Towards modelling bird migration using environment variables: A case study of Barnacle Geese, *Branta leucopsis*

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Towards modelling bird migration using environmental variables: a case study of Barnacle Geese, *Branta leucopsis*

by

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Abstract

The observation data of bird migration offers the potential to understand spatiotemporal movement of birds. However, it is not easy to link such data to dynamical models of movement (Patterson, *et al*., 2008). This study used Geese data for developing spatiotemporal model in the context of geographical information system (GIS) for increasing the understanding about bird migration. The three main objectives of the research were to identify the criteria to use as an input in model building and to increase the understanding about bird migration, model the possible locations of migrants using criteria identified previously and lastly evaluate the models performance. The developed model is based on expert information (literature based) using two different approaches, Boolean logic and Weighted Index Overlay (WIO) methods. Using the Boolean approach two different models varying based on number of input parameters were developed. We used Global Weather Forecast Model (GWF) data for six environmental variables: atmospheric air temperature, surface observations, cloud cover, precipitation, wind speed and direction.

In the WIO method Analytical hierarchical process (AHP) process was applied for calculating the weights for all six variables. The weights were multiplied with corresponding layers after assigning the membership function using fuzzy logic technique. An attempt was also made for validating the Boolean models performance using independent data set. Though, the validation of model is not highly accurate due to the uncertainty in the satellite tracking data. The test based on the kappa statistics reflected that the model performance was below average in both the cases. The poor performance of model may be explained by the uncertainty in the tracking data, upper and lower limit of thresholds and due to the discrete properties of environmental variables. The weighted index overlay model with continuous data may give better results, full validation can be part of future investigation. The study revealed that bird migration model involves consideration of just more than applying Boolean and weighted overlay functions. Additional inputs may be added such as distance from the adjacent suitable pixels within the layer and the accumulation of values of parameters of interest with time rather than simply overlapping different layers of geographical information.

Keywords: Spatiotemporal, Migrants, Boolean logic, Weighted index, Global Weather Forecast Model, Analytical hierarchical process

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1. Introduction

This chapter gives a general introduction about bird migration including the factors influencing the onset of migration. The problem statement, objective of the study, research questions, hypothesis and the stages of research will be discussed.

Migration is an evolved behaviour among groups of many animals, such as birds, mammals, fish, reptiles, amphibians, insects and even marine invertebrates (Nakazawa, 2004). Every year millions of birds migrate from one place to another. They fly over long distance from hundreds to thousands of kilometres in search of suitable conditions for breeding and feeding (Patterson, 2005). Migratory birds rarely fly continuously to reach their destination, but interrupt their trajectory frequently for resting, feeding and for avoiding unfavourable weather conditions (Janaina and Yuanjian, 2007).

A number of techniques are being used for studying bird migration such as direct observation, bird ringing, radar and satellite tracking. The simplest and longest existing method is based on direct observations. Though this method has contributed to our knowledge a lot, but limited by the day and night timing and field observation either after or before the migration. Another method is bird ringing which provides important information such as population, disease outbreak and demography of bird. However, this method is prohibitive in terms of obtaining meaningful information, as it requires many individuals to be equipped with rings. The radar has opened a new window for studying bird migration. The quantification of bird migration has been done using radar observation in the past (Gauthreaux and Belser 1998, Schmaljohann, *et al*., 2008). It deals with small to large samples of bird's area range from 0.1 to 100 km (Bruderer, 2003) and is effective in measuring the distribution of birds in space. In addition it provides information about altitude, speed, direction, date and time of departure and height of travel, particularly in night. Perhaps the major disadvantage is because of the disturbing echoes due to the large electromagnetic wave. It creates problems in the quantification of migrant densities (Lincoln, *et al*., 1998). Another technique of determining bird movements is radio telemetry. This method has been use for studying different species during movement (Lincoln, *et al*., 1998). The limitation is due to the size of the transmitter for detecting the signals from the distance. This technique is more useful for studying short distance migrants (Lincoln, *et al*., 1998).

The possibilities of studying bird migration have increased with the use of satellite and radar tracking. Earlier research work related to bird migration is mainly based on ring recovery data. Satellite tracking offers more detail about the animal migration routes, wintering ground, home range, behaviour and habitat selection (Seegar *et al*., 1996, Bobek *et al*., 2008). In the past, many birds species such as cranes (Kanai *et al*., 2002), bar-tailed godwits (Gill Jr *et al*., 2008), pelicans (Izhaki *et al*., 2002), raptors (Hake *et al*., 2001), white storks (Berthold *et al*., 2001 and 2002) and black stork (Bobek *et al*., 2008) have been tracked successfully during the time of migration. These methods have provided an easy and faster way of capturing information about the migration than ever. The data available from the Platform transmitter terminal (PTT) and radar provide formidable challenge to understand the spatiotemporal distribution pattern, habitat use and flight locations of migrating birds over large and site specific areas.

1.1. Factors influence the bird migration

A number of factors were considered for the understanding of the migration pattern. Such factors include air temperature, surface temperature, precipitation, cloud cover, wind speed and direction. In the past decades various authors have reported changes in the migration timing. The exact timing of movements is scheduled by the weather condition (Richardson, 1990). According to Gauthreaux and Able (1970) and Butler *et al*., (1997) the direct influence of weather conditions were observed on speed and direction of migration. However, the indirect influence is reported in terms of activity budget for determining the range of flight (Cochran and Wikelski 2005).

Furthermore, factors related to the bird itself also influence the pattern of migration. These factors are also divided into two categories, static and dynamic. Static factor includes species age, sex and inherited migration program (Berthold, 2001). Dynamic factors includes body weight and water content (Smith *et al*., 2007). Though, there are many more factors for defining the migration pattern of birds such as orientation mechanism (Tankersley and Orvis, 2003) and migration physiology. The factors related with environment and birds itself are responsible for the behavioural decision. The activity budget of an individual bird, habitat selection, weather conditions and static and dynamic internal conditions interact for determining an individual bird energy status and survival. Nevertheless, all these aspects are important to understand the spatial and temporal course of bird migration. The physiological mechanism of migration is almost unclear to account for model optimisation. Furthermore, due to the simplicity of work and time limitations not all the aspects of migration can be included in the current research work. Thus, the research work will consider only the weather conditions to increase the understanding about bird migration for developing model.

1.2. Problem statement

Large populations of avian species undertake seasonal migration from their breeding ground to their wintering ground each year. A massive amount of data is collected by many people including volunteers and professionals. These data helps in drawing the distribution boundary of a species. However, radar and satellite tracking help in identification of precise migration path. It could be link further for studying outbreak of avian-borne disease and bird collision risk assessment. It requires to present data in such a way as to provide possible migration positions at space and time. However, there has been limited research on developing the migration model for such situations. Thus, the approach towards modelling bird migration may help in knowing the migration route and timing in advance. Therefore, may solve the issue of predicting risk associated with migration for taking the effective measurements. In order to develop migration model, it is necessary to increase the understanding about bird migration and to investigate the available data for model development.

1.3. Research objectives

The overall objective of the study is to increase the understanding of bird migration for the model development. The intensive component of the research is to identify important criteria for developing model. However, the extensive component of the research is focused on model development and validation using observation data for better understanding the usefulness of satellite tracking data. The specific objectives and the research questions are as following:

1.3.1. General objective

Increase the understanding of bird migration in order to develop a GIS model.

1.3.2. Specific objectives

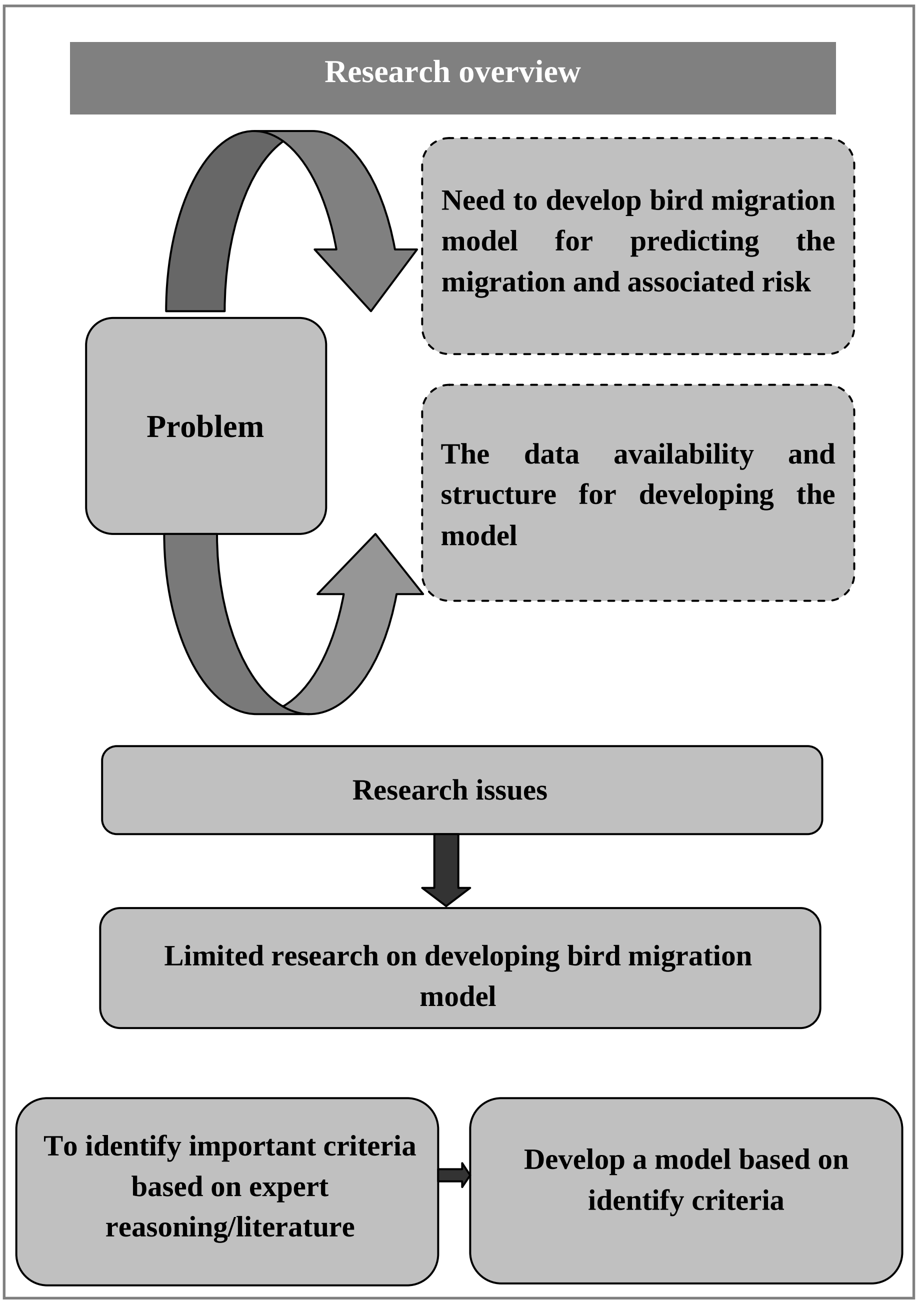
(1) To identify the important criteria for developing a model explicitly in space and time.
(2) To build a model based on identified criteria.
(3) To evaluate the model performance using observed satellite tracking data.

1.3.3. Research questions

In light of the above research objectives, the following research questions are formulated.

(1) Does literature provide sufficient information for developing the bird migration model?
(2) Is the existing data adequate to meet the demand for model development?
(3) Does the literature based model perform acceptably?

Figure 1.1: Overview of the research



1.4. Conceptual diagram

Figure 1.2 is the conceptual diagram for the bird migration model showing factors influence the onset of migration. Dark blue boxes indicates the primary variables, light blue boxes indicates derived constraint maps.

1.5. Research hypothesis

In order to achieve the research objectives the following hypothesis is formulated:

- H_0: The model combining all six variables is not perform significantly different from the model relaying on three variables ($\mu 1 > \mu 2$)
- H_a: The model combining all six variables is perform significantly different from the model relaying on three variables ($\mu 1 < \mu 2$)

- H_0: The model combing all six variables is not significantly better to model relaying on three variables ($\mu 1 > \mu 2$)
- H_a: The model combining all six variables is significantly better compared to model relaying three variables ($\mu 1 < \mu 2$)

1.6. Research stages

The research carried out over a period of 5 months followed the following phases.
The first phase included literature review to develop a firsthand concept for starting the research work. This phase included the formulation of objectives, research questions and hypothesis. This was the phase for collecting the available information such as satellite tracking data and images.

In the second phase, one week field work was done for collecting the bird tracks information from the radar station. A field work was done for a week in Malaga and Tarifa, Spain. Radar data was collected from the NGO (Fundacion Migres). The pre-processing of radar data was done during the field trip for extracting useful information.

The third phase included developing a questionnaire for collecting the expert knowledge. Improvement in the methodology was made during the same phase. The questionnaire was circulated to various scientists working in the field of bird migration along with a poster for explaining the reason and method for estimating the expert knowledge.

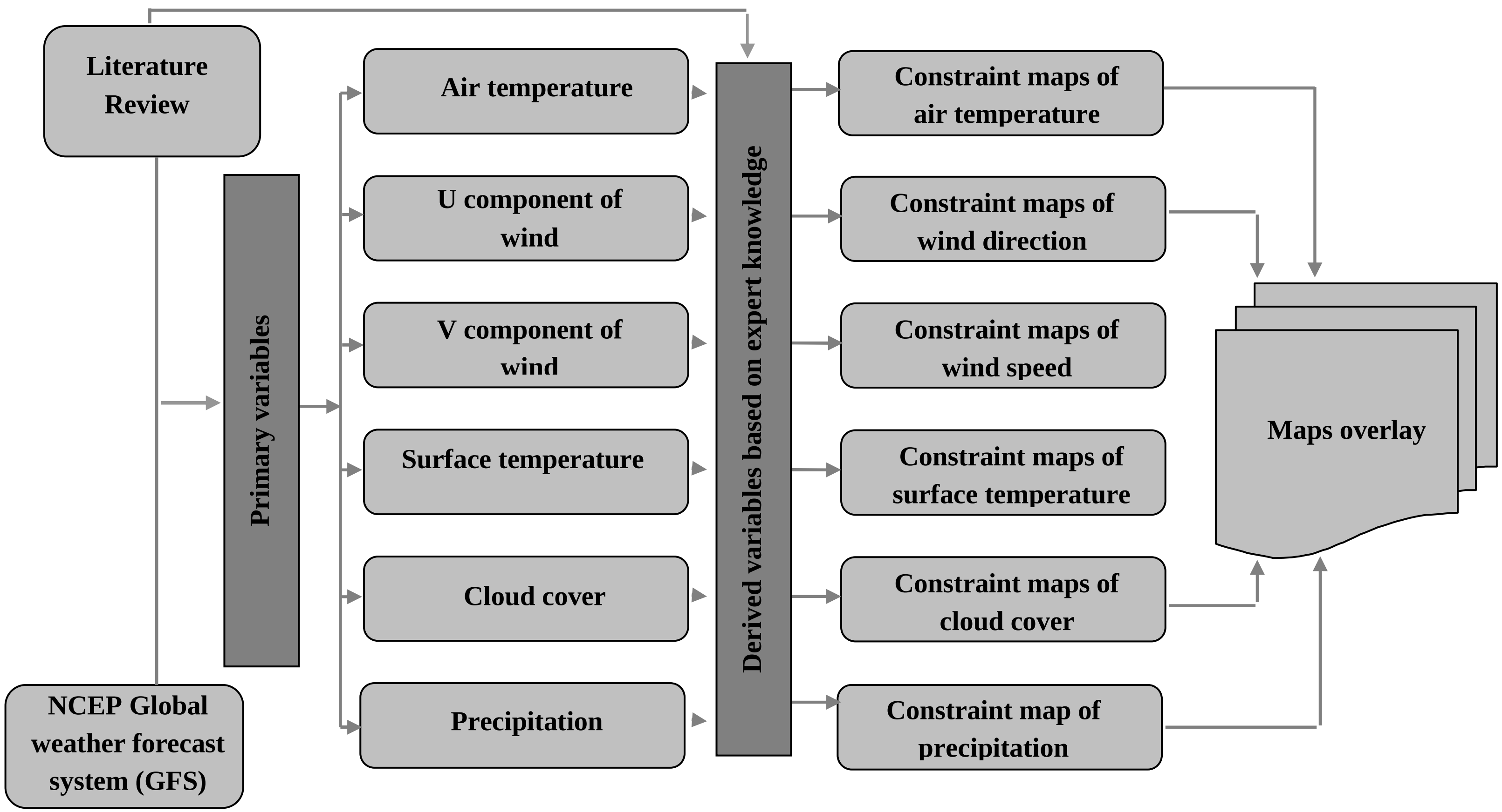
The fourth phase included the processing of the raw data such as wind, temperature and precipitation and to identify the threshold range for the parameters of interest based on existing literature, expert reasoning and personal communication. In the same phase data analysis was done for drawing the result and conclusion of the study.

