COASTAL SCENARIOS DOCUMENTED WITH DIGITAL ATLASES - COMPUTATIONAL MODELING AND METADATA

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Digital atlases with the facility for interpolation between pre-calculated states are introduced as fast alternative tools for detailed computational modeling in coastal studies. Standardized metadata used in coastal zone management are applied to document these scenarios. The generalized interpolation methods presented are metadata-driven and embedded in databased web services and interactive wind- and wave-atlas applications.

INTRODUCTION

Collections of maps, traditionally bound into book form, and sometimes accompanied by supplementary illustrations and graphic analyses are valuable sources of synoptic information. Such atlases represent the principal natural, physical or climatic elements of specific regions for rather long time periods. Information portals like the Schleswig-Holstein Environmental Atlas (2007) in Germany offer thematic maps for sediment distributions or water quality parameters online. Sometimes the underlying data can be directly accessed from the web site. Digital atlases, like the World Wave Atlas outlined by Krogstad and Barstow (1999), which is based on remote sensing, available field data and global or regional model output, are increasingly applied. Coastal defense works, design of dikes, harbor design and operations, coastal erosion studies, risk assessment or planning fall into the scope of application of wave atlas data.

Process-based numerical models can be very time-consuming in producing simulation results for given events due to the amount of input data and boundary condition specifications. Generalized interpolation procedures applied to pre-calculated scenarios, which result from systematic parameter variations are considerably faster in modeling preselected events.

Online-simulations based on pre-calculated scenarios can be carried out in very little time and the resulting data can be visualized with map servers, which provide a portrayal of geographic information as a digital image file suitable for display on a computer screen. However, there is no mechanism to invoke interpolation procedures within the OGC standards specified by Beaujardière (2002) for map server technology.

The digital atlases presented here as web services go beyond simple maps. They provide functionality for the interpolation of events and the generation of space and time varying data sets.

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Both the experts responsible for decision making and the public information for non experts benefit from systematic studies of scenarios, which are provided as multimedia offerings. In addition to pre-fabricated maps, the results of online simulations taking into account user selected values of parameters are displayed, posing new challenges to quality assurance measures.

Metadata for computational modeling as introduced by Hill et al. (2001) can be used for sound documentation of models and scenarios. The North Sea and Baltic Sea Coastal Information System NOKIS (2007) provides an adequate information infrastructure to host and manage relevant metadata for reproducible simulation results. This is an important sustainability aspect for models applied in environmental impact studies.

DIGITAL ATLASES

Atlases are collections of thematic maps, which provide two-dimensional views of spatial data. Scalar parameters are presented as contour lines and surfaces. Vector quantities are usually visualized as arrows

Examples from coastal engineering are the depth distribution and, more importantly, those physical quantities with an impact on the coast such as water levels, waves, current velocities and meteorological parameters. All of these are varying over space and time, which poses problems to adequate representation in classical print media.

The digital atlases outlined in this paper are not limited to classical static maps but use animations to visualize the temporal evolution of dynamic physical quantities.

Topographic Maps

Topographic and bathymetric maps are typical components of atlases where elevations and under water depth distributions are represented by contours or surfaces. In general, the data base consists either of triangulated nodes resulting from irregularly distributed survey points or of regular grids and associated interpolation methods.

The continuously changing bathymetry in the Wadden Sea is best documented with space and time varying digital bathymetric models where each map represents a particular instant in time. Taking the difference of such maps gives an indication of erosion and sedimentation rates as indicated in Fig.1.

Computational fluid dynamics and transport models help to fill the spatial and temporal information gaps left by remote sensing and platform based monitoring of coastal waters. The objective in the context of digital atlases is not hind casting of individual recorded events, but rather a systematic variation and documentation of principle parameters governing the study domain.

Phenomena such as coastal morphodynamics depend on a wide range of variables. These include sediment characteristics and sediment availability, river discharges, tidally induced circulation patterns, the local wave fields and the wind fields, which drive both currents and waves. The data base compiled for a comprehensive coastal digital atlas ideally covers both the spatial domain characteristics (bathymetry, sediment) and the dynamic parameters obtained from modeling in a consistent manner. Morphological stability maps can be derived from time variable digital bathymetry atlases, which represent areas with significant depth variations shown as dark patches in the right panel of Fig. 1.

