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Process reduction in global aerosol modelling : Staying close to observations

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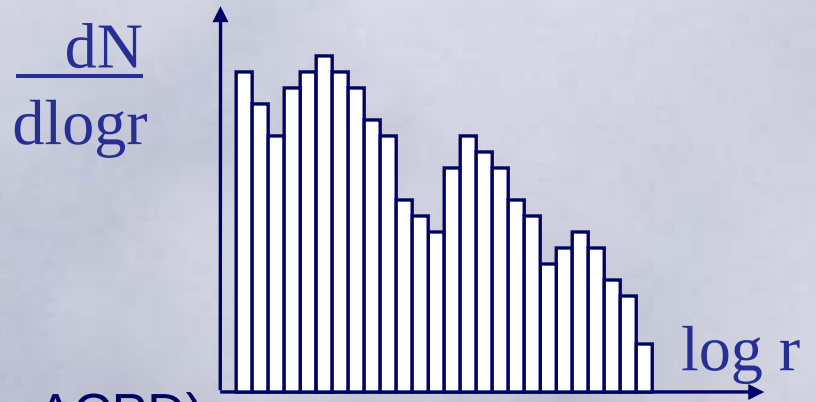
Background

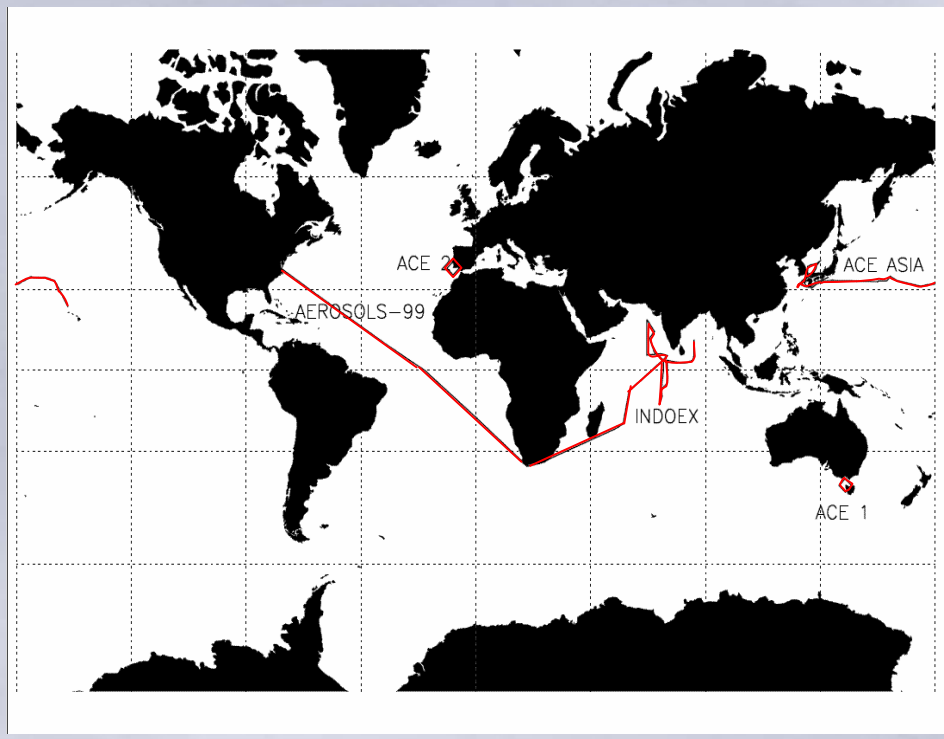
- Modelling aerosol-related feedbacks in general circulation and earth system models requires process reduction to minimise CPU cost.
- But need to retain realistic model response to changes in forcing agents.
- Need to ensure model stays close to observations.
- Need to transfer new understanding from process model studies through to GCM aerosol schemes

Recent aerosol modelling developments at Leeds

- GLObal Model of Aerosol Processes (GLOMAP) developed (Spracklen et al. 2005a,b; ACP) within CTM
  - Aims to include comprehensive treatment of aerosol, microphysical and chemical processes
  - Size- & composition-resolved in 2-moment bin scheme
  - Initially focussed on understanding the microphysical processes controlling sulfate and sea-salt aerosol on a global scale.
  - Fully resolved competition between nucleation and condensation for available sulfuric acid vapour.
  - Now also includes black carbon, organic carbon, dust
  - Simple scheme for secondary organic material based on biogenic monoterpene oxidation products (see Spracklen et al., 2006a, ACPD)



