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SUPPORTING THE EU AIR QUALITY DIRECTIVE OVER CYPRUS THROUGH MODELLING AND THE FAIRMODE BENCHMARKING METHODOLOGY

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Abstract: We present the evaluation of an air quality modelling application over the Eastern Mediterranean using the benchmarking methodology developed in the framework of the Forum for Air Quality Modelling in Europe (FAIRMODE). FAIRMODE aims to provide a harmonized approach of model evaluation for regulatory purposes. We apply the methodology to evaluate the performance of the Weather Research and Forecasting model coupled with chemistry (WRF-Chem) over Cyprus, a member state of the European Union (EU-28) and evaluate against ground-based air quality observations over background and urban stations of maximum daily eight-hourly mean ozone (O_3), hourly nitrogen dioxide (NO_2) and daily fine particulate matter (PM2.5) concentrations.
The model is found to satisfy the proposed performance objectives regarding all regulated species, despite an evident underestimation of NO_2 in urban areas possibly due to uncertainties in emission inventories. Fine particulate matter is in general well represented by the model except on days with strong influence from natural sources (mineral dust episodes), indicating a need for improved parameterization of dust mobilization and transport in the region. The discrepancies between model results and observations indicate the need for more stringent performance criteria at low concentrations, despite the fulfilment of objectives.
The methodology provides detailed information and relevant statistical metrics to guide assessments and identify the modelled processes that warrant investigation and improvement. Through flexible threshold exceedance analysis, the benchmark tool under investigation provides a comprehensive method for monitoring compliance with the EU Air Quality Directives and other guidelines regarding the impact of pollution on human health and ecosystems.

Key words: *Air pollution, chemical modelling, statistical evaluation, models for policy applications***.**

INTRODUCTION

Air pollution is an increasingly important problem worldwide, and particularly over the Eastern Mediterranean and the Middle East (EMME) region, influencing the quality of life, number of premature deaths and frequency and severity of various respiratory diseases. Air quality observations can give information on the level of pollutants at specific stations or times, while models can provide insights on the atmospheric processes, pollutant concentrations, transport and transformation over wider areas. Therefore, models that have skilful performance can be used to complement observations or replace them in cases of missing data, for policy applications and regulatory purposes. Comparison with observations is a standard procedure to assess the performance of models; however a harmonization on the criteria that deem a model

successful in capturing air quality features over a specific region is a necessity when such models are used for reporting and compliance with regulations. In the framework of the Forum for Air Quality Modelling in Europe (FAIRMODE) activities a procedure for unified model evaluation process has been developed.
Cyprus, a EU28 member located in the centre of EMME region is a receptor of pollution from multiple sources of both anthropogenic and natural origin. Accurate assessment of air pollution features such as chemical processes, origin and transport, trends, annual levels and peak episodes, population exposure to concentrations above regulation thresholds are of significance for both scientific and policy oriented application. We apply the FAIRMODE methodology over Cyprus elaborating on the applicability, capabilities and limitations for this particular location and indications for the transferability of the results to other countries.

METHODOLOGY

We use the Weather Research and Forecast model coupled with Chemistry (WRF-Chem) version 3.6.1 to simulate particulate matter over Europe for the year 2015 (Grell et al., 2005). WRF-Chem is configured over the EMME region utilizing two domains, of 50 and 10km respectively grid spacing (Fig 1a). The initial and boundary conditions for the meteorological data are provided by the National Center for Environmental Prediction (NCEP) global forecast system (GFS) at a resolution of 0.5° x 0.5°. The initial and boundary conditions for the chemical species are provided from global simulations with MOZART-4 (Model for Ozone And Related chemical Tracers version 4) model (Emmons et al., 2010). Emissions are calculated from the 0.1° x 0.1° global emission dataset EDGAR-HTAP v2 of NOx, SOx, non-methane volatile organic compounds (NMVOC), CO, NH_3, PM2.5 and PM10 (Janssens-Maenhout et al., 2012). The model results from the nested domain are compared against measurements from the national monitoring network of Cyprus that consists of 12 stations of different characteristics (Fig 1b).

