MULTIVARIATE VISUALIZATION OF DATA QUALITY ELEMENTS FOR COASTAL ZONE MONITORING

D. E. van de Vlag and M. J. Kraak

International Institute for Geo-Information Science and Earth Observation (ITC), Dept. of Geo-Information Processing , PO Box 6, 7500 AA Enschede, The Netherlands – (vandevlag, kraak)@itc.nl

KEY WORDS: GIS, coast, monitoring, identification, visualization, accuracy, quality

ABSTRACT:

Broad sandy beaches and extensive dune ridges dominate the Dutch coastal zone. The beach areas are subject to continuous processes as beach erosion and sedimentation, which influence its morphology. This in turn has an economic impact on beach management and public security. Beach nourishments are carried out if safety of the land is at risk. Here the problems are defined as: (1) how to localize and quantify beach areas that require nourishment, and (2) how to assist the decision maker to manage the process of nourishment in time. To tackle the above-mentioned problems we used geographic information of different sources. We introduced an ontology-driven approach to integrate the different data sources and to conceptualize the beach areas, their attributes and relationships. An ontological approach greatly helps to understand the role of the quality of the data sources and also the required qualities for the decision maker. To express the data quality derived from metadata as well as from user-required qualities, we presented a novel visual environment for illustrating quantitative values of quality elements using multivariate visualization techniques. Quality elements that we studied for the beach nourishment process are: positional accuracy, thematic accuracy, temporal accuracy and completeness. By combining multivariate visualization with the technique of multiple linked views different aspects of data quality can be conveyed in relation to the original data. We conclude that the prototype can be useful for interactive and explorative purposes and has its strengths to deal with non temporal, as well as multi-temporal data.

1. INTRODUCTION

The Dutch coastal zone has an extremely dynamic morphology due to tidal currents and storms. This morphology is influenced by processes such as erosion, transportation and sedimentation. Changes in morphology have consequences for the public safety of the hinterland and beach management. Beach nourishments are carried out if there is a risk to the hinterland. For economic reasons, areas suitable for beach nourishment need to be determined. This can be achieved with an ontological approach, whereby the quality elements of each area are described using quantitative methods. The ontological approach integrates both data and semantics in a common reasoning framework consisting of objects, attributes and relationships. To reach this, we need an extensive dataset.

Large geospatial datasets are now easily available to the public. These can be used to extract valuable information which requires new interactive (usually) multivariate tools (Matange et al., 1998). In recent years, applied researchers have become increasingly interested in multivariate visualizations in order to find low dimensional structures in higher dimensional data (Schmid and Hinterberger, 1994). After all, graphic displays show patterns in the data more clearly than plain numbers, leading to better descriptive and explorative models of the data.

For the visual representation of elements related to spatial data quality, there are two major approaches: (1) symbolization of an individual quality element such as uncertainty and (2) graphical representations showing multiple quality elements. Regarding symbolization, MacEachren (1992) and others (e.g., McGranaghan, 1993, Van der Wel et al., 1994) have examined Bertin's graphic variables for use in representing uncertainty and have added new variables, notably saturation (i.e., purity) of color and clarity. The latter can be further broken down into crispness, resolution, and transparency (MacEachren, 1995). Concerning graphical representations of quality elements, traditionally this includes single bivariate tools, map pairs and multiple maps, sequential presentation, and interactive displays (MacEachren, 1992). When dealing with several elements related to spatial data quality, the use of multivariate visualization tools can be efficient, due to their ability to simplify dimensions. However, this has mainly been studied for a single quality element within a time series (McGranaghan, 1993) or, in remote sensing applications, as a single quality element within the spectral behavior (Lucieer and Kraak, 2002).

Here, we propose a multivariate visualization prototype to detect trends and associations in the data and their quality elements and to present them in a visual form. Hence, the aim of this paper is to visualize all quality elements - taking an ontologically based approach - within an explorative use environment, using multivariate visualization techniques with dynamically linked views. The prototype will support in understanding where to locate areas suitable for nourishments, how they behave in time, and what the influences of several data quality elements are.

2. BACKGROUND

2.1 Study Area and Dataset

The study area is located at the north-western part of Ameland, a coastal barrier island on the fringe between the Wadden Sea and the North Sea (figure 1). Geomorphological processes such as erosion, transport and sedimentation of sandy materials are causing major changes along the north-western coast of Ameland.

