Biogeochemical cycles in forest ecosystems

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INRA
SCIENCE & IMPACT

Biogeochemical cycles in Forest Ecosystems

Carbon, water, nutrients and their interactions

Saint-Andre L, Granier A., Loustau D., Legout A., Augusto L.

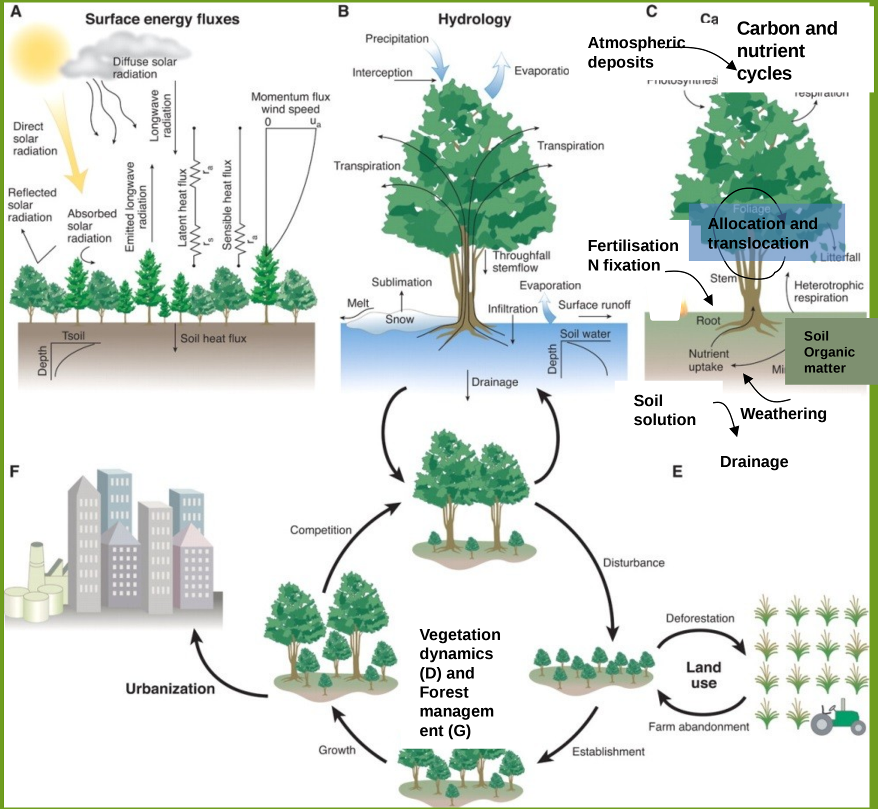
01/ 07/ 2013

INTRODUCTION

Forest Ecosystems, owing to their nature, are **complex** (temporally, spatially, …)

High expectation and pressure from the society (wood production, carbon sequestration, biodiversity, provision of drinkable water,..)

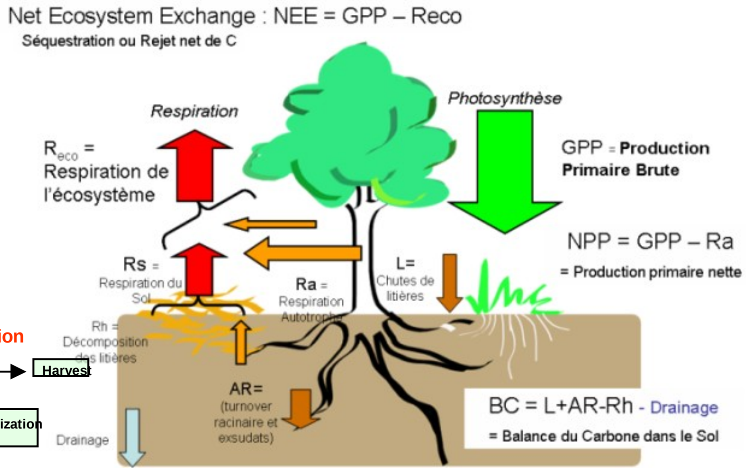
Impacted by global changes **but also regulates** biogeochemical cycles (climate change mitigation, interactions with the atmosphere, species impact on the biological cycles)

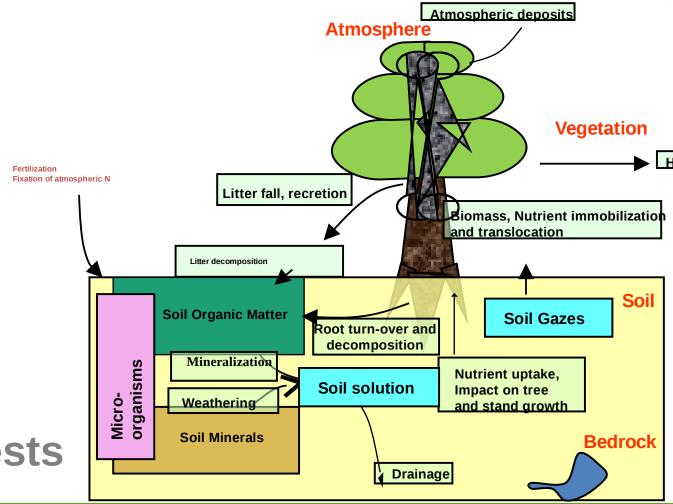


(adapted from Gordon B Bonan et al 2008, Science 320, 1444, DOI:10.1126/science.1155121)

Two Key Programs of Challenge 1 (*Develop the sustainable provisionning service of ecological systems*) and Challenge 2 (*Characterize and optimize ecosystem services)*

