Assessing the Influence of Wind on Movement Behavior of Migrating Birds: A Case Study of White Fronted Goose

GROUP 2

Final Project Report

MEMBERS

Alexys Rodríguez (500434), Annette Achieng (500409), Hassan Omar (500420), Senait Meles (500424), Somnath Chaudhuri (500441)

SUPERVISOR

Dr. Judith Verstegen

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1. Introduction

Speed and movement behavior of migratory birds depends on a number of environmental factors including temperature, seasonal variations, wind, among others (Vidal-Mateo et al., 2016). In all of these factors, wind is considered to be the most significant aspect determining bird's behaviors in every stages of their migration (Klaassen et al., 2011). It determines the flying speed, direction, flight pattern and even the selection of flight altitude (Kemp, 2010). In that sense, the need of understanding the relationship between wind components and movement behavior of the bird is crucial (Alerstam, 1979). This will provide a clear overview regarding the bird's migratory performance and ability to reach their destination. Thus, help in raising awareness on the threats faced by migratory birds relative to the wind conditions, as well as understanding on what effort does international cooperation should take to conserve and protect them (Alerstam, 1979).
The (Greater) white-fronted Goose (*Anser Albifrons Albifrons*) is a bird species that originates from the Arctic Tundra, breeds in areas surrounding the North Pole and winters in Europe and Southwestern Asia. The birds regularly shift between different sites in these areas, using a wide range of migratory routes which are not always the shortest connection between any two particular areas (Shamoun et al., 2003). These geese are found to have two distinct types of migration seasons, the spring migration which is typically from Netherland to the east, and the late northeast migration involved from Kolguev Island to Novaya Zemlya (Kölzsch et al., 2008). The flight path of the geese is highlighted in Figure 1.1 below.

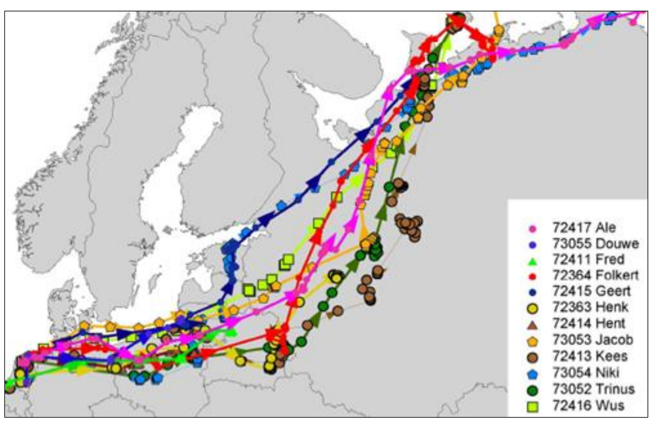


Figure 1.1. Flight path of the European white fronted Goose (Reference)

By considering the initial tracking of these geese, it has been observed that their migration patterns contain a number of short-term briefings depending on their flight distances and seasons. For example, for those involving in a long-distances flight, they spread up with 10 to 30 days long term breaks to retain their weight and health (Klaassen et al., 2011). On the other hand, in spring migration, the geese use multiple stopover sites during that period (Kruckenberg et al., 2006).This stopover can be determined with two step process. First the boundary between their resting sites and maximum hunting distances can be identified by considering the clusters of consecutive places where an individual bird did not move more than 30 km between pairs of positions (Kruckenberg et al., 2006), if the bird stayed in this region for at least 48 hours, then it is considered that they are in stopover sites. Alternatively, a return in this boundary within 8 hrs. of flight is also considered as a part of the same stopover. About to the flight altitude in relation to flight speed, the geese considered to have two flight categories (Buchin et al., 2006). The local flight (made in altitudes of less than 100m and at speeds of 10-50 km/hr.), and the migration flights which made at the altitude of above 100 -1000 m, this migration flight is accompanied with speed of greater than 50km/h. In all of these two flight categories the average flight altitude is agreed to be 400mts (Buchin et al., 2006). In general, the trend of flight speed seems to be proportionally increases with increase in flight altitude (Kruckenberg et al., 2006).

