INRA
SCIENCE & IMPACT

Changements du fonctionnement (carbone, eau) et de la productivité des écosystèmes forestiers en relation avec les itinéraires de gestion

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INRA SCIENCE & IMPACT

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French forestry context

- Raising the share of EU energy consumption produced from renewable resources to 20%

- Intensification of forest management, e.g. biomass harvesting, is promoted at national level

- Dramatic impacts of recent and successive storms, droughts and heatwaves question the management of production forests

- Climate scenarios predictions agree on enhanced soil and atmospheric drought in Southern Europe

FAST Objectives

- Analyse the potential effect of climate scenario on productivity, water and carbon cycle in managed forests at national level

- Investigate the role of forest management on CO_2 flux and in situ carbon balance

- Identify and quantify interactions between management, environment (soil type, climate scenarios) and key pathogens and defoliating insect species.

Approach proposed

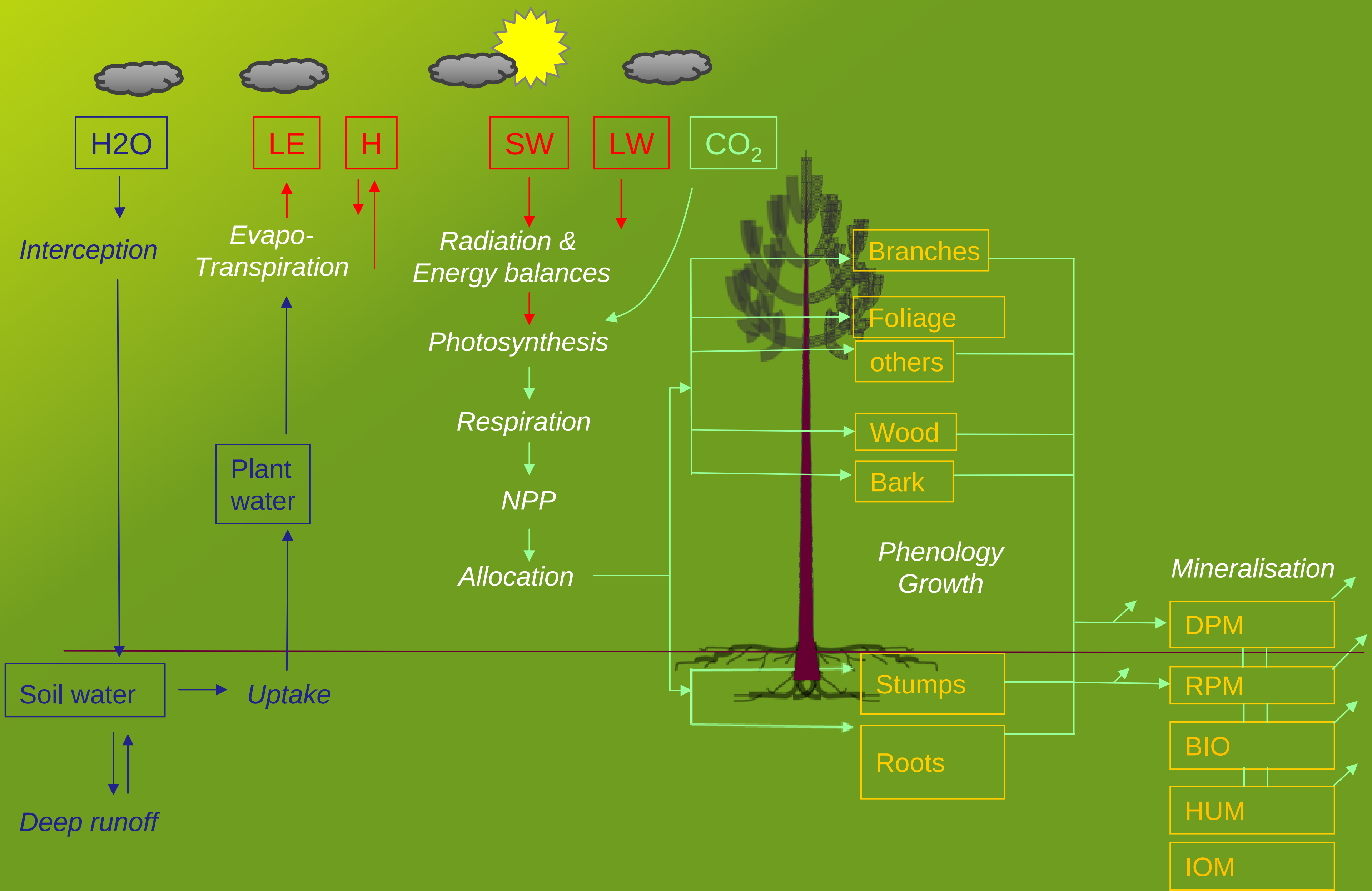
- Calibration and evaluation of process based model of managed forest using long term data sets (flux, growth and soil data)

- Implementation over France at hourly time step and 8x8 km resolution according to:
  - Factorial cross-sensitivity analysis (climate x soil x management)
  - Dynamic projections at 8 x 8 km and from 1970 to 2100

- Adjonction of defoliating damages by invasive insect species

1. GO+ model

Process based management model: GO+ diagram



Main references of the model

Main process	Reference model	Source Reference
Radiation balance	Beer-Lambert law, two layer model,	*unpublished*
Energy balance	Iterative	*unpublished*
Rainfall interception	Rutter-Gash	*Loustau et al. 1992 J Hydrol.*
Transpiration	Penman Monteith	*Granier and Loustau, 1994, AFM*
Stomatal conductance	Jarvis's or Hydraulic safety constrained	*unpublished but see Delzon et al. PC&E, 2005*
Photosynthesis	Farquhar's	*Porté and Loustau, 1998, Tree physiol.; Delzon, 2000, Masters thesis*
Respiration		*Bosc etal. 2001, Tree Physiol.*
Phenology	Temperature Sum	
Growth	Growth curve (sigmoid)	*Bosc, 1999*
C allocation	Inversion of allometric equation	*Shaiek et al. 2011*
Soil carbon	Roth-C	*Guillet et al. 2010, Moreaux 2012*
Management practices		*Moreaux 2012,*

Management operations and alternatives

Alternatives

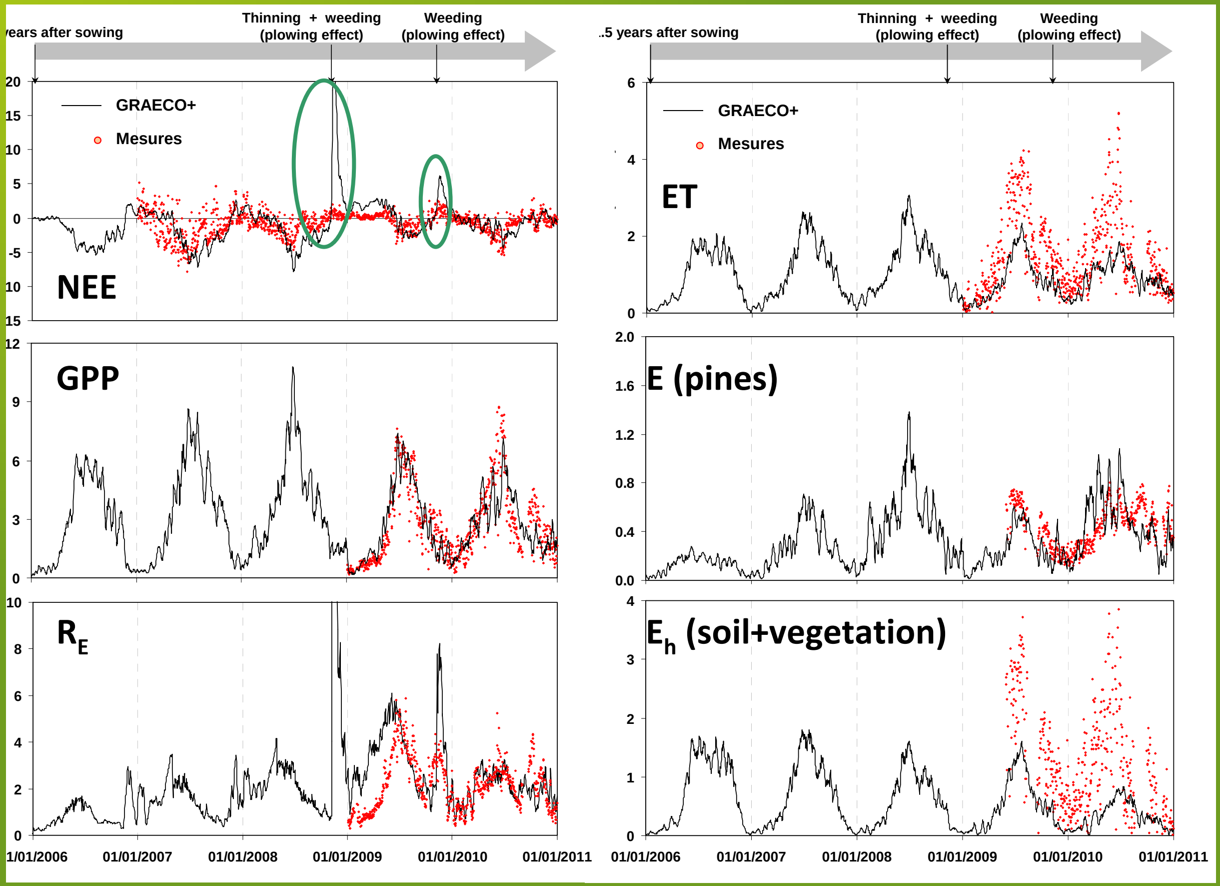
Operations

	Age at clearcut	Parts harvested	Soil tillage	Plantation	Thinnings
Extensive (E)	60 yrs	Stem only	0	1600	4 × Stem only
Standard (S)	45 yrs	Stem only	X	1600	6 × Stem only
Intensive (I)	36 yrs	Stem + Crown + Stump	XX	1600	3 × Stem + Crown 2 × Stem only
Very Intensive (VI)	30 yrs	Stem + Crown + Stump	XXX	1600	1 × Stem + Crown
COPPICE (C)	10 yrs	Stem + Crown + 1/3 Stumps	XX	3000	0
Others …					

Evaluation – atmospheric instantaneous flux

Maritime Pines: site preparation, regeneration and juvenile stages

Carbon flux ($gC\ m^{-2}\ d^{-1}$) Evaporation ($mm\ d^{-1}$)

