Background to UKCA

- Aerosol-chemistry sub-model in Met Office Unified Model environment for a range of applications (climate, Air Quality, Earth System science).
- Tropospheric and stratospheric chemistry schemes. Aerosol precursor extension to UKCA chemistry schemes so that climate model simulated aerosol is coupled to atmospheric chemistry.
- Improved representation of aerosol in UK climate model simulations
  - new particle formation & growth using GLOMAP aerosol microphysics
  - internally mixed aerosol (e.g. BC & sulphate) affect optical properties
  - biogenic secondary organic aerosol from monoterpene oxidation
- UKCA interactive ozone, methane and aerosol (direct/indirect) radiative effects for fully coupled composition-climate simulations.
- Enhances UK capability in aerosol-climate-earth system modeling and provides integration for NCAS and Met Office initiatives.
Extend datasets used to give observational constraints for climate model aerosol scheme.

Pull through knowledge gained from CTM process studies into climate model aerosol scheme.
Benchmark modal scheme vs complex bin scheme

Atlantic at surface: GLOMAP-bin
N. Pacific at surface: GLOMAP-mode (sigma-acc=1.59, dplim34=1000nm)
Southern Ocean at surface: GLOMAP-mode (sigma-acc=1.40, dplim34=500nm)
E. USA at surface: GLOMAP-mode (sigma-acc=1.40, dplim34=500nm)
Europe at surface: GLOMAP-mode (sigma-acc=1.40, dplim34=500nm)
China (continental) at surface: GLOMAP-mode (sigma-acc=1.40, dplim34=500nm)

Mann et al., (2012, ACP)
Aerosol-chemistry coupling in climate mode

Basic tropospheric scheme: 8 emitted species, 46 species, 102 gas-phase reactions, 27 photolysis reactions. Ox, HOx and NOx chemical cycles and the oxidation of CO, ethane and propane.

Aer-chem extension: Sulphur chemistry. Simple monoterpene oxidation for SOA.

Standard “IsopTrop/CheT” tropospheric scheme:
As above plus Mainz Isoprene Mechanism.
Aer-chem extension: As above but rates match as in TOMCAT-GLOMAP.
Not yet included isoprene-derived SOA

Standard “StratChem/CheS” stratospheric scheme
Simpler tropospheric chemistry beneath more complex stratospheric scheme.
5 heterogeneous reactions based on UKCA-MODE surface area concentration.
Aer-chem extension: Stratospheric sulphur scheme including COS.

Extended Tropospheric Chem (ExtTC): 63 tracers, 198 reactions. BVOCs (isoprene, terpenes, methanol, acetone) computed interactively. SOA sub-model: Includes isoprene, terpenes (lumped), aromatics (lumped), C4+-alkanes (lumped), ethene, propene, MEK, MVK, low-reactivity organic nitrate compounds, organic acids (formic, acetic), and semi-volatile SOA precursors. An extension to HadGEM2-ES. Not yet coupled to GLOMAP-mode (old CLASSIC aerosol scheme)

Regional Air Quality scheme in UM (RAQ): Not yet coupled to GLOMAP-mode
UKCA aerosol standard jobs

UKCA tropospheric aerosol-chemistry jobs

-- Early HadGEM3-A model at N96L38 now → HadGEM3-A r2.0 at N96L63.
-- Std Tropospheric Chem in B-E solver → IsopTrop/CheT with N-R solver.
  or IsopTrop/CheT extended with DMS, SO2 & monoterpenes oxidation.

-- Direct & 1st indirect aerosol forcing included (single-call to radiation).
  Uses “RADAER “module to calculate optical properties of each of the
  externally-mixed modes based on their size & internally-mixed composition.
  ACTIVATE module for mechanistic CDNC to provide indirect effects.

-- Can also run with double-call to radiation scheme to diagnose forcings.

UKCA stratospheric aerosol-chemistry jobs

-- HadGEM3-A r2.0 at N48L60 (high-top model up to 80km, QESM resolution)
-- StratChem/CheS extended with COS SO2, SO3, H2SO4 chemistry, photolysis

-- UKCA-MODE adapted for stratospheric aerosol
  (water content, density, nucleation, H2SO4 vapour pressure)

Next to merge these jobs for whole-atmosphere aerosol-chemistry simulations
GLOMAP aerosol in HadGEM-UKCA

Compare UKCA aerosol optical properties with existing “CLASSIC” mass-based aerosol scheme from Bellouin et al. (2012, ACPD)
**GLOMAP aerosol in HadGEM-UKCA**

CLASSIC scheme

All-sky direct forcing

Mean: -0.18 Wm$^{-2}$

All-sky 1$^{st}$ indirect forcing

Mean: -1.48 Wm$^{-2}$

GLOMAP-mode (in UKCA)

All-sky direct forcing

Mean: -0.49 Wm$^{-2}$

All-sky 1$^{st}$ indirect forcing

Mean: -1.17 Wm$^{-2}$

Compare UKCA aerosol forcings PD wrt PI with existing “CLASSIC” mass-based aerosol scheme from Bellouin et al. (2012, ACPD)
UKCA CheS + GLOMAP stratospheric aerosol for Pinatubo eruption. Inject 20 Tg of SO$_2$ from tropopause up to 28km in the model 15$^{th}$ Jun 1991. Investigate radiative, chemical and dynamical effects from eruption.