1.7. Assumptions

It assumed that altitude information on each position can be use for separating the data into two categories stop's and nonstop's[1]. Unfortunately, this information was not correct for validating the model. Thus, the assumption was made by estimating the distance between successive positions. It is assumed if the distance between two positions (A to B) is more than 6 kilometres in such case bird may be flying from position A to B. So we considered point A as a nonstop position. However, if the distance between two positions (A to B) is less than 6 kilometres in such case bird position is assumed on the ground. The weather conditions were assumed as a discrete medium for predicting the bird positions.

[1] Each satellite tracking point represent the moment when bird is stopped (not flying) or nonstop (flying) at a particular position

Figure 1.2: A Conceptual diagram for bird migration model



2. Literature rewiew

Chapter two presents a review of past studies related to bird migration. The weather factors associated with bird migration are discussed. In addition, migration theories and evolution, as presented by researchers, as well as the consequence of changing weather conditions on migration strategies is also discussed in brief. In the next part, models applied for bird migration studies, data source and different methods of studying bird migration are presented.

The existence of any species is based on the environmental conditions around at the globe. As the earth revolve around the sun on 23.5 ° tilt, produces seasonal variation in weather condition, day length and the food availability. Animals undertake migration to adjust with the shifting environmental condition (Patterson, 2005). In a broad term, migration allows year-round activity, unlike dormancy and hibernation, the means by which many animals live through severe seasons. The advantage of migration is that birds can exploit seasonal feeding opportunities, while living in favourable conditions throughout the year. Migration is a common activity for all groups of animals in a certain period of time. It occurs in simple forms such as the movement of marine animals that bury themselves into the sediments of a lake or stream. However, there are examples of long range and intercontinental migration in many groups of species but none of the groups migrate like birds do (Berthold 2001, Patterson, 2005).

It has been reported that 50 billion of 400-500 bird species migrate from one place to another each year (Berthold 2001, Patterson 2005). The probability of migration increases under favourable weather conditions. In the past many scientific papers have been published for highlighting the effect of weather condition on bird migration. Most of them include research analyzing the dependency of migration on weather conditions (Sinelschikova *et al*., 2007, Zalakevieius, 2001, Gauthreaux *et al*., 2005, Zalakevicius *et al*., 1995). However, results vary depending upon the species. Some of the studies suggest that temperature is the most prominent factor for triggering bird migration (Penuelas *et al*., 2002; Gordo *et a*l., 2005; Marra *et al*., 2005; Murphy-Klassen *et al*., 2005, Cotton, 2003), while others find that the migration is corresponding with precipitation, wind, humidity, cloud cover and atmospheric pressure (Cochran and Wikelski 2005, Zalakevieius, 2001, Green, 2001, 2004, Bridgman and Maddock, 1994). Seasonal variation in the supply of food is also reported as a motivation for starting the migration (Shamoun-Baranes, *et al*., 2006). The food supply may fluctuate depending on the surface temperature of earth. It affects the general timing of migration.

The maximum assimilation curve at light saturation determined by temperature indicates that the temperature requirement for C3 plants such as *Festuca rubra*, a major species for the important avian herbivores, ranges from 15 °C – 20 °C in a cool temperate climate (de Wit *et al*., 1978), (Fig. 2.1).

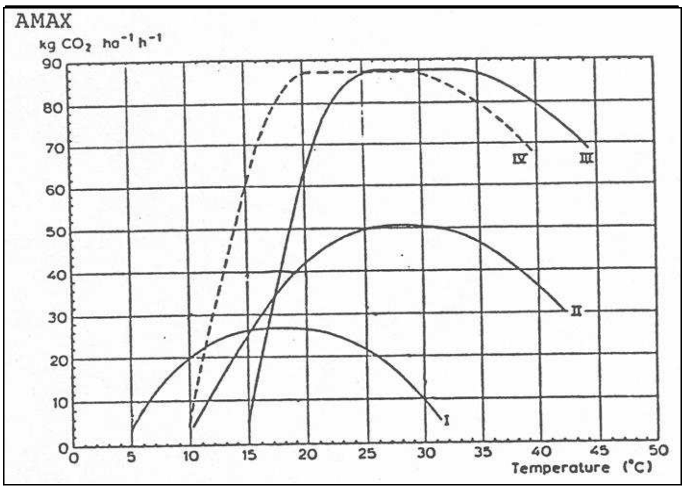


Figure 2.1: Light response curves at several temperature

I=C3-crops in cool and temperate climates, II=C3-crops in warm climates, III=C4-crops in warm climates, IV=C4-crops in cool climates. Source : (de wit *et al*., 1978)

In addition, some species migrate based on internal factors (Marra *et al*., 2005, Berthold 2001). In bird migration the level of difficulties varies depending upon the species. It is reported that many species tend to change migration according to environmental conditions. Moreover, others push the physiological limits to fly continuously. The flight of Bar-tailed Godwits is reported as an unbelievable journey. They spend their summer in Siberia and Alaska and migrate up to Australia and New Zealand to stay there during winter. In some cases these birds are reported flying up to 10, 000 kilometres without stopping (Gill Jr *et al*., 2008). While other species utilize many stopover sites on the way for gaining fuel. However, most Anatidae use this strategy to migrate between wintering to breeding sites. Apart from this, various migration strategies have been developed based on weather tolerance, habitat requirements and flying range (Patterson, 2005). There are two migration strategies explained, short distance and long distance.

Short distance migrant spends winter near to the breeding ground. Long distance migrants fly up to several hundreds of kilometres for finding the suitable area for wintering. Thus, the migration timing for short distance migrants fluctuate highly in response to change in climatic conditions (Jonzen *et al*., 2006). In the last 40 years the long distance migrants advanced their autumn passage through the Western Europe (Jenni and Kery, 2003). They fly through the Sahel and Shara at the starting of the dry season to reach their wintering ground. This could be a way for avoiding the dry season fastly. In contrast, short distance migrants delayed their migration (Jonzen *et al*., 2006).

2.1. Historical explanations towards bird migration

The most challenging question in ornithology is disappearance and reappearance of many bird species (Gauthreaux, 1982). The reason of this annual phenomenon is explained by Aristotle (Patterson, 2005). The migration of the Eurasian crane is well understood by Aristotle (Gill 1994, Patterson, 2005). However, migration theories are proposed on the basis of smaller bird. It is reported that many species hibernate in the hollow trees or mud of marshes (Patterson, 2005). According to his idea some birds disappear or hide in the winter and reappear during the favourable conditions. In 1757, Carolus Linnaeus supported his idea while explaining the hibernation theory in favour of swallows (Alerstam, 1993). According Woods, *et al*., (2005), the Common Poorwill spends time in hibernation during winter in North America.

Aristotle has given another theory of transmutation for explaining the reason of disappearance for the certain species during the winter. He observed that during the disappearance of Common Redstarts, the abundance of European robin increases. He explained that two different birds were alternating the plumage of a single species. The similar transmutation is observed between Orphean Warbler and Blackcap (Patterson, 2005).

Another theory suggested that the smaller birds were not capable for flying long distance by themselves. They latch themselves on the large birds such cranes and storks to migrate from one place to another. Patterson (2005) reported a theory published in 1703 “An Essay toward the Probable Solution of this Question: Whence come the Stork and the Turtledove, the Crane, and the Swallow, when they Know and Observe the Appointed Time of their Coming.” The writer of this story has given an idea that birds flew to moon for spending the time of winter (Lincoln *et al*., 1998, Patterson, 2005). In the previous time bird migration studies were quite difficult in terms of knowing the altitude and night migration (Lincoln *et al*., 1998). However, with the advancement of techniques bird migration studies are routine in wildlife research (Higuchi and Pierre, 2005). Special techniques of bird banding has been used for the identification and tracking of birds. However, the recovery rate is very little 1-2% (Pers. Comn., Rahamani, A.R., 2008). The radar and satellite tracking has opened a new window for studying the spatiotemporal patterns of bird migration (Berthold, 2001).

2.2. Bird migration, timing and conservation concern

The timing of migration is guided by internal rhythms that are linked with other aspects of the annual cycle as well. Many studies have assed the restless behaviour in a captured bird (Helm and Gwinner, 2006). In the experimental studies of both the physiology of migration and orientation behaviour, restless is measured based on the bird's activity. More generally, however, our knowledge of the endocrine control of the many different facets of migratory behaviour of birds is still poor (Wingfield *et al*., 1990). Increased day length stimulates restlessness, fat deposition and weight increase in many migratory birds. Migration activities of White-crowned Sparrows are under the direct control of increasing day length, mediated precisely by an internal clock (Rattenborg, *et. al*., 2007). The timing of migration relates first to internal physiological rhythms, but external weather factors also play important role (Gauthreaux and Able 1970, Butler *et al*., 1997). Daily weather conditions, temperature and favourable winds, in particular, also influence departure times. In past, many studies have demonstrated the role of weather conditions in determining the migration time (Owen, 1980).

In case the changes in migration timing does not fit with the ideal behaviour of migrants, it can lead to conservation concern (Visser and Both 2005, Quader and Raza, 2007). In temperate region spring migration is expected to advance due to warmer climatic conditions. The problem may occur due to difference between the availability of food and migration timing (Quader and Raza, 2007). For instance, in spring the abundance of caterpillars has advanced in the Netherlands. It is not corresponding with migration timing of Pied Flycatchers *Ficedula hypoleuca*. As a consequence, the decline is observed in the Pied Flycatcher population (Both *et al*., 2006, Quader and Raza, 2007). Such events have lead the conservation concern for many other species.

2.3. Bird migration modelling

In the past few studies have attempted to model bird migration schedule based on the energy expenditure, fuel deposition and load (Weber, 1998). These models describe energy dynamics as result of flight mechanism to simulate the timing and route of migration (Bouten, *et al*., 2005). These stochastic models are complex in nature and require large amount of data for predicting bird migration patterns. Frequently, to collect large amount of data is expensive using any of the techniques. Thus, the simple concept driven model based on existing literature and expert reasoning offers valuable tool for studying bird migration. The available satellite data combined with literature information and expert knowledge can enhance our understanding to model the migration movement. Such models help us to understand bird migration at multi spatial-temporal scales.

The relationship between bird migration and weather has been recognized (Bouten, *et al*., 2005). The regression model has facilitated the prediction of bird migration for preventing the collision of aircraft with birds (Ven Belle, *et al.,* 2007). In the concept driven model the major challenge is to bring the non quantitative literature knowledge into quantitative data. Fuzzy set theory is proposed as an alternative to deal with such kind of problem (Zadeh, 1965, Josphe, 2007). The fuzzy set theory is based on the classical set theory in which a membership function is assigned from zero to one. According to Juang, *et. al*., (1992) and Josphe (2007), fuzzy set is a group of elements with the degree of support for those elements. In contrast, classical theory permits to take only zero or one by adding the membership function value. The fuzzy set approach has been used to model the coral reef processing using various input parameters such as wind, SST and PAR (Josphe, 2007).

In the context of bird migration, fuzzy set theory can use for determining the membership function for the variable of interest. It shows the gradual change from member to non member class. It revealed from the existing literature that bird migration modelling is less common using such kind of approach. This approach may help us to understand the complex process of bird migration by the outlining of weather factors more clearly. The develop model can be use for future research in the bird migration field pointing the relevant questions.

2.4. Movement data, source and error

Various sources are available for collecting the animal movement data such as mark release recapture data, observed data using satellite telemetry technology. The possibilities of collecting movement data is increased with the advancement is technologies including satellite transmitter (Bobek *et al*., 2008), radar tracking (Gauthreaux and Belser, 1998, Bruderer, 1997) and the use of electronic tags (Block, *et. al*., 2005). The animal movement data is received using the US National Oceanic and Atmospheric Administration's satellite (NOAA, Fig. 2.2). The stored data is transmitted to ground station located in France and US. ARGOS receives data from ground stations and transmits further to the users via. internet. Location data is categorised into different classes such as Z, B, A, 0, 1, 2, 3 for giving the measurement of accuracy. It is reported that system doesn't calculate the error for Z, B, A due to the inadequate reception frequency (Ueta, *et al*., 2000).

Further, each method is associated with some kind of error. For instance, the mark recapture method is biased due the variation in capturing the individual. Satellite tracking is degraded due the poor satellite coverage. Radio tracking suffer due to triangulation error in estimation the position of animal. The calibration process helps in assessing the statistical properties of error in some cases e.g. by examining the locations of electronic tag captured at know point. In past attempt has been made for discussing the accuracy of movement data based on source of error (Patterson, et al., 2008). For instance, the incorrect locations of bird may lead to the wrong conclusion about the preferred weather conditions. Thus, it is vital to minimize the location error in analyzing the movement data. In dynamic movement models separating the error data from the observation data is quite challenging and includes various computational methods such as State Space Model (Patterson, *et al*., 2008). SSM analyze the data on the basis of statistical analysis, error correction and estimation of a movement matrix (Patterson, *et al*., 2008). The migration route of leatherback turtles (*Dermochelys coriacea*) is studied using the SSM approach for finding the diurnal differences during the movement (Jonsen, *et al*., 2006). SSM use non-spatial data such as temperature and pressure from the satellite transmitter along the model output for estimating the location of animal. The same model has been use for studying the movement of tuna, butterflies, pigeons and wolves (Patterson, *et al*., 2008). Though, in the current research work it is of interest to study how the SSM model works in estimating the error in observation data.

