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Building an indicator to characterize the thermal conditions for plant growth on an Arctic archipelago, Svalbard

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ABSTRACT

Plant growth in the Arctic is strictly dependant on thermal conditions. The purpose of our study is therefore to calculating temperature distributions on the Svalbard archipelago at a relatively high spatial resolution. The model is designed to reflect both the length of the growing season and the temperature sum for a given area (i.e. growing degree-days (GDD)). GDD on Svalbard is defined as the cumulative sum of positive mean daily temperatures in the months of June, July and August. The temperature distribution of GDD for the entire archipelago is calculated from both local and regional information. Local information is derived from data collected in a small area in northwestern Spitsbergen (Kongsfjorden) where a network of 45 thermal sensors recorded air temperatures for five years (2001–2005). A local GDD parameter is computed by a linear combination of elevation, valley depth and NDVI (normalized difference vegetation index). Then this local GDD is applied to the whole of Svalbard (GDD1) and refined stepwise by adding environmental variables such as cloud fraction, land surface temperature, sea surface temperature, distance to the ocean and number of snow-free days. Because the official network of climatological stations on Svalbard is not dense enough and sufficiently well-distributed across the archipelago to enable spatial interpolations for four years only (2011–2014), all outputs are statistically evaluated and adjusted using the values recorded at 9 (2011), 12 (2012) and 13 (2013–2014) meteorological stations (GDD_{ref}) and used as a set of evaluation data. The final model (GDD_{mean}), which is the mean of the annual models estimated by regression (GDD_{est}), performs well: the central parts of Spitsbergen, known for its comparatively high temperatures, contrast with the colder northern and eastern parts of the archipelago.

1. Introduction

The Arctic vegetation experience changing environmental conditions including higher temperatures induced by global change (Bliss, 1971; Callaghan et al., 1999; Lenoir et al., 2008). It is likely that we will see changes in the vegetation cover in near future, as species adapted to high arctic conditions may suffer decreasing populations, while others may be able to colonize habitats which has been too hostile until now. These spatial redistributions of plants patterns depend on many geographical features such as soil composition, texture and moisture, topography and climate elements, etc. Even if temperature is one of the most limiting factors of plants in the Arctic, energy alone does not help if, according the "Liebig's Law of Minimumm" first described by Sprengel in 1828, other conditions are below any minimum thresholds (water, nutrients, substrate, etc.). The problem is that, except for temperature, we have no other data available at large scale. That is why this work is only based on temperature data that enables us to have knowledge on how temperature is structured locally and to understand the thermal conditions in which plants currently grow.

The large-scale predictive temperature models developed by IPCC (IPCC, 2013) are by far too coarse to be useful in this context. Looking back to the last decades, mean temperatures during the summer months have often been used to define bioclimatic zones in both boreal and arctic regions characterized by distribution of vegetation units (Elvebakk, 1994; Moen, 1998; CAVM team, 2003; Karlsen et al., 2005; Walker et al., 2005) or single species of indicative value (Thuiller et al., 2004). However, in Svalbard, temperatures in most areas are poorly documented, and especially so in the remote eastern, northern and southern reaches of the

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archipelago. Hence, the correct distribution of the bioclimatic zones in the archipelago has been a matter of discussion for years due to mostly rather subjective approach, and the lack of empirical temperature data. This state of affairs detracts from our understanding of Svalbard's and the links between temperature and plants are not explained or validated.

Over the last years, several new automatic weather stations in Svalbard is yielding temperature data, improving the access to empirical temperature series. However, Svalbard will probably never be covered with a dense network of weather stations, and it will not be possible to map distribution of temperature on a local scale from such data alone. When empirical data is not available or the quality is not satisfactory, a natural approach is to use a model to fill in the gaps.

The objective of our work is thus to add some objectivity and accuracy to the knowledge of temperature distribution in Svalbard by presenting a geographical temperature model of the archipelago. We have chosen to use the parameter "growing degree days" (GDD), here defined as the sum of positive mean daily temperatures in the months of June, July and August. Some studies also refer to the same parameter as effective temperature sum' (Tuhkanen, 1993; Karlsen, 2003) which has been proved slightly better correlated to distribution of plants and vegetation than for example the mean July temperature, which also has been widely used. Our starting point was modelling distribution of GDD in the Kongsfjorden area of western Svalbard using available data from a network of 45 temperature sensors distributed throughout the area (Joly et al., 2010; Nilsen et al., 2013b). The objective is here wider and consists to develop a model for calculating temperature distributions throughout the Svalbard archipelago at high spatial resolutions similar to what was achieved in Kongsfjorden. The model should then be able to reflect both the variations in the length of the growing season as well as other more large-scale parameters affecting the GDD. The method for computing GDD for the entire archipelago was based on a series of regressions, and the first explanatory variable was the extrapolation of the local model developed in Kongsfjorden to every 100 × 100 m pixel of the archipelago. Four other explanatory variables are retained to take into account the temperature variation on a regional scale. The 'ground surface heating potential index' (GSHPI) reflects the thermal conditions under which plants actually grow. 'Sea surface temperature' (SST) and 'distance to the open sea' (DOS) are intended to capture the thermal influence of the sea on air temperature, which is highly dependent on the North-East Atlantic current and the relatively continental character of central Svalbard. The 'number of snow-free days' (NSFD) provides guidance as to the potential length of the growing season that starts as soon as the snow melts. The output was evaluated by comparing estimated results with empirical data from weather stations, and adjustments were done in order to improve the performance. The final result is presented as a map of Svalbard depicting the spatial variation of GDD at a spatial resolution of 100 m.

