School of Earth and Environment
INSTITUTE FOR CLIMATE AND ATMOSPHERIC SCIENCE
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The UK Chemistry and Aerosol Model (UKCA): An NCAS-Met Office collaboration. Advancing the realism of aerosol-climate effects in UK climate model simulations

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

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(University of Leeds)

Met Office

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Joonas Merikanto, Paul Manktelow, Kirsty Pringle, Dave Ridley
Martyn Chipperfield, Olivier Boucher, Colin Johnson.

Changes in aerosol strongly impact climate

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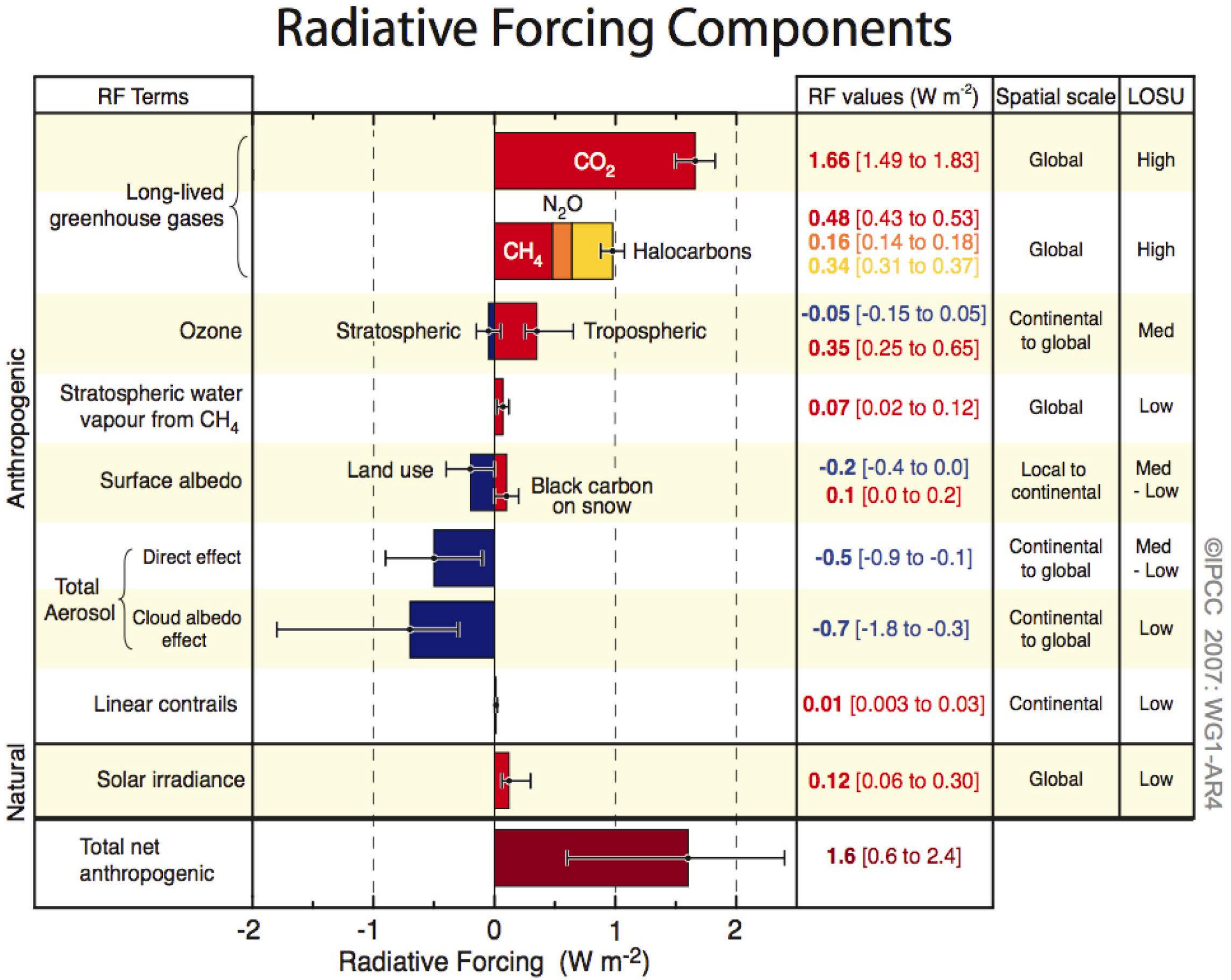

Aerosol representation in climate models

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IPCC models have so far included only a simple representation of aerosols when simulating climate effects.

Only <u>mass</u> of aerosol components is advected quantity: (e.g., sulphate, black carbon, dust, sea-salt mass)

For size-dependent processes: An assumed size distribution

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

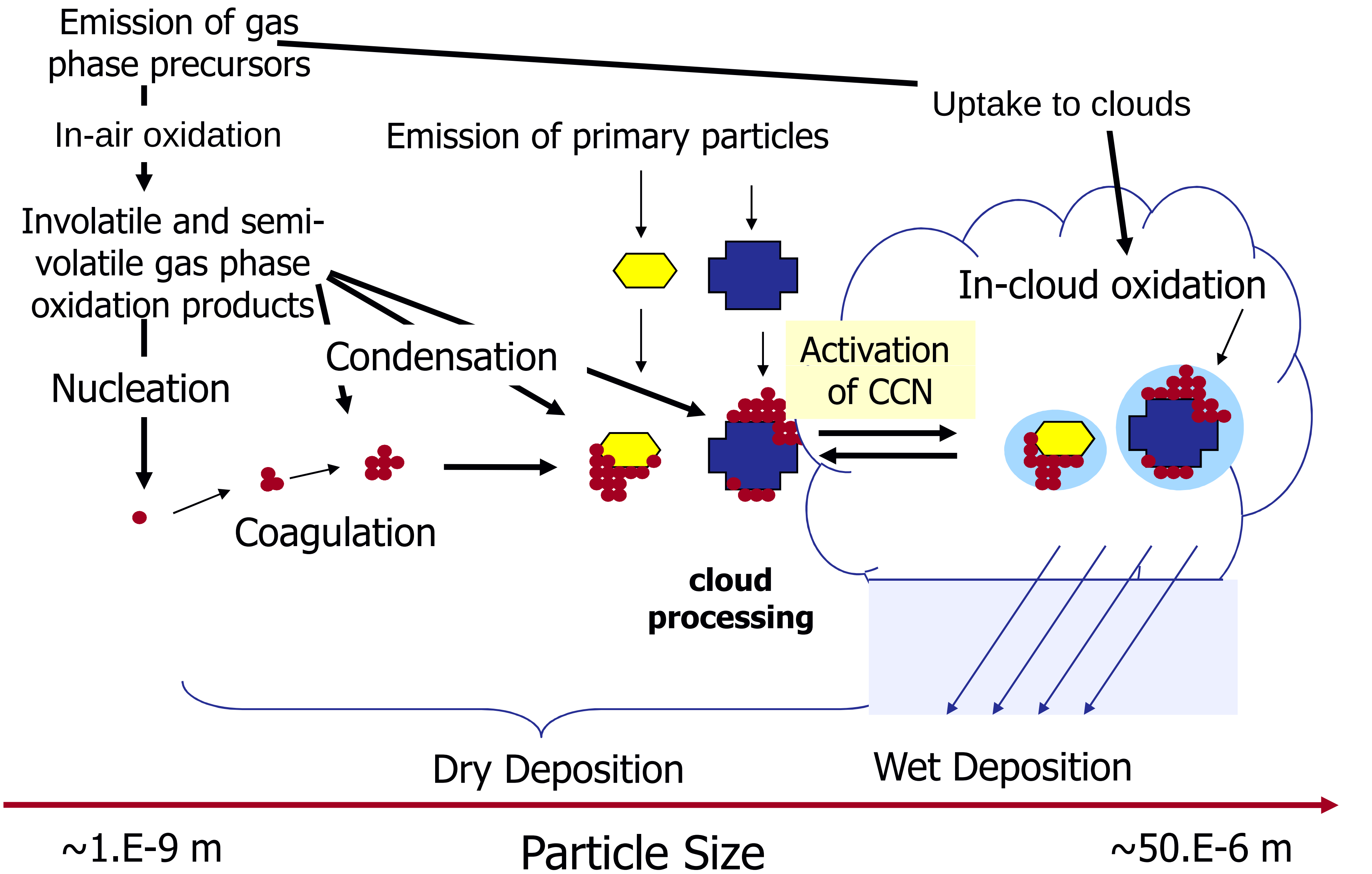
Indirect forcing: Use empirical cloud drop—aerosol relations,

New particle formation not included

Important aerosol types (e.g. organics, nitrate) omitted.

Models consider aerosol as external mixtures.

Processes control size & composition



MBL observations show large variation in size

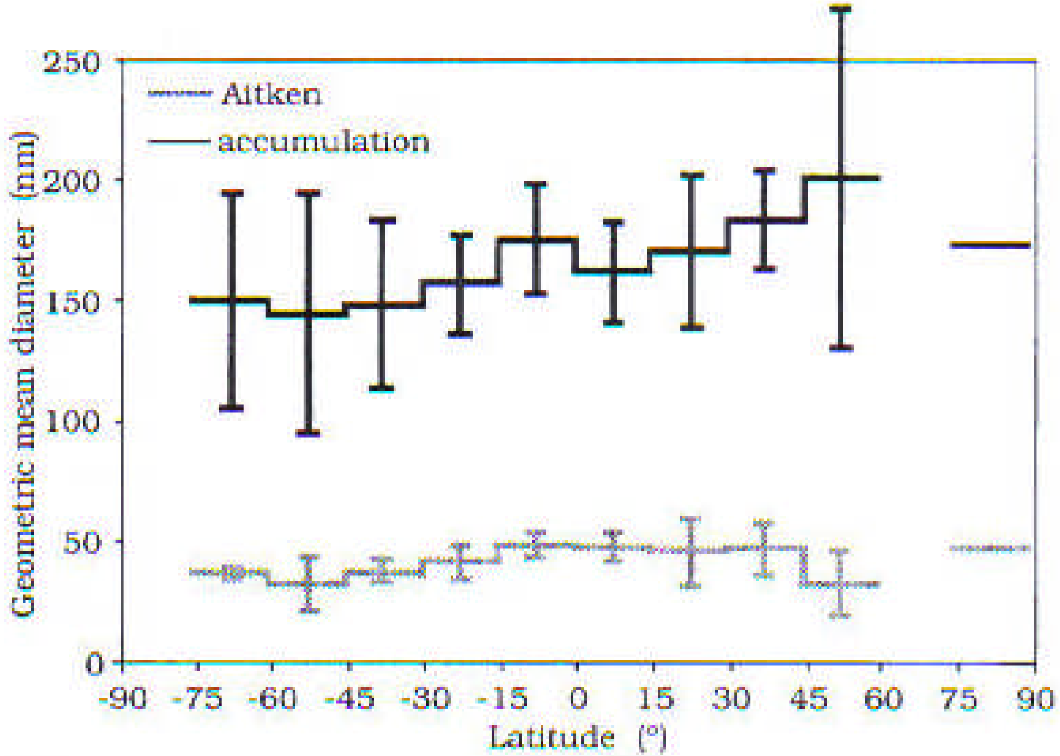
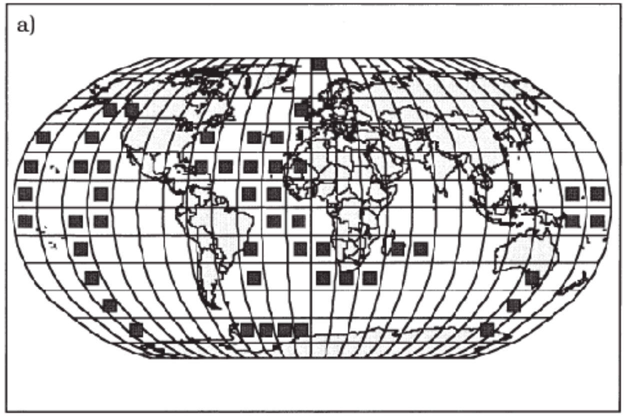


Table 1. *Sources of data on aerosol concentration and number-size distribution*

Source	Geographical area/ experiment
Bates et al., 1998b	Tasman Sea, Southern Ocean, ACE 1
Covert et al., 1996b	Arctic, IAOE91
Covert et al., 1996a	Central Pacific, MAGE
Covert et al. (unpublished data)	Equatorial Western Pacific, CSP
Davison et al., 1996a	Southern Ocean
Heintzenberg and Leck, 1994	Arctic
Jaenicke et al., 1992	Southern Ocean
Jensen et al., 1996	North E Atlantic, ASTEX
Leaitch et al., 1996	NW Atlantic
Quinn et al., 1990	Central N Pacific, MAGE
Quinn et al., 1993	Central Eastern Pacific, MAGE
Quinn et al., 1995	Central Pacific, MAGE
Quinn et al., 1996	Central Pacific, MAGE
Raes et al., 1997	Tenerife
Van Dingenen et al., 1995	North Atlantic
Van Dingenen et al. (unpublished data)	Tenerife, ACE 2
Wiedensohler et al. (unpublished data)	Tasman Sea, Southern Ocean, ACE 1
Nowak et al. (unpublished data	North and South Atlantic, Indic, AEROCRUISE 1999

Variation in size strongly affects climate effects.



Heintzenberg et al (2000, Tellus B)

Composite of CDN-aerosol observations from many sites

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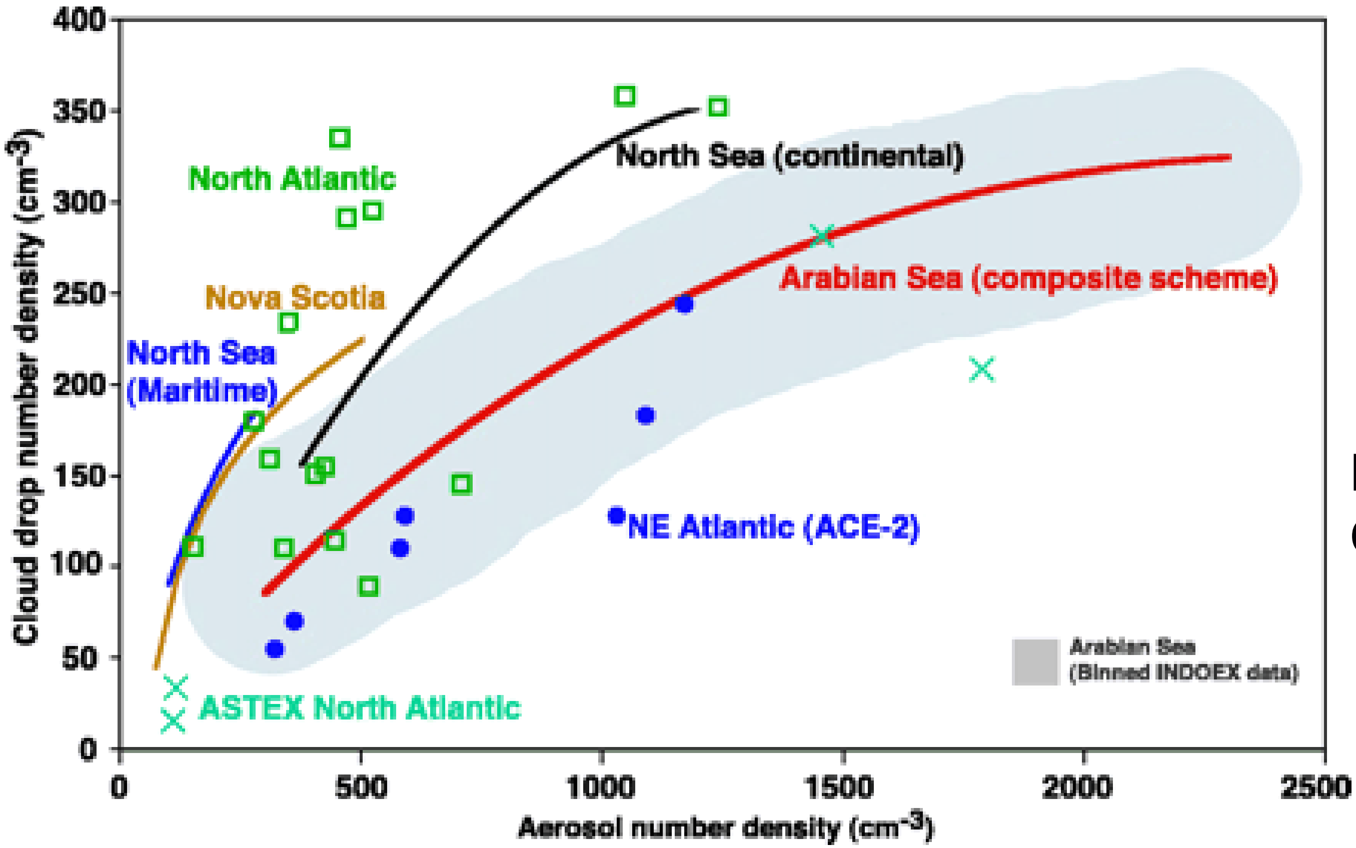


From Ramanathan, Crutzen et al (2001)

No single relationship fits observed CDN vs aerosol number.

Different regions have different particle types, size distbtn, etc.

