High-resolution CO_2 transport simulations using WRF-VPRM

R. Ahmadov[1], C. Gerbig[1], K.Dhanya[1], R. Kretschmer[1], S. Koerner[1], B. Neininger[2]
rahmadov@bgc-jena.mpg.de
[1]Max-Planck-Institute for Biogeochemistry, Jena, Germany; [2]MetAir, Switzerland

Atmospheric measurements of CO2 from global networks, mostly consisting of remote sites, have long been used in combination with inverse analysis to retrieve information on biosphere-atmosphere exchange. In order to retrieve information on regional scales, networks consisting of instrumented tall towers are currently being implemented over the continents. However, the location of the measurement sites close to variable sources is often located in meteorologically complex areas: terrain induced mesoscale phenomena such as sea-land, (lake, river, forest, etc.) breezes, mountain-valley circulations, urban heat islands etc. make the representation in atmospheric models quite difficult. Such effects, which are usually on the subgrid scale of current generation transport models used in inversions, need to be studied with high resolution mesoscale simulations that include CO2 in order to bridge the gap between the measurements and inversion models.

The main goals of our study:

1) To develop a new mesoscale modeling tool in order to simulate CO2 transport (by advection, turbulence and convection) at high vertical and horizontal resolution;
2) To simulate realistic biospheric CO2 fluxes from different vegetation types with a diagnostic biosphere model that uses remotely sensed vegetation indices and modeled meteorological drivers;
3) To allow for separation of the different components of CO2 in the model (biospheric CO2, anthropogenic CO2, advected global CO2 fields);
4) To analyze the ability of the coupled atmosphere-biosphere model to predict spatial and temporal variations of CO2 by comparing it to airborne and ground based measurements

The developed modeling system contains main two components. These are Weather Research and Forecasting (WRF) model and Vegetation Photosynthesis and Respiration (VPRM) model to produce biospheric CO2 fluxes (**Fig. 1**). Currently the VPRM model is embedded into the WRF code and it uses air temperature at 2 meters (T2) and downward short wave flux at ground surface (SWDOWN) as input. In addition VPRM uses Land Surface Water Index (LSWI) and Enhanced Vegetation Index (EVI) from MODIS satellite data (500 meters resolution). As initial and boundary conditions (ICs, LBCs) for CO2 we used LMDZ global model data. For specific CO2 tracers such as anthropogenic, biospheric we applied zero ICs and zero-inflow/zero-gradient-outflow LBCs. For WRF meteorology input we used ECMWF analysis fields. In order to initialize anthropogenic CO2 fluxes we used 10 km resolution, hourly CO2 emission inventory (updated in 2005) from Institute of Economics and the Rational Use of Energy (IER), University of Stuttgart.

Fig. 1. The modeling framework

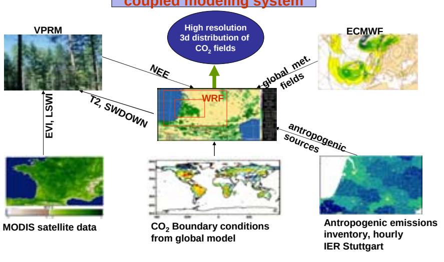


Fig. 2. Land-use map of the CERES domain and the observation stations

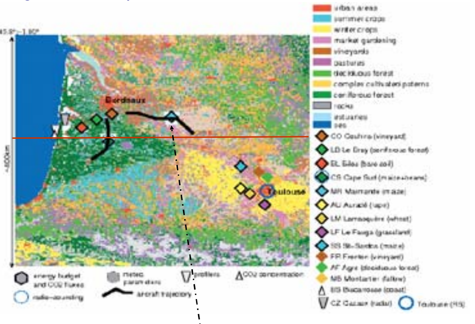


Fig. 3. CO_2 distribution on the vertical cross section, May-27; a) 06a.m., b) 2.p.m. UT

