# An intercomparison of CCN and size distribution among AeroCom models. Plans for the aerosol microphysics working group

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**AEROCOM modellers who've submitted all-aerosol-tracer data**
**The data Pis on the benchmark observational datasets.**

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

GLOMAP
Global Model of Aerosol Processes

# Aerosol in most climate models



Mass of chemical components (e.g., $SO_4$, black carbon, dust) as advected quantities

For size-dependent processes: An assumed size distribution

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

e.g. for $SO_4$, AOD can change only via change in mass.

Indirect forcing: Use empirical cloud drop—aerosol relations, e.g., Lowenthal et al: $\log(CDN) = 2.38 + 0.49\log(M_{SO_4})$,

--- any change in mass causes increase in CDN.

# Importance of size distribution: Aerosol optical depth

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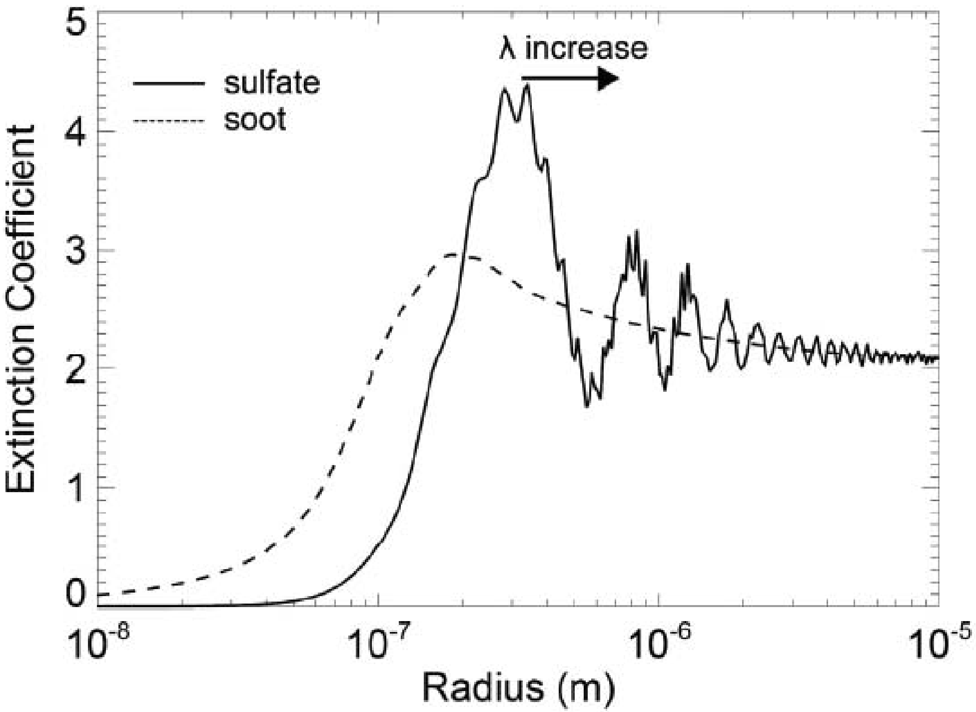
Differences in particle size distribution also affect the extinction.

Constant mass extinction efficiency will not capture variability from changes to the particle size distribution.



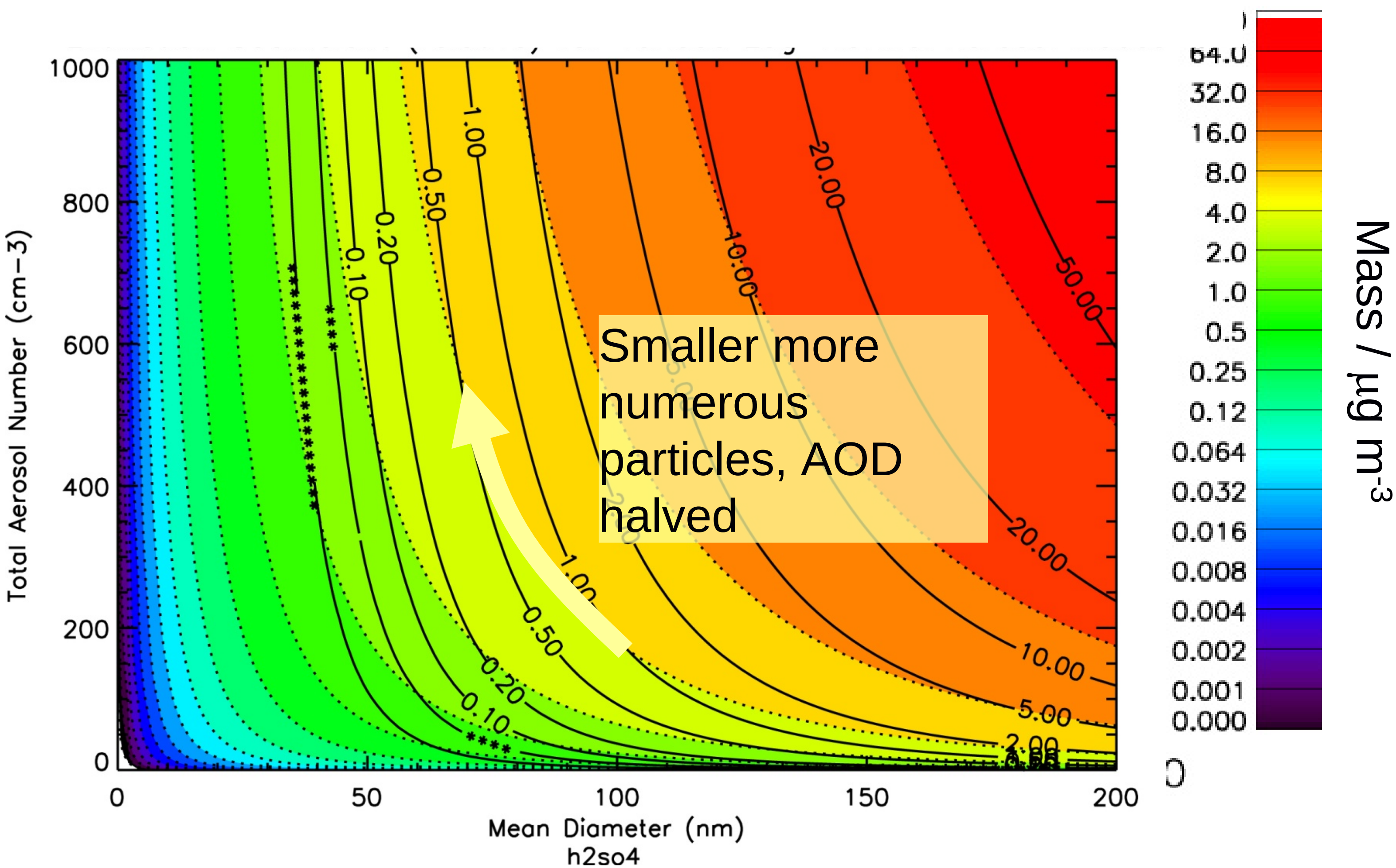

$$b_{ext} = \pi \sum_{i=0}^{n} Q_{ext} R_i^2 \frac{dN_i}{d \ln R_i} \Delta \ln R_i \qquad \tau_\lambda = \int_0^{z_{top}} b_{ext}(\lambda) dz ,$$

*__Changes in size distribution lead to different AOD__*
*__Even when the process conserves mass.__*

# Importance of size distribution: Aerosol optical depth

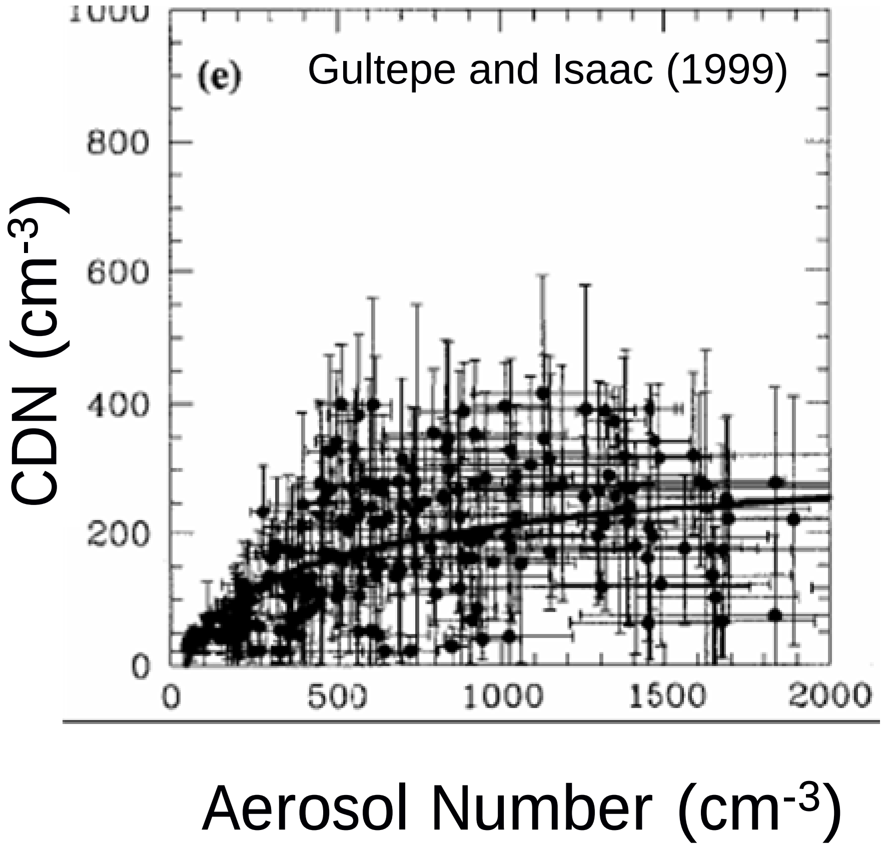


## Mie calculations based on log-normal sulphate aerosol




Kirsty Pringle, PhD thesis, 2007

# Calculating CDN in GCMs




**GCM procedure:**

1. Measure CDN and aerosol mass (or number) > certain size in same airmass

2. Fit CDN-mass (or number) relation

In mass-only GCM, number is diagnosed not prognosed (i.e., calculated by assuming a size distribution)

# Composite of CDN-aerosol observations from many sites

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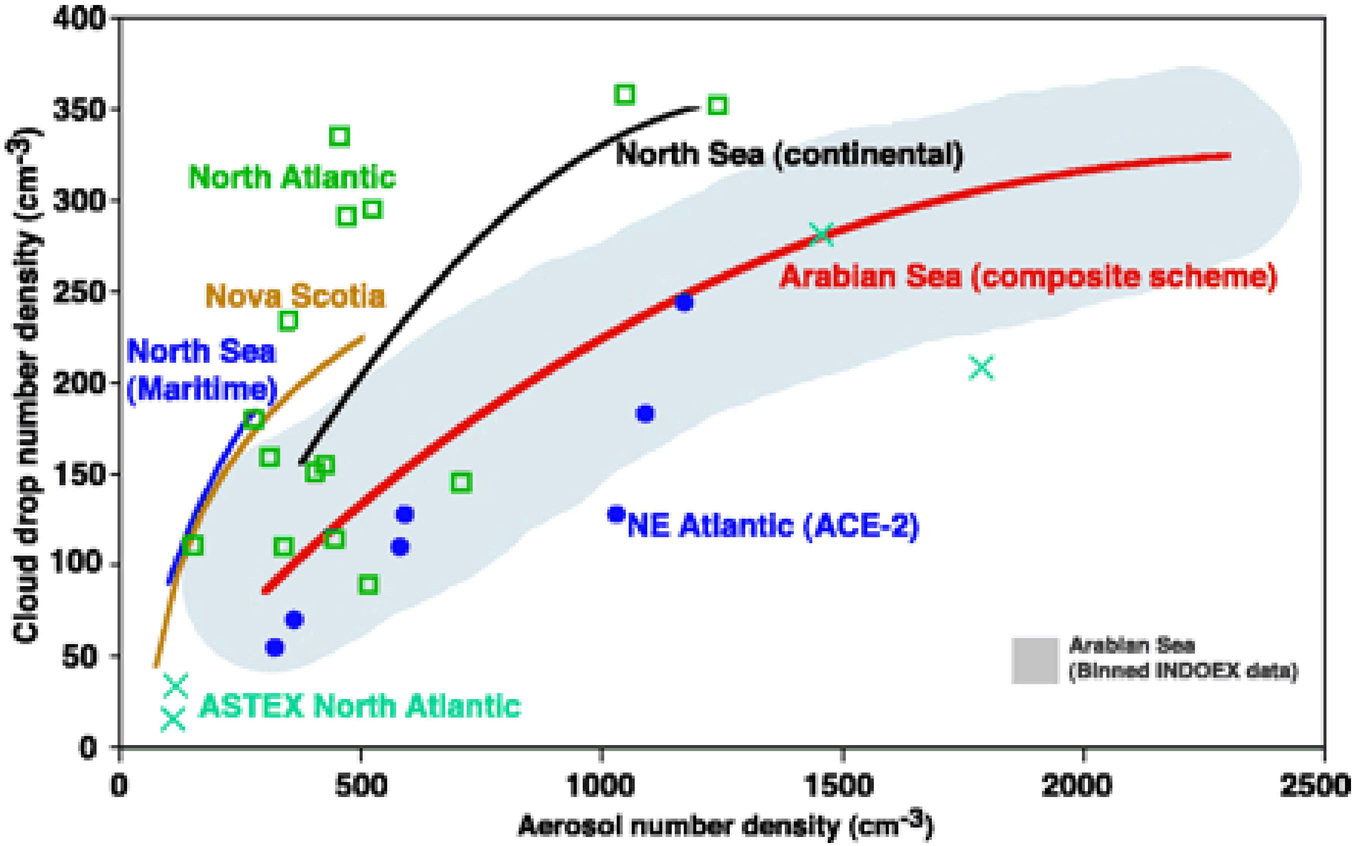


From Ramanathan and Crutzen

No single relationship

Different particle types, compositions, size distributions, etc

# Importance of the size distribution: Cloud droplet number → indirect effects

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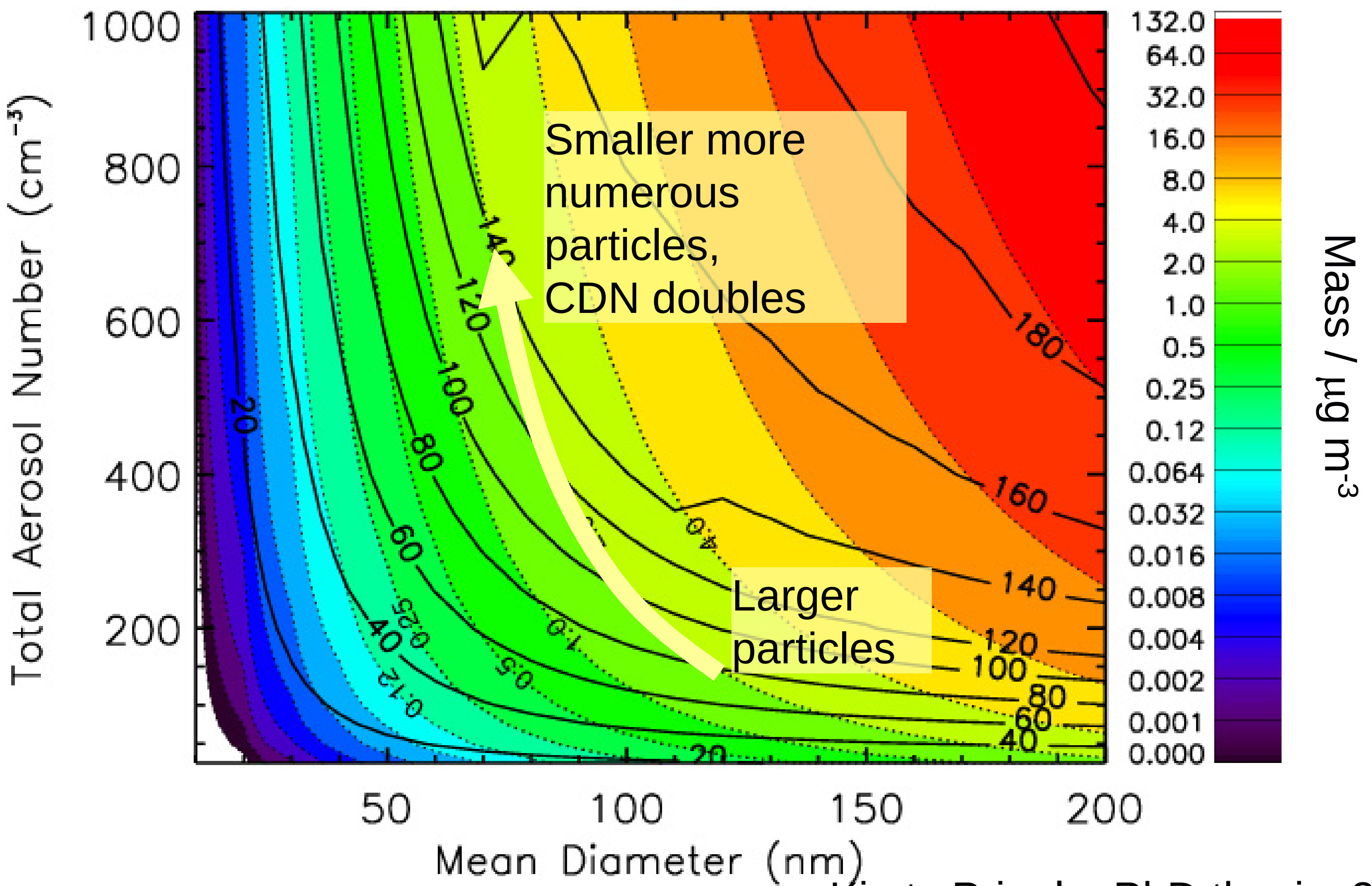
Parcel model calculation of cloud drop number from log-normal aerosol




Kirsty Pringle, PhD thesis, 2007

# Global Model of Aerosol Processes (GLOMAP)

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Global CTM forced by 6-hourly ECMWF winds

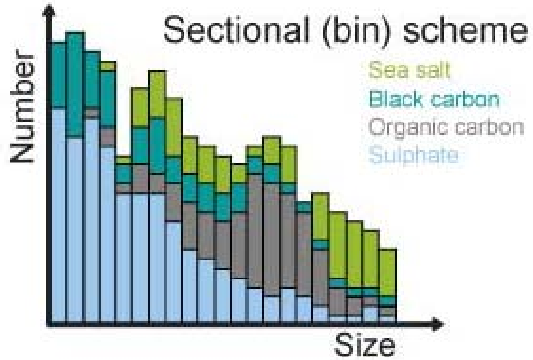
Usually run at T42L31 (2.8°x2.8°) resolution

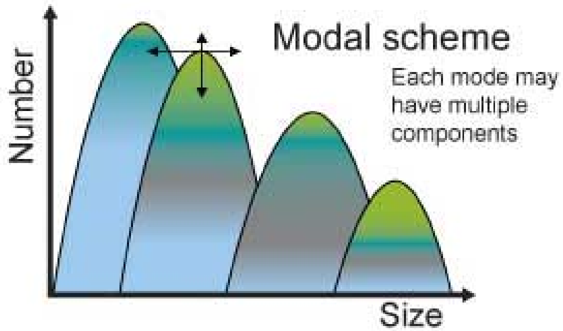
Sectional aerosol scheme: 20 bins, 3 nm – 20 μm
Modal scheme: 7 or 4 log-normal modes

In TOMCAT CTM usually driven by offline oxidants, now coupled to tropospheric chemistry

Aerosol transport, new particle formation, growth by coagulation, condensation, cloud processing.

Wet and dry deposition of gases & aerosol particles



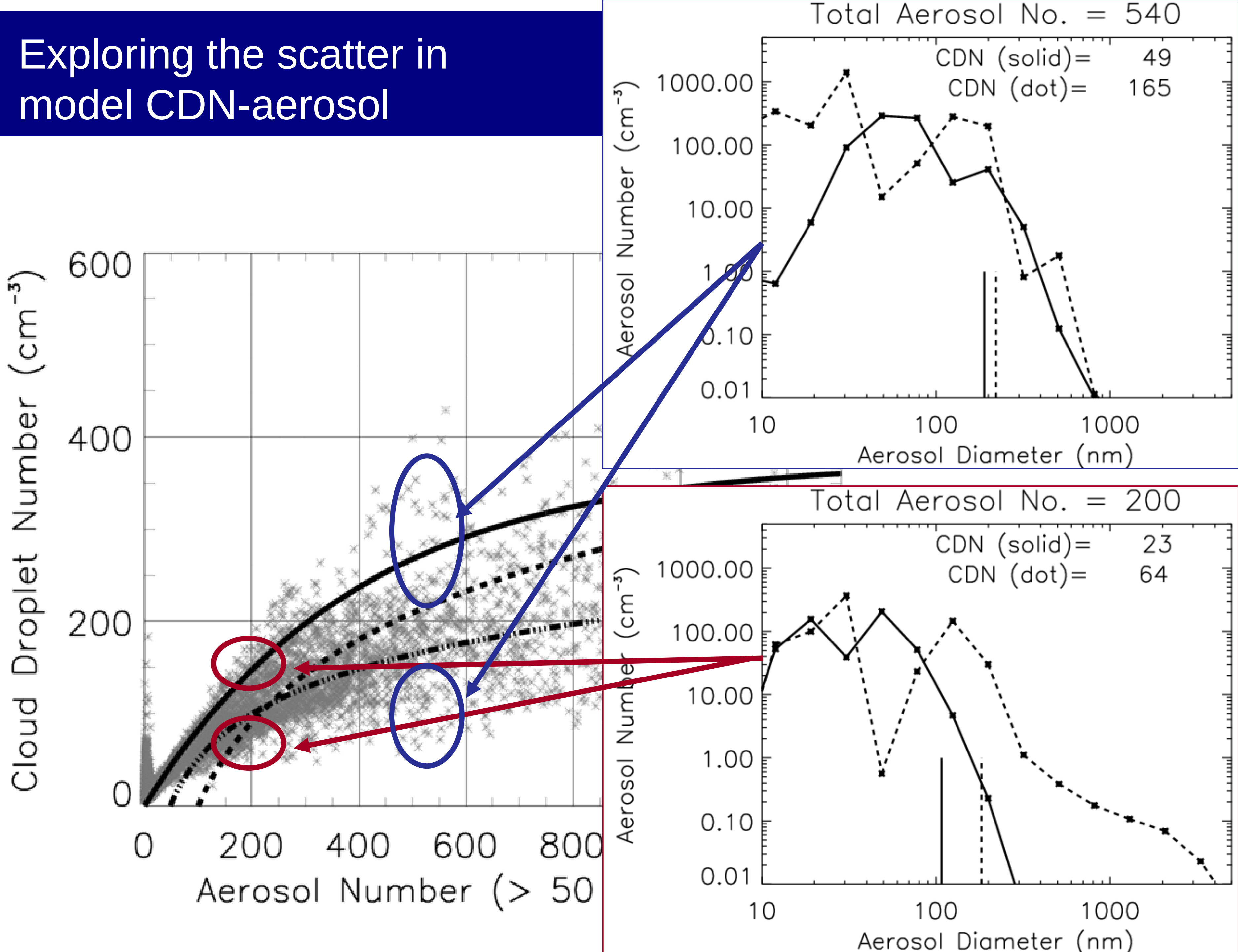

Emissions of DMS → $SO_2$ → $H_2SO_4$; monoterpenes → biogenic SOA

Primary emissions of sea salt, dust, black & organic carbon (fossil and biofuels, vegetation fires)

Nucleation via binary homogeneous nucleation of $H_2SO4\text{-}H_2O$ and also now implemented boundary layer nucleation mechanism

GLOMAP-bin : Spracklen et al. (ACP, 2005), Spracklen et al (GRL, 2008)
GLOMAP-mode: Mann et al (GMD, 2010), Woodhouse et al (2010), Schmidt et al (2010)

