Review on article egusphere-2024-526 with title "Evolution of Cloud Droplet Temperature and Lifetime in Spatiotemporally Varying Subsaturated Environments with Implications for Ice Nucleation at Cloud Edges"

This paper presents a study of the transient effects on the droplet temperature and lifetime when the droplet is suddenly immersed in a drier environment. The motivation is that this transient has been hypothesized to play an important role in ice nucleation. The authors find that the temperature reduction can be threefold the values found in the steady solution.

The paper could be an interesting contribution to the topic of ice micro-physics. However, some parts of the setup, the results and the explanations were a bit unclear. I provide the details below.

1. I am not sure about the novelty of the result that the gradients inside the droplet dissipate quickly. The standard estimate of a diffusive time is r_0^2/κ, where r_0 is the length scale, in this case the droplet's radius, and κ is the thermal diffusivity of water. For the typical values consider in this paper, one find time scales which are indeed less that $0.1\ s$. What would be the new contribution from the detailed simulations in this paper for this particular aspect of the gradients inside the droplet?

2. What is the physical mechanism that explains the large difference of the droplet's temperature with respect to the steady solution. I understand that the rapid evaporation cools the droplet quickly, but the water vapor needs to be diffused away for the evaporation to continue, and thermal energy is diffused similarly quick towards the droplet. Textbooks like Rogers and Yau [1989] and Lamb and Verlinde [2011] retain the effect of the gradients and the evaporative cooling. Normally, the effect on temperature is small but the effect on evaporative rates is large because of the nonlinearity of Clausius-Clapeyron, which why I was surprised to see the large changes in T. Why is the diffusion of thermal energy towards the droplet not compensating the evaporative cooling as efficiently as in the steady state case?

   The authors refer to the dependence of the vapor diffusion coefficient on T to explain part of this behavior, e.g. in line 769 in the conclusions. However, this dependence accounts for a change of D of only $\approx 7-8\%$, whereas the temperature difference between the droplet and the environment is 2-3 times, and this should lead to larger thermal energy flux towards the droplet.

3. In figure 4.2, it seems that the droplet's temperature never reaches a steady state. However, since the environment has fixed conditions, it should eventually reach a steady state, provided that the droplet does not evaporate before. How long does it take to reach this steady state in the cases where the droplet has not evaporated yet by the end of the

simulation? Somehow it looks like the thermal energy in the droplet is decoupled from the environment and cannot be warmed.

4. I was confused by the set-up of the problem. It seems that the authors use cylindrical coordinates instead of spherical coordinates. At the beginning of 3.1., I understood that still the droplet is spherical and it was only the overall domain that was cylindrical, which is fine. But then section 3.4 indicates that boundary conditions are applied at the center of the domain $r = 0$ and not at the center of the droplet, which would mean a whole diameter across the droplet. That was confusing because it seems to indicate that the authors do not consider a spherical droplet but a cylindrical droplet. Is this so? If so, what are the implications in the results? Maybe the authors can clarify this in the paper.

5. In section 3.2, the equations do not have a number, which makes it difficult to refer to them.

6. In section 3.2, the mass diffusivity retains the dependence on T but the other molecular transport coefficients dropt that dependence. Why? If the dependence of D on T plays a role, at least the dependence of the thermal conductivity k on T should be explored, since both transport phenomena are equally important for the problem. Maybe the effect of T on k is negligible compared to that of T on k, but then the authors could explain it.

7. In section 3.2, what is the mathematical expression to calculate Q_b?

8. In section 3.2, a reference for the interfacial conditions for the stresses would be useful.

9. In line 392, the authors use the term "the inflection point in the curves," but this might be misleading because those are not inflection points in the usual sense of calculus and curves, i.e., change in the sign of the curvature. Maybe a different term is convenient.

10. In section 4, most of the text repeats what one can see in the figures without adding more insight about the reasons behind that behavior. It might be more helpful to discuss more the physics behind the results.

11. For instance, in section 4.2, the dependence on T_∞ and P seems to be much smaller than that on RH_∞. Why? It might be more useful to differentiate those dependences and concentrate on the latter one instead of showing all figures. Otherwise, there are so many figures that it becomes difficult to distilled the new information that they convey.

12. In line 431, the authors write "while the decrease is 5 K in 120 s." However, figure 6 seems to indicate 2 K instead of 5 K. Is the reference to the figure correct?

13. In that same section, section 4.3, it seems that the main result is that the droplet's temperature is well approximate by the wet-bulb temperature. On the other hand, would not that be expected because of the definition of wet-bulb temperature?

    Also, it is difficult to see something in Fig 8. Why not plot the wet-bulb temperature in figure 4 and 5 and see how it approaches the droplet's temperature at a time T_i?

14. Line 489 indicates the "The droplet lifetimes vary widely...", but I am not sure what is meant by widely because the lifetime changes by a factor of 4 while the RH has been changed by a factor of 7. It seems that the lifetime simply follows the change in the control parameter RH.

15. Line 496 says "From Figs. 9-14, the decrease in droplet temperatures is independent of the initial droplet size if all other initial environmental conditions are kept constant.". I am not sure if I understand this because fig 9 shows a difference between panels a, d, an g. In fig 4 and 5, the initial decrease of T until T_i seems independent of r_0 but later on there seems to be a dependence...

16. In line 512, "The decrease in droplet temperatures and increase in droplet lifetimes depict similar relationships with RH_∞ and r_0." Why is the dependence on T_∞ smaller than the dependence on other parameters?

17. Line 634 indicates "the classical pure-diffusion-limited evaporation approach, which ignores evaporative cooling at the droplet surface". I am not sure what is meant because this effect is discussed textbooks like Rogers and Yau [1989] and Lamb and Verlinde [2011] which are often used to teach microphysics.

18. Line 669 seems to contain the main message "Comparing these values with reported droplet freezing timescales available from experimental studies, droplet freezing events can potentially occur within the time frame when these droplets can reach lower temperatures due to evaporative cooling before they completely dissipate into the subsaturated air."

    However, this message was a bit lost in the middle of a long paragraph. Maybe it helps to make the statement at the beginning and then elaborate it.

19. In the conclusions, the first sentence says "...internal thermal gradients within the droplet as well as resolving thermal and vapor density gradients in the surrounding ambient air." suggesting that this is new.

    However, this gradients are retained in the classical studies, e.g., Rogers and Yau [1989] and Lamb and Verlinde [2011].

    Do the authors mean the temporal variation of those gradients?

References

D. Lamb and J. Verlinde. *Physics and Chemistry of Clouds*. Cambridge University Press, 2011.

R. R. Rogers and M. K. Yau. *A Short Course in Cloud Physics*. Butterworth-Heinemann, third edition, 1989.