HRVATSKI ŠUMARSKI INSTITUT
CROATIAN FOREST RESEARCH INSTITUTE

University of Udine
Department of Agricultural
and Environmental Sciences

Inter-annual variability of CO_2 fluxes measured at mixed forest of pedunculate oak with eddy covariance

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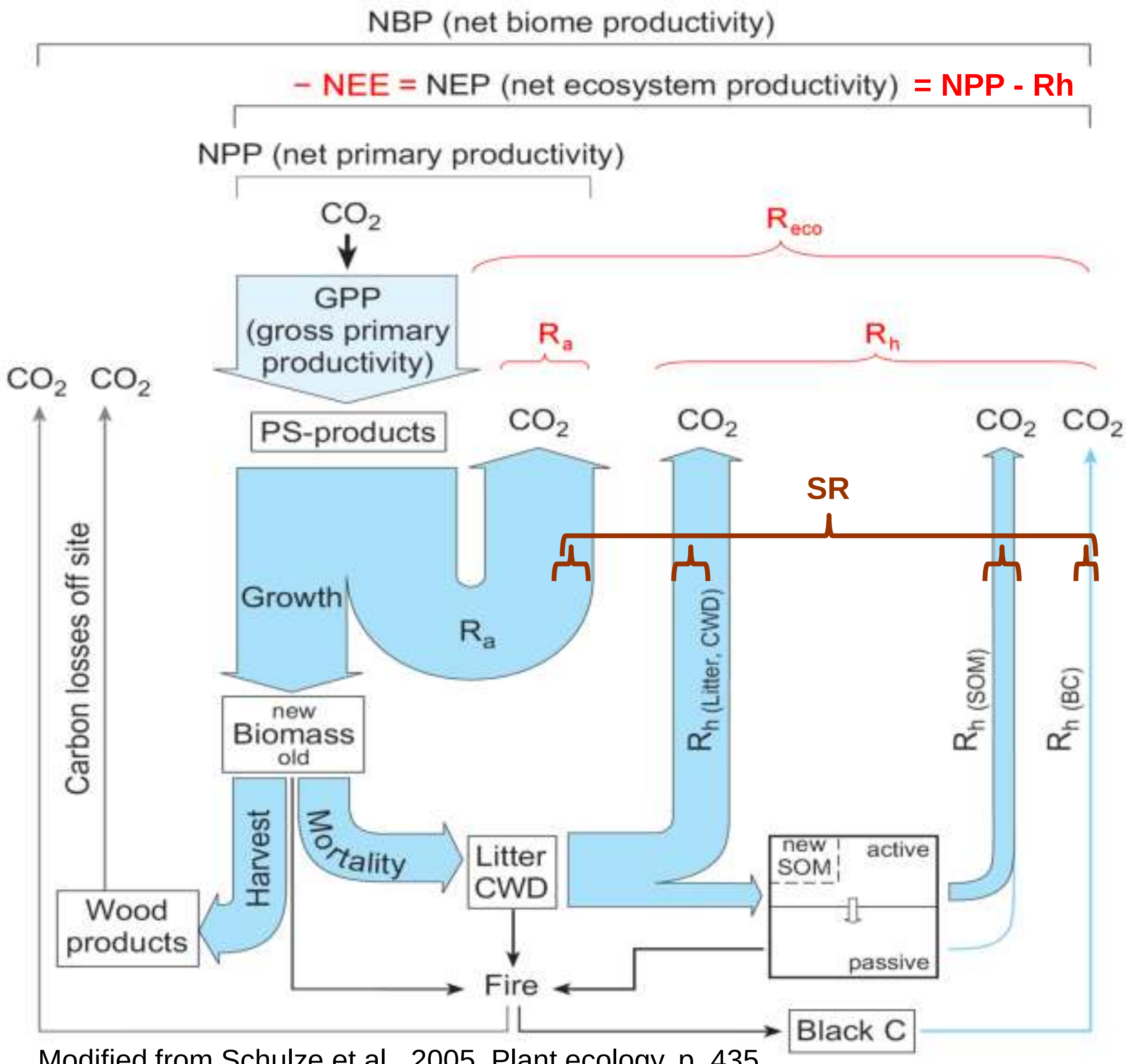
STRUCTURE OF THE PRESENTATION

1. Introduction – CO_2 fluxes in a forest ecosystem & (very) briefly about EC theory
2. Research area – Lowland forests in Croatia, & Jastrebarsko forest (EC site)
3. Measurements at Jastrebarsko EC site - instrumentation, anciliary measurem.
4. Limitatinos of EC – data gapfilling and flux partitioning methods
5. Fluxes at Jastrebarsko forest
6. Conclusions

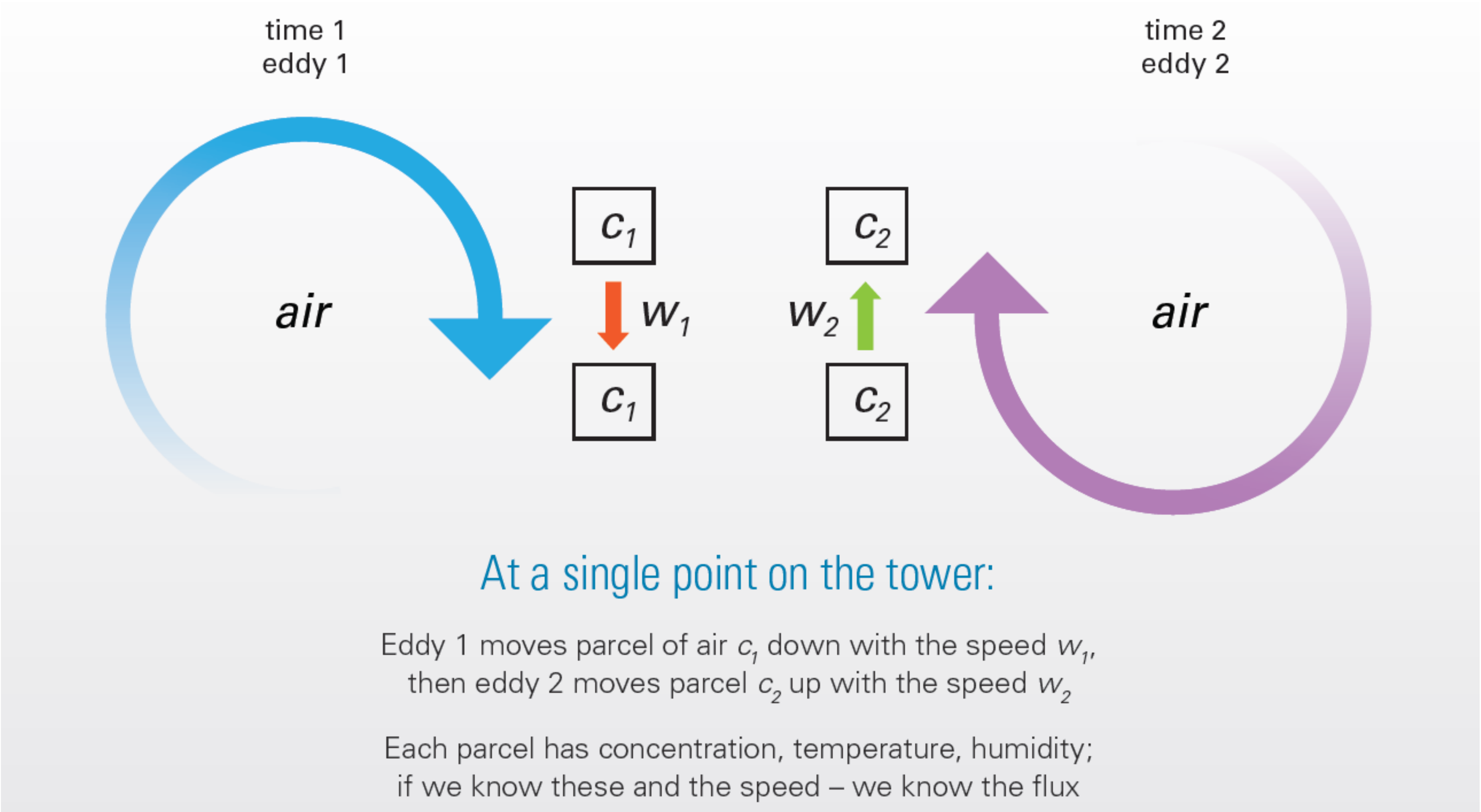
CARBON FLUXES IN FOREST ECOSYSTEM



Modified from Schulze et al., 2005, Plant ecology, p. 435.

VERY BRIEFLY ABOUT EC THEORY (from Burba 2013)

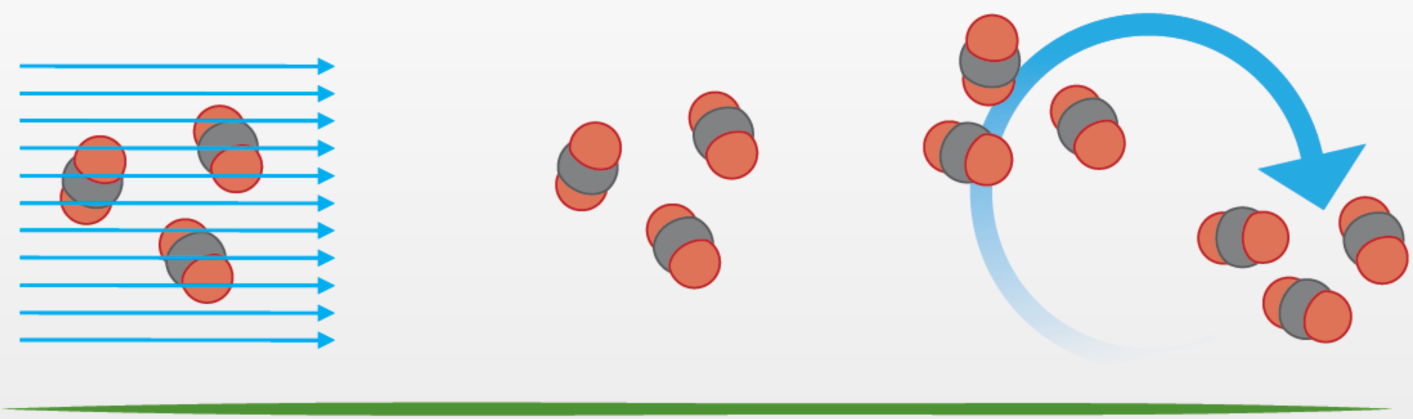
„Overall, the **general physical principle** for eddy flux measurement is to measure how many molecules are moving upward and downward over time, and how fast they travel."



