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IMPACT OF THE CLIMATIC CHANGE ON ANIMAL DISEASES SPREAD: THE EXAMPLE OF BLUETONGUE IN SPAIN
IMPACTO DEL CAMBIO CLIMÁTICO EN LA DIFUSIÓN DE ENFERMEDADES ANIMALES: EL EJEMPLO DE LENGUA AZUL EN ESPAÑA

Cianci [a], C, Granero Belinchon[b], R, Picado Alvarez[c], R, Pino Carrasco[c], FJ, Rodrigo Campos[c], N, Tamayo Mas[d], E, Vázquez[e], M, Ivorra[c], B, Martínez-López[e], B, Ramos[c], AM, y Sánchez-Vizcaíno Rodriguez[e] JM.*

[a] Universita degli Studi di Firenze. [b] Autonomous University of Madrid. [c] Applied Mathematics Department. Mathematics School. Universidad Complutense de Madrid. [d] Polytechnic University of Catalunya. [e] Animal Health Department. Veterinary School. Universidad Complutense de Madrid.

*Corresponding author: beatriz@sanidadanimal.info

RESUMEN

El cambio climático está afectando al ecosistema y con ello a muchos de los factores asociados con enfermedades humanas y animales. En particular, se ha demostrado cambios importantes en las enfermedades transmitidas por insectos. El ejemplo más claro se encuentra en Europa referente al virus de la lengua azul, enfermedad de los rumiantes transmitida por insectos (Culicoides spp.). Tradicionalmente esta enfermedad se distribuía por debajo del paralelo 40, pero desde 2006 se ha difundido hacia el norte de Europa y desde entonces la situación es endémica.

Esta difusión se ha podido producir por varios factores. En primer lugar, existe una relación directa entre el aumento de temperatura y la presencia de Culicoides. Además, es importante destacar el papel del viento en el movimiento de los insectos, y podría ser un modo de transmisión importante de enfermedades como la lengua azul desde zonas endémicas a las zonas libres.

En España, la introducción de Culicoides por el viento no está formalmente demostrada, pero hay muchos expertos y datos epidemiológicos que lo sugieren, sobre todo en los primeros brotes que se produjeron en 2004 en la Península Ibérica. El objetivo del modelo aquí descrito ha sido, en primer lugar, predecir el número de Culicoides introducidos por el viento y su potencial supervivencia en España y, en segundo lugar, evaluar el impacto que un potencial incremento de temperatura podría tener en la distribución y supervivencia de Culicoides en España. Este modelo permitirá la identificación de lugares y períodos de tiempo con mayor riesgo de introducción de los mosquitos y de su supervivencia, y ayudará a optimizar los esfuerzos de prevención y control de futuras epidemias de lengua azul en el país.

Palabras clave: modelización, difusión por viento, lengua azul, cambio climático

ABSTRACT

Climate change is affecting the ecosystem and many of the factors associated with human and animal diseases. In particular, significant changes in insect-borne diseases have been shown. The clearest example is found in Europe regarding the bluetongue virus (BTV), a disease of ruminants transmitted by insects (Culicoides spp.). Traditionally this disease was distributed below the 40th parallel, but since 2006 spread to northern Europe where the situation is now endemic.

This spread of BTV has been produced by several factors. First, there is a direct relationship between the increased of temperature and the presence of Culicoides. It is also important to highlight the role of the wind in the movement of insects, and could be a significant mode of transmission of vector-borne diseases (such as bluetongue) from endemic areas to free areas.

In Spain, the introduction of Culicoides by the wind has not formally been proved, but many experts and epidemiological data has hypothesized it, especially in the first outbreaks occurred in 2004 in the Iberian Peninsula.

The objective of the model described here has been, first, to predict the number of Culicoides introduced by the wind and its potential survival in Spain and, secondly, to assess the impact that a potential increase in temperature could have on the distribution and survival Culicoides in Spain. This model will help to identify locations and time periods at highest risk for mosquitoes introduction and survival, and will help to optimize efforts and better prevent and control future outbreaks of bluetongue in the country.

Keywords: Modeling, wind spread, bluetongue, climate change

INTRODUCTION

The climatic change is affecting the ecosystem and many of the factors associated with human and animal diseases. The clearest example of this has been observed in Europe in relation to bluetongue virus (BTV), a disease of ruminants transmitted by mosquitoes (Culicoides spp.), which traditionally occurs only below parallel 40 and now it has been spread further North.

