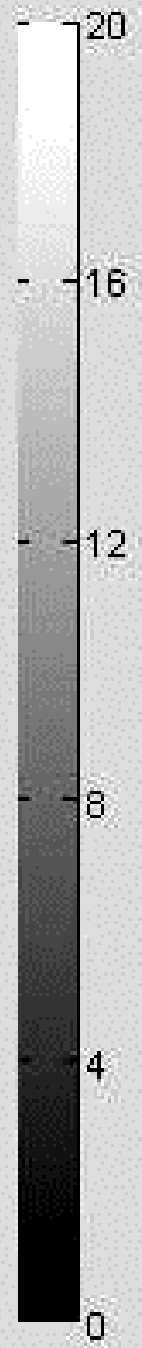
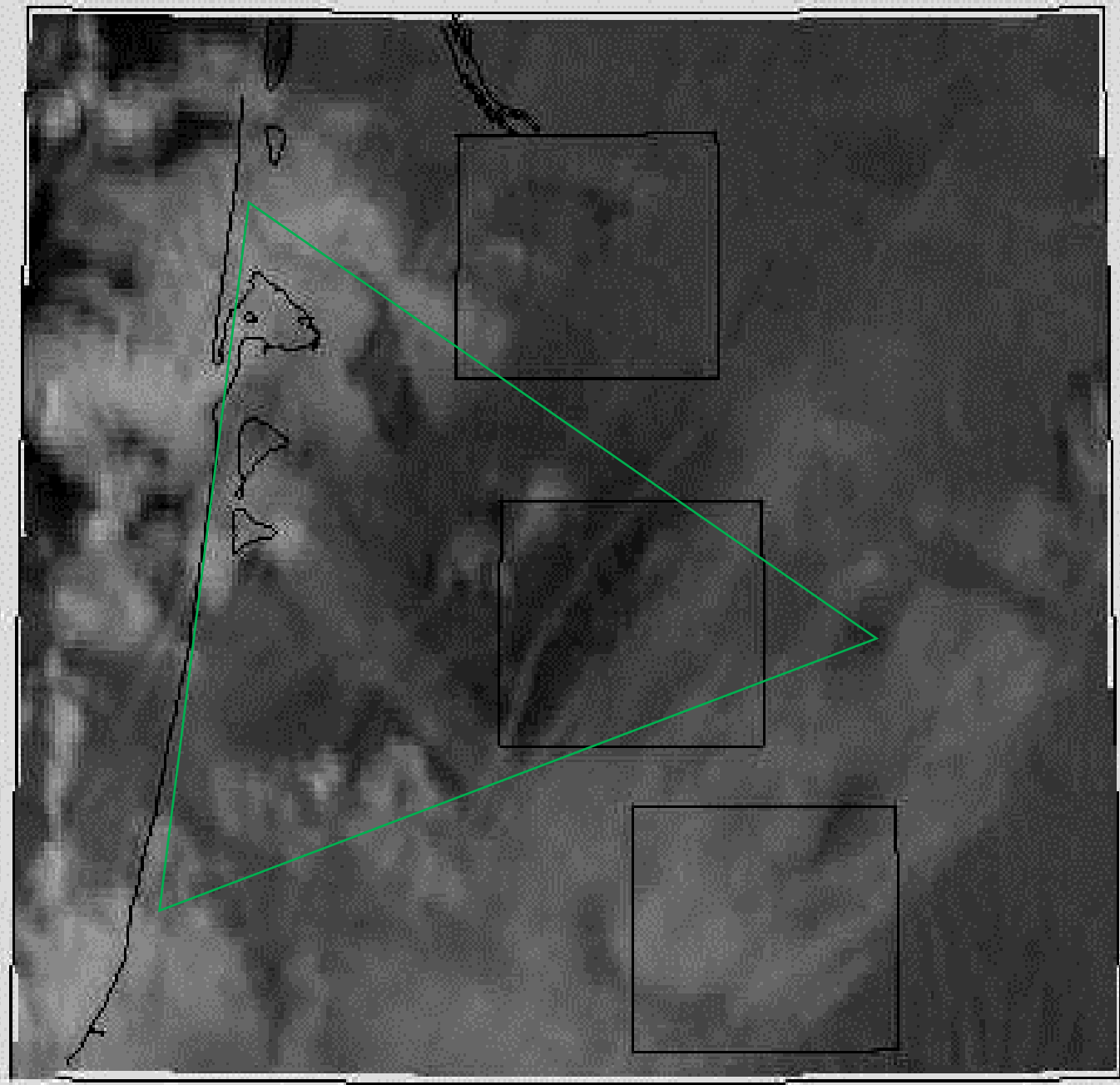




(Teuling et al., 2017)



Log(reflectance) (-)

An aerial photograph of a vast, dense tropical rainforest. The forest is a deep, dark green, stretching to the horizon. Above the forest, the sky is a vibrant blue, filled with large, white, puffy cumulus clouds. A prominent, large cloud mass is centered in the upper right quadrant, with smaller clouds scattered throughout the sky. The horizon line is clearly visible, separating the forest from the sky.

**Advancing understanding of land-atmosphere
interactions by breaking disciplines and scale barriers**

Jordi Vilà -Guerau de Arellano
Wageningen University



How do clouds and vegetation control
evapotranspiration and net CO₂ exchange on
sub-kilometer spatial scales and on time scales from seconds to days?

Large uncertainties on:

WATER CYCLE: Precipitation/evaporation/**energy**

CARBON CYCLE: Source/sink CO₂/**chemistry**

The four challenges of the unbroken cycle between carbon and clouds

How are photosynthesis and photolysis influenced by the disturbances of radiation due to the presence of clouds and due to the transference inside the canopy?

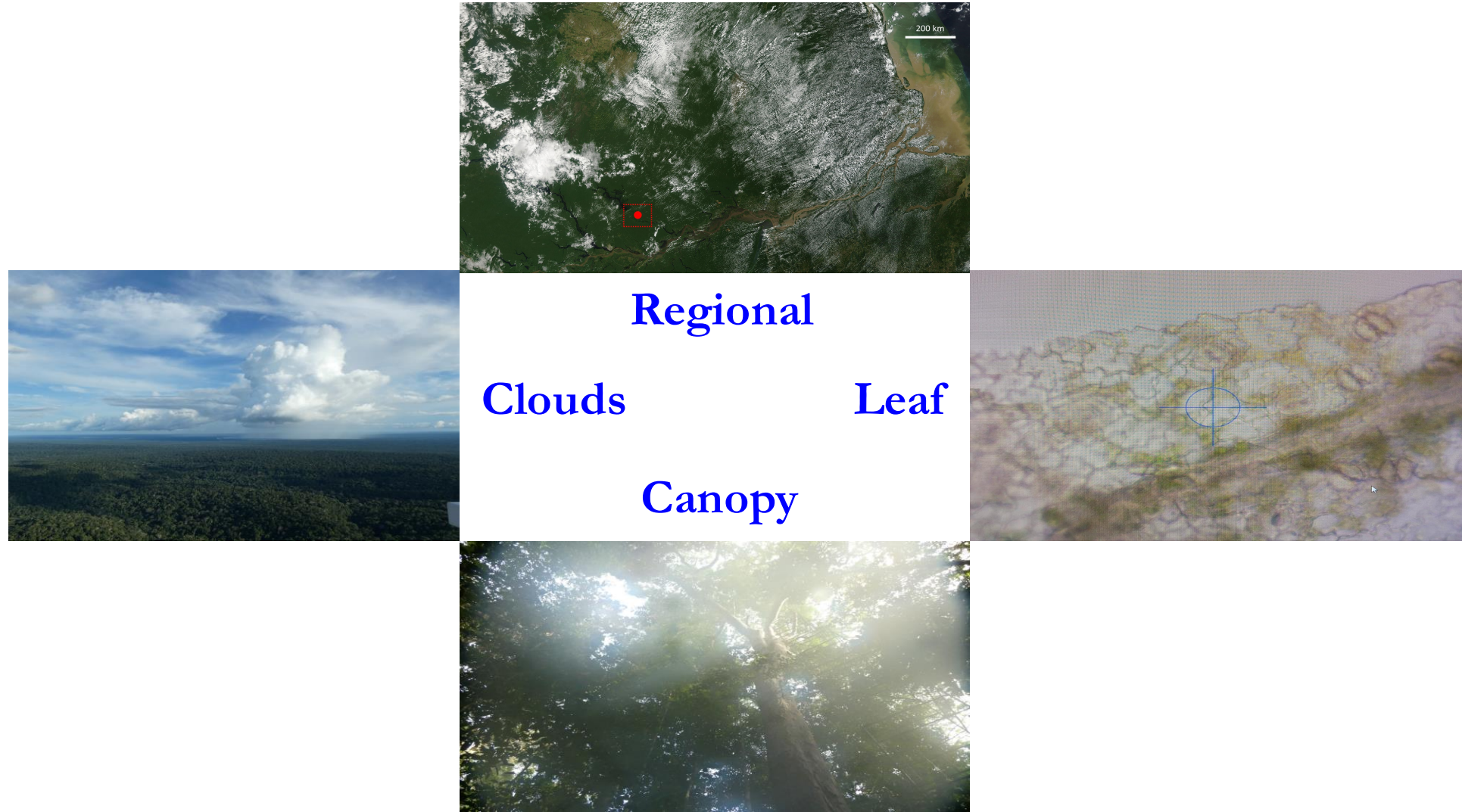
How is atmospheric composition (greenhouse gases and reactive species) impacted by turbulent transport, mixing, convection, weather variables (temperature, moisture and wind) and reactivity?

How do physical, chemical and biological processes interact between local and regional scales, and at different time scales?

How does the system energy, water and carbon cycles integrate over scales under present and future conditions?

The framing approach

Crossing scales: from leaves to the Atlantic Ocean



Aim:

- ✓ Study the system in terms of interaction of scales and of biochemical/physical processes
- ✓ Introduce the CloudRoots framework approach

IFS-ECMWF and others

REPRESENT TRANSPORT

Regional to global coverage

Evaluating and improving parameterizations

CloudRoots-Amazonia22

Large-eddy simulations
Conceptual Modelling

OBSERVE

Guiding and verifying

Comprehensive supersites and
field campaigns

UNDERSTAND

Explicitly solving processes

Dedicated experiments
Large-eddy simulation

Assessing and reducing uncertainties
carbon and water sub-diurnal cycles

Interconnecting scales and biochemical/physical processes

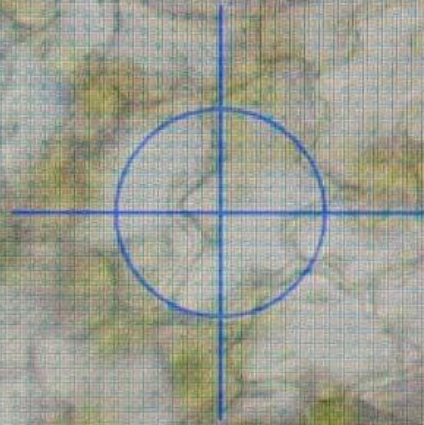
Comprehensive observational sets

Explicit simulation and as a continuum as much as we can

Connecting small to large-scales of
weather and atmospheric composition

Question 1:

How are photosynthesis and photolysis influenced by the disturbances of radiation due to the presence of clouds and due to the transference inside the canopy?

