9. Smoke from Wildland Fire: Just Hanging Around?

Lesson Overview: In this activity, students learn that smoke from wildland fires can either disperse readily or stick around, reducing visibility on the earth's surface and making it difficult to breathe. From a demonstration, they learn that long-term smoke episodes caused by inversions can be very harmful to human health – even though the smoke may benefit some plants. Finally, students they apply health guidelines regarding smoke to the problem of scheduling athletic practices on a smoky day.

Subjects: Science, Mathematics, Reading, Writing, Speaking and Listening, Social Studies, Health Enhancement

Duration: One to two half-hour sessions

Group size: Entire class

Setting: Classroom

New FireWorks vocabulary: *inversion, particulate/particulate matter, PM10/PM2.5, smoke, stable/unstable atmospheric conditions, visibility*

Lesson Goal: Increase students' understanding of smoke from wildland fires, how it disperses, and its effects on ecosystems on human health.

Objectives:

- Students can interpret information about air quality, dispersion, and visibility during a wildland fire.
- Students can recommend measures for protecting their own respiratory health and that of others.

Standards:		6th	7th	8th
CCSS	Speaking and Listening	1,2,4,5	1,2,4,5	1,2,4,5
	Language	1,3,6	1,3,6	1,3,6
NGSS	Weather and Climate	ESS2.D		
	Earth's Systems	ESS3.A		
	Human Impacts	ESS3.B,C		
EEEGL	Strand 1	B, C, E, F, G		

Teacher Background: There's no wildland fire without smoke, but the amount of smoke produced and the way in which it disperses differ from one fire to another and from one time to another on a single fire. If the smoke disperses upward rapidly, high-altitude winds will scatter it downwind, and the only result we notice may be the beautiful, orange-tinged sunrise and sunset colors produced by particles in the air. However, if the smoke is trapped near the fire by an inversion, it can make the air difficult to breathe and even difficult to see through. These conditions benefit some plants by increasing seed germination. For humans, however, they are hazardous, especially for anyone who has asthma or other respiratory illness and for those who engage in strenuous exercise.

In this activity, students learn that smoke can disperse readily or be trapped by an inversion. Then they consider who might benefit from smoke and who might be damaged by it. Finally, they use data on visibility and particulate matter to decide if and when smoke from a wildland fire may be hazardous to their health.

On most summer days, sunlight warms the earth's surface each morning, and the air lying on the earth's surface is heated too. This warming, expanding air rises, and its temperature decreases due to the expansion. If the air is dry, the temperature falls about 1°C for every 100-meter rise in altitude. As a result of this natural cooling, mountain tops tend to remain much cooler than valleys even on hot summer days. Because the air is constantly moving and mixing under these circumstances, we call it unstable.

Sometimes the sun doesn't warm the earth's surface very much during the day. Clouds may block the incoming sunlight. In winter, the ground may be covered with snow that reflects sunlight instead of absorbing its energy. In summer, the smoke from a fire may be too dense to let sunlight through. When this happens, the cold air is stuck on the ground, and a warm layer of air rests on top of it. It is not expanding, therefore not rising, and therefore it is "trapped" on the ground until something stirs up the atmosphere. This is called an inversion because the normal daytime pattern (warm air on the bottom, cool air on top) is upside-down. The blanket of warm air lying on top of the cold air is called the inversion layer. During an inversion, the cold surface air is very stable. It cannot be dislodged until it is heated or stirred up by wind.

During an inversion, dust and other particulates in the air are trapped in the cold air at the earth's surface. Inversions during wildland fires trap smoke, which may be so dense that you can't see very far and the city streetlights come on in the middle of the day. When seeds of some plants are exposed to dense smoke, it becomes easier for them to germinate. But when people are exposed to dense smoke, it becomes harder to breathe. Dense smoke is especially dangerous for babies and anyone with asthma or other respiratory illness. It is a good idea for some types of seeds to be outdoors during a smoke-filled inversion, but it is a good idea for people to limit aerobic activities and even stay indoors until the air quality improves.

Materials and preparation:

- Download PowerPoint ***M09-1_SmokeAndHealth.pptx***
- Make 1 copy/student of **Handout E07-1: Cancel a Sports Event?**
- Find these in the trunk or your lab supplies:
  - Two 1-qt freezer contains or two 500-ml beakers
  - Digital thermometer with thermocouple wire. Make sure the thermometer's battery works. Have a spare on hand.
- On the day before the activity, fill one of the containers half full with water and freeze it. If you forget, use ice cubes.