IPCC models use of different relations must cause part of large "model uncertainty" in estimated 1st indirect aerosol forcing

Global Model of Aerosol Processes (GLOMAP) UNIVERSITY OF LEEDS

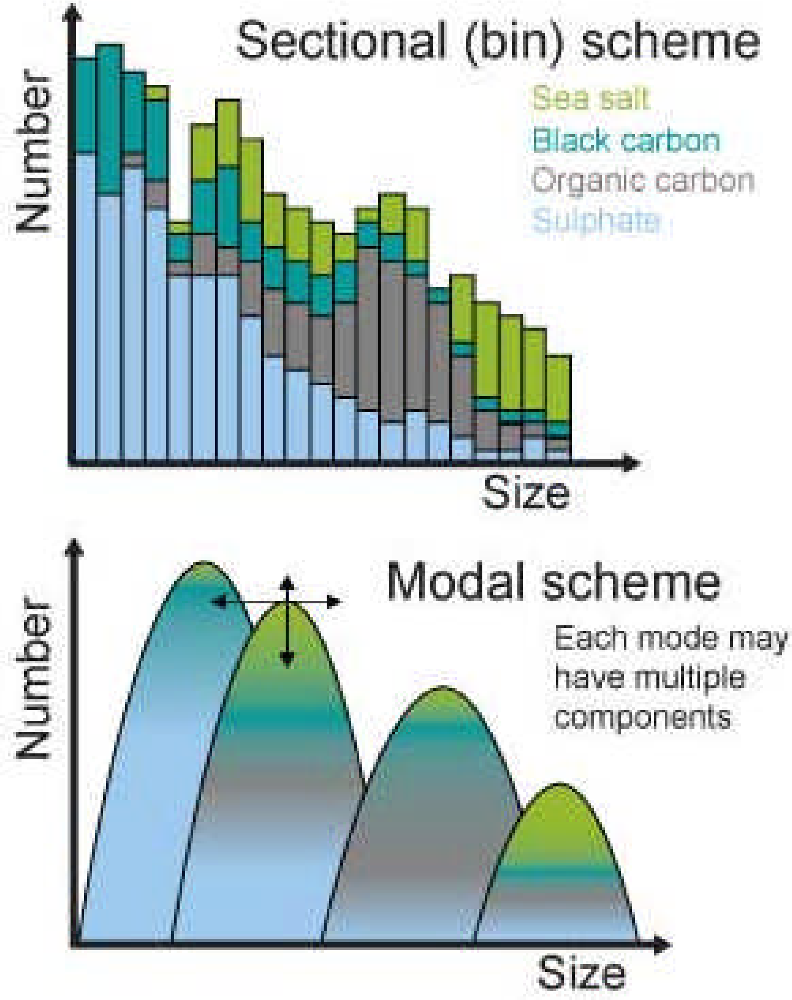
Developed in Leeds since 2003 to model global aerosol distribution with size-resolved representation of microphysics & chemistry.

Resolves processes that grow aerosol from nanometre sizes.

Attempts to simulate potential climate impacts with maximum degree of realism.

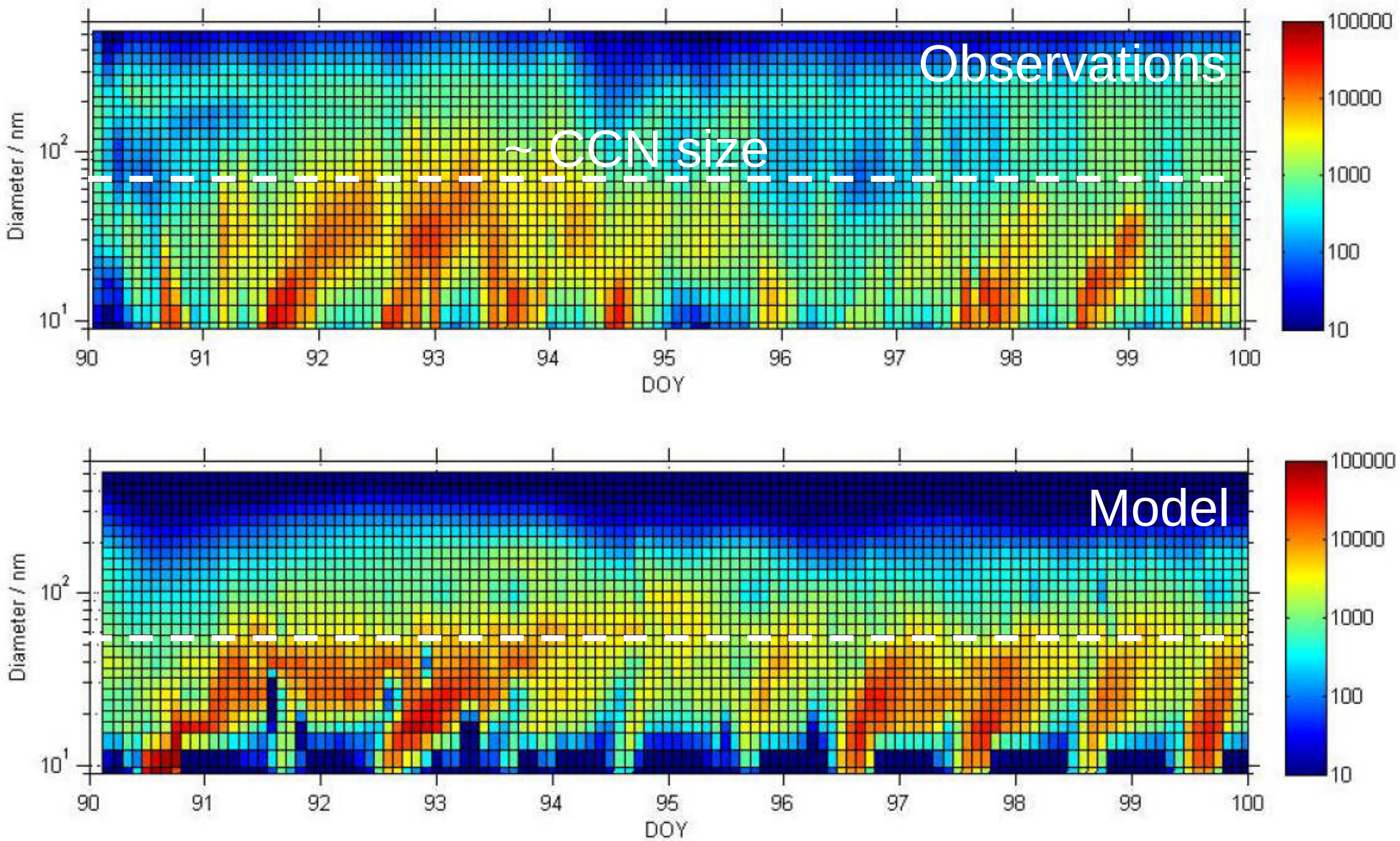
Analysed meteorology used to drive model.

Detailed (GLOMAP-bin) & simpler (GLOMAP-mode) versions



Growth of particles from nanometres to cloud nucleii

Observations at many sites show new particle formation at nanometre sizes and growth to cloud condensation nucleii (CCN) during long-range transport



Spracklen et al (2006, ACP)

Nucleation events important for climate models

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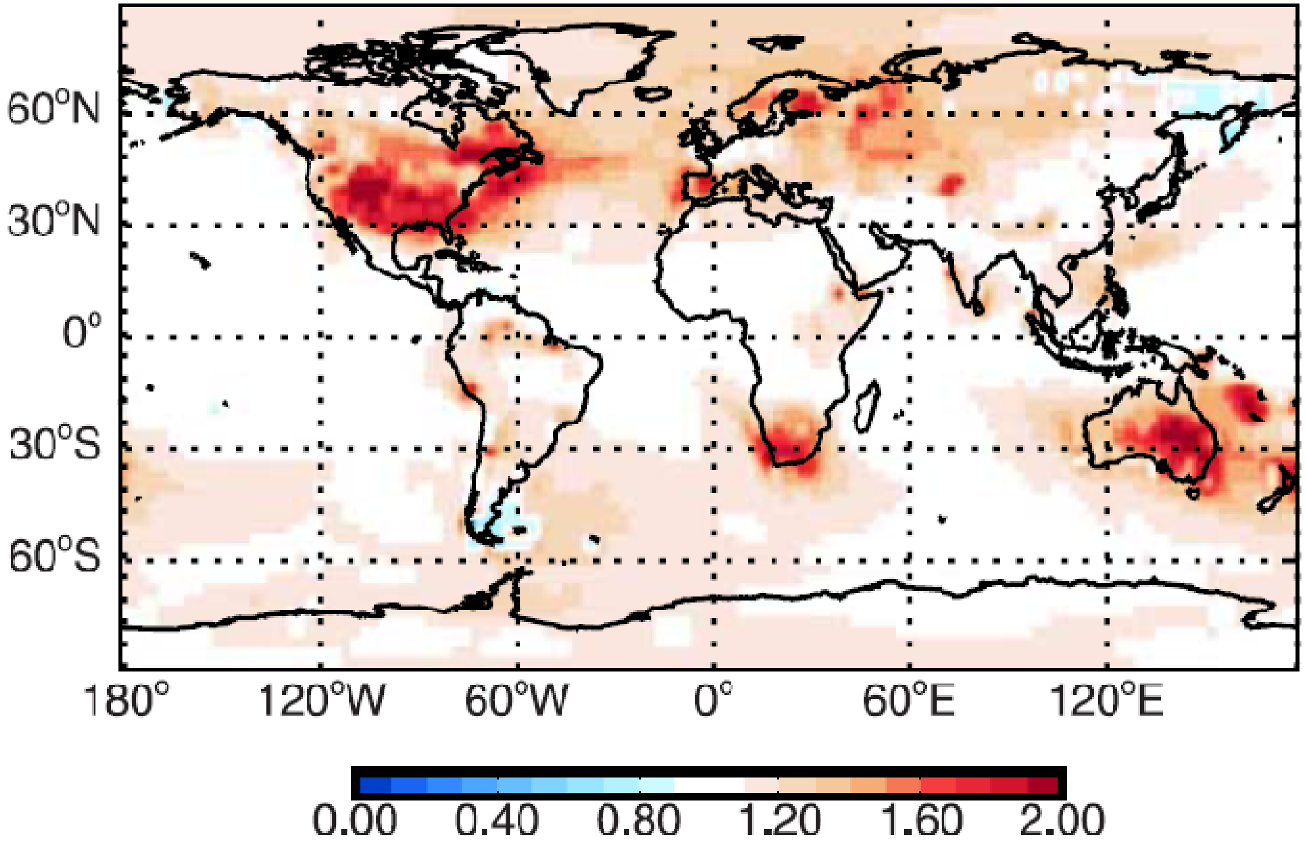
Ratio of March-May CCN (1%) with NPF (A=2x10^{-6} s^{-1}) : CCN without NPF



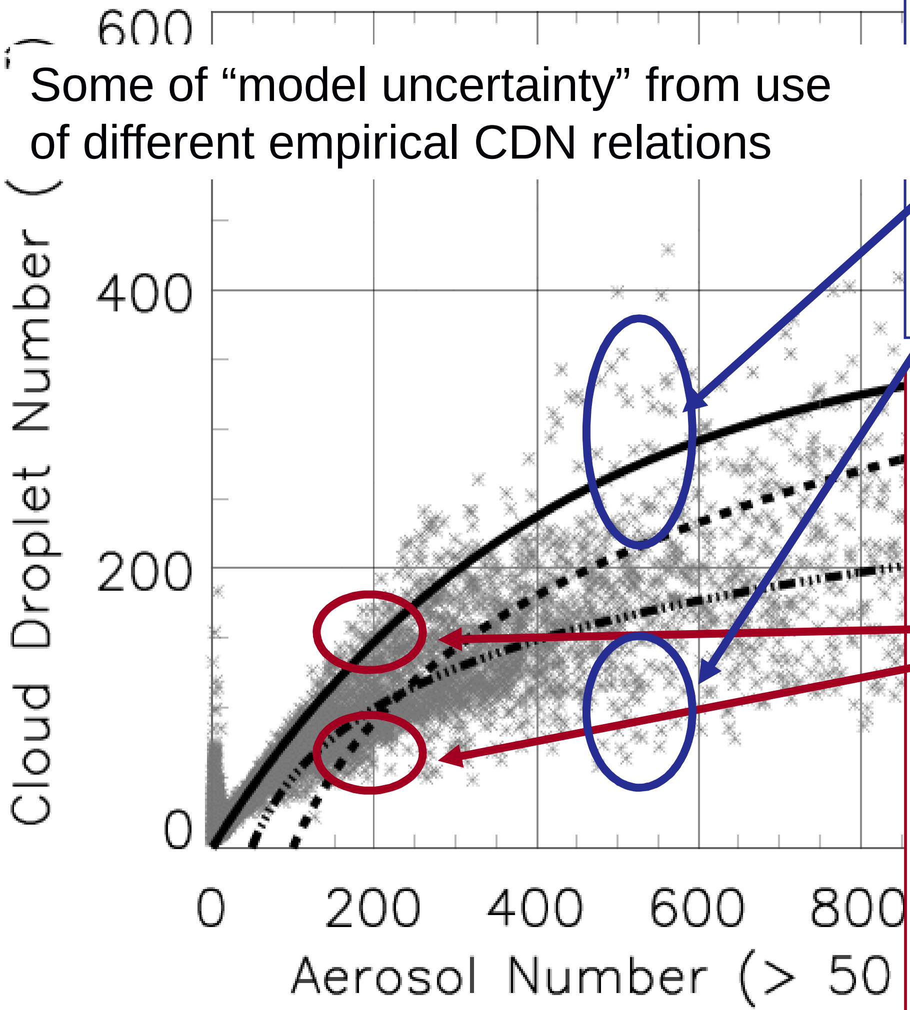
Spracklen et al (2008, GRL)

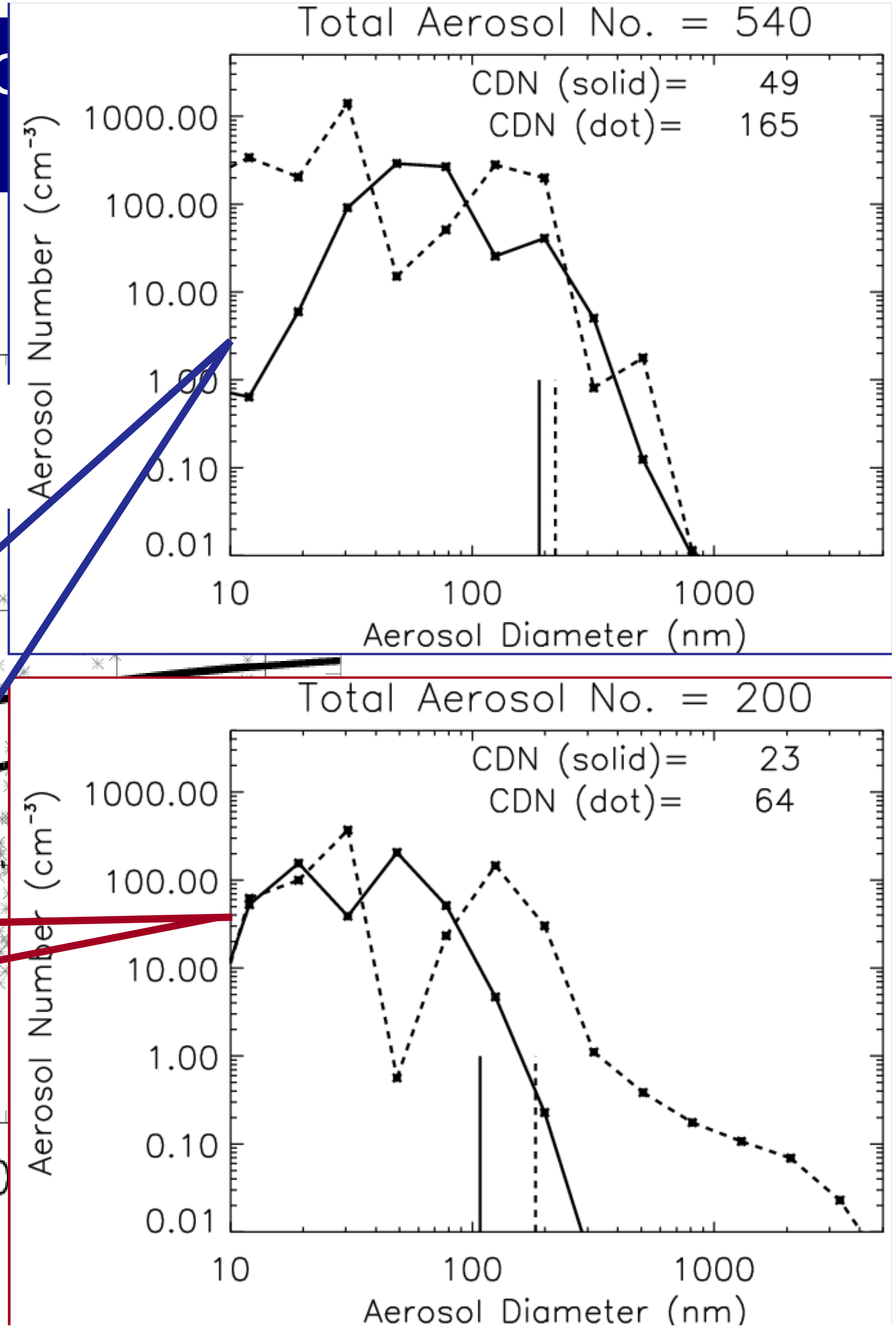
New particle formation increases global mean boundary layer CCN concentrations by 5-50%.

