# Climate and drought effects on forest carbon balance: lesson from three case studies

Denis Loustau, Damien Bonal

# Climate and drought effects on forest carbon balance: lesson from three case studies

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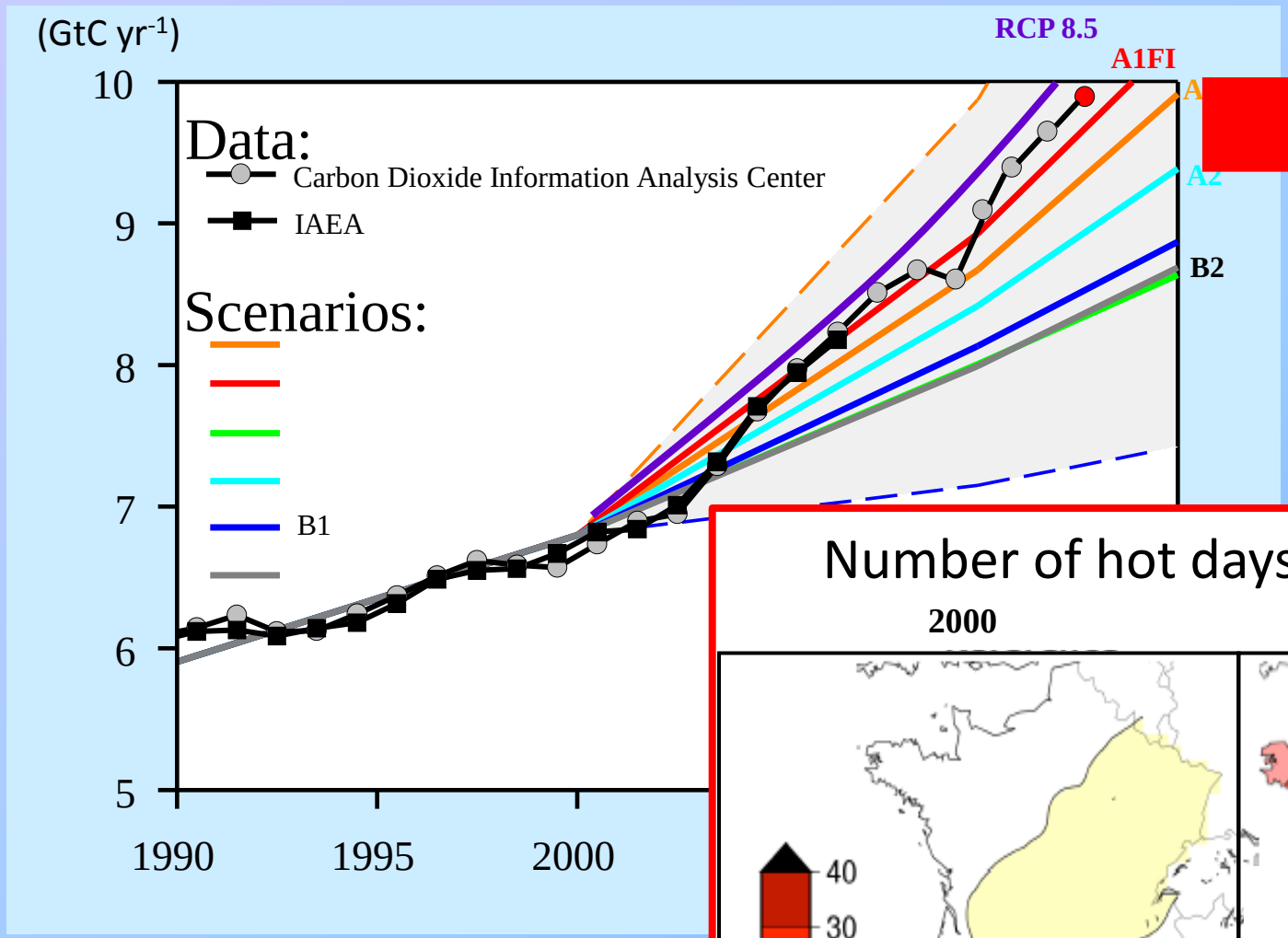
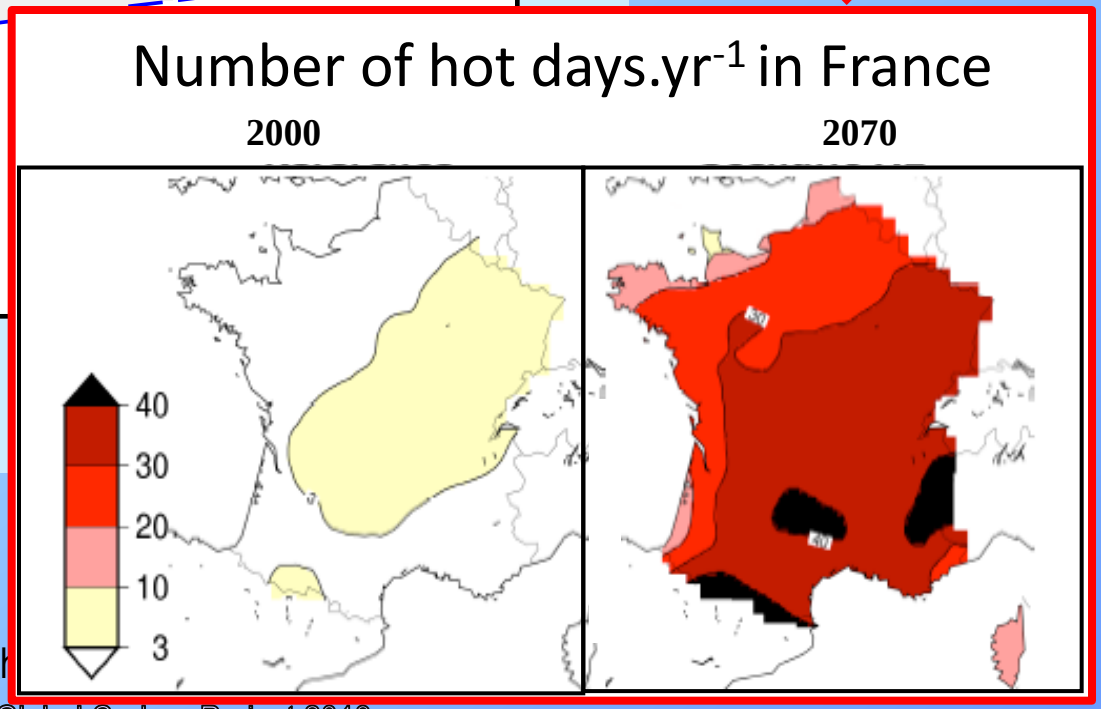
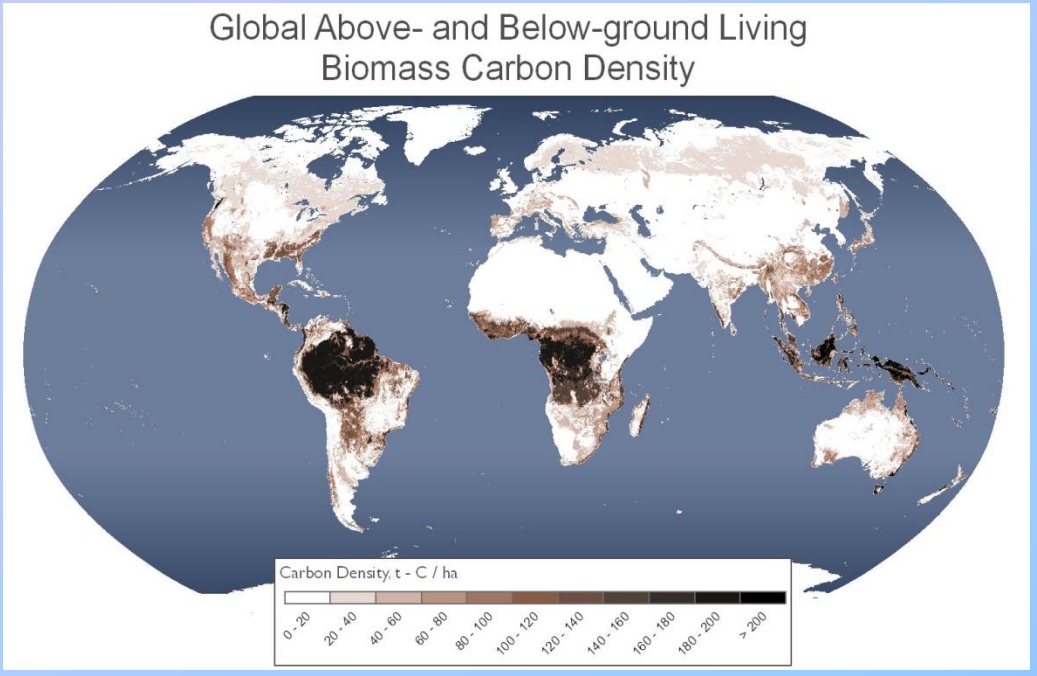
# Global fossil fuel emissions



