COUPLING ATMOSPHERIC CHEMISTRY/AEROSOLS TO REGIONAL CLIMATE MODEL IN HIGH RESOLUTION

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INTRODUCTION

There is significant problem for decision making process arising from the weak link between climate change information based on global climate models and impact studies necessarily based on real local conditions. Global Circulation Models (GCMs) can reproduce reasonably well climate features on large scales (global and continental), but their accuracy decreases when proceeding from continental to regional and local scales because of the lack of resolution. This is especially true for surface fields, such as precipitation, surface air temperature and their extremes, which are critically affected by topography and land use. However, in many applications, particularly related to the assessment of climate-change impacts, the information on surface climate change at regional to local scale is fundamental. To bridge the gap between the climate information provided by GCMs and that needed in impact studies, especially when aiming the interactions of climate and air-quality issues, dynamical downscaling, i.e., nesting of a fine scale limited area model (or Regional Climate Model, RCM) within the GCM is the most convenient tool.

In the region of Central and Eastern Europe the need for high resolution studies is particularly important. This region is characterized by the northern flanks of the Alps, the long arc of the Carpathians, and smaller mountain chains and highlands in the Czech Republic, Slovakia, Romania and Bulgaria that significantly affect the local climate conditions. A resolution sufficient to capture the effects of these topographical and associated land-use features is necessary. That is why 10 km resolution has been introduced in the project CECILIA of EC FP6. The main aim of the project dealing with climate change impacts and vulnerability assessment in targeted areas of Central and Eastern Europe is the application of regional climate modelling studies at a resolution of 10 km for local impact studies in key sectors of the region. The project contains studies on hydrology, water quality, and water management (focusing at medium-sized river catchments and the Black Sea coast), agriculture (crop yield, pests and diseases, carbon cycle), and forestry (management, carbon cycle), as well as air quality issues in urban areas (Black Triangle – a polluted region around the common borders of the Czech Republic, Poland and Germany). Climate change impacts on large urban and industrial areas modulated by topographical and land-use effects which can be resolved at the 10 km scale, are investigated by CECILIA.

The concentration of air pollutants depends on both anthropogenic and climate factors. A main issue is the quantity of emissions of primary pollutants as well as of precursors of secondary pollutants. Long range transport to the target regions will be taken into account by simulation for the whole Europe, driven by RCM with a grid resolution of 50x50 km. These simulations will be used to constrain nested higher resolution runs (10x10 km) for a smaller domain focusing in CEE both for present and future climate. The key species will be ozone, sulphur and nitrogen as well as PM, which have a central role in tropospheric chemistry as well as the strong health impacts. Emphasis will be given to future key species excedances of the EU limits for the protection of human health, vegetation and ecosystems as well as WHO guidelines. Climate change may affect exposures to air pollutants by a) affecting weather and thereby local and regional pollution concentrations; b) affecting anthropogenic emissions including adaptive response of increased fuel combustion for fossil fuel-fired power generation; c) affecting natural sources of air pollutant emissions; and d) changing the distribution and types of airborne allergens. In addition, the chemical composition of the atmosphere may in turn have a feedback effect on the local climate. Weather is also associated with energy demands (e.g., for space heating and cooling) that could alter patterns of fossil fuel combustion. In particular, individual responses to extremely hot weather can result in large increases in air conditioner use. In addition, high temperatures cause increased VOC evaporative emissions when people run motor vehicles. The health effects of air pollution are broad and diverse, including dramatic episodes of increased mortality at high concentrations. In humans, the pulmonary deposition and absorption of inhaled chemicals can have direct consequences for health. Nevertheless, public health can also be indirectly affected by deposition of air pollutants in environmental media and uptake by plants and animals, resulting in chemicals entering the food chain or being present in drinking-water and thereby constituting additional sources of human exposure. Furthermore, the direct effects of air pollutants on plants, animals and soil can influence the structure and function of ecosystems, including their self-regulation ability, thereby affecting the quality of life. The most sensitive groups include children, older adults and persons with chronic heart or lung disease.

