Whole-atmosphere aerosol microphysics simulations of the Mount Pinatubo eruption: an evaluation

National Centre for Atmospheric Science — NATURAL ENVIRONMENT RESEARCH COUNCIL
UNIVERSITY OF LEEDS

Graham Mann, Kathryn Emmerson, Ken Carslaw, Kirsty Pringle (U. Leeds)
L. Abraham, P. Telford, P. Braesicke (U. Cambridge), N. Bellouin, C. Johnson, M. Dalvi, O. Boucher (UK Met Office)

1. Introduction to UKCA

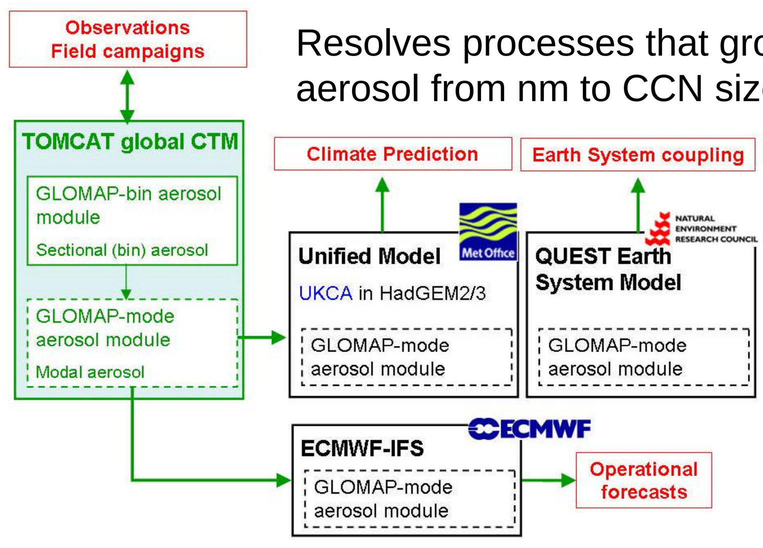
- Collaboration between NCAS & UK Met Office Hadley Centre since 2005. Universities of Leeds & Cambridge main NCAS partners
- Aerosol-chemistry sub-model in Met Office Unified Model environment for a range of applications (climate, Air Quality, Earth System science)
- Tropospheric and stratospheric chemistry 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.

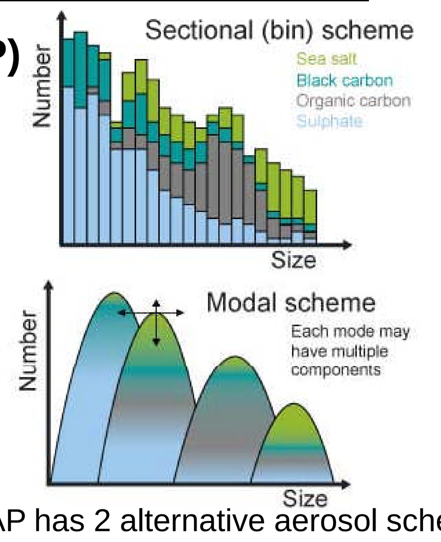
2. GLOMAP aerosol microphysics

Global Model of Aerosol Processes (GLOMAP)

Developed in Leeds since 2003 to simulate global aerosol with size-resolved number andcomposition.

Resolves processes that grow aerosol from nm to CCN sizes.



