Coupling Amazon Rainforest Fluxes to Clear-to-Cloudy Boundary Layer Conditions Using Integrated Observations and Large-Eddy Simulations

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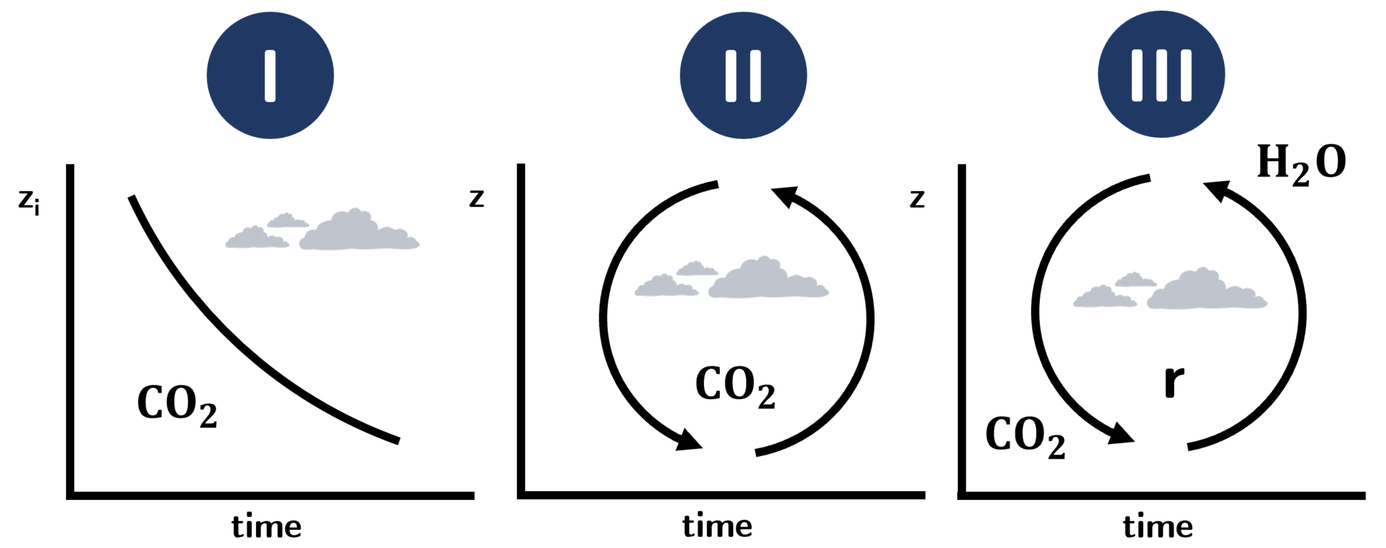
Role of Shallow Convective Clouds?

Amazon rainforest fluxes are tightly coupled to the atmosphere. Aircraft data from CloudRoots-Amazon22 show a shifting CO_2-H_2O correlation with height, previously observed up to only the clear boundary layer, now extending into the shallow cloud layer (**Figure 1**). **Are clouds driving this pattern?** To investigate the role of shallow convective clouds in the CO_2 budget, we assess:



I	II	III
Clear-to-Cloudy Boundary Layer Budget	Lower Tropical Tropospheric Budget	Role in Shaping the Vertical Correlation

