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Interactive comment on "Investigation of the effective peak supersaturation for liquid-phase clouds at the high-alpine site Jungfraujoch, Switzerland (3580 m a.s.l.)" *by* E. Hammer et al.

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The authors would like to thank Referee 1 for the positive comments which were very helpful and motivating. All comments of reviewer 1 are addressed below. The reviewer's comments are in italics and our responses in plain text.

General comments:

The authors introduce a method for calculating effective peak cloud supersaturation and apply it to in-cloud measurements at the high-altitude Jungfraujoch research station in the Swiss Alps. The introduced method uses total and interstitial aerosol size distributions to determine aerosol activation diameter, CCN measurements to determine particle hygroscopicity, and kappa-Kohler theory to combine these measurements and derive effective peak supersaturation. The method is applied to a large amount of data from a series of intensive field campaigns at Jungfraujoch (CLACE 2002, 2004, 2007, 2010 and 2011). Due to the local topography there is two prevailing wind directions at the site: NW and SE. It is found that supersaturations are generally higher in clouds approaching from the NW (0.41 %) than the SE (0.22 %). Through the use of observational data (updraft velocities, potential CCN concentrations, hygroscopicity) and box model simulations the authors conclude that updraft velocity, controlled by local topography, is the most important factor controlling the variability in cloud super saturations observed at Jungfraujoch. This paper presents an interesting method for calculating cloud supersaturations and applies it effectively to a large, quality dataset. It is well written and the results are presented clearly. The only major problem is the strength of the conclusion drawn from the non-optimal measurement/calculation of up draft velocity, as discussed further below. I recommend publication in ACP after the following comments are addressed. The airflows around Jungfraujoch and the updrafts responsible for cloud formation are not discussed in sufficient detail. Two measures of vertical wind speed are used: w_{act} *calculated from horizontal WS at JFJ and a simple trigonometric model of the local topography, and* w_{jfj} *measured by an imperfectly placed sonic anemometer at JFJ. The authors concede both parameters will not accurately represent the true updraft velocity at cloud base, but stop there. Further discussion should be added concerning the air flows around JFJ and how these relate to updraft velocities and cloud formation. The flow field around JFJ will likely be complex, determined by all the surrounding topography (not simply the 2 slopes to the NW and SE of JFJ), depend on height above the slope, and include both down- and up-slope flows. The measures* *of WS provided in the paper are not sufficient to resolve the complex flow field, as evidenced by the large scatter in Fig. 9. This is fine since this is not the main focus of the paper but the limitations must be appropriately presented and discussed. In particular, I think the conclusion that updraft velocity, controlled by slope angle, is the most important factor affecting* SS_{peak} *is overstated. The observational evidence and box model simulations suggest updraft velocity is certainly important. The link to slope angle seems like a possibility but the evidence presented here doesn't prove it.*

We discussed the wind field in the vicinity of the JFJ further in section 4.4 by adding following sentences: "The wind field around the JFJ is likely to be very complex due to the surrounding topography. The measurement location is situated atop a rocky pinnacle in a pass between two mountain peaks. Air approaching from the north or the south is therefore funneled from relatively wide valleys through the narrow pass. Additionally, low level air approaching along the Lauterbrunnen valley to the north will be forced to rise along the steep rocky northern slope, which includes numerous bluffs, ridges and other complex terrain features. Direct measurements of vertical wind velocities at the cloud base in such an area are extremely difficult to perform, and have therefore not been attempted. Thus it is not possible to determine the true updraft velocity at the cloud base. However, simplifying the topography in the vicinity of the JFJ with only two slopes (to the NW and SE of JFJ) is a possibility for retrieving a qualitative updraft velocity as a best estimate for the true updraft velocity present at the cloud base."

For a better understanding of the assumptions that we made for the wind field surrounding the JFJ, we adjusted Fig. 5 such that the streamlines reflect the underlying assumptions on the wind field (i.e. the lines represent the direction of the flow and the orthogonal distance between the lines is inversely proportional to the wind speed).

In section 4.5.2 we added "This shows that the mean difference in potential CCN can only have a minor influence on the systematic difference between the mean observed SS_{peak} for the two wind cases. Opposed to this, changing the updraft velocity in the model be a factor of two, which corresponds to the factor between the mean observed updraft velocities for the two wind cases, reduces the resulting SS_{peak} by about 34 % (when starting from the mean NW case). Thus, it is very likely that the difference in the mean observed SS_{peak} between NW and SE cases is for the most part caused by different updraft velocity, while systematic differences in the CCN number concentration only have a minor influence. The difference in updraft velocity is likely, at least to some extent, driven by the different topography, though we cannot directly prove this nor can we exclude some influence from differences in the meteorological conditions.", to highlight the point that we are speaking about the variability of the updraft velocities shown in Fig. 8 and not about the absolute values shown in Fig. 9.

