

AIR: SOME IDEAS P.Rhines, 21 Feb 2003

This is by no means a complete summary (see the lecture hand-outs, and available on the web site, and your own notes and lab books)...but it reviews some of the important ideas.

In the Air unit we described Great, Large and Small aspects of the atmosphere. Just as the problem of terrorism is that it does not respect or relate to national borders, air pollution is 'without borders, being global as well as local.

We spoke of James Lovelock's Gaia theory, which describes the Earth as a living organism, one in which the living plants and animals control the chemistry of the atmosphere and ocean, and in doing so stabilize them. We said that Darwin's evolution of species answers the question, 'Why are we here?' and 'why are all the living species here?'; Lovelock's Gaia tries to answer the question 'Why is the Earth the way it is?', with an oxygen rich atmosphere when its neighbors Venus and Mars are lifeless, burnt out planets with carbon dioxide atmospheres. Indeed, 'Why are rocks and oceans and ocean sediments the way they are?' Lovelock spoke of a redwood tree in analogy, the tree being mostly dead, but supporting the living layer just beneath the bark. A coral reef is mostly dead, yet its surface is alive, and it grows. Richard Feynmann's description of a tree is a beautiful counterpoint to this ('...a tree is made of air, mostly...').

We have seen the greenhouse effect at many scales: solar box cookers trap sunlight (short-wave, easily penetrating glass or clear plastic), converting it to 'heat radiation (long-wave, infra-red) which does not penetrate through glass or plastic. In just the same way the atmosphere traps solar heating and warms us; our average temperature is about 33 C (59F) greater it would be with no atmosphere (the moon which has no atmosphere but receives similar sunlight is about that much colder). CO₂ contributes only 1/2800 th of air, which is mostly nitrogen, then oxygen. The trapped radiation bounces back and forth between upper atmosphere and ground, at a rate 47% greater than the sunlight arriving above (Lovins p236).

The increasing greenhouse gas effect on climate (due to carbon dioxide, methane, ozone and other trace gases) appears to produce a definitely 'global' warming but it is not simple and uniform everywhere. Carbon dioxide has increased from about 280 parts per million (a concentration of 2.8×10^{-4}) before industrialization to 370 parts per million in 2000. Monitoring atmospheric CO₂ is pretty easy, because it is pretty uniform around the Earth. So the station on top of the volcano Mauna Loa on the big island of Hawaii established by Charles Keeling shows what we need to know: nearly steady increase, along with seasonal up-and-down due to the 'breathing' of the green plants which is greatest in northern spring season.

Earth's plant life uses solar energy to take in carbon dioxide and put out oxygen...photosynthesis...while animals do the reverse. The microcosm experiment

shows both sides of this cycle: millefoil plants and goldfish, with strong cycling of oxygen and nutrient 'foods'. Note that the solar energy is accessed only by the plants, and the animals become chemical-heat engines when they eat the plants.

The atmosphere has its general-circulation patterns like the westerly (that is, to the east) winds at middle latitudes and easterly (toward the west) at low latitudes (the tropics, roughly equatorward of latitude 22). The easterlies are called 'trade winds' because sailing ships could use them to go westward, rather than sail upwind at higher latitude.

In addition to the mean east-west winds the air veers north and south in a regular pattern of waves (see Lec air-2), due to the major mountain ranges and land-sea contrast (warm/cold contrast). Finally on top of this we have 'weather', the 1000 km wide cyclonic and anticyclonic wind systems associated with low and high pressure centers, respectively.

There are 'storm tracks' where the westerly winds come out over the ocean, and intensify. In the Atlantic the storms often then to do follow the mean winds northeastward toward Iceland. In the Pacific they come more eastward out across the Pacific. The storm tracks show up on maps of time-averaged pressure as bigger low-pressure regions (called the Icelandic Low [North Atlantic] and Aleutian Low [North Pacific]). In the southern hemisphere things are different because there is so little land. There we have a parade of weather moving more rapidly round the world in the westerlies.

