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IKG
Institute of Cartography
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Geomatics Semester Project

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Mapping Bird Mobility with an Interactive 3D Web Tool

Project report

Code repository: https://gitlab.ethz.ch/dpasiak/birdtracker/

Web application: https://ikgcartoapps.ethz.ch/project/birdtracker/

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Abstract

Bird mobility is complex and there is still much to learn. Understanding how birds master flying could not only enhance our knowledge of them but also, in the long term, for example, improve weather models where data is currently insufficient. With advancing technology, it is now possible to track birds' movements at second-level intervals over several years. To fully understand these journeys, it is necessary to consider all dimensions, including altitude. So far, researchers have mostly used R, which is excellent for computation and scientific plotting but has limited interactivity and 3D capabilities. An interactive 3D web application could provide better insights for scientists and serve as a communication tool for policymakers and the public. This application allows for a global and detailed inspection once the user uploads a file, which can contain data for several individuals. The map facilitates interaction with the route and all recorded points, while the dynamic dashboard supports further investigation. Combined, these features enhance the efficiency of visualizing and understanding the complex yet fascinating movements of birds, as demonstrated during testing with researchers. The results were promising, confirming some assumptions and revealing new insights when data was integrated with terrain and 3D visualization. The complexity and size of the data presented challenges and required several workarounds. While the application is functional, there is still potential for further improvement in data rendering and the addition of new features.

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1 Introduction

Understanding animal behaviour, especially mobility, is crucial for many disciplines, including biology, earth sciences and environmental studies. Some of the important benefits include improving conservation planning, acting as an indicator of climate change impacts, and inspiring technological advances. Currently, most analysis and visualisation in this area is done using R. This is a powerful tool, but has limited capabilities for interactive and 3D visualisation. This is particularly important when dealing with bird tracking data, which due to its multi-dimensionality (longitude, latitude, altitude and time) can be difficult to understand using the standard 2D approach. Exploring the data in an interactive rather than static way could also make it easier to analyse spatio-temporal movement. Being able to control the camera or filter the data reduces complexity and allows the user to focus on what is important. It will make the result accessible not only to researchers but also to policy makers and the public, making it easier to explain the situation.

1.1 Requirements analysis

The project is carried out in collaboration with Ph.D. Elham Nourani from the Max Planck Institute for Animal Behaviour, Department of Migration (MPI) to integrate knowledge between the geospatial and animal tracking parts. In the first week of the project, an interview was conducted to understand what functionality is needed in animal movement analysis. This involved discussions with four researchers with slightly different backgrounds and experiences. It turned out that while some features are essential in all cases, the tool also needs to allow flexibility in data exploration so that the user can choose which data to focus on. It also highlighted the importance of an accurate representation of the bird tracks and model used in the application, to show exact points and orientation. The interview also confirmed that the 3D visualisation tool could greatly improve both the understanding of the animal's movement and its presentation to the public.

1.2 Background knowledge

The mobility of birds is a complex phenomenon that continues to intrigue researchers, with much still to learn. Technological advances now enable scientists to track birds' movements with remarkable precision, capturing data at intervals as short as seconds over multiple years. This capability has opened new ways of understanding the dynamics of bird movement across various scales and contexts.

Birds engage in several types of movements, each serving distinct ecological and behavioural purposes. Local movements, for instance, involve short trips between roosting and feeding sites within a bird's home range. Foraging journeys, typical of seabirds and swifts, can extend over considerable distances as these birds search for food. Dispersal movements are crucial for gene flow and species survival. Among the most extensively studied bird movements is migration, which includes not only the familiar seasonal migrations but also nomadic and irruptive migrations.

The migration of birds can be characterised by distance and timing. Long-distance migrations exceed 5,000 kilometres, often crossing significant ecological barriers such as mountains, seas, or deserts. Migrations can be nocturnal, as in songbirds that travel at night to avoid predators, or diurnal, typical of larger birds like raptors and geese that migrate during the day using thermals or flying in flocks. On a larger scale, migratory patterns include 'leap-frog' migrations, where northern breeders spend the non-breeding season further south than their southern counterparts, and 'chain' migrations, where northern breeders winter in southern breeding areas. Broad front migrations involve a wide dispersion of the population over the migration routes, while funnel migrations concentrate the population in key stop-over areas. Other migration types include seasonal migrations with predictable patterns, nomadism driven by food availability, irruptive migrations triggered by environmental factors and partial migration, where only part of the population migrates.

Birds employ a variety of flight modes to navigate their movements, with flapping and soaring being the most common. Although flapping flight is energetically expensive, it is versatile and can be used under a wide range of conditions. In contrast, soaring is an energy-efficient mode of flight, but it is dependent on thermals or wind, which restricts its occurrence to certain weather and topographic conditions. Most birds are unable to feed while in flight, necessitating the use of stop-over sites where they can rest and replenish their energy reserves. These stop-over sites are critical for long-distance migrants, as the total travel distance often exceeds their maximum flight distance without refuelling.

Navigationally, birds use an array of cues to find their way, including the sun, stars, magnetic fields, landmarks, and even olfactory signals. This sophisticated navigation allows birds to undertake incredibly precise and often considerable risk journeys, demonstrating remarkable adaptability and resilience in the face of environmental challenges.

1.3 Current application state

The tool was implemented based on the application created during the course “Application Development in Cartography” (Fig. 1). Before it was possible to load the GPX track and then represent it on the map (Fig. 2), however large files covering several countries were not possible to load yet. Basic camera handling, basemap changing and charts with statistics were available.

