Center for Coastal and Ocean Mapping

9-2013

Designing Improved Sediment Transport Visualizations

Chris Englert
University of New Hampshire, Durham

Thomas J. Butkiewicz
University of New Hampshire, Durham, Thomas.Butkiewicz@unh.edu

Larry A. Mayer
University of New Hampshire, larry.mayer@unh.edu

Val E. Schmidt
University of New Hampshire, Durham, Val.Schmidt@unh.edu

Jonathan Beaudoin
University of New Hampshire, Durham

See next page for additional authors

Recommended Citation

Englert, C.M.; Butkiewicz, T.; Mayer, L.A.; Schmidt, V.; Beaudoin, J.; Trembanis, A.C.; DuVal, C., "Designing improved sediment transport visualizations Binding a GIS data model with human perception research," in Oceans - San Diego, 2013 , pp.1-9, 23-27 Sept. 2013

Authors
Chris Englert, Thomas J. Butkiewicz, Larry A. Mayer, Val E. Schmidt, Jonathan Beaudoin, Arthur Trembanis, and Carter Duval

Designing Improved Sediment Transport Visualizations

Binding a GIS data model with human perception research

Christopher M. Englert, Thomas Butkiewicz, Larry A. Mayer, Val Schmidt, Jonathan Beaudoin
Center for Coastal and Ocean Mapping Joint Hydrographic Center
University of New Hampshire
Durham, United States

Arthur C. Trembanis, Carter DuVal
Coastal Sediments, Hydrodynamics, and Engineering Lab
University of Delaware
Newark, United States

Abstract— Monitoring, or more commonly, modeling of sediment transport in the coastal environment is a critical task with relevance to coastline stability, beach erosion, tracking environmental contaminants, and safety of navigation. Increased intensity and regularity of storms such as Superstorm Sandy heighten the importance of our understanding of sediment transport processes. A weakness of current modeling capabilities is the ability to easily visualize the result in an intuitive manner. Many of the available visualization software packages display only a single variable at once, usually as a two-dimensional, plan-view cross-section. With such limited display capabilities, sophisticated 3D models are undermined in both the interpretation of results and dissemination of information to the public. Here we explore a subset of existing modeling capabilities (specifically, modeling scour around man-made structures) and visualization solutions, examine their shortcomings and present a design for a 4D visualization for sediment transport studies that is based on perceptually-focused data visualization research and recent and ongoing developments in multivariate displays. Vector and scalar fields are co-displayed, yet kept independently identifiable utilizing human perception's separation of color, texture, and motion. Bathymetry, sediment grain-size distribution, and forcing hydrodynamics are a subset of the variables investigated for simultaneous representation. Direct interaction with field data is tested to support rapid validation of sediment transport model results.

Our goal is a tight integration of both simulated data and real world observations to support analysis and simulation of the impact of major sediment transport events such as hurricanes. We unite modeled results and field observations within a geodatabase designed as an application schema of the Arc Marine Data Model. Our real-world focus is on the Redbird Artificial Reef Site, roughly 18 nautical miles offshore Delaware Bay, Delaware, where repeated surveys have identified active scour and bedform migration in 27 m water depth amongst the more than 900 deliberately sunken subway cars and vessels. Coincidently collected high-resolution multibeam bathymetry, backscatter, and side-scan sonar data from surface and autonomous underwater vehicle (AUV) systems along with complementary sub-bottom, grab sample, bottom imagery, and wave and current (via ADCP) datasets provide the basis for analysis. This site is particularly attractive due to overlap with the Delaware Bay Operational Forecast System (DBOFS), a model that provides historical and forecast oceanographic data that can be tested in hindcast against significant changes observed at the site during Superstorm Sandy and in predicting future changes through small-scale modeling around the individual reef objects.

Keywords— sediment transport; visualization; visual analysis; geodatabase

I. Introduction

The inner continental shelf off the eastern United States is an active sedimentary environment influenced by both currents and waves, and is of great importance to a range of user communities as it is the locus of a dense population base. Similar sedimentary environments exist seaward of many coastlines. Valuable natural resources derive from the regions' benthic, pelagic, and atmospheric zones. For example, investment in offshore wind turbine projects (worldwide) in April 2013 alone climbed over $3.3 billion [1]. Further, increased development in the coastal region has seen a broader stakeholder group realize the complex environmental and policy issues faced by those seeking to site structures offshore. Decades worth of research and experience has accumulated within the sediment transport and engineering communities regarding the design, installation, and monitoring of offshore structures on the inner shelf subjected to scour and erosion around their foundations. The present study intends to improve the communication of this knowledge to those performing siting evaluations. The scientific community provides data from laboratory and field observations and numerical models, in addition to developing tools for visualization and information extraction. We find limitations in the available tools for sediment transport visualization as well as the associated data management. Therefore, we propose a design to couple multiple sources of data (laboratory, field, and modeled) within a Geographic Information System (GIS) utilizing a geodatabase, and link to an improved analytical data visualization environment. We utilize a(n ongoing) repeat survey data set which contains obvious scour and sorted

978-0-933957-40-4 ©2013 MTS

bedform formation and evolution around hundreds of anthropogenic artificial reef features (see [2] for a site description) along with numerical models based on laboratory and field observations. The survey work is conducted by researchers from the Coastal Sediments, Hydrodynamics, and Engineering Lab (CSHEL) at the University of Delaware and the Center for Coastal and Ocean Mapping Joint Hydrographic Center (CCOM/JHC) at the University of New Hampshire. This survey work was originally supported in order to investigate feature detection within a dynamic bedform environment utilizing techniques developed in [3], yet is clearly becoming a more widely applicable high-resolution (25 cm gridded bathymetry and backscatter) field-study in active sediment transport within an inner continental shelf environment. We showcase one interoperability study.

