Tracing diurnal variations of carbon tracers over a tropical and temperate forest

TEAMS Utrecht, Wageningen, Sao Paulo Universities, INPA and MPI-Jena

Special thanks to: Raquel González-Armas, Lucas Hulsman, Gerbrand Koren, Ingrid Luijkx, Michiel van der Molen and Jordi Vilà-Guerau de Arellano

Why do we need tracers?

h: boundary layer height

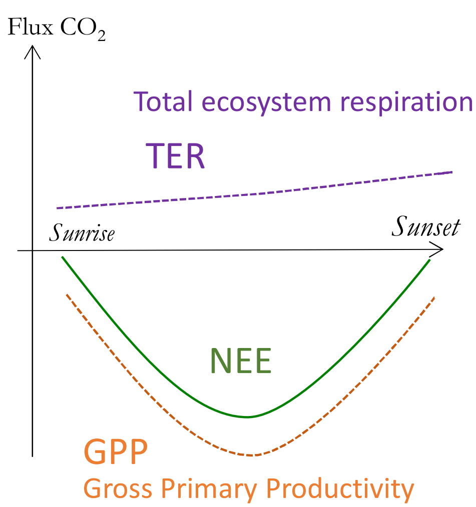
F_s: net surface flux (NEE)

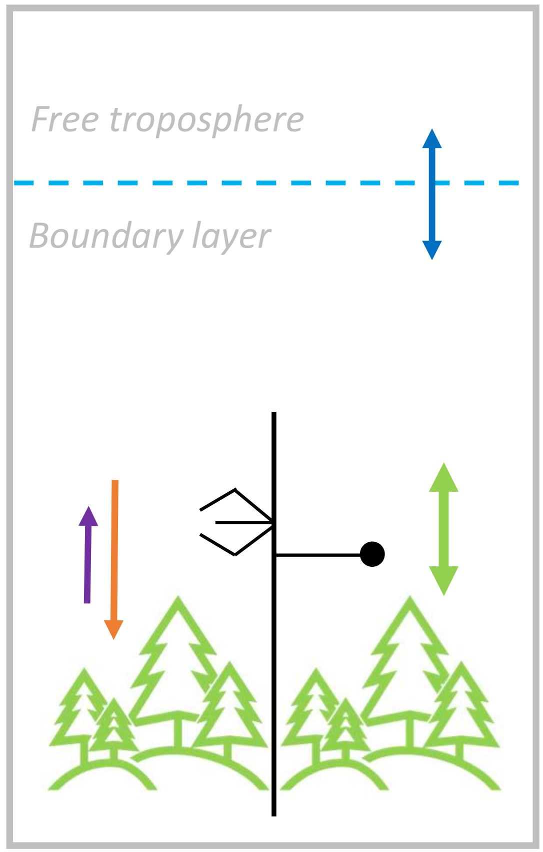
F_e: entrainment flux

Adv_{CO2}: advection CO_2

Fluxes

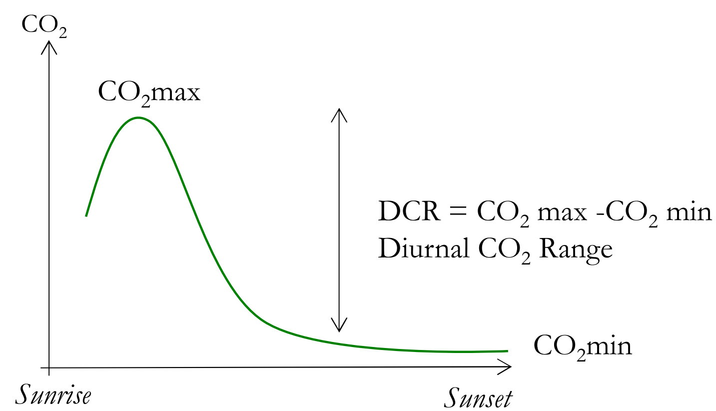
$$NEE\ (F_s) = -GPP + TER$$





Mole fractions

$$\frac{dCO_2}{dt} = \frac{1}{h}(F_s + F_e) + Adv_{CO_2}$$



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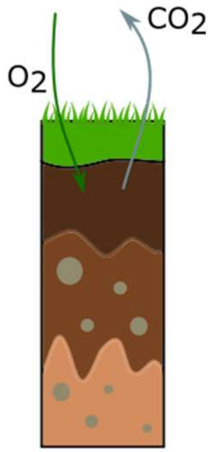
Link between O_2 and CO_2

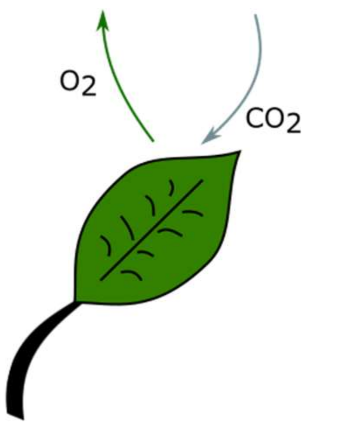
$$ER = \frac{\Delta O_2}{\Delta CO_2}$$

Total Ecosystem Respiration (TER)



ERr = -1.03

Gross Primary Productivity (GPP)



ERa = -0.96

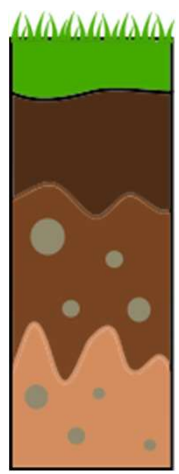
Faassen et al. (2023)

$\delta^{13}C$ works similar as the $O_2:CO_2$ ratio

Fractionation indicates now the process

$$\delta^{13}C = \left(\frac{\left(\frac{^{13}C}{^{12}C}\right)_{sample}}{\left(\frac{^{13}C}{^{12}C}\right)_{standard}} - 1 \right) * 1000$$

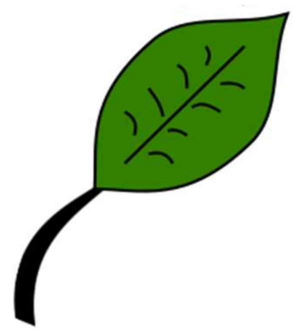
Total Ecosystem Respiration (TER)



Depletes air of $\delta^{13}C$

$\delta^{13}C$ = -26.5‰

Gross Primary Productivity (GPP)

