An Exploratory Visualization Tool for Mapping the Relationships between Animal Movement and the Environment

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ABSTRACT
Movement ecologists and environmental scientists are increasingly utilizing large volumes of spatiotemporal data collected from animal tracking and remote sensing of the environment to explore the environmental drivers of animal movements and long distance migrations. For scientists, the visual exploration and mapping of animal tracks in space and time and in relation to their environment is key to the generation of new hypotheses and investigation of dependencies. Effective visualization of such multidimensional data is a time consuming and challenging process. Creating professional, interactive, and fluid looking animations for public outreach and presentation purposes is similarly arduous. We present a new exploratory visualization tool for the analysis of animal movement datasets enriched with environmental variables and other miscellaneous data. This interactive visualization tool is designed to be effective and intuitive for users from biology and ecology disciplines, who are rather unfamiliar with GIS and mapping software. The tool is able to illustrate how environmental factors influence movement patterns of animals by offering to the user a variety of visual variables that can be combined in novel ways. We demonstrate the capabilities of this new visualization tool by analyzing the movement data of nine Galapagos Albatrosses and one Turkey Vulture migration track.

Categories and Subject Descriptors
H.5.2 [**User Interfaces**]: Graphical user interfaces (GUI)

Keywords
Geospatial Visualization, Interactive Animation, Movement, Environment, Geographic Context, Processing, Movebank

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1. INTRODUCTION
Learning even the most basic biology of animals, specifically long-distance migrant birds, has been incredibly difficult because of the logistical challenges introduced when studying such large-scale movements. The rapidly developing technology of satellite and radar tracking (e.g. GPS, Argos, and RFID tags) and the emerging discipline of movement ecology, coupled with remote sensing science, offer a new working paradigm for understanding the internal and external factors that affect the movements of organisms [6]. With the growing availability of movement tracking data and remote sensing data of the environment, there remain methodological challenges when investigating these large volumes of spatiotemporal datasets and exploring patterns and dependencies.

Movebank[1] is an online data repository for the collection and dissemination of animal tracking and migration data [10]. Movebank provides researchers with a variety of services, including data management and validation, simple visualization, and data editing tools. Recently, the Env-DATA System (Environmental Data Automated Track Annotation System) was developed within Movebank to link environmental datasets, weather models, and satellite imagery to the animal movement data [7]. The Env-DATA service creates a large amount of annotated data that are difficult to interpret without specialized statistical and spatial analysis packages, as well as exploratory visualization tools. In their recent Symposium on Animal Movement and the Environment[2], Movebank users have identified the need for the ability to better visualize their data.

This interdisciplinary research aims at developing an interactive and exploratory visualization tool that allows for the creation of intuitive, interactive, and high quality animations suitable for presentations of animal movement data and public outreach. The visualization also serves as a preliminary and exploratory analysis tool, allowing biologists and movement ecologists to investigate their data and identify potential correlations and environmental drivers of movement, and generate hypotheses to test. Moreover, the tool can serve as a platform for users (i.e. data owners) to

[1]https://www.movebank.org
[2]http://amovee2014.com

quickly inspect the spatial and temporal extents of the collected tracks and check the quality of their datasets in terms of possible errors, gaps, outliers, and other tracking default. The user is able to ultimately create and export map images and video clips of their customized animation in order to disseminate information to large audiences.

The novelty of this research is twofold: first, to dynamically visualize the link between two heterogeneous spatio-temporal datasets (i.e. animal movement and environmental data) by combing visual variables, e.g.- color, vector direction, and line weight, and to develop an integrative tool for movement ecologists for mapping the relationships between animal movement patterns and environmental variables within a geographic context (i.e. underlying satellite map). The aim is to visualize and animate movement in relation to its environmental and geographic context. The tool is aimed to be effective for large datasets of enriched animal tracking data.