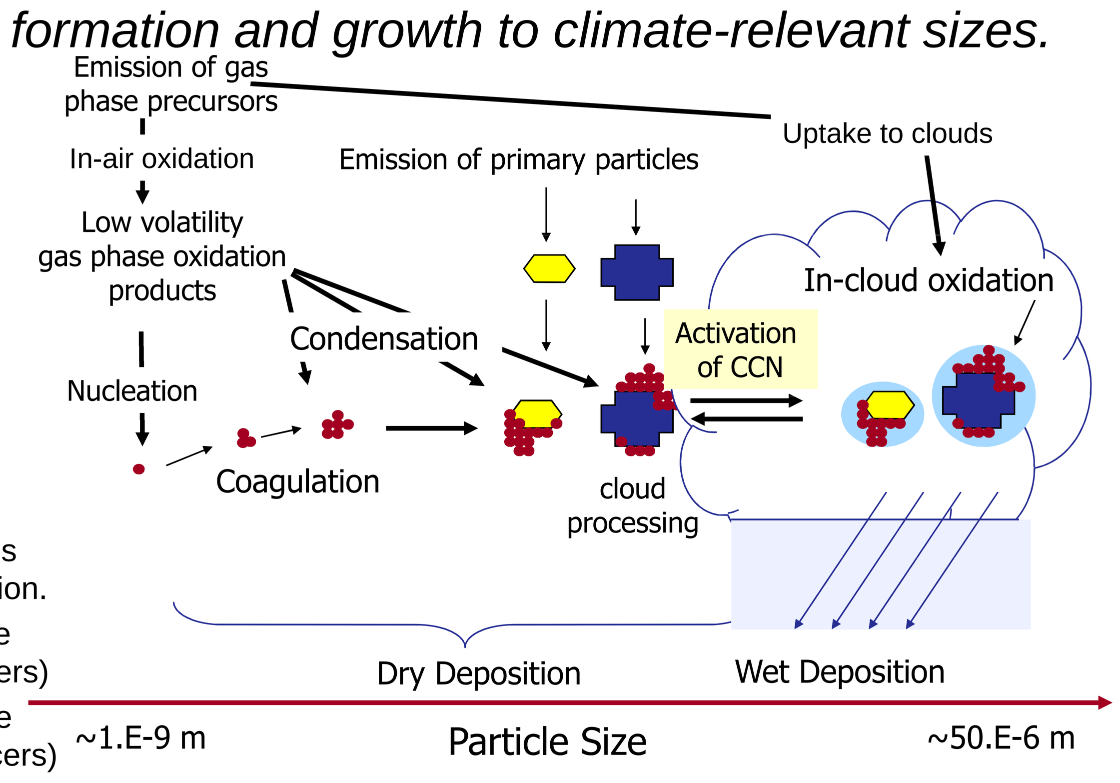


GLOMAP has 2 alternative aerosol schemes using the same/similar process representation.

GLOMAP-mode = 2-moment modal scheme (Mann et al, 2010) (~15-30 aerosol tracers)

GLOMAP-bin – 2-moment sectional scheme (Spracklen et al, 2005) (60-250 aerosol tracers)

Simulates aerosol lifecycle resolving new particle formation and growth to climate-relevant sizes.



4. Impacts of Pinatubo eruption

- Mount Pinatubo eruption in June 1991 injected 20 Tg of SO_2 into the tropical stratosphere between about 21 and 28km altitude.
- Sulphur dioxide chemically converted to sulphuric acid vapour which is readily taken up into the stratospheric aerosol particle phase.
- Thick stratospheric aerosol layer in tropical stratosphere heated stratosphere causing enhanced upwelling and stronger vertical transport
- Global veil of enhanced stratospheric sulphuric acid aerosol formed over 3-6 months with surface area density factor-100 higher initially, and still factor-10 higher at all latitidues 2 years after the eruption.
- Enhanced surface-area-density reduced NO_x via heterogeneous hydrolysis of N_2O_5 to less reactive HNO_3..
- Led to enhanced reactive chlorine and enhanced polar stratospheric ozone loss in subsequent spring.
- Stronger tropical upwelling also transported more low-ozone air into stratosphere causing a dynamical decrease in stratospheric ozone.
- The heating of the stratosphere also caused unusual stratospheric dynamics with the Quasi Bi-ennial Oscillation being locked into an easterly Phase and
- The stratospheric heating also caused an anomolously positive Arctic Oscillation causing Europe to be much warmer in subsequent winters.

