Journeys in the Sky: Visual Insights into Bird Migration

DSK 808: Visualization

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Abstract

This project investigates individual variability in the migration patterns of three seagulls within the same species. Using GPS tracking data, we analyze trajectories, altitude, speed, and resting behavior, and present static and animated visualizations to explore temporal and spatial differences. Our findings reveal distinct migratory strategies among the birds, highlighting the importance of individuality in migration studies. The modeling framework is flexible, applicable to additional individuals or species, and can be extended with further ecological or environmental features to deepen understanding of avian migration.

1 Introduction

For centuries, epic journeys of migratory birds have inspired curiosity and scientific exploration. Over the past decades, advances in technology have transformed this field, uncovering remarkable insights into the behavioral, cognitive, physiological, and evolutionary mechanisms behind these journeys. Building on these scientific foundations, our visualization project explores differences in migratory timing and patterns among three individual seagulls, presented in an accessible and interactive way. Using both dynamic and static visualizations, this project enables users to explore how these birds move through time and space.

2 Related work

Shamoun-Baranes et al. [1] present innovative visualization techniques for studying nocturnal bird migration. They discuss the challenges of monitoring broad-front nocturnal movements using weather radar networks and describe the development of interactive, open-source flow visualizations. These visualizations provide intuitive representations of migration dynamics across large spatial and temporal scales and are applied to radar data from Europe and North America. The authors highlight the utility of these visualizations for ecological research, conservation, human–wildlife conflict mitigation, meteorology, and public engagement.

National Geographic [2] presents an interactive map showcasing the vast scale and seasonal dynamics of bird migration across the Western Hemisphere. The tool visualizes long-distance journeys of billions of birds, highlighting migration routes, timing, and broad patterns that would otherwise be hidden in nocturnal or large-scale movements. It serves as an accessible resource for understanding migratory behaviour, raising public awareness, and supporting conservation communication.

Hoekstra et al. [3] map nocturnal bird migration in the Netherlands to inform energy infrastructure planning. Using high-resolution radar data, they quantify vertical and spatial patterns of migration. According to their studies, a large proportion of migration occurs at altitudes overlapping wind turbine rotor heights, with clear seasonal variation: for example, in Den Helder, 54% of spring and 61% of autumn migration occurs below 200m. The combination of migration intensity with wind power density reveals that areas of high bird activity do not always align with optimal wind conditions. These visualizations support proactive planning by identifying sites with reduced ecological conflict, enabling a nature-inclusive energy transition.

Building on these approaches, our work aims to examine the differences in migration patterns of three individuals within a single species, with the goal of revealing behavioral individuality. By analyzing temporal and spatial trajectories, flight altitude, speed, and rest stop patterns, we explore how even birds of the same species may exhibit distinct migratory strategies. This focus on individual variation complements broader-scale studies, providing insights into the diversity of migratory behavior that may be obscured in aggregated analyses.

3 Data and Problem Overview

3.1 Data Sources

Our dataset contains GPS-based movement records for three individually tracked seagulls: Eric, Nico, and Sanne. Each record includes geographic coordinates, altitude, estimated flight speed, and a timestamp, resulting in a detailed account of each bird's migratory behavior over time.

Summary statistics:

- Total observations: 61,920
- Number of tracked birds: 3 (Eric, Nico, and Sanne)
- Sampling period: August 2013 - April 2014
- Data collected: GPS coordinates, altitude, speed, and timestamps
- Resting periods: Identified through extended intervals of very low speed

3.2 Problem Statement

The following research questions were formulated lead by our curiosity and with alignment the structure of the dataset. Each question is paired with a visualization designed to address it directly, to let the users explore the birds' migration from multiple perspectives.

- **RQ1:** How do the migration trajectories differ among the tracked birds?
- **RQ2:** How do altitude, speed, and resting patterns vary across the birds?
- **RQ3:** How do altitude and speed change over the course of each bird's journey?
- **RQ4:** How does migration activity change when represented as a time-based movement animation?

3.3 Relevance of the dataset

A preliminary correlation analysis (Figure 1) revealed strong relationships between the spatial features (latitude and longitude), indicating consistent directional movement across the dataset.

In contrast, altitude shows only moderate correlation with spatial variables, and speed displays almost no correlation with any other feature. These findings justify the structure of our research questions. RQ1 focuses on spatial trajectory differences, supported by the strong spatial correlations. RQ2 and RQ3 explore altitude and speed, whose weak correlations suggest behaviour varies independently and must be compared across individuals and over time. Finally, the low correlation with direction highlights the need for temporal animation in RQ4 to fully interpret progression and pacing throughout the migration.