Exploring the scatter in model C
with mechanistic CDN scheme

Pringle et al (to be submitted)

Some of “model uncertainty” from use of different empirical CDN relations





Variability in predicted CDN

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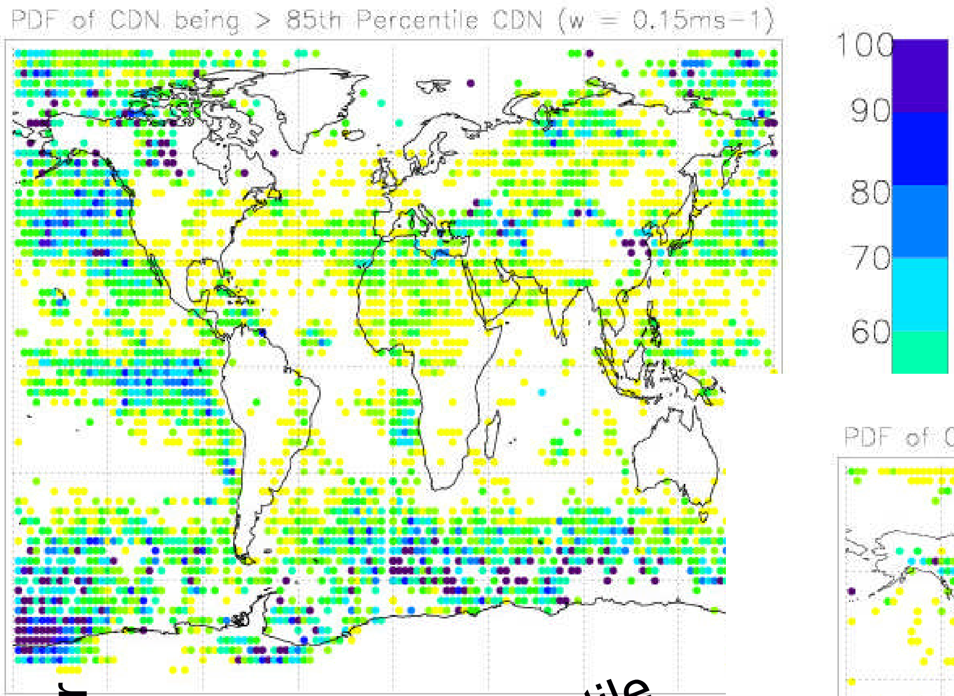
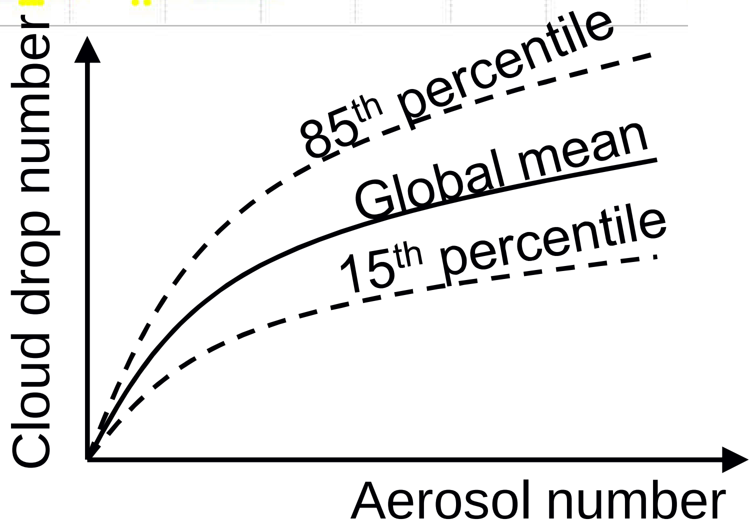
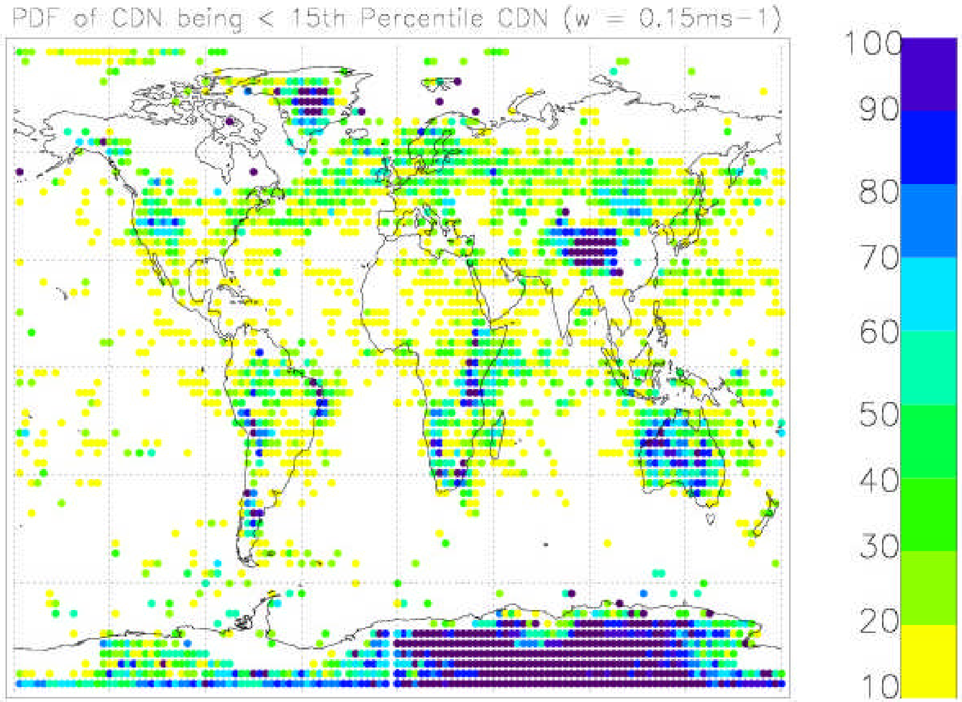


Percent of days that exceed 85th percentile

Pringle et al (to be submitted)





Global CDN prediction based on single-region CDN-aerosol relation

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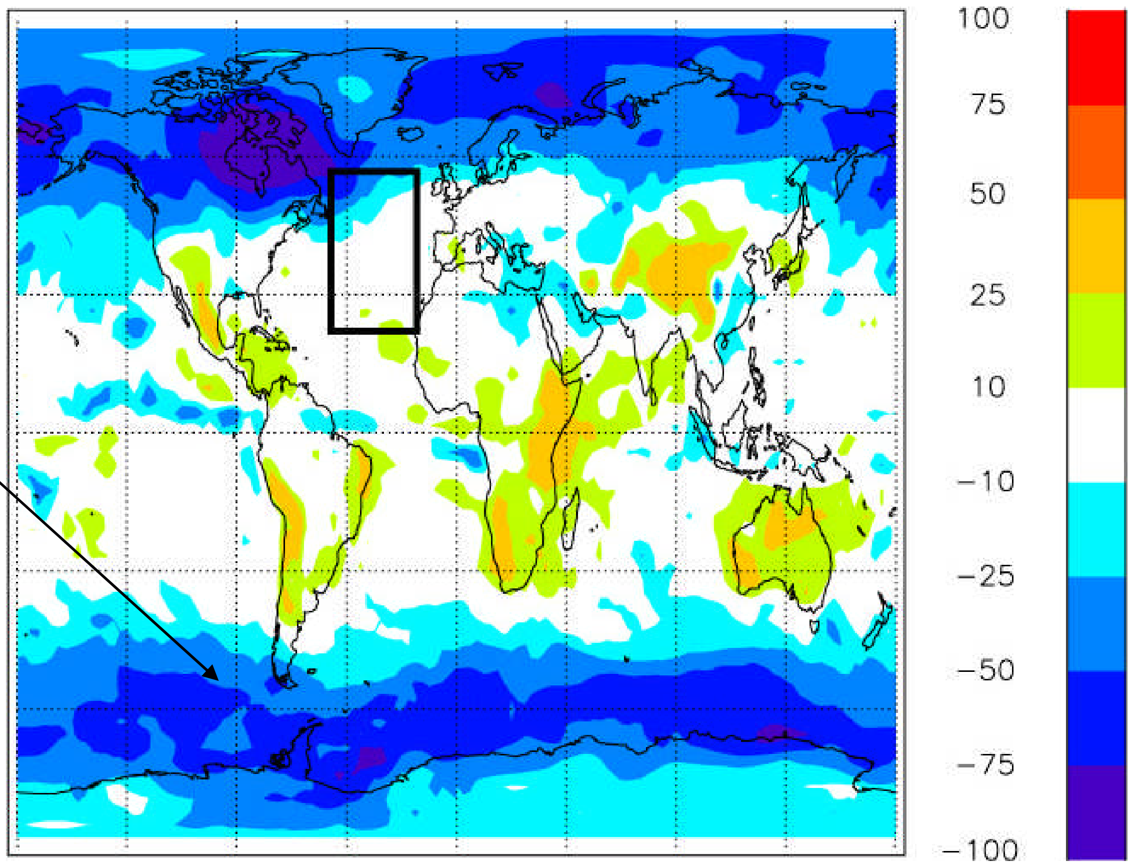
Use model output to generate CDN-aerosol empirical fit

Use the fit to calculate global CDN

Calculate the %difference from mechanistic CDN calculation

75% more CDN than predicted from CDN-aerosol relation over the Atlantic



Pringle et al (to be submitted)

UK Chemistry & Aerosols project (UKCA)

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- 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 etc.)

- Tropospheric and stratospheric chemistry schemes in L38/L60 configuration. Aerosol precursor extension to standard tropospheric chemistry scheme.

- 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
  -- secondary organic aerosol from monoterpene oxidation

- UKCA interactive ozone, methane and aerosol (direct/indirect) radiative effects extend HadGEM to become a coupled composition-climate model.

- Enhances UK capability in aerosol-climate-earth system modeling and provides integration for NCAS and Met Office initiatives.

UKCA aerosol representation

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Climate model at N96L38 resolution (N48L60 for QESM, LAM for AQ/dust-only)

5-mode version of GLOMAP aerosol scheme (SO4, sea-salt, BC, OC).
Dust carried using existing UM 6-bin mass-only scheme (option for 2-mode).

Two-moment aerosol dynamics has number and mass conc'ns in size modes.

Emissions of DMS (ocean), SO_2 (anthrop., volcanic), monoterpenes (biogenic)
Primary aerosol particles from emissions of sea salt, dust,
black & organic carbon (fossil- and bio-fuels, vegetation fires)

UKCA tropospheric chemistry drives in-air/in-cloud oxidation of precursor gases

Secondary aerosol particles by binary homogeneous nucleation of H_2SO_4-H_2O
Secondary aerosol mass added by production of sulphate & biogenic organics.

Growth to CCN sizes simulated by condensation, coagulation, cloud processing
Size-resolved impaction & nucleation scavenging and dry deposition.

Internally mixed aerosol direct radiative effects via UKCA radiation module

UKCA mechanistic cloud droplet number to be included (P. Stier, Oxford)

See Manktelow et al (2007), Woodhouse et al (2008) for GLOMAP-mode.
Spracklen et al. (2005a,b, 2006, 2007) for process descriptions in GLOMAP-bin

UKCA to be used at Met Office on range of scales

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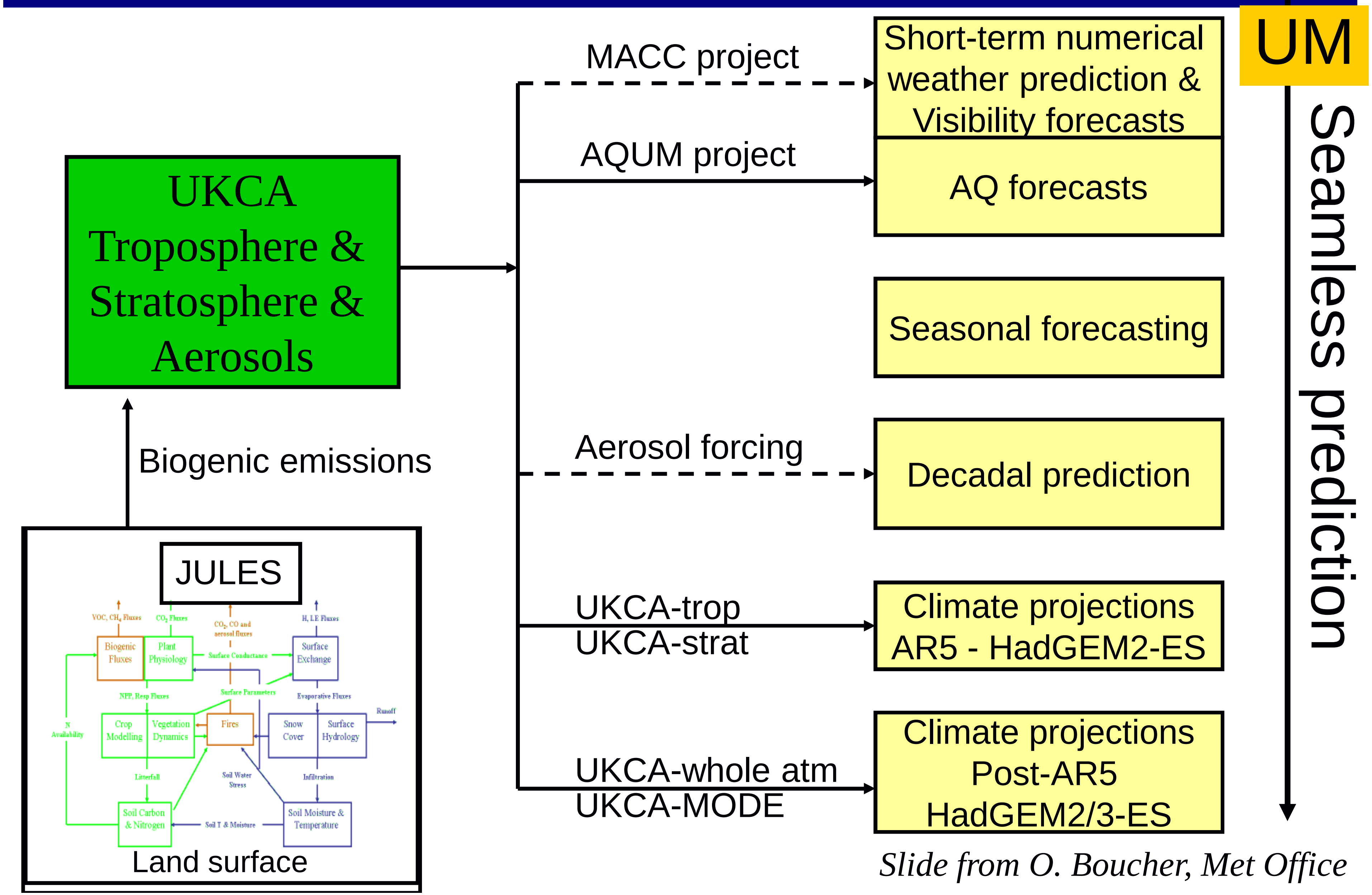

Slide from O. Boucher, Met Office

UKCA strong link to NERC QUEST programme

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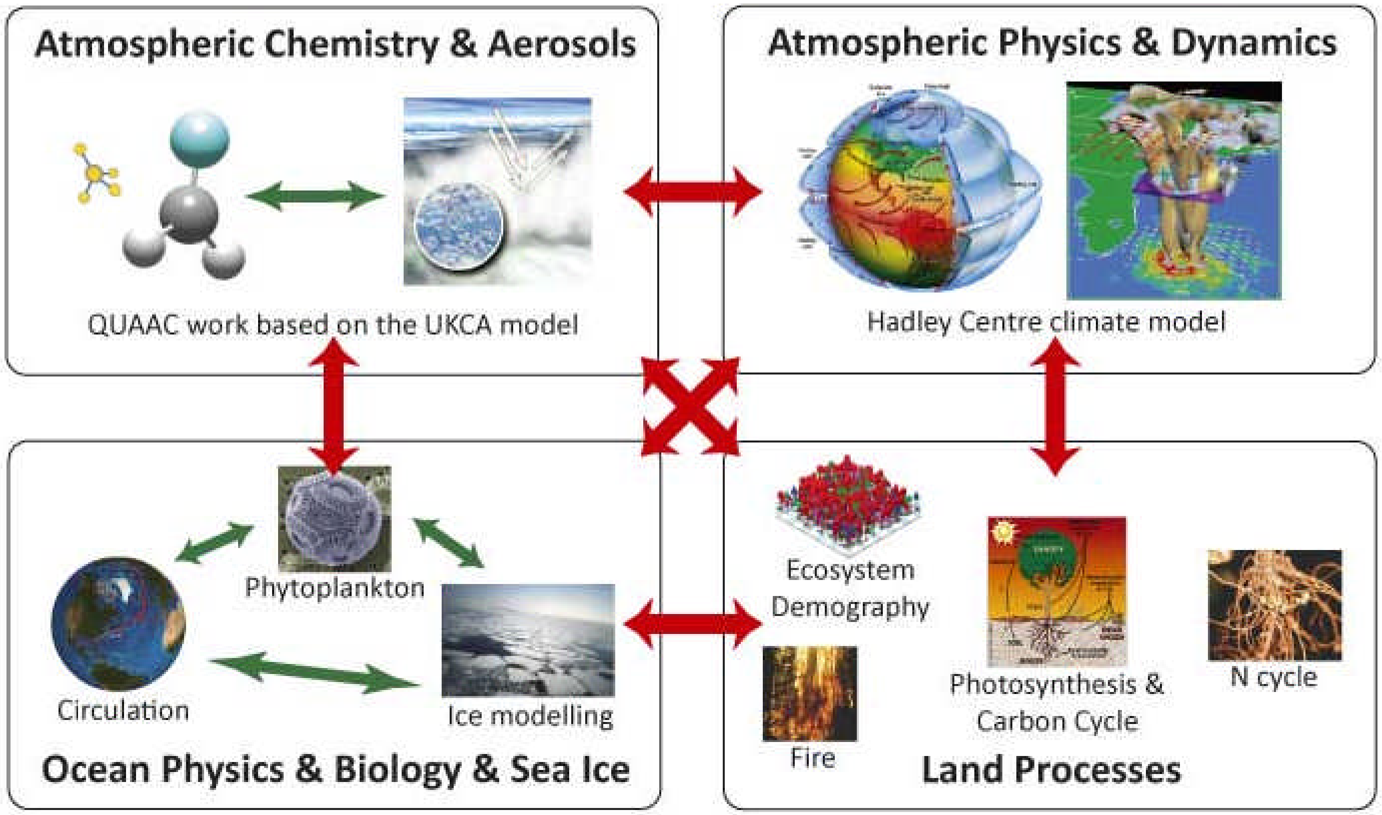
- Organic aerosol module for UKCA being developed via QUAAC project
- UKCA aerosol extended with dissolution module with mixed aerosol including ammonium, sulphate and nitrate ions (and impact of organics).
- 1-yr QUEST funding to progress UKCA modal dust & sandblasting schemes
- UKCA central component of QUEST Earth System Model (QESM)



Earth system modelling within QUEST. Based on a diagram by M. Joshi

Diagram from Paul Young.