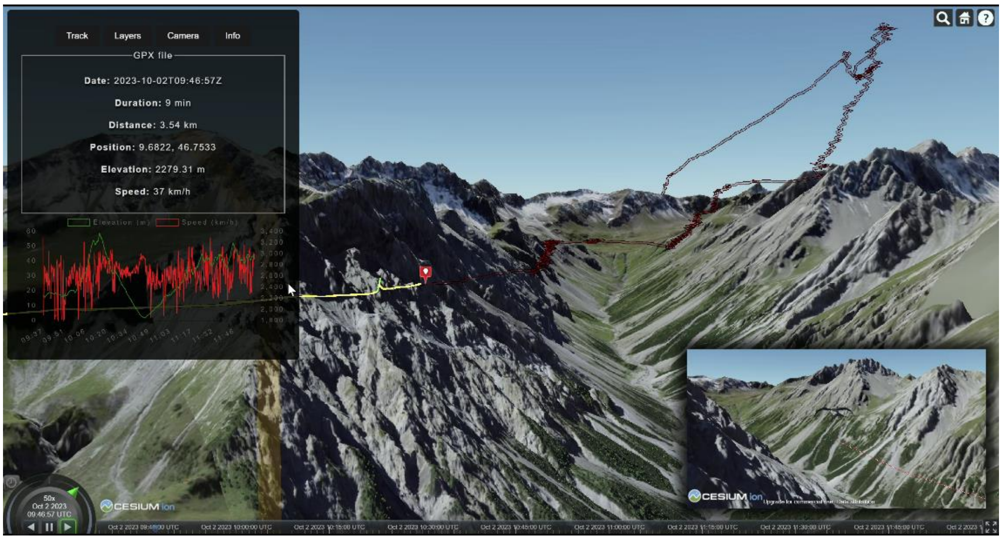

Fig.1 Main view of the application with loaded Honey Buzzard data

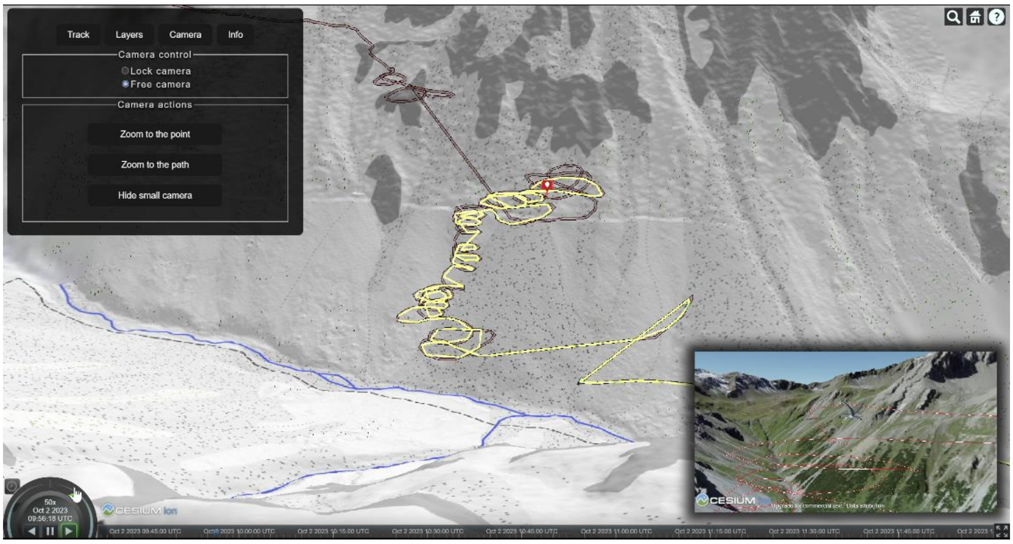

Fig. 2 Close view of the loaded track

2 Goals and target users

The main objective of the project was to develop a web application that enables interactive 3D visualisation of bird tracking data uploaded by the user. The target groups are both researchers and the public, with the focus on the first one. The tool does not attempt to substitute R, but rather adds a way to test hypotheses and examine the data from different perspectives. Its main function is also to present the results in a more attractive and more comprehensible way. The combination of elevation data with time animation and camera control offers a full insight into the path taken by the animal.

The old version of the application already provided a simple overview of the track, but several aspects such as flexibility and data loading had to be improved to make it usable for actual research. The project also aimed to improve the user experience when analysing the data by adding more appealing visualisation and filtering options. Details are described in the functionalities section.

3 Approach and methods

3.1 Schedule

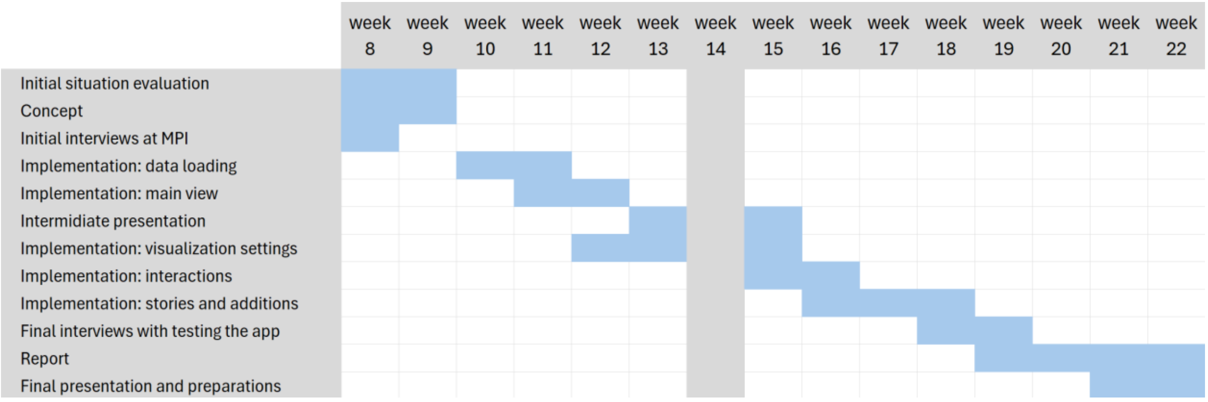

Fig. 3 Schedule

3.2 Libraries

The main functionality was handled by the Cesium library which allows the integration of 3D mapping into the web application. Vue was used as a JavaScript framework to allow the application to be split into components. For geospatial analysis like generalization turf.js library was used and Plotly for advanced visualizations and charts. The application is server-less with the possibility to upload data at the beginning.

3.3 Data

Animal tracking data is stored as a private repository on a Movebank platform (a globally used online database of animal tracking data hosted by the Max Planck Institute of Animal Behavior) and shared as part of the collaboration. Although the application aims to work with any kind of bird-tracking data, it was tested primarily on two datasets, with a focus on the Honey buzzard sample. Both datasets include large amounts of data, one more global and one more local, making them a great case for representing the needs in the field for different types of visualizations. The data is downloaded in CSV format.