GLOMAP evaluation vs observed MBL aerosol statistics



See Spracklen et al (2006b, ACPD)

Observations

(Heintzenberg et al., 2004)

- compiled from 5 experiments in 4 oceans
- only data with back trajectories > 120 h without land contact

GLOMAP

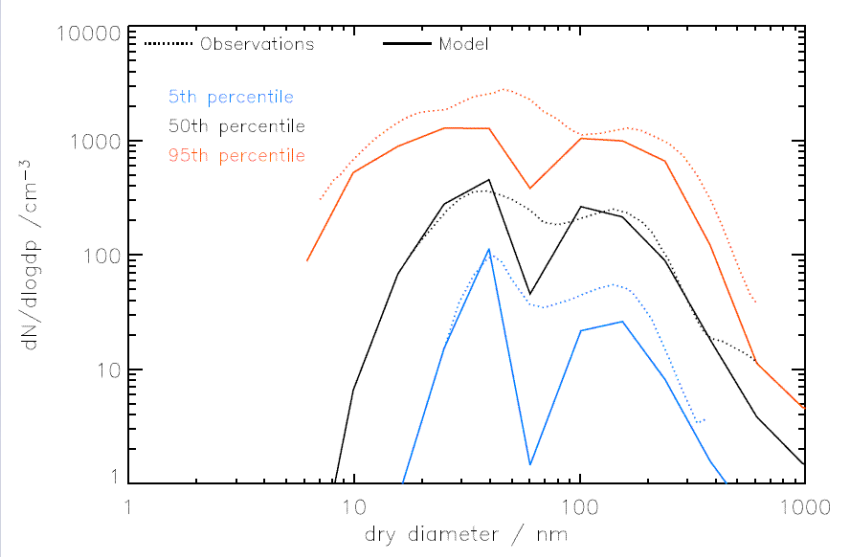
- output collocated in space and time (simulation for 1996)
- continental influence filtered as for observations
- baseline simulation with sulphate and sea spray only

Number-size distribution statistics comparison

Good overall agreement

- median total number concentration
  - modelled: 250 cm^{-3}
  - observed: 248 cm^{-3}
- bimodal structure with correct modal number concentrations
- ‘closed’ size distribution
- mode diameters too small.

Average over all regions



	Aitken		accumul.	
	N	D_p	N	D_p
ACE-1	0.45	0.88	0.57	1.4
ACE-2	0.06	0.89	1.1	0.83
INDOEX	1.5	0.68	1.1	0.73
ACE-Asia	7.4	0.64	1.9	0.85

But regionally, large differences between model and observed size distributions

- Aitken mode ptcls too small [all locations] (cause: no SOA in model?)
- Too many Aitken mode ptcls in ACE-Asia (cause : lack of dust in model?)
- Too few Aitken mode ptcls in ACE-1/2 (cause : sub-micron sea-salt?)

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See Spracklen et al (2006b, ACPD)