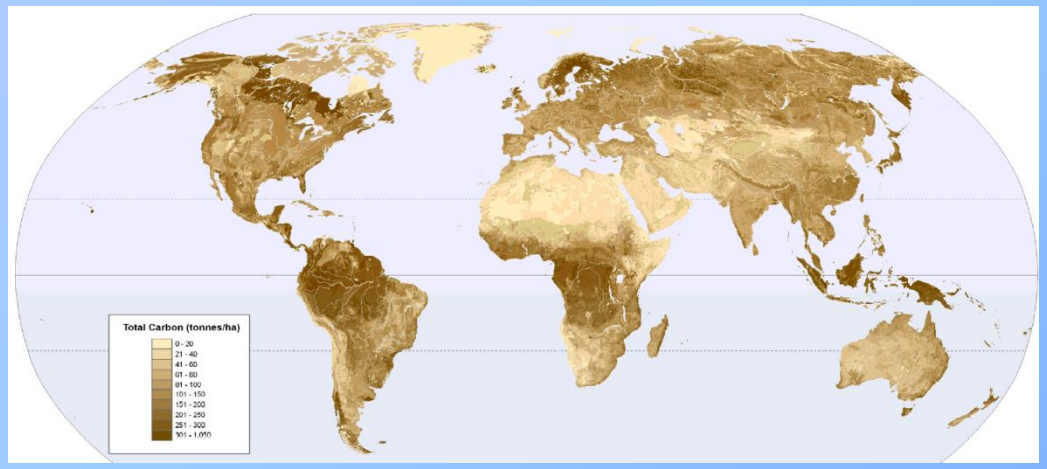




- With leap year adjustment: 2012 growth
- Source: Le Quéré et al 2013; CDIAC Data; Global Carbon Project 2013

# Threatened areas include the largest terrestrial carbon stocks.




Ruesch, et al. 2008. New IPCC Tier-1 Global Biomass Carbon Map For the Year 2000.




Scharlemann, J., Hiederer, R., Kapos, V. (2009). *UNEP-WCMC* & EU-JRC, Cambridge, UK.

- Biomass in tropics

(Philips et al. 2009, 2010, Lewis et al, 2011)

- Soil carbon (permafrost & boreal zone)

(Schuur et al. 2008, Muskett et Romanovsky, *Natural Science,* 2011)

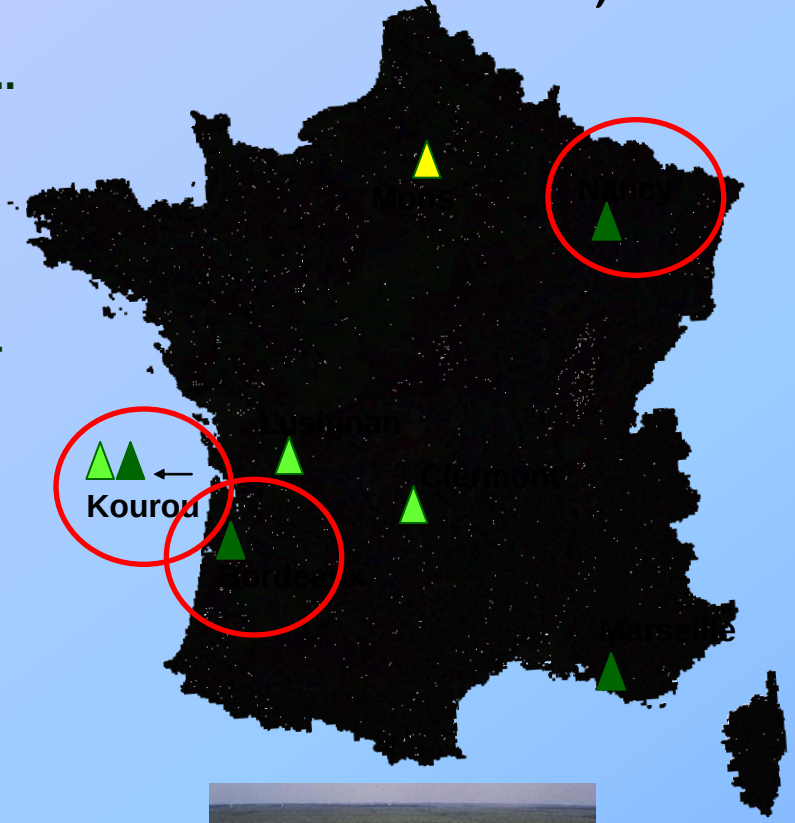
# Climate and drought effects on forest carbon balance: case studies

1. Tropical forests
2. Broadleaved forests
3. Fast growing pine forest

# INRA long term forest network

## (1996- )

- ✓ **Fluxes of CO2, O3, N,..**
- ✓ **Phenology**
- ✓ **Radiative balance**
- ✓ **Energy balance**
- ✓ **Hydrology**
- ✓ **Soil carbon and water**
- ✓ **Growth and Biomass**




Broadleaved temperate forest (Nancy)

Broadleaved tropical forest (Kourou)

Coniferous forests (Bordeaux, Marseille)

Bioenergy forests (Estrées-Mons)

# 1. Amazonian forest: stand scale impacts.

**The Guyaflux site in French Guiana (Europe)**
**(French overseas department)**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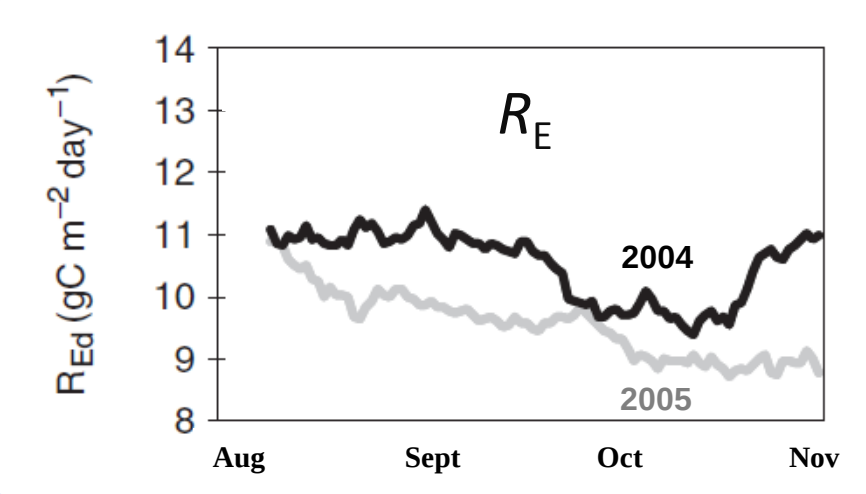
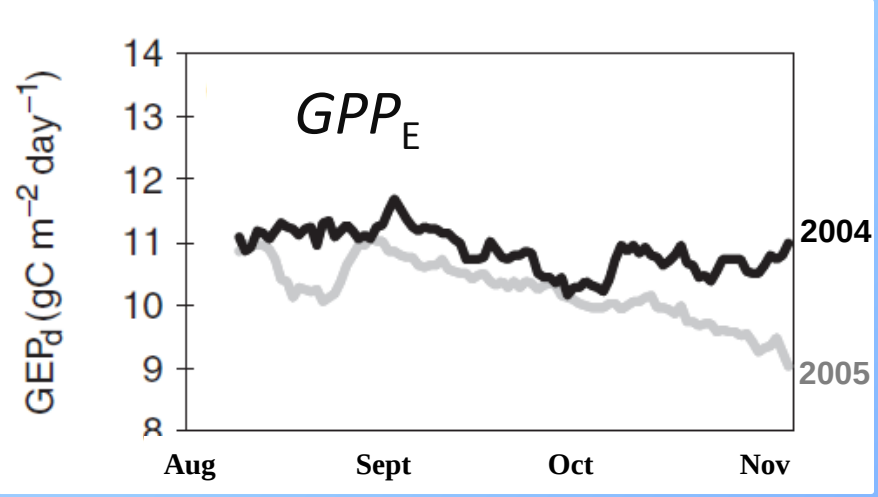
ECOSYSTEMES FORESTIERS