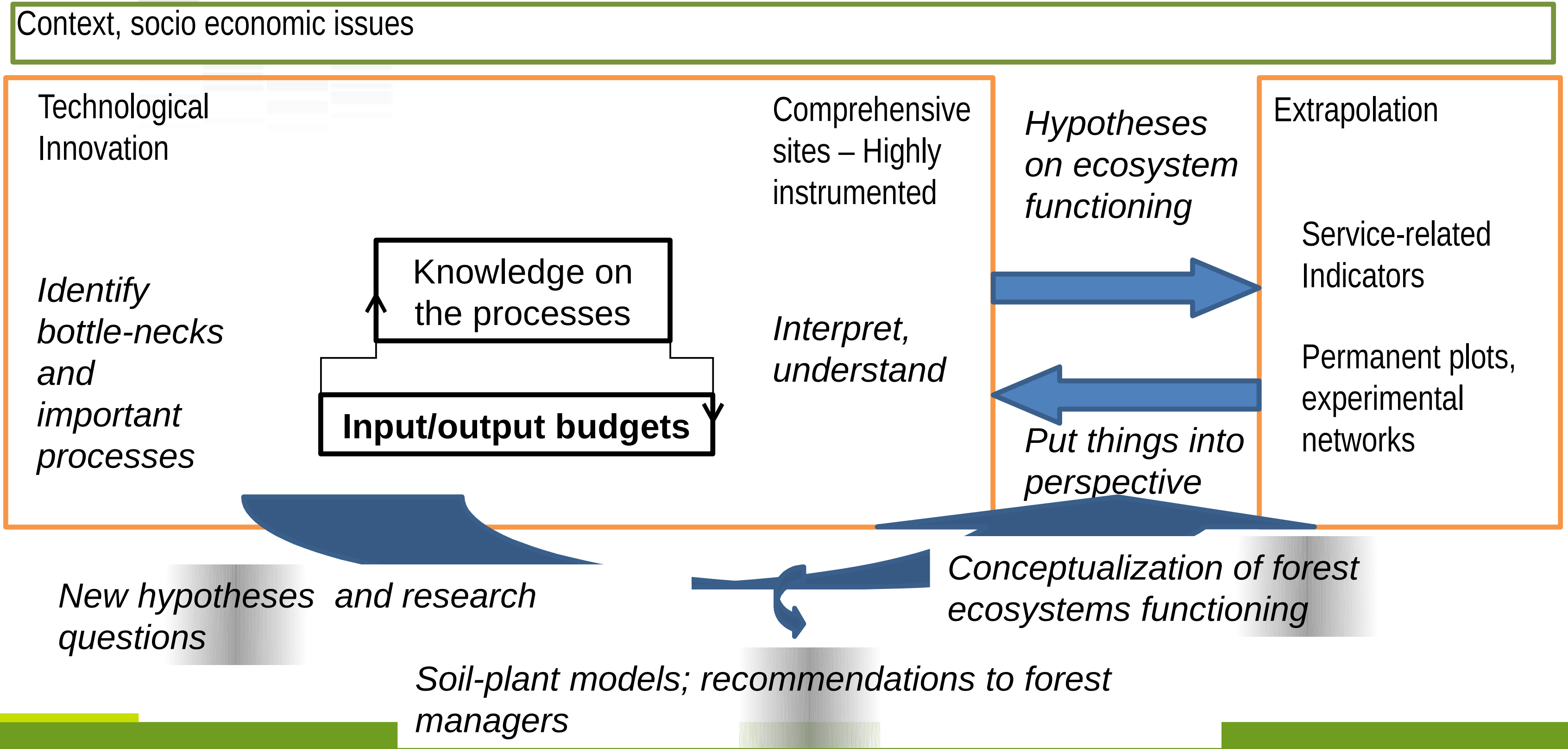
- Carbon, water and balances in temperate and tropical forests.





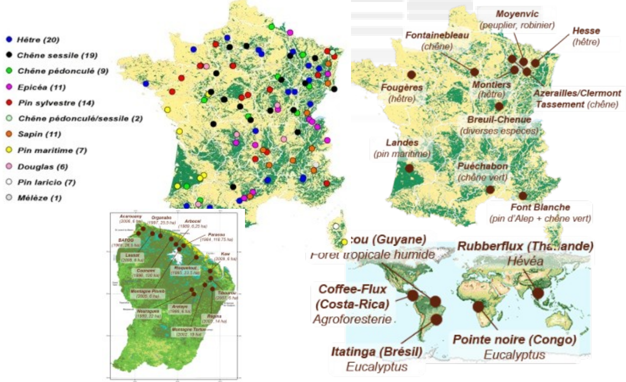
- Nutrient cycling in forests

For which we have a method

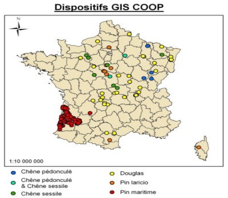


….in-situ and in lab consistent tools

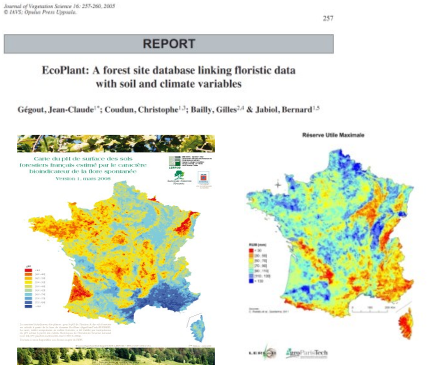
Comprehensive sites
SOERE F-ORE-T



National experimental networks
GIS-COOP/PLANTACOMP

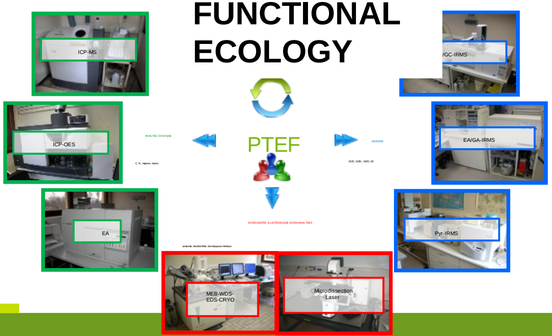


Large database
ECOPLANT/ Digitalis



M-POETE
(ANAEE-S)

