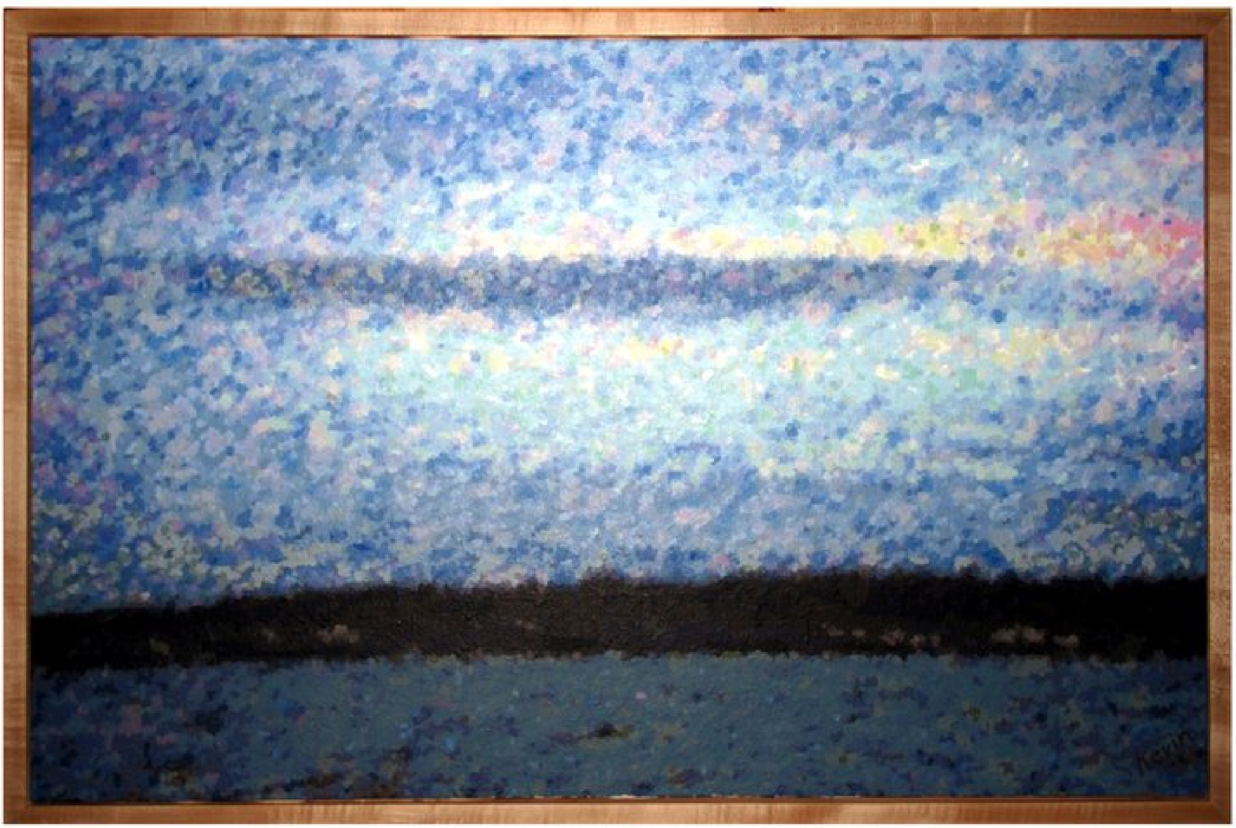
Workshop on Data Visualization to Support Ecosystem Based Management



North Atlantic Regional Team, NART
Gulf of Maine Research Institute
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February 5-6, 2013

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Cover art by K. Friedland

Introduction

Artists need to put as much time, energy, and resources into marketing their work as they put into creating it. If you spend 10 hours creating your artwork, you need to match that with 10 hours of promotion and marketing of your art.

-Kenneth Proudfoot

As NOAA moves to an ecosystem based management approach, it will be important to ensure an understanding of the science available, its application to management, and how to best communicate this to the public. NOAA offices have varying core responsibilities that have led to the development of a diverse range of data visualization tools within the agency. Many of these tools have the potential to help solve the data visualization problems of other NOAA offices; however, researchers and managers often do not have a working knowledge of data visualization capabilities developed outside their own office. NOAA also has agency and academic partners that can provide visualization capabilities to apply to the shared goal of a better understanding of ecosystem structure and function.

What is the level of investment in transmitting data effectively that NOAA should make? As the quotation above suggests for artists, a concomitant amount of time promoting and marketing art should match the initial investment in the creative process. The analogy can be applied to science, and ecosystem management in particular, that scientists should consider investing more time and resources to insure their findings are effectively communicated to other scientists, managers, stakeholders, and the public.

What continues to be an area of relative data visualization weakness is the presentation of the science supporting an ecosystem based approach to management. NOAA has tremendous fisheries and environmental data holdings, yet in some areas the data are only shared among scientists, managers and stakeholders with the use of tables and simplistic graphs. It is important that NOAA improve its understanding of the available ecosystem information in order to better inform resource management decisions. For example, fishery management councils and the fishing industry are being asked to incorporate ecosystem considerations and to adopt an ecosystems approach to management, yet many members of this community are still developing an understating of ecosystem concepts and the models being used for the provision of management advice. Management scenario testing and comparison under conventional stock management has been relatively tractable, typically taking the form of bracketed comparisons involving a limited set of options. However, scenario testing under an ecosystem approach will be more challenging to conduct and explain. The range and depth of data from ecosystem simulations should be presented in a way that reflects the increased information content of these models. It could be envisioned that management councils might meet in a visualization capable meeting room to consider models and scenarios, where testing is conducted interactively with the participants seeing not only the fishery response, but also the way climate drivers are affecting the physical aspects of the ecosystem and how all levels of the biological community are responding . The biological communities that NOAA needs to consider in an ecosystem manner for the fishery management process and other management processes are broad (e.g. protected resources, habitat, and climate drivers). Ecosystem scientists across the agency have a responsibility to better inform the public about ecosystem function and change; better visualization tools would also address this issue.

The goal of this workshop was to facilitate information exchange between NOAA units, cooperating agencies and academic institutions that have data visualization capabilities and/or requirements to institute ecosystem based approaches to management. The workshop provided an opportunity for practitioners to share information and develop synergies to address the general problem of data visualization to support ecosystem based management. The workshop was held February 5-6, 2013 at the Gulf of Maine Research Institute, Portland, Maine. The agenda for the meeting can be found in Appendix 1. The workshop was chaired by K. Friedland, Samuel Chavez served as rapporteur, and a full list of participants, including those joining the meeting remotely, can be found in Appendix 2. The workshop participants also collated a table of Visualization Products and Services which can be found in Appendix 3. Throughout the text, figure numbers are in reference to the section in which they appear.

This report is a summary of the activities of the workshop provided by the workshop participants to the NART; the report has no peer-review status and is not part of any report series.

Presentations

Changing perspectives about a changing ecosystem

Kevin Friedland, National Marine Fisheries Service, Narragansett

The Northeast Shelf Ecosystem is experiencing dramatic change in its physical environment and the response of the biotic community. This past year, 2012, was the warmest year ever recorded for the ecosystem. Long and short term time series are being used to express the trends in ecosystem temperature. Long term trends are based on temperature records dating back to the 1800s and show that the dramatic increase in temperature in 2012 exceeded previous high temperatures recorded in the 1940s (see figure 1). It was suggested by the workshop that temperature for the ecosystem

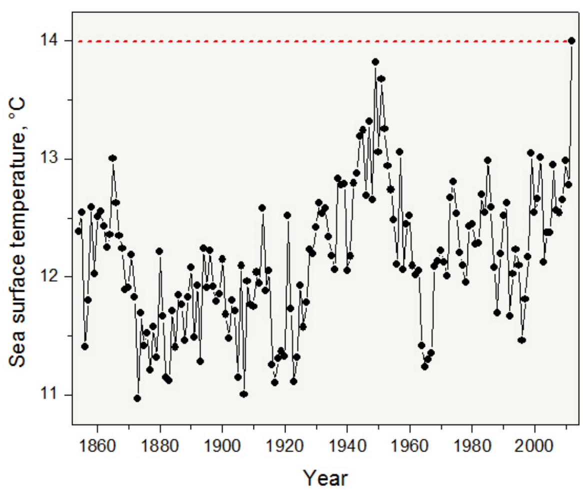


Figure 1. Long term sea surface temperature for the Northeast Shelf ecosystem derived from the ERSST database.

should be shown in context to the changes in temperature on a global scale. These global analyses show that the Northeast Shelf is one of the most rapidly warming ecosystems in the world, suggesting the ecosystem poses unique management challenges. Most comprehensive depictions of ecosystem temperature are based on sea surface temperature since it has been measured more frequently over the long term and is readily available from satellite sensors. However, recently developed model hind casts may provide source data to develop similarly comprehensive gridded bottom temperature data products to complement the sea surface data products. These data resources should be developed for complementary use with existing observational data resources. With the release of new IPCC AR5 assessment data, the community should be made aware of the projected trends for water temperature in the ecosystem.

The base of the food chain is driven by plankton production that is patterned in distinct season bloom cycles. With the changes in temperature and salinity occurring in the ecosystem, there have been changes recorded in both primary production and in the abundance and species composition of zooplankton, which form the base of the food chain for resource species. Temperature and salinity will have a direct effect on production through physiological effects on lower trophic level organisms and through other habitat alterations like change in the stratification of the water column, which can affect bloom timing and dimensions. In recent years, the spring bloom on the Northeast Shelf has stated earlier (see figure 2). The blooms have also been associated with higher water column plankton biomass as indicated by chlorophyll

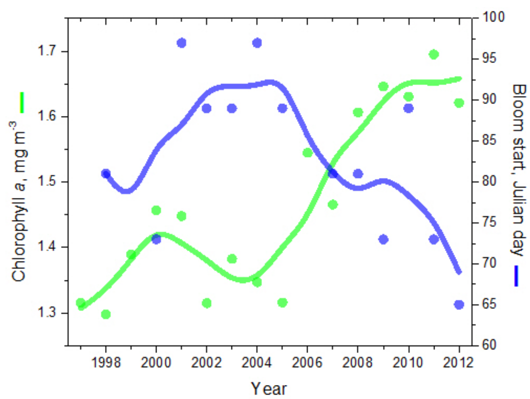


Figure 2. Spring bloom chlorophyll concentration and start day for the Northeast Shelf ecosystem using data from SeaWiFS and MODIS ocean color sensors.

concentrations. This may impact other species in a variety of ways such as changing feeding opportunities for early life history stages or impacting the flow of energy in the ecosystem. How this information is perceived by a broader audience was discussed. It was agreed that supporting illustrations of how physical factors combine to shape blooms would be useful. These same illustrations should also draw attention to the linkages between the production of lower and upper trophic levels.

A well documented consequence of recent change in the ecosystem has been change in the distribution of species. Species distribution has been reported in the research literature and is described in a number of web resources that generally supply point of occurrence data. The workshop discussed a number of ideas for both a framework to advance regional description of species distributional and some of the data elements that might be useful to provide to both research and management sectors. There are a number of data products that provide distribution point of occurrence of species, it was agreed that statistical depictions of continuous distribution would be useful on a number of levels. And, characterization of distribution could be enhanced with measures of center of mass and kernal density data.

Visualization tools to relate species distribution to other parameters like temperature would be desirable, as would animated depictions of distribution. Finally, the more comprehensive development of niche space models for a wide range of species should be encouraged so that future distributions can be projected with the data from climate projection models. The workshop recommended the formation of a working group on visualizing species distribution (see recommendations).

Visualizing complexity: how can we view food web and multi-species data and dynamic ecosystem model outputs

Sarah Gaichas, National Marine Fisheries Service, Woods Hole

Food webs show the energetic relationships between many species or components within an ecosystem. This information can be useful when considering management options for human impacts on interacting species or on the ecosystem as a whole; however, food webs can be incredibly complex in large marine ecosystems where hundreds of species have thousands of interactions, many of them not directly observed. Therefore, much of our understanding of marine food webs comes from organizing available data into various model frameworks. Models of food webs and multispecies systems can be generally divided into static and dynamic types. Static food web models show the relationships between components at a snapshot in time, while dynamic models (sometimes based on the static models) show how the related species change over time. Both types of model can be implemented at any spatial scale. The purpose of this presentation was to show a range of existing visualizations of food web data and model output, to get feedback on which visualizations might be most useful for which target audiences and purposes. Further, this presentation was intended to provoke discussion or development of improved visualizations that 1) adequately capture complexity without overwhelming the target audience; 2) are visually appealing while preserving scientific content; and 3) communicate an appropriate level of uncertainty in observational data or model outputs.

Visualizations of static food webs (Fig 1) can range from simple drawings of predators and prey connected by arrows (1a) to highly complex box diagrams (1b), engineering diagrams with numeric flows (1c), and abstract networks with nodes and links coded for interaction strengths and flow relationships (1d). The least complex food webs are those with the fewest compartments and relationships; reduction of compartments can be achieved by either focusing on the food web supporting a single species (Fig 1a) or by aggregating many species into fewer, more generalized functional groups (Fig 1c). However, there are times when complexity is the point of the visualization. Also, with interactive visualization capability, users can work though the complexity of a food web such as Figs 1b or 1d by selecting individual species to see their relationships within the larger context of the full food web. The visualization software used to produce both Figs 1b and 1d has this interactive capability, although only the network software (Gephi, http://gephi.org/) is widely available.

Visualizations of dynamic ecosystem model outputs (Fig 2) can similarly range from simple time series plots of multiple attributes for a single species (2a) or the biomass trend of an aggregated group from the food web (2b) through more complex multispecies time series plots or aggregate species results over a range of modeled conditions. Uncertainty in the model outputs can be expressed as envelopes around results (2c), variations of box and whisker plots (2d), or ordinations of results over a wide range of parameter values and modeled conditions (2e). These visualizations require considerably more explanation to orient viewers than the static food web visualizations, and are likely to find a more receptive audience among scientists than among the general public in their current form. However, the results of dynamic models are likely to be useful in a management context where managers need to visualize the potential impacts of climate, species interactions, or human activities on complex systems over time. Here, a more interactive format may also be helpful, as well as creative use of animation to show changing system attributes over time. The challenges of reflecting appropriate complexity and uncertainty in dynamic multispecies model visualizations are considerable, but may be overcome with a combination of iterative work with target audiences and creative use of interactive media.

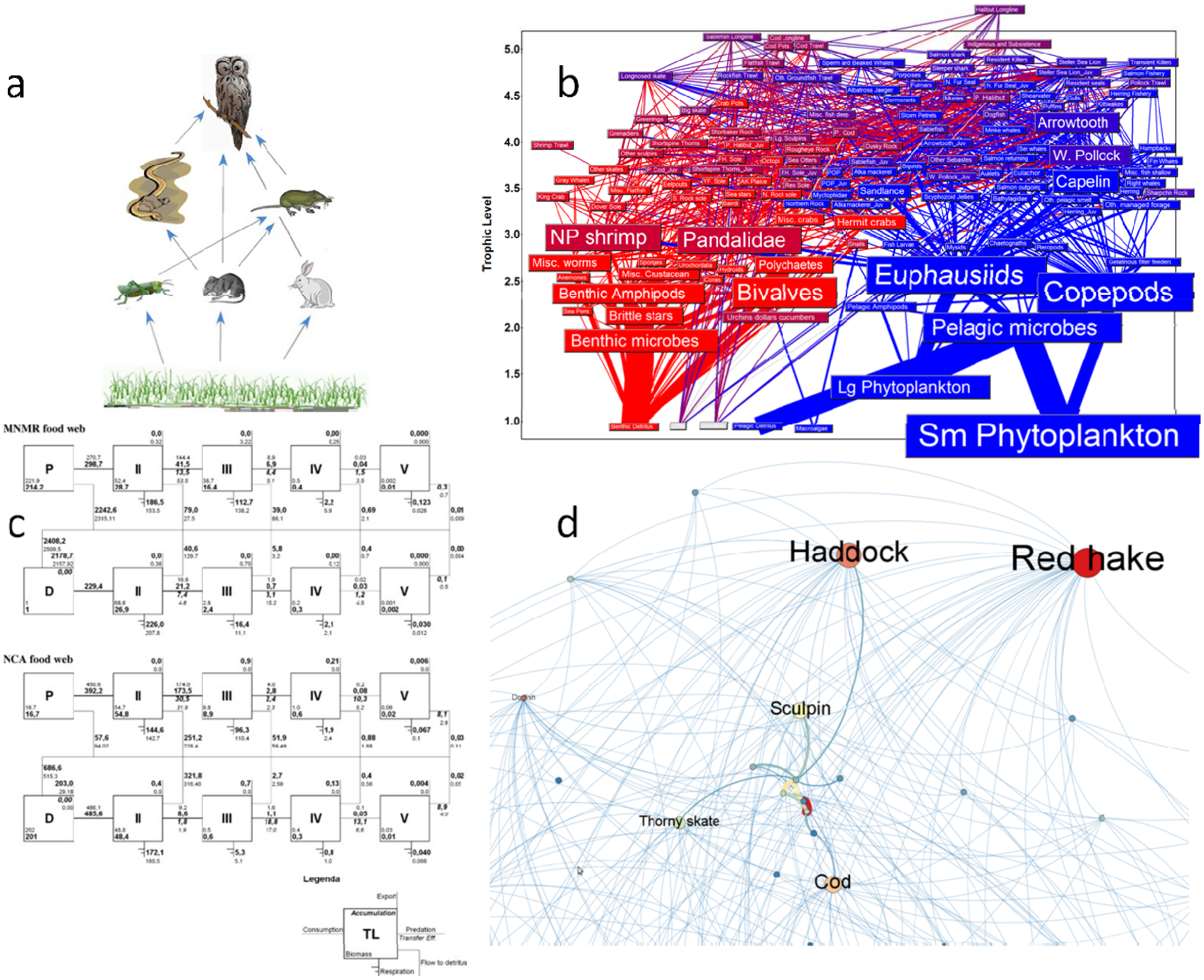


Figure 1. Static food web visualizations.

