Visual Analytics in the Aviation and Maritime Domains

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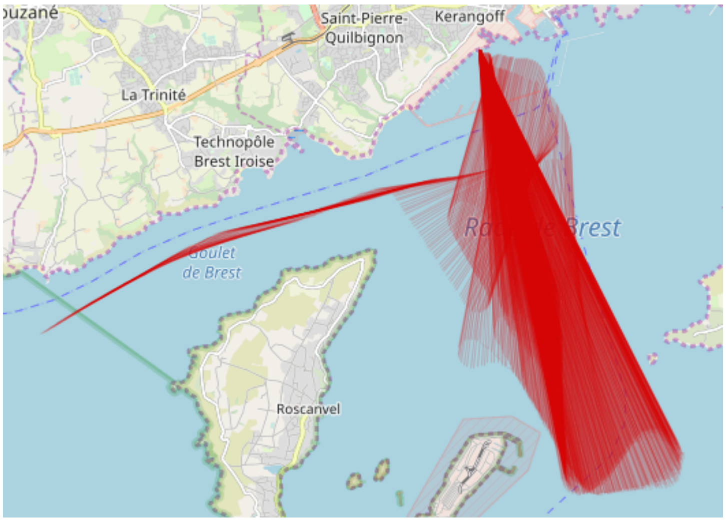
Visual analytics (VA) is a research discipline that is based on acknowledging the power and the necessity of the human vision, understanding, and reasoning in data analysis and problem solving. It develops a methodology of analysis that can support the unique capabilities of humans by providing appropriate visual displays of data and involving as much as possible the capabilities of computers to store, process, analyse, and visualise data. VA techniques and tools can be used at all stages of analytical workflows for

- investigating available data: seeing distributions and detecting errors, outliers, gaps in coverage, and other quality problems;
- comprehending real-world phenomena reflected in the data: grasping and understanding essential features, relationships, patterns, trends; and
- creating valid and useful model of the phenomena by involving critical thinking in model design, preparation, configuration, evaluation, comparison, and iterative improvement.

This chapter includes several examples of applying visual analytics approaches to data and tasks in the domains of air and maritime transportation. The aim is to demonstrate how interactive visual displays in combination with relatively simple computational techniques support the involvement of human understanding and reasoning in the analytical process.

To demonstrate the use of VA techniques for investigation of data and detection of quality problems, we include several examples of problematic movement data and show how different problems are manifested in visual displays. Thus, Figure 2 demonstrates a non-trivial error, a trajectory with a very complex zigzagged shape, which may, in fact, be a combination of positions from trajectories of two or more distinct vessels that were erroneously designated by the same identifier.



