Water and carbon turbulent land-atmospheric fluxes across scales: from leaf to canopy to boundary layer

Raquel González Armas, Jordi Vilà Guerau de Arellano, Hugo de Boer, Mary Rose Magnan, Oscar Hartogensis

Motivation

How Well Can Land-Surface Models Represent the Diurnal Cycle of Turbulent Heat Fluxes?

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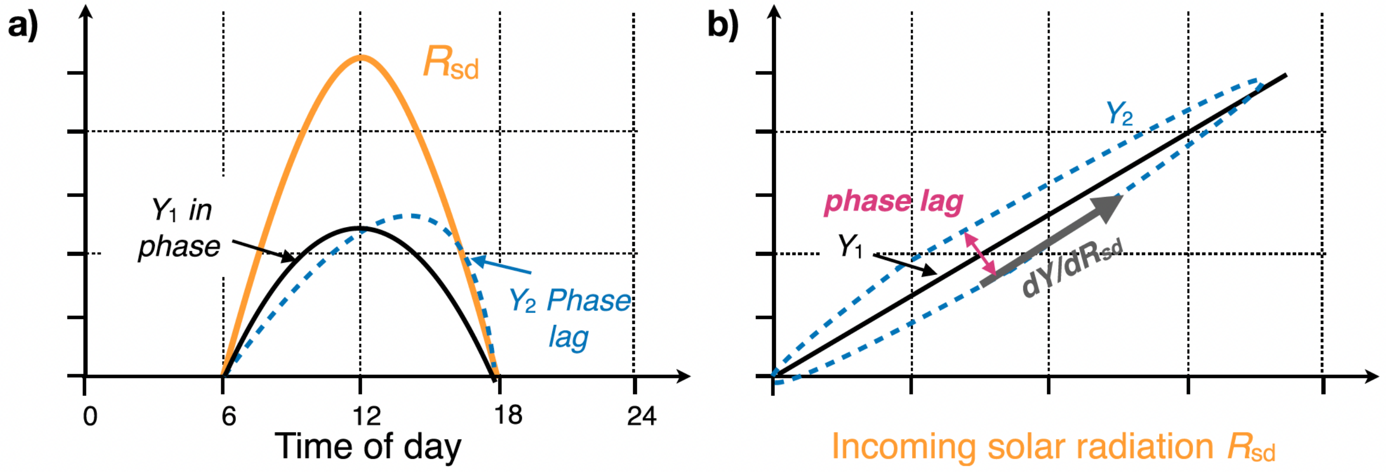
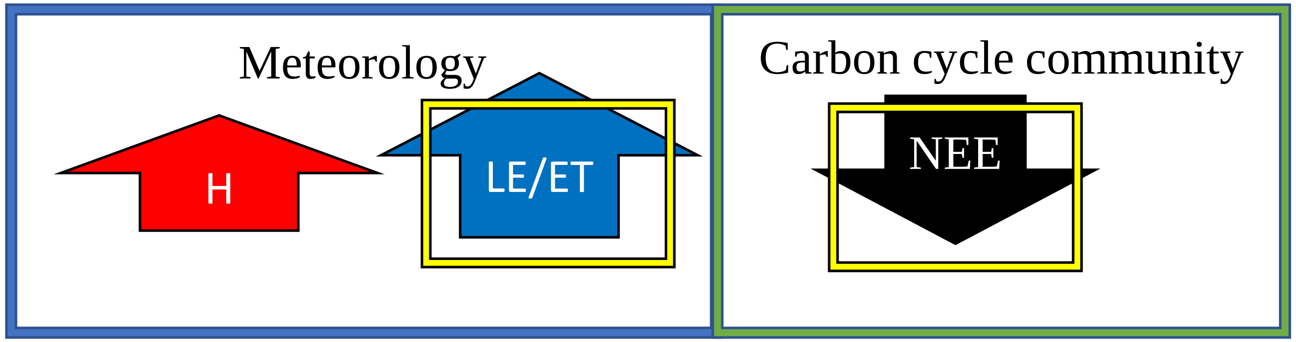


"[…]All LSMs show a poor representation of the evaporative fraction and thus the diurnal magnitude of the sensible and latent heat flux under cloud-free conditions. In addition, we find that the diurnal phase of both heat fluxes is poorly represented.
[…]We conclude that a systematic evaluation of diurnal signatures is likely to help to improve the simulated diurnal cycle, better represent land–atmosphere interactions, and therefore improve simulations of the near-surface climate. "

Motivation

Overarching aim: Understand the drivers of the diurnal variability of surfaces turbulent fluxes



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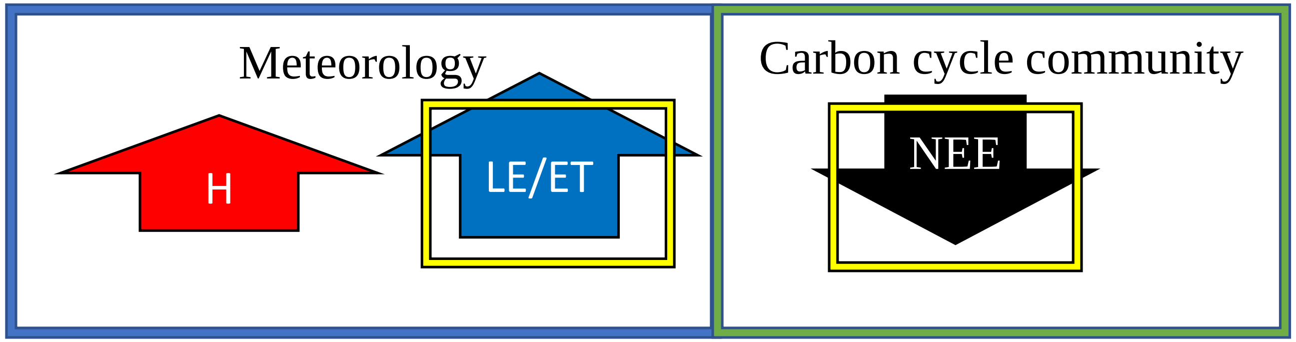

Aim: Understand the impact of the diurnal variability of the leaf level gas exchange on the diurnal variability of surface turbulent fluxes

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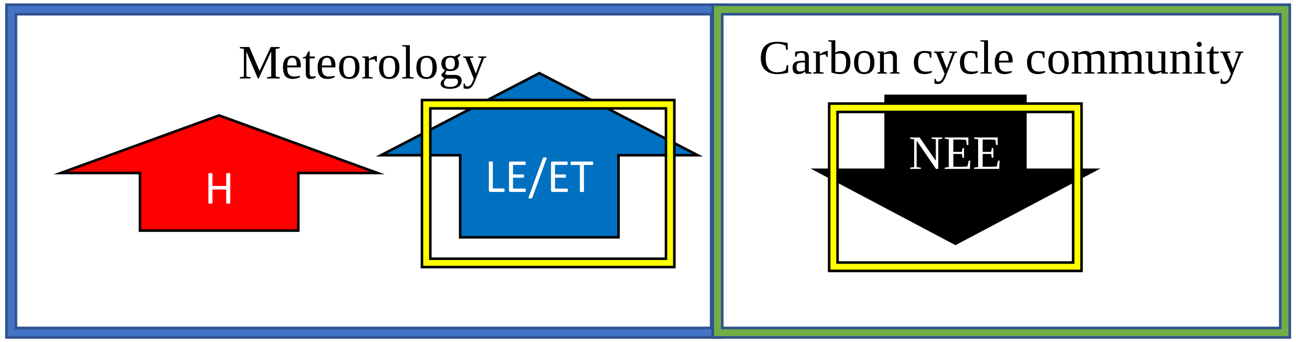

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Specific RQ: How do environmental variables influence the diurnal variability of the leaf gas exchange?

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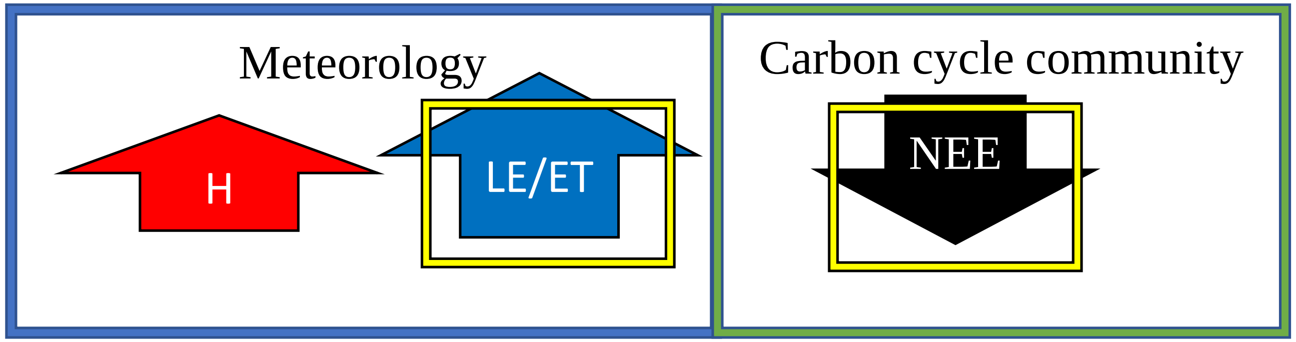

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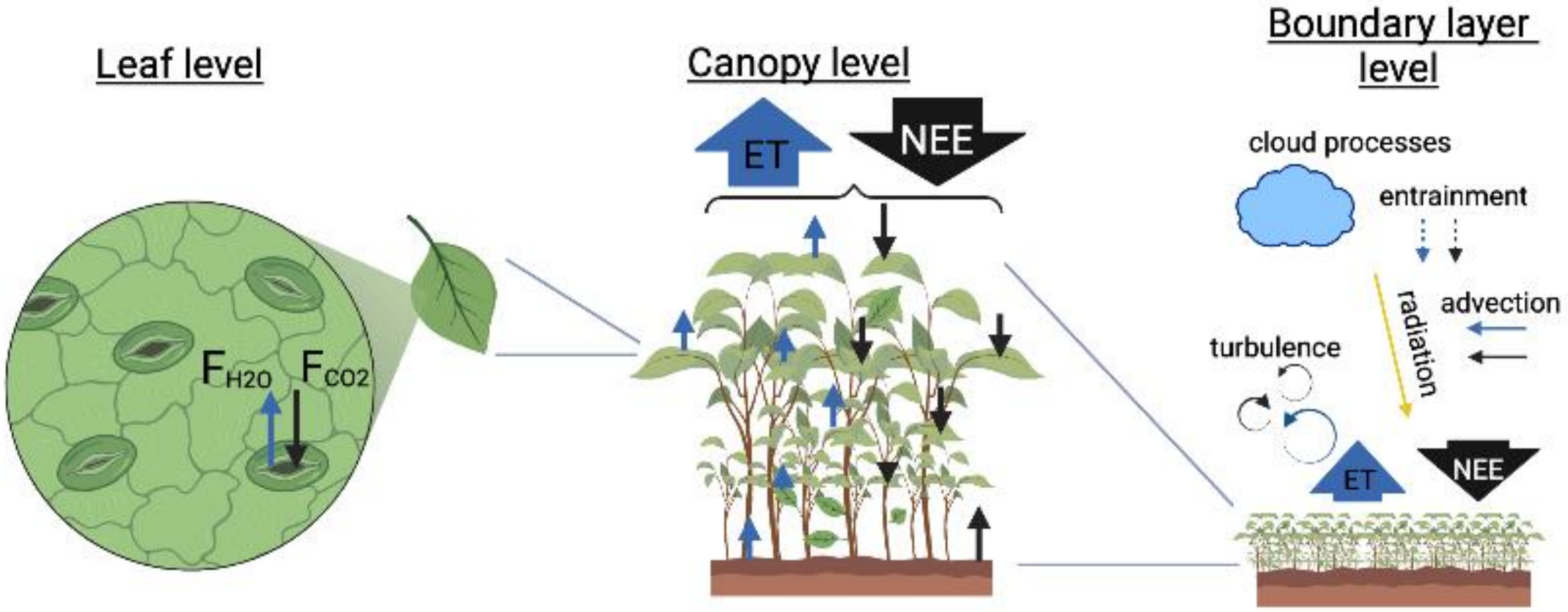
g_{sw} , TR_{leaf}, A_n

Three levels of our system



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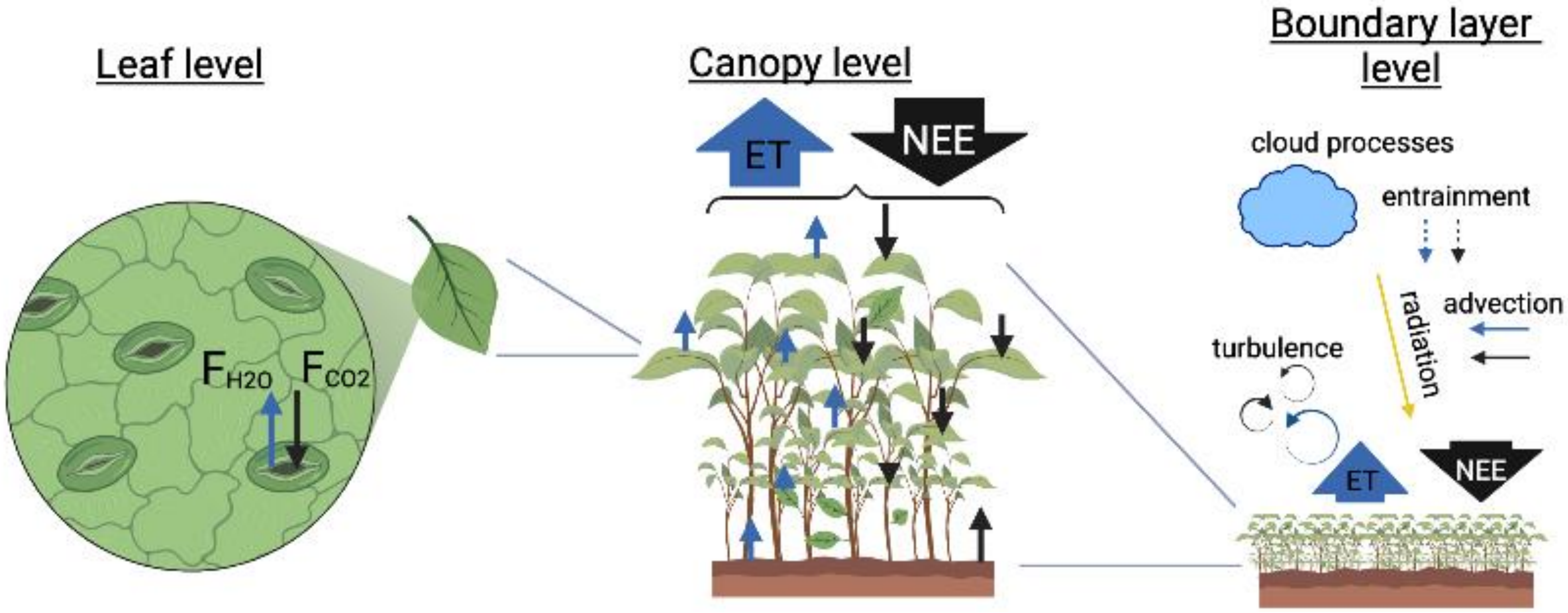
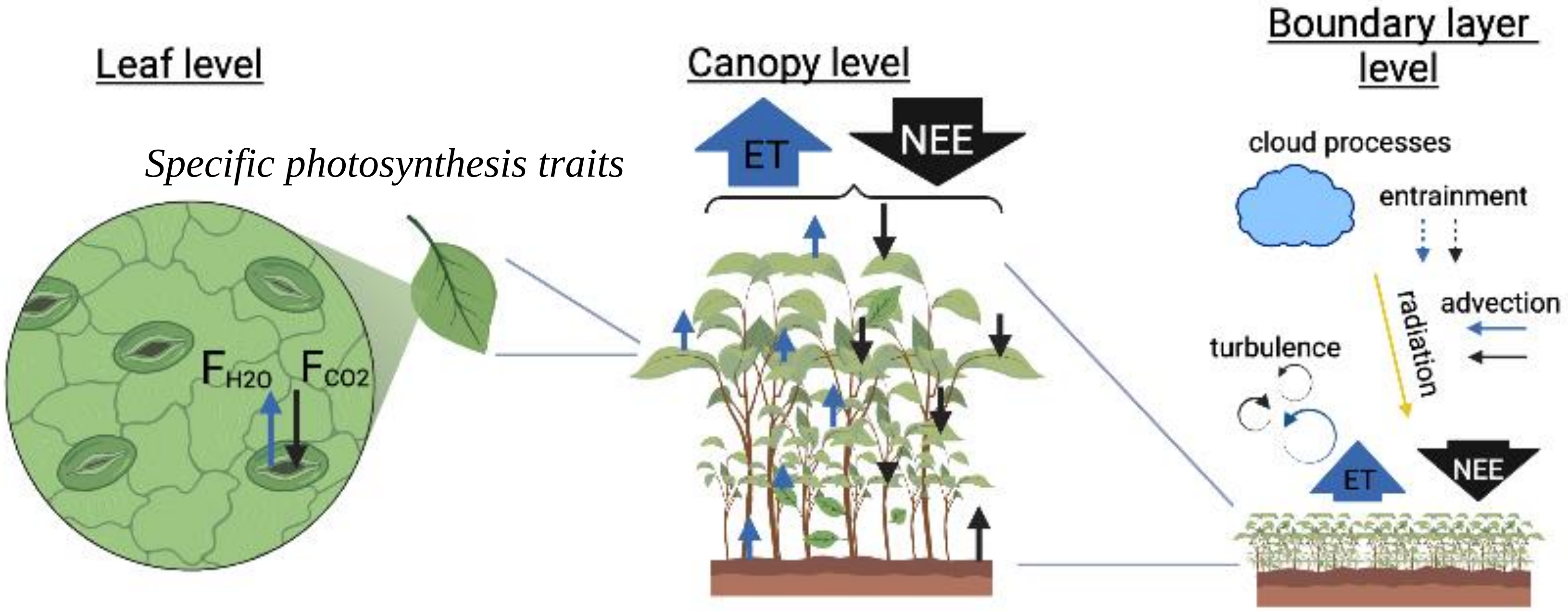


