School of the Environment

Improving aerosol size representation in the UKMO Hadley Centre climate model

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Motivation

- Aerosol optical properties are very sensitive to their assumed size distribution.
- Accurate direct aerosol radiative forcing calculation requires adequate characterisation of size distribution.
- The number of aerosol particles that can be activated as CCN depends critically on their size distribution.
- Accurate indirect aerosol radiative forcing calculation also requires adequate characterisation of size distribution

Aerosol in existing UKMO Hadley Centre scheme

- Sulfate aerosol exists in Aitken, accumulation or dissolved modes.
- Only aerosol mass carried for each mode.
- Fixed geometric mean radius and standard deviation for each mode.
- Jones et al. (2001) estimated indirect effect using

$$N_d = \max \{ 3.75 \times 10^8 [1 - \exp(-2.5 \times 10^{-9} N_{tot})] , N_{min} \}$$

$N_{tot} = N_{Ait}+N_{acc}+N_{dis}+N_{jet}+N_{film}$ [$N_{jet}+N_{film}$ from O' Dowd et al (1999)]
$N_{min} = 5.0 \times 10^6$ over water and 3.5×10^7 over land
N_{Ait}, N_{acc}, N_{dis} calculated from mass assuming r_{med}, σ_g

Processes in existing Hadley Centre sulfur cycle

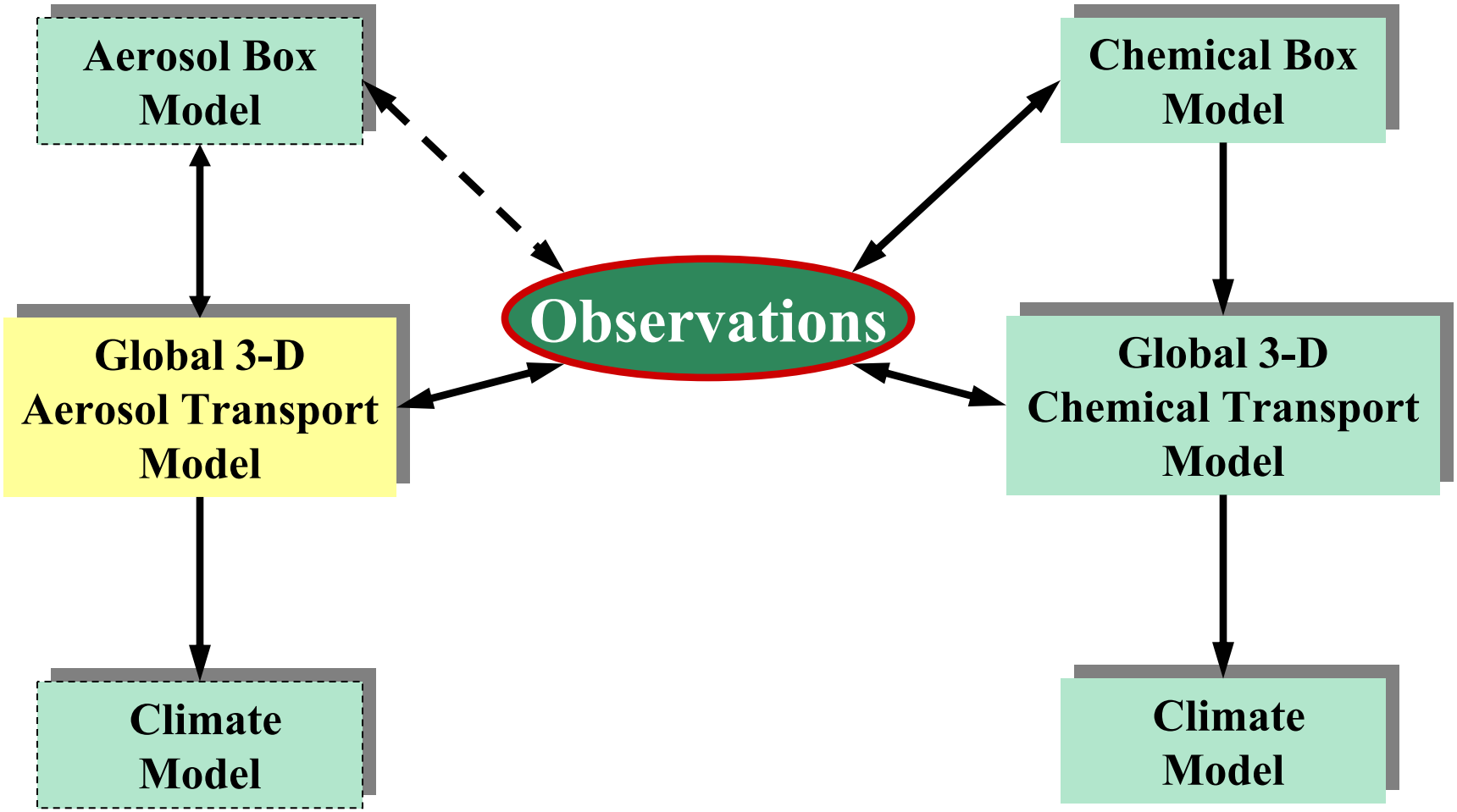
- Gas phase oxidation of SO2 to Aitken & accum mode according to ratio of surface areas
- In-cloud aqueous phase oxidation of SO2 to dissolved mode
- Activation of accumulation mode to dissolved mode
- Evaporation of dissolved mode to accumulation mode
- Coagulation of Aitken mode with accum mode to more accum mode
- Diffusion of Aitken mode aerosol to dissolved mode
- Dry deposition of aerosol
- In cloud scavenging included and assumed to dominate over below cloud scavenging (BCS neglected).

For details see Jones et al., (2001)

A new UK Chemistry and Aerosol model (UKCA)

- Collaboration between University of Leeds, Cambridge University and UKMO Hadley Centre to develop next generation aerosol-chemistry module for use in century-scale climate GCM simulations.
- Implemented existing Hadley Centre scheme within an aerosol-chemistry transport model framework.
- Comparing size distributions using existing scheme with those from microphysical sectional GLOMAP scheme (in same framework) and measured size distributions – which processes/aspects need particular improvement?
- GLOMAP is described in Spracklen et al. (2004, ACPD) [single-component sulfate-seasalt version]

Hierarchy of Model Development



TOMCAT

- 3D Offline CTM
- Forced by ECMWF Winds
- Convective transport
- Convective and resolved rain

GLOMAP

Aerosol size spectrum (~ 1 nm – 24 μm)
Two-moment sectional scheme
20 bins in ptcl number & average mass

Sources

Emissions
- Anthrop + volcanic SO_2 emissions
- DMS emissions from wind stress and DMS sea surface concentration
- Sea salt aerosol generation function

Sulfur Chemistry
- 8 sulfur species, 8 sulfur reactions
- Aqueous phase chemistry
- Oxidants from full chemistry run

Microphysics

Nucleation and Condensation
- Binary H_2SO4/H_2O nucleation
- Condensational growth

Coagulation
- Semi implicit fast numerical solution

Hygroscopic Growth
- Equilibrium size given by solution of Kohler equation

Removal

Dry Deposition
- Dry deposition of aerosol

Clouds
- Convective and frontal rain
- In-cloud nucleation scavenging
- Below cloud scavenging