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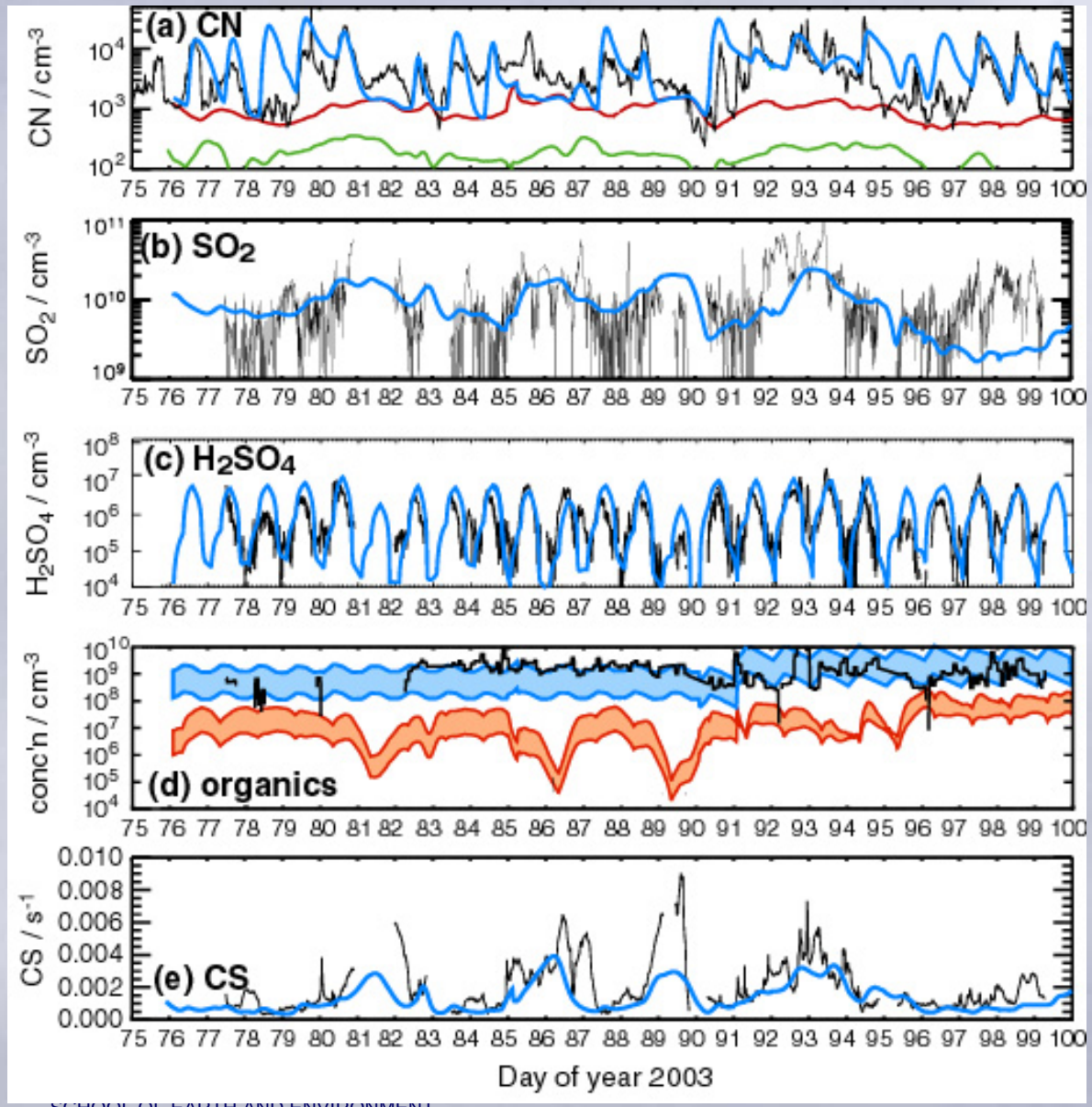
GLOMAP used to investigate boundary layer nucleation events



Observed CN
Model CN (BHN only)
Model CN (BHN+primary)
Model CN (BLN + primary)

- Binary homogeneous nucleation and primary sulfate cannot explain observed nucleation events
- Model can reproduce events well with boundary layer nucleation scheme proportional to $[H_2SO_4]$

Observed monoterpene
Model monoterpene
Model condensible organic

Obs. condensation sink
Model condensation sink

See Spracklen et al (2006a, ACPD)

The UK Chemistry and Aerosols Project (UKCA)

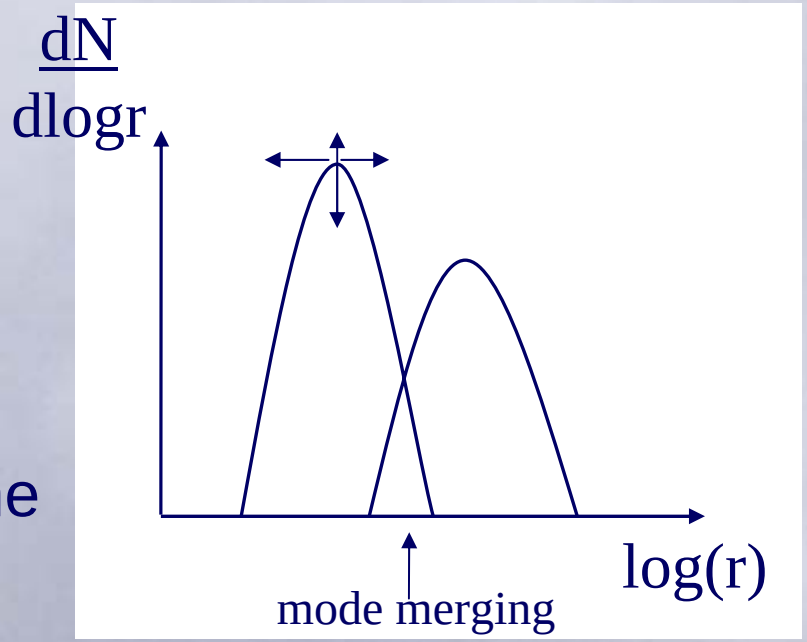
- A flexible global model for chemistry-aerosol-climate studies (in the UK Met Office Unified Model)
  - Coupled troposphere and stratosphere
  - Coupled chemistry, aerosols and climate
- A 100 year validated, demonstration run
- A model suitable for community use
- A single aerosol/chemistry sub-model sufficiently flexible to handle new understanding, but cheap enough for 100 year runs

