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Analyzing the response of a chemical transport model to emissions reductions utilizing various grid resolutions

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16. Kurzfassung
Das chemische Transportmodell REM-CALGRID wurde auf den Großraum Berlin in 4 verschiedenen Auflösungen von 30 km bis zu 1km angewandt. Im Vergleich mit Messungen erbrachte die Rechnung mit der höchsten Auflösung die besten Ergebnisse. Die modellierte Wirksamkeit von Maßnahmen (CLE2010 Szenario und eine 50% Reduzierung aller anthropogenen Emissionen) als Funktion der horizontalen Gitterauflösung zeigte, dass das urbane Signal deutlich unterschätzt wird, wenn die Auflösung zu gering ist. Dies bedeutet, dass die Wirksamkeit von Maßnahmen in Stadtgebieten unterschätzt wird, falls sie auf großräumigen Modellrechnungen beruht. In Stadtgebieten mit einer inhomogenen Emissionsverteilung kann sogar eine Maschenweite von 5 km zu gering sein, um das urbane Signal vollständig zu erfassen.

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16. Abstract

Applying the REM-CALGRID chemical transport model to the greater area of Berlin in four different grid sizes decreasing from 30 km down to 1 km, it turned out that model performance was best for the run with the highest grid resolution. The modelled effectiveness of control measures (CLE2010 scenario and a 50% reduction of all anthropogenic emissions) in an urban area as a function of a horizontal grid resolution showed also, that the urban increment is underestimated by the regional model resolution of 30 km. This implies that the effects of measures will be underestimated in urban areas if they are based on a regional scale model application. In urban areas with a highly inhomogeneous emission pattern even a resolution in the range of 5 km as used in the City-Delta exercise, can be too large for a complete capture of the urban signal.

17. Keywords

EU directives for air quality, dispersion modelling, REM-CALGRID-model, grid size effects, effectiveness of control measures

Contents

1. Introduction

Many efforts are underway in Europe to control the emission sources that are responsible for harmful air pollution effects. The ambient air quality framework directive 96/62/EC (FWD) of the European Commission provides an EU-wide framework for national, regional and local measures to assess, manage, and protect European air quality. The Clean Air For Europe (CAFÉ) programme of the European Commission (http://europa.eu.int/comm/environment/air/cafe/index.htm) encompasses technical analysis and policy development and focuses on the development of long-term, strategic and integrated policy advice for the improvement of Europe's air quality. The likely evolution of air quality in Europe is assessed taking into account the effects of current and planned emission control legislation and future economic development. The assessment is based on a Europe-wide evaluation of the cost-effectiveness of emission-control strategies utilizing the results of the EMEP regional-scale, Eulerian chemical transport model (Amann et al., 2005). This model has been used to calculate source-receptor relationships that reflect the response of air quality to changes in emissions at a spatial resolution of 50*50 km^2. Such an integrated assessment modelling resolution is sufficient to cover all the aspects of long-range transport across Europe, but is too coarse to resolve the inhomogeneities in urban emissions patterns or the resulting high-concentration pollution patterns in areas where a large fraction the European population lives. Thus, a question arises whether concentration changes (or deltas), resulting from emissions deltas and calculated using a coarse-resolution regional model, can be transferred from the regional scale to the urban scale. This question was the motivation for the City-Delta Project (Cuvelier et al., 2006, Vautard et al., 2006). Based on an extended inter-comparison of 17 urban and regional atmospheric transport models applied to six different European cities, this project developed functional relationships that quantify the increments in concentrations that occur within cities compared with those modelled for the regional environment. These relationships describe the difference between the concentrations averaged over 5x5 km^2 in an urban core and the average concentrations calculated over a 50*50 km grid cell covering the whole urban area and its surroundings. This so-called urban increment shall be used later in a modified version of the RAINS cost-effectiveness, optimization model (Amann et al., 2005). In the City-Delta exercise, each model was applied in its own standard configuration without attempting to harmonize input data except for emissions. The urban increment was derived from the differences of model predictions utilizing the two model resolutions combined with the "ensemble modelling" concept (Cuvelier et al., 2006, see also http://aqm.jrc.it/citydelta/), where it is assumed that the average of the model responses, or "ensemble response", gives the most reliable prediction of the emission reduction impact.

The aim of the present study was to supplement City-Delta by using a single model to analyze the relationships between regional and urban air quality levels and the modelled effectiveness of control measures in an urban area as a function of horizontal grid resolution over the range from 30 km down to 1 km. This study should help answer the questions of (a) how reliably regional scale model calculations can be used to compute air quality in urban areas and (b) what grid size

seems to be adequate to describe air quality within a city. In this German EPA (Umweltbundesamt) funded project, photochemical and aerosol modelling simulations over Europe, Germany, the Federal State Brandenburg and the agglomeration/metropolitan area of Berlin for all of 2002 were performed using the REM-CALGRID (RCG) chemical transport model.

For the year 2002, RCG was applied on four grids for the following three cases:

- Base case simulation 2002;
- The CLE-scenario (Implementation of current legislation until 2010); and,
- A 50% emissions reduction of all anthropogenic species in each domain.

2. The RCG model

The REM-CALGRID model is an urban/regional scale model development designed to fulfil the requirements of the ambient air quality framework directive 96/62/EC of the European Commission (Stern et al., 2003). Rather than creating a completely new model, the urban-scale photochemical model CALGRID (Yamartino et al., 1992) and the regional scale model REM3 (Stern, 1994; Hass et al., 1997) were used as the starting point for the new urban/regional scale model, REM-CALGRID (RCG). The premise was to design an Eulerian grid model of medium complexity that can be used on the regional, as well as the urban, scale for short-term and long-term simulations of oxidant and aerosol formation.

The model includes the following features:

- A generalized horizontal coordinate systems, including latitude-longitude coordinates;
- A vertical transport and diffusion scheme that correctly accounts for atmospheric density variations in space and time, and accounts for all vertical flux components when employing either dynamic or fixed layers;
- A new methodology to eliminate errors totally from operator-split transport and ensure correct transport fluxes, mass conservation, and that a constant mixing ratio field remains constant;
- Inclusion of the recently improved and highly-accurate, monotonic advection scheme developed by Walcek (2000). This fast and accurate scheme has been further modified to exhibit even lower numerical diffusion for short wavelength distributions;
- Updated releases of the SAPRC-93 and CBM-IV photochemical reaction schemes including Carter's (1996) 1-product isoprene scheme and SO_2 oxidation to SO_4;
- Two equilibrium aerosol modules, that treat the thermodynamics of inorganic aerosols;

- An equilibrium aerosol module, that treat the thermodynamics of organic aerosols
- Simple modules to treat the emissions of sea salt aerosols and wind blown dust particles
- A simple wet scavenging module based on precipitation rates;
- An emissions data interface for long term applications that enables on-the-fly calculations of hourly anthropogenic and biogenic emissions, and greatly facilitates emissions reduction scenario studies.

RCG uses the bulk approach for the aerosol modelling. Aerosol dynamics are not considered. The model employs two different equilibrium aerosol modules: a) The MARS-A module (Binkowski and Shankar, 1995) that treats the thermodynamics of the inorganic sulfate, nitrate, ammonium aerosols and water, and b) the ISORROPIA module that additionally treats sodium and chloride aerosols (Nenes et al., 1999). Secondary organic aerosols (SOA) that are formed by condensation of biogenic and anthropogenic hydrocarbon oxidation products are considered employing the SORGAM module developed by Schell et al. (2001).

The sea-salt aerosol emissions are parameterized according to Gong et al. (1997) as a function of size and wind speed. For the calculation of land-use dependent wind blown dust emissions the following release mechanism are treated: Direct release of small dust particles by the wind (Loosmore and Hunt, 2000), and indirect release by collisions with bigger soil grains, that are lifted by the wind but return to the surface because of their weight („saltation“ process, Claiborn et al.,1998).

The aerosol components are assigned to two size fractions: fine mode PM2.5 and coarse mode PM10-PM2.5. The anthropogenic emissions data base has to provide the primary emissions split into these two size categories. The anthropogenic PM emissions are allocated to 4 model species: one coarse mode species $PMCO_{prim}$ = PM10-PM2.5, 3 fine mode species, EC, OC, and a mineral rest (MR). The photochemical mechanisms include the oxidation of SO_2 to gaseous sulphate, which is assumed to be gaseous sulphuric acid. The aerosol modules treat the thermodynamics of the inorganic aerosols, depending on the gas phase concentrations of nitric acid, ammonia, sulphuric acid, HCl, humidity and temperature. In RCG, all secondary aerosols are assigned to the PM2.5 fraction. All aerosols are transported and subjected to wet and dry deposition. PM10 concentrations are then defined as the sum of primary PM10 and secondary organic and inorganic aerosols via the relation:

$$PM10 = PMCO_{prim} + EC + OC + MR + SO_4 + NO_3 + NH_4 + SOA + Na + Cl$$

RCG uses a resistance-based model (aerodynamic resistance, viscous sub-layer resistance, surface resistance) for the computation of dry deposition rates as a function of geophysical parameters, micrometeorological conditions, and gaseous or particle pollutant species including the gravitational settling speed of particles. Species dependent deposition velocities are calculated for each land-use class within each grid cell, and deposition fluxes are computed by summing over the fractional land-use terms.

