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# **A multiscale Air Quality Forecast System for Europe and selected regions**

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**Abstract:** A real-time forecast system for atmospheric pollutants is presented. The air quality forecast system is based on the EURAD Model (European Air Pollution Dispersion Model). The daily updated forecast of atmospheric constituents is operational since November 2001. The chemistry transport model EURAD calculates the transport, transformation and deposition of atmospheric constituents for a period of 72 hours on a daily basis. Major products of the AQ forecast system are the atmospheric pollutants O<sub>3</sub>, NO<sub>2</sub>, SO<sub>2</sub>, CO, PM10 and benzene. An intensive effort is done to carry out a verification procedure of the model forecast using observational data from the German Environmental Agency (UBA) monitoring network. Examples of major air pollution events and parts of the verification procedure are shown in section 4. The results of the forecasts on the different regions are published and are updated every day on the EURAD homepage **[www.eurad.uni-koeln.de](http://www.eurad.uni-koeln.de)**.

**Keywords:** Chemical weather, Modelling, Ozone, Particulate Matter.

## **1. INTRODUCTION**

One major challenge in the last decade was to build up an air quality forecast system compared to numerical weather prediction systems. With increasing computer power it is now possible to run complex chemical weather forecast under near real time conditions. The complex EURAD Model (European Air Pollution Dispersion Model) was established 20 years ago at the Rhenish Institute for Environmental Research (RIU) at the University of Cologne. It calculates the transport, transformation and deposition of atmospheric constituents. The applicability of the model system has been proven through numerous regional simulations of tropospheric composition and boundary layer air quality (e. g. Jakobs et al., 2002; Memmesheimer et al., 1997). In order to apply the EURAD model for operational forecast, a special version of the model was used to speed up the consuming computer time. The features of the EURAD AQ Forecast System and the some results of the daily prediction together with validation results are presented in this paper.

## **2. THE EURAD AIR QUALITY FORECAST SYSTEM**

The air quality forecast service is provided by the multiscale Eulerian chemical transport model system EURAD (European Air Quality Dispersion Model). The EURAD model is well-tested over the course of many case studies (Ebel et al., 1997). The model system was extended for use as a forecast model and has run operationally since 1st November, 2001 with its standard configuration at the RIU in Cologne. Meanwhile the EURAD AQ forecast system was applied for other regions of interest: Turkey, Ireland, the German State of Lower Saxony.

The key features of the model are: High flexibility for selecting forecast domains, an advanced heterogeneous chemistry mechanisms with comprehensive aerosol and photo oxidant chemistry and a focalized and high resolution forecasting by hemispheric/continental to regional scale (optionally 1 km resolution) nesting techniques with an integrated meteorological driver model.

The EURAD Air Quality Forecast System consists of three major components: The PennState/NCAR mesoscale model MM5 (Anthes and Warner, 1978; Grell et al., 1994) which predicts the required meteorological variables, the EURAD Emission Module (EEM) (Memmesheimer et al., 1991) which calculates the temporal and spatial distribution of the emission rates of the major pollutants and the EURAD Chemistry Transport Model (EURAD-CTM) which predicts the concentrations and deposition of the main atmospheric pollutants. Figure 1 gives an overview of all major components, its pre- and post-processors and the relevant input and output data sets. The chemical mechanisms employed in the EURAD system are the so-called RADM2 and its successor RACM.

They have been completed by the aerosol mechanism MADE (Modal Aerosol-Dynamics model for EURAD). The RADM2 mechanism contains 63 reactive species treated in 158 chemical reactions. There is an option to run the code with the more sophisticated RACM chemistry as well. Detailed aqueous phase chemistry for the treatment of the air pollutants is incorporated. The horizontal and vertical transport is carried out using the 4<sup>th</sup> order Bott advection scheme. Vertical mixing of the species is treated by an implicit vertical diffusion scheme. The sink at the lower boundary of the model is treated by wet and dry deposition parameterization. The major driver for wet deposition is the predicted precipitation. The dry deposition is calculated via the deposition velocity for each species, which depends from the particle itself, the atmospheric dynamic and the given land-use type.

