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Map Maker's Guide: A Decision Support System for Interpolation, Aggregation, and Disaggregation

Technical documentation

WOt-werkdocument 350

D.J.J. Walvoort, M. Knotters & T. Hoogland

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Map Maker’s Guide: Technical documentation

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Abstract
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This report documents a decision support system (DSS) that has been developed to assist environmental researchers in selecting interpolation, aggregation, and disaggregation methods. The DSS has been implemented as a web-application. This facilitates updating and makes the DSS generally accessible. The DSS asks the user several questions. The answers are compared with those given by experts. The degree of similarity between both sets of answers is used to assign suitability scores to a huge set of interpolation, aggregation, and disaggregation methods stored in a database. These methods are ranked from most to least suitable and presented to the user in a dynamic table. The user can compare recommended methods (backgrounds, available software, literature, performance) and evaluate dynamically which methods would have been recommended if deferent answers had been given (what-if analysis).

Keywords: interpolation, aggregation, disaggregation, validation, space, time, space-time, decision support system, internet, website, knowledge base, inference engine

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Preface

This report documents a decision support system (DSS) that has been developed to help environmental researchers, in particularly those at the Netherlands Environmental Assessment Agency (PBL), in choosing from a large variety of interpolation, aggregation and disaggregation techniques. The research is commissioned by the Statutory Research Task Unit for Nature & The Environment (WOt Natuur & Milieu, Wageningen UR).

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Martin Knotters
Tom Hoogland

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Summary

A decision support system (DSS) has been developed to assist environmental researchers in selecting interpolation, aggregation, or disaggregation methods. The DSS has been implemented as a website to facilitate updating and to make the information accessible for everyone with internet access (see `www.mapmakersguide.org`). The DSS guides the user through a number of questions which he has to answer. For less experienced users, additional information on each question is provided. Experienced users, on the other hand, only have to focus on the questions and answers and can therefore complete the questionnaire more quickly. After the questionnaire has been completed, the DSS evaluates the similarity between the given answers and those provided by experts on interpolation, aggregation, and disaggregation methods. This results in suitability scores for each interpolation, aggregation, and disaggregation method that is available in the database of the DSS. These methods are sorted from most suitable to least suitable and presented in a dynamic table. The user can compare recommended methods, select additional information (theoretical backgrounds, lists of available software, references, the relative performance of methods, etc.). The user may also perform 'what-if'-analyses to explore the result of giving different answers in the questionnaire. The DSS will update the dynamic table accordingly.

1 Introduction

1.1 Problem statement

Knotters *et al.* (2010) have written an elaborate overview of interpolation, aggregation and disaggregation methods in space, time and space-time. Although their overview is well structured, for less experienced practitioners it may not always be immediately clear which method is most appropriate for tackling specific interpolation, aggregation or disaggregation problems. To provide some guidance in this respect, a decision support system (DSS) is needed that fully employs the information contained in Knotters *et al.* (2010) and preferably even more.

1.2 Aims

The aim is to develop a DSS that helps practitioners find suitable methods to solve their interpolation, aggregation and disaggregation problems. In addition, objective information on the performance of the documented methods in Knotters *et al.* (2010) is required to facilitate selection of methods.

1.3 Outline

In Chapter 2, the requirements, the design principles, and the technical backgrounds of the DSS are given. In Chapter 3, the expert system forming the heart of the DSS is explained in more detail. Finally, some conclusions are given. Further details about the expert system and validation methods for interpolation are given in the appendix.

2 Design of the Decision Support System

This chapter gives an overview of the decision support system. We will start with summarizing the requirements for a suitable DSS (Section 2.1). Next, its design and functionality are briefly described (Section 2.2). More technical details about the DSS are provided in Section 2.3.

2.1 Requirements

The DSS should at least comply with the following requirements:

1. The DSS should be generally available for practitioners within *and* outside Wageningen University & Research centre (Wageningen UR) and 'The Netherlands Environmental Assessment Agency' (PBL);

2. The DSS should should be intuitive and easy to use by practitioners with various backgrounds and degrees of experience;

3. It should be possible to update information on interpolation, aggregation, and disaggregation methods regularly with limited effort;

A DSS that fulfills these requirements is a web-based application. We have therefore implemented the DSS as a website.

2.2 Basic design and functionality

The website starts with a home page that tells the user what the website is about, how the website works, and about the intended audience (Figure 2.1). After clicking the start button, a questionnaire will be launched with a limited number of questions about the interpolation, aggregation, or disaggregation problem at hand. Since, the DSS aims at a broad audience, one may optionally request for additional information to make the questions more clear. After the questionnaire has been completed, the DSS processes the answers and uses an expert system to assign suitability scores to interpolation, aggregation, and disaggregation methods residing in a database. Most of these methods are also described in Knotters *et al.* (2010). These methods are sorted by suitability score and presented in a dynamic table. Optionally, the user may request additional information about each recommended method, like for instance, a brief description of the method, more details about the method, the availability of software (including license information), and its performance relative to alternative methods. In addition, one can also perform a what-if analysis to find out how the order of recommended methods changes if different answers would have been given in the questionnaire. The table with recommended methods will be updated accordingly.

2.3 Technical backgrounds

The website consists of three main ingredients (Figure 2.2):

contents: All text, tables, and figures that make up the website.

style and layout: The 'look-and-feel' of the website. Think about font type, font size, colors, and the position of text, tables and figures on the screen. The style and layout have been typeset in HTML5 and CSS3.

engine: a computer program that handles user interaction (clicking buttons, dragging sliders, etc.) and does all the (mathematical) calculations for the DSS. The engine is coded in JavaScript.