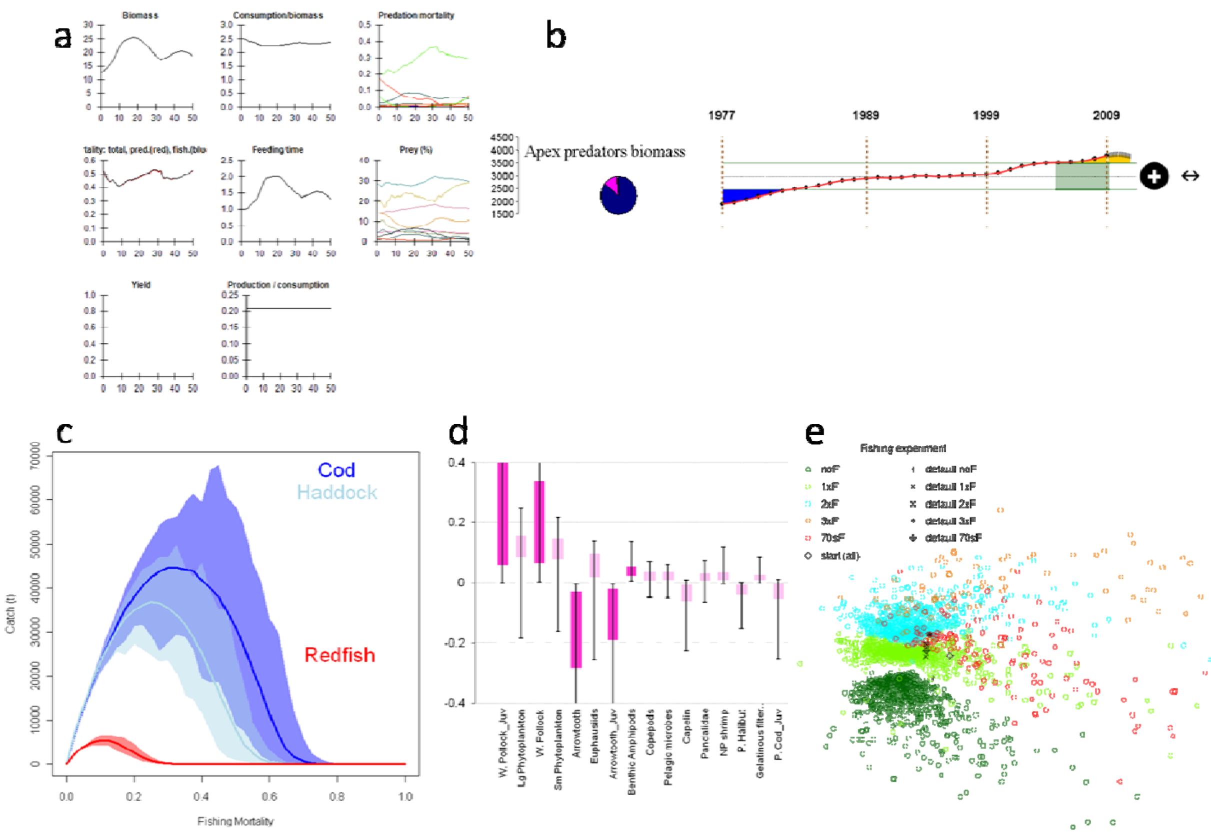


Figure 2. Dynamic food web model visualizations, without (top) and with (bottom) uncertainty.

Visualization and Gaming of Ecosystem Model Scenarios

Robert Gamble, National Marine Fisheries Service, Woods Hole

Visualization of the outputs from ecosystem models is not an easy task. There will be many scenarios run, with multiple outputs of importance. Specifically, managers will want to know things like: biomass of target species (ecologically or commercially important species as well as protected groups), economic impacts, unanticipated impacts on the ecosystem from management actions, and many other possibilities. This reinforces the need to have clear management objectives before running any model, but the presentation of the results still will not be trivial. One example of outputs potentially useful to managers is the proportion of impacts from fishing, environmental, and species interactions and how those might change under different scenarios (Figure 1). In the figure below, all groundfish in a multispecies surplus production model had their growth rate reduced by 10% in a climate scenario. The model was designed to separate out the effects on biomass from fishing, climate, and species interactions. The figure shows that results in even relatively simple scenarios can be complex and unintuitive. In spite of Yellowtail flounder being included in the group with a 10% reduction of growth rate, it increased in biomass by the end of the run due to competitive release by other members of the groundfish group.

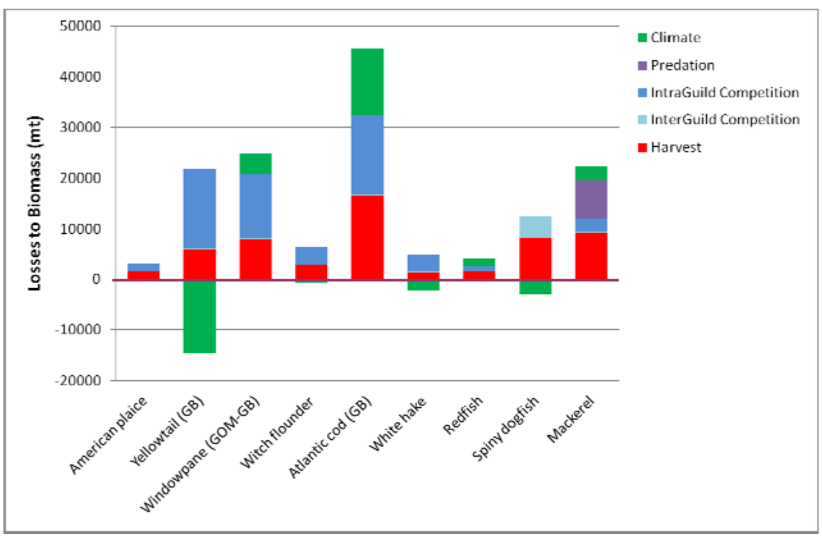


Figure 1. Changes to biomass over the run of a multispecies production model due to different pressures. Values below the 0 line indicate an increase in biomass due to a pressure, values above the 0 line indicate a decrease.

Often, what will be most important to managers when looking at results from ecosystem models, is a comparison of tradeoffs in various outputs compared to objectives. For example, one could balance biomass of commercially important species against marine mammal protection as well as forage fish which support both groups. A radar or spider plot is one way to display such data, and the example given is from a multispecies production model in which forage fish are fished at different levels. The plot shows the response of ratios of biomass to a target value for 6 different objectives, where the target value is represented by the 1.0 line on the plot (Figure 2). Other visualization environments such as Google Earth or TerraViz should also be explored in the context of ecosystem models with a geospatial component.

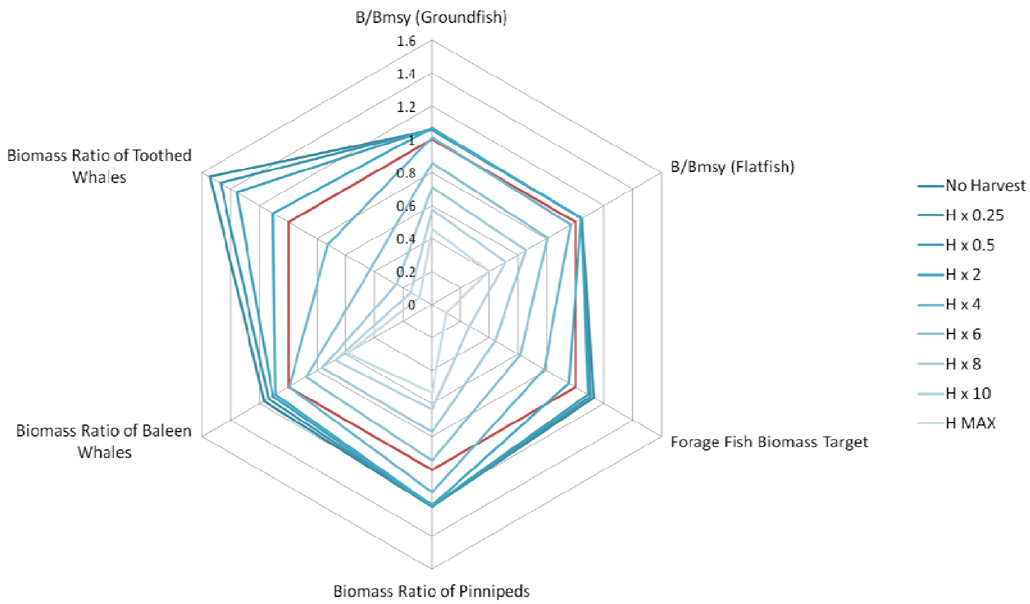


Figure 2: A radar/spider plot showing the effects of different levels of harvest on forage fish compared to 6 target reference points (represented by the 1.0 red line).

It will also be of great use to managers and to be able to interactively explore scenarios. These can range from more complex GUI interfaces that hide the underlying models (although the equations should always be made available in some fashion), to web based interfaces which allow picking specific sets of parameters to view the changes in a number of types of visualizations illustrating tradeoffs, to even simpler exploratory models. The gaming environment could be dynamic with a model being run based on the changed parameters, or static with the model runs already having been done in advance (likely necessary for some of the more complex ecosystem models). Exploratory models could be as simple as whiteboards, or other “hands on games” such as using multiple decks of cards to represent important mechanisms in an ecosystem model. While no management decisions would be made from such simple gaming environments, they could provide an understanding of what the most important features of an ecosystem may be.

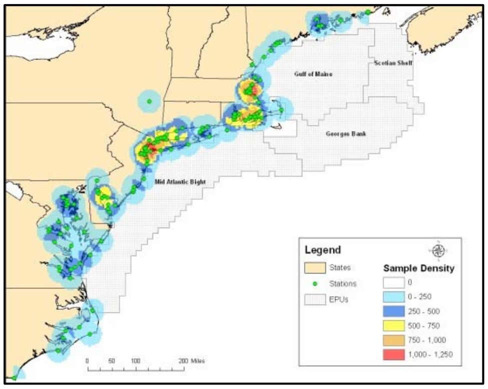
Getting more from data than just where the fish are

Scott Geis, National Marine Fisheries Service, Woods Hole

ArcGIS is a system designed to display, integrate, and synthesize geographic and descriptive information from various sources. This platform allows scientists to present complex information by combining imagery and datasets from multiple sources into visually appealing maps. The myriad of tools provided by ArcGIS allow for statistical analysis to be performed, and recent advancements in Arc 10.1 allow for enhanced evaluation and visualization of time-series data. Common approaches to time-series data visualization with Geographic Information Systems (GIS) have been met with criticism because they attempt to display data with three dimensional characteristics on a two dimensional map. Since data has both a spatial and a temporal context, response to these criticisms has been to move towards analyses that rendered data on a three dimensional surface and a shift to tools that perform space-time analyses. In the end, no one tool provides a one stop shot to successfully visualizing time-series data. Instead it is a combination of tools and techniques that can produce the best results.

Common Approaches to Time-Series Visualization:

While the visualization of fisheries data in GIS is an established practice, common approaches to the extension of GIS to time-series data has been met with mixed reviews. Common approaches to analyzing data with spatial and temporal trends have focused on the use of density tools to produce “heat maps” (Figure 1), or animations to break the data up into a series of snapshots displaying changes in some variable over time (Figure 2). While both of these methods provide a good method for exploring patterns in the data, they contain limitations when representing three-dimensional data (x and y location, plus time) with a two-dimensional map.



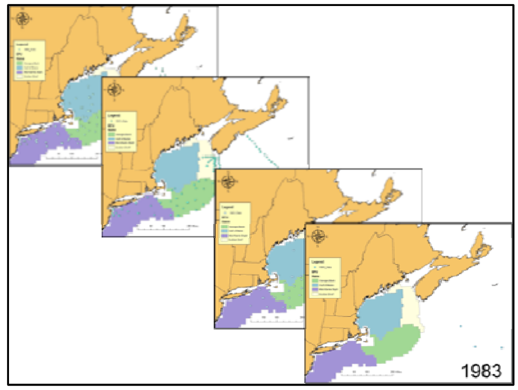


Figure 1: "Heat Map" example

Figure 2: Series of snapshots from a time-series animation

"Heat maps" are beneficial for representing the geographic density of point features. They are often easy to remember, and typically utilize color ramps showing high-density areas in red and low-density areas in blue. While heat maps can provide a spatial summary of the data, they fall short of temporal analysis. This is particularly evident when point data is stacked (samples occurring at the same location through time) and it is necessary to represent data trends with respect to time.

Animations provide a powerful method for portraying patterns or progressive change over time; such as those exhibited by changes in sample distribution, perspective, data attribute level or geography. Separate datasets may be generated for periods of time within a dataset (daily, weekly, yearly, etc.), and can then be analyzed separately with results presented as a series of maps captured in an animation. While this is an effective method for visualizing temporal and spatial data trends, how the data is divided is somewhat arbitrary and multiple animations may be needed to uncover temporal and spatial patterns. Additionally, the focus of animations can be placed too heavily on the beginning and end stages of the data with reduced emphasis on intermediate steps. Audiences are therefore required to remember multiple data iterations at a given point to understand associated trends. As a result, management decisions based on animations may be weighted too heavily on the before and after components of a study versus generating policies that reflect an understanding of trends.

The goal of time-series analysis is to present data with significant spatial and temporal ranges in an easily understood format for diverse audiences. One tool for time-series analysis is the ArcGIS Hot Spot Analysis tool. The tool uses the Getis-Ord Gi* statistic, and can be set to perform analysis within a space time window that isolates neighboring sampling events and illustrates hot and cold spots at intervals within the project timeline. The resulting output layer indicates areas where observed spatial clusters of high or low values are more pronounced than expected from a random distribution of those values (Figure 3).

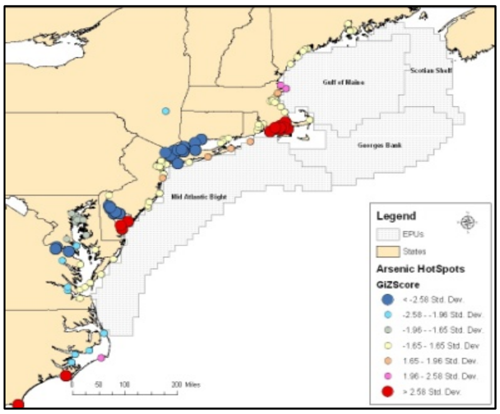


Figure 3: Output layer from Hotspot Analysis tool; statistically significant clusters of high values (hotspots) and low values (coldspots) are indicated by larger red and blue circles respectively

Hotspot analyses are enhanced by combining the tool's layer output with three dimensional (3D) rendering of the data on a surface like Arc Globe. To maximize the effectiveness of this visualization technique, it is advisable to first run the hot spot tool and then add a field representing the time interval between samples. Specifically, this time lapse field represents time passed between the first sampling event and each following event. This field is used as a multiplier in a mathematical expression to extrude point features on a 3D plain and reflect temporal progression (Figure 4). In 3D, data trends can be more easily visualized because the added elevation allows the audience to separate the sampling events of one time period from another. By extruding features based on a time lapse field, it becomes clearer which features are related and which are separated by time. 3D visualization is most effective with a smaller study area when you have a limited number of features.

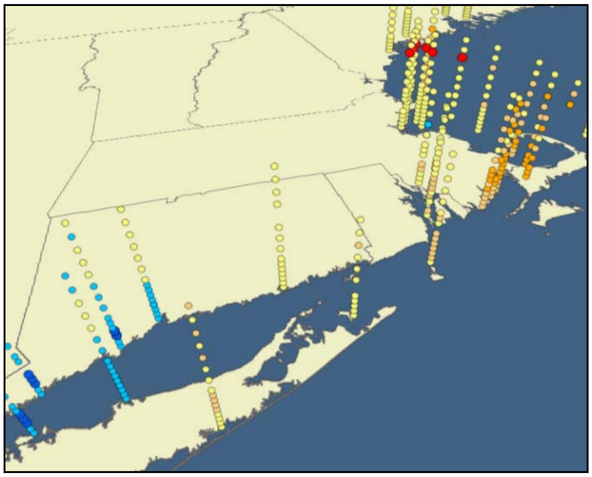


Figure 4: Example of Hotspot Analysis output combined with 3D data rendering in Arc Globe

As with any presentation, the preferred method of data visualization must be paired with the intended audience, and it is often a combination of techniques that must be utilized to effectively engage the audience and leave an impression of data trends. These are just a few tools that may help the visualization of time-series data.

