

## STSM Report

# Implementation of a visualization tool used for understanding and communicating complexity of bird behaviour related to different influencing factors

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## 1. INTRODUCTION

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This is the report relative to the Short Term Scientific Mission (STSM) of Annika Aurbach (Laboratory of Energy Conversion, Swiss Federal Institute of Technology (ETHZ) and Swiss Ornithological Institute (SOI)) in the COST Action ES1305 (European Network for Radar surveillance of Animal Movement, ENRAM) under Working Group 3: Visualizing Spatio-temporal Patterns of Animal Movement.

**Host instruction:** Dr. Judy Shamoun-Baranes and Dr. Adriaan Doktor, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Amsterdam, The Netherland.

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### **Purpose:**

Bird migration depends on a wide range of factors that have different temporal and spatial variations. In my research, which is jointly supervised by ETHZ and SOI, I am developing an explicit forecast model of bird migration. A mesoscale weather simulation model is used to simulate the wind field with high temporal and spatial resolution. The migration of the birds in the simulated wind field is modeled from the numerical integration of the velocity in the Eulerian frame of reference. At each integration step the behaviour of birds is modeled. In this STSM exchange I implemented a new method of data visualization, as visualizations can help to provide more detailed insight and to improve our understanding of the complex behaviour of migratory birds. In particular I focused on showing how birds may ascend different and may fly at different heights in relation to topography.

### **Tasks:**

- Implementation of visualization tools for simulated bird migration
- Assessment of different bird behaviour models
- Comparison of bird behaviour in complex and flat terrains

### **Comparison of Visualization Tools**

To obtain a useful visualization tool, two different software (CartoDB and MATLAB) have been compared. CartoDB is a platform to perform analysis of GIS data and data visualization. Accounts are free up to a certain size and users can upload their own data or make use of open source data for their analysis. With SQL Server the data structure can be modified. Cascading Style Sheets (CSS) can be used for changing built-in functions to meet the needs of a specific user. I used CartoDB as

the group of Dr. Judy Shamoun-Baranes uses CartoDB for the visualization of GPS-tracking data of birds (Bouten , Stienen 2014). The second software, MATLAB (**Matrix laboratory**), is a numerical computing environment and programming language (The MathWorks 2015). MATLAB has various packages and functions for visualization and one could create his/her individual visualization programme. To obtain such visualization, programming is required as, unlike CartoDB, there is not a userfriendly interface in MATLAB. Furthermore MATLAB is not available as freeware.

## **2. MATERIAL AND METHODS**

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### **Bird Migration Simulation as source for visualization**

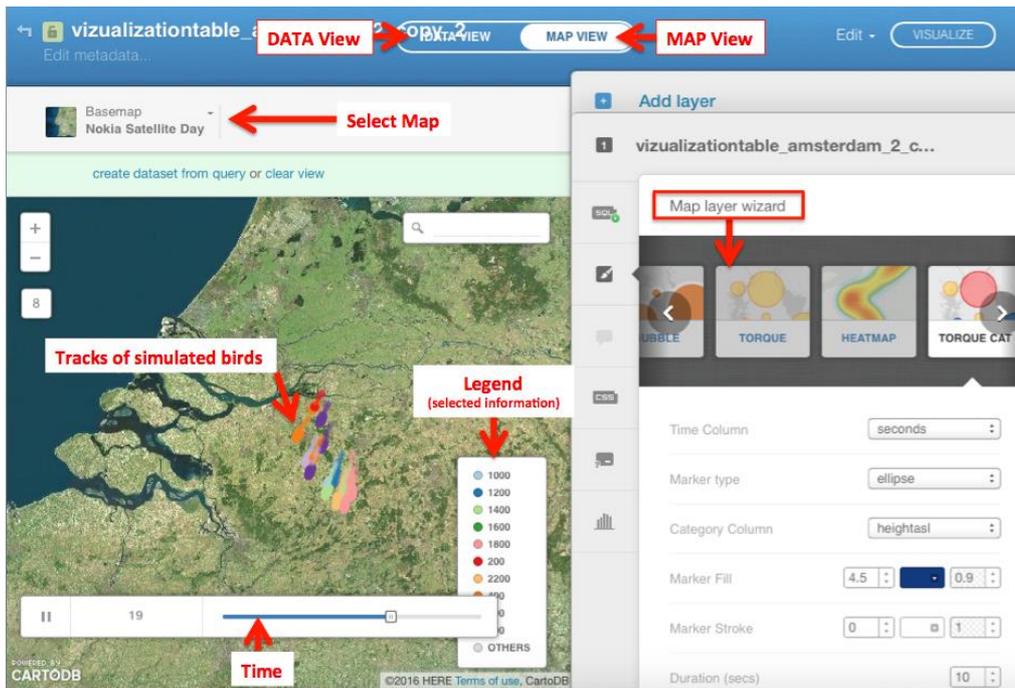
As input information for the different visualization approaches I used simulations of autumn bird migration that I have conducted in my research. In advance of the STSM bird migration simulations were conducted and post processed for Switzerland and Netherlands. The flights of 15 birds whose simulated flight started at different heights over the first 2000m AGL were simulated. In the case of Switzerland the simulated flights started within the Jura mountains and at De Bilt for the Netherland case.

