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Short Papers

OceanPaths: Visualizing Multivariate Oceanography Data

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Abstract

Geographical datasets are ubiquitous in oceanography. While map-based visualizations are useful for many different domains, they can suffer from cluttering and overplotting issues when used for multivariate data sets. As a result, spatial data exploration in oceanography has often been restricted to multiple maps showing various depths or time intervals. This lack of interactive exploration often hinders efforts to expose correlations between properties of oceanographic features, specifically currents. OceanPaths provides powerful interaction and exploration methods for spatial, multivariate oceanography datasets to remedy these situations. Fundamentally, our method allows users to define pathways, typically following currents, along which the variation of the high-dimensional data can be plotted efficiently. We present a case study conducted by domain experts to underscore the usefulness of OceanPaths in uncovering trends and correlations in oceanographic data sets.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: User Interfaces—Graphical user interfaces (GUI)

1. Introduction

Spatial visualization of properties in the ocean is a key component of the work of many researchers in the field of oceanography. Oceanographic data can be collected using in situ methods (ship expeditions), remote sensing (satellites), or can be the output of computational models. The default method for visualization and analysis for oceanographers are maps, overlaid with color-coded marks. The analysts goal is to better understand property distribution and *advection*, i.e the transfer of heat or matter by the ocean. The challenge that arises with oceanographic measurements is that they are often multivariate (e.g., measuring temperature, salinity, oxygen content, etc.) and available for multiple depths and/or time points resulting in a high-dimensional spatial dataset. As noted by Lipsa et al. [LLC*11], attempting to include multiple dimensions in a map-based visualization can lead to cluttering which can significantly hinder the effectiveness of the visualization.

Exploring trends in these properties, usually as a function of time and geographic location, is a common task in oceanography. In an attempt to reduce the spatial data to a single dimension, researchers often use either latitude or longitude to plot against these properties, e.g., in scatterplots where one axis corresponds to a spatial dimension. While this approach accomplishes the goal of reducing dimensionality, it also confines the user to assessing movement in pathways along equal longitude or latitude. Moreover, as discussed by Anderson et al. [AAD*10], oceanographers still use predominantly static maps, which are often restricted to a single depth and time.

The authors of a study on the deep circulation in the Arctic Ocean [SFM*14] acknowledge the shortcomings associated with using either latitude or longitude as a proxy for spatial variability. The paper points out that complex features in the local bathymetry, i.e, the topography of the ocean floor, can have a significant impact on local dynamics, a factor that can not be effectively quantified when the spatial component of data is restricted to plotting along latitude or longitude, or a straight vector of a different orientation.

In this paper, we present OceanPaths, a novel visual tool for exploring multidimensional oceanographic datasets, addressing the shortcomings discussed above, by enabling users to define custom pathways along which to plot the multivariate data. OceanPaths is an open source web application and can be accessed at http://cnobre.github.io/oceanpaths.

OceanPaths was developed in collaboration with a team of oceanographers at the Woods Hole Oceanographic Institution (WHOI) on Cape Cod in Massachusetts, USA. The team consisted of researchers from the physical, chemical,

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and biological oceanography departments and included experts in arctic circulation, dispersion of radioactive elements in the ocean, and permanence of radioisotopes on marine organisms. The design of our tool was guided by the following domain tasks, which we elicited through interviews with these domain experts:

1. Determine current trajectories.
2. Explore the variation of various measurements along currents.
3. Compare data distribution at several distinct depth and time intervals.

Ocean currents play a fundamental role in shaping the earth's climate and heat distribution. As such, a better understanding of this data can inform policies on ocean warming, ice melt, and overall environmental awareness.

2. Related Work

Multivariate data visualization in the domain of earth science has previously been addressed by several authors [LFH08, YXG*10, CFG*05, BvL06, JKM06, DMB*06, MDHB*07]. Lipsa et al [LLC*11] present a comprehensive overview of data visualizations used in the physical sciences and notes that there is no shortage of challenges in this field. Our work focuses on visualization for multivariate geospatial oceanography datasets. Researchers have employed various methods for handling multivariate spatial visualization in other domains. Li et al. [LFH08] visualized multivariate 2D astronomy data by mapping user-defined wavelengths to color values. Similarly, Yuan et al. [YXG*10] used time as a third dimension in a study of seismic and satellite-based observational data. Our map interface encompasses these techniques by allowing the user to select which field is encoded as color on both the map and the associated scatterplots.