The current study used data from Movebank. It is an open portal system which allows users to manage (store, visualize, download) data related to animal tracking. In addition, it allows to annotate (download) a huge amount of environmental variables from multiple online weather and environmental web portals (Dodge et al., 2013).

The study is focused to assess the influence of wind on movement behavior of migrating birds. The project initiated by reviewing related literatures to understand their ecological conditions and habitats for feeding, breeding and raising. We went deeper to understand their flight speed in relation to the wind speed, considering other factor like migration season, and different stages of the migration trajectory.

2. Research Questions

How does the wind speed influence the movement behavior of individual migratory birds? According to the literature review, it is important to consider a subset of the dataset taking into consideration that not in all the stages of the bird movements it is possible to relate wind and bird velocity, because the tracked paths not only include the actual migration of the bird. To further investigate our research question it is required to consider the velocity of the bird, time of migration (for instance season), type of wind affecting the movement of the bird, and other possible conditions that can be identified during the analysis phase of the methodology. Thus it is possible to frame few potential sub-questions:

What is the threshold velocity of the bird to identify actual migration?

Which time period is optimum to analyze the relation between the velocity of wind and bird?

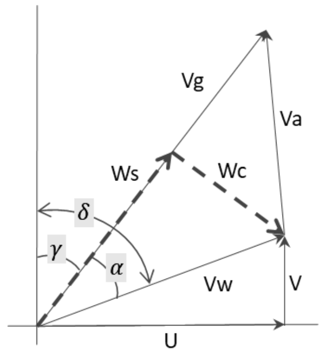
3. Methodology

To answer the research questions mentioned above, we divided our workflow in four main steps. To answer the research questions mentioned above, we divided our workflow in four main steps. The main components are literature review, input data and data preprocessing, tool design and implementation, and output data for analysis, to get the results organized by scenarios, as files inside folders, and attribute tables and vectors inside a geographic database. Then with all the results a suitable model was identified to answer the research question. The detailed workflow structure is depicted in Figure 3.1.

Figure 3.1. Methodological proposal

3.1 Literature Review

Literature review allowed to formulate a research question to explore the relationship between wind speed and the speed of the birds when they are migrating, next following (Dodge et al., 2013) a theoretical model was structured to deal with the aim of the research. Then a statistical model was designed to validate and test if the variables in the theoretical model can confirm or deny the research question. In Figure 3.2 the vector Va appears by vector subtracting Vg and Vw, and is called the air speed of the bird. Va represents the speed of the bird when there is no cross wind and wind support.



Vg: Ground speed of the bird

U: Component west-east of wind speed

V: Component south-north of wind speed

Vw: Speed of the wind.

$$Vw = \sqrt{(U^2 + V^2)}$$

Wc: Cross wind.

$$Wc = Vw * \text{Sin}\, \alpha$$

Ws: Wind support.

$$Ws = Vw * \text{Cos}\, \alpha$$

Va: Air speed of the bird

$$Va = \sqrt{((Vg - Ws)^2 + Wc^2)}$$

Figure 3.2. Theoretical Model adapted from *(Dodge et al., 2013)*

The statistical model formulates a linear regression using the method ordinary least squares and raises Vg as an independent variable, and Ws, Wc, and the interaction term of Ws and Wc as independent variables. In Equation 1, Va represents the intercept of the linear model, so the predicted intercept need to be close to the average of actual Va calculated using the dataset. C1, C2 and C3 are the coefficients of the regression model.

$$Vg = Va + C1 * Ws + C2 * Wc + C3 * Ws * Wc$$

Equation 1. Linear regression model from *(Dodge et al., 2013)*

According to (Safi et al., 2013) the median airspeed (Va) under no wind condition was recorded as 15.98 mts/sec. The stability of the deviance in the proposed statistical model used in the referred research work is established by calculating the R square value against the estimated intercept (Va). This helps in identifying the threshold value of the ground speed (Vg) to filter out stationary locations of the birds. The threshold value of Vg is found to be greater than 4 m/s with a consistent R square value of 0.45.