MODEL COUPLE

It is now well established that climatically important (so called radiatively active) gases and aerosols can have substantial climatic impact trough their direct and indirect effects on radiation, especially on regional scales (Qian and Giorgi, 2000, Qian et al., 2001, Giorgi et al., 2002). The study of these effects requires coupling of regional climate models with atmospheric chemistry/aerosols to assess the climate forcing to the chemical composition of the atmosphere and its feedback to the radiation, eventually other components of the climate system. For this coupling, existing regional climate model and chemistry transport model are used. At our Department climate is calculated using model RegCM while chemistry is solved by model CAMx, for the projects the attempt is done to develop and to use the couple ALADIN-Climate and CAMx as well.

The model RegCM used here was originally developed by Giorgi et al. (1993a,b) and then has undergone a number of improvements described in Giorgi et al. (1999), and, finally, Pal et al. (2005). The dynamical core of the RegCM is equivalent to the hydrostatic version of the mesoscale model MM5. Surface processes are represented via the Biosphere-Atmosphere Transfer Scheme (BATS) and boundary layer physics is formulated following a non-local vertical diffusion scheme (Giorgi et al. 1993a). Resolvable scale precipitation is represented via the scheme of Pal et al. (2000), which includes a prognostic equation for cloud water and allows for fractional grid box cloudiness, accretion and re-evaporation of falling precipitation. Convective precipitation is represented using a mass flux convective scheme (Giorgi et al. 1993b) while radiative transfer is computed using the radiation package of the NCAR Community Climate Model, version CCM3 (Giorgi et al. 1999). This scheme describes the effect of different greenhouse gases, cloud water, cloud ice and atmospheric aerosols. Cloud radiation is calculated in terms of cloud fractional cover and cloud water content, and the fraction of cloud ice is diagnosed by the scheme as a function of temperature. For more details on the use of the model see Elguindi at al. (2006).

CAMx is an Eulerian photochemical dispersion model developed by ENVIRON Int. Corp. (Environ, 2006). Currently in version 4.40 CAMx is used for air quality modeling in more than 20 countries by government agencies, academic and research institutions, and private consultants for regulatory assessments and general research. It is available for free in the form of the source code with various supporting programs. CAMx can use environmental input fields from a number of meteorological models (e.g., MM5, RAMS, CALMET) and emission inputs from many emissions processors. CAMx includes the options of two-way grid nesting, multiple gas phase chemistry mechanism options (CB-IV, SAPRC99), evolving multi-sectional or static two-mode particle size treatments, wet deposition of gases and particles, plume-in-grid (PiG) module for sub-grid treatment of selected point sources, Ozone and Particulate Source Apportionment Technology, mass conservative and consistent transport numerics, parallel processing. It allows for integrated "one-atmosphere" assessments of gaseous and particulate air pollution (ozone, PM2.5, PM10, air toxics) over many scales ranging from sub-urban to continental. CAMx simulates the emission, dispersion, chemical reaction, and removal of pollutants in the troposphere by solving the pollutant (eulerian) continuity equation for each chemical species on a system of nested three-dimensional grids. These processes are strongly dependent on the meteorological conditions, therefore CAMx requires meteorological input from a NWP model or RCM for successful run.