Studies involving 3D multivariate physics data employed glyphs to encode additional dimensions [CFG*05, BvL06, JKM06, DMB*06, MDHB*07]. Parallel coordinates [QCX*07] as well as multiple linked views [CFG*05, KLM*08] have also been employed in physics to handle multidimensional data sets.

In contrast to these methods, OceanPaths takes a unique approach in handling multivariate, spatial datasets by meaningfully condensing the spatial dimensions of a dataset while still preserving the spatial variability. Our tool allows the user to define a set of branching pathways along which currents flow. As such, it is related to previous work on visualizing multivariate networks [PLS*13], yet uses significantly different types of data, visual encodings and interaction techniques.

3. Visualization Approach

In order to support the elicited domain tasks, we use two coordinated views (see Figure 1): a map, where selected attributes can be directly plotted and pathways can be interactively defined, and a "Scatterplot Network", showing the multivariate data along the pathways.

Map

We plot points on the map to show where measurements are available. On demand, these points can be color-coded to visualize a selected attribute at a chosen time and depth, or an aggregate thereof. The background layer shows the depth of the ocean. Based on the data, the depth information (currents tend to follow lines of constant depth), and their background-knowledge about currents in the ocean, experts can create and edit pathways in the map interface, addressing domain task 1. The pathways can have multiple incoming and outgoing branches, typically resulting in a crossing-free, directed, acyclic graph. We use the distance along these pathways as a one-dimensional representation of the spatial variation of data points.

The map in Figure 1 shows measurement points that are color-coded by the statistical mean temperature from the Arctic Regional Climatology dataset, provided by the National Oceanographic Data Center (NODC) [BBB*12]. Overlaid on the map is a user-created path network representing the main Norwegian Atlantic Current, an extension of the Gulf Stream, as it travels north and branches off into the Greenland and Barents Seas.

Pathways are created by clicking on the map to define nodes, which are automatically connected to a previously selected node. Users can easily add or remove nodes and segments, thus creating a system of branches that represents the underlying currents.

Scatterplot Network

The Scatterplot Network, shown below the map, visualizes the selected data as a function of distance along the defined pathways. It consists of individual scatterplots that correspond to the branches of the network defined in the map, with the (user-defined) main path shown without branches and highlighted in blue. The support points of the paths are indicated on the horizontal axes. The positioning of the subplots is defined by the path's relative positions to each other: a path to the right of another path is shown below it, a path to the left is shown above. Branching points are indicated with red, stippled lines. We devised this method of subplot ordering and positioning to clearly visualize the properties along contiguous branches.

The properties encoded by both the vertical axis and by the color of the marks can be defined by the user. In Figure 1 the vertical axis represents depth while we show temperature using color. The data displayed in the scatterplot shows a clear cooling of the water column starting at the point where the current spawns a branch into the Greenland sea. The branch that veers east and follows the east coast of Norway then experiences greater cooling than the Greenland sea branch.

