Chemistry in the Unified Model: Climate-Chemistry Studies with UKCA

N.L. Abraham[1], P. Braesicke[1], F. O'Connor[2], C. Johnson[2], P. Telford[1], A. Archibald[1], R. Pike[1], G. Folberth[2], N. Savage[2], C. Ordonez[2], O. Morgenstern[3], P. Young[4] and J.A. Pyle[1]

1. University of Cambridge, UK; 2. Met Office, Exeter, UK; 3. NIWA, New Zealand; 4. NOAA, Boulder CO, USA.

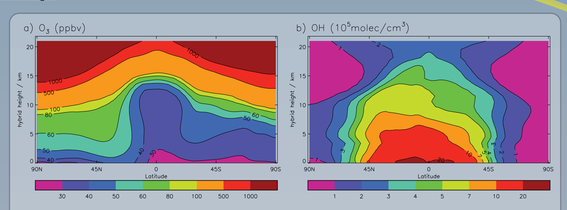
The UKCA Family

UKCA is a community Climate-Chemistry-Aerosol model which is built as a sub-model of the UK Met Office's Unified Model. There is support for a number of chemistry schemes which are suitable for several different applications, ranging from chemistry-climate integrations at centennial time scales to air-quality forecasts running in the operational suite. The simplest scheme is the StdTrop scheme, which has been built on to form the TropIsop and ExtTC schemes.

Standard Tropospheric Chemistry *StdTrop*

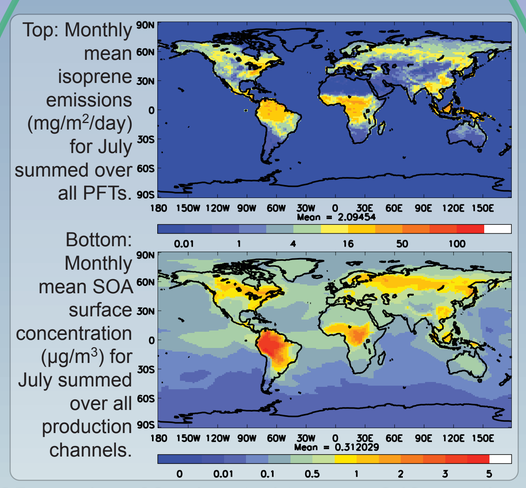
46 species, 26 advected tracers, 129 reactions

This is a basic chemistry scheme with 8 emitted species, 102 gas-phase reactions, 27 photolysis reactions and interactive deposition schemes. The scheme simulates the O_X, HO_X and NO_X chemical cycles and the oxidation of CO, ethane and propane. Sulphur chemistry can be added (*AerChem*) to allow the use of the MODE aerosol scheme.



Multi-annual zonal annual mean distributions of a) ozone, b) OH. GRL, **36**, L16801 (2009).

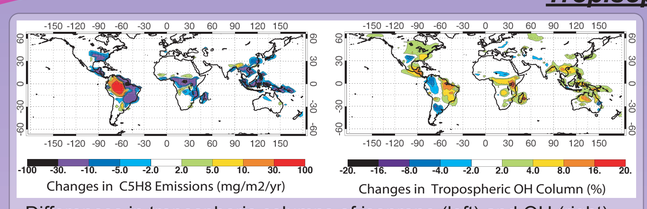
Extended Tropospheric Chemistry *ExtTC*



85 species, 63 advected tracers, 243 reactions

UKCA-ExtTC is an extension to the standard chemistry increasing the number of tracers to 63 and the total number of species to 85 (37 additional tracers and 7 additional non-advected short-lived species). Emissions are taken into account for 17 of the tracers, and emissions of the four most important BVOCs (isoprene, terpenes, methanol, acetone) are now computed interactively. This process-based model can easily be extended to other species. The scheme comprises 198 reactions with 45 photolysis reactions. It includes a simple SOA sub-model consisting of 21 individual chemical and pseudo-chemical processes (e.g., gas-to-solid phase transition coefficient). The list of additional species includes isoprene, terpenes (lumped), aromatics (lumped), C4+-alkanes (lumped), ethene, propene, MEK, MVK, low-reactivity organic nitrate compounds (similar to CH_3ONO_2, lumped), organic acids (formic, acetic), and semi-volatile SOA precursors.
This scheme is currently implemented as an extension to HadGEM2-ES.

