

# INDUSTRIAL SNOW

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## ABSTRACT

This paper describes the phenomenon of industrial snow. In freezing conditions with stagnant low stratus/fog industrial snow is observed locally. Nocturnal radiative cooling at the top of the stratus initiates and drives convective mixing. Near localized sources of water vapour the supercooled droplets in the supersaturated stratus crystallize and fall out as industrial snow. Predictions of industrial snow are possible if the air temperature and the cloud base and top, respectively, of low stratus can be predicted.

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## 1 INTRODUCTION

At several locations in Switzerland local snowfall is observed regularly in freezing conditions with a stagnant low stratus. The phenomenon is named «industrial snow» in Switzerland and «beer snow» in Munich as it occurs in the vicinity of waste disposal plants and of production plants for beer, steel and paper. Snow depth is usually small and can be countered by salting roads and sidewalks. The very local occurrence of a snow cover on otherwise dry roads can be surprising for drivers. Road maintenance services would appreciate to anticipate the conditions that lead to industrial snow. Based on reported cases of industrial snow the corresponding meteorological conditions and processes have been analyzed.

## 2 PHENOMENOLOGY

Industrial snow has been reported for a number of locations on the Swiss plateau between the Jura mountains and the Alps (Figure 1). Most frequently industrial snow is reported for Bern, Zurich airport, Winterthur, and St. Gallen. Complete documentations of cases with industrial snow could be collected for the city of Winterthur and for Zurich airport. During the four winter seasons from 1999/2000 to 2002/2003 industrial snow occurred on 4.5 days per winter as an average value at both sites. In most cases industrial snow occurs at both locations simultaneously.

Industrial snow is basically a nocturnal phenomenon. Fall out occurs most frequently in the hours before and around sunrise (Figure 2) after low stratus/fog has formed during the night. If low winter stratus does not dissipate during the day industrial snow may already fall a few hours after sunset (Figure 3).

Snow depth is typically 1 to 2 mm and not evenly distributed in the affected area. In Winterthur a local snow depth of 20 mm has been observed. As extreme values local snow depths of 50, 100, and 150 mm have been reported for the motorway near Kriegstetten on a distance of about 1000 m requiring mechanical removal of the snow.

The area affected is on the order of 4 km<sup>2</sup> in Winterthur (Figure 4). Starting out from the source chimney at the waste disposal plant the affected area extends into one of three directions: NE, W, or SE.

Industrial snow is also reported for locations near the runways of Zurich airport where aircraft climb and sink through the low stratus.

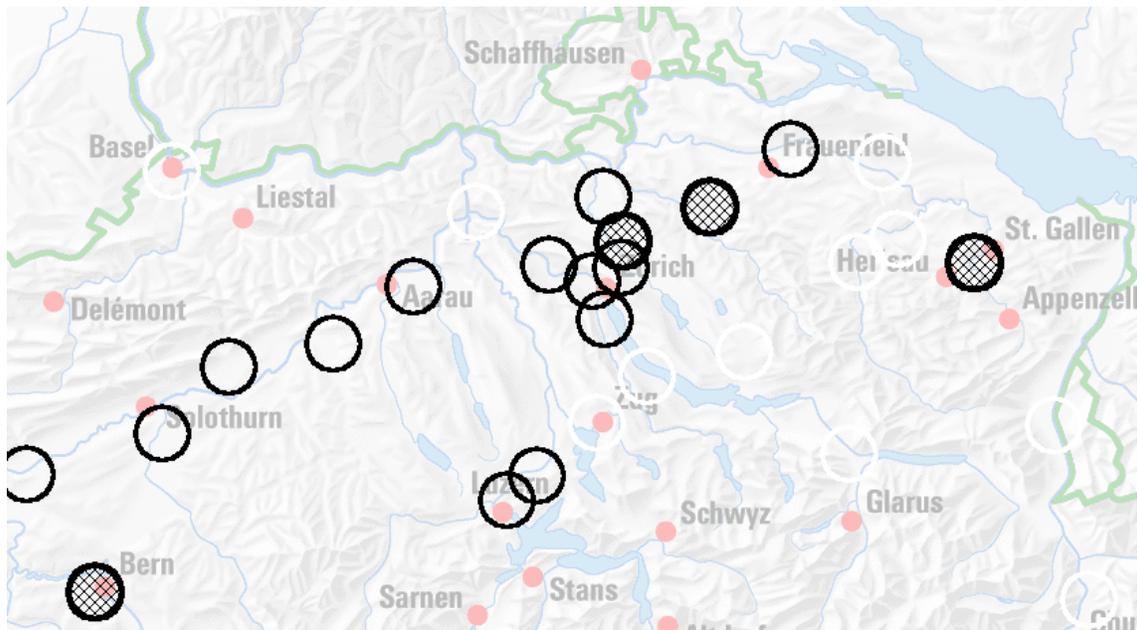


Fig. 1 Locations with industrial snow in Switzerland (hatched: most frequent)

