Towards Visualizing Geo-Referenced Climate Networks

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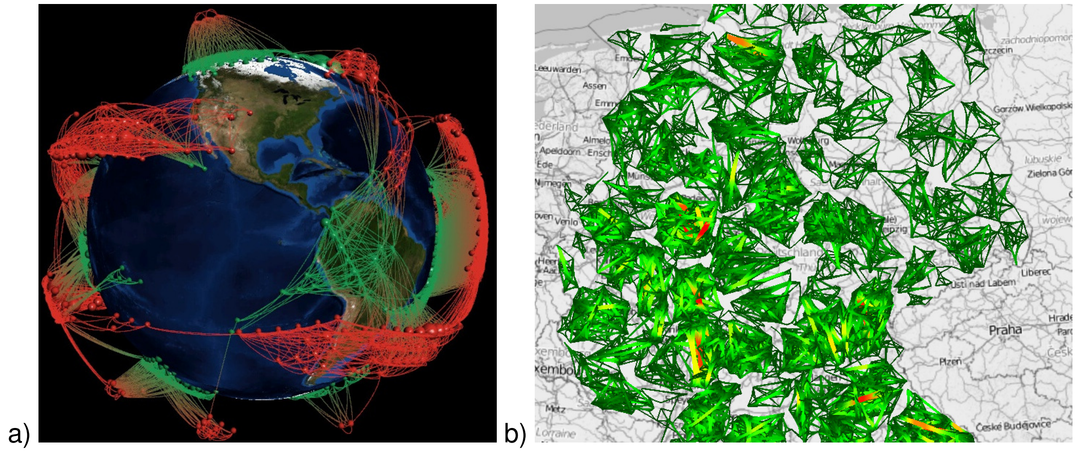

Fig. 1. Visualization of climate networks: a) 3D visualization of a two-layered pressure network on a virtual globe; b) 2D visualization of a climate network with edge bundling, where edge width and color encode bundling strength.

Abstract—In the last few years, network construction from climate data has developed to a promising analysis method. We discuss challenges for the interactive visual analysis of such geo-referenced networks and present first ideas for addressing the challenges. In particular, we present visualizations of 3D geo-spatial networks and of large networks within cartographic contexts.

Index Terms—Geo-spatial visualization, network visualization, climate research.

1 Introduction

In climate network analysis, similarities of time series from grid or station based climate data are transfered into a network structure of nodes and edges (see e.g. [1]). This structure is being analyzed using network measures and visualization techniques. Our work investigates the chances arising from interactive visual analytics methods for exploring and presenting climate networks [5]. We identify challenges for the visual analysis of geo-referenced climate networks (Sec. 2) and illustrate first ideas how to address these challenges (Sec. 3).

2 Problem Analysis

Challenges for the interactive visual analysis of climate networks can be identified from four perspectives: data, tasks, visual representation, and interaction.

From the data perspective, climate networks contain a large number of nodes and edges (usually 1.000–300.000 nodes with high edge density). They are geo-referenced, and an additional third dimension (e.g., elevation or atmospheric levels) may be present. Further, climate networks are often time-varying (e.g., prediction models for several years). Associated with nodes and edges are multiple data attributes, which can be derived network measures, or data computed or collected at the corresponding locations. Therefore, challenges lie in data management and interactive visualization of large multi-variate data sets.

Climate researchers analyze such networks according to different tasks. First, the researchers are interested in developing an overview of a network's structure. Next, they will analyze specific structural details (certain regions or sub-networks) in conjunction with detailed cartographic information (e.g., topography, land cover, and land use). This requires the interactive application of structure and attribute filtering to emphasize relevant parts in the data. This analysis also includes identifying relations of attributes in conjunction with the network structure and comparing different paths within the network. Tools need to provide climate researchers with the possibility to perform these tasks efficiently.

Standard network visualization techniques that could be applied to climate networks include network measure charts, node link diagrams, and matrix representations. Depending on the particular type of techniques, data attributes can be encoded in visual variables such as color, size, or position. The network structure can be made visible by an appropriate 2D or 3D layout of nodes. However, visualization techniques need to reflect the specific characteristics and restrictions of climate networks (e.g., their geographic nature).

Although there are a number of accepted network visualization tools, the existing approaches do not take the special requirements of climate network analysis into account. Especially, the following key aspects remain unsolved in current tools.

Spatial restrictions / occlusion: Representing climate networks on a 3D globe results in occlusion of at least half of the network, which is always hidden on the backside. On the other hand, representing climate networks in a projected 2D space results in distortion of neighborhoods and clutter. Nodes that are rather close together can end up at opposite sides of the 2D map; edges between such nodes would cross the entire map and give a wrong impression of the actual geo-distance between nodes. Visibility problems aggravate when researchers have to analyze networks with an additional 3rd dimension.

Edge clutter: When the focus lies on the geographic character of the data, node positions need to be fixed according to their geo-position. In such cases, edge clutter becomes a major problem, since large numbers of edges occlude the view. Suitable edge routing or

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edge bundling algorithms are needed to resolve this issue. However, current algorithms reach their limits in interactive analysis settings, where frequent updates and re-computations are commonplace. More efficient alternatives need to be investigated.