2. RELATED WORK

Movement research is a multidisciplinary field, and often scientists of different backgrounds are involved in the analysis of movement and exploration of relevant data. Visual exploration of movement data is key in such collaborative efforts. Often researchers without knowledge of Geovisualization approaches need to visualize and interact with data to explore patterns and relationships in movement. It is therefore essential to develop user-centered and interactive approaches in the form of open-access visualization tools in order to better facilitate movement research.

Recognizing the significance of movement research, over the last several years a surge of attempts in the Geovisualization community have focused on the development of new techniques for the visual analysis of dynamism, movement and change [1, 18, 17, 16, 2, 14]. In their recent book, Andrienko et al [1] summarize the significance and challenges of visualization analytics of movement data that are often inherently heterogeneous and large in volume. The authors suggest that it is essential to develop new and integrative methods of visualization and data analysis in a way to allow end-users to visually inspect and work with extremely large volumes of movement data in a simple and intuitive way.

In GIScience studies, movement is often visualized in three ways: using space-time cube representation [5, 9], animation [3], and using static multi-variate maps such as tree maps [14] or origin-destination maps [16]. A recent study on the usability of visualization techniques for movement data suggests that the three dimensional space-time cube representation is not very effective for users when inspecting movement data, especially when the number of tracks increases [11]. The same study indicates that the context parameters such as geographic landscape is essential when visualizing movement patterns. Shipley et al [13] suggest that effective animated displays can help humans more efficiently to detect relationships in complex events in spatiotemporal phenomena including movement.

In [15], Slingsby et al. developed a visualization tool for the exploratory analysis and presentation of simulated hurricane tracks. This tool was developed in Processing[3], an open-source Java library and IDE, which was chosen for its ability to rapidly prototype interactive visualizations. The tool allowed the user to scan through thousands of storm tracks, and adjust the temporal window and animation speed. Storm tracks were displayed via simple lines, varying in thickness with wind speed. The tool also allowed the user to export video clips of interesting observations. Inspired by this simple but effective mapping tool for spatiotemporal phenomena, this research takes a user-centered approach to facilitate visualization of movement data by providing additional interactivity and more visual variables to map dynamic patterns and relationships between movement and environmental variables.

3. THE TOOL

In this study, we develop an integrative visualization approach using animation together with multivariate representations of movement, based on a combination of visual variables, to map movement within geographic and environmental context. The animation is used to present the natural flow of movement for users. The multivariate representation is used to visualize the relationships between movement parameters and environmental variables. Moreover, a satellite basemap is applied to show the geographic context underlying movement.

Like the hurricane storm track visualization developed by Slingsby et al., we chose to develop the visualization itself with the open-source Java library Processing. We were able to save significant development time by implementing Processing 2.0's default OpenGL renderer for the core visualization [4]. We also utilized the Unfolding library[4], a set of geographic tools designed specifically for Processing, providing us with basic map functionality (conversion from spatial to canvas coordinates, tile-loaded base maps) and interactivity (zooming, panning) [12]. By employing these two libraries, the majority of our development efforts were directed to data management strategies, the implementation of additional modules, and improvements to the graphical user interface. For greater flexibility, the user interface and all modules were created with Java Swing and AWT components (see provided YouTube demo of the tool[5]). The decision to develop the visualization tool in Java allowed us to create a platform independent application with the ability to extend future versions to mobile devices.

3.1 Data Import

The tool was designed primarily to visualize datasets created by Movebank and the Env-DATA annotation service [7]. However, the tool is flexible enough to animate any spatiotemporal dataset containing point coordinates in WGS84 (e.g. obtained from GPS or Argos), provided it contains unique identifiers to create separate movement tracks. The visualization tool loads standard comma separated plain text (CSV) files and presents to the user an overview of the data. As seen in the demo[5], users can rename fields (i.e. variables included in the dataset), adjust acceptable maximum and

[3]http://www.processing.org
[4]http://unfoldingmaps.org
[5]https://www.youtube.com/watch?v=FckCJPOyEj4

