Ice Storm Learning Module

Figure 1. Images from an ice storm in Arkansas in 2009.
Source

In the United States there are over 1.4 million car accidents each year that occur due to freezing precipitation. From these accidents, there are over 600,000 injuries and 7,000 deaths. Freezing precipitation is responsible for about 20% of all weather-related fatalities, and thus it is abundantly clear why we must learn how freezing rain forms in winter low pressure systems [1]. Our goal in this learning module is to first uncover the meteorology of ice storms and then discuss winter storm safety.

Introduction

The National Weather Service will issue a freezing rain warning on the forecast of **at least ¼ inch accumulation of ice**. Aside from making automobile travel treacherous, ice is extremely heavy when it accumulates on trees and power lines. In fact, a ½" coating of ice on a single, standard length (300 ft) power line in a residential area can add nearly 300 lbs of weight. Put an inch of ice on the same power line and you will add 800 lbs! It is easy to see why the power lines are down in the images in Figure 1. As an interesting side note, at the University of Illinois all power lines are buried beneath the ground to protect the university's power infrastructure in the event of a major ice storm.

Before we dig into the meteorology behind an ice storm, let's take a few minutes to learn some important facts about ice.

1. Liquid water is more dense than ice. This is why ice floats in a glass of water.
2. When you look at the molecular structure of ice, each ice crystal always has 6 sides. This means that all ice crystals are hexagonal.
3. Ice will melt when its temperature is raised above 32°F (0°C). However, liquid water can remain a liquid at temperatures far below 32°F (0°C). In fact, pure water can remain in its liquid phase at temperatures as cold as -40°F (-40°C)!

Created by Tyra Brown, Nicole Riemer, Eric Snodgrass and Anna Ortiz at the University of Illinois at Urbana-Champaign. 2015-2016. Supported by the National Science Foundation CAREER Grant #1254428.

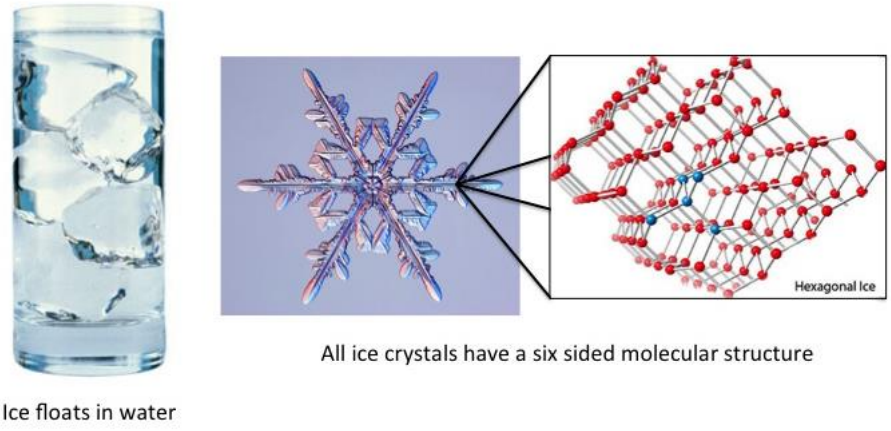


Figure 2. Ice floating in a glass of water, an ice crystal, and a molecular diagram of ice.

Supercooled Water

As we learned, it is possible for water to remain a liquid even though its temperature has fallen below 32°F (0°C). This is a key concept in understanding how the atmosphere can produce an ice storm so let's spend some time understanding how water can supercool.

In order for water to freeze, it needs something to freeze upon. In the atmosphere, impurities in the air like dust, serve as an excellent surface which water is able to freeze upon. If there are not enough of these impurities, the liquid water in clouds can actually remain a liquid even though the temperature of the cloud is below freezing! To see what this looks like, watch the videos below.