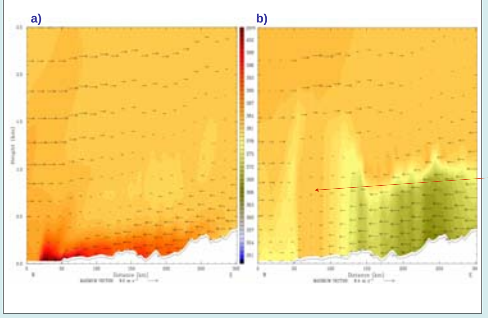


Fig. 4. Respired CO_2 signal, 2.p.m. UT, May-27, 2005

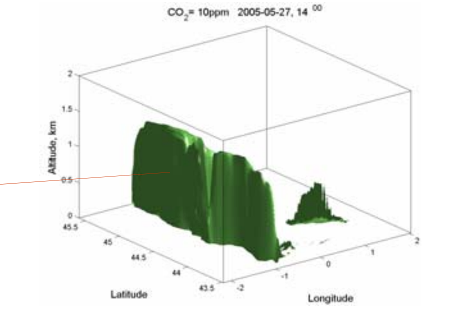


Fig. 5. Comparison of the near-surface temperature measured during the CERES

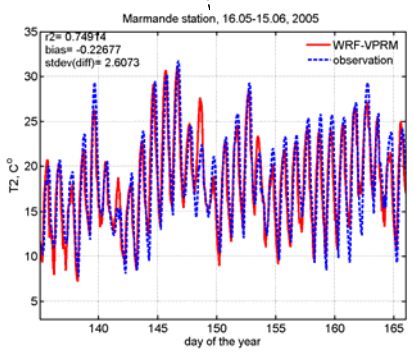


Fig. 6. Aircraft and model CO_2 profile comparison, 27 May, 8[30]–11[10] UT

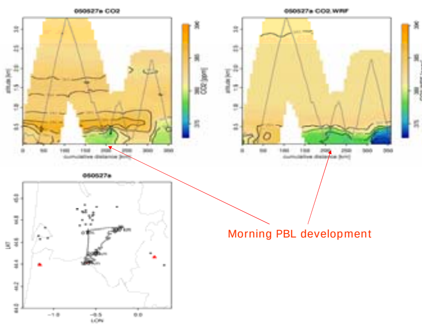
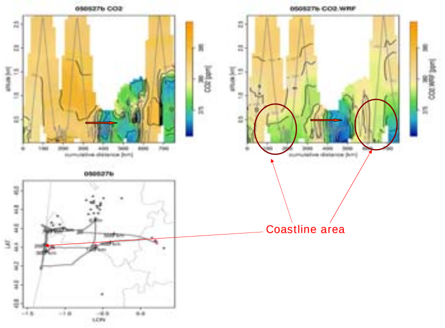


Fig. 7. Aircraft and model CO_2 profile comparison, afternoon flight, 27 May



Within the CarboEurope Regional Experiment Strategy (**CERES**), an intensive observation campaign was performed in Les Landes, South-West France (**Fig. 2**), May-June 2005, by several European research organizations. The main objective of the CERES was to determine spatial and temporal variability of CO2 fluxes and concentrations. A vast amount of data that was obtained during the campaign gives us an invaluable opportunity to validate WRF-VPRM modeling system. For this purpose we used two domains, one as outer with 6 km, second inner with **2 km** horizontal resolution. We ran WRF model in 2-way nested mode on these domains. Each WRF run for 30 hours starts at 18-00 UT (6 hours for spin-up) in the previous day.