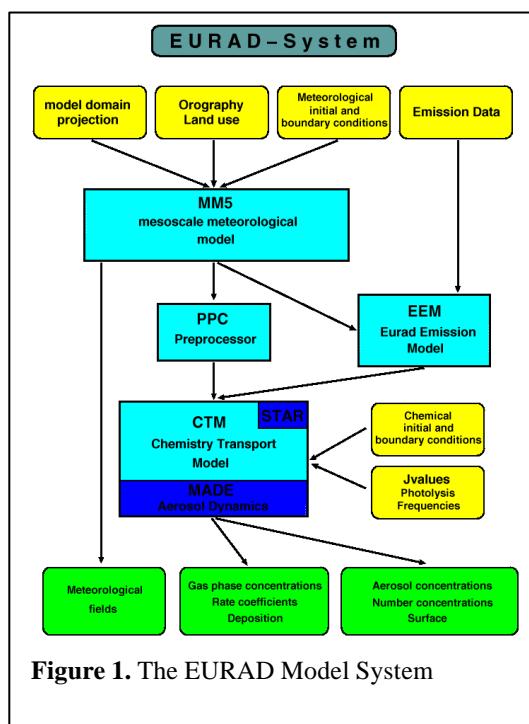


Figure 1. The EURAD Model System

### 3. THE FORECAST CYCLE

The standard RIU AQ forecast was designed for three different domains: Europe (D01 with 125 km grid resolution), Central Europe (D02, with 25 km grid resolution) and the German state Northrhine-Westfalia (D03, with 5 km grid resolution). The EEM calculates the temporal and spatial distribution of the emission rates of the major pollutants from the available data bases. The EEM was constructed to process different data bases, ranging from continental down to local scale. The biogenic emissions are calculated online with respect to the given atmospheric condition (temperature, radiation, wind) and the given land-use type. The meteorological forecast is obtained using the NCAR/PennState mesoscale model, MM5. For initial and boundary conditions, the model uses the NCEP/GFS global forecast and interpolates the variables on the selected domains.

The forecast model system uses the method of nested simulations. This enables consistent modeling of air quality from small (local) to large (continental) scales. The required geographical information (topography, land-use type) is taken from the USGS data base with respect to the selected horizontal resolution. Applications with coarse resolution usually cover the major part of Europe. They can be zoomed down to regions of the size of central Europe and fractions of it (e.g. Province level). The model uses terrain-following  $s$  coordinate in the vertical, with 23 unequally spaced layers, the more dense resolution being used in the lowest part of the model. The model top in the operational mode is 100 hPa.

