CityZen

megaCITY - Zoom for the Environment

Collaborative Project

7th Framework Programme for Research and Technological Development

Cooperation, Theme 6:

Environment (including Climate Change)

Grant Agreement No.: 212095

Deliverable D1.3.1, type R

First report on model tools and the implementation of a common approach to bridge scales in a dynamic fashion in models

Due date of deliverable: project month 16

Actual submission date: project month 18

Start date of project: 1 September 2008 Duration: 36 months

Name of lead beneficiary for this deliverable: metno

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Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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First report on model tools and the implementation of a common approach to bridge scales in a dynamic fashion in models

1. Introduction (metno)

(Michael Gauss)

CityZen involves research groups that have traditionally dealt with modelling or observations of atmospheric chemical composition on either local, regional or global scales. The CityZen project has one of its main objectives in bringing the different scale research communities closer together. In task 1.3 the goal has been to bridge spatial scales in a dynamic fashion in models. Several main strategies have been considered in CityZen:

1. online coupling of two versions of the same model (course resolution/large domain and fine resolution/small domain);
2. zoomed grid realizing high resolution in a region of special interest, with a continuous transition towards coarser resolutions outside that region;
3. offline coupling of two models of different scales, e.g. a global model delivers 3-hourly boundary conditions to a regional model, or the (fine resolution) output from a regional model is used to improve (coarse resolution) results of the larger scale model;
4. online coupling of two different models of different scales, e.g. one regional model and one global model exchange information at each model time step, within one combined model system.

Option 1 has been used by some of our partners for several years. Depending on whether information is exchanged both ways (from the larger to the finer scale and vice versa) or only one way (usually from the larger scale to the finer scale) the method is referred to as either two-way or one-way nesting. CityZen partner FRIUUK applies one-way nesting as described in Section 2.

The zooming option is a kind of two-way nesting, but it is realized in one single model run with one model code. It has been tested by CityZen partner INERIS and will be described in Section 3.

Option 3 can be realized in different ways. In CityZen a new nudging method has been developed by CityZen partner CNR-ISAC and will be described in Section 4.

The coordinated study led by INERIS involves the provision of boundary conditions from global scale models to regional scale models. One of the global scale models is run by CityZen partner UiO. The method will be described in Section 5.

Option 4 in the above list has been discussed on several meetings within CityZen. It has been decided for the time being that the numerical problems would be too large and the scientific benefit too small to justify the effort implied by this fourth approach. As the different models use different meteorological drivers and are run on different resolutions, the errors caused by interpolation steps and inconsistencies between the different meteorological data sets used would overcompensate the small benefits gained. The other options are considered much more promising from a scientific point of view although they are less appealing from a collaboration point of view. Still the exchange of boundary conditions will be pursued within CityZen where it is reasonable (e.g. 10-year trend study led by INERIS, and flux study led by CNR-ISAC).

2. Nesting (FRIUUK)

(Michael Memmesheimer, Hermann Jakobs)

FRIUUK have done nesting experiments with 3 different model resolutions (Rhine/Ruhr). The different model domains and their resolutions are indicated in Figure 1. During the first phase of the project a standard model configuration has been used to perform and analyse decadal variations in the Central Europe/BeNeLux-Ruhr area. The model design is shown in Figure 1. Grid resolutions are 125 km, 25 km and 5 km for North-Rhine-Westphalia, and 1 km for the Ruhr area. Development of methods to perform the simulations and their analysis has been done with this model configuration, which has been used successfully for daily forecasts and standard applications before. In the second period the modelling region will be extended into a larger domain with the aim to improve the applicability and performance of the whole system leading to a scientifically more sophisticated model design which will be investigated in the second phase, grid sizes in that case are selected to 45, 15, 5 and 1 km. Vertical resolution in both cases is done by 23 layers from the surface up to about 16 km, 16 layers are within the convective boundary layer (3 km), the thickness of the lowest layer is about 40 m.