It has been described that there is a positive directed relationship between increases on temperatures and Culicoides abundance. Furthermore the presence of more insects due to the increase of temperature amplifies the probability that these insects are transported by the wind. Previous studies suggest that Culicoides spp. could be transported by the wind up to distances of 170 km (Gloster et al., 2007).

In Spain this introduction of Culicoides by the wind has not been formally proved, but there is evidence suggesting this possibility. Knowing locations and time periods at higher risk for introduction of mosquitoes and their survival once has been introduced it would help to allocate prevention and control measures to the reduced future BTV outbreaks.
The aim of the model is to forecast the number of mosquitoes introduced by the wind and their survival in Spain.

In the following sections we explain the advection-diffusion, deposition and Culicoidessurvival models we consider to quantify the number of Culicoides entering in Spain and the numerical schemes.

I.   Model description

2.1 Data

Data regarding temperature, winds, dust deposition and capture of Culicoides was used in this model.

Data on winds and temperature are provided by the State Agency of Meteorology (AEMET). Data consisted on wind speed (km/h) and direction (tens of degrees Celsius, see Figure 1), temperature (maximum and minimum) and relative humidity of 58 Spanish regions per day during 2005. Latitude and longitude of those locations were also available. Two considerations were made before using the available data. Firstly, we ruled out the last seven regions (i.e. Canary Islands) to provide a better interpolation of any point of Spain. Secondly, we considered the arithmetic mean of the direction and speed of wind, which were taken at certain times of day (00h, 07h, 13h and 18h Universal Time Coordinated) to get one value per day.

Figure 1: A wind direction of 36 tens of degrees (i.e. 360 degrees) is a north wind and a wind direction of 9 tens (90 degrees) is heading east. (Source: *www.clubmaritimocastelldefels.com*).

Data regarding dust deposition was provided by the Dust Regional Atmospheric Model (*DREAM*). The assumption made was that deposition of dust particles coming from North Africa could be a good approximation to estimate the deposition of Culicoides. Information consisted on the surface concentration of dust per m2 per day during 2005 in 21 regions of Spain, for which northern and eastern coordinates were available. The surface concentration measures the concentration of dust at 1000 meters height.

Information about captures of Culicoides imicola was provided by the Ministry of Environment and Rural and Marine Affairs (*MARM*) (courtesy of Javier Lucientes). Data consisted on the number of mosquitoes caught in 168 Spanish municipalities (including its coordinates) per day during 2005.

1.2 Advection model

We are interested in c(x, t), the quantity of Culicoides imicola females, which are the only ones acting as vectors of BTV. This mosquito is a bad flying one and very small (1-3 mm), which mathematically implies that its movement is mainly by the wind, w(x, t). We consider only 2D-spatial model (without high) in order to simplify the model.

Our main model is based in an advection-diffusion PDE:

$$\frac{\partial c(x,t)}{\partial t} = \frac{\varepsilon^2}{2}\Delta c(x,t) + \nabla \cdot c(x,t)\mathbf{w}(x,t) \ \text{ if } \ x \in \Omega, \quad c(x,t) = 0 \ \text{ if } \ x \in \partial\Omega \qquad (1)$$

where Ω is a big enough domain to consider that all mosquitoes are inside. Spain, Morocco and Algeria are contained inside Ω. We need a initial value function, *f(x)* the initial population of mosquitoes.

We have wind data each day for 2005, and using interpolation techniques we have *w(x, t)* for all points.

1.3 Deposition model

The aim of the deposition model is to study the number of Culicoides imicola that, coming from the North of Africa, finally fall to the soil. This model would depend on the number of Culicoides in the cloud, size and weight of the Culicoides and speed of the wind. The number of Culicoides in the cloud was assumed to be the same than the number of particles of dust (i.e. surface concentration). Size and weight of the Culicoides were assumed to be 1 mm and 0.5 microgram, so they are sensitive to the prevailing wind. This way, we can assume that the mosquito falls to the surface since the dust would do on having been taken by the wind. Therefore, we will base on a model for prediction of desert dust cycle. This model is the Eta/NCEP model (Nickovic, S., 2001).

We consider a cloud of powder of 1000 meters of height and we will study the quantity of mosquitoes that fall for m^2 to the surface. Besides the speed of the wind, also it is

necessary to bear other information in mind as the weight of the mosquito (0.5 µg), the viscosity of the air (1.78 10^{-5} kg / (ms)) and the gravity force (-9.8 ms^2).

