Influence of an Idealized Valley on the Carbon Budget

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Motivation

- **Hypothesis:** topography influences biogenic CO_2 exchange [Rotach et al., 2014]
- **Problem:** global climate models use resolutions on the order of 100 km which, with certainty, cannot resolve the actual carbon dioxide exchange at the surface.
- **Goal:** identify topographic effects on the **surface CO_2 exchange** (as e.g. temperature, humidity, ambient CO_2, plant type ...)

Methods

- Coupling of the the Weather Research and Forecasting Model **WRF-Chem** [Grell et al., 2005], the Community Land Model (**CLM**, [Oleson et al., 2010]) and the TPGPP-LAI model [Migliavacca et al., 2011])
- **Net ecosystem exchange (NEE)** is calculated as the **respiration** of TPGPP-LAI **less** the **photosynthesis** of CLM.
- Analysis of differences between mean variables on flat terrain and the idealized topography.

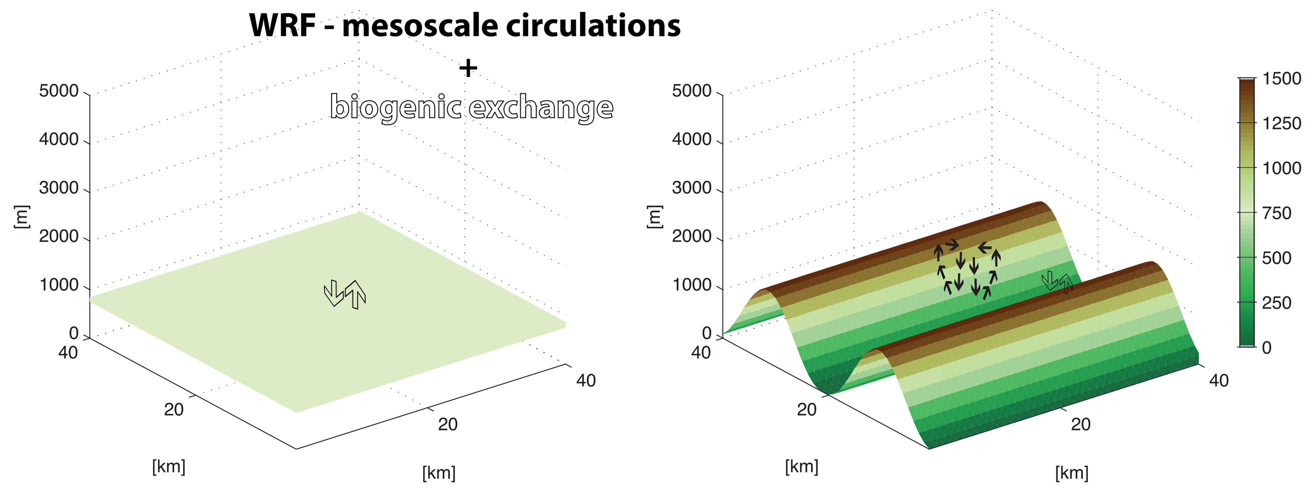

Figure 1: Model topography of the flat domain (left) and the idealized valley (right - created with the sine function. The flat domain is on 750m, which is the mean height of the valley. Solid arrows indicate afternoon mesoscale circulations from WRF and contoured arrows the biogenic CO_2 exchange from CLM photosynthesis and TPGPP-LAI respiration.

Model setup:

- 40×40 km domain at $\Delta\mathbf{x} = \mathbf{1}$ km using 57 vertical levels with $\Delta z =$ 25-320 m
- **topography:** idealized sine function **valley with 1500 m height; plain on 750 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
- **720 simulations** with varying initial conditions have 280, 285, 290 and 300 K potential temperature for the lower isothermal layer with 30 - 80% relative humidity at 30, 45 and 60°N latitude
- **plant functional types (PFT)** are: evergreen needleleaf temperate (**ENT**), deciduous broadleaf temperate (**DBT**), shrubland (**SHB**) and C_3 and C_4 grassland (**GR3** and **GR4**).

