# LINKING HORIZONTAL AND VERTICAL MODELS TO PREDICT 3D + time DISTRIBUTIONS OF BIRD DENSITIES

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## Abstract

The BAMBAS (Bird Avoidance Model/Bird Avoidance System) team aims at developing a Bird Avoidance Model (BAM) to predict spatial (horizontal and vertical) and temporal bird densities under changing meteorological conditions. The BAM will be used as a decision support tool for experts in the Royal Netherlands Air Force providing bird hazard warnings in real time and predictions for flight planning to reduce the risk of bird aircraft collisions. The BAM consists of several models that will be linked after their completion. In this paper we present results from the flight altitude and bird distribution models and describe how these will be integrated into an operating system.

The distribution of birds in the Netherlands is being modelled based using the large SOVON database of a spatially dense network of counts in the breeding season and around Christmas. Observations have been analysed in relation to several variables including land cover, landscape characteristics, and vegetation to interpolate densities at places and at times where measurements are lacking. Regression analysis and spatial statistics have been integrated to develop these predictions, visualized in GIS. These spatial distributions with low temporal resolution were combined with time series obtained from systematic daily observations at airfields, to generate a 2D+time evolution over 25 years.

Several models have been developed that predict flight altitudes of birds using different flight strategies in relation to local meteorological conditions. A bird's flight altitude and flight strategy is strongly influenced by weather. Weather has a stronger influence on the flight altitudes of birds using predominantly soaring and gliding flight. The main factors influencing flight altitudes differ between flight strategy groups.

Local real time or forecast weather conditions are used as input to the flight altitude models directly linked to the distribution models to create the high-resolution full 3D+time predictions of bird densities under changing environmental conditions.

## 1. Introduction

In the Netherlands, a unique multidisciplinary team is developing a Bird Avoidance Model (BAM) for northwest Europe predicting spatial (horizontal and vertical) and temporal bird densities under changing environmental conditions. This model will be used by experts from the Nature Bureau of the Royal Netherlands Air Force as a decision support tool to reduce the risk of bird aircraft collisions. In reality, the distribution of birds at different temporal and spatial scales cannot be modelled effectively with one single model but requires a broader approach and the development of multiple complementary models (fig. 1).

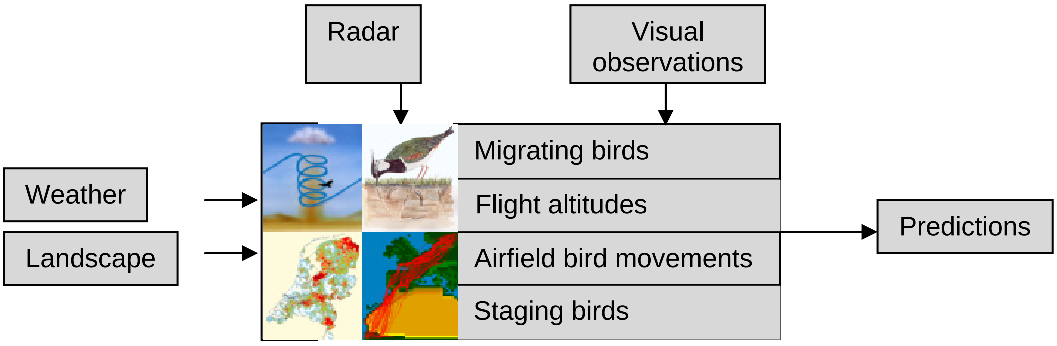


**Figure 1**. Submodels of the BAM developed in the Netherlands. Input for various models include weather and environmental data as well as radar measurements and visual observations of birds. Predictions from the models will be integrated to form decision support tools.

In order to develop a realistic three-dimensional temporal model of bird densities, quantitative data are needed on bird densities, movements and flight altitudes together with a clear understanding of how these patterns are related to their environment at different scales. The current paper focuses on the methodology and results the of flight altitude and staging bird models as well as the tools developed to provide predictions of the spatial and temporal distribution of birds in the Netherlands. The migration models are discussed in the paper by Bouten et al. 2005, in these proceedings.

