CARBON DIOXIDE EXCHANGE IN COMPLEX TOPOGRAPHY

An idealized modelling study

Matthias Reif[1], Mathias W. Rotach[1], Georg Wohlfahrt[2] and Alexander Gohm[1]
University of Innsbruck, Institute of Meteorology and Geophysics[1] and Institute of Ecology[2]

IMGI
Institut für Meteorologie und Geophysik · Universität Innsbruck
Innrain 52, A-6020 Innsbruck, Austria

Phone: +43 - (0)512 - 507 5466
Email: `matthias.reif@uibk.ac.at`

Abstract

On a global scale the budget of carbon dioxide (CO_2) bears a quite substantial uncertainty, which is commonly understood to be mainly due to land-surface exchange processes. In this project we investigate to what extent complex topography can amplify these land-surface exchange processes. The hypothesis is that, on the meso-scale, topography adds additional atmospheric mechanisms that drive the exchange of CO_2 at the surface. Simulations with the atmospheric numerical model Weather Research and Forecasting (WRF) coupled to the community land model (CLM) are conducted to study the effect of complex topography on the CO_2 budget compared to flat terrain. The magnitude of differences in CO_2 exchange ranges between ±2 ppm per day. The sign of the valley effect and the magnitude are strongly dependent on the CLM plant functional type, the initial temperature, the initial relative humidity and the latitude, but are independent from local circulations.

Motivation

- The global **carbon cycle** cannot be closed yet, **there is a residual terrestrial sink**
- **Hypothesis:** mesoscale circulations due to topography influence biogenic CO_2 exchange [Rotach et al., 2014]
- **Problem:** global climate models use resolutions in the order of 100 km which, with certainty, cannot resolve the actual carbon dioxide exchange at the surface (purple vs. blue arrow in Fig. 1). **A subgridscale CO_2 parameterization is mandatory**
- **Goal:** to quantify the range of topographic influencing factors (temperature, humidity, ambient CO_2, plant type ...) on the surface CO_2 exchange

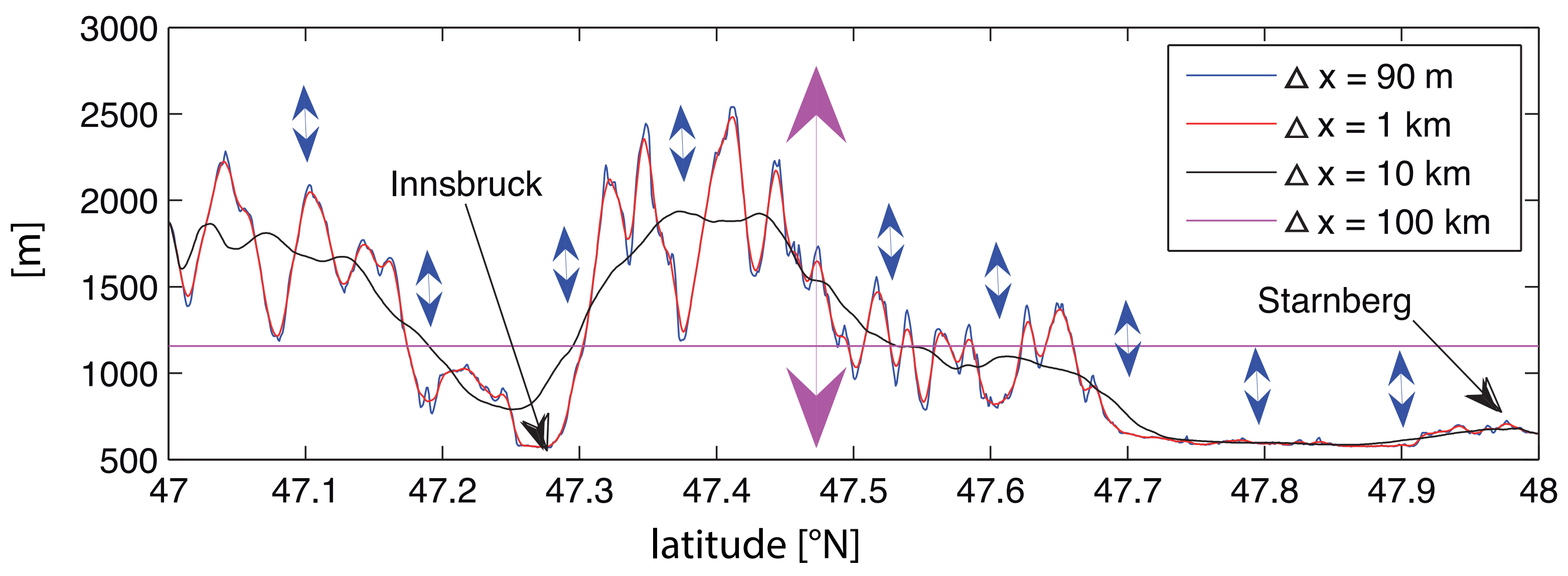

Figure 1: Topography of the Alps in a South North cross section over 1° (≈111 km) through Innsbruck and Starnberg at 90 m resolution (blue), smoothed with a moving average over 1 km (red) and 10 km (black) and the mean over all values (purple). Arrows indicate possible differences of CO_2 exchange in the high (blue) and coarse (purple) resolution.

