Evaluation of the diurnal cycle of O_2 and CO_2 above the canopy of a forest and its application to further constrain the forest carbon balance

The different O_2:CO_2 ratios above a forest and how to use them

Kim Faassen

Linh Nguyen, Eadin Broekema, Bert Kers, Ivan Mammarella, Janne Levula, Timo Vesala, Penelope Pickers, Andrew Manning, Harro Meijer, Bert Heusinkveld, Wouter Peters, Jordi Vilá -Guerau de Arellano and Ingrid Luijkx

The Exchange Ratio (ER)

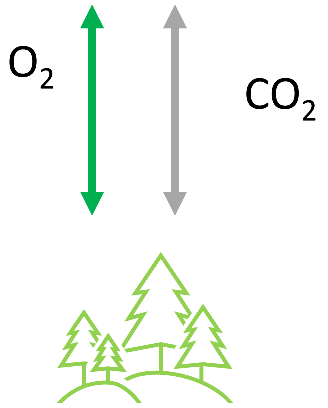
- Short time scale
- Continuous Time series
- Mole fractions
- Fluxes
- Local scale

$$ER = \frac{\Delta O_2}{\Delta CO_2}$$

$$CO_2 + water \leftrightarrow glucose + O_2$$

$ER/\alpha_B = -1.1$

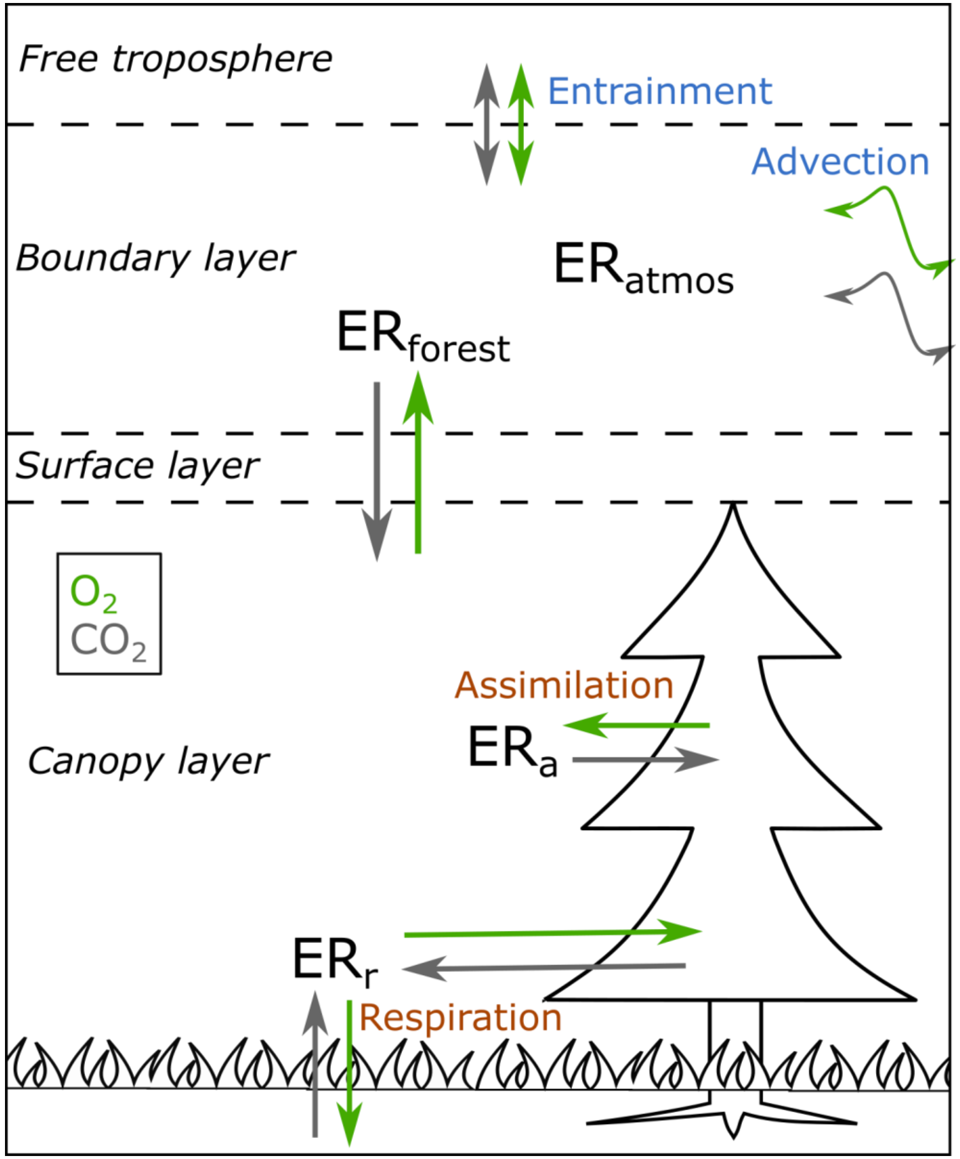
Severinghaus, 1995



Local scale

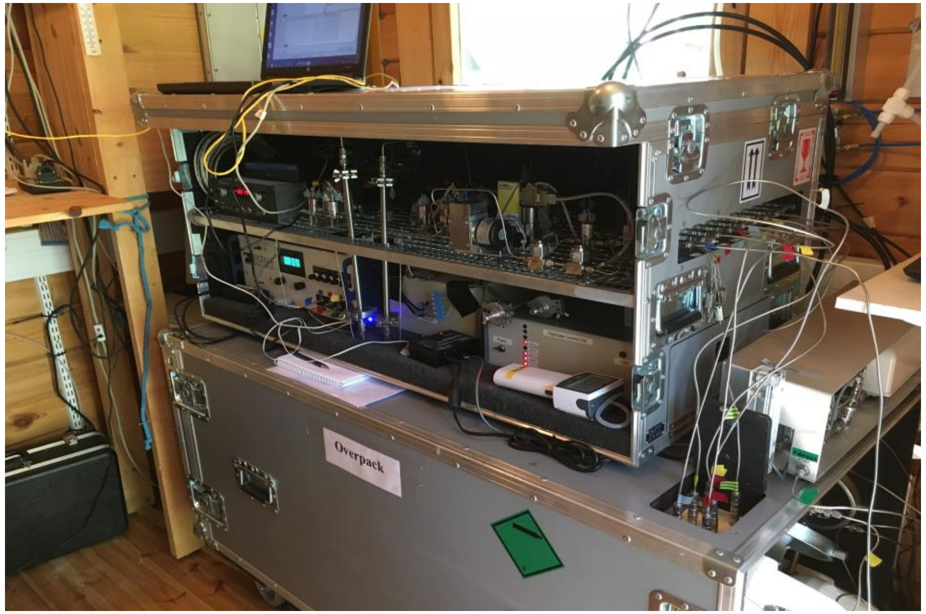
- ER_{atmos} = 1 single height
- ER_{forest} = surface fluxes
  - Multiple heights

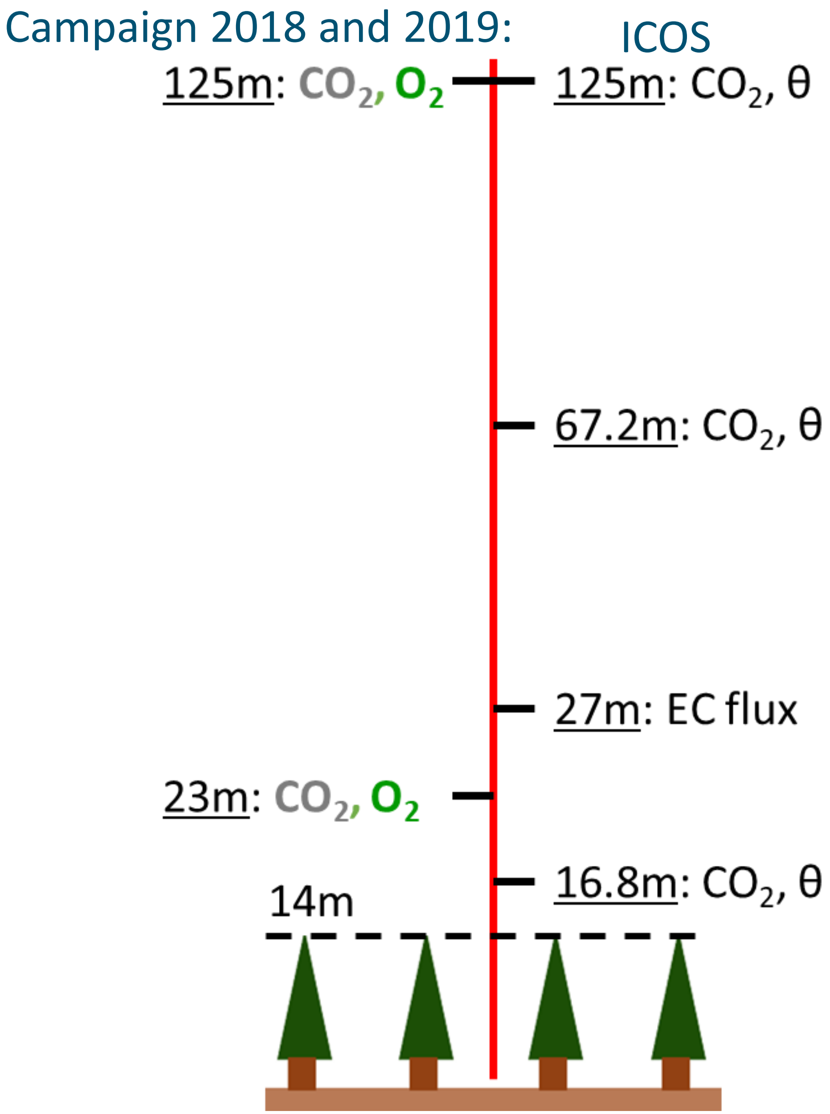
Get new insights into ER signals of boreal forest