Meteorological data needed by RCG at hourly intervals consist of layer-averaged gridded fields of wind, temperature, humidity and density, plus 2-d gridded fields of mixing heights, several boundary layer and surface variables, precipitation rates and cloud cover. All this meteorological data is produced employing a diagnostic meteorological analysis system based on an optimum interpolation procedure on isentropic surfaces. The system utilizes all available synoptic surface and upper air data (TRAMPER, Tropospheric Realtime Applied Procedure for Environmental Research, Reimer and Scherer, 1992).

The RCG model also requires annual emissions of VOC, NO_x, CO, SO_2, CH_4, NH_3, PM10, and PM2.5, split into point and gridded area sources. Mass-based, source group dependent NMVOC profiles are used to break down the total VOC into the different species classes of the chemical mechanisms. Hourly emissions are derived during the model run using source-group dependent, month, day-of-week and hourly emissions factors. Biogenic VOC-emissions are derived using the E94 emissions factors for isoprene and OVOC (Other VOCs) as described in Simpson et al. (1995). Terpene emissions factors are taken from the CORINAIR emission hand-book. These biogenic calculations are based on the land-use data for deciduous, coniferous, mixed forests and crops. Light intensity and temperature dependencies are also considered.

Monthly varying lateral and top boundary conditions for ozone are taken from clima-tological background data (Logan, 1998). Boundary data for all other species are chosen as time- and space-variing typical background values similiar to the procedure used in the EMEP-model.

RCG model evaluation was performed mainly within the framework of several European model inter-comparison studies (Stern et al., 2003; Hass et al., 2003; Van Loon et al., 2004, Cuvelier et al., 2006). The comparison of the RCG results with the results of other models involved in these model intercomparison studies shows that the RCG medium complexity model is performing very well in comparison to other models.

3. The four domains and model set-up

For this study, the RCG model was run in a Latitude/Longitude (Lat./Lon.) coordinate system at four different horizontal grid resolutions to assess the air quality in Berlin:

- A European scale grid, covering N. Europe with resolution of 0.25° (Lat.) by 0.5° (Lon.) (i.e., nominally about 30-km);
- Nest 1: a national scale grid, covering Germany and having twice the resolution of grid #1 (i.e., approx. 15-km);
- Nest 2: A German Federal State grid, covering Brandenburg and Berlin, and having 8 times the resolution of grid #1 (i.e., approx. 4-km); and,

- Nest 3: An urban scale grid, covering Berlin, and having 32-times the resolution of grid #1 (i.e., approx. 1-km).

Figure 1 shows the four different modelling areas. For all domains, RCG was applied using the CBM-photochemical mechanism, the ISORROPIA module for the inorganic aerosol formation and the SORGAM module for the organic aerosol formation. The model was run with five vertical layers: a 20 m thick surface layer, two equal-thickness layers below the mixing height, and two above the mixing height and extending to the domain top at 3000m. Grid-dependent meteorological input data were produced employing the TRAMPER diagnostic meteorological analysis system based on an optimum interpolation procedure on isentropic surfaces. The system utilizes all available synoptic surface and upper air data as well as topographical and land use information. The boundary conditions for the nested applications (Nests 1-3) were taken from the next larger grid. The European scale run uses monthly-varying lateral and top boundary conditions for ozone taken from climatological background data. Boundary data for all other species are fixed and chosen as typical background values.

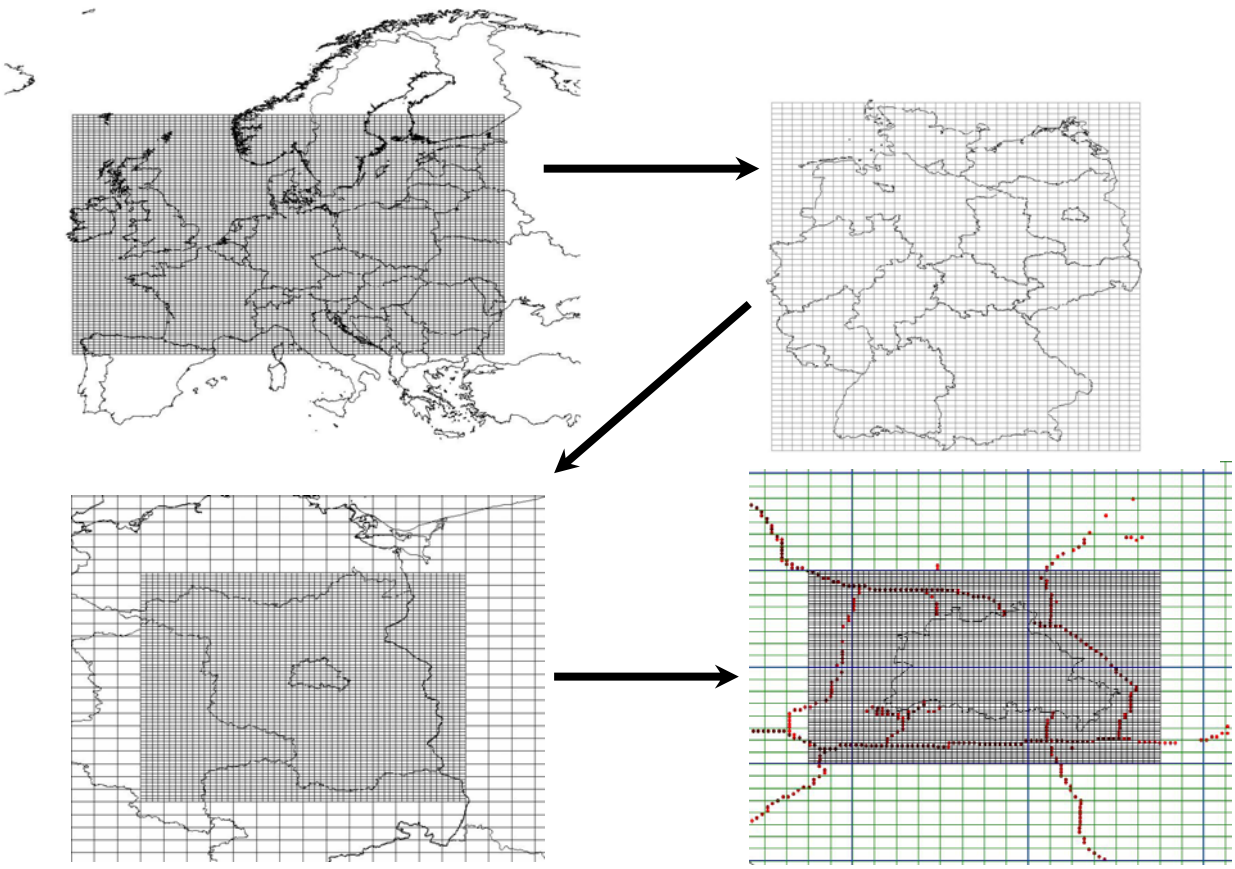

Figure 1 : RCG modelling domains. Upper left: European scale grid with resolution of 0.25° Lat., 0.5° Lon. Upper right: Nest 1, national scale (Germany) grid with resolution of 0.125° Lat., 0.25° Lon. Lower left: Nest 2, the Federal State (Brandenburg) grid with resolution of 0.03125° Lat., 0.0625° Lon., embedded in Nest 1. Lower right: Nest 3, urban grid Berlin with resolution of 0.0078125° Lat., 0.015625° Lon., embedded in Nest 2 (and Nest 1) and also showing in red the major “ring” motorway around Berlin.

4. Harmonizing of Emissions

A major problem for nested grid applications is the necessity of establishing consistency between the top-down emission data, typically used on the continental and regional scales, and the bottom-up emission estimates, typically used in urban-scale modelling. This study utilized two different sets of emissions data: the regional TNO emissions inventory (Visscherdijk and van der Gon, 2005), which covers all of Europe at a horizontal resolution of 0.125° latitude and 0.25° longitude; and, the local inventories of the States of Brandenburg and Berlin, available at a resolution of 1x1 km^2 (Kerschbaumer and Stern, 2005). The sectoral totals of the TNO emissions data set conform to the country submissions to EMEP for the year 2000, i.e. the national totals agree with the officially reported national emissions to the Convention on Long Range Transboundary Air Pollution (CLTRAP, see EMEP, 2003). The local emissions are also for the reference year 2000, and both emission inventories have a future emissions projection for 2010 based on the assumption of the so-called CLE-scenario (Current Legislation scenario, which assumes full implementation of the presently decided emissions-related legislation in all EU-countries, see Amann et al., 2005). However, as could be expected, the two inventories differ substantially for the Brandenburg and greater Berlin areas covered by Nests 2 and 3, respectively. Because the differences between the TNO emissions and the urban emissions were too large to be neglected for the focus of this study, the TNO emissions within the Nest 2 and Nest 3 area were substituted by the fine-scale local emissions. On the other hand, the expected relative emission changes from 2000 to 2010 for the local inventory were set identical to those of the regional TNO data set for Germany on a sector-by-sector basis. This procedure guaranteed the use of harmonized emissions at all scales and assures that differences in the calculated concentration data were solely due to the differing grid resolution and not due to differing emissions. The modified regional scale TNO inventory was used for the European and Nest 1 model runs, the local inventory for the Nest 2 and Nest 3 runs. The emission totals in the European grid cells covering the greater Berlin area are identical at all scales, but the emission density distribution is different, depending on the resolution of the grid (Figure 2).