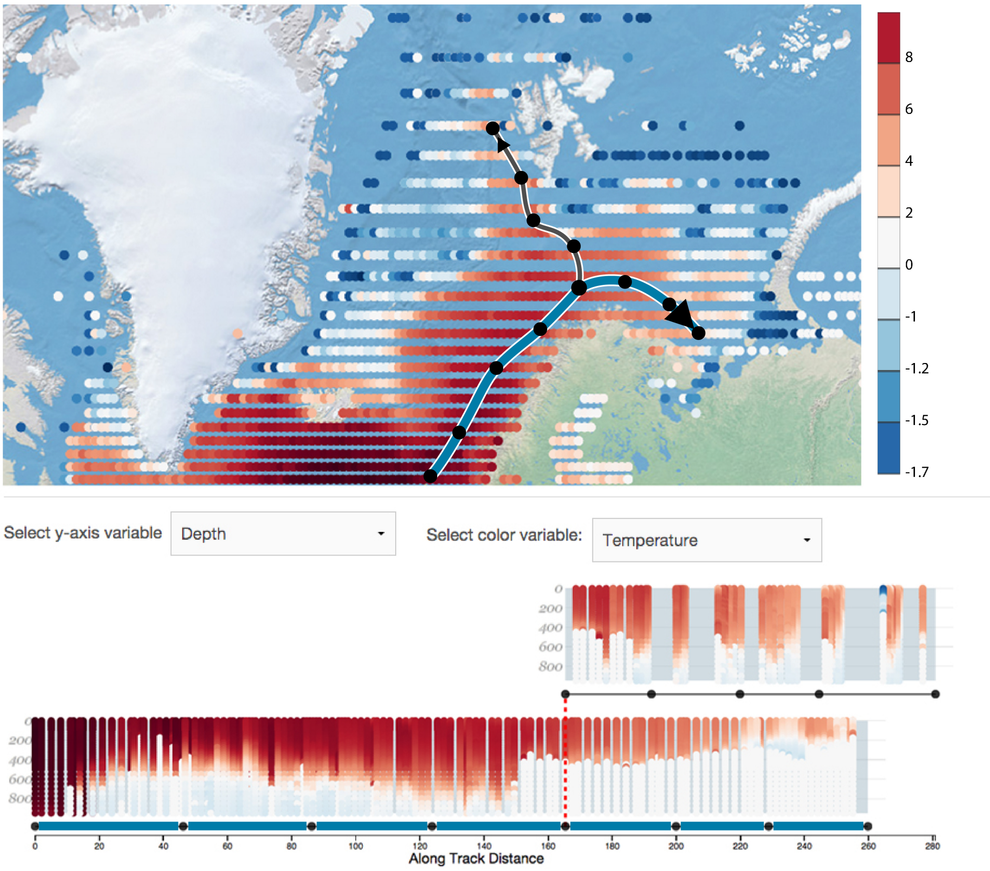

Figure 1: *Screenshot of OceanPaths with the map as the top view and the scatterplot network as the bottom view. The map shows points of measurement color-coded by temperature averaged across the depths, as well as a user-defined path based on currents. The color scale used is non-linear in order to bring out the variability in sub-zero temperatures. The scatterplot network shows one scatterplot per path segment where depth is plotted on the vertical axis and temperature is encoded as color. The user-defined "main" path is shown in blue without branches at the bottom.*

We determine which measurement point is associated with which exact position along a path using two alternative methods. By default, we automatically select all data points that fall within a user-editable distance of the pathway. Editing this distance can account for varying width of currents. Selected data points are then projected onto the closest position on the closest branch, i.e., they are assigned an along-track distance and a branch. An alternate method of selecting and/or refining the selection of data points is manual selection, which makes fine-tuning of the measurement assignments possible. The map and the scatterplot network are fully coordinated views. Selecting a measurement point or a path in one plot will highlight the corresponding point in the other view.

4. Case Study

In this section we present a case study that illustrates the usefulness of OceanPaths for oceanographers to explore the variability and correlation of selected properties in both time and space. We report on an analysis session conducted by an oceanographer, Dr. Bob Pickart, from WHOI. The study was done with hydrographic data collected during two oceanographic expeditions in the Pacific Arctic and aimed to elucidate the circulation and ultimate fate of the cold Pacific winter water on the northeast Chukchi shelf. Figure 2a shows a schematic of the current understanding of the circulation in the Pacific Arctic. The dataset used in this study includes temperature and salinity as a function of space (latitude, longitude, depth) and time.

Bob started his analysis by looking at the temperature distribution at the bottom 15 meters of the water column (Figure 2b). He noted that the coastal pathway known as the Alaskan Coastal Current (ACC) is characterized by the warmest temperature values on the shelf. The data suggested that the pathway extends into Barrow Canyon and is clearly broadest along a specific section.

