Air Quality in a changing climate: improved understanding from Earth system modelling

Supervisors: Dr. Steve Arnold (SEE), Prof. Dominick Spracklen (SEE), Dr. Steven Turnock (Met Office)

Background

Poor air quality affects major cities in regions all around the planet, including the UK and Europe (e.g. Fig 1.), leading to millions of premature deaths every year worldwide. Mitigation measures to improve air quality and climate are inherently interlinked, as changes to Near Term Climate Forcers (NTCF), such as tropospheric ozone and aerosols, impact both atmospheric pollution abundances and climate (Arneth *et al*., 2009: Fiore *et al*., 2012: von Schneidemesser *et al*., 2015). A changing climate can affect chemical and physical processes in the atmosphere controlling spatial and temporal distributions of air pollutants (Rasmussen *et al*., 2013). Understanding Earth system feedbacks on NTCF and air quality are important within a future climate context, as feedbacks could result in "climate penalties", reducing or negating the effectiveness of emission reductions targeting improvement of air quality.

Fig. 1: Pollution haze in London, UK. Image: David Holt / Flickr.

There are numerous ways for air quality and climate to interact and feedback on to one another, including ventilation rates, large scale circulation, wet and dry depositions rates, chemical production and loss rates, temperature, natural emission rates and background concentrations (see Fig. 2). The impacts of NTCFs on climate offer the opportunity for developing emission mitigation strategies that have co-benefits for air quality improvement and climate change mitigation. However, the interactions between climate change, air quality, and feedbacks on the Earth system are currently poorly understood (Jacob & Winner, 2009).

The recent development of the United Kingdom Earth System Model (UKESM) for the CMIP6 simulations couples together various Earth system modelling components and their interactions into a single model framework, including atmospheric chemistry and aerosol interactions with land surface processes such as emissions of biogenic volatile organic compounds (BVOCs) and emissions from fires. This increased complexity presents the opportunity for a novel study into interactions and feedbacks between air quality and climate, driven by Earth system interactions and responses in the context of future policies relating to climate and air quality.

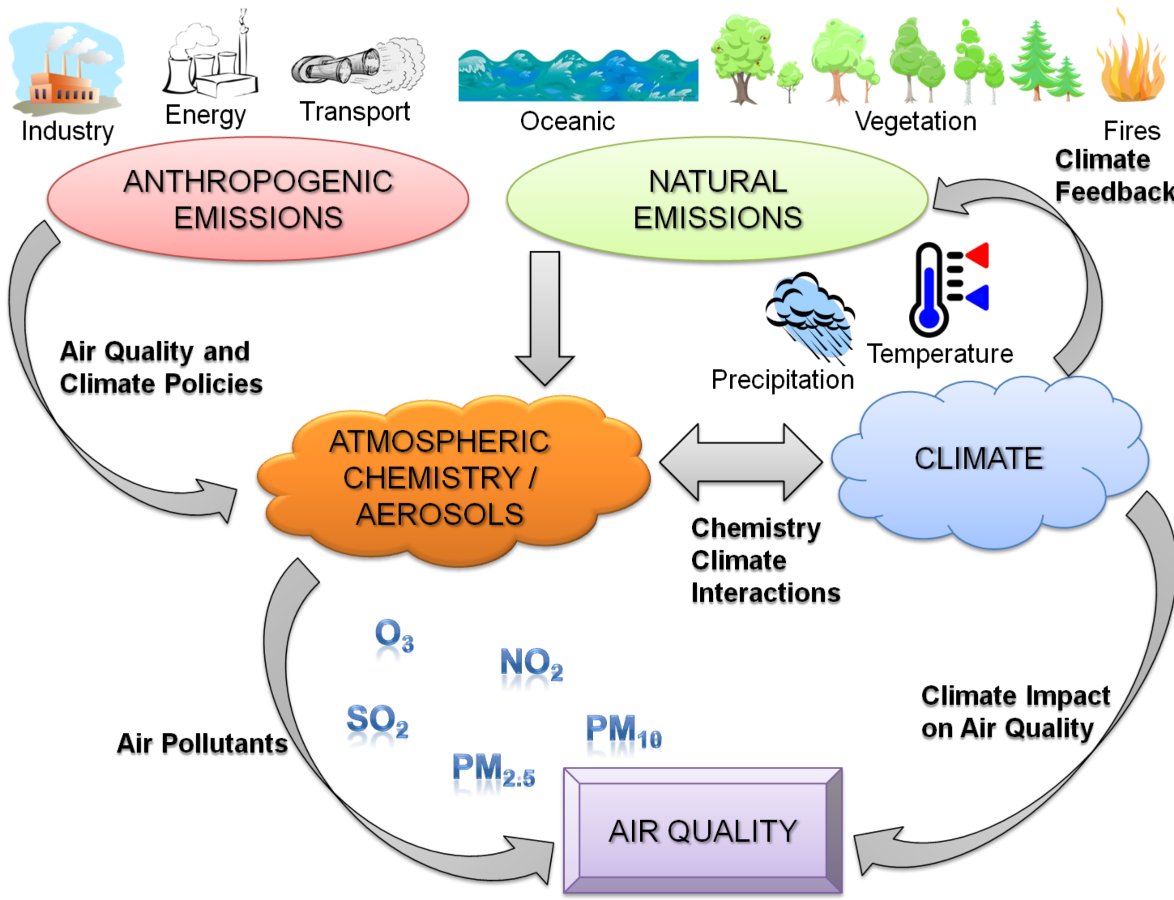

Fig. 2: Schematic summarizing the various different chemistry climate interactions and feedbacks within the Earth system

Aims and approach

The over-arching project aim is to understand and quantify how Earth system feedbacks affect air quality.