Three elements of the research

1. Observations at **all levels**
2. A land-surface-atmospheric model → **integration** of the three levels (CLASS mixed atmospheric layer model)
3. New analytical method to **quantify** the environmental contributions of the leaf gas exchange → **tendency budget equation**

Three levels of our system



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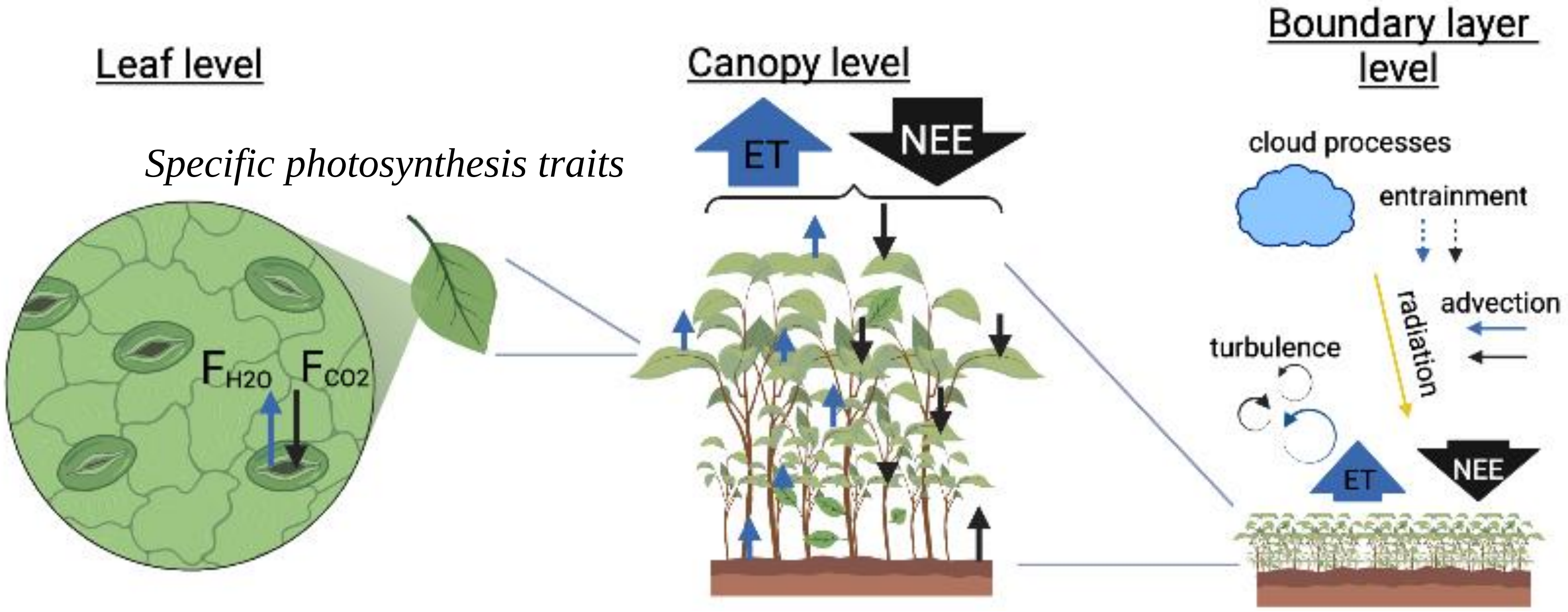

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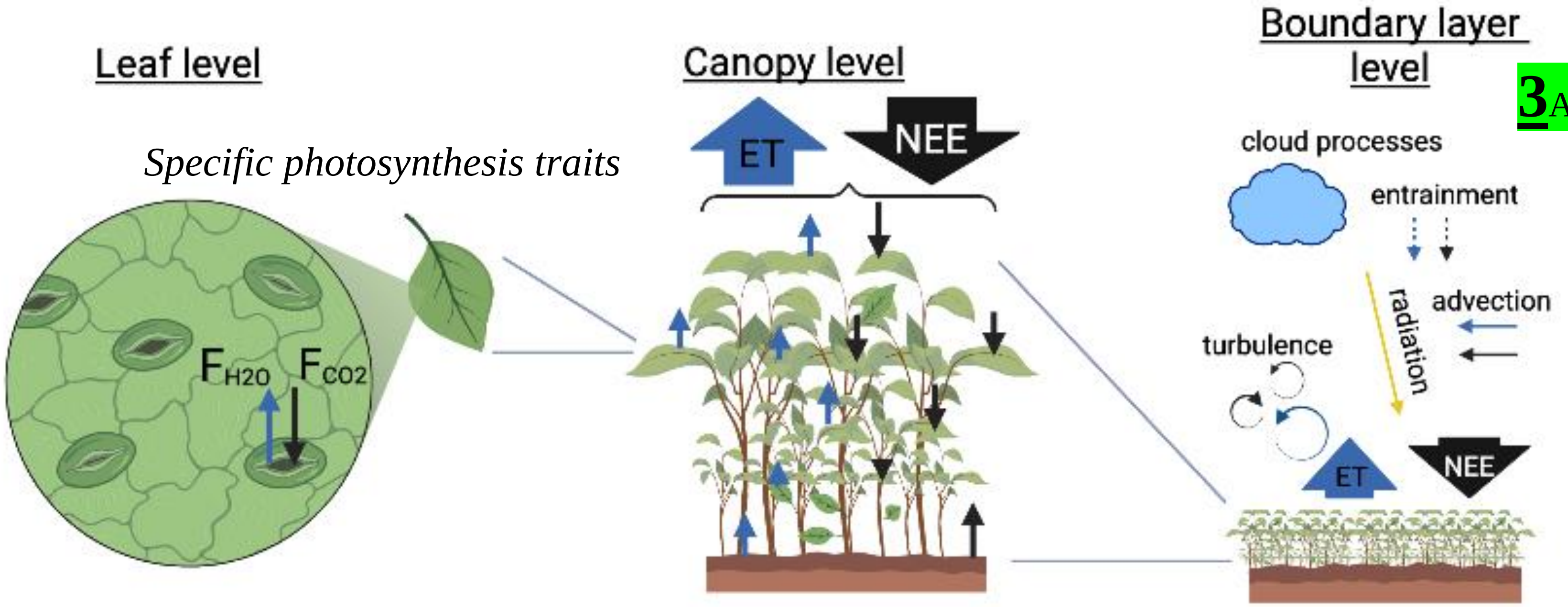

3 Application

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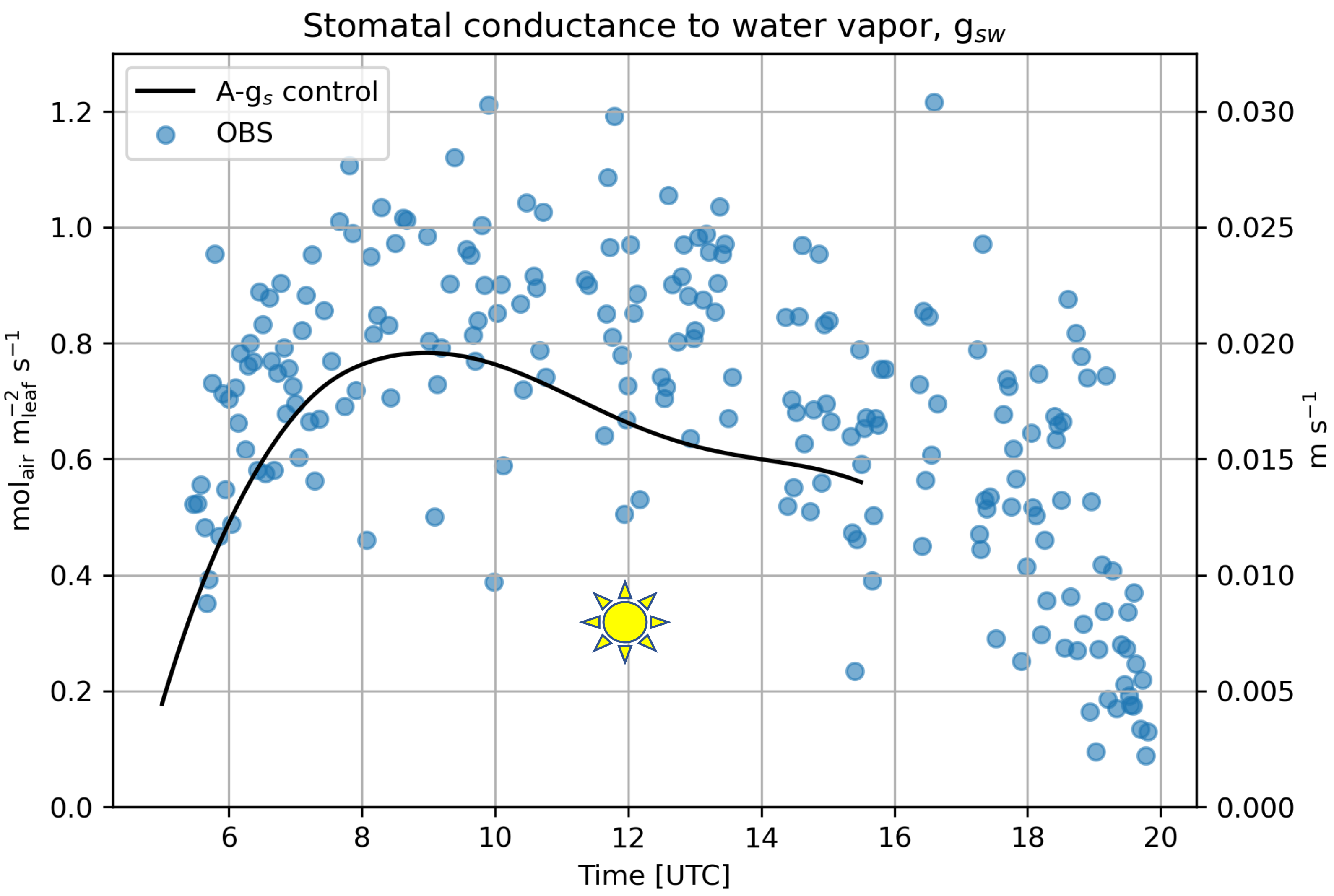
Control case

Control case: leaf level



- Intensive measurements of stomatal conductance.
- Asymmetry with respect to solar noon.

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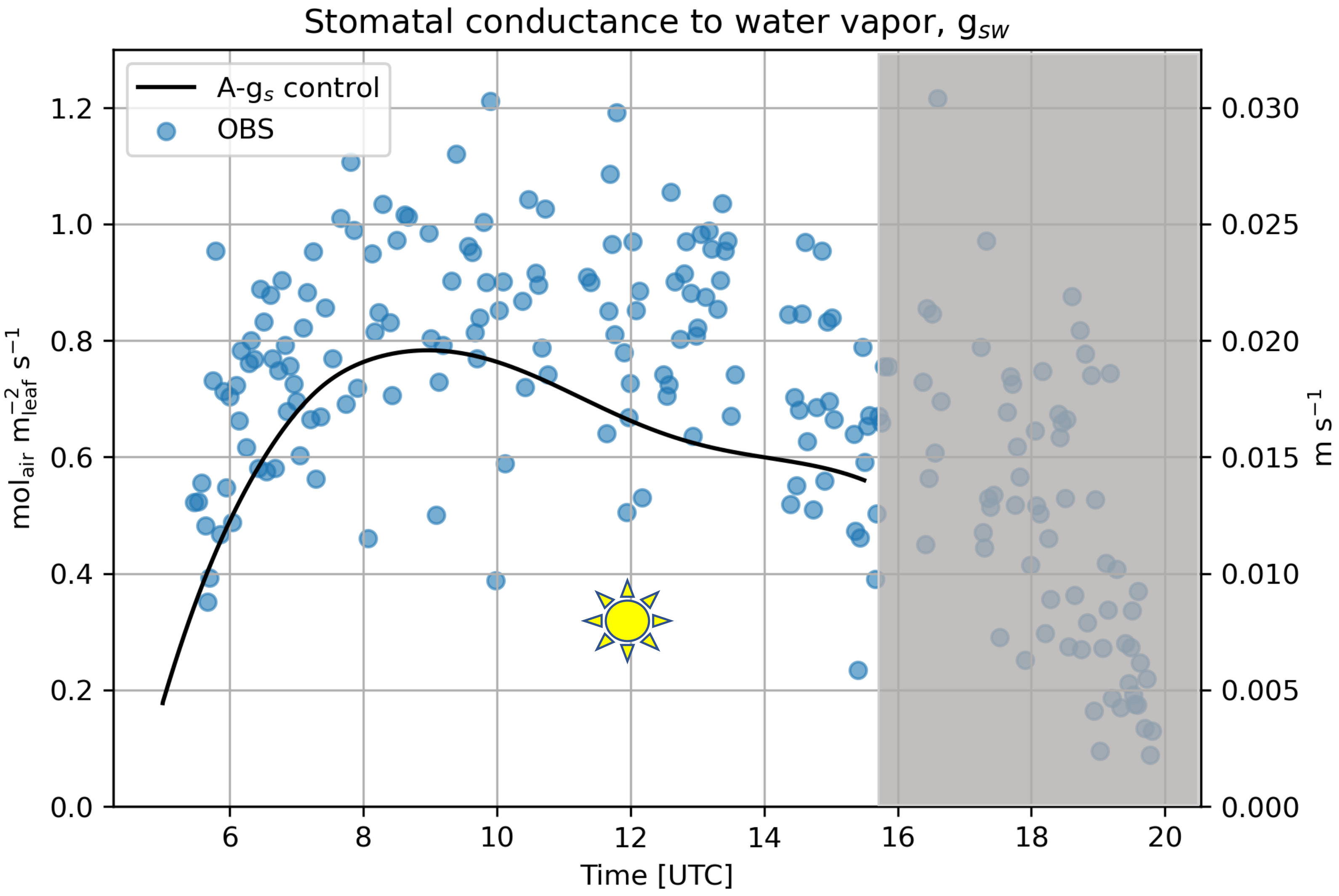
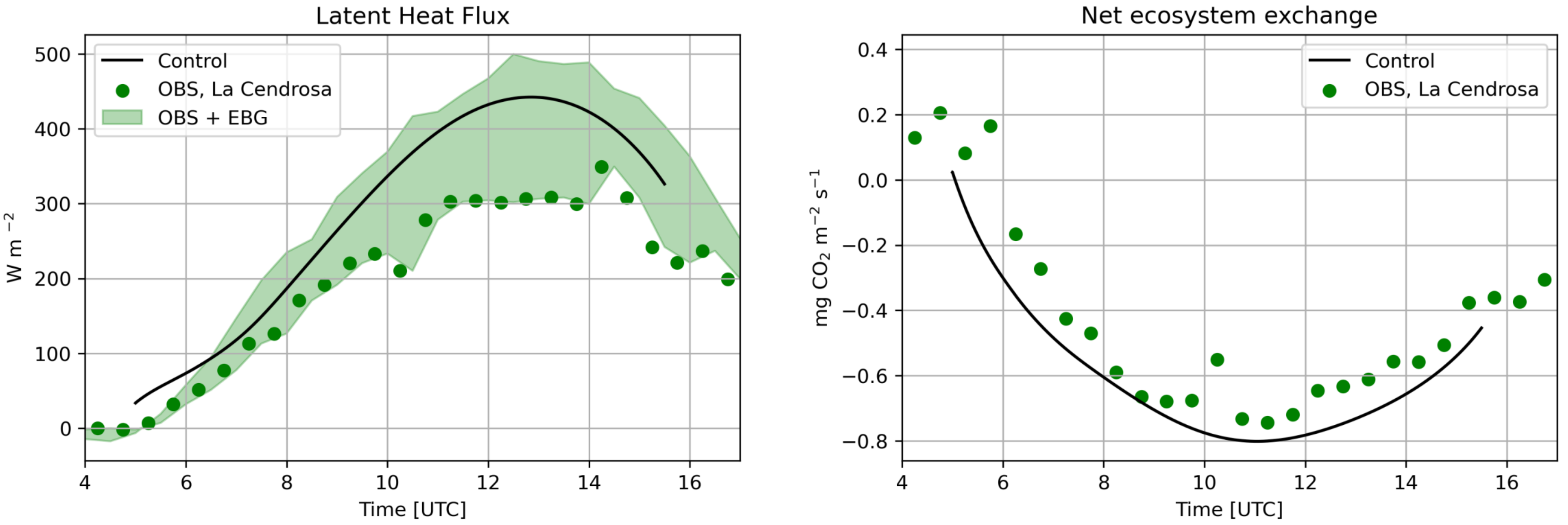