Measurements at Hyytiälä

Oxzilla O_2 analyser & NDIR CO_2 analyser

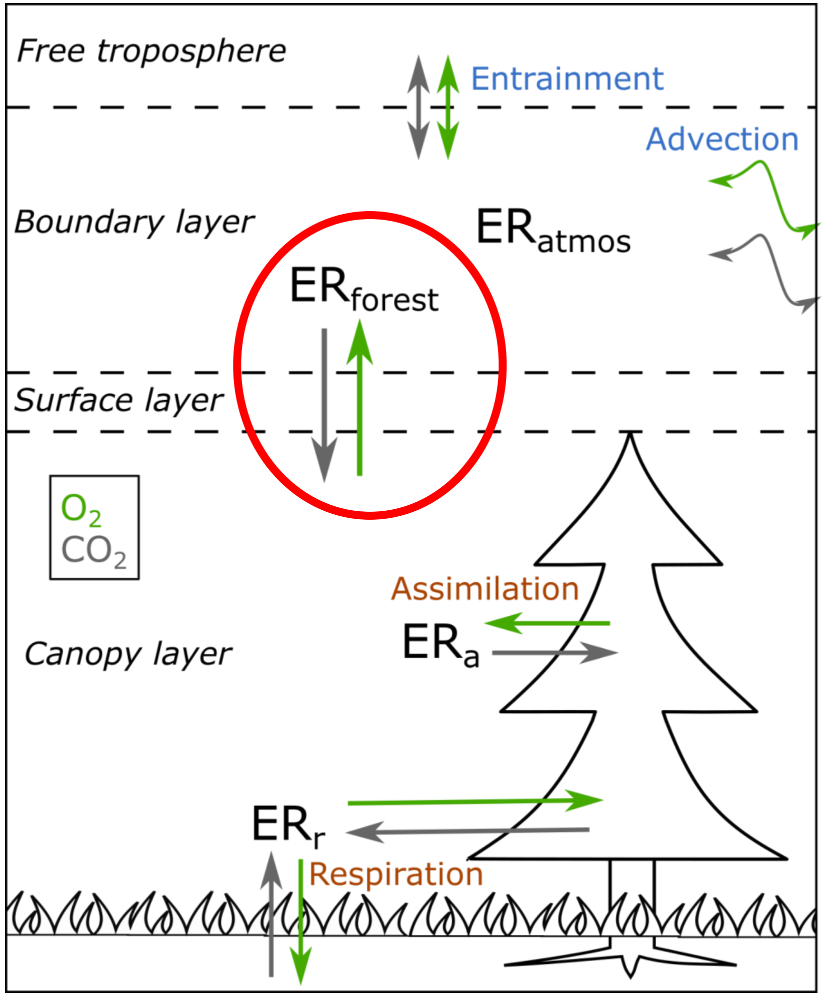




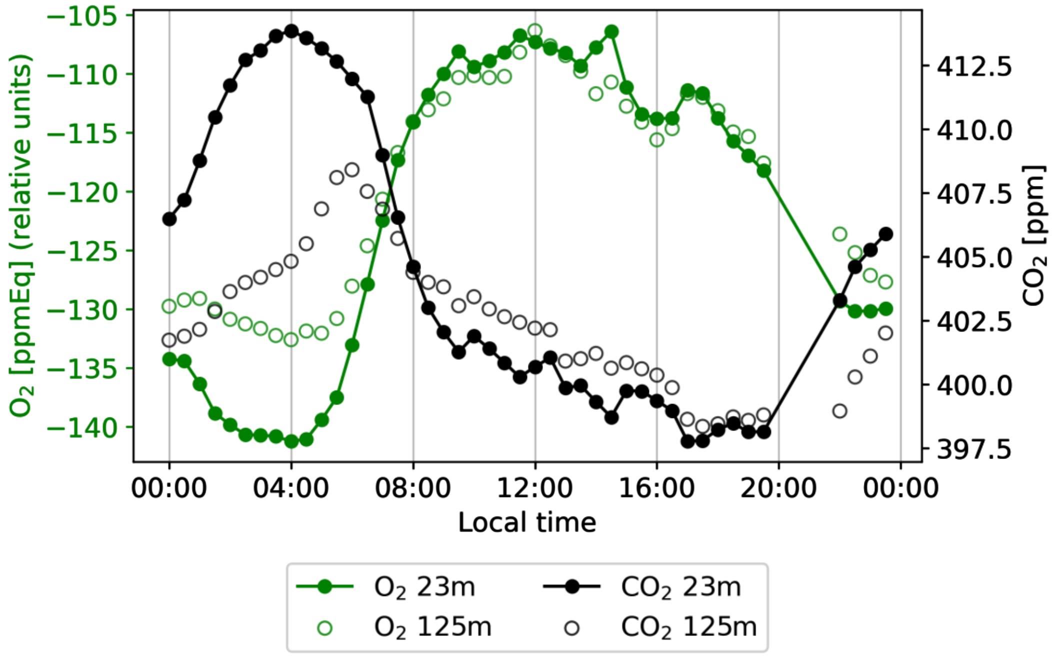
Faassen, K. A. P., Nguyen, L. N. T., Broekema, E. R., Kers, B. A. M., Mammarella, I., Vesala, T., Pickers, P.A., Manning, A.C., Vilà-Gueraude Arellano, J., Meijer, H.A.J., Peters, W., & Luijkx, I.T. (2023). Diurnal variability of atmospheric O_2, CO_2, and their exchange ratio above a boreal forest in southern Finland. *Atmospheric Chemistry and Physics*, 23(2), 851-876

ER_{forest}: surface fluxes (multiple heights)

$$ER_{forest} = \frac{F(O_2)_s}{F(CO_2)_s}$$



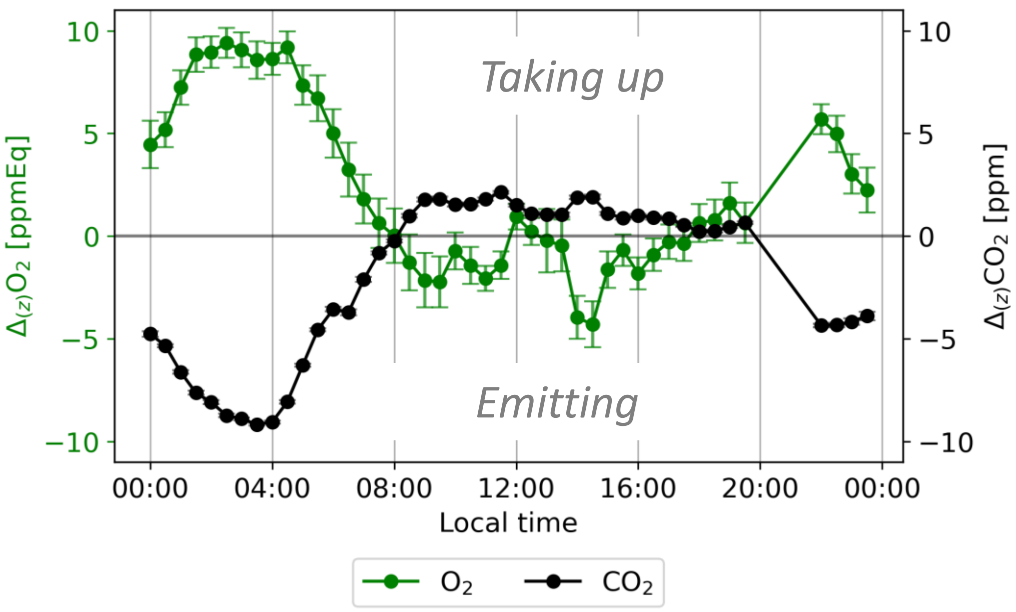
Gradient (125m – 23m):



Respiration dominant

Photosynthesis dominant

Respiration dominant



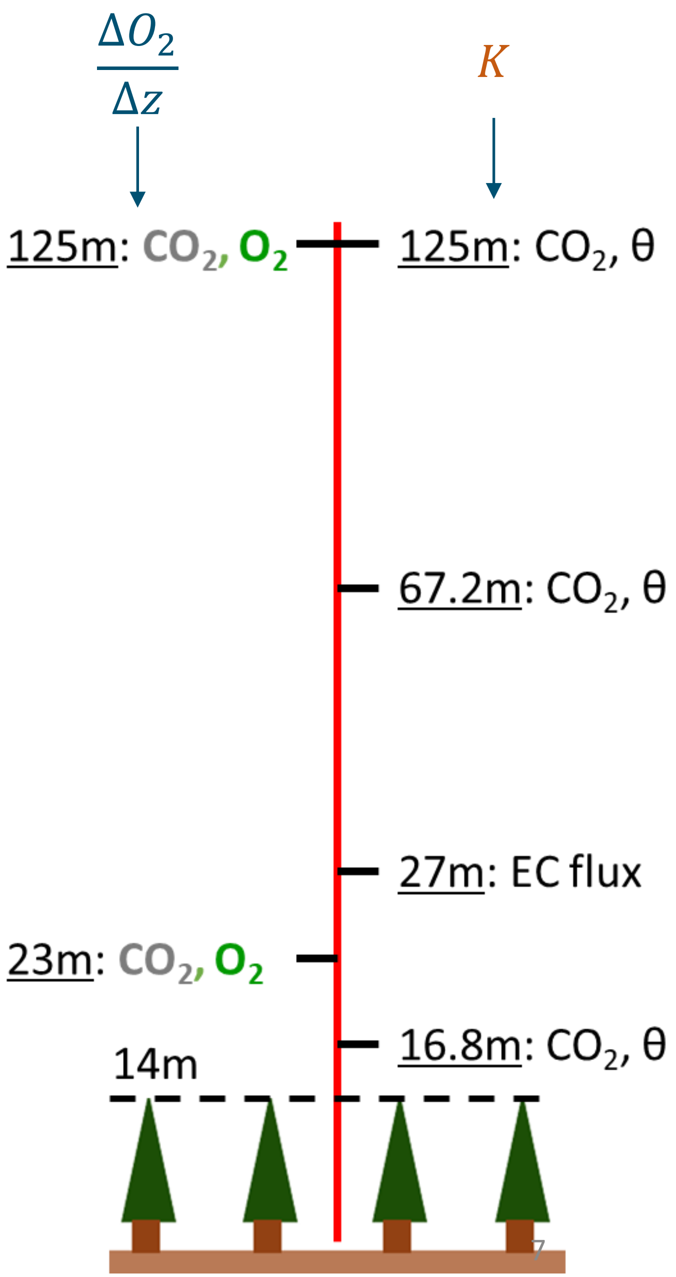
Flux ≈ -K Gradient*

Flux calculations

Flux ≈ -K Gradient*

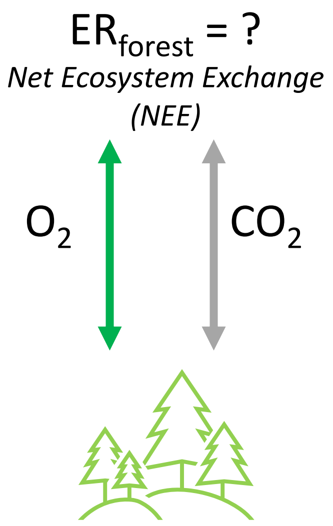
$$K = -\frac{\partial CO_2}{\partial z} / F(CO_2)_s$$

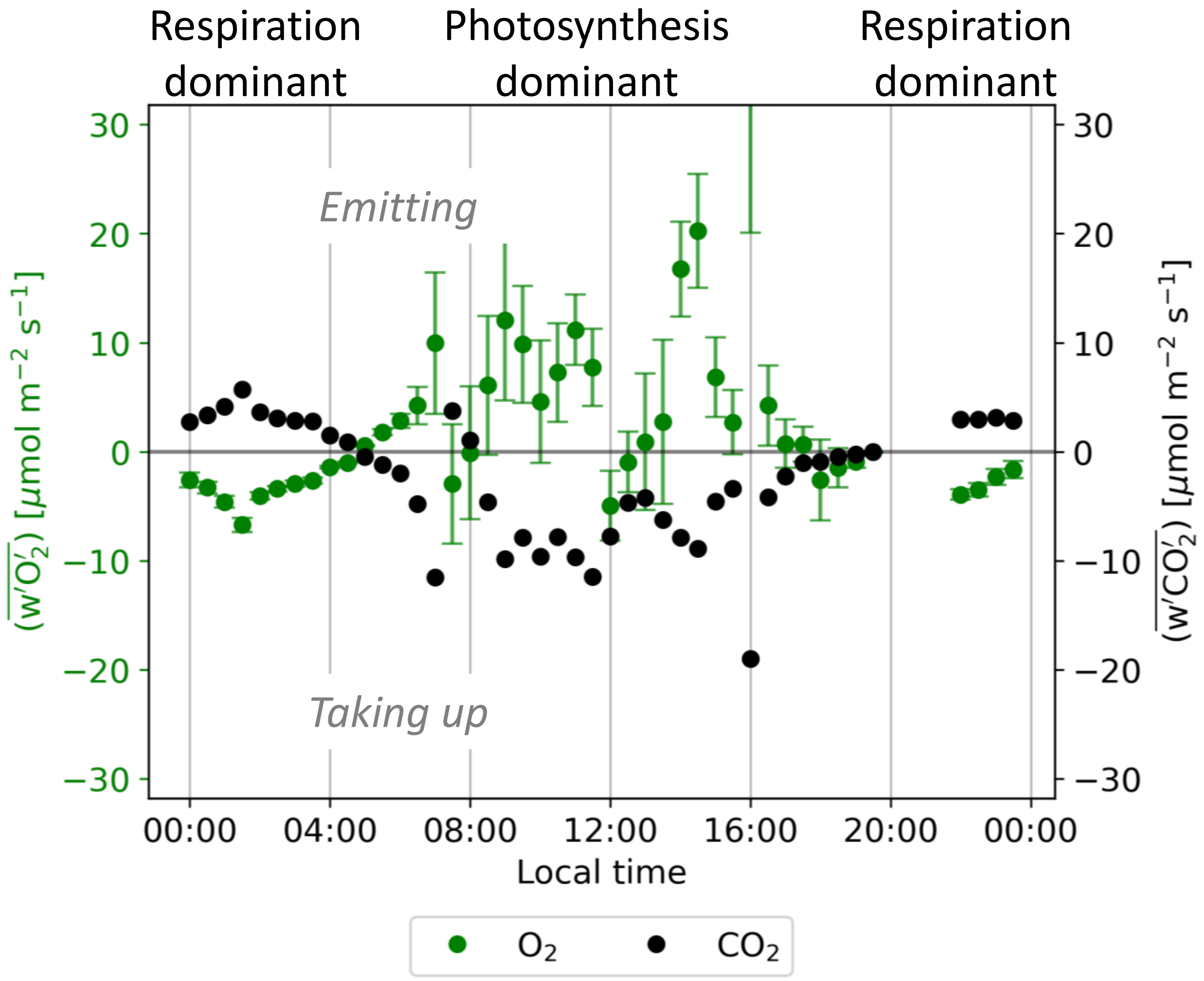
$$F(O_2)_s = -K * \frac{\Delta O_2}{\Delta z}$$