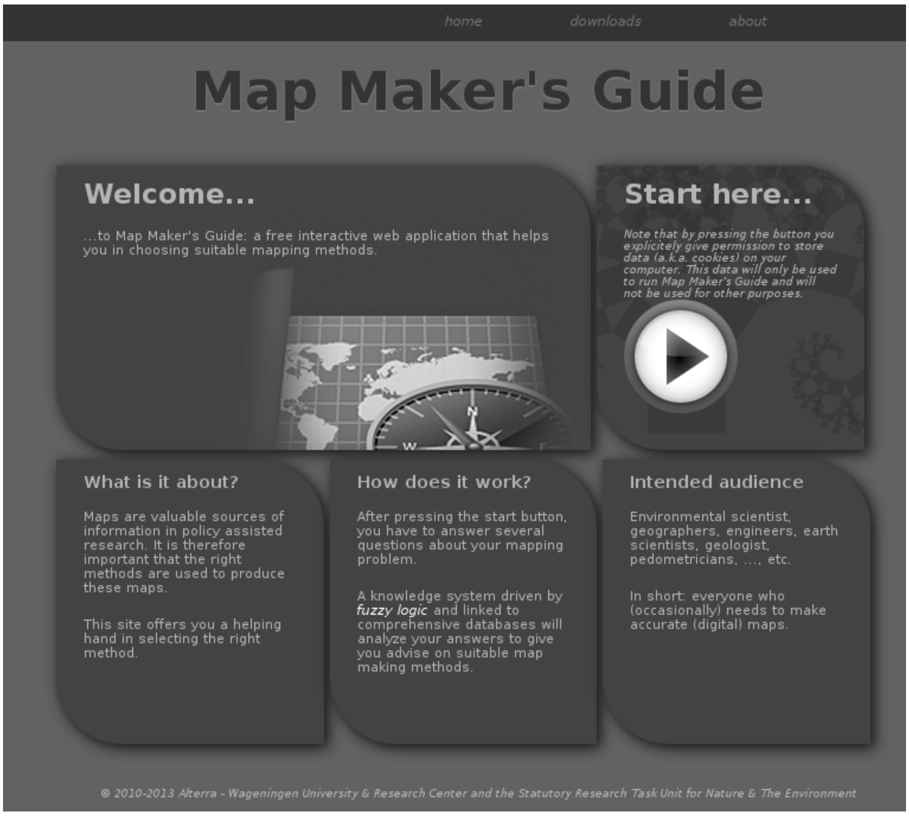

Figure 2.1: Home page of the DSS 'Map Maker's Guide'

Most updates of the website are usually related to its contents only. Think about adding new interpolation methods, adding new background information, or applying corrections and additions to the questionnaire. The style and layout of the website and its engine usually need less maintenance.

The main design principle of the website is therefore to keep these three ingredients apart. This greatly facilitates maintenance of the website. A maintainer who wants to add or modify only contents does not necessarily have to be familiar with the inner workings of the engine, or how to code a specific style and layout in HTML5 and CSS3.

The structure of the DSS is schematically depicted in Figure 2.2.

At the heart of the website is an engine that, together with webserver software, handles user's requests (button clicks, database queries, etc.). The engine is written in JavaScript. It guides users through the questionnaire (Section 2.2), and processes the answers to find a set of interpolation methods that is potentially useful to solve the interpolation problem at hand. The engine also takes control of the communication with the databases, and dynamically fills tables and text blocks.

The website reads its contents from databases. All data are stored in JavaScript Object Notation (JSON). This facilitates efficient data retrieval and processing by the engine. The data are organized in several JSON-files. One file contains all text the user sees on the screen, another file contains characteristics of many interpolation, aggregation and disaggregation methods based on expert knowledge and the parameters of the expert system that will be used to select methods of interest. Other files contain information on available software for interpolation, and information on the relative performance of interpolation methods, as determined in validation studies (see Appendix A for an overview of validation methods (Appendix A.1) and validation studies (Appendix A.2) that are also available in the database).

To facilitate updating, a maintainer does not need to modify the information in the databases directly. Instead, he has to modify MS-Excel worksheets and (simplified) LaTeX documents. The information in these documents will be automatically uploaded to the databases.

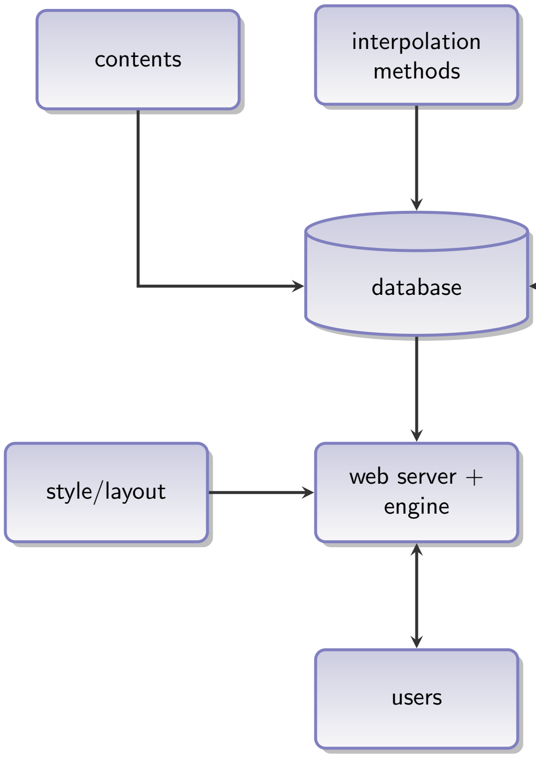

Figure 2.2: Structure of the decision support system. See Section 2.3 for more details.

