Impact of the climatic changes on animal diseases spread

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Part I: Problem definition

Biological Problem

- The climatic change is affecting the ecosystem and many of the factors associated with human and animal diseases.

- Here we focus on the mosquito (*Culicoides* spp.) which transmit to bluetongue virus (BTV): a ruminant disease. traditionally concentrated below parallel 40.

- Problem: We are interested in studying the impact of temperature increase on the introduction and survival of *Culicoides* in Spain.

- Mathematical modelling can help to have a qualitative idea of the previous problem.

Mathematical modelling

During this work we have considered an hybrid model describing:

- The advection of Culicoides due to the high altitude winds (PDE/SDE).
- The deposition of Culicoides in the Spain ground (PDE model).
- The survival of Culicoides depending of the temperature (regression model).

Part II: Model description

Data treatment

We have considered:

- Data on winds and temperature provided by the State Agency of Meteorology AEMET in 51 points of Spain: wind speed (km/h) and direction (tens of degrees Celsius), temperature (maximum and minimum).
- Data regarding to dust deposition was provided by the Super Computational Center of Barcelona: the information consist on the surface concentration of dust per m ^{2} measured at 1000 meters height per day during 2005 in 21 regions of Spain.
- Data of captures of *Culicoides imicola* was provided by the Ministry of Environment and Rural and Marine (MARM) (courtesy of Javier Lucientes). Data consist on the number of mosquitoes caught in 168 Spanish municipalities per day during 2005.

All data have been interpolate, in the considered study domains, using 2D-cubic splines.

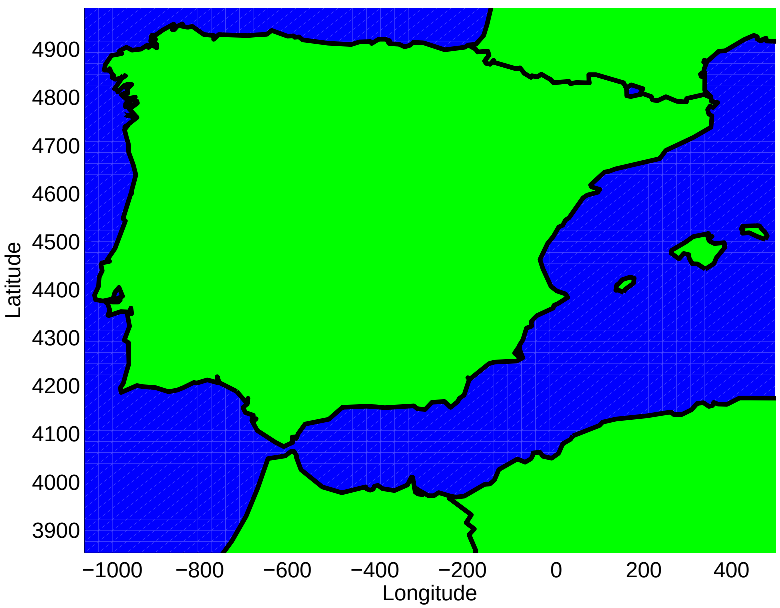
Data interpolation

Data interpolation

Advection model

We are interested in studying the movement of $c(x,t)$, the quantity of *Culicoides imicola* females in a sand cloud at time $t \in [0,T]$ at position $x \in \Omega$ due to the wind.

- Ω is the study domain (including peninsular Spain, part of Morocco, Algeria, Portugal and France).
- $[0,T]$ is a one year time interval.



Advection model

We consider two approaches:
1)PDE approach:

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

$c(\cdot,0)$ is given. This model is approximated with an implicit finite volume upwind scheme.