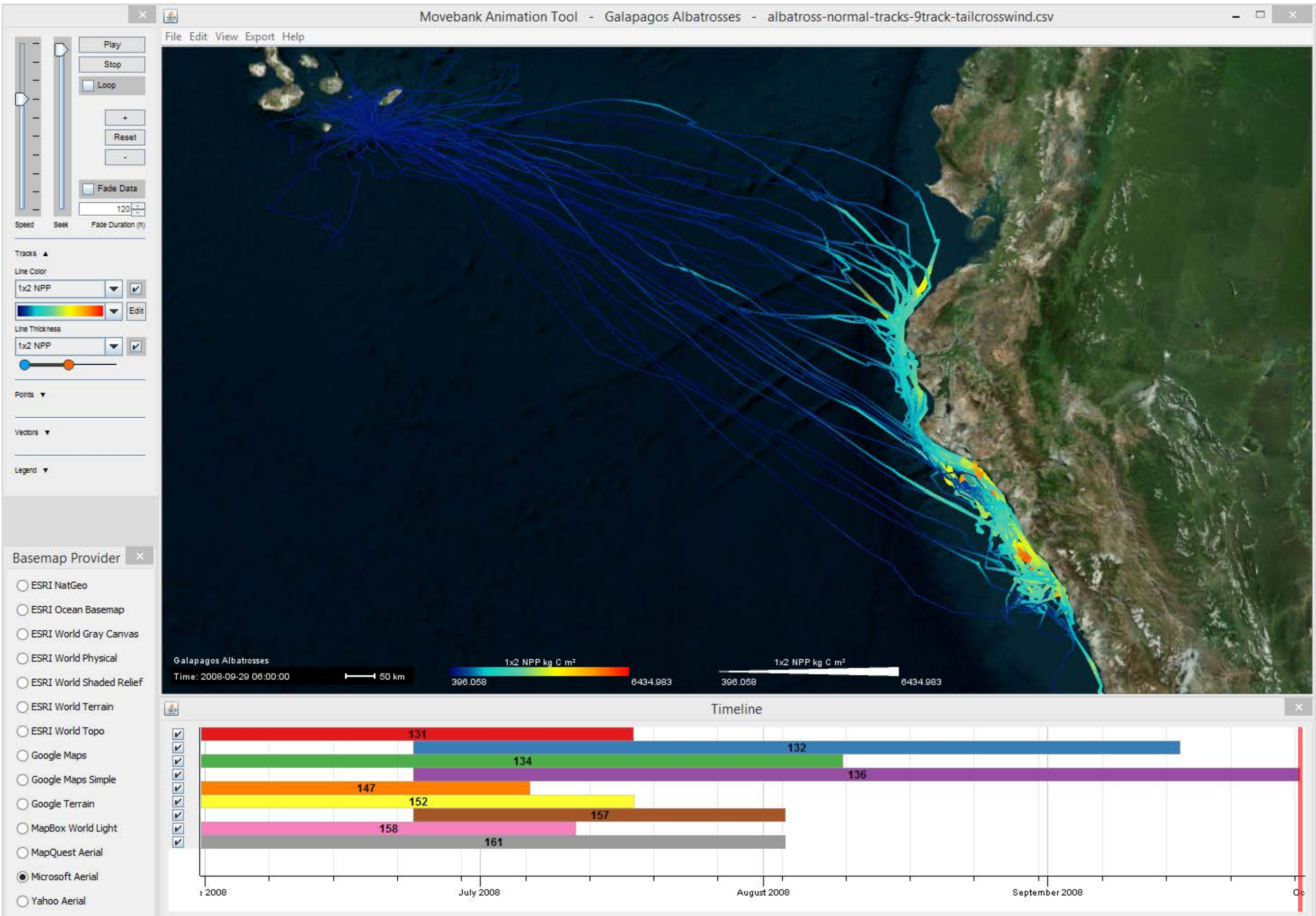

Figure 1: The visualization program displaying nine Galapagos Albatross tracks colored and scaled by ocean productivity. The concentration of chlorophyll on the coast indicates greater foraging potential.

minimum range values for each variable, set units, and select which fields and tracks they wish to visualize.

