The French National Forest Inventory survey

Covering space and time at country level

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Context

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- European forests in expansion (~**40%** of land area)
  - Forest transition after a minimum (19-20th century)
  - Abandonment of the poorest cultivated lands
  - Intensification of agriculture
  - Switching to fossil energies

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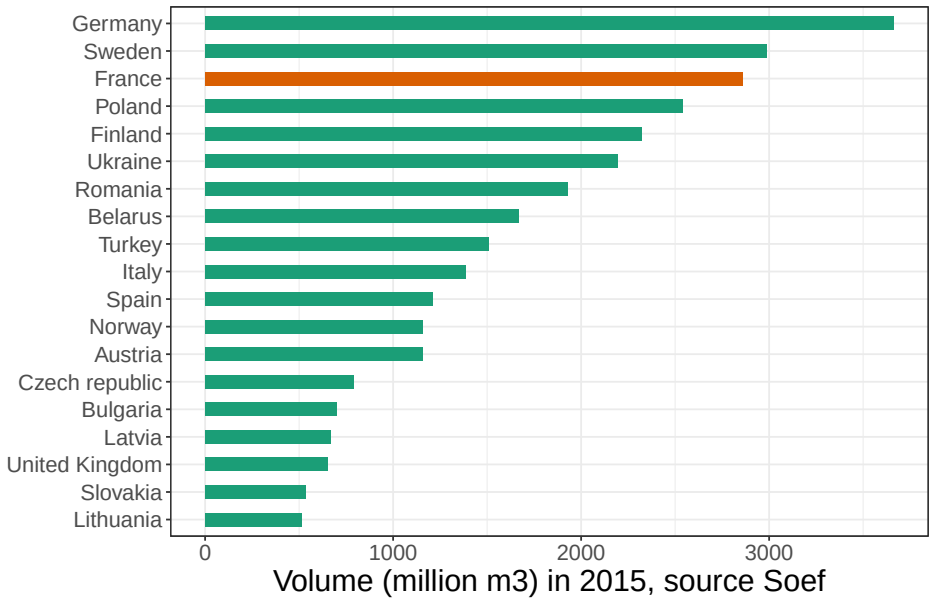

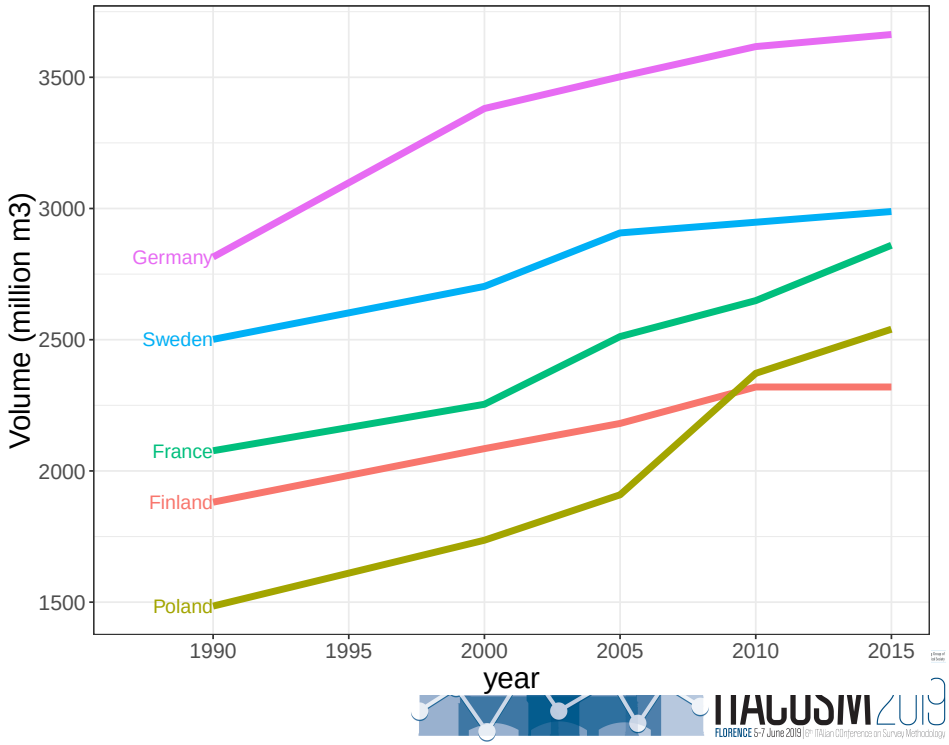

French forests

- Almost 17 millions of ha
  - 30% of the country
- **Area doubled in one century** (still ~100.000 ha/year)
- **Volume doubled in the last 60 years**
- Third stock of Europe
  - First broadleaved stock
- Highly diverse
  - compared to other European forests
  - many macroclimates
- One of the most exposed to climate change (CC)

New challenges

- (European) forests at the heart of new challenges
  - Bioeconomic transition (Wood = renewable material)
    - Direct effect (carbon sequestration)
    - Substitution effect (avoidance of energy-intensive material *eg* concrete, steel)
  - Climate change mitigation (carbon stock)
  - Ecosystem services (air/water depollution, protection, biodiversity, . . .)
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  - Climate change itself (temperature, precipitations)
  - Biotic diseases (Ash dieback, pine wood nematode, . . .)
  - Abiotic threats (storms, fires)
- They have to adapt (or die) : undergone or organized evolution ?

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Forests are dynamics ecosystems

How to tackle the challenge to follow and measure the forest ecosystems ?
→ Some highlights from the French National Forest Inventory (NFI)

The French National Forest Inventory

Countrywide continuous inventory

- After the 1999 storms (Lothar and Martin : ~ 180 millions de m^3)
  - NFI was not able to give quick and accurate estimate of the damages
  - Need for a new type of inventory
  - In 2005 from discontinuous to continuous inventory in **space and time**

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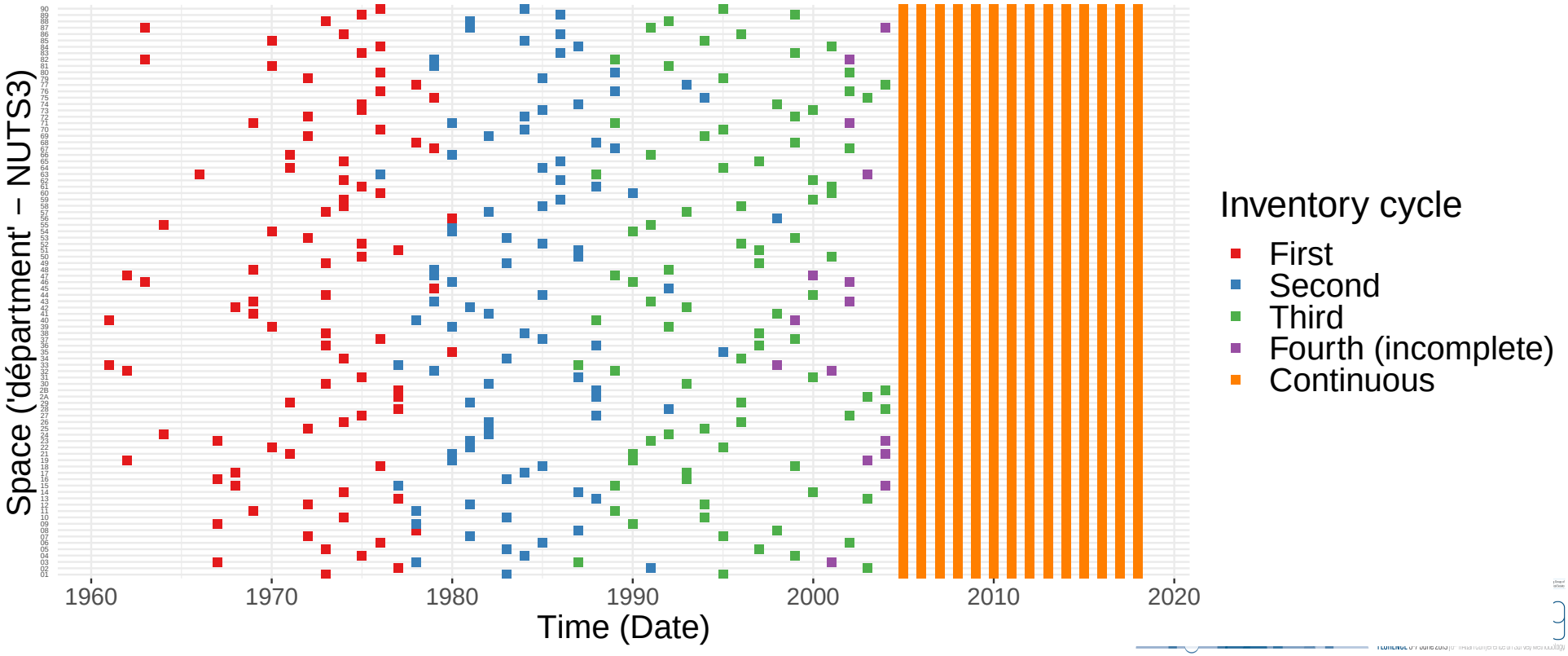

A two phase inventory

- Annual sampling
- Two (main) interest (populations) :
  - The territory (point)
  - The ressources (trees)
- A “systematic” first phase :
  - Photo-interpretation (80 000 to 100 000 plots/year)
  - Data on land coverage and land use

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  - And phase 1 plots for all other categories (inland water, infrastructure, agriculture, . . .)
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  - Less constraints on the sampling design → **More flexibility**
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Nonresponse

Not really, trees have no choice. . . and do not lie !