Nationwide maps of bird distribution or abundance at a high spatial and temporal resolution, needed for the BAM, are not readily available. They require intensive fieldwork of hundreds or thousands of volunteers and can only be carried out every few decades. Only a small number of rare or very aggregated species can be monitored on a national scale every year, and rarely every month. In order to map the distribution and abundance of birds in space and time we have to rely on information obtained at sample sites, which do not cover the entire area of interest. Therefore we developed a method to fill in the gaps between observation sites in order to create distribution maps from observational surveys.

Detailed measurements of the vertical distribution of different species of birds are sparse in scientific literature. Most of these studies have concentrated on migrating birds rather than local movements, the focus of the flight altitude and staging bird submodels. The flight altitudes of birds differ among species and vary greatly from day to day. External factors such as meteorological conditions are known to have a strong affect on the flight altitudes of soaring birds relying on thermal convection during flight (Pennycuick 1972; Spaar 1995; Shannon et al. 2002; Shamoun-Baranes et al. 2003a,b). Thus, the flight altitudes of birds during local movements over land, from different taxonomic groups using different flight strategies were measured using tracking radar and modelled in relation to local meteorological conditions (for more details see Shamoun et al. *accepted*).

## 2. Methods

66 species were selected as key species to be included in the BAM. These species were selected based on a combination of criteria including involvement in birdstrikes, proportion of damaging bird strikes, abundance, flocking behaviour, size of birds, availability of data, high conservation interest.

### 2.1 Distribution of birds in the landscape

Data from the SOVON bird atlases and bird monitoring program (Sierdsema 2003, www.sovon.nl) were used to develop the distribution and abundance maps for the BAM. In order to illustrate the method used for all species to create distribution maps from count survey data, the Point Transect Counts of wintering Common Buzzards (*Buteo buteo*) were selected (fig.2). Results will focus on data analysed from the December 2000 Buzzard counts. The Point Transect Counts collect data on mainly terrestrial wintering birds annually along about 400 transects with 20 observation points each. A total of over 1000 transects have been monitored since the start of the project in 1980. Fieldwork was carried out by thousands of volunteers and a small group of professional ornithologists. Observers are requested to count all species at each point during exactly 5 minutes (Sierdsema et al. 1995). Original counts for the month of December were used for the spatial modelling to predict the number of birds per square kilometre using a technique called regression kriging (Hengl et al. 2004).