Multi-faceted analysis: Climate network data are rich and complex sources of information. They may contain spatial, temporal, structural, and attribute components. It is obvious that such an abundance of information cannot be encoded into a single visual representation. It is rather necessary to use multiple linked views to enable climate researchers to focus on the aspects relevant to the task at hand and to compare and relate different aspects interactively. This requires sophisticated techniques that help the users (1) to navigate and orientate within the visual representations, which is particularly relevant for 3D approaches, (2) to dynamically filter the data for detailed analysis, and (3) to coordinate visualization and interaction across multiple views and potentially across application boundaries.

While existing network visualization tools may support the one or the other requirement, they are not tailored to the context of climate network analysis. It is our ongoing research to integrate existing and develop novel concepts to come up with practical solutions for climate scientists.

3 New approaches to climate network visualization

To provide first solutions, we (1) extended the interactive network analysis tool CGV [4] and (2) built up a network visualization tool based on osgEarth. With these two tools, the climate scientists can interactively visualize large climate networks, filter network parts based on network measures, zoom in/out in geographic space, and focus on sub-network structures and relate them to cartographic information.

The CGV tool provides both 2D map and 3D globe representations for networks, the possibility to show information in multiple linked views, and dynamic interactive filtering based on node and edge attributes. Addressing 3D geo-referenced networks, we extended CGV's globe representation with facilities to layout nodes according to elevation or atmospheric levels. Figure 1 a) illustrates two such layers from a three-dimensional pressure network, where node color indicates layer affiliation and cross-betweennes is encoded by size. Interlayer connections are shown as red-green curves, while intra-layer connections are either solid red or green.

Handling even larger and/or time-dependent networks, CGV reaches its limits due to internal data structure optimization and edge rendering. To address size and time dependency of climate networks and to provide highly flexible cartographic information at different levels, we develop an alternative interactive network visualization tool based on osgEarth. This tool is able to process large numbers of edges at interactive frame rates by combining sophisticated computer graphics and GIS technologies. Figure 1 b) shows a network based on temperature data from weather stations accross germany. We can see very localized structures emphasized by edge bundling. The number of edges contributing to a bundle are mapped to both color and line width. Figure 2 shows a detailed view of one of the discovered clusters, using a geographic map based on OpenStreetMap to cross-reference network data with geographic features.

Both of our tools provide a number of approaches with regard to the identified requirements for visualizing climate networks.

Geo-referenced network visualization: Climate networks are displayed as node link diagrams, either planar or in a spherical view on top of a 3D interactive globe. A configurable map layer can be used to quickly cross-reference the data with topological or thematic features.

Visualization of large datasets: To visualize big climate networks, e.g., multi-layer and time-dependent networks, efficient data structures and algorithms for storing and analyzing the resulting large data sets have been integrated. Efficient GPU-based rendering approaches are applied to achieve real-time interactive visualizations for large networks. Our GPU-based implementation helps reducing the memory footprint of the data, allowing for bigger networks to be visualized. Node and edge attributes are stored directly on the GPU, which supports on-the-fly mapping of data values to visual variables (e.g., color and size). This significantly improves performance and flexibility of the visualization methods.

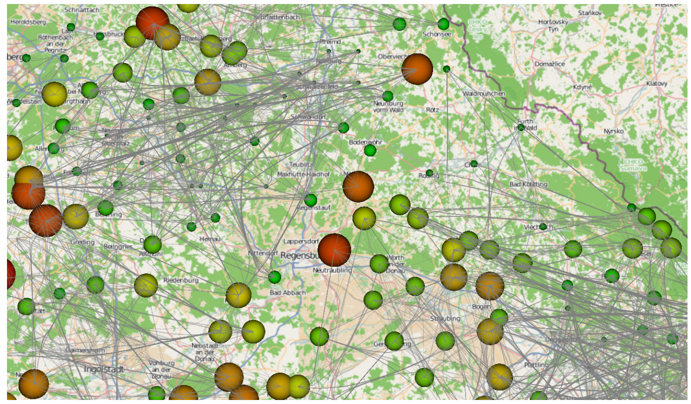

Fig. 2. Detailed view of clusters inside a climate network, where vertex color and size encode betweenness of nodes, and a background map.

Edge bundling: To visually emphasize substructures in climate networks and to alleviate the problem of edge clutter, on-demand edge bundling approaches can be utilized. Our tools integrate force-based edge bundling [3] and recursive edge bundling [2]. Considering two bundling methods helps to find a trade-off between accurate bundling at slower speeds and faster computation with less structured results.

Interactive filtering and mapping: The tools support interactive zoom and filter. Zoom operations help to focus on interesting spatial regions and dynamic filters enable climate researchers to focus on those parts of the network that exhibit certain characteristics in terms of data attributes. Filters can be stored and re-used in later sessions.

4 Conclusion

In this work, we have identified a number of problems that need to be addressed to come up with helpful visualization tools for climate researchers. As first solutions, we provide two tools based on CGV and osgEarth for real-time visualization and analysis of geo-referenced climate networks. While not comprehensive in terms of the identified challenges, our tools are first steps towards a better support of visual climate network analysis.

As our initial steps primarily address the challenge of data size (e.g., efficient rendering and edge clutter removal), there are still open questions for future work. A key issue is the task-based adaptation of visual and interactive analysis tools. Close collaboration between climate researchers and visualization experts is necessary to eventually come up with tools that really support climate network analysis.

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