Birds' flight path was simulated in a wind field obtained from mesoscale weather simulation (WRF 2010). The migration of simulated birds in the wind field is modeled from the numerical integration of the velocity in the Eulerian frame of reference. At each integration step the behaviour of birds is modeled and birds are tracked. A range of different bird behaviour models have been developed based on research on bird migration (Bruderer and Boldt 2001, Zehnder, Liechti et al. 2001, Erni et al. 2005, Liechti et al. 2005, Dokter et al. 2010, Liechti et al. 2010). The bird behaviour model that is used for the present visualization simulates birds that can adapt their flight altitude regarding wind in their target direction and that can also adapt their flight behaviour to avoid physical obstacles. The birds were simulated for a flight period of 11 h.

### **Visualization of Bird Migration**

#### **CartoDB**

In a first step the bird migration simulation data were reformatted: CartoDB requires information on longitude and latitude of each track point that are georeferenced in the EPSG:4326 (WGS 1984) coordinate system. I used information on flight height AGL and groundspeed. CartoDB applies spatial information on a chosen map (Fig. 1). Different map styles can be applied as well as different visualization tools in the Map Layer Wizard (i.e. Heatmap, Bubble, Torque (Animation), Category, etc.) to show information of each simulated birds. Modifications in the visualization tools were done via CSS to define color code, transparency of colors, graphical display of color and time resolution for animation tool (Torque Cat). I visualized the simulated autumn bird migration across the Netherlands in CartoDB showing flight height / groundspeed.



**Fig. 1: CartoDB platform. Map View. Left: Visualization of tracking data in time. Gives color on selected information (category). Right: Layers with properties and specifications.**

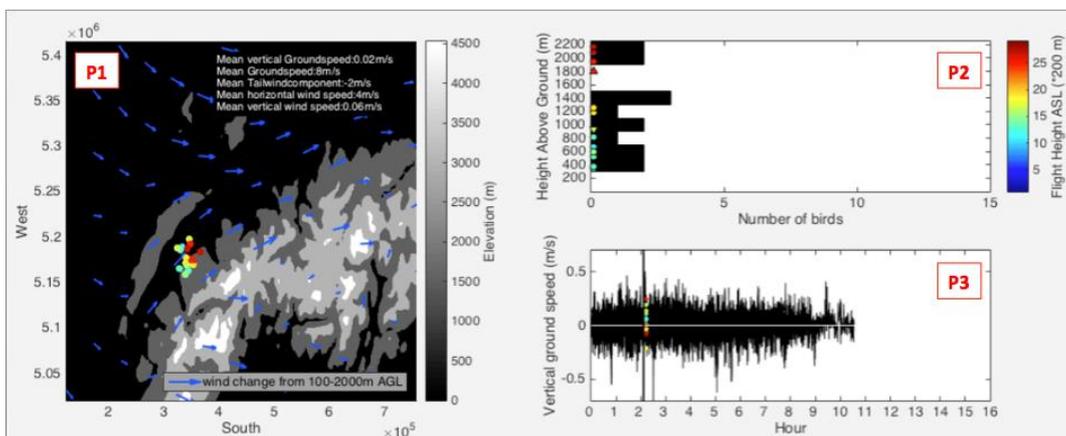
As CartoDB displays colors only for categories, a new variable “groundspeed\_category” was defined. Also for ‘flight height’ a similar procedure was done to obtain flight height categories for 200m height ranges.

