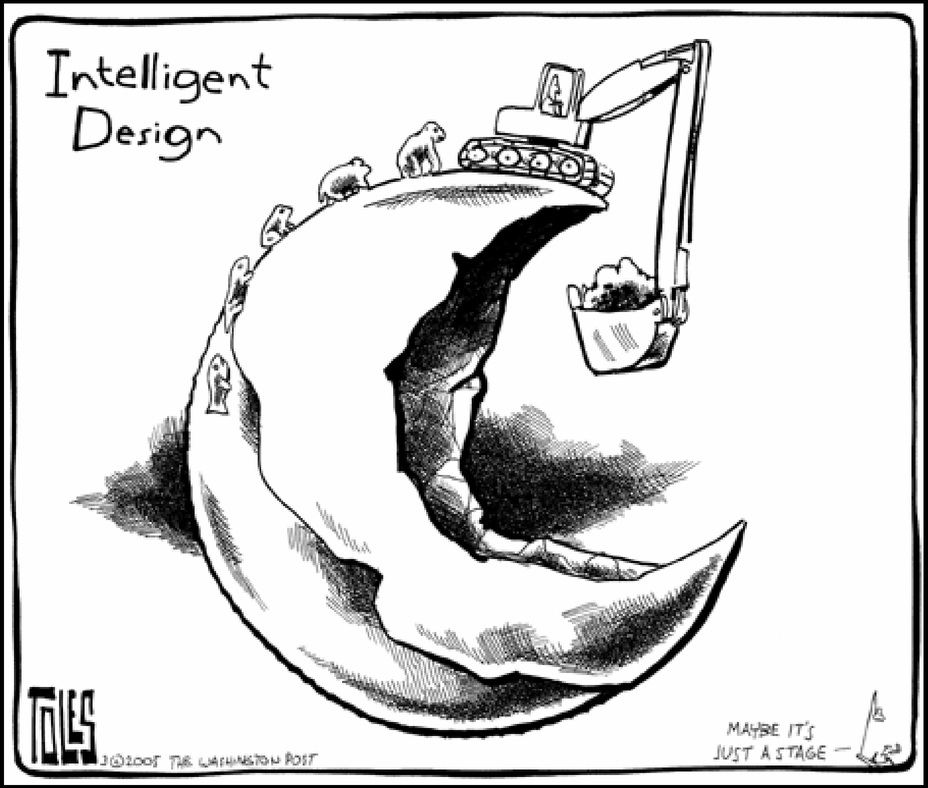
The role of flux networks to understand terrestrial biosphere feed-backs to the global carbon cycle



Washington Post, **March 30, 2005**

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e delle sue Risorse (DISAFRI)

rik@unitus.it
http://gaia.agraria.unitus.it

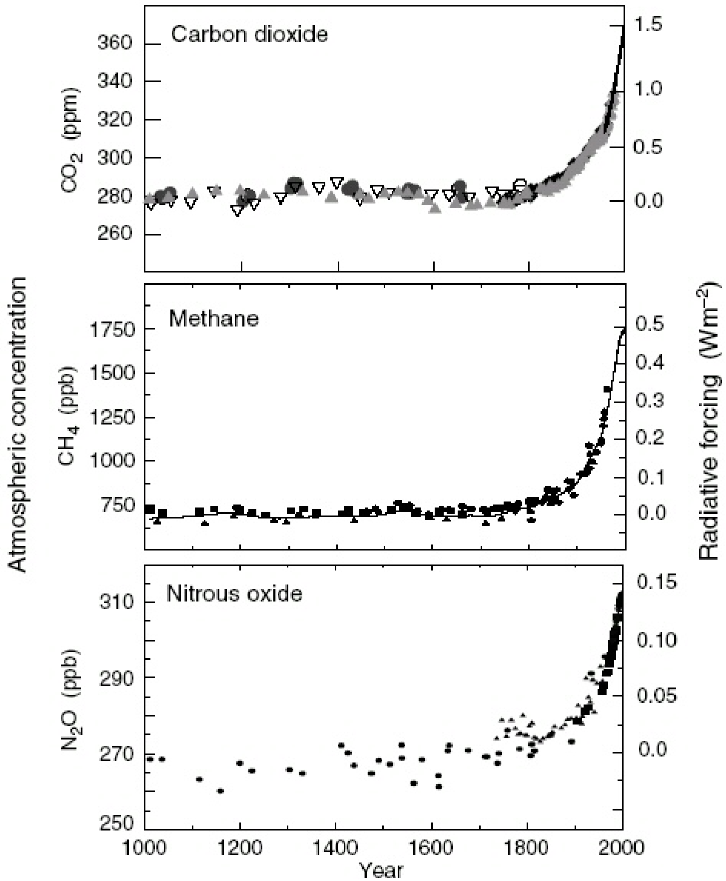
Do we need long term measurements ?

Human influence on the atmosphere during the industrial era (Anthropocene)

CO_2

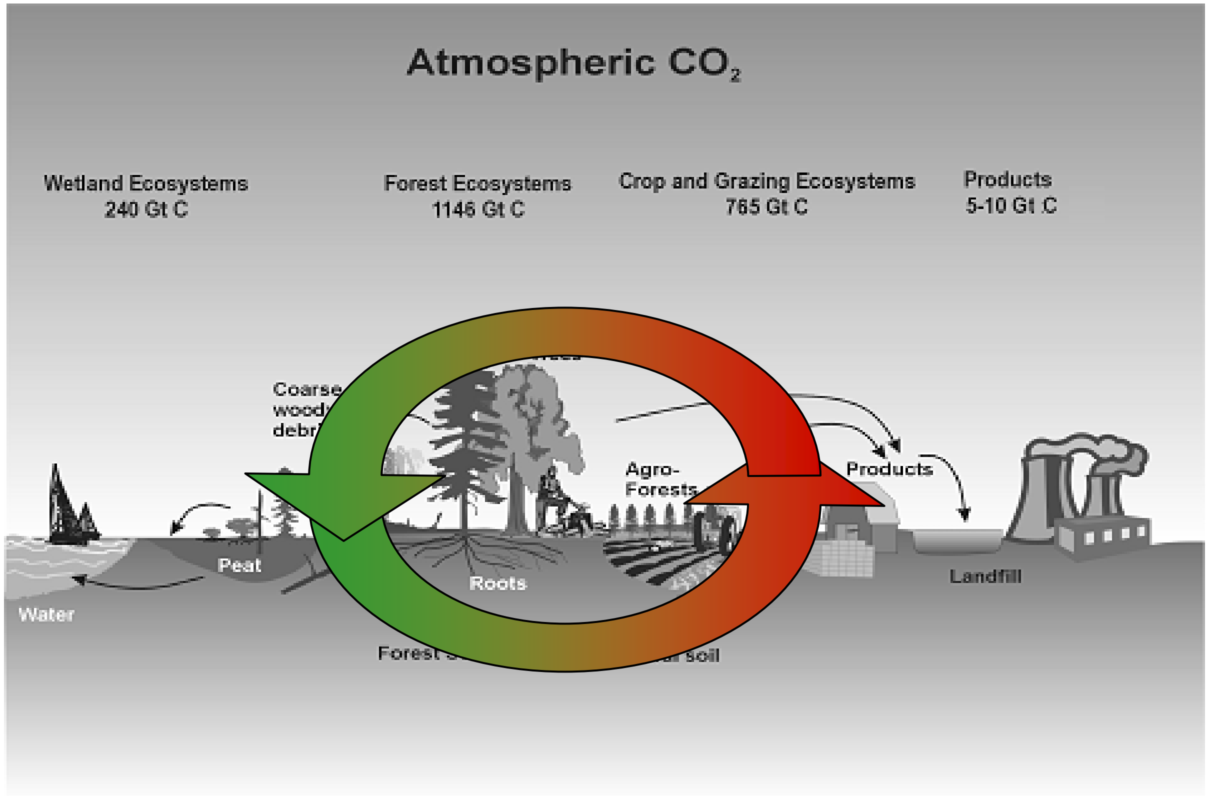
CH_4

N_2O



IPCC, 2001

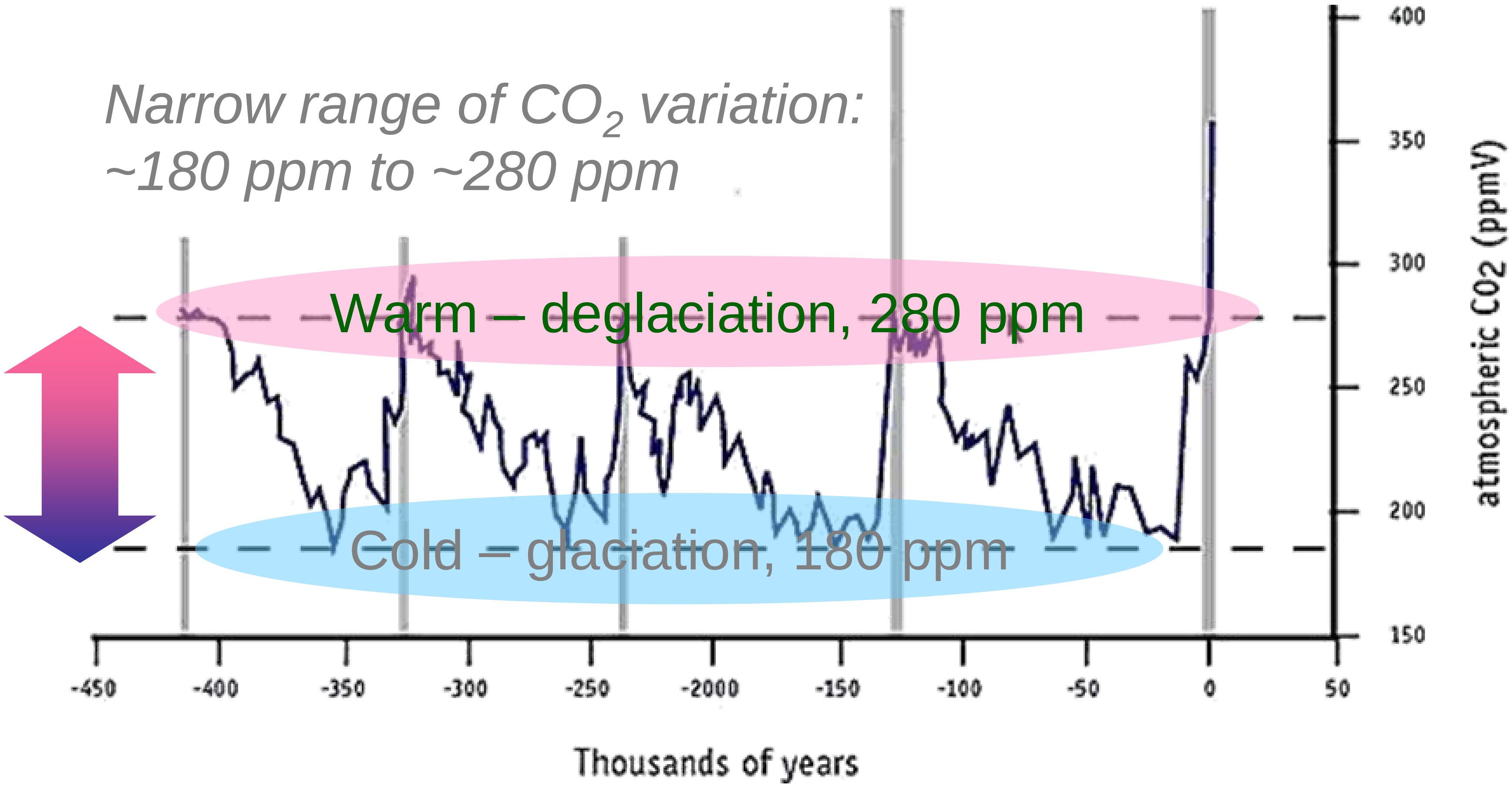
Active Carbon Cycle



A natural cycle which has been working for the last 4 glacial-interglacial period

Carbon cycle behaviour over multiple glacial cycles

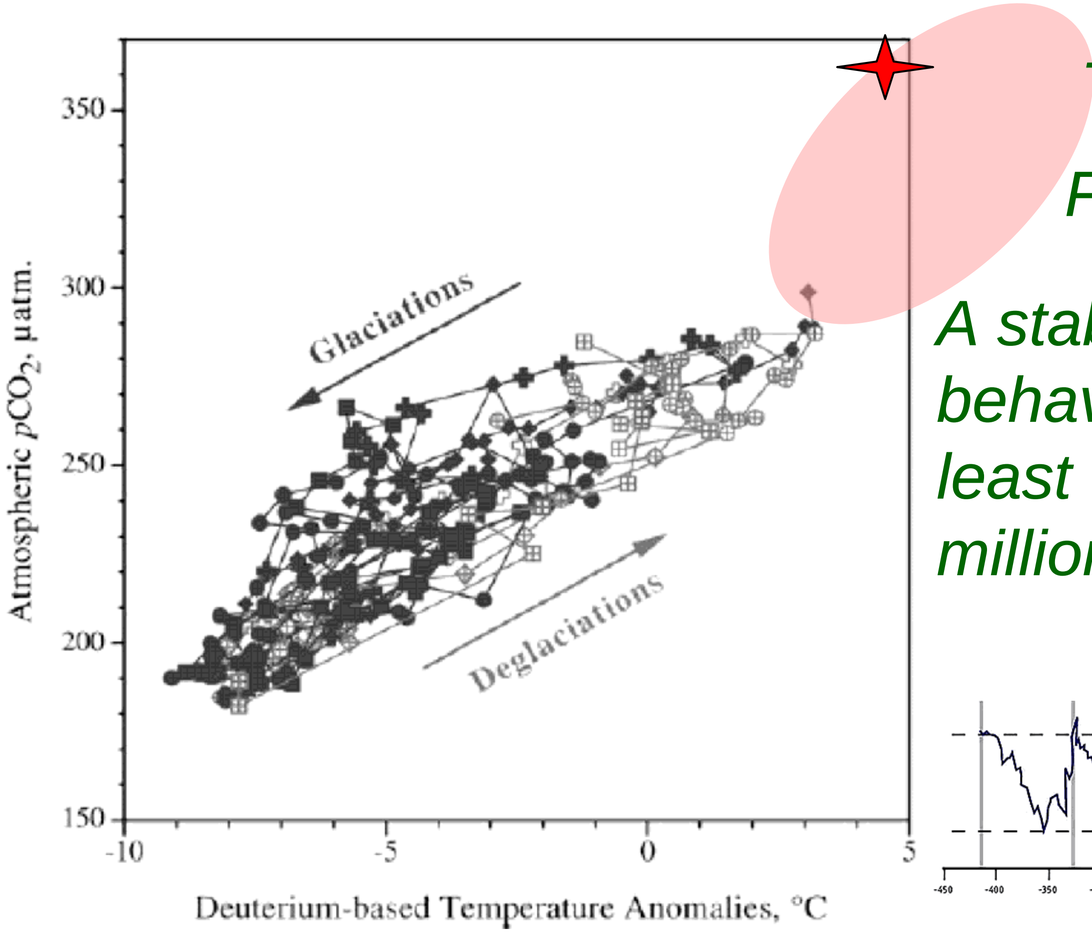
Narrow range of CO_2 variation:
~180 ppm to ~280 ppm



Petit et al., 1999

Variation in T and CO_2 over last 4 glacial cycles

CO_2

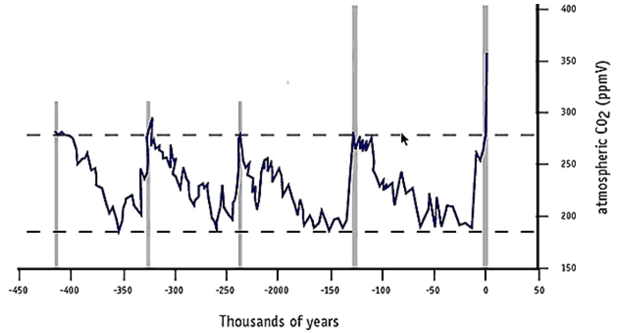


Temperature

Today

Future?

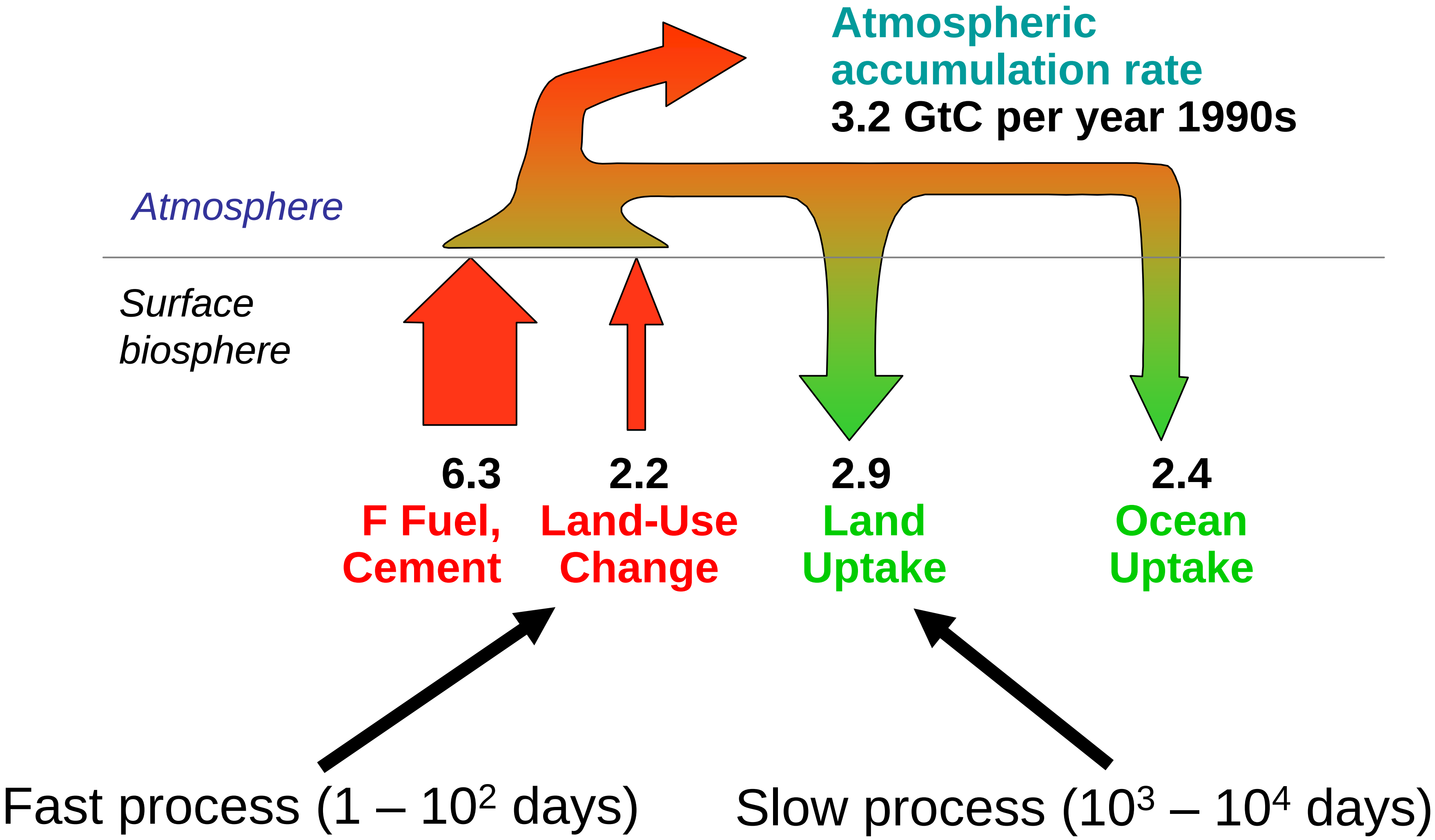
A stable mode of behaviour for at least the past ½ million years