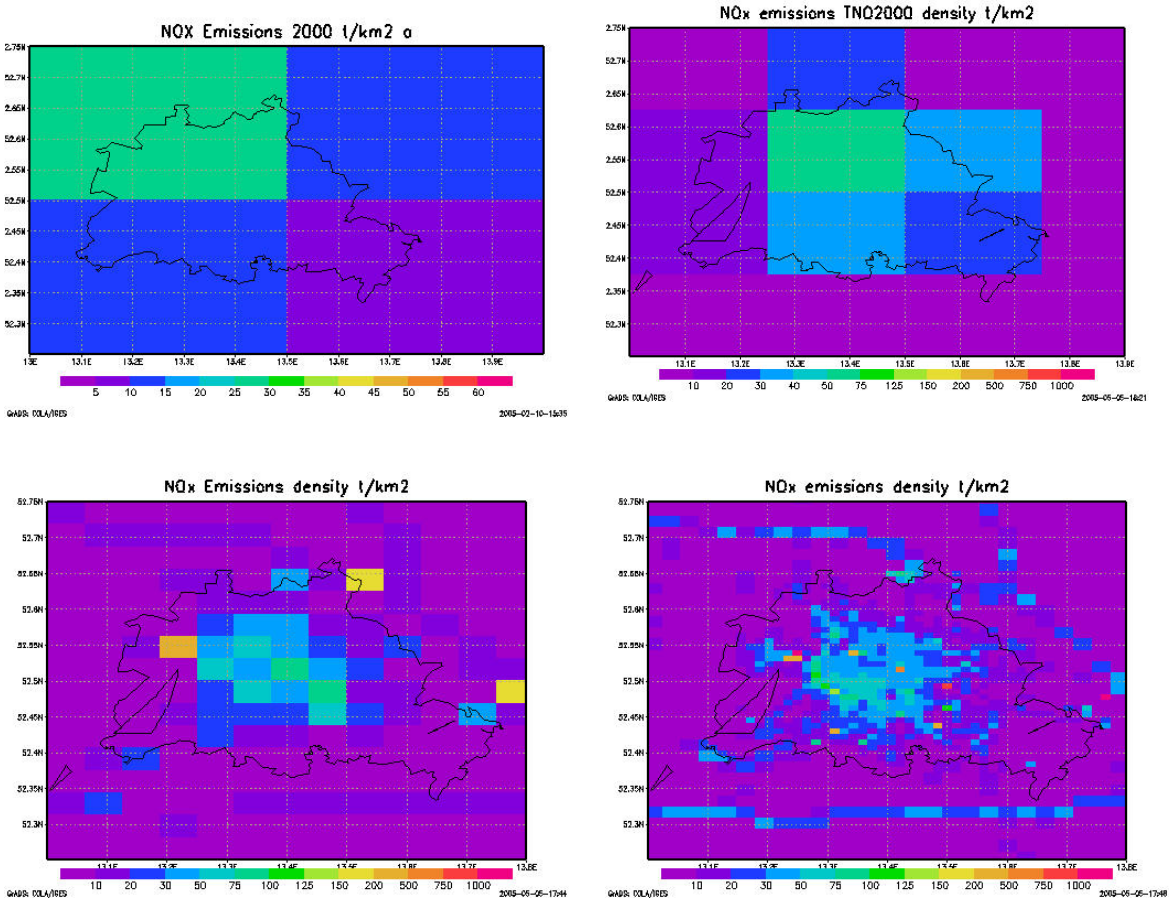

Figure 2 : NOx annual emissions density in t/km^2 at four scales for the greater Berlin area. Upper left: European scale grid, Upper right: Nest 1, national scale (Germany) grid Lower left: Nest 2, the Federal State (Brandenburg). Lower right: Nest 3, urban grid Berlin. For grid resolutions, see Fig. 1. Note the different scaling for the European grid.

5. Base case simulations

The base case simulation results at all scales were compared to available PM10- and NO_2-measurements in the greater Berlin area to quantify how regional model predictions differ from those obtained with finer resolution modelling. Examination of concentration isopleths plots for NO_2 (Figure 3) indicates that the European- and national-scale grids fail to capture any of the inner-urban concentration variability. The city core of Berlin starts to be resolved by the 4x4 km^2 grid of Nest 2, but really becomes clear only in the 1x1 km^2 grid of Nest 3. The calculated NO_2-concentration ranges in the greater Berlin area are 10-22 µg/m^3 for the European scale, 10-26 µg/m^3 for Nest 1, 10-30 µg/m^3 for Nest 2, and 10-35 µg/m^3 for Nest 3. A similar picture emerges for PM10 (Figure 4). The respective PM10 concentration ranges are 15-22 µg/m^3 for the European scale, 15-28 µg/m^3 for Nest 1, 15-28 µg/m^3 for Nest 2, and 15-33 µg/m^3 for Nest 3.

Figure 5 shows the comparison of the calculated NO_2 and PM10 annual mean values with the measurements at all stations which are not directly influenced by nearby traffic emissions. In particular, for NO_2, the agreement between predictions and observations steadily improves from the European scale to the Nest 3 scale. The European scale model run and also the Nest 1 model run completely fail to capture the high NO_2 observations. The Nest 2 model runs does a much better job, but the best simulation of the peak values is achieved in the Nest 3 model run. The model performance for PM10 is clearly worse than that for NO_2 at all scales, but it is also obvious that a PM10 model calculation with a regional grid resolution is not able to reproduce the observed pattern in urban areas. For PM10, the Nest 1 run exhibits a little better correlation than the Nest 2 run, while Nest 2 yields a nearly perfect regression slope of 0.98 and suggests an under-prediction by about 5.5 $\mu g/m^3$. However, in view of the small number of stations one should be careful not to over-interpret these statistical results. Again, most of the observations are underestimated, which is a well-known feature of current PM10 simulations (van Loon et al., 2004). This underestimation can primarily be attributed to un-inventoried particle sources, known to exist but difficult to quantify (e.g., biogenic sources; wind blown dust from agricultural sources and natural surfaces; re-suspension of road dust). Also particle-bound water which contributes to gravimetrically measured PM mass can be responsible for some of the underestimation, because the models usually only consider dry aerosol mass (Tsyro, 2005). In Nest 1 and Nest 2, the underestimation is approximately the same (i.e., about 5-6 $\mu g/m^3$) in all observed concentration ranges. In Nest 3, the lower observed PM10 concentrations at the border of the Nest 3 modelling area are underestimated to the same degree as in Nest 1 and Nest 2, but the peak observations in the urban core are captured better. If the uniform underestimation can be attributed to too low a background level, this would lead to Nest 3 overestimation of some of the observed, urban core PM10 concentrations. This situation might indicate possible errors in the 1x1 km^2 emission inventory, which are then diffused in the data sets with a higher spatial aggregation. Presently however, there are too few stations to draw final conclusions.

Figure 6 shows the concentration difference between the European scale run and the nested runs at the NO2- and PM10 measurements stations in Berlin and surroundings. These differences can be interpreted as the urban increments that cannot be resolved by regional scale model runs having grid resolutions of 30 km or larger. The stations are further characterized as urban (city), suburban and rural/suburban stations. At most city stations, the urban increments increase with decreasing grid size. The urban increments for Nest 3 (resolution approx. 1 km x1 km) are as large as 16 $\mu g/m^3$ for NO_2 and 10 $\mu g/m^3$ for PM10; however, away from the urban core, the increments decrease, and even turn negative, for stations in the suburbs and rural outskirts. Figure 7 shows the urban increments for PM2.5 and SIA, the sum of the secondary inorganic aerosols. The SIA urban increments are very small because most of the secondary aerosols are formed during the long range transport outside of the city. PM2.5 exhibits quite a large urban increment at the urban core stations indicating that in the city center of Berlin the primary contribution to the total PM2.5 concentration can be rather large.