# Exploring the scatter in model CDN-aerosol



# Variability in predicted CDN

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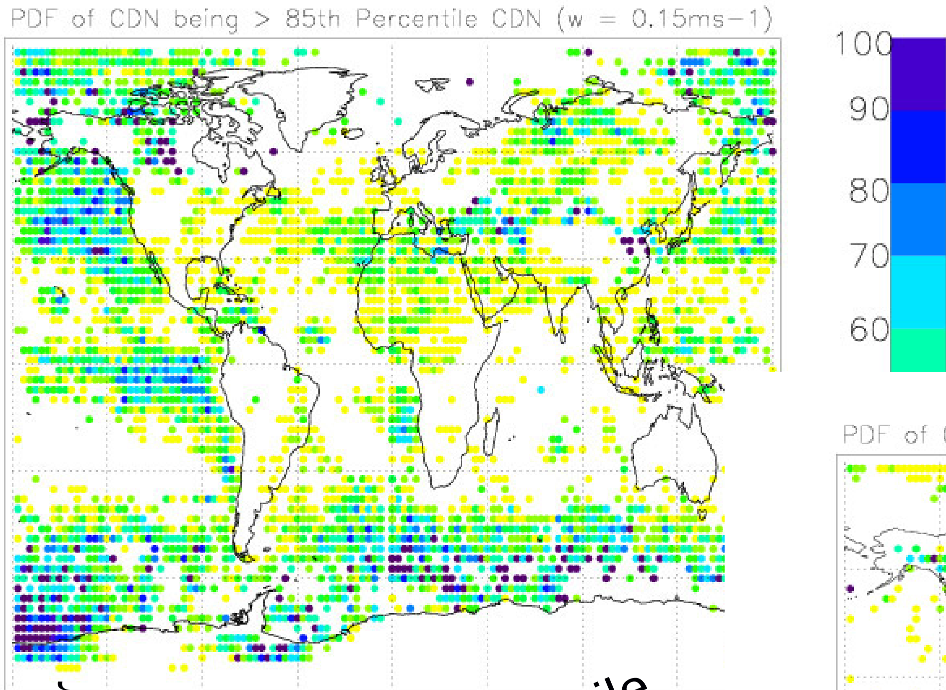
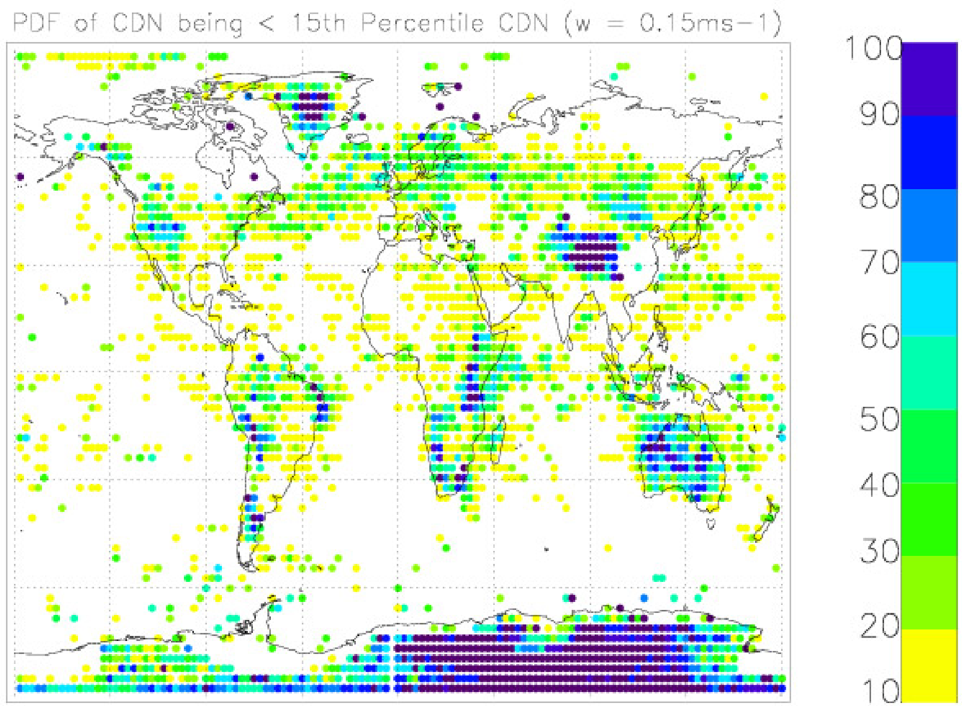
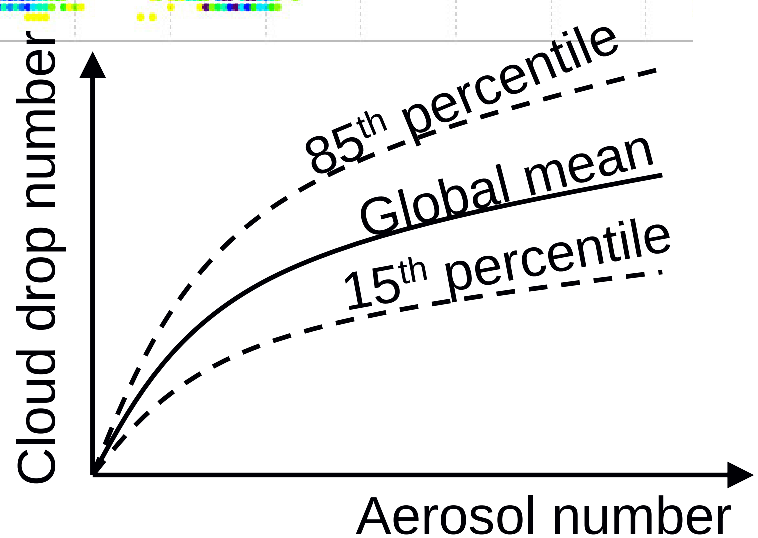



Percent of days that exceed 85th percentile

Pringle et al (2009, ACP)



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

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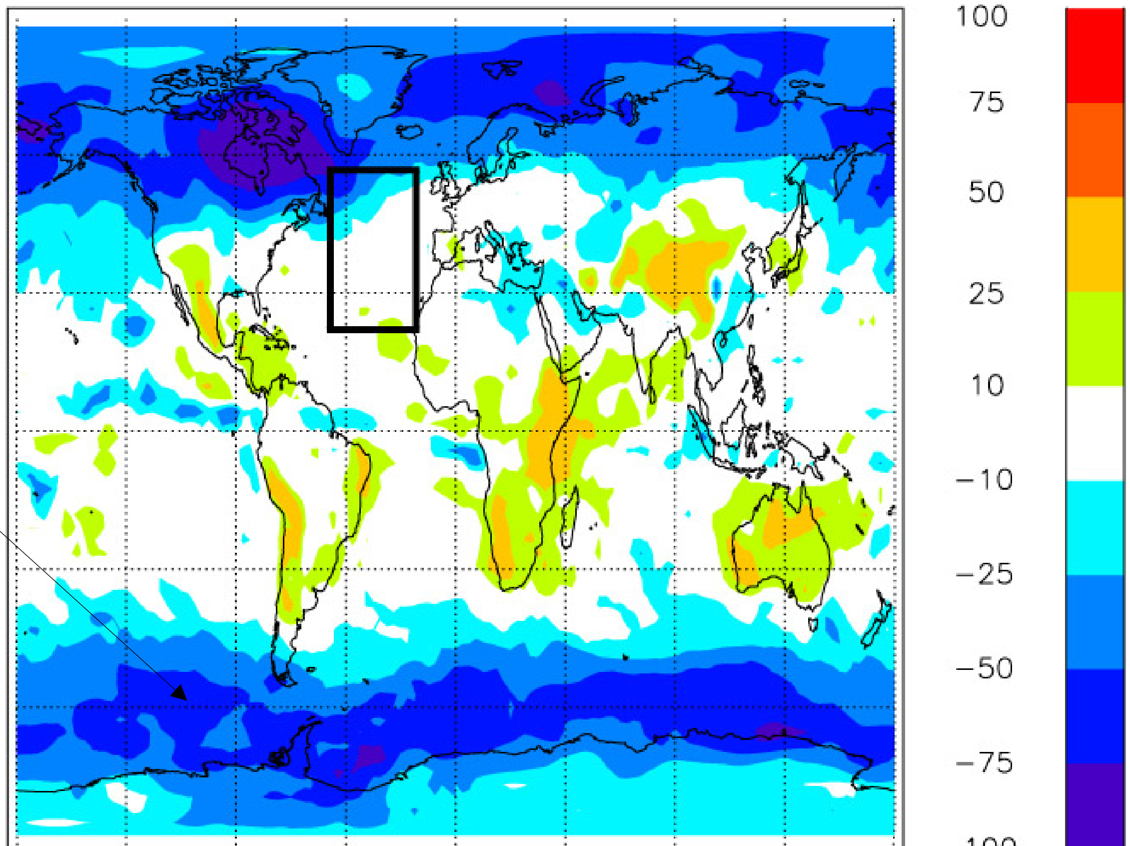
Use model output to generate CDN-aerosol empirical fit

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 (2009, ACP)

# AEROCOM microphysics working group

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At 2008 AEROCOM workshop in Iceland, working group established to evaluate aerosol microphysics models against range of available in-situ observations.

Use syntheses of in-situ observations as benchmark to evaluate the models.

Evaluate & document diversity of AEROCOM models in simulated number conc'n

Common modelling experiments set up:

- -- Control simulation reference year 2006 (A2-CTRL-2006)
- -- As CTRL but with condensational growth switched off (A2-SIZ1-2006)
- -- As CTRL but with coagulation switched off (A2-SIZ2-2006)
- -- As CTRL but with primary emissions of SO4 and BC/OC off (A2-SIZ3-2006)
- -- As CTRL but with new particle formation switched off (A2-SIZ4-2006)

A2-SIZ1,A2-SIZ2 compare role of growth processes in different models.

A2-SIZ3 allows multi-model assessment of contribution of primary particles to CCN

A2-SIZ4 allows multi-model assessment of nucleated CCN in different models.

Use HCA-0 emissions in models to minimise differences between model simulations.

Ask models to extend A2-CTRL-2006 through 2007 and 2008 to run through EUCAARI period with EUCAARI Different models

# Challenges when evaluating number concentrations

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Models characterise size distribution in many different ways
-- mass-only in aerosol types each with fixed size distribution (~10 aerosol tracers)
-- number & mass concentrations in size modes (20-30 aerosol tracers)
-- number & mass in concentrations size bins (100-200 aerosol tracers)

CCN observations retrieve CCN at many different supersaturations
(and different models use different methods to calculate CCN concentrations).

CN measurements can use different minimum diameter (e.g. 3nm or 10nm).

Size distribution observations made across different size ranges.

<u>Approach settled on at 2008 workshop:</u>
Instead of asking for extra complicated diagnostics, just make life simple:
Ask modelers to <u>write "all-aerosol-tracer" output</u> to AEROCOM database
And to provide README file with information on how size is handled in model.

Then can compare CN, CCN, size-resolved N ensuring consistent methodology.

<u>Also ask modellers to interpolate to selected sites outputting at hourly resolution</u>
-- makes separation into different air mass types possible
-- generate statistics of size distribution over daily cycle
-- how well do microphysics models reproduce new particle formation events?

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# Required output for aerosol microphysics group:

-- Monthly-mean all-aerosol-tracer output on full 3D model grid (3D-M)
-- Daily-mean all-aerosol-tracer output over vertical profile at sites (1D-D)
-- Hourly-mean all-aerosol-tracer output at surface at sites (0D-H)
Use CMOR tables: Aerocom_table_1DD, Aerocom_table_0DH on website.

<u>50 selected sites for high-temporal resolution all-aerosol-tracer data:</u>

GAW & ARM sites (CPC, nephelometer, aethalometer, some with lidar)
Alert, Barrow, Bondville, Mauna Loa, Neumayer, Samoa, South Pole, Southern Great Plains,

21 EUSAAR supersites (many with DMPS, AMS, lidar)
Aspreveten, Auchenworth, Birkenes, Cabauw, Finokalia, Harwell, Hohenpeissenberg, Hyytiala, Ispra, Jungfraujoch, Kosetice, K-puzta, Mace Head, Melpitz, Montseny, Moussala, Pallas, Preila, Puy de Dome, Valvihill, Zeppelin.

Additional sites with observations
Cape Grim, Cape Point, Capo San Juan, Elandsfontein, Guangzhou, Manaus, Monte Cimone, Mount Waliguan, Paverne, Shang Dianzi, Sonnblick, Summit, Tahkuse, Trinidad Head, Varrio

<u>Need model README file giving full detail of size assumptions with model</u>

# Global aerosol microphysics models in AEROCOM phase2

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Many groups have now submitted the model all-aerosol-tracer data:

| Model | Aerosol Dynamics | # of aerosol tracers | Contact |
|---|---|---|---|
| GLOMAP-mode | Modal (N,m) | 26 | Graham Mann (Leeds) |
| ECHAM-HAM2 | Modal (N,m) | 45 (20 SOA) | Kai Zhang (MPI-Hamburg) |
| GISS-TOMAS | Bin-resolved (N,m) | 72 | Yunha Lee (Carnegie Mellon) |
| GLOMAP-bin | Bin-resolved (N,m) | ~200 | Dominick Spracklen (Leeds) |
| EMAC [ECHAM-MESSy] | Modal (N,m) | 30+ | Kirsty Pringle (MPI-Mainz) |
| TM5 | Modal (N,m) | 25 | Elisabetta Vignati (JRC) |
| PNNL-CAM5-MAM | Modal (N,m) | 15 | Xiaohong Liu (PNNL) |
| FMI-SALSA | Bin (N,m) | ~70 | Tommi Bergman (Univ Helsinki) |
| GISS-MATRIX | Moments (N,m) | 60 | Susanne Bauer (GISS) |
| CCCma AGCM4 | PLA-bin (N,m) | 240 | Knut Van Salzen (Env Canada) |
| GEOS-CHEM-APM | Bin-resolved (N,m) | 780 | G. Luo & F. Yu (NY State Uni, Albany) |
| HadGEM3-UKCA | Modal (N,m) | 26 | Graham Mann (Leeds) |

Also several mass-based models have submitted results, for which CN and CCN concentrations can be re-constructed and compared against those from the aerosol microphysics models.

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# Assembled benchmark observational datasets.

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Wide range of observational datasets being used at Leeds to evaluate the bin and modal versions of GLOMAP.

1) CN concentrations from CPC observations at GAW & other sites
2) size-resolved number concentrations & mean size against compilations of multiple field campaign measurements (e.g. Heintzenberg et al, 2000, 2004).
3) vertical CN, CCN profiles from models against compilations of aircraft observations (e.g. TRACE-P, PEM-Tropics, INCA, UFA-EXPORT, LACE field campaigns)
4) CCN concentrations from field campaigns and monitoring sites.
5) size distributions against DMPS observations at EUSAAR sites

Evaluate AEROCOM size-resolving global aerosol models.
Use mean-bias and correlation coefficient to score models

*Provide observational constraint for simulated size distribution.*

# GLOMAP-mode v4 vs marine BL size distribution (Raes00)

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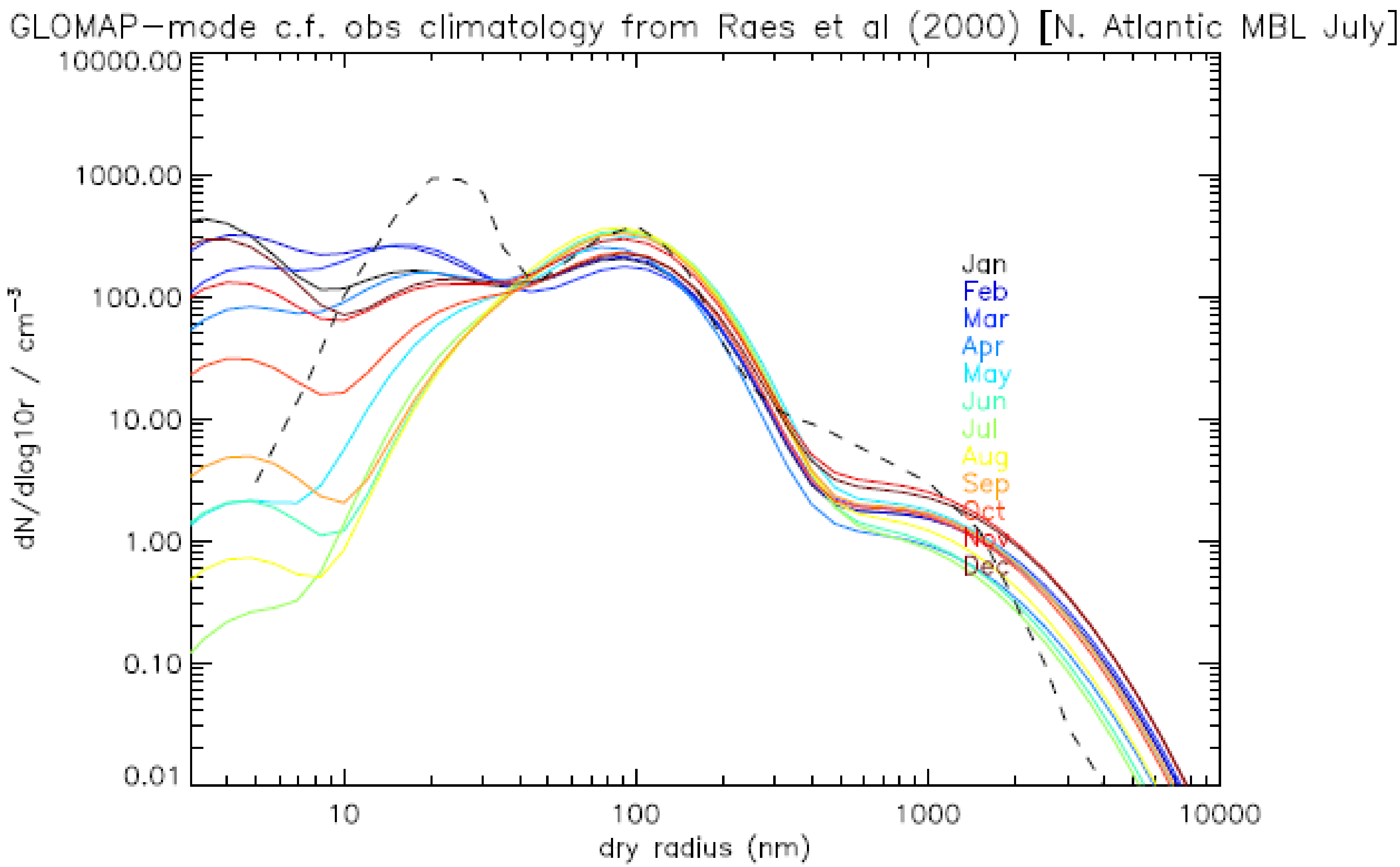

# GLOMAP-mode v6R vs marine BL size distribution (Raes00)

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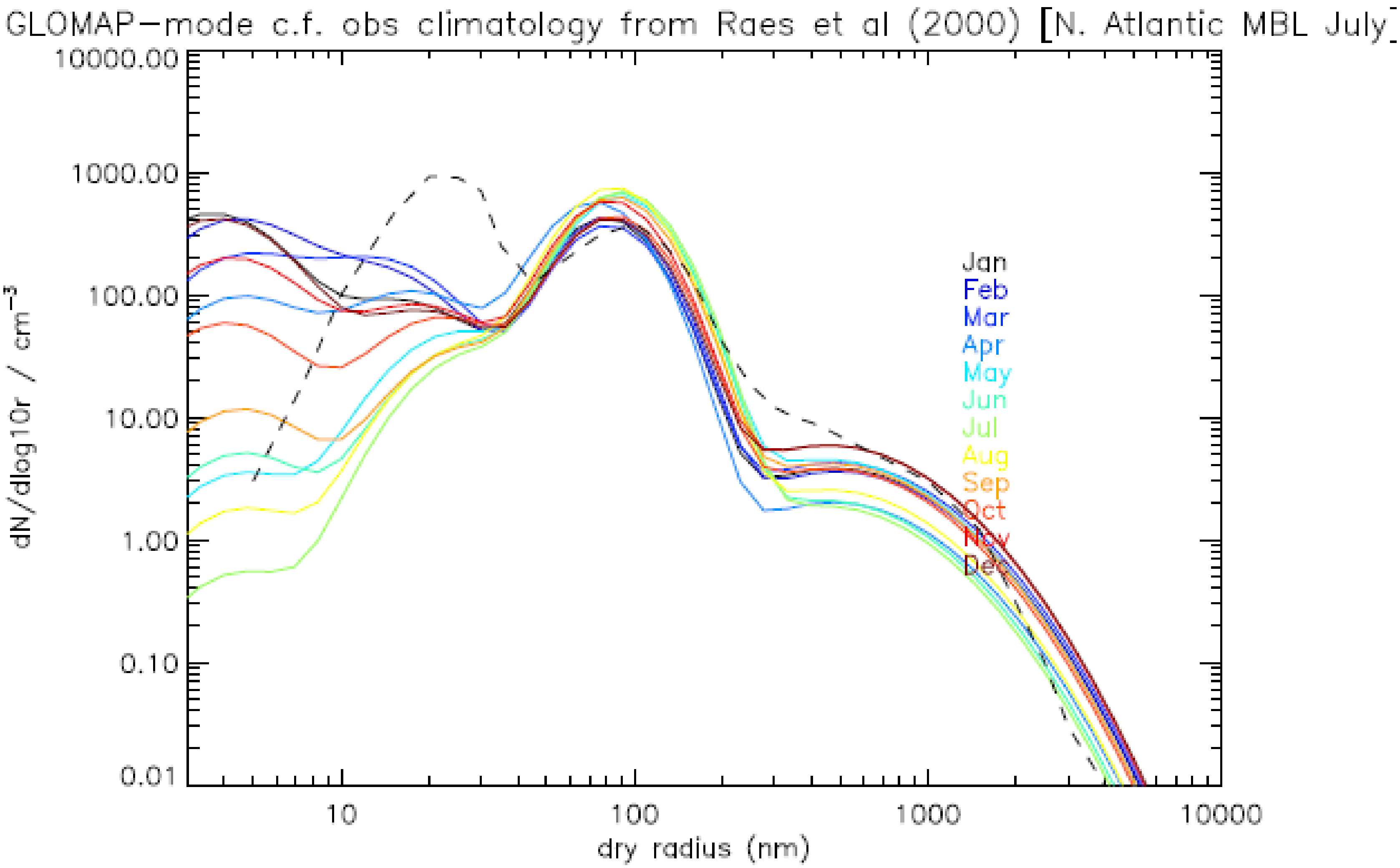

# ECHAM-HAM2 vs marine BL size distribution (Raes00)

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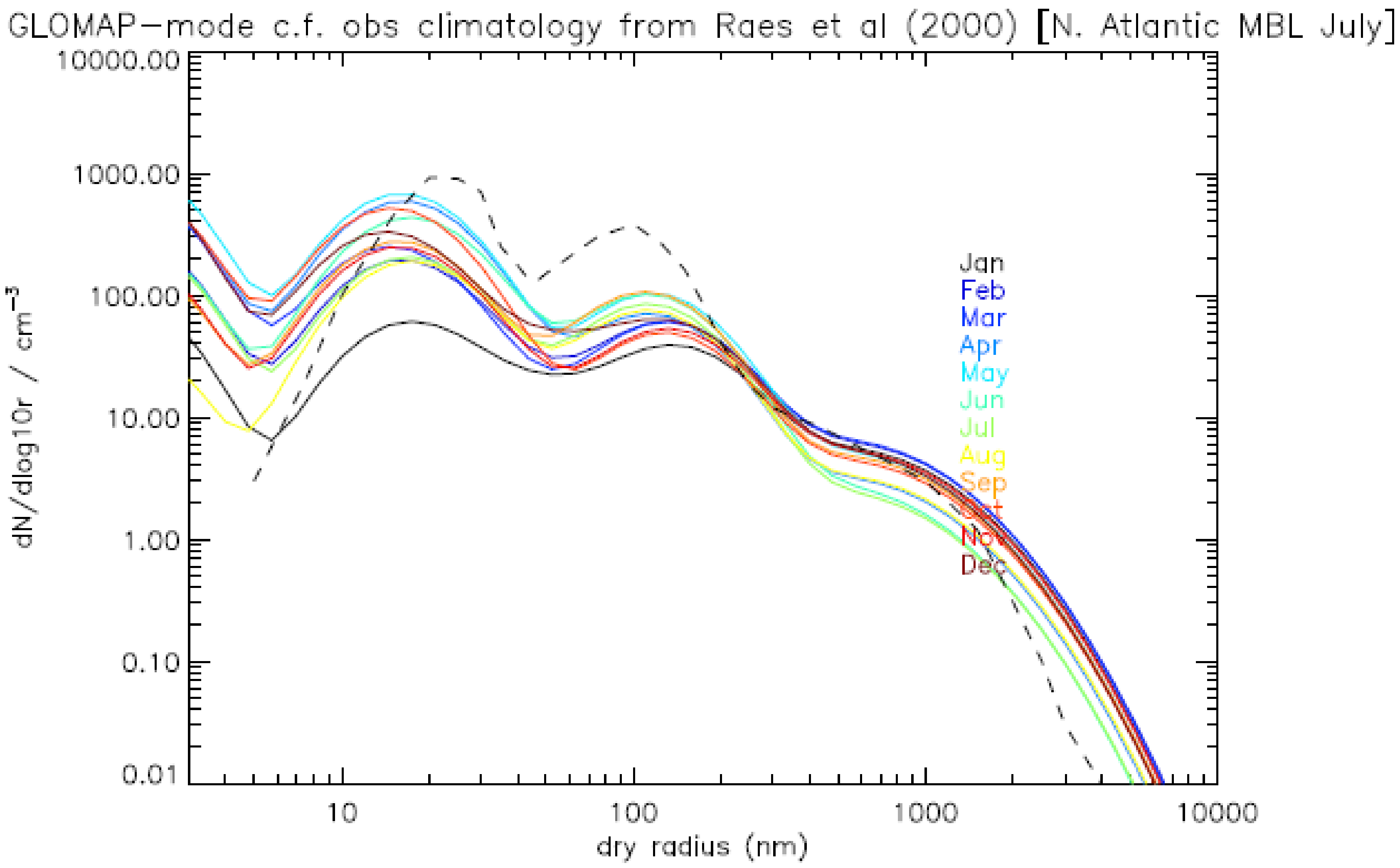

