So I'm a climate scientist, and based on that, I bet you think I'm here to tell you about all the ways that we're making the climate warmer. But I'm not actually going to do that today because I think you already know that part of the story. I want to tell you instead a story about unintended consequences.

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For many of us, it's really easy to forget that in addition to emitting a lot of greenhouse gases, humans have been adding a lot of particulate pollution to the atmosphere. These small particles, which we scientists call aerosols, are responsible for the death of between four and 10 million people a year around the globe. For much of the world, this remains a major public health crisis. And because of that, there are significant efforts underway to clean up the source of these emissions, which is fantastic.

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But here's the thing. The unintended consequence of doing that is that we might actually be accelerating climate warming. And that's because most of these aerosols actually cool climate.

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I spent my career as a climate scientist studying how aerosols in the atmosphere around the globe absorb sunlight in the atmosphere and increase the reflection of sunlight away from our planet. Aerosols directly scatter sunlight back to space, and when they mix into clouds, they can make clouds brighter or more reflective. And both of these effects act to cool the climate by reducing the amount of sunlight that's available to heat the surface. We estimate that right now, aerosols from human activities are cooling climate by about half a degree Celsius. In other words, if it weren't for these climate effects, we would already be experiencing significantly worse climate impacts than we already are.

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So here's a conundrum. As we clean up the air for human health, we're reducing the concentration of these aerosols in the atmosphere, and we're removing the source of climate cooling. And because these aerosols only last in the atmosphere for about a week, their cooling effect goes away almost immediately after we stop emitting them. Unlike greenhouse gases, which continue to warm for decades to centuries.

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Here's a second conundrum. While our best estimate is that aerosols are cooling climate by about half a degree Celsius, this effect could be quite a bit smaller, or it could be a lot bigger. It's possible that aerosols right now are cooling climate by up to almost a full degree Celsius. And because we don't know how much of a cooling effect these aerosols are currently providing, we don't know how much of a climate warming they're going to unmask as we clean up the air.

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So let's step back and talk a little bit more about how it is that aerosols cool climate and why these effects are so uncertain. So aerosols mostly cool climate by increasing the reflection of sunlight from clouds. This increase in cloud brightness from aerosols is not generally very visibly apparent because clouds are just so naturally variable in their brightness. But a case where it is really visually obvious is in what we call ship tracks. So what you're looking at here is a satellite image off the west coast of North America. And you can see that there are these lines of clouds that are brighter or more reflective than the clouds around them. So to understand what's going on here, you first have to know that cloud droplets always form on an aerosol. Out over the ocean, there's just not generally that many aerosols in the atmosphere. So what you end up with is a cloud with a small number of larger droplets. Well, along comes your ship, and it's adding aerosols to the atmosphere and to the clouds. The water gets distributed over those aerosols, and you now have a cloud with a large number of smaller droplets. This change in droplet size increases the reflectivity of the cloud. Now this is not just happening where ship emissions are mixing into clouds. This is actually mostly happening over broad regions of the planet where pollution aerosols mix into clouds. So I've shown you here a very striking example of where pollution aerosols are clearly making clouds more reflective. But this actually doesn't always happen. And why is that? Well, I'm going to give you scientists' two very favorite answers. It’s complicated. And it depends.

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(Laughter)

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If you have ever looked at clouds for very long, you could see that they're incredibly complex, and they are constantly evolving. When you add aerosols to clouds, it doesn't just change their droplet size, it actually can then change how they evolve in ways that also affect cloud brightness. Depending on the details of the atmospheric conditions, clouds can be made either more or less reflective with the addition of aerosols, or not really changed at all. But what we do know is that under the right conditions, aerosol additions to clouds can make them quite a bit brighter.

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So this poses an interesting question. Might it be possible to rapidly reduce climate warming by mimicking this effect that pollution aerosols are already having on clouds, but do so by adding natural aerosols rather than pollution to clouds? Specifically by adding sea salt aerosol to clouds over the ocean, where sea salt aerosols already act as seeds for cloud droplet formation.

