The Aerosol Component of UKCA

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Martyn Chipperfield, Olivier Boucher, Colin Johnson
Content

Background and motivation
Existing CLASSIC aerosol scheme versus UKCA
Description of model microphysics
Some results and evaluation
Model applications
Role of UKCA team
IPCC climate models have mostly included only a simple representation of aerosols

**Mass of aerosol components is only advected quantity** (e.g., sulphate, black carbon, dust, sea-salt mass)

**Assumed size distribution**

**Chemical components not mixed**

**Direct aerosol forcing:** Use composition-dependent mass scattering efficiency (or assume a fixed size distribution)

**Indirect forcing:** Use empirical cloud drop—aerosol relations

Important aerosol types (e.g. organics, nitrate) omitted.
Processes control size & composition

- Emission of gas phase precursors
  - In-air oxidation
  - Involatile and semi-volatile gas phase oxidation products
  - Nucleation
  - Coagulation

- Emission of primary particles
- Condensation
- In-cloud oxidation
- Activation of CCN

- Uptake to clouds

- Particles processed in clouds

- Dry Deposition
- Wet Deposition

- Particle Size
  - ~1.0E-9 m
  - ~50.0E-6 m
Observations show large variation in size

Heintzenberg et al (2000, Tellus B)
Cloud drop number-aerosol relations

From Ramanathan, Crutzen et al (2001)

- No single relationship fits observed CDN vs aerosol number.
- Different regions have different particle types, size distbn, etc.
Importance of driving processes

Growth of new particles to cloud condensation nuclei

Observations

Model
Priority UKCA aerosol developments

Dynamic aerosol size distribution (particle size distribution)

Internal mixing of particles

Missing components (NH$_4^+$, NO$_3^-$, SOA, etc)

Coupled aerosol-chemistry

Dedicated UM sub-model
Existing UM aerosol scheme (CLASSIC)

Sea salt
Biomass
Aged
Sulphate
Organics
Soot
Dust

DIAGNOSED

Transported tracers=13

Condensation according to
Ψ=ratio of surface areas of Aitken, accum mode aerosol

number concentrations derived from assumed size distribution (fixed)
UKCA standard aerosol structure

**Sulphate, sea salt, black carbon, organic carbon, dust**

**PRIMARY EMISSIONS**
- Wildfires, industrial, marine, etc
- Condensation

**MONOTER**
- OH, NO₃, O₃

**SEC_ORG**
- OH, NO₃, O₃

**H₂SO₄**
- Condensation

**SO₂**
- OH, NO₃

**DMS**

**Insoluble Aitken**
- N₅
- BC
- OC, BC, Cl

**Soluble Aitken**
- N₂
- BC
- SO₄, OC

**Soluble Accum**
- N₃
- SO₄, OC
- BC
- Cl

**Soluble Coarse**
- N₄
- SO₄, OC
- BC
- Cl

**Dust**
- DU₁, DU₂, DU₃, DU₄, DU₅, DU₆

6 dust
16 mass
5 number

Transported tracers=27

Component mass conc.

No. conc’ns controlled by NPF, primary emissions, coagulation, removal.
## CLASSIC and UKCA compared

<table>
<thead>
<tr>
<th></th>
<th>CLASSIC</th>
<th>UKCA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transported particle types</strong></td>
<td>Associated with emissions (sulphate, biomass, etc)</td>
<td>Defined by microphysics (Aitken, accumulation, etc)</td>
</tr>
<tr>
<td><strong>Size distribution</strong></td>
<td>Prognostic m</td>
<td>Prognostic N, m</td>
</tr>
<tr>
<td></td>
<td>Fixed size</td>
<td>Variable size</td>
</tr>
<tr>
<td></td>
<td>N derived from m and size</td>
<td>Log-normal modes</td>
</tr>
<tr>
<td><strong>Mixed composition</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Chemistry</strong></td>
<td>Offline oxidants</td>
<td>Coupled chemistry</td>
</tr>
<tr>
<td><strong>Cloud drop number</strong></td>
<td>From mass</td>
<td>From size, N, mixed composition</td>
</tr>
<tr>
<td><strong>Particulate tracers</strong></td>
<td>13</td>
<td>27 (min 24)</td>
</tr>
</tbody>
</table>
**Leeds:** aerosol dynamics, composition, evaluation

Inorganic mixed aerosol composition was supported by Manchester’s DIAC work. Secondary organic aerosol development as part of the QUEST-QUAAC project.

