School of Earth and Environment
INSTITUTE FOR CLIMATE AND ATMOSPHERIC SCIENCE

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Global size-resolved dust modeling with GLOMAP

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NATURAL ENVIRONMENT RESEARCH COUNCIL

Global Model of Aerosol Processes (GLOMAP)

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Global CTM forced by 6-hourly ECMWF winds

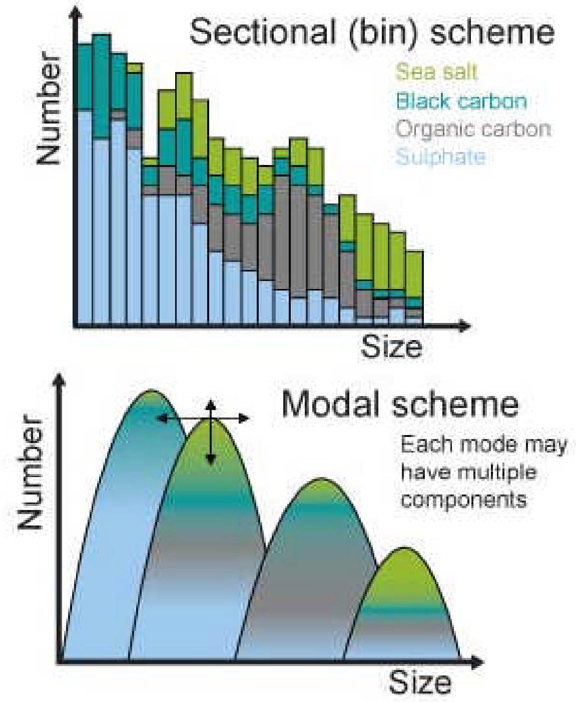
Usually run at T42L31 (2.8°x2.8°) resolution
(nested version in development → ~10km)

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

Chemistry usually driven by offline oxidants,
now coupled to CTM 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-H_2O
and also now implemented boundary layer nucleation mechanism

Spracklen et al. (ACP, 2005a,b, 2006, 2007)

UKCA uses GLOMAP-mode

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The Global Model of Aerosol Processes (GLOMAP) was developed in Leeds to model aerosol microphysics & chemistry with detailed size-resolved composition.

2 aerosol schemes → **GLOMAP-bin** (no. & mass conc. in size **bins**)

The most complete aerosol scheme that can be run globally

GLOMAP-mode (no & mass conc. in log-normal **modes**)

A *reduced GLOMAP, cheap enough to run in the UKCA composition-climate model & coupled to Earth System.*

Observations
Field campaigns

↓

TOMCAT global CTM

GLOMAP-bin
aerosol module
(sectional aerosol)

or

GLOMAP-mode
aerosol module
(modal aerosol)

APPRAISE
Community Model

→

Unified Model
HadGEM climate model
QUEST Earth System Model

Met Office

GLOMAP-mode
aerosol module
(modal aerosol)

UKCA
Community Model

→

Climate Prediction

UKCA in QUEST & HadGEM Earth System models

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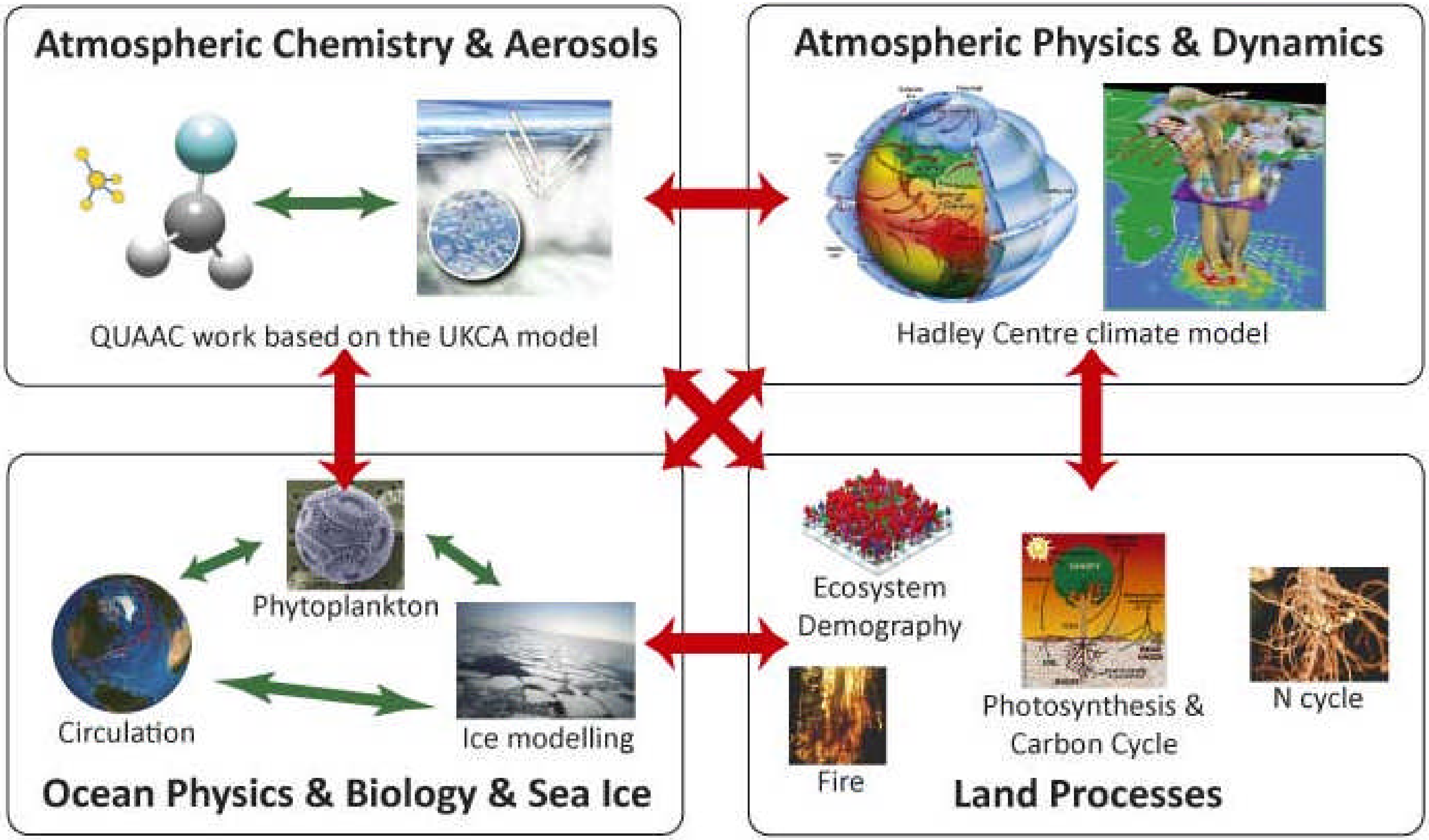

Earth system modelling within QUEST. Based on a diagram by M. Joshi

GLOMAP dust simulations

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Size distribution of dust emissions is a key uncertainty in dust modelling and is critical for the climate impact of dust.

Smallest dust particles (<1μm) have long lifetimes and are the most important particles with respect to climate.

Have implemented scheme of Alfaro & Gomez (2001) which represents the physics of the sand-blasting process.

Experiments in a wind tunnel (Alfaro et al, 1998) showed that saltating aggregates impacting on surface dust release smaller sized particles only in stronger wind events

mode 1 (14.2 μm mass median diameter)
mode 2 (6.7 μm mass median diameter)
mode 3 (1.5 μm mass median diameter)

Modes only released once binding energies exceeded by energy of saltating aggregates.
Small modes have larger binding energies (more energy required)

GLOMAP dust simulations

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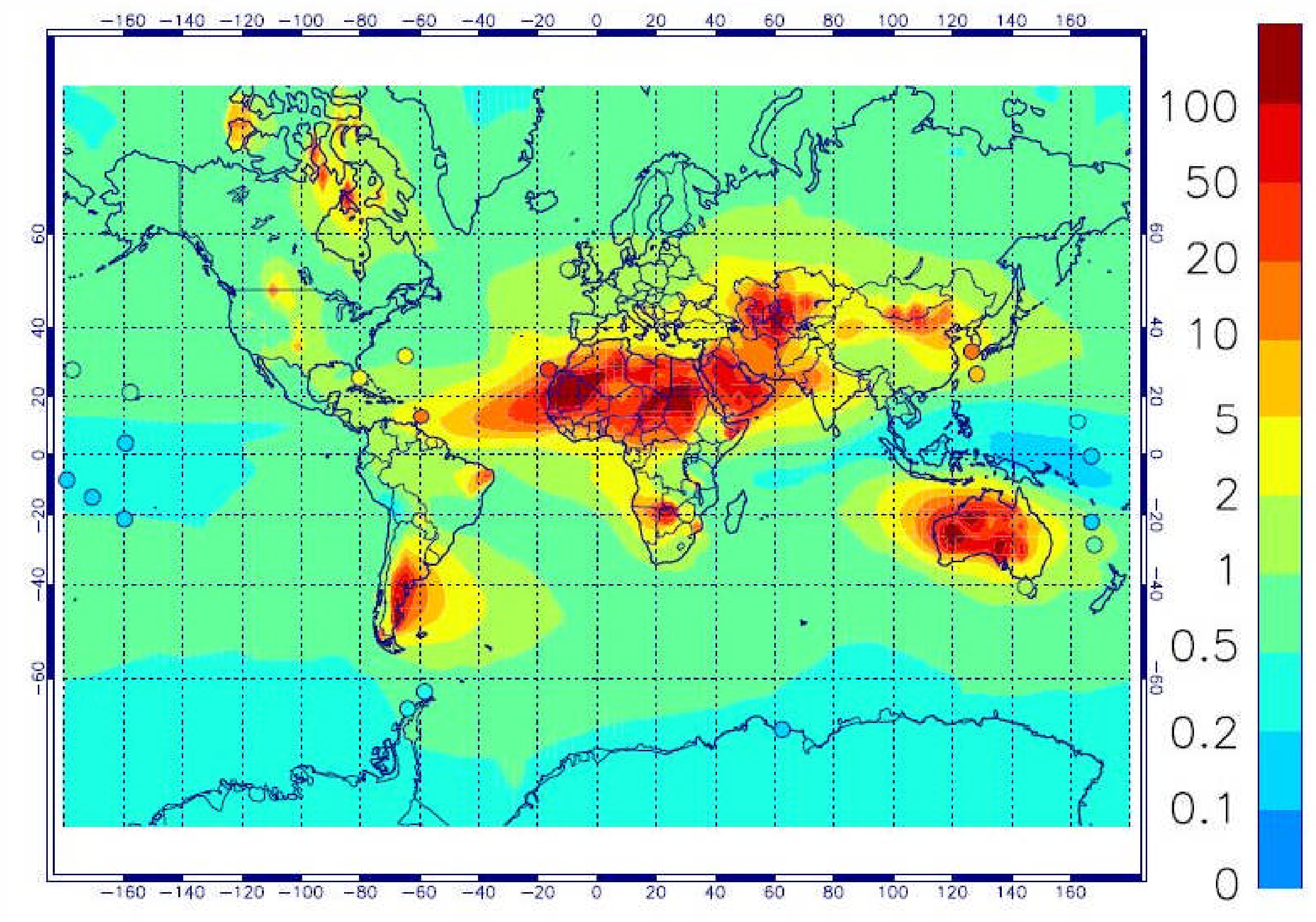
Annual mean surface dust concentration



Influence of particle size and soil moisture on threshold friction velocity following Woodward (2001)

Here 2.8x2.8^{o} averaged ECMWF winds drive dust flux

From Manktelow PhD thesis.

