A Training Course on CO_2 Eddy Flux Data Analysis and Modeling

Flux Partitioning: Theory

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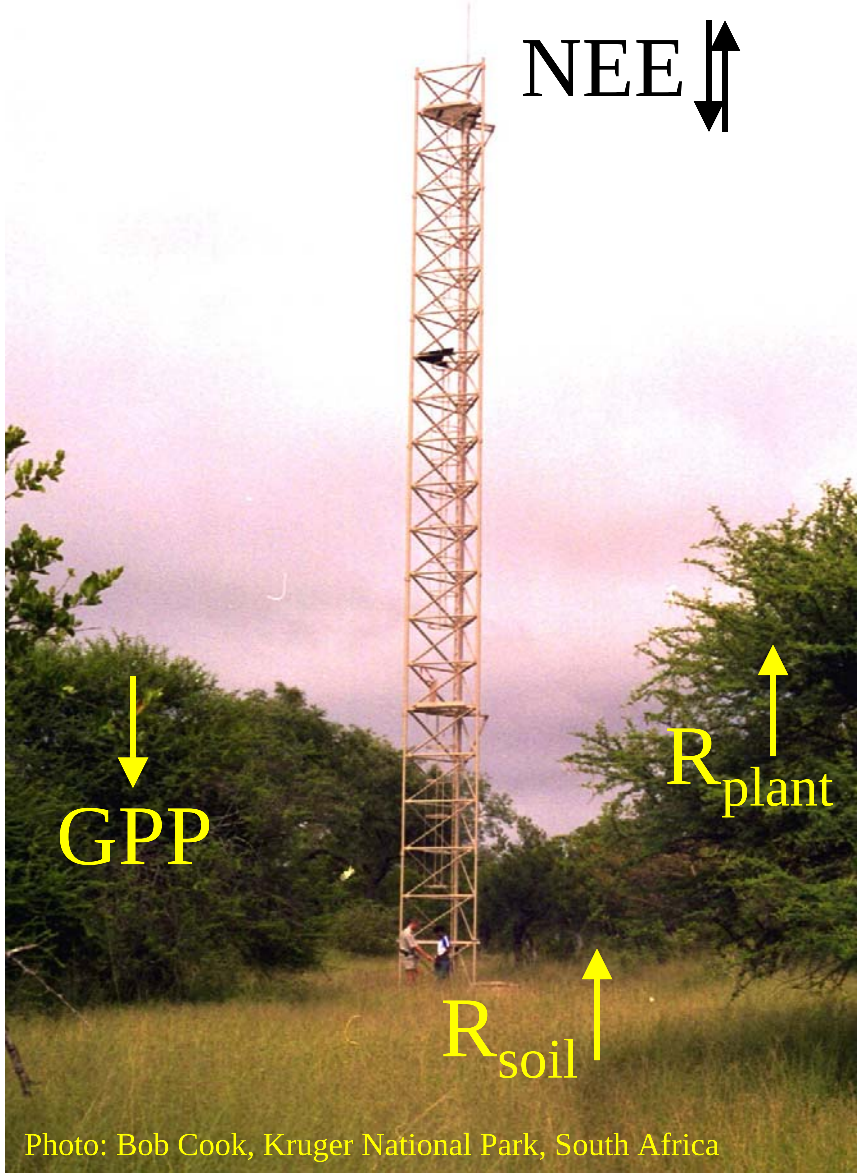
Theory: Why flux partition data?



Only NEE (Net Ecosystem Exchange of CO_2) measured

Stand: CO_2 source or sink? When? How much? Why?

How much respiration (Reco)?