Burba, G., 2013, Eddy Covariance Method for Scientific, Industrial, Agricultural and Regulatory Applications, LI-COR Biosciences, Lincoln, Nebraska, 331p.

VERY BRIEFLY ABOUT EC THEORY (from Burba 2013)

- The eddy covariance method works by measuring vertical turbulent transport of gas to and from the surface
- With no flux added into the mean flow by the measured area, the eddies move the same number of gas molecules up and down



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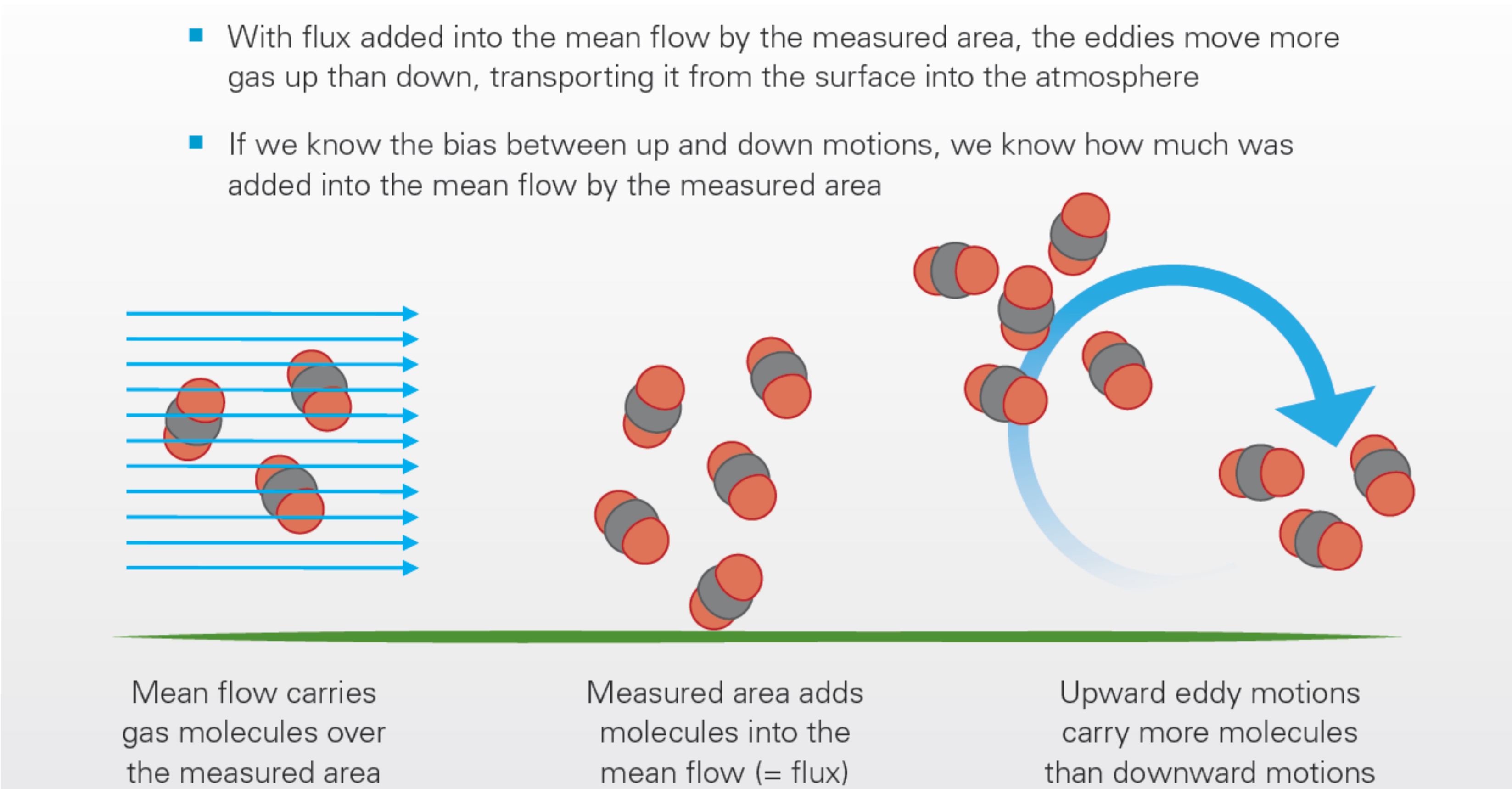

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VERY BRIEFLY ABOUT EC THEORY (from Burba 2013)

„Mathematically such vertical flux can be represented as a covariance between measurements of vertical velocity, the upward and downward movements, and the concentration of the entity of interest."

In turbulent flow, vertical flux can be presented as:
(*s* is the dry mole fraction of the gas of interest in the air)

$$F = \overline{\rho_d w s}$$

Reynolds decomposition is then used to break terms into means and deviations:

$$F = \overline{(\overline{\rho}_d + \rho'_d)(\overline{w} + w')(\overline{s} + s')}$$

Opening the parentheses:

$$F = \overline{(\overline{\rho}_d \overline{w}\,\overline{s} + \cancel{\overline{\rho}_d \overline{w} s'} + \cancel{\overline{\rho}_d w' \overline{s}} + \overline{\rho}_d w' s' + \cancel{\rho'_d \overline{w}\,\overline{s}} + \rho'_d \overline{w} s' + \rho'_d w' \overline{s} + \rho'_d w' s')}$$

averaged deviation from the average is zero

Equation is simplified:

$$F = (\overline{\rho}_d \overline{w}\,\overline{s} + \overline{\rho}_d \overline{w' s'} + \overline{w}\,\overline{\rho'_d s'} + \overline{s}\,\overline{\rho'_d w'} + \overline{\rho'_d w' s'})$$

Burba, G., 2013, Eddy Covariance Method for Scientific, Industrial, Agricultural and Regulatory Applications, LI-COR Biosciences, Lincoln, Nebraska, 331p.

VERY BRIEFLY ABOUT EC THEORY (from Burba 2013)

Now an important assumption is made (for conventional eddy covariance) – air density fluctuations are assumed to be negligible:

$$F = (\overline{\rho}_d\,\overline{w}\,\overline{s} + \overline{\rho}_d\,\overline{w's'} + \cancel{\overline{w}\,\overline{\rho_d' s'}} + \cancel{\overline{s}\,\overline{\rho_d' w'}} + \cancel{\overline{\rho_d' w' s'}}) = \cancel{\overline{\rho}_d\,\overline{w}\,\overline{s}} + \overline{\rho}_d\,\overline{w's'}$$

Then another important assumption is made – mean vertical flow is assumed to be negligible for horizontal homogeneous terrain (no divergence/convergence):

$$F \approx \overline{\rho}_d\,\overline{w's'}$$

'Eddy Flux'

„The flux is computed from the mean dry air density multiplied by the mean covariance between deviations in instantaneous vertical wind speed and dry mole fraction (e.g., mixing ratio).

Burba, G., 2013, Eddy Covariance Method for Scientific, Industrial, Agricultural and Regulatory Applications, LI-COR Biosciences, Lincoln, Nebraska, 331p.

VERY BRIEFLY ABOUT EC THEORY (from Burba 2013)

But, in practice, obtaining reliable flux data from measurements is complicated due to possible errors and inevitable data gaps. This is addressed through data processing and gapfilling.

Data processing includes:

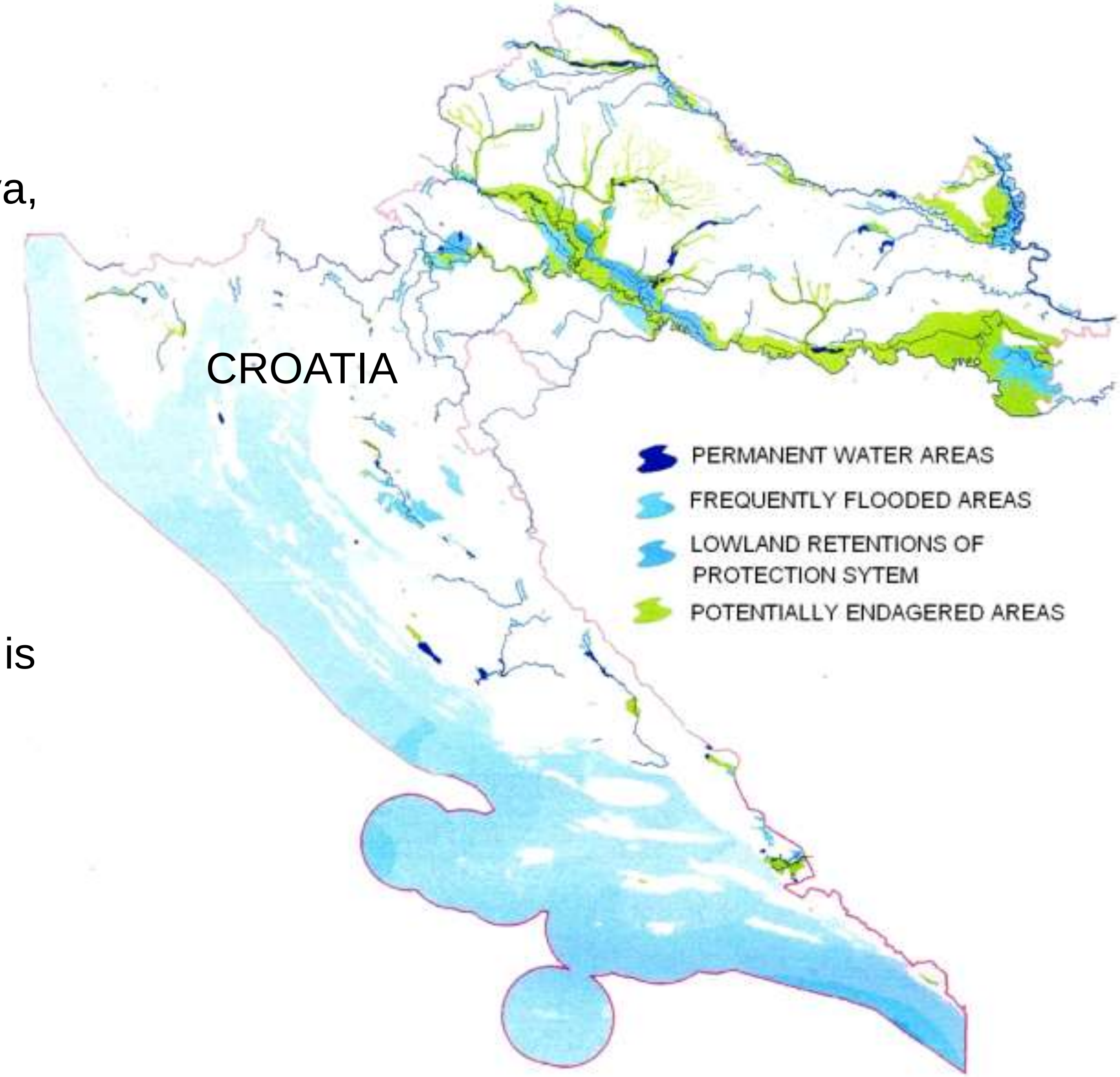
- Extracting raw values for u, v, w, CO_2 and H_2O
- Converting signals in appropriate units
- Despiking (random electronic spikes, water on the open path IRGA or sonic transducers)
- Remove lag (sensor separation)
- Compute wind direction
- Compute means for all measurements (block averaging, linear detrending, running mean)
- Coordinate rotation (rotat. coef. with e.g. planar fit, removing tilt of sonic anemometer)
- Calculation of friction velocity u*
- Spectral corrections for high- (eg. sensor separ.) & low-freq. losses (large eddies)
- Schotanus correction (Impact of the cross wind and of air humidity on Ta & H)
- Webb-Pearman and Leuning (WPL) correction (fluct. in temp. & humidity -> affect Fc)

In our case processing was performed with EdiRe software (University of Edinburgh) for raw flux calculation, and post processing with own procedures with Stata IC 10 (StataCorp, USA).