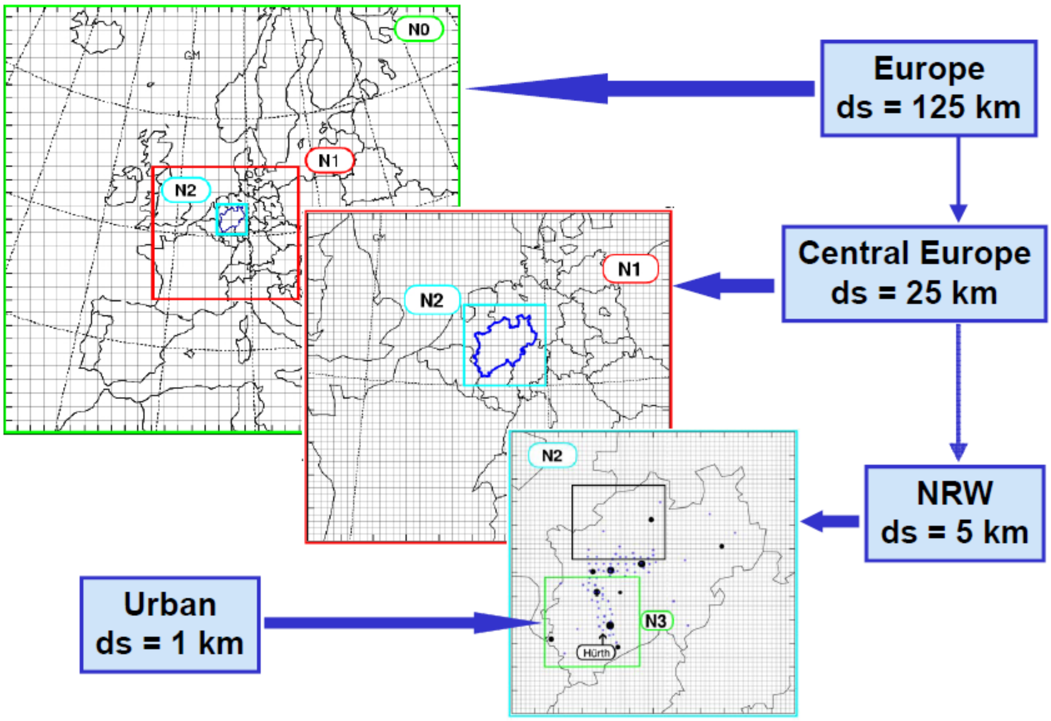

Figure 1: Nesting in the EURAD model by FRIUUK.

3. The zooming technique (INERIS, IPSL-CNRS)

(Guillaume Siour, Bertrand Bessagnet, Laurent Menut, Frédérik Meleux, Laurence Rouïl)

INERIS have done zooming experiments by gradually increasing grid resolution towards selected hot spot region (BeNeLux). See figure 2 for a visualization of the zoomed model grid.

Megacities provide a large part of anthropogenic emissions. And trace species emitted from these relatively localized hotspots have an impact on air quality at all scales. At the local scale, the accumulation of these primary compounds is responsible for severe respiratory problems and for the alteration of buildings. At the regional scale, they lead to the formation of secondary compounds such as ozone or organic particulate matter witch - in addition to their adverse effects of health - have an impact on the climate equilibrium.

Investigations of the impact of megacities on the atmospheric environment would thus benefit from a multiscale approach bridging the local and regional scales in a dynamic fashion in order to improve the characterisation of local pollution export from megacities and their regional impact.

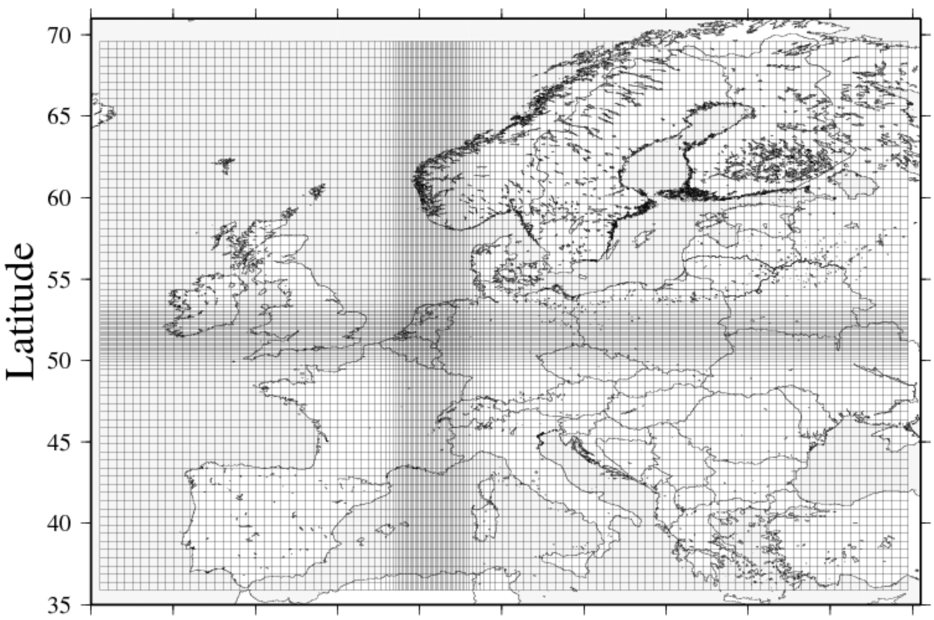

Figure 2: Nesting in the CHIMERE model by INERIS.

One of the main objectives of WP1 in the CityZen project is to assess the impact of megacities across a variety of spatial scales. In most existing Chemistry Transport Models (CTM), the range of spatial scales is usually covered by a number of refined nests coupled off-line. And the downward interactions from the global to the regional scale are well represented by state-of-the-art nested models. Such phenomena can be captured by means of two-way nesting in a coupled model or making use of nudging or data assimilation of the nested domain within the larger mesh. We present here the development and the results of an innovative multiscale approach based on a horizontal stretched spatial discretization in the Eulerian CTM CHIMERE.

The method consists in stretching the horizontal resolution of the model grid over a given latitudinal and longitudinal bands. At the intersection of these bands, we obtain a finer grid than the rest of domain. So that a wide range of spatial scales is covered within a unique mesh.

This type of stretched-grid approach has been widely used in global circulation models (GCM) to represent adequately the regional scale over an area of interest. However, solving the momentum transport in such a configuration models is challenging and requires specific conditions in the geometry of the stretched-grid: the stretching must be uniform, the ratio between the neighboring meshes resolution should not deviate from unity by more than about a few percents, and the fine resolution should to be no larger than a few degrees, the typical resolution of uniformly spaced GCMs.