Honey buzzard (*Pernis apivorus*)

- Spatial extent: Europe and Africa (Fig. 4)
- Time: 28.07.22 – now
- Number of individuals: 32
- Number of records: more than 6'000'000
- Frequency: no regular intervals, between seconds to hours
- Recorded data: GPS, Orientation, Magnetometer, Acceleration

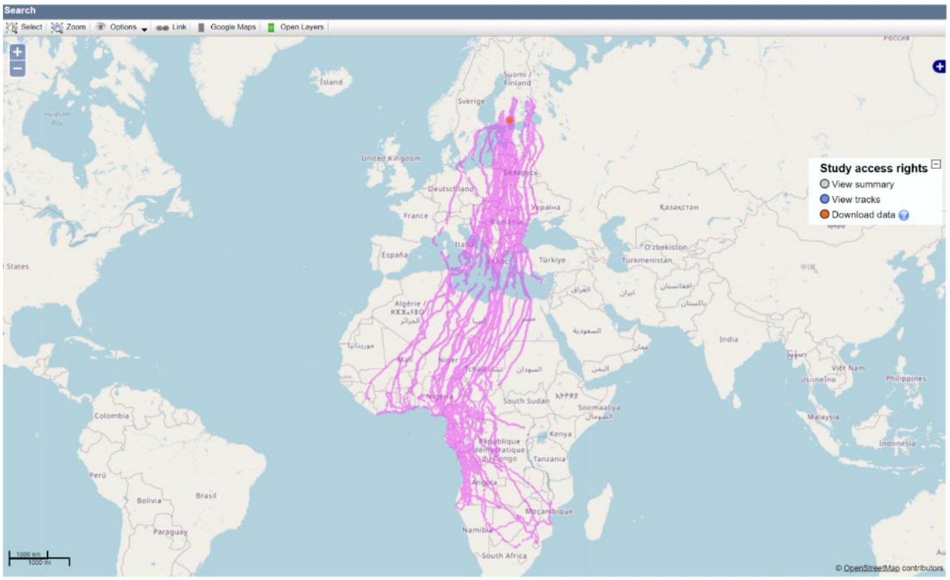

Fig. 4 Honey buzzard dataset

Golden eagle (*Aquila chrysaetos*)

- Spatial extent: Alpine range in Switzerland, Italy, Austria, Germany (Fig. 5)
- Time: over 1 – 4 years
- Number of individuals: around 50
- Frequency: no regular intervals, between seconds to hours

Fig. 5 Golden Eagle dataset

Other data

The terrain data is provided by Cesium along with a base topographic map, satellite map and 3D buildings. In order to understand a route in a broader context, additional thematic layers with global coverage were added. These include commonly used environmental data such as NDVI, human footprint, land use and human footprint. Some of them are also time-dependent, like imagery useful for example for areas with big seasonal changes. No preprocessing will be required, and they will be available through a WMS or WMTS service. The providers are: NASA's Global Imagery Browse Services (GIBS), ESRI and OpenStreetMap. They can be selected using a basemap picker (Fig. 6).

Fig. 6 Basemap picker

4.3 Design

Prior to the implementation of the code, a sketch of the application was created and a list of functionalities was compiled based on the results of the requirements analysis. The application was divided into several components, that helped with design and later implementation in Vue. The main ones are: data loading, main view, visualization settings and interactions.

4.3.1 Data loading

The important part was to allow the loading of data in CSV format, which is commonly used in this field, and thus handle a non-standardised version of location information. A considered alternative was to load the data using the Movebank API, which was not used in the end due to the difficulties with an incorporation authentication process.

The application was planned to be used with pre-processed data, and if the user wants to analyse aspects other than position and time, adequate data must be included in the file. This may include derived parameters (flapping, type of movement) or environmental conditions (temperature, wind). As the information provided by the sensors varies, the application must allow for flexible presentation, but also indicate which attributes correspond to which (Fig. 6).

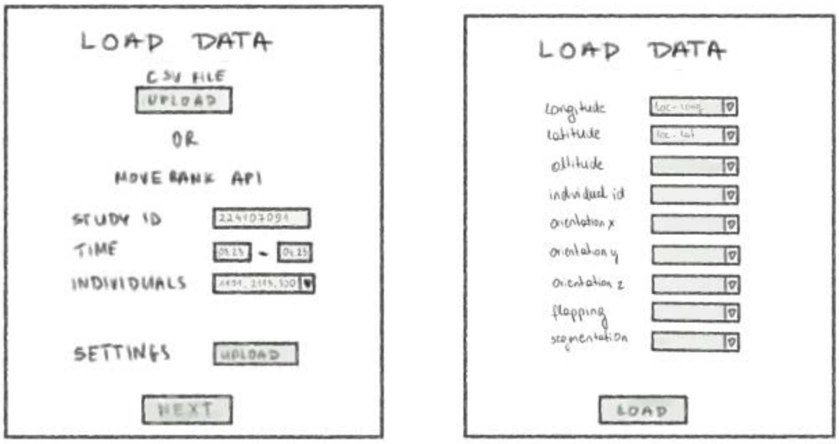

Fig. 7 Loading data

4.3.2 Main view

The application was designed to consist of a 3D map covering the entire window, as well as a menu and a small hideable window (Fig. 8).

The statistics and charts window were aimed to provide insight into selected individuals. The charts focus on the whole period, while the two indicators show the current state.