FORESTS IN FOCUS – Lowland forests of pedunculate oak (*Q. robur* L.)

Lowland forest in Croatia:

- Along rivers Kupa, Sava, Drava, Danube
- In the pas those areas have been regularly flooded
- Most productive agricultural & forest areas
- Dominant tree species is pedunculate oak (*Quercus robur* L.)



FORESTS COMMUNITIES OF LOWLANDS

Tree species in lowland forests have naturaly adapted to various degrees of soil water saturation:

Common soil water status	Corresponding tree species
• stagnant water	Black alder (*Alnus glutinosa* Gearnt.)
• high groundwater table	Narrow-leafed ash (*Fraxinus angustifolia* L.)
• periodical flooding	Pedunculate oak (*Quercus robur* L.)
• not flooded areas	Hornbeam (*Carpinus betulus* L.)

BLACK ALDER

(*Frangulo–Alnetum glutinose* Rauš 1968)

NARROW-LEAFED ASH

(*Leucoio-Fraxinetum angustifoliae* Glav. 1959)

PEDUNCULATE OAK

(*Genisto elatae-Quercetum roboris* Ht. 1938)

PEDUNCULATE OAK WITH HORNBEAM

(*Carpino betuli -Quercetum roboris* Anić 1959 / em. Rauš 1969)

RESEARCH AREA – Forests of the river Kupa basin (Jastrebarsko forest)

Location of Jastrebarsko forest and eddy covariance site

RESEARCH AREA

- Pedunculate oak stands in Jastrebarsko forest which is part of the 13,600 ha forest complex of the river Kupa basin.
- The terrain is mainly flat - altitudes ranging from 106 masl (central part) up to 120 masl (SW parts) and 130 masl (N parts)
- Soil is mainly gleysol, low vertical water conductivity (stagnating water).
- Climate (Köppenu) Cfwbx", T_{av}=10.4°C (Jan -0.2 °C, Jul 20.7 °C), p_{av} ~ 900 mm (500mm Apr – Sep)

JASTREBARSKO FOREST EC SITE

- Young (35 -40y), managed, stand dominated by pedunculate oak (*Quercus robur* L.).
- Result of regeneration cuts in 1972-1973.

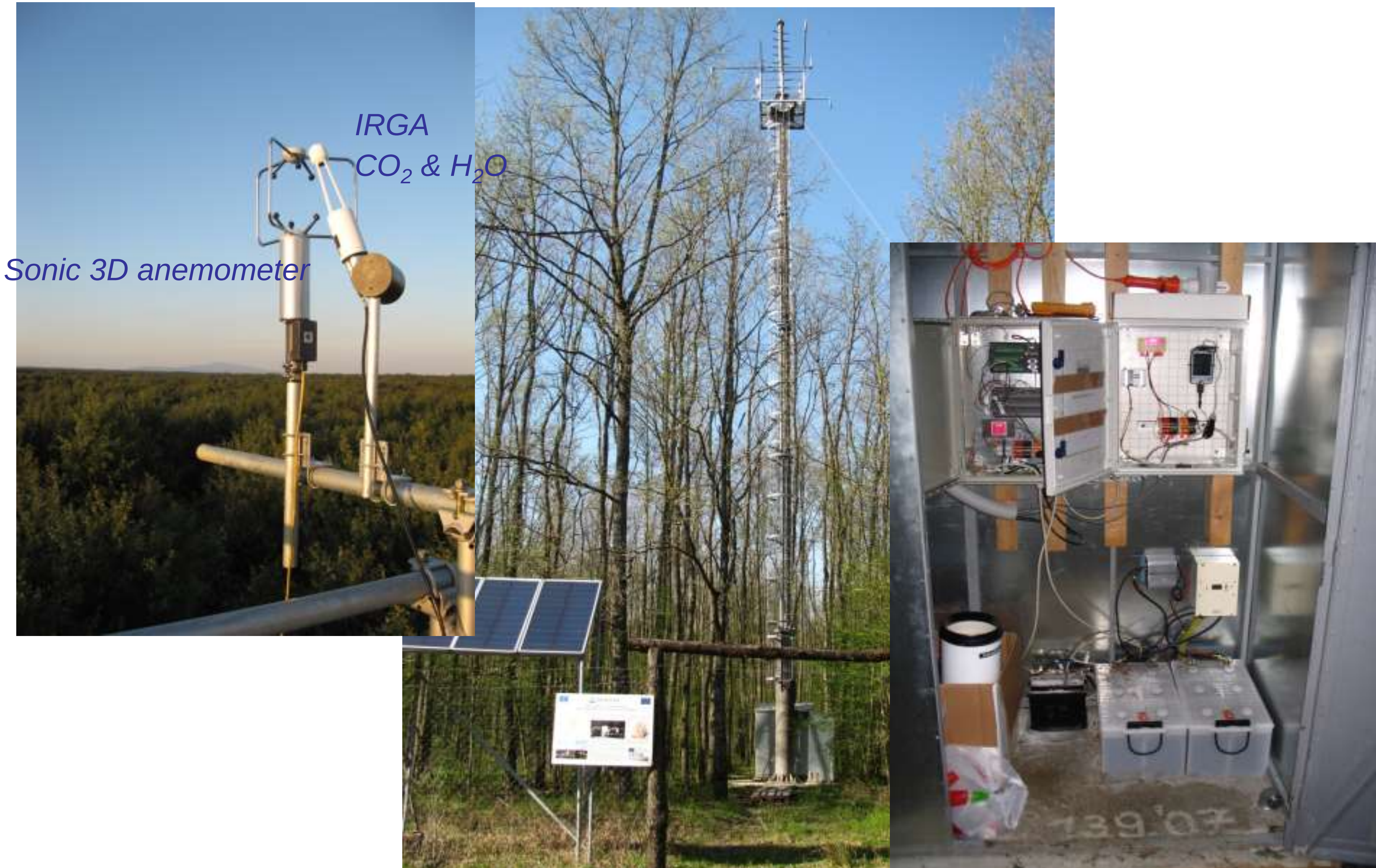
Young forest as a result of regeneration cuts in 1972-1973.

JASTREBARSKO FOREST - EC site selection (February 2007)

JASTREBARSKO FOREST EC SITE – setting the foundations (April 2007)

JASTREBARSKO FOREST EC SITE – putting the tower (May 2007)

JASTREBARSKO FOREST EC SITE – putting the instruments (Sep 2007)



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INSTRUMENTATION AND MEASUREMENTS

Meteorological measurements:

- air temperature and humidity (HMP45AC, Vaisala),
- total rainfall (52202 tipping bucket rain gauge, R.M. Young)
- incoming short wave radiation (CMP3, Kipp and Zonen),
- incoming and outgoing photosynthetic photon flux density - PPFD (LI-190SL quantum sensor, Li-Cor),
- net radiation (NR-LITE, Kipp and Zonen),
- soil heat flux (5 and 15 cm) using four soil heat flux plates (HFT3, REBS)
- soil temperature at three depths using thermocouples (5, 15 and 25 cm from the top),
- soil water content (0-30 cm) using two time domain reflectometers (CS616, Campbell Scientific),
- all variables were measured at 30 s intervals with datalogger (CR1000, Campbell) and then averaged half-hourly

INSTRUMENTATION AND MEASUREMENTS

Eddy covariance system:

- sonic anemometer (81000V, R.M. Young)
- open path infra-red gas analyser (LI-7500, Li-Cor)
- data from the sonic anemometer and the open path IRGA were recorded at a frequency of 20 Hz by a hand computer

CO_2 profile and soil respiration (CO_2 efflux) measurements:

- half hourly CO_2 concentration at different heights in the canopy (1, 2, 4, 8, 16, 24 m from the soil surface) for calculation of storage flux
- Automatic, closed, dynamic soil respiration system for measurements of CO_2 efflux every four hours

