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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Aerosol-landscape-cloud interaction: Signatures of topography effect on cloud droplet formation" *by* Sami Romakkaniemi et al.

Anonymous Referee #1

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General comments:

This Paper investigates the suitability/applicability of the Puijo observation station site data for investigation of cloud-aerosol interactions that occur in the free (i.e. non orographically perturbed) atmosphere. It does this by investigating the wind direction (and hence terrain and aerosol source) dependency of cloud and aerosol properties observed over a number of years at the observing station (on a 75m tower atop a moderately sized (150m high) forested hill) and by comparing these with model sensitivity studies of the same dependencies. The measurement data set was gathered from a standard set of cloud and aerosol instrumentation, while various pre-published models were used for the latter comparison (and so having already been reviewed in various

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previous publications, details and use of these models will not be commented on in this review).

Unsurprisingly, the main outcome of the analysis of the observational data set is that the cloud properties observed at this site are mainly influenced by the properties of the aerosols that act as Cloud Condensation Nuclei (CCN) within this system, and also, but to a lesser extent, by the effects of the enhanced updraughts (and hence enhanced supersaturations) experienced by the aerosol-cloud system as the airmass they are contained within approaches and rises over the Puijo hill. The effects of the complexity of the terrain profile and aerosol sources in the different wind directions were simplified by confining the model sensitivity studies to investigations for the wind direction generating the biggest orographic effect in the observations, and by using a standardised aerosol input for that direction. This also allowed identification of the conditions when the orographic effect is a maximum, and when this has to be taken into consideration when applying results from the Puijo site to non orographically influenced clouds.

Although the conclusions of this work are not particularly unexpected, I find the treatment of the observational data generally acceptable, and the initialisation and use of the LES model (PALM) to generate trajectories along which a separate cloud parcel model was then run to investigate various sensitivities, wholly satisfactory. Previous studies in the areas of work undertaken here (including the use of the same models as used here) are well referenced, and the description of methods used in this study is clear and understandable. The conclusions are also clearly stated and correct based on the results presented. I therefore consider the outcome of this work to be useful and the paper to be worthy of publication subject to dealing with a few very minor changes/typographical corrections/clarifications (listed below).

Specific issues / comments / suggestions:

Page 3, line 13: “In hill cloud studies, the updraft caused by the hill is strongest near the

surface and decreases as a function of altitude" Suggest ".... decreases as a function of height above terrain surface" – i.e. it is localised to the hill rather than it being the actual altitude of the hill/surrounding terrain height

Page 3, line 14: change "would be located" to "were located"

Page 3, paragraph 3: just because the hill can generate additional orographic enhancements in cloud properties (generally an increased droplet number for a simple hill profile where the lifting generates increased updraughts and supersaturations) it does not mean the results are not applicable to understanding processes where similar updraughts are present in other cloud types. The issue becomes more difficult when the terrain is more complex (multiple hills/valleys, varying terrain coverage) which introduces a significant complexity and uncertainty in the supersaturation history of the ground based cloud parcels, a situation which may not be observed in the free troposphere.

Page 4 line 1: suggest change "All local aerosol sources are located within 10 km from the tower at an approximately 200 m lower altitude...." to "All local aerosol sources are located within 10 km of the tower at an altitude approximately 200 m lower ....."

Page 4, line 9: "The CDP at Puijo tower is mounted on a swivel, which keeps the inlet facing the wind". Does this swivel tilt as well as rotate? What is the average wind angle (in the vertical)? Since a tubular inlet has been fitted to the instrument to fix the sample flow (like an older FSSP) it will be crucial that the probe is rotated into the wind both in the horizontal and vertical when measuring, particularly if there is a significant vertical wind angle at the measurement site (this will be less of an issue on the tower top 75m above the hill surface). This could affect the droplet size distribution measurements. Please clarify this situation.

Page 4, line 10: The inclusion of a tubular inlet may also introduce sampling artefacts through droplet breakup on the inlet edge. This should be discussed as to why this is/is not an issue.