Global surface fields of soil moisture, leaf area index, snow/ice cover & preferential source areas [paleolake basins] from Tegen et al (2002) determine horizontal saltation flux

Global soil texture dataset (Zobler, 1986) drives size distribution of saltating aggregates

GLOMAP dust simulations

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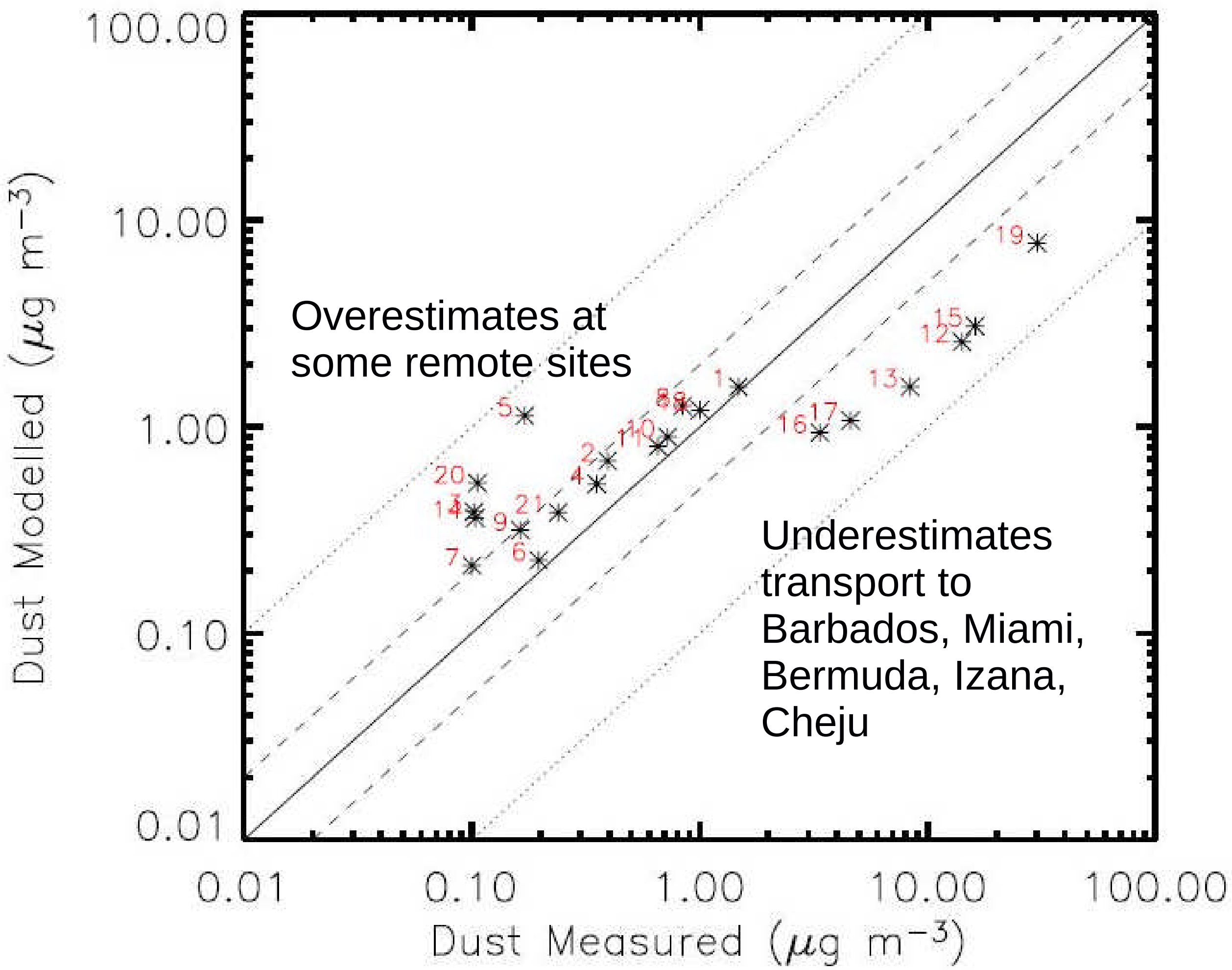

1. Cape Grim, 2. King George Is., 3. Mawson Antartica, 4. Palmer Antartica, 5. Yate, 6. Funafuti, 7. Nauru, 8. Norfolk Is., 9. American Samoa, 10. Midway., 11. Oahu, 12. Cheju, 13. Hedo Japan, 14. Fanning Is., 15. Barbados, 16. Bermuda, 17. Miami, 18. Mace Head, 19. Izana, 20., Rarotonga and 21. Enewetak.

Modelled spatial dust mass distribution in reasonable agreement with observations (log correlation coefficient of 0.8).

Annual mean

From Manktelow PhD thesis.

GLOMAP dust simulations

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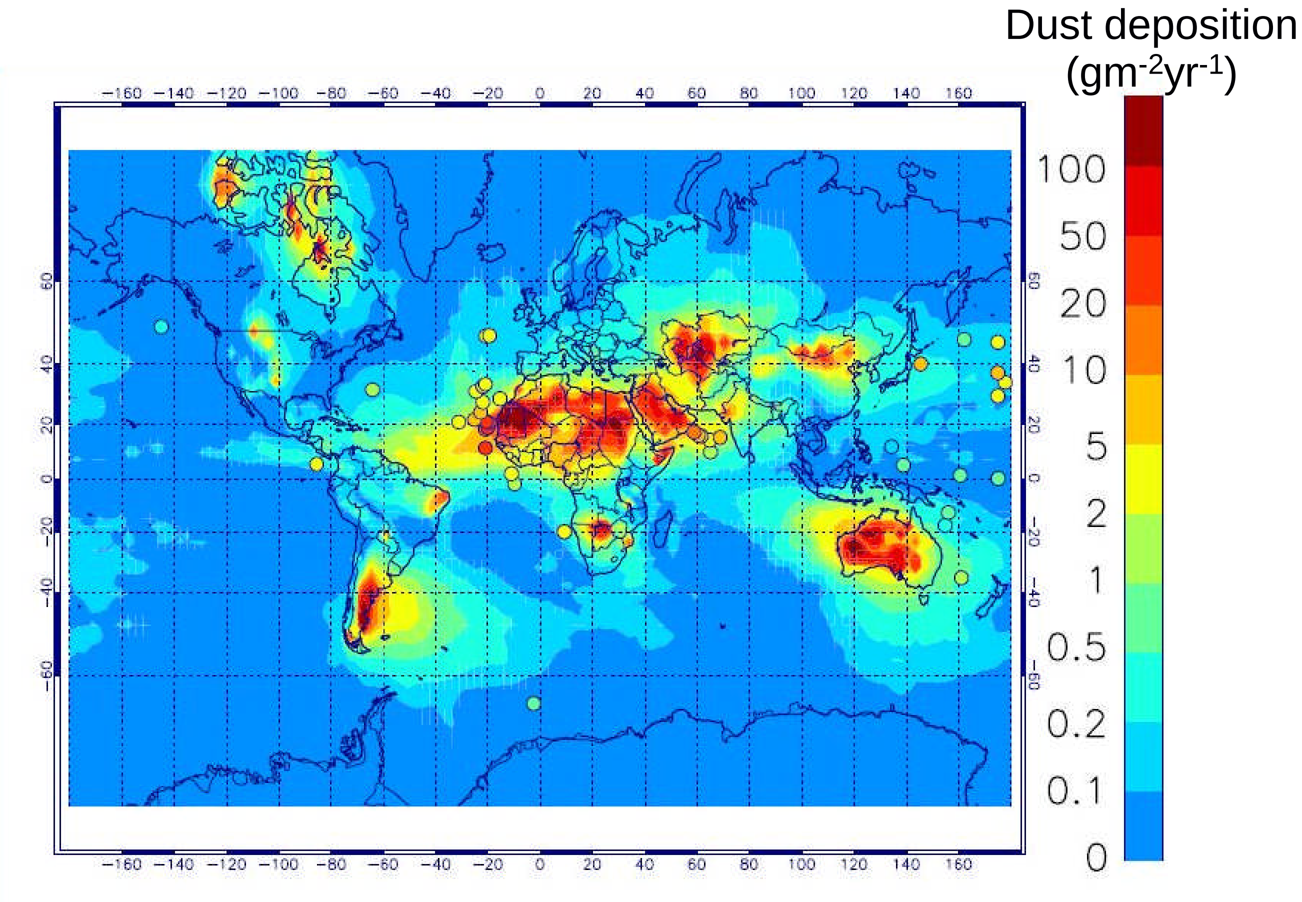

Marine sediment trap measurements of dust deposition using screened dataset in Tegen et al (2002)

Deposition to ocean provides nutrients to ocean phytoplankton

From Manktelow PhD thesis.

Generally encouraging spatial distribution of dust deposition vs observations

Sandblasting scheme seems to give too short a lifetime → too low deposition.

Not enough smaller particles with longer lifetimes → could be caused by use of T42 averaged wind speeds to calculate saltation flux. (Non-linear source function)