The advection of tracers in CTM is less stringent than momentum advection in a GCM. And we are not subject to the constraints mentioned above. However, we still need meterological forcing fields covering all scales. Mesoscale simulations making use of two-way nesting provide meteorological fields covering various spatial scales. With an appropriate interpolation methodology, these two distinct yet consistent datasets can be projected onto a single grid with variable resolution: the coarse meteorological mesh providing information over most of the CTM domain, and the fine mesh being used at the intersection of the stretched latitudinal and longitudinal bands. Note however that, except at the intersection, the meteorological forcing is interpolated from the coarse field at a higher resolution over the stretched bands.

The anthropogenic emissions are obtained from the EMEP inventory provided at a resolution of 0.5°x0.5° and downscaled following a top-down methodology onto the stretched grid as a function of a 300m-resolution landuse database (globcover).

Finally, our stretched domain scale benefits of fine meterological and emissions resolution on the region target and a coarse meterological and emissions resolution on the rest of domain. This difference in resolution allows a better representation of the impact from local to regional scale and particularly in term of import/export fluxes.

Whereas this method represents a significant improvement for scale interaction studies, it also has some drawbacks. Indeed, the local zoom increases the number of cells. For a regular domain of 0.5° of resolution under Europe, the number of cells is 7171. A stretched grid covering the same domain with local zoom down to 0.1° over a megacity, the number of cells is 17649. This increase of the number of cell therefore introduces an increase of the computation time. Moreover the resolution change imposes to decrease the advection timestep to satisfy the Courant-Friedrichs-Lewy condition on whole domain. Hence, a simulation with a stretched grid takes 3 times longer than the regular approach with a coarse domain and nested fine domain. However, unlike our innovative stretched grid, this classical approach – although computationally cheaper – cannot yield information on the impact of megacities on the larger scale.

4. The nudging technique (CNR-ISAC)

(Massimo D'Isidoro, Alberto Maurizi, Felicita Russo, Francesco Tampieri)

Processes determining the atmospheric composition cover a wide interval of scales, ranging from global, which is interesting for climate and large scale transport episodes (volcanic eruptions, large forest fires, global meteorology) to the inertial range of the turbulence spectrum and to the molecular scale, where dissipation of energy takes place along with the basic transformation processes (chemical reactions).

Studying the interactions between climate and anthropogenic activities, specifically those concentrated in megacities/hot spots, requires the handling of a very wide range of scales from local, where anthropogenic emission are concentrated, to global where we are interested to study the impact of these sources.

The explicit description of processes at very different scales is limited by computer resources. The need to allow different scales to interact stimulates a variety of approaches to bridge them. Here we describe the nudging approach to realize such bridging. The nudging technique permits models of different design and resolution to interact, so that they are suitable, for instance, to force global models using regional or local models, without a direct dynamic two-way interaction.

In this report we shall describe the general approach, the experimental setup and the results of a numerical experiment performed looking at the Po Valley hot spot. For sake of simplicity this first experiment is realized using the same model BOLCHEM, a limited area model, at different space resolution.

Bridging the scales: the nudging technique

The basic idea of the nudging technique is to force the concentrations in a certain region of the model domain during a low resolution run with the fields obtained from a high resolution simulation. The technique consists in adding a term in the concentration tendency equation into the model running at low resolution. This term acts to force the computed concentrations towards the high resolution concentrations obtained from a fine scale model.

In general the forcing is applied to the low resolution model in the following form:

$$C_{LR}(x,y,z,t) = C_{LR}(x,y,z,t) + \Delta t/\tau \, (C_{HR}(x,y,z,t) - C_{LR}(x,y,z,t)) \qquad (1)$$

where C_{LR} refers to the actual Low Resolution Concentration and C_{HR} is the High Resolution Concentration computed by the fine resolution model, τ is the relaxation time, which regulates how fast the actual fields are relaxed to the high resolution, and Δt the integration time step of C_{LR} .

The point to focus on is that this technique can be applied not only to the same model running at different resolution but also to two different models (e.g. a global, coarse resolution model and a regional, high resolution model). Therefore the nudging technique finds an interesting application within a project like CITYZEN where a number of different scale models are involved.

Experimental setup and results

The nudging procedure is applied using the BOLCHEM model (Mircea et al.,2008) running at different horizontal resolutions: a high resolution run is used to force the low resolution one, and the forced run is compared with the original one, to check whether is closer to the high resolution, taken as reference.

We performed the three different model runs for the month of august 2009:

-a low resolution run (LR) over a European domain

-a high resolution run (HR) over the Mediterranean region driven by boundary conditions taken from LR run.

-a low resolution run (LR-N) over the same domain as LR run applying the nudging over the Po Valley (7.5°E-13°E, 44°N-46°N, Fig 3) every forecast hour and for all model species.

In this application of the nudging technique, the relaxation time in equation 1 was set to 20 min, so that in steady conditions and for a passive tracer the LR run would converge to the HR run before the updated forcing value is used. The integration time step Δt was set to 400 sec. The value of C_{HR} , that has been chosen to be the average of the HR values over the grid cell of LR run, is updated every hour which is the time interval ΔT_{HR} on which the HR values are saved.

It is expected that the main effects of this techniques occur within the forcing area; but is also evident that the aim is an overall improvement of the skill of the low resolution run also outside of the forcing area. Therefore we also studied the effects of the nudging technique outside of the Po Valley area and the diagnostic of the method has been done on both the Po Valley region and the Adriatic area (13°E-17°E, 41.5°N-46°N) that are illustrated in Figure 3.