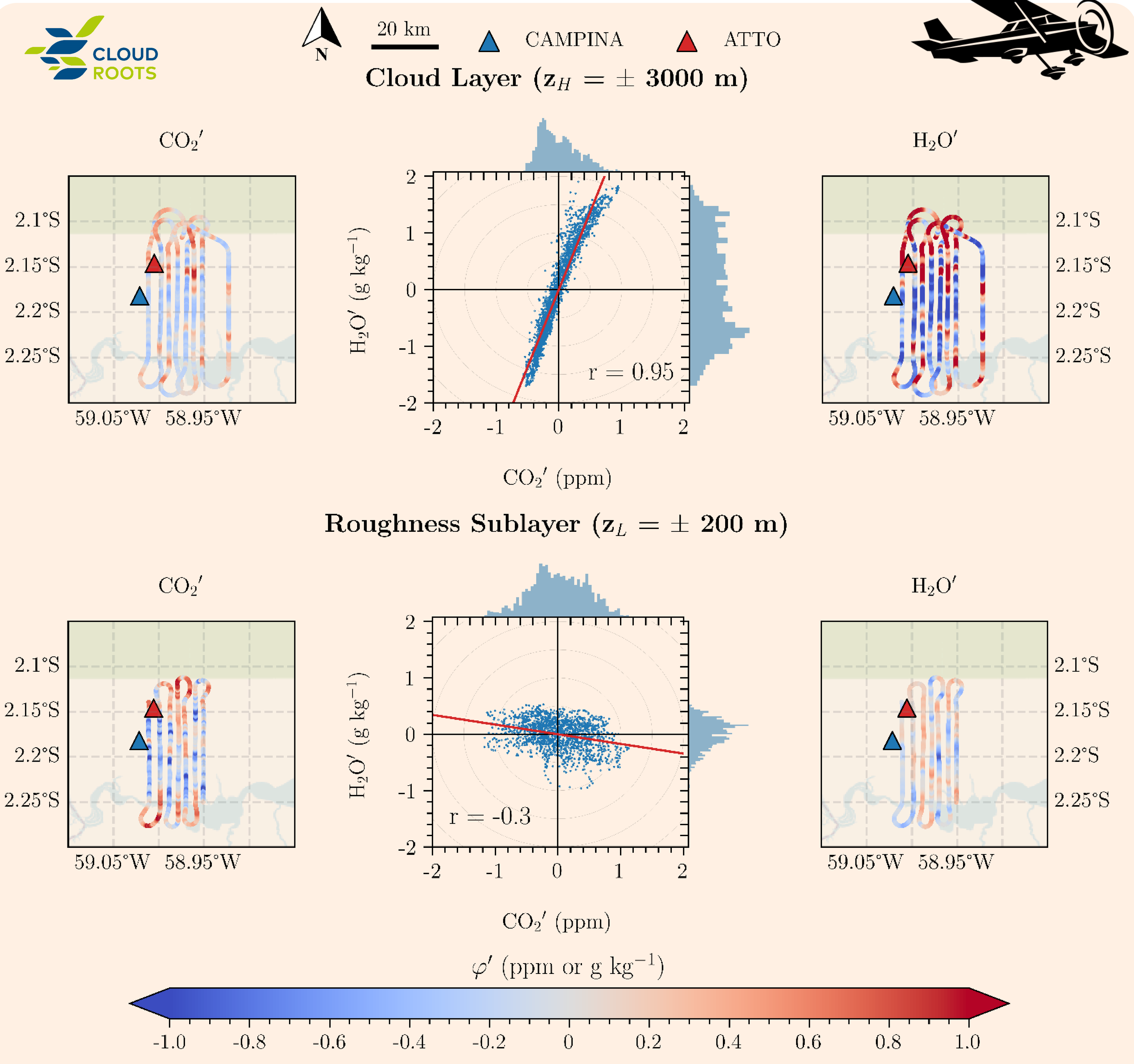
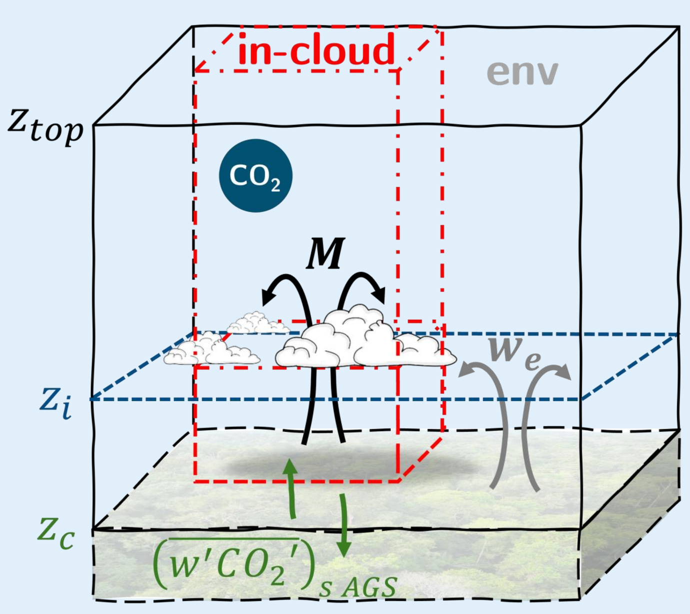