O_2 and CO_2 surface fluxes

Flux ≈ -K Gradient*



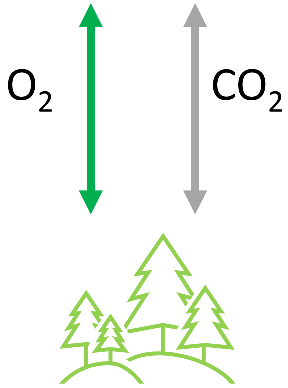


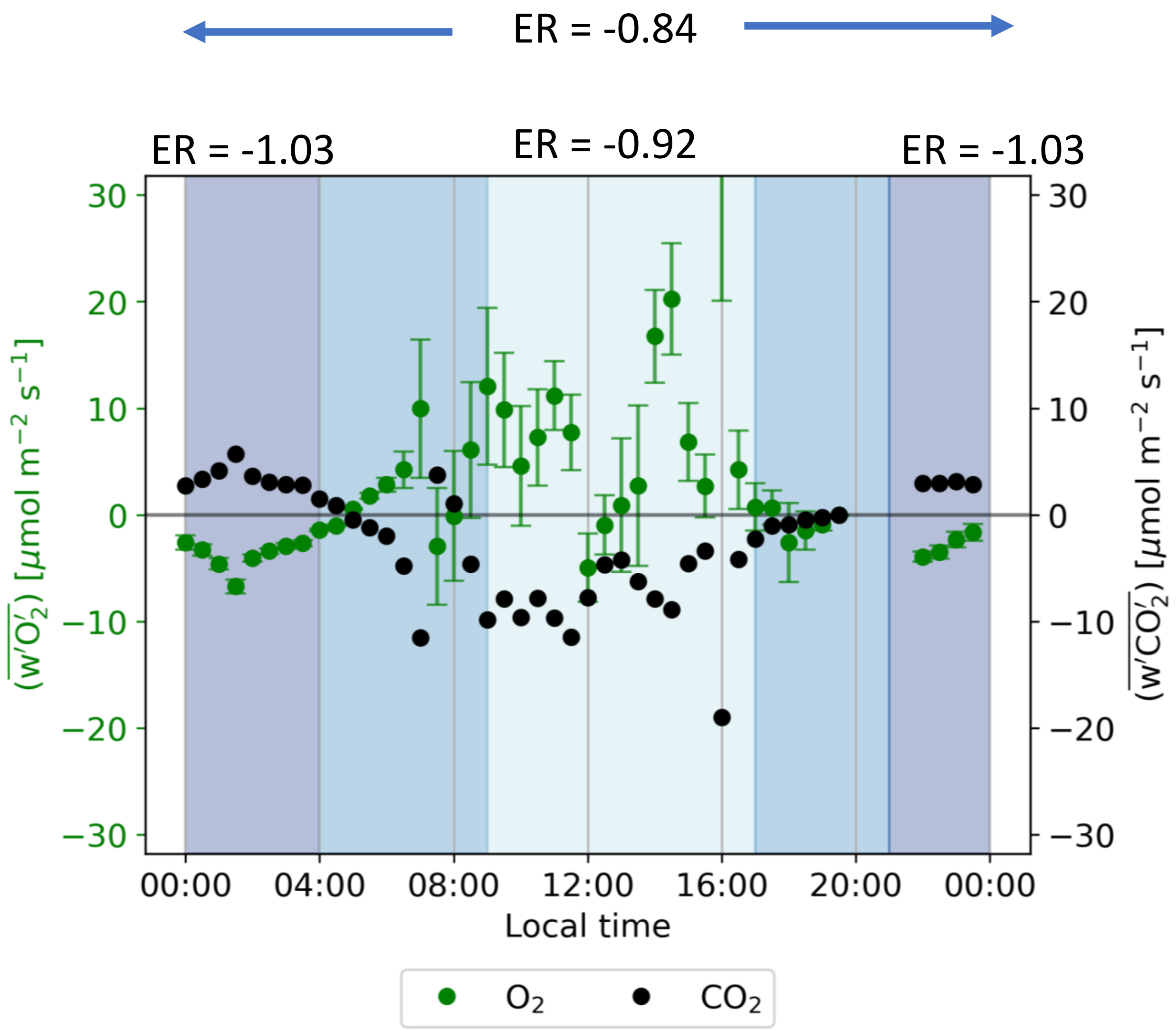
Faassen et al. (2023)

ER_{forest} signals

$$ER = \frac{Surface\ flux\ O_2}{Surface\ flux\ CO_2}$$

ER_{forest} = -0.84
Net Ecosystem Exchange (NEE)



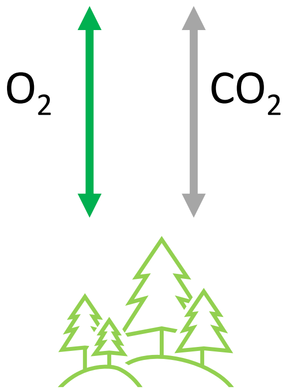


Faassen et al. (2023)

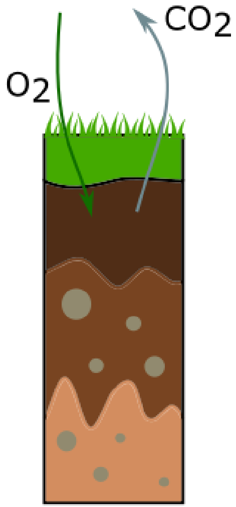
Got values for ERa and ERr

- ER respiration = ER night
- ER assimilation = based on day ER and day GPP and TER

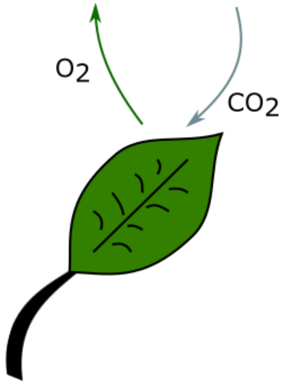
ER_{forest} = -0.84
Net Ecosystem Exchange (NEE)



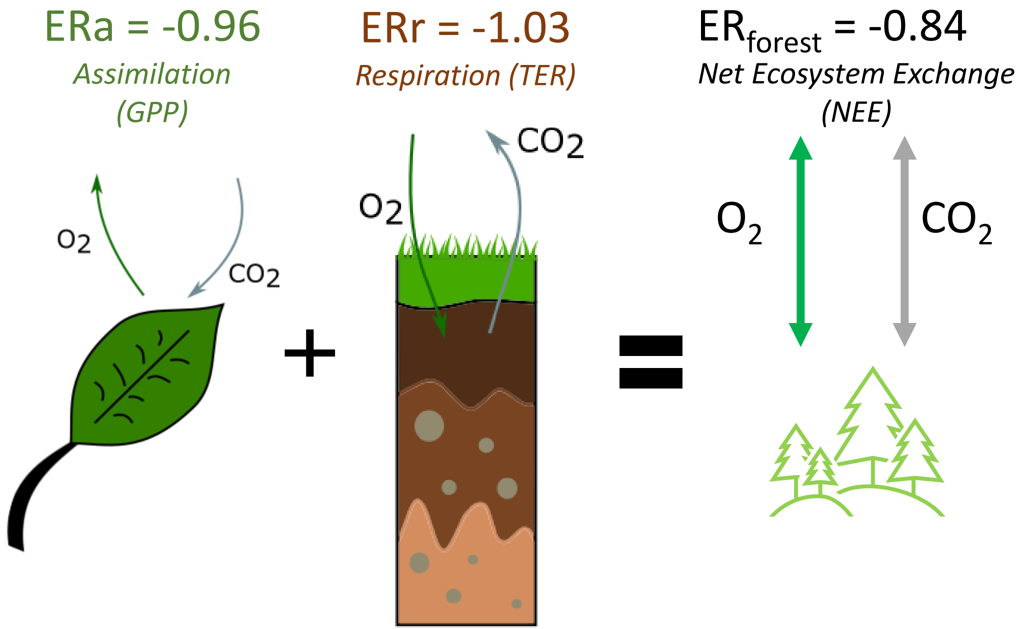
ERr = -1.03
Respiration (TER)

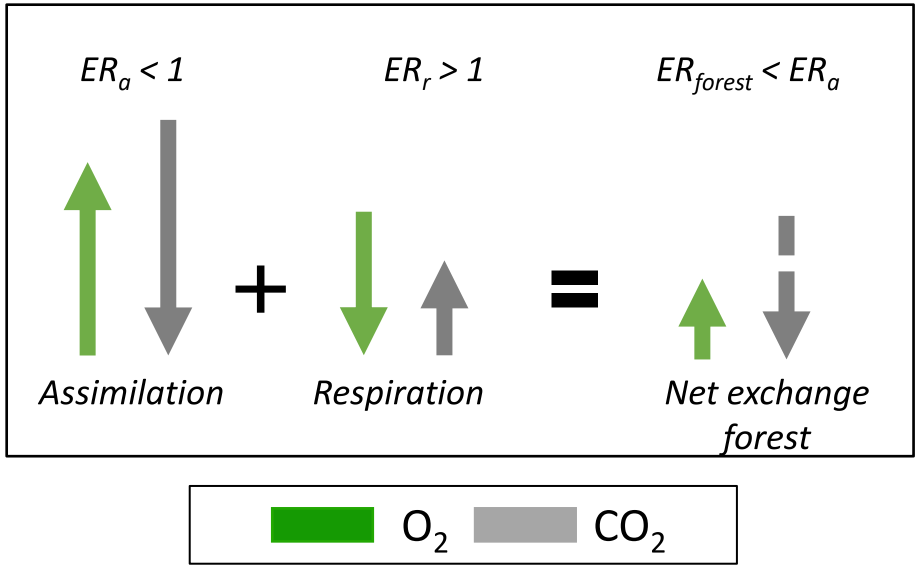


ERa = -0.96
Assimilation (GPP)



Averaging of ER signals





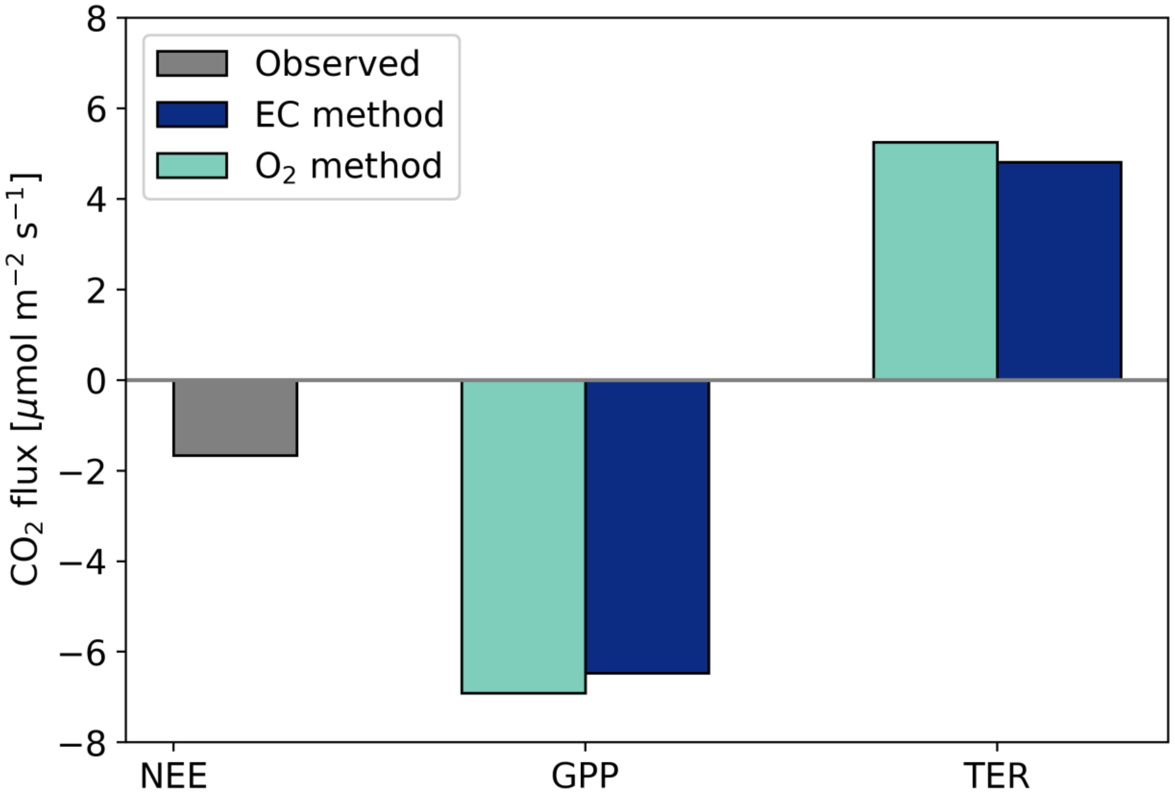
ER values cannot be averaged when fluxes are in opposite directions.

