Aerosols
. Liquid or solid particles suspended in the air
. Some occur naturally, originating from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray.
. Some are anthropogenic: burning of fossil fuels, slash and burn, alteration of natural surface cover due to land use changes.
. Aerosols from human activities ~10% of total, mostly conc. in N. Hemisphere, downwind of industrial sites, slash-and-burn, overgrazed grasslands.
. Aerosol particles > 1 µm produced by windblown dust and sea salt; < 1 µm mostly formed by condensation processes (e.g., SO₂ to sulphate particles)
. Aerosols produce more vivid sunsets
. We are not sure whether aerosols are overall warming or cooling the planet.
This and other figs. from http://www.earthobservatory.nasa.gov/
Two main types of atmospheric aerosols: 
- **directly emitted**
  - e.g., soil dust, sea salt, industrial dust, organic and black carbon, carbonaceous aerosols from fossil fuel & biomass combustion, plant debris, microorganisms, pollen, spores, volcanic aerosols, meteoritic particles, atmospheric nuclear explosions, dust storms (desertification)
- **formed in atmosphere from gaseous precursors**
  - e.g., Many sulphate and nitrate aerosols, hydrocarbons
Aerosols, cont....
. Have a direct radiative forcing because they both scatter and absorb solar and IR radiation in the atmosphere.
  . upward scattered radiation lost to space, downward scattered affected by underlying Earth surface albedo
. Although reduction in sunlight reaching ground produces net cooling, absorption by particles and surrounding atmosphere causes net warming.
  . magnitude of cooling depends on size and composition of aerosol particles, and reflective properties of unerly ing surface.
. It is thought that aerosol cooling may partially offset global warming due to CO₂, etc.
. Alter warm, ice and mixed-phase cloud formation by increasing droplet and ice particle concentrations.
. Decreaseppt. efficiency of warm clouds and cause indirect radiative forcing associated with changes in cloud properties.

Aerosols are nuclei for drop formation and hence crucial for clouds.
If there are more aerosols, more cloud drops form. Since the total amount of condensed water in the cloud is ~ the same, the average drop must become smaller. Clouds with smaller drops reflect more sunlight, and such clouds last longer (takes more time for small drops to coalesce into drops large enough to fall to the ground.)
. Both effects increase the amount of sunlight that is reflected to space without reaching the Earth's surface.
. Some debate on effects of aerosols on rainfall... On the one hand, aerosols are important for cloud formation; on the other hand, aerosols decrease cloud rainfall efficiency.
. Team of scientists from the Hebrew University (Israel) and NASA used NASA satellites and remote sensing to determine how man-made aerosols change clouds. Aerosol particles from factories and power plants increase the number of droplets in clouds they pollute, causing clouds to retain their water and not produce rain.
. Research on ship smoke stacks (air over oceans less polluted): SO₂ released from ships’ smokestacks could be forming sulfate aerosol particles in the atmosphere= the clouds are more reflective, carry more water and possibly stop precipitating.

. Aerosols likely have a significant negative effect on overall radiative forcing.
. Have short atmospheric lifetimes and cannot be considered as long-term offset to greenhouse gases.
. Average residence time for aerosols before being washed out by rain = 1-2 wks.

Volcanic Aerosols:
. Explosive eruptions inject large amts. of dust and gases (e.g., SO2) into the stratosphere, where SO2 rapidly converted to sulf. acid aerosols.
. Volcanic material ejected into lower atmosphere removed in a few days by rainfall and gravity.
Stratospheric material can remain for several years.
Scattering by highly reflective sulf. acid aerosols can cause 5-10% reduction in energy received at Earth's surface.
Individual large eruption can cause global cooling to 0.3°C, 1-2 yr. effect (Mt. Pinatubo, 1991)
Volcanic aerosols may be responsible for at least some previous climate change; for example, the Little Ice Age 1450-1850 was marked by more sulphate-bearing, volcanic-derived aerosols in ice cores, indicating greater volcanic activity. the Medieval warm period (1100 - 1250) linked with lower volcanic activity.
More explosive silicic eruptions (e.g., Mt. Pinatubo) have more climate effects than basalt flows (e.g., Hawaii)
Figure 3. As volcanoes erupt, they blast huge clouds into the atmosphere. These clouds are made up of particles and gases, including sulfur dioxide (SO₂). Millions of tons of sulfur dioxide gas from a major volcanic eruption can reach the stratosphere. There, with the help of water vapor (H₂O), the sulfur dioxide converts to tiny persistent sulfuric acid (H₂SO₄) aerosols. These aerosols reflect energy coming from the sun, thereby preventing the sun’s rays from heating Earth’s surface. Volcanic eruptions are thought to be responsible for the global cooling that has been observed for a few years after a major eruption. The amount and global extent of the cooling depend on the force of the eruption and, possibly, on its location relative to prevailing wind patterns. (Graphic by Robert Simmon, Goddard DAAC)
Black carbon
Operationally defined species based on measurement of light absorption and chemical reactivity and/or thermal stability; consists of soot, charcoal, and/or possible light-absorbing refractory organic matter.
- Results primarily from burning of forests and fossil fuels.
- On the one hand, black carbon can absorb light, resulting in warming of atmosphere around particles. This can result in as much as 50% warming.
- On the other hand, black carbon can reflect light, resulting in as much as 10% decrease in light reaching Earth's surface and thus a cooling of the Earth's surface.
- Currently, a good deal of research is focusing on characterization of black carbon and its complex effects on global climate/radiative forcing.

- Mean atmospheric lifetime may be ~6-10 days
Major study today going on in Indian subcontinent: black carbon produced by industrialization blown out over Indian Ocean.