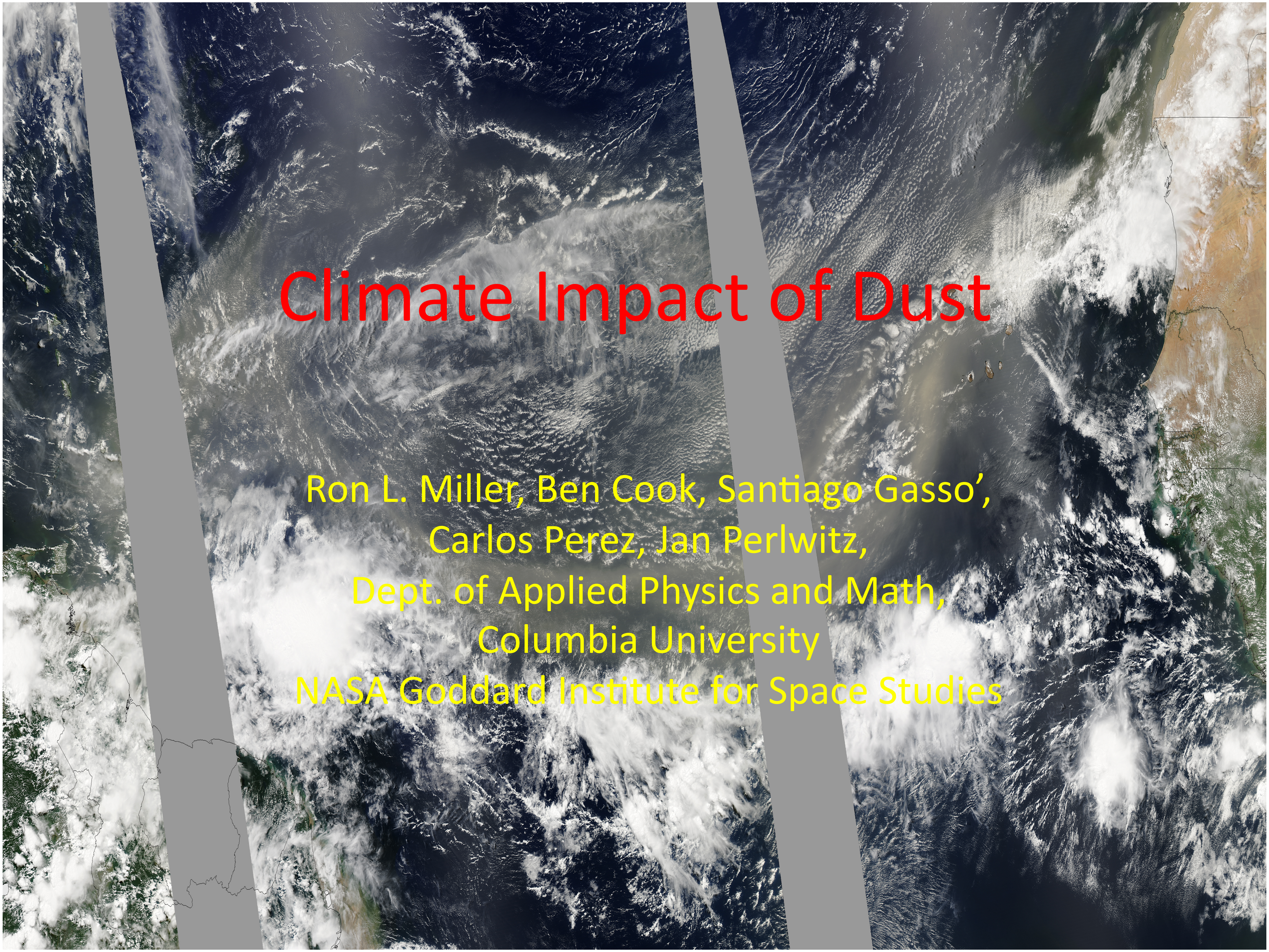

Climate Impact of Dust

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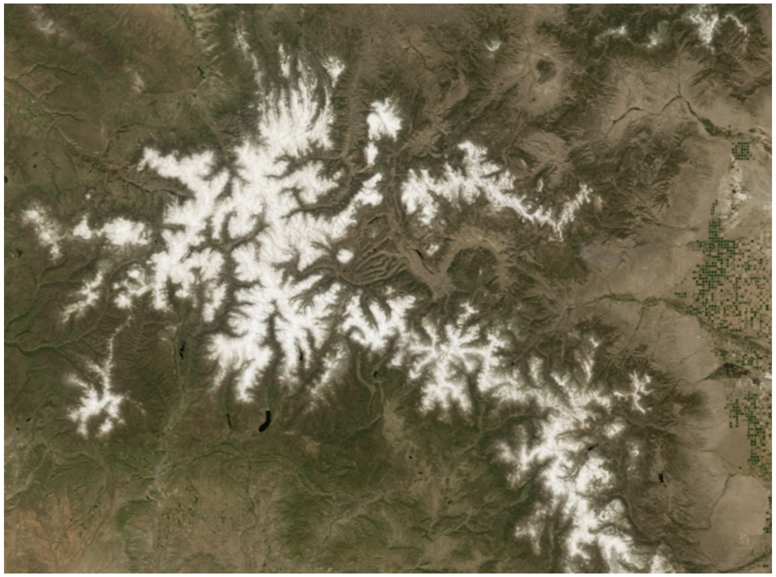
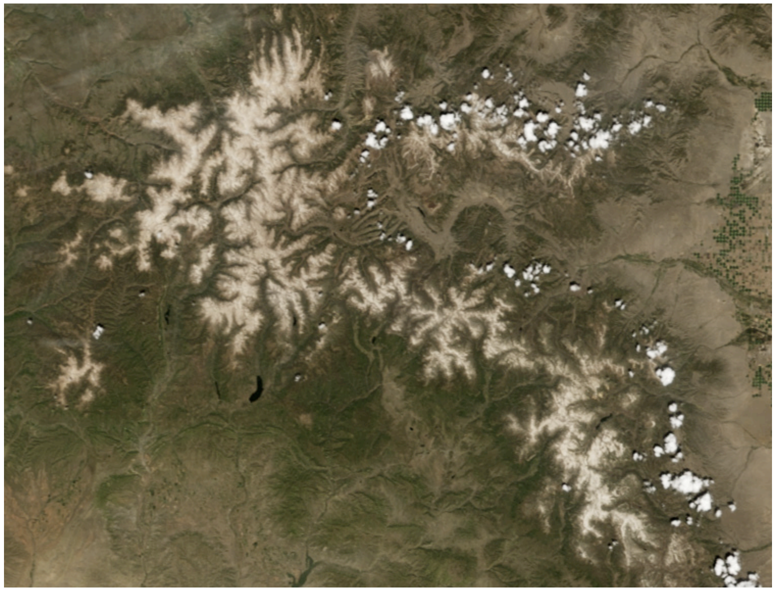
Climate Impact of Dust: Dirty Snow

- When dust aerosols are deposited on a bright surface such as snow, the particles absorb sunlight that would otherwise be reflected. The snow becomes darker, and melts more rapidly.
- *(right:)* This reduces the lifespan of a snowpack in mountains with seasonal snow, such as the San Juan Mountains in Colorado. (Painter et al. *Geophys. Res. Letts.* 2007)
- Deposited black carbon (BC) has a bigger melting effect than dust in the present-day Arctic, because BC absorbs sunlight more strongly (Flanner et al *J. Geophys. Res.* 2007).
- Dust has a bigger effect than BC in glacial climates because the dust load is larger than at present. Dusty snow amplifies glacial melting, creating a negative feedback loop where glaciers create rock flour and dust aerosols which ultimately help to melt the glacier.



