Modelisation of the French forest Sector
Antonello Lobianco

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“I recognize the right and duty of this generation to develop and use our natural resources, but I do not recognize the right to waste them, or to rob by wasteful use, the generations that come after us.”

-- Theodore Roosevelt (26th President of the United States from 1901 to 1909, naturalist and Nobel Peace Prize winner)
Today’s objectives

Understand how the complex interactions of the (French) Forest sector, linking forest dynamics, people pursuit's of own goals, markets “behaviours” and society objectives for a better environment, can be accounted, represented and modelled.

- Forest resources dynamics
  - recognition of forest diversity
  - path dependency
  - environmental changes

- HWP markets
  - supply, demand, trade
  - price transmission channels

- Forest investments decisions
  - how we modelled them
  - a bit more complicated: CBA analysis

- Climate change
  - cc effects on the forest (already seen)
  - do forests really mitigate climate change?
  - implementation of a carbon module
French Forest Sector Model (FFSM)
FFSM development

Multidisciplinary team at the Laboratoire d’Economie Forestiere (UMR INRA/AgroPArisTech)

Current Team
- Ahmed Barkaoui
- Sylvain Caurla
- Philippe Delacote
- Antonello Lobianco
- Claire Montagné-Huck
- Alexandra Niedzwiedz

Past members
- Frank Lecocq
- Julien Barthès
- Alexandre Sauquet
- Iason Diafas

External contributors
- Jean-Daniel Bontemps (LERFoB)
- Hélène Chevalier (IGN)
- Antoine Colin (IGN)
- Pierre Mérian (IGN)
- Holger Wernsdörfer (LERFoB)
FFSM++ development
Uses

FFSM has been used for a wide range of analysis, of both positive and normative nature:

- Should policies subsides targeted to sequestrated carbon or fuelwood?
- Economic and resource impact of fuelwood subsidies
- Carbon tax and mitigation policies: impact on the French forest sector
- Is it better to store or export the excess of timber following large windfalls?
- How much the future of French forests depends from human management and forest managers risk-aversion
- What is the climate change mitigation potential of the French forest sector?
- Which is the ecological and economic effect of the introduction of the ash pathogen?
Ok, we developed a model.. but what is a *model* ??

**Reality** $\rightarrow$ model $\rightarrow$ math. form.
Ok, we developed a model.. but what is a *model*??

**Reality → model → math. form.**

A model is useful if it helps us to predict something, in this case if a crash will happen.
Ok, we developed a model.. but what is a model??

Reality → model → math. form.