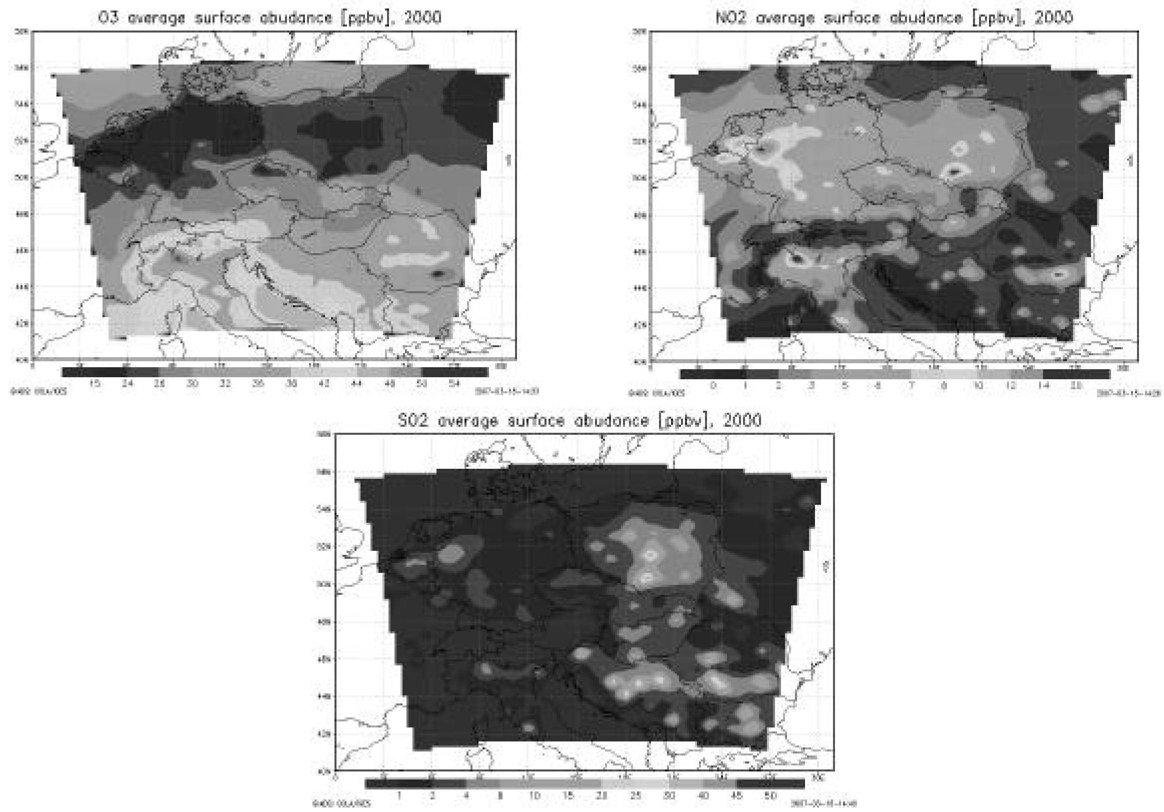

Fig. 1; Average concentration of O_3 (upper left), NO_2 (upper right) and SO_2 (bottom panel) for year 2000 in ppbv.

PRELIMINARY RESULTS

Meteorological fields generated by RegCM drive CAMx transport and dry/wet deposition. A preprocessor utility was developed for transforming RegCM fields to CAMx input fields and formats. Briefly, it takes RegCM's outputs and convert them to fields and formats accepted by CAMx. As the first step, the distribution of pollutants can be simulated for long period in the model couple. There are problems with the emission inventories available, at this stage emissions from EMEP 50 km x 50 km database are interpolated. We are testing VOC speciation technique, biogenic emissions of isopren and monoterpenes calculated as a function of 2m temperature, global radiation and landuse by Guenther et al. (1993,1994). We use 23 vertical s-levels reaching up to 70hPa, with time step of 150 s, at 45 km resolution in preliminary experiments for RegCM configuration, the same horizontal grid for CAMx. Initial and boundary conditions are set to CAMx's top concentrations (independent of time) (Simpson et al., 2003) for 45 km resolution run, the results are used for driving the same couple of RegCM-CAMx in 10 km resolution on smaller "CECILIA" region. In our setting CB-IV chemistry mechanism is used (Gery et al.,1989). Some examples of the high resolution integration for year 2000 are presented in Fig. 1 for selected species. More interesting comparison of the results with selected time series can be seen in Fig. 2. Underestimation of the ozone concentration by the model especially during warm season appears for some stations of the Central Europe whereas significant overestimation is presented in comparison for Ispra.