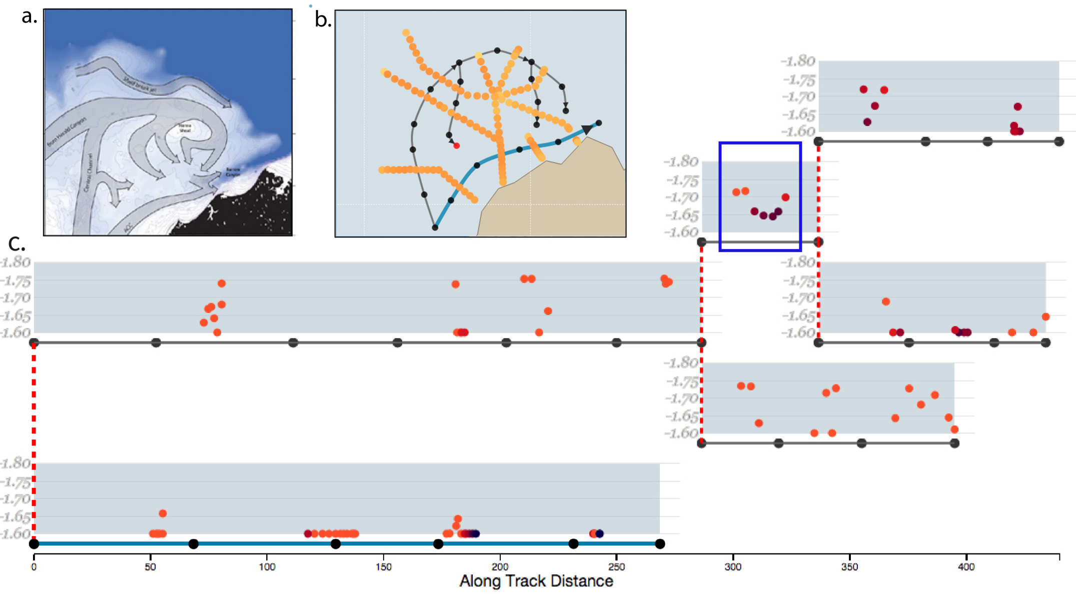

Figure 2: *Circulation and measurements in the Pacific Arctic. (a) A schematic of the circulation [PMM14]. (b) The system of pathways as defined by the analyst in the case study and the measured points color coded by salinity. (c) The Scatterplot Network corresponding to the pathways. Temperature is encoded on the vertical axis, salinity is encoded by color on a scale from orange to red (not shown).*

The analyst then relied on a combination of the temperature distribution near the bottom and the bathymetry information to construct a flow schematic of what he believed to be representative of the progression of winter water across the shelf. Once the pathway was determined, he used the automatic selection of data points to choose the points that fell within the pathways and were therefore relevant for the ensuing analysis of property evolution along the central pathway. He took advantage of the single point data selection toggle to exclude the portion of the flow that emanated from Herald Canyon since that water has a different source than the rest of the sampled data points in the pathway.

When generating the accompanying scatter plot, Bob selected temperature as the vertical axis and salinity as color. A particularly notable feature was a simultaneous decrease in temperature and increase in salinity in one of the sub-branches (highlighted in blue box).

In order to pinpoint the spatial location of this property inversion, he used his mouse to hover over the area in the scatter plot revealing that the feature in question was downstream of the Hanna Shoal North section. Bob used this information to postulate a possible seasonal variation in the water masses entering the Chuckchi sea.

As noted in the literature, bathymetry can often play an important role in determining current paths. The analyst found that the bathymetric information often informed his decisions when generating pathways and interpreting the corresponding data points. He concluded the study by noting that this close inspection of properties along the determined pathway revealed aspects not previously documented in numerical modeling studies allowing for an unprecedented evaluation of current pathways in the region.

5. Conclusion and Future Work

In this paper, we have presented OceanPaths, an exploratory visual analysis tool designed to assist oceanographers in understanding how water-properties vary in space and time along currents. Despite the previous existence of studies which address multi-variable datasets in earth sciences, OceanPaths is a unique and novel solution for reducing the dimensionality of spatial oceanographic data by condensing geographic coordinates into a network of meaningful paths.

Moreover, the application of well-documented visualization techniques such as brushing, linked plots, as well as customizable axes, applied specifically to the domain of oceanographic data, proved to be a valuable tool enabling a more efficient process of data exploration and a better understanding of the spatial distribution of prominent features.

Future work will include methods to increase scalability of the Scatterplot Network by introducing more compact representations for the network view and only showing the full scatterplots on-demand. We will also address the issue of data sparsity, a common attribute of observational oceanographic data, by exploring different interpolation techniques and by enabling analysts to “collapse” empty regions, so that more space is used for denser parts.