The field of offshore wind energy is still relatively young, with Denmark installing the first large-scale wind array in 2002 [4]. To date, the major offshore wind farms in operation are located in the coastal waters of the UK and Europe (with the UK containing the largest installed capacity). The United States recently saw the installation of the first grid-connected floating offshore turbine pilot project in the Gulf of Maine and have approved standard monopile wind turbine farms in the states of Delaware, Maine, Massachusetts, Texas and Rhode Island. For a description of installed capacity, see [5] and [6]. The majority of installed turbines use the monopile or gravity base structure. Lessons learned through monitoring installed wind farms in the UK have included better preliminary siting assessments, with an emphasis by many experts on stricter site layout and design as part of the planning process. An informative layer missing from these assessments identified by a literature search and from publicly available spatial planning documents is an impact assessment to benthic communities due to scour and the subsequently altered surficial sediment distribution. This is important reasoning for our focus on sediment transport. Continental shelves will be increasingly populated by marine structures in future years, with ambitious development goals set by many countries. In short, these structures, when placed in the marine environment, act to increase flow turbulence, increasing the potential for scour. Vetted impact assessments should require local scour to be included. Although the related works section of this paper does list a number of investigations into scour prediction and scour prevention around offshore wind turbine foundations, the policy community is missing a tool for suitably incorporating these impacts with traditional assessment studies. A capable site design, planning and impact assessment system will require interactive navigation in space and time through a complex and usually heterogeneous data set. We find that the components required for such a system are currently available in both open-source and proprietary format, and our original contribution is to bring a collection together within a spatially aware GIS data model.

Data modeling is an effort, often used as a predictor, to capture the attributes and relationships of each piece of data utilized within a study in order to address the typical problems of data management occurring at multiple stages of interaction (acquisition, storage, analysis, dissemination). Advantages of a data model include ease of access through querying tools, more speedy software development utilizing Computer Aided Software Engineering (CASE) tools and reverse engineering or "development without programming" and a platform independent description of the data. A data model can save time in analysis, reduce costs, provide quality control, re-purpose model components, ensure consistency and traceability of model results, and offer scalability to solve complex modeling problems. A developer can create software with rich functionality by mapping out data interactions. Data modeling requires a substantial effort with numerous revisions. Therefore, it is beneficial for reasons of time and interoperability to inherit applicable behavior from previously developed data models adhering to community-defined standards in aspects of data collection, storage and manipulation. Luckily, there are dedicated research efforts in each of these fields with a wealth of information in the literature. Based on our search, we develop a data model that derives from the Arc Marine Data Model, established by efforts of the marine GIS community [7]. We find the Arc Marine Data Model suits the data type needs of this study. Although the important variables and governing equations (e.g. shear stress, threshold of motion) are generally universal, sediment transport research has some inherent data management issues. These come in the form of scale differences between investigations, model coupling when written in different languages, and various data production formats. The Arc Marine Data Model, however, is built to relate different data types by organizing into Marine Points, Marine Lines, Marine Areas and Marine Meshes. These were identified by the Arc Marine developers to be the most generic and widely applicable data formats found in marine applications. The data set chosen for this study is from a sorted bedform study at the Redbird artificial reef site 18 nautical miles seaward of Cape Henlopen, Delaware Bay. The Redbird site has been mapped with swath bathymetry systems aboard two survey platforms, the R/V Hugh R. Sharp, and an Autonomous Underwater Vehicle (AUV) manufactured by Teledyne Gavia. A multi-repeat survey program has been established utilizing the same sonar settings and survey lines. Auxiliary data include side-scan sonar data, bottom grab samples and bottom imagery. Customization of the Arc Marine Data Model is performed by definition of a Project Data Model (Fig. 1). We design based on a single case study application while keeping attention to the abstract classes required for a more widely applicable system. For example, our primary Marine Point data are bottom grabs. We inherit the attributes of a Marine Point in a bottom_grab child class, without limiting the use of other point data types.

An original contribution of this work in addition to the data model is a new data visualization environment. We believe the visualization environment itself is as important to improved visualizations as the data model itself. Data visualizations may be summed up by their purpose in enhancing a user's understanding of data over their raw form. Visualization can take the shape of charts, graphs, maps, videos, etc. Users require the ability to explore and manipulate their data in order to gain a better understanding. The visualization techniques within this study might best fit into a growing subdiscipline of data visualization known as visual analytics. Visual analytics is a multidisciplinary field with focus areas including: visual representations and interaction techniques designed for the human eye's perceptual pathway into the mind; data representations and transformations for converting sometimes dynamic data to support visualization and analysis; and techniques to support production, presentation and dissemination of analytical results in a user-centric context [8]. By design, the user can see, explore and understand large amounts of information simultaneously by maximizing the human capacity to perceive. In other words, visual analytics promotes analytical understanding and reasoning. Prior work by CCOM/JHC researchers has adapted visual analytic techniques to oceanographic and meteorological data [9]. A similar incorporation of these techniques for sediment transport related data has not yet been presented.

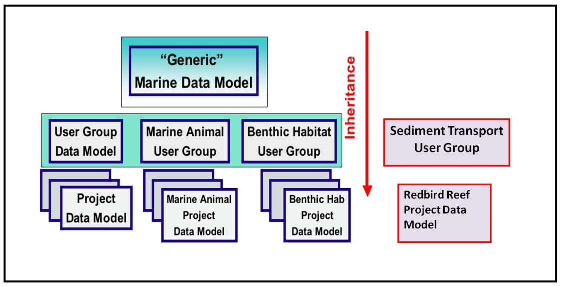

Fig. 1. The relationship of the Redbird Reef Project Data Model developed for this project with the overall Arc Marine Data Model inheritance scheme. The Sediment Transport User Group and Redbird Reef Project Data Model are applied in this study. Designing the Redbird Reef Data Model within this inheritance structure allows for tools developed at the "Generic" and other User Group levels to be retained alongside any customizations made in this study (Adapted from Arc Marine Data Model).