$t_{A1} = \frac{x_{A1}}{v_A}$

$t_{A2} = \frac{x_{A2}}{v_A}$

$t_B = \frac{x_B}{v_B}$

$t_{A2} \leq t_B \leq t_{A1} \Rightarrow \text{crash}$

Models can be “wrong” in both the translation of elements that matter in the modelling idea (assumptions) or in their formalisations (e.g. Mariner 1, 1962 satellite, Mars Climate Orbiter 1998)

```cpp
int main (){  
    float xa1, xa2, yb, va;  
    float vb, ta1, ta2, tb;  
    cin >> xa1;  
    cin >> xa2;  
    cin >> yb;  
    cin >> va;  
    cin >> vb;  
    ta1 = xa1/va;  
    ta2 = xa2/va;  
    tb = yb/vb;  
    if (tb >= ta2 && tb <= ta1){  
        cout << "Crash..." << endl;  
    } else {  
        cout << "No crash.." << endl;  
    }
}
A modular approach

Recursive bio-economic model with coupled biological forest growth model and partial equilibrium market of forest products.

Four interconnected modules:

- **Forest dynamics module**: model forest resources
- **Market module**: HWP markets (supply, demand, trade..)
- **Area allocation module**: forest investment choises
- **Carbon module**: mitigation potentials of the forest sector
- **Pathogen module**: simulation of a spatially explicit pathogen
Spatial representation

Decoupling the spatial scale of the market module (country and regional) from those of the resource and management modules (pixel level)

- regional scale reasonably adequate for the market module
- pixel level (area fraction) for resource and management model
Forest resources
- definition

Box 18.1 Forest, other woodland, and other land with tree cover: definitions of terms

<table>
<thead>
<tr>
<th>Forest</th>
<th>Land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other wooded land</td>
<td>Land not classified as forest, spanning more than 0.5 hectares; with trees higher than 5 m and a canopy cover of 5–10 percent, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use.</td>
</tr>
<tr>
<td>Other land with tree cover</td>
<td>All land that is not classified as forest or other wooded land is called ‘other land’. Of this, ‘other land with tree cover’ is defined as land spanning more than 0.5 hectares with a canopy cover of more than 10 percent of trees able to reach a height of 5 m at maturity.</td>
</tr>
</tbody>
</table>

“The group considers the FAO definition of a forest as the basic one, but acknowledge that many other useful definitions of "forest" exist in published form. The fact that "forest" has been defined in many ways is a reflection of the diversity of forests and forest ecosystems in the world and of the diversity of human approaches to forest” (Convention on biological diversity)
Forest resources
- types

**Primary forest**
A primary forest is a forest that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age.

**Secondary forest**
A secondary forest is a forest that has been logged and has recovered naturally or artificially. Not all secondary forests provide the same value to sustaining biological diversity, or goods and services, as did primary forest in the same location.

**Plantation forest**
A plantation forest may be afforested land or a secondary forest established by planting or direct seeding. A gradient exists among plantation forests from even-aged, single species monocultures of exotic species with a fibre production objective to mixed species, native to the site with both fibre and biodiversity objectives.

P.S.: Classification may vary
## Forest resources
- how, which and where

<table>
<thead>
<tr>
<th>Region</th>
<th>Forest 1000ha</th>
<th>Primary</th>
<th>Type %</th>
<th>Oth. wooded land 1000ha</th>
<th>% land area</th>
<th>Wooded land ha cap.</th>
<th>% world</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- east &amp; south</td>
<td>274,886</td>
<td>2.1</td>
<td>96.3</td>
<td>1.7</td>
<td>171,344</td>
<td>44.6</td>
<td>1.04</td>
</tr>
<tr>
<td>- north</td>
<td>36,217</td>
<td>3.7</td>
<td>53.3</td>
<td>23.3</td>
<td>60,091</td>
<td>10.1</td>
<td>0.40</td>
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<tr>
<td>- west &amp; central</td>
<td>313,000</td>
<td>40.9</td>
<td>51.9</td>
<td>1.0</td>
<td>135,606</td>
<td>43.4</td>
<td>0.92</td>
</tr>
<tr>
<td>Asia</td>
<td>593,362</td>
<td>19.8</td>
<td>58.1</td>
<td>21.7</td>
<td>234,729</td>
<td>26.6</td>
<td>0.19</td>
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<tr>
<td>- east</td>
<td>257,047</td>
<td>12.9</td>
<td>51.3</td>
<td>35.7</td>
<td>108,762</td>
<td>31.6</td>
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<tr>
<td>- south &amp; south-east</td>
<td>292,804</td>
<td>27.6</td>
<td>62.1</td>
<td>10.2</td>
<td>60,673</td>
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<td>0.15</td>
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<tr>
<td>- west &amp; central</td>
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<td>15.6</td>