Petit et al., 1999

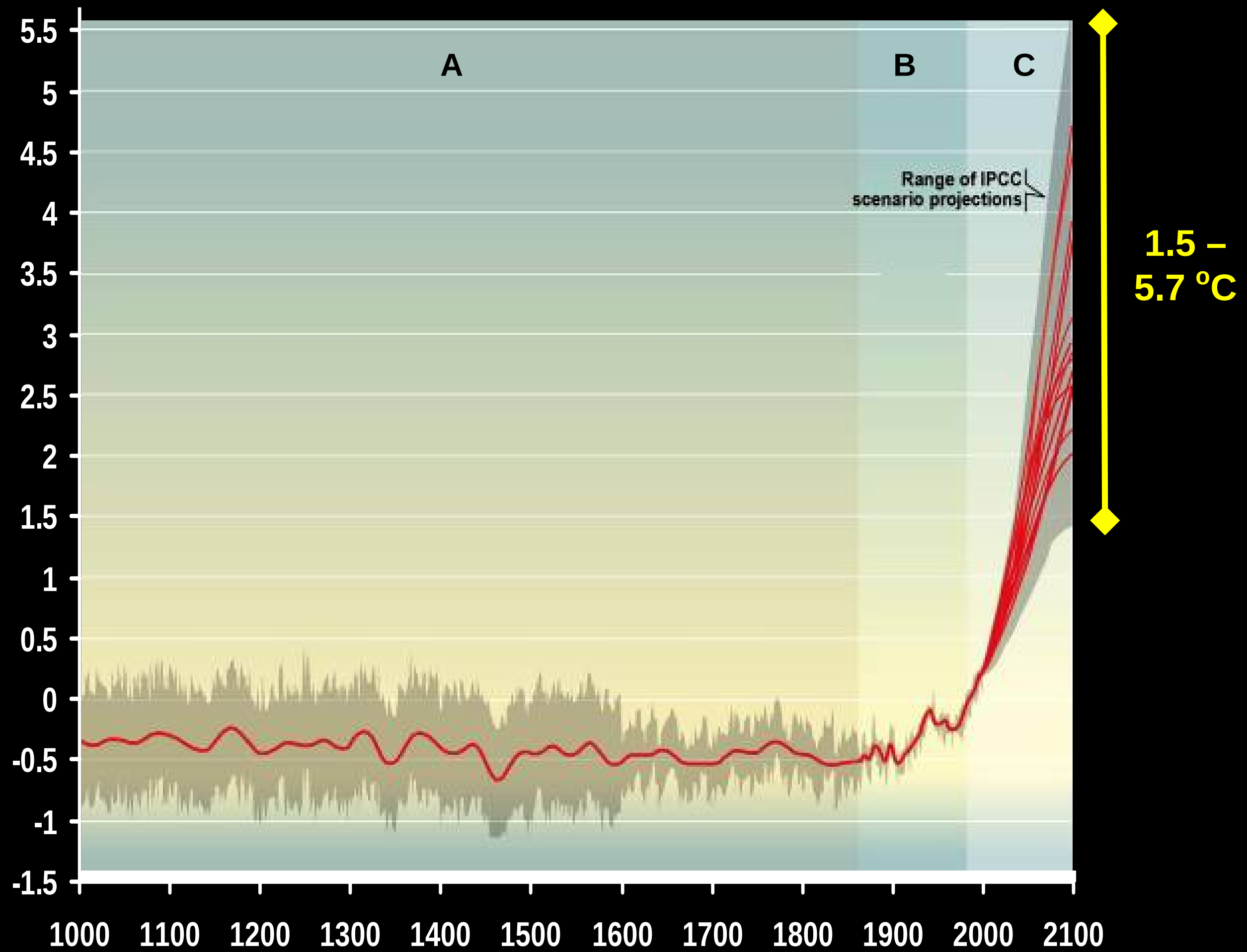
Falkowski et al., 2000

Global C Budget: “Slow in – Fast out”



Gruber et al 2003 , SCOPE project

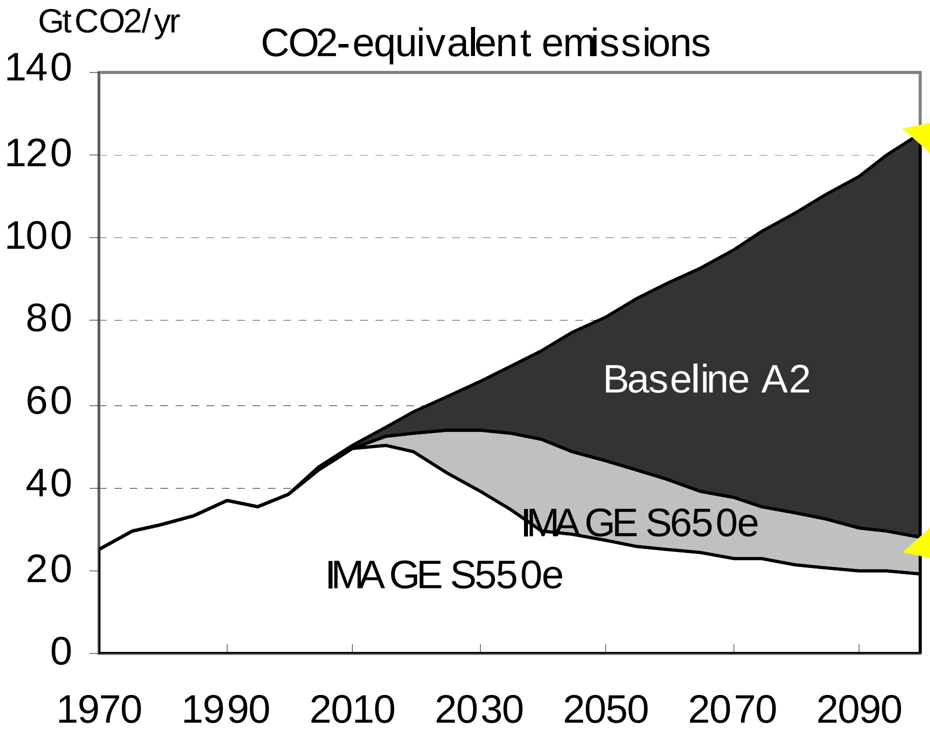
Temperature Change (°C) from 1990



A: Observations, Northern Hemisphere, Proxy data
B: Global Instrumental Observations
C: IPCC 2001 Scenario Projections (SRES)

Source: IPCC 2001

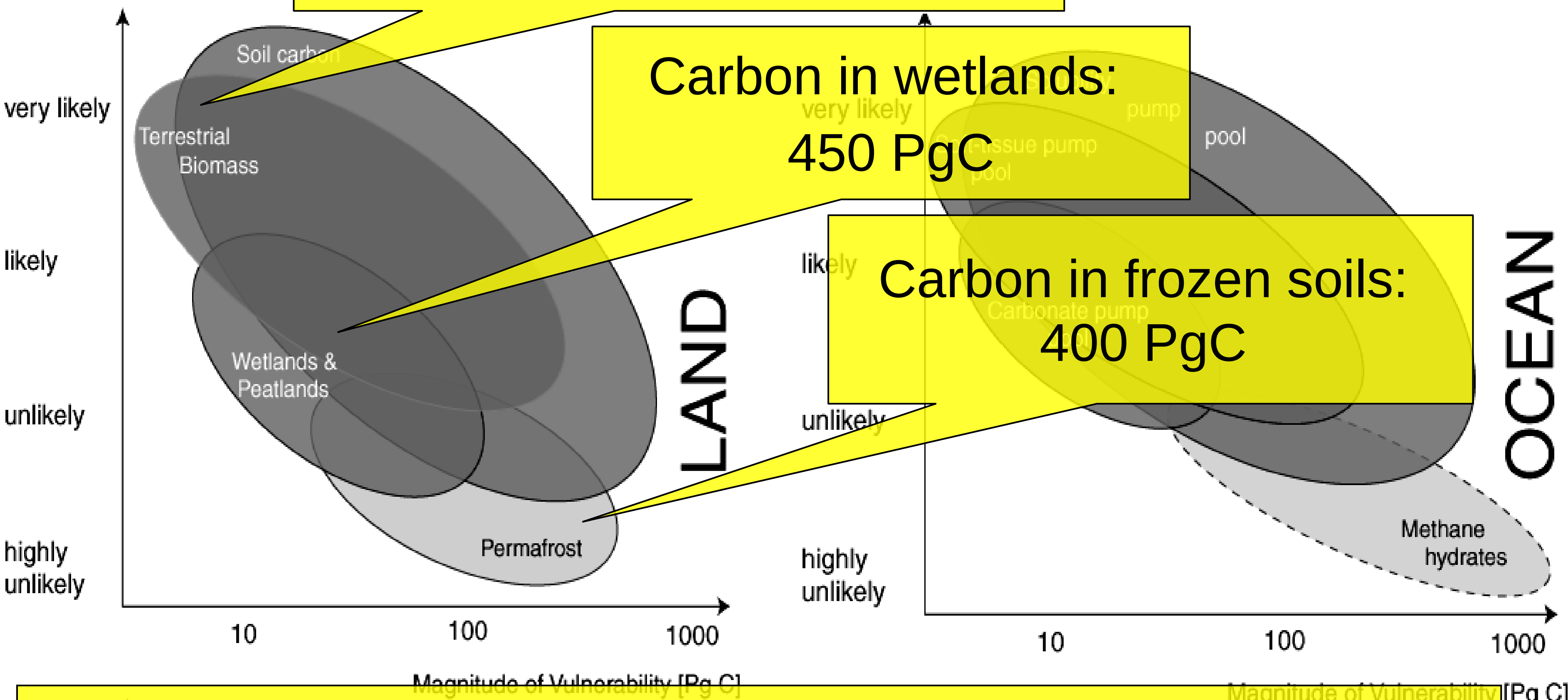
The "Gap Paradigm"



BIOSPHERE

Source or sink ?

Vulnerability of Carbon Pools



Carbon in tropical vegetation:
340 Pg

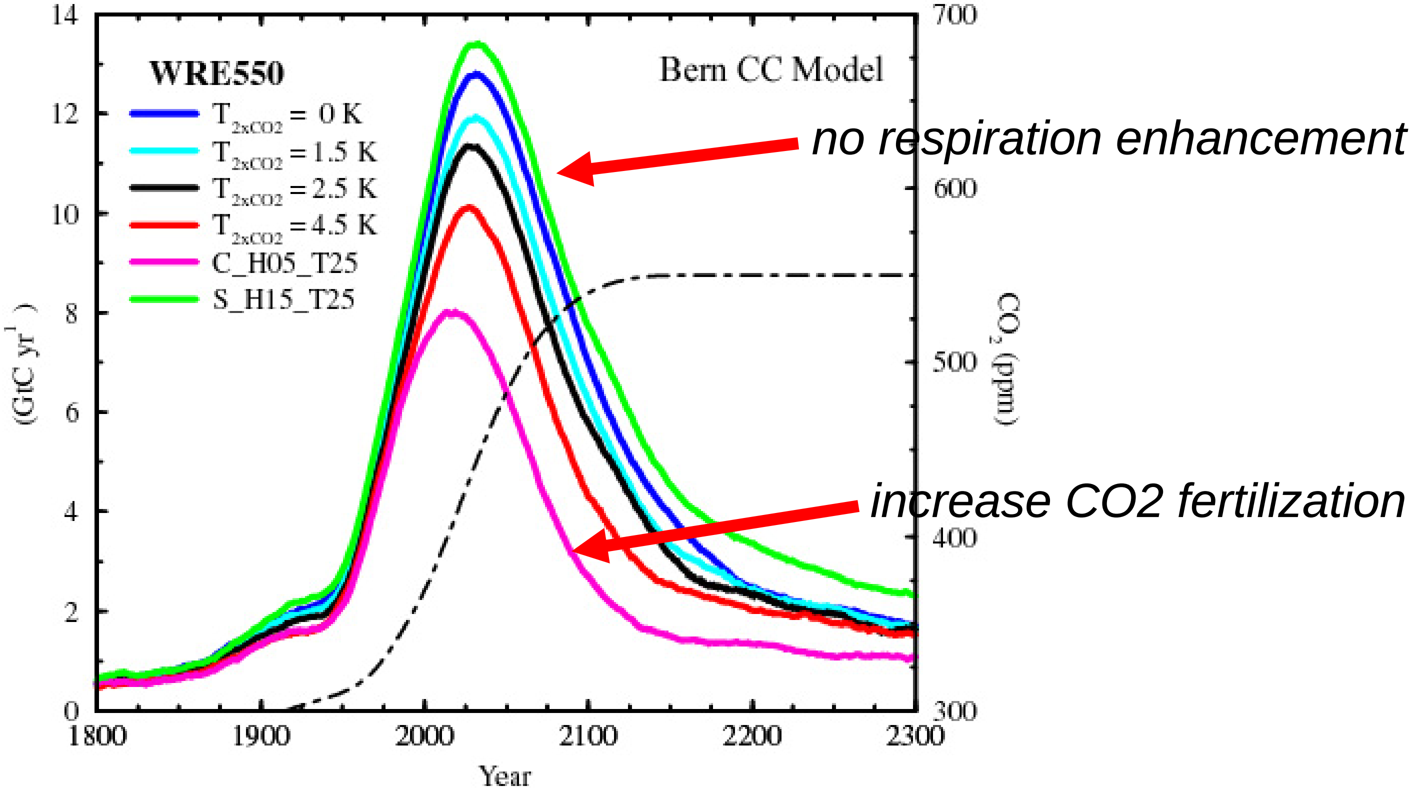
Carbon in wetlands:
450 PgC

Carbon in frozen soils:
400 PgC

- Risk over the coming century of up to 200 ppm of atmospheric CO_2
- Not included in most climate simulations.

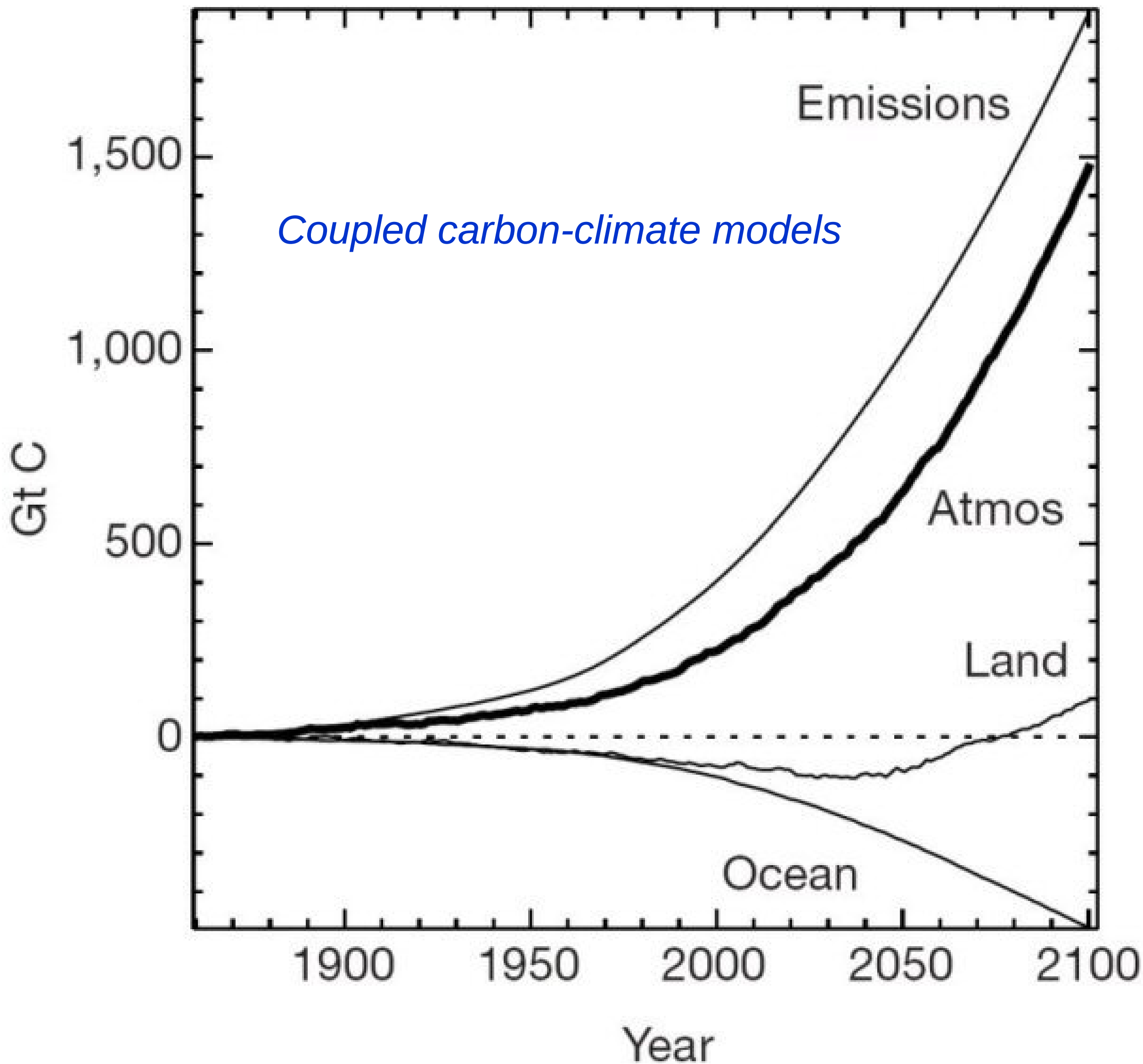
Gruber et al. 2004

Global models start to include terrestrial ecosystem feed-backs



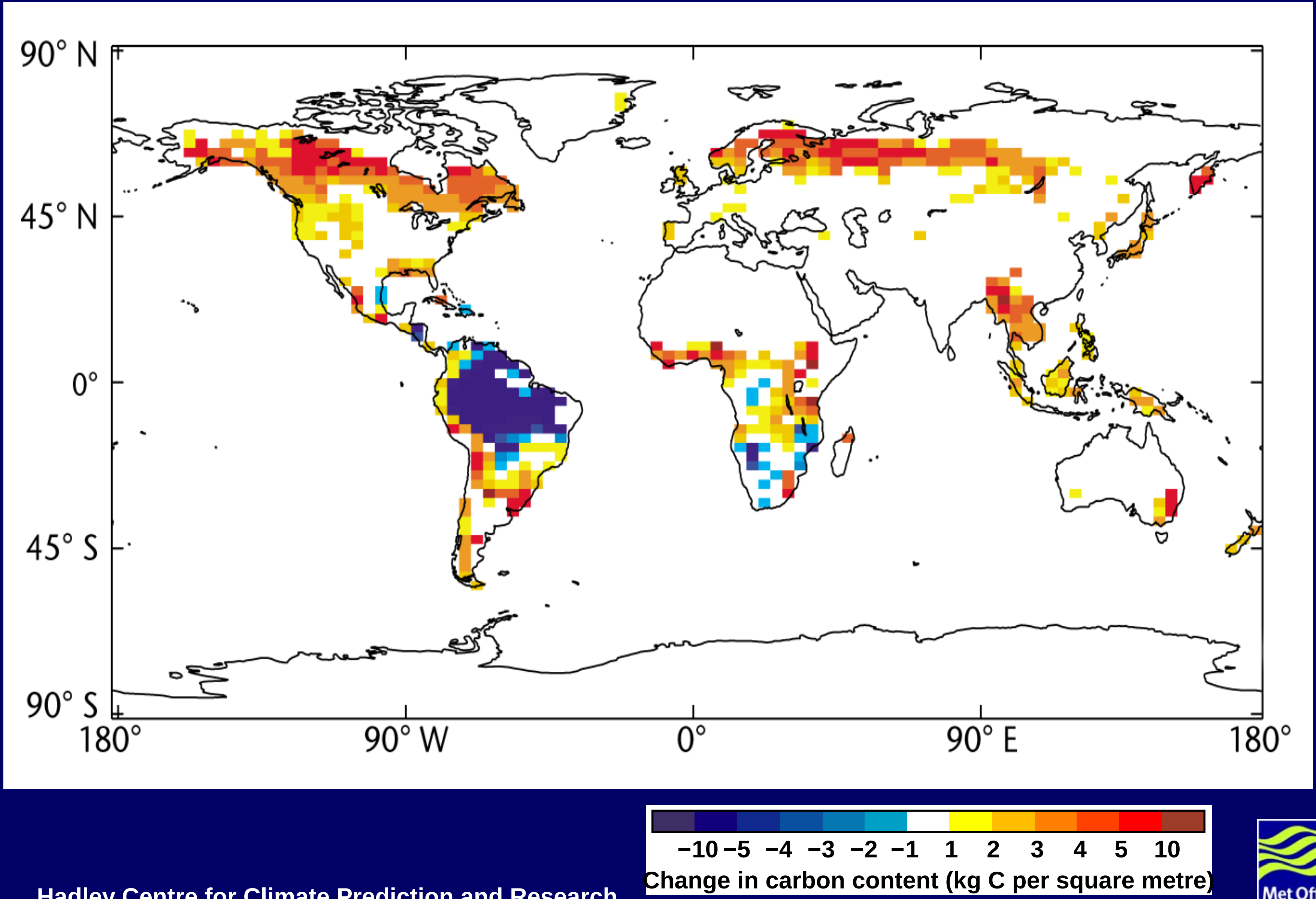
Allowed carbon emission for the WRE550 pathway where atmospheric CO2 is stabilized at 550 ppm (dot-dash line, right axis) as obtained with the Bern CC model (Joos et al., GBC, 2001). The model's climate sensitivity expressed as equilibrium temperature increase for a doubling of atmospheric CO2 has been varied between 0oC (no climate feedbacks), 1.5 oC, 2.5 oC (standard case), and 4.5 oC. The lower bounding curve has been calculated by phasing out CO2 fertilization, the major terrestrial sink process in the model, after year 2000 and by setting slow ocean mixing rates. The upper bounding case has been obtained by implementing no dependence of soil respiration rates on soil warming, thereby suppressing the major terrestrial source process in the model