'Clean' snow, San Juan Mtns, May 31, 2008

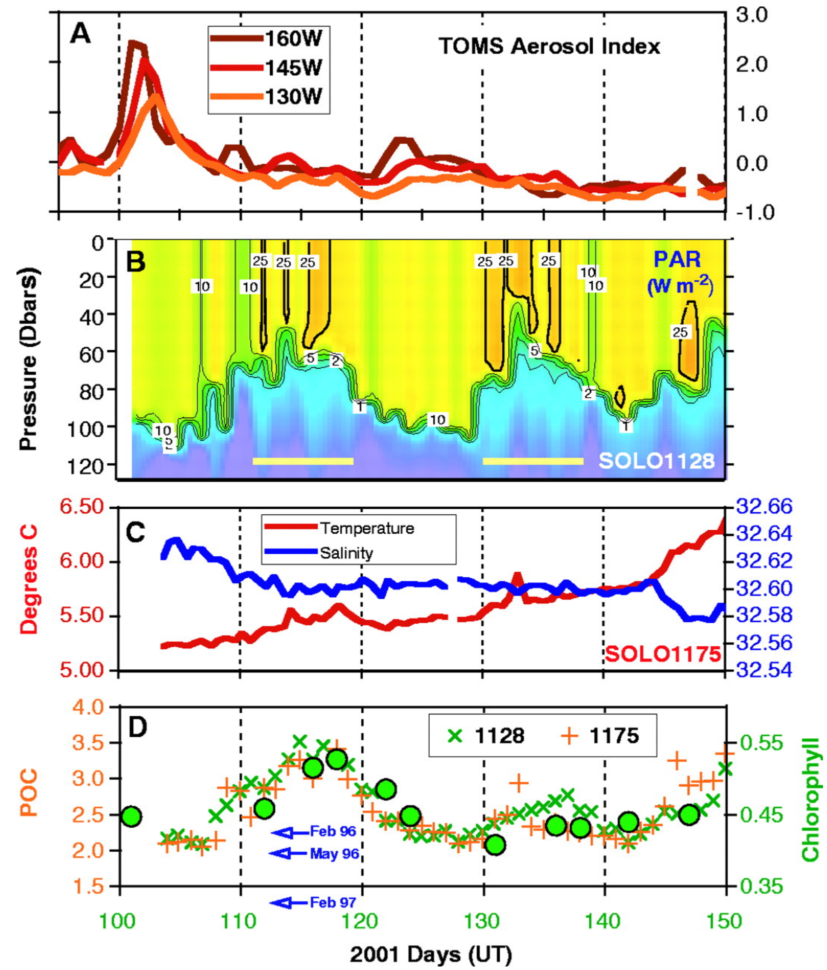


Dusty snow, San Juan Mtns, May 18, 2009

http://earthobservatory.nasa.gov/IOTD/view.php?id=39164

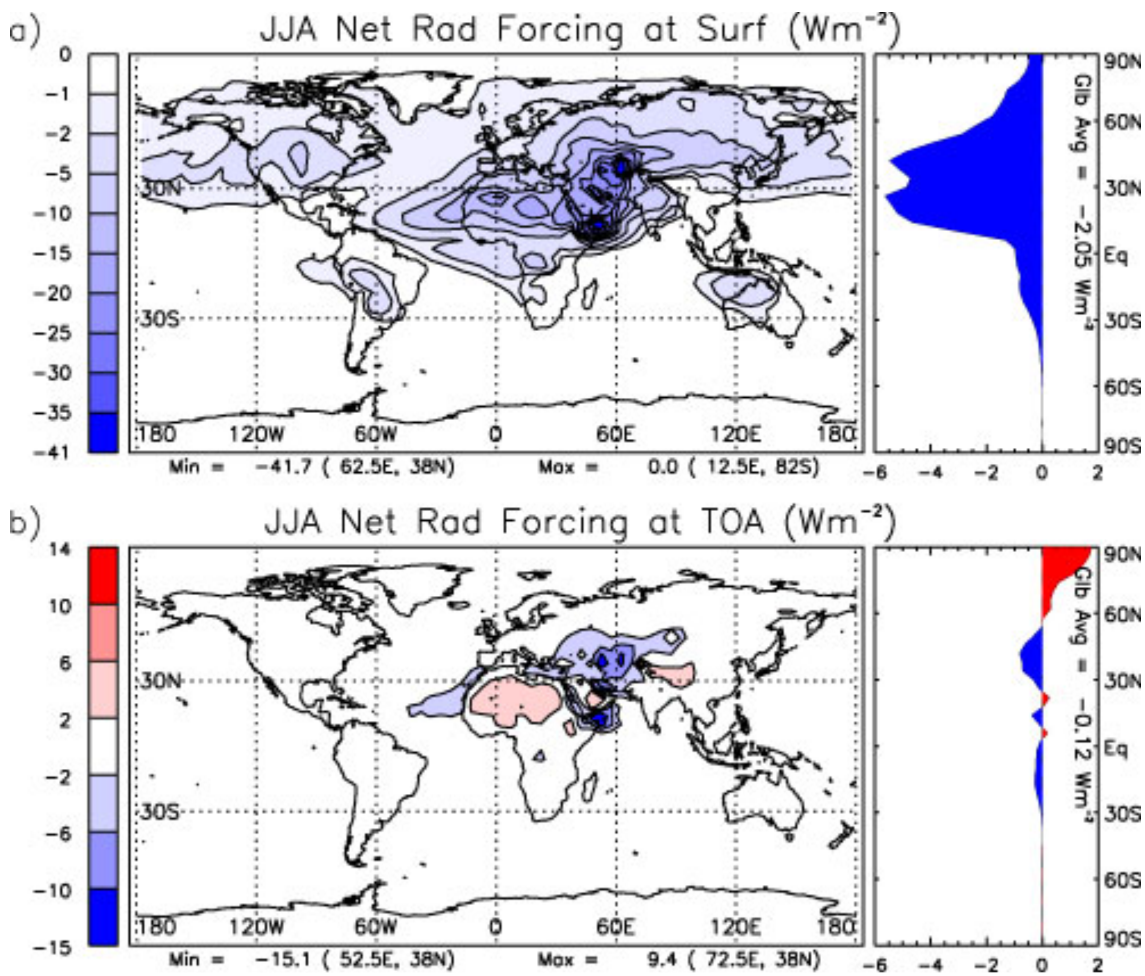
Climate Impact of Dust:
Iron Fertilization of Ocean Phytoplankton

- (*right:*) Over the North Pacific Ocean, particulate organic carbon (POC) increases a week or so after deposition beneath an Asian dust outbreak (Bishop et al. *Sci.* 2002).
- The POC increase is inferred to result from increased photosynthesis within the mixed layer, which draws down atmospheric CO_2.
- Does the large glacial dust load draw down atmospheric CO_2, amplifying the glacial cycle. Was the last glacial maximum terminated by a reduction of the dust aerosol?
- Fertilization depends upon the iron content of dust. Some sources like the Sahel have soils with relatively high iron content. Global maps of soil iron are uncertain. Observations of iron content in deposited dust would be a valuable constraint upon soil iron maps.