Develop GCM aerosol scheme in other model frameworks

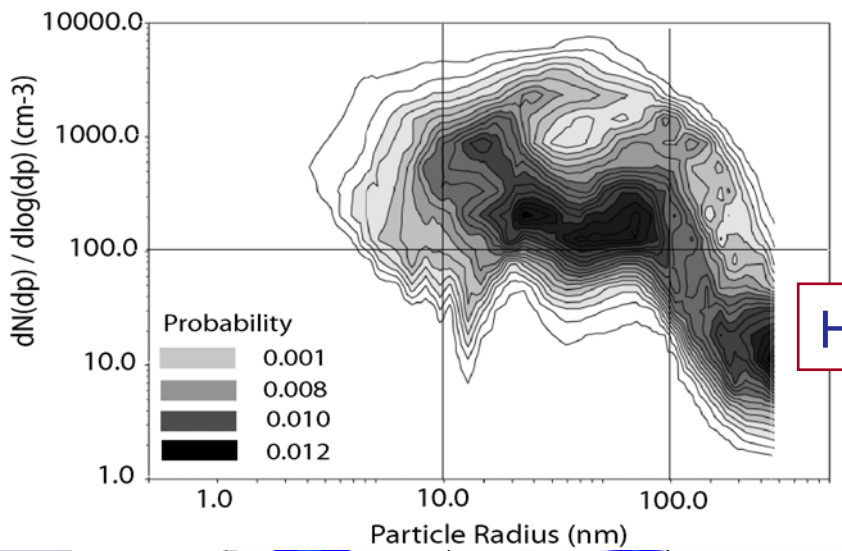
- TOMCAT offline CTM with both UKCA and GLOMAP
- CiTTyCAT Lagrangian model - same aerosol modules
- Facilitate comparisons with observations