# GISS-TOMAS vs marine BL size distribution (Raes00)

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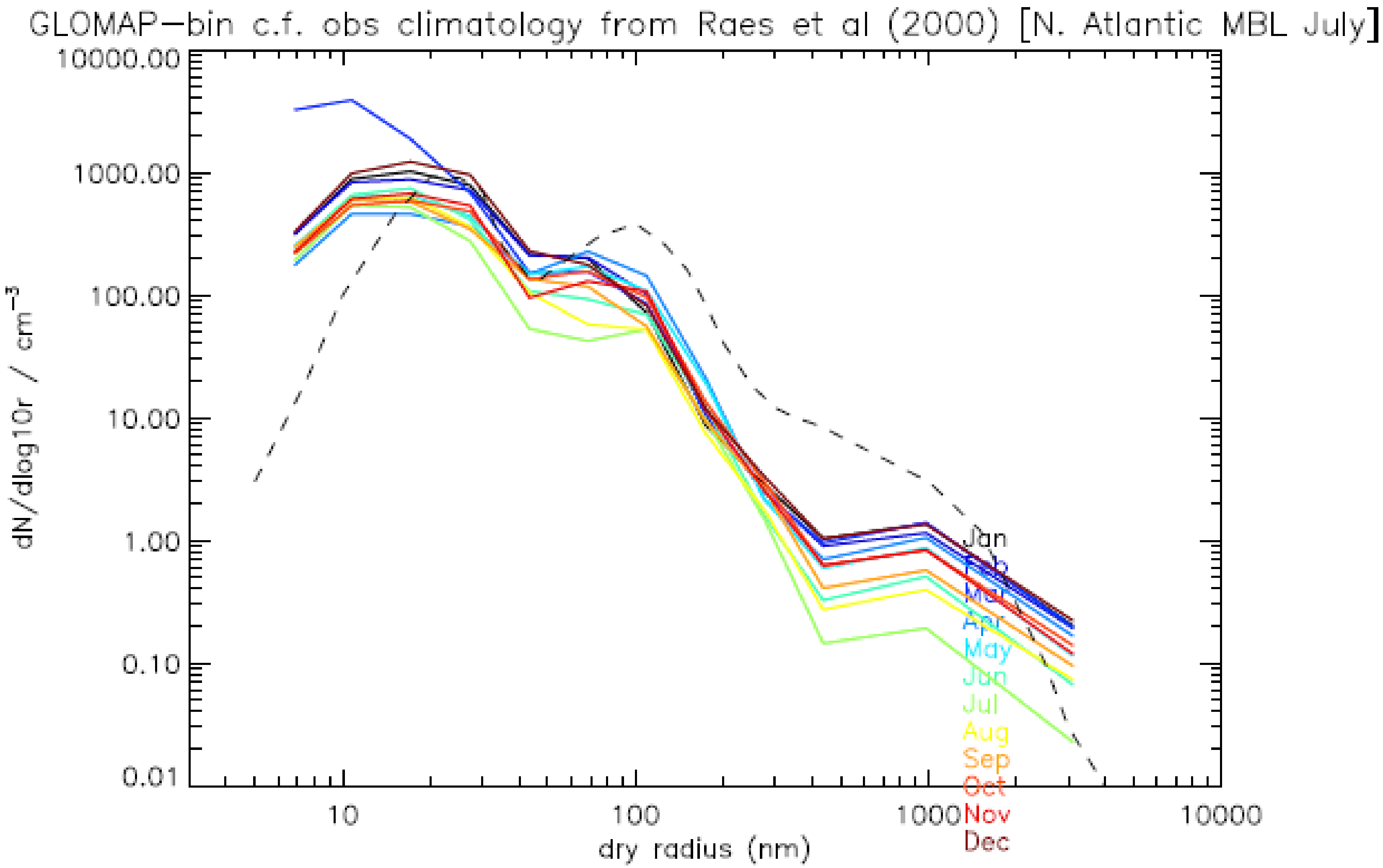

# GLOMAP-bin vs marine BL size distribution (Raes00)

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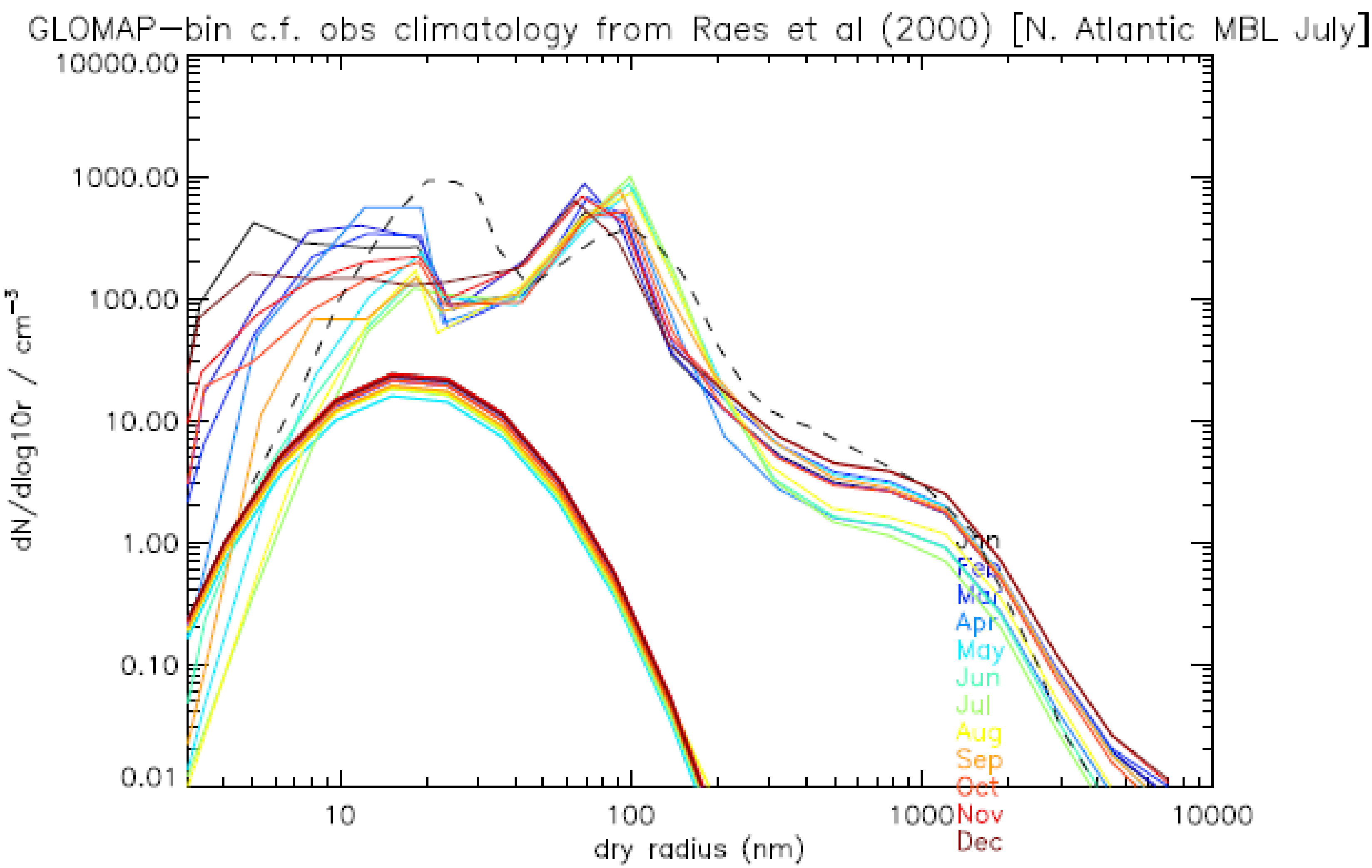

# TM5-HAM vs marine BL size distribution (Raes00)

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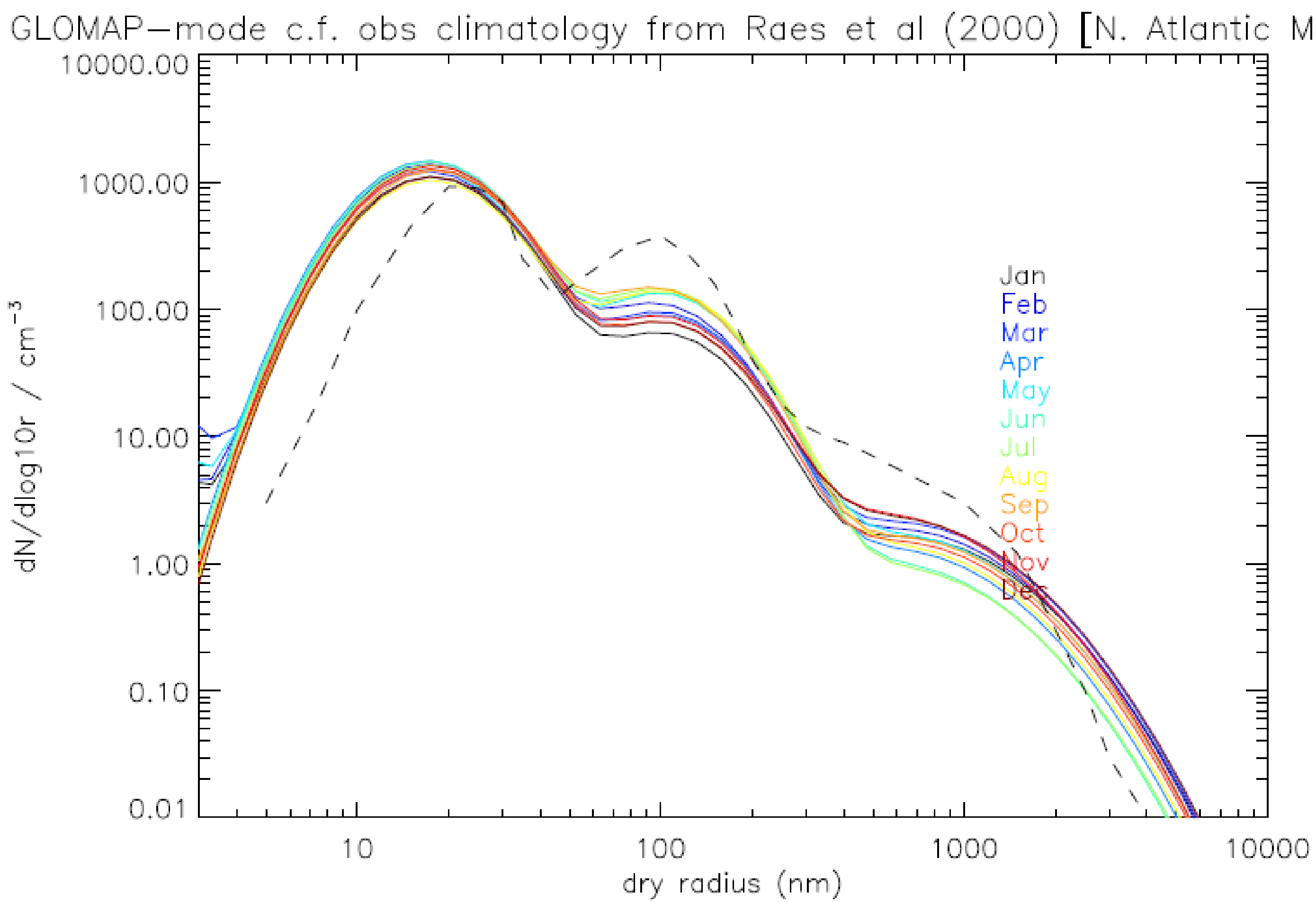

# ECHAM-MESSY-GMXe vs marine BL size distribution (Raes00)

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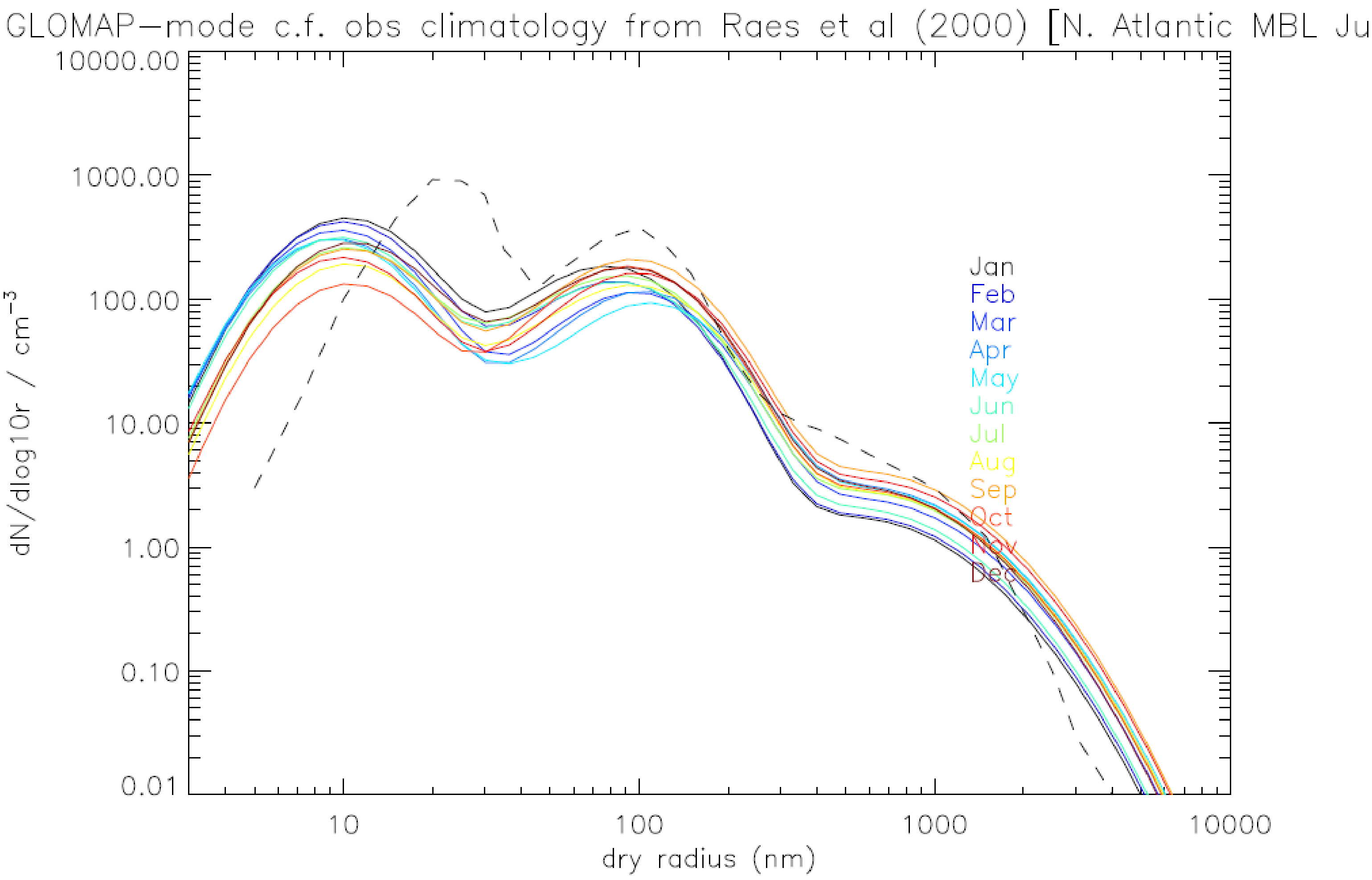

# Diversity in simulated MBL size distributions

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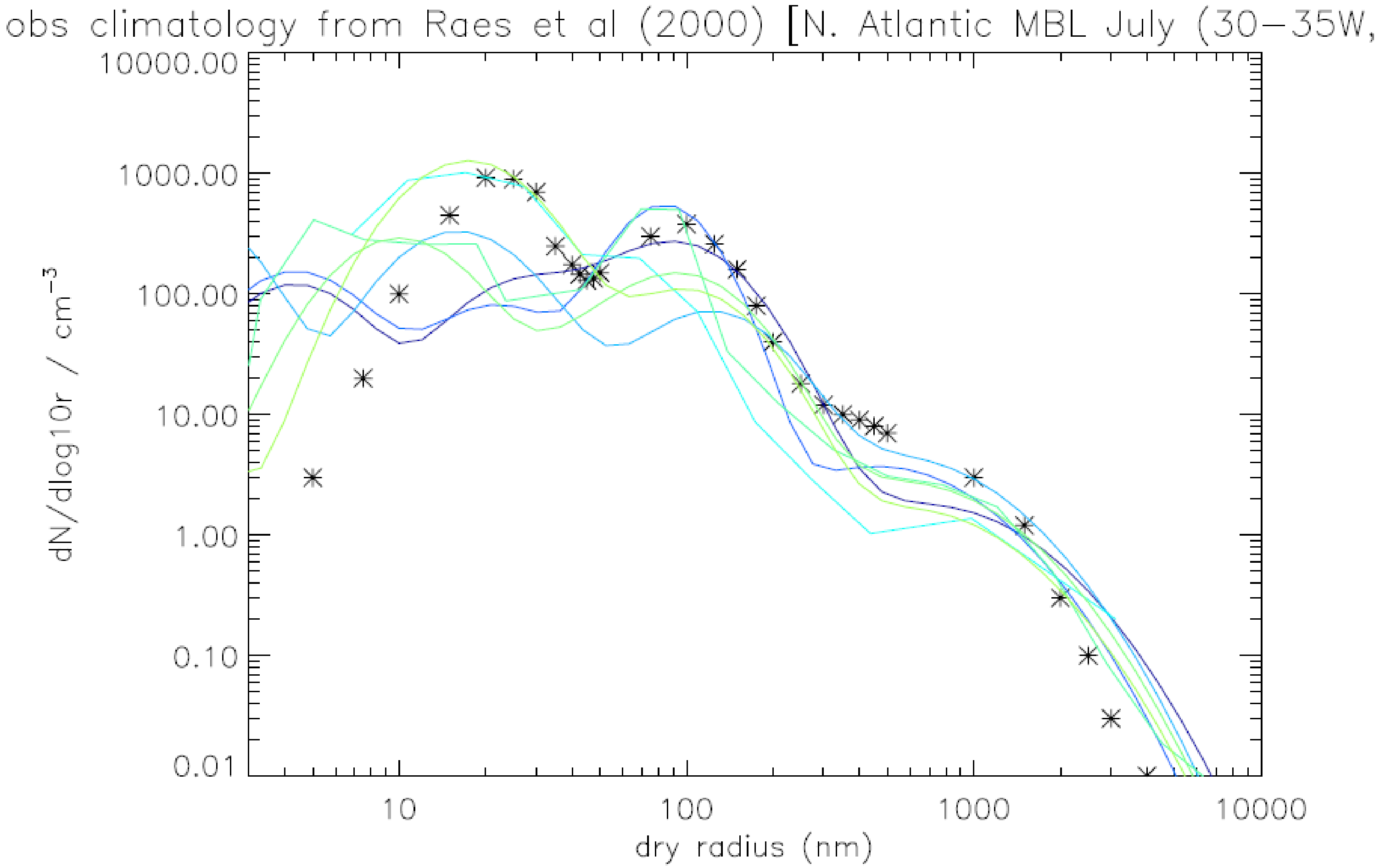

# Diversity in simulated CN concentrations

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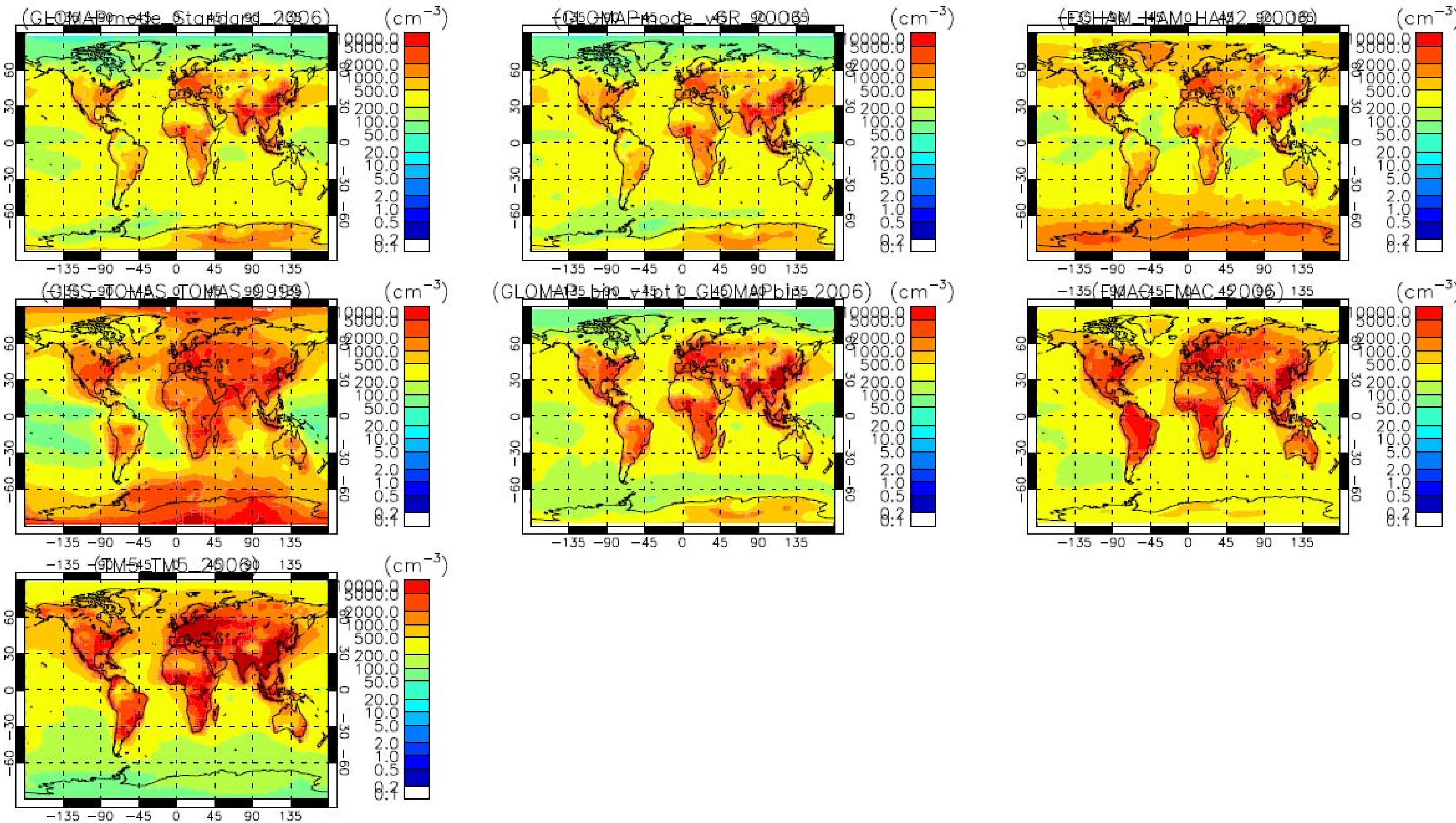

