Contributions of road traffic emissions to tropospheric ozone on global and regional scale

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I) Motivation

Road traffic is an important anthropogenic source for carbon monoxide (CO), non-methane hydrocarbons (NMHCs) and nitric oxides (NOx). These trace gases act as precursors for tropospheric ozone. Ozone chemistry is highly non-linear and strongly depends on the background atmosphere, which significantly differs in rural and urban areas. However, current global Chemistry-Climate Models (CCMs) with their coarse resolutions mix emissions from rural and urban areas within one gridbox, similar as in the example of Fig 1. Due to the nonlinearity this can lead to different ozone production rates compared to high resolution models. Therefore we investigate the effect of the horizontal resolution on complex ozone diagnostics. The focus of our work is the contribution of road traffic emissions, which we quantify using a tagging technique.

Fig. 1: Adriatic coastline; left original picture, middle "global" and right "regional" resolution. The coarse global resolution leads to a mixing of colors from many pixels.

II) MECO(n) Model System

MECO(n) stands for MESSy-fed CHAM and COSMO models nested n-times and combined:

- The global atmospheric chemistry model EMAC
- The regional scale climate and atmospheric chemistry model COSMO/MESSy

MESSy (Modular Earth Submodel System) is an interface, which couples processes and diagnostics (as submodels) to different base models. The same formulation of processes (i.e. submodels) running with different base models leads to a highly consistent model chain on different scales.

The coupling between EMAC and COSMO/MESSy is done on-line. Therefore the boundary data must not be stored on disk, but is exchanged directly online via the MMD (Multi Model Driver)-library (Kerkweg & Jöckel, 2012).

Fig. 2: Blockchart of the MECO(n) model system. The individual submodels can be switched on/off in each instance.

III) Tagging method

We implemented the tagging method described by Grewe, 2013 and Grewe at al., 2010, which is an accounting system following the relevant reactions. Tagged are O, OH, NO, NO2, NMHCs, PAN and CO for ten different sectors (i.e. road traffic, ship etc.).

Simple example (HNO3 formed by sector j):

\[ \text{OH} + \text{NO} \rightarrow \text{HNO}_3 \]
\[ \text{HNO}_3 \rightarrow \frac{1}{2} \text{OH} + \text{NO} \]

The tagging method is technically working, allowing a direct comparison of the sectors over the European area doesn’t change significantly going from 2.8° - 0.44° resolution.

In May 2008 (see Fig.5) COSMO/MESSy gives a better agreement over England, Germany and France. However we observe too high ozone concentrations over Northern/Eastern Europe, which are only present in the planetary boundary layer.

Reason: Chemistry? Dynamics? Overall there is a positive ozone bias, which will be investigated with different boundary conditions.

The individual submodels can be switched in an instance. Displayed is the topography.

IV) Model Setup

- EMAC in T42L31ECWMF (~ 2.8°; ~300 km; up to 10 hPa); timestep 720 s; nudged towards ECMWF operational analysis data
- COSMO/MESSy with 0.44° resolution (~50 km; up to 22 km); timestep 240 s; on-line coupled with new boundary data every 720 s
- MACCity emission dataset for anthropogenic emissions (Granier et al., 2011)
- Biogenic and lightning emissions calculated in EMAC and transferred to regional domain
- TAGGING and MECCA Atmospheric Chemistry Module (Sander et al., 2005) running globally and regionally

In January 2008 we see almost identical patterns (as the NOx molecule to consumed NOx). In May (~20 DU). The results of EMAC for the same area are comparable, but the impact of stratospheric ozone is lower in general by ~ 1-3 DU.

Enhanced photochemistry roughly doubles the contribution of the road sector (5 DU) and industry (11 DU) in June, compared to January. The stratospheric contribution peaks in March (~20 DU). The results of EMAC for the same area are comparable, but the impact of stratospheric ozone is lower in general by ~ 1-3 DU.

The ozone production efficiency, defined as \( \frac{\text{O}_3 \text{production}}{\text{O}_3 \text{formation}} \), gives the ratio of produced O3 molecules to consumed NOx molecules. The comparison (Fig. 7) shows, that the overall pattern in COSMO/MESSy and EMAC look similar. However, the finer resolution reveals more details (e.g. lowered efficiency over the main ship tracks). Generally, COSMO/MESSy shows slightly higher efficiency over North-East Europe. For the other months between Jan-Jun 2008 we see almost identical patterns (as the NOx hotspots does not change).

V) First steps of the chemical evaluation

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Fig. 4: Ground-level ozone concentrations as monthly mean for January 2008. Colored dots show measurements (source: ebas.nilu.no).

Fig. 5: As Fig.4 but for May 2008.

The higher resolution of COSMO/MESSy results in a much more detailed ozone distribution compared to EMAC. Compared to observations of ground-level ozone in January 2008 (see Fig. 4) we see a better agreement especially over Southern France.

VII) First conclusions

- model chain with MECO(n), MECCA and TAGGING is technically working, allowing a direct comparison of global and regional effects
- comparison with observations benefits from increased resolution
- first simulations suggest, that the contribution of the sectors over the European area doesn’t change significantly going from 2.8° - 0.44° resolution

VIII) Outlook

- further evaluation and detailed analysis of TAGGING results
- reason for too high ground-level ozone concentrations in May 2008 will be analyzed
- regional emissions database will be tested (ozone bias)
- calculation of lightning and biogenic emissions in COSMO/MESSy
- further increase of resolution

IX) References and Acknowledgement


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