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AN AIR QUALITY MANAGEMENT SYSTEM FOR CYPRUS: DEVELOPMENT AND EVALUATION

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Abstract: The new Air Quality Directive (2008/50/EC) encourages the introduction of modelling as a necessary tool for air quality management and assessment. Towards this aim, a new Air Quality Management System has been developed and installed in the Department of Labour Inspection of the Republic of Cyprus. The AQMS comprises of two operational modules, providing hourly nowcasting and daily air quality forecasting, implemented as an integrated model system that performs nested grid meteorological and photochemical simulations. A third operational module provides the capability to study emission scenarios and assess their effect on air quality in the five major urban areas of Cyprus or over user defined domains.

As part of the continuous evaluation and improvement of the system's performance, a range of modifications on its structure, as well as enhancements in the main computational procedures have recently taken place. Statistical indicators are calculated at the end of each day for the measurement locations of DLI's air quality monitoring network. Moreover, a novel infrastructure has been developed, which enables the integration of both air quality measurements conducted by DLI, as well as results of larger scale models as initial and lateral boundary conditions for the model calculations. An upgraded methodology has been developed and incorporated in the system's core for providing increased flexibility in the coupling of the nested domains. In addition, a dynamic dust increment has been included in the boundary PM_{10} and $PM_{2.5}$ concentrations used for the operational calculations, so as to improve the system's performance during Saharan dust episodes. These upgrades significantly enhance the operational prognostic skills of the AQMS in the cases of elevated concentration levels that are associated with transboundary transport of air pollutants.

Key words: *Statistical indicators, coupling, nested domains, Saharan dust, transboundary transport, boundary conditions.*

INTRODUCTION

Operational air quality modelling has been increasingly recognised as an indispensable component of any integrated air quality assessment strategy, especially in view of the provisions of the new European Union Directive (2008/50/EC) which encourages the use of computational methods along with direct monitoring and remote sensing-based assessment methodologies. In view of this emerging need for better incorporation of modelling methods in air quality management, integrated informational systems known as Air Quality Management Systems (AQMS) have been developed aiming to provide technical users and policy makers with a consistent and robust environment for their regular workflows. In this framework, a newly developed AQMS has been installed and used operationally in the Department of Labour Inspection (DLI) of the Republic of Cyprus (Moussiopoulos *et al.*, 2010). The core of the new AQMS consists of a model system which performs nested grid meteorological and photochemical model simulations in two parallel operational modes, providing users with updated air quality nowcasting and forecasting, respectively, for the entire island of Cyprus. Air quality assessment and decision making is supported by the AQMS by enabling DLI users to interactively configure custom emission scenarios and computationally assess air quality trends over user-defined domains of interest.

Following an operational evaluation of the system performance and by continuously evaluating user feedback, a range of improvements on the model core as well as structural modifications on the system's user interface have recently taken place. Tools for validating the chemical dispersion calculations have been implemented, including the automatic calculation and visualisation of a number of statistical indicators for selected locations in the computational domain, at the end of each day. In the direction of the optimisation of the system's performance, a new boundary condition module has been developed, increasing the system's flexibility in assimilating data obtained both from air quality measurements as well as from results of larger scale models. A dynamic dust component has been added in the calculation of particulate matter (PM) boundary conditions for the chemical transport model, aiming to improve estimations of PM dispersion during Saharan dust episodes. Finally, an improved system of domain nesting has been developed and incorporated in the model core, offering significant flexibility in the ways that the coupling of nested domains can take place.

METHODOLOGY

In order to better evaluate the system's performance, suitable statistical indicators are calculated and presented to the user at the end of each day. Indicators are calculated from simulated and measurement data series on the sites where DLI's air quality measurements take place (URL1). An automated procedure operating on an around-the-clock basis undertakes the downloading of the available observation data from DLI's data server, and the subsequent processing and storage in the main AQMS data base. At the same time, model results calculated for the same locations are registered in a parallel data pool and are archived for later inspection by the user. At the end of each day, a wide range of statistical indicators are calculated according to the guidelines set in COST728 (2008), for the station locations and pollutants of interest, and numerous charts are produced for visually assessing the accuracy of the simulations in both nowcasting and forecasting mode. In order to have a better overview of the system's performance, validation charts for meteorological parameters are also produced presenting comparisons between the calculated and the observed timeseries of wind speed and wind direction.