Wide range of UKCA projects and collaborations

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European Integrated Project (EUCAARI) using UKCA as part of the Earth System modeling work package; GLOMAP-bin/mode for campaign analysis

BC ageing/absorption, aircraft/satellite evaluation via APPRAISE-ADIENT

Edinburgh (Palmer): organic aerosol in APPRAISE-ACES

Marine aerosol is being investigated as part of a SOLAS project with a tied studentship investigating halogen/sulphur cycle.

Stratospheric aerosol & geoengineering in NERC Cambridge/Leeds project

PhD studentship (Leeds) on flood basalt eruptions and paleoclimate.

EU Marie Curie on ion-induced nucleation and cosmic rays

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)

UKCA is the basis for QUEST ESM and will be implemented in the ECMWF-IFS via EU MACC project (GEMS2)

UKCA : Ensures knowledge transfer of NERC science

NCAS-CMS & JCRP post to support UKCA.

NCAS core UKCA scientists at Leeds & Cambridge

ADIENT, EUCAARI campaigns will improve UKCA.

UKCA in HadGEM ensures Knowledge Exchange for NCAS research to IPCC & other assessments.

UKCA-mode to be in ECMWF IFS via MACC project

Observations
Field campaigns

TOMCAT global CTM

GLOMAP-bin
aerosol module
(sectional aerosol)

or

GLOMAP-mode
aerosol module
(modal aerosol)

NERC APPRAISE Community Model

Unified Model
HadGEM climate model
QUEST Earth System Model

Met Office

GLOMAP-mode
aerosol module
(modal aerosol)

UKCA-UM Community Model

Climate Prediction
Air quality forecasts
Dust Forecasting

ECMWF Integrated Forecast System (MACC)

Example UKCA results (UMv6.6) – October mean

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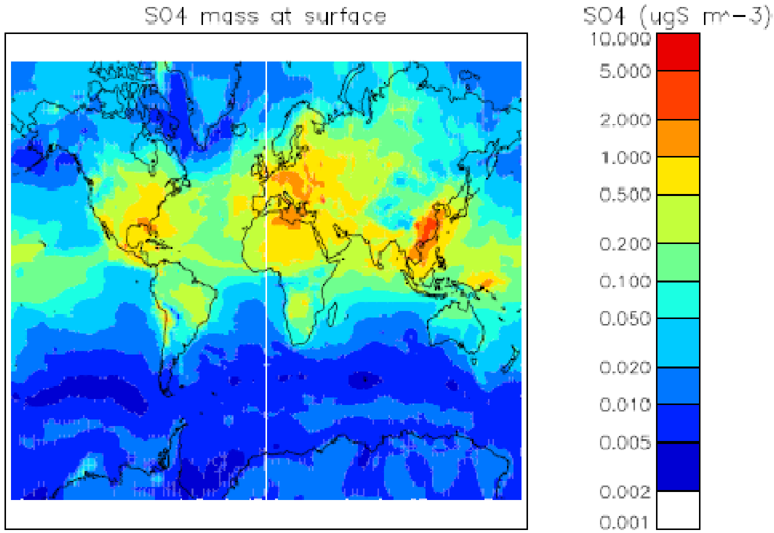
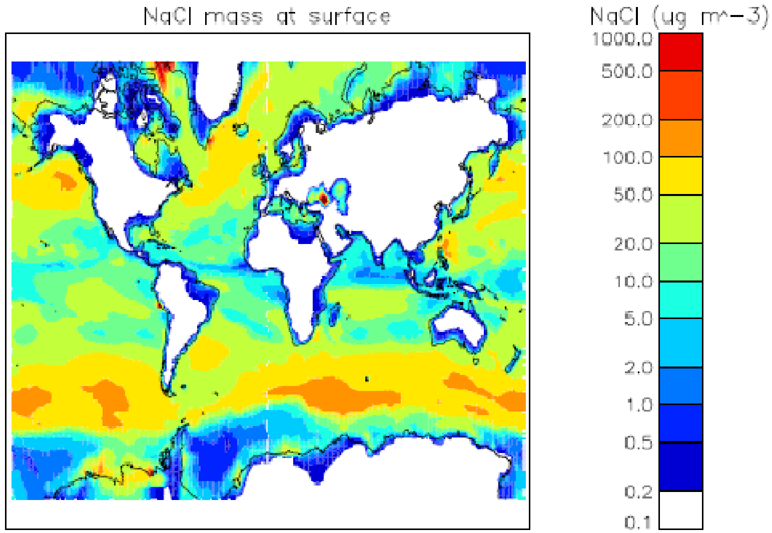
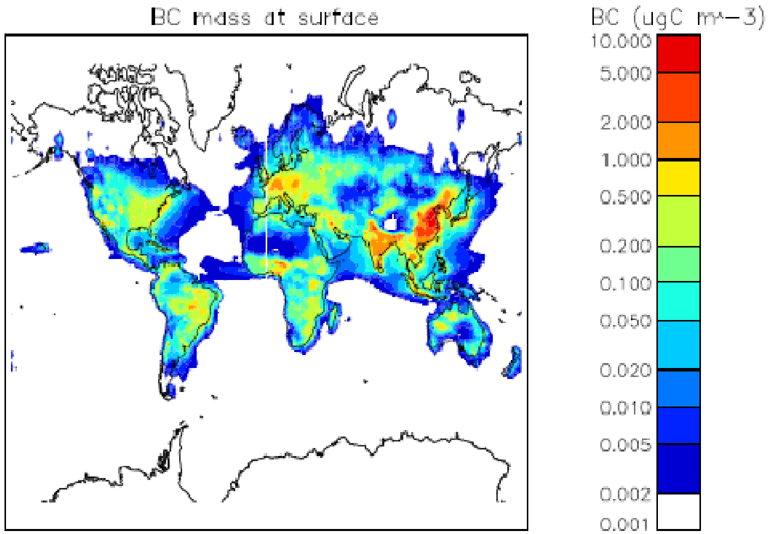


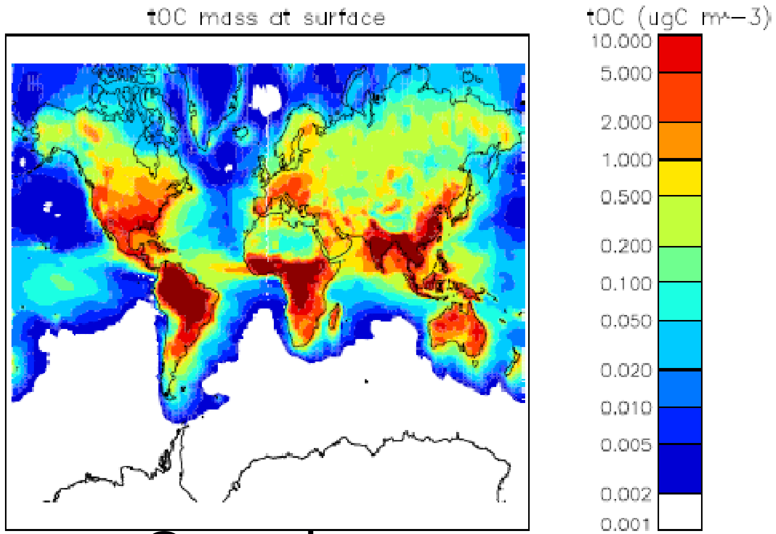
Sulphate



Sea salt



Black carbon



Organics

Example UKCA results (UMv6.6) – October mean

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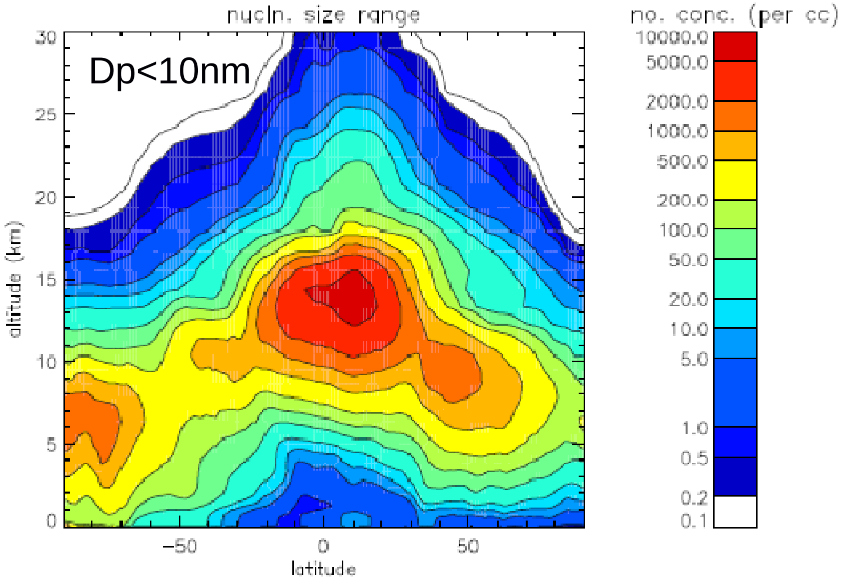
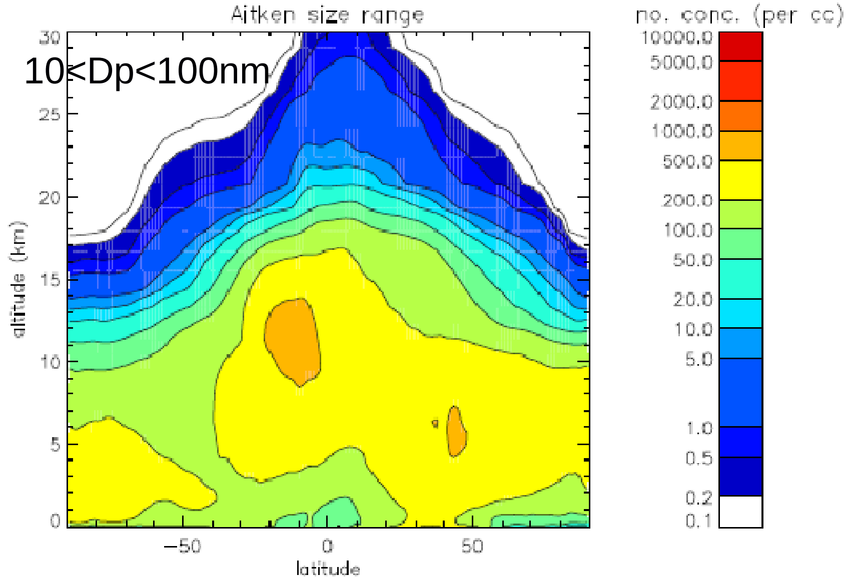
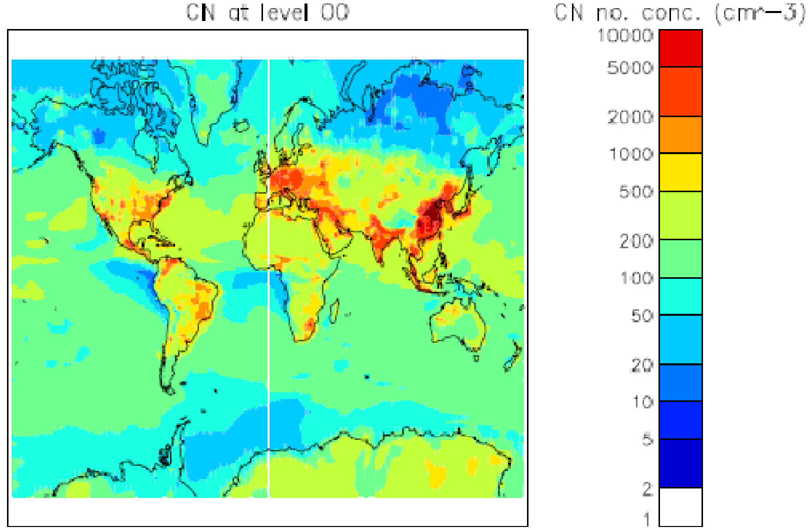
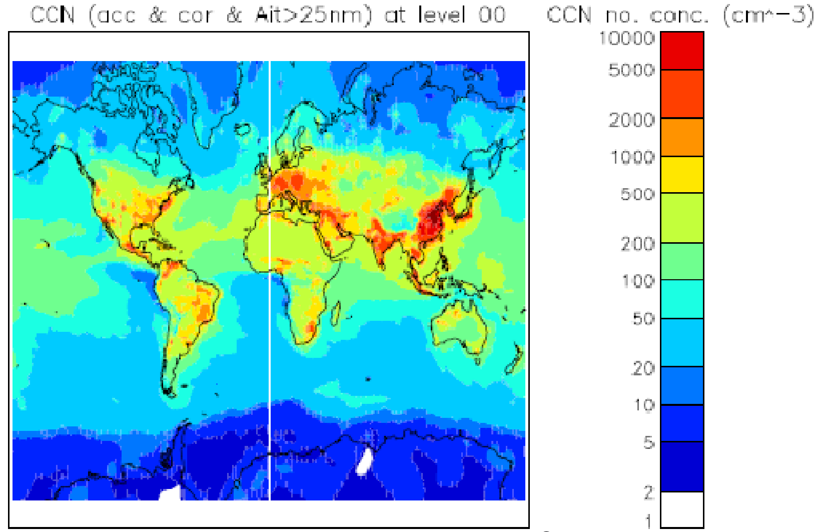






Condensation nucleii (cm^{-3})
(Dp>3nm)



Cloud condensation nucleii (cm^{-3})
(Dp>50nm -- S~0.3%)

Simulated global CCN distribution being evaluated against a wide range of observations

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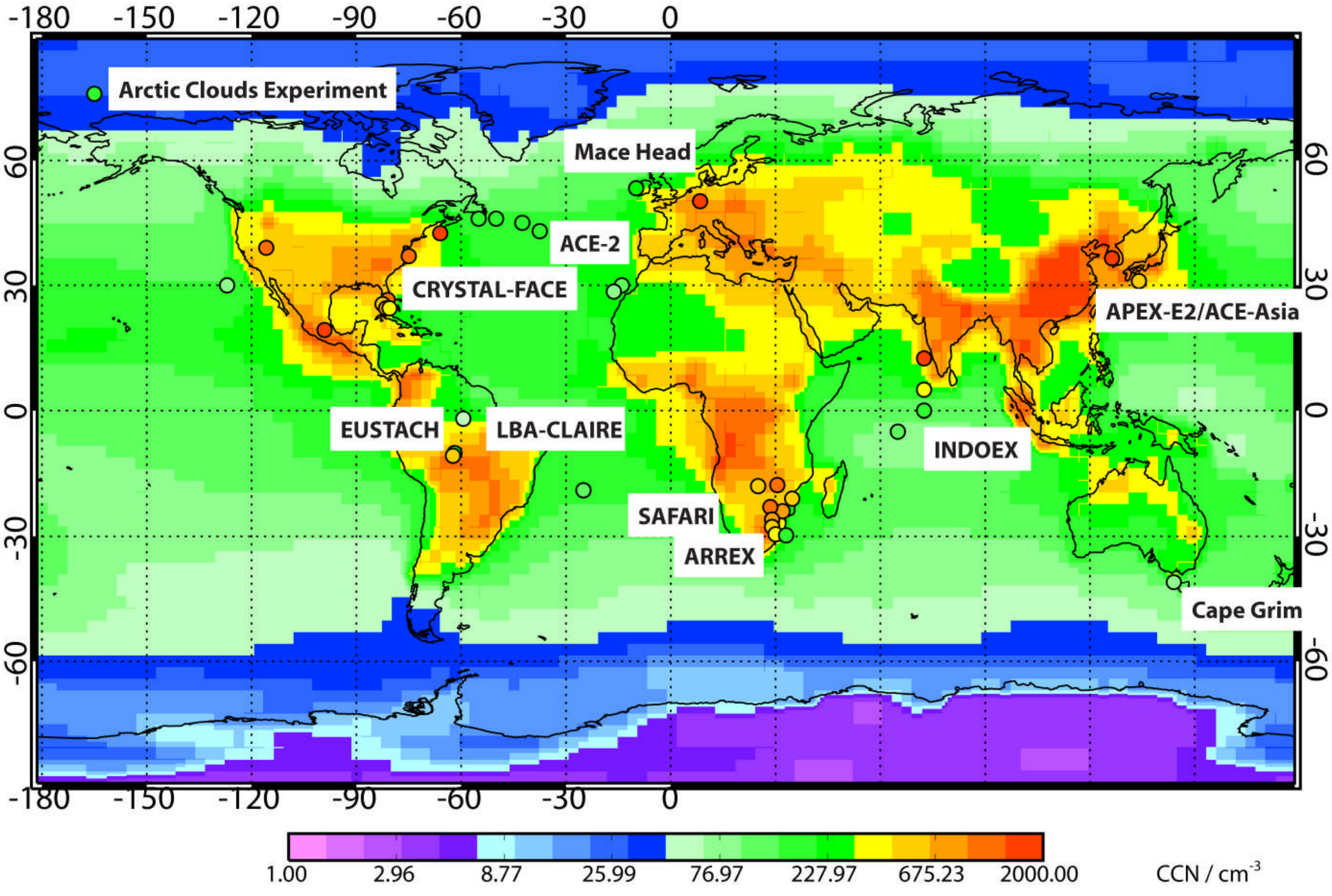