Groundspeed (m/s)	0-2.5	2.5-5	5-7.5	7.5-10	10-12.5	12.5-15	>15
Groundspeed_category	1	2	3	4	5	6	7

**Table 1: Groundspeed\_categories**

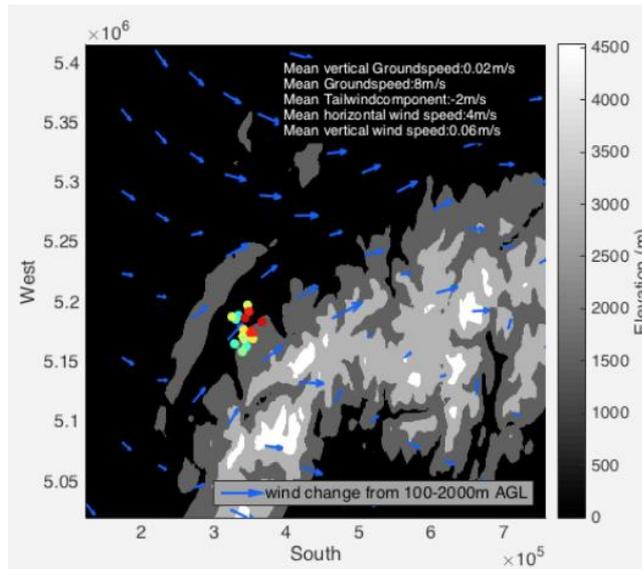
## **MATLAB**

I established a script to graphically show changes in bird behaviour over time and with respect to the spatial occurrence of birds. I focused on showing interactions between flight altitude, ascending/descending behaviour and spatial occurrence. The visualization is an animation of bird migration in time. Three plots (P1, P2, P3) are simultaneously displayed showing different aspects of the birds’ behaviour (Fig. 2). I visualized simulated autumn bird migration across Switzerland using MATLAB.



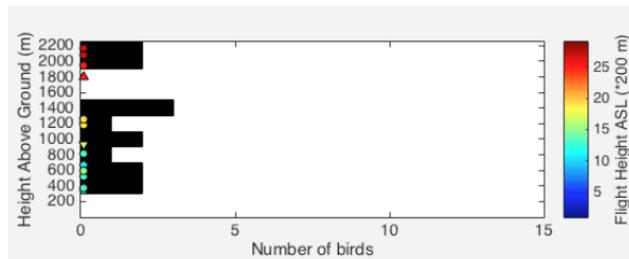
**Fig. 2: Visualization of Autumn Bird Migration Simulation using MATLAB.**

The first plot (Fig. 3, P1 left in Fig.2) shows the topography with the simulated wind field at a specified height. The wind field is uploaded for every simulated 5 min. Further information about the wind conditions at the birds' location is shown; These include mean vertical groundspeed, mean groundspeed, mean tailwind-component, mean horizontal wind speed and mean vertical wind speed. The simulated birds are displayed as colored symbols, in which the color gives information on previously specified bird behaviour (groundspeed (vertical/horizontal), airspeed (vertical/horizontal), flight height (AGL, ASL)). The colorbar is displayed at P2. The symbol provides information on ascending/descending behaviour (vertical groundspeed  $>0.2\text{m/s}$  "▲",  $<-0.2\text{m/s}$  "▼",  $-0.2\text{m/s} < \text{vertical groundspeed} >0.2\text{m/s}$  "●").



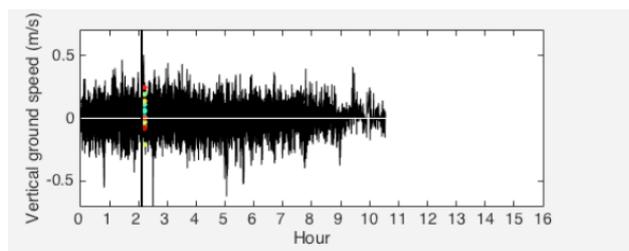
**Fig. 3: Topography map with windfield and spatial distribution of simulated birds. (P1)**

The second plot (Fig. 4, P2 right top in Fig. 2) shows number of birds per height AGL (with black colored bars at 200 m height intervals) for each timestep. The colored symbols correspond to the simulated birds shown in P1.