3.2 Visualization Variables

After the visualization is built, the user is presented with the interactive temporal map and several control panels to customize how the data are displayed (Figure 2). The tool currently supports four primary visualization strategies, the elements of which may be combined in unique animations:

- movement point (varied by size and color): to show movement or environmental parameters at a certain point in space and time
- movement track line weight (thickness): to visualize the degree of variations in one parameter along movement path
- movement track line color: to visualize the degree of variations in a second parameter along movement path
- directional vector (varied by size, direction, and color): to show change in directional parameters (e.g. movement direction and speed; wind direction and wind speed)

Using these visual variables, tracks connecting movement points may be scaled in thickness and graded in color, allowing the user to visually investigate spatiotemporal correlations between two variables. Simple movement points may be similarly scaled and colored, used in lieu of tracks, or added as a layer to display additional variables. For instance, Figure 4 shows how movement speed, visualized by scaled line weights, relates to wind support, visualized by color grades, along movement tracks (see section 4.1 and demo[5]). If the dataset contains directional or magnetic heading data, vectors may be projected from each point that scale in length to the magnitude of the related variable (wind direction and wind speed), and potentially colored with a third.

3.3 Color Ramps

The GUI allows the user to select from a list of continuous and diverging Colour Brewer [8] and custom color ramps. Tracks may also be colored according to their unique identifier using sets of discrete Colour Brewer tables. As seen in Figure 3, color ramps are able to be fully customized in a method similar to graphic design programs, and custom Colour Table[6] ramps are able to be saved to an XML file