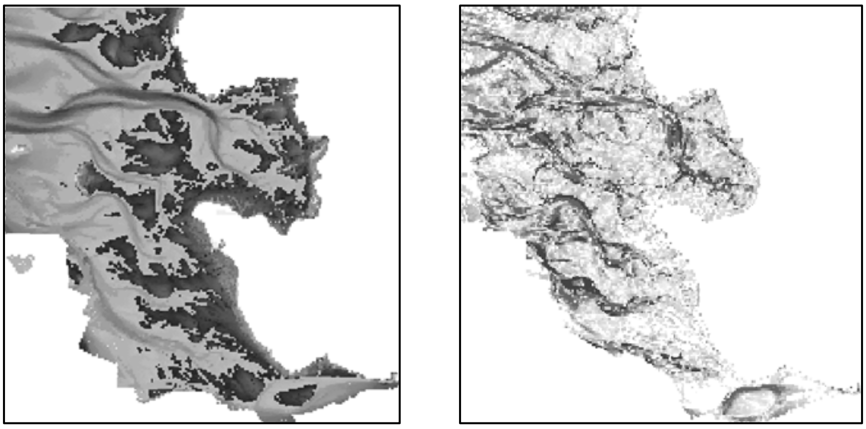

Figure 1. Estuarine bathymetry (left). Morphological stability map (right).

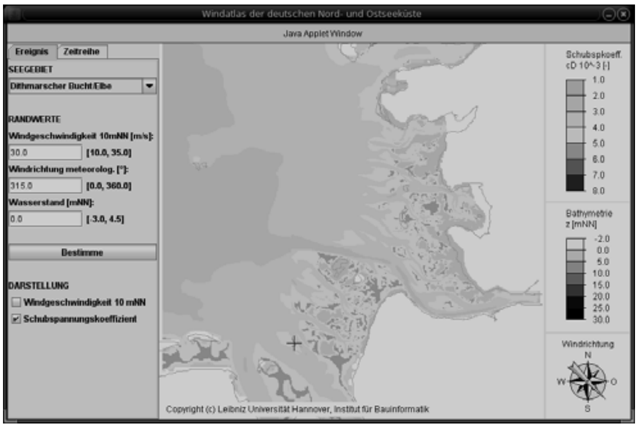

Figure 2. Digital wind atlas. Display of shear velocities along the North Sea coast of Germany in Dithmarschen Bight and Elbe estuary.

Wind Atlas

The German Meteorological Office carried out a systematic modeling study of wind fields in the German Bight of the North Sea. Ganske et al. (2007) present the large scale meteorological simulations resulting in locally mass consistent wind fields, which can be used to set up a digital wind atlas.

Boundary conditions for these studies are the wind velocity U [m/s], the meteorological wind direction θ [°] and the reference water level η [mNN]. Result parameters of the simulations are the near-bottom wind velocity u_{10} [m/s] and the shear velocity u_*, which can be used as input parameters for coastal flow and wave models.

Fig. 2 shows a classical wind atlas view for shear velocities along the German North Sea coast in Dithmarschen Bight and Elbe estuary. This scenario is characterized by a wind velocity of 30m/s, north westerly wind direction and mean water level.

Wave Atlas

In the case of wave studies there are model runs necessary with l different wind speeds u [m/s], m different wind directions θ_W [°] and n different water levels η [m] to capture spring, mean and neap tidal conditions, which result in l•m•n steady wave states for the domain. The wave model used in this study was developed by Milbradt (2007). At each computational node the parameters wave height h [m], wave length l [m], wave direction θ_S [°] and wave period T_P [s] are stored.

Fig. 3 illustrates a visualization prototype Java applet with zooming capability. Selection menus for the scenarios (input parameters u, θ_W and η) and the desired data layers (h, l, θ_S, T_P and bathymetry) provide display options well known from GIS environments.

This user interface shows the results of an online simulation in the vicinity of Sylt Island at the German North Sea coast. The wave heights in the entire domain are represented by surfaces, and the according wave directions and wave lengths are displayed on a regular visualization grid. Wave height values at particular locations, e.g. at the southern tip of the island, can be retrieved by clicking on the map, which results in printing of the value at the top the window.