- On the day of the activity, have boiling water ready to fill the other container half-way. Keep it hot until you need it.
- Set up your lab bench or demonstration table with the container of ice on the right side (facing the class) and the empty container on the left. Make two signs ("Ice cold" and "Boiling"), and place them next to the appropriate containers. Place the digital thermometer and boiling water on the table too.
- Write the following table on the board or project it:

Classroom temperature (°C):		
	Ice	Boiling water
Temperature °C, level with top of container		
Temperature °C, inside container, 0.1 cm above ice or water		
Is air right above ice/water warmer or colder than air above?		
Describe the movement of the air right above the ice/water surface:		
Air above the water: stable or unstable?		
Inversion present?		

Procedures:

1. **Hook:** Select 3-4 students to sit in a circle around a prop (box, book, stool, other object) that represents a campfire. Have them pantomime some fun things to do. Maybe they'll start a song, roast marshmallows, add sticks to the fire, etc. Then have another student be wind and circulate around the fire or back and forth, blowing on the smoke. Ask those sitting around the fire to react. As they cough and hack or move to a different spot, ask what the problem is. SMOKE BOTHERS US!
2. Ask: What is smoke? Smoke consists of water, gases, and tiny particles of unburned and partially burned fuels. These are called *particulates* or *particulate matter*. The particulates are light enough to circulate in the atmosphere instead of settling immediately to earth, as larger particles do.
3. Explain: In this class, we'll learn about where the smoke from wildland fires goes.
4. Project PowerPoint *M09-1_SmokeAndHealth.pptx* – **ONLY SLIDES 1-4,** which illustrate where smoke goes and how it can hang around for days or even weeks. (Use the handout and narrative shown at the end of this activity.)
5. **Stop the slides and start the lab demonstration.** Explain: To understand how smoke moves around, we have to understand the daily movement of air. Every day, sunlight reaches the earth's surface, heats it up, and then heats the air next to it. Every night, the earth cools off because the sun isn't heating it anymore, and the surface air cools off too. We're going to

investigate how air behaves – how it moves around – above hot and cold surfaces. This will help us understand how smoke behaves.

6. Get 3 students to help with the demonstration and begin:

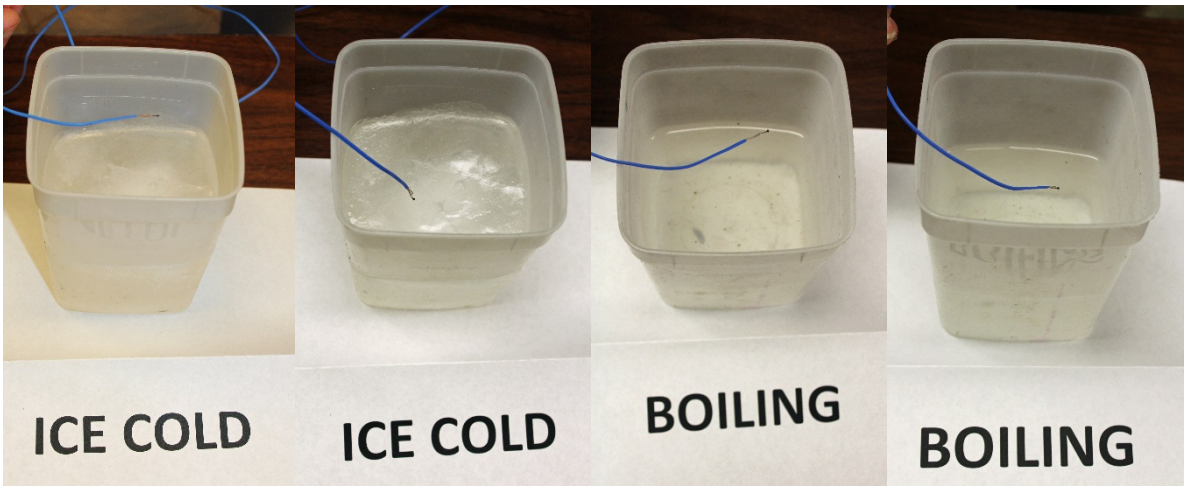
   a. Have one student turn on the digital thermometer and hold its display up so the class can see it. Measure in degrees C.

   b. Have another student hold the thermocouple tip at shoulder level. Have the class call out the temperature, discussing until they agree on it.

   c. Have a third student record that temperature in the top row of the table on the board.

   d. In the "ice" container, have students measure and record temperatures at these 2 locations:

      - Level with top of container, over its center (see photos)
      - Inside container, about 1 mm above surface of ice (not touching ice/water). If the thermocouple touches the ice/water, you'll know because the temperature will changes very fast. Just dry it off and try again.



   e. In the "boiling" container, do the same thing. (It may be hard for the class to decide what the temperatures really are because the air above the water should be very turbulent. That's OK.)

   f. Now complete the table. See the example below.