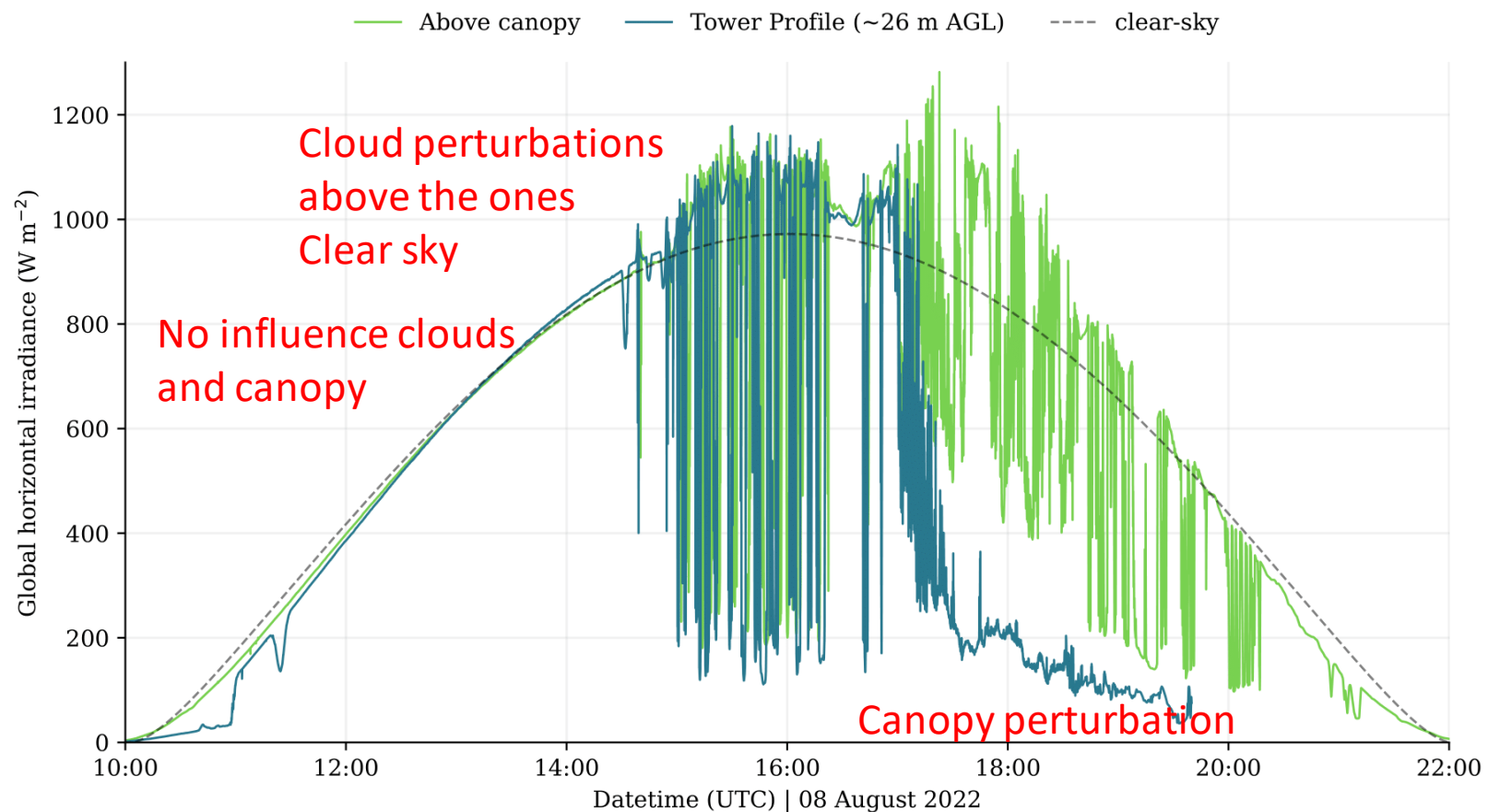


Leaf scale



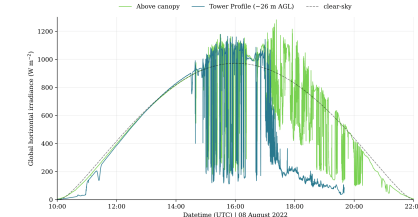
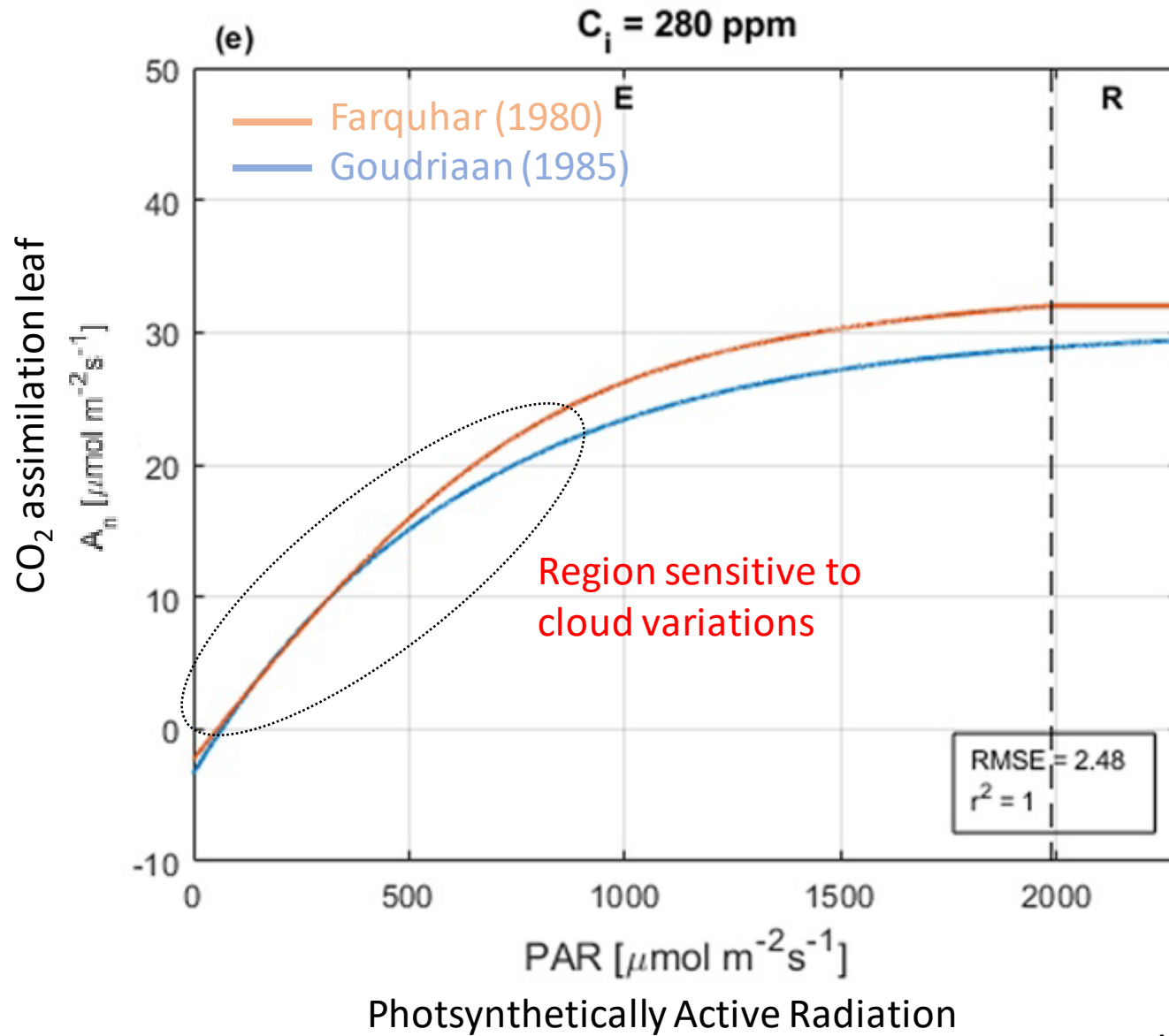
RADIATION: Clouds and canopy perturb radiation

Canopy height 38 meters

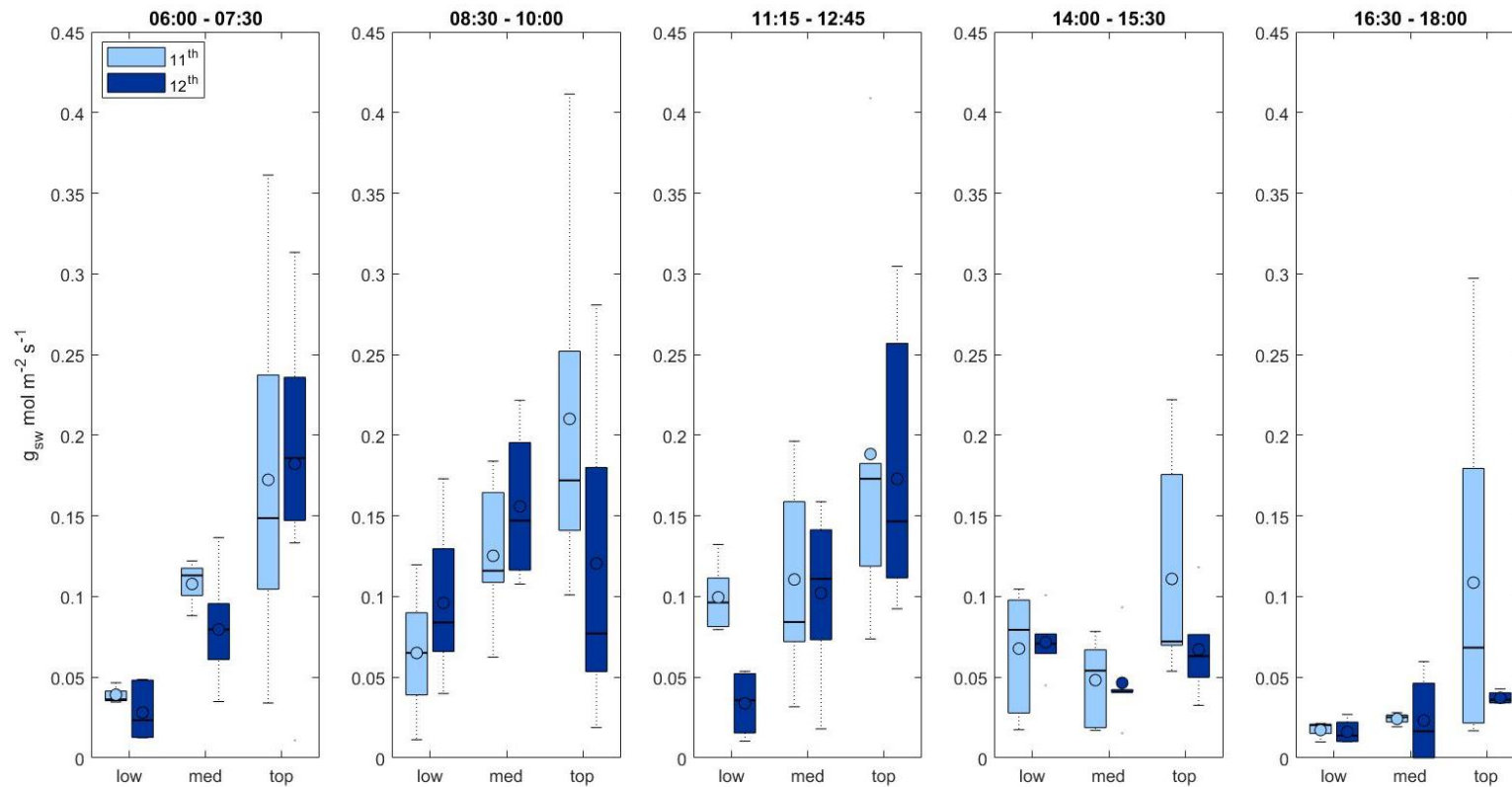


(Wouter Mol, Chiel van Heerwaarden/Bert Heusinkveld, <https://chiel.ghost.io/slocs/>)

RADIATION and PHOTOSYNTHESIS: Assimilation and leaf level



ECO PHYSIOLOGY: Stomatal aperture: diurnal variability



- ✓ Canopy height dependency
- ✓ Similar values sun and shaded leaves
- ✓ Long midday depression
- ✓ Impact clouds on stomatal opening: 12 characterized by deep convection

A low-angle photograph looking up at a large tree trunk and its dense canopy. Sunlight filters through the leaves, creating a dappled light effect. A metal research rig is attached to a branch in the upper right quadrant of the image.

