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Characteristics and environmental context of the late snow patches in the high Vosges mountains (eastern France)

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The Vosges mountains result from the Hercynian orogenesis. Despite their relatively low elevation (1424 m at the "Grand Ballon") and because of their cold /cool and wet climate, the Vosges mountains experience persistent snow patches on their east-facing high slopes (at about 1200-1300 m). The topography and the land cover of the high Vosges mountains are favourable to the development of extensive snow patches: the wind sweeps the snow from the high and relatively flat tree-less surfaces (*hautes-chaumes*) and accumulates it on the high leeward edges of the glacial cirques. The snow accumulation is observed in cornices or firns. Some snow cornices cause avalanches and slope erosion. All the snow patches disappear each year during the summer, but one snow patch would have persist until the next winter in 1860. The date of disappearance of the last snow patch is a good indicator of the amount of snow deposited during the previous winter. The east-facing glacial cirques of the high Vosges mountains have ideal topographical features for a snow accumulation in cornices or firns: 30 sites were identified, including 13 "cornices" sites and 17 "firn" sites. For each site the altitude and the slope aspect were specified and the median date of disappearance of snow patches was estimated. The climatic and environmental features of the snow firns and cornices development have been analysed and a detailed inventory of the favourable areas for the development and for a long duration of snow patches was drawn up, especially on the Hohneck massif (1362 m). The risk of avalanches was described too.

The Vosges mountains are included in the cool temperate climate area of northwestern and central Europe (the *Cfb* type of climate, according to the Köppen's classification), but they are subjected to a colder and wetter climate than the surrounding lowlands. The western and southwestern slopes are exposed to the Atlantic disturbed weather systems and locally receive an average annual precipitation of more than 2000 mm. Therefore, the high Vosges mountains are subjected to an oceanic precipitation regime, with high late autumn and winter precipitation amounts allowing a high snowfall occurrence. The snow ratio is about 30 % of the total precipitation at 1000 m and 60 % at 1350 m. Only July and August do not experience ground snow. Between 70 and 90 days with snowfall are estimated between 1200 and 1400 m, with more than 160 days of snow cover at about 1200 m. The occurrence of frost days (about 120 days at 1000 m and 140 days at 1200 m) has an effect on the snow cover development and duration.The first snowfalls occur about mid-October, but the snow cover is significant from the second decade of November and reaches an average height of 100 cm in late February or mid-March. The snow cover quickly disappears during the first two weeks of May. On the main tree-less and windswept high ridge, the snow height do not exceeds 20 or 30 cm, because a great part of snow accumulates in cornices and firns.

The persistence of the snow patches depends on the snow accumulation in winter and on the prevailing wind direction associated with the heaviest snowfalls. The variability and succession of weather types during the cold half-year have an effect on the snow height and the cornices and firns development and duration. A high frequency of south or southwest cyclonic or anticyclonic circulation types hampers the development of a thick, stable and long-lasting snow cover (eg. winter 2006-2007). A high frequency of northwest or north cyclonic circulation types (or possibly with periods of snow-producing east circulations), in alternation with cold anticyclonic weather patterns, allows a thick, stable and long-lasting snow cover (eg. winter 2005-2006). The occurrence of anticyclonic weather patterns in winter allows a long-lasting snow cover, if there is a pre-existing ground snow for early winter. The persistence of the snow cornices and firns depends on the height of snow accumulation during the winter and on the frequency of the observed weather patterns in spring. A high frequency of north cyclonic or anticyclonic circulation types hampers the snow melting and sometimes causes new snowfall events. Rainfall in spring and high temperature in summer (eg. July 2006) speed the melting of the snow patches and their disappearance.

The Schwalbennest firn occasionally reaches 20 m height and it is the last one to disappear (latest date: 15.09.1978). The other snow patches usually disappear between early June and early July. Snow accumulation in cornices or firns slides by gravity effect on the slopes of the glacial cirques and causes an erosion of the slopes by uprooting the

herbaceous vegetation. Solifluxion due to this erosion is occasionally observed. The cornices disappear before the firns, by melting and falling. The risk of avalanches exist in the high Vosges mountains following snowy winters (eg. 1910, 1952, 1970, 1988 and 2006) ; human and material damages have been mentioned since the XIXth century.

The possible evolution of the snow patches (number of sites, extent and thickness, dates of disappearance and interannual variability) must be discussed and analysed in the context of the climatic change. Such a study must be developped using observations and data from other low mountains areas of northwestern and central Europe (eg. Grampians in Scotland, Jura in France / Switzerland, Black Forest in Germany, Giant Mountains on the Czech-Polish border).