Dust and Climate:'DUSTSPEC'

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and the QUEST/INQUA Dust Working Group

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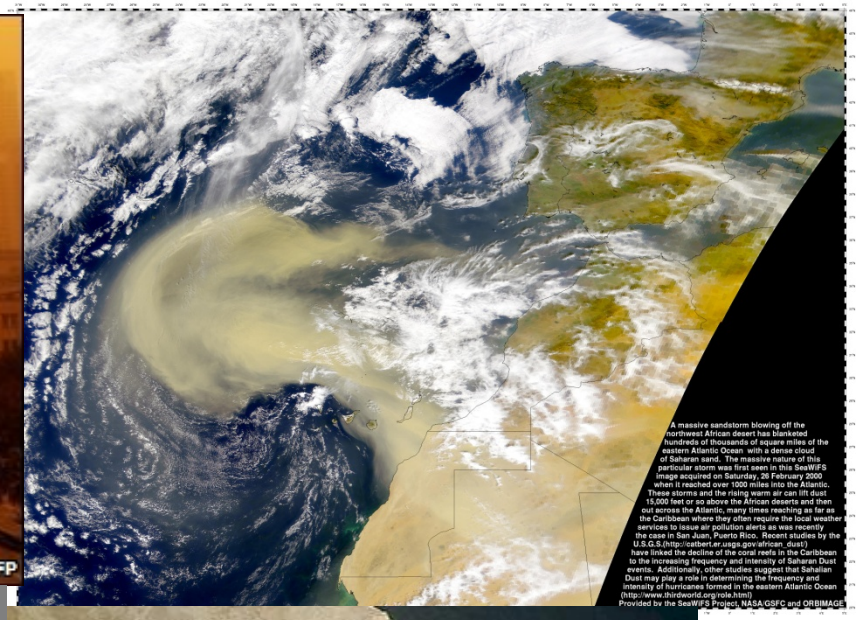
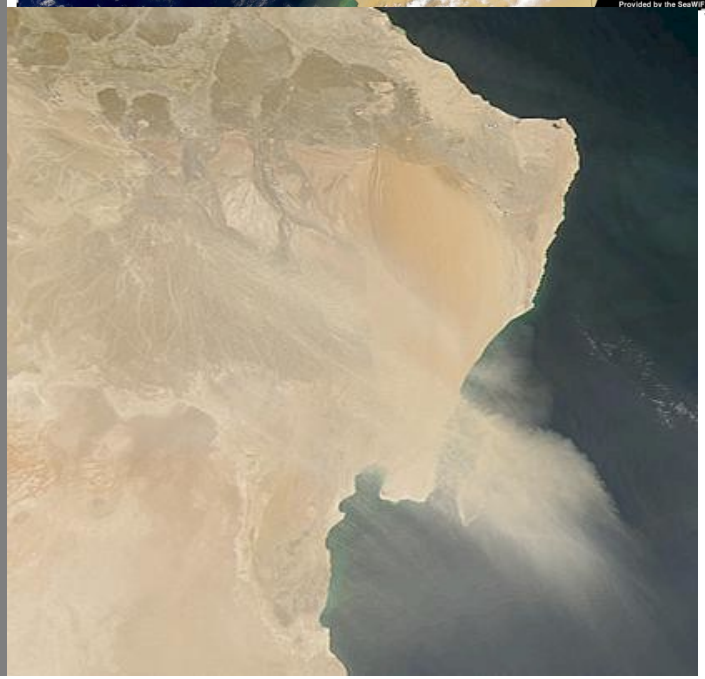
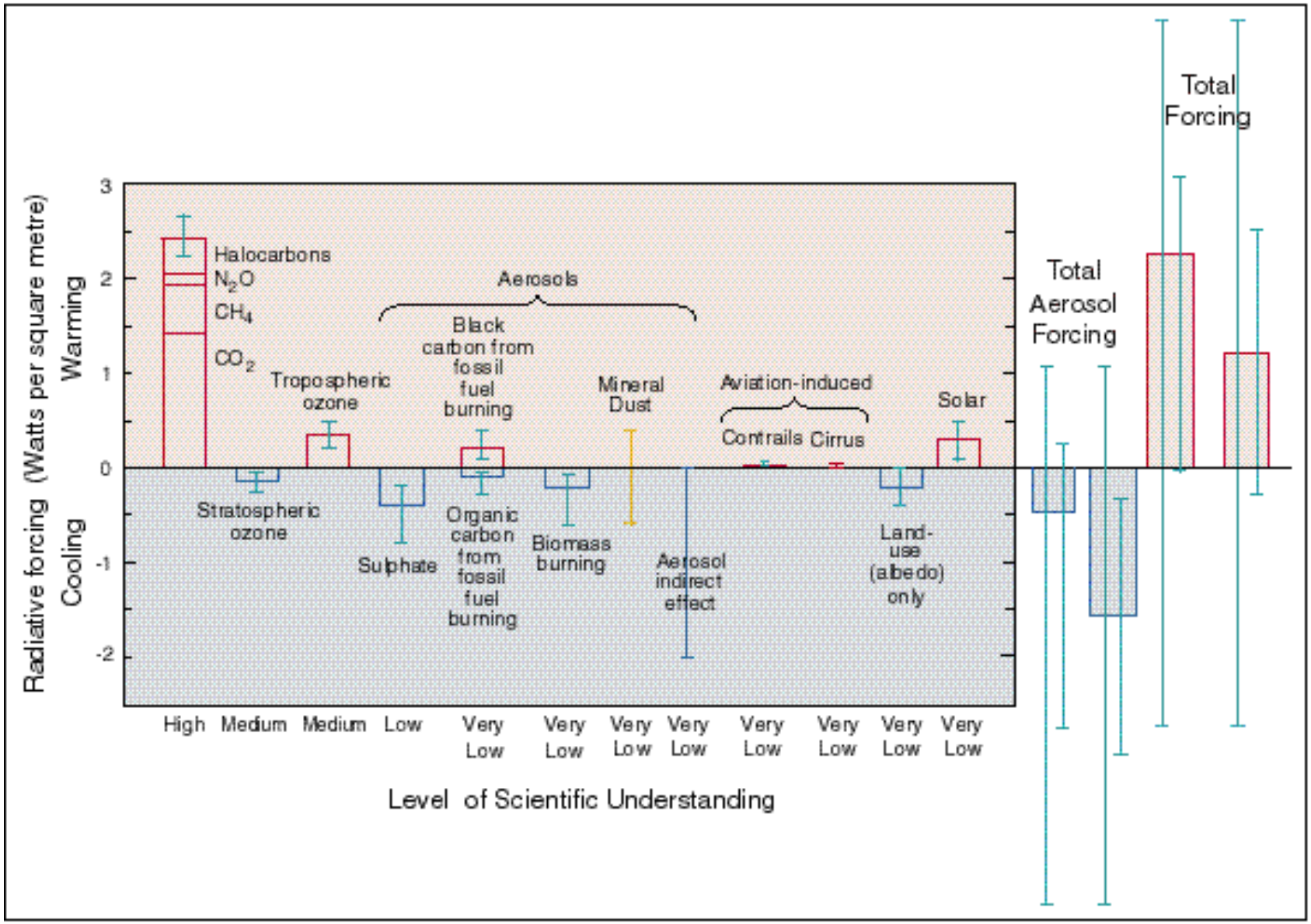
Dust transport: a global phenomenon



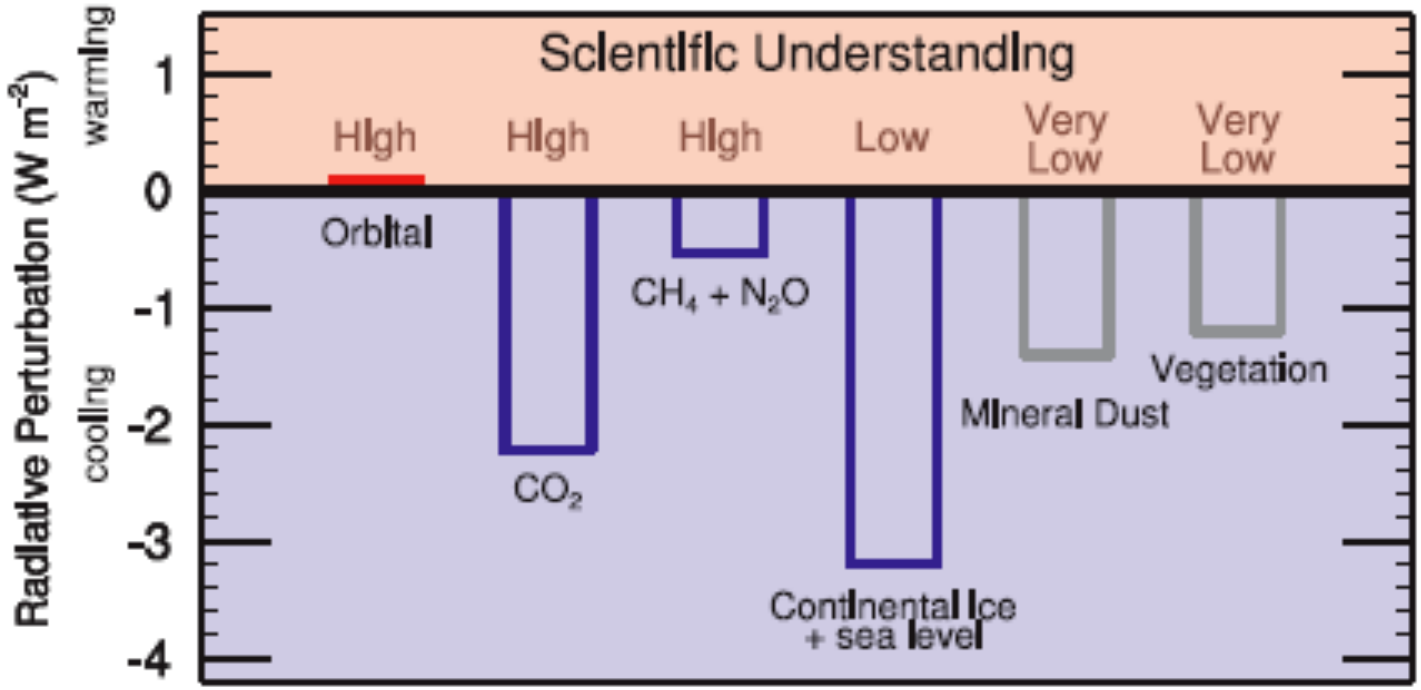


But the role of dust in climate change remains poorly understood……..
E.g. Present day (in context of a warming world), uncertainties/ magnitudes in climate forcing by aerosols:

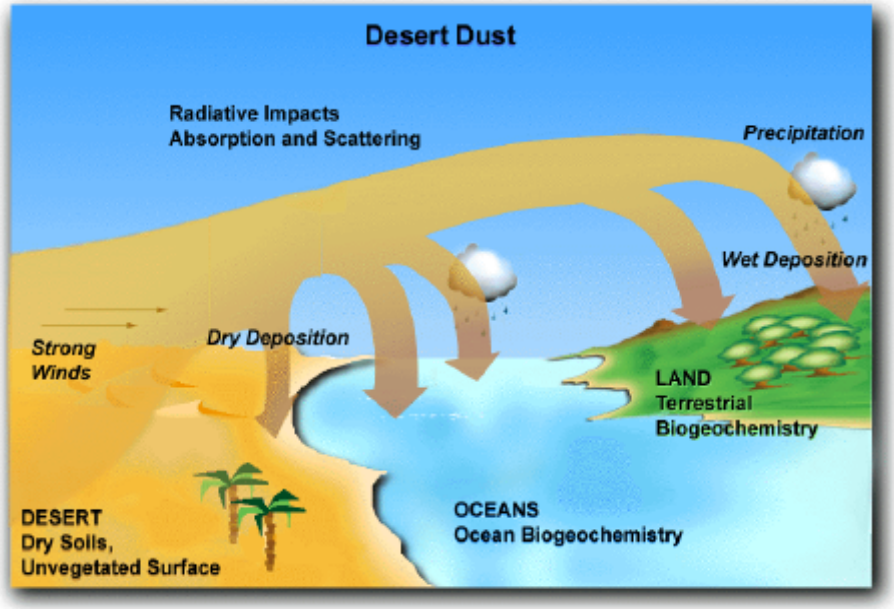


(IPCC, 2001 and Schwartz, 2004).

And LGM: Global annual mean radiative influences (W m-2) of climate change agents



(IPCC FAR, 2007)



Potential Effects of Mineral Aerosols on Climate

DIRECT:

Radiation Budget

- short wave (scattering, absorption, surface albedo)
- long wave (absorption, emission)

INDIRECT:

Biogeochemical - micronutrient fertilization of marine and terrestrial ecosystems

Physical - influence on cloud properties

Chemical - interactions with sulphate and ozone cycles

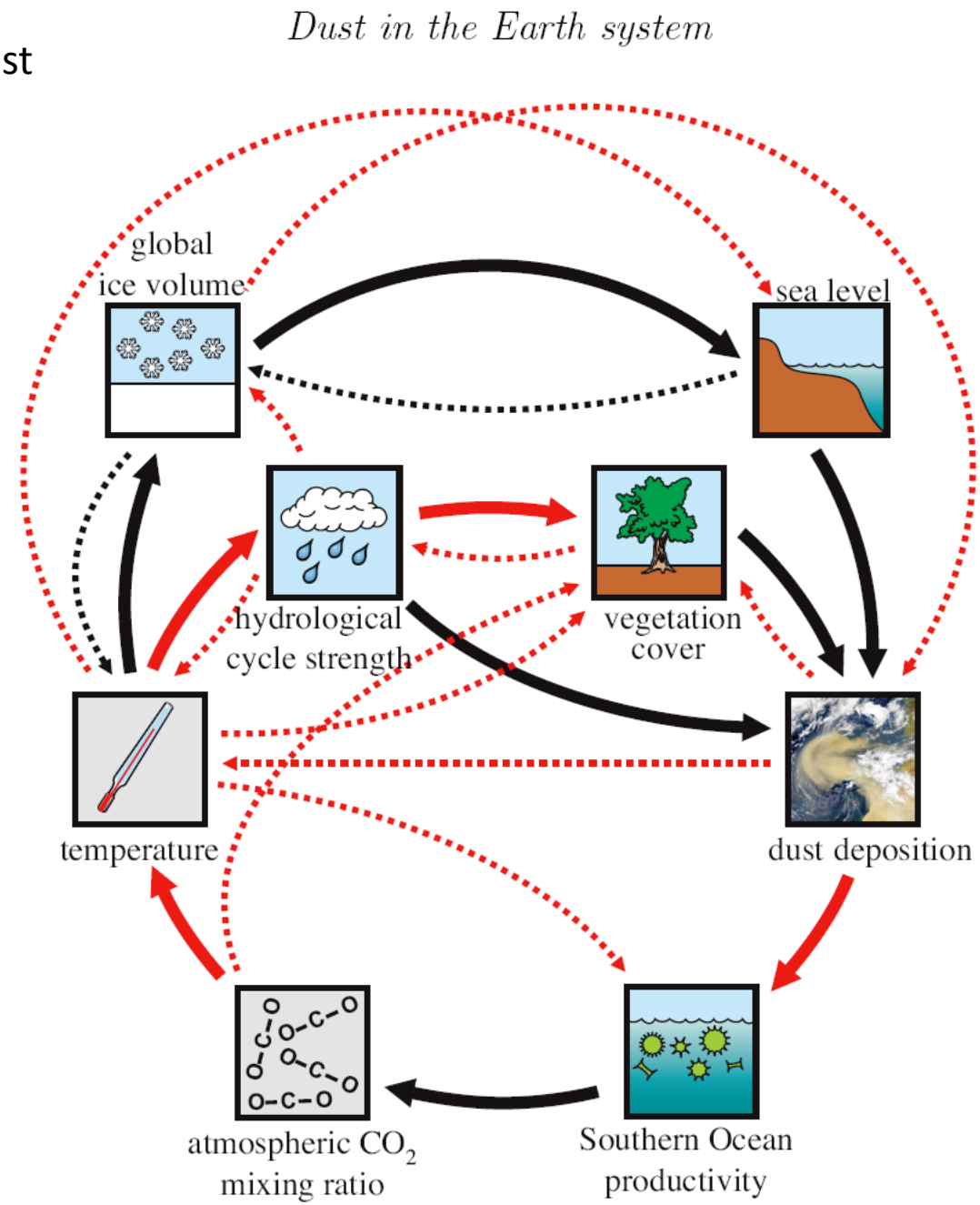
WHY BOTHER ?

Mineral dust and climate:

- Influence of dust on climate (radiative forcing, &/ or influencing the CO_2 content of oceans & atmosphere) remains a poorly quantified & actively changing element of the Earth's climate system.

- Dust-cycle models presently employ a rel. simple representation of dust properties; these simplifications may severely limit the realism of simulations of the impact of changes in dust loading on either or both radiative forcing & biogeochemical cycling.

