Air quality in urban areas: modeling with variable grids

A contribution to the subproject SATURN

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Summary

Urban air pollution phenomena encompass a wide range of spatial and temporal scales: from few meters (street canyon pollution) to hundreds of kilometers (secondary pollutant formation in city plumes). However a unique model is not able to resolve explicitly the smallest scale and, at the same time, the large domain without a considerable cost in CPU time. Nevertheless the interactions between the different 'urban' scales are of great importance and should be taken into account.

Aim of the research

The aim of the EPFL-LPA (Swiss Federal Institute of Technology in Lausanne - Laboratory of Air Pollution) contribution is to develop and test new algorithms, in a close link with field measurements, in order to improve the ability of meso-scale models to reproduce the urban scale.
The EPFL-LPA contribution can be split in two parts: the field experiments (EXP2) and the model developments (MOD2).

Activities during the year

For our experimental contribution, we have continued our development of the Raman lidar and Pump and Probe OH methods. Both methods are studied keeping in mind the final objective of the development of techniques ideally suited for comparison with model results. The Raman lidar allows to simultaneously measure the ozone and water vapor even in highly polluted atmosphere. This system has been used during the PAUR II -EU project in Crete in spring 1999 and further developed since that time (PhD thesis work, Benoît Lazzarotto, Feb. 2001). The Pump and Probe OH experiment is an in situ method proposed to measure the total hydrocarbon reactivity with OH, a measure that was never reported so far. With the PP OH method, the determination of this OH reactivity in different air pollution conditions, a new indicator is gained for the NOx/VOC control of the ozone secondary production and thus will directly contribute to test and validate model results. Finally the data acquired during the Grenoble 1999 field campaign with the ozone lidar, the DOAS and wind profiler were analyzed in details in 2000, and the final data base elaborated in particular for one base case (photo-smog episode of 4 days) that is currently used for the model development. For the modeling contribution in 2000, the development of the algorithm for pressure and transport (based on a finite volume approach) was finalized and implemented in a 3D meso-scale model, called FVM (Finite Volume Model).

This model is currently under test considering idealized cases (e.g. participation to MESOCOM, a project of meso-scale model inter-comparison, in the frame of SATURN) as well as real 3D cases (Grenoble, France and the Obwalden Valley, Switzerland).

In FVM, a new parametrization for the estimation of heat and momentum surface fluxes in urban areas was developed and implemented.

A new model (called TAPOM, Transport of Atmospheric POllutants Model)for the computation of transport and chemical transformation (including the aerosol formation and its interaction with the solar radiation) of the pollutants is in development.

Principal results

Laboratory development:

The development of our Raman lidar system has shown a number of promising features. For the first time, this system was used in a field campaign in Crete, Greece in May 1999. Measurements were performed at that time simultaneously with balloon borne ozone and relative humidity measurements. Inter-comparison of the results have analyzed and published in Applied Optics (Lazzarotto et al., in press AO 2001). This work corresponds to the principal task of a PhD dissertation that has recently been submitted (Benoît Lazzarotto, Feb. 2001).The ozone production is controlled by the presence of primary emissions such as hydrocarbons (VOC) and nitrogen oxides. With the development of the Pump and Probe LIDAR technique, a method based on the measurement of the atmospheric OH life time in very different air quality conditions, we have obtained a first *in situ* technique able to directly caricaturized whether the probed volume is "NOx or VOC controlled" in terms of ozone production. Furthermore, this technique is designed as a range resolved method. After a precise calibration of the sensitivity of the technique, first range resolved OH spectra were obtained (Calpini et al. 1999, Jeanneret et al. 2001, Kirchner et al. 2001).

Modeling development:

Development of new 3D meso-scale model (FVM)

The algorithm of pressure and transport in the new meso-scale model FVM is based on a control volume and finite element discretisation techniques. The main achievement of these algorithms is to improve the grid resolution in the zone of interest (ex. the city center) and to improve the precision of the calculation when the meshes are strongly deformed (e.g. very complex topography). The model was able to reproduce very well the main characteristics of the flow for classical 2D tests (mountain waves analytical solutions, the Boulder storm, sea breezes, etc.) and the first 3D tests (MESOCOM, Grenoble and Obwald Valley, two regions with very complex topography characterized by high mountains and steep and narrow valleys) are very promising.