Look at the O_2 and CO_2 budgets separately

O_2 as a partitioning method

- Applied to different day
- Shows promising results to use O_2 as a tool to split NEE into GPP and TER
- Works for 1 day in Hyytiälä

Faassen et al. (2023)



(Net Ecosystem Exchange)
(Gross Primary Production)
(Total Ecosystem Respiration)

New PhD project: O_2/CO_2 measurements from lab to field

Lucas Hulsman

RQ: What is the variability of the ER on leaf- plant- and ecosystem- scale under different environmental conditions?

Leaf

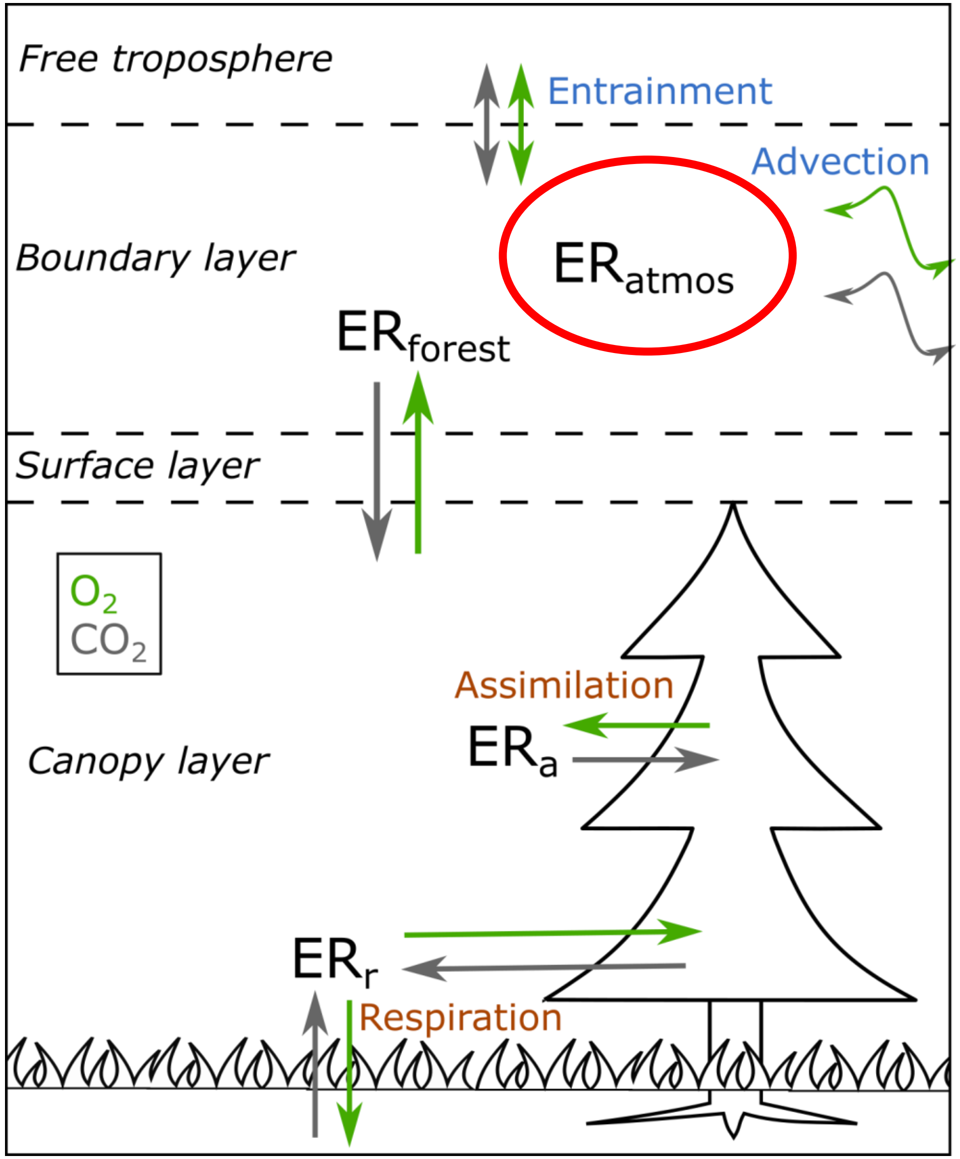
Plant

Ecosystem

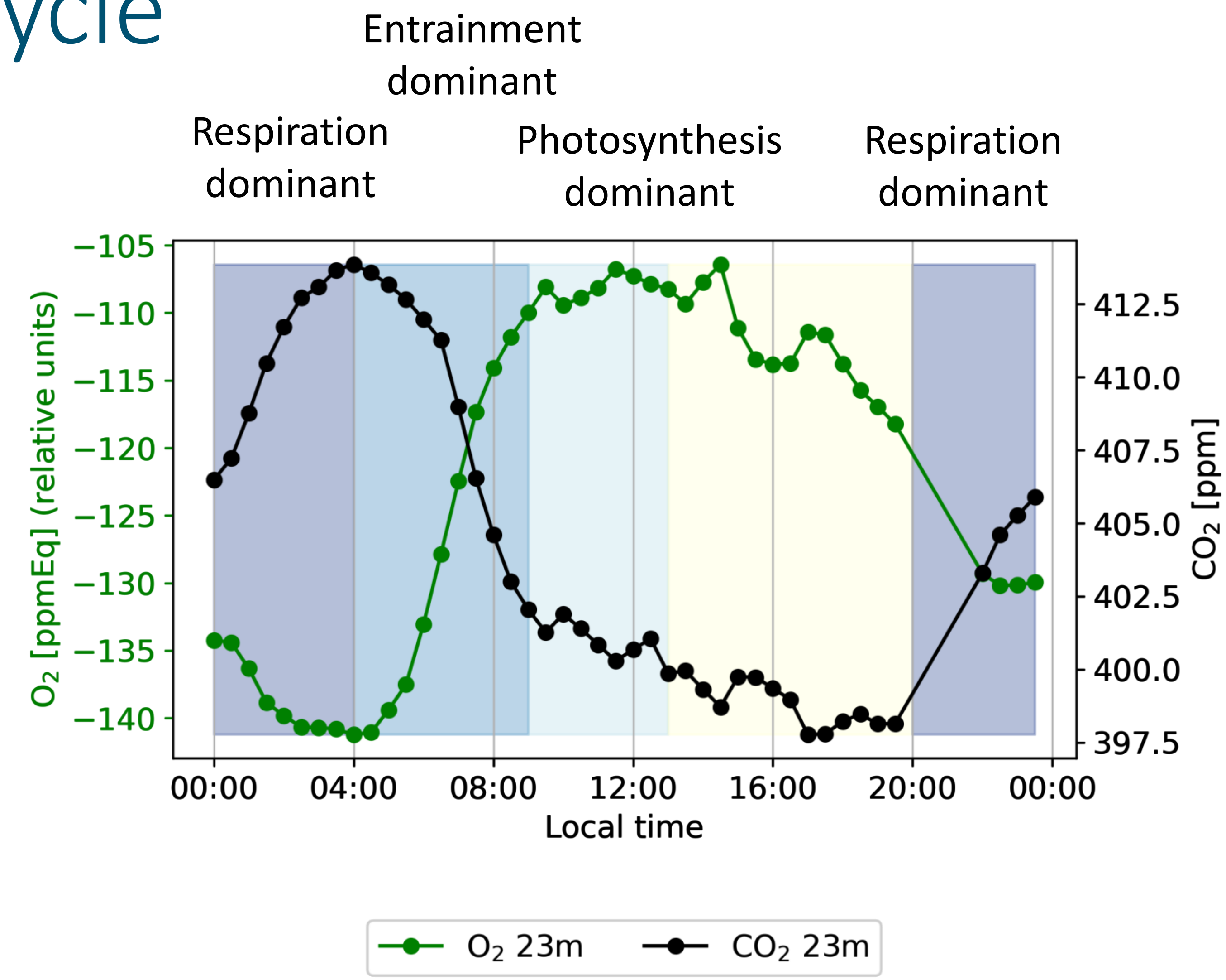
WAGENINGEN UNIVERSITY & RESEARCH

ER_{atmos}: 1 height

$$ER_{atmos} = \frac{\Delta_{(t)}O_2}{\Delta_{(t)}CO_2}$$