2. Study area and material

2.1. Svalbard

The target area to be modelled was the entire archipelago of Svalbard except for the island of Bjørnøya, which although part of the archipelago, lies far to the south. Svalbard's three main islands (Spitsbergen, Nordaustlandet and Edgeøya) lie between 76.5 and 80.5° north, about 1000 km from the North Pole and astride the boundary between the Barents Sea and the Arctic Ocean (Fig. 1). The total land area of the archipelago is approximately 63,000 km^2 with its largest island, Spitsbergen, covering some 38,000 km^2. Except a low coastal line called "Strandflat" which elevation do not exceed 100 m, most of Svalbard consists in mountains (maximum altitude 1717 m at the Newtontoppen) with steep slopes and large glaciers (Table 1).

Meteorological data show that Svalbard has a polar oceanic climate with cool and wet summers. At low elevations, mean summer temperatures vary, depending on the year, from −1 °C, 1 °C in the northern and eastern areas (Karl XII Øya, Kvitøya) to 5 °C, 7 °C in the central parts of Svalbard (Table 2). A positive thermal gradient occurs between the west coast (Hornsund, Sørkapp, Ny-Ålesund) and the central part of Spitsbergen (Sveagruva, Longyearbyen, Pyramiden) with mean summer temperatures of 4.5 °C and 6.1 °C respectively in 2013–2014 (http://eklima.met.no).

The Meteorological Institute of Norway operated meteorological stations for an extended time at only a very few locations before 2010 (Table 1). Accordingly, the study concentrates on the years 2011 to 2014, which are the only ones in which enough stations

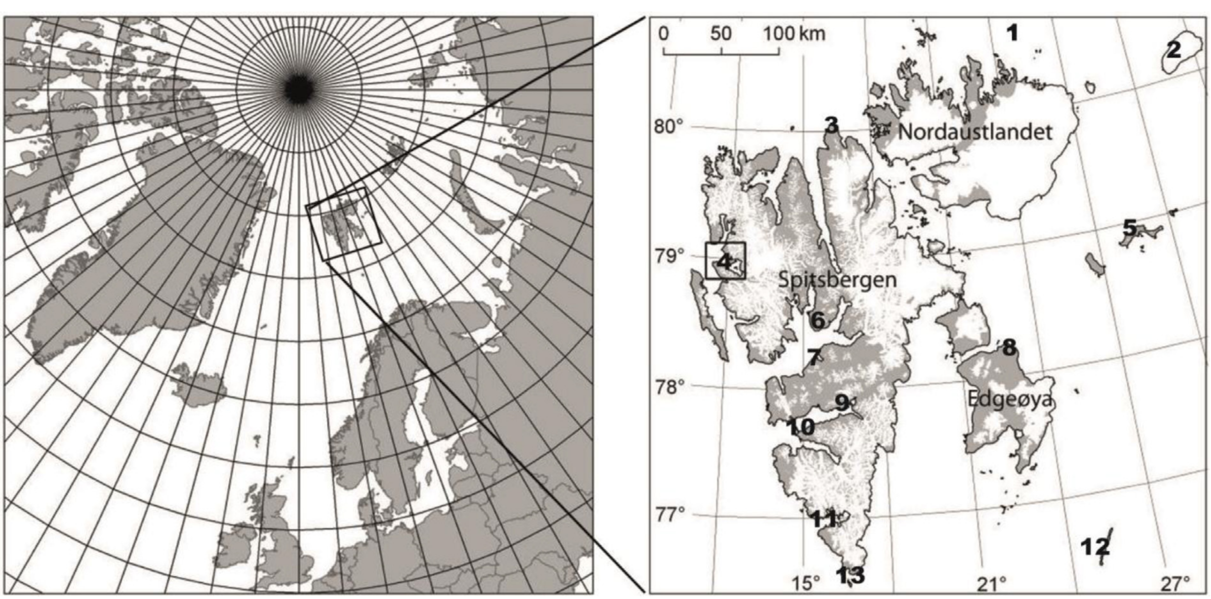

Fig. 1. The location of the Svalbard archipelago in the Arctic and locations of the weather stations. The numbers refer to those of Table 2. The square with number 7 on the north-west coast of Spitsbergen marks the Kongsfjorden area where the 45 temperature loggers were installed.