3 Expert System

After guiding the user through a series of questions about the interpolation, aggregation or disaggregation problem at hand, the DSS processes the given answers to assign suitability scores to all methods in the database. The methods will be sorted from most suitable to least suitable and presented in a dynamic table. In this Chapter it will be explained how these suitability scores are calculated by means of an expert system.

3.1 Expert elicitation

To feed the website with information on interpolation, aggregation, and disaggregation methods experts were asked to complete a table with characteristics of these methods. Most methods were extracted from Knotters *et al.* (2010), but also new methods were added that were underexposed in Knotters *et al.* (2010). In addition to the table, also instructions and background information were provided to the experts (including a paper copy of all text on the website).
An excerpt of the list of methods is given in Table 3.1. The first column gives the name of the method, the second column the skill of the expert, the remaining columns give the characteristics of each method. The experts were asked to fill out the characteristics for each method and also to asses their own experience with the method. The column names are:

interpolation method: Name of the interpolation as given in the literature (*e.g.,* Knotters *et al.* , 2010);

assessor's skill: The expert has to indicate his familiarity with the methods on a qualitative scale as 'ignorant', 'novice','advanced beginner', 'competent', 'proficient' or 'expert'. Although subjective, these estimates can be used to weigh the expert opinion on a specific method;

domain: Does the method pertain to space, time, or space-time? Note that the methods in Table 3.1 may refer to more than one domain. For instance, a method that is suitable for interpolation in space may also be suitable for interpolation in time;

data type: What kind of data does the method process? A distinction is made between 'continuous', 'categorical', 'binary' and 'ordinal' data. The website gives more information on these different data types and also provides examples;

software: is a software implementation of the interpolation method available? Two options are possible 'available' and 'not available';

uncertainty: Does the method also quantify our uncertainty about the resulting maps? And if so, how is this uncertainty quantified. Options are 'none', 'variance', 'quantile', or 'entire distribution';

complexity: How hard is it to apply the method and interpret the results. Options are: 'very simple', 'simple', 'average', 'above average', 'advanced', or 'varies';

secondary data: Some methods make it possible to use so called secondary data to improve the maps of the property of interest (= primary data). Is it possible to take advantage of secondary data? And if so, what kind of secondary data can be used? Options are: 'none', 'exhaustive', or 'non-exhaustive';

change of support: Does the method aggregate or disaggregate the data? Options are: 'none', 'aggregation', or 'disaggregation';

amount of data: Does the method generally require large amounts of data or does a limited data set suffice? Options are: 'small' 'intermediate' 'large' or 'huge';

spatial/temporal distribution: Does the method impose restrictions on the spatial and/or temporal distribution of the data locations? For instance, for some methods, equidistant time-series are required. Options are: 'regular', 'nearly regular', or 'irregular';

Table 3.1: Example of worksheet with properties of interpolation, aggregation and disaggregation methods.

method	domain	data_type	accessor's skill	..	uncertainty	complexity	secondary_data	change_of_support
autoregressive integrated moving average	time	continuous	advanced beginner	..	variance	average	none	none
Bayesian maximum entropy	space	categorical	novice	..	quantiles	advanced	none	none
Bayesian maximum entropy	space	continuous	novice	..	quantiles	advanced	none	none
Bayesian maximum entropy	space-time	categorical	ignorant	..	distribution	advanced	exhaustive	none
Bayesian maximum entropy	space-time	continuous	ignorant	..	quantiles	advanced	exhaustive	none
classification	space	categorical	ignorant	..	none	average	non-exhaustive	none
classification	space	continuous	competent	..	none	average	non-exhaustive	none
classification	time	categorical	ignorant	..	none	average	non-exhaustive	none
classification	time	continuous	competent	..	none	average	non-exhaustive	none
classification and regresssion trees	space	categorical	proficient	..	none	average	non-exhaustive	none
classification and regresssion trees	space	continuous	proficient	..	none	average	non-exhaustive	none
classification and regresssion trees	time	categorical	proficient	..	none	average	non-exhaustive	none
classification and regresssion trees	time	continuous	proficient	..	none	average	non-exhaustive	none
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
smooting splines	space	continuous	advanced beginner	..	variance	average	none	none
smooting splines	time	continuous	advanced beginner	..	variance	average	none	none
space-time ARIMA	space-time	continuous	ignorant	..	variance	advanced	none	none
space-time ARMA	space-time	continuous	ignorant	..	variance	advanced	none	none
space-time kriging	space-time	continuous	ignorant	..	variance	advanced	none	none
space-time kriging with external drift	space-time	continuous	ignorant	..	variance	advanced	exhaustive	none
state-space approach	space-time	continuous	ignorant	..	variance	above average	exhaustive	none
stratified kriging	space	continuous	proficient	..	variance	above average	none	none
stratified kriging	time	continuous	proficient	..	variance	above average	none	none
trans-Gaussian kriging	space	continuous	advanced beginner	..	variance	average	none	none
trans-Gaussian kriging	time	continuous	advanced beginner	..	variance	average	none	none
transfer function noise models	time	continuous	advanced beginner	..	variance	above average	non-exhaustive	none
trend surface analysis	space	continuous	advanced beginner	..	variance	simple	none	none
triangular irregular network	space	continuous	proficient	..	none	simple	none	none

process knowledge: Is process knowledge (*e.g.,* a process model) available to improve the results? Options are 'available', or 'unavailable';