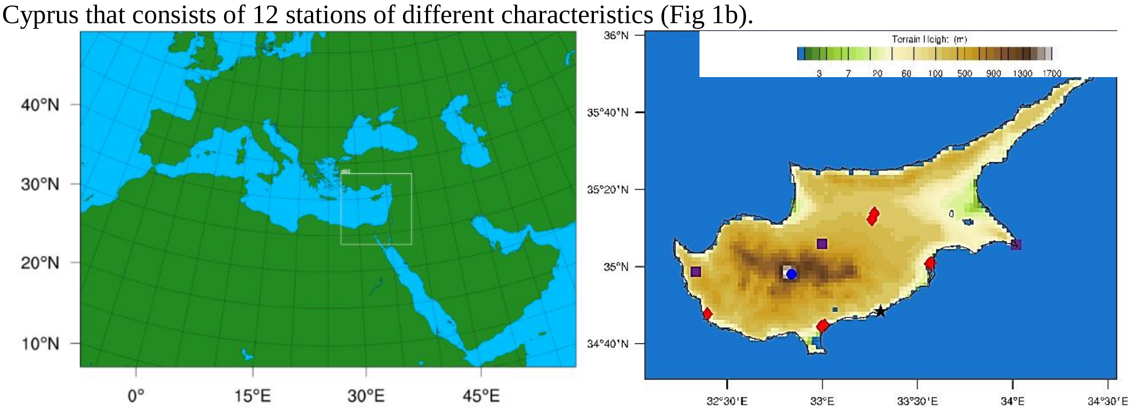

Figure 1. a) The domains covered by this study, b) the location and type of the air pollution monitoring stations over Cyprus. Background stations in purple squares, urban in red, industrial in black and the PBL in blue circle.

The evaluation methodology is presented in detail in Thunis et al. (2012a, b). It investigates model capabilities by introducing two indicators, namely the Modelling Quality Indicator (MQI) and the Modelling Performance Indicators (MPIs), taking into account the measurement uncertainty of each pollutant. MQI, linked to the root mean square error (RMSE), defines the allowed deviation between model and observation as a factor of the measurement uncertainty and a scaling factor (e.g. a scaling factor of two means the allowed deviation should be within a factor two of the measurement uncertainty gap). The Modelling Quality Objective (MQO) is the criterion for the value of the MQI to be satisfied for satisfactory model performance for reporting application.. MQO is fulfilled if the MQI is less than or equal to unity for at least 90% of the available monitoring data. For the visualization of the MQO a target diagram adapted from Jolliff et al. (2009) is used (results of current study shown in Figure 2). The horizontal axis represents the Central Root Mean Square error (CRMSE) while the vertical axis refers to BIAS, normalised by measurement uncertainty of the respective pollutant levels. For each station a dot is placed on the target diagram and the distance of the dot from the centre of the diagram represents the MQI for that station. Stations with MQI within the green area are identified as stations that fulfil the performance criteria with values in the green area but outside of the dashed line representing the zone for which model results are within the measurement uncertainty range. The four zones on the plot can help identify the reasons for observed model-observations differences in terms of standard deviation (SD), bias and correlation (R).

RESULTS AND DISCUSSION

Regarding compliance with the model performance objectives set in the evaluation methodology, Fig 2 presents the assessment target plot for the MQI of ozone (top plots) in background (left), urban stations (centre) and all stations combined (right). For hourly values the MQI calculation is based on RMSE. MQI for both group of stations for ozone (4 background and 3 residential) is satisfied with MQIbackground=0.387 and MQIurban=0.391 for hourly values and MQIbackground=0.231 and MQIurban=0.519 for annual means under a measurement uncertainty of 18%. When all stations are merged in the analysis the MQIall reaches values of 0.4 for the hourly assessment and 0.5 for the annual mean values, satisfying the MQO of less than one. The location of the station dots on the diagram reflects the slightly positive bias of the model as well as the fact that the statistical metric of correlation is the one performing less satisfactory. Regarding NO_2 the MPI indicators are satisfied in both categories of stations (rural and urban) (Fig 2 bottom plots). At the background stations the objectives are fulfilled more closely with both annual and hourly MPI less than 0.1. In the urban stations the MPI is again below unit with the hourly MPI = 0.5 and the yearly MPI = 0.7. The two coastal stations (Larnaca and Limassol) are located on the left side of the plot indicating that correlation is the most erroneous metric, while Nicosia is on the right part where standard deviation is captured poorly.

The standard statistical metrics summarized in Fig 3 (left plots for ozone and right for NO_2) i.e. the bar plots of mean annual, mean bias, correlation and standard deviation values show that the model captures with a slight overestimation the distribution of ozone over the island, the latter most noticeable in urban areas due to the inability to represent local residential and traffic ozone precursor emission fluxes, especially of NO. Factors contributing to this overestimation may be related to the lateral forcing from the global model and low local emission fluxes of ozone precursors such as nitrogen oxides, as shown in Kushta et al., (2017). There is a difference of max 8h O_3 values between background and urban stations with the residential sites showing lower annual mean max 8h concentrations as a result of ozone titration by nitric oxide from traffic. This outcome highlights a local-scale intense conversion effect (of O3 by NO into NO_2) near emission sources where higher levels of NOx emissions are present relative to rural areas.

