Impacts of climate change on air quality levels in southwestern Europe for the XXI century

Pedro Jiménez-Guerrero, Sonia Jerez, Juan J. Gómez Navarro, Raquel Lorente, Juan A. García Valero, Juan P. Montávez

Regional Atmospheric Modelling (RAM), Physics of the Earth
E-mail: pedro.jimenezguerrero@um.es
Phone: +34 868 88 8175

HARMO’13, Paris, France, 1-4 June 2010
Motivation:

The impacts of climate change on air quality may affect long-term air quality planning. However, the policies aimed at improving air quality have not accounted for the variations in the climate (Racherla and Adams, 2006, JGR; Giorgi and Meleux, 2007, CRG). **Climate change alone will influence future air pollution** through modifications of gas-phase chemistry, transport, removal, and natural emissions (Pye et al., 2009, JGR).

Objective:

The goal of this study is to determine how the **concentrations** and the **patterns of variability** of atmospheric aerosols respond to changes in climate over southwestern Europe and the Iberian Peninsula for the 21st century (2071-2100), because of their importance as a climate change hot spot (Giorgi, 2006, GRL).
**Future scenario, 21st Century (1991-2100)**

**ECHO-G Erik-a08 (SRES A2)**

**ECHO-G:**
- ECHAM4 → **T30 resolution (3.75°)**, 19 vertical levels up to 10 hPa
- OASIS coupler
- HOPE-G → **T42 resolution (2.8°)**, 20 levels

**Erik-a08 experiment:** the 1000 to 1990 period is forced following Crowley (2000), Science, 289, 270-277. The GHGs concentrations follow the **IPCC SRES A2 Scenario** from the year 1991 to 2100.

The coarse horizontal resolution of current global simulations does not permit an estimate of the effects of climate change on tropospheric pollutants distributions on the regional scale (Forkel and Knoche, 2006, JGR).
Dynamical downscaling with MM5-EMEP-CHIMERE

Horizontal resolution: 80-25km; Vertical Resolution: 23 layers (100 hPa)

**MM5** parameterizations:
- Microphysics → **Simple Ice**
- Cumulus → **Grell**
- PBL → **MRF**
- Radiation → **RRTM**
- Soil → **Noah LSM**

**CHIMERE** parameterizations:
- Chemical Mechanisms → **MELCHIOR2**
- Aerosol chemistry → Inorganic (thermodynamic equilibrium with **ISORROPIA**) and organic (**MEGAN SOA** scheme) aerosol chemistry
- Natural aerosols → **dust, re-suspension and inert sea-salt**
- **BC** → **LMDz-INCA+GOCART**

**EMEP** emissions: year 2005. In order to isolate the possible effects of climate change on the ground concentrations of air pollutants, the assumption of unchanged anthropogenic emissions was implemented in the chemistry transport model.
For gas-phase pollutants, the general increase in ozone concentrations found under A2 forcing is due to a multiplicity of climate factors, such as increased temperature, decreased wet removal associated with the general decrease of precipitation, increased photolysis of primary and secondary pollutants due to lower cloudiness and increased biogenic emissions due to higher temperatures. As observed from the NO$_2$ variation under future climates, our simulations suggest that the enhanced ozone chemical activity is mainly driven by the warming-induced increase in biogenic emissions and not because of the variation in nitrogen dioxide levels, which hardly change (or even decrease in the south of the Iberian Peninsula).
Changes in seasonal aerosol levels

The most frequent approach adopted for the evaluation of the projected concentrations of pollutants and other climate predictors is the future-minus-present method. This is based on the assumption that biases in simulated present-day and future climates should tend to cancel each other, and thus their difference captures the change signal.

The Winter (DJF), Spring (MAM), Summer (JJA) and Autumn (SON) 2071-2100 levels for different aerosols are compared to those of 1991-2010.
The trends of variation of aerosols are influenced by the higher temperatures modelled for the future climates, since it favours the formation of organic aerosols and sulphates (increasing their concentrations) and the decomposition of ammonium nitrate, remaining in the gas phase.
Further, the changes in precipitation have a strong effect on the frequency of the washout and therefore in the levels of aerosols. The concentrations of aerosols increases with decreasing precipitation as wet deposition provides the main aerosol sink.
Sulphate 2071-2100 vs. 1991-2010 (µg m⁻³)  
Difference in the seasonal concentration of aerosols

The critical variable is precipitation frequency rather than precipitation rate, since scavenging within a precipitating column is highly efficient (Balkanski et al., 1993). For summer, gas phase sulphate production may decrease in the future as a result of lower OH concentrations due to climate change. Although higher specific humidities are expected to increase HOx production, higher temperatures and higher biogenic emissions can result in decreasing OH and increasing HO₂ (Pye et al., 2009).
Sulphate 2071-2100 vs. 1991-2010 (µg m⁻³)
Difference in the seasonal concentration of aerosols

The critical variable is precipitation frequency rather than precipitation rate, since scavenging within a precipitating column is highly efficient (Balkanski et al., 1993).

