Simulation of atmospheric CO_2 variability with the mesoscale model TerrSysMP

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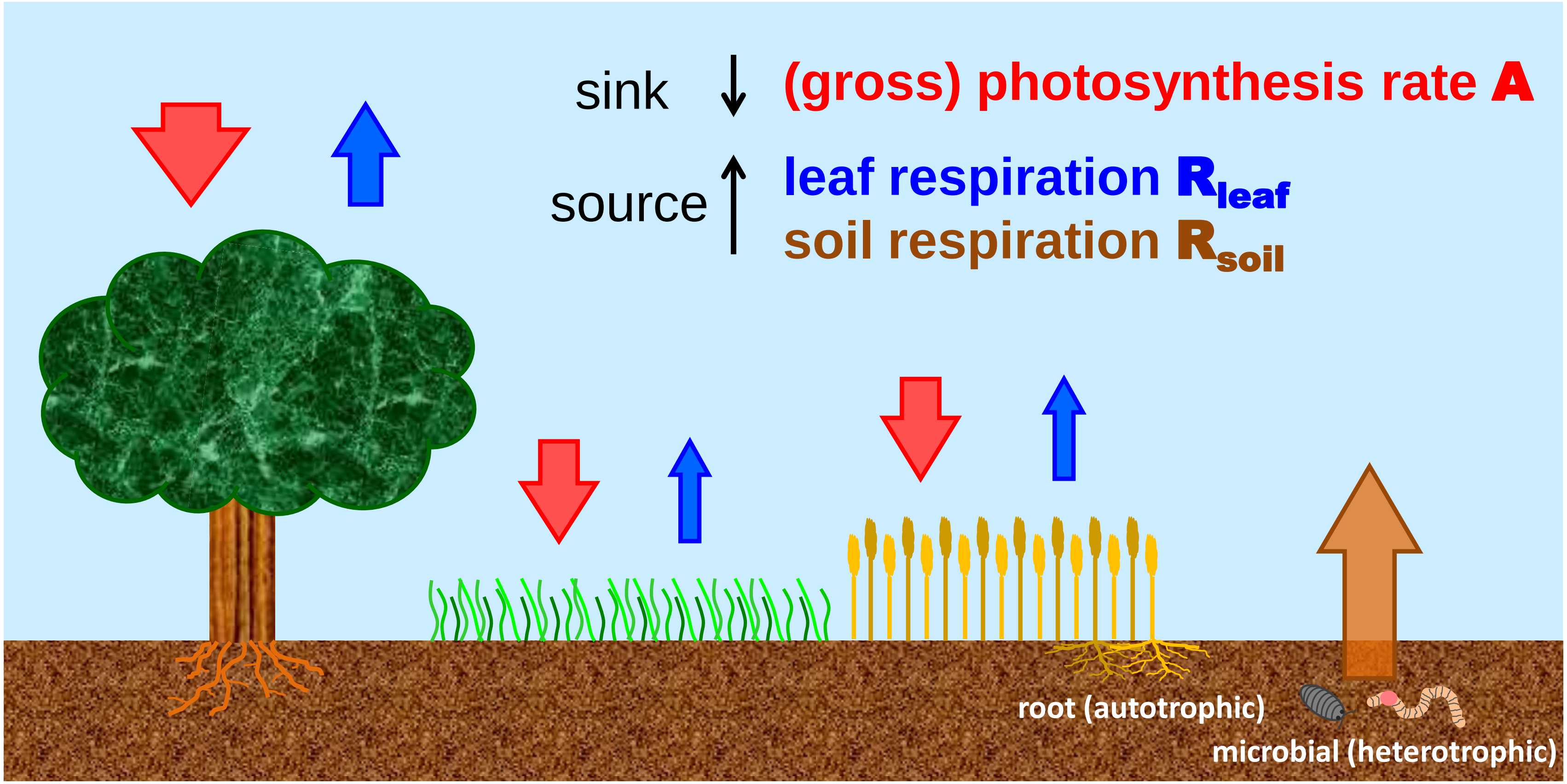
University of Bonn

Transregional Collaborative Research Centre 32

COSMO-User-Seminar 2015

Introduction

Introduction: CO_2 sources/sinks



- ***Natural*** *CO_2 fluxes depend on:*
  - **plant type** (e.g. agriculture, forests, grassland, ...)
  - **soil conditions** (texture, temperature, moisture)

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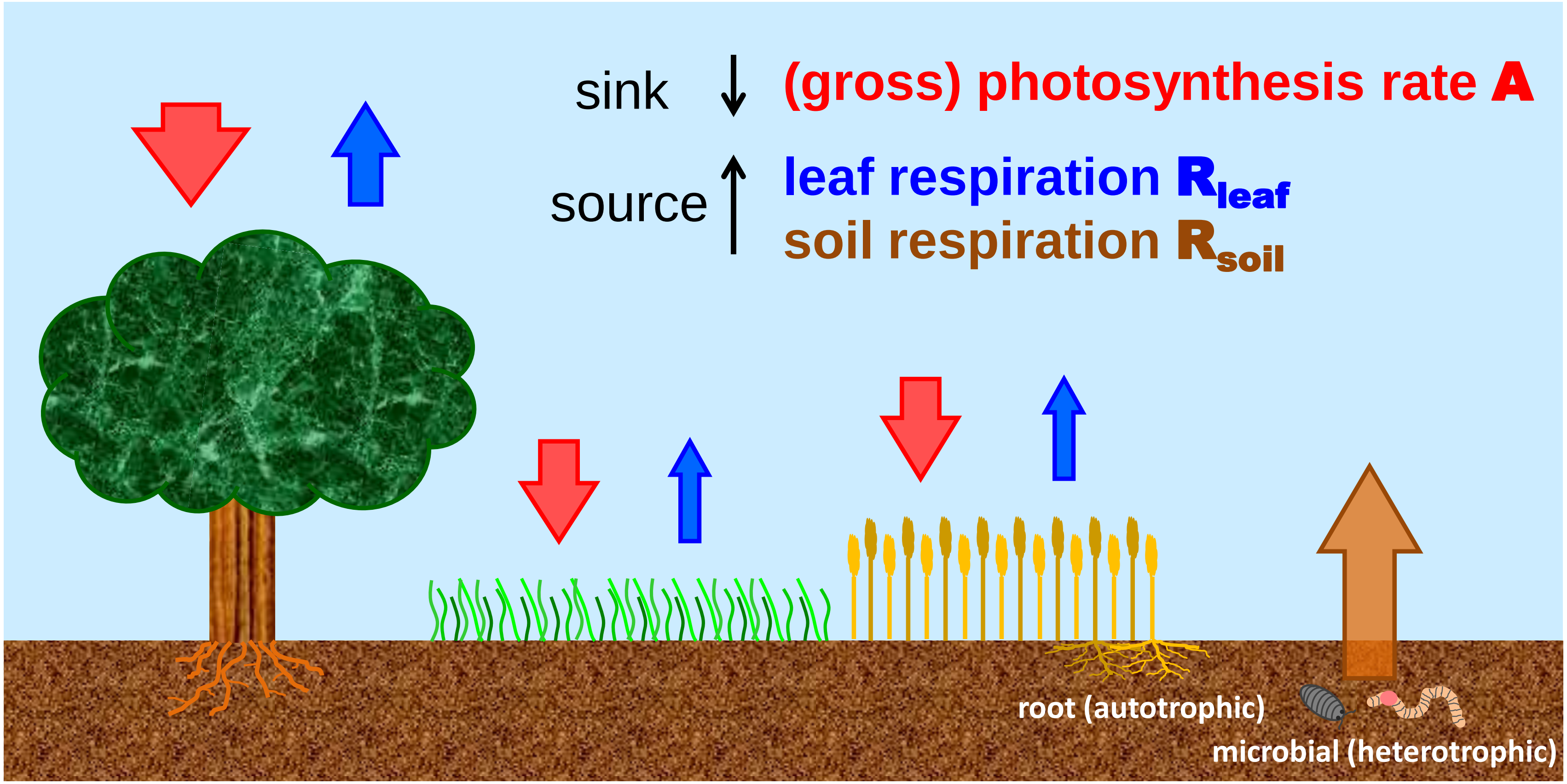

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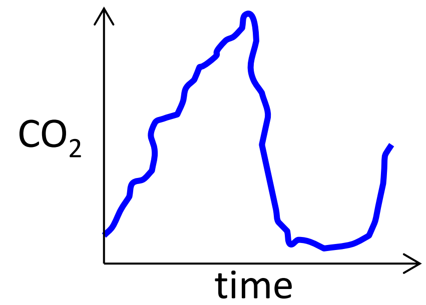
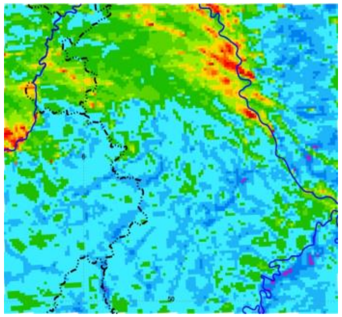
  - **plant type** (e.g. agriculture, forests, grassland, …)
  - **soil conditions** (texture, temperature, moisture)
- ***Anthropogenic** emissions*

atmospheric CO_2 variability

- **Diurnal cycle:**
  - net **gain** of CO_2 during **night** (R_{leaf} + R_{soil})
  - net **loss** of CO_2 at **daytime** (R_{leaf} + R_{soil} – A)



- **Spatial heterogeneity:**
  - atmospheric transport
  - land surface heterogeneity (land use, orography)



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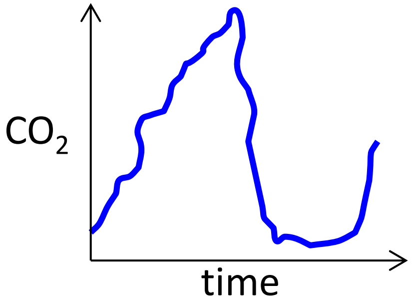

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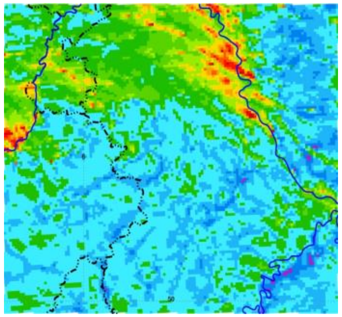


➢ Motivation:

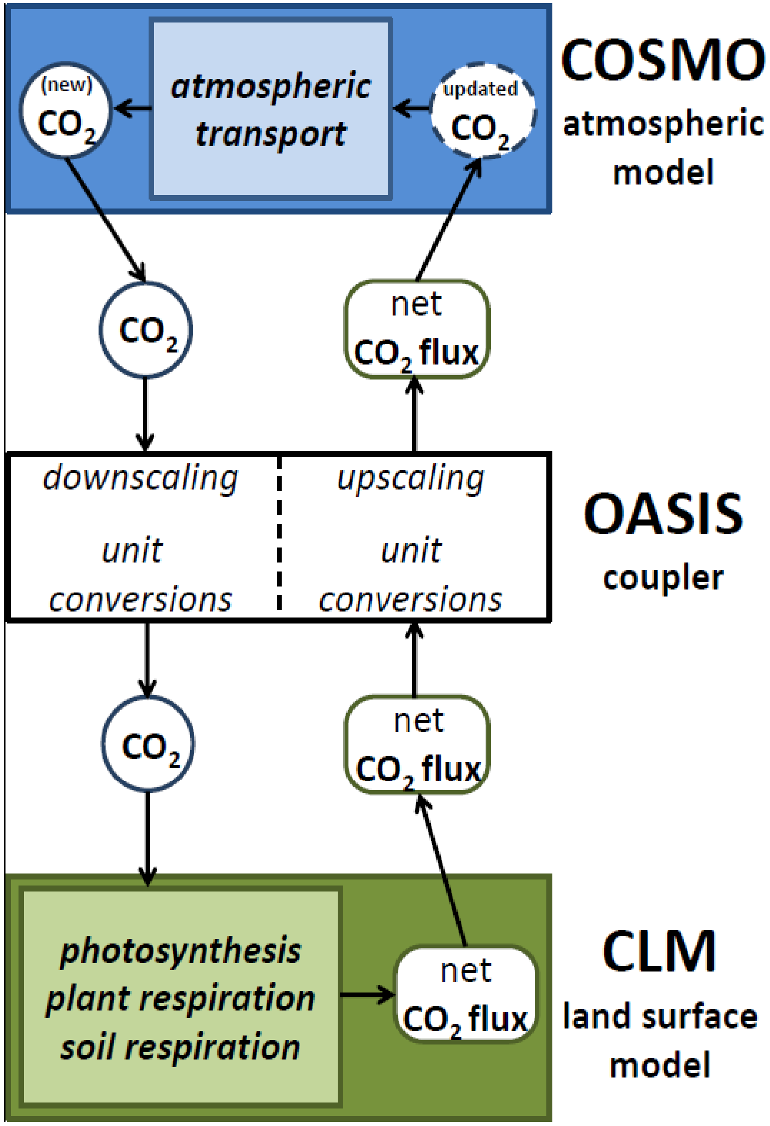
Mesoscale simulation of atmospheric CO_2 variability

