1) Motivation

An essential part of numerical weather prediction models is the accurate simulation of the interaction of the land surface with the atmosphere. With a fully coupled model system (COSMO-CLM-PARFlow) that comprehensively calculates the exchange processes between the soil, the vegetation and the atmosphere.

Field measurements on the regional scale indicate distinct spatio-temporal heterogeneities in the distribution of atmospheric carbon dioxide (CO₂). This variability of CO₂ induces a direct response on the stomatal resistance of plants resulting in a modified transpiration that influences the near surface atmospheric moisture. Thus, for a consistent modeling of latent and sensible heat fluxes the net CO₂ flux between the land surface and the atmosphere will be included in our coupled model system. This flux consists of the photosynthesis rate A as an atmospheric sink as well as plant and soil respiration, \( R_{\text{P}} \) and \( R_{\text{soil}} \) as sources for the atmospheric CO₂ concentration (see Fig. 1). Now, the atmospheric CO₂ is no longer a constant value but a prognostic variable used for calculating canopy processes.

2) Coupling of CO₂

The atmospheric CO₂ distribution is initialized in the atmospheric model COSMO and sent to the external coupler OASIS which organizes the downscaling to the finer grid resolution of the Community Land Model (CLM) and unit conversions of all variables and fluxes that are exchanged between the models. The CLM receives the CO₂ partial pressure as forcing and uses this for the calculation of the CO₂ fluxes (see Fig. 1). The determined net CO₂ flux is sent to the COSMO model as CO₂ source to be upscaled to the atmospheric grid. The atmospheric CO₂ content is updated by this net CO₂ flux and the COSMO model performs the atmospheric transport. This coupling cycle is repeated every coupling time step. The coupling frequency can also be varied with the OASIS coupler.

3) Model simulations

The selected day (8th of May 2008) was dominated by fair weather conditions with unattenuated solar radiation over the western part of Germany. All model simulations with the coupled model system COSMO – CLM were initialized with 390 ppmv of CO₂ in all atmospheric model layers:

- **Reference run**: no coupling of CO₂ fluxes (standard model coupling)
- **Turbulence run**: coupling of photosynthesis rate \( A \) and turbulent vertical mixing of CO₂ in the COSMO model (no advection)

Real run: coupling of photosynthesis rate \( A \), influence of all transport processes on CO₂

4) Atmospheric CO₂ transport

The atmospheric CO₂ of our coupled model system is the non-hydrostatic, incompressible local weather prediction model COSMO provided by the German Meteorological Service (DWD). With this model we perform mesoscale weather forecasts with a grid resolution of 0.5 km. For the atmospheric transport of the specific CO₂ content \( q_{\text{CO2}} \) a 

### Budget equation

\[
\frac{\partial (q_{\text{CO2}})}{\partial t} + v \cdot \nabla (q_{\text{CO2}}) = \text{SCO}_2 + \text{MCO}_2
\]

After the coupling with the CLM the tracer becomes active (influence on other variables).

### Spatial patterns

The spatial patterns in Fig. 3a) are mainly the result of different photosynthesis rates depending on the plant type whereas in b) also advection transport occurs. The red regions in a) are urban areas or bare soil without photosynthesis so that the initial concentration remains.

5) Canopy processes

The photosynthesis rate \( A \) as well as the plant transpiration \( T \) is controlled by the stomatal resistance \( e_s \) which describes the permeability of the stomata of leaves:

\[
\frac{1}{e_s} = \frac{A}{e_s} \frac{c}{e_s} = \frac{P_{\text{atm}} + b}{c}
\]

The water vapor saturation pressure inside the leaf \( b \) and stomatal conductance

**Standard model coupling**:

- atmospheric pressure \( P_{\text{atm}} \)
- water vapor pressure at leaf surface \( e_s \)
- CO₂ partial pressure at leaf surface \( e_c \)

**Coupling of CO₂ fluxes**:

- atmospheric pressure \( P_{\text{atm}} \)
- water vapor pressure at leaf surface \( e_s \)
- CO₂ partial pressure at leaf surface \( e_c \)

6) Summary and outlook

The simulations show that the coupling of the photosynthesis rate \( A \) with the COSMO model results in a reduction of the near surface atmospheric CO₂ content and in a diurnal vertical variation of the CO₂ distribution due to vertical turbulence and advection with the wind field. This decrease of atmospheric CO₂ leads to a reduced photosynthesis rate and as a direct consequence to an increase of plant transpiration compared with the reference run (Fig. 7 and 8). Plants react on the modified availability of CO₂ with opening their stomata to take up more CO₂ for producing photosynthesis.

In our future research the plant respiration as well as the soil respiration will be included in our model system to calculate the accurate net CO₂ flux which will be exchanged between the CLM and the COSMO model. We will perform sensitivity studies both for idealized cases and for different real weather conditions. Different atmospheric CO₂ distributions will be used in order to assess the response of the stomatal resistance and the moisture and heat fluxes on these variations. Modifications in the atmospheric moisture distribution and their possible impact on the simulation results will be analyzed. Further, we will validate our model results with field and remote sensing measurements performed by other working groups of the TR32 project.

References:


Shrestha P. et al. (2012). "Development of a Scale-Consistent Soil-Vegetation-Airmospheric Modeling System Using COSMO, Community Land Model and ParFlow". (to be submitted)