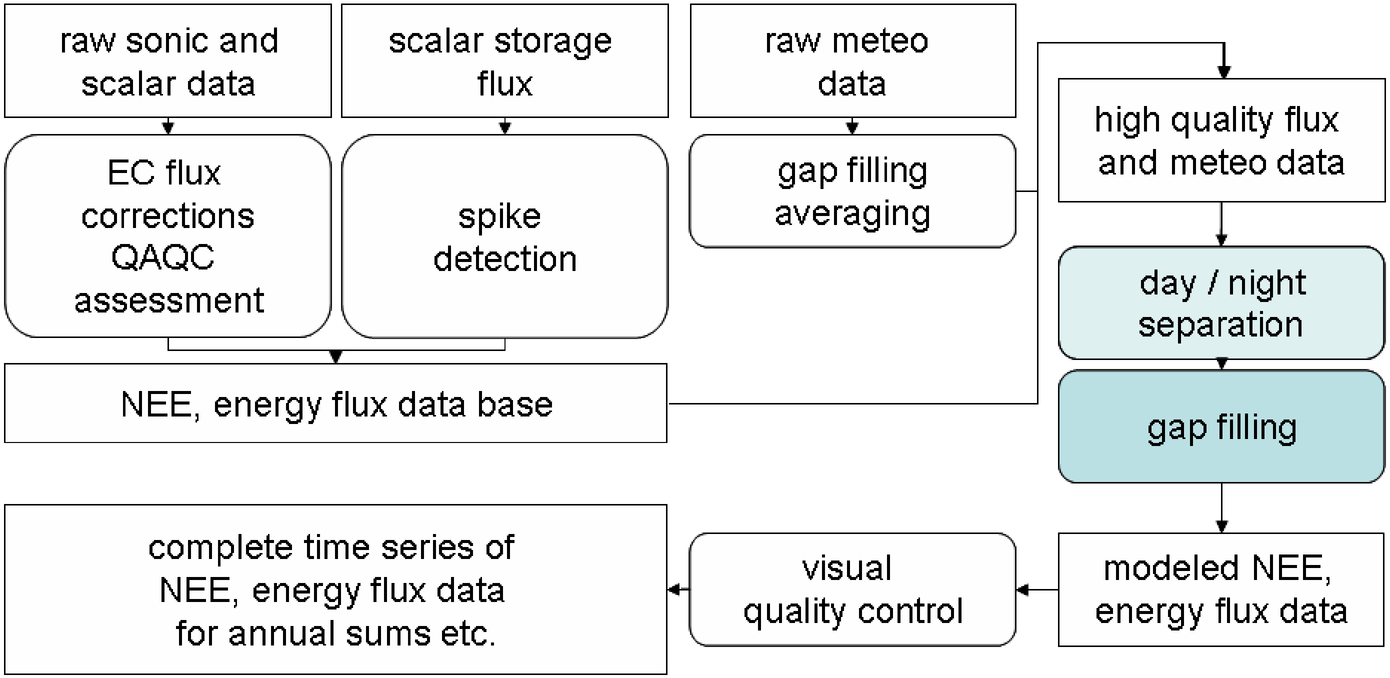
INSTRUMENTATION AND MEASUREMENTS

May 2008 beginning of periodic SR measurements

Chamber of the soil respiration system.

INSTRUMENTATION AND MEASUREMENTS

Data processing, gapfilling and flux partitioning:



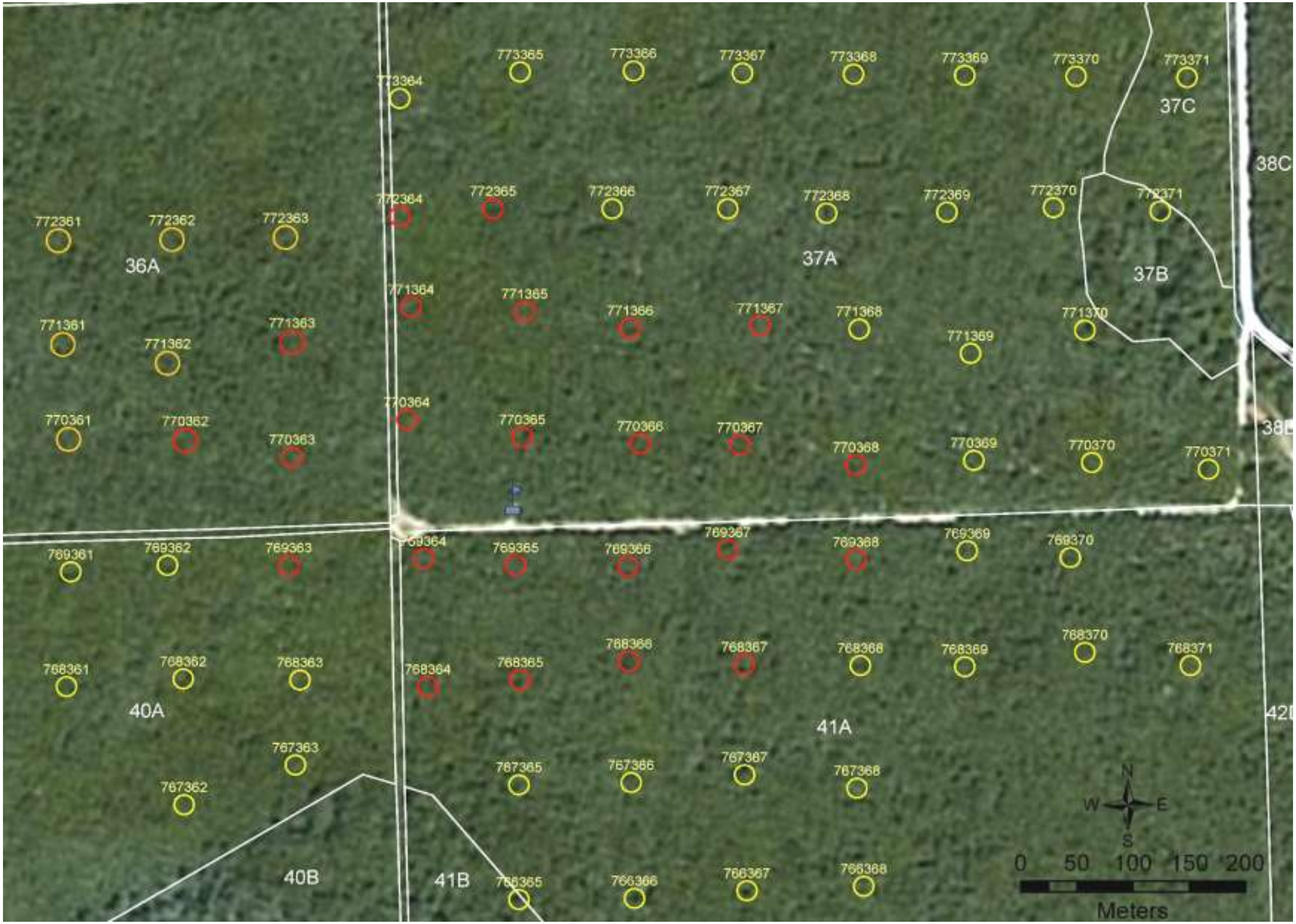
- A gap-filling procedure was applied to obtain daily fluxes (Reichstein et al. 2005, Lasslop et al 2010) when the QA/QC criteria were not satisfied and when a lack of turbulent transport was evidence by the data.
- Online tool of Department Biogeochemical Integration, Max Planck Institute for Biogeochemistry

INSTRUMENTATION AND MEASUREMENTS

Ancillary measurements:

- Stand volume growth, for independent estimate of NPP, was calculated from weekly stem increment measurements
- Stem diameter increments were measured with dendrometer bands (640) on 24 circular plots around EC tower
- NPP was calculated from estimated volume increments and species specific root-to-shoot ratios.
- litterfall collection
- decomposition experiment

JASTREBARSKO EC SITE – forest mensuration plots



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JASTREBARSKO EC SITE – forest mensuration plots

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JASTREBARSKO EC SITE – incement plots & decomposition experiment

JASTREBARSKO EC SITE – carbon stocks

CARBON STOCKS	[kgC m^{-2}]	Share
Total live biomass	**8.05**	**38.6%**
Aboveground biomass	**6.31**	30.2%
Belowground biomass (R/S=0.257)	**1.62**	7.8%
Leaves	**0.22**	1.0%
Snags	**0.59**	**2.8%**
Coarse Woody Debris	**0.30**	**1.4%**
Litter	**0.15**	**0.7%**
$C_{soil\ 40\ cm\ depth}$	**11.77**	**56.4%**
C_{total}	**20.87**	**100%**