II. RELATED WORKS

The Bureau of Ocean Energy Management (BOEM) provides federal oversight to offshore wind in federal waters in the US. In 2010, the first lease for commercial wind energy in the US Outer Continental Shelf (OCS) was approved for the *Cape Wind* project, but construction has not yet begun. Therefore, when reviewing previous successes and failures of planning efforts, we must defer to experience in the UK and Europe where large offshore wind projects have been in operation since 2002. Leasing in the UK follows a developer-submitted-proposal approval process with evaluation based on four criteria: the financial and technical capacity of the applicant, the development plan, the business plan, and the decommissioning plan [10]. The present study is concerned with the development plan, which usually contains an environmental assessment. For information on previous studies regarding wind energy development and its environmental impact see [11] and [12]. We notice that benthic impacts are not present as a concern in these studies. Similarly, a methodology researched for the design of offshore wind farms [13] and an operational data integration proposed [14] give no attention to benthic impacts. Another insight from previous studies is the integral role of GIS-based spatial planning in aiding development of offshore wind [4]. The Northeast Regional Ocean Council provides a useful collection of the data layers typically available in spatial planning assessments. By visiting their Data Portal website (http://www.northeastoceandata.org/) one can find Northeast ocean data tailored to different users including Energy, which is split into three tabs: Potential (wind speeds), Planning Areas (leased and permitted blocks) and Infrastructure (submarine cables and energy facilities). We again see the lack of bottom type assessment and how this may be impacted due to the presence of new man-made structures. These are traditionally a more engineering concern (e.g. how much riprap to design for) rather than a concern for the environment. Also, the information gained has seemed to remain mostly within the sediment transport and engineering communities. A look into historical efforts by these groups is required.

The consequences and general importance of sediment transport in the inner shelf environment has resulted in a spectrum of research efforts documented in the literature. The research community is well-equipped with an assortment of theory, data collection methods, tools, and prior datasets to call upon (a short list includes [15] [16] [17] [18]). One branch of sediment transport investigation has been the development of 1D, 2D, and 3D numerical models, originating in that order. There is useful information gained through each perspective, as well as the ongoing effort to incorporate a 4th dimension: time. After all, scour development, growth, and/or filling under time-varying waves and currents is a time-varying process [19]. An example of a completed sediment transport modeling and visualization study is the USGS Woods Hole work on simulated evolution of sediment grain distribution on the seafloor in Massachusetts Bay [26]. Key variables in this study were bottom suspended sediment concentration, bottom stress, significant wave height, mean grain fraction of the sediment, and bathymetry change. GIS has only yet been mentioned in this paper for its contribution to spatial planning, yet it has also been utilized to benefit numerous sediment transport studies including [20] [21] [22] [23] [24] [25] [26]. The use of GIS principles and tools can contribute much to optimizing offshore wind energy projects [27] [28] [29]. Previous studies on scour around structures start with early work by [30] and have progressed to predictive models of scour depth and potential scour protection specifically in regard to offshore wind turbine foundations [31] [32]. Investigations have focused on multiple environmental settings including wave-induced scour in sand and silt [36] to nonlinear random waves plus a current [37]. Scour has been studied at vertical piles and at marine gravity foundations [31]. Whitehouse et al. [31] also provide a formal scour evaluation protocol. Furthermore, the Scour Time Evolution Predictor (STEP) model was developed by Harris et al. [19]. Equilibrium scour has been studied in noncohesive sediments under currents and waves [33], as have coherent structure dynamics and sediment particle motion in developing scour holes [34]; see also the review by Gosselin and Sheppard [35].

The sediment transport community has often faced the following challenges when investigating someone else's sediment transport or stratigraphic numerical model: need for source code familiarization, models written in different languages, high performance cluster (supercomputer) access, integration of field data and model simulations, and dissemination of information to the non-expert. One community effort driven by these challenges is the Community Surface Dynamics Modeling System (CSDMS - pronounced 'systems') for a full review, see [38]. CSDMS is an open-source modeling environment offering a growing library of community-generated models, developed to facilitate more rapid idea generation and hypothesis testing through linked and stand-alone models. As of March 2011, CSDMS repository held 4 million lines of code (53% in C or C++; 30% in Fortran; and remaining in Python and MATLAB code) underpinned by dozens of peer-reviewed papers. The component-based modeling of CSDMS splits a hosted model's code into three functions: Initialize, Run and Finalize (or an IRF interface). A calling program is then used in a larger application to run each required component. The CSDMS Modeling Tool GUI provides users a common interface to models constructed in different languages by different authors and for different purposes - for models even lacking an original GUI. The CSDMS, in summary, is a modeling framework aiding to reduce modeling complexity as it involves data transfer, grid meshing, up- or down-scaling, time stepping, computational precision, multi-processor support, cross language interoperability, and visualization. The advantage of incorporating this modeling system into the current research data model is to prevent a reinvention of the wheel - mostly in terms of model coupling.

Our improvement to data visualization tools available with model systems like CSDMS stem from current research into user-perception and multivariate displays. Perceptual theory guides the usability of variable displays, or whether or not variables interfere with one another [39]. Advancements in visual analytics build upon theoretical foundations of reasoning, sensemaking, cognition, and perception and combine these with practical experience with user tasks and processes. Examples where visual analytics built upon the human mind's ability to understand complex information visually include prior developments of a multi-touch 3D interactive software for analysis of ocean flow models [40] and a methodology for designing a perceptually clear multivariate display of weather data [9]. Ware and Plumley [9] determined that information was lost or diminished through use of an age-old meteorological information representation, the wind barb. Visualizing continuous multivariate maps is a task common to many disciplines including geology, physics, meteorology and oceanography. The lessons learned in [9] for meteorology are adapted for the sediment transport visualization environment developed in this study.

