Contribution of Environment Factors to the Temperature Distribution According to Different Resolution Levels; Test on the Forefield of the Loven Glaciers (Svalbard)

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The temperature distribution is controlled by numerous factors related to topography (such as altitude, gradient, slope facing, landforms) and land cover (such as vegetation, bare ground, water). Additional elements worth to be considered like distance to significant objects like sea, crest lines or glaciers. The influence of these environment features on temperature distribution can be effective according to different scale-ranges as it is the case when comparing, for instance, the effects of two water bodies: the effect of a small lake is only local whereas the oceanic influence is still sensible far from the coast line, beyond several hundred miles. Thus, we see that the key point for solving the problem is to establish, factor by factor, the scale level for which its contribution to temperature variation is the highest before integrating, in a further step, these segmented results in a global model of temperature distribution.

In order to carry out this protocol, we choosed an experimental site, located at the front of two glaciers in Svalbard, so called *Loven East and Loven Middre* (79°N). This place offers appropriate characteristics for such an experiment: (i) the environment conditions are very contrasted in term of topography, vegetation cover and soil properties, (ii) some significant objects (fjord, glaciers, mountain ridges) are present in the surroundings and thus, it is possible to identify their specific influence on temperature, (iii) a rather complete data base is available for this area: DEM and images at different resolutions, reference measurements made on the field with the help of a dense network of data loggers. Linear correlations will measure the influence of the environment factors (explanatory variables) on temperature (variable to be explained).

1. Study area

The study area, which covers about 10 km^2, is located 6 km in the East of Ny-Ålesund, on Brøgger Penninsula (Svalbard). It corresponds to a coastal plain, so called strandflat in geomorphological terms. This plain is made of several raised marine levels due to the isostatic adjustment after the last main quaternary glaciation. For the Little Ice Age of which the peak took place here at the end of the 19th Century, the two local glaciers have built up important morainic systems giving nowdays a high diversity of forms: inner detritic cones, hills and ridges, bowls and valleys (fig. 1). Out of the morainic belts, rivers coming from the glaciers have made a complex outwash plain (sandur) combining different stages of detritic cones. Beside the two glaciers which are represented on the map, the Kongsfjorden makes another cold body northward. Close to the fjord, the wind is mostly coming from the Northeast and, on the glacier forefields, catabatic winds frequently blow from the South. Between these two cold zones, there is an area where the temperature is much higher and can vary according to the weather conditions and the balance between the different local air masses.

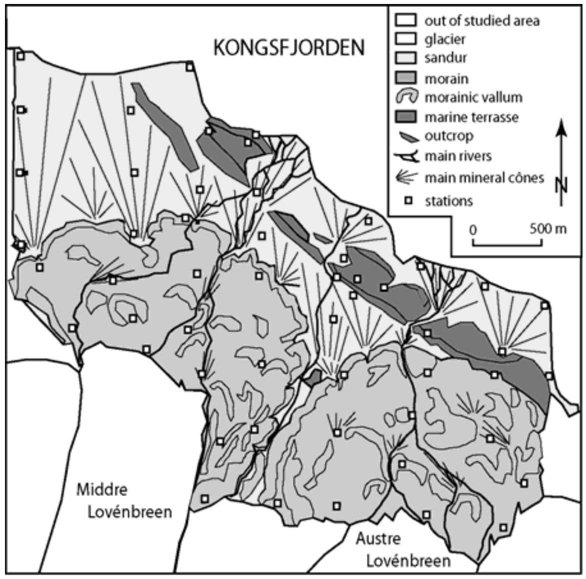

Figure 1: study area

2. Materials

Two main categories of data are applied for the modelling process. The first one deals with temperature which was recorded once every 6 minutes on 53 stations by means of data loggers (HOBO) within the limits of the summer season. These measurements are taken as variables to be explained. In the present experiment, only daily minima are considered for processing. The georeferenced positionning of the loggers was determined and optimized by a stratified sampling procedure which took into account two constraints: the spatial distribution and the diversity of environment conditions (Joly et al., 1999).

