Module 1: Lecture 3

In this lecture we conclude our discussion of air pollutants. Here is some basic information about sulfur dioxide (SO_2), the third and last of the gaseous pollutants that we will be discussing. Sulfur dioxide is produced by the combustion of sulfur containing fuels such as coal. Combustion of fuel also produces carbon dioxide and carbon monoxide. People probably first became aware of sulfur dioxide because it has an unpleasant smell. Carbon dioxide and carbon monoxide are odorless. Volcanoes are a natural source of sulfur dioxide.

$$\text{Fuel (coal)} + O_2 \longrightarrow \begin{array}{l} CO \text{ or/and} \\ CO_2 \text{ or/and} \\ SO_2 \leftarrow \text{has a smell.} \end{array}$$

SO_2 - Sulfur Dioxide

1

First recognized air pollutant.

Natural emissions - volcanoes, sea spray, biological decay (0.2 ppb natural background concentration)

Manmade emissions - combustion of coal or other fuels with high sulfur content. Often a problem in regions with cold climates.

US NAAQS: <24 hour period> 0.14 ppm
< 3 hour period> 0.5 ppm

prolonged exposure to levels > 1ppm can be fatal to people with existing lung disease.

SO_2 is the major component of what is called London-type smog, named after the famous Great London smog event of 1952. London-type smog is most common during the winter. Photochemical or Los Angeles-type smog contains ozone and is most common in the summer.

The Great London smog is still one of the two or three deadliest air pollution events in history. Because the atmosphere was stable, SO_2 emitted into air at ground level could not mix with cleaner air above. The SO_2 concentration was able to build to dangerous levels. 4000 people died during this 4 or 5 day period. As many as 8000 additional people died in the following weeks and months. The sulfur dioxide did not kill people directly. Instead it aggravated an existing condition of some kind and hastened death. The SO_2 probably also made people susceptible to bacterial infections such as pneumonia. [This link] discusses the event and its health effects in more detail.

At fault in many of the world's worst air pollution disasters:

2

London-type smog.

(a) Great London Smog, Dec. 5-9, 1952
4000 "excess" deaths still the world's worst air pollution disaster.

Stable atmospheric conditions trapped SO_2 and soot in a foggy layer next to the ground. Tops of most of the factory smoke stacks were below the top of the stable layer. One of London's "pea-soup" fogs - at times visibility dropped to less than 5 feet. Origin of the term *smog* = smoke + fog. Also called London-type smog.

(b) New York City, Nov. 24-30, 1966, 168 deaths

(c) Meuse Valley, Belgium, Dec. 1-5, 1930, 63 deaths

(d) Donora, Penn., Oct. 26-31, 1948, 20 deaths

The photographs below come from articles published in 2002 on the 50th anniversary of the event.

from: http://news.bbc.co.uk/1/hi/uk/2542315.stm

from: http://news.bbc.co.uk/1/hi/health/2545747.stm

from:
http://news.bbc.co.uk/1/hi/england/2543875.stm

from:
http://www.npr.org/templates/story/story.php?storyId=873954

In 1948, one of the deadliest American air pollution episodes occurred in Donora, Pennsylvania. The eerie photograph on the left below was taken at noon on Oct. 29, 1948. As the deadly smog enveloped the town of Denora, PA, 20 people were asphyxiated and more than 7,000 became seriously ill. "When Smoke Ran Like Water" is a book that you may find interesting. The author, Devra Davis, lived in Donora Pennsylvania at the time of the 1948 air pollution episode.

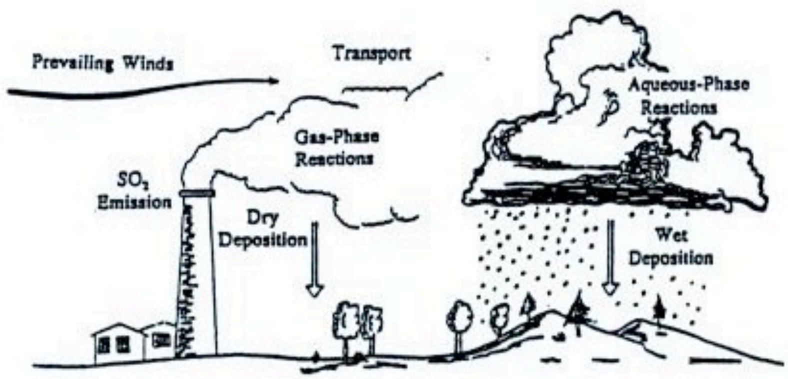
from:
http://oceanservice.noaa.gov/education/kits/pollution/02history.html

from:
http://www.eoearth.org/article/Donora,_Pennsylvania

Sulfur dioxide can react with water in clouds to form acid rain. Some of the oxides of nitrogen can also react with water to form nitric acid, another component of acid rain.