# Diversity in simulated CN concentrations

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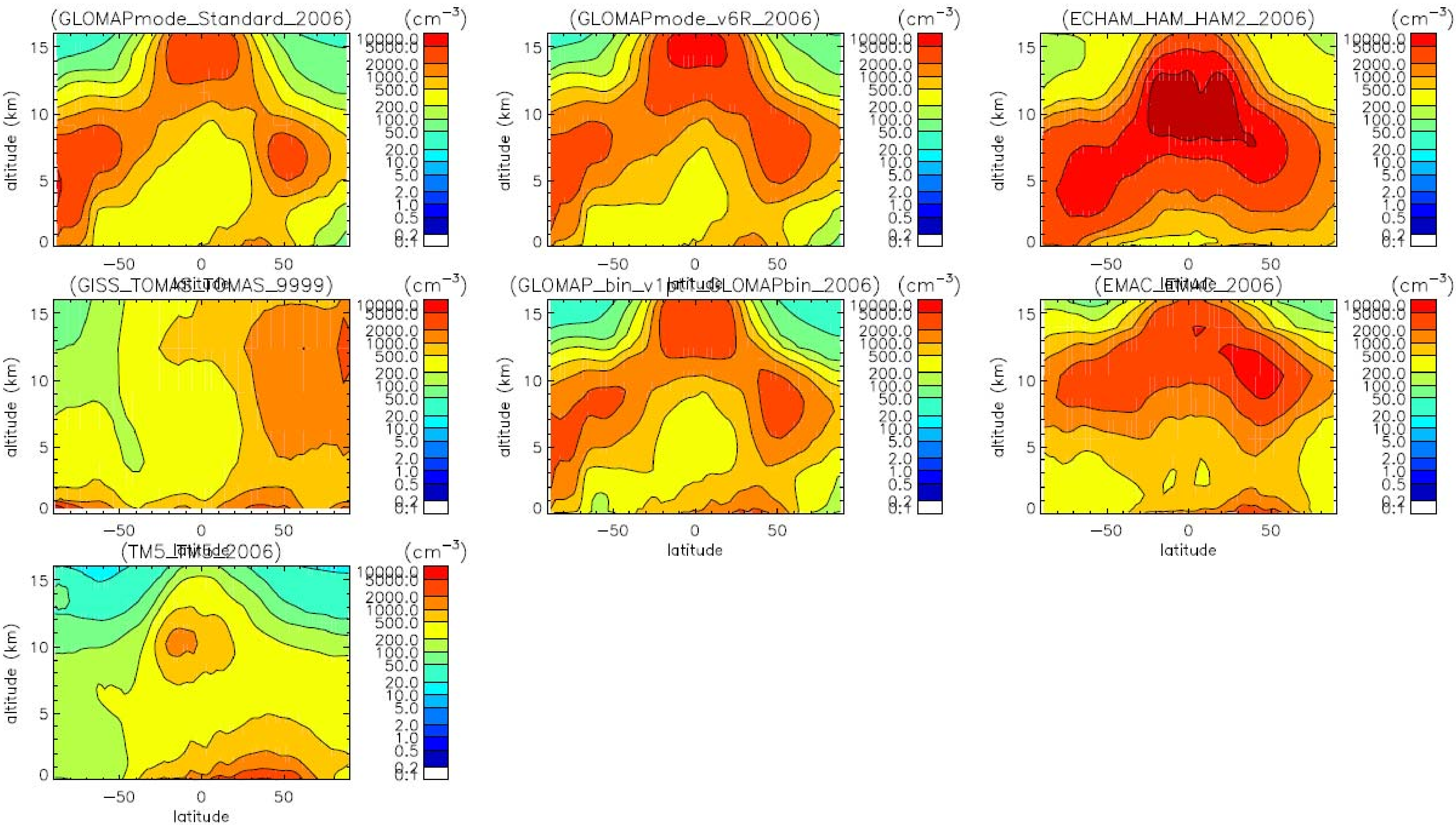
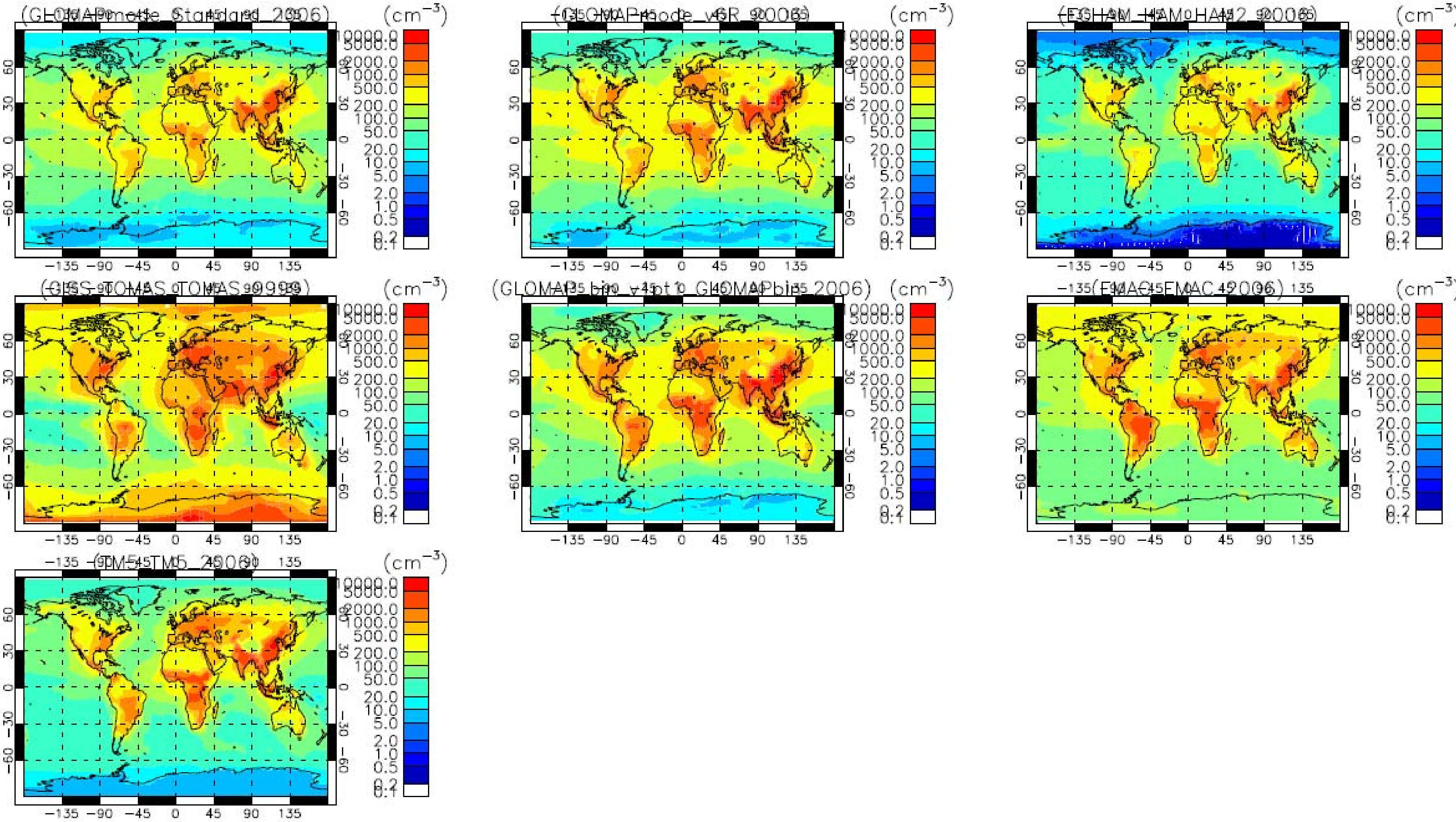
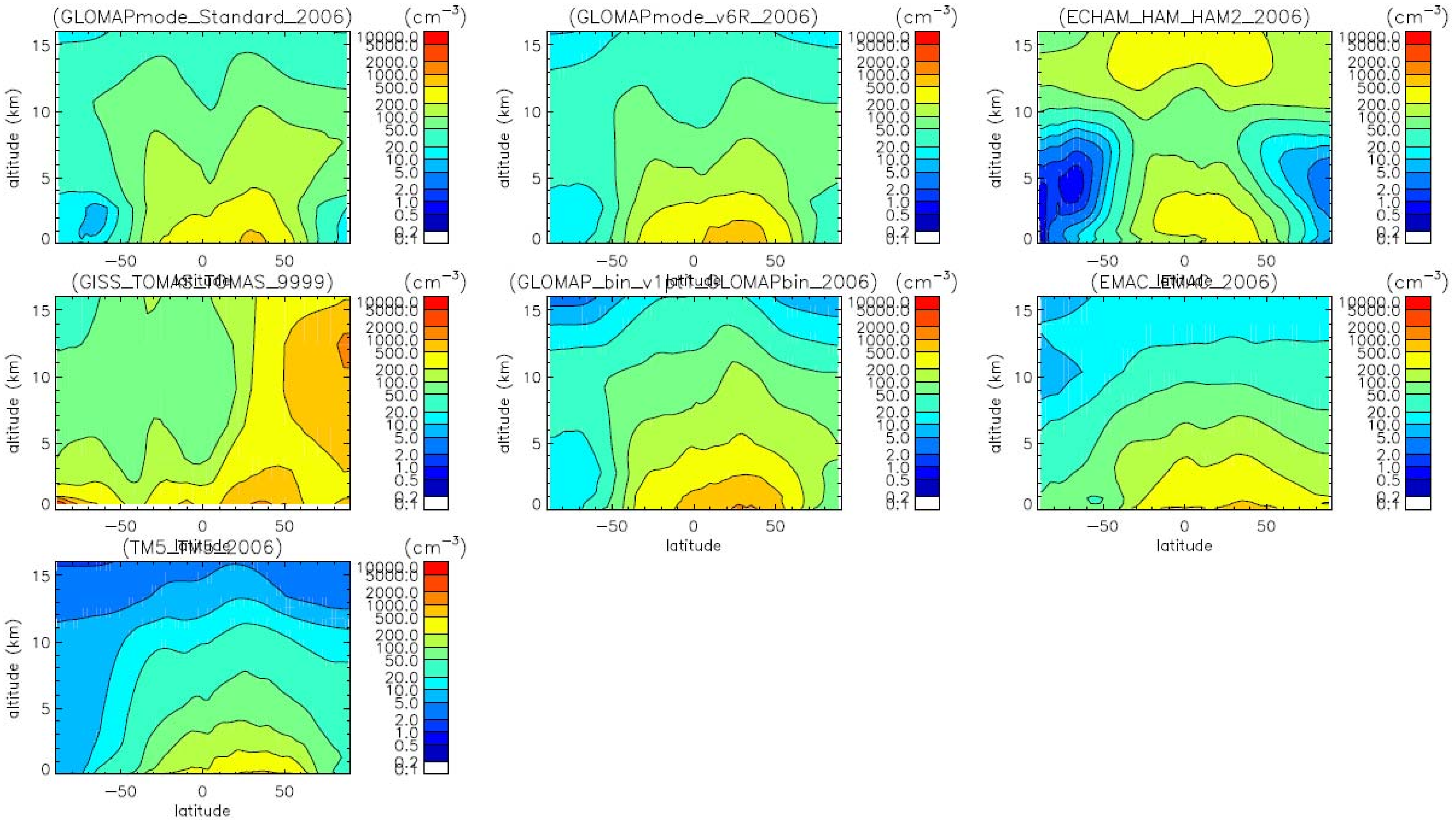


# Diversity in simulated CCN concentrations



# Diversity in simulated CCN concentrations





# 1. CN concentrations from GAW and other sites

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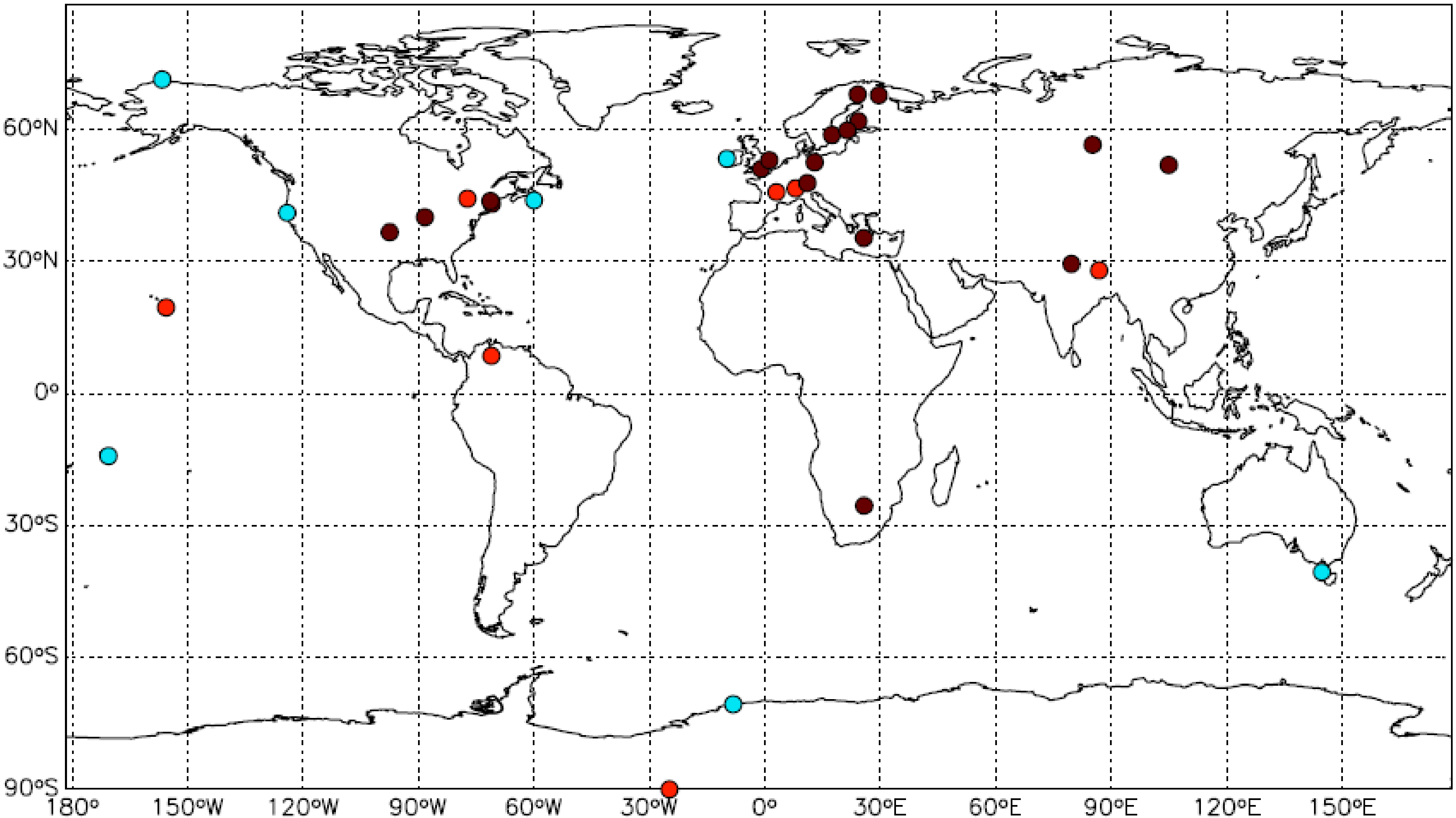
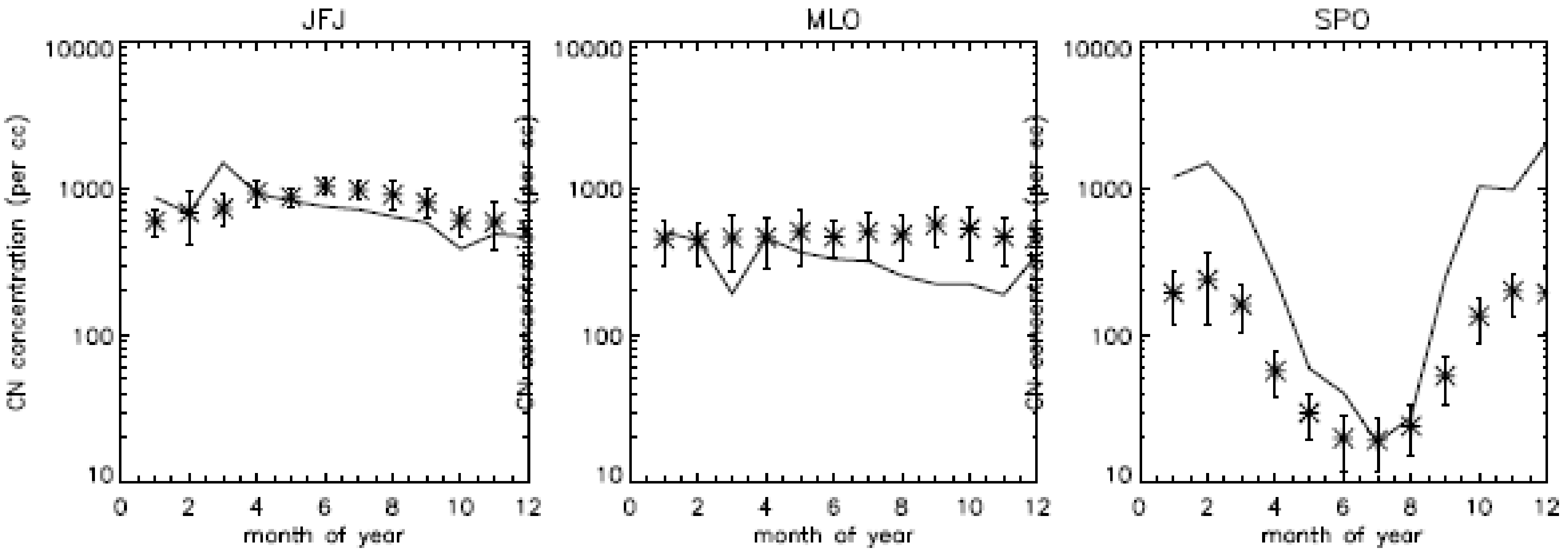


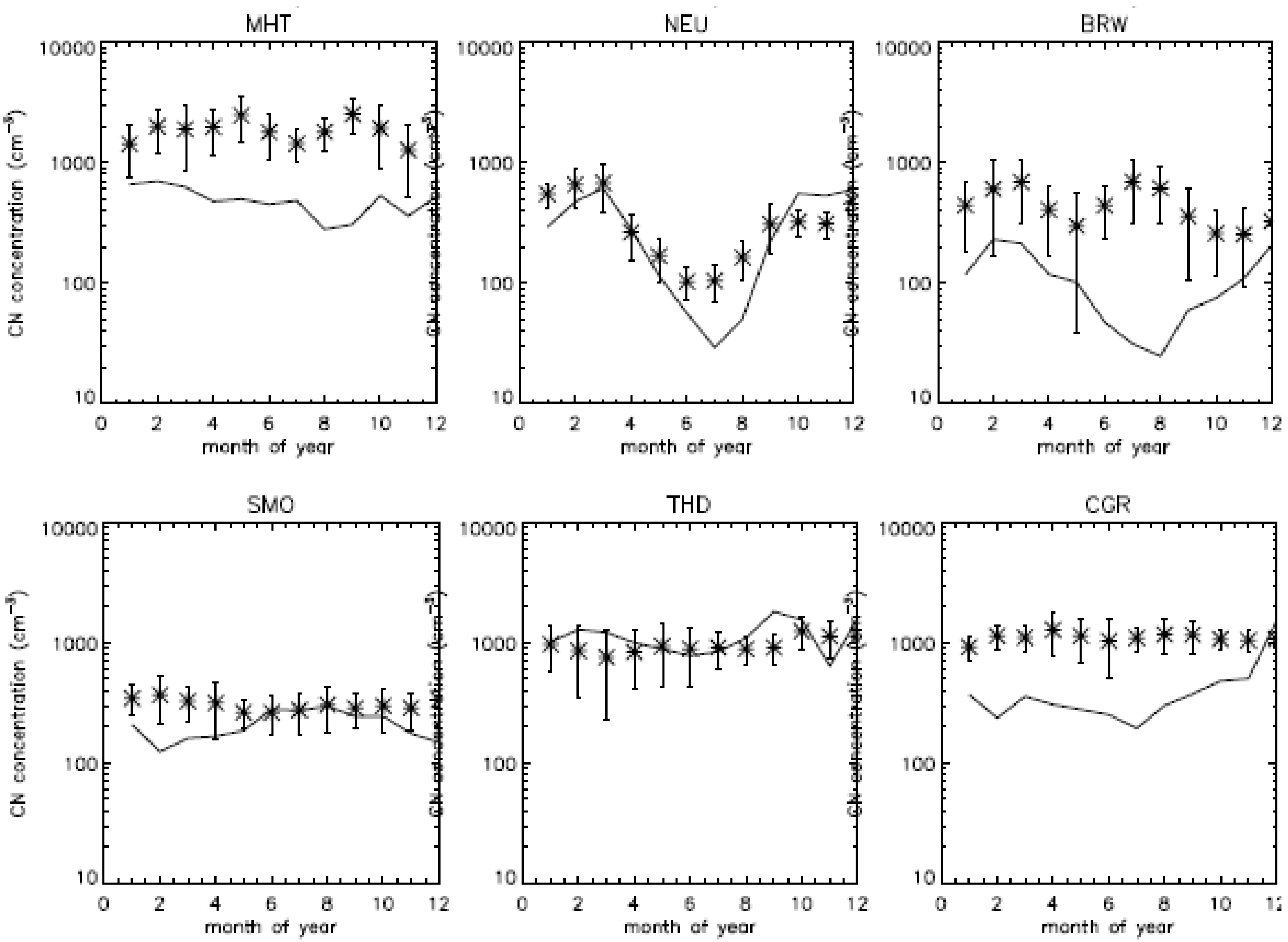

**Remote marine BL sites**
**Continental BL sites**
**Free Troposphere sites**

# GLOMAP-bin vs CN annual cycle GAW sites (FT)



# GLOMAP-mode v4 vs CN annual cycle GAW sites (MBL)





# 2. Compilation of MBL aerosol observations

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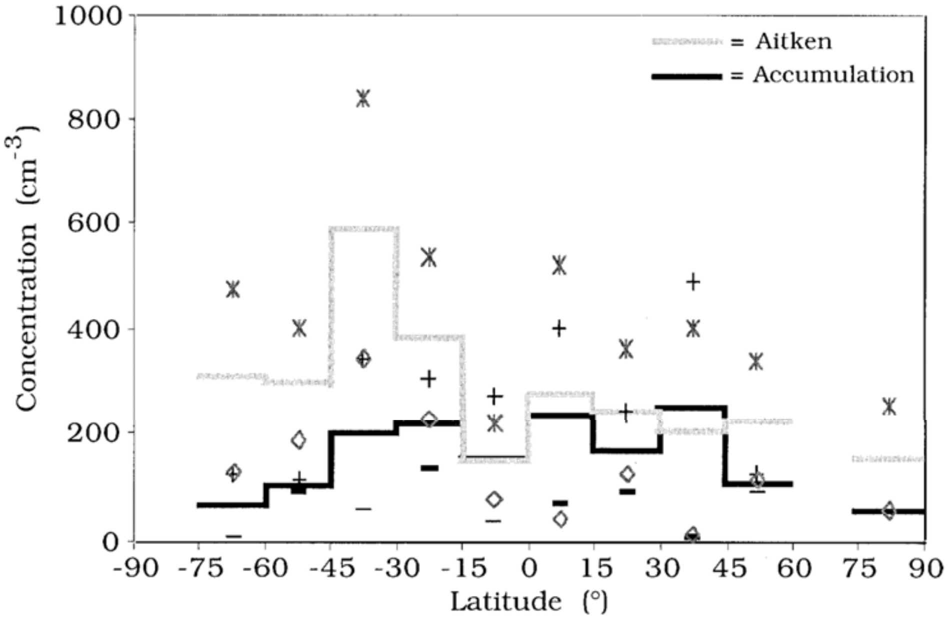


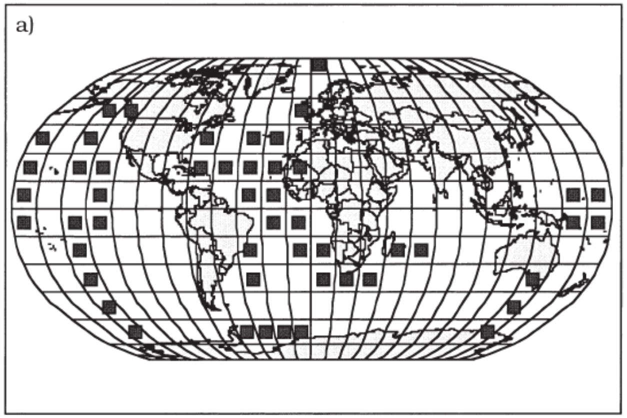


Heintzenberg et al (2000, Tellus B)