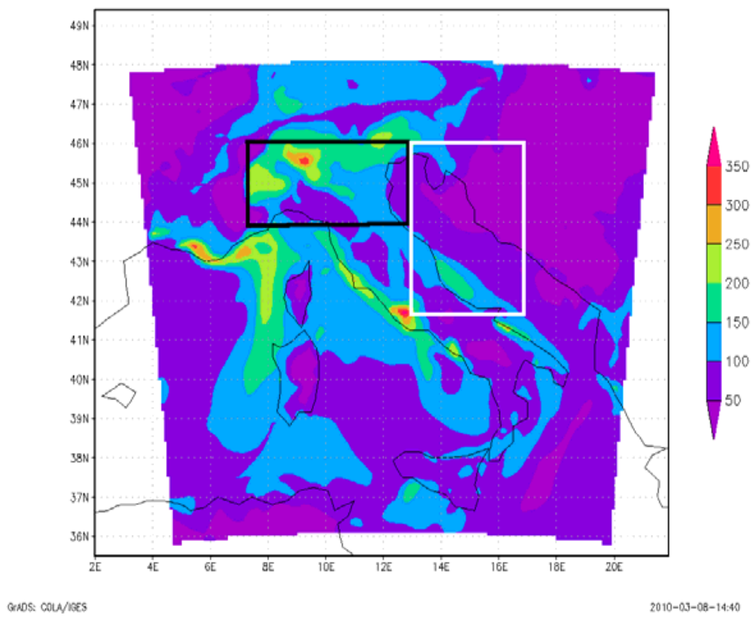

Figure 3: Illustration of the BOLCHEM domain on which the HR run was done. The area included within the black lines is the Po Valley region on which the nudging was performed. The Adriatic area, on which the diagnostic was done, is indicated by the white rectangle.

For each run we simulated a period of 24 days. Figures 4 and 5 show the time dependence of respectively PM10 and CO concentrations, averaged over the Po Valley, obtained with the three runs. The main feature is that the mean values of concentrations computed by LR-N run generally lie between run LR and HR.