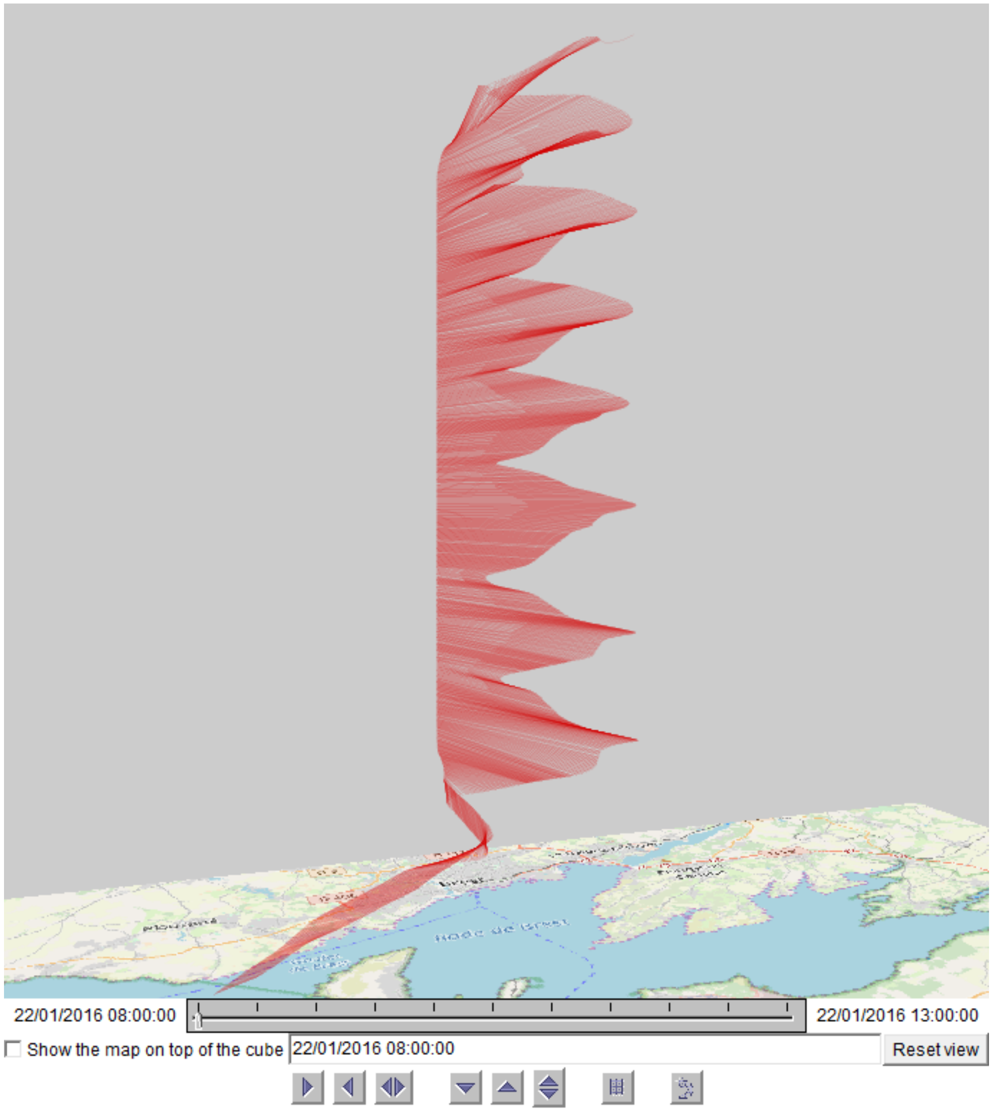


Fig.2. Visual investigation of a trajectory with a high number of erroneous positions. The trajectory is shown on a map and in a space-time cube, where the base represents the geographic space and the vertical dimension represents the time.

To demonstrate the use of visual analytics approaches for gaining understanding of different phenomena in the air and maritime traffic, we briefly present several case studies. The examples do not merely demonstrate application of visual analytics techniques to data, but they also highlight the importance of human perception, interpretation, understanding, and analytical reasoning and show how visual analytics techniques provide inputs to these cognitive processes.

A case study performed in the maritime traffic domain aims at demonstrating the use of data transformations for supporting visual analysis and reasoning. The transformations include extraction of relevant parts of trajectories, detection and extraction of particular events, and spatio-temporal aggregation of events and movements. As an example of using a computational analysis method, two case studies include clustering of flight trajectories based on geometric similarity of the routes. The specifics of the case studies was that not all parts of trajectories were relevant to the analysis goals. To exclude the irrelevant parts from the comparison of the trajectories, interactive visual filtering was applied to segments of trajectories. The distance function that compares trajectories was adapted to account for results of filtering, which are represented by segment-wise binary masks. One case study in the aviation domain demonstrates exploratory analysis made with three different kinds of data, planned flight trajectories, geometries of airspace configurations, and temporal succession of the configurations.

In the first example, visual analytics approaches were used for exploration and analysis of trajectories of cargo vessels coming in the port of Brest (France). The aim was to study when, where, and for how long the vessels were anchoring and understand whether the events of anchoring may indicate waiting for an opportunity to enter or exit the bay (through a narrow strait) or the port of Brest. The analysis process included multiple steps in which interactive visual techniques were used for selecting relevant pieces of data and deriving different kinds of information that allowed answering the questions of the study. In particular, the process included extraction of anchoring and strait passing events from vessel trajectories, delineation of anchoring zones, determination of the temporal relationships between the anchoring and strait passing events, spatial and temporal aggregation of events and trajectories, and others. Figure 3 shows the subset of relevant trajectories selected for the analysis and the anchoring events identified in the trajectories. In Figure 4, groups of trajectories with particular properties are represented in an aggregated form in flow maps. These maps reveal how the anchoring events in these groups of trajectories are related to visiting the port of Brest.