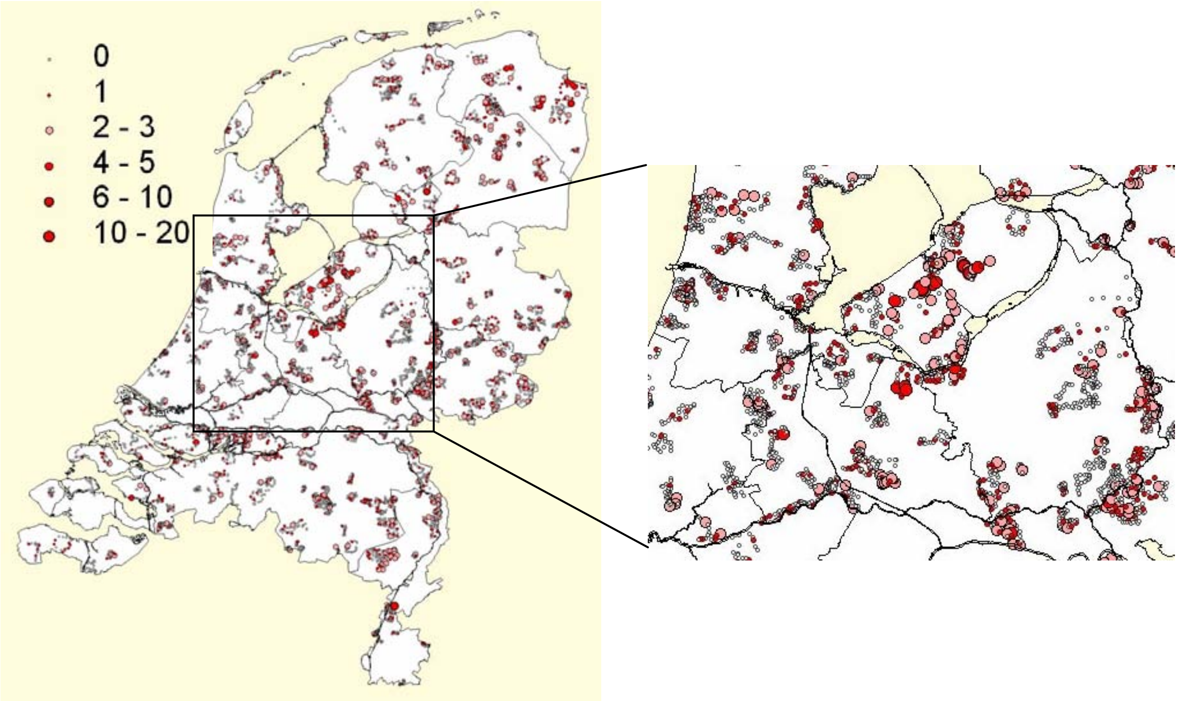


**Figure 2.** Number of Common Buzzards *Buteo buteo* in The Netherlands, per sample point in December 2000, with the central Netherlands enlarged on the right.

Based on the literature, a number of variables were selected that are known to influence the distribution of Buzzards and for which maps with complete coverage for the Netherlands exist. A total of 20 variables were tested: 8 land-use variables derived from the 1:10,000 topographical map of the Netherlands (Topografische Dienst, Emmen), openness of the landscape (Alterra), physical geographical regions (or bioregions) and snow and ice coverage (table 1). For the land-use variables both the area in a circle of 0-200 m and 200-1000 m around each point was used, resulting effectively in 16 land-use variables.

**Table 1.** Variables and their parameter estimates, standard error (s.e.), t-values and nominal p-values for the regression model (GAM) of wintering Common Buzzards in 2000.

| Variable | Estimate | s.e. | *t*-value | *p*-value |
|---|---|---|---|---|
| FGR | 298.74 | 19.92 | 23.50 | < 0.001 |
| Ice | 11.33 | 5.66 | 6.68 | 0.001 |
| Snow | 8.62 | 4.31 | 5.08 | 0.006 |
| X Lin | 0.0000070 | 0.00000081 | 8.62 | < 0.001 |
| Y Lin | -0.0000032 | 0.00000085 | -3.82 | <.001 |
| Arable-1000m | 0.0026 | 0.00094 | 2.79 | 0.005 |
| Grassland-1000m | 0.0026 | 0.00095 | 2.73 | 0.006 |
| Small waterbody-200 m | -0.086 | 0.030 | -2.88 | 0.004 |
| Small waterbody-1000 m | -0.0039 | 0.0017 | -2.24 | 0.025 |
| Large waterbody-200 m | -0.094 | 0.047 | -2.01 | 0.044 |
| Builtup –200 m | -0.16 | 0.030 | -5.27 | < 0.001 |
| Builtup –1000 m | -0.0080 | 0.0015 | -5.27 | < 0.001 |
| Forest –200 m | -0.067 | 0.022 | -3.11 | 0.002 |

A regression model (General Additive Model, 'GAM') was built for each year for the number of Buzzards per sample point in the December-count. The Poisson-distribution, with a log link was selected in the modelling procedure for the following reasons: (1) the number of Buzzards per point is always positive (2) many points contain zeros (3) variance increases with increasing abundance. The dispersion parameter, describing over- or under-dispersion of the counts, was estimated from the residual deviance. Variables were selected by fitting all possible regression models and evaluating these according to the $C_p$-criterion of Mellows for goodness of fit. Most variables were added as linear predictors. Openness of the landscape was added as a 3rd-degree smoothing spline, the coordinates as a 4th degree smoothing spline. As an indication of the variance explained by the regression model, the percentage of explained mean deviance was used. The deviance depends on the number of positive observations and is not a direct measure of fit, nevertheless it can be used to compare models of different complexity applied to the same data (Pebesma et al. 2000). The best fitting model predictions and standard errors were calculated at a 1 $km^2$ resolution for The Netherlands. These predictions were mapped with the Geographical Information System ArcGIS (ESRI).