Model

- **CN**
- CN $>$ 150nm
- CN $>$ 250nm

Observations

- **CN**
- CN $>$ 150nm
- CN $>$ 250nm

Balloon measurements of number concentration at Laramie, Wyoming (Deshler et al, 2003)

(Kathryn Emmerson, Leeds, now CSIRO; Sandip Dhomse, Leeds)
Volcanic aerosol

Laki eruption: impact on CCN (Schmidt et al., 2010) & AQ (Schmidt et al. 2011)
Continuously degassing volcanoes: effect on aerosol forcing (Schmidt et al., 2012)
Pinatubo eruption → Pinatubo ensemble study planned: Leeds & Cambridge.

Stratospheric geoengineering simulations

Schmidt et al., (PNAS, 2011)

Schmidt et al., (ACP, 2012)
Understanding Earth System feedbacks

Marine aerosol ES feedbacks

Quantify aerosol-related Earth System feedbacks
CASE studentship with Met Office (Gerd Folberth)
Also plan QESM-AO simulations UKCA+PlankTOM.

Carslaw et al. (2010, ACP)
UKCA aerosol science themes

Air Quality-Climate Interactions

Leeds-Met Office CASE studentship – aerosol changes/mitigation (Carslaw, Haywood)

Leading role for UKCA in the EU IP *Pan European Gas-Aerosol Interaction Study* (PEGASOS) -- 50-year HadGEM-UKCA aerosol hindcast runs in next few months.

Understand how European air quality exceedances & climate forcings have/will evolve

Intend to use regional climate model configuration nesting to higher resolution in regional domains to combine high spatial resolution & global forcings with high physical realism

Aerosol impacts on NWP and aerosol-cloud interactions

Running UKCA-MODE at convection-permitting resolution → done idealised 1.5km runs.

Use dust-only UKCA configuration (no chemistry or other aerosol) for dust forecasting

UKCA-MODE now implemented in ECMWF IFS from MACC → BCs for regional models

Composition-dynamics interactions

Whole-atmosphere chemistry-aerosol in HadGEM allows simulation of changes in large-scale dynamics from changes in composition and vice versa.

Improved representation of polar stratospheric clouds in the composition-climate model.
1. Extended inorganic composition (nitrate) for ECLIPSE & PEGASOS
   -- has “UKCA dissolution module” handling NH3, HNO3 → NH4/NO3
   within GLOMAP-mode soluble modes already developed and tested in
   CTM version (Francois Benduhn, Kirsty Pringle)
   -- ported code to v7.3 merged branch for tropospheric UKCA aerosol
   -- current work at MO to add in new aerosol tracers & test (Steve Rumbold)

2. Coupled GLOMAP-mode up to CheST + merged aerosol-chemistry
   -- basic system coded-up & in testing at v8.2 (Fiona O’Connor)

3. Offline-oxidant version with only aerosol-chemistry to GLOMAP-mode
   -- system coded-up & tested at v8.2 (Colin Johnson)

4. Idealised LAM configuration at 1km for testing hi-res aerosol (ASCI).
   -- short 2/3-day runs done (Celine Planche, Mohit Dalvi)

5. Nested NWP configuration for aerosol-cloud interactions (ASCI)
   -- being tested at v8.2 (Mohit Dalvi)

6. Simpler GLOMAP-mode configurations (single-component, fewer modes)

7. Dust in GLOMAP-mode framework in full chem-aero & 2-mode dust-only.
The GLOMAP aerosol code has now been successfully coupled to TOMCAT CTM, UM and ECMWF-IFS.

The TOMCAT CTM is used as a testbed for GLOMAP development (feeding into UM and IFS) as well as directly in scientific applications.
Benchmark datasets to evaluate models

xfxiy UKCA-UM N96L63 2000 (free-running) : N-R IsopTrop+achem

Sulphate
EMEP, IMPROVE, U. Miami
Monitoring Networks
Benchmark datasets to evaluate models

xfiy UKCA-UM N96L63 2000 (free-running) : N-R IsopTrop+achem

Black Carbon
IMPROVE Monitoring Network

Black Carbon
Cruise data (Van Dingenen, 1995)