Figure 1: Linearly-detrended correlation between fluctuations in CO_2 and H_2O and corresponding Pearson correlation coefficient (r) as observed during the CloudRoots-Amazon22 campaign, shifting from negative to positive correlation with height. Canopy height (z_c) at ± 40 m.

Methods



LES with **CLOUDS** & without (**NO CLOUDS**)
Note: no advection or large-scale subsidence

$$\frac{\partial \langle CO_2 \rangle}{\partial t} = \frac{1}{z_i}\int_{z_c}^{z_i} \frac{\partial \overline{CO_2}}{\partial t}\, dz = \frac{\overline{(w'CO_2')}_s - \overline{(w'CO_2')}_e}{z_i}$$

with:

in-cloud | env(ironment)

$$\overline{(w'CO_2')}_e = \overline{(w'CO_2')}_e\, a_{c,w} + (1 - a_{c,w})\overline{(w'CO_2')}_e$$

$$\approx \quad M \quad + \quad w_e$$

Results

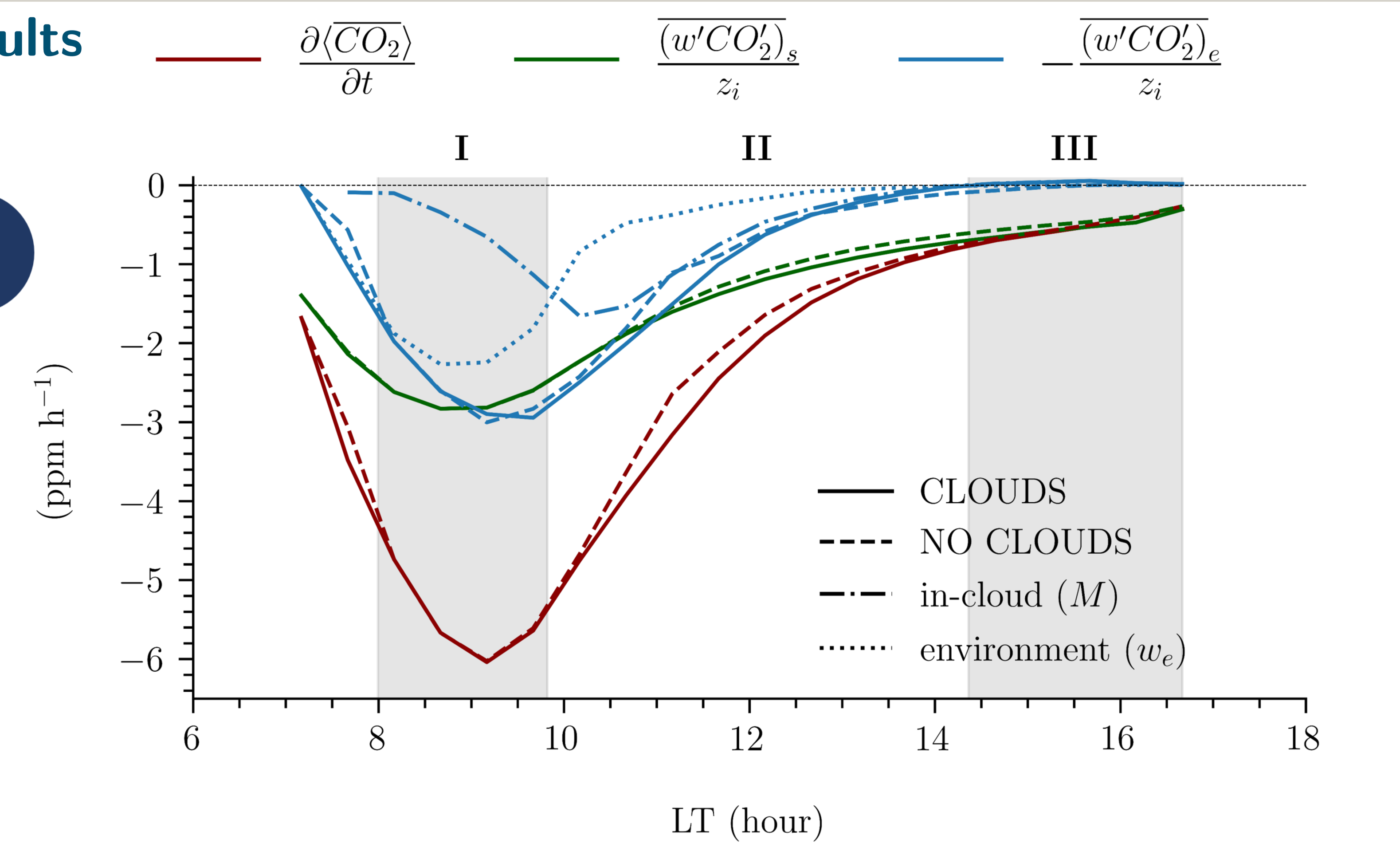


Figure 2: Simulated clear-to-cloudy boundary layer CO_2 budget for the CLOUDS and NO CLOUDS simulation, along with the **in-cloud** and **environment** contributions. Three diurnal regimes: entrainment-diluting (w_e), cloud-ventilation-and-entrainment ($w_e > M$) and CO_2-assimilation ($w_e = M = 0$). Without clouds, w_e alone drives the budget. Interplay with z_i makes *CLOUDS = NO CLOUDS*.