Subgrid parameterizations in urban areas

After an analysis of the existing measurements of turbulent fluxes in urban areas, a new parameterization was developed in order to improve the estimation of 'urban' heat and momentum fluxes for mesoscale models. Three active surfaces are considered: the roofs, the walls and the canyon floor. For the momentum, two different roughness length are defined for roof and canyon floors, while the contribution of the walls is parameterized with a drag force approach. The sensible heat fluxes are determined as a function of the difference between the air temperature and the surface temperature. A complete energy budget equations is solved for each of the three surfaces. The short and long wave radiative fluxes are computed taking into account the shadowing effects and multiple scattering effects of the street canyon element. This parameterization was implemented in the FVM mesoscale model and tested against 2D idealized cases. These tests show that this parameterization is able to reproduce the main features measured in urban areas for heat fluxes, heat storage, temperatures and momentum fluxes and that the development of the urban boundary layer is very sensitive to these parameters and to their interactions with the city's surroundings (Martilli et al., 2000). This model is currently used to simulate the wind circulation over Athens and study the city impact on land and sea breeze.

Transport of Atmospheric POllutants Model (TAPOM)

A deeper knowledge of the role of suspended particulate matter in the atmosphere is essential for modelers to increase the accuracy of their results. Most photochemical models currently in use do not take into account the solar radiation extinction by atmospheric aerosols. This can lead to incorrect results on atmospheric chemistry calculations. As the gas phase chemistry and the solar radiation affect the aerosol load, the link between the solar radiation, the gas phase and the aerosol chemistry processes should lead to important improvements of the air quality models. In order to implement these interactions, solar radiation, gas phase and aerosol chemistry modules are used together in a new model called TAPOM (Transport and Air POllution Model). As usual in a 3D air quality model the modules must be accurate enough to give adequate results but must need low computational time:

- -The solar radiation module calculates the actinic fluxes and the photolysis rate constant.
- -The gas phase chemistry module calculates the chemical transformation of the gas phase species.
- -The aerosol module calculates chemical equilibrium between the gas and the aerosol phase.

For model validation purposes we used the well referenced Southern California Air Quality Study of August 1987 on the Los Angeles basin. A huge amount of data (emissions and atmospheric concentrations) is available for this episode, including aerosol measurements. We first proceeded different gas phase chemistry runs, without aerosol calculation. These runs were performed in order to validate the gas chemistry calculations as well as the wind fields. Our results for photochemical chemistry show a good agreement with the measurements. These results validate the transport, solar radiation and gas chemistry modules of TAPOM. Aerosols calculations still have to be compared to measurements, and therefore are not yet validated. The first runs including aerosol calculations do not show significant changes on ozone concentrations. The main effects are seen on aerosol precursors such as nitric acid which is almost totally consumed when aerosol calculation is performed. The interactions between aerosol concentrations and solar radiation will be studied as soon as the aerosol results are validated.

Main conclusions

Laboratory development

Both techniques, as well the ozone Raman DIAL as the Pump and Probe OH lidar methods, are designed to create new tools for our understanding of the atmospheric chemistry at low altitude. They are specially designed for observations at meso- and sub-mesoscale, and should be developed further for direct application in field measurements. Along with these laboratory development, field measurements such as the Grenoble experiment were performed to analyze in particular the temporal and spatial dynamic of a photo-smog formation from a densely populated area, in a topographically complex environment.

These experimental developments are also a first step towards the measurements of atmospheric parameters of relevance at higher altitude in the troposphere and even stratosphere. Parameters that will be used to validate satellite observation (ozone, water vapor content, aerosol, temperature) on one hand while they will also contribute to improve global scale climate models.

Modeling development

The new mesoscale model FVM is proving good performances in simulating wind fields in real cases with very complex topography and strong mesh deformations. Moreover, the parameterization of heat and momentum fluxes in urban areas implemented in the code, has made FVM an appropriate tool to study the development and the structure of the planetary boundary layer in urban sites with complex topography. This ability is very important for air quality simulations. In this context, the new transport/chemistry model TAPOM is under development and first tests have shown promising results, in particular for the study of the aerosol contribution to the gas phase chemistry in the atmosphere.

Aims for the coming year

In the next year:

Laboratory development

In 2001 the EPFL LPA will be one of the main contributor of the ESCOMPTE experiment in Marseille France. This experiment is a follow up of the previous work performed in the Milano area during the PiPaPo experiment in spring 1998 (also embedded in the LOOP II project) .Both experimental and numerical groups of the LPA will participate to this campaign which ideally corresponds to their research themes.

Modeling development

Tests and developments of FVM and TAPOM model will continue:
The urban impact on turbulence exchanges and its influence on air quality will be study over Athens and Basel.

The link between gas phase chemistry, aerosol and solar radiation will be study over the Milan area.

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