Visualizing highly spatial and temporal data

Kimberly Hyde, National Marine Fisheries Service, Narragasett

Satellite remote sensing generates an extraordinary amount of highly spatial and temporal data that can provide views of the global ocean not attainable by ship-based sampling. Visualizing qualitative and quantitative details from these large datasets and comparing the data with *in situ* or modeled data can be a challenge. Seasonally averaged composites and animations are two ways to qualitatively compare and contrast the temporal and spatial variability of multiple satellite products. To achieve a more quantitative analysis, a common practice is to extract regional means from mapped satellite imagery. Simple time series plots can show regional differences among the subareas in a given time period, however comparing several regions over multiple time periods can become difficult (figure 1a). An alternative approach is to use a color scale to represent the magnitude of the product and to stack the time series in a way that one can easily compare the intra- and inter-annual variability (figure 1b). The example figure provided shows seasonal chlorophyll *a* variability within a region (e.g. there is a general pattern of increased chlorophyll concentration during the spring months in the Scotian Shelf region), inter-annual variability within a region (e.g. differences in the timing and magnitude of the spring and fall peaks of chlorophyll in the Gulf of Maine), and regional differences (e.g. the difference between the summer chlorophyll concentrations in the Georges Bank and Middle Atlantic Bight subareas).

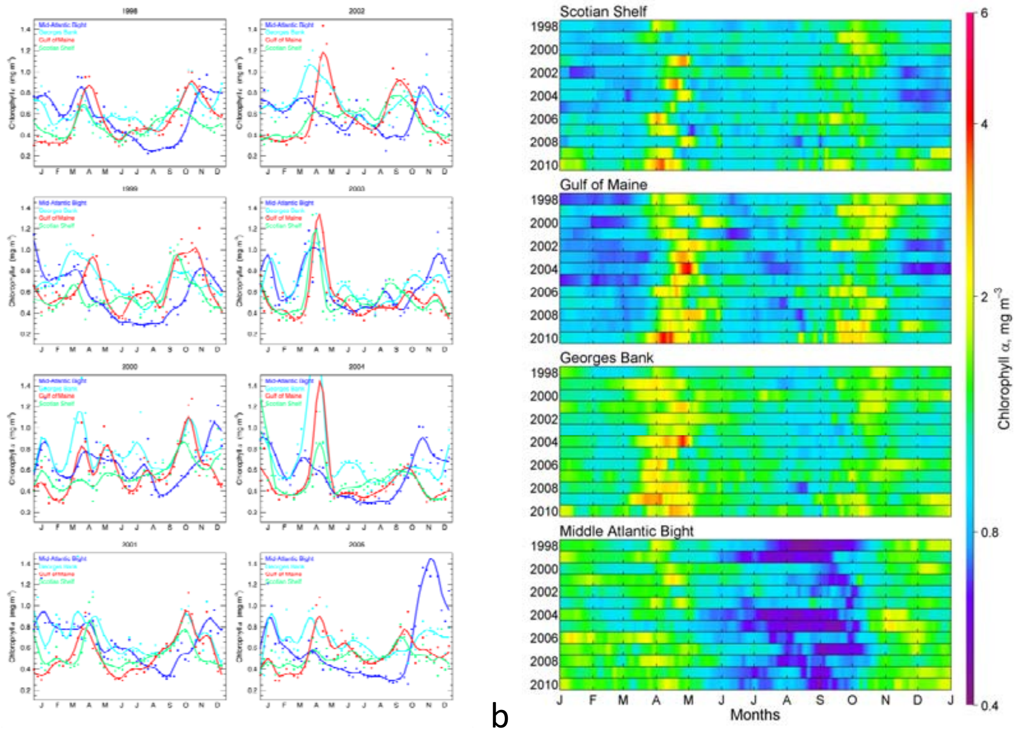


Figure 1: Two examples of how to compare and contrast time series data extracted from satellite imagery: a) shows an annual time series as a series of line plots, and b) uses a color scale to represent the data value and stacks multiple years from a given region together.

A second way to compare spatial datasets (i.e. satellite data to model output, data from two different satellite sensors, satellite data from two different time periods) is to calculate a difference or ratio anomaly (Figure 2). The ratio anomaly is the preferred method for log-normally distributed data such as chlorophyll *a*. In the example below, the remotely sensed chlorophyll concentration (Figure 2a) is compared to output from a biogeochemical model (Figure 2b). The ratio product (Figure 2c) indicates that the model output has higher concentrations (the yellow to red colors) compared to the satellite data throughout most of the model domain. The two-dimensional histogram (Figure 2d) compares the satellite and model output data in a xy plot and uses a color scale to represent the histogram frequency.

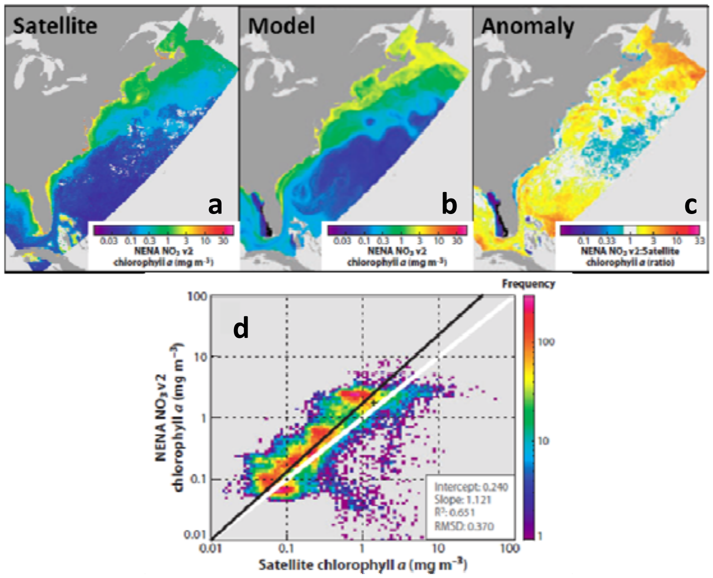


Figure 2: Composite of a) satellite data, b) model output, c) the ratio anomaly between the satellite data and model output and d) a two-dimensional histogram comparing the satellite data and model output. This figure was prepared by K. Hyde and adapted from Hofmann et al. (2011, Annual Review of Marine Science 3(1): 93-122).

A major challenge of highly spatial and temporal data is creating qualitative and quantitative visualizations that summarize the data while also retaining the fine scale resolution. The two examples presented here work well in a static setting (e.g. figures in a manuscript), however when this type of data is presented in other outlets such as websites and kiosks, developers should work to create visualization tools that allow the user to interactively explore this multi-dimensional data.

Challenges, lessons learned, and a FEW potential visualization solutions for synthesizing science to inform Management in south Florida

Christopher Kelble, Atlantic Oceanographic & Meteorological Laboratory

The transition from single-sector or single-species management to multi-sectoral Ecosystem-Based Management (EBM) requires that we provide management with useful visualizations that synthesize our integrated scientific knowledge about the biophysical and human dimensions of the ecosystem. The first step in this process is to develop tools that integrate our knowledge across disciplines in a manner that will be useful to EBM. To this end we have developed Driver, Pressure, State, Ecosystem Service, Response (EBM-DPSER) conceptual models that synthesize our biophysical and human dimensions knowledge by highlighting key ecosystem characteristics and their connections to each other and human society. There are often 20 or more components in each module resulting in greater than 100 ecosystem components in the conceptual model and greater than 1,000 connections among just the pressures, states, and ecosystem services.

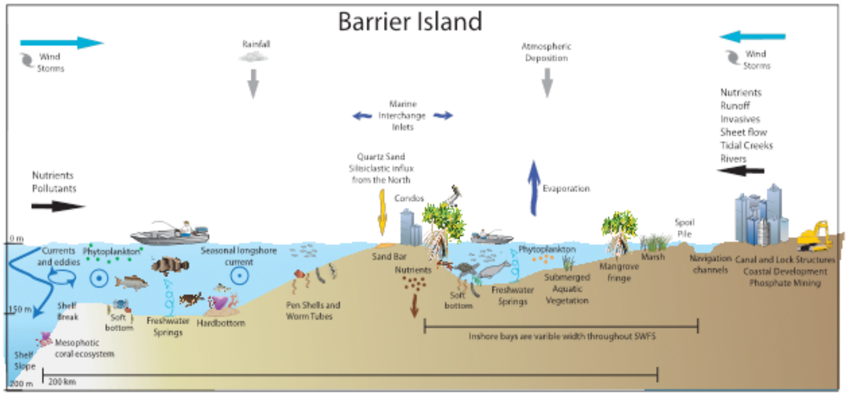


Figure CK-1. The infographic for Barrier Island ecosystems in southwest Florida shows the dominant pressures upon the key state components and human uses within the ecosystem.

Given the immense number of components and connections, it is difficult to visually represent these models in a manner that is easily understood, but still conveys important, useful information. One way to attempt to achieve this goal is through infographics (Fig. CK-1). These infographsic show through cartoon images the major pressures impacting the ecosystem, the key components of the state module and human uses intended to yield the benefits from ecosystem services. We discussed how these infographics could be modified or made into movies to depict the affects of pressures and potential management scenarios.

The main goal of EBM is to sustainably produce the ecosystem services that benefit society. To accomplish this goal we must quantify the cumulative effect of multiple pressures upon these ecosystem services. Quantifying the connections between pressures, states, and ecosystem services in the EBM-DPSER model leads to the development of a network models. This network

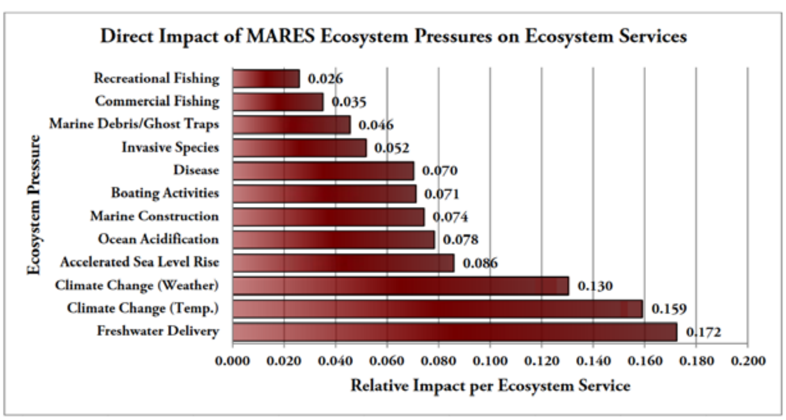


Figure CK-2. A bar chart depicts the relative impact of each pressure on all ecosystem services.

model can be analyzed to conduct a holistic risk assessment that determines the cumulative effect of all pressures on ecosystem services. It can also be used to determine the pressures causing the most stress on the entire range of ecosystem services. This information summarizes the impact of a multitude of pressures upon a multitude of ecosystem services making it difficult to visually display. One options is to develop a bar chart depicting the cumulative impact of each pressure upon all ecosystem services (Fig. CK-2). The inverse can be done to show the degree to which each ecosystem service is impacted by the multitude of pressures. However, these are of little utility if you are making a decision based upon a single ecosystem service or pressure. In this case a spider graph could be useful which shows the relative impact of each pressure on each Ecosystem Service (Fig. CK-3). These radar plots quickly become difficult to interpret as the number of variable increases and a new visualization technique would be preferred. These visualization examples are preliminary attempts to convey scientific synthesis to managers attempting to implement EBM. It is intended that all of these products will be refined and improved through interactions with managers and as visualization techniques advance.

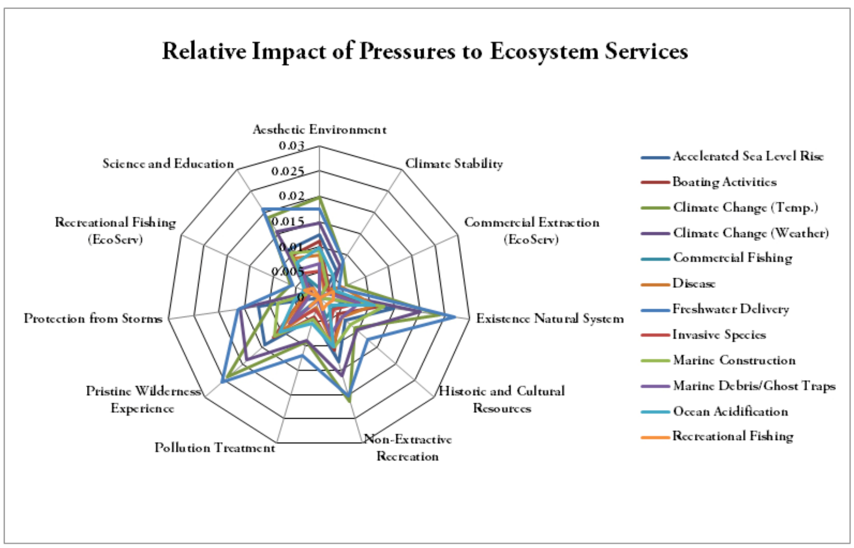


Figure CK-3. A radar plot shows the relative impact of each pressure on each ecosystem service.

Dynamic conceptualization of habitat

John Manderson, NEFSC; Gavin Fay, NEFSC; Eric Fredj, Jerusalem College of Technology; Josh Kohut, Rutgers University; Scott Large, NEFSC

Habitats in the sea are fundamentally defined by properties and processes of the ocean's fluid. Carefully designed ecological models including species niche models can now be integrated with hydrodynamic models to develop hydrodynamic information systems (HIS). HIS can then be used to visualize and analyze the dynamics of key ecosystem processes, including seascape and habitat dynamics in the way that geographic information systems (GIS) are used to visualize and analyze terrestrial landscape and habitat dynamics. We have developed a HIS that integrated a simple thermal niche model for an important forage species in the mid-Atlantic Bight with temperature hindcasts from 1957-2007 derived from a Regional Ocean Modeling System model. The HIS allowed us to visualize thermal habitat dynamics and to calculate statistics describing temporal dynamics of spatial habitat characteristics that could influence important processes regulating the dynamics of the regional population as well as strongly interacting species. We performed preliminary statistical analyses to investigate relationships between seascape indices and ecosystem responses within a Driving force-Pressure-State-Impact-Response (DPSIR) indicator framework.

Designing geospatial data visualizations for a general audience

Tom Butkiewicz, Center for Coastal & Ocean Mapping, University of New Hampshire

Dynamic ocean simulations are generating increasingly complex multi-layer 3D ocean models containing depth-varying flow vectors, temperature, salinity, etc. However, many oceanographers and other marine science researchers are still using traditional 2D software to consume this data. Properly designed 3D visualization tools can be highly effective for performing analysis within, and revealing the complex, dynamic flow patterns and structures present in these models.

CCOM's experimental dynamic ocean visualization system incorporates the perceptual benefits of stereoscopic rendering, to best reveal and illustrate 3D structures and patterns, and multi-touch interaction, allowing for natural and efficient navigation and manipulation within 3D environments. Exploratory visual analysis is facilitated through the use of a highly-interactive toolset which leverages a smart particle system.

Configuring particles with specialized behaviors can provide limited simulation capabilities. This includes pollutant release scenarios, such as predicting the path of the oil plume in the Deepwater Horizon oil spill, or the path of radioactive coolant from the Fukushima nuclear disaster. Habitat mapping can similarly be supported by modeling larval transport, etc. (Figure 1).

Other uses include planning survey missions within forecasted flow models, to plot courses that take advantage of currents to maximize energy budgets. Real time data from remote sensors, such as the ARGO float network, can be directly compared to the simulation's predictions, allowing for model validation and detection of sensor malfunctions (Figure 2).

This system was designed to be more intuitive, and allow for direct interaction with onscreen elements. Compared to most commercial analysis packages, it requires far less training to use, making it easier for the general public to utilize. The interface encourages exploratory analysis, where the user can quickly try out many different ideas and analyses without the burden of first rigidly defining parameters (Figure 3). This can lead to the discovery of more insights that might otherwise be missed.

This style of intuitive exploratory analysis is also central to the success of the Urban Growth Decision Support System. The UGDSS allows stakeholders and other members of the general public to perform simple spatial analyses on the output of a complex urban growth simulation. By providing a number of easy to use tools for visually querying the data, the users can investigate their own regions of interest (Figure 4). When the user compares regions of interest, the system automatically detects any potentially misleading factors that the user might be unaware of. It alerts the user to these issues, and provides semi-automated methods for refining their regions to rectify them (Figure 5).