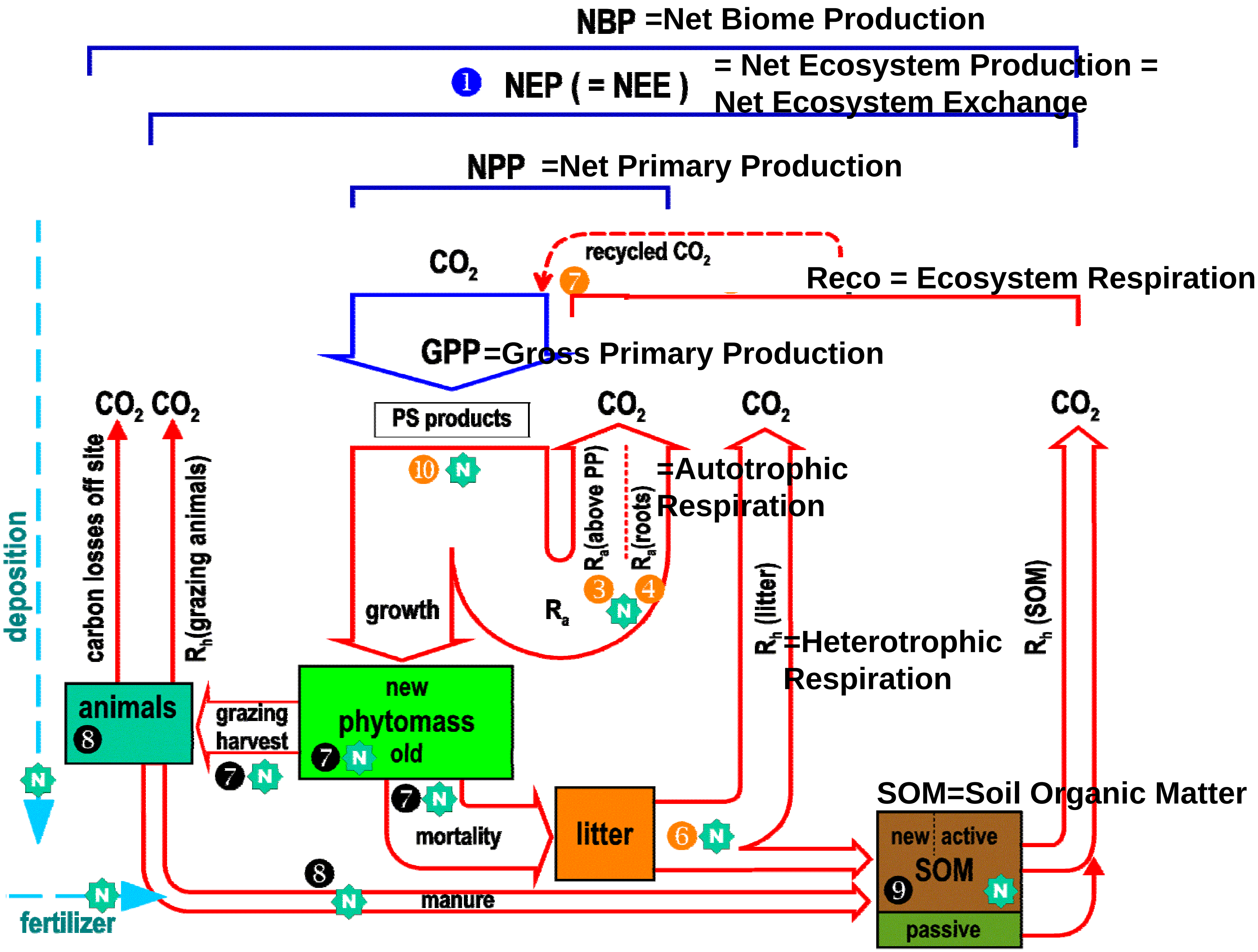
How much CO_2 uptake/photosynthesis (GPP)?

NEE = Reco - GPP

Why flux partition data?

- Stakeholders (i.e., funding agencies, government environmental agencies, policy makers, etc.) may want complete annual sums of all fluxes - NEE, Reco, GPP
- Some models require GPP or Reco input

Different variables describing CO_2 fluxes



Different variables describing CO_2 fluxes

Reco = Ra + Rh

Ra = Autotrophic Respiration = from leaves, stems, roots and growth of plant

Rh = Heterotrophic Respiration = from litter and soil carbon

GEP = Gross Ecosystem Productivity $\approx$ GPP

In this presentation, we use GPP & GEP interchangeably.

“GEP does not take into account any internal recycling of CO_2 within the leaf via reassimilation of ‘dark’ respiration and is thus analogous, but not identical, to chamber-based GPP estimates.” Stoy et al. (in review)

What data to use to flux partition?

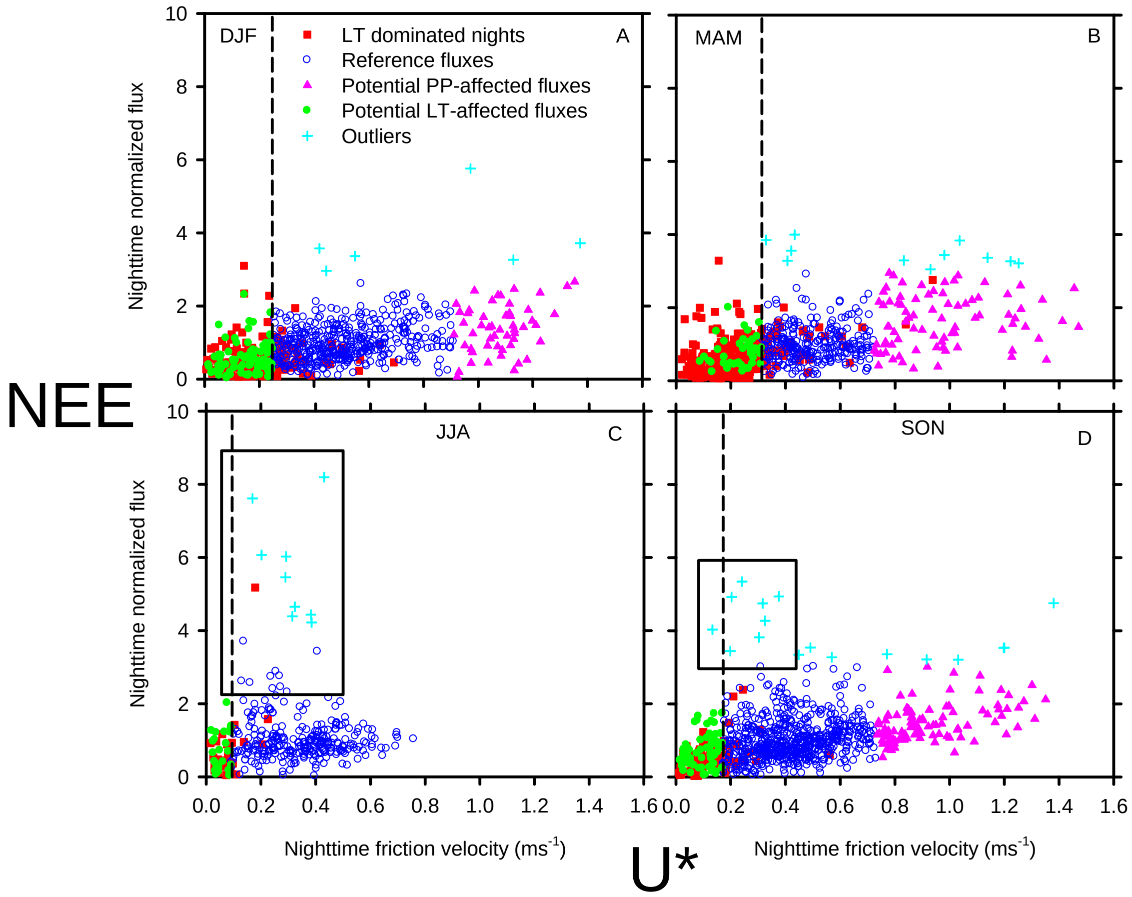
Raw NEE fluxes should not be flux partitioned without corrections & elimination of “bad quality” data