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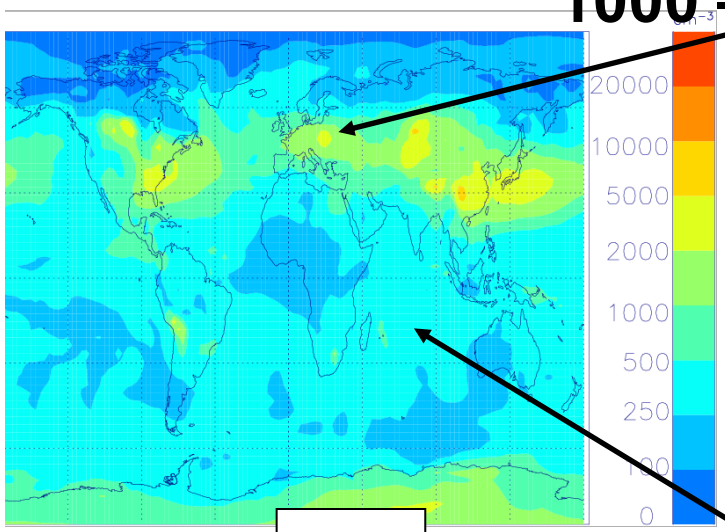
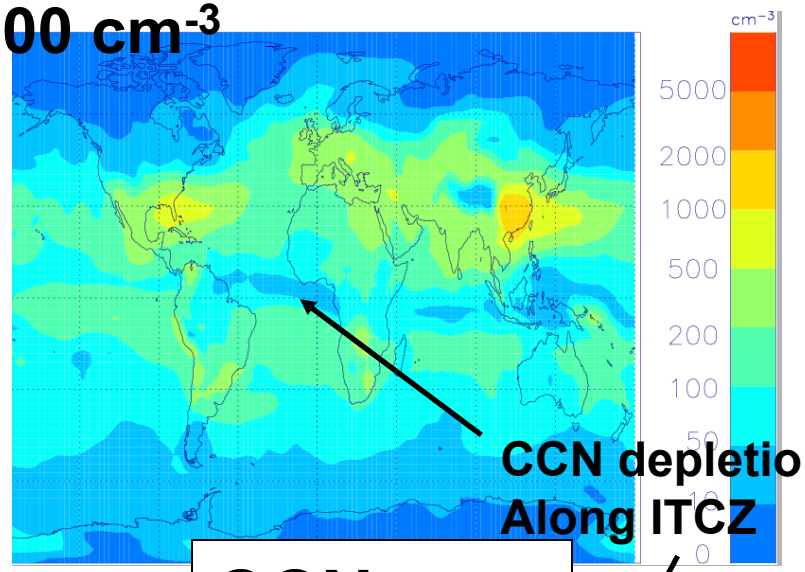
GLOMAP Aerosols

1000 – 5000 cm^{-3}



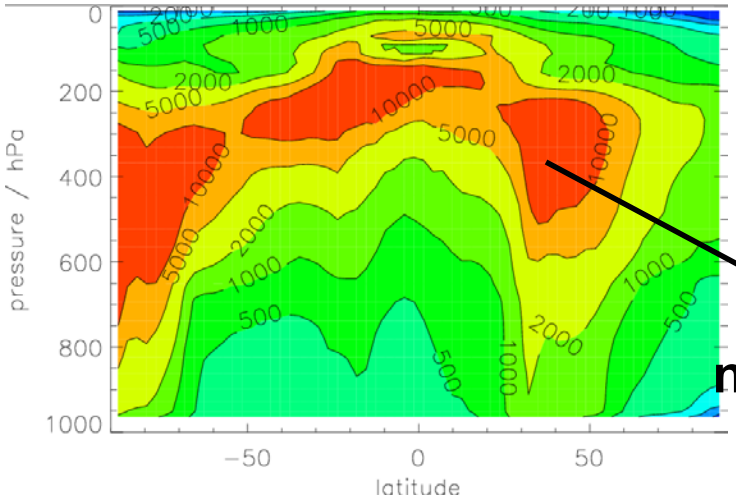
CN



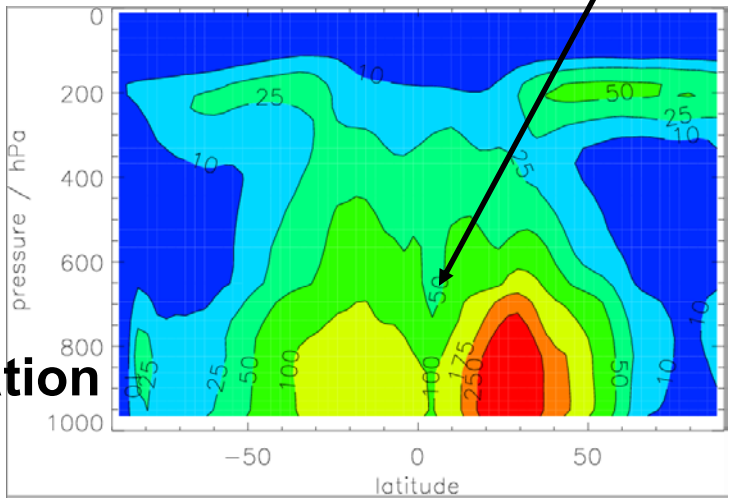
CCN depletion Along ITCZ

CCN (0.2%)

100- 500cm^{-3}



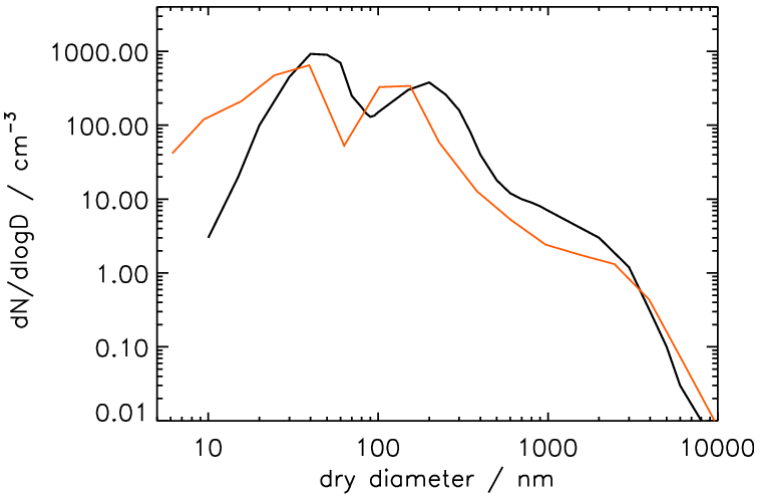
UT nucleation

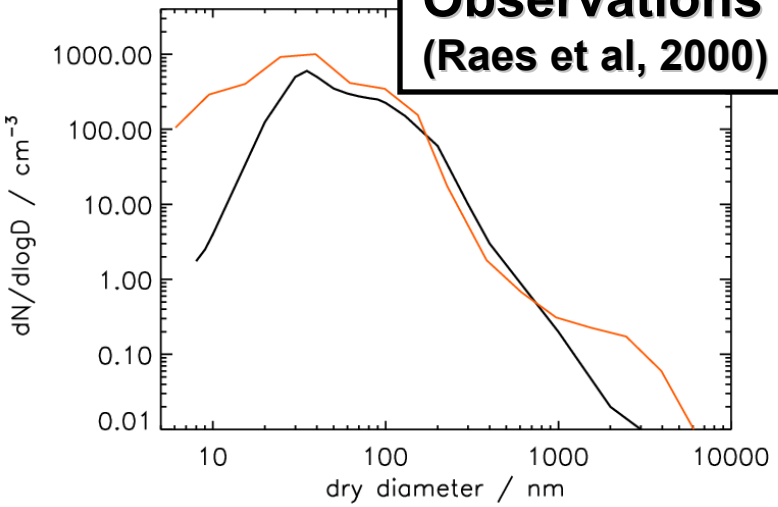


North Atlantic

GLOMAP
Observations
(Raes et al, 2000)