The second data set comprises remote sensed images and digital terrain models (DTM). It takes the form of information layers in the raster format. Each of them is available with two primary resolutions:

- 2 meters. The image source is a scanned infrared aerial photo provided by Norsk PolarInstitutt. The DTM is processed by an interpolation method applied to 40000 coordinates measured on the field by a GPS.
- 20 meters. The information sources are a resampled and orthorectified SPOT image and a section of the Svalbard DTM provided by Norsk PolarInstitutt.

The first step of the procedure consists in deriving from the two primary data bases several spatial subsets having different resolutions (fig. 2). These ones will be requested to determine, by means of appropriate tests, among all the corresponding scale levels, which one is the most significant for a given explaining factor. Thus, an aggregation process (tab. 1) is applied in order to obtain (i) from the 2m primary base, six subsets (6, 14, 30, 60, 140 and 300 m resolution) (ii) from the 20m primary base, three subsets (60, 140 and 300 m resolution).

2 m primary base						
Window size (cells)	3x3	7x7	15x15	30x30	70x70	150x150
Resolution (m)	6 m	14 m	30 m	60 m	140 m	300 m
20 m primary base						
Window size (cells)	3x3	7x7	15x15	---	---	---
Resolution (m)	60 m0	140 m	300 m	---	---	---

Table 1: size of the subsets identified on the primary bases at 2 m and 20 m resolution

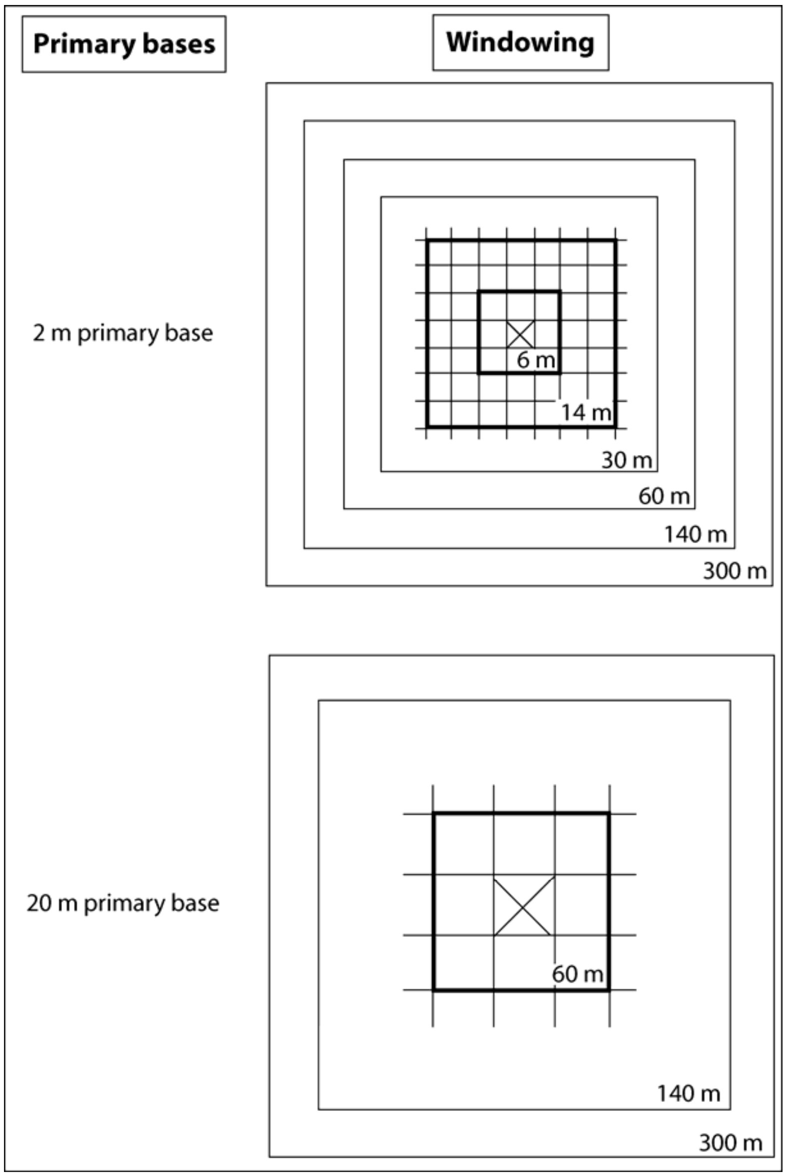

Figure 2: Primary bases and windowing

The second step achieves the spatial links between the measurement points and the different data layers, as shown also by fig 2. Around each point, several windows corresponding to the different resolutions derived from the two primary bases are established (tab. 1). On this basis, the environment conditions of the 53 reference climatic stations are able to be systematically described in the same way within each window frame. A great number of variables able to explain the observed temperature values can be obtained from such data sets and then tested to see if they are significant or not. The following list identifies some of these variables (Gardner at al., 1990):