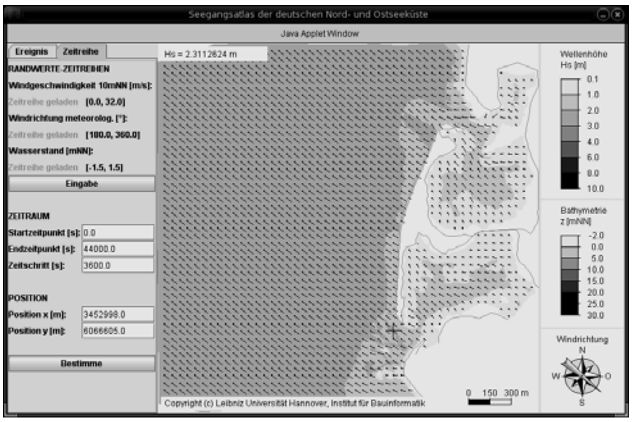

Figure 3. Digital wave atlas. Visualization of wave heights and directions near Sylt Island at the German coast of the North Sea.

The digital atlas can also be used to create time series of wave parameters at selected locations in an online simulation. In this case, time series for the input parameters wind velocity, wind direction and water elevation are imported and evaluated for a given time interval at a particular location within the study domain. The input and output parameters are plotted as shown in Fig. 4 and Fig. 5 and can also be exported/saved as tables.

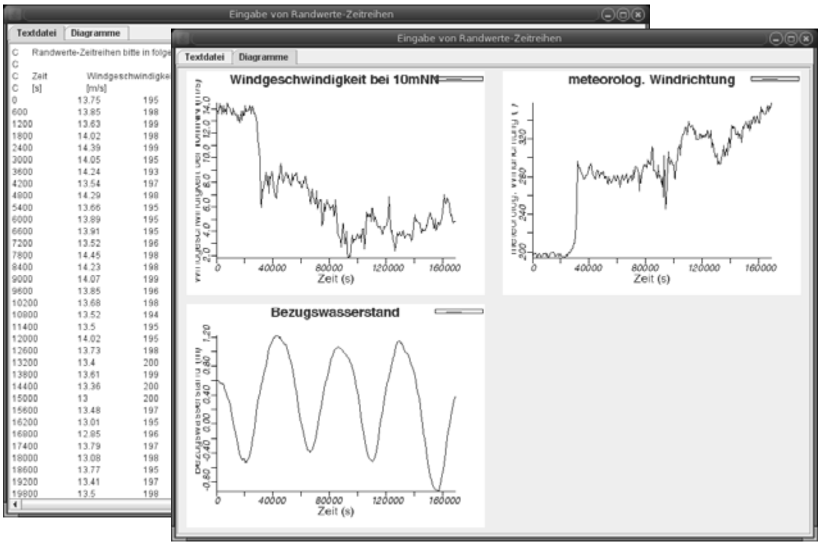

Figure 4. Import of boundary value time series as text file and according diagrams.

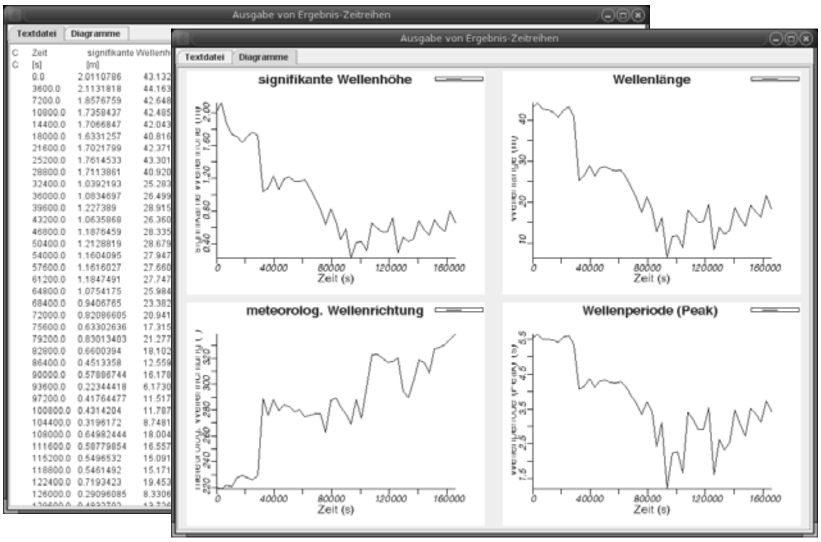

Figure 5. Output of resulting time series as text file and according diagrams.