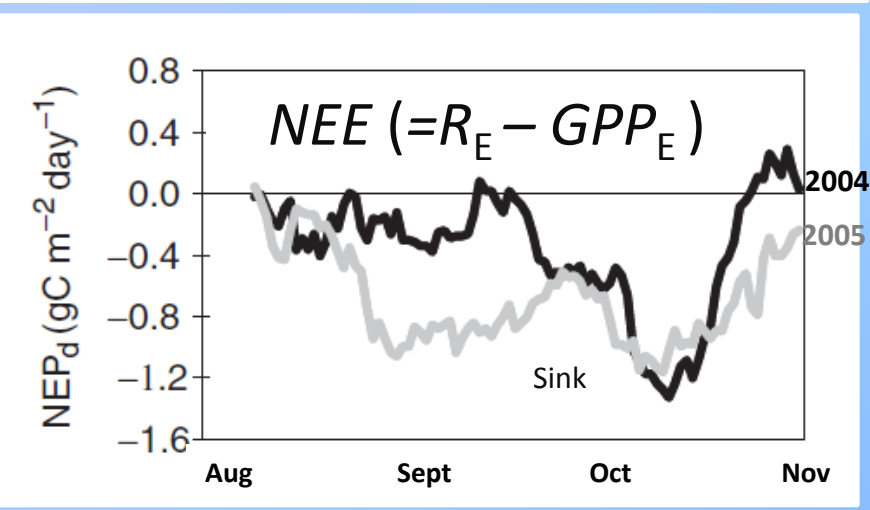
ICOS

Integrated Carbon Observation System

# 1. Amazonian forest: immediate impacts at stand level.



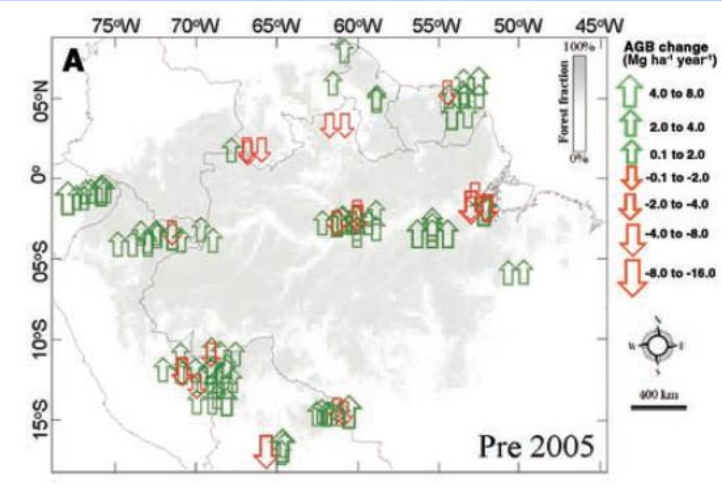



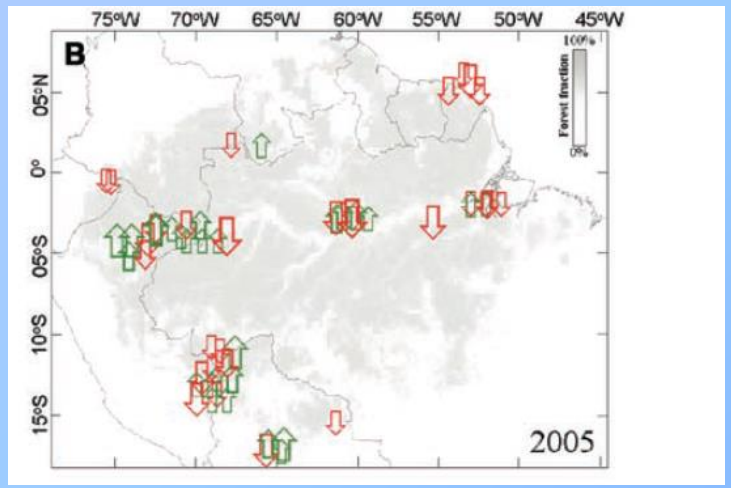

## Carbon Flux and Balance

| gC m$^{-2}$ for 92 days | Dry 2004 | Dry 2005 |
|---|---|---|
| $R_E$ | 975.6 | 888.6 |
| *GPP* | 1008.4 | 953.2 |
| | | |
| *NEE* | 32.7 | 64.6 |

- Counter-intuitive increase in net $CO_2$ uptake during drought
  - explained by a larger decrease in ecosystem respiration -.

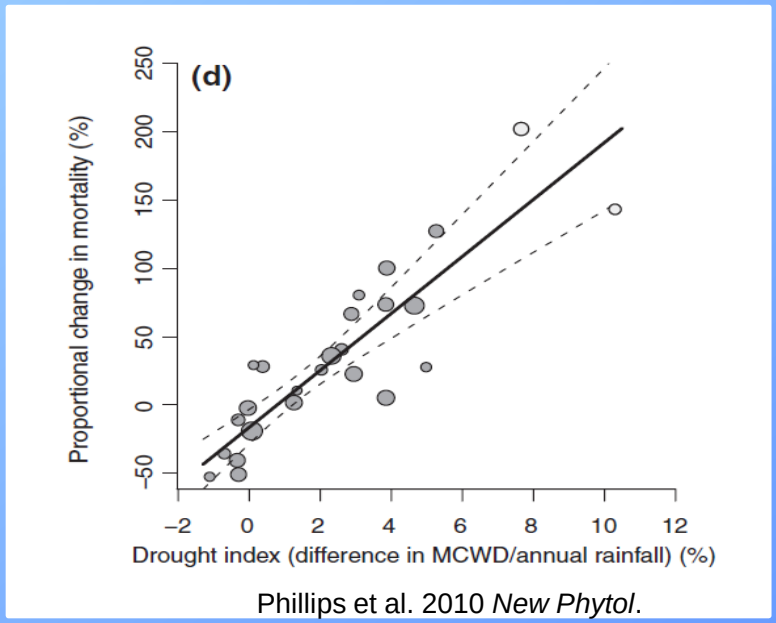
# 1. Amazonian case: delayed drought impacts at large-scale.



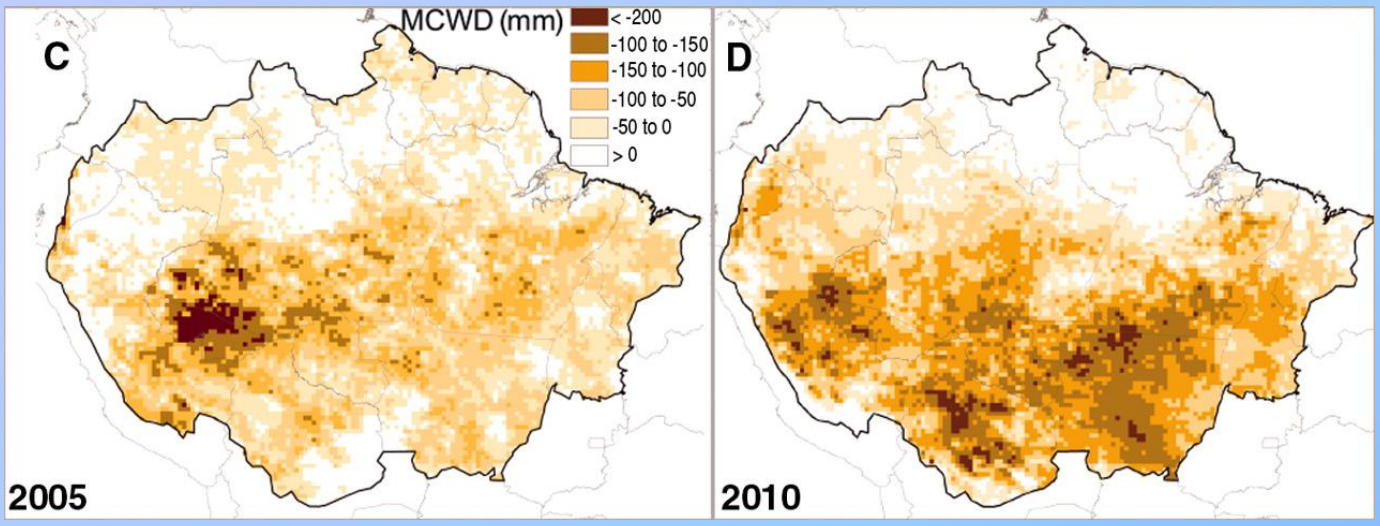

- Large scale inventories have shown Amazonian rainforests were converted into a source of carbon by the <u>2005</u> drought (Philipps et al. 2009, *Science*)

- The increase in tree mortality correlates with drought intensity.