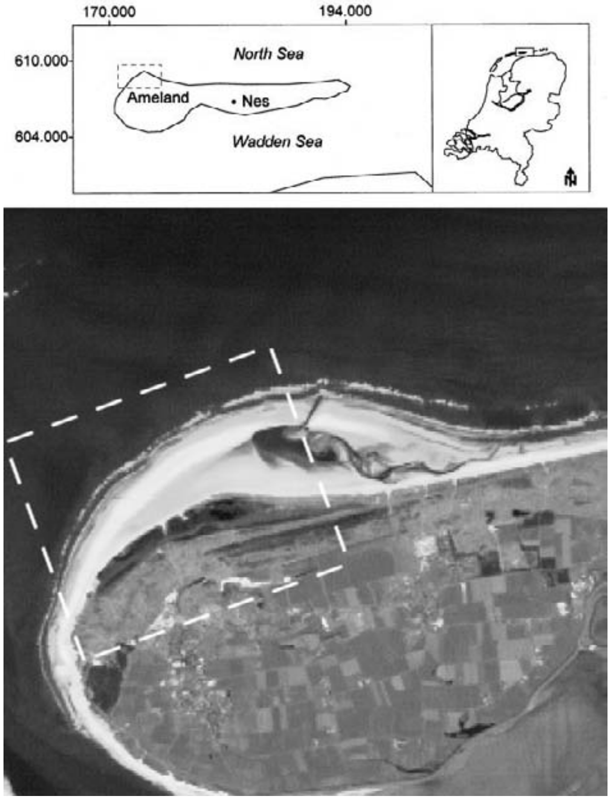

Figure 1: A landsat image (1999) from the north-western part of the Isle of Ameland. The white box shows the study area. The bottom part of the study area contains mainly dunes, the middle part is beach, the upper part is sea.

The dataset for the Ameland case study consists of multi-temporal digital elevation models and satellite imagery. Each digital elevation model of Ameland is derived from the JARKUS data from the DONAR database (Eleveld, 1999). The DONAR database contains annual beach and foredune profiles derived from stereometric analysis of aerial photographs for the dry part of the coastal transect. The underwater part of the profile is measured with echosoundings from ships with automatic position-finding systems. The transects are 200 to 250 m apart and elevation is measured at 5 m intervals along a cross-shore line. From the point data, we interpolated the profiles towards a 30 m × 30 m grid. Satellite images are derived from Landsat5-TM and Landsat7-ETM+ satellites. Landsat images contain pixels corresponding to 30 m × 30 m ground surface.

The beach objects are structured in compartments within a higher conceptual level, based on perceivable regions on the beach. Compartments are the regions between two transects.

2.2 Beach Nourishment

To counteract beach erosion, sand nourishments have to be carried out. Either beach nourishments or underwater nourishments are applied for sand nourishments (Roelse, 2002). In this study we focus on beach nourishments as their effects on the maintenance of the coastline are better known.

According to Dutch policy regulations, beach nourishments are carried out (1) if safety of the hinterland is at risk, (2) to safeguard dune objects, (3) to stimulate and manage beach recreation, or (4) to reduce the loss of nature areas (Roelse, 2002). To calculate the required volume of sand, the expected erosion, the recurrence interval and the sand reserve have to be determined. The sand reserve, i.e. the beach volume at time (t, is the most important variable and can be calculated from the dataset. Reference is made to the basal coastline, being the coastline position on 1 January 1990. The beach volume at basal coastline is the standard for preservation of the coastline. Beach nourishments are carried out when the beach volume at actual coastline is below the volume at basal coastline. The actual beach volume can be calculated by multiplying the beach area, i.e. the area between the dune feet and the actual coastline, with the surface area.

For beach management purposes, Rijkwaterstaat - the part of the Ministry of Public Works responsible for the maintenance of the coast - divide the beach area into compartments. Each compartment has two boundaries to its adjacent compartment (CL), a beach-sea boundary (BS) and a beach-dune boundary (BD). Rijskwaterstaat use these compartments to calculate sand volumes and treat them as crisp objects (Roelse, 2002). The interest of this application is to take into account the 'fuzzy' nature of objects, and their 'dynamism' in time. Hence, we propose to describe the boundaries between beach-sea and beach-dune as vague boundaries (Van de Vlag et al., 2004).

Next, it is possible to calculate structural erosion per compartment, by plotting the beach volumes from before 1990 against the beach volume with the basal coastline. A negative trendline indicates erosion, whereas a positive trendline indicates sedimentation.

Two constraints apply when deciding upon nourishment; first constraint (C_1) is that a coast compartment shows structural erosion, the second constraint (C_2) is that the volume for beach nourishment should exceed 0.2 Mm^3. Constraint C_2 is a soft constraint, as nourishment may be carried out, depending on local and regional policies.

