ENVIR 202: AIR LABS WINTER 2003 GETTING STARTED 4 ii 2003

Our second unit will deal with air: from the great scale of the circulation of the atmosphere to the quality of air that you breathe. It will have new ideas but also will continue the flow of ideas from the Energy unit. One of the most pressing issues of our time, global warming, involves both Energy and Air. These are complex issues which lead even the most savvy scientists to disagree. The response of the air to our machinations is not simple to predict, and there is much that goes on at the emotional and aesthetic level.

Readings: Lovins Ch. 12 eventually 15
McNeill Chs 3, 4

In some cases we use water instead of air for experiments, where it is more convenient.

As we said about the Energy experiments, this hand-out is meant to get you started. After progressing with these basic questions*, please pose some of your own questions of the experiment, and report on them in your lab-book.* Often this will involve changing something about the experiment to see the effect on the primary phenomenon. A useful idea is, when looking at a steady process (like a steady tornado) you can often learn something by seeing how it develops from 'the beginning'; in this case watching the tornado develop as the flow is turned on, and by doing something to change its intensity.

A1. A miniature planet: weather, heat transport, climate on a rotating planet.

The general circulation of the atmosphere is driven by heating and cooling: the Sun once again. The tropical band near the Equator receives more solar radiation than the high latitudes near the Poles. At all latitudes heat is radiating to space, and so there must be a flow of heat from low latitudes to high. The most obvious circulation of the atmosphere is the east-west winds: the 'westerlies' in middle latitudes and 'easterlies' nearer the Equator. Yet it is the north-south, up-down circulation (called the 'meridonal circulation') that moves heat from hot regions to cold. The two kinds of circulation, east-west and north-south interact with one another.

1. Using a rotating platform, create a model of the atmosphere's circulation, driven (as it is driven) by temperature differences between pole and equator). A plexiglas cylinder with a smaller glass cylinder inside it will give a 'gap', or annulus in which to put water (which simulates the air of the atmosphere). To create the solar heating contrast, put ice in the central, small cylinder. Observe the fluid motions with dye and small particles, sketching and measuring some velocities.

2. The flow will have features which model atmospheric jet streams, convection, westerly and easterly wind. Measure temperature field with electronic thermometer, with and without rotation of the 'Earth'. Sketch and describe streamlines in the fluid ('streamlines' are curves drawn parallel with the velocity of the fluid).

3. What happens if there are mountains at the base of the fluid?

applications: climate change, variability, greenhouse, patterns (modes) of climate variability, global warming.

A2. Violent Storms: hurricanes and tornadoes.

Tornadoes are particularly strong vortices (vortexes) that form when conditions are just right (more than 90% of tornadoes on Earth apparently are in the US Midwest). Wind speeds can exceed 200 m.p.h. and they can lift pickup trucks and cows high in the air. They occur when clusters of cumulus clouds become intense, which involves upward air movement that can be very strong, drawing air in toward their center. Here we simulate this inward movement by withdrawing fluid at the bottom rather than the top.

1. Make tornadoes in a plexiglass cylinder with a hole in the bottom (sitting in a lab sink); do this by injecting a water stream, through tygon (plastic) tubing so that it enters at the upper rim of the cylinder and swirls around before exiting at the bottom. Make the flow very gentle at first, then increase it.

2. Using colored dye and particles study and record the motion of the fluid, its rate of spin at different distances from the axis, and its (more subtle) movement from the water source at the rim to the outlet at the center.

3. "Desymmetrize' the experiment: that is, make it not so symmetrical, for example by putting a clay 'mountain' on the bottom, or moving the outlet away from the exact center, and see if the tornado still can form.

4. Hurricanes are much larger storms energized by the warm, tropical ocean. Whereas the tornado cannot *directly* feel the Earth's rotation, the hurricane does. Build a simulation using a rotating platform (using water instead of air, lab bench labeled A2). You could heat it from below (with a heating pad) or, what is quite similar, simply use warm water and let cool from above. Explore the relation of the size and intensity of the 'hurricanes' and the rotation speed of the 'planet'

applications: cyclones (hurricanes) in Bangladesh; why is that low-land country so vulnerable? Possible change in hurricanes due to global warming; geography of tornados, why are most in the central US?