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 |

# GLOMAP-mode v4 vs marine NAit & Nacc vs latitude (Heintz00)

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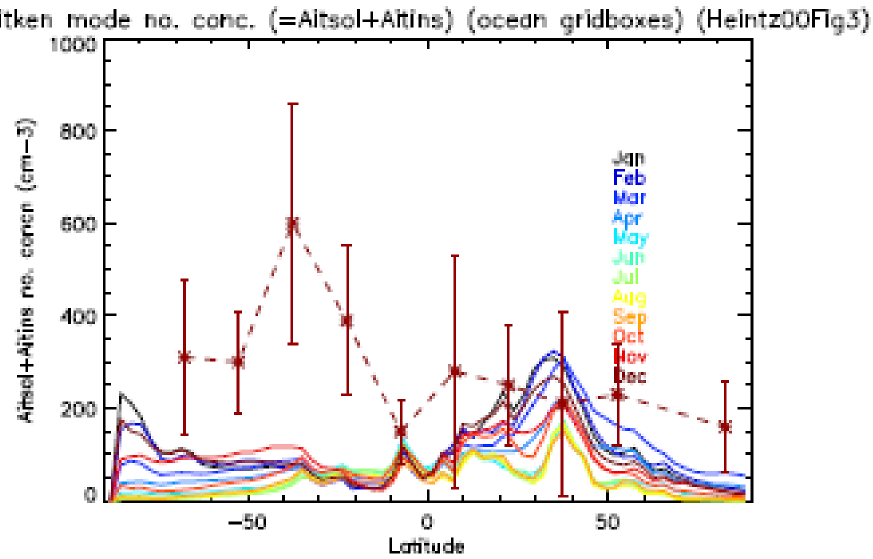


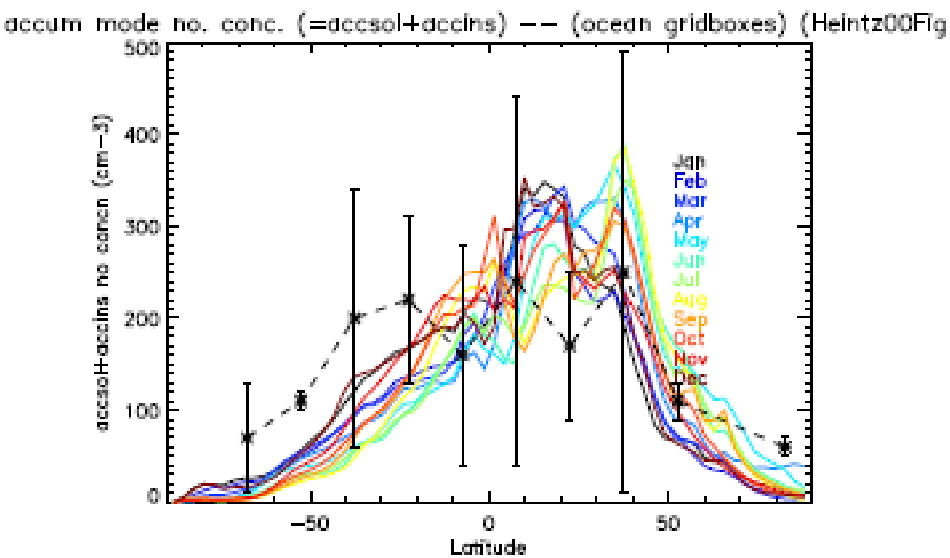


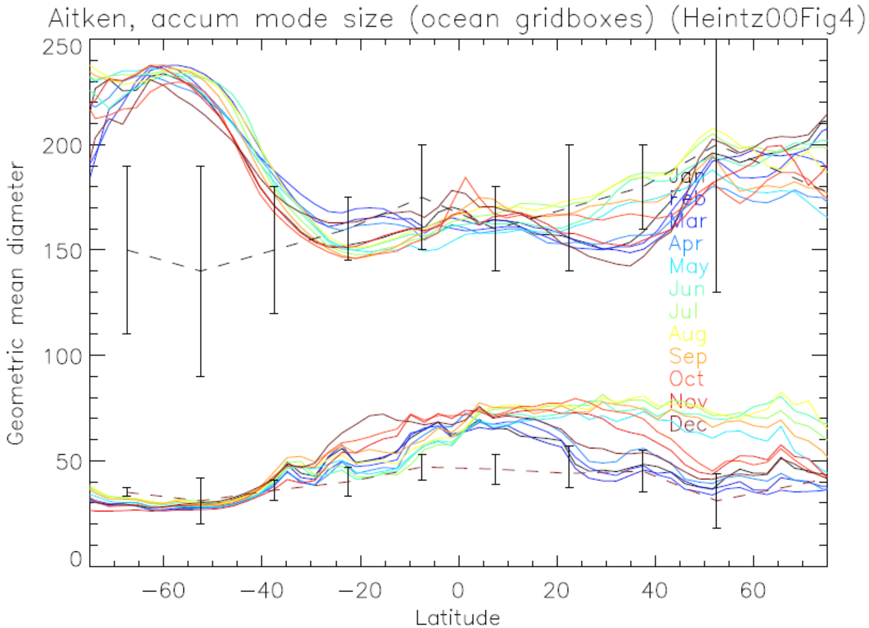

# 3. Vertical profiles of  size-resolved number conc

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Aircraft observations

Continental Europe (Germany)

LACE campaign – Petzold et al (2002)

Marine regions (Pacific and Southern Oceans)

Several field campaigns – Clarke & Kapustin (2002)

# Lindenberg Aerosol Characterization Experiment (LACE)
# Size distribution from PCASP and FSSP on DLR-Falcon

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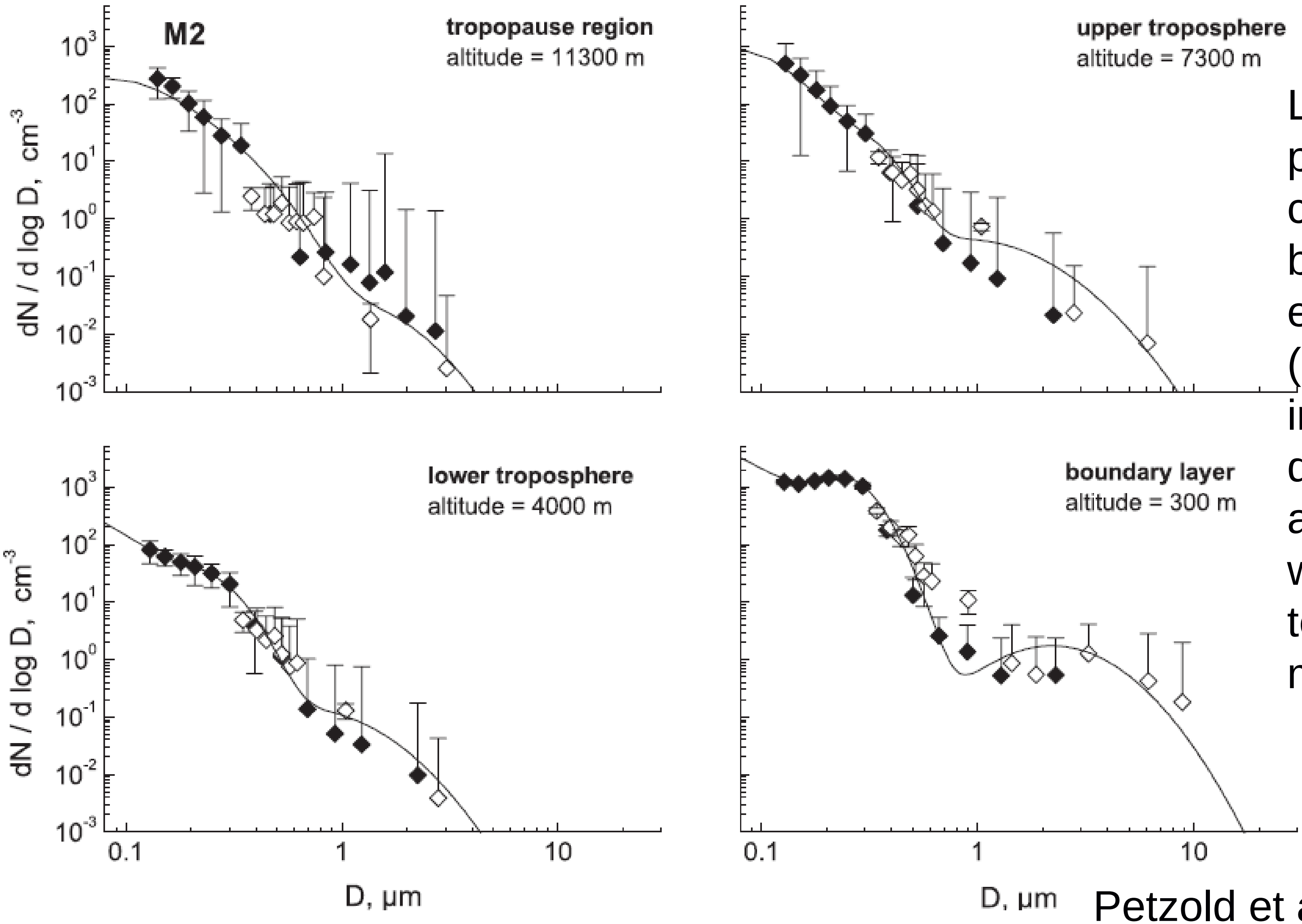


LACE profiles compiled by Lauer et al (2005) into datasets against which to test models

Petzold et al (2002)

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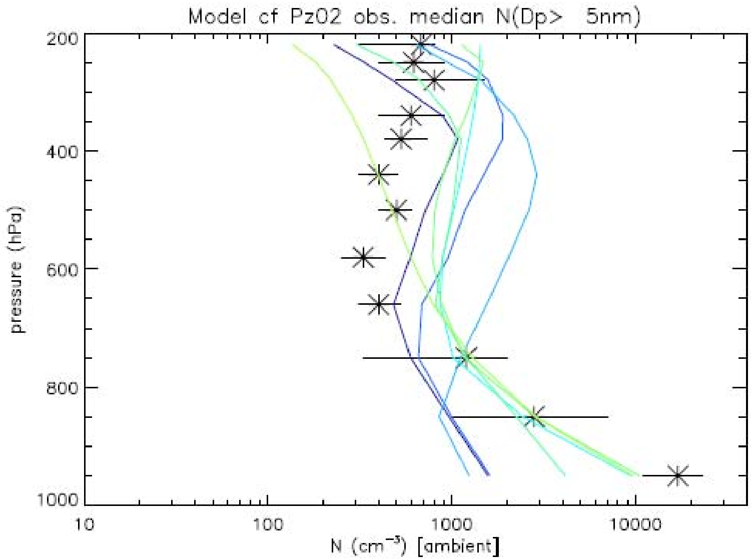


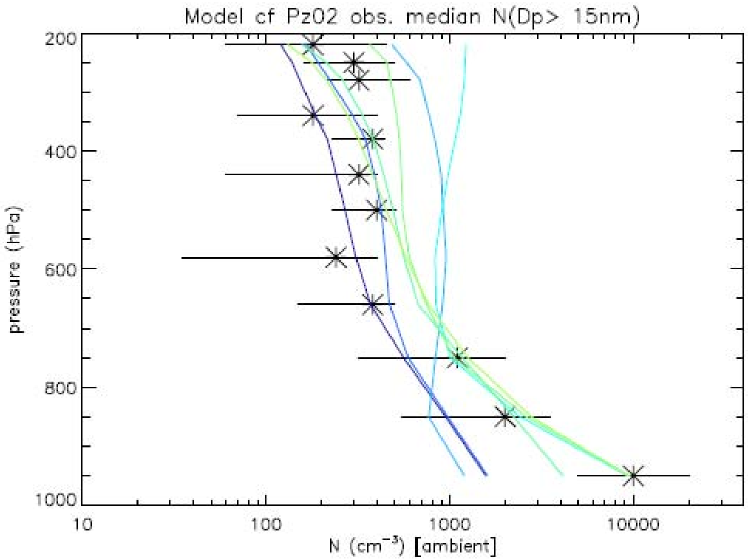


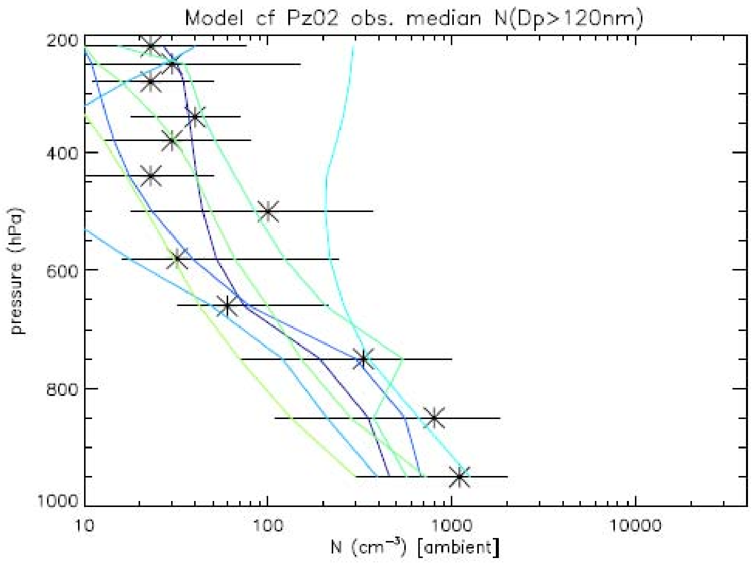

# GLOMAP-mode v4 vs N(Dp>5,15,120nm) LACE campaign

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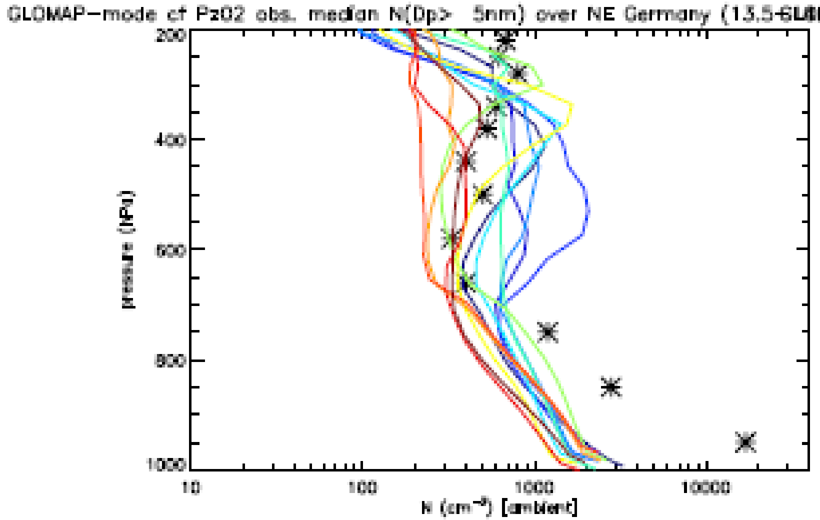


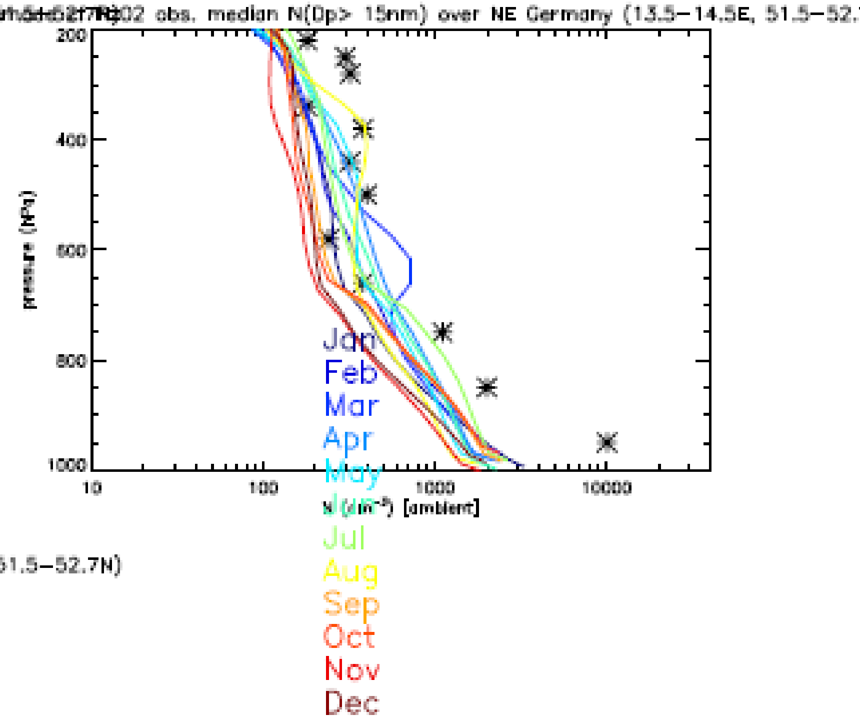


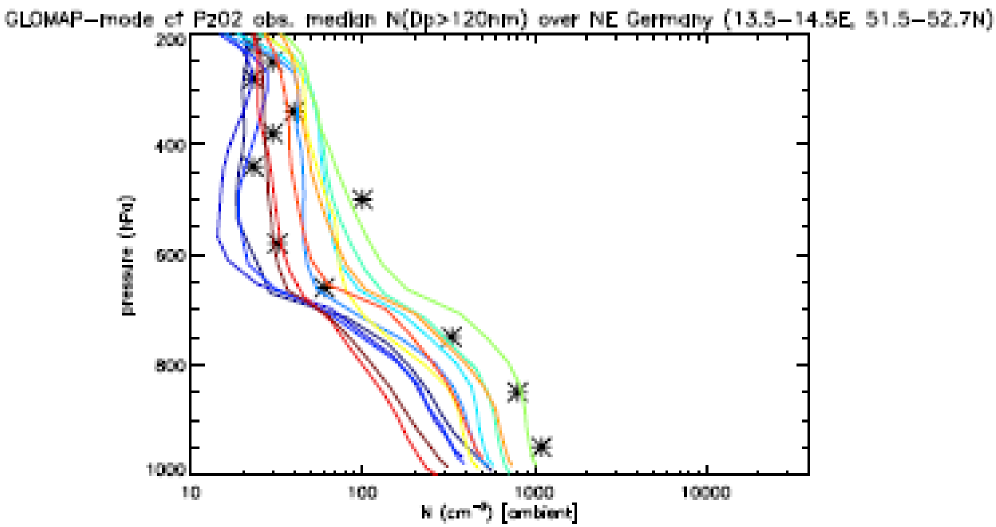

# Compilation of aircraft-borne CNC measurements from several field campaigns

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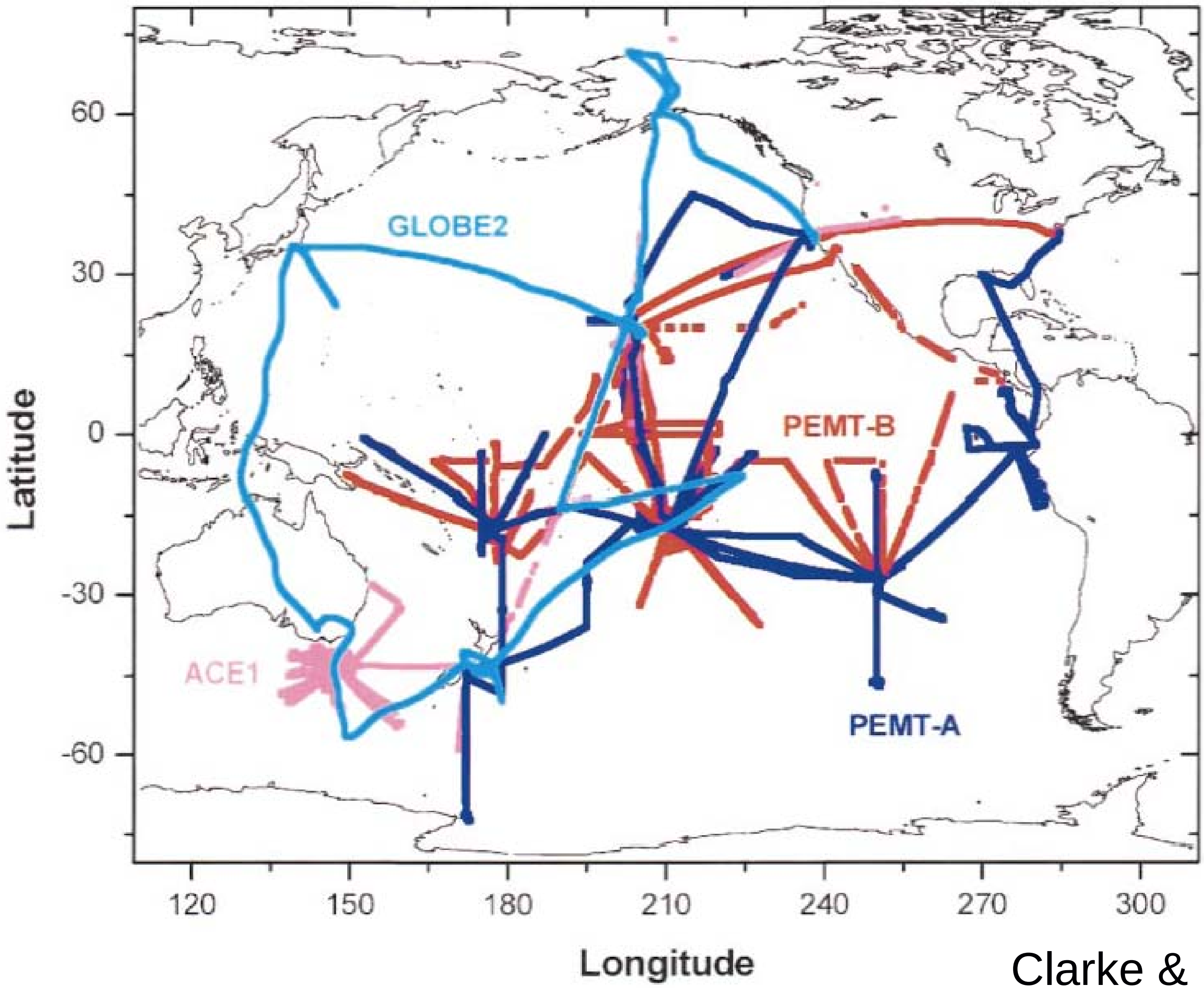


Clarke & Kapustin (2002)

# Compilation of aircraft-borne CNC measurements from several field campaigns

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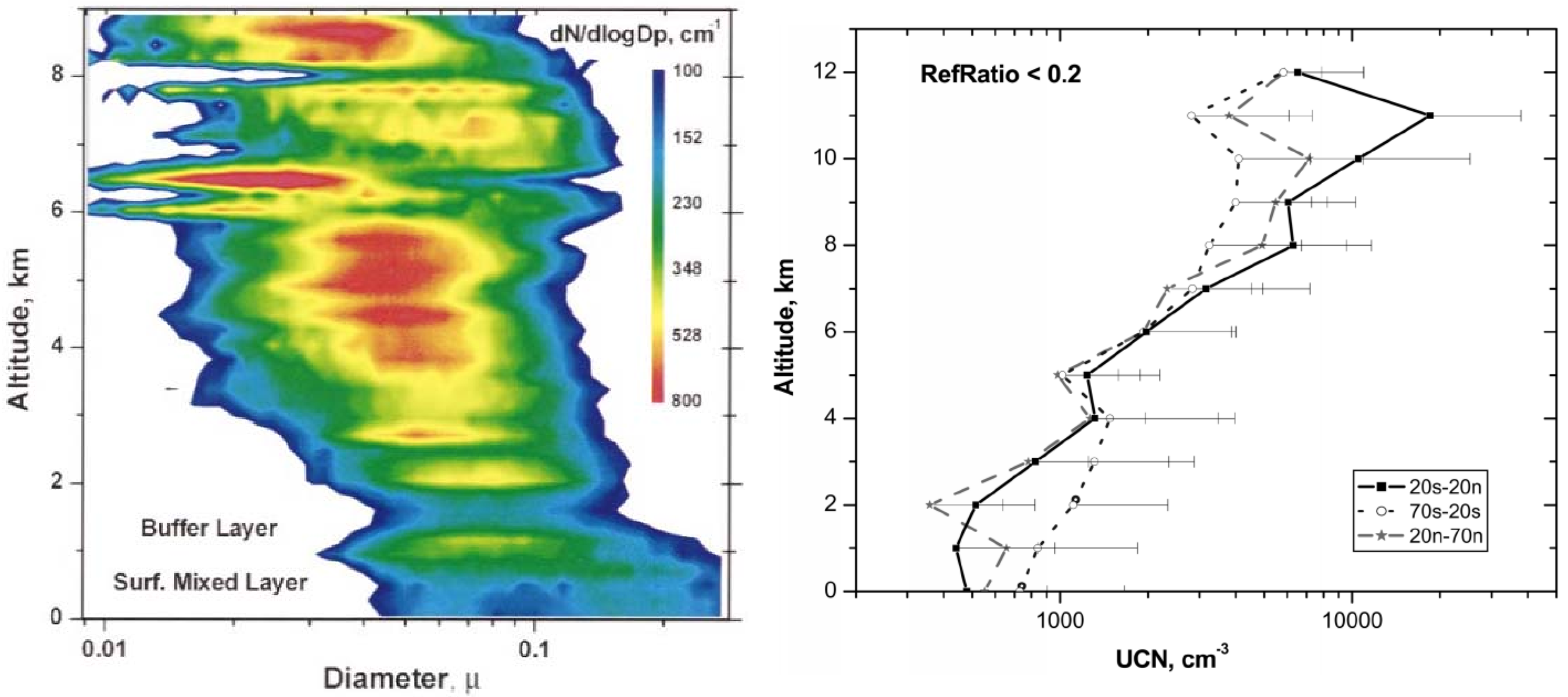


