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Advancements in the design and validation of an air pollution integrated assessment model for Spain

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A B S T R A C T

This paper describes the design and application of the Atmospheric Evaluation and Research Integrated model for Spain (AERIS). Currently, AERIS can provide concentration profiles of NO_2, O_3, SO_2, NH_3, PM, as a response to emission variations of relevant sectors in Spain. Results are calculated using transfer matrices based on an air quality modelling system (AQMS) composed by the WRF (meteorology), SMOKE (emissions) and CMAQ (atmospheric-chemical processes) models. The AERIS outputs were statistically tested against the conventional AQMS and observations, revealing a good agreement in both cases. At the moment, integrated assessment in AERIS focuses only on the link between emissions and concentrations. The quantification of deposition, impacts (health, ecosystems) and costs will be introduced in the future. In conclusion, the main asset of AERIS is its accuracy in predicting air quality outcomes for different scenarios through a simple yet robust modelling framework, avoiding complex programming and long computing times.

Software availability

Name of Software: AERIS
Developer: Michel Vedrenne
Year first available: 2013
Hardware required: PC Compatible
Software required: Windows®, MATLAB® 7.10
Program language: C/C++, Java 1.6
Program size: 31 MB
Availability and cost: Contact developer. m.vedrenne@upm.es

1. Introduction

Integrated Assessment (IA) models are tools aimed to describe quantitatively the cause–effect relationship of events, cross-linkages and connections between issues of a given problem, seeking to analyse it under a synoptic perspective (Alcamo et al., 2002). These models provide a comprehensive framework for a shared and focused understanding of environmental challenges and have been applied to different sectors under various perspective. To this respect, issues such as climate change, air pollution, water management or environmental security are currently being addressed under integrated assessment approaches (de Vos et al., 2013; Kelly (Letcher) et al., 2013).

In line with the abovementioned, modelling air pollution under an IA approach is appropriate since the entire phenomenon is a consequence of complex interactions between physical and human systems. Typically, air pollution IA models (IAMs) describe the links between the emissions of pollutants, their atmospheric transport and chemical transformations, as well as the

Abbreviations: AERIS, Atmospheric Evaluation and Research Integrated model for Spain; AOT_{40}, Accumulated dose over a threshold of 40 ppb of ozone; AQMS, Air Quality Modelling System; BAT, Best available technique; BS, Baseline scenario (2007); CB, Carbon Bond mechanism; CMAQ, Community Multiscale Air Quality model; CPU, Central Processing Unit; E, Emissions; ECMWF, European Centre for Medium Range Weather Forecasts; EMEP, European Monitoring and Evaluation Programme; FAC2, Factor of two; GAINS, Greenhouse Gas and Air Pollution Interactions and Synergies model; GUI, Graphic User Interface; HS, Hypothetic scenario; IA, Integrated Assessment; IAM, Integrated Assessment Model; MB, Mean Bias; ME, Mean Error; NMB, Normalized Mean Bias; NME, Normalized Mean Error; PC, Personal Computer; PM, Particulate Matter; PNEI, National Emission Inventory of Portugal; PR, Projected Emissions; RAINS, Regional Air Pollution and Simulation model; RS_{11}, Real emission scenario for year 2011; RS_{14}, Real emission scenario for year 2014; S, Sector; SEP, Spain's Emission Projections model; SERCA, Sistema de Evaluación de Riesgos por Contaminación Atmosférica en la peninsula Ibérica; SIMCA, Sistema Integrado de Modelización de la Contaminación Atmosférica; SMOKE, Sparse Matrix Operator Kernel Emissions model; SNAP, Selected Nomenclature for Air Pollution; SNEI, National Emission Inventory of Spain; $SOMO_{35}$, Sum over means of 35 ppb of ozone; TM, Transfer Matrix; UNECE, United Nations Economic Commission for Europe; USGS, United States Geological Survey; VP, Variation Percentage; WRF, Weather Research and Forecast model.

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environmental and health impacts they produce (Carnevale et al., 2012). In other words, air pollution IAMs cover the complete chain of events that links human activities (emissions) to environmental effects that can ultimately be translated into economic losses (impacts).

The use of IAMs as policy-support tools in Europe has become common in the recent decades as a consequence of the application of the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP) (Kaldellis et al., 2007). Examples of these are the Abatement Strategies Assessment Model (ASAM) (Warren and ApSimon, 1999) and the RAINS/GAINS Integrated Assessment system (Schöpp et al., 1999; Amann et al., 2011). While RAINS/GAINS is the most widely-used IAM for policymaking and negotiations at the European level, the need of operative IAMs at the national level has originated country-specific adaptations such as the GAINS-Italy (Vialetto et al., 2005; D'Elia et al., 2009), RAINS-NL (Aben et al., 2008) or the IMP model from Ireland (Kelly, 2006). Other models such as the United Kingdom Integrated Assessment Model (UKIAM) (Oxley et al., 2003) or the MINNI model for Italy (Zanini et al., 2005) have been developed independently.