Page 4, lines 11-12: “The accuracy of the CDP is estimated to be 20–30 %”. This needs additional clarification i.e. is this a 20-30% accuracy in sizing, counting, or what? This is particularly important in order to understand how this progresses through to the integrated cloud liquid water contents which are then calculated. State the uncertainty in the calculated LWC.

Page 4, lines 13-24: “All weather instruments are located approximately 2 m above the roof of the tower except for the anemometer, which is mounted on a mast at a height of 5 m above the roof in order to decrease the effect of the tower on the measured winds”. This is an issue if the CDP is one of these” weather instruments” mounted at 2m. If the anemometer is mounted 3m above the other instrument to reduce the effects introduced by the tower itself on the wind, it follows that the other instruments are sitting in air perturbed by the tower. The mounting height of the CDP needs to be stated. Anemometer, CDP and particle sampling inlets should have been mounted at a similar height on the tower (and as close to each other as possible).

Page 4, line 25: “The data from these instruments is saved as one-minute averages.” Change “is” to “are” i.e. “The data from these instruments are saved as one-minute averages.”

Page 5, line 1: ”The CDP data were restricted to be valid only during low-level cloud events”. So is this for situations where the cloud base of low level stratus clouds advecting over the region was sufficiently low to envelop the measurement tower in cloud?

Page 5, lines 1-2 “: suggest changing: “.... and the possibility for broken clouds was additionally excluded through visibility measurements.” to “.... and the potential inclusion of periods of broken clouds reduced through use of visibility measurements.” Page 5, line 3: insert “cloud” into: “The numerical value for the minimum cloud LWC was set to 0.02 gm-3.

Page 5, lines 4-5: “.... for larger LWC values the cloud droplets become so large, that the cloud can no longer be classified as non-precipitating”. This will be true unless

there are cases where the droplet concentration is higher (in polluted events) and the LWC is spread out over that higher droplet number. So suggest adding a line like " ... for typical droplet number concentrations observed at the measurement site in such cases" or similar.

Page 5, line 9: "...while the boundary layer depth was about 370 m from the lake level". Comment on why the BL depth was set to this value (was it validated by any measurements at the time or previously?). Also change ".... from the lake level" to "..from above the lake level"

Page 5, line 16: "using the logarithmic law of the wall for neutrally stratified conditions". Is this a correct statement (... because I am not familiar with the "wall" here) – apologies if correct! (in which case describe this a bit more)

Page 6, line 5: delete "have" in "We have used a similar approach earlier 5 in Romakkaniemi et al...."

Page 8, line 11: insert "an" in "However, as the air masses arrive at Puijo hill, they experience an updraft, which depends..."

Page 8, line 32: suggest insert "at times" into: ... both significant and at times comparable in magnitude to the N100 trend".

P10, line 3: ".....typical composition measured during different campaigns (Hao et al., 2013; Portin et al., 2014; Väisänen et al., 2016) at the station." Without reading these references in detail, was a direction dependent aerosol composition used as input here (since it was mentioned earlier that some directions included sources of aerosol. i.e. was the aerosol composition input appropriate for the wind direction chosen that maximises the orographic effects in these sensitivity tests?

As an aside, since the primary control of cloud properties comes from the properties of the aerosol available as CCN, was this whole sensitivity test repeated for a quite different aerosol input? In the extreme case the shape of the aerosol distribution input

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to the model could change the activation pattern of CCN and result in a different cloud response in the sensitivity tests. However I would not expect the results to change significantly. Comments?

Page 11, lines 10-11: " changes in the sign of the updraft are reflected as a change of sign in the supersaturation." Maybe emphasise by saying "changes in the sign of the updraft (i.e. changes from updraughts to downdraughts) are reflected in a change in the sign of the supersaturation (i.e. from supersaturation to subsaturation)"

Page 12, line 8: delete superfluous "also" in ".... droplets form also inside the cloud"

Page 12, line 14: delete superfluous "already" in "The in-cloud supersaturations may also be higher than at the cloud base already before the cloud parcel reaches Puijo hill"

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