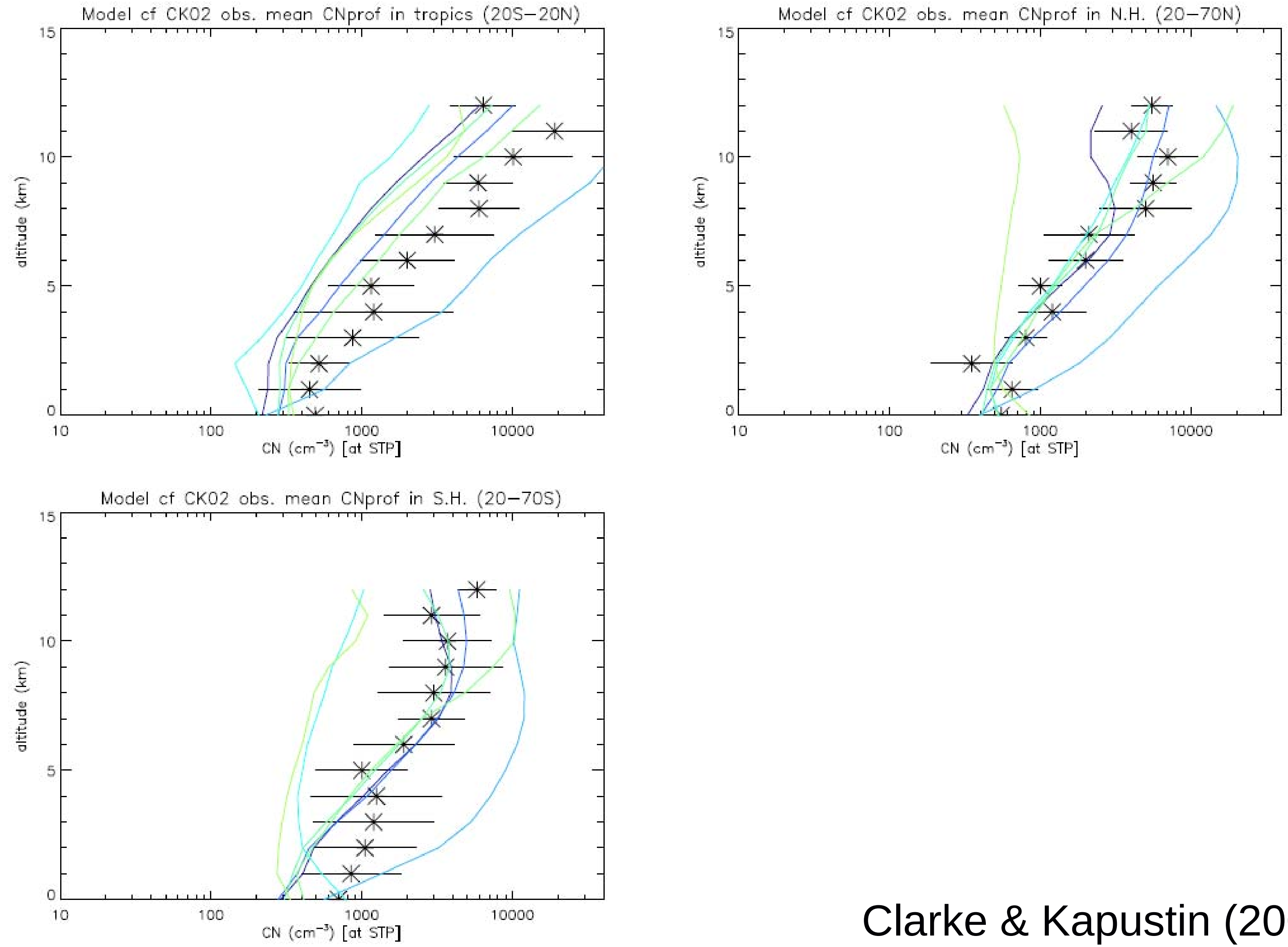

Size distributions unimodal in FT growing from 5km→2km over Pacific.
Bi-modal MBL size distributions withHoppel gap following cloud processing.

CN peak in FT – nucleation layer.

Clarke & Kapustin (2002)

# Compilation of aircraft-borne CNC measurements from several field campaigns

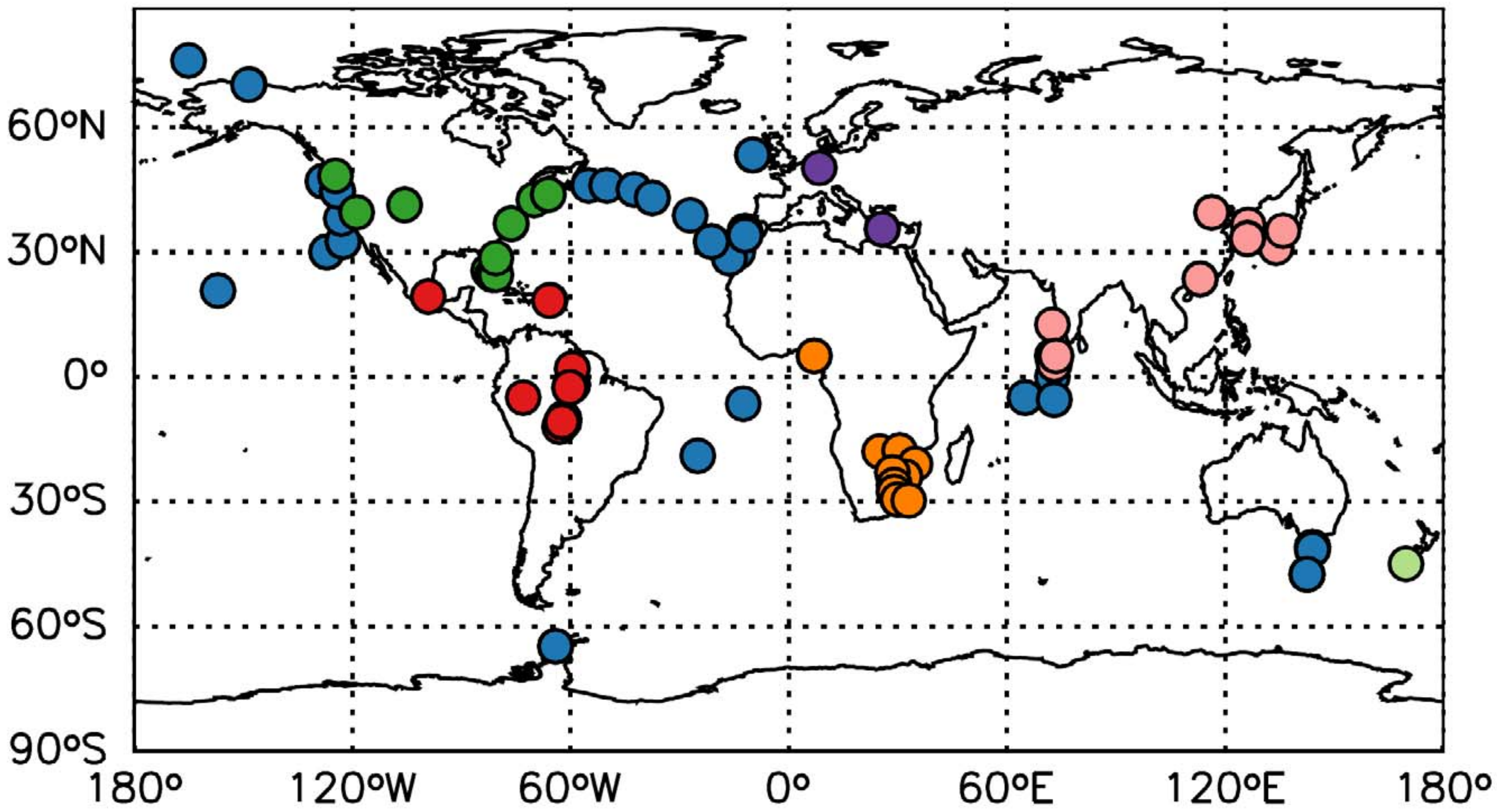
UNIVERSITY OF LEEDS




Clarke & Kapustin (2002)

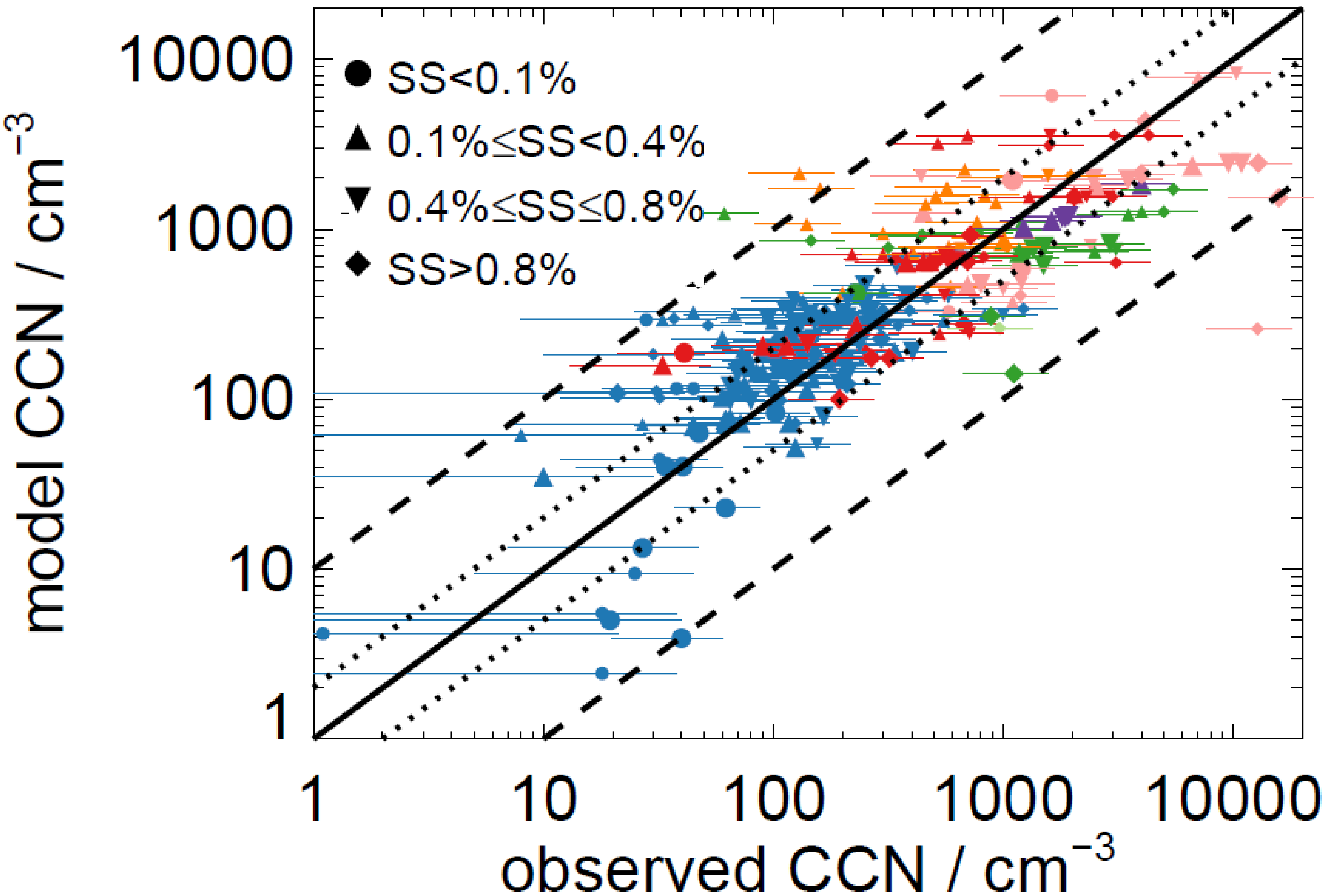
# 4. Compilation of CCN counter measurements

UNIVERSITY OF LEEDS




Compilation of CCN observations gathered by Dominick Spracklen (Leeds) (Spracklen et al, 2011, ACPD)

UNIVERSITY OF LEEDS



# 5.Size distribution at EUSAAR supersites

UNIVERSITY OF LEEDS

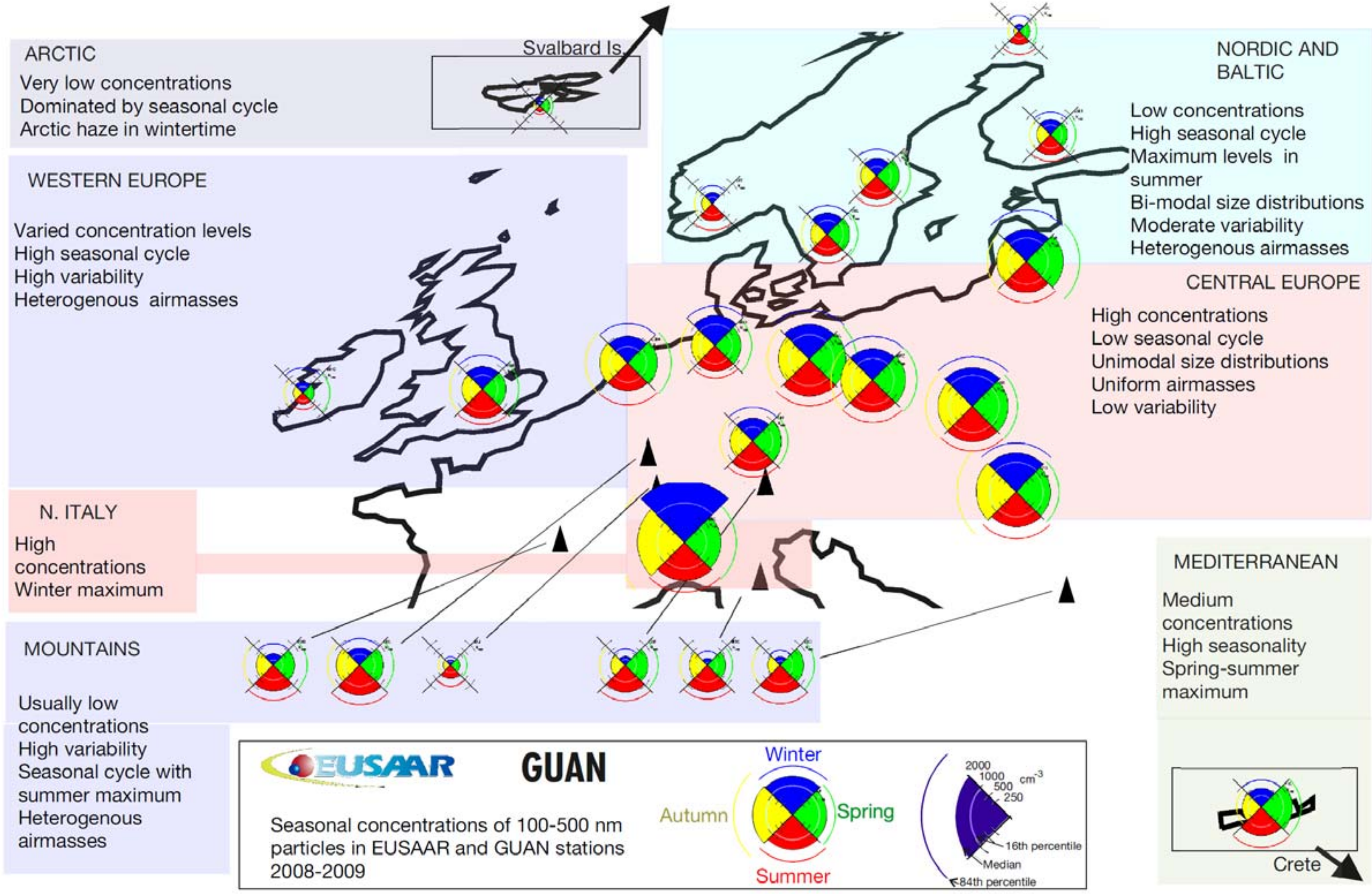



**Fig. 15.** Overview of EUSAAR and GUAN station measurements – spatial distribution of particle number concentrations on particle (in $cm^{-3}$ STP). The coloured areas are relative to the median concentration observed in each season, and the lower and higher arcs show 16th and 84th percentile concentrations. The colours and location of the segments show different seasons. The locations of the stations are approximate. Stations ZEP (Arctic) and FKL (Mediterranean) are located in inserts.

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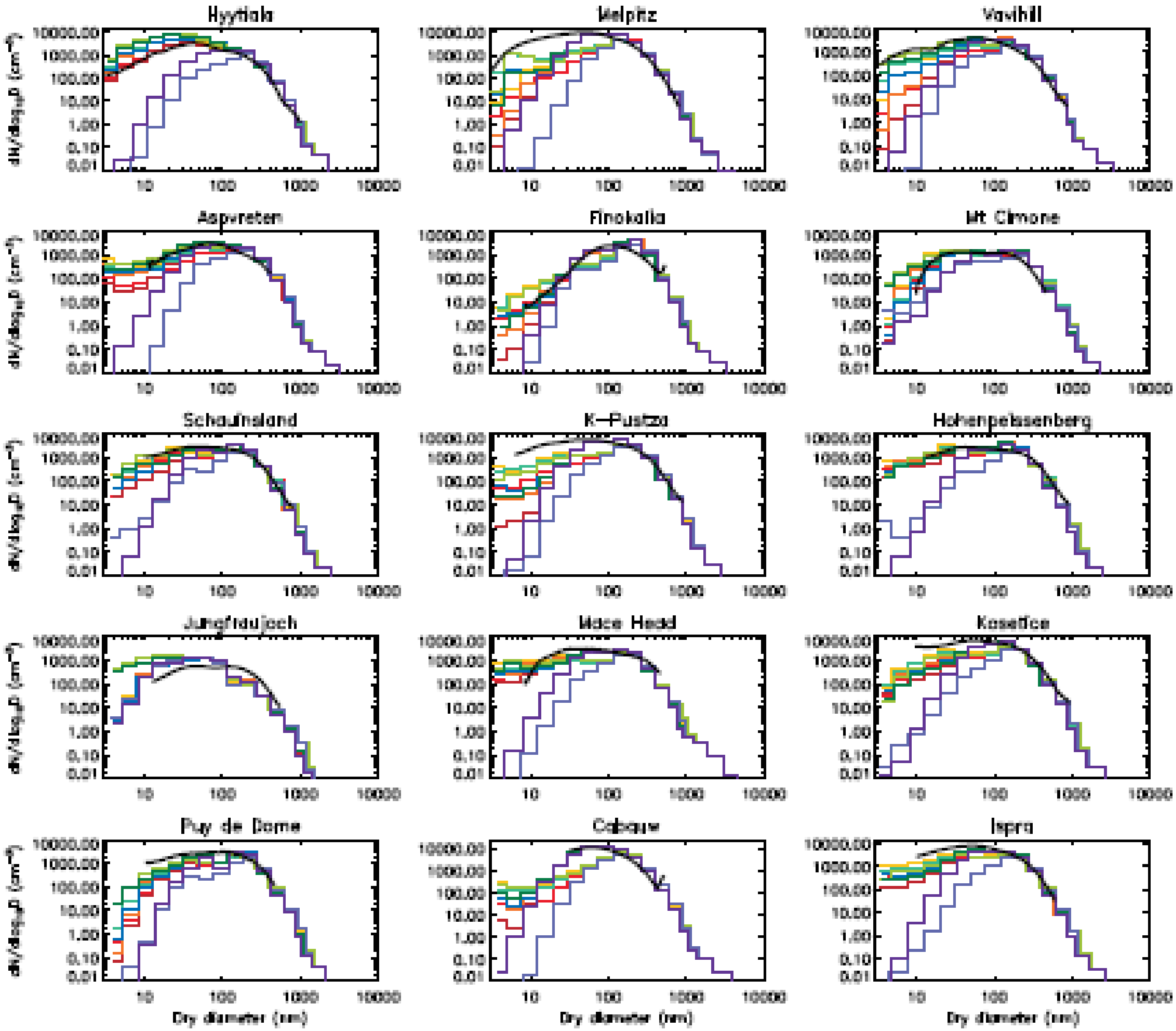
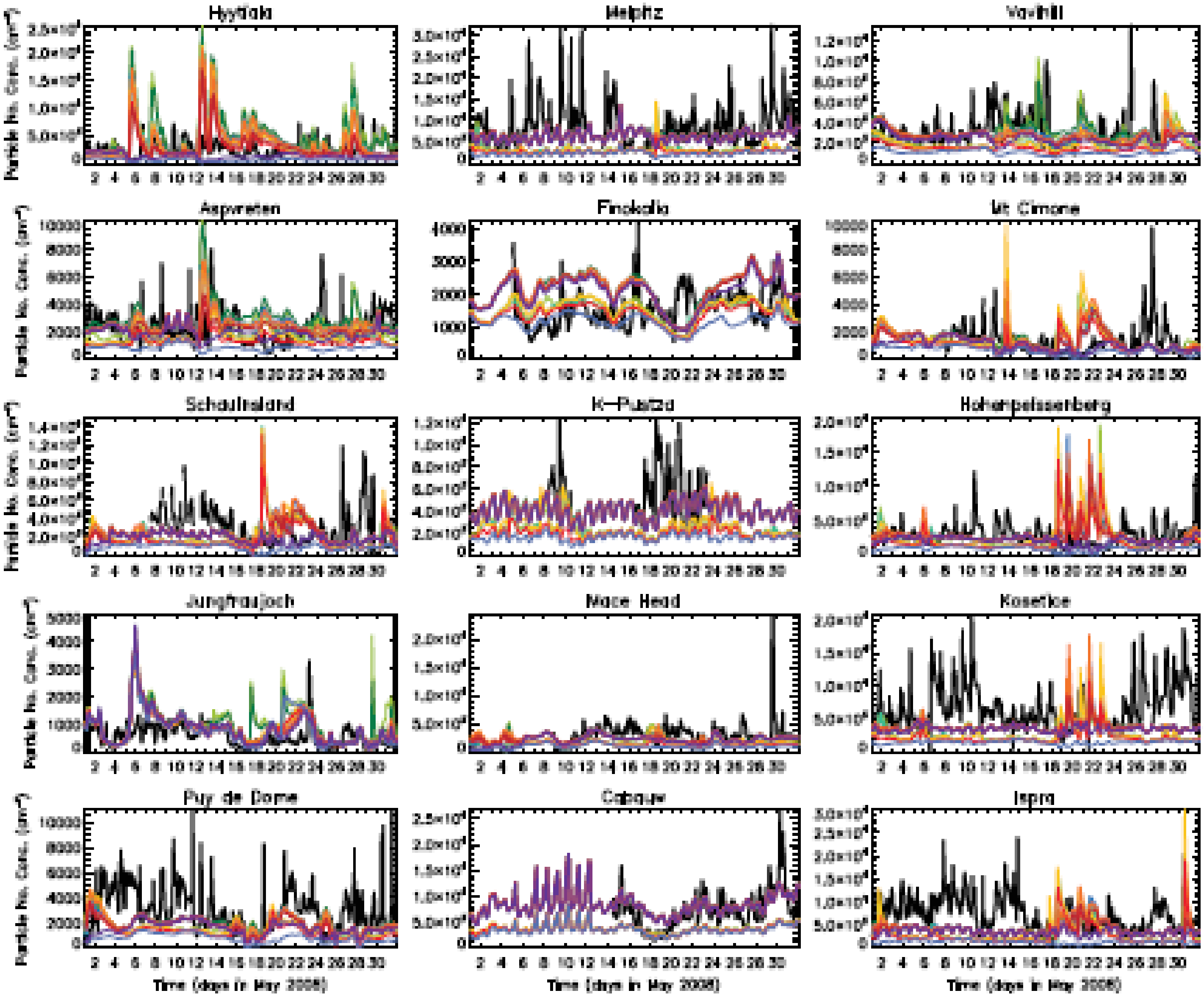
# 5.Size distribution at EUSAAR supersites