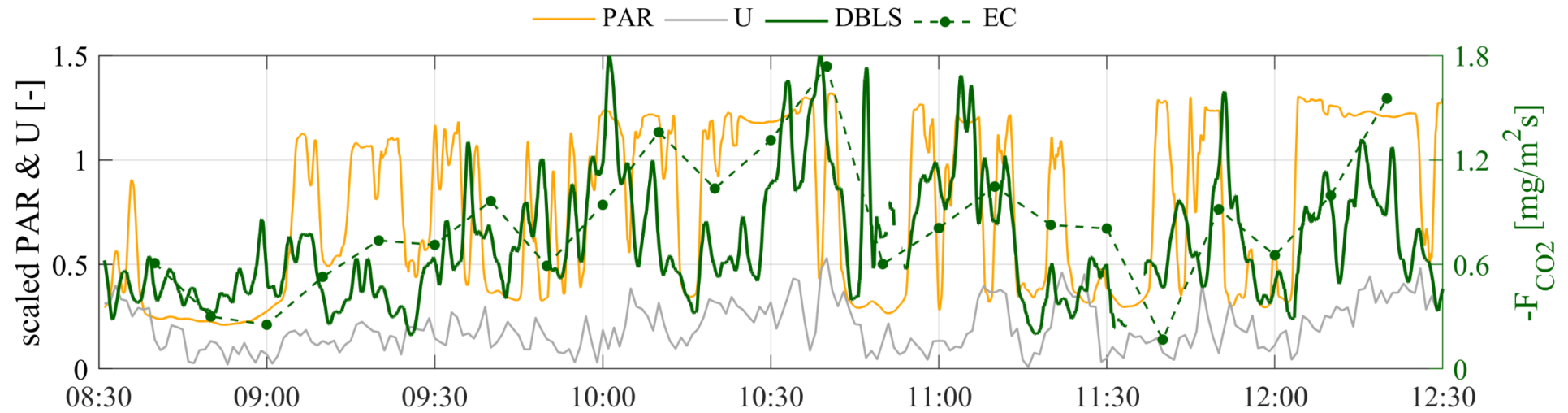
Question 2:

How is atmospheric composition (greenhouse gases and reactive species) impacted by turbulent transport, mixing, convection, weather variables (temperature, moisture and wind) and reactivity?

Canopy-ABL scales

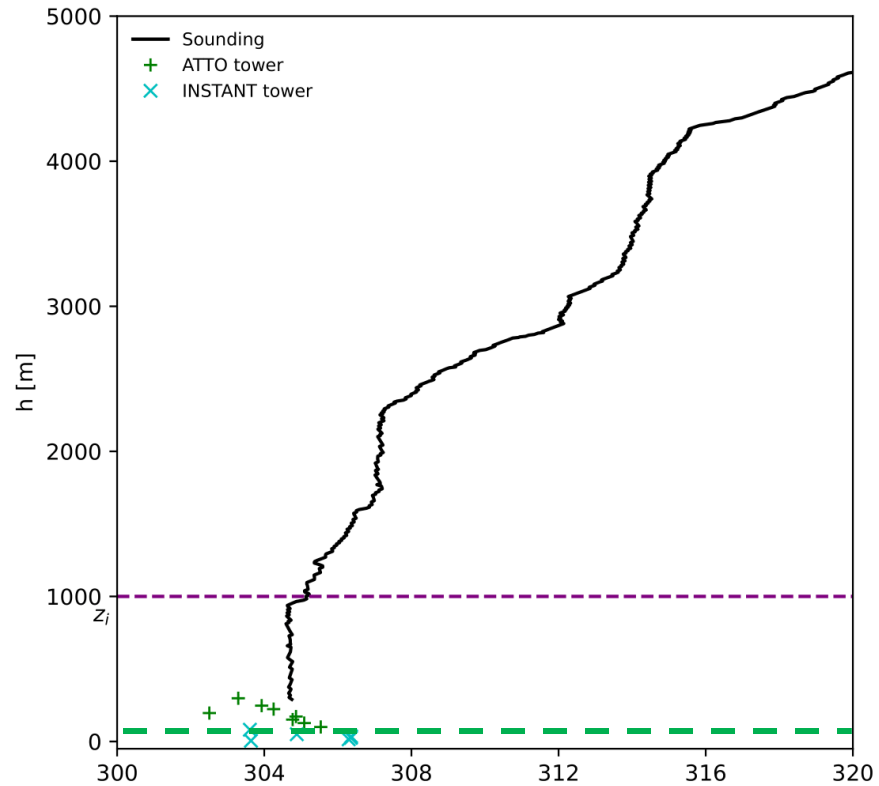
Non-steady turbulent fluxes

Relating radiation to turbulent fluxes

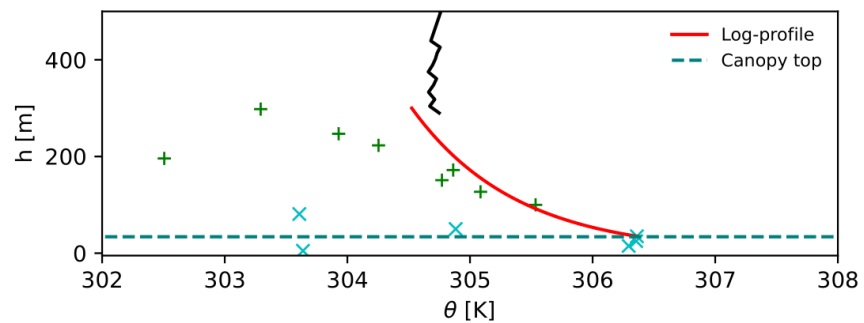


DBLS: Laser scintillometer
EC: edy covraince

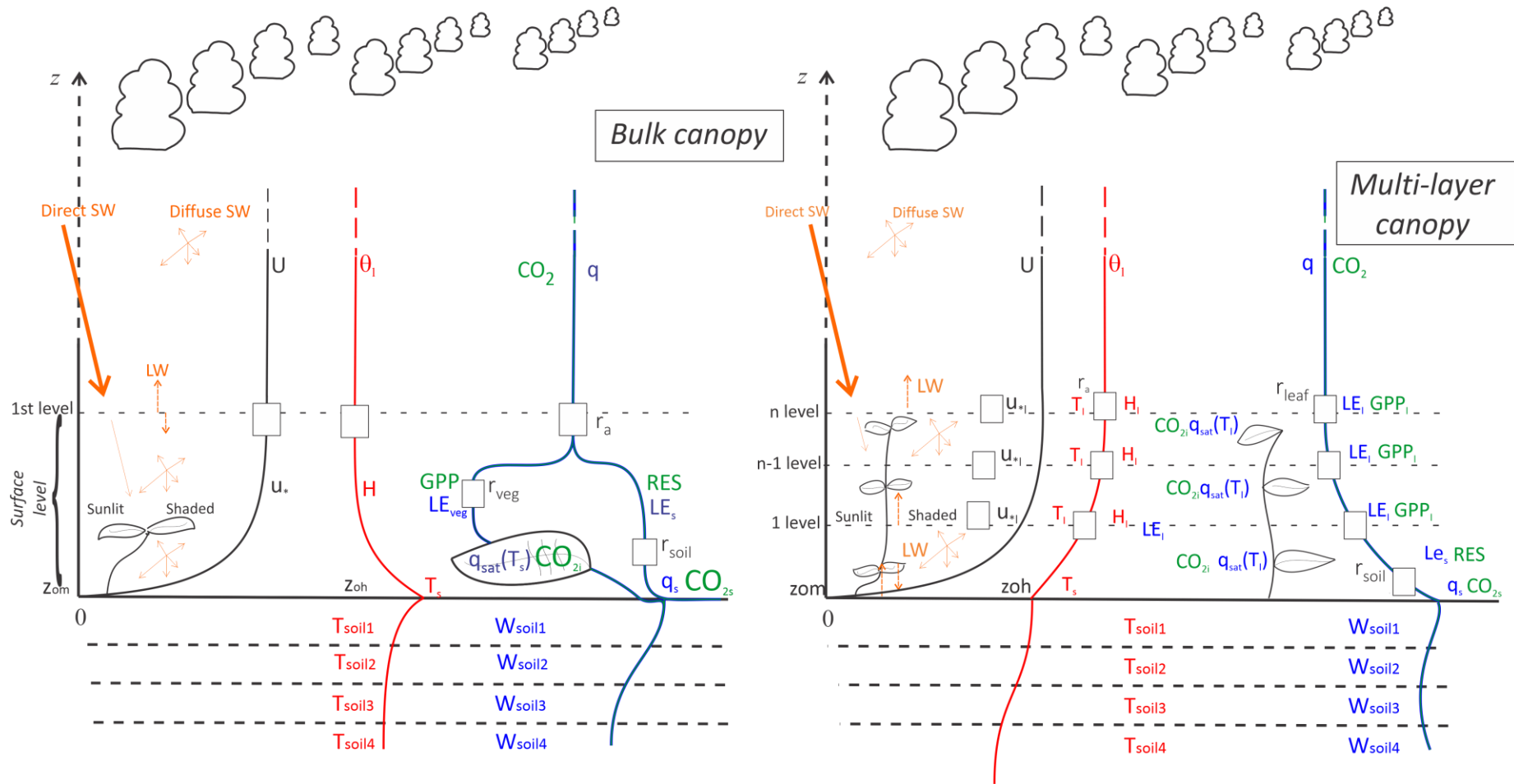
Interconnecting processes with the canopy-atmosphere interaction as the main actor