SO_2 can react with water (sulfuric acid)
3 in clouds to make
ACID RAIN. $SO_2 + H_2O \rightarrow H_2SO_4$

SO_2 is converted to sulfuric acid, H_2SO_4, in clouds and falls to the ground as acid rain.



Acid rain was first observed in Scandinavia in the 1950s; in the United States in the 1960s.

Dissolved CO_2 in natural rain forms weak carbonic acid, H_2CO_3.

pH (pure rain) = 5.6
pH (acid rain) < 5.6

pH scale
< 7 acidic
7 neutral
> 7 basic

Note that clean unpolluted rain has a pH of less than 7 and is slightly acidic. This is because the rain contains dissolved carbon dioxide gas. We will see how this happens in a class demonstration next Monday. Acid rain is often a problem in regions that are hundreds or even thousands of miles from the source of that sulfur dioxide that forms the acid rain. Acid rain in

Scandinavia came from industrialized areas in other parts of Europe. Some of the problems caused by acid rain are listed below.

Effects of Acid rain

(1) can upset the ecology in lakes and streams. Fish can't live in water with pH < 4.5.

(2) Attacks plant foliage and roots:

Removes the protective coating on leaves. Plant becomes susceptible to pests, disease, and other pollutants such as ozone.

Dissolves and carries away nutrients in the soil. Also dissolves toxic materials that enter roots and water supply

(3) Damages materials, especially stone monuments and buildings.

$$CaCO_3(s) + H_2SO_4(aq) \dashrightarrow CaSO_4(s) + H_2O + CO_2(g)$$

limestone, marble	sulfuric acid	gypsum slowly dissolved by rain water.

The last pollutant that we will cover is Particulate Matter (PM) - small solid particles or drops of liquid (but not gas) that remain suspended in the air (sometimes referred to as aerosols). The designations PM_{10} and $PM_{2.5}$ refer to particles with diameters less than 10 micrometers and 2.5 micrometers, respectively. A micrometer is one millionth of a meter.

Particulate matter can be produced naturally from windblown dust, clouds above volcanic eruptions, smoke from lightning-caused forest and brush fires. Human activities such as construction can also produce particulates. Particles with dimensions of 10 micrometers and less (PM_{10}) can be inhaled into the lungs. (Larger particles get caught in the nasal passages). Inhaled particulates are a health threat. The particles can cause cancer, damage lung tissue, and aggravate existing respiratory diseases. The smallest particles can pass through the lungs and get into the blood stream (just as oxygen does) and damage other organs in the body.

Particulate Matter (PM)

small particles (liquid or solid)
- smoke or soot
- chemicals
- metals
- soil, dust, pollen

diameter < 10 μm　　　diameter < 2.5 μm.

primary and secondary sources, produced by nature and human activities

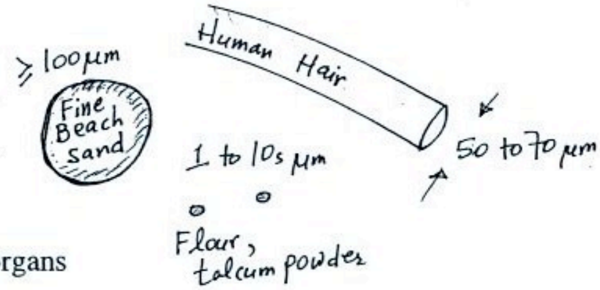
PM 10　　　PM25

μm = micrometer
= 1 millionth of a meter.

<10 μm - inhaled, pass through
the nose and throat into the lungs
(into the bronchi and bronchioles?)

<2.5 μm - penetrate deeper into the lungs
(into the alveoli?)