Number-Size Distribution

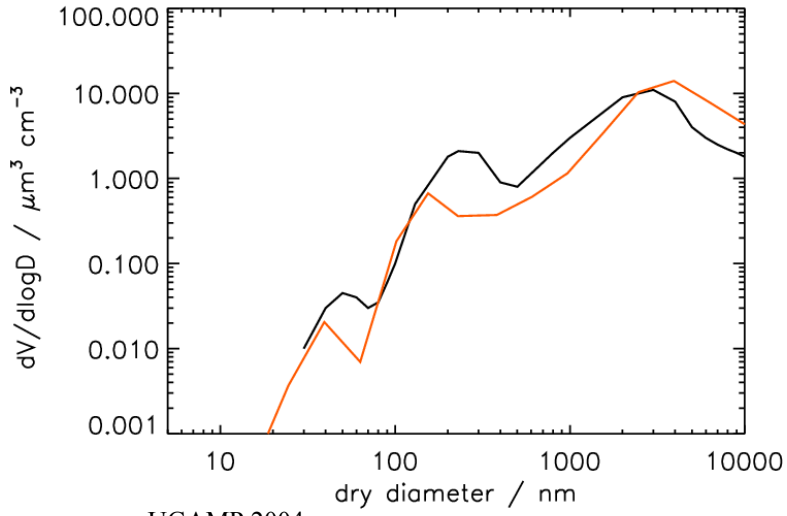


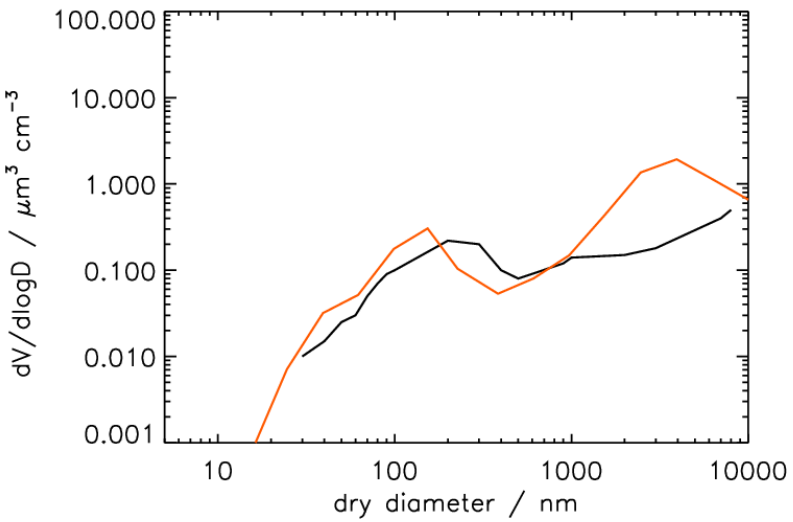


MBL

Volume-Size Distribution

FT (2.3km)



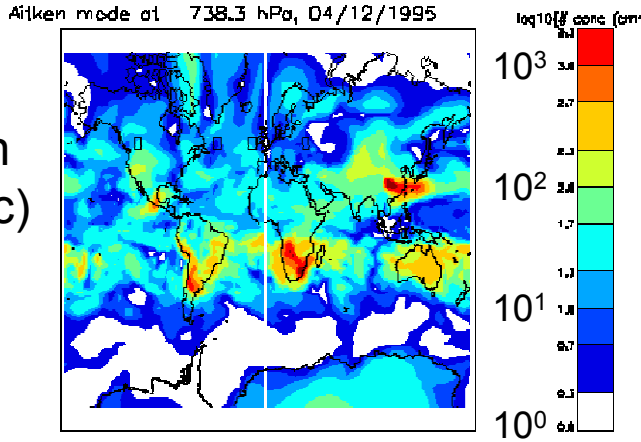


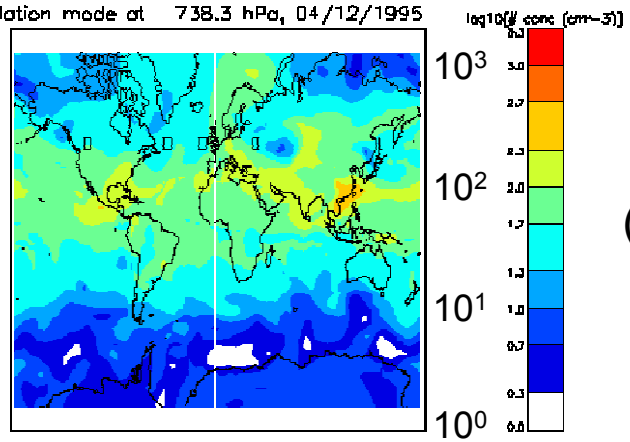
GLOMAP vs Hadley Comparison Experiment

- Spin-up from an aerosol-free atmosphere, October – December 1995 at T42 (2.8^o x 2.8^o) horizontal resolution, 31 vertical levels
- GLOMAP --- Sulfate and sea salt aerosol only, treated in the same distribution. 20 bins of numbers and mass.
- Hadley --- Aitken, accum, dissolved mode sulfate aerosol scheme used. Only mass carried, number deduced from r_{med}, σ_g
- Equivalent emissions of SO2, DMS & sea-salt, oxidant (OH, H2O2, NO3) & cloud fields, precipitation rates and gas phase chemistry schemes
- More sophisticated aqueous phase oxidation scheme in GLOMAP (cloud droplet spectrum produced for assumed cloud water content)
- No nucleation in Hadley centre scheme, condensation parameterized by Aitken/accum surface area ratio and coagulation treatment very basic.
- Both runs have aerosol dry deposition although aerosol wet removal only by in-cloud scavenging (no BCS) in Hadley Centre run.