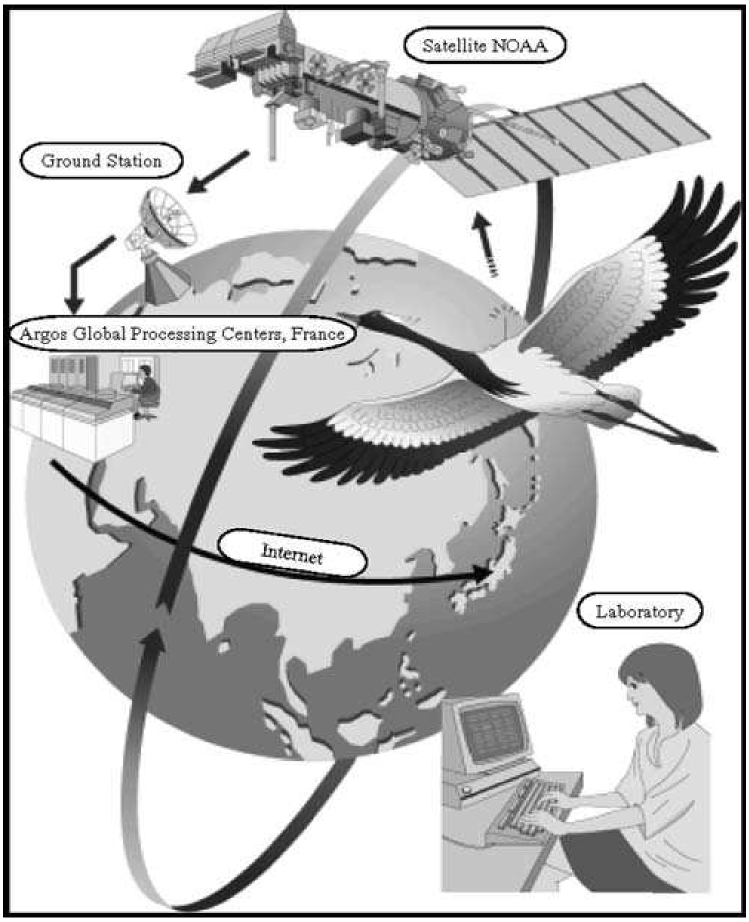


Figure 2.2: Mechanism of satellite tracking with ARGOS system; Source: (Higuchi and Pierre, 2005)

2.5. Techniques, options and challenges

In the bird migration studies, conventional methods have been used since long. The techniques developed such as direct observation, bird ringing, radio tracking, satellite tracking and radar tracking are independent of each others and used for answering different questions related to bird migration.

2.5.1. Direct observation

The most oldest and frequent method for studying bird migration is direct observation. Because this is the longest existing method, it yields long term information about population and distribution patterns. Direct observations data is compiled for knowing the longest and interesting migration routes based on thousands of observation at a certain time and location. The volunteer based direct observation technique is applied in many countries for the bird monitoring programme. Quader and Raza (2007) included the examples, Audubon Society's Christmas Bird Count, USA, the Breeding Bird Survey, UK and the Southern African Bird Atlas. In Britain, 1.5 million people are involved every year in collecting observation data (Greenwood, 2007). The method has become the source of valuable information for increasing our knowledge of migration. However, it is being limited due to day and night time, ground based information about the departure and arrival of birds.

The first volunteer based study for collecting the direct observation started in Finland in 1974 (Greenwood, 2007). This has contributed in drawing a line for arrival dates to conclude about the migration timing of many European birds. A similar approach is applied in many other countries; consequently detailed information is available about the changes in population and the distribution of species in many parts of the world (Greenwood, 2007). More recently, migrant watch has begun a volunteer based monitoring programme for collecting the information about the timing of migration of nine target species in India (Quader and Raza, 2007). Wetland International is also involved in conducting Asian Waterfowl Census since 1987 (Wetlands International, 2007).

2.5.2. Bird ringing

Another most effective method is ringing for studying bird migration pattern. It provides information about the population, behaviour, disease outbreak, breeding productivity and demography of bird. In this method a captured bird is marked and released for collecting the information. The recovery records of ringed bird allow us to know about the movement fact and consequently lead to detail information of migration. In Europe many banding stations work simultaneously throughout the year for providing information concerning of migratory birds. EURING, European Union for Bird Ringing is actively involved in coordinating the bird banding activities in Europe.

Furthermore, this method is useful for studying migration habitat of a few species but have shortcoming as well. The major issue in bird ringing is that ringed bird must encounter again after the ringing. In case the species is hunted the recovery chance decreases. Thus, large numbers of birds are required to be ringed for obtaining meaningful information about the migration path, breeding and wintering ground. The results of ringing reflect the distribution of people instead of bird distribution.

2.5.3. Radio tracking

Radio tracking is a technique developed for determining the migration process of birds using electronic tag. It has been used often for tracing the migration progress. Javed *et al*., (2003) has reported that the use of radio tracking is restricted to limited species with the certain movement range. The main advantage of this technique is birds can be relocated easily in comparison of using other marking methods. However, the limitations are in tracing the bird or animal in dense vegetation and hilly area due to limited detection range of signals. It requires more logistic planning for detecting the birds than satellite tracking. Another challenge in tracking the long range migrant is due to limitation of the distance in receiving the signals from the electronic device. In many cases small birds are tracked from the aircraft using the radio tag method. This method is found useful for observing the orientation pattern of thrushes (Cochran *et al*., 2004). With prior knowledge the method is found successful in terms of collecting data. The automatic receiving stations can be located all along the migration track for detecting the signal from a particular tag.

2.5.4. Radar tracking

Radar is a powerful tool for tracking birds in flight. The radar can track and identify single bird for assessing their flight, speed, altitude and orientation. Radar has been used for studying the flight directions of barnacle geese, *Branta leucopsis*, and brent geese, *B. bernicla bernicla*, based on wind conditions during the spring migration over Sweden (Green, 2001). The use of radar is also demonstrated useful for studying the wing-beat pattern of migrants (Ruth, *et. al*., 2005). Migrating birds appear on the radar screen as small targets that move at predictable speed. Flocks of migrants can be distinguished from single individuals, and the intensity of each migration can be quantified. This system provides unique sets of data by including the ecological interaction with the environment (Ruth, *et. al*., 2005). The advantages are that this method is weather independent, light independent and generally less restricted in terms of distance covered. However, the major challenges in handling the radar data are the identification of the birds on the digital screen, dealing with a massive amount of data, and the limitation of covering the area. The long electromagnetic waves restrict the radar to focus the energy beam on the target, resulting backscattering disturbance echoes, which may lead to wrong identification of the target (Ruth, *et. al*., 2005). In spite of all these challenges application of radar technology is quite useful for detecting the migration intensity to avoid the risk of aircraft collision with the birds (Ven Belle, *et. al*., 2007).

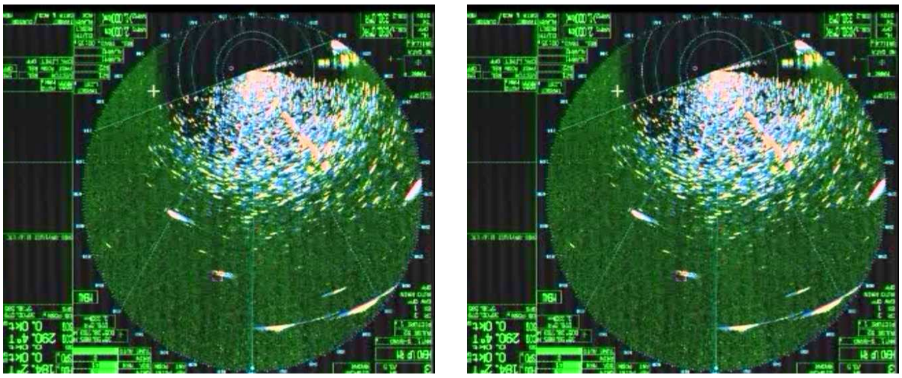


Figure 2.3: The raw radar images showing clutter and flock of bird
Source: (Fundacion Migres, Spain)

2.5.5. Satellite tracking

The advancement of technology from radio tracking to satellite tracking has added new dimension to avian studies. The potential of satellite tracking has been demonstrated by many studies (Bobek *et al*., 2008, Berthold *et al*., 2001). Detailed information about the spatio-temporal migration pattern, wintering and breeding areas, behaviour and habitat selection is captured
using satellite tracking method (Kanai *et al*. 2002). The information about the incredible journey (10,000 km) of bar-tailed godwit (*Limosa lapponica*) from New Zealand to china is also a result of satellite tracking (http://www.werc.usgs. gov/sattrack/shorebirds/overall.html). The main advantage of this technique is assessing the individual bird locations over a large area. In the last few decades satellite tracking became more popular due to the refinement in transmitter weight, shape and size (Javed *et. al*., 2003).

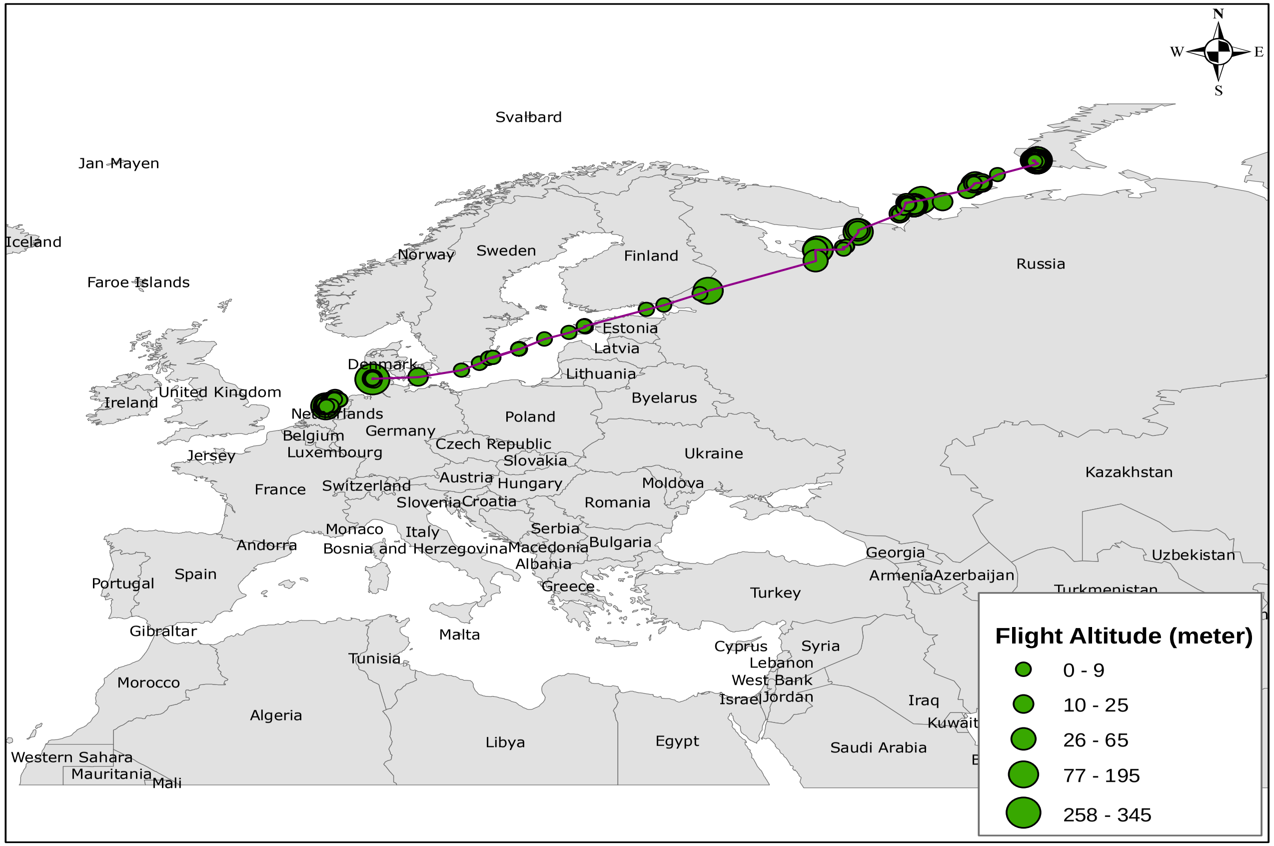
3. Materials and Methods

Evidences are given for utilizing the model to determine the favourable and unfavourable weather conditions. Acquisition of data in terms of availability is taken in consideration for retrieving the parameters of interest. The reason for selecting the parameters of interest including the threshold range is also discussed. This approach is used for producing an output in the form of suitable and unsuitable conditions resulting from combined maps in time series using the developed criteria.

3.1. The Study area

The study area includes one of the most potential flyway, connects Europe to Russia and Siberia. This is a well know migratory route between breading and non breading sites of Russia and Europe. In Europe many species (geese, swans and ducks) traditionally migrate from their wintering ground (The Netherlands and Germany) to their breeding ground (Russia) using different routes. They mainly travel using three recognized routes from Europe to Russia; Western Palaearctic continental flyway along with North Sea and Black Sea flyway. The main focus of the study is on the North Sea flyway (Fig. 3.1). The North Sea flyway connects Russia to Europe via Scandinavia, the Baltic basin and the North Sea. The Western Palaearctic flyway connects tundra and taiga belt of Russia with Europe (Van Eerden, *et al*., 2005). However, Black Sea flyway connects Russia to Europe through the Mediterranean Europe and Western Asia. In terms of migrant number, North Sea flyway is reported as an outstanding route for many migratory species (Gilbert *et. al*., 2006). The western Palaearctic continental flyway is used by approximately 9.3 million herbivorous (Van Eerden, *et al*., 2005). The approximate length of the migration routes are 3,500 km. In the month of October birds starts to arrive in Europe (The Netherlands) and may stay up to mid April. On the migration routes few sites such as Gotland in Sweden and Estonia are reported to be used as stopover along the flyway for refuelling and resting (Ganter *et al*., 1999). However, agriculture field and costal salt marshes provides foraging sites. The winter staging site is mainly located in the Dutch islands (e.g., Schiermonnikoog) for many Anatidea species. However, West Siberia lowlands (WLS) are reported as important breeding site for waterfowl, covering an area of 2,745,000 km2 (Gilbert *et al.*, 2006). Two distinct migratory avenues have been defined depending on species. The narrow route between the Netherlands and Baltic Sea to Russia is used by dark-bellied brent geese and barnacle geese. In contrast, the greater whitefront and bean geese migrate using the wide front from the Netherlands to Russia through Eastern Europe (Van Eerden, *et al*., 2005).

