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SNOW COVER EVOLUTION IN THE HIGH ARCTIC, NORDENSKIÖLD LAND (SPITSBERGEN, SVALBARD)

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I. INTRODUCTION

Snow is the most common element in the Arctic and High Arctic environments, and the snow processes have a close relationship with the periglacial ones. The characteristics of the snow cover, its structure, thickness, distribution and ablation processes, are fundamental for the glacial features as well; both snowfall and snow avalanches are the most important accumulation ways for glaciers. On the other hand, a thin snowpack means for permafrost presence and intense periglacial processes development, due to the less isolation and greater cold penetration in the ground. The little nivation received in many areas of the High Arctic, where there is not solar radiation during half year, has a great influence on the snow characteristics and on other processes derived from it, such as snow avalanches and geomorphological features due to the water availability and phenology of the snow.

The snow study in Svalbard has been mostly focused on snow avalanches, climate monitoring and distribution. However, there are not so many studies about the snow cover phenology and its relationship with the main periglacial landforms and processes in Nordenskiöld area.

The aim of this paper is the study of the structure, duration, and distribution of the snow cover in the High Arctic, in order to understand the water availability and the snow cover relevance in the morphogenesis as well.

II. STUDY AREA, NORDENSKIÖLD (SPITSBERGEN, SVALBARD)

The studies areas are localized in the Adventdalen and Reindalen valleys, both found in Nordenskiöld Land, Spitsbergen Island, Svalbard Archipelago. Despite its Northern latitude position, 78º, the temperatures are not as cold as expected at that latitude: MAAT -5.8ºC for the period 1975-2000. The coldest month is February, -15.2ºC on average, and the warmest July with 6.2ºC. Precipitation at sea level is 190 mm/a^{-1}, although at higher altitudes it must be more elevated. Snow cover lasts from beginning of October to beginning of June.

The study area morphology is basically composed by plateaus and incisions. Geologically, there are Jurassic and Paleocene-Eocene sandstones, limonites and slates. There are glaciers in the secondary valleys, ice free U shape valleys and moraine deposits from the Little Ice Age. Periglacial landforms and processes are abundant and intense. Permafrost is continuous, with maximum thickness of 450 m.

III. METODOLOGY

The study is based on both fieldwork (one warm season –July 2002–, one cold season –March-April 2004–, and one melting season -June 2010) and photography analyses. Snow cover distribution study has been carried out using photographs from Adventalen (2000-2004) from the *University of Svalbard* (UNIS). This methodology has been previously used in the Arctic.

IV. SNOW DISTRIBUTION AND CHARACTERISTICS IN THE VALLEYS OF ADVENTDALEN AND REINDALEN

The snow characteristics in Spitsbergen depend on: solar radiation, topography and wind. Due to the lack of radiation and the low temperatures during the polar night, the snow in the High Arctic has a slow metamorphism and therefore low densities as well; between 273 kg/m^3 and 310 kg/m^3. There is not important variation between low altitudes and high ones. The topography determinates the snow distribution in the Arctic. Snow drifting is responsible of the very irregular snow distribution, and it is conditioned by its physical properties, depending on the temperature and humidity. Snow is transported and redistributed by saltation and suspension. When the density is very low, a wind speed of just 0.07 $m\ s^{-1}$ is able to transport a thin layer of powder snow, and with higher speeds the snow particles move by suspension. Highest wind speeds are registered during the winter,

Snow redistribution is the key to understand the snow cover in the valleys of Adventdalen and Reindalen. According to our observations, some areas completely covered with snow can be snow free in just some hours due to the wind redistribution. During January the snow covers the valley, while in the higher areas it is regular since November. The accumulation of the snow in the valleys of Adventdalen and Reindalen is higher where the ground is irregular, as for example the small creeks that reach the main river perpendicularly. Because of this, there is a banded snow distribution in the bottom of the Adventdalen and Reindalen valleys, and maximum snow accumulations in the perpendicular smaller valleys that reach the main one.

There is a correlation between snow accumulation and the vegetation typology. For instance, where the density of thufurs is elevated, the snow is trapped and the accumulation is higher.

V. SNOWPACK STRUCTURE AND SNOW COVER EVOLUTION IN THE ADVANTDALEN AND REINDALEN VALLEYS

The snowpack structure in the Adventdalen and Reindalen valleys during the winter is very simple:

(i) An icy base layer, stable and permanent, either formed by the exposition to the winds, or the rain water freezing.

(ii) An unstable snow top layer, which can be transported by wind repeatedly during the cold season.

The evolution of the snowpack complicates its structure and stratification. The transformation begins from the surface, producing a thin suncrust due to the temperature contrast. While the snowpack receives more heat, it increases the density (445 kg/m^3 at the beginning of the melting season), becoming thinner. The active layer is not generated until the complete disappearance of the snow. The meltwater which circulates trough the snowpack freezes in contact with the permafrost, in a similar process as the glacier superimposed ice. The snow stratigraphy is more complicated in the snowdrifts and cornices, with the presence of depth hoar crystals.

According to some investigations, the snow thickness varies from 30 cm (Drønbreen and Blekumbreen glaciers), to 70 cm (Ny Ålesund), both of them in Spitsbergen as well.