UKCA aerosol scheme

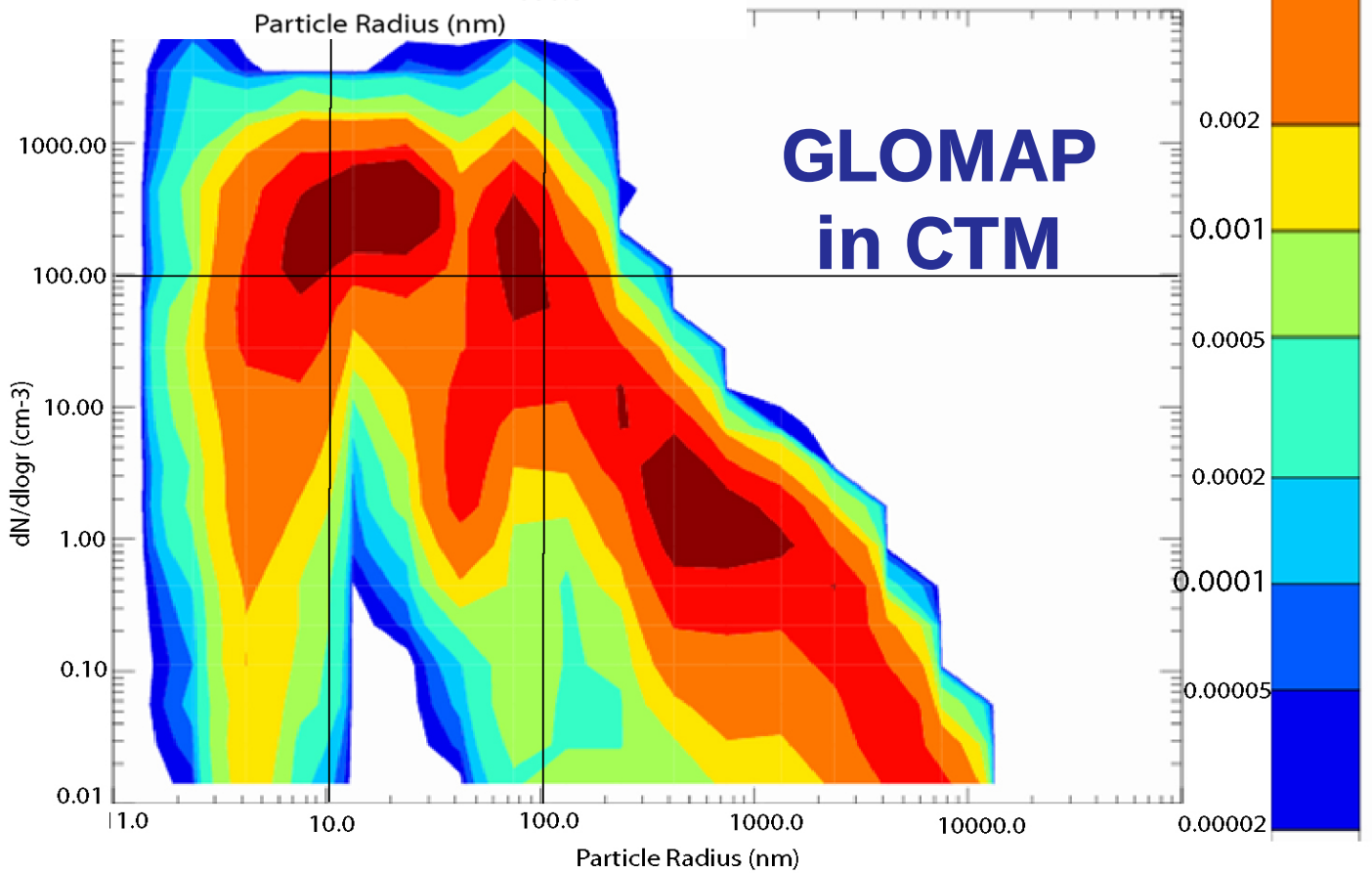
- Multi-component incorporating internal mixtures
  - Initially include as much of GLOMAP aerosol processes as possible and then carry out process reduction.
  - Size- & composition-resolved in 2-moment modal scheme
  - Initially include SU,SS,BC,OC and dust
  - Use 7-mode framework of HAM/M7 to separate fresh and aged aerosol particles
  - Retain resolved competition between nucleation and condensation for available sulfuric acid vapour (and condensible organic).
  - Also retains simple SOA scheme