Apart from simple visualization and statistical analysis the pre-calculated data of a digital atlas for wind, currents and waves can serve to get fast estimates for impacts of exceptional events, for instance oil spills. It could also be used to identify tendencies of morphodynamically active regions by taking into account the bottom shear stress related to the dynamical scenarios and the sediment characteristics.

New online calculation tools for wave overtopping have recently been published by Pullen et al. (2007). Numerical results from the digital wave atlas can be used here as input data for empirical overtopping predictions as described in the manual. They can also be used in neural network applications, which constitute alternative calculation methods for loads on sea defence structures.

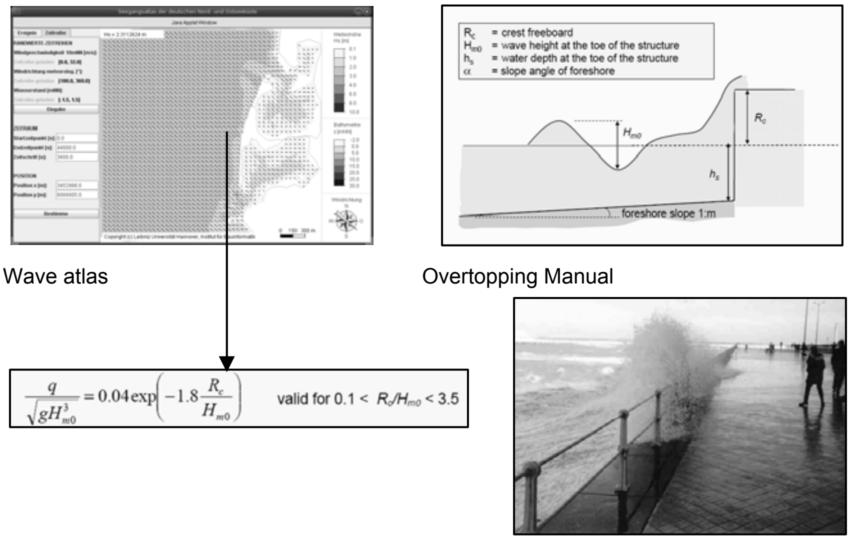

Figure 6. Services derived from the wave atlas.

INTERPOLATION

Interpolations based on steady state simulations with systematic parameter variation have the advantage of being much faster than simulations with numerical models, in particular for extensive datasets related to digital atlases. Although interpolations can only be approximations, they are in general sufficient for an impact assessment of selected scenarios.

Interpolation aims at finding a function for given discrete data that represents these data. Best known and widely used in practice is linear interpolation, which dates back to Newton. Two points (x_0, f_0) and (x_1, f_1) are connected by a straight line with

$$f(x) = \lambda_0 f_0 + \lambda_1 f_1 \tag{1}$$

and

$$\lambda_1 = \frac{x - x_0}{x_1 - x_0} = 1 - \lambda_0 \quad (2)$$

Adjacent nodes are connected with a straight line in piecewise linear interpolation in order to determine the intermediate values which results in a discrete scalar function. Usually, interpolation is carried out for spatial variables but interpolations in other dimensions are also conceivable.

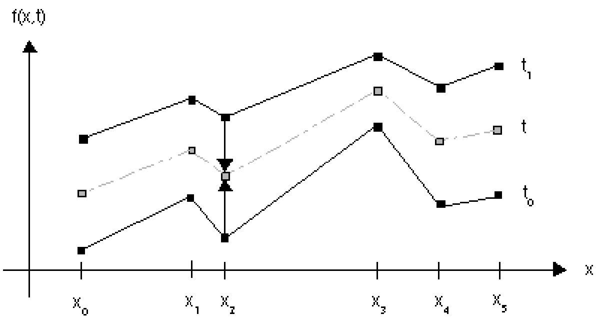

Figure 7. Linear interpolation between two discrete scalar functions.

An interpolation function for two discrete scalar functions with different given values at identical nodes can be constructed by linear interpolation of the nodal values. The linear factors λ_0 and λ_1 in Fig. 7 are dependent only on time. For several attributes per node typically resulting from numerical simulations the linear factors are identical for each attribute and are calculated only once.

In the case that several different global boundary conditions are applied, several interpolation directions need to be considered. The given data sets can be sorted into an n-dimensional lattice according to these directions. The interpolation is then carried out along the edges of this lattice. In the first step all necessary solutions for the first parameter are determined, followed by solutions for the second parameter based on the already interpolated parameters until in the end there is only one final solution left. In general, 2^n-1 linear interpolations are necessary for an n-dimensional parameter space.