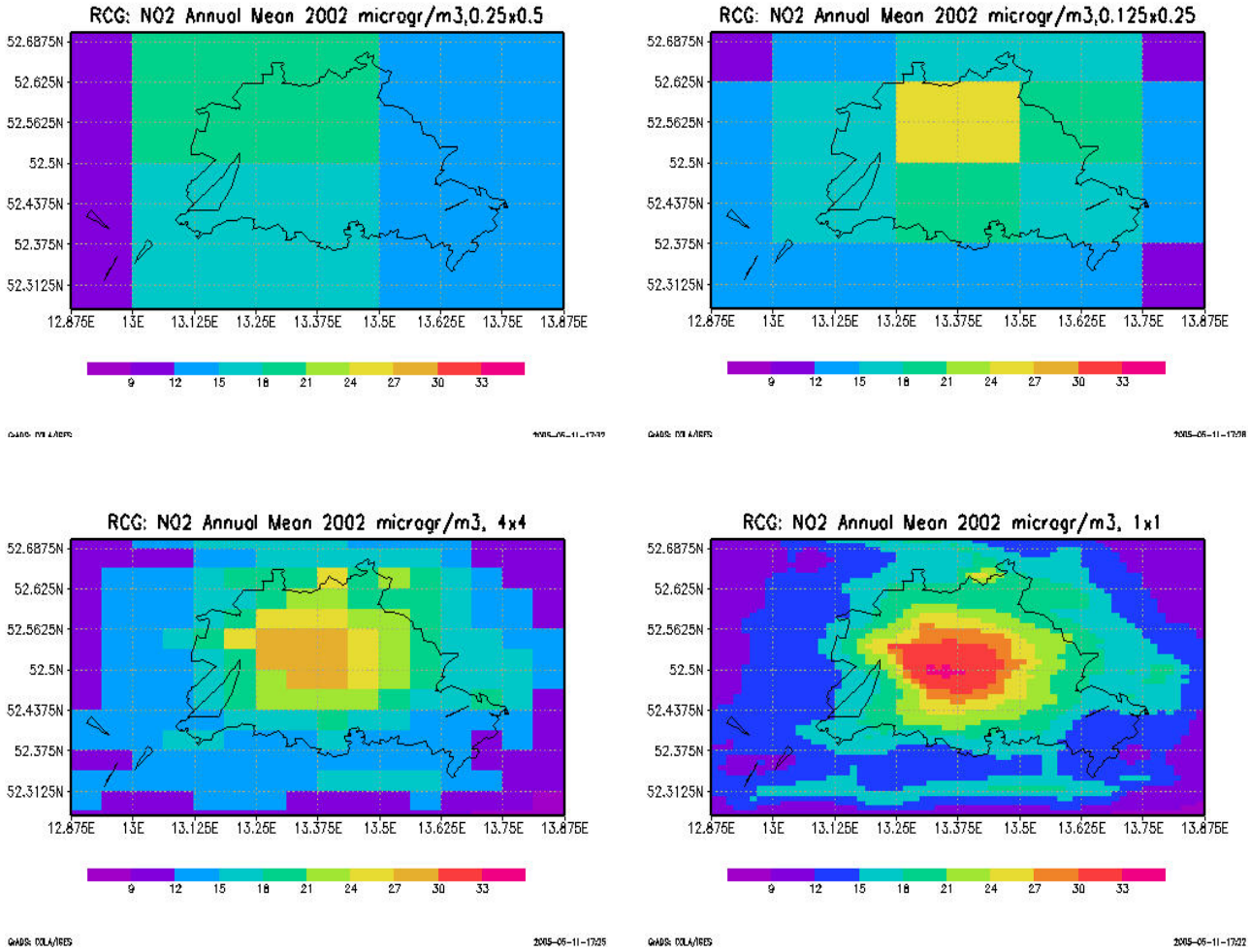

Figure 3 Calculated NO_2 annual mean at four scales for the greater Berlin area. Upper left: European scale grid, Upper right: Nest 1, national scale (Germany) grid Lower left: Nest 2, the Federal State (Brandenburg). Lower right: Nest 3, urban grid Berlin. For grid resolutions, see Fig. 1.

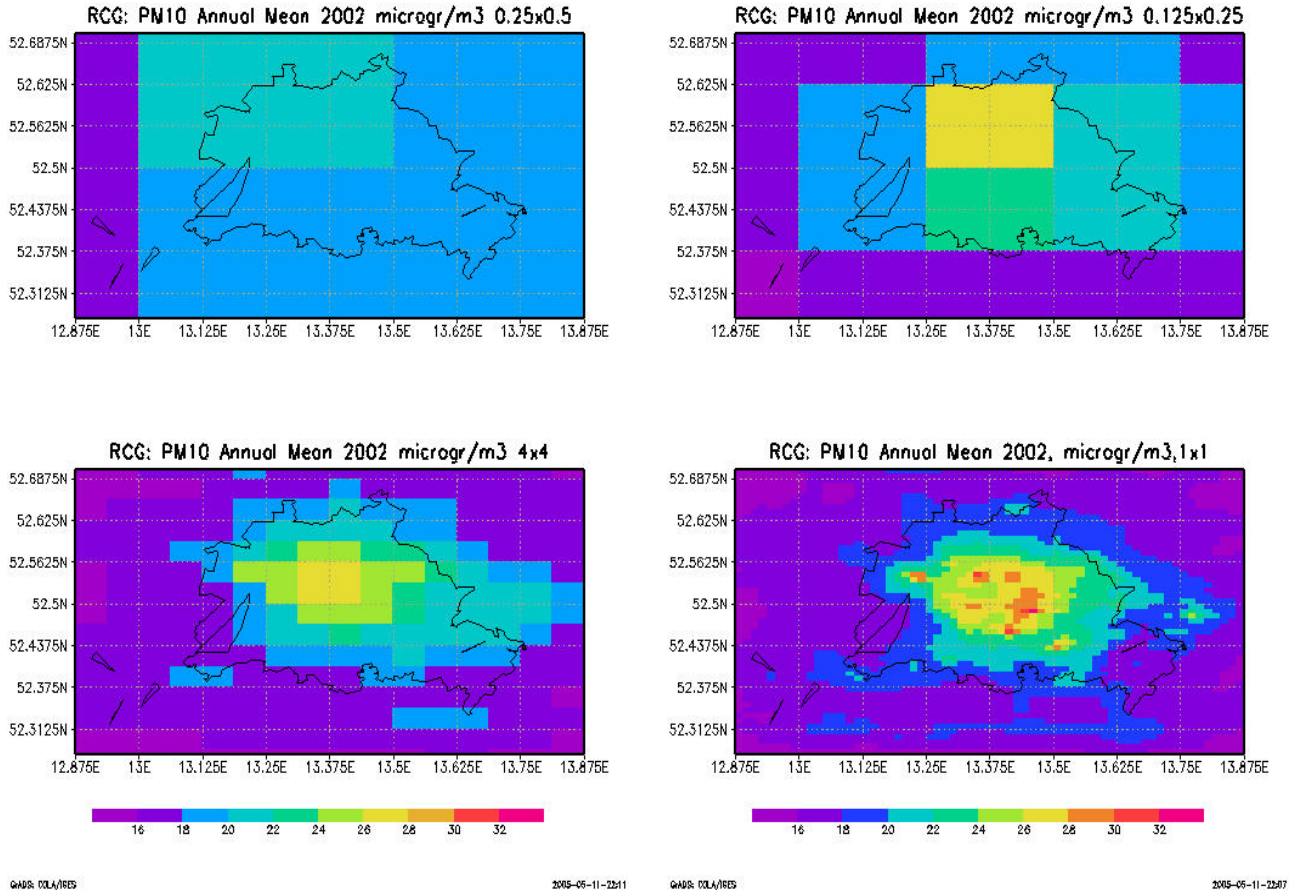

Figure 4 Calculated PM10 annual mean at four scales for the greater Berlin area. Upper left: European scale grid, Upper right: Nest 1, national scale (Germany) grid Lower left: Nest 2, the Federal State (Brandenburg). Lower right: Nest 3, urban grid Berlin. For grid resolutions, see Fig. 1.

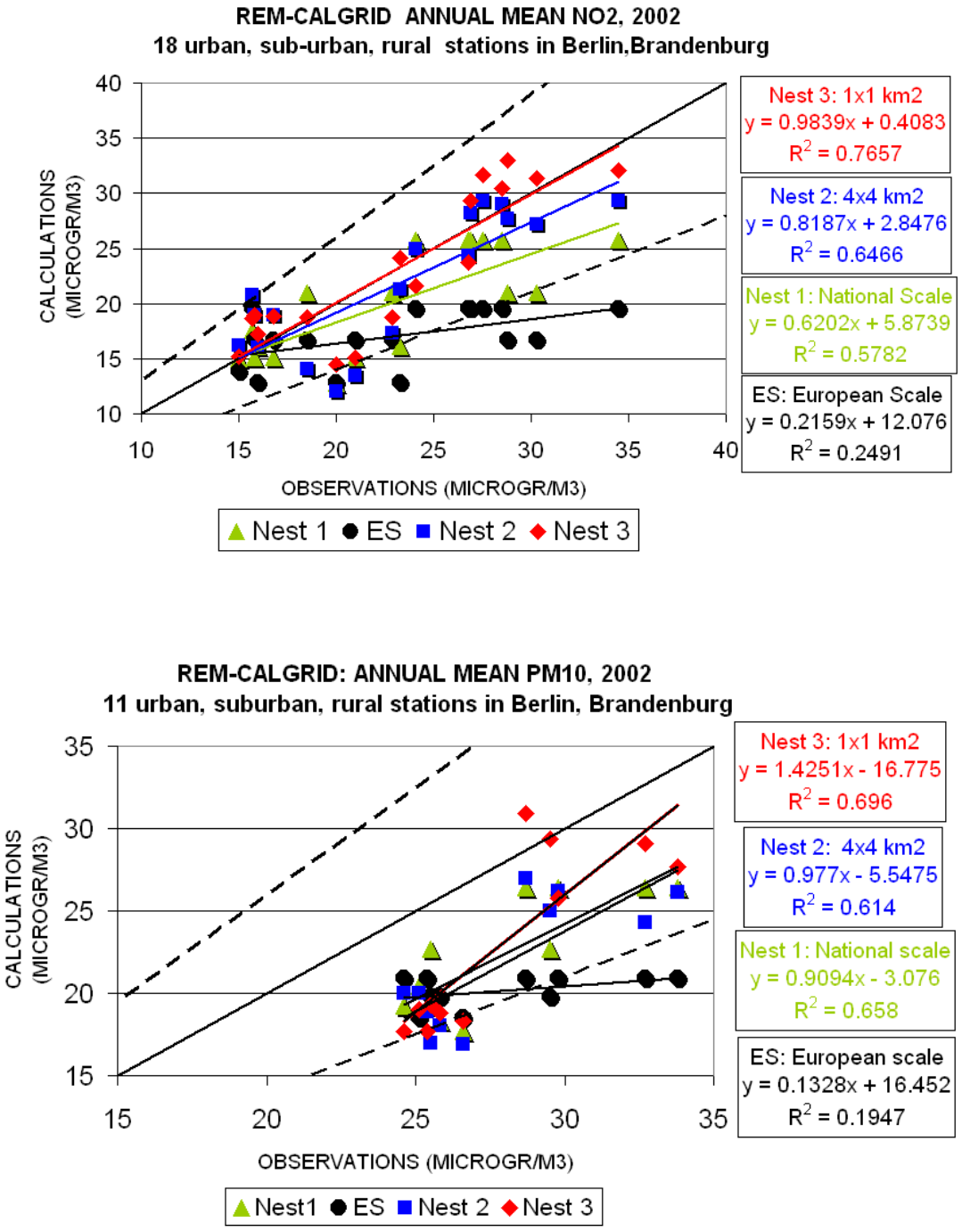

Figure 5 Scatter diagram of observed and calculated NO_2 and PM10 annual means in the greater Berlin area at four scales, including regression lines and correlation coefficients. Dashed lines indicate the range of +/- 50% of the observations. For further explanations see text.