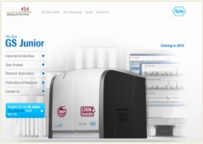
Platform for FUNCTIONAL ECOLOGY



XYLOFOREST

ECOGENOMIC

Genomic



HT-DNA sequencing
& RNA-Seq

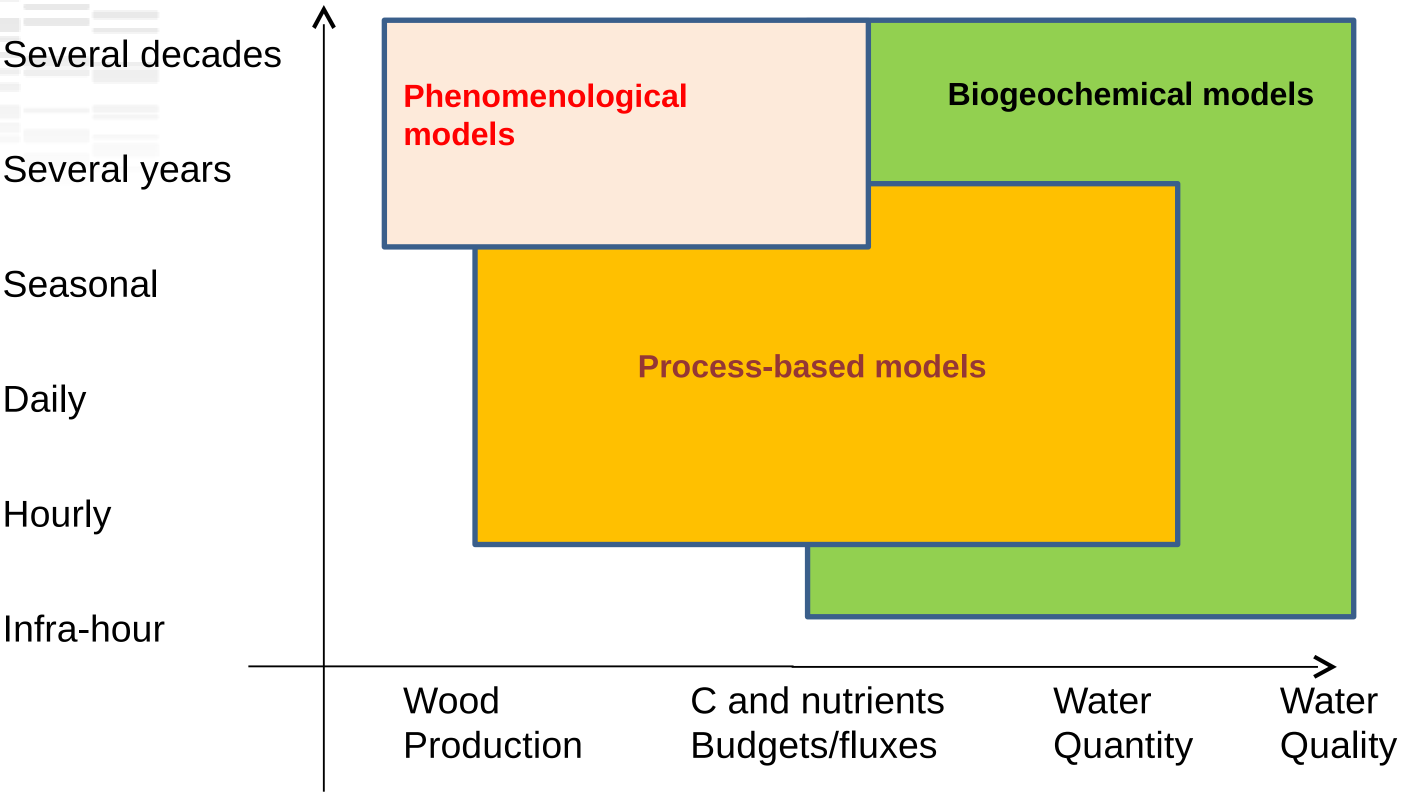
Micro-dissection

station

Bioinformatic

Bioinfo Xserve
Cluster

….models at different scales



....models at different scales

Data for calibration, validation and forcing

Remote sensing

National networks of permanent plots

National Forest Inventories (NFI)

Comprehensive sites

Continent

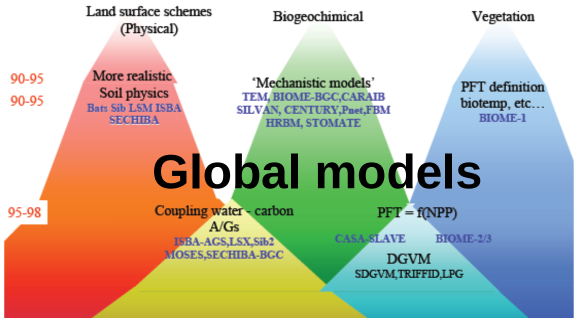
Country

Region

Forest

Stand

Tree



Spatialized models

Fagacée
PP3, E-Dendro

3PG
CO2Fix
ForNBM

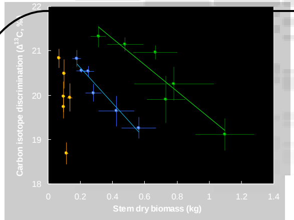
PnET; Lignum, GreenLab,
G'Day, ForSafe, Castanea,
GO+

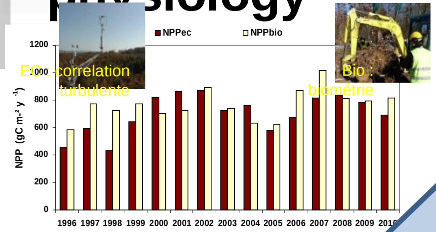
Tree and stand models

Empirical ⟷ Process-based

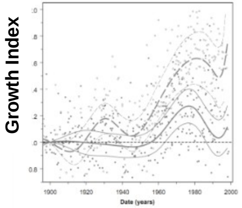
…. a strong disciplinary and inter-disciplinary settlement

