High Resolution Simulations of the Terrestrial Carbon Flux Using the Community Land Model (CLM) Coupled to COSMO

Empa Materials Science and Technology

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Introduction

The largest uncertainty in our current understanding of the **global carbon cycle** lies within the role of the terrestrial biosphere. Uptake and release of carbon dioxide (CO_2) from and to the atmosphere by photosynthesis and respiration, respectively, are sensitive to a large number of environmental and physiological factors. **Terrestrial biogeochemistry models** (TBMs) that simulate the aforementioned processes in detail are utilised in global to regional scale climate models, but their resolution often remains too coarse to be evaluated against atmospheric observations, within regional-scale atmospheric flux inversions and in heterogeneous environments such as encountered in most of western and central Europe.

Within the **CarboCount-CH** project we derived a new, high resolution (**kilometre scale**) dataset of external parameters for the use with NCAR's **Community Land Model** version 4 ([1], **CLM4.0**) and evaluated CLM's performance in terms of biosphere-atmosphere exchange of CO_2 when coupled to **COSMO**.

External Parameter Set

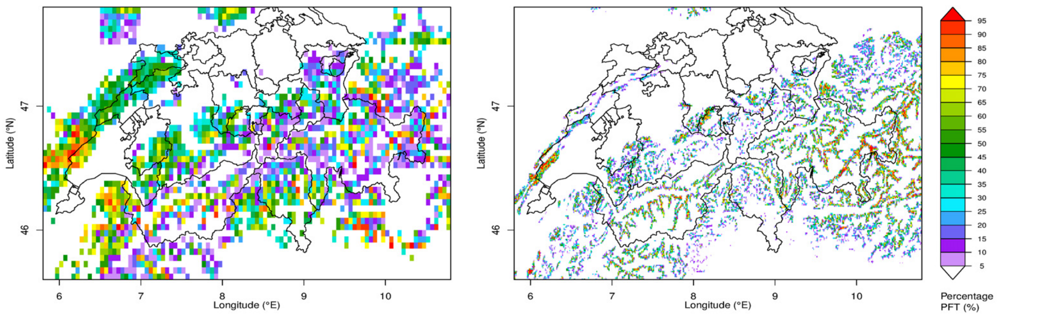


Fig 1: Fraction of CLM plant functional type 'boreal evergreen forest' in Switzerland for (left) standard NCAR and (right) newly derived CarboCount CH external parameter set

The newly derived external parameter dataset comprises per-gridcell percentages of CLM **land units** (vegetated, urban, lake, glacier, wetland) and **plant functional types** (16 vegetation classes), **soil texture** and **organic carbon content**, **maximal fractional saturated area** and monthly vegetation parameters (**leaf and stem area index, vegetation height**) at a spatial resolution of **0.01° by 0.01°** for the larger Alpine area.

The dataset was compiled from various high-resolution data sources, such as

- CORINE 2006 land cover
- ASTER digital elevation model
- MODIS leaf area index (MOD15A3)
- Homogenised World Soil Database (HWSD)
- SRTM/SWBD coastlines and waterbodies

Spin-Up

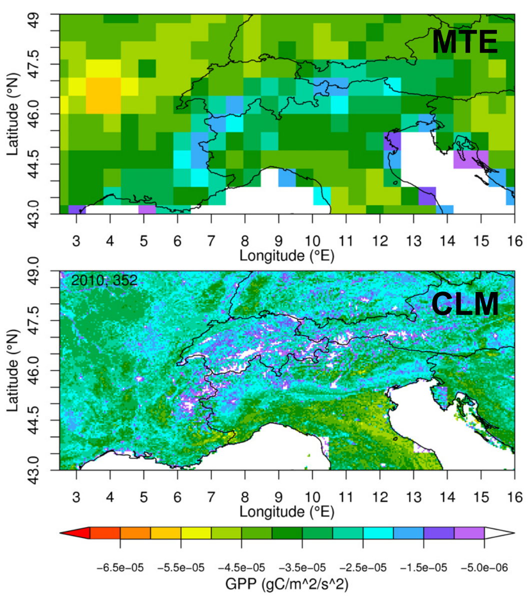
In CLM4.0 terrestrial carbon and nitrogen interactions are considered by activating the carbon and nitrogen module (C/N). The carbon and nitrogen pools in soils and vegetation require a spin-up run to reach equilibrium. Two different strategies were followed:

- Coldstart with empty pools and accelerated decomposition (AD) for 600 year, followed by an additional 60 year spin-up without AD
- Interpolated from a previous run with COSMO-CLM2 ([2], CLM-CORDEX in the following) at 0.5° horizontal resolution followed by a 300 year spin-up without AD

Both spin-ups were driven offline by a 32-year climatology of CLM-CORDEX and run at a horizontal resolution of **0.04° by 0.04°**. Here, we only present results form the interpolated set-up. The following parts of CO_2 exchange in CLM were evaluated

- **Gross primary production (GPP, photosynthetic uptake, negative sign)**
- **Ecosystem respiration (RESP, positive sign)**
- **Net ecosystem exchange (NEE = RESP + GPP, negative for uptake)**

Domain total GPP, NEE, and RESP were only changing slowly during spin-up and were generally in line with the coarse CLM-CORDEX run. Compared to the observation based MTE GPP [3] estimate both CLM configurations showed significantly lower CO_2 uptake during summer (Fig. 2).



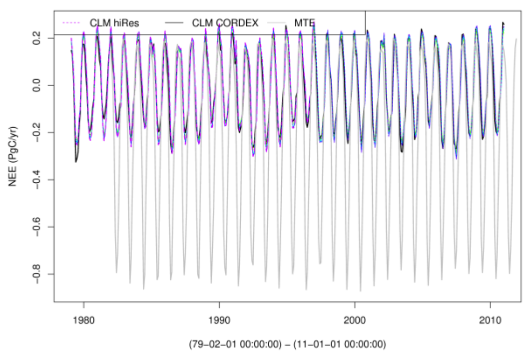


Fig 2: (left) monthly mean time series of NEE during spin-up (CLM-CORDEX: black, CLM: various colors for different iterations, MTE: gray). (right) spatial distribution of annual mean (2010) GPP (MTE: top, CLM: bottom).

Evaluation

After spin-up CLM was run for the period 2010 – 2015 offline coupled to hourly COSMO analysis by MeteoSwiss. Hourly output of CO_2 fluxes was created and evaluated against the satellite-based VPRM flux dataset [3].

The spatial distribution of summer time (July 2013) CO_2 fluxes (Fig. 3) reveals both similarities and discrepancies between CLM and VPRM. In general GPP was almost a factor of 2 smaller in CLM, resulting in relatively small CO_2 uptake (NEE). Some geographical features were similar (e.g., increased GPP in forested areas like Apennine, south-eastern Alps, Black Forest, Vogeses), whereas others largely differed (e.g., inhomogeneous respiration in CLM).

Domain total fluxes strongly differed between CLM and VRPM (Fig. 4), mostly driven by a factor of 2 smaller GPP in CLM during summer, resulting in a factor 3 smaller NEE in summer. Over the year this translates into a net domain-wide uptake of only 27 TgC/yr in CLM as compared to 197 TgC/yr in VPRM. Potential reasons for lower GPP in CLM could be neglected fertilisation of crops and neglected forest harvest/regrowth .