- Intensive measurements of stomatal conductance.
- Asymmetry with respect to solar noon.
- Model capture the trend
- Because of atmospheric model, predictions are not reliable after 15:50 UTC
- Slight underestimate of model compared to observations

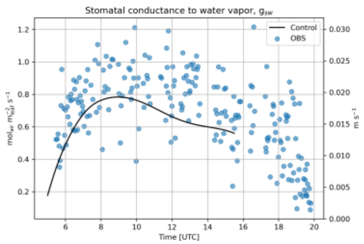
Control case: canopy surface fluxes



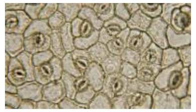
- Surface fluxes follow the same pattern as observations
- Surface fluxes are within the range of observations

Tendencies budget equation of leaf gas exchange

Tendencies of leaf gas exchange (g_s, TR_{leaf}, A_n)



A-g_s: $g_{s,w} = f(PAR, D_s, T, C_{air}, w_2)$



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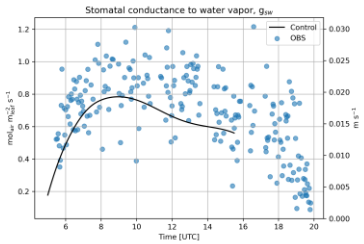

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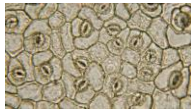

↑ PAR
↑ aperture

↑ D_s
↓ aperture

↑ T
↑ or ↓ aperture

↑ C_{air}
↓ aperture

↑ w_2
↑ aperture

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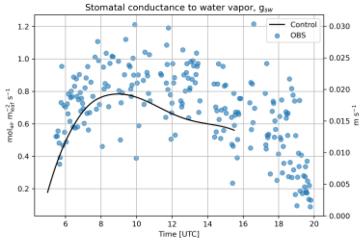

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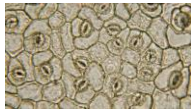
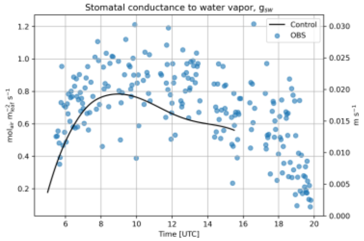


↑ PAR	↑ D_s	↑ T	↑ C_{air}	↑ w_2
↑ aperture	↓ aperture	↑ or ↓ aperture	↓ aperture	↑ aperture

How much is the contribution of every environmental variable at each time?

Tendencies of leaf gas exchange (g_s, TR_{leaf}, A_n)



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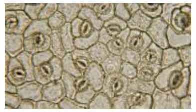

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$$\frac{dg_{s,w}}{dt} = \frac{\partial g_{s,w}}{\partial PAR} \cdot \frac{dPAR}{dt} + \left(\frac{\partial g_{s,w}}{\partial D_s}\right) \cdot_{T=cte} \frac{dD_s}{dt} + \left(\frac{\partial g_{s,w}}{\partial T}\right) \cdot_{D_s=cte} \frac{dT}{dt} + \frac{\partial g_{s,w}}{\partial C_{air}} \cdot \frac{dC_{air}}{dt} + \frac{\partial g_{s,w}}{\partial w_2} \cdot \frac{dw_2}{dt}$$

Total time tendency

Variations due to radiation changes

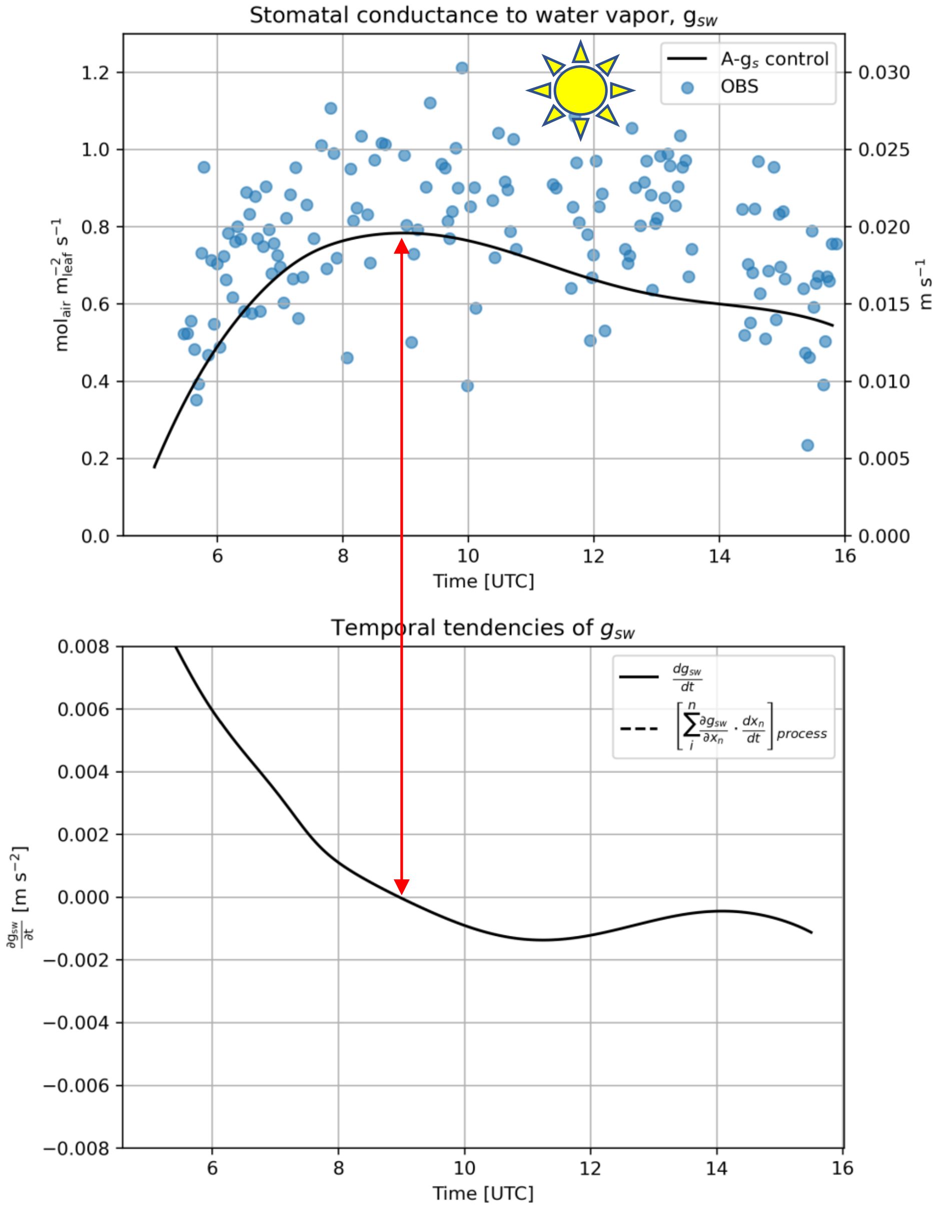
Variations due to leaf to air vapor pressure deficit changes

Variations due to temperature changes for explicit dependent temperature processes

Variations due to ambient CO_2 concentration changes

Variations due to changes in soil water content at root zone

Tendencies of leaf gas exchange



- Tendencies are an exact method.
- It indicates the observed maximum of stomatal conductance and shape of the signature

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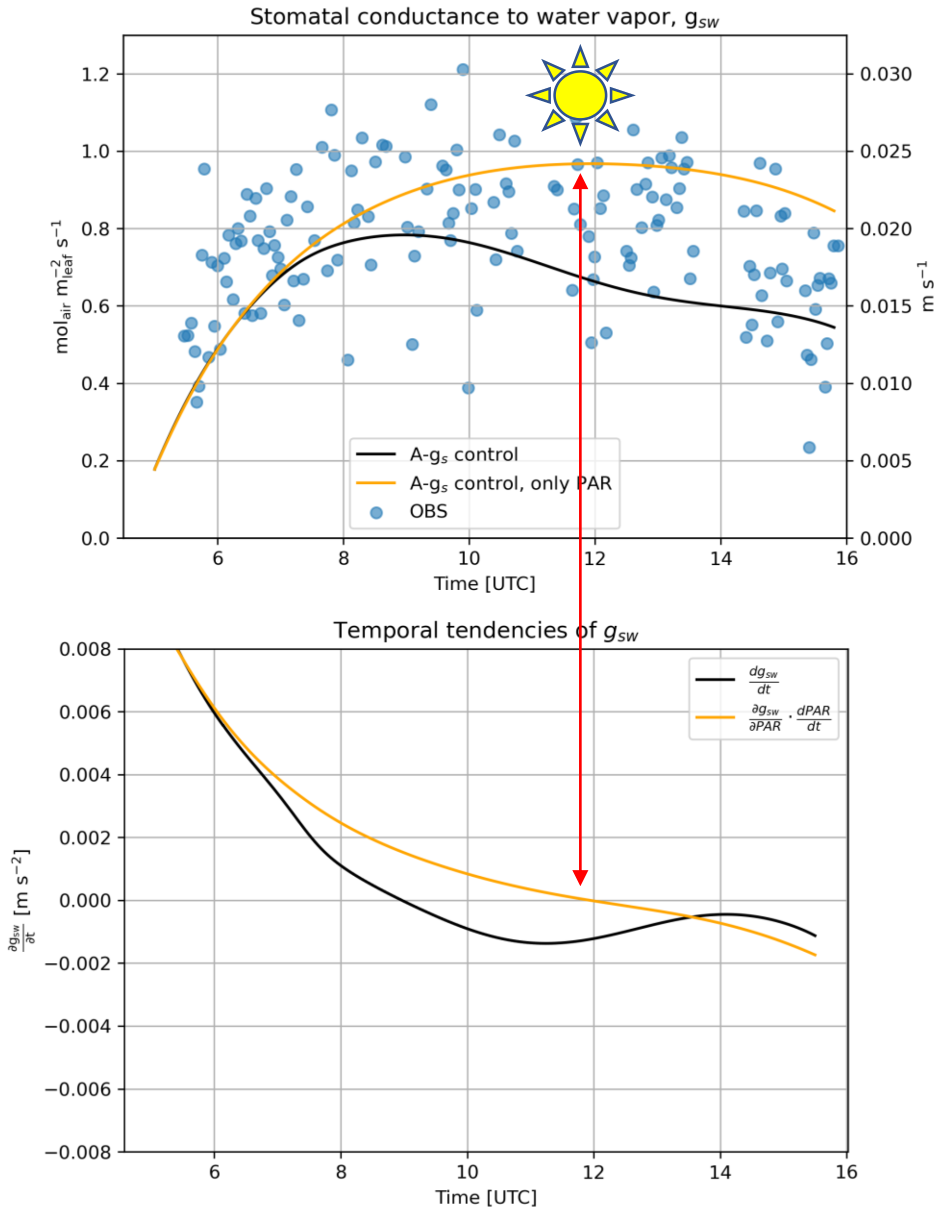

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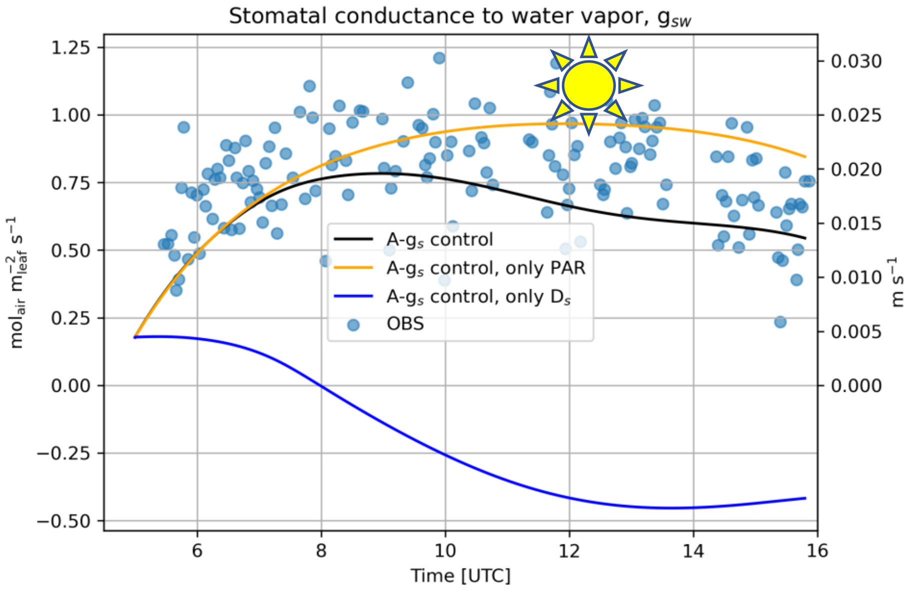
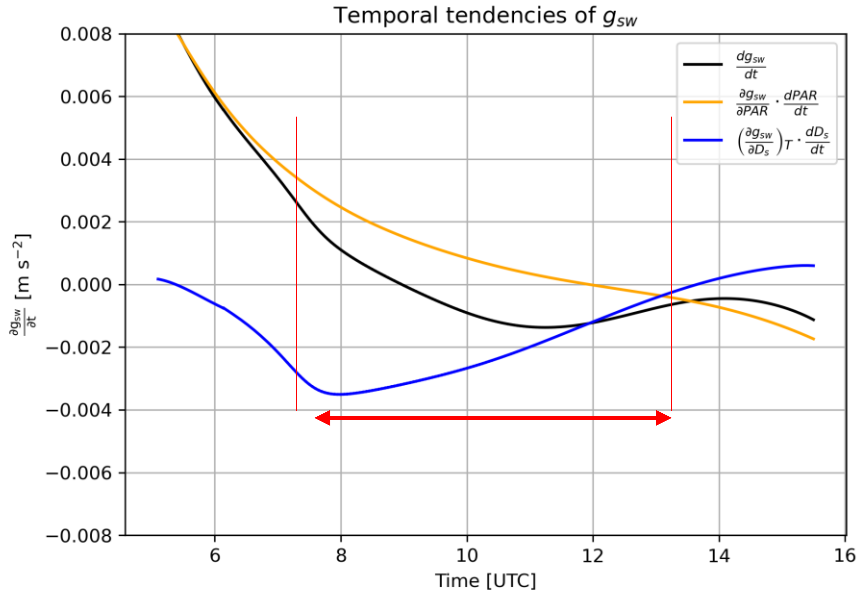
<u>CONTRIBUTIONS OF ENVIRONMENTAL VARIABLES</u>

- PAR:
  - Stroger driver in early morning and late afternoon
  - Symmetric around solar noon (≈12 UTC)

Tendencies of leaf gas exchange





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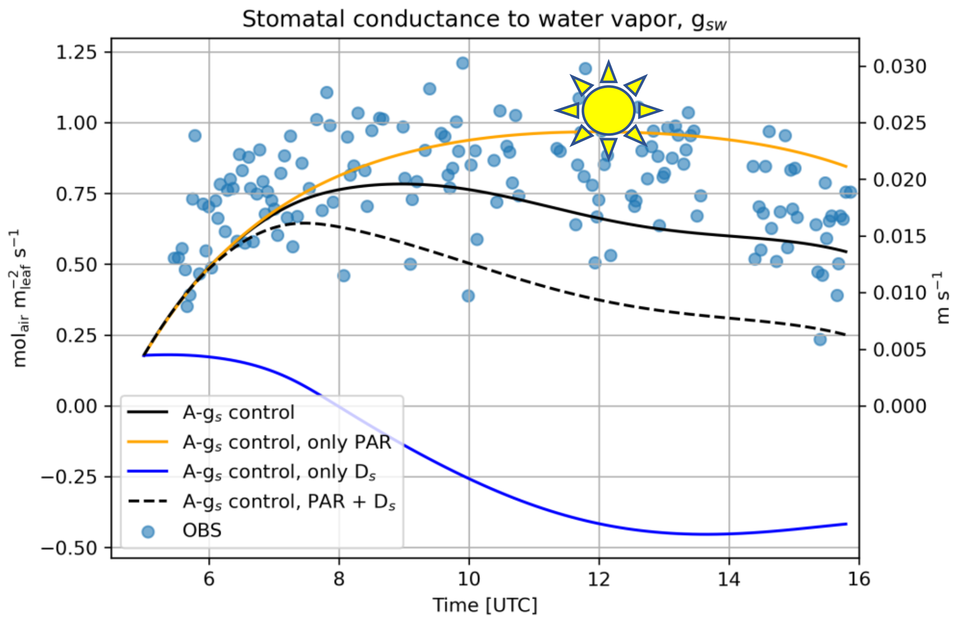