Figure 3.1: Satellite tracked migration route of Geese



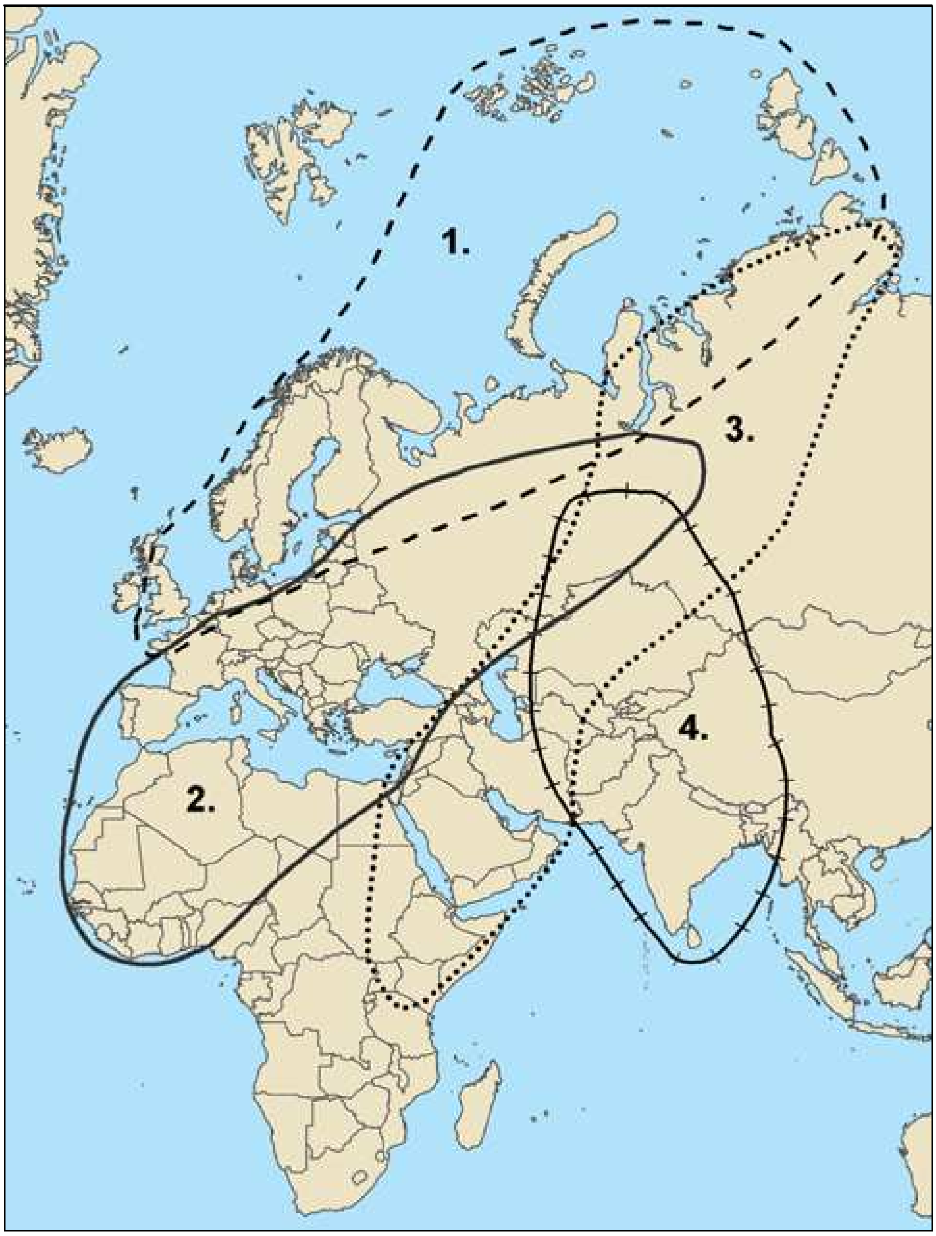


Figure 3.2: Generalized flyway in western Eurasia for Anatidae poulation 1. North Sea population; 2. Black Sea-Mediterranean population; 3. Caspian Sea population; and 4. Siberian- Kazakhstan population. Source: Boere and Stroud (2006) and Isakov's (1967).

3.2. Data description and processing method

3.2.1. Geese migration data

This Geese migration data is provided by SAVON, the Netherlands. On 14th April, out of the eight Geese which were equipped with (PTT) transmitters in Holland in 2008, six of them flew towards Russia. The available data includes the information about the position of the birds, ring number and time.

The attached transmitters were supplied with the solar recharge batteries (Microwave Telemetry PTT 100). The transmitter signals is intercepted by the polar orbit satellites (NOAA) and received at headquarters of American-French Company ARGOS. The ARGOS system is described in the part of literature review. The data was filtered to exclude the inaccurate points found away from the nearest tracking times and locations. A total of 4,297 locations were obtained and 934 of them were used for constructing the migration track of 3 individuals. The tracks were constructed on the basis of directional movement recorded away from the wintering site. All the individuals were also tracked during the migration from breeding to wintering ground, but the data is not included for constructing the migration route due to the incomplete tracks. The winter migration started from the mid to early may. The observed mean departure date for the Geese was April, 11th, 2008 (rage April, 07th – April, 14th, 2008, n=5).

The individuals equipped with the transmitter number 4801 and 48045 left the wintering site on April 7th, 2008. However, another individual equipped with the transmitter number 48044 departed on April, 8th, 2008. Two individuals, transmitter number 48046 and 48047 left on April, 13th, 2008. The remaining individual (transmitter number 48043) started migration on April 14th, 2008. The Geese traversed using the North Sea migration route across the Germany, Denmark and Estonia to the breeding areas. The migration distance of tracked Geese from wintering area to breeding area ranges from 3,500 km-3,600 km. Most of them used one or more sites as stopover.

3.2.2. Metrological data

The influence of weather condition on temporal and spatial migration is investigated using meteorological data from the NOAA National Operational Model Archive and Distribution System (NOMADS), USA (http://nomads.ncdc.noaa.gov/). The gridded data is produced using NCEP Global weather forecast system (GWF) and has a 0.5° latitude × 0.5° longitude global grid. Each grid cell represents a value for two different forecast hours (09 and 15) for selected variables. The attempt was made to use the initial hour data for avoiding the error propagation from one hour to another. However, the initial hour dataset was not having all the selected variables and the timing of forecast was not matching with the timing of bird migration. Therefore, the decision was taken to analyze the forecast data at 09 and 15 hours. The dataset includes forecast for 180 hours (temporal dimension). However, the research has used only the 2 temporal dimensions for the sake of experiment. The dataset includes many variables such as surface temperature, air temperature, relative humidity, solar radiation, precipitation, and U and V component of wind, calculated up to 26 vertical layers. Wind speed, direction, precipitation, cloud cover, air temperature and surface temperature are used to determine the weather condition during the migration from April 11th to June 30th, 2008. The GWF model data were extracted from several grid cells across the migration route. These grid cells were used for finding the positions suitable and unsuitable for bird migration.

3.2.3. Input variables

The first stage in modelling is the selection of variables required for the analysis. The variables were selected based on two basic facts. Firstly, the model is used for the simplification of complex processes. Therefore, the variables about which information is not available for drawing the conclusion are omitted from the analysis. Secondly, some of the variables are not used due to the difficulties in obtaining. The availability of data is the prime importance when applying GIS. In the current research work, weather data was retrieved from the high resolution GWF model, operated by the National Oceanic Atmospheric Administration (NOAA). All the datasets were retrieved at 00:09 and 00:15 UTC (Universal Time Code). The 8 bit GRIB data files, containing forecast data were downloaded by constructing URL links from various data catalogue. A total of 324 data files were retrieved. The surface temperature, precipitation and cloud cover data were obtained at 2D level. However, wind U and V component and air temperature were obtained at 100000, 92500 and 85000 pa pressure levels (approximately 0, 750 and 1500m altitude). These variables are shown in table 3.1 and will be described here very briefly. Wind speed and direction are computed using U and V component of wind at selected pressure levels. All the retrieved files were processed for sub setting the study area. The time aggregation function was used for integrating the data over the corresponding migration period (April, 11th – June, 30th, 2008). The details of forecast data used are given in appendix 1.

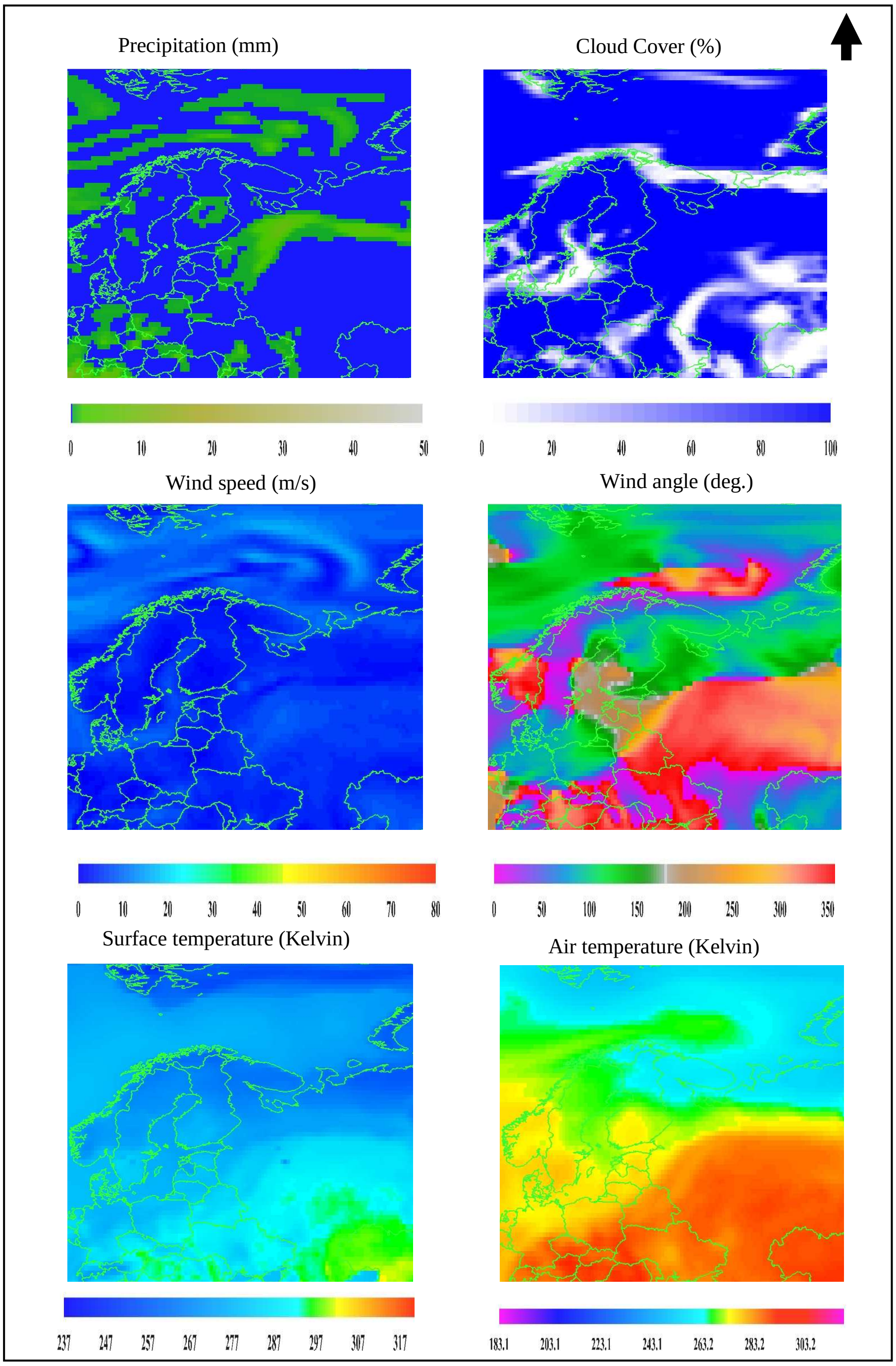


Figure 3.3: Global weather Forecast model (GWF) data products

Table 3.1: Description and threshold range of input variables

	Name	Variable selection based on the literature	Unit	Variabl e range	Threshold range	Non quantitative description based on literature
Weather parameters	Air temperature	Zalakevieius, 2001, Gordo *et al*., 2005	^{o}C	-36.15 to 47.75	1 to 10	Bird take-off under low day air temperature
	Surface temperature	Xiao *et al*, 2007, Shamoun-Baranes, *et al*., 2006	^{o}C	-42.25 to 47.75	15 to 20	Temperature requirement for the growth of C3 grass in cool and temperate climate is 5 to 30 ^{o}C assuming optimum light condition
	Cloud amount	Zalakevieius, 2001, Gauthreaux *et al*., 2005, Mingozzi, *et al*., 2008	%	0 to 100	0 to 25	Clear sky to partial cloud is preferred during migration
	Precipitation	Zalakevieius, 2001, Maddock and Howard Bridgman, 1992	mm	0 to 50	0 to 1	Specified in terms of absence of rain
	Wind direction	Green, 2004, Green, 2001	deg.	0 to 360	220 to 280	Tailwind is reported as a preferred wind direction
	Wind speed	Green, 2004, Zalakevieius, 2001	m/s^{-1}	0 to 31.4	0 to 16	Specified in terms of calm wind