For summer, gas phase sulphate production may decrease in the future as a result of lower OH concentrations due to climate change. Although higher specific humidities are expected to increase HOx production, higher temperatures and higher biogenic emissions can result in decreasing OH and increasing HO₂ (Pye et al., 2009).
The changes in ventilation (mixing height) have stronger effects on aerosols than on gaseous pollutants because of their lower background concentrations. The trend from a decreasing (increasing) mixing height found in several areas of Spain is associated with a decrease (increase) in precipitation, and therefore represents a positive feedback.
Nitrate 2071-2100 vs. 1991-2010 (µg m⁻³)
Difference in the seasonal concentration of aerosols

Effects of climate on nitrate are more complicated than sulphate due to high vapor pressure for particle-phase ammonium nitrate (Seinfeld and Pandis, 2006). Aw and Kleeman (2003) present that nitrate aerosol may slightly increase with cool temperature (<290 K) but decrease with hot temperature (>290 K) as temperature increases.
Effects of climate on nitrate are more complicated than sulphate due to high vapor pressure for particle-phase ammonium nitrate (Seinfeld and Pandis, 2006). Aw and Kleeman (2003) present that nitrate aerosol may slightly increase with cool temperature (<290 K) but decrease with hot temperature (>290 K) as temperature increases.
The seasonally-averaged change in ammonium closely resembles that of sulfate, and most ammonium would likely be in the form of ammonium sulfate. Higher temperatures favor ammonium nitrate (NH$_4$NO$_3$) to remain in the gas phase.
The seasonally-averaged change in ammonium closely resembles that of sulfate, and most ammonium would likely be in the form of ammonium sulfate. Higher temperatures favor ammonium nitrate \((\text{NH}_4\text{NO}_3)\) to remain in the gas phase.
Non-anthropogenic aerosols

The levels seasonal levels of natural aerosols are analysed for the Iberian Peninsula.

The Winter (DJF), Spring (MAM), Summer (JJA) and Autumn (SON) 2071-2100 levels for different aerosols are compared to those of 1991-2010.
Non-Anthr. PM10 2071-2100 vs. 1991-2010 (µg m⁻³)
Difference in the seasonal concentration of aerosols
The changes in natural PM10 are strongly related to those of sea salt and mineral dust matter. They are strongly correlated to the temperature increase and precipitation. The marine aerosols are also related to future change in circulation patterns (increase of stagnant conditions for extended summertime).
Biogenic SOA 2071-2100 vs. 1991-2010 (µg m\(^{-3}\))
Difference in the seasonal concentration of aerosols

Biogenic SOA is predicted to be influenced by changes in biogenic VOC emissions as well as modifications in the formation rates under the effects of the extreme climate scenarios.
Analysing the anomalies of SIA by using the EOFs in a full transient simulation

The results of the future-minus-present method may be highly dependent on the chosen control period due to the inherent internal variability of the climate models, specially at regional scales (Raisanen, 2001, J. Clim.). Although computationally expensive, full transient simulations minimise the internal variability uncertainty due to the longer time series obtained.

For applying the EOFs analysis, the variables have been normalised (for establishing common variation patterns removing the areas with a higher variability due to emissions) and the annual variation cycle has been removed, so that the EOFs and PCs represent the anomalies with respect to the 1991-2100 averages.
Establishing the variation patterns: the use of Empirical Orthogonal Functions

The EOFs approach decomposes a space-time field into spatial patterns and associated time indices. This allows increasing the signal to noise ratio, reducing the high dimensionality of complex phenomena and summarizing its main properties in a much smaller number of prominent modes of variability (Hannachi et al., 2007, Int. J. Clim.):

\[ C(t, s) = \sum_{i=1}^{N} PC_i(t) EOF_i(s) \]

where \( N \) is the number of modes contained in the field \( C \) (concentration), \( EOF_i(s) \) are a set of functions defined for space and \( PC_i(t) \) their temporal coefficients, usually called Principal Components (PCs).
Anomalies in Sulphate for 1991-2100, SRES A2
Principal Components (PCs): trends

Universidad de Murcia MM5–ROM+CHIMERE EOF1, Sulphate, 27.33%
1991–2100, ECHO–G A2, Europe Resolution: 80km

Universidad de Murcia MM5–ROM+CHIMERE EOF2, Sulphate, 9.77%
1991–2100, ECHO–G A2, Europe Resolution: 80km

ΔSulphate (µg m⁻³)
Spatial correlation of the EOF1s
Sulphate vs. 2-m temperature, Precipitation and Mixing Height

Corr. Sulphate-T2m: 0.387
Corr. Sulphate-Prec: -0.584
Corr. Sulphate-MH: -0.525
Conclusions:

Climate change impacts gas-phase compounds and aerosols by increasing the mean concentrations of these components in most regions over southwestern Europe. This may be driven by an enhanced secondary production (especially of BSOA) as a consequence of the temperature increase, the changes in precipitation patterns, the decrease of the mixing heights hampering the dilution of pollutants and the stagnant conditions found for the Mediterranean, which are substantially modified in the future SRES A2 scenario for 2071-2100.

The pattern for the spatial variability of sulphate (and other compounds, not shown) is explained by the EOF1; which is able to filter out the trend of the anomalies. The PC1 indicates a high correlation of these compounds with temperature and anti-correlation with precipitation and mixing height.

Questions that are currently being addressed by the RAM group:

Do the patterns of variability change under different SRES scenarios or global-driving models? Or do they just produce a change in the magnitude of the variation?

Which is the impact of the physico-chemical parameterizations of the regional model on the patterns and magnitude of change?
Thank you for your attention

Acknowledgments: This work was funded by the Spanish Ministry of the Environment (project ESCENA, Ref. 20080050084265) and the Spanish Ministry of Science and Technology (projects INVENTO-CGL2005-06966-C07-04/CLI and SPECMORE-CGL2008-06558-C02-02/CLI). The authors also gratefully acknowledge the funding from the Regional Agency for Science and Technology of Murcia (Fundación Séneca, Ref. 12033/PI/09, 11124/AC/09 and 11047/EE1/09).