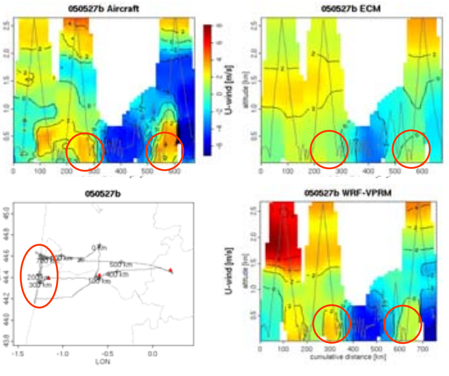
Here we showed results only for two days – May-27 and June-6. In **Fig. 3** it is shown CO2 concentration distribution and wind vectors on a vertical WE cross-section (the red line in **Fig. 2**). One may see the respired CO2 accumulation near the ground in **Fig.3a**. In the afternoon (**Fig.3b**) we see first – backward transport of the earlier respired CO2 by westerly winds, second – the strong horizontal gradient from the ocean towards inland, third – depletion of CO2 due to photosynthesis and mixing in the western part. We presented here (**Fig. 4**) a 3D isosurface (10 ppm) of respired CO2 signal at the same time as in **Fig. 3b**. It is obvious that over the land in the vicinity of the coastline there is accumulation of the respired CO2 because of the wind convergence. This effect mainly causes higher CO2 concentration within ≈50 km inland in the afternoon. The secondary reason for this is a relatively lower CO2 uptake by the forest in this area (see **Fig. 2**) compared with the cropland in the western part.

Comparison of T2 at the Marmande surface station is given in **Fig. 5**. The graph also shows the weather evolution during the campaign.

Fig. 6 shows a vertical "cross-section" (height + cumulative horizontal distance) of CO2 concentration profile measured by the ECO-Dimona (www.metair.ch) aircraft and predicted one by WRF. In addition a horizontal trajectory of the aircraft flight is given. The model exhibits morning CO2 "mixing layer" development with small bias. Afternoon flight (**Fig.7**) revealed strong horizontal CO2 concentration gradient in WE direction (red arrows) and CO2 depletion in the low atmosphere. This behavior was well captured by the model. Some bias in the concentration occurs over the shoreline area, which is due to the transport inaccuracy of the model in that area. **Fig. 8** shows comparison for the wind component between the observation, WRF model and ECMWF analysis. The simulation of the observed sea breeze is obvious in high resolution WRF model simulation which is not captured by ECMWF model. In addition we compared surface fluxes, different kind of meteorological data obtained from surface, radiosounding stations and aircrafts.

The modeling system also is applied for another domain **(Fig. 9)** around a tall tower located over the mountainous area. This gives us an opportunity to validate our model at the same time for PBL and free atmosphere, since the tower has several measurement levels (**Fig. 9**) and the top one is most of the time out of the PBL. We have started using MODIS satellite data: land-use, vegetation fraction and albedo for WRF input files in order to more accurately simulate land-surface processes.

Fig. 8. Aircraft and model west-east wind profile comparison, 27 May



Main conclusions of our study:

- High-resolution WRF is able to capture phenomena such as sea-land breeze
- The comparison of WRF-VPRM for the CERES campaign demonstrated a good agreement for both meteorological and CO2 data
- Aircraft measurements are essential in validation of such mesoscale models
- WRF-VPRM is a flexible tool to investigate long term measurement sites in different regions, but also for planning measurement campaigns
- Further validation of WRF-VPRM based on the long-term data is needed
- Preliminary results of WRF runs for the Ochsenkopf domain with MODIS surface data instead of the USGS data show similar results for summer days

Fig. 9. The model domain setup for the Ochsenkopf tall tower

References:

1. *Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang and J. G. Powers. A description of the Advanced Research WRF Version 2.NCAR Technical Note, 2005.*
2. *Pathmathevan M., Wofsy S., Matross D., Xiao X., Dunn A., Lin J., Gerbig C., William C., Munger J., Chow V., Gottlieb E. A Satellite-Based Biosphere Parameterization for Net Ecosystem CO2 Exchange: Vegetation Photosynthesis and Respiration Model (VPRM). Submitted to GBC, 2006.*
3. *Dolman, A. and CERES team. The CarboEurope Regional Experiment Strategy. BAMS, 2006, DOI: 10.1175/BAMS-87-10-1367.*
4. *Ahmadov, R., C. Gerbig, R. Kretschmer, S. Koerner, B. Neininger, A. J. Dolman, and C. Sarrat (2007), Mesoscale covariance of transport and CO2 fluxes: evidence from observations and simulations using the WRF-VPRM coupled atmosphere-biosphere model, J. Geophys. Res., doi:10.1029/2007JD008552, in press.*