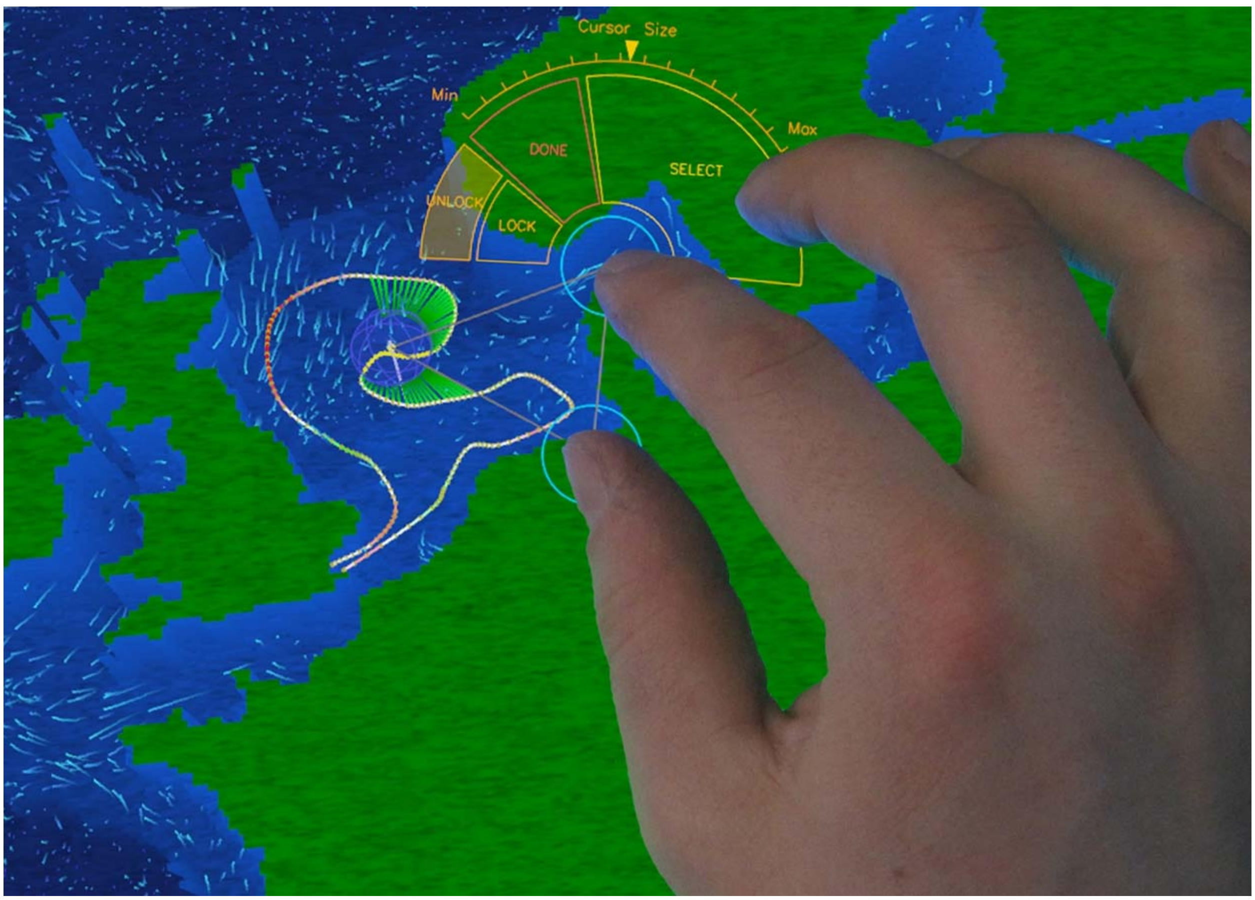


Figure 1. Interactive path editing.

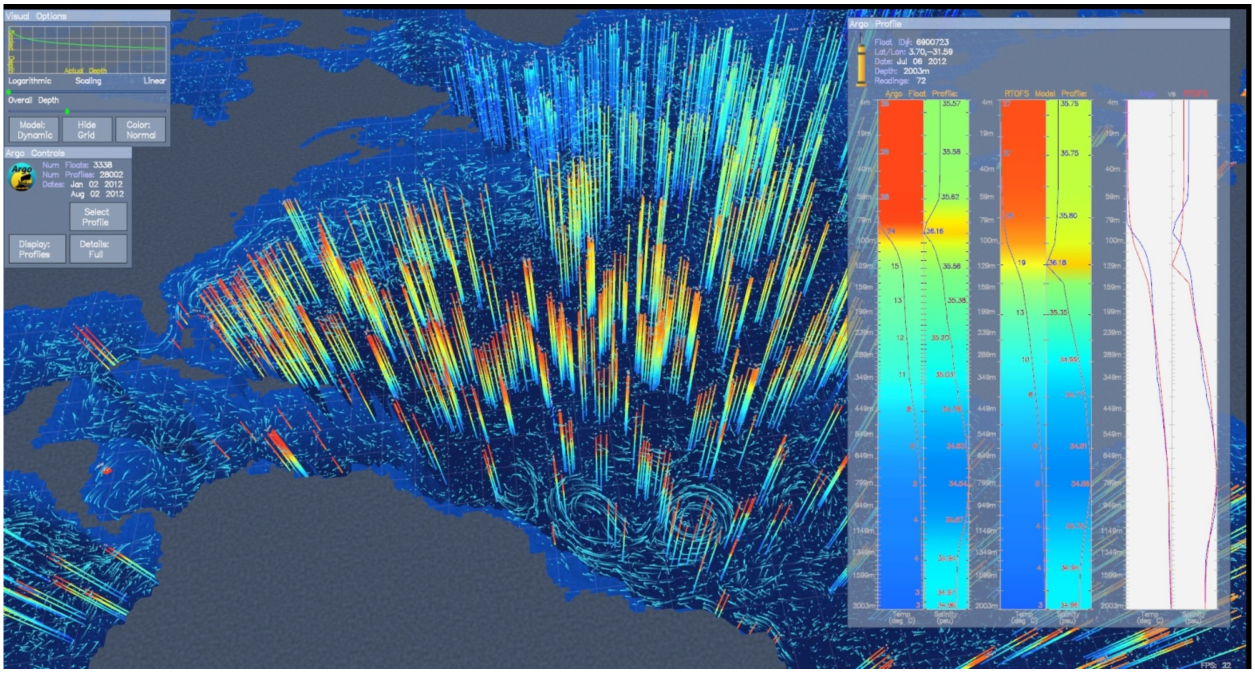


Figure 2. Real time data from RTOFS ARGO floats facilitates comparison.

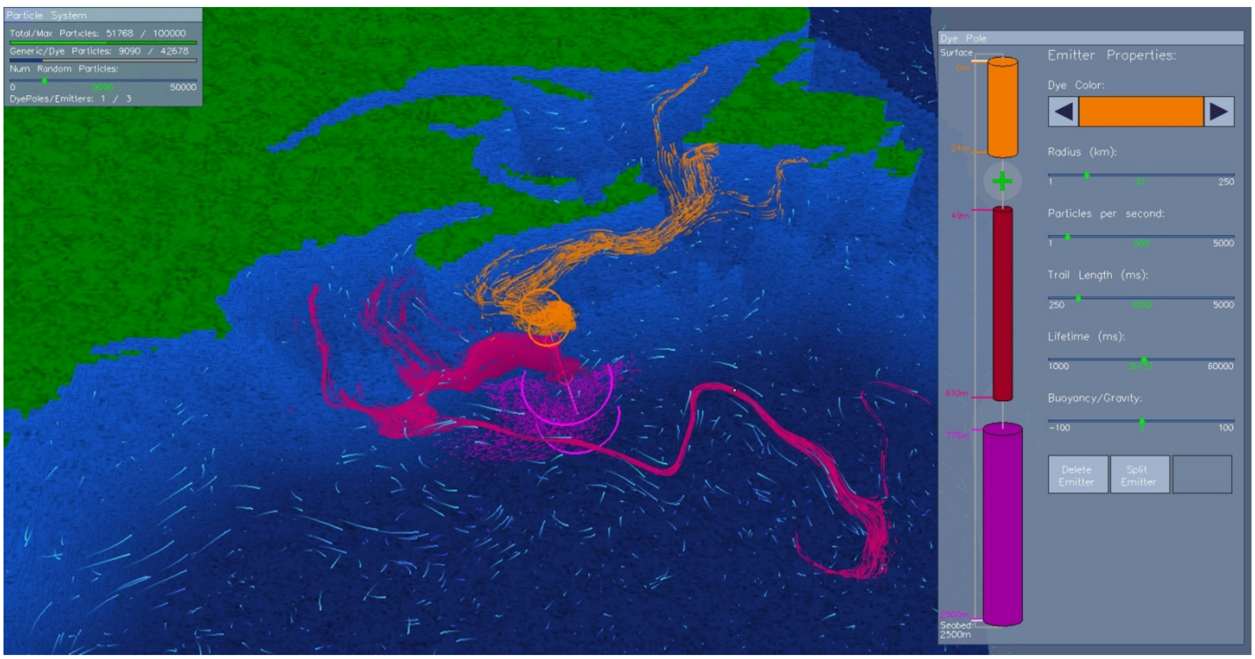


Figure 3. Multipole path comparisons.

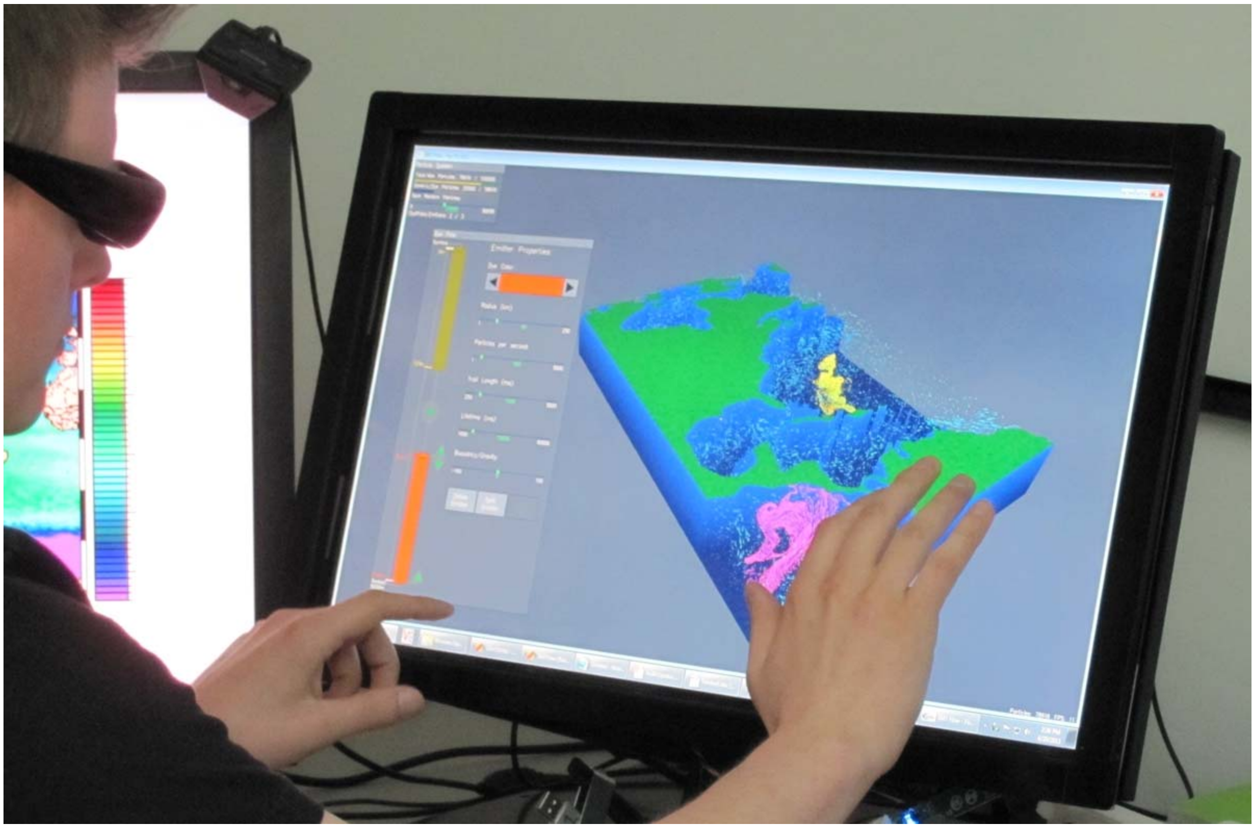


Figure 4. Ecosystem use comparisons.

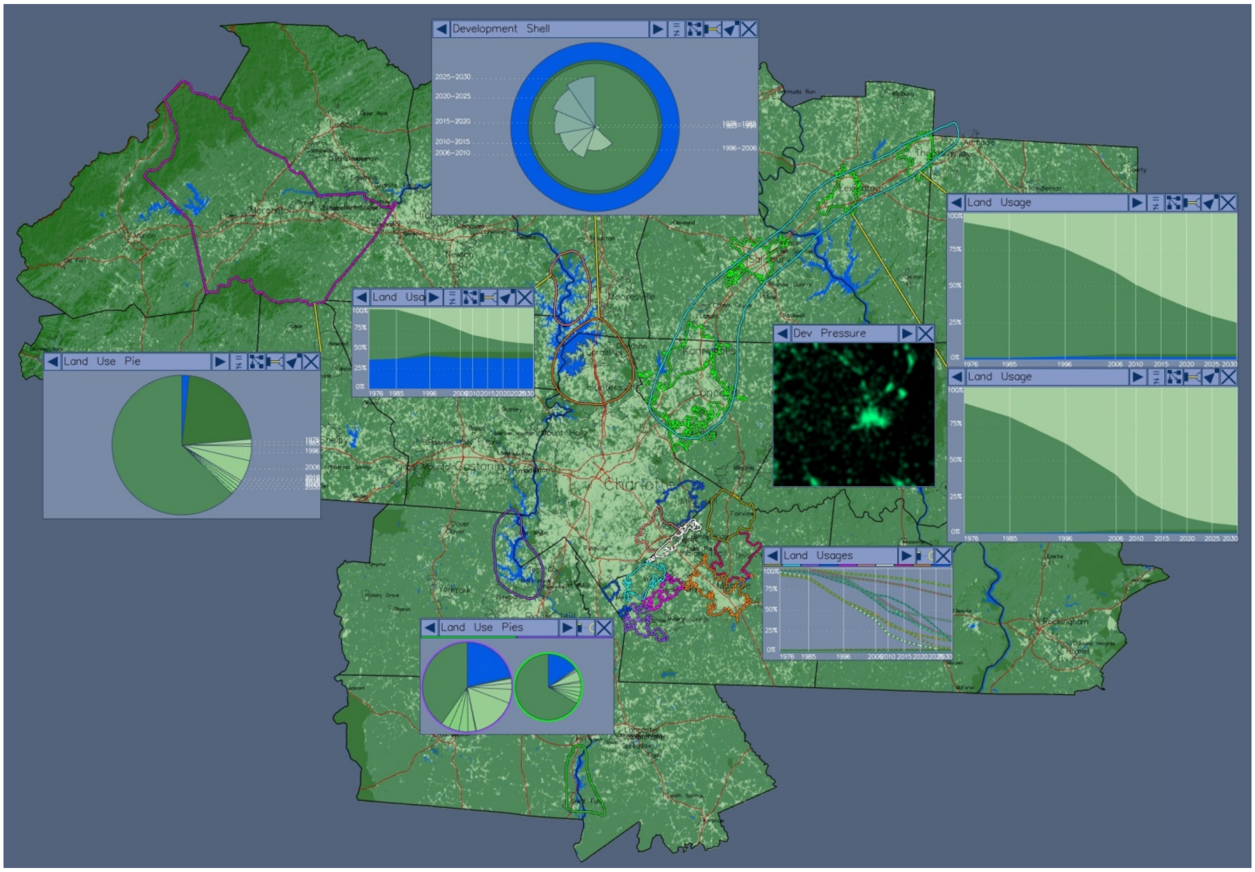


Figure 5. Example workspace of regions of interest comparisons.

Dealing with scientific and communication uncertainty through data visualization

Howard Townsend, NMFS/OHC/NCBO

Ecosystem-based management (ebm) is complex and fraught with uncertainties. Ecosystems are complex and interactions are non-intuitive. Keeping track of them with data is messy. Trying to understand and manage them is difficult but necessary. Understanding the uncertainty associated with ebm and properly communicating the uncertainty should help the transition towards ebm. Ecosystem scientists and modelers have taken steps to categorize the uncertainty associated with ebm (Figure 1).

Modelers have developed approaches for visualizing data and model output to demonstrate the scientific uncertainty (e.g., natural variability, observation error, and structural complexity); however, some many of these approaches result in fairly complex output. Typical approaches for uncertainty include: using Monte Carlo simulations to incorporate natural variability and observation error, using multiple models to account for structural uncertainty in models, and using multiple scenarios to account for outcome uncertainty. These approaches are very useful for scientific uncertainty, but often add to the complexity of output presented to managers and may exacerbate management-associated uncertainty.

Ecosystem scientists and modelers also need to consider the management uncertainties (e.g., specificity and communication uncertainty). Most managers are familiar with single sectors (fisheries, water quality, etc.), but as ebm is a new paradigm, sometimes managers' mental models, based on single sector management, conflict with what the ecosystem models are showing. Overcoming this cognitive gap requires lots of communications and different approaches of demonstrating data – iterative two-way interactions (the Subway method) – and some tools that allow data exploration. This is difficult because of time constraints on managers and modelers.