3.2 Input Data and Data preprocessing

The provided original dataset, *White-fronted goose full year tracks 2006-2010 Alterra IWWR* (Kölzsch et al., 2008) contains a series of variables including time-stamp, latitude and longitude of *seven* GPS tracked birds' migratory path. It was necessary to compliment it using the annotation service of Movebank. From there data related to horizontal (U) and vertical (V) component of the wind was obtained for each point in the dataset, whose original source was European Center for Mid-range Weather Forecast (ECMWF), but using an average height of 400 mts, due to lack of elevation information in the GPS track. The value of 400 mts. to annotate wind was selected based on the average height of migrating flight of *the white-fronted goose* described in (Kruckenberg, 2006). In order to calculate Vw, Ws, Wc, Vg, and Va using the theoretical model, the proposed schema in Figure 3.3 was used. All the variables were calculated between each consecutive points in the tracked dataset. For angles between local distances the Web Mercator Projection (EPSG: 3857) was used. For the flying distances "great circle distance" calculations were used using R package "sf" (Pebesma, 2018).

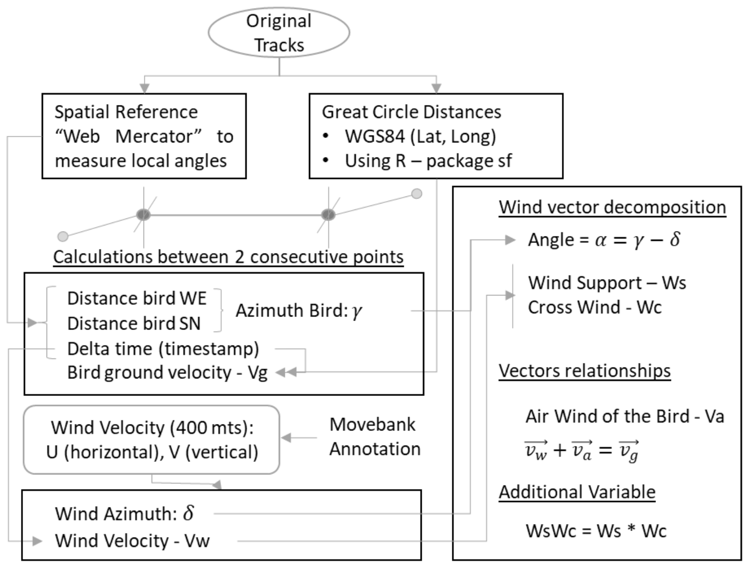


Figure 3.3. Input data and data preprocessing

3.3 Tool Design and Implementation

Literature review gave the main concept of the tool: the filters. Because the tracked files include all the stages of the movements (breeding, feeding, migrating, staging sites for refueling or wintering), and as our main objective were only those points where the birds were not stepping over (stepping-stone sites), this is, flying with the purpose to migrate to its destination. The first step to design the tool was to allow the user to define scenarios of analysis based in the use of filters. The final user can create filters by birds (choose the bird or group of birds to analyze), time or distance (choose an initial and final time or distance to restrict the analysis only to that range), and attributes (specific values inside the database using a query type SQL *where* clause). Filters by time and distance are based on dynamic segmentation and linear referencing ("ESRI ArcGIS Pro", 2018) and (Cadkin, 2002). After filtering, exploratory data analysis as graphics and basic summary statistics are created and stored as files (csv, png and txt) in the computer file system. Finally, the linear regression analysis result is generated and saved to the file system in PDF format and as vectors and attribute tables inside the file geodatabase. The tool was deployed using *Python 3.6 in ArcGIS Pro*, and allows the user to change all the inputs for the analysis. However, there is not yet a detailed user manual, no automatic input validation of user input parameters, and the code does not have an appropriate structure to control data errors and failures due to incorrect input of parameters. Refer to *Appendix 1* for the Python Script functions and *Appendix 3* for the System Manual Documents and *Appendix 5* for the Zipped Python codes and the Tool.

