Impact of Cloud Microphysics Parameterization on Model Simulation of Chemistry-Aerosol-Cloud Interaction: a Case Study

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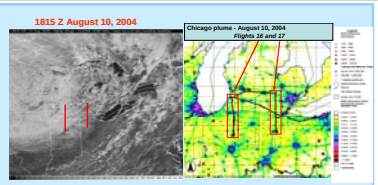
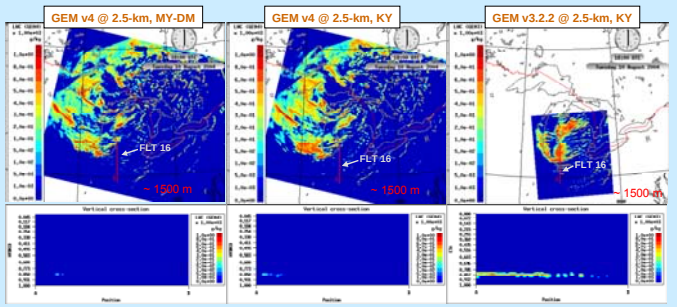
Poster 777

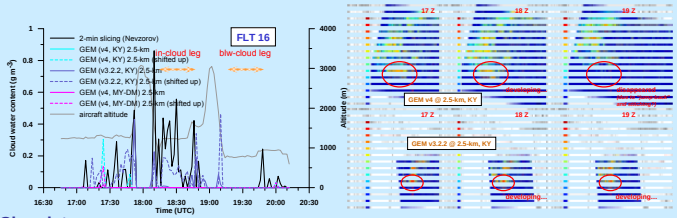
Part I Study Case

- Cloud processing of urban and industrial plumes downwind of Chicago, focussing on two research flights conducted on August 10, 2004 during ICARTT campaign.
- **FLT 16** and **FLT 17** (see right) were conducted during the time period of 1700 UT to 2400 UT, consisting in-cloud and below-cloud flight legs with various instruments on board [6].

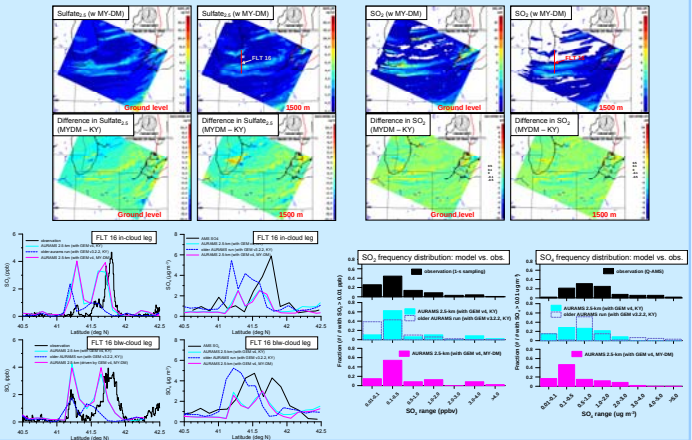


Liquid water content





Chemistry



Objectives of the Study

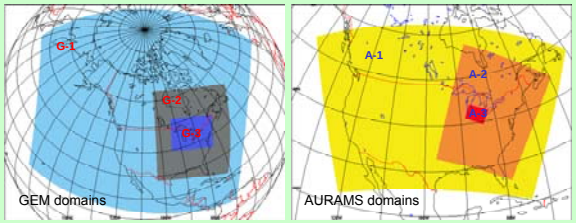
A two-part study to examine the modelling of chemistry-aerosol-cloud-dynamics interaction on a regional scale.

Part 1 : Looking at how different cloud microphysics parameterizations affect modelled cloud and dynamics, which in turn impact model prediction of chemistry via cloud processing, in an off-line modelling system.

Part 2: Introducing on-line (size- and chemically-resolved) aerosol feedback to cloud microphysics (via droplet nucleation) to look at the full interaction of aerosol and cloud and the impact on modelled dynamics and chemistry, in an in-line modelling system. This is also a part of the Air Quality Model Evaluation International Initiative (AQMEII) phase 2 activity in assessing and evaluating the value and approaches of integrated modelling with fully coupled chemistry and meteorology.

