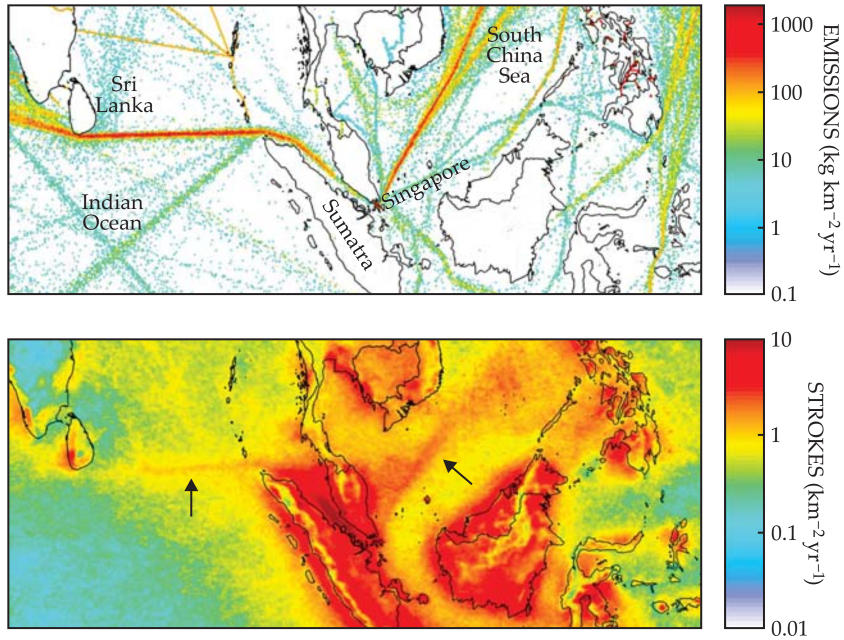
Ships cause their own stormy seas

Increased lightning frequency over maritime trade routes links pollution to the development of thunderclouds.



LIGHTNING OVER SHIPPING LANES. The lanes are evident in a map of estimated ship emissions of aerosol particles less than 2.5 μm in diameter (upper panel) for 2010. Average yearly lightning density during 2005–16 in the eastern Indian Ocean and the South China Sea (lower panel) shows two regions of enhanced lightning, indicated by arrows, directly above two heavily trafficked lanes. (Adapted from ref. 1.)

In centuries past, trading companies established shipping lanes—regularly trafficked routes for commercial vessels—based on prevailing winds and ocean currents. Commercial ships no longer use wind and sail for power, but many continue to travel those lanes. Two of the world's busiest lanes—one running due west from the northern edge of Sumatra to the southern end of Sri Lanka in the Indian Ocean and one running northeast from Singapore into the South China Sea—happen to cut through two of the world's rainiest regions.

If rain didn't make life aboard cargo ships tough enough, the lanes also turn out to be particularly prone to thunderstorms. From 12 years of global lightning data, Joel Thornton, Todd Mitchell, and Robert Holzworth of the University of Washington and Katrina Virts of NASA's Marshall Space Flight Center have found that lightning occurs above the two busy lanes twice as often as over adjacent regions.[1] But it's not that 16th-century ship captains had to put up with lightning for the sake of favorable winds. The researchers surmise that modern ships, through their aerosol emissions, are the cause of the increased lightning activity.

Polluted clouds

In addition to greenhouse gases, humans have pumped aerosol pollution into the atmosphere. Aerosol concentrations over land today may be an order of magnitude higher than in preindustrial times. Uncertainties about their overall effects remain one of the main uncertainties in modeling Earth's climate.

In principle, an aerosol-free sky would be a cloud-free sky. To form, cloud droplets must have aerosolized particles bigger than 50 nm in diameter that act as cloud condensation nuclei. But aerosols can play contradictory roles in cloud development.