5. GLOMAP-mode simulates stratospheric aerosol evolution in whole-atmosphere UKCA composition-climate model

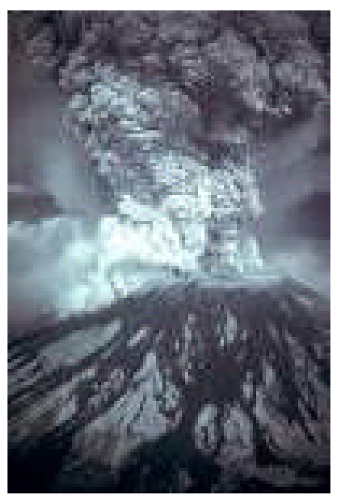


Fig 1. Pinatubo erupted on June 15th 1991, injecting 20 Tg SO_2 up to 28 km in the atmosphere

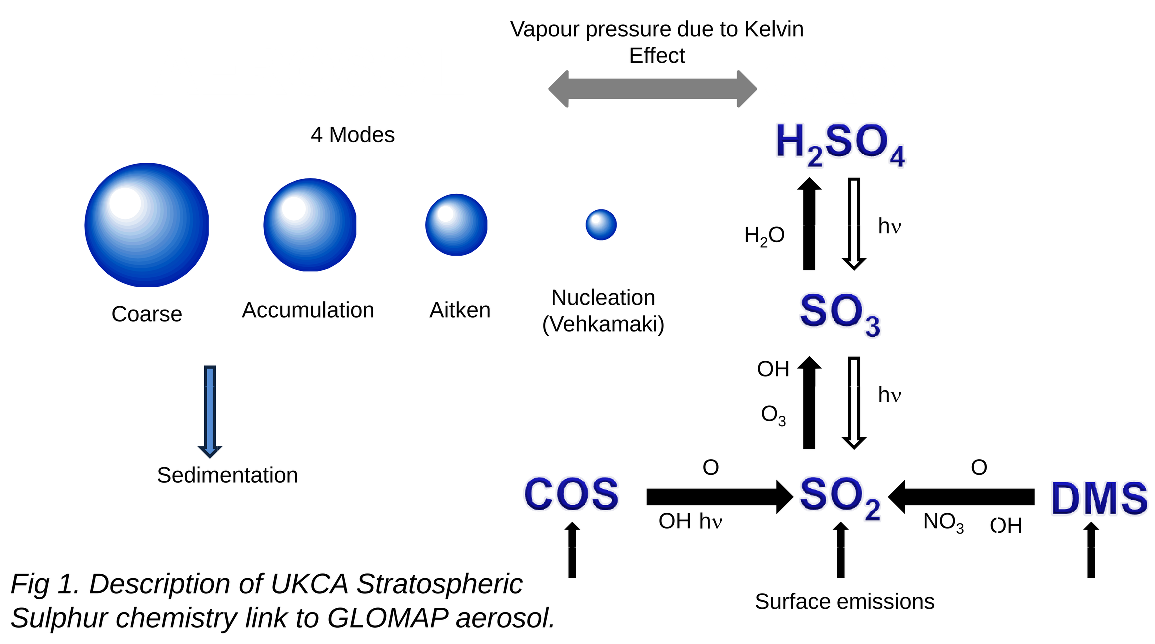
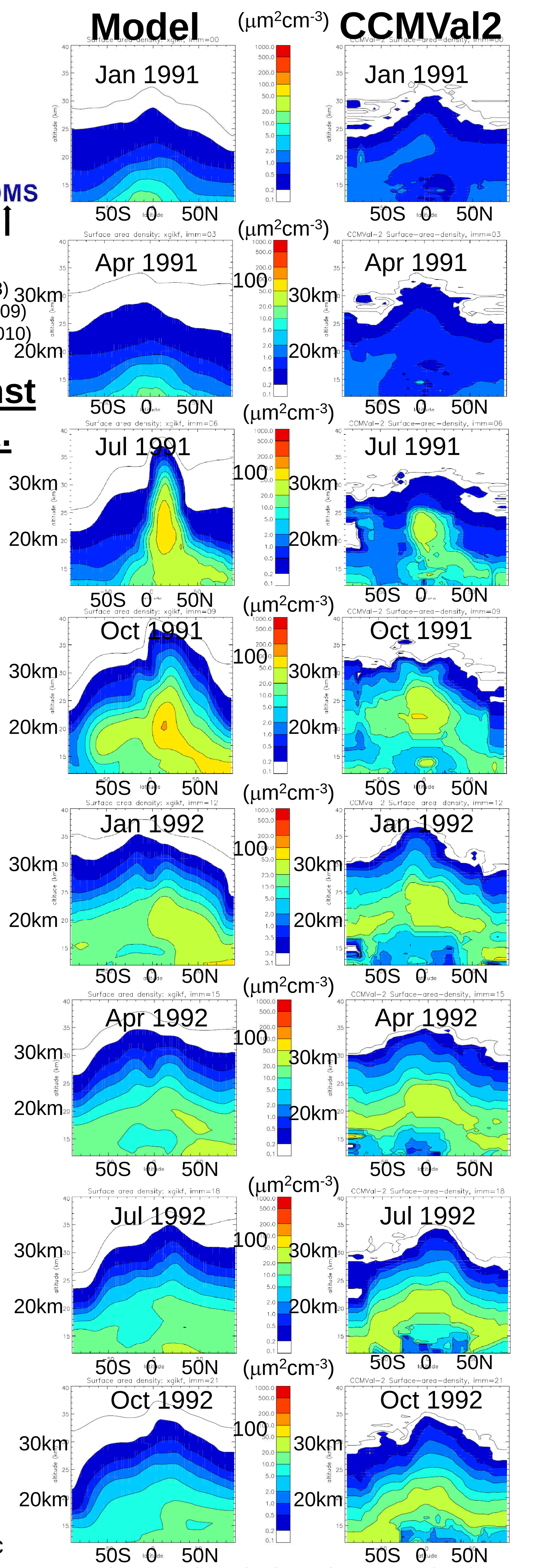


