

The QUEST Working Group on Dust and the future of dust-cycle research

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Atmospheric dust both absorbs and scatters solar radiation (the direct radiative effect, RE), which alters the energy balance of the atmosphere. In addition, dust plays an important role in cloud microphysics, and impacts the formation and lifetime of clouds (the indirect RE), which influences the planetary albedo. According to the IPCC Fourth Assessment Report [Forster *et al.*, 2007, pp. 167-168], state-of-the-art dust cycle modelling estimates of net top of the atmosphere (TOA) direct radiative forcing by dust range between -0.56 to $+0.1 \text{ W m}^{-2}$. Thus, there remains considerable uncertainty in both the sign and the magnitude of dust direct radiative forcing.

The overall magnitude of the direct and indirect radiative effect (RE) is determined by the amount of dust present in the atmosphere and the physical characteristics of dust particles. Dust emission estimates, including location, duration, and vertical flux of deflated dust, require high temporal and spatial resolution observations over an extended observation period. Satellite remote sensing provides a valuable tool for addressing these issues, but has relatively limited temporal coverage, and time-series measurements from key locations provide longer records but may not sample the spatial variability of dust loading adequately; there are relatively few studies that have attempted to address, in necessary detail, global dust emission and atmospheric loading. Consequently, estimates of the total global dust burden vary by over a factor of 2. Furthermore, dust cycle models still employ relatively simple representations of dust particle characteristics, with the largest uncertainties resulting from: poor description of (1) dust composition, related to the natural variability in dust mineralogy and inadequate knowledge of refractive indices, (2) particle shape, specifically the assumption in most dust-cycle models that dust particles are spherical, (3) the size distribution of transported dust particles, related to poor specification of dust-source particle size distributions, and (4) the vertical distribution and amount of dust in the atmosphere. The absorptivity of dust particles remains one of the greatest uncertainties associated with the impact of dust on climate. Recent remote-sensing measurements indicate that dust is a poor absorber and effectively attenuates solar radiation. However, the standard shortwave refractive index commonly used in modelling the radiative effects of dust is derived from laboratory experiments carried out in the 1970s and early 1980s, and results in greater absorption of solar radiation than is implied by the remote-sensing data (Figure 1). This discrepancy may shift the modelled direct RE TOA forcing from negative to positive.

The location and characterisation of dust sources is another weakness in state-of-the-art dust-cycle models. Many models treat palaeolake basins or low-lying areas more

generally as preferential dust sources. Remote-sensing studies and field-based geomorphic mapping show that dust is emitted from a wide variety of different geomorphic settings, including e.g. inter-dunal depressions, the marginal areas of lakes and fluvial/alluvial fans. Dust sources are highly localised, with considerable temporal variability in emissions from specific sources. Furthermore, discrete sources within a region can be active at different times through the year. Incorporating this complexity in a modelling framework is challenging. The characterisation of sources in terms of dust physical and chemical properties poses another challenge: most modelling groups specify dust size distribution characteristics based on global soil data sets which provide “average” properties over large areas, apply a standardised mineralogy to emitted dust, and assume a constant proportion of bio-available iron in dust that is transported to oceans. This approach clearly exacerbates the uncertainties in radiative impact and, perhaps ultimately even more importantly, will compromise the realism of simulations to evaluate the role of dust in atmospheric chemistry and ocean fertilisation.

Testing and validation of dust-cycle models is hampered by the relative paucity of observations. Furthermore, the ability to simulate present-day conditions is not a sufficient test of model performance; the ability to reproduce the known and large changes in the dust cycle during e.g. glacial periods is crucial in order to build confidence in future predictions of changes in atmospheric dust loading and, hence, climate forcing. The DIRTMAP database was originally conceived as a tool for model validation under both modern and palaeo-conditions. The original version of this database [Kohfeld and Harrison, 2001] contained records from dust traps, from marine and ice cores, and from a limited number of terrestrial sites. Additional terrestrial sites were incorporated in an updated version presented in Kohfeld and Tegen [2007]. However, neither version of the database reflects the considerable amount of recent work that has generated new records of dust deposition, better characterisation of the physical and biological properties of dust deposits, and improved chronological control on new and existing records.

These uncertainties and concerns have motivated the formation of a Working Group on Dust by the QUEST (Quantifying Uncertainty in the Earth System: <http://quest.bris.ac.uk>) programme of the UK Natural Environmental Research Council (NERC). The QUEST Working Group on Dust is an international group of experts in all aspects of the dust cycle, which met for the first time in November 2007 to develop a strategy for collaborative research aimed at improving understanding of the dust cycle under past, present and future climates. Here we summarise some of the key recommendations from this meeting.

Model improvements. Improved dust cycle modelling requires a major emphasis on the characterisation of dust source regions, building on the ongoing investigations of the geomorphic controls on dust emissions. Additionally, large improvements would result from improved description of the characteristics (particle size, mineralogy, shape) of deflated/airborne dust. New global data sets that allow the physical and chemical properties of material in potential source areas need to be developed, through refining global input data sets already available and using information derived from field studies.

Continued work on the sensitivity of radiative forcing to the specification of dust physical properties is important as it will serve to guide the creation of such data sets.