Phillips et al. 2010 *New Phytol*.

# 1. Amazonian case: large-scale potential impacts.

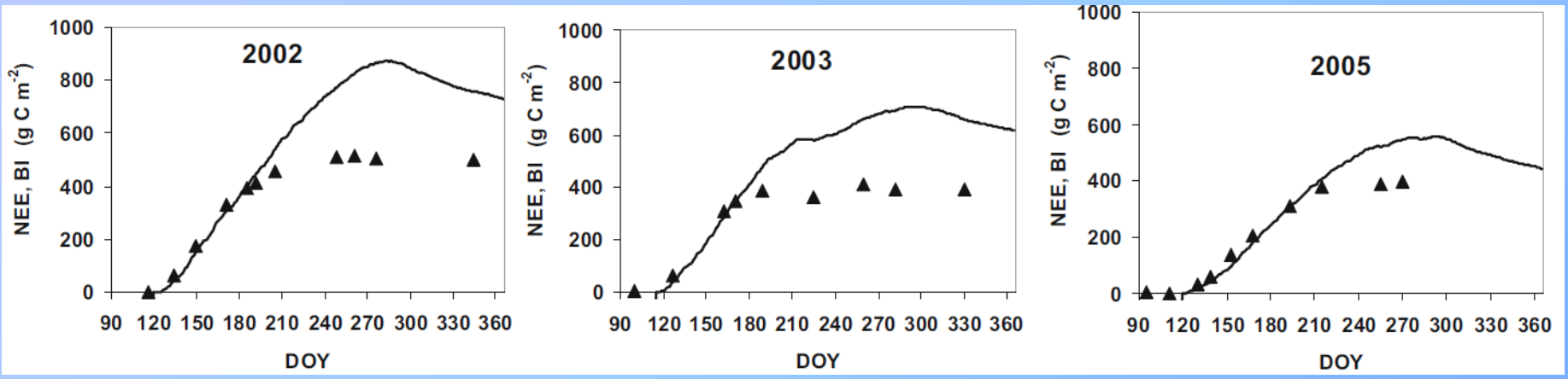



S L Lewis et al. Science 2011;331:554-554

- 2010 drought had a larger extend and severity;
- Repeated drought events have been leading the Amazonian rainforest from a weak sink (Mahli, Grace, Lewis,…) to a source;

# 2. Drought effects observed in temperate forest: instantaneous impacts.

- 35 y-old beech forest in N-E France carbon cycle monitored since 1996.



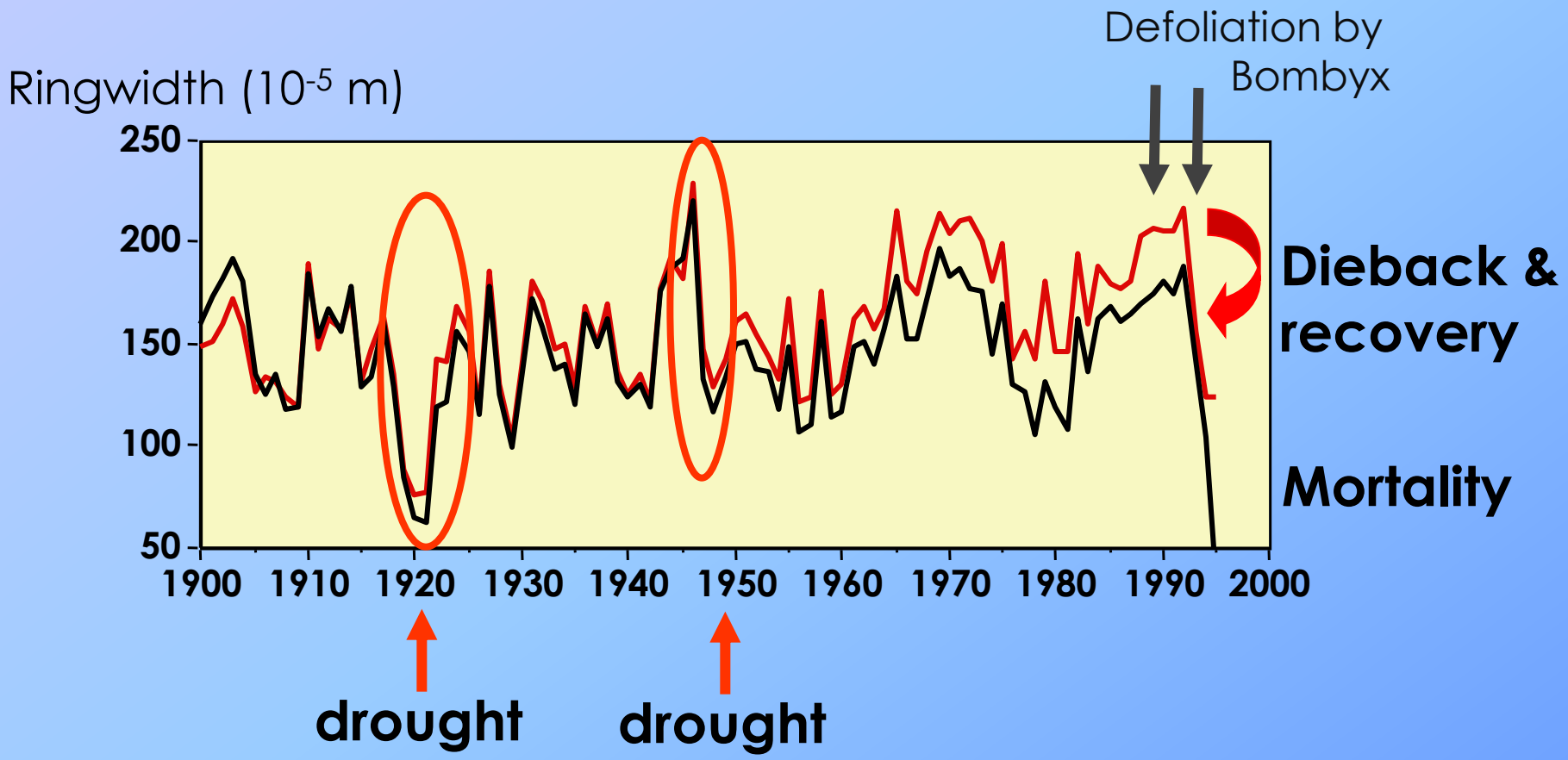

Wet year | Driest year | Dry year

- Annual stem growth (▲) is more resilient to concurrent soil water deficit than CO2 exchanges (——)

- But next year growth is severely depleted (Granier , unpublished)

# 2. Drought effects observed in temperate forest: Long-term predisposition to mortality by previous drought.

Oak Forests in Haguenau (Alsace) –
*Bréda & Badeau, 2008, Geosciences*

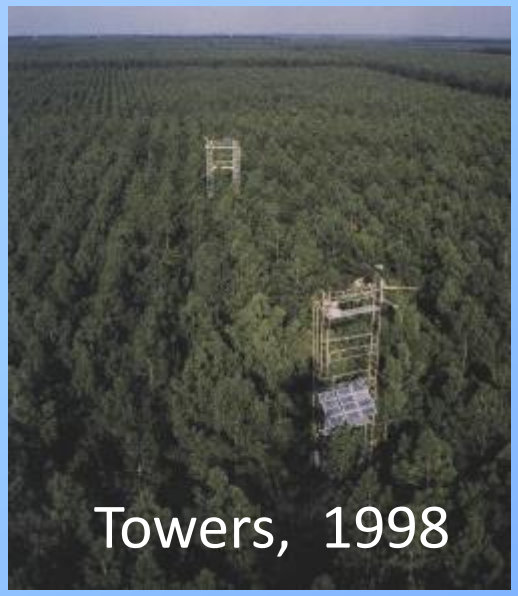



- Droughts render individuals more vulnerable to subsequent stresses (defoliation by caterpillar)

# 3. Drought effects observed in temperate forest: Interaction with management in fast growing pine forests.

Chronosequence of Pine sites, SW France.