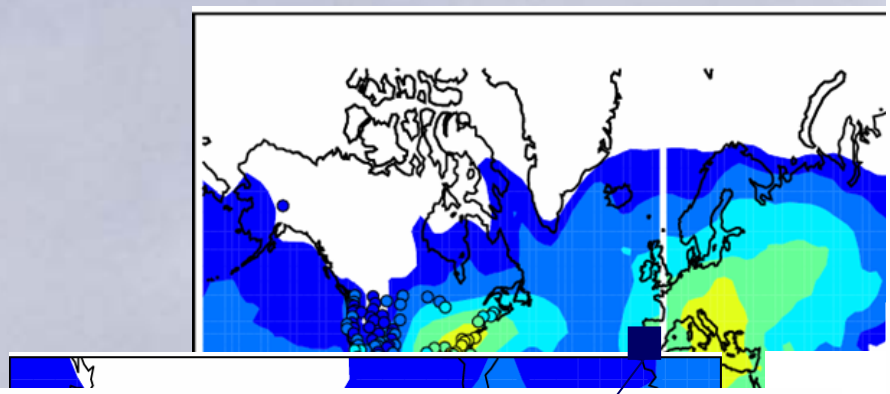
MBL aerosol observations

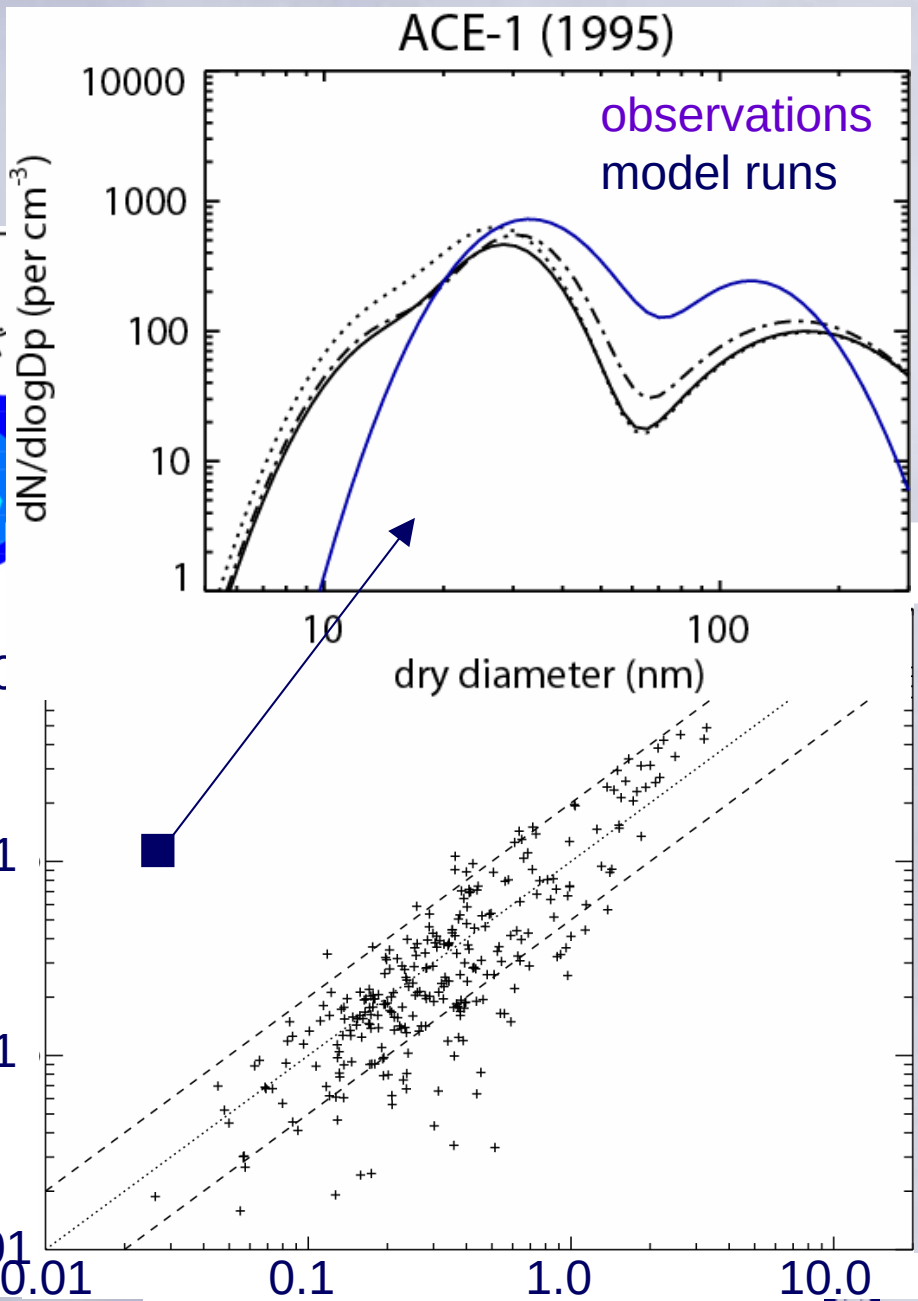


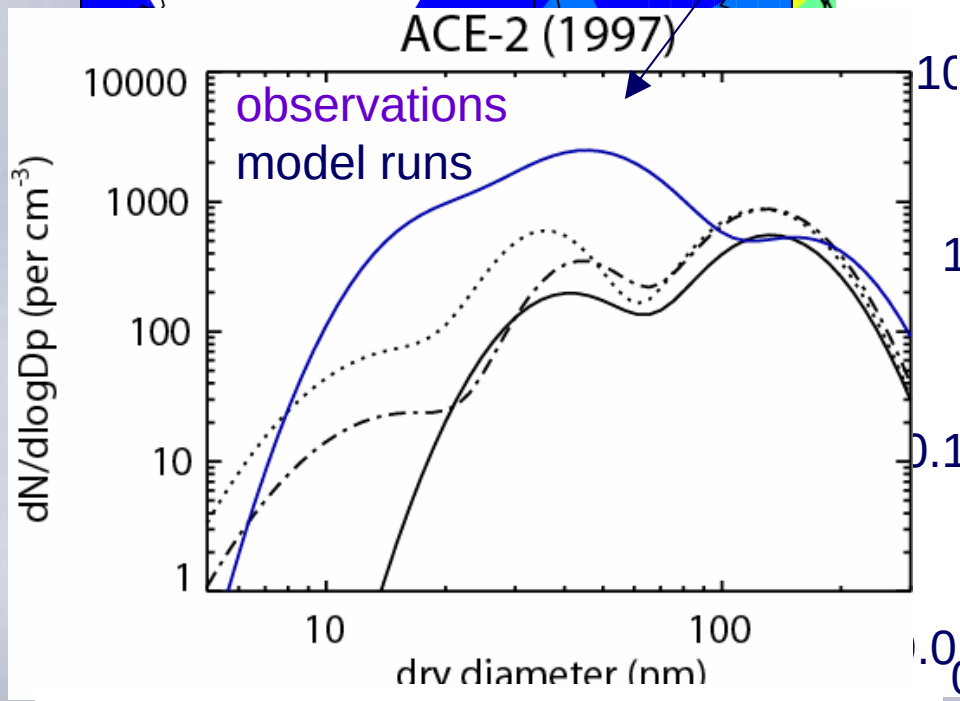
Heintzenberg (2004)



UKCA-mode in tomcat CTM for







These plots from Spracklen et al (2006)

Observed at IMPROVE sites

A Suite of Aerosol-Chemistry Models in UK:

Several models using the same or related aerosol modules

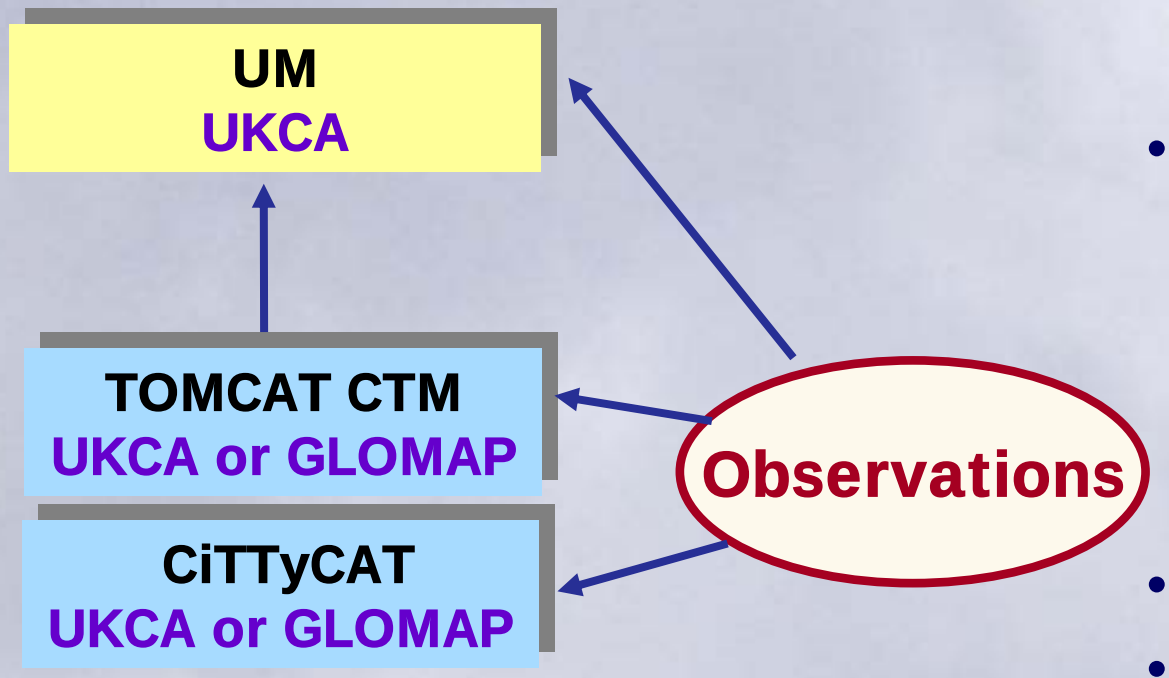
Models used to analyse data are consistent with climate model

- Fully coupled aerosol-chemistry-climate model
  - UKCA in the UM
  - 100 year climate simulations, coupled chem-climate, forcings
- Offline global 3-D aerosol-chemistry CTM
  - UKCA in TOMCAT
  - GLOMAP in TOMCAT
  - Testing process understanding, comparison with obs., development of better climate model
- Aerosol-chemistry trajectory model
  - UKCA or GLOMAP in CiTTyCAT
  - Field campaign analysis, long-range transport

Earth System Modelling developments in the UK.

