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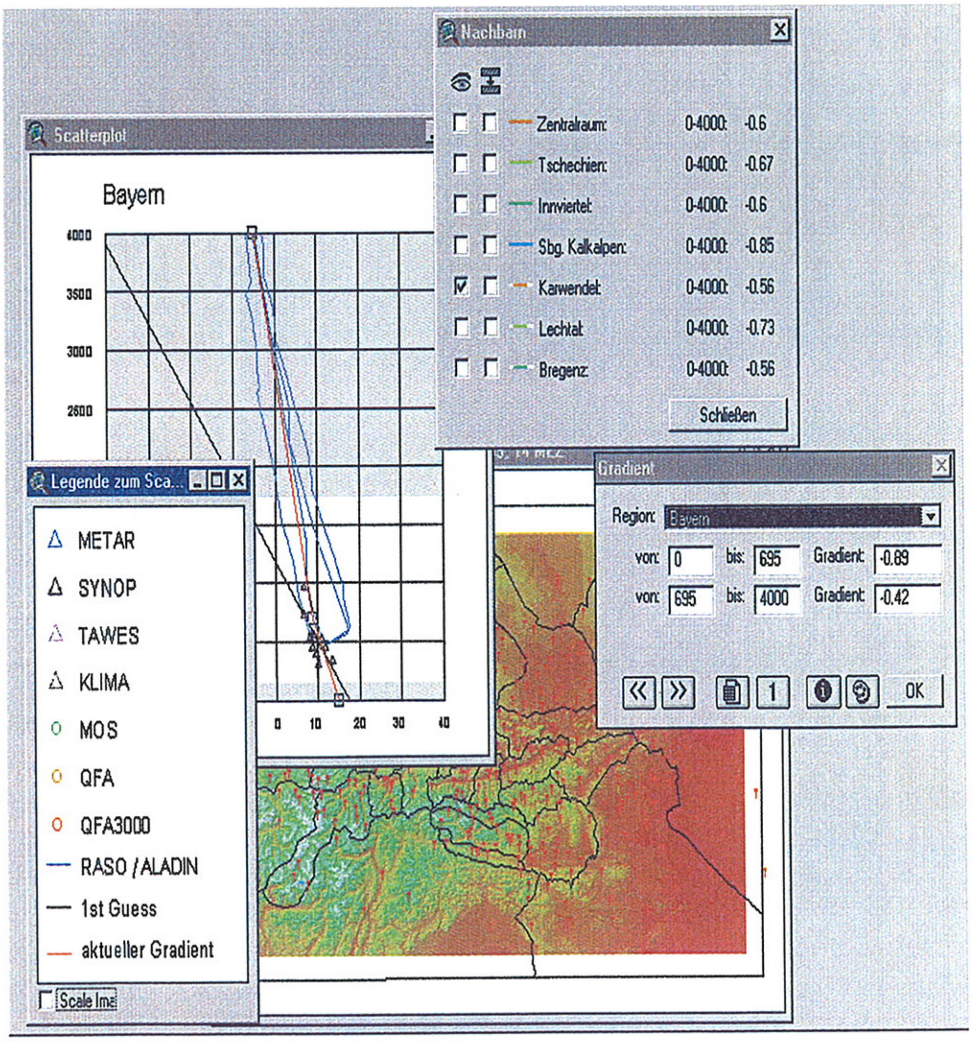
Project no. 5 in the framework of the climatological projects in the application area of ECSN

Report no. 13/01

Geographic Information Systems in Climatological Application

H.Dobesch, O.E.Tveito, P.Bessemoulin



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Project no. 5 in the framework of the climatological projects in the application area of ECSN

Geographic Information Systems in Climatological Application

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SUMMARY:

This report is the summary of the work done within the ECSN project on GIS application. The project has its emphasise on spatial interpolation schemes used in the field of climatology and on GIS applications which has been developed or are under development in the participating NMSs (National Meteorological Services). GIS techniques together with user-friendly applications can make the meteorological products more understandable for users. With its fast and cost efficient processing, it improves productivity quantitatively and qualitatively in the NMSs. Further, it shows clearly that applications must be standardised by the use of commercial software. The project experienced a growing wish within the participating NMSs towards a harmonisation of hard- and software, closer cooperation and task-sharing.

KEYWORDS:

Climate applications, Geographical information systems (GIS), ECSN.

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1. Introduction

1.1. General remarks

Substantial advances in deriving information of various kinds from different sources, e.g. climatological networks, remote sensed and other data, has been achieved until now and will become even more important in near future giving more and better spatial resolution and accuracy. Therefore it is mandatory to establish *Digital Data Bases* (*DDB*) at suitable levels (global, European, national, regional) in combination with *Geographic Information Systems* (GIS) to achieve the best possible representation of climate data. Recognising that there exists a considerable lack in that kind of data presentation. GIS technologies flourish but to apply the full possibilities of them their strengths have to be augmented by models and algorithms to integrate imaging technologies with physical knowledge in climatology for a wide range of applications. This will either define a problem more clearly or bring users closer to a solution. From the viewpoint of climate application and research several key topics must be addressable by a GIS (e.g. climate impact due to climate variability and change on regional and local scales, land use and its change, water resources and management, pollution sources and distributions, location and extend of natural or environmental disasters, human health and exposure, agriculture and energy use).

To address these topical areas the *DDB*s should contain the data sets about all kind of climate-relevant data, land use/ land cover, topography, hydrology and soils, air and water quality and economy, demographics and infrastructure.

This implies that these data are multi-disciplinary, have access to classical ground based data networks and have governments endorsement. This ambitious task can be done within reasonable time only by a joint effort of interdisciplinary working groups, adding all their experience and skills to solve the manifold arising problems.

National Meteorological Services (NMSs) are facing in their work many problems arising from the increasing commercialisation and technological development which can be solved easier with the application of GIS tools. Therefore the implementation and operational application of such tools should fulfil objectives as:

- the new techniques together with user-friendly applications are expected that they will make the meteorological products more understandable for users;

- the processing will be faster and more cost-efficient;

- this tools will introduce new products and perspectives for the future, improves productivity quantitatively and qualitatively in the NMSs and can be used in research adequately.

An other important aspect is that the applications will be in some kind standardised by the use of commercial software packages implying that there should be only minor problems in exchanging results and in upgrading new releases. In the operational section this may be of great advantage. Especially within data quality control which should be always on the same high level of accuracy in near and farther future which certainly can not be maintained by frequently changing software products. Further on a stimulus is given to harmonise hard- and software within the participating NMSs together with new experience in closer cooperation and in task-sharing.

1.2. Objectives of the project

Because there exists a broad field of possibilities in using GIS in climatological application it was necessary to focus on certain items which are:

- Inventory and survey of the requirements of the climatological community to achieve successful GIS application
- Inventory of the computer system architecture and GIS software.
- Inventory of products, skills and experience already in existence in the participating NMSs in the field of GIS.
- Asses the needs and potentials in implementing GIS tools at the NMSs (COST719)
- Asses the potentials in harmonisation of the existing hard- and software with the GIS requirements within the NMSs. (COST719)
- Development of user friendly and cost-efficient procedures for visualisation and mapping of different climate variables in time and space which can be used operationally for data quality control and as a general tool for representing climate data.
- Identify specific requirements of the climatological and other related communities to achieve successful applications of GIS.

1.3. Activities in the frame of the project

- Formation of a working group (Austria, Norway)
- Designing and performance of a questionnaire (*"On the status of GIS usage within the ECSN member NMSs"*)
- Evaluation of this questionnaire
- Inventory of spatialisation schemes
- Survey of applications
- Knowledge base exchange on certain GIS application
- Workshop *On the use of GIS within the ECSN community* (Oslo Oct. 13th, 1999)
- Several presentation on GIS applications at different meetings and workshops (e.g. EGS, ECAC2000, Pisa).
- Establishing an information network on GIS use between the NMSs.

2. Some aspects of spatialisation of climatological elements

2.1. Overview

One important task of climatological services is to provide meteorological fields derived from observations, on a daily, monthly, trimestrial or annual timescale, or on an extreme event basis. This is especially necessary to get information there where no observations are available. This raises immediately the problem of data interpolation. A large number of factors, e.g. the topography (height above sea level, orientation of slopes, curvature, etc.), aerodynamic roughness, vegetation coverage, soil types, distance from the sea can influence atmospheric parameters locally.

There are several methods of interpolation schemes, which can be categorized in different ways. One possibility is to consider the variables used to predict the climatological field. This may lead to the following three classes:

i) methods using raw data without any additional information:

Only the information from the observing network is used. Interpolation methods rely generally on the supposed continuity of the analysed fields, and on the distance within which observations remain correlated.

ii) Methods using topographical information as additional information

Meteorological fields are mostly strongly influenced by topography, e.g. rainfall and temperature. The method accounts for any grid point the surrounding topography, originally described by its altitude.

iii) Methods using meteorological information as additional information

Among the methods of this kind is co-kriging and optimal interpolation. Promising methods consist also in using information derived from other techniques of observation (e.g. interpolation of rainfall as measured by rain gauges taking into account the structure of precipitation fields derived from radar). Also analyzed fields (synoptic maps) used in weather forecasting models can be applied as co-variables in such approaches (Häggmark et al., 1997).

Another way to categorize spatial interpolation methods is to consider the mathematical foundation of the method, as in Figure 2.1 (Bourroughs, 1986).

Principles of Geographical Information Systems for Land Resources Assessment — P. A. BURROUGH

Table 8.3 A comparison of methods of interpolation

Method	Deterministic/ stochastic	Local/ global	Transitions abrupt/ gradual	Exact interpolator	Limitations of the procedure	Best for	Output data structure	Computing load	Assumptions of interpolation model
'Eyeball'	Subjective/ deterministic	Global	Abrupt	No	Non-reproducible, subjective	Field data, aerial photo interpretation	Polygons	None	Intuitive understanding of spatial processes; homogeneity within boundaries
Edge-finding algorithm	Deterministic	Global	Abrupt	No	Often requires shapes to be defined and stored; better for man-made features than for natural landscapes	Raster images from remote sensors	Raster	Moderate	Homogeneity within boundaries
Proximal (Thiessen poly)	Deterministic	Local	Abrupt	Yes	One data point per cell; no error estimates possible; tesselation pattern depends on data point distribution	Nominal data from point patterns	Polygons	Light/ moderate	'nearest neighbour' gives best information
Trend surface	Stochastic	Global	Gradual	No	Edge effects, outliers, complex polynomials do not necessarily have meaning; errors are rarely spatially independent.	Demonstrating broad features and removing them prior to other methods of interpolation	Points on a raster	Light/ moderate	Multiple regression phenomenological explanation of trend surface; independent Gaussian errors
Fourier series	Stochastic	Global	Gradual	No	Not applicable to data; lacking periodicity	Periodic features such as sand dunes, ripple marks or gilgai, or man-made features	Points on a raster	Moderate	Strict periodicity in phenomenon of interest.
B-splines	Deterministic	Local	Gradual	Yes	No estimates of errors; masks all uncertainties in surface	Very smooth surfaces	Points on a raster	Light/ moderate	Absolute smoothness of variation
Moving average	Deterministic	Local	Gradual	No unless constrained	Results depend on configuration of data points and size of window; simple versions assume isotropy; no error estimates unless retrospectively calculated	Quick contour plots of moderately smooth data.	Points on a raster	Moderate	Continuous, differentiable surface is appropriate
Optimal interpolation (kriging)	Stochastic	Local	Gradual	Yes	Practical and theoretical problems of non-stationarity in data; large computing costs for mapping	Situations where the most detailed estimates and their errors are required	Points on a raster	Heavy (very heavy for universal kriging)	Intrinsic hypothesis (homogeneity of first differences); average local values can be represented by a continuous surface.

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Figure 2.1: Classification of different spatial interpolation schemes (after Burroughs, 1986)

2.2. Interpolation methods

As indicated in the previous chapter there is a number of different concepts approaching the problem of deriving a continuous description of climatological fields. They are all based on theoretical considerations, assumptions and conditions which must be fulfilled in order to use the method properly. Therefore, when selecting a spatial interpolation algorithm, the purpose of the interpolation, the characteristics of the phenomenon to be interpolated and these constraints have to be considered. With this in mind the methods can be divided into four classes:

i) Mathematical methods:

These methods are characterized by using only geometric or polynomial characteristics of a set of point observations to create a continuous surface. Inverse distance weighting (IDW) and curve fitting methods like spline functions belong to this class. The methods are exact interpolators, by the fact that observed values are retained at points where they are measured. While IDW always will have the same parameterisation, polynomial methods fit to the properties of the actual in-situ point observations to form a continuous surface that goes through these values.

ii) Deterministic methods:

These methods are based upon a known relation between an in-situ observation (predictand) and attached observations of other variables (predictors). This relation is often based on empirical knowledge between the predictand and the predictor. The empirical relation can be found by both physical and statistical analysis, and is frequently a combination where a statistical relation is derived from observations based on the knowledge of a physical process. Statistical methods like linear regression are often used to establish such relations. The deterministic approach is stationary in time and space and must therefore be regarded as a global method reflecting the properties of the entire sample. The predictors may be both physiographic parameters or other observed variables.

iii) Stochastic methods:

These methods allow the variance, or since it is a spatial problem, the spatial co-variance to be included into the interpolation process. These methods, to which geostatistical methods like kriging and objective interpolation (Gandin, 1963) belong, are usually based upon a model of the spatial co-variance or correlation structure. These methods demand that certain statistical assumptions are fulfilled as e.g. should the process follows a normal distribution, is it stationary in space, is it isotropic, etc.

iv) Physically based methods:

The most advanced models are physically based models, including e.g. a description of the dynamics of the atmosphere. Such models require a high computer capacity and are not very suitable for climatological mapping. Weather forecasting models belong to this class. The method is mentioned here because it also has future possibilities within climatological monitoring. There also exist some application where output fields from such models form the first guess of a field for objective interpolations (e.g. the Swedish mesoscale analysis system MESAN (Häggmark et al., 1997)).

In the following methods frequently used in climatological mapping are presented.

2.2.1. Mathematical models.

Inverse distance weighting (IDW)

Inverse distance weighting is a pure mathematical method. It is based on the distance between points of observations and the point to be interpolated. It is an advanced nearest neighbours approach, allowing a number of neighbouring stations to be included in the estimation of interpolation weights. The closest stations will get a larger weight than stations further away. The "cut-off" criterion may be maximum distance or maximum number of points. The latter is the most common. Mathematically the *IDW* can be expressed as:

$$Z_j^* = \frac{\sum_{i=1}^{n} \frac{Z_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{n} \frac{1}{h_{ij}^{\beta}}}$$

where: Z_j^* = estimated value in point j;
Z_i = value in point I;
i = index (coordinate) for neighbouring points;
j = index (coordinate) for point to be estimated;
h_{ij} = the distance between point to be estimated (j) and neighbouring points (i);
β = the weighting power.

