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Are 2000 m asl a last frontier in hydrology?

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In spite of several advancements in monitoring systems in the last decades our understanding of some key hydrological processes and measurements in mountain areas still remain affected by large uncertainties. Above 2000 m asl in the Alps, and at higher altitudes in other mountain ranges, precipitation measurements with raingauges are still affected by the snow/rain partitioning uncertainties and wind-induced losses. The network density is not sufficient to capture heavy localised storms triggered by orography, which sometimes induce extreme debris flow events; today, in some cases, raingauge density at high altitudes is coarser than several decades ago, when networks were installed for designing hydropower plants. Radar measurements, which can be more effective in monitoring localised storms, are disturbed by the melting layer and ground clutter. Areal snow water equivalent estimates are still based on point measurements of snow density and depth and, over complex topography, remote sensing is helping for estimating snow cover areas only, while distributed information on vertical snow profiles is still difficult to be obtained. Also micrometeorological measurements of turbulent fluxes are sparse for logistic reasons and data spatialisation needs meteorological modelling or complex geostatistical interpolation algorithms to be effective. Runoff is difficult to be measured in winter because of freezing of streamwater. These examples show how the key components of the hydrological balance, i.e. precipitation, snow storage, evapotranspiration losses and runoff at the basin scale are difficult to be estimated with the accuracy required by several challenging scientific investigations, as those concerning adaptation of forests to climate changes and resulting feedback, or the assessment of the benefit for aquatic systems derived from new environmental flow releases in mountain creeks. Some examples from recent experiments to measure, for energy-balance studies, eddy-correlation fluxes of moisture, heat and momentum on glaciers; of freezing-thawing of snow with passive microwave radiometers and radars for avalanche risk forecast, of katabatic winds and of heat fluxes over debris cover glaciers are presented, to move some little steps in the direction of this frontier of hydrology.