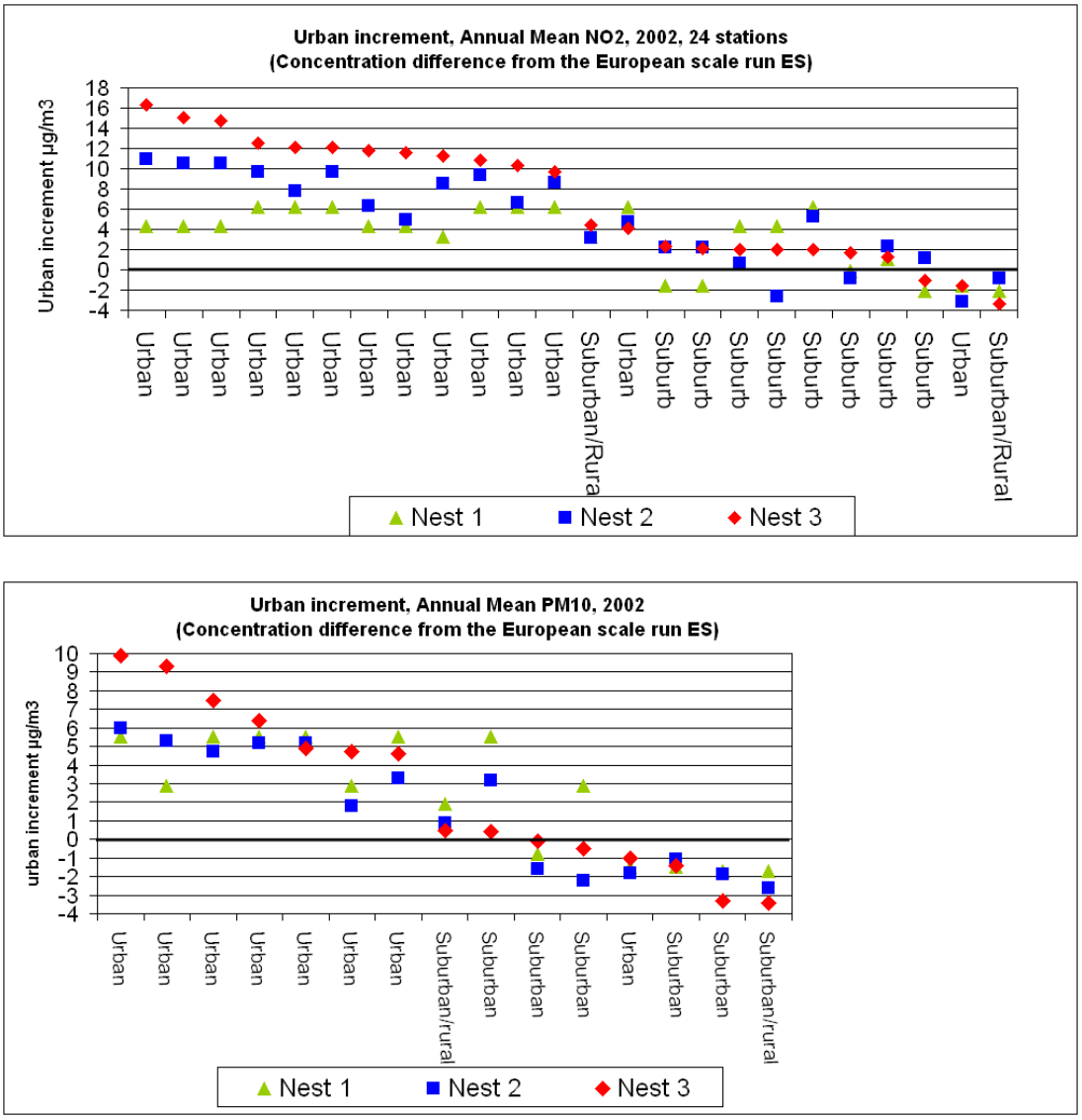

Figure 6 NO_2 and PM10 annual mean urban increments in µg/m^3 at NO_2 and PM10 measurement locations in the Berlin area, characterized as urban, suburban and rural/suburban type stations. For further explanations see text.

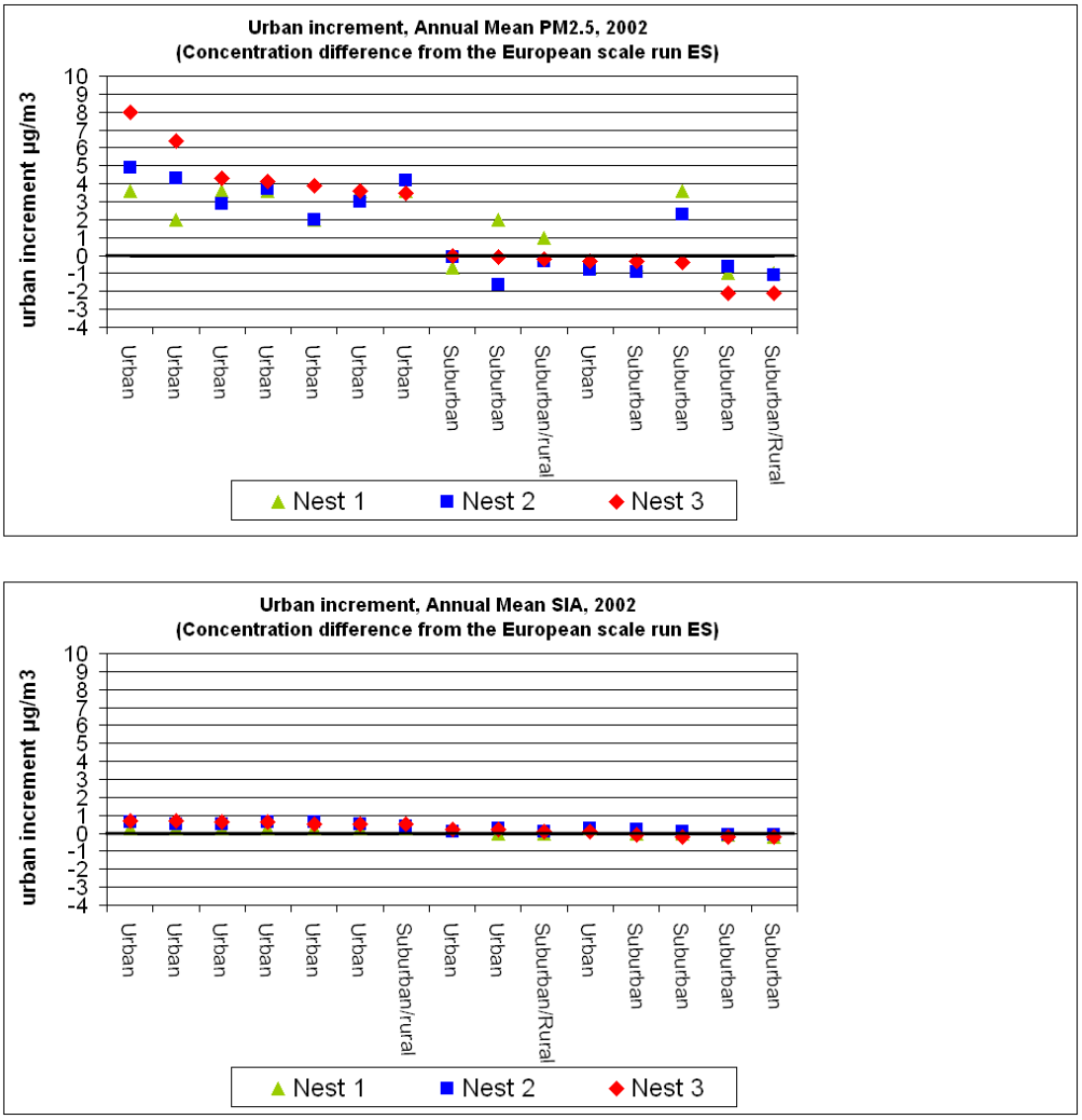

Figure 7 PM2.5 and SIA (sum of the secondary inorganic aerosols) annual mean urban increments in µg/m^3 at PM10 measurement locations in the Berlin area, characterized as urban, suburban and rural/suburban type stations. For further explanations see text.