→ understand diurnal variability and spatial CO_2 patterns

→ useful information i.e. for inverse modeling, plant science, …

CO_2 processes in TerrSysMP

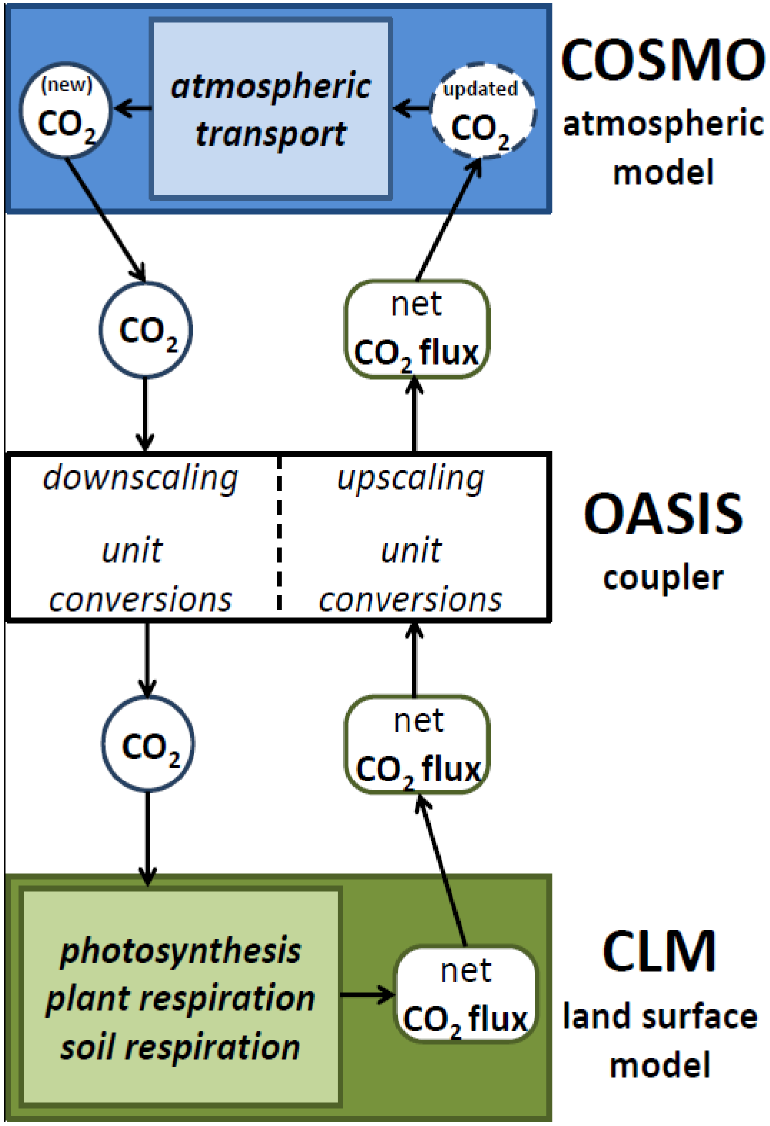
TerrSysMP with CO_2 coupling



- **TerrSysMP:** ☞ *Poster Shrestha et al.*
  - Coupling of **COSMO** (4.21) with the Community Land Model (**CLM3.5**) via the external coupler OASIS3

    → TERRA is replaced by CLM
  - further coupling to the hydrological model ParFlow possible (not used for this study)

TerrSysMP with CO_2 coupling



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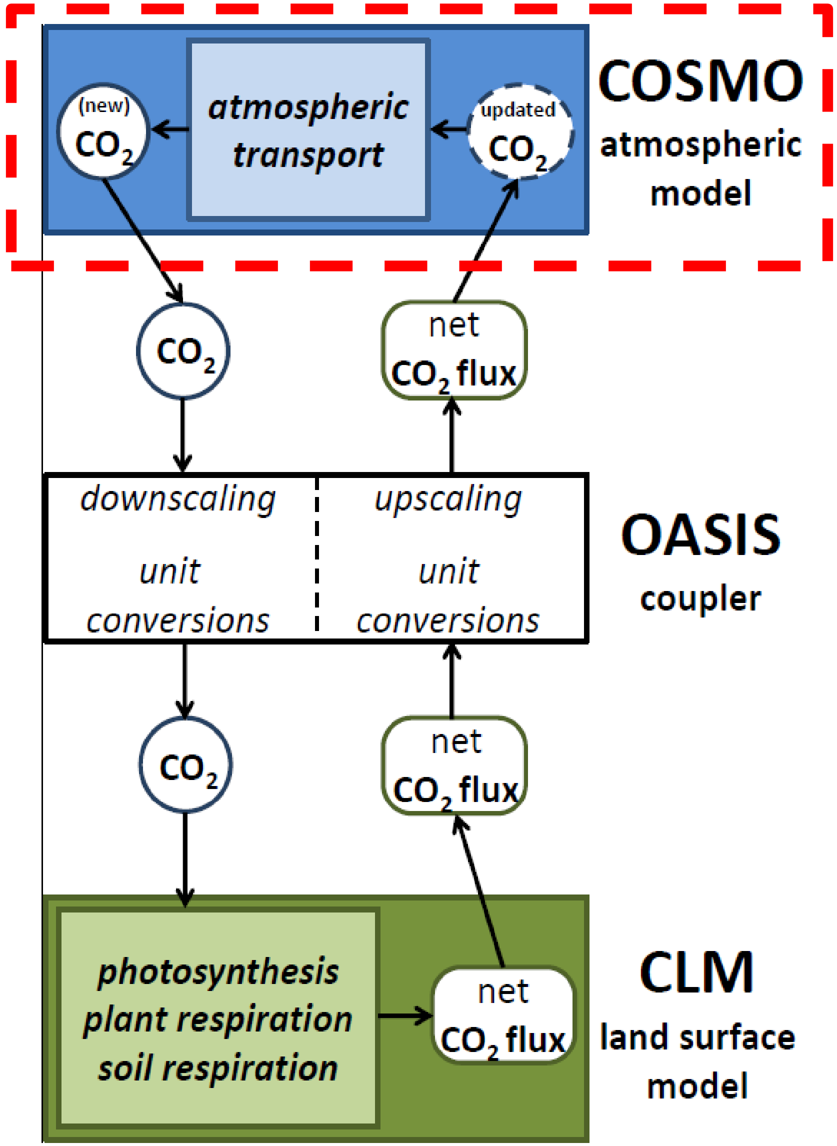
- Extension with **CO_2 coupling (two-way)**
  - **CLM** calculates **natural CO_2 fluxes** using atm. CO_2 from COSMO
  - COSMO receives **net CO_2 flux** from CLM
  - **COSMO** performs atmospheric **CO_2 transport**

TerrSysMP with CO_2 coupling

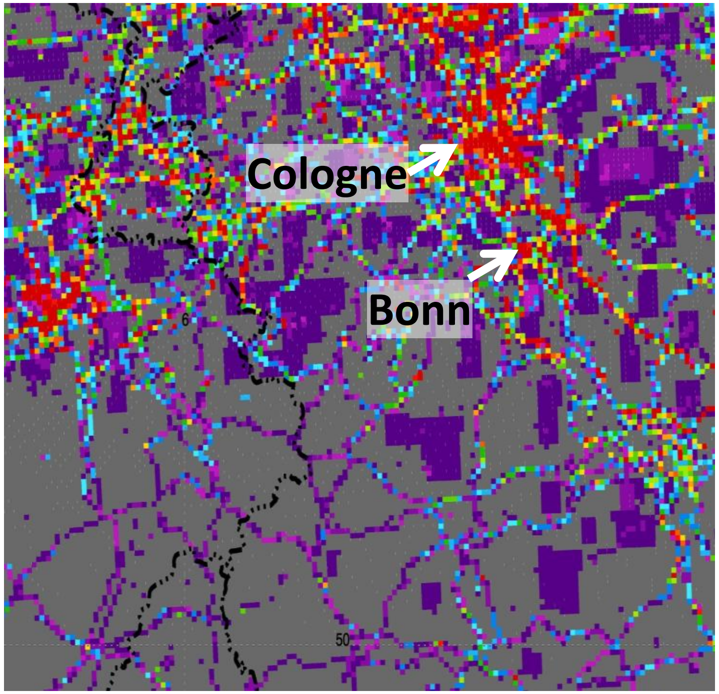


CO_2 transport and anthropogenic emissions

- Inclusion of an **atmospheric tracer** in COSMO_4.21
  → needed for the **atmospheric transport of CO_2**

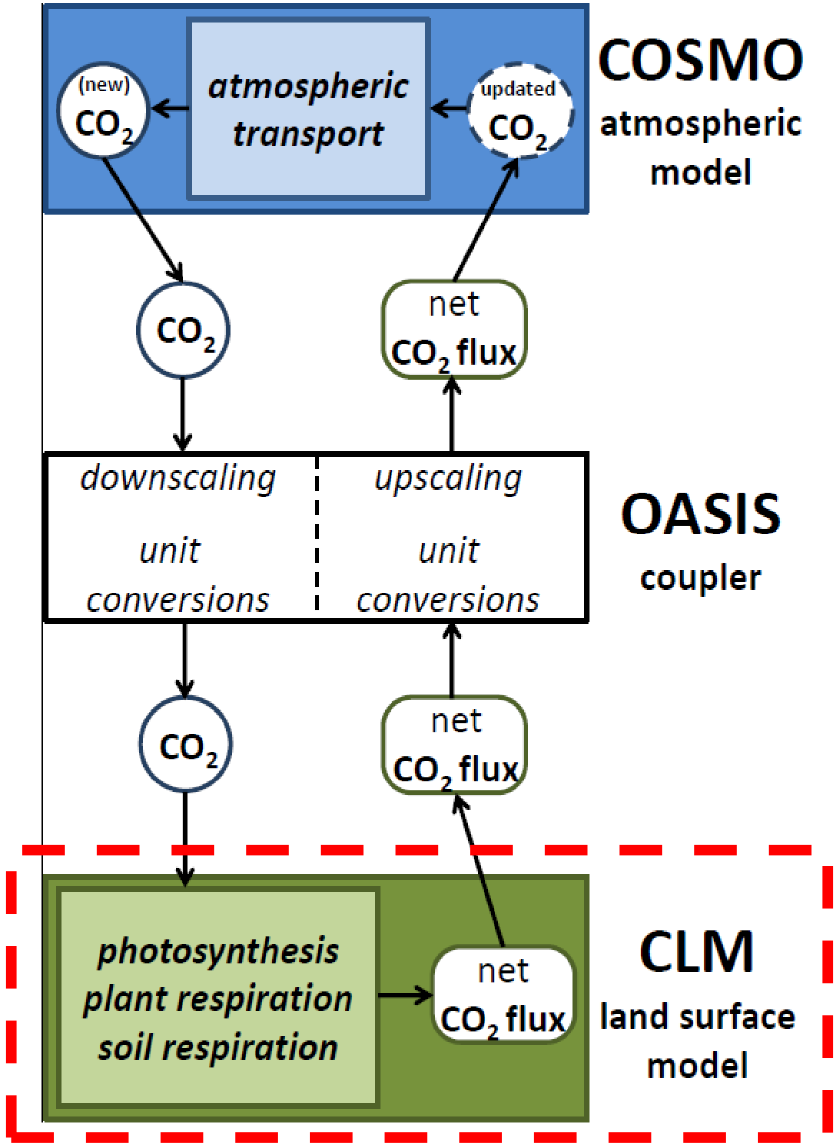
- **Anthropogenic emissions:**

  - use of **CO_2 emission data**
    [provided by TNO, The Netherlands]
  - **downscaling** to 1 km resolution
    [provided by P. Franke, E. Bem (RIU Köln)]
  - calculation of **hourly emissions** depending on month, weekday, time of day
    → introduced as **CO_2 source** to the CO_2 tracer in COSMO



Downscaled (1 km) anthropogenic CO_2 emission [mg m^{-2} s^{-1}]

TerrSysMP with CO_2 coupling

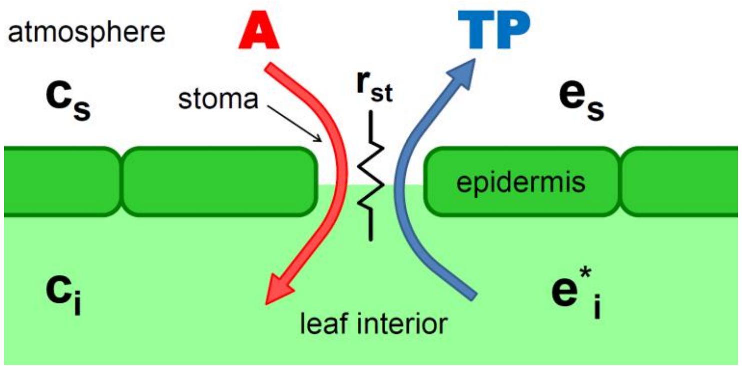


Photosynthesis and leaf respiration

- **photosynthesis** (**A**) and canopy **transpiration** (**TP**) is controlled by the **stomatal resistance r_{st}** of leafs:

$$\frac{1}{r_{st}} = \frac{A}{c_s}\frac{e_s}{e_i^*} P_{atm} + b$$

based on Collatz et al. (1991, 1992)



$m = m(\mathrm{PFT})$

A	gross photosynthesis	e_i	saturation vapor pressure in the leaf
c_s	CO_2 partial pressure	P_{atm}	atmospheric pressure
e_s	vapor pressure at leaf surface	b	minimal stomatal conductance