Dust-climate-dust interactions
(Ridgwell, 2002)



Dust-climate-dust
(Jickells et al., 2005)

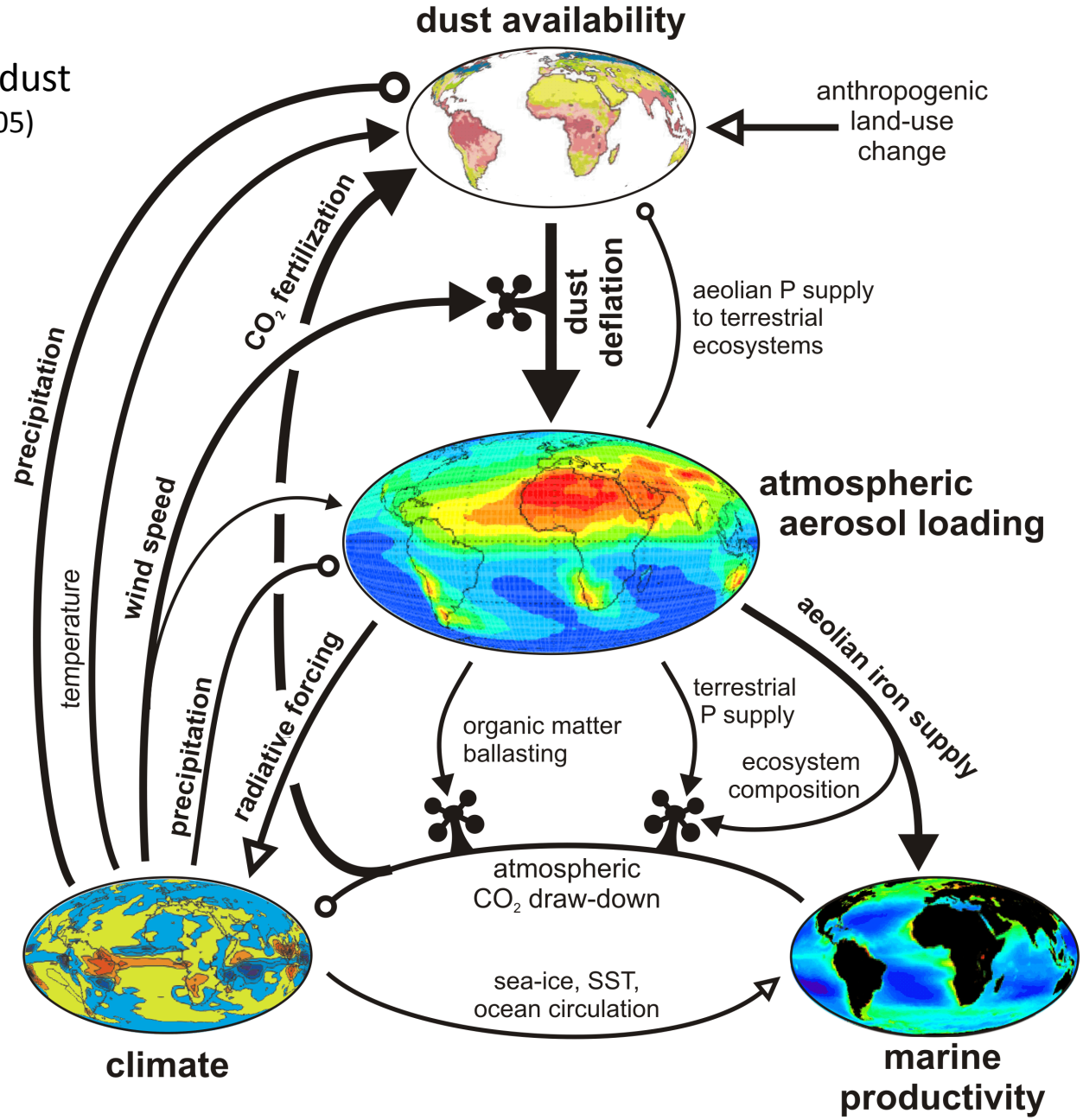


Figure 5

Modelling the dust cycle: state of the art in modelling

- Controls on dust emissions
  - by surface moisture
  - by vegetation phenology
  - preferential sources
  - wind strength/gustiness
- Transport
- Deposition processes
  - dry deposition
  - wet deposition

E.G.

Mahowald et al., 1999

Tegen et al, 2001

Tegen et al.,, 2002

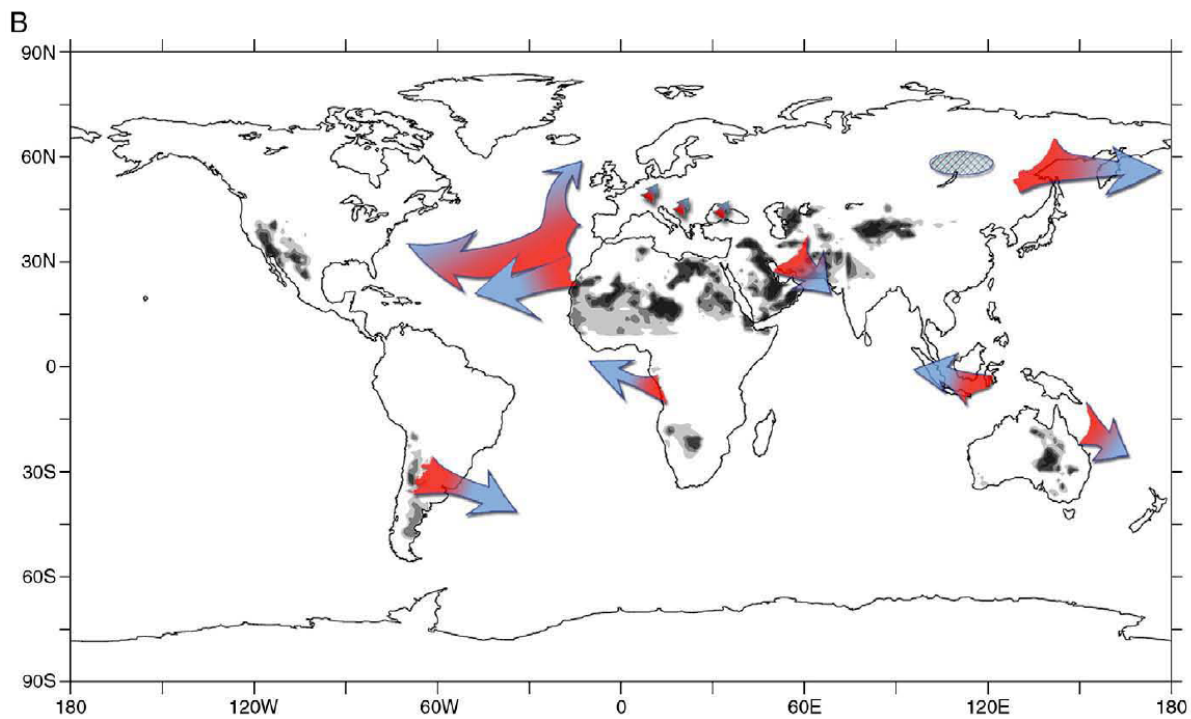
Werner et al., 2003

Tegen et al., 2004

But……e.g. dust cycle model estimates of net TOA direct RE span -0.6 to +0.4 W m-2 (IPCC, 2007).

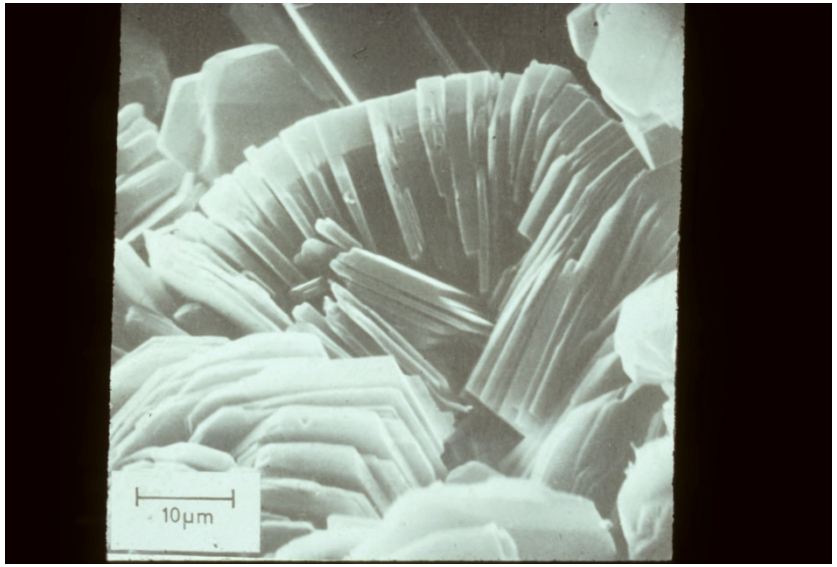
Where do these uncertainties arise?

- Poor specification of the atmospheric dust loading through time and space.



Dust uncertainties (cont.)

- Poor understanding of dust particle absorptivity (poorly known dust concentrations, mineralogy, grain size & shape).



Spheres error ≅ RI uncertainties

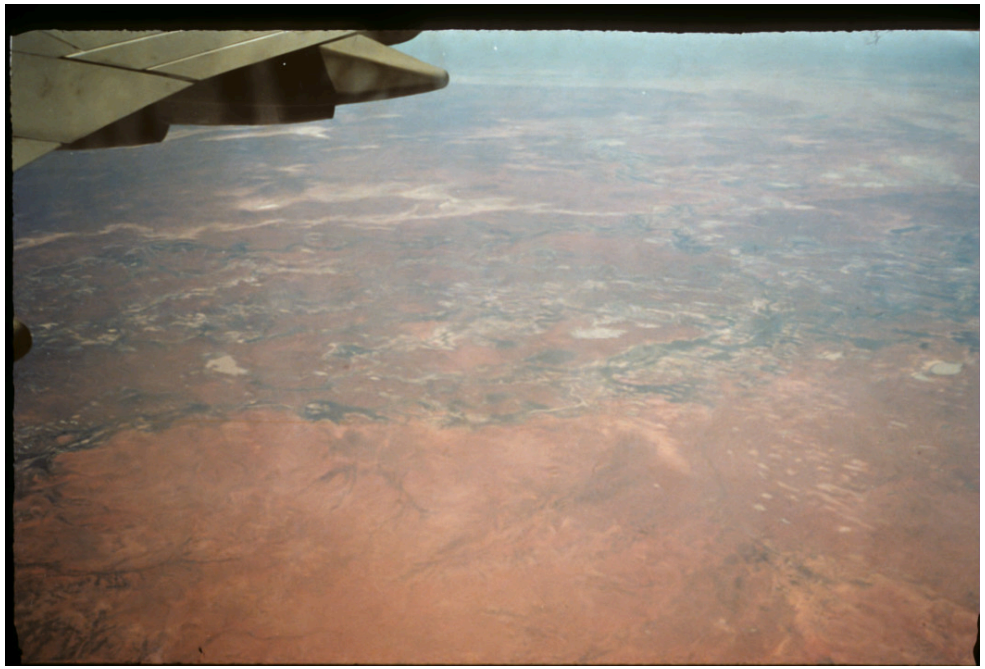
Dust uncertainties (more…..):

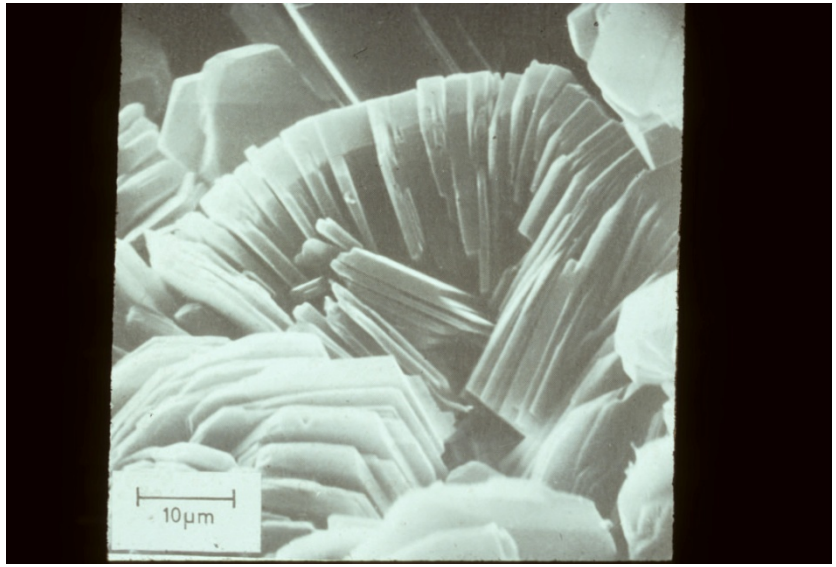
Fe oxides/oxyhydroxides, as sub-μm particles (&/or grain coatings) can affect dust optical properties (and Fe bioavailability…..); e.g.

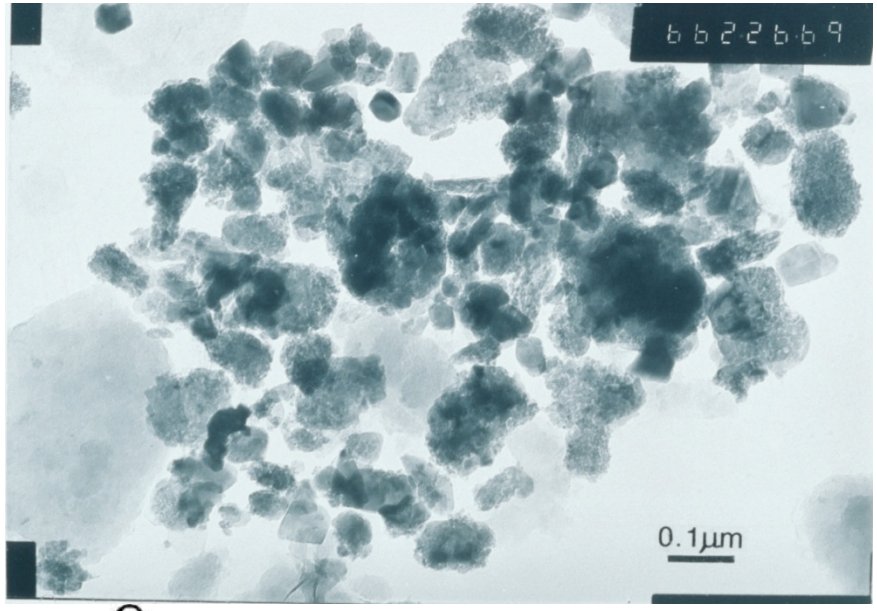
haematite (αFe_2O_3, ~ 0.6-3.4% by vol in arid/semi-arid dust) and

goethite ($\gamma FeOOH$)

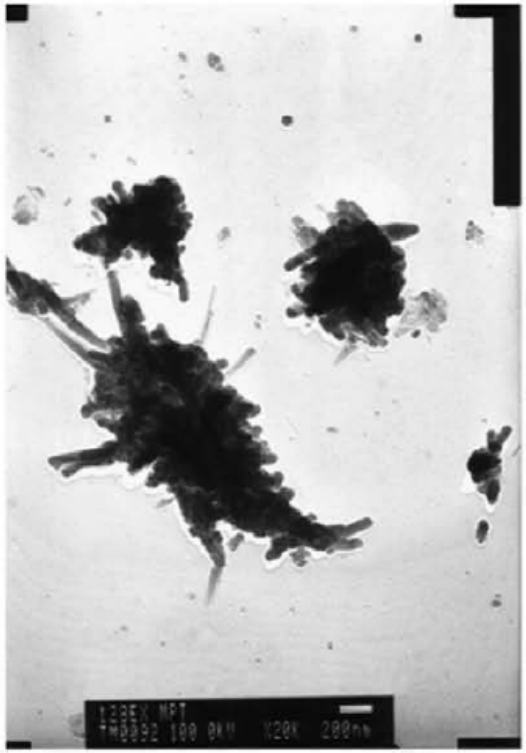
potentially key influences.