Interactive data visualization techniques hold promise for facilitating iterative two-way data and model output exploration and overcome management uncertainties. Frequently with static presentations, ecosystem scientists and modelers are limited to demonstrating portions of a model output to communicate focal points for ebm technical guidance for a given; however, static representation of complex ecosystems does not allow the flexibility of demonstrating other aspects of the ecosystem. As a focal point of an ecosystem is demonstrated to managers, questions about other portions of the ecosystem may arise. Developing static visualizations of all components of complex ecosystems is not feasible, so using dynamic visualization tools allows flexibility to respond to managers' questions and facilitates an iterative, two-way exploration of data and model outputs. Hans Rosling provides a good demonstration of interactive data visualization and data exploration (http://ed.ted.com/lessons/hans-rosling-shows-the-best-stats-you-ve-ever-seen).

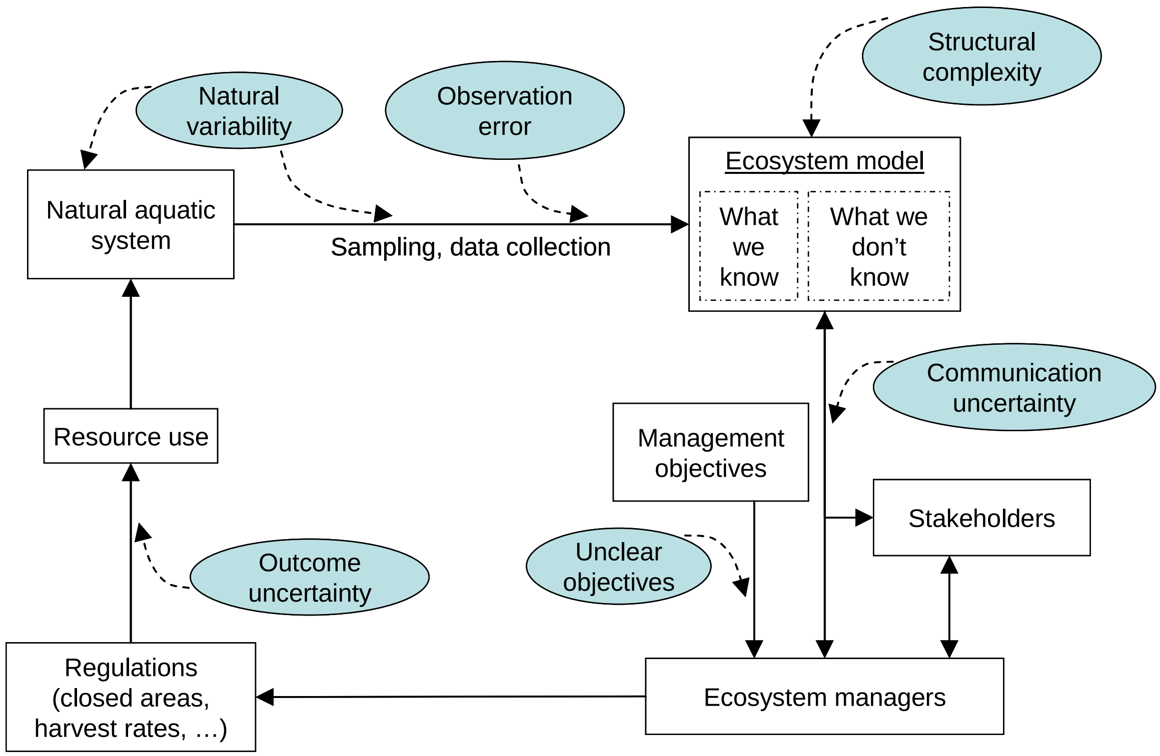


Figure 1. Sources of uncertainty associated with ebm.

NEFSC Data Server: access & visualization with Python

Jim Manning, NOAA/NEFSC

The simple idea of posting computer code in addition to data was expressed. While we are promoting the use of PYTHON code as an alternative to MATLAB, the actual language is secondary to the primary idea of sharing code. The talk outlined the history of our efforts from the initial formation of the Woods Hole Python Users Group in mid-2011 through our present day directions on how we hope to proceed. This was an introductory presentation leading up to related and more-detailed information to be delivered in Signell's and Di Stephano's subsequent talks.

As a point of motivation, it is difficult to build a website that can be useful to all types of users. Given the quantity of the data that is served through the NEFSC Oceanography Branch website (profiles, trawl data, mooring time series, drifter tracks, plankton distributions), for example, it is hard to provide a graphical user interface and mapping tool that would be ideal for all disciplines and level of scientific inquiry. Instead, we hope to point to repositories of open source code that users can download and run on their own machine. This code will allow them to both access the data according to specific criteria and plot it in a variety of ways. With a little experimentation and practice, they should be able to modify the code to get exactly what they need.

Another motivation for the project arises from the recent call for STEM activities in the classroom. Since we are now focusing on open source software, we can offer these routines to teachers who can instruct their students to do more than navigate complicated websites. They

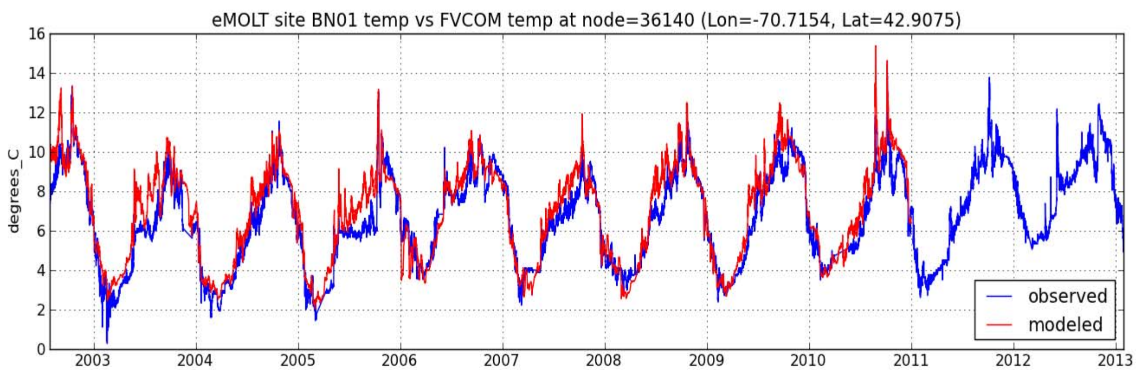


Figure 1. Observed and modeled water temperature based in lobster trap sensor.

can actual install the programs on their machines, learn to run simple plotting packages, and perhaps begin to appreciate the art of computer programming. We are in the process of writing a proposal to NOAA's Environmental Literacy Grant Program to suggest this strategy of exploring NOAA data.

While it was not possible to run at the conference, a couple of simple examples were prepared to demonstrate the idea. One program accesses both observed and modeled ocean bottom temperatures from a particular site and plots their time series (figure 1). Another overlays multiple variables like SST, CODAR surface currents, and drifter tracks on a map. In all cases, the data is stored on remote machines and is accessible via IOOS data standards. While still under-development and not well-documented, the code is stored on the “jamespatrickmanning” GitHub code repository with “Sphinx” documentation.

Web access, analysis and visualization of standardized oceanographic and meteorological data

Rich Signell, USGS

This talk focused on the importance of web services and common data models to allow developers to efficiently and effectively write applications to access structured and unstructured grid model output and other standard data types, such as time series, profiles, swaths and trajectories. A system based on Unidata technologies has been deployed throughout the Integrated Ocean Observing System (IOOS) and has made dozens of models throughout all 11 IOOS regions available through common services, without forcing model providers to rewrite their non-standard model output (Figure 1). A layer of XML (NetCDF Markup Language – NcML) is created that maps existing data into the common data model by providing missing metadata, which then becomes available via a variety of standard services. The success of this technique with model output has led IOOS to start delivering time series, profiles and other data via this technique. This allows generic applications like IDV to access data from many different models without regard to model specifics (Figure 2).

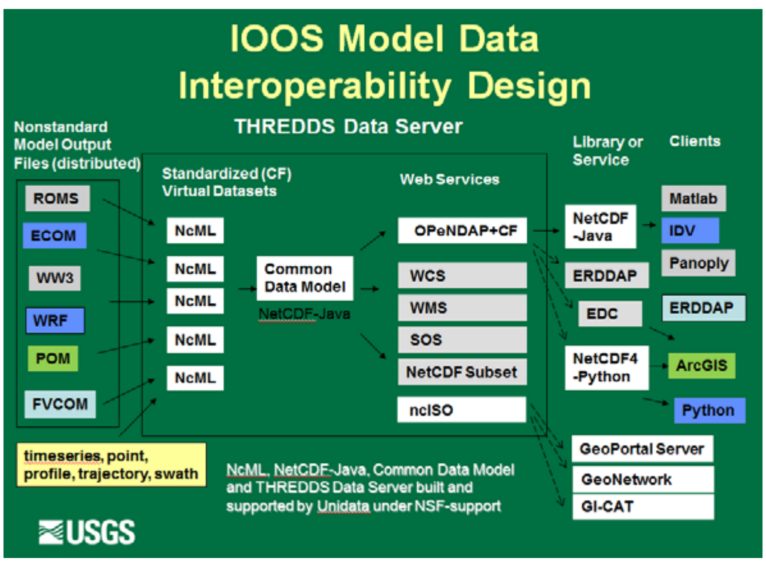


Figure 1. Model data interoperability diagram for IOOS.

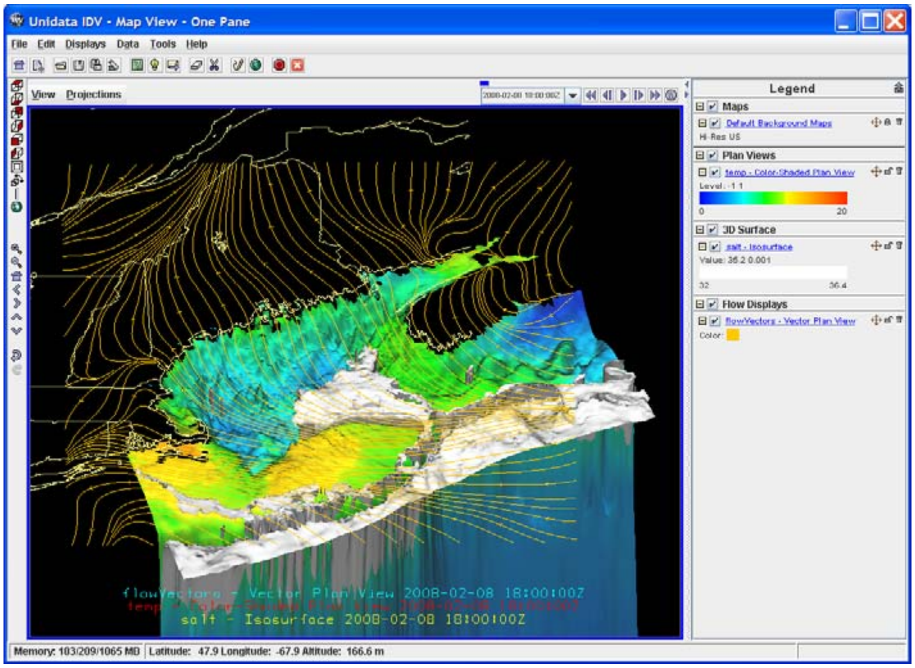


Figure 2. Visualization of two common data model datasets – streamlines from the WRF atmospheric model and bottom temperatures and a salinity isosurface from the University of Maine POM ocean model.

Oceanographic data and data-services at PacIOOS, a regional association of IOOS

James Potemra, PacIOOS

The Integrated Ocean Observing System (IOOS) is organized around 11 regional associations (RA). The Pacific Islands Ocean Observing System (PacIOOS) is the RA for the insular Pacific, including the State of Hawaii. The main purpose of PacIOOS is to provide timely, useful information about the ocean environment to a wide variety of users. PacIOOS is considered an end-to-end system in the sense that with the system are ocean observing platforms (autonomous gliders, buoys, moorings, *etc*.), numerical models, and remote observations, but PacIOOS also maintains a set of data servers that provide the data (and data-derived products) to the general public.

The forecast models and observations are geared around providing information in four general areas: coastal hazards, maritime safety, water quality and ocean circulation. Users of this information include everything from recreational swimmers, fishermen, management and planning entities, search and rescue personnel, *etc*.

Web access is obviously a key component to the PacIOOS data system. The main access mechanism is via a map-based browsing tool. The back-end system is built upon OPeNDAP services, mainly THREDDS. THREDDS, or "thematic realtime environmental distributed data system", was developed at Unidata and provides direct, binary access to data. At PacIOOS, THREDDS is used to both to expose all the data but also to provide data via services to the PacIOOS viewers.

The main viewer, http://pacioos.org/voyager, allows users to generate overlays of any/all PacIOOS data in a map-based view (see Figure 1). The data are listed at the left of the screen, and users can select specific times, geographic and/or temporal ranges and generate a custom map. The background is based on the Googlemap API, and most overlays are generated on-the-fly by taking advantage of the THREDDS web map service (WMS). Once users create a map of interest, there are options at the top to either save the image for printing or saving a link to the exact image (*e.g*., to include it into a web page or to email to someone).

In addition to this data browsing tool, PacIOOS also offers a geospatial server based on GeoServer and OpenLayers (http://pacioos.org/geoexplorer) and several pre-generated information and data-based products, such a particle trajectory maps, high-water forecasts, inundation plots, and more.

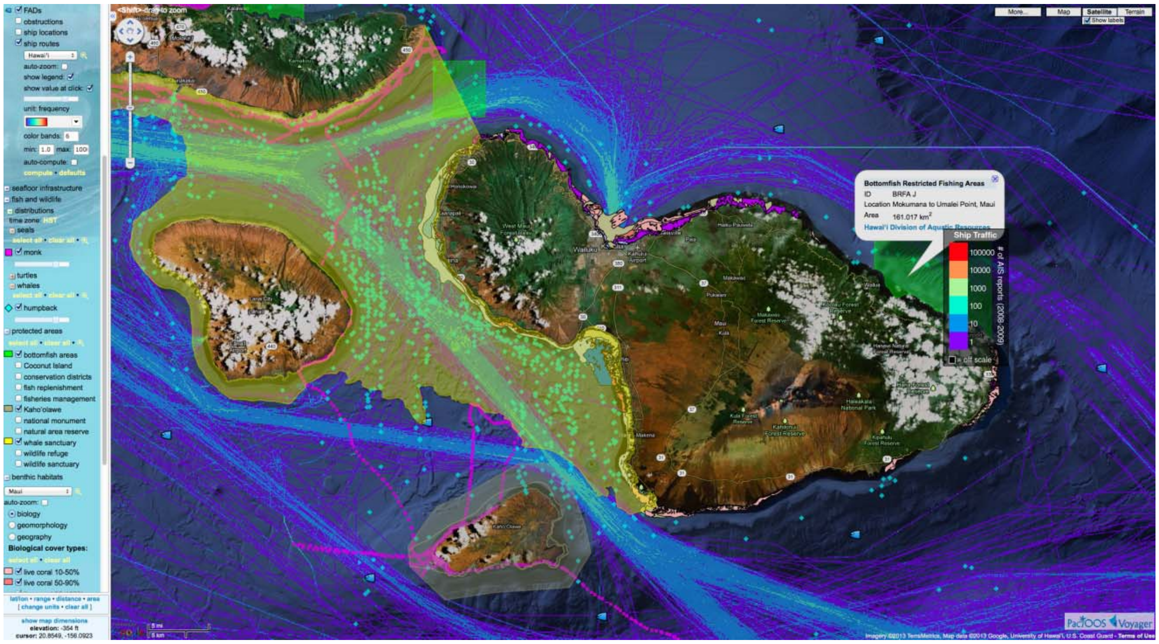


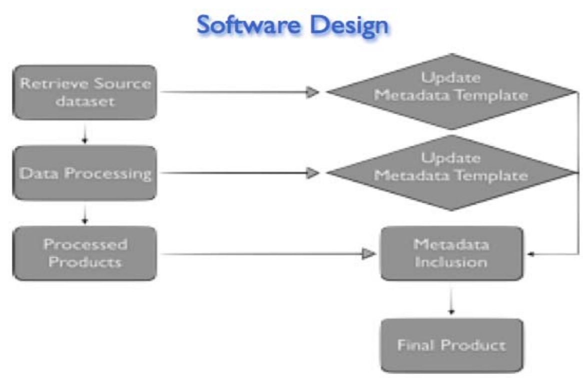
Figure 1. Example map overlay from PacIOOS Voyager (http://pacioos.org/voyager).

Data and visualization integration via web based resources

Massimo Di Stefano, WHOI

Development of cyberinfrastructure to facilitate collaboration and knowledge sharing for marine Integrated Ecosystem Assessments (IEAs).

The main tool is based on a web application (IPython Notebook) that provides the ability to work on very diverse and heterogeneous data and information sources, providing an effective way to share the source code used to generate data products and associated metadata as well as save and track the workflow provenance to allow the reproducibility of a data product.



Here, is a simplified schematic of the software design, starting with a source dataset and ending with a final product for an Ecosystem Status Report.

A key feature is that metadata, embedded in the final product, are acquired during the processing and plotting of the data.

In this way we are able to record the provenance needed to reproduce the data products.

We are using the IPython Notebook as tool for collaborative data Processing, workflow Provenance and produts Publishing.

IPython (Interactive Python) can be run interactively over the web providing to the user an effective way to work on his data.