The difference between the counts and the regression predictions, residuals, were calculated. These residuals were spatially interpolated with ordinary kriging, resulting in a 1 $km^2$ map with complete coverage for the Netherlands. Prediction maps for the Buzzard densities were finally obtained by adding the estimated densities from the GAM to the interpolated values of the residuals.

### 2.2 Flight altitudes of birds

For full details of this study see (Shamoun-Baranes et al. accepted).

Between April and August 2000, during 15 days, the flight altitudes of several species of birds were measured at De Peel (south-eastern Netherlands) using an Flycatcher radar with a fan beam antenna for selection and a pencil beam antenna for tracking of birds. The following species were studied as representatives of flight characteristic groups: the buzzard, a soaring bird; the swift (*Apus apus*), an obligatory aerial forager; and the black-headed gull (*Larus ridibundus*) representing an intermediate group using both flapping and soaring/gliding flight.

Multiple linear regression models were built by fitting explanatory variables to maximum hourly flight altitude as the response variable. Explanatory variables included several meteorological variables such as temperature, wind speed and direction, boundary layer height, relative humidity, lifted index (a measure of atmospheric instability), time of day and time of year. Each species was analysed separately. In order to keep models relatively simple, models were limited to no more than four significant ($p \leq 0.05$) explanatory variables.

### 2.3 Seasonal, daily and general altitude patterns

Information on the seasonal abundance (24 bimonthly periods), daily activity pattern (4 periods), altitude distribution (5 altitude layers) and ratio of birds in the air (activity factor) of each of the key species, was collected from a variety of sources including the RNLAF bird control unit counts, SOVON waterbird counts (SOVON 2004), visual migration counts (LWVT/SOVON 2002), Eurbase (e.g. Dekker et al. 2003), tracking radar measurements and expert knowledge. This information is stored in a relational database. Abundance, daily activity pattern, activity factor and altitude distribution were integrated with the spatial distribution maps developed in order to create composite density distribution maps for each combination of time of year, time of day, altitude layer, resulting in 480 static density maps. Densities are represented in two ways, kg/km$^3$ and # of birds/km$^3$, these densities are then grouped into 8 classes to produce hazard maps presented in the expert system.

## 3. Results

### 3.1 Modelling buzzard spatial distribution

Significant predictors of buzzard distribution in 2000 are summarized in table 1. Annual models explained 13% to 16% of the variation in Buzzard numbers per point in the years 1978-2003. In all years physical geographical region and spatial trend (x- and y-coordinates) were significant. In general a positive relationship was found with the amount of arable land and grassland with comparable regression coefficients and a negative relationship with built-up area, open water and forest. In most models, land use within a 200 m radius or a buffer of 200 to 1000 meters was included in the model. For small water bodies and built-up areas though, both distances were included. Ice, snow and openness of landscape had a significant influence in a limited number of years. In 2000 ice and snow had a significant negative influence.

Figure 3 shows the results of the predicted number of Buzzards per km$^2$ using the GAM. The residuals of the regression model are spatially correlated. The interpolated residuals of the model of 2000 are shown in figure 4. In this map there are distinct regions with higher or lower numbers of counted Buzzards than predicted by the regression model. The combination of the predicted distribution from the regression model and the spatially interpolated residuals, results in the final prediction for December 2000 (fig. 5).