Spline functions

A spline function is a polynomial function describing a surface going through all observation points. This is also a pure mathematical expression. In ArcINFO one SPLINE option uses the following expression to estimate the surface (ESRI, 1997):

$$Z_j^{*} = T_j + \sum_{i=1}^{n} \lambda_i R(h_{ij})$$

with

$$T_j = a_1 + a_2 x_j + a_3 y_j$$

$$R(h_{ij}) = \frac{1}{2\pi}\left\{\frac{h_{ij}^2}{4}\left[\ln\left(\frac{h_{ij}}{2\tau}\right) + c - 1\right] + \tau^2\left[\kappa_0 \frac{h_{ij}}{\tau} + c + \ln\left(\frac{h_{ij}}{2\pi}\right)\right]\right\}$$

where: τ = weight parameter which produces smoother surfaces;

κ_0 = modified Bessel function;
c = a constant (0.577215);
$a_1,..a_3$ = coefficients calculated by solving a linear equation system.

The smoothing parameter is added to ensure smooth surfaces. If this parameter is not used, the resulting surfaces will tend to have a wave patterns in order to fulfill the criterion of exact interpolation. It may result in very strange results and invalid values can be obtained.

2.2.2. Deterministic models.

To establish empirical models relations between the behaviour of one process (the predictand) is explained as a function of one or more other variables (called predictands). The choice of these predictands is usually based on the knowledge of the physiccal background of the process or on a statistical analysis. The most used method to express such relations is linear regression.

Linear regression

The purpose of linear regression is to express the relation between a predictand and one ore more predictors. In its simplest form it can be used to fit a straight line through points scattered in a plane to form a realtion between x and y. This may be expressed as:

$$Y = a + bX$$

where a and b are the parameters describing the empirical trend line. These parameters can easily be found by least square estimation.

If the process Y is complex, more predictors may be necessary to find the empirical expression with sufficient degree of explanation. This multiple linear regression looks like:

$$Y = a + \sum_{i=1}^{n} b_i X_i$$

The parameters a and b_i can also be estimated by the least square method. To use a regression the assumption of unbiased parameter etimators has to be fulfilled. Regression can be used directly in spatial modelling (e.g. by including the position as predictors). The PRISM approach (Daly et al.1994) is an example of such an approach applying terrain characteristics in precipitation mapping. Regression is also frequently used to define trends to be used in detrended kriging (see next section).

2.2.3. Stochastic methods

Stochastic methods for spatial interpolation are often referred to as geostatistical methods. Common to these methods is that they use a spatial covariance function to describe the spatial coherence as a function of distance (often called the spatial structure function). The interpolation itself is closely related to regression in the way that it is expressed as a linear sum of weighted observations:

$$\hat{Y}_0 = \sum_{i=1}^{n} \lambda_i Y_i + \varepsilon$$

where $\lambda_{1,\dots,n}$ are the interpolation weights estimated from the spatial structure function (e.g. variogram; see below). ε is an error term describing the estimation uncertainty which is attached to the model. This description of the uncertainty is one of the major advantages using the stochastic approach.

The most used of these approaches is *kriging* but also others, like the optimal interpolation (Gandin, 1963) are frequently applied in the atmospheric sciences.

Other approaches that belong to stochastic methods are multivariate methods like the principal component analysis and its "relative" the method of empirical orthogonal functions (see end of this chapter).

Kriging

Although Kriging used for mapping is not significantly better than other deterministic interpolation techniques accounting for spatial anisotropy, but is broadly used and applied. Here the "classical" approach will be is described. The algorithms with computer program codes can be found e.g. in the GSLIB (Deutsch et al. 1992).

In the following sections, algorithms for mapping a data field of a certain (climate) parameter should be considered only as a step by step help how to apply a geostatistical method for spatial interpolation like kriging. For certain cases or applications another approach may be more appropriate but the following is widely applied in this context. Here the characterization of the *variogram* model and the use of the kriging error variance as a measure of estimation accuracy is emphasized.

Evaluation of the Experimental Variogram (EV)

The variogram is a measure of spatial variability and is such a key to any geostatistical study. Mathematically the variogram is formulated as :

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i,j=1}^{N(h)} y_i - y_j$$

where $\gamma(h)$ is the semivariogram, $N(h)$ is the number of observations within the distance lag, and j are indexes of the observations. In Figure 2.2 an example of a variogram is presented.

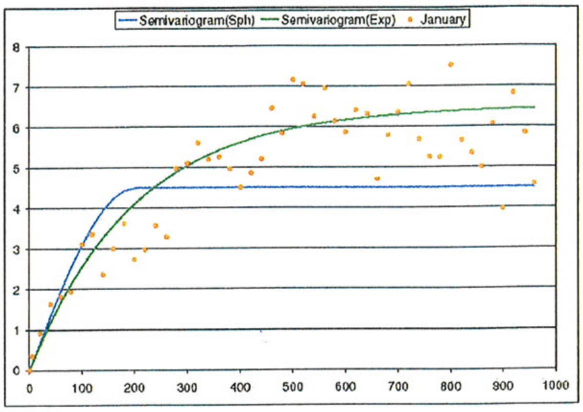


Figure 2.2 Example of an experimental variogram (*EV*, the dots), with two fitted theoretical variogram (*TV*) models (spherical and exponential). (Detrended mean monthly January temperatures in Fennoscandia, from Tveito et al. 2000).

The *EV* is a convenient tool for the analysis of spatial data because it is based on a simple measure of dissimilarity. The average dissimilarity of a regionalized variable with respect to separation - the *EV* - is obtained from the variogram scatter (dissimilarities computed from pairs of sample as squared difference between the values, are plotted against the separation of sample pairs in geographic space). This scatter is subdivided into classes according to the separation in space and an average for the dissimilarities for each class is computed. Such the *EV* is powerful in identifying special features in the spatial data (usually it can be observed that the average dissimilarity between values increase when spacing between the pairs of sample plots increases too). One has here to consider the following parameters and procedures:

Lag and direction parameters

- Lag spacing, lag tolerance
- Direction vector, direction tolerance

Spatial continuity analysis

- Detection of data clusters, trends, discontinuities and other features
- Finding the directional anisotropy in the variogram.

With the already mentioned GSLIB the following ten experimental measures of spatial variability can be computed:

- Semivariogram
- Cross-semivariogram
- Covariance
- Correlogram
- General relative semivariogram
- Pair wise relative semivariogram
- Semivariogram of logarithms
- Semirodogram
- Semimadogram
- Indicator semivariogram

Defining a Theoretical Variogram (TV).

The *EV* is replaced by a set of *TV* functions to give the variogram model a physical meaning. The *TV* is defined by the *intrinsic hypothesis*, which is merely a statement about the type of stationarity characterizing the random function.

The basic models are

-Spherical model
-Exponential model
-Gaussian model
-Power model.
-De Wijsian model
-Linear Model

the parameters of a *TV* are:

-Sill (the level of variance explained by the spatial model, total variance is described by sill + range)
-Range (the largest influence distance of the model)
-Nugget effect (describes the a discontinuity at h=0, e.g. due to measure uncertainties).

A combination of different basic models (nested variogram) can be fitted to the *EV* with the criterion that the resulted variogram is positive definite (in fact, the covariance must be positive definite to ensure existence and uniqueness of solutions of the kriging equations).

Kriging interpolation

Kriging is the final step in the interpolation and is used to estimate a value at a point or a grid cell in a region for which a variogram is known, using data in the neighborhood of the estimation location. It comprises a collection of generalized linear regression techniques for minimizing an estimated variance derived from a selected model for spatial variability (variogram). In the following list the main Kriging algorithms are given.

- **Simple kriging** (*SK*): requires an a-priori knowledge of the stationary mean of random variable (*RV*)
- **Ordinary kriging** (*OK*): is the most commonly used variant of kriging; *OK* filters the mean from the SK estimator by requiring that the kriging weights sum to 1.
- **Kriging with a Trend Model, universal kriging, detrended kriging, residual kriging** (*KT*): Kriging with a prior trend model, the ***random function*** (*RF*, a set of random variables defined over some field of interest; should be specified by the physics of the problem) is modelled as a sum of trend component (drifts) plus a residual. The trend component is usually modelled as a smoothly varying deterministic function and the residual as stationary *RF* with zero mean.
- **Kriging the Trend:** Estimates only the trend component of *RF*; this can be interpreted as a low-pass filter that removes the random (high frequency) component.
- **Kriging with an External Drift** (an extension of *KT*): is a simple and efficient algorithm to incorporate a second variable in the estimation of the primary variable where the trend model must make physical sense. The secondary (external) variable must satisfy 2 conditions before applying the algorithm:

  - must vary smoothly in space, otherwise the results may be unstable;
  - must be known at all locations of the primary data values and at all locations to be estimated.
- **Factorial Kriging** (*FK*): Here the *RF* model is considered as a sum of 2 or more independent stochastic components (also called "factors" in relation to factor analysis), rather than splitting the *RF* model into a deterministic trend plus a stochastic component as in the *KT*.

- **Indicator Kriging** (*IK*): provides a least-squares estimate of the *conditional cumulative distribution function (ccdf)* at given cut-off values. The *ccdf* is built from assembling the *IK* estimates; the *IK* represents a probabilistic model for the uncertainty about the unsampled value.
- **Indicator Pricipal Component Kriging** (*IPCK*): consists of kriging the principal components of the indicator covariance matrix defined at some separation vector, usually taken as zero or as a very small distance.
- **Soft kriging: the Markov Bayes Model:** is an extension of *IK* to incorporate supplementary information of different types.
- **Block Kriging:** Estimation of an average (block) value of a variable instead of a point value within a certain local area (block). It allows sensitivity analysis of the impact of the variogram models at shoprt scale.
- **Cokriging** (*coK*)**:** The term "kriging" is traditionally reserved for linear regression using data on the same attribute as that being estimated; the term "cokriging" is reserved for a linear regression that also uses data defined on different attributes. There are three most commonly used types of *coKs*: traditional *coK*, standardized *coK* and simple *coK*.
- **Indicator Cokriging** (*coIK*): It considers all indicator data for the estimation of each *ccdf* value.

AURELHY

Meteorological fields are strongly influenced by topography, which is the case very often with rainfall. The AURELHY method (Benichou, 1986) accounts for any grid point the surrounding topography, originally described by its altitude. This information is then condensed and reduced to the first principal components, which allow to describe schematically how local topography is structured. These are calculated to find explicative variables, which allow to derive the field under consideration from topographical parameters using a linear multiple regression. The part of the field that is not explained by topography is then interpolated using kriging techniques, and the result is finally obtained as the sum of the two components. It is worth to mention that such methods based on statistical relationships DO NOT apply on an event basis.

In the Annex in Table 1 a compilation of spatial interpolation schemes frequently used in climatology which are well documented in the appropriate literature are given.

Principal component analysis (PCA)/ Empirical orthogonal functions (EOF)

These methods decompose a number of correlated observations into a new set of uncorrelated (orthogonal) functions. These functions will contain the original variance of the observations, and the original observations and the functions are linked through a set of loadings, which are unique for each of the original observations. The new functions, or *principal components*, are ordered such that the first component is the one explaining most of the variance, the second component the second most share of the variance and so on. Usually most of the variance is explained by a few components, and the methods are therefore also often used to reduce noise from an observed field (e.g. in remote sensing problems).

These methods is frequently used for classification and filtering purposes since the resulting components/functions describe typical patterns of the observed process. But they can also be used for interpolation purposes, e.g. by directly interpolating the loadings (Hisdal and Tveito, 1992), or by include the *EOF* in a detrended kriging approach as in the AURELHY method.

2.2.4. Validation

Validation is a key topic whenever performing spatial interpolation. Beside a number of statistical measures, *cross validation* is a simple and effective quantitative and/or qualitative tool to compare various assumptions either about the models (e.g. the type of variogram and its parameters, the size of kriging neighborhood) or about the data, using only the information available in the given sample data set. *Cross validation* offers quantitative insights in how any estimation method performs. So an analysis of the spatial arrangement of the residuals often suggests further improvements of the used estimation model. *Cross validation* is carried out by taking one observation out of the sample, and estimate it based on the remaining observations. This is done step by step until all observations in the sample are estimated based on the respective others. Then the residuals between the observed and estimated values can be further analyzed statistically, or can be mapped.

3. Examples of Applications

In this chapter some examples of the manifold use of GIS among the ECSN member institutions are presented. They cover a wide variety of applications, spatial analysis, data management and visualisation, and they are thereby giving a good description of the different facets of applying a GIS.

3.1. Snow accumulation maps

For about 50 years, the Norwegian meteorological institute (DNMI) has produced "snow accumulation" maps for Norway. These show the accumulated total precipitation during the winter season from a stable snow cover started and until fixed dates (31.01, 28.02, 31.03, 30.04) as a percentage of the normal (1961-90) accumulated precipitation. The maps are traditionally presented for three different altitude levels, and the start of the snow season is determined for each individual year. The presentation has a long tradition since it started in 1950. The way the information is given is based upon these traditions and how such maps could be produced before the age of computers and geographical information systems.

Since the winter season 1996-97 these maps have been produced in a GIS (ArcINFO). The application is an AML(Arc Macro Language)-script, also including FORTRAN-programs and UNIX-system commands. It consists of the following steps:

1. Interpolation of missing values. The application is using observations from both the synoptic and climatological stations, and since the climatological stations are not reporting in real time (up to 10 day delay), interpolations are always needed for the last 5-10 days. Weekly precipitation sums are interpolated as percent from the monthly normal precipitation for that particular month. The interpolation algorithm used is TOPOGRID in ArcINFO.
2. The observed values are copied to a temporary ORACLE database table, and in case of missing values the interpolated values from step 1 is used.
3. Accumulated precipitation as percent of normal precipitation accumulation from the first day of stable snow cover is calculated for 108 typical regions in Norway for three altitude levels (400, 800 and 1200 m a.s.l.)
4. Based on values for these 108 regions, maps are derived by using the TOPOGRID algorithm in ArcINFO.
5. The final maps are distributed on paper, via Internet (on the commercial Web-service of DNMI as JPEGs, EPS-files and TIFF-images) and as digital maps (ArcView shape files).

Since 2000 the maps are produced every second week from mid-January until the end of April.