**Fig. 4: Vertical profile of bird abundance AGL. (P2)**

The third plot (Fig. 5, P3 right bottom in Fig. 2) displays the time series of the vertical groundspeed. As above the colored symbols indicate the simulated birds shown for each timestep. A vertical line shows the observation time.

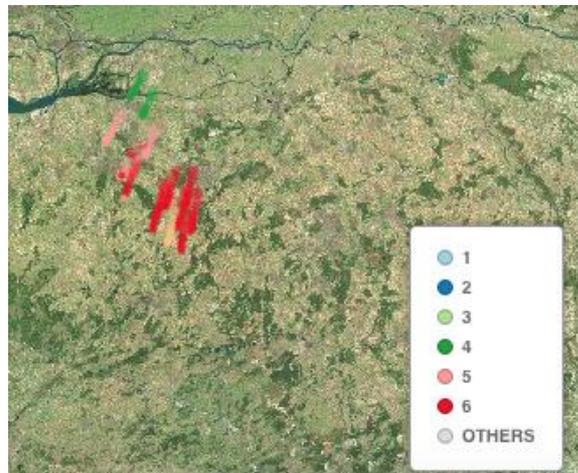


**Fig. 5: Change of vertical groundspeed in time. (P3)**

### 3. RESULTS AND DISCUSSION

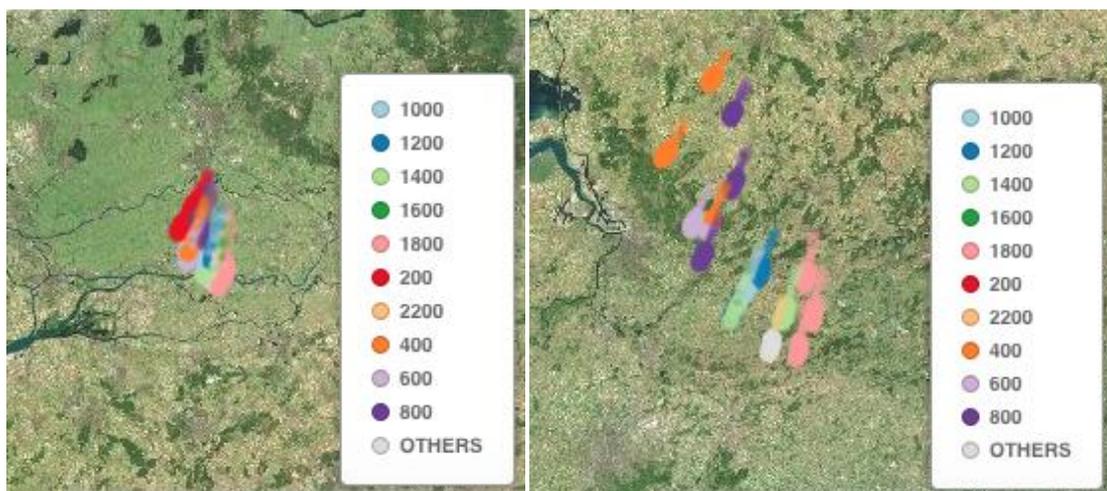
#### CartoDB

CartoDB shows simulated bird migration across Netherlands (Fig. 6). The visualization displays color of simulated birds for groundspeed\_category. Most simulated birds fly in their target direction and at high groundspeeds. We can assume that there are favorable winds in the target direction, as the groundspeed of most simulated birds was higher than 12 m/s, which was set as maximum possible groundspeed for simulated birds.



**Fig. 6: Visualization of autumn bird migration simulation across Netherlands in CartoDB. Legend shows categories of groundspeed of simulated birds.**

The visualization does not show the wind field, as the wind field information was too huge to be uploaded in the free CartoDB-Account. The map gives information on occurrence of water bodies and greenness, but doesn't show topographical features. As there is no possibility to show information on flight height in the same picture, another visualization on flight height information was performed; this shows that birds slightly ascend with time (Fig. 7).