Reddington et al, 2011, ACPD)

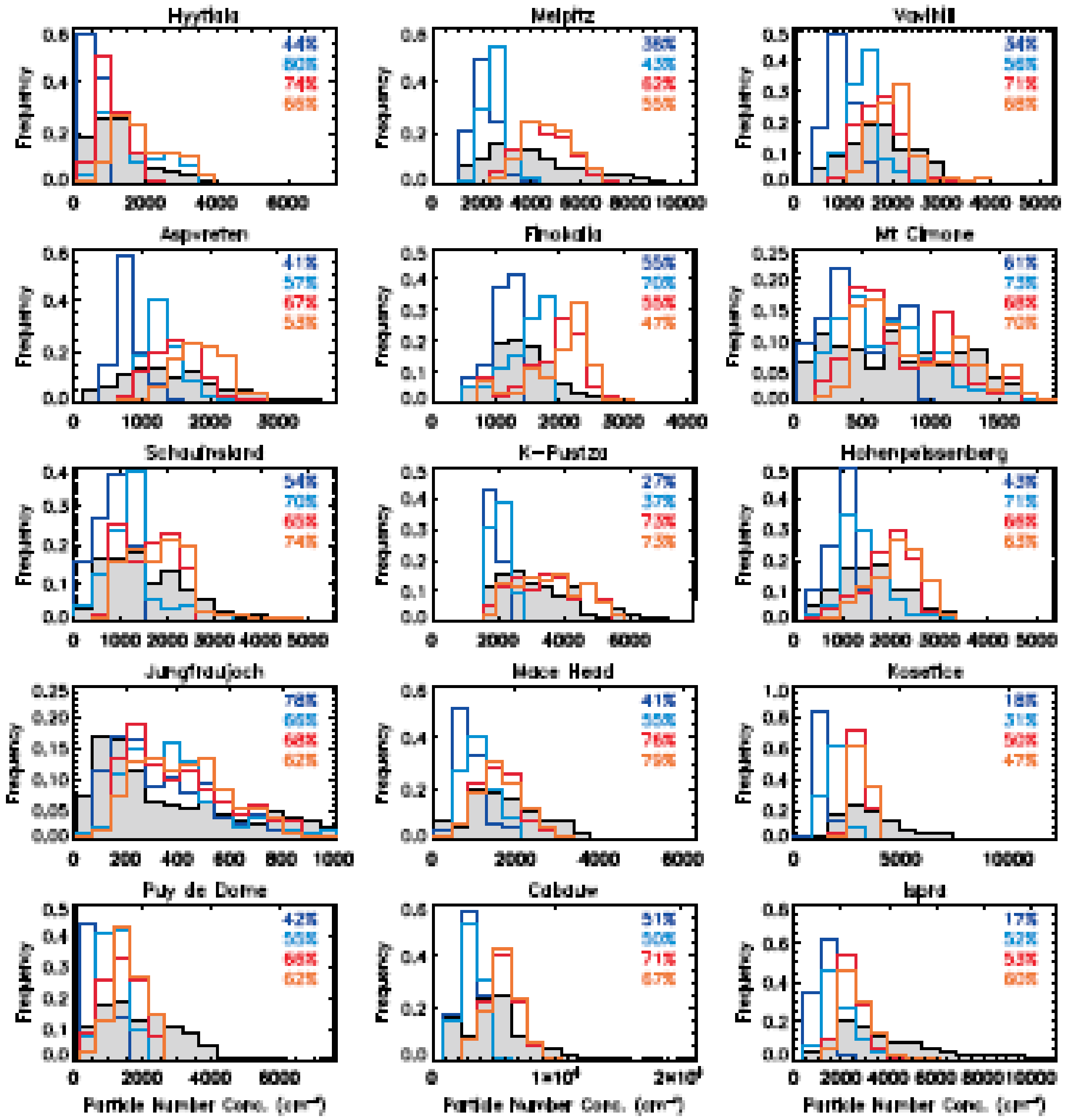
# 5.Size distribution at EUSAAR supersites

UNIVERSITY OF LEEDS




Reddington et al, 2011, ACPD)

# 5.Size distribution at EUSAAR supersites




Reddington et al, 2011, ACPD)

# Influence of microphysics on CN and CCN,

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In addition to scoring vs observations, evaluate diversity in simulated influence of primaries/nucleation/coagulation/condensation on simulated CN and CCN

**Table 2.** Summary of ground level contribution from primary particles (PR), boundary layer nucleation (BLN) and upper tropospheric nucleation (UTN) to ground level total number (CN) and cloud condensation nuclei (CCN) concentrations at 0.2% and 1.0% supersaturations. The marine regions refer to west of North America (NAM), west of South America (SAM), west of North Africa (NAF), west of South Africa (SAF), and East of North-East Asia (NEA) (see Figure 7).

| | CN | | CCN(1.0%) | | CCN(0.2%) | |
|---|---|---|---|---|---|---|
| Region | Tot [$cm^{-3}$] | PR-UTN-BLN [%] | Tot [$cm^{-3}$] | PR-UTN-BLN [%] | Tot [$cm^{-3}$] | PR-UTN-BLN [%] |
| **Total Global** | 1064 | 27-25-47 | 513 | 49-33-18 | 314 | 61-31-8 |
| **Total Marine** | 758 | 19-33-48 | 331 | 41-44-15 | 204 | 52-40-9 |
| NAM | 596 | 20-63-18 | 384 | 28-63-8 | 396 | 36-56-9 |
| SAM | 567 | 14-41-45 | 273 | 31-58-11 | 148 | 41-53-7 |
| NAF | 1003 | 12-31-57 | 413 | 28-52-20 | 414 | 36-48-15 |
| SAF | 619 | 23-41-36 | 345 | 40-50-10 | 266 | 48-45-7 |
| NEA | 1423 | 35-35-30 | 877 | 52-35-13 | 886 | 62-30-8 |
| **Total Continental** | 1921 | 36-18-46 | 1024 | 57-23-20 | 625 | 69-23-7 |
| Europe | 2611 | 47-11-42 | 1647 | 63-15-22 | 932 | 67-24-10 |
| Africa | 1279 | 50-20-29 | 900 | 63-25-12 | 719 | 71-24-6 |
| N. America | 2600 | 20-12-69 | 1079 | 40-24-36 | 554 | 51-32-17 |
| S. America | 1713 | 36-15-49 | 922 | 61-25-14 | 613 | 71-26-3 |
| N. Asia | 1119 | 22-26-53 | 554 | 38-34-28 | 288 | 56-31-13 |
| SE Asia | 4543 | 46-14-40 | 2443 | 70-15-14 | 1384 | 83-13-4 |
| Oceania | 1335 | 21-20-59 | 778 | 34-31-36 | 431 | 51-38-11 |

Merikanto et al (ACP, 2009)

# Summary

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Large number of global aerosol microphysics models have submitted the all-aerosol-tracer data to the AEROCOM phase-2 experiments.

Enables a ground-breaking intercomparison of simulated size distributions, CN and CCN concentrations amongst the models.

Document the diversity that exists amongst the aerosol microphysics models

Assembled 5 syntheses of in-situ observations from a wider range of field campaigns and monitoring sites that allow the models to be evaluated objectively and quantitatively.

Produce Taylor-diagrams of model skill-scores in terms of normalised-bias and Pearson correlation coefficient for each datasets/metric.

Generate regional CN, CCN concentrations from the models.

Add other observational syntheses to comparison (although plenty already!)?

Analyse the high-temporal-resolution (0D-H) datasets and produce pdf-based comparisons against those at the EUSAAR-GUAN supersites

Quantify multi-model contributions of primary/secondary aerosol to CCN.

# 1. CN concentrations from GAW and other sites

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| Station Name | Location | Altitude (m) | Observation period | Min. cutoff diameter (nm) | Reference |
|---|---|---|---|---|---|
| | | | Free troposphere | | |
| Jungfraujoch | 8.0E , 46.6N | 3580 | 1995-1999, 2003-2007 | 10 | Weingartner et al. (1999) |
| Puy de Dome | 3.0E, 45.8N | 1465 | 2005-2008 | 3 | Venzac et al. (2009) |
| Nepal C.O. | 86.8E, 28.0N | 5079 | 2007-2008 | 10 | Venzac et al. (2008) |
| Mauna Loa | 155.6W, 19.5N | 3397 | 1975-2000 | 10 | Bodhaine (1996) |
| South Pole | 24.8W, 90S | 2841 | 1974-1999 | 10 | |
| Pico Espejo | 71.1W, 8.5N | 4775 | 2007-2009 | 10 | |
| Mount Washnigton | 71.3W, 44.3N | 1910 | 2002-2005 | 10 | |
| | | | Marine boundary layer | | |
| Mace Head | 350.1E, 53.3N | 0 | 2000, 2002-2007 | 10 | O'Dowd et al. (1998) |
| Neumayer | 8.3W, 70.7S | 42 | 1993-2006 | 10 | Weller and Lampert (2008) |
| Point Barrow | 156.6W, 71.3N | 11 | 1994-2007 | 10 | Bodhaine (1989) |
| Samoa | 170.6W, 14.2S | 77 | 1977-2006 | 10 | |
| Trinadad Head | 124.2W, 41.1N | 107 | 2002-2007 | 10 | |
| Cape Grim | 144.7E, 40.6S | 94 | 1996-2007 | 3 | Gras (1995) |
| Sable Island | 60.0W 43.9N | 5 | 1992-2000 | 10 | |

Spracklen et al, (ACP, 2010)

# 1. CN concentrations from GAW and other sites

UNIVERSITY OF LEEDS

| Station Name | Location | Altitude (m) | Observation period | Min. cutoff diameter (nm) | Reference |
|---|---|---|---|---|---|
| Continental boundary later | | | | | |
| Hyyti¨al¨a | 24.3E, 61.9N | 180. | 2000-2004 | 3 | Aalto et al. (2001) |
| Pallas | 24.1E, 68.0N | 340. | 2000-2004, 2007 | 10 | Komppula et al. (2003) |
| Finokalia | 25.7E, 35.3N | 0 | 1997, 2006-2007 | 10 | |
| Hohenpeissenberg | 11.0E, 47.8N | 995 | 2006-2007 | 3 | Birmili et al. (2003) |
| Melpitz | 12.3E, 51.2N | 86 | 1996-1997, 2003 | 3 | |
| Bondville | 88.4W, 40.1N | 213 | 1994-2007 | 10 | |
| Southern Great Plains | 97.5W, 36.6N | 320 | 1996-2007 | 10 | |
| Tomsk | 85.1E, 56.5N | | 2005-2006 | 3 | Dal Maso et al. (2008b) |
| Listvyanka | 104.9E, 51.9N | | 2005-2006 | 3 | Dal Maso et al. (2008b) |
| Harwell | 359.0E, 51.0N | 60 | 2000 | 10 | |
| Weybourne | 1.1, 53.0N | 0 | 2005 | | |
| Botsalano | 25.8E, 25.5S | 1424 | 7/2006-6/2007 | 10 | Laakso et al. (2008) |
| India Himilaya | 79.6E, 29.4N | 2180 | 2005-2008 | 10 | Komppula et al. (2009) |
| Aspvreten | 17.4E, 58.8N | 25 | 2000-2006 | 10 | Dal Maso et al. (2008a) |
| Ut¨o | 21.4E, 59.8N | 8 | 2003-2006 | 7 | Dal Maso et al. (2008a) |
| Varri¨o | 29.6E, 67.8N | 400 | 1998-2006 | 8 | Dal Maso et al. (2008a) |
| Thompson Farm | 289.1E, 43.1N | 75 | 2001-2009 | 7 | Ziemba et al. (2007) |
| Castle Springs | 71.3W, 43.7N | 406 | 2001-2008 | 7 | |

| Location | Latitude/Longitude | Time | S (%) | CCN Instrument[1] | Platform[2]; Field Campaign | Reference |
|---|---|---|---|---|---|---|
| Japan, SW Islands | 132–136° E, 30-32° N | 16–28 Apr 2001 | 0.3 | TGDCC | A; APEX-E2/ACE-Asia | Adhikari et al., 2005 |
| South Atlantic | 40–10° W, 19° S | Feb–Mar 1991 | 0.3 | TGDCC | Sh | Andreae et al., 1995 |
| Cape Grim, Tasmania | 144.7° E, 40.7° S | Long term | 0.23–1.3 | | Su | Ayers et al., 1997; Ayers et al., 1991 |
| Mexico City | 99.1° W, 19.3° N | 13–29 Sep 2000 | 0.5 | STGDCC | Su | Baumgardner et al., 2004 |
| Indian Ocean | 60–75° E, 15° S–15° N | Feb-Mar 1998 | 0.5; 0.75 | CCNR | Sh; INDOEX; | Cantrell et al., 2000 |
| Coastal Florida | 83–81° W, 24–27° N | Jun–Jul 2002 | 0.85 | CCNS | A; CRYSTAL FACE | Conant et al., 2004; Van Reken at al., 2003 |
| Taunus Observatory, Germany | 8.4° E, 50.2° N | 20 Jul–11 Aug 2004 | 0.4 | SDC | Su | Dusek et al., 2006 |
| N. Atlantic | 75° W–37.5° W, 37–43° N | May 1977 | 0.16–0.85 | TGDCC (0.2–1%), IHC (< 0.2%) | Sh | Hoppel, 1979 |
| N. Atlantic, Tenerife | 17.7–10.5° W, 28–32° N | Jun–Jul 1997 | 0.1 | CCNS | A, ACE-2 | Chuang et al., 2000 |
| Korea Global Atmospheric Watch | 126.3° W, 36.5° N | 1–22 May 2004 | 1.0 | DRI | Su | Yum et al., 2005 |
| Arctic, 500 km N of Alaskan coast | 165° W, 76° N | May 1998 | 0.8 | DRI | A; Arctic Clouds Experiment | Yum and Hudson, 2001 |
| Southern Africa | 22–36.5° E, 15–30.5° S | Aug–Sep 2000; Jan 1999; Mar–Apr 2001 | 0.3 | Wyoming STGDCC | SAFARI-2000; ARREX-1999; ARREX-2001 | Ross et al., 2003 |
| Off west coast of US | 130–124° W, 38–44° N | Apr 2004 | 0.2–1.0 | Wyoming STGDCC/DMT-CCNC | Sh, CIFEX | Roberts et al., 2006 |
| Mace Head, Ireland | 9.9° W, 53.3° N | Mar 1994–Sep 1002 | 0.5 | M-1 | Su | Reade et al., 2006 |
| Pacific Ocean off coast of California, USA | 125–120° W; 31–34° N | Jun–Jul 1987 | 0.02-1.0 | DRI | A, FIRE-1 | Hudson and Xie, 1999; Hudson and Frisbie, 1991b |
| Atlantic Ocean between Canaries and Azores | 25–17.5° W, 27.5–37.5° N | Jun 1992 | 0.02–0.6 | DRI | A, ASTEX | Hudson and Xie, 1999; Yum and Hudson, 2002 |
| Balbina, Amazon basin | 59.4° W, 1.92° S | Mar–Apr 1998 | 0.15–1.5 | STGDCC | Su, LBA-CLAIRE | Roberts et al., 2001 |
| Indian Ocean | 72–74° E, 8° S–0° S | Feb–Mar 1999 | 0.1–1.0 | DRI | Sh, INDOEX | Hudson and Yum, 2002 |
| Southern Ocean, off Cape Grim, Tasmania | 144° E, 43–44° N | Jan–Feb 1995; Jul 1993 | 0.02–1.0 | DRI | SOCEX-I and SOCEX-II | Yum and Hudson (2004) |
| Pacific Ocean, near Hawaii | 156.9° W, 20.7° N | Jul–Aug 1990 | 0.8 | DRI | HaRP | Hudson (1993) |
| Pacific Ocean, off the coast of Washington State, USA | 128° W, 47° N | Dec 1988; June 1989, April 1990 | 1.0 | CCNS | A | Hegg et al., 1991 |
| Reno, USA | 119.8° W, 39.5° N | Dec 1988–May 1990 | 0.75 | DRI | Su | Hudson and Frisbie (1991a) |
| North Atlantic | 11–13° W, 32–38° N | Jul 1997 | 0.2–1.0 | CCN spectrometer | A; ACE-2; | Johnson et al. 2000 |
| Puerto Rico | 65.6° W, 18.4° N | 9–18 Dec 2004 | 0.5; 0.6 | Mainz SDC | Su | Allan et al., 2008 |

| Location | Latitude/Longitude | Time | S (%) | CCN Instrument[1] | Platform[2]; Field Campaign | Reference |
|---|---|---|---|---|---|---|
| Puerto Rico | 65.7° W, 18.3° N | 29 Mar–9 Apr 1992 | 0.5 | M-1 | Su | Novakov and Penner, 1993 |
| Rondonia, Amazon Basin | 61.9° W, 10.9° S | Jan–Mar 1999, Oct–Nov 1999 | 1.0 | M-1 | LBA-EUSTACH | Williams et al. 2002 |
| Amazon Basin | 73° W, −5° N & 63° W, 12° S | Oct 2002 | 1.0 | STGDCC | LBA-SMOCC | Andreae et al., 2004 |
| Atlantic Ocean | 11–14° W, 33–40° N | Jul 1997 | 0.2 | CCNS | A; ACE-2 | Osborne et al., 2000 |
| Atlantic Ocean | 11–13° W, 30–38° N | Jul 1997 | 0.2–1.0 | CCN Spectrometer | A; ACE-2 | Wood et al., 2000 |
| NW Korea | 126.2° W, 33.3° N | Mar–Apr 2005 | 0.6 | DMT-CCNC | Su | Yum et al., 2007 |
| Nagoya, Japan | 135.9° E, 35.1° N | Dec 1998–Jan 1999 | 0.5 | CCNC | Su | Ishizaka et al., 2003 |
| Palmer station, Antarctica | 64.1° W, 64.8° S | Jan–Feb 1994 | 1.0; 0.3 | CCNS | Su | Defelice et al., 1997 |
| Finokalia, Greece | 25.7° E, 35.5° N | Jun–Oct 2007 | 0.21–0.73 | DMT-CCNC | Su | Bougiatioti et al., 2009 |
| East coast of Florida, USA | 80.5° W, 28.5° N | Jul–Aug 1995 | 1.0 | DRI | A; SCMS | Hudson and Yum, 2001 |
| Jeju Island, Korea | 126.1° E, 33.2° N | Mar–Apr 2005 | 0.09-0.97 | DMT-CCNC | Su, Atmospheric Brown Cloud | Kuwata et al., 2008 |
| Kaashidhoo Climate Observatory | 73.47° E, 4.97° N | Feb–Mar 1999 | 0.3, 0.5 | CCNR | Su, INDOEX; | Cantrell et al., 2001 |
| Laramie, Wyoming, USA | 105.6° W, 41.3° N | Jun–Sep 1996; Nov 1995; Jan 1997 | 1.0 | STGDCC | A | Delene and Deshler, 2001 |
| Lauder, New Zealand | 169.7° E, 45.0° S | Feb 1996 | 1.0 | STGDCC | A | Delene and Deshler, 2001 |
| Ivory Coast, Africa | 7° E , 5° N | Dry & wet season | 0.32-0.85 | TGDCC | Su | Désalmand, 1985 |
| Tenerife, Atlantic | 16.3° W, 28.5° N | Jun–Jul 1997 | 1.0 | Wyoming STGDCC | A; ACE-2 | Snider and Brenguier, 2000 |
| Arctic, Near Prudhoe Bay, Alaska | 70.3° N, 148.3° W | Jun 1995 | 1.0 | CFDCC | A | Hegg et al., 1996 |
| NW Atlantic, off Nova Scotia | 43.8° N, 66.1° W | Aug–Sep 1993 | 0.06; 0.4 | M1 (0.4%); IHC(0.06%) | A, NARE | Liu et al., 1996 |
| El Yunque peak, Puerto Rico | 65.75° W, 18.32° N | Mar–Apr 1992 | 0.5 | M1 | Su | Rivera-Carpio et- al., 1996 |
| Point Reyes, California coast, USA | 122.98° W, 38° N | Oct 1993, Jun–Jul 1994 | 0.5 | M1 | Su | Rivera-Carpio et- al., 1996 |
| Amazon basin | 59.5° W, 1.9° S | Jul 2001 | 0.12–1.2 | STGDCC | Su | Rissler et al., 2004 |
| Oregon Coast, USA | 124.1° W, 44.6° N | Jan and Jul 1971 | 0.1–1.0 | TGDCC | Sh | Elliot and Egami, 1975 |
| Southern Ocean, near Tasmania | 137°–160° E, 40°–55° S | Nov–Dec 1995 | 0.02-1.0 | DRI | A, ACE-1 | Hudson et al., 1998 |
| Arctic Ocean, near Deadhorse, Alaska | 148.5° W, 70.2° N | Apr 1992 | 1.0 | CCNS | A, DEADEX | Hegg et al., 1995 |
| Amazon Basin, near Manaus, Brazil | 60.21° W, 2.59° S | Feb–Mar 2008 | 0.1–0.82 | DMT-CCNC | Su; AMAZE | Gunthe et al., 2009 |
| Fallon, Nevada, USA | 118.78° W, 39.47° N | Aug–Oct 1975 | 0.91 | CFDCC | Su | Hudson and Squires, 1978 |

| Location | Latitude/Longitude | Time | S (%) | CCN Instrument[1] | Platform[2]; Field Campaign | Reference |
|---|---|---|---|---|---|---|
| Cheeka Peak, Washington State, USA | 124.62° W, 48.3° N | Apr 1991 | 0.3 | STGDCC | Su | Quinn et al., 1993 |
| NE Atlantic Ocean | 27.1° W, 38.8° N | Jun 1992 | 1.0 | CCNS | A | Hegg et al., 1993 |
| Fazenda Nossa, Amazon basin | 62.35° W, 10.8° S | Oct to Nov 2002 | 0.2–1.12 | TGDCC | Su, LBA-SMOCC | Vestin et al., 2007 |
| Guangzhou, China | 113.1° E, 23.54° N | 1–30 Jul 2006 | 0.07-1.27 | DMT-CCNC | Su | Rose et al., 2010 |

[1] DRI: Desert Research Institute (DRI) airborne instantaneous CCN spectrometer (Hudson, 1989); CCN spectrometer (Hoppel et al., 1979; Saxena and Kassner, 1970; Fukuta and Saxena, 1979a, b; Radke at al., 1981); DMT-CCNC: Droplet measurement technologies (DMT) stream-wise thermal-gradient CCN counter (Roberts and Nenes, 2005; Lance et al., 2006; Rose et al., 2008); CCNR: CCN Remover (Ji et al., 1998); TGDCC: Thermal-gradient diffusion cloud chamber (Désalmand, 1985); STGDCC: Static thermal-gradient diffusion cloud chamber (Delene et al., 1998; Delene and Deshler, 2000); IHC: Isothermal Haze Counter (Fitzgerald et al., 1981); M-1: DH Associates, parallel-plate diffusion cloud chamber (Phillipin and Betterton, 1997); SDC: Static parallel-plate thermal-gradient diffusion cloud chamber (Frank et al., 2007); CFDCC: Continuous-flow diffusion cloud chamber (Hudson and Squires, 1976; Hudson and Alofs, 1981); CCNC: CCN counter (Model 130, Mee) (Ishizaka et al., 2003).

[2] Su: surface; Sh: ship; A: above the surface (aircraft or balloon).