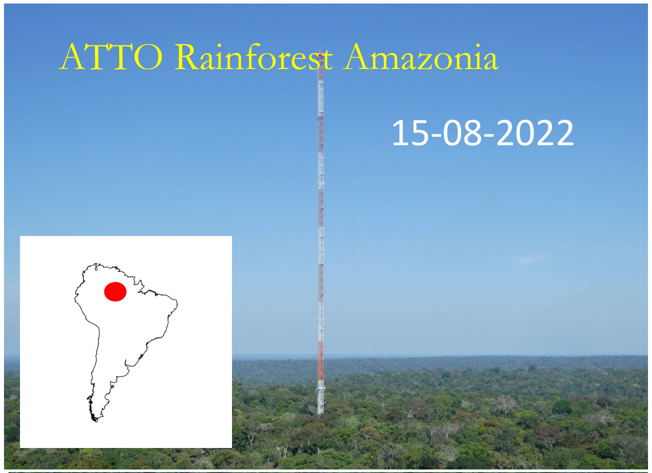


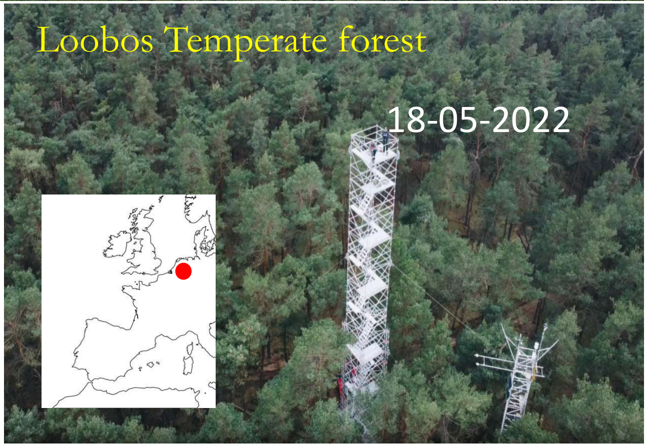
Increases $\delta^{13}C$ in air

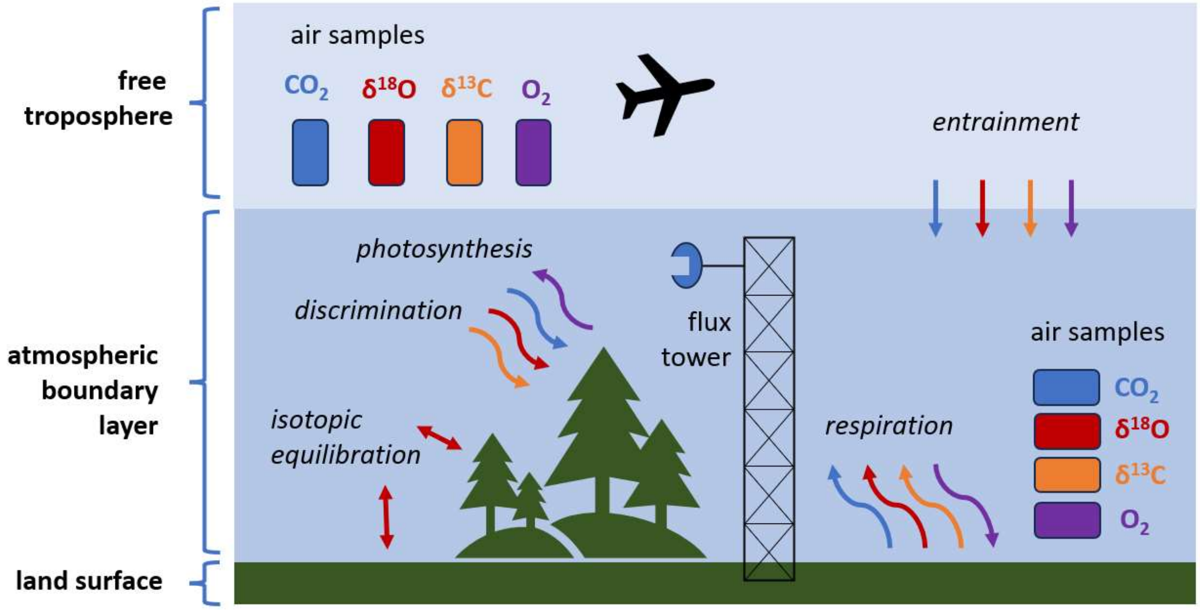
$\delta^{13}C$ = -25.5 ‰

Wehr et al. (2015)