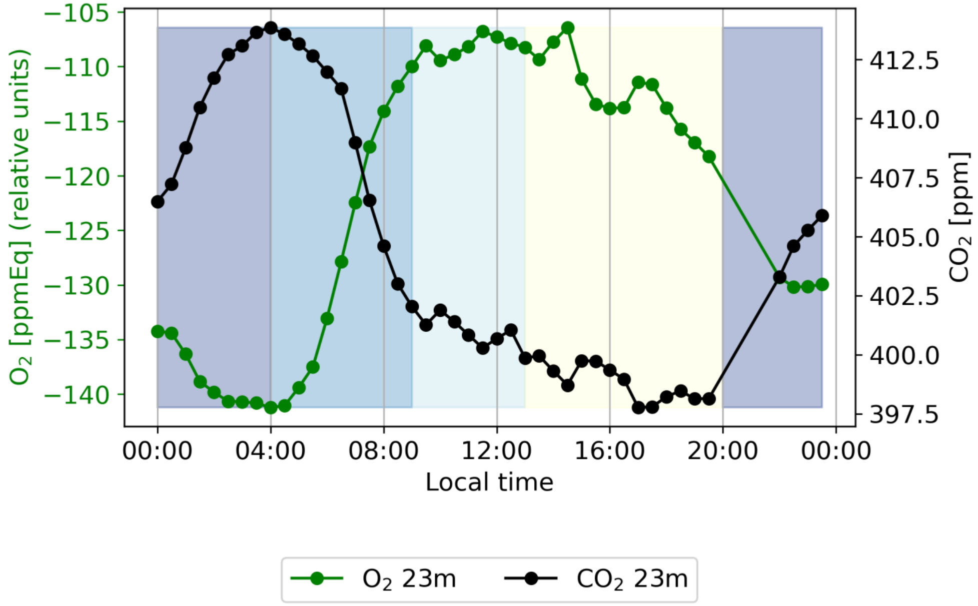
Diurnal cycle

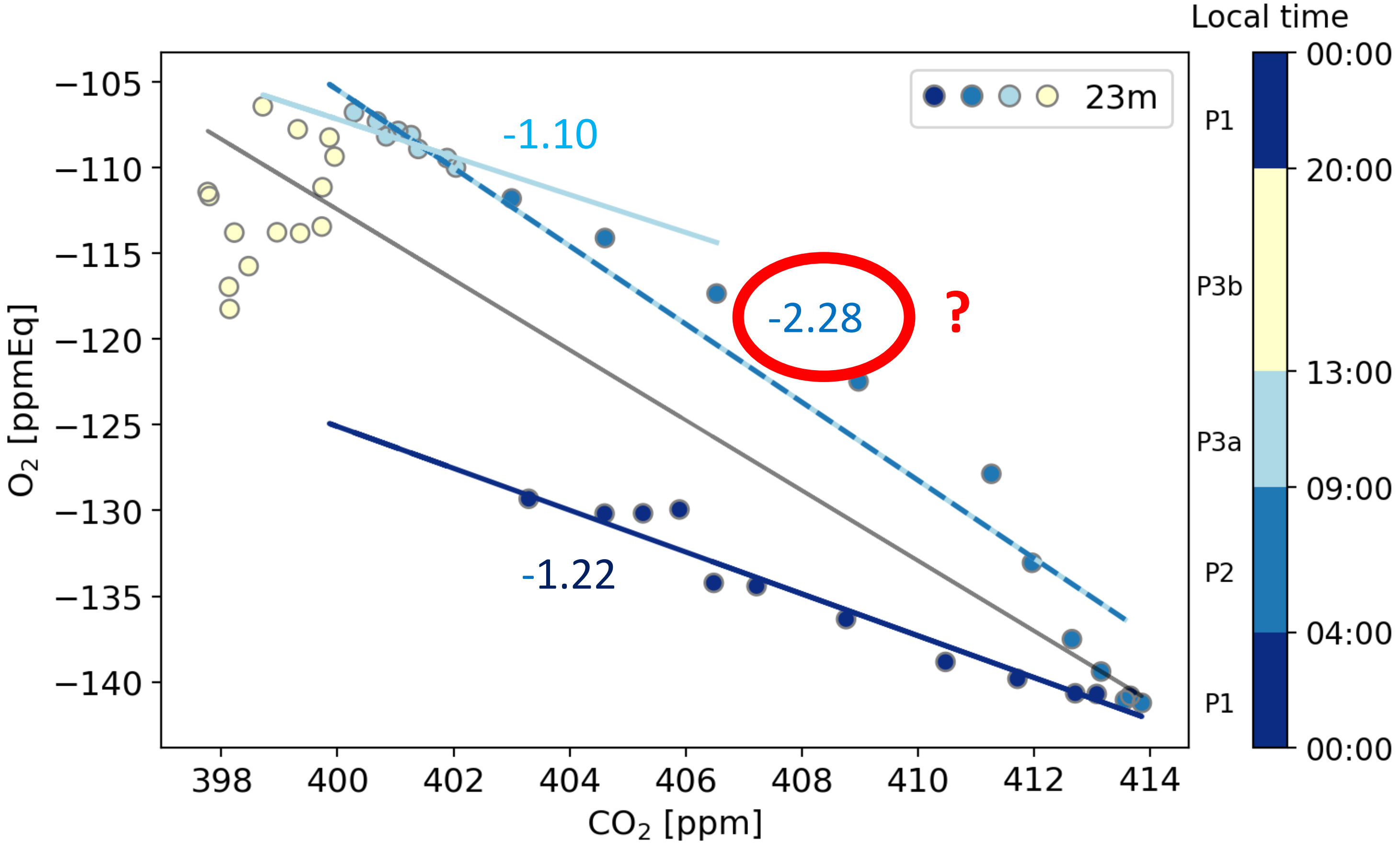


Faassen et al. (2023)

ER_{atmos} signals

$$ER = \frac{\Delta_{(t)} O_2}{\Delta_{(t)} CO_2}$$



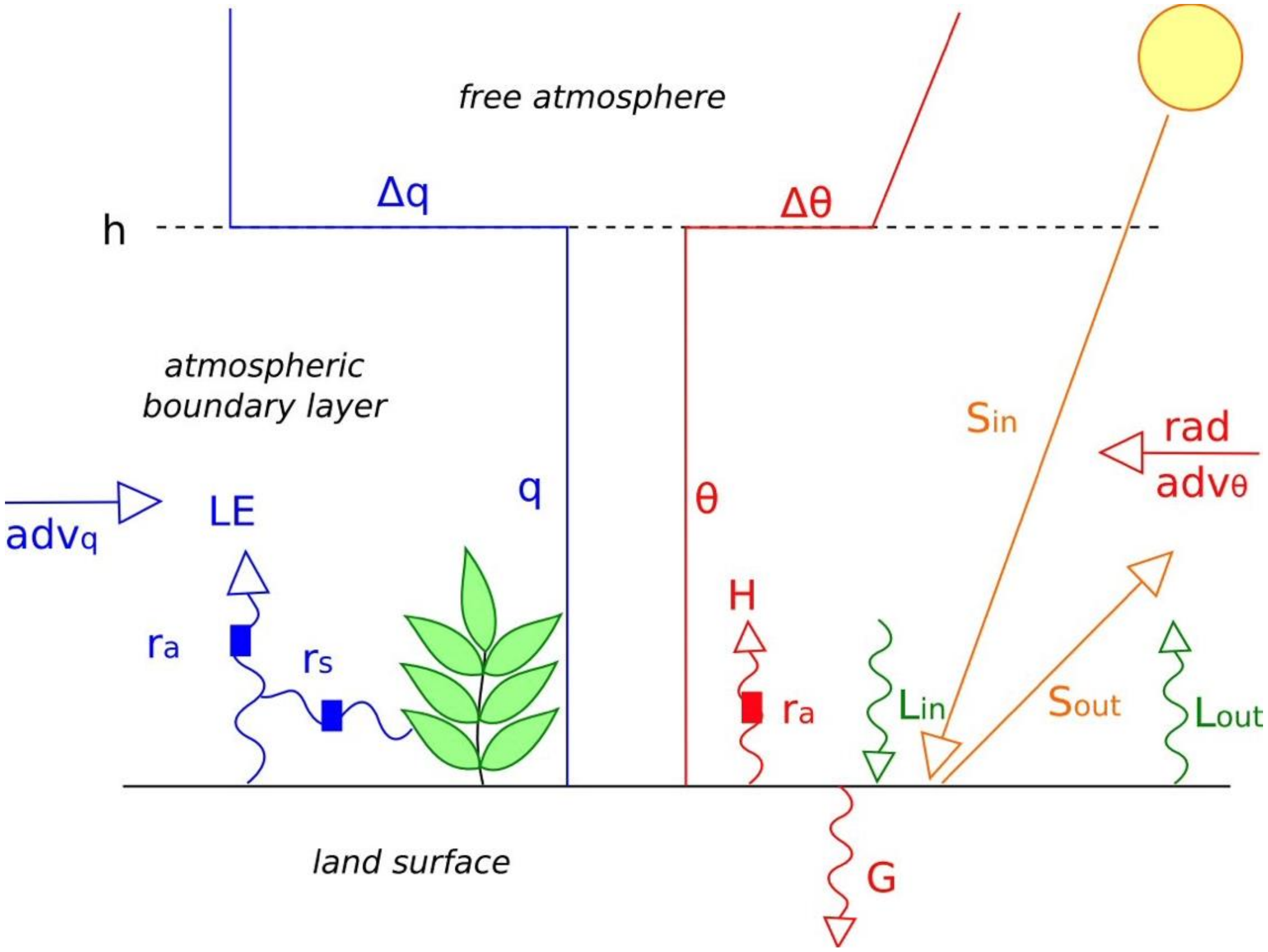


Faassen et al. (2023)

Explain ER_{atmos} signal

CLASS

- Chemistry Land-surface Atmosphere Soil Slab model
- 1-Box model (growing)
- Assumes mixed-layer theory
- Runs for 1 day
- Added O_2 (Faassen et al. (in prep))



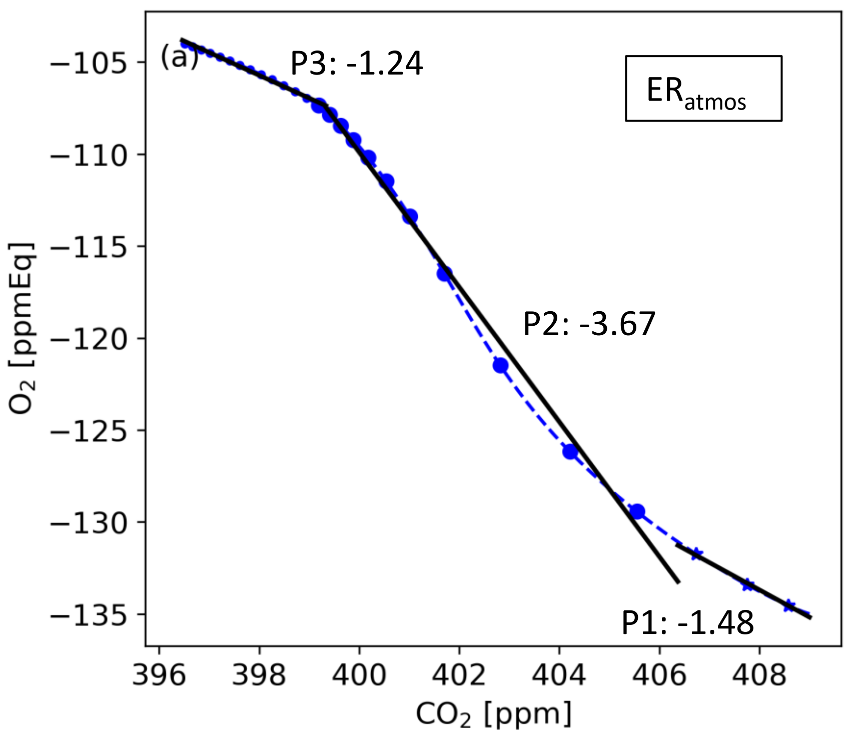
Jacobs & de Bruin 1997; Ronda et al., 2001; Jacobs et al., 2007

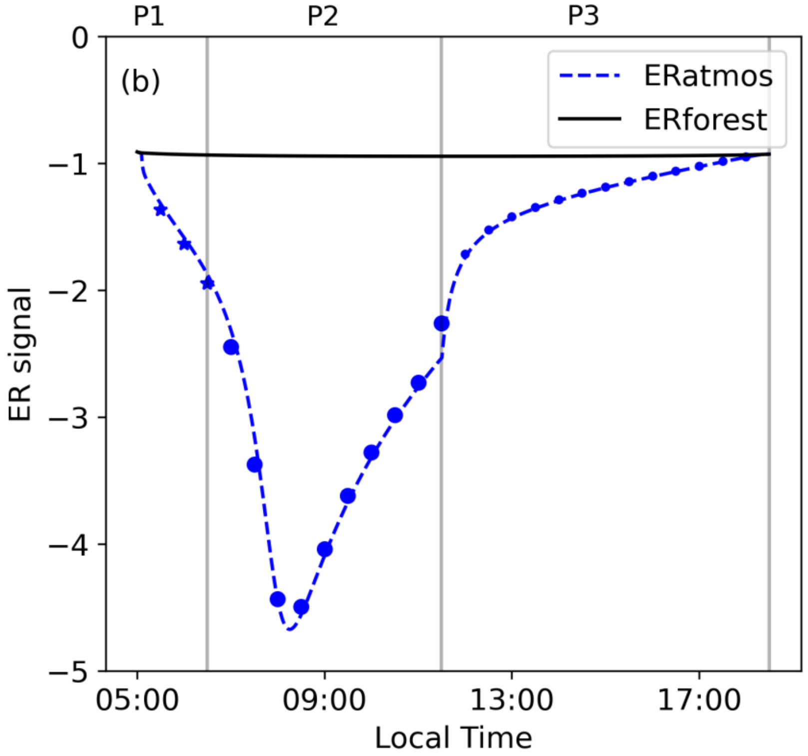
Vilá-Guerau de Arellano, J., van Heerwaarden, C. C., van Stratum, B. J. H., and van den Dries, K.: The Atmospheric Boundary Layer, Cambridge University Press, 2015