Hadley Centre Aerosol Modes in FT (at ~2.5km)

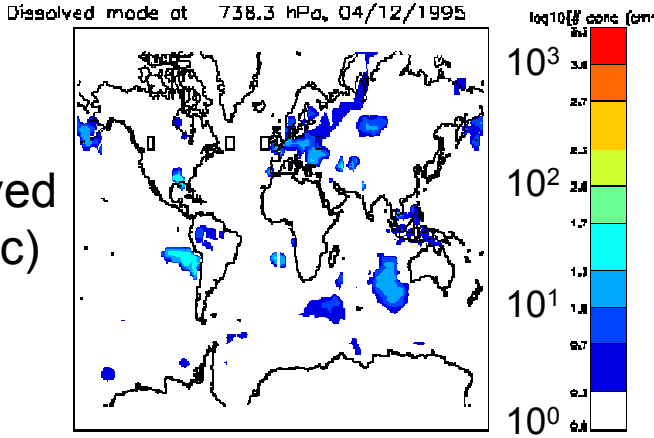
Aitken (# conc)

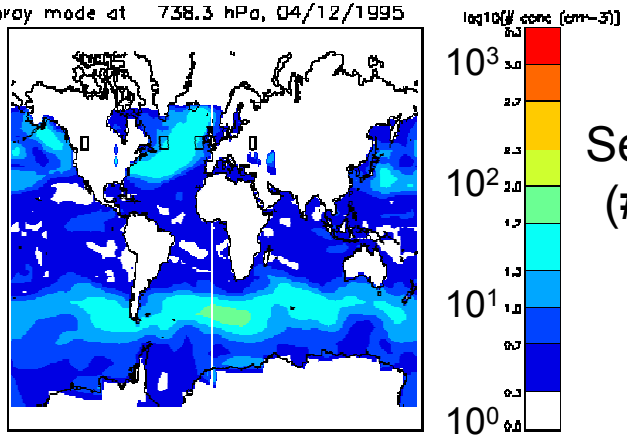




Accum. (# conc.)

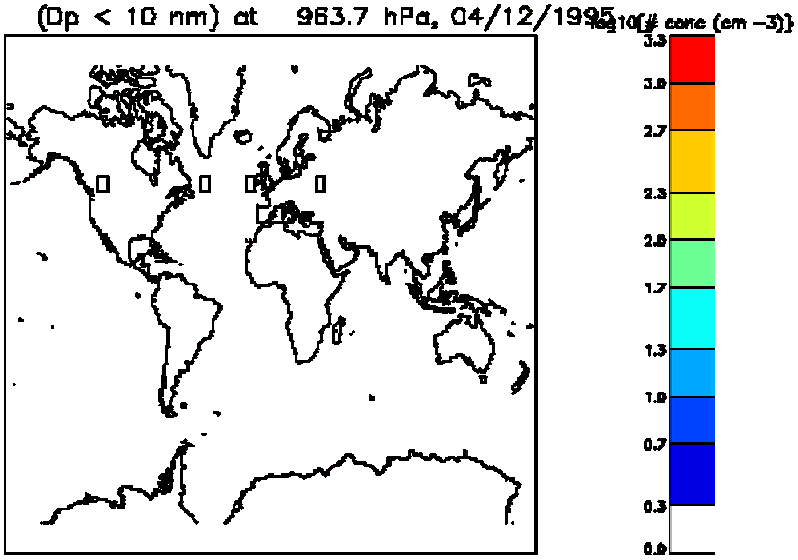
Dissolved (# conc)



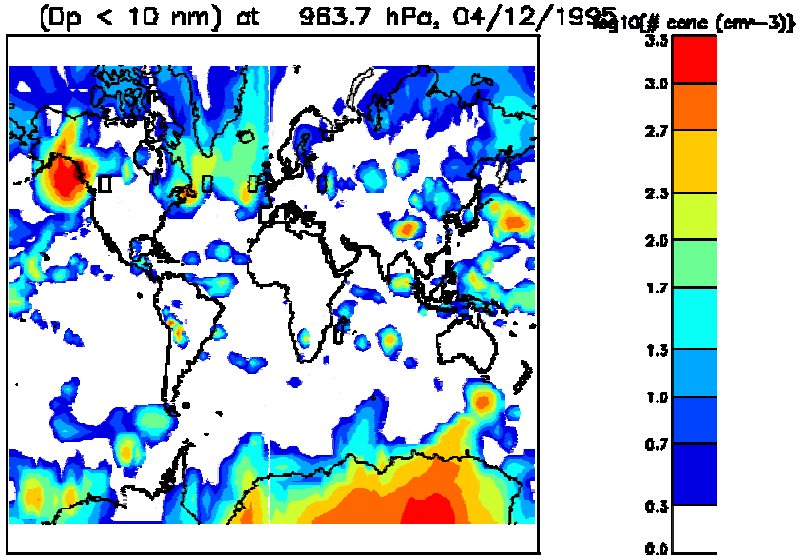


Sea Spray (# conc.)

Hadley vs GLOMAP sectional at surface (Dp < 10 nm)

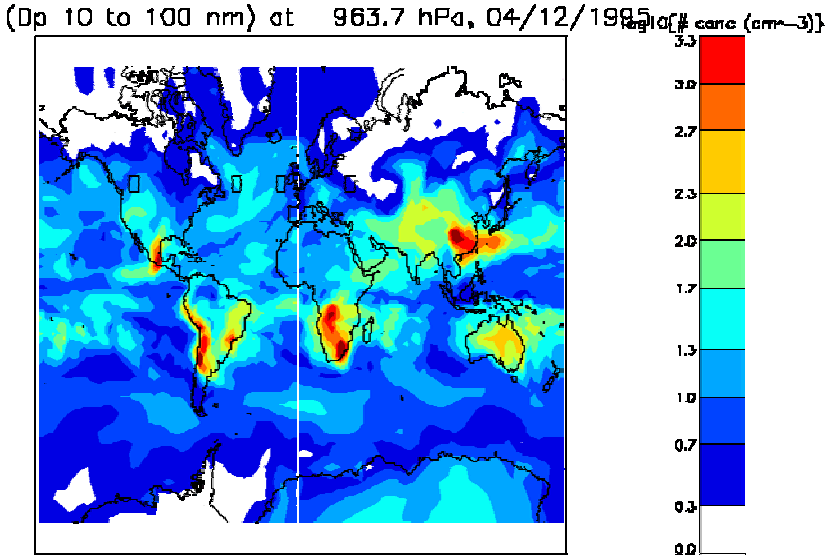


Hadley centre

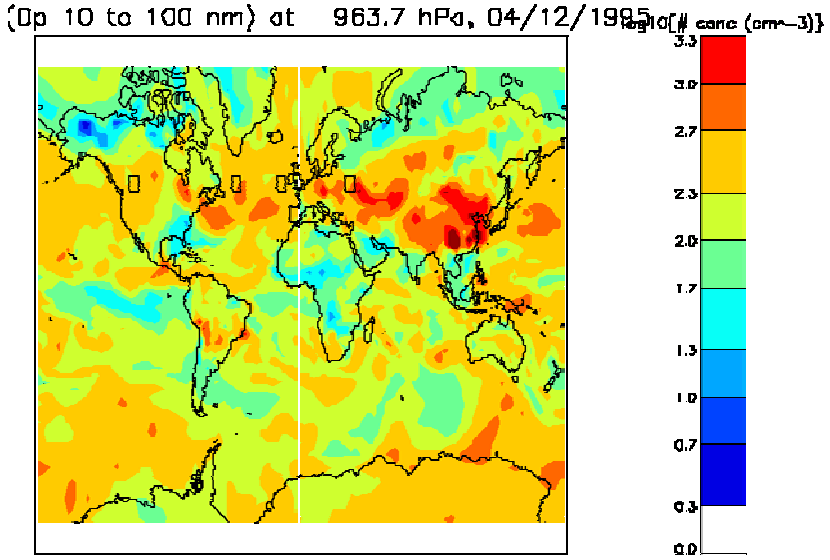


GLOMAP-sectional

Hadley vs GLOMAP sectional at surface (Dp 10-100 nm)

