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Pollution tracks in clouds provide direct observational evidence for weak cloud water response to aerosols

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Aerosol-cloud interaction is the most uncertain mechanism of anthropogenic radiative forcing of Earth's climate, and aerosol-induced cloud water changes are particularly poorly constrained in climate models. Ship tracks, linear cloud features in marine stratocumulus clouds impacted by ship emissions, have been long recognized as real-world experiments of aerosol-cloud interactions. We demonstrate that similar cloud tracks occur in various type of warm clouds over ocean and land as a response to aerosols from various natural and anthropogenic sources. Using aerosol-induced tracks in clouds, we compare polluted cloud properties with the properties of the nearby unpolluted clouds using remote sensing data from MODerate-resolution Imaging Spectroradiometer.

In this research, we extend observations of volcano and ship tracks from Toll et al. (2017, GRL; https://doi.org/10.1002/2017GL075280) with observations of industry (oil refineries, smelters etc) and wildfire tracks over land. Industry and wildfire tracks have been detected on most continents providing a near-global observational constraint on cloud responses to aerosols together with volcano and ship tracks over oceans. Track observations suggest that cloud water both increases and decreases in tracks, resulting in weak average cloud water response. Strong decreases in cloud droplet sizes are seen in all types of tracks. Track observations show that cloud water increases in precipitating clouds due to suppression of rain. Cloud water decreases in non-precipitating clouds with dry air above the clouds. The relative humidity dependence of the cloud response suggests that enhanced entrainment leads to decreased cloud water in non-raining clouds. Preliminary results suggest that the cloud water tends to decrease more readily over land, partly offsetting the radiative forcing through the first aerosol indirect effect.

Finally, we compare track observations with cloud water responses in the Hadley Centre climate model and Community Atmosphere Model. In stark contrast to observations, strong systematic cloud water increases occur in climate models as only aerosol-induced suppression of rain is accounted for in the models. The discrepancy between climate models and track observations suggests that model estimates of radiative forcing through aerosol-cloud interactions may be overly negative.