When the concentration of particles in the air is low, clouds form large droplets that fall out quickly as rain. In general, the addition of condensation-inducing particles causes cloud droplets to be smaller and more numerous. Clouds with many small droplets might be expected to last longer, but small droplets evaporate away more easily. Highly polluted clouds may never develop into rain clouds. And because aerosols both absorb incoming sunlight and increase cloud reflectivity, they cool Earth's surface below and suppress water evaporation. Without enough water vapor, large clouds may not form in the first place (see PHYSICS TODAY, May 2004, page 24).

Small droplets should be more easily lofted via convection to heights of tens of kilometers. There, they can freeze, collide, electrify, and form thunderstorm-producing cumulonimbus clouds. That hypothesis has been dubbed the aerosol convective invigoration effect.[2] Evidence for the effect has come mostly from observations of soot-producing fires and other sporadic events.[3] But the presence of other meteorological factors such as winds and surface temperatures has muddled the results. If Thornton and his colleagues' conclusion that aerosols from ship exhaust increase lightning frequency proves true, their findings would be the clearest evidence to date that human-made aerosol pollution invigorates convection.

Lightning the way

How Thornton's team made their discovery starts with the World Wide Lightning Location Network (WWLLN), a global lightning detection network maintained by the University of Washington. As with other such networks, the WWLLN's radio receivers detect the very-low-frequency electromagnetic pulses that emanate from lightning. By examining the arrival times of those pulses at different receiving stations, the network can locate lightning anywhere on Earth to within 5 km.

Last spring, Thornton was chatting with Mitchell about wanting to use WWLLN data to look for signatures of aerosol effects. Mitchell told him that Virts had just found enhanced lightning over shipping lanes. While working on an unrelated project, Virts had decided to plot some WWLLN data at 10 km resolution. Although the WWLLN can locate individual strokes more precisely, previous global lightning distribution studies never looked at resolutions finer than 25 km. Virts, who had used WWLLN data for her PhD work, had noticed straight lines of lightning enhancement before in those coarser-resolution plots. But as can be seen in the figure, they were unmistakable in her high-resolution plots.

"I was floored to see something so clear," says Thornton. He realized immediately that ships' aerosol emissions might be the culprit. On land, researchers studying how aerosol pollution interacts with clouds have to contend with variations in terrain, heating of the lower atmosphere by the ground, and other confounding factors. Shipping lanes on the open ocean are largely free of such factors. And because archived WWLLN data go back to 2005, the group could investigate the lanes over a prolonged period of time.

The increased lightning activity, they found, was persistent. For example, even during summer, when the South Asian monsoon shifts storm activity northward in the Indian Ocean, lightning density showed a local maximum above the Indian Ocean lane. In addition, the enhancements above both lanes appeared to grow over time, perhaps suggesting the growth of ship emissions.

To rule out natural causes of lightning enhancement, the group consulted available satellite data and weather records. They found that sea-surface temperatures, rainfall rates, average convective available potential energy—a measure of thunderstorm updraft strength—and other meteorological measures exhibited no anomalous changes across the lanes.

Laboratory at sea

Thornton and his colleagues have yet to see comparably obvious signs of lightning enhancement over other shipping lanes. However, they note that the Indian Ocean and South China Sea lanes are particularly narrow, highly congested, and serendipitously located in warm regions with active convection. Data from other lanes may need more refinement to tease out the effect.

Importantly, the lanes can double as a kind of controlled experiment that's been going on for years. Aircraft-borne instruments flying over the lanes to measure droplet size distributions, aerosol concentrations, and other cloud properties will help cloud researchers refine their models of aerosol–cloud interactions. If they can get a good handle on the relationship between aerosol particle numbers and storm development in the relatively pristine ocean environment, they could apply their models to more complex situations over land.

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References

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3. E. Williams et al., *J. Geophys. Res.* **107**, LBA 50–1 (2002); M. O. Andreae et al., *Science* **303**, 1337 (2004).