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Interactive Comment

Interactive comment on "Arctic low-level boundary layer clouds: in-situ measurements and simulations of mono- and bimodal supercooled droplet size distributions at the cloud top layer" *by* M. Klingebiel et al.

Anonymous Referee #2

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General Comment: Mixed-phase Arctic clouds were sampled during the VERDI project in 2012. While monomodal drop size distributions (DSD) were observed for most of the cloud depth, at cloud top bimodal DSD were observed. The authors postulate that there are two possible reasons for the bimodal DSD at cloud top – 1) secondary activation from entrained particles or 2) differential evaporation "occurring with cloud droplets engulfed in different eddies". The authors do not discuss the possibility that wapor - ice – liquid interactions could factor in to the bimodal DSD observed. Lebo et al (2008) showed that large droplets and ice crystals can grow simultaneously by condensa-

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tion/deposition while smaller droplets evaporate, since the evaporating droplets "must rise over the maximum of their Kohler curves" leading to a slight liquid supersaturation, which could lead to a bimodal DSD. I was disappointed that there was so little discussion of interactions of the liquid and ice phases, which is one of the most interesting aspects of Arctic mixed-phase clouds. The focus on liquid-dominated clouds should have been stated up front in the abstract. I would also like to see a short discussion on how the authors know the ice phase is not playing a significant role in the case studies chosen.

Since the authors focused on liquid-dominated clouds in the Arctic, I wondered: How do the bimodal DSDs observed at the top of Arctic stratiform clouds compare to DSDs at the top of stratiform clouds in temperate latitudes? There was brief discussion of LWC in Arctic clouds versus tropical (presumably marine stratiform) clouds and the depth of "holes" at cloud top between those two different environments, but what about the bimodal DSDs? Are bimodal DSDs observed at cloud top in marine stratus in temperate environments?

Page 14601: I'm not sure what is meant by this statement: "Satellite measurements (CALIPSO and ICESat) between 2003 and 2008 showed that cloud cover and optical depth reach a maximum over ice-free waters in the Arctic (Palm et al., 2010)" I figured out later that this statement was meant to be understood as "In the Arctic, there are more clouds and thicker clouds over water than over ice", but at first I wondered if it meant that there were more clouds and thicker clouds in the Arctic than in other locations. I think "in the Arctic" should be moved from the end of the sentence to clarify the important parameter that is being evaluated ("ice-free waters" versus "iced-covered waters")

Page 14601: "The microphysical characteristics of clouds, e.g., particle phase, size, number concentration, and shape determine the radiative properties which influence the atmospheric radiation budget ... On the other hand climate simulations indicate that the sea salt emissions may increase with receding ice coverage leading to . . ." It

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would help to have a transition statement between these two sentences, to clarify what is being compared. Something like "Therefore, reductions in sea-ice leading to greater cloud coverage and cloud optical thickness may have a substantial radiative impact."

Page 14602: "However, in the Arctic, boundary layer clouds mostly warm the below-cloud atmosphere." This depends upon the season (See Curry et al, 1993)

Page 14603: "...showed that a small fraction of ice crystals in the cloud top layer may change the cloud top reflectivity significantly what may also has consequences for the accuracy of cloud remote sensing..." Poor grammer.

Page 14604: At the same time as the NASA ARCTAS project, there was the DOE ISDAC project and the NOAA ARCPAC project. Lance et al (2011) showed bimodal drop distributions at cloud top in mixed-phase stratus during ARCPAC (only observed in less polluted clouds, i.e. clouds with lower CO concentrations). The DOE MPACE project took place in 2004 http://www.arm.gov/campaigns/nsa2004arcticcld .

Page 14605: "...and an optical particle counter..." do you mean an aerosol optical particle counter? CDP is an optical particle counter too.

Page 14607: "While the measured and calculated LWCs are fairly close within the lowest 90m of the cloud the influence of the entrainment processes becomes increasingly evident by the deviations between the two in the upper regions of the cloud"

It has not been established yet in the paper that this cloud system does not contain appreciable ice, which could of course also deplete water vapor and LWC due to the Wegener Bergeron Findeison process. Also, is there a bulk LWC measurement available? LWC from size distributions is highly dependent on accurate sizing, which was not mentioned in the methods section (only sample area calibrations were reported).