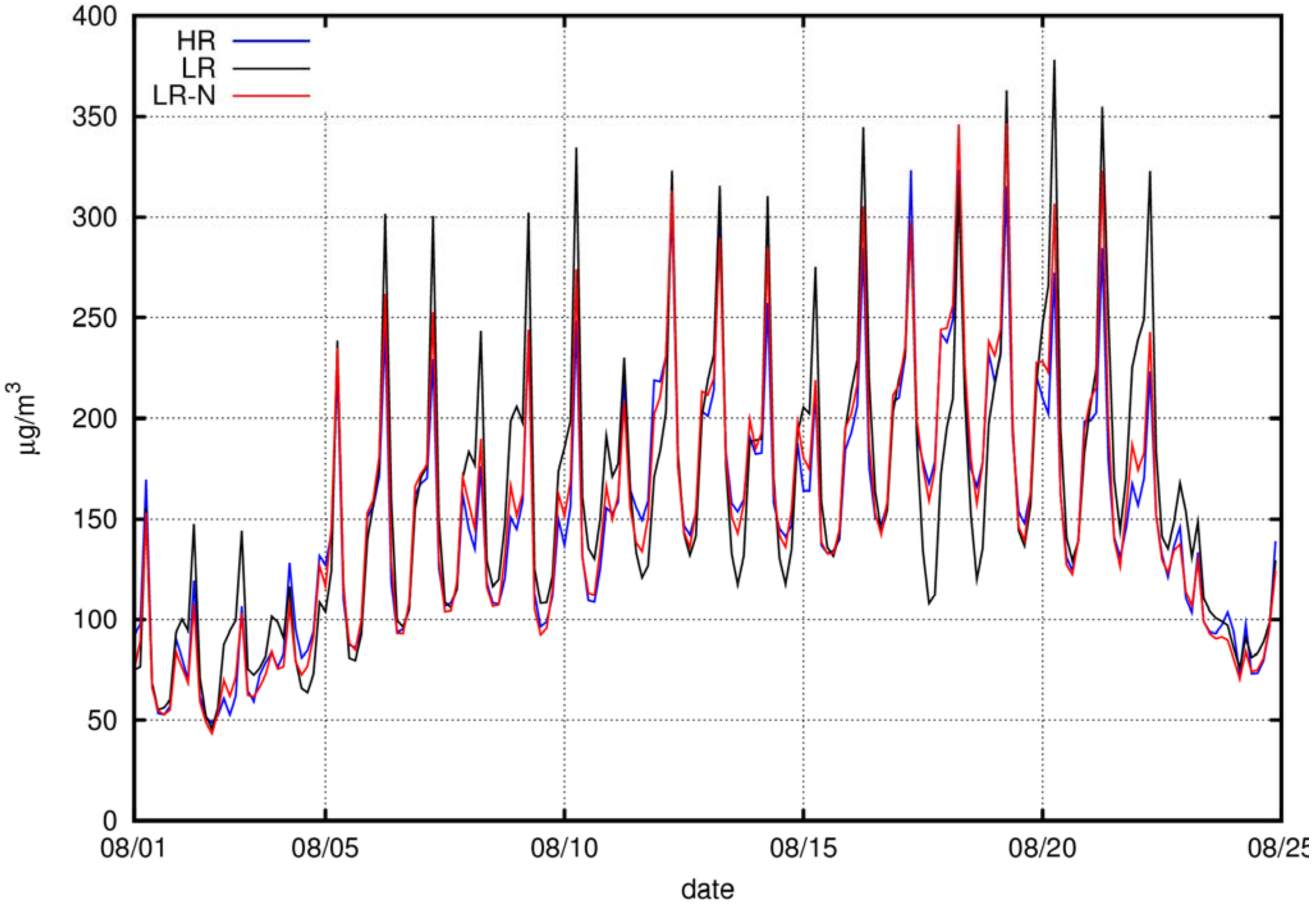

Figure 4: Time series of the surface CO concentrations during the 25 days simulation period. The blue line indicates the time series obtained in the HR run, while the black line indicates the values obtained in the LR run and the red line indicates the values of the LR-N forced by the HR run. All the time series show clearly the diurnal cycle of CO, which reaches a minimum during the night and has diurnal maxima due to the urban traffic peaks. As expected the values of the LR-N run lie mostly between the HR and the LR runs.

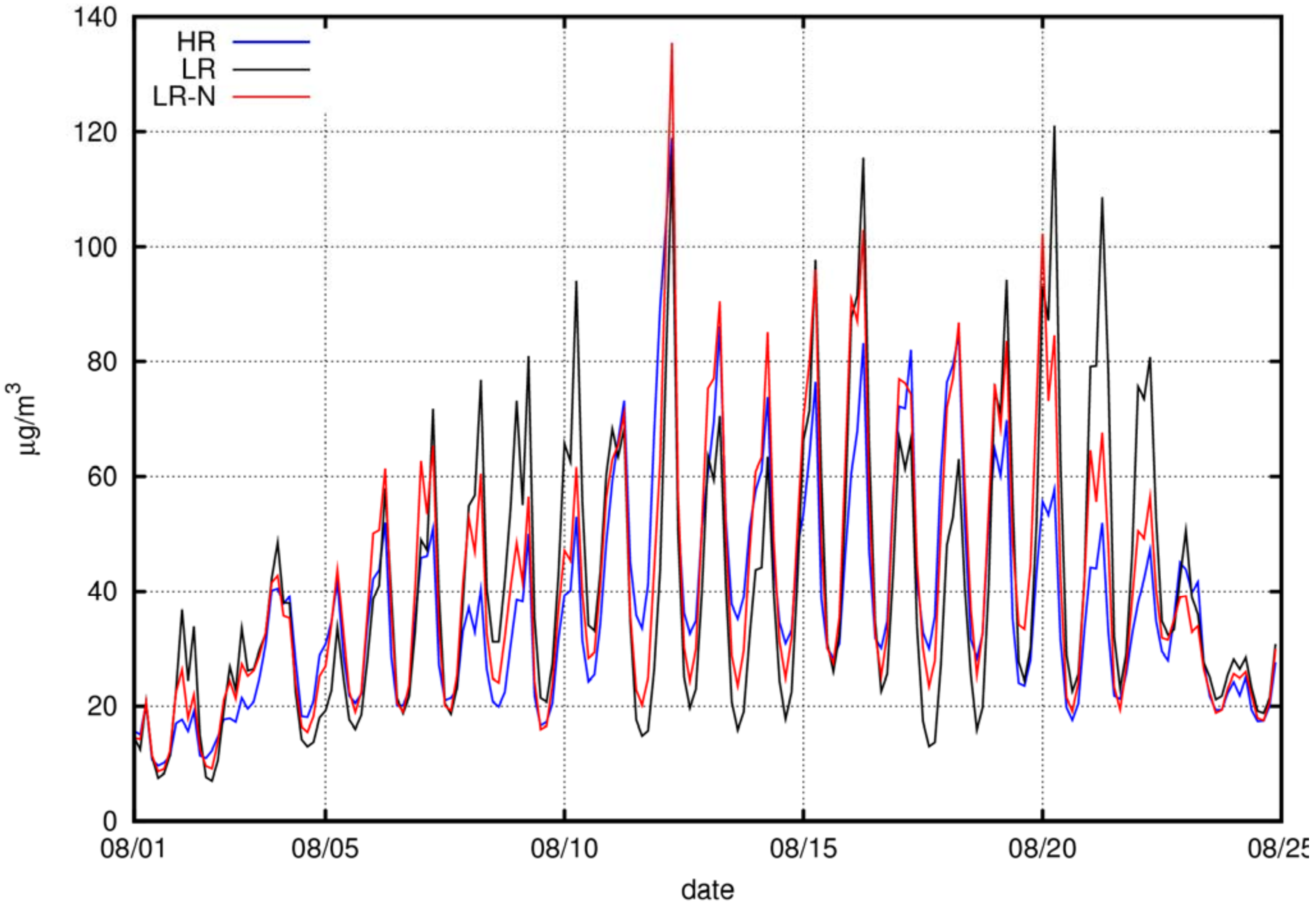

Figure 5: Time series of the PM10 concentrations during the same period as Figure 4. The blue line indicates the time series obtained in the HR run, while the black line indicates the values obtained in the LR run and the red line indicates the values of the LR-N forced by the HR run. Also in this case the time series show clearly the diurnal cycle of PM10 very similar to that of CO.

To better highlight the differences between LR run and LR-N run we can use the HR run as a reference and the performance of the model runs LR and LR-N will be studied in reference to HR run. It is useful therefore, to study the regressions of both LR run and LR-N run with respect to the HR run. Figure 6 shows the scatter of the average values of CO concentrations in run LR versus HR and run LR-N versus HR together with the corresponding least square fit lines. Figure 7 shows a similar scatter plot for the PM10 concentrations. In both figures it is evident that the nudging process results in a lower scattering with respect to the traditional LR run, even though the CO concentrations show a more evident improvement with respect to the PM10. This translates in an increased linear correlation for run LR-N with respect to run LR. Moreover in both cases the slopes of the least square regression lines are consistent with the unity.