Inventory plots

- More than 200 observations per (forest) plot

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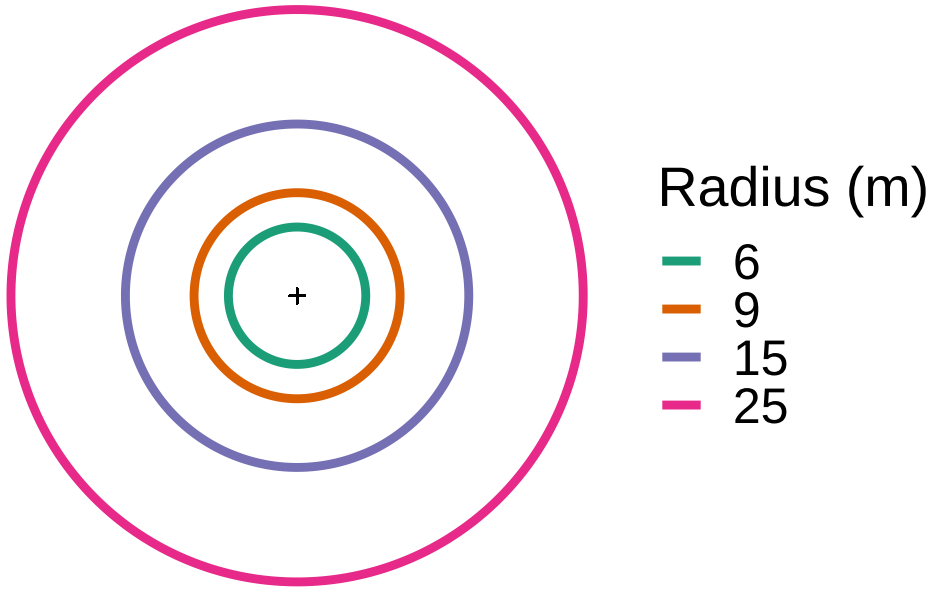
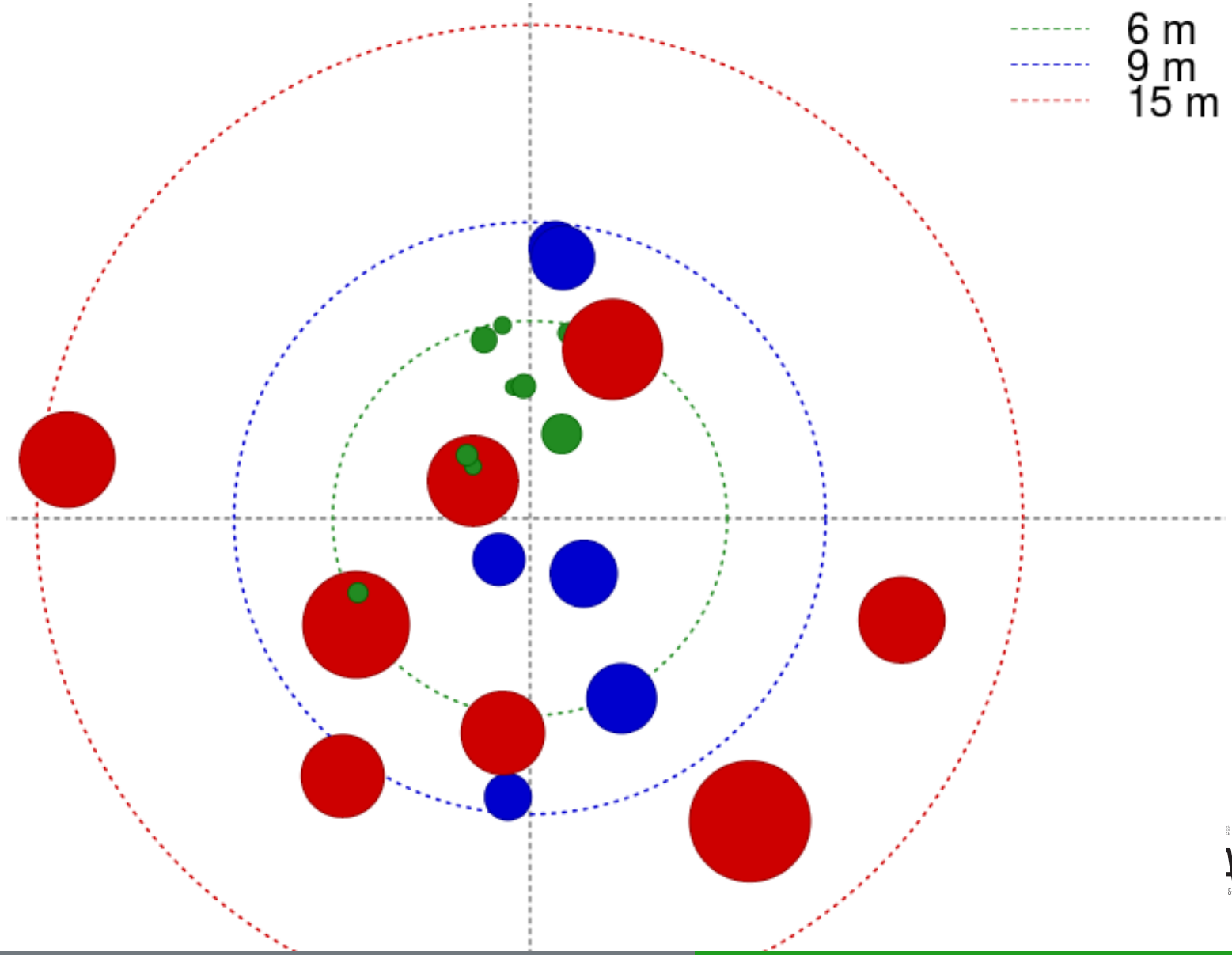
- Plots "regularized" the spatial micro structure of the forest variables (ex : V/ha)
- A system of circular concentric plots
- Plot of 25 m radius
  - Stand description
  - Common between phase 1 and 2
- 15 m plot
  - Ecology and bigger trees ($d \geq 37,5\ cm$)
- 9 m plot
  - Intermediate trees ($22,5\ cm \leq d < 37,5\ cm$)
- 6 m plot
  - Small trees ($7,5\ cm \leq d < 22,5\ cm$)



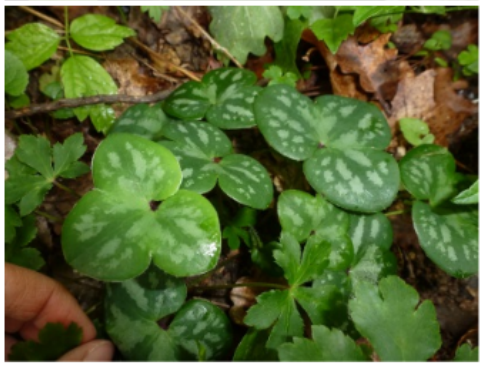
- An example of a real plot :
  - One color per plot and tree dimension class



Dendrometric (tree) measurements on 6, 9 and 15 m

- More than 150 tree species in (metropolitan) France
- Measure of tree circumference, height, growth, *etc.*
- Initially for all trees
- Now :
  - Simplification (less trees measured) $\rightarrow$ Imputations
  - Lightening of the field tools

Ecology (15 m plot)