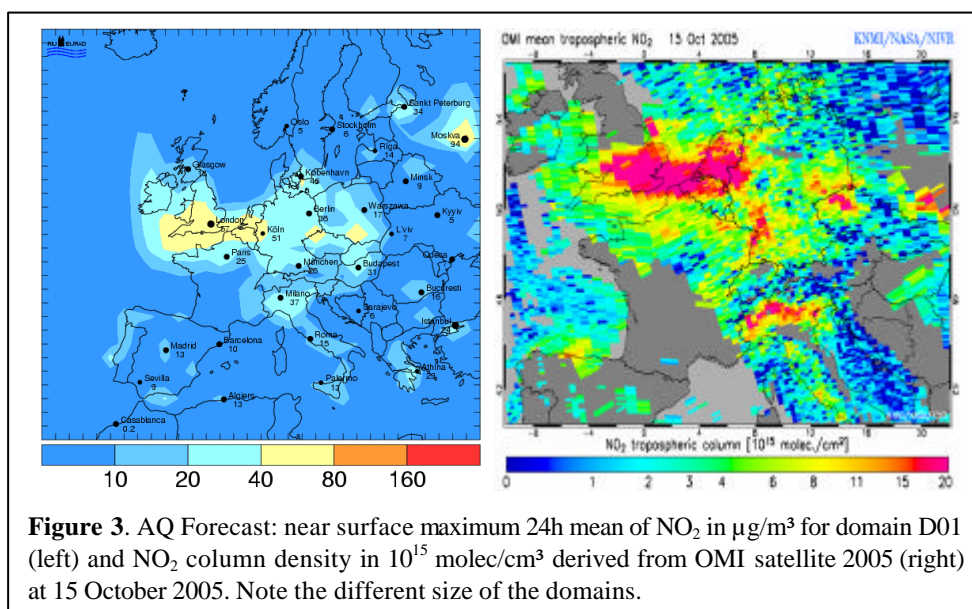
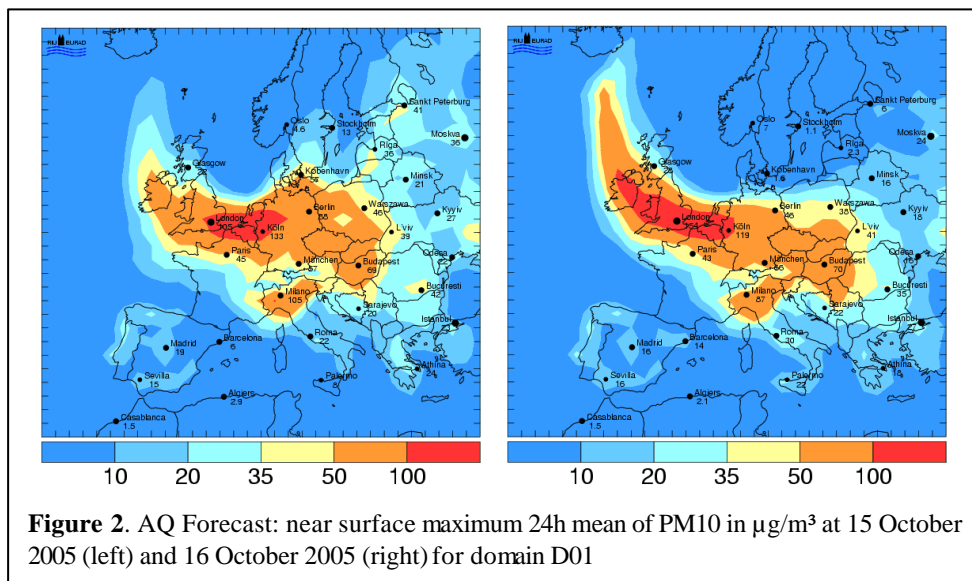
The regular forecast system starts automatically with the download of the 00 UTC NCEP GFS global meteorological forecast via ftp. Then consecutively the chemical weather forecast was performed from the mother domain (D01) down to the domain covering the German State of Northrhine-Westfalia (D03). Usually the forecast cycle for the standard configuration is finish at around 08:00 MET in the morning, delivering the needed data for three consecutive days.

#### **4. DAILY AQ FORECAST RESULTS AND VALIDATION**

Every day, an extensive amount of data is produced by the EURAD forecast system for Europe, Central Europe and the German State of Northrhine-Westfalia. This includes the meteorological prediction variables and the concentrations of the atmospheric constituents at all model levels. In order to be able to subsequently compare the modeled concentrations of air pollutants with the observational data, a considerable effort was made to accurately model the near surface concentrations of the main air pollutants and to produce a combined Air Quality Index (AQI) for the above mentioned domains. For assessment studies, the ranges for the concentration thresholds were selected according to the EU directives. The daily maxima, the daily maximum 8h running mean and the daily maximum 24h running mean of each of the pollutants are calculated. In addition, animations and chemograms of selected regions are produced. These products are graphically processed and published on the EURAD website (<http://www.riu.uni-koeln.de>). As results, two characteristic episodes are shown to demonstrate the performance of the model.

