfraujoch, this results in updraught speeds between 1 and 2 m s^{-1}. The relative humidity over water stayed close to saturation throughout the whole day, which indicates ice supersaturation at the measurement site. There was no cirrus or altostratus cloud above, so the majority of the measured ice crystals should have formed via deposition freezing. Some stratocumulus was present at lower levels, some hundred metres below the site.

4. DIAMOND DUST CHARACTERISTICS

On a ten minute average, size distributions of the ice particles were calculated for both instruments (see Fig. 2 for details). Log-normal fits were performed which represent the individual size distri-

Figure 1: Location of the instruments used during CLACE2013. GipfelHolo is marked by a red circle, the instruments from the University of Manchester (which include the 2D-S) are marked with a black circle. The north-south line goes from the lower right to the upper left corner of the photo.

butions quite well (normalized R^2 close to 0.9). Over time, the number concentrations tend to decrease slightly in the first 30 minutes, then significantly decreases. The mode particle size tends to increase slightly with time which is likely due to an increase of the particle fraction from blowing snow.

The particle habit classification was done by eye and should have an accuracy of ~ 20 % or better. Irregular particles are fairly easy to identify, but the classification of small particles is much more difficult (the boundary between spheroids, small plates and small columns is hard to draw if the particle size is 10 pixels / 55 μm or less). A time series of the particle habit number concentration is given in Fig. 3. According to the results, temperature does not seem to have a strong effect on the diamond dust characteristics as the presented results were obtained at temperatures which were between 10 and 15°C higher than in the Antarctic cases from Lawson et al. (2006a).

All individual size distributions in Fig. 4 agree quite well with a monomodal lognormal distribution. The fits which were performed yield normalised R^2 values between 0.62 and 0.94 where the best fits were obtained for the columns and the spheroids. As one should expect, the mode particle size is smallest for the spheroids and largest for the irregular particles. The size distribution of the irregular particles is much flatter than all others which raises confidence that these particles are mostly from blowing snow and have not formed in-situ via deposition freezing.

The time series of the two instruments in Fig. 5 show maximum number concentrations in the same order of magnitude for the 30 second average. However, both series are virtually uncorrelated ($\rho \approx 0.15$). This fact allows us to conclude that the cloud is likely spatially inhomogeneous, even on a length scale of 5 m (which is the distance between the two instruments). The number concentrations vary by one order of magnitude and more with time.

Both instruments show similar size distributions on the 40 minute average as shown in Fig. 6. The maximum number concentrations match quite well but some discrepancies are found which exceed the error bars from statistical calculations. It might be due to the spatial distance of the two instruments or because both instruments use different principles to measure.

5. CONCLUSION

Similar to the findings of Lawson et al. (2006a) we found columns being the dominant crystal habit. The size distributions look also quite similar with a maximum around 70 - 80 μm.

The intercomparison of the two instruments shows similar size distributions. However, there are some differences in the cumulative size distributions which cannot be explained by counting statistics. At least the maximum number concentrations and the size at maximum number concentration match very well. The reason why GipfelHolo detects more small particles and less large particles than the 2D-S might be either inhomogeneities of the cloud or effects from particle sizing in the holographic data set. The methods for obtaining the particle sizes and positions are still preliminary. This discrepancy has to be investigated and corrected in further studies. Also, the images from the 2D-S and CPI have not been examined yet.

The particle habit analysis shows that the mode diameter increases from spheroids via plates and columns to the irregular particles. Most of the irregular particles are likely blowing snow. The irregular particles have a very flat size distribution whereas the size distributions of the other particle habits are a lot steeper.

Additional tests were performed to check if the particle habits and the particle sizes are correlated. When using quartiles of the particle sizes, no correlation was observed (large particles follow large particles almost as often as large particles follow small particles). A similar test for the particle habits showed that columns and irregular particles have the highest autocorrelation (which means, the next particle is from the same habit class).

It is not yet clear if the size distributions and particle habit distributions presented in this study are common for diamond dust in the Alps or if it was a special event. From the CLACE2013 field campaign, there are other days with measurements of diamond dust events which can help to answer this question.