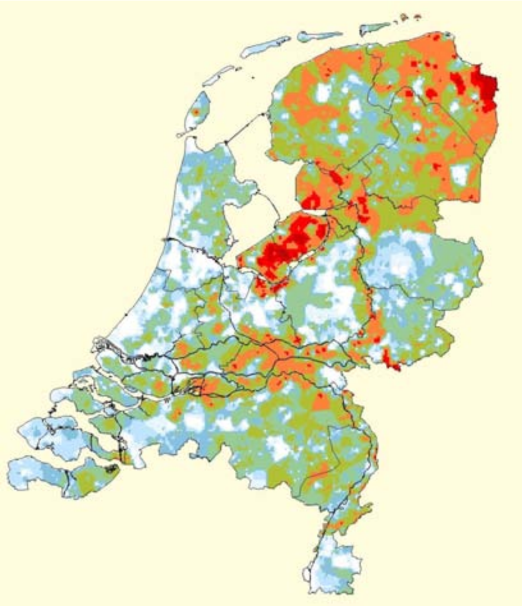


**Figure 3**. Number of Common Buzzards per km$^2$ in December 2000 as predicted by the GAM.

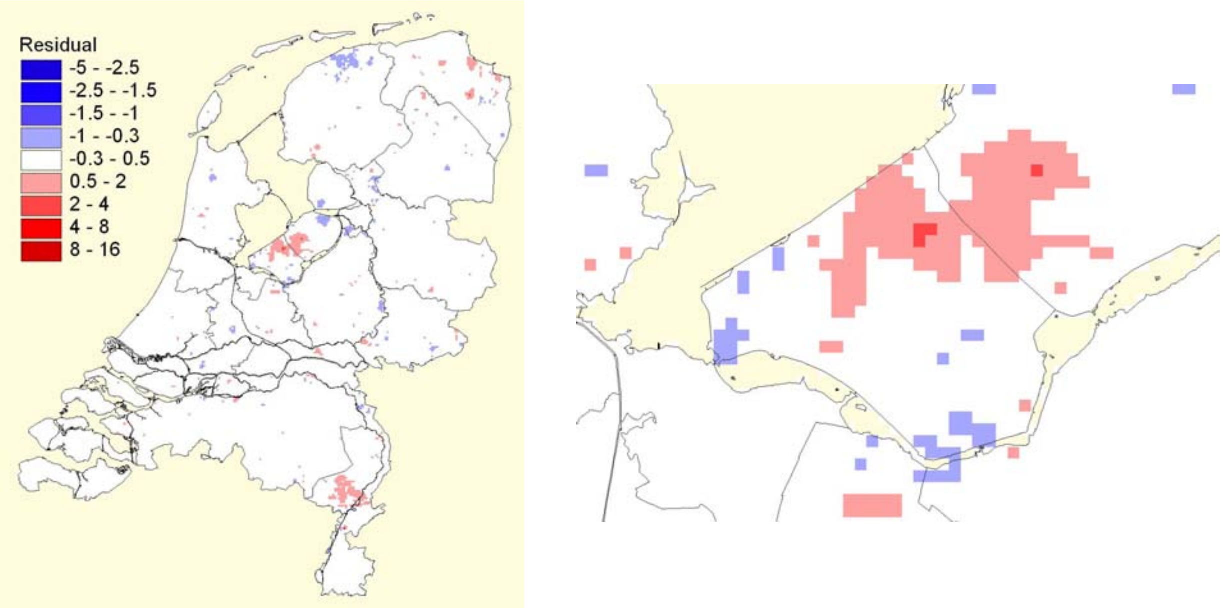


**Figure 4**. Spatially interpolated map of the residuals (measurement-prediction) of December 2000 for the Netherlands and an enlargement of the central Netherlands on the right. Red indicates an underestimate of buzzards by the model, blue indicates an overestimation.

