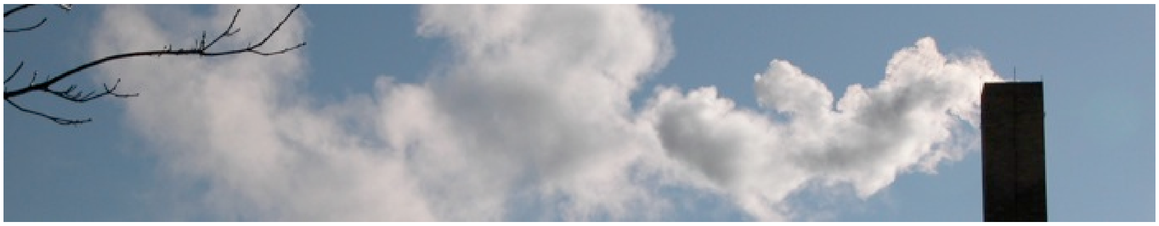


Instructor's Manual

Module 3: *Meteorology and Transport of Air Pollution in the Mid-Atlantic United States*

A. Typical class length:
45-60 minutes (edited); 90 minutes (un-edited)

B. Target students:
Entry-level state employees

C. Module objectives:
The goals of this module are to have the students:
- Explain atmospheric transport processes that move air pollutants in the Mid-Atlantic United States
- Describe atmospheric conditions that can elevate or reduce air pollutant concentrations

D. Instructor preparation:
Go to the course web site and download all relevant materials for Module 3:
Instructor's Slides (Powerpoint)
Student Handouts (PDF)
Instructor's Manual Overview (PDF)

http://bigmac.cee.mtu.edu/marama/Modules/Modules.html

Review all the materials, make any changes you feel are necessary for your version of the course (this module has much more material than can covered in a one-hour class), master the material, then deliver your class!

E. Understand the sub-module objectives
Each course module is constructed of a series of sub-modules based on modern learning theory. The sub-module typically focuses on a narrow aspect of the module topic. The module can be viewed as the collection of several discrete topics presented in a fashion more appropriate for the range of learning styles among students in your class. Most sub-modules are constructed around a *motivation-theory-application-analysis* learning cycle. While it is good practice to have this cycle for each sub-module, it is acceptable to have a portion of the sub-modules that do not have all four components of the cycle. In general though, it is poor practice to have only the theory sections, as this will likely achieve the low-retention rates found in lecture-based learning environments. The rest of this manual

provides tips and insight into specific slides. Please refer to the *Module 3 Instructor's Slides* to follow along.

Sub-Module 1: Introduction (Slides 1-6)
The primary purpose of these slides is to engage the student immediately upon entering the classroom. Educational research suggests that in a typical class, the first ten minutes is lost on most students as they are disconnecting from what they were previously doing. A suggested approach for this phase of the module is:

Slide 1 – Have this projecting before the students enter the classroom. Each module starts with a photograph connected to the content. Most students will subconsciously begin thinking about the course material when looking at a photograph. This photo clearly depicts the complex patterns resulting from atmospheric transport of emissions from a elevated point source (the stack).

Slide 2 – Introduce the topic and the class. This will make sure everybody in the room belongs in the class.

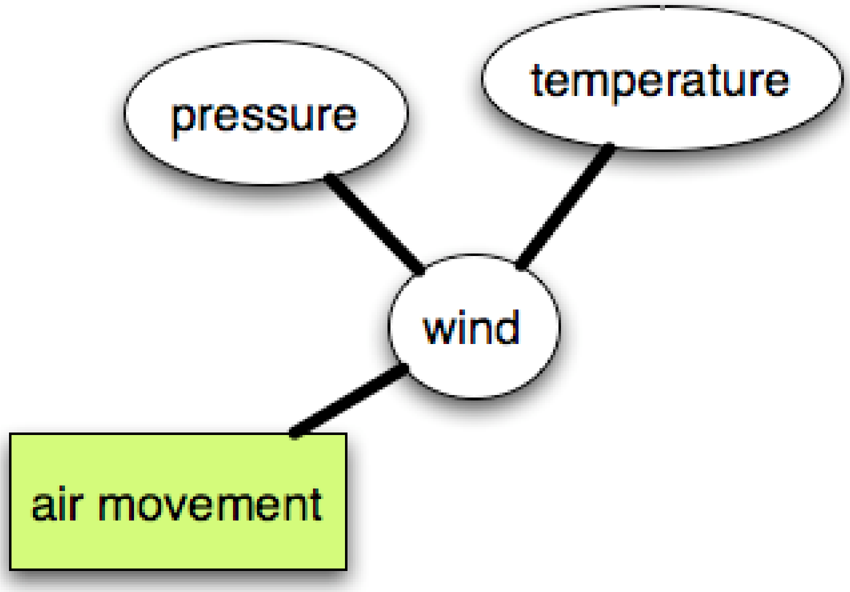
Slide 3 – This slide serves as the initial motivation. Feel free to substitute a similar compelling fact, observation, or finding from your own experiences. This slide should be put up long enough for the students to review, and perhaps some short comment from you. In this case, a reasonable comment is that water quality can be linked to air quality in some locations – the connection is transport of air pollutant emissions to the point of impact (the Chesapeake in this case).