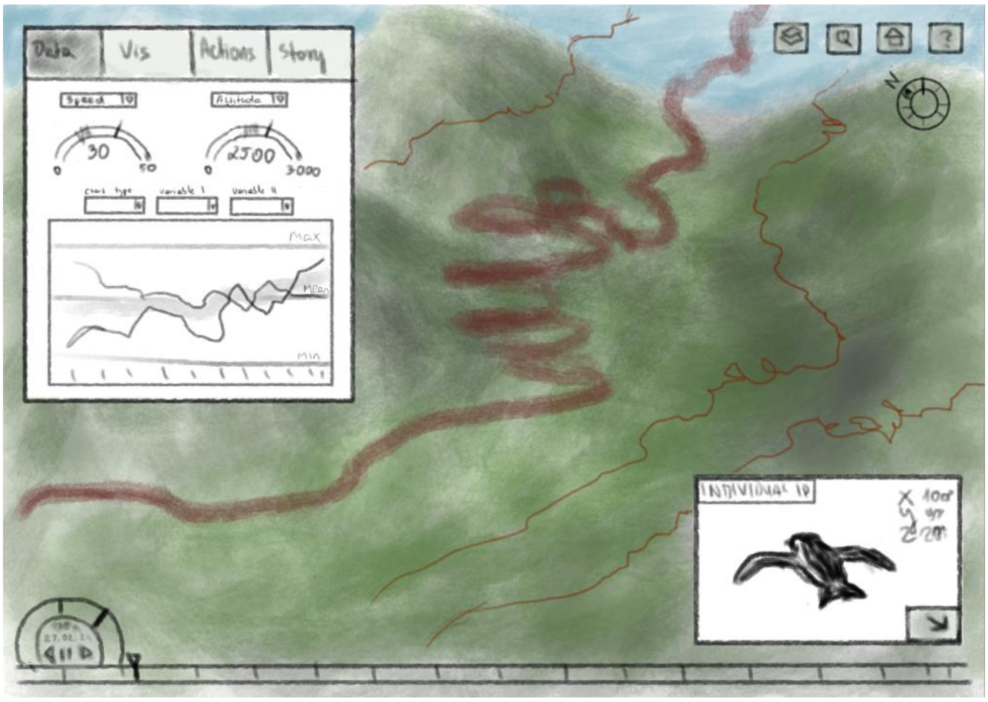

Fig. 8 Main view with charts

4.3.3 Visualizations settings

Different shapes and colours were planned to indicate changes in parameters and for the user to be able to decide which one to visualise. The menu should allow different variables to be selected for different display modes (Fig. 9). These include colouring the track based on the value, presenting the points as spheres or cylinders with changing colours and shapes (Fig. 10). Additionally, control over displaying labels, terrain contours and additional 3D building should be possible. Choosing the basemap layer itself will be possible from the Cesium widget.

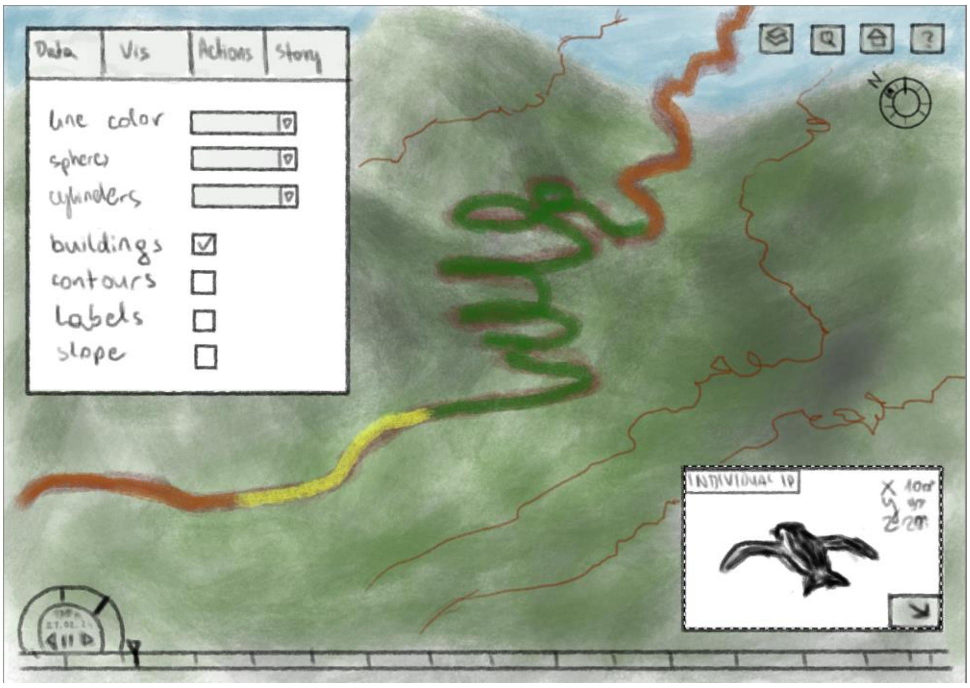

Fig. 9 Visualization of movement parameters with colouring the track

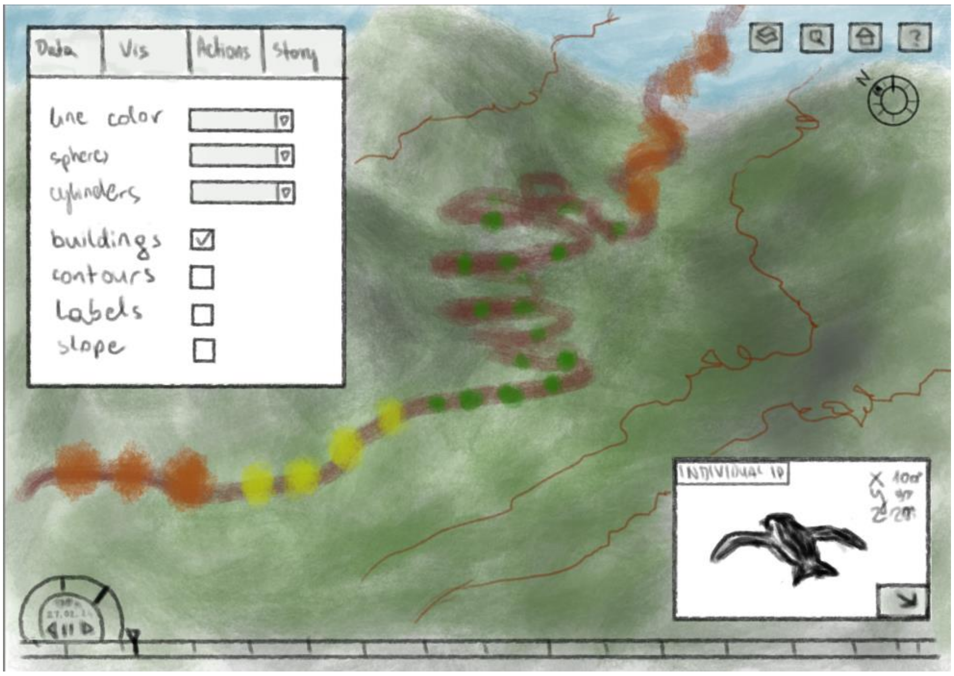

Fig. 10 Visualization of movement parameters with spheres

4.3.4 Interactions

Apart from the existing interactions like time adjustment and camera settings, filtering should be added. The filter should work for any available variable and depending on its type will adjust the filtering methods. Some possible cases would be to present the parts, where the segmentation indicates soaring.

Bookmarking functionality was also planned to be added to allow the user to save interesting places including both position and time. It should be possible to move the camera to the saved location using the list in the menu or to automatically jump from place to place to show the whole story. Furthermore, the list could be downloaded as a simple JSON file and used the next time the data is loaded. As it was not a necessary component it implementation was moved outside the scope of this project due to time constrains.