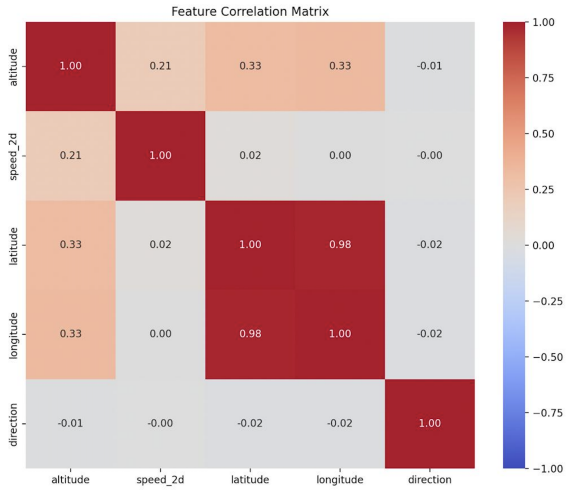

Figure 1: Correlation matrix of the variables

4 Visualization

In developing our visualizations, we focused on several key aspects to ensure clarity, usability, and meaningful insight. Each view was designed to highlight a different aspect of the data, allowing users to explore the dataset from multiple perspectives without redundancy. We maintained a consistent color scheme across all visual elements to support visual coherence and reduce cognitive load.

4.1 Visualization Goals

As spatial variables (latitude and longitude) are highly correlated, the data clearly reflects consistent, directional migration patterns. This supports RQ1, and our aim is to compare how these routes differ across birds using static and animated maps.

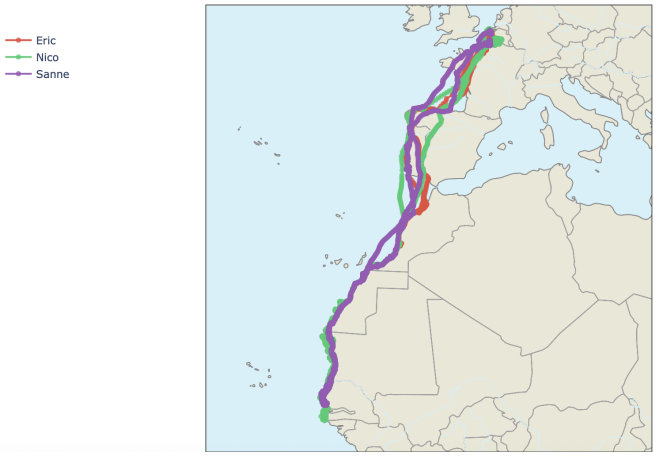

Figure 2: Static migration trajectories of the three seagulls, shown without temporal information

Altitude shows modest relationships with spatial dimensions, while speed is largely uncorrelated with other features. This independence justifies the examination of altitude and speed as behavioral characteris-

tics among birds, which form the basis for the comparative bar chart related to RQ2.

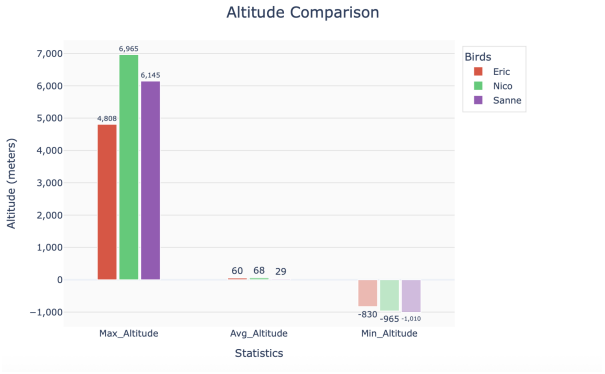

Figure 3: Altitude comparison across the three birds.

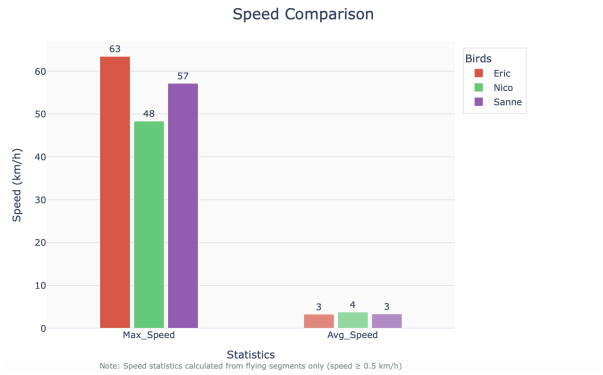

Figure 4: Speed comparison across the three birds.