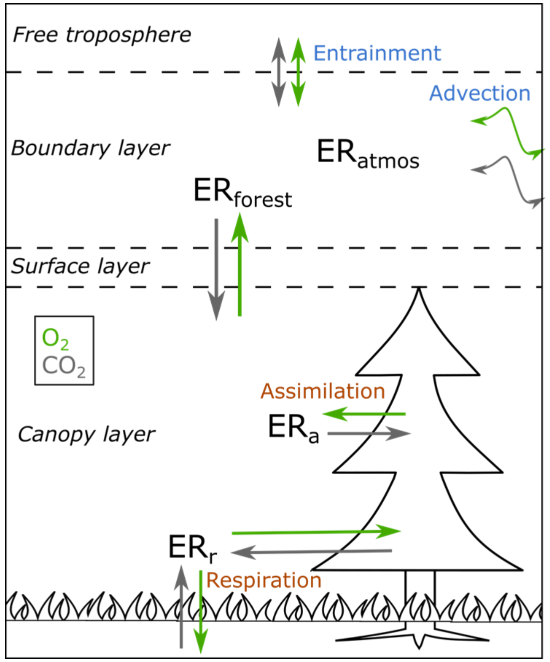
Model O_2 with CLASS

$$ER_{atmos} = \frac{\Delta_{(t)}}{\Delta_{(t)}}$$

$$ER_{forest} = \frac{F(\Delta_{(z)})}{F(\Delta_{(z)})}$$





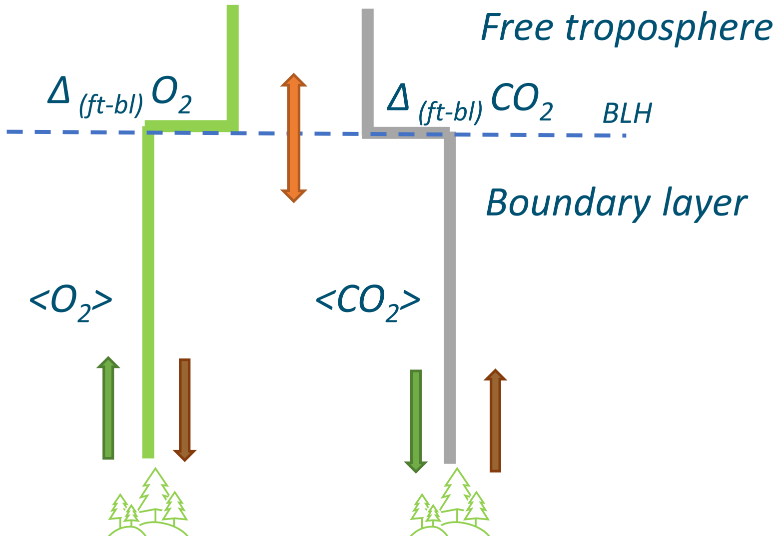


We can reproduce the high values for ER_{atmos} that we observed in Hyytiälä

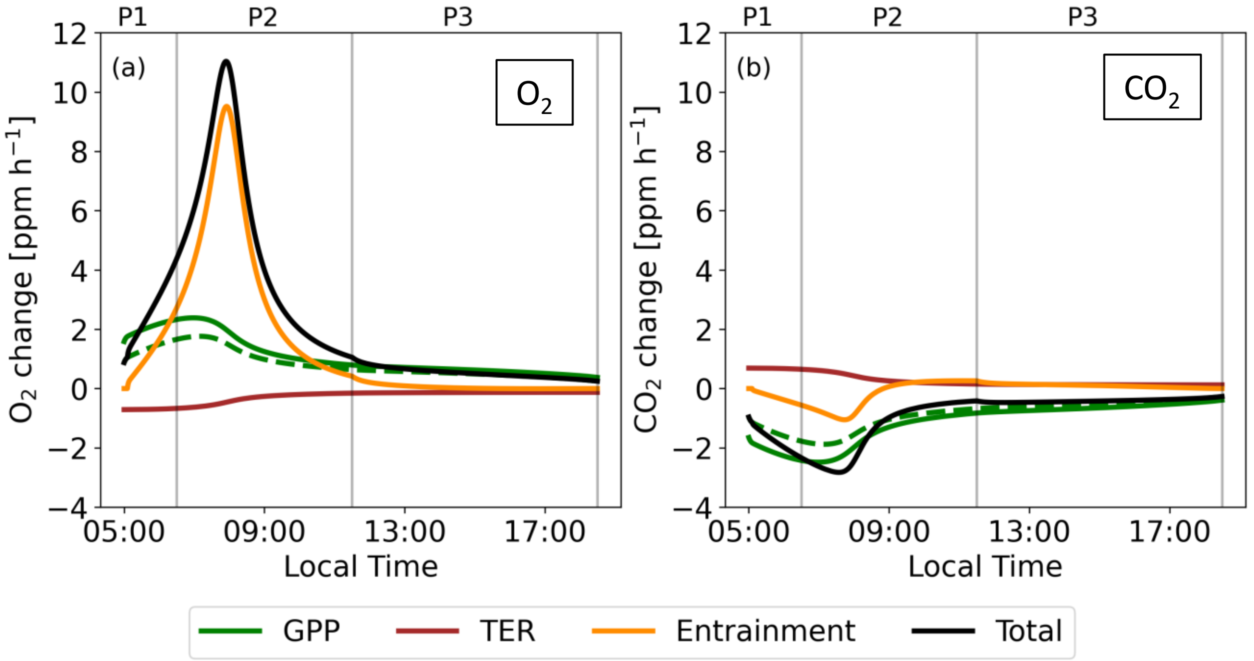
Explain P2: why such high values?

Explain P3: can ER_{atmos} be used as ER_{forest}

Importance of entrainment



- First clue look at tendencies
  - Entrainment is important
  - Both budgets behave differently



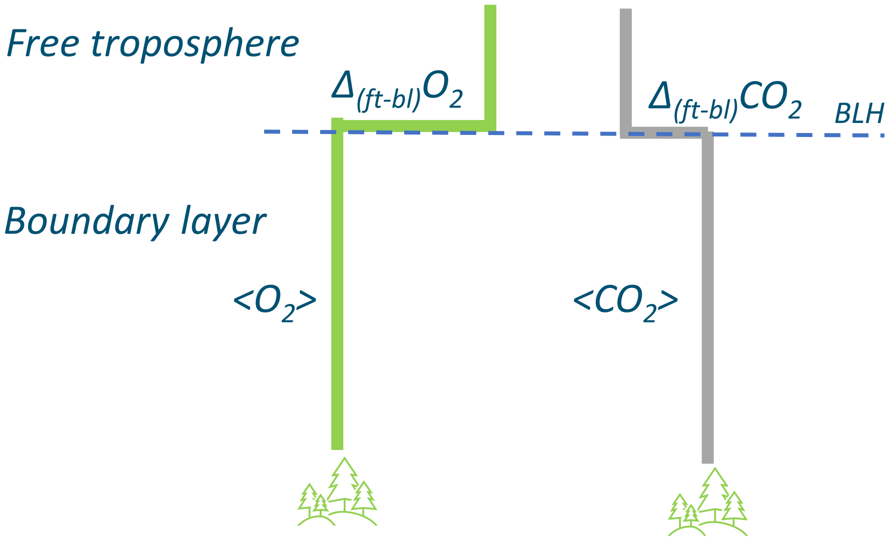
Relationship between ER_{forest} and ER_{atmos}

$$ER_{forest} = \frac{(F_{O_2})_s}{(F_{CO_2})_s}$$

$$ER_{atmos} = \frac{dO_2/dt}{dCO_2/dt} = \frac{((F_{O_2})_s - (F_{O_2})_e)/h}{((F_{CO_2})_s - (F_{CO_2})_e)/h}$$

$$ER_{atmos} = ER_{forest} * \left(\frac{1+\beta_{O_2}}{1+\beta_{CO_2}}\right)$$

$$\left(\frac{1+\beta_{O_2}}{1+\beta_{CO_2}}\right) = \frac{1+(w_e * \Delta_{(ft-bl)}O_2)/(F_{O_2})_s}{1+(w_e * \Delta_{(ft-bl)}CO_2)/\left(F_{CO_2}\right)_s}$$



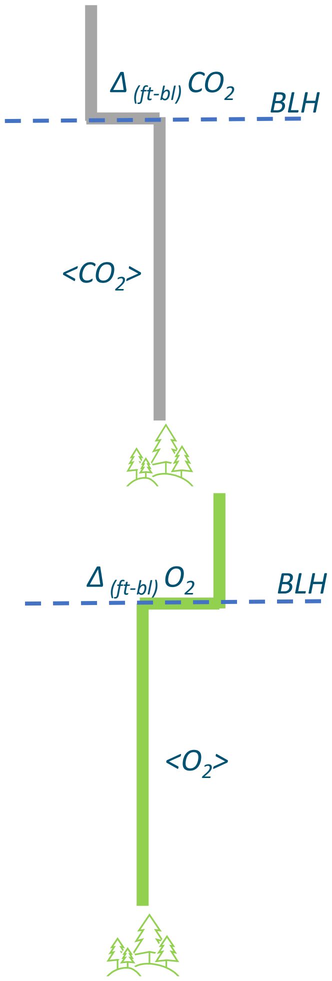
- Entrainment
- Jumps
- Surface fluxes

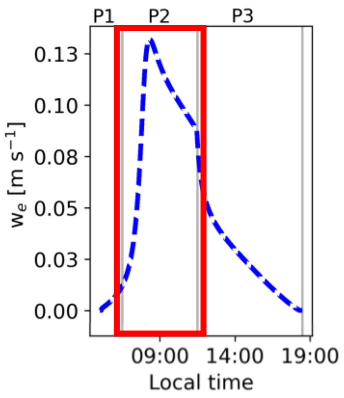
Why such high numbers?

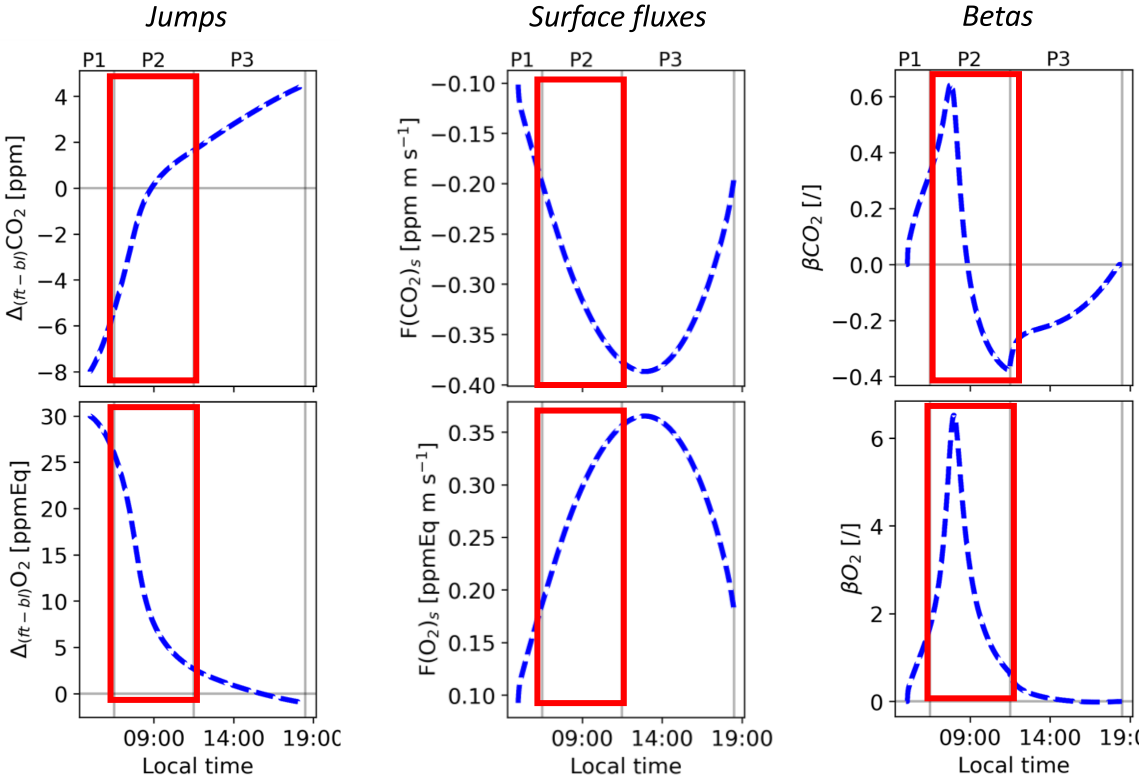
Disentangle the equation: P2 (morning)