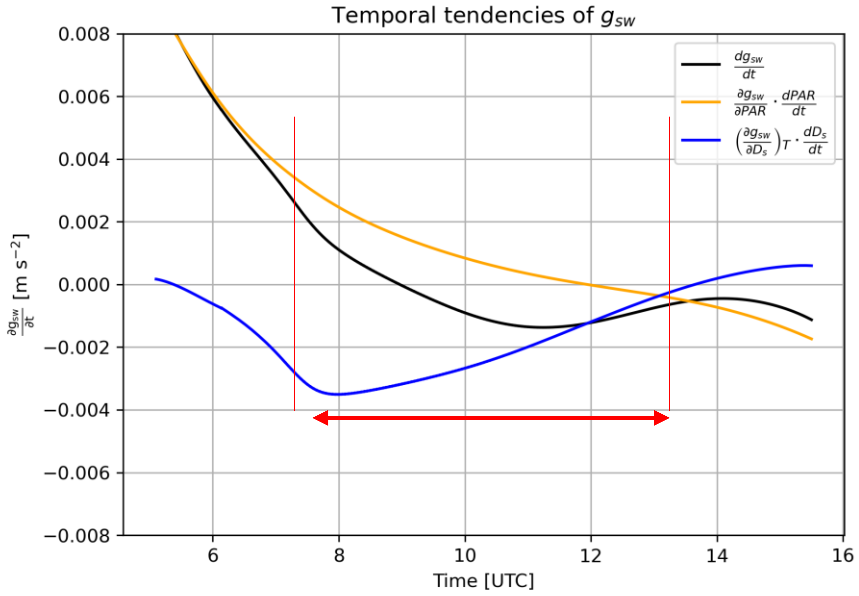

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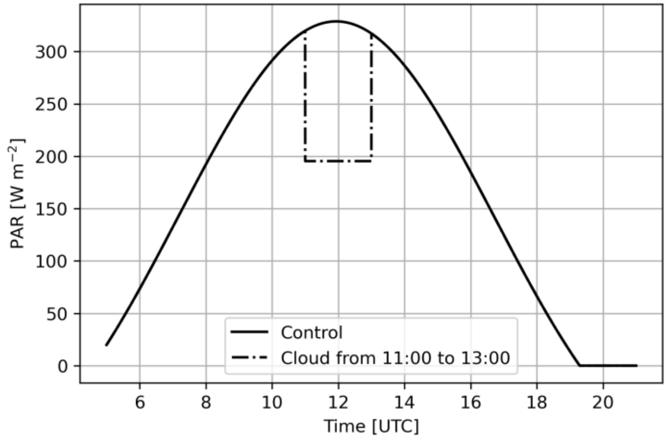
Gap on stomatal conductance (solid black versus dashed black line) is attributed to changes in T and C_{air}

Applications of the framework: exploring other environmental conditions

Advected cloud

Step 1: environmental forcing



- Reduction of PAR from 11:00 to 13:00 UTC. (Swin to 600 W/m2). I used values from other days when clouds occurred

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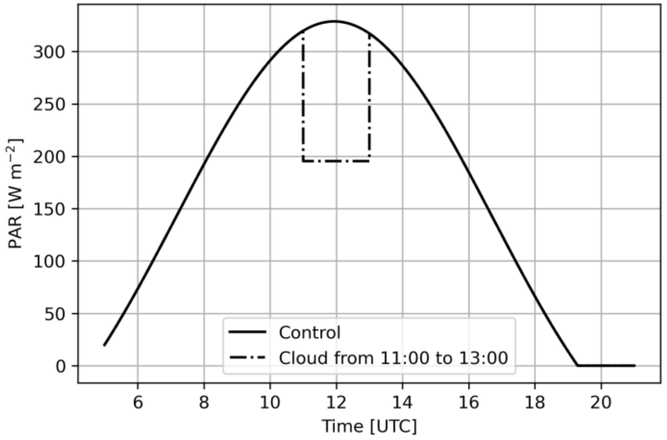

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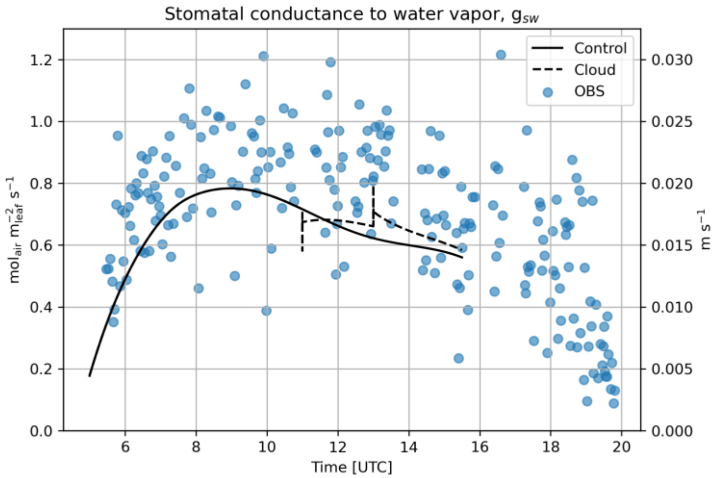
Step 2: Exchange at leaf level



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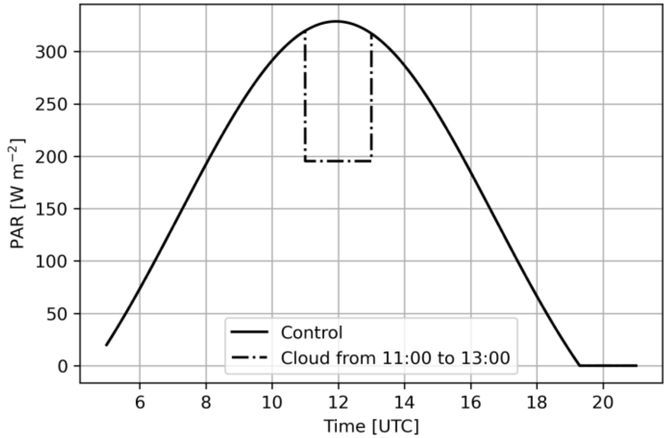

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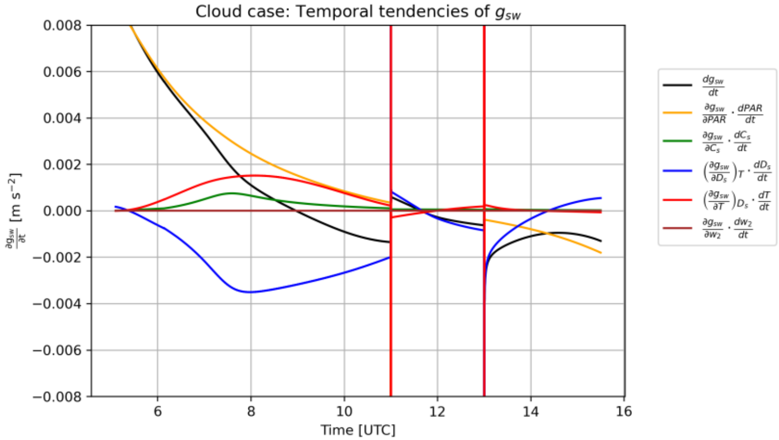

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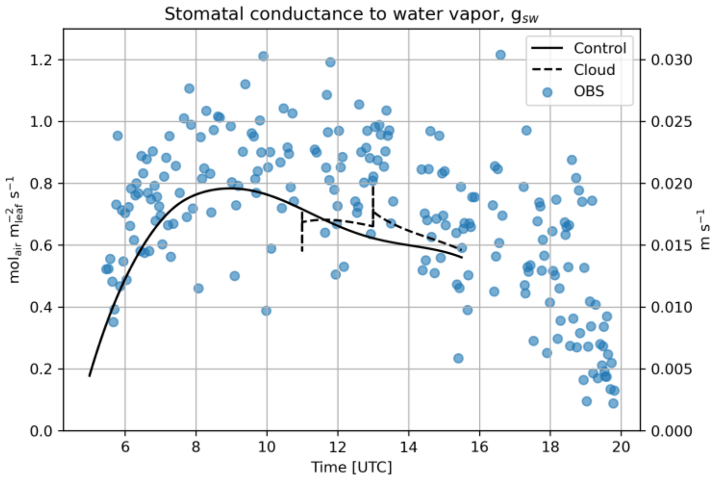

Step 3: Tendencies to understand and quantify the contribution of environmental variables to leaf gas exchange

Advected cloud

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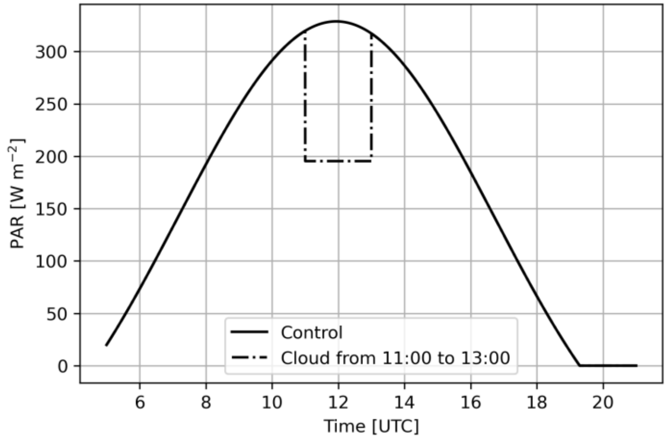

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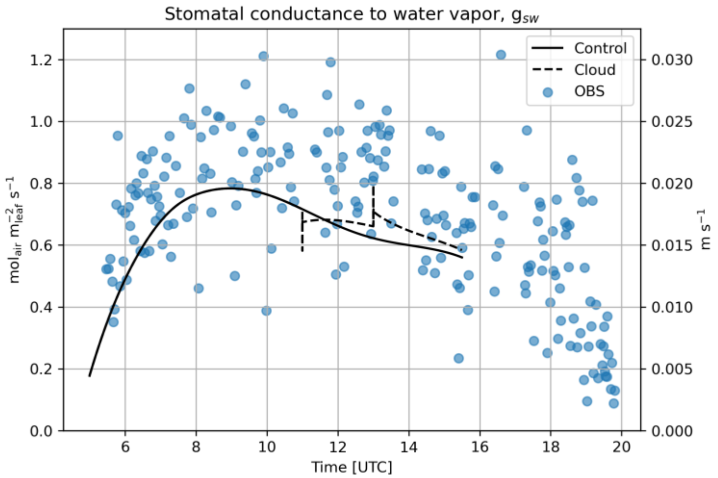

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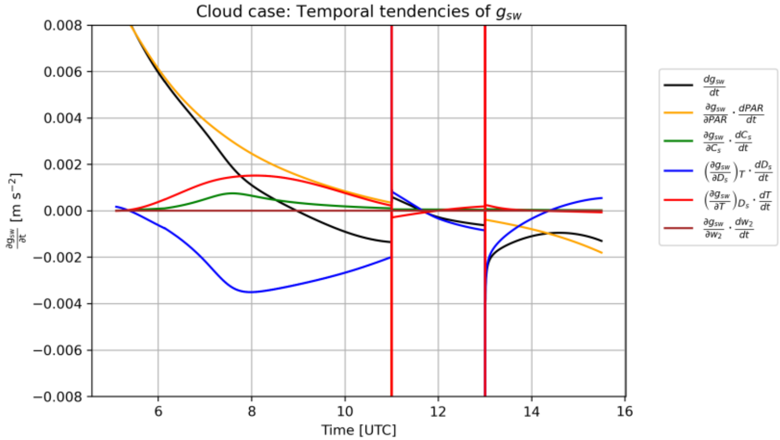
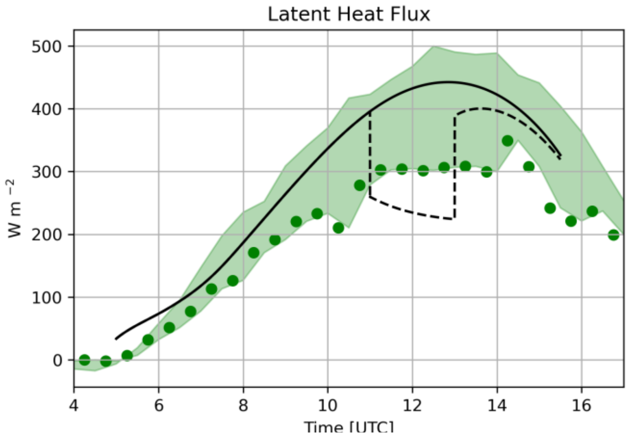
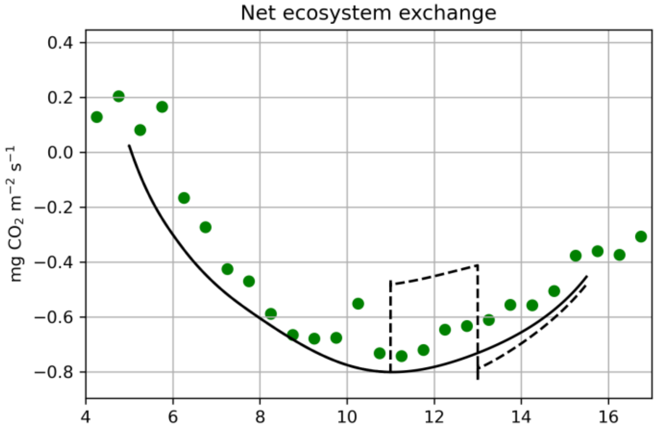


Step 3: Tendencies to understand and quantify the contribution of environmental variables to leaf gas exchange

Step 4: Exchange at canopy level

Exemplary result:
Water use efficiency
is enhanced after the cloud!!





RQ: How do environmental variables influence the diurnal signature of the leaf gas exchange?

Given a leaf gas exchange model, contribution of each environmental variables can be quantified at any moment of time!!

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We have done the tendency budget equation for

1. g_{sw}, stomatal conductance
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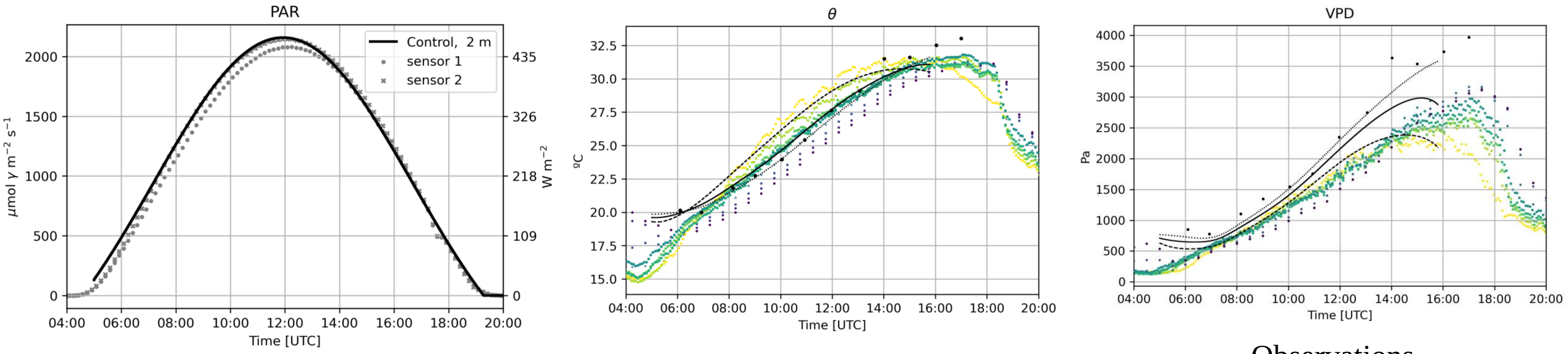
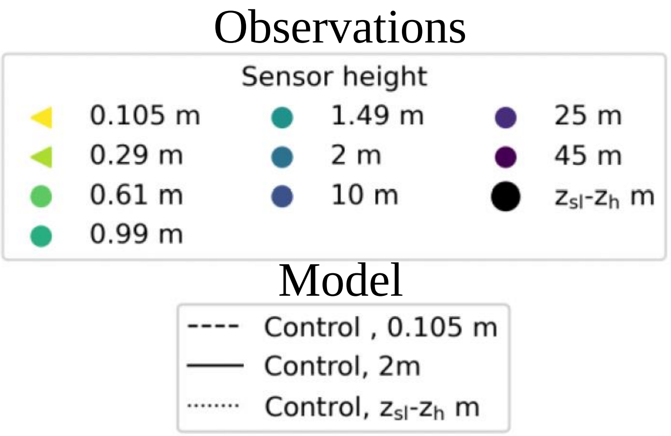
Ongoing work

- Find interesting applications (comparison of different leaf gas exchange scheme, sensitivity to environmental variables, or understanding of the leaf gas exchange in different environmental conditions) and systematic evaluation procedures to analyse many cases (metric)
- Connect with canopy diurnal signature

Appendix

Control case: environmental drivers





- Agreement between models and observations of radiation, temperature and vapor pressure deficit at different heights
- Confidence that the atmosphere is well reproduced