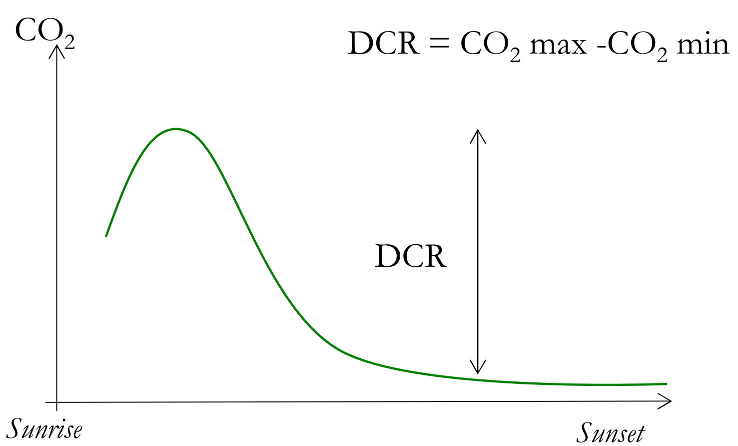
Two campaigns



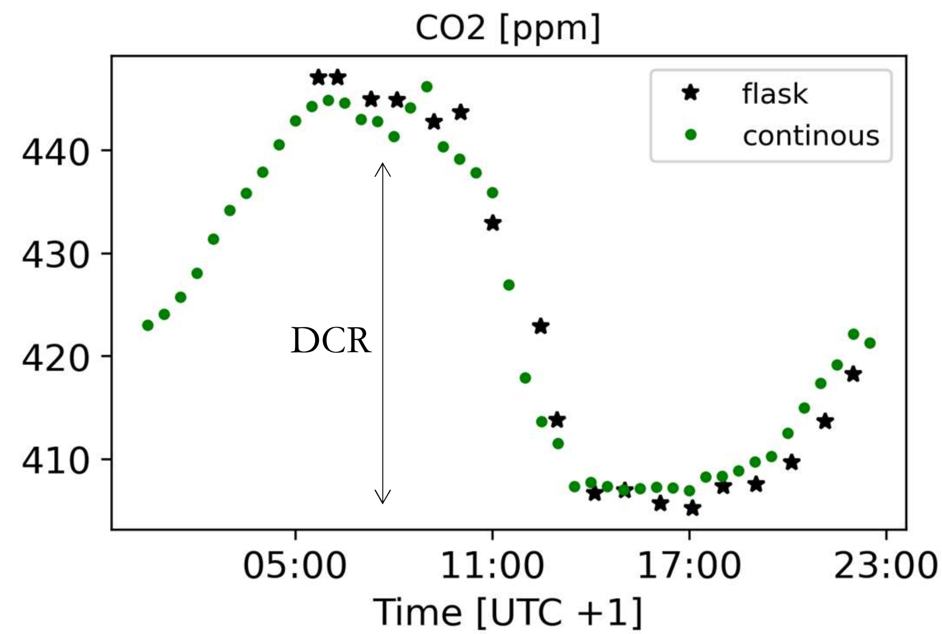




Diurnal cycles: CO_2

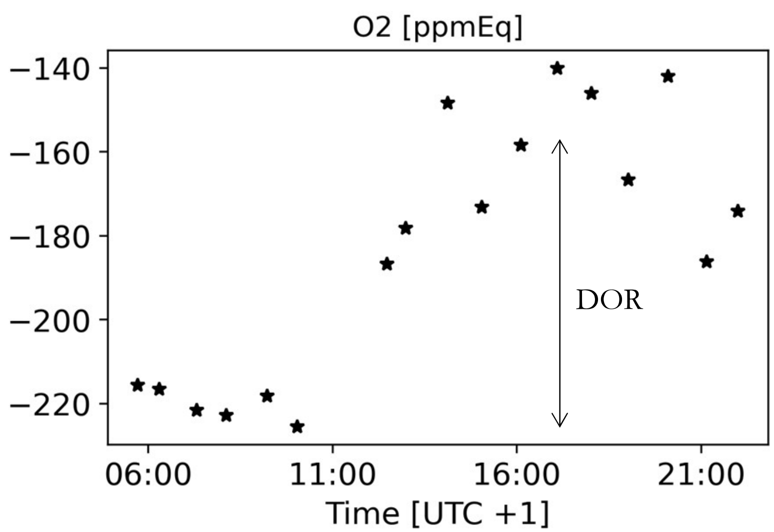


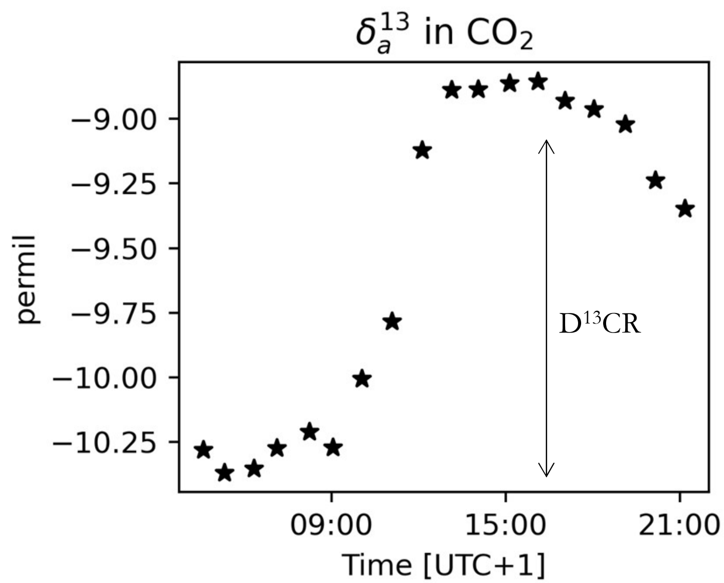
Flask measurements at 34 m



Diurnal cycles: O_2 and $\delta^{13}C$

Flask measurements at 34 m





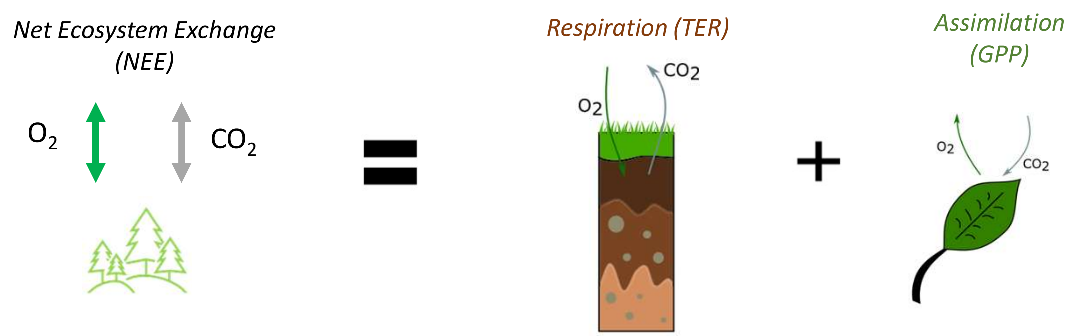
Atmospheric processes seem to be important for the diurnal cycle of the different tracers because the surface cannot explain the DXR

Still uncertainty in how diurnal cycles of tracers are formed

Need to understand these tracers further

- Terrestrial sink still has high uncertainty of carbon cycle
- How to use them as a partitioning method for NEE

NEE = -GPP + TER



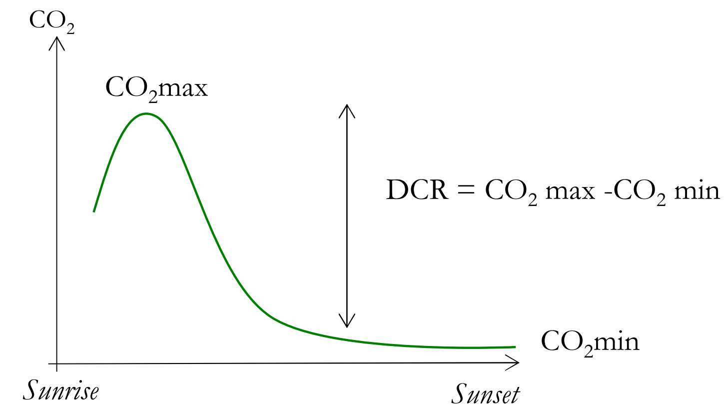
- Reproducing the diurnal variability becomes a must with higher resolution models

The main goal

- Get a better understanding what drives the diurnal cycles of different carbon tracers

Focus on:

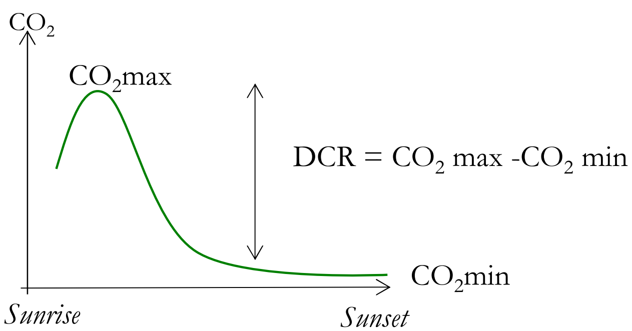
- DXR
- Importance of atmosphere vs surface



Only the analysis of the temperate forest is shown (Ruisdael campaign)

Betas: importance of entrainment

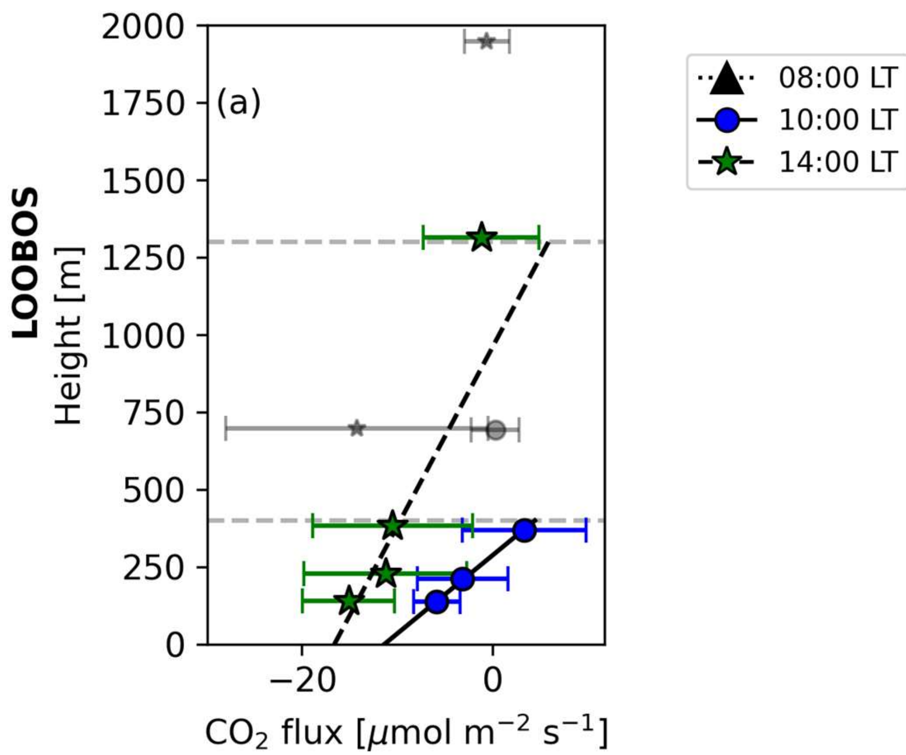
$$\frac{dCO_2}{dt} = \frac{1}{h}(F_s - F_e) + Adv_{CO_2}$$



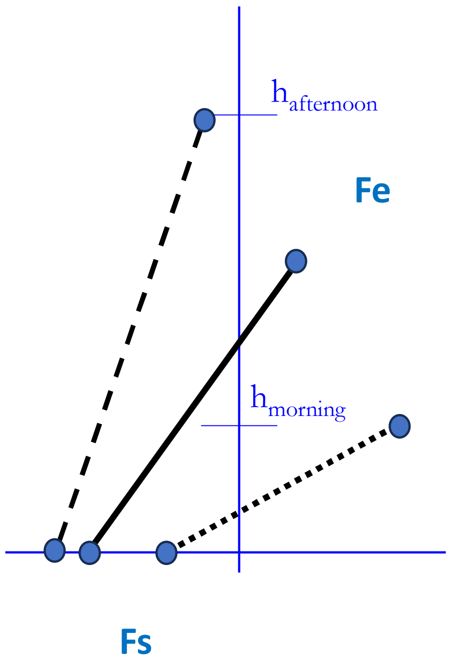
$$\frac{dCO_2}{dt} = \frac{1}{h}(F_s - F_e) = \frac{1}{h}F_s\left(1 - \frac{F_e}{F_s}\right)$$

$$\beta = \frac{F_e}{F_s} = \frac{\text{Entrainment flux}}{\text{Net surface flux}}$$