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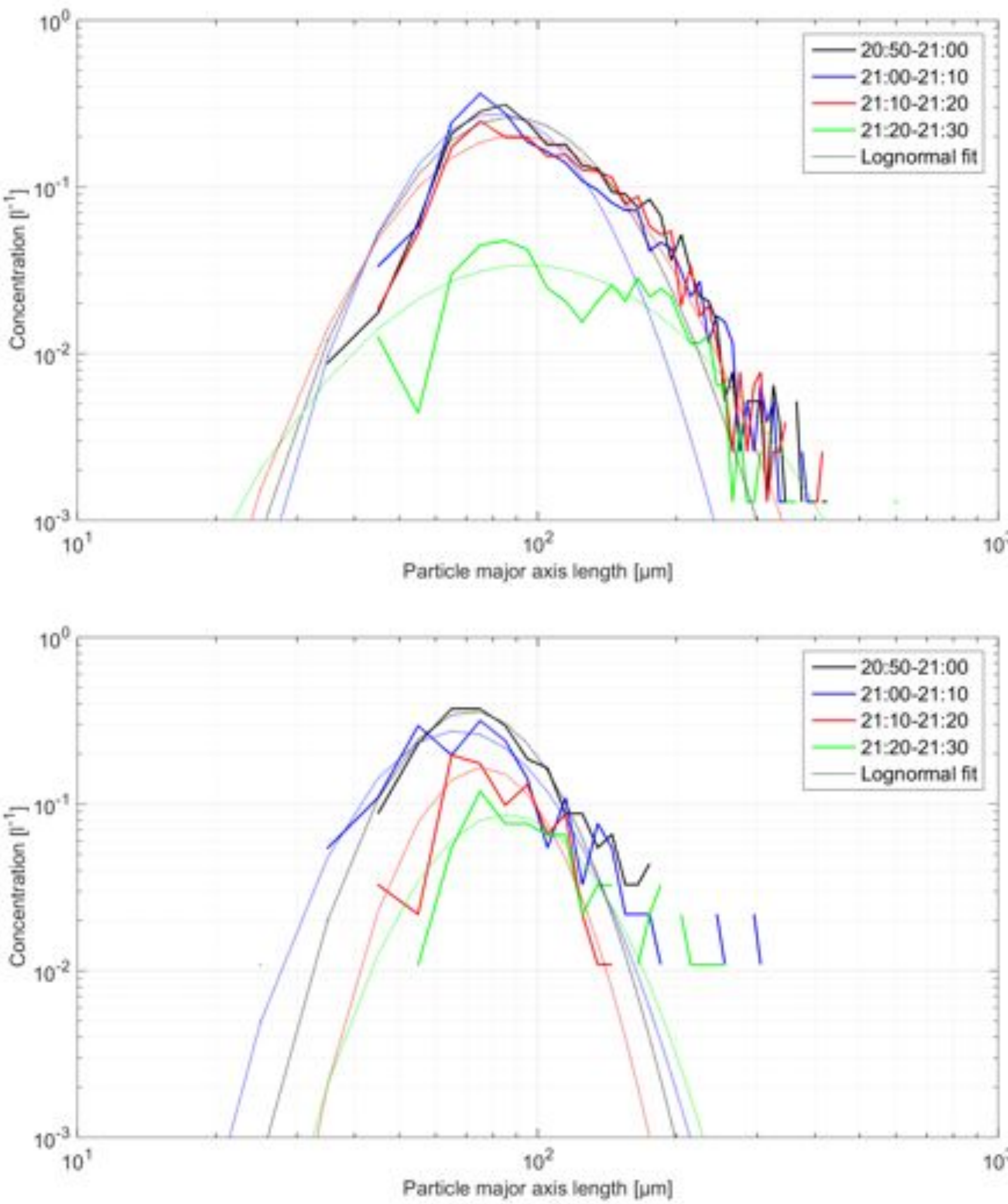

Figure 2: 10 minute average size distributions of the 2D-S (top) and GipfelHolo (bottom).