Figure 5: Frequency of rest stops for each bird during migration.

Since altitude and speed do not show strong linear correlations with latitude, longitude, or direction, their behavior must be understood through temporal changes rather than spatial associations. This supports RQ3, and for answering it, we focus on time-based line charts to reveal behavioral evolution during migration.

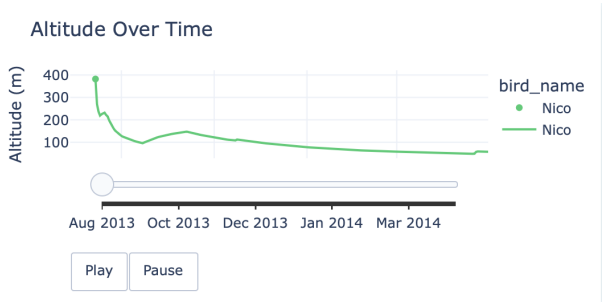

Figure 6: Animated line chart of Nico's flight altitude during migration, derived from timestamped observations and smoothed with rolling averages.

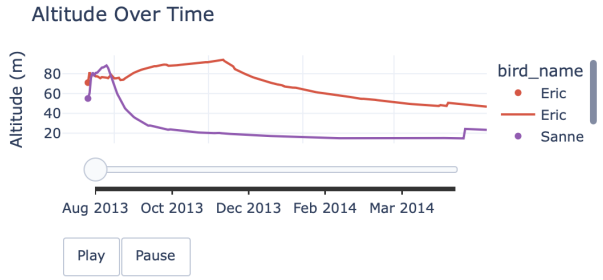

Figure 7: Animated line chart of Eric's and Sanne's flight altitude during migration, derived from timestamped observations and smoothed with rolling averages.

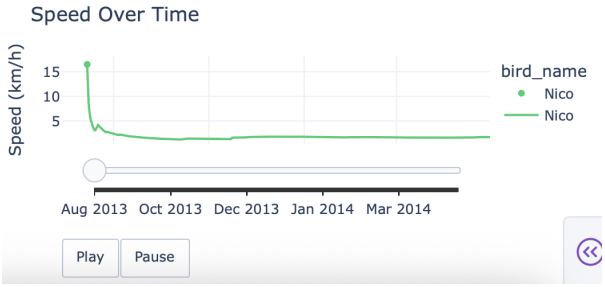

Figure 8: Animated line chart of Nico's flight speed during migration, derived from timestamped observations and smoothed with rolling averages.

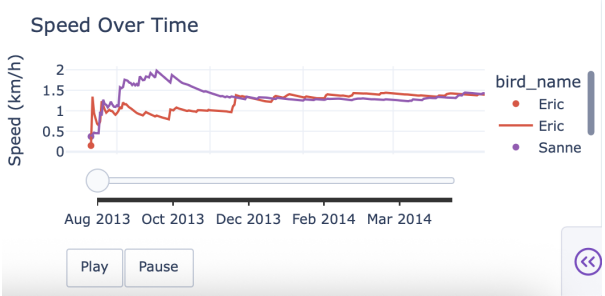

Figure 9: Animated line chart of Eric's and Sanne's flight speed during migration, derived from timestamped observations and smoothed with rolling averages.

Because direction and motion-related variables show minimal linear correlation with the spatial and temporal features, a time-based animation becomes essential to interpret migration and to answer RQ4.

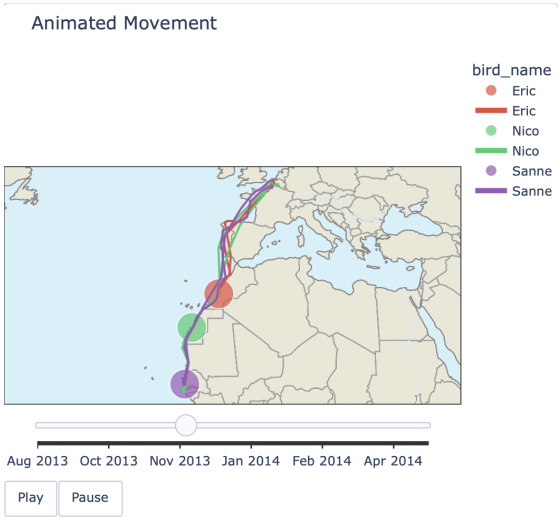

Figure 10: Animated migration trajectories of the three seagulls, using temporal information