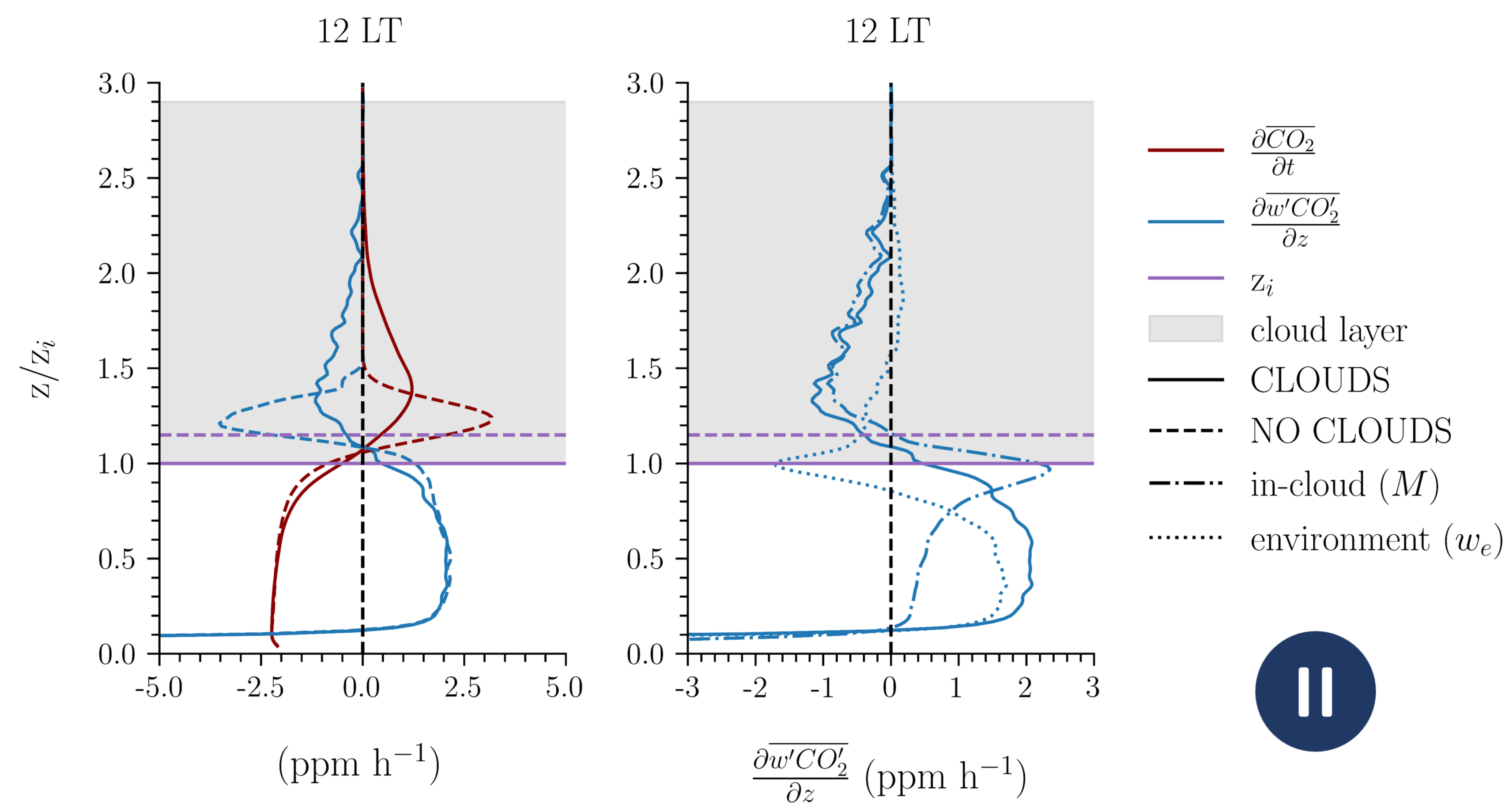


Figure 3: Simulated clear-to-cloudy lower tropospheric CO_2 budget for the CLOUDS and NO CLOUDS simulation, along with the **in-cloud** and **environment** contributions. Clouds actively ventilate CO_2, transporting up to heights twice the boundary layer height. Without clouds, w_e takes one hour longer to get a well-mixed lower troposphere.

