2 Operational Measurement of Precipitation in Mountainous Terrain

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2.1 Introduction with a Focus on the Variability of Precipitation in the Alps

To put a weather radar in a mountainous region is like pitching a tent in a snowstorm: The practical use is obvious and large – but so are the problems.

The orography interferes both with what we want to observe and with the how we can observe it. First, by lifting, channelling, blocking, supplying moisture, and heating on sun-exposed slopes, the mountains influence the flow and the stability of air masses from the synoptic down to the microscale. The orography thus plays a key role in precipitation mechanisms. The result is a complex picture of precipitation regimes and high variability on many scales. The vast influence of an orographic barrier on the distribution of precipitation is glaring when looking at climatological maps (Frei and Schär, 1998). Second, the orography complicates precipitation measurements by radar because of beam occultation, overshooting, severe ground clutter, and partial shielding, as well as difficult operating conditions on mountain sites. The result is a complex error structure. So, on the one hand, a weather radar with its high resolution in time and space provides the meteorologist and the hydrologist of a mountainous region with unique observations of a highly variable quantity, but, on the other hand, poses particular difficulties to the radar scientists and engineers.

The meteorologist wants to have observations from the first signs of precipitation of 0.1 mm/h to heavy hailstorms with over 100 mm/h, within the full range of radar coverage, for example, between 1 and 230 km as for the Swiss radars. Including the range of signal fluctuations this corresponds to 20 orders of magnitude in terms of signal power between the transmitted and the weakest signal to be received and analysed. This is more than we can cope with using today’s receiver technology. The hydrologist, on the other hand, may need high precision because 10% more rain may break the dam! A really challenging engineering application.

The dominant sources of errors involved in quantitative estimates of precipitation by radar are ground clutter including anaprop, shielding combined with the vertical profile of reflectivity (Joss and Waldvogel, 1990), partial shielding, overshooting, beam-broadening and partial beam filling, variations in the relation between radar reflectivity and rainfall rate ($Z-R$ relation), hardware faults, as well as attenuation in heavy rain, in the melting layer and in the water cover on the radome (Germann, 1999). Variations in the $Z-R$ relation are attributed
to changes in the phase and size distribution of hydrometeors. Although all these errors occur both with and without orography, some of them are much more severe in a mountainous context. There, the most challenging problem is the combination of shielding, partial shielding and ground echoes, which often inhibit a direct view of precipitation close to the ground (Figs. 2.1 and 2.2, Gabella and Perona, 1998; Germann and Joss, 2002; Pellarin et al., 2000). If we determine, for each pixel of the radar volume, to what extent precipitation at that location can be observed from the radar without being disturbed by the horizon or clutter, we obtain the radar visibility map. In a mountainous region, this map is rather complex and shows pronounced spatial discontinuities, particularly, close to the ground. To fill the holes in badly visible regions, measurements from several kilometres above the ground or from neighbouring regions must be extrapolated. Yet, this implies a high resolution in azimuth, in range and in elevation. In order to limit the size of holes produced by the elimination of ground echoes, for instance, in the Swiss network, clutter removal is done at the highest possible radial resolution of 83 m. Any type of extrapolation procedure used to fill holes requires a careful analysis of the four-dimensional map of visibility and considerably reduces the accuracy of ground level precipita-