Fig 1. Description of UKCA Stratospheric Sulphur chemistry link to GLOMAP aerosol.

- UKCA includes comprehensive stratospheric chemistry scheme (CheS) --. Mortgenstern et al (2008)
- Within HadGEM general circulation model -- can nudge to re-analysed meterology (Telford et al, 2009)
- Here extend CheS with stratospheric sulphur chemistry & couple to GLOMAP-mode (Mann et al, 2010)

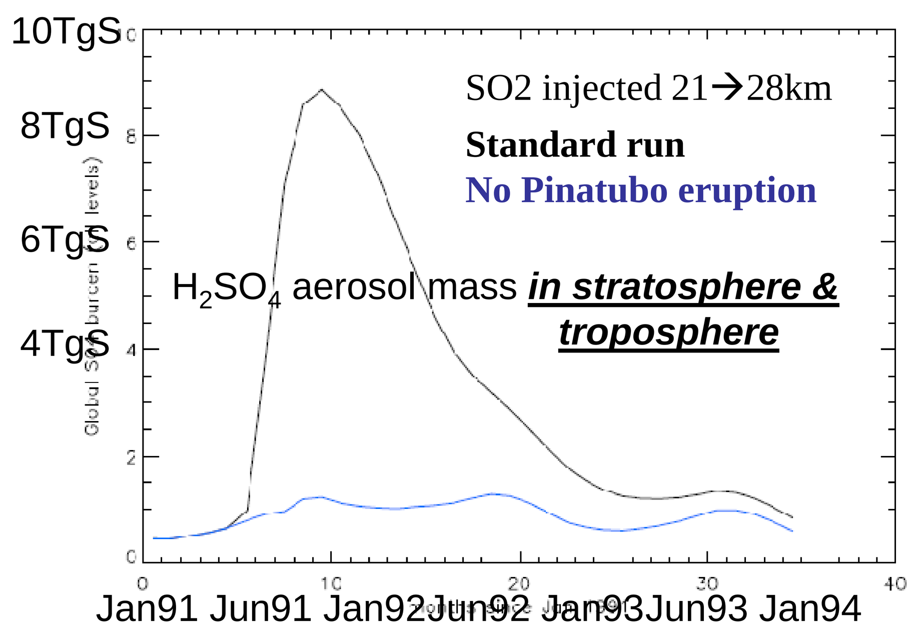
6. Compare simulated stratospheric surface area density CCMVal-2 dataset (Eyring et al, 2010) (from SAGE satellite profiles).