Figure 3.4: Flow chart of Boolean index overlay method

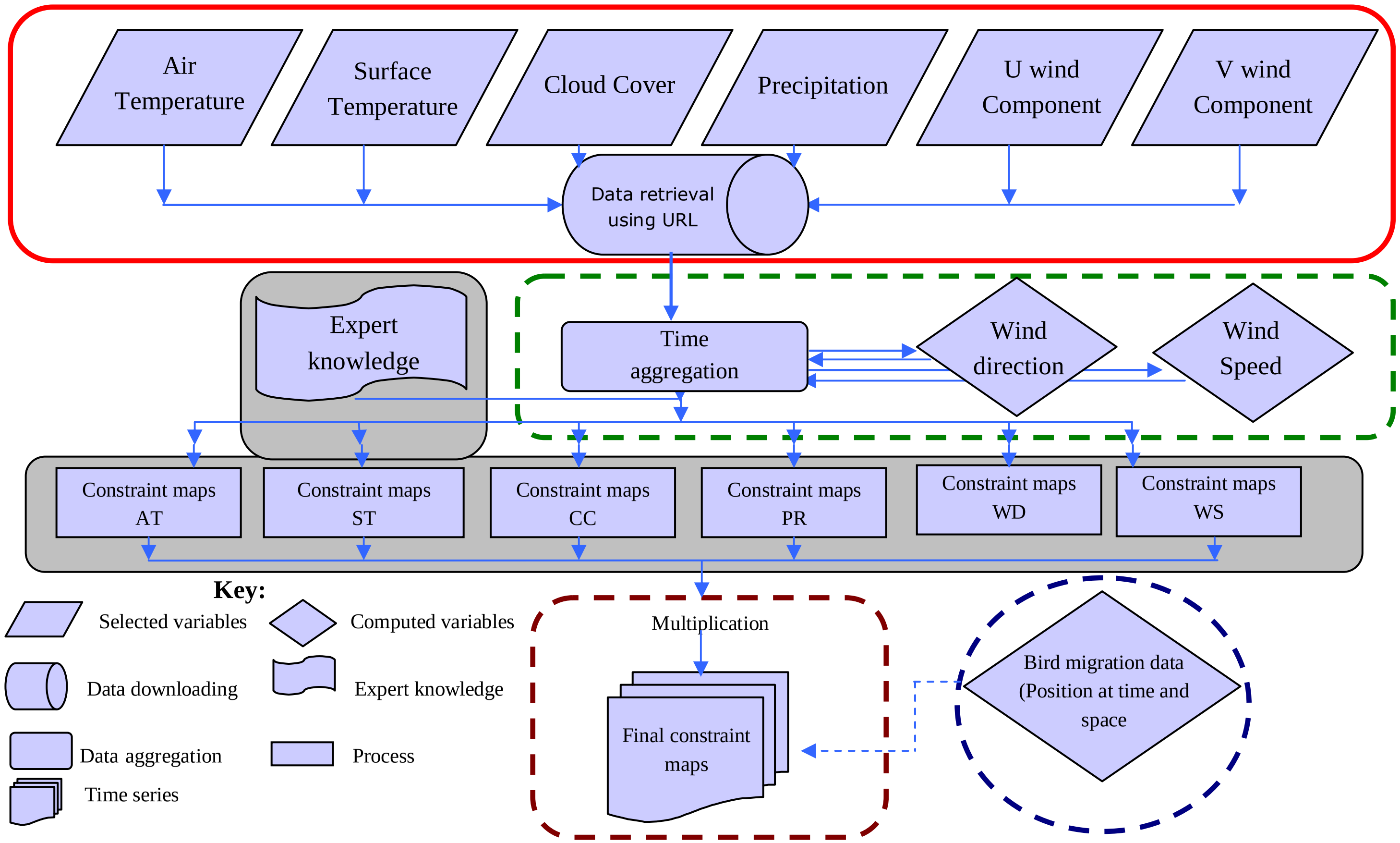
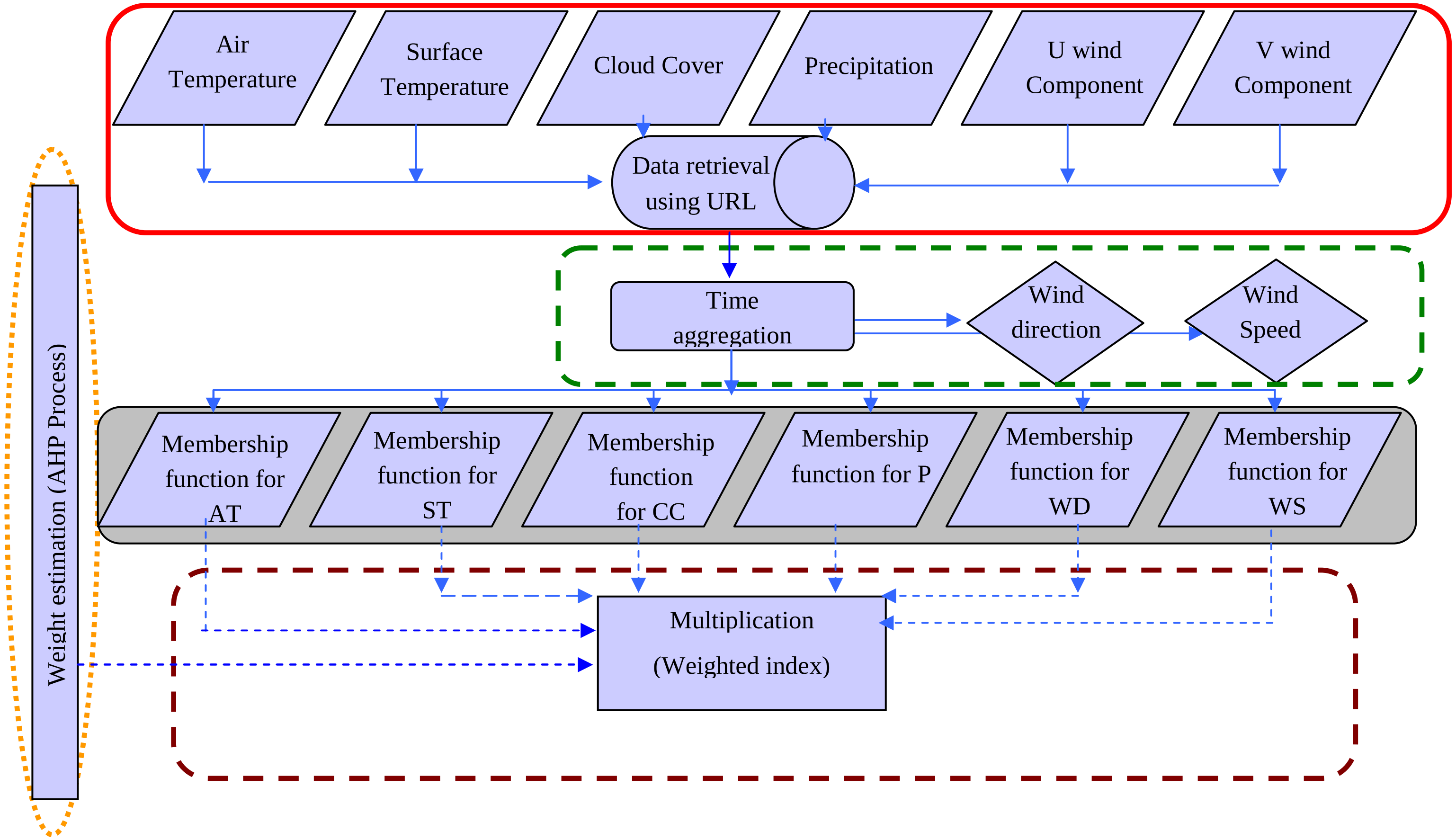


Figure 3.5: Flow chart of weighted index overlay method



3.2.4. Air temperature

According to the literature, air temperature is one the important factor for triggering the onset of migration (Zalakevieius, 2001). Thus, given the air temperature is a significant consideration for querying the suitable weather condition. The low day air temperature (4.92 ± 0.53 °C) is reported for triggering the take-off for the geese (Zalakevieius, 2001). Therefore, temperature of 274.15 k – 283.15 k is considered as suitable conditions while less than 274.15 k and more than 283.15 k temperature region considered as not suitable.

3.2.5. Wind direction

Another important weather variable is wind direction. Depending upon the wind direction bird appears to adjust their migration timing for maximizing the tailwind. Thus, include the wind direction with the speed is a key element in modelling the migration phenomenon. Wind directions computed using U and V component of wind at 3 different heights (100000, 92500 and 85000 pa) and at different hours of the day. The average calculated track angle was 70 degree from the North. The flight of birds can be limited with the 20-30 degree angular deviation in the wind direction (Pers. Comn., Green, 2008). Therefore, movement aligned with track direction, 220 – 280 degree is considered a suitable wind direction. However, below 220 degree and above 280 degree angle is defined as not suitable conditions of wind.

3.2.6. Wind speed

Several studies indicate that migration activity is positively correlated with wind speed. Hence it's important to take wind speed into account for determining the suitable weather conditions. Wind speed is also commuted using U and V component of wind at 3 different heights and at different hours of the day as wind direction. In many other studies, calm wind is defined as suitable wind speed for birds to fly. Green (2004) has analyzed several bird tracks over the Sweden using radar and observed 95% of the tracked flocks were following tailwind with the speed of 8.3 m s-1 (Green, 2004). The geese can fly with the speed of 16-18 m s^{-1} irrespective of the of wind direction (Pers. Comn., Green, 2008). Therefore, the speed of wind from 0-16 m s^{-1} is defined as most suitable in the criteria. However, wind speed exceeding 16 m s-1 is included as not suitable conditions.

3.2.7. Surface temperature

The surface temperature is another trigger for migration onset. The motivation for starting the migration also depends upon seasonal variation in food supply (Shamoun-Baranes, *et al*., 2006). The food supply may fluctuate depending on the surface temperature. The temperature requirement for the growth of C3 plants such as *Festuca rubra*, a major foraging species for the avian herbivores ranges from 5 °C–30 °C in the cool temperate climate under optimum light conditions (de Wit *et al*., 1978). Thus, in order to establishing criteria for surface temperature, range of temperature from 5 °C–30 °C is assigned as a suitable condition for the growth of grass. However, the rage below 5 °C and above 30 °C is classified as not suitable conditions.

3.2.8. Cloud cover

Mingozzi, *et al*., (2008), state that clear sky can favour the departure from the stopover sites. Thus, cloud cover is also an important factor when demining the suitable weather conditions for bird migration. As a matter of fact (Zalakevieius, 2001), suggest that little cloudiness with other favourable variables triggers bird migration. Wege and Raveling, (1983), tracked 13 Geese and observed that maximum birds departed under the clear to partial sky due to the clear visibilty. Therefore, 0-25% cloud cover was assigned as a suitable cloud condition. Cloud cover more than 25% is defined as not suitable condition for birds to migrate.

3.2.9. Precipitation

The amount of precipitation also influences the migration of birds. Bridgman and Maddock (1992), has reported that migrating birds avoid rainy weather conditions. The reason for avoiding extreme rainfall is due high energy expenditure and poor visibility. Therefore several authors suggested that migration take off occurs in the absence of precipitation followed by other variables (Zalakevieius, 2001). In order to create binary map for Boolean integration method, precipitation layers were classified into two categories namely suitable and unsuitable conditions. The area with the precipitation of 0-1 mm considered as suitable condition. However, the precipitation rage exceeding 1 mm is included in unsuitable class.

3.3. Expert model development

The bird migration modelling section provides evidence for the model utilized for determining the suitable weather conditions in time series. The suitable weather conditions were determined based on identify criteria, resulting from the weighted and combined climatic layers. Clevenger *et al*., (2002) used weighted linear combination for incorporating the expert opinion individually and from the published literature for the black bear (*Ursus americanus*) study. It is reported that numerous criteria must be consider for applying the weighted or linear combination (Thoso, 2007). One of the criteria is to process large amount of data as quickly as possible. Thus, Geographical Information System (GIS) is found as a most suitable tool for processing and analyzing the large amount of data. It is indeed an ideal method for determining the suitable conditions for bird migration due the efficiency for storing, analyzing and displaying the large amount of information based on user-defined specification. The justification of this study, after identify the criteria for determining the suitable conditions, was to develop bird migration model using Geographical Information System (GIS).

In this research work composite suitability analysis approach is used for determining the suitable and unsuitable weather conditions using map overlays. The further extension includes analyzing the predicted suitable conditions using statistical analysis. The main approach was to utilize developed model for combing and integrating of maps to determine the suitable migration conditions. In GIS a number of integration models are reported. The study, however, used two, Boolean Logic and Weighted Index Overlay models (Frantzis, 1993).

The Boolean operation is the simplest available model in GIS. It includes the combination of binary maps resulting from conditional function. The method is found practical and most applicable for establishing a set of deterministic rules (Dikshit *et al*., 2000, Thoso, 2007). The model used for applying the Boolean function for classifying a set of inputs maps. The classified maps used as a layer of evidences in time series. The various map layers combined together for supporting the result. Each location in the final output represents either suitable or unsuitable weather conditions. However, this approach involves the comparison of pixel values. The comparison is a process for matching the pixel values of one class to another. Therefore, the value of two same pixels at one location must be combined for representing the suitability or unsuitability in final output. The miss match between any of the pixel at a particular position will limit the all variables for that location.

Furthermore, as a second approach, variables were weighed on the basis of there importance. This approach has benefit over the simple Boolean logic operation. In this approach, each class is assigned a value ranging from 0 to 1 based on importance. The same steps are applied to other variables also. Finally, these layers are combined using multiplication. Thus, a low suitability class of one layer may combine with the higher suitability class of other. The output will be suitability map ranging from 0-1. In past several techniques has been reported for assigning the weight to variable such as Analytical Hierarchical process (AHP) (Satty, 1977), Indices Weight Method (IWM) (Diakoulaki, *et al*., 1995) and direct weighing method. However, weight estimation is controversial issue and depends upon the criterion and their importance in defining the phenomenon (Siddiqui, *et al*., 1996).

The selected variables were scored using pairwise matrix developed by Satty (1977) for applying an analytical hierarchy process (AHP). The Eigen vector was calculated in the context of assigning weight to each parameter. The subjectivity associated with assigning the rates and weight to all the variables is unavoidable. The output can be influence on the basis of assigned weights. The author has no prior knowledge about the importance of variables and believes there was no bias in assigning the weight from the literature.

The fuzzification of all the parameters was done before multiplying with the respective weights. It involves assigning a function which best represent of changing weather conditions during bird migration. All the parameters were normalized from 0-1 using appropriate function based on the available information. Burrough and McDonnel (2005) have discussed different curves (linear, sigmoidal, triangular, etc) for obtaining the grade of membership. The most common membership functions are linear, S shaped, J shaped, trapezoidal and Gaussian The gradual increase or decrease between 0 and 1 is assigned using different membership function. The S-shaped curve represents the smaller changes near the control point than halfway. The J shape function gives the steep drop from high suitability. The Gaussian function represents Bell-shaped curve and be easily related with the statistical value of parameters (Robinson, V. B., 2003, Josphe, 2007). We used the linear, S-shaped and trapezoidal membership functions depending upon the nature of parameter of interest. The membership curves were constructed before implementing the function into software (Fig.3.5-3.6). Finally, the suitability maps are computed by multiplying all the calculated weight with the respective fuzzified parameter. Finally all the maps were added together.

3.4. Variables at pressure level

Air temperature, wind direction and speed data was processed at three pressure levels (100000 mb, 92500 mb and 85000 mb). The altitude of geese was not determined and it is unlikely that they migrate at constant altitude. In the current research this was beyond the scope to analyze data at various heights; so we selected 95000 mb geopotential[2] height. This was based on height at which geese flight direction was analysed for studying the shift in migration path (Green, 2001).

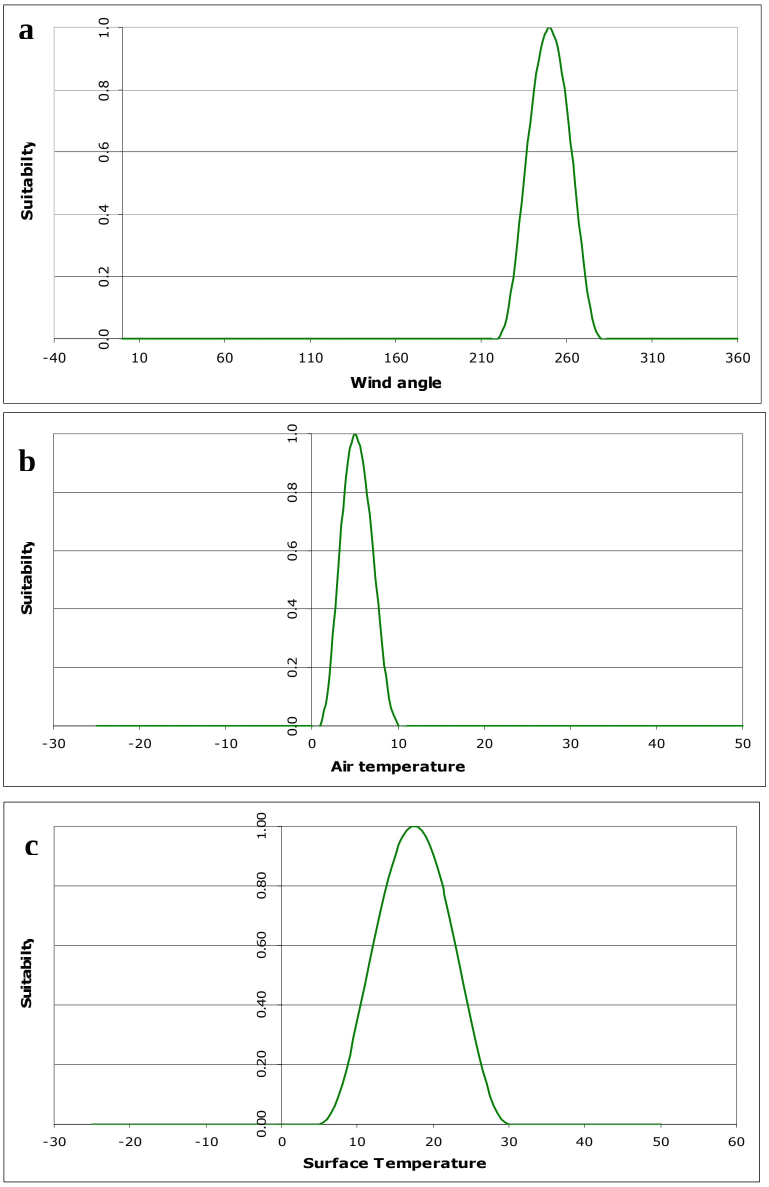


Figure 3.6: Membership function used for assigning the gradual transition a) Wind angle (degree), b) Air temperature (Kelvin), c) Surface temperature (Kelvin)

