

Hi Reddit, I'm Joel Thornton, Professor of Atmospheric Sciences, here to talk about how tiny particles from ship exhaust can make more lightning. Ask Me Anything!

AmGeophysicalU-AMA ¹ and r/Science AMAs¹

¹Affiliation not available

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Abstract

I am Joel Thornton, Professor of Atmospheric Sciences at the University of Washington. My research focuses on microscopic nano-scale particles in the atmosphere, where they come from, and what they do to air quality, weather, and climate. These particles come in many shapes and sizes, from a variety of sources like wildfires, sea spray, desert dust, vegetation, and our own pollution from power plants, diesel trucks, cargo ships and so on. These particles can be toxic to human health, with the smallest more numerous ones getting into our lungs, but they are also good at reflecting sunlight to space, and they are the seeds on which every cloud droplet or snowflake forms so they have an out-sized influence on weather and climate. For example, my colleagues and I recently showed (<http://onlinelibrary.wiley.com/doi/10.1002/2017GL074982/full>) that lightning is twice as frequent above busy shipping lanes, likely because of the particles emitted in the ships exhaust! Ask me anything about atmospheric particles and how the nano-scale can effect the global scale. Ask me anything! I'll be back at 12 pm Et to answer your questions, ask me anything! The AGU AMA series is conducted by the Sharing Science (sharingscience.org) program. Sharing Science: By scientists, for everyone. More at sharingscience.agu.org.

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AMGEOPHYSICALU-AMA [R/SCIENCE](#)

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I've seen some really interesting talks recently on the importance of mixed-phase (liquid water and ice coexisting) clouds and their climate feedbacks (especially stuff out of the Czisko group at MIT and Storelvmo group at Yale). The main results I'm thinking of are basically that radiative forcing is incredibly sensitive to things like the size distribution of nucleating particles, your nucleation parameterization, and how you represent the WBF process that determines how much ice forms in a cloud.

It is hard for me to evaluate the science in this talks as cloud microphysics is such an esoteric field -- so what are your thoughts on this debate with some much radiative forcing on the line?

[aClimateScientist](#)

Good question, the complexity of clouds and their interactions with aerosol particles and the thermodynamic environment can make it difficult to assess what is important.

The way I think about this issue is that there is no question that clouds (very much including mixed phase clouds, but also generally all types of clouds) play an enormous role in the climate system and our understanding of how sensitive the climate is to various perturbations. The response of clouds to perturbations in the form of aerosol particles and greenhouse gas forcings is one of the great uncertainties we face in making accurate predictions of future (or past) climate.

From that standpoint, it is important to recognize that cloud microphysics is fundamental to the response, whatever that response is. The work of Storelvmo's group, e.g. *Science* 2016, makes this

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clear in terms of the amount of ice compared to liquid water drops. The microphysics of the clouds determines their optical properties and thus basic radiative effect, and so changes in the microphysics due to external perturbations are of major importance. Therefore, I personally wouldn't think of cloud microphysics as "esoteric" – which has the connotation of being a curiosity with uncertain importance. The importance of understanding and accurately describing the microphysics is fairly clear. That said, the radiative properties of an individual cloud are only part of the net cloud effect on climate. So it is also important to recognize that cloud microphysics is not the only feature to consider, we need to also understand cloud fraction, depth, location in altitude, precipitation probability, and so on.

Results about lightning frequency are sort of inherently cool but it's not clear to me why they matter. What are the most important consequences of increased lightning frequency (or intensity)?

[aClimateScientist](#)

Lightning is indeed inherently cool, but there are several reasons to understand lightning frequency and spatial distribution. It is one of the most powerful phenomena that occurs in the atmosphere, and causes damage to lives and property. It is the dominant natural source of nitrogen oxide radicals in the upper troposphere which regulate the formation of ozone (a greenhouse gas) and therefore the oxidizing capacity (self-cleansing ability) of the atmosphere. The natural frequency of lightning and how it has or will change impacts our understanding of how human activities have perturbed the self-cleansing ability of the atmosphere over time and the climate forcing from short-lived greenhouse gases like ozone and methane. Lightning is also a sensitive indicator of storm microphysics and vertical development. It is used in weather forecasting systems as part of severe storm warning determinations, and for basic research on the microphysics and dynamics of convective systems. Therefore, if more lightning is detected in a region with similar environmental (weather) conditions, it suggests that the vertical development and cloud microphysics are different. Changes to these have implications for the climate effects of clouds and for the vertical distribution of mass and heat, all important for Earth's energy balance. Lightning is a rather sensitive indicator of such changes, and so because it is something we can measure, it brings an observational context to these problems.