•Quality classes - Foken & Wichura 1996
•Storage correction
•Advection correction
•u* threshold

u* = friction velocity

Importance of u* threshold

- low u* values- Low Turbulence (LT) - typically at night & if used leads to an underestimate of NEE values
- high u* values- Pressure Pumping (PP) - additional flux contributions from air pores inside snow or soils released due to change in atmospheric pressure & high wind speed



Gu et al. 2005 AFM
Moving Point Test
Harvard Forest, MA, USA
mixed deciduous forest

Importance of u* threshold

No universally accepted method:

Moving Point Test (Gu et al., 2005 AFM)

•Reproducible, objective, statistically-based, site independent determination of lower (LT) and **upper** (PP) *u** thresholds

•*u** threshold = mean *u** of the group that separates high-*u** groups with statistically identical NEE means from low-*u** groups with significantly smaller NEE

•Takes into account diurnal and seasonal cycles of ecosystem respiration and *u** and correlative changes between them

•Temperature response function created to fill gaps created from u* filtering

95% u* Threshold Method (Reichstein et al., 2005 GCB) *Method used in Bayreuth

•Reproducible, objective, statistically-based, site independent determination of only lower (LT) threshold

•NEE data ordered according to 6 temperature classes, each with 20 u* classes.

•Threshold is the u* class where the nighttime flux reaches more than 95% of the average flux of the higher u* classes. The final threshold is the median of the thresholds of the 6 temperature classes.

•Minimum threshold of 0.1 m/s. If no u* threshold can be found, it is set at 0.4 m/s.

Simple Method

•Plot *u** vs. NEE

•Set *u** threshold where NEE levels off

•Site-dependent, subjective to site investigators opinion, does not allow for *u** to vary with time & space

Flux partitioning methods

No universally accepted method:

- Q_{10} annual
- Rectangular hyperbola
- Non-rectangular hyperbola
- Short term exponential *Method used in Bayreuth

More methods exist, but I will only discuss these

** Flux partitioning is done after u* threshold & corrections & filtering out "bad" data*

NEE = Reco - GPP

with - NEE indicating CO_2 sink

+ NEE indicating CO_2 source

Q_{10} annual method

$$NEE_{night} = \mathrm{Re}\,co_{night} = R_{10} \cdot Q_{10}^{\frac{T_{air}-10}{10}}$$

- R_{10} = base Reco at some reference temperature (10ºC)
- Q_{10} = exponential temperature response of Reco
- T_{air} = air temperature
- R_{10} & Q_{10} calculated annually -then used to recalculate Reco during night & day

