SCIENCE BRIEFS

## Do Clouds Clean or Clutter the Atmosphere with Sulfate?

*By Dorothy Koch, Jeffrey Park, and Anthony Del Genio — January 2004*

Our ability to predict future climate change hinges on our understanding of aerosols, microscopic particles suspended in Earth's atmosphere. One of the most important types of aerosol, sulfate, cools the climate by reflecting sunlight and by serving as condensation points for clouds which also reflect sunlight. Industrial and fossil fuel burning emissions of sulfur dioxide gas into the atmosphere are the primary source of sulfate particles.

Since these pollutants are increasing with time, we expect sulfates to partly offset the global warming due to greenhouse gases such as carbon dioxide. But just knowing how much sulfur dioxide is emitted is not enough. How much sulfate is in the atmosphere also depends on the poorly understood atmospheric processes that produce and remove sulfate from the atmosphere. Clouds generate aerosol mass by taking up sulfur dioxide gas and converting it to sulfate aerosol inside cloud droplets, but precipitation washes some this sulfate out of the atmosphere. Meanwhile, significant amounts of sulfate may also be made outside of clouds, in sunny conditions via photochemical reactions.

Conventional wisdom among scientists has leaned towards a positive link between clouds and sulfate aerosols, that is, the production of sulfate by clouds is more important than either its removal by rain or its production under clear skies. Surprisingly, the data tell a different story, with a significant impact on our efforts to model future climate change.

In order to analyze the relationship between clouds and sulfate, we sought a statistical "correlation" between them. Correlation describes the tendency of two phenomena to increase and decrease together. Phenomena that are anti-correlated tend to change in opposite senses; when one increases, the other decreases, and vice versa. Changes in the amount of money in your checking account tend to be correlated with the arrival of your paychecks, but tends to be anti-correlated with the occurrence of spending events, such as trips to the mall.

With observations of natural climate phenomena, statistical analysis of long-term data sets can tell us if two processes are correlated, anti-correlated, or uncorrelated. The type of correlation, or lack of it, can tell us a lot about how the climate system works and tell us how to improve our climate models to give more accurate predictions of climate change.

If clouds and sulfate are correlated then we may conclude that clouds produce large amounts of sulfate. However, if clouds and sulfate are anti-correlated then we may

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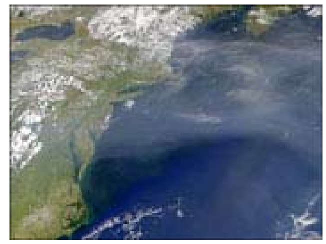
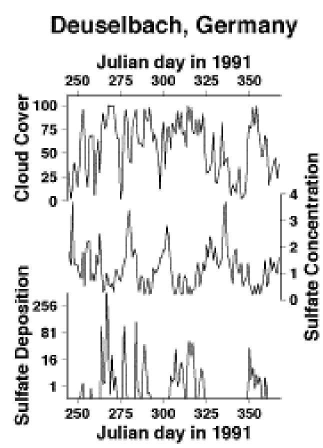


**Haze Over the North Atlantic**
This true-color image acquired May 4, 2001, by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) reveals a large, thick plume of aerosols blowing eastward over the North Atlantic Ocean. The aerosol plume is the regional haze produced by the industrial northeastern United States that you typically see during the summer months. The haze is composed of sulfates and organics that originate from power plants and automotive sources. *(Image: NASA/GSFC SeaWiFS and ORBIMAGE, via NASA Visible Earth)*




**Clouds and Sulfate in Western Germany**
These line-plots show the change in time of cloud cover (%), sulfate surface concentration, and sulfate in rainwater at Deuselbach, in the

conclude that clouds wash out more aerosols than they produce, or that clouds block photochemical sulfate production. Given the number of significant, but opposing, cloud-related processes, we might expect to find no correlation in real-life data, just as the balance in your checking account might not change if you spend money as fast as you earn it.

Moselle region of Germany, during the last 125 days of 1991. (View as large GIF or PDF)

We examined more than four years of daily average sulfate concentrations from about 50 locations in Europe and North America, together with cloud cover data obtained from satellite observations. The results indicate that clouds and sulfate are strongly anti-correlated. An example of data from Germany is shown in the line-plot graph. When cloud cover is high, sulfate amount decreases (and often rain removes the sulfate as shown in the lowest panel). Indeed, following a careful statistical analysis of all the data, we concluded that the most important influence of cloud cover is to inhibit sulfate production and to wash existing sulfate from the atmosphere. Other cloud-sulfate interactions are probably occurring, but their cumulative impact is not evident.

Using computer climate models that include sulfur production, transport, and removal in the atmosphere, we can distinguish the sulfate that is produced in clear skies from that produced inside clouds. We confirmed that clouds are anti-correlated with the sulfate made via photo-chemical reactions, but (unsurprisingly) this is not the case with sulfate made in clouds. In its original formulation, our computer model made too much sulfate within clouds, and could not reproduce the anti-correlation seen in the observations. After improving our model's treatment of cloud production and removal of sulfate, cloud production of sulfate decreased and the model anti-correlation now looks similar to the observations.

Aerosols and cloud-aerosol interactions are important factors in future climate change. Since computer climate models like ours are required for predicting climate change, it is crucial that these models have accurate interaction between clouds and aerosols. One of our greatest challenges is finding ways to use observations of the current climate to provide constraints that affect these predictions. By teasing out the relationships between clouds and sulfate in datasets like those analyzed in this study, we help reduce uncertainty in our predictions and provide a benchmark that other climate models must match as well.

### Reference


- Koch, D., J. Park, and A. Del Genio 2003. Clouds and sulfate are anticorrelated: A new diagnostic for global sulfur models. *J. Geophys. Res.* **108**, no. D24, 4781, doi:10.1029/2003JD003621.


### Contact

Please address all inquiries about this research to Dr. Dorothy Koch.