Methods

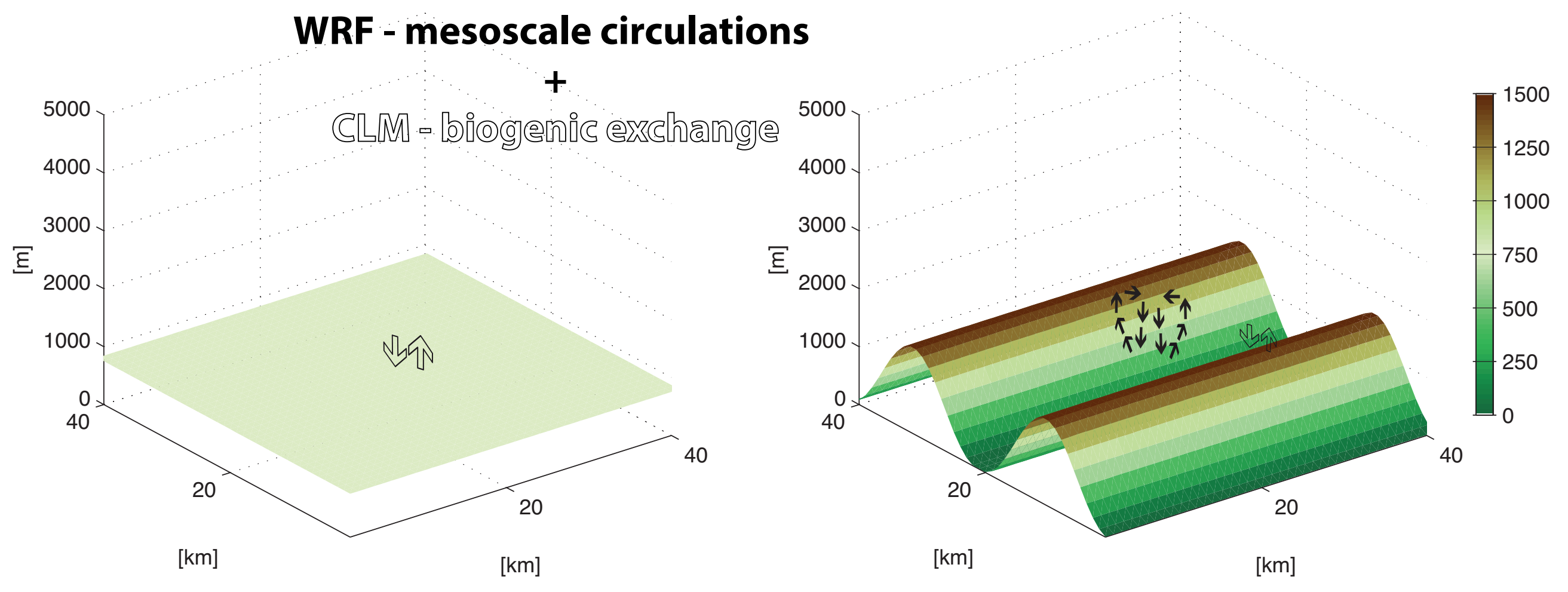

Figure 2: Idealized model topography. Solid arrows indicate afternoon mesoscale circulations from WRF and contoured arrows the biogenic exchange from CLM.

- Coupling of the the Weather Research and Forecasting Model **WRF-Chem** [Grell et al., 2005] and the Community Land Model (**CLM**, [Oleson et al., 2010])
- CLM **photosynthesis** reacts interactively on ambient WRF-Chem CO_2 concentration,
  additional plant and soil **respiration** is implemented [Migliavacca et al., 2011] as CLM respiration is for long term simulations only

WRF Setup:

- 40×40 km domain at $\Delta x = 1$ km using 57 vertical levels with Δz = 25-320 m
- 18 h spin up using a two layer stability initial sounding with an isothermal layer until 3500m agl. with N=0.018 ($\frac{d\theta}{dz}$ $0.01\frac{K}{m}$) with 1 ms^{-1} south wind and stable layer with N=0.01 ($\frac{d\theta}{dz}$ $0.003\frac{K}{m}$) with 3 ms^{-1} above
- varying initial conditions have 280, 285, 290 and 300 K potential temperature for the isothermal layer and 30 - 80% relative humidity at 30, 45, 60 and 75°N latitude
- plant functional types (PFT) are: evergreen needleleaf temperate (ENT), deciduous broadleaf temperate (DBT), shrubland (SHRUB) and C_3 and C_4 grassland (GRA C3 and GRA C4).