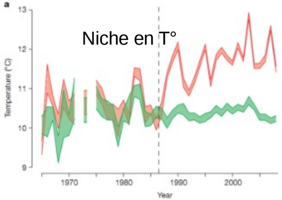
Eco-physiology



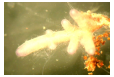


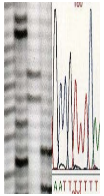
Ecology of tree and stand growth

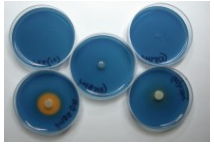


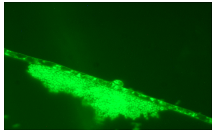


Microbiology

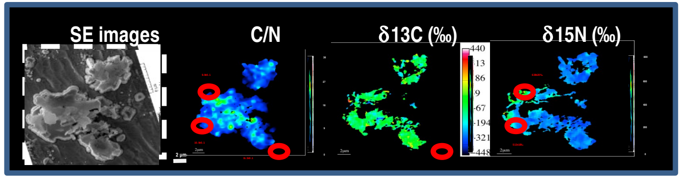




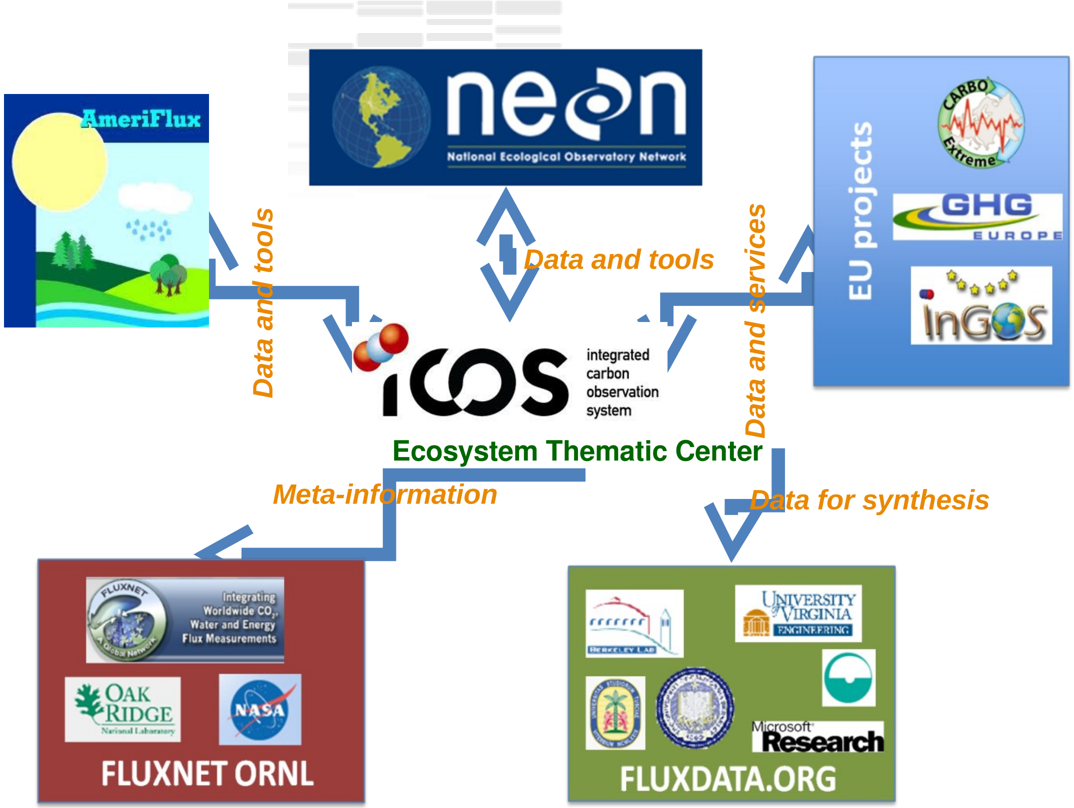




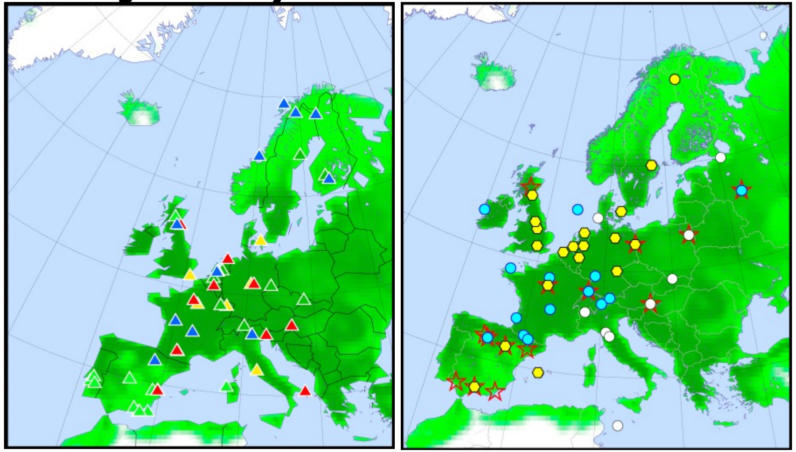
Biogeochemical cycles, Soil science



…. and collaborations through international networks



e.g. ICOS (Integrated Carbon Observation System)