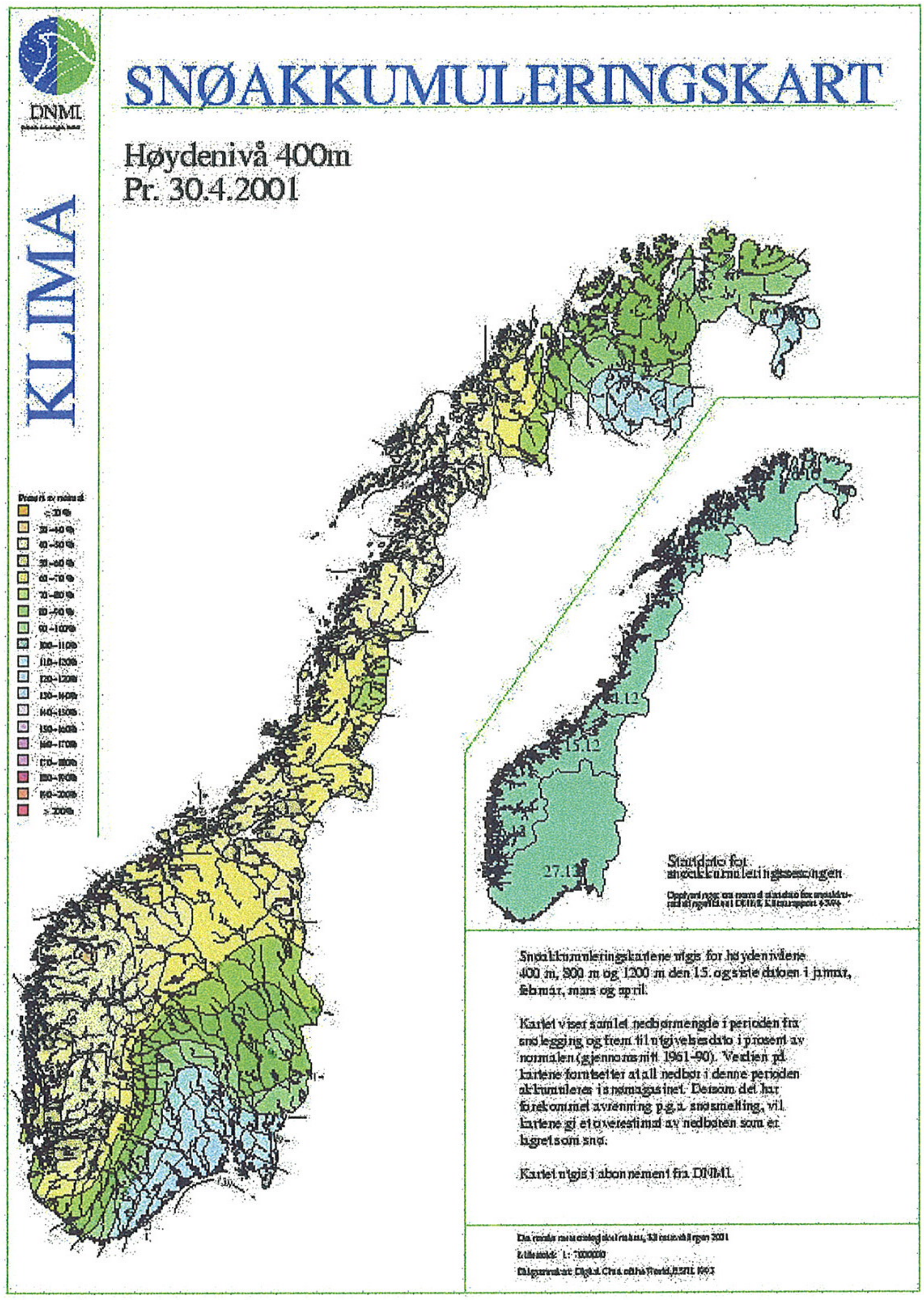


Figure 3.1 An example of DNMI snow accumulation map for Norway, representing altitude levels below 400 m a.s.l. The large map shows the precipitation accumulated in the period with stable snow cover as percent of the normal precipitation accumulation in the period 1961-90. Blue and red colours are representing accumulation above the normal, green, yellow colours are representing values below. The small map shows the start of the snow accumulation period for the current accumulation season.

3.2. Nordic temperature maps (NORDKLIM).

The Nordic temperature maps (Tveito et al, 2001) are a result of the NORDKLIM-cooperation between the Nordic NMSs. These maps show the mean monthly, seasonal and annual temperature for the period 1961-90. The maps are derived by the use of detrended kriging. Five independent predictors defined the external trend: altitude at the station, mean altitude within a 20km radius, lowest altitude within the same distance, longitude and latitude. The trend was defined independently for each month, based on monthly mean temperatures from almost 1250stations in Denmark, Finland, Norway, Sweden and Iceland by using multiple linear regression. Iceland was analyzed separately from the Fennoscandia region. The analysis showed a clearly defined variation in the significance of these five variables throughout the year. The trend was removed from the observations, and the residual was interpolated applying kriging. The seasonal and annual maps are derived from the monthly maps. Figure 3.2.1 shows the mean annual temperature in the Nordic countries in 1x1 km^2 resolution.

The monthly maps are the background for maps of temperature seasons and degree day maps. Daily normal temperatures can be estimated by applying a cubic spline function through the twelve monthly values. These is done for each grid cell, resulting in maps as shown in the figures 3.2.2 and 3.2.3, with the length of the growing season as areal distribution functions (Figure 3.2.2) and as a map (Figure 3.2.3).

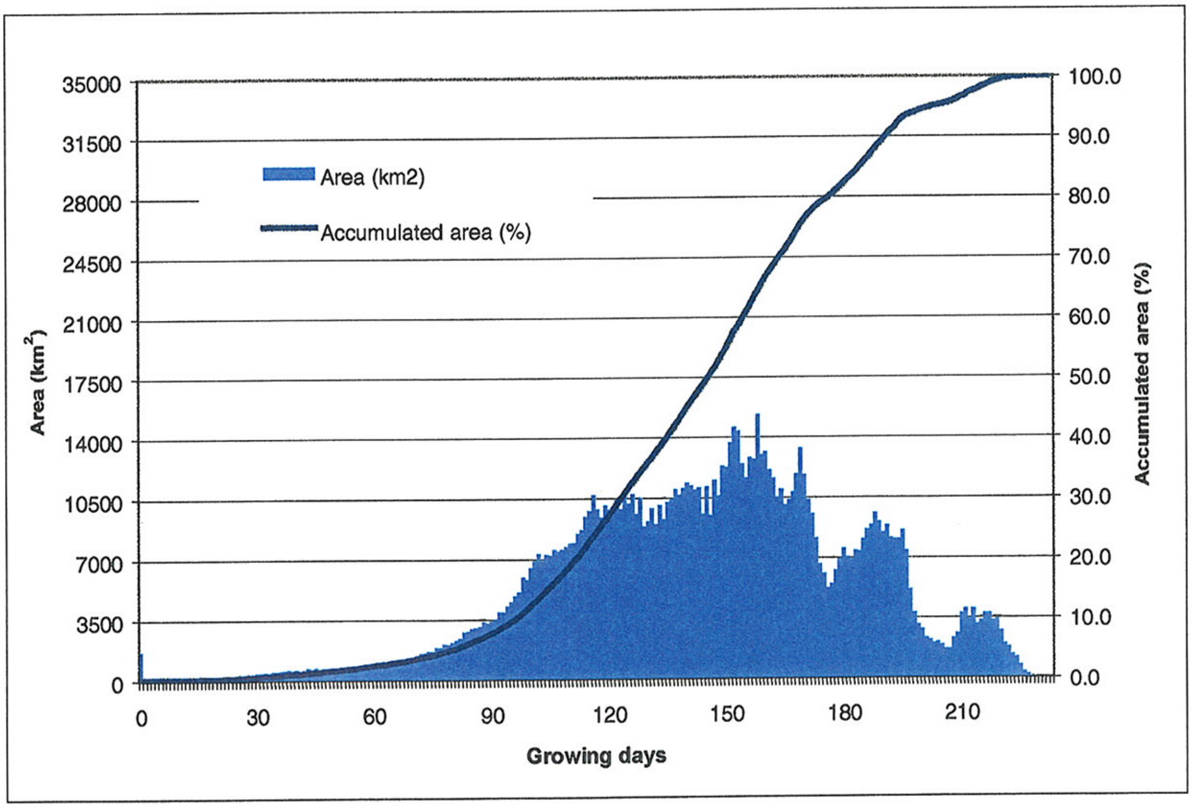


Figure 3.2.2: The areal distribution of number of growing days (>5°C). From Tveito et al.(2001).

Mean annual temperature 1961-90

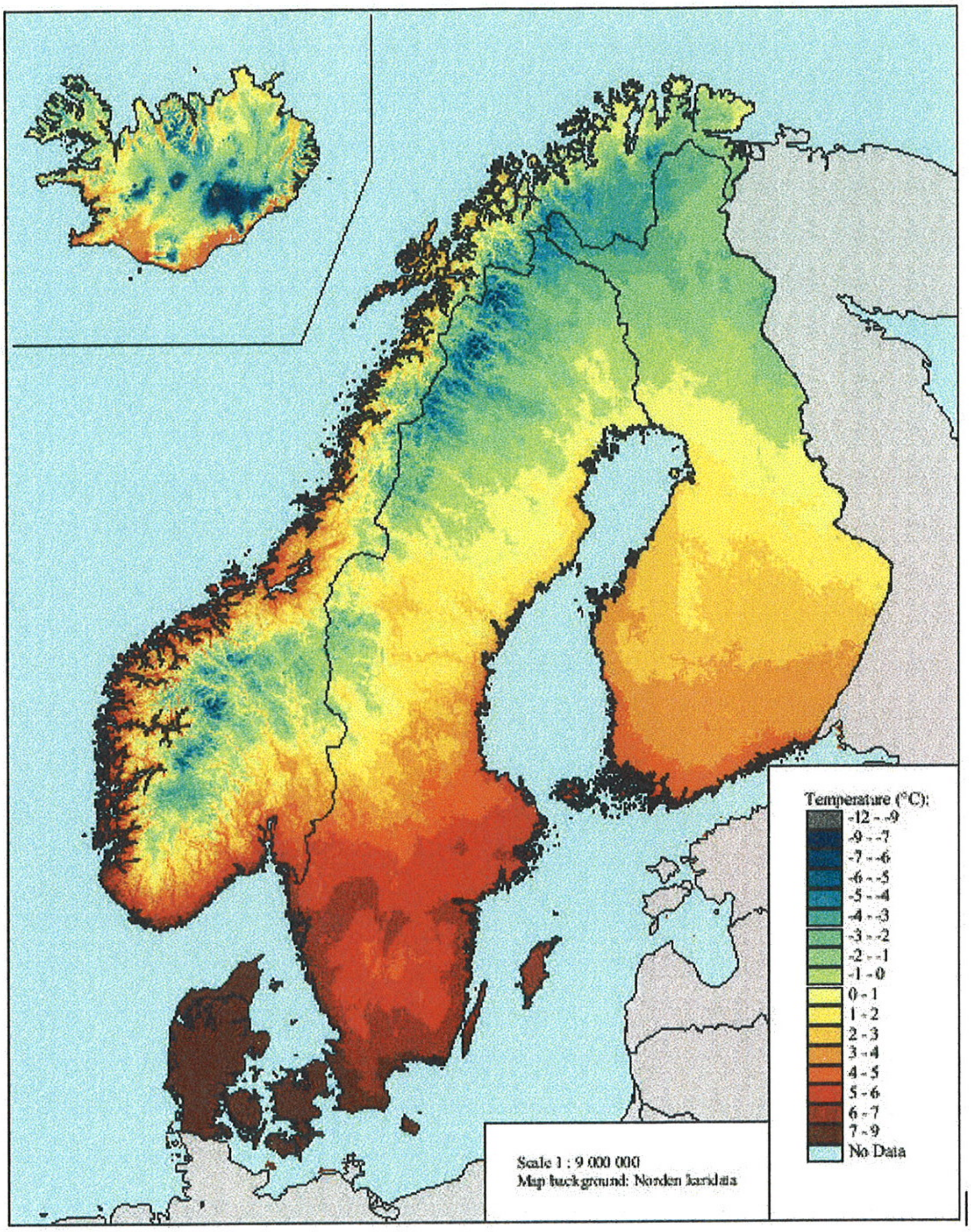


Figure 3.2.1 Mean annual temperature 1961-90 in the Nordic countries (Tveito et al., 2000)

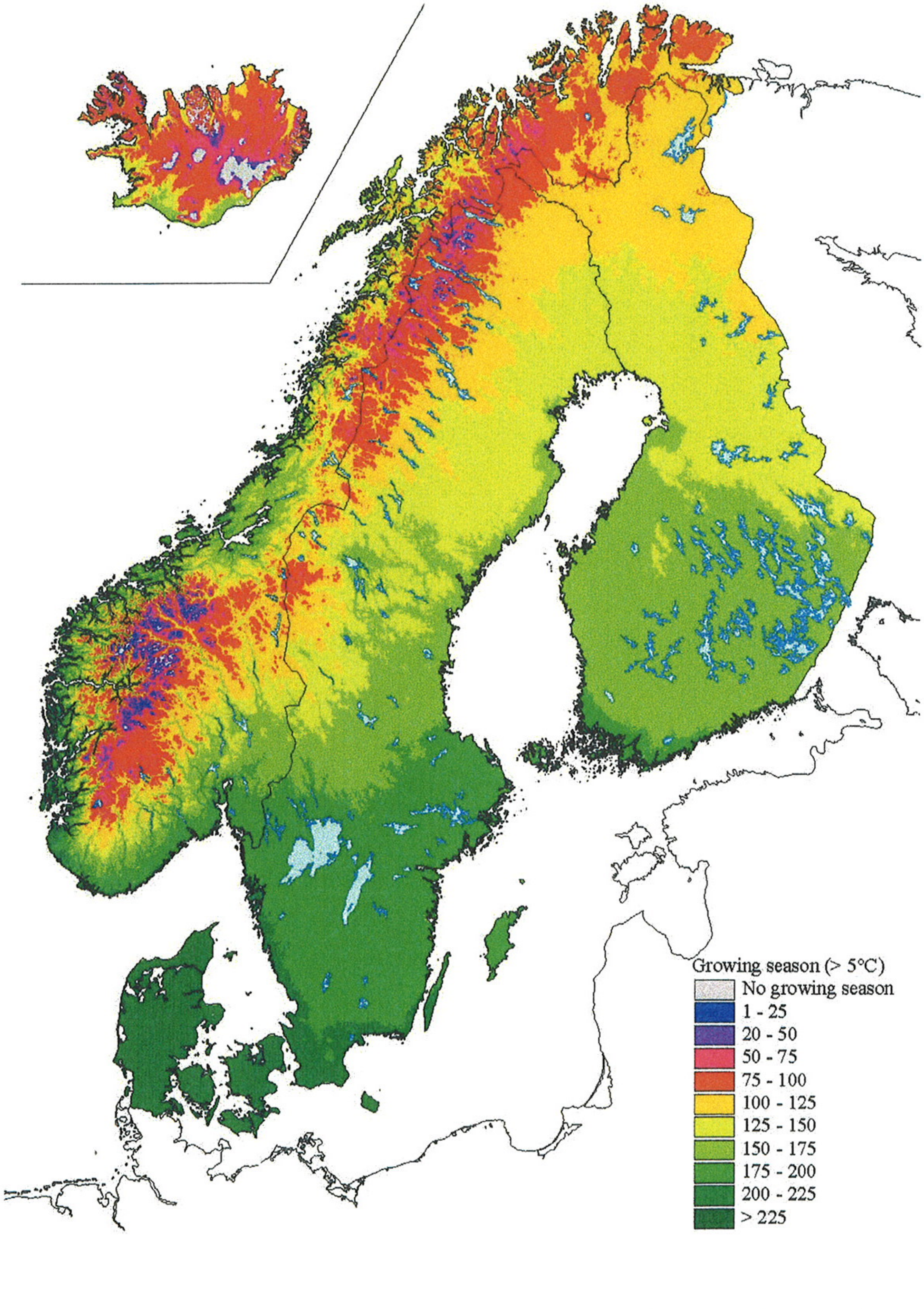


Figure 3.2.3: Mean number of growing days (>5°C) 1961-90 in the Nordic countries (Tveito et al., 2001).

