ERROR SOURCES IN THE ASSESSMENT OF PRECIPITATION ALTITUDE RELATIONSHIPS

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It is generally accepted that altitude is the main variable governing the spatial distribution of precipitation in the mountains. The reason, in principle, is decreasing temperature and increasing condensation with altitude. This is the basic assumption on which nearly all regionalisation and mapping techniques of precipitation in the mountains are based. The effects of topography are generally not accounted for explicitly for the simple reason that there are not enough gauge sites to do this properly. Moreover, they are distributed in such a way as to meet the practical requirements of the national meteorological services rather than the scientific ones. The questions in the foreground, by order of importance, include: the general need, availability of an observer, good accessibility, connections, safeguards against avalanches, distance to the next gauge site, altitude zone, climate representativeness, hydrological aspects, etc. As a matter of fact, most gauges are located in the valleys and almost no gauges are available on slopes and near ridges. It is quite clear that such one-sided positioning of precipitation gauges, as practised generally by meteorological services, cannot sufficiently express the complex distribution processes of precipitation in the mountains. In addition to the already sufficiently complex situation pertaining to the assessment of precipitation-altitude relationships, the point-precipitation measurements, using common, elevated and can-type gauges, are subject to systematic error which is not regularly corrected.

In view of state-of-the-art precipitation measurement and network design in the mountains, it is not surprising that precipitation totals can vary considerably in the same altitude zone and the effect of altitude may not be evident at all. This is reflected in many cases by a great scatter in the precipitation-altitude plots or even by decreasing precipitation with increasing altitude. Consequently, the question arises concerning the accuracy of precipitation maps and water balance computations in the mountains, which are based on such simplified precipitation-altitude relationships. Therefore, there is a need to analyse the error sources. They can be divided into two main groups.

Group One dealt with the systematic measurement error, particularly the losses due to wind, wetting, evaporation, and snow blowing, and with the specific problems of precipitation measurement on slopes using gauges with horizontal orifices. Investigations of corrections of systematic error have been made in Switzerland for almost 30 years. This includes field and laboratory tests, wind tunnel experiments, and simulation of wind-induced losses using computational fluid dynamics. Mean monthly corrections were assessed for the 30-year reference period from 1951 to 1980. The correction methods are based on simplified physical concepts (Sevruk 1986). The correction values increase with altitude, from approximately 5 to 25 % of the measured values. At lower altitudes, the wind speed tends to be low as a result of the greater roughness (forests and built-up areas) and the topographic barriers. The small fraction of snow and the substantial wind protection of the stations also have a positive effect. Compared to this, the correction values in the snow-rich and wind-exposed high alpine regions are excessively high. However, snow blowing into the gauge can cause the losses to result in a surplus of more or less the same magnitude. Yet, applying the suitable correction procedures, the systematic measurement error can be partly eliminated. Concerning the precipitation measurement on slopes, it is evident that gauges with orifices parallel to the slopes are better suited. But they are not used. Under extreme conditions, on the steep exposed slopes, the error magnitude during snow storms amounts frequently to up to 80-90 % (Sevruk 1972).

Errors in **Group Two** arise from the insufficient consideration in a given network of both the effects of topography on precipitation distribution, particularly the windward and leeward slopes and redistribution processes of precipitation by wind over the mountainous ridges. These errors are caused by the unsuitable design of gauge networks, particularly a small number of gauges, and the nonrepresentativeness of locations of gauge sites with respect to the topography and geometry of basins. What matters is a suitable network configuration over the entire area of the mountain, including, in sufficient numbers, gauges located on windward and leeward slopes and in valleys in all altitude zones. In this way, it is possible to differentiate precipitation-altitude relationships according to the main topographic features. Therefore, the transect precipitation measurements along the main mountainous ridges and in valleys, as preferred for practical reasons until the present day, should rather be completed by more important transects across the mountains, including the highest regions, windward and leeward slopes, and ridges. As shown by Sevruk (1989), different values of vertical gradients in seasonal precipitation totals resulted for the three groups of storage gauges located in the valley, on the leeward and the windward slopes in the same small mountainous basin in the Swiss Alps. The greatest gradients were registered for the group of gauges in the valley and the smallest ones for those on the windward slopes. This indicates that the application of gradients on the slopes, based on precipitation measurements in valleys, can result in the overestimation of areal precipitation in the mountains. Additional errors can be caused by the small-scale precipitation variability induced by local topography.

The present report deals with error sources in the estimation of precipitation-altitude relationships in the Swiss Alps. Examples are presented and analysed based on precipitation data from 340 gauge sites, corrected for the systematic error of precipitation measurement. The correction methods used and results obtained are also discussed. The suitability of the gauge site distribution with respect to topography is being checked in large basins using the water budget computations. For this aim, the area-mean values of precipitation were assessed from the precipitation map of Switzerland and related to the mean basin altitude. The vertical gradients in annual area-mean precipitation of basins were compared with the corresponding runoff gradients. In the high alpine regions, precipitation gradients were frequently greater than the runoff gradients. This resulted in unrealistic great basin evaporation values. The reason is the overestimation of area-mean precipitation derived from the precipitation map. The latter is based on precipitation measurements from gauges situated almost exclusively in the valleys where most precipitation is accumulated and does not reflect the real precipitation conditions on the windward and leeward slopes.

The results show that the accuracy of precipitation maps in the mountains depends significantly on the correct assessment of precipitation-altitude relationships. Yet, the one-sided distribution of precipitation gauges and missing corrections for the systematic measurement error appear to be the limiting factor to a better understanding of the spatial distribution of precipitation in most mountainous regions.

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