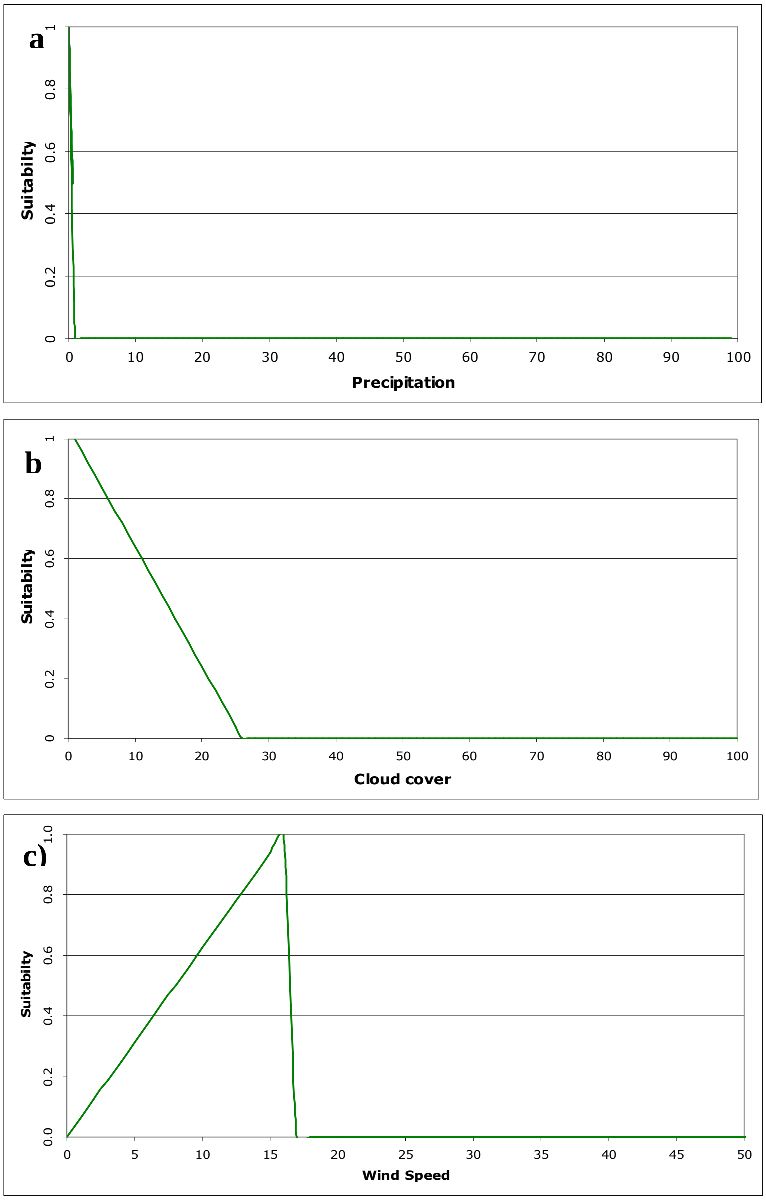


Figure 3.7: Membership function used for assigning the gradual transition a) Precipitation (mm), b) Cloud cover (%), c) Wind speed (ms-1)

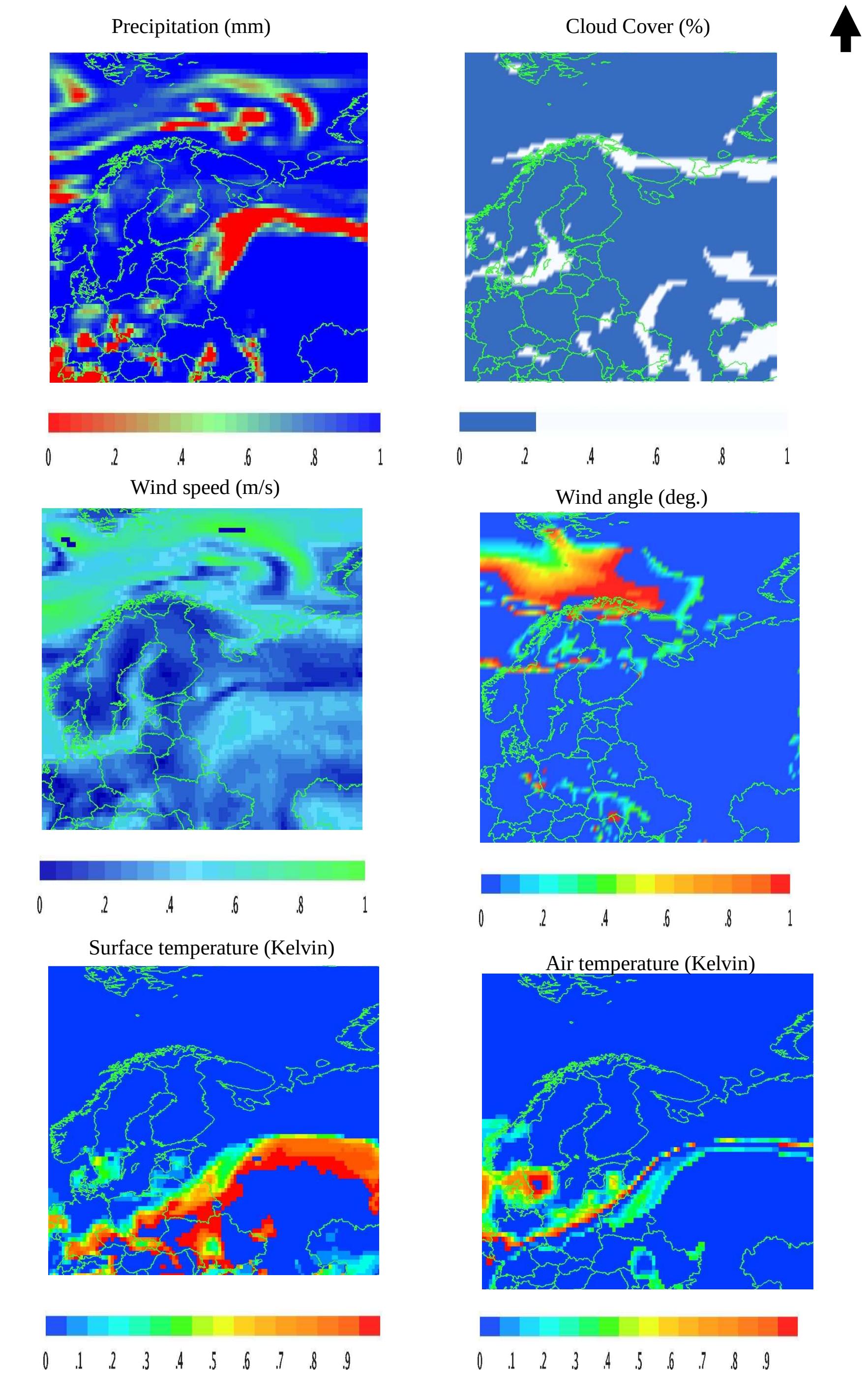


Figure 3.8: Environmental variables after application of membership function onto original parameters

4. Analysis and results

The criterion was taken into account for developing the model in chapter four. The model development engaged three steps, described in the methodology part (Fig. 3.4 and 3.5) such as preliminary data processing and criteria identification, Boolean logic and weighted index overlay process and model validation. In the preliminary analysis few of the input variables were processed for deriving the parameter of interest such as U and V component of wind. However, some parameters were directly used for the further step. Boolean login and weighted overlay process was applied for producing the constraint maps. The model validation step involved comparison between predicted and observed records. The technical approach was also employed to look into the detail of data availability and requirement for the modelling purpose.

4.1. Satellite tracking data

The positional data was linked with the model data for comparing the observed viz. predicted records at particular positions. The following file format prepared for data linking.

Bird Transmitter number	The number of the transmitter used for tracking the individual
The date captured	The date of capturing position of bird, formatted with DD.MM.YYYY
Position$_X$	The latitude of the stop/nonstop (degree)
Position$_Y$	The longitude of the stop/nonstop(degree)
Distance	Distance between successive locations (Km)

Table 4.1: File format for intersecting positional data with model outputs

Following the data structure, .csv files were created for representing the non-stop and stop positions of birds for comparing with the models prediction.

4.1.1. Data requirement and availability

A number of techniques are being used for studying bird migration (described in literature review). In the current research two different techniques viz. satellite and radar tracking were explored for understanding the requirement and availability of data as a researcher for developing a model. The research has outlined the necessary information required with the available data. The current available satellite tracking data is attributed with very limited information. The information required and available is shown in the table 4.1. The tracking data is supplied by ARGOS (discussed in literature review) containing technical and engineering data. In the current research only the technical data is used for modelling purpose. The engineering data is also required for adding more information into technical data. These two data sets were not having the same information for any of the attribute to link together. Thus, the engineering data is not linked with the technical data.

Further, the radar data set includes information about the date, time and position of birds. The radar data explored in the current research was lacking the necessary information (table 4.2). These two data sets can be supplied to the user with the necessary information for effective use. These data sets are composed by the attributes that are the feature for correlating the information with target data using ViSAD data model. The feature with geometry described the data object such as position of birds during the display. Thus, the mathtype of data is important for supporting ViSAD data model. The metadata is defined on the basis of mathtype, Unit, Coordinate system.

The following syntax is used for defining the mathtype of object:
(latitude, longitude) =>
   (air temperature... air temperature))

`Example:`
Index =>(latitude, longitude, Day, Month, Year) => (air temperature. day 1, ...,air temperature. Day n……variables....,n)
#time sequences of multivariate 3-D grids

The output of the model is as following:
(time => ((latitude, longitude, Day, Month, Year) =>(air temperature. day 1, ...,air temperature. Day n……variables....,n)))
#time sequences of multivariate 3-D grids

Taking the user requirement into consideration the additional information is needed to improve the modelling approach using VisAD. The mathtype of object should define on the basis of additional information given in table (4.1).

Index =>(latitude, longitude, Day, Month, Year, altitude, positional error, pressure, air temperature)=>

Output:
time =>(latitude, longitude, altitude, positional error, pressure, air temperature)=> =>(air temperature, surface temperature, cloud cover, precipitation, wind speed, wind direction)))
#time sequences of multivariate 3-D grids.

Data available		Data required												
		A	B	C	D	E	F	G	H	I	J	K	L	M
A	PTT ID	√		√			√	√	√	√	√	√	√	
B	Position$_{X,Y}$		√											
C	Time	√												
D	Day				√									
E	Year					√								
F	Altitude													
G	Wind speed													
H	Wind direction													
I	Air temperature													
J	Positional Error													
K	Pressure													
L	Satellite Count													
M	Satellite data													√

Note: √ indicates available and required data

Table 4.2: Information required and available for model input

	Satellite Tracking	Radar Tracking	Radio Tracking	Bird Ringing	Direct observation
PTT ID	√	×	–	–	–
Position	√	√	–	–	–
Time	√	×	–	–	–
Day	√	√	–	–	–
Year	√	√	–	–	–
Altitude	×	×	–	–	–
Wind speed	×	×	–	–	–
Wind direction	×	×	–	–	–
Air temperature	×	×	–	–	–
Positional Error	×	×	–	–	–
Pressure	×	×	–	–	–
Satellite Count	×	×	–	–	–

Note: √ indicates available and required data

Table 4.3: Information available at present

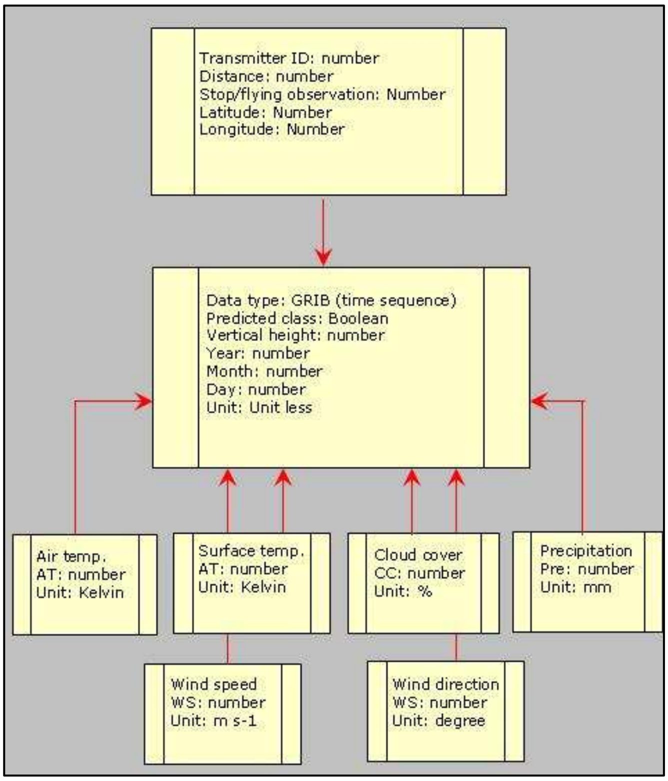


Figure 4.1: Flow diagram showing data structure

4.2. Results

4.2.1. Results of Boolean logic models

Each of the variables is classified into 0s and 1s which have an influence on migration. The adopted criteria was applied to spatial data using else and if functions. The final constraint maps were computed as the multiplication of all the temporal layers (see Fig. 3.4). The values of threshold limit are given in table 3.1. The model including all the selected variables namely air temperature, surface temperature, cloud cover, precipitation, wind speed and direction is shown in the equation 1 (Model 1).

$$S_{(A)} = AT \times ST \times CC \times PRE. \times WS \times WD \text{..........[equation 1]}$$

In second approach, model was run including only three variables namely cloud cover, precipitation and wind speed. The model with three variables is shown in equation 2 (Model 2).

$$S_{(B)} = CC \times PRE. \times WS \text{..........[equation 2]}$$

4.2.2. Models performance assessment

The model data structure is shown in Fig. 4.1. In the first test, observation data was overlaid on the final constraint maps. A total of 934 positions were pooled from three different tracks for comparing the models. McNemar's test was used for comparison (de Leeuw, *et al*., 2006). The results of McNemar's test shows that there is highly significant difference between the two models at a confidence interval of 95% (track 78041; $P<0.00$, track 78043; $P<0.00$ and track 78044; $P<0.00$). Model 1 had classified 3 positions as 1 for track 78041 which has been misclassified by Model 2. However, Model 2 had classified 94, 94 and 104 positions as 1 for track 78041, 78043, 78044 respectively. These positions had been misclassified by Model 1. Hence, based on the results the hypothesis of equal performance of two models cannot be accepted. There would have been chance that the one model may have performed better than the other for any of the events (stop and nonstop events). Thus, both the model data was filtered for further investigation. The distribution of observed stop and nonstop events are shown in Fig. 4.2.

		Model 2		
Model 1		0	1	**Total**
	0	221	94	315
	1	3	7	10
Total		224	101	325

Table 4.4: Frequencies of correctly and wrongly classified positions for track 78041 by model 1 and 2

		Model 2		
Model 1		0	1	**Total**
	0	219	94	313
	1	0	6	6
Total		219	100	319

Table 4.5: Frequencies of correctly and wrongly classified positions for track 78043 by model 1 and 2

		Model 2		
Model 1		0	1	**Total**
	0	185	104	289
	1	0	1	1
Total		185	105	290

Table 4.6: Frequencies of correctly and wrongly classified positions for track 78043 by model 1 and 2

Tracks	78041	78043	78044
Difference of proportion 95%CI	0.28	0.295	0.395
P value	<0.0001	<0.0001	<0.0001

Table 4.7: McNemar's test

It was expected that the models performance would be significantly different for one of the event (stop or nonstop). The observed data used further for separating the model 1 and 2 data into stop and non stop events. The frequencies of stop and nonstop events of model 1 and 2 are shown in table 4.8.