<td>65,294</td>
<td>9.7</td>
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<td>64.0</td>
<td>8.1</td>
<td>100,014</td>
<td>50.4</td>
<td>1.51</td>
</tr>
<tr>
<td>- Italy</td>
<td>9,297</td>
<td>1.0</td>
<td>92.1</td>
<td>6.9</td>
<td>1,813</td>
<td>37.8</td>
<td>0.18</td>
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<tr>
<td>- France</td>
<td>16,989</td>
<td>0.0</td>
<td>88.4</td>
<td>11.6</td>
<td>590</td>
<td>32.1</td>
<td>0.27</td>
</tr>
<tr>
<td>- Germany</td>
<td>11,419</td>
<td>0.0</td>
<td>53.6</td>
<td>46.4</td>
<td>0</td>
<td>32.8</td>
<td>0.14</td>
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<tr>
<td>- Sweden</td>
<td>28,073</td>
<td>8.6</td>
<td>42.5</td>
<td>48.9</td>
<td>2,432</td>
<td>74.3</td>
<td>3.17</td>
</tr>
<tr>
<td>North and central Am.</td>
<td>750,653</td>
<td>42.6</td>
<td>51.6</td>
<td>5.8</td>
<td>89,049</td>
<td>39.3</td>
<td>1.48</td>
</tr>
<tr>
<td>- central</td>
<td>20,250</td>
<td>26.9</td>
<td>71.4</td>
<td>1.7</td>
<td>6,116</td>
<td>51.9</td>
<td>0.57</td>
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<tr>
<td>- caribbeans</td>
<td>7,195</td>
<td>3.2</td>
<td>85.4</td>
<td>10.2</td>
<td>1,066</td>
<td>36.7</td>
<td>0.19</td>
</tr>
<tr>
<td>- north</td>
<td>723,207</td>
<td>43.5</td>
<td>50.7</td>
<td>5.8</td>
<td>81,868</td>
<td>39.1</td>
<td>1.68</td>
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<td>Oceania</td>
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<td>81.7</td>
<td>2.5</td>
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<td>10.96</td>
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<tr>
<td>South America</td>
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<td>47.6</td>
<td>43.7</td>
<td>1.8</td>
<td>156,429</td>
<td>57.2</td>
<td>2.42</td>
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<tr>
<td>World</td>
<td>3,999,134</td>
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<td>58.5</td>
<td>7.2</td>
<td>1,204,471</td>
<td>39.9</td>
<td>0.72</td>
</tr>
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</table>

Source: FAO FRA 2015
## Forest resources

### - trends (1)

<table>
<thead>
<tr>
<th>Region</th>
<th>Wooded land</th>
<th>Forest</th>
<th>Other wooded land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- east &amp; south</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>- north</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- west &amp; central</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asia</td>
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<td></td>
<td></td>
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<tr>
<td>- east</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- south &amp; south-east</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- west &amp; central</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe</td>
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<td></td>
<td></td>
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<tr>
<td>- Italy</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>- France</td>
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<td></td>
<td></td>
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<tr>
<td>- Germany</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Sweden</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North and central Am.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- central</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- caribbeans</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- north</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oceania</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South America</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>World</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: FAO FRA 2015
## Forest resources

- trends (2)

<table>
<thead>
<tr>
<th>Region</th>
<th>Primary forest</th>
<th>Natural regeneration</th>
<th>Plantations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>-4.3</td>
<td>-2.2</td>
<td>-2.4</td>
</tr>
<tr>
<td>- east &amp; south</td>
<td>-8.5</td>
<td>-3.8</td>
<td>-4.9</td>
</tr>
<tr>
<td>- north</td>
<td>-7.4</td>
<td>-4.0</td>
<td>-4.2</td>
</tr>
<tr>
<td>- west &amp; central</td>
<td>-4.1</td>
<td>-2.1</td>
<td>-2.3</td>
</tr>
<tr>
<td>Asia</td>
<td>78.0</td>
<td>-1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>- east</td>
<td>12.2</td>
<td>-2.3</td>
<td>5.9</td>
</tr>
<tr>
<td>- south &amp; south-east</td>
<td>139.7</td>
<td>-0.7</td>
<td>-1.6</td>
</tr>
<tr>
<td>- west &amp; central</td>
<td>0.4</td>
<td>0.9</td>
<td>-4.2</td>
</tr>
<tr>
<td>Europe</td>
<td>6.7</td>
<td>-1.0</td>
<td>7.1</td>
</tr>
<tr>