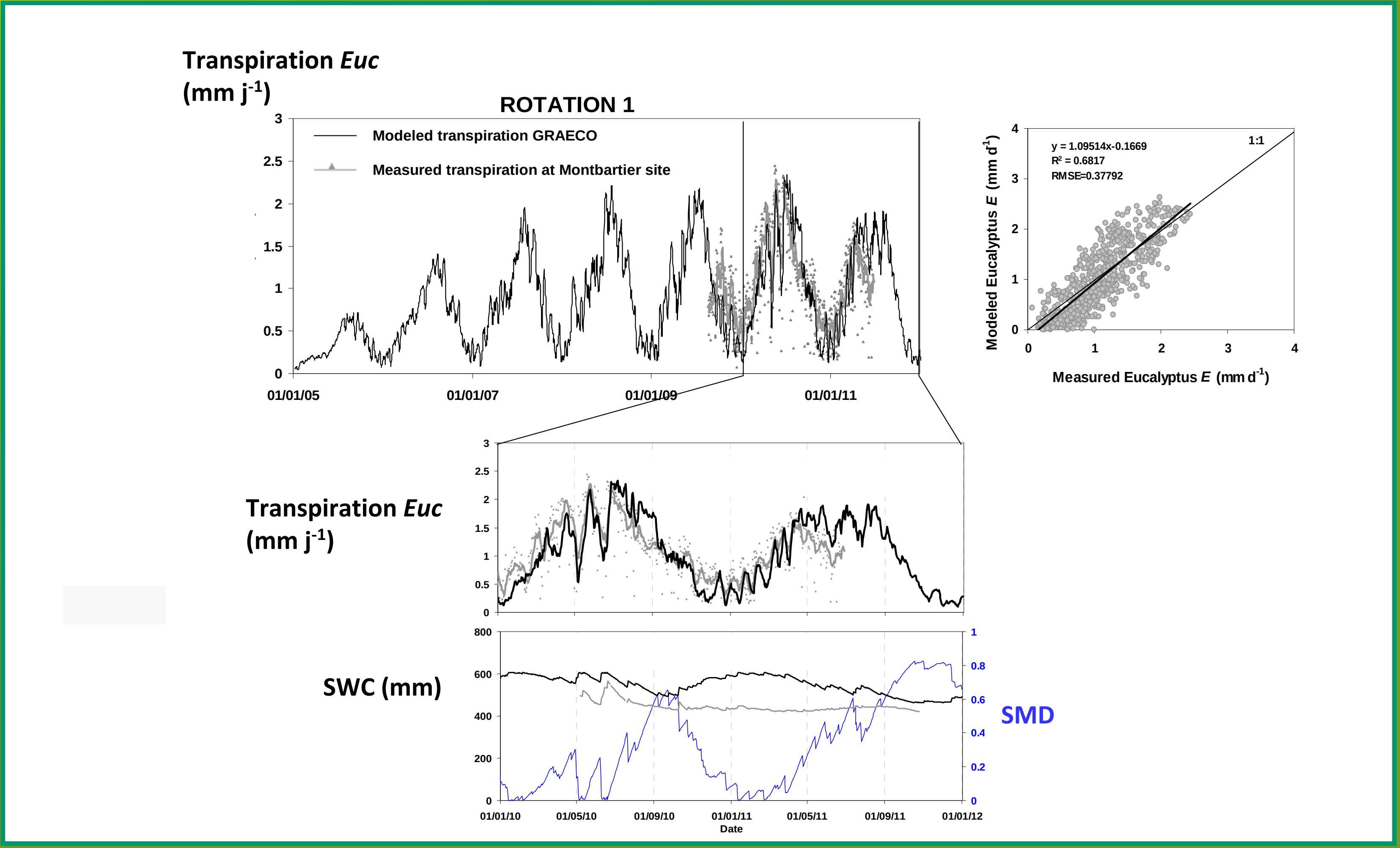


- Main temporal dynamics is captured (GPP : R^2=0.63)
- Some inconsistencies at half hourly scale, e.g. understorey ET underestimated.
- Overstory carbon, water exchanges and growth along >10-yr-long series are well described

Moreaux, 2012, Projet « Optimal » / Fondation TUCK.

Evaluation – atmospheric instantaneous flux

- *Eucalyptus* en 1ère rotation



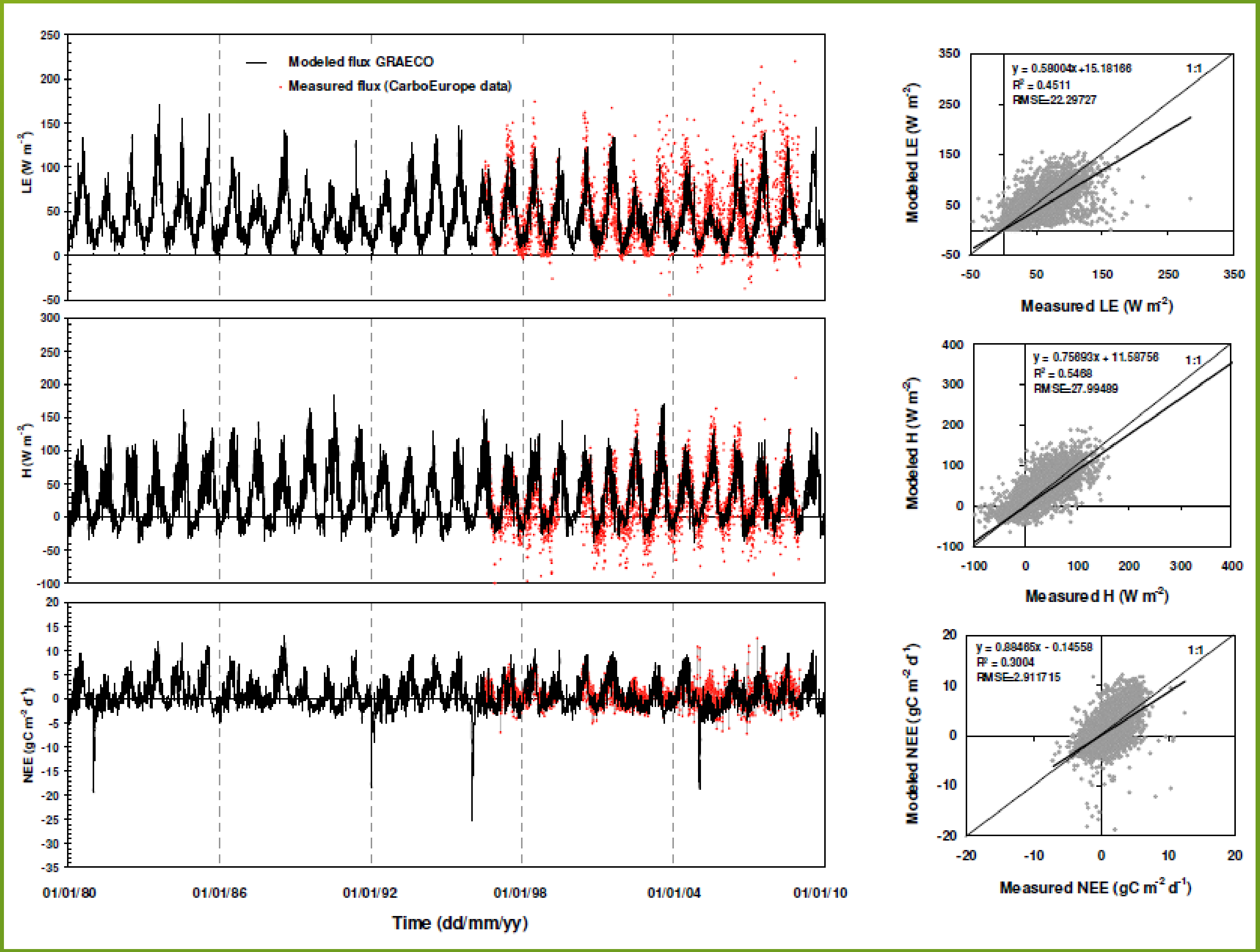
- Trajectoire à moyen terme des flux bien capturée
- Flux demi horaires simulés sans biais, faible erreur non systématique

Moreaux, 2012, Projet « Optimal » / Fondation TUCK.

Evaluation – atmospheric instantaneous flux

Maritime Pines: mature stage

Latent - , Sensible Heat and CO_2 daily fluxes

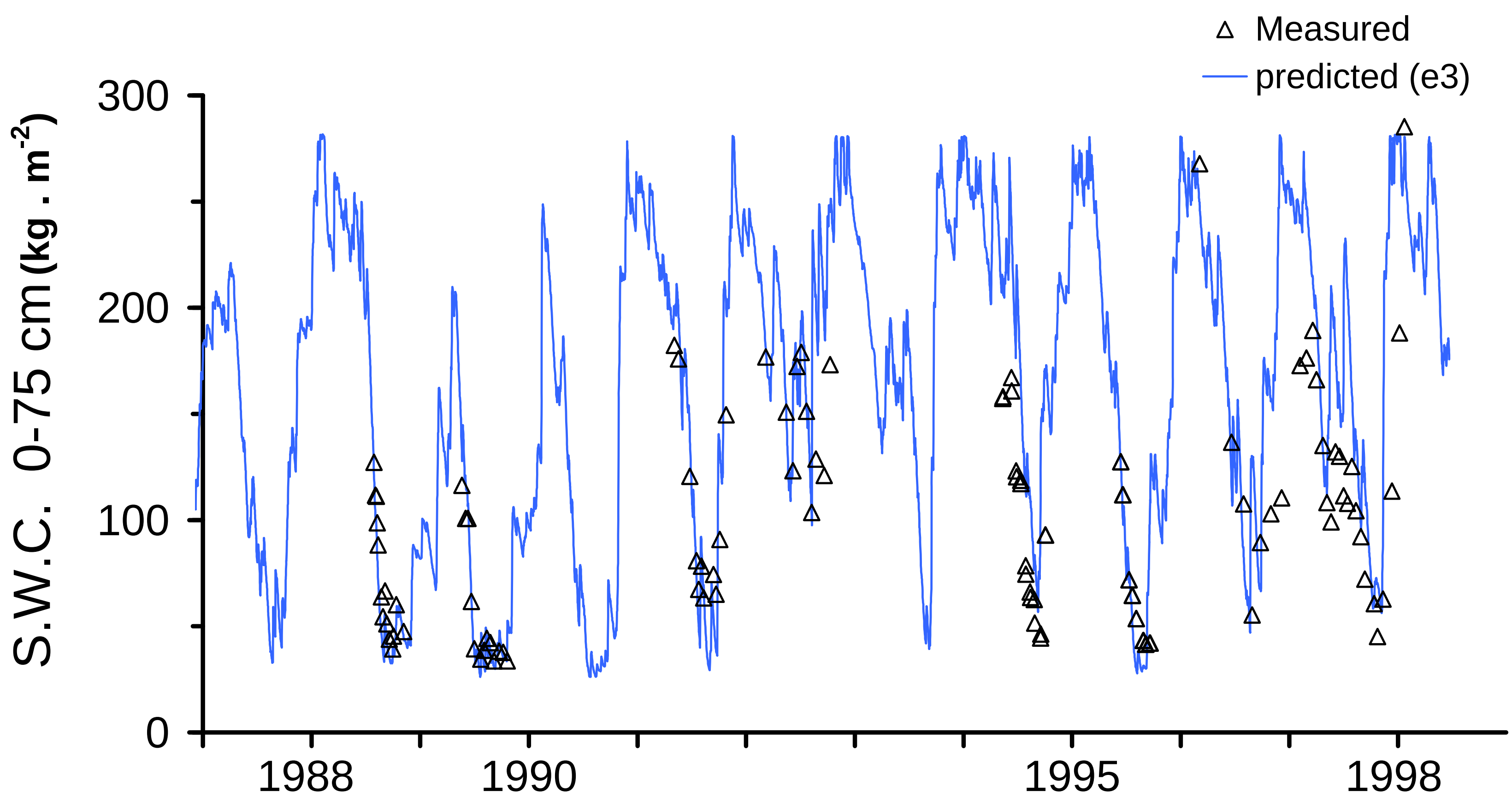


Moreaux, 2012, Projet « Optimal » / Fondation TUCK.