- Ecological and tree inventories from 1987
- Water balance 1988 -2008
- $CO_2$ flux from 1996 to 2008
- $^{14}C$ Soil carbon dating in 2002


Towers, 1998


Ground view 1999


Top view 2006

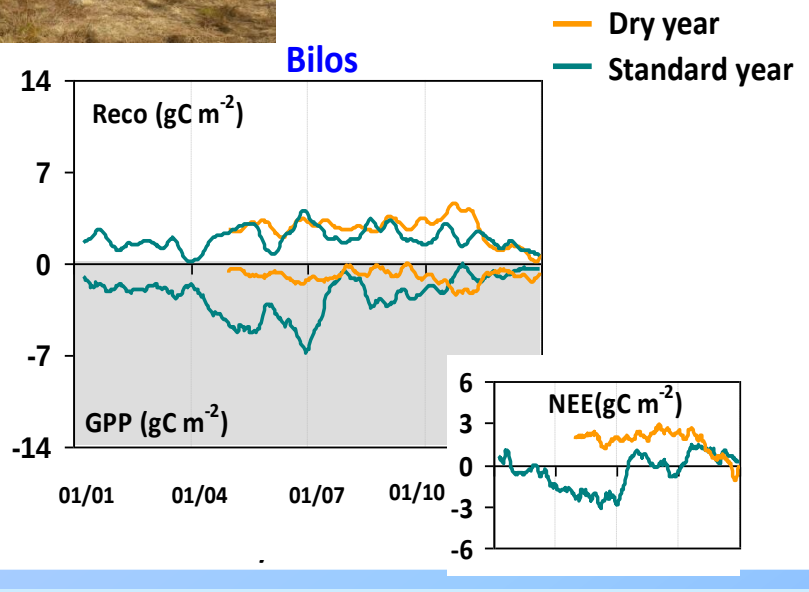
REGION AQUITAINE

ECOFOR ECOSYSTEMES FORESTIERS

ICOS

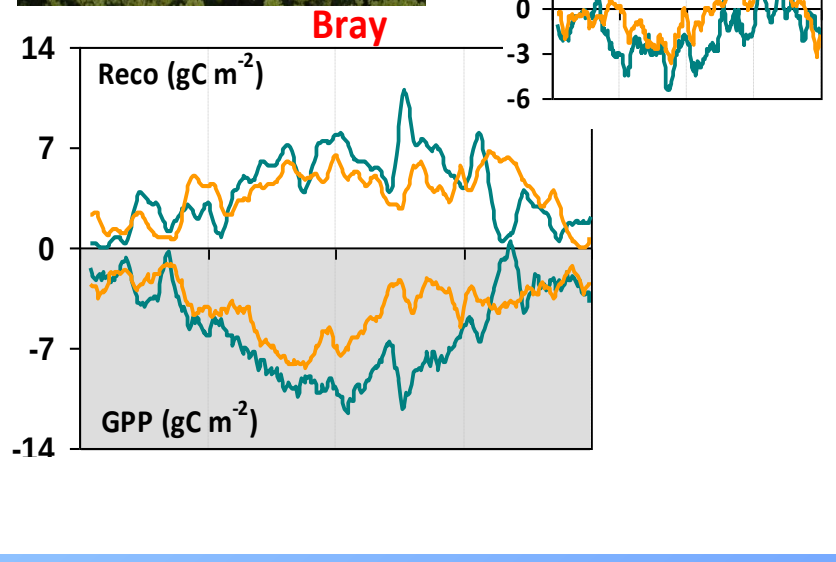
# 3. Drought effects observed in temperate forest: Interaction with management in fast growing pine forests.

## Regenerating stand



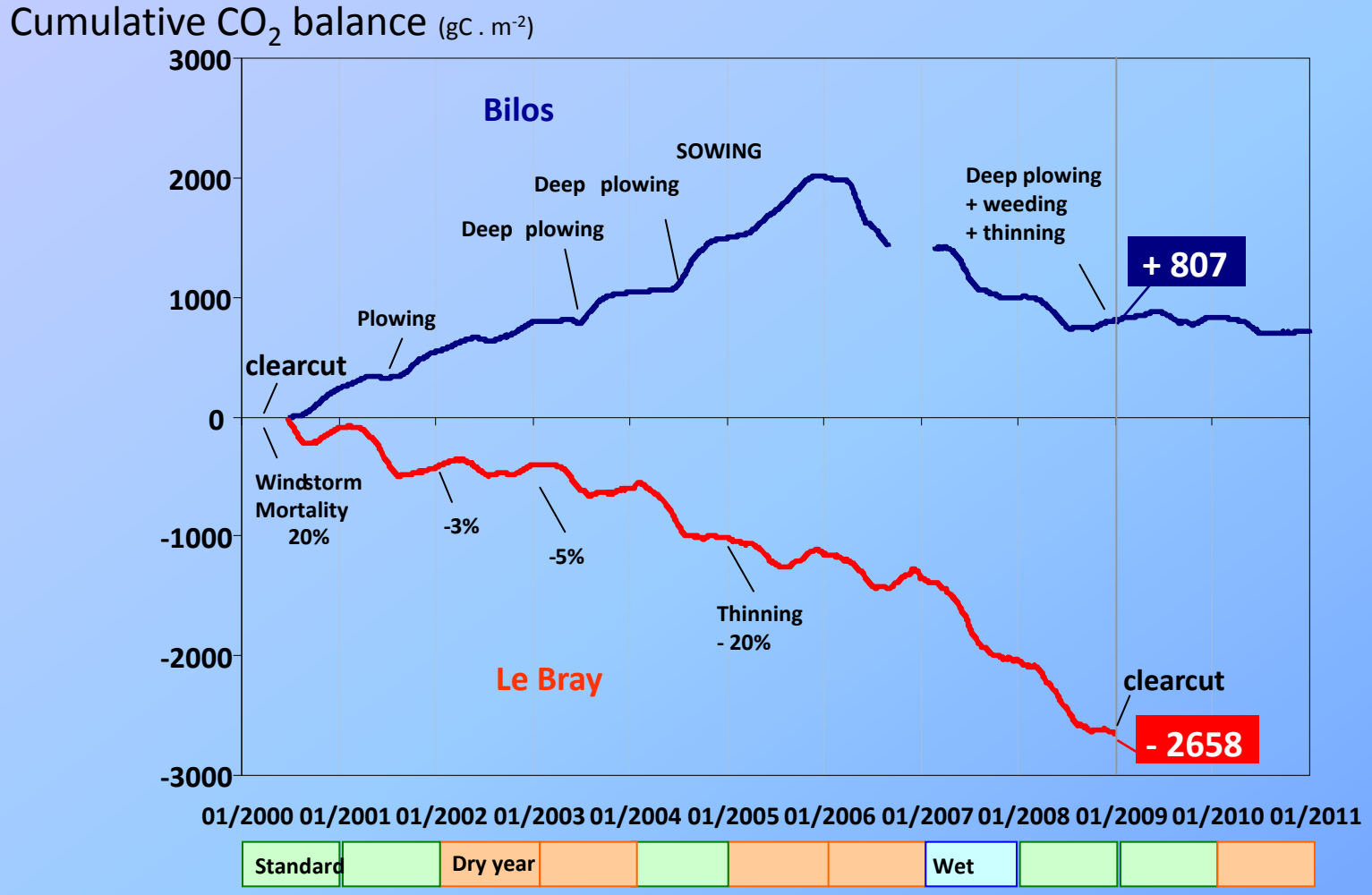

- Drought turns NEE from sink into source
- Heterotrophic respiration is maintained
- Soil is still partly wet !

## Mature stand




- Ecosystem NEE depleted but not reversed
- Respiration is strongly affected
- Soil is 100% dry

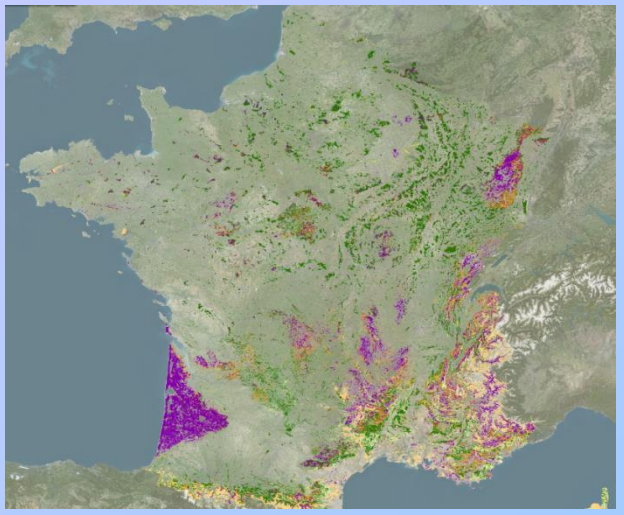
# 3. Drought effects observed in temperate forest: Interaction with management in fast growing pine forests.



