Tip of iceberg: indirect forcing from ship emissions from bottom-up and top-down approaches

Tianle Yuan, Hua Song, Michael Diamond, Lili Boss

Ship emissions are a major source of aerosol particles over oceans, affecting not only air quality but also clouds and energy balance of the climate. However, estimates on the magnitude of climate forcing due to ship emissions are highly uncertain with studies relying on detected ship-tracks reporting much smaller forcing than model-based ones. Here we show that forcing due to detectable ship-tracks accounts for less than 10% of the total forcing, i.e., only the tip of an iceberg over the southeast Atlantic shipping-lane. We make three forcing calculations, one bottom-up approach based on detected ship-tracks and cloud adjustments, one on simulated cloud droplet number concentration change dNd and cloud adjustments, and one on top-down constraints. The method based on adjustments and simulated dNd has excellent agreement with the top-down method while method that relies on detected ship-tracks reports forcing orders of magnitude smaller than the other two. Our results suggest that most of the impact from ship emission comes from aerosols that do not form detectable ship-tracks, and provide a way to reconcile a discrepancy reported in previous results. More importantly, they highlight that cloud adjustments derived from ship-tracks provide solid constraints to study aerosol-cloud interactions in marine low clouds. We also highlight the importance of high quality cloud retrievals in studying aerosol-cloud interactions and how polarimetric retrievals may help.