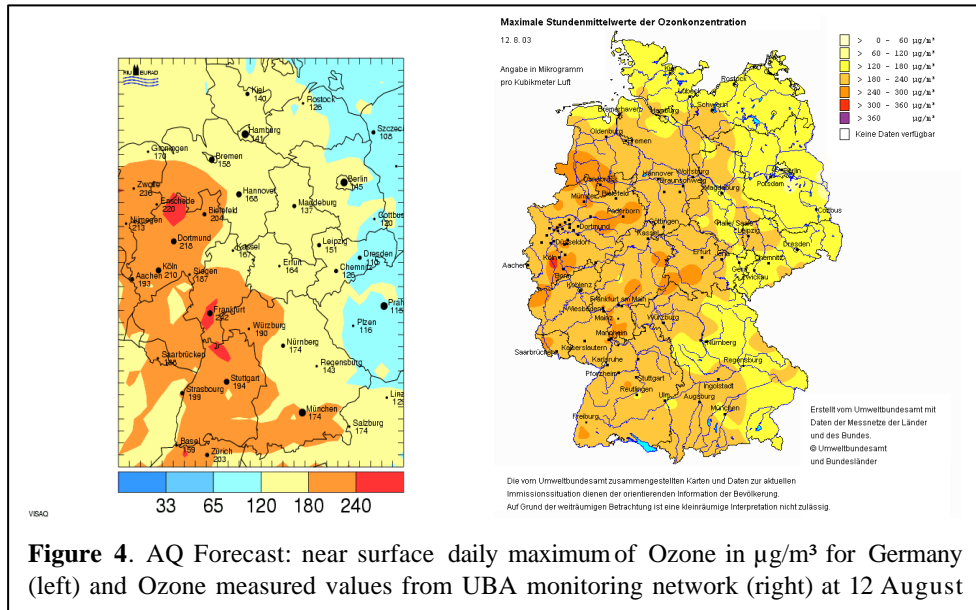
##### **4.1. Long range transport of PM<sub>10</sub>, NO<sub>2</sub>**

One major long range pollution event took place at 15/16 October 2005. With a high pressure system located over Scandinavia, easterly winds were predominant in the central and western part of Europe. Thus pollutants were transported from the main emission centres in Germany, Benelux, UK towards west and reached the relatively clean regions: Ireland and even Iceland at the end of the period. Figure 2 shows the maximum 24h mean of PM<sub>10</sub> at the days 15 and 16 October 2005. In addition high concentrations of NO<sub>2</sub> were forecasted during this event over Central Europe. For the validation of the forecast besides the forecasted NO<sub>2</sub> near surface concentrations, the NO<sub>2</sub> column densities, derived from measurements of the OMI satellite are also shown in Figure 3. Since the vertical distribution of NO<sub>2</sub> exhibit an exponential decrease with height above the mixing height, near surface concentrations can be used for comparison with column density values. The comparison of the results shown in Figure 3 indicates that there is a good agreement of the forecast products with observational data.