6. Scenario runs

Both scenarios, the 50% reduction of all anthropogenic emissions and the implementation of the CLE scenario, were performed at the four grid resolutions. For Germany, the CLE 2010 scenario implies an average reduction of the NOx emissions of 29%. The respective reductions for NMVOC, SO_2 and PM10 are 30%, 31% and 14%, respectively, relative to the 2000 emissions figures. The predicted NO_2 concentration reductions based on the CLE scenario assumptions indicate that for the greater Berlin area calculated NO_2 decreases are estimated at 3-5 $\mu g/m^3$ in the European scale run, 2-6 $\mu g/m^3$ for the Nest 1 and Nest 2 runs, and 2-7 $\mu g/m^3$ for the Nest 3 run (Figure 8). The highest resolution Nest 3 run shows the most inhomogeneous concentration delta field over the Berlin area, with larger deltas in the city core and smaller deltas at the outskirts of the city, and these inhomogeneities are progressively diffused as one moves to the coarser resolution runs. Such smearing at coarser resolutions distorts the efficacy of the CLE strategy in that it suggests greater reductions in the urban outskirts and smaller reductions in the urban core. A similar picture emerged for PM10 predictions (Figure 9). The respective PM10 concentration decreases in the greater Berlin area due to the CLE 2010 emission decreases are: 2-3 $\mu g/m^3$ for the European scale run, 2-4 $\mu g/m^3$ for Nest 1 and Nest 2, and 2-5 $\mu g/m^3$ for Nest 3.

Figure 10 shows the scale dependent concentration deltas at 25 NO_2 and 15 PM10 measurement sites in the greater Berlin area. The deltas predicted in Nests 1 thru 3 are expressed relative to (or normalized by) the deltas calculated in the European scale run. At city stations, the concentration decreases due to the CLE scenario and predicted by the high-resolution model run can be up to 50% larger than those estimated by regional models. On the other hand, the regional run tends to predict somewhat larger decreases than the higher resolution modelling runs at the suburban outskirts of the city.

In the second scenario, involving the uniform 50% reduction of all anthropogenic emissions, the absolute differences of the concentration deltas calculated in the four scales are larger than for the CLE-scenario runs (Figure 11, Figure 12), due to the larger emissions reduction rates. In the city center, also the normalized concentration deltas are higher (Figure 13). The concentration decreases due to a 50% reduction of all anthropogenic emissions predicted by the high-resolution model run can now be up to 70% larger than those estimated by the regional model run.

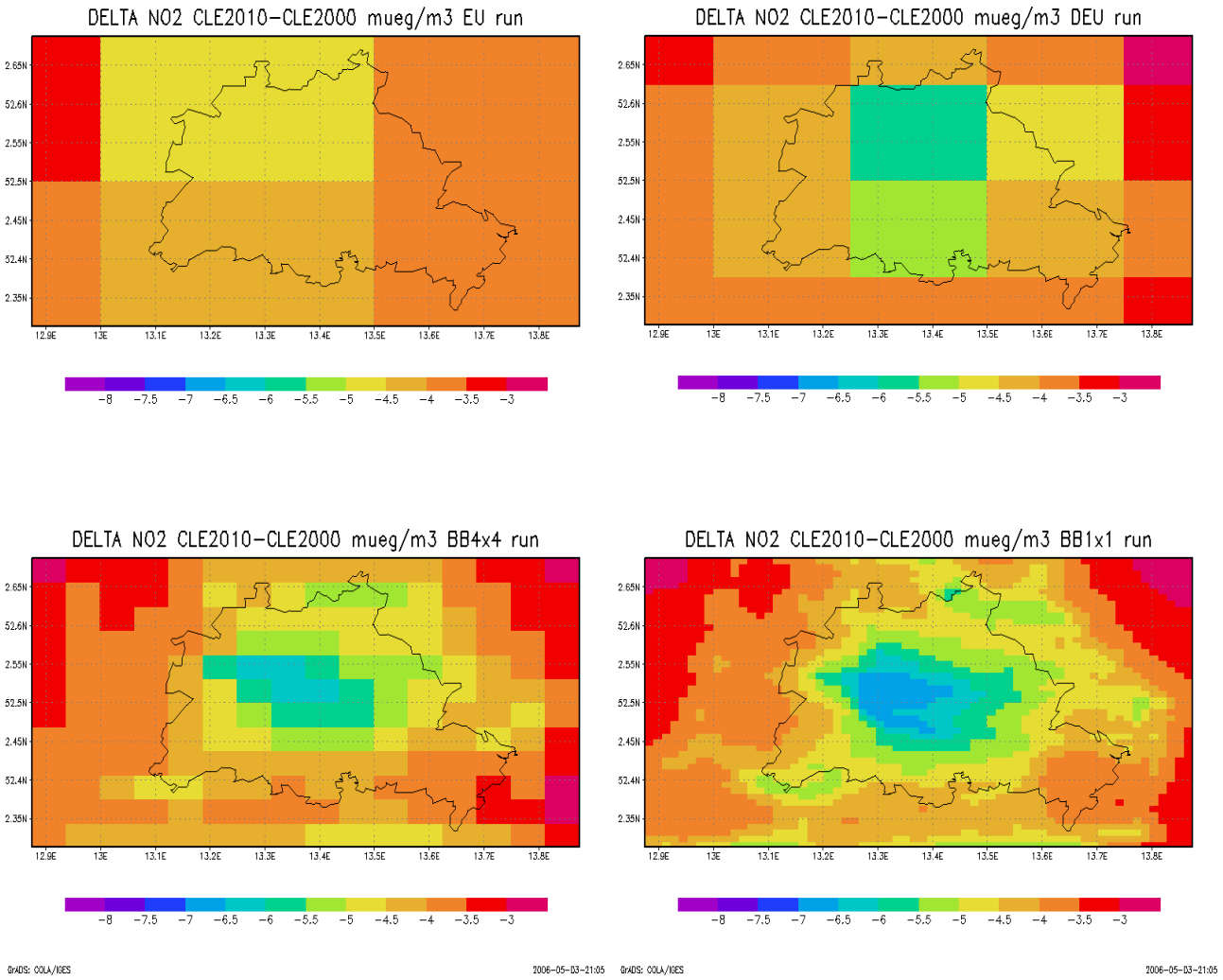

Figure 8 Calculated changes (µg/m^3) in the annual mean NO_2 concentrations from the emission situation 2000 to the CLE emission situation 2010. Upper left: European scale grid, Upper right: Nest 1, national scale (Germany) grid lower left: Nest 2, the Federal State (Brandenburg). Lower right: Nest 3, urban grid Berlin. For grid resolutions, see Fig. 1

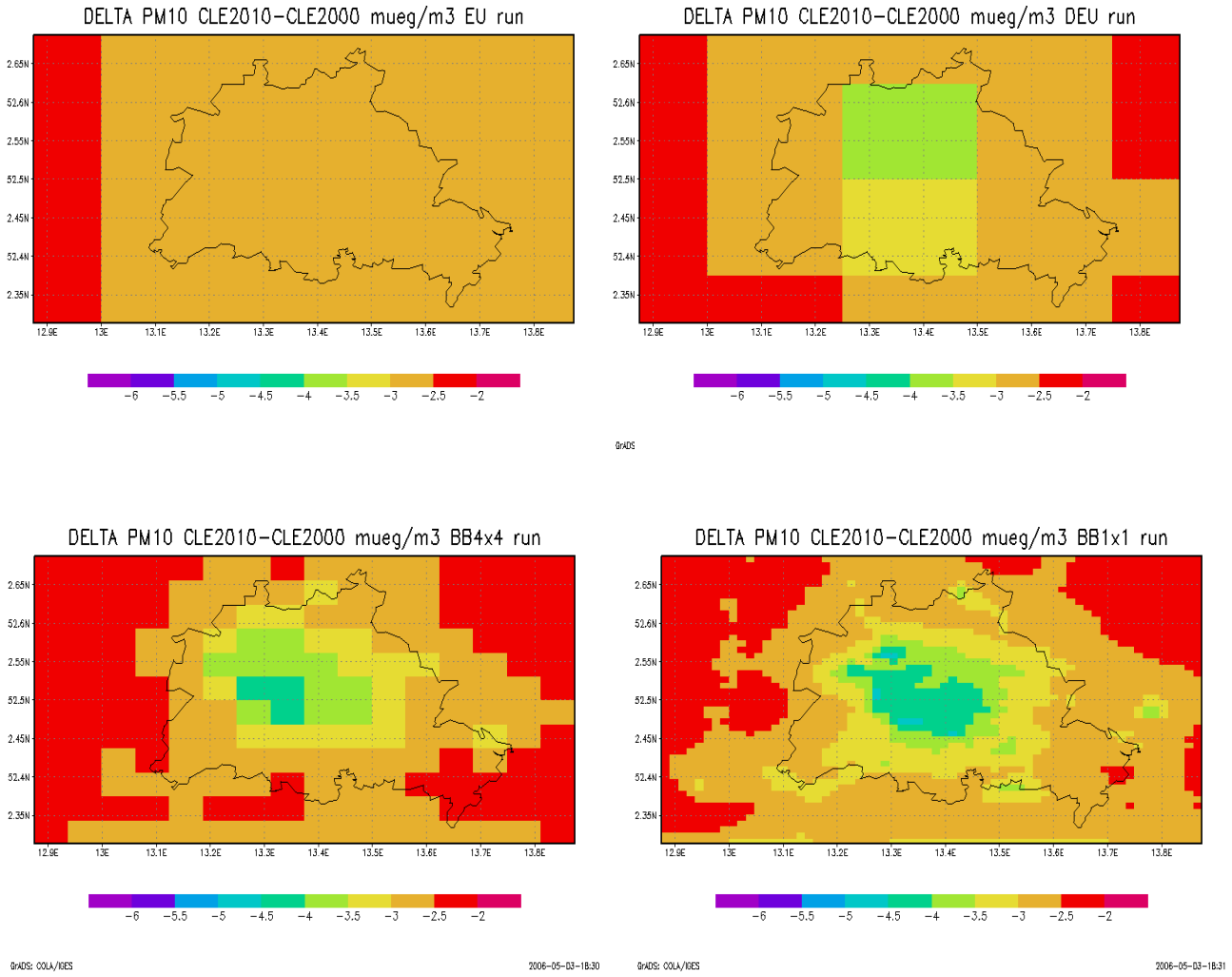

Figure 9 Calculated changes (µg/m^3) in the annual mean PM10 concentrations from the emission situation 2000 to the CLE emission situation 2010. Upper left: European scale grid, Upper right: Nest 1, national scale (Germany) grid lower left: Nest 2, the Federal State (Brandenburg). Lower right: Nest 3, urban grid Berlin. For grid resolutions, see Fig. 1

