Coupling experimental data and CMAQ to investigate the carbon monoxide field formation in the North-West region of Russia

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Background

The tropospheric burden of carbon monoxide, like that of many other trace gases, has been increasing due to man's activities, although its upward trend ceased around 1995. The lifetime of CO is on the order of a few months only, and its significance in atmospheric chemistry lies mainly in its competition with many other gaseous pollutants—importantly the greenhouse gas CH_4—for the hydroxyl radical (OH, $CO + OH \rightarrow CO_2 + H$). Increased CO emissions cause higher CO burdens and more reaction with OH, leaving less OH for cleansing the troposphere of other reduced gases. In the background troposphere, about one third of all OH is removed by CO that reacts rapidly with OH (contributing to the latter's very short lifetime of 1 second only).

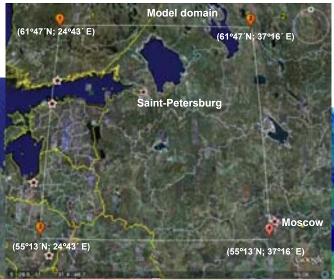
Until recently, we were mostly informed about tropospheric CO concentrations via surface measurements. Now, results from remote sensing and an increasing number of aircraft flights give improved global coverage and some vertical resolution. Since the launch of the MOPITT satellite instrument, followed by SCIAMACHY, AIRS and others, we have a much better picture of large scale continental pollution plumes. The vertical resolution of satellite based remote sensing is limited to several km at best, and vertical profiles coordinated with satellite overpasses are needed to better define vertical variability. Before the satellite, surface and aircraft measurements are combined, their relative calibration must be accurately determined.

Analysis of data on carbon monoxide in the atmosphere shows significant temporal and spatial variations of both concentration fields and column amount. In this study, we applied CMAQ to investigate the main factors which influence the CO distribution in the North-West region of Russia during August-September 2002. Experimental data include:
1. ground-based measurements of CO total column (NDACC, Network for Detection of Atmospheric Chemistry Composition; three Russian stations);
2. measurements of CO concentrations (NOAA ESRL/GMD CCGG Cooperative Air Sampling Network);
3. satellite measurements of CO (MOPITT, Measurements of Pollution in the Troposphere) over model domain.

Comparison of model results and measurement data are presented.

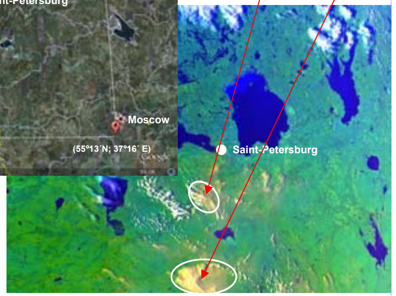
Model domain

includes North-west region of Russia



Modeling period

2-13 of September 2002.
Strong forest fires near Saint-Petersburg.



CO Observations

- Ground-based
  - Total column amounts (remote sensing, spectroscopic measurements)
  - Mixing ratios (air sampling)
- Satellite
  - Columns and mixing ratio profiles (remote sensing)

Russian Sites
Zvenigorod (near Moscow), Institute of Atmospheric Physics RAS;
Obninsk (near Moscow), Institute of Experimental Meteorology;
St. Petersburg, St. Petersburg State University.

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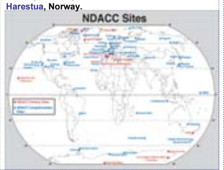
Sites of Network for Detection of Atmospheric Chemistry Change:
Ny-Alesund, Norway (Spitsbergen);
Kiruna, Sweden;
Harestua, Norway.

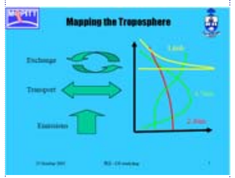


http://www.ndsc.ncep.noaa.gov/

Sites of NOAA ESRL/GMD CCGG Cooperative Air Sampling Network:
Ny-Alesund, Norway (Spitsbergen);
Pallas-Sammaltunturi, Finland;
Baltic Sea, Poland;
Bremen, Germany;
Obninsk, Russia.

MOPITT (Measurements Of Pollution In The Troposphere)

- Correlation radiometer
- 4.7μm only (vertical resolution)
- 2.4μm channels (boundary layer measurements) not reliable
- Launch on NASA's EOS Terra
- 22x22km pixel
- NASA/CSA
- PI J.R. Drummond



Models: MM5 → MCIP → SMOKE → CMAQ

MM5 V3.

NCEP GDAS data (ds083.0 FNL 2.5x2.5 12-hourly analyses) for August-September 2002.

SMOKE V2.3.

Two sources: most intensive forest/marsh fires. Both are in smoldering phase.
Location of the centers of the sources: (57°10´ N; 31 °15´E) and (58°57´ N; 30 °28´).
First approximations of CO emission from chosen fires are of $3 \cdot 10^6$ ton/yr and $1 \cdot 10^6$ ton/yr accordingly. Emissions were already estimated using total column amount measurements near St. Petersburg and HYSPLIT dispersion model [1,2].

CMAQ V4.6.

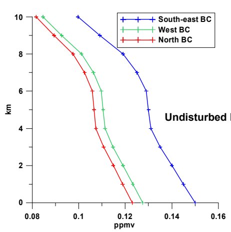
Boundary and initial conditions are based on analysis of ground-based measurements of CO concentration and total column amount [ ].
NOAA ESRL/GMD CCGG Cooperative Air Sampling Network ≡ NOAA
Network for Detection of Atmospheric Chemistry Composition ≡ NDACC
Two types of boundary/initial conditions were formed:
1. "undisturbed" (measurements for the period of July-September 2002 were used);
2. "disturbed" (measurements for the period of 20 August – 15 September 2002 were used).