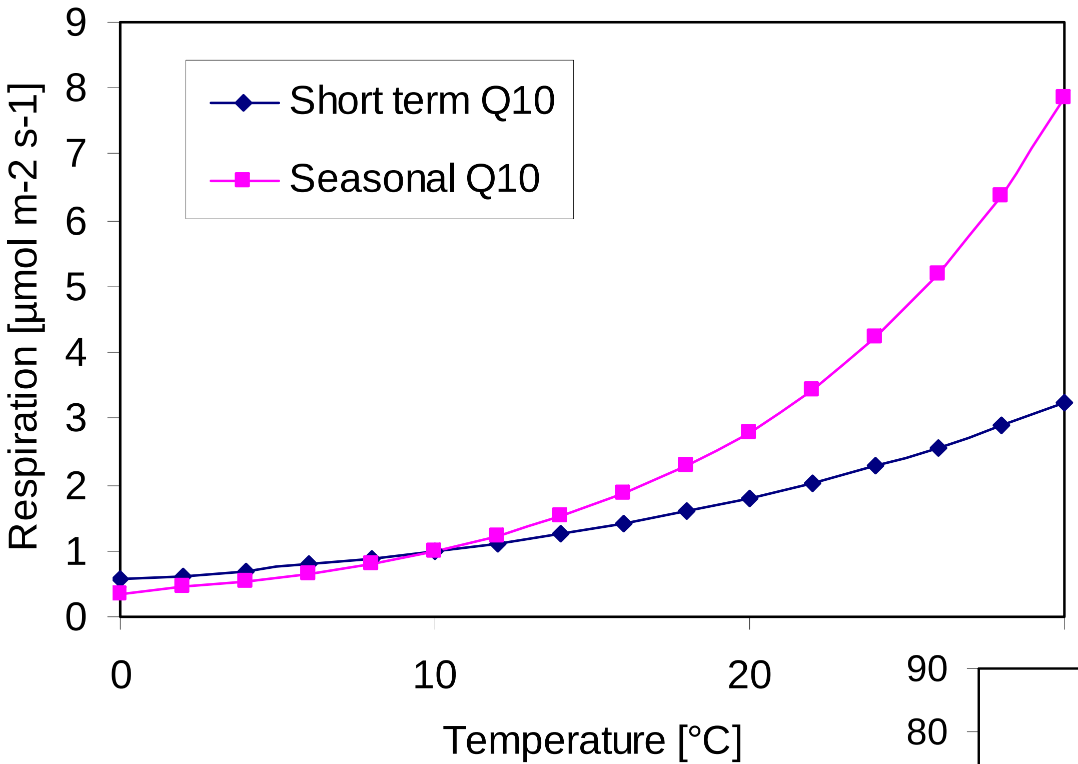
<u>Advantages</u>

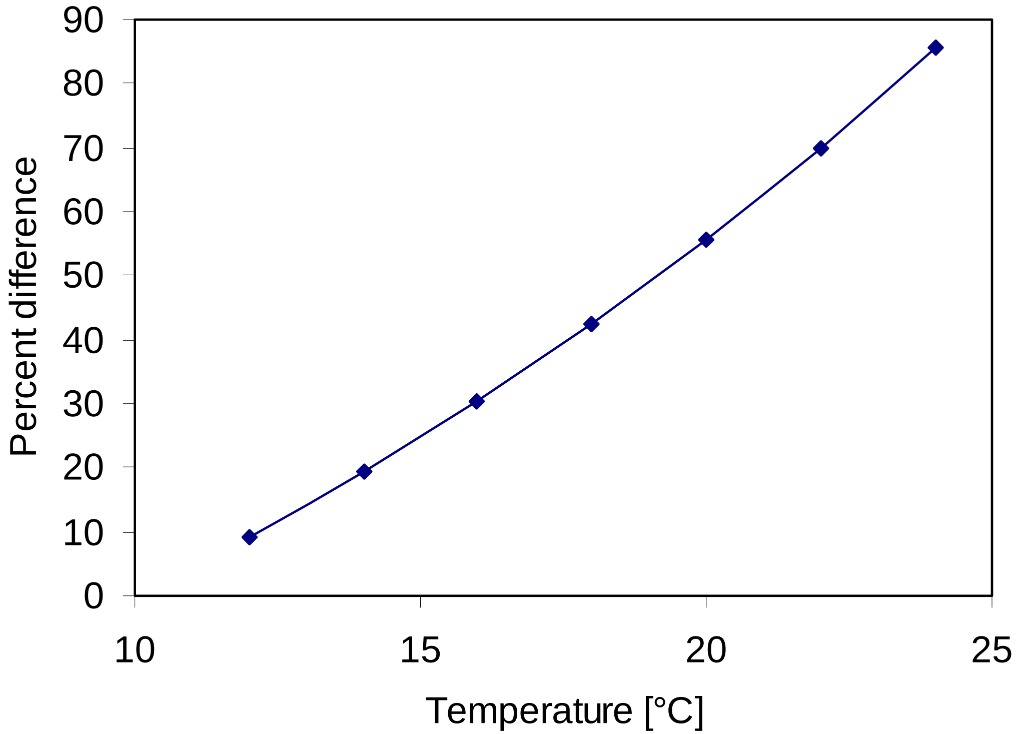
- Simplicity
- Allows for seasonally varying temperature sensitivity

<u>Disadvantages</u>

- Long-term temperature sensitivity may not reflect short-term response (i.e., winter dormancy, water balance, growth effects) - can lead to overestimation for daytime respiration of summer active vegetation

(Morgenstern et al. (2004) Agricultural & Forest Meteorology)





Source: Markus Reichstein

Rectangular Hyperbola method

$$NEE_{night+day} = -\frac{\alpha \cdot \beta \cdot Q}{\alpha \cdot Q + \beta} + \gamma$$

- α = apparent ecosystem quantum yield
- β = NEE at light saturation - maximum CO_2 uptake rate
- γ = estimate of Reco
- Q = PAR = photosynthetically active radiation
- α, β & γ estimated for every month. γ = Reco for each month

Advantages

- Simplicity
- Not only dependent on night values

Disadvantages

- No temperature or VPD sensitivity
- Reco is constant over an entire month - it should change over the course of a day
- Dependent on the equation form of the model

(Ruimy et al. (1995) Advances in Ecological Research)

Non-Rectangular Hyperbola method

$$NEE_{night+day} = -\frac{2}{2\eta}\left(\alpha Q + \beta - \sqrt{(\alpha Q + \beta)^2 - 4\alpha\beta\eta Q}\right) + \gamma$$

- α = apparent ecosystem quantum yield
- β = NEE at light saturation - maximum CO_2 uptake rate
- γ = estimate of Reco
- η = model curvature (0 <= η <= 1)
- Q = PAR = photosynthetically active radiation
- α, β, η & γ estimated for every day. γ = Reco for each day. Gaps are filled by the average monthly value

Advantages

- Simplicity yet day-to-day variation in Reco
- Not only dependent on night values

Disadvantages

- No temperature or VPD sensitivity
- Reco is constant over each day - it should change over the course of a day.
- Dependent on the equation form of the model

(Gilmanov et al. (2003) Global Biogeochemical Cycles)

Short term exponential method

*used in Bayreuth

$$NEE_{night} = \mathrm{Re}\,co_{night} = R_{ref} \cdot e^{E_0\left(\frac{1}{T_{ref}-T_0}-\frac{1}{T_{air}-T_0}\right)}$$