4.2 Design and User Interaction

To support an intuitive and user-friendly experience, we incorporated several interactive elements into the dashboard. A fixed title banner provides consistent context as users navigate through the views. We included a fixed filter for selecting the bird species, ensuring that all visualizations update cohesively based on the user's choice. For the bar chart, we added category selectors that allow users to switch between different dimensions of the data. The animated map and line charts include a toggle switch and a play/pause button, enabling users to control the animation at their own pace. Together, these features enhance accessibility, improve ease of use, and give users flexible control over how they explore the data.

5 Evaluation of Findings

This section evaluates the results in relation to Research Questions 1 to 4, focusing on similarities and differences in migration trajectories, movement dynamics, and behavioral patterns among the three seagulls.

At first glance, the static migration trajectory map (Figure 2) suggests that the three birds follow broadly similar migration routes. However, incorporating temporal information into the movement modeling reveals substantial differences in their migration behavior. When accounting for timestamps, the trajectories diverge markedly: the birds initiate migration on different dates and utilize distinct stopover locations. These temporal and spatial discrepancies are clearly illustrated in the animated migration map and in (Figure 10). This indicates that, despite apparent spatial similarity in static representations, the birds migrate independently rather than as a coordinated group.

Comparative analysis of movement metrics shows that the three birds exhibit similar average flight speeds. In contrast, notable differences are observed in average flight altitude and resting behavior. Sanne flies at approximately half the average altitude of Nico and Eric, while Eric exhibits the highest number of rest stops during migration. These differences are summarized in (Figures 3, 4 and 5).

Further insights are provided by the animated line charts addressing how altitude and speed evolve throughout each bird's journey. In particular, Nico operates on a substantially different scale during the initial phases of migration, both in terms of altitude and speed, compared to the other two birds. In contrast, Eric and Sanne display more comparable patterns across these variables over time. These trends are illustrated in (Figures 6, 7, 8 and 9).

Overall, the findings suggest that although the birds belong to the same species, their migration behaviors differ considerably. The observed variation in timing, altitude, speed dynamics, and rest patterns points to individual-specific migration strategies, highlighting the role of behavioral variability—or "individuality"—within the species.

6 Conclusion

Our analysis demonstrates that even within a single species, individual birds can exhibit markedly different migration patterns in terms of timing, altitude, speed, and rest behavior. These findings highlight the importance of considering individual variability when studying migration, rather than relying solely on aggregated data. The modeling approach presented here is flexible: it can be directly applied to additional individuals within the same species, and with minor adaptations, it could be extended to birds of other species. Furthermore, the framework can easily incorporate additional features—such as weather, wind, or habitat data—allowing deeper exploration of the ecological and behavioral factors driving migration. Overall, this study provides both methodological tools and biological insights that can enhance understanding of avian migration at multiple scales.

References

[1] Shamoun-Baranes J, Farnsworth A, Aelterman B, Alves JA, Azijn K, Bernstein G, Branco S, Desmet P, Dokter AM, Horton K, Kelling S, Kelly JF, Leijnse H, Rong J, Sheldon D, Van den Broeck W, Van Den Meersche JK, Van Doren BM, van Gasteren H. *Innovative Visualizations Shed Light on Avian Nocturnal Migration.* PLoS One. 2016 Aug 24;11(8):e0160106. doi: 10.1371/journal.pone.0160106. PMID: 27557096; PMCID: PMC4996449.

[2] National Geographic Society, *Interactive Map: See How Birds Migrate Throughout the Western Hemisphere*, 2025. Available at `https://www.nationalgeographic.com/magazine/graphics/bird-migration-interactive-maps` (accessed 2025-11-06).

[3] Bart Hoekstra, Bart Kranstauber, Maja Bradarić, Johannes De Groeve, Stacy Shinneman, Berend C. Wijers, Hidde Leijnse, Hans van Gasteren, Adriaan M. Dokter, Emiel van Loon, Judy Shamoun-Baranes, Large-scale mapping of nocturnal bird migration to accelerate a nature-inclusive energy transition, Journal of Environmental Management, Volume 395, 2025, 127753, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2025.127753. (https://www.sciencedirect.com/science/article/pii/S0301479725037296)