Evaluation – decadal water balance

Maritime Pines: mature stage

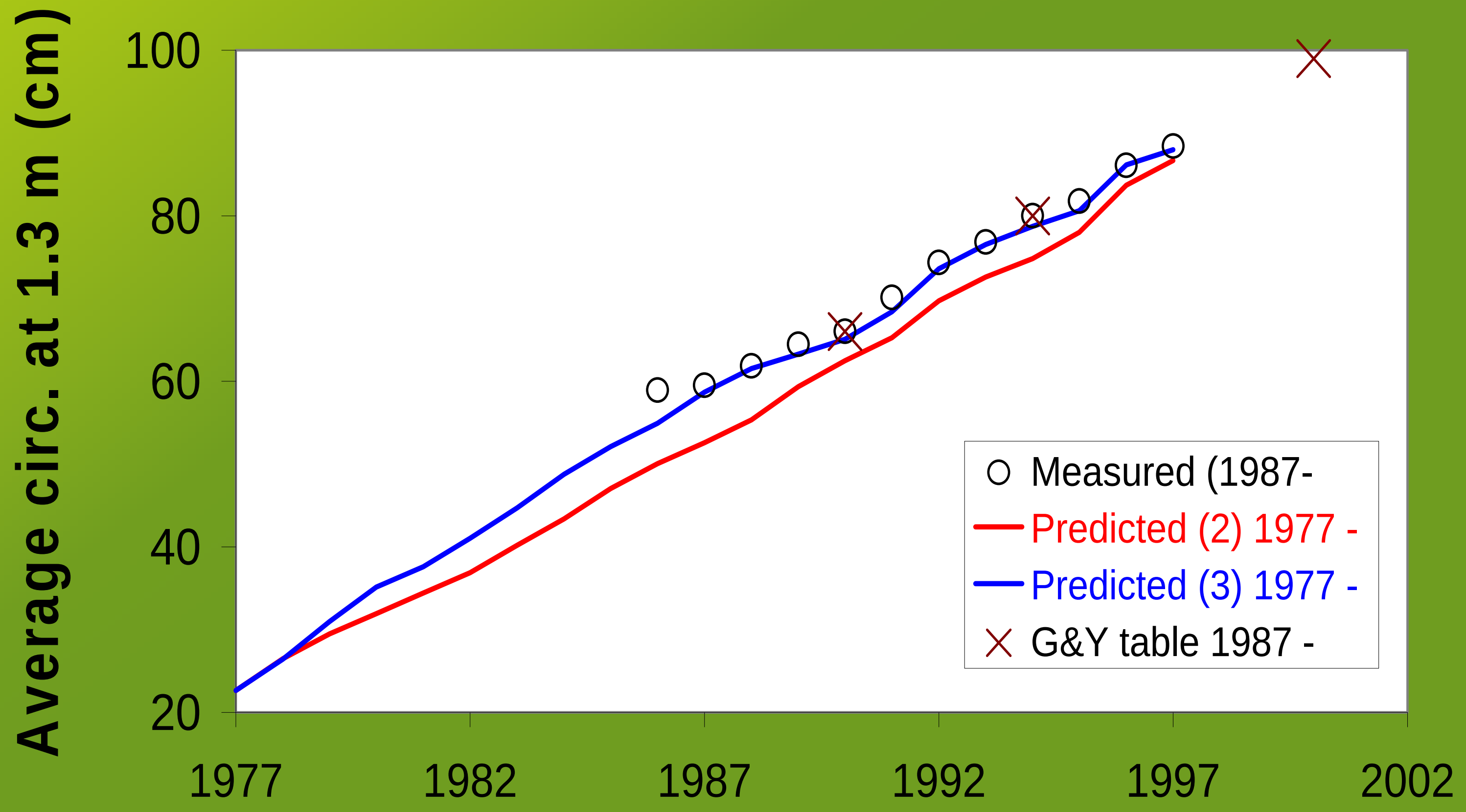
Predicted *vs* measured soil water content at the Bray site.



Evaluation – Growth data (stand level)

Stand growth:

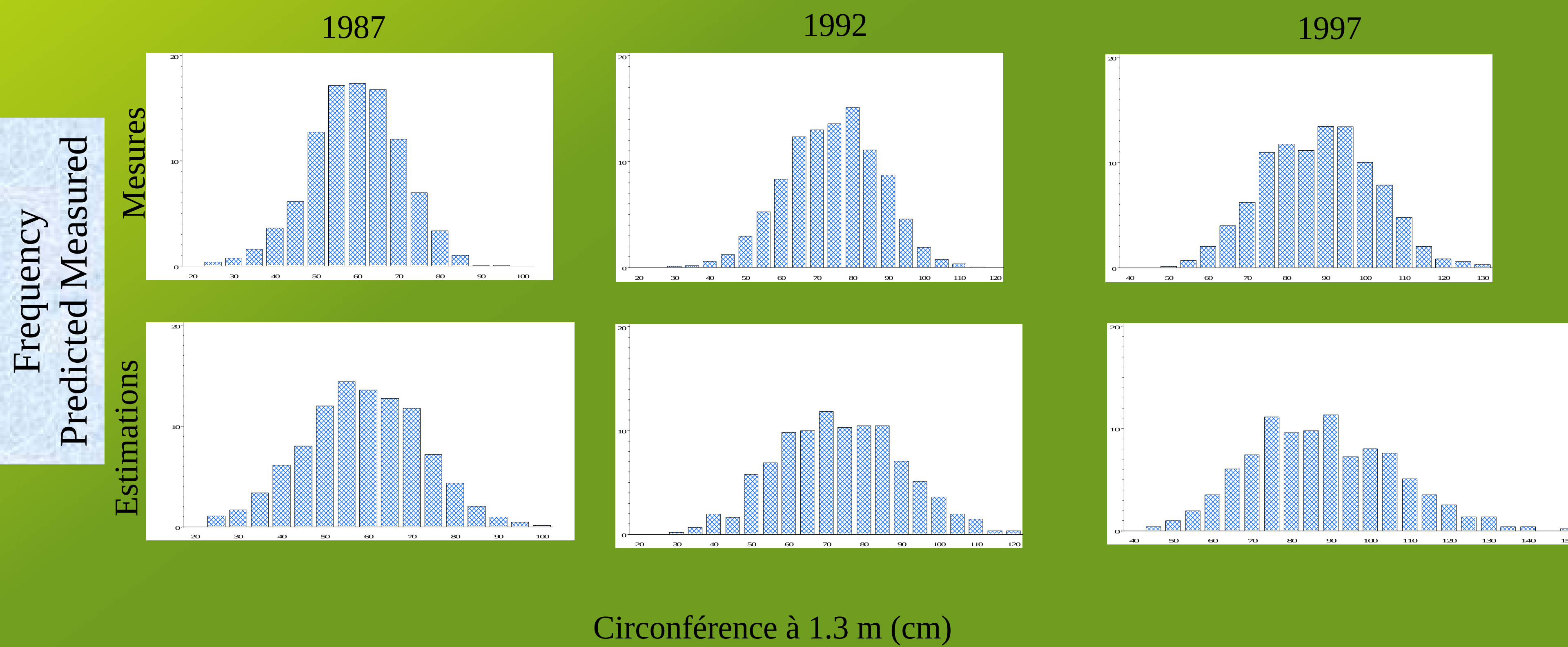
Time course of the average tree circumference at 1.3 m from 1977 to 1997



Evaluation – Growth data (stand level)

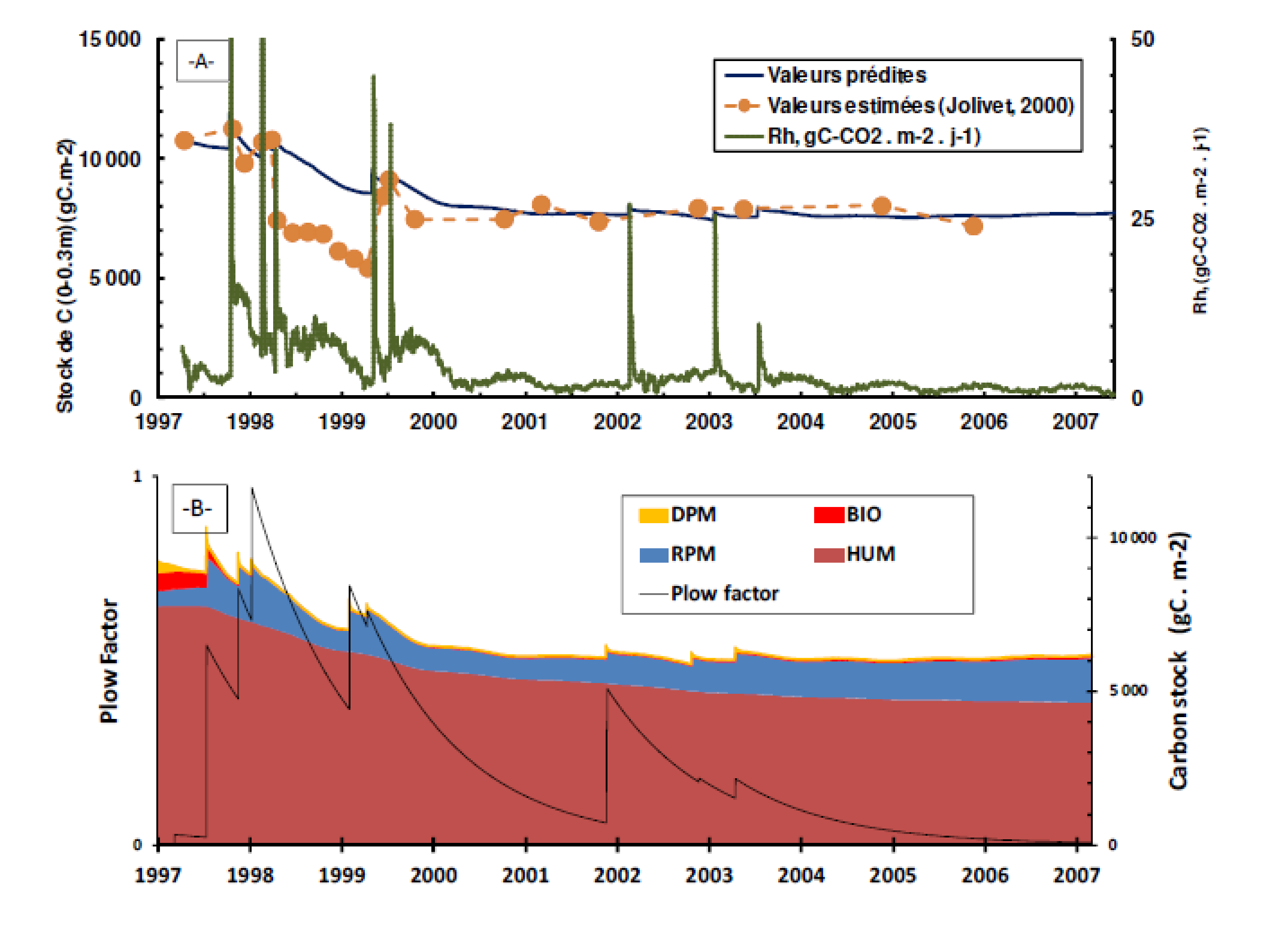
Individual Growth:

Observed and predicted distributions of circumference in the stand at three dates.