The specific feature of the presented wave atlas is the facility for interpolation between existing states. The underlying data base is created by using three different global boundary conditions for wind velocity u, wind direction θ_w and water level η. For the interpolation of new scenarios, a three-dimensional lattice of nodes with metadata sets is constructed. Each metadata set in Fig. 8 contains the existing values of the spatially varying parameters (u, θ_w, η) and a link to a pertaining data set, which represents in this case an existing wave parameter set h, l, θ_S and T_P .

Fig. 8 illustrates that 7 interpolations are necessary to determine the local wave parameters for a requested data point: 4 in the u-direction, 2 in the θ_w-direction and 1 in the η-direction.

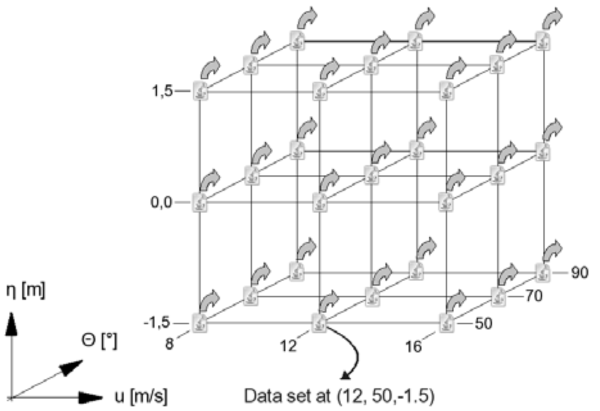

Figure 8. Lattice of nodes with given parameter sets and related data sets.

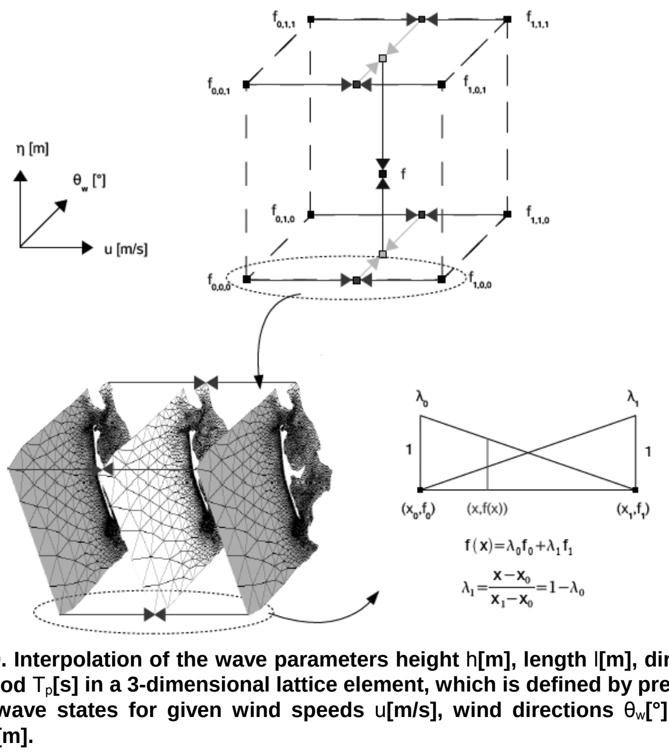

Figure 9. Interpolation of the wave parameters height h[m], length l[m], direction θ_s[°] and period T_p[s] in a 3-dimensional lattice element, which is defined by pre-calculated steady wave states for given wind speeds u[m/s], wind directions θ_w[°] and water levels η[m].

The algorithm for interpolation of wave parameters according to user input of boundary values proceeds as follows: First, the lattice element pertaining to the requested parameter set (u, θ_w, η) is identified by comparison with the metadata available for all lattice nodes. If data exist for these boundary values, they are loaded from the database. If not, interpolations along the edges of a lattice element are carried out as illustrated in Fig. 9: Starting with 4 interpolations in the u-direction (wind velocity), followed by 2 interpolations in the θ_w-direction (wind direction) and finally 1 interpolation in the η-direction (water level). The individual data sets are loaded from the database as needed.

To speed up the interpolation process, all data are stored in a database. Due to the large number of nodes (more than 1 million for the presented wave atlas) efficient data reduction algorithms are applied in visualization procedures.