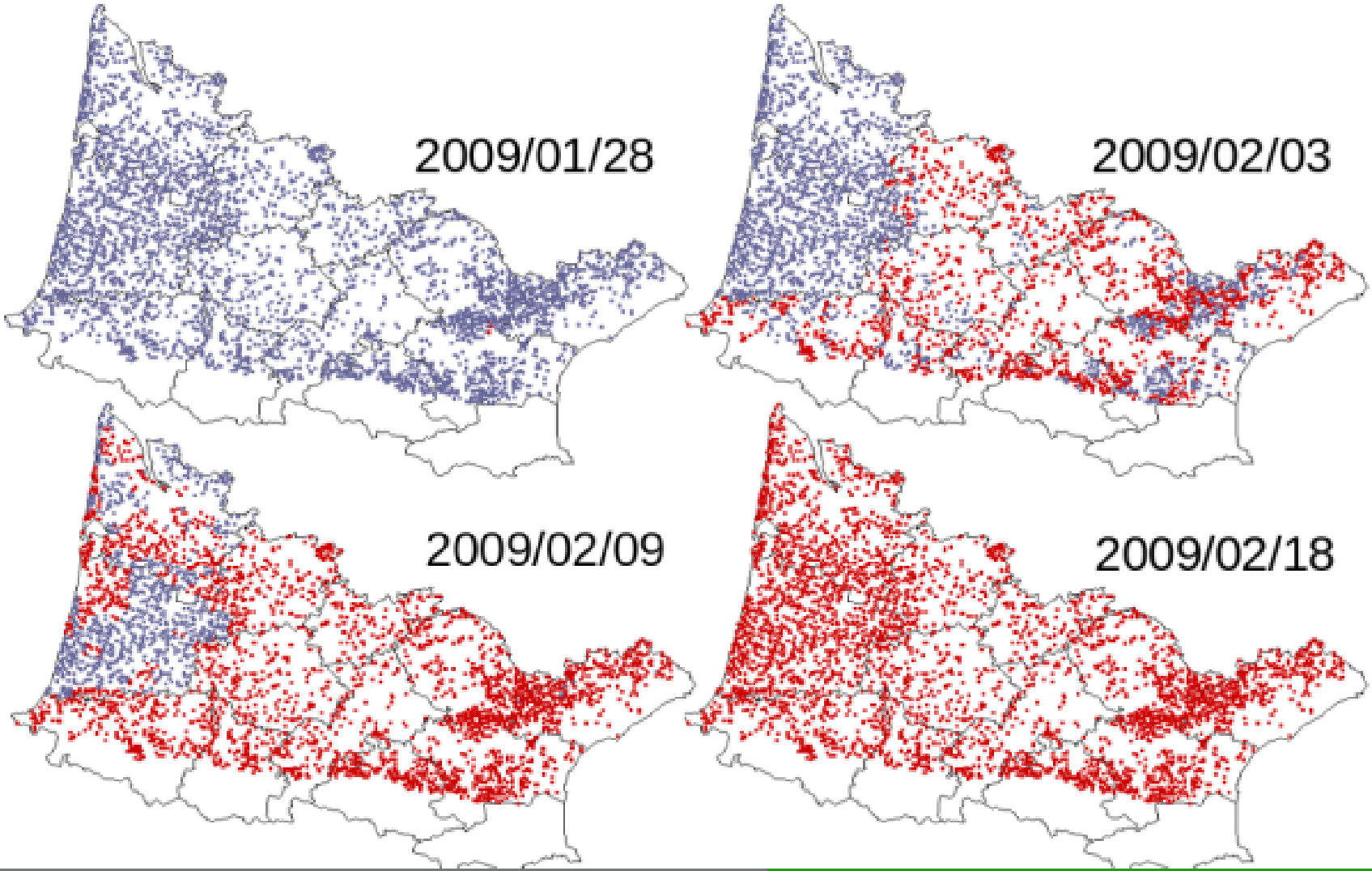
- Ecological data since the 80's
  - Flora ($>$ 3000 plant species)
  - Geology
  - Pedology (soils)
  - *etc*

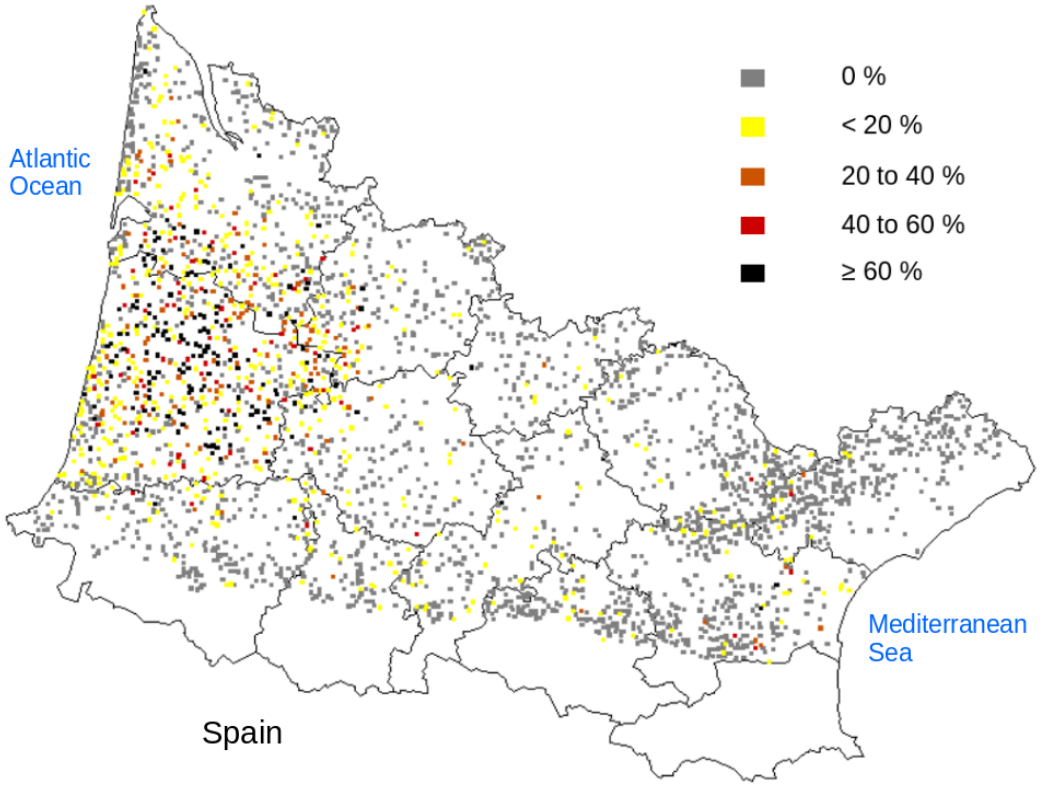
A responsive tool : example of the Klaus storm (2009/01/24)

Klaus impact on south-west pine forests

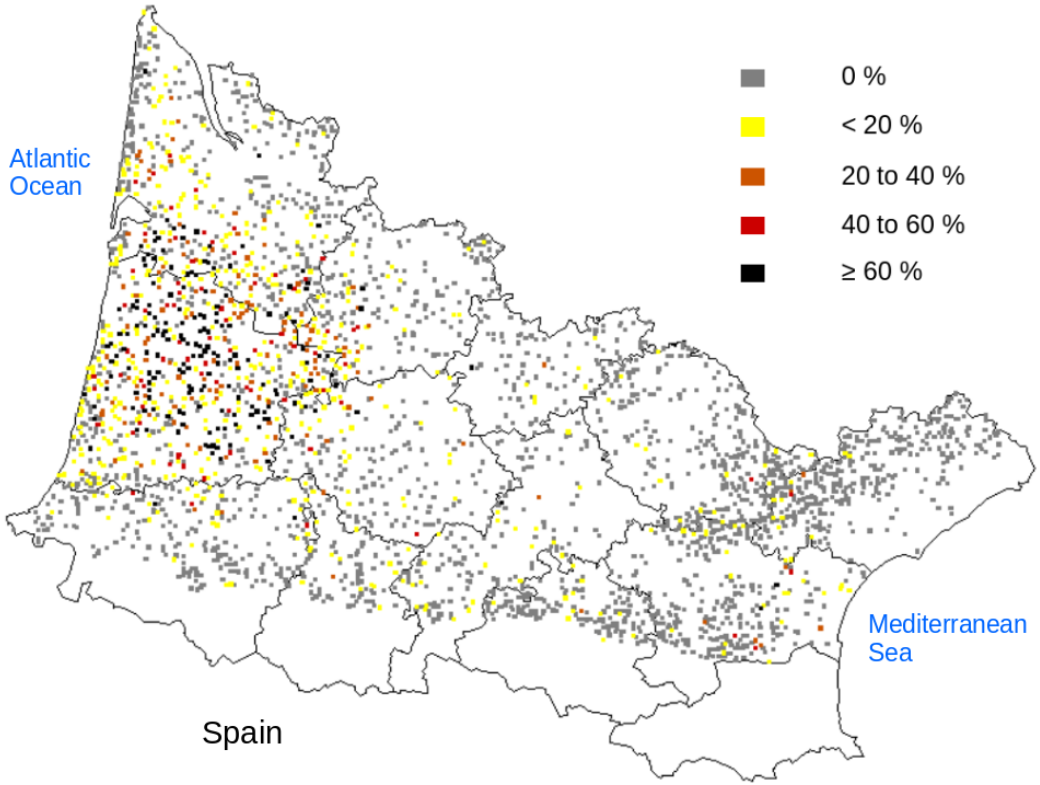
A responsive tool : example of the Klaus storm (2009/01/24)