Note that all options are qualitative (binary, categorical or ordinal) and seem rather subjective at first sight. To reduce the degree of subjectivity, descriptions of the options have been provided in the instructions and also on the website. For instance, the option a 'large' amount of data has been described as ranging from 250-1000 data points. However, even when these data have not been provided, experts probably tend to attach similar meanings to the options. That is because the options are interpreted on a relative scale over the entire set of listed interpolation methods. This will temper the degree of subjectivity.

3.2 Questionnaire

An important part of the website is the questionnaire (Section 2.2). The website asks the user several questions to get a better understanding of the interpolation, aggregation, or disaggregation problem at hand.
Not surprisingly, the questions in the questionnaire are related to the characteristics of the methods stored in the database (Section 3.1). Examples are questions about the domain, or about the change of support.

3.3 Similarity matrices

After having completed the questionnaire, the website assigns suitability scores to each method in the database, based on the answers that have been provided. This is accomplished by evaluating similarity matrices. For each question in the questionnaire, a similarity matrix is available. Each row of the matrix corresponds to a potential answer that can be given. Each column of the matrix corresponds to an answer the experts have been given during expert elicitation (Section 3.1).
The website uses similarity matrices with the following format:

$$\begin{array}{ll|ccc} & & \multicolumn{3}{c}{\overbrace{\hspace{6em}}^{\text{expert}}} \\ & & x_1 & x_2 & x_3 \\ \hline \text{user} \left\{ \right. & u_1 & s_{11} & s_{12} & s_{13} \\ & u_2 & s_{21} & s_{22} & s_{23} \\ & u_3 & s_{31} & s_{32} & s_{33} \end{array}$$

where similarities s_{ij} are in the closed interval $[0, 1]$.
As a first example of a similarity matrix, consider the matrix $\mathbf{S}_{\cos}$ (Table 3.2). This matrix belongs to the interpolation method characteristic 'change of support' (Section 3.1). Each row in $\mathbf{S}_{\cos}$ corresponds to an answer to the question if interpolation involves aggregation, disaggregation, or no change of support. The possible (abbreviated) answers are 'aggregation', 'disaggregation' and 'none', respectively. During expert elicitation (Section 3.1), each expert has assigned one of these answers to each interpolation method in the database.

Table 3.2: Similarity matrix: `change_of_support`

	none	aggregation	disaggregation
none	1.00	0.00	0.00
aggregation	0.00	1.00	0.00
disaggregation	0.00	0.00	1.00

The similarity matrix now specifies to what degree the answer given in the questionnaire corresponds to what experts say about the interpolation methods. Suppose a user is interested in aggregation (second row) then methods that do neither aggregation nor disaggregation get similarity index $s_{\cos} = s_{2,1} = 0$ (first column), the same is true for disaggregation methods (third column, $s_{\cos} = s_{2,3} = 0$), only aggregation methods get score $s_{\cos} = s_{2,2} = 1$ (second column).

As a second example consider the availability of software. The user has been asked if software should be available to tackle his interpolation problem. He or she can choose from three answers:

1. Software should be available.
2. I prefer to use existing software. However, if existing software is not suitable for my interpolation problem, I just write it myself.
3. The availability of software is not important. I am only interested in the theory behind the interpolation method.

The first answer will be abbreviated as 'available', the second and third answers as 'not available'. The similarity matrix $\mathbf{S}_{\text{soft}}$ is given below (Table 3.3). If the user wants software to be available (first row), then all interpolation methods that have software implementations get similarity $s_{\text{soft}} = s_{1,1} = 1$. Methods without software get similarity $s_{\text{soft}} = s_{1,2} = 0$. If the user does not care about the availability of software (second row), then all interpolation methods get a similarity of 1 ($s_{\text{soft}} = s_{2,1} = s_{2,2} = 1$). Note that this similarity matrix is asymmetric.

Table 3.3: Similarity matrix: `software`

	available	not available
available	1.00	0.00
not available	1.00	1.00

As a final example, consider the question in which the user is asked about the maximal complexity of the method he his willing to apply. The answer may range from 'very simple' to 'advanced' (*cf.* Section 3.1) depending on the available expertise, time, and finance. This table is also asymmetric. Someone who is not afraid to use advanced methods (fifth row) will also be interested in simpler (usually cheaper and less time-consuming) methods. Therefore, all entries in the fifth row get a similarity of 1. A user who asks for a very simple method (first row) will not be interested in advanced methods (fifth column) but may still be slightly interested in simple methods (second column). Hence, not only 'very simple' methods get a similarity larger than zero ($s_{\text{comp}} = s_{1,1} = 1$) but also 'simple' methods ($s_{\text{comp}} = s_{1,2} = 0.5$). However, because the user actually prefers 'very simple' methods, 'simple' methods get a similarity score less than 1.