A3. 'Bad air': particles in the atmosphere and the lungs: dust, smoke, raindrops

Small solid particles (soot from diesel vehicles, smoke, and dust from blowing soils) are a serious health hazard. Water droplets also hang in the air. Large particles fall out of the air quickly while small ones linger on. We want to determine what size and density (kg per m^2) the particles must be if they are to remain floating in the air rather than settling out. This can be done by using much larger particles and extrapolating what they tell us to smaller size. At slow fall rates the critical quantities are: the diameter of the particle, a, its density relative to that of the fluid, ($\rho_{particle}/\rho_{fluid}$) and the viscosity of the fluid, ν, and the gravitational acceleration, g.

1. Measure the falling velocity of spheres in fluids (air, water, syrup) to learn how quickly particles settle out of the atmosphere. We have a collection of steel and glass spheres of various sizes, and fluids like water and sugar syrup with different viscosities.

2. View smoke particles, chalk dust and water mist droplets in a tall plexiglass box, with a laser or light-sheet from a slide-projector, and look at their settling, removal by electrostatic fields, and removal by 'rain'. From their settling velocity deduce their size (using the data from part 1. extrapolated).

applications: Sub micron sized particles in air, health effect, inner lung. Deposition on a solid surface. Geography of particles, 'Loess' or white soils from China raining out in Seattle.

What is the largest diameter of a particle that is likely to get deep into your lungs? On the web, satellite survey of smoke and forest fires, vertical distribution of particles after a volcanic eruption. See A4 too.

A4. Atmospheric inversions over a city

Much of the pollutants in air are produced by cars, factories, etc., near the ground. They can be trapped by layers of atmosphere which have different density, known as 'stable density stratification'. The situation can be made much worse by mountain ranges that block the winds, and by strong summer sunshine that can create density stratification and worsen the chemistry of the pollutants. We can make a model of the situation with stratified gas, but using a mixture of carbon dioxide (from dry ice) and air. Condensed water droplets make the cold CO_2 visible for some time. The carbon dioxide has no chemical role here, it just comes along with the cold ice. If the sun heats up the lower atmosphere, it may convect upward but bump into the stratification. It can produce an 'inversion' or very big density change at the top of the convecting layer.

1. Create a stratified gas in a plexiglass rectangular container, with a small beaker of dry ice. Measure some temperatures or make a full temperature profile (the density will depend both on temperature and amount of $CO_{2,}$ which unfortunately we can't measure.
2. Observe waves in the stratified 'atmosphere'.
3. Introduce some candle smoke near the bottom, as a pollutant. Observe how it develops. Use a slide projector to make a sheet of light to illuminate the gas. A laser beam may tell more: in ideal circumstances it can actually tell the size of the particles it hits.
4. Put a small, weak heat source at the base of the fluid (heating pad or a resistor connected to a d.c. power supply), to simulate the morning sun; what happens to the pollution and density stratification? Could you measure the concentration of smoke pollutant using a light beam and radiometer?

applications: air quality of LA, Denver, Seattle. What added factors make pollutant levels worse? Add chemical reaction, estimate photochemical effects (making smog). See A3 too. Look on the web for information about particle sizes in air pollutants (lately, diesel fumes in Seattle and blowing dust in eastern Washington). Look at the daily air cycle in a city like Los Angeles, where there is confinement by mountains and hot sun.

A5. Rain ,clouds and snow: Ice crystal growth, freezing of water, cloud chamber

The temperature of the atmosphere decreases rapidly with height above ground. On a partially clear day we see clear air up to an altitude, known as the condensation level, where the bottoms of clouds are found. This level is usually quite definite. When air flows over mountains, it has to rise and when it reaches the condensation level cloud (water droplets) appears: then when it flows down the other side the cloud disappears (the air flows *through* the cloud). Higher up, water vapor forms ice crystals there rather than rain drops. Above -40C temperature there has to be a dust particle or other nucleus for the ice to form on.