The project will address the following research questions:

Q1. What are the key Earth system interactions impacting the concentrations of air pollutants (aerosols, ozone)? How do these interactions change under a future warming climate?
Q2. What are the magnitudes of individual Earth system feedback mechanisms linking changes in climate and air quality?

Q3. To what extent will Earth system feedback mechanisms reduce the efficacy of future air quality policies targeting emission reductions of NTCFs? How much do individual mechanisms reduce the benefits from future air quality policies?

The student will analyse UKESM simulations being carried out as part of the international AerChemMIP assessment (Collins *et al*., 2017). These will be used to identify important Earth system interactions (Q1). In order to delve deeper into understanding specific processes, and investigate and quantify feedback mechanisms, the student will carry out their own additional simulations (Q2). Future simulations with the UKESM will be used to quantify the impact of feedback mechanisms on future air quality under both high and low air pollutant emission scenarios and different future climates (Q3).

This project presents an exciting and novel way to look at the interaction and feedback of Earth system processes on air quality, which has not previously been possible. This is important to understand, in order to robustly make predictions of future air quality and climate, and develop policies that can effectively meet targets for future global temperature changes and regional air quality.

Potential for high impact outcome

The project will develop scenarios and process understanding for how air quality will respond to projected changes in climate. The project aligns well with international climate science priorities and the Met Office Hadley Centre Climate Programme. The availability of information on the potential coupled climate-air quality impacts of emission changes is lacking. More robust understanding from this project will be of benefit to policy makers in designing future emission mitigation strategies, ensuring that reductions benefit both the climate system and air quality, and providing a more robust basis for evaluation of likely impacts. Outcomes of the project will also help to improve future estimates of health-related impacts of air pollution in different world regions, accounting for the potential role of Earth system feedbacks in worsening or alleviating health burdens associated with particulate and tropospheric ozone pollution.

Training and research group

The student will benefit from training in expertise in both numerical atmospheric chemistry-climate modelling and analysis of large geophysical datasets. The student will be involved in analysis of a large suite of Earth system model simulations undertaken as part of the international AerChemMIP model comparison project, and will design and run their own model experiments on the Met Office supercomputing facility.

The student will join a group of around 8 students and postdoctoral researchers working on projects in atmospheric composition and its links to climate, air quality and the biosphere. For more information about our research and recent publications, see: http://homepages.see.leeds.ac.uk/~lecsra. We encourage interested applicants to get in touch and arrange an informal visit to Leeds to meet and talk informally with the group.

Partners and Collaborations

The student will be co-supervised by the UK Met Office, and will be part of the UK contribution to the AerChemMIP project but also to the wider global multi-model intercomparison that would be undertaken as part of AerChemMIP's contributions to CMIP6. This would present the opportunity for research and development both within the UK scientific community but also around the globe.

Extended visits for the student to the Hadley Centre at the Met Office will be expected (minimum 3 / yr, 1-2 weeks duration) for scientific discussion, mentoring on Met Office systems, further training in

Earth System Modelling, and to take advantage of relevant training courses that are available at the Met Office.

References

Arneth A, Unger N, Kulmala M and Andreae M O, (2009) Clean the air, heat the planet? Science 326 672–3

Collins, W. J., Lamarque, J.-F., Schulz, M., Boucher, O., Eyring, V., Hegglin, M. I., Maycock, A., Myhre, G., Prather, M., Shindell, D., and Smith, S. J. (2017): AerChemMIP: quantifying the effects of chemistry and aerosols in CMIP6, Geosci. Model Dev., 10, 585-607, doi:10.5194/gmd-10-585-2017.

Fiore, A. M., Naik, V., Spracklen, D. V, Steiner, A., Unger, N., Prather, M., Bergmann, D., Cameron-Smith, P. J., Cionni, I., Collins, W. J., Dalsøren, S., Eyring, V., Folberth, G. a, Ginoux, P., Horowitz, L. W., Josse, B., Lamarque, J.-F., MacKenzie, I. a, Nagashima, T., O?Connor, F. M., Righi, M., Rumbold, S. T., Shindell, D. T., Skeie, R. B., Sudo, K., Szopa, S., Takemura, T. and Zeng, G. (2012) Global air quality and climate., Chemical Society reviews, 41(19), pp. 6663-83. doi: 10.1039/c2cs35095e.

Jacob, D. J. and Winner, D. a. (2009) Effect of climate change on air quality, Atmospheric Environment. Elsevier Ltd, 43(1), pp. 51-63. doi: 10.1016/j.atmosenv.2008.09.051.

Rasmussen D. J., Jianlin Hu, Abdullah Mahmud, and Michael J. Kleeman (2013) The Ozone–Climate Penalty: Past, Present, and Future, Environmental Science & Technology 47 (24), 14258-14266, DOI: 10.1021/es403446m

von Schneidemesser, E., Monks, P. S., Allan, J. D., Bruhwiler, L., Forster, P., Fowler, D., Lauer, A., Morgan, W. T., Paasonen, P., Righi, M., Sindelarova, K. and Sutton, M. a. (2015) Chemistry and the Linkages between Air Quality and Climate Change, Chemical Reviews, 115(10), pp. 3856-3897. doi: 10.1021/acs.chemrev.5b00089.