Circumference at 1.3 m high (cm)

Evaluation – Soil carbon data and management impacts(stand level)



Decadal dynamics of soil carbon following clearcut in a m.Pine stand

Evaluation – Growth data (stand level)

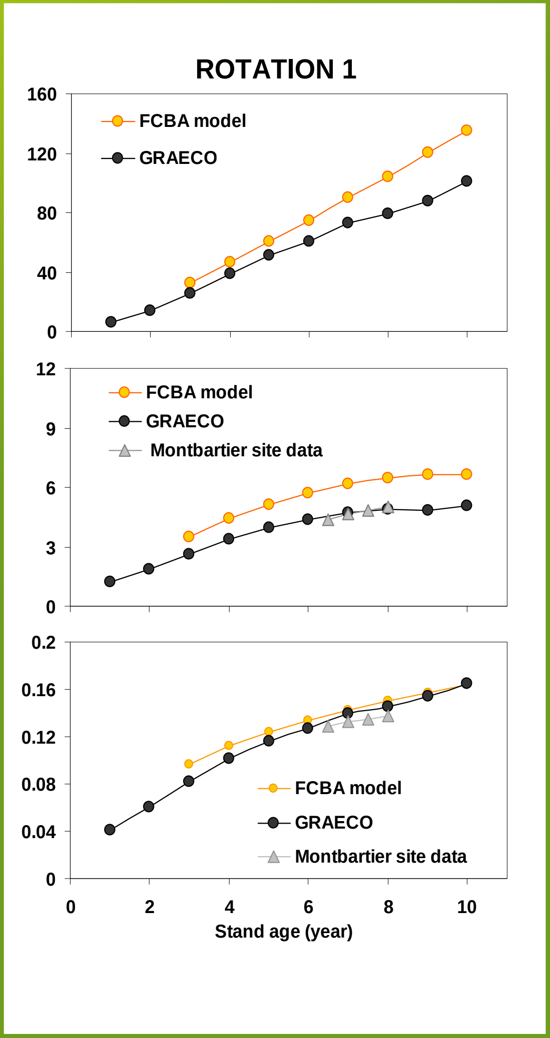
Eucalypt coppice (2011) in Southwestern France

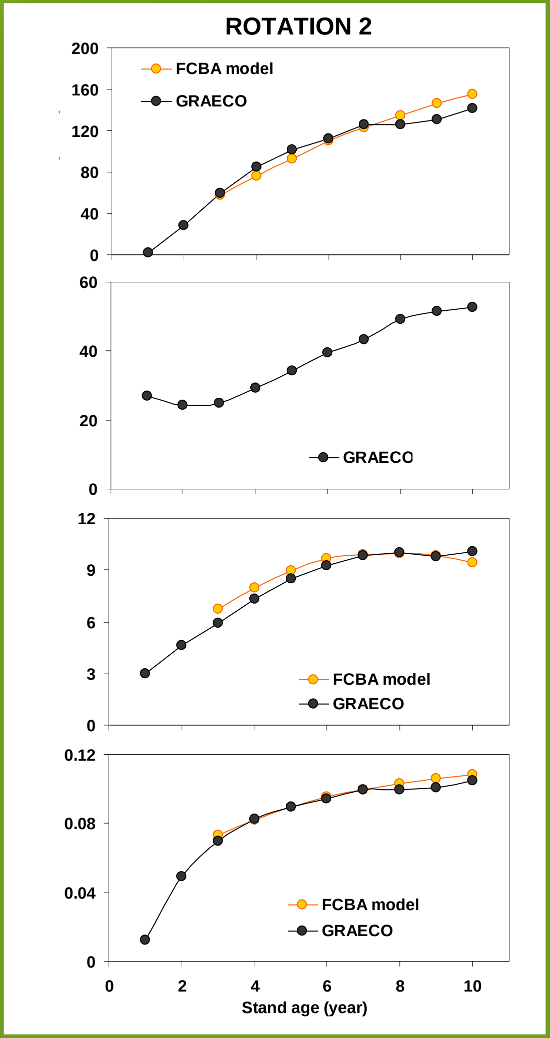
(Growth curves from Cavaignac et al. 2011, FCBA)

Biomasse sur pied (t ha^{-1})

Indice foliaire(m^2 m^{-2})

Circonférence moyenne (m)





Biomasse sur pied (t ha^{-1})

Biomasse souche (t ha^{-1})

Indice foliaire(m^2 m^{-2})

Circonférence moyenne (m)

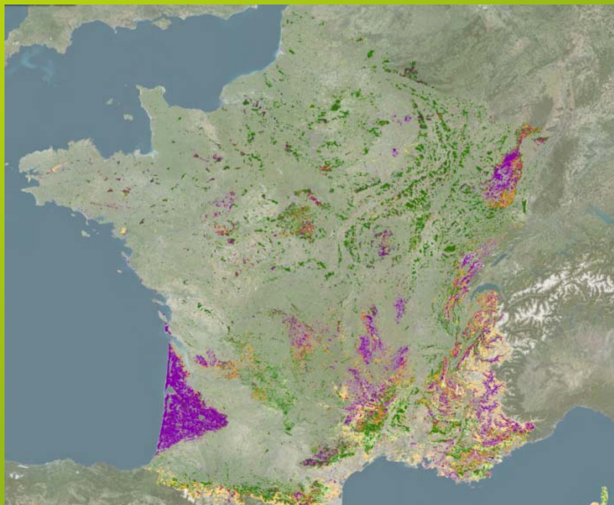
Cavaignac et al. (2011), Fiche FCBA

Moreaux, 2012, Projet « Optimal » / Fondation TUCK.

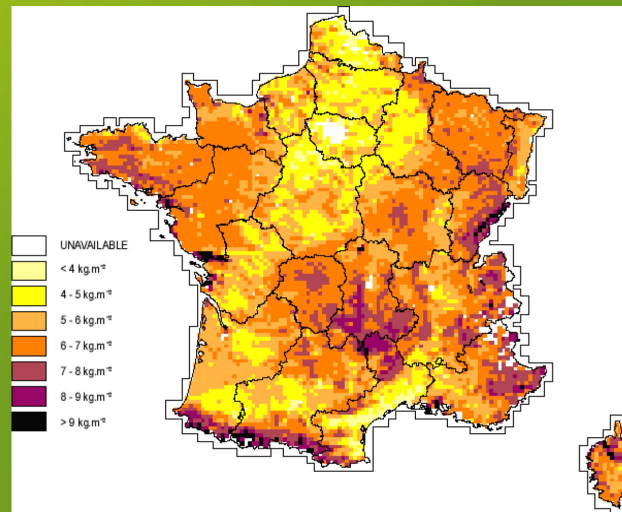
Fin partie 1

GO+ applications to FAST project objectives

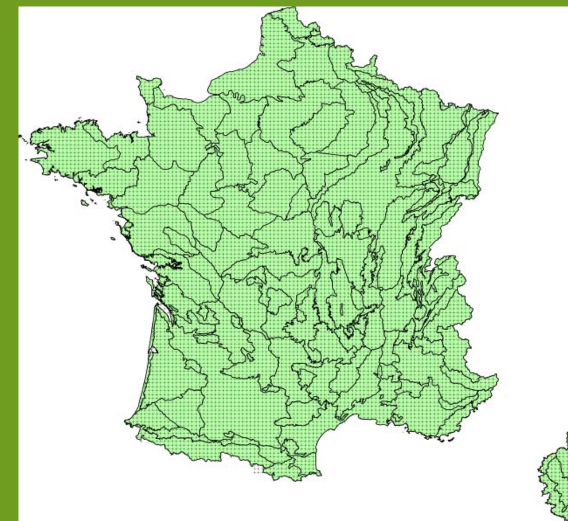
Species & age distribution



Soil Inventory



Climate



GO+ model

- Biophysics
- Biogeochemistry
- Carbon & water cycles
- Tree growth, production
- Management & Harvest

×

Gridded data sets

- Soil class
- Forest area (species, age)
- Climate

=

3. Regional estimates

2. Mapped Sensitivity

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- So

1. Local Point Sensitivity (Stationnary mode)

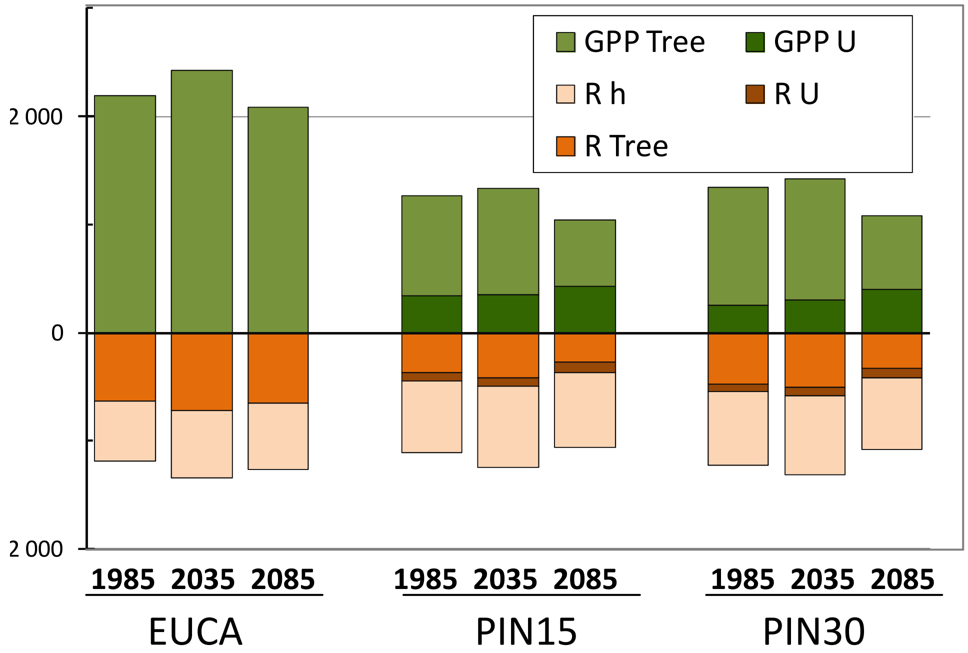
- Climate
- Management
  - Pinus
  - Eucalyptus
  - (Fagus)

Management alternatives implemented

Alternatives	Operations				
	Age at clearcut	**Parts harvested**	**Soil tillage**	**Plantation**	**Thinnings**
Pine30	30 yrs	Stem + Crown + Stump	XX	1600	3 × Stem + Crown 2 × Stem only
Pine15	15years	Stem + Crown + Stump	XXX	1600	0
Eucalypt coppice	10 yrs	Stem + Crown + 1/3 Stumps	X	3000	0

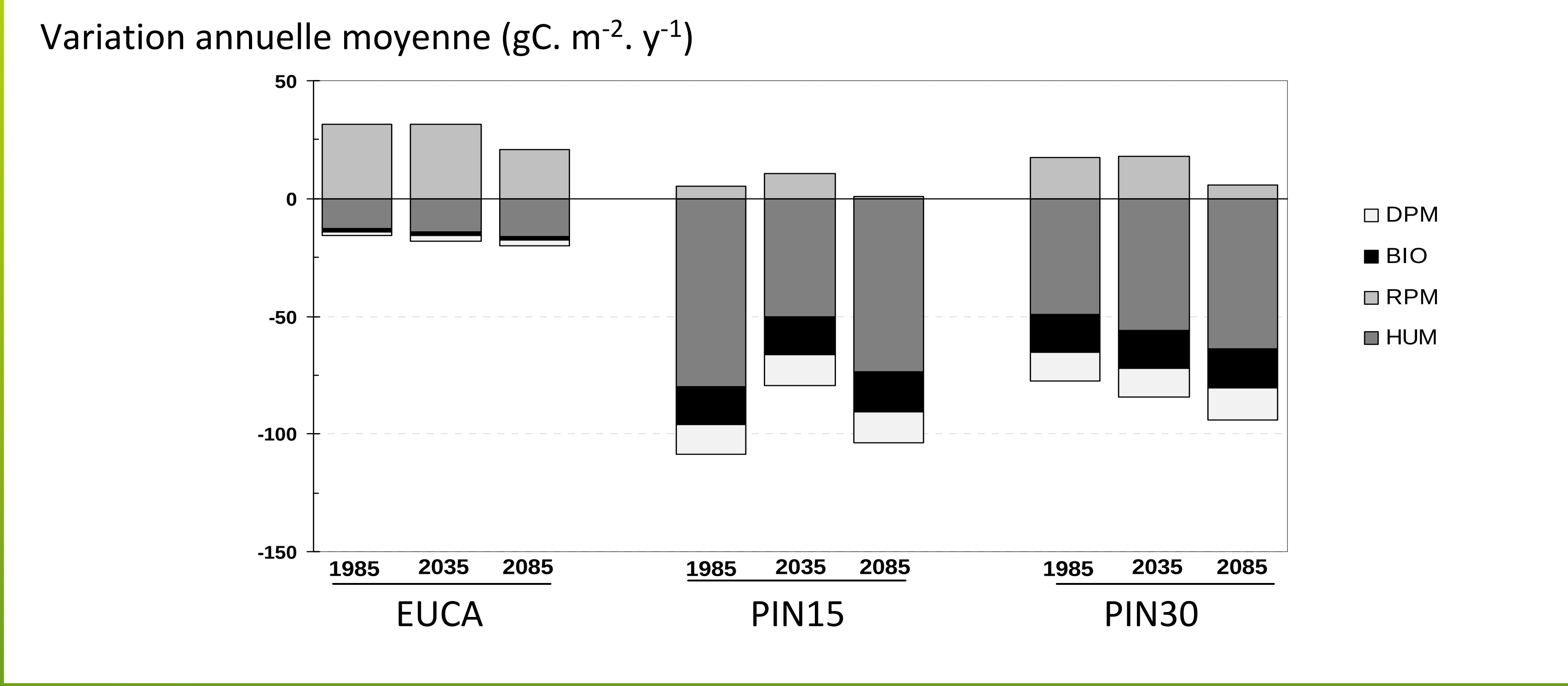
GO+ projection forced by climate management × scenarios

Flux annuel moyen (gC. m^{-2}. y^{-1})



- La production moyenne des arbres faiblit de façon accélérée en fin de siécle
- L'impact climatique simulé confirme les résultats antérieurs (***Ciais et al. 2010***, ***Bréda et al. 2011***) ;
- Ces impacts s'interprètent par les effets antagonistes du CO_2, de la température et des précipitations (***Davi et al. 2006***).