Note: map shows CCN at 0.2% supersaturations.
Coloured circles show observations at range of supersaturations

Simulated global CCN distribution being evaluated against a wide range of observations

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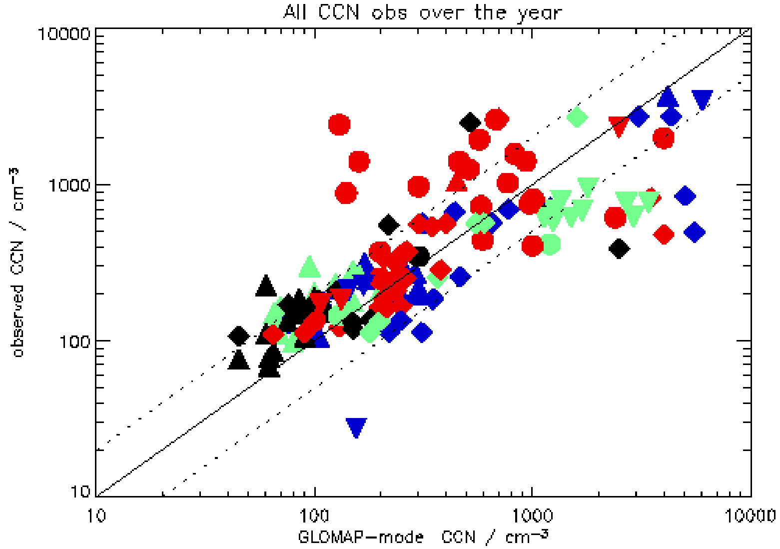
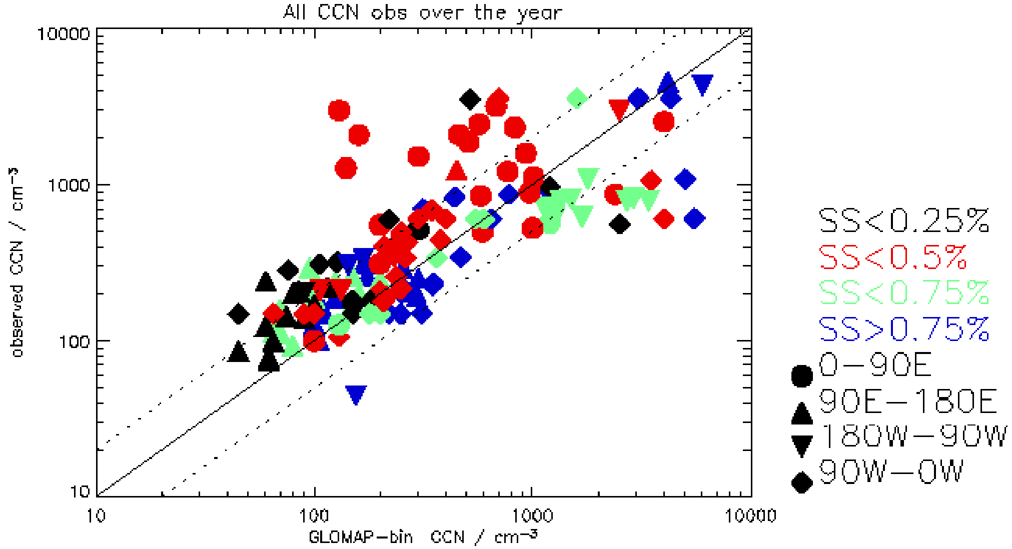
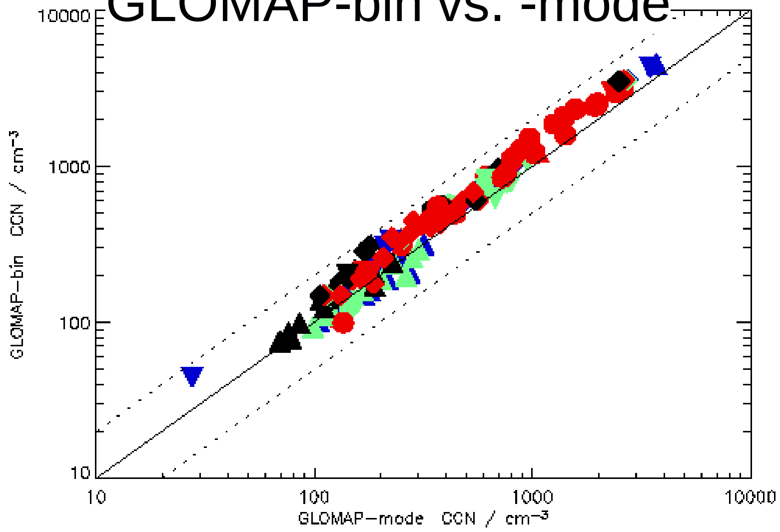
GLOMAP-mode vs. observations

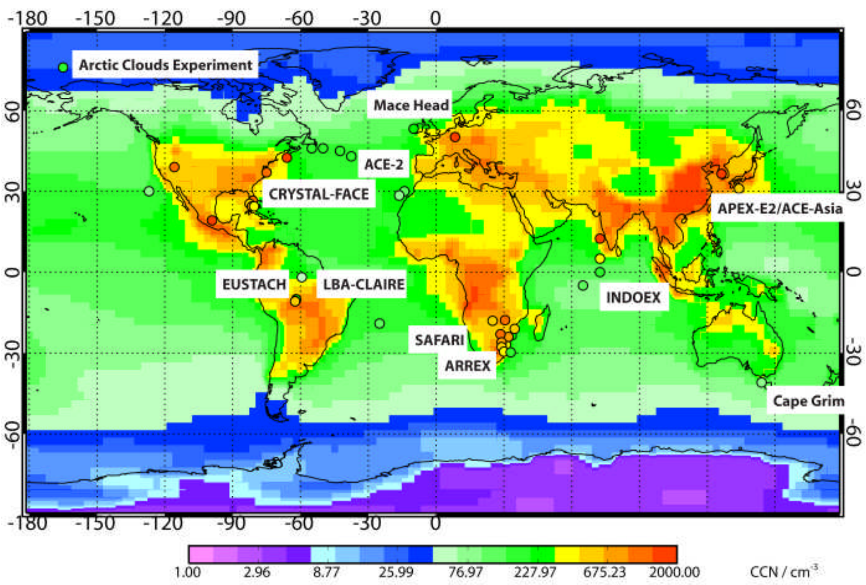


GLOMAP-bin vs. observations



GLOMAP-bin vs. -mode





Size distributions between GLOMAP bin/mode

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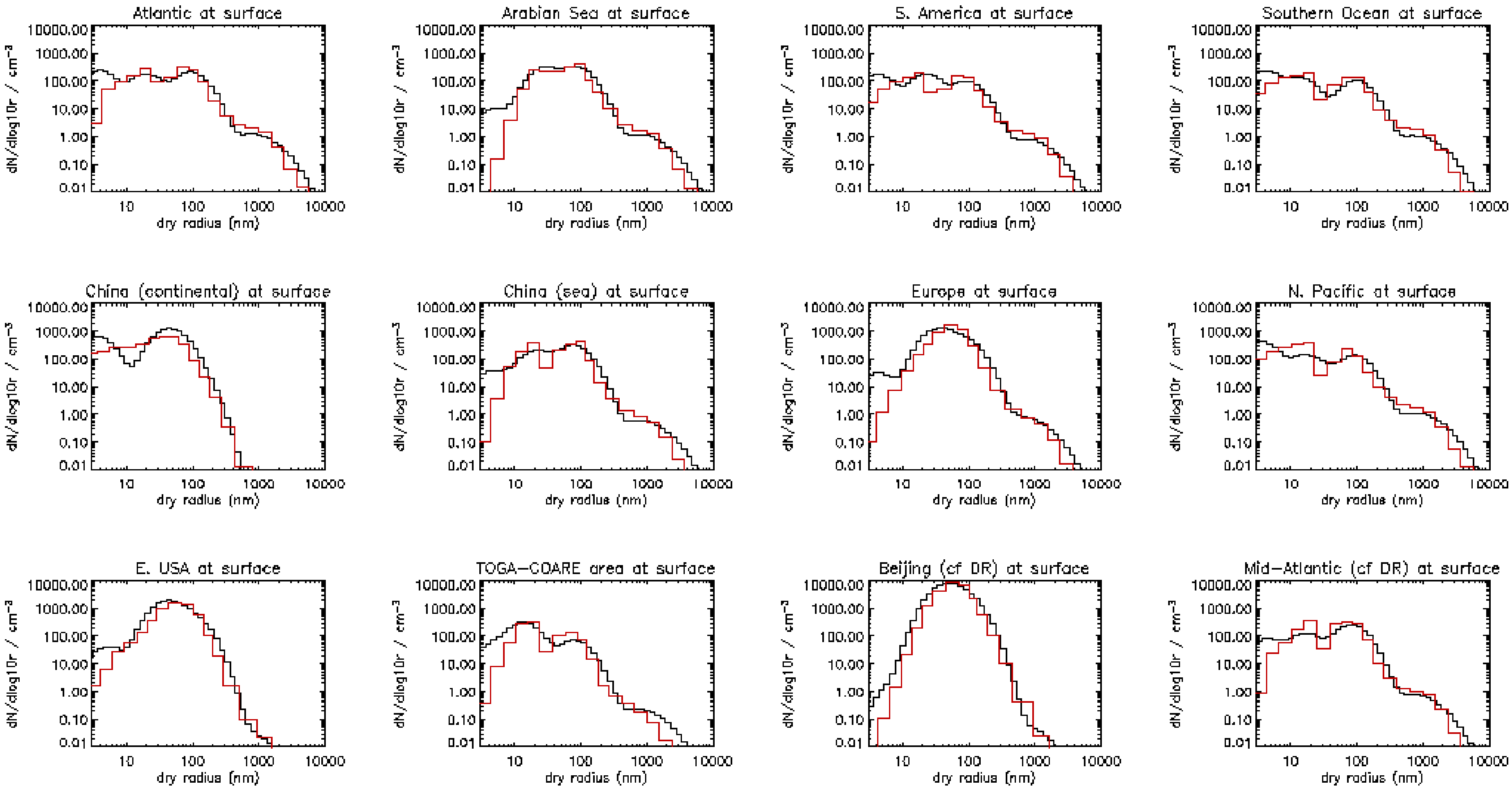

GLOMAP-mode
GLOMAP-bin

12 varied BL sites in marine & continental locations

Remarkably good agreement between GLOMAP-bin & -mode

AERONET size distributions vs model

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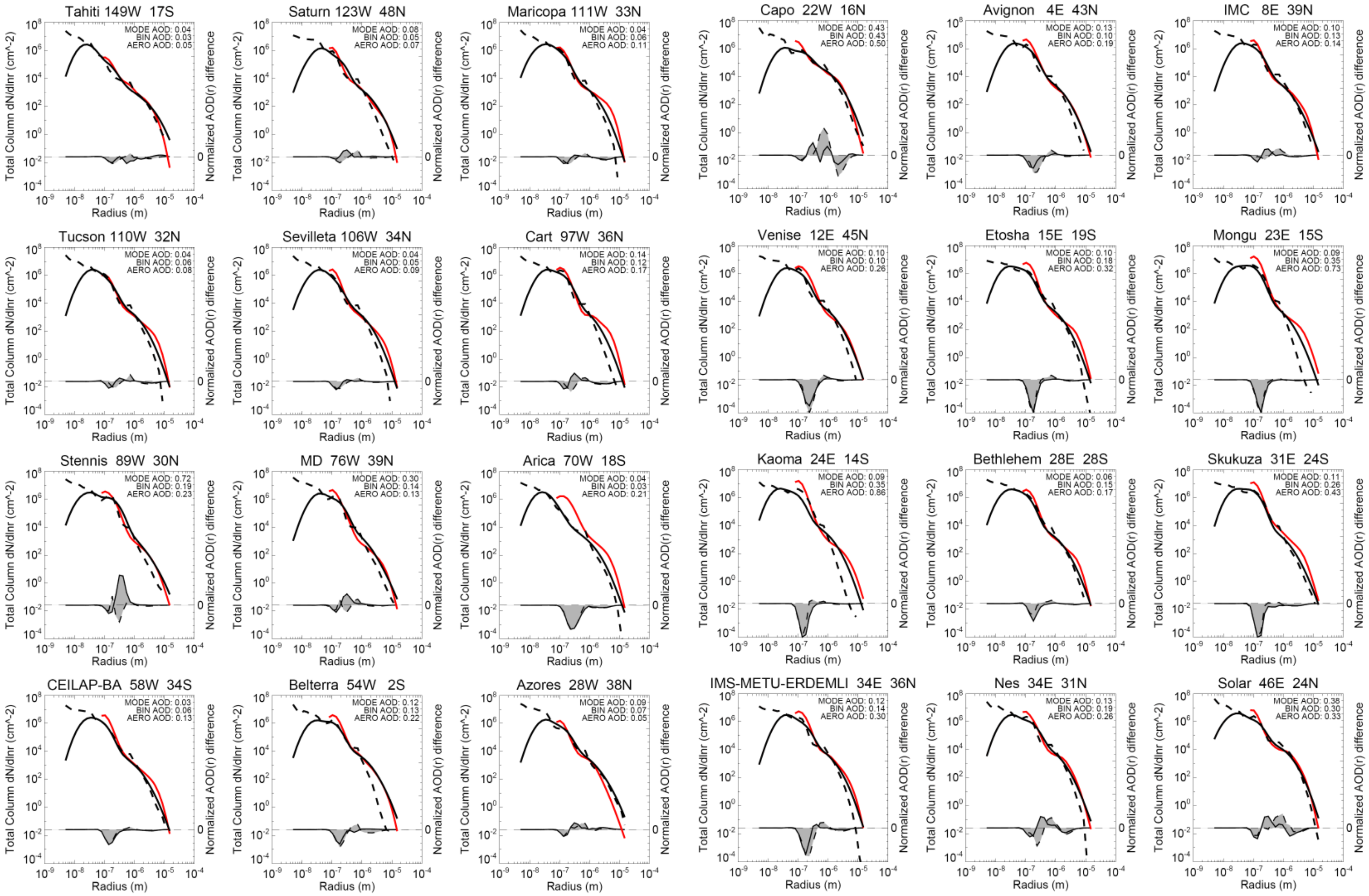

AERONET-retrieval **GLOMAP-mode** **GLOMAP-bin**

Dave Ridley (Leeds)

Aerosol Optical Depth model vs MODIS, AERONET

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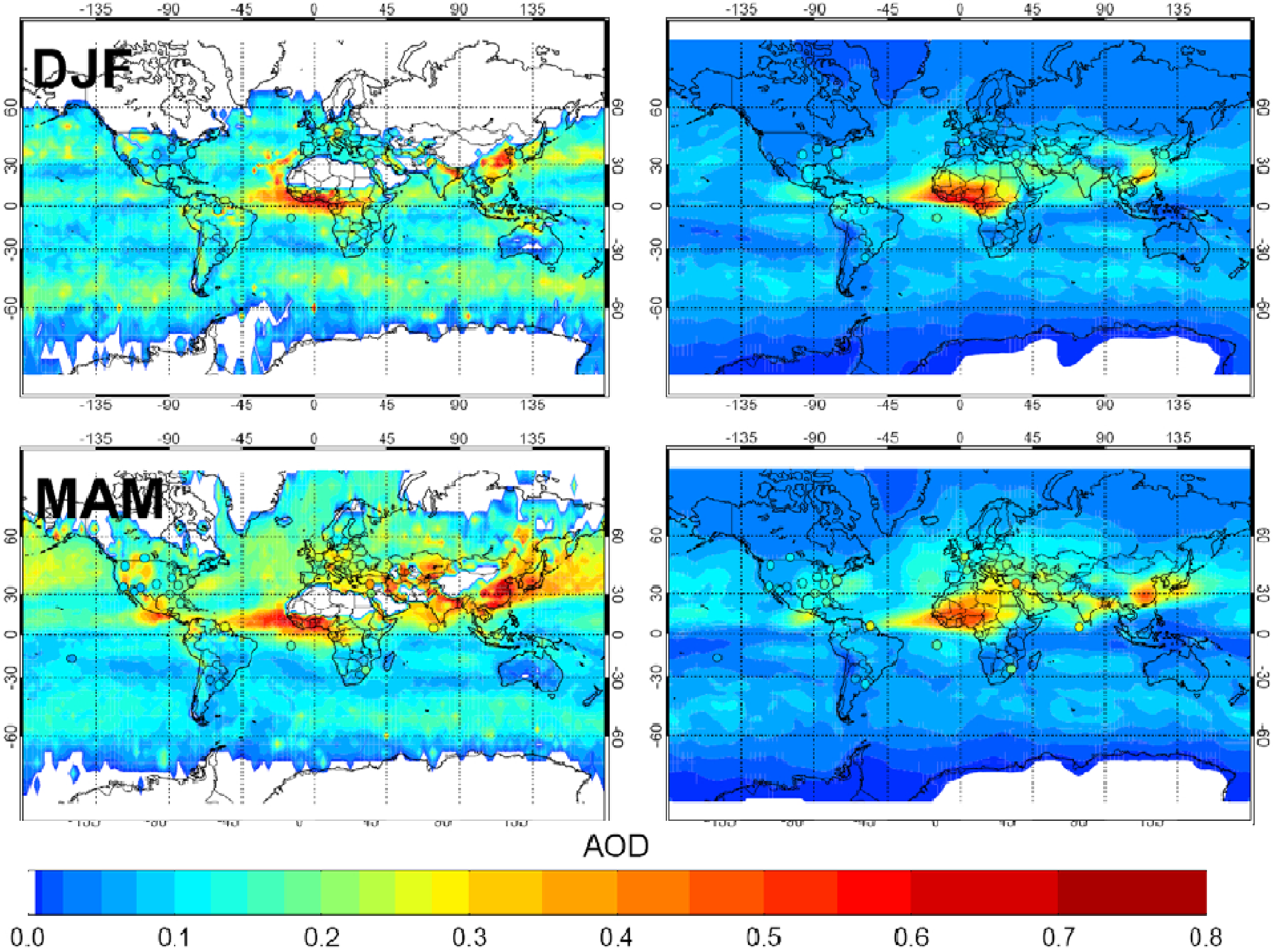