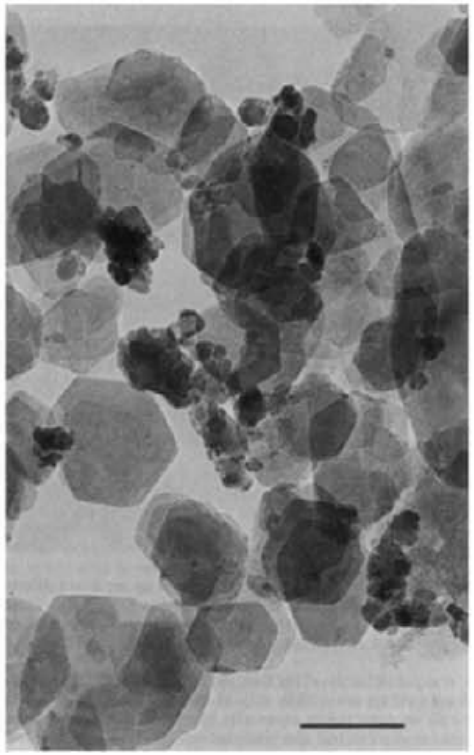




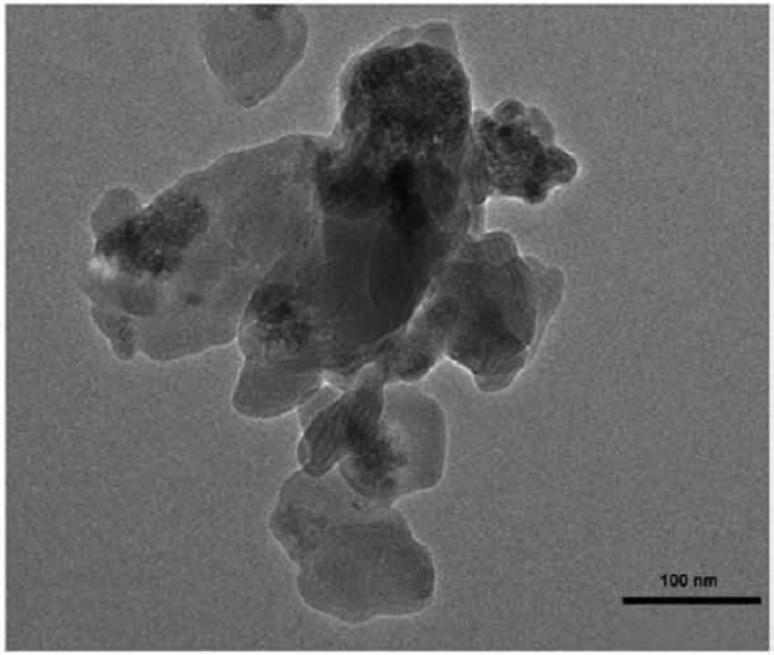
A



B



C



DUST Radiative Effect:

Over most surfaces, the dust RE is cooling:

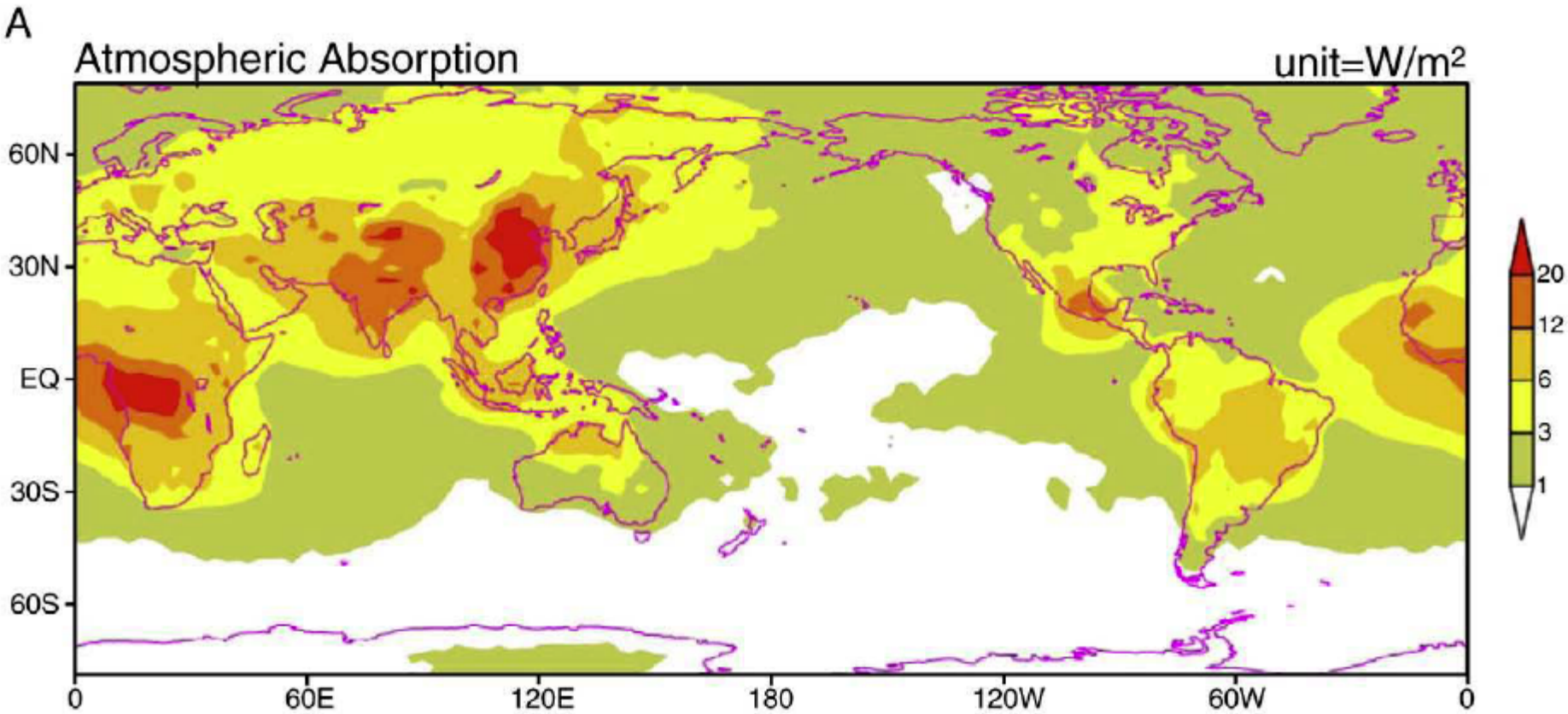


Fig. 7. (A) Atmospheric warming from absorption of radiation by dust; (B) resultant net surface cooling. Integration of satellite and ground-based data for 2002. (From Chung et al., 2005).

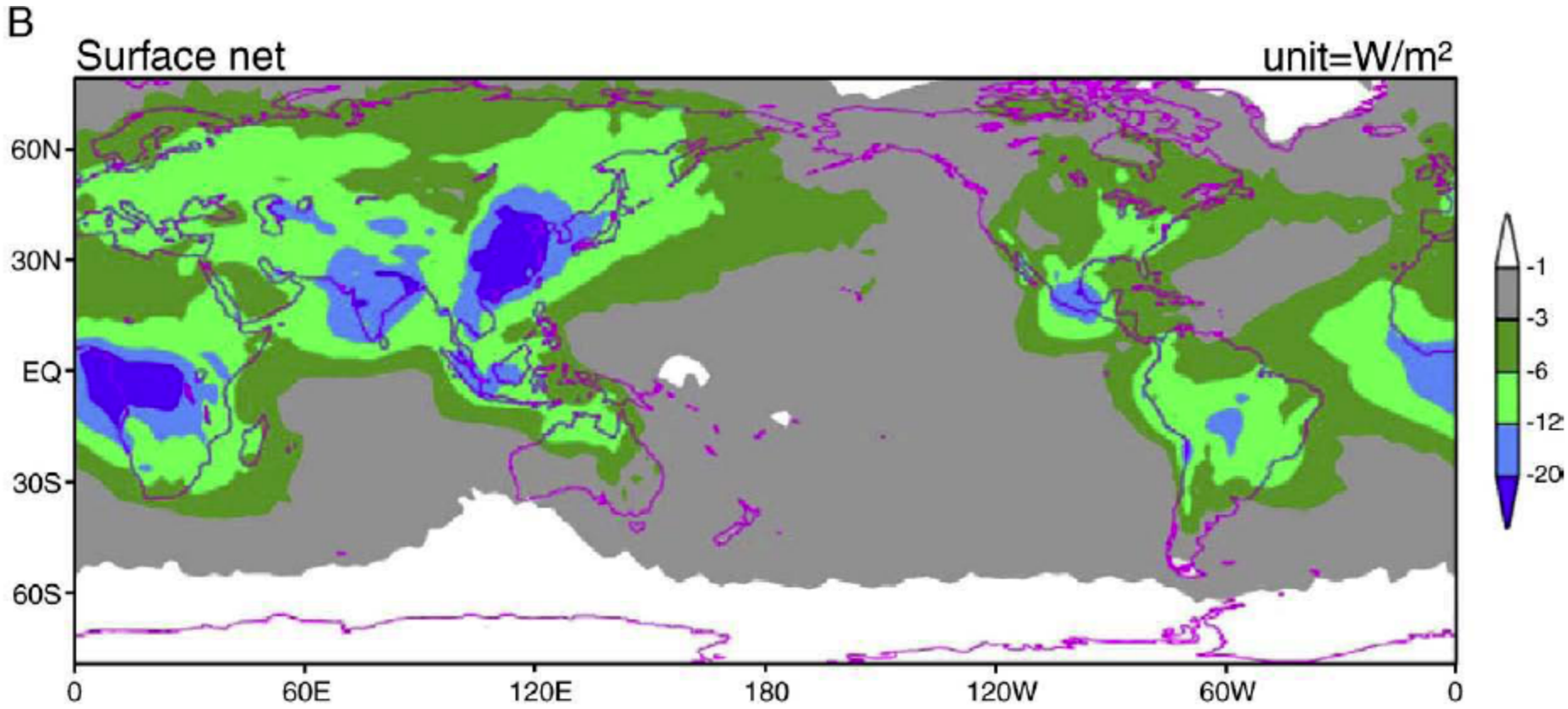


Fig. 7. (A) Atmospheric warming from absorption of radiation by dust; (B) resultant net surface cooling. Integration of satellite and ground-based data for 2002 (From Chung et al., 2005).

Fe fertilisation of HNLC regions of the world oceans: e.g. Southern Ocean…….

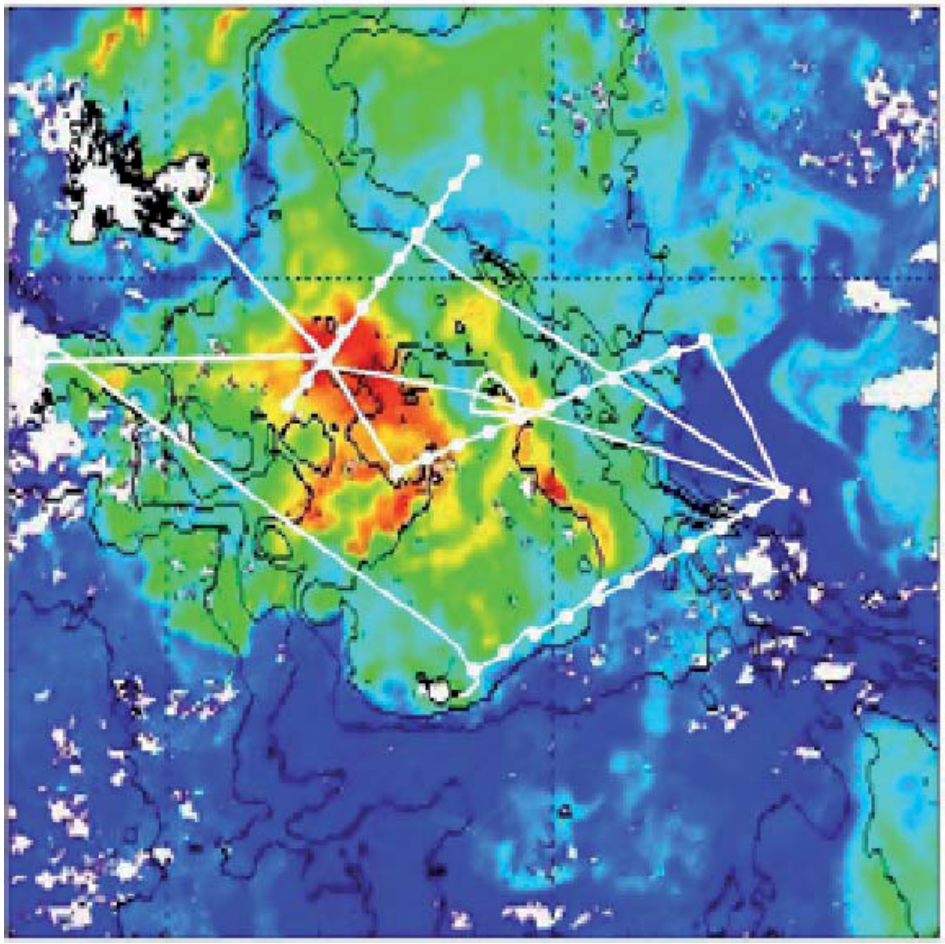
But Fe source?

Aeolian dust?

Regional or extra-regional?

Upwelled Fe from marine sed. sources?

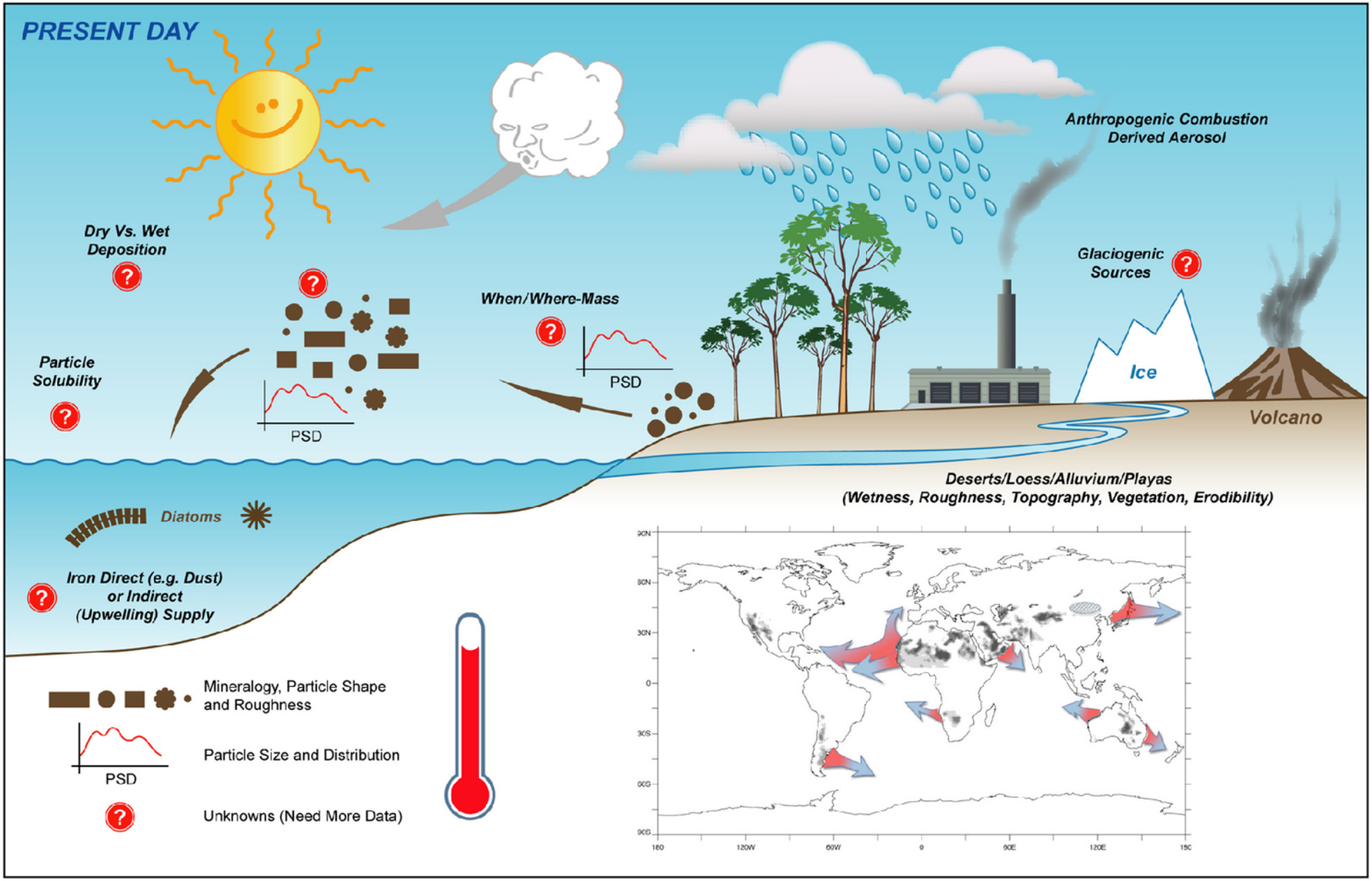
Other sources (IRD?)