      - For each container, is the temperature 1 mm above the ice/water "warmer" or "colder" than the temperature at the top of the container?
      - How would you describe what the air is doing above the two surfaces? Use pairs of "contrast" words, such as *quiet* vs. *wild*, *still* vs. *busy*, *unmoving* vs. *moving, or peaceful vs. turbulent*.

- For each container, would you call the air above the ice/water surface *stable* or *unstable*?
- Explain: If the air is stable, there is an *inversion* present. That is, the usual pattern of warm air on the bottom and cooler air on top is now upside-down, trapping the cold air at the bottom. That's how smoke can get stuck and make the air murky and hard to breathe. The same thing can happen with dust and automobile exhaust on winter days.

Here is an example of the information that should be in the table when you're done:

Classroom temperature (°C): 20		
	Ice	Boiling water
°C, level with top of container	19	25
°C, inside container, 1 mm above ice or water	7	83
Is the air right above ice/water surface warmer or colder than air above?	colder	warmer
Describe the movement of the air right above the ice/water surface:	still dull peaceful etc.	wild crazy turbulent etc.
Air right above the water: stable or unstable?	stable	unstable
Inversion present?	yes	no

g. Ask: What conditions might keep the surface air from rising and thus create an inversion? Clouds may block the incoming sunlight. In winter, the ground may be covered with snow that reflects sunlight instead of absorbing it. In summer, the smoke from a fire may be too dense to let sunlight through.

h. Review and summarize: Air heated by the earth's surface rises and is constantly replaced by cool air flowing down from higher elevations. These forces keep the air in motion, so we call the atmosphere *unstable*. If the earth's surface is too cold to heat the air on the ground, the dense valley-bottom air cannot rise; it is trapped. Then we call the atmosphere *stable*, because air will not begin moving until the surface air warms up or is disturbed by wind. We call this condition an *inversion*, because the usual temperature gradient (warm below, cold above) is upside-down.

7. **Return to** PowerPoint ***M09-1_SmokeAndHealth.pptx,* slides 5-11**, which illustrate the effect of smoke on visibility. They show a single viewpoint with different amounts of smoke.
   - Slide 6 explains the metric used to measure air quality: micrograms/cubic meter ($\mu g/m^3$) is the weight of smoke particulates of a certain size (and smaller) in a specific volume of air. PM10 is the weight of particulates 10 micrometers across or smaller. PM2.5, which students will use in the assessment, is the weight of particulates 2.5 micrometers across or smaller.

- Slide 11 is a summary of slides 5-10. It shows the changes in visibility with 5 vs. 90 μg/m^3 of PM10.

8. Ask: How does very smoky air affect us? It obviously reduces visibility, but it also gets into our lungs, where it interferes with our ability to absorb oxygen and release carbon dioxide – making it harder to breathe.

9. Ask what else may be affected by smoke. Students may say animals, soil, plants. When students mention plants, explain: Seeds can be affected by smoke. Some types of seeds *germinate* better after being exposed to smoke. In the western United States, several plants have *dormant* seeds that germinate more readily after being exposed to smoke. Examples include big sagebrush, antelope bitterbrush, and basin wildrye. Other plants that germinate well after smoke include 2 garden vegetables - lettuce and celery. Scientists don't know the exact reasons why some plants germinate well after exposure to smoke.

10. Explain: While smoke might be good for some seeds, it's not good for us. Medical experts have provided guidelines for outdoor recreation to help us humans protect our lungs from smoke. Give each student a copy of **Handout M09-1: Cancel a Sports Event?**

11. Have students read the guidelines on the handout. Discuss how the air quality in the final photo of the PowerPoint presentation would be rated ("very unhealthy," since you can faintly see the ridge 7 km away, and the peak 17 km away has almost disappeared). Decide together if plans for various sports events should be changed. Include indoor as well as outdoor sports so they get the idea that indoor sports need not be restricted.

Assessment:

1. Pair off. One of you be the school nurse, the other be a coach for a sports team. (You get to pick the sport.) You know that two members of the team have asthma. You look out the window together, and you can just barely see the top of a hill 7 kilometers away. Talk the situation over and decide what to do about today's after-school practice. Make sure you decide if your asthmatic team members should do anything differently from the rest of the team.