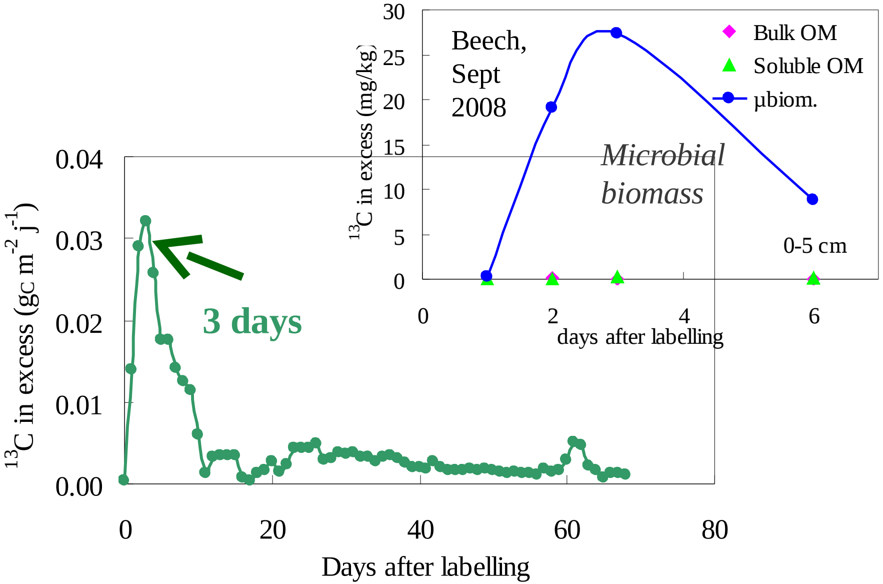
Ecosystems (50 stations)

Atmosphere(30 stations)

_01

Snapshots on Carbon, water and balances in temperate and tropical forests

Carbon Allocation in Trees and Soil ANR-07-BLAN-0109 C.A.T.S. (Fontainebleau, Hesse, Landes), 13C Leaf Labeling



Time lag in soil

- Beech: 12 ~ 32 h
- Oak: 14 ~ 26 h
- Pine: 39 ~ 110 h

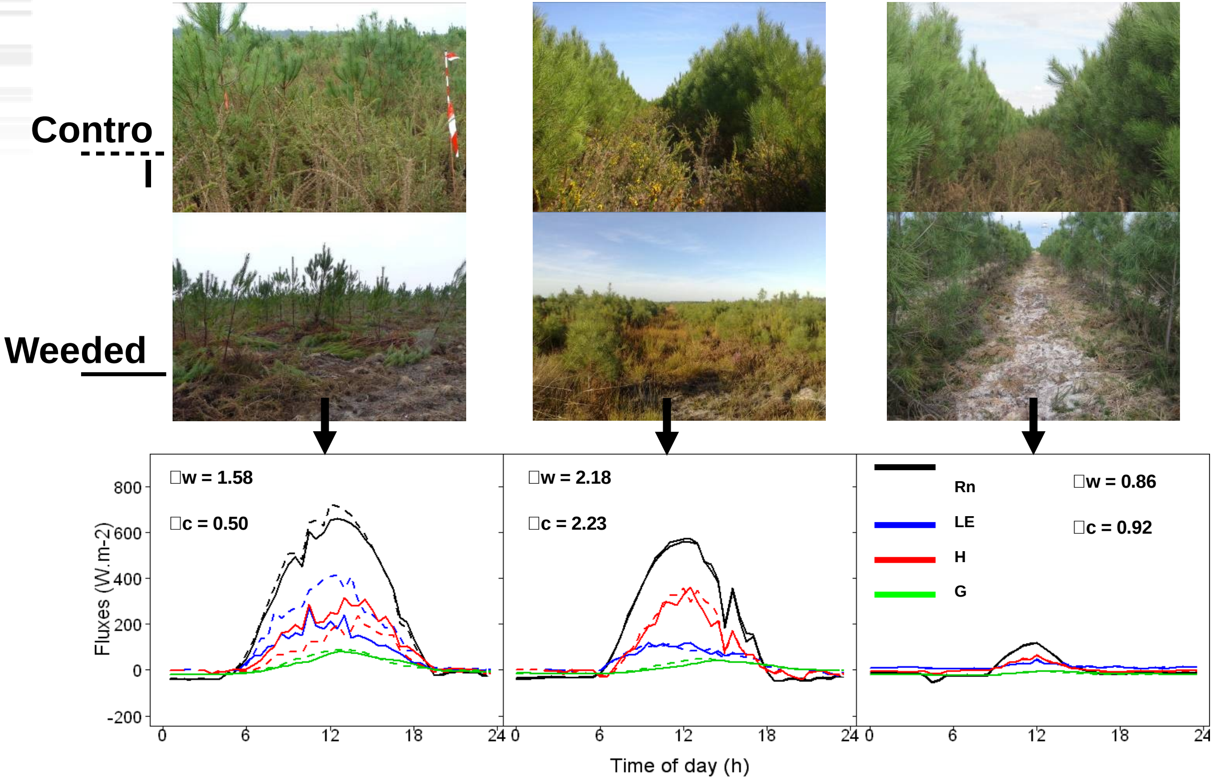
Peak time in soil

- Beech: 41 ~ 89 h
- Oak: 38 ~ 89 h
- Pine: 89 ~ 278 h

Epron et al. 2012,TREE PHYSIOLOGY 32(6): 776-798
Epron et al.2011 BIOGEOSCIENCES 8(5):1153-1168

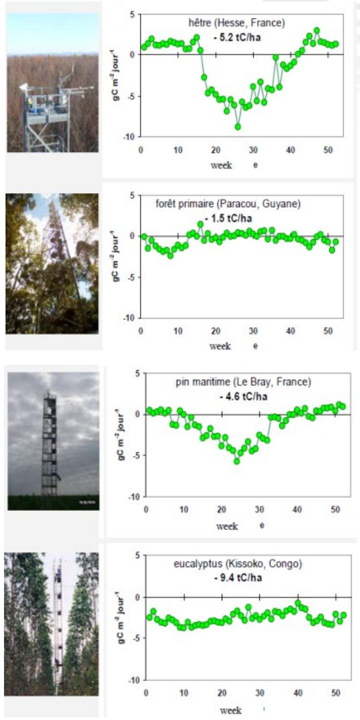
Impact of weeding and thinning on forest energy balance

Moreaux et al. 2012
Tree Physiology



Coll. Inra, U Grenade, U McQuarie Sydney

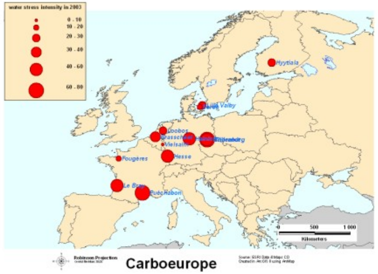
Carbon balance in different ecosystems, long term trends, and drought effects



