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Long-term changes of aerosol optical and radiative properties and their role in global dimming and brightening

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Global dimming and brightening (GDB) have profound effects on the Earth's environment. For example, GDB counteracts or supplements greenhouse warming. Atmospheric aerosols, through their interaction with solar radiation (direct, indirect and semi-direct effects) can affect GDB. Changes in aerosol burden or other physical and optical properties can modify tendencies of GDB. For example, satellite observations of aerosol amounts, available since the early 1980s, but only over the oceans, indicate a downward trend since about 1990, consistent with the observed brightening during this period. There is a need, however, to investigate similar trends, but also over land, and to relate them with contemporary GDB.

The seasonal and inter-annual variability of the natural, but also anthropogenic aerosol direct radiative effect on solar radiation at the Earth's surface (DRE$_{surf}$) and the contribution of aerosols to global dimming and brightening (GDB) is estimated over the period 1984-2001. This is achieved by using a spectral radiative transfer model together with Total Ozone Mapping Spectrometer (TOMS) aerosol optical thickness (AOT) and other satellite (International Satellite Cloud Climatology Project, ISCCP-D2), NCEP/NCAR reanalysis and Global Aerosol Data Set (GADS) data for surface and atmospheric parameters. The major findings are mostly related to natural and less to anthropogenic aerosols because of limitations of the TOMS observational technique. The model results indicate that aerosols exert a strong surface cooling over the globe by reducing locally the incoming surface solar radiation by up to 70 W m^{-2}. This direct radiative effect averaged over the globe for the period 1984-2001, is equivalent to 5 W m^{-2}, associated with 6.5 and 3.5 W m^{-2}, for the Northern and Southern Hemispheres, respectively. However, this aerosol DRE$_{surf}$ effect shows an important inter-annual variability as large as 200%. A strong solar brightening, or decreased aerosol DRE$_{surf}$, by as much as 13 W m^{-2}, from 1984 to 2001 is found in the northern tropical and sub-tropical latitudes. This is due to decreased AOT levels in areas with strong production and transport of dust by trade winds, and in the northern mid-to-high latitudes, e.g. in South Europe and East USA due to clean-air legislation and decreased emissions. In contrast, significant increases in AOT (by more than 100%) and DRE$_{surf}$ (by more than 17 W m^{-2}) are found in areas like East Asia (China) or the southern Amazonian basin, where increasing emissions of anthropogenic aerosols and biomass burning activities have persisted from 1984 to 2001. On a global basis (60˚S-60˚N) the AOT has slightly increased (by about 4%) over the two-decadal study period, mainly in the Southern Hemisphere. Consequently, the magnitude of aerosol DRE$_{surf}$ has also increased by 0.38±0.1 W m^{-2} (or by 6%) indicating thus an aerosol solar dimming from 1984 to 2001. The aerosol-induced dimming in the 1980s is in accord with the model-estimated overall solar dimming during the same period, whereas the aerosol dimming during the 1990s and up until 2001 is not in accord with the estimated solar brightening in the same period. Although on a global basis the contribution of aerosols to GDB can be exceeded by the effects of other radiative components such as clouds, aerosols are found to significantly contribute to GDB at the regional scale, being responsible for almost 100% of the solar brightening over large areas extending from the Arabian Sea through North Africa and the tropical Atlantic Ocean, which is characterized by transport of African dust over to the coast of South America. Aerosols are also responsible for solar dimming over areas such as East China or the South Amazonian basin. The surface cooling due to aerosol dimming, and especially its spatial and temporal

variability, can have significant effects on the hydrological cycle, surface energy budget and atmospheric dynamics.