[6]http://www.gicentre.net/utils/colour/

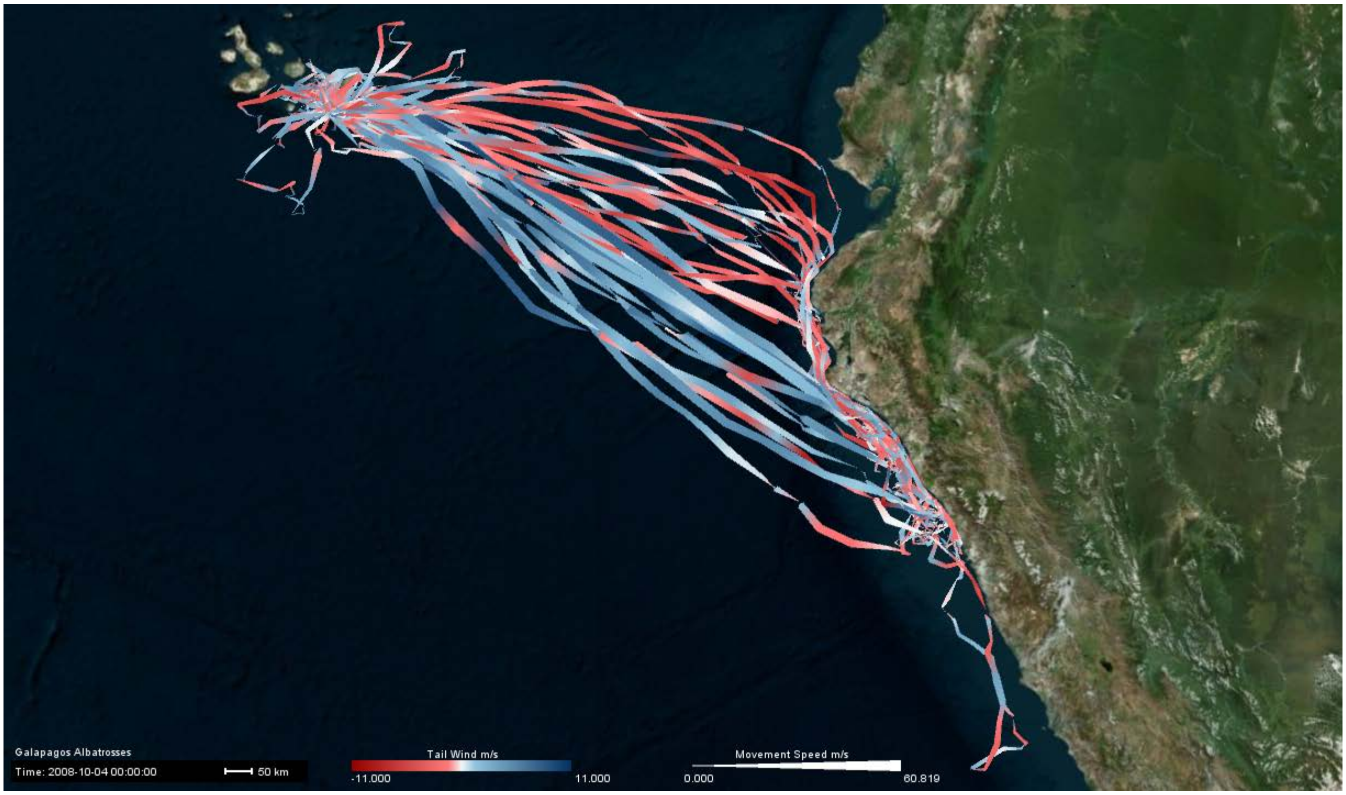

Figure 4: The movement tracks of nine Galapagos Albatross colored by wind support and scaled by movement speed. Northern tracks to the coast are slower and impeded by strong head winds (red), while returning tracks are assisted by strong tail wind support (blue).

that can be edited and shared between users and other visualization tools. This interaction method has been previously adopted by Golden Software for their surface and contour mapping application (Surfer[7]), and we agree that it is an improvement over the current standard in mapping toolboxes, where the user is generally only able to either select from an existing list, or create basic color ramps with unintuitive dialogs. The ability to easily and intuitively adjust color ramps allows for the visual classification of portions of the data. This is especially important when manually classifying movement or environmental variables that are not normally distributed in data, or when the user needs to create custom classes of such variables.

3.4 Legend Customization

All legend elements are able to be directly moved, resized, and colored by the user. Custom legend layouts and styles may be saved as XML files similar to the color tables generated by the tool.

3.5 Interactive Timeline

The tool constructs a timeline of the displayed movement tracks. The timeline is linked to the mapped tracks, and assists in interpreting which tracks are currently being displayed. The timeline also serves as an interface to identify, highlight, and toggle the visibility of tracks, and can be used to navigate the data directly. The time line components may also be colored with a data variable, allowing the user to quickly see periods of time that may warrant closer investigation (see Figure 1 and demo[5]).

[7]http://www.goldensoftware.com/products/surfer

3.6 Animation Output

The tool provides the user with the ability to customize a great number of design settings in order to create a high quality and attractive animation. Interesting visualizations can be identified and exported to video clips with a simple recording module for outreach and presentation purposes.

4. EXPLORATORY VISUAL ANALYSIS

The visualization tool allows researchers to quickly and efficiently map and explore their data. As an example, the movement patterns of nine Galapagos Albatrosses (*Phoebastria irrorata*) [7] and one Turkey Vulture (*Cathartes aura*) [6] were inspected with the tool.

4.1 Galapagos Albatross *(Phoebastria irrorata)*

In the first case study, the developed tool is used to map movements of nine Galapagos Albatrosses tracked from June to September 2008. The aim was to illustrate the role of wind and food availability (represented by Ocean productivity) on the albatross' flight patterns. As seen in Figure 4, these birds make extensive movements between the Galapagos Islands (i.e. nesting site) and the Peruvian coast (i.e. foraging site). Using the Movebank Env-DATA service, the