<td>- Italy</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>- France</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>- Germany</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>- Sweden</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>North and central Am.</td>
<td>-1.1</td>
<td>0.8</td>
<td>-0.1</td>
</tr>
<tr>
<td>- central</td>
<td>-27.7</td>
<td>21.3</td>
<td>22.7</td>
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<tr>
<td>- caribbeans</td>
<td>-0.9</td>
<td>-0.4</td>
<td>-0.4</td>
</tr>
<tr>
<td>- north</td>
<td>-0.7</td>
<td>0.6</td>
<td>-0.4</td>
</tr>
<tr>
<td>Oceania</td>
<td>-16.6</td>
<td>16.8</td>
<td>-9.1</td>
</tr>
<tr>
<td>South America</td>
<td>-3.7</td>
<td>-1.8</td>
<td>10.9</td>
</tr>
<tr>
<td>World</td>
<td>3.3</td>
<td>-0.5</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Source: FAO FRA 2015
Forest resources
- FFSM implementation (forest dynamics module)


- For each pixel (8x8 km) and forest type:

\[
Vol_{dc,t} = \left(1 - \frac{1}{timeOfPassage_{dc,t}} - mortality_{dc,t} - harvestedRate_{dc,t}\right) \times Vol_{dc,t-1} \\
+ \left(\frac{1}{timeOfPassage_{dc-1,t-1}}\right) \times beta_{dc} \times Vol_{dc-1,t-1}
\]

\[
\begin{align*}
Volums_t & \quad \text{dc15} & \text{dc30} & \text{dc45} \\
B, HF & \quad \text{B, Mix} & \quad \text{B, C} & \quad \text{C, HF} \\
Volums_{t+1} & \quad \text{dc15} & \text{dc30} & \text{dc45} \\
B, HF & \quad \text{B, Mix} & \quad \text{B, C} & \quad \text{C, HF}
\end{align*}
\]
Forest resources
- modelling CC effect on forest resources

CC effects on the forest dynamics are exogenous to FFSM. Conversely, consequences on the management of the forest are explicitly accounted for.

Using multipliers subscripts key input biological variables can change from the regional average along the spatial and temporal dimensions according to the CC scenario under study:

- time of passage: \( tP_{sc,px,ft,dc,t} = tP_{r,ft,dc,t=0} * \text{tpMultiplier}_{sc,px,ft,t} \)
- mortality rate: \( \text{mort}_{sc,px,ft,dc,t} = \text{mort}_{r,ft,dc,t=0} * \text{mort}_{sc,px,ft,t} \)

An exogenous parameter allows the model to consider (again, exogenously) land use changes with reference to the forest (\( \text{forestChangeAreaIncrementsRel}_{sc,r,t} \) or \( \text{forestChangeAreaIncrementsHa}_{sc,r,t} \))

Scenario based analysis:

Socioeconomic development

CC models

Vegetational model scenarios..

Forest managers adaptations

Uncertainty
**HWP markets**

- **Market module**: 3 primary products and 6 transformed products (Leontief transformation), imperfect substitutability national vs international products, regional trade.

![Diagram of HWP markets]

- **Forest resources**
  - Broadleaved: dc15, dc25, dc35....
  - Coniferous: dc15, dc25, dc35....

- **Primary products**
  - Hardwood Roundwood
  - Softwood Roundwood
  - Industrial wood

- **Transformed products**
  - Hardwood Sawnwood
  - Pannels
  - Plywoods
  - Softwood Sawnwood
  - Pulp
  - Paper

- **Exports (transformation)**
  - Hardwood Roundwood
  - Softwood Roundwood
  - Industrial wood

- **Imports (supply)**
  - Hardwood Sawnwood
  - Pannels
  - Plywoods
  - Softwood Sawnwood
  - Pulp
  - Paper

- **Demand (national consumers)**
HWP markets

Supply
It depends from own price and availability of the resource:

$$\frac{\text{supply}_{r,pp,t}}{\text{supply}_{r,pp,t-1}} = \left( \frac{P_{r,pp,t}}{P_{r,pp,t-1}} \right)^{eSP_{pp}} \left( \frac{\text{inv}_{r,pp,t}}{\text{inv}_{r,pp,t-1}} \right)^{eSI_{pp}}$$

Demand
It depends uniquely from the own price (recently a cross-price elasticity has been added):

$$\frac{\text{demand}_{r,pt,t}}{\text{demand}_{r,pt,t-1}} = \left( \frac{P_{r,pt,t}}{P_{r,pt,t-1}} \right)^{eDP_{pp}}$$

International trade
While products in different regions are assumed perfectly homogeneous (and hence regional price depends diverge only by transport costs), national vs international products are assumed partially heterogeneous. A parameter (the Armington elasticity) defines how local prices are more or less dependant by local market condition vs external international prices:
Forest investment decisions

- Net Present Value

Net Present Value

The Net Present Value (NPV) is the sum of all the benefits and costs involved during the investment, each discounted at the indicated interest rate from the planned time to the starting time of the investment.

It is therefore computed as:

\[
NPV = \sum_{t=0}^{T} \left( \frac{B_t - C_t}{1+i} \right)^t
\]

where \( T \) is the total length of the forest investment (its rotation period), \( B_t \) are the total benefits coming from the activities planned at time \( t \) in current prices, and \( C_t \) are the total costs arising from such activities and \( i \) is the interest rate.

A NPV value greater than zero means that the investment is profitably at the given interest rate.