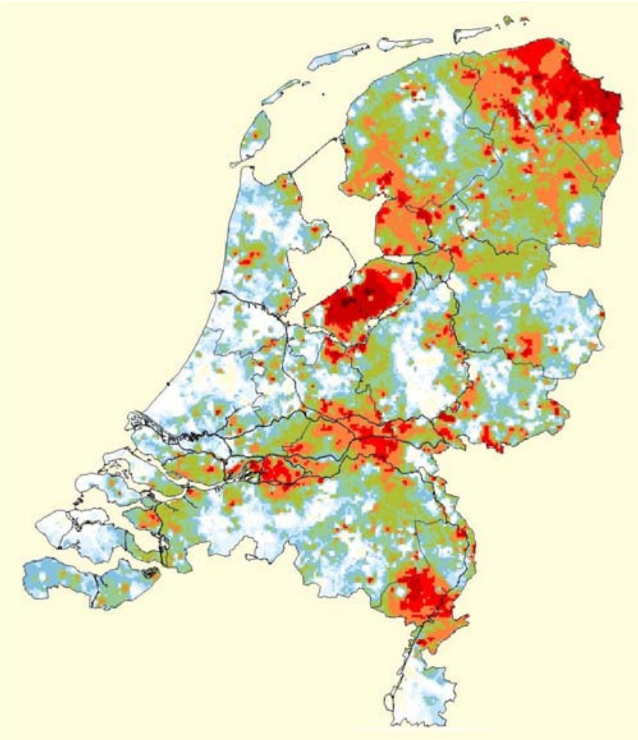
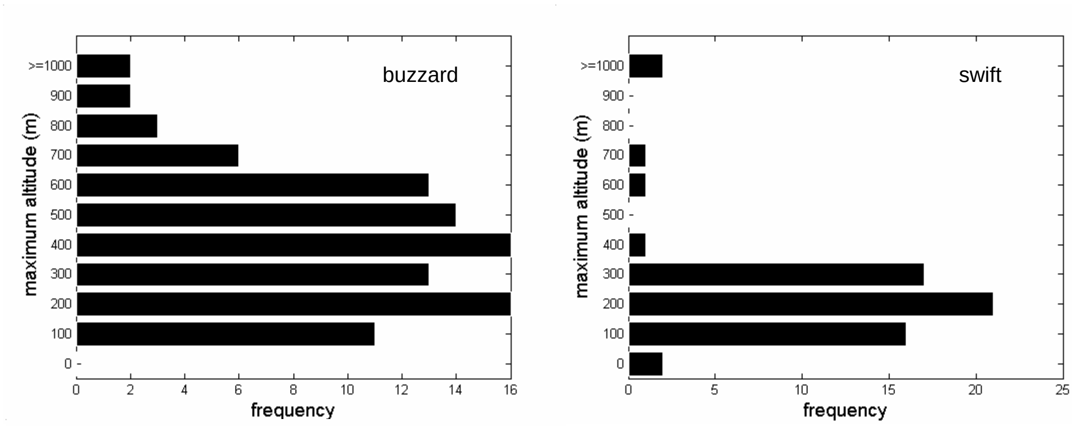


**Figure 5**. Final predictive map of the distribution of Common Buzzards in December 2000, as a result of regression kriging (a combination of techniques used to generate the maps in figs. 3 and 4).

### 3.2 Modelling flight altitudes

Of the three species studied, buzzards flew highest 423 ± 252m (mean ± S.D.), followed by swifts 243 ± 201m and black headed gulls 182 ± 116m (fig. 6).



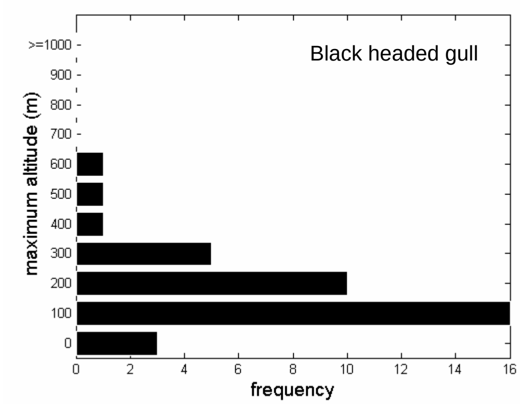


**Figure 6**. Frequency histogram of measured maximum hourly altitude distribution for the buzzard, swift and black-headed gull.

Flight altitudes of all species were related to meteorological conditions. Maximum hourly flight altitudes of buzzards are related to relative humidity, maximum temperature, hourly boundary layer height and lifted index ($r^2$ = 0.50, $p < 0.001$, $n$ = 96). Lifted index is a measure of atmospheric instability due to the difference between the temperature at a certain air layer and the temperature an air parcel would acquire when lifted from the surface to that layer; negative values indicate instability. Maximum hourly flight altitudes of swifts increase with a combination of increasing temperature, decreasing relative humidity, total cloud cover and lifted index ($R^2$ = 0.49, $P < 0.001$, $n$ = 60). Maximum hourly flight altitudes of black-headed gulls are related to a combination of total cloud cover, hourly temperature, and sea level pressure ($R^2$ = 0.55, $P < 0.001$, $n$ = 31).

Buzzards and swifts showed similar between and within day patterns of increasing flight altitudes and a strong relationship with the development of thermal convection (fig.7). However gulls did not show a similar relationship with weather.