<0.1 μm - pass through the lungs
into the bloodstream and into other organs



① Affect health
- difficulty breathing
- aggravate asthma, make lungs susceptible to infection
- lung disease, lung cancer
- heart disease

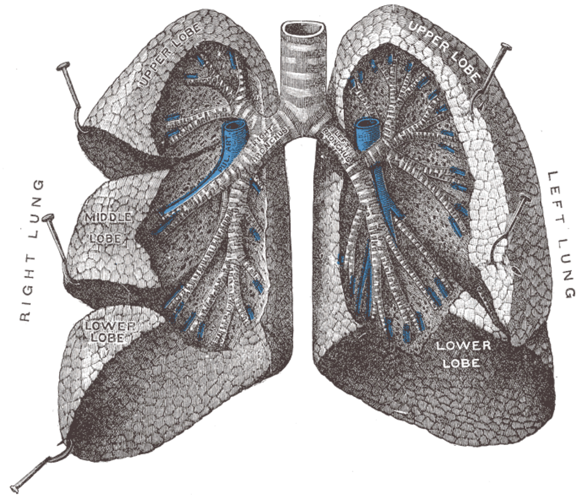
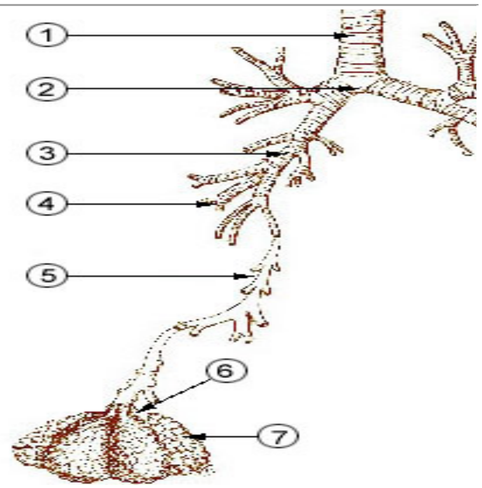
② Affect visibility

National Ambient Air Quality Standards (NAAQS)

PM10	(50 $\mu g/m^3$)*	annual
	150 $\mu g/m^3$	24-hour
PM2.5	15 $\mu g/m^3$	annual
	35 $\mu g/m^3$	24-hour

* revoked in 2006 revision of the NAAQS

The figure below identifies the parts of the human lung mentioned in the figure above.

 Crossectional view of the human lungs: http://en.wikipedia.org/wiki/Lung	 1 - trachea, 2 - main stem bronchus, 3 - lobar bronchus, 4 - segmental bronchi, 5 - bronchiole, 6 - alveolar duct, 7 - alveolus http://en.wikipedia.org/wiki/Image:Illu_quiz_lung05.jpg

Beijing has high levels of particulate matter. There was some concern during the most recent summer Olympic Games that the polluted air in Beijing would keep athletes from performing at their peak. Chinese authorities restricted transportation and industrial activities both before and during the games in an attempt to reduce pollutant concentrations. Rainy weather during the games may have had the greatest effect, however.