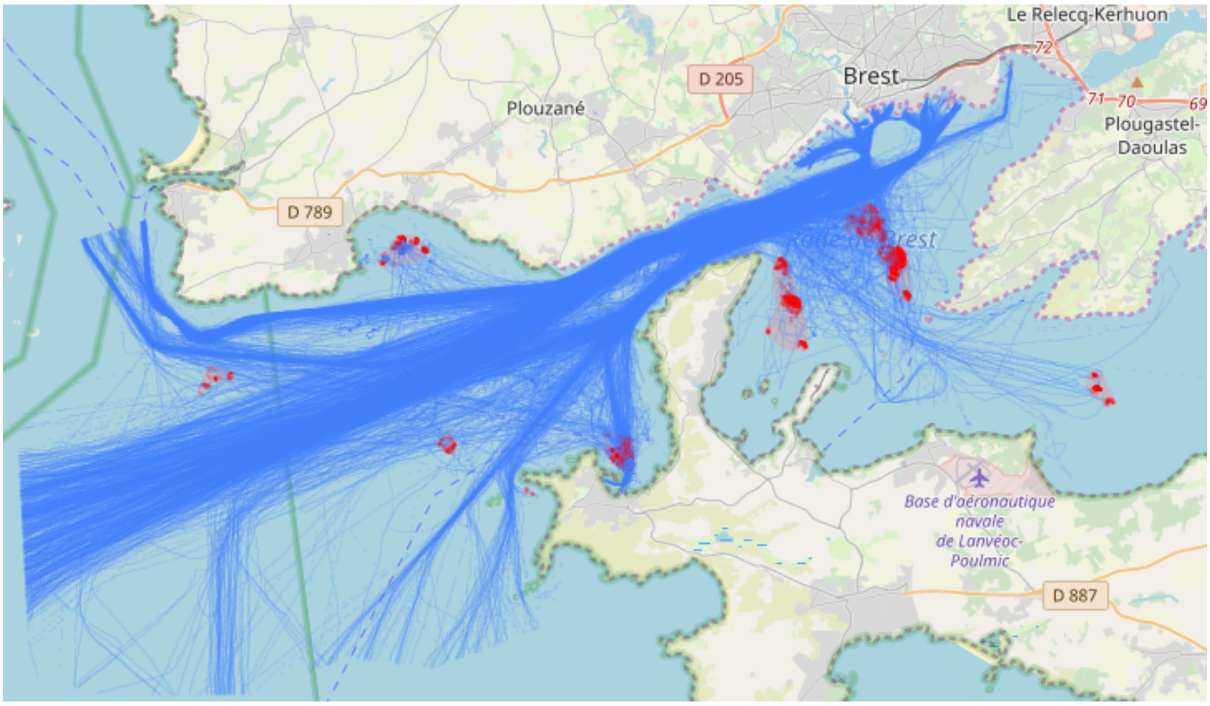


Fig. 3. The trajectories selected for analysis with the anchoring events (stops) marked in red.