The Eta/NCEP model maintains monotonicity in the calculation of the vertical advection of d, the total concentration. Through a number of readjustment iterations for a given time step, the vertical profile of d is represented by piecewise linear segments. The slope of the d-line segment is never adjusted in layers that contain local extremes. This result in no new minima or maxima created in the vertical profile of d. Given the values of d on the layer interfaces, the change in d due to the vertical advection is computed according to:

$$\frac{\partial d}{\partial t} = -W\frac{\partial d}{\partial z} = -\frac{\partial(dW)}{\partial z} + C\frac{\partial W}{\partial z}$$

$W = w - vg$ is the relative vertical velocity of concentration, where w is the air velocity and v is the gravitational settling velocity calculated from the Stokes formula:

$$v_g = \frac{2g\rho R^2}{9\nu}$$

with ρ to be the midge density, R the midge's radius, υ the air viscosity, and g the gravitation acceleration.

1.4 Survival model

Once the Culicoides imicola have been introduced into Spain by the wind, the most interesting aspect is to quantify how many would survive and potentially could transmit BTV. As widely reported in the literature, see for example (Gloster et al., 2007), the temperature is the most important factor for the survival of Culicoides imicola, although there are other aspects such as relative humidity and precipitation that also a.ect their survival. More explicitly, Culicoides imicola are not able to survive neither with very low temperatures nor with very high ones. The optimal temperature for their survival is considered to be between 18°C and 38°C.

We use data on Culicoides imicola captures provided by MARM (courtesy of Javier Lucientes) to estimate the relationship between temperature and amount of Culicoides imicola. For example, in Figure 2, we can see the relationship between the amount of

Culicoides captures (plotted in black crosses) and the maximum and minimum temperature (in red and in blue) respectively. The peak of captures occurs when temperatures were between 20 and 30°C. These results agree with the ones in Braverman et al. (2003).
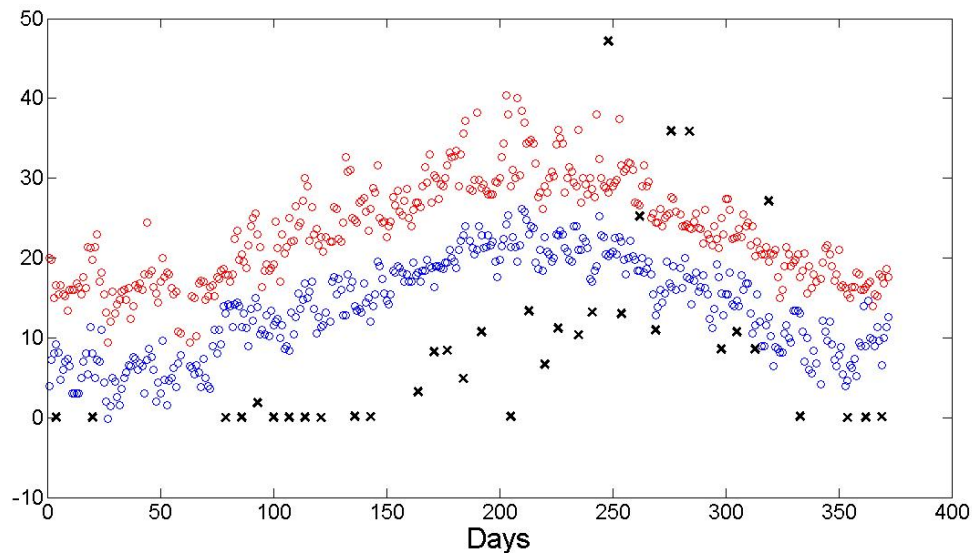

Figure 2: Relationship between temperature minimum (blue circles) and maximum (red circles) and captures (black crosses) of Culicoides imicola.

In order to formulate a more realistic survival model, other factors such as relative humidity and precipitation may be considered. Nevertheless, as reported in (Braverman et al. 2003), these aspects may be neglected, so we decide not to include it in order to simplify the model. Therefore, only temperature is taken into account. More explicitly, the following assumptions are considered:

• For a period of 3 days at temperature of 0 degrees, Culicoides imicola die.
• For a period of 10 days at temperature of 10 degrees, Culicoides imicola die.

Assuming these two facts, the linear law, see Figure 3, is obtained. Using this linear law, it is very easy to know the number of Culicoides imicola in one day, if the temperature and the number of them in the previous day are known. In Table 1 the number of Culicoides imicola are calculated assuming a initial population of 10000 Culicoides imicola.