- R_{ref} = reference ecosystem respiration at 15° C
- E_0 = activation energy
- T_{ref} = reference temp = 15° C
- T_0 = base temp = -46.02° C
- T_{air} = air temperature in ° C

Advantages

- Accounts for temporally varying respiration rates at reference temperature & seasonally varying temperature sensitivity

- E_0 (short-term) estimated w/ 14day window & 5day time step. The average E_0 of each window weighted by the inverse of the standard error was averaged and set as a constant E_0 over the year.
- R_{ref} estimated w/ 8day window & 4day time step. Missing values were linearly interpolated
- Reco during night & day was calculated with estimated E_0 & R_{ref} parameters

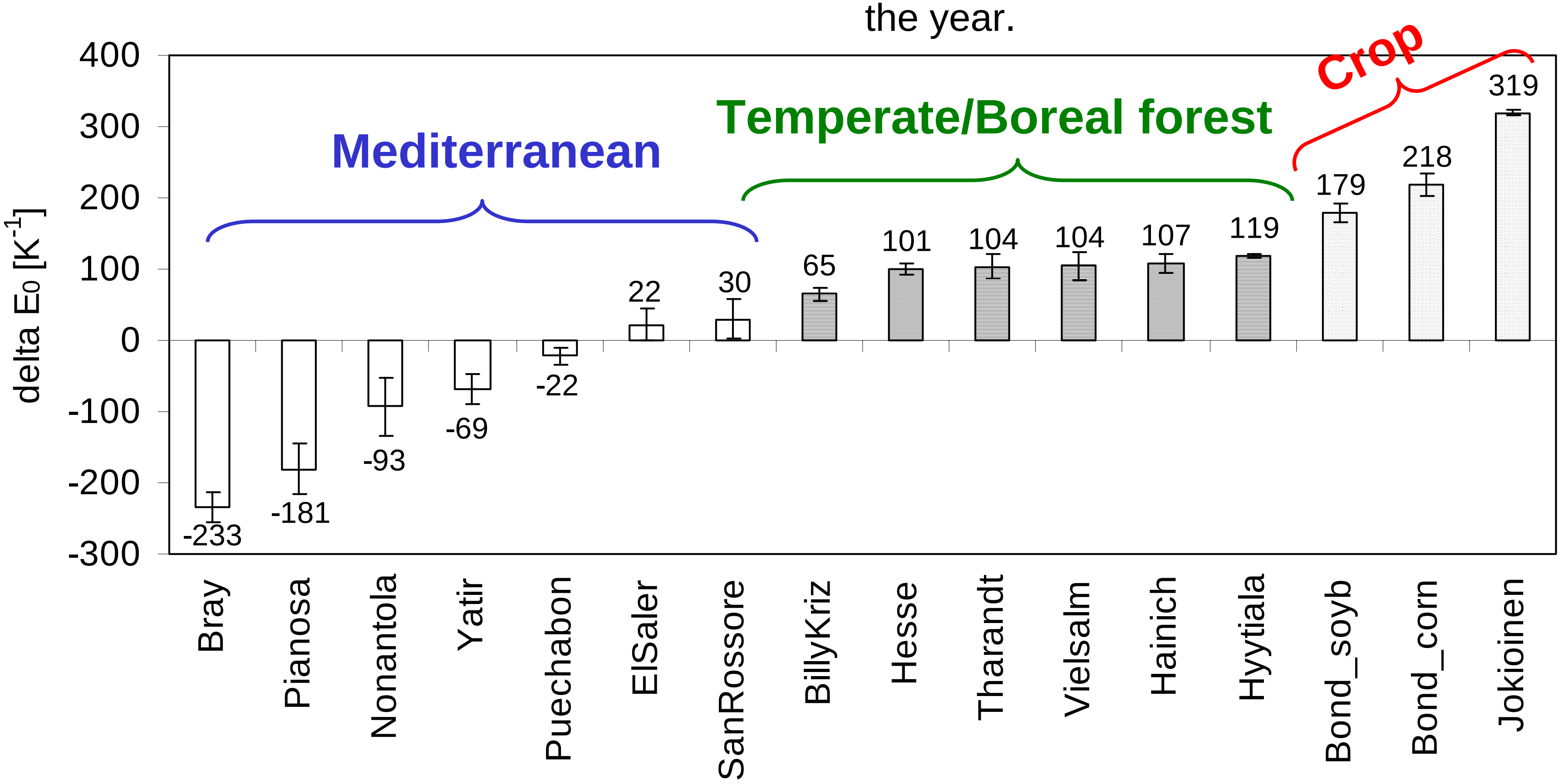
Disadvantages

- Noisiness of data does not always allow for derivation of parameters over all periods of the year.
- Enough “good” but not representative data can cause usually high or low values of Reco.

(Reichstein et al. (2005) Global Change Biology)

Long-term minus short-term E_0

- E_0 estimated as a constant over the entire year.
- E_0 estimated w/ 15day window & 5day time step. The average E_0 of each window weighted by the inverse of the standard error was averaged and set as a constant E_0 over the year.