However it is not directly comparable between investment of different length.
Forest investment decisions

- Soil Expected Value

**Soil Expected Value**

The Soil Expectation Value (SEV) is the maximum amount that you would pay for the bare land holding the forest, given the expected flow of incomes and costs of the project under analysis. It is effectively the Net Present Value of an infinite series of identical forest rotation for the project under analysis.

It is computed as:

\[
SEV = \frac{NPV \times (1+i)^T}{(1+i)^T - 1}
\]

Where \( NPV \) it the Net Present Value of a single rotation (the production cycle), \( T \) is the rotation length (typically the number of years) and \( i \) is the market interest rate.

Differently from the NPV, it allows to compare forest investments of different duration.
Forest investment decisions
- CBA analysis to retrieve NPV, SEV and IRR

The computation of the NPV or SEV (and the closely related Internal Rate of Return - IRR, that is the value of interest rate that lead the NPV to zero) is often done numerically and in discrete form: following “guidelines” for the specific forest investment, each year are reported the expected operations that will generate revenues or costs and then the NPV is the actualised present value of both of them.

This easily allows to include in the analysis also externalities and compute a separate profitability for the forest owner (“Financial Analysis”) or for the society as a whole (“Economic Analysis”) and to include risk analysis.
Forest investment decisions

- FFSM implementation (area allocation module)

  - **Area allocation module**: agent based micro-economic model; area allocation endogenised; regeneration = f (π(prices, growth, mortality)); forest managers heterogeneous for (a) managed forest resources, (b) degree of risk-aversion (prices and growth vs. mortality), (c) level of expectations (observed vs. future prices, growth, mortality);

  - Forest investments are chosen based (comparing) on the SEV.

  - Two corrections are made before the comparison:
    - Transaction costs are subtracted from the SEV. These transaction costs are defined for each couple of *current forest type, compared forest type*.
    - As (a) forest investments involve a certain risk, (b) this risk is different for the different investments, and (c) the aversion for the risk is different for the various managers, the comparison is carried on over a certain equivalent SEV of the investment, computed as:
      \[
      CESEV_{i,j} = SEV_i \times (1 - ra_j \times cumMort_i)
      \]
      where \( CESEV_{i,j} \) is the certain equivalent SEV of forest investment \( i \) for the forest manager \( j \), \( SEV_i \) is the original SEV, \( ra_j \) is the risk aversion coefficient for forest manager \( j \) and \( cumMort_i \) is the average cumulative mortality expected for forest investment \( i \) before maturation.
    - Future mortality and growth rates needed to compute the SEV can be those forecasted by the specific scenario or those prevailing at time to make the investment, depending from forest manager expectations.
Forest investment decisions

- FFSM implementation (area allocation module)

Heterogeneous expectations are important as... we don’t all have the same opinion about climate change!
Climate change
- introduction

Global Annual Mean Surface Air Temperature Change

Combined Land-Surface Air and Sea-Surface Water Temperature Anomalies
(Land-Ocean Temperature Index, LOTI)

Source: NASA GISS Surface Temperature Analysis
Climate change
- introduction

1751 – 2012 global fossil fuels and cement production CO$_2$ emissions

Source: Carbon Dioxide Information Analysis Center (CDIAC)
Climate change
- introduction
Climate change
- forest mitigation potential

ATMOSPHERE
829 PgC

TERRESTRIAL BIOSPHERE
4,200 PgC

LITOSPHERE
1,471 (~6,000) PgC
(fossil fuels)

OCEANS
38,703 PgC

fast domain (few years to millennia)

slow domain (> 10,000 years)

Source: Lobianco et al. (2016), adapted from Ciais and Sabine (2013)
Climate change  
- forest mitigation potential

Storing carbon in the terrestrial biosphere, within the fast domain sinks is a bit like *sweeping the dirt under the carpet*
Climate change
- forest mitigation potential

Simulation of carbon stocks in the French forests

There is large scientific evidence that the pool is becoming saturated – hence it will be less able in the future to absorb additional CO2 from the atmosphere.
Climate change
- FFSM carbon module

- **Carbon module**: “registers and accounts” forest and forest sector carbon emitted/sequestrered/substituted;

Squares: carbon pools; ellipses: processes. The clock icon denotes multi-period flows. Elements accounted for in the module are drawn using wider contours.
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