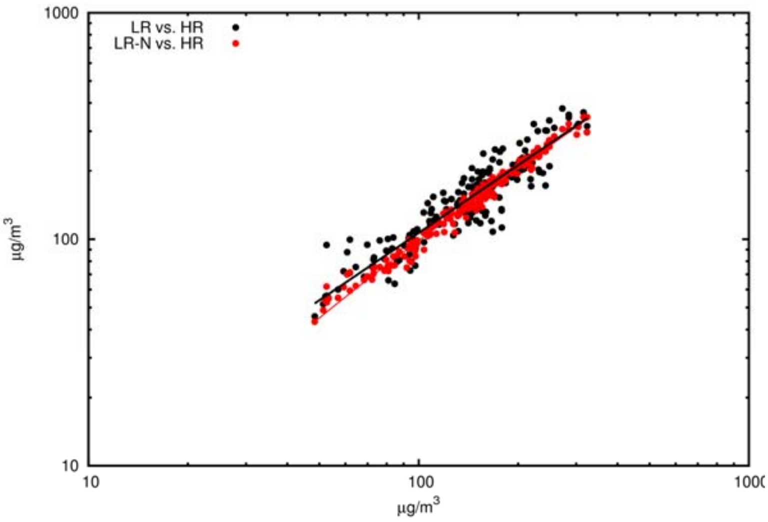

Figure 6: Scatter plot of the average values of the CO concentrations simulated in the HR run (x axis) versus the CO concentrations simulated in the LR run (y axis, black circles) and versus the CO concentrations simulated in the LR-N run (y axis, red circles).

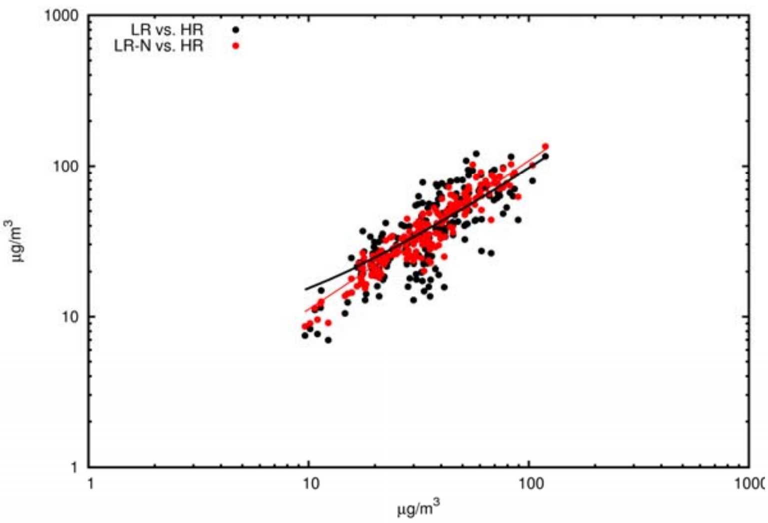

Figure 7: Scatter plot of the average values of the PM10 concentrations simulated in the HR run (x axis) versus the PM10 concentrations simulated in the LR run (y axis, black circles) and versus the PM10 concentrations simulated in the LR-N run (y axis, red circles).

The Taylor diagrams provide concise two-dimensional plots of statistical properties, which show how well simulated patterns match a reference (Taylor, 2001). In this case, the comparison between low resolution simulations (with and without nudging) and the reference (HR run) is made. The axes refer to the normalised standard deviation of the reference; the correlation coefficient between a given field and the reference is given by its azimuthal position while the root mean square difference between a run and the reference (in units of standard deviation) is proportional to their distance. Therefore each point plotted on the diagram defines how a simulation is close to the reference in terms of the above statistical properties.

Figure 8 represents the Taylor diagram resulting from the comparison between run LR and HR (black symbols) and run LR-N and HR (red symbols) for some of the species. It is clear the improvement due to the nudging in terms of increase of the correlation and decrease of the centered root mean square difference.

