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Transport of very short-lived halocarbons from the Indian Ocean to the stratosphere through the Asian monsoon circulation

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Halogenated organic compounds are naturally produced in the ocean and emitted to the atmosphere. The halogenated very short-lived substances (VSLS), such as bromoform, have atmospheric lifetimes of less than half a year. When VSLS reach the stratosphere, they enhance ozone depletion and thus impact the climate. During boreal summer, the Asian monsoon circulation transfers air masses from the Asian troposphere to the global stratosphere. Still, the extent to which VSLS from the Indian Ocean contribute to the stratospheric halogen burden and their exact origin is unclear. Here we show that the monsoon circulation transports VSLS from the Indian Ocean to the stratosphere. During the research cruises $SO_2$34-2 and $SO_2$35 in July-August 2014 onboard RV SONNE, we measured oceanic and atmospheric concentrations of bromoform (tropical lifetime at 10 km = 17 days), dibromomethane (150 days) and methyl iodide (3.5 days) in the subtropical and tropical West Indian Ocean and calculated their emission strengths. We use the Langrangian transport model FLEXPART driven by ERA-Interim meteorological fields to investigate the transport of oceanic emissions in the atmosphere. We analyze the direct contribution of observed bromoform emissions to the stratospheric halogen budget with forward trajectories. Furthermore, we investigate the connection between the Asian monsoon anticyclone and the oceanic source regions using backward trajectories. The West Indian Ocean is a strong source region of VSLS to the atmosphere and the monsoon transport is fast enough for bromoform to reach the stratosphere. However, the main source regions for the entrainment of oceanic air masses through the Asian monsoon anticyclone are the West Pacific and Bay of Bengal as well as the Arabian Sea. Our findings indicate that changes in emission or circulation in this area due to climate change can directly affect the stratospheric halogen burden and thus the ozone layer.