- In red, the revisited plots





- Post-storm update of all plots
- Less than a month after the event to produce the final estimates



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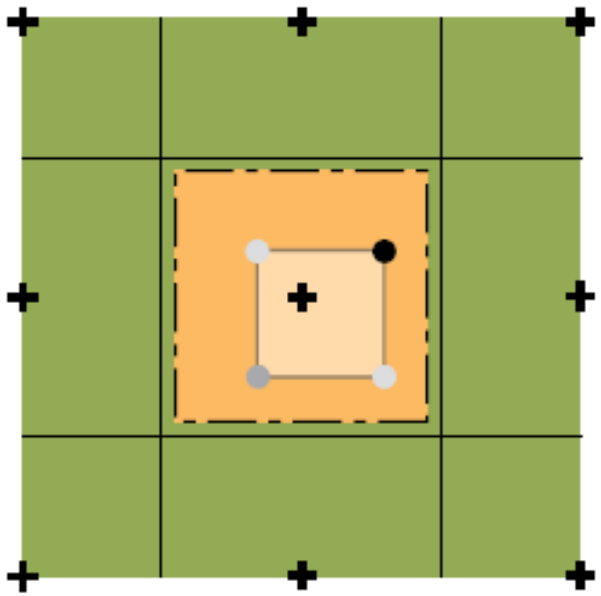
Damages

42.5 millions m^3
37 millions m^3 for the sole maritime pine

The sampling grid

A kilometric grid

- Defined since 2005
- Regular organization of annual sample
  - Optimization of spatial distribution (5-year moving averages)
  - Logistic optimization
- Random drawing of the plots in the kilometric cell
  - Spatial stratification / Tesselation stratifified sampling
- Eventually densification ($\leq$ 4 points per cell)



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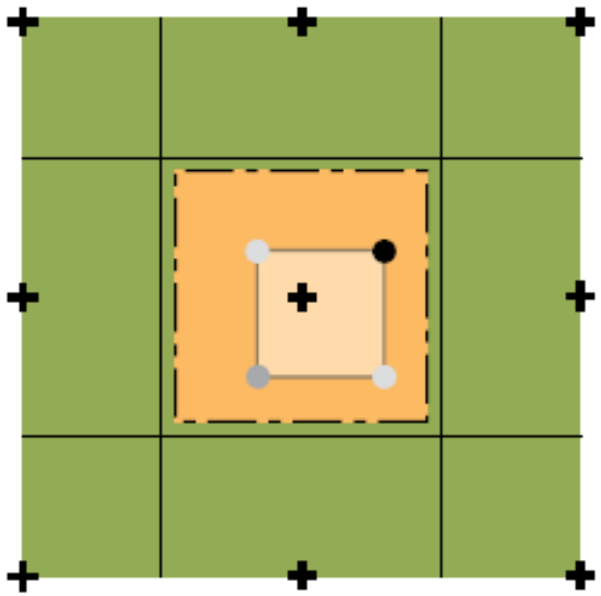
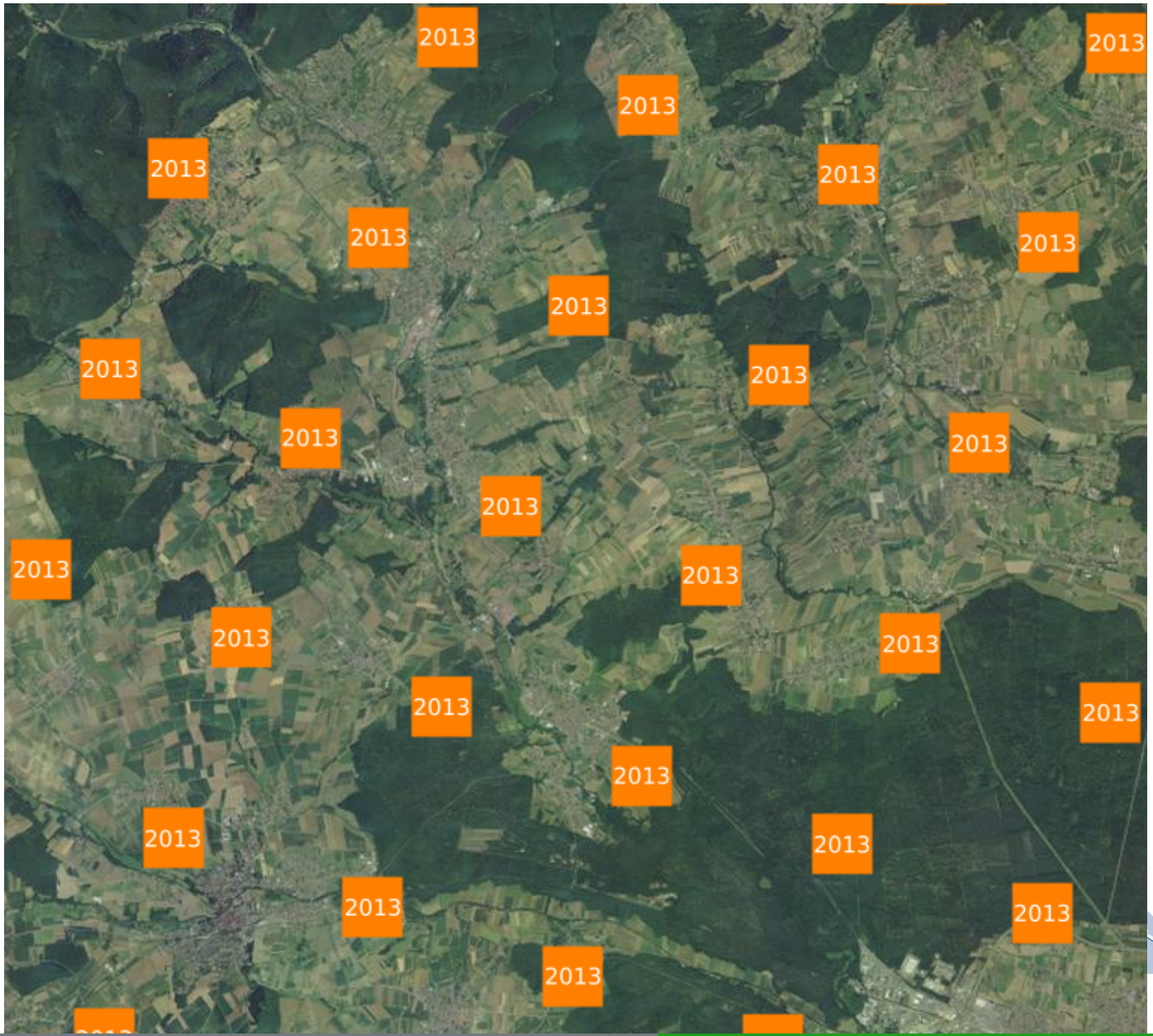


- Each cell of the grid belongs to a level that allows regular subsampling
- Division by 2 of the number of points each time a level is raised