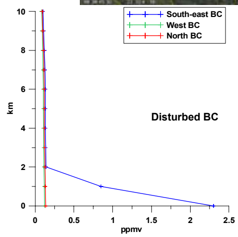
North boundary:
Ny-Alesund, Norway (Spitsbergen), NDACC and NOAA (concentrations and total column amounts);
Kiruna, Sweden, NDACC (total column amounts);
Pallas-Sammaltunturi, Finland, NOAA (concentrations).

West boundary:
Harestua, Norway, NDACC (total column amounts);
Baltic Sea, Poland, NOAA (concentrations);
Bremen, Germany, NOAA (concentrations).

South and East boundaries:
Zvenigorod, Russia, Institute of Atmospheric Physics RAS, (total column amounts);
Obninsk, Russia, Institute of Experimental Meteorology and NOAA (concentrations and total column amounts).

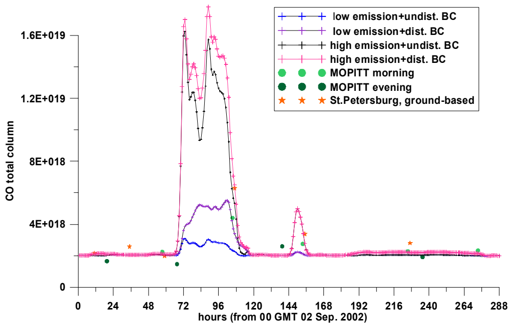
Initial conditions:
Harestua, Norway, NDACC (total column amounts);
Baltic Sea, Poland, NOAA (concentrations);
Bremen, Germany, NOAA (concentrations).
St. Petersburg, Russia, St. Petersburg State University (total column amounts).



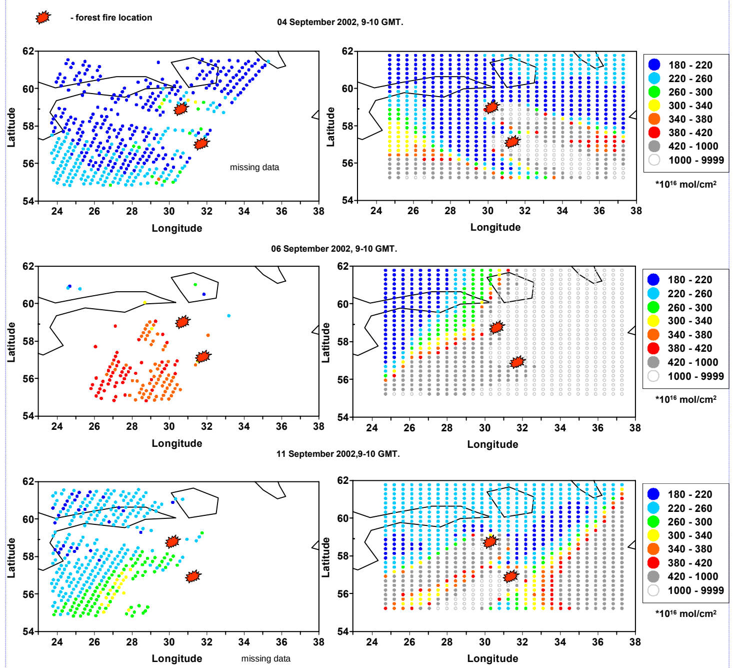


Analysis of CMAQ results and observational data

- CMAQ model results are compared with observations. CMAQ data are extracted for the 27-km grid cell corresponding to the monitoring site in St. Petersburg
- Different scenarios are considered to investigate model's sensitivity to various boundary conditions (disturbed and undisturbed) and various emission rates (low bound: 8220 ton/day / 2740 ton/day and upper bound: 13 times higher)
- Results indicate that emissions should be 13 times higher than the default value to match with the observations



Comparison of MOPITT and CMAQ CO fields



Summary

The CMAQ modeling system has been used to simulate concentration fields of CO in Russia. Simulation period: September 2002 when intense forest fires occurred. Modeling domain: 750x750km. Resolution: 27km.

CMAQ results were compared with observations. Observations included: 1) satellite data from MOPITT; 2) ground-based measurements from NDACC and St. Petersburg University, Russia.

Our analysis indicated that spatial patterns of simulated and observed CO total column amount (TCA) are similar.

However, there are differences in TCA values. Differences can be explained by several factors:
1. Information cannot be derived from satellite measurements when clouds are present;
2. Smoke is interpreted as cloud cover, therefore – missing data;
3. Low sensitivity of MOPITT instrument (only one channel, 2.4μm channels not reliable);
4. A lot of missing data from satellite measurements, therefore – difficult to compare for specific time periods.

Using CMAQ modeling system, in combination with satellite and ground-based data, allowed us to improve emission estimates. In this study, matching CMAQ results with observations suggested that emissions are significantly higher than default values.

Future work

Expand this prototype to simulate concentration fields of multiple pollutants in the North-Western region of Russia

Use CMAQ to estimate the impact of anthropogenic sources in St. Petersburg metropolitan area to the entire region.

Use the combined modeling/monitoring approach to obtain reliable emission inventory in the North-Western region of Russia.

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