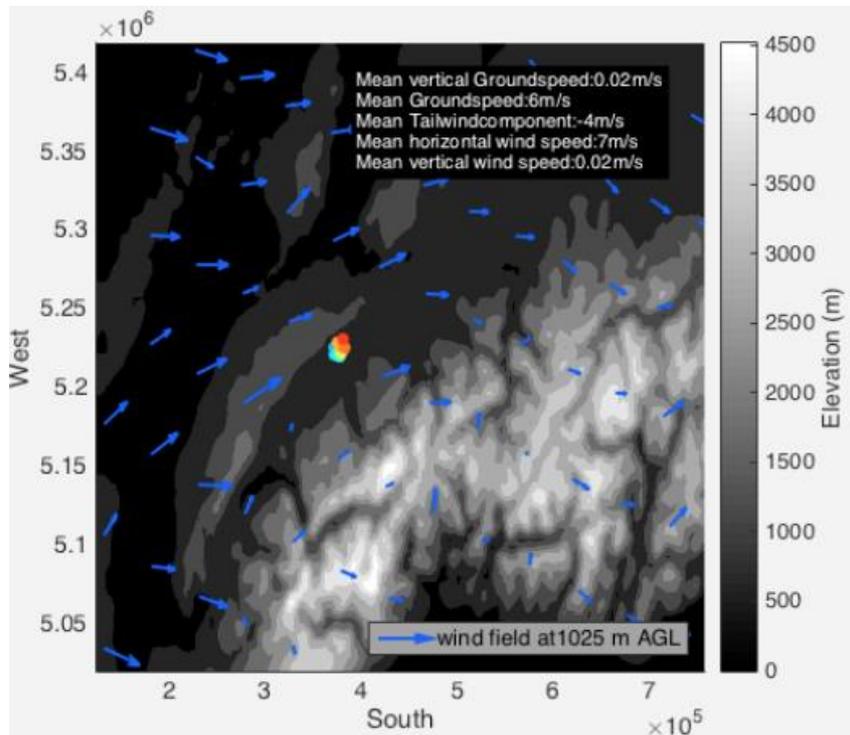


**Fig. 7: left: Simulated autumn bird migration after ~0.5 h showing birds at all flight altitudes ASL. Right: after ~5 h low flying birds ascended while generally birds kept flight height.**

## MATLAB

The visualization showed that simulated birds adapt their flight behaviour to wind conditions in order to fly in the target direction as well as a change in behaviour of adapting flight height or/and changing direction in regards to obstacles. When an obstacle is encountered, simulated birds slow down and adapt their flight direction and/or vertical flight behaviour to avoid the obstacle. Simulated birds released at high altitudes and thus flying in stronger winds are pushed more quickly towards the Alps, and thus are forced to fly over the Alps. Simulated birds flying at low heights were only slightly pushed towards the Alps and could follow their target direction.

Time: ~25 min. Migrating birds encounter a head wind condition as seen from the wind arrows and summary information (mean horizontal wind speed: 7 m/s; mean tailwind-component: -4m/s), while at higher altitudes the wind speed is faster and blows in a more northerly directions (Fig. 8a). Furthermore birds encounter a slightly upward wind (mean vertical wind speed: 0.02 m/s).



**Fig. 8a: Simulated autumn bird migration after ~25min.**

The heights of the simulated birds' flight cover the complete range as that when the birds' simulated flight was started (Fig. 8b: Plot on top). The third figure (Fig. 8b: Plot on bottom) shows that birds explore different flight altitudes but try to proceed horizontally with smaller changes in vertical height. Birds flying at higher altitudes encounter stronger winds (also the vertical wind speeds were larger at higher altitudes) such that birds at high altitudes ascend more than birds at low altitudes. Simulated birds' groundspeed is 6 m/s.