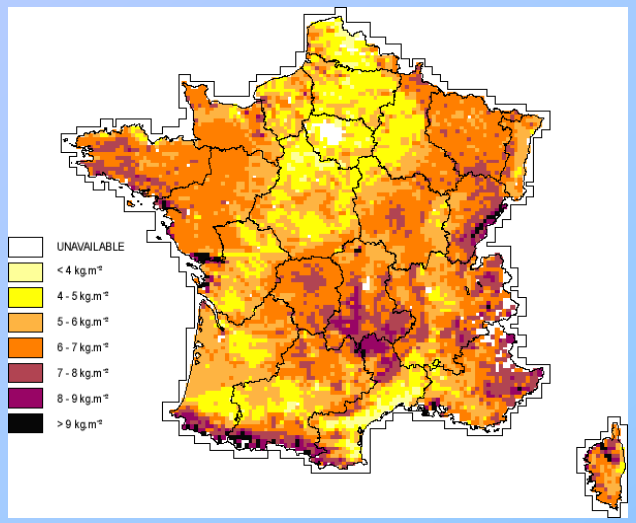

- No significant post-drought effects
- Drought maintains young forest as a net source of carbon
- Temporal fluctuations in mature stand NEE are controlled by climate

# Numerical investigations for the French Pine Forests case

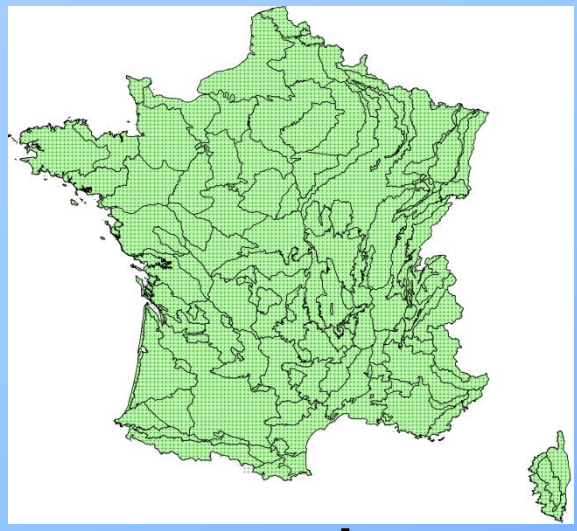
## Species & age distribution



## 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

=

**1. Transitory mode: predictions mapped over country area**

- Management scenarios
- Soil class
- 1970-2100

3. Drought effects modelling in temperate forest:
Mapping the interaction between climate and management in fast growing pine forests.

| | | Tillage | NPK | Stocking | Thinnings | Parts harvested | Age at clearcut |
|---|---|---|---|---|---|---|---|
| **Pine Extensive** | **(P60)** | **0** | **0** | **1600** | **4** | **Stem** | **60** |
| **Pine Standard** | **(P45)** | **X** | **+** | **1600** | **6** | **Stem** | **45** |
| **Pine Intensive** | **(P30)** | **XXX** | **+++** | **1600** | **1** | **Stem Crown Stump** | **30** |





# 3. Drought effects modelled in temperate forest: Mapping the interaction between climate and management in fast growing pine forests.

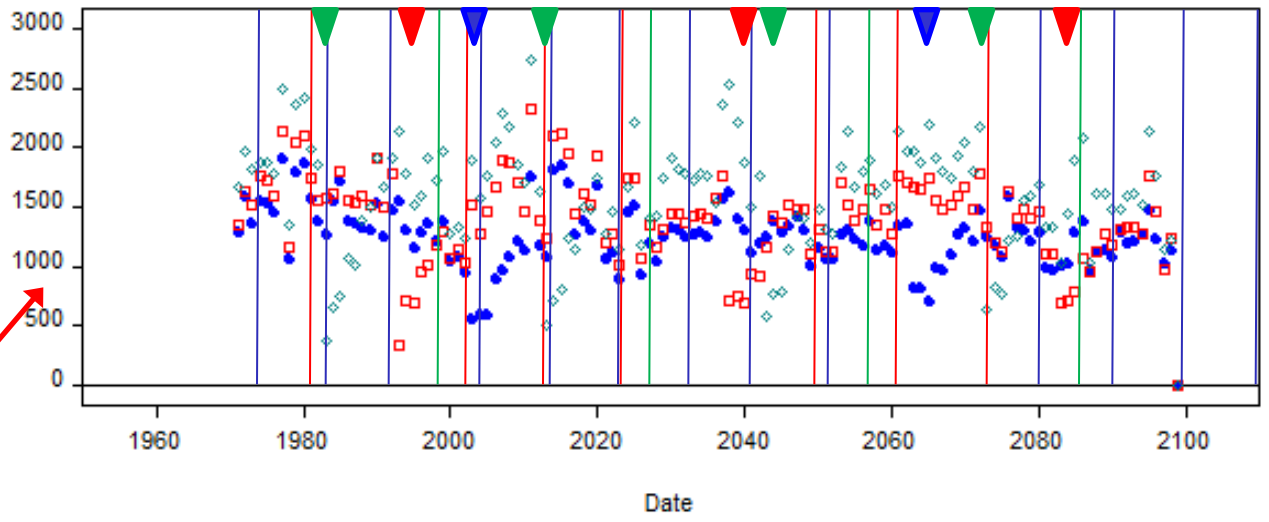
Tillage /fertilisation/plantation:

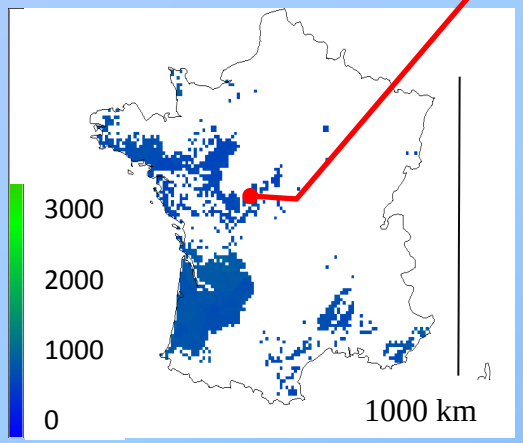
Thinning / disking :

Gross Primary Production ($gC.m^{-2}.yr^{-1}$)

Management class:

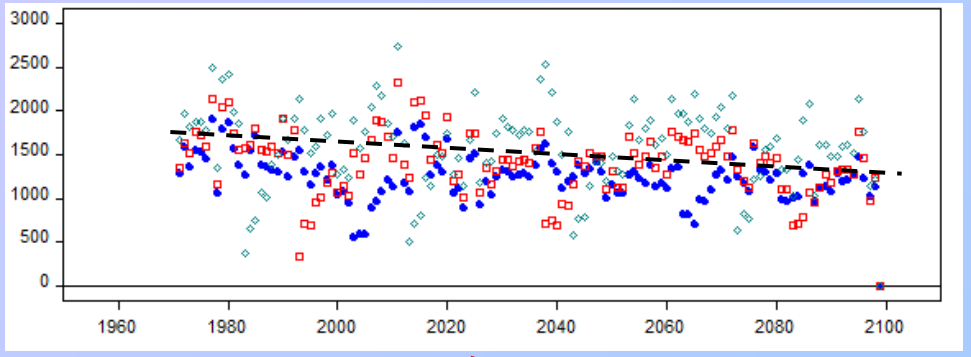
- P30
- P45
- P60

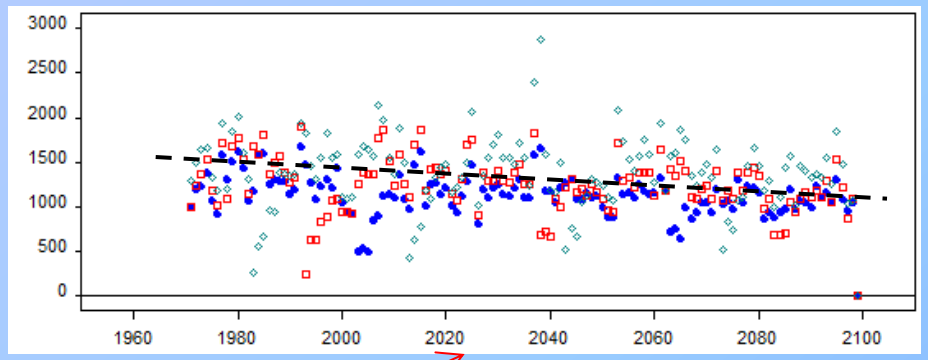



Predicted GPP according to management class 1970-2100 (as forced by A2 Scenario downscaled by model ARPEGE).