Results

- the **sine valley CO_2 exchange effect**, defined as the difference between plain and valley of the mean net ecosystem exchange $\Delta\overline{\mathbf{NEE}} = \overline{NEE}_{flat} - \overline{NEE}_{valley}$ ranges from **-1.0** to **1.7** g C m^{-2} day^{-1} with differences of vegetation temperature $\Delta\overline{\mathbf{Tv}}$ ranging from **-1.5** to **0.9** K and vapor pressure deficit $\Delta\overline{\mathbf{VPD}}$ of **-607** to **116** [Pa] (See Tab.1 and Fig. 2)
- Figure 2 and 3 show how variations of the plant functional type, the initial temperature, the initial relative humidity and the latitude (see WRF-Setup Box) result in a $\Delta\overline{\mathbf{NEE}}$. $\Delta\overline{\mathbf{NEE}}$ depends linearly on the vegetation temperature difference $\Delta\overline{\mathbf{Tv}}$ with a weaker and nonlinear dependence on the vapor pressure deficit $\Delta\overline{\mathbf{VPD}}$
- Figure 3 shows a decreasing CO_2 uptake (positive $\Delta\overline{\mathbf{NEE}}$) of the valley compared to the plain for lower VPD (positive $\Delta\overline{\mathbf{VPD}}$) even though a wetter atmosphere at constant temperature increases the CO_2 uptake (see e.g. [Oleson et al., 2010], wetter atmospheres with lower VPD simultaneously emerge with cooler temperatures). Hence, **the temperature dominates the dependency of VPD on the NEE**.
- **The sine valley can be a CO_2 sink or source** compared to the plain with positive or negative $\Delta\overline{NEE}$, respectively. For a warmer valley the slope of the mean fit in Fig. 2 shows 0.64 g C m^{-2} day^{-1} K^{-1} additional carbon uptake per Kelvin.
- the sine valley CO_2 exchange effect increases with increasing ridge height, or standard deviation of the topography (not shown)

Table 1: Ensemble means of 720 simulations (see WRF-Setup box) of net ecosystem exchange (NEE) and its main drivers - vegetation temperature and vapor pressure deficit (VPD). Means are averaged over the entire model domain and 24 h of simulation.

	min	mean	max	unit
$\overline{NEE}_{flat}$	-8.0632	-3.6024	2.6209	
$\overline{NEE}_{valley}$	-8.3496	-3.6872	2.2934	[g C m^{-2} day^{-1}]
$\Delta\overline{\mathbf{NEE}}_{flat-valley}$	**-1.0328**	0.0848	**1.7475**	
$\overline{Tv}_{flat}$	285.9123	295.2538	309.3535	
$\overline{Tv}_{valley}$	285.7109	295.2792	308.7926	[K]
$\Delta\overline{Tv}_{flat-valley}$	**-1.4783**	-0.0254	**0.8879**	
$\overline{VPD}_{flat}$	469.93	1027.3	3371.1	
$\overline{VPD}_{valley}$	461.83	1058.6	3388.5	[Pa]
$\Delta\overline{VPD}_{flat-valley}$	**-606.70**	-31.349	**115.65**	