3.4 Output Data: Scenario based

Once the tool was implemented, the first scenario was executed (all birds, all times, and all attributes), then the exploratory data analysis was done with the resulting graphics and basic statistics files, the statistical results depicts the need to use filters to improve the model. Then a complete series of scenarios were executed, based on the combination of different times (all, spring, spring-autumn) and different attributes (all, tail wind, head wind and bird speed minimum value). Criteria used to evaluate the robustness and validity of the scenarios were: a) similarity between the calculated intercept and the mean of Va, b) similarity of Vg threshold with literature review, for instance greater than 50 km/hr. (Kruckenberg, 2006), c) number of points after filters as input for linear regression method, d) adjusted R-square, and e) significance of variables (p-value).

4. Results

Initial analysis is performed to identify the relationship between ground velocities of the geese (Vg) and the two components of the wind speed namely, Wind Support (Ws) and Cross wind (Wc). The data set used in this case contains all the seven geese with a time span of one year which includes all non-null values of Ws and Vg. Figure 4.1 depicts the seasonal variation of Vg with emphasis on the mean velocities of individual birds. It is obvious from the higher Vg mean value that the geese have two distinct phases of migration, one during the spring and the other during autumn.

According to the proposed regression model (Equation 1), the dependent variable is Vg and the explanatory variables are Ws, Wc and an interaction term of both Ws and Wc as (WsWc). But the model has a low R-Squared value (0.000694) see

Table 4-1. It suggests that the proposed regression model is not statistically significant. That implies, the explanatory variables (Ws, Wc and WsWc) are contributing little to the explanation of the dependent variable (Vg).

As mentioned in section 3.4 the filter operation was required to examine further. To filter out the stationary locations of the geese, the points having Vg value higher than 4 mts./sec are only considered in the following analysis process (Safi et al., 2013). Similarly, Figure 4.1 intrigues the seasonal filtering of the dataset as there is a significant difference between the mean Vg in different seasons. Another important parameter is direction of Ws. Ws having positive values are called “tail wind” and the negative values are usually referred as “head wind”. So, to answer our research question we need to investigate further with some filtered parameters and with certain threshold value ranges of the variables. As discussed earlier about the filter parameters of previous research works and based upon the initial analysis results we identified the threshold values of Vg and head or, tail wind and particular seasons that can have a significant effect on the regression model. The regression analysis was performed for *32 different scenarios* having unique combinations of filtered parameters.