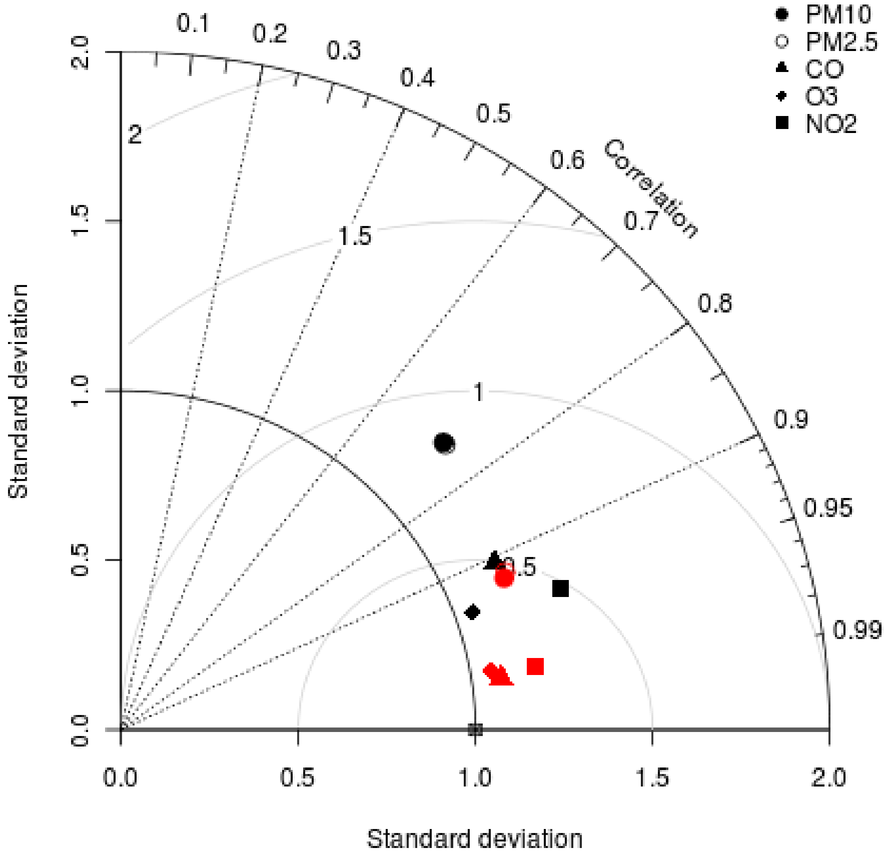

Figure 8: Taylor diagram showing the comparison between the average results of BOLCHEM in the Po Valley area before (black symbols) and after the nudging (red symbols). In this illustration each species is separately indicated.

In order to study the effects of the nudging outside of the Po Valley region we computed for the Adriatic area indicated in Figure 3, a Taylor diagram similar to that done for the Po valley. This diagram, reported in Figure 9, shows a much less pronounced change between LR and LR-N compared to the diagram in Figure 8, with the exception of the PM25 and PM10 species for which a small improvement is noticeable.

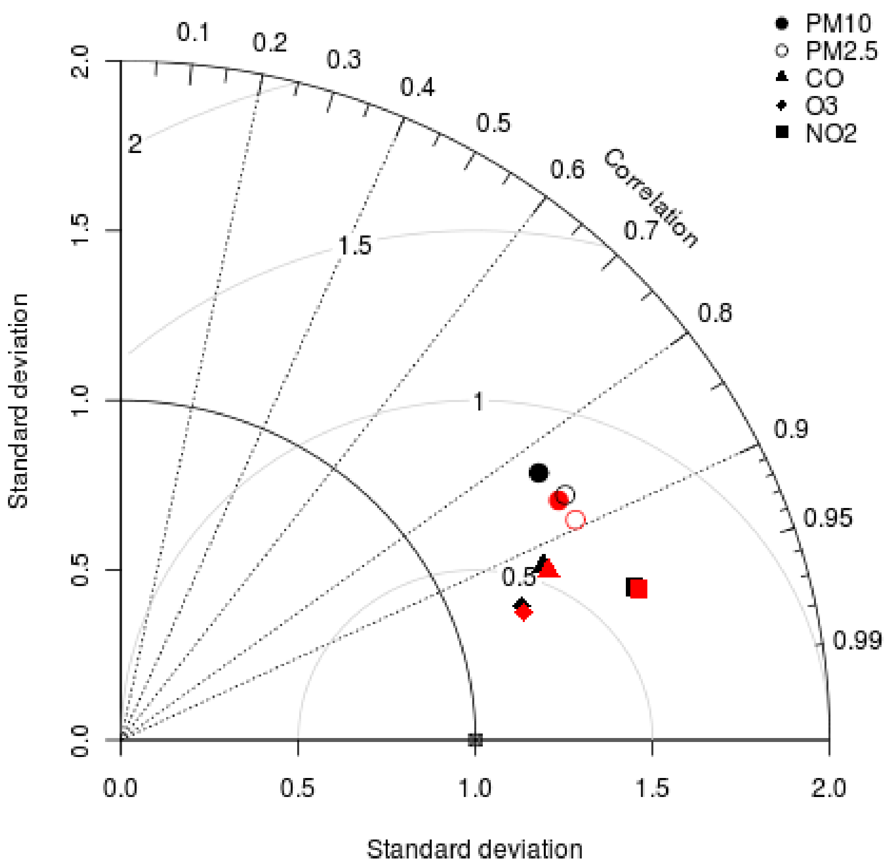

Figure 9: Taylor diagram showing the comparison between the average results of BOLCHEM in the Adriatic area before (black symbols) and after the nudging (red symbols).

Conclusions

To investigate a new method for allowing different models with different spatial scales to interact, we performed a numerical experiment using two runs of BOLCHEM at different spatial resolutions focusing on the Po Valley hotspot. As the Taylor diagrams show (Figures 8 and 9) the application of the nudging technique to force the low resolution model to the high resolution area has two important consequences:

- the performance of the nudged coarse model is significantly closer to that of the fine resolution model
- the performance of the nudged coarse model outside the forcing region is also closer to the finer resolution and is more evident in the case of PM25 and PM10.

The point to be stressed again is that this technique can be applied to the same model running at different resolution but more importantly to two different models (e.g. a global, coarse resolution model and a regional, high resolution model). Furthermore, different choices of the parameters (ΔT_{HR} and τ) must be investigated in order to allow the best agreement with the reference (which should be either a model or observations).