3.3. Finnish climate maps

The maps in this example are established by using ordinary kriging, with support of the physiographical parameters topography, lake and sea percentage. ArcView is used to present the final maps.

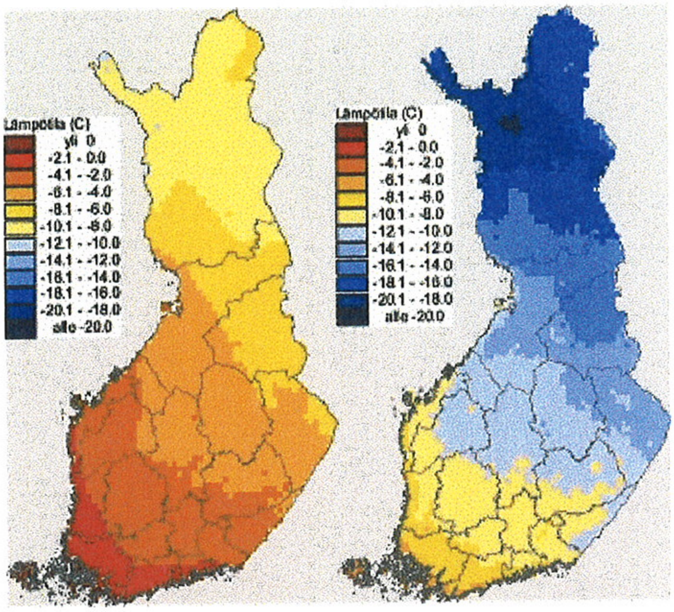


Figure 3.3.1 December monthly mean maximum (left) and mean minimum (right) temperatures in Finland 1961-90.

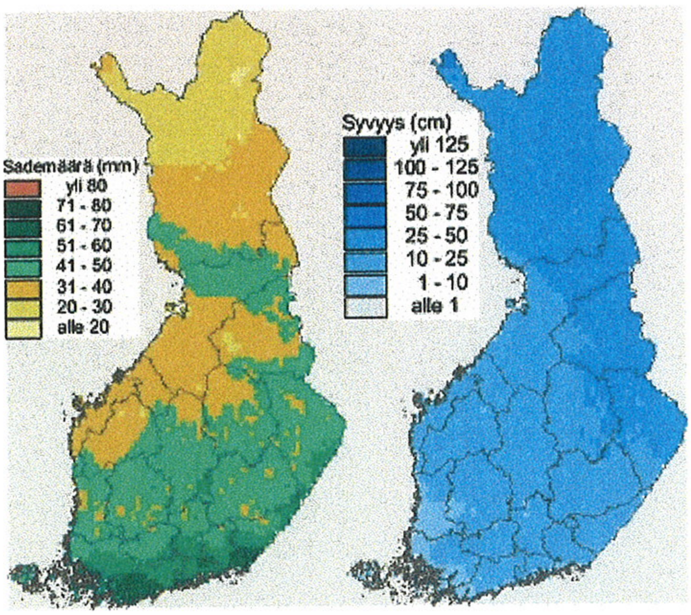


Figure 3.3.2 December monthly mean precipitation 1961-90 (left) and mean snow depth on 15. December (right).

3.4. Precipitation map analysis

In connection with the analysis of climate normals 1961-90 of Sweden (Raab & Vedin, 1995), a system was worked out for gridding precipitation values. This system includes the effect of increased precipitation with altitude.

Local height coefficients were established based on an extensive data set of Swedish precipitation normals 1961-90 (Alexandersson et al., 1991). A monthly regression analysis was performed for each cell in a grid with a resolution of 1°x1°. A smoothing algorithm was applied afterwards. The system uses a digital terrain model with a resolution of 5 x 5 km covering Sweden, and the grid precipitation value is estimated from the nearest stations and the relative difference between these and the grid cell applying a Gaussian weighted distance function. The resulting grid is post-processed in a GIS for map layout and presentation.

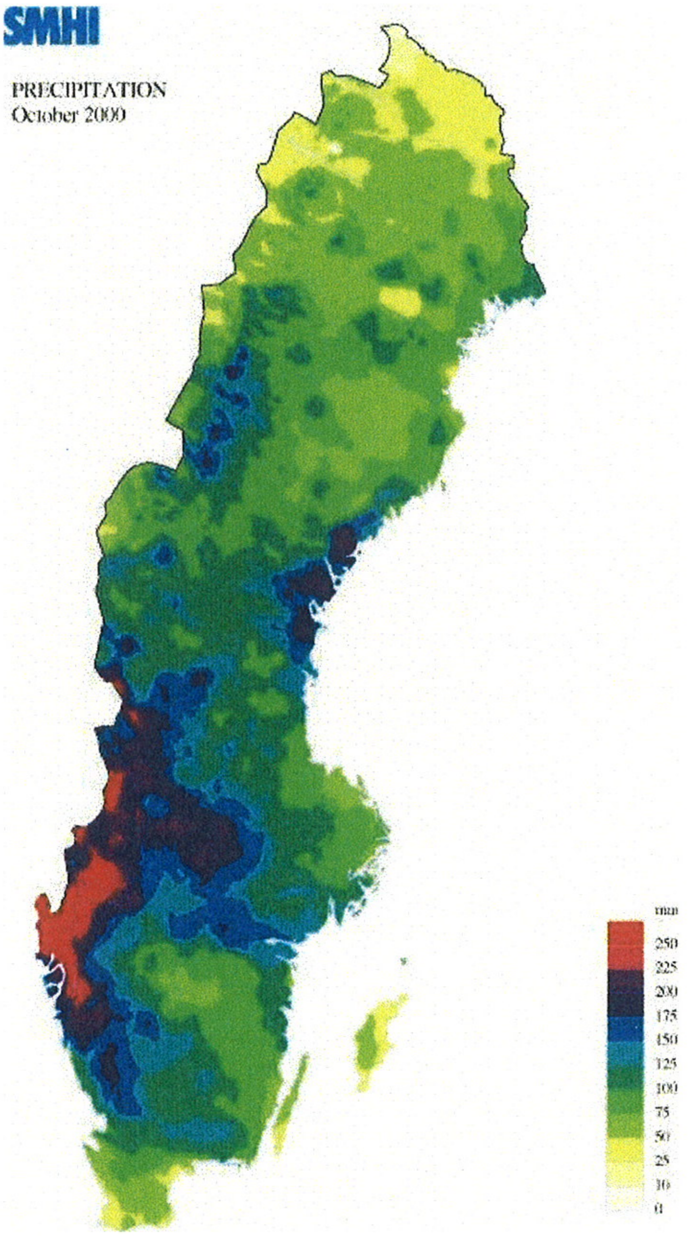


Figure 3.4 Automatically generated map of precipitation in Sweden October 2000 (from Dahlström, 2001).

3.5. GEKIS, a data quality management and visualisations system on climate data sets based on the desktop GIS

The Geographical Climate-Information-System **GEKIS** was developed at the ZAMG, Vienna/Austria, in order to improve data quality by combining the classical computer aided controlling with a modern visualization and information tool. GEKIS was set up on the client side by PCs under WINDOWS/NT 4.0. The tabular data representation and treatment is performed with Microsoft ACCESS which is connected over ODBC (Open Database Connectivity) with Sybase data bases (SUN servers under Solaris 2.6) within a LAN (Local Area Network) as well as a WAN (Wide Area Network). The graphic and spatial representation and treatment takes place with the desktop GIS ArcView, which communicates by DDE (Dynamic Data Exchange) with ACCESS and other programs.

The storage of the data is done within a four-table-structure (original-, final-, flag- and suggested values) in SYBASE data bases as well as in ACCESS. The original table holds all original values and editing and changing these values is not allowed. The final table is for data processing, the flag table describes the final values (original, incorrect, completed) and the suggestion table supports the editing of missing or incorrect values.

The climatological data sets are linked with a DEM (Digital Elevation Model), satellite images, radar images, lightning data and additional geographical information as roads, rivers, boundaries.

In the *Start window* a username and password is required because the write-access on the database is user dependent (e.g. different users check different geographical regions). The user has to select the time (*Zeitstempel, "timestamp"*), the table (*Tabellenname*) and the meteorological elements (up to five are possible at once) to be edited. Checking routines can be started from this window. These datasets are stored locally in Access and all further changes will be done to this local dataset. At the end of the edit session the changed data will be written back to the SYBASE -Database. The button "*Editieren*" opens the *Edit window* (Figure 3.5.1).

GEKIS provides three possible ways of checking data manually. In the first one the data can be seen in the following figure for all locations one is allowed to work with for one "timestamp". The lowest row is the edit row, where the values of the selected station can be edited.

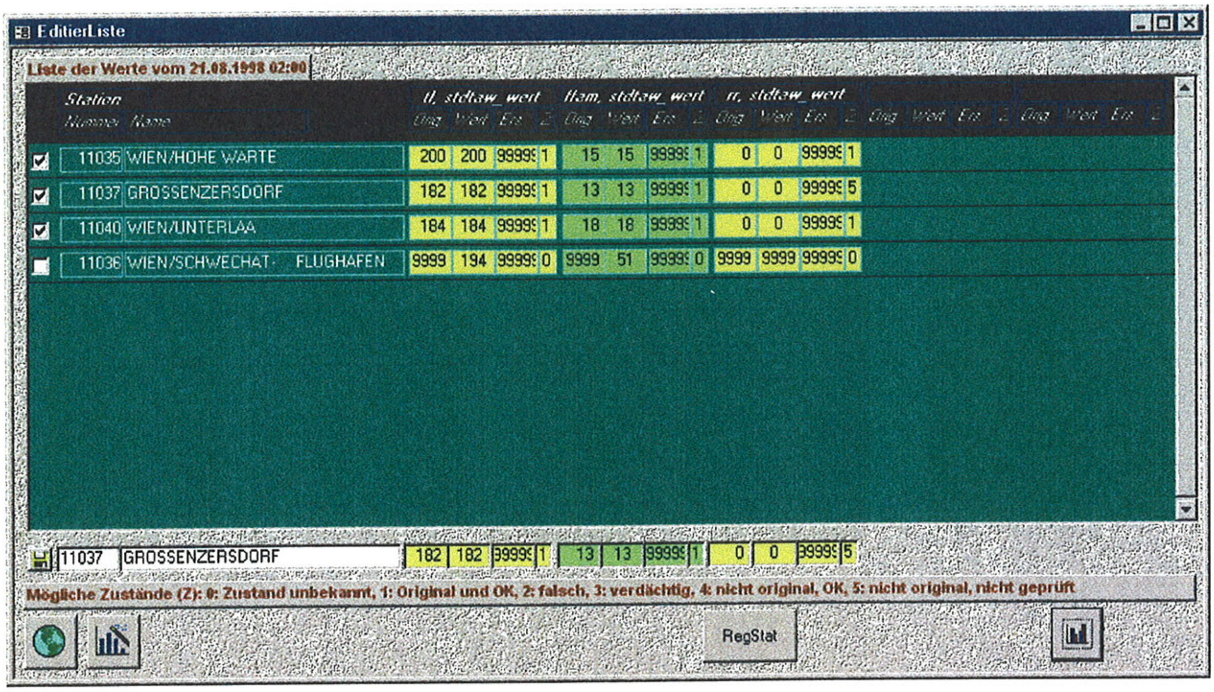


Figure 3.5.1: The *Edit window* of GEKIS (Potzmann, 1999)

The second way of manually handling is to check the time series of up to seven stations at once in the *Chart window* (Figure 3.5.2). Here the values can be edited by keyboard input in the edit row or by drag & drop in the chart. This is a good way to add some missing values of a station if there are one or more comparable stations with complete time series available. It is also a good visual error check.

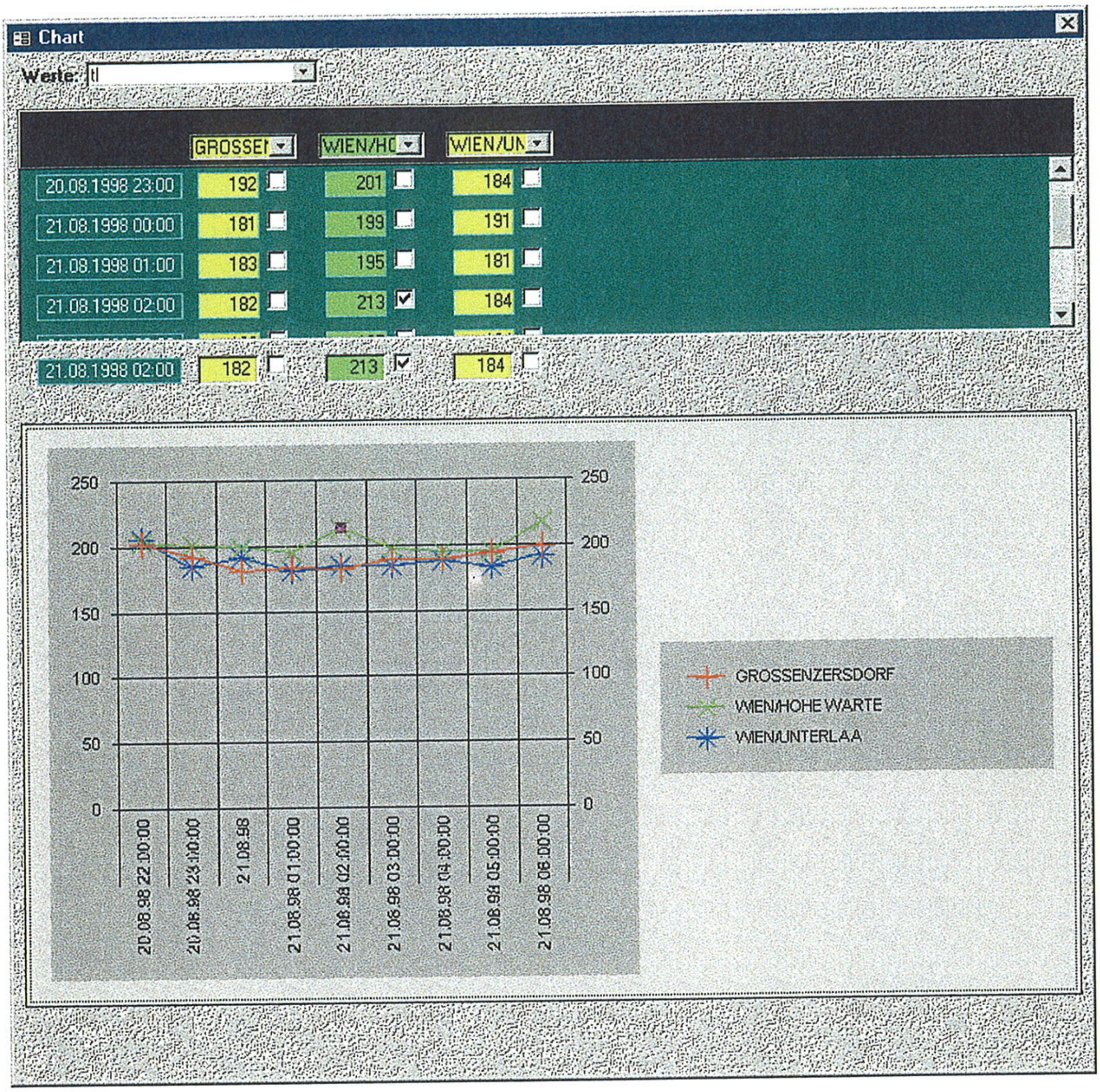


Figure 3.5.2: The *Chart window* of GEKIS (Potzmann, 1999)

