Spatio-temporal modelling for preventing cereal aphids' outbreaks at France scale

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PhD-thesis in collaboration with ARVALIS-Institut du végétal
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Date: 02/10/2012

Plan

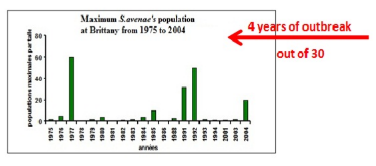
1. Subject presentation
    - Agricultural issues
    - Hypothesis and aim
2. From biological realities to mathematical representation
    - Biological realities in our model
    - Mathematical representation
3. In this presentation
    - Landing rate (α_1)
    - Apterous growth rate (r)
4. Discussion and conclusion
    - Discussion and conclusion

Agricultural issues

Questioning

The grain aphid (*Sitobion avenae*): causes **occasionally strong damages** to wheat during spring

The systematic insecticide sprays against these aphids are often neither efficient nor necessary



Plan

Hypothesis and aim

The facts:

- Obligate parthenogenesis: no sexual generation
- apterous and winged adults
- Survival of parthenogens above a temperature around -10 C

Our hypothesis:

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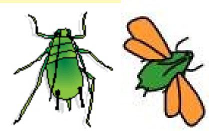

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Our hypothesis:
Possible representations of in situ overwintering success of parthenogens

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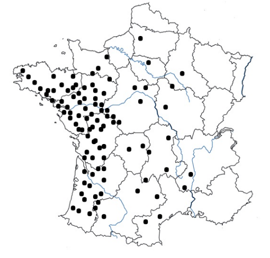

Sitobion avenae

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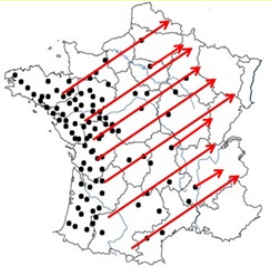

Aim: Explicit modelling of spring invasion of cereal growing areas from overwintering sites at France scale **in order to optimize the use of insecticide spray**

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Biological realities

1. Initial conditions
2. Differentiation between apterous (A) and winged (C) aphids
3. Active flight (Diffusion) and passive flight (Convection)
4. Take-off rate (α_2)
5. Landing rate (α_1)
6. Apterous growth rate (r)
7. Boundary conditions

Biological realities

1. Initial conditions
    - At the end of the winter
    - Model running during spring
2. Differentiation between apterous (A) and winged (C) aphids
3. Active flight (Diffusion) and passive flight (Convection)
4. Take-off rate (α_2)
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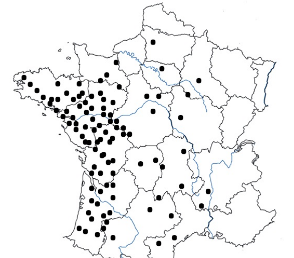

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5. Landing rate (α_1)
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7. Boundary conditions

Biological realities

1. Initial conditions
2. Differentiation between apterous (A) and winged (C) aphids
    - winged: flying aphids
    - apterous: aphids on the wheat
3. Active flight (Diffusion) and passive flight (Convection)
4. Take-off rate (α_2)
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Biological realities

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3. Active flight (Diffusion) and passive flight (Convection)
   - Low wind speed: active flight
   - High wind speed: passive flight
4. Take-off rate (α_2)
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4. Take-off rate (α_2)
    - proportion of winged larva
    - phenological stages of wheat
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    - proportion of cultivated cereals
    - auto-correlation of cereal patches
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    - temperature
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Mathematical representation

Equations

$$\begin{cases} \frac{\partial C}{\partial t} + (1-\lambda_v)v(t,x)\nabla_x(C) = \lambda_v D(t,x)\Delta_x(C) + C + A\alpha_2 - C\alpha_1 \\ \frac{\partial A}{\partial t} = rA + C\alpha_1 - A\alpha_2 \end{cases}$$

Estimation

- Differentiation between apterous (A) and winged (C) aphids
- Convection (passive flight) and diffusion (active flight)
- Definition of growth rate
- Landing rate (α_1)
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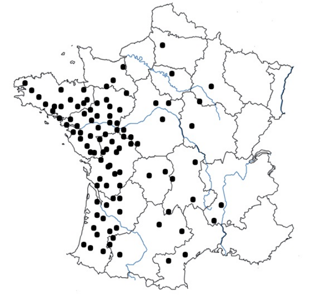
Mathematical representation

Initial conditions

$$\begin{cases} C(0,x) = C_0(x) \\ A(0,x) = A_0(x) \end{cases}$$

Initial conditions

Estimations of aphids' reservoirs at the end of winter



Mathematical representation

Boundary conditions

$$\begin{cases} C = 0 \\ A = 0 \\ D\nabla C.\eta = I \\ \nabla A.\eta = I \end{cases}$$

Witch mean

1. marine area and higher mountains : no flow
2. land borders and other mountains: constant flow

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In this presentation

Model

- Mathematical study is done
- All coefficients are deterministically determinated
- Focus on 2 interresting parameters