Dave Ridley (Leeds)

Aerosol Optical Depth model vs MODIS, AERONET

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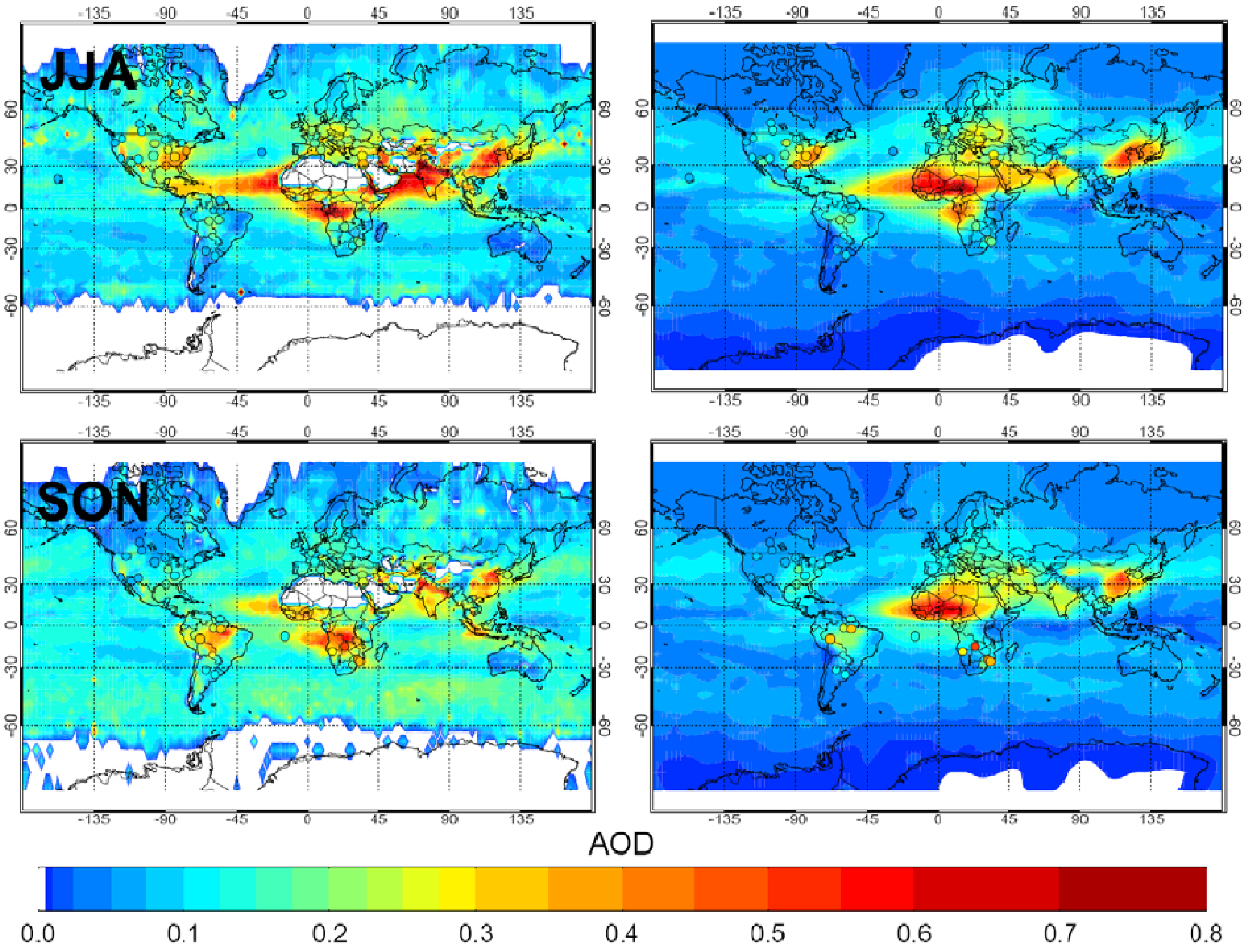

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Aerosol Optical Depth annual cycle in bin/mode

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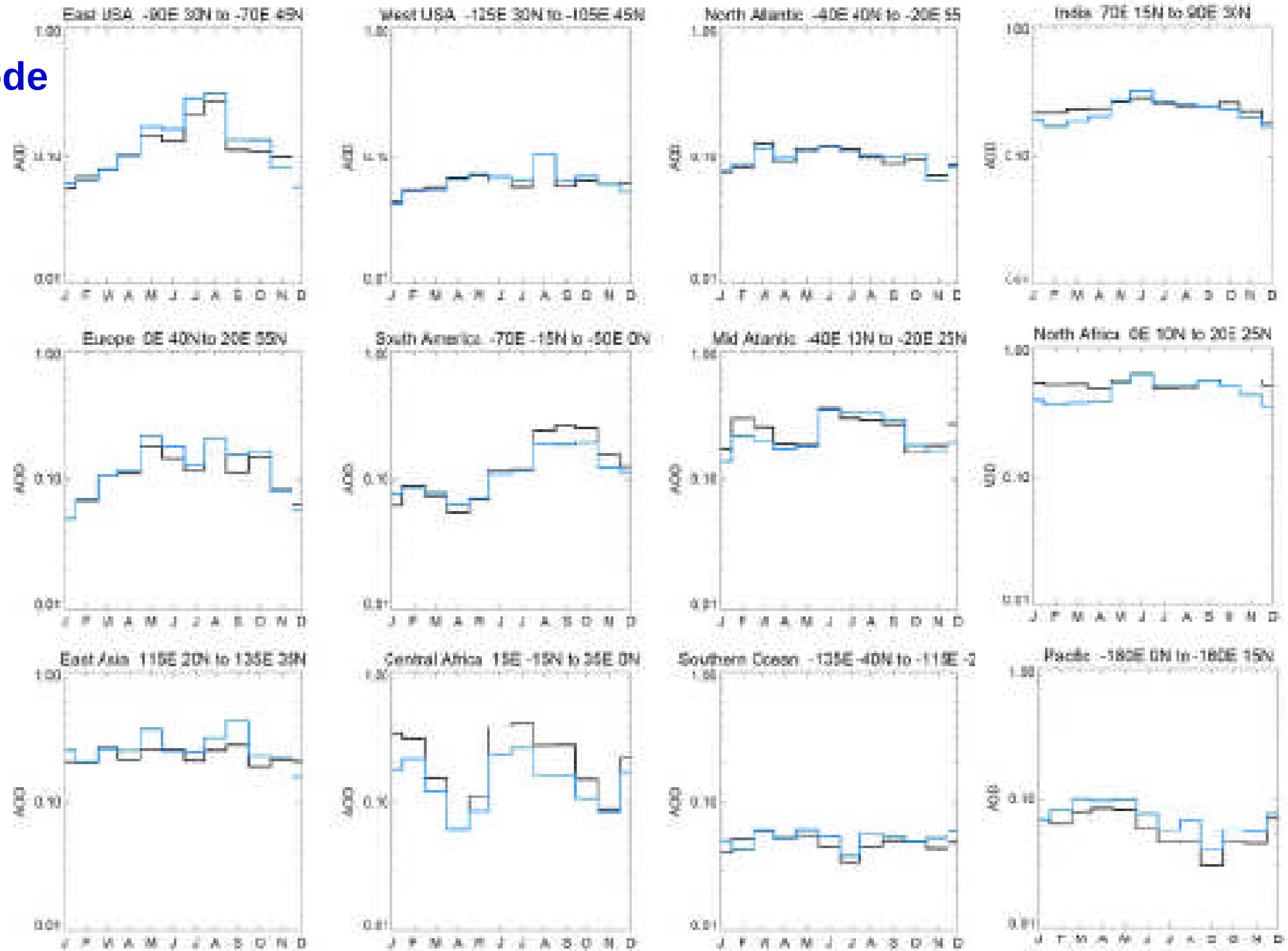
GLOMAP-bin
GLOMAP-mode



Dave Ridley
(Leeds)

CN profiles vs Clarke & Kapustin (2002) profiles

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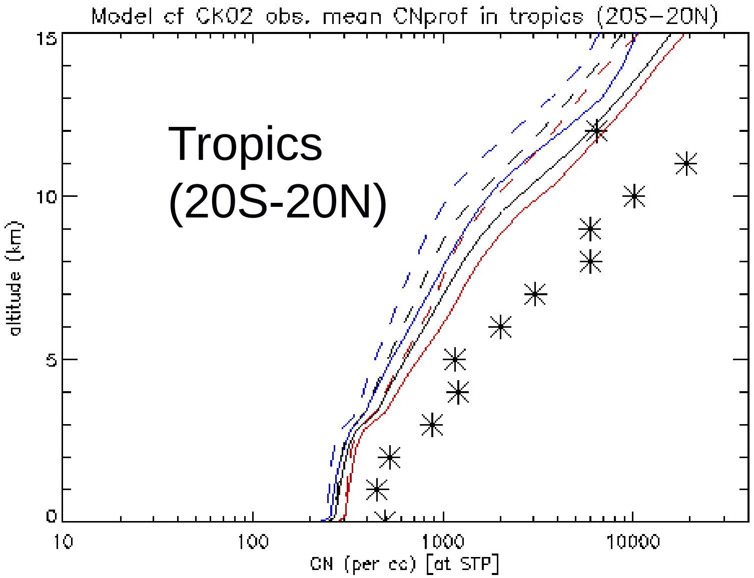

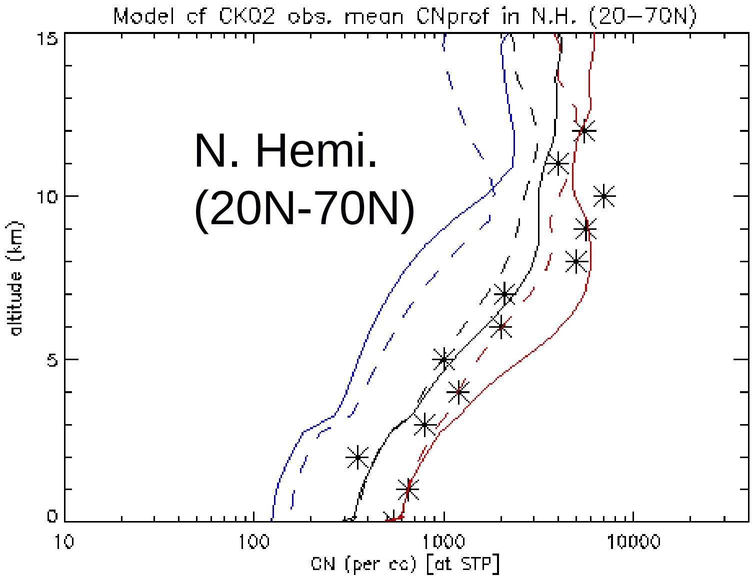

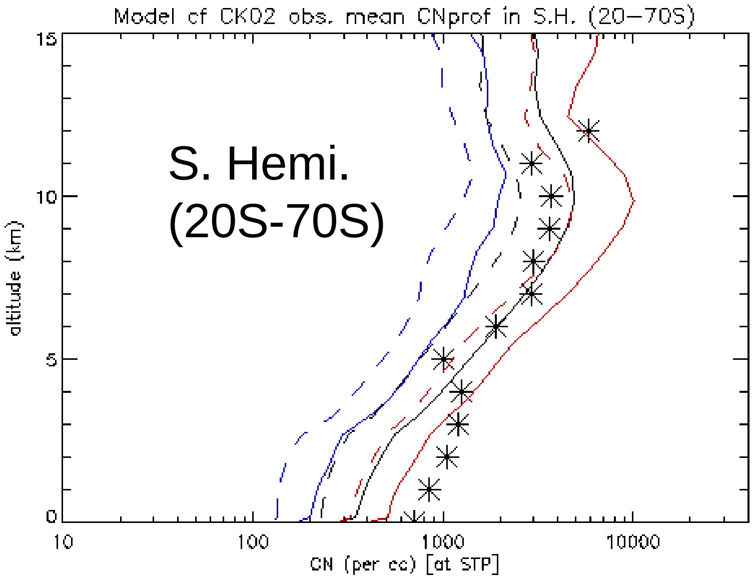

—— GLOMAP-mode
- - - - GLOMAP-bin
* aircraft CN obs

Max. month value
Annual mean
Min. month value

Both model versions underestimate tropical FT CN (~2) over Pacific.

NH & SH Pacific compare better but BL concentrations too low
(remedied when BL nucleation included).

Zonal mean surface MBL CN concentrations, GLOMAP-mode vs –bin vs observations

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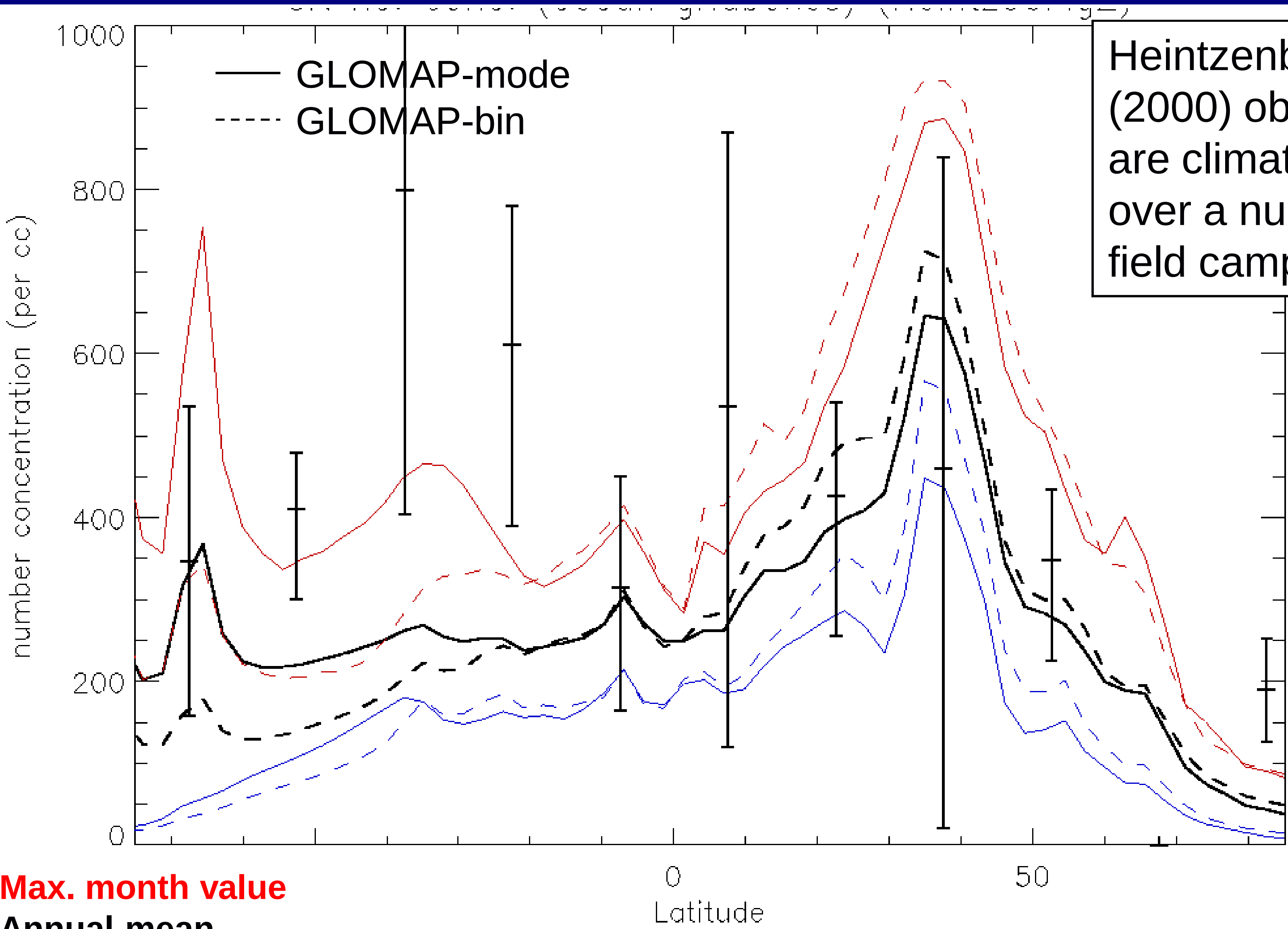