Satellite image of diatom bloom close to Kerguelen Plateau, Nov. 2004 (Blain et al., 2007)

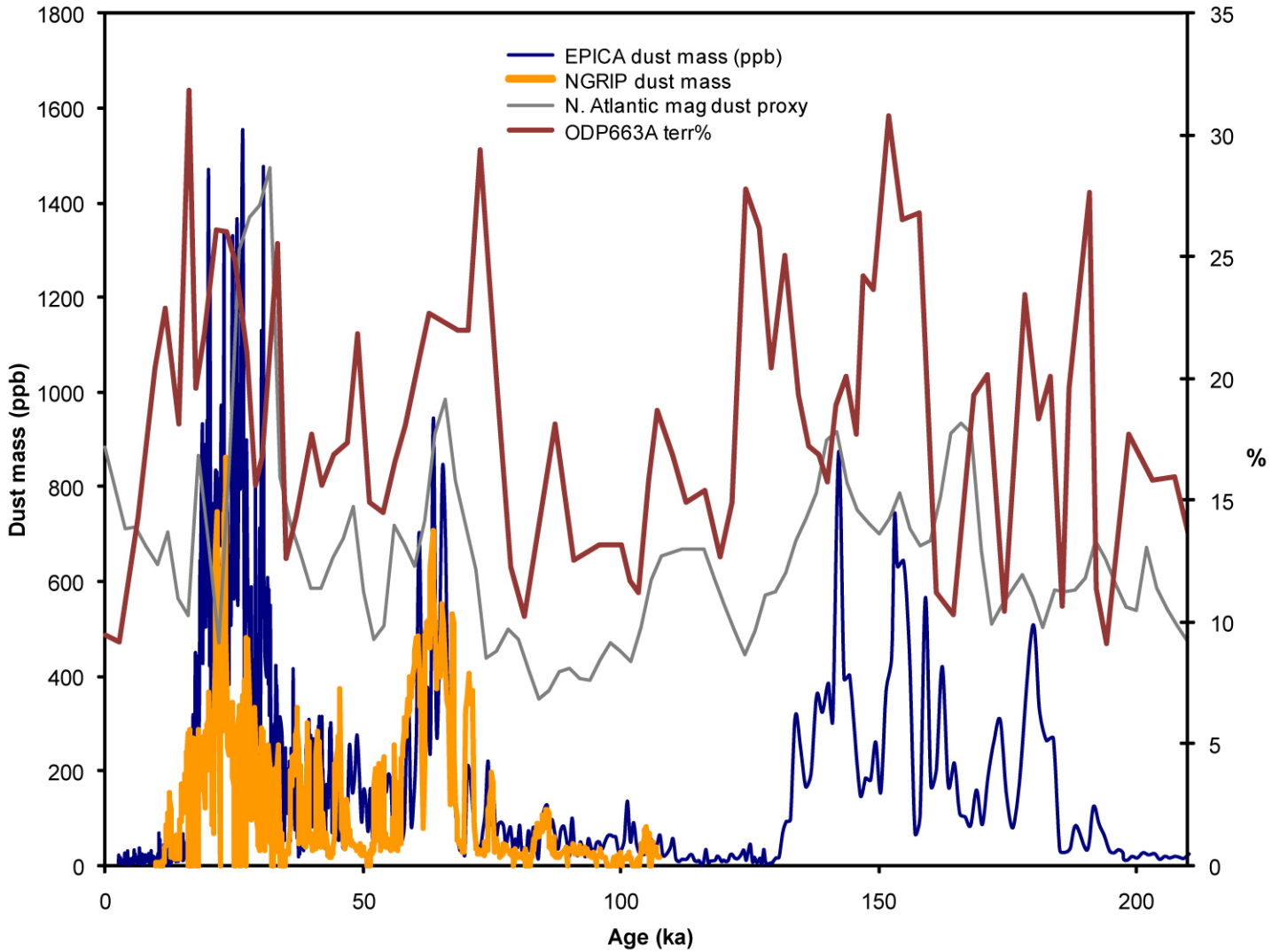
Orange = > 1 ug Chl a/l
Green = 0.5 - 1 ug Chl a/l
L blue = < 0.5 ug Chl a/l

‘Earth system science’ approach…….?



(Maher et al., 2010)

And what about the palaeo-dust situation? Pole-to-pole 'synchroneity' in dust flux changes



(Maher et al., 2010)

So, past RE changes from dust?

And past changes in ocean biogeochemistry?

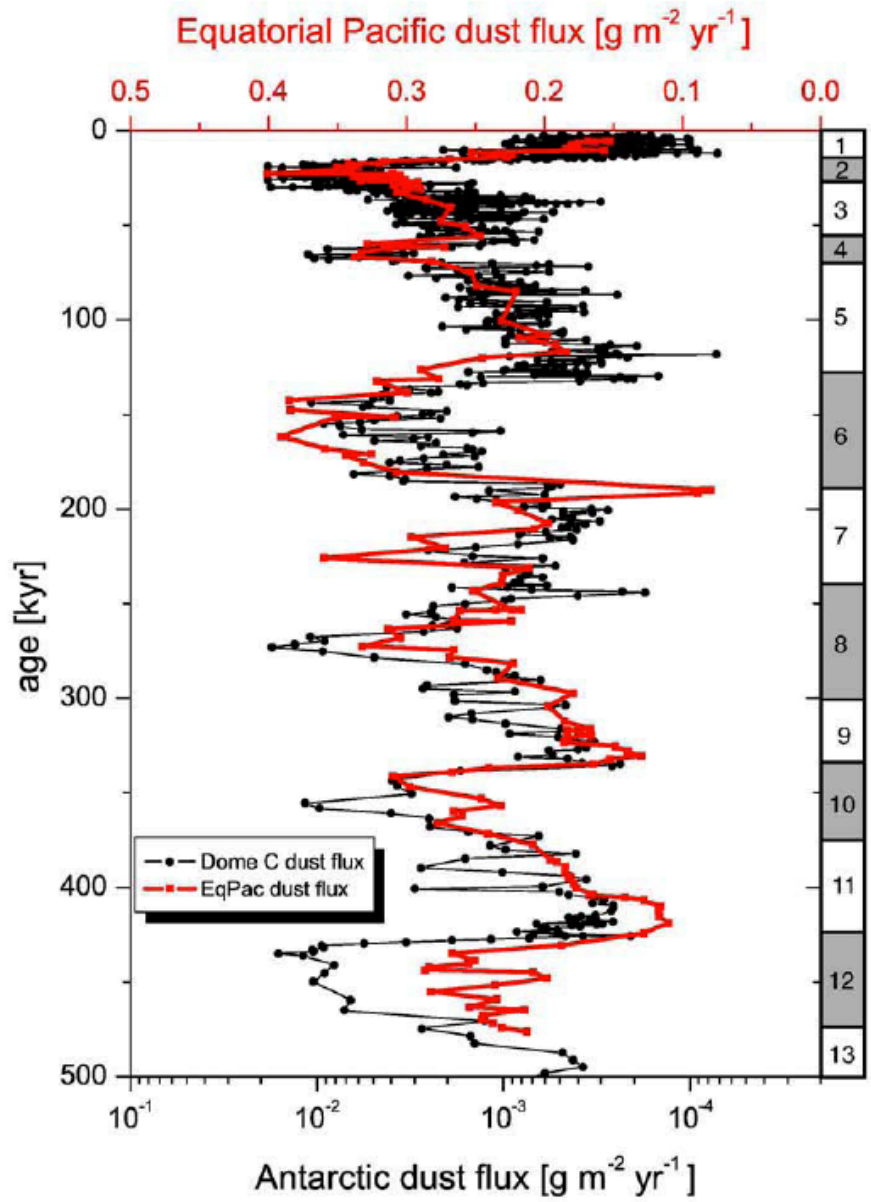
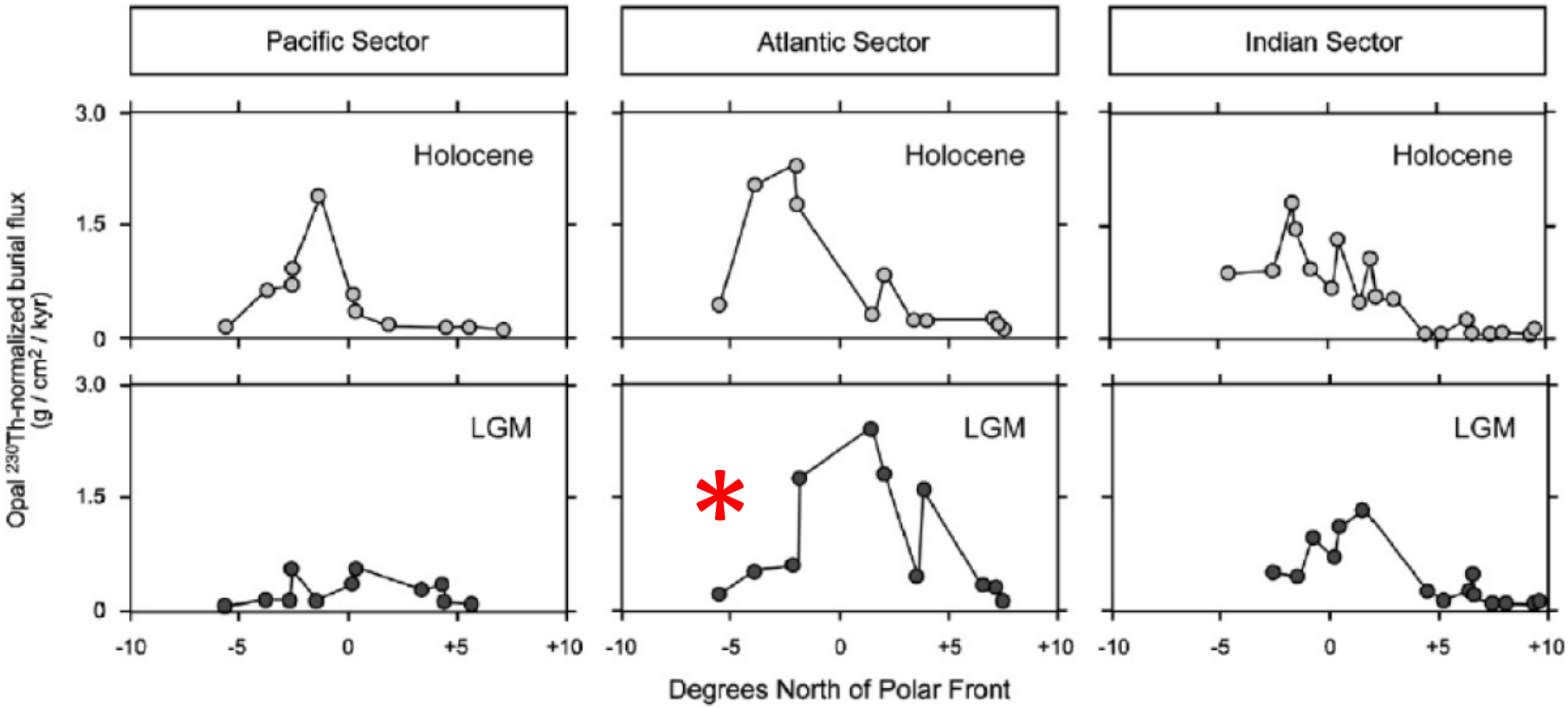


Fig. 14. Time series of dust flux to the central equatorial Pacific (TTN013-PC72; 0.1°N, 139.4°W) and to the EPICA Dome C Antarctic ice core. (From Winckler et al., 2008).

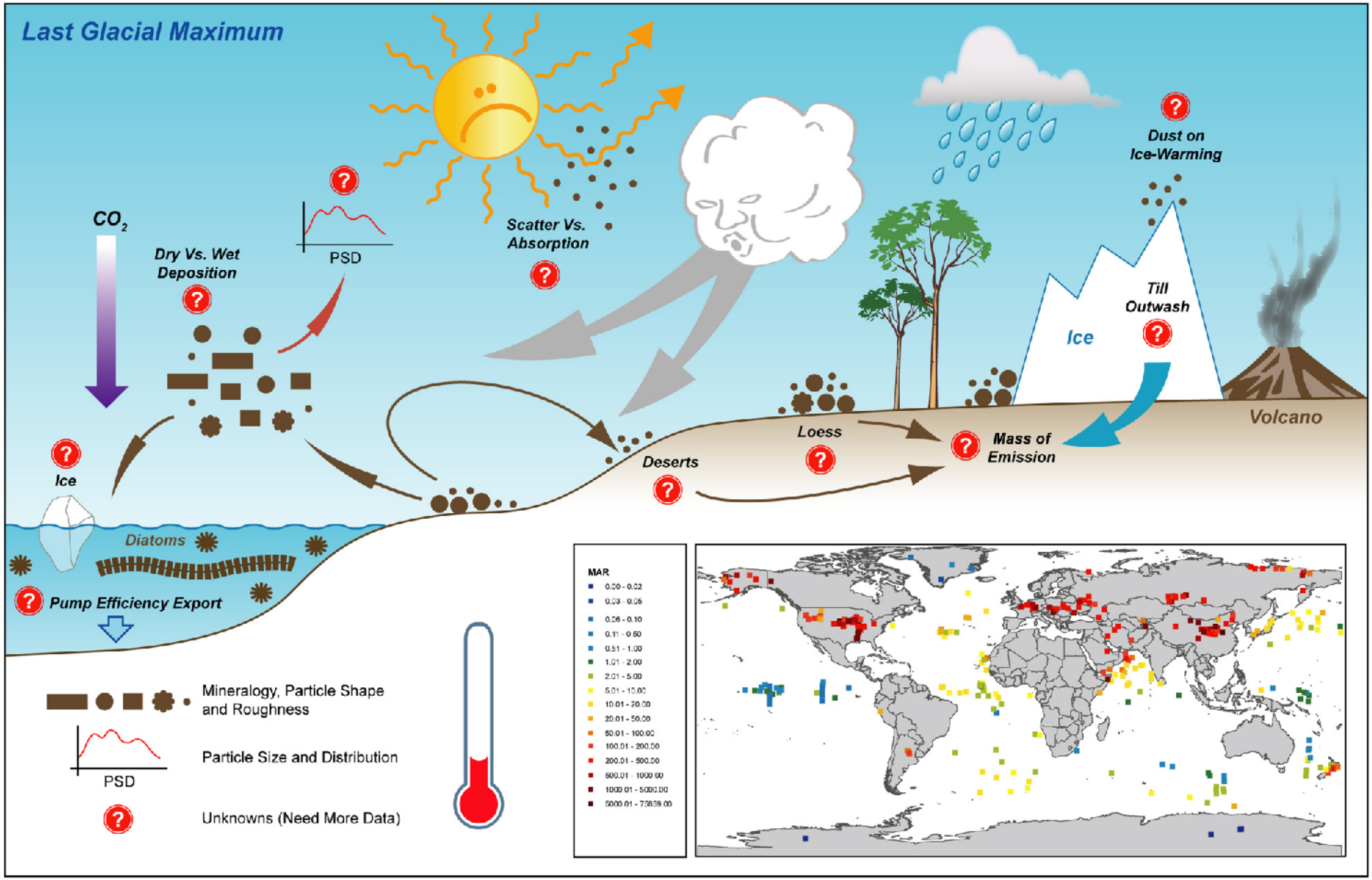
LGM-Holocene changes in productivity, Southern Ocean by sector



Most dust?
Most IRD?

(Diekmann, 2007)

LGM ‘earth system science’?



Maher et al., 2010

Value and Significance of Palaeo-data and Palaeo-modelling.....

- inform us of Earth system responses during times of very large changes in climate & environment;
- critically, provide data integrated over periods of 100 years & longer;
- such information (impossible to gain from any modern observational campaign) an essential requisite for climate modelling, &
- directly complementary to present day dust & process studies.

Simulating the past:
how well can we simulate radically different climates (and what data exist to 'benchmark' the models)?

- E.g. Dust mass accumulation rates (MARs) for the LGM?

The **D**ust **I**ndicators and **R**ecords of **T**errestrial and **MA**rine **P**alaeoenvironments (**DIRTMAP**) Database ……..history and future

Developed in Lund, Sweden, 1997

Mineral **A**erosols and **G**lacial-**I**nterglacial **C**ycles (**MAGIC**) Project (1997-2001)

Goal: Understanding the direct and indirect role of dust in climate change

PIs: SP Harrison, IC Prentice, H. Rodhe
Participants: Sandy P. Harrison, I. Colin Prentice, Karen Kohfeld, Ina Tegen, Martin Werner, Sebastian Engelstaedter, Corinne LeQuéré, Laurent Bopp, Helen Pfuhl, Henning Rodhe, Natalie Mahowald, Margareta Hansson, Yves Balkanski, Tanguy Claquin, Michael Schulz

‘DIRTMAP1’, ‘2’ and NOW ‘3’

Maher, B.A. and Kohfeld, K. E., 2009, DIRTMAP Version 3. LGM and Late Holocene Eolian Fluxes from Ice Cores, Marine Sediment Traps, Marine Sediments, and Loess Deposits,
http://www.lec.lancs.ac.uk/dirtmap3

(Fairly basic) data held in an Access database (DirtmapDataV3.mdb), accessed by a front end program (DirtmapProgV3.mdb).

