AGU BOOKSHELF

Lagrangian Modeling of the Atmosphere

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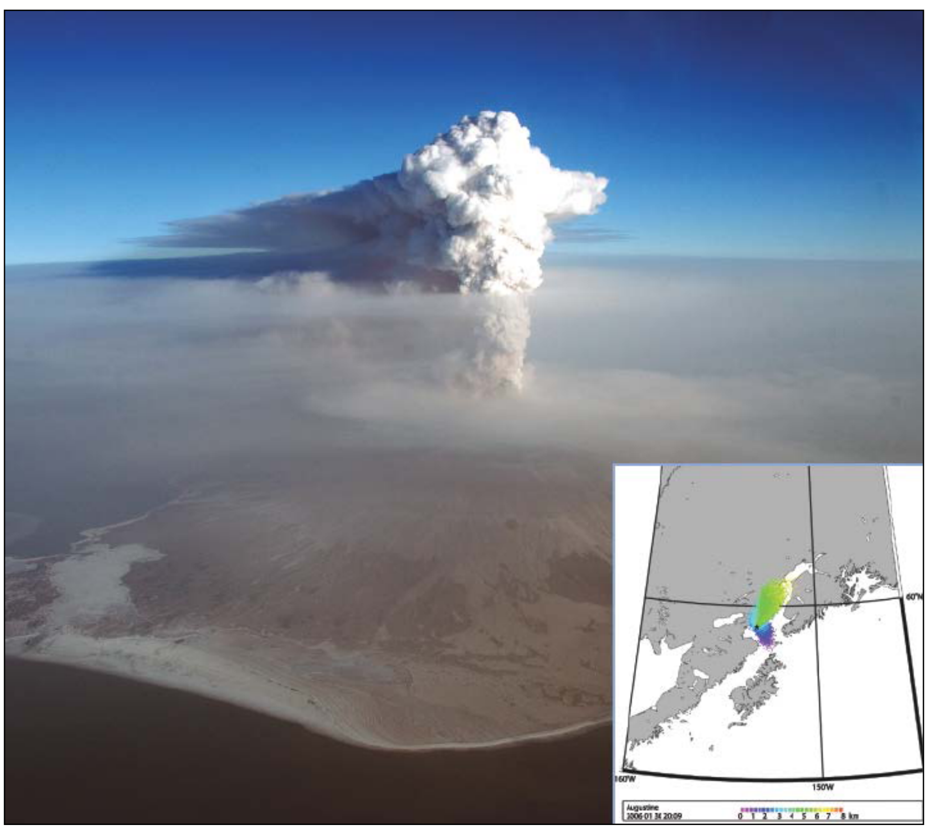
Like watching a balloon borne by the breeze, a Lagrangian model tracks a parcel of air as it flows through the atmosphere. Whether running forward or backward in time, Lagrangian models offer a powerful tool for tracking and understanding the fates, or origins, of atmospheric flows. In the AGU monograph Lagrangian Modeling of the Atmosphere, *editors John Lin, Dominik Brunner, Christoph Gerbig, Andreas Stohl, Ashok Luhar, and Peter Webley explore the nuances of the modeling technique. In this interview* Eos *talks to Lin about the growing importance of Lagrangian modeling as the world settles on climate change mitigation strategies, the societal value of operational modeling, and how recent advances are making it possible to run these complex calculations at home.*

Eos: *Are there any recent examples of when Lagrangian modeling of the atmosphere has played a particularly important societal role?*

Lin: Oh, absolutely. Two that were very much in the news and everyone would know are the 2010 eruption of the Eyjafjallajökull volcano in Iceland and the 2011 disaster at the Fukushima Daiichi nuclear power plant.

The Eyjafjallajökull eruption of course shut down European airspace for a very long time and cost billions of dollars in lost economic activity. During that event, different weather bureaus in Europe were running Lagrangian models to predict where the ash plume would go. There are several operational forecasting centers around the world that are just on standby, if an eruption happens, to do these simulations and to try to guide airports and general citizens as to what they should do.

The other example was the Fukushima nuclear power plant disaster and the release of radionuclides into the atmosphere. That is probably pretty fresh in readers' minds as well, how devastating that was for Japanese citizens. In that case, Lagrangian models were used to track the dispersion of the radionuclides that were being released from the power plant.



Ash plume from Augustine Volcano on 30 January 2006 during its eruptive stage. Photo credit: Game McGimsey. Image courtesy of Alaska Volcano Observatory/U.S. Geological Survey. (inset) A Lagrangian model with ash particles indicated by altitude above sea level. Courtesy of Peter Webley, Geophysical Institute, University of Alaska Fairbanks.

