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# Space-time patterns of temperature in Sweden and Europe

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**Abstract**

Statistical analysis of the space-time patterns and trends in temperature is central to improve the knowledge about climate variability and change. In this study, geostatistical techniques are used to assess the spatiotemporal patterns of temperature in Europe (1888–2010) and Sweden (1995–2008). A space-time coordinates system is proposed to evaluate possible trends in annual mean temperature throughout Europe. Results show a warming pattern after 1970 in Europe, particularly for areas with latitude of around 50°N.
*Keywords*: climate change, GIS, interpolation, Ordinary Kriging, temperature.

## 1 Introduction

Climate change is affecting virtually every sector of society, including, but not limited to, commerce and economic development, human settlements, water resources, natural resources, food production, energy use, transportation, recreation, and even national security [1, 3, 5]. European society is particularly vulnerable to changes in the frequency and intensity of extreme events such as heat waves and heavy precipitation [2]. Many of the impacts are costly, far-reaching, and damaging to local communities in the long term. This has called for concerns regarding the mitigation of its impacts.

The main objective of this study is to assess spatiotemporal patterns of temperature in Sweden (1995–2008) and in the rest of Europe (1888–2010). Another specific objective is to build a map with the time dimension included for a better temporal visualization of the spatial patterns in Europe.

The first part of the study covers the whole of Sweden and a series of maps were generated through Ordinary Kriging, each modeling the annual mean temperature from 1995 to 2008.

In the second part of the study, a special temporal approach is undertaken. Time dimension is always difficult to handle in Geographical Information Systems (GIS) and by cartographic applications, because it is difficult to visually detect changes among a series of maps. Therefore, another approach was considered with the goal of detecting changes in temperature patterns for the whole Europe in a much longer period from 1888 to 2010. In this case, instead of using the map's spatial coordinates system, a space-time coordinates system was considered.

The data used in this study was compiled from the European Climate Assessment & Dataset website (http://eca.knmi.nl).

## 2 Methodology

Ordinary Kriging interpolation was used to produce annual temperature maps for Sweden and Europe. In Sweden, the annual mean temperature was modelled for each year separatelly (1995–2008). In the case of Europe, the usual geographical coordinates system was changed to enhance the detection of patterns in time. A map frame offers a two dimensional environment where the X (longitude) and Y (latitude) coordinates are usually mapped. Our approach includes the time dimension in the map by assigning the year to the horizontal axis while the vertical axis corresponds to the latitude as usual. Ordinary Kriging was then applied to interpolate the spatiotemporal data of the annual mean temperature in Europe from 1888 to 2010.

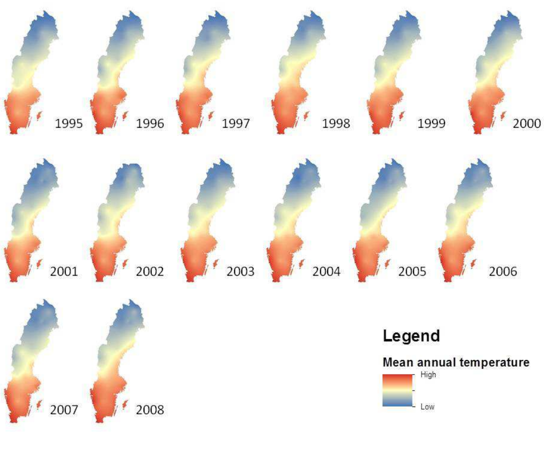
The Ordinary Kriging method used Exponential variogram models [4] to produce all surfaces in both Sweden and Europe. The spatial behaviour of temperature was considered isotropic in Sweden, whilst it was modeled as anisotropic in Europe with the major direction of 'spatial' continuity defined by the horizontal axis (year).

## 3 Results and discussion

### 3.1 Space-time patterns of annual mean temperature in Sweden

In general, the distribution of the temperature values is identical for all the years in Sweden (Fig. 1).