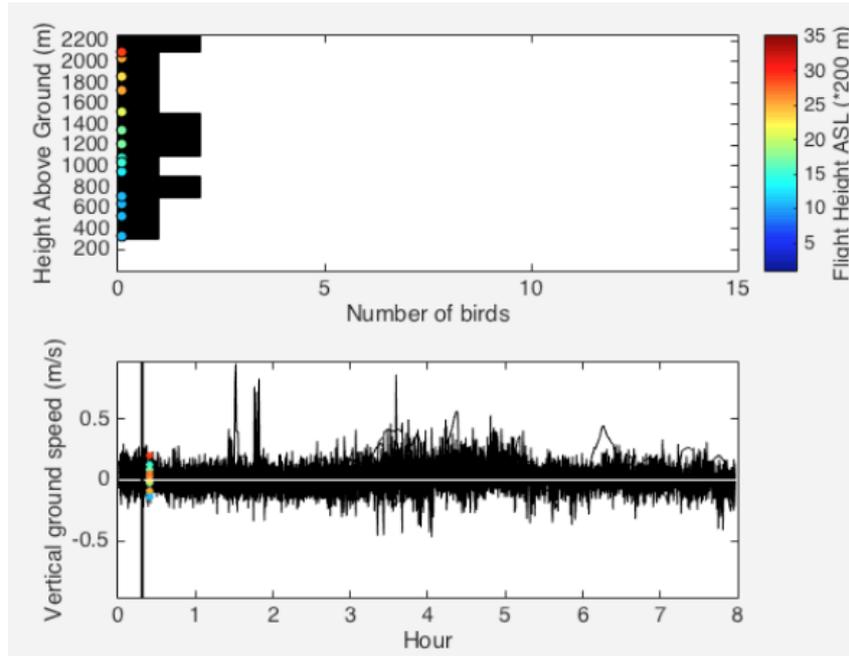


Fig. 8b: Simulated autumn bird migration after ~25min.

Time: ~4 h. After 4 hours the simulated birds are pushed towards the foothills of the Alps, while the wind conditions have not changed considerably (mean horizontal wind speed: 7 m/s; mean tailwind-component: -4m/s, vertical wind speed: 0.03 m/s) (Fig. 9a). Birds' ground speed is much less than before (5 m/s) which shows simulated birds have changed their flight behaviour. This is due to the topography as simulated birds encountered obstacles (Alpine mountain structures) in their flight direction and thus adapted their flight behaviour to those obstacles.

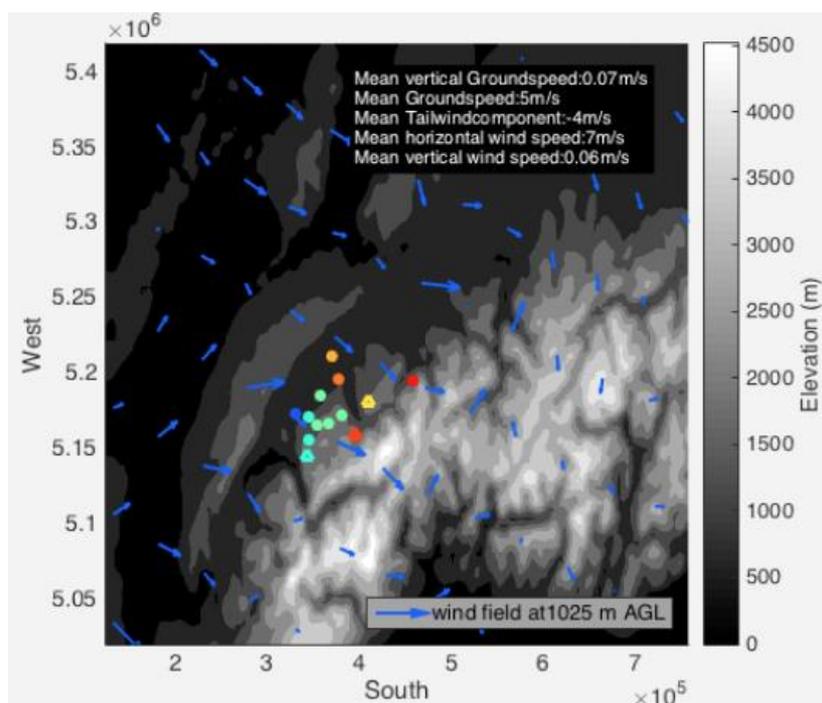
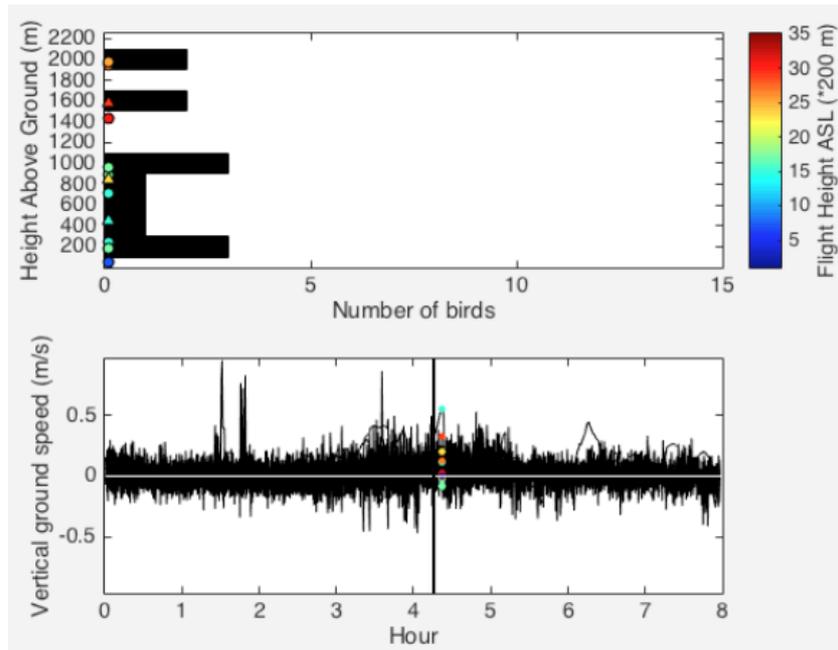