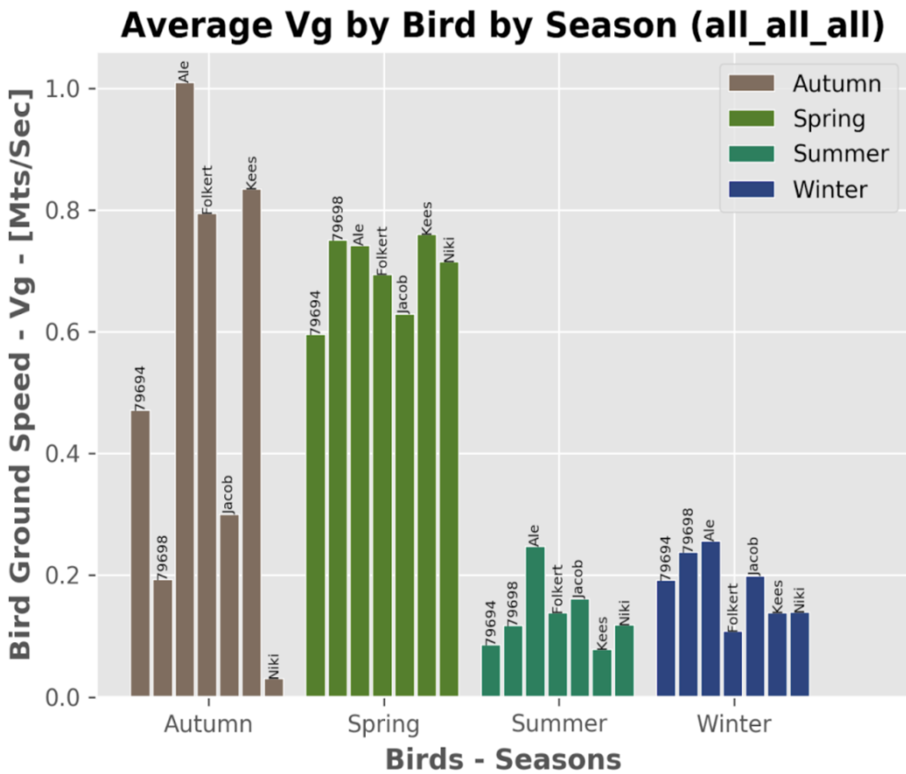


Figure 4.1. Mean ground speed of individual tracked white fronted goose categorized by season

Most of the results were found to be insignificant in terms of R-square value or p-value of the explanatory variables. Five relatively significant combinations and the initial un-filtered dataset with their respective regression analysis results are depicted in Table 4.1. In context to our research question the dependent variable in each case is Vg.

Table 4-1. Statistical Significance Comparison Table for Filtered Dataset

Scenario Name	Filters		Adj. R-square	Va (mean)	Intercept	Sig. p-value
all_all_all	Birds	**All**	0.000694	18.196	0.433274	**Ws (0.023)**
	Time/Distance	**None**				
	Attributes	**None**				
all_all_tailvg8	Birds	**All**	0.160281	24.831	15.62916	**None**
	Time/Distance	**None**				
	Attributes	**vg_mtss_gcd > 8** **Ws > 0**				
all_all_tailvg14	Birds	**All**	0.102926	28.525	19.00933	**Wc (0.04)** **WcWs (0.04)**
	Time/Distance	**None**				
	Attributes	**vg_mtss_gcd > 14** **Ws > 0**				
all_spring_tailvg10	Birds	**All**	0.243232	23.869	16.94552	**None**
	Time/Distance	**Spring**				
	Attributes	**vg_mtss_gcd > 10** **Ws > 0**				

Scenario Name	Filters		Adj. R-square	Va (mean)	Intercept	Sig. p-value
all_spring_tailvg13	Birds	**All**	0.124556	25.907	16.73588	**None**
	Time/Distance	**Spring**				
	Attributes	**vg_mtss_gcd > 13** **Ws > 0**				
all_springautumn_tailvg14	Birds	**All**	0.152616	27.301	19.416282	**None**
	Time/Distance	**Spring, Autumn**				
	Attributes	**vg_mtss_gcd > 14** **Ws > 0**				

From the following table, it is found that scenario ***all_all_tailvg14*** only has significant Wc and interaction term WsWc. The low p-value (0.04 < 0.05) for both the variables in this case indicates the rejection of the null hypothesis and implies that Wc and WsWc is likely to be a meaningful addition to the model (Siegel, 2012). To establish the fact we conducted further statistical analysis on this particular scenario. Figure 4.2 shows the scatterplots for each explanatory variable and the dependent variable. The plot does not depict any significant relationship between the dependent and explanatory variables. Similar interpretation can be drawn from the calculated correlation matrix, refer to *Appendix 6 (Output scenario results)*. It provides no significant relation of Vg with Wc (-0.09) and Vg with WsWc (0.15).