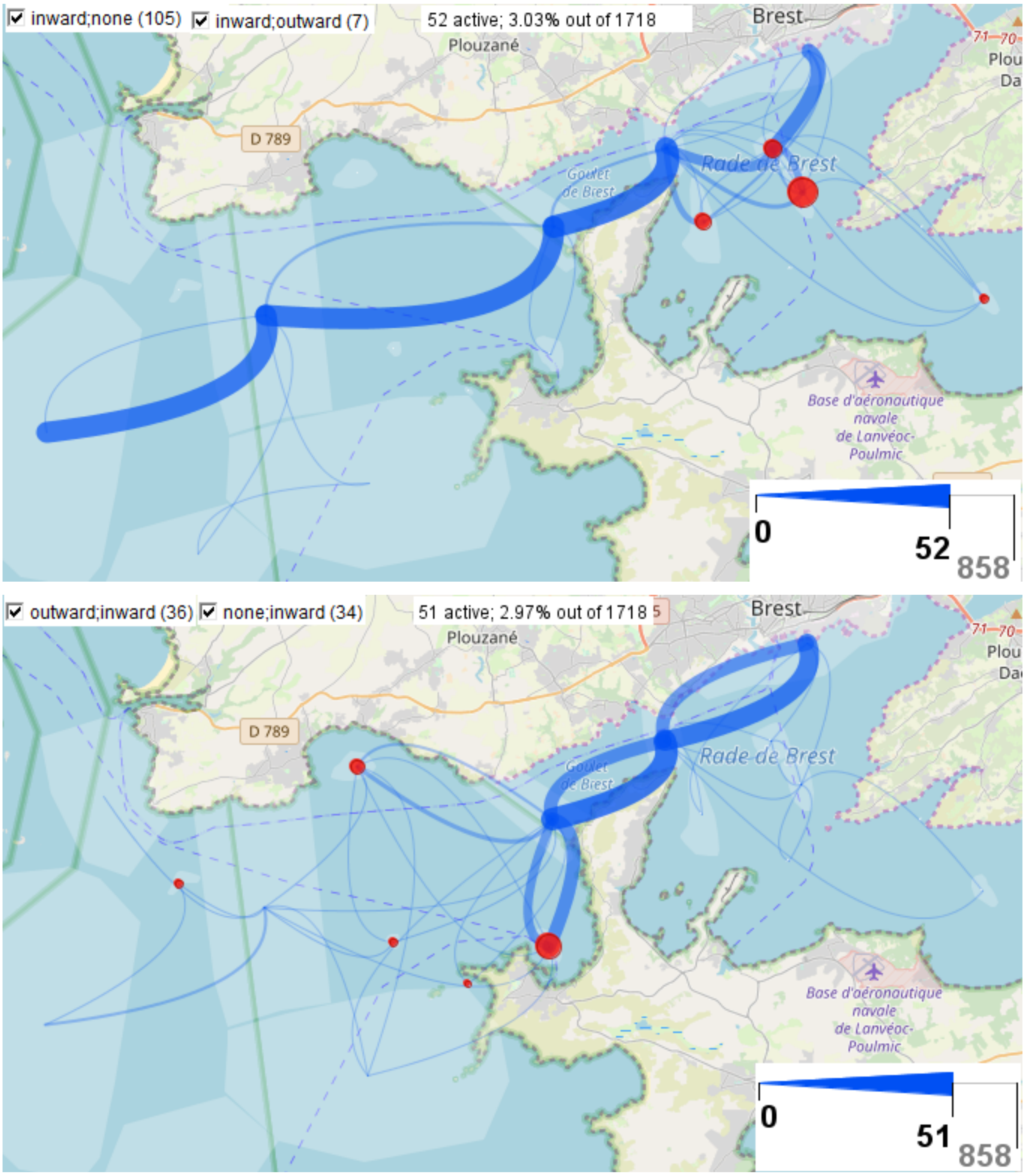


Fig. 4. Subsets of the trajectories under study are represented in an aggregated form on flow maps. Upper map: The trajectories having stops after entering the bay of Brest. Lower map: The trajectories having stops before entering the bay.

One of the case studies performed in the aviation domain aimed at investigating the horizontal and vertical separation between the approach routes to different airports in London. The study included identification of holding loops in trajectories of aircraft (Figure 5) and exclusion of these loops from the process of clustering of the trajectories by route similarity. In Figure 6, the resulting clusters of the trajectories with the excluded loops are represented by colouring of the trajectory lines.