Model

$$\begin{cases} \frac{\partial C}{\partial t} + (1-\lambda_v)v(t,x)\nabla_x(C) = \lambda_v D(t,x)\Delta_x(C) + C + A\alpha_2(s,N4) - C\alpha_1(p,\eta) \\ \\ \frac{\partial A}{\partial t} = r(\theta,s)A + C\alpha_1(p,\eta) - A\alpha_2(s,N4) \end{cases}$$

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- experimental data non available, partially known process,...,numerical simulations
- proportion of cultivated cereals
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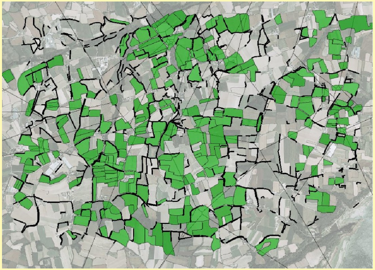

Figure: Studied landscape with wheat fields in green

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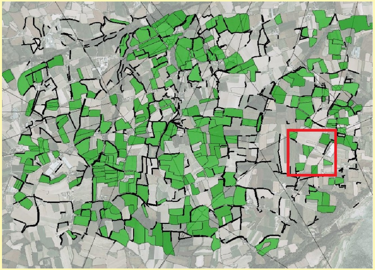

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Multiscale model

A multiscale model:

1. Macroscale system: behavioral rules
    - Mathematical model previously described
    - Discretization of our space: 5km X 5km
2. Microscale system: mathematical functions
    - Microscale cells: for each macroscale pixel we have 400 cells (25m X 25m)
    - Cellular automata
3. Link between microscale system and macroscale sysytem
    - Summary statistics
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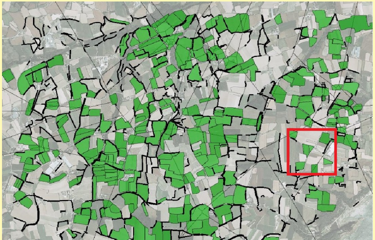

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Figure: Microscale pixel

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From behavioral rules to mathematical functions

5 assumptions on the landing behaviour

1. Aphids land once they have perceived a cereal field
2. Landing rate is linked to landscape discontinuances (*e.g.* field edges)
3. In opposite of the 2nd rule, the landing rate is inversely linked to landscape discontinuances
4. A combination of the 1st rule and the 2nd rule
5. A combination of the 1st rule and the 3rd rule

lead to 5 functions in the macroscale model

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Simulations of α_1 functions in the macroscale system

At Brittany: western of France

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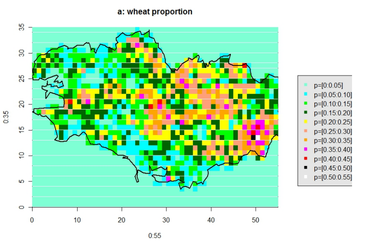

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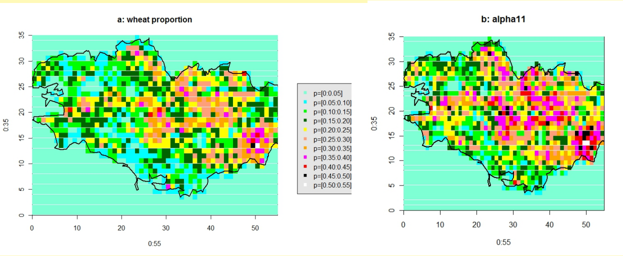

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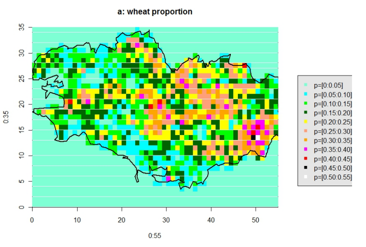

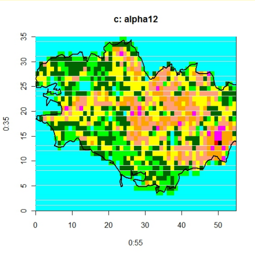

Simulations of α_1 functions in the macroscale system

1. Aphids land once they have perceived a cereal field
2. Landing rate is linked to landscape discontinuances (*e.g.* field edges)
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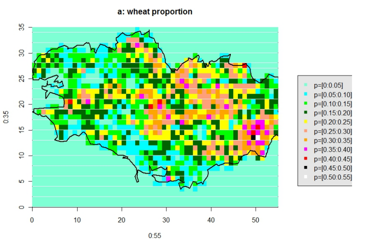

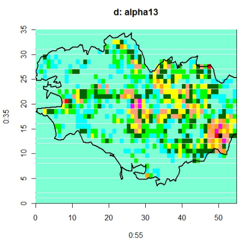

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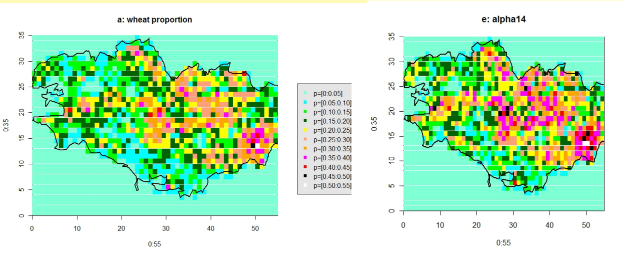