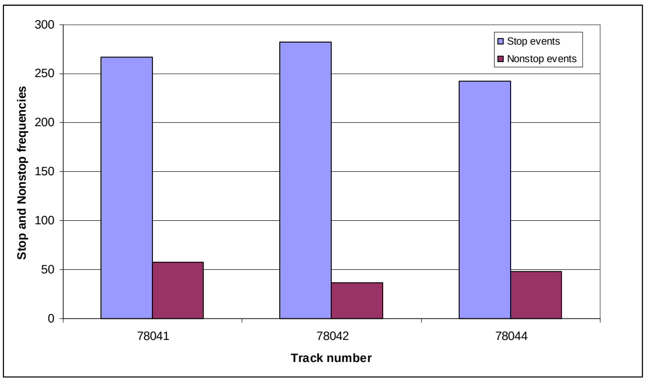


Figure 4.2: Graph showing frequencies of stop and nonstop events

Tracks	Model 1		Model 2	
	Stop events	Nonstop events	Stop events	Nonstop events
78041	315	10	224	101
78042	313	6	219	100
78043	229	1	185	105

Table 4.8: Frequencies of stop and nonstop events (Model 1 and Mode2)

4.2.3. Models comparison

The Chi square statistic was applied for comparing model 1 and 2 based on observed stop and nonstop events. The results are given in table 4.15. The degree of freedom is calculated as (r-1)(c-1) in which r is number of rows and c is number of column (see table 4.15). The critical value at 1df is 3.84 (p=0.05). It is observed in table 4.15, that averagely model 1 is significantly different from model 2 for the stop events of track 78041 and 79043 ($\chi 2_{stop\ events} > \chi 2_{critical}$). Thus, reject the null hypothesis (two models are not significantly different for stop events). However, for the nonstop events averagely these two models are not significantly different ($\chi 2_{nonstop\ events} < \chi 2_{critical}$). Therefore, fail to reject null hypothesis, cannot accept alternation hypothesis at 95% CI for nonstop events. This need to be investigates further by changing the threshold (distance assumption) for stop and nonstop events.

Further, the Chi square statistics was used to infer the superiority of one model to another using observed data. The Chi square value is an index of the goodness of fit of each model. The difference between two models is computed by looking at the difference between Chi square values, used to test each model with observed data. Nine hundred thirty four positions were used from three different tracks for models comparison. The results of models comparison are shown in table 4.24. The results indicate that the model 1 is not significantly better than the model 2 (Chi square statistics $_{model\ 1}$ = $0.03_{track\ 78041}$, $2.82_{track\ 78043}$ and $0.02_{track\ 78044}$, Chi square statistics $_{model\ 2}$ = $0.09_{track\ 78041}$, $0.02_{track\ 78043}$ and $3.13_{track\ 78044}$). The results suggested that the migration events (stops and nonstops), is not explained better using any of these models.

		Model 2		Total
Model 1		0	1	
	0	183	76	259
		(179.5)	(79.5)	
	1	2	6	8
		(5.5)	(2.5)	
Total		185	82	267

Table 4.9: Chi square test for stop events (track 78041)

		Model 2		Total
Model 1		0	1	
	0	38	18	56
		(37.7)	(18.3)	
	1	1	1	2
		(1.3)	(0.7)	
Total		39	19	58

Table 4.10: Chi square test for nonstop events (track 78041)

Model 1		**Model 2** 0	1	Total
	0	194	84	278
		(191.2)	(86.8)	
	1	0	4	4
		(2.8)	(1.2)	
Total		194	88	282

Table 4.11: Chi square test for stop events (track 78041)

Model 1		**Model 2** 0	1	Total
	0	25	10	35
		(23.6)	(11.4)	
	1	0	2	2
		(1.4)	(0.6)	
Total		25	12	37

Table 4.12: Chi square test for nonstop events (track 78041)

Model 1		**Model 2** 0	1	Total
	0	149	92	241
		(148.4)	(92.6)	
	1	0	1	1
		(0.6)	(0.4)	
Total		149	93	242

Table 4.13: Chi square test for stop events (track 78041)

Model 1		**Model 2** 0	1	Total
	0	36	12	48
		(36)	(12)	
	1	0	0	0
		(0)	(0)	
Total		36	12	48

Table 4.14: Chi square test nonstop events (track 78041)

Tracks	**78041**	**79043**	**78044**
Stop events $\chi 2$	7.6	8.95	1.61
Nonstop events $\chi 2$	0.28	4.4	0
DF	1	1	1
Alpha level	0.05	0.05	0.05
$\chi 2$ critical		3.84	

Table 4.15: Comparison of Chi square values (Stop and non stop events)

		Model 1		
Obs.		0	1	Total
	0	259	8	315
	1	56	2	10
Total		249	76	325

Table 4.16: Chi square test (track 78041)

		Model 2		
Obs.		0	1	Total
	0	185	82	267
	1	39	19	58
Total		224	101	325

Table 4.17: Chi square test (track 78041)

		Model 1		
Obs.		0	1	Total
	0	278	4	282
	1	35	2	37
Total		313	6	319

Table 4.18: Chi square test (track 78043)

		Model 2		
Obs.		0	1	Total
	0	194	88	219
	1	25	12	37
Total		219	100	319

Table 4.19: Chi square test (track 78043)

		Model 1		
Obs.		0	1	Total
	0	241	1	241
	1	48	0	0
Total		289	1	290

Table 4.20: Chi square test (track 78044)

		Model 2		
Obs.		0	1	Total
	0	149	93	242
	1	36	12	48
Total		185	105	290

Table 4.21: Chi square test (track 78044)

Tracks	78041	78043	78044
χ^2 Model 1	0.03	0.02	0.02
χ^2 Model 2	0.09	2.82	3.13
DF	1	1	1
Alpha level	0.05	0.05	0.05
$X^2\Delta$	1.64	0.09	0.13
Chi square critical	3.84	3.84	3.84

Table 4.22: Comparison of Chi square values

4.2.4. Models validation

There are different ways of comparing the accuracy of prediction. The well described methods for presence/absence of data are confusion matrices, classification tables and Kappa statistics, (Valavanis, *et al*., 2008) which we have also used. The confusion matrix was used for illustrating the number of true positive, false positive, false negative and the records correctly predicted by model (table. 4.16–4.23). The correctly classified pixels are shown on the diagonal column of the matrix. Error of commission and omission are shown in off diagonal column (table. 4.16–4.21). The producer and user accuracies were estimated for calculating the error. Also, the kappa statistics were calculated for model 1 and 2, this statistics serve as an indicator of the extent to which the percentage correct value of an error matrix are due to true agreement versus chance agreement. The overall accuracy was equal to expected accuracy (Fig. 4.3-4.4). The Kappa states the accuracy if the truth is known. The results of the kappa statistics have been graphically depicted in Fig.4.3 and 4.4. Interestingly the kappa results depict that the model accuracy are random. In the current research the subjectivity is involved in producing the model and categorizing the observed data. The total number of nonstop events was very low in comparison of stop events. Thus, the proper evaluation of models is difficult based on the confusion matrix.

	Producer Accuracy (%)	User Accuracy (%)
Stop events	0.83	0.69
Nonstop events	0.19	0.33

Table 4.23: Producer and user accuracy resulting from the error matrix (track 78041)

	Producer Accuracy (%)	User Accuracy (%)
Stop events	0.89	0.69
Nonstop events	0.12	0.32

Table 4.24: Producer and user accuracy resulting from the error matrix (track 78043)

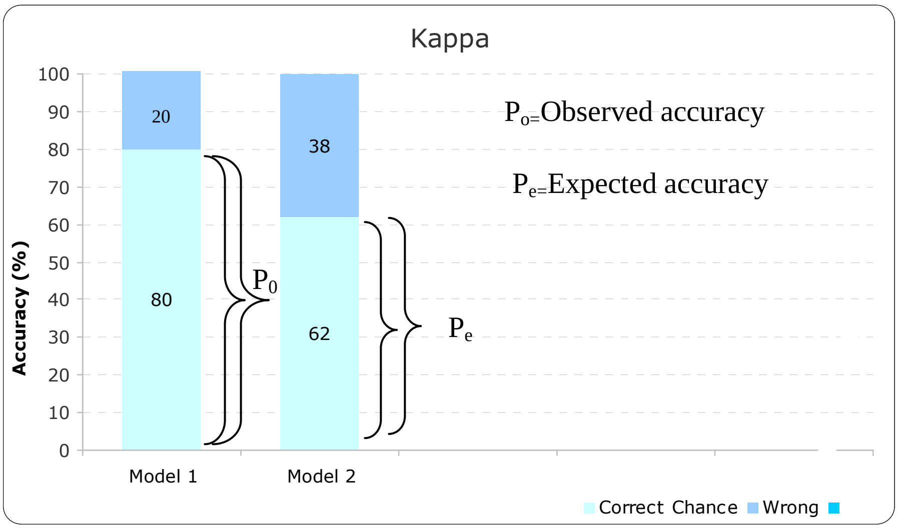


Figure 4.3: Graph showing observed and expected accuracy for track 78041

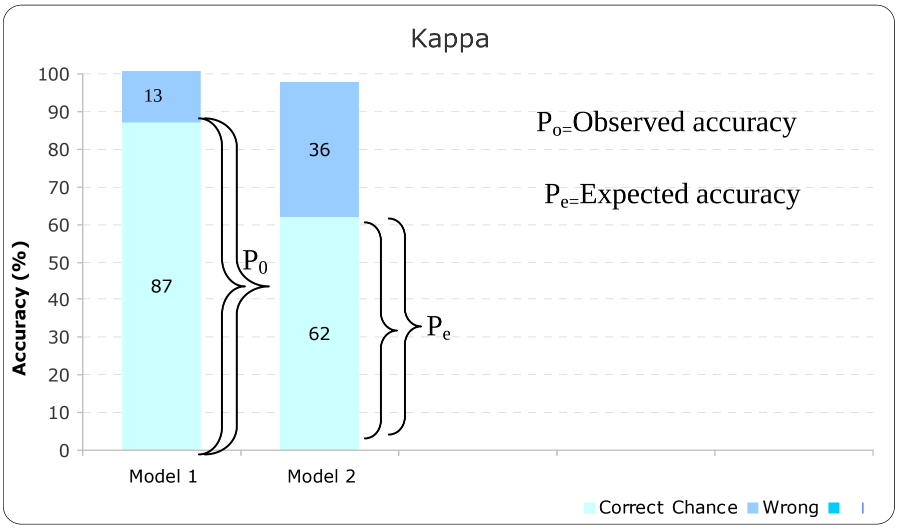


Figure 4.4: Graph showing observed and expected accuracy for track 78043

4.2.5. Results of weighted index overlay model

In the weighted index overlay model all the six variables were used for predicting the suitable and unsuitable weather condition. Each of these layers was classified into ranges from 0 to 1 using fuzzy logic technique (Fig. 3.4 and 3.5). Further, these layers were multiplying with estimated weights (see in table 4.25) and then combined for production the final model, shown in equation 3.

$$S_{(A)} = AT * 0.318 \times ST * 0.210 \times CC * 0.057 \times Pre. * 0.043 \times WS * 0.150 \times WD * 0.221$$

.[equation 3]

The class boundary could not define due to the time constraint. Therefore, the model validation is not performed. From the results given above, it is proved that the results of the models are not as accurate as expected. However, the model including three variables has given slightly better results than the model with all variables. We have to be caution about the uncertainty in observed data. The observed data is not attributed with necessary information such as correct altitude, temperature and positional error (see section 4.2). It’s not the result expected in the beginning of experiment. Therefore, it is expected that in future more accurate data will be collected and change the situation.

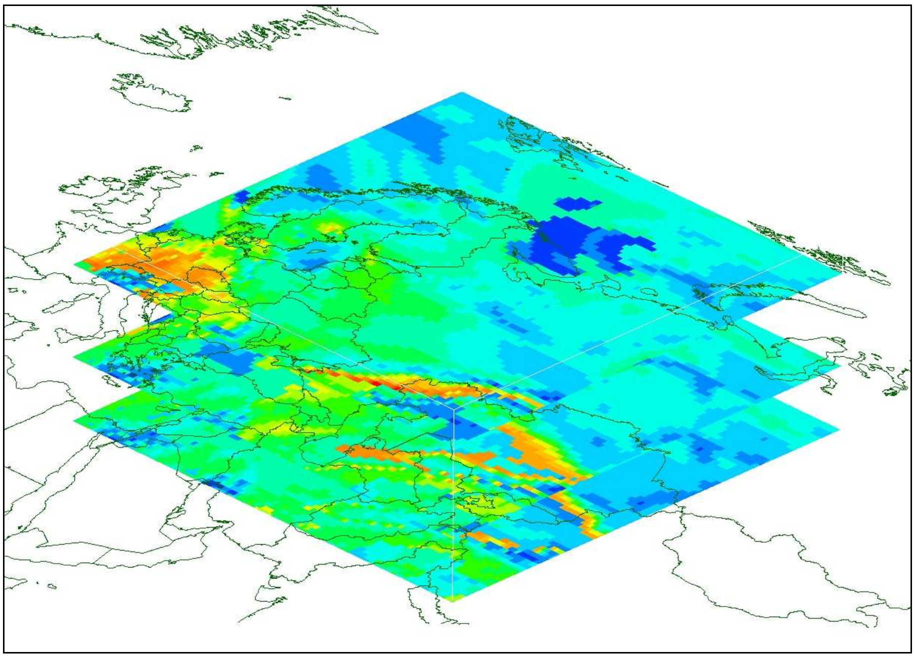


Figure 4.5: A 3D view of weighted index overlay model

Table 4.25: Pairwise-comparison matrix for assessing the relative importance of variables

	Wind speed	Precipitation	Cloud cover	Air temperature	Wind angle	Surface Temperature
Wind speed	1	4/1	3/1	1/2	1/3	2/1
Precipitation	1/4	1	1/1	1/6	1/4	1/2
Cloud cover	2/1	1/1	1	1/5	1/3	1/2
Air temperature	3/1	6/1	5/1	1	2/1	3/1
Wind angle	3/1	4/1	3/1	1/2	1	2/1
Surface Temperature	1/2	2/1	2/1	3/1	1/2	1

							Eigen vector	Weights
Wind speed	7.000	18.833	17.500	8.567	5.167	7.917	64.983	0.150
Precipitation	2.475	5.500	5.000	1.600	1.608	2.350	18.533	0.043
Cloud cover	3.475	7.500	6.500	1.850	1.942	3.350	24.617	0.057
Air temperature	17.250	41.000	36.000	14.500	10.250	18.500	137.500	0.318
Wind angle	11.000	29.500	25.500	9.900	6.500	13.250	95.650	0.221
Surface Temperature	13.000	25.000	24.000	7.300	8.667	13.000	90.967	0.210
							432.250	1.000

5. Discussion and conclusion

This chapter presents some important points that have been unearthed by the research. Selecting and applying methods for finding the suitable and unsuitable weather condition involves consideration of more than just the combination of various layer. Additional consideration should include the distance from the adjacent suitable pixel within the layer and the accumulation of values of parameters of interest with time rather than simply overlapping different layers of geographical information. The approach based on the accumulation of values of parameter of interest and distance from the adjacent suitable pixel may extract the strong and interesting pattern with the tracking data in order to understand bird migration more clearly. This is something need to be tested further.

5.1. Literature based information

The study revealed that the literature based information is too general to use as an input for model development on a large scale. This information can be use in case data necessary for empirical model is not available. The available literature based information is non quantitative in nature. Thus, the research does not advocate the modelling bird migration exclusively on the basis of literature only.