Core ID	Lon	Lat	BULK Modern g/m2/yr	LGM/Modern	BULK LGM g/m2/yr	LGM Fraction <10 um	FINE LGM g/m2/yr < 10um	Reference 1
Onaero, North Island, New Zealand	174.38	-39			5			Alloway et al., 1992: Kohfeld and Harrison, 2001
Waitui, North Island, New Zealand	174.25	-39.13			4			Alloway et al., 1992: Kohfeld and Harrison, 2001
St. Pierre-les-Elbeuf, FR	1.23	49.6			242	0.25	60	Antoine et al., 1999; Mahowald et al., 2006
Canteen Creek, IL	-90.02	38.64			1,486	0.28	416	Bettis et al., 2003; Mahowald et al., 2006
Core G39, IL	-90	38.72			911	0.28	255	Bettis et al., 2003; Mahowald et al., 2006
Core GT-6, WI	-90.83	42.68			433	0.28	121	Bettis et al., 2003; Mahowald et al., 2006
Core OP-16, TN	-89	36.42			286	0.24	69	Bettis et al., 2003; Mahowald et al., 2006
Crawford, IA	-95.67	41.9			1,147	0.27	310	Bettis et al., 2003; Mahowald et al., 2006
Dunlap, IA	-95.65	41.83			1,982	0.27	535	Bettis et al., 2003; Mahowald et al., 2006
Earlham, IA	-94.1	41.48			578	0.32	185	Bettis et al., 2003; Mahowald et al., 2006
Greenbay Hollow, IL	-90.61	38.98			711	0.28	199	Bettis et al., 2003; Mahowald et al., 2006
Greenfield, IA	-94.45	41.37			670	0.33	221	Bettis et al., 2003; Mahowald et al., 2006
Hancock, IA	-95.27	41.35			1,047	0.26	272	Bettis et al., 2003; Mahowald et al., 2006
Harvard, IA	-93.27	40.7			371	0.28	104	Bettis et al., 2003; Mahowald et al., 2006
Hokah, MN	-91.3	43.75			371	0.3	111	Bettis et al., 2003; Mahowald et al., 2006
Hornbeak, TN	-89.3	36.37			494	0.24	119	Bettis et al., 2003; Mahowald et al., 2006
Hummeston, IA	-93.52	40.75			410	0.32	131	Bettis et al., 2003; Mahowald et al., 2006
Keller Farm, IL	-90	38.75			1,542	0.28	432	Bettis et al., 2003; Mahowald et al., 2006
La Sena, NE	-100.2	40.4			775	0.19	147	Bettis et al., 2003; Mahowald et al., 2006
Last Chance, CO	-103.6	39.7			435	0.26	113	Bettis et al., 2003; Mahowald et al., 2006
Loveland, IA	-95.88	41.5			6,048	0.25	1512	Bettis et al., 2003; Mahowald et al., 2006
Murray, IA	-93.95	41.03			491	0.32	157	Bettis et al., 2003; Mahowald et al., 2006
Naponee, NE	-99.09	40.09			572	0.2	114	Bettis et al., 2003; Mahowald et al., 2006
Natchez 3, MS	-91.29	31.58			1,744	0.3	523	Bettis et al., 2003; Mahowald et al., 2006
Old River, TN	-89.97	35.42			1,327	0.24	318	Bettis et al., 2003; Mahowald et al., 2006
Palermo, IA	-92.87	42.32			453	0.3	136	Bettis et al., 2003; Mahowald et al., 2006
Panama/Bentley, IA	-95.58	41.37			1,502	0.29	436	Bettis et al., 2003; Mahowald et al., 2006
Phillips Bayou, AR	-90.63	34.63			2,109	0.28	591	Bettis et al., 2003; Mahowald et al., 2006
Ruby Lane, IL	-90	38.62			283	0.28	79	Bettis et al., 2003; Mahowald et al., 2006
Salt Creek, IA	-92.52	42.1			565	0.3	170	Bettis et al., 2003; Mahowald et al., 2006
Vicksburg 1, MS	-90.67	32.38			1,227	0.28	344	Bettis et al., 2003; Mahowald et al., 2006
Wempletown SE, IL	-89.14	42.32			179	0.28	50	Bettis et al., 2003; Mahowald et al., 2006
Woodbine, IA	-95.73	41.82			2,100	0.26	546	Bettis et al., 2003; Mahowald et al., 2006
Alburnett Paha, IA	-91.63	42.17			1,595	0.3	478	Bettis et al., 2003, Mahowald et al., 2006
Athens Quarry N., IL	-89.71	40			314	0.15	47	Bettis et al., 2003; Mahowald et al., 2006
Barton County, KS	-98.7	38.4			143	0.25	36	Bettis et al., 2003; Mahowald et al., 2006
Beecher Is., CO	-102.1	39.9			1692	0.26	440	Bettis et al., 2003; Mahowald et al., 2006
Beisel-Steinle, KS	-98.5	38.8			264	0.25	66	Bettis et al., 2003; Mahowald et al., 2006
Bellevue, NE	-95.97	41.13			850	0.33	280	Bettis et al., 2003; Mahowald et al., 2006
Belovo	83.6	52.6			379	0.4	152	Chlachula, 2003; Mahowald et al., 2006
Berezov	86.1	55.6			189	0.4	76	Chlachula, 2003; Mahowald et al., 2006
Biysk	85.1	52.3			732	0.4	293	Chlachula, 2003; Mahowald et al., 2006