Heintzenberg et al (2000) observations are climatology over a number of field campaigns

Max. month value
Annual mean
Min. month value

Zonal mean surface MBL mean mode radius, GLOMAP-mode vs observations

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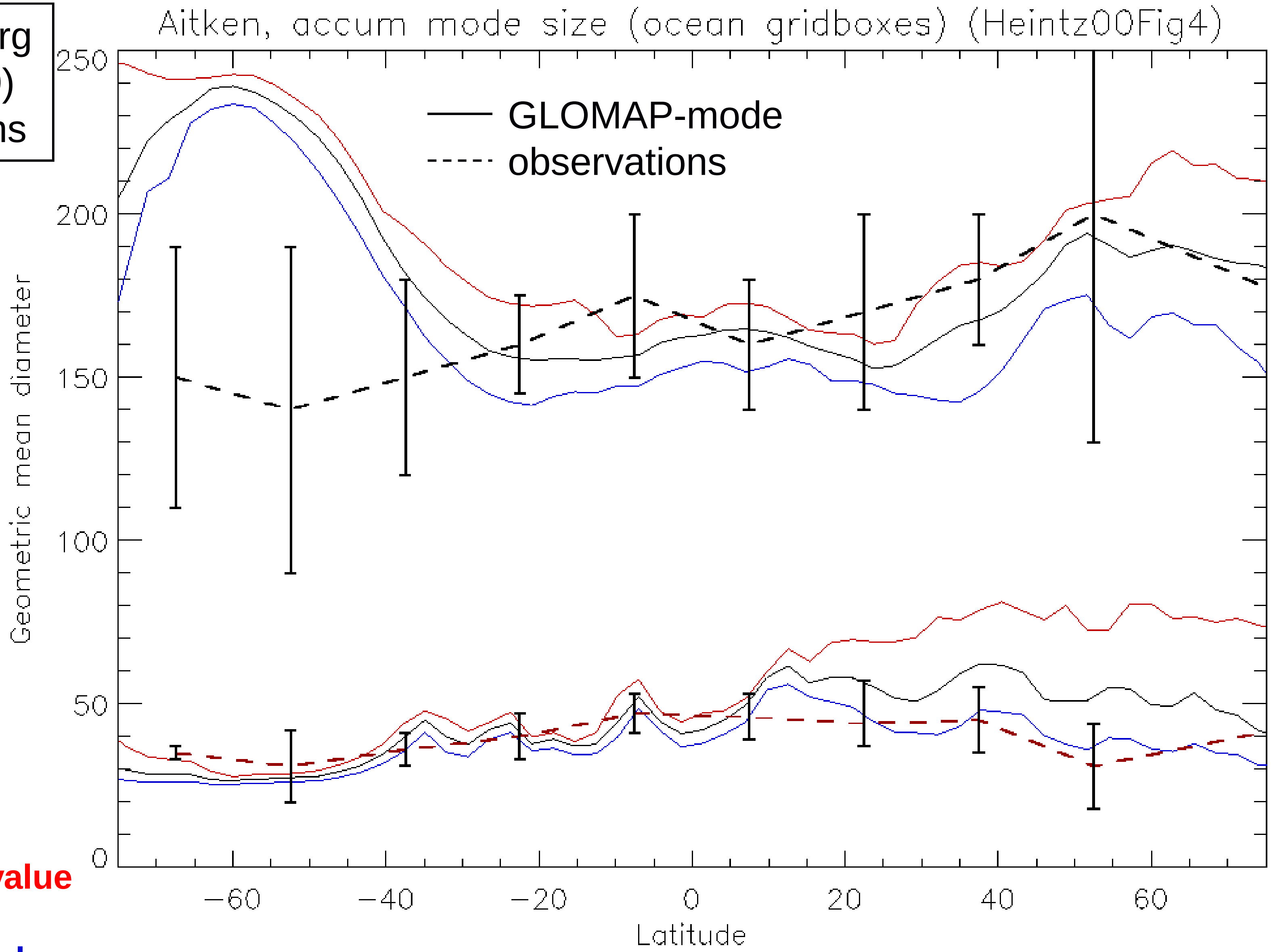
Heintzenberg et al (2000) observations



Max. month value
Annual mean
Min. month value

Conclusions

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GLOMAP aerosol microphysics model simulates new particle formation and processes which control growth to CCN

IPCC climate models tend to have simplistic treatment of aerosol-climate effects – mass-only, assumed size distribution

Model representations will be more sophisticated in IPCC AR5.

UKCA coupled aerosol-chemistry-climate model contains GLOMAP aerosol microphysics via faster modal scheme.

UKCA will have mechanistic cloud droplet number module to use size-resolved particle information in CDN calculation

UKCA scheme in GLOMAP model provides added confidence to UK climate model aerosol by evaluation against detailed bin scheme & in-situ observations from field campaigns, supersites.

UKCA achieves pull-through of new NERC science to UK climate model via link to range of ongoing GLOMAP projects.

GLOMAP-mode/-bin SO4 mass concentration against IMPROVE (US), June mean

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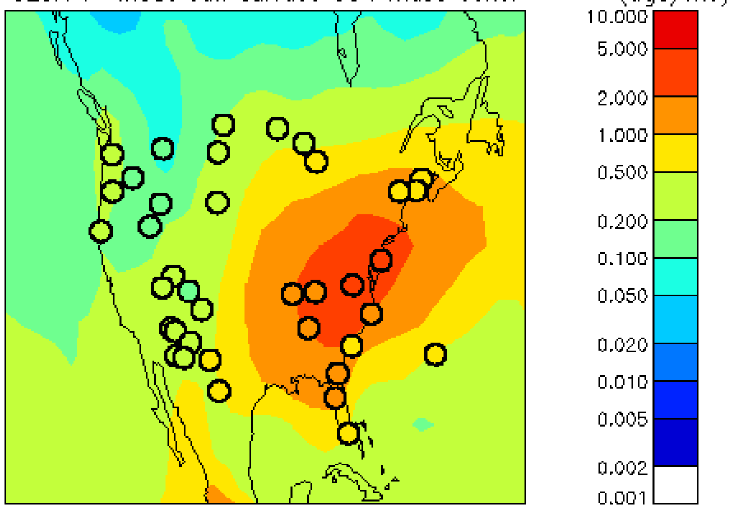

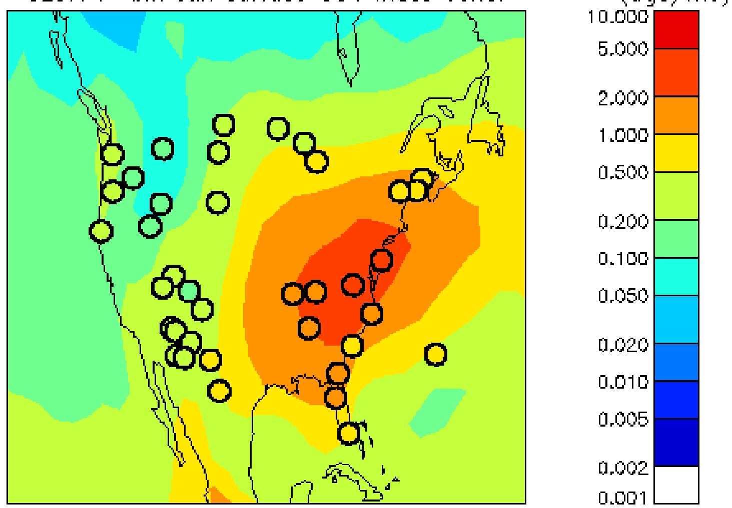

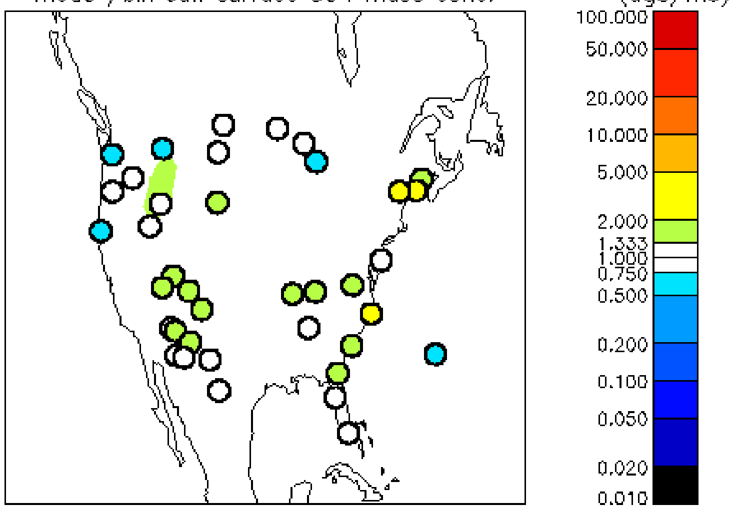

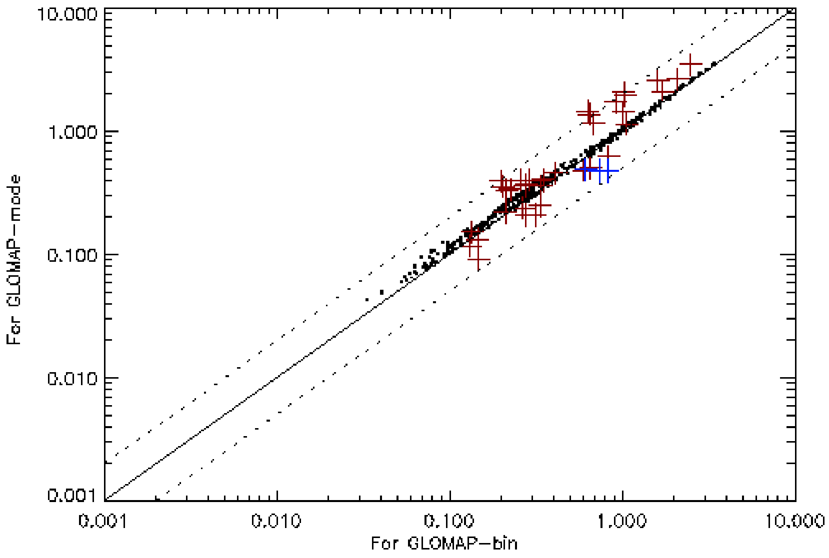

GLOMAP-mode/-bin SO4 mass concentration against U. Miami (Global), Annual mean

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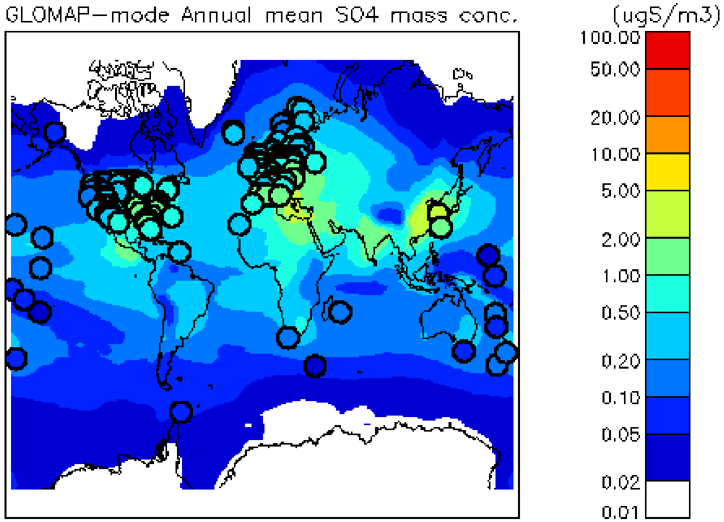

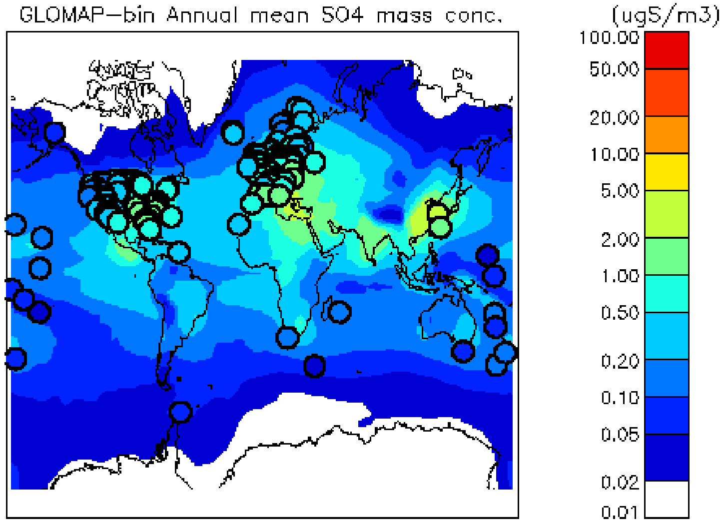

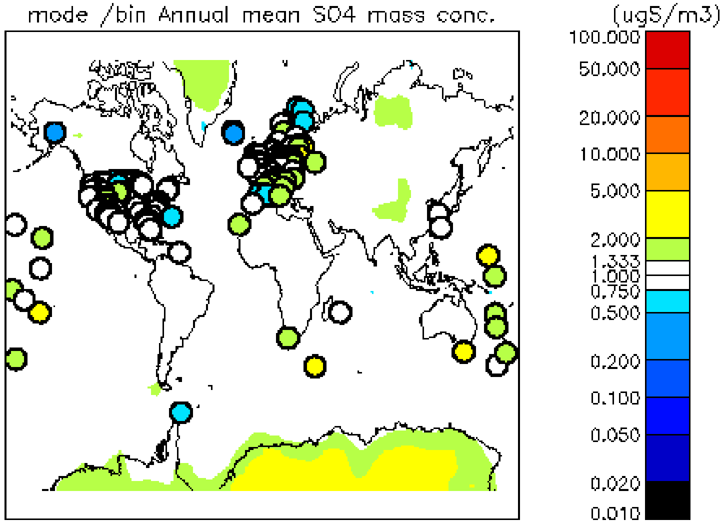

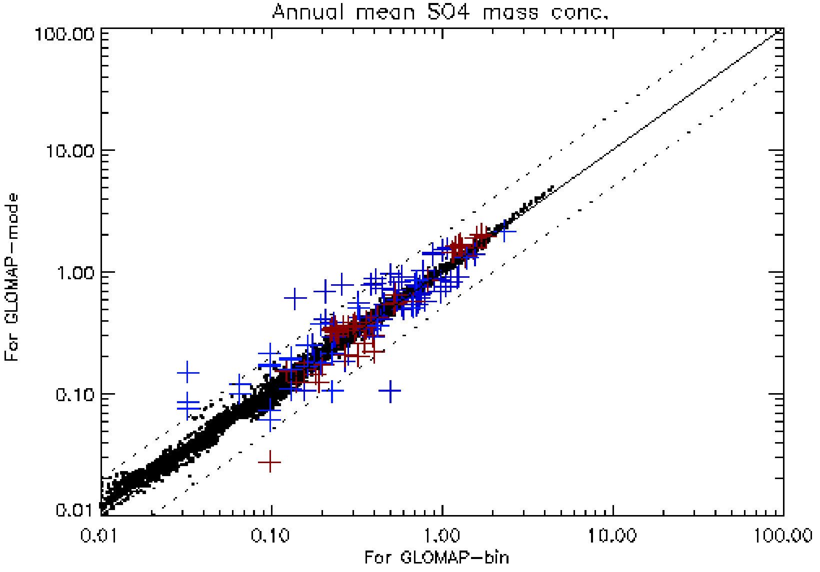

GLOMAP-mode/-bin NaCl mass concentration against U. Miami (Global), Annual mean

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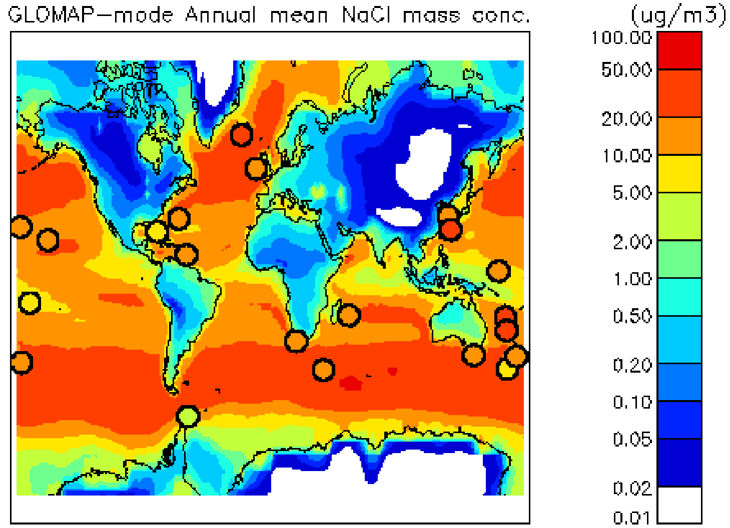