The third way is to check data for one timestamp in a geographical overview with additional background information in ArcView

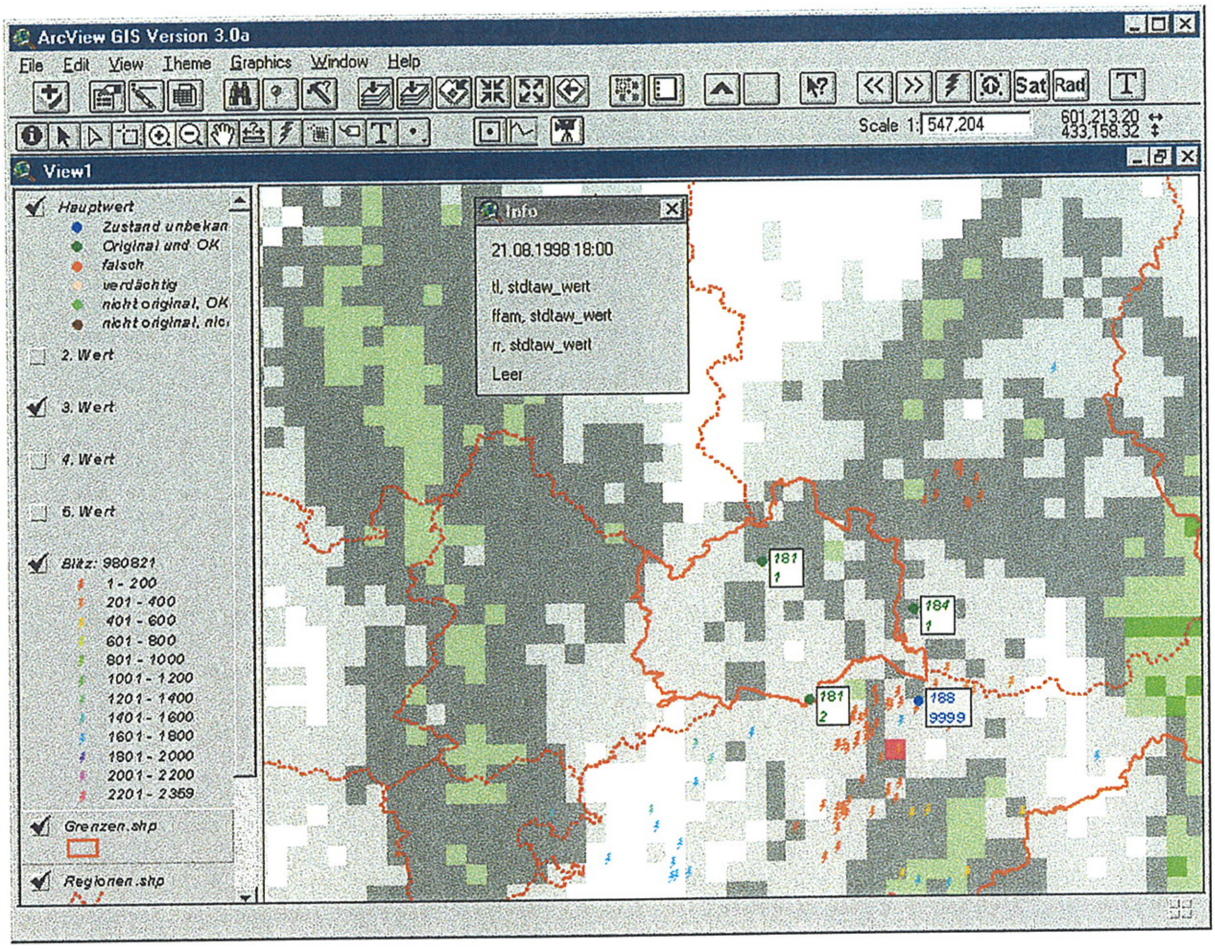


Figure 3.5.3: Example of the ArcView window of GEKIS (Potzmann, 1999)

In this window one can see the stations with the values of the selected elements (colour depends on the flag value), geographical information (borders, rivers, digital maps, DEM), meteorological image information (satellite images, radar images) and other meteorological information like model outputs (e.g. ECMWF), lightning detection system, etc. As an example of the ArcView window of GEKIS in Figure 3.5.3 the combination of station data (air temperature, hourly precipitation sum), a radar image and lightning data for a situation with heavy thunderstorms are shown.

GEKIS is open to many possible extensions, because it works with tabular-, point-, vector-, raster- and image data.

3.6. REGIS

The aim of the REGIS project in Austria is to make available weather-charts for experts as well as for customers. Only a limited number of points of forecast-data are available and can be shifted to an area. This allows a complete delineation of forecast data for the registered area – Austria and adjoining countries. REGIS is to be seen as a tool for the elaboration of charts based on a GIS software ArcView application. The calculation of temperature- charts is based on the values of forecast- data of ZAMG's ECWMF-MOS data for about 120 stations spread all over Austria. The capacity of interpolation could be extended also abroad by including selected foreign SYNOP stations, for which ECMWF-MOS temperature forecast are being calculated. Additionally, for an accurate interpolation of an area structured like Austria a *DEM* (digital elevation model) is necessary too.

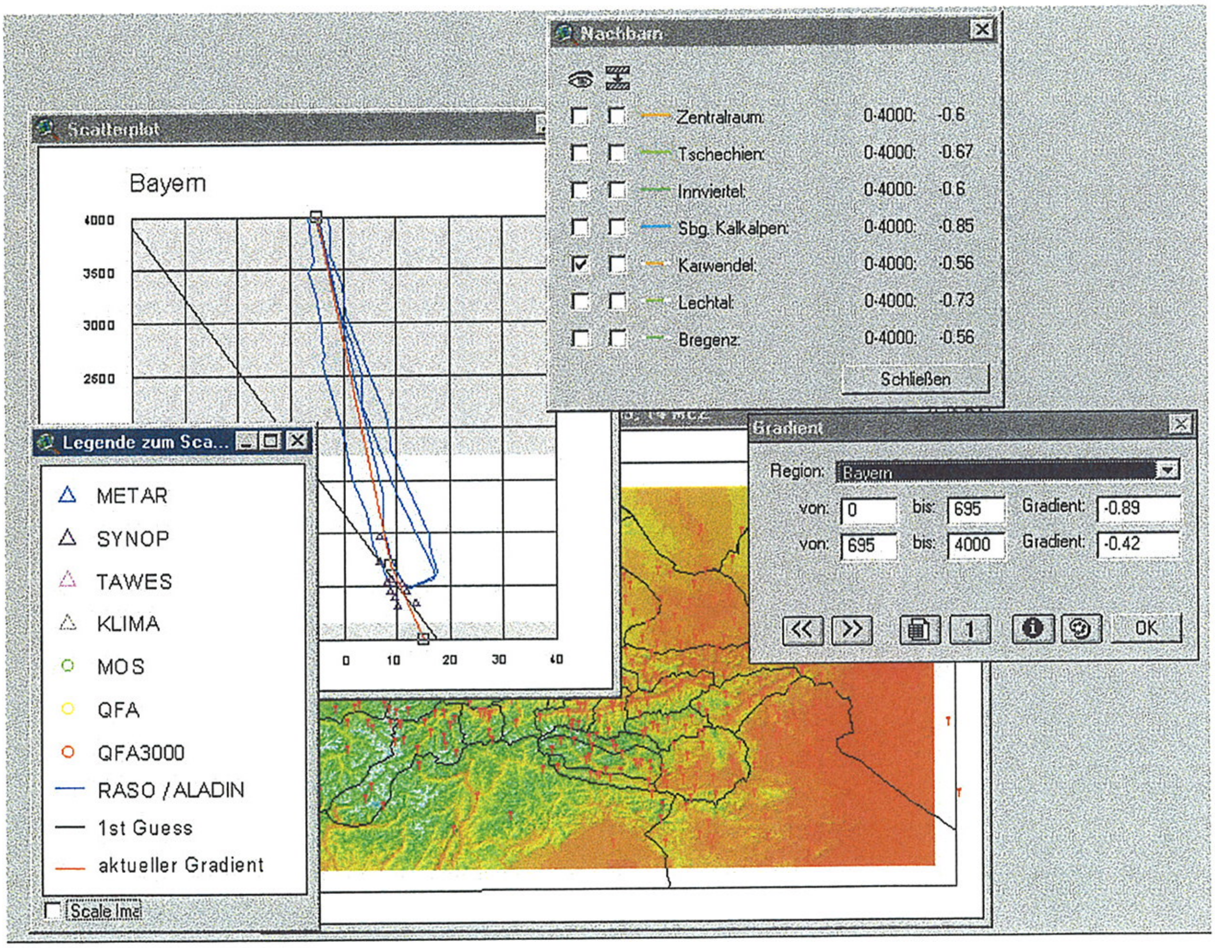


Figure 3.6: Snapshot of weather information within a REGIS window (Haslhofer et al., 2000)

3.7. ÖKLIM

It is the aim of the project ÖKLIM to produce a digital climate atlas of Austria on a multi-media CD ROM for the most important climatological elements. These are temperature, precipitation, sunshine, cloudiness, humidity, etc. for the WMO standard period 1961-1990 including climate maps, diagrams, tables, scripts, photos and videos.

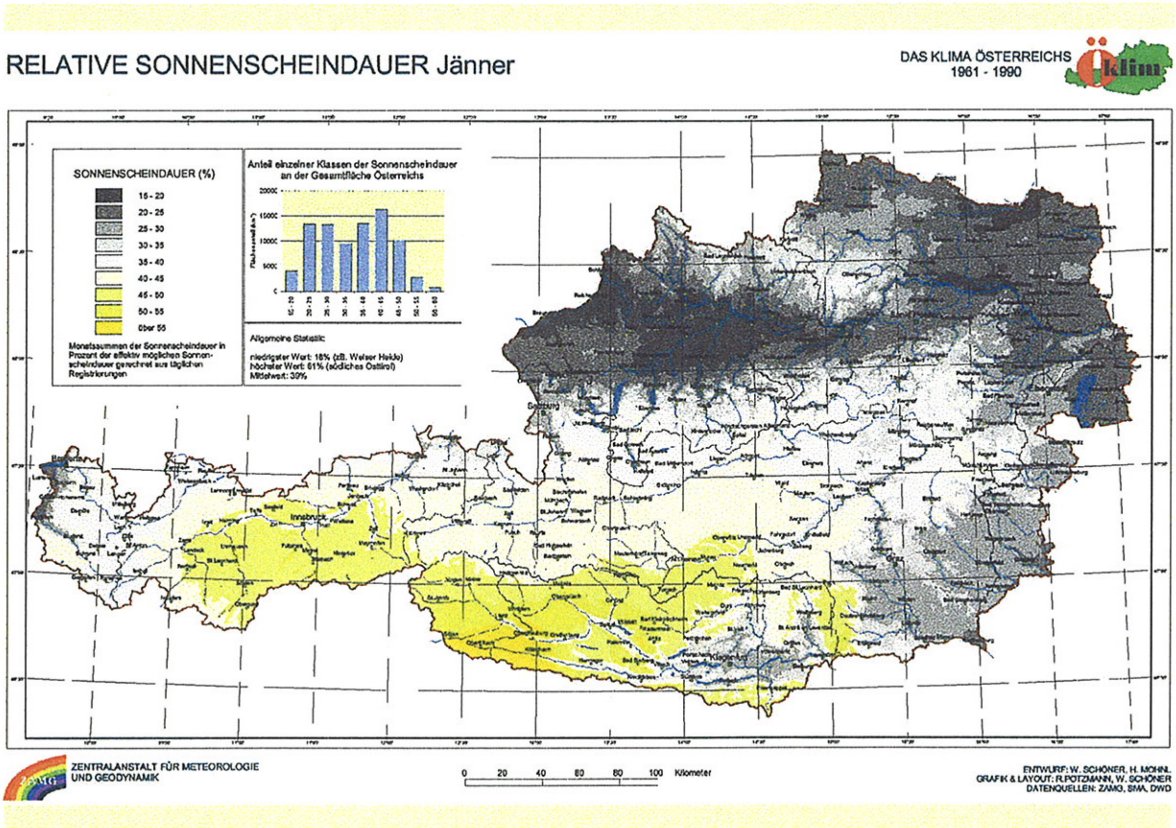


Figure 3.7: Example map from ÖKLIM (Auer et al., 2000)

3.8 GIS application in the Climate Atlas of Hungary

From the Hungarian Climate Atlas three different maps are shown. These maps were done by different interpolation methods as:

- Simple interpolation methods included in GIS software (inverse distance, spline, kriging). They were used for daily and monthly data and for other parameters where a dependency on topography is not too important or the number of input data was very small. Therefore they were applied for:

    - representation of daily data for internal purposes
    - regular climate studies and publications from short time data
    - nowcasting
    - analysis of forecasts, radar and satellite images
    - preparation of maps of Climate Atlas for some elements (sea-level pressure, global radiation, maps of atmospheric chemistry)

- AURELHY method which were used for long term averages of monthly, seasonal and annual data, when their correlation with topography is high. This methods is therefore applied for:

    - preparing maps of the Climate Atlas
    - different climate studies for the whole country or smaller regions.

As the experience show that the simple methods are useful to make quick analysis and decisions without taking into account influence by topography. The AURELHY method produce better spatial patterns, however in some cases then correlation with elevation is very high waves rise in hilly regions.

The following map of global radiation was done by ArcINFO spline method (Fig. 3.8.1), the two others (temperature, Fig. 3.8.2 and relative humidity, Fig.3.8.3) by the AURELHY method. The map of the annual mean temperature is a good one, but the map of relative humidity shows the mentioned waves.