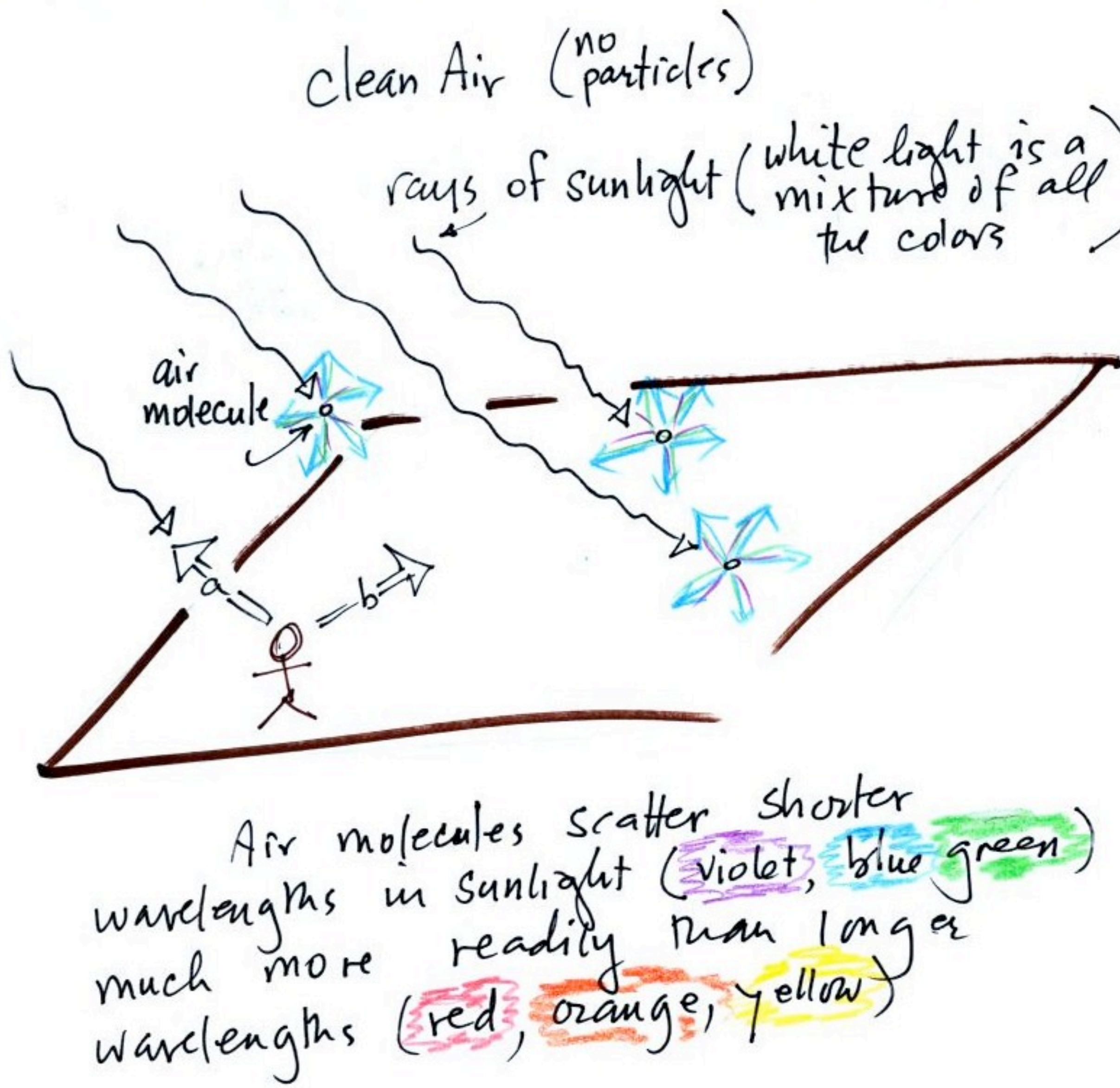
Clouds & rain are the best way (nature's way) of removing pollutants (gases & particulates) from the air.

The following list shows that there are several cities around the world where PM_{10} concentrations are higher than the annual PM_{10} NAAQS value of 50 micrograms per cubic meter.

City	Population (millions) (a)	Average Annual PM concentration ($\mu g/m^3$) (b)	(c)
Tokyo	33.6	40	35
(Chongqing)	31.4	123	
Seoul	23.4	41	70
Mexico City	22.4	51	55
NY City	21.9	21	25
Mumbai (Bombay)	21.6	63	
Delhi	21.5	150	170
Sao Paulo	20.6	40	40
Los Angeles	18.0	34	45
Shanghai	17.5	73	110
Osaka	16.7	35	
Cairo	16.1	169	150
Buenos Aires	16.1		
Calcutta	15.7	128	110
Manila	15.6	39	
Jakarta	15.1	104	
Karachi	15.1		230
Dhaka	12.8		125
Beijing	12.7	89	105
Lahore	12.6		
London	12.5	21	30
Paris	12.0	11	
Istanbul	11.8	55	
Rio de Janeiro	11.5	35	55
Tehran	10.2	58	
Lagos	10.1		
Moscow	10.1	21	