Based on the education I have had I assume the nanoparticles lower the electrical resistance of the air, the particles will then be struck by the lightning what will be the effect on the particles. Also what are nanoparticles made of ? Mostly carbon or something else ?

[ROGGOGG](#)

The effect of lightning on nanoparticles is an interesting question that I hadn't really considered. One thought is that the air in the stroke reaches temperatures of 30,000 Kelvin or degrees C) – very hot! That is hot enough to vaporize a lot of materials such as organic carbon, ammonium sulfate, and even soot. The duration of the very high temperature is fairly short (less than 1 second) and the stroke itself occupies a small fraction of the air volume, so I doubt the effects are significant in an average sense, but still interesting to consider! In the atmosphere, aerosol particles have a range of sources and therefore compositions. The most ubiquitous components are sulfate (from combustion of sulfur rich fuels, volcanic emissions or phytoplankton), organic carbon (oxidized hydrocarbons or biological material), elemental carbon (i.e. soot), soil dusts, and sea salt. In ship exhaust, there is a mix of soot, lubricating oil residuals (organic carbon), and sulfate (either directly emitted or formed from atmospheric oxidation of sulfur dioxide also emitted in the exhaust). Diesel fuel (and especially bunker fuel used by ships) has a high sulfur content.

What prompted you to research this specific topic/How did you discover this information, and why does

it happen?

[useful_person](#)

On how we discovered this: Like many “discoveries” our research into this topic was part serendipity and part incremental. My co-authors and I had worked together before on studying spatial and seasonal patterns of lightning frequency and its relationship to nitrogen oxides (see answer to another question about importance of lightning) in the region of Indonesia/Malaysia, known in Earth Science as the “Maritime Continent”.

My own research interests are to understand sources and effects of atmospheric aerosol particles, especially the small ones (from a few nanometers up to a few hundred nanometers). These play an important role in affecting cloud formation and properties and I had been following work of others on how these can affect the microphysical properties of deep convective (e.g. thunderstorm) clouds. Given that lightning is an indicator of such clouds, and that I knew from our previous work that the World Wide Lightning Location Network operated by my colleagues at UW was a great resource, I started asking Katrina Virts about opportunities for further studies on lightning. At the same time, Katrina Virts was still analyzing the lightning data in part to understand better the energy distribution of lightning strokes detected by the network. She decided to re-grid the data into smaller latitude/longitude bins, that is, she decided to make higher-resolution maps of the lightning frequency. When she made the higher resolution map – the enhanced lightning over the shipping lanes stuck out like a sore thumb and we quickly determined it was collocated with major shipping lanes (which we knew about from previous work studying nitrogen oxides and sulfur dioxide emissions in the area).

I then put forth the hypothesis that the lightning was a result of ship emissions of aerosol particles changing the nature of the tropical storms that develop in the area and we set out to test that hypothesis (or in reality we set out to disprove other competing hypotheses).

On why it happens: Every cloud droplet in every cloud has formed due to water vapor condensing (or freezing) on a pre-existing aerosol particle. If more aerosol particles are put into the same environment, then the same amount of water vapor condenses upon more particles to create more cloud droplets, but each cloud droplet is now smaller because the same amount of water is divided up into more pieces. Smaller cloud droplets do not turn into rain as efficiently as bigger ones, and so now as the cloud continues to rise, less water rains out and so more water enters higher into the atmosphere where it is colder and eventually cold enough to cause freezing of some droplets (or aerosol particles). Lightning is the result of interactions between clouds of different phases, so having more water droplets in the presence of newly formed ice particles and hail leads to more lightning. Thus, more aerosol particles (especially in usually clean environments) can lead to changes in lightning.

Where is the most populated shipping route in the world?

[j938920](#)

A fun website to visit is www.shipmap.org that shows an example hourly global distribution of maritime vessel traffic. Two of the busiest, if not the busiest in terms of number of ships traveling per year in the most highly localized route (i.e. the “most concentrated”), are in the Indian Ocean, between Sri Lanka and Singapore, and the South China Sea. These are connections between two of the world’s busiest ports in terms of cargo tonnage (Singapore and Shanghai) and the Persian Gulf. The answer sort of depends on how you ask the question – busiest in terms of number of ships? Tonnage of cargo? Amount of fuel burned per kilometer of route? But, hopefully my answer gives you some idea of what I consider the busiest (cargo tonnage which relates to fuel burned and thus exhaust emitted per area of the ocean traveled).

Thanks for doing this event! I've a couple of questions: 1. How long does it take for these particulates to disperse from their point of origin? I'm sure it depends on size/composition, but are there some general trends you can tell us about? 2. What are some of the particulate sources (i.e. diesel, wildfires, volcanoes) that you're most worried about -- in terms of their impact on weather, climate, human health, etc.? Are there sources that you think we're not paying enough attention to?