2.3 Ontological Approach

The ontological approach chosen in this paper is to handle the underlying data management problem as an integration of both data and semantics, within a common reasoning framework (Jeansoulin and Wilson, 2002). The ontological approach clarifies the structure of knowledge, and leads to coherent knowledge base. An ontology exists of objects, their attributes and relationships (that may be time dependent), events, processes and states. Ontologies may enable knowledge sharing and reuse for different domains or time intervals. For the Ameland application, ontologies will be used as a common reasoning framework with different, yearly, time intervals. In the Ameland case study, the spatio-temporal problem can be defined as: 1) How to localize and quantify beach areas that require nourishment, and 2) How to assist the decision maker to manage the process of nourishment in time.

Identification of areas that require beach nourishment depends upon terrain altitude (height around zero), vegetation index (non-vegetated zones) and wetness index (dry zones). Altitudes between –1 and 2 m at Dutch standard sea-level (NAP) are considered as beach areas. Such areas are derived from digital elevation models (DEMs). Similarly, non-vegetated and dry zones are derived from Landsat TM imagery. Non-vegetated zones are selected as areas with negative NDVI values; dry zones are selected as areas with a wetness index lower than zero. The delimitation of the object beach should satisfy the constraints for altitude, non-vegetated and dry zones (Vasseur et. al., subm.).

The description of the spatio-temporal ontology depends on two factors: the spatial variation of the attributes within a compartment and its changes in time. The spatial variation is inherited in several attributes, as altitude, vegetation index and wetness index. In the definitions for beach nourishment, the attributes are vaguely described in contents and geometry. Beach compartments can be described by a membership of dry, non-vegetated beaches (Van de Vlag et al., 2004). Additionally, each attribute has a different timescale. Hence, different temporal scale issues need to be incorporated. Beach volumes derived from altitude can be described on yearly trends. The vegetation index has monthly fluctuations, while wetness index is characterized by tide fluctuations on a daily scale.

The spatial variation of the attributes can be modeled using fuzzy logic, whereby beach compartments suitable for beach nourishment are determined by its membership to dry, non-vegetated beaches. Hence, a compartment is bound by two static compartment boundaries (*CL.geo*) and by two vague boundaries: the sea-beach boundary (*BS.geo*(*t*)) and the beach-dune boundary (*BD.geo*(*t*)).These boundaries are illustrated in figure 2, lower image.

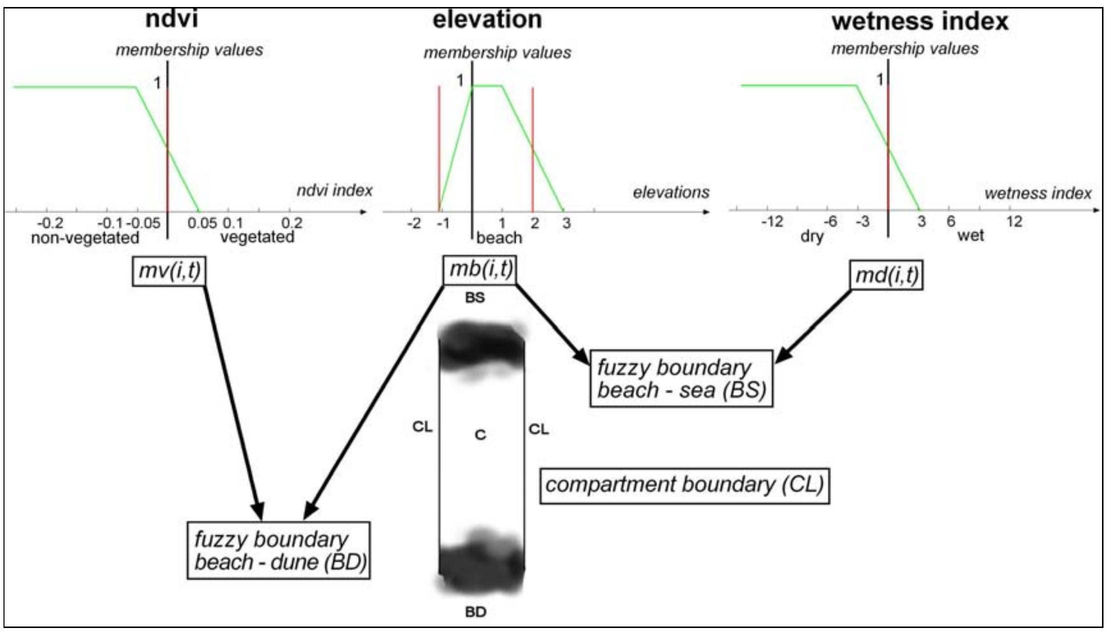

Figure 2: Compartment, boundaries and their various fuzzy membership functions. The lower image visualizes a compartment (C), with two adjacent crisp boundaries (CL) and two fuzzy boundaries (BS) and (BD).