GO+ projection forced by climate management × scenarios



- Les trois ITK se contrastent par l'effet du travail du sol :
  - labour absent chez EUCA, x1 chez PIN30, x2 chez PIN15;
- Le climat diminue les stocks de carbone du sol en tendance dans les trois ITK
- La fraction humifiée (HUM) est affectée par travail du sol et température
- L'augmentation de la fraction résistante (RPM) correspond aux variations de GPP

1. Local Sensitivity

Incrément annuel en biomasse et indice foliaire au cours d'une rotation

Biomasse aérienne cumulée (t.dm. ha^{-1})

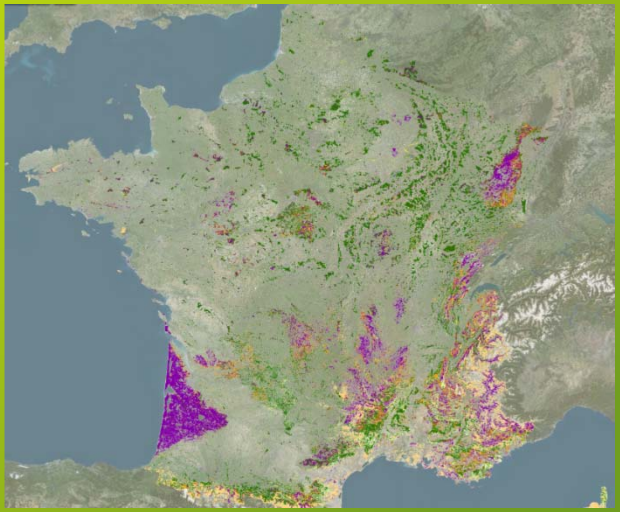
Biomasse Souterraine cumulée (t.dm. ha^{-1})

Indice foliaire (m^2.m^{-2})

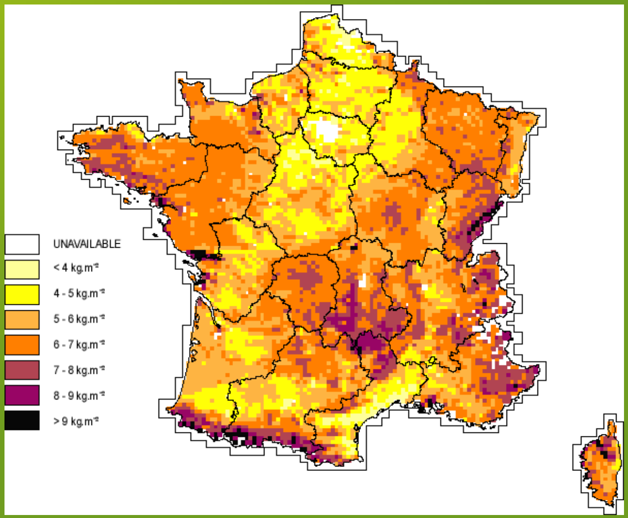
- L'incrément en biomasse amplifie les variations de GPP:
  - faible variation en 2035 , réduction de 31% (EUCA) à 61% (PINs) en 2085
- Biomasse aérienne plus sensible (allocation)
- Conclusions cohérentes avec la littérature (projets Carbofor, Climator et suivants)

GO+ applications to FAST project objectives

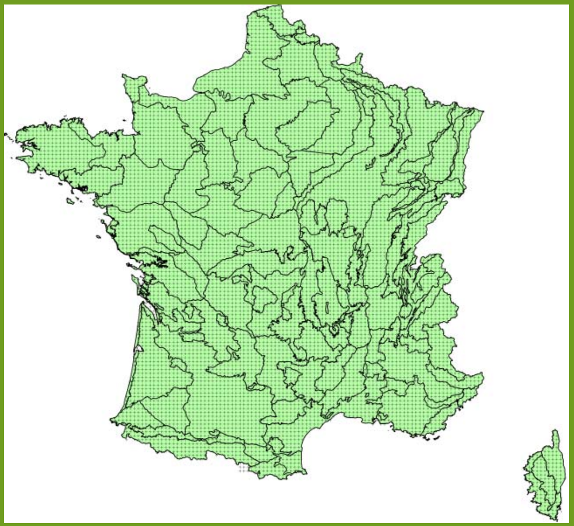
Species & age distribution



Soil Inventory



Climate



GO+ model

- Biophysics
- Biogeochemistry
- Carbon & water cycles
- Tree growth, production
- Management & Harvest