Conclusions and future work

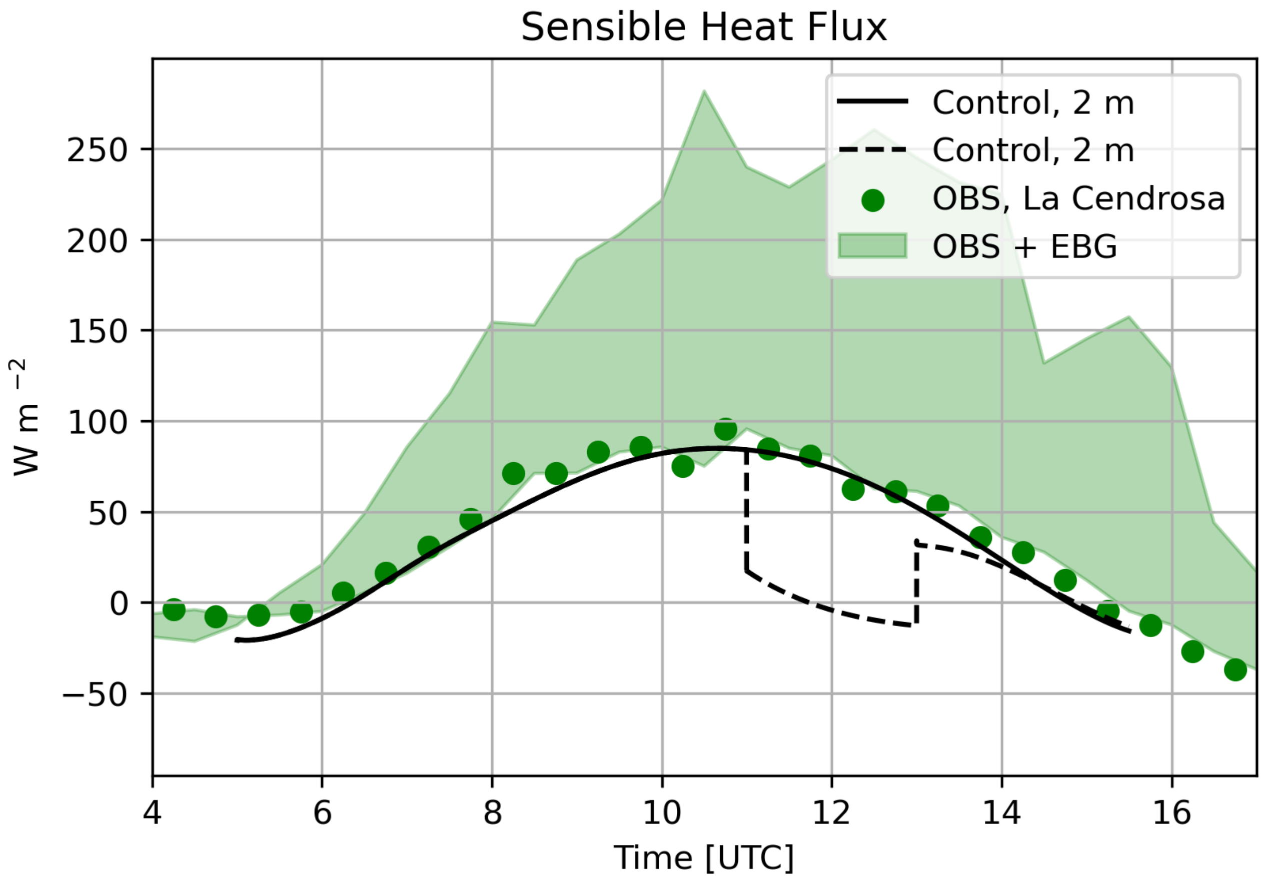
- It is possible to contrain leaf and canopy fluxes accordingly
- The dynamics of leaf gas exchange can be understood and subdivided by its individual forcings
- Models allow the creation of realistic cases to understand the relations between levels
- After a passage of a thick cloud, water use efficiency is increased

➢ Sensitivity of environmental input (Ts or T2m…) → need of a leaf energy balance?

➢ Check if the implementation of adaptation time of stomatal conductance change conclusions

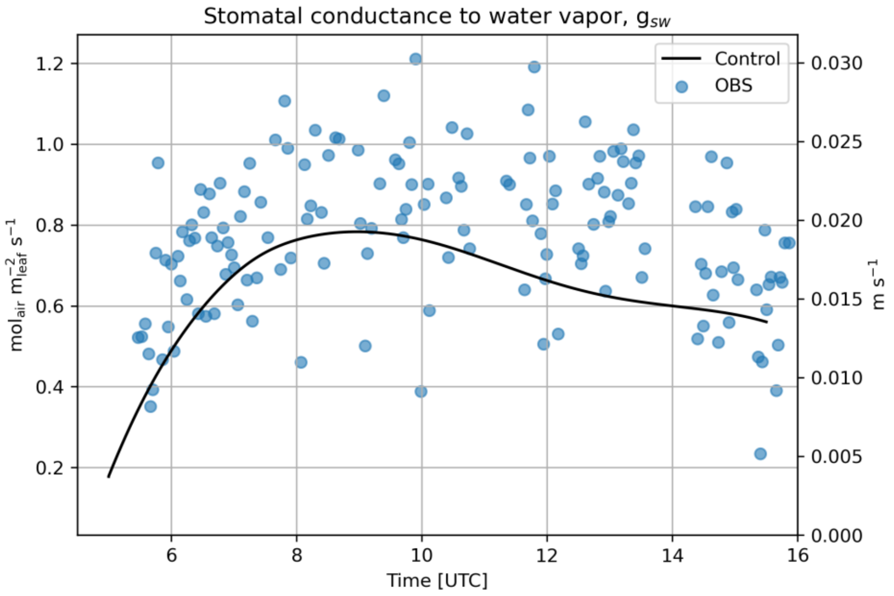
➢ Metric based on tendencies to analyse systematically more days

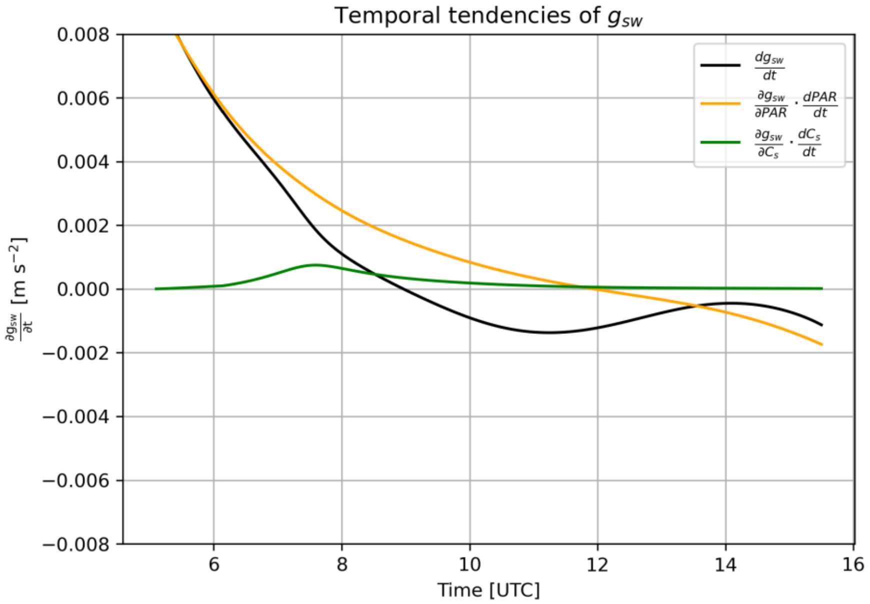
Cloud case



Sensible Heat Flux
Control, 2 m
Control, 2 m
OBS, La Cendrosa
OBS + EBG
W m −2
250
200
150
100
50
0
−50
4
6
8
10
12
14
16
Time [UTC]

Tendencies of leaf gas exchange



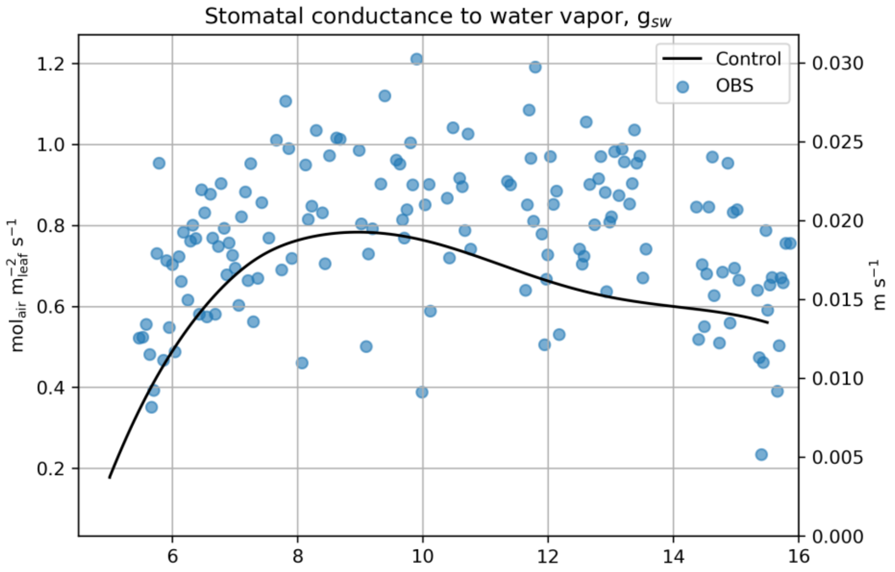


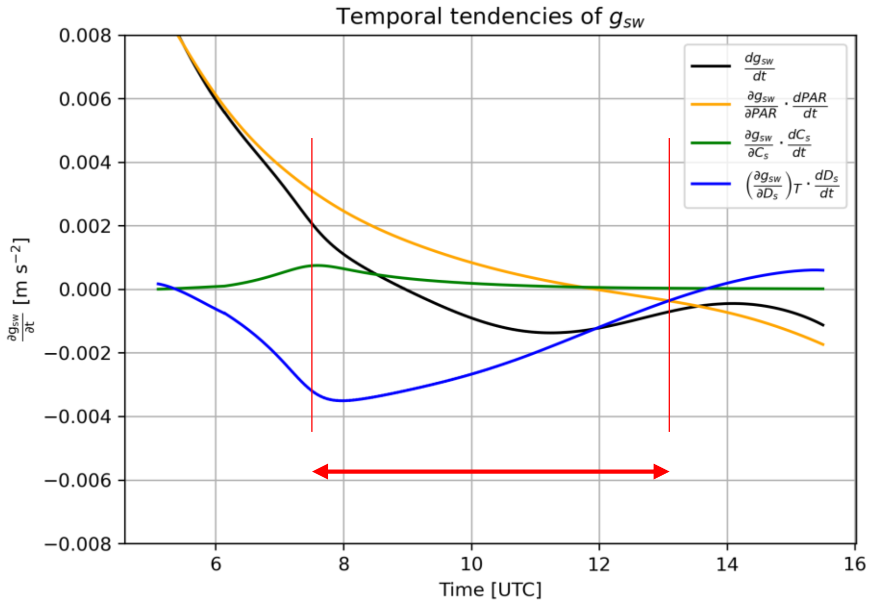
What is the contribution of each of the drivers of the diurnal variability of stomatal conductance?

PAR influences greatly the early morning and late afternoon and decreases its effect at noon. Its effect is symmetric around noon

CO_2 only influences in the morning when the bulk of entrainment occurs. Because CO_2 is reduced at that point, stomata open further to receive enough CO_2 to make photosynthesis

Tendencies of leaf gas exchange





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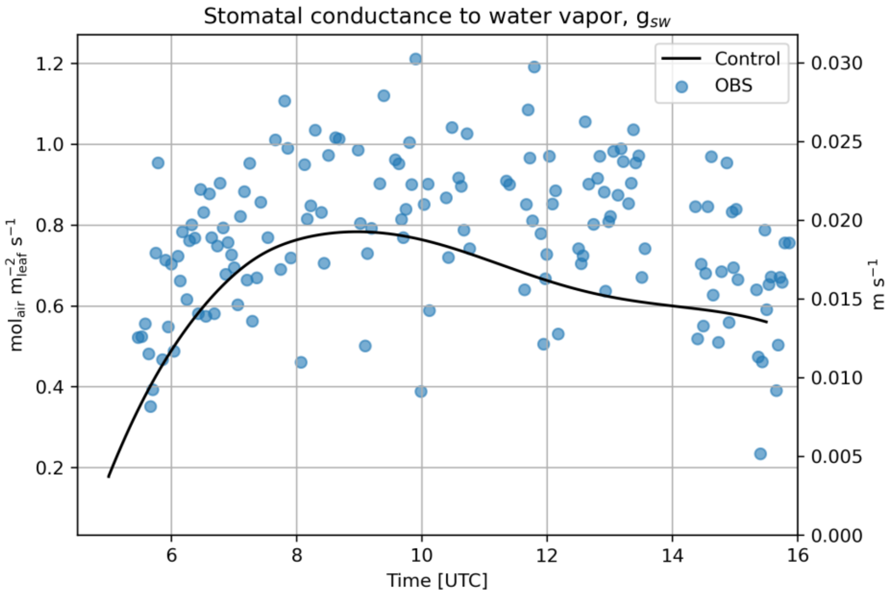
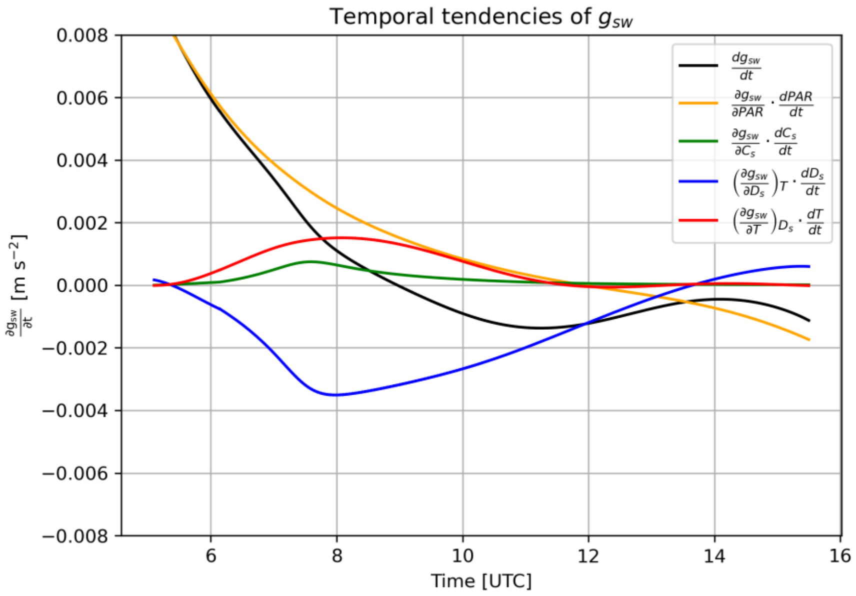
D_s is the more influencial factor of the diurnal variability of stomatal conductance from 7:30 to 13:00 UTC. D_s forces stomatal conductance to close.

T has a positive effect on stomatal conductance, because in the morning T increases and get closer to the optimal temperature of the crop. From 11 to 15:30 the temperatures have not changed so much and are closer to the optimal temperature and as a consequence, the temperature does not control the variability.

Tendencies of leaf gas exchange





What is the contribution of each of the drivers of the diurnal variability of stomatal conductance?

PAR influences greatly the early morning and late afternoon and decreases its effect at noon. Its effect is symmetric around noon

CO_2 only influences in the morning when the bulk of entrainment occurs. Because CO_2 is reduced at that point, stomata open further to receive enough CO_2 to make photosynthesis

D_s is the more influencial factor of the diurnal variability of stomatal conductance from 7:30 to 13:00 UTC. An increase on D_s always forces stomatal conductance to close.

T has a positive effect on stomatal conductance, because in the morning T increases and get closer to the optimal temperature of the crop. From 11 to 15:30 the temperatures have not changed so much and are closer to the optimal temperature and as a consequence, the temperature does not control the variability.