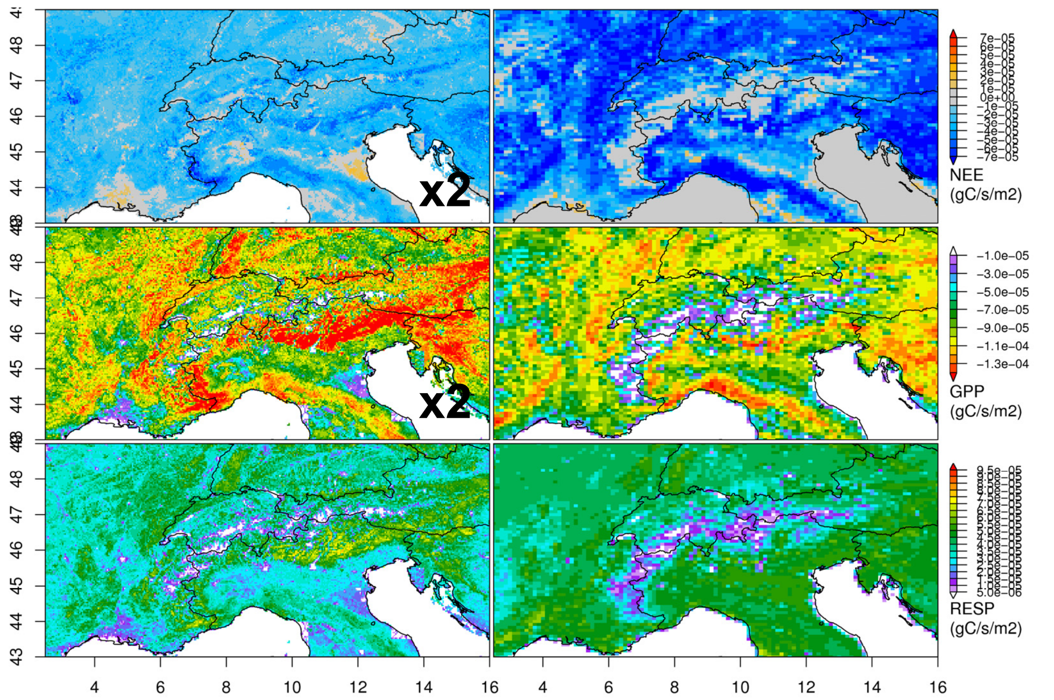


Fig 3: Monthly mean spatial distribution of (top) NEE, (middle) GPP and (bottom) RESP for (left) CLM and (right) VPRM for July 2013. Note that NEE and GPP were multiplied by a factor of 2 for CLM to emphasize similarities in spatial structures!

To further evaluate the obtained CO_2 fluxes we combined them with the transport model **FLEXPART-COSMO** (again coupled to COSMO analysis from MeteoSwiss) and simulated resulting excursions in **atmospheric mole fractions of CO_2** at the CarboCount CH measurement sites (Fig. 4). The biospheric fraction of the observed CO_2 signal was extracted by removing baseline mole fractions and fossil fuel contributions and can be compared to simulated NEE.

VPRM NEE overestimated CO_2 uptake during the vegetation period (more negative than observations), whereas CLM generally underestimated NEE. The split in GPP and RESP again suggests that this is mainly due to smaller GPP in CLM .

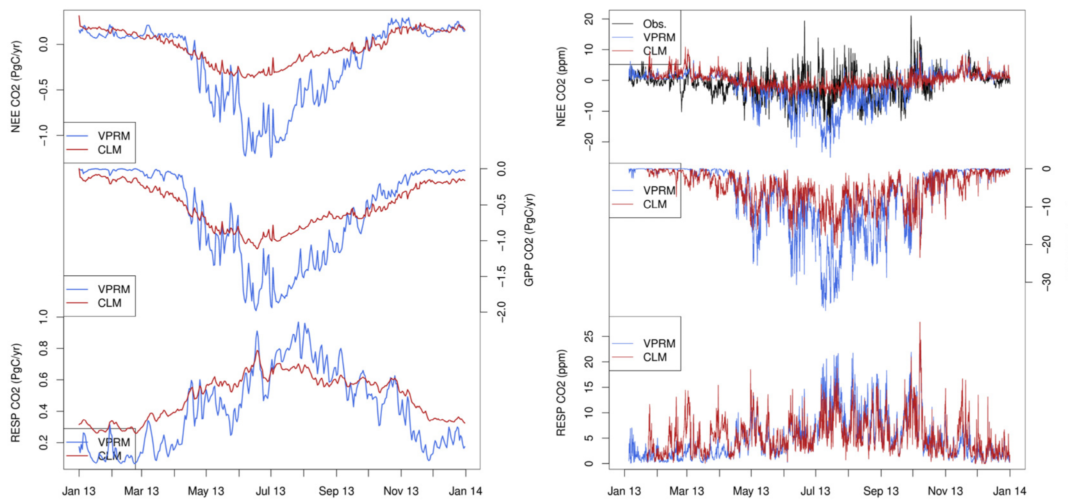


Fig 4: Time series of (top) NEE, (middle) GPP and (bottom) RESP for (left) domain total flux (daily mean) and (right) atmospheric CO_2 signal (3-hourly) at Beromünster tall tower (Switzerland) and the year 2013. CLM: red, VPRM: blue, observation based: black.

Conclusions & Outlook

- High-resolution external parameters for the use with the Community Land Model (4.0)
- Simulation with interactive carbon/nitrogen cycles requires long spin-up of pools
- Domain total GPP, RESP and NEE similar to coarse resolution COSMO-CLM^2 run
- Comparison with observation-based spatial flux datasets (MTE, VPRM) suggest underestimation of summer photosynthetic CO_2 uptake in CLM
- Transport simulations and comparison with atmospheric CO_2 observations suggest a similar tendency

- Outlook: High resolution COSMO-CLM^2 run and use of CLM4.5 crop module

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