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Dynamic evaluation of air quality models over European regions

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HIGHLIGHTS

- Air quality model responses to emission reduction scenarios are presented.
- Maximum potential for local emission abatement is identified.
- Relative importance of the various precursor emissions is assessed.
- Degree of non-linearity of the model responses is estimated.
- Three case studies in Europe are considered.

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ABSTRACT

Chemistry-transport models are increasingly used in Europe for estimating air quality or forecasting changes in pollution levels. But with this increased use of modeling arises the need of harmonizing the methodologies to determine the quality of air quality model applications. This is complex for planning applications, i.e. when models are used to assess the impact of realistic or virtual emission scenarios. In this work, the methodology based on the calculation of potencies proposed by Thunis and Clappier (2014) to analyze the model responses to emission reductions is applied on three different domains in Europe (Po valley, Southern Poland and Flanders). This methodology is further elaborated to facilitate the inter-comparison process and bring in a single diagram the possibility of differentiating long-term from short-term effects. This methodology is designed for model users to interpret their model results but also for policy-makers to help them defining intervention priorities. The methodology is applied to both daily PM_{10} and 8 h daily maximum ozone.

1. Introduction

Air quality models are increasingly used in Europe for simulating air quality. In the past, assessment and reporting of air quality was largely based on monitoring data but the situation has changed in recent years when more emphasis has been put on the use of air quality models to complement monitoring data. This is the result, among others, of the 2008 European Directive on Ambient Air Quality and Cleaner Air for Europe which encourages modeling as one of the means to perform AQ management tasks such as air quality assessment, forecasting and planning (EEA, 2011). With increasing number of air quality modeling applications, the need of harmonizing the methodologies to check the quality of air quality model applications is high. It is in this context that validation protocols are currently being developed in the frame of the Forum for Air Quality Modeling – FAIRMODE initiative (see http://fairmode.jrc.ec.europa.eu/). Since air quality models can be used to perform various tasks (assessment, forecasting, planning) specific validation protocols (i.e. Dennis et al., 2010, i.e. for assessment) should be developed and used.

Regarding assessment (or operational model evaluation, i.e. the reconstruction of past/present pollution episodes) the validation procedure usually makes use of real measurement at monitoring stations, that allows quantifying the quality of a given model simulation. In this context various protocols/tools have already been developed (e.g., Delta Tool, http://aqm.jrc.ec.europa.eu/DELTA/, see Thunis et al., 2012; Carnevale et al., 2014; Dennis et al., 2010; etc.)

Regarding forecasting (i.e. the application of a model to foresee

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short-term pollution concentrations, see i.e. Aguilera et al., 2013), measurement can also be used to assess model performances. Specific indicators can then be used. We refer to Zhang et al. (2012) for an interesting overview of possible validation approaches.

The situation is more complex (and challenging) for planning applications, i.e. when models are used to assess the impact of realistic or virtual emission changes (Lefebvre et al., 2011). The FAIRMODE guidance document (EEA, 2011) reviews some possible methodologies to achieve this evaluation task:

(1) Trends analysis (i.e. the reproduction of two (or more) years characterized by change of emissions). Although this provides valuable information on the model capability to react properly to emission changes, the main disadvantage is to mix various factors in the analysis, in particular meteorology and emissions. In addition, the emission change across years remains affected by uncertainty (Fagerli and Aas, 2008).
(2) Time segregation. With this methodology a split of a long time period in smaller clusters (week-end vs. week days, day vs. night, summer vs. winter, etc.) is performed. Each of these clusters is characterized by different emissive characteristics (e.g., traffic emissions would mostly occur during week-days and decrease substantially on week-ends). By splitting data into clusters, meteorological conditions are mostly filtered out and the impact of emission changes can then be more easily identified.

Note that both of these two methodologies rely on the availability of measurement data to test the dynamic response of the air quality models.

Complementary to these two approaches, a method to further pursue the planning evaluation process is based on model inter-comparison exercises. Although measurement data could also be used if this inter-comparison is combined with one of the two above mentioned approach, the inter-comparison can also focus on virtual emission scenarios for which no measurement data exists. No comparison with the "truth" can then be made but this type of exercise however proves to be extremely useful to better understand/flag out "strange" model behaviors (Cuvelier et al., 2007; Pernigotti et al., 2013; Giannouli et al., 2011).