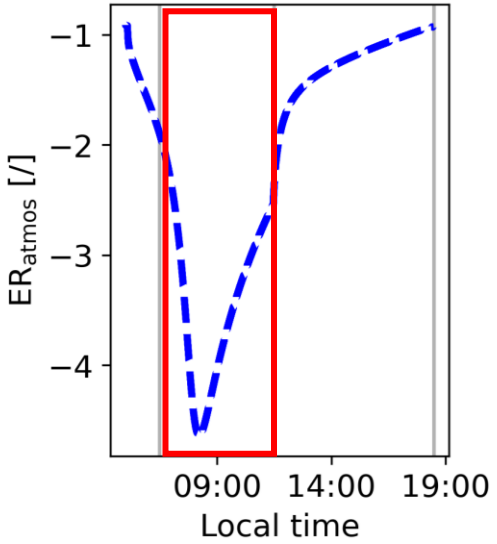
$$ER_{atmos} = ER_{forest} * \left(\frac{1+\beta_{O_2}}{1+\beta_{CO_2}}\right)$$

$$\beta = \frac{F_e}{F_s} = \frac{w_e * \Delta_{(ft-bl)}}{F_s}$$





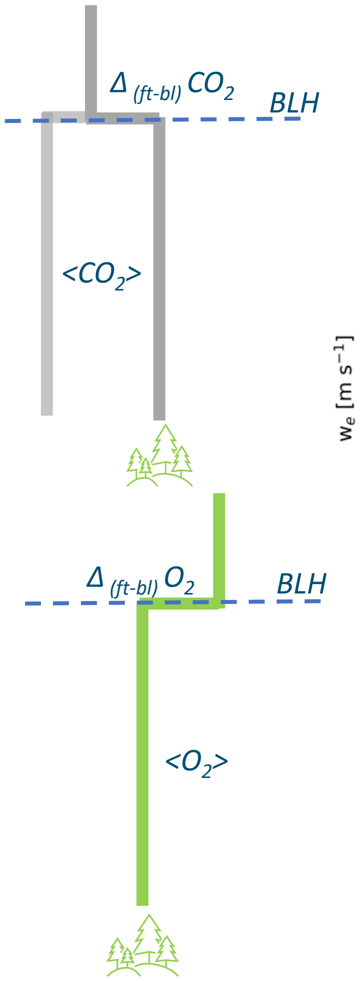


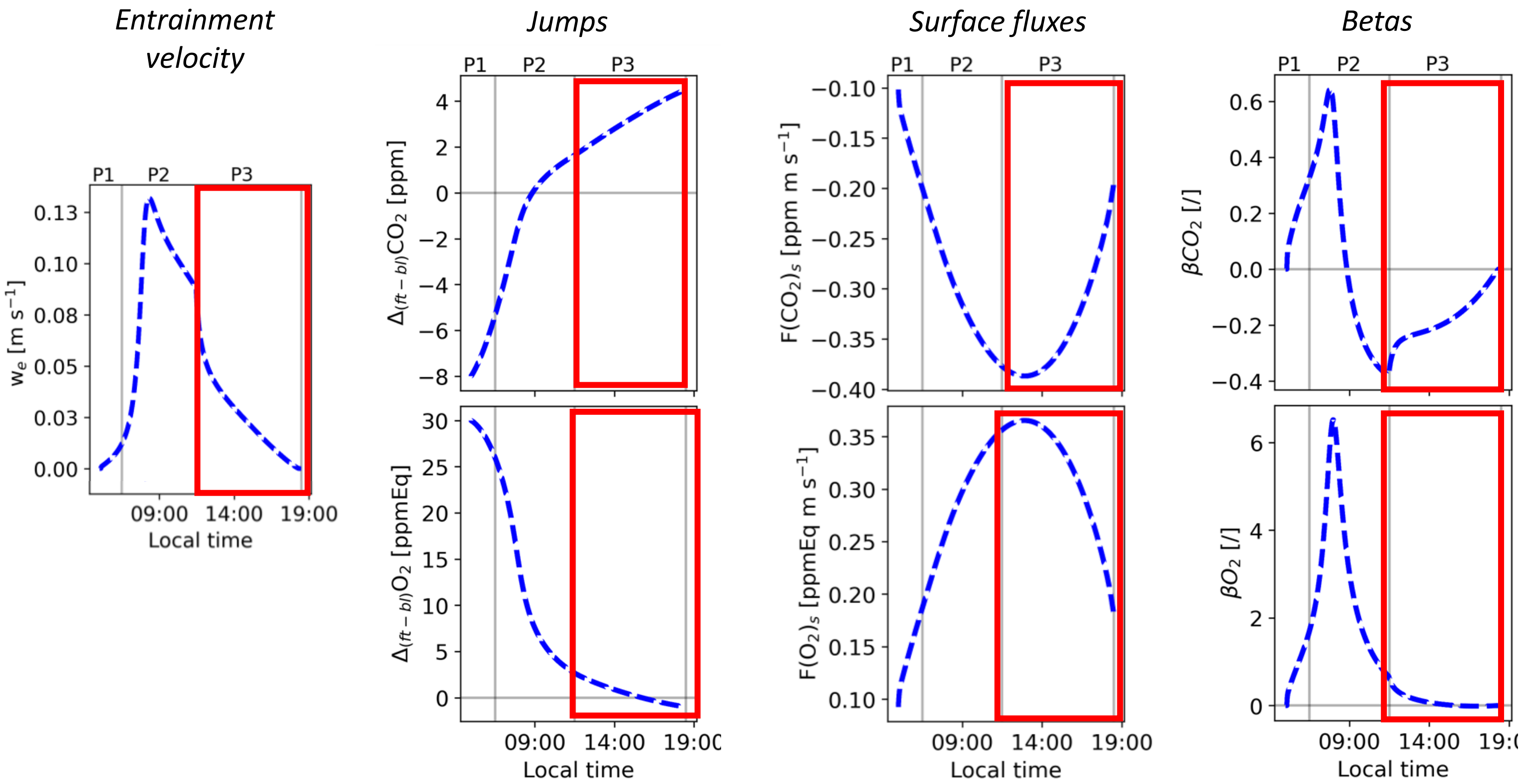


- Jump size → $\Delta_{(ft\text{-}bl)}$
- Jump ratio → $\Delta O_2 : \Delta CO_2$
- ERforest → $FO_2 : FCO_2$

Could ER_{atmos} be used for ER_{forest}?

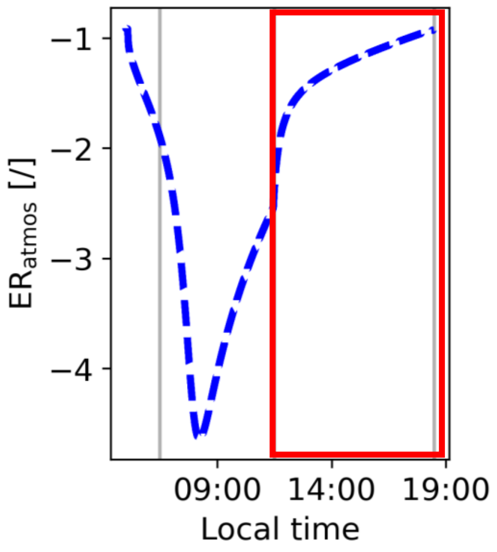
Disentangle the equation: P3 (afternoon)





$$ER_{atmos} = ER_{forest} * \left(\frac{1+\beta_{O_2}}{1+\beta_{CO_2}}\right)$$

$$\beta = \frac{F_e}{F_s} = \frac{w_e * \Delta_{(ft-bl)}}{F_s}$$



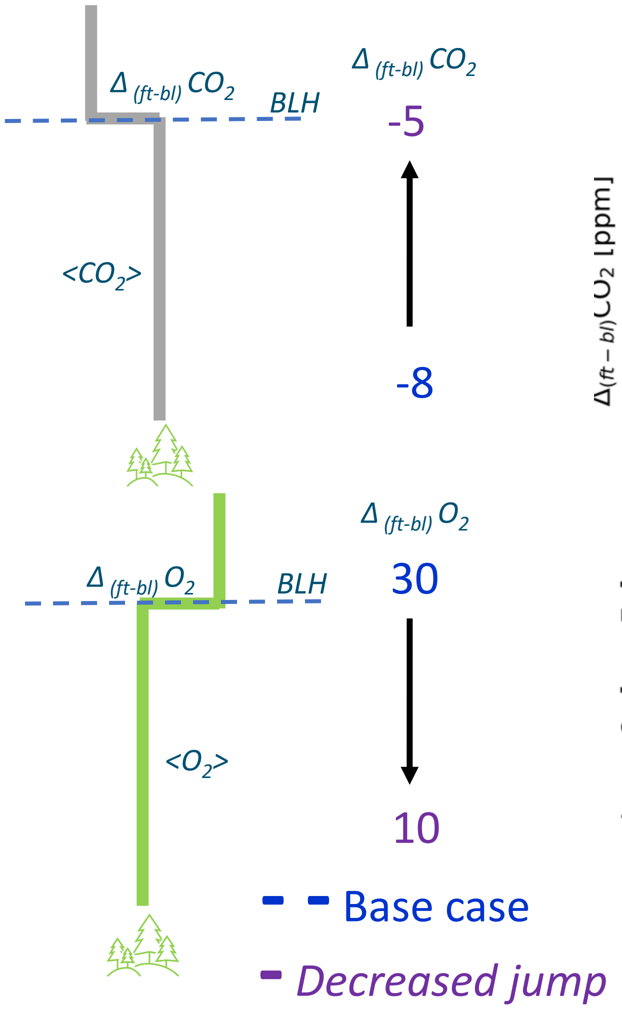
- Jump size → $\Delta_{(ft\text{-}bl)}$
- Jump ratio → $\Delta O_2 : \Delta CO_2$
- Flux size → $F(\Delta_{(z)})$

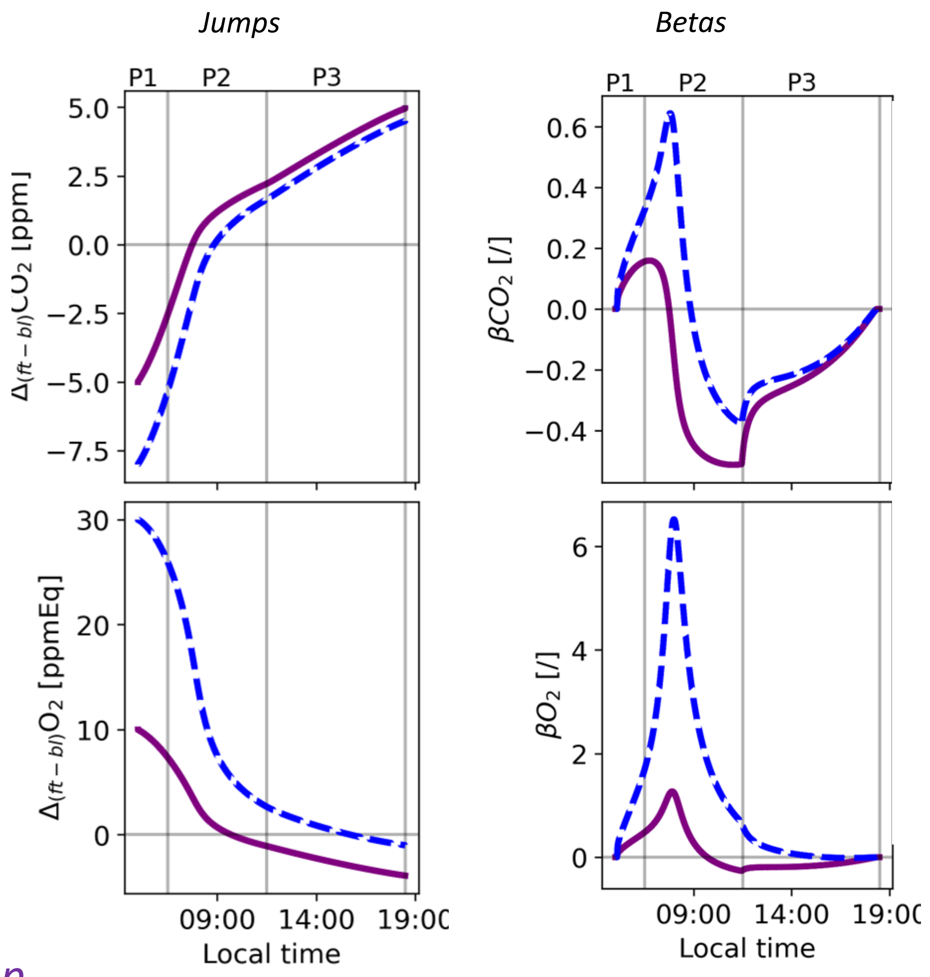
Is this a specific case?