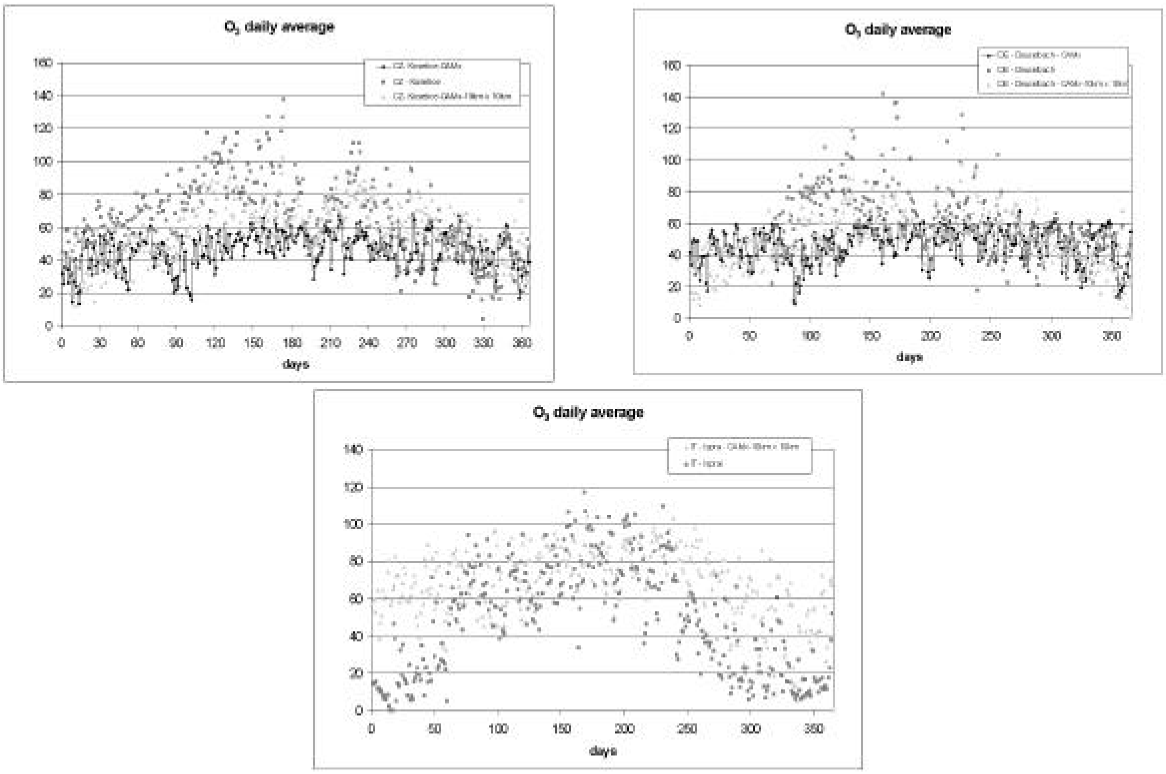

Fig. 2; Comparison of simulated and measured daily average concentration of O_3 for Kosetice station (upper left), for Deuselbach (upper right) and Ispra (bottom panel) in year 2000 ($\mu g/m^3$). — for 45 km resolution, ▲ for 10 km resolution, squares for observations.

FUTURE OUTLOOKS

At present we are running the longer experiment in very high resolution of 10 km. The next step will be the inclusion of the radiative active agents from CAMx into RegCM radiative transfer scheme to calculate the changes of heating rates. Only the modification of radiative transfer due to atmospheric chemistry/aerosols will be taken into account first, the indirect effect of aerosols will be taken into account later, there are still many uncertainties in understanding of this issue and possibility of inclusion of appropriate processes into the model. The feedback of chemistry/aerosols on climate will be studied in terms of monthly and yearly averages of 2 m temperatures and of the top-of-the-atmosphere (TOA) radiative forcing, the results will provide the estimate of the effect of interactive atmospheric chemistry and aerosols on climate in regional and local scales.

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