Observed betas: airplane



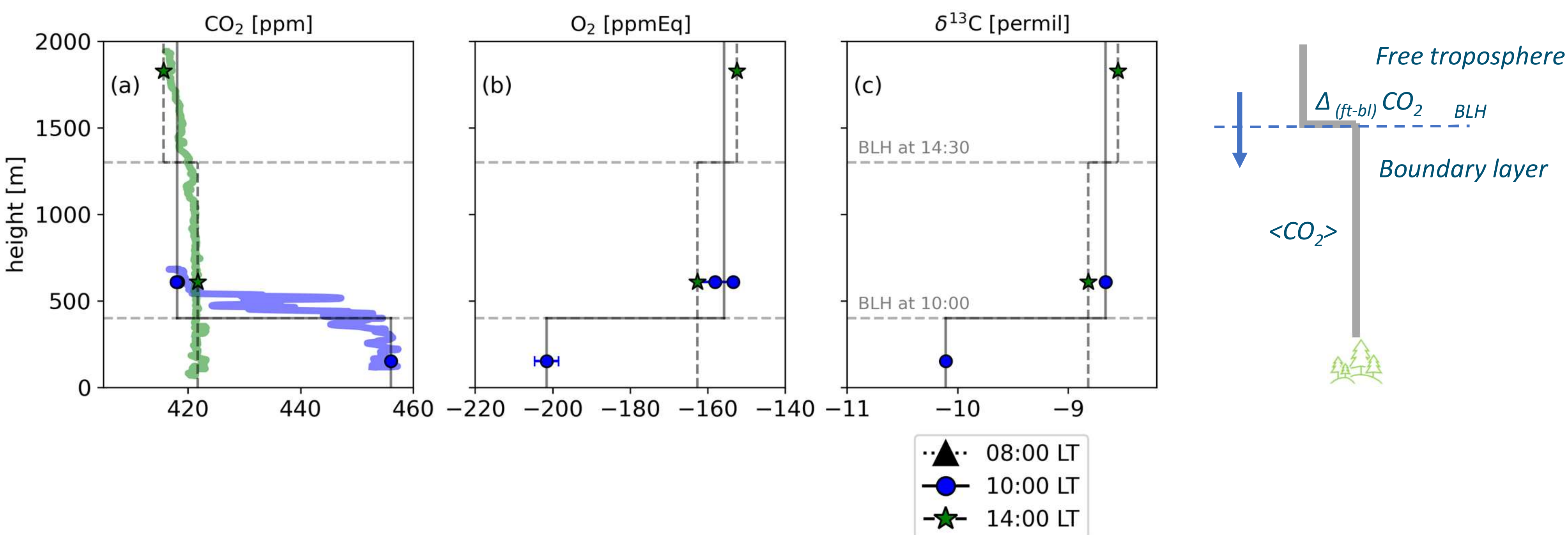
$$\beta = \frac{F_e}{F_s}$$



Estimation of F_e of tracers

$$F_e = w_e \cdot \Delta_{ft-}$$

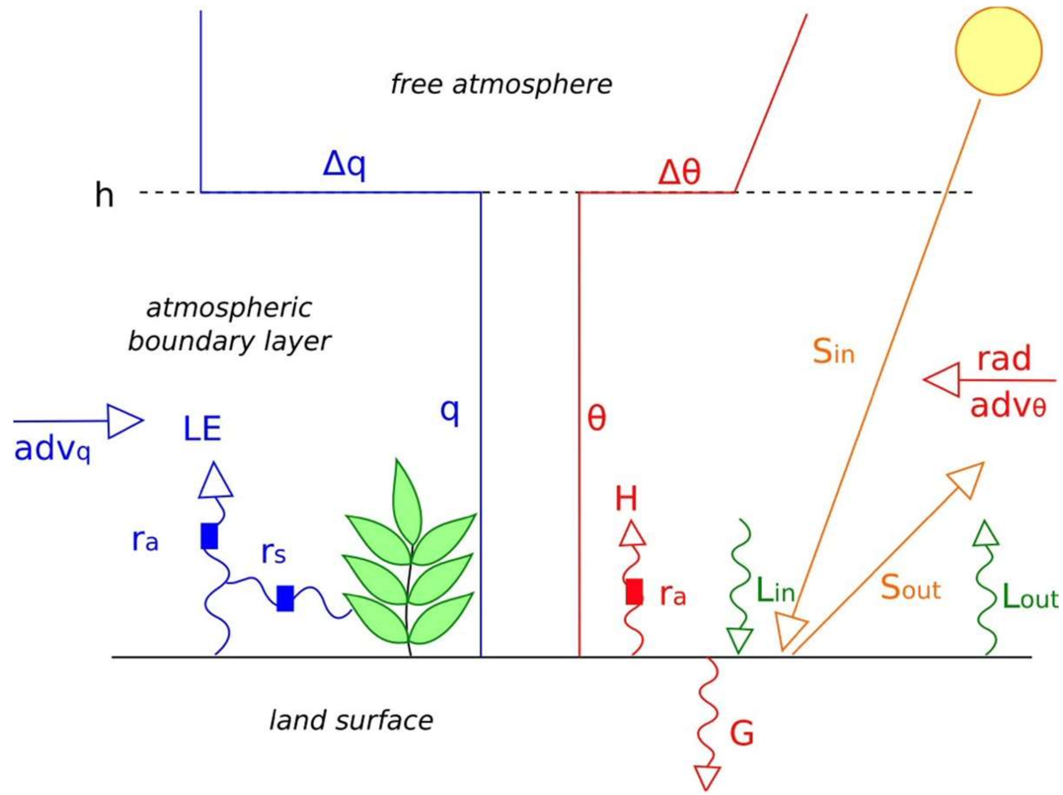
$$w_e = \frac{\partial h}{\partial t} - w_{subsidence} \approx \frac{\partial h}{\partial t}$$



To disentangle complete signal -> we need a model

CLASS

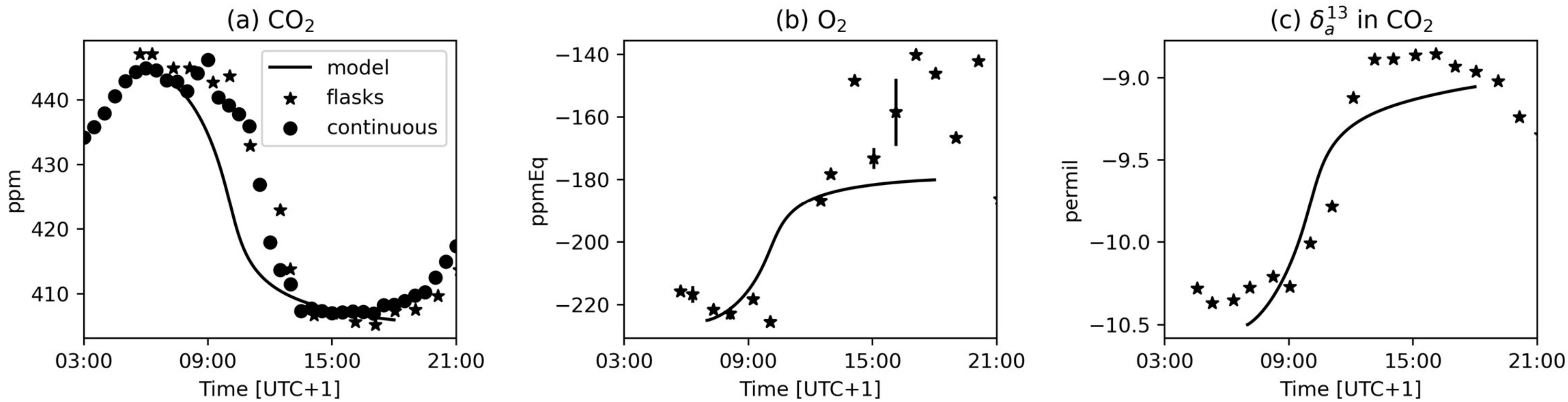
- Chemistry Land-surface Atmosphere Soil Slab model
- 1-Box model (growing)
- Assumes mixed-layer theory
- Runs for 1 day



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 validation



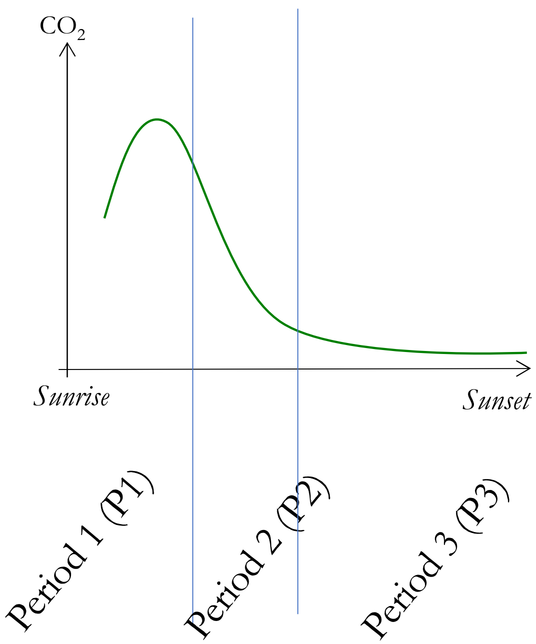
CLASS can reproduce the diurnal variability of CO_2 and its tracers