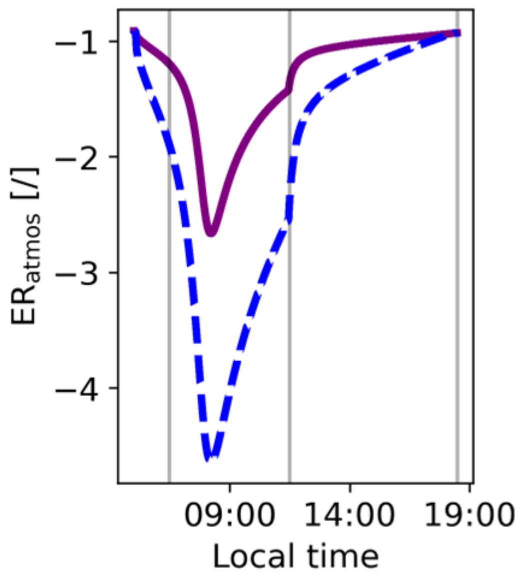
Other option: decrease jump size ($\Delta_{(ft\text{-}bl)}$)

$$ER_{atmos} = ER_{forest} * \left(\frac{1+\beta_{O_2}}{1+\beta_{CO_2}}\right)$$

$$\beta = \frac{F_e}{F_s} = \frac{w_e * \Delta_{(ft-bl)}}{F_s}$$







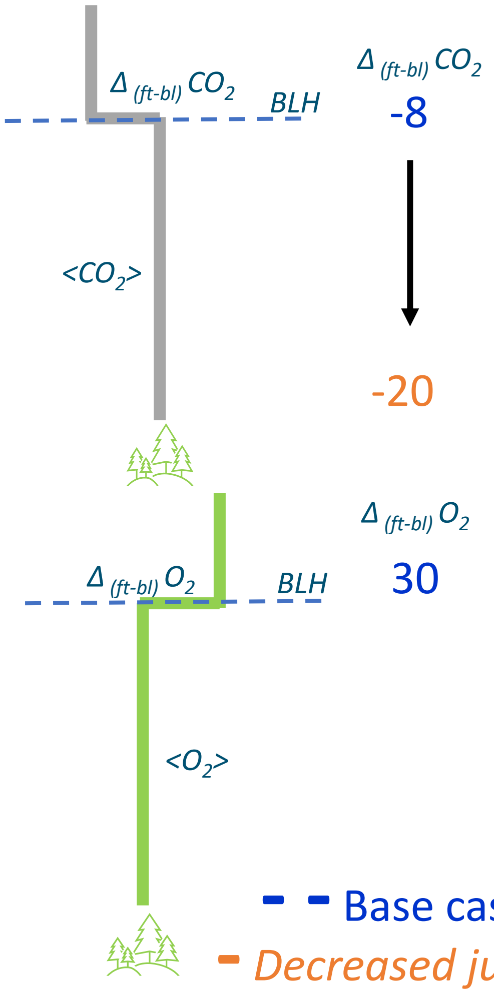
P2: still high ER_{atmos} values

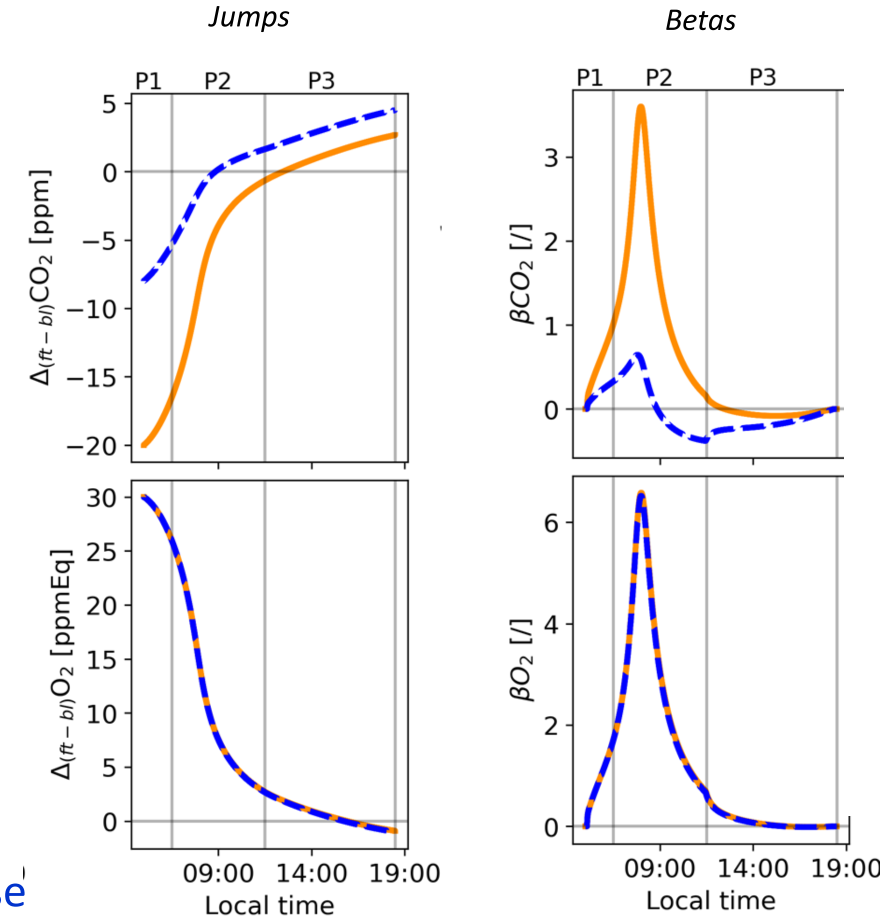
P3: ER_{atmos} closer to ER_{forest}

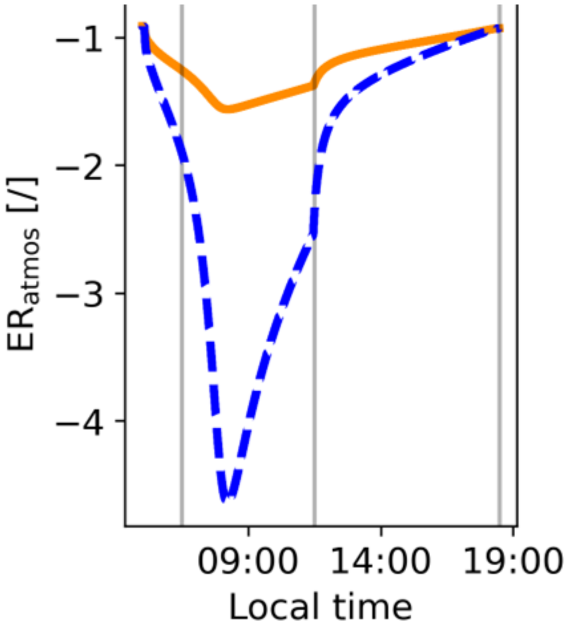
Other option: decrease jump ratio ($\Delta O_2 : \Delta CO_2$)

$$ER_{atmos} = ER_{forest} * \left(\frac{1+\beta_{O_2}}{1+\beta_{CO_2}}\right)$$

$$\beta = \frac{F_e}{F_s} = \frac{w_e * \Delta_{(ft-bl)}}{F_s}$$







- - Base case

- Decreased jump ratio

P2: now lower ER_{atmos} values

P3: ER_{atmos} a bit closer to ER_{forest}

Contact: kim.faassen@wur.nl

Take home message

BL processes are of importance to understand O_2 and CO_2 mole fractions and their ratios

ER_{forest}: based on 2/more heights

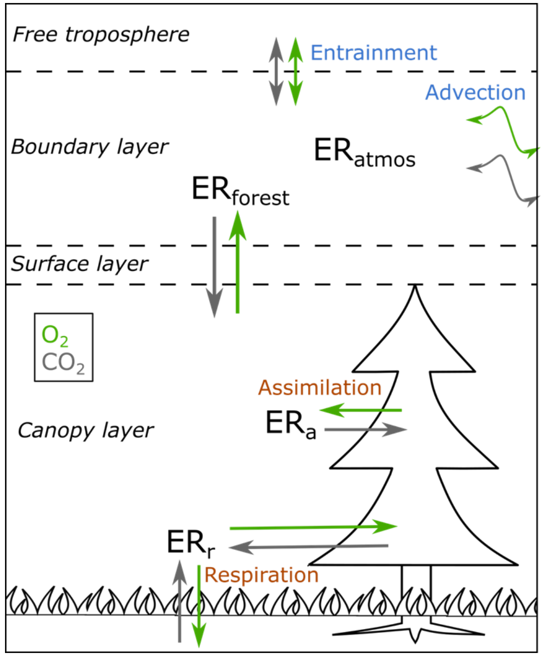
- This signal should be used to indicate surface
- O_2 fluxes can be calculated with the flux-gradient method
- New ER signals for boreal forest

Faassen et al. (2023)

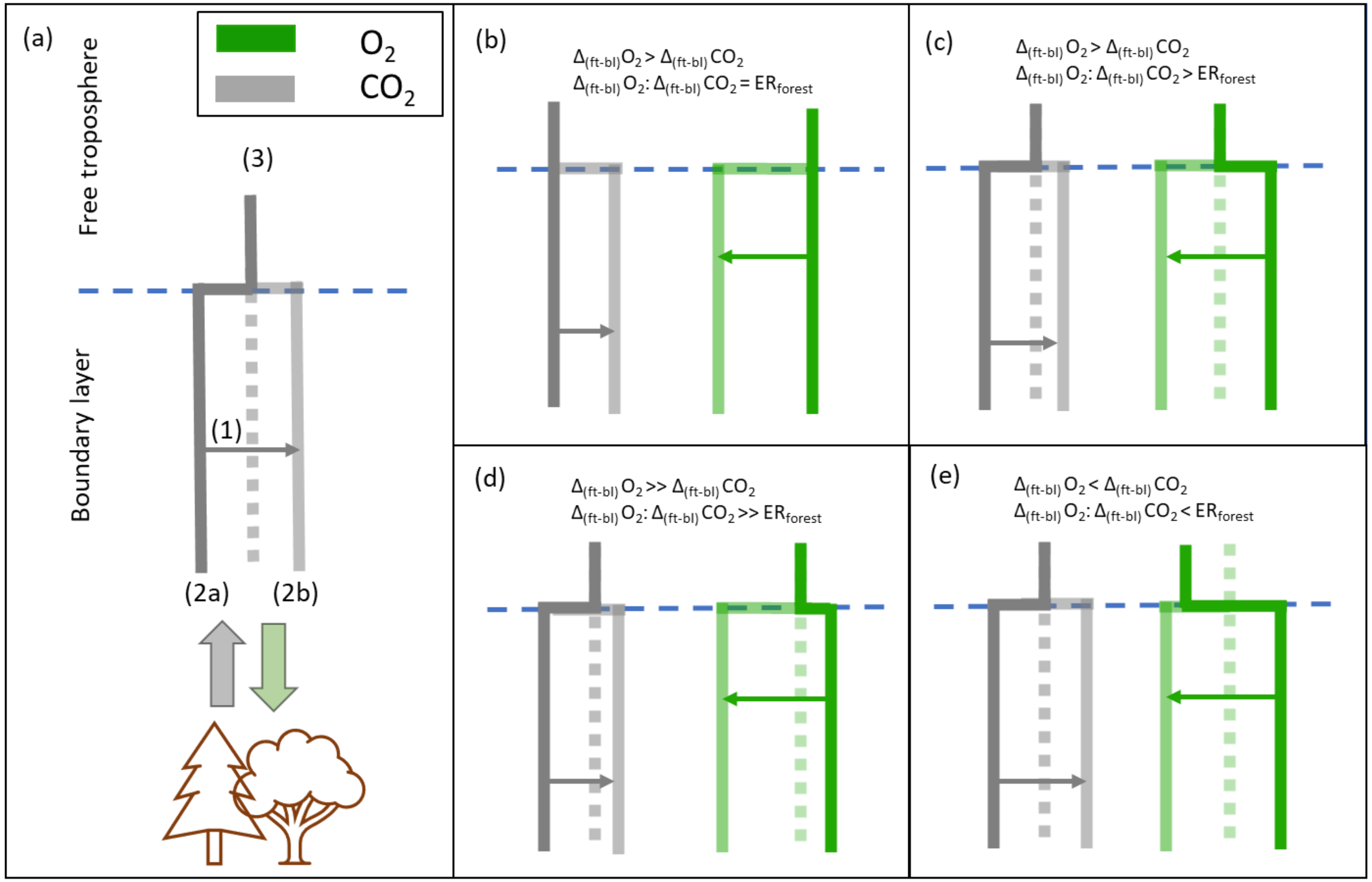
ER_{atmos}: based on 1 height

- Give more insights in non-local processes
- Handled with care
- Can get 'strange' values
- Budgets should be look at separately

Faassen et al. (in prep)



Jump options



(1) Surface flux size during night (2a) mixed layer mole fraction just before sunset (2b) mixed layer mole fraction just before sunrise (3) Mole fraction in the free troposphere

Flux calculations