Annual cycle of GLOMAP dust (A&G) vs ACE-Asia size distbn

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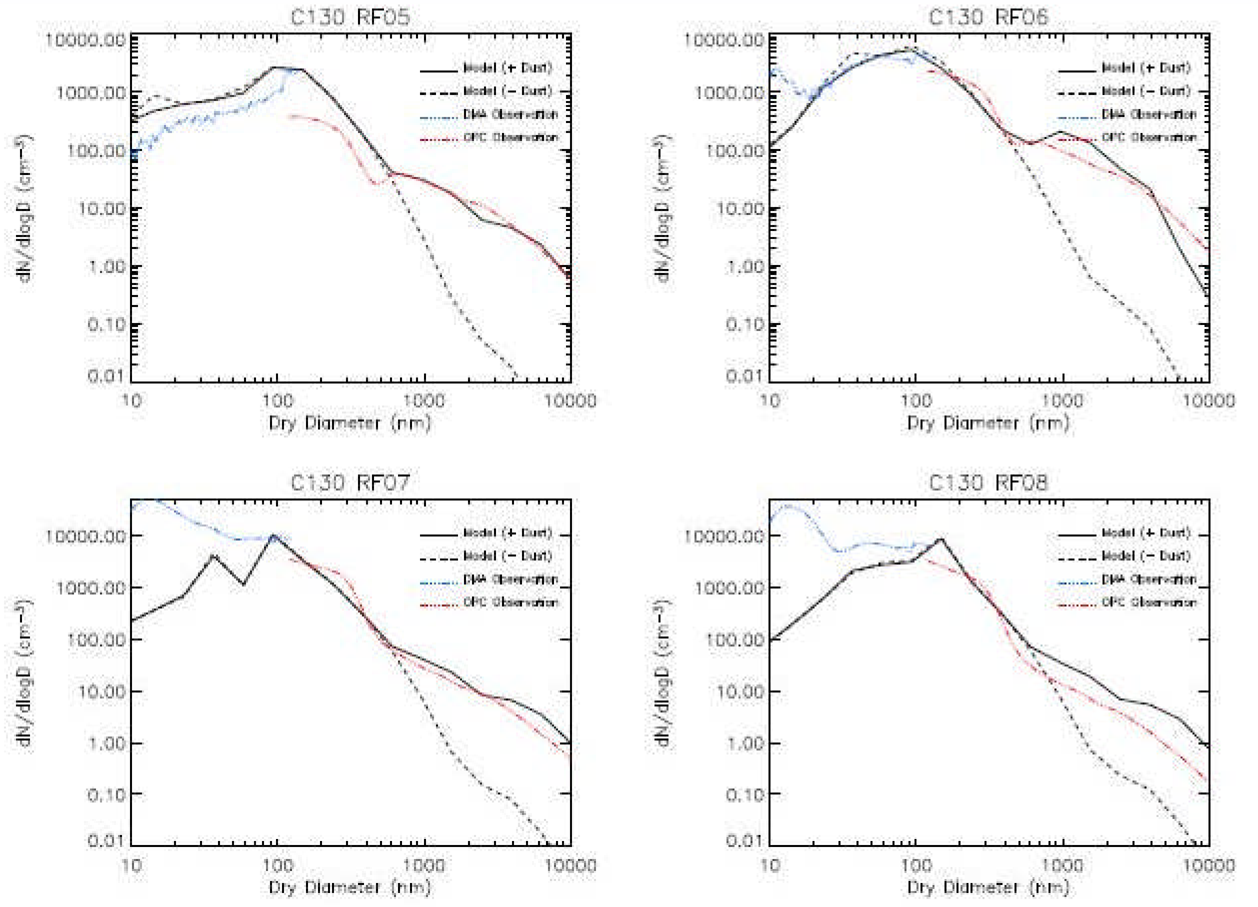
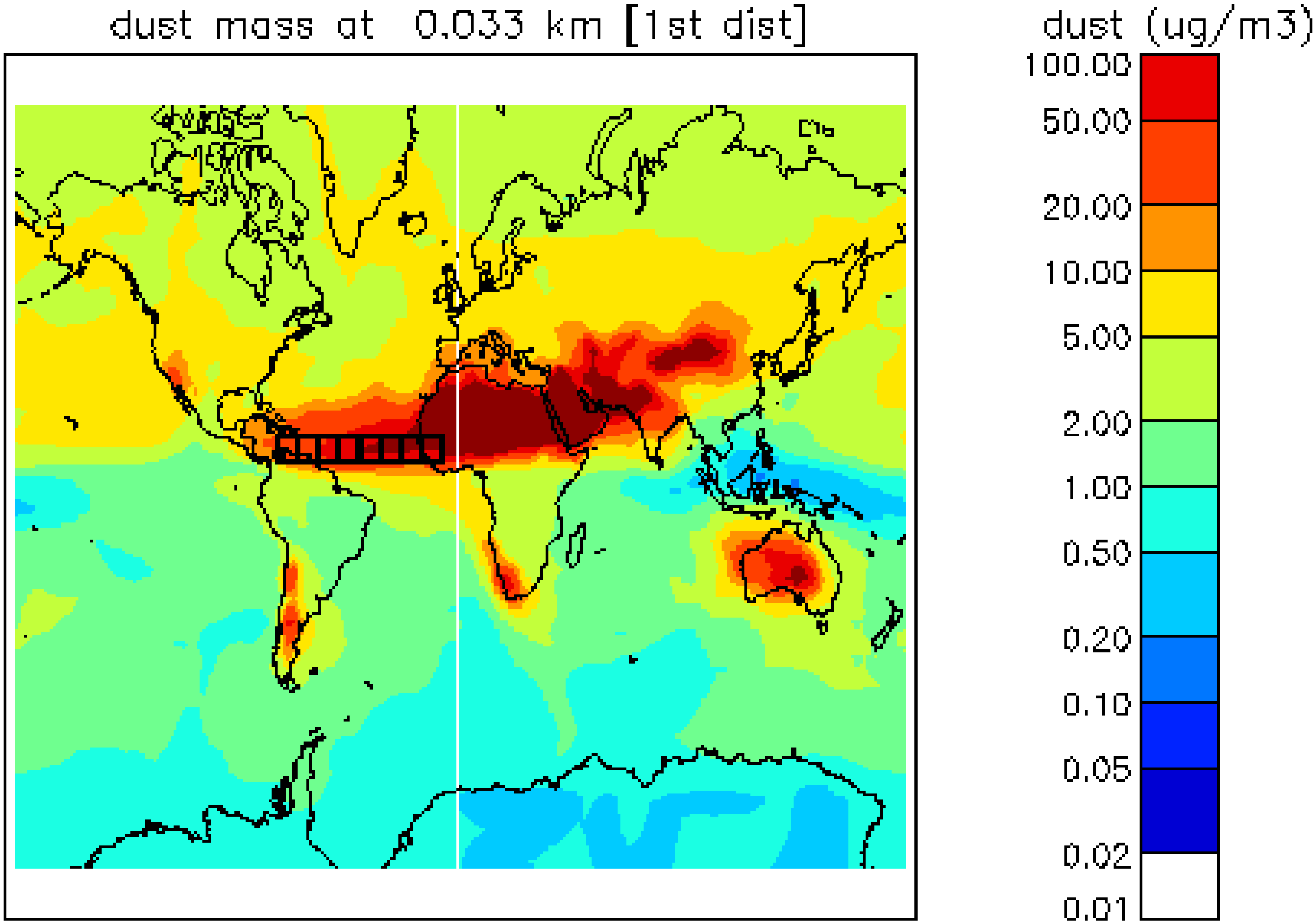
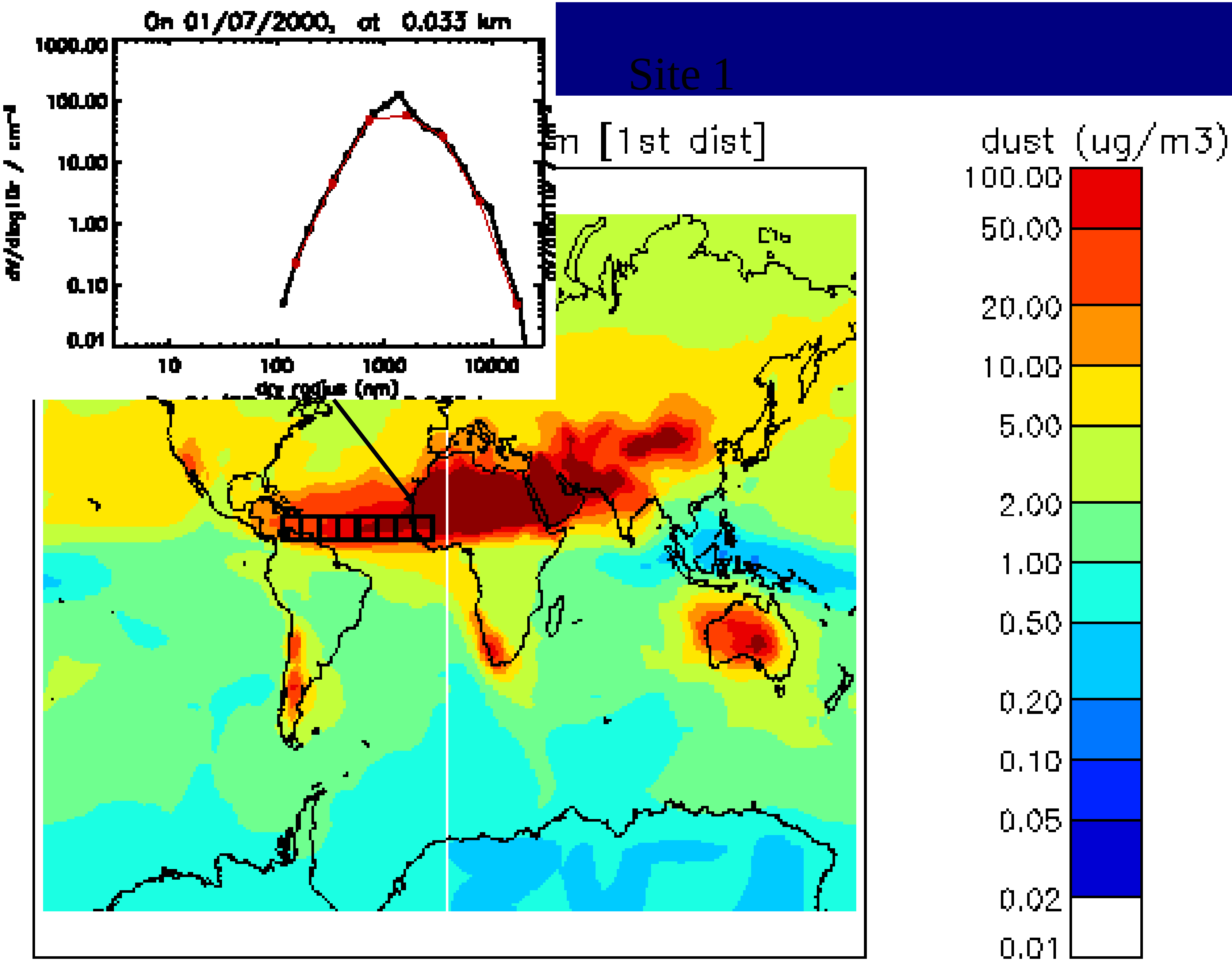


Figure 2.10: *Average size distribution observed and simulated over periods when the dust concentration exceeded 100 $\mu g\ m^{-3}$. Observations from the DMA (blue dashed) and OPC (red dashed) instruments are shown together with model results obtained from the STANDARD (black solid) and NODUST (black dashed) simulation.*

From Manktelow PhD thesis.