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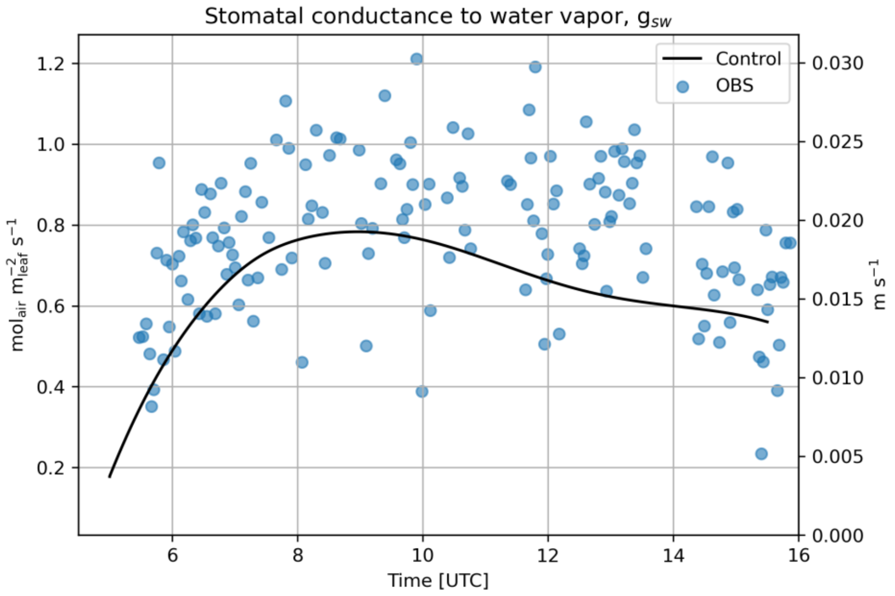

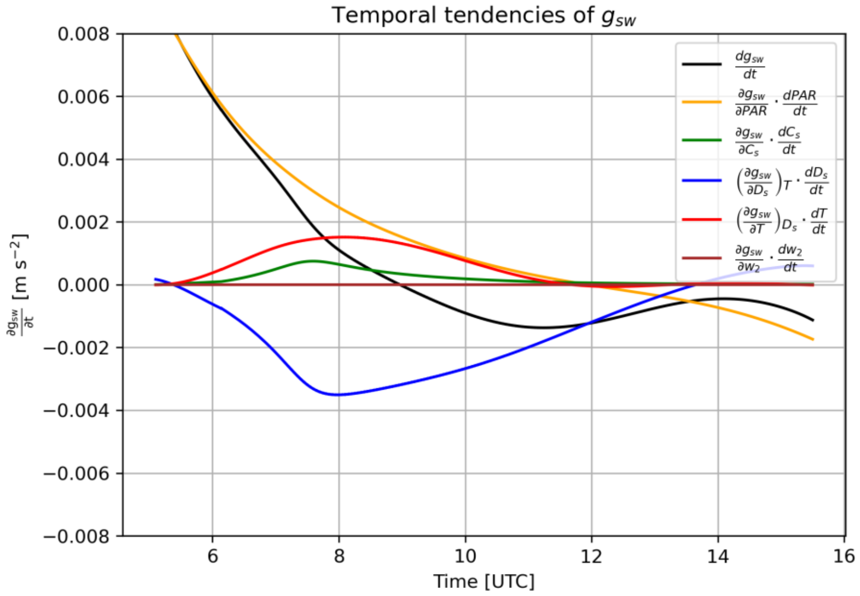

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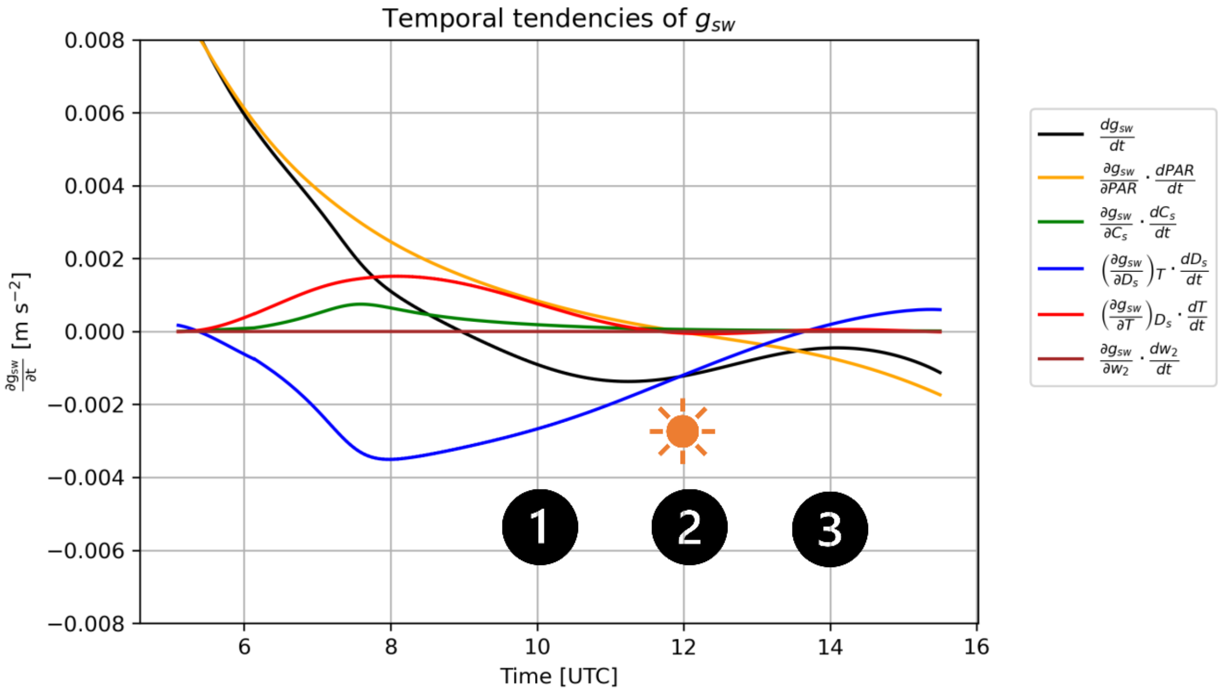
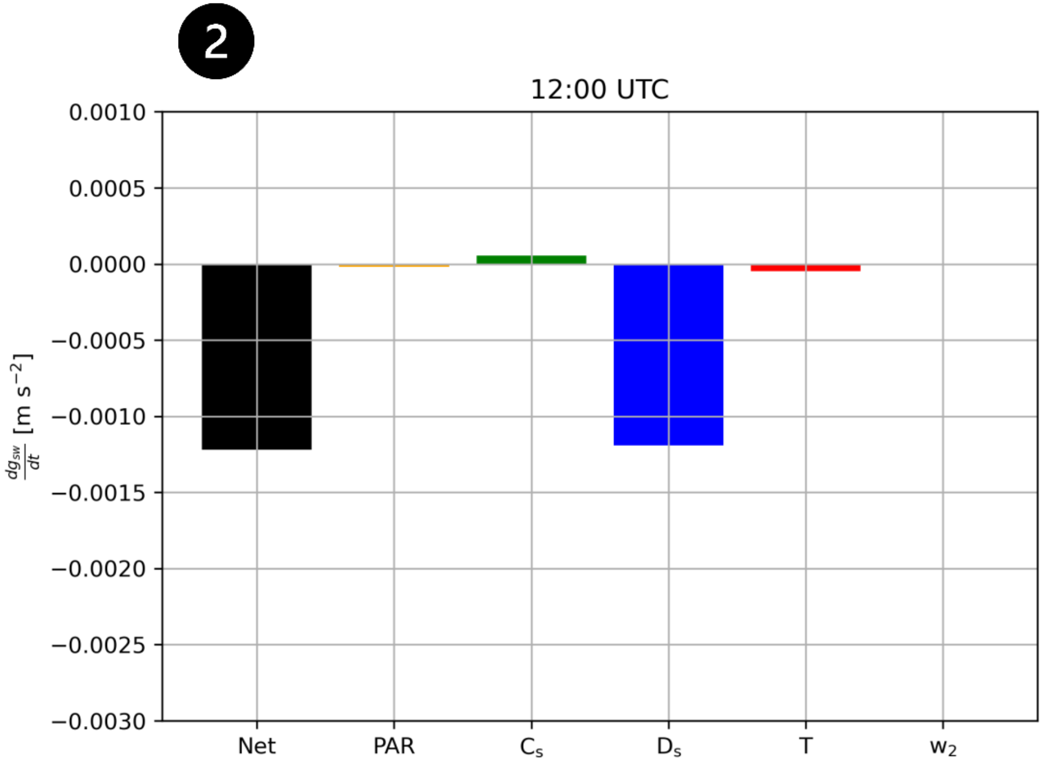
w_2 has no effect because it is assumed to be constant during the day