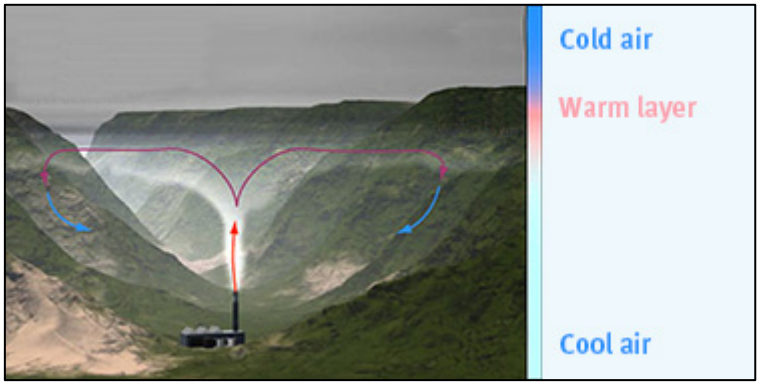
2. Together, report to the class:

   - what sport you were discussing
   - what activity levels the handout recommends for the amount of smoke in the air
   - what you decided to do about practice and why – including any special instructions for students with asthma

Evaluation:

Full Credit	Partial Credit	Less than Partial Credit
-Students identified the sport they discussed and whether it is indoor (like swimming or basketball – and not likely to be affected by smoke) or outdoor. -Students used recommendation from handout to explain that visibility of 7 km fits in the **unhealthy** health effect category -Students decided to postpone or delay or shorten time for outdoor practice or to move practice indoors, and students decided that athletes with asthma would not participate in outdoors practice.	-Students identified the sport they discussed -Students used recommendations from handout but used the wrong health effect category or did not show understanding of health effects of smoke. -Students made appropriate decisions for the health effect category chosen but did not identify special instructions for athletes with asthma.	-Students identified the sport they discussed -Students did not use recommendations from handout. -Students did not indicate a general understanding of the correlation between sports practice, smoke levels, and health.

Handout M09-1: Cancel a Sports Event?



This diagram shows pollutants from an industrial smokestack being trapped by an inversion (from https://www.qld.gov.au/environment/pollution/monitoring/air-monitoring/meteorology-inversions/).

Recommendations for Sports Events during Wildfires[9]

Health Effect Category	μg/m³ of PM10 or PM2.5	Visibility*	Recommendation
Good	Up to 19	21 km or more	Hold outdoor sporting events as usual. Athletes with asthma should keep rescue inhalers handy.
Moderate	19 to 51	8 to 21 km	Hold outdoor sporting events as usual, but athletes with asthma or other respiratory illness should limit outdoor activity and stop if they start having trouble breathing.
Unhealthy	51 to 115	3.5 to 8 km	Consider postponing outdoor sporting events, especially high exertion activities like soccer and track field. If possible, move practice indoors.
Very unhealthy	115 to 195	2 to 3.5 km	Consider postponing all outdoor sporting events. Move all practices indoors. Everyone should avoid prolonged outdoor exercise.
Hazardous	More than 195	Less than 2 km	Cancel all outdoor sporting events or relocate indoors. Move all athletic practices indoors.

*Visibility: How far can you see? To figure this out:

1. Face away from the sun.
2. Look for landmarks at a known distance from you.
3. If you can't see a landmark, then you know that visibility is less than that distance.

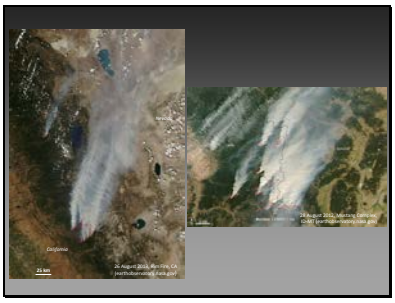
[9] Based on "Decision making recommendations during wildfire season for Outdoor Sporting Events" and "Draft Missoula County Wildfire Smoke Emergency Episode Avoidance Plan" dated 7/20/2009, by the Missoula City-County Health Department, Missoula, Montana (http://www.co.missoula.mt.us/airquality/pdfs/2009EEAP.pdf). These guidelines are adapted from more general ones provided by the National Incident Information System (http://inciweb.nwcg.gov/photos/OKCHP/2014-12-21-0939-Chickasaw-NRA-RXfy2015/picts/2015_01_22-08.19.09.768-CST.pdf).