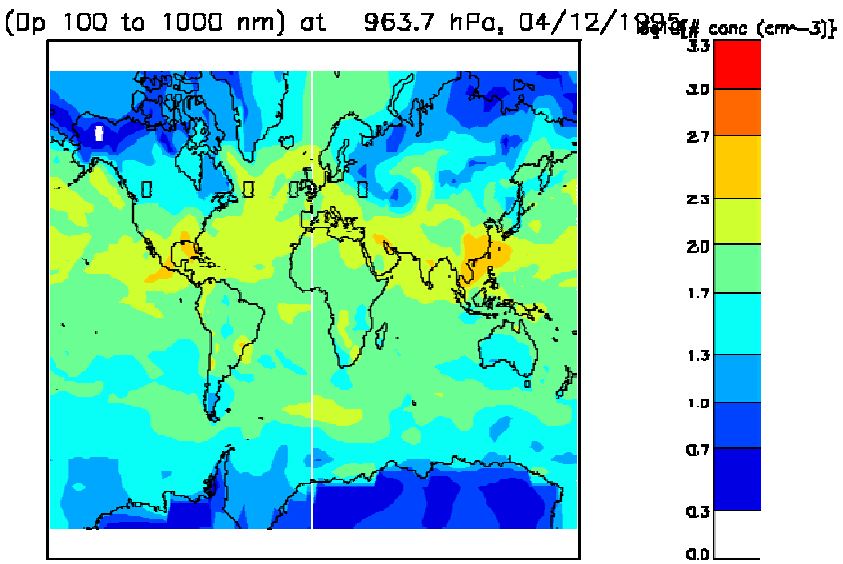


Hadley centre

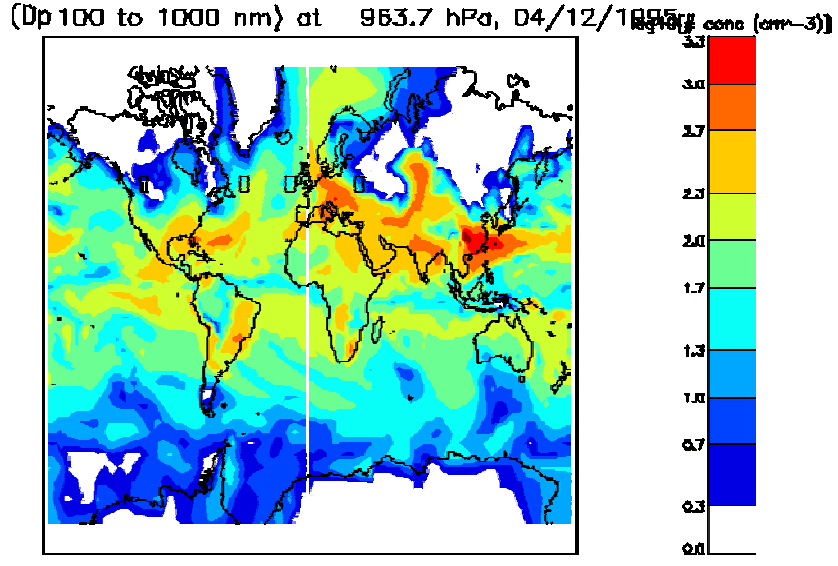


GLOMAP-sectional

Hadley vs GLOMAP sectional [surface] (Dp 100-1000 nm)

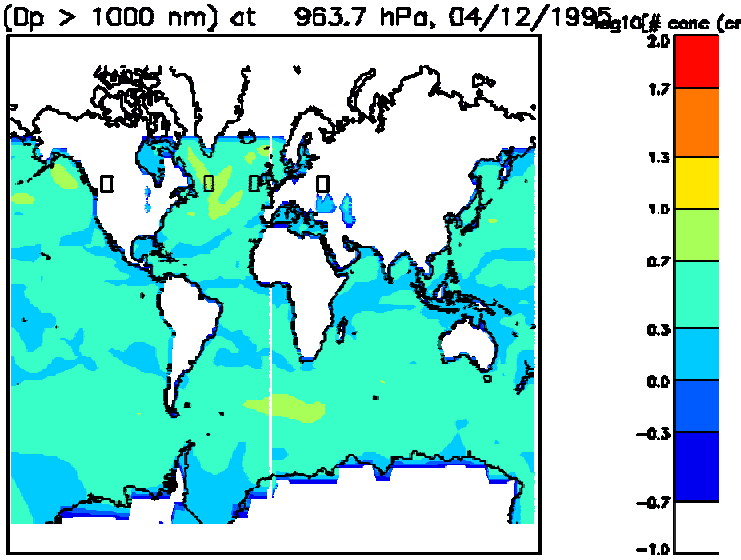


Hadley centre

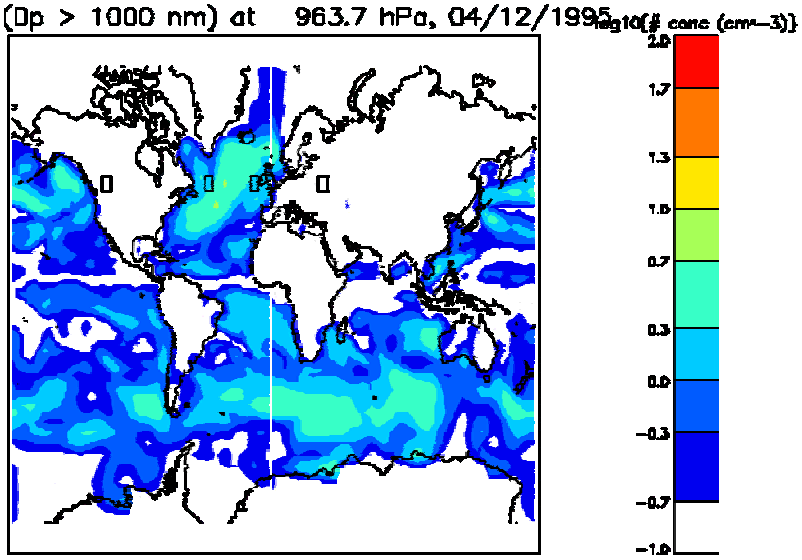


GLOMAP-sectional

Hadley vs GLOMAP sectional [surface] (Dp > 1000 nm)