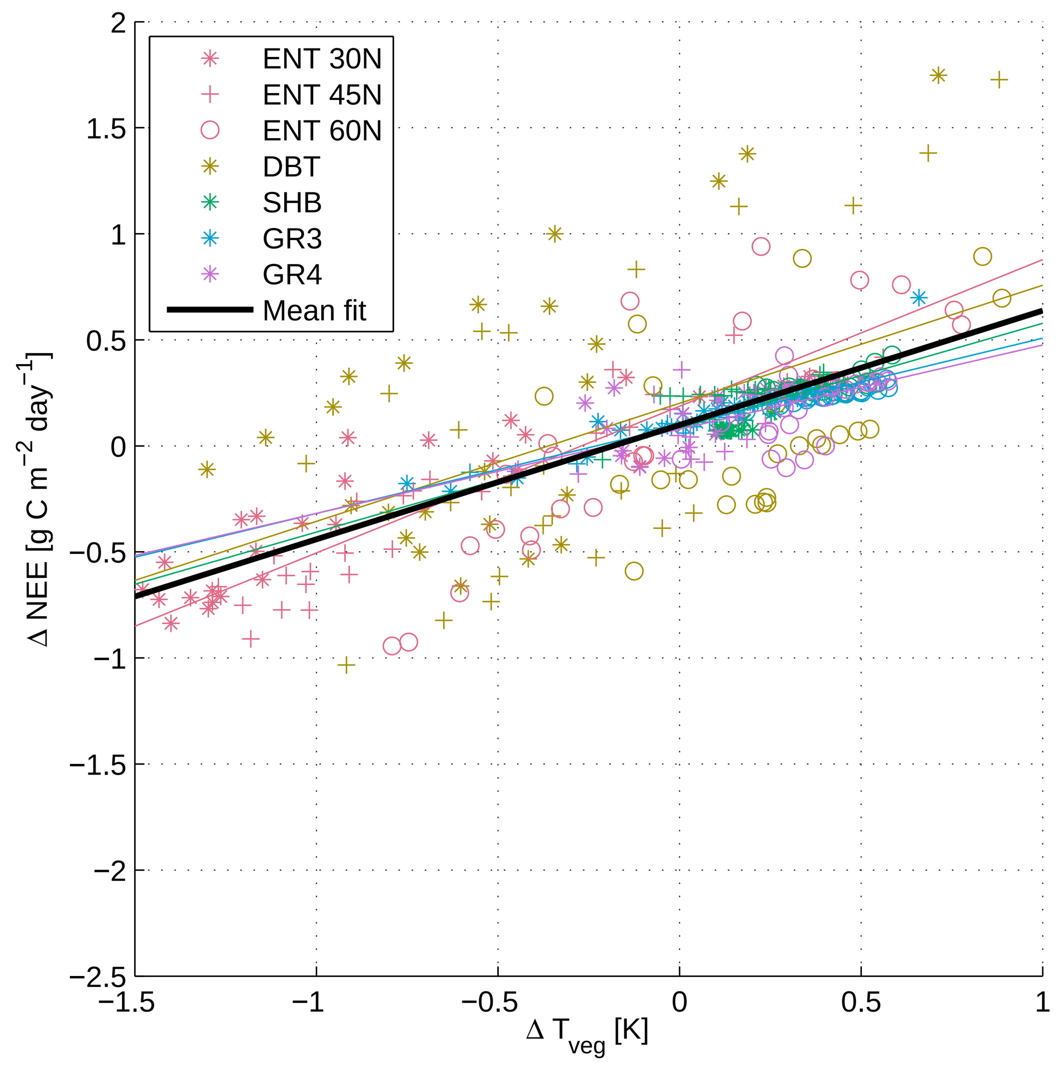

Figure 2: The **sine valley CO_2 exchange effect**, defined as ΔNEE = NEE_{plain}-NEE_{valley} plotted against the mean vegetation temperature difference ΔTv = Tv_{plain}-Tv_{valley} for 5 plant functional types: Evergreen Needleleaf Temperate (ENT), Deciduous Broadleaf Temperate (DBT), Shrubland (SHB), C_3 grassland (GR3) and C_4 grassland (GR4), at three latitudes: 30N, 45N and 60N indicated with an asterisk, a plus and a circle respectively.