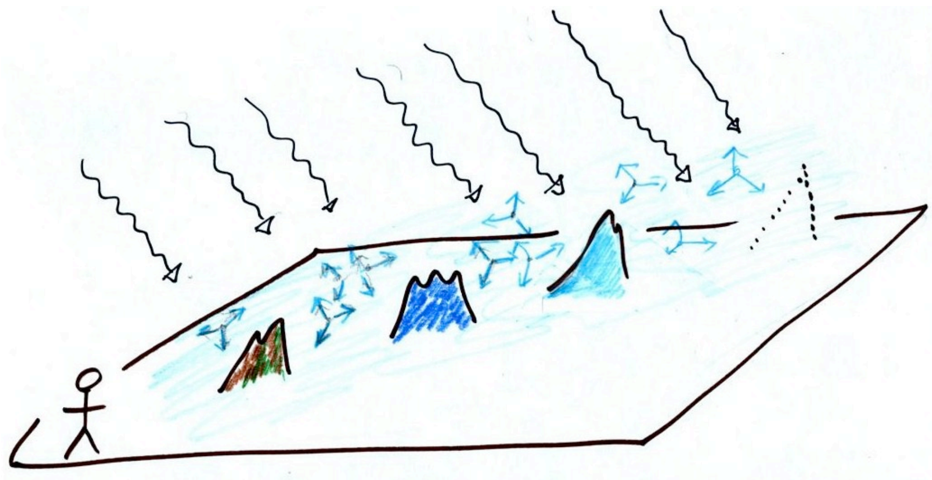
(a) http://en.wikipedia.org/wiki/Megacity
(b) World Bank data:
http://siteresources.worldbank.org/DATASTATISTICS/Resources/table3_13.pdf
(c) World Health Organization data: Air Quality Guidelines - Global Updata 2005
http://www.who.int/phe/health_topics/outdoorair_aqg/en/index.html

Particulates can affect visibility and can make the sky appear hazy. To understand this we need to look at how air molecules and particles scatter sunlight.



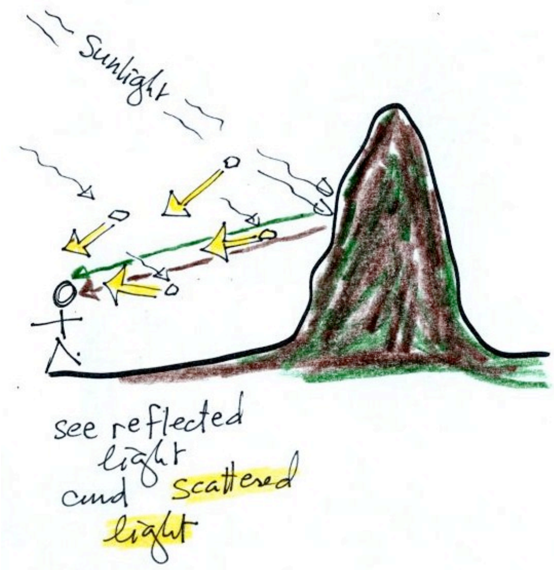
Rays of sunlight are passing through clean air above. You would not normally be able to see the sunlight unless you looked back along one of the rays **(A)** in the figure, i.e. back toward the sun. You'd see the sun in that case (at least up until you caused some serious damage to your eyes). If you look away from the sun toward the sky **(B)** you see blue light. This is light that is being scattered by air molecules.

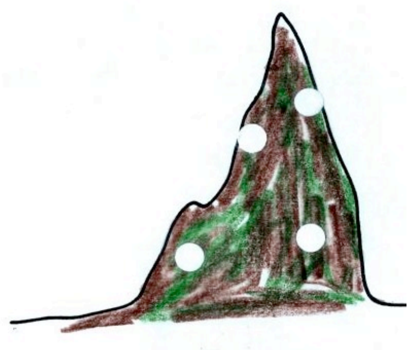
Sunlight is white light, which tells you it is a mixture of all the colors. Because air molecules are small (relative to the wavelength of visible light) they scatter shorter wavelengths more readily than longer wavelengths. When you look away from the sun and toward the sky you see this scattered light, it has a deep blue color. This is why the sky is blue. If the earth did not have an atmosphere (or if air molecules did not scatter light) the sky would be black. Scattering of sunlight by air molecules turns distant mountains blue and eventually makes them fade from view. A nearby mountain tends to appear dark green or brown because you are seeing light directly reflected by the mountain. As the distance to the mountain increases, you start to also see blue light which is sunlight scattered by air molecules in between you and the mountain. Eventually the mountain becomes so far away that all you see is blue sky light and the light reflected by the mountain itself cannot be seen.