(Reichstein et al. (2005) Global Change Biology)

Comparison of effect of short- and long-term E_0 on estimates of Reco

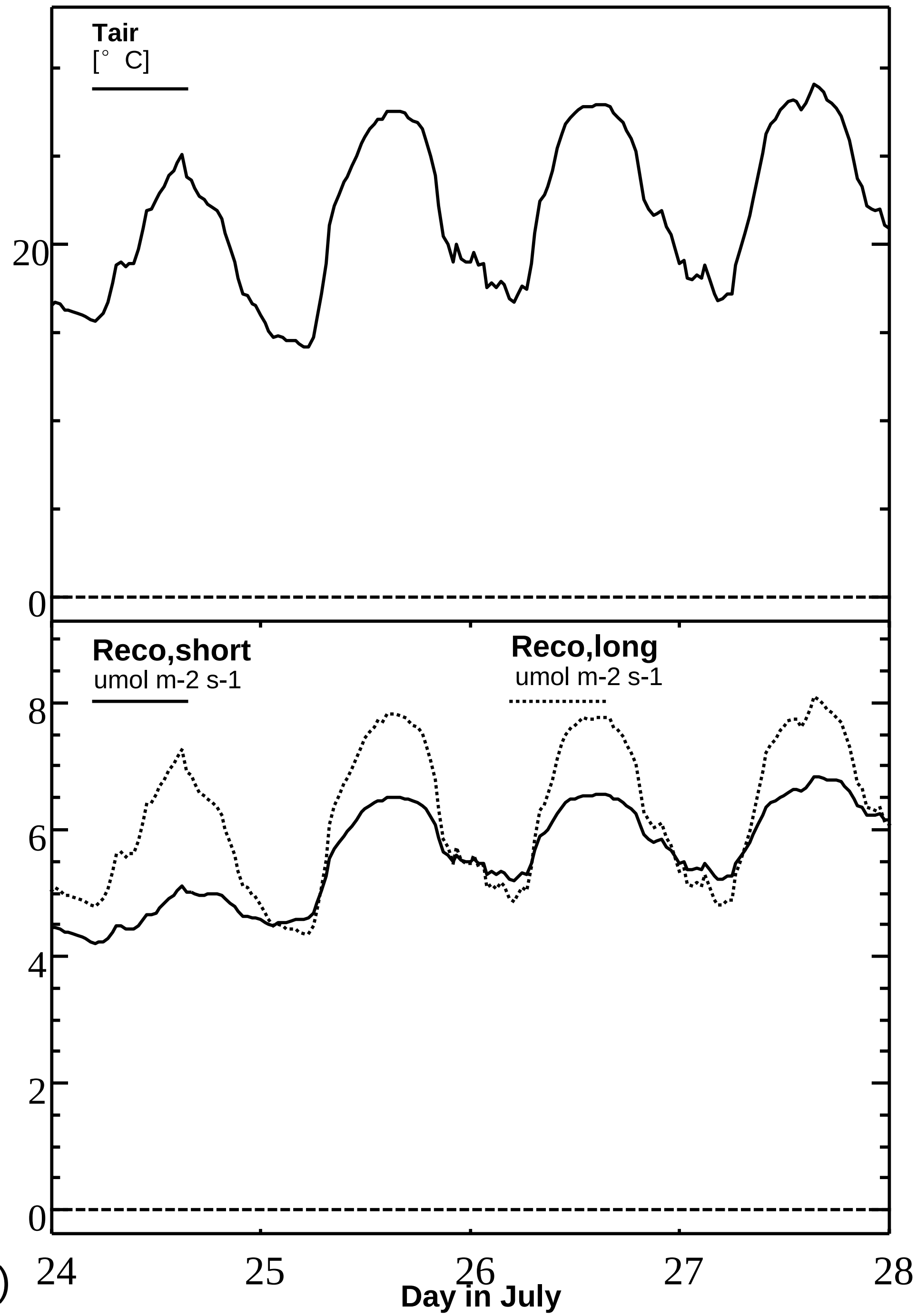
- $E_{0\mathbf{short}}$ = 104 K^{-1}
- $E_{0\mathbf{long}}$ = 205 K^{-1}

When $T_{air} >> T_{ref}$ then error in Reco is dominated by error in E_0, not in the error in R_{ref}. Then an overestimate of E_0 leads to an overestimate of Reco.