Clouds
Entrainment



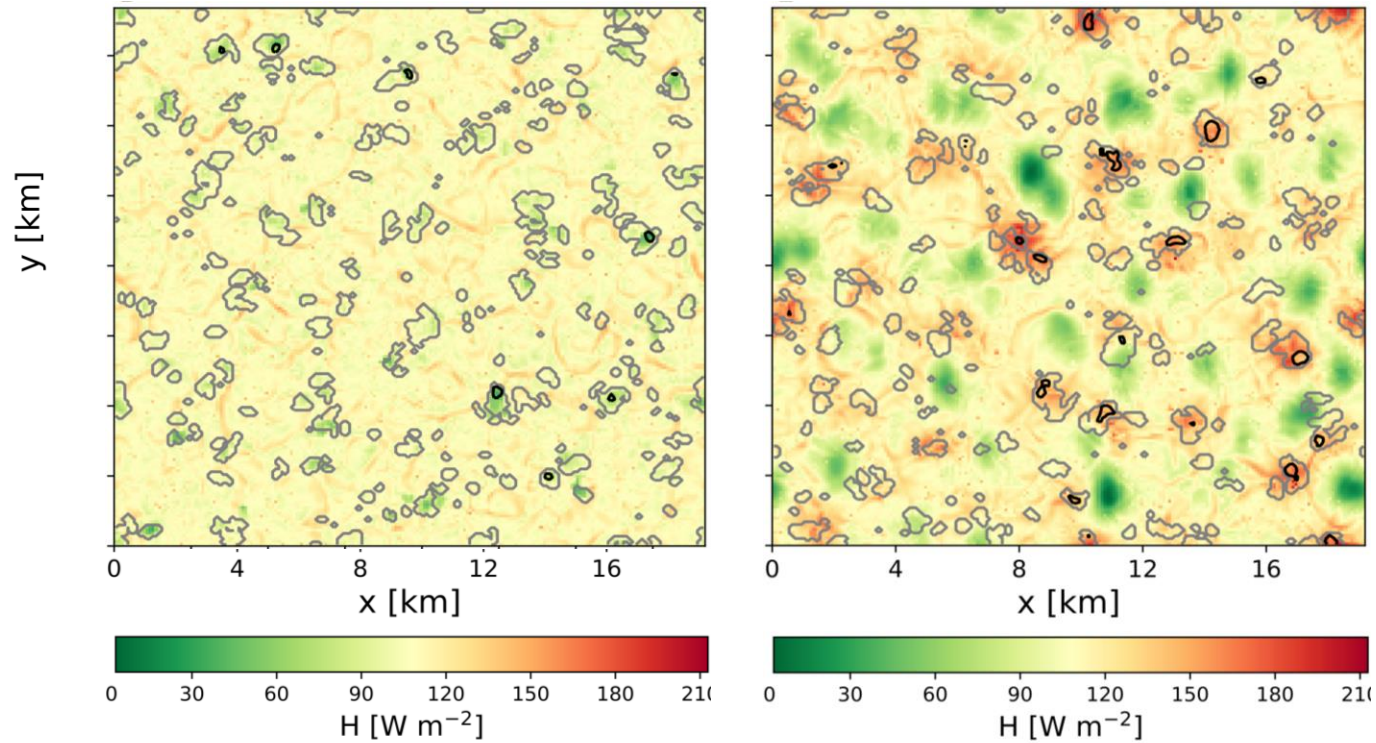
Canopy-atmosphere interface



(Patton et al., 2016)

(Bonan et al., 2016)

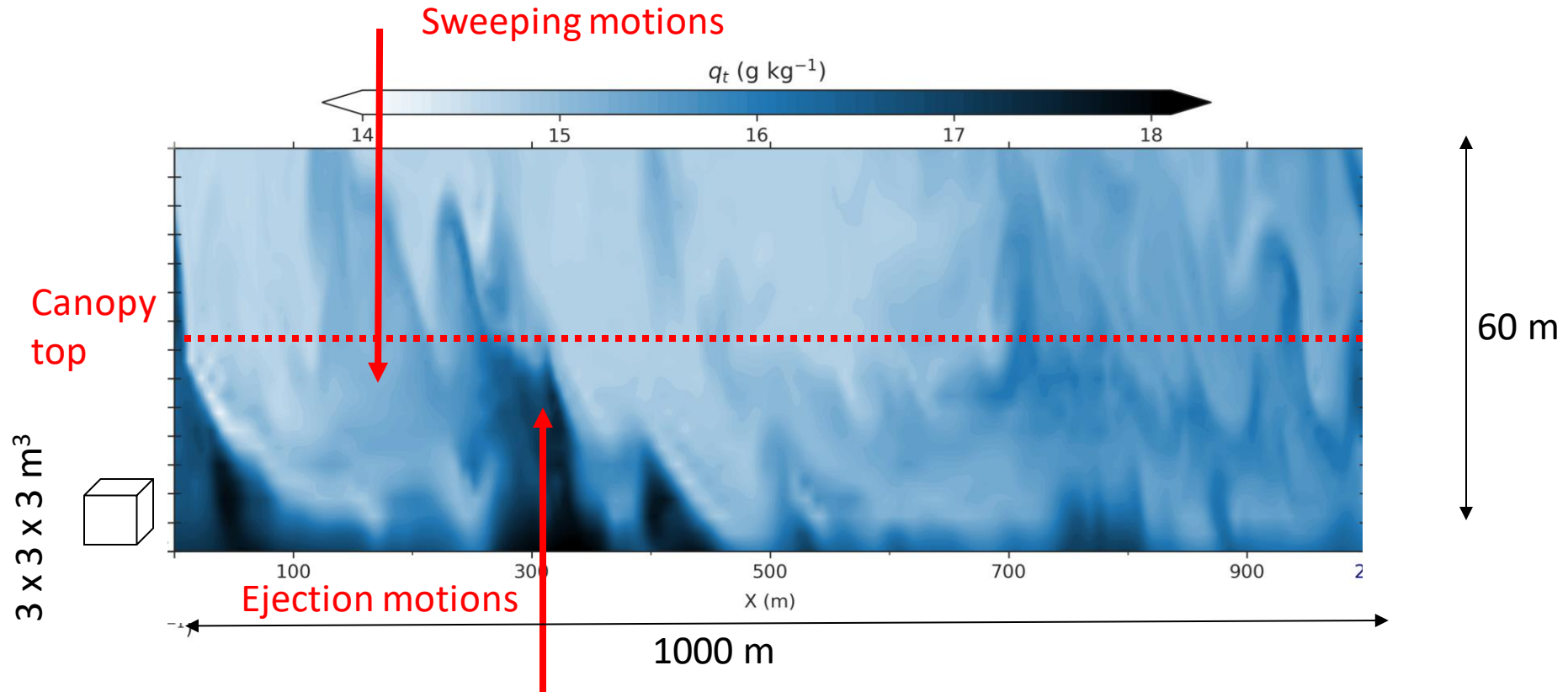
RADIATION: Effects of three-dimensionality



- 3D radiation leads to large impact on the surface fluxes
- As a result, there are changes on turbulence and cloud formation

TURBULENCE canopy-atmosphere: spatial and profile distribution

Specific humidity



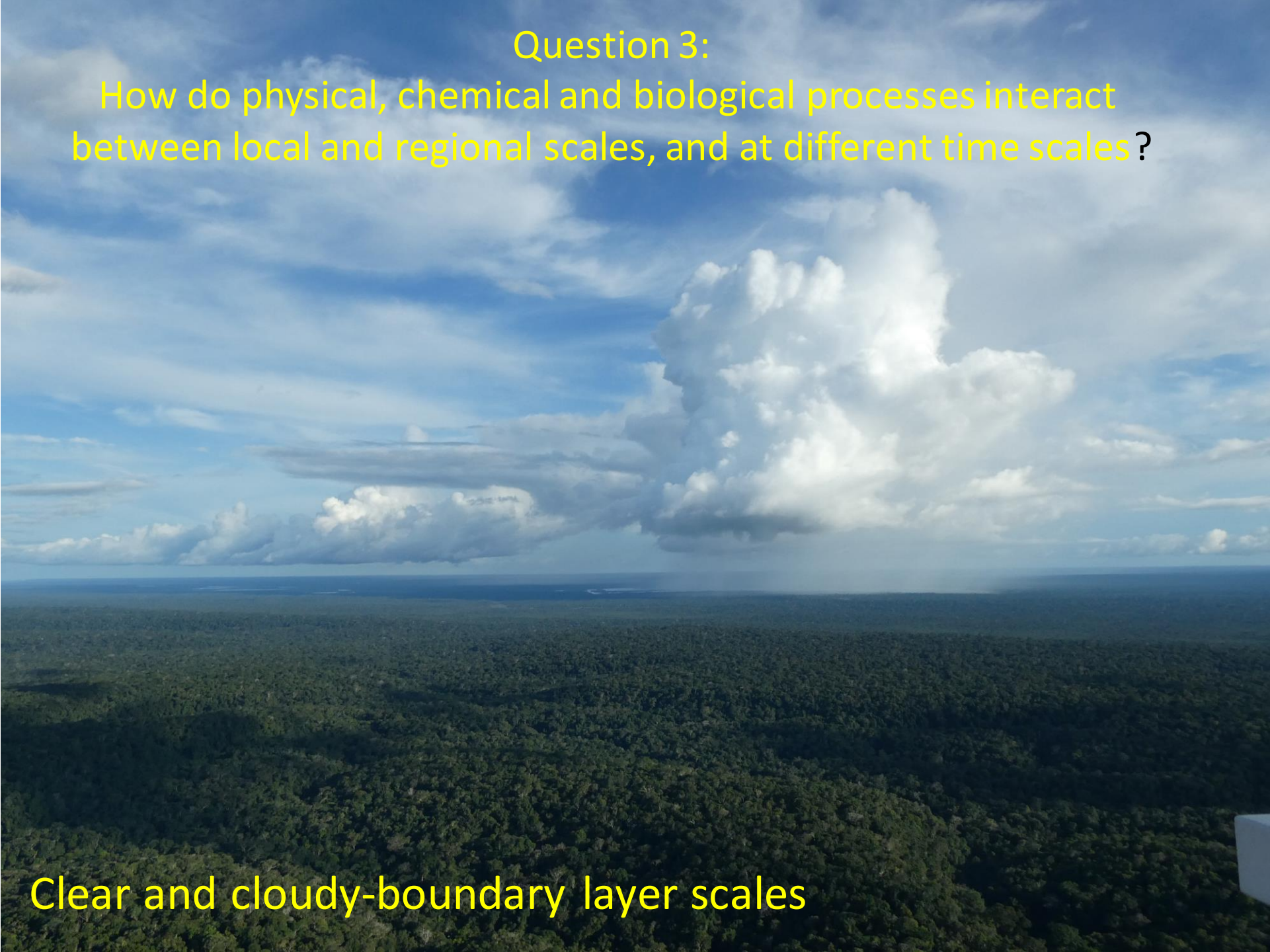
- ✓ Importance to account for sweeping and ejection motions
- ✓ Large variation fluxes in the vertical direction
- ✓ Need to solve motions at very high ($3 \times 3 \times 3 \text{ m}^3$) resolution

(Patton et al., 2016)

(Pedruzo-Bagazgoitia et al., 2023)

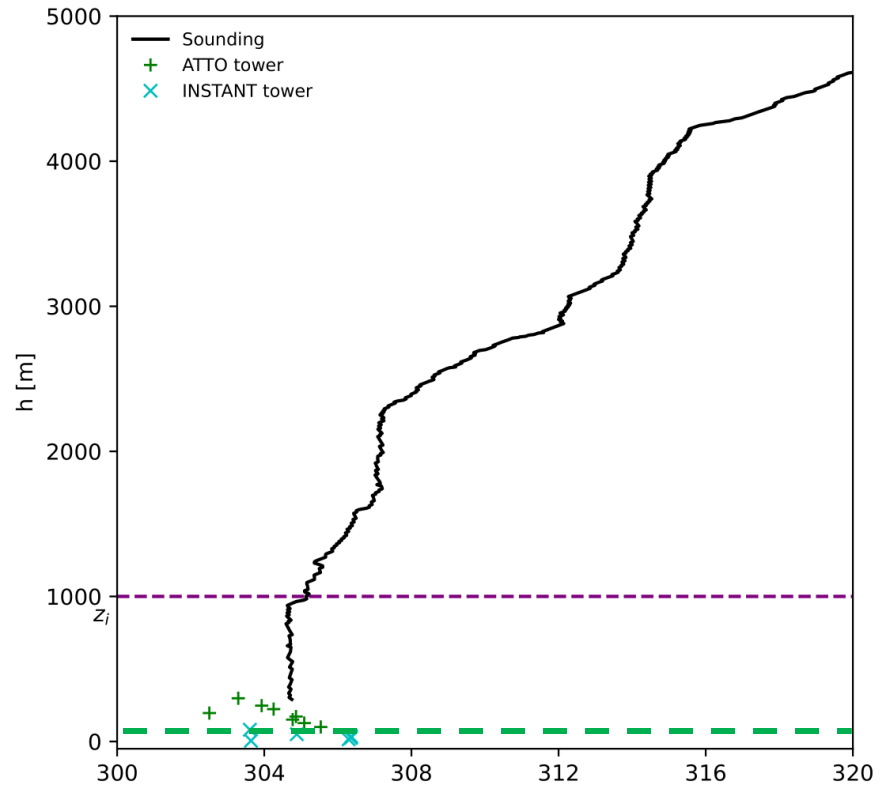
Question 3:

How do physical, chemical and biological processes interact between local and regional scales, and at different time scales?



