3.2 Quasi-steady supersaturation and limiting cases

If we set the time-derivative of supersaturation to zero we can define a *steady-state* supersaturation where the expansion of the parcel is rapid enough to maintain a constant supersaturation:

$$0 = \left[\left(\frac{g}{c_p} - \frac{g}{R_a T} \right) w - \left(\frac{1}{w_v} + \frac{L_v^2}{R_v T^2 c_p} \right) N_l \frac{4\pi a_l S_l}{A_1} - \left(\frac{1}{w_v} + \frac{L_v L_s}{R_v T^2 c_p} \right) N_i \frac{4\pi a_i \left\{ (S_l + 1) \times \frac{e_{sat,l}}{e_{sat,i}} - 1 \right\}}{A_2} \right] \tag{3.8}$$

therefore, rearranging Equation 3.8:

$$\left(\frac{g}{c_p} - \frac{g}{R_a T} \right) w = \left(\frac{1}{w_v} + \frac{L_v^2}{R_v T^2 c_p} \right) N_l \frac{4\pi a_l S_l}{A_1} + \left(\frac{1}{w_v} + \frac{L_v L_i}{R_v T^2 c_p} \right) N_i \frac{4\pi a_i \left\{ (S_l + 1) \times \frac{e_{sat,l}}{e_{sat,i}} - 1 \right\}}{A_2} \tag{3.9}$$

This can be solved for S_l to find the *steady state supersaturation* for given concentrations and sizes of drops and ice crystals to give a solution of the form:

$$S_l = \frac{a_0 w - b_{1,i} N_i a_i}{b_l N_l a_l + b_{2,i} N_i a_i}$$

Early laboratory measurements have shown that once we have a mixed phase cloud the ice phase grows very rapidly and the liquid phase evaporates. This is known as the B–F process. It originally led to global models assuming that supercooled clouds are very rare in nature. Thankfully this is now being corrected.

3.2.1 Liquid clouds

The supersaturation in a liquid only cloud is usually maximum several 10s of metres above cloud base. The maximum depends on how many there are and the updraft speed (Figure 3.1). Eventually a steady-state will be reached (Figure 3.1), which corresponds to the steady-state superaturation with no ice terms:

$$S_l = \frac{a_0 w}{b_l N_l a_l}$$

as can be seen this depends on the updraft speed, w, and the number of drops, N_l.

3.2.2 Ice clouds

Ice only clouds behave similarly to liquid only clouds the difference is that because there are usually much less ice crystals than liquid drops the supersaturation can go higher initially and take longer to be depleted due to the growing ice crystals (see Figure 3.2).

3.2.3 Mixed phase clouds

In mixed phase clouds the supersaturation usually has to be at or above water saturation. When it drops below saturation the droplets evaporate until we are left with an ice cloud. The rate at which this happens depends on the updraft speed

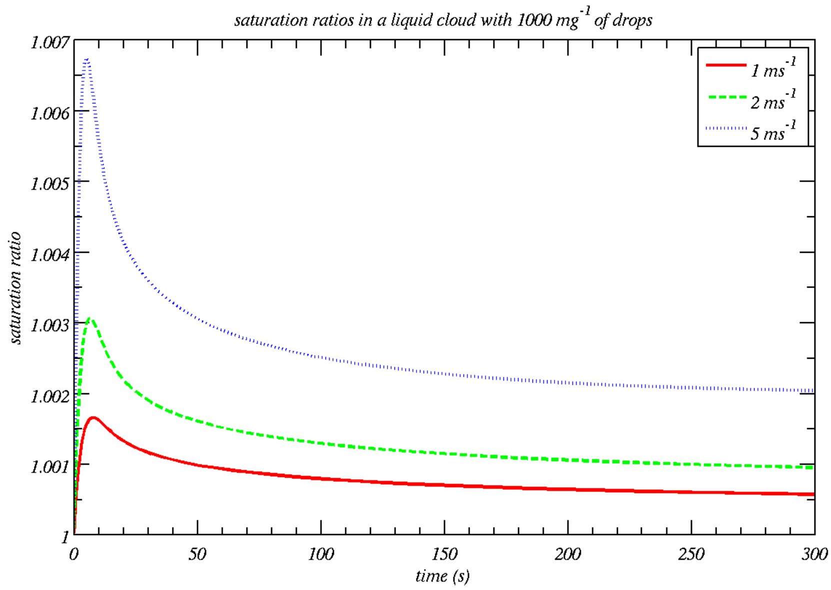

Figure 3.1: Supersaturation in liquid clouds with different updraft speeds.