Table 3.4: Similarity matrix: `complexity`

	very simple	simple	average	above average	advanced	varies
very simple	1.00	0.50	0.00	0.00	0.00	1.00
simple	1.00	1.00	0.50	0.00	0.00	1.00
average	1.00	1.00	1.00	0.50	0.00	1.00
above average	1.00	1.00	1.00	1.00	0.50	1.00
advanced	1.00	1.00	1.00	1.00	1.00	1.00

3.4 Inference

All n answers in the questionnaire are processed by evaluating the corresponding similarity matrices (see Appendix B). This results in a vector $[s_{\cos}\ s_{\text{soft}} \ldots\ s_{\text{comp}}]'$ of n similarities for each interpolation, aggregation, and disaggregation method in the database. Each entry in this vector relates to a specific answer. The suitability of a specific method can be found by aggregating the similarities by multiplication:

$$S = \prod_{i=1}^{n} s_i = s_{\cos} \times s_{\text{soft}} \times \ldots \times s_{\text{comp}}$$

where S is the suitability of the method.

There are as many S-scores as there are experts. Each S-score gives the suitability of a specific interpolation, aggregation, or disaggregation method rated by a specific expert. Large differences between the S-scores for a single method indicate that experts disagree about the suitability of this method. This disagreement may point to inconsistencies in Table 3.1 and should be solved first.

For presentation purposes (*e.g.,* sorting the methods from most to least suitable in a table), it is more convenient to express the suitability of a method by a single value rather than by multiple values given by different experts. This can be accomplished by aggregating the individual S-scores by using the the assessor's skill value (see Section 3.1) as a weight. In the current implementation of the DSS, this aggregation has been kept relatively simple. It is accomplished by removing the scores of the expert(s) with the lowest skill (*i.e.,* 'ignorant') and taking the arithmetic mean of the remaining scores.

4 Discussion and Conclusions

This report documents a decision support system that can be used to help researchers in the earth and environmental sciences to select interpolation, aggregation, and disaggregation methods that can be used to solve their problems. The decision support system is implemented as a website to reach a broad audience. Separating source code from contents greatly facilitates maintenance of the website. The databases that feed the website can therefore be modified without any knowledge of web-design or internet languages.

Users of the website first have to answer a number of questions. The answers are compared with a knowledge base about interpolation, aggregation, and disaggregation methods to compute suitability scores. The suitability scores are presented in a dynamic table that can be queried by the user for additional information like the availability of software, details about the methods, or performance statistics. The user may also try different answers to evaluate the effect on the suitability scores of the recommended methods ('what-if' analysis).

A website is never finished. Feedback from users may be used to improve the website, add missing methods, en update the questionnaire. A hands-on workshop at the Netherlands Environmental Assessment Agency (PBL) resulted in several valuable improvements and additions.

5 Afterword

The decision support system can be accessed by typing the following URL in the address field of a web browser:

`www.mapmakersguide.org`

Only modern browser are supported that adhere to web standards, *e.g.*, Mozilla Firefox, Chrome, or Chromium.

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Appendix A Validation techniques

A.1 Validation of models for interpolation

In this study we use the following definition of validation: "*Validation* is a test procedure, the outcome of which determines whether a model satisfies its purpose" (Bohlin, 1991). Crucial in validation is confirmation by independent observations, i.e., the data have not been used in modelling. Model validation needs to be carried out on a completely new set of data (Chatfield, 1995). To establish inferential validity these data are preferably collected by probability sampling. Furthermore, by definition the validation measure summarizing the observed differences between model outcomes and truth must be directly related to the *purpose* of the model.

If an independent set of observations is not available, *cross-validation* can be decided to. In cross-validation a part of the observations is not used in constructing the model. Predictions for the locations and time instances associated with these observations are made applying the model being constructed using the remaining observations. This procedure is repeated until all observations have been compared with predictions. Cross-validation procedures in which repeatedly one observation is set aside are referred to as leave-one-out (LOO) or set-one-aside (SOA) procedures. We give these abbreviations for information purposes only, we do not recommend to use them.

Interpolation models are constructed to make predictions at unvisited locations or at time instances at which no observations were made. Let us consider a space-time domain, that is, a geographical area in which during a period of time observations have been collected. The geographical area can be one location, a transect, a 2D or a 3D area. We refer to the spatial coordinates by $\mathbf{s}$. The period of time can be restricted to one time instance, or can have any length. We refer to time instances by t. In case of spatial interpolation the period of time is restricted to one time instance, in case of temporal interpolation the geographical area is restricted to one location.

Observations on either continuous or categorical variables can be interpolated. First, we consider continuous variables. Let $z(\mathbf{s}, t)$ be the observation on variable z at location s and time instance t and $\hat{z}(\mathbf{s}, t)$ be the prediction. The interpolation error $e(\mathbf{s}, t)$ is calculated by subtracting the predicted value from the observed value: $e(\mathbf{s}, t) = z(\mathbf{s}, t) - \hat{z}(\mathbf{s}, t)$. If the validation data have been collected by probability sampling, validation measures such as mean error (ME) and root mean squared error (RMSE) can be estimated using the selection probabilities (Cochran, 1977; De Gruijter *et al.* , 2006). For any other sampling design, a model of spatial and/or temporal variation of interpolation errors is needed to estimate validation measures.

Measures such as ME, RMSE and standard deviation of error (SDE) are often used in validation studies. However, these measures do not clearly inform about the resemblance between mapped *patterns* and true *patterns* (either, spatial patterns, temporal or both). In interpolation it is assumed that the interpolation model describes the spatial structure, the temporal structure or the spatiotemporal structure. Thus it might be expected that no structure is left in the interpolation errors. This can be checked by estimating a variogram of the interpolation errors. If the variogram indicates the presence of spatial, temporal or spatiotemporal correlation, then it can be concluded that the interpolation model does not effectively describe the spatial, temporal or spatiotemporal structure of the variable of interest.