Respectively for NO_2 (hourly values) the overall fulfilment of the objectives set by the methodology is accompanied by a significant underestimation over the residential stations. The mean bias is low in the background stations; in urban areas, where the horizontal resolution of the regional model (10 km) cannot accurately reproduce the magnitude and variation of the local emissions, the bias is mostly negative at about -5 to -6 ppbV. The correlation of the observed and modelled hourly values varies from 0.2 in background stations to 0.6 in rural stations. Overall the NO_2 levels over Cyprus are relatively low and well within the regulated concentrations limits but the model underestimates observed values possibly due to a limitation of the national emissions in these areas as represented in the emission database (~10 km resolution, same as the nested grid spacing). It is anticipated that the use of an updated high resolution national emission inventory and an accompanying model configuration with similar grid spacing (< 2km) may help capturing the magnitude of urban emission fluxes and reflect also on the ozone levels in residential areas.

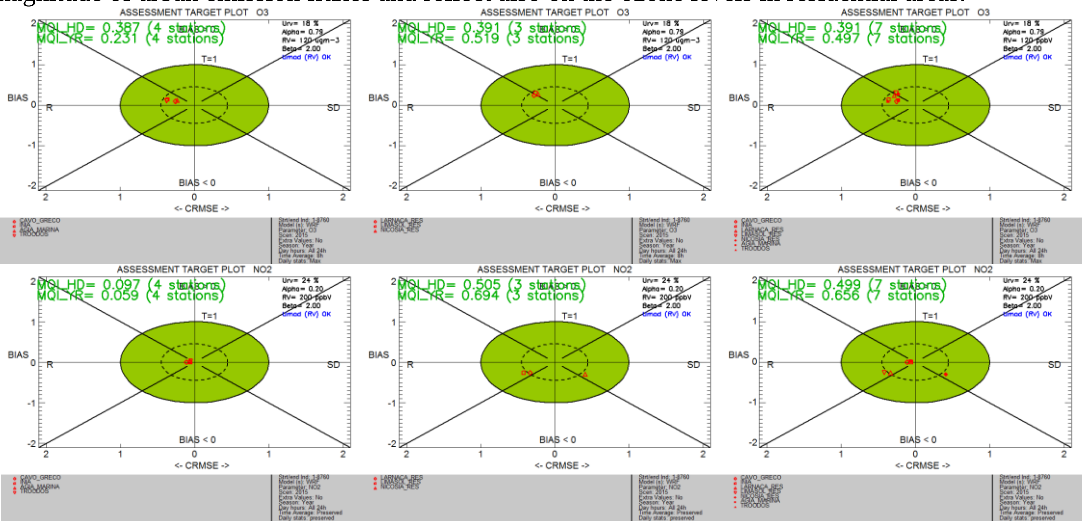

Figure 2.Target plot for ozone (top plots) and nitrogen dioxide (bottom plots) for background (left), residential (centre) and all stations (right)

