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Non-stationary modelling of snow-related extremes in the French Alps: analysis of past and future trends

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ABSTRACT

The anticipation of extreme climate events often relies on the quantification of T-year return levels, i.e. large values exceeded each year with probability $\frac{1}{T}$, which are widely used to design critical infrastructures. Return levels are typically estimated with a two-step approach: i) a stationary generalized extreme value (GEV) distribution is fitted on a time series of annual maxima ii) return levels are computed using the fitted distribution. In the context of global warming, changes in return levels are usually assessed using GEV distributions that can vary with time, i.e using non-stationary GEV models where the parameters of the GEV distribution can vary with time.

This thesis analyses past and future changes of 50-year return levels of snow load and 100-year return levels of snowfall in the French Alps using non-stationary GEV models. Snowfall (solid precipitation) is one of the key variables both for avalanche risk and for avoiding the disruption of transportation systems, while snow load (pressure exerted by the snowpack on the ground) is central both for water resource management and for the structural design of roofs. Time series of annual maxima of snowfall and snow load are provided every 300 m of elevation for the 23 massifs of the French Alps: by the S2M reanalysis (1959-2019), and by an ensemble of 20 climate projection of the EURO-CORDEX experiment (1951-2100). Each projection is adjusted against the S2M reanalysis for a high emission scenario called RCP8.5, which leads to more than $+4°$C of global warming w.r.t. pre-industrial levels in 2100.

To study changes in return levels, we develop novel non-stationary GEV models that i) are based on a simple and robust statistical methodology for the S2M reanalysis ii) rely on piecewise-linear functions for the climate projection ensemble iii) can gather strength across consecutive elevations and within a climate projection ensemble.

We quantify changes in return levels using these models. Between 900 m and 3600 m of elevation, 50-year return levels of snow load have been decreasing for the period 1959-2019 and are projected to decrease when compared with $+1°$C of global warming (reached in 2017). Averaged on all massifs, 100-year return levels of snowfall i) have been increasing above (decreasing below) 2000 m for the period 1959-2019 ii) are projected to increase above (decrease below) 3000 m at $+4°$C of global warming when compared with $+1°$C.

This thesis has implications for natural hazard management in the French Alps. First, despite their decrease, our 50-year return levels of snow load are sometimes exceeding 50-year return levels of French building standards. For example, at 1800 m, French standards are exceeded by 15% on average, and by half of the massifs. These exceedances are likely due to questionable assumptions concerning the computation of these standards. A second implication is that the design of critical infrastructures needs to be verified above 2000 m for snow-related hazards, i.e. where 100-year return levels of snowfall have increased.

Keywords: Climate change, French Alps, Return levels Snowfall, Snow load, Non-stationary generalized extreme value models.