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One critically important estimate is how aerosol has changed due to anthropogenic activities. In this part of the lecture we will consider how these estimates are made. Sulfate aerosol is anthropogenically generated from fossil fuel combustion.

About 70% of sulfate is natural, whereas about 30% is anthropogenic. Organic aerosol is poorly constrained. The anthropogenic source is mainly from fossil fuel combustion, and accounts for about 40% of the atmospheric burden.

Black carbon is mainly from fossil fuel combustion. It is a minor component of natural biomass burning. It should be noted that black carbon is actually a net absorber. That is to say, it warms the climate. Biomass burning is different from black carbon in that it is normally incomplete combustion aerosol. It comes from plant material. Biomass burning, unlike black carbon, is net scatterer, it cools the climate.

Nitrate aerosol can come from both anthropogenic as well as natural sources. And mineral dust aerosol is estimated to be about 30% to 50% due to human activities. This is because of land use changes.

One means by which anthropogenic aerosol versus natural aerosol can be estimated is by using ice cores to determine aerosol concentration and composition, over time scales longer than those for which we have instrumental records. In this example from McConnell and coworkers, ice was melted and re-aerosolized to determine the amounts of soot, sulfate, and other aerosol components.

This record can be used to understand natural aerosol, such as from volcanic sulfate, as well as anthropogenic aerosol, such as combustion products. Relationships of components, for example, vanillic acid is used as an indicator for wood combustion, but not coal burning. And sulfate is indicative of fossil fuel combustion. It can also be used to provide information on the sources of particles, and historic changes in human energy sources.

Another historical source of data is peat, which provides an ice core-like time recorder of aerosol composition and concentration. In this example from Shotyk and coworkers, the rise of leaded fuel, and the subsequent removal of lead from gasoline is recorded. Further back in time, lead smelting from the Roman Empire is observable, as is natural dust generated in the Younger Dryas period.

Using these types of data, anthropogenic aerosol effects can be de-coupled from natural. Optical depths from satellite, which combine both natural and anthropogenic aerosols, can be broken into individual components in climate models. Residuals, the difference between the measurement and the model, is still on the order of the signal, which leads to the large error bars discussed in a previous part of this lecture.

We can consider the suite of models used in the most recent Intergovernmental Panel on Climate Change report. This illustrates the wide range of estimates on the direct effect, with the best estimate of negative 0.5 watts per meter squared. It should be noted, that with two exceptions, all estimates are negative. There's almost complete agreement that aerosol effects represent a cooling in the climate system, which counteracts some global warming from greenhouse gases.

To recap this part of the lecture, we have discussed what aerosols are, and where they're from. We've discussed why we should be considering aerosols, both climatically and for human health. We've gone into depth on how aerosols affect the radiative balance of the planet.

It is presented how aerosols are measured. We've discussed the optical depth of aerosols, and their effect on radiative balance. We've also discussed how aerosols are measured over historic periods longer than our instrumental record. And we concluded with a best estimate of anthropogenic direct effects due to aerosols.