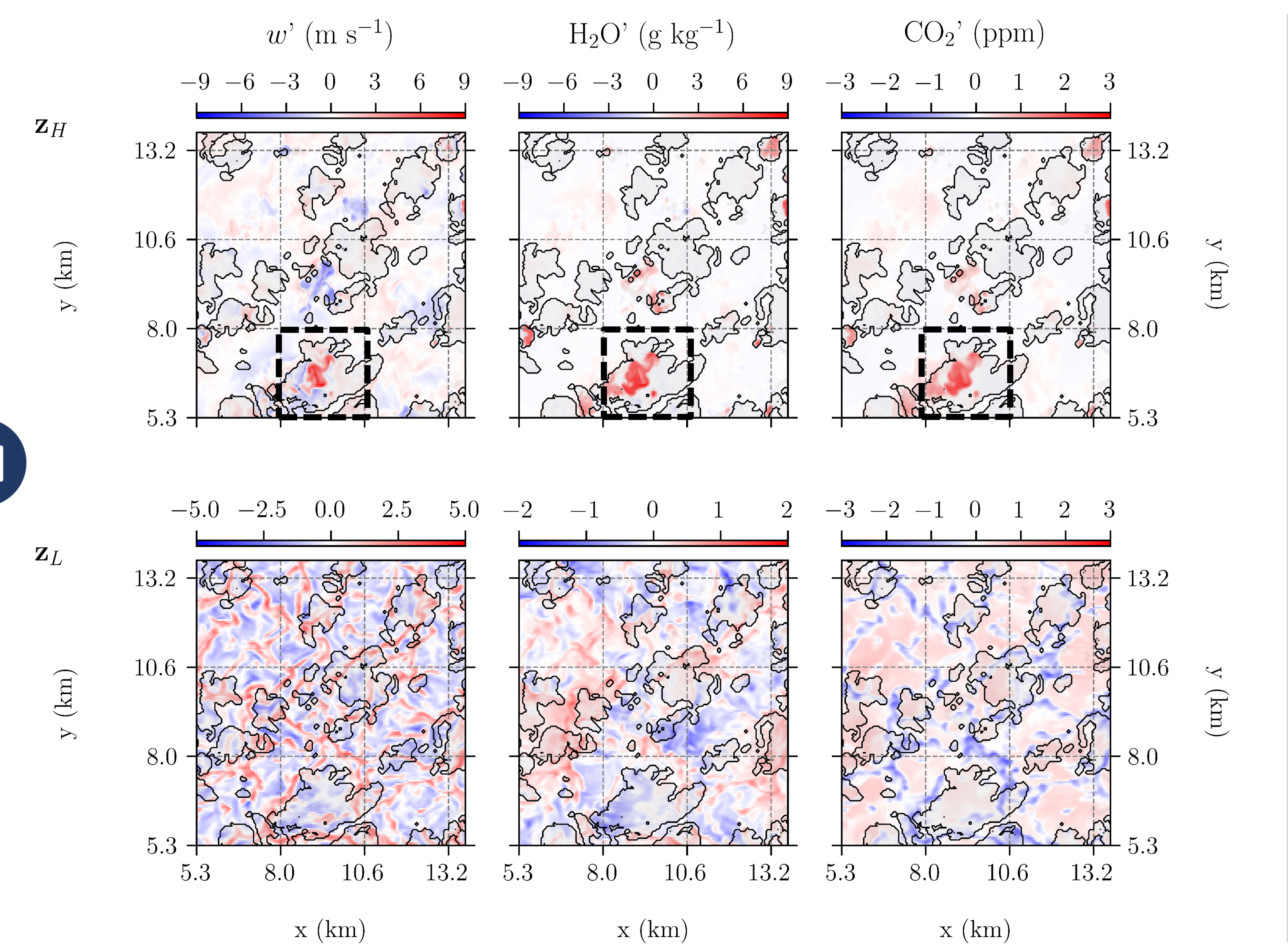


Figure 4: Simulated (x, y) cross-sections at 13 LT of fluctuations in H_2O, CO_2 and vertical velocity (w) for the CLOUDS simulation at z_L and z_H. DALES accurately represents the changing correlation with height ($z_L \rightarrow z_H$). Clouds actively organise the vertical transport, but it is confined to strong updraughts at cloud-scales.

Conclusions

I. Shallow convective cloud ventilation and clear-air entrainment collectively shape the turbulent exchange of CO_2 in the clear-to-cloudy boundary layer.
II. Shallow convective clouds significantly influence the vertical distribution of CO_2 until late afternoon, reaching heights double the tropical boundary layer.
III. Shallow convective clouds actively organise the vertical turbulent exchange at shallow cloud-scales, shaping a strong negative-to-positive CO_2-H_2O correlation.