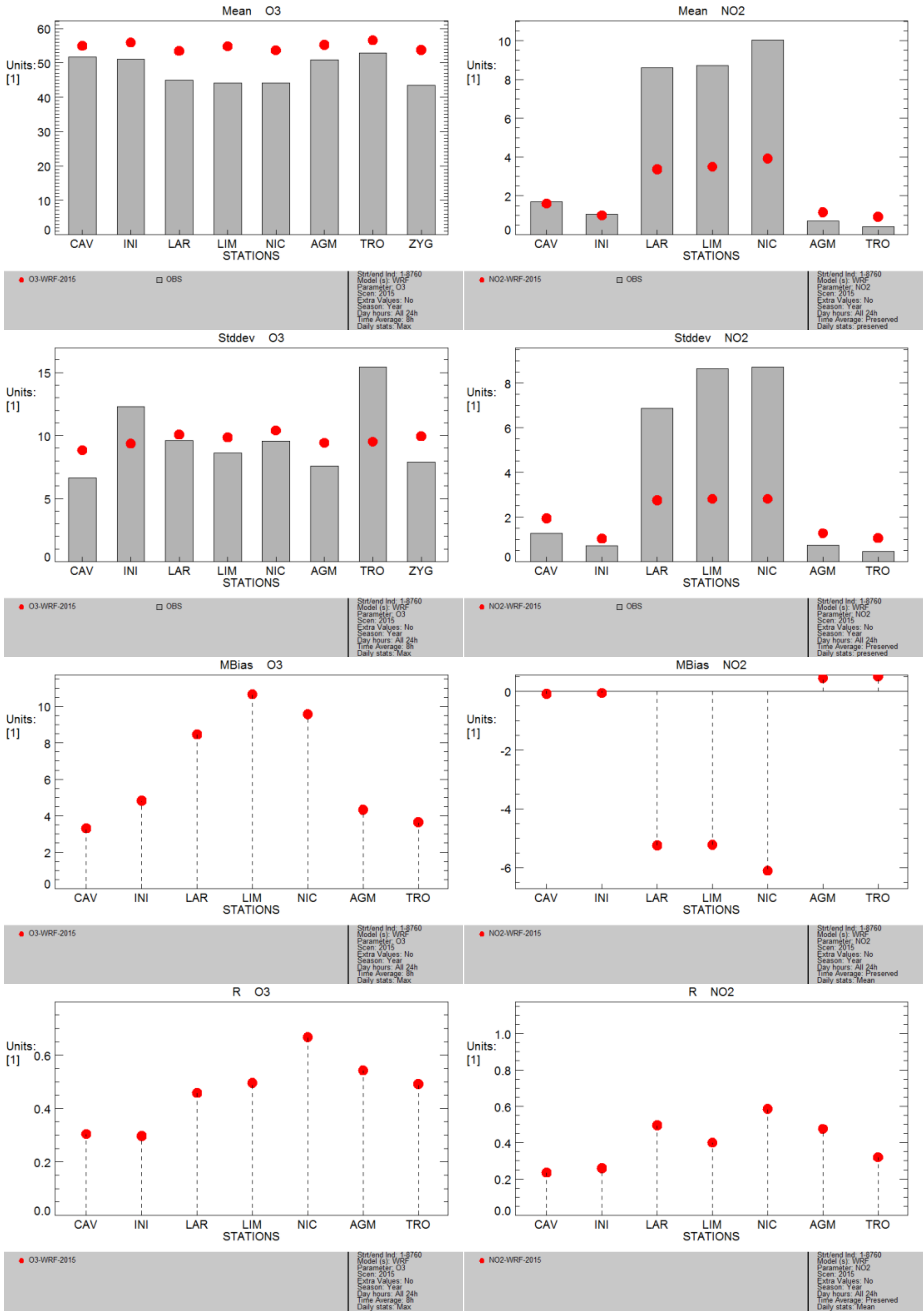

Figure 3. Mean, standard deviation, mean bias and correlation plots for ozone (left) and NO_2 (right)

The fine particulate matter (PM2.5) analysis is performed using daily mean values. Cyprus is frequently affected by dust storms from both North Africa and the Middle East (Gkikas et al., 2017; Solomos et al, 2017, 2018) and these exceedances can contribute to the overall exceedances of the health safety thresholds set in the Air Quality Directive. The model includes an online dust mobilization and transport module that simulates the sources and transport of mineral dust particles in the atmosphere, but an evaluation and fine tuning of its performance in the region of this study has not been performed in an integrated way (rather than event-based analysis). The situation in the Eastern Mediterranean is complex due the proximity (and influence) of two large dust sources, North Africa and the Middle East. In our analysis we exclude two days of an intense dust episode by omitting PM2.5 concentrations above 100 μg m-3 on 8-9 September 2015 while other dust episodes that occurred in 2015 are included. Regarding the objectives set by the current evaluation methodology, the model fulfils the performance criteria relative to both the normalized standard deviation and the correlation coefficient. The error related to the correlation coefficient dominates the model performance for both the background and industrial stations. The model depicts a smaller range of variation in PM2.5 distribution from site to site than observed. All model results fall within the green target area and significantly close to the 1:1 line. We notice that even though the model evaluation benchmarking methodology is not fit for traffic and industrial sites, in our analysis the model objectives are also satisfied over these sites.

CONCLUSIONS

The benchmarking evaluation methodology developed in the framework of FAIRMODE, driven by the necessity of harmonizing model evaluation criteria for regulatory purposes, was applied over Cyprus, an EU member country located in the Eastern Mediterranean and Middle East region, providing an ideal case study due to its relatively isolated location at the crossroads of pollution. It is shown that the model captures satisfactorily, based on the performance targets of the methodology, the ozone landscape over the island. Regarding nitrogen dioxide, there is a need for an improved, high resolution, representation of local emission fluxes. Particulate matter levels over the region are adequately simulated. However, it is shown that the statistical metric of correlation between mean daily modelled and observed values needs further improvement. Overall, the model exhibits less variability in the pollutant concentration fields than the observations.

The benchmarking evaluation methodology can provide comprehensive and detailed insights into the model performance related to regulated pollutants both from a scientific scope and for policy applications. Since a large number of the objectives (and indicators) depend on the measurement uncertainty of the different pollutants, it is necessary to perform an assessment of this component in the region, identify whether the MQO are stringent enough for regimes with low concentrations of the regulated pollutants (below AQD directives) and to assess whether the methodology is applicable in these cases.

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