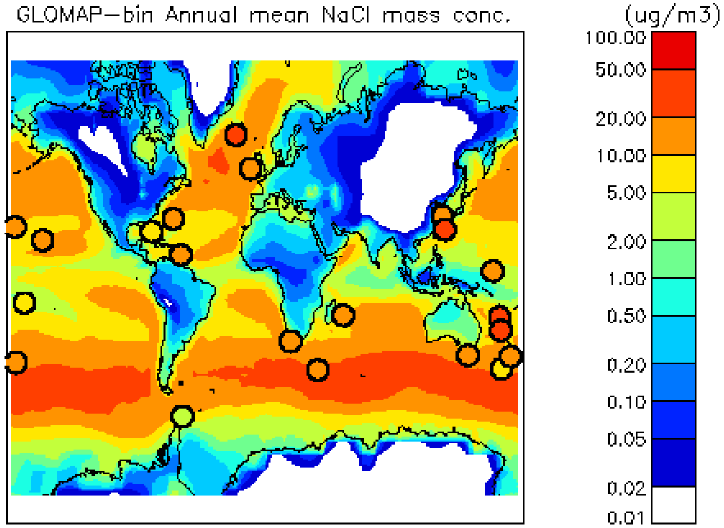

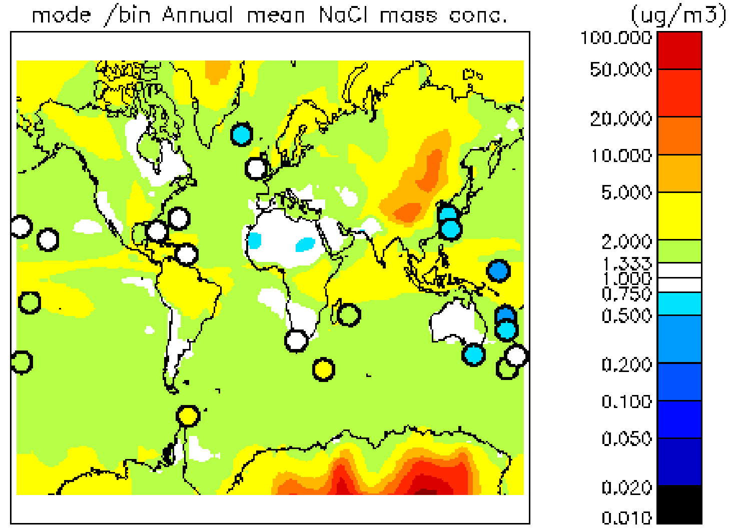

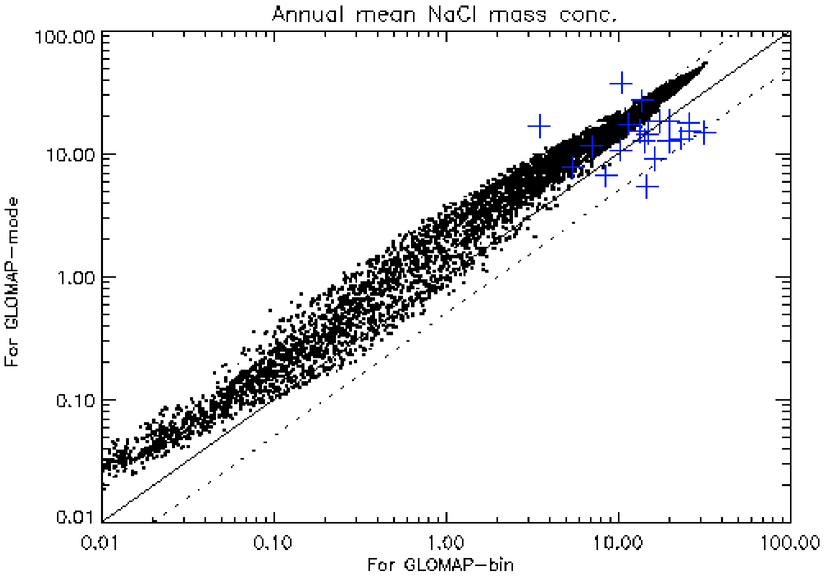

GLOMAP-mode/-bin EC mass concentration against IMPROVE (US), annual mean

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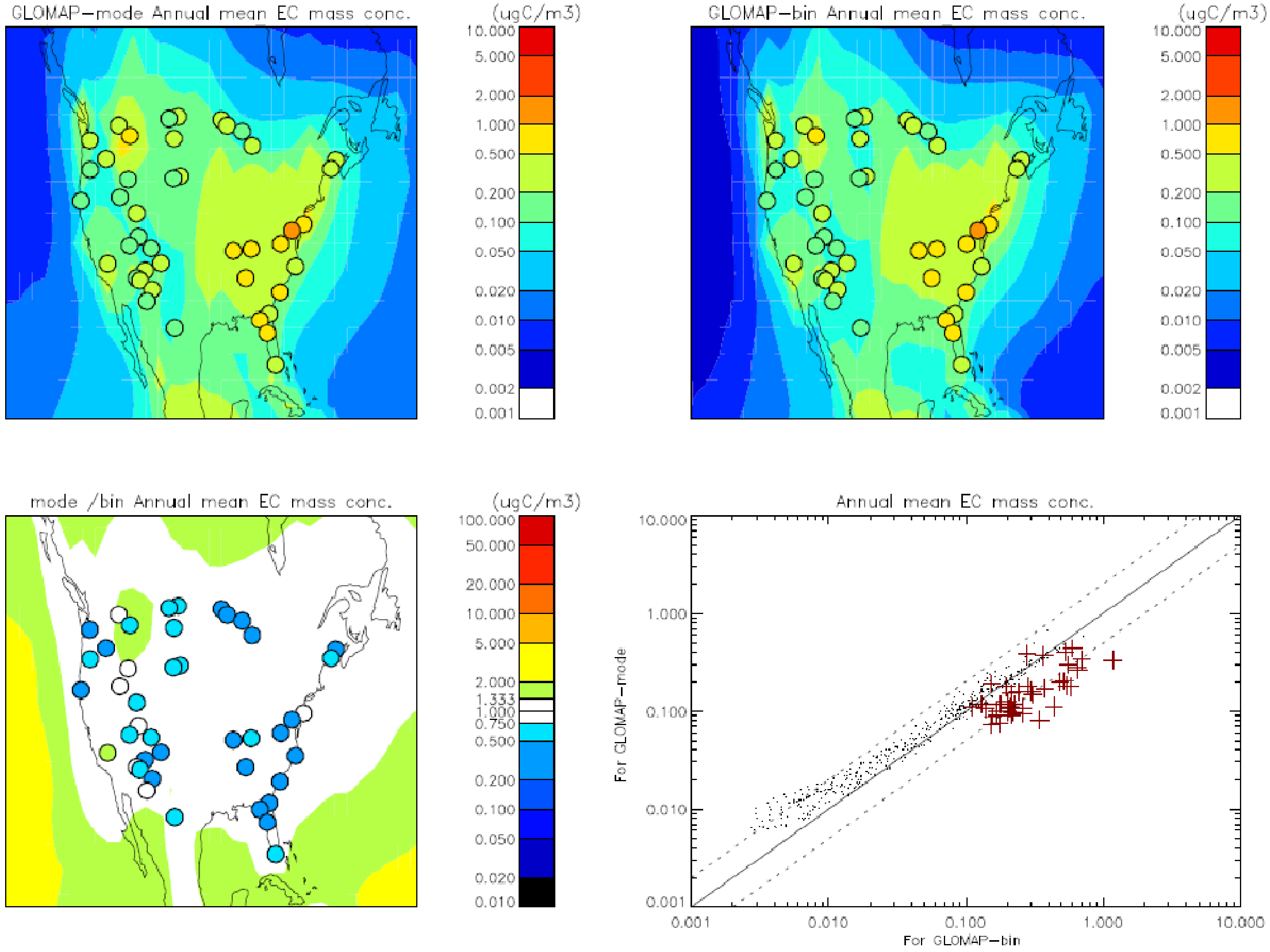

GLOMAP-mode/-bin OC mass concentration against IMPROVE (US), annual mean

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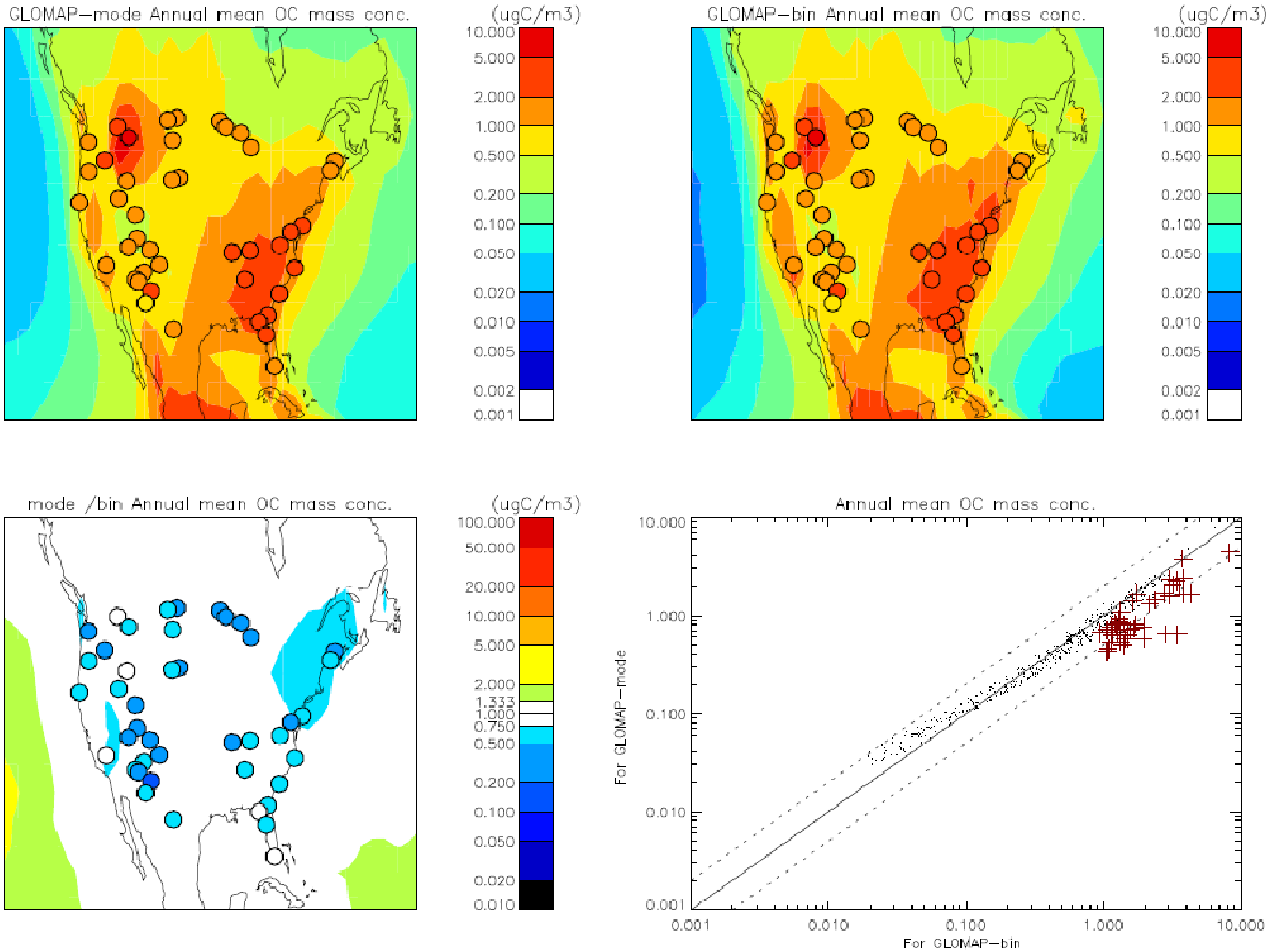

GLOMAP-bin size distributions vs observations

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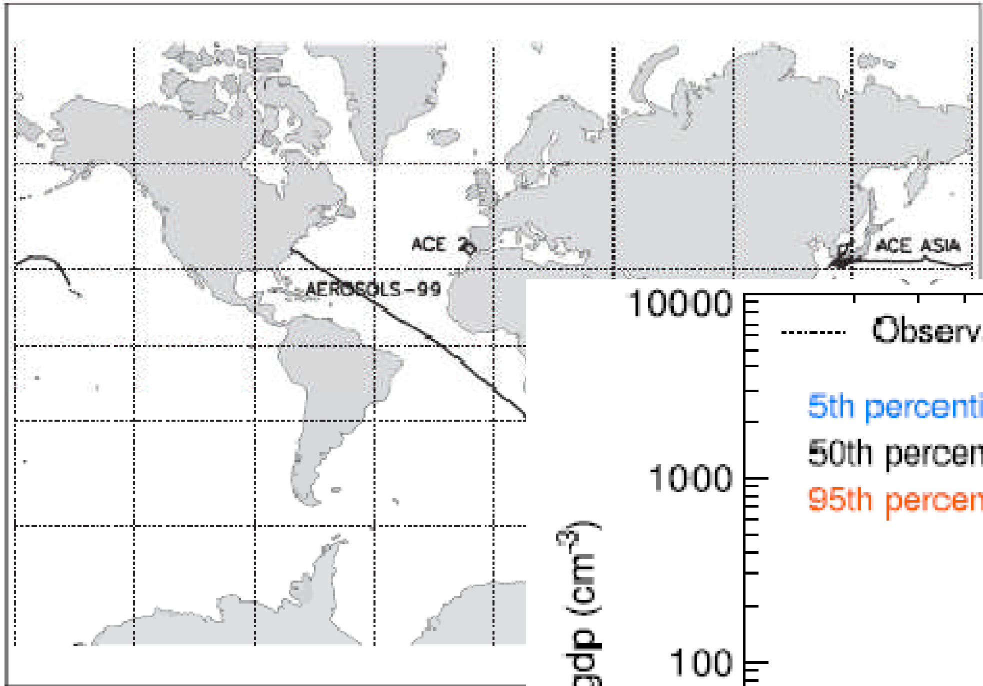
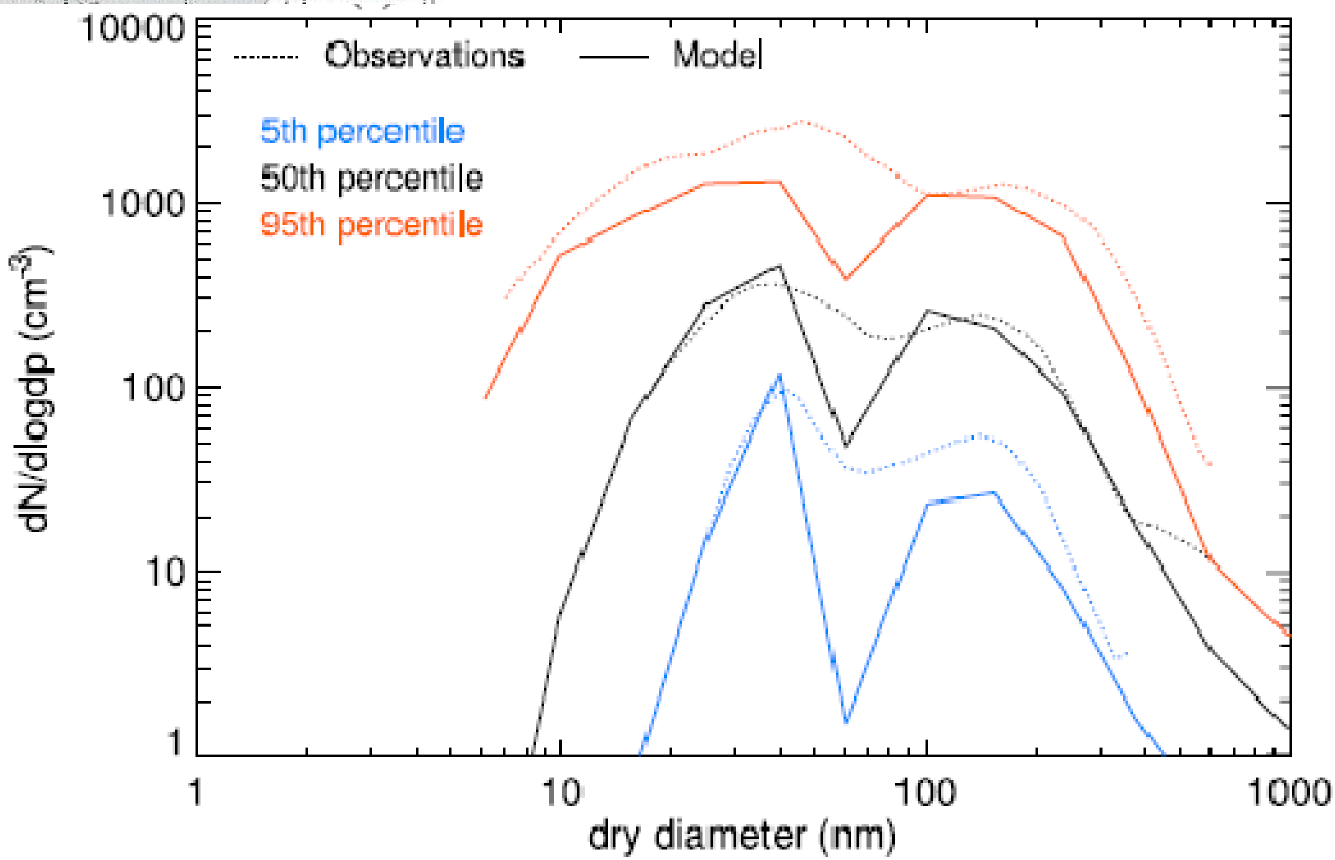
Spracklen et al. (2007)





Experiment	Locatio
ACE-1	Cape Grim, Sout 40.8° S, 14
ACE-2	Sagres, NE A 37° N, 9°
Aerosols99/	Atlanti
INDOEX	Indian Oc
ACE-Asia	Pacific Oc