×

Gridded data sets

- Soil class
- Forest area (species, age)
- Climate

=

2. Mapped Sensitivity Analysis

86 forest ecoregions

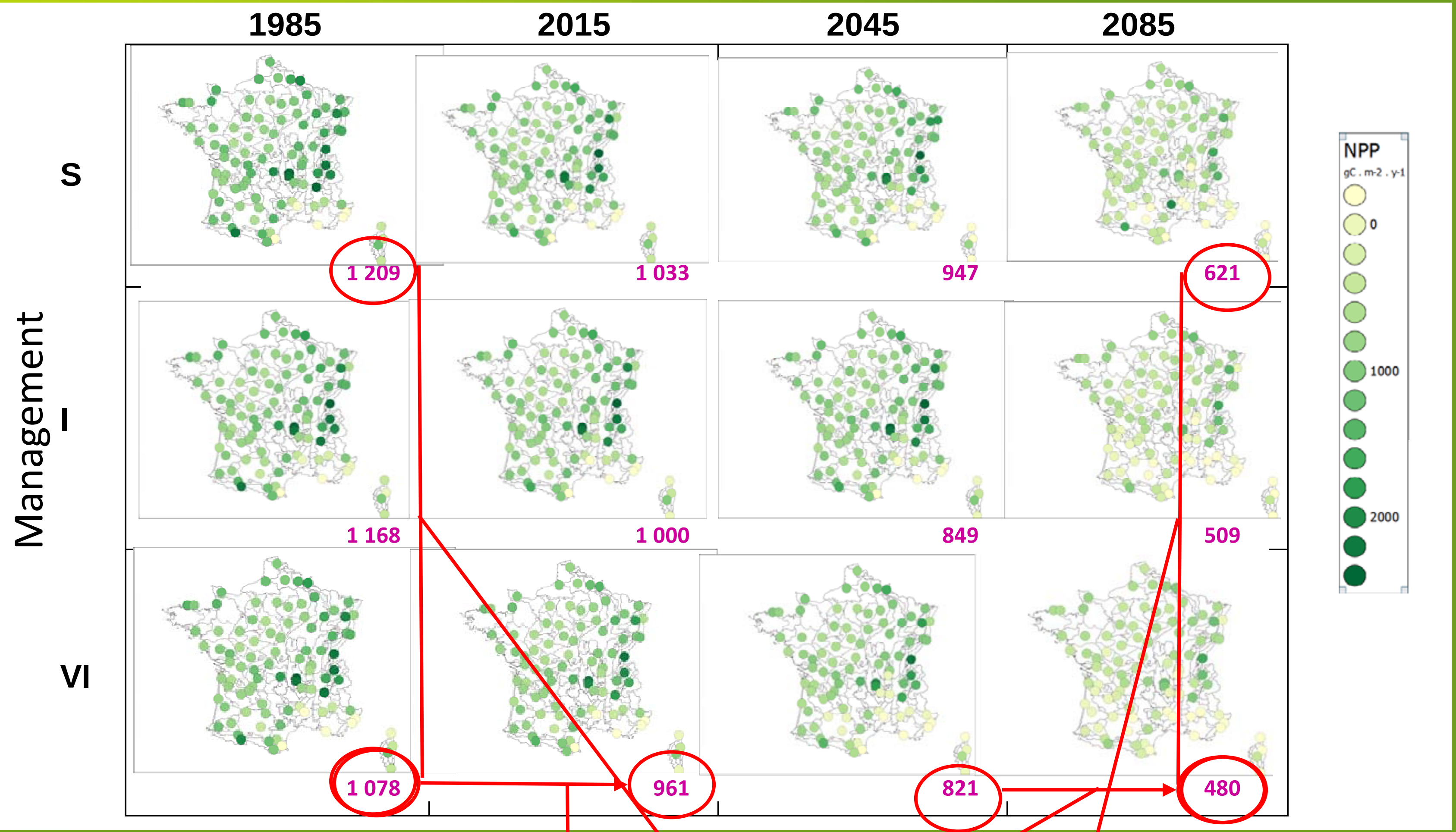
- Climate
- Management
- Soil classes

} Interactions

Management alternatives implemented

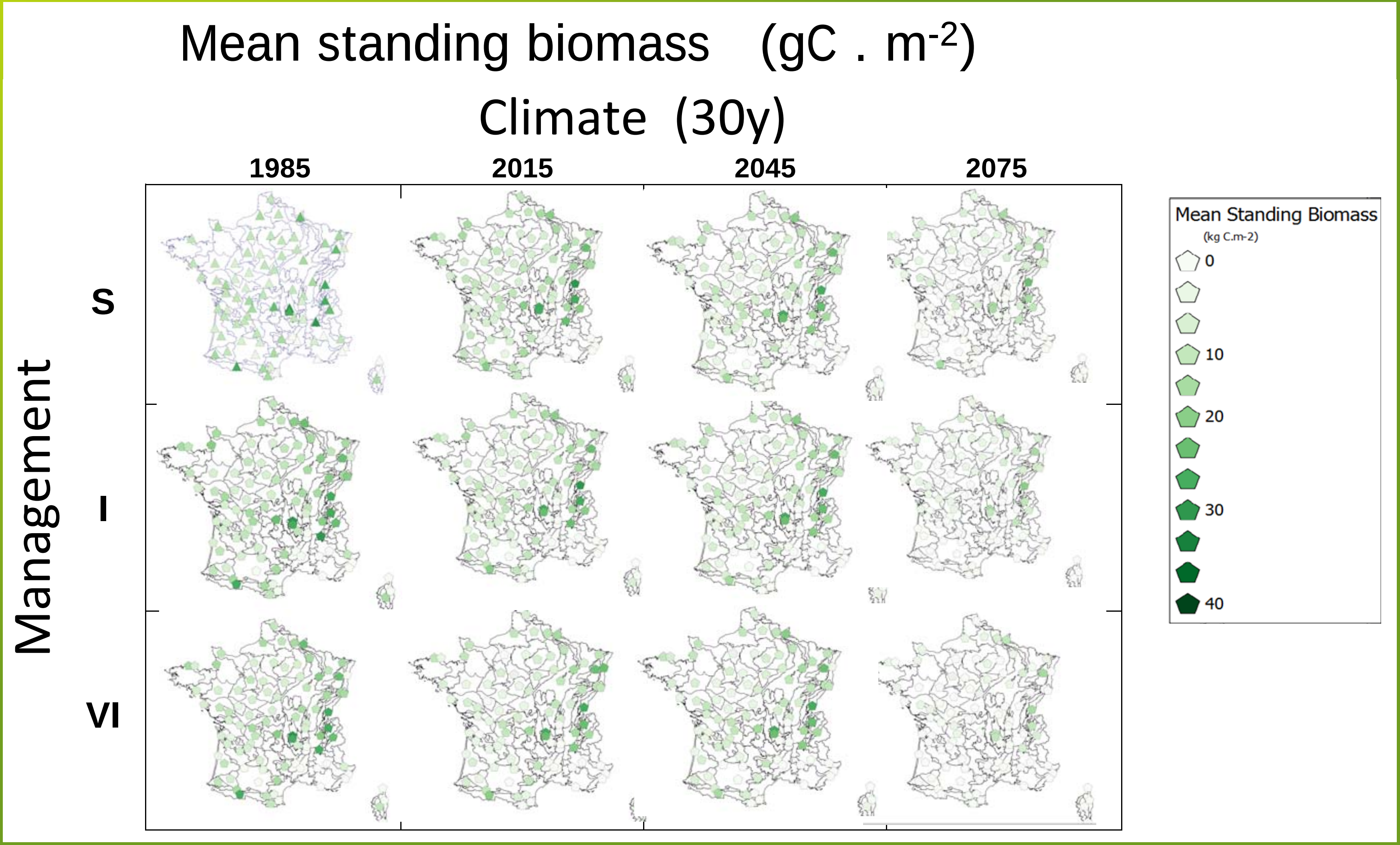
Alternatives	Operations				
	Age at clearcut	Parts harvested	Soil tillage	Plantation	Thinnings
Standard (S)	45 yrs	Stem only	X	1600	6 × Stem only
Intensive (I)	36 yrs	Stem + Crown + Stump	XX	1600	3 × Stem + Crown 2 × Stem only
Very Intensive (VI)	30 yrs	Stem + Crown + Stump	XXX	1600	1 × Stem + Crown

Total Net Primary Production



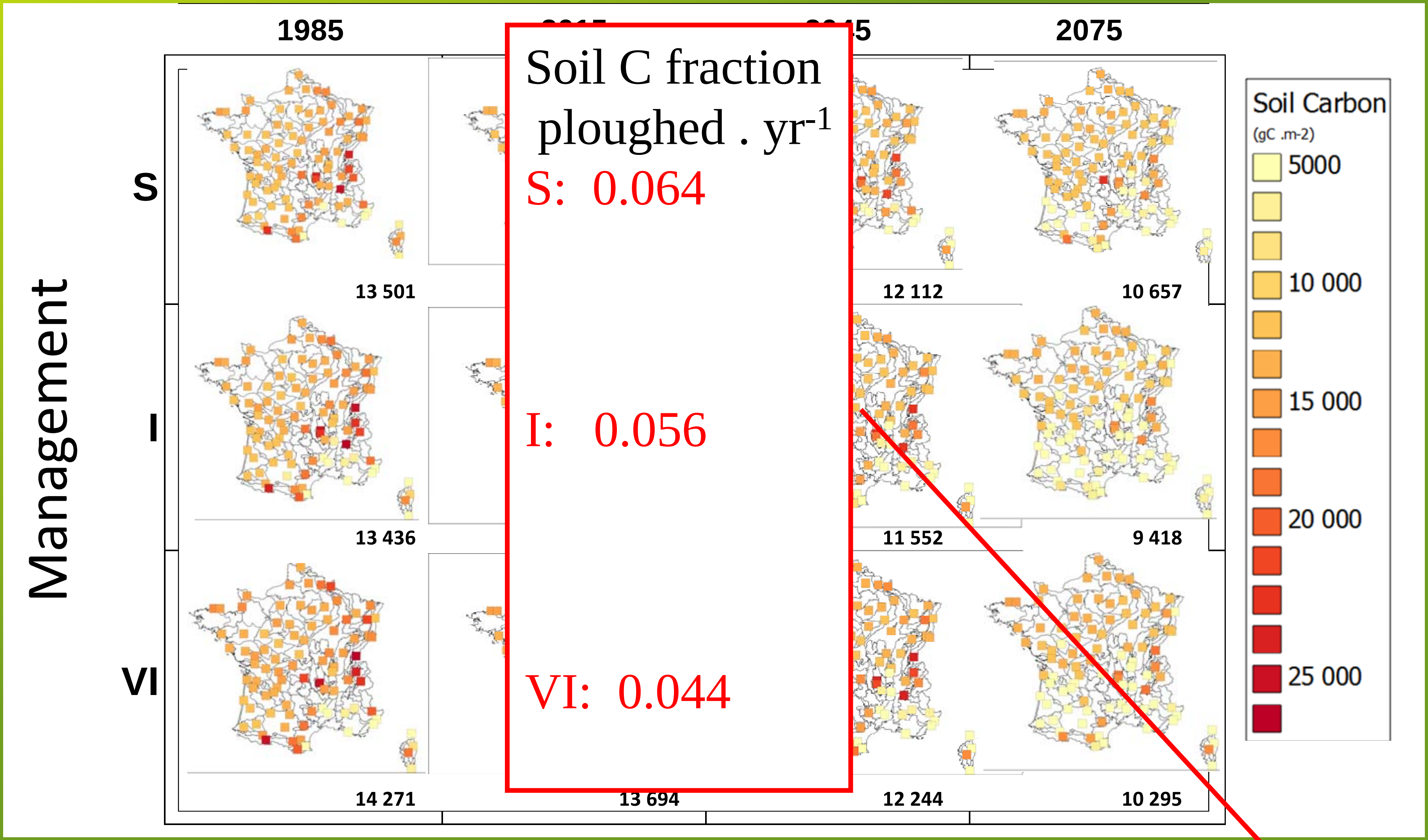
- Intensification reduces NPP by -15% (1985) to -23 % (2075)
- The climate driven NPP reduction accelerates :
  - from 1985 to 2015: - 3.6 gC m^{-2} yr^{-2} ~ - 0.4 % yr^{-1}
  - from 2045 to 2075: - 11.4 gC m^{-2} yr^{-2} ~ - 1.8 % yr^{-1}
- VI is most resilient in 2000 and least in 2060

Standing biomass



- Strongly conserved across soil and climate (except 2075)
- Closely controlled by of management (thinnings)

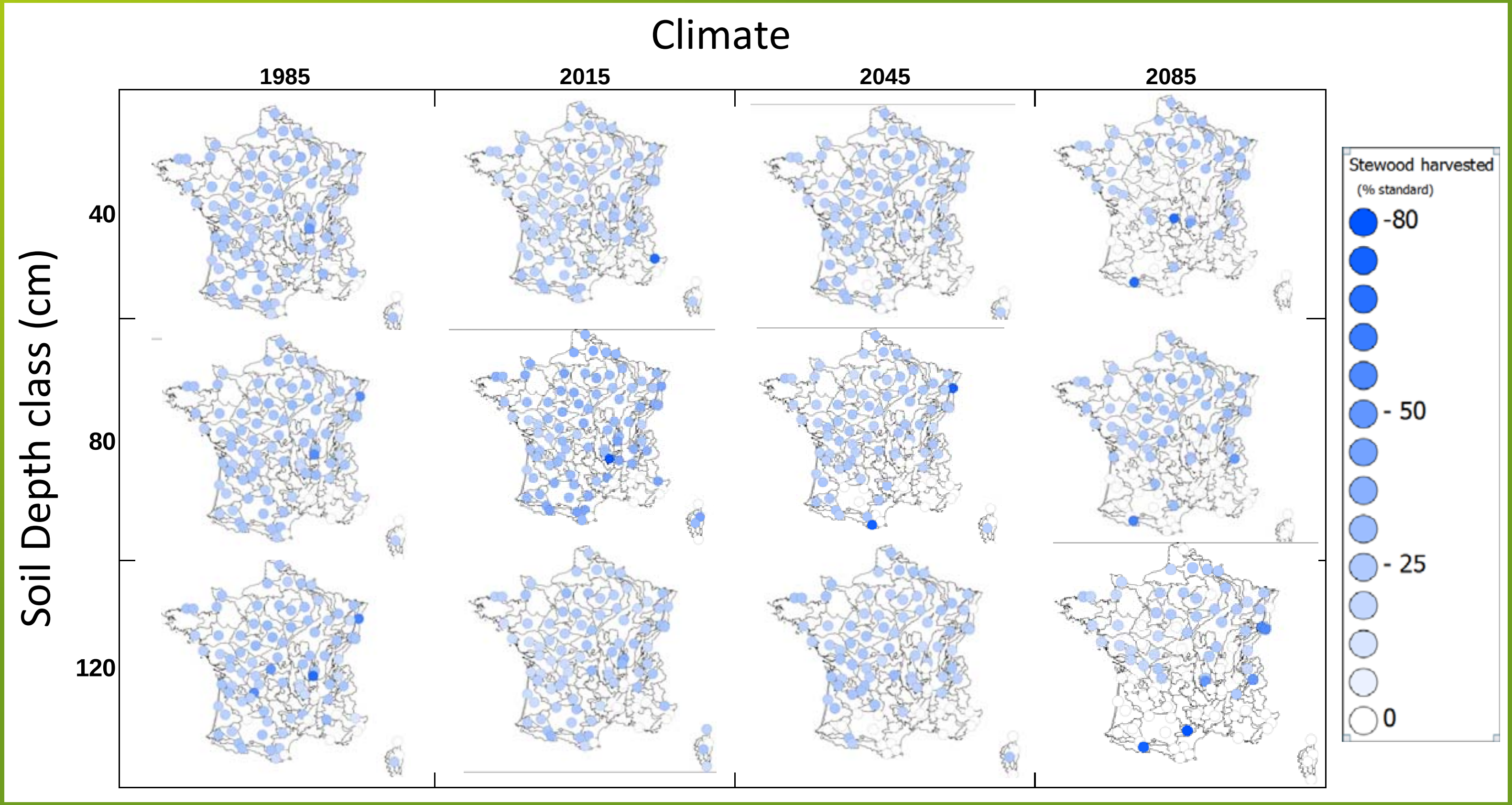
Soil carbon stock over root depth (class 0.8m)



- Controlled mainly by soil operation frequency
- More resilient in longer rotations
- Most changes would not be detected by soil inventories

Stemwood harvested

Net intensification effect on Stemwood harvested (% standard)



- Management pressure has a negative effect of 0 to – 50%
- More pronounced in high fertility classes
- Effect is conserved under different climates

Impacts on mean country NEE (Net exchange of CO_2)

Mean annual values over France (soil class 0.8m)

(gC.m-2.yr-1)	Climate			
Management	**1985**	**2015**	**2045**	**2075**
Standard	-561	-376	-368	-232
Intensive	-565	-428	-351	-129
Very Intensive	-432	-305	-295	-56

- Intensification results in a net-net emission of +21%
- This net-net emission reaches +75% under 2075 climate
- Locally, intensification depletes mean annual NEE by between -10 % and - 46% at 85% of sites.