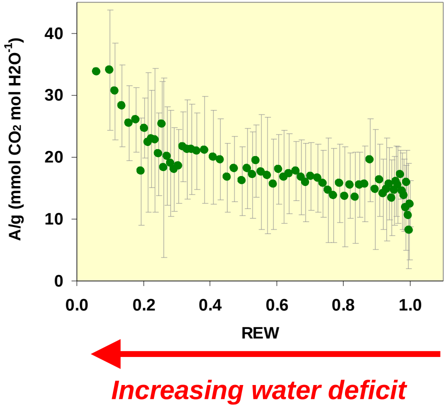
Yearly variations of net C balance

Inter-annual variations of net C balance (Hesse site)

- Average NEE: -3.9 ± 1.7 tC ha-1 an-1
- 30% of GPP (or 60% of NPP) used for tree growth
- High inter-annual variability (7 to 8 years are required to have a good idea of mean Reco; 5 years for GPP and 6 years for NEE

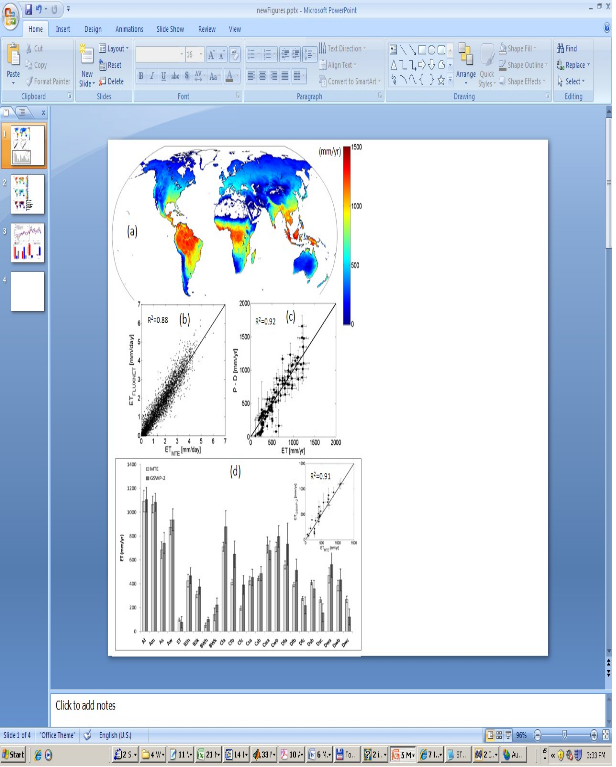


Hesse, 1997 to 2007
box averages of 20 values



Instrinsic water use efficiency at canopy scal

Evapotranspiration at continental scale - ICOS Ecosystem



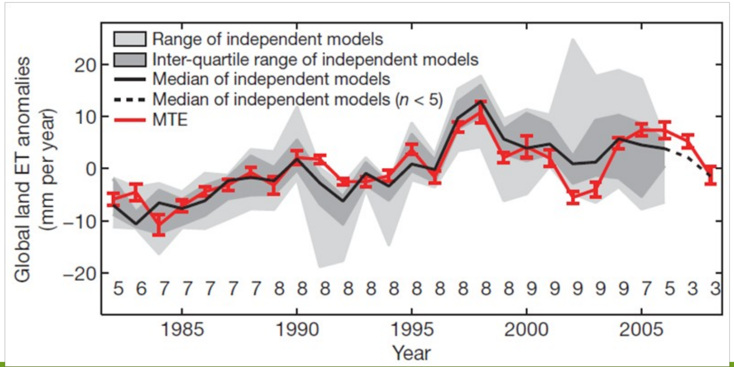
Jung et al. 2010, Nature

Global average: 550 mm/yr
~ 60 Eg/yr (±10-15%)

(1Eg = 1018g ~ 1000 km3)

(a)Map of mean Evapotranspiration from 1982-2008
(b)Predicted vs. Observed ET at FLUXNET sites (10-fold cross-validation from MTE training)
(c)Corroboration against river catchment water balances
(d)Comparison against GSWP-2 land surface model ensemble (16 models) stratified according to bioclimatic zones

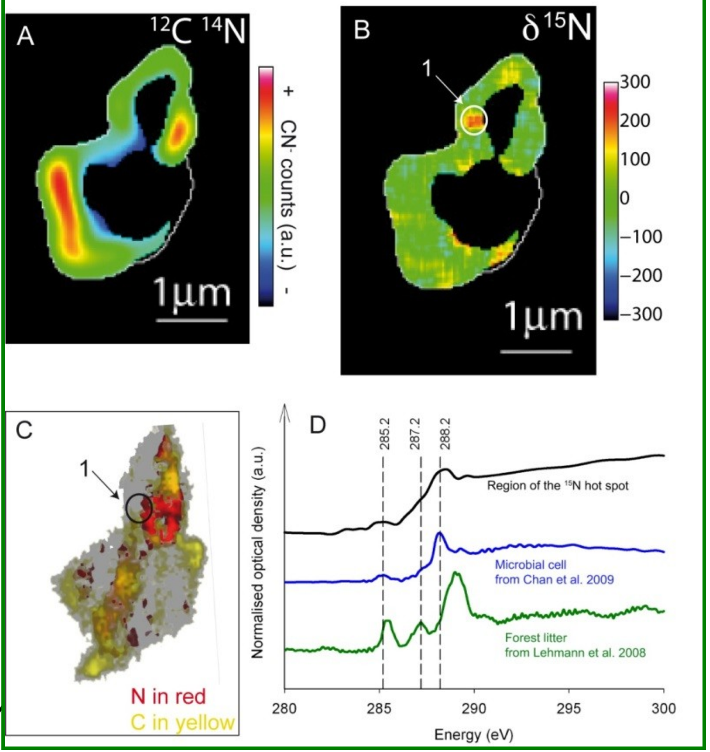
Evapotranspiration leveling off due to water limitation