#### 4.2. Ozone production

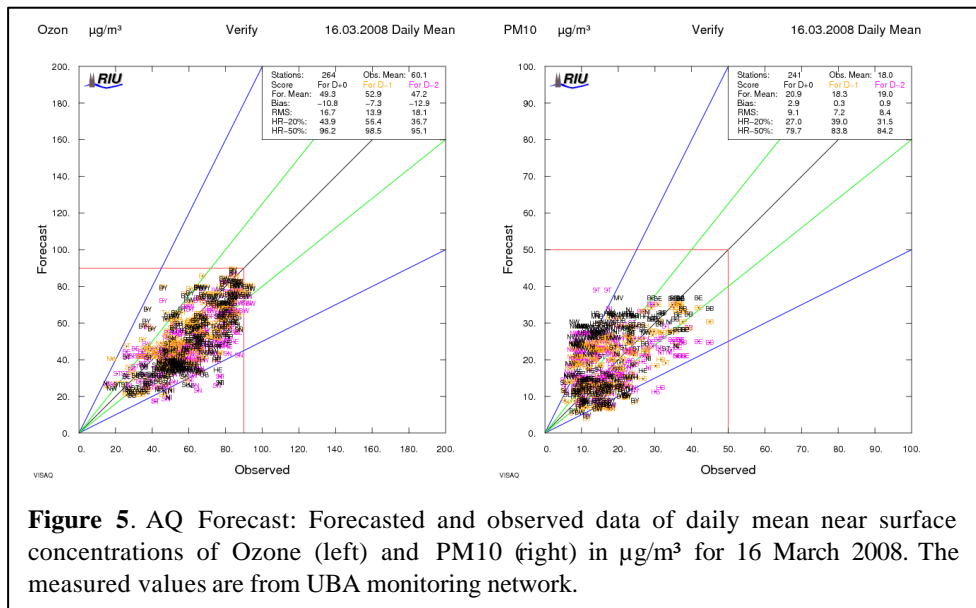
The summer 2003 in Europe was characterized by extreme temperatures and dry episodes and thus accompanied by high ozone values exceeding critical values. Thus was especially true for Germany, where the information alert ( $180 \mu\text{g}/\text{m}^3$ ) and even the alarm threshold ( $240 \mu\text{g}/\text{m}^3$ ) were exceeded in many parts of the country. This Ozone values in the first half of August 2003 were well predicted over Germany (see Figure 4). The predicted values are in good agreement with observations (UBA monitoring network).



**Figure 4.** AQ Forecast: near surface daily maximum of Ozone in  $\mu\text{g}/\text{m}^3$  for Germany (left) and Ozone measured values from UBA monitoring network (right) at 12 August

### 4.3. Validation

Besides these examples of episodic validation of the predicted atmospheric pollutants a daily full validation of the products is evident and demonstrated on the RIU forecast website. The predictions are compared with over 300 measurement stations of the German UBA network: The observational data are assimilated with the forecast data as first guess and results in a daily analysis of the observed data. In addition scatter diagrams are shown to demonstrate the performance of the model. Figure 5 shows exemplarily the diagrams for an arbitrary selected day in March 2008. The different colours indicate the forecast start (black: start same day, yellow: start 1 day before current day, magenta: start 2 days before current day). The calculated scores are: Bias, Root Mean Square (RMS), Hit rate within a 20% interval (HR-20%) and hit rate within a 50% interval (HR-50%).



**Figure 5.** AQ Forecast: Forecasted and observed data of daily mean near surface concentrations of Ozone (left) and PM10 (right) in  $\mu\text{g}/\text{m}^3$  for 16 March 2008. The measured values are from UBA monitoring network.

Even this verification present only one day scatter data, again these arbitrary chosen results demonstrate the relatively good performance of the AQ forecast system.

## 5. CONCLUSIONS

The results of the operational EURAD AQ forecasts on different regions are published and are updated every day on the EURAD homepage ([www.eurad.uni-koeln.de](http://www.eurad.uni-koeln.de)). Besides ozone, additional atmospheric pollutants as NO<sub>2</sub>, SO<sub>2</sub>, CO and PM<sub>10</sub> were predicted every day for a 72 hour cycle. For assessment studies the ranges for the concentration thresholds were selected according to the EU directives. The verification of the forecast system is shown for selected events. The results of this verification demonstrate that the EURAD air quality forecast system performs reasonably well in predicting the spatial distribution of the main air pollutant concentrations over Europe and Germany and thus it could be used as a tool to support informational strategies for the public. The results of the prediction are also linked to several internet weather portals for distribution to the public. In addition, the predictions are used for assessment and policy making by several regional and local environmental agencies: The forecast maps are linked to the websites of the agencies, information of the public via radio or television, when exceedances of limit values are predicted.

An intensive verification of the forecast data will be performed for the year 2007. Another future task will be the incorporation of observational data within data assimilation techniques to improve the forecast results. In addition a intensive model output statistics will be outlined in order to remove typical prediction errors under certain weather conditions.

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