Interpolation models for categorical variables can be validated by comparing the predicted category $\hat{c}(\mathbf{s}, t)$ with the observed category $c(\mathbf{s}, t)$. Validation measures are based on an indicator variable $y(\mathbf{s}, t)$, which has value 1 if $\hat{c}(\mathbf{s}, t) = c(\mathbf{s}, t)$, otherwise $y(\mathbf{s}, t) = 0$. The estimated space-time mean $\hat{\bar{y}}(\mathbf{s}, t)$ is an estimate of the correctly classified fraction of the domain. If the validation data have been collected by probability sampling $\bar{y}(\mathbf{s}, t)$ can be estimated using the selection probabilities (Cochran, 1977; De Gruijter *et al.* , 2006). For any other sampling design, a model of spatial and/or temporal variation of interpolation errors is needed to estimate $\bar{y}(\mathbf{s}, t)$.

In validation of thematic maps $\bar{y}$ is referred to as purity: the fraction (or percentage) of a map that resembles with reality. High purity means high reliability of the map. Despite of its clear and straightforward meaning, two critical remarks about purity as validation measure must be made. First, purity informs about misclassification, but not about the extent of misclassification: misclassification by one category has the same weight as misclassification by two or more categories. Second, purity does not inform about systematic and random errors, and likewise the quality of mapped patterns. Both drawbacks of purity can be taken away by presenting an error matrix (contingency table, confusion matrix; Hay (1979); Card (1982); Congalton (1991)). An error matrix is a square array of numbers set out in rows and columns which express the number of sample units assigned to a particular category relative to the actual category as observed in the field. The diagonal elements reflect the resemblance between map and field truth, the off-diagonal elements inform about the deviations between map and field truth.

A.2 Summary of validation studies

- ADW = angular distance weighting
- ANN = artificial neural networks
- CI = conditional interpolation
- CK = cokriging
- Cl = classification
- GK = global kriging (simple variogram)
- IDW = inverse distance weighting
- IK = indicator kriging
- ISDW = inverse squared distance weighting
- K = kriging
- KED = kriging with an external drift
- LCPM = localized per-class means (Borak & Jasinski, 2009)
- LK = local kriging (variograms for each interpolation point)
- MCMC = Markov Chain Monte Carlo
- NaN = natural neighbour
- NeN = nearest neighbour
- NN = neural network
- OCCK = ordinary collocated cokriging
- OK = ordinary kriging
- PCM = per class means
- RK = regression kriging
- SS = smoothing splines
- TC = climatology
- TCS = temporal cubic splines
- TLA = temporal linear averaging
- TPS = thin plate splines
- UK = universal kriging