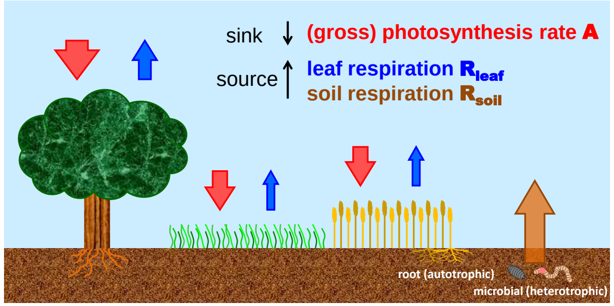
→ c_s, e_s and P_{atm} are derived by COSMO variables **p**, q_v and q_{CO2} at surface level

- **leaf (dark) respiration:**

$$R_{leaf} = 0.015 \cdot V_{c\,max}$$

$V_{c\,max}$ maximum rate of carboxylation

based on Collatz et al. (1991)



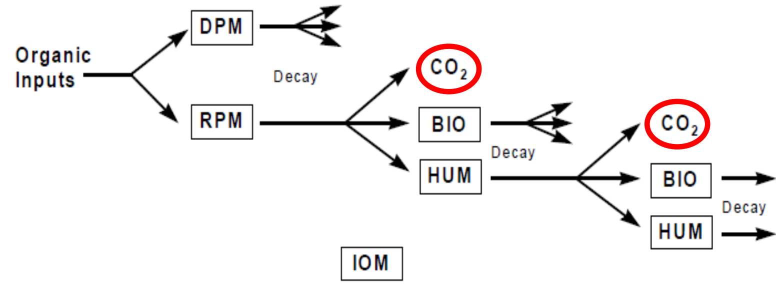
Soil respiration

- **Heterotrophic soil respiration:**

- Implementation of the carbon turnover model **RothC-26.3** (Coleman and Jenkinson, 2008) into CLM3.5

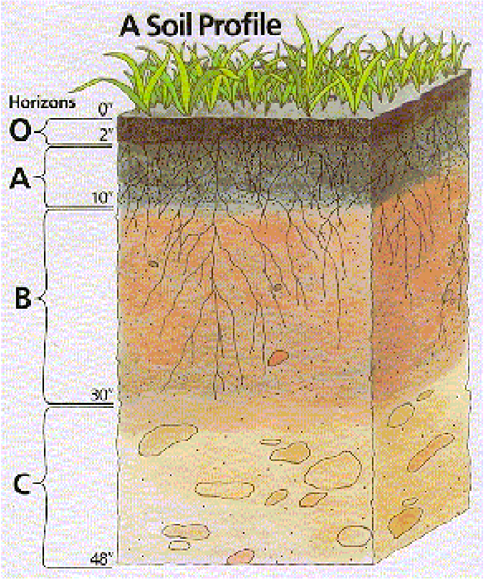
→ calculates **decomposition** of organic carbon into carbon pools and **CO_2** (A, B horizon)

→ generated CO_2 is released to the atmosphere



Coleman and Jenkinson (2008)

- Decomposition of **leaf litter** and **organic matter** (O horizon)



www.nesoil.com

- **Autotrophic (root) respiration** depending on plant activity (photosynthesis, carbon allocation)

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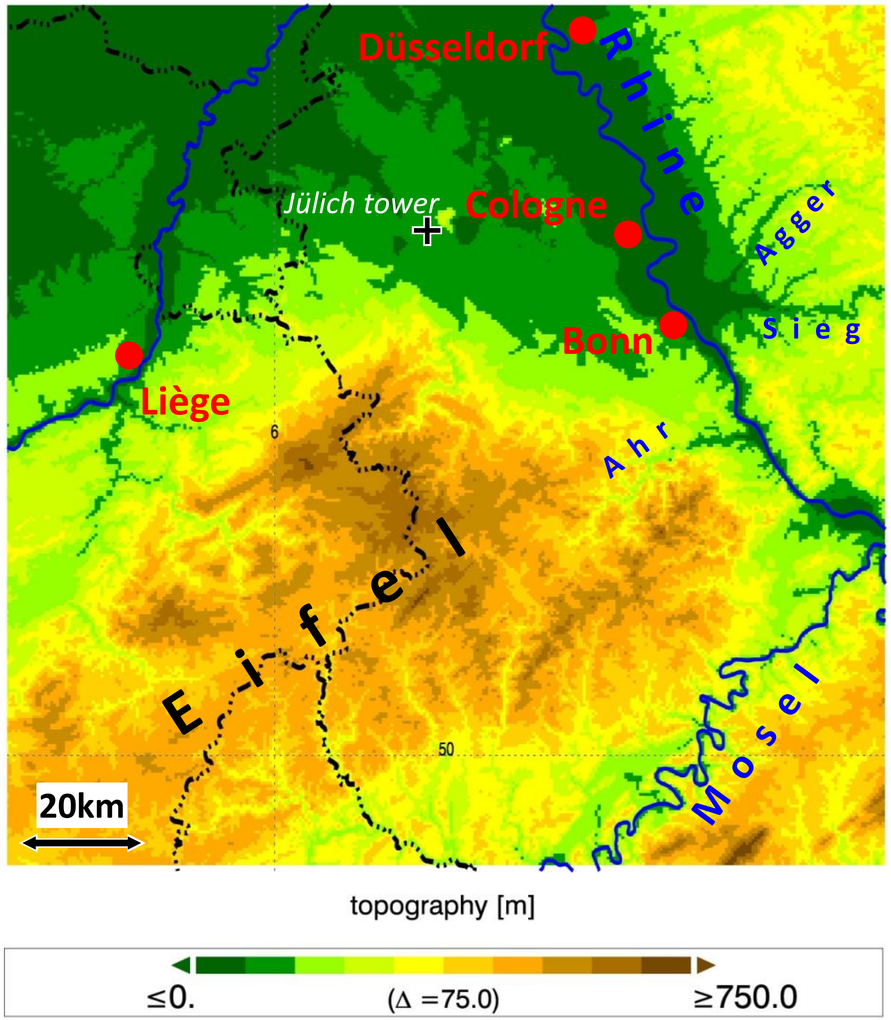
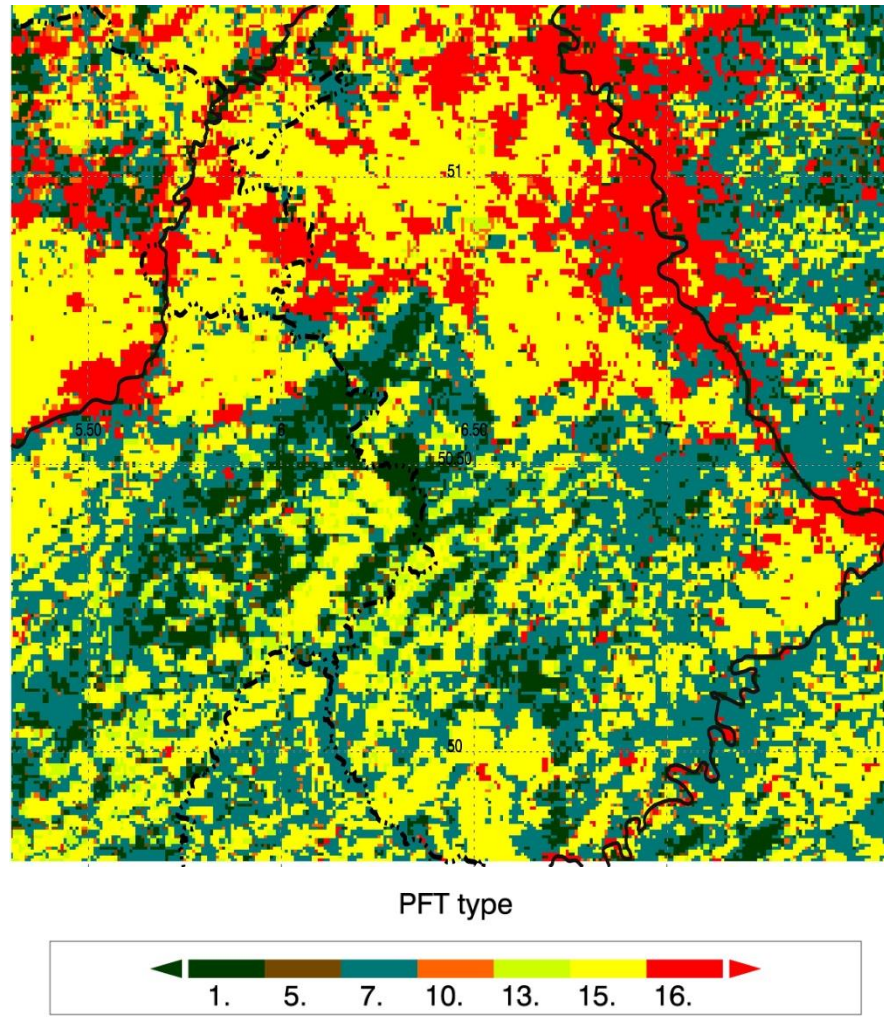
Simulation of diurnal and mesoscale CO_2 variability

Model domain

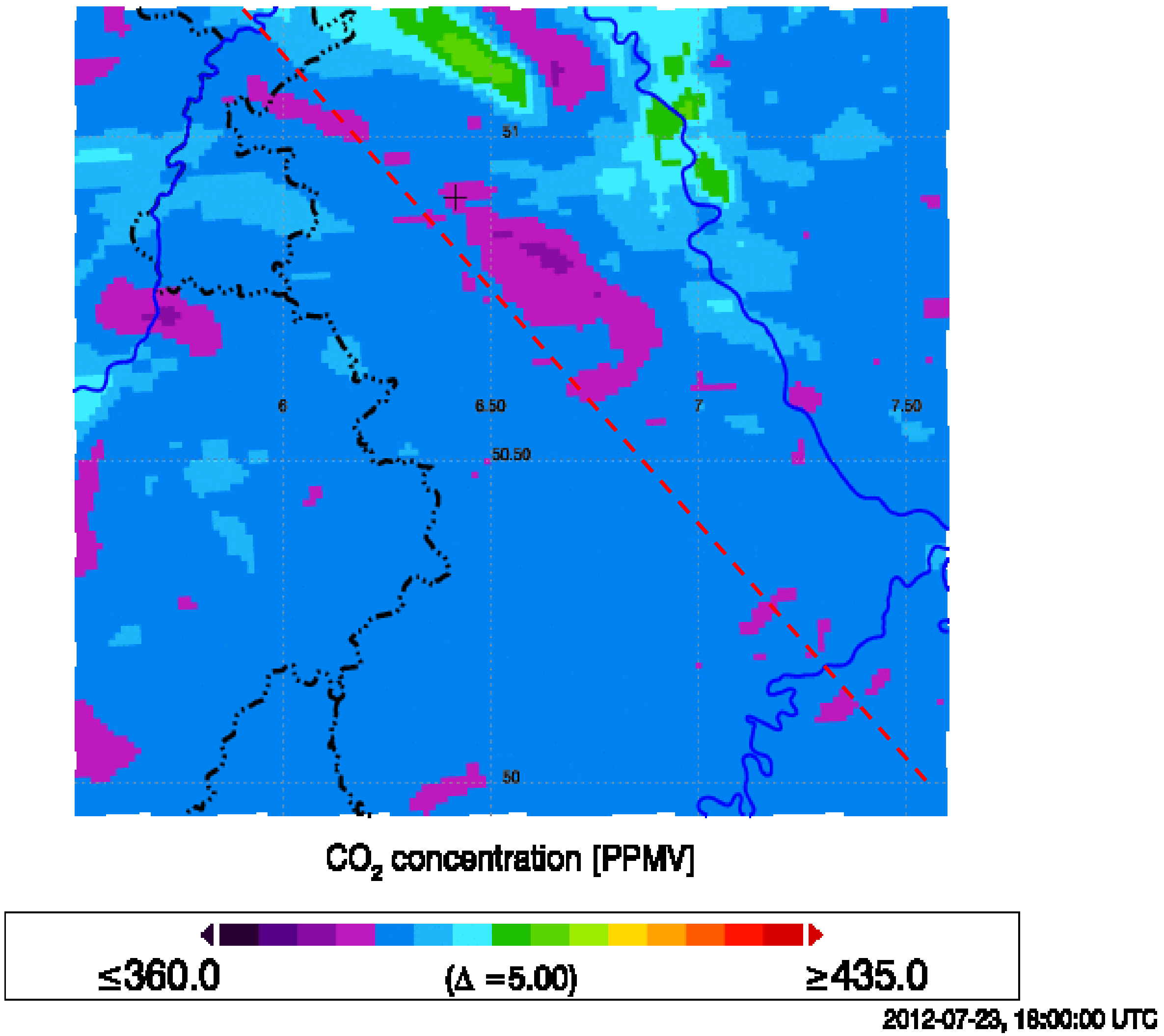




1 needleleaf trees (9.7%)
7 broadleaf trees (30.8%)
13 grassland (5.4%)
15 crops (36.6%)
16 urban (13.5%)
rest (3.9%)