**Met Office:** Precursor chemistry (Rae, Johnson), cloud chemistry (Rae), radiation coupling (Bellouin), UM sub-model coding (Johnson)

**Cambridge:** Trop and strat chemistry, nudging
UKCA aerosol strategy

UKCA is part of a wider development of global aerosol models

**GLOMAP-mode:** As in UKCA (also in TOMCAT CTM)
**GLOMAP-bin:** a bin-resolved version in TOMCAT

Strong connection between the future development of UKCA and new observations and process knowledge
Example UKCA results (UMv6.6) – October mean

- **Sulphate**
- **Sea salt**
- **Black carbon**
- **Organics**
Example UKCA results (UMv6.6) – October mean

- Nucleation mode N
- Aitken mode N
- Condensation nuclei
- Cloud condensation nuclei (cm$^{-3}$) (Dp>50nm -- S~0.3%)
Model evaluation

An ongoing task
Much bigger task than for CLASSIC

Using AOD, component masses, CN, CCN, particle number, size, vertical profiles, seasonal cycles

Field campaigns
European SO4 in December and June
US SO4 in December and June

Dec

June
Particle size versus latitude

In GLOMAP offline model

Data from Heintzenberg, 2000
CN vertical profiles

Model of CK02 obs. mean CN prof in tropics (20S-20N)

Model of CK02 obs. mean CN prof in N.H. (20-70N)

Model of CK02 obs. mean CN prof in S.H. (20-70S)

UKCA-UM CN no. conc.
CCN comparison

Run not complete yet…
Remote CCN annual cycle

CCN cycle driven by DMS and sea spray

Cape Grim ss=1.2%

Cape Grim ss=0.23%
AERONET size distributions vs model

Dave Ridley (Leeds)
Model applications

UKCA aerosol microphysics/chemistry is universal and flexible
It’s a case of tailoring

CLIMATE
Re-evaluation of global dimming/brightening, IPCC

AIR QUALITY
Climate/air quality interactions
Basis of GEMS-2 in ECMWF Integrated Forecasting System

PROCESSSES
Natural cycles: DMS, CLAW, interaction with sea spray
Geoengineering: sea-spray/cloud interaction, stratosphere, ocean fertilisation

EARTH SYSTEM RESEARCH…
UKCA is integral to NERC QUEST-ESM

- 1-yr QUEST funding to progress UKCA modal dust & sandblasting schemes

**EARTH SYSTEM**
Ecosystem-climate interactions (SOA, CCN…)

Dust-ocean-atmosphere coupling

Volcanic aerosol-biosphere feedbacks

Palaeo-aerosol

Diagram from Paul Young.
UKCA to be used at Met Office on range of scales:

- Short-term numerical weather prediction & Visibility forecasts
- AQ forecasts
- Seasonal forecasting
- Decadal prediction
- Climate projections AR5 - HadGEM2-ES
- Climate projections Post-AR5 HadGEM2/3-ES

Slide from O. Boucher, Met Office
Projects exploiting UKCA

European Integrated Project (EUCAARI) using UKCA as part of the Earth System modeling work package

Direct effect (BC ageing/absorption) in APPRAISE-ADIENT

Marine aerosol (SOLAS) project on coupled halogen/sulphur cycle

Stratospheric aerosol & geoengineering (Cambridge/Leeds NERC project)

Palaeo aerosol from flood basalt eruptions

Ion-induced nucleation and cosmic rays (EU Marie Curie)

QUEST Earth System Model …

Met Office CASE projects: Heterogeneous chemistry (M. Evans, Leeds);
Dust and DMS in the Earth System (G. Mann);
Arctic aerosol/climate (K. Carslaw, Leeds);
Ozone indirect effects (S. Arnold, Leeds);
CDN & aerosol indirect effect (P. Stier, Oxford)

Will be implemented in the ECMWF-IFS via EU MACC project (GEMS2)
Ongoing role of the UKCA team

To maintain and further develop an evaluated and documented state-of-the-science global aerosol-chemistry model

Evaluation, inter-comparison, benchmarking

\textit{AEROCOM} (new initiatives in microphysics, OA, etc)

\textit{NERC-AEROS} (Uncertainty importance analysis, necessary level of complexity)

Improvement and extension

SOA, nitrate, nucleation, dust, marine OC, etc

Coupling

Radiation, clouds, Earth system sub-models

Collaboration and coordination… and support (NCAS, JCRP)