Solar radiation is the dominant factor in the snow ablation in Spitsbergen. Ablation in the High Arctic takes place by two ways: sublimation (which counts about 5-50%), and fusion (between 50 and 95%). The disappearance of the snow is very heterogeneous as the distribution is in the Adventdalen and Reindalen valleys. The difference in the snow cover between the North and South faces is not so important as in the mid-latitudes mountains.

In Adventdalen the fusion of the snow is organized in belts according to the altitude:

0-100 m. In the valley bottom the snow cover is very thin, less than 35 cms. Only in some snowdrifts the accumulation can be much bigger. The snow cover is irregular from October; while the in December and late January is regular but thin. The maximum accumulation is reached in February, March and April. At this altitude the valley is snowfree during 5 months per year.

100-400 m. At this altitudinal belt there is not snow during 80 days. Snow cover is continuous during more than 6 months from the beginning of October, and it disappears in one month (mid-April to mid-May).

400-550 m. From September the snow cover is continuous, and takes 15-45 days to become discontinuous. In this altitudinal belt there are only 2 months and half free of snow.

550-750 m. This is the last belt with total snow ablation (40 days snowfree). Total snow continuous cover ablation is fast (10-15 days), while the discontinuous takes longer time (55 days).

>750 m. Above this altitude there are always snow patches. Snow continuous cover to discontinuous takes 30 days.

The total disappearance of the snow cover in Adventdalen takes 40 days at sea level and 35 at 700 m of altitude, from late April to the beginning of July. It has been estimated the delay in the periglacial and snow processes with the altitude in 250 m/month, being 3 months of ablation time from the sea level to 700 m.

The permafrost contributes in the snow melt delay, and produces the saturation of the active layer. This meltwater generates the most active morphogenetic period and an important transfer of sediments.

In those snow patches on flat topographies the meltwater saturates the snow and pools on it (<50 cms). When there is more inclination, the meltwater circulates either over the frozen snow layer at the base, or producing small slush avalanches over the ice. This makes the developing of some periglacial processes, such as thufurs or lobes.

In the High Arctic the snow cover disappearances in about three weeks. In those areas with less accumulation it might takes even less time.

VII. SNOW AVALANCHES IN ADVENTDALEN AND REINDALEN

Due to the recent interaction with the human activities, there is an increasing interest regarding the snow avalanches in the High Arctic. In valleys of Adventdalen and Reindalen the snow avalanches are common processes, and can be found in different typologies: slab, loose snow and cornices avalanches. According to the frequency and phenology we found the following typologies of snow avalanches, winter and spring snow avalanches.

Winter snow avalanches represent 40% of all of them in the secondary valleys such as Todalen during the cold season. The typologies during this period include snow slab avalanches and cornices, associated as well with drifted snow. Transfer of snow from the plateaus to the slopes and valleys delays the snow disappearance here during the spring, but not have geomorphological consequences.

Spring snow avalanches are more frequent during May and June, when the temperature may reach 0ºC and the direct solar radiation destabilizes the snowpack. In Todalen, during the cold season of 2008/2009, 60% of the snow avalanches took places from mid March to mid May, when the slopes are still covered with snow. Most of them are wet snow avalanches, due to the increase in temperatures and rain, and cornices failure until the summer. The snow avalanches produced from the cornices failure have geomorphological consequences since they might incorporate debris from the wall, accumulated in debris cones due to the permafrost agradation and rock glacier genesis. Despite their geomorphological significance, they are also the less frequent (20%)

The discontinuous snow permanence and the snow patches in the lowest slopes (0-100 m.) are related with both winter and spring snow avalanches. Therefore, the importance of the snow avalanche is fundamental on the slope dynamic, extending the snow processes until June in the lowest areas (0-500 m), and until mid-July in the mid-slopes (500-700 m.)

VIII. CONCLUSIONS

The High Arctic snowpack is relatively simple and, in general, not very thick. Both, topography and snow drifting processes are responsible of its complexity and thickness. The differences between the North and South faces are not so significant, due to the prevalence of E-W winds, the snow redistribution, and the constant solar radiation during the summer.

Snow transformation in Adventdalen and Reindalen is result of the refreeze and mostly wind redistribution, which prevail over the precipitation. During the cold season the snow pack consists in two layers, one stable and frozen (very influenced by the permafrost), and another unstable and not united. Only on the slopes and in the terrain hollows the internal structure of the snow is more complex, with depth hoar layer and wind slab developing. The snow pack increases the density as starts to transform in spring, when there is solar radiation, and appear for the first time sun crust, fast snow transformations and small slush avalanches.

The cold permafrost (<-4ºC) helps the slow melting of the snow in Spitsbergen. The disappearance of the snow varies with the altitude. From 0 to 400 m. it takes two or two months and a half. At higher altitudes, over 700-800 m, there is a discontinuous snow cover, with snow patches and cornices which may last the whole year.

At the sea level, snow total disappearance takes an average of 40 days, while at higher altitudes, 700 m., are 35 days. Periglacial and snow processes associated with the snow cover melting extend 3 months, from April to June in the 0-700 m. belt, and from July to August over 700 m., with an average of 250 m./month in high. This period is the most active geomorphological time -due to the meltwater abundance and the thermal oscillations-, generating gelifluction, frost shattering, frost heave and icing.

During the spring and summer the snowpack destabilizes. The highest snow avalanches frequency are found in May and June, which may delay the complete snow melting. Snow cornices collapsing have a geomorphological significance although are not the most frequent. Finally, spring snow avalanches are very efficient in both erosion and debris transport, modeling gullies and debris cones.