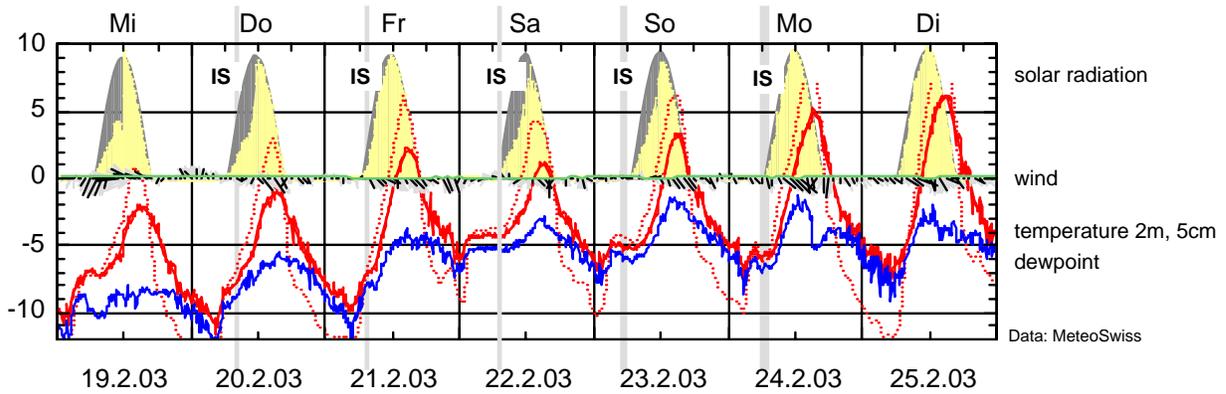


Fig. 2 Industrial snow (IS) at Zurich airport with dissipating stratus

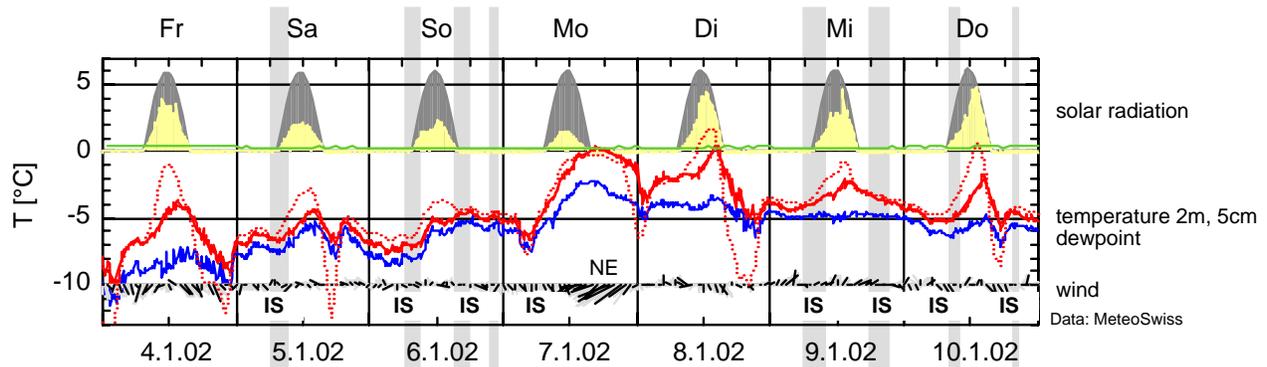


Fig.3 Industrial snow (IS) at Zurich airport with persisting stratus

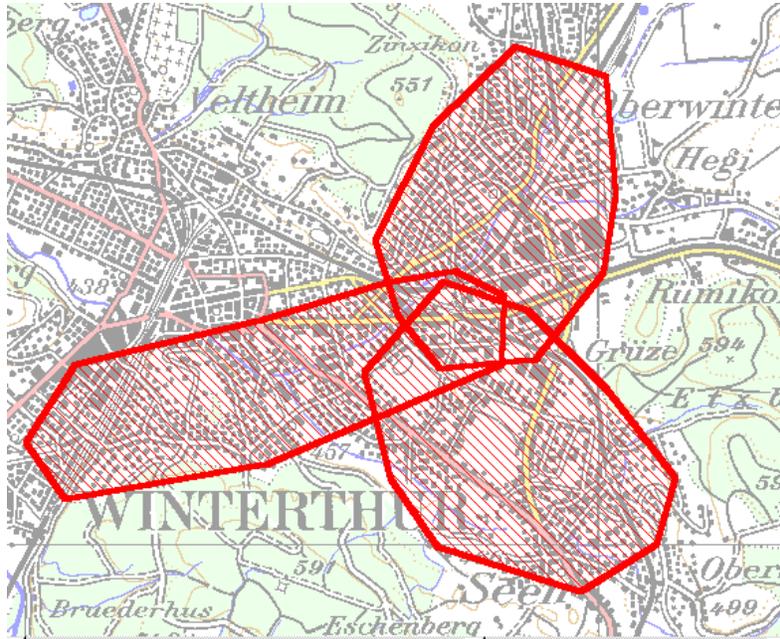


Fig. 4 Areas with industrial snow in Winterthur

Industrial snow on the Swiss plateau requires a stagnant cold air pool topped by a stratus cloud with temperatures in the freezing range. Such conditions are found in winter (Dec, Jan, and Feb) during periods of high pressure. The cloud base of the stratus must be low (0-150m above ground), the depth of the stratus is on the order of 200 m (Figure 5). Above the stratus the sky must be clear .

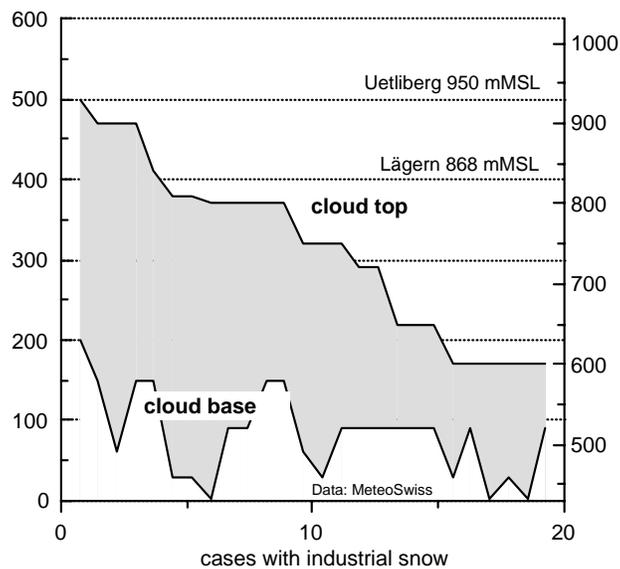


Fig. 5 Cloud base and top of stratus during industrial snow