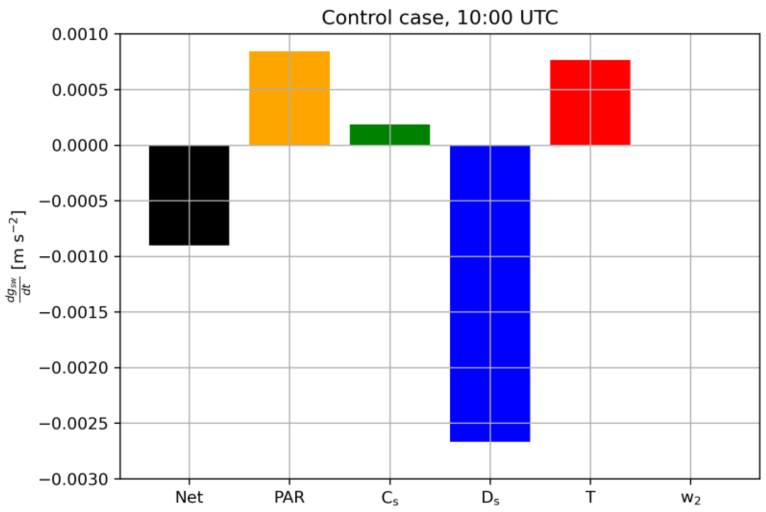
Another way to analyze tendencies



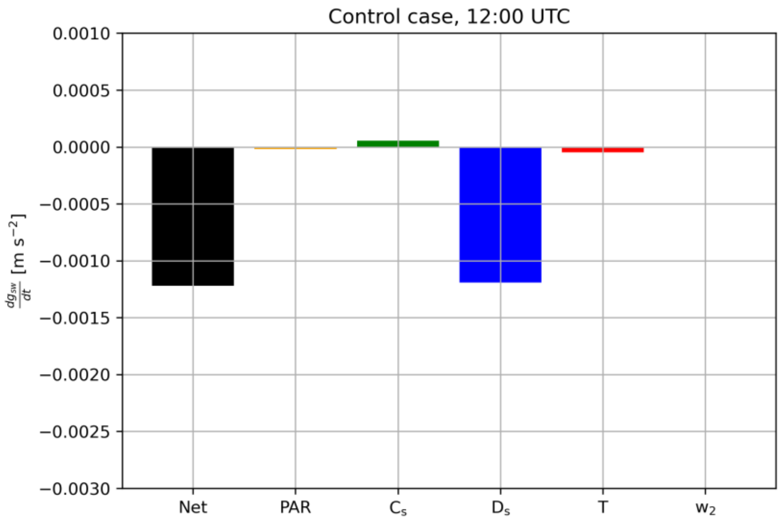


Another way to analyze tendencies

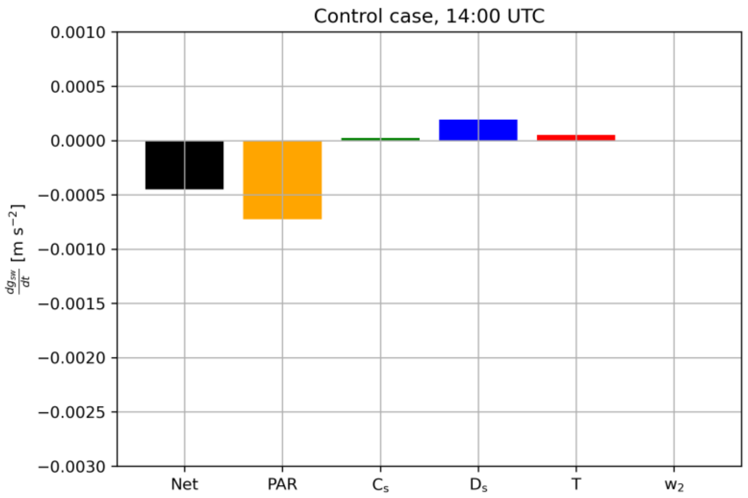
1 10 UTC



2 12 UTC

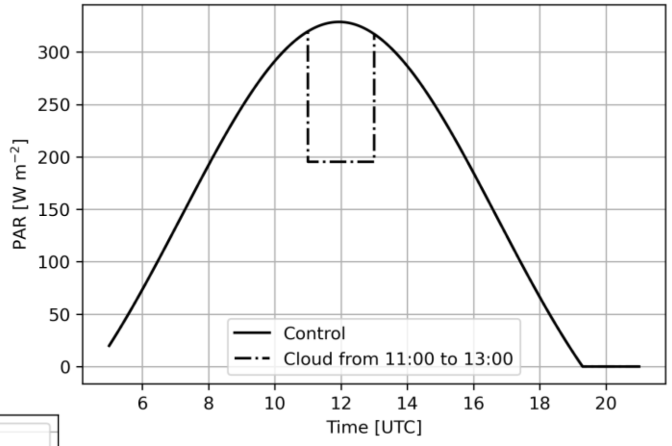


3 14 UTC

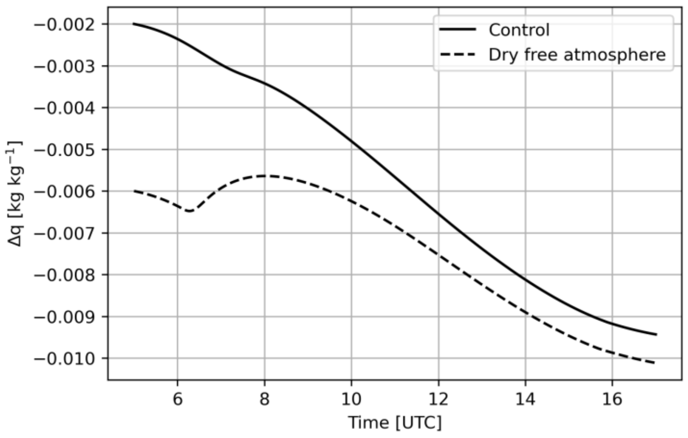


Three cases

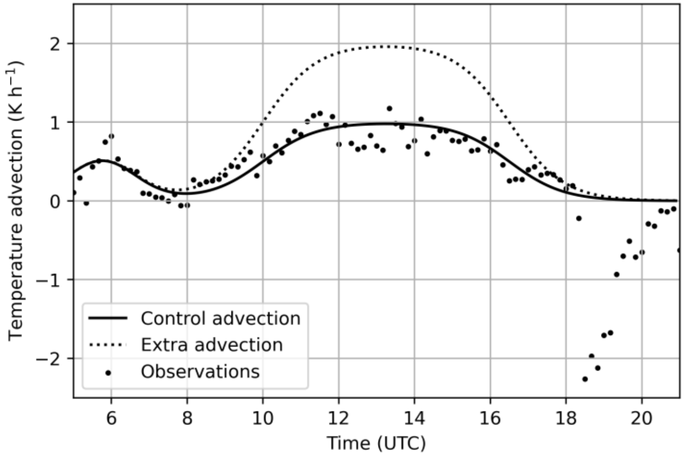
1. Passage of a cloud



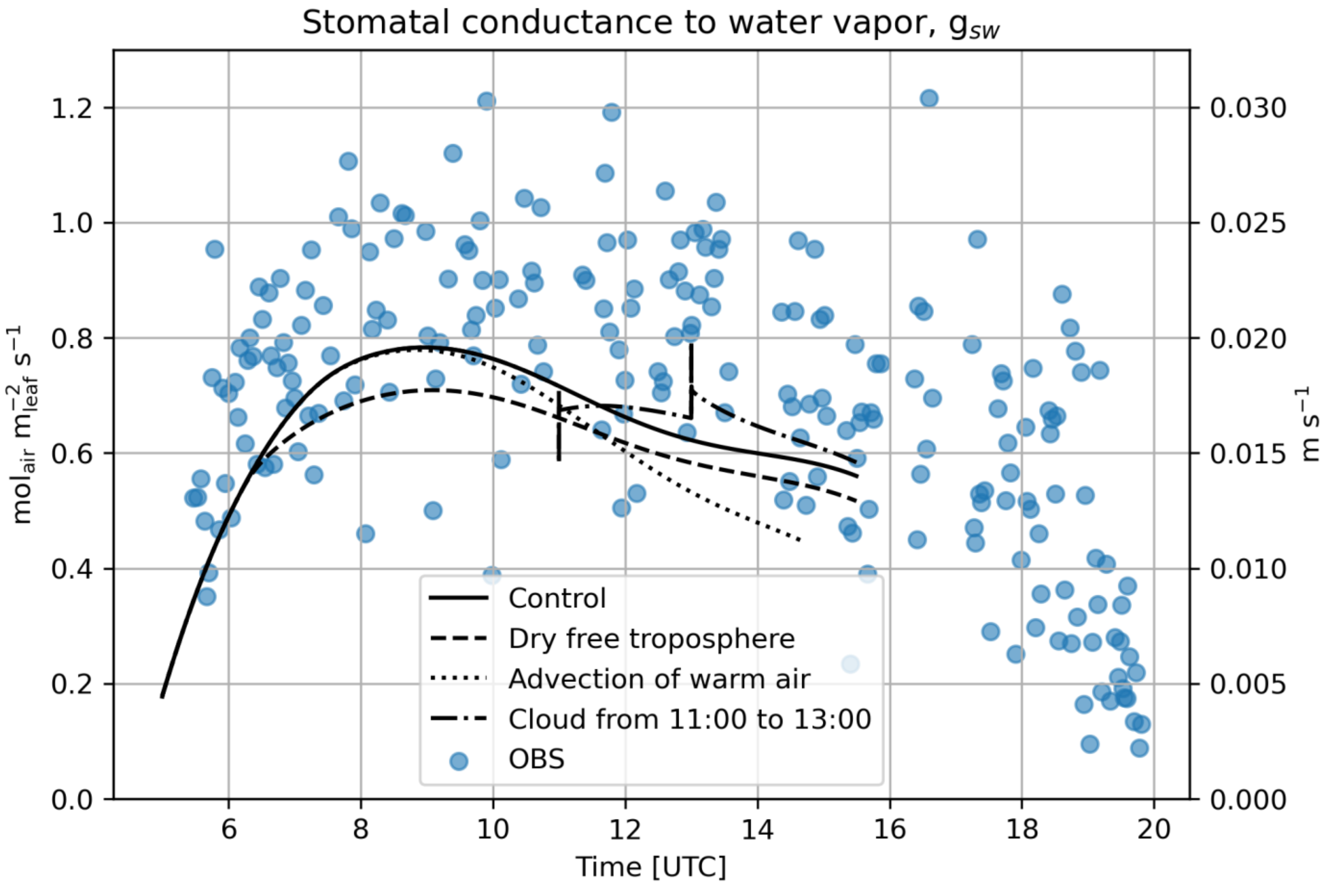
2. Entrainment of dry air



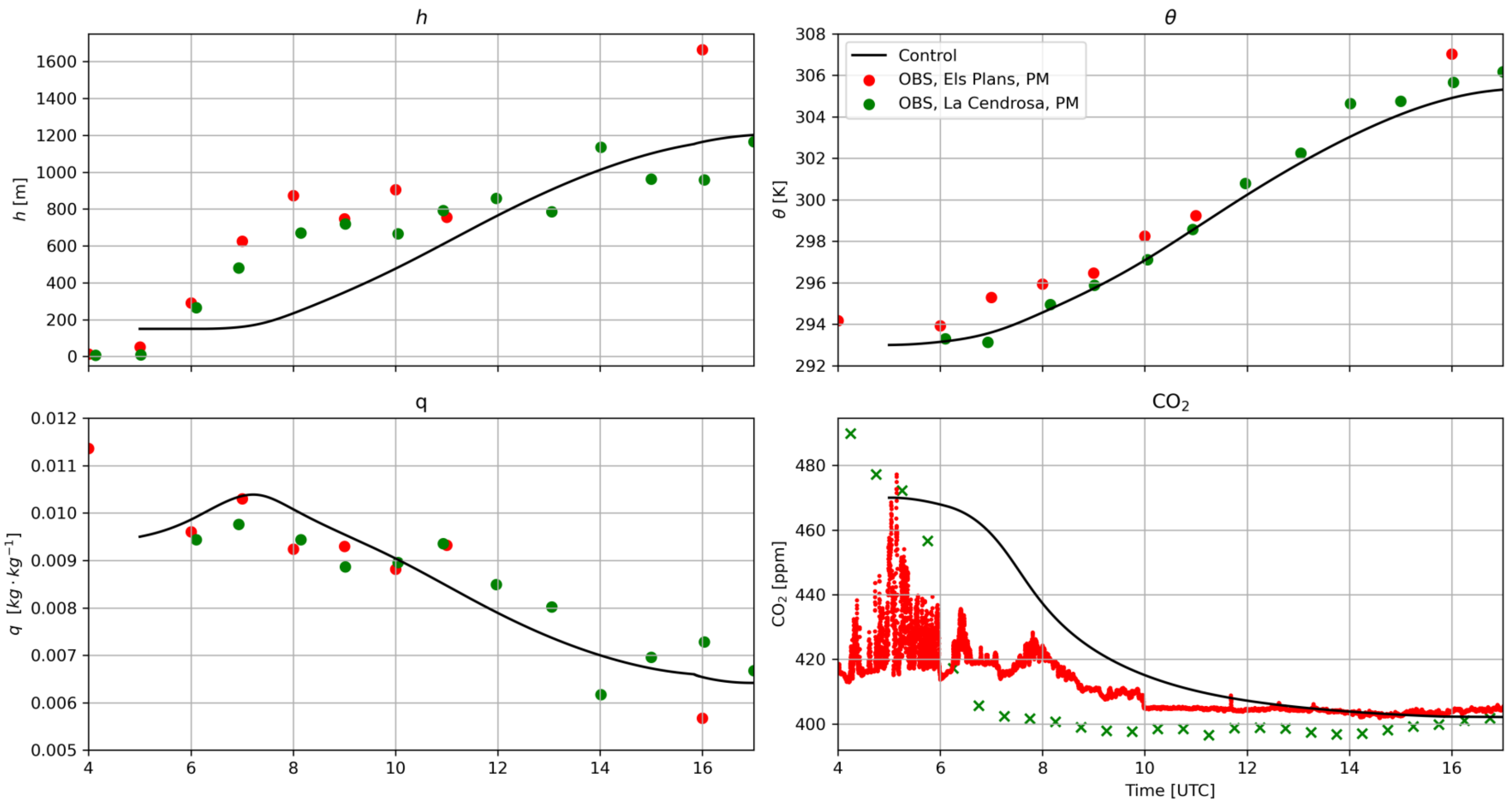
3. Advection of warm air



Three cases: set-up



Control simulation: boundary layer



Appendix: Tendencies of leaf gas exchange

$$\frac{dg_{l,c}}{dt} = \frac{\partial g_{l,c}}{\partial PAR} \cdot \frac{dPAR}{dt} + \left(\frac{\partial g_{l,c}}{\partial D_s}\right) \cdot_{T=cte} \frac{dD_s}{dt} + \left(\frac{\partial g_{l,c}}{\partial T}\right) \cdot_{D_s=cte} \frac{dT}{dt} + \frac{\partial g_{l,c}}{\partial C_{air}} \cdot \frac{dC_{air}}{dt}$$

Variations due to radiation changes

Variations due to leaf to air vapor pressure deficit changes

Variations due to temperature changes for explicit dependent temperature processes

Variations due to ambient CO_2 concentration changes

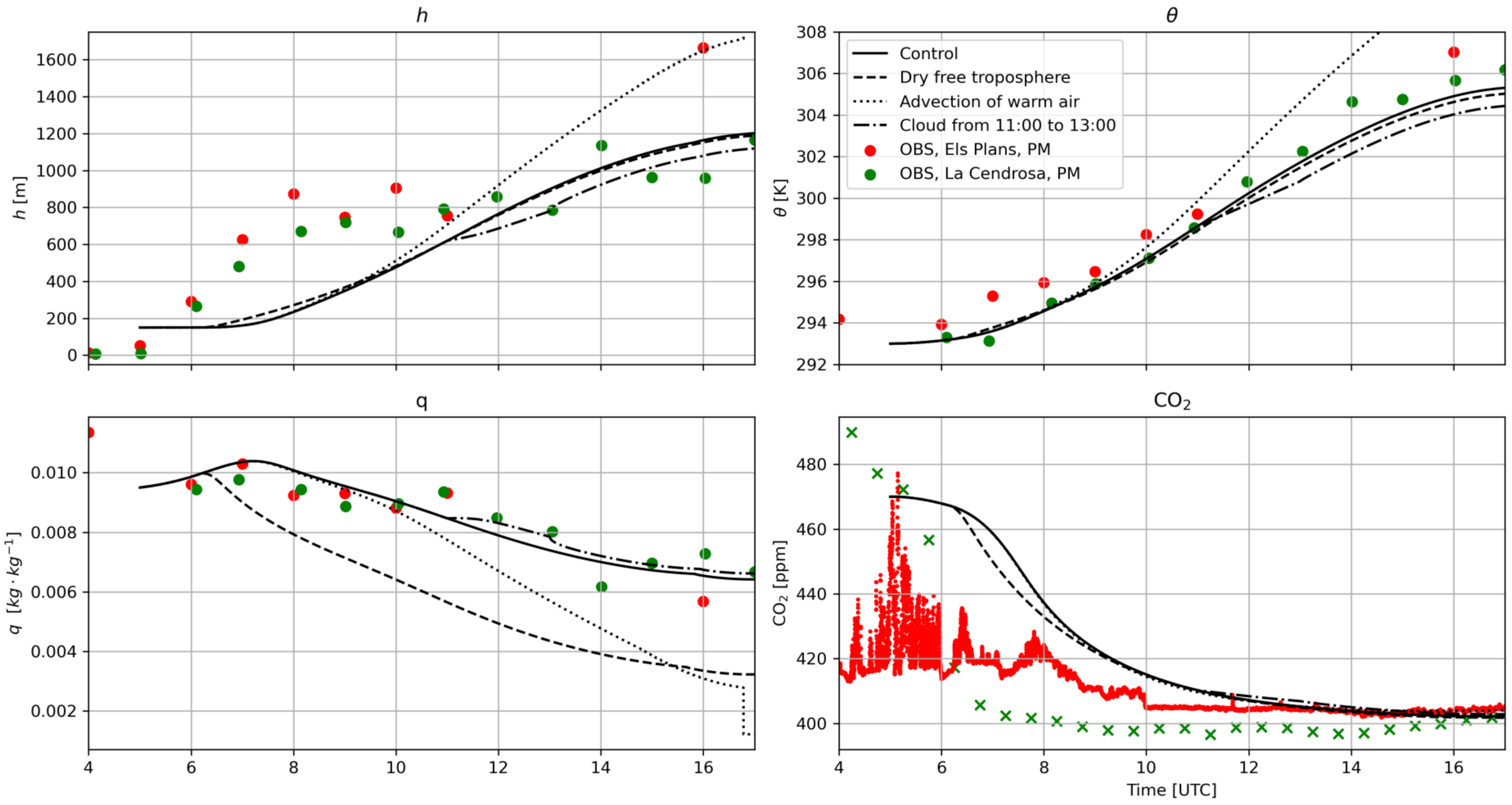
Total time tendency

Variations due to leaf to air vapor pressure deficit changes

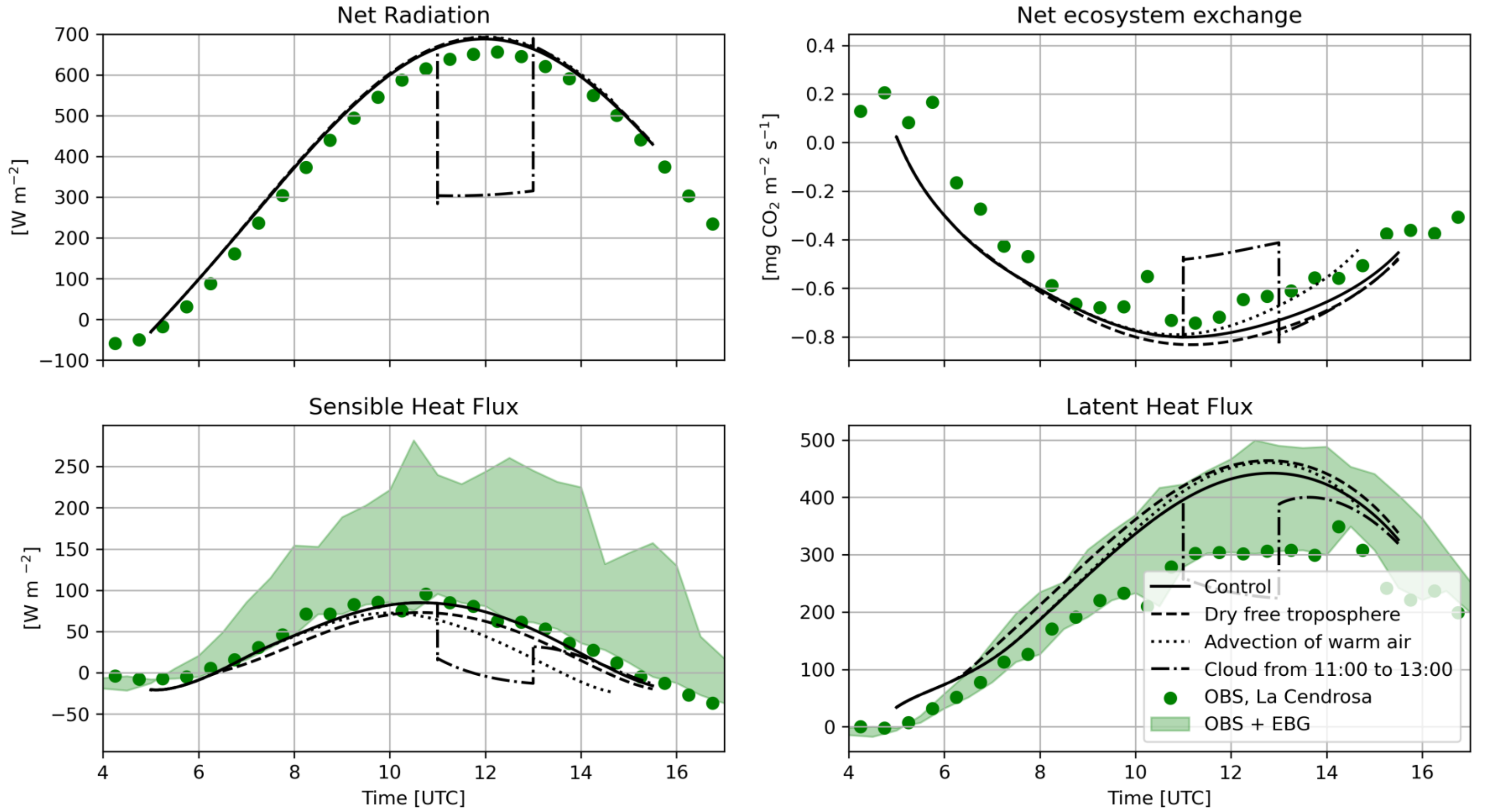
Variations due to temperature changes

$$\frac{dg_{l,c}}{dt} = \frac{\partial g_{l,c}}{\partial PAR} \cdot \frac{dPAR}{dt} + \frac{\partial g_{l,c}}{\partial e} \cdot \frac{de}{dt} + \frac{\partial g_{l,c}}{\partial T} \cdot \frac{dT}{dt} + \frac{\partial g_{l,c}}{\partial C_{air}} \cdot \frac{dC_{air}}{dt}$$

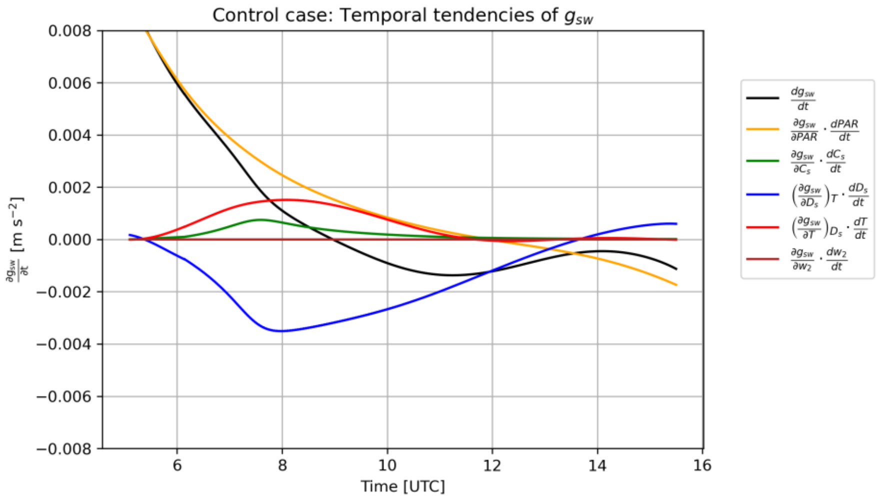
Appendix: three cases (ABL)