- from DTM: altitude, gradient, slope facing, theoretical solar energy, topographical contrast, landforms, distance to crest lines.
- from images (scanned aerial photo and satellite data): land cover, distance to the sea and glaciers.

As our aim is to suggest a methodological issue for recognizing, variable by variable, what is the most significant scale level, we only present hereby the detailed results for only two variables, showing how the procedure works. In the both cases, the daily minimum of temperature is taken as the variable to be explained whereas the theoretical solar energy and the vegetation cover are taken as explaining factors. These tests concerns two dates which were choozed for their contrasted weather conditions, fine for the 17st of July and bad for the 5th of August. Let us remarks that, (i) in the case of the aerial photo (2 m primary resolution), the vegetation is valued through a quantitative index (PVI) giving the “probability that the considered pixel is 100% vegetated”, (ii) in the case of the satellite image (20 m primary resolution) the vegetation is valued through the usual index, NDVI.

3. Results

The procedure is based on linear correlation which is applied on the different variables couples (Joly et al., 2003; Wilmott & Robeson, 1995). By using graphs, one can see how the correlation coefficients vary, for each factor, from the highest to the lowest resolution. On figure 3, the correlation coefficients are defined as to follow:

- light lines = solar energy (values derived from the 2m primary DTM according 6 windows sizes)
- bold lines = solar energy (values derived from the 20m primary DTM according 3 windows sizes)

3.1. Solar energy

The coefficients are positive when the weather conditions are good (17st of July) because the income of energy from the sun is not disturbed by clouds and can have a direct effect on air temperature. The reverse case is observed on the 5th of August (bad weather conditions) with rather strong negative correlation values.

On the first date, light filled curve shows a convex profile of which the maximum (r=0.73) is related to the window 2 and the minimum (r=0.19) is observed for window 6. A symmetrical concave structure appears with the second date, light filled curve shows a negative peak (r=-0.75) for the window 3. This both structures indicate that scale determines the hierarchy of factors able to explain the temperature distribution. The dependence of temperatures on solar energy is weak (r ± 0.2) for the window 6 whatever the weather conditions are.

The results obtained from the two primary data sources (2 m. DTM from GPS and 20 m from Norsk PolarInstitutt) can be compared for the windows 4, 5 and 6 which are common to the both series of layers. At 20 m, both sources provide almost the same coefficient. At 100 m resolution, the deviation is maximum.

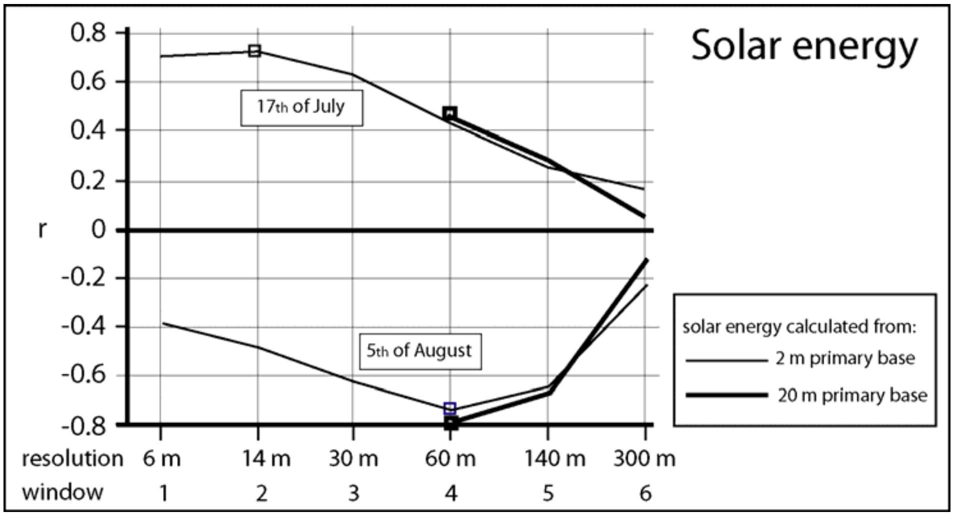

Figure 3: Correlation coefficients between temperature minima (17st of July, 5th of August) and solar energy income