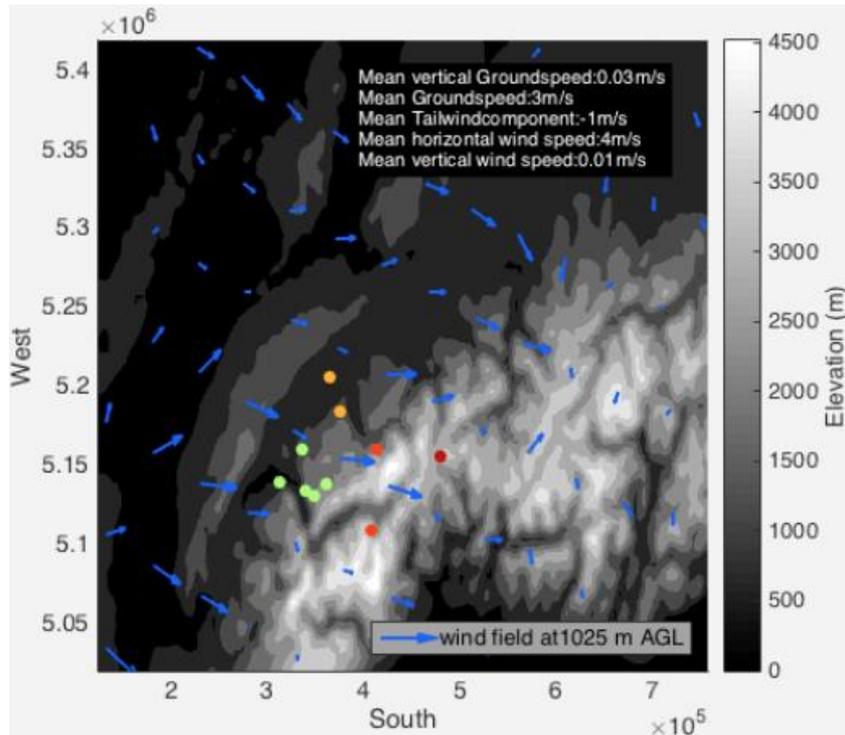
Fig. 9a: Simulated autumn bird migration after ~4h.