Modelling system and setup for Part 1

AURAMS: version 1.4.1, off-line CTM, driven by Environment Canada's weather forecast model ***GEM*** [1], gas- and aqueous-phase chemistry (ADOM II), aerosol dynamics and microphysics (CAM), inorganic heterogeneous chemistry (HETv - a variation of ISORROPIA), IAY for SOA, sectional representation (12 bins 0.01 – 40.96 μm, 9 chemical components); see [2] for the description of model representation of cloud processing of gases and aerosols in AURAMS.



One-way nested GEM v4 (meteorology) runs: regional LAM on **G-1** at 15-km resolution, using Sundqvist scheme for condensation and precipitation at resolved scale; parallel intermediate LAM runs on **G-2** also at 15-km resolution, with two different explicit microphysics schemes respectively: a **bulk single moment** Kong-Yau scheme ("**KY**") [3] and a **bulk double moment** Milbrandt-Yau scheme ("**MY-DM**") [4]; and parallel 2.5-km LAM runs on **G-3**, with the two different microphysics schemes, piloted by the respective intermediate 15-km LAM runs. Kain-Fritsch convective (KFC) parameterization for sub-grid scale deep convection was used for both regional and intermediate 15-km runs but not used for the 2.5-km runs.

Cascading AURAMS runs: 42- (on **A-1**) to 15- (on **A-2**) to 2.5-km (on **A-3**) resolutions. Both 42-km and 15-km runs were driven by the regional 15-km (**G-1**) GEM LAM run, while two parallel 2.5-km AURAMS runs were driven by the 2.5-km GEM LAM runs (each with different microphysics scheme); anthropogenic emissions (2005 U.S., 2006 Canadian, and 1999 Mexican inventories), biogenic emissions (BEIS 3.09/BELD3); O3 climatology and other prescribed profiles for chemical IC and BC (for the 42-km run).

Modelling system for Part 2

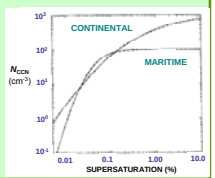
GEM-MACH: Environment Canada's in-line air quality prediction model, with full process representation of oxidant and aerosol chemistry and microphysics (adapted from AURAMS, including gas-, aqueous- & heterogeneous chemistry, aerosol dynamics, dry and wet deposition, both in- and below-cloud scavenging); operational version with a 2-bin sectional representation of PM size distribution (i.e., 0-2.5 and 2.5-10 μm) and 9 chemical components (sulfate, nitrate, ammonium, primary organic carbon, secondary organic carbon, elemental carbon, crustal material, sea salt, and aerosol-bound water); tracer transport is done in the model's dynamic core with one-way interaction only, i.e., meteorology-to-chemistry, but no chemistry feedback to meteorology.

Setup for testing aerosol feedback to cloud microphysics:

Cloud droplet number density N_c is currently included as a predictive variable in Milbrandt-Yau double-moment cloud microphysics scheme, where the nucleation of cloud droplets is represented following a simple function of supersaturation [5], for prescribed, fixed, continental and maritime aerosols.

Given supersaturation (diagnosed from w, T, and p), number density of CCN (N_{CCN}) is determined from the curves shown on the right; and

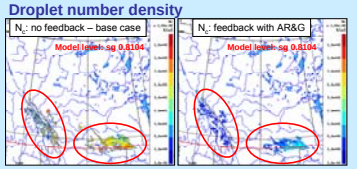
$$N_c^t = \max[N_c^{t-1}, N_{CCN}(ssat)] \qquad (1)$$



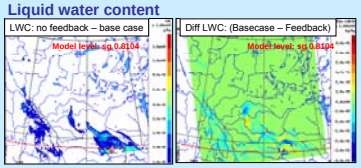
Part 2 – implementation of feedback through activation/nucleation