Weather involves intense storms (low-pressure centers), in the extreme case hurricanes, tropical cyclones and tornadoes. Hurricanes are 'heat engines' driven by very the warm tropical ocean surface. When they come over land they quickly die out. Generally they are born near the Equator and as they intensify, the Coriolis force carries them away from the tropics toward middle latitudes.

Intense storms do damage: roughly \$35 billion for Hurricane Andrew which hit south Florida in 1992. It is widely thought that it would have cost \$100 billion if it had hit Miami. In under-developed countries there is not so much real estate to be lost but instead lives are lost: more than 12,000 died in Hurricane Mitch which sat over the highlands of Central America in 1998. One of the great sadnesses of tragedies in the 3d World is that the number of victims, and the identities of many, will never be known. It dumped several feet of rainwater on the steep slopes, which had in places been denuded of vegetation. Villages were swept away. The prime minister of Honduras said that the countries infrastructure was nearly totally destroyed.

So the lesson is that poor countries suffer casualties and rich countries lose real estate. But the case of Bangladesh, where tropical cyclones are particularly fierce, is important. The loss of jobs, farms, fresh water, infrastructure may be as devastating as the loss of lives (which exceeded 300,000 in one day in Nov. 1970). Yet to put even this tragedy in perspective, in the civil war with Pakistan at about the same time, more than a million

lives were lost as India and 'east Pakistan' created the independent country of Bangladesh. .

At the smaller scale we briefly described the major pollutants in the lower atmosphere, which are reviewed both in McNeill's and Lomborg's books. We noted that besides the standard list (oxides of nitrogen, sulfur dioxide, ozone, soot, carbon monoxide) there is also a large number of big molecules, hydrocarbons like benzene, and metals like mercury, which are a health threat (in Seattle diesel exhaust is particularly bad in this way).

Small particles, whether soot or soil, are bad for the lungs. At about 2.5 microns (millionths of a meter) they can enter deep into the lung. Lungs wash out dust with a steady flow of sticky fluid, but the deep inner lung cannot do this. We did not do a very important experiment: put a clean piece of cloth over the end of a vacuum cleaner hose and suck air through it for 10 or 20 minutes. Then look at the cloth. The trapped dust and soot may surprise you. Smokers, if they blow one gulp of smoke through a napkin, produce a deep brown deposit.

The daily cycle of the lower atmosphere was described, with layering at night due to cooling (radiation upward of heat). Then with sunrise we often get convection and (jump) at the top. Pollutants collect at the inversion, to where smokestack effluent and other warmed air rises. Oxides of nitrogen are produced by cars and factories...these are unstable nitrogen-oxygen molecules. Sunshine tends to turn these into ozone (O₃) which is also very unstable...very reactive.

Many cities have cleaner air now than in the mid 1900s. Yet things are getting worse in some areas (sulfur dioxide in China and India from coal burning, for example) and getting worse globally. London is much cleaner now but it exports its pollution eastward. Lomborg (Skeptical Environmentalist) tends to pick out the success stories and sometimes ignore the problem areas, in painting a rather rosy picture. He points out that GDP and air pollution have a definite relationship, with richer countries making moves to clean out their air. But, again, the problems are global.

The air labs have been well summarized in other handouts. The ones looking at particles in the air (fall out rates which become very slow for small particles) showed how indeed candle smoke particles simply hung in the air for very long periods, and with layering (due to CO₂ stratification) the effect was greater. Layering of atmosphere and ocean controls much about the movement of water, trace chemicals, nutrients, ecosystems and pollutants. The 'smokestack' lab was meant to show how a buoyant plume coming into a fluid will mix with its surroundings and gradually stratify (layer) the density in the whole region. The plume engulfs other air greatly increasing its volume while diluting its concentration. This is similar to the estuary we modeled under Water, where the river inflow diluted greatly, and in doing so drove a much larger transport of overturning circulation.