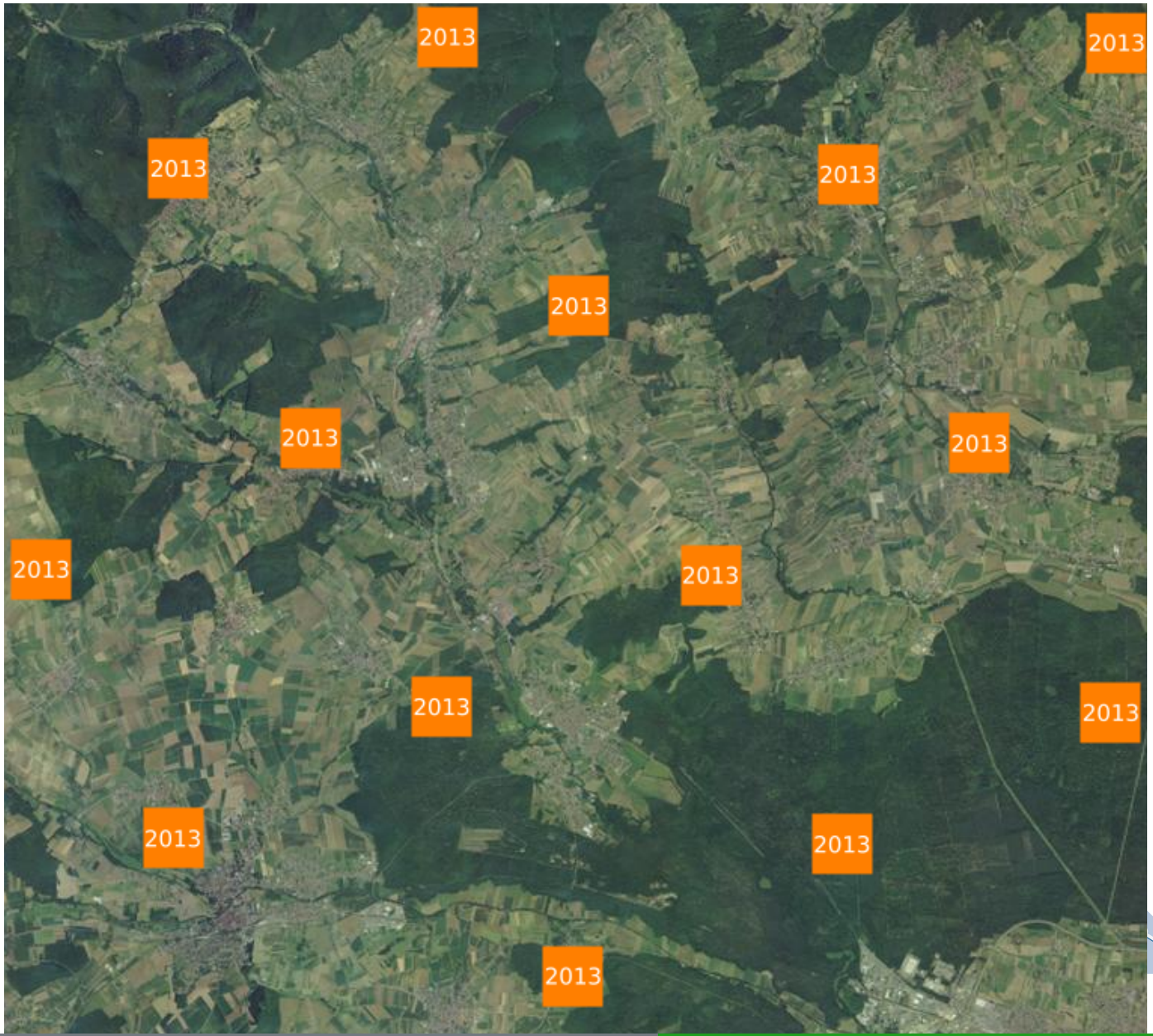
Essentially

The grid is a support for systematically distributing samples in space and time

Level 1 : annual grid of 10 km^2



Level 2 : annual grid of 20 km^2



Niveau 3 : annual grid of 40 km^2

Niveau 4 : annual grid of 80 km^2

Annual splitting

- Annual sample grid are square
- Valid property for a subset of grid dividers d which verify :