Slide 4 – All modules have a preliminary quiz. The purpose of the preliminary quiz is two-fold: (1) it gets the students thinking more about the subject, and (2) gives you a comparative benchmark at the post-module quiz. Feel free to substitute questions with some of your own, but bear in mind that the total time expended here should be no more than two minutes. It is fine if the students don't know the answers, that's why they are in your class. Simply have the students circle the answers on their copies of the student handouts, or produce a handout quiz if you want to tally the results. One way to engage the class as a whole is simply to ask for a show of hands for each answer. The solutions to this quiz can be found in the post-course quiz slide below.

Slide 5 – The course goals slide is a good one to emphasize. Tell the students clearly what they will learn by the end of the class. If you add to, or delete, any material, modify the course goals as needed.

Sub-Module 2: Transport Fundamentals (Slides 6-9)
The primary purpose of this sub-module is to address the first course objective, explaining how atmospheric transport processes influence the movement of air pollution in the Mid-Atlantic region of the United States.

Slide 6 – There is no better way to assess what the current state of knowledge among students than concept mapping. The technique is simple: in the middle of the page write the key concept and put a box around it. In this case it might be "air movement". From there, the student groups simply connect concepts to this central concept. For example one related concept might be "wind", and then connected to wind, might be "pressure" and "temperature".



There are no right or wrong ways to do this. If possible provide some large sheets of paper and markers so the students can share their work. If such paper is not available, blackboards, or transparencies work. Be careful, you can easily eat up a lot of time on this activity. Tell the students they have five minutes to work on this. This activity also helps the class reach a higher comfort level.

Slide 7 – This slide presents three key definitions: source, receptor, and airshed. It also establishes the importance of transport, specifically that it is the great connector between emissions and impacts

Slide 8 – This slide provides a numerical example showing the influence of transported air pollutants to the Chesapeake. Additionally, it illustrates the linkage of distant sources (or long-range transport). A rhetorical question to pose might be "how does this influence water quality solutions for the Chesapeake"?

Slide 9 – This is intended to be a quick sharing activity. Have the students offer their thoughts. As this module focuses on transport processes, this activity is simply to make sure the endpoint is in mind; transport is only the means to the ends, so to speak.

Sub-Module 3: Transport Processes (Slides 10-26)
The goal of this sub-module is provide depth into several important transport processes that influence the movement of air pollution in the atmosphere.

Slide 10 – A critical point upfront is to underscore that in the atmosphere air is always moving (even on a "still" day). This movement is always due to a combination of processes, some operating on the "large" scale (100s to1000s km), some on "small" scale (10s to 100s km), and some on "micro" scale (micrometers to a few meters). As we are interested in air quality in this course (versus say air pollution interactions) we will focus on the bigger scales (in this case "small" to "large"). At any given moment, one or a couple of these processes can be dominating the transport of air pollutants.

Slide 11 – The purpose of this slide is to start with the big picture and understand that local air movement is partly influenced by global forces. These motions also have an environmental connection, resulting in wet and dry regions on the planet.

Slides 12-13 – These slides introduce a topic that most students will be somewhat familiar with from weather forecasts. High and low pressure systems exert strong influence on the air quality (high pressure generally degrading it, low pressure generally improving it). The photo on slide 12 shows a typical high pressure day, noted by the clear skies and gently rising plumes. The photo on slide 13 simply shows an extreme low pressure system (a hurricane). Note its rotation is clearly counterclockwise.

Slide 14 – This slide illustrates how these pressure systems affect air quality. In this example the typical wind patterns, resulting from the annual average pattern of pressure systems, creates transport of emissions (the grey circles) from the southwest to northeast. Does this suggest anything about solutions?

Slide 15 – The activity in this slide is simply to get the students to connect any observations about the weather (easier for lifelong residents in the Mid-Atlantic, perhaps) to a hypothesis on unique issues for the region. One such issue is the "Bermuda High" discussed next.

Slide 16 – The Bermuda High is an example of air quality complications imposed on a region. There is nothing the Mid-Atlantic region can do about the existence of the High, so the region must simply tolerate the consequences, or come up with unique solutions (say, on emissions control) to minimize the impacts from this atmospheric phenomenon.

Slide 17 – This is a simple visual example of the importance of atmospheric transport processes. In this case emissions are influencing distant sources. If available, it would make a good addition to provide a time series of particulate matter concentration from a monitoring site in the Mid-Atlantic before, during, and after this forest fire event.