Vulnerability of the Land compartment



Cox et al., 2000

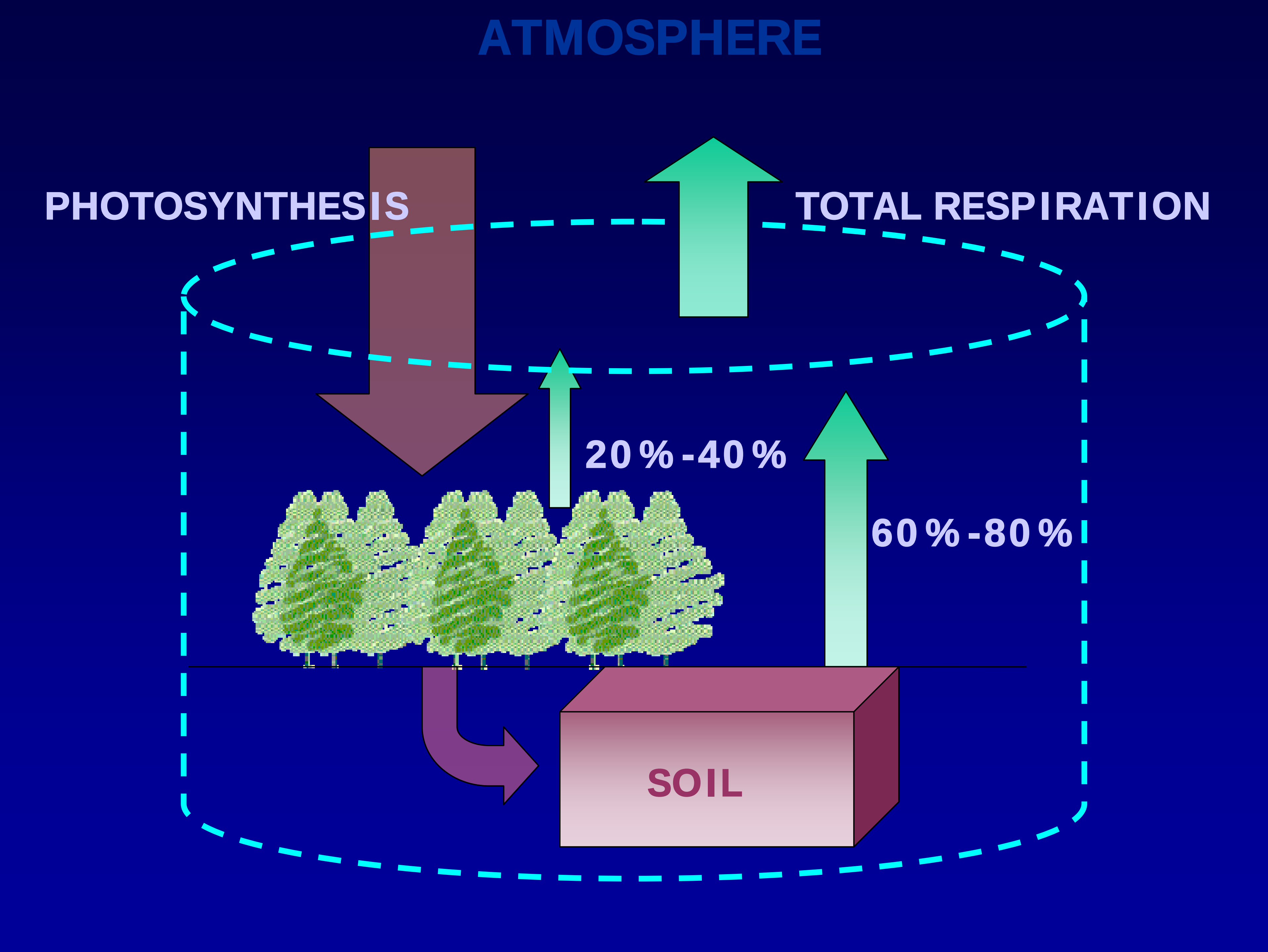
CHANGE TO CARBON STORED IN VEGETATION
1860 - 2100



Hadley Centre for Climate Prediction and Research

Met Office

Are global models of terrestrial carbon cycle right ?


ATMOSPHERE
PHOTOSYNTHESIS
TOTAL RESPIRATION
20%-40%
60%-80%
SOIL

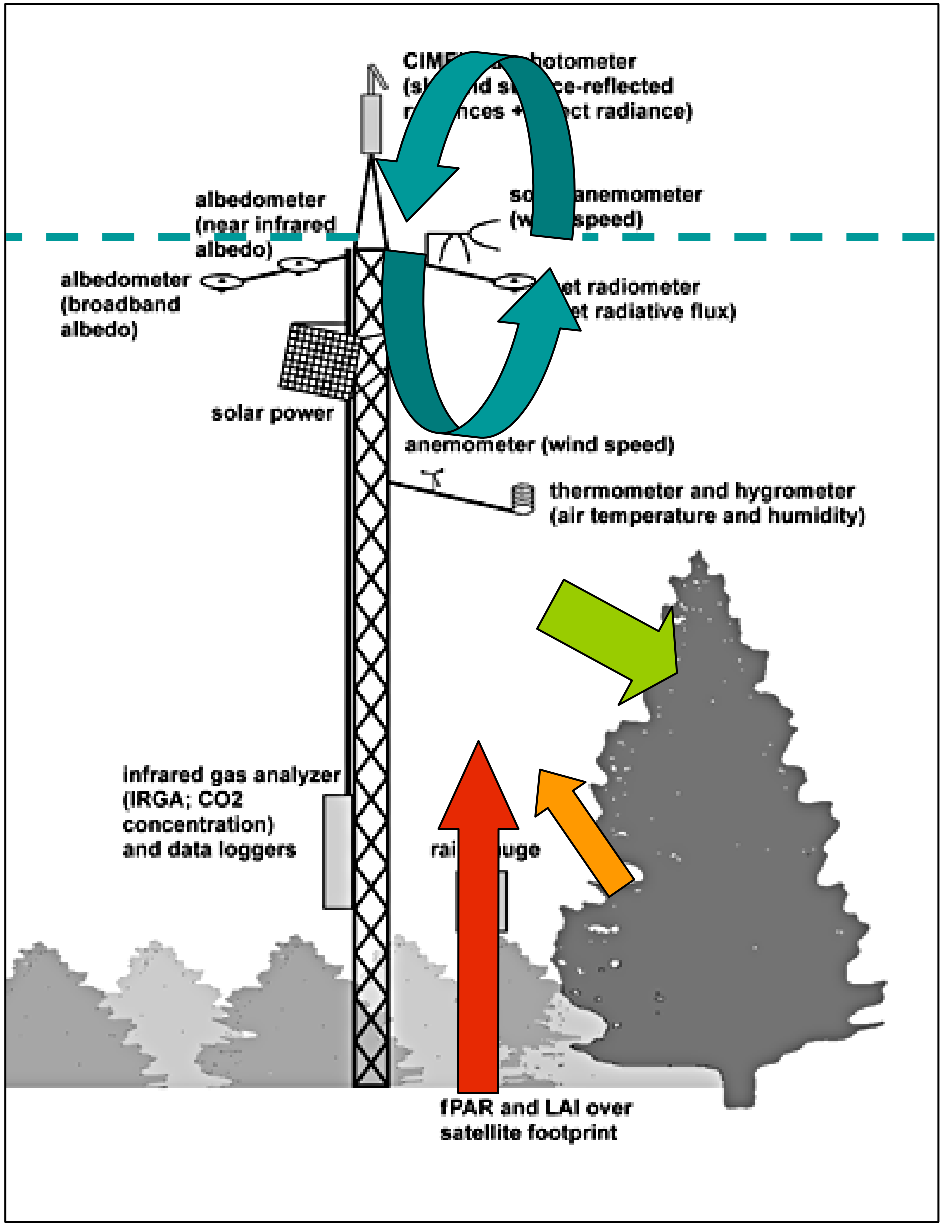
Eddy covariance technique

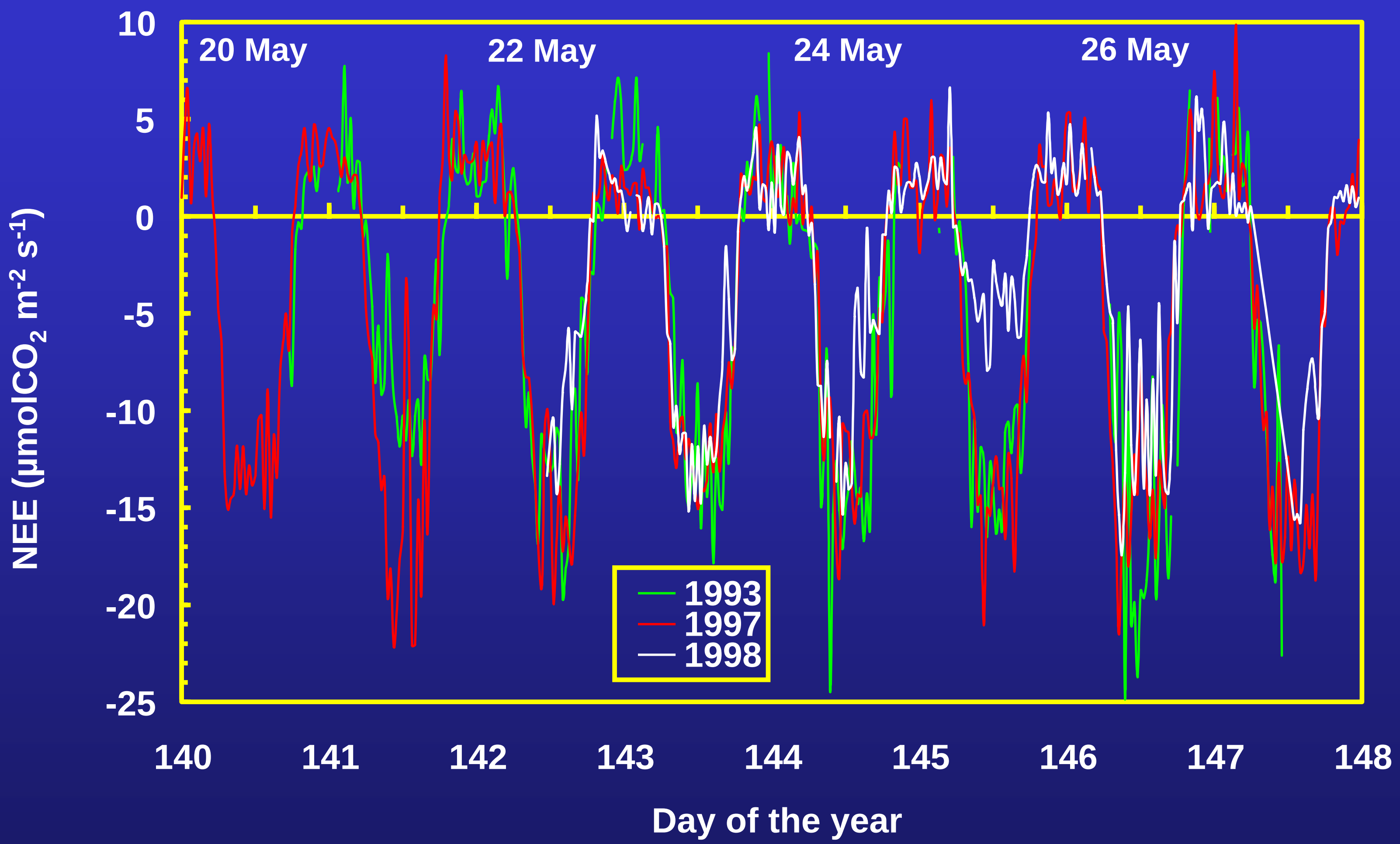
+ Measures whole ecosystem exchange of CO_2 and H_2O
+ Non-destructive & continuous
+ Time-scale hourly to interannual

- relies on turbulent conditions
- source area varying (flux footprint)
- only “point” measurements

Does not deliver compartment fluxes, but:

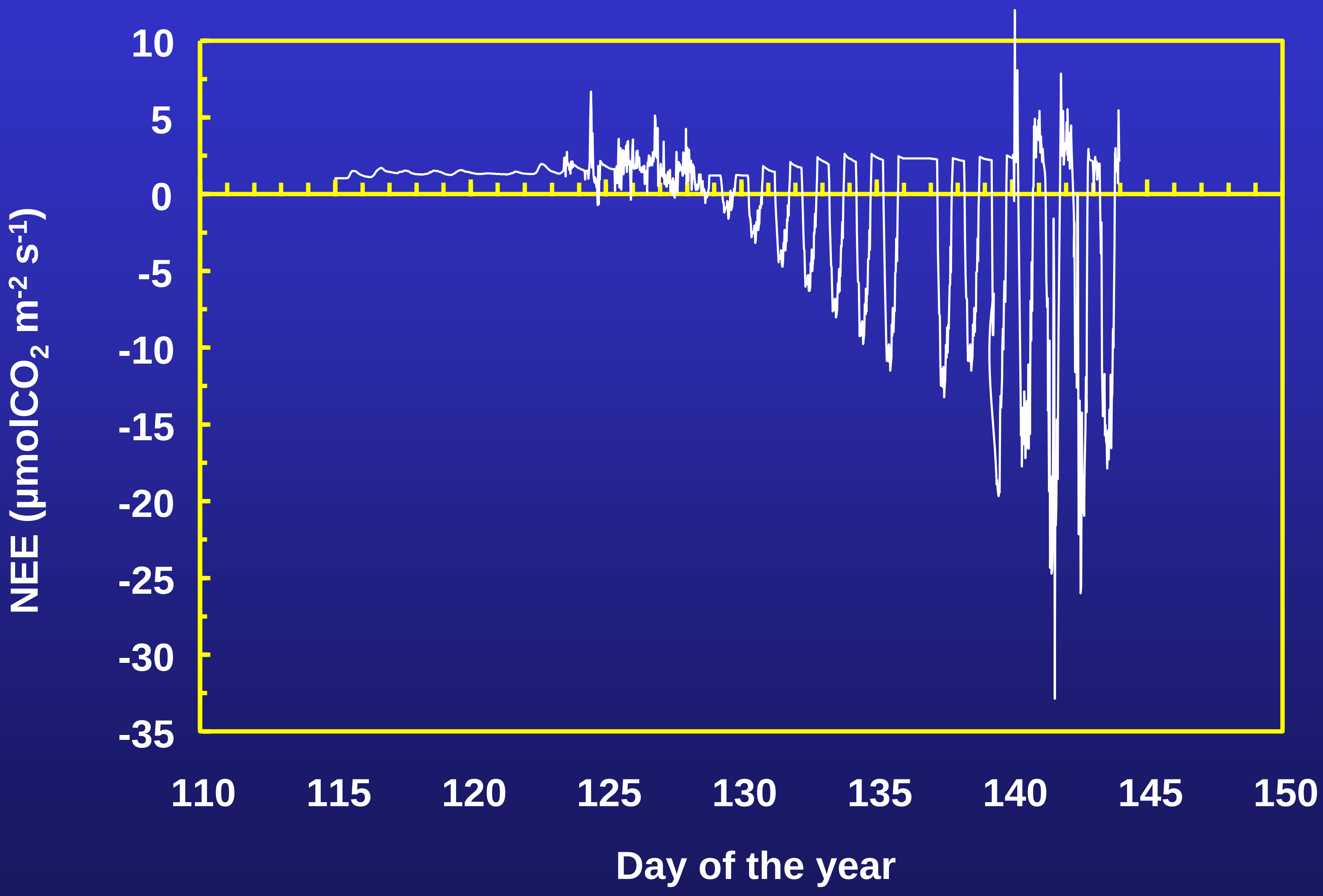
NEP = GPP - Reco

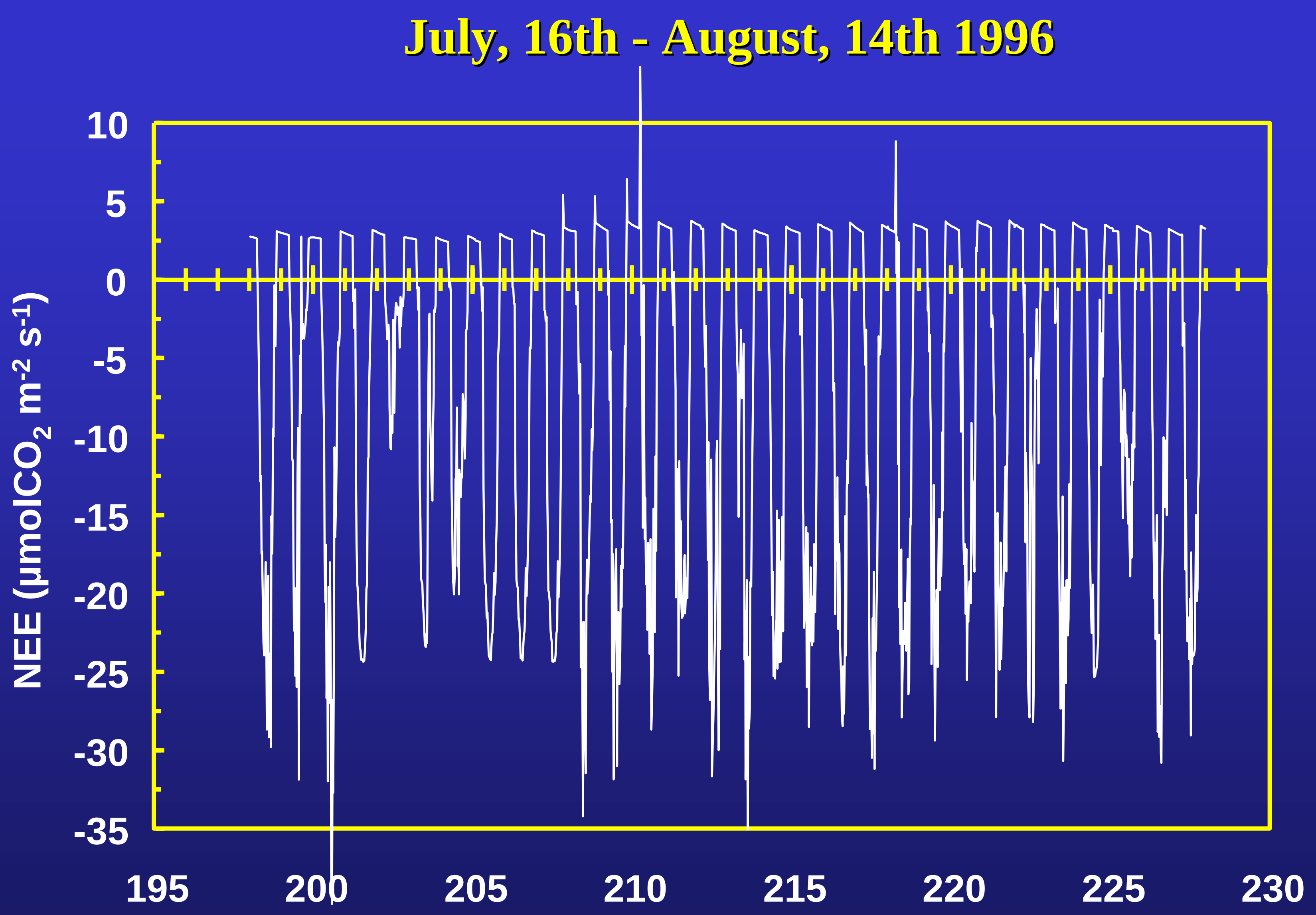




20 May
22 May
24 May
26 May
1993
1997
1998
10
5
0
-5
-10
-15
-20
-25
140
141
142
143
144
145
146
147
148
NEE (µmolCO2 m-2 s-1)
Day of the year