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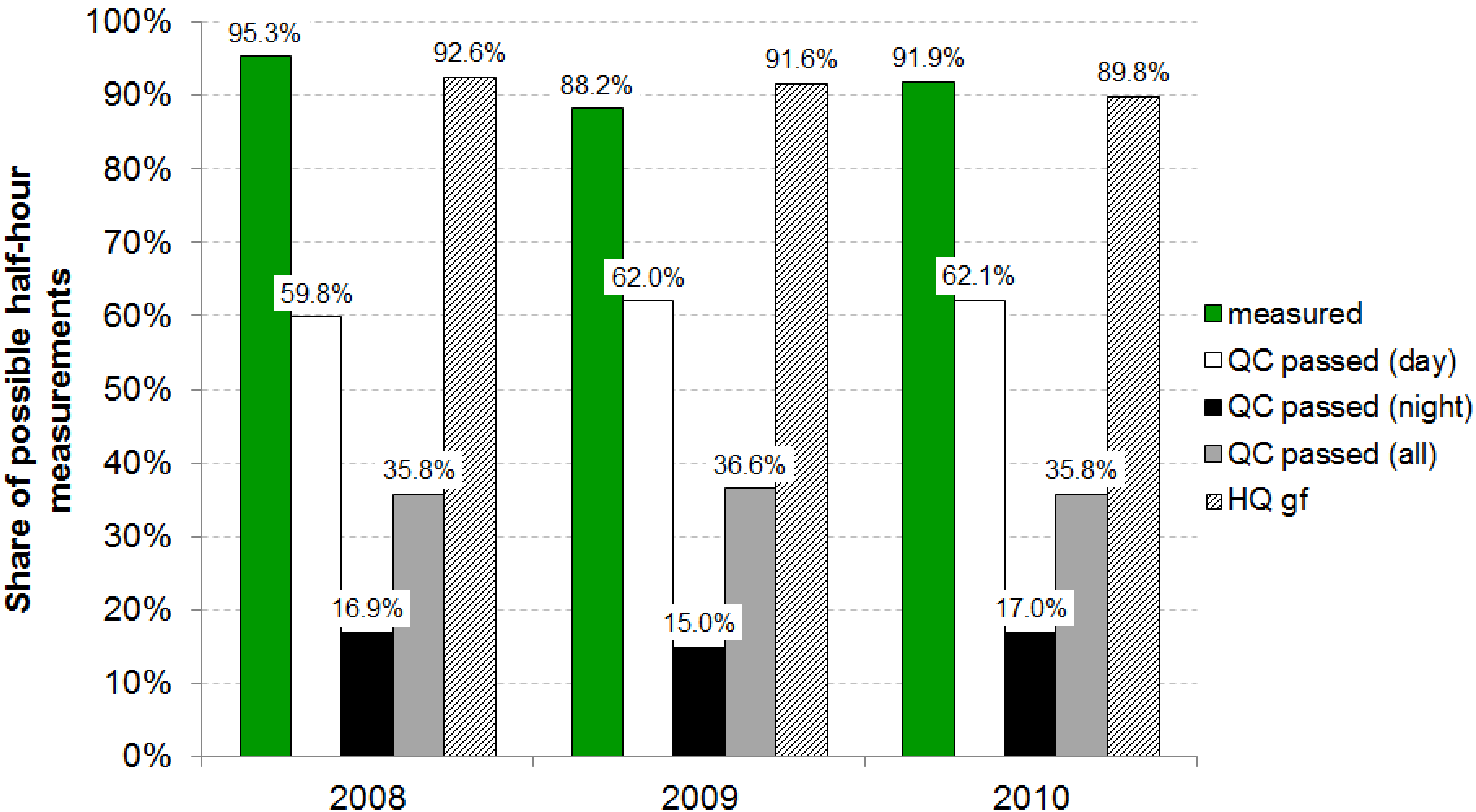
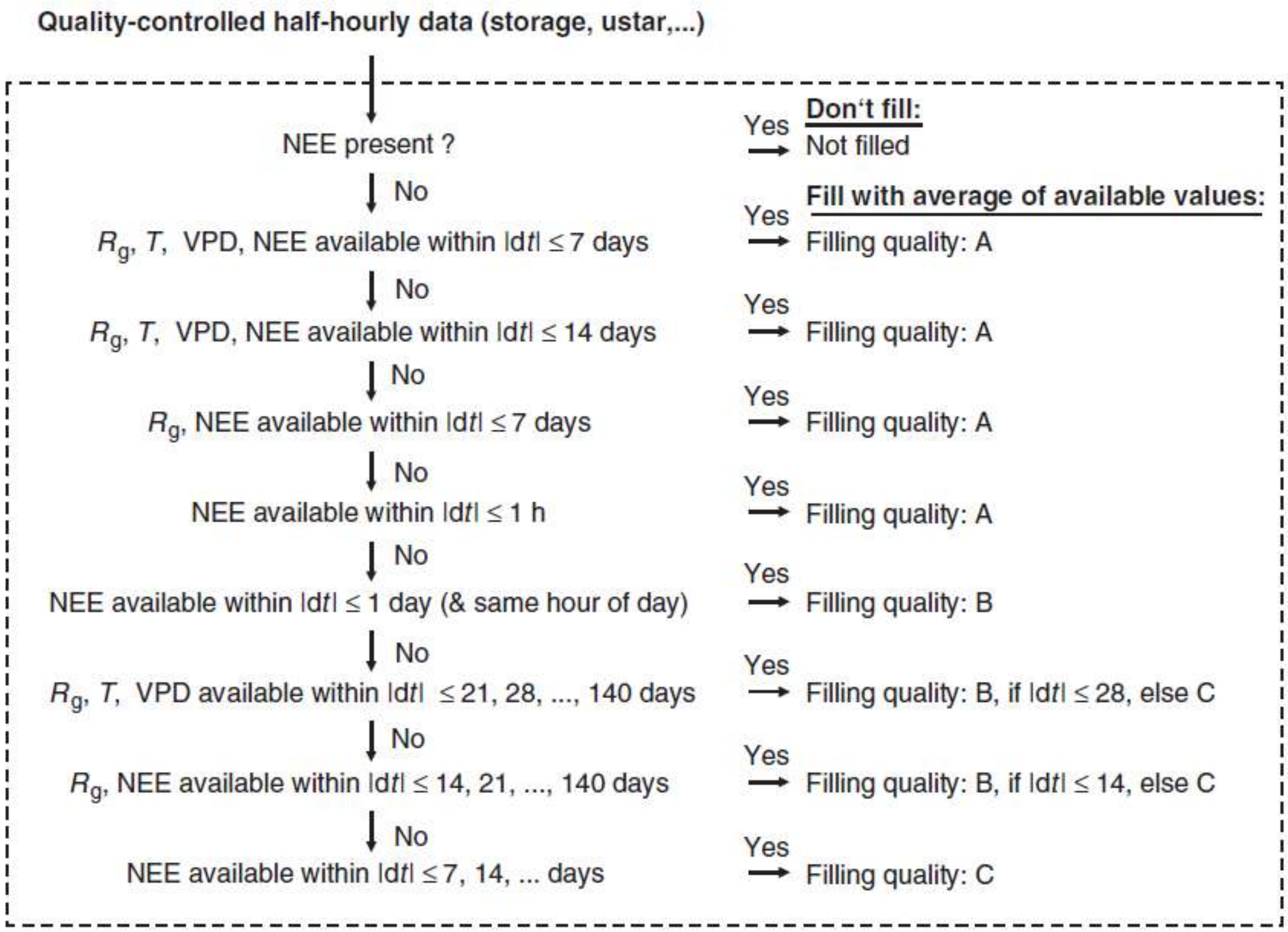
Back to EC data (i.e. what is left of it after QC)



GAP-FILLING

Gap-filling method by Reichstein et al. 2005, GCB

(on-line tool of MPI-BGC in Jena, http://www.bgc-jena.mpg.de/~MDIwork/eddyproc/index.php)



FLUX PARTITIONING

NEE = - GPP + Reco

Method 1: Reco = $rb \exp\left(E_0\left(\frac{1}{T_{\text{ref}} - T_0} - \frac{1}{\text{T}_{\text{air}} - T_0}\right)\right)$ (Lloyd & Taylor 1994)

- estimated from night time NEE, extrapolated to daytime Reco (Reichstein et al. 2005, GCB)

Method 2 (HBLR): NEE modeled using Hyperbolic Light Responce (HBLR) curve with modified β for VPD and temperare sensitive Reco (Lasslop et at. 2010, GCB)

- Reco estimated independantly for daytime, NEE_HBLR are modeled values!

$$\text{NEE} = \frac{-\alpha\beta \text{R}_\text{g}}{\alpha \text{R}_\text{g} + \beta} + rb \exp\left(E_0\left(\frac{1}{T_{\text{ref}} - T_0} - \frac{1}{\text{T}_{\text{air}} - T_0}\right)\right)$$

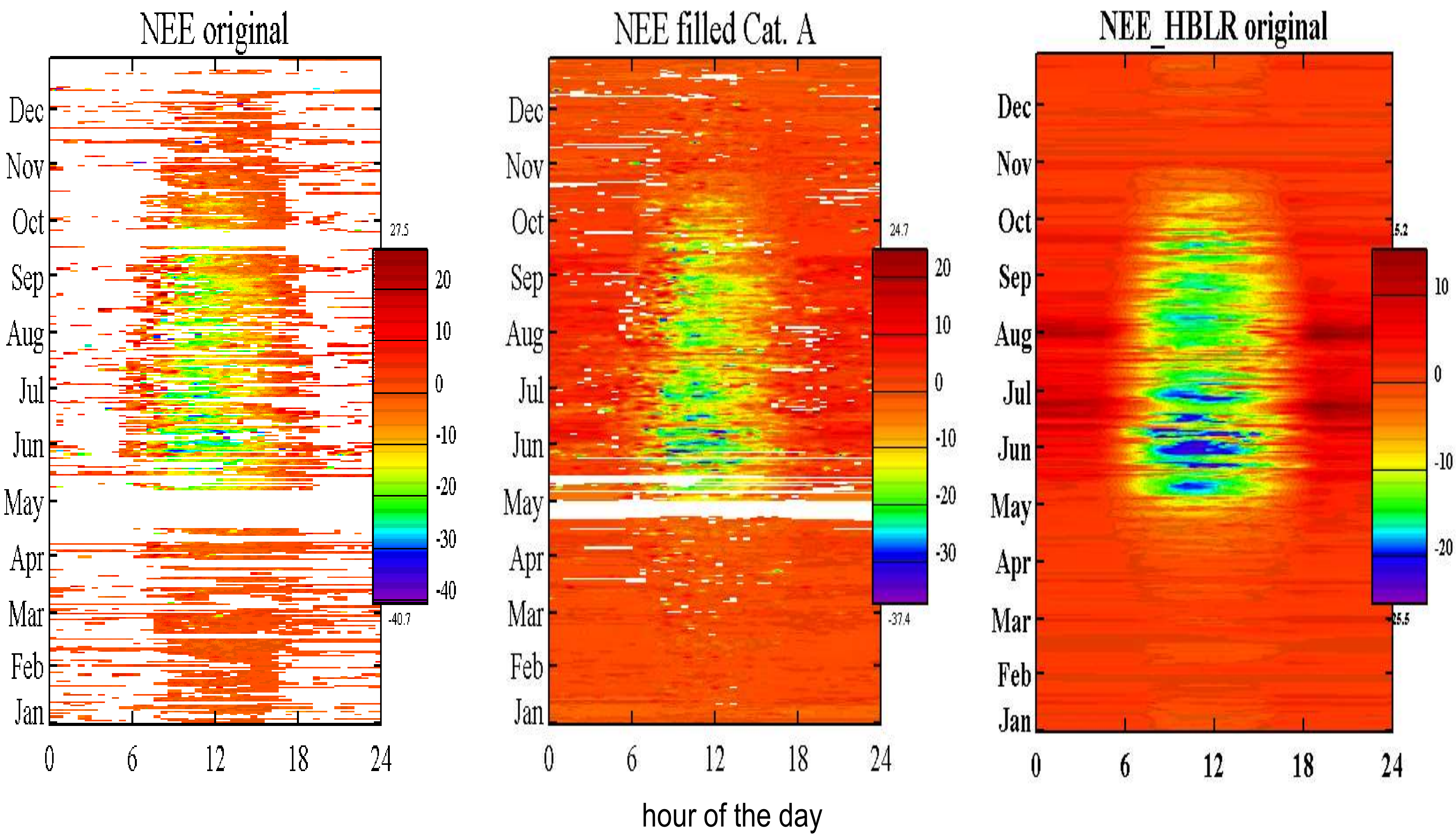
α (μmol C J^{-1}) = canopy light utilization efficiency (initial slope of the light–response curve)

β (μmol C m^{-2} s^{-1}) = maximum CO_2 uptake rate of the canopy at light saturation