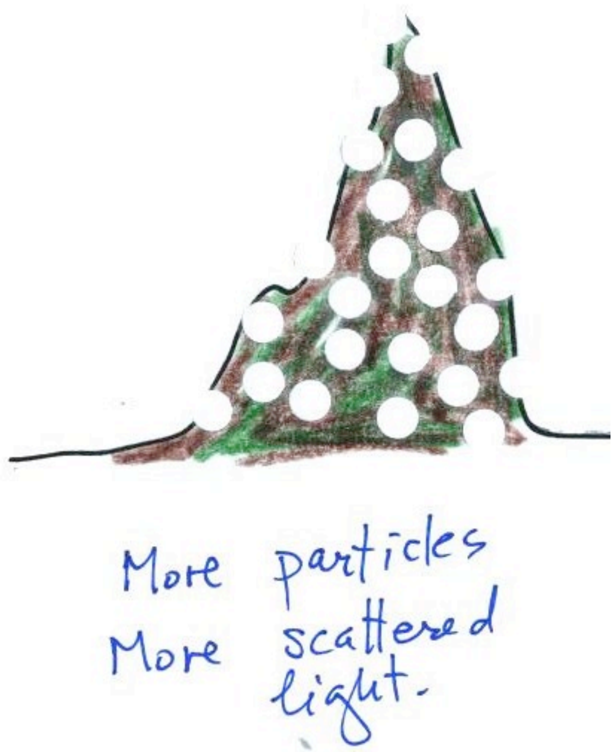
We have added some airborne particles to the picture above. Particles also scatter light. The particle size is about equal to or somewhat greater than the wavelength of visible light. Consequently the particles scatter all the colors equally and the light is white in color. This is why clouds are white. As the amount of particulate matter in the air increases, the color of the sky changes from deep blue to whitish blue. The higher the particle concentration, the whiter the sky becomes. Have a look at the color of the sky before and after a rainstorm. Before the storm, the air will be full of particulate pollution and will appear whitish blue. After the storm, the rain has removed a lot of the pollutants so that the sky often has a much deeper blue color.

The next set of figures explains how particles in the air can affect visibility. The air is free of particles in the first picture. You are looking at a relatively nearby mountain. The "side view" at left explains that you are able to see the mountain because it reflects sunlight back toward you. The picture at right is what you see when you look at the mountain. We are ignoring any light scattered by air molecules.

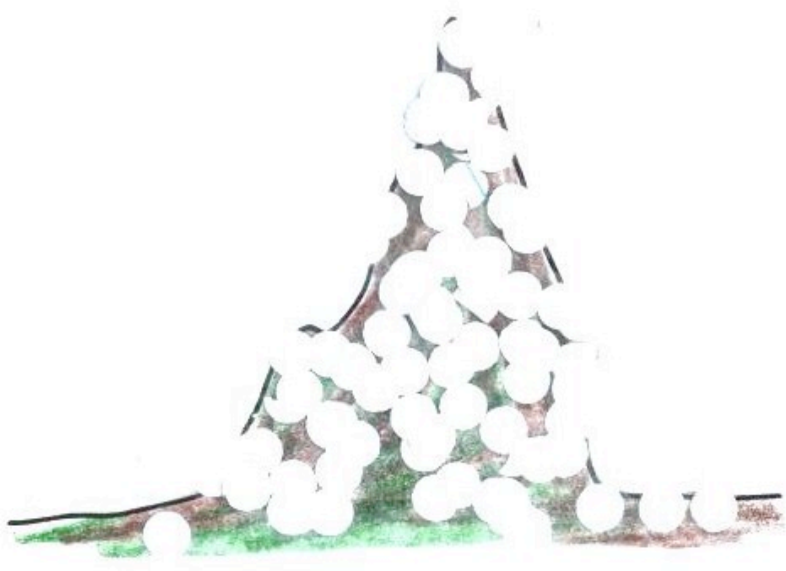




.Now some particulates have been added to the air. They scatter sunlight, the scattered light is white (it's highlighted in yellow in the picture at left for emphasis). So now you still see the brown and green reflected light but also some white scattered light. Some unrealistically big spots of white light have been added to the picture at right.



More particles have been added to the air which means there will be more scattered light. We will add even more particles to the air in the next picture. Because there is more scattered light (more spots of white light in the picture of the mountain) you have a harder time seeing the mountain. Eventually all you see is the scattered light and the mountain fades from view.



More still