Page 14609: "As shown in Fig. 2d, deviations between the measurements and the expected adiabatic LWC due to an adiabatic ascent are obvious and indicate that the in-cloud air does not experience fully adiabatic conditions in our case." I don't believe this

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until you do an uncertainty analysis of LWC derived from the droplet size distribution measurements.

Page 14610: “Considering the clear Arctic atmosphere with generally low number densities in the measured size range this represents a significant difference.” Can you provide a reference for this? This statement seems to conflict with the statement on the following page: “Therefore, the detected aerosol above the cloud on 25 May 2012, might well be considered as dry Arctic background aerosol which seems to be continuously present in this region.”

Page 14613: “Further bimodal SDs from Flight 9 and Flight 16 were examined and also integrated in Fig. 9” Please label Figure 9 with the Flight # in addition to the date, to make it easier to compare the manuscript text and the information in the figure.

Page 14613: “In summary, four bimodal SDs (marked by circles) seem to result from well mixed air parcels” Actually, all of the data falls below the “Uniform distribution” curve, which is interesting. Does that suggest there is always some degree of clustering (moreso for the 3 pluses than for the circled data points)?

Page 14613: “In these clustered cases, the cloud droplets essentially were sampled from two disjoint particle ensembles.” Wouldn’t that be true only if the joint probability in (y-axis in Figure 9) fell at zero? So the clustered particles are not entirely separated, and they aren’t perfectly mixed either. All points seem to fall between those limits.

Figure 10 Caption: “Isobaric condensation occurs when in mixing of two parcels results in a composition that lays below the condensation line, due to the nonlinearity (or curvature) in the saturation-vapor-pressure function. The dashed line in the figure illustrates such a mixing process.” Instead of “below the condensation line”, this should read “above the red curve” or “above the saturation vapor pressure curve”. Isobaric condensation occurs when mixing of two parcels results in a composition that lies ON the “condensation line”, only because the line is above the saturation vapor pressure curve. The “condensation line” drawn on Figure 10 is only an example, and it is not mentioned why it is drawn here (it does not represent the actual situation for these observations).

The caption also states: “However, the temperature range covered by our measurements (shown by the continuous line) is so small that the saturation-vapor-pressure is almost linear in this range. As a consequence, condensational mixing is very unlikely.” I don’t understand what “continuous line” means, but I think the authors are referring to the line drawn between points (T2,e2) and (T1,e1). All values on this line fall below the saturation vapor pressure curve, since the point (T1,e1) falls so far below the curve, which means that mixing between those two air masses will never produce condensation no matter what ratio of the two air masses is mixed. Basically the above cloud air is too dry to ever lead to condensation by isobaric mixing. This leads to my next question: why was an RH1 of 59% used, when the above cloud RH was reported earlier to be 80%? This likely won’t cause the “mixing line” to be supersaturated at any point, but it would increase the mixed relative humidity compared to using 59% for e1, so I wonder why this choice was made.

Page 14614: “. . .depending on the thermodynamically properties of the cloud and adjacent free atmosphere.” Typo.

Page 14615: “We neglect the short-wave radiation due to its small warming contribution in Arctic clouds”. This should be substantiated. It is a mistake to always assume that shortwave radiation has negligible impact on Arctic clouds, because whether it does or not depends significantly on the season/time of day (i.e. solar zenith angle) and the cloud optical depth. If you want to model the nighttime situation, then it’s fine to simply assume that shortwave radiative effects are negligible.

Page 14615: Again RH1 is set to 59%, though that does not seem to match the observations as reported in Figure 2b, or the text earlier in the manuscript.

Page 14615: “In comparison to the previously observed holes, the holes in our simulations contain more liquid water and stay closer to the cloud top.” By “previously

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observed holes” are the authors referring to the work by Gerber et al (2005) in tropical clouds referenced in the preceding sentence? How do the LWCs from the eddy simulations compare with the observed and the adiabatic LWCs?

Page 14616: You can also discuss the conclusions in terms of total droplet concentrations. If new activation of droplets was occurring at cloud top due to entrainment of fresh aerosols and supersaturation from isobaric mixing, then you'd expect the drop concentration to increase at cloud top. If the 2nd droplet size mode is instead due to drop evaporation, you'd expect the drop concentration to decrease at cloud top. Right? I suppose the two mechanisms could be happening at the same time, too (activating new droplets in some entrained filaments and evaporating droplets in other entrained filaments)... The argument was always posed as either/or.

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 14599, 2014.