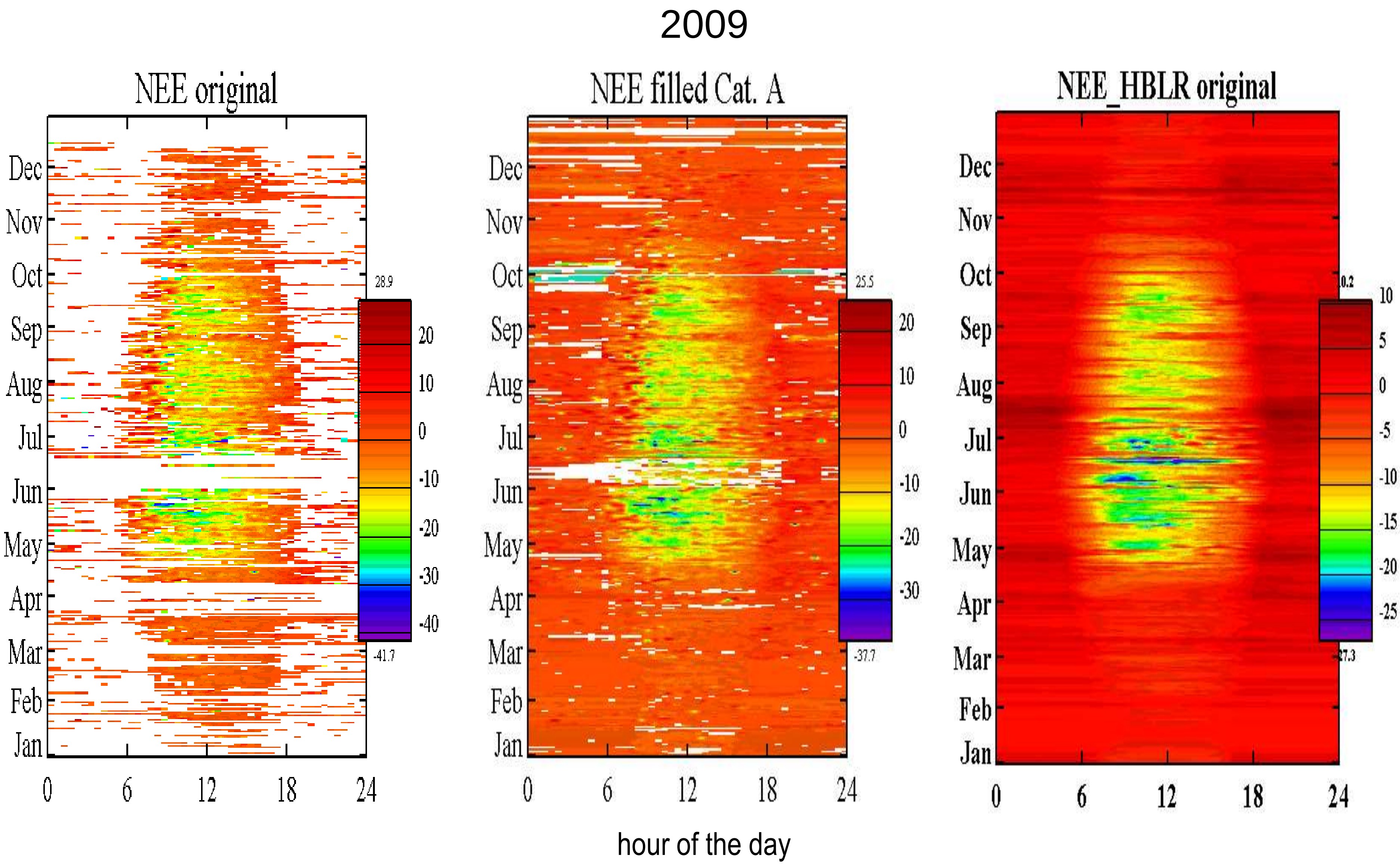
$$\beta = \begin{cases} \beta_0 \exp(-k(\text{VPD} - \text{VPD}_0)), & \text{VPD} > \text{VPD}_0, \\ \beta = \beta_0, & \text{VPD} < \text{VPD}_0. \end{cases}$$

Results

2008



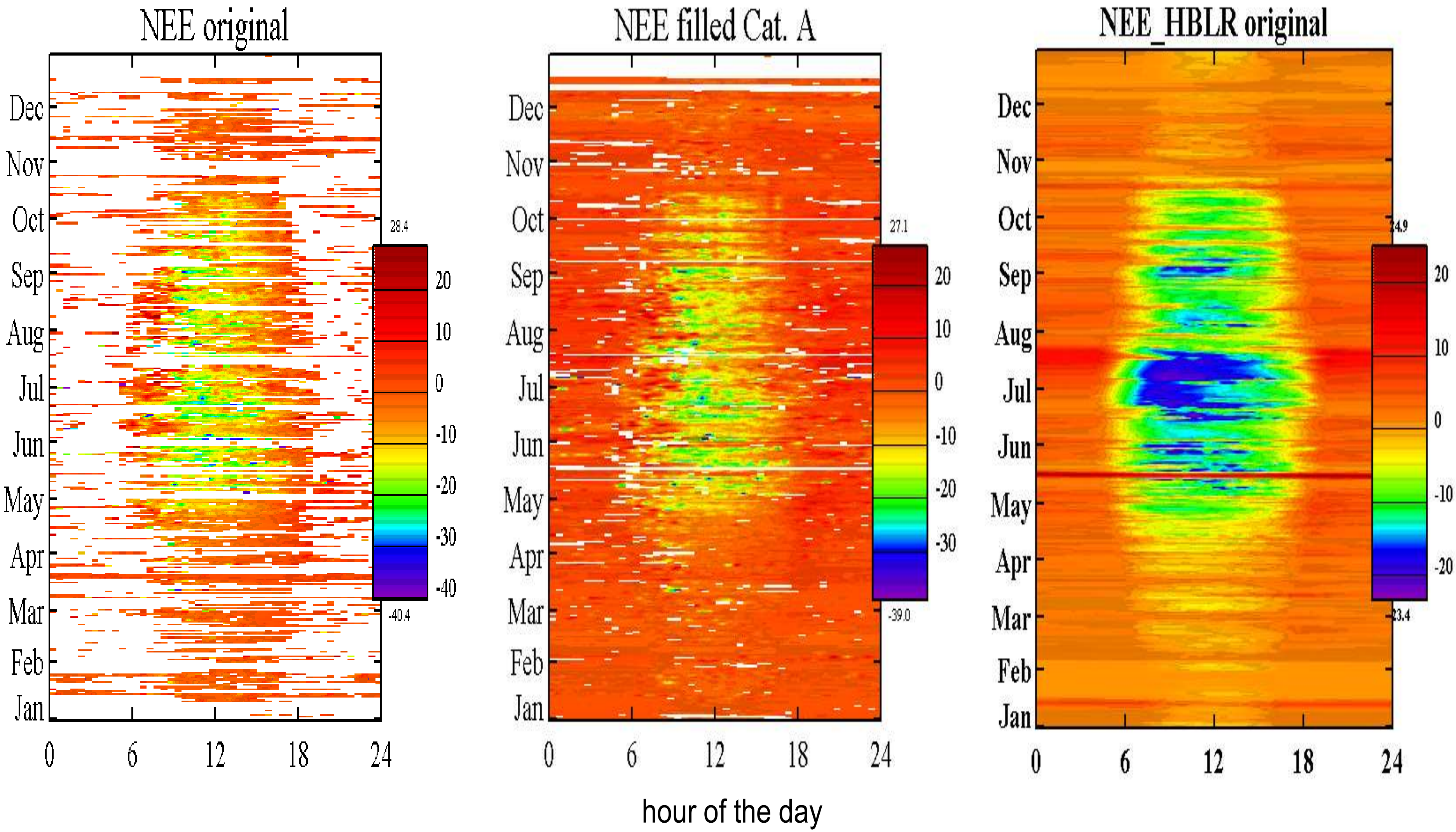
Results



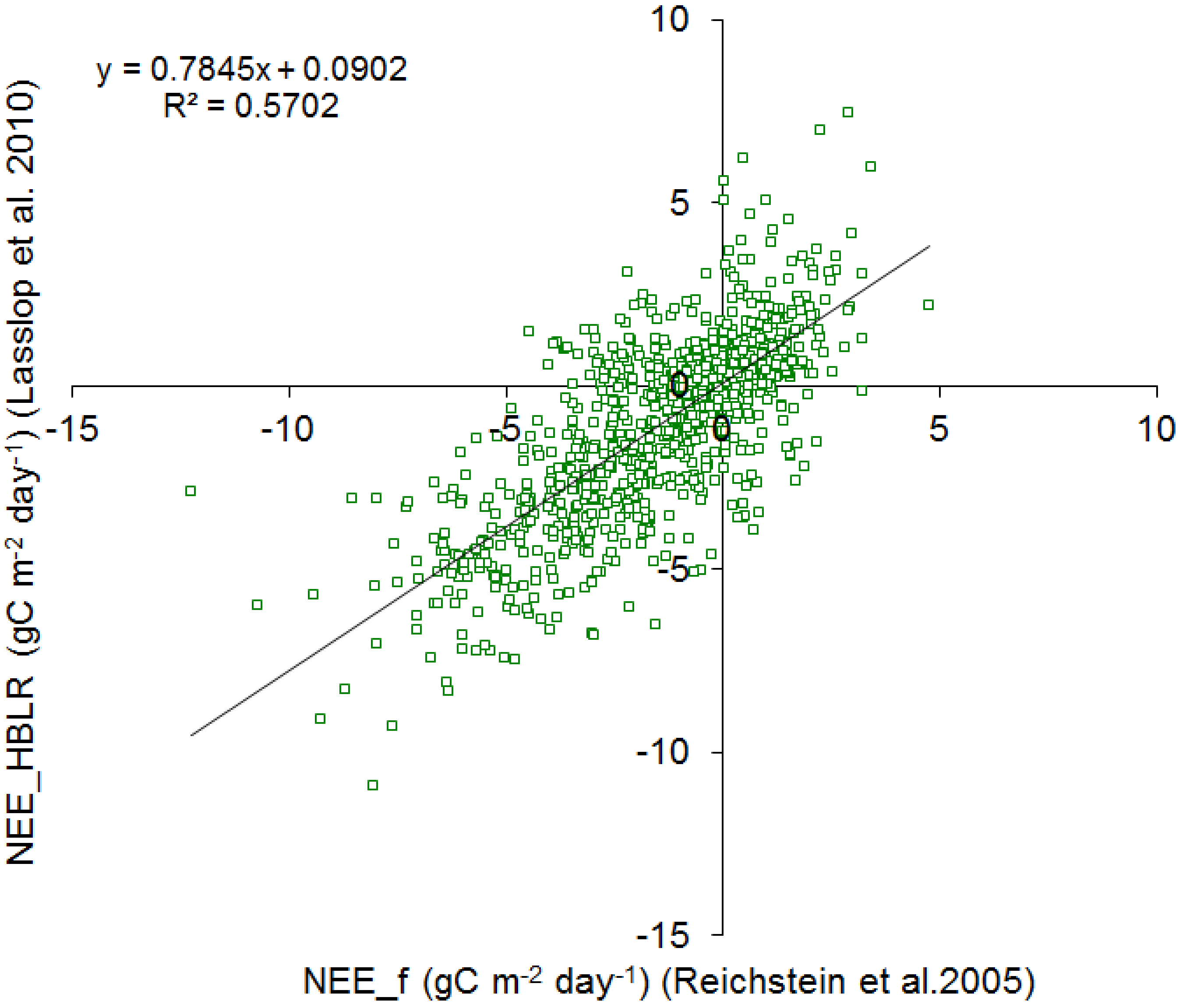
2009
NEE original
NEE filled Cat. A
NEE_HBLR original
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
0
6
12
18
24
28.9
-41.7
25.5
-37.7
20
10
0
-10
-20
-30
-40
5
-5
-15
-25
hour of the day

