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Interior Temperature T related to Snow Temperature To in Clouds

John H Jennings
Jennings Research & Editing, 2530 Hillegass Ave. #307, Berkeley, USA

Corresponding Author: **John H Jennings**

Abstract
Jennings (2021) [1] wrote a paper where the dew point is the nucleation limit in a cloud. He came up with this equation for onset of rain.

$$T - To = (3\ k\ To^2 / \sigma_o\ a_o)\ (P^*_{H2O} / P_{air})\ RH$$

Where T = temperature Kelvin inside the cloud and To = temperaure Kelvin at onset of rain. In this paper, I assume that onset of snow is described by.

$$To - T = (3\ k\ To^2 / \sigma_o\ a_o)\ (P^*_{H2O} / P_{air})\ RH$$

Where the T and To are flipped because of undercooling and T is still the interior undercooling temperature with To being the snow temperature in the cloud. In another paper, Jennings (2023) [2] derives an equation for snow formation with To – T = ΔT.

$$T = D\ (7.15 \times 10^7)\ /(k\ a\ ns\ \Delta T^{0.69})$$

Then, in a bath experiment, based on Hillig (1958) [3], To is the melting point and T is the temperature of the bath. It is valuable to calculate To, so that has to be done by iteration on a computer, as some variables depend on T and others on To.

Keywords: Interior Temperature (T), Snow Temperature (To), Clouds

Introduction

In cloud-seeding, this is done in the mountains during the cold season to get clouds to snow and produce water flow in rivers. Knowing more about how ice particles are generated enables cloud-seeding. Putting Jennings (2021) [1] and Jennings (2023) [2] together yields a relation between T and To.
Seeds for a cloud include AgI, NaCl, dry ice or possibly CH3-O- Na+. An atmospheric chemist will know the best time to seed and how.

Results

Both of Jennings' equations have To – T = ΔT, so ΔT must be eliminated. In NOMENCLATURE every variable is explained and its dependence on T or To. The next two equations are from the ABSTRACT and (1) and (2) are combined to give (3).

$$To - T = \Delta T = (3\ k\ To^2 / \sigma_o\ a_o)\ (P^*_{H2O} / P_{air})\ RH \quad (1)$$

$$T = D\ (7.15 \times 10^7)\ /(k\ a\ ns\ \Delta T^{0.69}) \quad (2)$$

$$T = C\ (B\ To^2)^{0.69} \quad (3)$$

$$C = D\ (7.15 \times 10^7)\ (k\ a\ ns) \quad (4)$$

$$B = (3\ k / \sigma_o\ a_o)\ (P^*_{H2O} / Pair)\ RH \quad (5)$$

To solve (3) requires iteration by a computer, as the variables either depend on T or To.

Discussion

Here is the list of which varaibles depend on T or To.

Table 1: Nomenclature

a	atomic spacing of ice (independent of To)
a_o	surface area of water molecule (depends on density at To before nucleation)
k	Boltzmann constant
D	self-diffusion coefficient of water (depends on To before nucleation)
T	temperature inside cloud or temperature of the bath (Kelvin)
To	temperature of water droplet before nucleation or cloud ice point (Kelvin)
ns	number density of ice (independent of To)
P_{air}	air pressure in cloud (depends on T)
P_{*H2O}	equilibrium water vapor pressure in cloud (depends on T)
RH	relative humidity in cloud (depends on T)
σ_o	surface tension of water before nucleation (depends on To).

In the cloud, picture a single water droplet surrounded by ambient. The ambient drops to T and by nucleation, the droplet forms into an ice crystal at To. This is mimicked by the bath at T dropping to a temperature were an ice crystal forms at To. This is why To – T = ΔT shows up in Eqs. (1) and (2), so ΔT can be eliminated to get (3).

Nucleation is a rapid process once the critical limit is reached. There are two assumptions here: 1) Jennings (2021) [1] is assumed to apply to ice formation in a cloud and 2) the bath in Hillig (1958) [3] corresponds to a snow-producing cloud even though it is in the laboratory.

This paper is speculative, so the author admits there are shortcomings. First ΔT is unknown for the cloud. Second, it is only an assumption that laboratory experiments with ice formation mimic what happens in a snow-producing cloud. Finally, the self-diffusion coefficent needs to be for water at, say, - 20 ˚C, so that might be done by extrapolation. See Krynicki, *et al* (1978) for determination of D.

Conclusion

All of the variables in NOMENCLATURE can be obtained. T would be measured by the cloud-seeding aircraft and this treatment enables calculation of To, the snow formation point. The point of this is to give a rationale for seeding clouds in mountains during winter months.

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