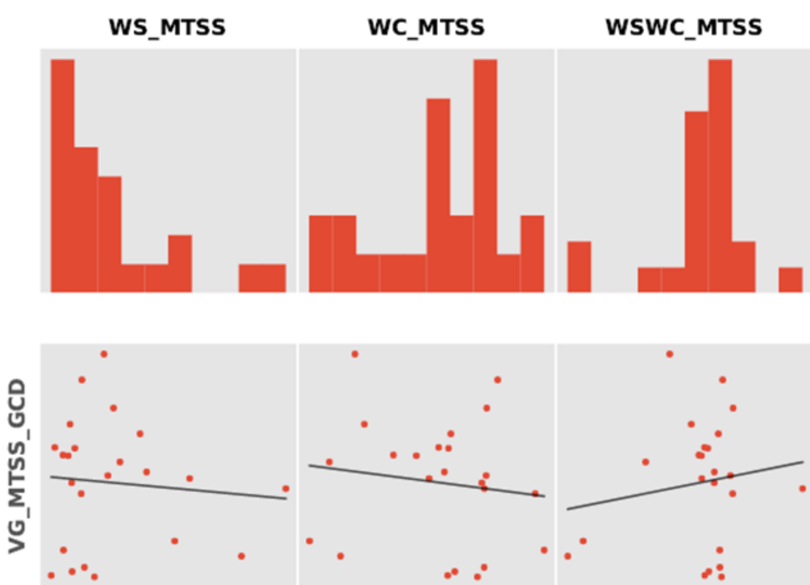


Figure 4.2. Scatter plot of ground speed of goose against explanatory variables

To further investigate the relationship between the model and the dependent variable Vg a standard residual graph is generated. Figure 4.3 depicts graph of residuals (model over and under predictions) with respect to the predicted Vg values. In this case, the random nature of the residual plot indicates a good fit for a linear model (Siegel, 2012).

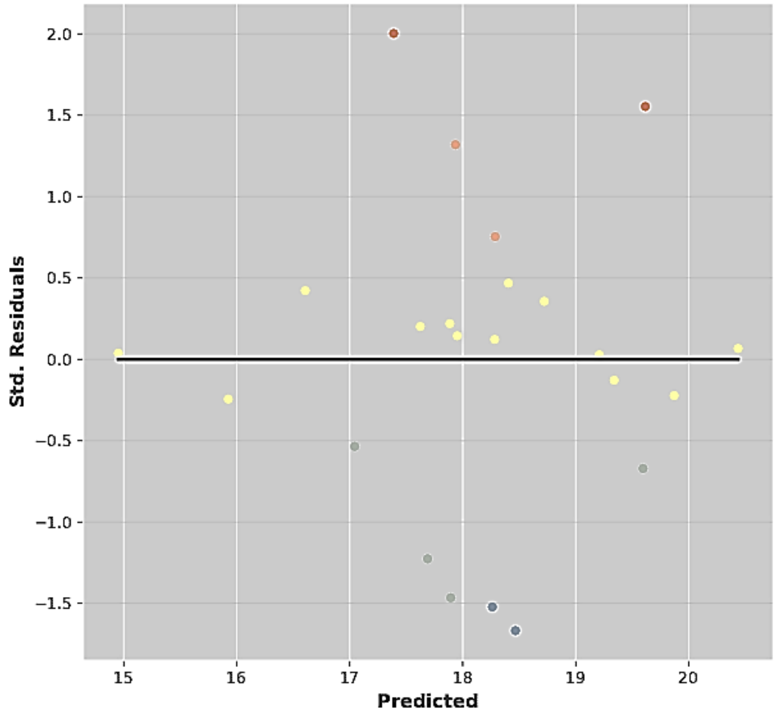


Figure 4.3. Standard residual plots of ground speed of goose

From the above results it can be concluded that the proposed regression model is significant when Vg is greater 14 mts./sec. Among the explanatory variable, Ws is contributing little to the explanation of the dependent variable (Vg). But Wc and WsWc are significant components in the model.