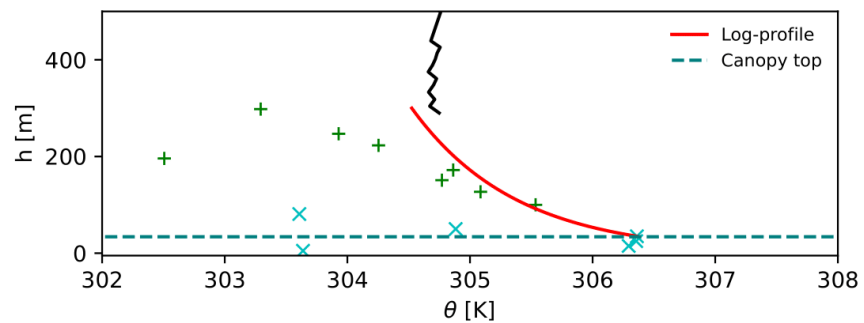
Clear and cloudy-boundary layer scales

Interconnecting processes with the canopy-atmosphere interaction as the main actor



Clouds

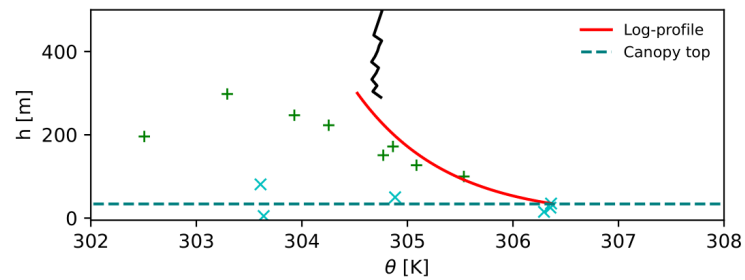
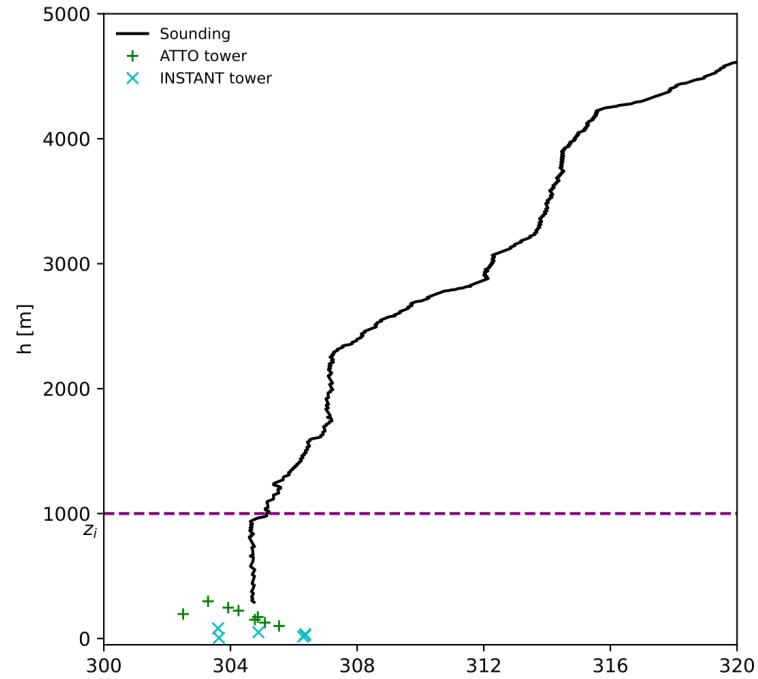
Entrainment



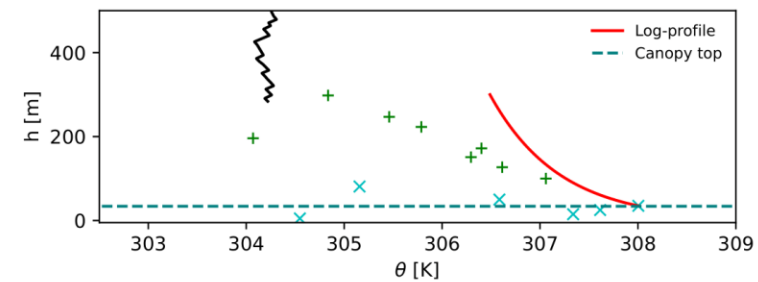
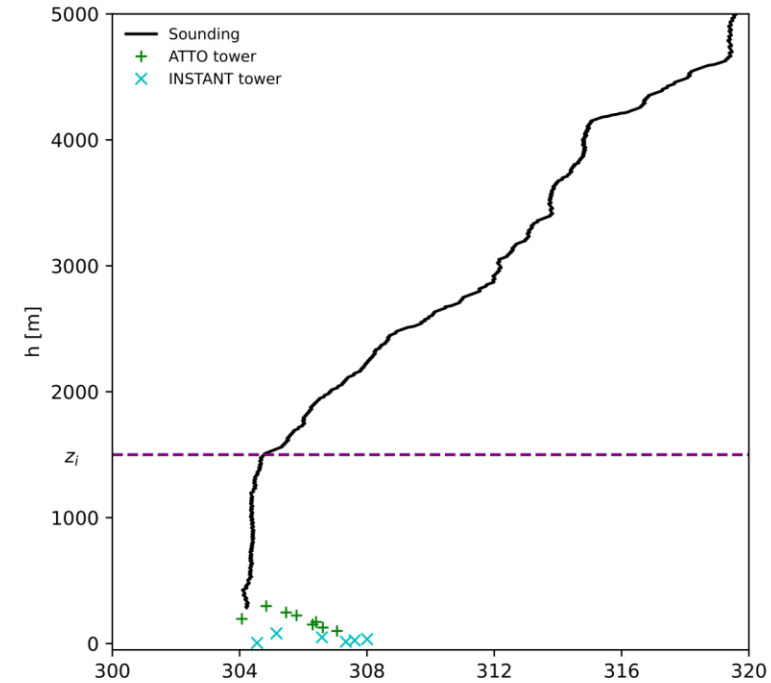
Canopy-atmosphere interface