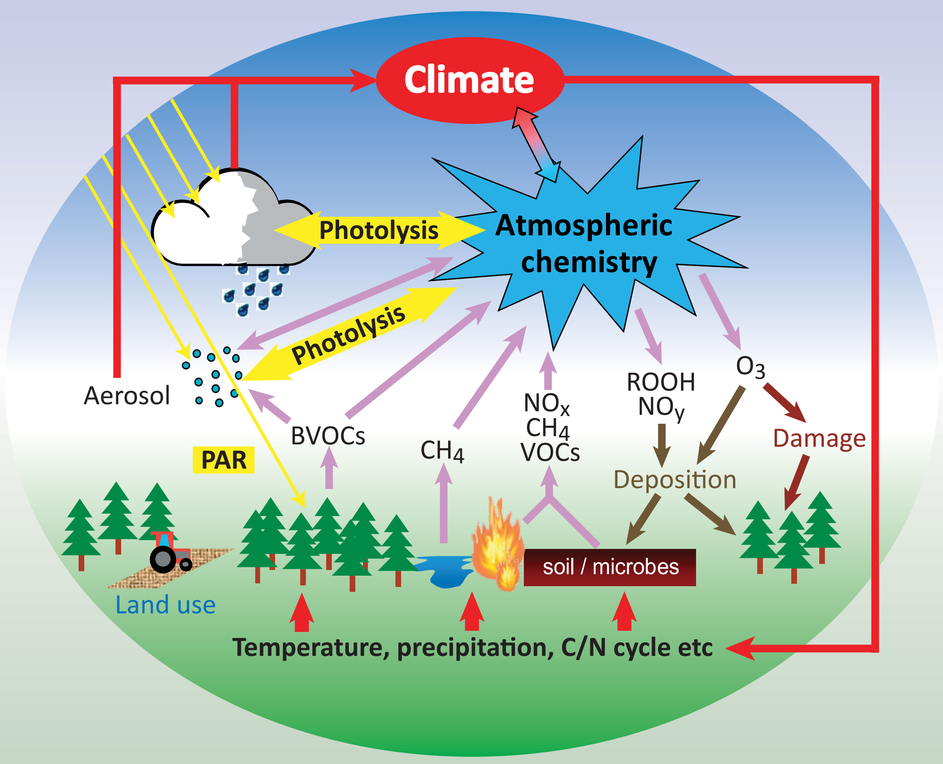
Tropospheric Chemistry with Isoprene *TropIsop*



Differences in tropospheric columns of isoprene (left) and OH (right) caused by changes to emissions between 1990 and 1992 caused by the eruption of Mt. Pinatubo. This study was performed by nudging the model to ERA-40 re-analysis. Telford *et al*, submitted to ACPD (2009).

55 species, 48 advected tracers, 164 reactions

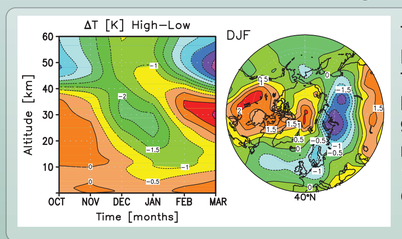
The addition of the Mainz Isoprene Mechanism to the Standard Tropospheric Chemistry scheme allows for more detailed studies of land-surface-climate interactions and this scheme can be run at decadal to centennial time scales. This scheme has 129 gas-phase reactions with 35 photolysis reactions and has emissions into 9 species, with isoprene oxidation now considered. Emissions of isoprene are scaled to be diurnally varying.



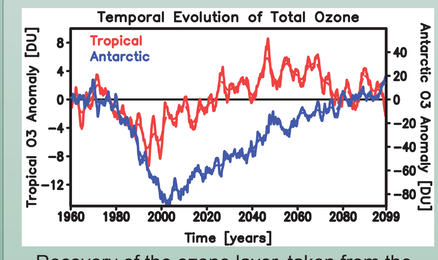
Stratospheric Chemistry *StratChem*

41 species, 36 advected tracers, 169 reactions

This scheme is designed to be run on centennial time scales for studying climate-chemistry feedbacks and research into ozone depletion. It allows for interactive ozone from UKCA to be used in the model's radiation scheme. This scheme has been run as part of the CCMVal model intercomparison for up to 150 years. It has a simple tropospheric chemistry running beneath the more complex stratospheric chemistry which considers the emission of 8 species. There are 34 photolysis reactions, 120 gas-phase reactions, and 5 heterogeneous reactions.