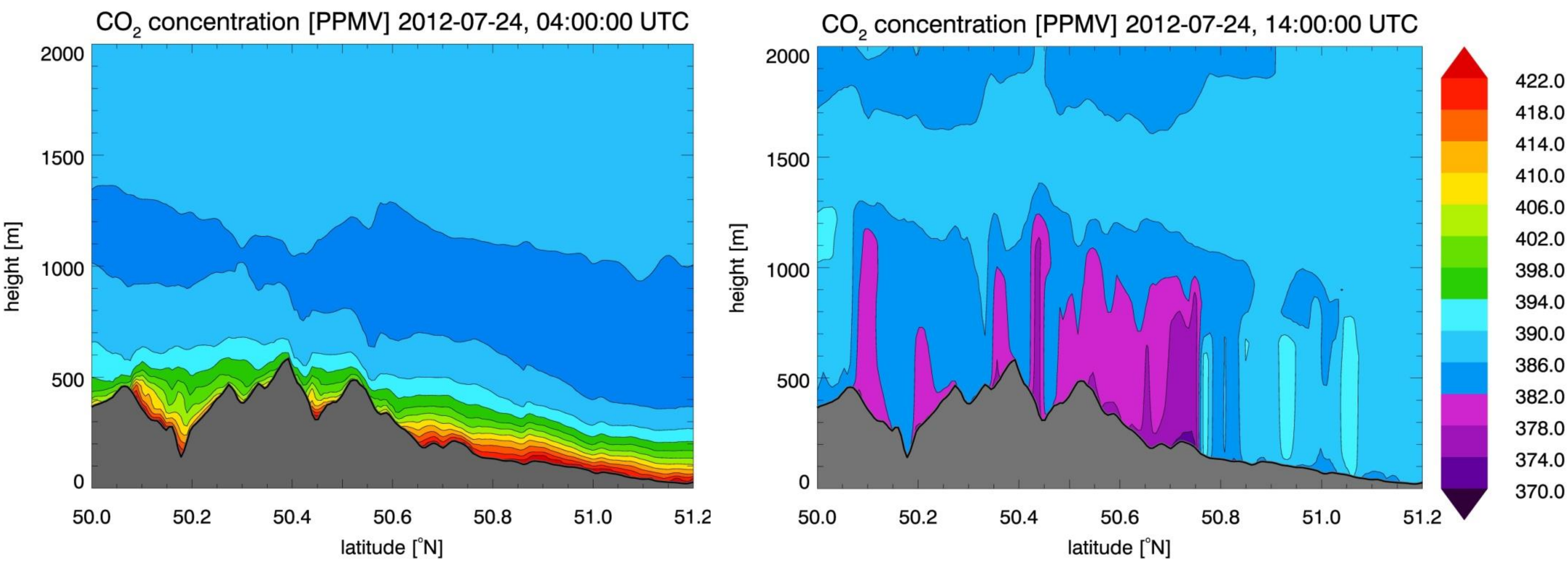
Diurnal CO_2 cycle and mesoscale heterogeneity

- **Horizontal CO_2 distribution:**



Diurnal CO_2 cycle and mesoscale heterogeneity

➢ Vertical cross section of CO_2:

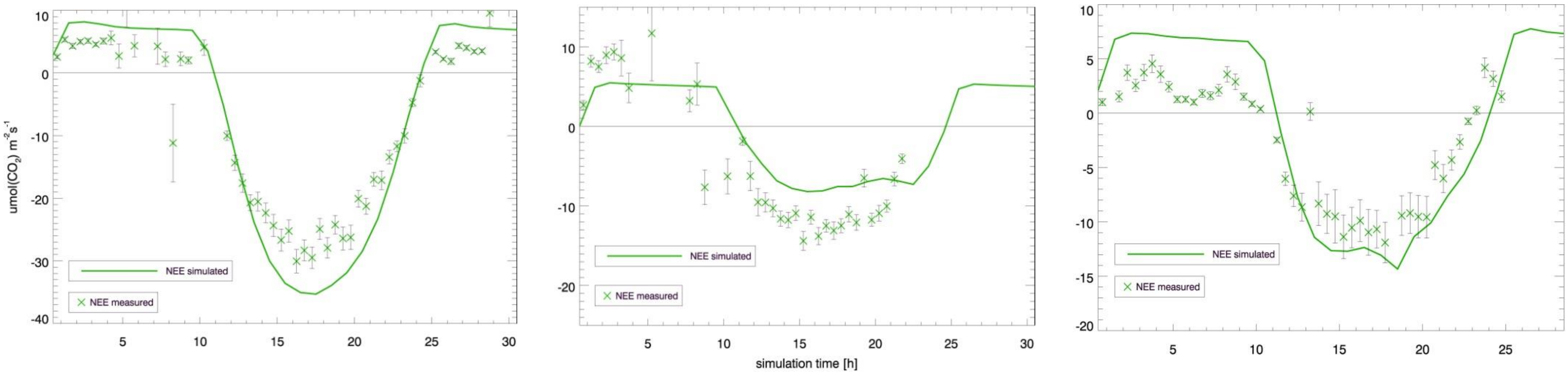


- **early morning (04 UTC):**
  - accumulation of CO_2 only near the surface during night
  - strong decrease of CO_2 in the lowest 100 m → stable stratification (clear sky)
- **afternoon (14 UTC):**
  - influence of photosynthesis in the whole atm. boundary layer → convective ABL

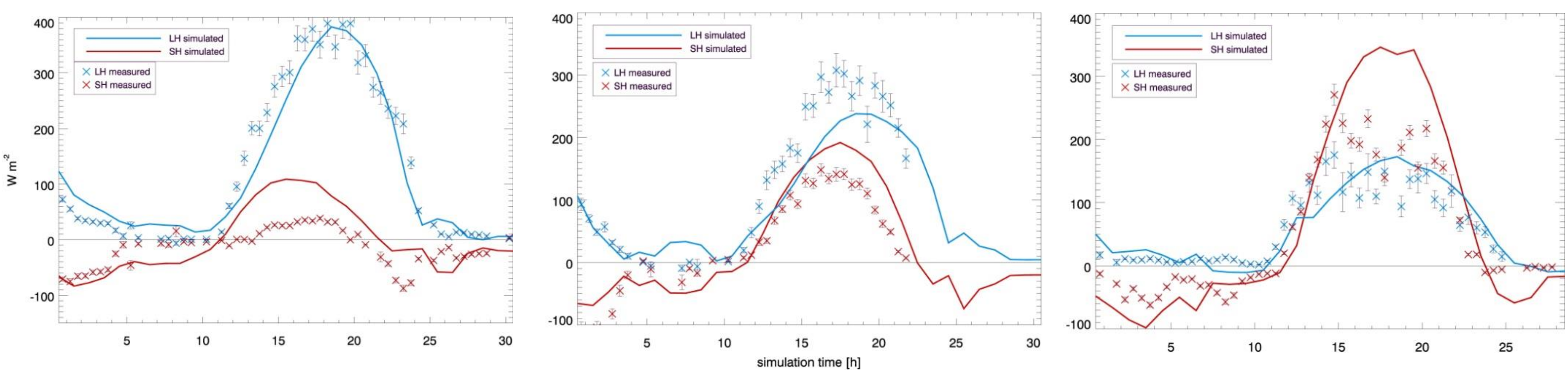
CO_2 and energy fluxes

- **net ecosystem exchange (NEE)**

winter wheat (Merzenhausen) | *grassland (Niederzier)* | *needleleaf forest (Wüstebach)*



- **latent heat flux (LH) / sensible heat flux (SH)**

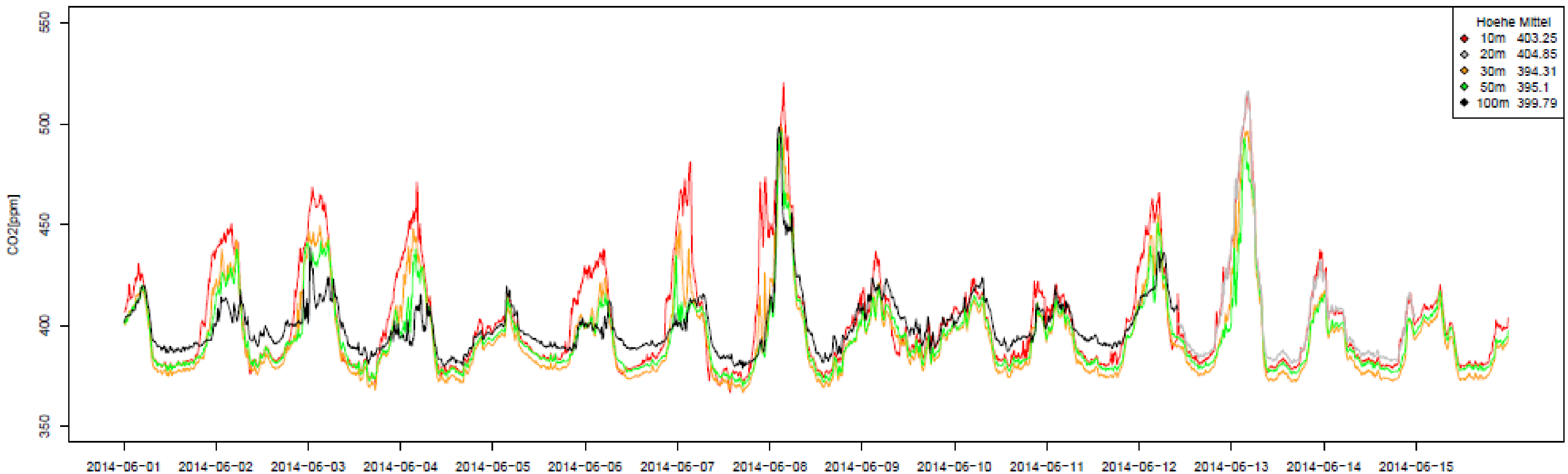


Vertical profile measurements of CO_2

measurements of **CO_2 concentrations** at a 120m tower of Research Centre Jülich GmbH in

10m, **20m**, **30m**, **50m** and **100m**

www.fz-juelich.de



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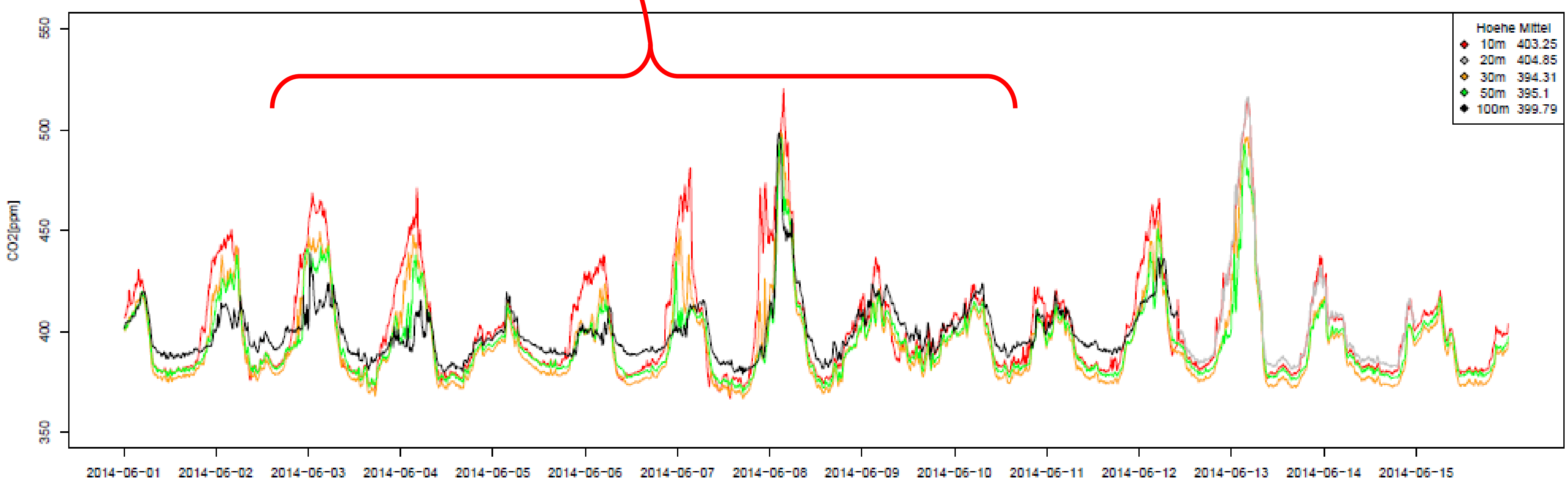
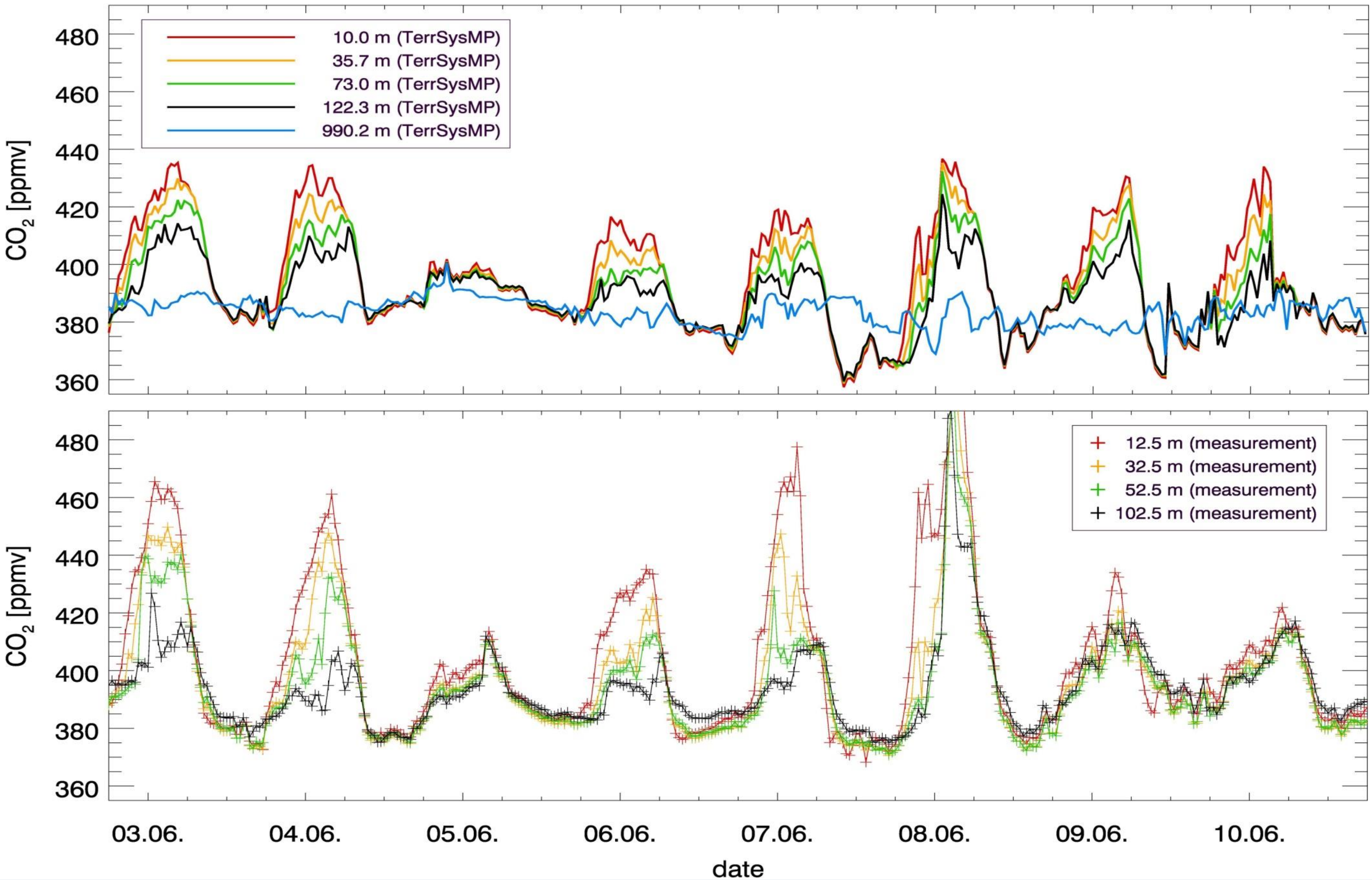
Simulation with TerrSysMP:
03. – 10. July 2014