Results

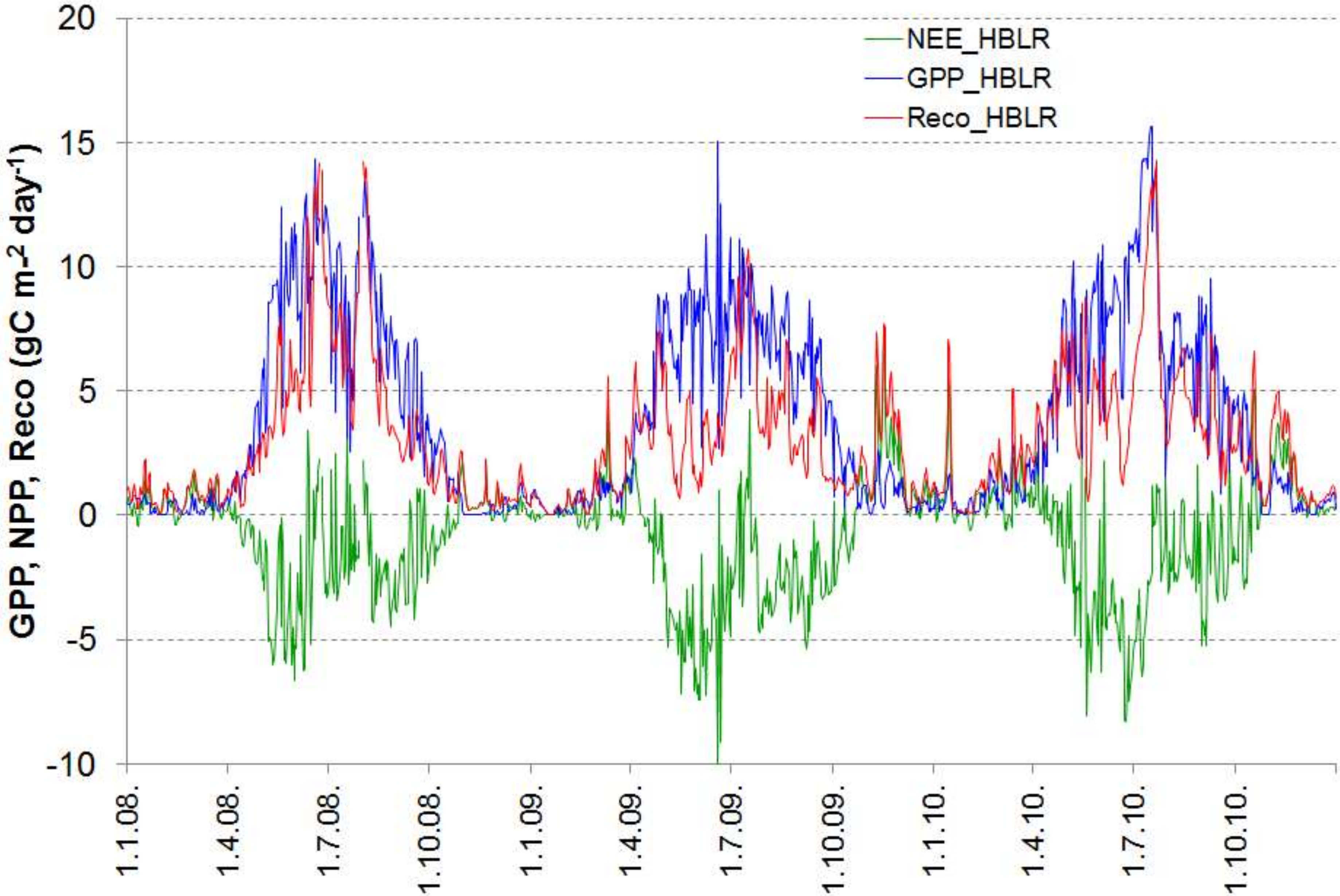
2010



Results


y = 0.7845x + 0.0902
R² = 0.5702
10
5
0
-5
-10
-15
-15
-10
-5
0
5
10
NEE_HBLR (gC m-2 day-1) (Lasslop et al. 2010)
NEE_f (gC m-2 day-1) (Reichstein et al.2005)

Results



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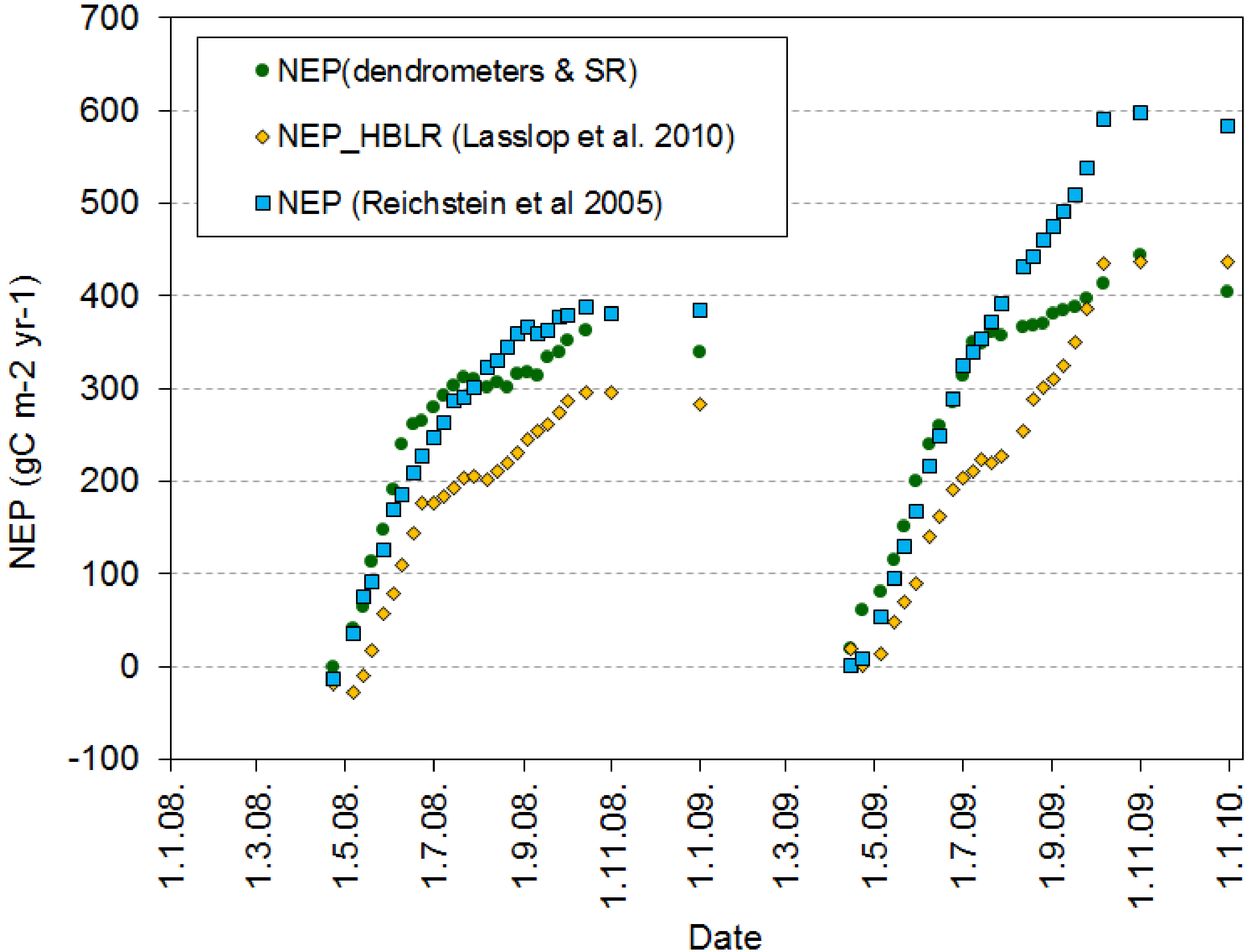
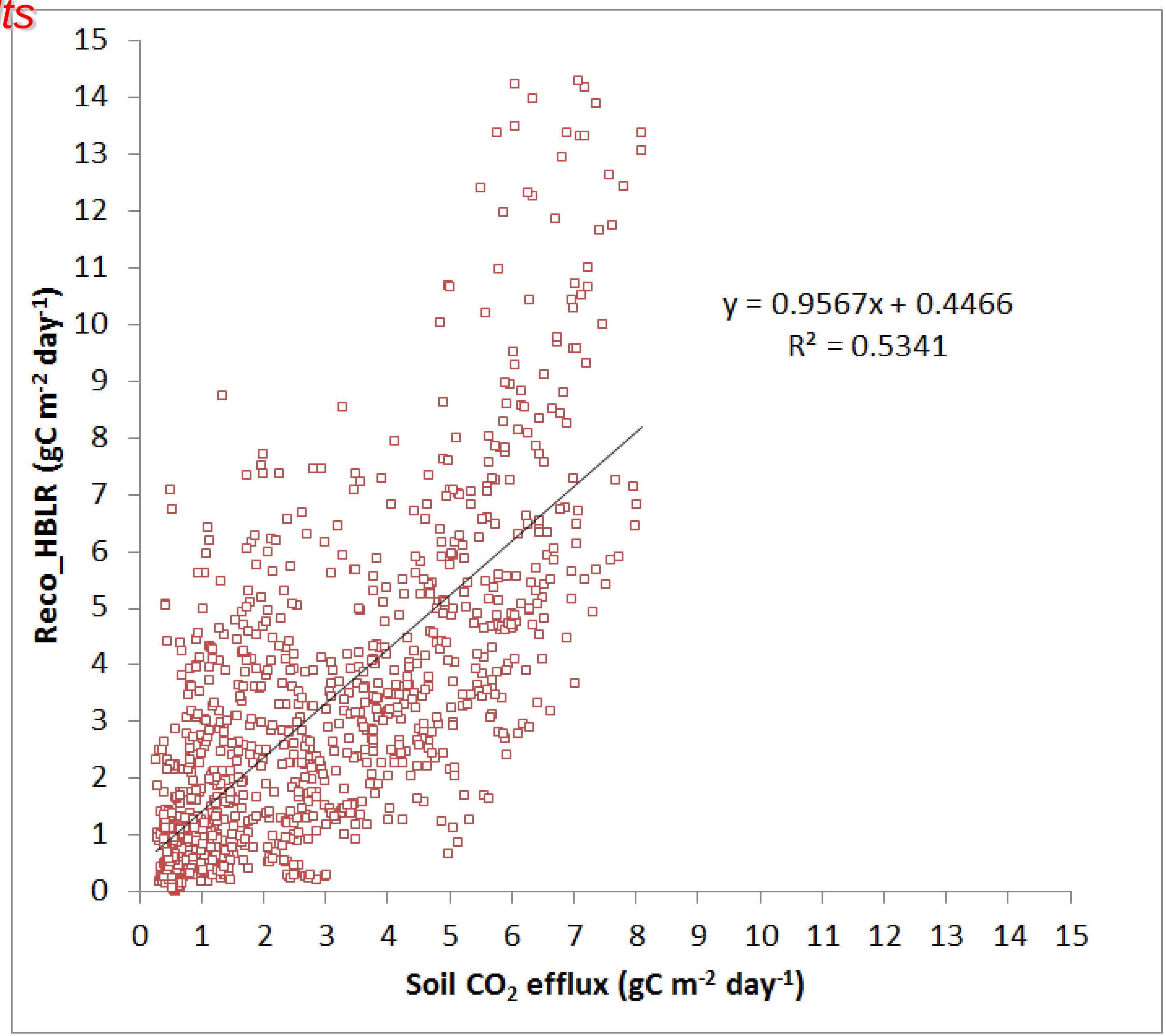
Results