Furthermore, a data model following the guidelines of the Arc Marine Data Model is incorporated in this study in order to organize the appropriate sediment transport modeling variables and relationships and link them easily into the visualization software. Arc Marine is a geodatabase model created by researchers from Oregon State University, Duke University, NOAA, the Danish Hydrologic Institute and ESRI in support of the marine GIS community. Arc Marine was designed to provide a standardized geodatabase template upon which to develop and maintain marine research data model applications. A geodatabase is an organized hierarchy of data objects consisting of a collection of feature classes, object classes (tables), relationship classes, and feature data sets (feature classes that share a common spatial reference). All feature classes in a geodatabase are geographic objects representing a real world object (such as a sunken vessel), and have a defined spatial location. Conversely, object classes are not represented geographically (they are simply a table full of object-related information) yet can be linked to spatial information through a relationship class. Object classes store non-spatial objects like equipment specifications or survey information. The empty geodatabase schema, when filled with data becomes automatically organized with the appropriate feature classes and relationships for assembling, managing, analyzing and even publishing data [41]. For a proper tutorial on Arc Marine Data Model see [7] or the online tutorial at the Arc Marine website. These resources will quickly get one up to speed on the basics of a geodatabase, data loading, data display, and data model customization.

III. ANALYTICAL NEEDS

The design efforts of a visual analytic system should take into consideration the following topics: data processing and preparation, view generation & multiple view, exploration techniques, coordination & control, human interface, and usability and perception. The ocean is an under-sampled environment, so researchers must rely not only on the observation nodes they can sample, but use models to interpolate between observation nodes in space and time. Models are a representation of our current extent of what we know (and what we cannot yet quantify). Field and laboratory experiments test models under a range of conditions for benchmarking model performance in spatial and temporal tests. Data preparation for integrating a collection of data observation points and modeled results is usually a non-trivial task. User-interaction with models currently requires a significant investment in scripting customized data parsers. Even after years of developing visualization solutions, the data preparation phase still takes a long time and the ability to collect data far outstrips the ability to analyze the collected data [8]. We believe the transition between dimensions, reference frames and grid resolutions between models within the analysis and visualization stages should be seamless. Consistent data processing is an important consideration. To the benefit of this study, ongoing standardization efforts at the national and international research community levels are tackling interoperability in data definition (metadata), collection, interpretation, and sharing with the definition of standards such as the ISO series. In this study, the same processing scripts have been used for each survey when human-driven (and error prone) processing is not required.

Visualization could end by simply displaying variables within a static view. We believe, however, that view generation informed by user-needs is a lesson learned and highlighted in the current literature on data visualization and provides a greater deal of understanding for the end-user. To fully address view generation and multiple views would require another paper and therefore cannot be properly summarized here. One critical aspect, however, can be mentioned, which is the user-centric view generation design. Multiple views should be generated with a purpose in support of the user at the particular phase of data analysis. Populating an interaction with numerous and irrelevant displays will detract from the ease of perception. The user needs must be studied in advance. The user needs involved within this work include volume differencing, wave analysis, identification of the trends and events leading to present conditions, identifying possible alternative future scenarios and the signs that one or another of these scenarios is coming to pass and supporting the decision maker in times of crisis. The views generated must account for the proper scale of investigation, the parameters involved at the particular use-stage, and the source and associated quality of the information in that display (either observation or simulated). These aspects to the data are crucial when designing a visualization environment that will contain the information recognized by experts and utilized in their established algorithms, tools, workflows, etc. Examples of data aspects highly valued by sediment modelers include three-dimensional deposit shapes, sequences of chronostratigraphic 2-D surfaces, dynamic observations of flow properties, and spatial properties within a sediment volume [38]. Several studies have addressed user needs for offshore wind siting analysts [42] [43]. No matter the user-context, effective visual representations require a solid understanding of the visualization pipeline, the characteristics of the data to be displayed, and the analytical tasks at hand - although most visualization software is developed with incomplete information about the data and tasks [8].

The exploration techniques and coordination and control elements of this study are all within the capacity of the GIS data model. The user requires the ability to view and update model parameters within the visualization environment. These involve viewing of static versions of the data with rapid querying of associated data. The data model provides the required coordination and control with a well-defined network of data elements, attributes and relationships. When changes are made to the project, they must be recorded within the data model framework. Coordination and control also determine the data formats appropriate for an application. Arsenault et al. [44] found in order to support real-time tracing and animation of large numbers of particles that it was necessary to modify the structure of the data from the original model format (an irregular mesh sigma coordinate data structure) into a regular mesh sigma coordinate structure and store in NetCDF. NetCDF is a popular data format which has been shown to be useful in atmospheric and marine modeling [44]. We chose early on to support NetCDF imports into the data model and visualization environment. Methods to synthesize different types of information from different sources into a unified data representation so users can focus on the data's meaning in the context of other relevant data, regardless of data type; and develop methods and principles for representing data quality, reliability, and certainty measures throughout the data transformation and analysis process.

The human interface is a design aspect that should also be tailored to best fit the user need. Most visualization tools rely on the well-established mouse and keyboard interaction paradigm, and this trend is likely to continue. However, there are several attractive alternatives available. The most popular of these is touch-based interaction, which is becoming commonplace with the proliferation of mobile devices. One advantage of touch interaction is “direct manipulation” of onscreen entities, which makes interfaces more intuitive. Multi-touch enabled displays allow for the use of more complicated, multi-finger gestures and commands. For positioning and selection tasks, this includes the ability to input additional degrees-of-freedom: Whereas a mouse can only move in x and y, multi-touch interaction can support fluid movement in x, y, and z simultaneously[40]. For 3D visualization tools, this type of fluid interaction is critical, and has traditionally been enabled through either iterative mouse movements (e.g. move x,y first, then adjust z) or specialized (and often expensive) 3D positioning devices.