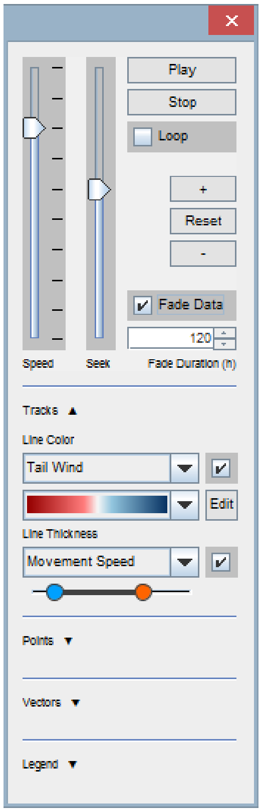

Figure 2: The control panel allowing the user to set multiple visual variables. Movement track widths can be scaled with a simple range slider.

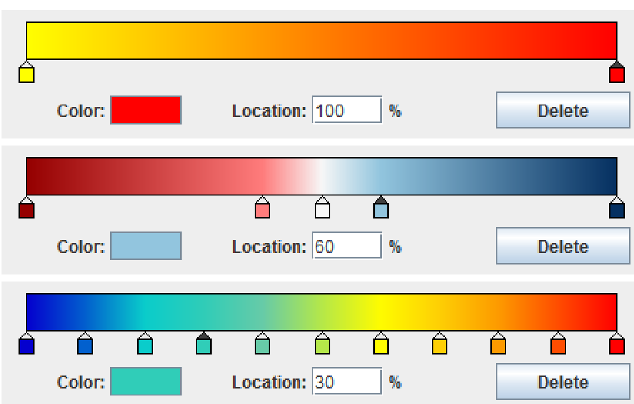

Figure 3: Three color ramps built using a GUI similar to the ones found in graphics design programs. The user is free to add and remove as many breakpoints as desired. Top: Simple linear gradient, Middle: Diverging gradient, Bottom: Spectral gradient

nine albatross tracks were first annotated with wind speed (m/s) and wind direction (degrees from North) computed from u- and v-wind components obtained from the NCEP Reanalysis 2 dataset[8], and Ocean Net Primary Production (NPP)[9] data from Oregon State University [7].

Using the developed tool, one can quickly map and scan through the entire dataset. First, we aimed to map the relation between albatross movement to the availability of food represented by ocean productivity. As seen in Figure 1, the annotated ocean NPP values along tracks during foraging movements near the Peruvian coast and along flight tracks around the Galapagos were mapped using color grades or by scaling the weights of movement tracks. The visualization showed that these expeditions to the coast were likely motivated by the abundance of food concentrated in this area (highlighted in turquoise and yellow colors) as compared to the lower food availability around the Galapagos (dark blue tracks). The albatrosses slowly moved in a southernly direction as they foraged along the coast, and then returned quickly and directly to the Galapagos Islands to feed their chicks.

In Figure 4, we used the tool to examine the effect of wind support on movement speed by applying a diverging color ramp and line weight (thickness) to the movement tracks. Here, two variables were mapped along the tracks to visually explore their dependencies. The tracks were colored from red to white (negative wind support, or head wind) and white to blue (positive wind support, or tail wind assistance). Line weight was scaled by computed movement speed. This visualization effectively demonstrated how outbound flights to the Peruvian coast were slower (thinner tracks) and hampered by strong head winds (red color), while returning flights to the Galapagos were faster (thicker tracks) and assisted by tail wind support (blue color).

4.2 Turkey Vulture *(Cathartes aura)*

The mid-Western migration paths of one adult Turkey Vulture, tracked between September 2009 and November 2011, were chosen to visualize the relationships of environmental variables on movement speed (Figure 5). Using the Movebank Env-DATA service, the track was first annotated with wind speed (m/s) and wind direction (degrees from North) computed from u- and v-wind components and thermal uplift (m/s) derived from temperature data obtained from the ECMWF global atmospheric reanalysis[10] [7, 6].