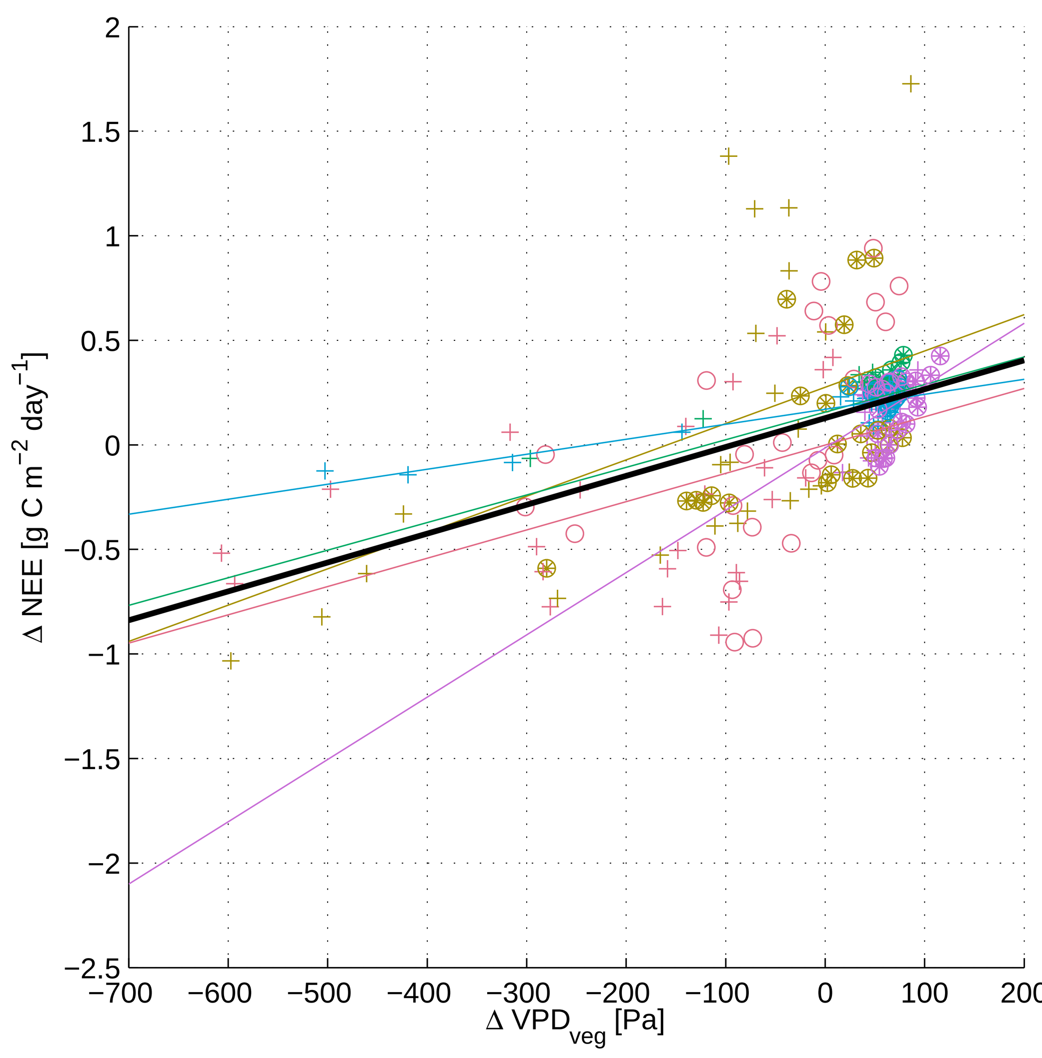

Figure 3: as Fig. 2 but for VPD

Conclusions

- ensemble simulations over a sine valley (1500 m) and a flat plain at average height (for a sine valley 750 m) result in differences of the respective **net ecosystem exchange (NEE) ranging from -1.0 to 1.7 g C m^{-2} day^{-1}**
- **the sine valley CO_2 exchange effect is primarily caused by vegetation temperature differences ΔTv** between the valley and plain simulations resulting from variations in the plant functional type, the initial temperature, the initial relative humidity and the latitude
- **a warmer sine valley is a CO_2 sink** compared to a plain (or vice versa - a CO_2 source for a colder valley)

References

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