The sand volume within the fuzzy compartmental method can be calculated, using:

$$\mathrm{C.vol(t)} = \mathrm{ps} \times \sum_{\mathrm{i=1}}^{\mathrm{np}} \mathrm{m(i,t)} \times \mathrm{e(i,t)} \tag{1}$$

where *m*(*i*,*t*), membership value of location (i) in compartment *C* at time *t*. It is calculated as:

$$m(i,t) = \min\{mb(i,t), md(i,t), mv(i,t)\} \tag{2}$$

where *mb*(*i,t*) is the membership function of the beach object, *md*(*i,t*) that of dry object and *mv*(*i,t*) that of a non-vegetated object in which pixel *i* occurs at time *t* (see figure 2). Membership functions are compiled as triangular functions and are semantic based. The *mb*(*i,t*) equals 1 if altitude ranges from 0 to 1 m amsl (i.e. above mean sea level). It increases linearly from 0 to 1 between –1.1 to 0 m amsl and decrease linearly from 1 to 0 between 1 and 3 m amsl, and it equals 0 elsewhere. The *md*(*i,t*) equals 1 if wetness index is less than -3, and decrease linearly from 1 to 0 for the wetness index moving from -3 to 3 m amsl, and it equals 0 elsewhere. Finally, the *mv*(*i,t*) equals 1 if the ndvi value is less than -0.05, it equals 0 if the ndvi is larger than 0.05 and it decrease linearly from 1 to 0 in between.

To include temporal uncertainty into the beach nourishment processes, we consider daily fluctuations for the wetness index, monthly fluctuations for the vegetation index and yearly fluctuations for altitude. These assumptions are based on observation methods and applied on the most appropriate time scale for these attributes. However, weather influences are neglected as these are complicated to observe and difficult to model due to several time dimensions.

Temporal membership functions are introduced, which have the highest values when the most reliable data can be collected. For vegetation, the *nv*(*t*) equals 1 between 1 June and 1 August, it equals 0.5 between 1 November until 1 March, and it is linear in between. Similarly *nd*(*t*) equals 1 during flood time and equals 0.5 during low tide, and further follows a sine form, i.e. $nd(t) = 0.75+0.25\cdot\cos(2\pi\cdot t/12.5)$, with *t* expressed in hours in relation to high tide. Finally, the function *nb*(*t*) is included to describe the actual digital elevation model. For the simplicity, we correct the slopes of the membership functions derived from equations (1) and (2) with a correction factor related to the temporal (un)certainty of the vegetation- and wetness index, as described above.

2.4 Quality Elements and Quality Matrix

2.4.1. Quality elements: For the spatial uncertainty of the beach compartments, we encounter the following ISO quality elements and subelements as most essential (ISO 2003):

- *Positional accuracy*
  Relative or internal: closeness of the relative positions of objects in a dataset to their respective relative positions accepted as or being true.
  Gridded data position: closeness of gridded data position values to values accepted as or being true.
- *Thematic accuracy*
  Accuracy of quantitative attributes: the correctness of quantitative attributes and of the classifications of objects and their relationships.
  Classification correctness: comparison of the classes assigned to objects or their attributes to a universe of discourse (e.g. ground truth or reference dataset).
- *Completeness*
  Data completeness: the commission and omission of datasets.

For the temporal uncertainty of the compartments, we recognize for different time scales:

- *Temporal accuracy*
  Accuracy of a time measurement: correctness of the temporal references of an item (reporting of error in time measurement).

2.4.2. Quality matrix: By applying an ontological approach, we can construct a quality matrix, whereby ontological features as objects, attributes relationships, processes and events are projected against quality elements, as described above. Table 1 describes the quality of objects, attributes and processes in a general fashion that applies to the case study. Different membership functions occur, whereas spatial and temporal accuracy apply to a limited set of objects.

The prominent feature of interest is the amount of beach volume, represented by C.vol in table 1. Within one year, C.vol can be calculated for each compartment, as well as its quality parameters (see table 2).

3. VISUALIZATION OF THE QUALITY MATRIX

In the beach nourishment application, we can easily depict a map with beach compartments suitable for nourishment. However, trends and associations between compartments, changes in time and quality elements involved in the decision making, are more complicated to visualize. As quality elements are multivariate in purpose – i.e. there are many quality elements studied for each ontological feature – multivariate visualization tools are the most appropriate display technique. Furthermore, to detect trends and the evolution of the quality elements in time, a temporal element should be included in the visualization tool.