2)Path integral approach:

$$d\mathbf{X} = \mathbf{w}(x,t)dt + \varepsilon d\mathbf{B}, \quad \mathbf{X}(0) = x \tag{2}$$

where **B** is a brownian motion. thus the contraction semigroup (in L^∞)

$$c(t,x) = T_t f(x) = E_x[f(\mathbf{X}_0^t(x))]$$

solves

$$\frac{\partial c(x,t)}{\partial t} = \frac{\varepsilon^2}{2}\Delta c(x,t) + \nabla c(x,t)\cdot \mathbf{w}(x,t), \quad c(x,0) = f(x)$$

We note that our problem is on a unbounded domain.
This second model is solved using a Monte-Carlo algorithm.

Models comparison: This second approach is very useful for 'difficult' equations, but for this simple equations the finite volume is faster.

Deposition model

We are interested in studying the ground deposition $d(x,t)$ of *Culicoides* in a sand cloud at time $t \in [0,T]$ at position $x \in \Omega$, where Ω is the study domain (peninsular Spain).

To do so, assuming that the *Culicoides* have the same properties than sand dust, we consider the following PDE:

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

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

$$v_g = \frac{2g\rho R^2}{9\nu} \text{(Stokes formula)}$$

With ρ to be the midge density, R the midge's radius, ν the air viscosity, and g the gravitation acceleration. Transport is approximated with a implicit finite difference scheme.

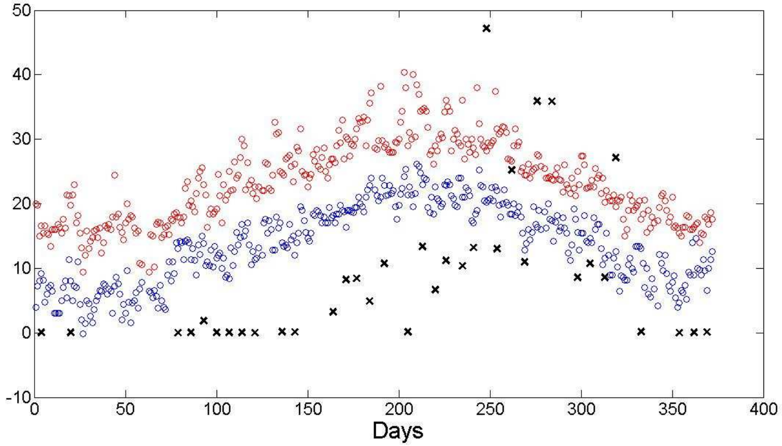
Survival model

We are interested in studying the impact of the temperature on $d(x, t)$.

We assume that:

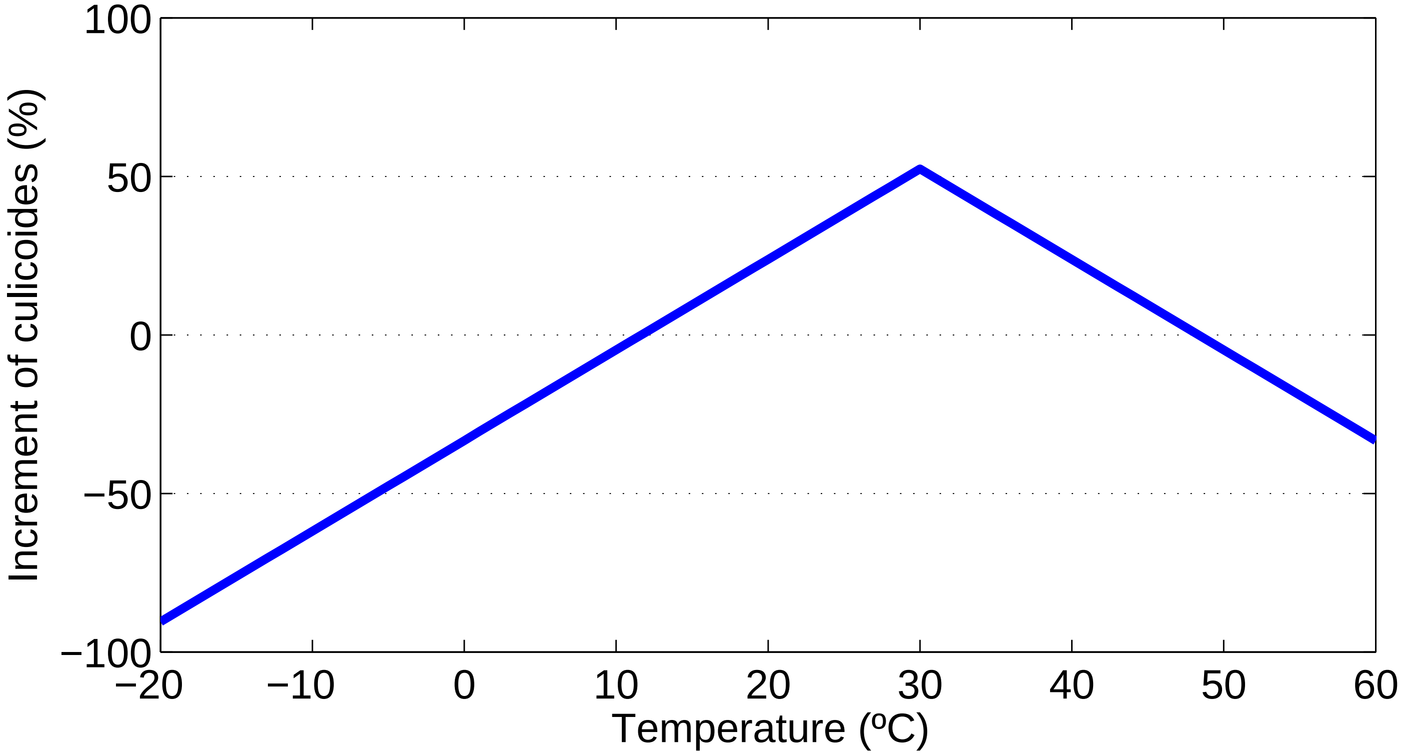
- The range [20ºC,30ºC] is optimal for mosquito survival (peak of captures).
- For a period of 3 days at temperature of 0 degrees, all *Culicoides* colony die.
- For a period of 10 days at temperature of 10 degrees, all *Culicoides* colony die.

and we analyze the capture distribution:



Survival model

We obtain the following relation between the increment of *Culicoides* and temperature:



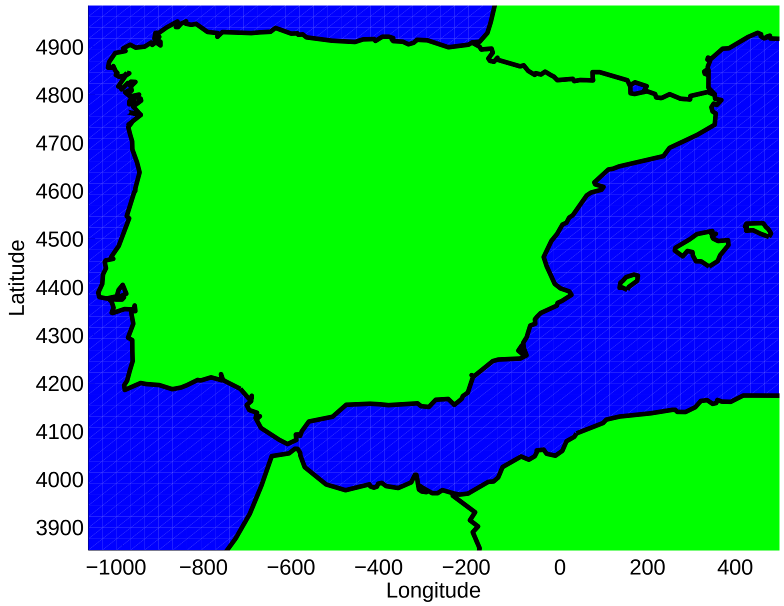
Part III: Numerical experiments

Experiments description

In order to study the impact of climatic change on the amount of *Culicoides imicola* in the Spanish ground, we have considered two numerical experiments:

- Experiment 1: Data are kept to their initial value.
- Experiment 2: Temperature is increased by 5^{o}C.