NEP(dendrometers & SR)
NEP_HBLR (Lasslop et al. 2010)
NEP (Reichstein et al 2005)
700
600
500
400
300
200
100
0
-100
NEP (gC m-2 yr-1)
1.1.08.
1.3.08.
1.5.08.
1.7.08.
1.9.08.
1.11.08.
1.1.09.
1.3.09.
1.5.09.
1.7.09.
1.9.09.
1.11.09.
1.1.10.
Date

Results



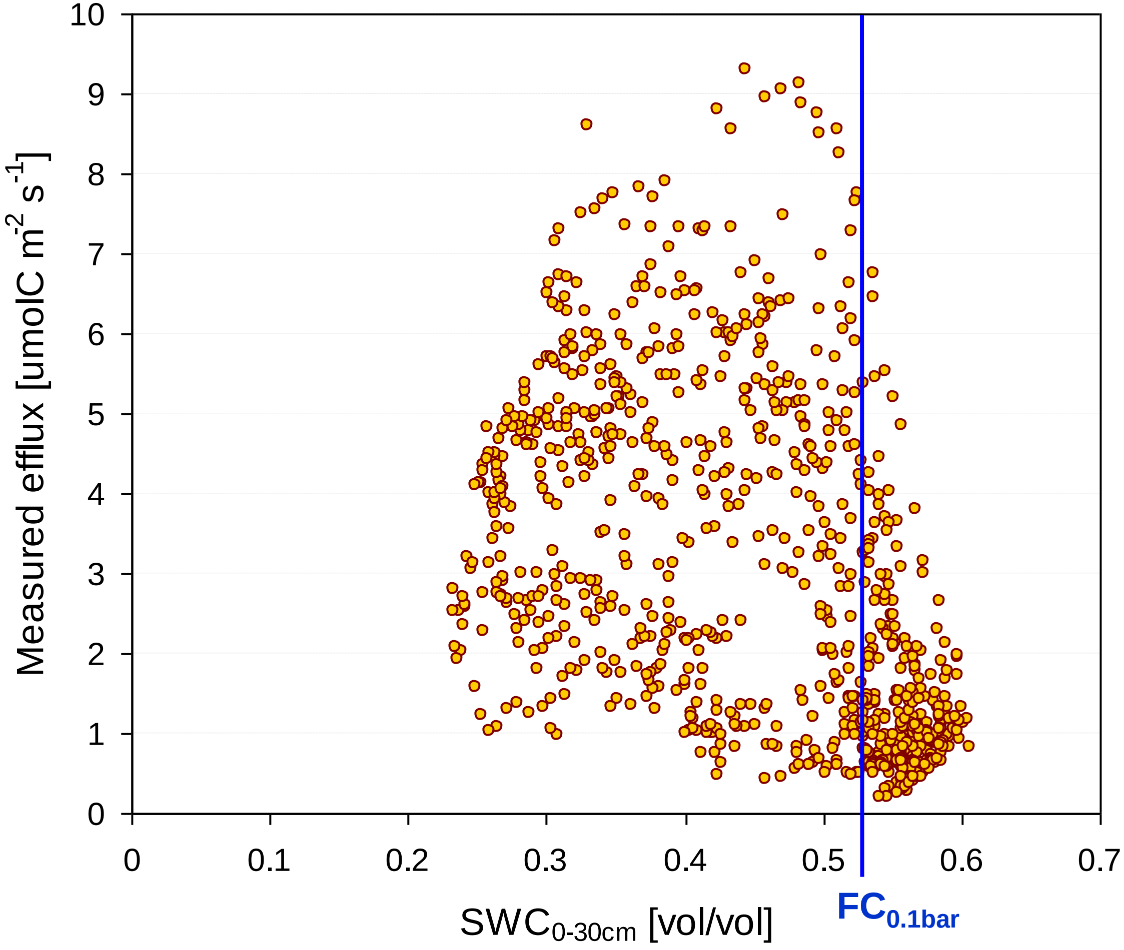
y = 0.9567x + 0.4466
R² = 0.5341
Reco_HBLR (gC m-2 day-1)
Soil CO2 efflux (gC m-2 day-1)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Results

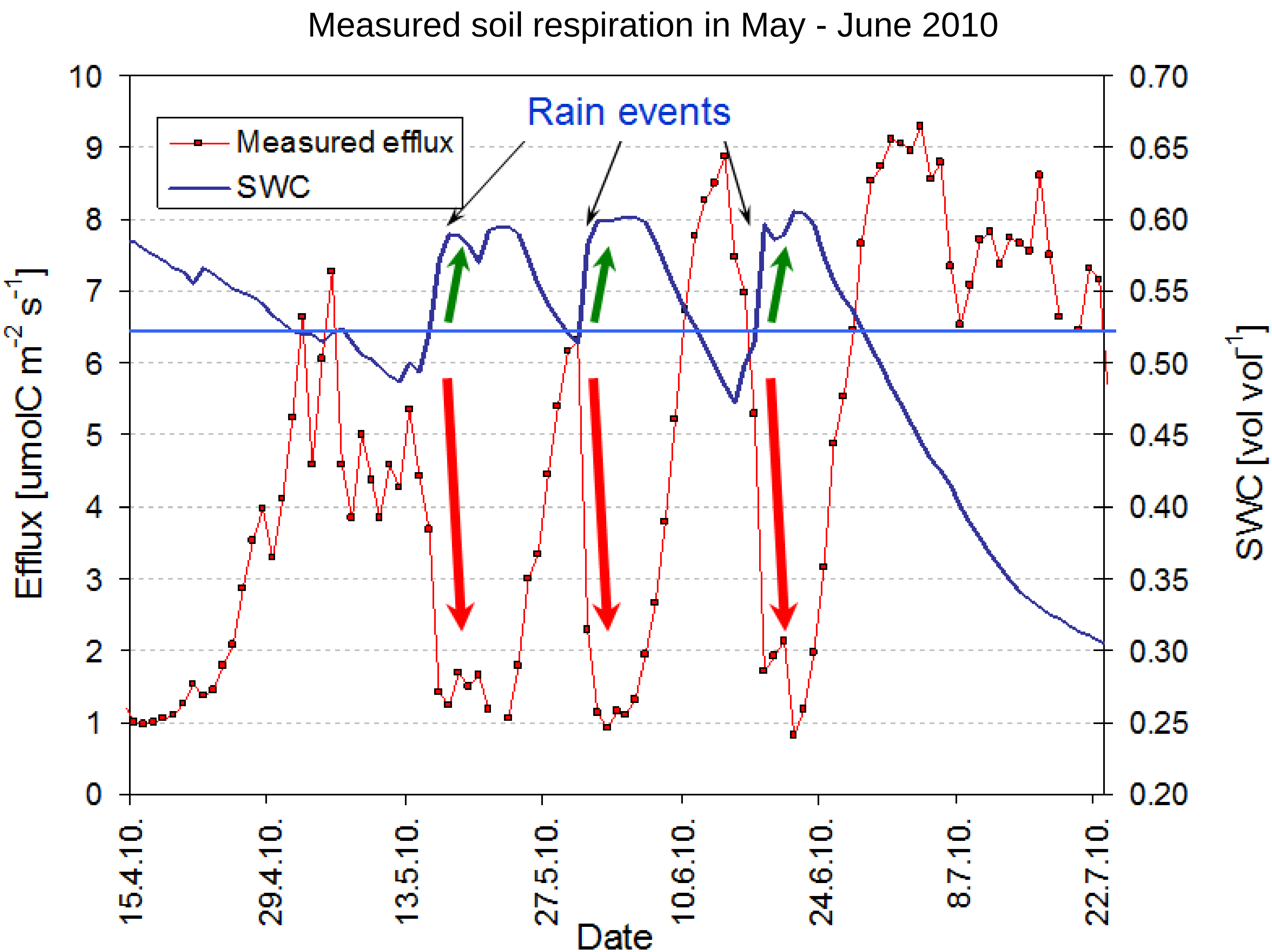
Year	NEE_f	NEE_HBLR	GPP_HBLR	SE_GPP_HBLR	Reco_HBLR	SR
	gC m^{-2} yr^{-1}					
2008	-377	-290	1373	19	1083	999
2009	-588	-393	1424	20	1031	993
2010	-360	-258	1474	24	1216	984
Average	-442	-314	1424		1110	

Results

Dependence of SR on soil water content (SWC, 0-30cm)



For future considerations: observed sharp drop in SR when for swc>swc_{FC}



Conclusions

- Average sink of C in young pedunculate oak forest between 2008-2010 was estimates to be between -442 and -314 gC m^{-2}
- Environmental service of value ~70 – 90 eur/ha (6 eur/tCO_2)
- During the wet 2010 highest R_{eco} and lowest R_s were obtained wich is is counter-intuitive, since R_s is part of R_{eco}.
- Optimization of gapfilling and flux partitioning methods for high soil water content is required.
- Overall re-evaluation of data and processing routins is pending.

Acknowledgments

Setting up of EC site was partly supported by EU Interreg IIIB/CARDS project Carbon-Pro, and Croatian Forest Ltd. within the project "Sustainability of carbon storage in managed forest of pedunculate oak".

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Thank you!

Hvala!