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Interactive comment on "Comparing model and measured ice crystal concentrations in orographic clouds during the INUPIAQ campaign" *by* R. J. Farrington et al.

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This paper by Farrington et al. (2015; F15) and the companion paper by Lloyd et al. (2015, L15) present extensive observations and analyses of the "anomalous" ice crystal concentrations observed at the Jungfraujoch mountain station. Thanks to the more complete data sets and model studies of the two papers under discussion, calling the phenomenon anomalous is less justified today than when first referred to it this way by Rogers and Vali (1987; RV87), but essential features of the process are still unknown. Thus, use of the phrase is still appropriate. The purpose of this note is to highlight gaps in our current knowledge. For clarification, the meaning of 'anomalous' in this case is

not because of its infrequency, but because the observed high ice concentrations go against expectations by their magnitude and by the reversal of the normal trend of higher concentrations of ice higher in the atmosphere.

By discounting better known processes, evidence seems to accumulate in favor of ice particles originating from the snow-covered, or hoar-frost covered ground. The main questions are what this process really is, what parameters control it, and how to quantify it.

It is argued both in L15 and F15, that blowing snow is not likely to be a sufficient explanation. Dependence on wind speed is one of the criteria considered to be important is gaging the potential for blowing snow to account for the observations. L15 shows essentially no correlation with windspeed. However, this argument is weak because local wind speed may not be the relevant quantity to use. Ice crystal sources have to be upwind of the observation point by about a kilometer (depending on conditions) to account for the observed sizes of the crystals. Also, as suggested by the radar observations of Vali et al. (2012; V12) sources are frequently associated with terrain features which increase local wind speed and this can be expected to be the case of the Jungfraujoch study as well.

If blowing snow were to account for the observations it has to also explain why observed crystals exhibit vapor growth (L15 and RV87) with no visible chunks of ice in them (RV87). This led to postulating (RV87) that snow particles are $< 10\mu m$ in size at the origin, but that is not consistent with results from blowing now studies. That contradiction is resolved however by recognizing that blowing snow studies are normally carried out in cloud-free conditions when airborne particles evaporate, rather than grow as expected in a cloud. Locating sources within the cloud-covered portion of the mountain surface is consistent with the sizes of the observed crystals and model growth calculations. Those are the essential parts of the argument that led to suggesting (in RV87 and in V12) that blowing snow, using that phrase in a broader than normal sense, is a likely source of the anomalous ice crystals. It must be admitted that fragmentation, saltation, lofting and other parts of the blowing snow processes have a multitude of variables. Snow particles undergo rapid metamorphosis after falling to the surface. Falling snow itself can take many different forms.

If hoar frost is the source, as suggested in L15 and F15, then the source region is assumed to be below cloud base, further upwind from the observation point. In the presence of supercooled cloud, hoar frost crystals would rapidly get combined with rime. Changes in the forms of hoar frost crystals are also expected once radiative cooling is cut off. The similarity to sea-ice frost flowers, as mentioned in L15, is somewhat questionable on the basis that those crystals grow from a brine and that the aerosol release rates from the frost flowers refer to conditions of evaporation.

A possibly critical element in considering surface sourse mechanisms is knowing how close to the ground supercooled liquid clouds actually reach. Uncertainty arises from the fact that an upward heat flux near the surface may be expected, small as it may be in the presence of snow cover. Thus, a thin cloud-free layer may be present even at altitudes above the condensation level of the air lifted along the mountain surface. Turbulence is an important modulator of any of these gradients. In any case, these conditions may be sufficient for small particles lofted from the snow surface to survive and grow. There is no conflict with the hoar frost assumption either, since crystal growth would be helped by the flux of vapor from the cloud. Whether fragmentation of growing frost crystals could be expected is unknown. Perhaps snow particles lofted from the ground collide with hoar frost crystals and produce fragments.

All of the foregoing may be classified as speculative, because there are few constrains on the arguments due to the practically total lack of directly relevant observations or theories. The phenomenon is not intractable but neither is it easy to study. Field observations along various points along the mountain surface would be helpful. Controlled experiments of blowing snow in the presence of cloud are conceivable. The potentially large effects of the surface sources of ice crystals should provide impetus to further studies of the problem. The results in L15 and F15 are welcome contributions toward

that goal.