4.4 Known Uncertainties

From the beginning, several known uncertainties were anticipated during the development of the application. Given the entire dataset spans several gigabytes, the limits to the amount of information that could be loaded and processed efficiently were unknown and a key part of the investigation during implementation. To manage this, the application aimed to employ different data sampling strategies based on the zoom scale. Additionally, to simplify the loading process, it includes the capability to load data individually for each bird, ensuring manageable data chunks and improved responsiveness.

It was also anticipated that the flexibility of the presentation might need to be restricted if accommodating all visualization modes for all variables proved infeasible. This decision was necessary to balance the application's performance and usability.

Due to time constraints, certain aspects such as validation and verification of inputs, as well as outlier handling, were considered out of scope for this version of the application. It was assumed that users would have a basic understanding of data visualization principles, including which charts to use for categorical versus continuous data. This assumption allowed a focus on core functionalities while deferring comprehensive validation and error handling to future versions of the application.

4.5 Implementation

The application was implemented gradually, beginning with the most critical components. The code was committed to GitLab, where it was stored. It was also then automatically deployed and could be accessed online via the IKG website. Major updates were discussed with the supervisor, and potential improvements were regularly reviewed and considered.

4.6 Testing

The application was tested on a regular basis by the developer with different data. Once most of the functionalities were implemented, the application was tested also by the researchers at the Max Planck Institute (by the same people who participated in the first interview). They could use sample data as well as their own that they were working with currently. After a short introduction, they could freely explore the application and use the most interesting parts for them. Small changes that could be achieved in the remaining time of the project were implemented based on the feedback and the rest will be used as an outlook for further enhancements.

5 Results

The application allows a global and detailed inspection after the user has uploaded the file, which can contain several individuals. The map allows interaction with the route and all the points recorded, while the changing dashboard allows further investigation.

The data used is downloaded directly from Movebank (globally used database for animal tracks hosted by MPI). A file of this nature may comprise upwards of several hundred thousand points, each with several tens of properties. The number of points and the number of properties influence the loading time. Due to lack of standardization of CSV file, user needs to recognize necessary columns like longitude and latitude, but they are preassigned if the standard naming from Movebank is used (Fig. 11). The file is parsed and divided into different individual paths by checking bird ID and converted into GeoJSON and CZML format necessary for different visualizations.

Fig. 11 Data loading window

Data is also used to create interactive plots and indicators, that show both overview and current values with indicators and changing time bar. As the line plot can contain a lot of information, zooming in to specific parts is possible.

Once the data is loaded it is possible to inspect the route of the bird as for example the part of the path the Honey Buzzard took through the Swiss Alps (Fig. 12-17). The black semi-transparent path show the whole, but generalized road as displaying accurate representations was working only for smaller distances. That is why there is a 24-h moving path that is represented on the main path and synchronised with the timeline. It can be also inspected in the small viewer together with the model, to be able to see at once both small and bigger picture (Fig. 12). Using a time slider allows the user to see updating path and numbers in the widget with the speed of their choosing.

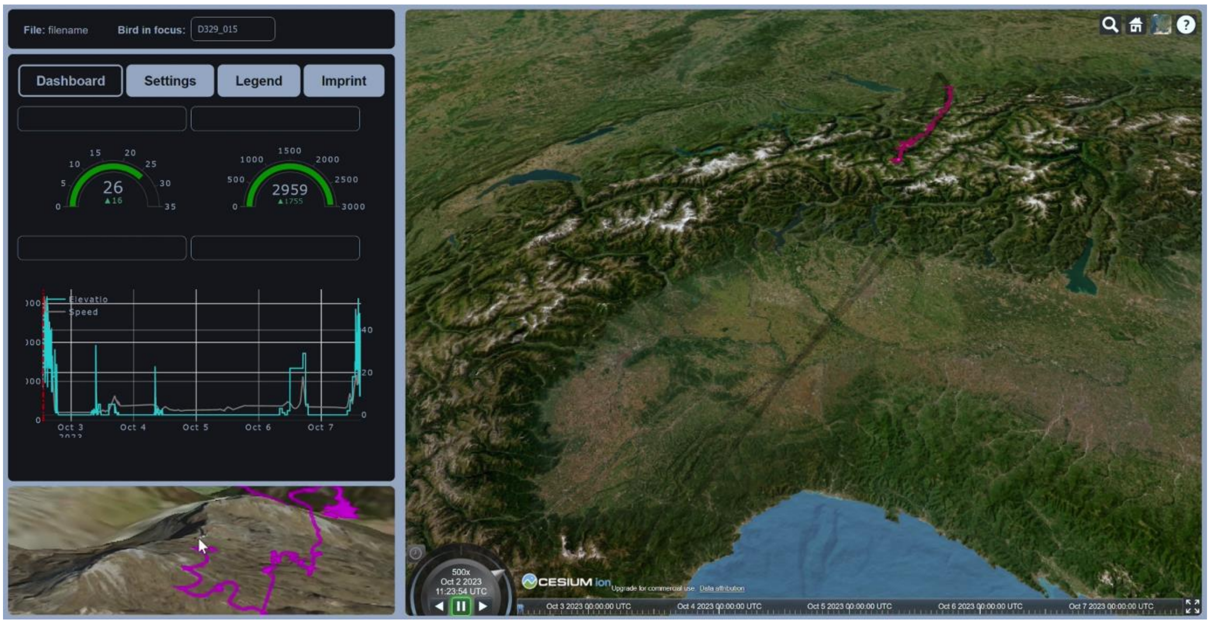

Fig. 12 Dashboard, main viewer and small viewer

To be able to explore other properties of the track, user can choose the name of the corresponding column both for line and point representation as well as filter wanted values (Fig. 13). The filter works both as a single value or range and it adapts to the type of value. Color classes are calculated automatically taking into account minimum and maximum values for continuous data and unique categories for categorical data (Fig.14). Two different color scales are used for point and line linear data, so it is easier to distinguish them. As for the categorical data there are up to 7 classes (and the colors start repeting if more), where the one for lines has increased saturation and brightness compared to the one for points. As this part uses quite a lot of resources the user can decide if to display all the points at the exact recorded position or use only every 100th point for general overview if the path is long.