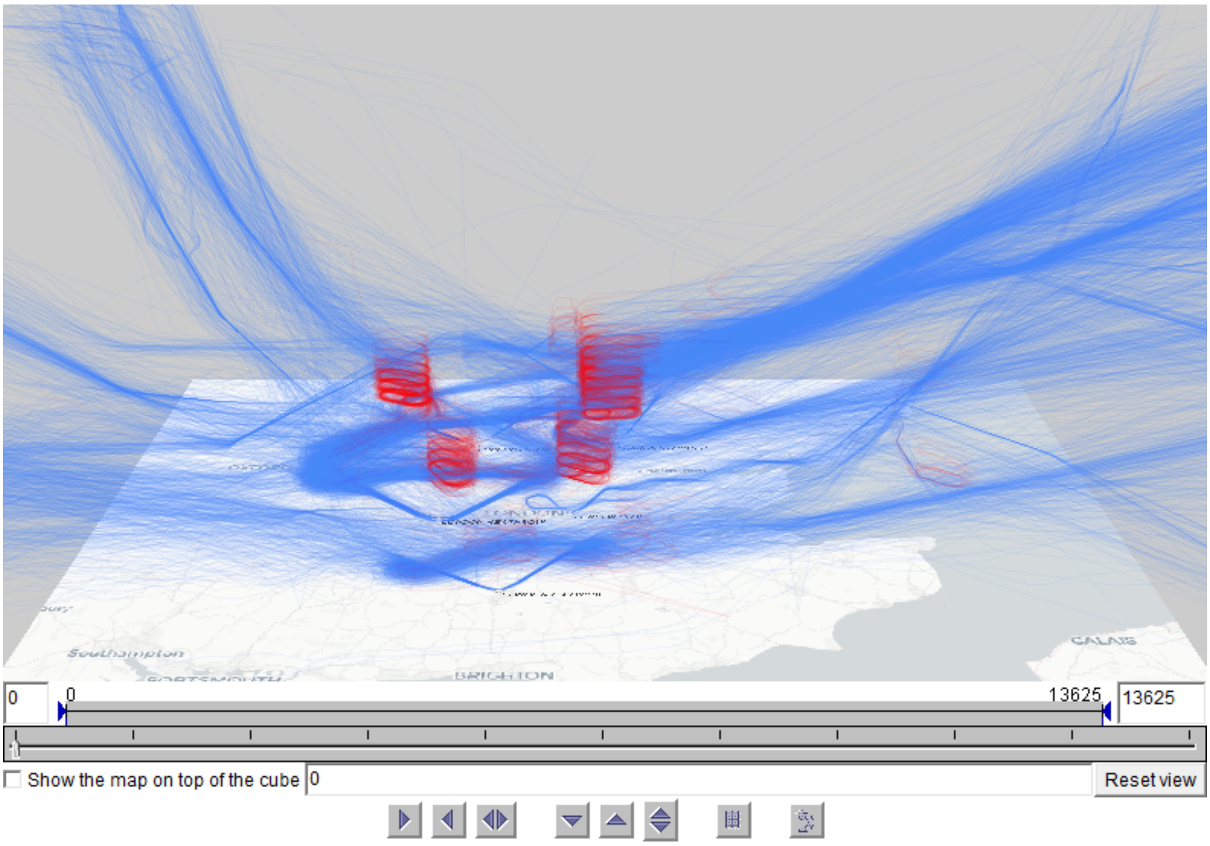
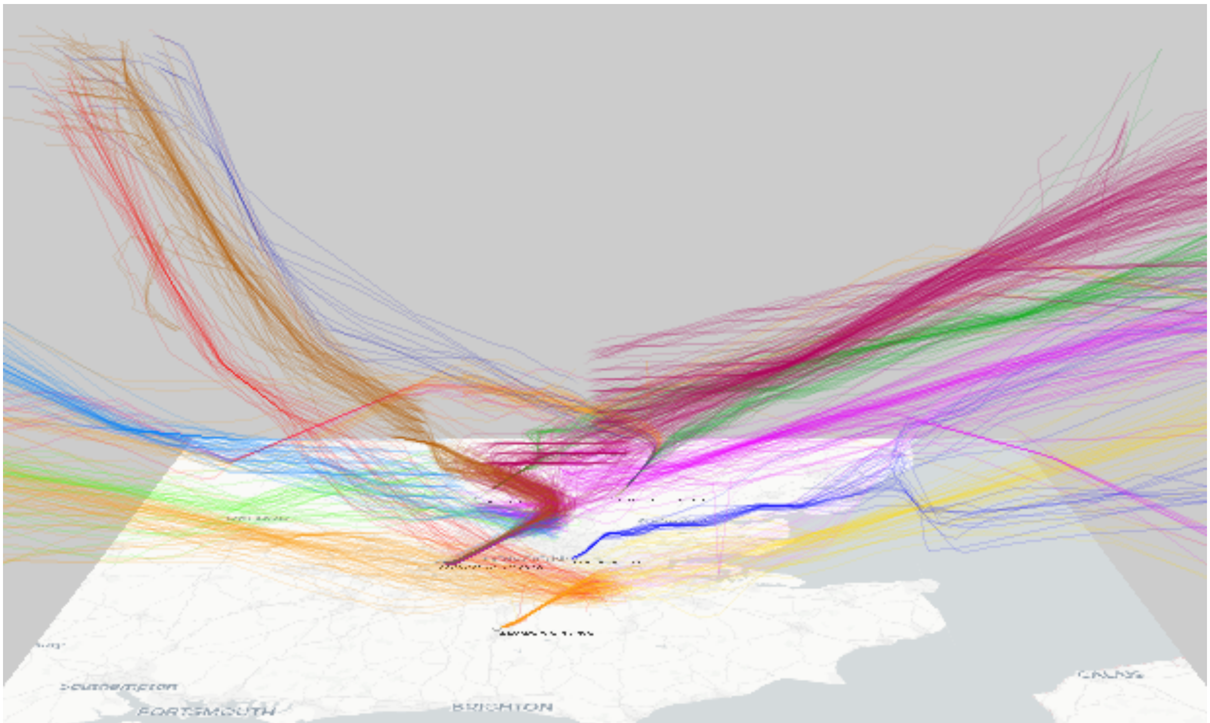