CO_2 transport in the boundary layer



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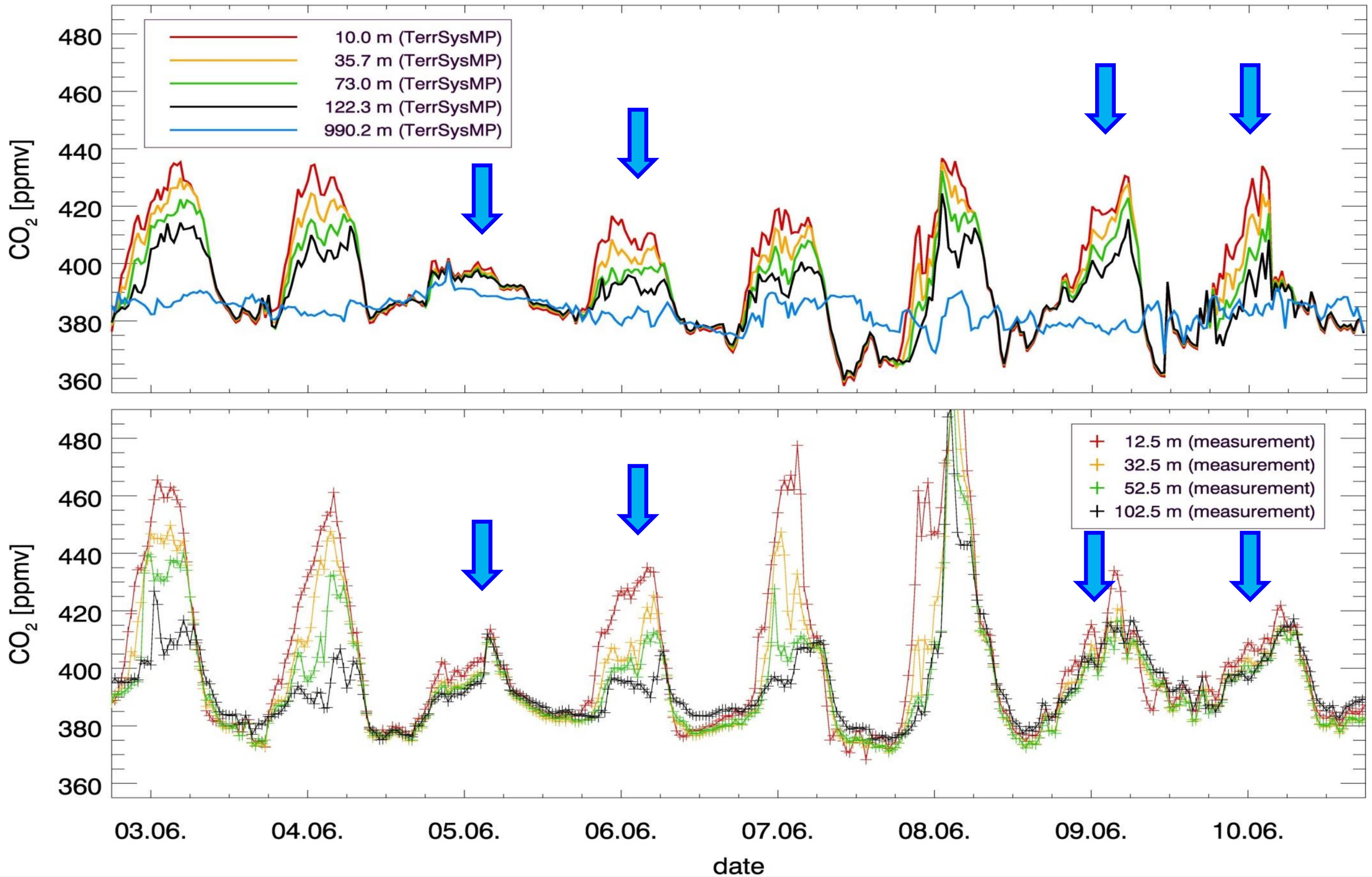

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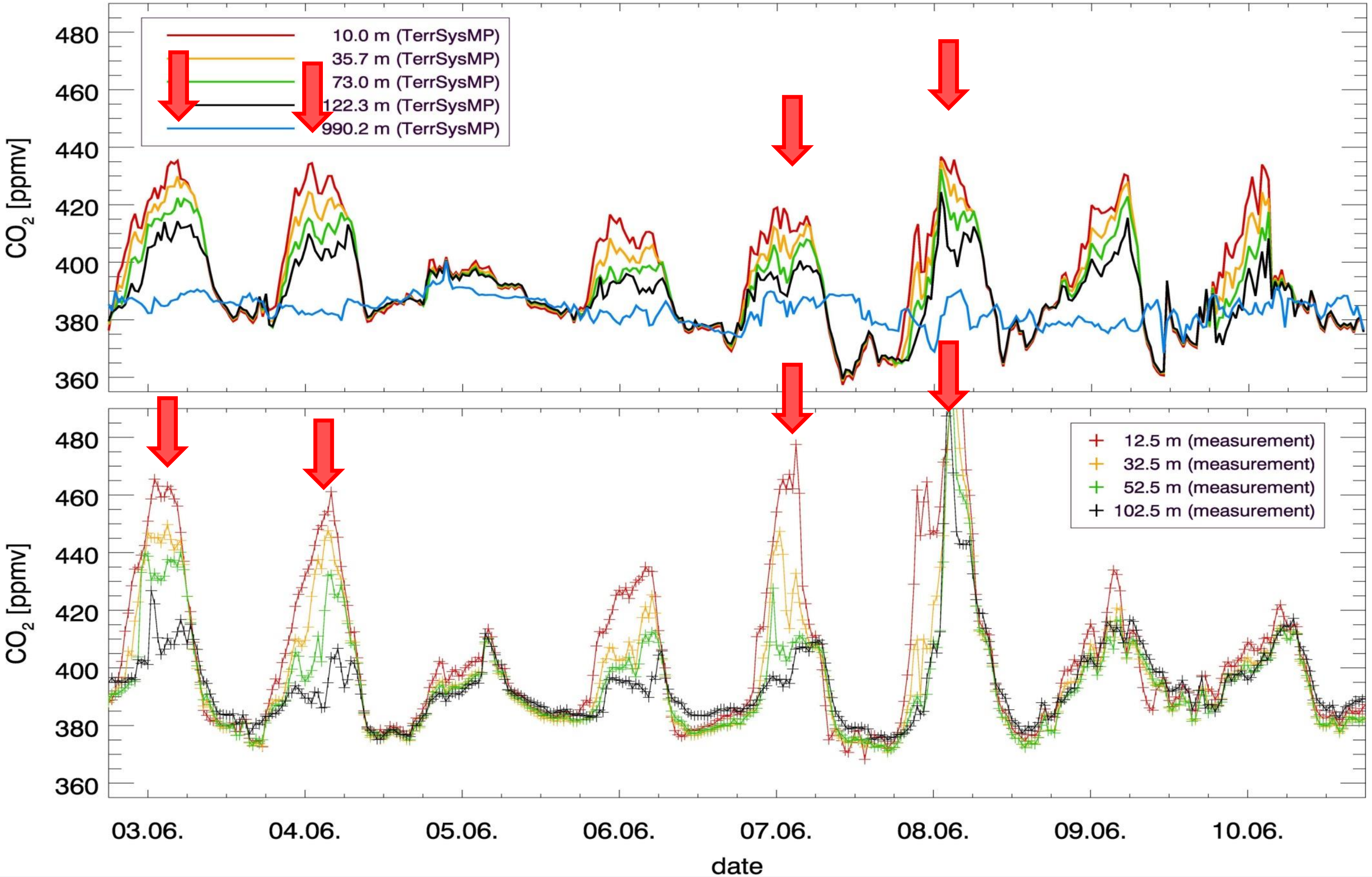
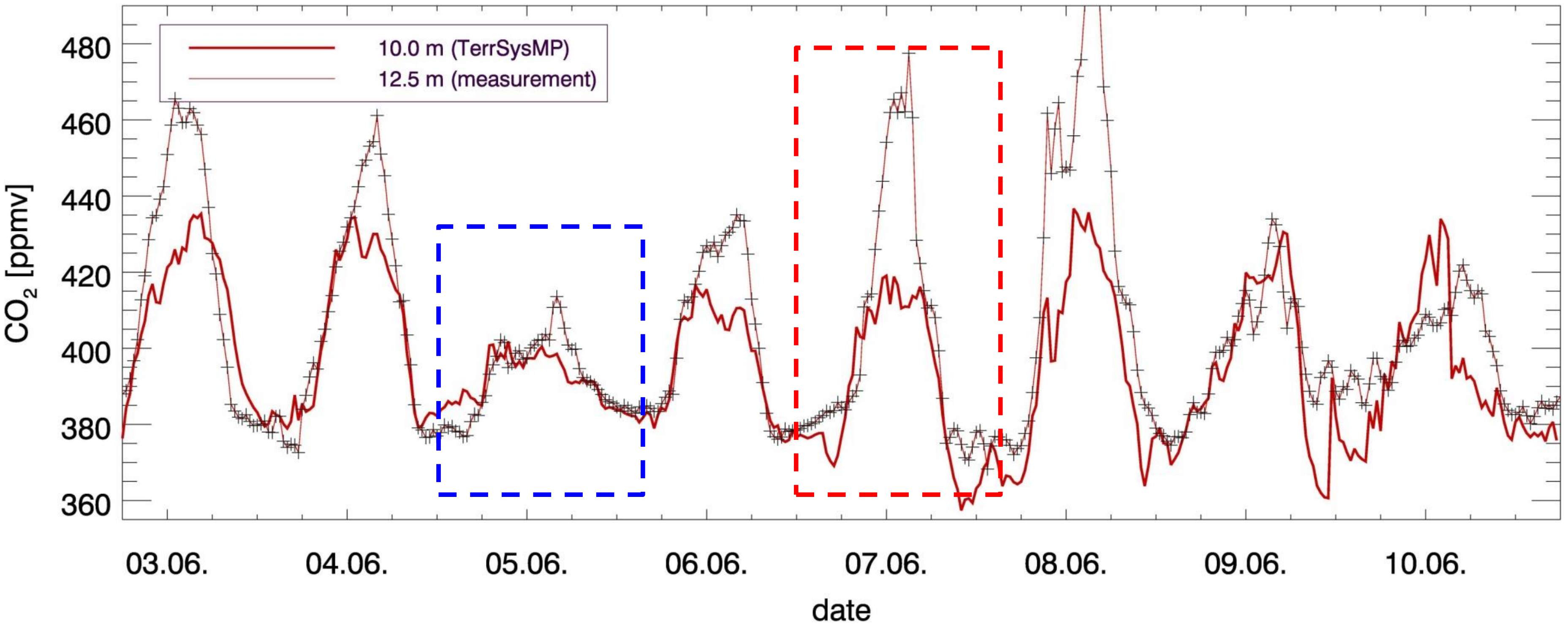