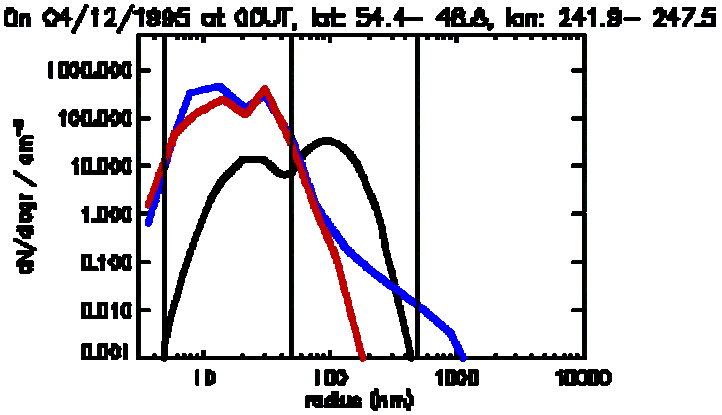
Hadley centre



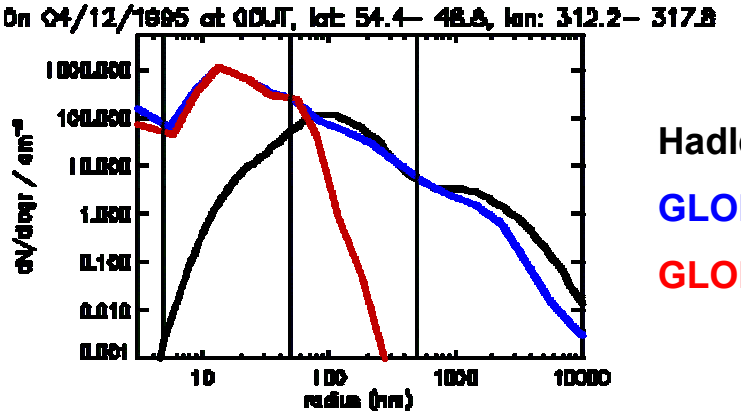
GLOMAP-sectional

Number conc. size distributions (surface)

Continental U.S.A.



MBL off E coast of U.S.A.

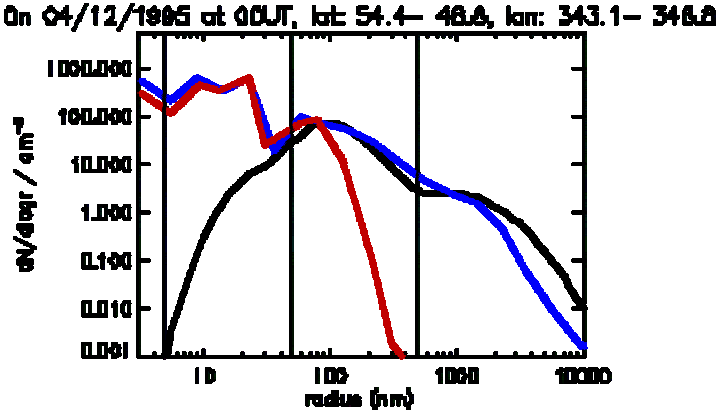


Hadley Centre

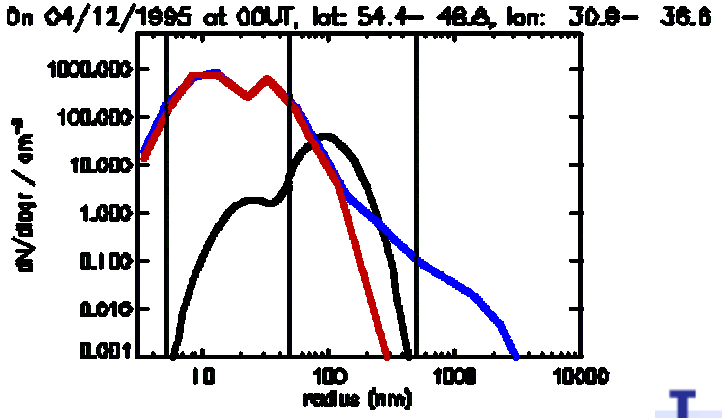
GLOMAP

GLOMAP (nossalt)

MBL off W coast of Europe

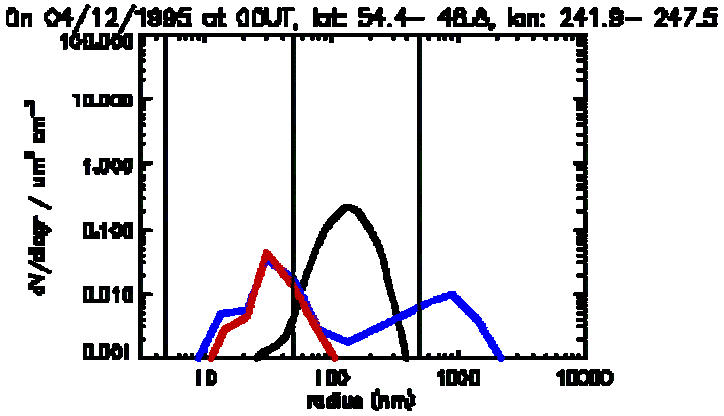


Continental Europe

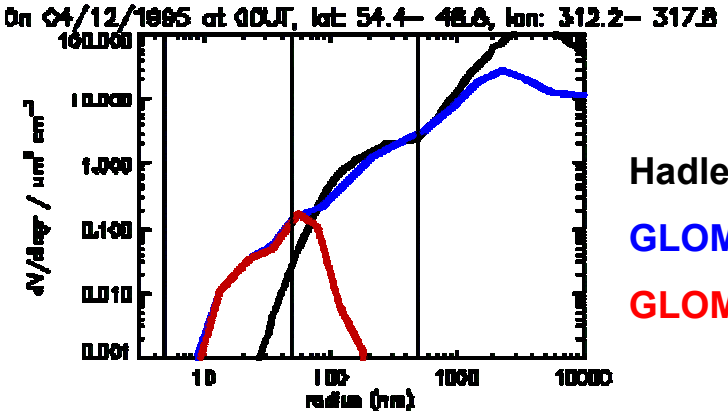


Size distributions in volume concentration

Continental U.S.A.



MBL off E coast of U.S.A.

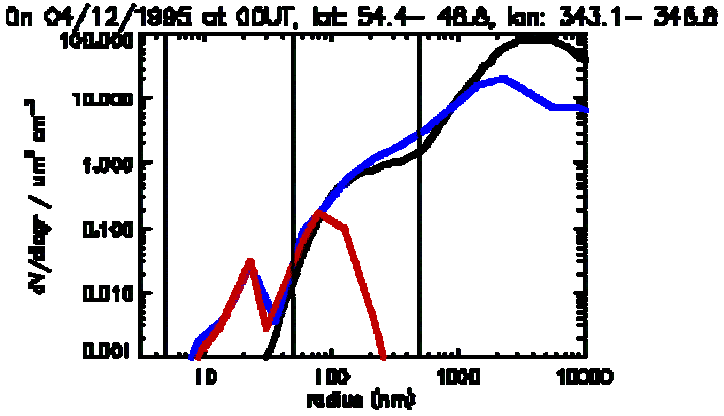


Hadley Centre

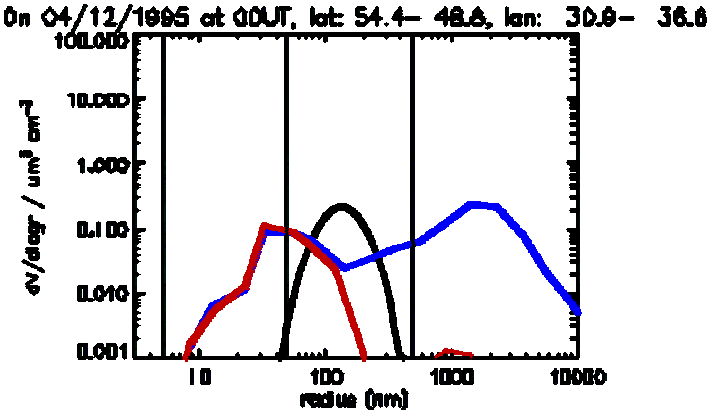
GLOMAP

GLOMAP (nossalt)