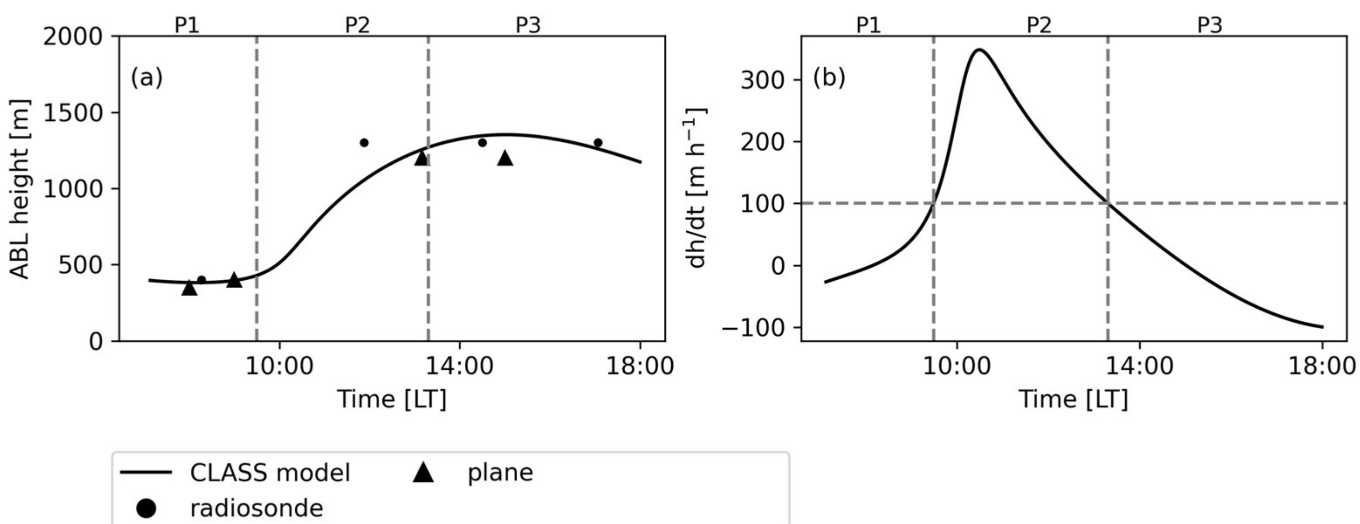
Now we can disentangle the diurnal ranges

Periods during the day

$$w_e = \frac{\partial h}{\partial t} - w_{subsidence} + M \approx \frac{\partial h}{\partial t}$$

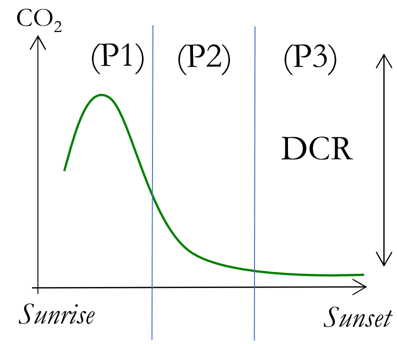
Determine betas for each period to determine the importance of entrainment vs the surface.

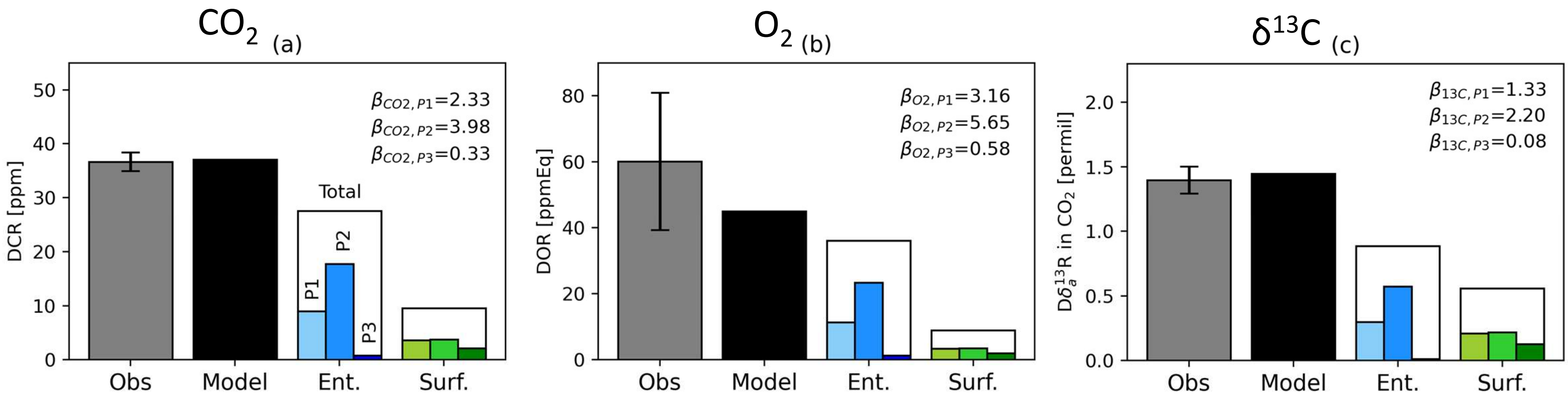




Budget analysis

$$\beta = \frac{F_e}{F_s}$$





Conclusion

Get a better understanding what drives the diurnal cycles of different carbon tracers