The results are as expected: at temperatures of 10°C (or less), the population of Culicoides imicola decrease while at optimal temperature, they are able to survive.
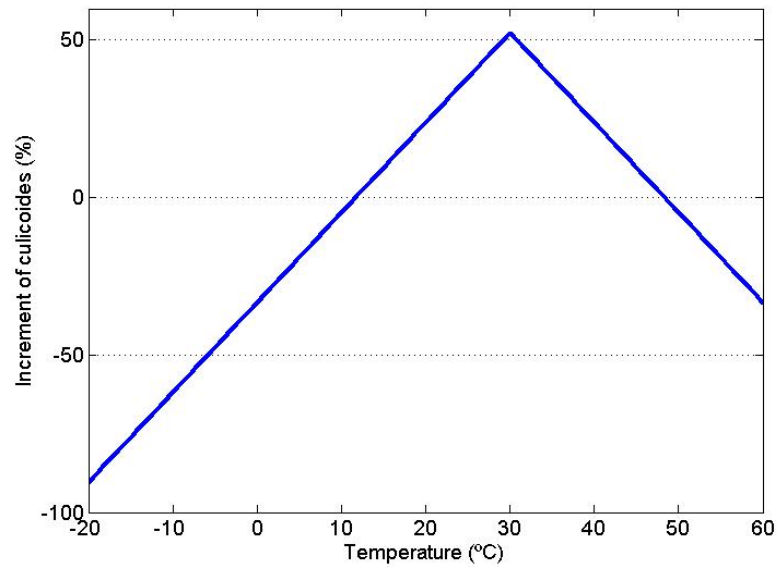
Figure 3: % of increment in population of Culicoides imicola versus temperature.

T	-10°C	0°C	10°C	20°C	30°C
n	3810	6667	9524	12381	15238

Table 1: Number n of Culicoides imicola (n0 = 10000)

II.   Numerical experiments

3.1 Interpolation

The data on wind and temperature were only available for certain regions of Spain, but within the model we need to know the wind and temperature for each particular location at time t. Therefore, to achieve winds and temperatures of any point of the study area, interpolation methods were used.

Since our domain is not rectangular (see Figure 4) and our interpolation nodes are not uniformly distributed over a Cartesian grid, the interpolation problem is difficult to solve. So that, we had to move four nodes to get a rectangular domain and with a software application we also made a grid getting the nodes uniformly distributed. The method that we have used is interpolary cubic splines are those splines are particularly significant since:

• They are the splines of minimum degree that yield C^2 approximations.
• They are sufficiently smooth in the presence of small curvatures.
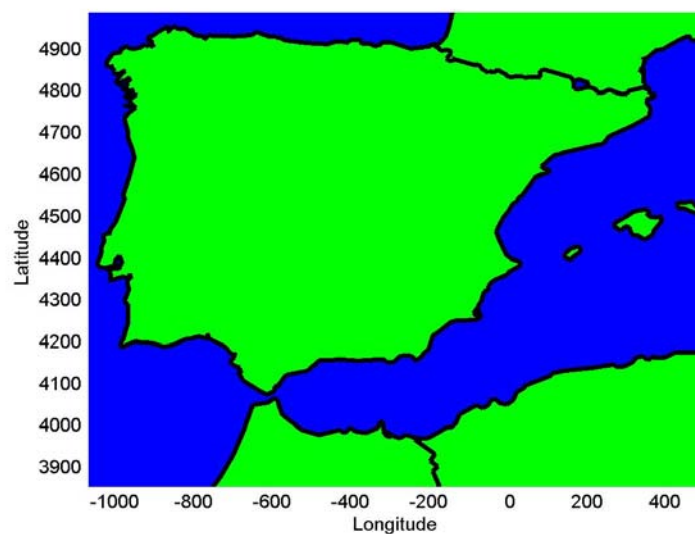
Figure 4: Study domain

Several packages exist for dealing with interpolating splines. In the case of cubic splines, we have used the command '*griddata'* with the method '*cubic*' of Matlab (Quarteroni et al., 2000)

2.2 Advection model

The model for the mosquitoes' transport is approximated with a finite volume scheme (Glowinski et al., 2003).

2.3 Deposition model

To solve 2.3 we use an implicit numerical scheme.

