Inferring spatio-temporal patterns in extreme snow variables using max-stable processes

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Heavy snow events are among the most severe natural hazards in temperate and polar mountainous countries. Every year, winter storms can hinder mobility by disrupting rail, road and air traffic. Extreme snowfall can overload buildings and cause them to collapse, and can lead to flooding due to subsequent melting. Deep snow, combined with strong winds and unstable snowpack, contributes to the formation of avalanches, and can cause fatalities and economic loss due to property damage or reduced mobility. Also, from a more "positive" point of view, extreme snow depths are relevant to quantify the winter water storage in the snowpack. For extrapolating beyond the highest observed values in a spatial context, Max Stable Processes (MSPs) is the natural framework to work with. In addition to justifications from multivariate extreme value theory, it allows estimating various quantities of high geophysical and operational interest such as dependence ranges in possibly anisotropic spatial fields of extreme values, and/or joint exceedence probabilities among a set of stations taking into account the entire dependence structure. However, strong altitudinal gradients, possible non-stationarity induced by climate change and various theoretical and practical issues make the use of MSPs complicated in practice. In this work, we illustrate how some of these challenges can be addressed with, as case study, an exceptionally rich data set of various snow variables from the French Alps, namely maximum cumulated snowfall over 1-7 days and maximum snow depth. Specifically, we implement five MSP models coupled with spline regressions on spatial coordinates for the margins and select for each data set the most adapted one using an information criterion and cross validation on multivariate exceedence probabilities. From the best fitted models, for extreme snowfall and snow depth, we evaluate and compare spatial dependence ranges (norm and direction) altitudinal gradients, and how these have been modified by warming over the last decades.

Keywords: Extreme climatic events; spatial dependence; climate change; French Alps.