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Global model simulations of the impact of ocean-going ships on aerosols, clouds, and the radiation budget

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Abstract. International shipping contributes significantly to the fuel consumption of all transport related activities. Specific emissions of pollutants such as sulfur dioxide (SO_2) per kg of fuel emitted are higher than for road transport or aviation. Besides gaseous pollutants, ships also emit various types of particulate matter. The aerosol impacts the Earth's radiation budget directly by scattering and absorbing the solar and thermal radiation and indirectly by changing cloud properties. Here we use ECHAM5/MESSy1-MADE, a global climate model with detailed aerosol and cloud microphysics to study the climate impacts of international shipping. The simulations show that emissions from ships significantly increase the cloud droplet number concentration of low marine water clouds by up to 5% to 30% depending on the ship emission inventory and the geographic region. Whereas the cloud liquid water content remains nearly unchanged in these simulations, effective radii of cloud droplets decrease, leading to cloud optical thickness increase of up to 5–10%. The sensitivity of the results is estimated by using three different emission inventories for present-day conditions. The sensitivity analysis reveals that shipping contributes to 2.3% to 3.6% of the total sulfate burden and 0.4% to 1.4% to the total black carbon burden in the year 2000 on the global mean. In addition to changes in aerosol chemical composition, shipping increases the aerosol number concentration, e.g. up to 25% in the size range of the accumulation mode (typically >0.1 µm) over the Atlantic. The total aerosol optical thickness over the Indian Ocean, the Gulf of Mexico and the Northeastern Pacific increases by up to 8–10% depending on the emission inventory. Changes in aerosol optical thickness caused by shipping induced modification of aerosol particle number concentration and chemical composition lead to a change in the shortwave radiation budget at the top of the atmosphere (ToA) under clear-sky condition of about −0.014 W/m² to −0.038 W/m² for a global annual average. The corresponding all-sky direct aerosol forcing ranges between −0.011 W/m² and −0.013 W/m². The indirect aerosol effect of ships on climate is found to be far larger than previously estimated. An indirect radiative effect of −0.19 W/m² to −0.60 W/m² (a change in the atmospheric shortwave radiative flux at ToA) is calculated here, contributing 17% to 39% of the total indirect effect of anthropogenic aerosols. This contribution is high because ship emissions are released in regions with frequent low marine clouds in an otherwise clean environment. In addition, the potential impact of particulate matter on the radiation budget is larger over the dark ocean surface than over

polluted regions over land.

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