Location/ID

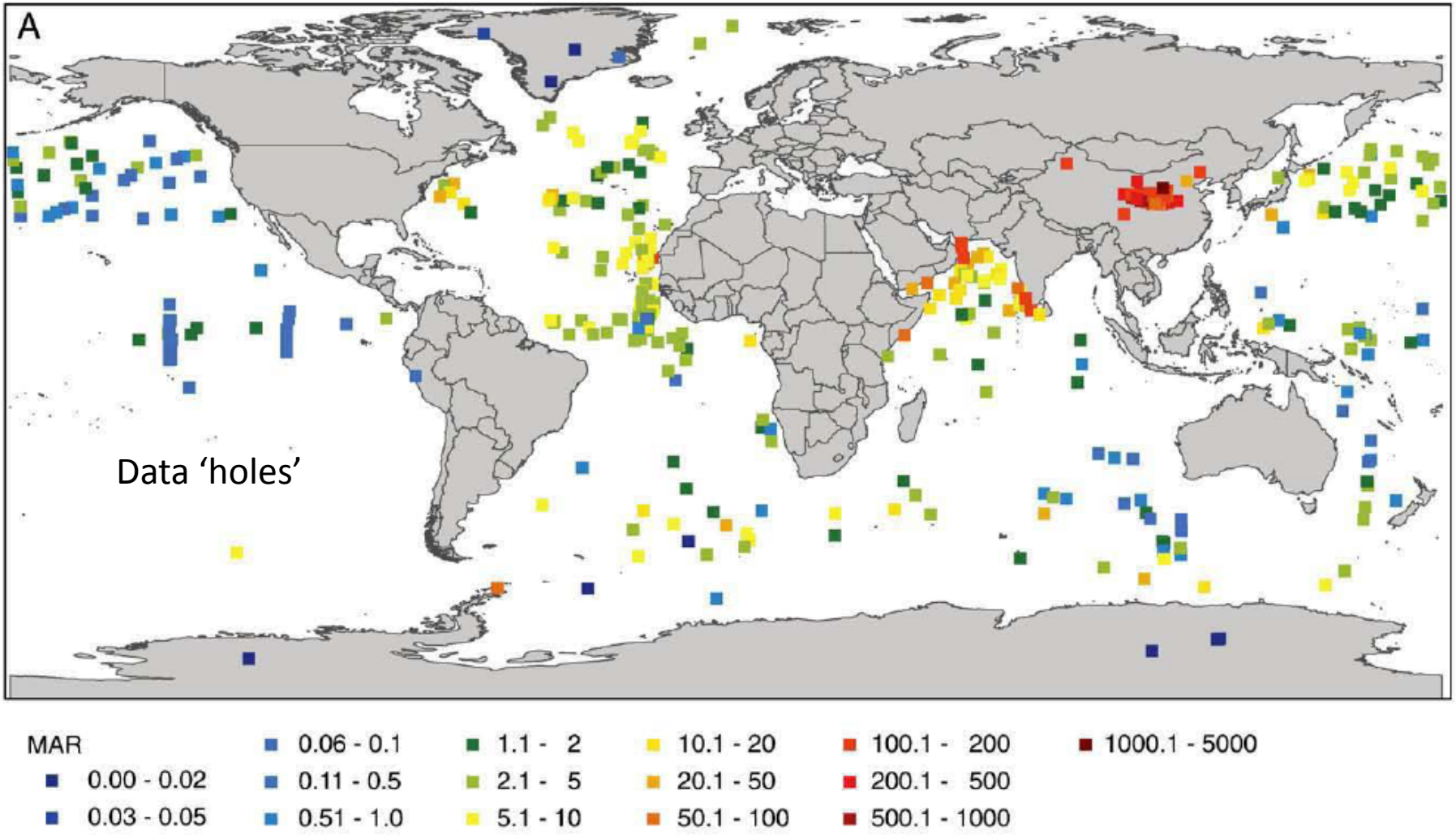
Bulk MAR

<10 um MAR

Author source

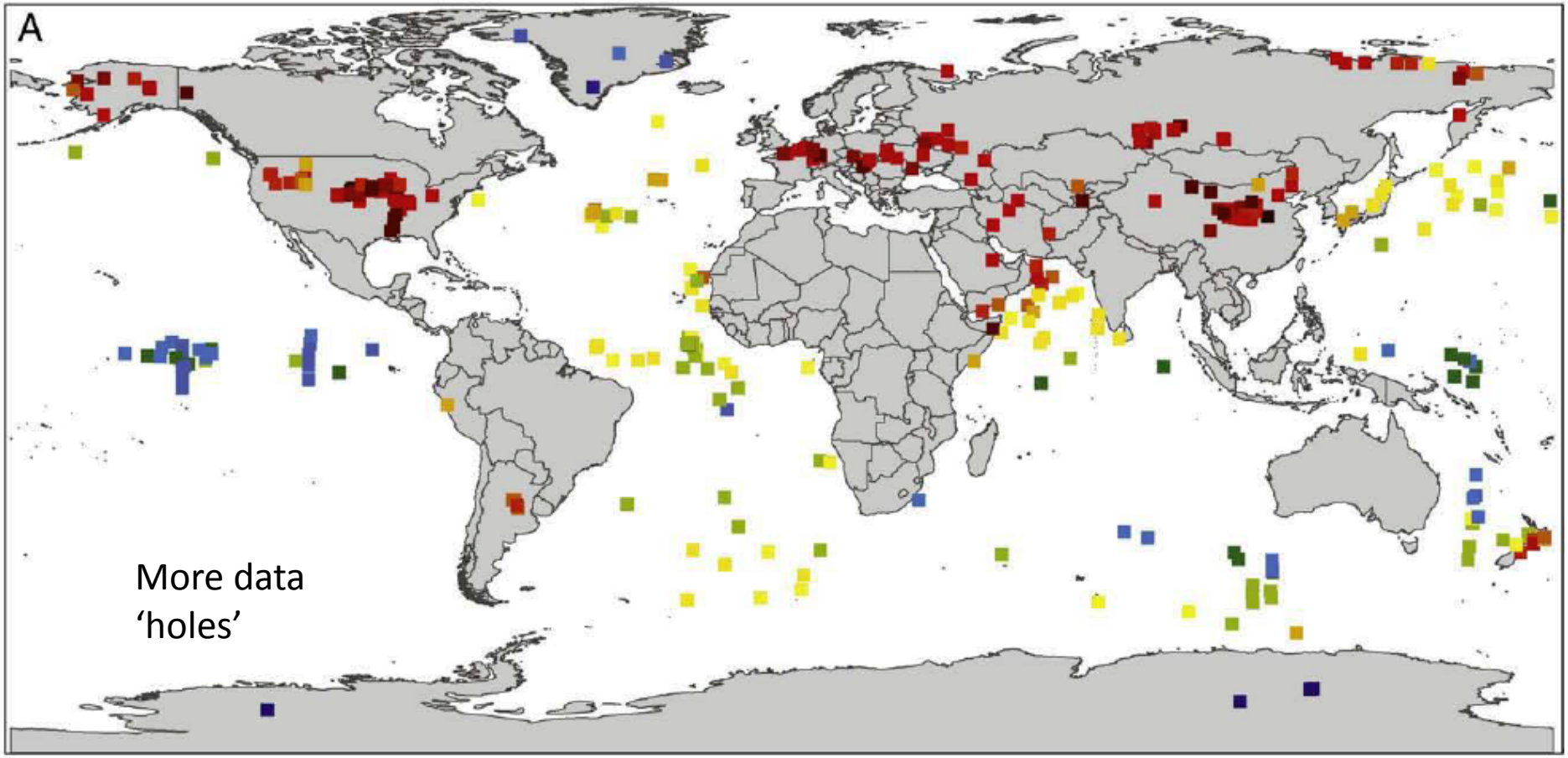
PRESENT DAY

B.A. Maher et al. / Earth-Science Reviews 99 (2010) 61–97



g/m2/yr

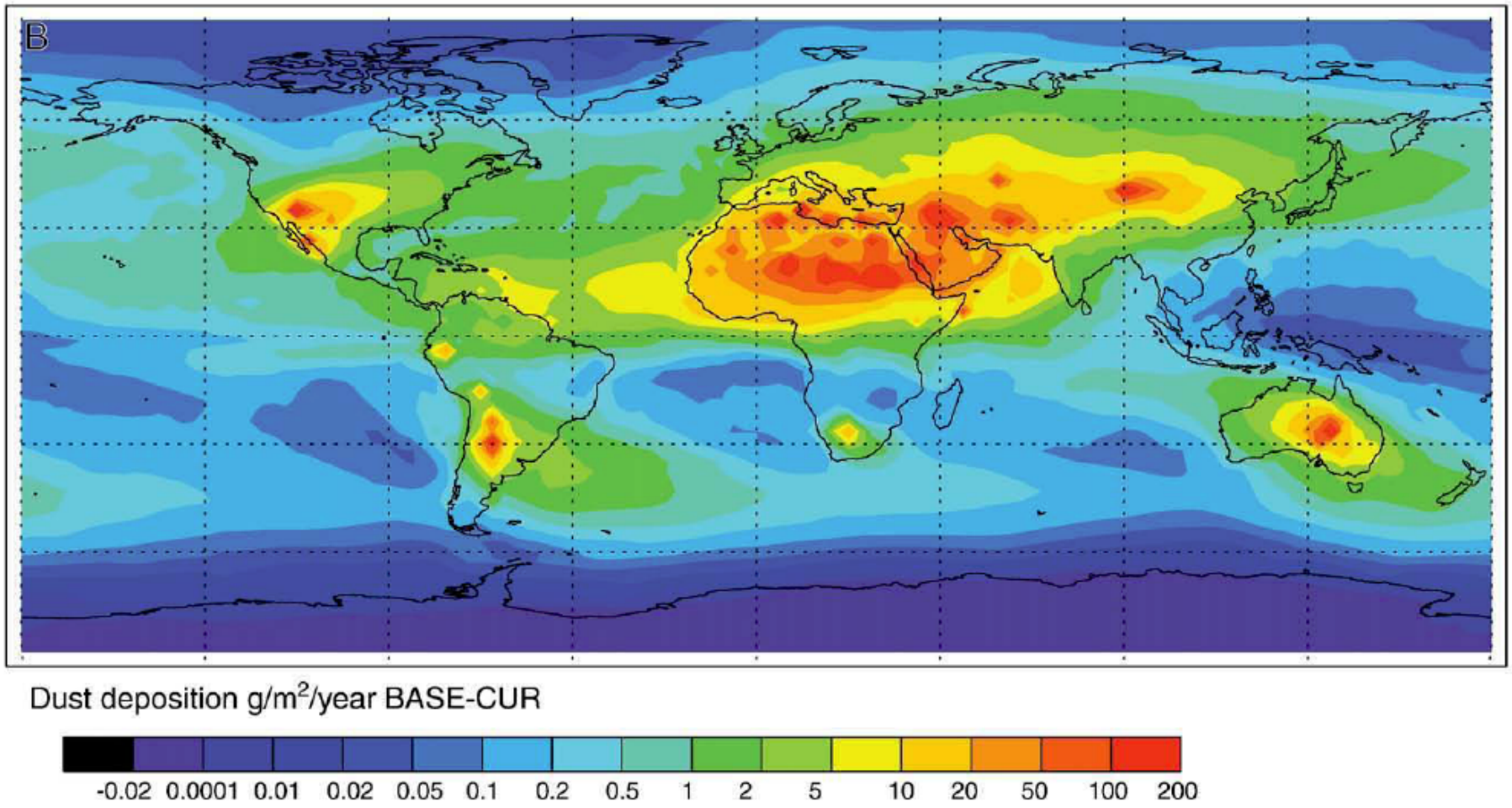
LGM



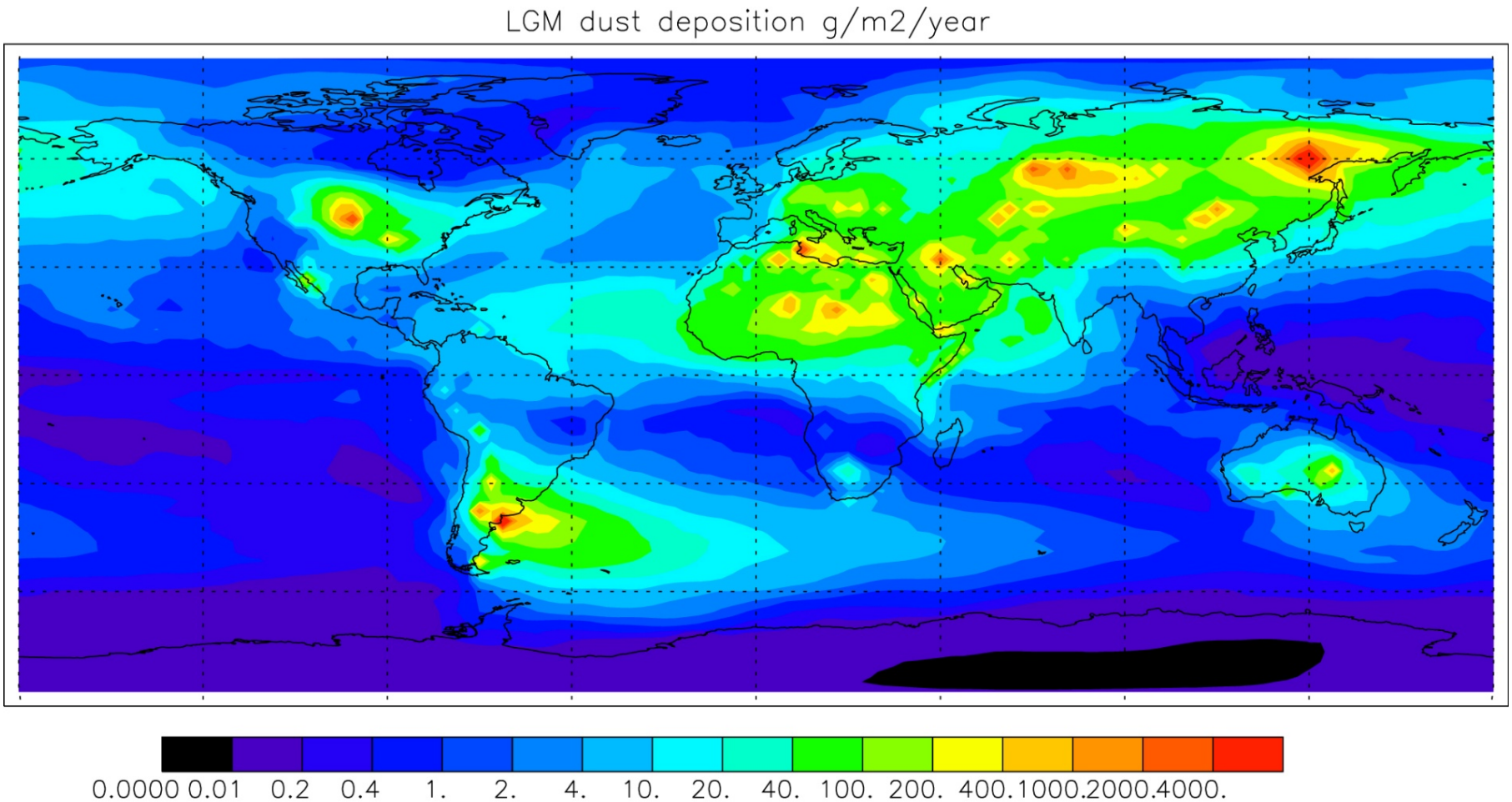
MAR

- 0.00 - 0.02
- 0.03 - 0.05
- 0.06 - 0.1
- 0.11 - 0.5
- 0.51 - 1.0
- 1.1 - 2
- 2.1 - 5
- 5.1 - 10
- 10.1 - 20
- 20.1 - 50
- 50.1 - 100
- 100.1 - 200
- 200.1 - 500
- 500.1 - 1000
- 1000.1 - 5000
- > 5000.1

g/m2/yr



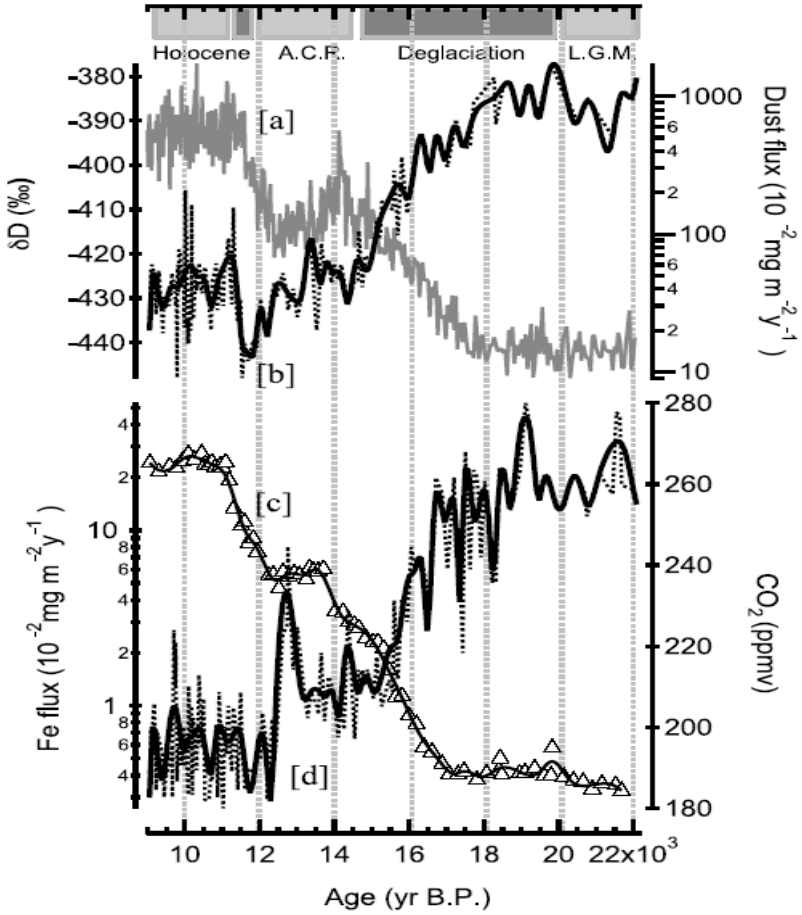
Mahowald et al., 2006



Mahowald et al., 2006

.....Son/daughter of 'DIRTMAP', e.g. 1. Beyond 'The Slice' (Kohfeld)

- Changes of dust, (Fe), CO_2, temperature
- Can we simulate transient feedbacks between these biogeochemical parameters?
- Can we get a global picture of transient changes in dust?
- In which sedimentary environments?



2. New Data, Proxies, Environments (Kohfeld)

- New data (at new and old locations)?
- New proxies +/or new components of dust ?
- Environments not previously incorporated into DIRTMAP?
    - E.g. Terrestrial, lacustrine environments

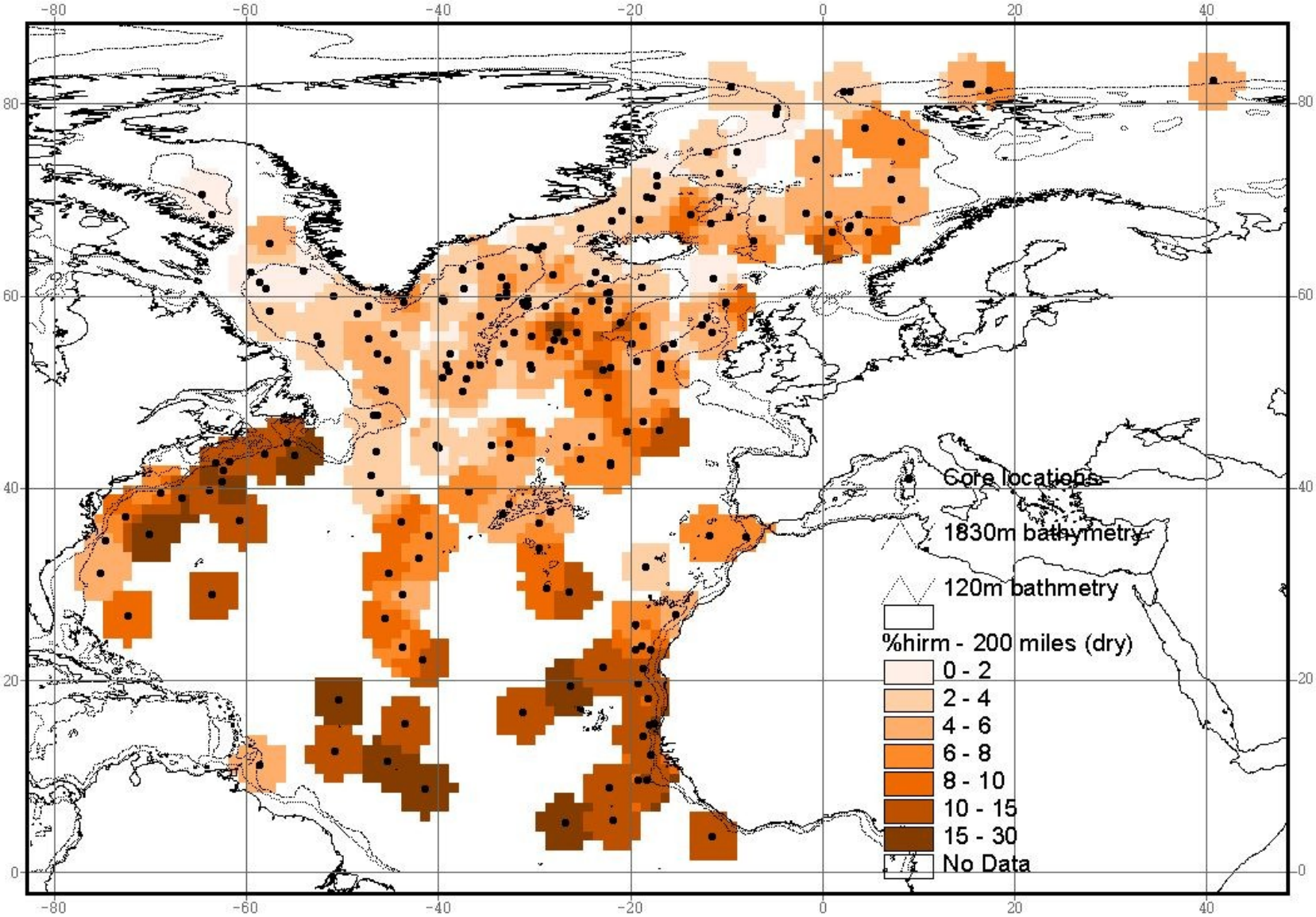
New proxies +/or new measured components of dust?

- ^{232}Th (marine sediments)
- Fe (…but which extractable fractions?....)
- Electron microscopy, + QEMSCAN (or similar) elemental analysis.
- Diffuse reflectance spectrophotometry
- Magnetic measurements….of ice, marine, terrestrial archives & potential source areas (PSAs)……

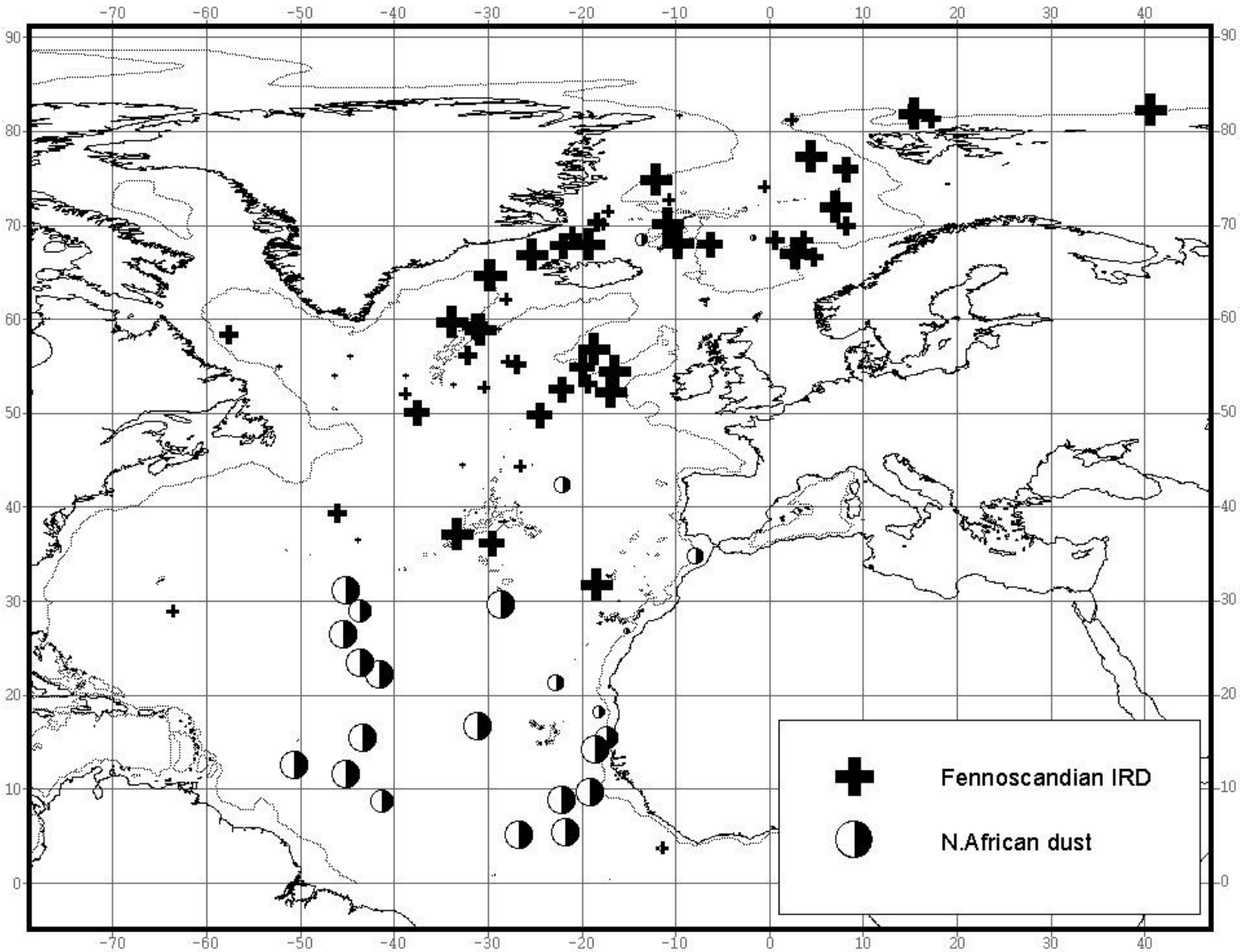
  e.g. 1. dust deposition, N Atlantic Ocean, and

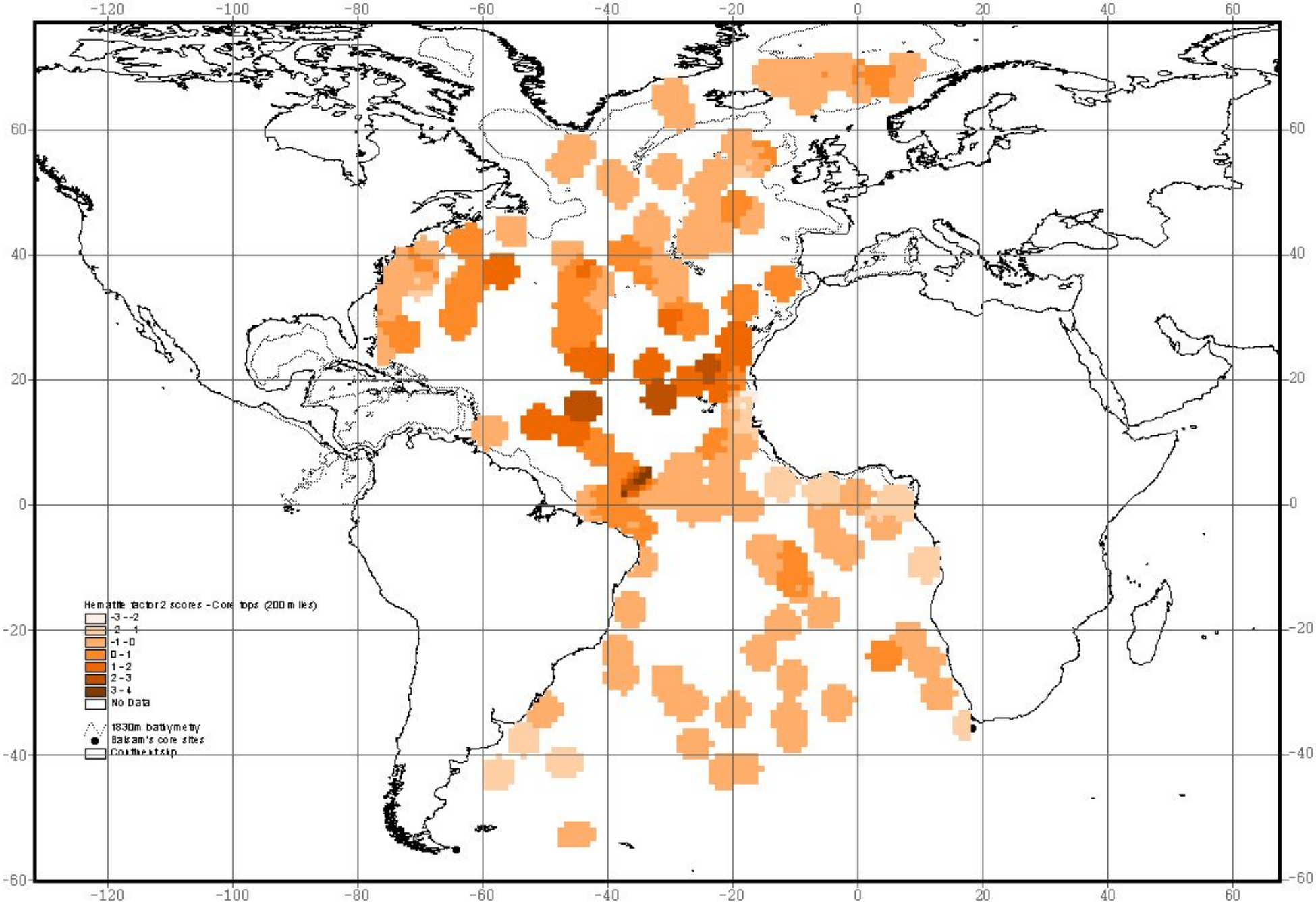
  2. dust sourcing, Chinese Loess Plateau.