Slides and notes for PowerPoint *M09-1_SmokeAndHealth.pptx*

Slide 1

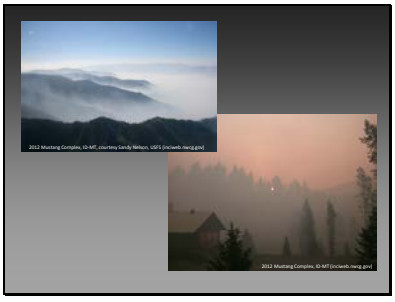
We've measured the shape of the heat plume from small fires, and we've watched the smoke from our classroom experimental fires. Here are photos of smoke from wildland fires. Where does the smoke usually go? (Up, and then in the same direction as the wind. It also stays around the base of the fire where it is being produced.)

Slide 2



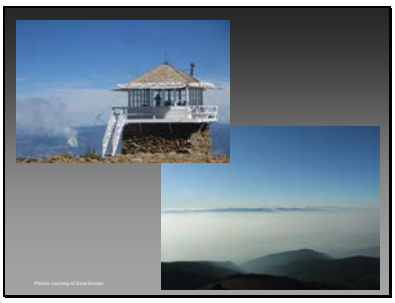
Smoke doesn't just disappear into the air. Satellite photos show that it can travel a long way. Discussion: Use the 25-km scale on the left photo to figure out how wide the smoke plume is (50-75 km) and how far it has traveled (at least 300 km). Think of some towns or other landmarks that are that far away.

Slide 3



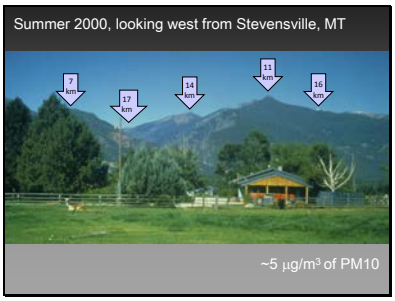
Smoke sometimes settles down near the ground and stays there for days or even weeks. This might be smoke from a fire nearby, or it could be smoke from fires hundreds of miles away.

Slide 4



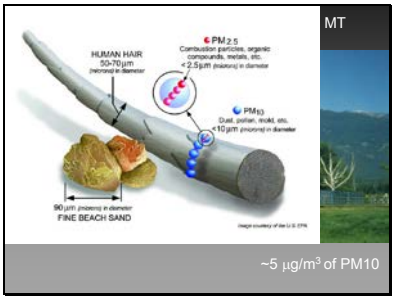
Here are two contrasting views, looking eastward from St. Mary Lookout, Bitterroot National Forest, MT. Top: Summer 2013. Smoke disperses upward from a fire in the valley, then drifts northward. Bottom: Smoke has settled into the valley overnight. Now it keeps sunlight from reaching the valley floor, so the air above the smoke layer is warmer than in the valley. The smoke is trapped in the cold, heavy, dense valley air.

Slide 5



Let's see how smoke can affect visibility. The arrows show how far away various mountain and ridge tops are.

Slide 6

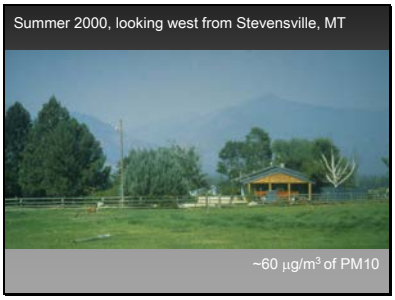


What is that number at the bottom of the slide – ~5 micrograms/m^3 of PM10 ? It is a way of measuring the concentration of particulates in the air and is read "micrograms per cubic meter of particles less than 10 micrometers in diameter". Whew! That's a long name for a very, very small thing. This diagram shows how big 10 micrometers are in relationship to the size of a human hair. We use PM2.5 (particles less than 2.5 micrometers in diameter) more often than PM10 because the smaller particles, though less visible, cause more damage to human lungs.

Slide 7

Slide 8

Slide 9

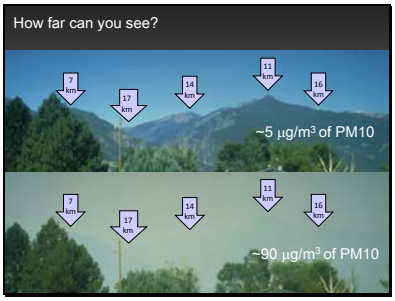


The farthest mountains have nearly disappeared.

Slide 10

Now the far mountains have completely disappeared, and the near ones are very hard to see.

Slide 11



The arrows show how far away the mountains and ridges are in clean air and unhealthy air.