References

[AAD10] ANDERSON J. C., ANDRES J. M., DAVIS M., FUJIWARA K., FANG T., NEDBAL M.: Voyager: An interactive software for visualizing large, geospatial data sets. Marine Technology Society Journal, 44, 4 (2010), 8-19.

[BBB*12] BOYER, T. P., BARANOVA, O. K., BIDDLE, M., JOHNSON, D. R., MISHONOV. A. V., PAVER, C., SEIDOV, D., ZWENT, M.: Arctic Regional Climatology, Regional Climatology Team, 2012, NOAA/NODC (www.nodc.noaa.gov/OC5/regional_climate/arctic).

[BvL06] BURAKIEWICZ W., vAN LIERE R.: Analyzing Complex FTMS Simulations: a Case Study in High-Level Visualization of Ion Motions. IEEE Transactions on Visualization and Computer Graphics, 12, 5 (2006), 1037-1044.

[CFG*05] CO C. S., FRIEDMAN A., GROTE D. P., VAY J.-L., BETHEL E. W., JOY K. I., : Interactive Methods for Exploring Particle Simulation Data. In EG/IEEE VGTC Symposium on Visualization (EuroVis), (2005), pp. 279-286.

[DMB*06] DEINES E., MICHEL F., BERTRAM M., HAGEN H., NIELSON G.: Visualizing the phonon map. In EG/IEEE VGTC Symposium on Visualization (EuroVis), (2006), pp. 291-298.

[JKM06] JANKUN-KELLY T.,MEHTA K.: Superellipsoid-based, real symmetric traceless tensor glyphs motivated by nematic liquid crystal alignment visualization. IEEE Transactions on Visualization and Computer Graphics, 12, 5 (2006), 1197-1204.

[KLM*08] KEHRER J., LADSTADTER F., MUIGG P., DOLEISCH H., STEINER A., HAUSER H.: Hypothesis Generation in Climate Research with Interactive Visual Data Exploration. IEEE Transactions on Visualization and Computer Graphics, 14, 6 (2008), 1579-1586.

[LFH08] LI H., FU C.-W., HANSON A.: Visualizing Multiwavelength Astrophysical Data. IEEE Transactions on Visualization and Computer Graphics, 14, 6 (2008), 1555-1562.

[LLC11] LIPSA D. R., LARAMEE R. S., COX S. J., ROBERTS J. C., WALKER R.: Visualization for the Physical Sciences. In EG 2011 - State of the Art Reports (2011), Eurographics Association, pp. 49-73.

[MW95] MARTIN, A. R., WARD, M. O.: High Dimensional Brushing for Interactive Exploration of Multivariate Data. In Proceedings of the IEEE Conference on Visualization (1995), IEEE Computer Society, p. 271-278.

[PLS*13] PARTL, C., LEX, A., STREIT, M., KALKOFEN, D., KASHOFER, K., SCHMALSTIEG, D.: enRoute: Dynamic Path Extraction from Biological Pathway Maps for Exploring Heterogeneous Experimental Datasets. BMC Bioinformatics, 14(Suppl 19), p. S3, 2013.

[PMM14] PICKART, R. S., MOORE K.W.G., MAO C., BAHR F., NOBRE, C., WEINGARTNER, T.:Circulation of Winter Water on the Chukchi Shelf in Early Summer. To be submitted to Deep-Sea Research.

[QCX*07] QU H., CHAN W.-Y., XU A., CHUNG K.-L., LAU K.-H., GUO P.: Visual analysis of the air pollution problem in Hong Kong. IEEE Transactions on Visualization and Computer Graphics, 13, 6 (2007), 1408-1415.

[SFM14] SPENCE, P., FYFE J. C., MONTENEGRO A., WEAVER A. J.: Southern Ocean response to strengthening winds in an eddy-permitting global climate model. Journal of Climate, 23, 19 (2010), 5332-5343.

[YXG10] YUAN X., XIAO H., GUO H., GUO P., KENDALL W., HUANG J., ZHANG Y.: Scalable multivariate analytics of seismic and satellite-based observational data. IEEE Transactions on Visualization and Computer Graphics, 16, 6 (2010), 1413-1420.