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Well we start with studying this problem using computer models. And when we add tiny sea salt aerosols to the clouds over the ocean in global climate models, we find that brightening just a fraction of the clouds over the ocean does, in fact, rapidly and significantly reduce climate warming from greenhouse gases. So these models indicate it is possible. But here's the problem. These global-scale models used to study the climate impacts of marine cloud brightening, lack the ability to resolve all of these detailed interactions between aerosols and clouds. So they can't tell us how much cloud brightening is possible or where. For that problem, we have to turn to models that cover much more localized areas of the globe but that include many, many more details about aerosols, clouds and how they interact. So what we really need is better real-world data that we can use to test and inform these models that we use to study marine cloud brightening.

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Now with this problem, as with many problems in the world, the devil is in the details. Many of the most uncertain aspects of the potential for marine cloud brightening have to do with how really small-scale air motions in clouds, we're talking over like a few square kilometers, respond to the addition of aerosols. So being able to systematically study how clouds respond to aerosols, just like a single plume of aerosols, over a small area of clouds, could go a long way to improving these climate models. And I want to tell you today about a powerful approach that our team is developing to do just that.

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So based on what I just said, you probably won't be surprised to learn that that approach is to add a single plume of sea salt aerosols to a small area of clouds over the ocean and see how those clouds respond. Basically, to make a single clean ship track. Now, the observations for studies like this would look a lot like those we've been doing for decades to study how pollution aerosols are already affecting clouds. Research aircraft filled with specialized instruments can be used to measure in great detail the atmospheric conditions the aerosols, the clouds and how they all vary. The difference between what we've done here in the past and what we would do with these new controlled aerosol studies, is that we would be able to actually compare clouds that have different aerosol concentrations but that are otherwise the same. This would allow us to quantify where changes in cloud reflectivity are actually being caused by the aerosols, rather than just varying due to other factors.

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Now it turns out that generating the sea salt aerosol plume with the right characteristics for doing these controlled aerosol studies is a significant technological challenge. The aerosols need to be just right. To date, no one has demonstrated the ability to generate both the size and quantity of aerosols you would need to do these studies where you would consistently and appreciably brighten marine clouds. As a climate scientist trying to better understand how aerosols affect clouds and climate, I am really thrilled to be part of a team that is developing a new instrument to meet that challenge. Our new cloud aerosol research instrument is specifically designed to generate a very large number of very, very tiny sea salt aerosols. These aerosols are about 1,000th of the width of a human hair, because that's the size that's ideal for marine cloud brightening. I'm also really excited to be able to tell you that we've just started our first scientific studies with this instrument. This happened just two weeks ago. We've set up our new Coastal Atmospheric Aerosol Research and Engagement Facility on the flight deck of the USS Hornet Sea, Air and Space Museum in Alameda, California. So on the Hornet, we are making observations at multiple locations along the flight deck of the sea salt aerosol plume that is being generated with our new instrument. These measurements are going to allow us to study how the aerosol evolves as it's transported towards clouds. It's also letting us study whether or not this instrument is delivering the right aerosol, with the right characteristics for use in later studies at sea, of the single plume experiment and how clouds respond. We've set up this study specifically at a museum to make it easily accessible to the public, educators and other researchers. And we consider this level of openness to be a really important part of our program. And that's because we're hoping that the work at the CAARE research facility can be the start of broader international engagement in this research, particularly by our colleagues in historically marginalized communities who are the most vulnerable to climate change. Their direct engagement in this research is absolutely critical to having equitable and informed discussions about whether we ever would use marine cloud brightening to cool climate as a way of addressing climate risks.

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Now don’t get me wrong, marine cloud brightening will not reverse the effects of greenhouse gases. This is not a solution to the climate crisis. I really have to repeat that. This is not a solution to the climate crisis. However, marine cloud brightening might be a way of treating the main symptom of the problem, which is too much heat in the atmosphere and ocean. We believe that the world needs the best information possible to decide whether approaches like marine cloud brightening might be a component of how we chart a safer course into a future that now includes a rapidly and dangerously warming climate. We also believe it's really critical that we better understand the evolving role of aerosols in climate change and the climate system if we don't want to be flying blind into the coming couple decades of climate change.

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I hope that I've left you as excited as I am about these new capabilities we're developing to study these really important questions. And I invite you all to come join us at our new CAARE research facility.

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Thank you.