	Positional Accuracy		Thematic Accuracy		Compl.	Temp. Acc.
Objects	Rel.	Grid.	CC	QAA	Data	ATM
C.id	48.6 m	30.3 m			86.7%	< 1 year
CL.id	NR	30.3 m			86.7%	< 1 year
BD.id	48.6 m	30.3 m			86.7%	< 1 year
BS.id	48.6 m	30.3 m			86.7%	< 1 year
Attributes						
C.vol	48.6 m	30.3 m	mv(i,t)	± 0.28 m	86.7%	nb(t)
C.vol90	48.6 m	30.3 m	mv(i,t)		NR	nb(t)
CL.geo	NR	30.3 m			86.7%	
BD.geo	48.6 m	30.3 m	mv(i,t)		86.7%	
BD.ndvi	48.6 m	30.3 m		NR	86.7%	nv(t)
BD.z	NR	30.3 m		± 0.28 m	86.7%	
BS.geo	48.6 m	30.3 m	mv(i,t)		86.7%	
BS.wi	48.6 m	30.3 m		NR	86.7%	nd(t)
BS.z	NR	30.3 m		± 0.28 m	86.7%	
C.se	48.6 m	30.3 m	mv(i,t)		86.7%	nd(t)
Processes						
C.vol/t						< 10 year
TL.id						< 1 year
TL.trend						< 1 year

Table 1. Quality elements for the ontological features for 1995. Abbreviations: CC = classification correctness, QAA = quantitative attribute accuracy, ATM = accuracy of time measurement, NR = not relevant.

C.id	C.vol	Positional Accuracy		Thematic Accuracy		Compl.	Temp. Acc.
		Rel.	Grid.	CC	QAA	Data	ATM
#	m3	m	m	%	m	%	%
260	1.02E+04	48.6	30.3	0.212	0.28	0.133	0.326
280	6.87E+03	48.6	30.3	0.185	0.28	0.133	0.331
300	2.01E+03	48.6	30.3	0.169	0.28	0.133	0.275
301	4.82E+02	48.6	30.3	0.123	0.28	0.133	0.255
302	2.56E+03	48.6	30.3	0.253	0.28	0.133	0.324
303	3.18E+03	48.6	30.3	0.167	0.28	0.133	0.313
304	5.33E+03	48.6	30.3	0.198	0.28	0.133	0.290
320	…	…	…	…	…	…	…

Table 2. Amount of beach volume for each compartment (*C.vol*) and its quality elements for 1995. Abbreviations: C.id = compartment id., C.vol = beach volume per compartment, CC = classification correctness, QAA = quantitative attribute accuracy, ATM = accuracy of time measurement, NR = not relevant.

Here, we discuss some aspects to fulfil the aim to construct a prototype illustrating the quality elements involved in a beach nourishment process. First, it should incorporate interactivity between separate windows, i.e. it should have dynamically linked views. Second, the prototype should handle high dimensionality of the attributes, using multivariate visualization tools. Last, it should be able to deal with multi temporal datasets and to detect trends in the beach nourishment process and its quality elements during multiple time observations.

3.1 Dynamically Linked Views

With dynamically linked views we mean that graphs (e.g. multivariate visualization techniques) and maps are displayed separately but dynamically linked. If one element in a map is clicked, the corresponding elements in other maps or graphs will be highlighted. Conversely, by clicking on these information elements in a graph, the particular object will be highlighted in the map. Dynamically linked views increase the user interactivity and are now considered indispensable for supporting data exploration.

In the beach nourishment application, these information elements concern the quality elements from table 2, which can be activated by pressing the mouse button at a compartment. A separate graphic will show the quality values for that particular compartment. Also, by clicking on a phenomenon in a graphic, the compartment concerned will be highlighted in the map.

3.2 Multivariate Visualization Tools

There are several methods to visualize spatial data quality (McGranaghan, 1993; Lucieer and Kraak, 2002; Van der Wel et al., 1994). Here, we focus on multivariate visualization techniques for illustrating the quality elements for beach nourishments derived from the ontological approach.

Over the past decade, many different visualization techniques have been developed (Card et al., 1999). For geographic data, visualization techniques can be categorized in geometrically transformed displays or iconic displays. The geometrically transformed displays include the scatterplot matrix, a commonly used method in statistics, and the parallel coordinate plot (Inselberg, 1985), that is a popular technique in exploratory visualization. Star plots (Chambers et al., 1983) and Chernoff faces (Chernoff, 1973) are techniques of iconic displays that visualize each data item as an icon and the multiple variables as features of the icons. From all these techniques, the dynamic parallel coordinate plot has been demonstrated as a powerful multivariate visualization technique (Spence, 2001) and has been used in several applications (McGranaghan, 1993; Lucieer and Kraak, 2002).

The dynamic parallel coordinate plot was introduced in 1985 by Inselberg (Inselberg, 1985). The display is obtained by taking dimensions as vertical axes thereby arranging them parallel to each other. The individual data values are then marked off for each dimension onto corresponding coordinate with the highest data value as maximum value and the lowest as minimum. From the structure of the resulting display one can draw conclusions for the relationship of the corresponding data values. A group of lines with a similar gradient can, for example, indicate that their data records correlate positively. Furthermore, outliers in values are easy to detect.