Another emerging interaction technology uses cameras to track the users hands as they move in front of the display. Microsoft’s Kinect device is the most popular example, and can be used to supplement touchscreen interaction with knowledge of which hand touches were made with as well as the user’s eye position, which enables more accurate 3D rendering. These devices can provide many of the same benefits as touch surfaces, with increased flexibility and support for more complex gestures. It is likely that the best solution is to provide support for these advanced technologies, while ensuring every action can still be performed with a mouse & keyboard.

IV. APPLICATION

The procedure adapted for this study follows a conceptual model - logical model - implementation - revision workflow (Fig. 2). Our conceptual model is created in the Unified Modeling Language (UML). We were able to import the prior defined Arc Marine Data Model from provided UML on the Arc Marine website and begin immediate customization. As suggested by [7] the core of the Arc Marine Data Model was kept intact. All core classes retain their original attributes and relationships to ensure compatibility with tools and code developed for use with Arc marine. Any customized versions of the core classes were created using class inheritance. The logical model was realized in the Geographic Markup Language (GML), and implementation performed with a mixture of XML, C++, Python, and Matlab code. The efforts taken within the conceptual and logical stages reward later efforts during implementation. The conceptual and logical data model serve to transform the raw data into representations that are suited to the analytical task of the user by appropriately capturing the important content and relationships from a large, complex, dynamic data set. A visualization's quality is directly affected by the quality of the data representation underlying the visualization, so it is crucial that there be an appropriate data model described within this application. The original complexity of the data is reduced to a usable format. Without defined boundaries, the same raw data could be represented for any number of applications through any assortment of data transformations, each with the potential to derive additional data or to represent the data (with tens or hundreds of dimensions) in a 2D or 3D representation.

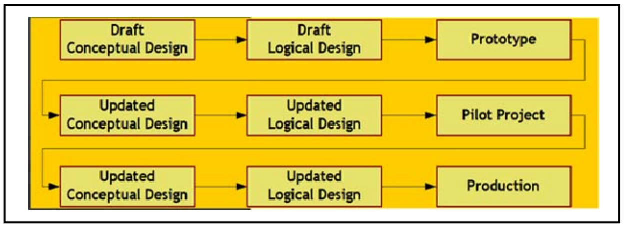

Fig. 2. Development procedure from conceptual design to logical design to revisions and eventual production. This study is currently in the Prototype stage testing a well-known sediment transport model scenarios (From Arc Marine Data Model).

The most important consequence of the data model is that imported model entities and their relational joins provide guaranteed relationships between data tables allowing for complex querying [41]. As with any database, the schema design is a time consuming part. There are 4 possible ways to build geodatabase schemas in ArcCatalog 10.1:

Create Schema with ArcCatalog wizard

Create Schema with Computer Aided Software Engineering (CASE) tools

Use software for development of Unified Modeling Language (UML)

Create Schema in the ArcToolbox geoprocessing framework

This work used the third approach. The Arc Marine Data Model in UML was exported to an XML Interchange file to be used as an ESRI geodatabase template. A Personal Geodatabase was created in ArcCatalog utilizing the Schema Creation Wizard which can apply existing schemas from either an XMI file (created using a CASE tool) or a repository database (Microsoft Access formatted). The Arc Marine Data Model may be found and downloaded at their website. XML Metadata Interchange (XMI) is a standard that specifies how to store a UML model in an Extensible Markup Language (XML) file - thereby an XML file is actually needed to be loaded. Once the geodatabase was created, data related to the incorporated surveys can be loaded and related to the full data model (Fig. 3). Further advancement with the geoprocessing framework will see the inclusion of an Arc Toolbox with custom functionalities. As shown in Fig. 3, the visualization work presented here is only one component of the complete application framework.

We decided to prototype the visualization with a standard test scenario that is familiar to the community at large and will potentially aid in the visualization software's acceptance. This simpler scenario also allowed a more rapid deployment. We chose to begin development with the Coupled Ocean Atmosphere Wave Sediment Transport (COAWST) modeling system's Test Inlet case.

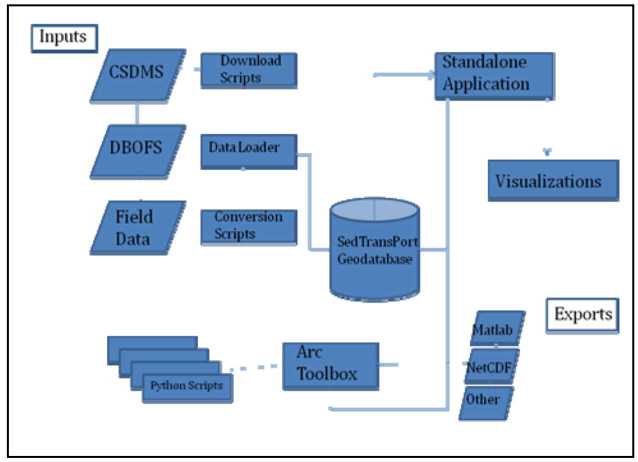

Fig. 3. The SedTransPort Geodatabase data model. Inputs enter the system in the upper left of the model and can be seen exporting in the bottom right. This is truly more of a circular and not linear behavior in practice. The visualization environment is linked in the upper right. Custom Python scripts to populate an Arc Toolbox are located in the lower right.

This test case represents a shallow inner waterway with one inlet opening through a solid wall to a region sloping deeper as it increases in distance away from the shallows. Sediment is allowed to move (be eroded and deposited) based on the changing hydrodynamic conditions, which advance through multiple shifts in the tide. Fig. 4 and Fig. 5 are two different time-steps represented from two different vantage points.As sediment accumulates or erodes, the bathymetry surface is updated accordingly. In addition, regions of recent deposition are colored blue and regions of erosion colored red. Streamlet particles are spawned throughout the grid, and their velocities are determined by the flow conditions at any x,y,z data point.