Slide 18 – The boundaries between the high and low pressure systems are fronts. As such, the air is different on the two sides of the front; these changes have an impact on air quality.

Slide 19 – This is simply an illustration of the rain that forms ahead of a front. This is due to the lofting of moist air up, cooling it, and condensing the moisture out as rain. What might happen to air pollutants in the same air?

Slide 20 – This photo taken from the Space Shuttle shows a clear layering of air due to a very stable layer being formed in the atmosphere as cold air wedges under warmer air. This layer is where the "smog layer" is noted on the photo. Due to the stable layer, the air does not mix, and the smog stays trapped. Above the warmer air, the air cools with altitude (as is normal) and clouds form as the moisture condenses.

Slide 21 – The low level jet typically forms above the very stable (little mixing) layers called inversions. As the inversion starts at the surface and generally is a few hundred meters in height, the low level jet generally moves pollution that is higher in the atmosphere. A corollary would be that the low level jet does little to influence the ground-level air pollutants (or change the air quality that people are most affected by). It can move this pollution though after the inversion breaks down, the ground-level pollution moves to higher altitudes, and then is transported by the next low level jet to form. Note the geographic conditions generally needed for formation. This is not a process for every part of the Mid-Atlantic.

Slide 22 – The diagram depicts a couple important features of the low level jet: (1) the typical location (altitude, or height) of formation, and (2) the diurnal (daily) nature of the jet (it forms after sunset and disappears shortly after sunrise. The reason for this daily behavior is that heating of the surface by the sun causes convection and a breakdown in the inversion (the "stable nocturnal boundary layer"). The inversion re-establishes after sunset, when rapid cooling of air near the surface creates an inverted temperature profile (warmer with height) and stable air. The cycle can then repeat itself.

Slides 23-24 – The important point here is that the students realize that this is another location-dependent transport process. In the Mid-Atlantic this process results in air pollution moving up the coast; problematic for the urban corridor in that area as emissions accumulate with those from upwind cities, as depicted in Slide 24.

Slides 25-26 – A feature of most coastal settings, the sea/land breezes are daily features moving air inland and seaward. These movements have obvious impacts on moving emissions in particular directions. How might this change the air quality in areas surrounding an urban downtown? Remember, that generally the larger scale air movement in the U.S. is from west to east. How might the land/sea breeze affect this larger scale transport of air pollutants?

Sub-Module 4: Inversions and Stability (Slides 27-37)
The goal of this sub-module is to address the second objective of the course module, identifying a critical atmospheric condition that influences air pollutant levels.

Slide 27 – Defines *inversion* and its consequences. This slide is simple because it is such an important concept. Take time to stress these points.

Slide 28 – Introduces two types of inversions. The schematics are typical representations of how the air temperature might change if you were to measure at different altitudes (maybe from the ground up to a few kilometers). The inversion is any region where temperature is increasing with altitude, instead of the normal decrease with altitude. An example of the elevated inversion is shown in the photo from the Space Shuttle in Slide 20.

Slide 29 – This diagram depicts the daily creation and destruction of the surface (or nocturnal) inversion. Particularly on clear nights, the surface cools very quickly and cools the nearby air. This creates cool air near the surface, and warmer air above – an inversion! After sunrise, the surface is heated, the air heats up, and breaks down the inverted temperature profile – inversion disappears! Additionally, subsidence inversions could be present at higher altitudes; note how these are not affected by this daily cooling/heating cycle. What might this daily cycling mean for air quality in the area?

Slide 30 – These are simply two photographs showing the inversion layers. Most such layers are more noticeable when looking horizontally through the layer (as done in these two cases) versus from the surface upward.

Slide 31 – One way that inversion frequency can be increased is when certain topographical constraints are present. Valleys allow cool air to pool effectively at night, enhancing inversions (strength and frequency). Coastal environments bounded by mountains are also inversion prone due to confinement of air movement. In these diagrams, U is simply a representation for the free air movement (above the surface inversion), or below and above the elevated inversion.

Slide 32 – A map showing the likelihood that an area in the U.S. will have an inversion. In the Mid-Atlantic, areas in the Appalachians have more frequent inversions. Mid-Atlantic coastal areas have some of the lowest rates in the entire country.

Slide 33 – Similar inversion frequency data as in Slide 33, but now presented by season. The most important point here is that seasons influence frequency (slightly); in general there is less in the summer, more in the winter for many places in the Mid-Atlantic. Also, it is clear that certain patterns persist – higher frequencies in the mountains, lower along the coast. Feel free to ask the students why these patterns exist.

Slide 34 – This is an activity for the students to digest the inversion information. It also will help them connect this knowledge with past (or future) observations. Ask for the groups (3-5 people) to share their thoughts with the class.