3.3 Temporal Ordered Space Matrix

To deal with multi-temporal datasets, we propose a novel visualization technique, whereby linear elements (as with coastline compartment) are portrayed against the temporal variations of a particular user-defined quality element. Therefore, we construct a matrix of squares, named temporal ordered space matrix. In horizontal direction, the matrix is a sort of schematized map and represents each compartment as a cell in identical order as in Cartesian space. Hence, compartments in the west of the study area are depicted in the matrix left of compartments in the east. The decision maker needs to reflect each quality element with a conformance quality level, i.e. a threshold value. When quality elements fulfil the threshold value, they are shown as green cells. However, if they fail, they are show as red cells. Quality elements close to the threshold value are shown as orange cells. The time is projected in vertical direction. Hence, the evolution of quality elements can be easily interpreted from the temporal ordered space matrix.

The main advantage of using ordered space is the preservation of the adjacency relations between the compartments. This will assist the decision maker in understanding and detecting areas where effects of quality elements are important.

4. PROTOTYPE

Using the results of table 2 and visualization techniques as mentioned above, we designed a prototype for multivariate visualization, composed of three sections (see figure 3). The first section is the main interface that displays a base map of the study area. A pull-down menu gives the user the selection of maps illustrating the beach volume or particular quality elements for each compartment.

The second section consists of a parallel coordinate plot (PCP). In the PCP each line represents a compartment. The vertical axis shows the quality elements derived from table 2 for each compartment. Here, the lower a line is located in the plot, the better the dataset meets the user's preferences. In the PCP the user can also the possibility to display the available datasets for all times. Consequently, the PCP will display a particular quality element as a time series, with the recorded date on the vertical axis. A menu next to the display will give the opportunity to display the quality elements per compartment or as a timeserie.

The third section is the temporal ordered space matrix. Next to the matrix is an entry menu, where the user can select a particular quality element. Additionally, the user can enter a threshold value for a particular quality element. The distribution of this quality element in (ordered) space and time, as well as its ability to meet the threshold value, will be depicted in this matrix.

The prototype enables interactivity between the sections. The user can explore the dynamically linked displays by pointing the mouse on a compartment in the map and the corresponding PCP-axis or matrix cell becomes highlighted. Vice versa, the user can point on specific line or matrix cell leading to the highlighted contour of the corresponding compartment. Even more, the user can select a dataset by a moving window in the temporal ordered space matrix. Besides, the user can select a threshold value, changing the color legend of the map and the PCP (see figure 3).

5. DISCUSSION

The prototype for multivariate visualization of spatial data quality elements can be useful for interactive and explorative purposes. Further elaboration of the prototype will help in understanding datasets and their quality elements by instant view. Its effectiveness towards insight of the data and their shortcomings related to their quality, help decision makers to determine which objects are of interest for beach nourishments.

For general purposes, a multivariate visualization tool as proposed by this prototype is useful for decision makers to understand the dataset and to support the decision makers in their analyses or predictions.