$$d = a^2 + b^2, \{a, b, d\} \in \mathbb{N}$$

where a and b are coordinates of the sub-sample

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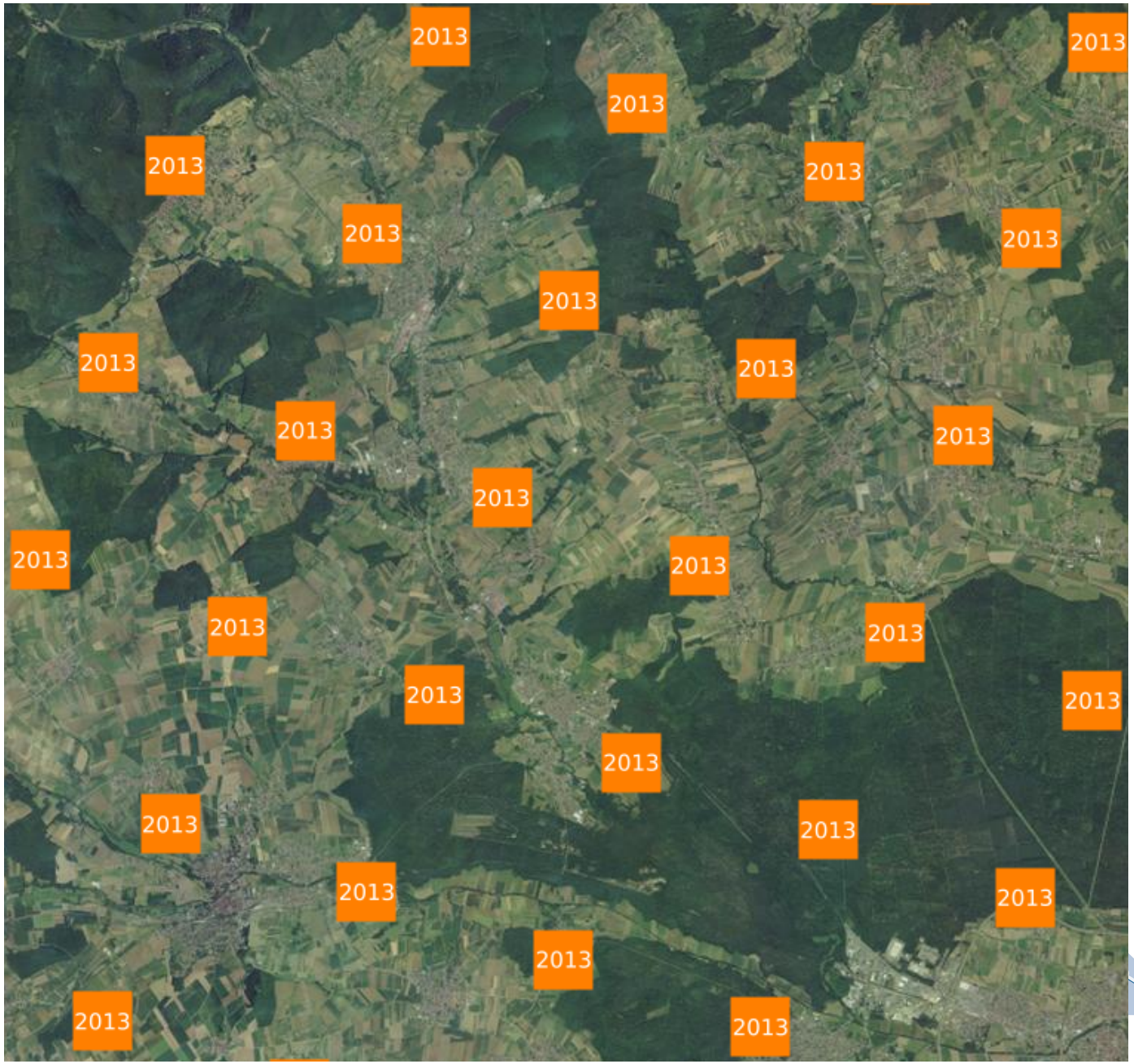
- Initial choice of $d = 10$ $(3^2 + 1^2)$
- Five first annual fractions positionned
- Next five years shifted by 1km to the east
  - Remeasurments of 5 years old plots *rigtharrow* “rectangular” sampling grid !
  - But (still ?) no **permanent plots**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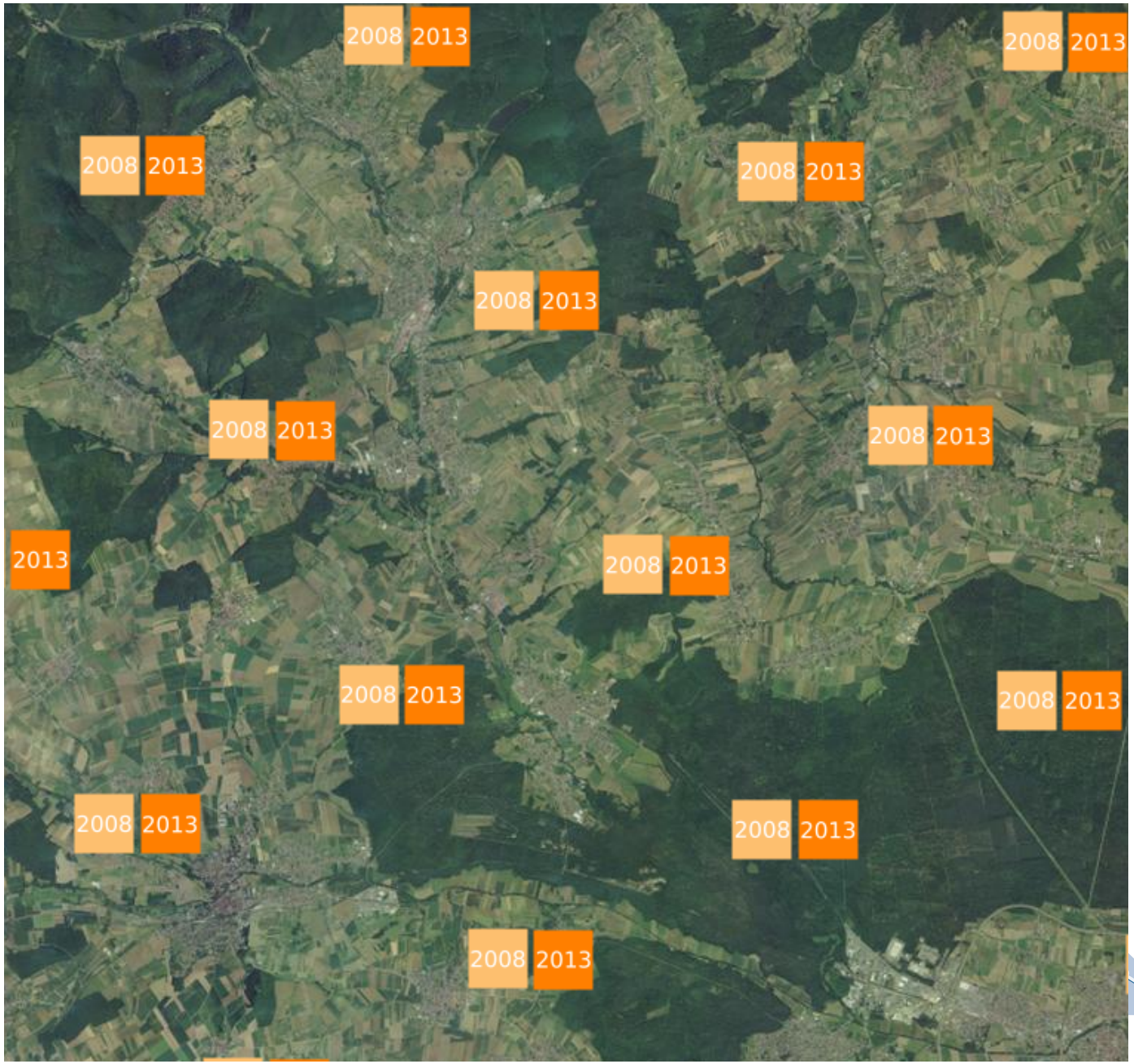
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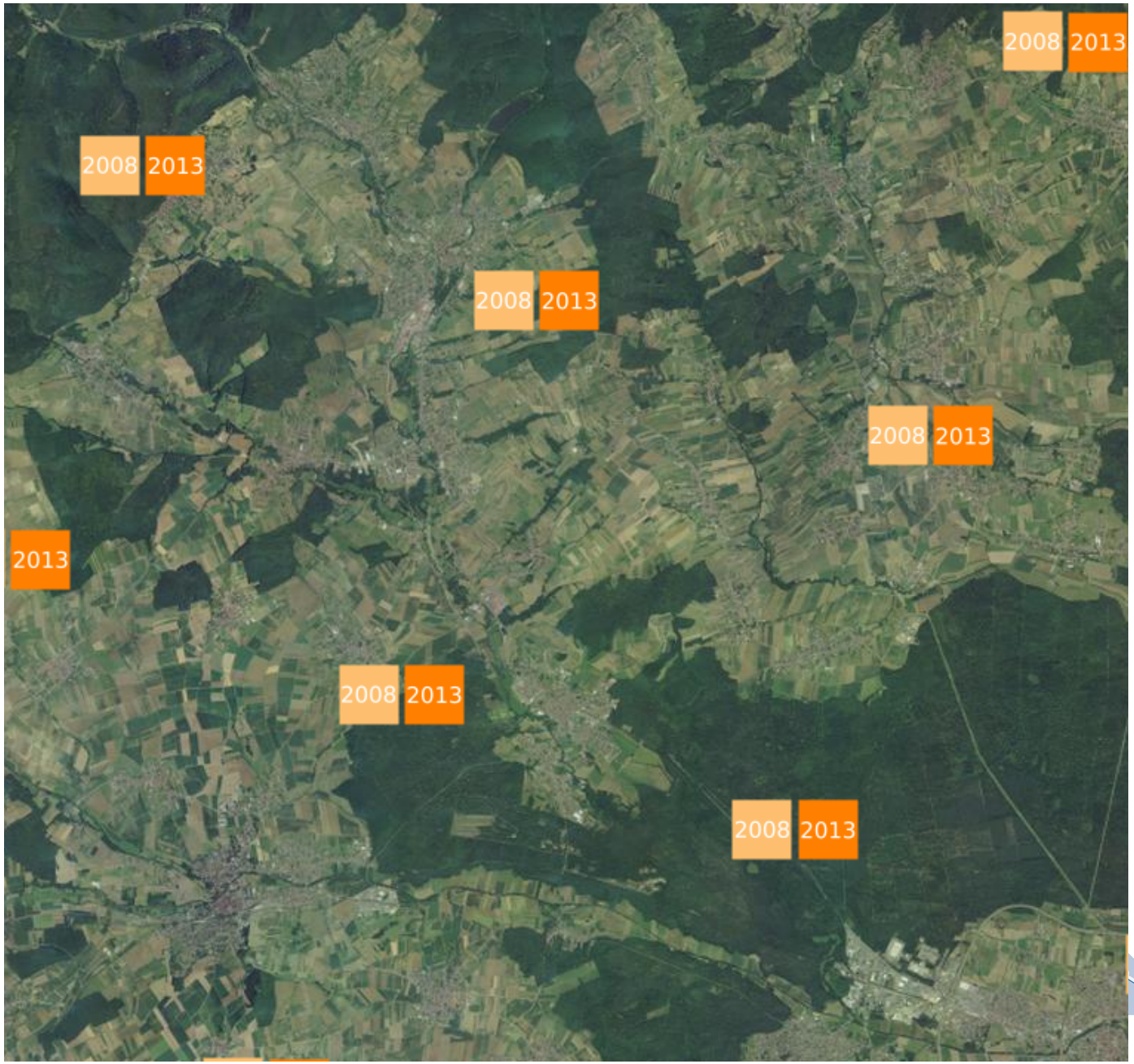
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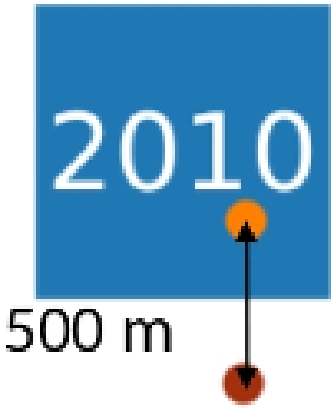
From 2015 to 2019

- More measures on the five year old (return) plots
- Same grid as the previous one but :
  - New point positionned at 500 m to the north or the south
- Samples (too much) constrained by previous ones