*(Loustau et al., AGU 2013)*



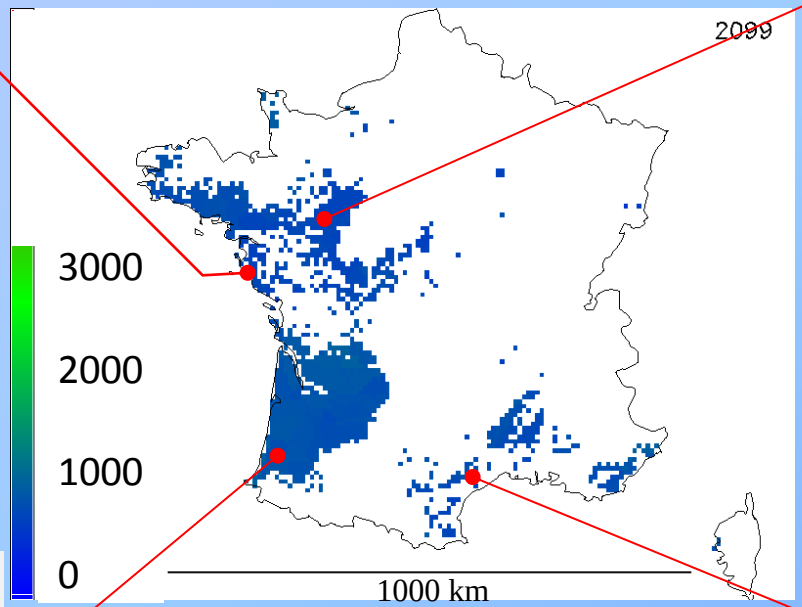




## Atlantic

## Centre

**1. Transitory mode predictions: mapping over country area (9600 grid points)**

- **Management scenarios**
- **Soil class 80**
- **1970-2100**

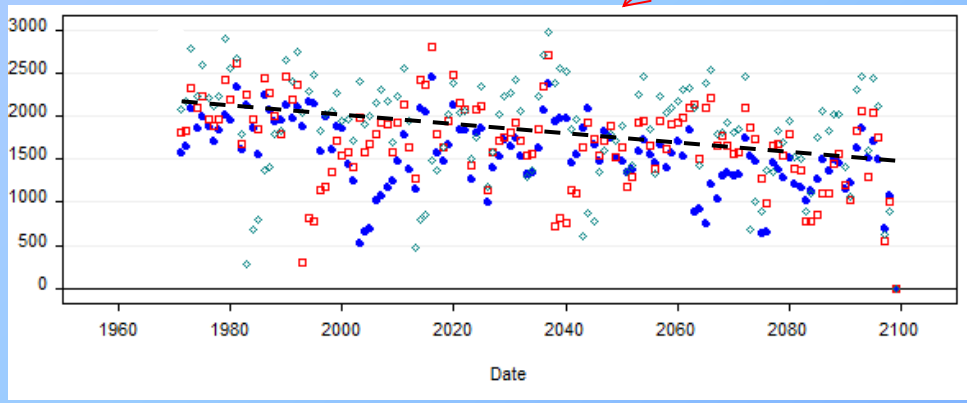


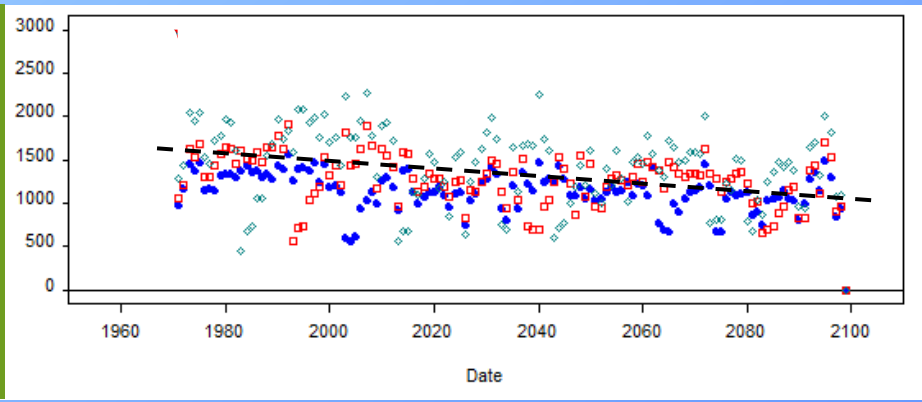

Gross Primary Production ($gC.m^{-2}.yr^{-1}$)