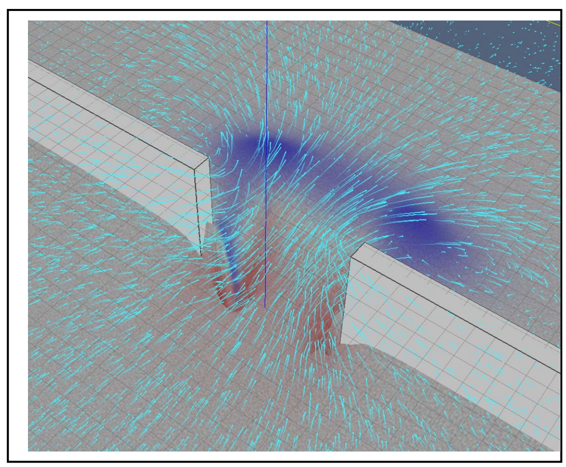

Fig. 4. Fig. Screenshot of prototype visualization environment. The blue areas are colored over grid points of sediment accumulation while the red areas are colored grid points of erosion. The view is looking towards the shallow area of the Test Inlet example. The streamlets are spawned across the grid and follow the modeled current velocities.

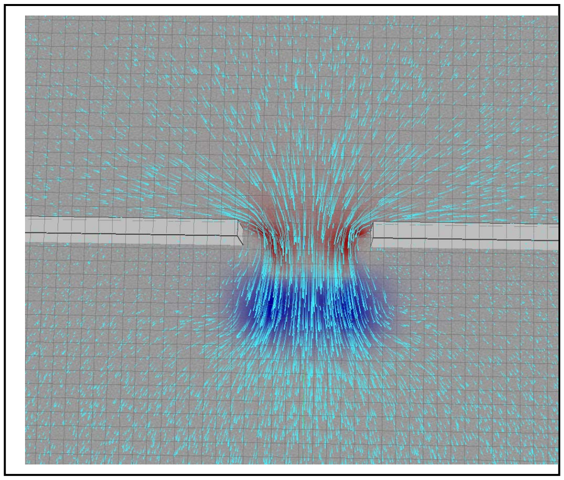

Fig. 5. Map view of the Test Inlet example at a different time-step than in the previous figure. Here the tide is ebbing. Blue represents areas of deposition, red represents areas of erosion.

V. DISCUSSION & FUTURE WORK

Our investigation into design considerations for improved sediment transport visualizations has focused on the requirements of the offshore planning community. It is evident that the use of a geodatabase to create a "smart" dataset is becoming more popular as standardized data models are being produced and quickly disseminated and adapted with tools like UML, CASE and XML. This study has benefitted from the prior work of the Arc Marine development team by providing a data model that fit our multiple data types. The clearly defined data attributes and relationships provided a framework for a visualization environment tailored to our intended user needs. Perception research is gaining insights into the human brain's capabilities of perceiving multiple types of information through different channels. The geodatabase model allows for rapid access to the data most important to the user throughout an interaction, speeding the redrawing of their data representation. It has been shown that an improved visualization system should contain the following to better facilitate analytical reasoning: provide a framework for analyzing spatial and temporal data; support the understanding of uncertain, incomplete information; provide user- and task-adaptable guided representations that enable "full situation awareness" while supporting development of detailed actions; and support multiple levels of data and information abstraction, including integration of different types of information into a single representation (i.e. multiple variables at the same time, bathymetry change, currents, grain size distribution etc). The visualization environment we present was further improved by addressing the design concepts of data processing and preparation, view generation and multiple view, exploration techniques, coordination and control, human interface, and usability and perception.

We find that the introduction of pilings and subsequent scour is one concern that has not been addressed currently in offshore wind turbine siting analyses. In order for informed decisions, the question should be asked, how will a structure alter the bottom compared to no structure. The coastal environment is dynamic, and there is great supporting evidence for an ephemeral background natural state (through both observation and theoretical understanding). Therefore, a constant updating of initial and boundary conditions is required at short intervals for any accurate modeling effort. Our study area has the benefit of daily forecasts made by NOAA's DBOFS model. However, other planning considerations, such as the full life cycle effects also need to be considered, and the life cycle of an offshore wind turbine is roughly 20 years. We have not yet begun to address the visualization solution to this difference in temporal scale. Although we do believe our proposed data model has the capacity to deal with such varying scales. In terms of quantifying impact to the bottom, we will require task-relevant view generations to present the user with analysis tools previously developed to assess habitat type. The United States Geological Survey (USGS) at Woods Hole, MA has conducted studies of this type utilizing their own application of the Arc Marine Data Model [48] and these are a basis for our pilot project.

There will be additional developments to the Arc Marine Data Model in the near future with a new course for 2013 announced recently by the development team on their website. The Arc Marine Data Model has been adapted in numerous case studies in its first decade of use, yet requires some revamping based on current knowledge. Our design revisions will need to address any new developments. There is also no doubt that a new direction for offshore wind farms will be to incorporate floating turbines, with the first test turbine connected to the grid in the US in 2013, and projects underway on the French and Cornish coast [1]. The work presented here started with monopile and gravity base foundations but must be flexible enough to also address the impact of floating turbine structures to the hydrodynamics in the water column and the related resources being affected.

The pilot project can now begin development seeing that a prototype has been successfully loaded into our data model and visualization environment. The pilot project will use the Redbird Reef surveys to begin asking the impact assessment questions motivating this work. Rather than just a test model case (the Inlet Test case), the pilot project will include the full Redbird Reef data collection of Marine Points, Marine Lines, Marine Areas, and Marine Meshes, and connect to appropriate hydrodynamic and sediment transport models - most likely utilizing the CSDMS modeling tools. This research group has received a login account for access to the computer cluster Beach, which will increase the speed of model computations. Model validation (e.g. through statistical analysis) is another future component that will need to be designed in terms of view generation in order to enhance a user's experience with the data model. Already, strange streamlet behavior within the visualization software has drawn human attention to focus areas containing possible modeled numerical outliers. Model error quantification has been addressed formally with models of ranging scales [45] [46]. A user-based validation and review of the software in addition to a questionnaire of an experienced user-base similar to [47] should also be addressed in the future. Finally, study of the scour and bedform development and evolution at the Redbird Reef site will only be seen as one possible application of our data model. The production version will adapt easily to new sedimentary environments with datasets that can be loaded into our geodatabase.