From 2020

- Based on the original grid
- The grid is shifted by 1km to the north
  - Year = year + 15
  - Same levels
- Thus "complete" coverage of the country
- Twice at level 1 (first phase)
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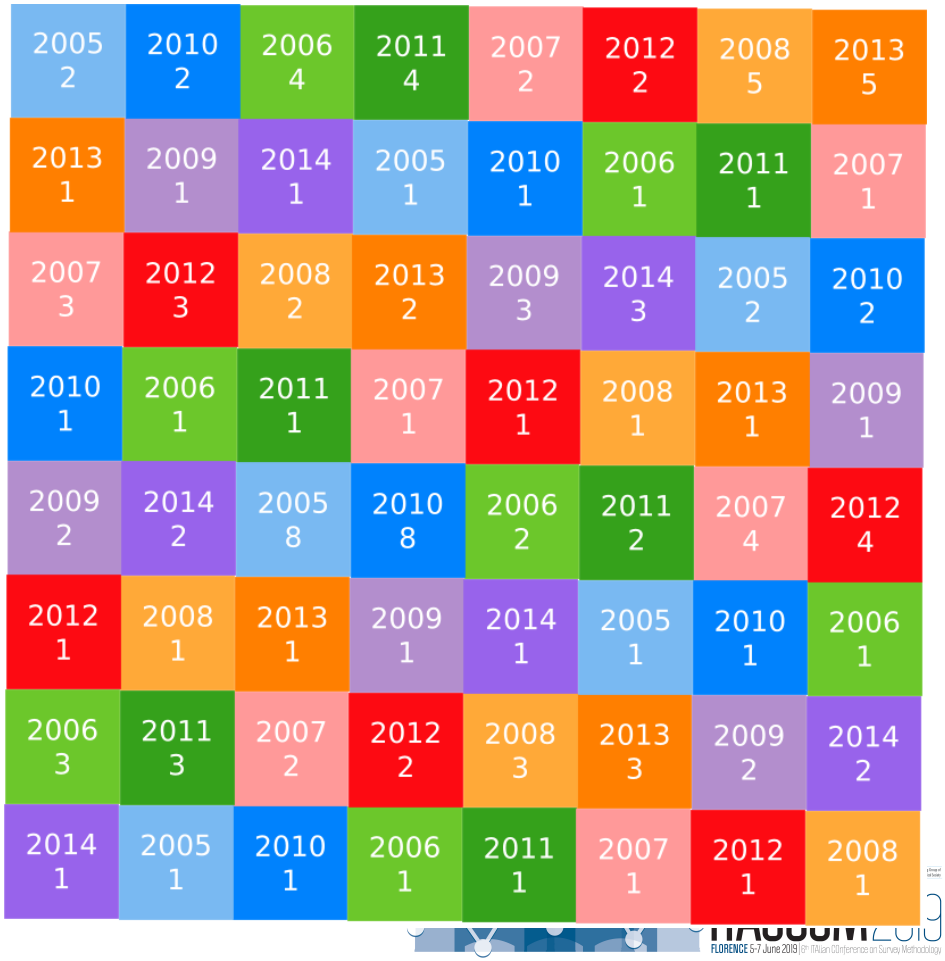

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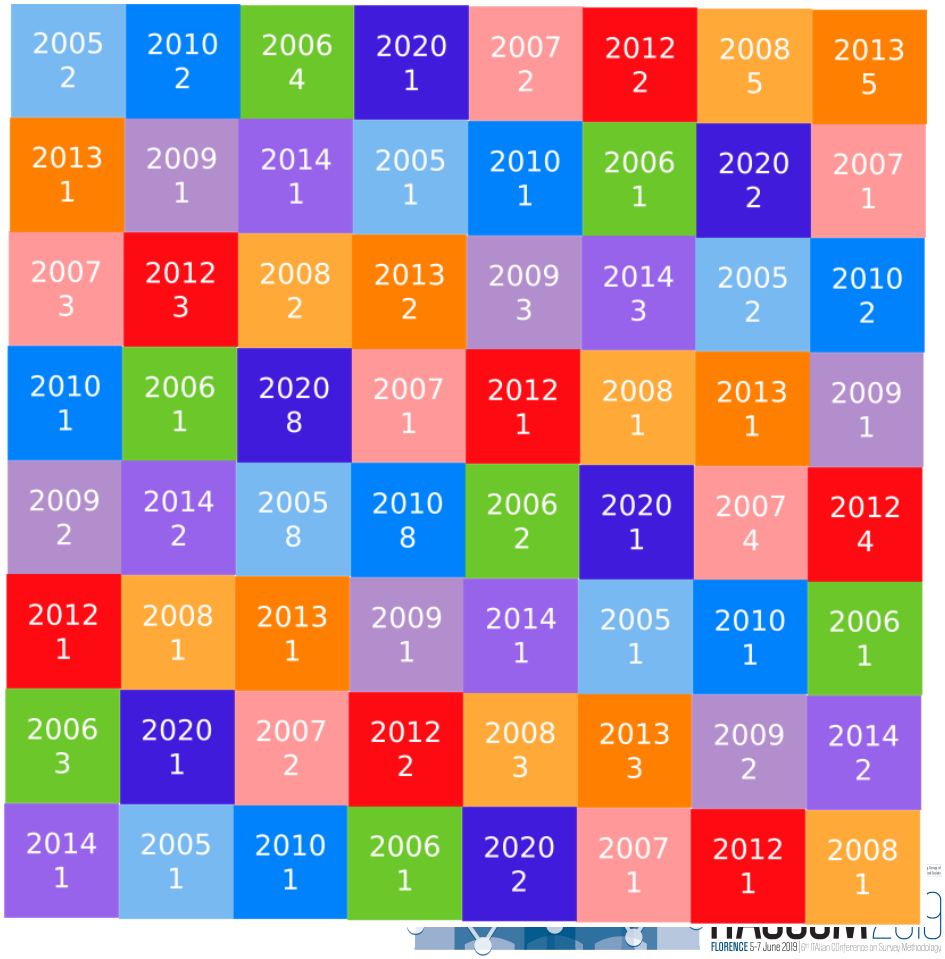
→ The same grid during 20 years !



Some (statistical) perspectives

New auxiliary data

- Use of auxiliary data is familiar through post-stratification
- But :
  - Limited to a small set of administrative and internally produced maps
  - Sometimes complex thus restricted to the scientific / technical team
- Auxiliary data need to be RARE :
  - **R**elevant : correlated with field attributs
  - **A**t marginal cost : budgetary constraints
  - **R**egularly updated : avoiding large time lag
  - **E**xhaustive over the territory : generalization

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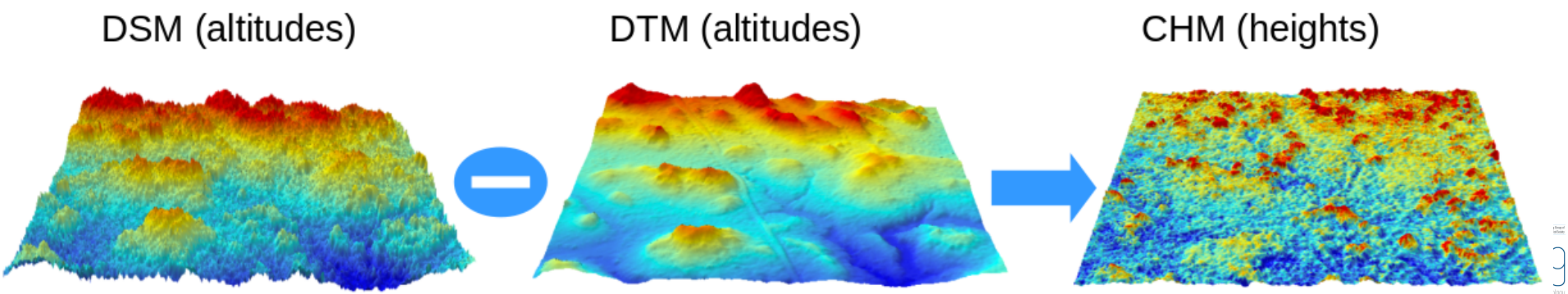