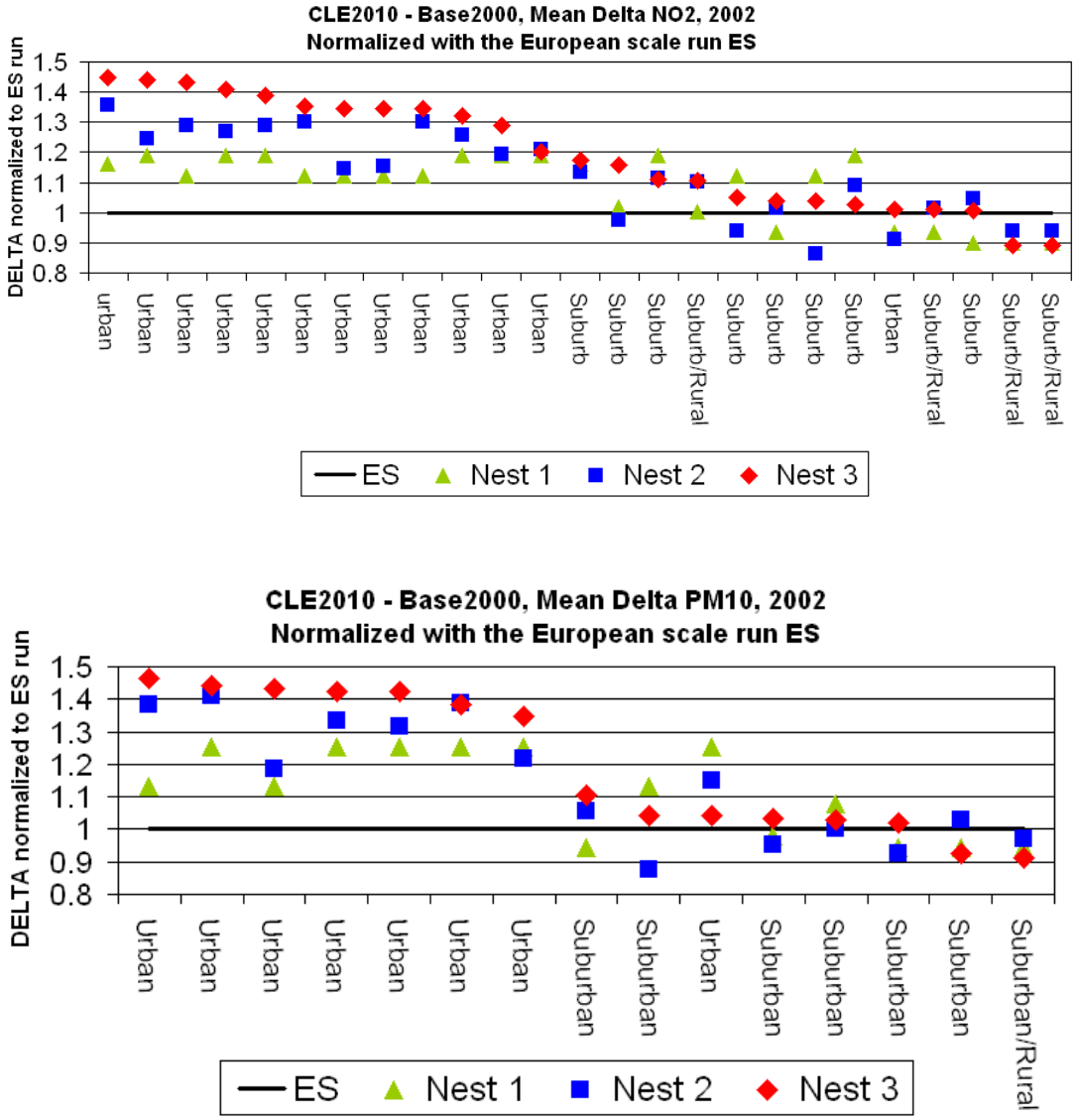

Figure 10 NO_2 and PM10 concentration deltas at 25 NO_2 and 15 PM10 measurement sites characterized as urban, suburban and rural/suburban type stations. The deltas for Nest 1 to 3 are expressed relative to (i.e., divided by) the normalized deltas calculated for the European scale run. CLE 2010 Scenario. For further explanations see text.

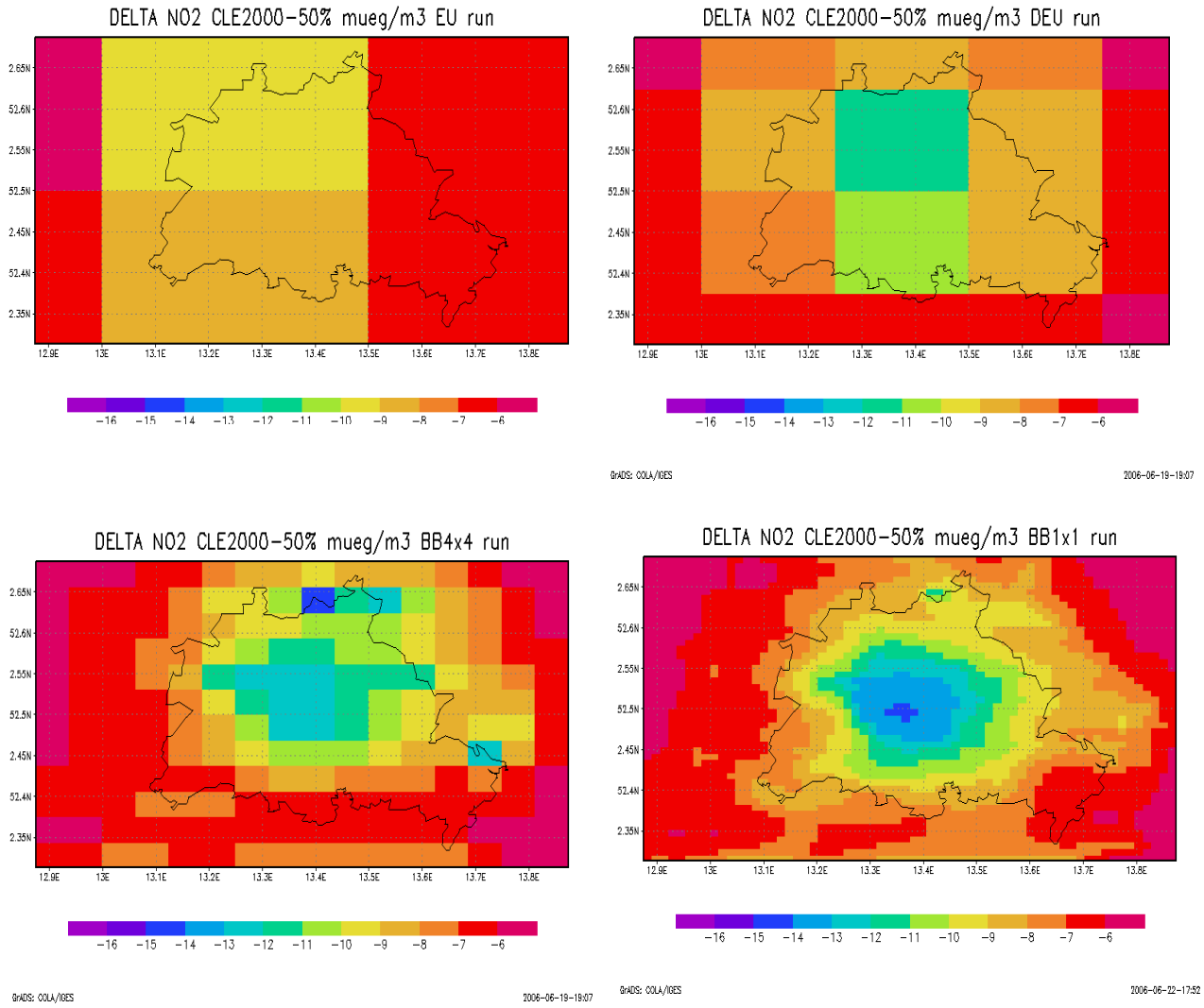

Figure 11 Calculated changes (µg/m^3) in the annual mean NO_2 concentrations from the emission situation 2000 to a uniform -50% emission situation. Upper left: European scale grid, Upper right: Nest 1, national scale (Germany) grid lower left: Nest 2, the Federal State (Brandenburg). Lower right: Nest 3, urban grid Berlin. For grid resolutions, see Fig. 1