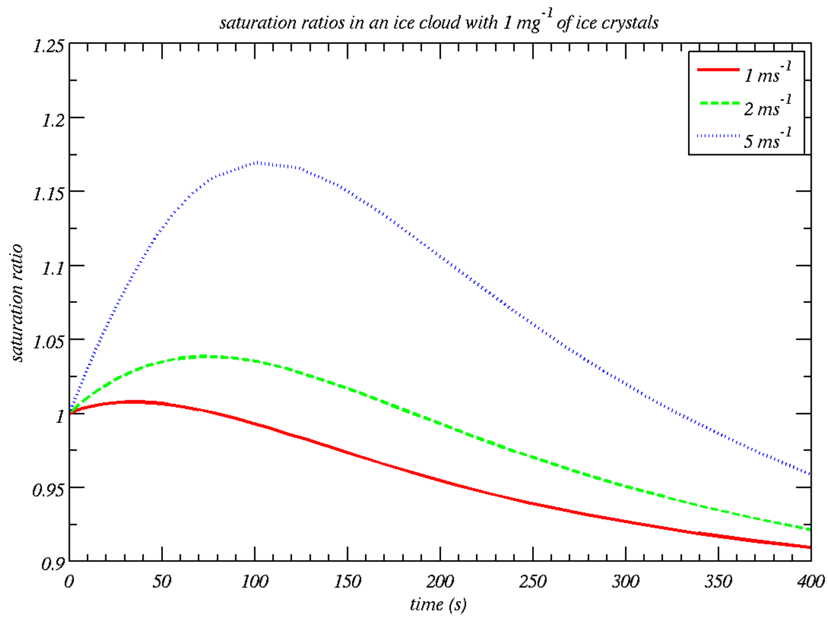

Figure 3.2: Supersaturation in ice clouds with different updraft speeds.

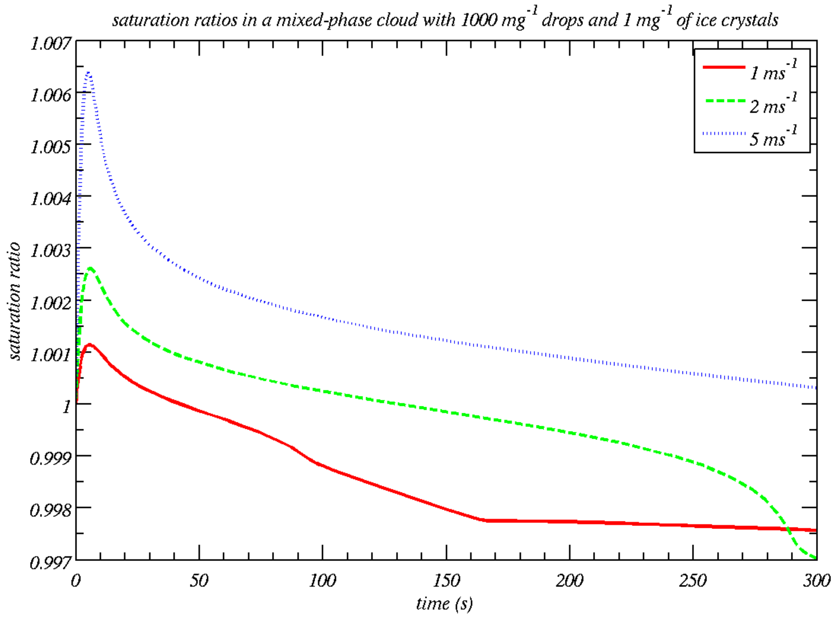

Figure 3.3: Supersaturation in mixed-phase clouds with different updraft speeds.

(Figure 3.3). A steady-state updraft speed can be defined by setting the steady-state supersaturation to 0, which is the minimum updraft required to maintain long lived mixed phase clouds.

$$w = \frac{b_{1,i} N_i a_i}{a_0}$$

3.2.4 Bergeron-Findeisen process

In a mixed-phase cloud eventually the ice crystals will grow so large that they will take up all of the water vapour so that the humidity drops below 1. This happens because the saturation vapour pressure of ice is lower than that for liquid water, so that it can grow when liquid water is evaporating.

3.2.5 Glaciation time-scale

In mixed phase clouds people have often thought about a glaciation time-scale, which is the time it takes the cloud to completely change to an ice only cloud if there were no vertical wind. Glaciation time-scale is depicted in Figure 3.4. It can be seen that the more ice crystals there are the quicker the glaciation time-scale.