Adding the following text to section 5, we state again the limitations of the retrieved updraft velocity: "…because the qualitative estimate of the updraft velocity at cloud base inferred from the wind measurements at the Jungfraujoch potentially overestimate the true updraft velocity at cloud base. The increasing spread in observed SS_{peak} with increasing updraft velocity is most likely due to an increase in the variability of the wind velocity at higher wind speeds."

Specific comments:

P 20424, L7: Give the dates for each campaign. Have measurements also been conducted in winter? Are there any interesting seasonal differences that could be expected?

We added the dates for each campaign in Sect. 2.1. All campaigns were carried out in summer, since in winter ice and mixed-phase clouds are almost the only cloud types present and these are not the focus of the study presented in this paper. The presented method in this paper is not applicable for ice or mixed-phase clouds measured during winter periods. The activation plateau drops towards 0 due to the Bergeron-Findeisen-Process (Verheggen et al., 2007) and thus valid activation diameters cannot be calculated.

P 20424, L28: How efficiently does the total inlet sample cloud droplets and the SMPS measure these as residual particles less than 600 nm Dp? Earlier it is stated cloud droplet size distributions were also measured during the campaigns, how well do the integrated cloud droplet concentrations compare to the residual (total – interstitial) particle concentrations? If less than 100 %and not corrected for this will affect the calculated SS_{peak} *values.*

We will add following information to the revised manuscript in section 2.2: "Since the difference of the number concentration measured behind the total minus the interstitial number concentration corresponds to the number of cloud residuals, i.e. of particles that have been activated to cloud droplets, the sampling efficiency of the two inlets can be compared to the number of cloud droplets measured at ambient (see sect. 3.3). So, compared to the study of Henning et al. (2002) shows a good correlation between the residual particle concentrations and the integrated cloud droplet number concentrations measured with a forward scattering spectrometer probe (FSSP-100) during CLACE2000. During CLACE2010 a Fog Monitor (FM-100) was employed to measure the cloud droplet size distribution. Unfortunately, it was very difficult measuring the cloud droplets with this instrument at the JFJ because high wind velocities led to strong measurement artifacts, as described by Spiegel et al. (2012). However, the study showed that a good agreement between integrated cloud droplet

number concentration and cloud residuals (total-interstitial) was found after accounting for these droplet losses of the FM-100, by applying experimentally and theoretically derived formulas for the different loss mechanisms based on Spiegel et al. (2012)."

P20425, L6: I think this should say three instruments? (2 SMPS + CCN)

We corrected this typo.

P 20425, L16: 600 nm is a low upper limit, can you give an estimate for the percentage of particles above this?

Based on Jurányi et al. (2010) as well as from our long-term size distribution measurements at JFJ, we find that above a diameter of 600 nm we usually measure a particle number concentration between 1 and $5\,\mathrm{cm}^{-3}$. Therefore, the number of particles above 600 nm is negligible compared to the number concentration of CCN, even for the lowest applied supersaturation.

P 20425, L26: What correction factor was applied in-cloud?

Since the total and interstitial aerosol size distributions are comparable during cloud-free periods, the time dependent correction factor was determined during cloud-free periods and applied for in-cloud periods. It has been done by interpolating the retrieved correction factors of the start and end of the cloud periods. In the revised version of this manuscript we made this point clearer by adding to section 2.2: "A size and time dependent correction factor was determined by comparing the total and interstitial number size distributions during all cloud-free periods. This correction factor was then applied to the interstitial aerosol size distribution during the cloud periods by interpolating the retrieved correction factors of the start and end of the cloud periods (Verheggen et al., 2007)."

P20427, L20: This cloud criterion is not very strict. How does it compare to similar previous studies in the literature. Also, do the results change much if the higher criterion used in the previous CLACE studies is applied to CLACE2011.

In earlier campaigns before 2010 only one SMPS was running, and this instrument was switching between the total and interstitial inlet. Thus, one measurement cycle lasted 12 min, instead of 6 min as was the case during CLACE2010 and CLACE2011 where two SMPS instruments were running in parallel. Nevertheless, if we apply the stricter criterion (85 % of time during a SMPS scan the LWC value must be over the $25\,\mathrm{mgm^{-3}}$) for CLACE2011, we would get $22\,\%$ less cloud periods compared to the less strict criterion and it would result in a 1 % relative increase of the median SS_{peak}. The definition of a less strict cloud criterion for the shorter measurement interval takes into account the fact that the probability for cloud patchiness is lower for 6 min compared to 12 minutes.

P20432, L25: I think I'm missing the point here. Doesn't this calculation (from horizontal WS and alpha) produce the vertical component of WS at JFJ? Or is it assumed the vertical component of WS is constant between the point of activation and JFJ. If so this contradicts the statements just a few lines previous that the vertical WS at JFJ differs from that at the point of activation. More explanation required.