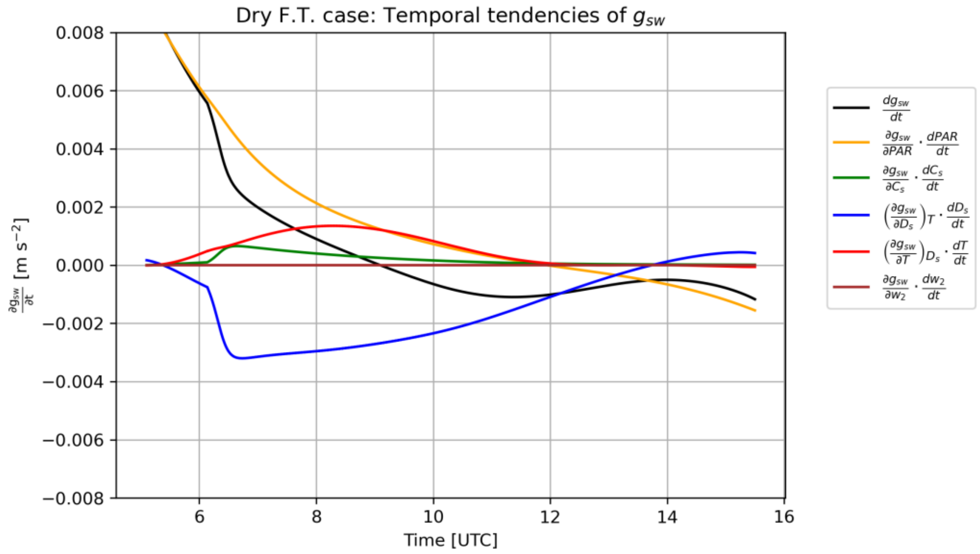


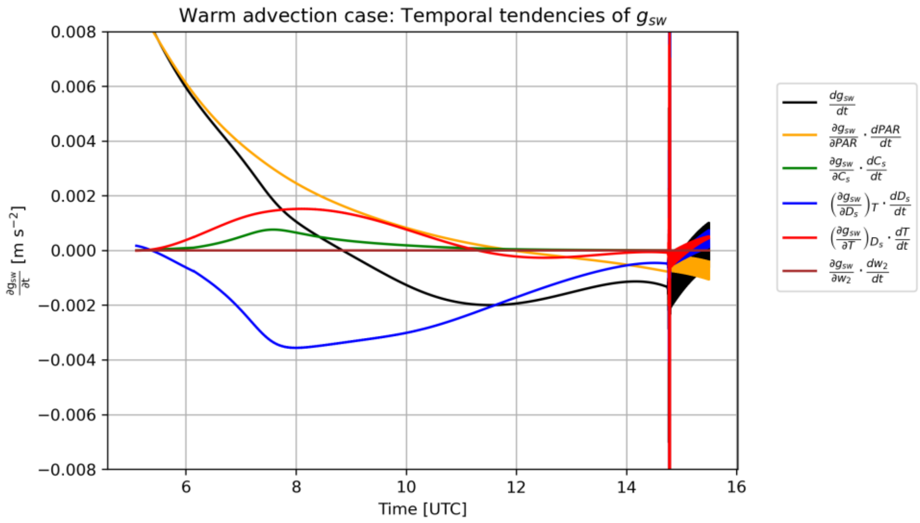
Appendix: three cases (radiation and local fluxes)

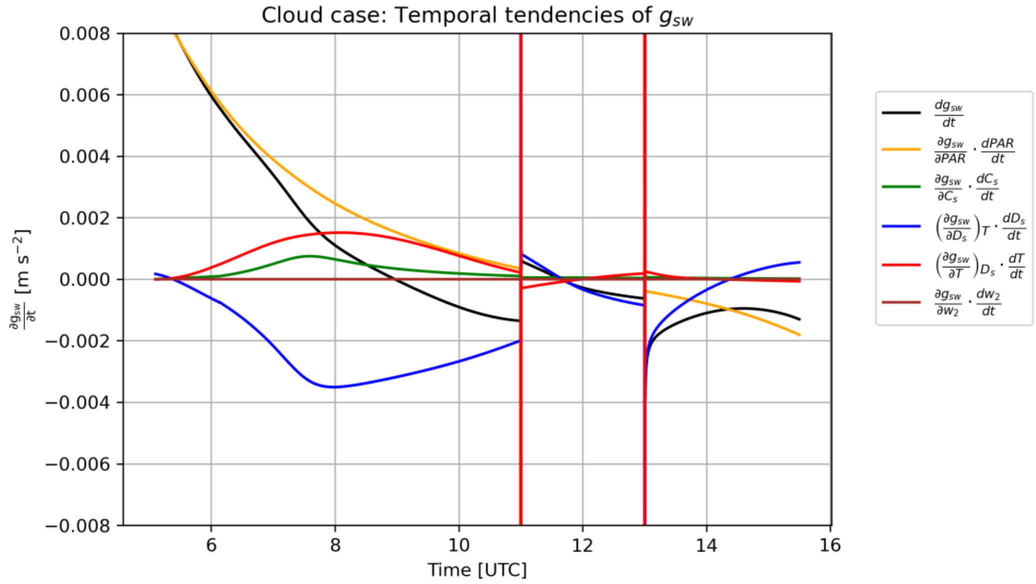


Appendix: tendencies of control + 3 cases

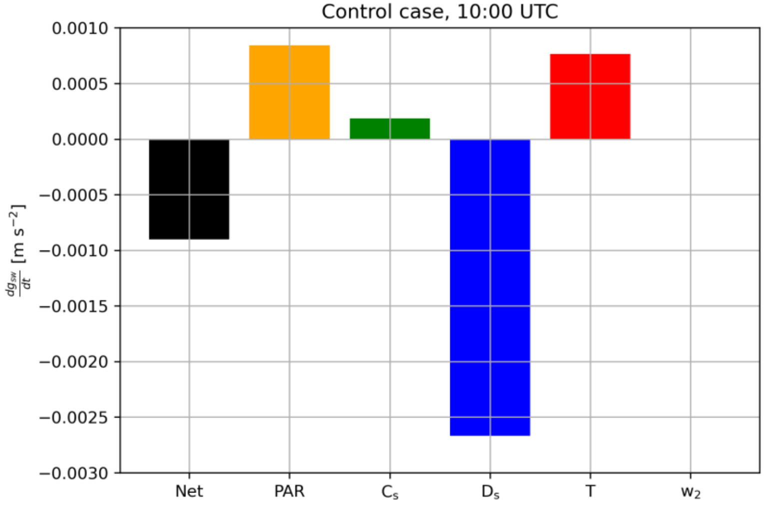


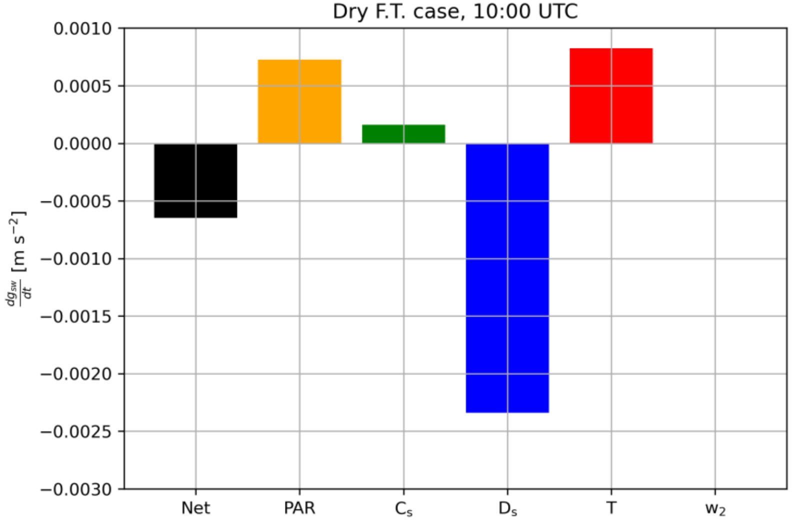


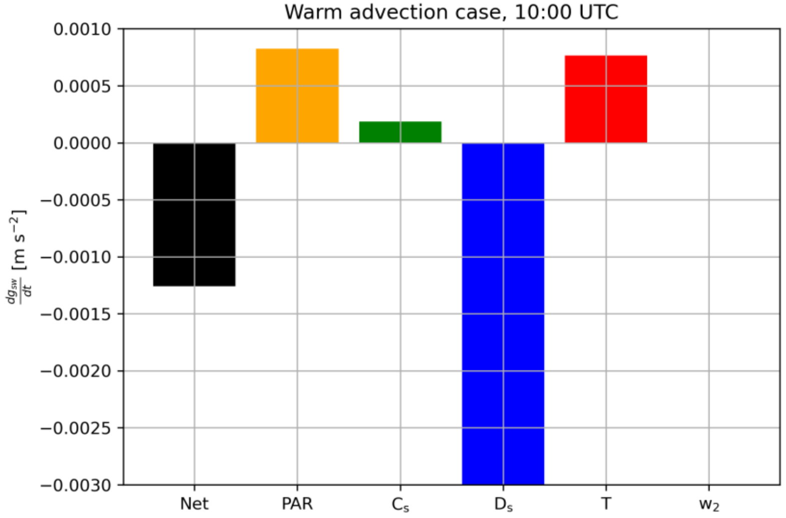


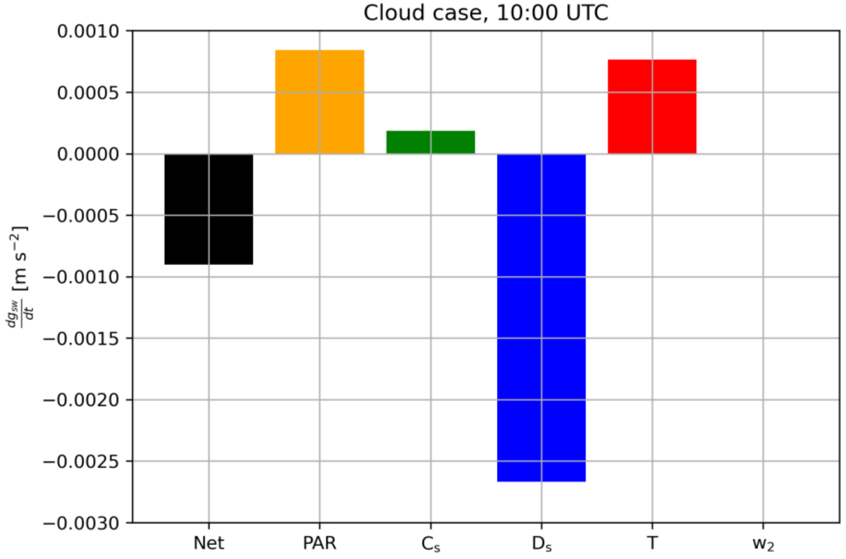


Tendencies at 10:00 UTC

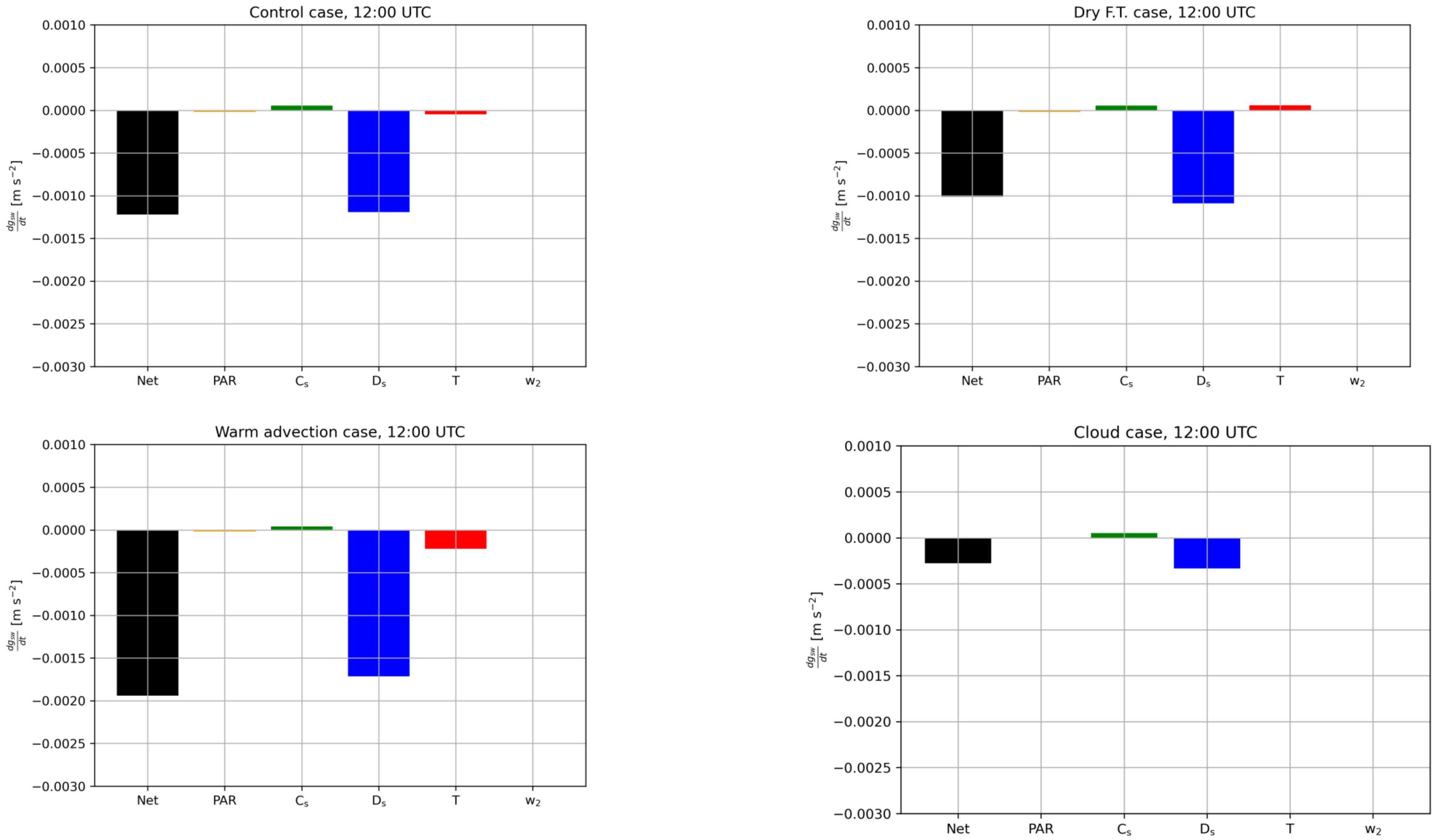




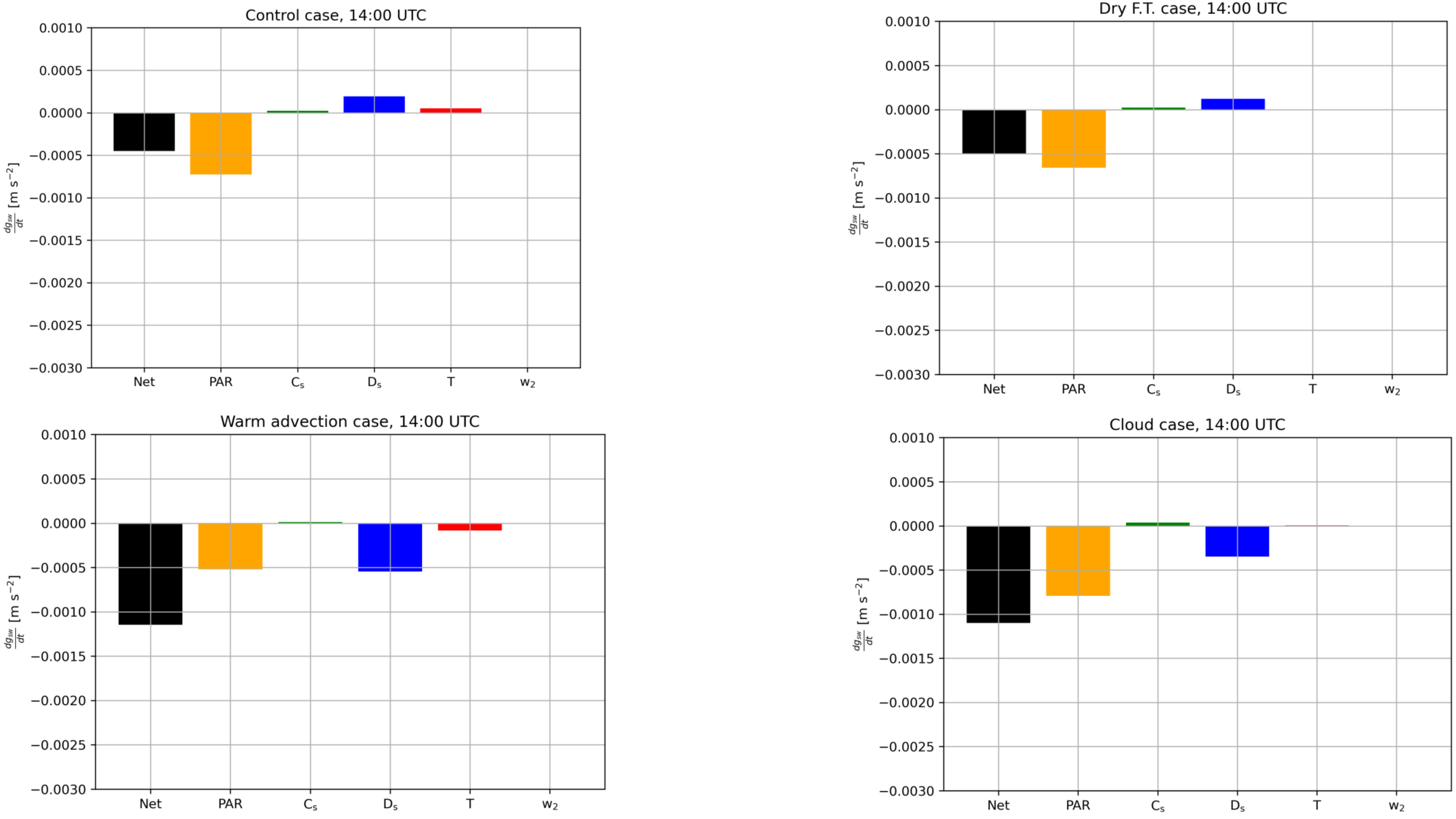




Tendencies at 12:00 UTC



Tendencies at 14:00 UTC



Overshooting

1. Increase h (to 500) when h = 200 m
2. Model the residual layer with gammatheta = 0