The domain of study is:

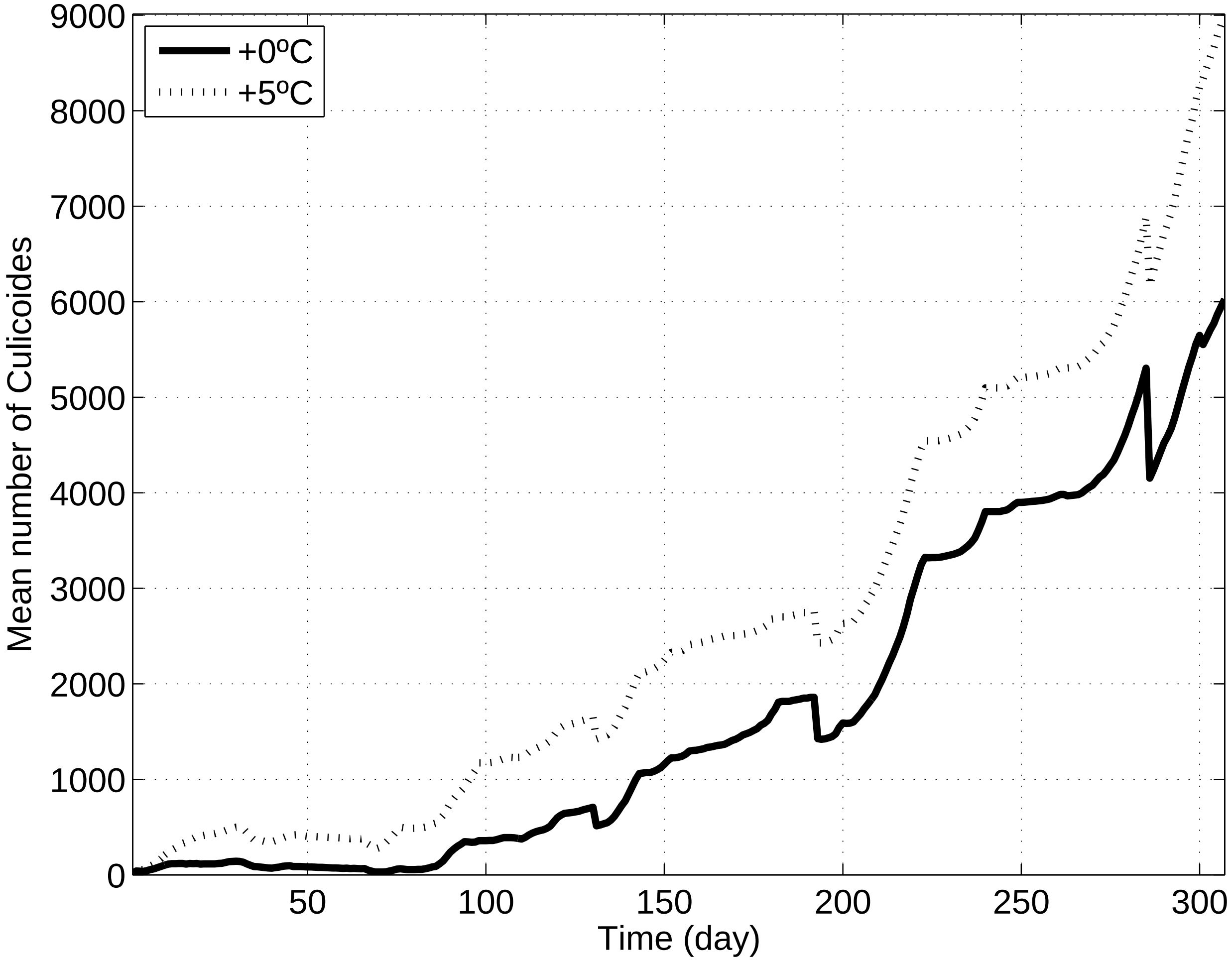


c evolution

Experiment 1: d evolution

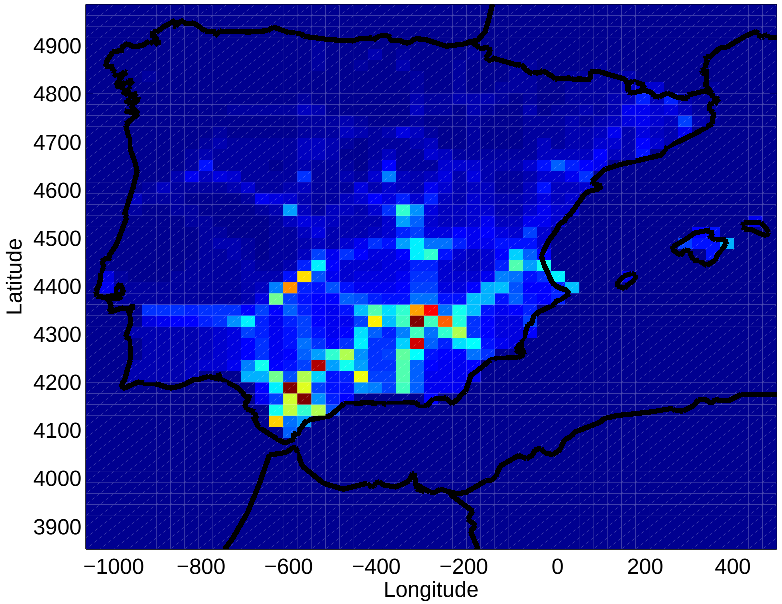
Experiment 2: d evolution

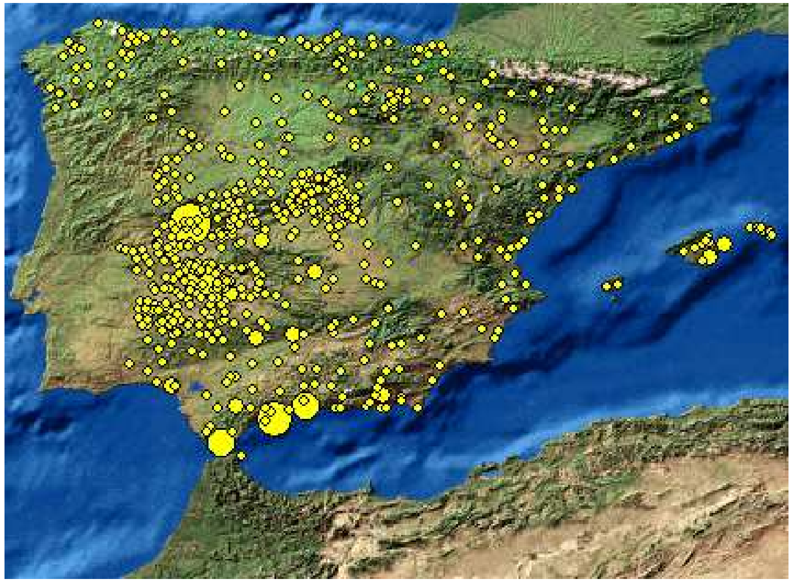
Comparison of mean d evolution



Model validation

In order to validate our model, we can compare the solution given by experiment 1 and data obtained in 2005:





Conclusions and perspectives

Conclusion and perspectives

Conclusions:

- The model has given coherent results.
- We can observe that the increase of temperature should rise the risk of development of the *Culicoides imicola* in Spain.

Perspectives:

- Complete the model using more data (humidity, pesticide).
- Equations can be refined (deposition, survival model, ...) in order to be more realistic.
- Add BTV spread model.

Conclusion and perspectives

!!! Thank You !!!

We want to thanks to the Ministry of Environment and Rural and Marine Affairs, particularly to the Animal Health division, the State Agency of Meteorology and to Javier Lucientes for the provision of data.