In conditions with fog or low stratus nocturnal cooling is either very slow or air temperature is constant. During fallout of industrial snow temperature tends to fall slightly and the stratus becomes inhomogeneous. The snow falls for about half an hour, snow depth is usually 1 to 2 mm only. The fallout can occur

again after some time, if temperature does not rise. An increase of temperature after sunrise will usually stop the phenomenon.

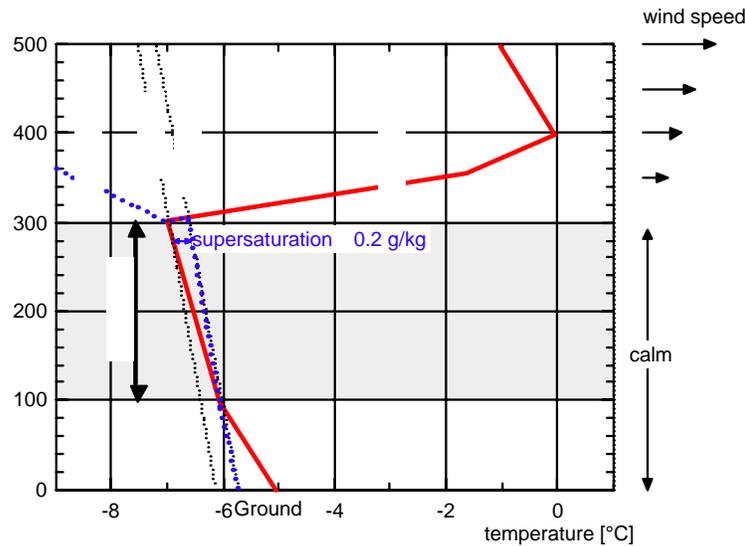


Fig. 6 Temperature, humidity and wind profile for industrial snow

When industrial snow falls the atmospheric lapse rate is wet-adiabatic within the stratus cloud and dry-adiabatic below. The stratus is confined by a marked temperature inversion of dry air (Figure 6). Relative humidity near ground is very high (the dewpoint depression is less than 1°C) and the cloud base of the stratus is very close to the ground.