- The sectional Abdul-Razzak and Ghan activation scheme (AR&G) [7], based on the on-line (dynamically varying) aerosol size and composition, is implemented in place of the Cohard et al formula [5] for N_{CCN} in (1).
- Bring the resulting cloud droplet number back into GEM-MACH's chemistry for aqueous processing, i.e., chemistry's aerosol is allowed to affect cloud droplet number, and the resulting cloud droplet number feeds back to the chemistry.
- 24 hour simulation of GEM-MACH at 2.5km resolution, stand-alone (no nesting); model domain inside boundaries 596x526 grid points, covering Canadian provinces of Alberta and Saskatchewan.
- Compare {Nc, LWC, precipitation flux, temperature, humidity, SO2 and particle sulphate at ground level and aloft} with and without feedbacks – snap shots at 22 Z (16 MDT), or 22 hr into simulations.

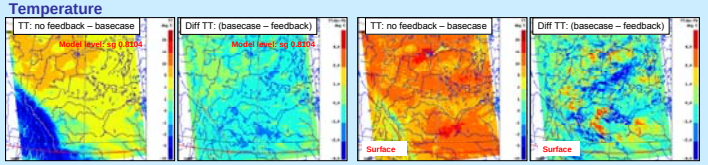
Droplet number density



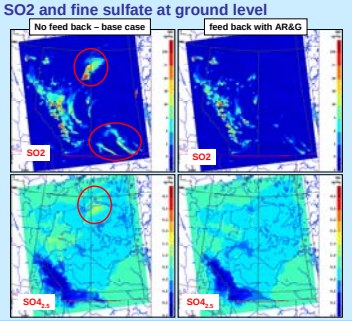
Liquid water content



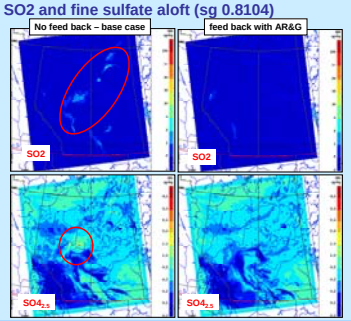
Temperature



SO2 and fine sulfate at ground level



SO2 and fine sulfate aloft (sg 0.8104)



Concluding Remarks and Future Work

The new model simulations of the ICARTT case were not as successful in producing the cloud fields correctly, partly due to the 6-hour "jump-back" in carrying out the simulations. New tests are underway. Nevertheless, from the comparison to a previous simulation, it is indicated that cloud processing plays an important role in the transformation of the urban-industrial plumes.

The preliminary test on feedback through aerosol activation showed a significant impact on the model predicted N_c (as compared to the original no feedback case), and the feedback has a modest impact on modelled cloud liquid water content and precipitation production (not shown here), mostly at a local level (due to changes in cloud and precipitation locations). These changes, along with the changes in other meteorological fields are complex. The impact from the feedback on chemistry is significant. More work is underway to address the insufficiency of size resolution in the current GEM-MACH. Tests and evaluation with more carefully selected cases (including cases with available aircraft observations, e.g., during ICARTT) will be pursued.

References

1.Côté, J. et al. (1998), ***Mon. Weather Rev***.,126,1373-1395.
2. Gong, W. et al. (2006), ***Atmos. Res***., 82, 248-275.
3. Kong, F. and M.K. Yau (1997), ***Atmos. Ocean***, 33, 257-291.
4. Milbrandt, J.A. and M.K. Yau (2005), ***J. of Atmos. Sci***., 62, 3065-3081.
5. Cohard, J.-M. et al. (1998), ***J. Atmos. Sci***., 55, 3348-3357.
6. Hayden, K.L. et al. (2008), ***J. Geophys. Res***., 113, D18201, doi:10.1029/2007JD009732.
7. Abdul-Razzak, H. and Ghan, S. J. (2002), ***J. Geophys. Res***., 107, D3, 4026, doi:10.1029/2001JD000483.