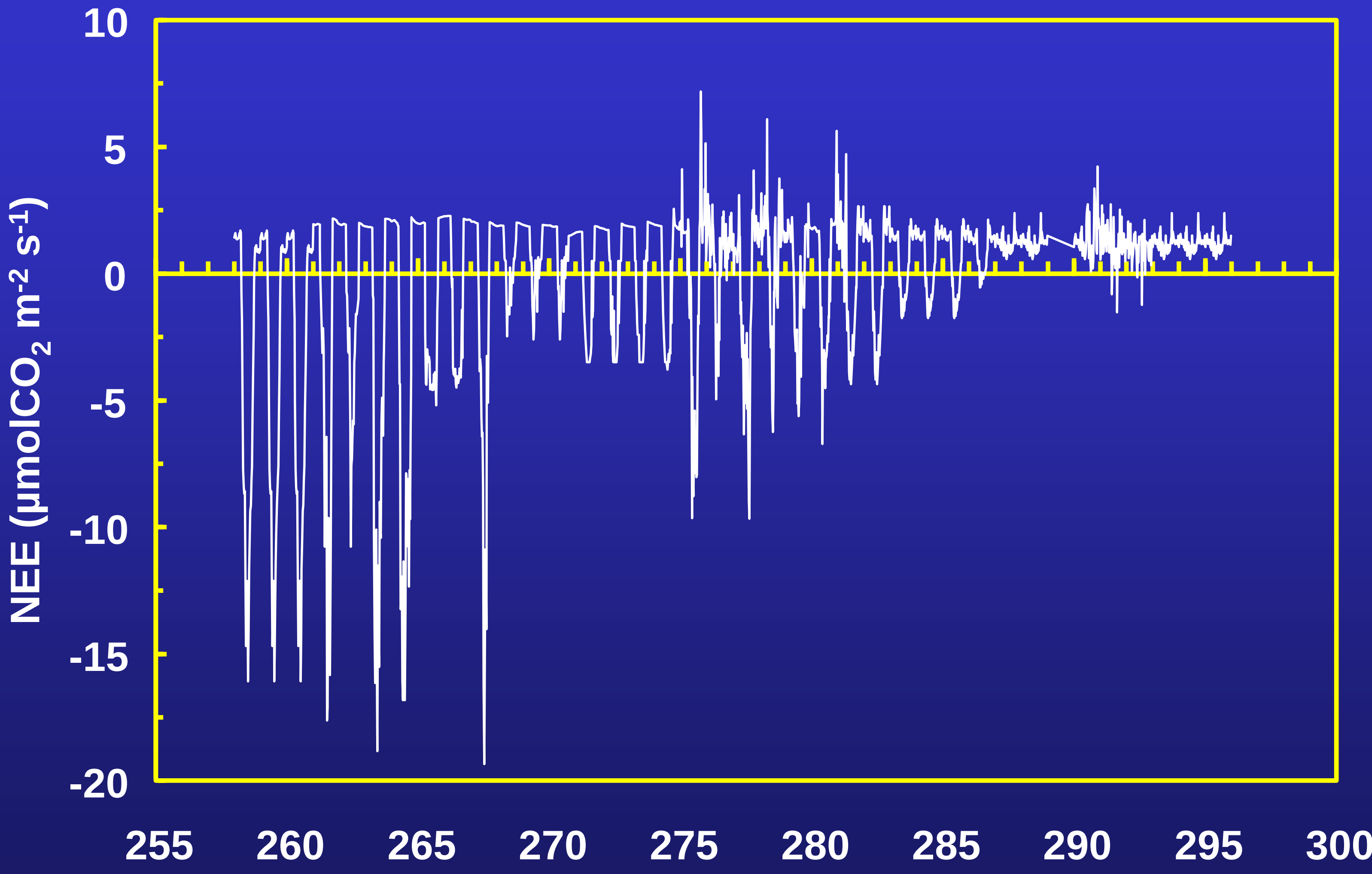
April, 25th - May, 23rd 1997



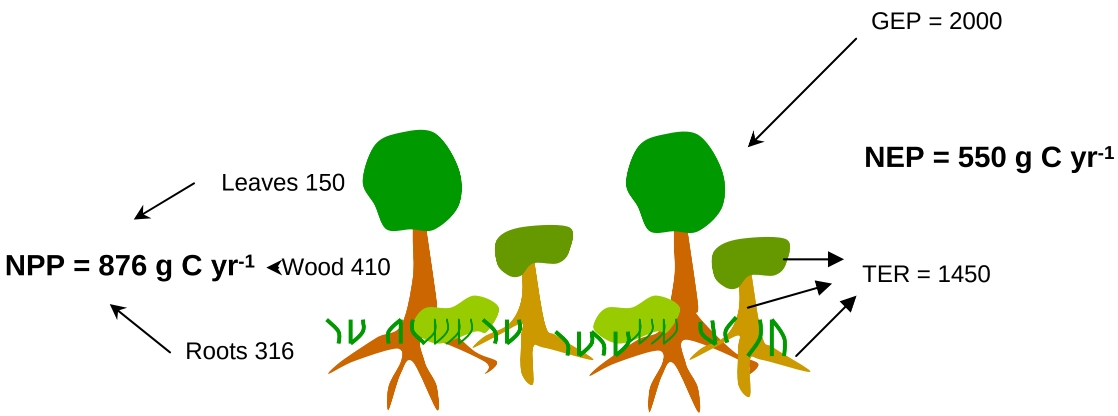


July, 16th - August, 14th 1996
NEE (µmolCO2 m-2 s-1)
10
5
0
-5
-10
-15
-20
-25
-30
-35
195
200
205
210
215
220
225
230
Day of the year

September, 14th - October, 21st 1996

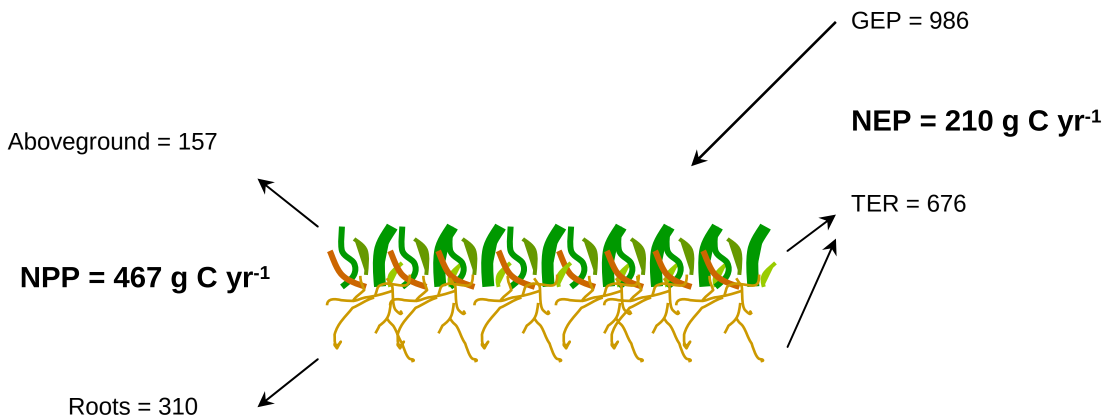


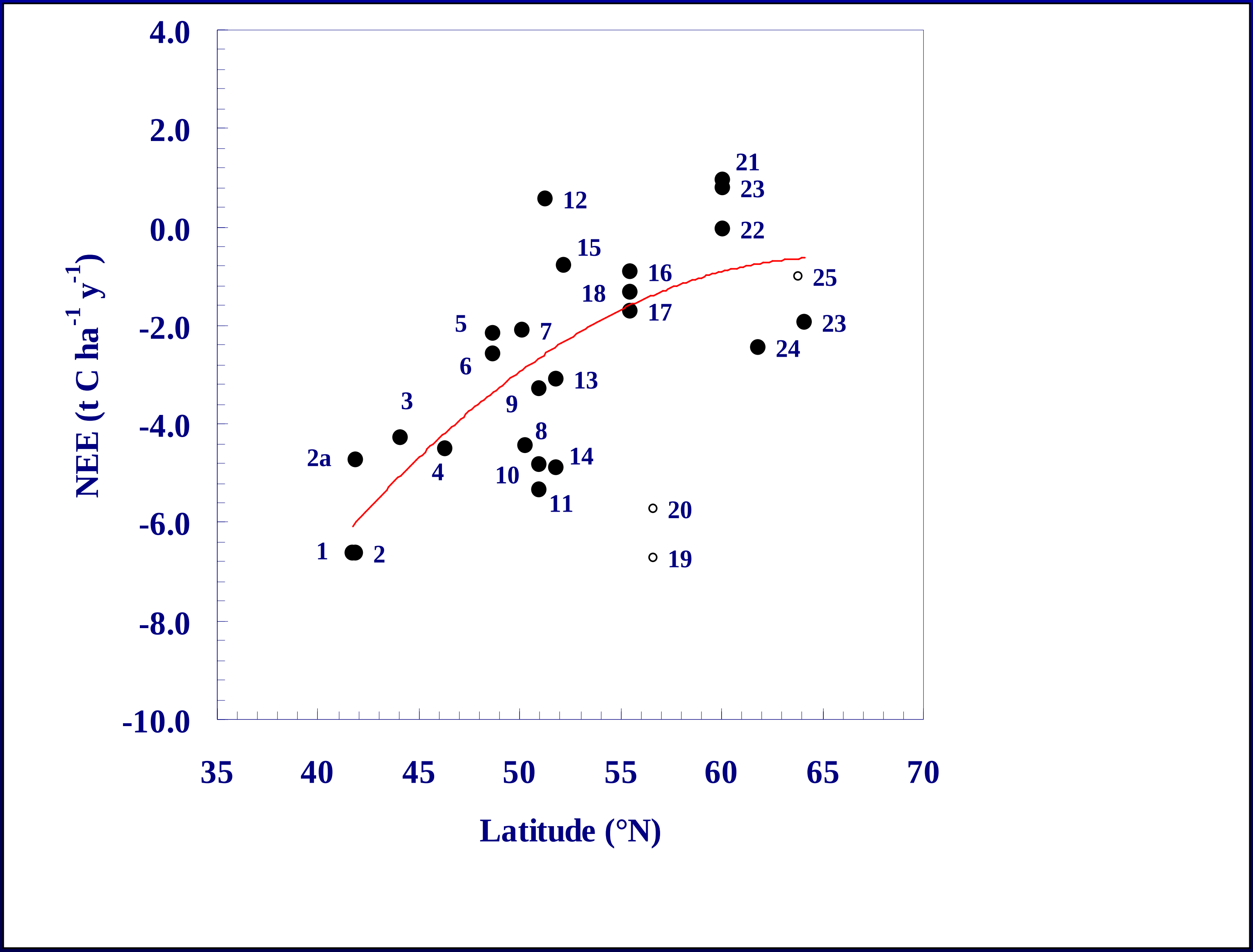
A) *Quercus ilex* forest



Hymus and Valentini 2006

B) Mountain Grassland



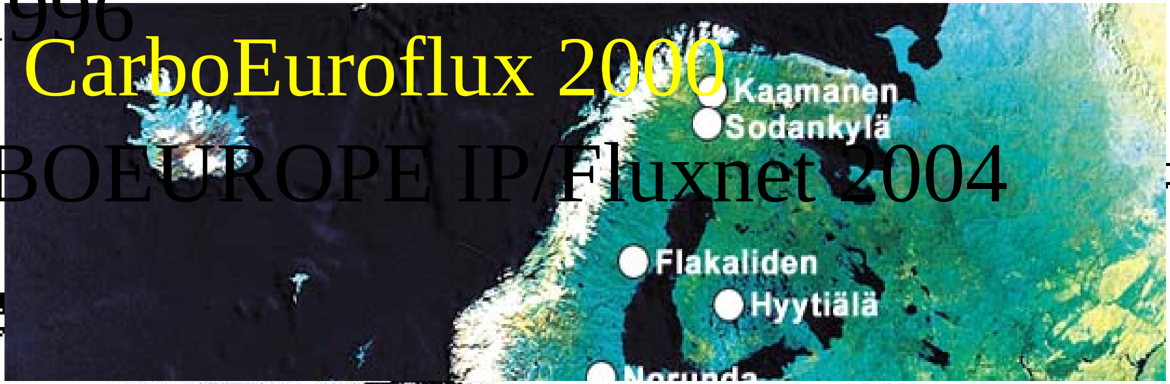


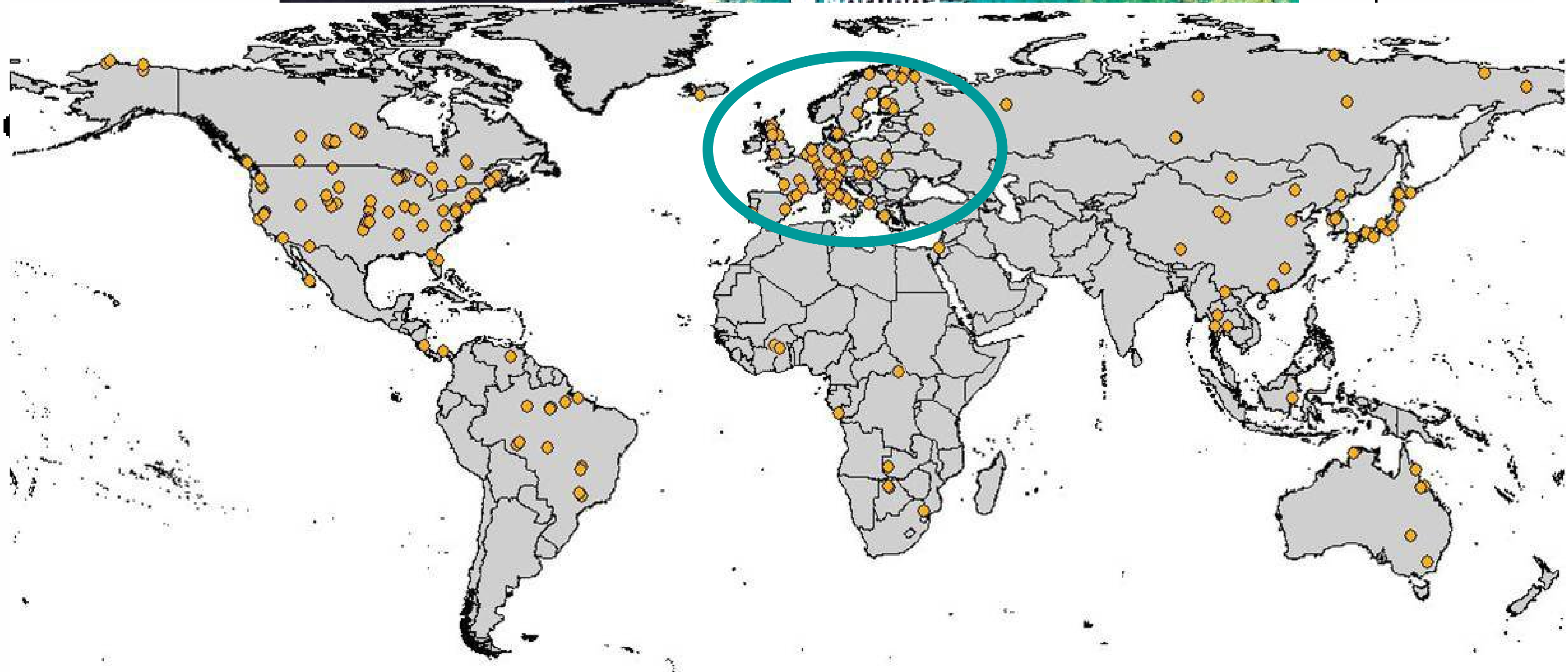
Valentini, Dolman, Matteucci et al. Nature 2000

Euroflux 1996

CarboEuroflux 2000

CARBOEUROPE IP/Fluxnet 2004

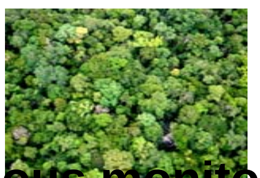




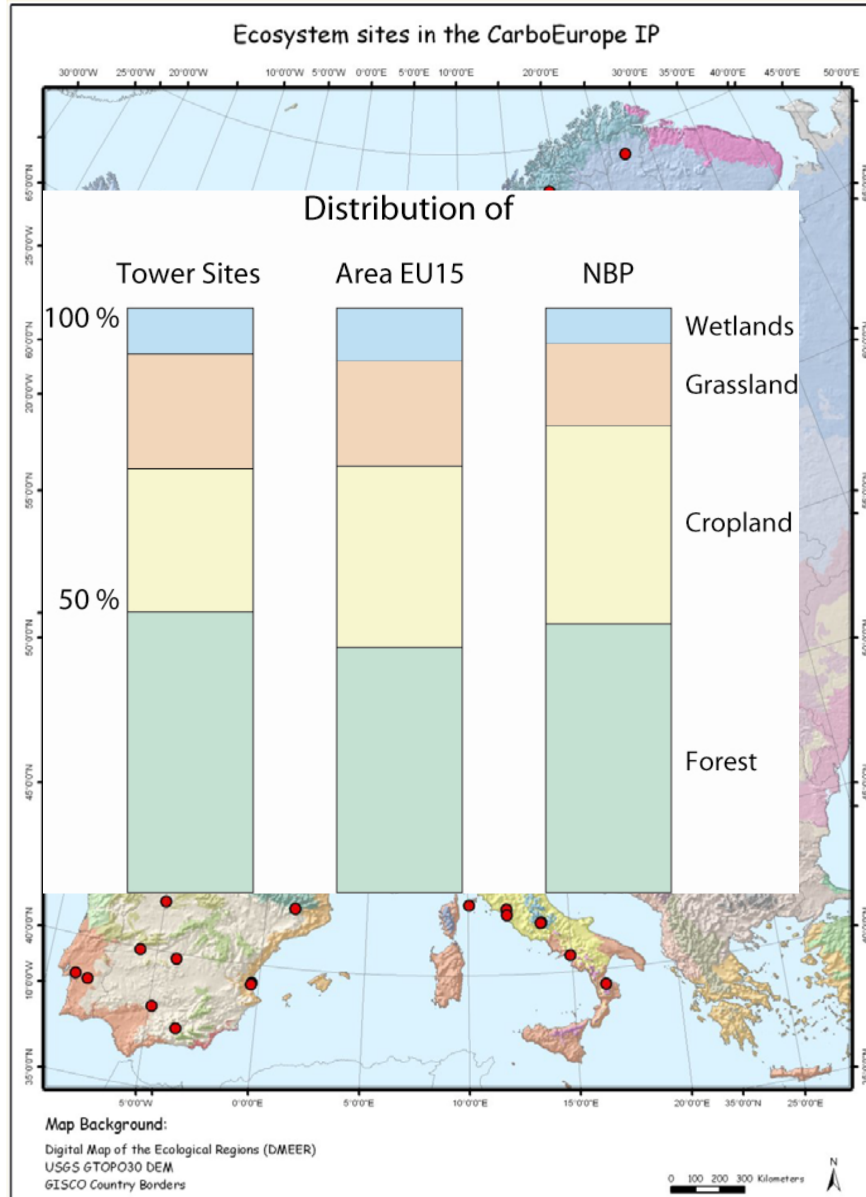
Current Eddy covariance network in Europe

16 Clusters of sites
(different land uses/covers)

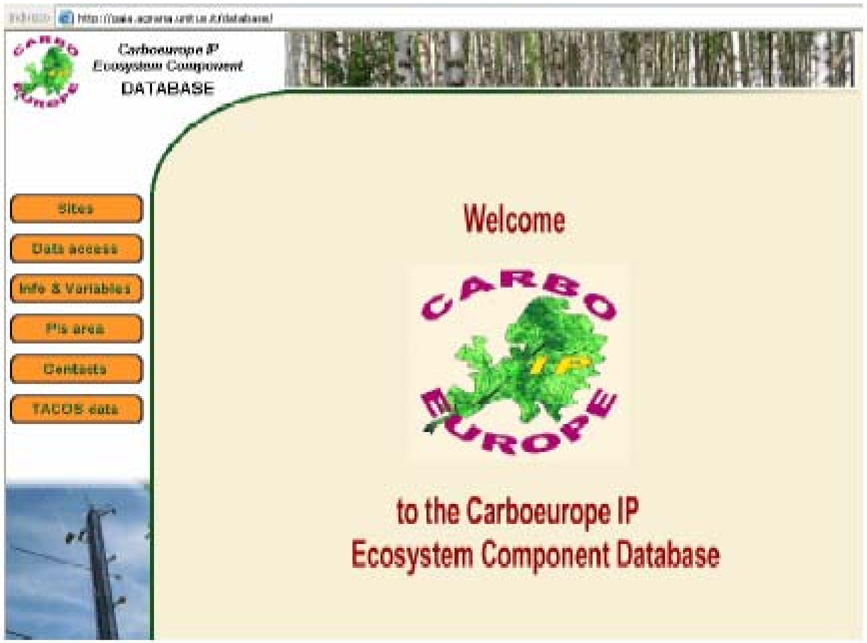
CarboEurope – IP
103 Eddy covariance sites
50 forests
28 grasslands
22 crops
3 others



Continuous monitoring
(51 sites for 5 years)