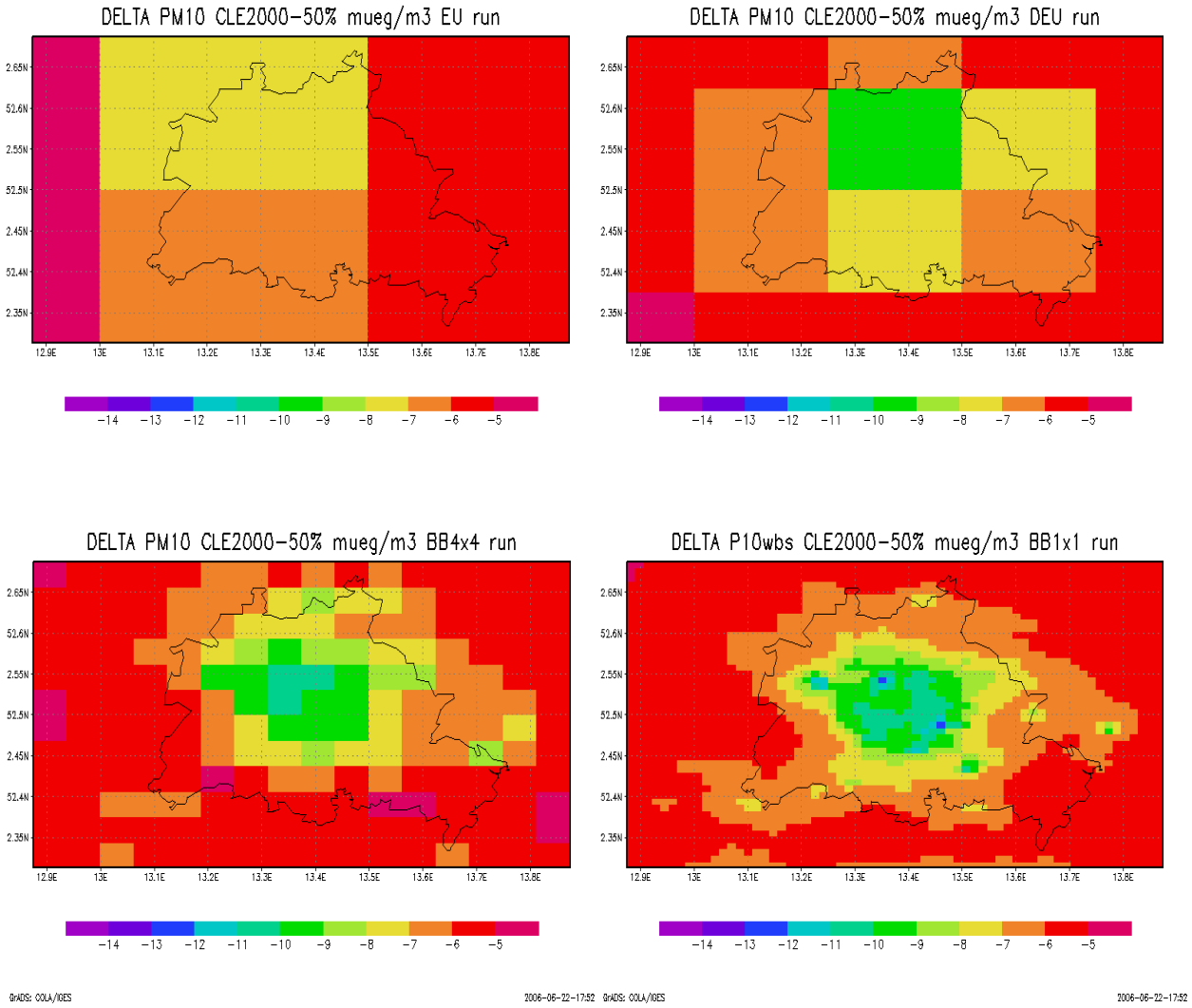

Figure 12 Calculated changes (µg/m^3) in the annual mean PM10 concentrations from the emission situation 2000 to a uniform -50% emission situation. Upper left: European scale grid, Upper right: Nest 1, national scale (Germany) grid lower left: Nest 2, the Federal State (Brandenburg). Lower right: Nest 3, urban grid Berlin. For grid resolutions, see Fig. 1

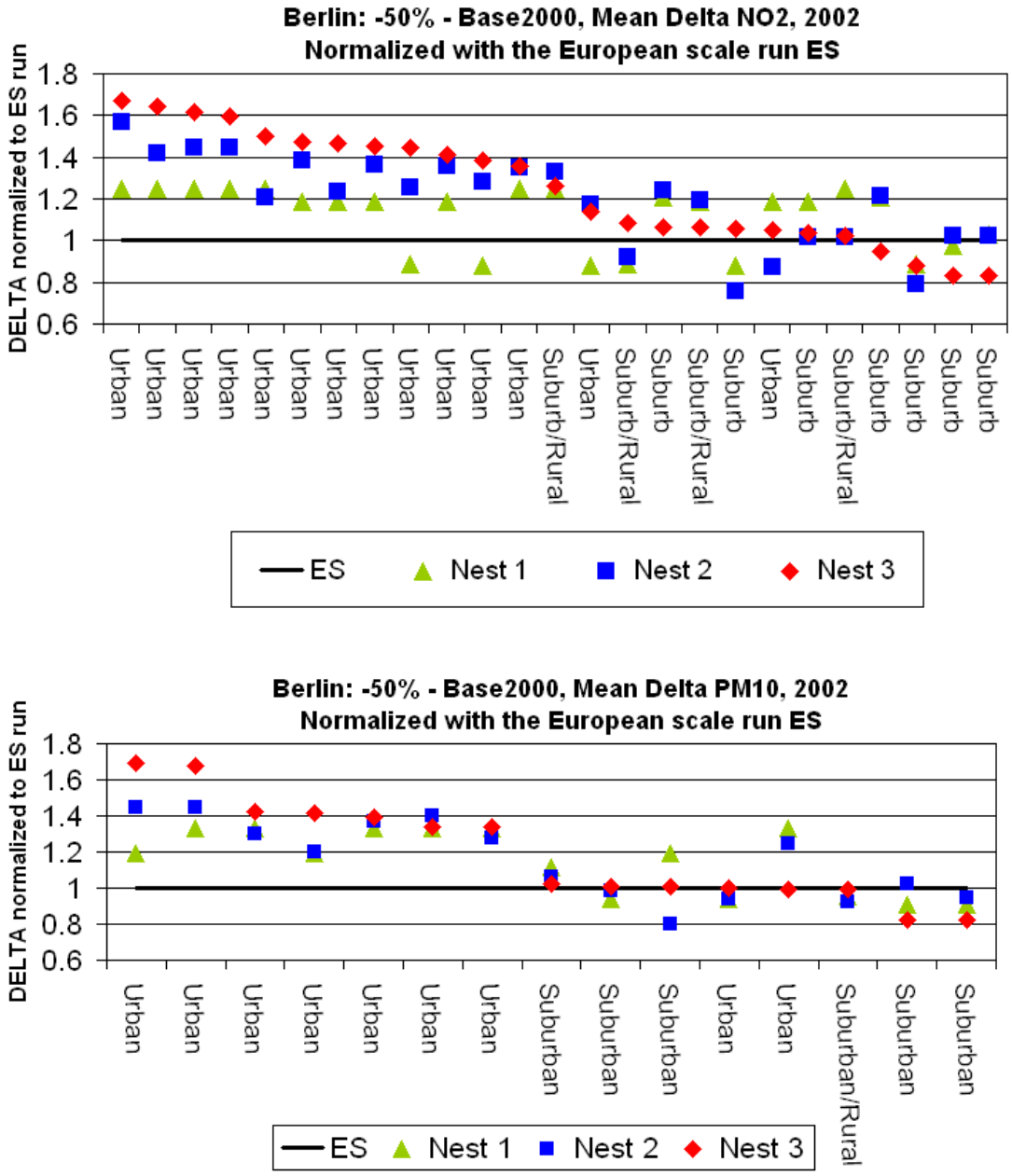

Figure 13 NO_2 and PM10 concentration deltas at 25 NO_2 and 15 PM10 measurement sites characterized as urban, suburban and rural/suburban type stations. The deltas for Nest 1 to 3 are expressed relative to (i.e., divided by) the normalized deltas calculated for the European scale run. Uniform -50% reduction of all emissions. For further explanations see text.

7. Summary and conclusions

Applying the RCG chemical transport model to the greater area of Berlin in four different grid sizes decreasing from 30 km down to 1 km, it turned out that model performance was best for the run with the highest grid resolution. The modelled effectiveness of control measures (CLE2010 scenario and a 50% reduction of all anthropogenic emissions) in an urban area as a function of a horizontal grid resolution showed also, that the urban increment is underestimated by the regional (grid #1) model resolution of 30 km. This implies that the effects of measures will be underestimated in urban areas if they are based on a regional scale model application. In urban areas with a highly inhomogeneous emission pattern even a resolution in the range of 5 km as used in the City-Delta exercise, can be too large for a complete capture of the urban signal.

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9. Figure captions