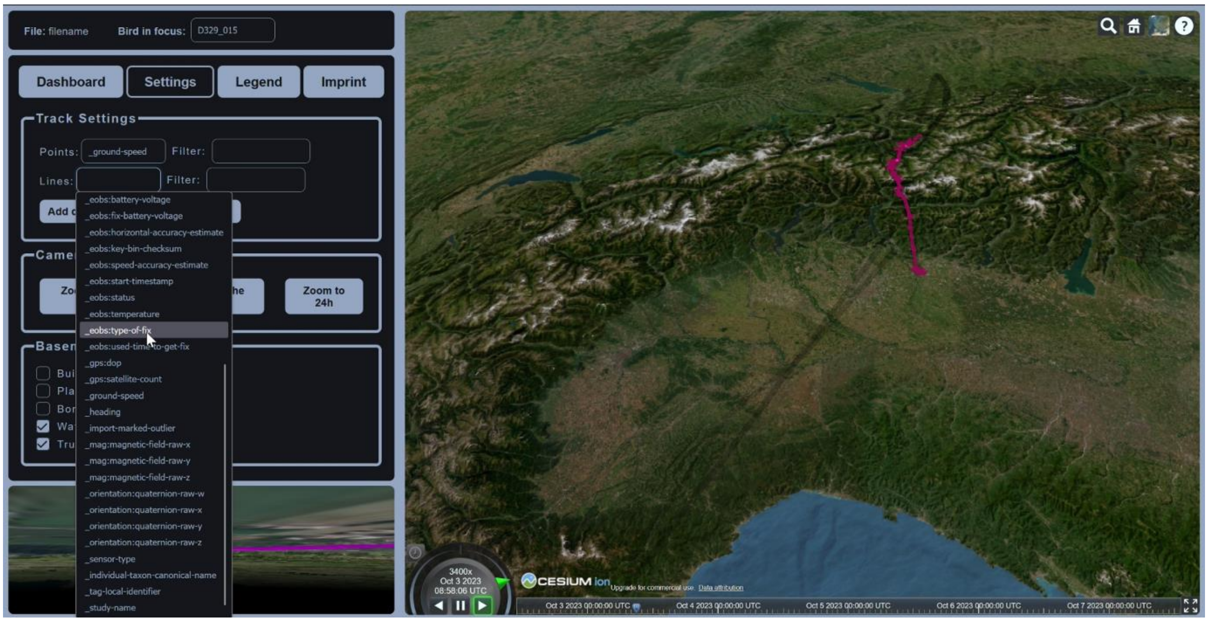

Fig. 13 Choosing settings for track visualisation

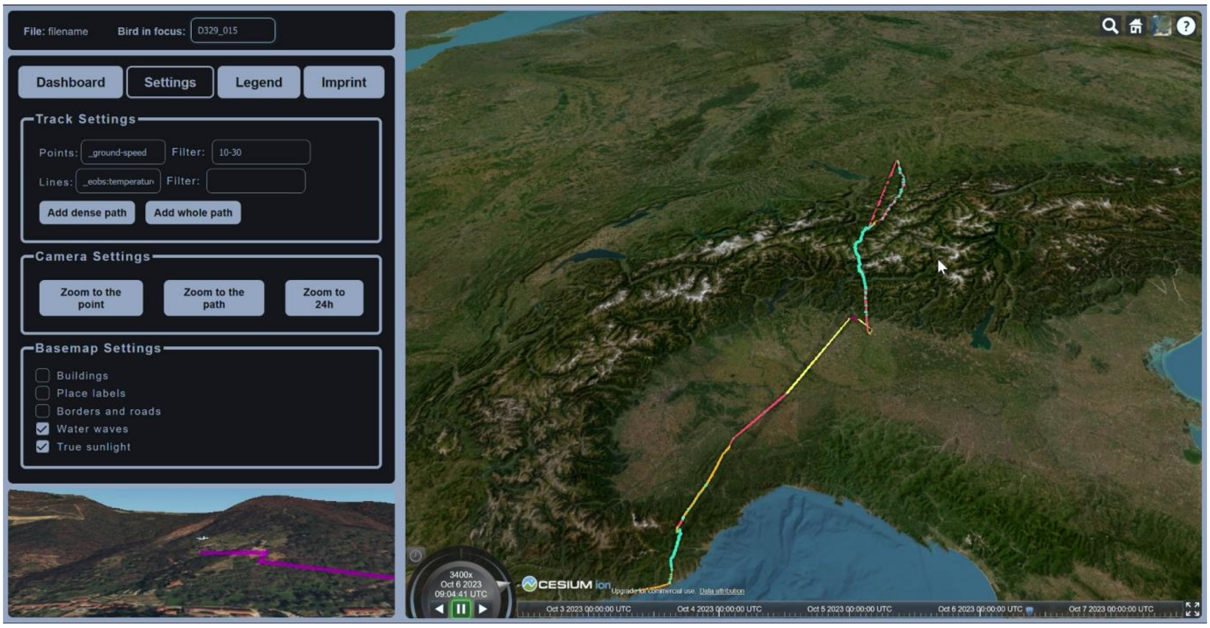

Fig. 14 Dense track visualisation on a country scale

The scale of the points changes based on the distance, making it possible to display such densely populated information (Fig. 15). There is also a line with different properties generated from the points, so at the same time, the user can get insight into two variables. Through this visualization it is clearly visible how the bird interacts with the terrain (Fig. 16) and pop-ups allow the user to check also all the other's properties at the same time to see if they influence each other (Fig. 17).