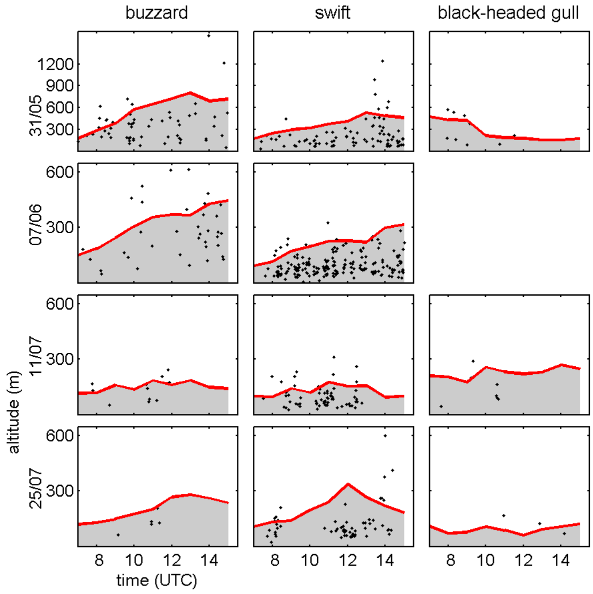
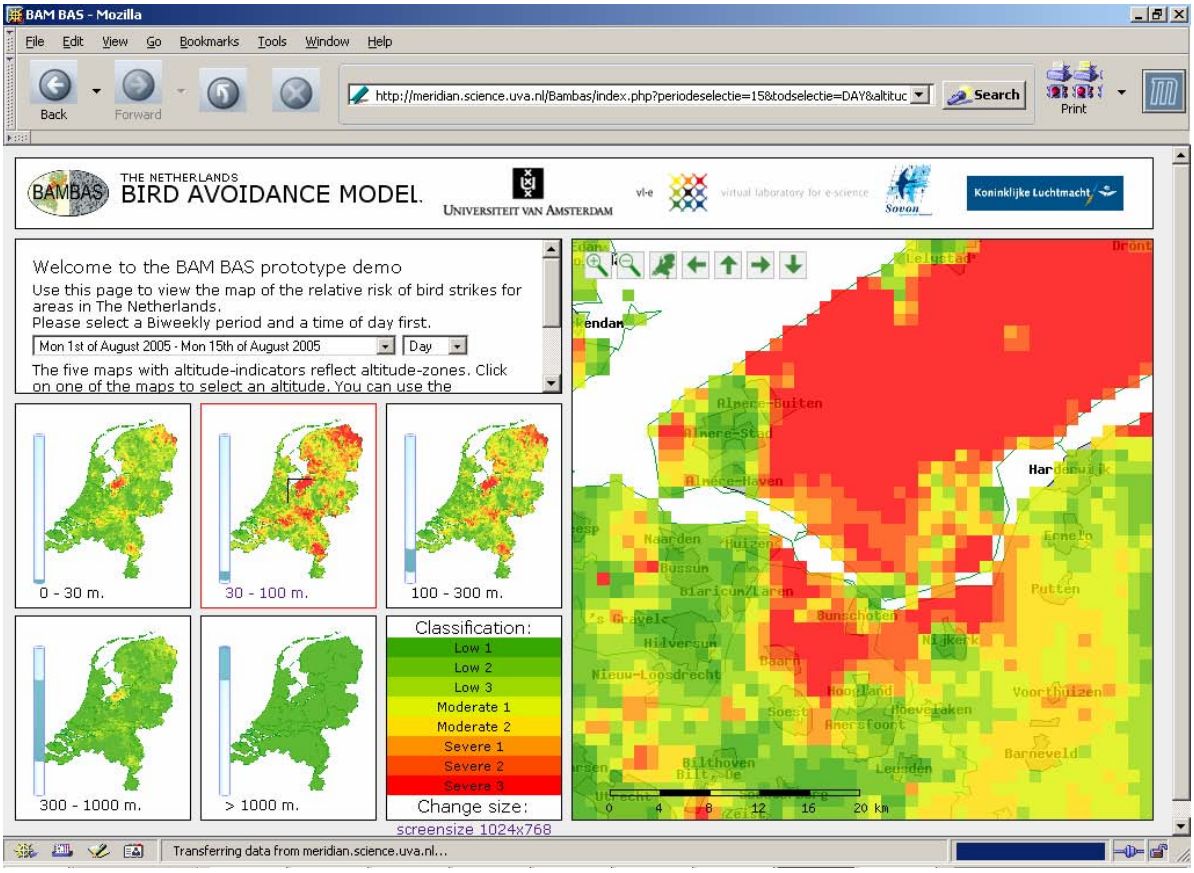