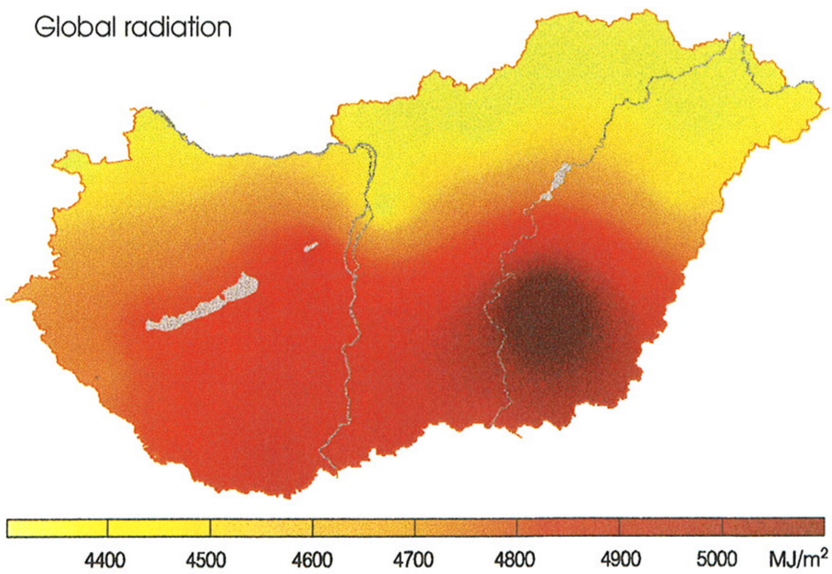


Figure 3.8.1: Annual sum of Global radiation in Hungary (from *Hungarian Climate Atlas,* interpolation by ArcINFO spline method)

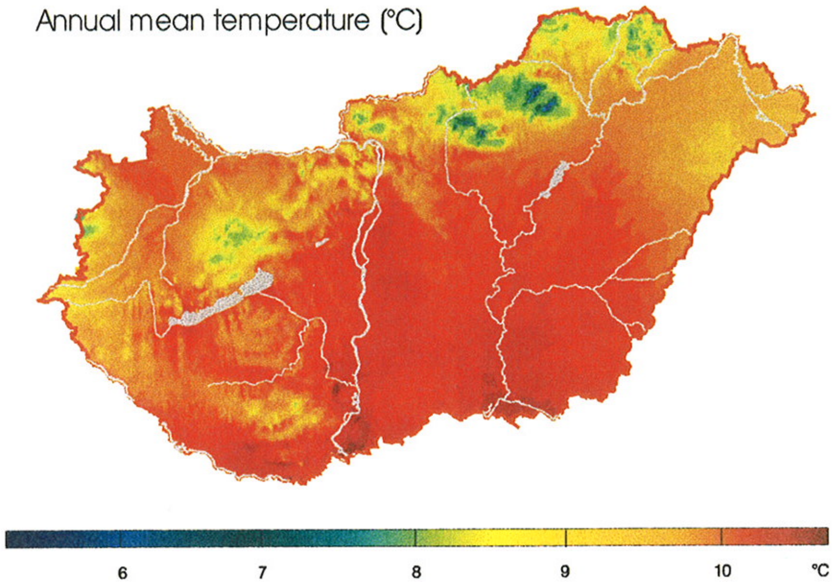


Figure 3.8.2: Annual mean temperature in Hungary (from *Hungarian Climate Atlas*, interpolation by AURELHY method)

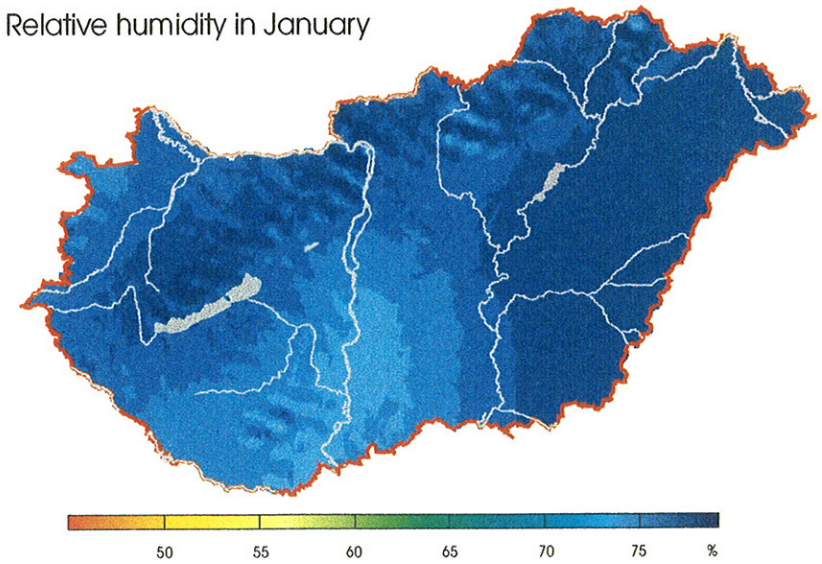


Figure 3.8.3 : Mean relative humidity in January in Hungary (from *Hungarian Climate Atlas*, .interpolation by AURELHY method)

3.9. Examples from *Le climat de la France, 1961-1990*

The two maps presented here are examples of the techniques described in chapter 2.2. The first one presents the annual rainfall (interpolated, using AURELHY) while the second shows the annual number of days with frost (simple interpolation with a kriging algorithm).

The advantage of such maps are numerous:

- they allow to check data (e.g outliers are usually doubtful);
- they allow as any graphical product to present in a simple and easily understandable way a lot of data;
- they provide estimates where no observations are available;
- they represent a satisfying production tool.

However this production is highly specific to Météo-France, strongly related to the structure of the climatological database, and the methods are difficult to export to another NMS, especially AURELHY. This is the reason why Météo France is considering a production based on a GIS as very favourable:

- the ArcView GIS which is in use for some applications at Météo-France is more or less a standard in western European met services. This should foster the development of production tools based on GIS, which could be shared among west European met services.
- ArcView already includes some interpolation tools but is mostly used without taking advantage of the real capabilities of GIS. In particular, it is expected that the use of mapped information within the GIS, such as soil types, vegetation coverage, roughness, etc. will improve significantly the interpolation of meteorological parameters.
- Improved interpolation schemes (e.g. AURELHY types) could be added to the existing GIS software to take into account the specific properties of meteorological fields.

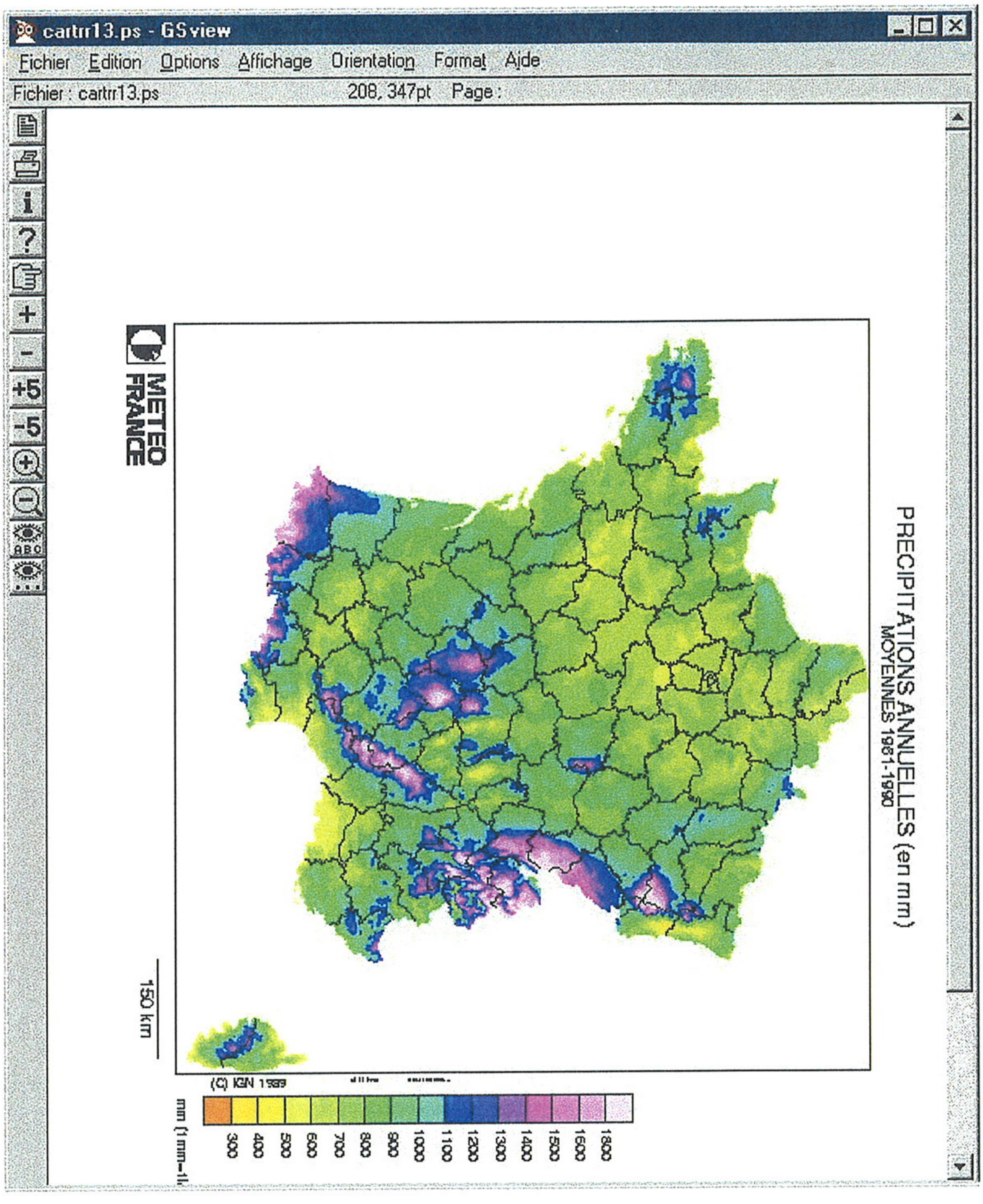


Figure 3.9.1: Annual rainfall in France, interpolated using AURELHY (from *Le Climate de la France 1961-1990*, Météo France 1999)

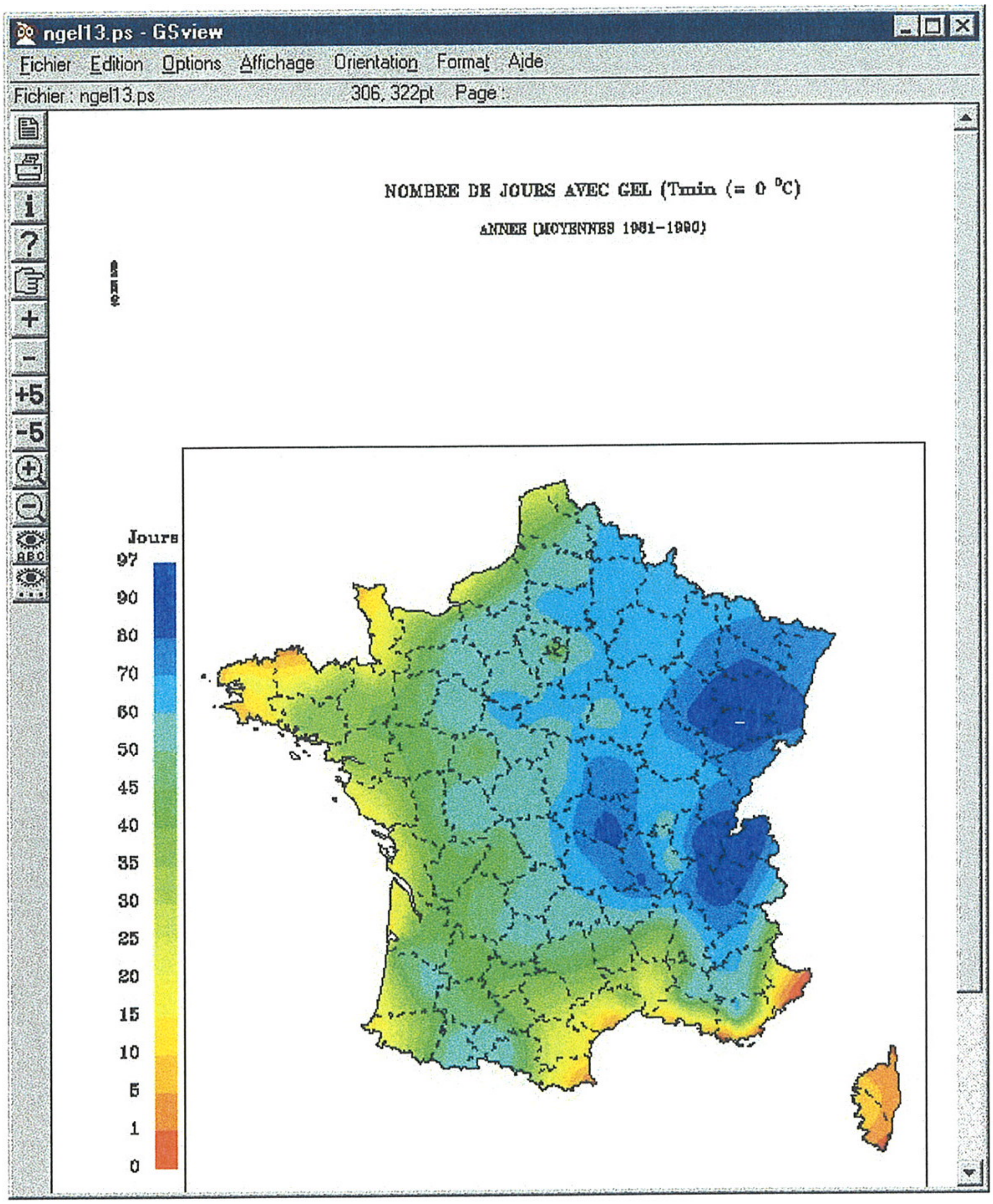


Figure 3.9.2: Annual number of frost days in France, interpolated by a simple kriging algorithm (from *Le climat de la France 1961-1990,* Météo France 1999)

3.10. Examples from the Climatological Atlas of Germany

Klimaatlas Bundesrepublik Deutschland, 1961-1990

Production of the maps

The three maps presented here are produced using the same method:

- Regression functions between the climatological parameter to be mapped and the topography are computed for certain regions.
- The regression coefficients are interpolated spatially, so that grid fields of these coefficients result.
- With these fields of regression coefficients the climatological parameters at each station are reduced to some common reference level.
- The reduced climatological parameters are interpolated spatially.
- The field of reduced parameters is transformed into a field of the actual parameters using the fields of regression coefficients and a grid field of topographic elevation.

As far as applicable this procedure was used to develop maps of mean values or average sums for each month for the reference period 1961-90. Map of seasons, half years and years were then produced computing mean values or sums for each grid point.

The data basis

Generally data of all stations with at least 25 years of observation within the reference period have been used. The mean values for the reference period have been computed. All time series were tested for inhomogeneities before and homogenised as far as possible.

For precipitation, data of about 4000 stations were available. Thus, regression coefficients could be computed for fields of 1 square degree. For other parameters, data of about 550 climate stations could be used and regression coefficients were computed for 10 regions in Germany.

As topographical basis, a grid field with a horizontal resolution of 1 km and an accuracy in elevation of 5 m was used.

The practical application of the procedure

Only linear regressions between the climatological parameter and elevation were used as regressions functions. Other effects of topography like differences between windward ad leeward side of mountain chains could be derived directly from the dense network of stations, because observations were available for each major windward or leeward region.

As far as regression coefficients were unrealistic or correlation coefficients were too low for certain regions, the values were interpolated from neighbouring regions. This was mainly the case for northern Germany, where differences in elevation are rather small, while horizontal differences in climatological parameters may be quite large, especially in coastal regions. All maps are produced with the resolution of the topographic data base, i. e. 1 km.

The three climate parameters used as examples are

- air temperature (example s. fig. 1, *Karte 1.18*),
- precipitation (example s. fig. 2, *Karte 2.19*),
- sunshine duration (example s. fig. 3, *Karte 3.15*).

While correlation with elevation was very good for temperature, it was weaker for precipitation and sunshine.