Bishop et al. *Sci.* 2002

Climate Impact of Dust: Direct Radiative Forcing



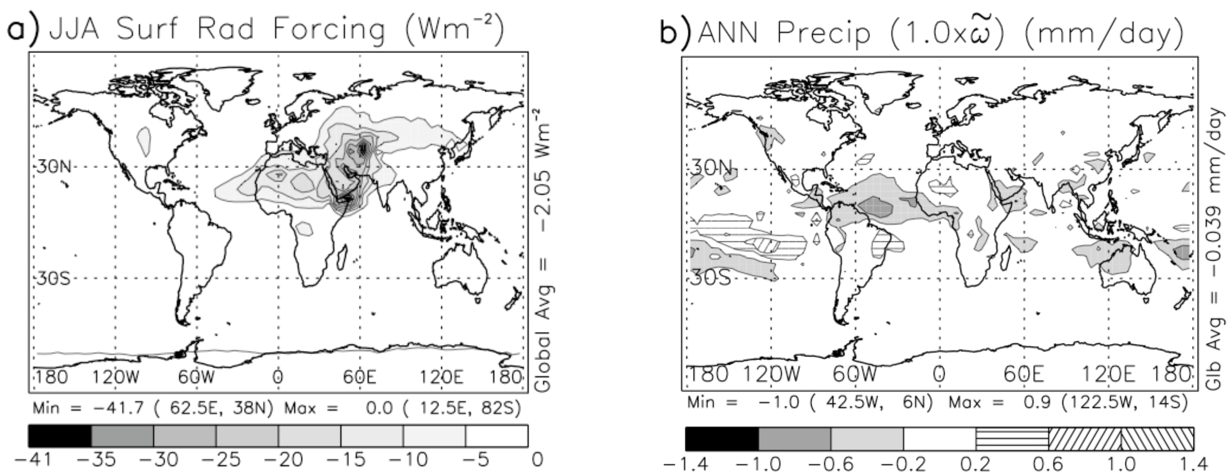
Global Average Surface Forcing: -2.05 Wm^{-2}

Global Average TOA Forcing: -0.12 Wm^{-2}

Dust reduces solar heating of the surface. Reduction of the net incoming flux at the top of the atmosphere (TOA) is much smaller, and its sign depends upon the albedo of the underlying surface.

Miller, Tegen, and Perlwitz, *J. Geophys. Res,* 2004

Surface Radiative Forcing And Precipitation



Surface aerosol forcing alters the surface energy balance. Globally:

$$F_S = LE' + S'_e + R'_{LW} + R'_{SW}$$

- The reduction in net radiation $R'_{SW} + R'_{LW}$ beneath the aerosol layer is partially compensated by a reduction in evaporation E'.
- This decreases global precipitation (Miller and Tegen *J. Climate* 1998, Ramanathan et al. *Sci.* 2001, Yoshioka et al. *J. Climate 2007*).
- However, rainfall may increase locally.
- Regional changes in rainfall feed back upon the extent of the dust source region by altering vegetation, and alter the uptake of atmospheric CO_2 by the land biosphere: +6 ppm atmos CO_2 during 20C (Mahowald et al. *Atmos. Chem. Phys. Disc.* 2010)

Local Increase In Precipitation By Dust

Column moisture balance: Column precipitation P’ equals evaporation E’ along with moisture converged at low levels:

$$P' \approx E' + \delta q(-\nabla \cdot v)'$$

Eliminate mass convergence using the column energy budget: Radiative imbalance at the top of the atmosphere R'_T equals the mass convergence times the difference in total (or moist static) energy *h* between the exit level at the top of the column and the entry level at the bottom:

$$R'_T \approx \delta h(-\nabla \cdot v)'$$

$$\boxed{P' \approx E' + \frac{\delta q}{\delta h} R'_T}$$

For the atmosphere: $E' \sim F_S, R'_T \sim F_T, \dfrac{\delta q}{\delta h} \approx 4$

Chou et al. *J. Climate* 2005

Compensation of Surface Radiative Forcing With Evaporation Over Land and Ocean

- GCM experiments: the surface radiative forcing is varied by making the particles more absorbing.
- Over the ocean, evaporation decreases as the surface forcing becomes more negative.
- Over land, the opposite is true: As less radiation reaches the surface, evaporation increases (supplied by an increase in precipitation).
- Precipitation increases as the particles become more absorbing and the TOA forcing becomes increasingly positive. The positive forcing drives a direct circulation that converges moisture at low levels.