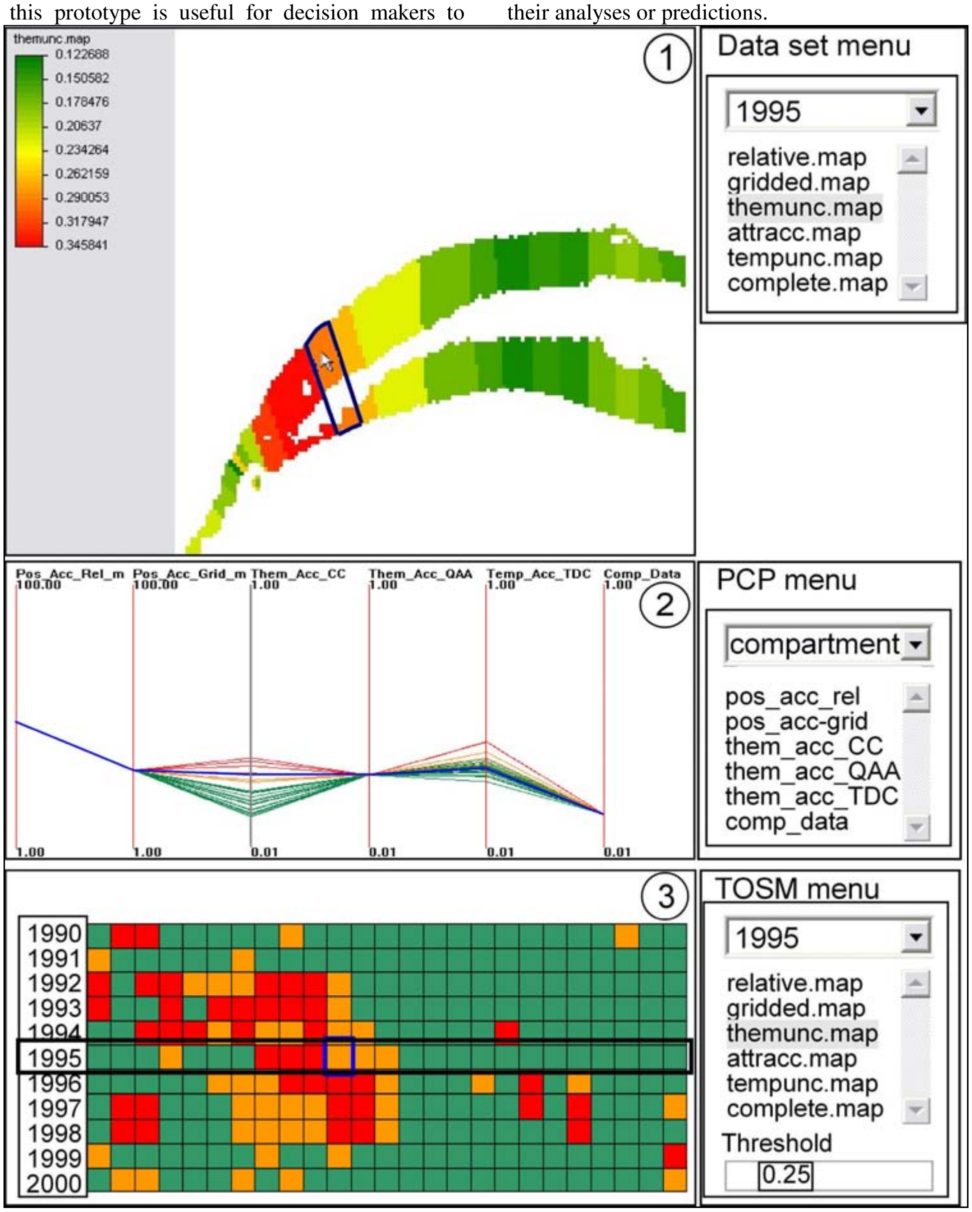

Figure 3: A prototype for multivariate visualization of quality elements for the beach nourishment process. Section 1 is the main display, showing the thematic uncertainty of the compartments for 1995. Section 2 is parallel coordinate plot, showing all quality elements for every compartment. In the PCP menu the user can select to visualize all quality elements per compartment or as a timeserie. Section 3 is the temporal ordered space matrix. In the TOSM menu, the user can enter a threshold value for an user-required quality. With a window slider the user can select a specific observed dataset.

For proper use of the visualization tool, it is essential that a user understands the objectives of the visual exploration and the meaning of what is visible in the patterns displayed. The visualization tool must be straightforward and uncomplicated in order to support rather than obstruct understanding. Therefore, a working prototype needs to be developed and introduced to several users for empirical assessment and comments. Users' comments will be vital to determine whether the techniques are comprehensible, and also to determine the degree to which users may be able to benefit from visualization of quality elements. These comments are needed in order to refine design requirements for a prototype visualization environment.

Hence, the usability of the prototype will be tested by a group of target users. The users have a chance to try out the working of the prototype. Furthermore, the users' performance with the prototype will be measured against predefined quantitative and qualitative usability specifications. Subsequently, the outcome of the usability test will show whether the product is a success or not. Faulkner (2000) states that usability information gathered from this final stage of a usability evaluation process is important for future projects, although the shortcomings are, that the test only last for limited time periods and the method emphasize first time usage.

When visualizing multi-temporal data, it seems obvious to use animation techniques. Animation produces strong visual effect on the viewer and it is able to demonstrate some rather apparent trends, like beach erosion or sedimentation. On the other hand, the usefulness of animation for data exploration, i.e. for the detection of new knowledge, must not be overestimated (Adrienko et al., 2000). It is hard to differentiate between images when we compare states of a phenomenon at different time moments or when changes over time are minimal or scattered. Recently a number of tools for controlling animation have been suggested that improve its suitability for analysis (Kraak, 2003). Further advancement of the map animation technique can be achieved by means of combining it with additional displays of the same data as well as various transformations of the data. In particular, the amount of change between two time moments can be computed and visualized. For visualizing multivariate multi-temporal datasets, animation tools might not be the most appropriate visualization technique. Therefore, we chose to show individual quality elements for each compartment in a temporal ordered space matrix.