Data requirements. Tools and protocols for benchmarking dust-cycle model simulations under modern and past conditions need to be developed. The DIRTMAP database provides a useful tool for validating spatial patterns in dust deposition under both present-day and palaeo-climates states, but urgently needs to be updated and expanded. The emphasis should be on including records from areas currently under-represented in the database, such as South America, Eurasia, the Middle East and the Southern Ocean. Priority should also be placed on the generation of high-resolution sediment records that document changes in dust deposition during climate oscillations, such as Dansgaard-Oeschger events. Documenting stratigraphic changes in size characteristics, and drawing on new high-resolution particle size analysis techniques that permit quantification of the sub-micron scale particles (highly relevant for modelling radiative effects) is important. Mineralogical and isotopic information relevant to provenancing, radiative forcing and bio-fertilisation should be included in the database. Finally, because of the diversity of the records already included in the database, more metadata needs to be included to facilitate the selection of records for specific types of model evaluation in an objective way.

Modelling strategy. There are many opportunities for using observations and carefully-designed model simulations to understand changes in the dust cycle. Meso-scale models, for example, could provide an opportunity to test global model parameterisations of spatial heterogeneity in dust emissions. Dust-cycle feedbacks are not yet incorporated dynamically into simulations of past climates. There is clearly a need to design transient simulations with fully-coupled climate-dust models to address the potential role of dust in abrupt climate changes.

The next meeting of the QUEST Working Group on Dust, to be held in the autumn of 2008, will focus in more detail on dust-source modelling and characterisation. The QUEST Working Group on Dust is an inclusive group and invites participation from all scientists working on the dust cycle, though most particularly observationalists and modellers interested in aspects of the palaeo-dust cycle.

For more information, please visit: <http://www.bridge.bris.ac.uk/projects/dust>

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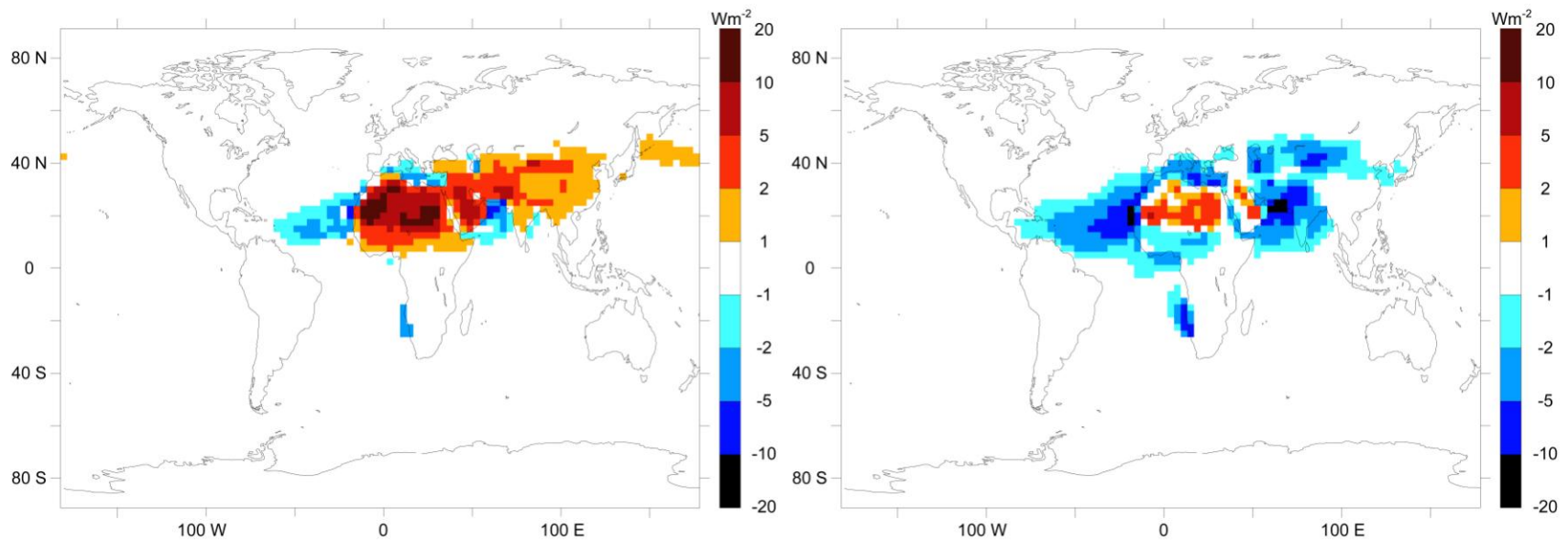


Figure 1 Comparison of yearly-averaged TOA direct radiative forcing (Wm^{-2}) from dust using different refractive indices (taken from Figure 7 of *Balkanski et al.* [2007]). (Left) Refractive index used assumes dust is an effective absorber in the shortwave (low single scattering albedo) and has previously been used as standard in dust cycle models; in this case there is a large positive forcing over the continents due to the presence of dust in the atmosphere, which is especially strong over desert regions. Globally-averaged total forcing is $+0.35 \text{ Wm}^{-2}$. (Right) Refractive index used is constrained by ground-based remote sensing measurements which indicate dust is an effective scatterer (high single scattering albedo); in this case negative forcing dominates over continental regions. Globally-averaged total forcing is -0.39 Wm^{-2} .