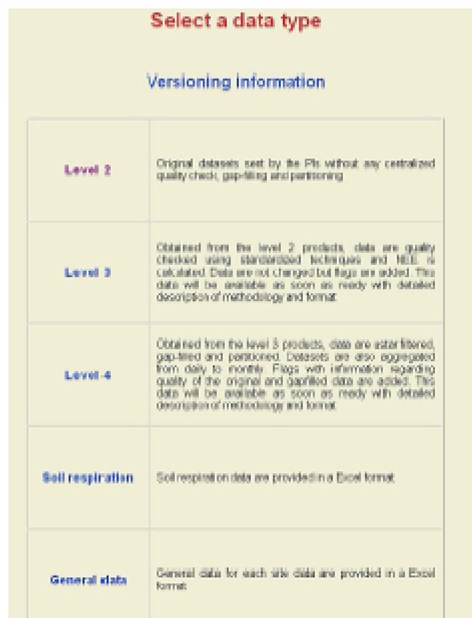


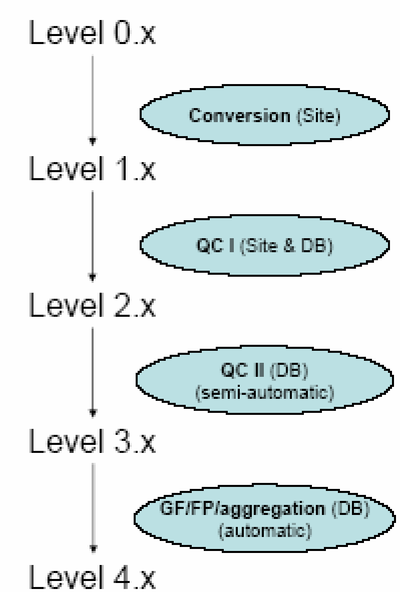
CARBOEUROPE ECOSYSTEM DATABASE



http://gaia.agraria.unitus.it/database

Data quality and standardization





New surprises coming from long term observations……

Temperature – Respiration relationship

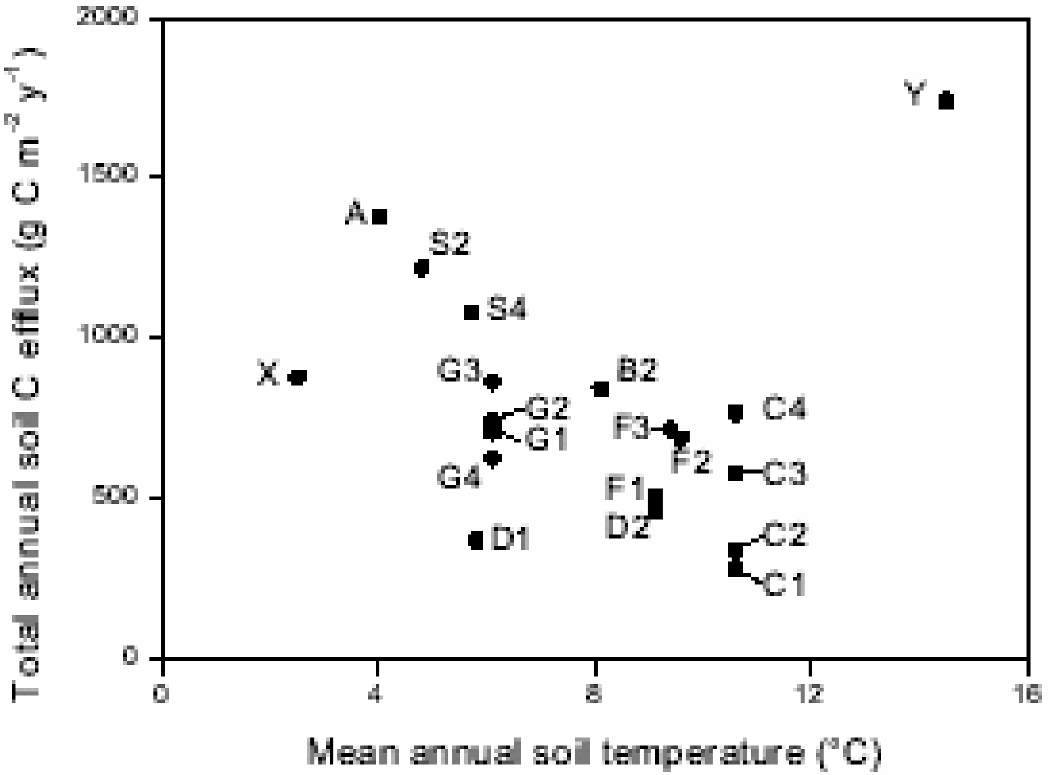
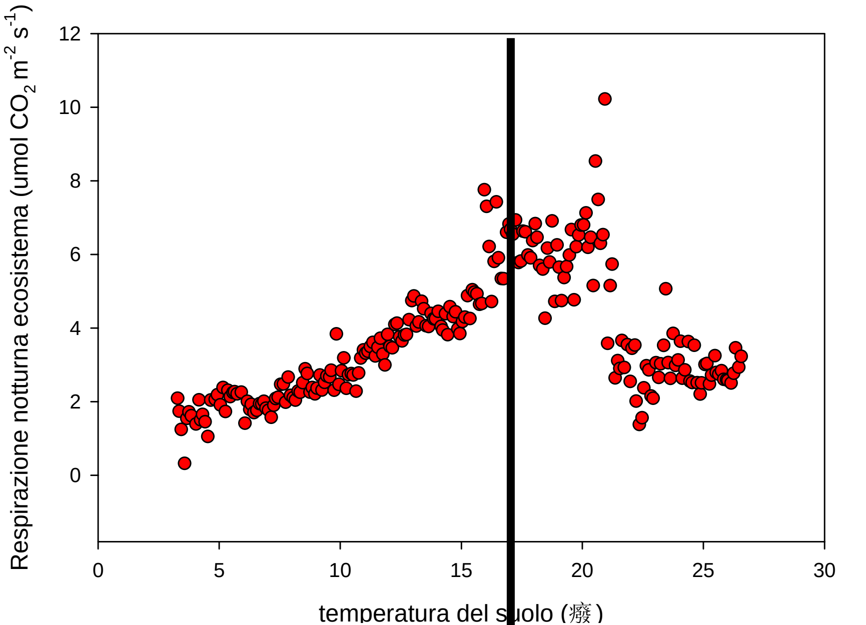
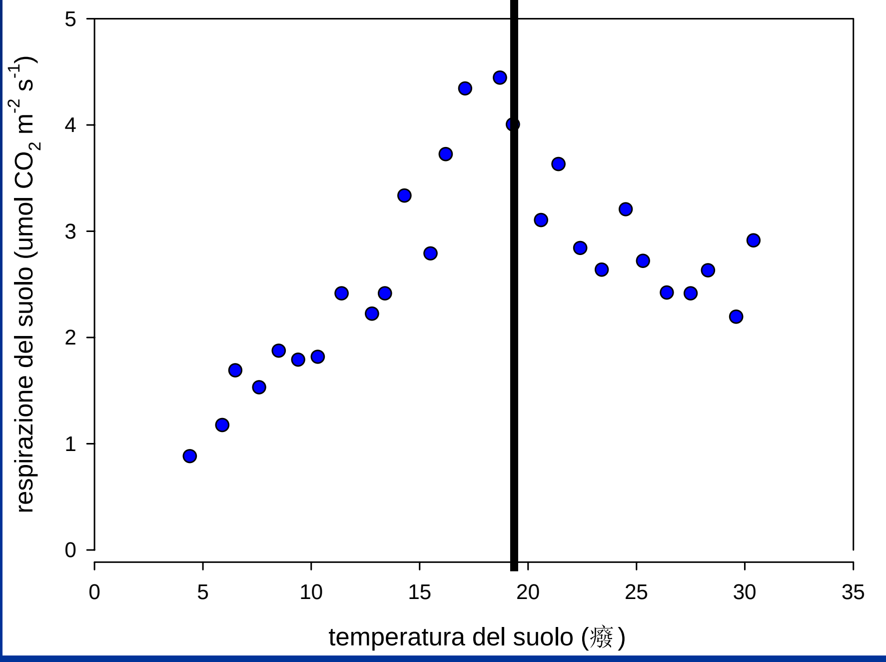


Fig. 12.6. Total annual soil CO_2 efflux versus mean annual soil temperature in the different EUROFLUX forests. Codes for different sites are explained in Table 12.5

Deciduous oak (Italy 05)



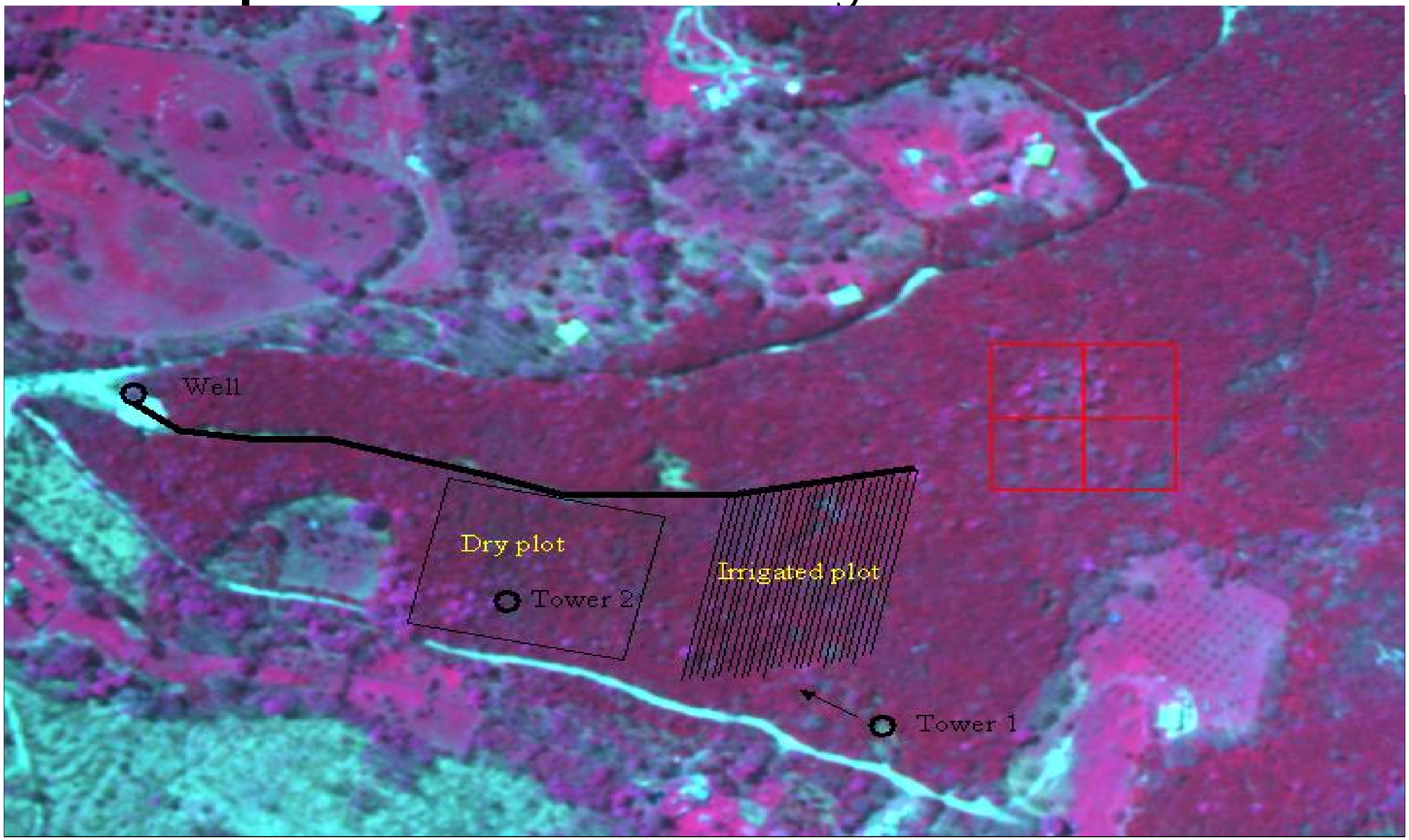
Night time respiration measured by eddy covariance as function of soil temperature

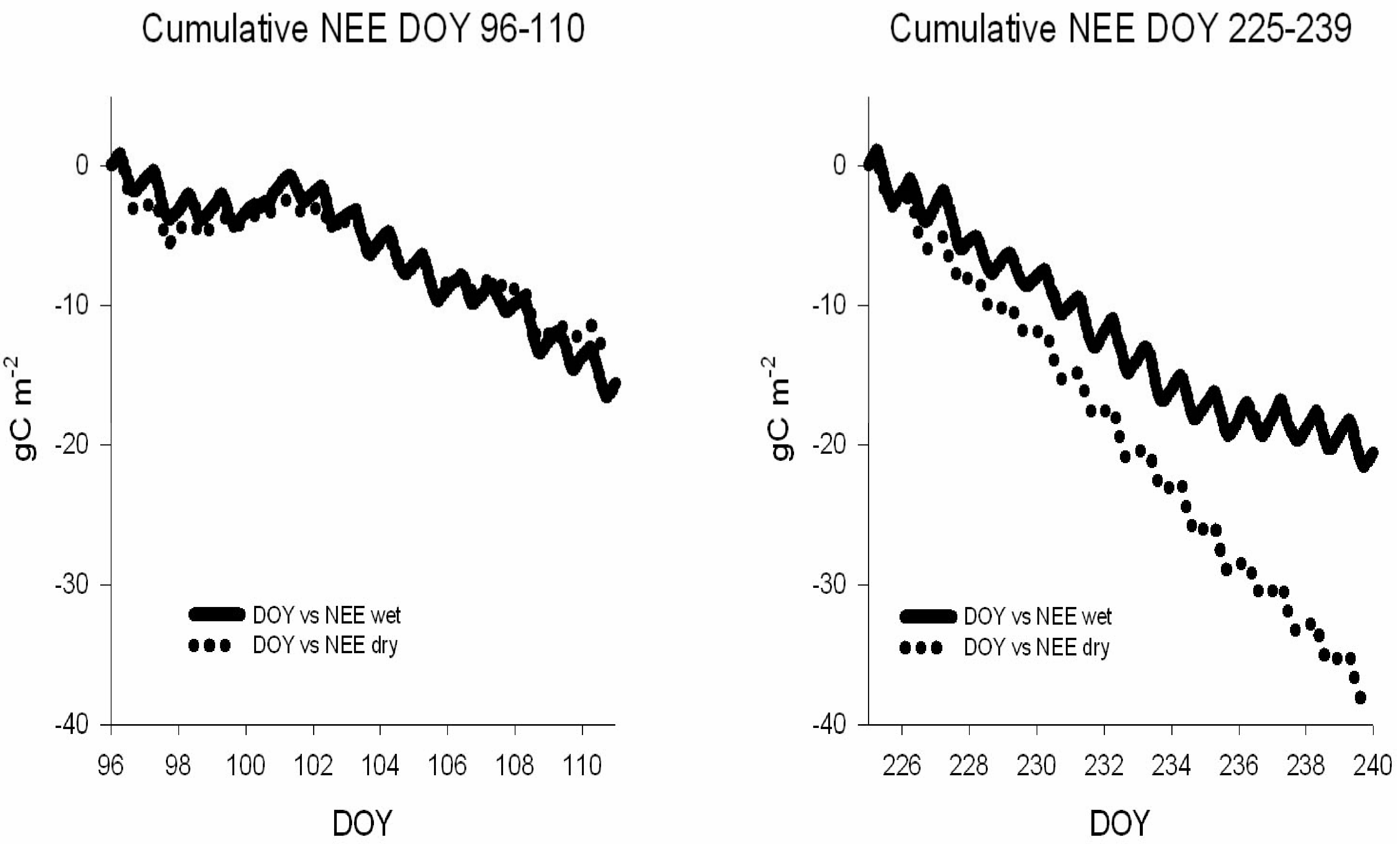


Soil respiration (EGM-2, PP Systems) as function of soil temperature

(Manca G. et al)

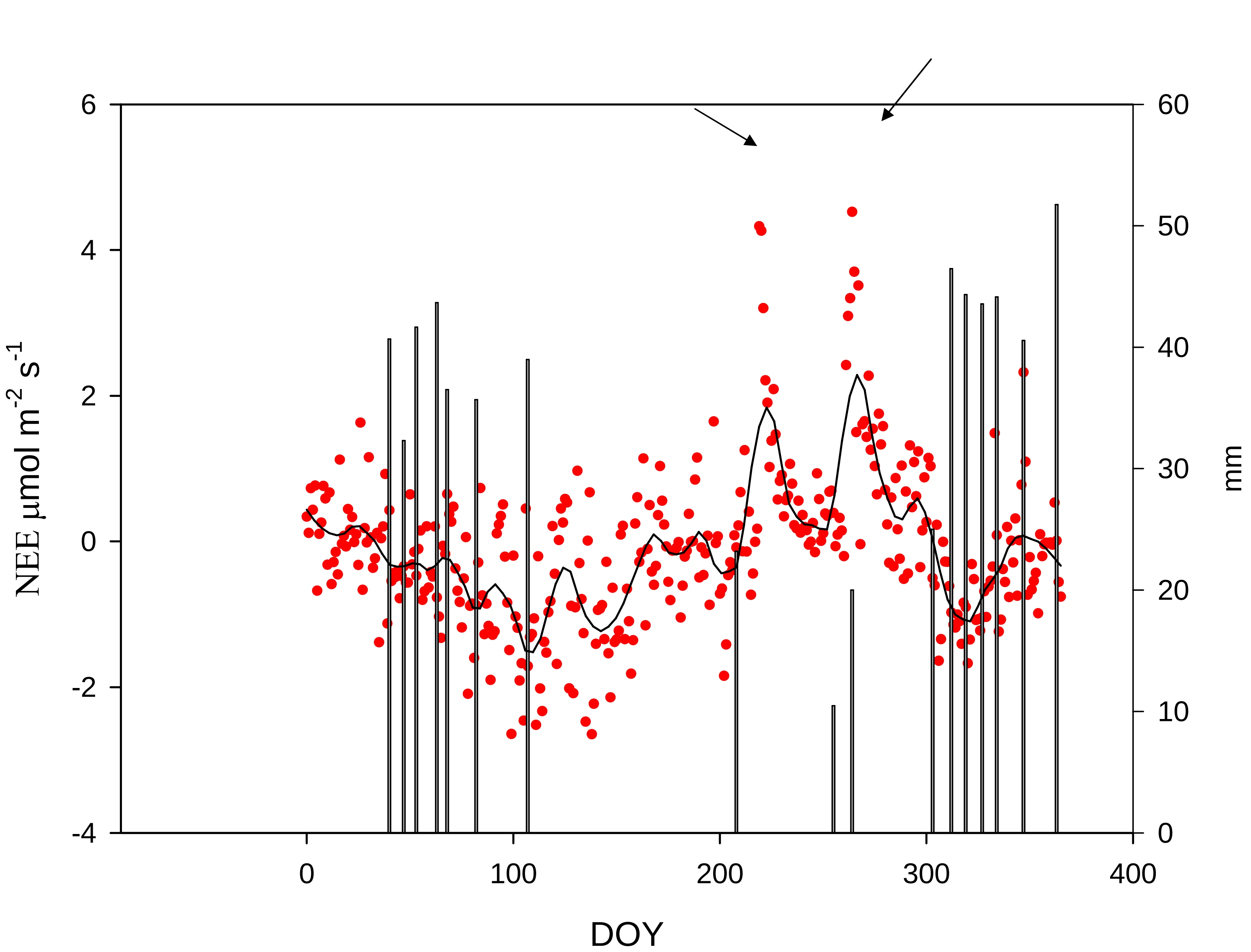
MIND – Water manipulation experiment at ecosystem scale





Cumulative NEE DOY 96-110
gC m-2
0
-10
-20
-30
-40
96
98
100
102
104
106
108
110
DOY
DOY vs NEE wet
DOY vs NEE dry
Cumulative NEE DOY 225-239
gC m-2
0
-10
-20
-30
-40
226
228
230
232
234
236
238
240
DOY
DOY vs NEE wet
DOY vs NEE dry