MBL off W coast of Europe

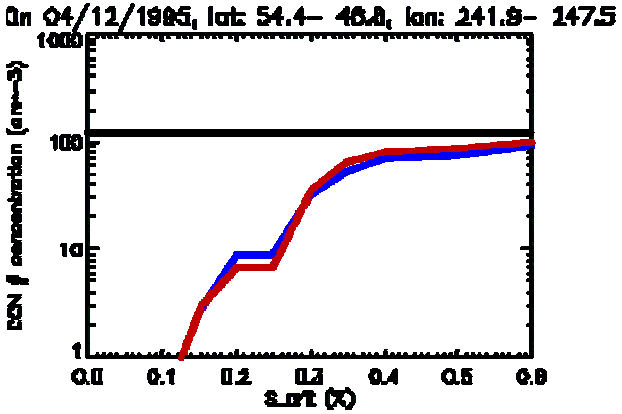


Continental Europe

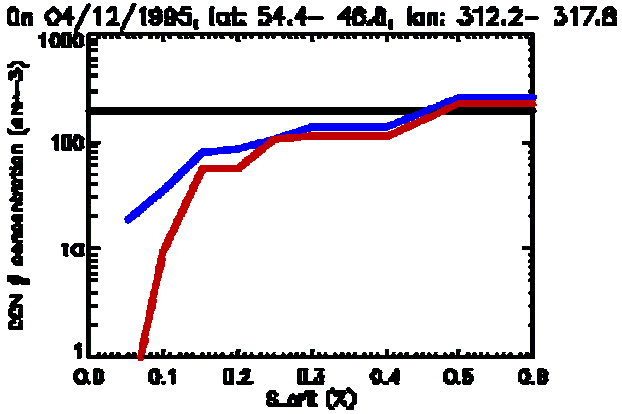


GLOMAP CCN no. conc. (surface) using Kohler theory vs Hadley Centre CCN no. conc. (surface) - Jones et al (2001)

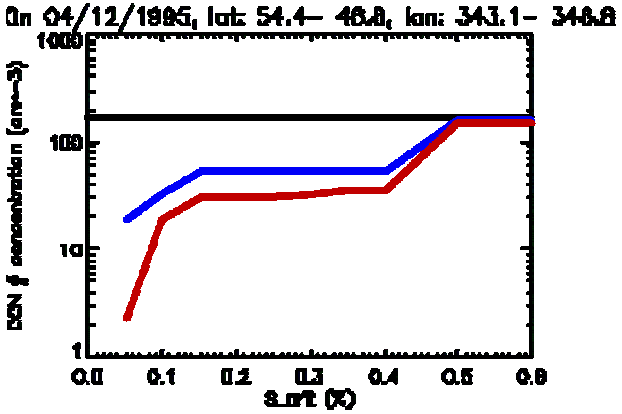
Continental U.S.A.



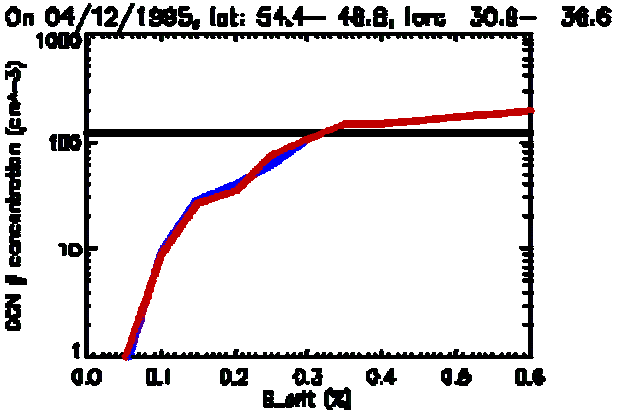
MBL off E coast of U.S.A.



MBL off W coast of Europe



Continental Europe



Hadley Centre

GLOMAP

GLOMAP (nossalt)

Summary

- GLOMAP model framework will be useful for identifying areas for improvement in Hadley Centre aerosol scheme
- By comparison of Hadley scheme with observations and GLOMAP sectional scheme (and using method of "process reduction") we will identify which processes are the most important to include in a new computationally affordable scheme for runs on centennial timescales
- For example does nucleation in FT and subsequent coagulation and condensation growth need to be included for accurate forcing calculation?
- Does sea salt need to be included as an interactive component?

Plan for next 6 months

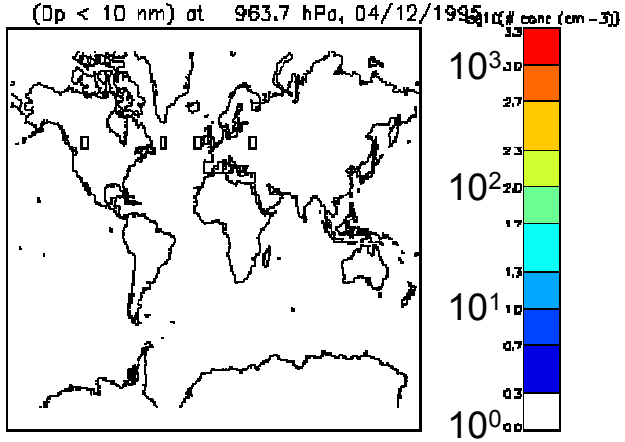
- Thorough evaluation of existing Hadley scheme against GLOMAP and observations
- GLOMAP already evaluated against observations
- Investigate:
  - Response to changing emissions
  - Relative change in Aitken/accumulation modes (critical for direct and indirect forcing)
- Identify key model updates/refinements to sulphate/sea salt scheme
- Initial development of new scheme