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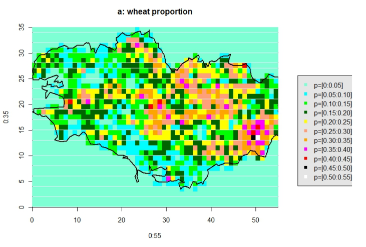

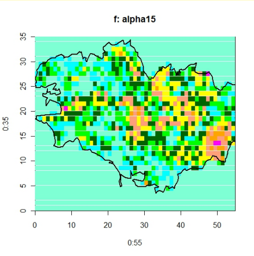

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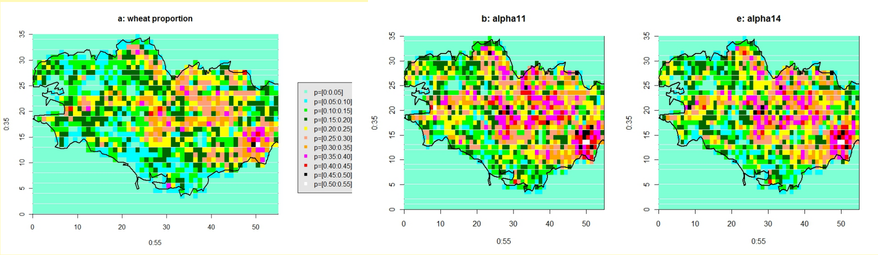

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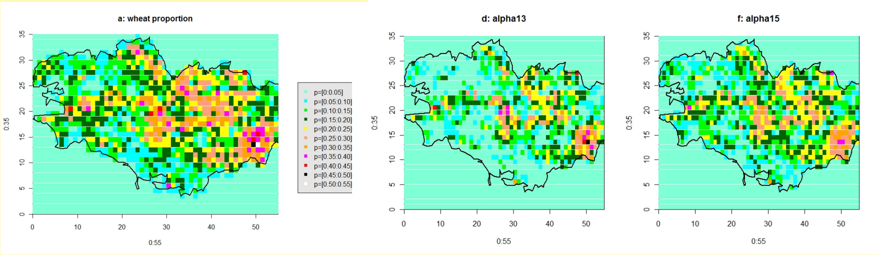

Conclusion on the landing-rate

1. Modelling of a complex process only partially known
2. Combining of a macroscale (mathematical analysis) and a microscale model(numerical resolution)
3. Modelling of aphid landing rate behaviour
4. An accepted article: Ciss, M., Parisey, N., Dedryver, C.-A., Pierre, J.-S., 2012. Understanding flying insect dispersion: multiscale analyses of fragmented landscapes. *Ecological Informatics*, in press

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   - Agricultural issues
   - Hypothesis and aim
2. From biological realities to mathematical representation
   - Biological realities in our model
   - Mathematical representation
3. In this presentation
   - Landing rate (α_1)
   - Apterous growth rate (r)
4. Discussion and conclusion
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Apterous growth rate (r) depends on:

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For the modelling:

- data collected on fields
    - *S. avenae* population densities measured in wheat fields from 1975 to 2004
    - Phenological stages of wheat recorded according to Zadoks' numeric scale
    - minimum, maximum and mean temperature data daily recorded
- Method: nonlinear regression

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For the modelling:

- data collected on fields
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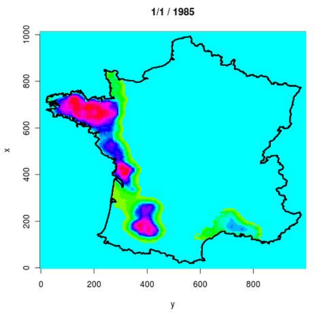
Discussion and conclusion

- Model's definition
- Mathematical study is done
- All coefficients have been estimated
- Next step: model's validation on data
- Next step: making of Decision Support System (DSS)

The first simulation of our model



using the parametrized and validate model in order to optimize the use of insecticide spray

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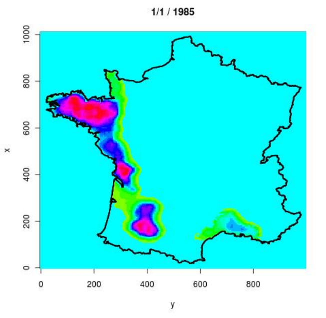

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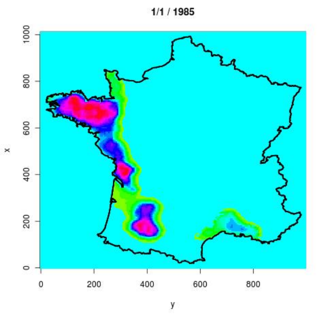

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Acknowlegments

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- Lucie, Patricia, Stéphanie, Géraldine, Pierre, Gaël, Solenn, Régis, Anne-Sophie

THANK YOU FOR YOUR ATTENTION