Table A.1: Summary of validation studies of methods for spatial interpolation

Reference	target variable	validation method; validation measures	ranking of techniques
Allard (2003)	daily rainfall (mm)	purposive sample ($n = 367$); ME, SDE, RMSE, MAE, MRE	OK < probability class K < NeN
Atkinson & Lloyd (2003)	daily rainfall (mm)	purposive sample ($n = 367$); ME, SDE, RMSE, MAE, MRE	OK < IK
Attorre *et al.* (2007)	climatic and bioclimatic variables	cross-validation ($n = 201, n = 102$); RMSE	UK < NN < IDW
Bargaoui & Chebbi (2009)	rainfall intensity (mm/h)	cross-validation ($n = 13, 8$); correlation predicted-observed, SDE	$n = 13$: 3D KED < 3D OK < 2D OK < 2D KED. $n = 8$: 3D OK < 3D KED < 2D OK < 2D KED
Bierkens *et al.* (2001)	water table depth	probability sample ($n = 20$, 20 time series); RMSE, MAE, ME	RARX model and ST Kalman Filter
Bishop & McBratney (2001)	soil cation exchange capacity	modified jackknife method; RMSE	regression kriging < kriging with external drift < multiple linear regression < generalized additive model < regression tree
Borak & Jasinski (2009)	leaf area indices	random validation sample ($n = 100$); R^2, CV-RMSE	(CV-RMSE) Evergreen needleleaf forest: LPCM/TLA/PCM hybrids < LCPM, LCPM/TC hybrid < Kang method < TLA < TC < Kang 9x9 < PCM < TCS; Deciduous broadleaf forest: LPCM/TLA hybrid, LPCM < LPCM/TC hybrid, LPCM/TLA/PCM hybrids < Kang method < TLA < TC < Kang 9x9 < TCS < PCM; Mixed forest: LPCM, Kang, Kang 9x9, LPCM/TC hybrid, LPCM/TLA hybrid, LPCM/TLA/PCM hybrids < TC < TLA < PCM < TCS; Woody savanna: TC < LPCM, Kang, LPCM/TC hybrid, LPCM/TLA hybrid < LPCM/TLA/PCM hybrids < TLA < Kang 9x9 < TCS < PCM; Open shrubland: LPCM/TLA/PCM hybrid < LPCM, Kang, LPCM/TLA hybrid < LPCM/TC hybrid < Kang 9x9 < TC < TCS < PCM; Grassland: cover-specific LPCM/TLA/PCM hybrid, TLA < TC < Kang 9x9 < TCS < LPCM, Kang, LPCM/TC hybrid, LPCM/TLA hybrid, LPCM/TLA/PCM hybrid < PCM; Cropland: TC < TLA, cover-specific LPCM/TLA/PCM hybrid, TLA < TCS < Kang 9x9 < LPCM, Kang, LPCM/TC hybrid, LPCM/TLA hybrid, LPCM/TLA/PCM hybrid < PCM; Cropland mosaic: TLA < cover-specific LPCM/TLA/PCM hybrid < TC < LPCM, Kang, LPCM/TC hybrid, LPCM/TLA hybrid, LPCM/TLA/PCM hybrid < TCS, Kang 9x9 < PCM
Brus *et al.* (1996)	thickness of A1 horizon, maximum areic mass of P_2O_5 adsorbed by soil above mean highest water table, mean highest water table, mean lowest water table	validation set ($n = 96$); RMSE, MAE	thickness of A1 horizon: OK-3 < GM-3 < GM-6 < LSS-3 < ISD-3 < ISD-0 < OK-0 < GM-0 < N3-3 < LSS-0 < N1-3 < N3-0 < RP < N1-0; maximum areic mass of P_2O_5 adsorbed by soil above mean highest water table: GM-6 < LSS-3 < N3-3 < OK-3 < ISD-3 < GM-3 < OK-0 < ISD-0 < N3-0 < GM-0 < LSS-0 < N1-3 < N1-0; mean highest water table: OK-3 < N1-3 < ISD-3 < GM-6 < N3-3 < RP < LSS-3 < OK-0 < ISD-0 < GM-3 < LSS-0 < N3-0 < GM-0 < N1-0; mean lowest water table: GM6 < ISD-3 < OK-3 < N1-3 < ISD-0 < N3-3 < OK-0 < LSS-3 < RP < N3-0 < LSS-0 < GM-3 < GM-0 < N1-0
Coulibaly & Becker (2007)	annual precipitation	cross-validation; ME, RMSE	UK, OCK < OK, SK < IDW
Denby *et al.* (2005)	PM10, ozone	cross-validation (ozone: $n = 1270$, PM10: $n = 929$); RMSE	process model + OK < OK < IDW
Erxleben *et al.* (2002)	snow depth, snow density	cross-validation ($n = 550$); ME, RMSE, MAE, G	Binary regression tree + kriging < Binary regression tree < Modified residual kriging < OK < IDW < TSA
Hengl (2007)	sand content, silt content, clay content	validation set ($n = 222$)	RK < OK

Table A.2: Summary of validation studies of methods for spatial interpolation; continued

Reference	target variable	validation method; validation measures	ranking of techniques
Hernandez-Stefanoni & Ponce-Hernandez (2006)	number of (vegetation) species, Exponent Shannon, Reciprocal Simpson	cross-validation ($n = 141$); ME, MAE, RMSE, correlation coefficient	(RMSE) number of species: stratified K < CI < stratified inverse distance < stratified cokriging < kriging < inverse squared distance < cokriging; Exponent Shannon: stratified kriging < classification < stratified inverse distance < kriging < inverse squared distance < cokriging; Reciprocal Simpson: stratified kriging < classification < stratified inverse distance < kriging < inverse distance < cokriging
Hofierka (2005)	radioactivity level	purposive sample ($n = 808$); RMSE, MAE, ME, Pearson's r	regularized splines with tension 1
Hofstra *et al.* (2008)	precipitation, mean temperature, minimum temperature, maximum temperature	cross-validation (very large n); compound relative error, MAE, RMSE, linear error in probability space, Pearson correlation, percent correct, critical success index	precipitation: GK < ADW 2 < LK < NaN < ADW 1 < TPS2D < TPS3D < Regression < CI; mean temperature: GK < TPS3D < LK < ADW 1 < TPS2D < NaN < Regression; minimum temperature: GK < TPS3D < LK < ADW 1 < TPS2D < NaN < Regression; maximum temperature: TPS3D < GK < LK < NaN < TPS2D < ADW 1 < Regression
Jones *et al.* (2003)	concentration of contaminant in ground water	cross-validation (3D) ($n = 656, 328, 146, 530$); RMSE	OK = IDW < NaN
Knotters *et al.* (1995)	depth to soft soil layer	SI ($n = 117$); RMSE, RMKV	IRF-2 K combined with regression < IRF-2 K < IRF-2 CoK
Luo *et al.* (2008)	wind speed	cross-validation; ($n = 189$); ME, RMSE	OCCK < OK < local polynomial < UK (spatial coordinates) < IDW < thin plate splines < TSA
Mardikis *et al.* (2005)	long-term mean daily reference evapotranspiration	preferential validation sample ($n = 19$); ME, MAE, RMSE	gradient plus inverse distance squared, kriging with a guess field< ordinary kriging, inverse squared distance
Odeh *et al.* (1994)	depth of solum, depth of bedrock, topsoil gravel, subsoil clay	purposive validation sample ($n = 71$); ME, RMSE	depth of solum: kriging combined with linear regression < kriging with a guess field < multi-linear regression < universal kriging with spatial coordinates < cokriging < ordinary kriging; depth to bedrock: kriging with a guess field < kriging combined with linear regression < multi-linear regression < cokriging < universal kriging with spatial coordinates < ordinary kriging; topsoil gravel: kriging with a guess field < multi-linear regression < cokriging < kriging combined with linear regression < universal kriging with spatial coordinates < ordinary kriging; subsoil clay: kriging combined with linear regression < kriging with a guess field < multi-linear regression < cokriging < universal kriging < ordinary kriging
Palaseanu-Lovejoy (2005)	radioactivity level	purposive sample ($n = 808$); RMSE, MAE, ME, Pearson's r	Bayesian automatic fitting functions
Pebesma (2005)	radioactivity level	purposive sample ($n = 808$); RMSE, MAE, ME, Pearson's r	OK
Rigol-Sanchez (2005)	radioactivity level	purposive sample ($n = 808$); RMSE, MAE, ME, Pearson's r	ANN