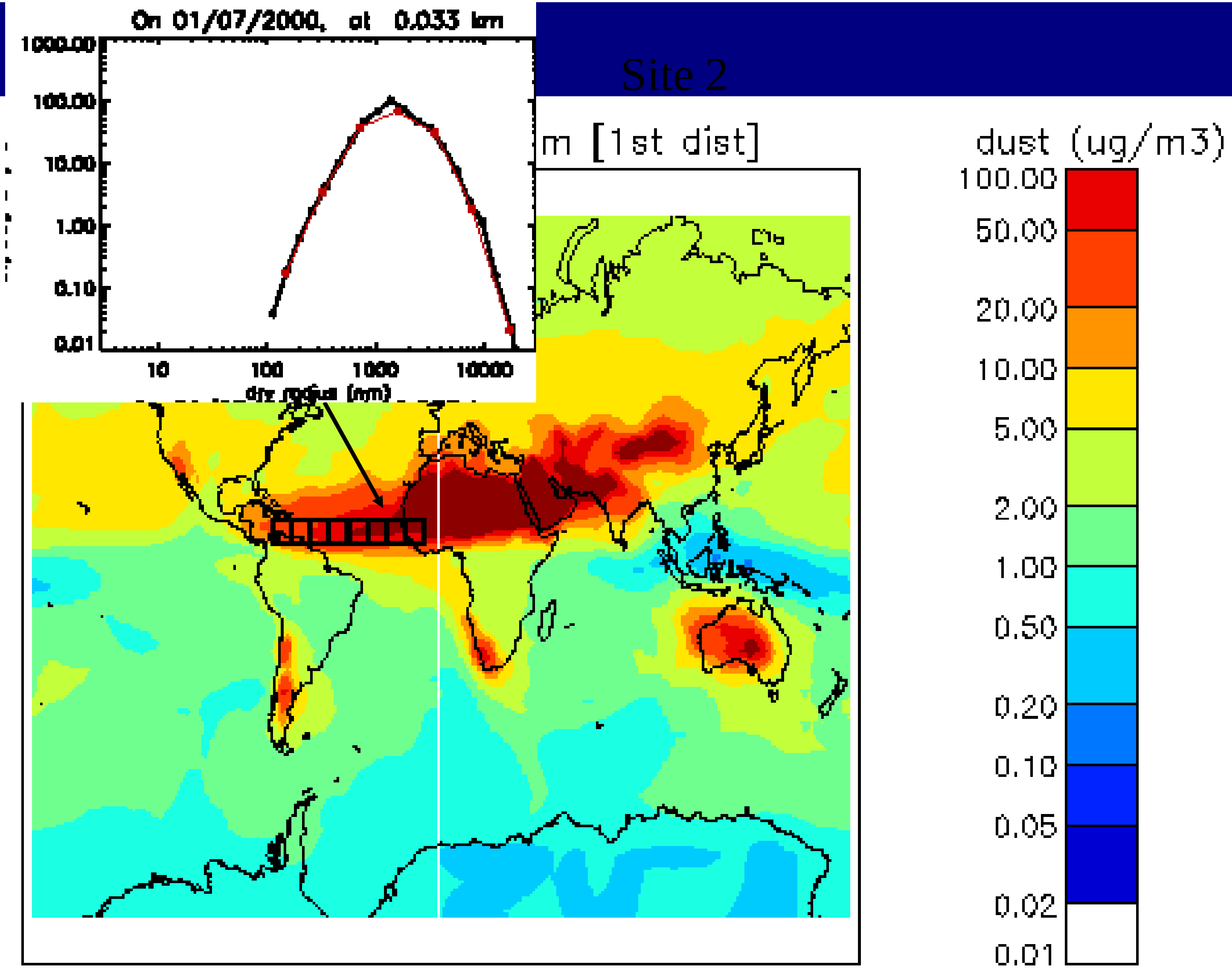

dust mass at 0.033 km [1st dist]
dust (ug/m3)
100.00
50.00
20.00
10.00
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01

Site 1



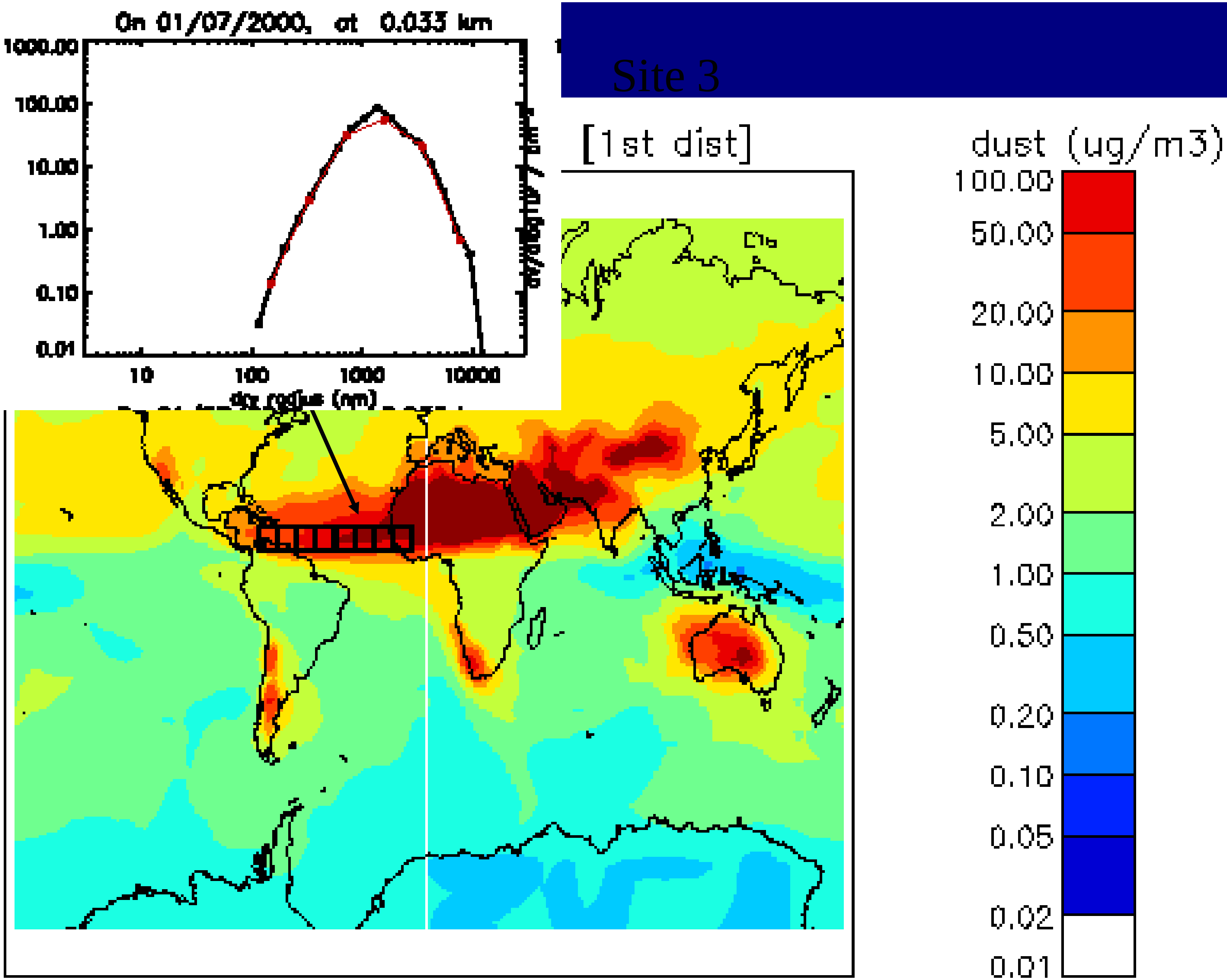
On 01/07/2000, at 0.033 km
1000.00
100.00
10.00
1.00
0.10
0.01
dV/dlog10r / cm-3
10
100
1000
10000
dry radius (nm)
m [1st dist]
dust (ug/m3)
100.00
50.00
20.00
10.00
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01

Site 2

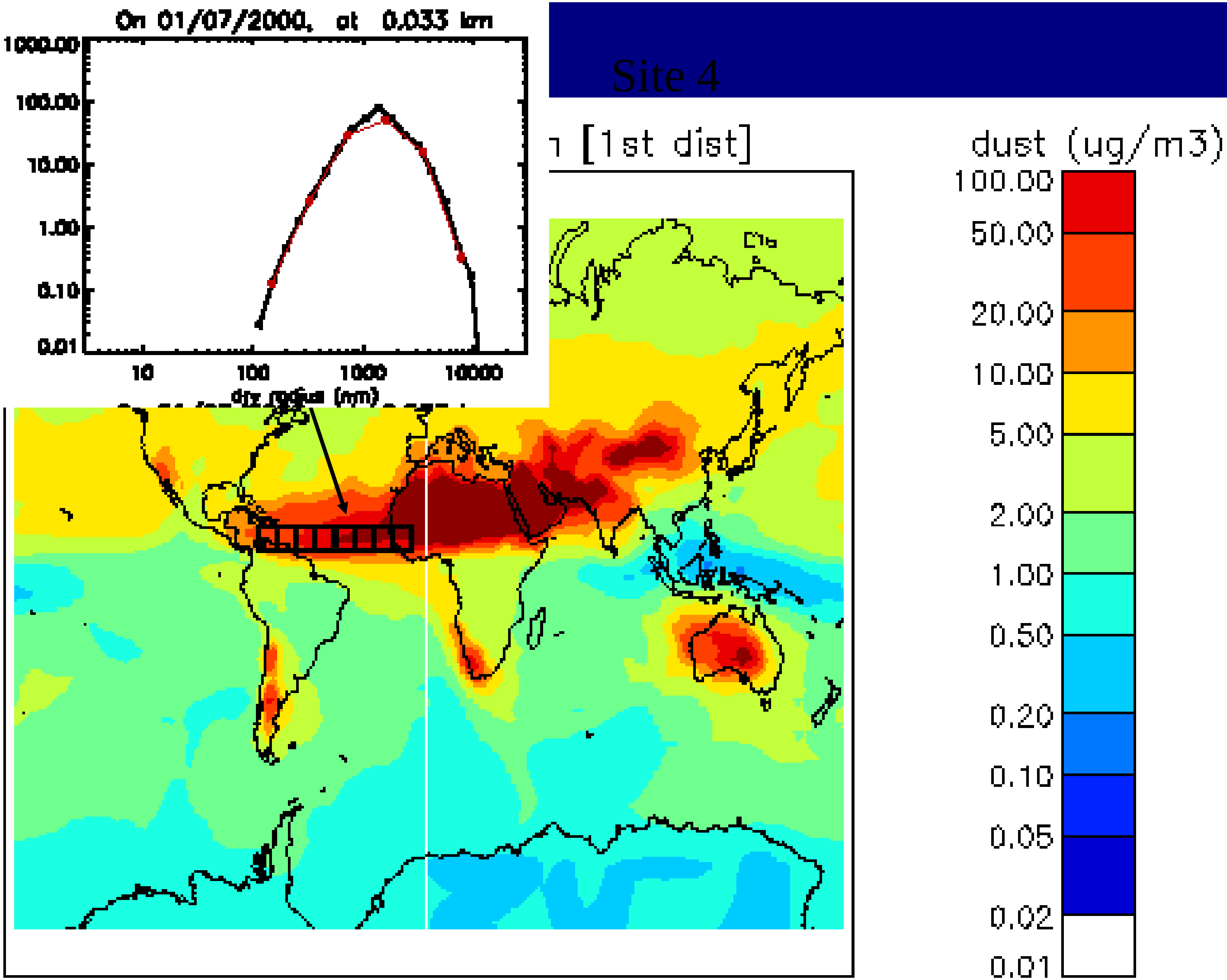


On 01/07/2000, at 0.033 km
1000.00
100.00
10.00
1.00
0.10
0.01
10
100
1000
10000
dry radius (nm)
m [1st dist]
dust (ug/m3)
100.00
50.00
20.00
10.00
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01