3.2.6 Effects of turbulence and overturning

Real clouds are turbulent, they dont necessarily have an organised updraft, but can have turbulent motions driving the cloud formation process. In this case the glaciation time in a mixed-phase cloud does not make that much sense. Recent obser-

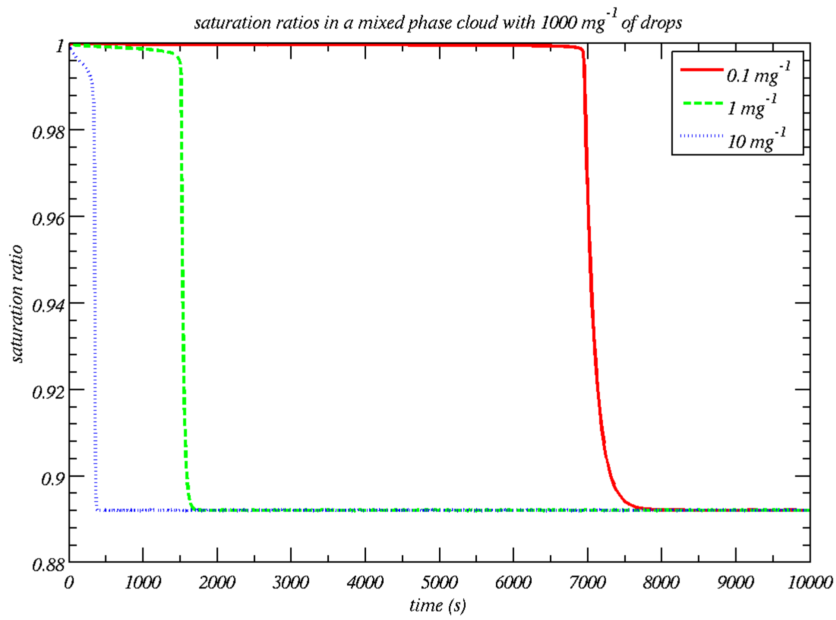

Figure 3.4: Supersaturation in mixed phase clouds with different concentrations of ice and no updraft

vations from the Chilbolton Observatory have shown that supercooled clouds can be very persistent even if they contain ice particles, which is inconsistent with the glaciation time-scale concept. The effects this has are depicted in Figure 3.5.

Questions to consider:

- Explain the Bergeron-Findeisen process.
- Explain what is meant by the concept of glaciation time-scale.
- Explain what is happening in the turbulent case.
- Be able to calculate steady-state supersaturations and critical ascent rates.

THE KEY POINTS TO TAKE HOME HERE ARE:

- Understand how these processes interact within clouds.
- Know what the B–F mechanism is and why it can lead to precipitation.
- Explain what is happening in the turbulent overturning case.

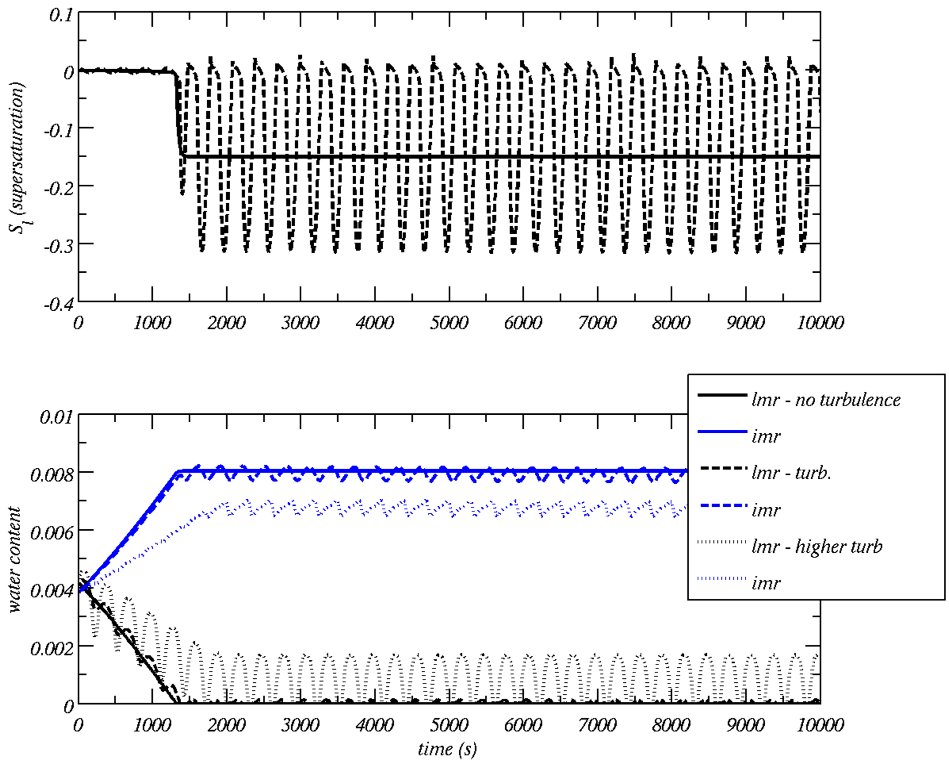

Figure 3.5: Supersaturation in a mixed phase clouds that is turbulent, $w = w1 \times \cos(2\pi t/\tau)$