In the same line, the Technical University of Madrid (UPM) has developed AERIS (Atmospheric Evaluation and Research Integrated model for Spain), an IAM especially suited for Spain and the Iberian Peninsula. AERIS was created to be a reliable tool for support needed by policymakers at local, regional and national levels, trying to be useful to as many stakeholders as possible. This is especially relevant for Spain, whose institutional division in 17 autonomous communities makes necessary the elaboration of different regional air quality management plans. Furthermore, it should provide answers about whether the environmental objectives will be sufficiently met, as well as the associated economic and environmental consequences. An additional motivation for creating AERIS is the fact that continental IAMs are unable to deliver spatially resolved results suitable for national or regional policies and are usually restricted to Europe-wide common features, being national particularities out of reach (D'Elia et al., 2009). Furthermore, the ancillary information used for the compilation of emission inventories (i.e. bottom-up approaches) or the description of the meteorological conditions is usually of a better quality (Moussiopoulos et al., 2012).

The presented version of AERIS is able to estimate ambient concentrations produced by changes in the emissions of airborne pollutants. AERIS was built relying on the application of a robust air quality modelling system (AQMS), developed through the SIMCA and SERCA projects, which concentrate the experience accumulated over the years in emissions and air quality modelling. It should be noted that AERIS is intended to mimic comprehensive systems used for scenario analysis and policy support in Spain (Guevara et al., 2013; Borge et al., 2014) as well as air quality impact assessment (de Andrés et al., 2012; Boldo et al., 2014), but it cannot be used as a screening tool for air quality forecasting (Baldasano et al., 2008).

Furthermore, AERIS was been created to be simple and flexible without sacrificing the quality of the results. Its construction implied using country-specific data provided by national administrations, always working with a fine resolution (16 × 16 km^2) which is very necessary when allocating abatement measures (Oxley and ApSimon, 2007; Moussiopoulos et al., 2009). This resolution can be considered an intermediate step between the continental and the urban scales, which is appropriate for the multi-scalar nesting of models (Oxley et al., 2009). It is also worth noting that the quantification of emissions relied on the use of inventories which were constructed using data referred to the regional and local scales rather than European-scale estimates (i.e. EMEP).

This work describes in its first part the methodology followed in the modelling and construction process of AERIS. The second part is devoted to evaluating the performance of AERIS against two different emission scenarios by comparing its outputs to those of the standard AQMS as well as air quality observations. Finally a discussion on the relevance and robustness of the outputs produced by AERIS is carried out. In general lines, the objective of this paper is the description and validation of the current developments in the advancement of integrated assessment modelling to the air pollution problem in Spain by the means of AERIS.

In a more general perspective, this paper intends to present AERIS as an example of wider integrated assessment modelling and to provide relevant guidance on generic issues on problem areas encountered by modellers and stakeholders. Furthermore, the AERIS example should help fostering a more informed and creative decision-making environment and respond to the challenges to science practice with other stakeholders such as politics, governance, media, etc (Kelly (Letcher) et al., 2013). The ultimate objective is to favour openness in front of bodies of expertise that lie beyond the boundaries of formal science (Berkhout, 2010).

2. The AERIS model

2.1. General overview

The AERIS model is a multi-pollutant modular IAM that addresses air quality changes, expressed in terms of policy-relevant indicators, as a function of variations in the emissions. The relevant compounds described by AERIS are sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), two fractions of particulate matter (PM_{10}, $PM_{2.5}$), and non-methane volatile organic compounds (VOC). The model also includes tropospheric ozone (O_3) and secondary particles. In general terms, AERIS has been created to take into consideration the emissions of each of the before mentioned primary pollutants in Spain and Portugal as well as their transport and transformation across the modelled domain. The results are presented as a series of air quality indicators derived from Directive 2008/50/EC on ambient air quality and cleaner air for Europe (EC, 2008). These indicators are linked to the possible impacts that air pollution has on human health, ecosystems, etc.

Table 1
List of policy-relevant air quality indicators considered by AERIS (Directive 2008/50/EC).

Pollutant	Indicators – (units)
NO_2	Mean monthly concentration – (μg/m^3)
	Mean annual concentration – (μg/m^3)
	19th highest hourly concentration – (μg/m^3)[a]
SO_2	Mean monthly concentration – (μg/m^3)
	Mean annual concentration – (μg/m^3)
	25th highest hourly concentration – (μg/m^3)[a]
	4th highest daily concentration – (μg/m^3)[a]
NH_3	Mean monthly concentration – (μg/m^3)
	Mean annual concentration – (μg/m^3)
PM_{10}	Mean monthly concentration – (μg/m^3)
	Mean annual concentration – (μg/m^3)
	36th highest daily concentration – (μg/m^3)[a]
$PM_{2.5}$	Mean monthly concentration – (μg/m^3)
	Mean annual concentration – (μg/m^3)
O_3	Mean monthly concentration – (μg/m^3)
	Mean annual concentration – (μg/m^3)
	26th highest maximum daily 8-h value – (μg/m^3)[a]
	Sum of means over 35 ppb ($SOMO_{35}$)–(μg/m^3 h)
	Daylight accumulated dose over a threshold of 40 ppb (AOT_{40})–(μg/m^3 h)[a]

[a] Indicators derived from Directive 2008/50/EC to define limit values, target values or critical levels.

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