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Modeling the chemical effects of ship exhaust in the cloud-free marine boundary layer

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Abstract. The chemical evolution of the exhaust plumes of ocean-going ships in the cloud-free marine boundary layer is examined with a box model. Dilution of the ship plume via entrainment of background air was treated as in studies of aircraft emissions and was found to be a very important process that significantly alters model results. We estimated the chemical lifetime (defined as the time when differences between plume and background air are reduced to 5% or less) of the exhaust plume of a single ship to be 2 days. Increased concentrations of NO_x (= NO + NO_2) in the plume air lead to higher catalytical photochemical production rates of O_3 and also of OH. Due to increased OH concentrations in the plume, the lifetime of many species (especially NO_x) is significantly reduced in plume air. The chemistry on background aerosols has a significant effect on gas phase chemistry in the ship plume, while partly soluble ship-produced aerosols are computed to only have a very small effect. Soot particles emitted by ships showed no effect on gas phase chemistry. Halogen species that are released from sea salt aerosols are slightly increased in plume air. In the early plume stages, however, the mixing ratio of BrO is decreased because it reacts rapidly with NO. To study the global effects of ship emissions we used a simple upscaling approach which suggested that the parameterization of ship emissions in global chemistry models as a constant source at the sea surface leads to an overestimation of the effects of ship emissions on O_3 of about 50% and on OH of roughly a factor of 2. The differences are mainly caused by a strongly reduced lifetime (compared to background air) of NO_x in the early stages of a ship plume.

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