Both of these examples actually are mentioned in the book in a section called "Operational Emergency Preparedness Modeling." It's a very important part of Lagrangian modeling that fulfills a real societal need.

Eos: *At its most basic, what is Lagrangian modeling?*

Lin: A Lagrangian model is a model where you follow the air. The air is moving and you can sort of imagine yourself being a fly on the wall—not on the wall, on the air—observing it as it moves around. Depending on the exact scientific problem you're interested in, you could be following the humidity of the air as it moves around or the wind speed, the wind direction, or some pollutant concentration. We talked about volcanic ash—you could be following the amount of volcanic ash that is in that air as it moves around. So that contrasts with the other dominant method of modeling the atmosphere, which is Eulerian modeling. A Eulerian model is where you stay in one location and observe the air moving past you. You're not traveling on the air, like the fly, but you are staying put and observing the changes at your location.

The way that Lagrangian models work is that we try to simulate the motion and properties of air parcels. An air parcel is a unit of the atmosphere—like the billiard ball we often encounter in introductory physics classes—that we can use to think about the atmosphere. An air parcel has enough molecules such that it has pretty well-defined physical properties: concentration of a pollutant, a temperature, or a humidity level. But it can't be big enough that within the parcel itself all those properties vary. So an air parcel is a piece of the atmosphere that we can focus on and imagine how it changes, how it moves.

There aren't well-defined rules of thumb as to when you'd use one over the other, but Lagrangian and Eulerian models do tend to perform better in certain circumstances. If you're naturally trying to track air, or something in the air, the Lagrangian is very good. Eulerian modeling tends to perform better if you want to do global simulations. That being said, Lagrangian and Eulerian models are often linked together, and the two types are complementary. It's very hard to do a Lagrangian model without some information being fed into it from a parent Eulerian model.

Eos: *What can atmospheric scientists do with a Lagrangian model that would be difficult otherwise?*

Lin: One thing that Lagrangian modeling allows is that it lets you look at things in the atmosphere that have really sharp changes. So that can mean sharp changes in space, like a plume of material with very sharp edges. Or, it could mean sharp edges in time. So you could be seeing a very sharp rise in some pollutant in the city during a very short period of time. Other kinds of models, because of something called numerical diffusion, create artifacts in which these sharp edges are smeared out. So, for instance, let's say you want to do air quality forecasting. By smearing out the sharp edges, other types of models can cause you to underestimate the severity of the pollution.

Eos: *As described in the book, there are two ways to use a Lagrangian model, either running it forward or running it backward. What do these options allow?*

Lin: The forward model run is probably easier to think about. Let's say you have some air and you want to know where it goes. So you run time forward, and by tracking the air parcels you can find out where the air ends up. The alternative option is to run the tape recorder backward, to ask the question: Where did the air I'm interested in come from? The two approaches answer different questions, and depending on the exact problem that you're trying to tackle, you will want to run the model one way versus the other. In the past, I would say the dominant paradigm has been running it forward in time, but recent developments are increasing the importance of backward runs.

With President Obama's recent announcement of the new U.S. climate policy of reducing carbon emissions and with similar efforts being made internationally, tracking emissions of carbon dioxide and other greenhouse gases has become a really important application of Lagrangian models. It provides a way to verify whether a region is reducing its emissions or not. There is a pretty active research program in the United States right now to have more measurements of carbon dioxide and other carbon gases in the atmosphere. Lagrangian models are used to go backward in time from those observations to figure out which source regions contribute to the measurements. So, backward Lagrangian modeling provides a way to verify whether what different political entities report is actually showing up in the atmospheric measurements.

Eos: *Tracking the movement of a particle through the atmosphere seems like a computationally expensive task. What does it take to use a model like this?*

Lin: Actually, there are Lagrangian models out there, including the one that I developed, that you could just download and run on your laptop. It depends on the problem you're trying to answer, of course. Some of these problems—let's say tracking individual plumes, even the Fukushima radiation dispersion—could be done on your laptop, depending on how much detail you add to it. The fact that you and I can do these simulations so easily on our laptops means that individual researchers can run away with this tool and use it. So these days, a lot of researchers, not just experts in this field, could download a Lagrangian model and analyze their own measurements.

Let's say they make some pollution measurements, but they want to know where the polluted air comes from; they need a Lagrangian model to do that. The ease with which we can run these models means that people these days can do that. That's actually one of the motivations for this book, to provide some sort of starting point for people who aren't familiar with the gory details of Lagrangian modeling but who want to learn how to apply the models properly. The book includes a combination of research papers using Lagrangian models and overview papers that put the research in a larger context, and I hope that the book will be helpful to both novices and experts.

—Colin Schultz, Writer

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