Fig. 15 Points with changing scale

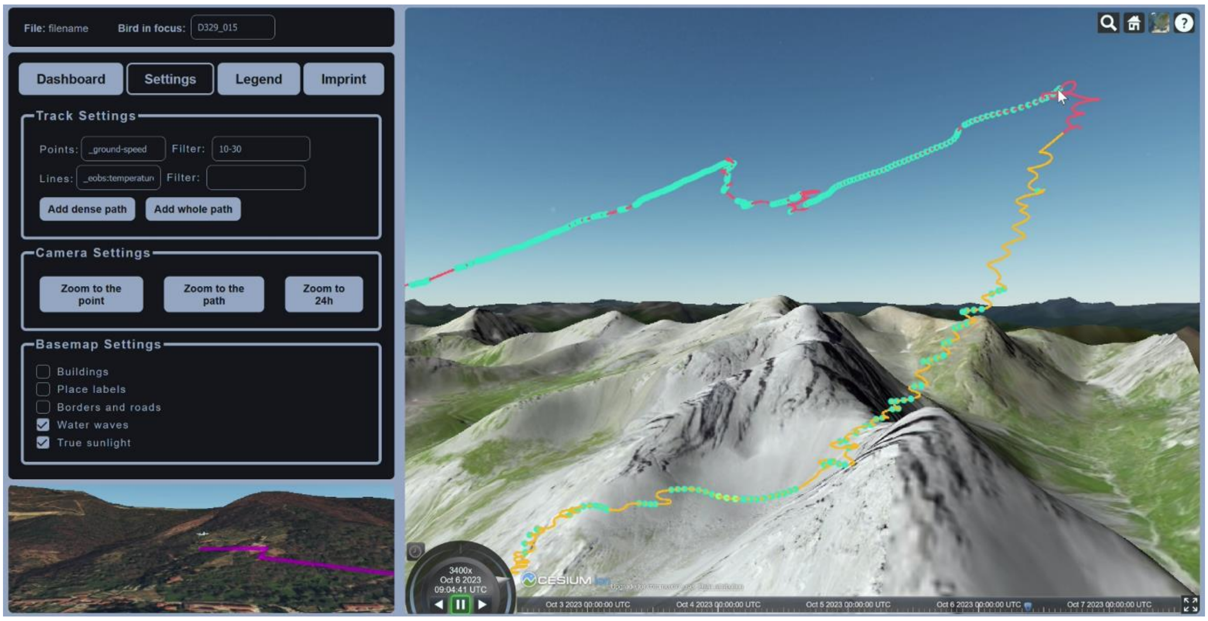

Fig. 16 Bird interacting with the terrain

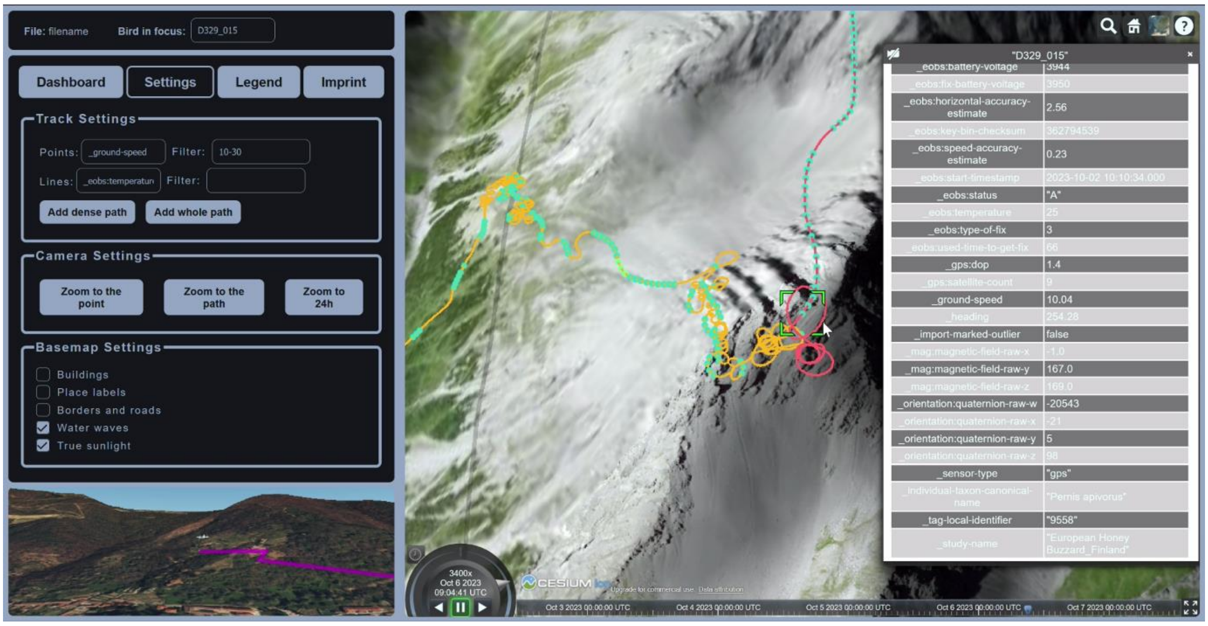

Fig. 17 Inspecting points with pop-up

It is also possible to investigate more individuals from the same dataset (Fig. 18). Looking at the global scale and considering daylight changes, is also see how the birds movement generally stops during the night. In order to display the entire path, a generalised path was created together with a 24-hour moving path. This combination allows both the entire uploaded track to be displayed, as well as detailed examination and rendering for multiple individuals on a global scale.

Fig. 18 Bird migrations of 18 individuals on a global scale

There are also other basemaps that could help in understanding the movement. One of them are time-dependent satellite images that with the different representation of every day, crucial in the places with high seasonal changes. In the basemap settings it is also possible to activate labels and boundaries and using the search field directly move to desired area (Fig.19). It is also possible to include nicer sea texture and stop the changing sunlight (Fig. 20). The camera settings simplify the navigation allowing the user to zoom to different parts of the path.