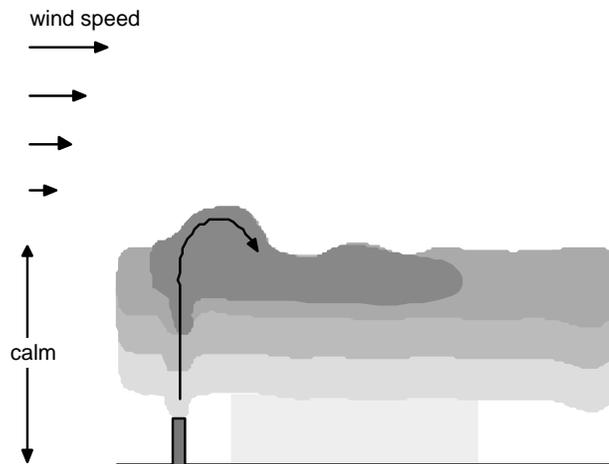


Fig. 7 Displacement of industrial snow is controlled by wind above the stratus

Warm and moist air from industrial sources climbs easily through convective low stratus and penetrates into the inversion. The vertical motion is not strong enough to break through the inversion. The warm and moist air returns into the stratus layer without significant entrainment of warm and dry air. Wind in the inversion layer, however, will displace the reflected plume. Industrial snow will then fall out on the downwind side of the source. The distribution of industrial snow around the source is basically controlled by the wind above the stagnant pool of cold air (Figure 7). In Winterthur (Figure 4) industrial snow is frequently observed to the NE of the source because the wind direction above the low stratus is often from SW.

### 3 RADIATIVE COOLING OF LOW STRATUS

The vertical profiles of temperature and moisture are the result of vertical mixing in the cold air pool. In stagnant air the mixing is due to convection driven by radiative cooling at the surface of the stratus during long winter nights under clear sky. The mixing depth grows downward from the cooling top of the stratus and eventually reaches the ground of the cold air pool.

As the cooled body of air is much deeper than in the absence of cloud, the cooling is slow ( $-0.05^{\circ}\text{C}/\text{h}$ ) when compared to clear conditions ( $-0.65^{\circ}\text{C}/\text{h}$  with deposition of hoar frost). In Figures 2 and 3, clear and cloudy conditions can also be distinguished by the temperature difference between 2 m and 5 cm above the surface. In clear conditions with rapid cooling the temperature at 5 cm is below the temperature at 2 m. In cloudy conditions with minor cooling temperature at 5 cm is equal or higher than at 2 m. In addition to the mass of air being involved in the nocturnal cooling the release of latent heat in cooling cloud also reduces the cooling rate in low stratus to some extent.

Under convective conditions the concentration of the supercooled water droplets within the stratus increases with height as temperature falls. Local sources of water vapour will increase the supersaturation, as long as the added water vapour can not escape vertically into and through the stable layer above the stratus.

Locally supersaturation in the upper part of the cooling stratus must reach values that allow spontaneous freezing of supercooled droplets at temperatures around  $-7^{\circ}\text{C}$ . Ice crystals colliding with supercooled droplets will grow at the expense of the supercooled droplets that will freeze. Crystal growth is supported by the vertical mixing of the cooling stratus. Concentrated industrial moisture sources are also heat sources and create good local growth conditions by feeding moisture and enhancing the convective mixing.

Larger crystals will fall out of the stratus cloud into warmer, unsaturated air. Sublimation will reduce the size of the falling crystals. Sublimating crystals will add moisture to the unsaturated layer below the stratus and cool the layer. As a result the rather diffuse cloud base of the stratus will be lowered. Falling ice crystals will only reach the ground as industrial snow, when the cloud base is close enough to the surface (Figure 5). The precipitation will remain frozen if the surface temperature is in the freezing range.

Industrial snow is observed mainly at nighttime. For industrial snow to occur already soon after sunset low stratus must persist during the day (Figure 3). Towards the end of daytime on a winter day the temperature profile of persisting low stratus is observed to be isothermal. With small solar elevations the absorption of global radiation seems to occur predominantly in the upper layers of the stratus and to exceed the cooling from infrared radiative loss. After sunset radiative cooling becomes dominant. Supersaturation increases first at the cooling top of the stratus. Radiative cooling at the top of the stratus leads to convective mixing of cooled supersaturated air downward into the stratus. At a certain degree of supersaturation spontaneous freezing occurs. In the absence of powerful local moisture sources the corresponding snowfall is negligible. When low stratus clears during the day industrial snow can only occur after low stratus has reformed during the night.

After sunrise industrial snow stops when absorption of solar radiation near the top of the stratus leads to stabilization and heating reduces the supersaturation.

### 4 CONCLUSION

Industrial snow is a convective phenomenon that occurs in the vicinity of localized heat and moisture sources in freezing conditions with a stagnant low stratus cloud. Radiative cooling of the stratus under clear sky is necessary and the base of the stratus must be close to the ground. Predictions of industrial snow depend on the predictability of fog and low stratus in pools of stagnant cold air.