2.4 Results

The highest number of Culicoides introduced by the wind and surviving during 2005 from North of Africa to Spain was concentrated in the South part of Spain and mainly in the months of April to July. In a few years the temperature will increase due to the climatic change. Supposing that the temperature increases 5 degrees, according to our model, the average number of Culicoides will increase considerably (see Figure 5).
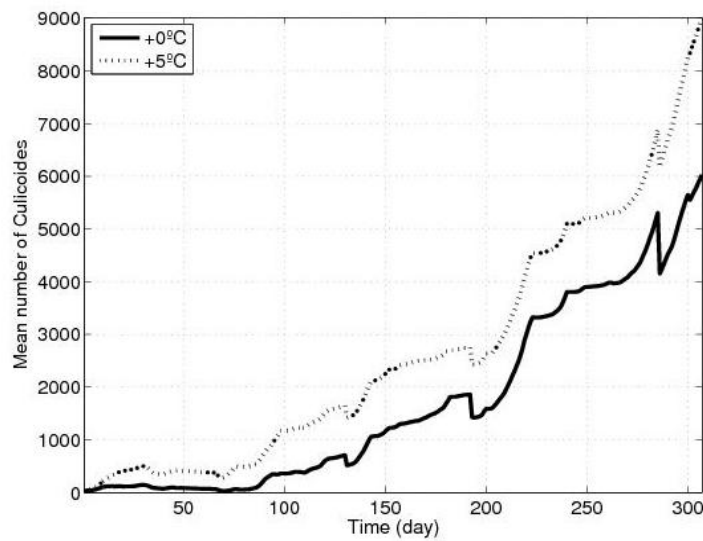

Figure 5: An increase on temperature would produce an increase of Culicoides population.

2.5 Validation

As we can observe on Figure 6, the 90% of the primary outbreaks occurring during 2005 were located in the areas identified by the model to be at higher risk of introduction/survival of Culicoides.
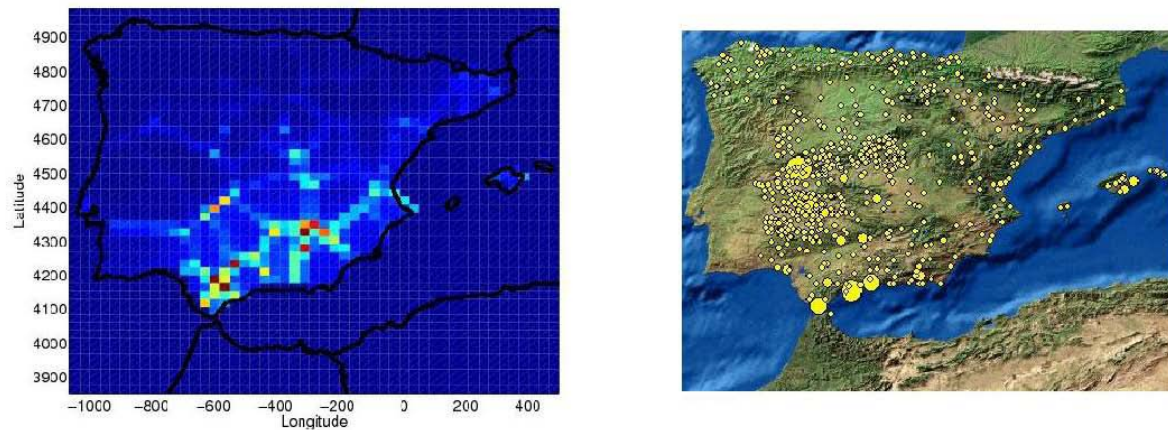
Figure 6: Solution given by the experiments (**Left**) and data obtained in 2005 (**Right**). In experiments, the red color corresponds to a zone of high risk and the blue color to zone of low risk.

III.   Concluding remarks

The methods and results presented in this work would be useful to identify areas and periods at higher risk of introduction of Culicoides from the North of Africa, which ultimately would help in the prevention and control of future incursions of BTV in Spain.

Acknowledgements

REFERENCES

Braverman, Y., Rechtman, S., Frish, A., Braverman, R. (2003). Dynamics of biting activity of C. Imicola kieffer (diptera: Ceratopogonidae) during the year. Veterinary Medicine, 58: 2-3.

Gloster, J., Mellor, P.S., Burgin, L., Sanders, C. and Carpenter S. (2007). Will bluetongue come on the wind to the United Kingdom in 2007? Vet Rec,160:422–426.

Glowinski, R.(2003). Numerical methods for fluids, part 3, North-Holland.

Nickovic, S. (2001). A model for prediction of desert dust cycle in the atmosphere, Journal of geophysical research. 106: 18,113-18,129.

Quarteroni, A., Sacco, R., Salieri, F. (2000). Numerical Mathematics, Text in Applied Math. vol 37, Springer.