Thanks for your time! I'm a UW alumnus and current employee. Go Huskies!

[kiri-kin-tha](#)

Go Dawgs! 1) How long to disperse? This most likely depends on the winds as the small particles important for cloud formation or human health are so small they don't fall to the ground very quickly (very small effect of gravity due to a very small mass), so they just follow the wind.

Horizontal wind speeds (winds that flow parallel to the Earth's surface, i.e. those we "feel" as wind) are typically a few meters per second, so in one day particles can travel 100 to 200 kilometers from their point of origin (usually to the west or east given prevailing wind directions). After two weeks, they could have circulated the globe! Most particles only last about a week in the atmosphere before being rained out, so they might not make it that far, but some will!

Vertical transport is a bit more complicated, but due to the turbulence of air near the surface particles are mixed from the surface up to about 1 kilometer altitude in less than a day. Storms that don't completely remove the particles will lift them higher, even up to 10 or 12 kilometers altitude, but this will take a few days to a week for the average particle to experience a storm.

2) In terms of effects on human health, the source of greatest concern is probably combustion, so diesel exhaust and wood smoke. In some places like Hawaii, volcanic aerosol is very important, but most people are exposed to enhanced particulate amounts due to fuel combustion. Which is worse diesel or wood smoke is still under some debate, and really what about the components of those particles are causing negative health effects is very much an active area of research.

3) I think one aspect of particle sources we are not "paying enough attention to," in terms of health effects, would be ultra-fine particles in general. These are particles that are smaller than 100 nanometers in size. The EPA regulates that the mass of particles smaller than 2.5 microns (2500 nanometers in size) be kept below a specific amount. However, the smallest particles don't make up much of that mass, but they can get much further into your body more easily. Measuring these ultra-fine particles more routinely so that we can determine whether they are associated with negative health effects is important in my opinion.

Do you believe it possible to design a study to show a direct, causative relationship between shipping emissions and lightning beyond the interesting work you've already done? Or is that a bit beyond our technological know-how at this moment?

[adenovato](#)

Great question. One unintended experiment in this regard is already in the works. The International Maritime Organization (a trade organization) has decided to (voluntarily) limit the sulfur content of the fuel used for international maritime traffic to be a factor of 5 lower than what is currently used. Typically the sulfur content of aerosol particles is a big driver for making them good cloud condensation nuclei. So, if all ships comply, then we would expect the number of aerosol particles impacting clouds in the region will go down and the lightning over the shipping lane should decrease. That prediction assumes that the ships aren't putting out so many particles that the effect is "saturated". That is, it could be that there are so many aerosol particles effect the clouds that over the shipping lane that just reducing them a little will not be enough to change the lightning.

Another way to test this hypothesis is to also conduct computer simulations of clouds in the region. We are already doing these simulations. These won't "prove" a causative relationship but they can certainly disprove it, if, e.g. the amount of aerosol particles emitted by the ships don't cause a sufficient change in the simulated cloud properties then it is not supported. Ideally, we would also conduct some observations with aircraft and ships in that region to get a better handle on how many aerosol particles are there and just what the properties of the clouds are in and near to the shipping lanes.

Very interesting field of study!

Question: In areas that have high wild fire concentration due to lightening strikes could there be an adaptation of this technology that could preemptively discharge lightening at a higher altitude?

Follow Up Question: The shipping area directly is reported to have a higher strikes of lightening. Does this also affect the areas directly adjacent to the shipping lane to have more / less strikes?

Thanks!

[St41n](#)

It is always great if the understanding gleaned from basic science research can be used to help mitigate some societal problem. Many wildfires are indeed ignited by a lightning strike, though the role of lightning compared to human-started fires will differ with region, and much of the area burned is caused by human-started fires. So from a goal to limit fire ignition, we might want to focus on reducing human-started fires. On the one hand, our recent work indeed shows that lightning frequency is quite sensitive to aerosol particles, which human activities have increased. Reducing sources of aerosol particles could lead to a reduction in lightning frequency, but there is a large amount of lightning that is naturally going to occur over continents - how much human activities have changed lightning frequency over land (where the forests are) remains a big question.

I think re-directing lightning by adding some component to the atmosphere will be a very difficult and likely unsuccessful endeavor due to the scale of the problem and the vigorous mixing in the atmosphere. My advice would be to *not* invest money into that effort if someone comes knocking...

Your follow up question is actually nicely related. The shipping lane is in fact quite narrow, with most ships traveling in the Indian Ocean lane within a 50 km strip. However, the lightning enhancement we observe is actually spread to 100's of kilometers on either side. We argue that this spreading of the effect is caused by the winds and the storms dispersing the ship exhaust far and wide.