VI. CONCLUSIONS

This paper has presented a data model and visualization environment for improved user interaction with sediment transport model results. Continued development will make use of field and laboratory observational data alongside the model results to aid in model validation. The development of offshore wind energy will likely continue to utilize GIS tools during siting evaluations as the process requires spatially aware tools. Our data model and visualization environment bring GIS capabilities together with recent research into human perception. Data modeling captures the attributes and relationships of each piece of data utilized within a study in order to address the typical problems of data management occurring at multiple stages of interaction. A data model can save time in analysis, reduce costs, provide quality control, re-purpose model components, ensure consistency and traceability of model results, and offer scalability to solve complex modeling problems. We find the Arc Marine Data Model suits the data type needs of this study, and have therefore utilized Arc Marine as the basis of our data model. A prototype has been loaded into our visualization environment using the NetCDF output of the COAWST Inlet Test case. The first pilot project is now in development and will utilize a repeat survey effort at the Redbird Reef site. The data model will be tested at sea by organizing the data collected on the survey's fifth leg (July 29-August 2). Successful integration of scour prediction models and impact assessment at the pilot project will move this work into the production stage. With floating offshore wind turbine designs on the future horizon, the production stage data model and visualization environment should also address the different types of impacts of these new structures. Model validation will be a critical tool not yet incorporated to provide quantitative evidence to the impact assessments made more tangible through the contribution of this work.

REFERENCES

[1] L. Lunn, "Hydro buoyancy; offshore floaters," Renewable Energy Focus, pp. 10-11, 2013.

[2] N.A. Raineault, A.C. Trembanis, D.C. Miller, and V. Capone, "Interannual changes in seafloor geology at an artificial reef site on the inner continental shelf," Continental Shelf Research, pp. 67-78, 2013.

[3] A. Skarke, and A.C. Trembanis, "Parameterization of bedform morphology and defect density with fingerprint analysis techniques," Continental Shelf Research, pp. 1688-1700, 2011.

[4] S. Jay, "Planners to the rescue: Spatial planning facilitating the development of offshore wind energy," Marine Pollution Bulletin, pp. 493-499, 2010.

[5] J.K. Kaldellis, and D. Zafirakis, "The wind energy (r)evolution: A short review of a long history," Renewable Energy, pp. 1887-1901, 2011.

[6] J.K. Kaldellis, and M. Kapsali, "Shifting towards offshore wind energy - Recent activitty and future development," Energy Policy, pp. 136-148, 2013.

[7] D.J. Wright, M.J. Blongewicz, P.N. Halpin, and J. Breman, Arc Marine: GIS for a Blue Planet. Redlands, CA. ESRI Press, 2007.

[8] J.J. Thomas, and K.A. Cook, "A Visual Analytics Agenda," Visualization Viewpoints, Published by the IEEE Computer Society, pp. 10-13, 2006.

[9] C. Ware, M. Plumlee, "'Designing a better weather display", unpublished.

[10] B. Snyder, and M.J. Kaiser, "Offshore wind power in the US: Regulatory issues and models for regulation," Energy Policy, pp. 4442-4453, 2009.

[11] D.Y.C. Leung, and Y. Yang, "Wind energy development and its environmental impact: A review," Renewable and Sustainable Energy Reviews, pp. 1031-1039, 2012.

[12] A. Arvesen, and E.G. Hertwich, "Assessing the life cycle environmental impacts of wind power: A review of present knowledge and research needs," Renewable and Sustainable Energy Reviews, pp. 5994-6006, 2012.

[13] M.D. Esteban, J.S. Lopez-Gutierrez, J.J. Diez, and V. Negro, "Methodology for the Design of Offshore Wind Farms," Journal of Coastal Research Special Issue 64, pp. 496-500, 2011.

[14] T.H. Nguyen, A. Prinz, T. Friiso, R. Nossum, and I. Tyapin, "A framework for data integration of offshore wind farms," Renewable Energy, pp. 150-161, 2013.

[15] W.S. Merritt, R.A. Letcher, and A.J. Jakeman, "A review of erosion and sediment transport models," Environmental Modelling & Software, pp. 761-799, 2003.

[16] J. Guillen, J.A. Jimenez, A. Palanques, P. Puig, and V. Gracia, "Bottom Sediment Variability in the Active Layer of the Inner Shelf off the Ebro Delta," Journal of Coastal Research, pp. 482-496, 2005.

[17] K. She, L. Trim, and D.J. Pope, "Threshold of Motion of Natural Sediment Particles in Oscillatory Flows," Journal of Coastal Research, pp. 701-709, 2006.

[18] L.A. Mayer, R. Raymond, G. Glang, M.D. Richardson, P. Traykovski, and A.C. Trembanis, "High-Resolution Mapping of Mines and Ripples at the Martha's Vineyard Coastal Observatory," IEEE Journal of Oceanic Engineering, pp. 133-149, 2007.

[19] J.M. Harris, R. Whitehouse, and T. Benson, "The time evolution of scour around offshore structures," Proceedings of the ICE - Maritime Engineering, pp. 3-17, 2010.

[20] P.J.J. Desmet, and G. Govers, "GIS-based simulation of erosion and deposition patterns in an agricultural landscape: a comparison of model results with soil map information," Catena, pp. 389-401, 1995.