Site 3

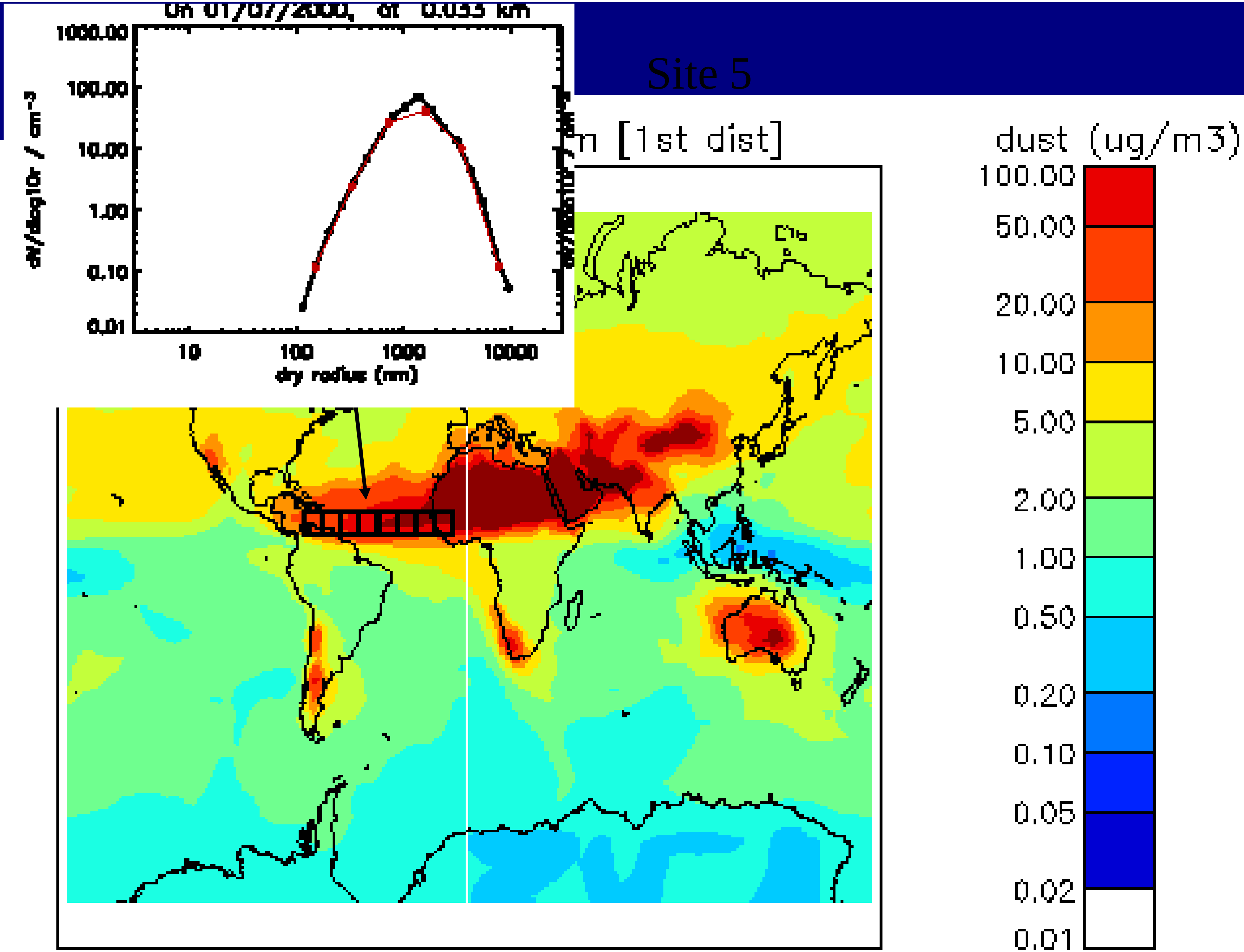

On 01/07/2000, at 0.033 km
1000.00
100.00
10.00
1.00
0.10
0.01
10
100
1000
10000
dry radius (nm)
[1st dist]
dust (ug/m3)
100.00
50.00
20.00
10.00
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01

Site 4



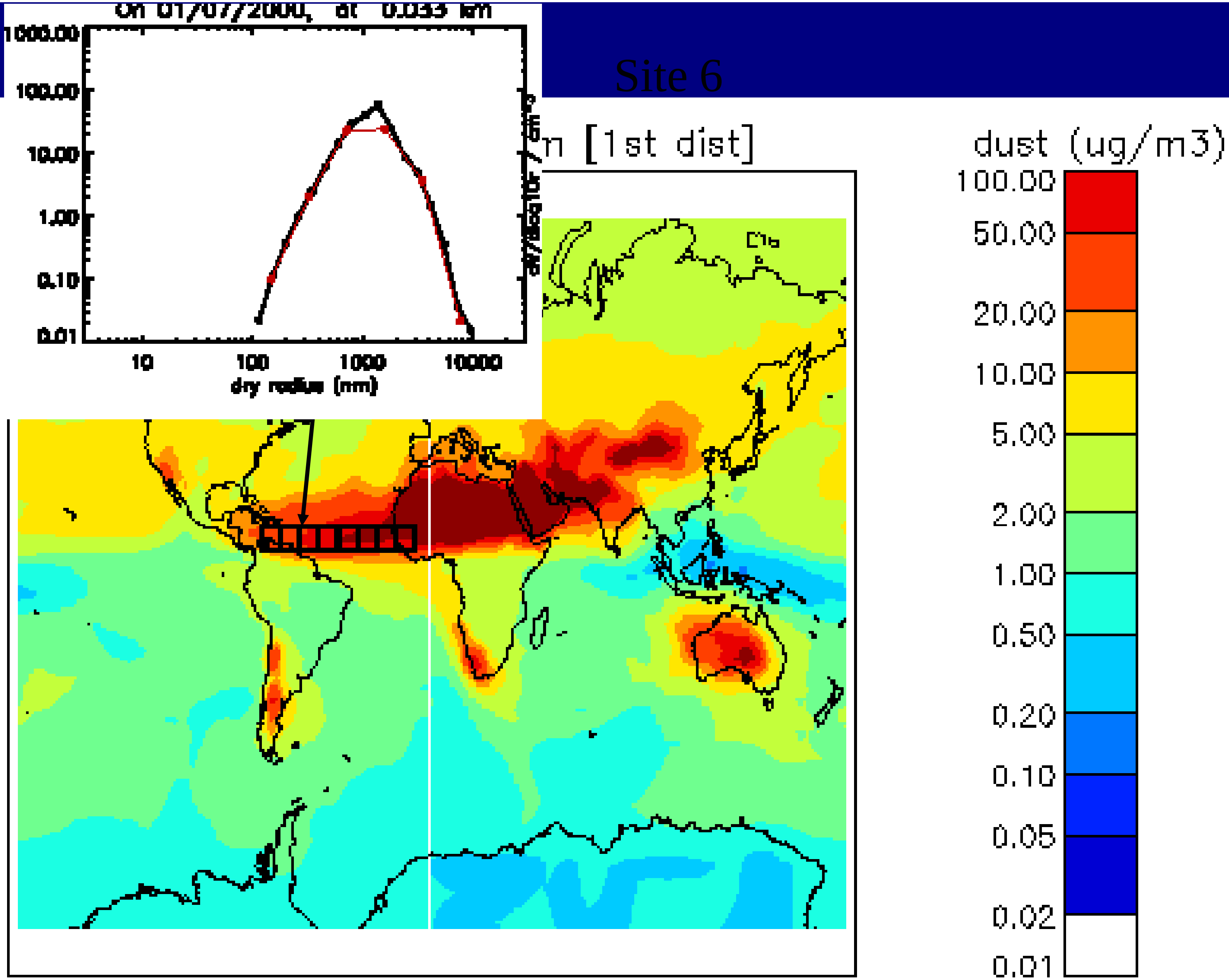
On 01/07/2000, at 0.033 km
1000.00
100.00
10.00
1.00
0.10
0.01
10
100
1000
10000
dry radius (nm)
[1st dist]
dust (ug/m3)
100.00
50.00
20.00
10.00
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01

Site 5



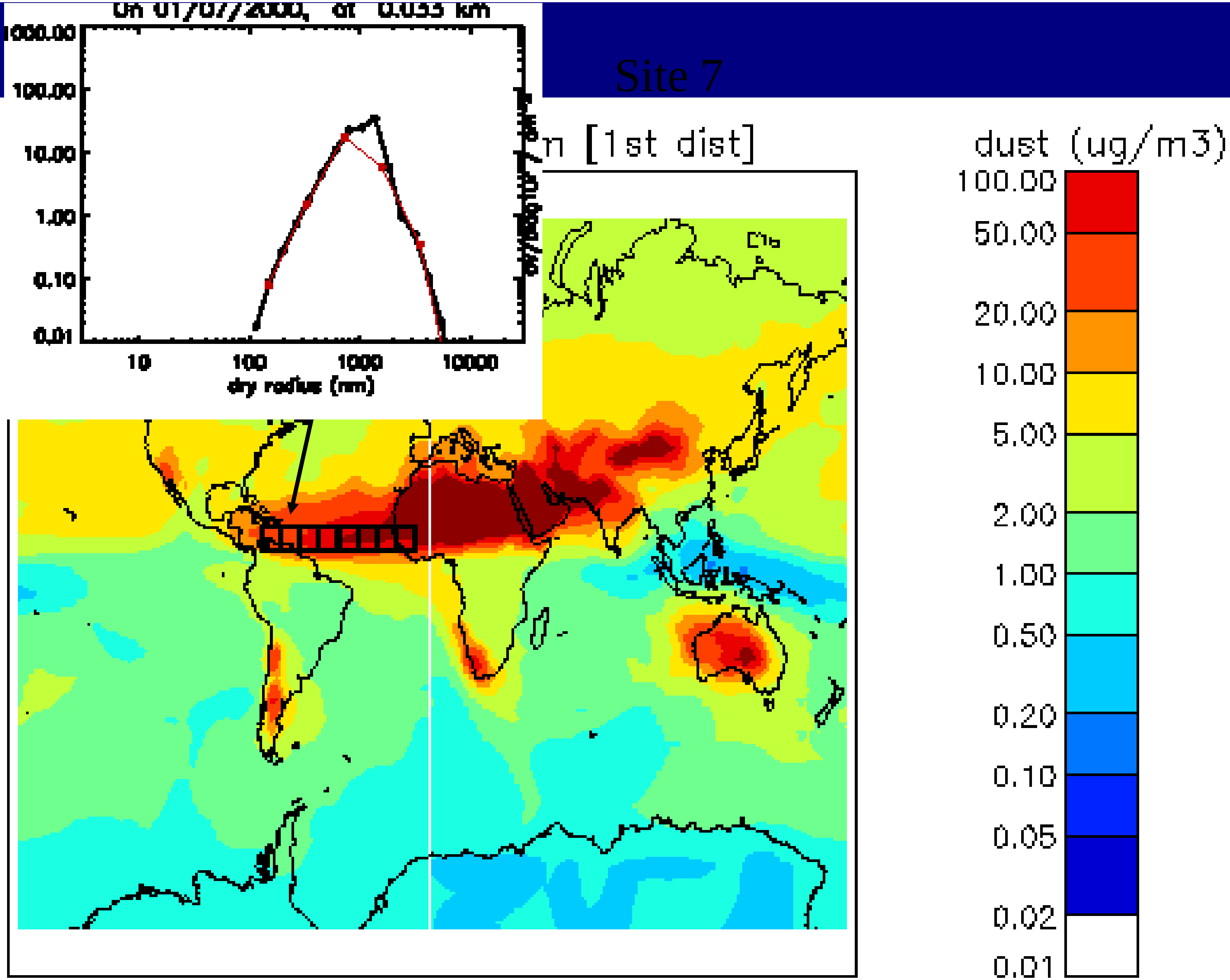
n [1st dist]
dust (ug/m3)
100.00
50.00
20.00
10.00
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01
dN/dlog10r / cm⁻³
1000.00
100.00
10.00
1.00
0.10
0.01
10
100
1000
10000
dry radius (nm)