Results

The **Valley CO_2 Effect** is defined as the difference between the change of CO_2 concentration in the valley compared to the plain.

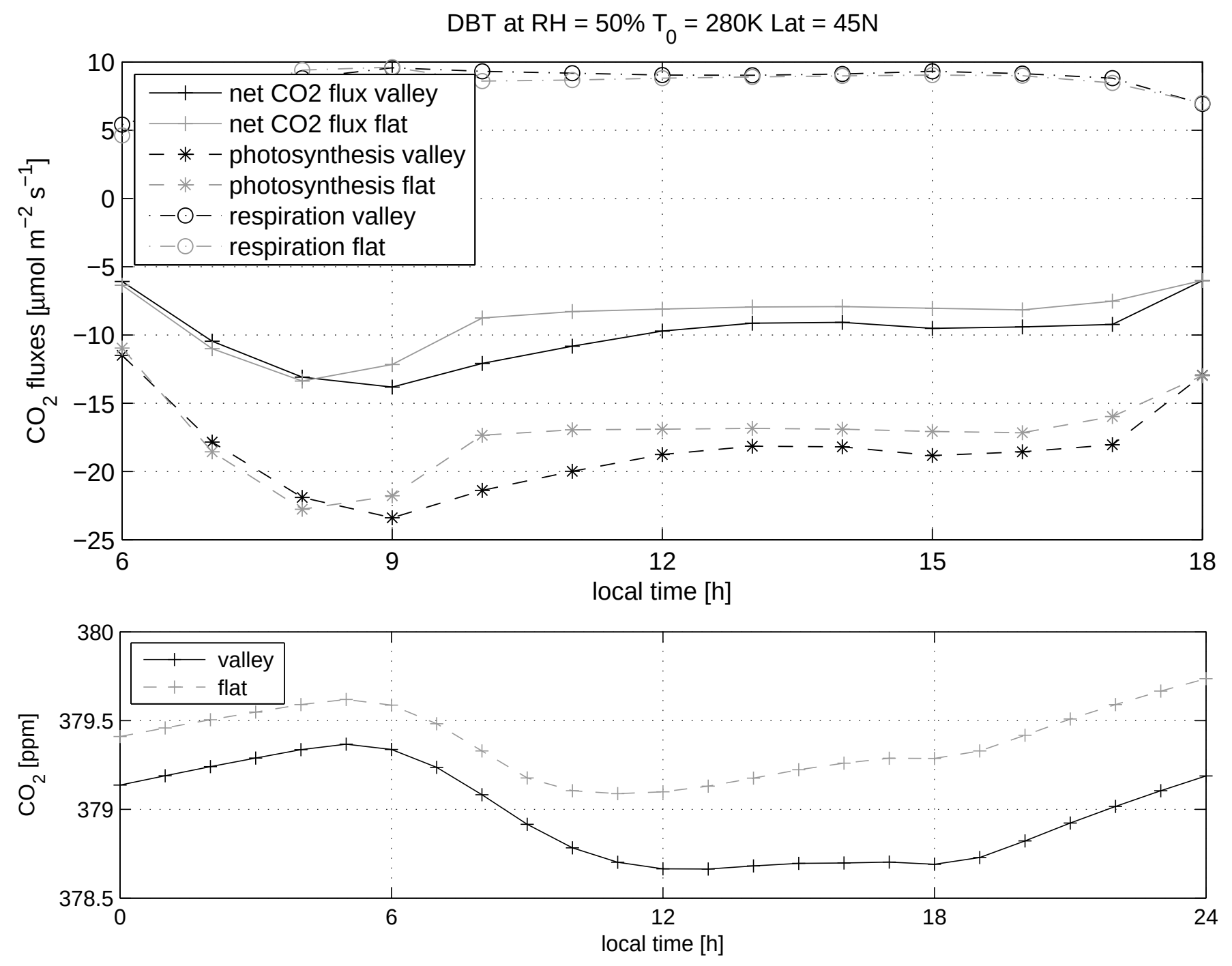

Figure 3: Deciduous broadleaf temperate (DBT) vegetation at 50% initial relative humidity, 280K initial temperature and 45°N latitude.
Top: CO_2 surface fluxes averaged over the entire idealized valley (Fig. 2): respiration (dash-dotted with circles) and photosynthesis (dashed with asterisks) are added up to total CO_2 flux (solid with plus signs).
Bottom: Mean CO_2 concentration [ppm] in the valley (solid) and over the plain (dashed)