In an effort to optimize the model core performance, a revised methodology has been incorporated in the boundary condition module which enables the combined use of concentration values obtained from the results of larger scale models and quality measurements conducted by DLI. A combination of concentration fields obtained by assimilating measurement values and downscaling larger-scale simulations can be used as initial and lateral conditions during the dispersion calculations. The use of regional model results greatly enhances the system performance in predicting elevated air pollution levels that are related to the transboundary transport of air pollutants. On the other hand, inclusion of observation data improves the predictive accuracy in calculations of high pollutant concentrations which are associated with local activity.

One of the most important adjustments in the boundary condition module is the integration of a dust increment in PM calculations. Transboundary transfer of dust constitutes one of the most pressing environmental problems in Cyprus, since its contribution to the total PM levels, combined with the relative influence of sea salt, leads to the occurrence of about 75% of the measured number of exceedances of the daily PM_{10} limit value prescribed by the European Union (EU) (Bari *et al.*, 2008). As an example, about 129 of the total 167 observed exceedances of the daily EU limit at the traffic station of Nicosia in 2007 occurred as a consequence of the contribution of natural sources and transboundary transport to the total PM concentration (URL3). Thus, a dynamic dust increment has being added in the calculation of initial and lateral PM_{10} and $PM_{2.5}$ concentrations used for the operational simulations. This increment aims to improve the system's prognostic skill in the cases of high PM levels associated with transboundary transport of Saharan dust. Initially, the implementation of the dynamic dust increment in the BC module was tested with publicly available data originating from larger scale dust models, such as Skiron (URL2). In the upcoming versions of the system, the functional integration of the trajectory model HYSPLIT4 (Draxler R.R. and Rolph G.D., 2003) in the system core will be finalized, enabling a continuous operational estimation of the dust increment.

A final set of enhancements focused on the improvement of the nesting capabilities of the meteorological and transport models. In the previous edition of the system, model simulations for the fine-grid domains covering the areas around the five major cities were perfomed using boundary concentrations downscaled from regional scale models. The upgraded nesting methodology which has recently been developed and incorporated in the system's core provides increased flexibility in the coupling of the nested domains by enabling the optional assimilation of initial and lateral concentrations obtained from the respective model calculations in the coarse domain. This flexible zooming approach enhances the system's performance of air quality assessment calculations at the local scale.

RESULTS

In Figures 1, 2 and 3, air quality and meteorological validation graphs are shown in the form they are presented to the AQMS user. Each graph shows comparisons between model simulations and the respective observation data regarding air pollutant concentrations, as well as wind speed and direction. Additionally, information about the model accuracy is also provided in the form of statistical indicators (COST728, 2008), namely Bias, Average Normalised Bias (ANB), Fractional Bias (FB), Root Mean Square Error (RMSE), Normalised Mean Square Error (NMSE), Correlation Coefficient (CC) and Index of Agreement (IA). In this field of the graphs, green colour indicates which mode (nowcasting or forecasting) achieved better simulation accuracy according to each statistical index. In the case of performance data shown in Figure 1, the models appear to accurately reproduce the O_3 timeseries on the suburban location, where concentration levels are mainly determined by the transboundary transport which enters the model domain as initial and lateral boundary conditions from larger scale models. On the other hand, the supplementary use of air quality measurements in the formation of boundary conditions leads to increased model efficiency in the cases of air pollutants which are directly related to human activities, such as NO_x and Benzene (see Figures 2 and 3). This occurs because most of DLI's measurement stations are located in areas with a significant degree of human activities, including transport and industry, leading to concentration values which are strongly affected by the aforementioned activities.

Figure 4 presents a subset of the calculated statistical indicators, namely Bias, Normalised Mean Square Error, Correlation Coefficient and Index of Agreement, for nitrogen dioxide (NO_2) and ozone (O_3) over a period of three days. As evidenced from the indicators, model calculations are in fairly good agreement with the observed concentrations, with the notable exception of the industrial and traffic stations. This is more or less expected for these hotspots which are highly affected by local and street scale activities.