5.2. Data requirment

There are various method used for collecting the migration data (described in chapter 2). However, none of these methods alone does not make it possible to forecast bird migration information. In the analysis, it was observed that the structure available satellite tracking data is not sufficient enough to meet the demand for model development. The available data lacks necessary information such as satellite coverage for calculating the positional error (see

4.1.1). Therefore, higher quality of data is required to meet the demand for developing and validating model with higher accuracy.

5.3. Model performance

The research has attempted to compare the model performance against each other. The test showed the overall performance of one model was different from the other. The further investigation indicates that models had performed differently for the stop events than the nonstop. This could be due to the surface weather conditions at stopover positions. However, these results remain uncertain due to the lack of necessary information such as accurate altitude for classifying observed data correctly into stop and nonstop events.

5.4. Merits and demerits of method

The methodology used in this study was considered to be appropriate. Beyond the calibration of model, research has envisioned approach towards modelling bird migration on a large scale. Though, we could not provide the strong evidences about the overall accuracy of the prediction due to the uncertainty in observed data. Further, it would be beneficial to incorporate additional information, which is not included in either of the model. For instance, the onset of migration could be due the deteriorating living conditions in terms of availability of food. Thus, the departure of migrant will depend not only on the current condition but on the prior conditions as well. The model tested in this research work implicitly assumes that the specific day conditions could trigger the migration. Although, the bird could be sensitive to the number of day's where weather conditions is above or below the threshold level than to the specific day conditions. Therefore, to flag a pixel as suitable on the basis of prior conditions with the accumulation of time may strongly influence the model.

Furthermore, the migration mechanism could be define based on the leaving conditions in the area bird are living, weather condition during migration and in the area birds are heading. The model shows only one mechanism, namely weather condition during the migration. However, these three mechanisms not necessarily function independently of each other but interact for triggering the migration. For instance, there could be linear relationship between average value of surface temperature and the time period birds are sensitive to meteorological conditions at breeding ground. However, at the same time the surface temperature may be optimum at wintering ground. Thus, in response to temperature influence either as a push or a pull birds start to migrates from one place to another. Incorporating such mechanism in the model will be interesting for future research work.

The choice of migration is influenced by highly dynamic weather conditions such as temperature. The temperature is a continuous variable and not limited to only a point. However, the model has used the temperature as discrete variable by converting into suitable and not suitable class. The dynamic model has to cope with continuous nature of the predictor variables. The effect of this could be influence the selection of suitable pixel. In reality bird might have fly near to pixel consisting suitable weather condition but at the same time pixel beneath the trajectory has unsuitable conditions. Thus, the distance measurement is required from adjacent pixel to flag a pixel as suitable or unsuitable (Fig. 5.1).

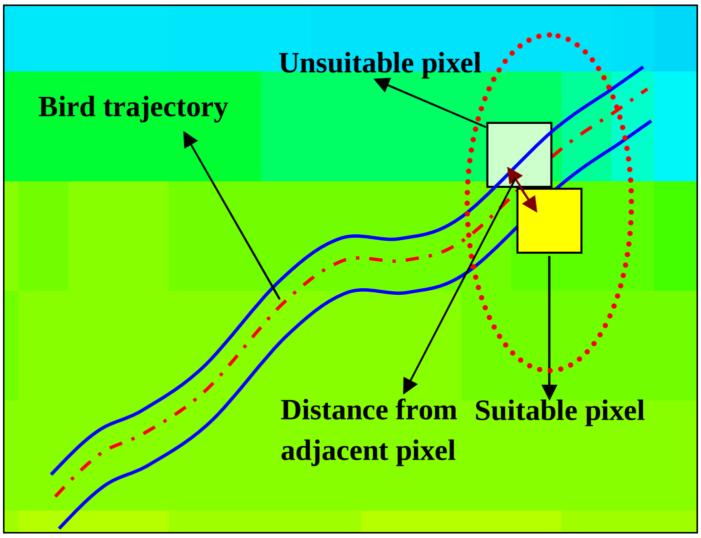


Figure 5.1: Air temperature as a discrete medium

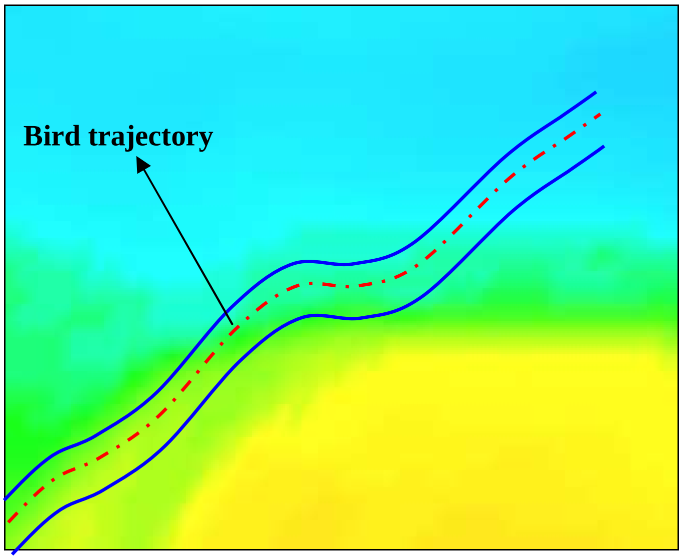


Figure 5.2: Air temperature as a continuous medium

5.5. Reasons to exclude variables

The research has decided to use six variables on the basis of published literature and the data available. Though, in the second mode three variables were considered after testing the various combinations. The published information could not ignore on the basis of unexpected outputs of model. There could be certain reasons that a particular variable has not contributed in the model. For example, it may be inappropriate to assume that the growth of grass would be correlated with the increasing temperature all along the migration route. There could be chances that the growth of grass may not be synchronizing with the increase temperature to include into the model. Predictability of grass growth could be higher between certain points and lower between others based on temperature. So the geese migration could better match with some part of migration route only. This could be a reason that model has not taken temperature into account for predicting the suitable conditions all along the migration route. Besides this, the air temperature is also excluded due to not making expected contribution in predicting the migration. The given air temperature was taken from the literature specifying the conditions for the geese migration over the Sweden. It may unlikely to assume that the bird migrate at a constant rage of air temperature over the entire migration route. The given air temperature may be appropriate for predicting the suitable conditions over the Sweden than the other areas.

The reason of excluding wind direction from the model is due to finding difficulties of tracking geese always with the tailwind. It has been reported that geese have possibility of flying with headwind and sidewind as well. Therefore, the suitability to pixels could not be assign based on tailwind only. The strategies of flying with the wind direction could be based on speed. For instance, if the speed of tailwind is higher than the speed of bird, the bird may drift from the original track. Thus, the bird can try to avoid the tailwind with higher speed. Another challenge was to find the sector of wind which could support the flight with tailwind. The decision of excluding wind direction was taking after testing the different threshold of wind direction from ±5 degree to ± 30 degree of tailwind. The sector of wind could also vary depending on the direction of wind. For instance in case of headwind with the low speed bird could fly with the wide wind sector. However, in case of tailwind birds can follow the narrow sector of wind even with the higher speed. Thus, the conditional function between wind speed and direction may help to improve the model.

5.6. Data quality

The study used satellite tracking data for comparing the models. In the analysis part as described in chapter 4 section 4.1.1 raw observation data was filtered with the assumption that the distance criteria may separate out stop and nonstop positions. This might not be the case, because these points were not attributed with the correct altitude information. Therefore, it may not categories exactly into the true condition. This means that the nonstops positions might have occurred but not be categorised as a true conditions. These could results to no or very low prediction as observed in table 4.2 and 4.3. The consequence of using such data could lead towards the incorrect conclusion. Thus, to use distance criteria between the successive positions is not adequate for separating the stops from nonstops positions. Other information such as speed, altitude, temperature and air pressure have to be considered.

Furthermore, (Patterson, et al., 2008) has commented that movement data is affected by the positional errors due to the poor coverage of satellite described in chapter 2, section 2.5. Thus, it is acknowledged that the observation data used in this study may have deficiencies in quality.

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Appendices

Appendix 1: Table showing details of data product used in this study

Data Product	Unit	Satellite/ Model	Spatial Resolution	Vertical levels	Vertical Resolution	Temporal Resolution	Total Images	Website Source	Data retrieved
Air temperature	^{0}C	GFS	0.5 degree	10000, 95000, 85000 Pa	3 layers	Daily, April 11 - June 30, 2008	972	http://nomads.ncdc.noaa.gov/thredds/catalog.xml	5/12/2008
U Component of wind	m/s	GFS	0.5 degree	10000, 95000, 85000 Pa	3 layers	Daily, April 11 - June 30, 2008	972	http://nomads.ncdc.noaa.gov/thredds/catalog.xml	5/12/2008
V component of wind	m/s	GFS	0.5 degree	10000, 95000, 85000 Pa	3 layers	Daily, April 11 - June 30, 2008	972	http://nomads.ncdc.noaa.gov/thredds/catalog.xml	5/12/2008
Surface temperature	^{0}C	GFS	0.5 degree	-	-	Daily, April 11 - June 30, 2008	324	http://nomads.ncdc.noaa.gov/thredds/catalog.xml	5/12/2008
Total Cloud cover	%	GFS	0.5 degree	-	-	Daily, April 11 - June 30, 2008	324	http://nomads.ncdc.noaa.gov/thredds/catalog.xml	5/12/2008
Precipitation	%	GFS	0.5 degree	-	-	Daily, April 11 - June 30, 2008	324	http://nomads.ncdc.noaa.gov/thredds/catalog.xml	5/12/2008

Appendix 2: Questionnaire

1. Details of the contact person:
   Name………………………………Organization:……………………………………
   Department: ……………………… Country:…………………………………………

2. Are you involve in any bird migration studies.
   a) Yes: b) No:

3. What are the limiting factors studying bird migration.
   a) Lack of ornithologist studying bird migration
   b) Lack of awareness among people across the countries
   c) Legislation and permission to carry out studies in countries (Israel and Palestine)
   d) Others

4. Do we lack the following level of information for studying bird migration.

Information	Yes	No	Not known
Flight pattern and behaviour			
Dates of arrival and departure			
Use of resources by bird			
Important migration routes			
General migration routes			
Others			

5. Which method you find effective for studying bird migration in combination of weather information.
   a) Satellite tracking
   b) Radar tracking
   c) Bird ringing
   d) Volunteer based monitoring
   e) Others

6. How would you evaluate the difficulties to study the bird migration using the following methods.

Methods	Ok	Easy	Difficult	Not Known
Satellite tracking				
Radar Tracking				
Bird Ringing				
Volunteer based monitoring				
Others				

7. Please rank the methods from 1-5 for studying long and short range migrants.

Methods	Long range migrants	Short range migrants
Satellite tracking		
Radar Tracking		
Bird Ringing		
Volunteer based monitoring		
Others		

8. Please rank the methods from 1-5 according to the skilled professionals required for collecting and processing the information.

Methods	Rank
Satellite tracking	
Radar Tracking	
Bird Ringing	
Volunteer based monitoring	
Others	

9. Please give your opinion about the failure of system/instruments in the following methods.

Methods	Very high	high	Moderate	Low
Satellite tracking				
Radar Tracking				
Bird Ringing				
Volunteer based monitoring				
Others				

10. Please rank the risk factors of losing information while using satellite tracking (Rank 1-4).

Factors	Rank
Death of bird	
Bad weather conditions	
Loss of transmitters	
Others	

11. Please rank the risk facors of losing information while using bird ringing data (Rank 1-5).

Factors	Rank
Death of bird	
Probability of recapture	
Wrong site selection for capturing birds	
Wrong season selection for capturing birds	
Others	

12. Please rank the risk factors of losing information while using radar tracks (Rank 1-5).

Factors	Rank
Unstrategical location of Radar	
Difficulties in locating bird in radar view	
Incomplete tracks	
Others	

13. Which methods give additional information such as population status, disease outbreak, survival and requirement of species.

Methods	Bird age	Population status	Health of individual	Death
Satellite tracking				
Radar Tracking				
Bird Ringing				
Volunteer based monitoring				

14. Have you ever combined remote sensing data with the bird migration data for predicting the migration routes.

a) Yes: b) No:

15. If yes, how do you rate the remote sensing data products in combination of different methods for predicting migration routes.

Methods	Excellent	Good	Average	Not known
Satellite tracking				
Radar Tracking				
Bird Ringing				
Volunteer based monitoring				
Others				

16. Please rank the causes of bird migration (Rank the causes from1-12).

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Causes for bird migration	Rank
Air temperature	
Surface temperature	
Cloud cover	
Biological clock	
Vegetation cover	
Precipitation	
Humidity	
Wind speed	
Wind direction	
Others	

17. What is the preferred atmospheric temperature for birds to depart from a particular place.

a) < 0 0C b) 1 to 5 0C c) 6 to 10 0C

b) 11 to 15 0C d) 16 to 20 0C e) > 20 0C

18. What is the preferred surface temperature for birds to depart from a particular place.

a) < 0 0C b) 1 to 5 0C c) 6 to 10 0C

b) 11 to 15 0C d) 16 to 20 0C e) > 20 0C

19. What is the preferred air temperature (2 meter above from the surface) for birds to depart from a particular place.

a) < 0 0C b) 1 to 5 0C c) 6 to 10 0C

b) 11 to 15 0C d) 16 to 20 0C e)> 20 0C

20. Preferred cloud condition for birds to depart from a place.
a) Clear sky (0/4) b) Partly cloudy (2/4)
c) Moderately Cloudy (3/4) d) Completely cloudy (4/4)

21. Preferred vegetation cover in terms of Normalized vegetation index (NDVI) for birds to start migration.
a) Bare ground (-1 to 0) b) Sparse vegetation cover (0 to 0.2)
c) Medium vegetation cover (0.2 to 0.6) d) High vegetation cover (>0.6)

22. Preferred amount of rainfall in centimetre (cm) for birds to start migration.
a) Absence of rainfall (0 cm) b) Low rainfall (1 to 25 cm)
c) Low to medium rainfall (26 to 100 cm) c) Medium rainfall (101 to 150 cm)
d) High rainfall (>150 cm)

24. Preferred amount of humidity in percentage (%) for birds to depart from a place.
a) 0 to 20% b) 21 to 40% c) 41 to 60%
d) 60 to 80% e) 80 to 100%

23. Preferred wind direction for birds to start migration.
a) Absence of wind a) Tailwind b) Headwind
c) Crosswind (either from the left or right side in relation to the migration direction)

24. How much angular deviation in wind direction in relation to migration path will affect the bird's decision to take off.
a) < 1degree b) 1-5 degree c) 6-10 degree d) >10 degree

25. Preferred wind speed in mile per hour (MPH) at 10 m above the surface for birds to start migration.
a) No wind (< 0) b) Weak wind speed (1 to 7 MPH)
c) Medium wind speed (8 to 18) d) Medium to high wind speed (19 to 31)
e) High wind speed (32 to 46 MPH) f) Very high wind speed (>47 to 63 MPH)
g) Storm (>63 MPH)

26. Please rank the threats for birds during migration. (Rank the threats from 1-7)

Causes for bird migration	Rank
Hunting	
Unfavorable weather conditions	
Food scarcity	
Habitat alteration	
Predation	
Disease	
Others	

27. What are the human caused hazards for migrants (Ranks the hazards from 1-4).

Hazards for bird migration	Rank
Tall structure (Lighthouses, Tower etc.)	
Electronic towers supporting cables	
Habitat degradation	
Others	

28. Any other information.