Unlike the Galapagos Albatrosses, this visualization failed to show a strong correlation between wind support and movement speed. Instead, periods of faster travel speeds (thicker lines) seemed to be influenced by increases in thermal uplift (shown using a yellow to red color ramp) in Figure 5. This illustration supported the biological hypothesis that during migratory movements, when flight is directional, weather conditions and uplift intensity influence movement patterns of the vulture, leading to lower cost of movement and faster migration [6]. The map also showed that flight speed was generally greater in the more northern latitudes. This correlated to both the longer periods of thermal uplift generated over this area, and the lower availability of food (low vegetation areas seen on the satellite imagery) discouraging frequent stops. As the Turkey Vulture approached Central America, food availability increased, thermal uplift de-

[8]http://www.esrl.noaa.gov

[9]http://www.science.oregonstate.edu/ocean.productivity/

[10]http://www.ecmwf.int

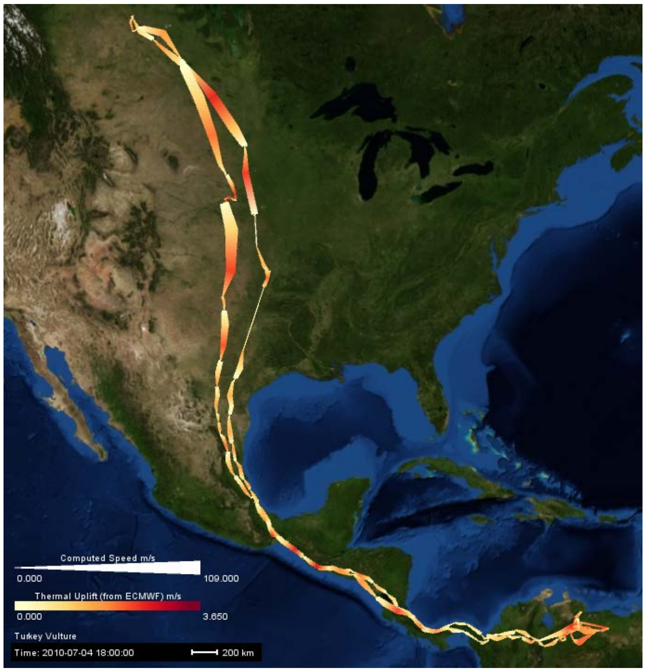

Figure 5: One full loop migration track of Turkey Vulture "Steamhouse 1". Periods of fast travel (line thickness) appear to be preceded by increases in thermal uplift velocity (orange-red).

creased, and travel periods grew shorter.

5. CONCLUSIONS AND FUTURE WORK

The article demonstrated an effective new visualization tool for researchers utilizing large animal movement datasets that are annotated with environmental and other geographic variables. Visual analytics tools developed to this date often provide a complex representation of spatiotemporal phenomena that is not intuitive. In this research, we aimed at developing a tool that allows even the novice user to visually interpret and analyze movement tracks for correlations between environmental variables, and produce high quality, easily customizable, and fluid animations for public outreach and information dissemination. We have presented the tool to Movebank scientists for an early stage test and feedback on the interface. As indicated by Movebank scientists, this is a highly needed and valuable tool that can serve the movement ecology community for visual exploration of their datasets. The animation and interactive capacities of the tool are key features for scientists that allows them to gain insight into animal movement behaviors and the environmental drivers of their movement, and as well to facilitate presentation of research results to public or fellow researchers.

The developed visualization package also provides a great tool for Geovisualization researchers to investigate the usability of various visualization techniques of spatiotemporal and multidimensional data for users without knowledge on Geovisualization approaches. For instance, the tool can facilitate the usability study of applying multiple visual variables and incorporating simple or complex satellite imagery basemaps in both static and animated maps for visualizing movement data.

The visualization tool in its current state is ready to be integrated within Movebank, either as a standalone desktop package or Java Web Start application. The release version will expand the visual analytic capabilities of the tool, provide greater control over visual elements, and allow the user to create a workspace to save and share animation states while progressively developing their data visualizations. Finally, working with Movbank scientists we plan to test the effectiveness and usability of the tool with an empirical evaluation study designed for both lay and experienced users.

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