Here in an example session showing the IPython Notebook interface used to run interactively the code to produce some figures for the NES LME Ecosystem Status Report and to execute some geospatial data analisys using tools like GRASS GIS as Geographic Information System , R for statistical analysis in combination with other free and open source software tools.

IP[y]: Notebook   Data Visualization Workshop   Last saved: Feb 27 10:30 PM   Logout

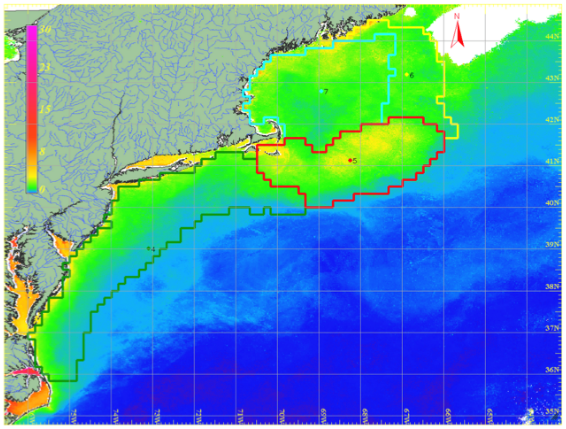
File   Edit   View   Insert   Cell   Kernel   Help

Code   Cell Toolbar: None

- Generate Hi-Res printed map - Chlorophyll-a

In [ ]:
```
os.system('gdal_translate -a_srs "+proj=lcc +lat_1=36.1667 +lat_2=43.8333 +lat_0=40 \
          +lon_0=-70 +x_0=0 +y_0=0 +no_defs +a=6378206.4 +rf=294.9786982 +to_meter=1" \
          -a_ullr -640000 -640000 640000 640000 -of GTiff -ot Float64 clh-a.hdf clh-a.tif')
grass.run_command('r.colors', map='clha', rules='clha.txt')
os.system('gdalwarp clh-a.tif clh-a-nup.tif')
grass.run_command('r.in.gdal', input='clh-a-nup.tif', output='clha', flags='oe', overwrite=True)
grass.run_command('r.null', map='clha', setnull='inf')
grass.run_command('ps.map', input='ices_map.map', output='ices_map.ps')
os.system("ps2pdf -dPDFSETTINGS=/prepress -r1200 ices_map.ps")
os.system('convert ices_map.pdf ices_map.png')
```

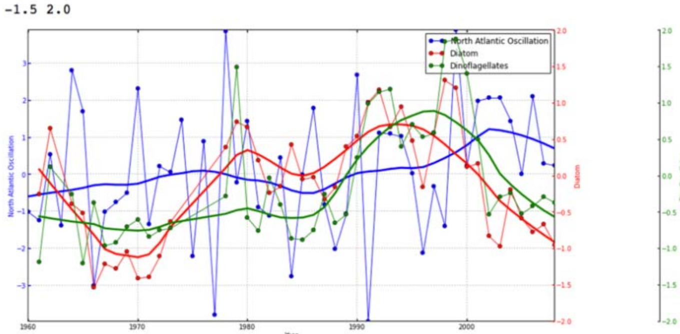
Out[54]:



- Time Series Overlay - Plot the NAO and Phytoplankton Data

In [43]:
```
phytoplancton = d.getPhitoplancton()
d.plotOverlay(data1=nao, data3=dino, data2=diatom,
              label2='Diatom', label3='Dinoflagellates', label1='North Atlantic Oscillation',
              datarange=(1960,2008), smooth=(0.25,3), aligny=True, grid=True)
```

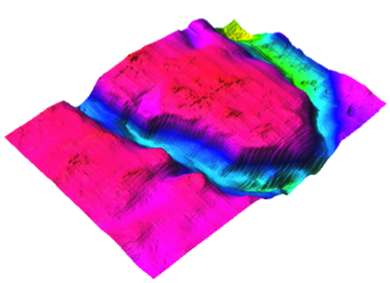
-1.5 2.0

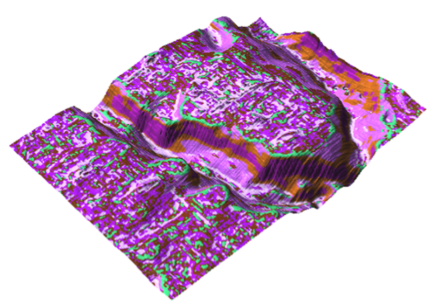


- Landform extraction from Bathymetric Grid 10m

In [15]:
```
grass.run_command('m.nviz.image', elevation_map='dtm1', output='dtm1_3d',
                  perspective=15, height=2000, color_map='dtm1', resolution_fine=1, resolution_coarse=1,
                  format='tif')
os.system('convert dtm1_3d.tif dtm1_3d.png')
Image(filename='dtm1_3d.png')
```

In [21]:
```
layer = 'dtm1'
img = makemorfo(input=layer, overwrite=True)
clusterize(img, 'dtm1k7', k=7, ss=10, ns=1500)
makemorfo(input=layer, remove=True)
Image(filename='dtm1k7.png')
```





Visualizing Fitness for Purpose

Robert Groman, WHOI

The Biological and Chemical Oceanography Data Management Office (BCO-DMO) works in partnership with ocean science investigators to publish data from research projects funded by the Biological and Chemical Oceanography Sections and the Office of Polar Programs Antarctic Organisms & Ecosystems Program (OPP ANT) at the U.S. National Science Foundation. Since 2006, researchers have been contributing data to the BCO-DMO data system, and it has developed into a rich repository of data from ocean, coastal and Great Lakes research programs. The end goals of the BCO-DMO are to ensure preservation of NSF funded project data and to provide open access to those data.

BCO-DMO has developed an end-to-end data stewardship process that includes all phases of the data life cycle: (1) working with investigators at the proposal stage to help them write their data management plan; (2) registering their funded project at BCO-DMO; (3) adding data and supporting documentation to the BCO-DMO data repository; (4) providing geospatial and text-based data access systems that support data discovery, access, display, assessment, integration, and export of data resources; (5) exploring mechanisms for exchange of data with complementary repositories; (6) publication of data sets to provide publishers of the peer-reviewed literature with citable references (Digital Object Identifiers) and to encourage proper citation and attribution of data sets in the future and (7) submission of final data sets for preservation in the appropriate long-term data archive.

We provide both a text-based and geospatial interface to the data we manage (see http://www.bco-dmo.org). Our use of visualization tools and techniques are there to help potential users of the data we manage to find the data, assess fitness for purpose, and eventually download the data they need from our site. To this end, we offer several types of plots and visualizations, consistent with the type of data being viewed, including X-Y plots (Figure 1), biological abundance plots (Figure 2), time-series plots (Figure 3), and exported KML files to Google Earth (Figure 4). Contacts: Robert C. Groman and M. Dicky Allison

A list of our “lessons learned” and recommendations include the following:

A good user interface to data should have effective visualization tools to aid the investigator in determining whether data will be useful to them.

Can we be “All things to all people”? We can try, and one of the important requirements is information about the data.

Tools must be “data driven”, and metadata enables this.

Attributes of data fitness include data location, data type, acquisition date and time, data and metadata quality, and the methodology used to collect and process the data.

A fundamental prerequisite for online data visualization is that investigators must be willing to share their data.

The richer the online options, the more complex the system is to use. Help text, video help files, and careful programming (such as good default values) can mediate this.

Recognize that different audiences require different interfaces. This adds to development time and cost, and can reduce one's focus.

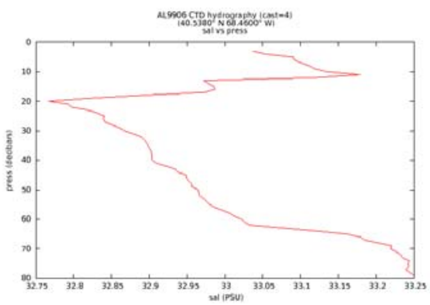


Figure 1: X-Y plot

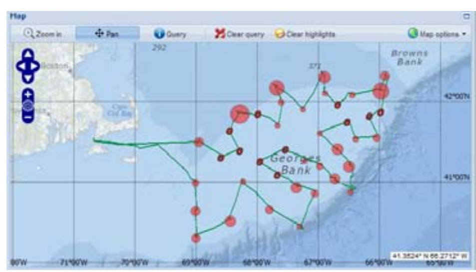


Figure 2: Abundance plot

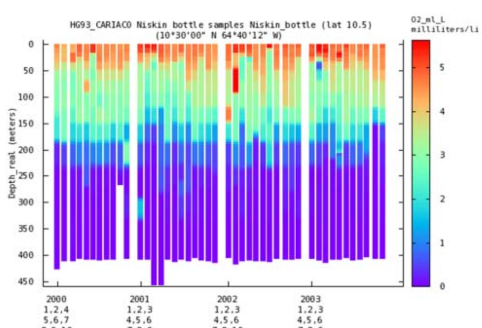


Figure 3: Time-series plot

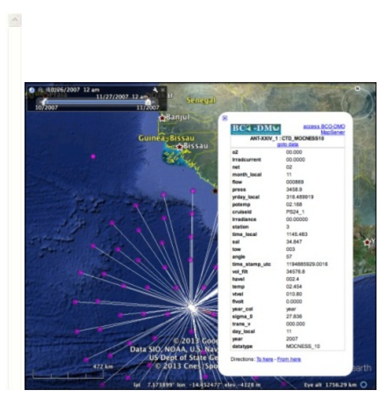
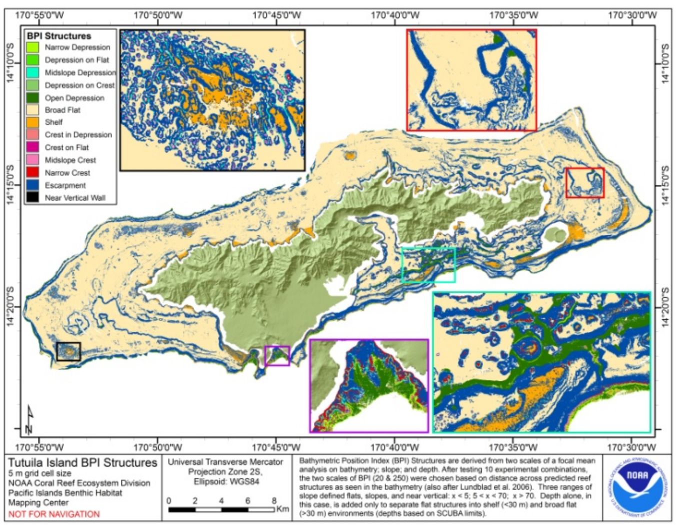


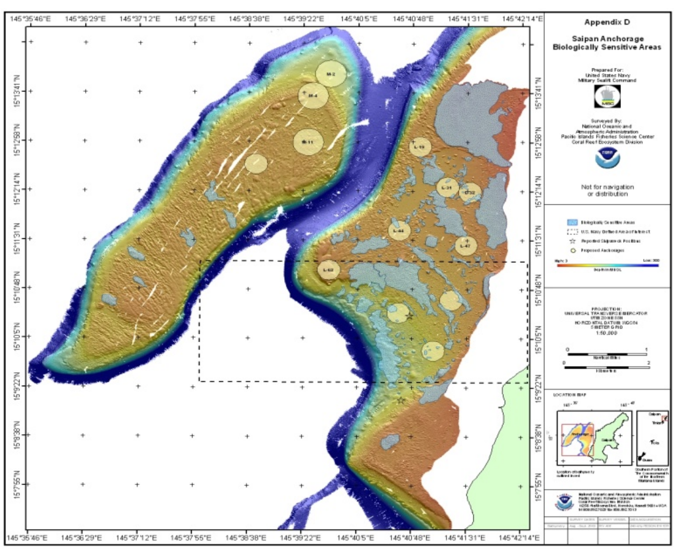
Figure 4: Exported KML file to Google Earth

Visualizations of Habitat and Siting Decisions

Michael Parke, National Marine Fisheries Service

The Pacific Islands Fisheries Science Center conducts a variety of visualization efforts that are designed to support habitat delineation and analysis, stock assessments, ecosystem-based management and marine spatial planning. Our benthic habitat mapping group uses multibeam sonars, multiple camera platforms and instruments, and diver observations to generate data that are visualized and analyzed using geographic information systems. A typical product from a multibeam data analysis would be a representation of geomorphological structures using a second-order bathymetry derivative called bathymetric position index. By explicitly incorporating data extracted from towed videos, we were able to visualize biologically-sensitive areas that should be avoided during anchoring in Saipan.

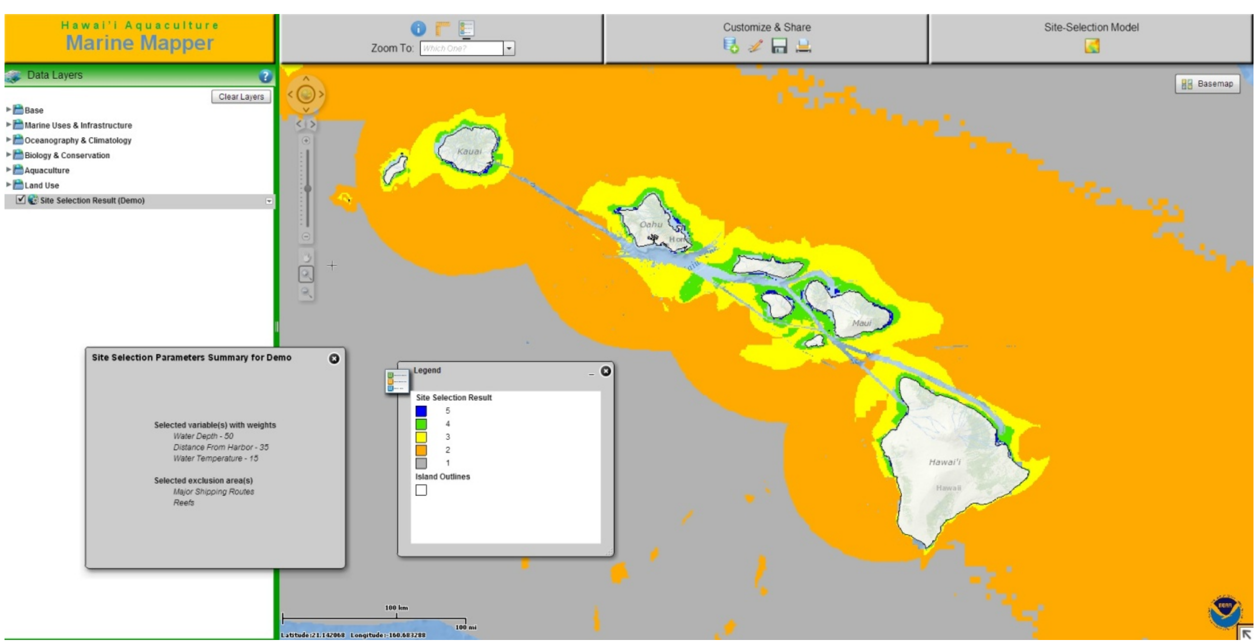




PIFSC modelers and visualization experts strive to deliver products that use appropriate temporal and spatial scales, contain adequate documentation and metadata, and offer some measure of uncertainty. Ongoing efforts to visualize more ephemeral phenomena that are needed to improve stock assessments and ecosystem-based management such as ocean currents and temperatures, boundary layers, larval transport, and life-history/habitat associations are constrained by lack of data, especially at finer scales, and model limitations.

One other ongoing visualization effort is the PIFSC Aquaculture Marine Mapper (www.pifsc.noaa.gov/MarineMapper), a web-based screening and visual communication tool designed to support responsible offshore aquaculture development in the Main Hawaiian Islands. The main premise of the tool is that interactive maps can be used to communicate oceanographic/ecological and ocean/land use patterns and thus empower people to explore their world, to communicate their values and vision for the future, and to engage with others about these values and visions.

The tool provides access to publicly available data (and metadata), allows users to view any combination of these data that they need, develop customized maps (visualizations), and run a “first-pass” site-selection model using user-defined parameters. It allows users to identify which areas have potential for aquaculture based on the parameters that are important to them. The site selection model is primarily designed to facilitate communication across user groups (entrepreneurs, regulators, community groups) by making value judgments explicit and providing immediate visualization of the impacts of such judgments. A major limitation of the tool is its inability to visualize or calculate risk or vulnerability of natural systems to any particular aquaculture operation.