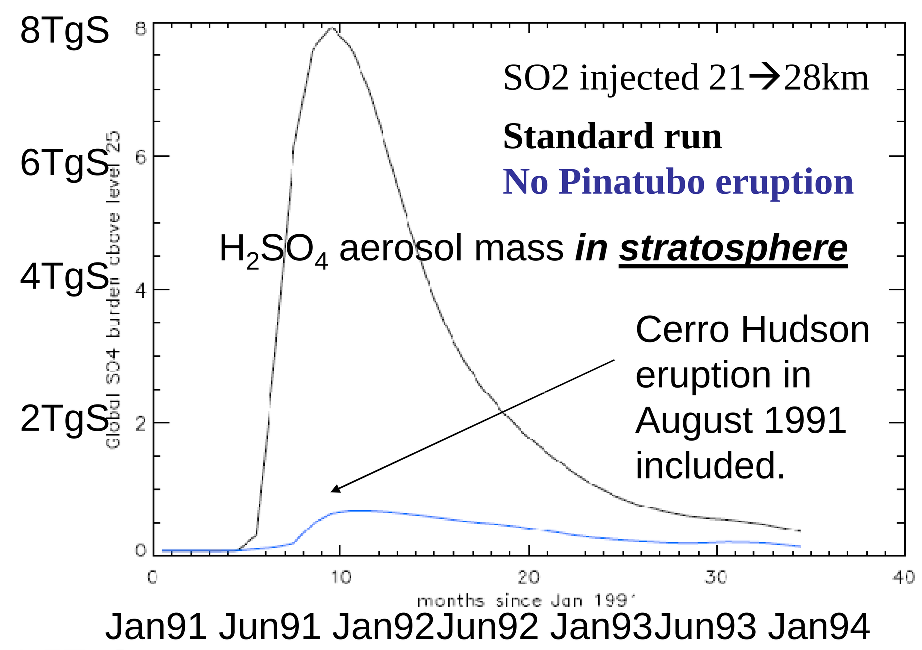


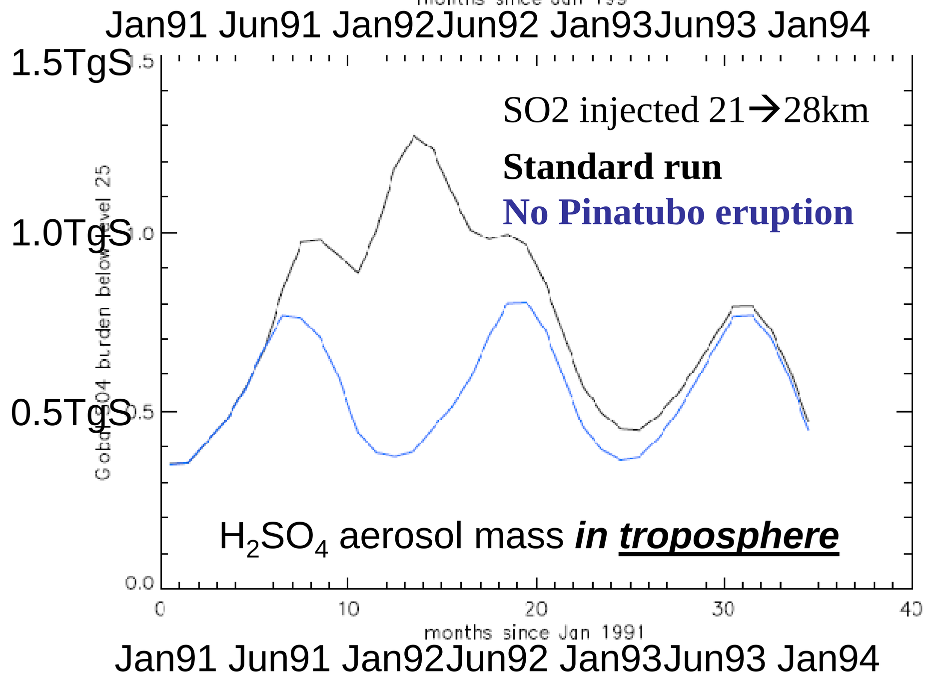
Background and Pinatubo-perturbed stratospheric Surface Area Density compare well to observations but removal from stratosphere too fast in model.