Site 6



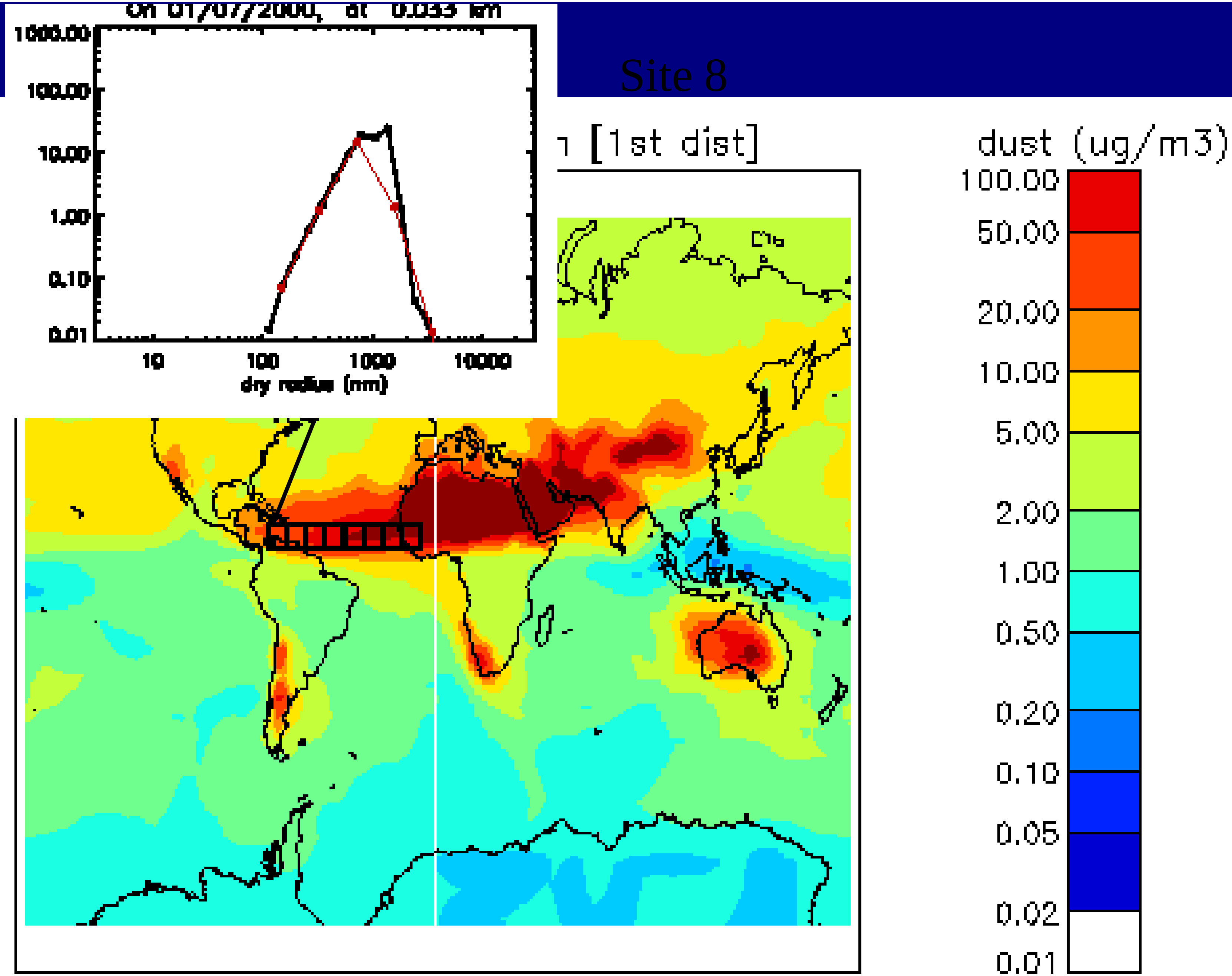
On 01/07/2000, at 0.033 km
1000.00
100.00
10.00
1.00
0.10
0.01
10
100
1000
10000
dry radius (nm)
[1st dist]
dust (ug/m3)
100.00
50.00
20.00
10.00
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01

Site 7

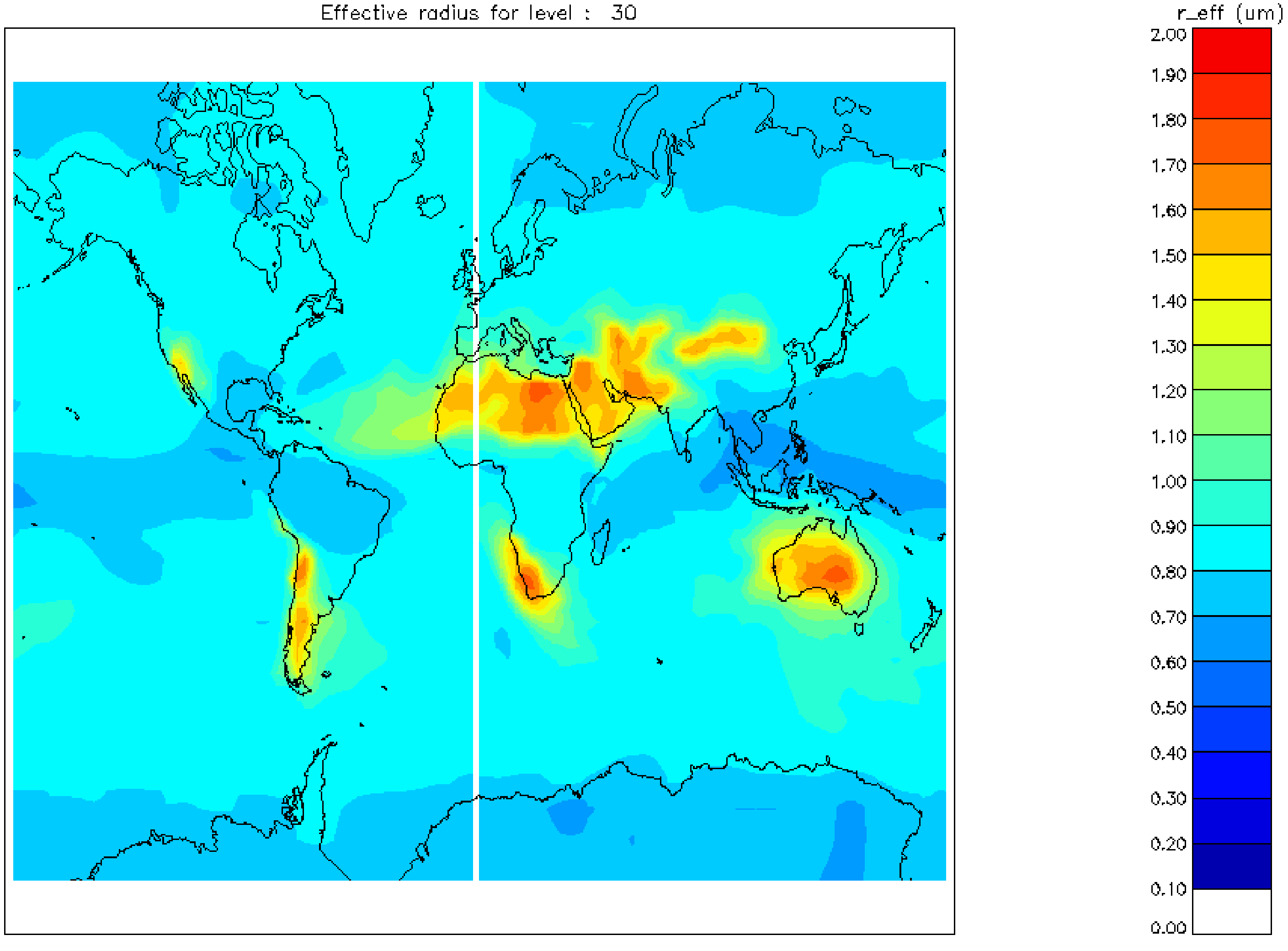


On 01/07/2000, at 0.033 km
1000.00
100.00
10.00
1.00
0.10
0.01
10
100
1000
10000
dry radius (nm)
n [1st dist]
dust (ug/m3)
100.00
50.00
20.00
10.00
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01

Site 8


On 01/07/2000, at 0.033 km
1000.00
100.00
10.00
1.00
0.10
0.01
10
100
1000
10000
dry radius (nm)
[1st dist]
dust (ug/m3)
100.00
50.00
20.00
10.00
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01

Eff. radius for 20-bin run = ratio of 3rd to 2nd moments = 1/3 volume conc./ surface area conc.



Confront GLOMAP dust with in-situ observations

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GLOMAP dust simulations driven by ECMWF winds, vegetation and soil moisture over 2006-2008 using bin & mode schemes.

Compare against in-situ observed size distributions (PCASP) and vertical scattering profiles (nephelometer) from DODO, DABEX and GERBILS (Simon Osborne, UK Met Office)

Also use multi-sensor (MODIS, MISR, SEVIRI) satellite IOP from March 2006 (Elisa Carboni, Oxford) & AERONET AOD.

Compare runs with (ECMWF T159 winds & N80 surface):
-- threshold velocity as Marticorena & Bergametti (1995) [f(Re)]
-- threshold velocity as Woodward01 [f(SWC, Dp)]
-- uplifted fraction constant value as Sahara [Balkanski, 2006]
-- uplifted fraction of horiz flux from clay fraction [Woodward01]
-- size-resolved uplift fn(texture of saltating aggregates) [AG01]
-- preferential source areas → set low u*t.
Also examine effect of calculating flux from winds averaged to N80 and to T42. Potentially also use ECMWF gustiness?