New statistical approaches

- kNN imputation
- Method successfully developped in Nordic countries (Erkki Tomppo)
- Still at research level in France (complexity of the forests)
- A way to produce estimates at finer scale
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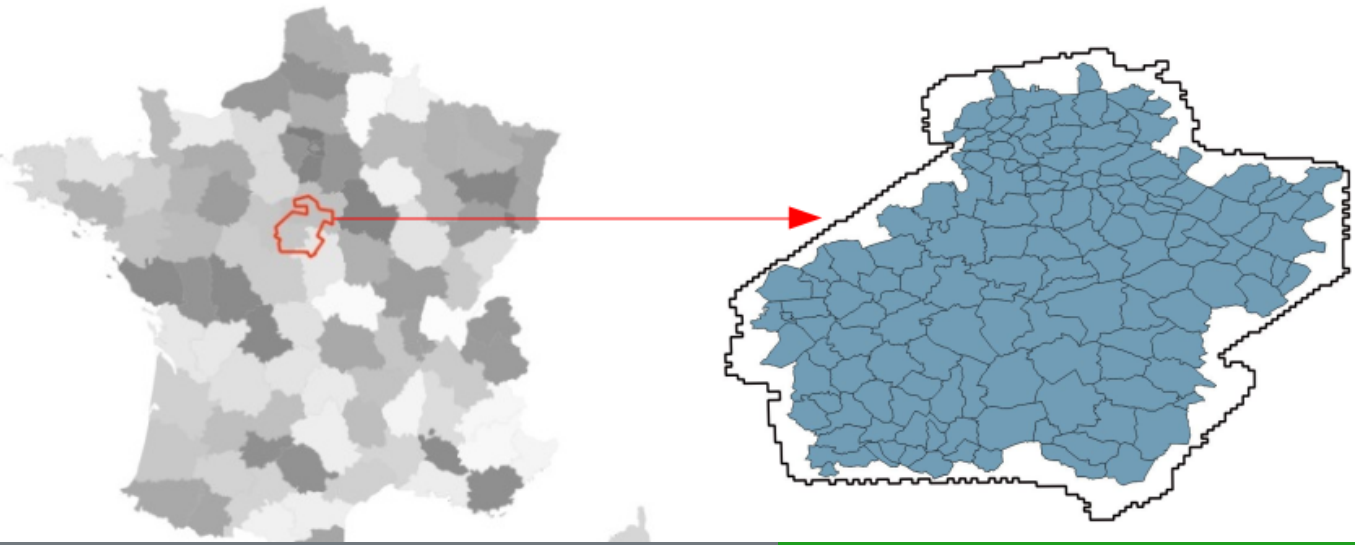
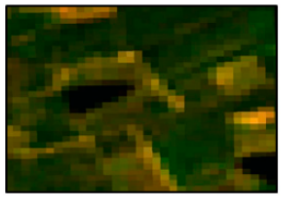
- The Sologne example (*cf.* Irulappa-Pillai-Vijayakumar *et al.* 2019)
  - 6500 km^2, ~ 50% of forests
  - 75% of broadleaves (mainly oaks), 75% of private forests
  - 800 NFI forest plots over 5 years (2010-2014)

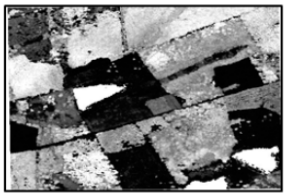


The Sologne example

- Auxiliary data


Forest type map


Landsat images (30 m)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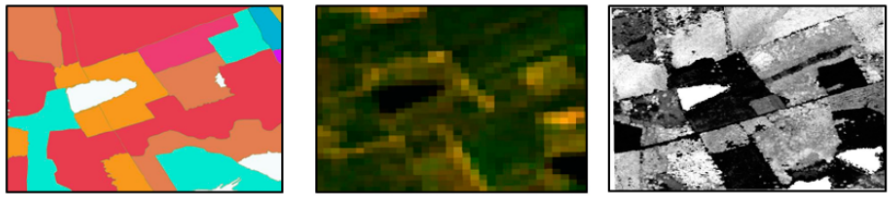
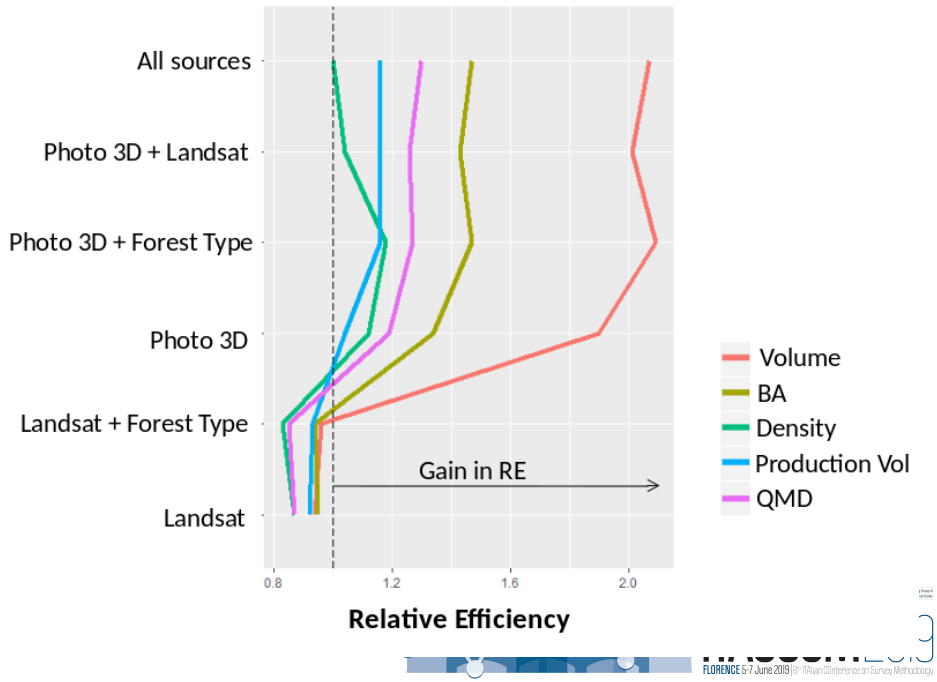

Forest type map | Landsat images (30 m) | Photogrammetric CHM

- Results in terms of Relative Efficiency (RE)
  - $RE = Var(\bar{Y}_{SRS}) / Var(\bar{Y}_{GREG})$
  - The gain can reach a factor 2
  - High contribution of 3D data



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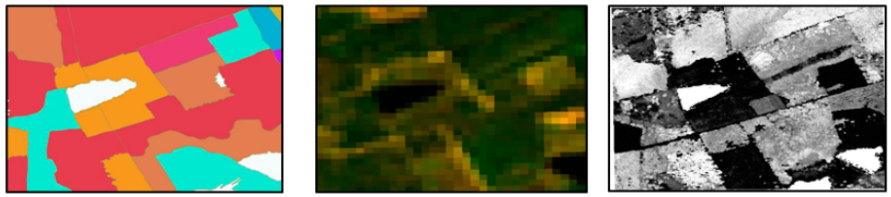
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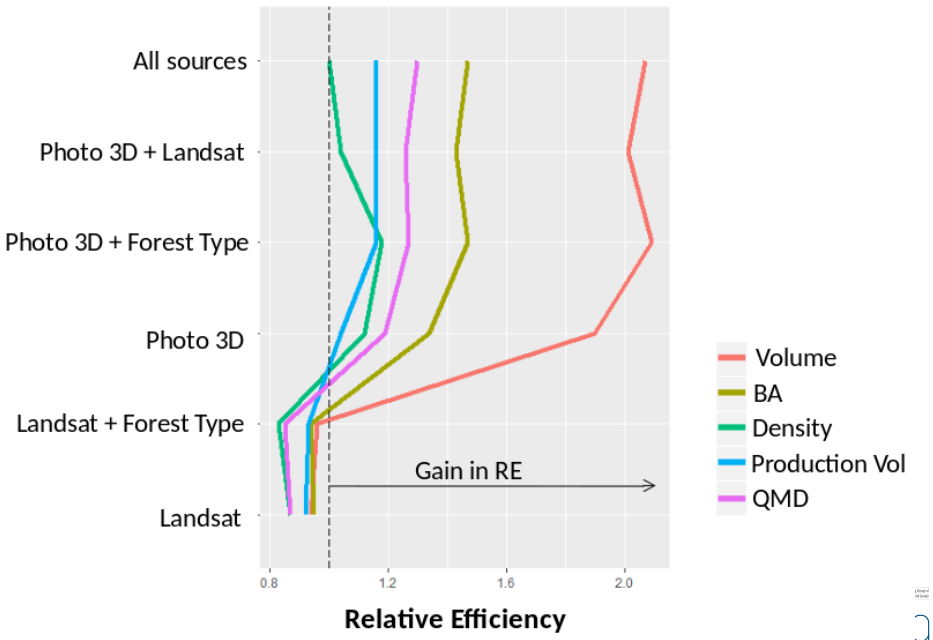

- Perspectives
  - Test in a more complex (mountainous) area
  - Compare RE with post-stratification strategy

Toward a European monitoring tool ?

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  - A European estimation and analysis system integrating auxiliary data

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  - A European estimation and analysis system integrating auxiliary data
- nFIESTA
  - Combination of different sampling design (one / country)
  - Horvitz-Thompson theorem for continuous populations (Cordy 1993)
  - Tested for 4 countries (to be published)

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- Possess historical data that give access to **temporal trends**
- Have integrated **ecology** for years (central for all CC questioning)

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But

They need strong statistical effort in order to take the full advantages of the open possibilities !

Questions ?

Thank you !