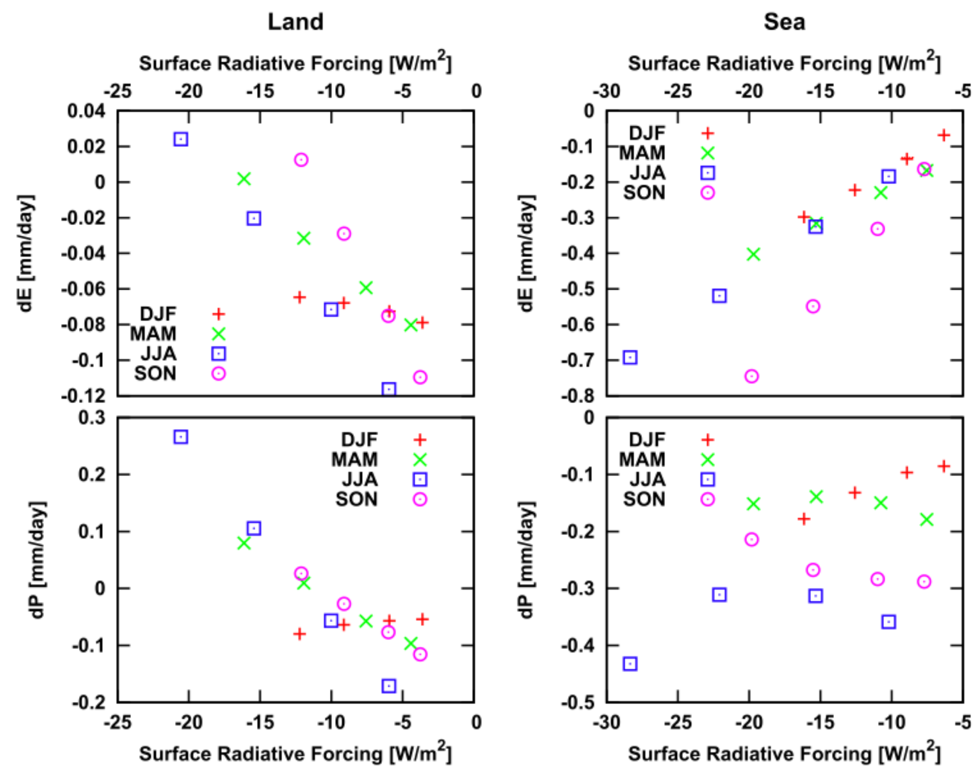
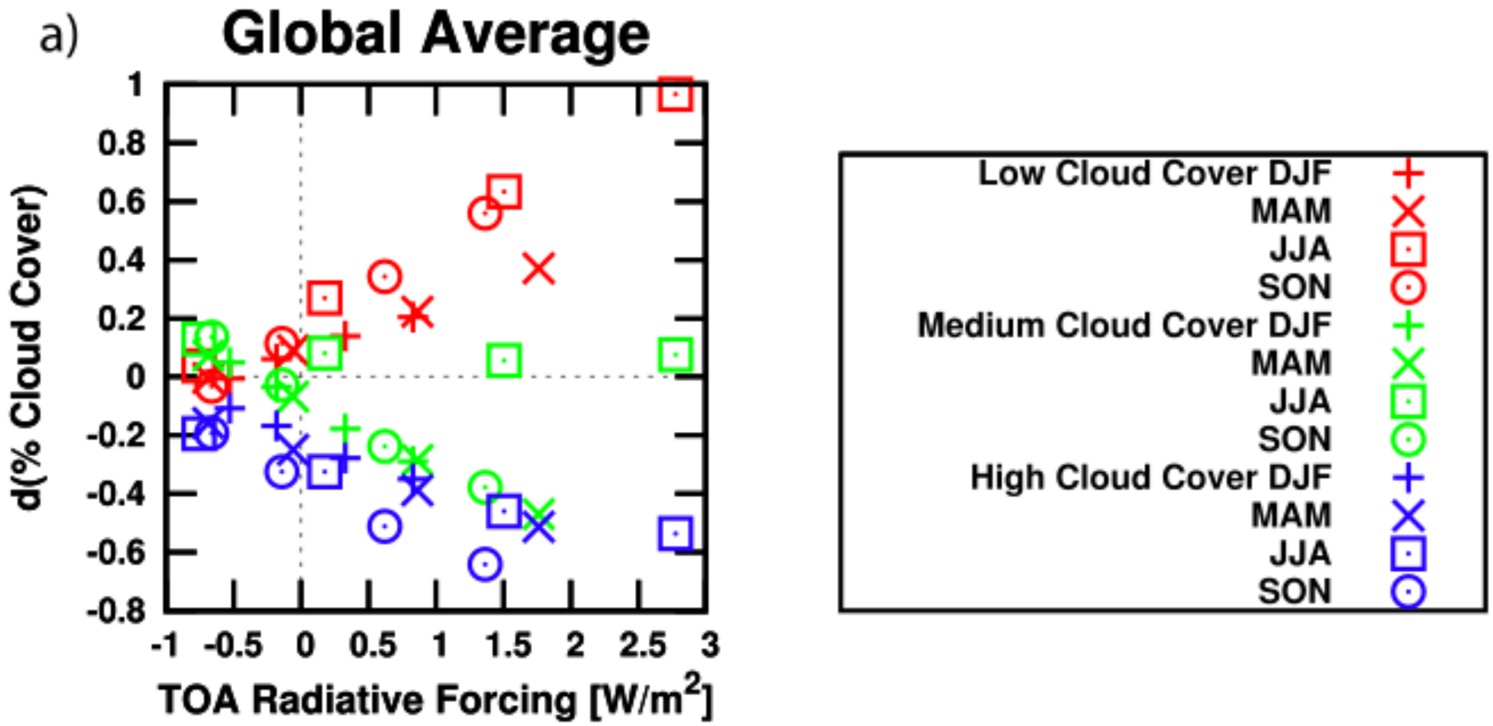