GLOMAP 2-mode vs 7-bin representation of dust transport

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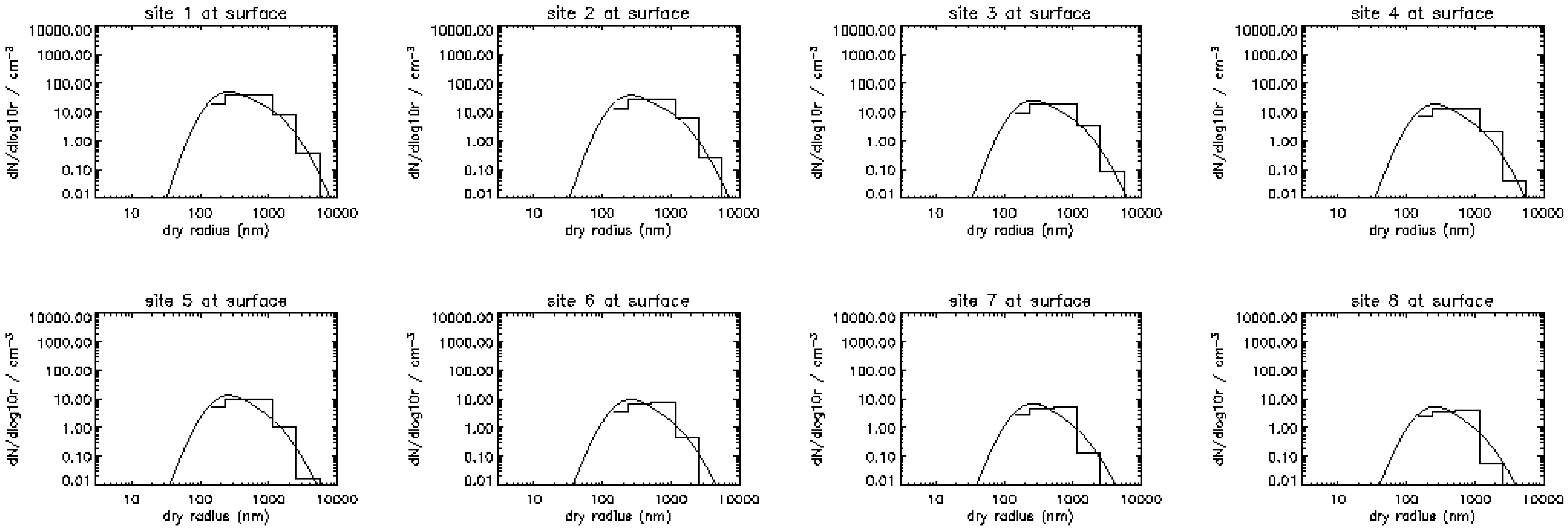
Shift in size distribution examined at 8 sites going out from Sahara over ocean.



GLOMAP-mode run using 2 size modes (4 tracers)
GLOMAP-bin run using 7 dust bins (14 tracers)

Here both use prescribed daily dust emission fluxes for year 2000 for AEROCOM model intercomparison by Paul Ginoux (GFDL)

Use GLOMAP-mode and –bin driven by Alfaro & Gomez sandblasting scheme for predicting dust deposition to ocean over multi-decadal timescales.
Collaboration with UEA (Le Quere, Buitenhuis) to model ecosystem response

Conclusions

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GLOMAP model simulates aerosol microphysics & particle size-resolved composition with either bin & mode approaches.

Dust simulations using Alfaro & Gomez compare reasonably against U Miami & DIRTMAP observations but burden too low downwind of source regions (too few small particles)

Model size distribution in strong dust events compares well with aircraft observations from ACE-Asia (DMA, OPC)

SOLAS CASE PhD studentship (Matt Woodhouse) will investigate dust deposition, test resolution effects, emissions approaches & bin/mode transport/removal vs observed aircraft size distrib'tn and satellite/AERONET Aerosol Optical Depth.

Plan to investigate inter-annual variability of GLOMAP-bin simulated dust deposition & impact on ocean iron cycle over 1960-2060 (collaboration UEA-Leeds-CEH via QESM link)

Annual cycle of GLOMAP dust (A&G) vs U. Miami observations

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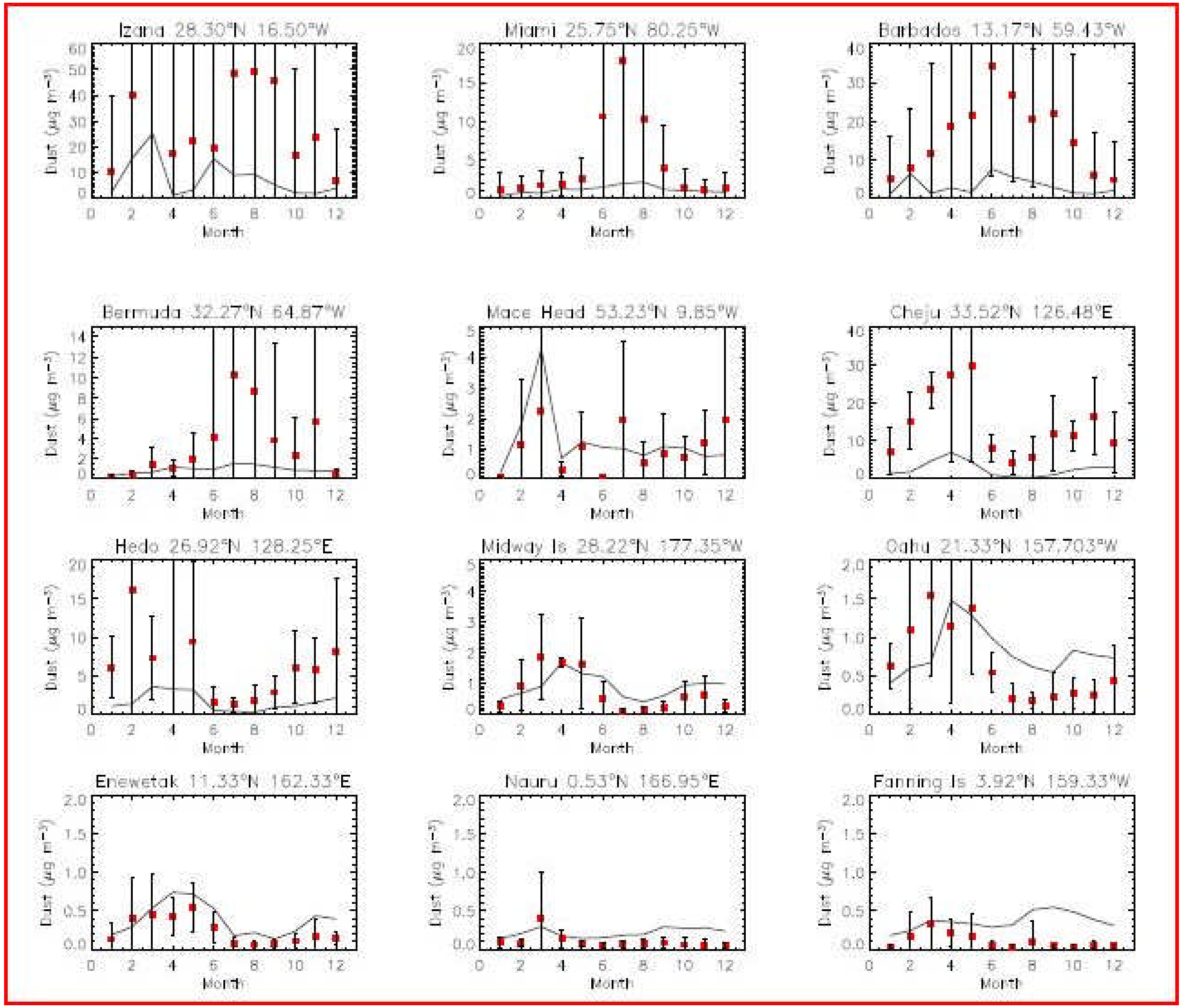

From Manktelow PhD thesis.

Annual cycle of GLOMAP dust (A&G) vs U. Miami observations

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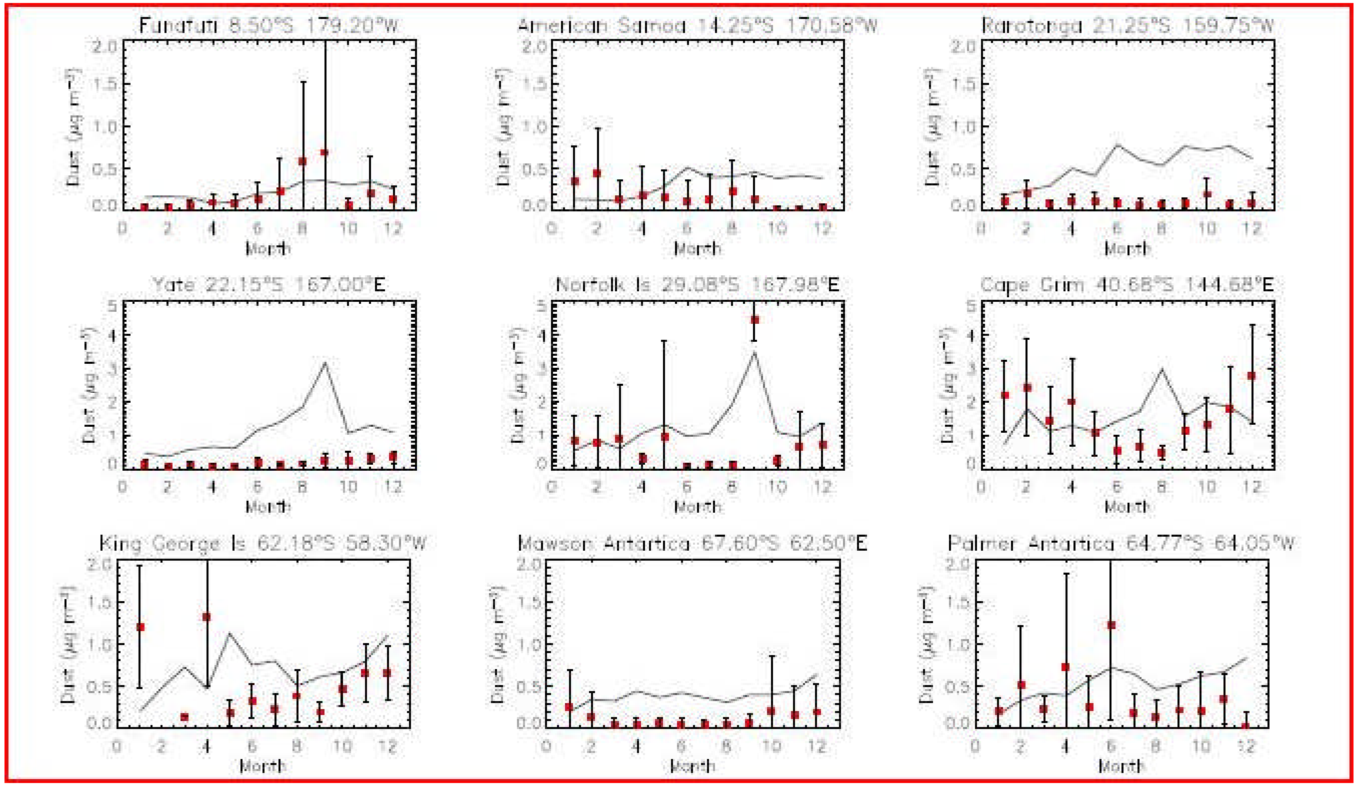

From Manktelow PhD thesis.