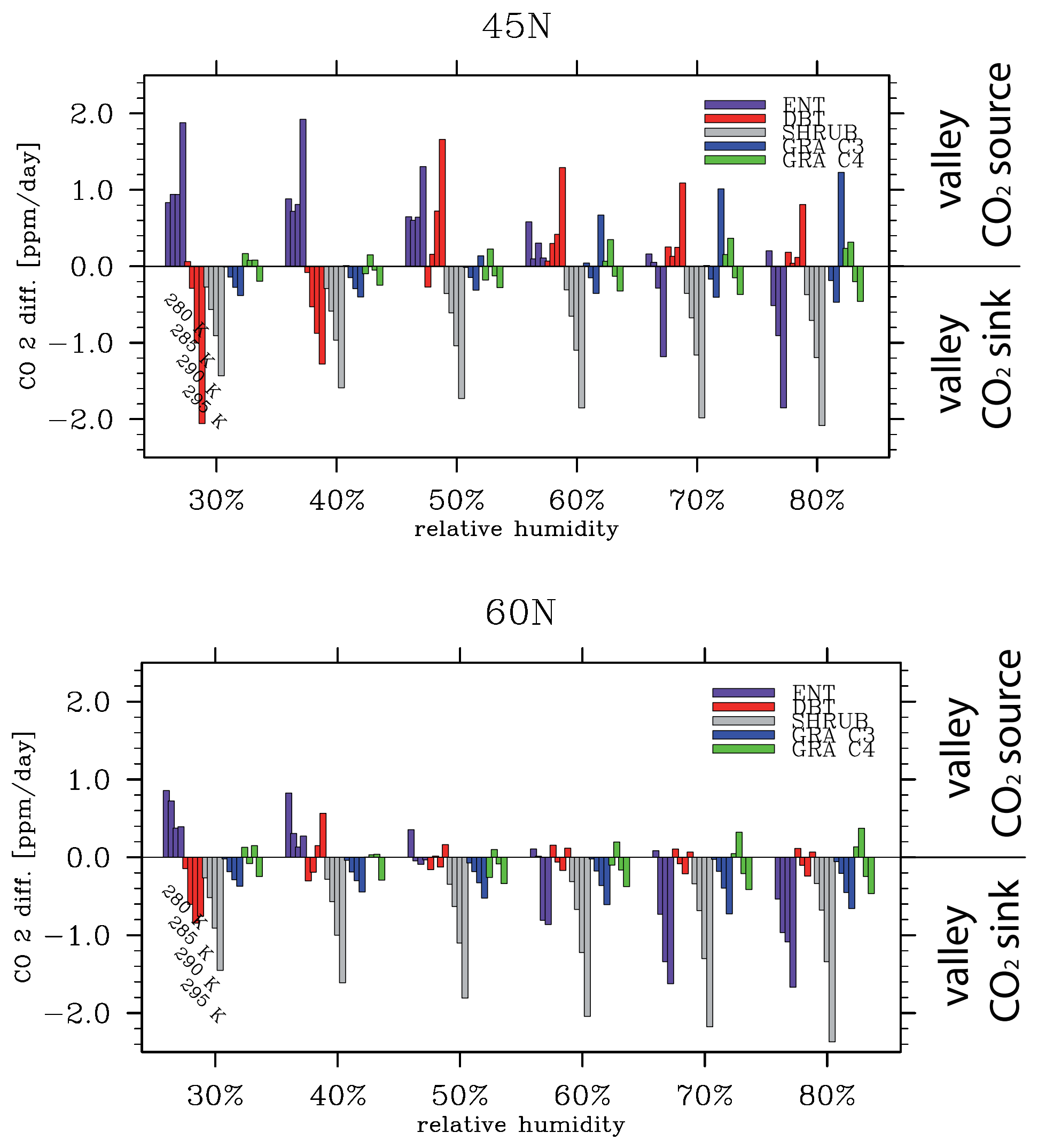

Figure 4: **Valley CO_2 Effect**: Difference of mean CO_2 fluxes over the valley less over plain for four initial potential temperatures (280-295K), six relative humidities (30-80%) and two latitudes (45 and 60N). Colors indicate plant functional types evergreen needleleaf temperate (ENT), deciduous broadleaf temperate (DBT), shrub land (SHRUB), C_3 Grassland (GRA C3) and C_4 Grassland (GRA C4)

- The **mean surface fluxes in the flat domain generally differ from the valley domain**. In Fig. 3 there is a stronger sink of CO_2 in the valley (black line) than over the plain (grey line). Differences of the mean fluxes are shown in Fig. 4: negative values indicate the valley to be a net sink of CO_2 as there is larger uptake by the valley compared to the plain and vice verca.
- As illustrated in Fig. 4 the **valley CO_2 effect ranges between ±2 ppm per day**. Its sign and magnitude are **dependent on the CLM plant functional type, the initial temperature, the initial relative humidity and the latitude**.
- Local circulations have a negligible effect on the valley CO_2 effect (not shown here).

References

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