VERTICAL TRANSPORT: Connecting canopy to the atmospheric boundary layer

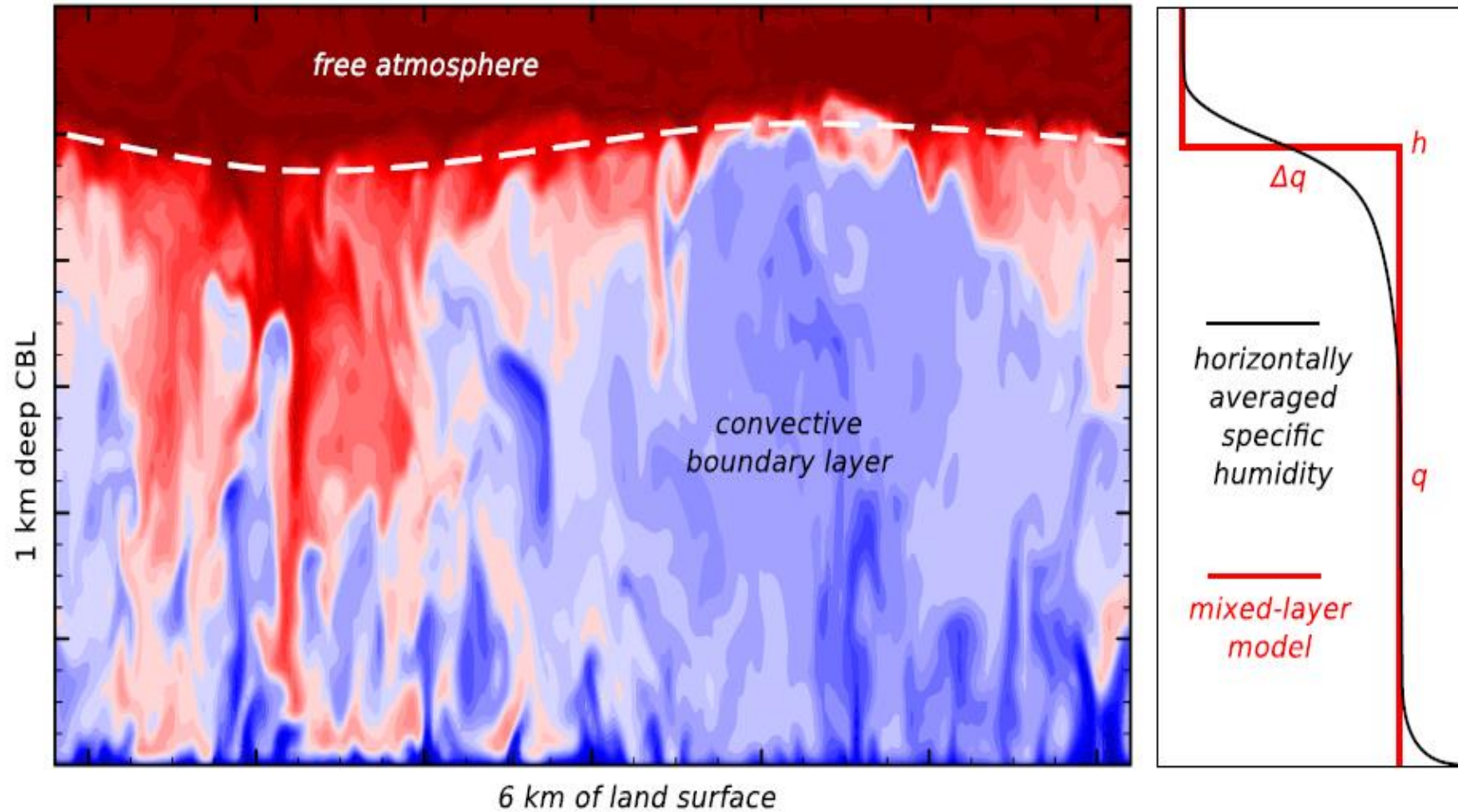
13 UTC, 09 LT



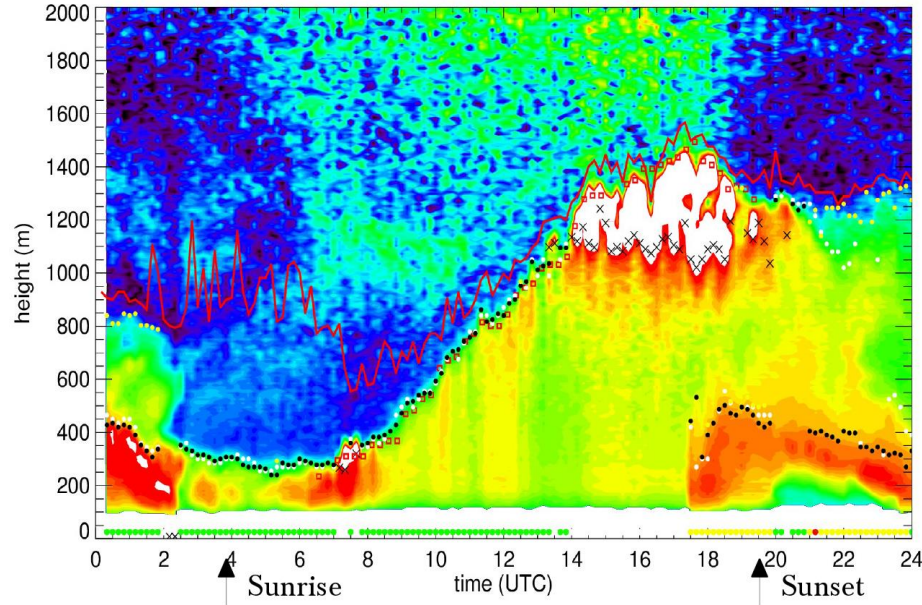
20 UTC, 16 LT



Budget diurnal variability CO2



Representing turbulent fluxes at the ABL-atmosphere interface

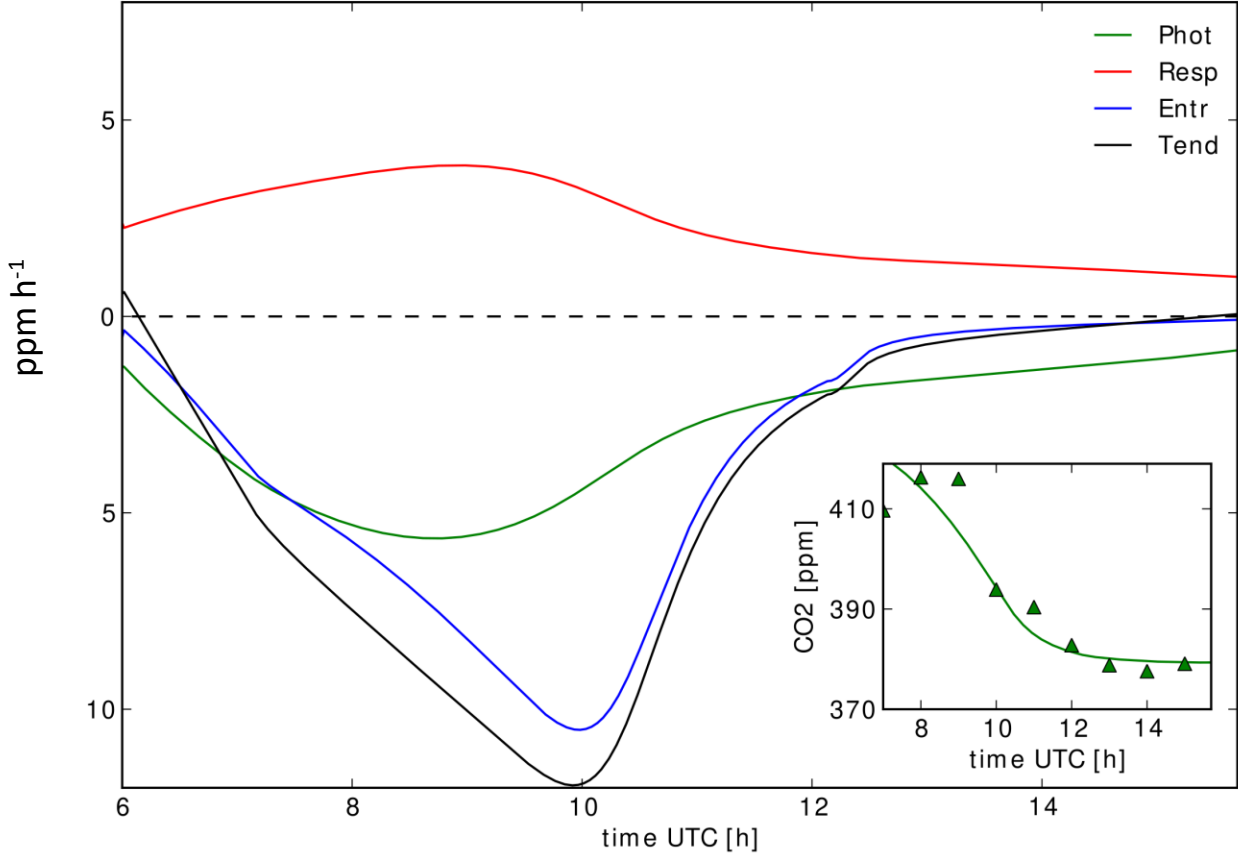


$$\frac{\partial \langle \phi \rangle}{\partial t} = \frac{(\overline{w' \phi'})_s - (\overline{w' \phi'})_e}{h}$$

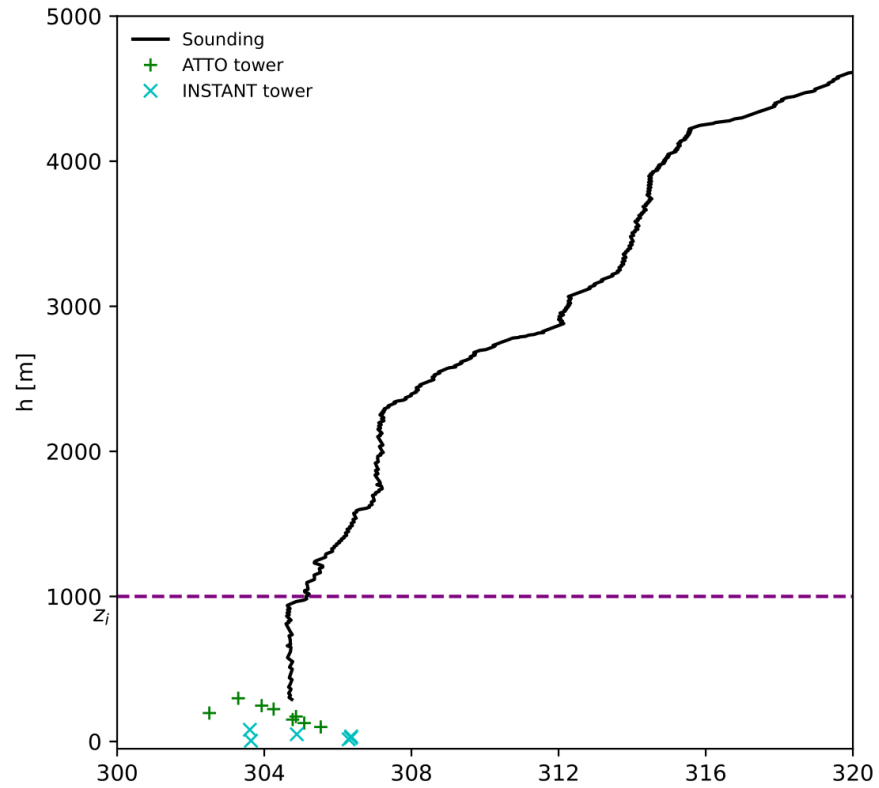
$$(\overline{w' \phi'})_e = - \left(\frac{\partial h}{\partial t} \right) (\phi_{FT} - \langle \phi \rangle)$$

Budget diurnal variability CO₂

$$\frac{\partial \langle CO_2 \rangle}{\partial t} = \frac{\overbrace{(w'CO_2'_{phot})} + \overbrace{(w'CO_2'_{resp})} - \overbrace{(w'\phi'_{ent})}}{h}$$