7. Evolution of H_2SO_4 aerosol mass

ERA-40-Nudged N48L60 CheS+achemS+GLOMAP-mode

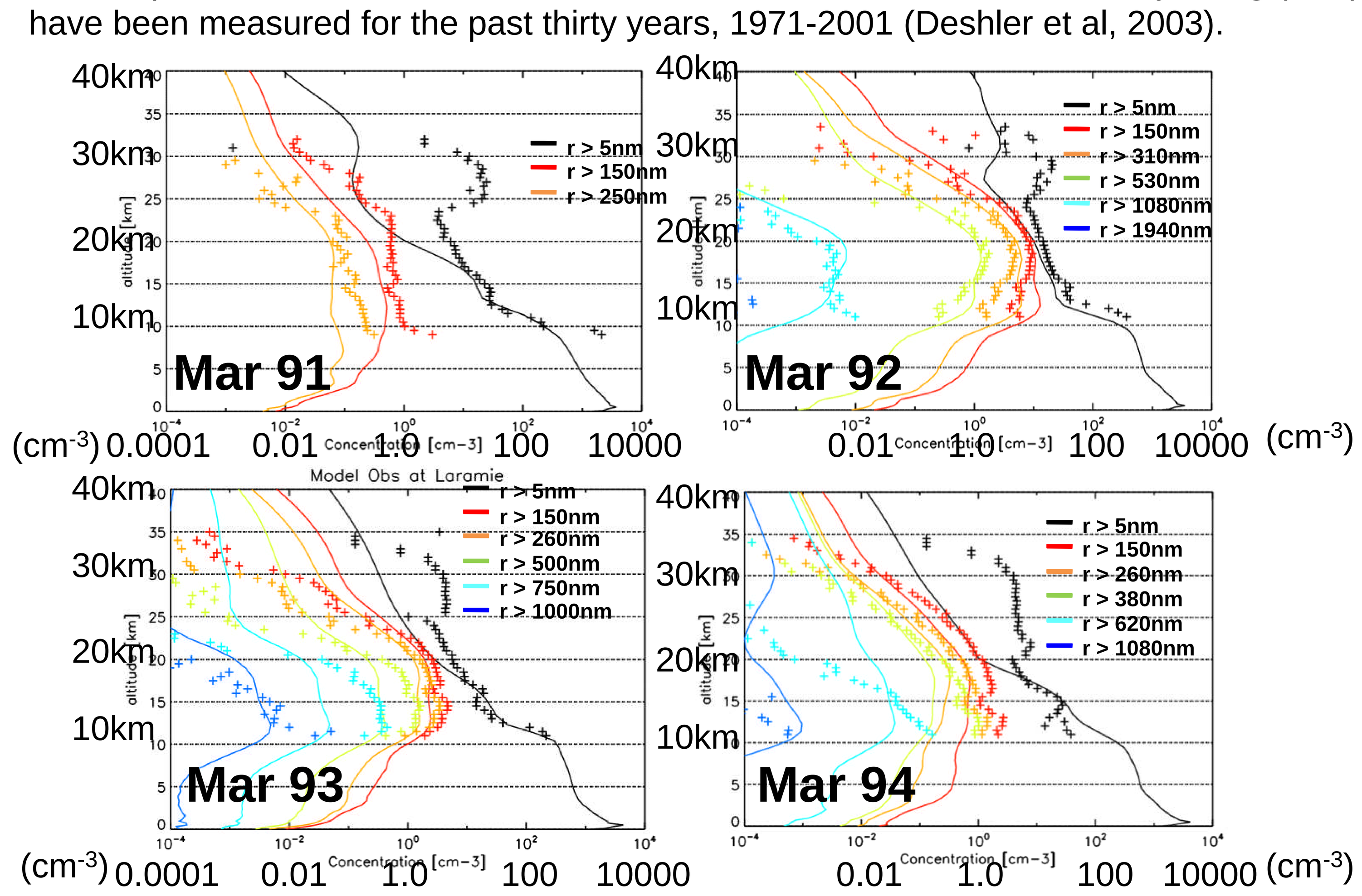




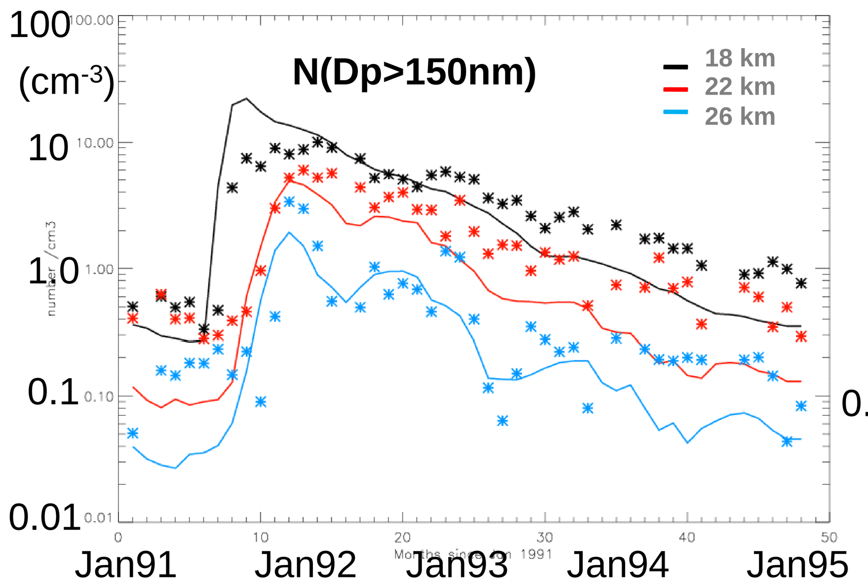