Water balance

Mean annual value of ET

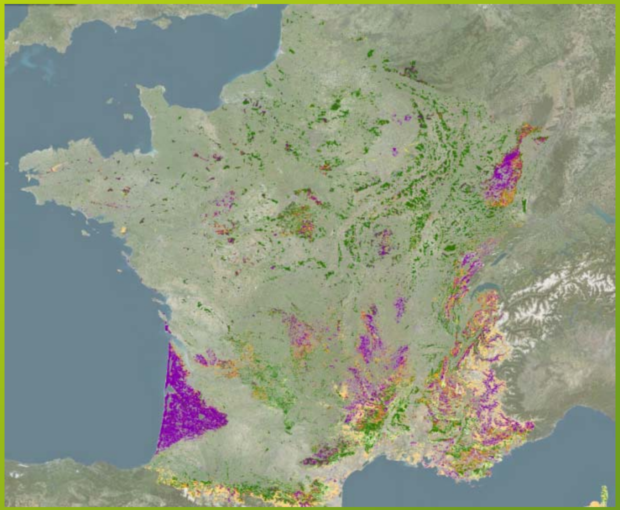
ET ($mm.y^{-1}$)	Climate 1985	2015	2045	2075
Standard	472	483	463	398
Intensive	471	479	460	397
Very Intensive	463	484	463	401

- Effect on total Evaporation ET negligible (median=0)
  - Compensation between overstory, soil and understory
- Runoff reduced by 11% in 2075 on average (not shown)

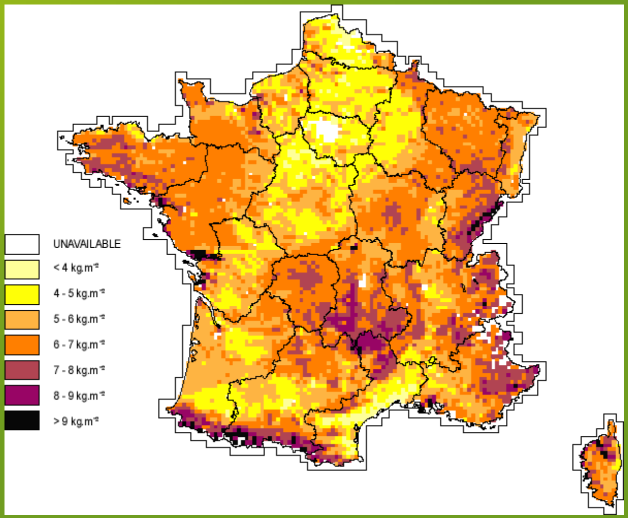
3. Transitory mode

Numerical investigations 2012-13

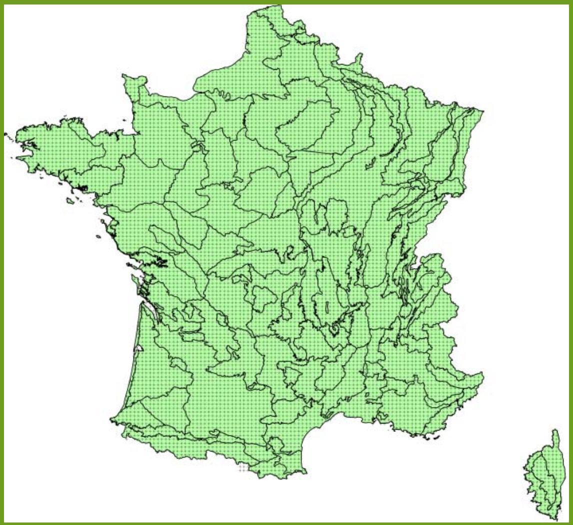
Species & age distribution



Soil Inventory



Climate



GO+ model

- Biophysics
- Biogeoclemistry
- Carbon, water cycles
- Tree growth & production
- Management
- Harvest

X

Gridded data sets

- Soil class
- Forest area (species, age)
- Climate

=

3. Regional estimates at 8 x 8 km

- Management scenarios
- Species Pines
- 2010-2050
- Processionary mot

Numerical implementation

1. N homogeneous dynamic maps at 8×8 km

With N =

3 species
× 2-3 management options
× 3-4 soil classes
× W/O insect damages

2. Attribution matrix at 8 × 8 km

(IFN/IGN, soil WHC map)

For each pixel :

Area fraction covered by species x management x soil WHC

Dynamic transitory simulations

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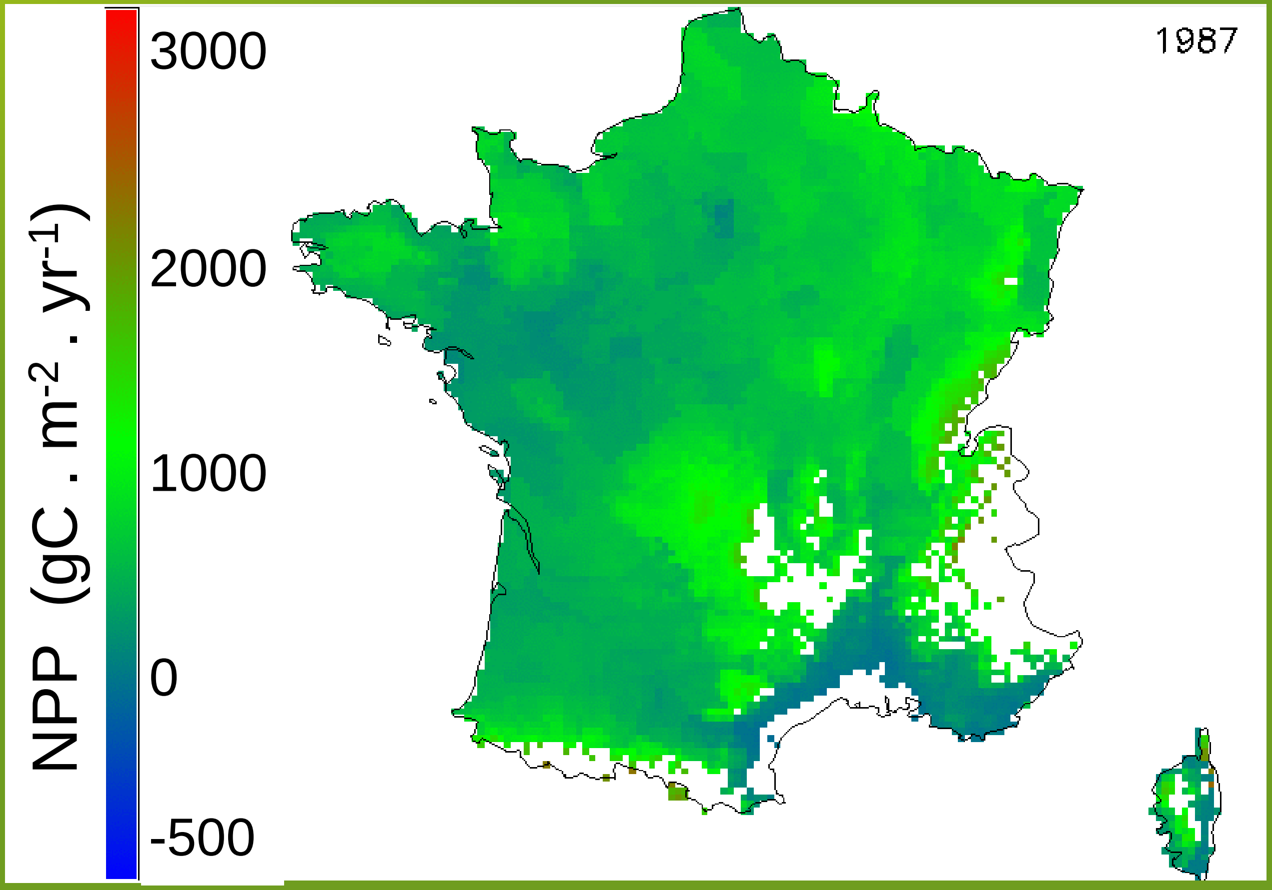
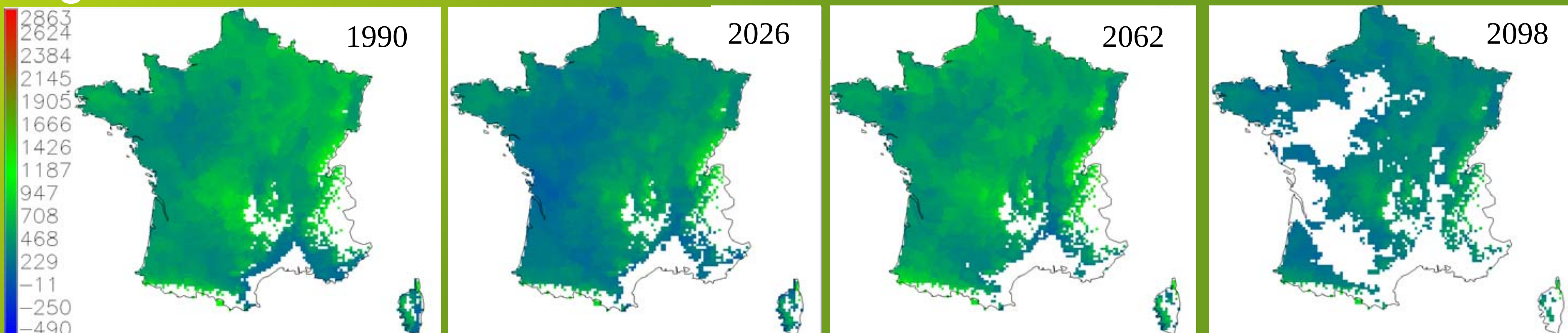
(1) × (2)