We modified the text in Sect. 3.4 to clarify the assumptions required to infer the vertical component of the wind speed from the horizontal component measured at the

Jungfraujoch: "... making the following assumptions about the wind field around the JFJ (see also Fig. 5): (1) the air approaching the JFJ research station strictly followed the terrain, i.e. the flow lines are parallel to the surface (at least in the lowest layers). (2) Neither sideways convergence nor divergence of the flow lines occurred between cloud base and the JFJ. Thus, the horizontal wind speed component stays the same between cloud base and the JFJ."
Figure 5 has also been improved in order to clarify the assumptions on the wind field.

P20434, Section 4.2: This section seems like it would be better placed in the 'Methods' section. At least the part explaining which kappa dataset was used to derive SS_{peak} for the different campaigns.

In the beginning of the first paragraph of section 4.2, we quickly remind the reader how the SS_{peak} is derived, and in the end of the paragraph we give some new information describing which dataset was used to derive SS_{peak} for the different campaigns. We agree that it could also fit in the "Method" section. However, because we would like to show the kappa dataset measured during CLACE2011 in the results part, and compare those with the CCNC climatology of Jurányi et al. (2011), we would like to leave this paragraph unchanged in this section.

P20442, L14: This result is difficult to see from Figure 9 alone. Suggest adding some numbers here to back up the conclusion. How much does SS_{peak} change with potential CCN concentrations?

With Figure 8a) and d), and the model simulation shown in Figure 9 we give information about a qualitative influence of the potential CCN on the variability of SS_{peak} but not a quantitative one. In Figure 9 we added now the SE case in 9a) and the NW case in

9b) for making the difference between SE and NW case better visible.
And we modified the last paragraph in section 4.4 as follow: "Summarizing, the results presented in Fig. 8 show that systematic differences of the mean updraft velocity and the mean CCN number concentration between NW and SE wind cases result in a systematic difference of the mean SS_{peak} in clouds formed in the vicinity of the JFJ. The relative importance of these two parameters cannot be quantified with the experimental results. However, the box model simulation showed that the difference of the mean CCN number concentration only had a minor influence on the difference between the observed SS_{peak} values."
And we modified the third paragraph in section 4.5.2 as follow: "An important result of the model simulation is the fact that the two model curves for SS_{peak} as a function of w_{act} differ only little between the northwestern and southeastern cases (the average difference is 11.4 %; for the median SS_{peak} for CLACE2011 the difference is 10.3 %), while the observed SS_{peak} differed on average by as much as a factor of 1.8. As the differences between the model runs for northwestern and southeastern winds in temperature and pressure at cloud base have only negligible influence, the main difference was the number of aerosol particles (which were taken to be the median of the distributions observed from each wind direction). This shows that the difference in potential CCN only has a minor influence on the variability of SS_{peak} as opposed to the stronger influence of the variations of the updraft velocity (as discussed in Sect. 4.4). "

And we added to the caption of Figure 9: "Panel **(a)** shows results for the northwest wind case, panel **(b)** shows results for the southeast wind case. The black line indicates the model simulations with mean input parameters for each wind direction for CLACE2011. The grey dotted line indicates the model simulations with median input parameters for each wind direction for CLACE2011 but with swapped aerosol size distribution as input parameter."

We used median values instead of mean values and therefore adapted the fol-

lowing sentences by changing "average" to "median", and modified the paragraph as follow to address the referee's comment:
"In order to simulate the SS_{peak} as a function of updraft velocity for CLACE2011, ZOMM was initialized with median values of the altitude, temperature and pressure at cloud base and of the dry aerosol number size distribution. Medians of these quantities were separately calculated for southeasterly and for northwesterly wind conditions from the values observed at the JFJ during CLACE2011, in order to obtain representative cloud simulations for the two wind sectors. The differences in temperature and pressure at cloud base between NW and SE had only negligible influence on the modeled updraft vs SS_{peak} relationship, whereas the difference in CCN number concentration had a detectable influence."

And we changed the following sentence: "Particle hygroscopicity was described with using a constant κ value of 0.2 in all simulations." to: "Particle hygroscopicity was described with using median κ values of 0.22 for the NE wind case and 0.26 for the SE wind case." Since we used now the median κ values for NW and SE case and not anymore the overall median κ value.
and as well in sect 5 we modified the second paragraph to: "Difference in the median particle hygroscopicity cannot explain these differences as the κ values are ..."

An ongoing work where we plan to show a sensitivity study on how strong several aerosol and meteorological parameters are influencing the SS_{peak} may hopefully further answer this question.
And we added to the second last paragraph in sect. 5: "The observed factor of 2 difference in median updraft velocity between NW and SE conditions can explain the difference of the median SS_{peak} for the most part according to the model simulations."

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 20419, 2013.