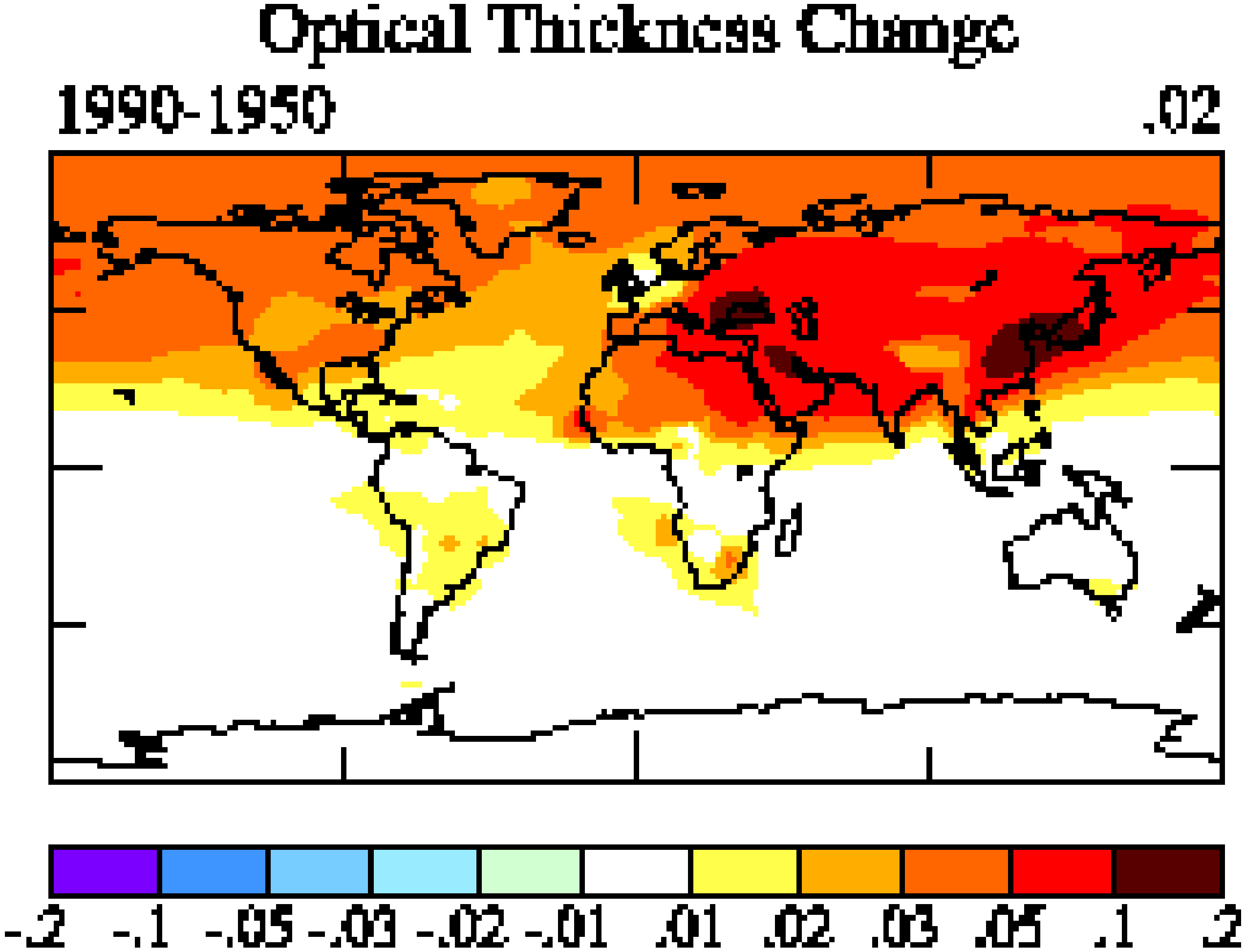
Rain pulses



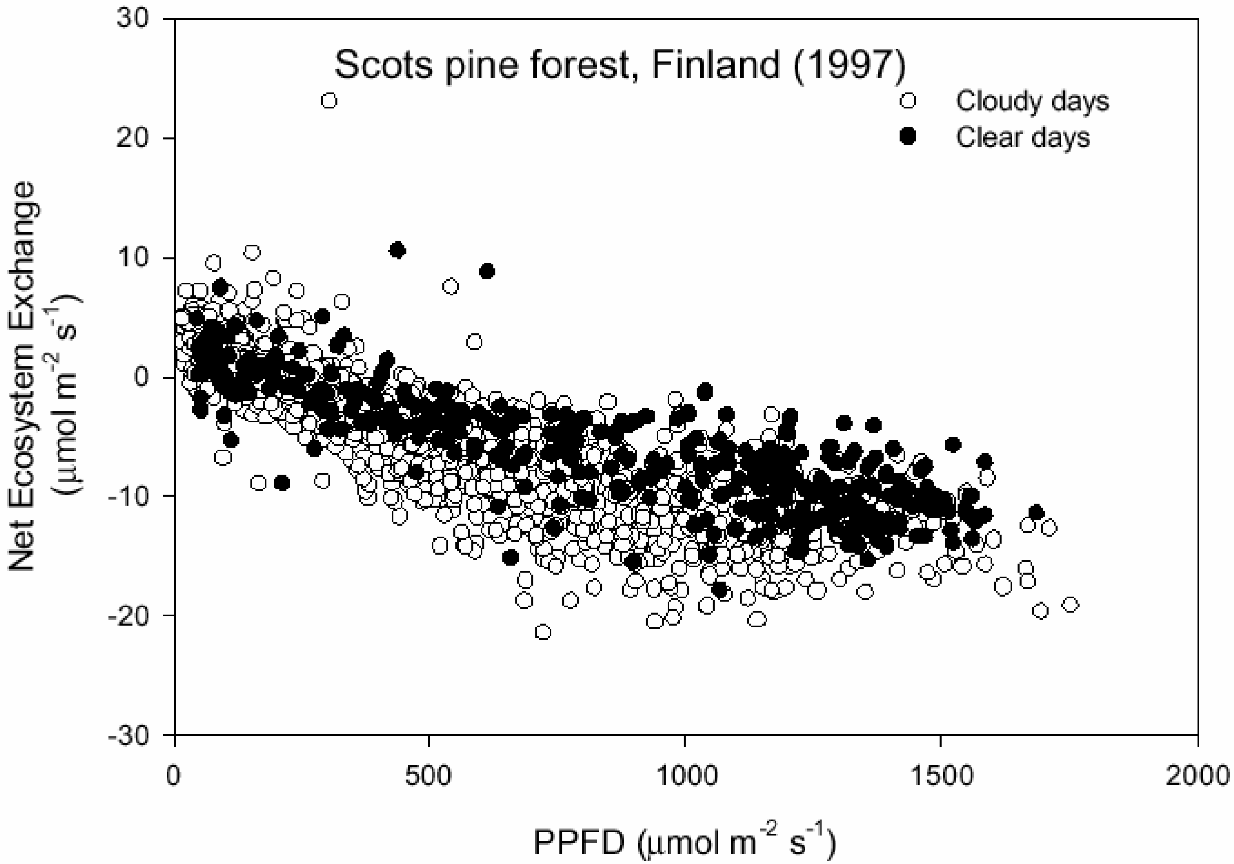
New surprises coming from long term observations……..

Diffuse light

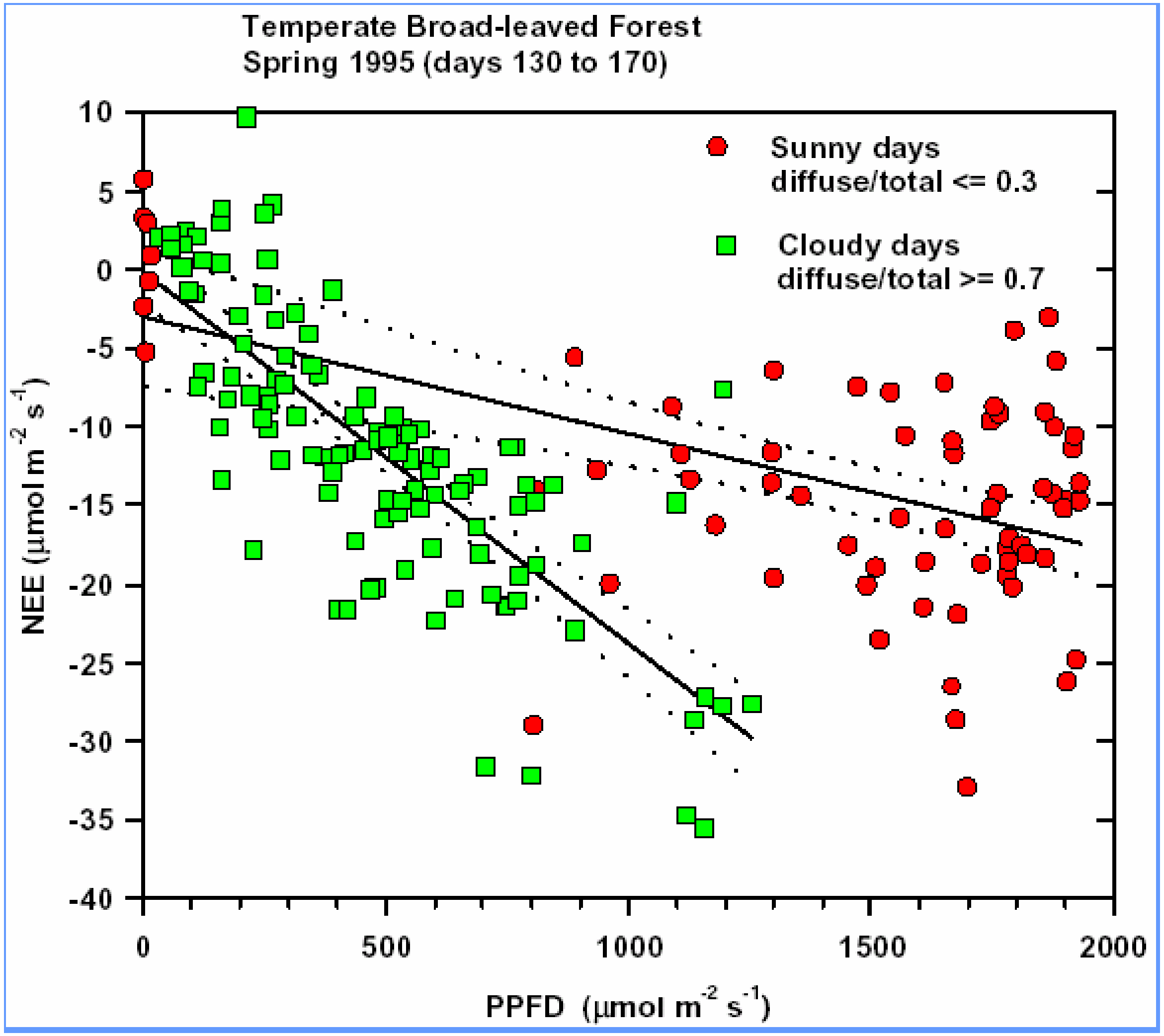
Changing Aerosols



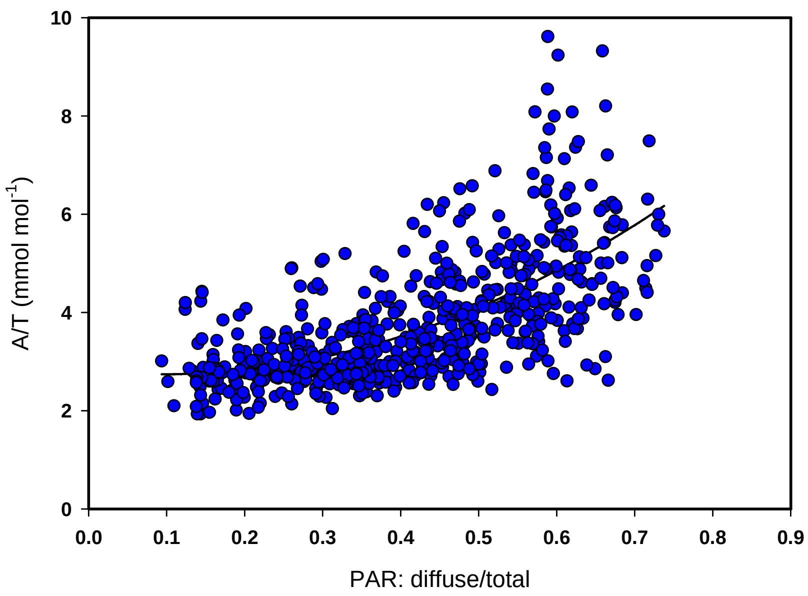
• http://www.giss.nasa.gov/data/si2000/trop.aer/



Scots pine forest, Finland (1997)
Cloudy days
Clear days
Net Ecosystem Exchange (μmol m-2 s-1)
PPFD (μmol m-2 s-1)
30
20
10
0
-10
-20
-30
0
500
1000
1500
2000


Temperate Broad-leaved Forest
Spring 1995 (days 130 to 170)
Sunny days
diffuse/total <= 0.3
Cloudy days
diffuse/total >= 0.7
NEE (µmol m^{-2} s^{-1})
PPFD (µmol m^{-2} s^{-1})
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
500
1000
1500
2000

Water use efficiency



MOD17+ - Remote sensing driven model

Absorbed Photosynthetically Active Radiation

Radiation Use Efficiency

GPP = APAR * ε

GPP = *(Rnet*0.45*Fpar)* * *{ε_{max}* [m_{Tmin}] [m_{vpd}] }*

Mod15
(remote sensing)

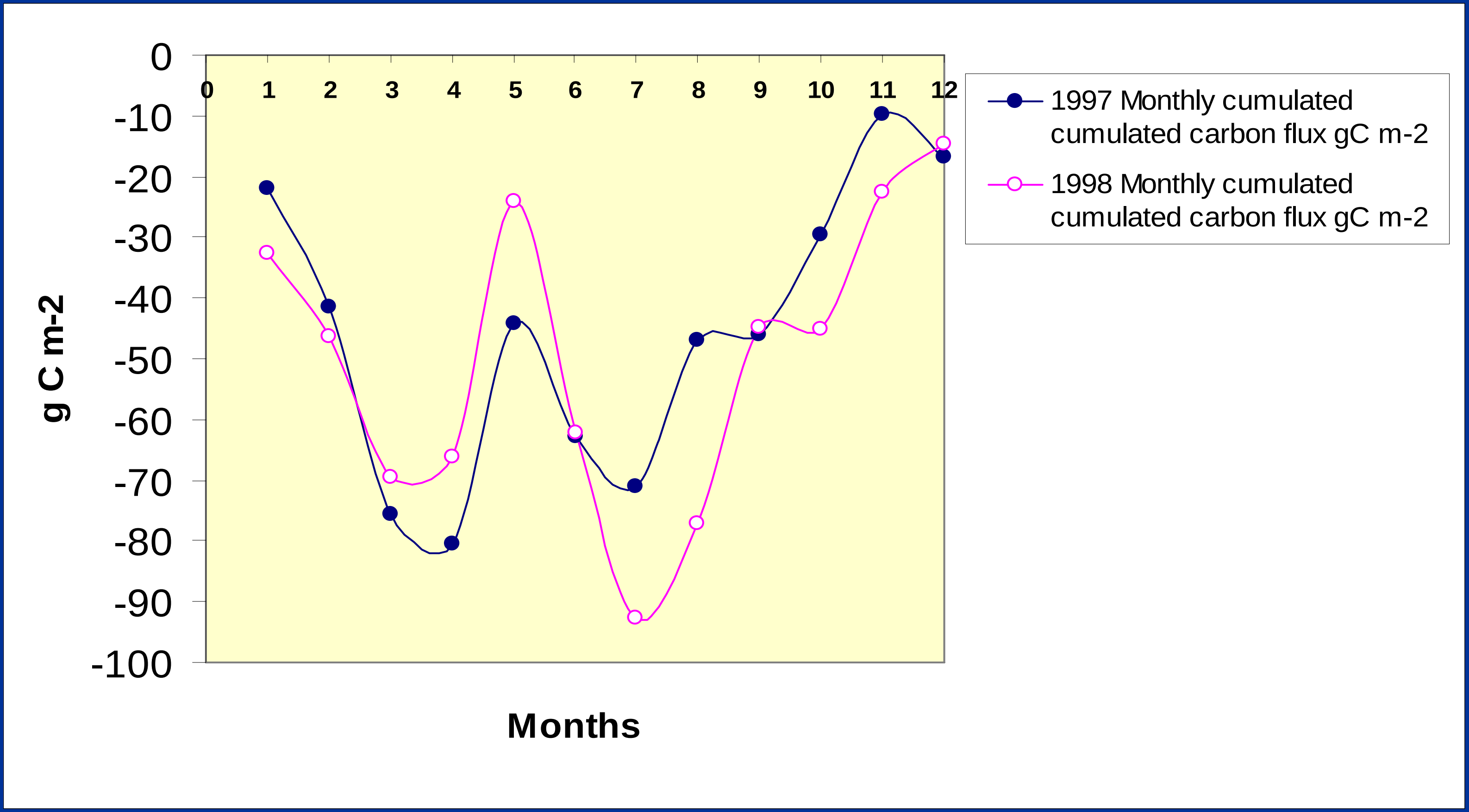
NEP= GPP – Reco

$$R_{eco} = \left[R_0 + \left(1 - e^{-k_1 \cdot LAI_{\max}}\right) \cdot R_1 + \left(1 - e^{k_2 \cdot GPP}\right) \cdot R_2\right] \cdot e^{E0 \cdot \left(\frac{1}{Tref - T0} - \frac{1}{T - T0}\right)} \cdot \frac{P + P_0}{k + P + P_0}$$

New surprises coming from long term observations……

Phenology

Phenology switches



Q. ilex forest stand, Italy

1997 = 547 g C m-2

1998 = 569 g C m-2

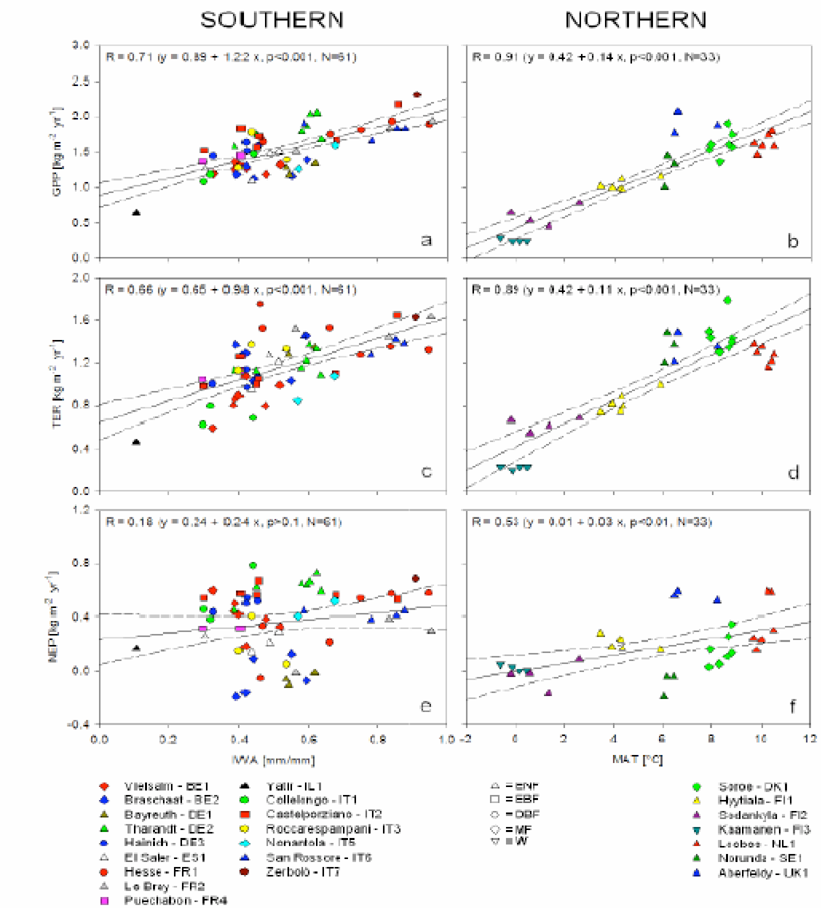
New surprises coming from long term observations……

Respiration and Photosynthesis behaviour

What are the controlling driving forces of biospheric fluxes ?

Photosynthesis is temperature driven in northern European ecosystems and water limited in southern European ecosystems

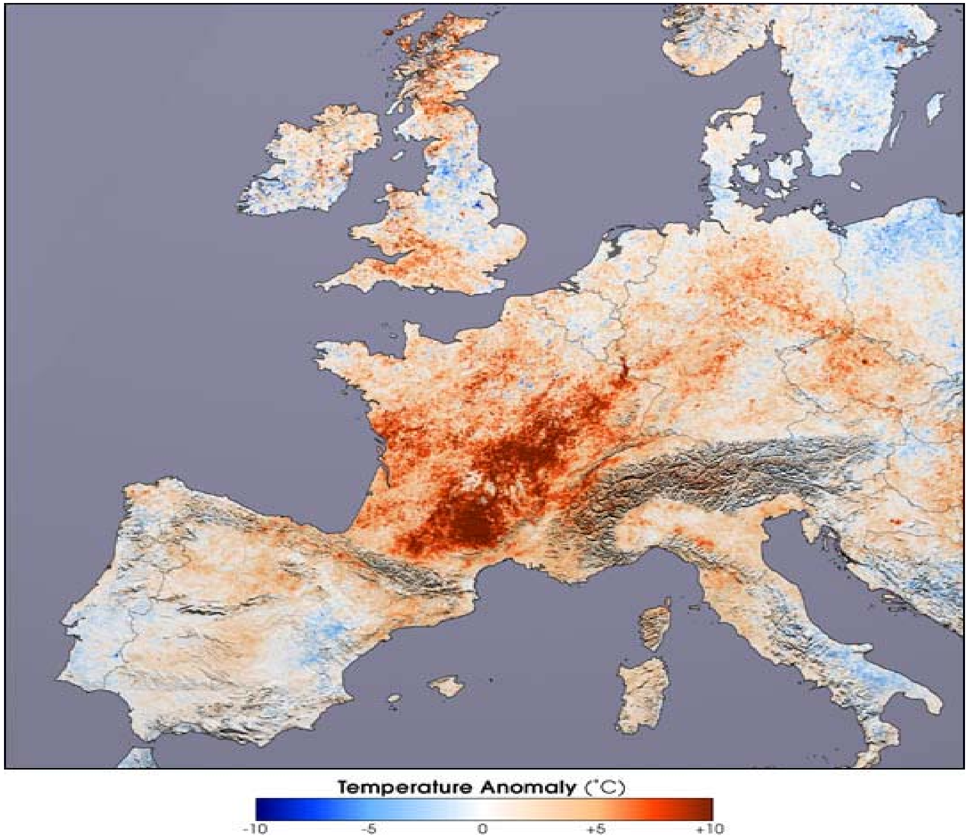
However terrestrial carbon uptake is weakly coupled with mean climate



Reichstein, Valentini, Papale GRL 2006

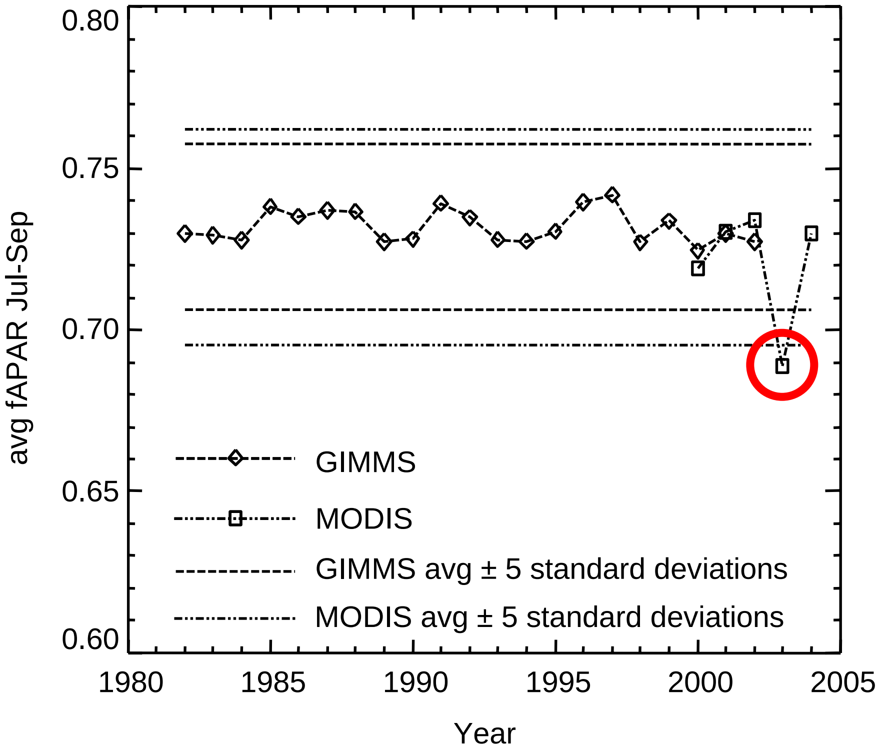
An example of long term observations carbon and its vulnerability: the Heat wave 2003