1. Using a cold chamber (tall foam plastic box) cooled by dry ice, capture ice crystals on a soap film and watch them grow; measure temperature at various depths in the box. Use a piece of

copper wire formed into a loop, with a dilute dish-washing soap solution to make a bubble film you can lower into the box.

There are relatively few ice crystals because only one particle in 10^8 (100 million) is the right shape and size. Note the eventual freezing of the soap film itself. On a thin layer of water observe freezing using polarized light. Perhaps look at ice crystals growing on the end of a needle left in the cold region.

2. With assistance set up the cloud chamber, and observe the condensation of water vapor in air that is cooled at the bottom (to -60^0C) by dry ice. Alcohol vapor may also be used and has some advantages. A remarkable side-effect of this experiment is the appearance of streaks…contrails of cloud. These are the tracks of atomic particles..*individual atomic nuclei and electrons!* Like magic. Measure the temperature profile if it is possible, with a small thermistor.

NOTE: if you use an electric field to 'clear the air', do it only with supervision.

applications: where are ice crystals found and what is their importance to clouds and weather, and to the chemical balances high in the atmosphere? Where are freezing levels geographically and by season? Interact with experiment A8.

A6. A biological microcosm: Oxygen production uptake by aquatic plants and animals, and exchange from air to water.

Here we have the opportunity to emulate the major biological cycle on Earth. We can attempt to make a small world where plants eat carbon dioxide and produce oxygen, while animals do the reverse. If things are not kept in balance this world will radically change (Amory Lovins describes the many-million-dollar attempt to build a 'Biosphere' in Arizona to keep 6 or so humans alive, in a self-contained 'world' isolated from the real one, for a year or more…it failed).

Air is: 23% oxygen by weight, 21% by volume
75.5% nitrogen " 78% "
1.3% argon " 0.934% "

So, dry air has 1.3 x 0.23 or 0.3 grams oxygen per liter of air. That amount of air and oxygen should be enough to oxidize roughly 0.3 grams of carbohydrates (sugar, starch, cellulose).

$$O_2 + CH_2O \rightarrow CO_2 + H_2O$$
32 g 30g 44g 18g

A typical reaction with the weights of the oxygen, carbohydrate, carbon dioxide and water is just above.

1. Estimate the oxygen consumed by a 1 gram gold-fish who eats 0.01 gram per day of fish-food (carbohydrate). What volume of air would contain this amount of oxygen?

2. Using a 3 liter flask with a stopper and electronic oxygen probe, design an environment which will provide one or more goldfish with enough air to survive. In particular the water level will determine the amount of air above, and this is the supply. We will measure the oxygen level using the probe and computer, over a period of a couple of days.

3. In a similar 3 liter Florence flask, with the same amount of water, place several grams of aquatic plant (weighed out of water). Insert the oxygen probe with tight stopper. Shine a light on the experiment, measuring its intensity with the radiometer. Log this data on the computer for a day or two. Determine how much oxygen is produced by the known weight of aquatic plant life.

4. Design a microcosm in which both of the above are present: green plants and gold-fish.

5. A separate but related question: oxygen moves across a water surface from the air, increasing the dissolved oxygen in water until no more can be taken up. Can we see this happening?[*Carry out this experiment with oxygen-sensitive dyes if the primary microcosm experiment is 'cooking' for a long period of time.]*

5.1 Take a 250 ml beaker, fill with 125 ml of potassium hydroxide (KOH) solution we will provide.

5.2 add a few crystals of methylene blue.

5.3 add 5 grams of dextrose sugar

5.4 stir and let sit

5.5 this solution should become clear (transparent)

5.6 shake the solution which will force oxygen into the water, causing it to turn deep blue. This will be temporary because the oxygen will be then taken up by the KOH.

