Dust and Climate:’DUSTSPEC’

Maher, B.A.¹
and the QUEST/INQUA Dust Working Group

(1) Centre for Environmental Magnetism and Palaeomagnetism, Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ, U.K. (b.maher@lancs.ac.uk).
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:

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 (αFe2O3, ~ 0.6-3.4% by vol in arid/semi-arid dust) and

goethite (γFeOOH)

potentially key influences.
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......?
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 Dust Indicators and Records of Terrestrial and Marine Palaeoenvironments (DIRTMAP) Database ...............history and future

Developed in Lund, Sweden, 1997


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’


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

- Alloway et al., 1992; Kohfeld and Hanson, 2001
- Antoine et al., 1999; Mahowald et al., 2006
- Bettis et al., 2003; Mahowald et al., 2006
- Bettis et al., 2003; Mahowald et al., 2006
LGM

More data ‘holes’

**g/m²/yr**
Dust deposition g/m²/year BASE-CUR

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
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).
Loess

Gobi

PSAs

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.
All interested colleagues warmly invited to participate:

Web and contact details:

INQUA DIRTMAP’2’ Working Group:
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

Leader: Prof. Barbara Maher,
Centre for Environmental Magnetism & Palaeomagnetism,
Lancaster Environment Centre, University of Lancaster
LA1 4YQ UK. b.maher@lancs.ac.uk

Co-leaders: Dr Diego Gaiero, Universidad Nacional de Córdoba,
Argentina, dgaiero@efn.uncor.edu
Dr Natalie Mahowald, 2140 Snee Hall, Cornell University,
Ithaca, NY 14850, USA, Mahowald@cornell.edu
Thank you

(and sincere apologies for unavoidable absence)