Temperature Anomaly July 2003/July 2002



Ciais et al. Nature 2005

Reichstein et al. Global Change Biology 2006



Heat Wave 2003
Amplero - Mountain grassland Italy

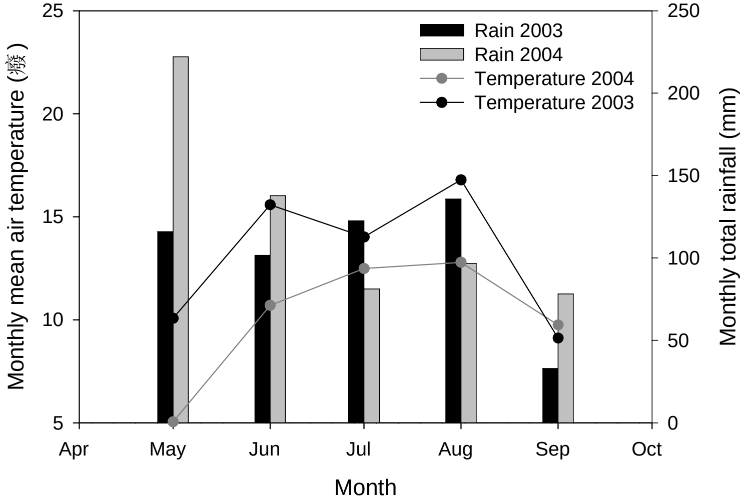
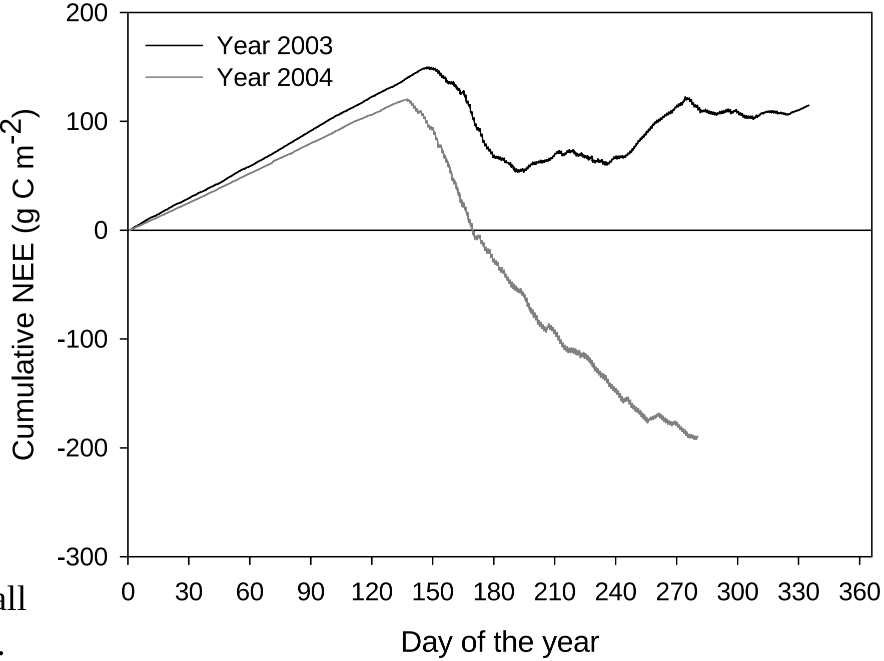
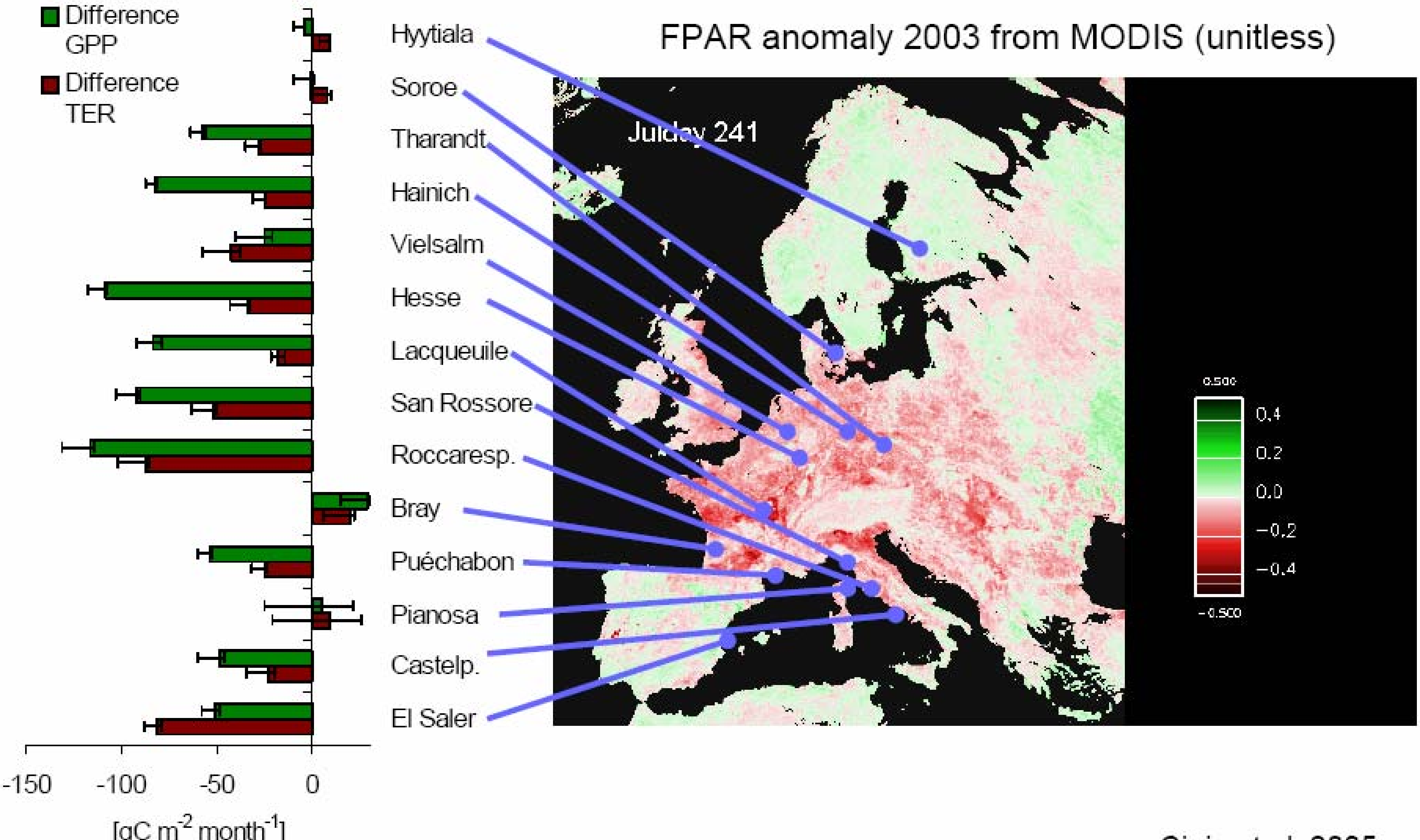


Figure 5. Malga Arpaco mean air temperature and total rainfall for periods May - September 2003 and May - September 2004.

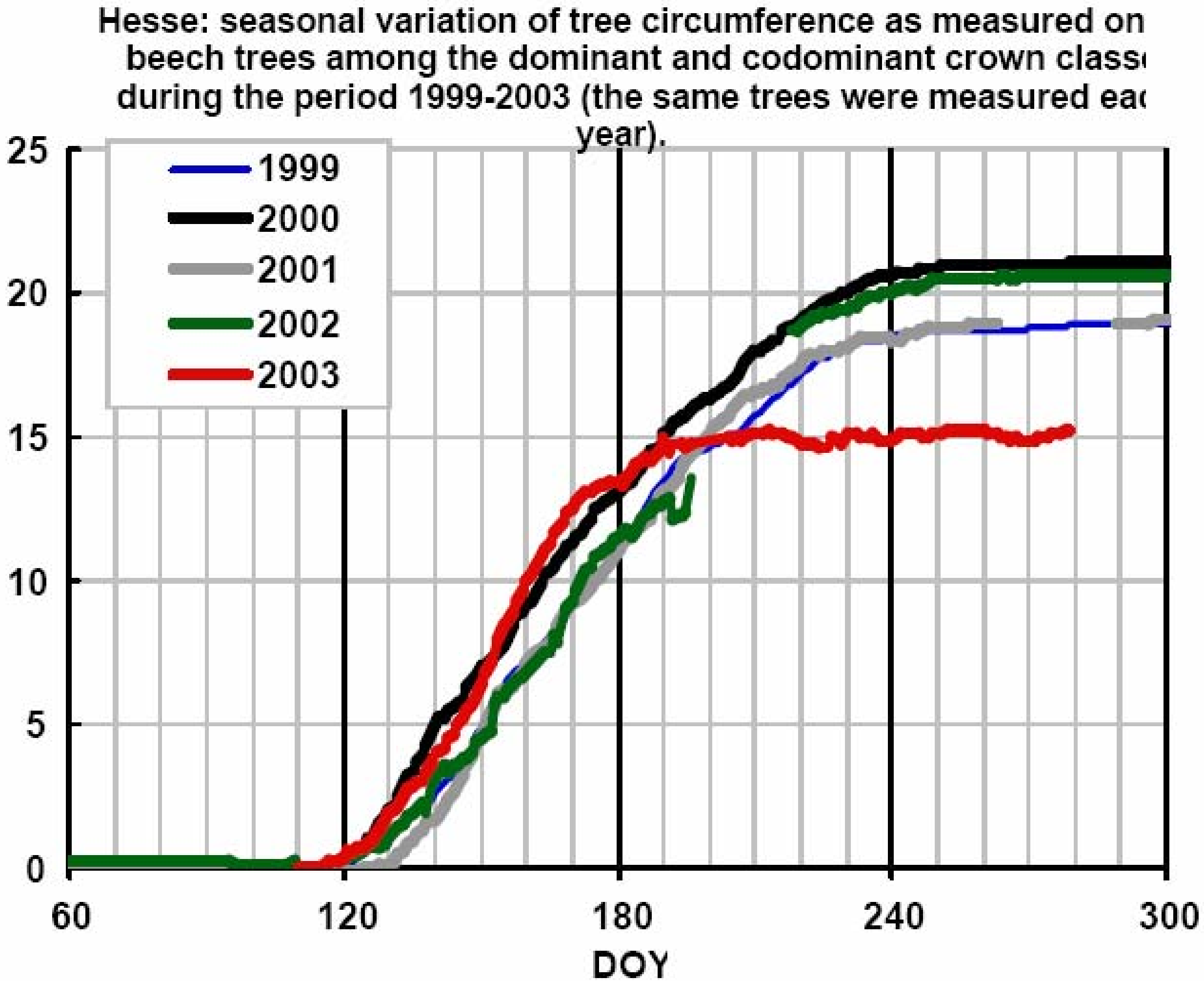


2003-2002 interannual variability



Ciais et al. 2005

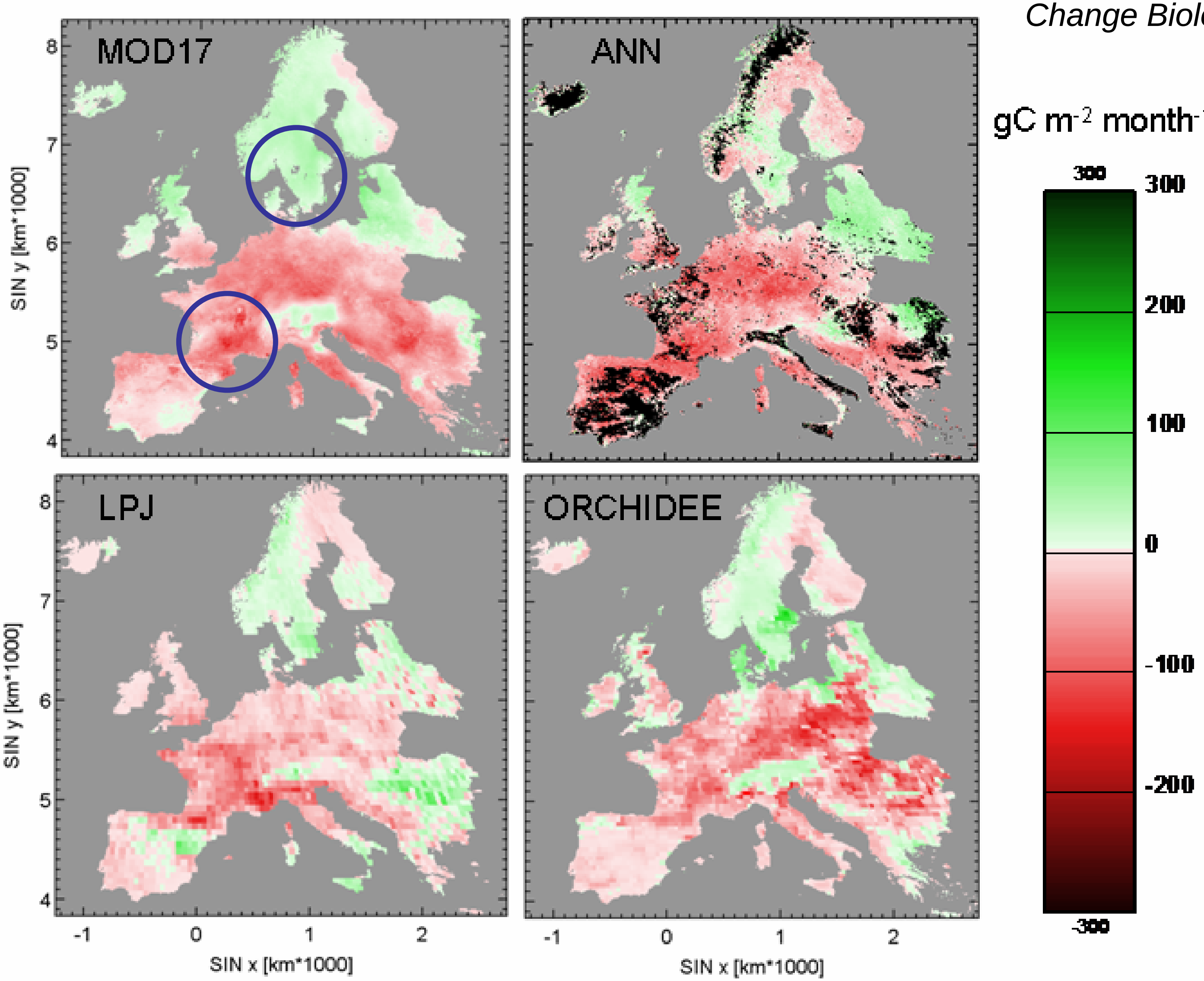
Independent tree ring verification

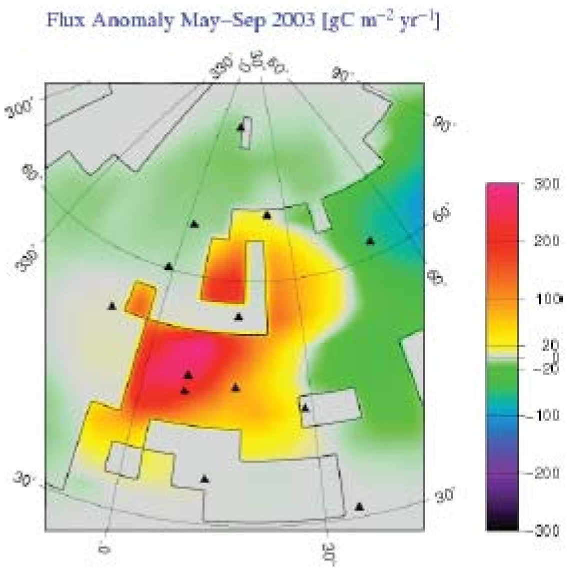


A. Granier et al. submitted

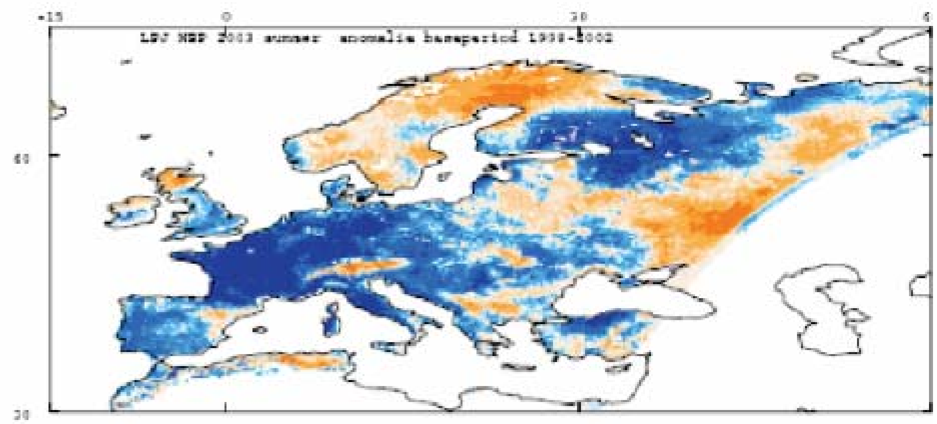
GPP anomaly July-September 2003 *vs* 2000-2002

Reichstein et al. Global Change Biology 2006





INV-BGC



LPJ

Blue color: source to atmosphere!

An example of long term observations carbon and its vulnerability: disturbances (storms, fires, humans..)

Extreme climate events or disturbances have a strong effect on biosphere-astmosphere exchanges

Annual mean 1850-2000: 35 M m3 of forest wood damaged by natural disturbances in Europe.

53% wind throw
16% fire
16% biotic (insects)
3% snow
5% other abiotic

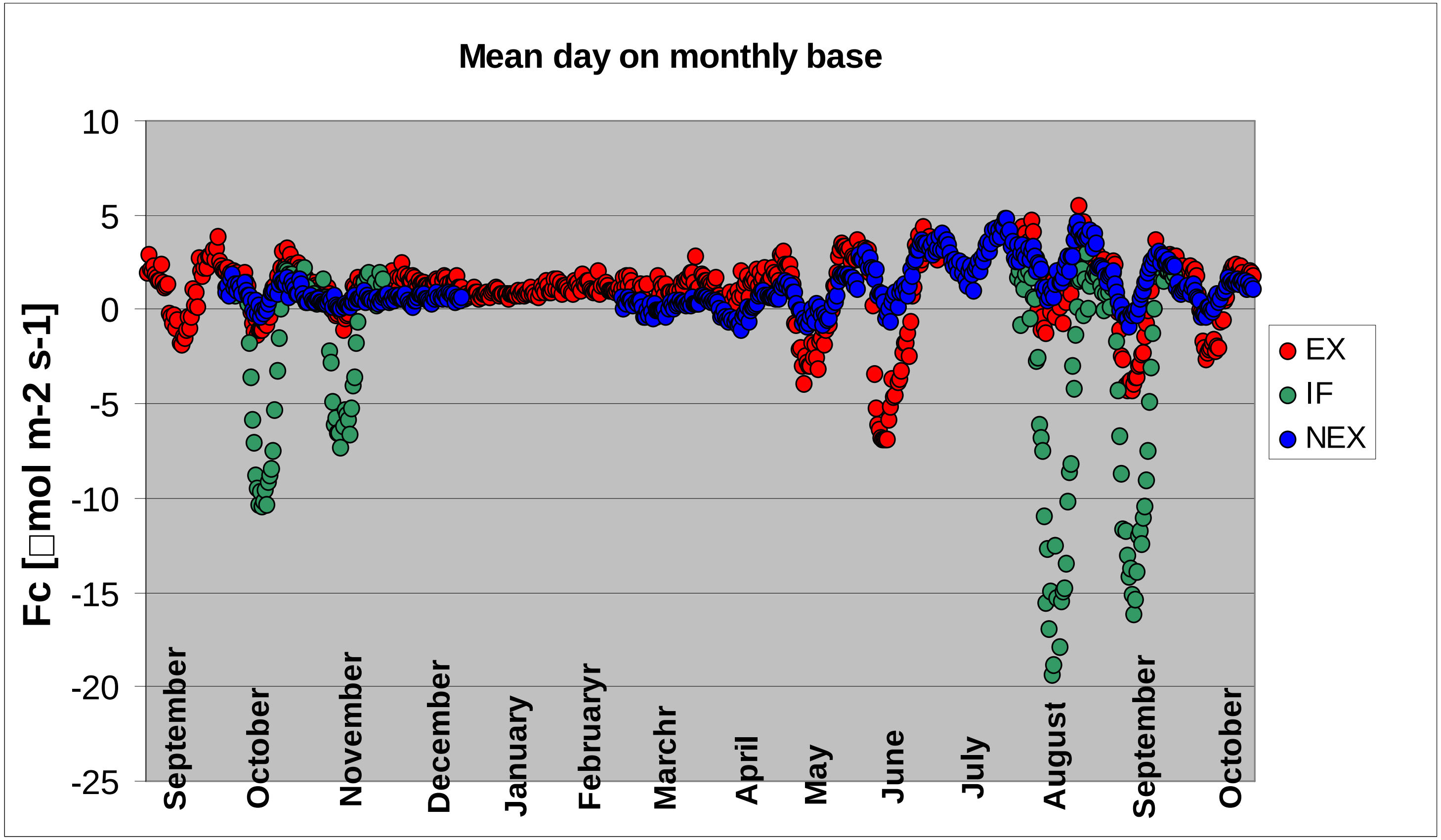
Tatra Experiment CarboEurope

Wind Storm Experiment Tatra Mountains

EX: all logs and snags removed

NEX: no post-disturbance management

IF: standing forest not affected by wind throw



Human impacts on land carbon

Deforestation and Kyoto Protocol

Table 1. Carbon emissions from fossil fuel, tropical deforestation, forest fires (Brazil and Indonesia), fires and emission reductions targeted by the Kyoto Protocol.