CO_2 transport in the boundary layer

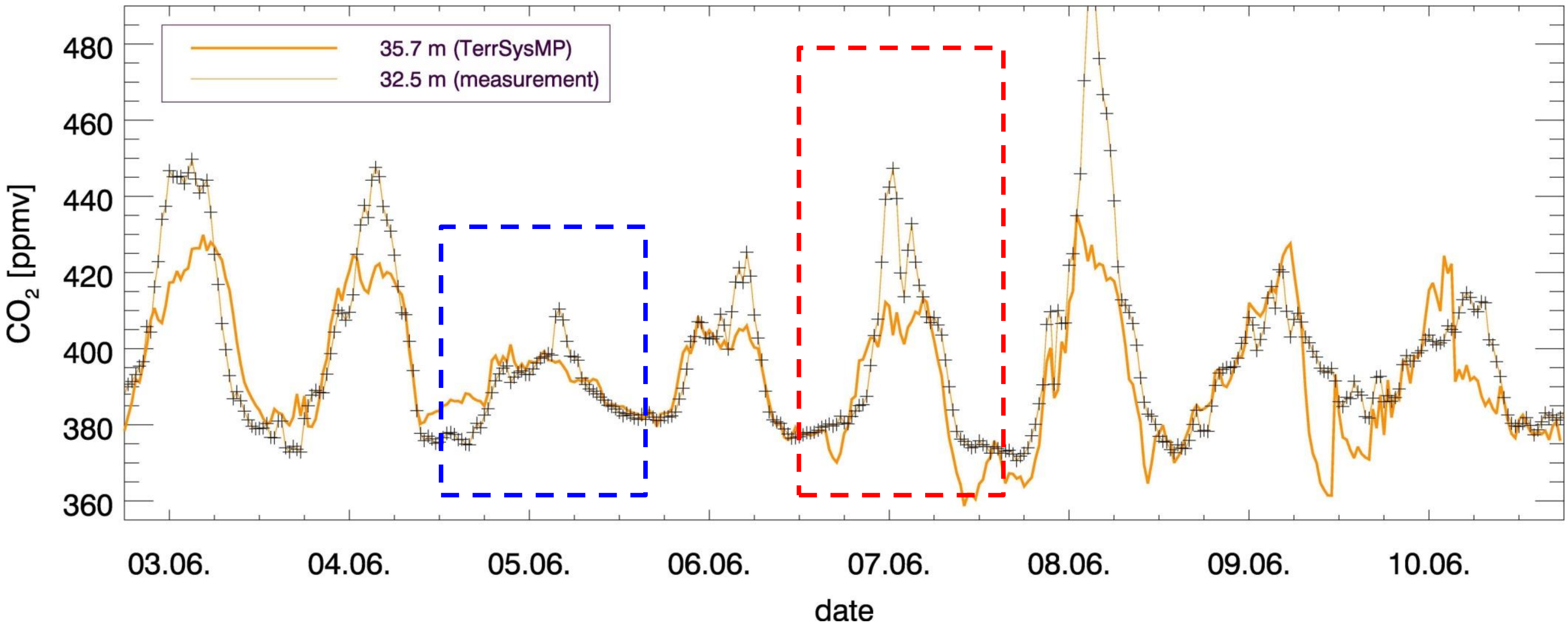
10 m above ground



- **good agreement** of diurnal CO_2 amplitude on days with cloudy nights and moderate wind
- **underestimation** of nocturnal CO_2 concentration in clear sky nights with weak wind

CO_2 transport in the boundary layer

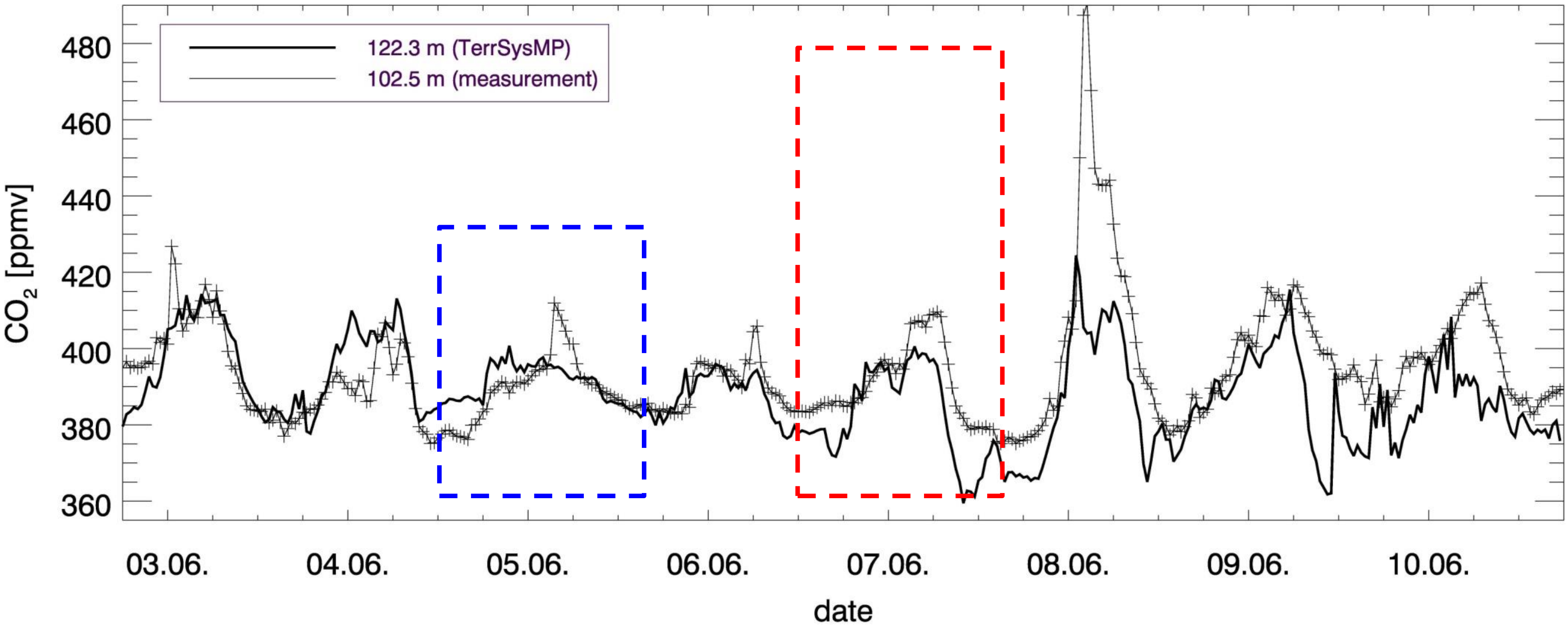
35 m above ground



- **better agreement** of nocturnal CO_2 concentration in 35 m above the ground
  → **slightly too low diurnal amplitude**

CO_2 transport in the boundary layer

≈ 100 m above ground



- **good agreement** of diurnal CO_2 amplitude independent of the weather situation

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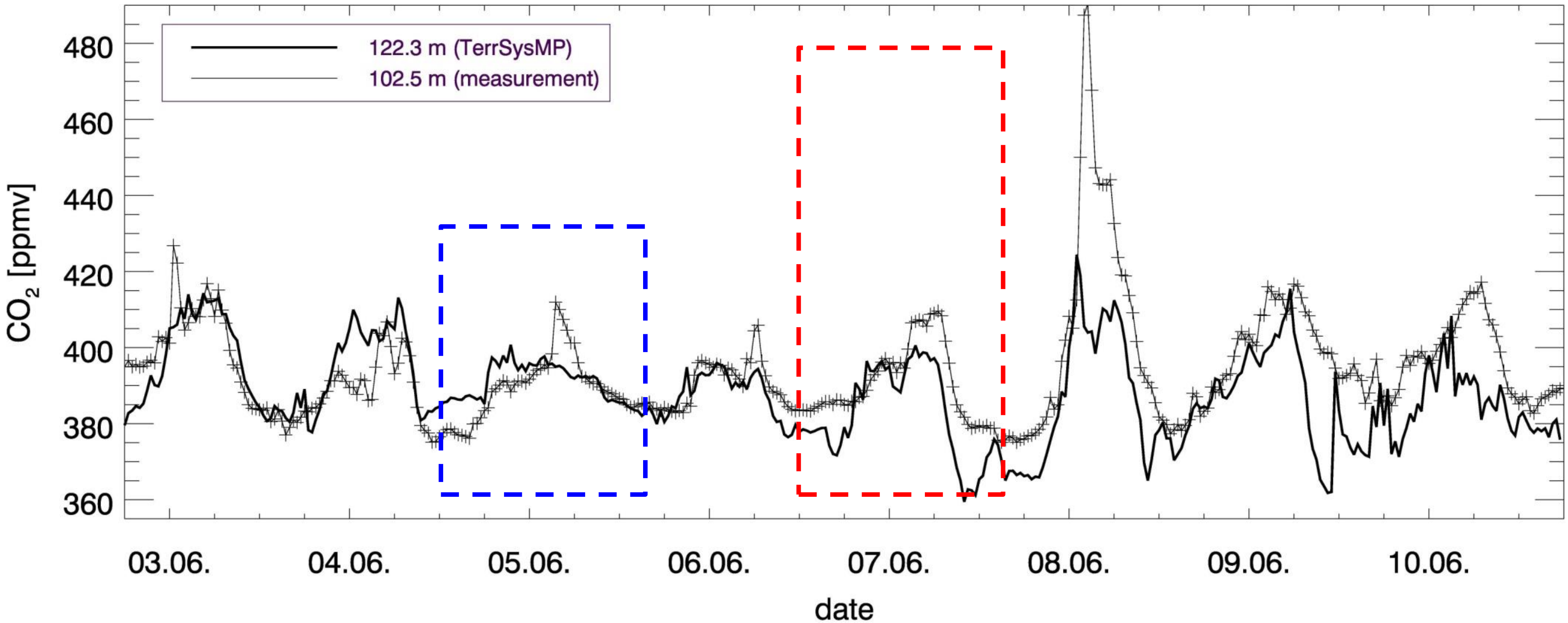
≈ 100 m above ground

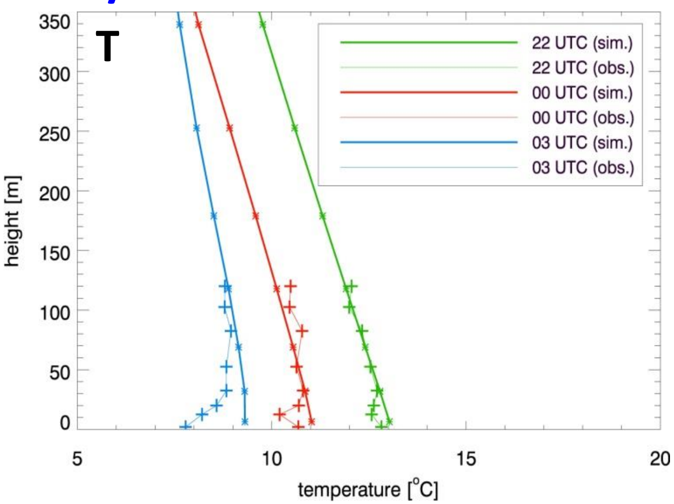


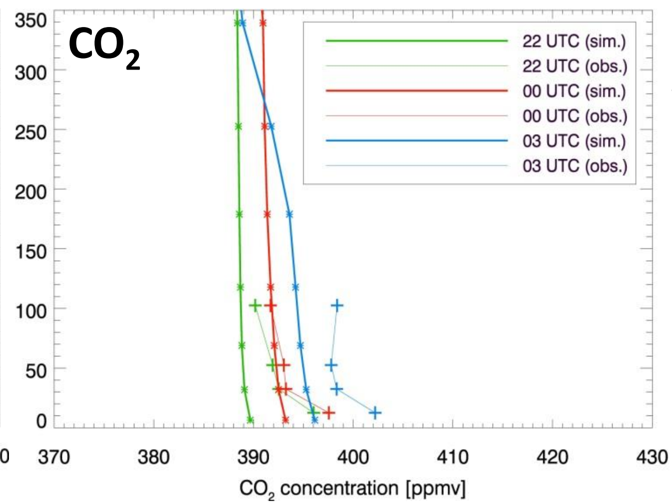
- **good agreement** of diurnal CO_2 amplitude independent of the weather situation

? What is the reason for the different behavior in different heights

CO_2 transport in the boundary layer

04/05 June 2014:

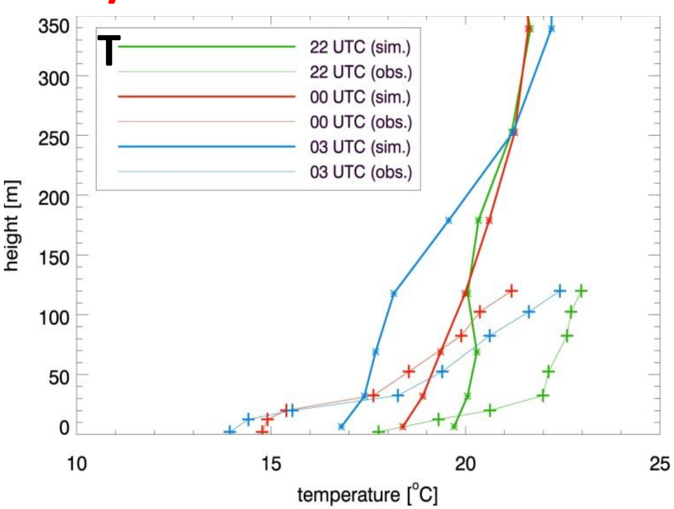


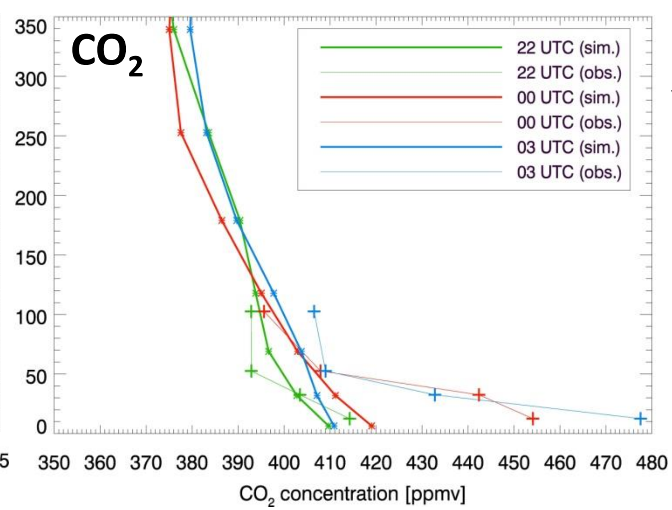


good agreement of vertical temperature gradient

➔ vertical CO_2 distribution realistically simulated with TerrSysMP

06/07 June 2014:





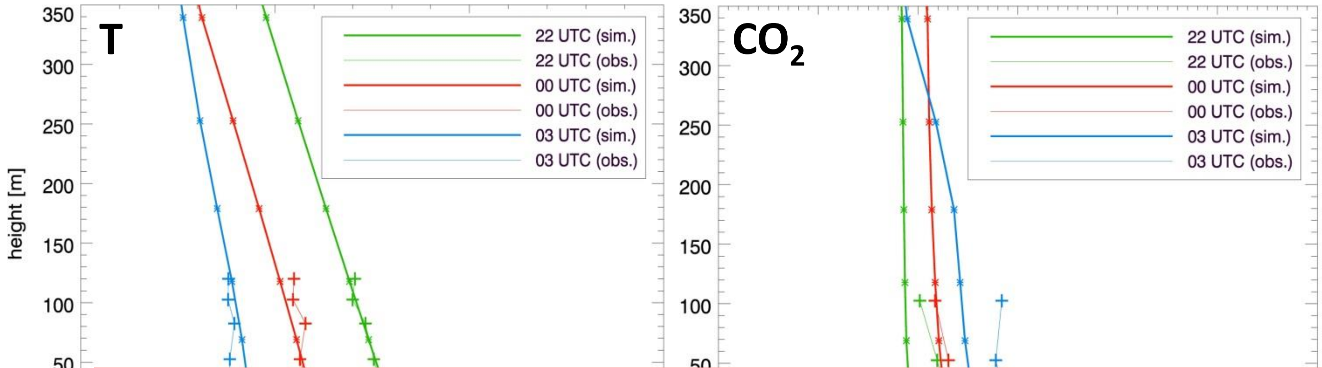
strong underestimation of vertical temperature gradient (near surface inversion) in TerrSysMP

➔ too strong turb. transport

➔ too less CO_2 accumulation near the surface

CO_2 transport in the boundary layer

04/05 June 2014:

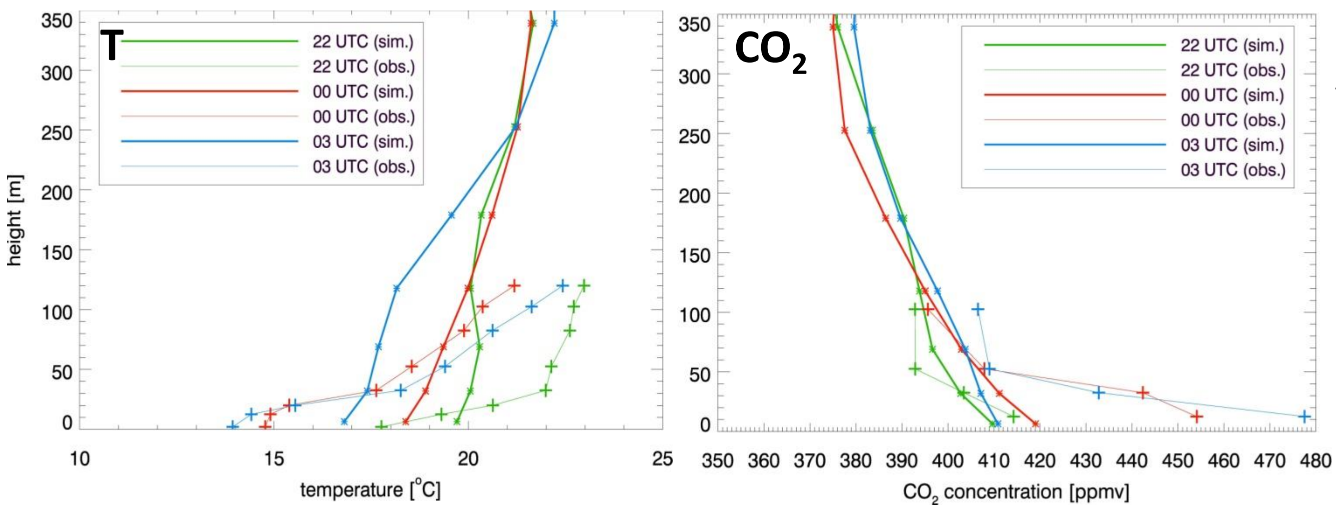


good agreement of vertical temperature gradient

➔ vertical CO_2 distribution realistically simulated with TerrSysMP

➔ Underestimation of near surface CO_2 amplitude in windless clear sky nights with strong nocturnal temperature inversion

06/07 June 2014:



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➔ too less CO_2 accumulation near the surface

Summary

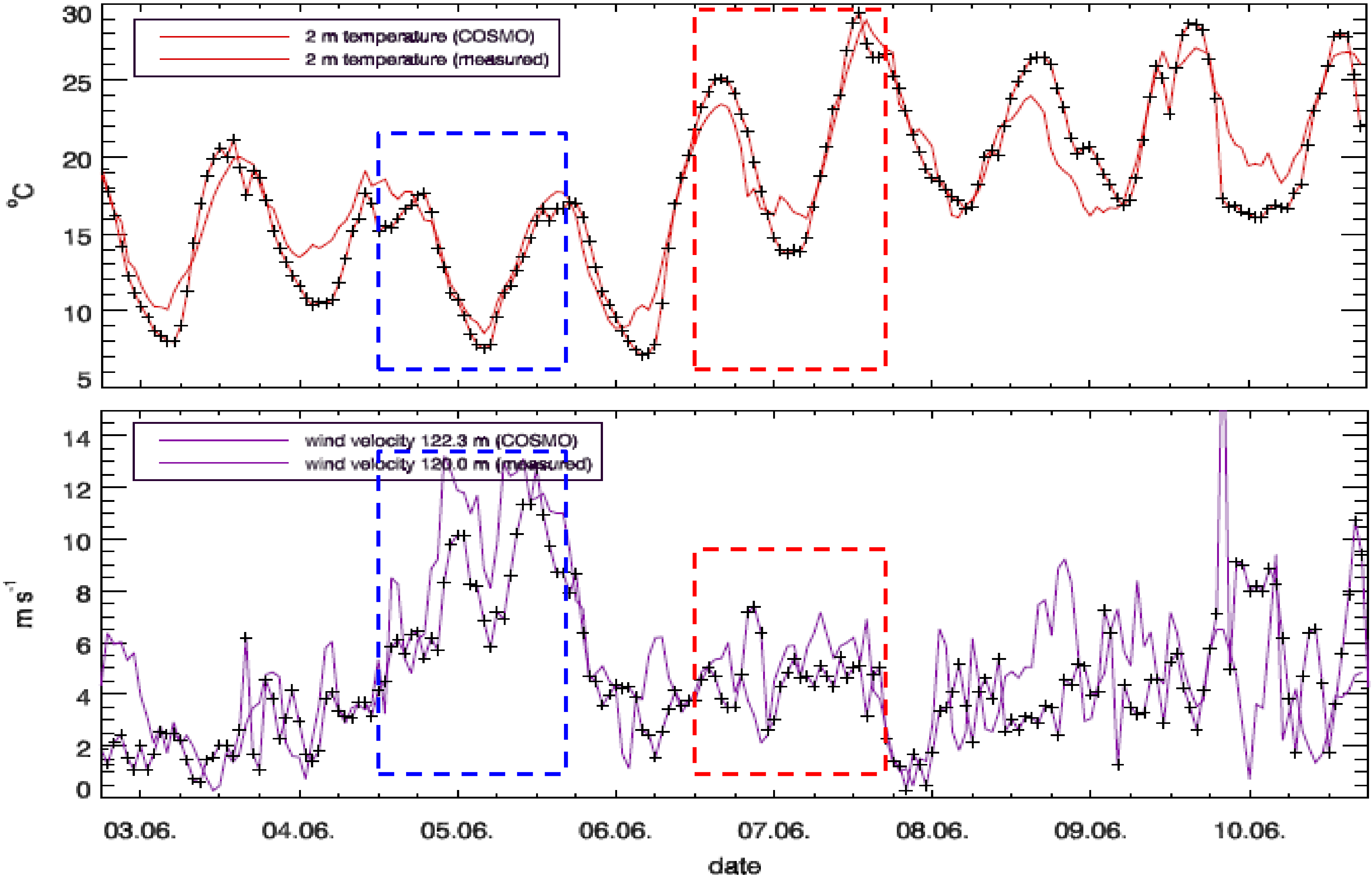
Summary

Results of the mesoscale simulations with TerrSysMP:

- CO_2 increase during night especially in flat area and in narrow valleys (mountain – valley breeze)
- CO_2 decrease during the morning and vertical influence of photosynthesis through the whole convective ABL
- **realistic simulation** of **CO_2 fluxes** and **latent/sensible heat fluxes** with CLM
- **good representation** of the vertical CO_2 distribution and the diurnal CO_2 amplitude in nights with moderate wind and **weak vertical temperature gradients**
- **underestimation** of the nocturnal CO_2 increase near the surface in **clear sky nights** → strong near surface **temperature inversion** not well captured in TerrSysMP

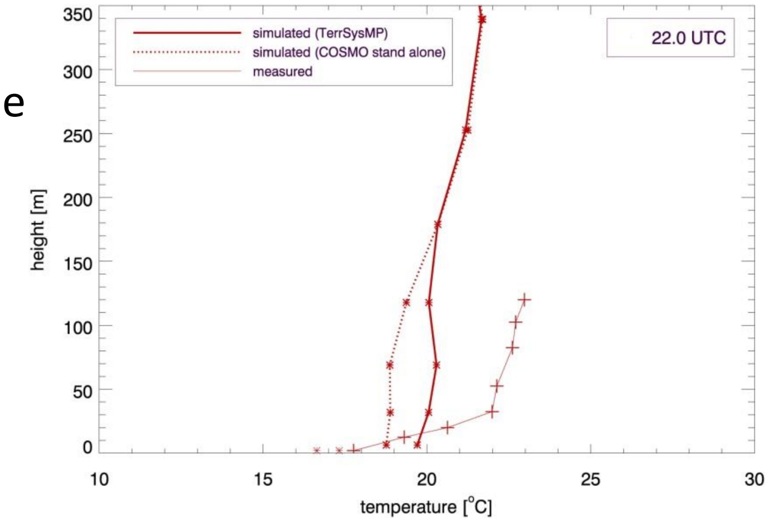
Thanks for your attention!

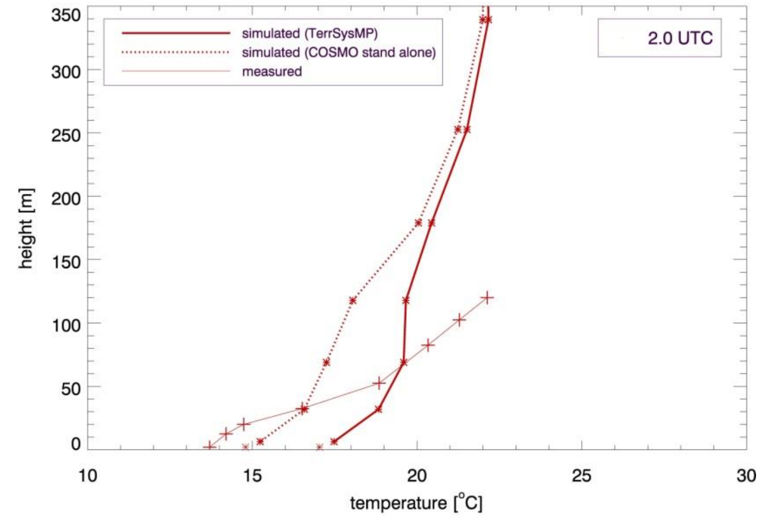
Appendix 1


30
25
20
15
10
5
°C
2 m temperature (COSMO)
2 m temperature (measured)
14
12
10
8
6
4
2
0
m s⁻¹
wind velocity 122.3 m (COSMO)
wind velocity 120.0 m (measured)
03.06.
04.06.
05.06.
06.06.
07.06.
08.06.
09.06.
10.06.
date