Figure 12. Surface dust radiative forcing versus change of ensemble mean evaporation dE and precipitation dP for dust AOD ≥ 0.1 over (left) land and (right) sea in the seasons.

Perlwitz and Miller *J. Geophys. Res.* 2010

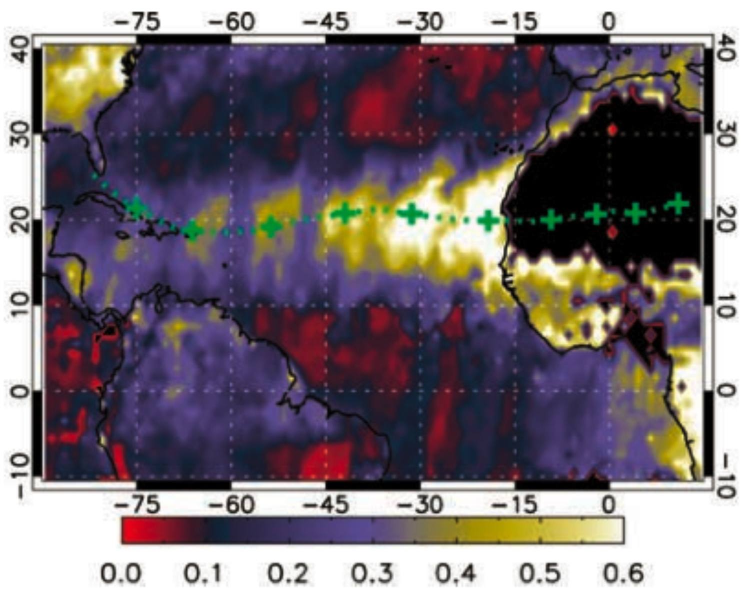
Semi-Direct Effect of Dust: Aerosol Heating and Cloud Cover