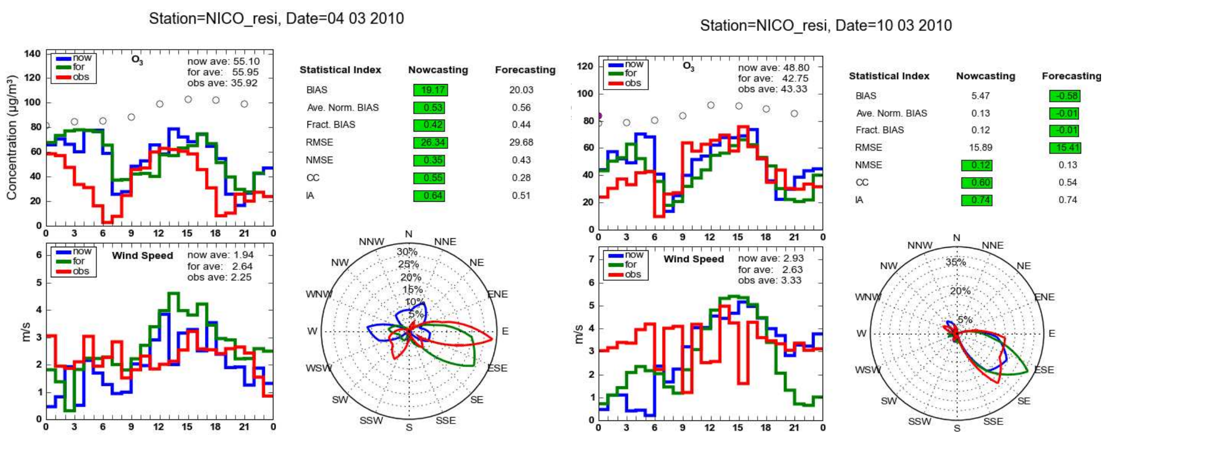

Figure 1: Air quality and meteorological validation graphs for the 4[th] and 10[th] of March 2010 for the residential station of Nicosia concerning O_3.

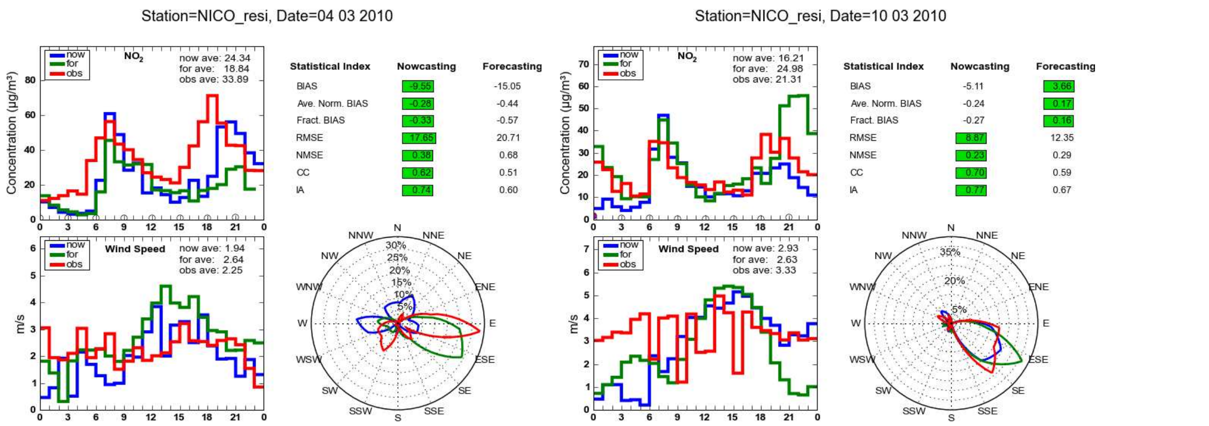

Figure 2: Air quality and meteorological validation graphs for the 4[th] and 10[th] of March 2010 for the residential station of Nicosia concerning NO_2.