In this work we apply and further develop the methodology proposed by Thunis and Clappier (2014) to illustrate to what extent this approach can support the evaluation of air quality models in planning mode, in the frame of an inter-comparison exercise. This methodology is based on indicators and diagrams that aim at synthetizing in a systematic manner the key aspects of air quality model responses to emission changes. These indicators aim at responding the following three questions:

(1) What is the concentration change related to an emission precursor reduction in a given geographical area (i.e. how much of the observed concentration levels is controllable from abatement actions taken within the domain of interest)?
(2) What is the ratio of the concentration change corresponding to the abated emissions of a given precursor with respect to the others?
(3) How robust are model responses to emission changes (i.e. assess the modeled concentration variability for different emission reduction levels)?

In this work the proposed indicators are applied on a series of geographical areas (characterized by high levels of pollution) to illustrate their potential in terms of interpretation and inter-comparison. Results for both daily averaged PM_{10} and daily 8 h maximum O_3 are presented.

Section 2 provides a description of the modeling set-up; Section 3 describes the methodological aspects whereas Section 4 includes the discussion of the results. Conclusions are presented in Section 5.

2. Modeling set-up

For the current work, simulations were performed with the chemistry transport model LOTOS-EUROS (Hendriks et al., 2013; Beltman et al., 2013; Manders et al., 2009). Gas-phase chemistry is simulated using the TNO CBM-IV scheme, which is a condensed version of the original scheme (Whitten et al., 1980). Hydrolysis of N_2O_5 is explicitly described following Schaap et al. (2004). LOTOS-EUROS explicitly accounts for cloud chemistry computing sulphate formation as a function of cloud liquid water content and cloud droplet pH as described in Banzhaf et al. (2012). For Aerosol chemistry LOTOS-EUROS features the thermodynamic equilibrium module ISORROPIA2 (Fountoukis and Nenes, 2007). Dry Deposition fluxes are calculated following a resistance approach as described in Erisman et al. (1994). Furthermore, a compensation point approach for ammonia is included in the dry deposition module (Wichink Kruit et al., 2012).

LOTOS-EUROS was applied over three different geographical areas in Europe (Benelux, South of Poland and Po Valley, Fig. 1) with a spatial resolution of 7×7 km^2. In these three domains, the emissions have then been reduced in a specific sub-area of the domain (indicated by the dark grey shaded areas in Fig. 1: Flanders, Silesia and Lombardy, respectively) while emissions outside these areas are kept at base-case level for all scenarios. This simulation setting is motivated by the objective of analyzing regional/local emission reduction measures to be implemented on-top of the EU-wide measures.

Following the methodology proposed by Thunis and Clappier (2014) (see next section for a brief description and publication for more details) a series of independent simulations in which the emissions of the different precursors are reduced either independently or contemporarily is requested. For two levels of emission reductions, the number of simulations is equal to $2^*n + 3$ where n is the number of emission precursors to be tested. In the case of PM10 which depends on emissions from the NO_x, SO_2, NH_3, Primary Particulate Matter (PPM) and Volatile Organic Carbon (VOC) precursors, the number of simulations requested to calculate the indicators is 12 in addition to the base case. These simulations consist of:

- A base case simulation.
- Five simulations where each precursor is abated by 50%. It represents a compromise between a large enough reduction to capture the main aspects of the model responses to significant changes in the input data and a level of reduction which remains realistically achievable in terms of human activity constraints.
- Five simulations where each precursor is abated by 20%. These simulations are used to calculate the indicators with a second level of reduction and test the robustness of the model responses.
- Two simulations in which all 5 precursor emissions are reduced contemporarily by 20 and 50%, respectively. These simulations are used to assess the degree of non-linearity in model responses.

For O_3 the number of runs may be reduced to 6 sensitivity simulations in addition to the base case since O_3 formation depends mainly on two precursors: NO_x and VOC. However, all simulations requested for O_3 are already covered with those performed for PM_{10}.