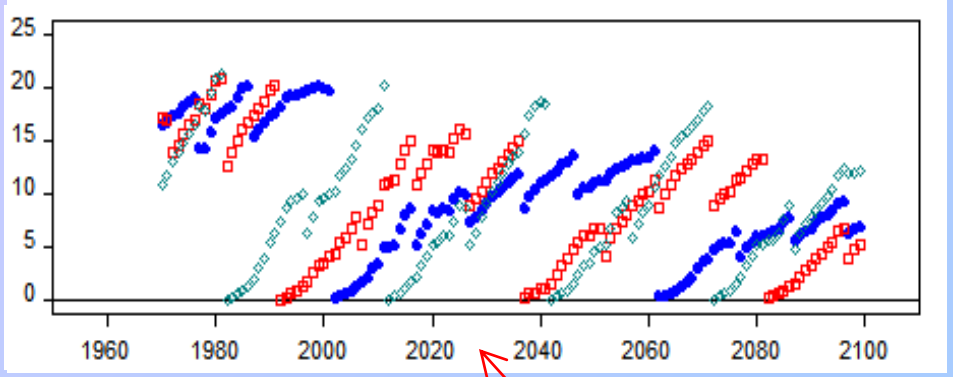
Managt class:
- P30
- P45
- P60

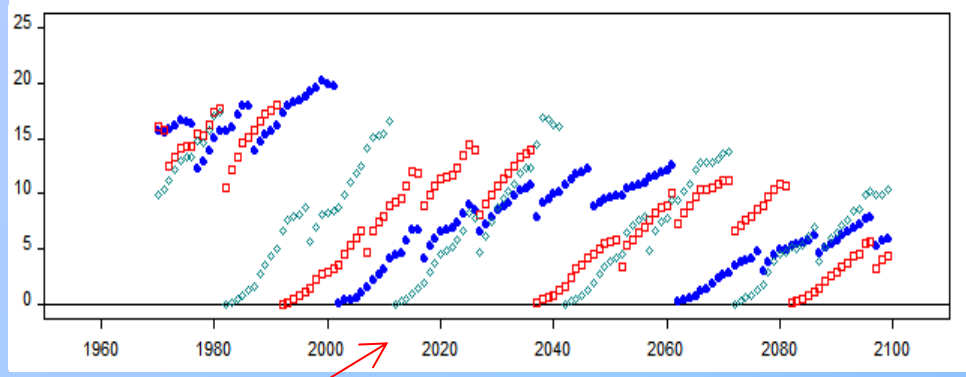
## Pyrenean Foremounts

## Mediterrannean



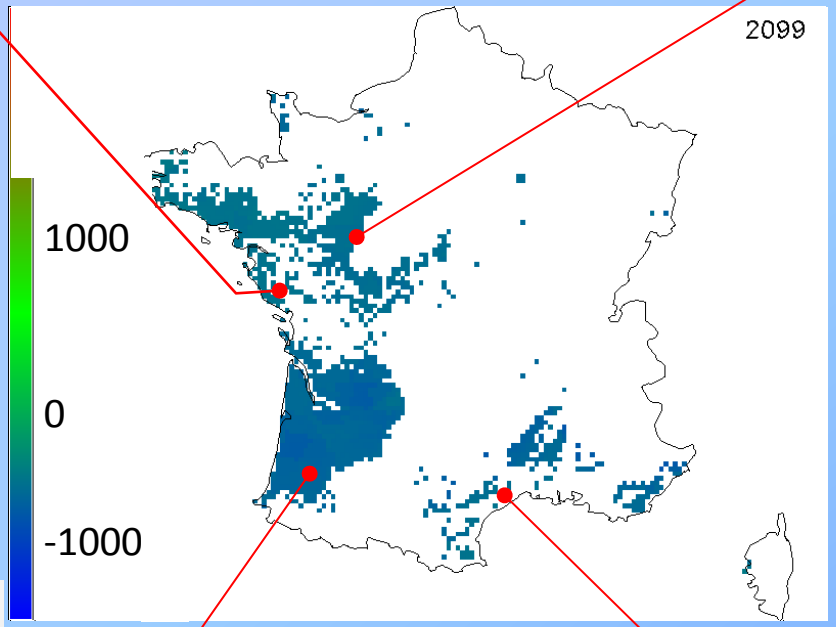



**Atlantic**

**Centre**

- NEE map
- Standing Biomass plots

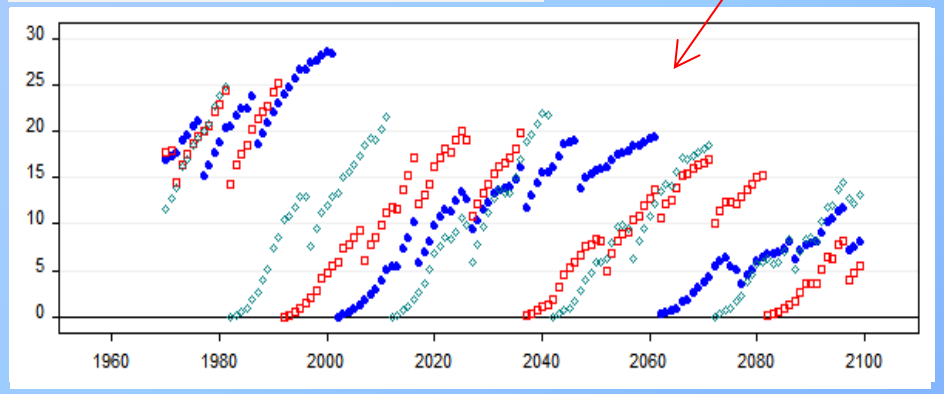


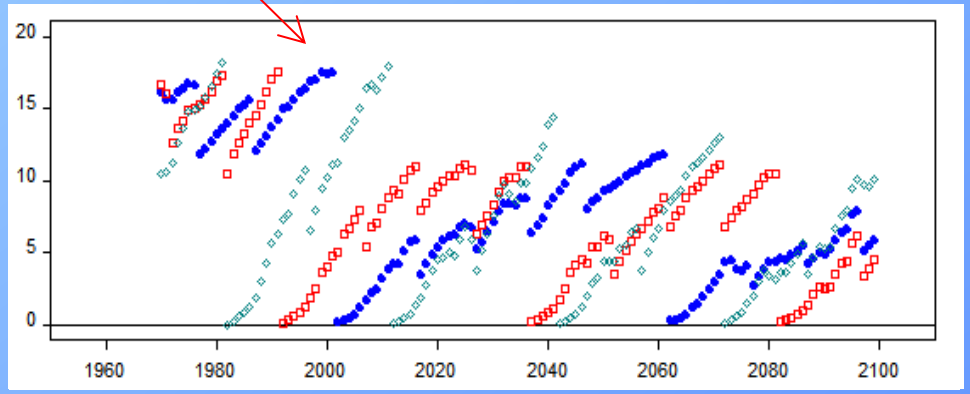

Plots of Biomass Stock (kg dm .m$^{-2}$)

- P30
- P45
- P60

**Pyrenean Foremounts**

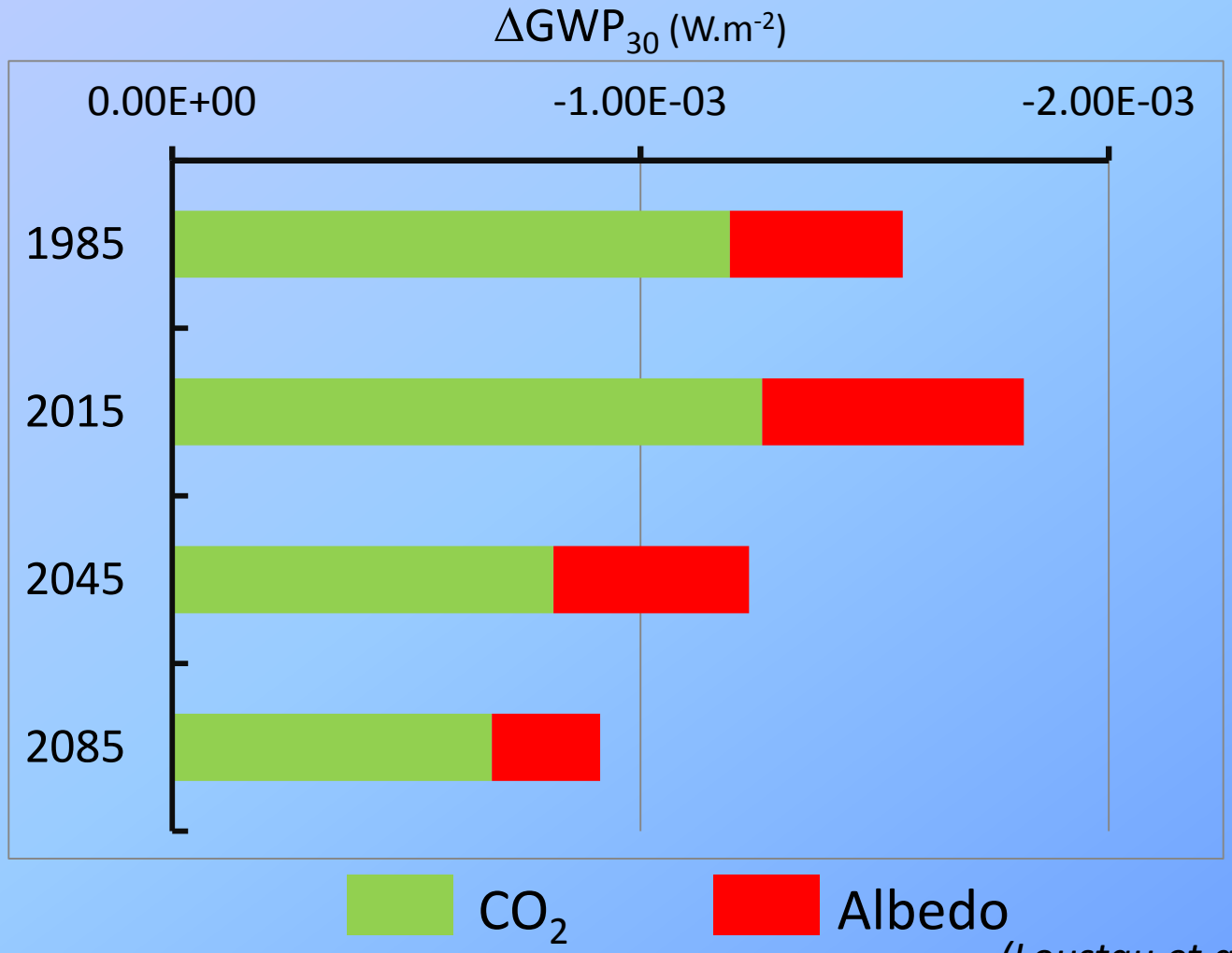
**Mediterrannean**



# 3. Drought effects modelled in temperate forest: Management impacts on climate are weakened under future drier climates

## Global warming potential of management intensification from P60 → P30




*(Loustau et al., EGU 2014)*

# Main points to take home.

- All forest types are exposed to droughts
- Trees respond at a range of time scale from hour to century
- How far does drought weaken the biosphere carbon sink is unknown.
- Release of carbon from declining forests will feed-forward the climate disturbance

INRA
SCIENCE & IMPACT

## INRA ISPA

- Denis Loustau
- Virginie Moreaux*
- Alexandre Bosc
- Delphine Picart
- Christophe Moisy

## INRA EEF

- Damien Bonal
- Nathalie Bréda
- Bernard Longdoz
- André Granier

## SUPPORT





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