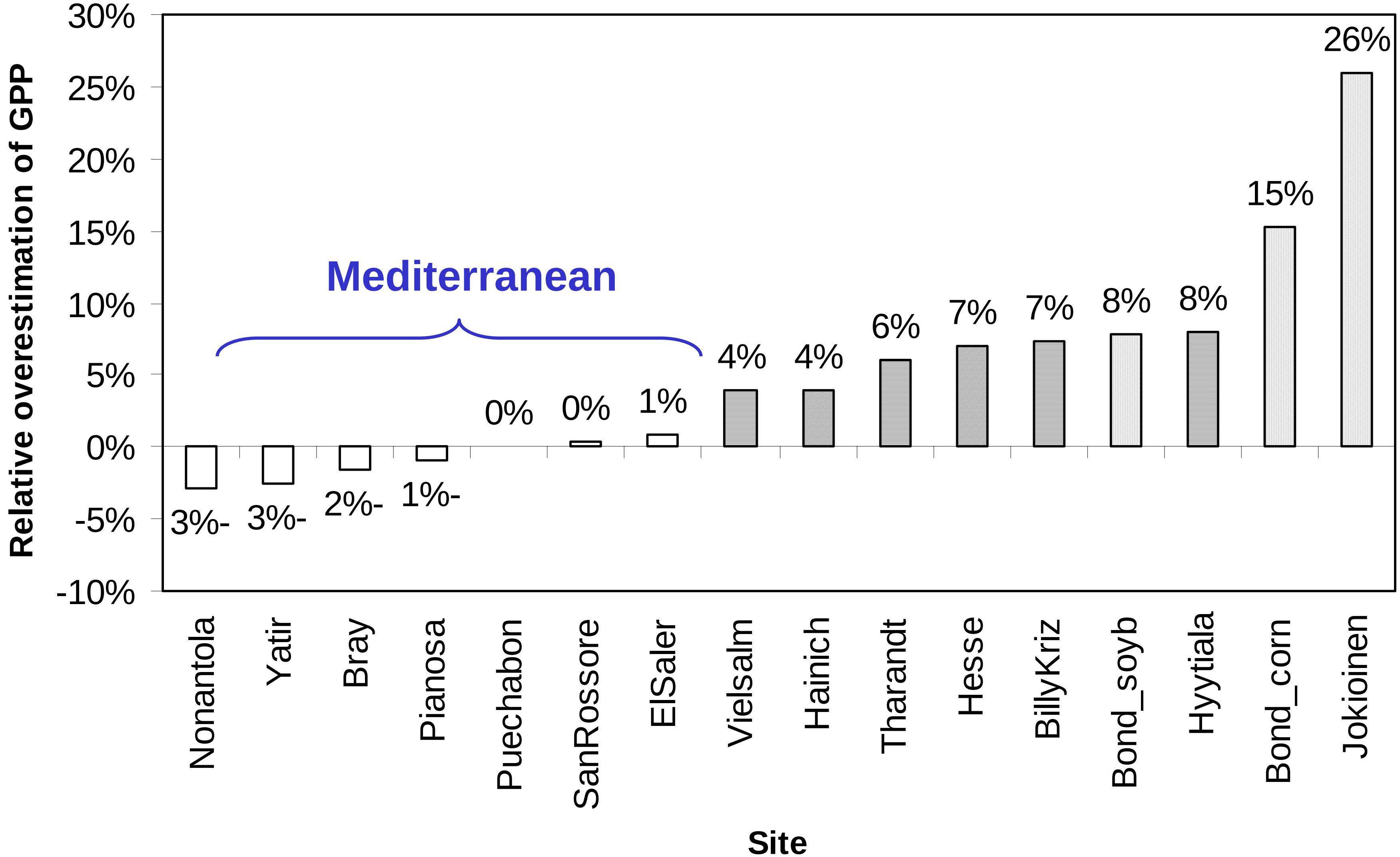
Hesse, France 2001

Deciduous Beech Forest

(Reichstein et al. (2005) Global Change Biology)