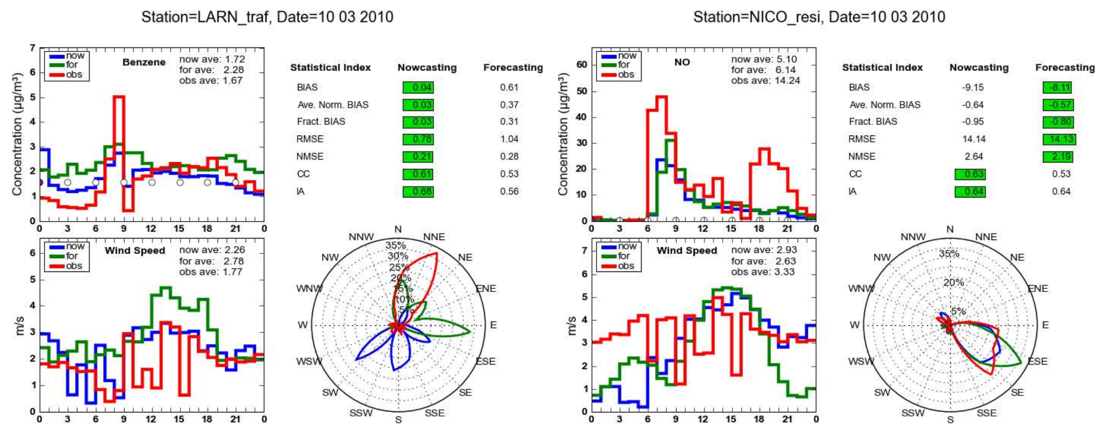

Figure 3: Air quality and meteorological validation graphs for 10[th] of March 2010 for the traffic station of Larnaca and the residential station of Nicosia concerning Benzene and NO, respectively.

Figure 4: Statistical indicators calculated for the 11[th] and 13[th] of March 2010 as regards NO_2 (upper left, upper right) and O_3 (lower left, lower right).

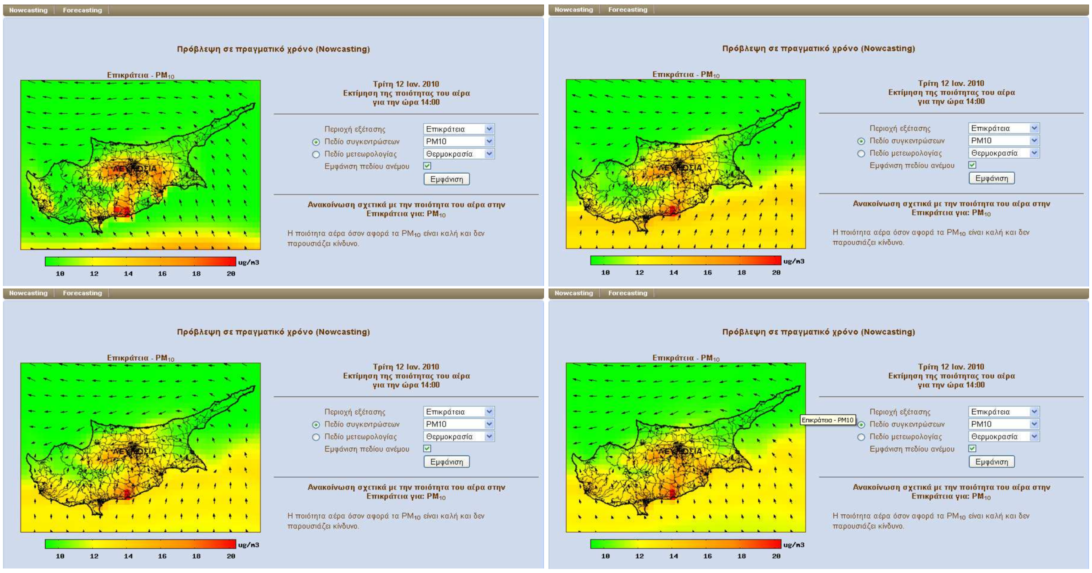

Figure 5: Snapshots of the system's results for PM_{10} during Saharan dust episode.

Figure 5 demonstrates the gradual dust transport over the Cyprus domain during a typical Saharan dust episode. The system performs reasonably well in predicting the occurrence of such episodes. Additionally, the model results presented in Figure 5 indicate the high ability of the system in reproducing the qualitative aspects of the spatial distribution of PM during dust episodes.

CONCLUSIONS

As part of the continuous evaluation and improvement of the ability of the Cyprus AQMS to computationally assess the air quality status for the entire island as well as in five major cities, a range of modifications on its model core structure have recently taken place. In order to operationally evaluate the system's performance, appropriate statistical indicators are calculated at the end of each day for the measurement locations of DLI's air quality monitoring network. In addition, validation charts are produced, presenting to the user comparisons between the calculated and the observed timeseries of pollutant concentrations, wind speed and wind direction. Aiming at improving the system's performance, several enhancements in the main model components were implemented. An appropriate methodology has been developed, enabling the integration of both observed concentrations and results of larger scale models in the initial and boundary conditions of the model calculations. Moreover, a highly configurable nesting module has been developed and incorporated in the system's core for providing increased flexibility in the coupling of nested domains. A dynamically estimated dust increment has been included in the boundary PM_{10} and $PM_{2.5}$ concentrations used in the dispersion calculations, so as to improve the system's performance during Saharan dust episodes.

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