[21] H. Mitasova, J. Hofierka, M. Zlocha, and L.R. Iverson, "Modelling topographic potential for erosion and deposition using GIS," International Journal of Geographical Information Systems, pp. 629-641, 1996.

[22] A.P.J. De Roo, "Modelling runoff and sediment transport in catchments using GIS," Hydrological Processes, pp. 905-922.

[23] I.K. Tsanis, and S. Boyle, "A 2D hydrodynamic/pollutant transport GIS model," Advances in Engineering Software, pp. 353-361, 2001.

[24] B.D. Andrews, P.A. Gares, and J.D. Colby, "Techniques for GIS modeling of coastal dunes," Geomorphology, pp. 289-308, 2002.

[25] S. Naoum, I.K. Tsanis, and M. Fullarton, "A GIS pre-processor for pollutant transport modelling," Environmental Modelling & Software, pp. 55-68, 2005.

[26] J.C. Warner, B. Butman, and P.S. Dalyander, "Storm-driven sediment transport in Massachusetts Bay," Continental Shelf Research, pp. 257-282, 2008.

[27] D. Degnbol, and D.C. Wilson, "Spatial planning on the North Sea: a case of cross-scale linkages," Marine Policy, pp. 189-200, 2008.

[28] C. Ehler, and F. Douvere, "Visons for a sea change. Report of the First International Workshop on Marine Spatial Planning," Intergovernmental Oceanographic Commission and Man and the Biosphere Programme, UNESCO, Paris.

[29] D. Tyldesley, "Making the case for marine spatial planning in Scotland," Report commissioned by RSPB Scotland and RTPI in Scotland, 2004.

[30] G.F. Caston, "Wreck Marks: Indicators of net sand transport," Marine Geology, pp. 193-204, 1979.

[31] R.J.S. Whitehouse, J.M. Harris, J. Sutherland, and J. Rees, "The nature of scour development and scour protection at offshore windfarm foundations," Marine Pollution Bulletin, pp. 73-88, 2011.

[32] C. Matutano, V. Negro, J.S. Lopez-Gutierrez, and M.D. Esteban, "Scour prediction and scour protections in offshore wind farms," Renewable Energy, pp. 358-365, 2013.

[33] U.C.E. Zanke, T.W. Hsu, A. Roland, O. Link, and R. Diab, "Equilibrium scour depths around piles in noncohesive sediments under currents and waves," Coastal Engineering, pp. 986-991, 2011.

[34] O. Link, C. Gonzalez, M. Maldonado, and C. Escauriaza, "Coherent structure dynamics and sediment particle motion around a cylindrical pier in developing scour holes," Acta Geophysica, pp. 1689-1719, 2012.

[35] M.S. Gosselin, and D.M. Sheppard, "A review of the time rate of local scour research," in Stream Stability and Scour at Highway Bridges, E.V. Richardson, and P.F. Lagasse, Eds. New York: ASCE, 1999, pp. 261-279.

[36] B.M. Sumer, F Hatipoglu, and J. Fredsoe, "Wave scour around a pile in sand, medium dense, and dense silt," Journal of Waterway, Port, Coastal, and Ocean Engineering, pp. 14-27, 2007.

[37] M. Chen Ong, D. Myrhaug, and P. Hesten, "Scour around vertical piles due to long-crested and short-crested nonlinear random waves plus a current," Coastal Engineering, pp. 106-114, 2013.

[38] J.P.M. Syvitski, E.W.H. Hutton, and S.D. Peckham, "A Modeling System to Aid Sedimentary Research," The Sedimentary Record, pp. 4-9, March 2011.

[39] C. Ware, Information Visualization: Perception for Design. San Francisco, CA Morgan Kaufman, 2004.

[40] T. Butkiewicz, and C. Ware, "Multi-touch 3D Exploratory Analysis of Ocean Flow Models," Proc. MST/IEEE Oceans ’11, pp. 1-10, 2011.

[41] B.K. Lord-Castillo, D.J. Wright, B.R. Mate, and T. Follett, "A Customization of the Arc Marine Data Model to Support Whale Tracking via Satellite Telemetry," Transactions in GIS, pp. 63-83, 2009.

[42] Danish Energy Authority (DEA), "Future offshore wind power sites 2025", Report of the Committee for Future Offshore Wind Power Sites. unpublished.

[43] Department of Energy & Climate Change (DECC), "UK Offshore Energy Strategic Environmental Assessment (OESEA): Environmental Report," unpublished.

[44] R. Arsenault, C. Ware, M. Plumlee, S. Martin, L. Whitcomb, D. Wiley, T. Gross, and A. Bilgili, “A system for visualizing time varying oceanographic 3D data," Oceans '04 Techno-Ocean '04 (OTO'04) Conference Proc., pp. 743-747, 2004.

[45] J.T. Holt, J.I. Allen, R. Proctor, and F. Gilbert, "Error quantification of a high-resolution coupled hydrodynamic-ecosystem coastal-ocean model: Part 1 model overview and assessment of the hydrodynamics," Journal of Marine Systems, pp. 167-188, 2005.

[46] K.P. Edwards, R. Barciela, and M. Butenschon, "Validation of the NEMO-ERSEM operational ecosystem model for the North West European Continental Shelf," Ocean Sci, pp. 983-1000, 2012.

[47] B. Berx, M. Dickey-Collas, M.D. Skogen, Y.-H. De Roeck, H. Klein, R. Barciela, R.M. Forster, E. Dombrowsky, M. Huret, M. Payne, Y. Sagarminaga, and C. Schrum, "Does operational oceanography address the needs of fisheries and applied environmental scientists," Oceanography, pp. 166-171, 2011.

[48] W.A. Barnhardt, B.D. Andrews, and B. Butman, "High-Resolution Geologic Mapping of the Inner Continental Shelf: Nahant to Gloucester, Massachusetts," U.S. Geological Survey Open-File Report 2005-1293, 2006.