Table A.3: Summary of validation studies of methods for spatial interpolation; continued

Reference	target variable	validation method; validation measures	ranking of techniques
Savelieva (2005)	radioactivity level	purposive sample ($n = 808$); RMSE, MAE, ME, Pearson's r	OK
Saveliev *et al.* (2005)	radioactivity level	purposive sample ($n = 808$); RMSE, MAE, ME, Pearson's r	multilevel B-splines
Schloeder *et al.* (2001)	clay content (g kg^{-1}); pH; Na, Ca, Mg (cmol$_e$ kg^{-1}); P (mg kg^{-1}); organic matter content (g kg^{-1})	cross-validation ($n = 46$); MAE, MSE, G	clay: IDW < SS < OK. pH: IDW = OK < SS. Na: OK < SS < IDW. Ca: IDW < OK < SS. Mg: IDW < OK < SS. P: OK < IDW < SS. OM: OK = IDW < SS
Schuurmans *et al.* (2007)	daily rainfall	cross-validation ($n = 30, 103, 330$); RMSE	KED < OCCK < OK
Timonin & Savelieva (2005)	radioactivity level	purposive sample ($n = 808$); RMSE, MAE, ME, Pearson's r	General Regression Neural Network
Thieken (2003)	daily rainfall (mm)	purposive sample ($n = 367$); ME, SDE, RMSE, MAE, MRE	radial basis functions: MQ2<MQ4<MQ1
Uboldi *et al.* (2008)	hourly temperature	cross-validation ($n = 270$); CV (RMSE)	optimal interpolation
Van de Kassteele *et al.* (2005)	annual number of ozone exceedance days	cross-validation ($n = 120$); RMSE	MCMC with Poisson model < MCMC with lognormal model
Voltz & Webster (1990)	clay content of topsoil	validations with purposive samples ($n = 212, 143, 63$); ME, MSE, mean square deviation ratio	within-class kriging ¡ simple kriging ¡ cubic splines
Wilks (2008)	meteorological variables	cross-validation ($n = 166$); RMSE	local regression < global regression < Thiessen polygons < domain average
Zimmerman *et al.* (1999)	synthetic data		OK < UK (spatial coordinates) < ISDW-6 < ISDW-12

Appendix B Similarity matrices

Below are similarity matrices as currently been used by the DSS. Note that these matrices may change as our experience with the DSS grows. For more information about the similarity matrices and their interpretation see Section 3.3.

Table B.1: Similarity matrix: `domain`

	space	time	space-time
space	1.00	0.00	0.25
time	0.50	1.00	0.25
space-time	0.00	0.00	1.00

Table B.2: Similarity matrix: `change_of_support`

	none	aggregation	disaggregation
none	1.00	0.00	0.00
aggregation	0.00	1.00	0.00
disaggregation	0.00	0.00	1.00

Table B.3: Similarity matrix: `software`

	available	not available
available	1.00	0.00
not available	1.00	1.00

Table B.4: Similarity matrix: `complexity`

	very simple	simple	average	above average	advanced	varies
very simple	1.00	0.50	0.00	0.00	0.00	1.00
simple	1.00	1.00	0.50	0.00	0.00	1.00
average	1.00	1.00	1.00	0.50	0.00	1.00
above average	1.00	1.00	1.00	1.00	0.50	1.00
advanced	1.00	1.00	1.00	1.00	1.00	1.00

Table B.5: Similarity matrix: `data_type`

	continuous	categorical	binary	ordinal
continuous	1.00	0.00	0.00	0.00
categorical	0.00	1.00	0.00	0.00
binary	0.00	0.00	1.00	0.00
ordinal	0.00	0.00	0.00	1.00

Table B.6: Similarity matrix: `data_availability`

	small	intermediate	large	huge
small	1.00	0.00	0.00	0.00
intermediate	1.00	1.00	0.00	0.00
large	1.00	1.00	1.00	0.00
huge	1.00	1.00	1.00	1.00

Table B.7: Similarity matrix: `distribution_of_points`

	regular	nearly regular	irregular
regular	1.00	1.00	1.00
nearly regular	0.75	1.00	1.00
irregular	0.00	0.00	1.00

Table B.8: Similarity matrix: `secondary_data`

	none	exhaustive	non-exhaustive
none	1.00	0.00	0.00
exhaustive	0.25	1.00	0.50
non-exhaustive	0.25	0.00	1.00

Table B.9: Similarity matrix: `uncertainty`

	none	variance	quantiles	distribution
none	1.00	1.00	1.00	1.00
variance	0.00	1.00	0.50	0.50
quantiles	0.00	0.50	1.00	1.00
distribution	0.00	0.50	1.00	1.00

Table B.10: Similarity matrix: `process_knowledge`

	available	unavailable
available	1.00	0.75
unavailable	0.00	1.00

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