Tropical Land Use Change: **0.8±0.2** *to* **2.2±0.8** *PgC yr*$^{-1}$

Kyoto Target: **0.5** *PgC yr*$^{-1}$

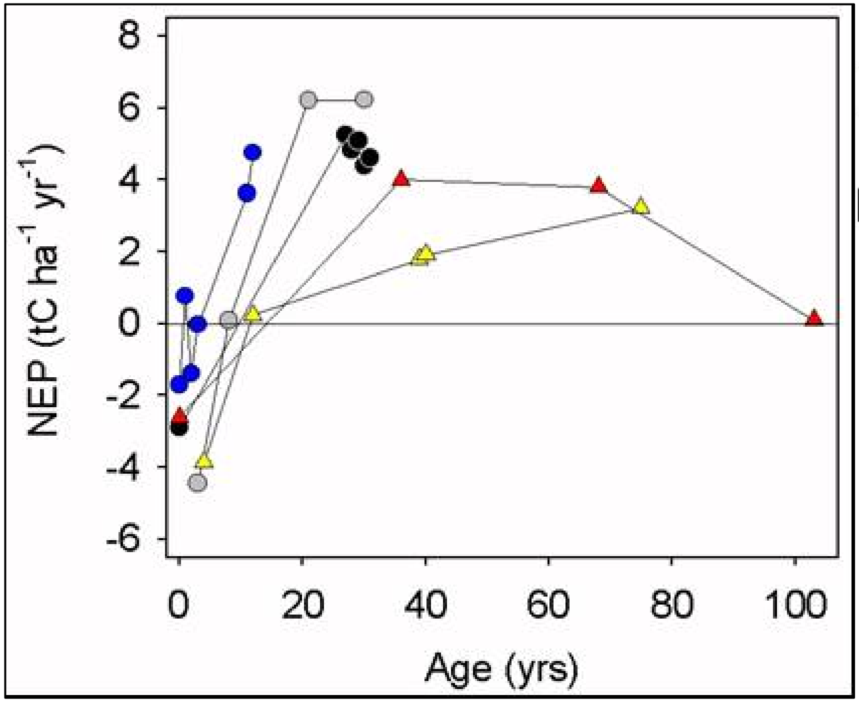
Brazil	Fossil Fuel	0.09	*
[illegible]	[illegible]	0.2 ± 0.2	Houghton et al. 2000
	…98)	0.2 ± 0.2	Mendonça et al., 2004
	Forest Fire (Non El Niño year - 1995)	0.02 ± 0.02	Mendonça et al., 2004
Indonesia	Fossil Fuel	0.09	**
	Deforestation	0.2 ± 0.2	Siegert et al., 2001; Holmes 2000; Pinard and Cropper 2000
	Forest Fire (El Niño year – 1997/8)	0.4 ± 0.5	Page et al., 2002
	Peat Fire (El Niño year – 1997/8)	0.2 ± 0.2	Houghton et al., 2001
Global	Fossil Fuel	6.3 ± 0.4	Prentice et al., 2001; Marland, et al., 2003
Tropical	Land Use Change	(0.8 ± 0.2) to (2.2 ± 0.8)	Houghton, 2003; Clini et al., 2003; Achard et al. 2002
Global	Fire (El Niño year – 1997/8)	2.1 ± 0.8	van der Werf et al., 2004
Kyoto Target		0.5	***

** Indonesia Country Analysis Brief (Energy Information Administration, EIA; http://www.eia.doe.gov/cabs/indonesia.html).

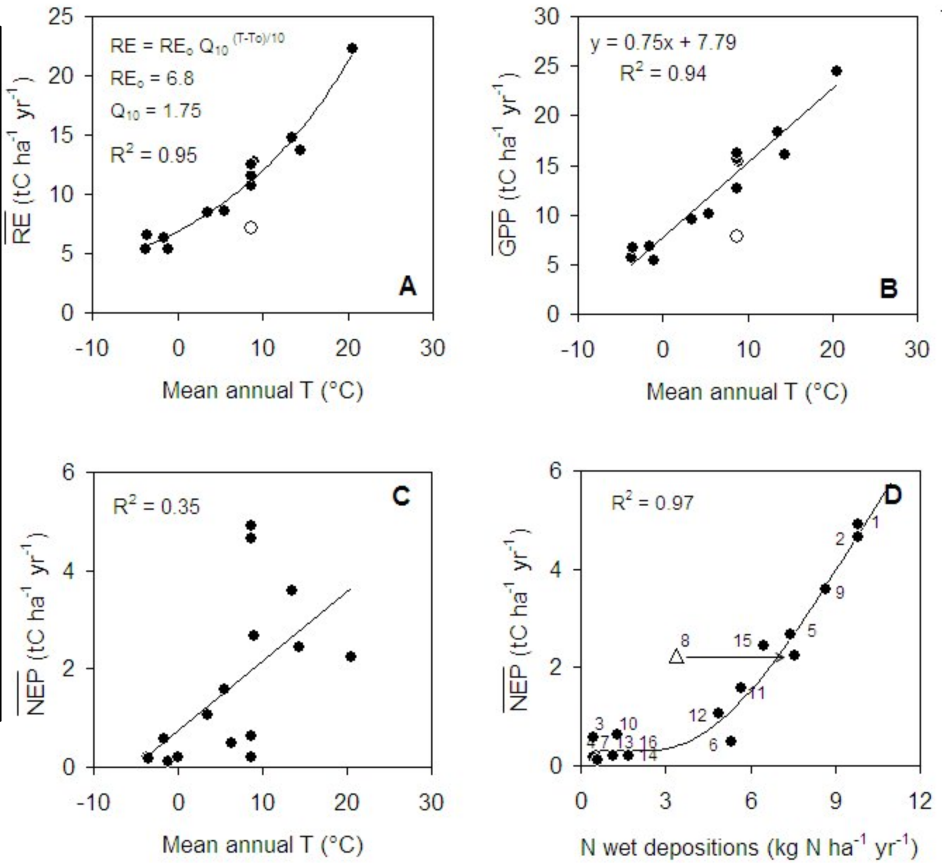
*** Carbon emissions forecast for 2010 for industrialized, Eastern European and Former Soviet Union countries (4.610 billion tons) (http://www.eia.doe.gov/oiaf/ieo/tbl_a10.html) minus the total annual reduction target established by the Kyoto Protocol for the same year (3737 billion tons) (Energy Information Administration-EIA, DOE/EIA-0573/99, DOE/EIA 0219/99).

Santilli et al. 2003

Effects of management (age)

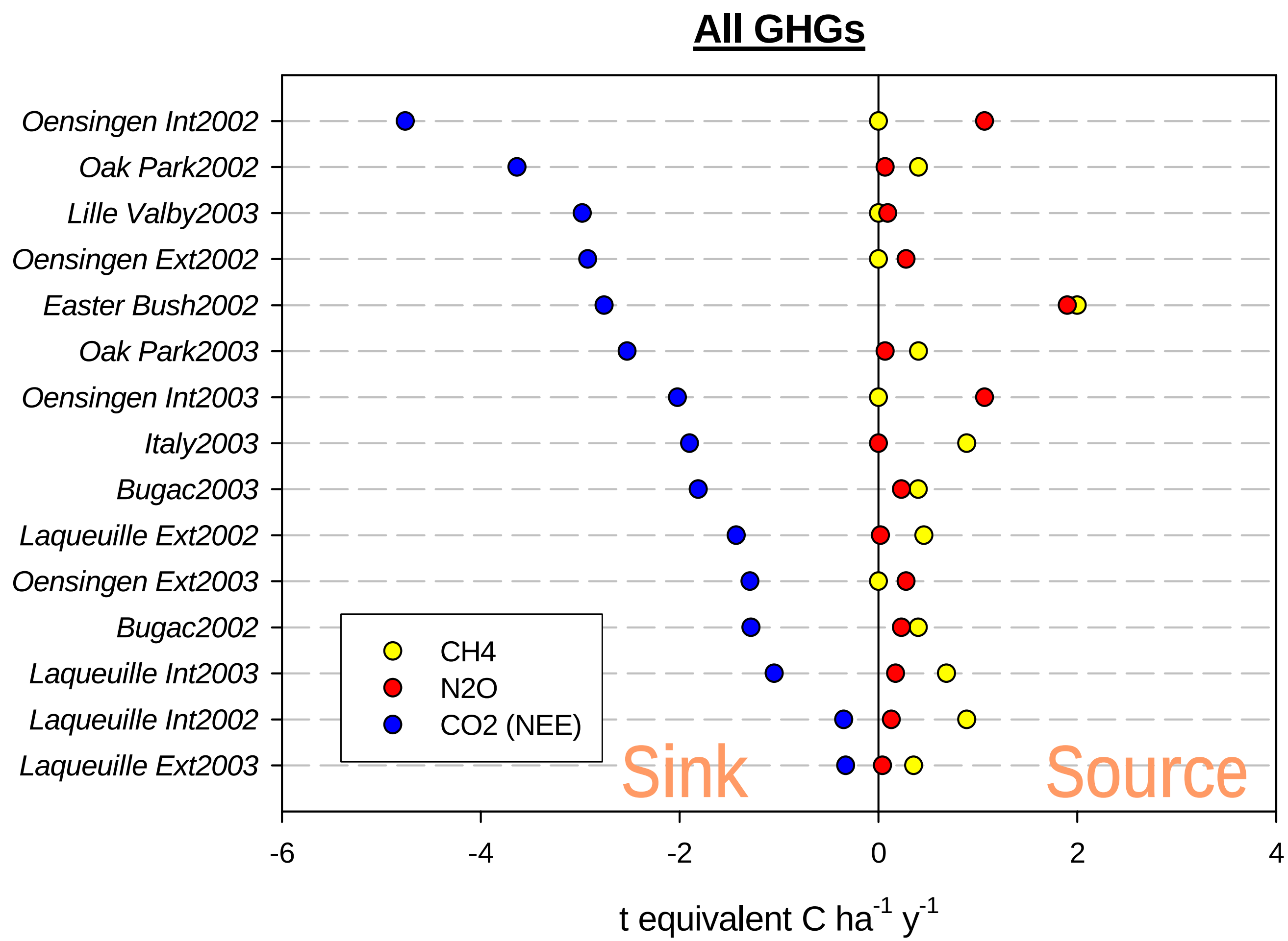


Magnani et al. (Nature 2007)



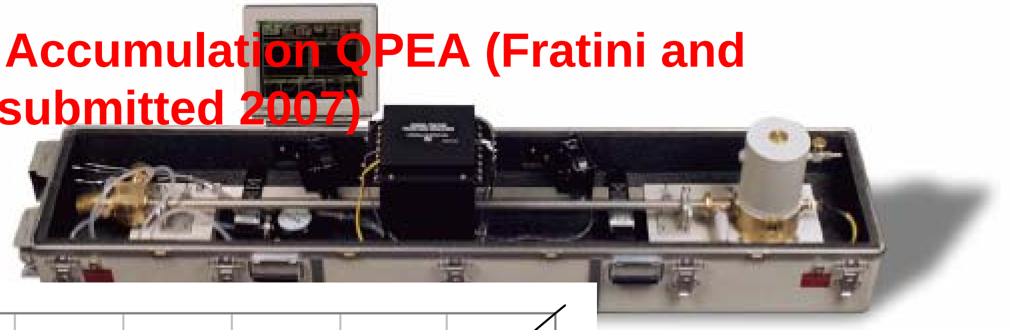
New Challenges

Global warming potential: N_2O and CH_4 trade-offs with CO_2



We need long term measurements of trace gases !

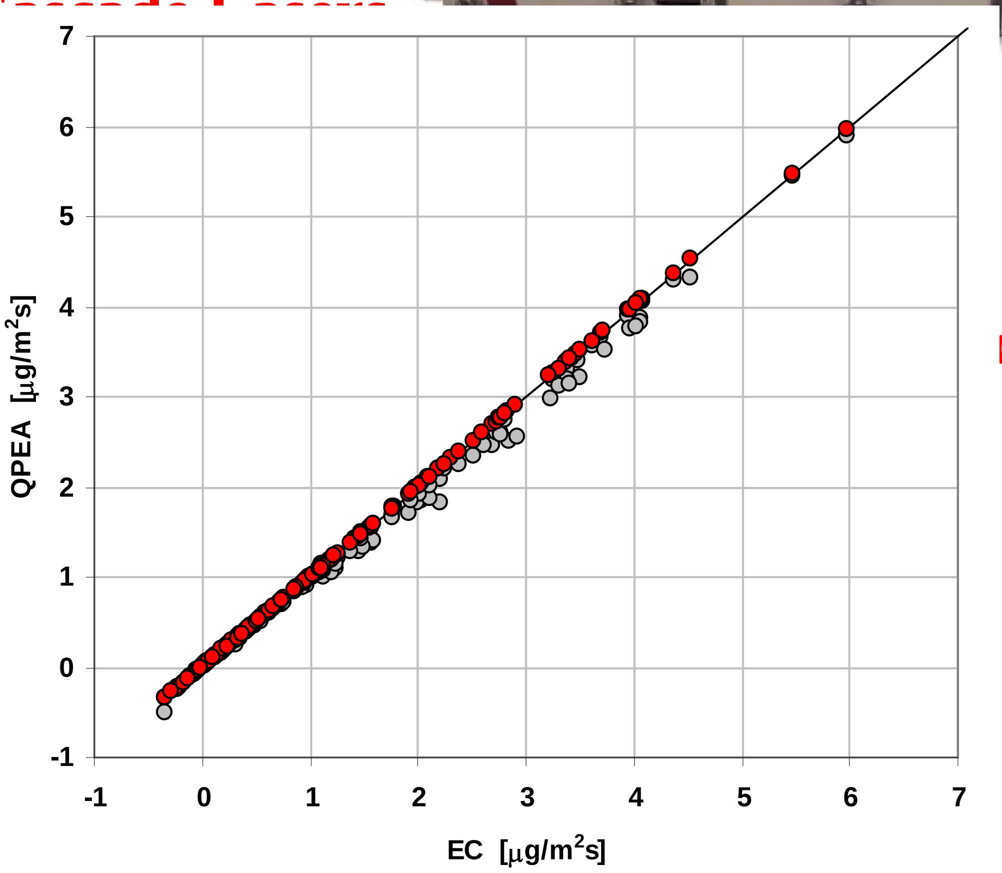
New instruments for trace gases flux measurements



Quasi - Proportional Eddy Accumulation QPEA (Fratini and Valentini submitted 2007)

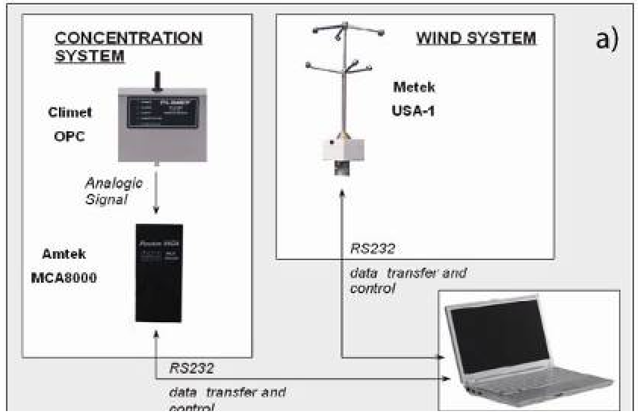
Tunable Diode Lasers

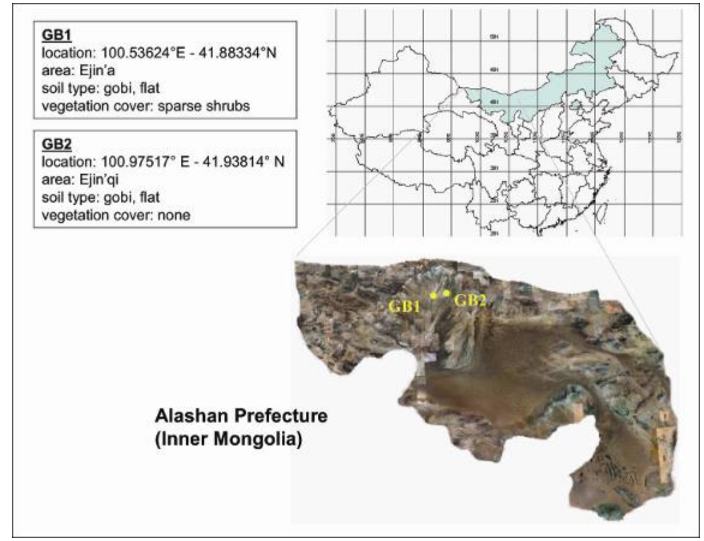
Quantum Cascade Lasers

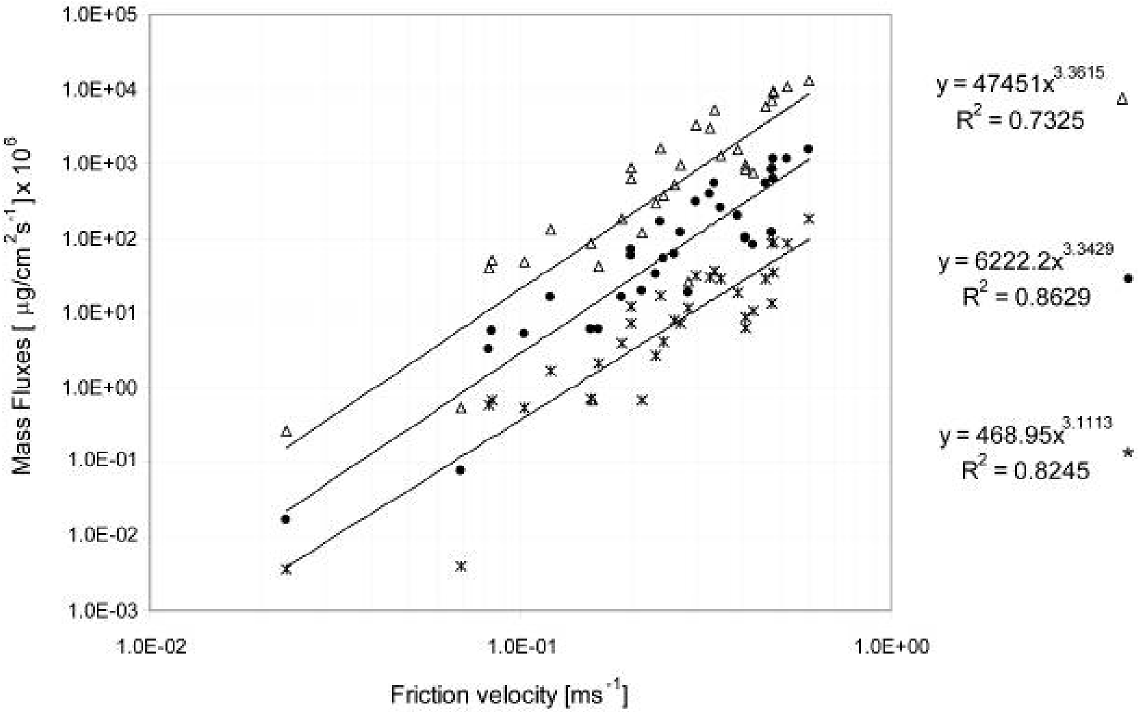


cumulation

Particle fluxes during desert storms in Inner Mongolia desert (Fratini et al. 2007 ACP)







Conclusions

- 1. Long term mesasurements are necessary to capture extreme events and natural disturbances as they are dominant feed-back to carbon cycle
- 2. A well designed and long term oriented flux network can help to improve global models with processes that are not adequately captured by current knowledge
- 3. Human impacts are dominant on age effects structure, forest management, deforestation and fires, thus long term observation sites should be also located in human dominated landscapes

Conclusions

- 4. Non CO_2 trace gases should be included in long term monitoring with improved instrumentation
- 5. Synergies with ecological/biodiversity inventory data is essential. Flux monitoring sites without a comprehensive “in situ” ecological data collection programme is useless!