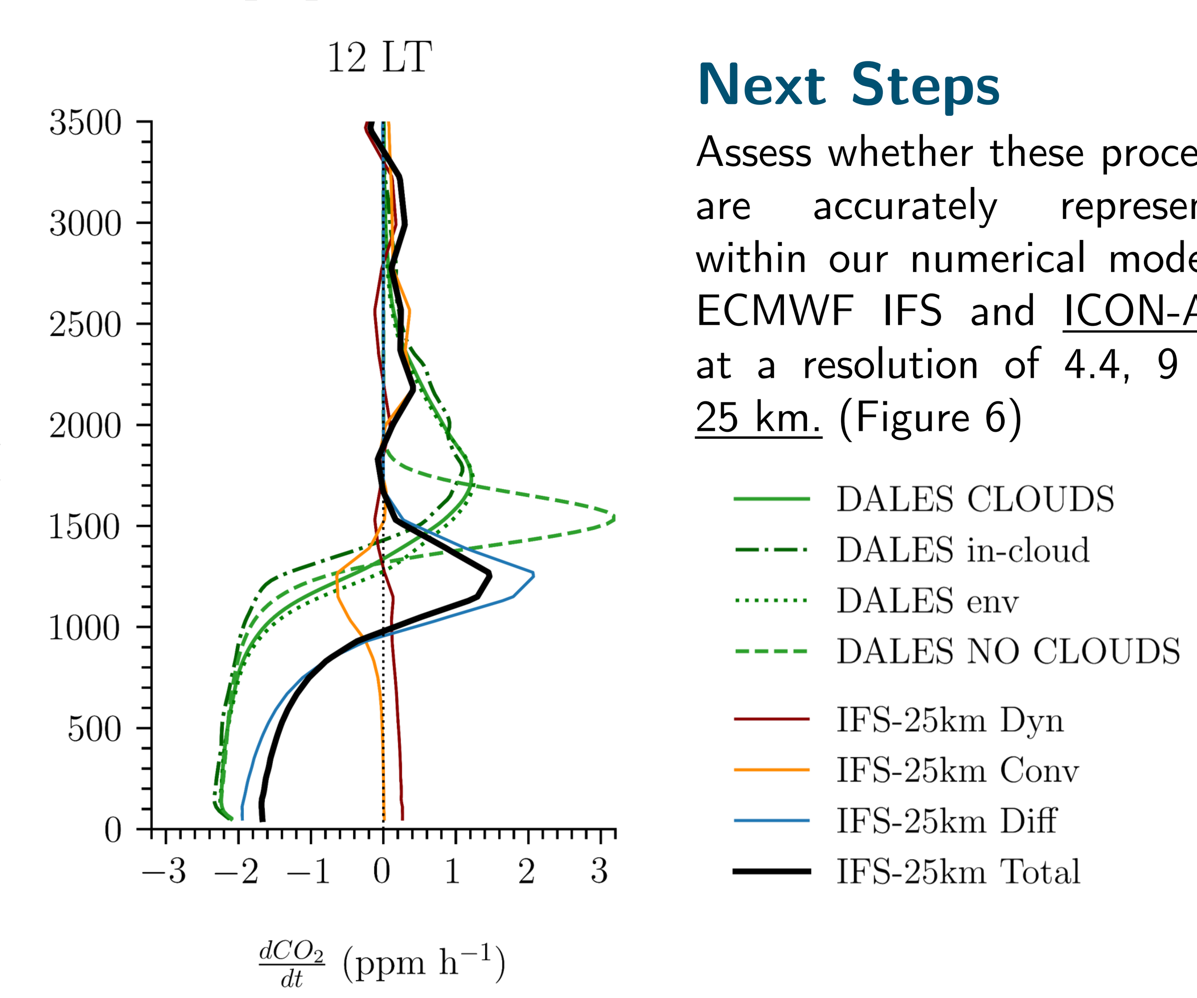


Figure 5: Tendency of CO_2 with height for DALES and IFS at a resolution of 25 km. IFS seems to underestimate the in-cloud contribution.

Next Steps

Assess whether these processes are accurately represented within our numerical models - ECMWF IFS and ICON-ART at a resolution of 4.4, 9 and 25 km. (Figure 6)

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Funded by the European Union

The CATRINE project (grant agreement No. 101135000) is funded by the European Union. Views and opinions expressed are, however, those of the authors only and do not necessarily reflect those of the European Union or the Commission. Neither the European Union nor the granting authority can be held responsible for them.