3.2. Vegetation cover

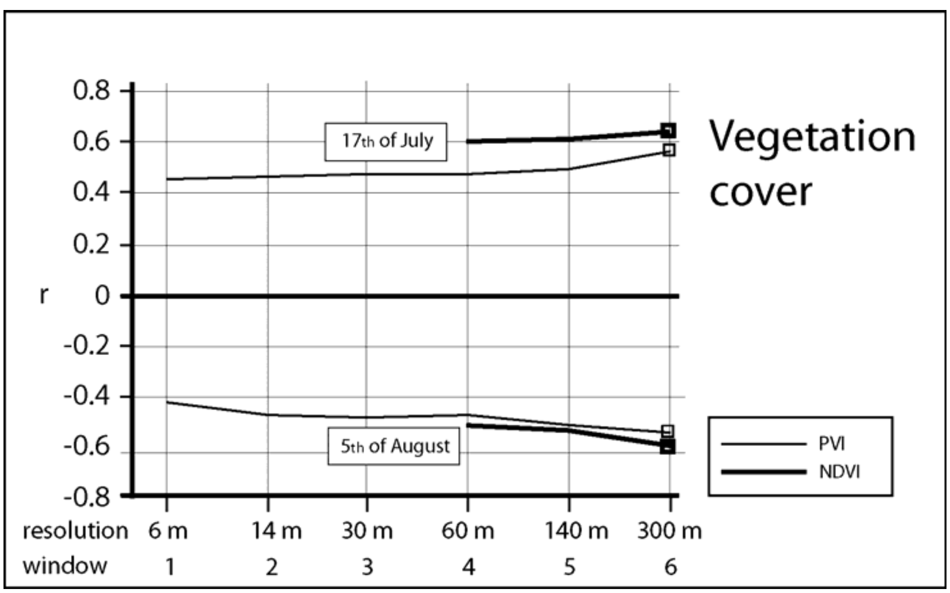

Figure 4: Correlation coefficients between temperature minima (17st of July, 5th of August) and vegetation cover indices (PVI and NDVI)

For the 17th of July, the correlation between temperature and vegetation probability index shows that the coefficients have an irregular distribution but trend to increase with coarser resolutions**.** For the 5th of August, the profile (negative coefficients) is also complex with a first negative peak at window 3 and a second one at window 6 when using NDVI which gives a better result than VPI in spite of a coarser resolution.

4. Discussion, conclusion

A set of windows having six different resolutions from 6 m to 300 m and derived from DTM and remote sensed data, provides means first, to describe systematically environment conditions and then, to identify, factor by factor, what is the most significant resolution level for explaining the temperature values. The procedure which lays on correlation processing tests the links between the daily minima measured on the field and two variables processed from the multi-scale data bases. The first one, solar energy, gives its highest correlation with temperature minima for the medium resolutions (14-60 m) whereas the second one, the vegetation index (PVI or NDVI), gives the best results when the coarser resolutions are taken into account for processing the coefficients. It means that the vegetation patches must reach a rather large size to have a sensible effect on temperature measurements (taken at 20 cm above the ground level).

Comparing the results according to the data sources, one see that the both primary DTM (from GPS or from Norskpolarinstitut) end at the same coefficient for the 60 m resolution (window 4), but beyond, the curves partly diverge. For the image sources, the coefficients are better with NDVI (satellite image) than with PVI (Infrared aerial photograph).

On the basis of these first tests, the considered environment factors show that their highest correlation with temperature minima is given when the data from the medium or coarser resolutions are processed. If this conclusion is confirmed by further tests taking into account other variables and maximum temperatures, it would mean that temperature distribution modelling is optimum when using usual (and cheaper) data sources such as satellite images and DTM available for wide areas.

References

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