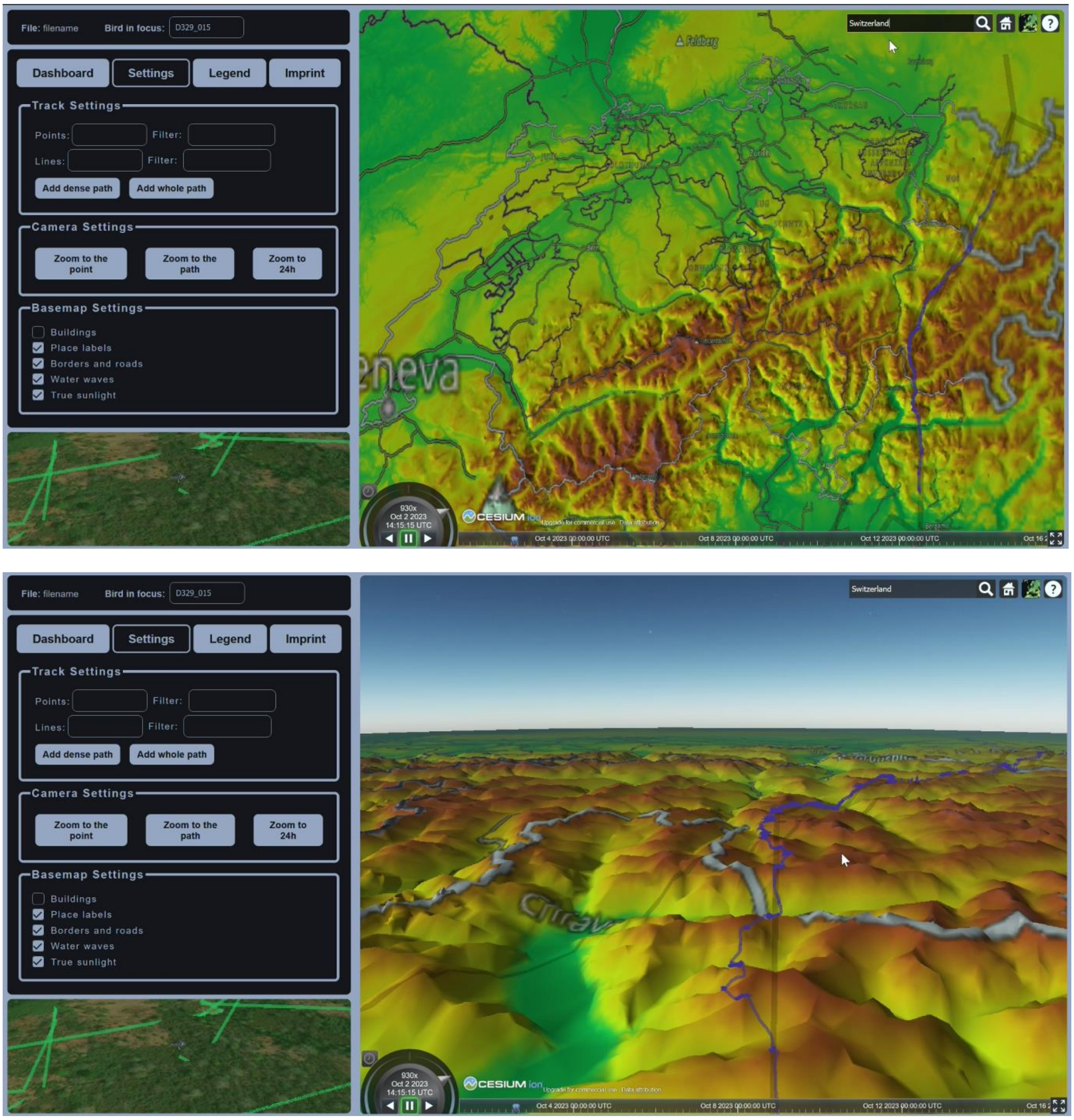

Fig. 19 DEM basemaps, with place lables, boards and roads

Fig. 20 Basemap settings: waves, buildings and sunlight

6 Discussion

The development of the interactive 3D web application encountered several significant challenges that required innovative solutions and considerable effort. One of the primary challenges was managing the multidimensionality of the data. Tracking the position and time for different individuals simultaneously added a layer of complexity to both the visualization and the data processing tasks.

Another major challenge was the lack of structure in the CSV files used for data input. These files often had no fixed naming conventions and included mixed data for different individuals, making it difficult to parse and organize the information correctly. This lack of standardization required the development of flexible parsing techniques and dynamic data handling processes to ensure that the application could accurately interpret and utilize the incoming data.

Additionally, the large size of the data files posed significant performance issues. Handling extensive datasets efficiently required not only powerful computing resources but also optimized algorithms to ensure smooth performance and responsiveness of the application. The data volume meant that a performance test was frequently needed to find and fix any problems with data processing and rendering.

The need for flexibility and interactivity in the application also presented substantial challenges. Ensuring that users could interact with the data in a meaningful and intuitive way required the implementation of advanced interactive features and responsive design elements. Balancing these needs with the constraints imposed by large data sizes and complex data structures was a continual balancing act throughout the development process.

These challenges had several consequences for the development process. A significant amount of time was devoted to testing performance and identifying problem areas, as well as exploring existing solutions that could be adapted or integrated. In many cases, compromises had to be made, and a combination of different implementation strategies was employed to achieve the desired functionality. For example, implementation of three types of route representation: a generalized path for all data points, a detailed 24-hour view, and an on-click generation of points and lines with attribute information. This approach allowed to balance the need for detailed visualization with the constraints of performance and data complexity.

Overall, addressing these challenges required a dynamic and iterative development approach, with constant refinement and adaptation of our methods. The solutions we developed not only improved the functionality and performance of the application but also provided valuable insights into managing and visualizing complex, multidimensional data in an interactive 3D environment.

7 Conclusion and Outlook

All things combined proved to increase the efficiency of the visualization and understanding of the complex but fascinating movement of birds, as demonstrated during testing with the involved researchers. The results were very promising, confirming some assumptions and revealing new insights when the data was integrated with terrain and 3D visualization. The complexity and size of the data presented many challenges and required several workarounds, which highlighted the need for ongoing development and refinement. While the application is functional, there is still potential for further improvement in terms of data rendering and the implementation of additional features.

A number of enhancements are planned for the coming weeks, as the collaboration is still ongoing and time constraints did not allow for the implementation of all planned features. These enhancements include improving model orientation, allowing users to change variables in indicators, and providing options to decide from where to plot dense tracks.

In terms of long-term development, there are a number of functionalities that could be implemented. One major feature in development would be the ability to export settings, which would allow users to save and share their configurations easily. Integration with the Movebank API is also considered, enabling the application to fetch data directly from Movebank, thereby streamlining the data import process. Additionally, the concept of "stories" presented in design section could be implemented. This storytelling feature will enhance the ability to present and share findings in a coherent and engaging manner. Validation and verification processes also should be strengthened to allow the application to be used by non-experts. Efforts should also be directed towards improving the overall performance of the application, ensuring it can handle large datasets efficiently.

There are also additional possibilities being explored, such as including weather data like wind for analysis. Integrating wind data could provide deeper insights into how weather conditions affect bird movements, further enriching the analysis. These developments aim to push the boundaries of what is possible in tracking and understanding bird mobility.

Overall, the ongoing enhancements and future plans for the application reflect a commitment to continuous improvement and innovation, ensuring it remains at the forefront of bird movement research. Collaboration with researchers and the integration of advanced features could make a significant contribution to the field, providing a comprehensive and interactive tool for studying the complex and fascinating patterns of bird movement.

8 Resources

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