6. CONCLUSION

We designed a prototype for multivariate visualization, to detect trends and associations in the data and represent its quality elements. As a case study, we apply an ontologically based approach on a beach management application, to derive to quality elements involved for beach nourishment. By means of multivariate visualization of quality elements, the prototype will help in understanding datasets and their quality elements by instant view. Its effectiveness towards insight of the data and their shortcomings related to their quality, help decision makers to determine which objects are of interest for beach nourishments. The prototype can be useful for interactive and explorative purposes and its strength to deal with non temporal, as well as multi-temporal data.

ACKNOWLEDGEMENTS

The work was funded by the European Community, under IST-1999-14189 project REV!GIS. The datasets have been made available by Rijkswaterstaat and RIKZ.

REFERENCES

Andrienko, N., Andrienko, G., and Gatalsky, P. (2000) Towards Exploratory Visualization of Spatio-Temporal Data. 3rd AGILE Conference on Geographic Information Science, Helsinki/Espoo, May 25-27, pp.137-142

Card, S.K., Mackinlay, J.D., Shneiderman, B. (Eds.) (1999) *Readings in Information Visualization*. Using Vision to Think. Morgan Kaufmann Publishers, Inc, San Francisco.

Chambers, J.M., Cleveland, W.S., Kleiner, B., & Tukey, P.A. (1983). *Graphical Methods for Data Analysis*. Belmont, CA: Wadsworth.

Chernoff, H. (1973). The use of faces to represent points in k-dimensional space graphically. *Journal of the American Statistical Association*, 68:361-368.

Faulkner, X. (2000). *Usability Engineering*. Palgrave, New York.

Inselberg, A. (1985). The plane with parallel coordinates. *The Visual Computer* 1(2): 69-91.

ISO (2003). "ISO/TC 211 Geographic information/Geomatics - 19113, 1914, Geographic information quality, and evaluation procedures, as sent to the ISO Central Secretariat for publication." 68 p.

Jeansoulin, R. and Wilson, N., (2002). Quality of Geographic Information: Ontological approach and Artificial Intelligence Tools in the REV!GIS project, 8th EC-GI&GIS Workshop, Dublin 3-5 July, 2002.

Kraak, M.J. (2003). Geovisualization illustrated. *ISPRS Journal of Photogrammetry and Remote Sensing*, 57 (1) pp. 1-10.

Lucieer, A. and Kraak, M. (2002). Interactive visualization of a fuzzy classification of remotely sensed imagery using dynamically linked views to explore uncertainty. In Hunter, G. and Lowell, K., editors, *Proceedings Accuracy 2002*, 5th International Symposium On Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, pages 348-356, Melbourne, Australia.

MacEachren, A.M., (1992). Visualizing uncertain information. *Cartographic Perspectives*, no. 13, p. 10-19.

MacEachren, A.M. (1995). *How maps work, representation, visualization, and design*. New York etc.: The Guiford Press.

McGranaghan, M. (1993). A Cartographic View of Spatial Data Quality, *Cartographica*, 30(2 & 3), pp. 8-19.

Matange, S, Beamon, J. and Huffman, C. (1998). Multidimensional Data Visualization Tools. SAS Institute Inc., Cary. NC. Proceedings of the Twenty-Third Annual SAS users group international, Nashville, Tennessee. 22-25 March 1998. http://www2.sas.com/proceedings/sugi23/Infovis/p145.pdf

Roelse, P., (2002). Water en Zand in Balans. Evaluatie zandsuppleties na 1990; een morfologische beschouwing. Internal Report Rijksinsituut voor Kust en Zee, 2002.003, Middelburg, The Netherlands, 108 pp.

Schmid, C. and Hinterberger H. (1994). Comparative Multivariate Visualization Across Conceptually Different Graphic Displays. *Proceedings of the Seventh International Working Conference on Statistical and Scientific Database Management*, SSDBM 94, Charlottesville, Virginia, September 28 - 30, 1994, IEEE Computer Society Press, Los Alamitos, California, 1994.

Spence, R. (2001). *Information Visualization*, Addison Wesley / ACM Press Books, Harlow.

Van der Wel, F.J.M., Hootsman, R.M., and Ormeling, F.J. (1994). Visualization of data quality, in MacEachren, A.M., and Taylor, D. R. F., eds., *Visualization in Modern Cartography*, Elsevier, Amsterdam, p. 67-92.

Van de Vlag, D.E., Stein A. and Vasseur, B. (2004). Concepts and Representation of Beach Nourishments by Spatio-temporal Ontologies. In *Proceedings of the ISSDQ '04*, GeoInfo Series, Vienna. pp. 353-369

Vasseur, B., Vlag, D.E. van de, Stein, A, Jeansoulin, R. and Dilo, A. (subm.), Ontologie Spatio-Temporelle d'Objets Flous et Dynamiques pour la Maintenance des Zones Côtières Hollande. In: *Revue Internationale de Géomatique*, Numéro Spécial 'les Ontologies Spatiales'.