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Another important forcing mechanism for climate are atmospheric aerosols which can absorb both solar and infrared radiation and re-emit infrared radiation. An important natural source of aerosols in the atmosphere are volcanic eruptions.

In this chart, you see a history of volcanic eruptions, as measured by the optical depth of aerosols that they inject into the atmosphere. This goes all the way back to 1750. And one can see that the history of volcanic eruptions is quite irregular from 1750 to the present.

There are quite a few large eruptions at the end of the 18th century through the middle of the 19th century. There was a period of very little volcanic activity in the early part of the 20th century. And we saw some rather large eruptions in the 1980s and 1990s on the planet. An expanded scale of the optical depth of volcanic aerosols over the past 20 years or so is shown in this inset here.

Volcanic eruptions are fairly chaotic in time and it's only really the very large eruptions that inject enough aerosols into the atmosphere to make a difference. The residence time of aerosols in the troposphere is only about two weeks or so, so natural aerosol injection into the troposphere doesn't seem to have very long-lived effects.

But very large volcanic eruptions inject aerosols well up into the stratosphere, where there's no weather, no real condensation of water vapor-- which is a big sink for aerosols in the troposphere. And so the residence time of aerosols in the stratosphere can be several years. It is thought that it is principally the large volcanic eruptions that inject material in the stratosphere that really affect climate.

An anthropogenic source of aerosols is sulfur dioxide emissions. Sulfur dioxide is a gas which-- in the atmosphere-- undergoes chemical reactions to become small particles of sulfuric acid or sulfate. And these particles principally reflect sunlight to space. As we heard in an earlier section of the course, they can also affect the optical properties of clouds.

Well, here is a history of global sulfur dioxide emissions, stratified by the type of source in the left diagram, and by the end-use sector, such as shipping or energy in the right-hand diagram. One can see a huge uptick in sulfur dioxide emissions starting at the end of the 19th century, but really accelerating in the middle of the 20th century, but then leveling off in the 1970s, and actually declining a little bit to about 2000.

This leveling off and decline is principally owing to legislation passed in various industrialized countries of Europe and North America, which limits sulfur dioxide emissions which come primarily from power plants. On the other hand, the last few years have seen an uptick again, which you can see here. This is due principally to the combustion of fairly dirty coal in rapidly developing countries, like China.

As we heard earlier in the course, again, sulfate aerosols which result from sulfur dioxide emissions are primarily a cooling effect on the climate. That's evident in this graph, which shows estimates of the radiative forcing by atmospheric aerosols of various kinds extending from 1850 to roughly the present.

The red curve at the top is black carbon, which is another type of aerosol. But because of its optical properties, it heavily absorbs sunlight, and is therefore a warming influence on the climate. Black carbon deposition on snow at the surface also decreases the albedo of snow and results in a small bit of warming.

Whereas on the negative side of the ledger, it is principally the sulfate aerosols that lead to a cooling, but with important contributions from organic carbon and secondary organic aerosol-- given by the green and purple curves here-- also nitrates, given by the brown curve. An estimate of the total aerosol forcing is given by the blue curve, and that appears to be mostly negative, but has leveled out in the last few decades.