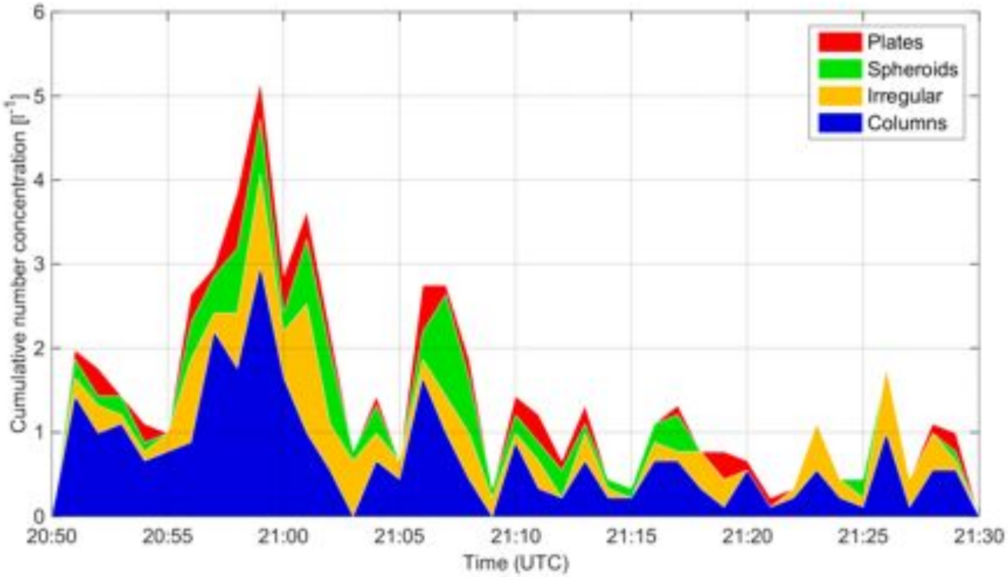

Figure 3: Time series for each particle habit from GipfelHolo.

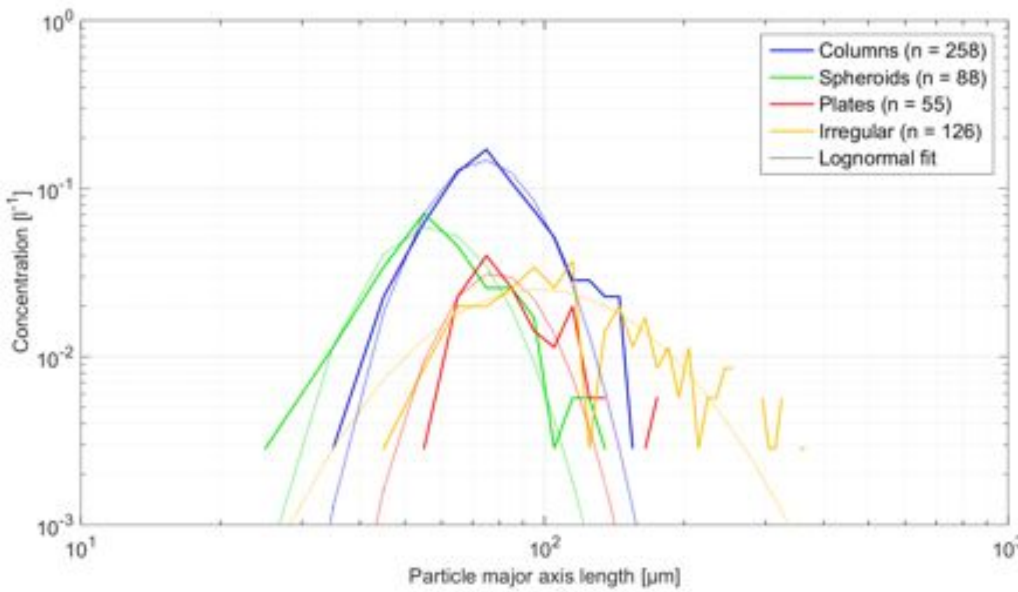

Figure 4: Size distributions of each particle habit from GipfelHolo with log-normal fits.