Habitat modeling and visualization

Scott Gallager, Woods Hole Oceanographic Institution and the HabCam Group

Habitat characterization and predictive modeling requires integration of information at multiple spatial and temporal scales on benthic and pelagic biological distributions, substrate composition, geomorphology, water column hydrography, as well as many other environmental features which provide suitable conditions for organisms to flourish. HabCam is a tool that provides a unique glimpse of the seafloor through optical and acoustic imaging. The HabCam vehicle flies over the ocean bottom taking six images per second creating noninvasive continuous image ribbons and environmental data in real-time. Habitat modeling (Fig. 1) begins

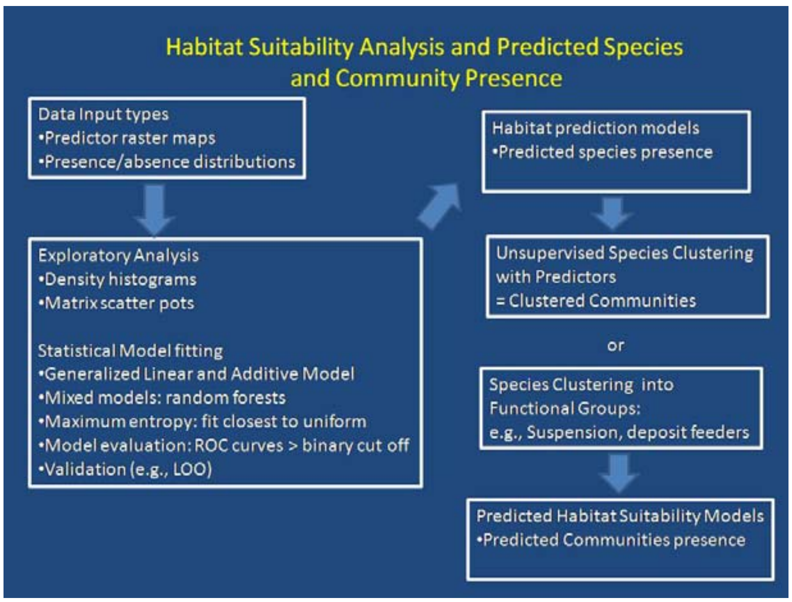


Figure 1. Flow chart for developing habitat suitability maps for single species and biological communities.

with creating standard size geolocated grids of predictor variables such as bathymetry, geomorphology (slope, rugosity, and gradient from both optic and acoustic data), substrate, epifauna cover (e.g., lacy tube worm, bryozoa, encrusting, sponge, tunicate, etc.) temperature, salinity, etc. The distribution of point presence data for biological targets such as ground fish, scallops, seastars, etc. is then overlaid on the predictor grids. Statistical models such as general additive, linear, random forests, or maximum entropy are then used to develop habitat classifications based on training data. For this study we developed a variation of the maximum entropy model Maxent (Phillips et al., 2006), whereby both presence and absence data contributed to the predicted model results (Fig. 2). The model output for each target species was then spatially clustered into four or more biological communities using all of the predictive raster and presence data. Accuracy of the model results are cross-validated using leave-one-out procedures. The results are maps of predicted distributions of individual species and communities that may be viewed over time to assess variation as a function of environmental change.

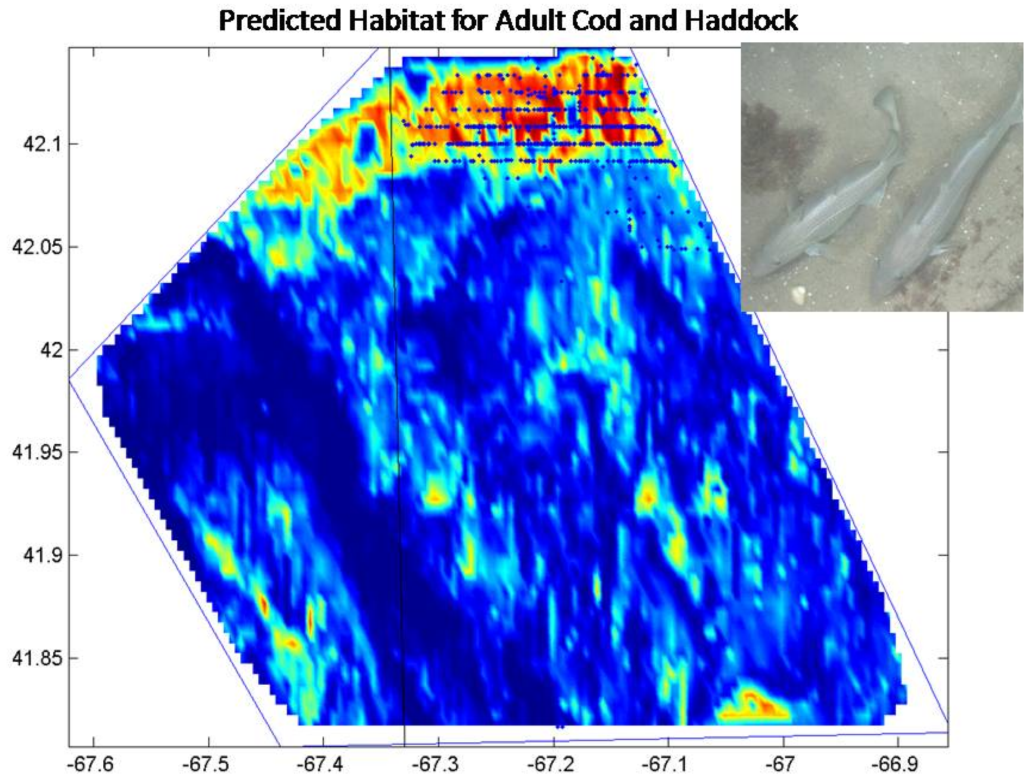


Figure 2. Predicted suitable habitat for adult cod and haddock in the northern section of Closed Area II, Georges Bank and regions to the west of the closure boundary (black line). Note absence of suitable habitat along three sand ridges extending northwest to southeast.

Communicating an understanding of lower trophic levels in marine ecosystems

Andy Pershing, University of Maine

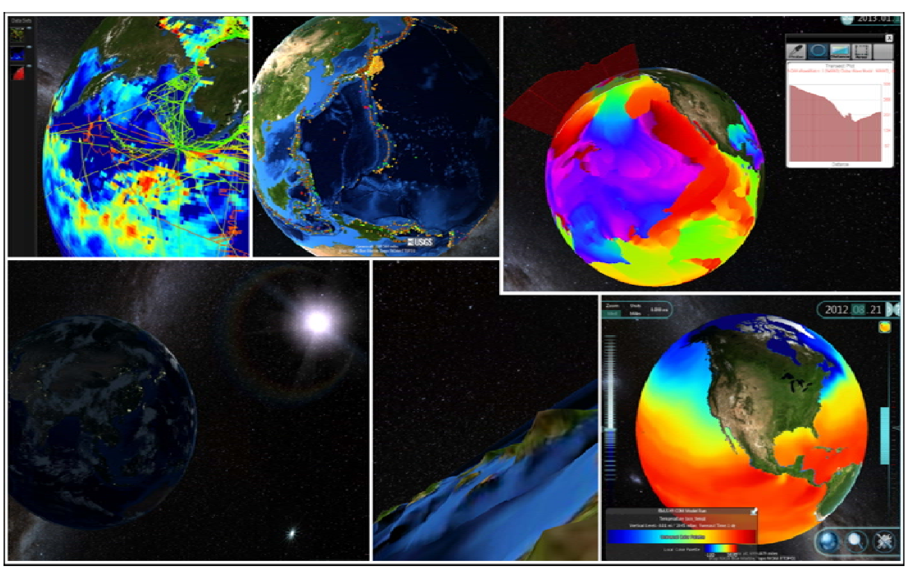
The northwest Atlantic, including the NE Shelf LME and the Canadian Shelf and Labrador Sea are changing rapidly. In particular, the Labrador Sea is warming faster than any region in the global ocean. The changes in the physical setting have far reaching impacts on ecosystems throughout the region, affecting primary productivity, plankton community structure, fish populations, and fisheries. Visualization is an important tool for understanding and communicating the causes and consequences of these changes. For many global change problems, the key challenge is to highlight components that are changing rapidly. Removing annual cycles exposes large deviations from expected conditions. When visualizing these deviations, using a color scheme that emphasizes the sign rather than the magnitude is useful. In this light, the 2012 SST anomaly stands out as the major feature in the North Atlantic last year, and one of the largest events ever. When communicating with broader audiences, careful thought is required to develop visualizations that quickly convey the intended message. However, a scientist exploring data often wants to see many variables plotted together. These ugly graphics, for example a large table of correlations between plankton abundance and physical indicators, can be very useful for an individual scientist for identifying patterns, but would be off-putting to many other audiences. Once a result is identified, communicating that result, regardless of audience, involves telling a story. Visualizations, for example, a food web highlighting correlations among species, are an important tool in telling the story, but they are not the whole story. A narrative, either through text, video, or a live presentation, are essential for guiding the viewer/reader through the story. Animations or diagrams can be especially helpful in developing the narrative.

Find And Visualize NOAA Data: An Overview of the NOAA Earth Information System (NEIS) and TerraViz

Jeff Smith, Earth Systems Research Laboratory

The NOAA Earth Information Services (NEIS) is a framework of layered services designed to help the discovery, access, understanding, and visualization of data from the past, present, and future. It includes a visualization component named TerraViz that is a multi-platform tool, running on desktops, web browsers, and mobile devices. The goal is to ingest "big data" and convert that information into efficient formats for real-time visualization. Designed for a world where everything is in motion, NEIS and TerraViz allow fluid data integration and interaction across 4D time and space, providing a tool for everything NOAA does and the people NOAA affects.

TerraViz is built using the Unity game engine. While a game engine may seem a strange choice for data visualizations, our philosophy is to take advantage of existing technology whenever possible. Video games are a multibillion-dollar industry, and are quite simply the most powerful tools for pushing millions of points of data to the user in real-time. Our presentation illustrated displaying environmental data in TerraViz at a global scale, visualizing regional data in “scenes” such as the flooding of the Washington DC area or rotating a coastal ecosystem in three axes, and developing environmental simulations/games like exploring the ocean floor in a submarine.



The NEIS backend similarly takes lessons from private industry as we use Apache Solr to allow faceted search of NOAA data, much as sites like Amazon and Netflix do.

We believe that to have an impact on society, data should be easy to find, access, visualize, and understand. Please contact us if you want to explore including your environmental data within NEIS/TerraViz or if you want to talk to us about developing custom simulations or games to showcase your important data.

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Submarine demo: http://www.youtube.com/watch?v=Ukaln8_ai3c

Getting to observing data usign the climatology toolkit

Riley Young Morse, Gulf of Maine Research Institute

"Is the water warmer this year than it was last year?" This is one of the most commonly asked questions by users of the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS). To help answer this question, a team of data providers and product developers at NERACOOS set out to develop an online interactive climatology visualization that would enable users of the system to see the data and answer that question for themselves.

The result is a tool called the NERACOOS Weather and Climate Display (http://www.neracoos.org/datatools/climatologies). The tool consists of an interactive line chart that displays the time series climatology data as a background shaded area, with the min monthly and max monthly means creating the upper and lower boundaries. The mean of the full climatology is plotted as well to make up the static background. Users can choose a buoy location, parameter and depth, and the background will automatically update with the relevant climatology data. Additionally, the means of a given year are displayed above the static climatology, and can be easily changed using navigation buttons. By mousing over any point on the chart, the precise values are displayed to the user. Additionally, the full data table can be displayed to access and download the data for further analysis in desktop tools of choice.

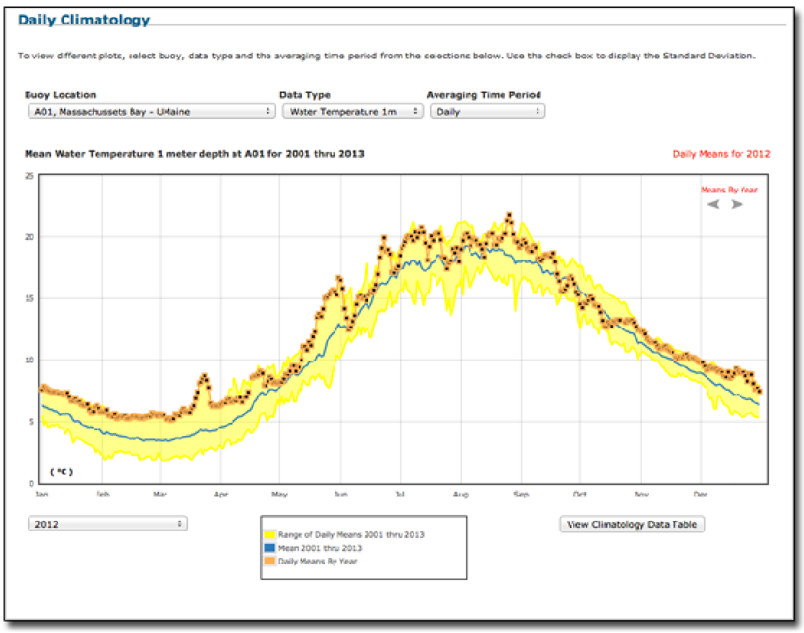

Figure 1: 2012 daily climatology of water temperature at 1 m depth for Buoy A

The buoy data providers developed a common protocol for calculating the daily, weekly and monthly climatology statistics for each buoy, parameter and each depth. The statistics calculated include: count, mean, median, mode, min, max, stddev, pct0.5, pct02.5, pct97.5, pct99.5, IQR (25%, 50%). The files are output as csv files into a web accessible FTP directory. Additional automated tasks include calculation of current year daily means at the end of each day, and monthly means at the end of each calendar month. The range of available data to calculate the climatologies was different for each buoy, with some going as far back as 2001. The background climatologies will be updated at the end of each year.

On the web interface side, a JavaScript plotting library called FLOT was used to create the web-based viewer. Scripts were developed to parse the csv files and output into JSON (JavaScript Object Notation) format, an object-oriented data interchange format used by the JavaScript FLOT library. This process is automated for a highly interactive, up to date display.

Future plans include development of a map-based interface, additional datasets and parameters, and display of more statistical information for advanced users. The tool has generated tremendous interest demonstrating the value of delivering complex information in a simple, interactive format to reach and engage a wide variety of users.

Developing a climate data visualization tool for marine ecosystem managers

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The National Oceanic and Atmospheric Administration is responsible both for the collection and archival of a vast proportion of the data collected from the nation's environmental monitoring activities, as well as providing stewardship over the nation's marine ecosystems and the valuable ecosystem services they provide to society. In order to ensure the latter, data available via the former must be accessible and provided in ways that marine ecosystem managers can readily comprehend.

Over the past few decades, the impacts of climate variability and change on marine ecosystems have become more acute and are acknowledged as a significant threat to their sustainable futures. However, although there is a great quantity of climate data held by NOAA, and a variety of tools by which these data may be obtained and displayed, marine ecosystem managers are faced with several obstacles in their attempts to transform raw climate data into meaningful visualizations capable of supporting sound management decisions.

Chief among these obstacles are the (1) lack of uniformity in data set access and format, (2) the requirement that data first be obtained before it may be visualized, and (3) the requirement that managers not only understand what data they require and where they may be found, but also that they understand which of several similar data sets may be most appropriate to address a given management question. What is more, there exist few data access tools that include the ability to visualize the data. This is an important issue, because the visualization of data often aids a user in determining what data are truly important to a particular management question. Without the ability to visualize the data, a manager must blindly download all available data, and then expunge any data that their subsequent visualization deems irrelevant. This presents an unnecessary burden on the manager's time, the server, and on bandwidth. In an effort to better address the needs of marine ecosystem managers and overcome these barriers, a NOAA-wide group has created the Integrated Marine Protected Area Climate Tools (IMPACT) project, within which data access and visualization tools are being developed. The overarching goal of IMPACT was to ensure that data access, visualization, and understanding were based upon the management questions being posed, and therefore could optimize the resources needed to facilitate the identification, access, visualization, and use of appropriate data.

WCT-IMPACT

One such tool is the WCT-IMPACT software. NOAA's National Climatic Data Center (NCDC) has been working with the Gulf of the Farallones National Marine Sanctuary (GOFNMS) Ocean Climate Center to enhance and expand the functionality of NOAA's Weather and Climate Toolkit (WCT). The WCT (Fig. 1) is a freely-available, Java-based tool (http://www.ncdc.noaa.gov/oa/wct/) designed to access and display a variety of NCDC's georeferenced climate data products (e.g., satellite, radar, reanalysis). However, the WCT requires the user to have already identified a data set of interest and gained access to it. This can limit its utility by users who are not knowledgeable about which data sets are relevant to their needs and where those data sets can be found. The Integrated Marine Protected Area Climate Tools (IMPACT) prototype modification to the WCT eliminates those requirements. Instead, WCT-IMPACT couples a user query approach with a quasi-expert system that determines, retrieves, and loads the appropriate data products for visualization and analysis by the user. Relevant data products are identified based on the environmental variables in which ecosystem managers have indicated are important to their ecosystems.