**Fig. 9b: Simulated autumn bird migration after ~4h.**

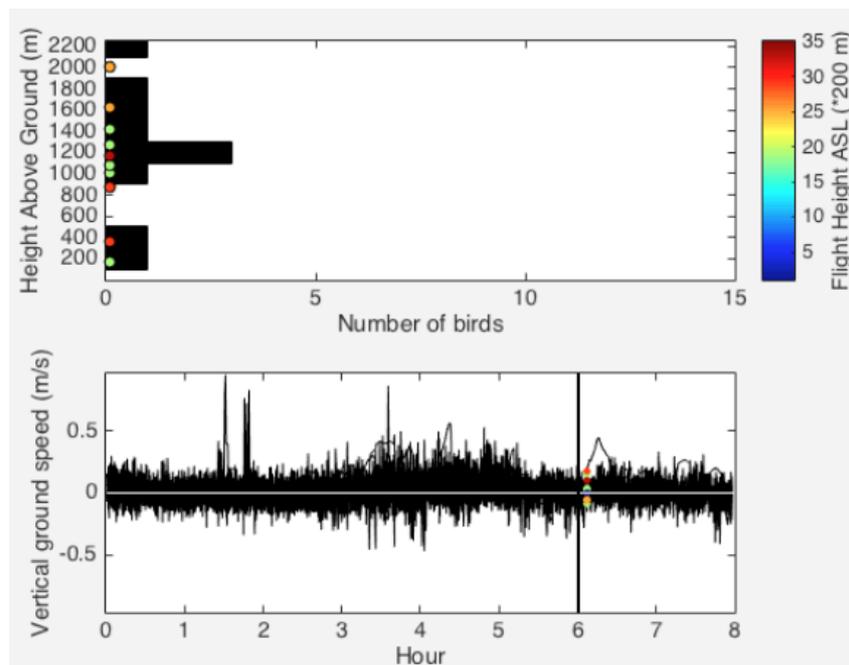
The second figure (Fig. 9b: Plot on top) shows that the ‘green birds’ at the foothills of the Alps fly at low altitudes AGL and accordingly these birds need to ascend more quickly as demonstrated in the third figure (Fig. 9b: Plot on bottom). Those birds are ascending as their vertical groundspeed is positive and compared to the first hours, when birds fly over lowland area, also relatively higher. Generally the vertical groundspeed is increased when the birds need to avoid obstacles.

Time: 6 h. After 6 hours of flight wind conditions are more favorable while simulated birds still have to deal with headwind conditions (Fig. 10). Wind speed decreased to 4 m/s with a tailwind-component of -1 m/s and only slightly ascending winds (0.01 m/s). Most of the birds were pushed towards the Alps while when studied in detail, only birds released at high altitudes need to cross the Alps and birds released at low altitudes could follow the lowland towards their target direction.



**Fig. 10a: Simulated autumn bird migration after 6 h.**

Most of the simulated birds fly at ~2000 m ASL while the flight height AGL of the migrating birds shifted slightly towards higher altitudes which can be explained by their ascending behaviour when encountering the Alps (Fig. 10b: Plot on top). As the birds ascend and are mostly flying at heights without obstacles, their ascending behaviour is again relatively calm (Fig. 10b: Plot on bottom). Only one simulated bird (red) crosses the Alps and has to ascend in order to avoid the mountains in its flight direction.



**Fig. 10b: Simulated autumn bird migration after 6 h.**

The video visualization which was created using MATLAB, shows that simulated birds which encounter the Alps slow down as they adapt their flight direction and/or flight altitude.

A comparison of bird migration across Netherlands and Switzerland shows great differences, as birds are not forced to react to obstacles in Netherlands and therefore could continue in their target direction S SW.

## 4. CONCLUSIONS

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**CartoDB** is an internet-platform with a very user-friendly interface and enables free usage until a certain amount of data volume, while **MATLAB** is a programming language and no freeware is available. Still, visualization of bird migration, which shows highly complex changes in birds' behaviour related to various factors, is limited when using CartoDB. The main reason why I switched to programming a visualization tool in MATLAB is due to the limitation of showing changes in the heights of flight with CartoDB as well as showing different relationships at the same time. CartoDB is a very useful tool if someone would like to quickly follow tracking data in time. However, for studying bird behaviour in more detail it is advantageous to analyze different relationships graphically changing with time, which was obtained by establishing a MATLAB programme on visualization of bird migration.

The first approach of the MATLAB visualization programme shows bird behaviour over time and with respect to the spatial (vertical and horizontal) occurrence of birds. It provides information on elevation, shows the simulated wind field at a specified altitude AGL as well as further information on wind birds' encountered. The use of color-coded symbols gives information on specified bird behaviour. Such a visualization tool could be beneficial for investigation of animal movements in more detail as well as communicating movement patterns to other parties.

## 5. ACKNOWLEDGEMENTS

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