Use 20-bin dust-only run to benchmark 7-bin/2-mode schemes

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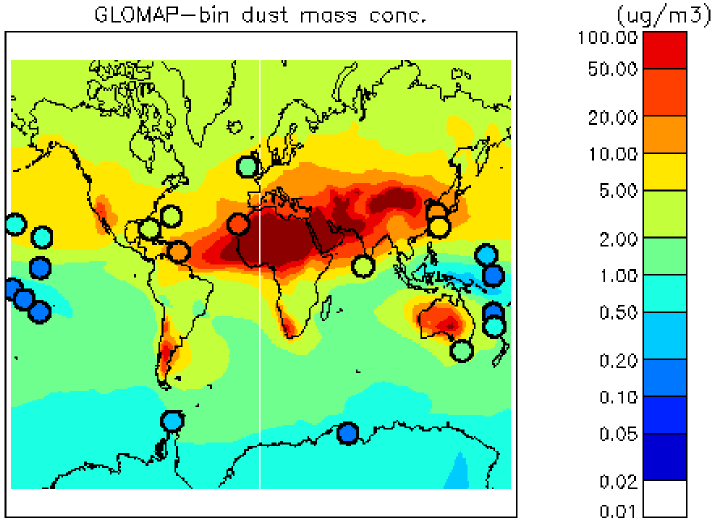
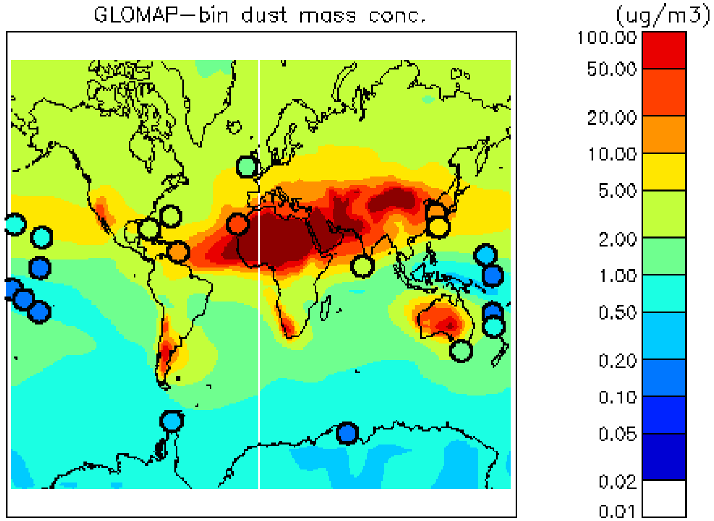
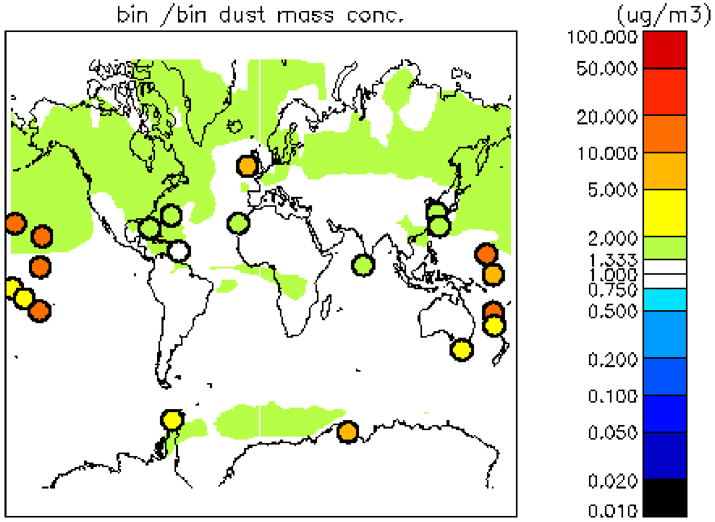
GLOMAP dust 20 bins



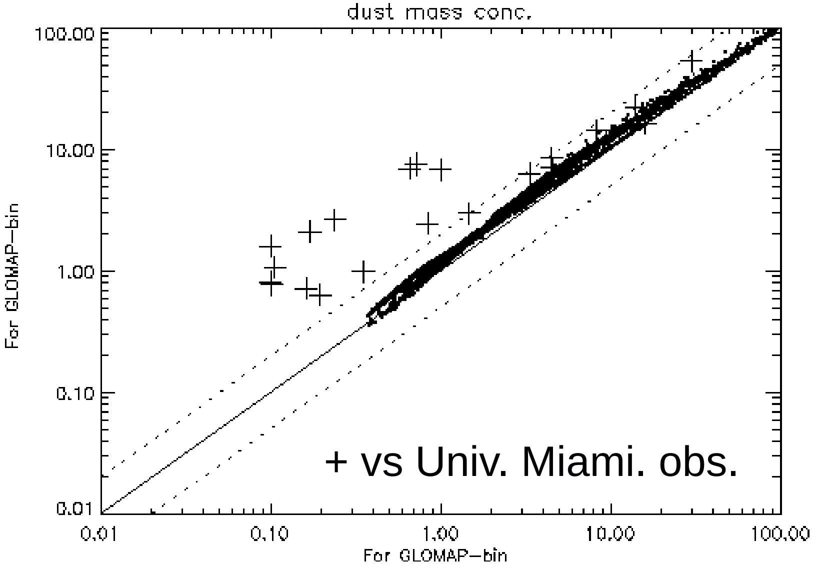
GLOMAP dust 7 bins



GLOMAP dust 20-bin / 7-bin



GLOMAP dust 20-bin vs 7-bin



Baker & Jickells (2006) find correlation size vs solubility

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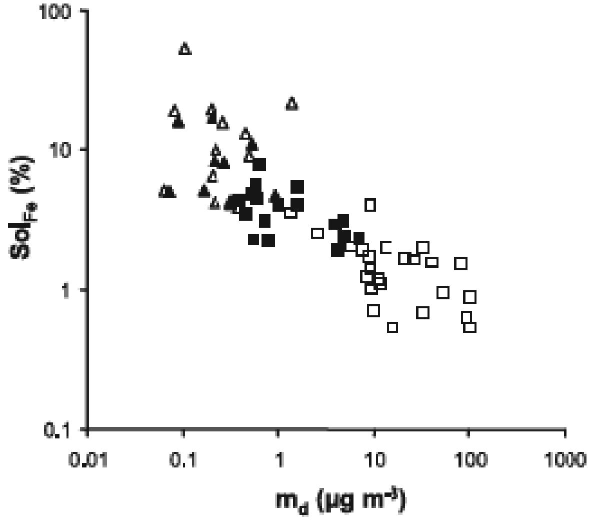

Figure 1. The percentage of soluble Fe (Sol_{Fe}) in aerosol collected over the Atlantic Ocean as a function of mineral aerosol atmospheric mass loading (m_d). Samples collected from the northern hemisphere are indicated by open symbols, those collected from southern hemisphere air by filled symbols. Squares indicate tropical/subtropical samples; triangles indicate temperate samples.

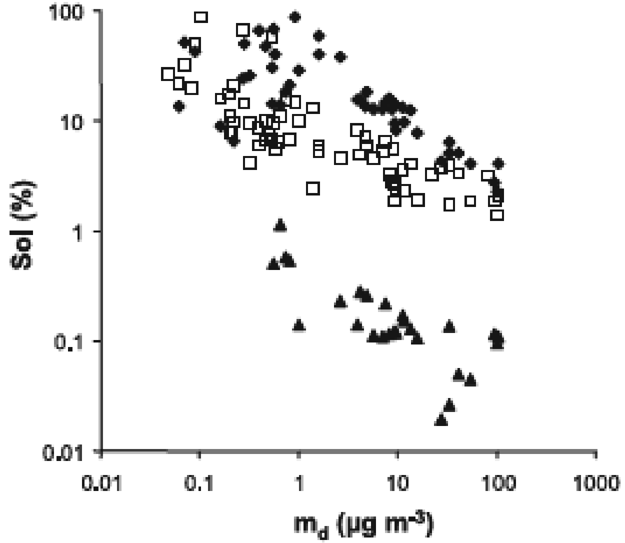

Figure 2. Aerosol solubility (Sol) versus mineral aerosol atmospheric mass loading (m_d) relationships for Al (open squares), Si (triangles) and P (diamonds). The Sol – m_d relationship is nonlinear for P at $m_d < 1 \mu g\ m^{-3}$, presumably because at lower mineral aerosol concentrations other sources of P (e.g. biomass burning) become significant and our m_d calculation assumptions do not apply to those samples.

Baker & Jickells (2006) find correlation size vs solubility

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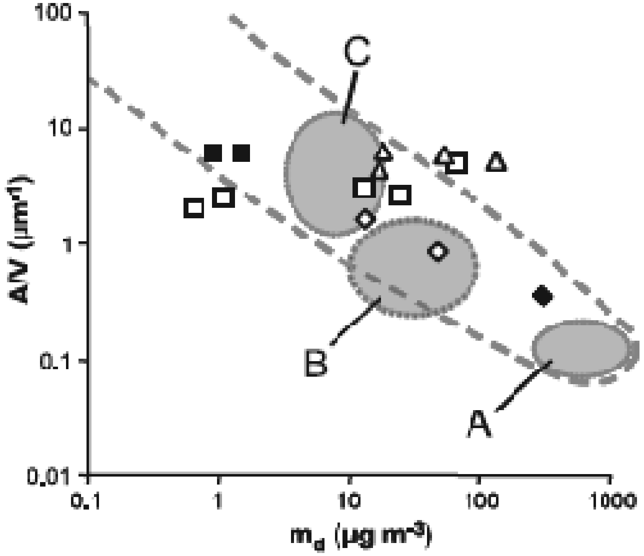

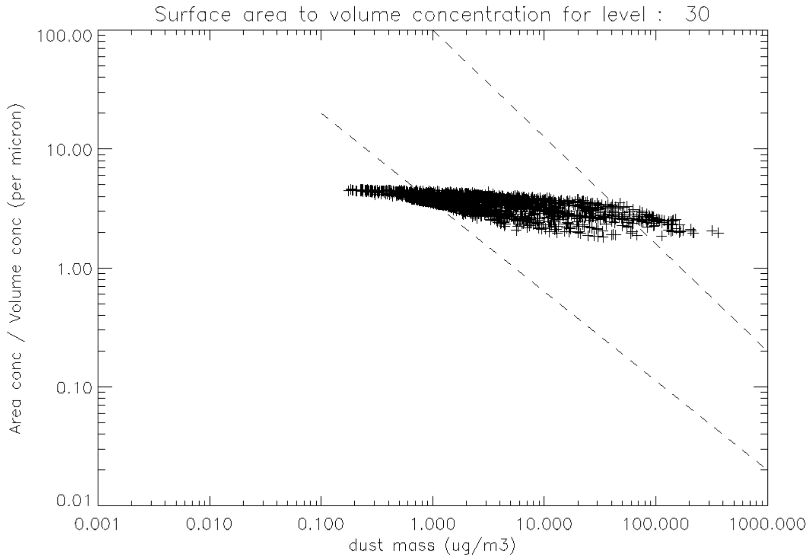

Figure 3. The variation in surface area to volume ratio (A/V) of a simple spherical particle with atmospheric concentration (m_d) calculated for observed mineral particle sizes and mass loadings for near-source mineral dust (A), dust sampled off the coast of West Africa (B), and Saharan dust observed over the Caribbean (C). Also shown are data for various literature reports of paired particle size and mineral aerosol concentration (filled squares [*Arimoto et al.*, 1985], open squares [*Arimoto et al.*, 1997], filled diamond [*Gillies et al.*, 1996], open diamonds [*Talbot et al.*, 1986], open triangles [*Afeti and Resch*, 2000]) and the general form of the A/V vs m_d relationship extrapolated to lower dust concentrations.

Size-sorting from sedimentation and impaction scavenging can explain some of observed signal in particle size vs mass burden.

But gradient in GLOMAP not steep enough – investigate impact of including interaction with sulphur cycle to accelerate removal & higher resolution winds to drive sandblasting