- Met Office have developed Earth System model HadGEM which will include UKCA as well as marine and terrestrial ecosystems sub-models within coupled AOGCM.
- UK University sector also developing ESM via QUEST (Quantifying and Understanding the Earth SysTem) programme based on HadGEM3 --- includes UKCA
- Sub-project --- QUAAC (QUEST Atmospheric Aerosols and Chemistry) to examine the role of surface processes in atmospheric composition --- develop interactive emissions and deposition of aerosol precursor gases.
- UK SOLAS (Surface Ocean Lower Atmosphere) programme includes investigations of dust deposition and impact on marine ecosytem, oceanic CO_2 uptake and DMS emissions --- CLAW hypothesis.
- Process reduction of UKCA required for applications

Strategy for process reduction

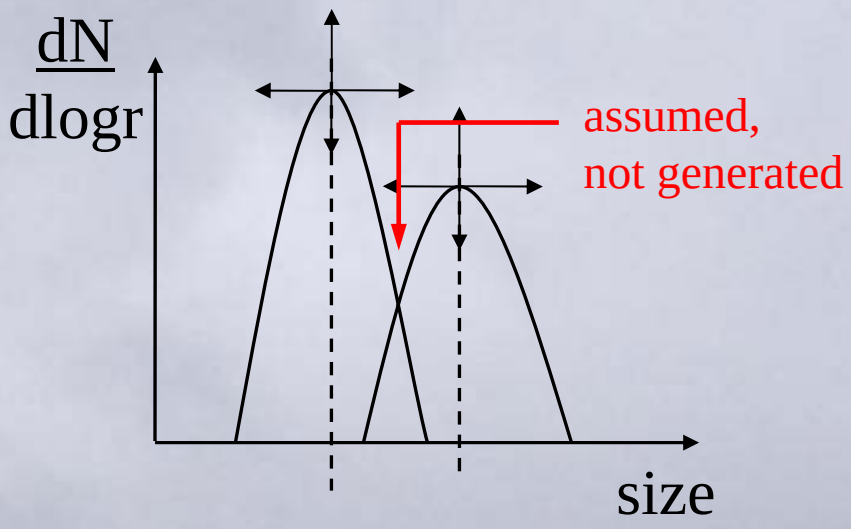


- Process of "justification of complexity"
- E.g., does the inclusion of a component, mode or process improve the model when compared against observations?
- Effect on climate.
- Evaluation against available long-term size-resolved and composition datasets.

- Ensures the GCM aerosol scheme captures as much of the observed aerosol behaviour as possible

Limitations of UKCA Scheme

Issue	Implication	How to test?
Limited range of compositions of same-size particles	Incorrect CCN spectrum Single HGF	HGF data AMS
Mode definition limits realism of cloud processing	Aerosol-cloud interaction not ideal	Against bin scheme



Evaluate impact of limitations of GCM scheme against observations and bin-resolved GLOMAP scheme within CTM or trajectory model framework.

Future versions of UKCA to include NH4, NO3, SOA

- University of Manchester (Gordon McFiggans) are developing look-up table for UKCA to evaluate inorganic aerosol composition and water content kinetically
- U. Leeds to implement this in UKCA via QUEST-ESM when available for 2nd version of UKCA-mode
- Later Manchester will also develop improved inorganic/organic thermodynamics scheme required for development of QUEST-QUAAC SOA scheme.
- 3rd version of UKCA will then also incorporate SOA scheme developed through QUEST-QUAAC.

Summary

- UK is developing a coupled aerosol-chemistry-climate model “UKCA” for incorporation into the Hadley Centre HadGEM model
- Aerosol scheme based on GLOMAP with modal aerosol dynamics scheme similar to HAM/M7
- Suite of modelling frameworks being used to facilitate transfer of new understanding from process model studies through to GCM.
- Also enables process reduction whilst retaining validity of aerosol behaviour against observations.
- Keen for UKCA to participate in AEROCOM both within CTM and GCM.