E.G. 1: Dust deposition, N Atlantic Ocean: Magnetic analysis of LGM haematite distribution

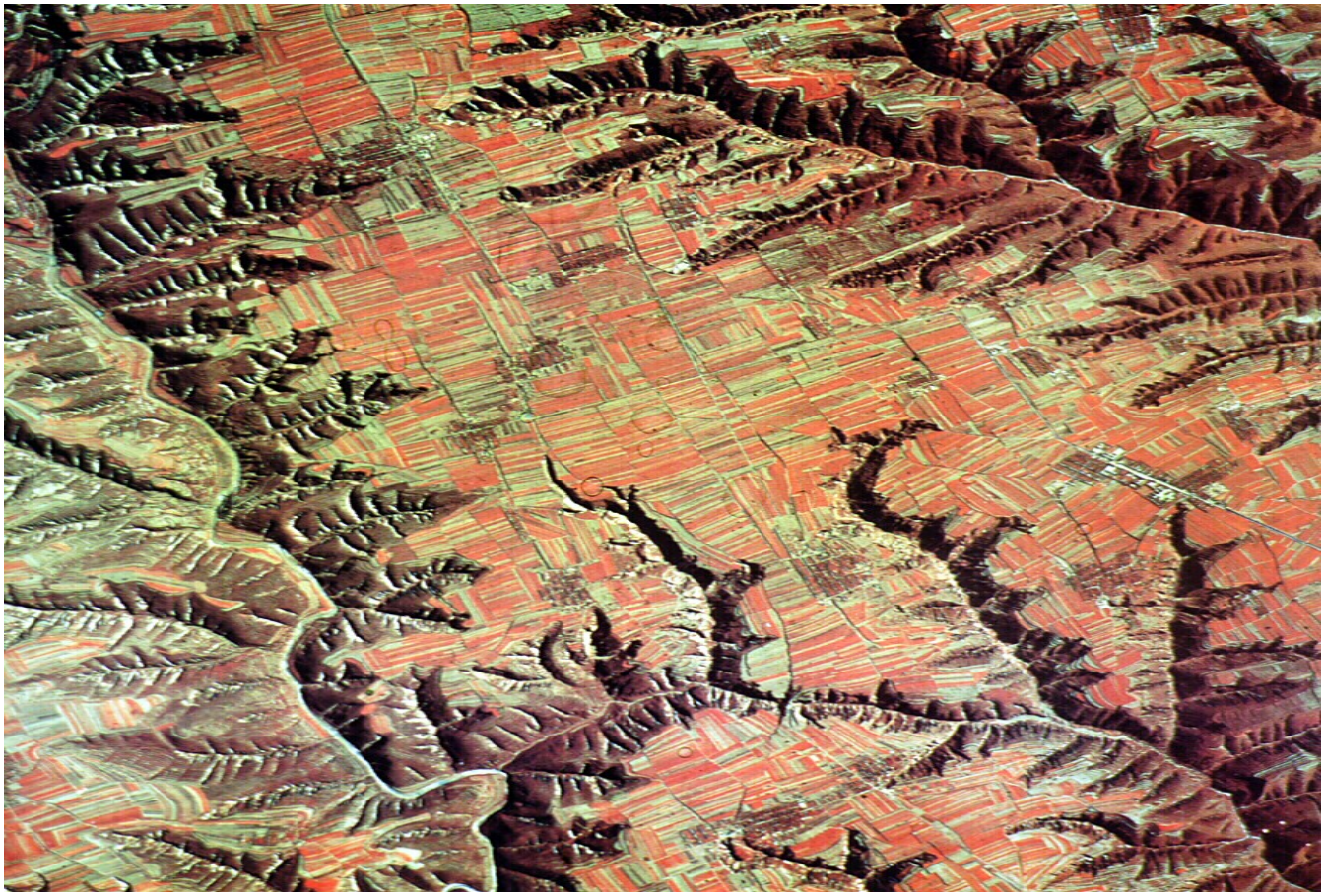


LGM dust, N Atlantic



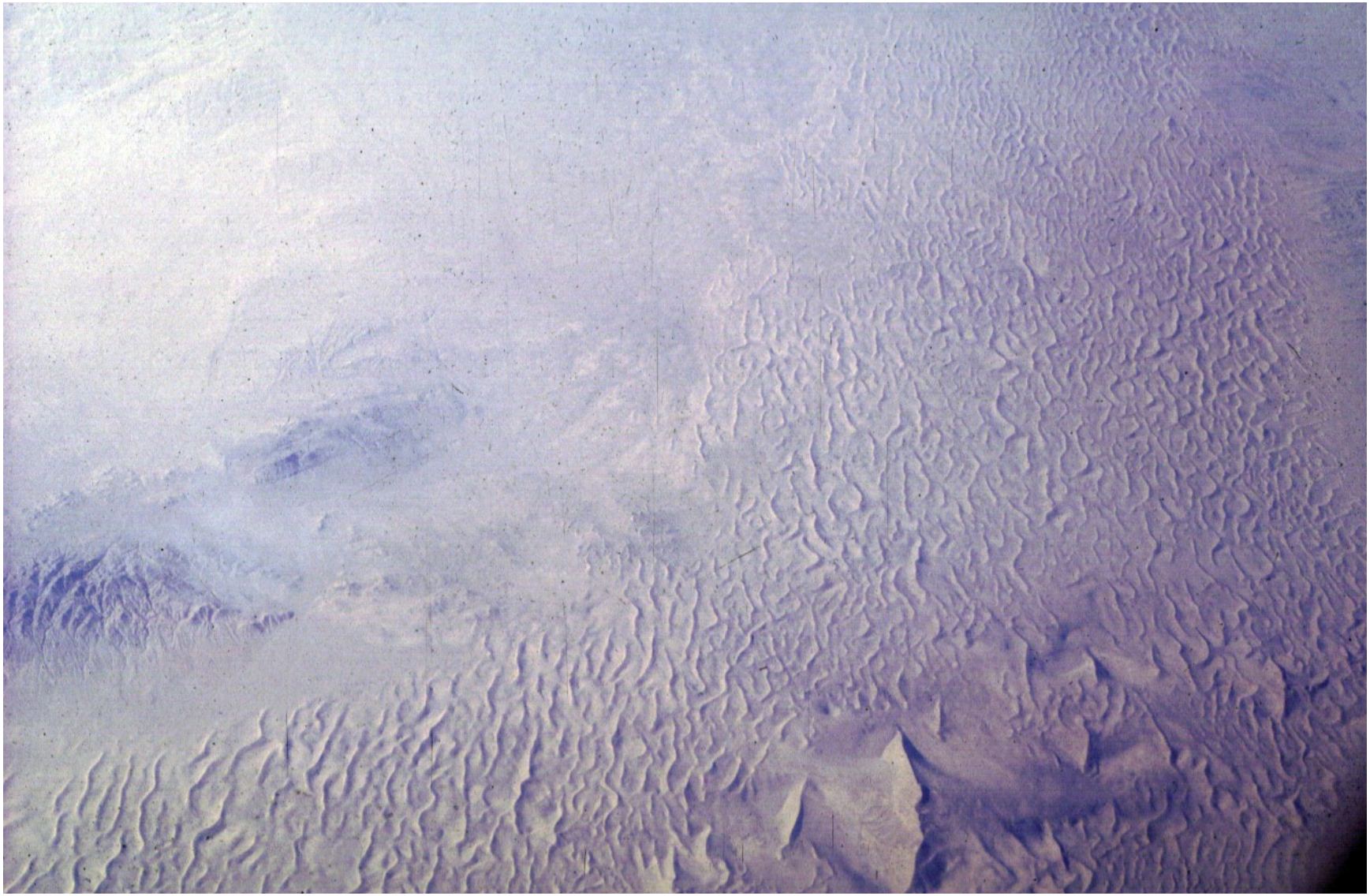

-120
-100
-80
-60
-40
-20
0
20
40
60
Hematite factor 2 scores - Core tops (200 miles)
-3 - -2
-2 - -1
-1 - 0
0 - 1
1 - 2
2 - 3
3 - 4
No Data
1830m bathymetry
Balsam's core sites
Coastline at skip

E.g. 2: Dust sourcing Chinese Loess Plateau

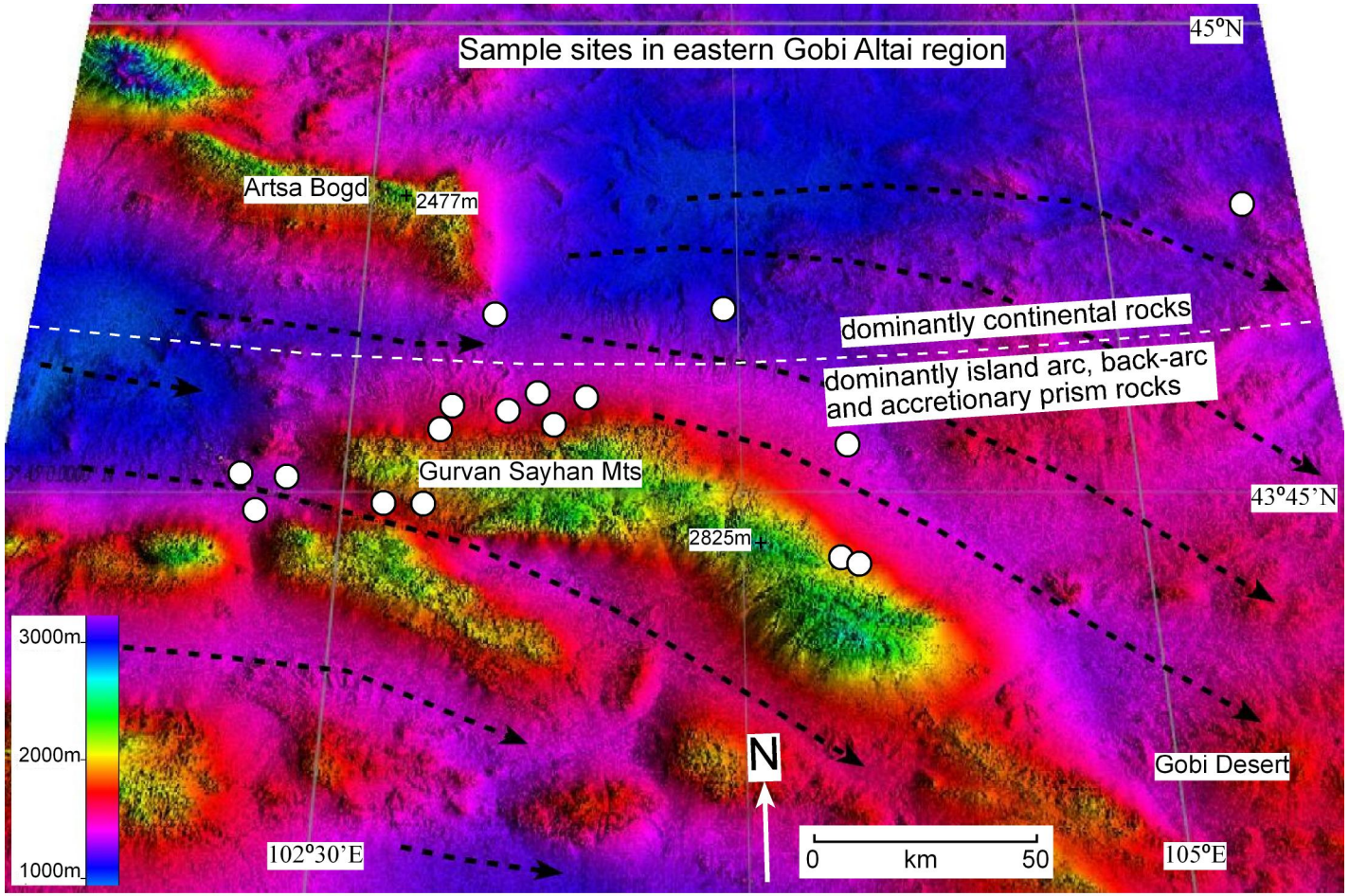


Sources for the famous Chinese Loess Plateau (classic view thought to be the Gobi Desert)

Gobi

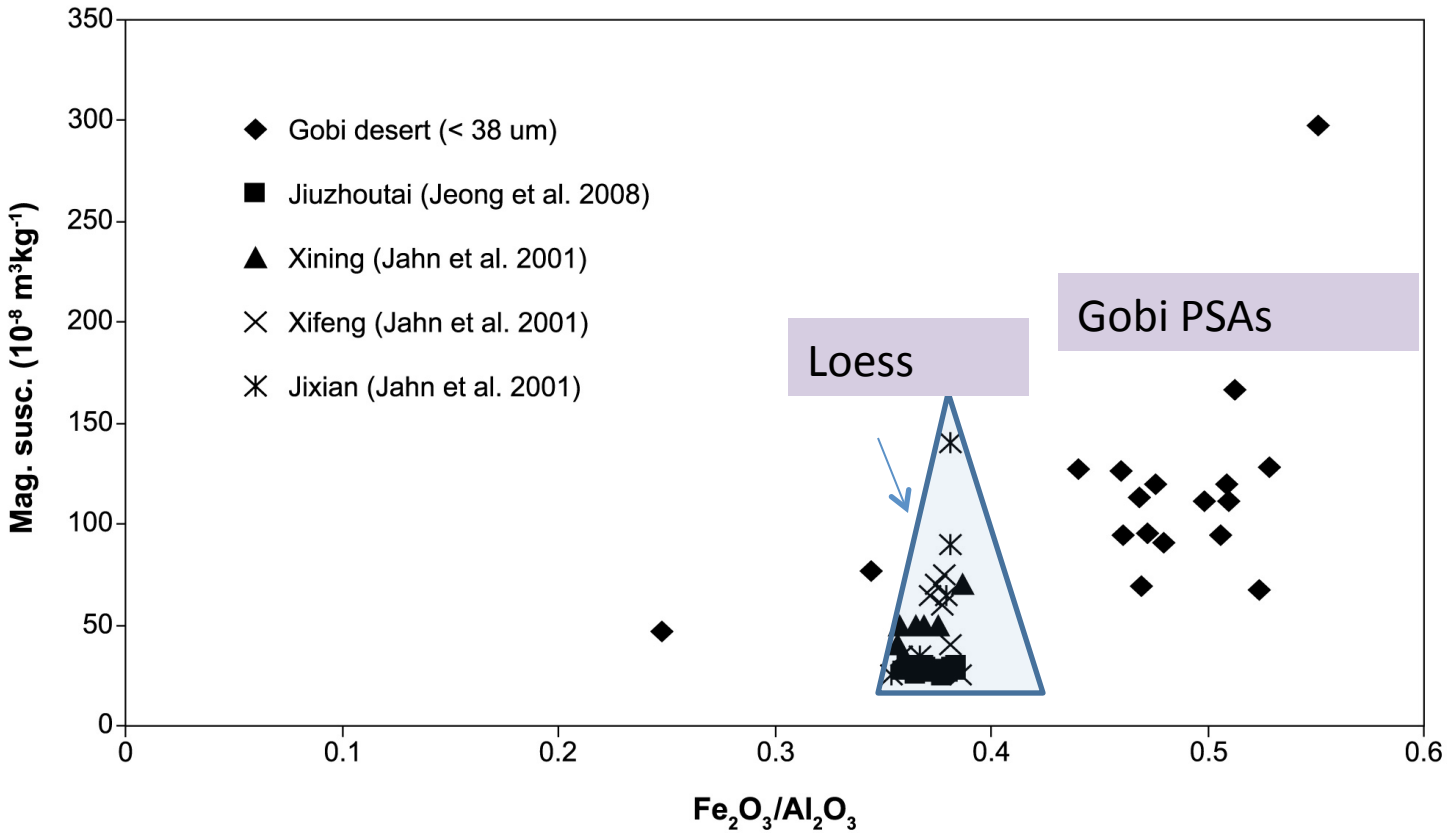


PSA samples from wind-streaked region, Gobi Altai:



Oblique perspective shaded relief model of eastern Gobi Altai, southern Mongolia. Sample locations shown as white circles. Black arrows indicate prevailing wind direction as indicated by wind streaking visible on satellite imagery.