_02

Snapshots on Nutrient cycling in forests

NanoSIMS Study of Organic Matter Associated with Soil Aggregates (Combination with STXM)



15N labelling of the litter

12 years after application:

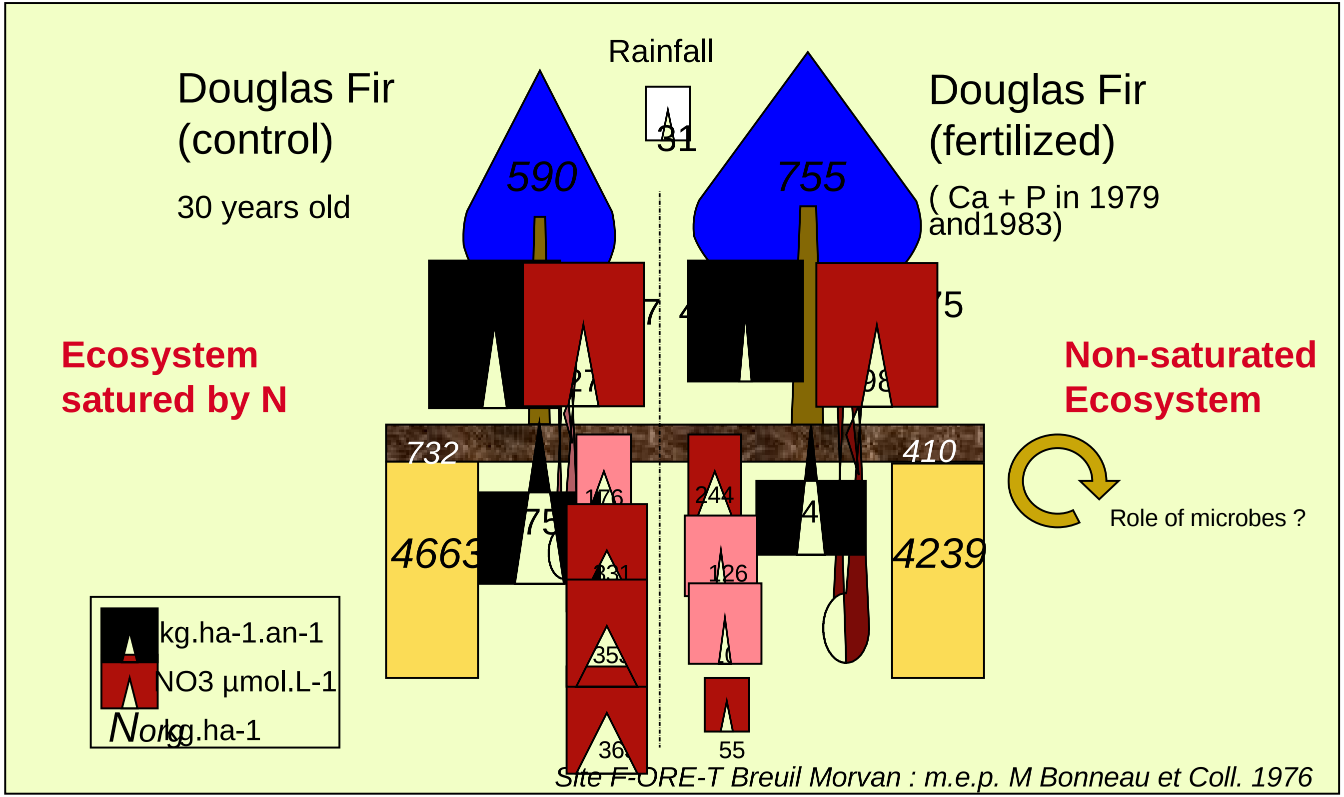
NanoSims = localisation of 12C, 14N and 15N in the aggregates

STXM = chemical composition close to microbial componds

Coll. Inra, Mnhn, Cnrs
LBNL Berkeley, USA
Oregon State University, USA

Remusat et al. 2012
ENVIRONMENTAL SCIENCE & TECHNOLOGY

Interaction between N and Ca/P cycles



Measuring 44Ca/40Ca and 26Mg/24Mg in environmental samples from a tracer experiment using ICP-MS and TIMS

		Concentration	Flux	Isotopic composition	
		meq.L^{-1}	kg.ha^{-1}	%	‰
15N	Nitrate	26.7	1	99	2.69E+07
44Ca	Calcium	9.6	0.53	96.45	1.26E+06
26Mg	Magnésium	29.6	0.96	99.25	1.09E+06
2H	Deutérium	-		99.85	2.37E+04

Coll. INRA, MNHN, CNRS
University of Nevada, USA
Lund University, Sweden
James Hutton Institute, UK

Van der Heijden G., et al. 2013, International Journal of Mass Spectrometry

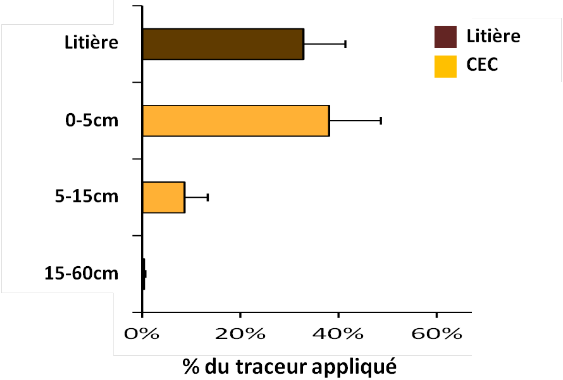
Monitoring in situ and measurement of isotopic ratios 26Mg/24Mg et 44Ca/40Ca (ICP-MS)

Humus, sol, biomasse microbienne

Pluie incidente, écoulement de tronc, pluviolessivats, solutions de sol

Racines fines, feuilles….