Fig. 5. Holding loops in the trajectories of the flights arriving to London are marked in red.



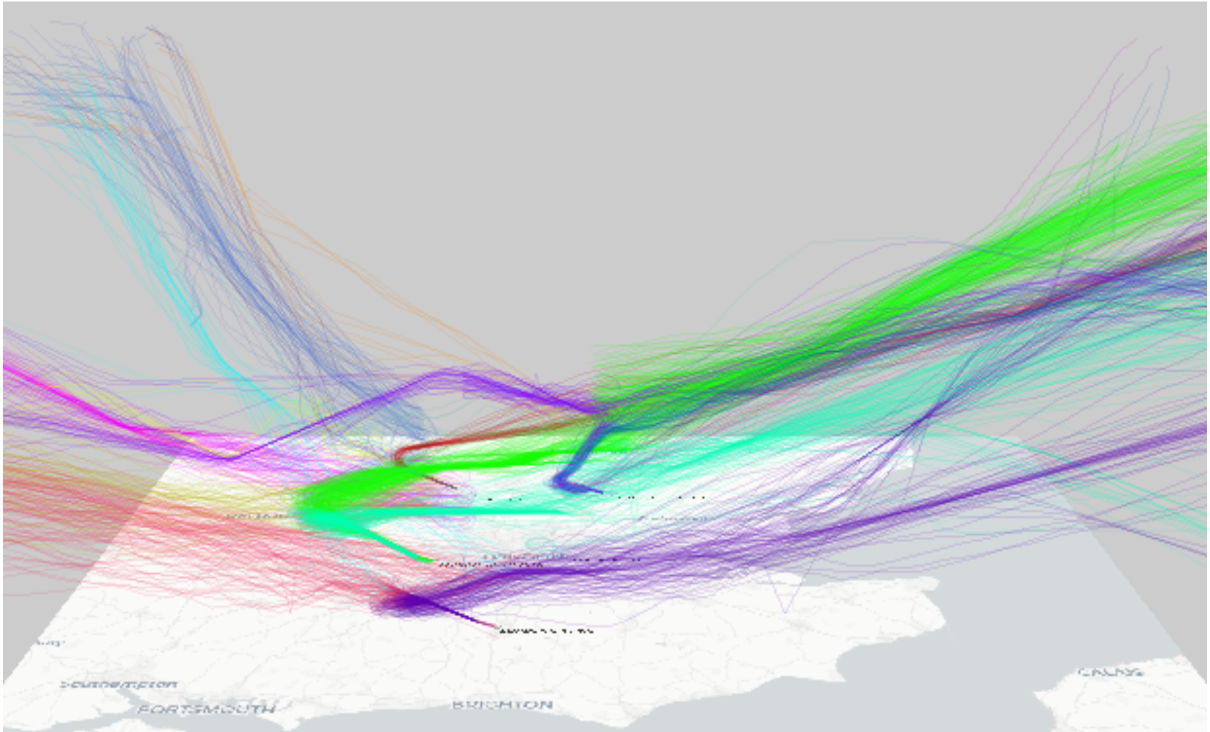


Fig.6. The routes that were used on the first day till 18:25 (top) and on the following days after the wind change (bottom).