**Figure 7**. Comparison of all measured flight altitudes (points) and predictions of maximum hourly flight altitudes (red lines) for buzzards, swifts and black-headed gulls on several days. Black-headed gulls were not measured on 7 June 2000. Predications are calculated using model parameters and meteorological data for each day shown and the maximum measured hourly flight altitude. The scale of the y-axis is 0-1500 m on 31 May and 0-700 m on all other days. 31 May was a day with good thermal mixing compared to 11 July, a day with scattered showers.

## 4. Design and implementation of the bird avoidance model

A web-based GIS user-friendly interface was designed using the UMN/MapServer open source software (http://mapserver.gis.umn.edu/) to facilitate the visualization and access of hazard maps. Through this system experts can select the time of year and time of day of interest and all 5 altitude bands will be visualized simultaneously (fig. 8). One selected altitude band is enlarged the user can pan and/or increase or decrease the area of interest within this selected map. Currently, the model and resulting maps are static and based on historic data. Real-time meteorological conditions are not integrated in the current product. The technical integration of meteorological conditions and the resulting changes in altitude distribution, based on models already developed, remain an aim for the future. It is important to stress that currently, the system is designed for expert interpretation by the Nature Bureau in the RNLAF and not for direct use by pilots. Experts will use the model to produce weekly summaries of expected bird hazards around the airfields and distribute this among the airfield bird control units. In the future and following relevant training, bird control units will be encouraged to use the system themselves to gain added knowledge about regions surrounding their airfields. Although the user interface of Netherlands Bird Avoidance Model is still under development the prototype can be viewed at http:\\meridian.science.uva.nl\bambas. Publication on the Internet of the complete model is estimated to occur by the end of 2005.



http://meridian.science.uva.nl/Bambas/index.php?periodeselectie=15&todselectie=DAY&altituc

Welcome to the BAM BAS prototype demo

Use this page to view the map of the relative risk of bird strikes for areas in The Netherlands.
Please select a Biweekly period and a time of day first.

Mon 1st of August 2005 - Mon 15th of August 2005 ▾ | Day ▾

The five maps with altitude-indicators reflect altitude-zones. Click on one of the maps to select an altitude. You can use the

Classification:

| Classification: |
|---|
| Low 1 |
| Low 2 |
| Low 3 |
| Moderate 1 |
| Moderate 2 |
| Severe 1 |
| Severe 2 |
| Severe 3 |

Transferring data from meridian.science.uva.nl...

**Figure 8**. Screen shot of the GIS based user interface available on the Internet at http:\\meridian.science.uva.nl\bambas. The selection of time of year, and time of day is possible through drop down lists. The particular altitude layer of interest is selected by clicking on the altitude layer on the left part of the screen and the selected layer is then enlarged on the right.

The BAM was developed between 2003-2005. However, it is based on data that has been collected, in some cases, over several decades. Although data of comparable quality, diversity and spatial and temporal scale is often not available in most countries the tools developed for the Netherlands model can be used in other countries based on local data. Furthermore, the model is designed in a modular format so that hazard maps can easily be updated when new data becomes available. For example, if more detailed altitude distribution data is collected, or very small scale local studies of high resolution are conducted, they can be integrated into the current system. It is clear that additional data is still needed for many species to improve predictions; for example, daily activity patterns or altitude distributions. Countries can benefit by pooling their efforts in data collection and focusing on aspects where data is most needed. The EuroBAM network was established to facilitate the exchange of expertise, methodologies in modelling and data (http://www.science.uva.nl/ibed/cbpg/projects/BAMBAS/EuroBAM/index.html) and new participants and similar efforts are encouraged in order to advance bird avoidance modelling internationally.

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