5. Discussions

The final conclusion related to the research question is, yes there exists linear relationship between the ground velocity (Vg) of the white fronted goose and the cross-wind component (Wc) of the wind. But it is not a significant relation as the correlation value for all the wind components are insignificant (less than 0.5) and the scatter plots do not provide any identification pattern of existing relationship. The answers for our potential sub-questions are, out of 32 different combinations the residual plot of only one set indicates a good fit for a linear model and the ground velocity considered in that case is 14 mts./sec. It can also be stated that though there is significant difference in the mean velocities of the goose in different seasons but season or, time do not play a significant role in identifying relationship between the velocity of the wind and the birds. Few important facts identified during the current study are discussed as follows:

Statistical results

One of the important reasons to get significant statistical results for correlation and linear regression between wind and bird velocity was the non-availability of the Z coordinate in the original dataset. This affected the input data for the model in two different ways. First we had to use and average height of 400 mts. for wind velocities, instead of using the real bird altitude. As the bird altitude for migration is estimated between 100 mts. and 1000 mts. (Kruckenberg, 2006), and wind velocity tends to decrease at low altitudes, it is clear that used values for this variable lacks precision for analysis.

Calculation of distance travelled by the birds

Initial results obtained and socialized during the presentation showed maximum bird velocity of approximately 200 km/hr., nonetheless in literature review (Kruckenberg) maximum bird ground velocity was 110 km/hr. This error in the result was due to the use of Web Mercator Projection (epsg 3857) which is conformal but with a particular increase of vertical and horizontal size near to the poles (Battersby, 2014). As our dataset is covering long distances from Netherlands to the vicinity of the North Pole, our calculation of distances was wrong with errors in some cases of 100% or more. Final decision was to use *Great Circle Distances - GCD* because they represent shortest distance between points in a sphere, and is the recommended method to calculate distances in GPS tracks with geographic coordinates (Carter, 2002). Our original dataset coordinates were provided in latitude and longitude for WGS84 (epsg 4326). Corrected bird speed using GCD and showed a realistic maximum value of 104 km/hr.

Angles calculation

Web Mercator projection was used to measure angles between consecutive tracked points. Despite this projection is not azimuthal (to measure correct azimuths but only from central point), conformal web Mercator projection preserve local shapes, meaning that “the angle between any two lines in one shape is mapped into the same angle in any other shape” or “a straight line drawn on the map crosses any meridian at the same angle, which is its (true) compass bearing” (Osborne, 2013). This concept in Mercator projection is true only for short to moderate distances. The average distance between points in our dataset is 10 km, and according to (Osborne, 2013) acceptable values for short distances are 20 degrees (approx. 2200 km) in Equator and 8 degrees (approx. 888 kilometers) in northern parts.

Segmenting trajectories

Further, research can be done on this topic is to filter step over and flight states of the movement, if we implement in our tool the segmenting trajectories methodology proposed in (Timf et al., 2012). Another quick approach to test this method is using the package "trajectories" (Pebesma, 2018).

6. Task Division

For this final assignment we used "Distributed Software Development" approach. This is a software programming approach where the complete project is divided into modules defined for specific operation. During the individual development phase each module should work independently having the basic software reusability features. Finally, the individual modules are merged following the sequential flow of the model (Rocha, 2011). One of the developers played the key role to merge all the distributed codes by resolving conflicts. The principal advantage of this approach is fast result by involving the project members to work simultaneously and in their own domain of interest. The detailed task distribution for individual team member is mentioned in *Appendix 4*.

Appendix List

Index	Name	Type	Contents
1	Appendix 1 (Python Script Functions)	File (PDF)	List of the functions used in the Python script with respective purpose.
2	Appendix 2 (User Manual)	File (PDF)	Installation and user guide for using the Tool.
3	Appendix 3 (System Manual Documents)	File (PDF)	Manual for the complete system with working principles and user guide for filter operation. Detailed description of the tool parameters, tools functionality and its related functions and python files.
4	Appendix 4 (Task Distribution)	File (PDF)	Table to show the work distribution of which group member has done what.
5	Appendix 5 (Tool and Python Code)	Folder	Complete Python code and Tool.
6	Appendix 6 (Output scenario results)	Folder	Python script output result files (pdf, csv, text)

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