Clustering of flight trajectories by relevant parts was also used in the third case study for identifying the existing variants of the flight routes from Paris to Istanbul (Fig. 7). After this was done, the route choice preferences of different flight operators were investigated in relation to the airspace navigation fees in different countries of Europe.

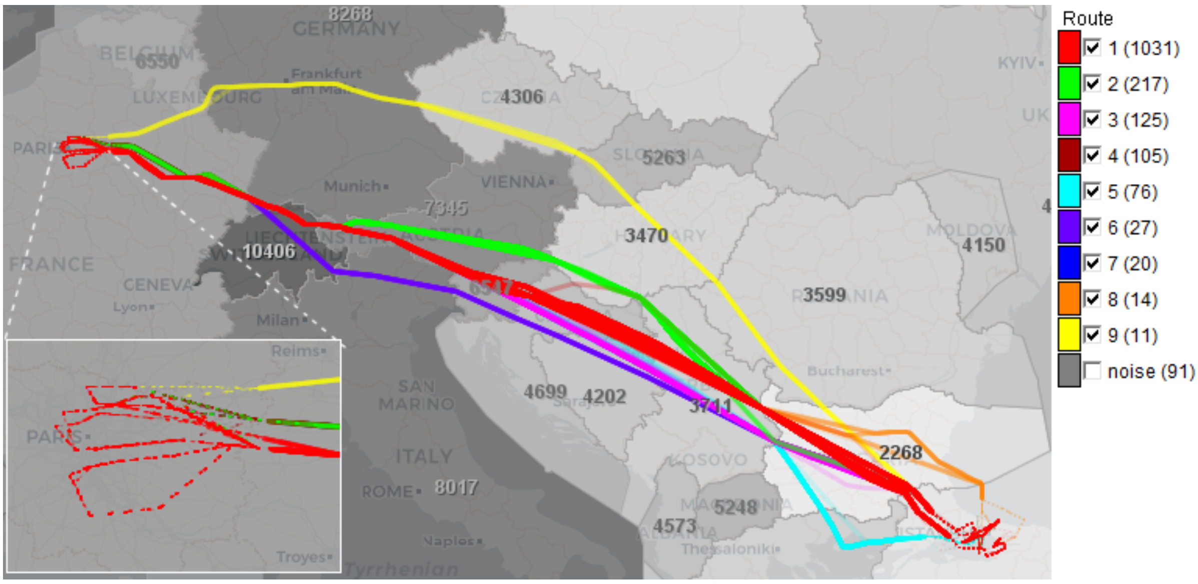


Fig.7. Trajectories according to flight plans have been clustered by route similarity to reveal the major flight routes from Paris to Istanbul. The initial and final parts of the trajectories, which are represented by dashed lines, were disregarded in the clustering.

In the fourth case study, we strove to understand the reasons for using particular variants of airspace configurations. Apart from the obvious variation of the number of airspace sectors over the daily and weekly time cycles depending on the traffic intensity, there are multiple variants of configurations with the same number of sectors, and there are no regular patterns in selecting these variants (Fig.8).

After clarifying the differences between the configuration variants in a selected region, we tried to relate the choices of these variants to properties of the flight trajectories crossing the region and found that the flight data are insufficient for explaining the choices.