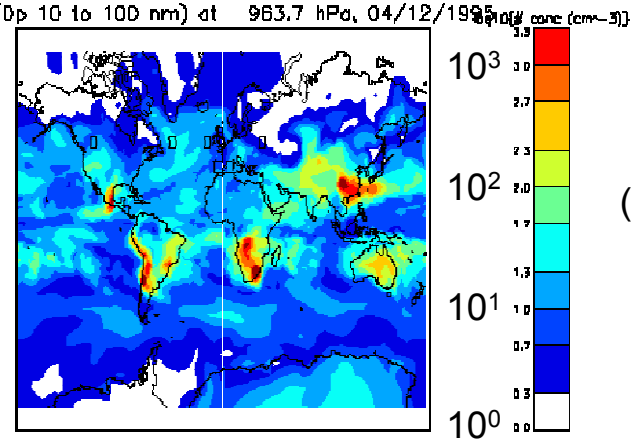
Plan for longer term

- GLOMAP multi-component version is currently being developed at University of Leeds
- Update dust, black carbon, organic carbon scheme in Hadley centre testing versus multi-component GLOMAP and observations
- Include secondary organic aerosol formation.
- Include improved chemistry scheme (nitrate, ammonium).
- Investigate bio-geochemical feedbacks --- iron fertilization of oceans from dust deposition --- increased DMS production --- increased sulfate aerosol --- increased cloud albedo --- investigate feedback on DMS production

Hadley Centre aerosol no. conc. by size (surface level)

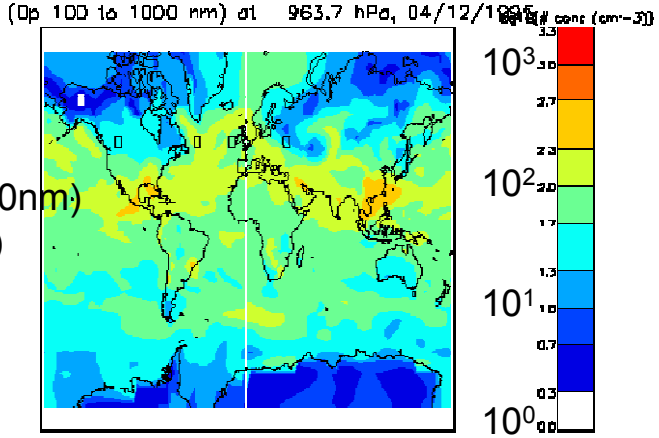
Nucln (D<10nm) (# conc)

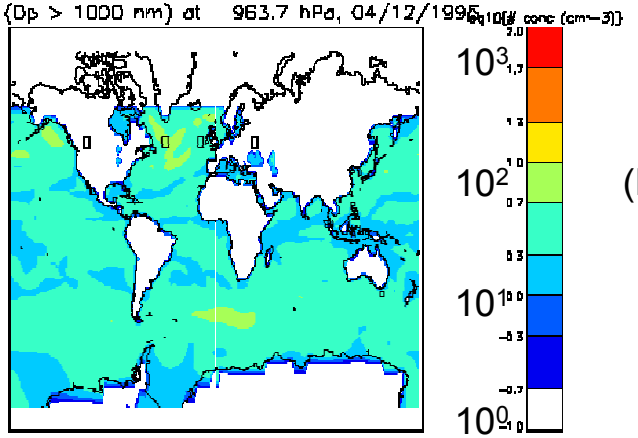




Aitken (10<D<100nm) (# conc.)

Accum. (100<D<1000nm) (# conc)

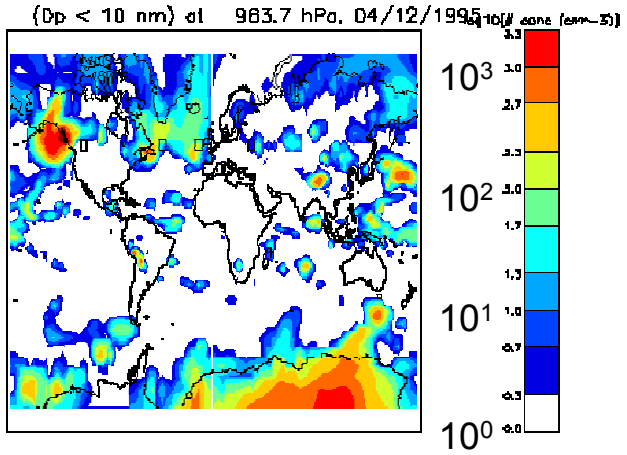


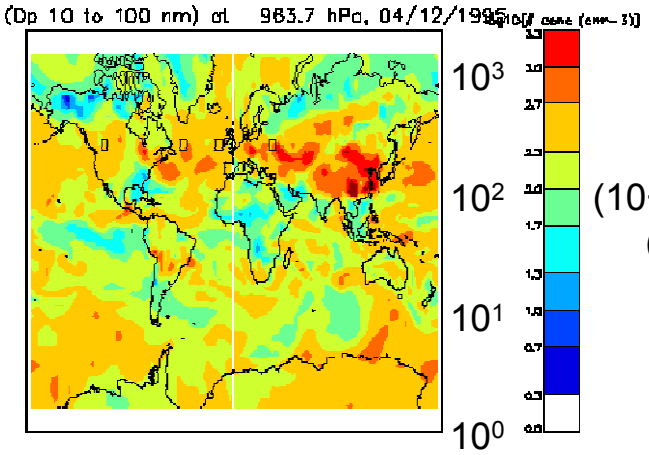


Coarse (D>1000nm) (# conc.)

GLOMAP aerosol no. conc. by size (surface level)

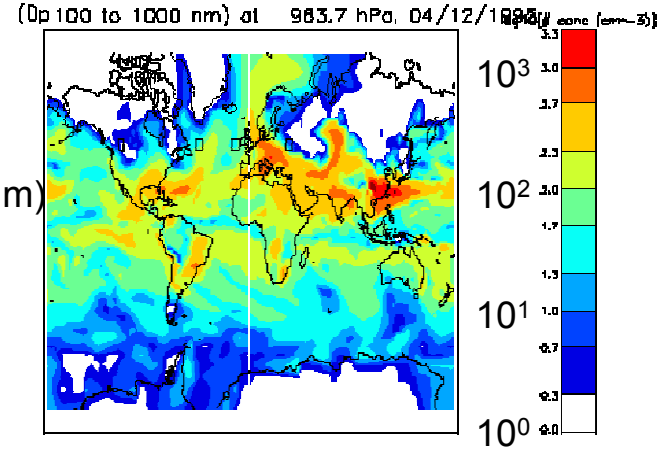
Nucln (D<10nm) (# conc)

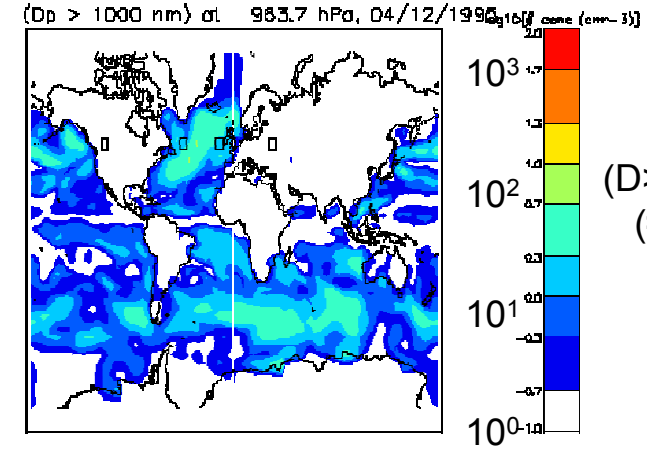




Aitken (10<D<100nm) (# conc.)

Accum. (100<D<1000nm) (# conc)





Coarse (D>1000nm) (# conc.)