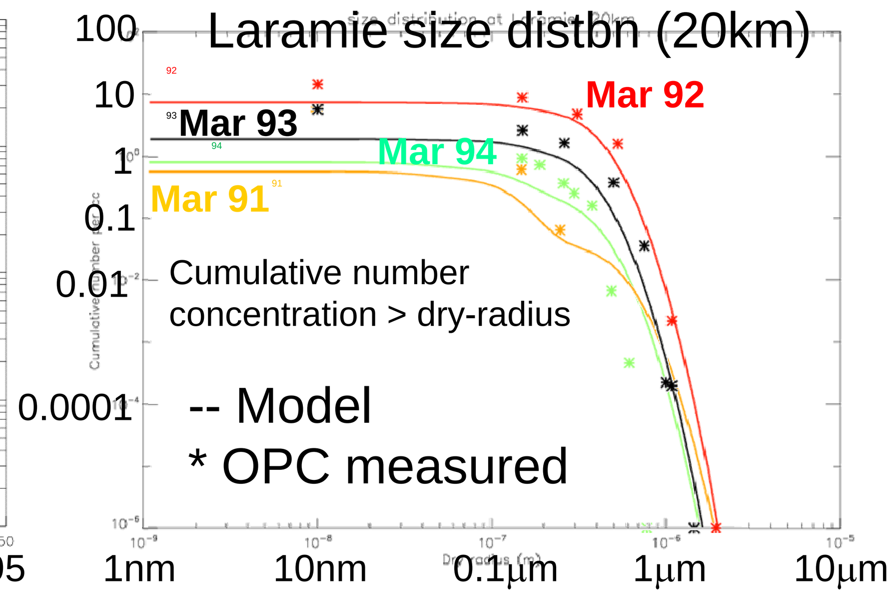
8. Evaluation of simuated size distribution against balloon-borne measurements, Wyoming, USA.