Overturning circulations have recurred often in this course. The Hadley circulation of the atmosphere (rising in tropics, sinking air farther north or south), the circulation inside a hurricane or tornado (up near the center, down elsewhere... actually the updrafts in a hurricane occur a little off center, leaving the 'eye' cloud-free. In weather, these overturning circulations make it cloudy where there is upward motion, and this occurs most strongly in low-pressure (cyclonic) regions. So your barometer is useful in predicting cloud and rain. Some areas of the world are located in perpetual downward-circulating regions, like the Sahara Desert. It is the downward air motion that keeps the clouds from forming, and keeps it a desert. [The connection here was seen in several labs... rising air expands because the air pressure drops with altitude. It then cools because of the expansion ('adiabatic cooling'). Colder air holds less water in gaseous form... so we have condensation, cloud, rain.]

The role of particles in the air carried over to ice crystals and rain; usually raindrops and ice need a particle to grow on, because a very small drop or crystal has too much energy to occur spontaneously. So smoke added to a moist air region produced fog when the pressure was reduced. In the cloud chamber a miniature rainstorm formed as vapor descended from the lid into the colder regions (dry ice below). Atomic particles added spectacular tracks of droplets, as their high energy collisions with air and vapor molecules shocked them into condensing as droplets.

In some cases these particles in fluid are dense and numerous, and weigh the fluid down. So, an avalanche flows down a mountain like a river, because the powdery snow acts like part of the fluid, giving it greater density. In the oval piece of fluid art in the oceanography building we saw this 'abyssal storm' of sandy particles making the fluid act as if it were stratified, with gravity waves on the internal layers.

Ice crystals form in the cold air high in the atmosphere (and can be seen in 'mares tails', those curved clouds high up, in which ice crystals are falling downward while being blown sideways). However, the freezing point for water is reached at quite low altitude (recall the temperature profile for the air... decreasing upward). Yet ice crystals do not form at 0°C unless there are dust particles or other 'condensation nuclei' around. And the *shape* of the dust particle has to be just right, so we don't have as much frozen water as we would first expect. Human activity is radically changing the dust and other smoke-related air pollutants, which can potentially alter the delicate ice crystal distribution. We had a lab experiment on this, with the connecting idea that the cold regions of the Earth, where ice and snow are found, are really very small in area. And they are shrinking as the Earth warms. Natives have lived successfully in the bitter cold of Greenland for more than 6000 years, yet now their white world is changing.

Earth's rotation acted in the experiments to greatly affect the atmospheric circulation. It produces the westerly winds from the basic Hadley circulation, where northward winds of the Hadley cell cause strong westerly winds to develop (see lecture notes). The great heat engine of the Earth, driven by the sun's heat, has cold air trapped near the north and south poles, separated from the warm tropical air by sloping fronts... the layers of constant (effective) density are tilted. They would rather not be,

and cold air surges in strong weather events toward the Equator, trying level off the density layers.

Global change...warming, droughts, deluges of rain...is happening not alone but in company with the continuing press of overpopulation (multiplied by increasing technology and wealth). It is a dangerous brew of natural and human-induced change: one that needs our best efforts to understand it and hold up our understanding, like a mirror in which our fellow humans can see themselves and their future.

This course seeks to show that looking at the environment with the eyes of a scientist can help one to think more clearly about the problems we face. The 'air' chapters of McNeill are a long story of the rise and fall of pollution generated by industry, home heating and cars...plus the more subtle substances like lead and CFCs. One is left with an empty feeling: how can we understand this? Observing simple models of the environment, where you isolate just a single effect, is our answer. Learning the power of measurement and new ways to 'see', like using a laser to view a dusty atmosphere, or dyes to view slow fluid motions, helps to add new dimensions to a problem like air pollution. We need maps and movies of bad air out in the city, observed so vividly that we can confront the sources defeat them. And we need to see a fuel cell and solar cooker in action to know that there are newer and better ways. Amory Lovins is one of those who not only sees the problem, but seeks the solution, and convinces us that there is prosperity and global equity hiding in the depths of the problems of the environment.