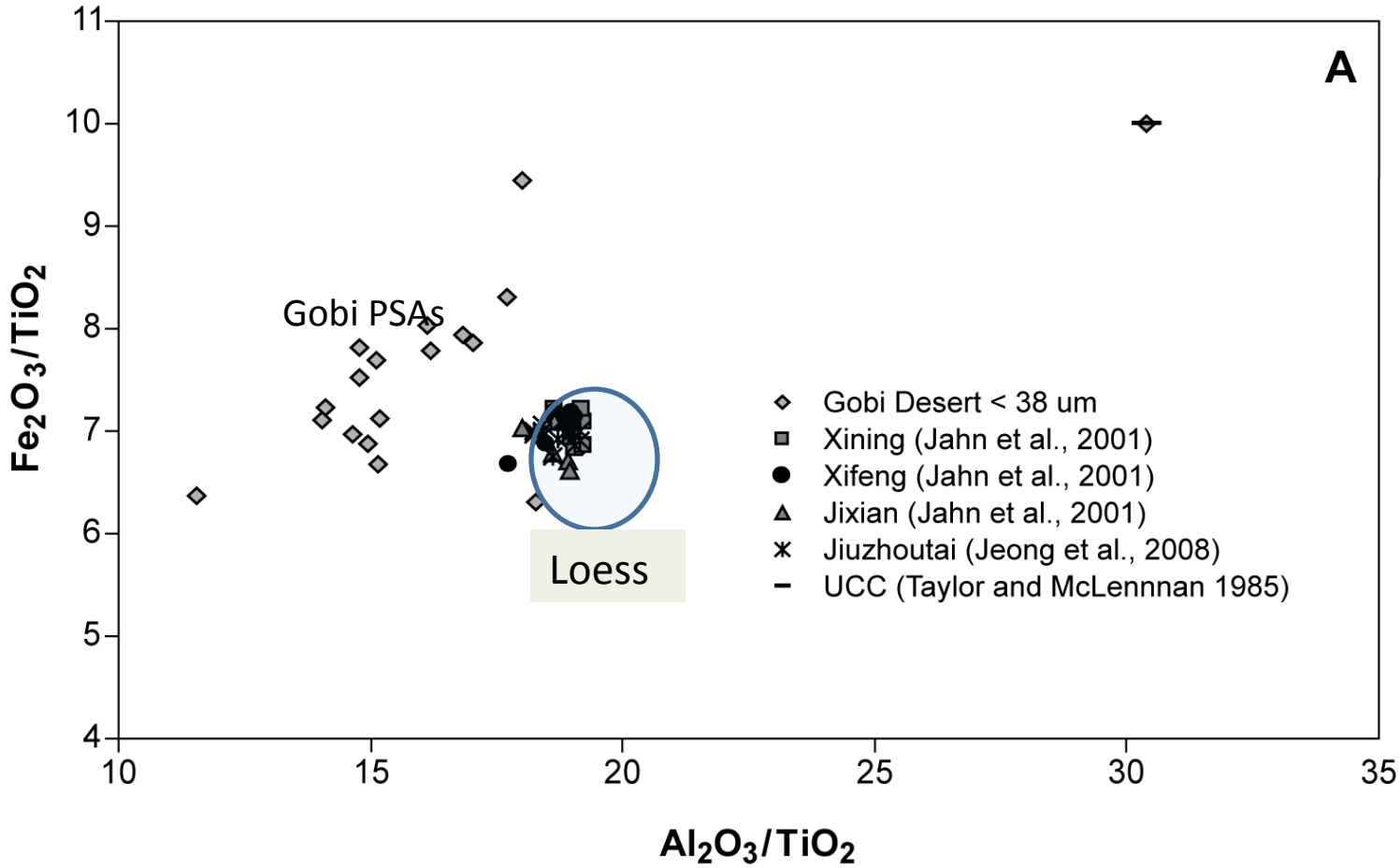
Magnetic and elemental analysis of PSAs and unweathered (LGM) loess



No (little) PSA/loess match

(*1 part 'mean Gobi source' would require > 80 parts negatively magnetic admixture, e.g. $CaCO_3$, to resemble the loess)*.

(Maher et al., Geology, 2009).



NB No PSA can be discounted or verified if not been sampled and characterised
(Mahowald et al., 1999)

.....Son/daughter of 'DIRTMAP'?

- considerable new (spatial and temporal) data exist/are now sought/can be obtained....
- thus can expect to improve simulation and evaluation of dust-cycle models .....

'DUSTSPEC '

DETAILED RATIONALE for 'DUSTSPEC'?

- ❑ Improved source identification (present and palaeo)

- ❑ New, integrated field and observational data studies, higher resolution & better-dated sequences, especially continental & HNLC areas; dust source discrimination.

- ❑ New methods for parameterization of dust source & emission variability

- ❑ Improved characterization of dust properties (mineralogy, grain size distribution, shape, source)

- ❑ Enhanced interaction between observationists (modern and palaeo), modellers and ocean biogeochemists

Additional specific components desirable for 'DUSTSPEC'?

- dust fluxes from time slices beyond the LGM & from higher resolution sediment sequences (e.g. at D/O cycle resolution → transient dust fluxes?)

- possible source, mineralogy (especially Fe oxides/ oxyhydroxides, re. both radiative properties & Fe bioavailability), clastic grain size, surface properties.

Updated/expanded 'DUSTSPEC' database:

Needs new data from:

- South America
- Eurasia and the Middle East,
- ice cores, and
- the Southern Hemisphere (esp. in the marine realm)

…….and probably needs a new home……

So, summary of ‘DUSTSPEC’ objectives:

- Incorporate newly available (spatial, temporal) data from e.g. S America, Eurasia, Middle East, S. Ocean, including for timeslices beyond LGM & for higher resolution sequences.

- Incorporate data on possible dust source, mineralogy, grain size and shape.

- Incorporate data ‘quality control’, establish protocols for the datasets, model/data comparisons, & dealing with uncertainties in the data & the models.

- Frame new model experiments (e.g. transient simulations, mesoscale modelling) & evaluate outcomes.

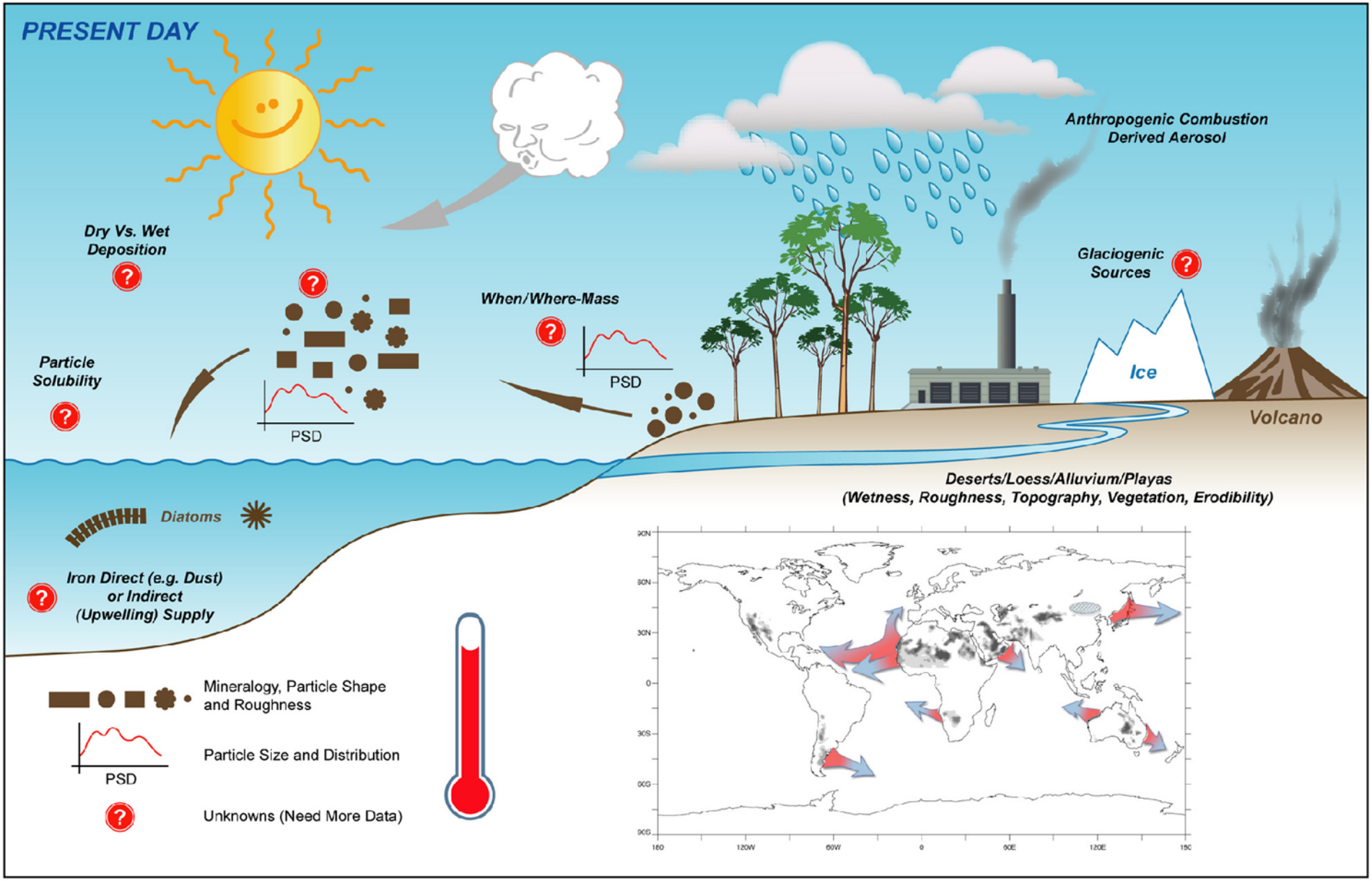
Anticipated results?

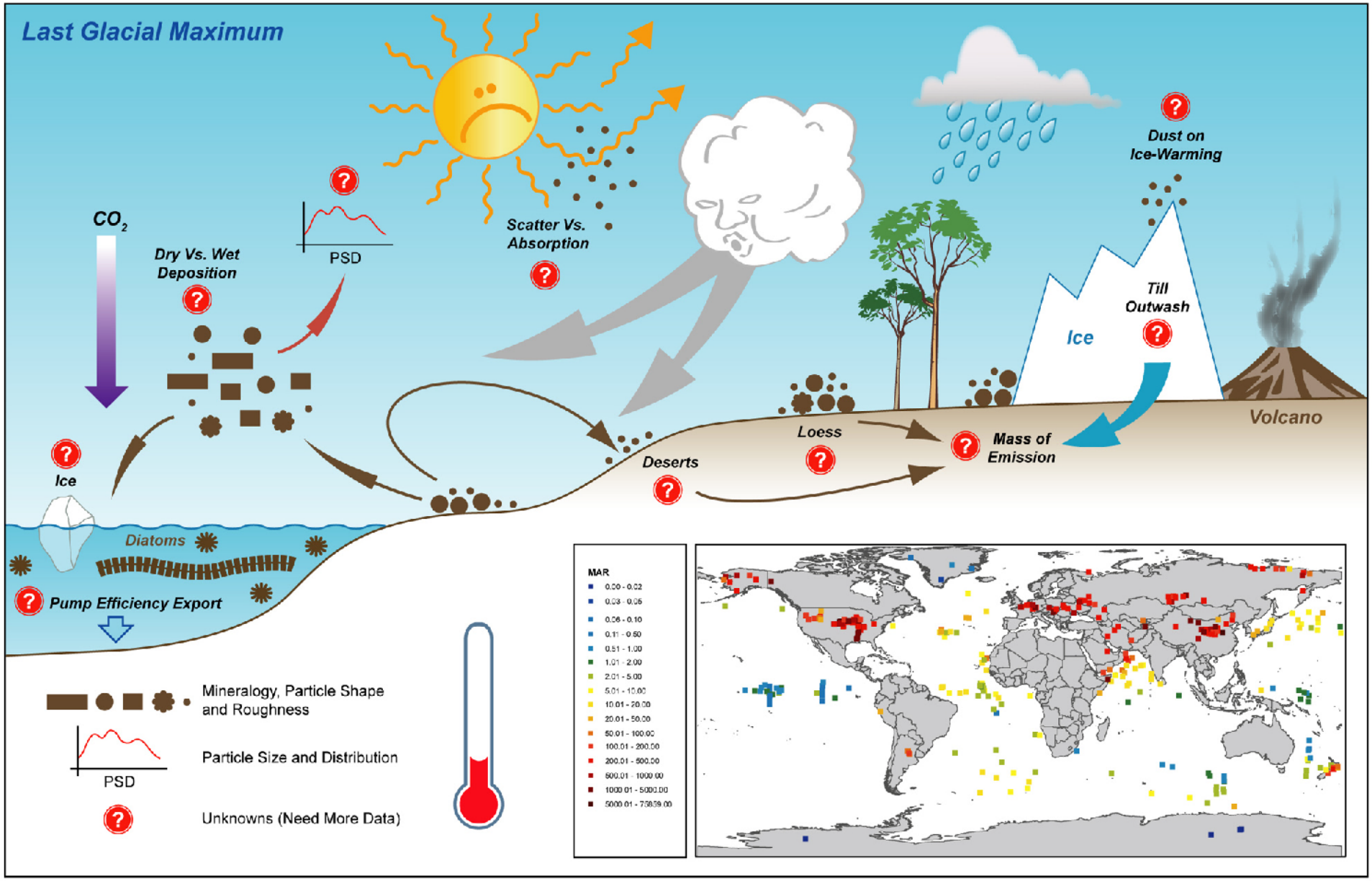
- Synthesis of new data on dust sources, fluxes & properties through the Quaternary.

- Improved modelling tools to resolve dust cycle problems

- Improved understanding of role of dust in past climate changes (RE and ocean biogeochemistry)

- Quantification of magnitude of dust forcing, & resultant climate changes, in the past and future.


PRESENT DAY
Dry Vs. Wet Deposition
Particle Solubility
PSD
When/Where-Mass
PSD
Anthropogenic Combustion Derived Aerosol
Glaciogenic Sources
Ice
Volcano
Deserts/Loess/Alluvium/Playas
(Wetness, Roughness, Topography, Vegetation, Erodibility)
Diatoms
Iron Direct (e.g. Dust) or Indirect (Upwelling) Supply
Mineralogy, Particle Shape and Roughness
PSD
Particle Size and Distribution
Unknowns (Need More Data)


Last Glacial Maximum
CO_2
Dry Vs. Wet Deposition
PSD
Scatter Vs. Absorption
Dust on Ice-Warming
Till Outwash
Ice
Volcano
Loess
Deserts
Mass of Emission
Ice
Diatoms
Pump Efficiency Export
Mineralogy, Particle Shape and Roughness
Particle Size and Distribution
PSD
Unknowns (Need More Data)
MAR
0.00 - 0.02
0.03 - 0.05
0.06 - 0.10
0.11 - 0.50
0.51 - 1.00
1.01 - 2.00
2.01 - 5.00
5.01 - 10.00
10.01 - 20.00
20.01 - 50.00
50.01 - 100.00
100.01 - 200.00
200.01 - 500.00
500.01 - 1000.00
1000.01 - 5000.00
5000.01 - 73839.00

All interested colleagues warmly invited to participate:

Web and contact details:

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http://www.lec.lancs.ac.uk/research/LU_themes/inqua_working_group.php

QUEST Dust Working Group:
http://www.bridge.bris.ac.uk/projects/dust

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Thank you

(and sincere apologies for unavoidable absence)