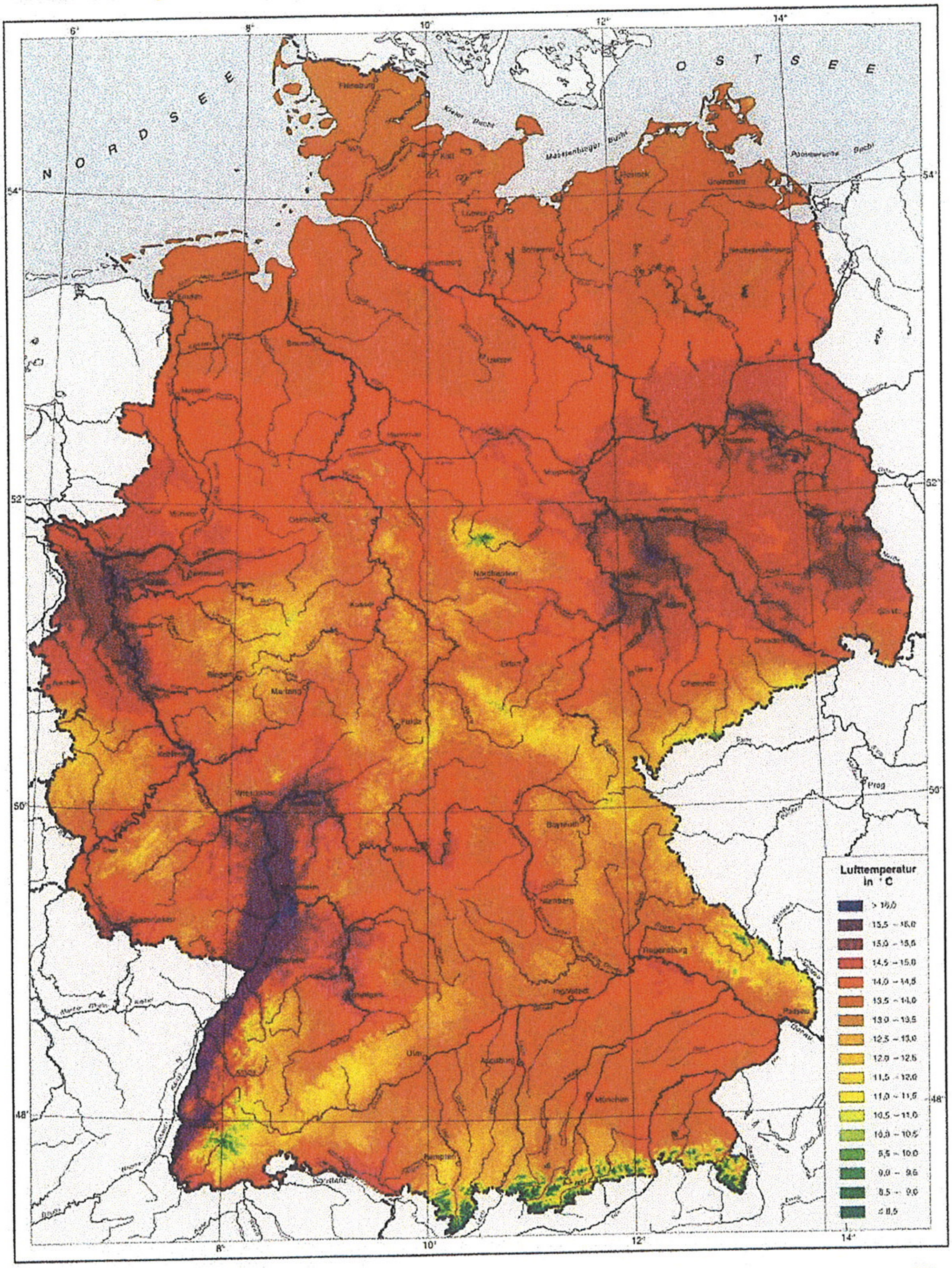
For precipitation, the weakness of the regression was compensated by the density of the station network. Nevertheless the resolution of these maps may be a bit too high, as there is no real correlation between precipitation and elevation, but rather a general intensification of precipitation activity of hills and mountains, which does not discriminate between narrow valleys and adjacent slopes.

For sunshine, there was a rather good correlation in some months (significant decrease of sunshine with elevation in summer and clear increase in winter), while months in between (spring, autumn) showed little influence of topography.

All maps for temperature and the monthly maps for precipitation and sunshine each have consistent colour scales for comparability reasons.

KLIMAATLAS BUNDESREPUBLIK DEUTSCHLAND

Karte 1.18 Mittlere Lufttemperatur, Sommerhalbjahr Zeitraum: 1961 – 1990



Maßstab 1 : 2 500 000

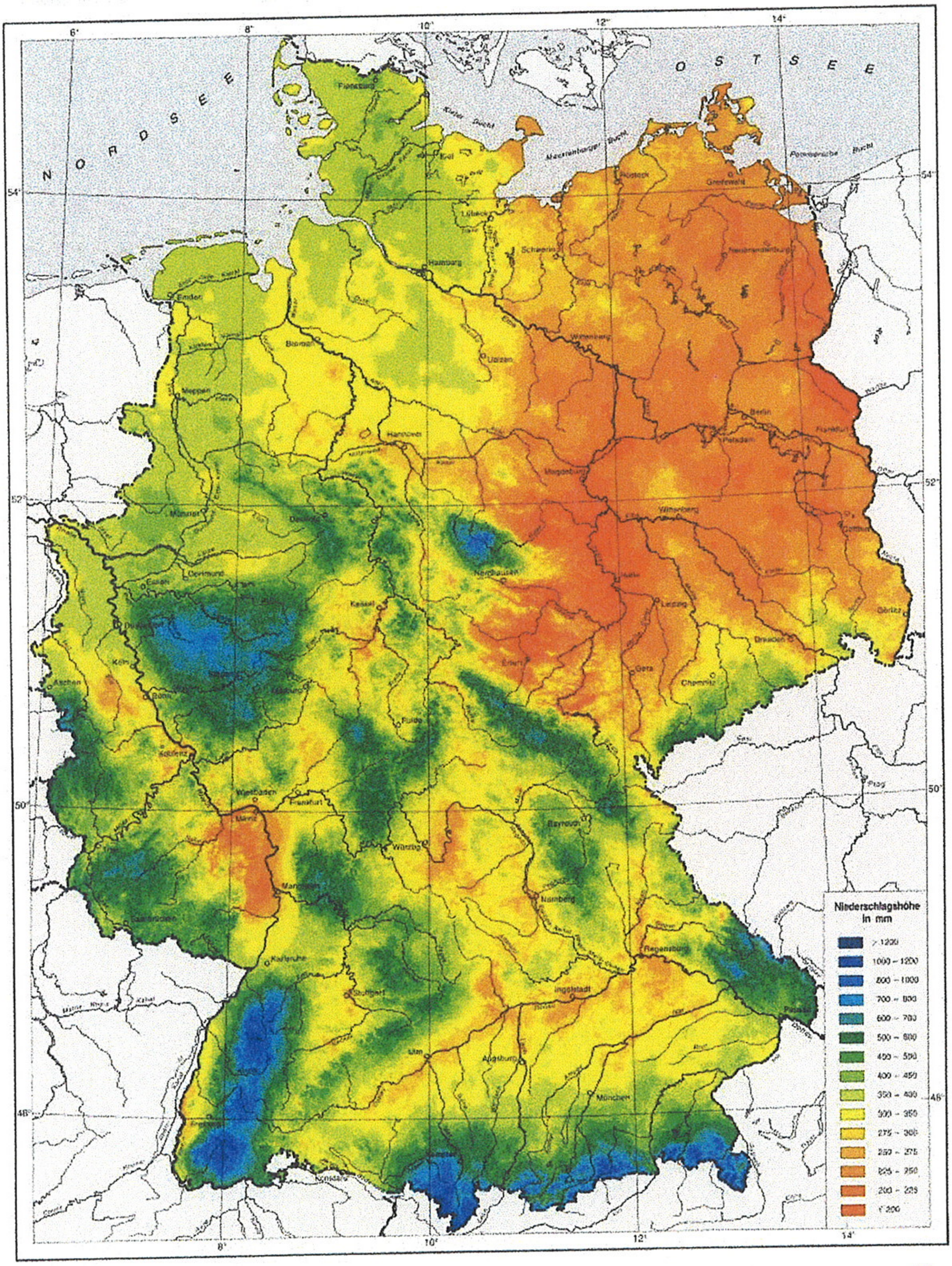
0 50 100 km

Lambert'sche Schnittkegelabbildung, Schnittparallelen 48°40' und 53°40'

Deutscher Wetterdienst

KLIMAATLAS BUNDESREPUBLIK DEUTSCHLAND

Karte 2.19 — **Mittlere Niederschlagshöhe, Winterhalbjahr** — **Zeitraum: 1961 – 1990**



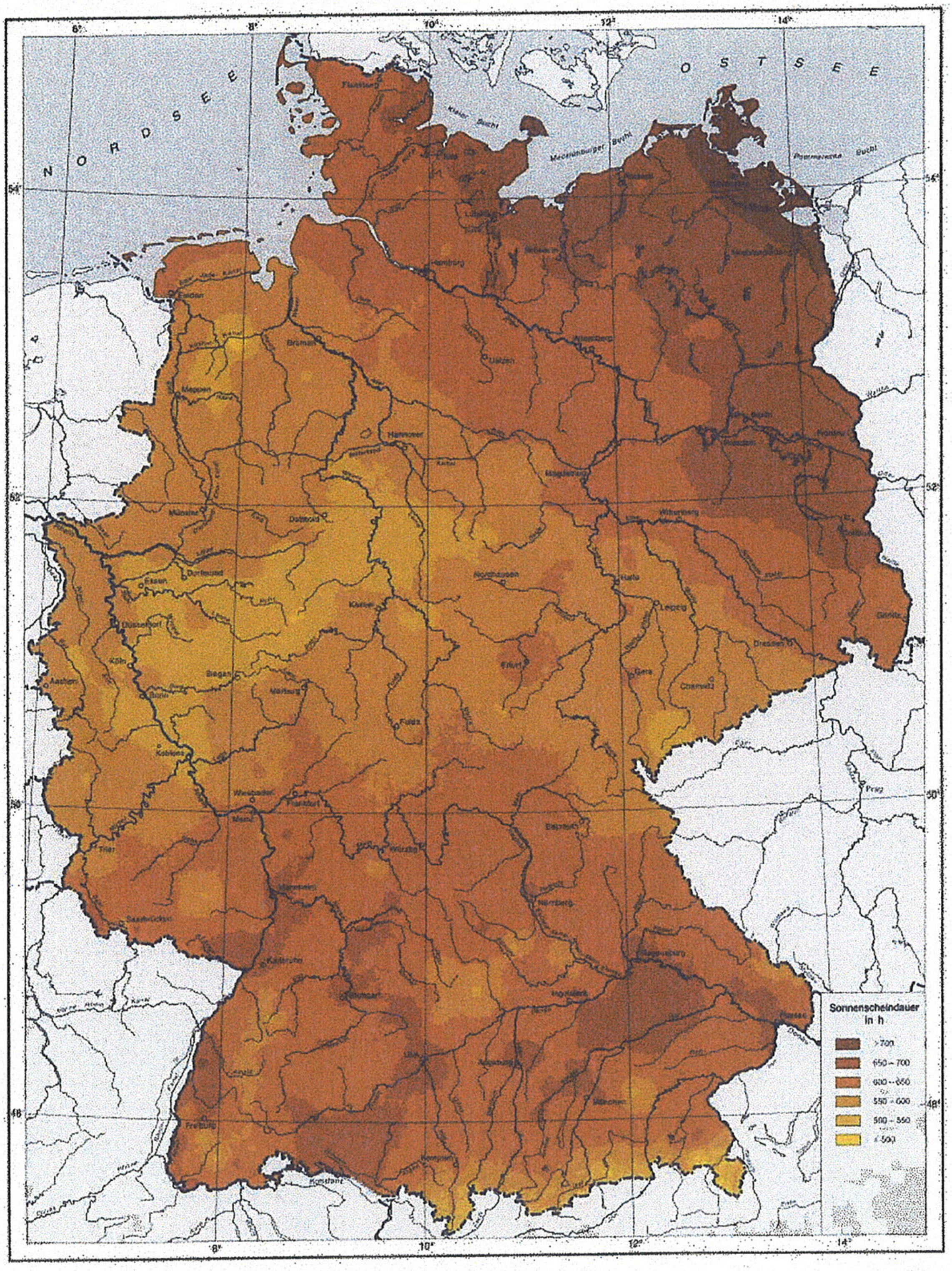
Maßstab 1 : 2 500 000
0 50 100 km

Lambertsche Schnittkegelabbildung, Schnittparallelen 48°40' und 53°40'

Deutscher Wetterdienst

KLIMAATLAS BUNDESREPUBLIK DEUTSCHLAND

Karte 3.15 **Mittlere Sonnenscheindauer, Sommer** **Zeitraum: 1961 – 1990**



Maßstab 1 : 2 500 000

0 50 100 km

Lambertsche Schnittkegelabbildung, Schnittparallelen 48°40' und 53°40'

Deutscher Wetterdienst

4. International activities and co-operation

A new action in the framework of COST was started (February 2001, COST719, *The Use of GIS in Climatology and Meteorology*). The aim of this action is to combine modern GIS technologies with the fundamentals of spatial interpolation schemes to end up with an instrument which can be used for climate research purposes as well as in operational applications. Other goals are to standardise and harmonise geo data to be used in GIS application and define adaptation tools for the different formats of area related data which are in use in meteorology and climatology.

Naturally there were some similarities between the two projects, actually the COST project emanates from the ECSN project, but generally the COST project has the emphasise on the scientific issues and is open for different institutions (including also universities and other research institutes). During the last years GIS technology had a stormy development and now the use of GIS became a necessary prerequisite at many institutions and authorities, therefore the ECSN project were focused on applications coping with this development and additionally should have a strong practical orientation. It should make the use of GIS more common within the NMSs and should serve as a platform for the participating NMSs solving their specific problems with modern technologies in a joint effort in training personnel and exchange practical knowledge and applications.

5. Conclusions and recommendations

A very rapid development in soft- and hardware technologies concerning GIS can be observed. Therefore the statements given here may have only a short life time of validity due to this development and the ongoing efforts within the NMSs to keep path with it. Nevertheless they reflect the general situation of GIS use within the NMSs nowadays.

5.1 Summary of the questionnaire

The questionnaire in Annex II was performed in order to get a categorized overview of the given situation how far the use and skills in applying GIS has been developed in the NMSs at a given date (December 1999). Although the development in GIS software and the capability in handling it has increased remarkably in the last two years the answers to the questionnaire generally reflects many facts which are still valid today with respect to the situation in the NMSs. Due to commercial soft- and hardware development all NMSs had within a quite short period build up GIS capabilities but with quite different number (mostly only a small number) of personnel. GIS was firstly used for data visualisation, control and simple mapping as well as for climate info for the customers. For the successful application of GIS it was stated that it is necessary to have enough time at the beginning to become familiar with the system, competence in climatology and GIS, additional geo-information data as DEMs. land cover classes, etc., an appropriate DB structure, and conversion tools. Further it was stated that the integration of remote sensed data is important but this has bee performed only in a few countries until yet. The full text of the questionnaire can be found in Appendix II.