44Ca Two years after application



Van der Heijden G., et al. 2013, Forest Ecology and Management

Van der Heijden G., et al. 2013, Geoderma

Van der Heijden G., et al. 2013, Plant and soil

Measuring and modeling 15N, 42Ca and 26Mg movement in tree xylem from a tracer experiment using ICP-MS and TIMS

		Concentration *g L-1*	Isotopic enrichment *%*
15N	Nitrate	4.3	99.0
42Ca	Calcium	1.4	79.0
26Mg	Magnesium	2.1	98.8

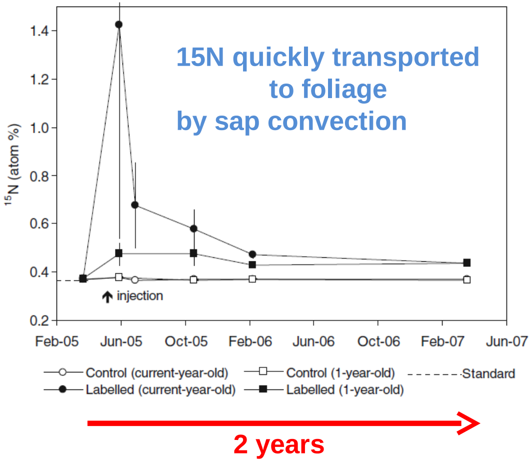
Coll. Inra,
Macaulay Institute, UK
US Forest Service, USA

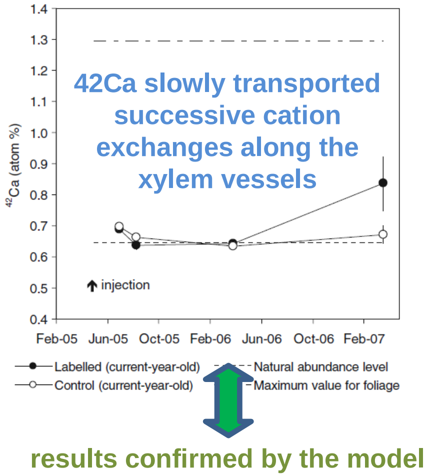
Augusto L. et al. 2011, Annals of Forest Science.

Monitoring *in situ* (2 years) and measurement of isotopic ratios: δ15N, 26Mg/24Mg and 42Ca/40Ca (ICP-MS)

Modeling of Ca transport in tree xylem (homothetic upsaling approach):

$$TRSP_{H2O-field} = TRSP_{H2O-lab} \times \frac{[Ca]_{sol-lab}}{[Ca]_{sol-field}} \times \frac{VOL_{sap-field}}{VOL_{sap-lab}}$$



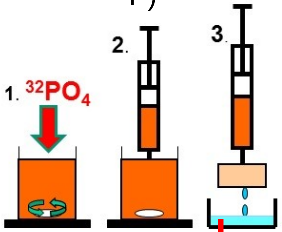


EFPA funding

Using radiotracers 32P and 33P to assess phosphorus nutritive status in forest soils

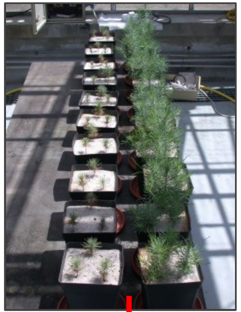
Batch experiments

(soil-solution suspensions with *P)

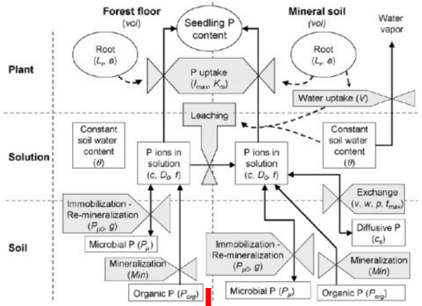


Incubation experiments

Greenhouse experiments



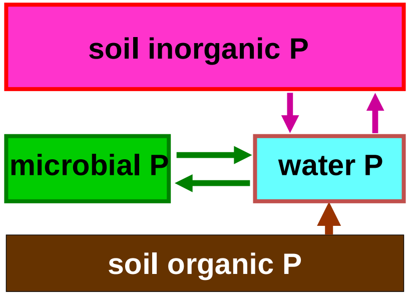
Modeling and Meta-

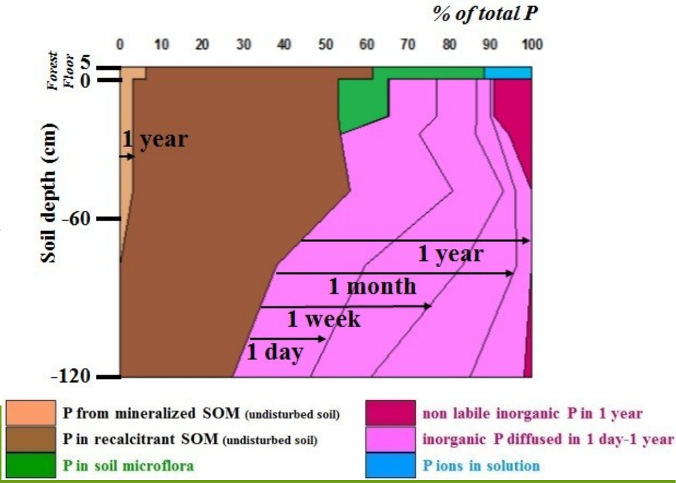


Coll. Inra,
Tomsk Univ., Russia
Novosibirsk Univ., Russia

Achat D.L. et al. 2009ab, 2010abc, 2011, 2012ab, 2013ab. Jonard et al. 2009, 2010. Trichet et al. 2009. Ann. For. Sci., Biogeochemistry, Biogeosciences, Ecol. Model., For. Sci., Geoderma, JSS, Soil Biol. Biochem., SSSAJ.

complete assessment of P nutritive status





ACCAF Meta-Program

CONCLUSION

Large advances have been made

Next challenges –

Interaction between cycles,
Data model integration,
Robust service-related indicators,
Mapping of forest ecosystem services

But we are already on the road……. –

ESFRI road maps (ICOS, EXPEER)
LABEX (ARBRE, COTE, CEBA)
EQUIPEX (XYLOFOREST)
Infrastructure (ANAEE-S)