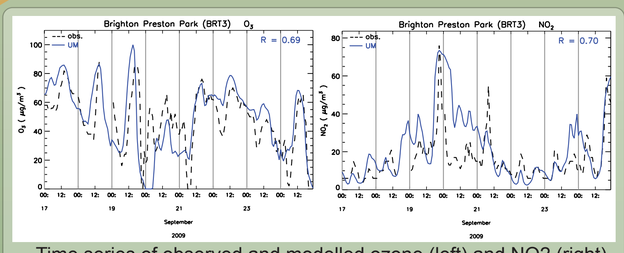
The World Avoided by the Montreal Protocol: Temperature differences between a model run with 9ppbv of Cl_y and a reference run of 3.5ppbv comparable to 1990 levels.
GRL **35** L16811 (2008)



Recovery of the ozone layer, taken from the CCMVal simulations.

Regional Air Quality Chemistry *RAQ*

58 species, 40 advected tracers, ~140 reactions

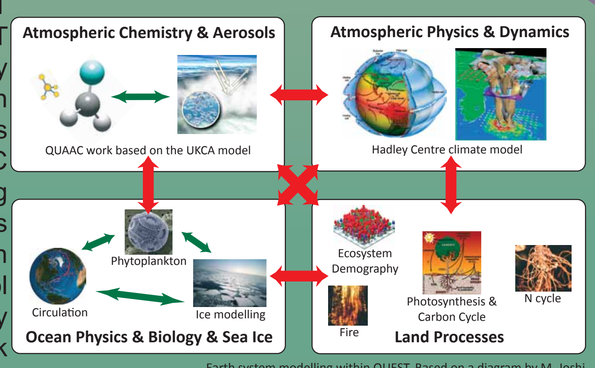


Time series of observed and modelled ozone (left) and NO2 (right) at Brighton.

RAQ is an intermediate chemistry scheme for the troposphere that includes some reactions from the Mainz Isoprene Mechanism. It involves 58 species, 40 of which are tracers (16 of them emitted), 23 photolysis reactions and ~115 gas-phase reactions. Removal by wet and dry deposition are considered for 19 and 16 species, respectively. Unlike the standard tropospheric chemistry, this scheme includes the oxidation of both C2-C3 alkenes (ethene and propene) and aromatic compounds such as toluene and o-xylene as well as the formation of organic nitrate. However it does not include HONO, which plays a role in urban-scale photochemistry. Primarily aimed at regional air quality (currently 12km resolution being implemented) but similar mechanisms have been used in the past for global model studies as well. Currently running in a 12km regional forecast model, but can also be run in global forecast models, such as N320.

QUEST *QUAAC, QESM and PIMMS*

UKCA is part of the QUEST project, both in the QUEST Aerosols and Atmospheric Chemistry (QUAAC) project and the QUEST Earth System Model (QESM). As well as leading to the development of the ExtTC scheme, QUAAC work is improving parameterisations for land-surface links such as the interactive dry-deposition scheme. UKCA will form the aerosol and atmospheric chemistry components of QESM. This work has also led to the Pinatubo Intercomparison Multi-Model Study (PIMMS).



Earth system modelling within QUEST. Based on a diagram by M. Joshi.

Further Information

Further information can be found on the UKCA website:

http://www.ukca.ac.uk

Evaluation of the new UKCA climate-composition model – Part I: The stratosphere. Morgenstern *et al, Geosci. Model Dev. Discuss.*, **1**, 381-432 (2008).

Evaluation of the new UKCA climate-composition model. Part II. The Troposphere. O'Connor *et al*, *Geosci. Model Dev. Disc.*, In Preparation.

Description and evaluation of GLOMAP-MODE: A modal global aerosol microphysics model for the UKCA composition-climate model. Mann *et al, Geosci. Model Dev. Disc.*, In Preparation.

The World Avoided by the Montreal Protocol. Morgenstern *et al*, *Geophys. Res. Lett.*, **35**, L16811 (2008).

Interactions between tropospheric chemistry and climate model temperature and humidity biases. O'Connor *et al*, *Geophys. Res. Lett.*, **36**, L16801 (2009).

Effects of Climate-induced Changes in Isoprene Emissions after the eruption of Mount Pinatubo. Telford *et al*, submitted to *Atmos. Chem. Phys. Discuss.* (2009).