6. Exchange of boundary conditions (UiO)

(Øivind Hodnebrog)

Boundary conditions have been provided by the University of Oslo (global Oslo CTM2 model) to regional modelers. Tables of required species, spatial and temporal resolutions had been exchanged beforehand. Tables 1 to 3 show a list of species and meteorological parameters that have been provided. The temporal resolution of the data is 6-hourly, horizontal resolution T42 (2.8x2.8 degrees), from the surface up to about 100 hPa. The domain comprises the entire Northern Hemisphere, thus allowing for studies within all the four selected CityZen areas.

Table 1: Meteorological variables from Oslo CTM2 (for interpolation and unit changes):

Hybrid coordinates A, 1D
Hybrid coordinates B, 1D
Surface pressure 2D
Real temperature 3D
Volume 3D
Air number density 3D

Table 2: 3D gas species from Oslo CTM2 (mixing ratios):

O3
HNO3
PAN
CO
C2H4
C2H6
C3H6
C4H10
C6H14
C6HXR (m-xylene)
CH2O
CH3CHO
H2O2 (hydrogenperoxide)
ISOPRENE (C_5H_8)
HO2
NO3

N2O5
NO
NO2
CH4
NH3
DMS (dimethyl sulphide, (CH3)2S)
SO2
H2SO4
MSA
TOTAL NMVOC

Table 3: 3D aerosol species from Oslo CTM2 (kg m-3, except number density):

Black carbon, 4 modes: - Aitken mode (~0.01 µm) - Accum. mode (~0.1 µm) - Coarse mode (1 µm) - Aitken mode insoluble
Organic carbon, 4 modes: - Aitken mode (~0.01 µm) - Accum. mode (~0.1 µm) - Coarse mode (~1 µm) - Aitken mode insoluble
Mineral dust, 4 modes: - Accum. mode (~0.1 µm) - Coarse mode (~1 µm) - Accum. mode insoluble - Coarse mode insoluble
Ammonium, 2 modes: - Fine mode - Coarse mode
Nitrate, 2 modes: - Fine mode - Coarse mode
Sulphate, 4 modes: - Nucleation mode(~1nm) - Aitken mode (~0.01 µm) - Accum. Mode (~0.1 µm) - Coarse mode (~1 µm)
Sea salt, 2 modes: - Accum. mode (~0.1 µm) - Coarse mode (~1 µm)
Number density: - Nucleation mode(~1nm) - Aitken mode (~0.01 µm) - Accum. mode (~0.1 µm) - Coarse mode (~1 µm)

- Aitken mode insoluble - Accum. mode insoluble - Coarse mode insoluble
Aerosol water, 4 modes: - Nucleation mode(~1nm) - Aitken mode (~0.01 µm) - Accum. mode (~0.1 µm) - Coarse mode (~1 µm)

7. Downscaling of emissions (metno, INERIS)

(Michael Gauss)

The improvement of model resolution has to go hand in hand with implementing emission data on a finer scale. Within CityZen, 50x50 km^2 EMEP data have been downscaled first using TNO data and later using GLOBCOVER data. In addition fine scale data sets are collected in the CityZen regions (see Figure 10). So far, data for the Rhine-Ruhr area and Istanbul are available to the CityZen partners. Arianet has developed fine scale emission data for the MEGAPOLI project. By the end of the MEGAPOLI and CityZen projects one could consider to combine this data sets into one set, in collaboration with other projects.

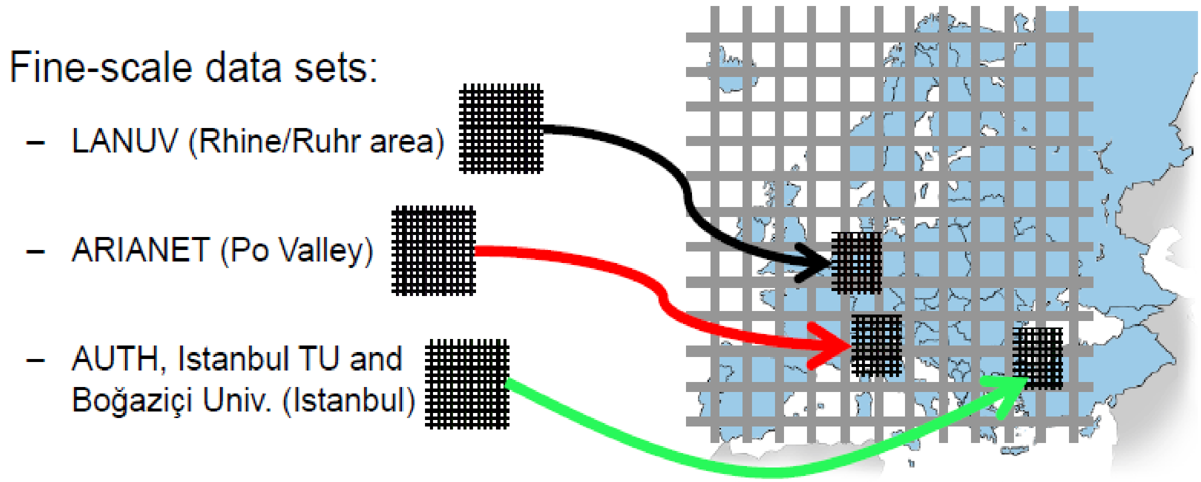

Figure 10: Fine scale emission scenarios to be implemented. The PoValley emission data sets have been developed by ARIANET for CityZen's sister project MEGAPOLI.

8. References

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