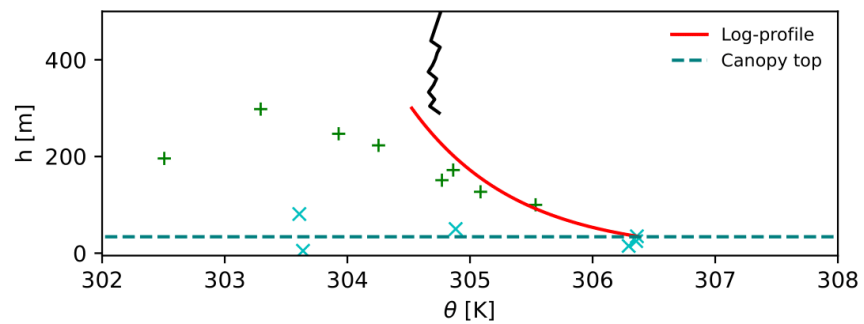


Interconnecting processes



Clouds
Sub-cloud layer-Cloud layer interface

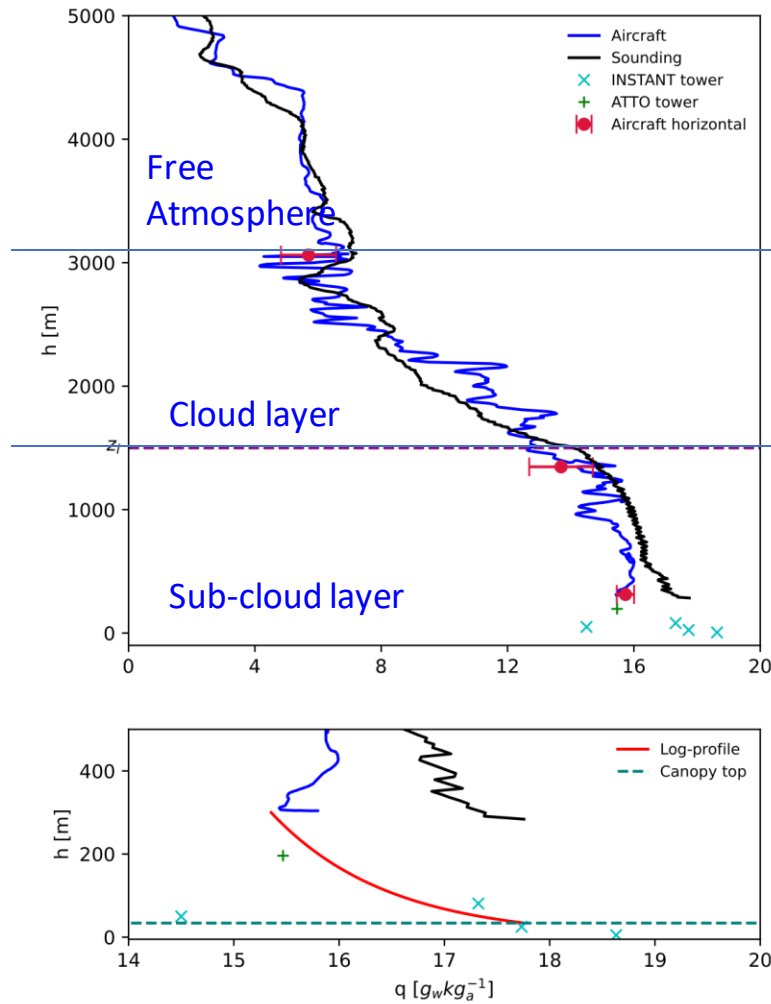
Entrainment
ABL-FT interface



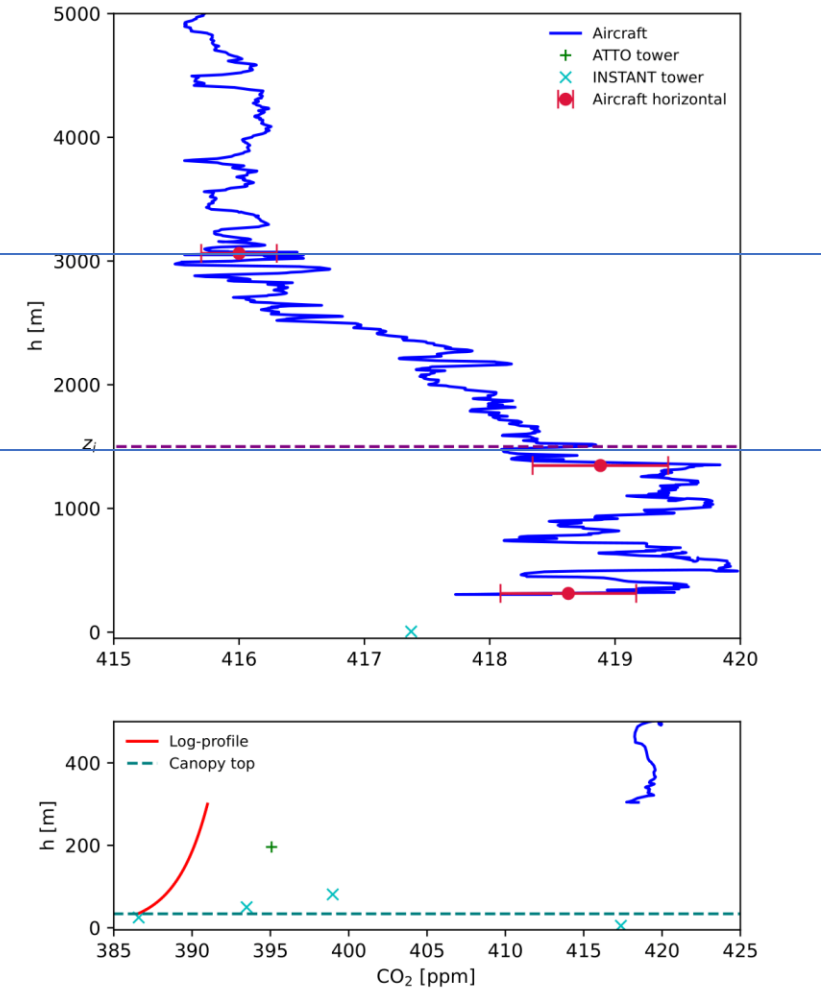
Canopy-atmosphere interface

VERTICAL TRANSPORT: Connecting canopy to the atmospheric boundary layer

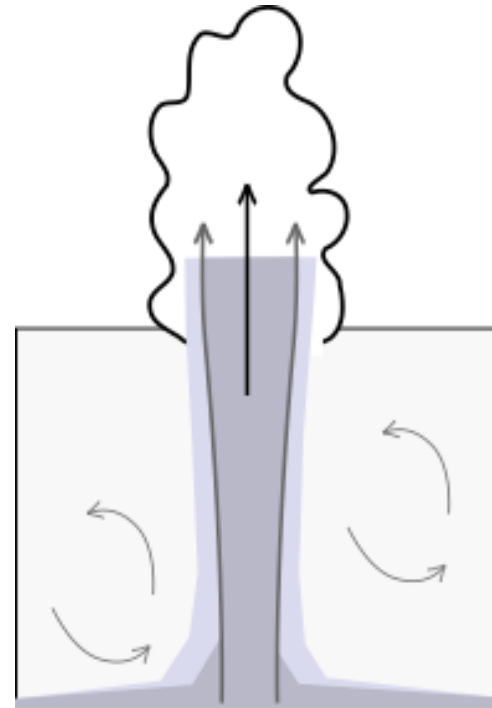
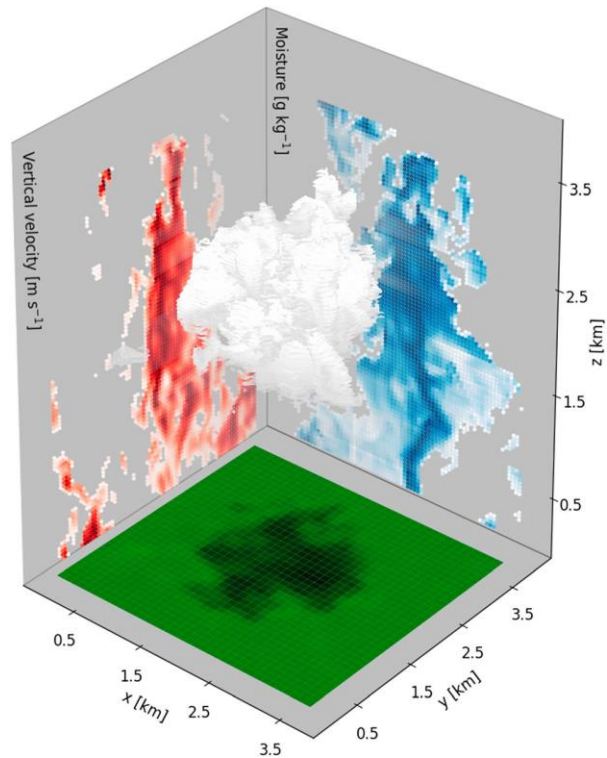
20 UTC, 16 LT



20 UTC, 16 LT



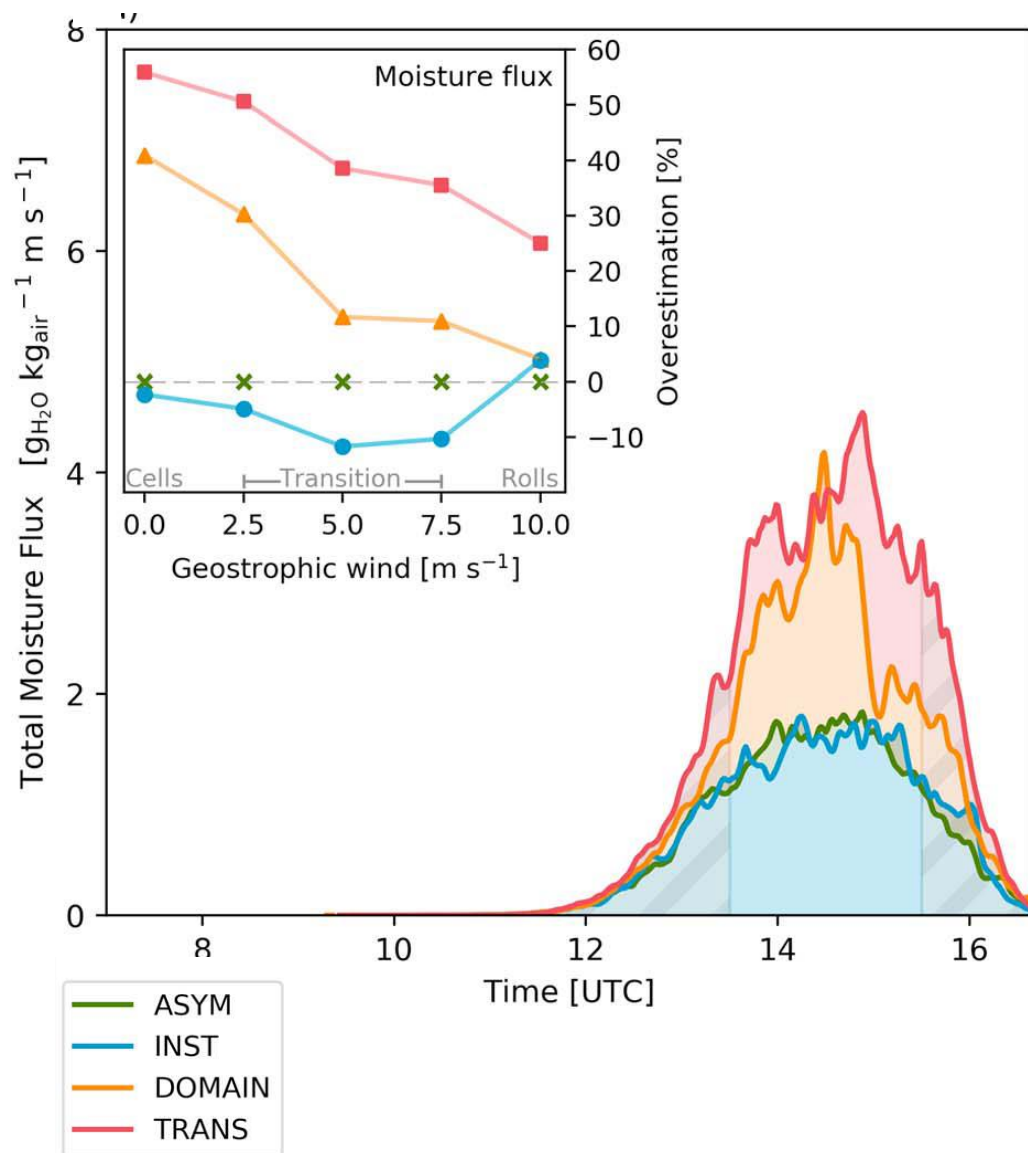
Representing turbulent fluxes at the sub-cloud and cloud-layer interface



$$M = w_c a_c \quad w_c \approx w_*$$

$$\overline{w'\phi'} \approx M (\phi_{\text{updraft}} - \phi_{\text{average}})$$

Moisture transport depends on the representation of coupling with plants



ASYM:
 Cloud shading
 Surface dynamic heterogeneity
 Asymmetric plant response light fluctuations