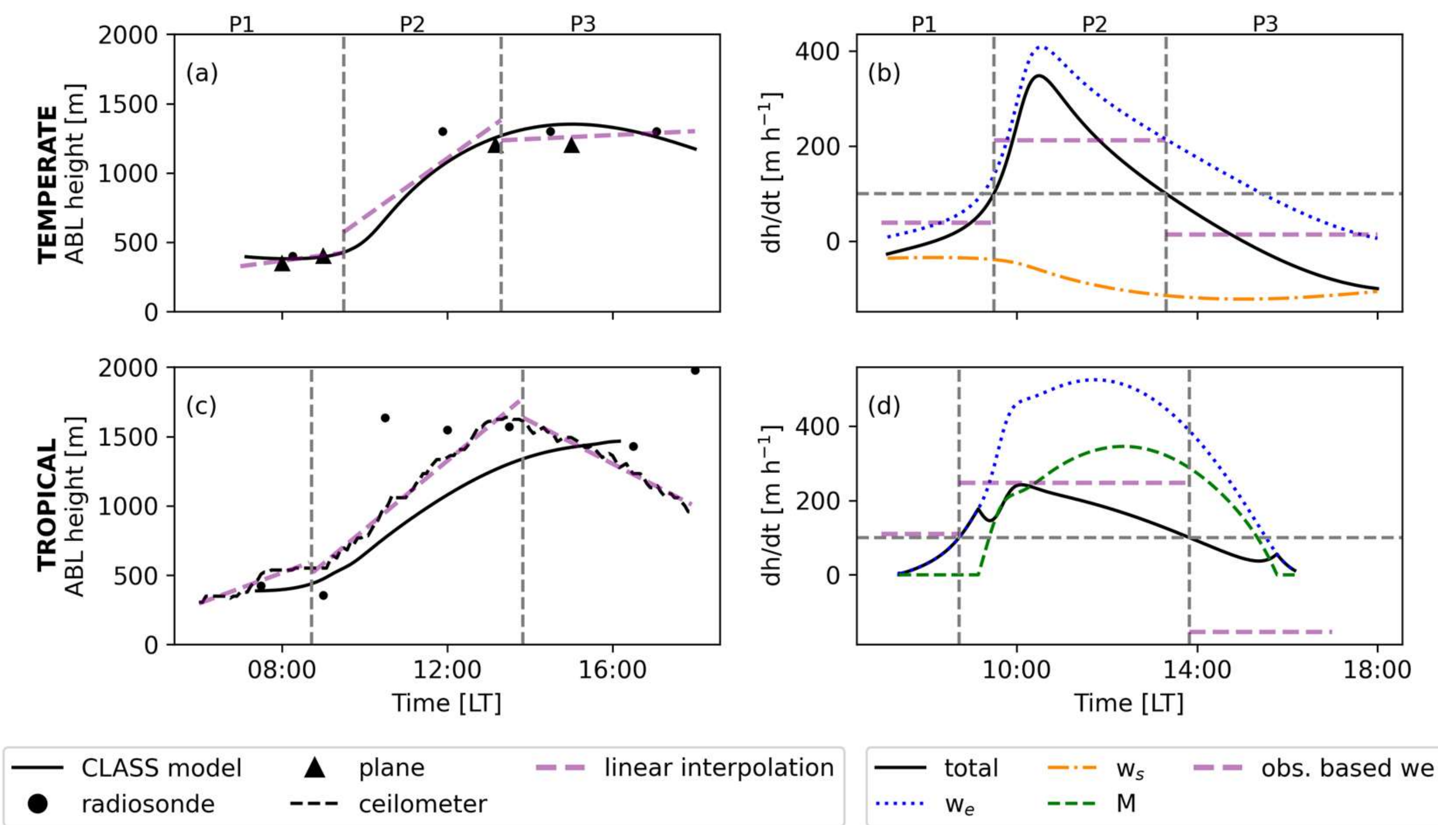
- The diurnal ranges (DXR) of the different tracers are large
- Entrainment + *subsidence* play a key role in these diurnal ranges
- It is important to understand the free troposphere concentrations
- Be careful to relate diurnal cycles of atmospheric tracers, to only the surface processes

- *Similar conclusions for the Amazon*

Extra slides

$$w_e = \frac{\partial h}{\partial t} - w_{subsidence} \approx \frac{\partial h}{\partial t}$$

Entrainment velocity of observations

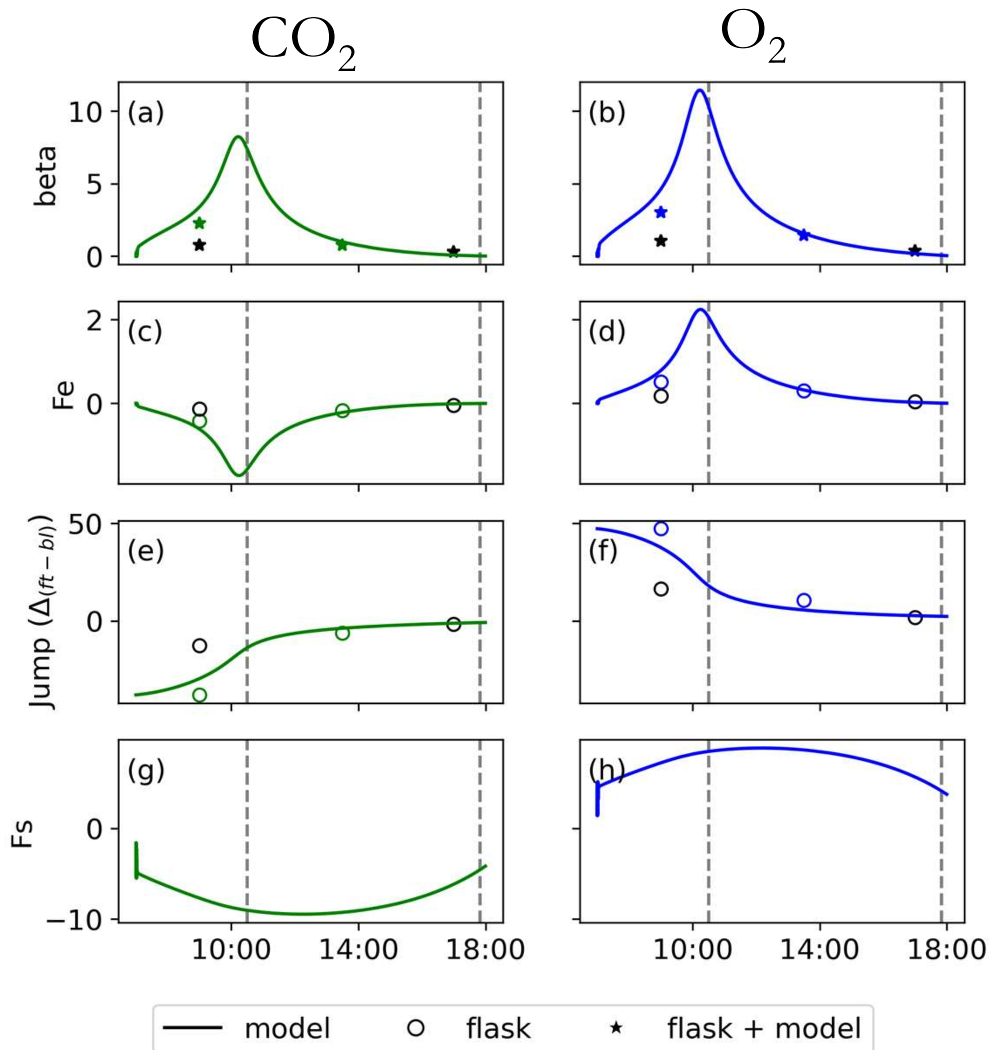


Beta over time

$$\beta = \frac{F_e}{F_s} = \frac{\text{Entrainment flux}}{\text{Net surface flux}}$$