5.7 place the solution in a beaker with an open surface. If the amounts of chemicals are right, you may see that the water very near the surface is blue, and plumes of blue descend from it. This is the remarkable process of oxygen 'invading' the water from the air.

applications: this experiment relates to the basic biology and chemistry of the Earth and the oxygen and CO_2 of its atmosphere. Greenhouse warming of the Earth is happening as the CO_2 gets out of balance following our fossil fuel burning (and burning of forests). There have beem very warm eras in the past (like the Cretaceous period that ended 66 million years ago: the age of dinosaurs. During the Cretaceous there seems to have been no ice or snow on Earth, with jungles in Antarctica.

A7. Winds in the lower atmosphere.

The lowest few hundred meters of the atmosphere are known as the 'atmospheric boundary layer'. Here the winds change from their high speed (farther up) to nearly zero at the ground. In doing so they become turbulent…unsteady, full of whirling eddies. Both the variation of wind-speed as you go up or down, and the turbulence have strong effect on the movement and dilution of atmospheric pollutants.

1. Using the water flume as a model of the lower atmosphere, we can look at the flow near lower boundary. Turn on the power to the propellers, and watch the flow develop. Use dye and eyedroppers to visualize the flow, particularly near the bottom.
2. Try to install a model 'smoke-stack' which can continuously inject dye ('smoke') into the flow. Track the dye (modelling smoke) down wind, for slow and fast flows.
3. Explore the effect of a hill or ridge on the flow: how does the average velocity change, and how will the mixing of a pollutant source change? What is the effect of the mean velocity of the water (as determined by the power setting of the propellers.

applications: effect of winds on pollutants in the lower atmosphere: the air we breathe; the role of mountains (and at smaller scale, buildings) in changing wind patterns and the 'ventilation' of the air near the ground.

A8. Evaporation, water vapor

Heat moves around the atmosphere in two forms: as hot air and as moist (humid) air. If you have been in the Great Plains or the east coast in summer, you know what high humidity feels like. At night the sun goes down but it doesn't cool off. You lie awake because sweat does not cool you. By contrast, try sailboarding on a high-mountain lake in Colorado in summer, where the humidity is very low. Don't wear a tee-shirt! It can take you close to hypothermia when it gets wet. We want to look at how much water can be held in gaseous form by air of a given temperature.

The tendency for water to evaporate is described by its 'vapor pressure', which is the pressure the water molecules produce when they are a gas rather than liquid. Air can hold only about 5 to 10 grams of water per kilogram of air, and the amount is often described by its 'relative humidity', the amount of water vapor in air as a percent of the full air pressure (water vapor + oxygen + nitrogen…). This amount changes greatly with the temperature of the air (warm air holds more moisture). How could we observe and measure some of these effects?

1. Using a mist sprayer and piece of liquid-crystal 'thermometer' sheet, look qualitatively at the cooling effect of a water mist. What is the energy cycle at work?
2. Measure the room temperature and then, using a thermometer with a moist cloth wrapped round its bulb, twirl it in the air on a string so as to ventilate the cloth (or arrange an electric fan). Measure the change in temperature as evaporation occurs, cooling the thermometer. Using printed tables, convert this into the humidity value (a chart showing this is on the bulletin board).
3. Boil some water and capture the steam, measuring the temperatures throughout the whole system. Beware: the word 'scald' is frightening, and it describes what happens when steam (hot water vapor) condenses on a cool surface. Use a metal plate and monitor its temperature.

applications: vapor pressure of a water surface; cumulus clouds taking up water vapor, condensing to visible droplets where heat is released (making the air more buoyant, so that it rises violently); heat engine in a single cloud and the global heat engine, latent/sensible heat flux. Interact with the ice crystal and cloud chamber experiment (A5).

Demonstrations: our environmental monitoring lab.

tornadoes, weather, atmospheric circulation
NOx (oxides of nitrogen)
column ozone (top to bottom of atmosphere), water vapor
ozone in the lower atmosphere, UV radiation
soot-o-meter
electric effects on particles in air: electrostatic air cleaner
gas diffusion
greenhouse gas: trapping of heat