# Development of process-based global aerosol microphysics models

# Process models can include high complexity

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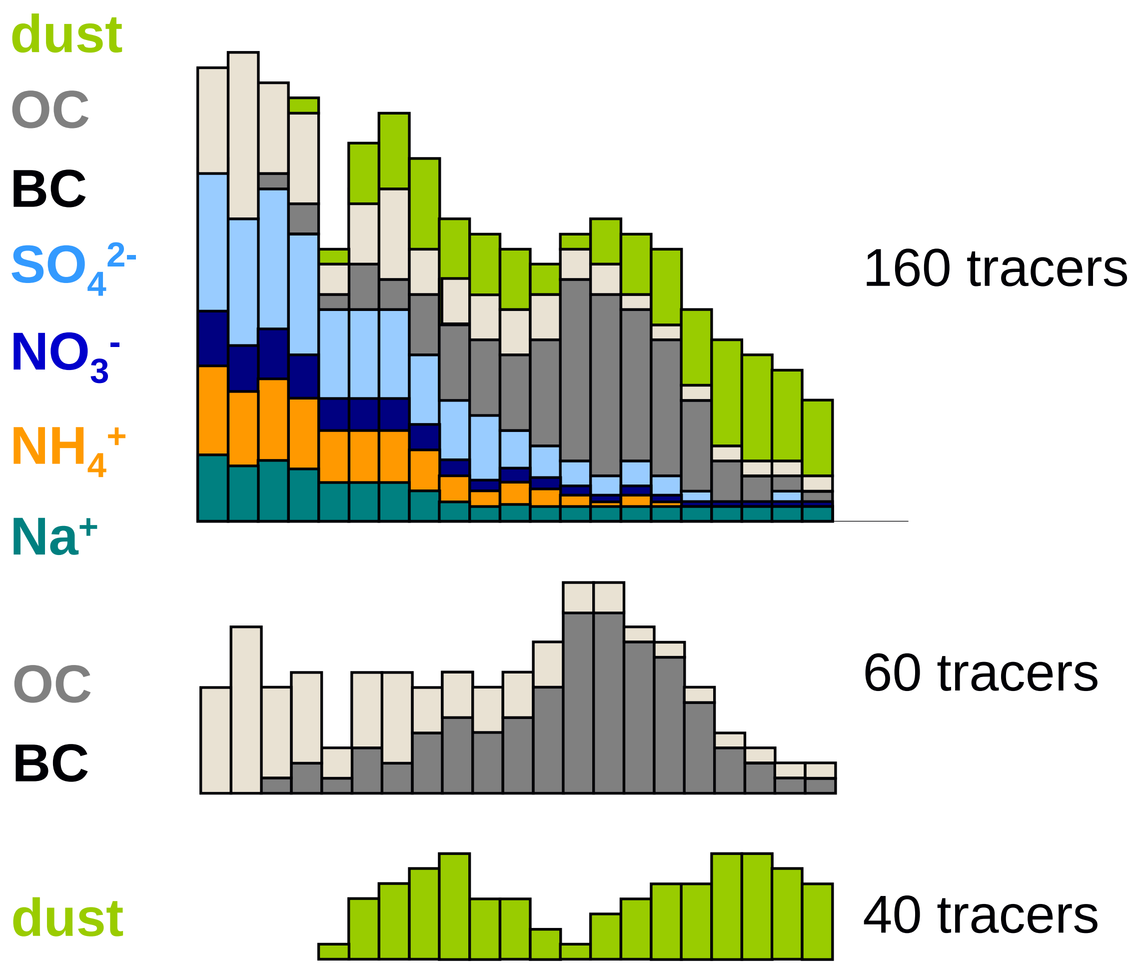
**In box models, 2D models or 3D offline models of short integrations, one can afford to track high degree of sophistication**

**160** tracers for a basic fully internally mixed size and composition resolved distribution

**~260** tracers to resolve basic 'fresh' particles

**>400** tracers to resolve ageing of fresh particles




But in a climate model (e.g. HadGEM):
**25** tracers for aerosol considered high

# Evolution of complexity in aerosol-climate models

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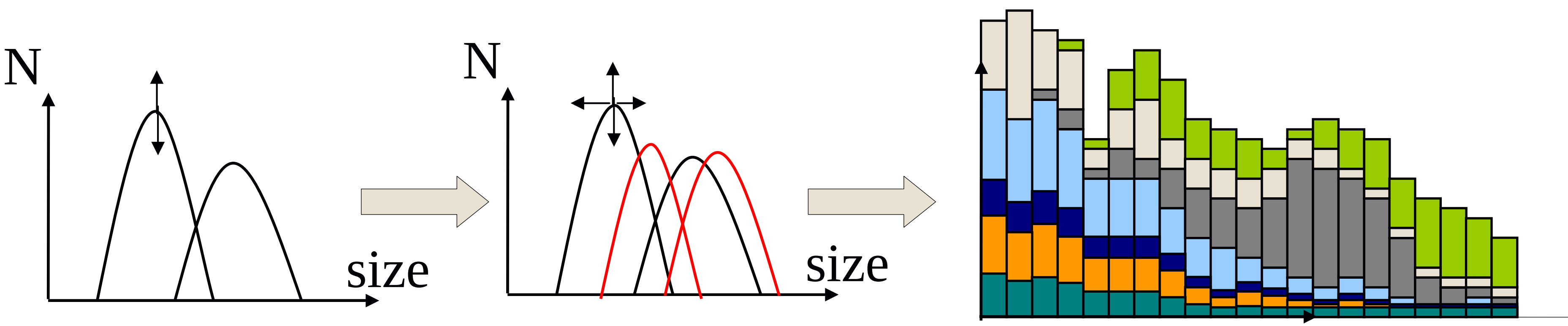
Current state-of-the-science in aerosol-climate models has moved on from 1st generation mass-based only models.

Established recognition now that aerosol-climate models need to simulate particle number to allow size distribution to evolve according to the chemical & microphysical processes, and represent of size-resolved chemical composition



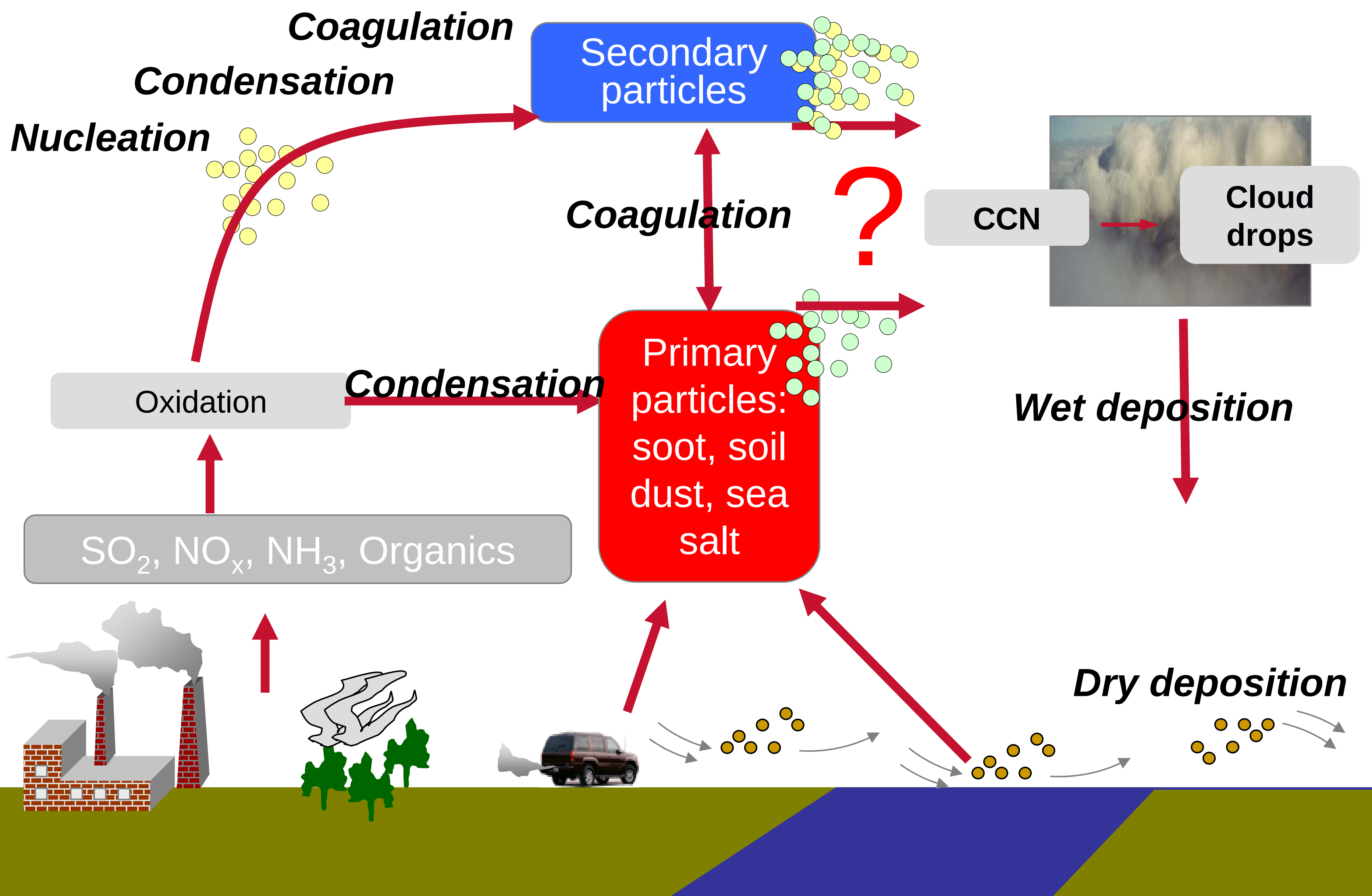

*1st generation climate model schemes*

*New generation of climate models with modal aerosol dynamics*

*"Research models" bin-resolved Future GCMs?*

# Primary & secondary sources of aerosol





# Benchmark GLOMAP-mode vs bin in CTM

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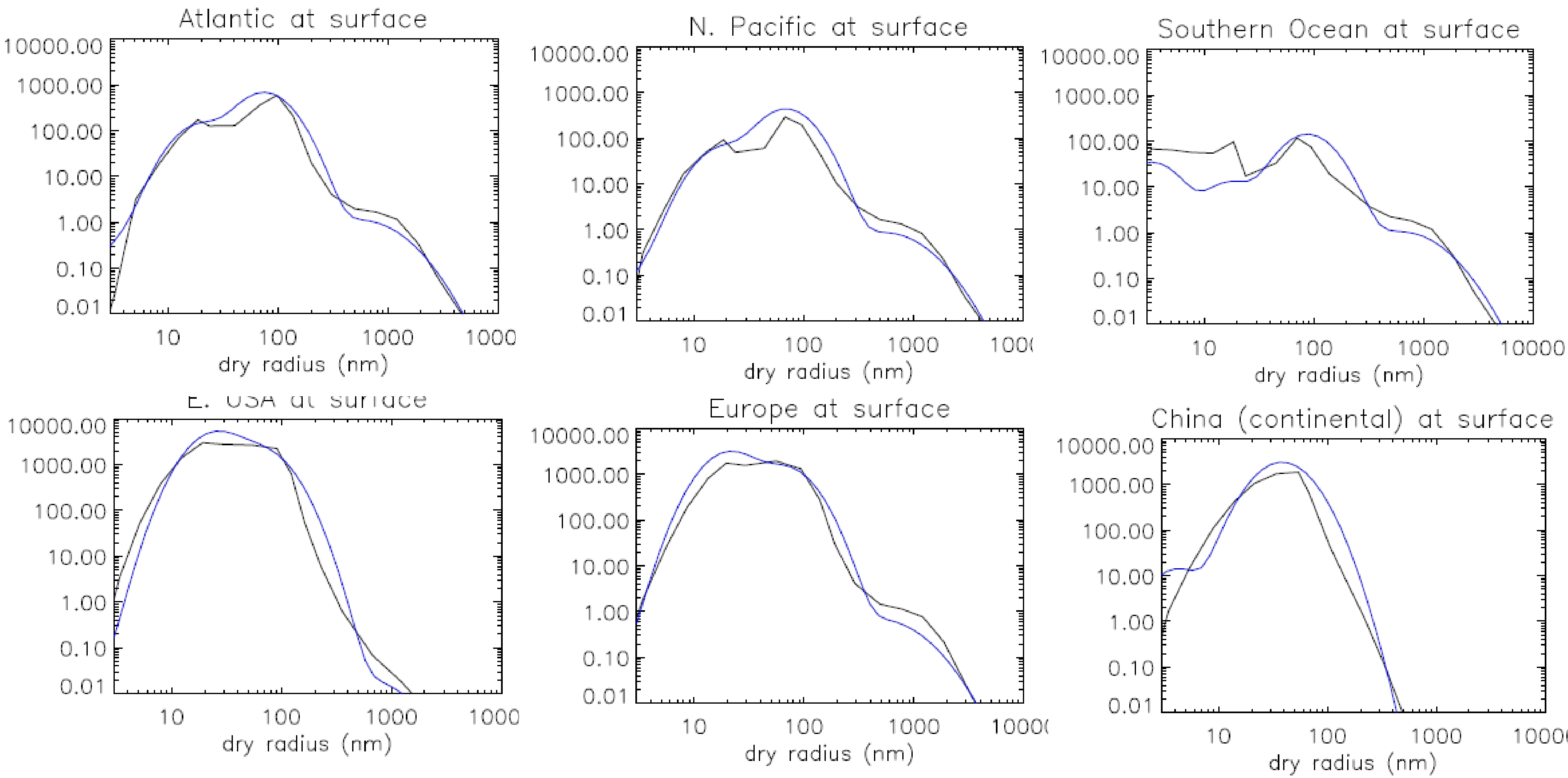


Mann et al, in prep, 2011

**GLOMAP-bin**

**GLOMAP-mode (sigma-acc=1.59, dplim34=1000nm as M7)**

# Improve GLOMAP-mode vs bin in CTM

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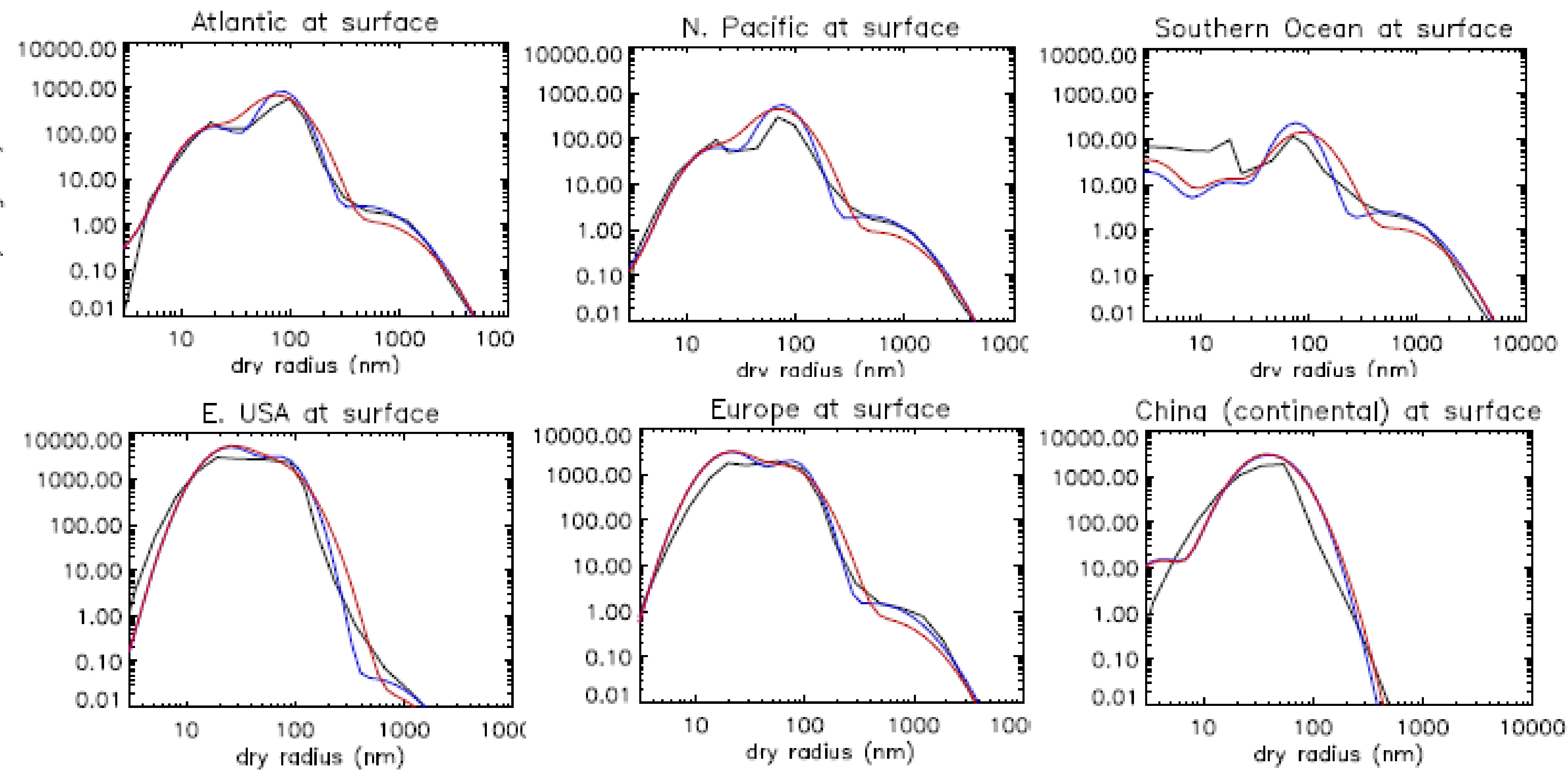


Mann et al, in prep, 2011

**GLOMAP-bin**

**GLOMAP-mode (sigma-acc=1.59, dplim34=1000nm as M7)**

**GLOMAP-mode (sigma-acc=1.40, dplim34= 500nm)**

# Improve GLOMAP-mode vs bin in CTM

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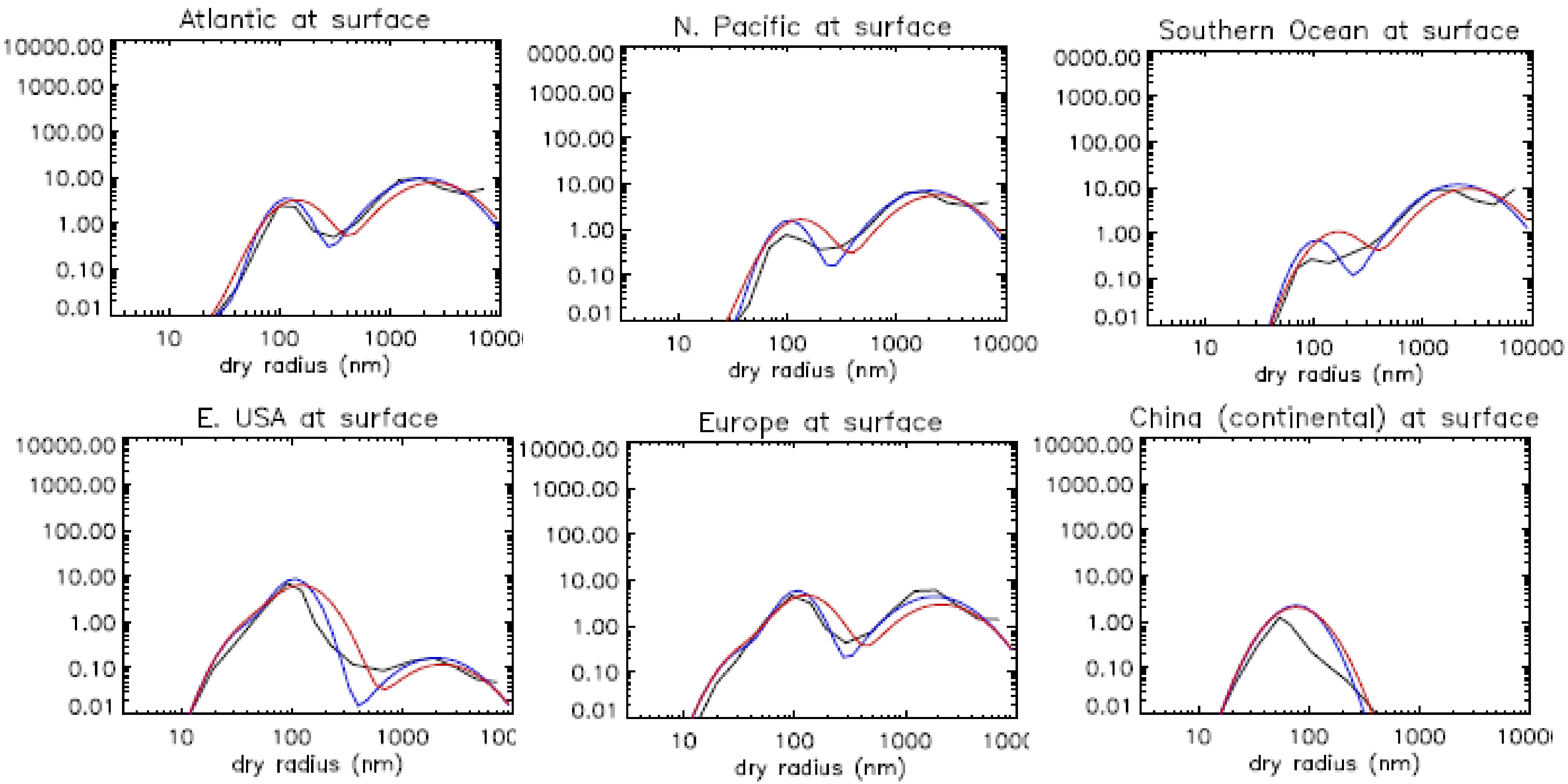


Mann et al, in prep, 2011

**GLOMAP-bin**

**GLOMAP-mode (sigma-acc=1.59, dplim34=1000nm as M7)**

**GLOMAP-mode (sigma-acc=1.40, dplim34= 500nm)**

# Improve GLOMAP-mode vs bin in CTM

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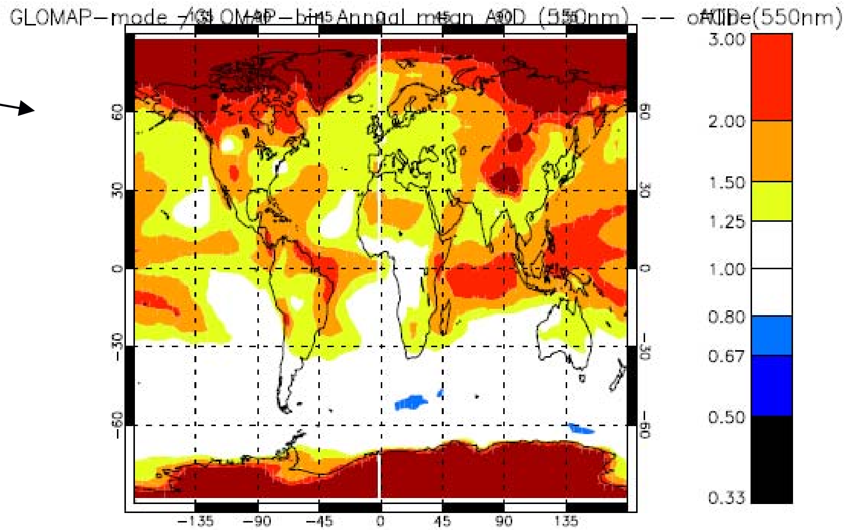
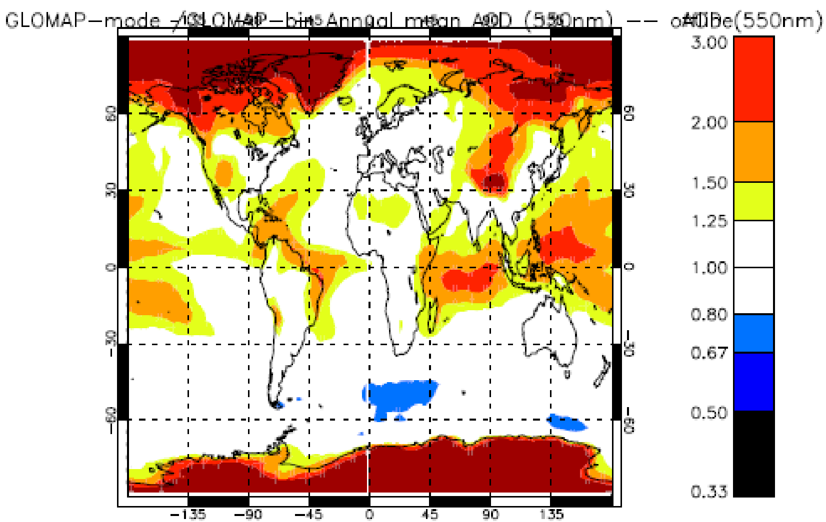
Original model




AOD high-bias greatly reduced due following examination of size-distbns

Revised model




Mann et al, in prep, 2011