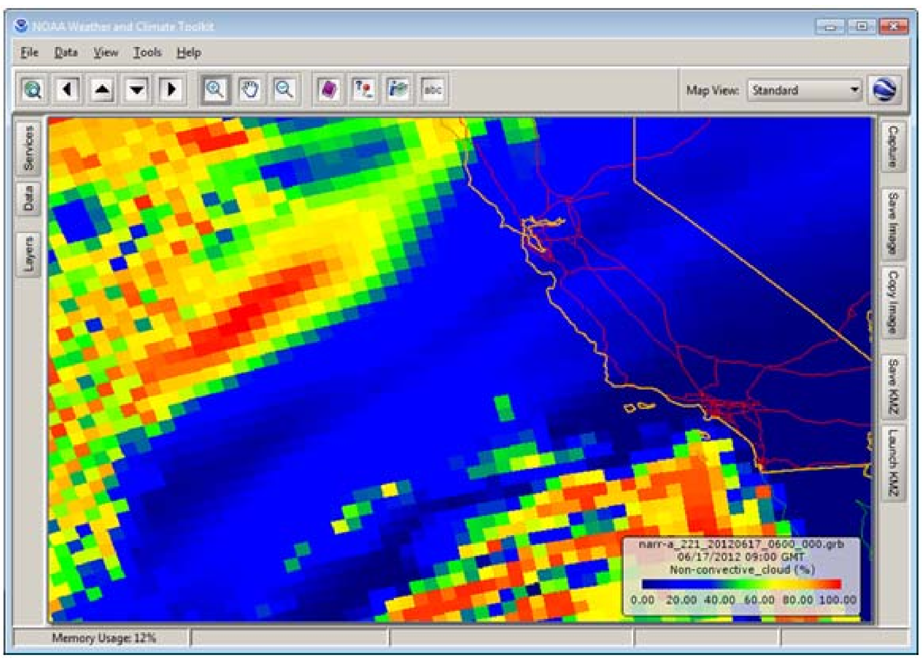

Figure 2. NOAA's Weather and Climate Toolkit image of NARR-A non-convective cloud cover (%) over the Pacific Coast on June 17, 2012 at 09:00 GMT.

At the core of WCT-IMPACT is a needs-assessment that was conducted through interactive and iterative dialog between NCDC programmers and GOFNMS managers and scientists. This dialog once again highlighted the aforementioned barriers to data acquisition, visualization and use. To address the data access barrier, climate data managers identified several of NOAA's Climate Data Records (CDRs) that would provide reliable, defensible, and homogeneous information about environmental variables that had been identified by the marine managers and scientists as important to addressing their climate-related questions. Direct access was built into WCT-IMPACT via an index file that eliminated the requirement that a user know where, and in what format the data resides before it can be accessed. In a departure from current data management practices, the variable names contained in the data file (e.g., irwin) were replaced with the names that marine managers associate with the data (e.g., cloud cover). To enhance understanding of what data were being accessed, what coverage was available, and what exactly was being described by the data, NCDC climatologists also included an information button that, when selected, displays a pop-up window with a description of the data and a link to more complete metadata.

Furthermore, WCT-IMPACT has the functionality to display data as an individual time slice over the area of interest, or if a range of time is specified, as an animation. The animation feature can be especially helpful for assisting a manager in determining the degree of variability that may exist within the data, or to bound periods when environmental conditions may have exceeded a critical threshold value.

A key aspect of WCT-IMPACT is that it is a Java tool, rather than a Web-based tool. This allows it to be used on a computer that is not connected to the Internet. The advantages include being able to visualize data while working in the field, or modifying an animation based on feedback from a stakeholder or policy-maker during a briefing at a remote site. WCT-IMPACT not only accesses data from remote servers, but also can access the data stored locally on the PC. Thus, a data set may be subsetted off NCDC's servers, stored as a file on a laptop, and then be referenced with the software without a further Internet connection. This can be very important for managers who have limited or costly access to the Internet. Locally-collected data files may also be visualized in WCT-IMPACT if they are stored in a recognized georeferenced format.

Visualization Needs

When it comes to the visualization of the data, ecosystem managers were in general agreement that there were certain considerations needed to achieve an effective marine ecosystem management tool for climate data. First of all, the tool had to be a one-stop shop. The manager wanted access to the relevant data directly from the software. This is achieved through the WCT-IMPACT data access code. Secondly, managers want a tool that doesn't require a steep learning curve, or complex steps in order to get to a visualization of the data. The consensus was that the tool's interface should have a look and feel that does not differ dramatically from tools with which they are familiar. The tool interface should also be simple, giving a novice user the ability to intuitively create a basic visualization, but with more complex options available through tabs or menus.

Currently, the WCT-IMPACT tool has a separate control window and visualization window. A complaint by managers was that on smaller screens (i.e., laptop), one window would inevitably obscure the other, and with many windows open, the control window could become buried with no option to bring it forward. WCT-IMPACT developers are currently considering a single-window tabbed version of the software so that a user may quickly transition between all active windows within the tool.

Managers also stated the importance of being able to visualize two or more variables in the same display (e.g., GIS layers). However, when overlaid, it becomes difficult to differentiate color schemes and patters from each individual variable. WCT-IMPACT developers first thought to combine shaded relief with vector contours, however such functionality is a complex undertaking. Instead, it was decided to provide a multi-frame window (Fig. 2), where up to four variables could be displayed simultaneously and in synchronization. When one frame is repositioned and/or zoomed in space, or cycled in time, the others, when linked, mirror the alteration.

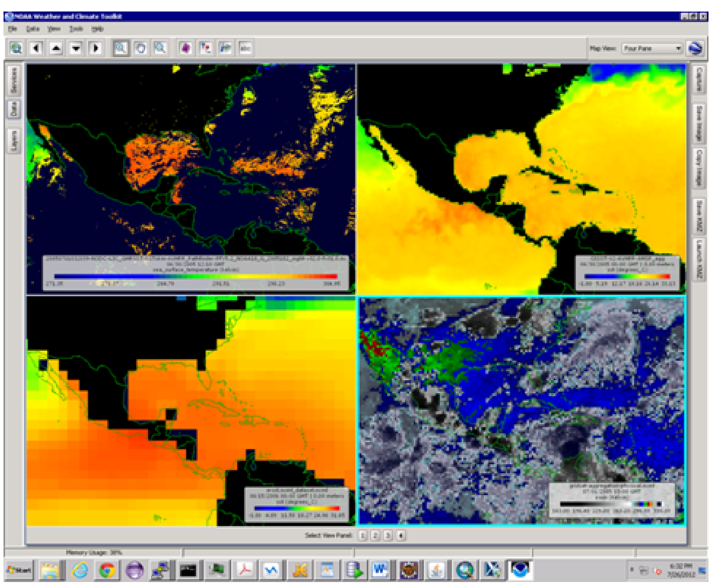

Figure 3. Four-frame data visualization window from the WCT-IMPACT software.

In addition, managers requested that a visualization tool also have the capacity to perform at least basic analyses of the data. These included the display of sums, averages, differences, anomalies, probabilities, extremes, and trends. Furthermore, a manager should have the option of saving the displays along with the data locally, for export to other software (e.g, Google Earth) or for inserting into reports and publications (e.g., briefing materials, fact sheets). For managers, one of the most common uses for visualization software is to provide visual aids for explaining a particular phenomenon to policy-makers, stakeholders, or the public.

SUMMARY

The WCT-IMPACT data access and visualization tool has been developed specifically to address the stated needs of marine ecosystem managers to combine data access and data visualization, and deliver relevant climate information to support management decisions, develop ecosystem-scale climate assessments, and produce visual aids in support of education and outreach efforts to the public, stakeholders, and policy-makers. At every step of development, marine ecosystem managers have been included in the framing of requirements, so that not only is the tool developed to be of optimal use by them, but that the climate data managers who maintain the tool also become more aware of the needs of the marine ecosystem community. Features are included because the marine managers have asked for them, rather than because the data managers desire the tool to serve every possible need of every possible user. WCT-IMPACT is currently still in a prototype stage, but is expected to be released operationally within the upcoming months, via NCDC's website.

Contributions via Correspondence

The Multiscale Integrated Model of Ecosystem Services (MIMES) is a modeling framework designed to address the magnitude, dynamics, and spatial patterns of ecosystem service flows, values, and tradeoffs. Theoretical principles, expert knowledge, and data-derived relationships are used to link diverse types of information about a system. The MIMES model couples the human and natural subsystems by considering the interdependencies present within and between the natural and human spheres that make up an ecosystem. In addition, MIMES provides an analytical framework for understanding the ecosystem-level consequences of scenarios that reflect specific management decisions. The model outputs are used to understand ecosystem service tradeoffs that occur in space and time as a result of specific management decisions or environmental shifts (e.g. climate change). MIMES has been applied to a number of case studies. Recent efforts have been focused on understanding a coastal and nearshore environment in northern Massachusetts that encompasses a large portion of Massachusetts Bay and Stellwagen Bank National Marine Sanctuary. For this case study two sets of resource management scenarios were explored. Forage Fish scenarios consider the effects of changing commercial fishing rates and targeted species of forage fishes including the impacts of opening a fishery on sand lance species (not currently targeted by commercial fishing) and changing rates of fishing on herring species (currently targeted by commercial fishing or taken as bycatch). Results demonstrate tradeoffs related to whale watching, commercial and recreational fisheries and conservation. Wind Energy scenarios consider the development of commercial and community scale wind energy sites and the associated tradeoffs involving whale watching, commercial and recreational fisheries and conservation. The MIMES model provides an essential analytical framework from which to determine the outcome of alternative decisions, yet additional tools are needed to translate model outputs to a diverse stakeholder audience (including managers) and support the decision-making process. The Marine Integrated Decision Analysis System (MIDAS) is a visualization tool designed to communicate the MIMES model's results and support understanding of ecosystem service tradeoffs related to alternative management decisions. MIDAS is a user-friendly, web-based interface that incorporates features of open source GIS, participatory mapping, and social collaboration. Overall, MIDAS embraces a Web 2.0 perspective incorporating features of participatory information sharing, interoperability, user-centered design, and collaboration. Through MIDAS, users can debate alternative policy options, propose new management scenarios, and contribute to an ongoing dialogue about the future of coastal and marine systems. Paths through MIDAS can be shared between users with similar or differing motivations helping to identify competitive or cooperative outcomes and generally fostering an appreciation for the disparate perspectives related to human use of marine resources.

For more information, please contact Prof. Les Kaufman (lesk@bu.edu) or Prof. Suchi Gopal (suchi@bu.edu).

Recommendations

Principles:

The workshop participants expressed interest in continuing the development of wider access to NOAA datasets, community standards on ways of attributing credit to researchers sharing data, and a more uniform approach to the summarization of data with privacy issues.

The workshop participants recommended the development of collaborations with social scientists and or communications experts to discuss how the visualization of ecosystem data varies according to the audience and the media available to the public.

The workshop participants recognized that different audiences require different interfaces and can process different levels of complexity.

It is essential to establish a dialog with the stakeholders and managers in order to understand the specific information that is needed.

The workshop participants noted that the developers of visualization tools should consider that the user interface should have effective tools to aid the users in determining whether the data presented will be useful to them. The fact is that with the advanced development of richer online options, the more complex the system is to use, the greater is the need to provide help text, video help files, and careful programming (such as good default values) which will facilitate the use of the end user interface.

The workshop participants identified the need to include the appropriate scale of the ecosystem (spatial and temporal) for the type of analyses needed, the inclusion of error and uncertainty representations in the products offered to the users and the inclusion of the human factor in all the representations related to the ecosystem visualization were also identified as needs.

The workshop participants identified specific criteria that could improve the success of the ecosystem data visualization used by the stakeholders and managers. Those criteria included the suggestion to break-up the ecosystem components/groups to help simplify the graphic representation, standardization of use of colors in the visualizations, the use of cartoon characters to help facilitate the understanding of the data, the need to include visual animation of the parameters' variability and of the ecosystem response to that variation in a graphic manner, the need to guide the audience through the use of homologies to establish connections with personally familiar concepts, and finally to walk through data exploration with the managers and stakeholders.

The workshop participants recommended that the attributes of data should include data location, data type, acquisition date and time, data and metadata quality, and the methodology used to collect and process the data. This should also include uncertainty within the data, and sources of potential error.

Actions:

The workshop participants recommend that a working group on visualizing species distribution driven by climate change and other factors, initially focusing on fishes, composed of regional scientists and individuals with practical knowledge, explore ways of expressing the key elements of where resources species have been distributed and where they will likely be distributed in the future. The workshop envisions that this working group will work mainly via correspondence utilizing web-based communications and may occasional gather for in-person workshops. The workshop identified Chad Keith (NEFSC) as a lead in this effort and a point of contact for those interested in participating.

The workshop participants noted that despite the comprehensive coverage and reach of the workshop, accomplished with modest resources, many NOAA offices from other regions were unable to participate, and likewise, many academic and non-NOAA agencies were not represented. The workshop encourages other NOAA regional teams to consider follow-on workshops building on the themes explored in this workshop engaging other regions and groups.

Currently, NOAA has ongoing interest/user groups that focus on subject areas of current interest to a broad audience both within and outside NOAA. The workshop suggests that an ecosystems data visualization users groups may be timely and of wide interest and the idea of developing such a group be explored. This proposal may be of overlapping interest to the GIS users group, which should be contacted to gauge interest. Michael Parke was identified as the lead to explore this effort.

The workshop participants recommended training be provided, specifically related to the development of applications using the Unity 3D game engine and TerraViz, as well as to increase the use among the scientific community of the Ipython environment.

The workshop encourages Science Communication and Information Technology training for marine scientists to better utilize current capabilities of the information age. Scientist should be informed on schema of colors, icons, representations that work best across a broad spectrum of audiences.

Appendix 1. Agenda

Day 1, February 5

Start (h:m)	Duration (h:m)	AGENDA	
9:00	0:15	WELCOME & INTRODUCTION	Annala, John and Friedland, Kevin
9:15	0:30	Changing perspectives about a changing ecosystem	Friedland, Kevin
9:45	0:30	Visualizing complexity: how can we view food web and multi-species data and dynamic ecosystem model outputs	Gaichas, Sarah
10:15	0:30	Visualization and Gaming of Ecosystem Model Scenarios	Gamble, Robert
10:45	0:15	BREAK	
11:00	0:30	Getting more from data than just where the fish are	Geis, Scott
11:30	0:30	Visualizing the base of the food chain	Hyde, Kim
12:00	0:30	Challenges, lessons learned, and a FEW potential visualization solutions for synthesizing science to inform Management in south Florida	Kelble, Chris
12:30	1:00	LUNCH	
13:30	0:30	Dynamic conceptualization of habitat	Manderson, John
14:00	0:30	Designing geospatial data visualizations for a general audience	Butkiewicz, Tom
14:30	0:30	Dealing with scientific and communication uncertainty through data visualization	Townsend, Howard
15:00	0:15	BREAK	
15:15	0:30	NEFSC Data Server: access & visualization with Python	Manning, Jim
15:45	0:30	Web access, analysis and visualization of standardized oceanographic and meterological data	Signell, Rich
16:15	0:30	Oceanographic data and data-services at PacIOOS, a regional association of IOOS (remote 5 hours)	Potemra, James
16:45	0:15	WRAP	
17:00		END	

Day 2, February 6

Start (h:m)	Duration (h:m)	AGENDA	
8:00	0:05	ORIENTATION	
8:05	0:30	Data and visualization integration via web based resources	Di Stefano, Massimo
8:35	0:30	Visualizing Fitness for Purpose	Groman, Robert
9:05	0:30	Visualizations of Habitat and Siting Decisions	Parke, Michael
9:35	0:30	Habitat modeling and visualization	Gallager, Scott
10:05	0:15	BREAK	
10:20	0:30	Communicating an understanding of lower trophic levels in marine eosystems	Pershing, Andy
10:50	0:30	Find And Visualize NOAA Data: An Overview of the NOAA Earth Infomation System (NEIS) and TerraViz (remote 2 hours)	Smith, Jeff
11:20	0:30	Getting to observing data usign the climatology toolkit	Young Morse, Riley
11:50	0:30	Developing a climate data visualization tool for marine ecosystem managers	Shein, Karsten
12:20	1:00	LUNCH	
13:20	1:40	WRAP	
15:00		END	

Appendix 2. Participants

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Appendix 3. Visualization Products and Services

Name	Organization	Contact Phone	Contact E-mail	Data Management	Visualization	Link to Product	Brief Product Description	Brief Description of Services Provided
TerraViz	NOAA/GSD	303.497.4437	Julien.Lynge@noaa.gov		X	http://esrl.noaa.gov/neis/	TerraViz is a high-end, 3D visualization tool being developed within NOAA with the goal of displaying nearly all NOAA data, past and future.	We create visualizations, simulations, and games for NOAA, DOE, DOD, and other organizations.
NEIS (NOAA Earth Information Services)	NOAA/GSD	303.497.6724	Jebb.Q.Stewart@noaa.gov	X		http://esrl.noaa.gov/neis/	NEIS is a collection of services to help users find, access, analyze, and manage NOAA data, past and future.	
Bob Groman	BCO-DMO/WHOI	508-289-2409	rgroman@whoi.edu	X	X	www.bcodmo.org	Text-based access to BCO-DMO managed datasets	Work with investigators to manage their data from proposal to preservation. Collect sufficient metadata to enable data reuse by others.
						http://mapservice.bco-dmo.org/mapserver/maps-ol/index.php	Geospatial access to BCO-DMO managed datasets	Metadata and data are searchable, with plotting/visualilzation options available to aid in deciding whether someone elses data would be of use to you. Data are accessible and can be downloaded in many formats,
Sarah Gaichas	NOAA NMFS Northeast Fisheries Science Center, Woods Hole	508 495 2016	Sarah.Gaichas@noaa.gov		x	http://gephi.org/ and http://pajek.imfm.si/doku.php	network visualization software--free and not produced by me	none
Genoveva Gonzalez-Mirelis	IMR	+47 55236376	genoveva.gonzalez-mirelis@imr.no		X	http://www.mareano.no/en	We provide distribution maps and/or predicted occurrence of benthic fauna and seafloor habitat	