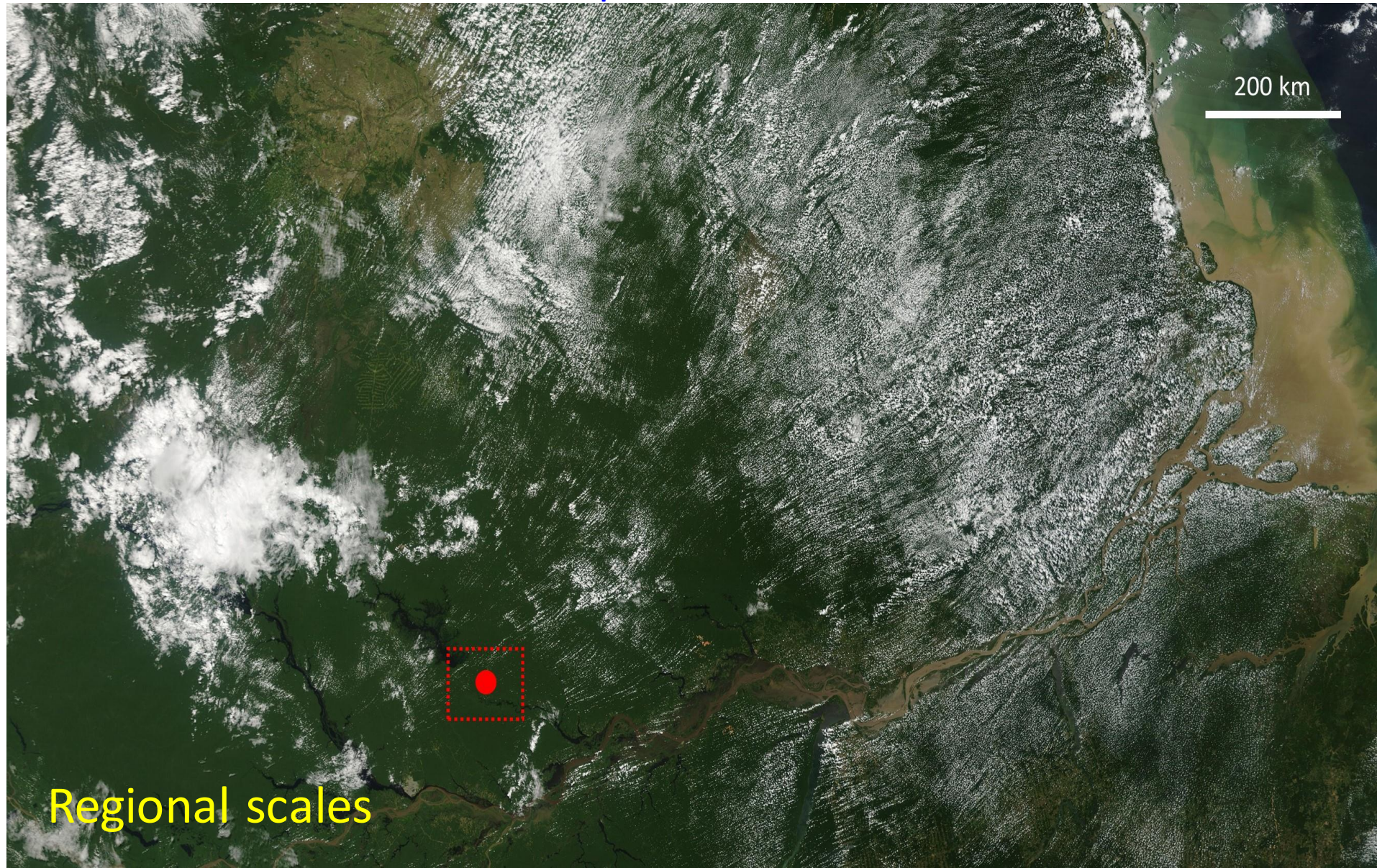
INST:
 Cloud shading
 Surface dynamic heterogeneity
 Instantaneous plant response light fluctuations

DOMAIN:
 Cloud shading
 Energy conserved buy homogenously distributed

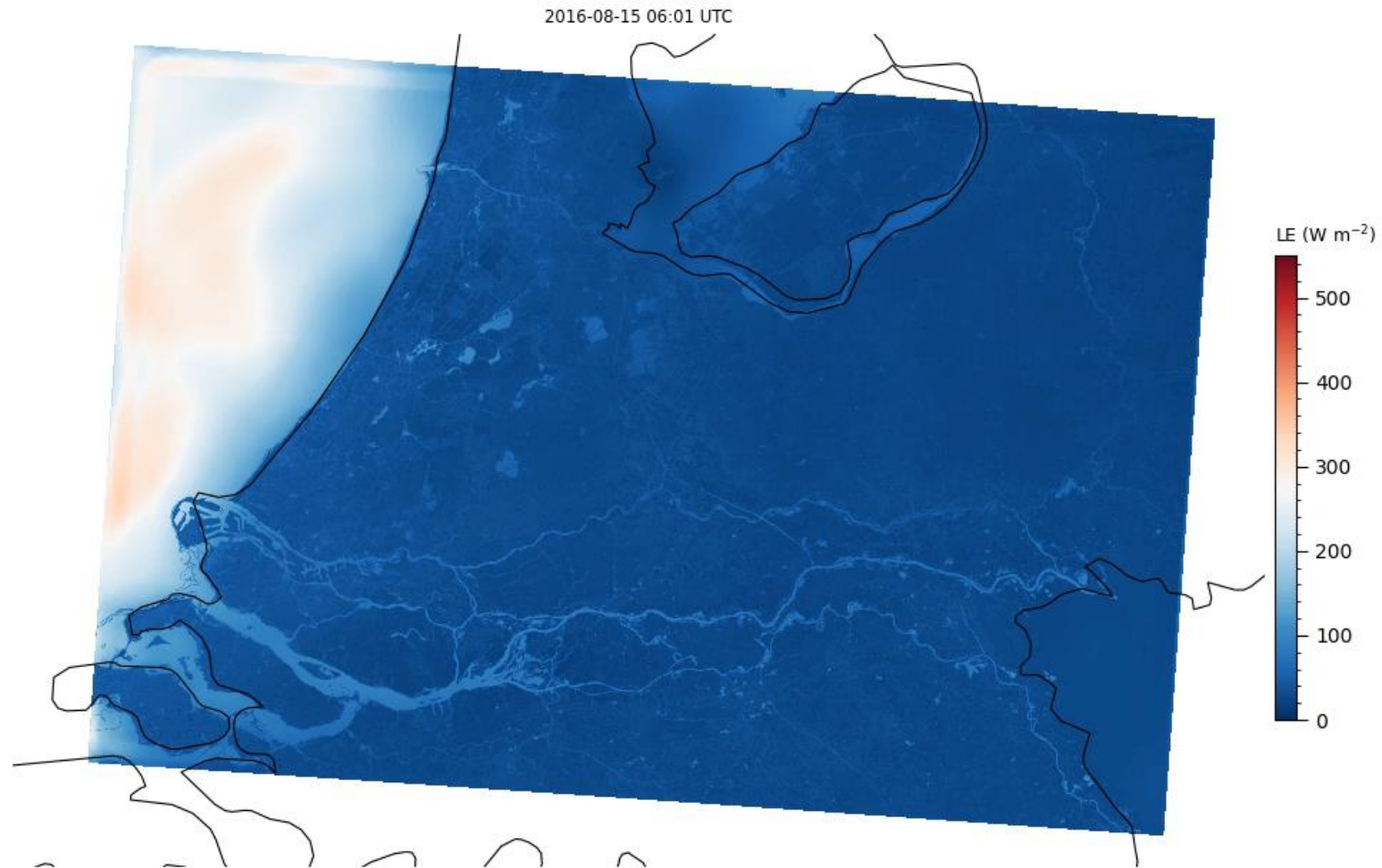
TRANS
 Clouds transparent

Question 4:

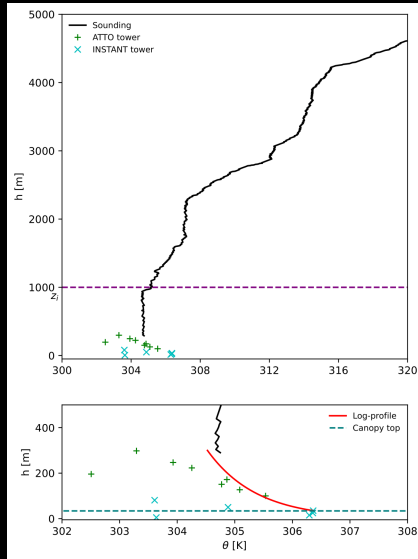
How does the system energy, water and carbon cycles integrate over scales under present and future conditions?



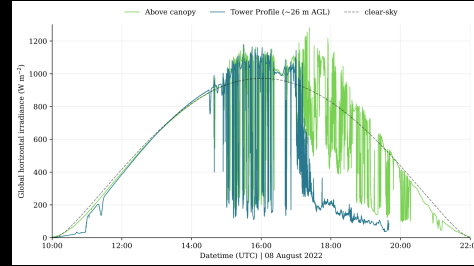
INTEGRATING processes as a continuum and as explicit as possible



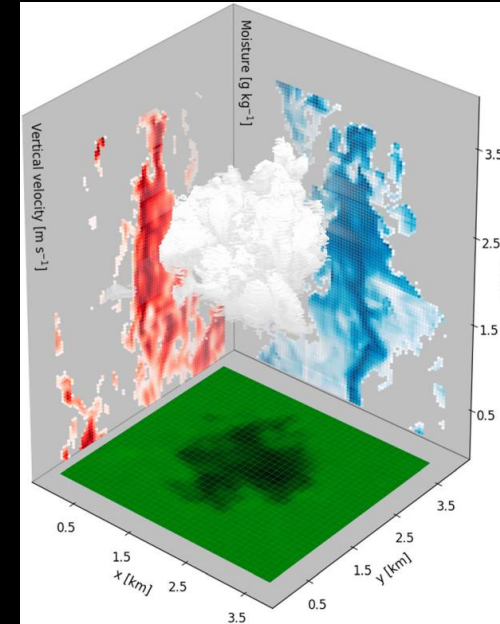
Turbulent Transport/Mixing



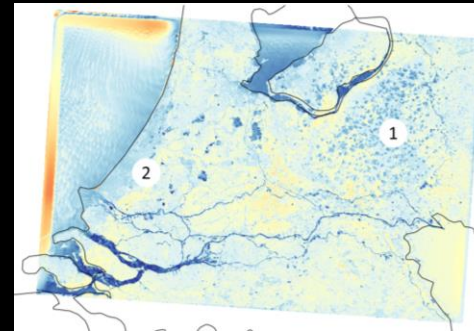
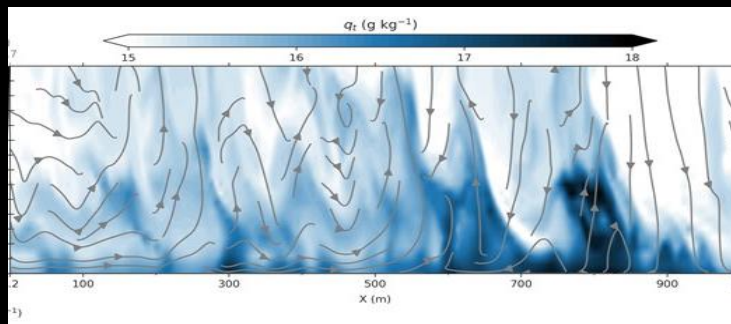
Radiation Direct/Diffuse



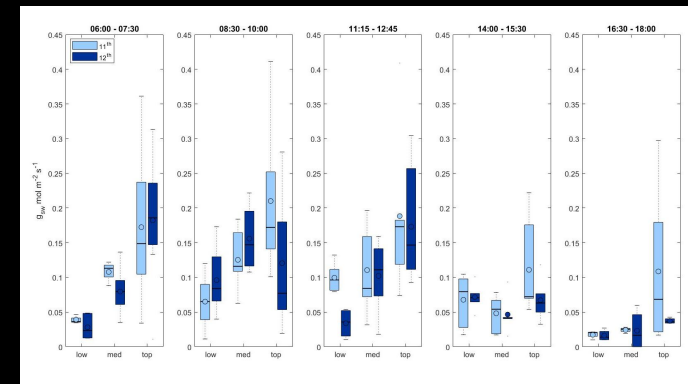
Clouds Aerosols/Chemistry



Surface Energy Balance Heat/Moisture fluxes



Canopy/Soil Photosynthesis/Respiration



The four challenges of the unbroken cycle between carbon and clouds

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