In order to determine the effect of aerosols on climate, accurate measurements need to be made of their size, concentration, and other properties. Techniques such as electron microscopy are offline -- particles are collected and brought to the lab for subsequent analysis.

Measurements are also made in situ. For example, a flow of particles is often passed through a light source, and scattering of light is used to determine the number. And the amount of scattering is used to determine the size of the particles. Aerosol concentration as a function of altitude is often accomplished by flying similar instruments aboard aircraft using the same techniques.

A true global picture of aerosols is not possible with only ground-based sites or even with aircraft instruments because of the vast number of sites and aircraft platforms that would be required for coverage. So-called remote sensing from satellites can be used to infer aerosol properties from their effect on natural light or light that is emitted from instruments.

There are significant issues with remote sensing or bulk studies of aerosol properties. Information on mixing state -- the partitioning of species by number, by size, or by time -- is often lost. For example, consider an assumption where the components are equally mixed verses distinctly separate. In the left hand case, all particles are assumed to have exactly the same composition.

Whereas in the right hand case, the exact same amount of each material is present, but all of one component is in one set of aerosols and the rest of the components are in the other set of aerosols. These situations would have distinctly different chemical, cloud-forming, and radiative properties.

One solution to this issue is to measure particles on a particle by particle basis. This technique is often termed single-particle mass spectrometry. Particles are brought in one at a time to a single particle mass spectrometer. Initially, they scatter light so that their size can be measured.

Subsequently, a laser is fired to ablate material off of the particle and create ions. Those ions can then be measured in a mass spectrometer, and the resulting mass spectrum provides information on the particle composition. Single particle mass spectrometry has given us a more accurate, albeit more complex view of particles.

As noted by Murphy and coworkers, particles are often highly complicated mixtures of many components. Furthermore, particles in the same air mass are often very different. As can be seen from the periodic table at right, which is shaded for aerosol components, a host of elements can be found in aerosol particles. Techniques such as single particle mass spectrometry also give us a new view of particle distribution.

For example, single particle mass spectrometry has shown that sulfates and organics are common through the depth of the atmosphere. Mineral dust and sea salt particles are most often found near the surface where they are emitted. Considerable meteoritic material is found in the upper atmosphere. Like mineral dust and sea salts, oil combustion aerosols are most often found at low altitude.

Using these techniques, it can be estimated how much aerosol is present in the atmosphere. This can further be broken down by natural or anthropogenic source. One important point is that although mineral dust and sea salt are very abundant in the atmosphere, they have very short lifetimes. As we've seen in the last plot, they're most often found near the surface of the planet, and they therefore deposit rapidly.

Conversely, particles from industrial dusts and combustion and sulfates are often found at lower abundances in the atmosphere. But they have much longer lifetimes because of their small size. We now return to our discussion of radiative effects by aerosols. The ability of aerosols to scatter or absorb light is most often considered as optical depth, a quantity measured globally by satellites, which is defined by the intensity of light is equal to the initial intensity times the exponent of negative m tao.

Tao in this case is the optical depth. And m is called a relative air mass to account for any slant in the light path. In a simple planar case, m can be visualized as the secant of the zenith angle, the angle of the sun relative to vertical. Optical depth is quoted for a particular wavelength of light.

Most commonly, 0.55 micrometers is used. By measuring optical depth and estimating the amount of aerosol that is anthropogenic, for example, from the measurements previously discussed, it can be estimated what effect aerosols have on solar radiation. From this previously shown figure in the lecture, we can see that the direct effect of aerosols is estimated at approximately 0.5 watts per meter squared.

This is roughly 1/3 of the warming of carbon dioxide. However, it has to be noted that there are significant error bars on the direct effect. Estimates range from almost nothing to a full watt per meter squared. Conversely, the radiative forcing of carbon dioxide is well known, and it has a very small relative error bars.