Vertical profiles of size-resolved aerosol concentrations above Laramie, Wyoming (41N), have been measured for the past thirty years, 1971-2001 (Deshler et al, 2003).

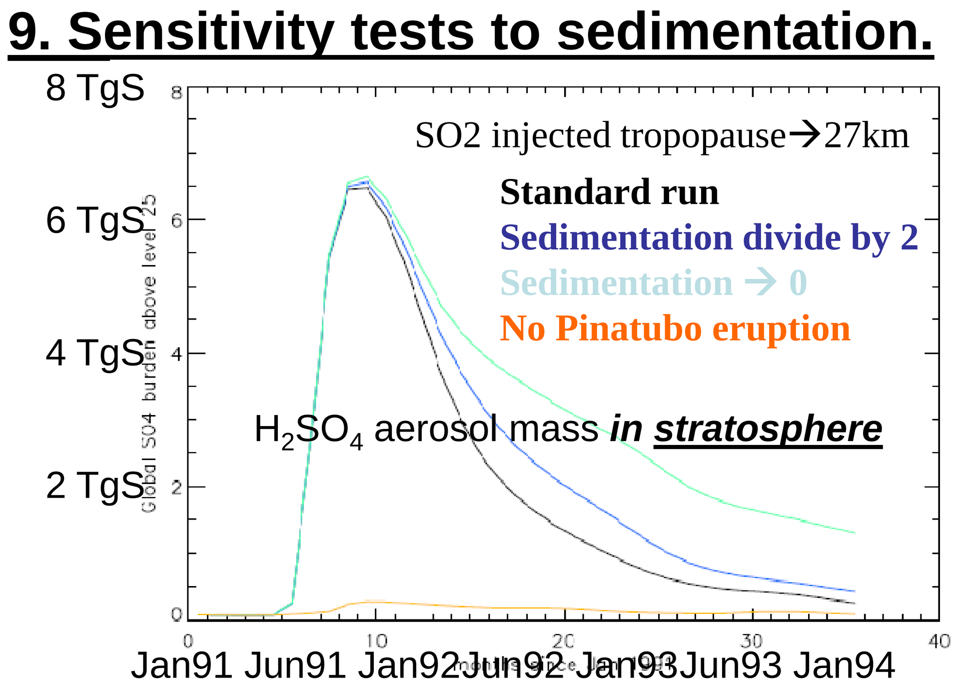


Simulated size distribution compares well against observations. Evolution of accumulation-mode peak (dry-diameter ~ 150nm) and of coarse-mode shoulder (dry-diameter ~1000nm) captured rather well by the model compared to the observations.





9. Sensitivity tests to sedimentation.



Model decay of Pinatubo aerosol too fast compared to observations

E-folding decay timescales of 7, 9 & 16 months for standard, halved & zero sedimentation runs.

16month e-folding timescale for no-sedimentation run is surprisingly short suggesting model strat-trop exchange is too fast in these ERA-40 nudged runs.

10. Summary and Conclusions

- UKCA model simulates evolving stratospheric aerosol size distribution with new particle formation and growth coupled to stratospheric chemistry in high-top HadGEM3-A (80km)
- Simulated stratospheric aerosol properties through Pinatubo-perturbed period (1991-5) compare well to observations in nudged runs.
- Soon to run Pinatubo ensemble simulations in free-running model across range of QBO and ENSO conditions quantifying influence of tropical volcanic eruptions on European climate

11. References

Deshler et al (2003) J.Geophys. Res., vol. 108 (D5)
Eyring et al (2010) SPARC report no. 5 – CCMVal-2.
Mann et al (2010), Geosci. Model Devel, 3, 519-551.
Morgenstern et al (2008), Geosci Mod Dev, 2, 43–57,
Spracklen et al (2005), Atmos. Chem. Phys, 5, 2227–2252
Telford et al (2009), Atmos. Chem. Phys. 9, 4251–4260.