5.2. Recommendations and future perspectives

The European Climate Atlas Project (Meteo France) in the framework of ECSN will subsume many of the above mentioned approaches and ideas. Once the first phase of this project is completed (data mining), in a second phase the aim will be to design European climatological maps using a higher density of observations. The production of maps itself could be undertaken in a follow-up project, benefiting from the results of the GIS project (e.g. COST719): each NMS will be provided with the appropriate interpolation software, will draw its national maps using the highest possible density of its own data and - in order to ensure continuity - of some specific border regions. This should minimize the recurrent problem of ownership of climatological data.

Further on, the work in developing and testing different spatialisation schemes has to be proceeded as well as the designing of algorithms for gridded data bases. Beside this, strong connections (or easier access to) GIS-based information tools with database applications has to be establish nationally and internationally. Special emphasise has to be put on GIS based climate data quality control tools. This all can be based on the GTOPO30 topographic data set as a basic DEM as long as no unique topographic data base is available for Europe.

It can be expected that the results of the ongoing activities in spatialisation on the European level will be beneficial for solving many problems arising now from the non-consistent methods and data treatment across the NMSs and other institutions. To standardize spatialisation tools in climatology must be considered as a mandatory regulation with respect to the up-coming web-GIS applications which are spreading already through different many web sites. This together with the needs of standardize generally data for geospatial information a cooperation with the Open GIS Consortium (OGC) is strongly recommended. Here the full integration of geospatial data and processing resources into mainstream computing and the use of interoperable geoprocessing software and geospatial data products is envisioned.

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Annex I

Table 1: Spatial interpolation schemes widely used in climatology
(DEM = digital elevation model; T= temperature; RR = precipitation; Alt.= altitude; Elev = elevation; Var = variable; Val = value; C.d. = Climate data; Topo = topography; EV = eigenvector, PC = Principal Component)

Model	Reference	Methodology	External variable - predictors for regression	Spatial and temporal scale	Application	Advantage	Disadvantage
AURELHY, Analysis Using RELief HYdrometeorology	P.Benichou (1986): 3rd Int. Conf. on Statistic. Climatology, Vienna	Calculated Val. of observed Var at any point as function of: local Topo regression function of the measurements + interpolation by kriging of residuals.	Local Topo: Alt, PCs of relief	5x5 [km] DEM, month	RR	Relationship between sampled data field and local topography is taken into account	Heavy computing load; the size of an EV in PCA says nothing about the explanatory power of the particular EV in relation to climate, the PCs are related to relief only; critical assumption for the step in which the regression residuals are spatialized by kriging and then added to the regression prediction.
	M.D.Agnew; J.P. Palutikof (1997): European Union, COST Action 79	Like AURELHY	Topo: Alt, slope, aspect Location: longitude, latitude, distance and direction to nearest coast	1x1 [km] DEM	C.d.	Spatial location and Topo are considered.	Critical assumption for the step, in which the regression residuals are spatialized by kriging and then added to the regression prediction (like AURELHY)
PRISM: Precipitation elevation Regressions on Inclined Slopes Model	C.Daly, R.P.Nelson, D.L.Phillips (1994): J. Appl. Meteorol., Vol. 33, pp.140-158	-Using DEM to estimate- the Elev of stations. -Using DEM + a windowing technique to group stations into individual topogr. "facets". - Estimating the observed Var at a DEM grid cell through regression of measured Vals versus DEM Elev on the cell's topogr. "facets".	DEM Elev	5x5-min DEM, month	RR	Also applicable in the cases where no overall relationship between Elev and RR exists; little computing load; estimates can easily updated for the latest station data.	For regional applications in mountainous terrain, RR is well estimated only at DEM resolutions greater than 6 [km]; RR is underestimated on the upper slope of steep mountains. This is the effect of using a coarse-grid DEM, which over smoothes the Elevs of steep mountain peaks.

Model	Reference	Methodology	External variable - predictors for regression	Spatial and temporal scale	Application	Advantage	Disadvantage
	O.E.Tveito, E.J. Forland: DNMI, Report Nr. 22/97 and 26/98	Ordinary Kriging		month, year	T, RR	Estimates and their errors are computed in detail.	Complexity of spatial distribution of RR and T in mountainous terrain does not warrant an a-priori assumption of first-order stationarity (immanent for ordinary Kriging)
	G. Hudson, H. Wackernagel (1994): Int. J. of. Climatol.,41, pp. 77-91	Kriging with external drift	Coordinate vector, elev	5x5 [km] DEM, month	T	Kriging with an external drift is an efficient algorithm to incorporate auxiliary variables in the estimation of the Var of interest; the a-priori assumption of first-order stationarity is not required, which is reasonable for modeling in complex terrain. The kriged estimates reproduce the correlation with Elev.	Auxiliary Vars must be highly linearly correlated with the Var of interest. Otherwise it is preferable to use the method of cokriging, which requires the fitting of a model for the cross-variograms between the different variables.
	D.L.Phillips, J.Dolph, D.Marks (1992): Agricult. and Forest Meteoro.,58, pp.119-141	Elevationally detrended kriging	Elev	1x1 [mile] DEM	RR	Like kriging with an external drift	Like kriging with an external drift

Model	Reference	Methodology	External variable - predictors for regression	Spatial and tempo ral scale	Appli-cation	Advantage	Disadvantage
	J.A.Hevesi at el. (1992a,b): J. Appl. Meteor.,31,pp .661-676	Cokriging with Elev as an auxiliary Var	Elev	10000 x10000 [ft] DEM	RR	Cokriging considers not only the local variation of the variable of interest (precipitation) within the search neighborhood, but the local variation of auxiliary variable (Elev) as well, and thus the cokriged estimates are more closely tied to local orographic features (in this case, Elev as covariate).	Heavy computing load; screening effect of better correlated data over the less correlated ones; application is limited to areas with a strong RR-elevation relationship
	X.Zheng, R.Basher (1995): Mon. Weather Rev.,123 pp.3086-3102	Thin-plate smoothing spline		1x1 [deg] DEM	RR	Can produce quickly a clear overview of data; flexibility to process any combination of data inputs	Dependence of the mapped fields on the particular statistical or mathematical assumptions involved; low reliability in those parts of the field where the data are very spare

Annex II

RESULTS

Questionnaire on the status of GIS usage within the ECSN member NMSs

H.Dobesch, ZAMG, Vienna, December 1999

Abbreviations of country names: A= Austria; B= Belgium; D= Denmark; G= Germany; F= France; Fin= Finland; E= Spain; H = Hungary; NL= Netherlands; N= Norway; P = Portugal; Slo= Slovenia; S= Sweden;

1. Are you using GIS in your service

YES: A; B, D, G, F, Fin, E, N, Slo, S, H, NL, P

NO: CH, G: not yet adopted for climatology but quite concrete plans

CH: co-operation with University; implementation parallel to ECSN project! First application is visualisation

No response: Greece, UK

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2. What did/do you expect to achieve in using GIS

- More effective and flexible analysis, standardisation and presentation of climate info with better interface to clients
- Data access for intra-/inter net ("GIS on the WEB")
- Better management of geographical data /query and overlay analysis
- Data visualisation and control
- Spatial data base
- Model initialisation

3. Since when do you use GIS in your service

A	B	D	F	Fin	G	E	N	Slo	S	H	NL	P
9/95	4y	2/98	9/97	98	x	96	1/96	5y	94	97	97	99

4. Which hard- and software do you use

A:	PC, Win NT, ArcView, Spat.Analyst, Arc/Info; Idrisi; UNIX Arc/Info with Grid&Tin
B:	Surfer
D:	PC, ArcView 3.1
G:	WS SGI Indy + O2, IRIX 6.5x
Fin:	PC, ArcView
F:	Unix systems, ArcInfo, TIN&GRID; ArcView, Spat.An., 1 ArcPress
E:	PC, ArcView, Idrisi
N:	PC, Win NT, ArcView, Spat.An.; UNIX Arc/Info with Grid&Tin; Internet Java Applications
Slo:	PC, Idrisi, Surfer

S:	Alfastation 200 UNIX Arc/Info 7.2.1, PC ArcView and MapInfo
H:	HP Server + PCs; Arc/Info on HP UNIX, 10 ArcViews (1 HP UNIX 9 PC)
NL	ArcView (PC, Silic.Graph, IRIX); Arc/Info Silic.Graph
P	ArcView, Arc/Info, Arc/View Spat.Analyst on Silic.Graph.

5. ***Which databank system do you use in combination with your GIS, how do you connect to this data bank (ODBC,...); can you give a short overview about your computer system architecture***

A	SYBASE on Sun Server, Conn. to GIS by ODBC
B	Database developed in Fortran
D	INGRES, ODBC
G	Hierarchical file system + ORACLE (info on www.dwd.de)
Fin	ORACLE
F	ORACLE; accessed with Arc/Info and ArcView DBI (Database Integrator)
E	ORACLE, ODBC conn., installed on HP-K640 server, HP-UNIX
N	ORACLE, ODBC conn.
Slo	ASCII, Fortran programs, VAX CDC and PC; ORACLE in development
S	INGRES, on the same server as Arc/Info
H	ORACLE, on same server as Arc/Info; ODBC conn.
NL	ORACLE, SQL conn.
P	RDBMS, INFORMIX

6. ***How many people are involved in GIS activities in your service and how many for climatological purposes alone** (whole service/only climate)*

A	B	D	F	Fin	G	E	N	Slo	S	H	NL	P
6/2	*1*	*5/2*	*20/*	*5/2*	*x*	*/3*	*6/5*	*2/1*	*ArcI 6* *ArcV 5* *MapInfo 20*	*1.5/0.5*	*10-15/3*	*/4*

7. ***Did they get a special training in applying GIS tools***

A	B	D	Fin	F	G	E	N	Slo	S	H	NL	P
Esri, only clim. dept.	*no*	*Univ. educ.*	*no*	*Esri*	*no*	*prov.*	*y*	*no*	*y*	*y*	*y*	*y*

8. ***Do you have close links with other departments of your service in the usage of GIS***

A	B	D	Fin	F	G	E	N	Slo	S	H	NL	P
~	*no*	*no*	~	*y*	~	*y*	*y*	*y*	*no*	*y*	*y*	*y*

9. ***Do you have close contacts with providers of GIS software (e.g. by timely product information, training courses and workshops)***

A	B	D	Fin	F	G	E	N	Slo	S	H	NL	P
~	*y*	*no*	~	*y*	*no*	*y*	~	~	*y*	*y*	*y*	*y*

10. Identify specific requirements to achieve successful applications of GIS

- Enough time, especially at the beginning (>50%) to become familiar with the system
- Competence in GIS *and* climatology
- Appropriate software, DEMs and DB structure and a good knowledge of these
- European dimension
- Data: high quality, georeferenced, interpolation schemes (for missing data)
- Conversion tools (e.g. GRIB data in GIS environment)

11. Which GIS applications/products do you already use (list) and which may be the terms/conditions to hand them over to other NMSs

- Viewing, querying and presenting climatological information
- Network representation
- Algorithms for mapping
- Monthly + seasonal maps
- Maps for agricultural purposes
- Data quality control
- Internet mapping application

12. Which GIS applications/products do you plan to implement (list) ++++

13. Which other applications/ products may be of great importance for your service (list)

- Further development of mapping tools for inclusion in a query/information application
- Interpolated climate parameters fields (for missing data, spatial data quality check)
- Integration of remote sensed data
- Air quality investigation (H)

14. Have you already or are you planning a GIS conform data base comprising area-related data of different kind, e.g. a digital terrain model, land use model, satellite remote sensed data, records of lightening events, etc. (give a list, its use and planned activities on that field) – see point 17 too

A	B	D	Fin	F	G	E	N	Slo	S	H	NL	P
DEM Sat.image OP from FC models	x	x	x	y	x	Land use	like A	x	Land use soil types veg.coverage	y	DEM Land use river basin	GPS survey

15. Do you use high resolution satellite images and data for climatological purposes, which do you use and on which software is it based

F: Solar radiation from METEOSAT 8, wind climatology from mesoscale model, rainfall amount

Slo: case studies

16. Do you plan or already use a gridded climate data bank derived from the usual climate variables

A	B	D	Fin	F	G	E	N	Slo	S	H	NL	P
y	x	y 10x10 40x40 km T,TT, u, Solar Rad.	y	y	y	x	y	n	MESAN T,RR	x	n	y

17. Do you have already special data sets e.g. for land use, vegetation coverage, soil types and other land surface related information - see point 14 too

A	B	D	Fin	F	G	E	N	Slo	S	H	NL	P
Land Use	x	x	% of lake,sea Coverage 10x10 km		x	y	y	~	y	y	y	y

18. Which variables with which time-resolution you consider as important

Monthly/daily/hourly/10': T, RR, snow cover, sunshine;

Further: radiation, wind, pp

Extremes T, RR, snow (monthly, daily)

19. Do you use a certain interpolation schemes for missing data

A	B	D	Fin	F	G	E	N	Slo	S	H	NL	P
x	x	x	x	y	x	~	y	y	y	x	x	x

20. Which spatial statistical software do you already use

A:	GSLIB,SPSS75, FAO, partially included in IDRISI
B:	STATISTICA
Fin:	home made
F	home made
E	FAO
N	GSLIB
Slo	Included in IDRISI, SURFERr
S	Internal Arc/Info
H	(Aurelhy-method)
NL	SURFER, but now replaced by GIS software
P	Spatial Analyst

21. If you have already land cover data which land cover classes you are using

A	B	D	Fin	F	G	E	N	Slo	H	NL	P
Corine	x	x	x	Corine	x	x	x	x	y but not used	x	x

S: Forest, water, marsh, populated area, build up area, bare mountains, glaciers, remaining land

22. Do you have/use a land-wide digital terrain model DEM; if yes with which resolution and map projection

B, D, E, Fin, P: x

A:	30/30" geogr.projection;	50/50m Lambert
F:	(see extra sheet!)	
N:	100/100m; 1/1 km geogr. + UTM (meters, zone 33)	
Slo:	100/100m GK	
S:	50/50m TM/GK	
H	1/1 km -> 100/100 planned	
NL	1 point/16m^2 in stereographic projection	

23. Which means do you apply to have the exact geographic position of the used climate stations especially in relation to the used DEM

Paper maps 1.50.000; GPS positioning

24. Are there any geographic-related information in your meta-data sets and if yes, which are these

Mostly	orgraph. co-ordinates, lat., long., height, WMO type classification
Partly	slope, orientation, land use, roughness,

25. Have you already experience in applying relationships between topography and spatial distribution in some kind of topographic model – if yes, which are these

A	B	D	Fin	F	G	E	N	Slo	S	H	NL	P
~	x	x	Kriging	Aurelhy	lin.regr. with z	y	y	y	x	x	x	y

26. Have you already experience in analyse and interpretation of the physical significance of the relationships between land cover data and spatial distribution; if yes which one

F:	in models (as others too)
Slo:	some
A, NL	surface roughness only for wind