SYSTEM ARCHITECTURE

Metadata for Computational Modeling

An earlier study of different morphodynamic models by Lehfeldt et al. (2002a) has shown the sensitivity to boundary conditions and modeling techniques. This clearly demonstrates the need for documentation of the models, i.e. the numerical engines, and of the data used for initial values (important for morphodynamic studies in particular) and all the boundary conditions as well.

Metadata to describe a given scenario thus have to contain information about the physical concepts and numerical modeling techniques of the applied models. Details about the origin and quality of the datasets used by the indicated model complete the documentation of a scenario. In analogy to geographic metadata where uniform resource locators URLs point to the documented geographic data sets, there are URLs given here for the various input files of a model so as to be able to reproduce simulation result, provided the executable of the model is available. Details on a corresponding metadata model for computational models and scenarios, which extends the information infrastructure for Integrated Coastal Zone Management, are outlined by Lehfeldt and Heidmann (2003).

The availability of digital atlases is a valuable service for coastal zone management when for instance used in the context of operational sediment monitoring. The NOKIS coastal zone metadata profile initially introduced by Lehfeldt et al. (2002b) together with the new elements for documenting numerical simulations and scenarios bridge the gap between disciplines and ensure proper use and interoperability of data and modeling tools.

Software Components

Digital atlases are very challenging regarding the turn around times for creating maps when extensive datasets from numerical simulations or hydraulic field data are to be visualized.

Three-tier architectures using Java applets or stand-alone applications such as Java Webstart as communication means with the client have been developed for the digital atlases. There is an application layer between the client-layer and the data management layer, which secures the communication with the client and carries out the necessary interpolations proper by accessing the simulation data. The core element of the system architecture is an object-oriented database system db4o described by Paterson (2008), which hosts the model metadata, the simulation data as well as the selection and interpolation methods. The communication between the tiers is based on the efficient Remote Method Invocation RMI standard.

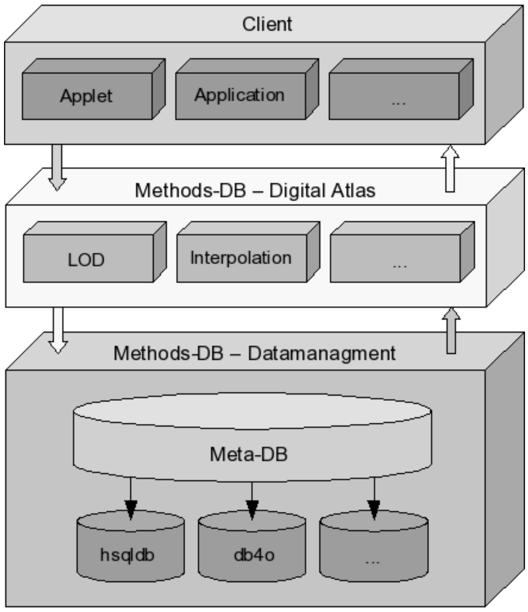

Figure 10. System architecture of digital atlases in NOKIS.

Data Management

Model metadata play a key role for fast and efficient data access of the digital atlas, in particular for high resolution simulation results. These extensive data sets are indexed in a specific way to support the interpolation process. The storage of objects and their mutual relations allows an initial identification by metadata before any links to the simulation data sets are activated in a second step if necessary. The db4o database supports this transparent activation of links as a valuable database feature.

The system architecture is open in that further database systems, which should be platform independent, can be added as needed.

Method Base

The method base contains the interpolation procedures discussed in this paper and complex data management procedures used in data reduction algorithms for data visualization. The required level of detail LOD for different zooming states is realized by refinement and coarsening techniques implemented for polygons and raster data.

The generic implementation of digital atlases provides for easy adaptation to further data sets either from field campaigns (e.g. sea survey, sediment distributions) or from numerical simulations (e.g. ground water).

CONCLUSIONS

Digital atlases with the facility for interpolation between pre-calculated states have been introduced as fast alternative tools for detailed computational modeling in studies of coastal scenarios. The documentation of these scenarios is carried out through standardized metadata, which fit into established national and international information infrastructures of coastal zone management.

The components of the digital wave atlas will be made compliant with the OPEN MI Standard outlined by Gregersen et al. (2007). Thus by way of web services, the results can be passed as boundary conditions to different simulation systems or specific analysis tools.

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