Homogenous dynamic maps
NPP coniferous in 1987
France, 8x8 km

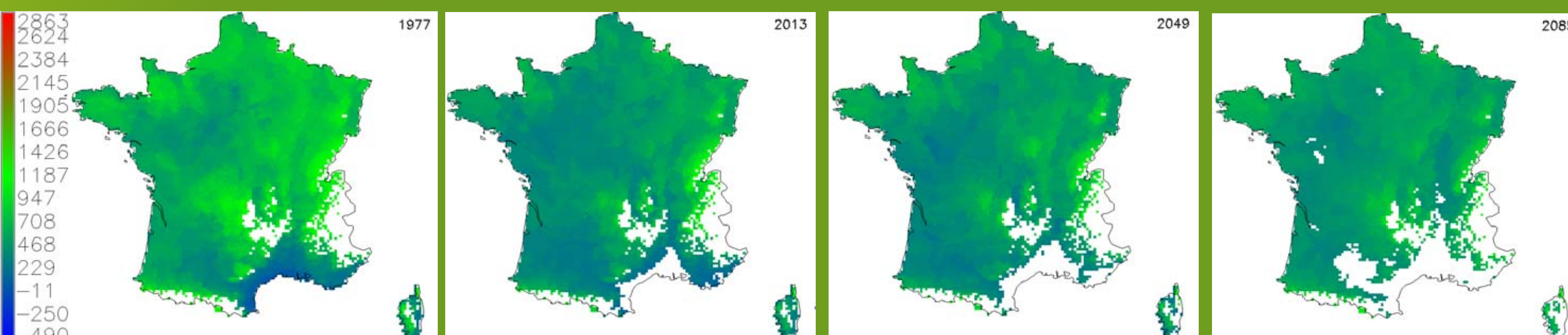


Homogenous dynamic maps
NPP independent of age distribution in the future

ages: 0, 10, 25



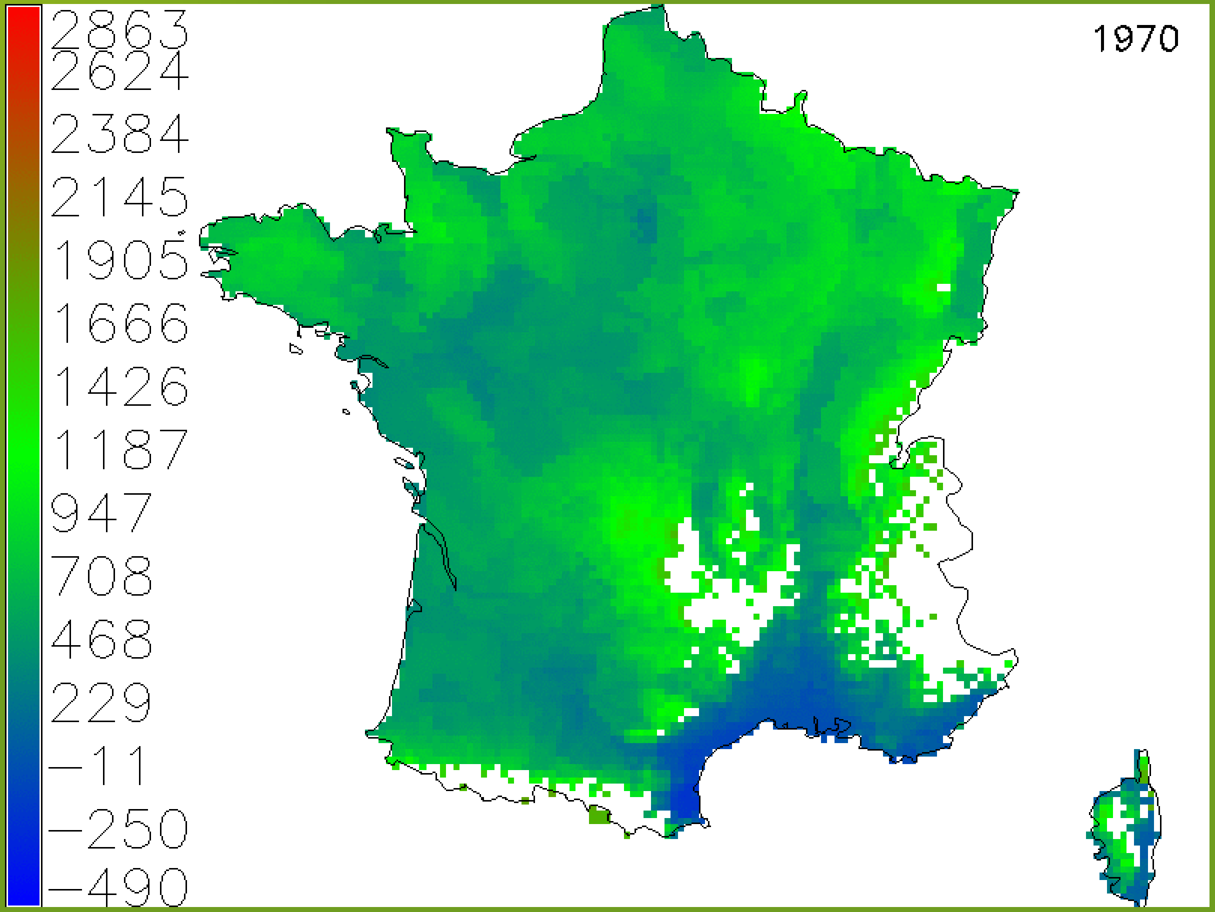
ages: 12, 24, 36



Homogenous dynamic maps NPP projected at 8x8 km over France metropolitan area, 1970-2100

Maritime Pine, even aged distribution, medium soil class, standard management, without insect.

(gC.m^{-2}.yr^{-1}).



Processionary moth model

1. Population Dynamics

(Robinet et al. 2012)

- Migration
  - Pine density
  - Caterpillar density
- Winter mortality
- 6-yr cycle

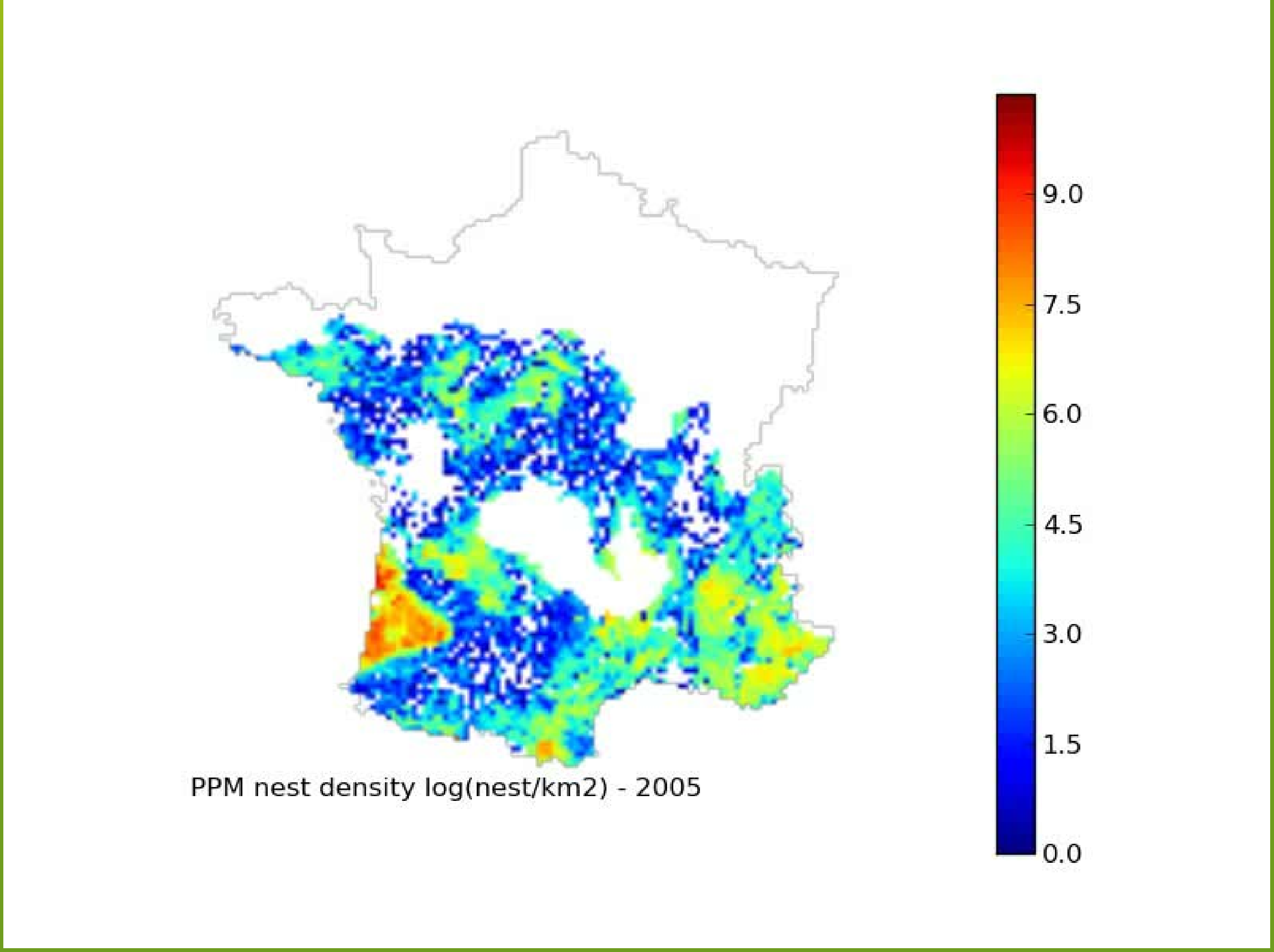
2. Defoliation activity

(Jacquet et al. 2012, 2013)

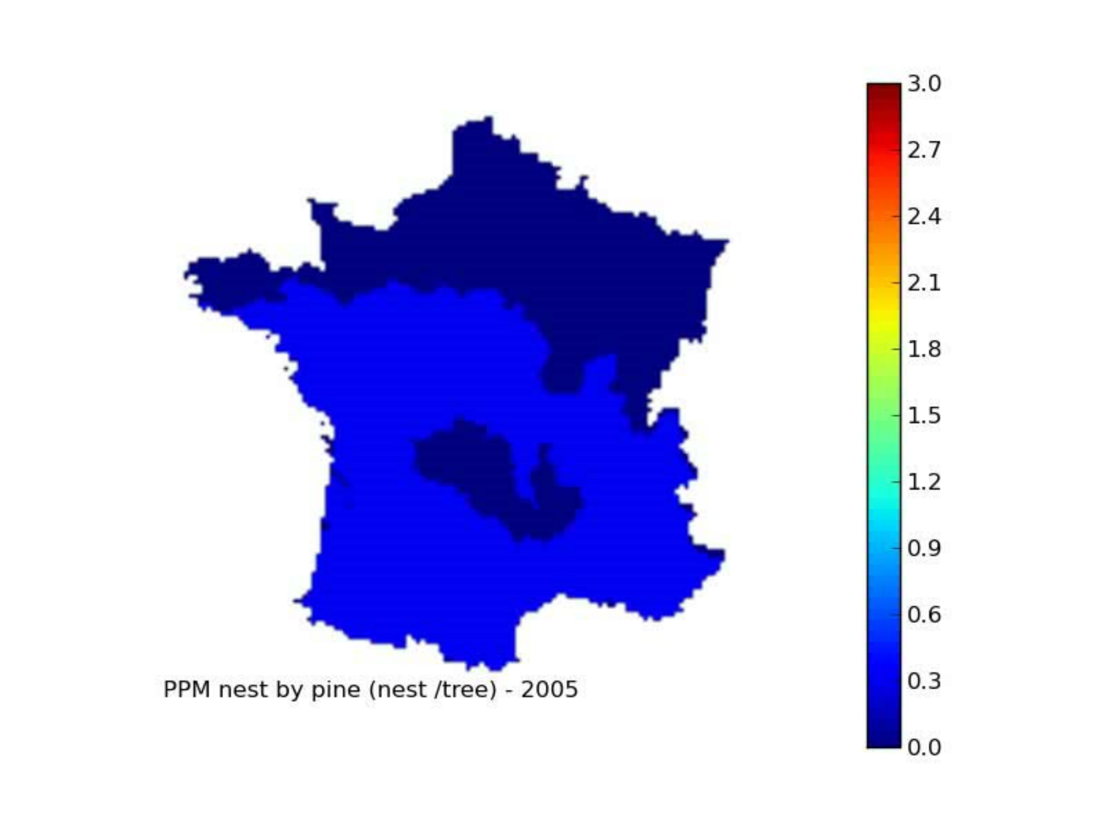
- Temperature dependent
- Bound by carrying capacity
- *f* (pine density, ha^{-1})
- *f* (caterpillar density . $tree^{-1}$)

Data: DSF observations, Jacquet et al, Robinet et al.)

Maritime Pine, processionary moth density, 2005-2100 projected at 8x8 km over France metropolitan area



Maritime Pine, processionary moth density /pine, 2005-2100
8x8 km French metropolitan area.



NPP projected at 8x8 km over France metropolitan area, 1970-2100

Maritime Pine, even aged distribution, 3 soil classes, 3 management, with/out insect.

In progress

AGU invited lecture dec. 2013, papers in preparation.

- Intensification for biomass production depletes the stand carbon balance (NEE) by forests.
- Strong interaction between climate, soil and management
- Stemwood harvest might be reduced by climate for each management alternative.
- Soil carbon is controlled by soil operations intensity and frequency
- Management effects are magnified in fertile sites but also under drier conditions
- No future for production forests in most part of Southern Europe beyond 2070 according to this scenario (Arpege-A2)

Perspectives

1. Achievement of FAST objectives
   - Complete dynamic mapping of management × climate x soil x insect interactions implementation over whole metropolitan area at 8 x 8 km
   - Focus on subregional case study (*FAST-Aquitaine*)

2. Spatial analysis of climate x management interactions
   1. ANR PEPS *ORACLE*, 2011-2013: France entière
   2. CNRS-Nancy *FOREVER*, 2013-2016: filière bois énergie, Pin, Hêtre

3. Development of scenarios modelling
   1. ANR Agrobiosphère *MACCAC*, 2014-2017, Landes de Gascogne, Costa Rica, Brésil
   2. ADEME Reactif-2, 2014-16, Montagne noire, Landes de Gascogne