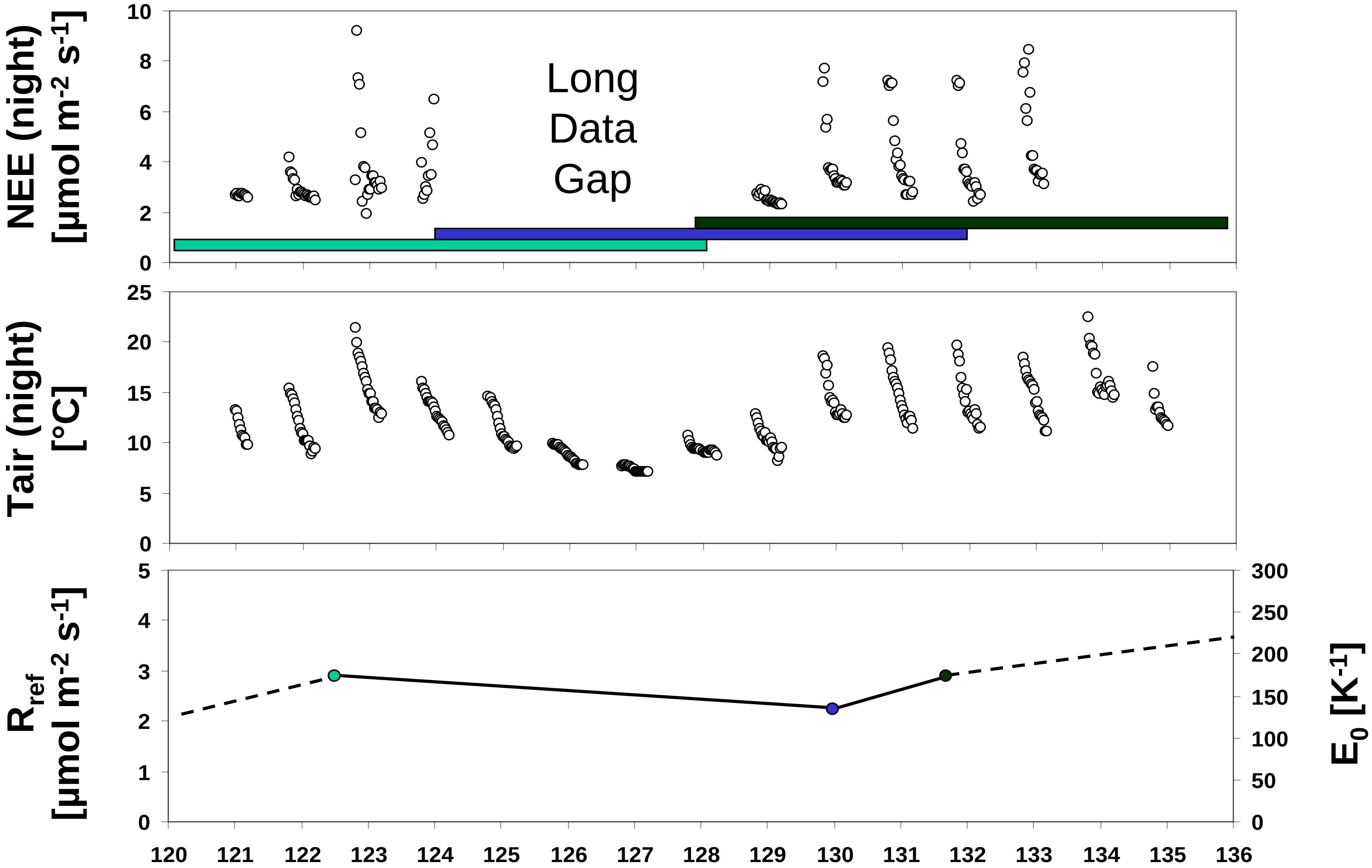


Effect of long-term estimation of E_0 on annual GPP



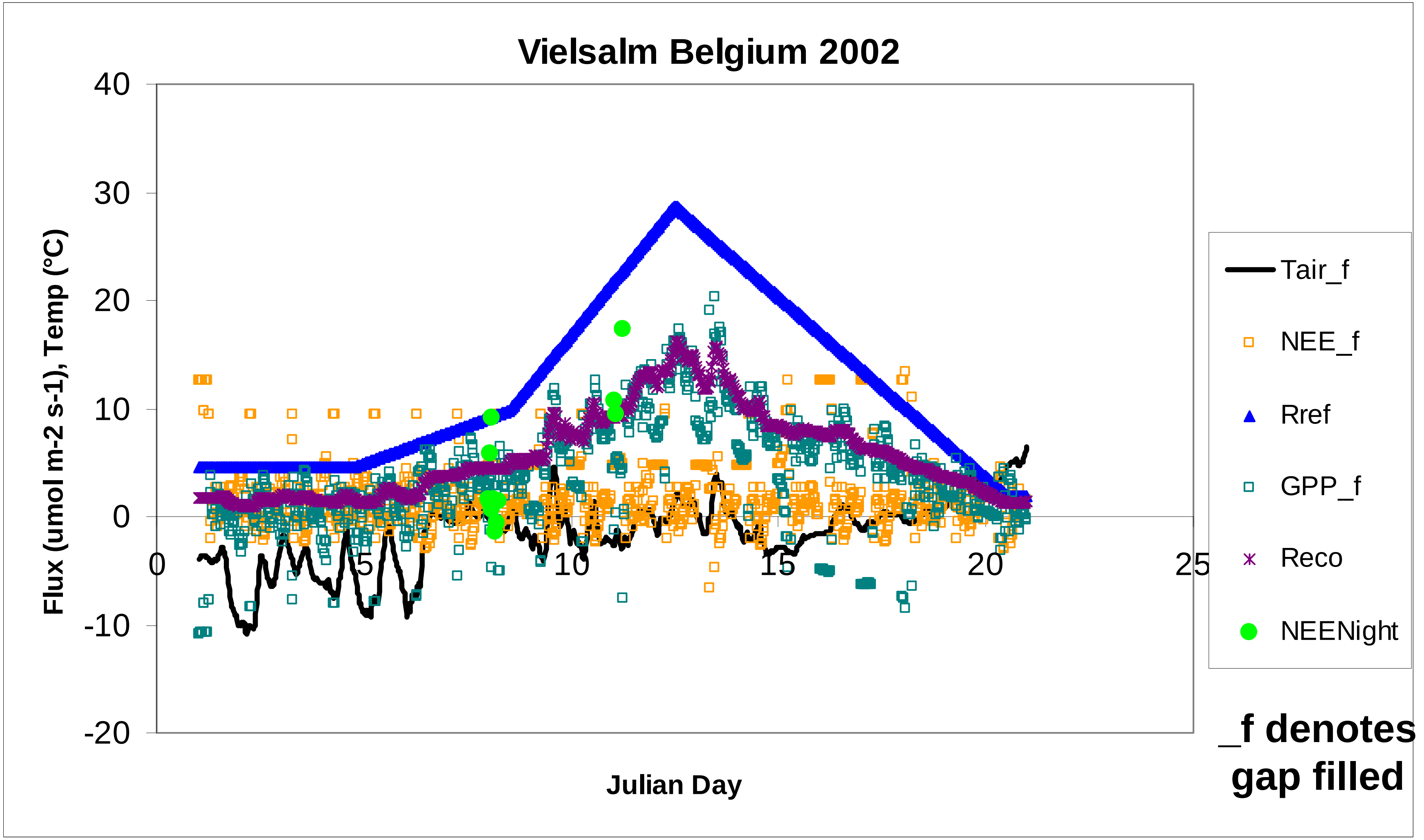
(Reichstein et al. (2005) Global Change Biology)

Estimation of Lloyd & Taylor parameters for Reco



From Markus Reichstein

Problems with short term exponential method



_f denotes gap filled

Theory: Conclusions

- No world-wide standard method exists.
- Different methods may be suitable for different sites
- Different methods may be suitable for different goals & modelling exercises
- In order to model a wide variety sites consistently, we chose Short Term Exponential Method (Reichstein et al. 2005)
- Differences in flux partitioning methods can cause different annual sums of Reco & GPP

Acknowledgements

- Presentations from Gap filling Workshop - June 9-10, 2004 in Viterbo, Italy