$$F_e = w_e \cdot \Delta_{ft-b}$$

$$w_e \approx \frac{\partial h}{\partial t}$$



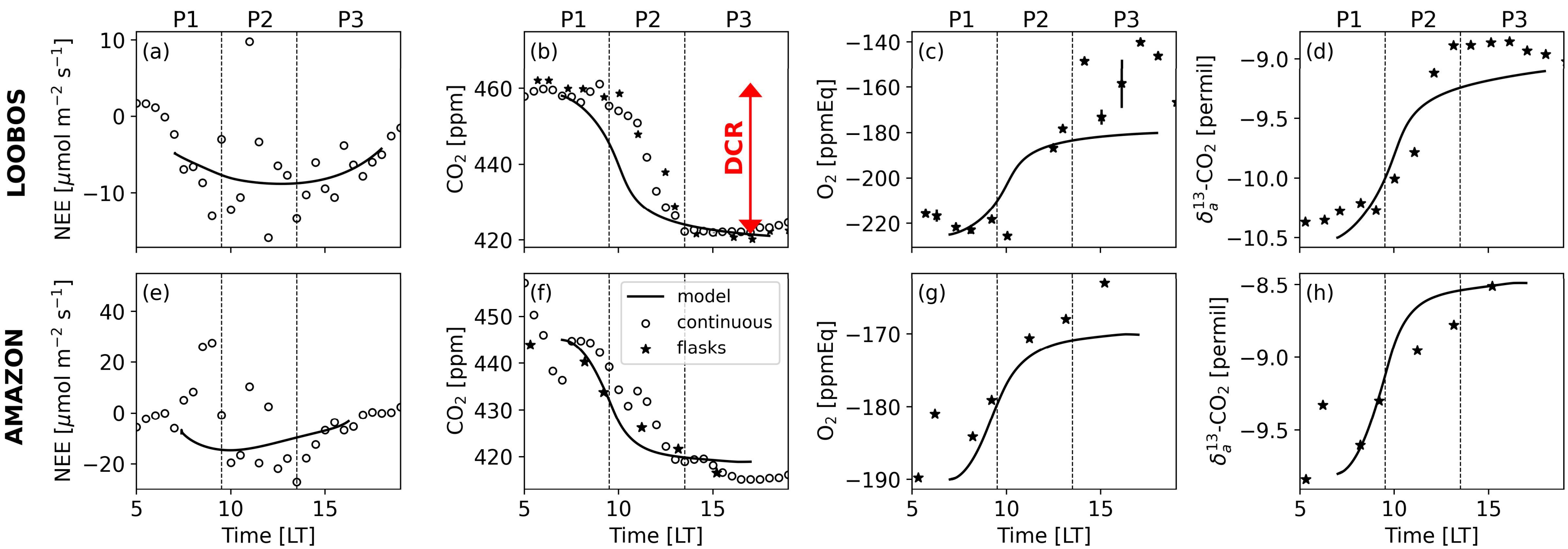
Measuring O_2

CO_2 → 1/400=0.25%

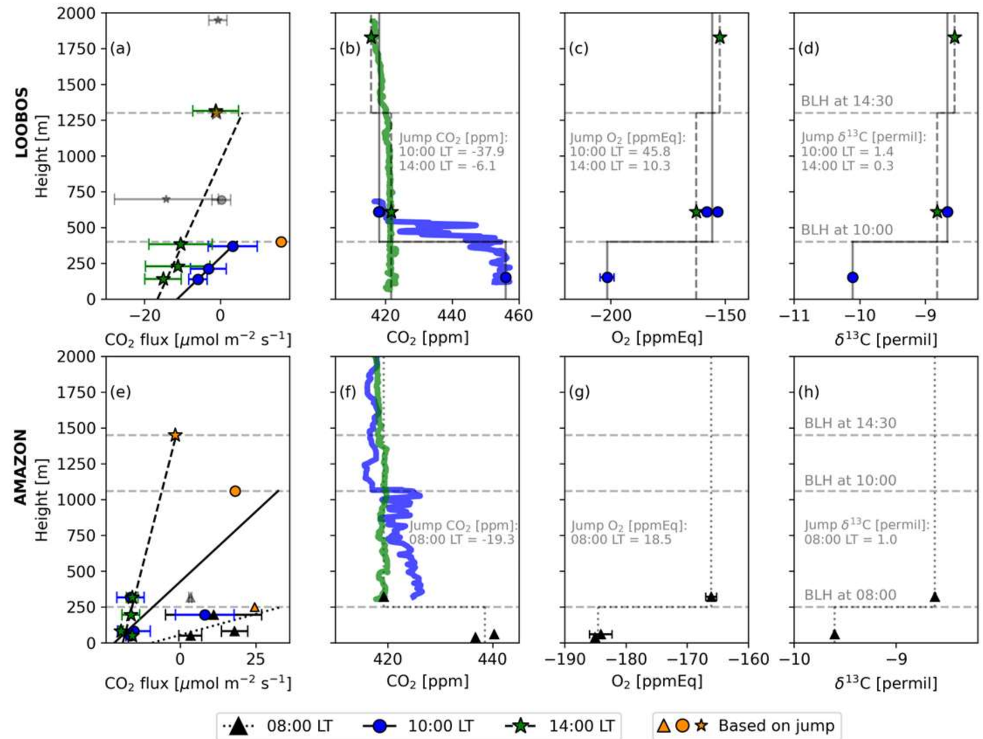
O_2 → 1/210 000=0.0005%

$$\partial\left({}^{O_2}/_{N_2}\right) = \left(\frac{\left({}^{O_2}/_{N_2}\right)_{sample}}{\left({}^{O_2}/_{N_2}\right)_{reference}} - 1\right) * 10^6 \qquad [per\ meg]$$

Diurnal ranges



Vertical profiles



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DXR contributions