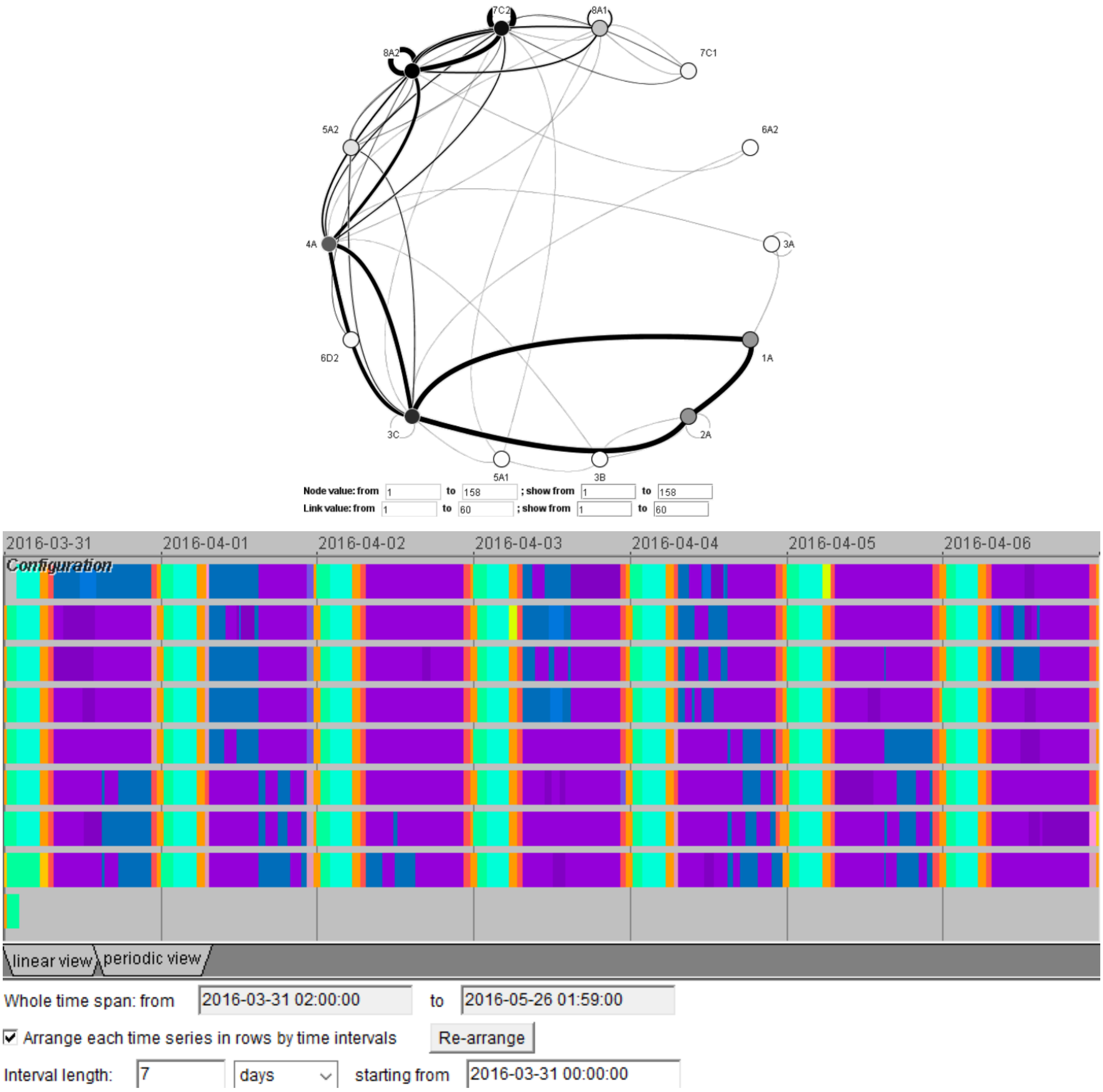


Fig. 8. Top: A state transition graph shows changes of airspace configurations in one region during a month. Bottom: The configurations are represented by differently coloured bar segments in a periodic time view. The rows correspond to time intervals of one week length.

All analysis examples included in this chapter resulted in gaining valuable knowledge concerning the design and planning of the business activities in the maritime and air traffic domains. This kind of knowledge can be potentially used for building predictive models and/or for improvement of the businesses. The results have been discussed and validated with domain experts to ensure applicability to operational needs. Particularly, in the domain of ATM, the analysis scenarios demonstrated the value of the VA methods to identify decision criteria as key aspects of the ATM system, able to feed predictive or analytic models applicable in planning phase. The scenarios especially highlighted the power of these techniques to derive knowledge from spatio-temporal patterns. The VA techniques also proved their utility for assessment of data quality.

We emphasise the absolute necessity of involving human reasoning in analyses aimed at gaining new knowledge and finding possible or new, better ways to solve problems. Visual analytics techniques, which support human reasoning, have therefore high importance and high potential.