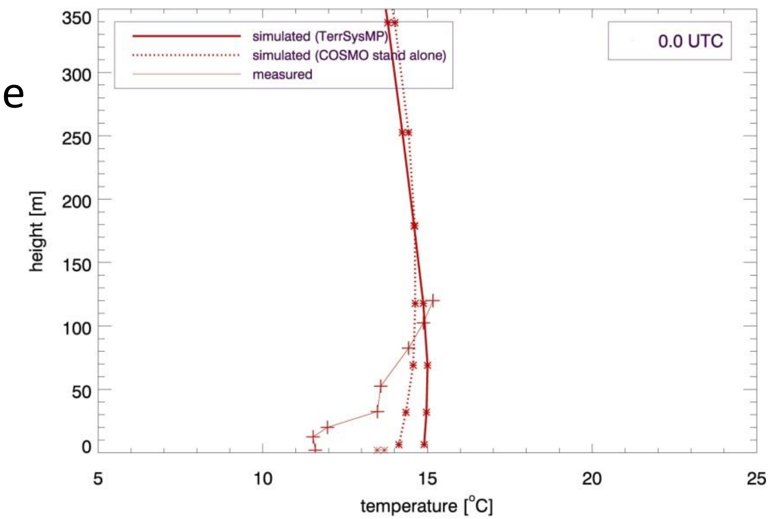
Appendix 2

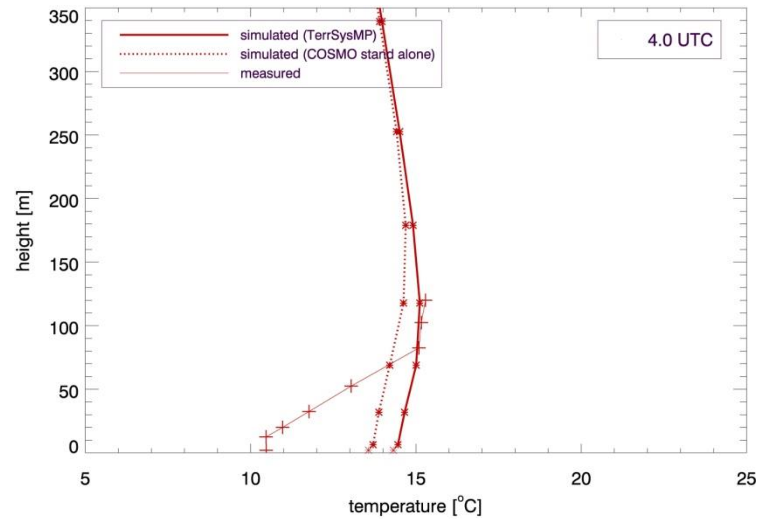
Jülich
06/07 June
2014





Jülich
03/04 June
2014

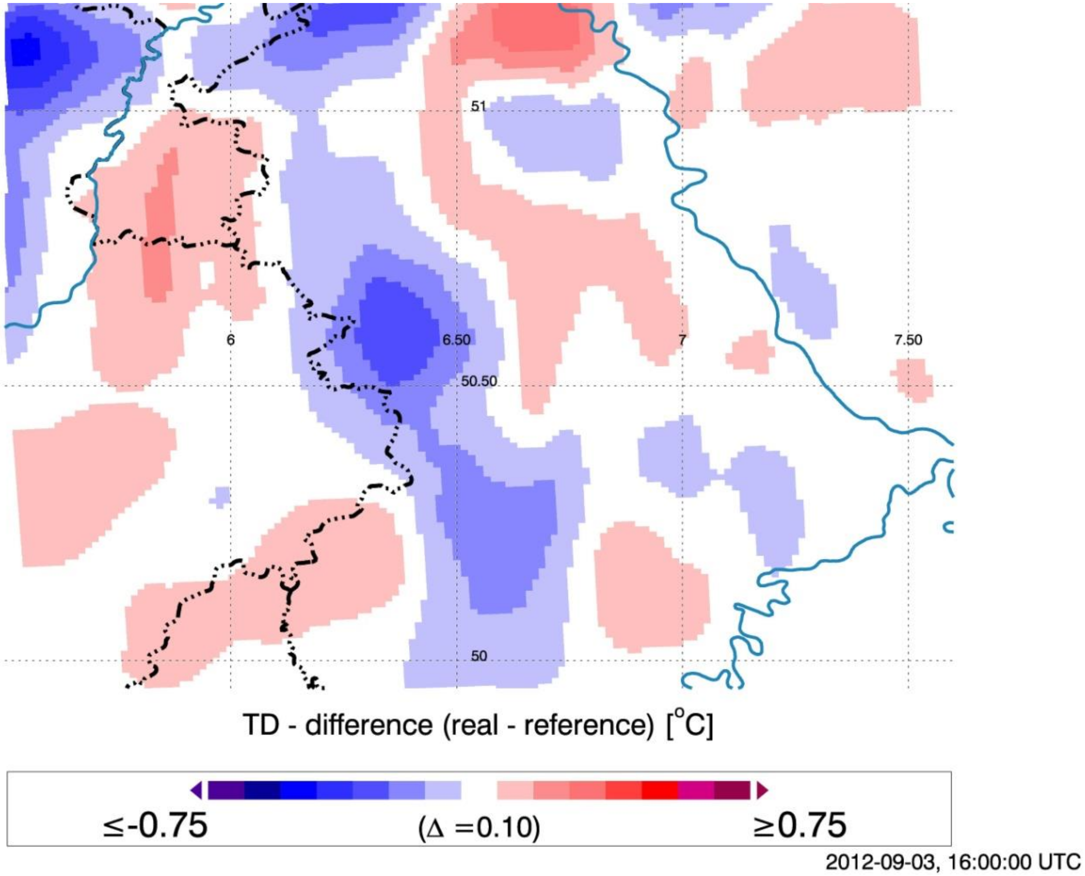




Comparison of temperature profiles with TerSysMP and COSMO (with TERRA_ML)
→ both model settings underestimate nocturnal temperature inversion

Appendix 3

Influence of CO_2 variability on atmospheric moisture



Difference of dew point in 2m between a TerrSysMP simulation with CO_2 coupling and a simulation with constant CO_2, 40 km-average (cloudy day)

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Appendix 4

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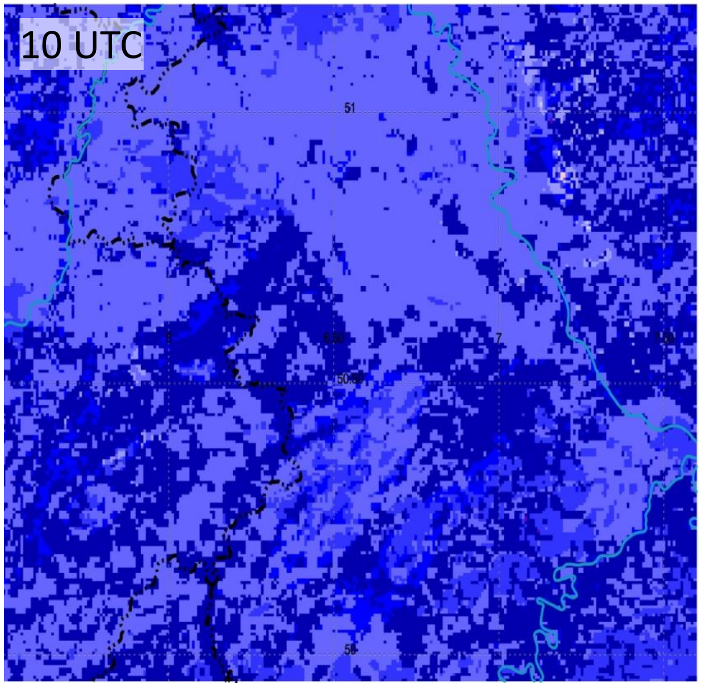
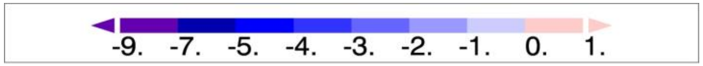
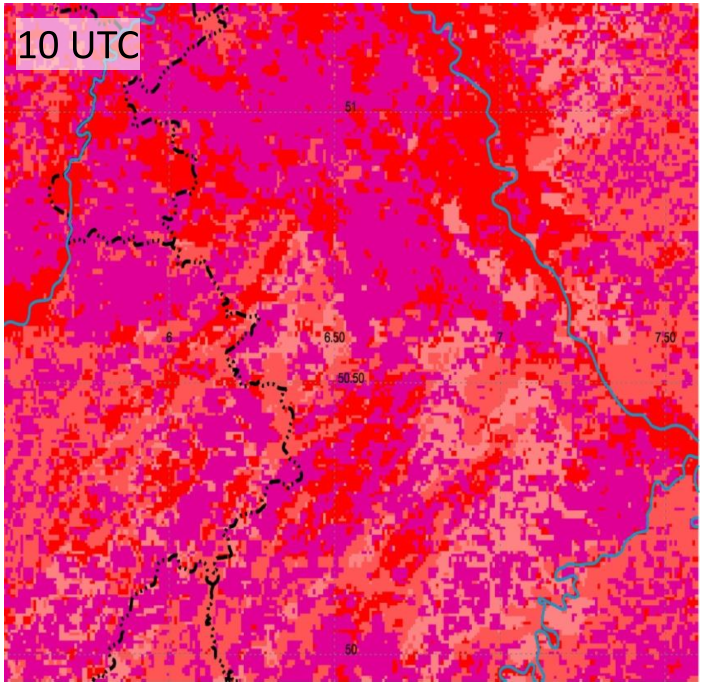
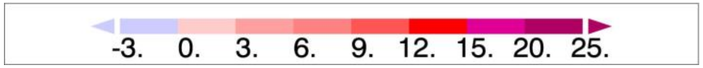


transpiration difference [%] (405 – 355 ppmv)





NEE difference [%] (405 – 355 ppmv)

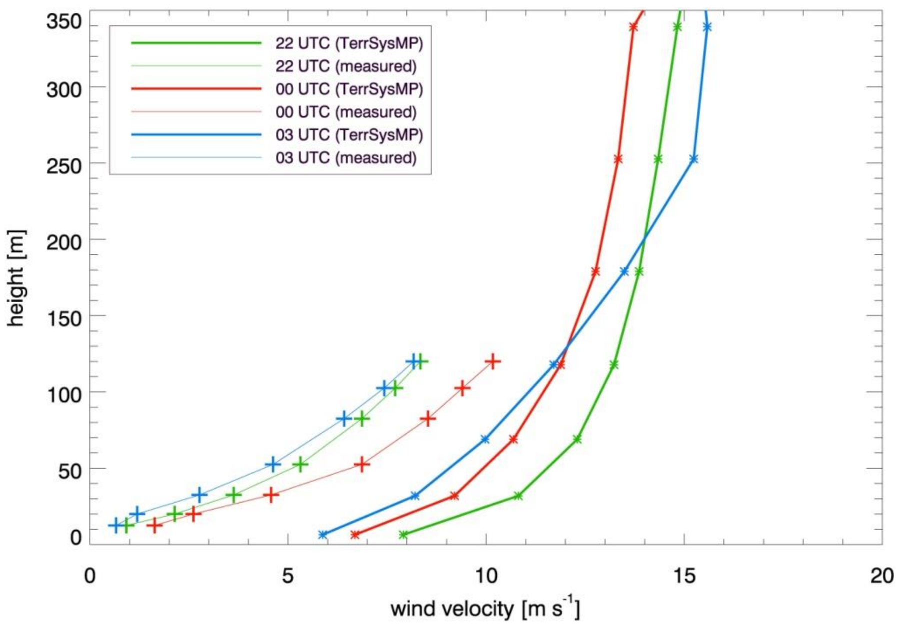


Sensitivity of NEE and transpiration [%] on a CO_2 increase of 14% (355 → 405 ppmv)

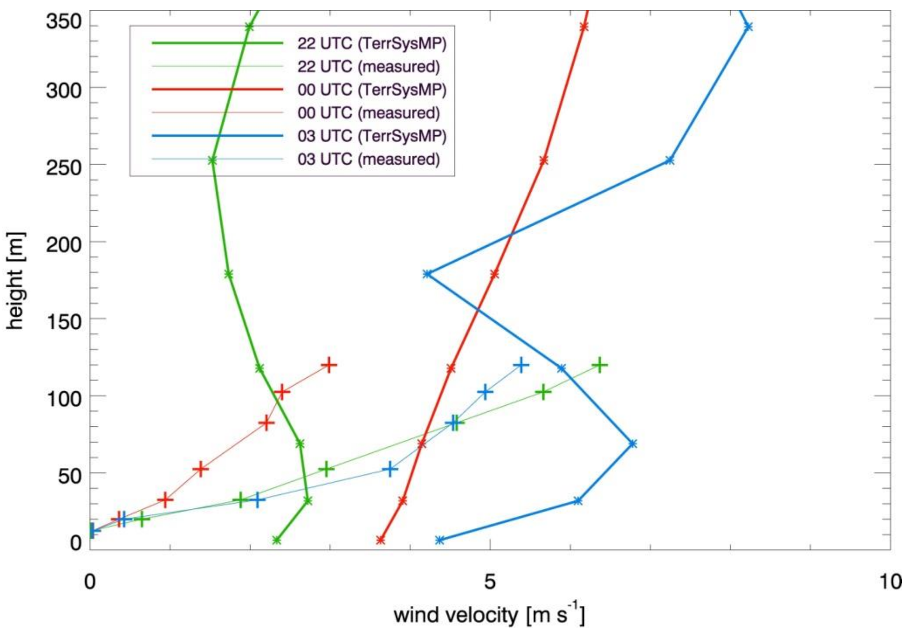
→ Comparison of simulation of 24 July 2012 (clear sky day) with constant atm. CO_2 of 355 ppm (≈ 1990) and 405 ppm (≈ 2018)

Appendix 5

04/05 June 2014:



06/07 June 2014:



Appendix 6

23 July 2012