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Human impact on direct and diffuse solar radiation during the industrial era

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We estimate direct and diffuse solar surface radiation changes during the industrial era and contribute to the understanding of the observed global dimming and the more recent global brightening. Using a multi-stream radiative transfer model, we calculate the impact of changes in ozone, NO_2, water vapor, direct and indirect aerosol effects, and contrails and cirrus on solar irradiances at the surface. Our results show that dimming is most pronounced in Central Africa, South East Asia, Europe, and Northeast America. We calculate that human activity during the industrial era accounts for a decrease in direct solar radiation at the surface of up to 30 Wm^{-2}, equivalent to a 30% to 40% reduction, and an increase in diffuse solar radiation of up to 20 Wm^{-2}. The large change in North America is mostly due to contrails and cirrus from aircraft traffic and the direct aerosol effect, while surface solar radiation in South East Asia is mostly influenced by direct and indirect aerosol effects. In this study we have shown that the spatial variability is large in our model results and further that some of the causal mechanisms of global dimming have a spatial resolution that cannot be fully resolved in global models. The observed brightening is found to be largest in many high latitude measurement sites in accordance with our model results, and it is likely that stratospheric ozone is one of several contributors. A contributor to the global dimming is NO_2 with a regional pattern but shown here for the first time to have a non-negligible impact on the global solar radiation. We find the physical processes that lead to the changes in direct and diffuse solar radiation to be remarkably different and we explain which mechanisms that are responsible for the observed changes.