Slide 35 – Stability is a general description for how much mixing is taking place in the atmosphere. Inversions are one (extreme) form of very *stable* atmosphere. The opposite is *unstable*, noted by much mixing of the air. Stability can be quantified by measuring temperature with altitude, and then estimate this change (or slope, if you were to plot it out on a graph). This change in temperature with height is called the lapse rate. Weather balloons are sent up routinely (every 12 hours) in certain locations, measuring temperature (and other properties) as they float up. This data is used to measure the atmospheric lapse rate; this value changes with time of day, and location. Air pollution from a source changes temperature according to a theoretical value, the adiabatic lapse rate. Adiabatic refers to an assumption that this air is not exchanging heat with surrounding (ambient) air as it moves upward from its point of release.

Slide 36 – A classic example of observing the stability of the atmosphere is presented in these diagrams. The shape of pollutant (often steam these days) plumes results from the stability of the atmosphere. In this slide, the name of the plume is given in black, and the corresponding stability condition is given in red. The temperature-altitude plots compare the ambient air pattern (the blue line) to the air pollutant pattern (the dotted red line). Note that the air pollutant temperature profile is always the same – according to theory it always follows the adiabatic lapse rate. The only thing that changes ever is the atmospheric temperature profile. When the atmosphere changes (due to any of the transport processes presented, plus other heating/cooling phenomena) it changes the behavior of pollutant movement away from the hypothetical stack sources.

Slide 37 – This is a fun exercise to get the students talking about how human-based observations can be useful, and maybe to realize that they have observed such stability without being aware of it. Some of these will be simple (e.g. seeing a plume or smog layer), some challenging (e.g. feeling cold air as you bike into a valley), some seemingly impossible (e.g. hear, taste, smell). Your students' creativity will be revealed on this one! They certainly won't see the world the same after sharing some good ideas, so go through the list of senses and see if a group can offer one for each.

Sub-Module 5: Combined Transport Processes (Slides 38-43)
The goal of this sub-module is to address the first objective while stressing how the transport processes typically work in combination.

Slide 38 – A reiteration of the processes previously covered. Atmospheric transport is a subject that most people have no intuition about (after all, it tends to be invisible), so a summary of the processes is a good reinforcement at this point to help some of this material stick.

Slide 39 – This example shows how regional ozone transport takes place in the Mid-Atlantic. These transport processes are part of the challenge in solving the persistent ozone problems in the region.

Slide 40 – One slide to acknowledge that many of the impacts (health or environmental) require the pollutants to move the last short distances from atmosphere to receptor via very different processes, usually operating at the molecular level. At this level, different pollutants (due to differences in chemical and/or physical make-up) can behave very differently. For example, some air pollutants easily move from air to water, others do not.

Slide 41 – This activity is primarily to get the students to think about their surroundings, and educate each other based on their observations and opinions of areas within the Mid-Atlantic.

Slides 42-43 – Another, more concrete, activity is given in these slides. Using a time series of PM10 measurements, the students are challenged to connect the material learned in this module to something they may encounter in their work (air quality monitoring data). Tell the students to assume that all changes are due to changes in transport or meteorology, not due to changes in emissions. As usual, have the groups offer a few observations.

Sub-Module 6: Conclusion (Slides 44-47)
These slides provide a meaningful ending to the learning. Don't underestimate their importance.

Slide 44 – The post-quiz goes here. The students should only need 30-60 seconds. Collect their responses, if assessment is needed, else a show of hands with discussion is fine. The purpose of the post-quiz is simply to force retention of key points. The answers for this quiz are:

1.) *False*, high pressure stagnates the air, allowing pollutants to build up. Ironically, high pressure often results in sunny days, what most people want.
2.) *a.) air temperature increases with altitude* (this profile is "inverted" from the normal profile)
3.) *False*, the movement of air from the ocean towards land, restricts the transport of air from land to sea and allows urban emissions to accumulate until the land breeze develops in the afternoon.

Slide 45 – This slide has some resources for the students to learn more on their own. Add to it, as relevant. Encourage additional learning with references that you know to be particularly helpful. The regional ozone transport example is covered in great detail in the first, the second source is a good site for looking at meteorological measurements (from surface and balloon instruments). The MARAMA Guide presents the module's material from a different perspective.

Slide 46 – The moment to reflect is an important pause before concluding the class. It helps the student sort and summarize what they have learned, and if desired can be a good summative assessment for your efforts. For example, as an assessment tool, simply ask the students to write their response to the question on a scrap of paper and leave it behind following the class. Read through the responses to adjust any future offerings of the class. What do the students say about living downwind? Do they mention that they are living upwind of somebody else? This activity could take some time, so set time limits up front. Nevertheless, this activity will probably leave the students talking as they leave the course. Exactly what you want!

Slide 47 –Thank the class for coming and for their participation! This is a simple yet powerful way to end the class.