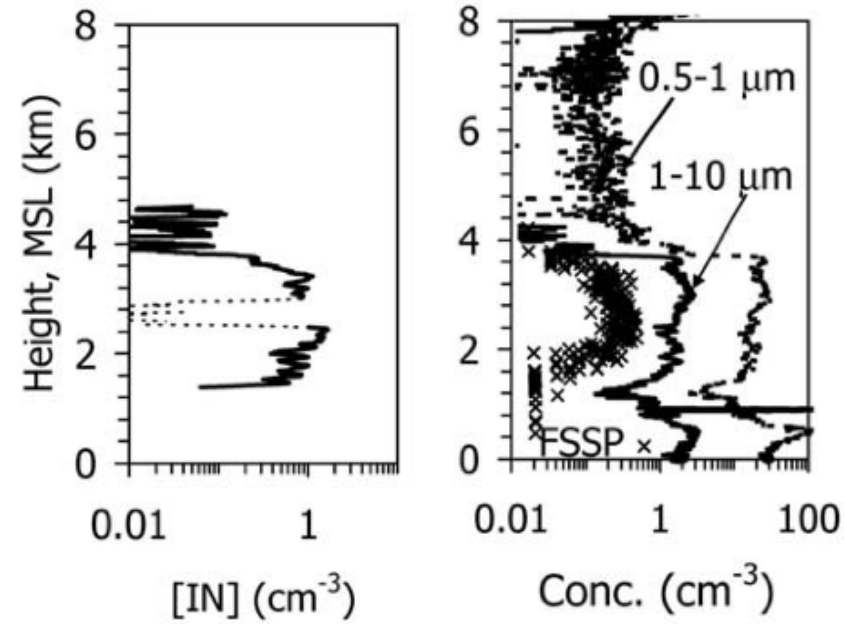


- As TOA forcing increases (corresponding to a more absorbing dust layer), low cloud cover increases during most seasons, as the forcing drives a direct circulation that imports moisture at low levels.
- This cloud cover increase is opposite to the classical semi-direct effect where heating of the aerosol layer warms the air, decreasing relative humidity and cloud cover. Here, the air is warmed, but relative humidity increases as a result of moisture imported by the anomalous direct circulation.

Climate Impact of Dust:
Ice Nuclei and the Aerosol Indirect Effect

DeMott et al. *Geophys. Res. Letts.* 2003





- A layer of large ice crystal concentration measured over Florida coincides with a high concentration of dust aerosols that can be traced back to Africa.
- Larger dust particles promote ice nucleation and precipitation of ice, in contrast to the effect of dust on warm (water) clouds where the aerosols inhibit droplet growth and rainfall.
- Ability of dust to act as cloud condensation nuclei depends upon its mineral content, which is not widely measured.

Conclusions

- Dust aerosols influence climate by darkening bright surfaces (like the Arctic or snow fields).
- Dust particles containing iron can increase photosynthesis within the ocean mixed layer, drawing down atmospheric CO_2.
- Dust aerosols reduce mixing within the boundary layer, confining pollutants near the surface (Perez et al *J. Geophys. Res.* 2006).
- Although soil dust aerosols are created by wind erosion of the driest environments, they affect precipitation because of downwind transport into wetter regions, and atmospheric dynamics that extends the influence of radiative heating beyond the dust layer.
- Precipitation is reduced globally by dust radiative forcing at the surface, although precipitation can increase locally in regions of positive forcing.
- Similarly, dust can increase cloud cover by driving a circulation that converges moisture.
- Dust particles inhibit rainfall in warm (water) clouds, and the larger particles are efficient ice nuclei that increase precipitation of ice phase particles.
- Measurements of deposition that resolve mineral content would be very useful.