Figure 1: Interpolated surfaces of annual mean temperature in Sweden from 1995 to 2008.

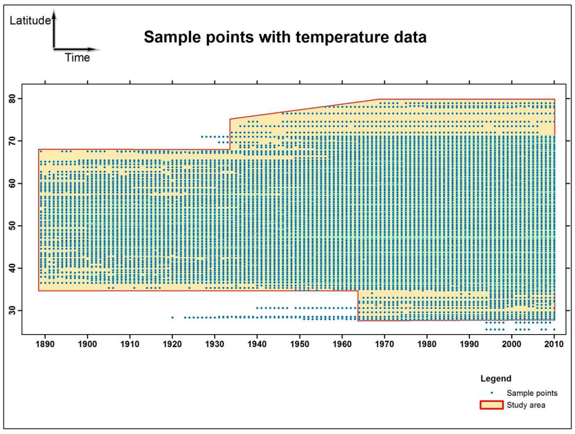


Slight differences can be observed in Sweden's temperature patterns (Fig. 1), such as in the year 1999 which has some low values in the northern part of the country. In 2008, high temperatures have encompassed the east central part in a larger degree than in the previous years.

### 3.2 Space-time patterns of annual mean temperature in Europe

The inclusion of the time dimension required the exclusion of one of the two spatial coordinates that define the map coordinates frame, either the latitude or the longitude. Using the proposed coordinates system, 109 912 points with mean annual temperature data for the whole Europe were imported using the ArcGIS® software (Fig. 2).

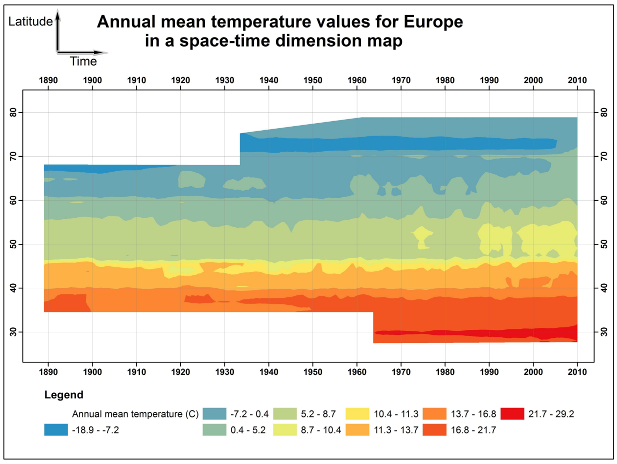
Figure 2: Distribution of temperature data points in the latitude-time coordinates system for the whole Europe.




There is a lack of points for the period 1890–1965 in the latitude interval 18°N–35°N, which corresponds to the north of Africa (Fig. 2). There is also a lack of points for the period 1890–1933 in the latitude intervals 68°N–79°N that corresponds to the area of the Arctic Sea, beyond Scandinavia (Fig. 2). The remaining area covers the whole Europe and has a vast amount of points comparing to those two almost pointless regions, thus they were not included in the interpolation operations to avoid misrepresentations.

The number of samples used to interpolate the data shown in Fig. 2 was extremely large, but there were no clustered data. The density of the sample points was calculated as 18 per one unit squared area. Fig. 3 shows the interpolated surface. Extreme values are located near and along the southern and northern boundaries of the map, respectively with high and low values. The overall trend of the values is also in accordance with the location of extreme values. Hence, there is a very obvious trend in the south-north direction as expected, which indicates that temperature decreases in the south-north direction.

Figure 3: Spatiotemporal interpolated surface of annual mean temperature in Europe from 1888 to 2010




The proposed approach allows identifying warmer and cooler periods along the same latitude (Fig. 3). A warming pattern is particularly noticeable after 1970, especially for latitudes between 45°N and 55°N. Generally, in the last 24 years, the temperature values have been the highest for the whole 122 year period from 1888 to 2010.

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