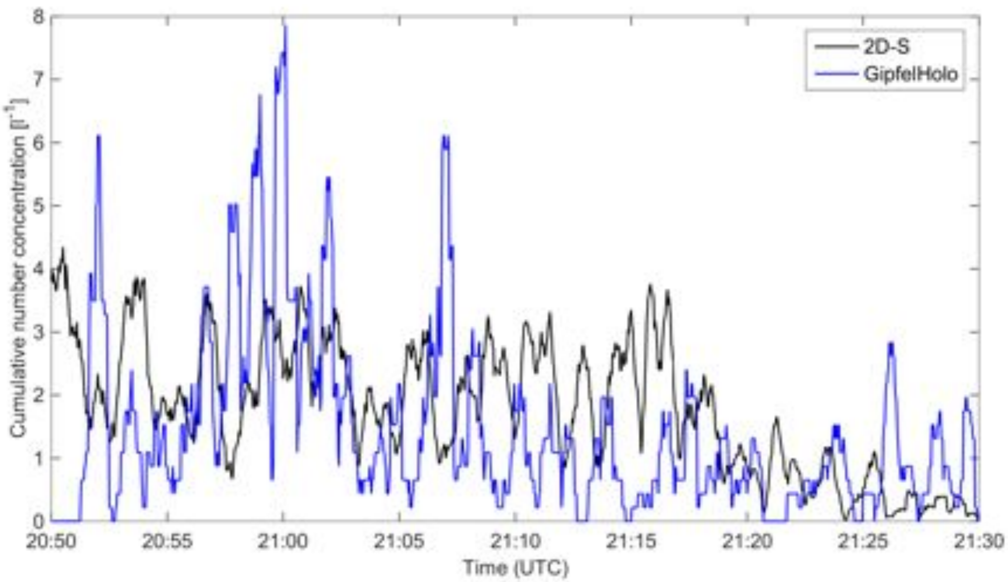

Figure 5: Comparison of the time series from GipfelHolo and the 2D-S. Typical statistical uncertainties are between 0.2 and 0.5 particles per litre.

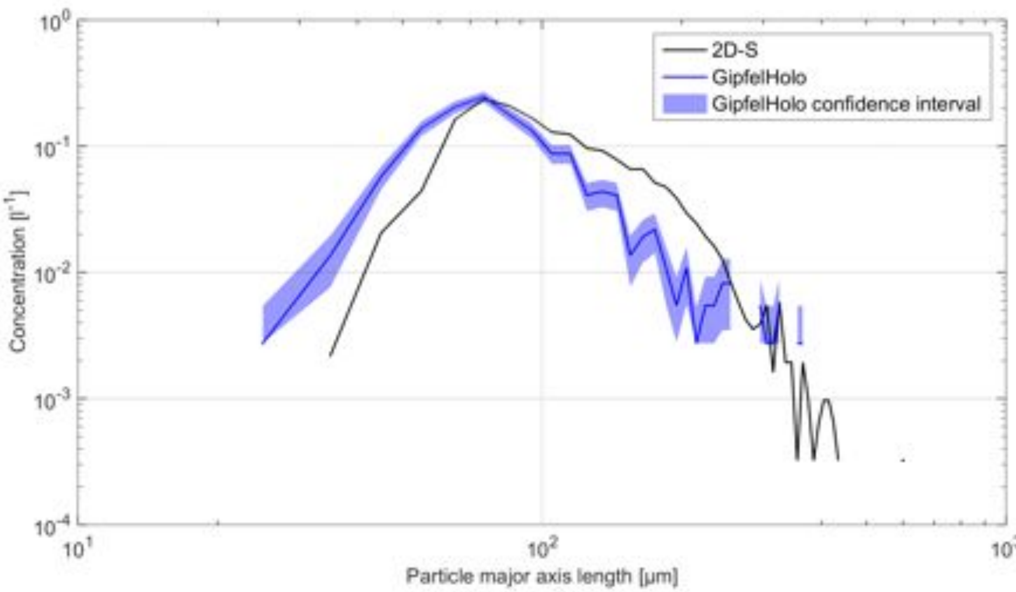

Figure 6: Comparison of the size distributions from GipfelHolo and the 2D-S.