Supercooled Water Demonstration (0:44)

Supercooled Water in a Bowl (1:07)

Water Freezes in a Water Bottle (0:14)

Figure 3. An image of supercooled water turning into ice as it is poured into a glass.
Source

Video Lecture Notes

- Ice will always melt at temperatures above 32°F (0°C), but liquid water may remain a liquid at temperatures below 32°F (0°C).
- Supercooled water is defined as liquid water that has a temperature below 32°F (0°C). Water can remain a liquid in the atmosphere at temperatures as cold as -40°F (-40°C).
- All ice crystals are 6-sided at the molecular level.
- Liquid water needs help becoming ice and it gets that help from ice nuclei.
- **Ice nuclei** are impurities in the atmosphere that serve as a site onto which liquid water can become locked into the ice phase if the temperature is below freezing.
- Ice nuclei are rare in the atmosphere and they are only effective at turning liquid water into ice at temperatures below -15°C. Without ice nuclei, liquid water will remain a liquid at temperatures as low as -40°C. This means that a significant portion of the water in the atmosphere is supercooled.

Ice Storms

In the videos and the picture above, you can see that as soon as the water splashes into a container, it freezes on contact. As it turns out, this is exactly what happens in an ice storm! Let's investigate how ice storms form within wintertime low-pressure systems so we can see how the atmosphere is able to recreate the same processes to create a freezing rain weather event. Ice storms typically form just north of the warm front in a wintertime low-pressure system [1]. To see this explained visually, watch the following video:

Ice Storms along a Warm Front (2:15)

On the weather map below, the warm front is indicated with a red line and red half circles extending to the east of a low-pressure system. Along this front, warm air from the Gulf of Mexico moves northward and overruns a colder wedge of air that is retreating to the north (see cross-section). Recall, cold air is more dense than warm air and tends to sink toward the ground. As this warm air slides over the top of the colder air, the perfect situation is set up to make a band of freezing rain.

There are two criteria needed to form a freezing rain or ice storm:

1. The air near the ground needs to have a temperature below freezing. This layer of the atmosphere is called the **surface sub-freezing layer**.

2. The air immediately above the surface sub-freezing layer must have a temperature above freezing. This layer of the atmosphere is called the **melting layer**.

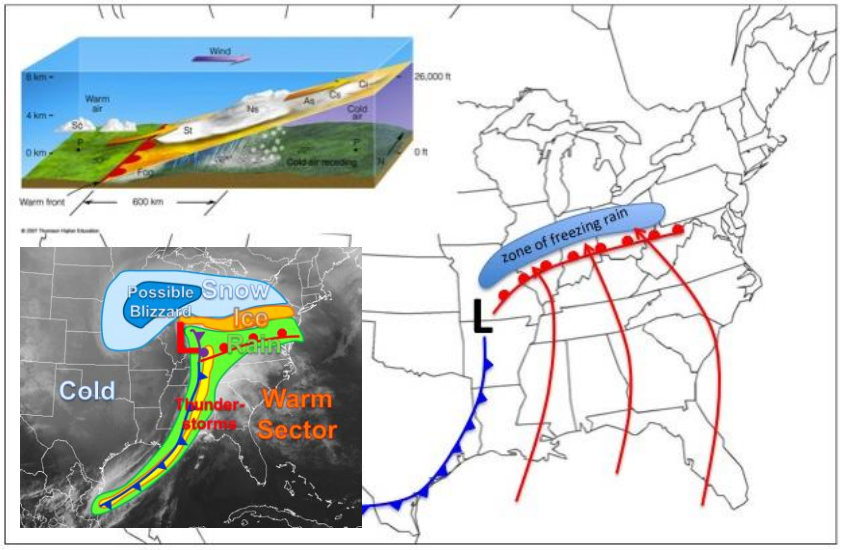


Figure 4. A wintertime low-pressure system over the central U.S. showing the position of the warm and cold front. Upper left – A cross-section of a warm front where warm air overruns cold air at the surface. Bottom left – The typical locations and types of precipitation in a wintertime low-pressure system.
Source

Freezing Rain

The band of freezing rain found north of the warm front is typically about 100 km wide and 500+ km long. If we were to look at a vertical profile of the atmosphere in the middle of the freezing rain band, it would look just like the figure on the next page. As warm air rises over the cold air, snow is produced in the clouds. As this snow falls, it enters into "melting layer" and melts into liquid rain. Once the raindrop falls out of the melting layer it eventually passes through the "surface sub-freezing layer." In this layer, the drop will supercool to a temperature below freezing and hit the ground as a raindrop that freezes on contact with the ground [4].

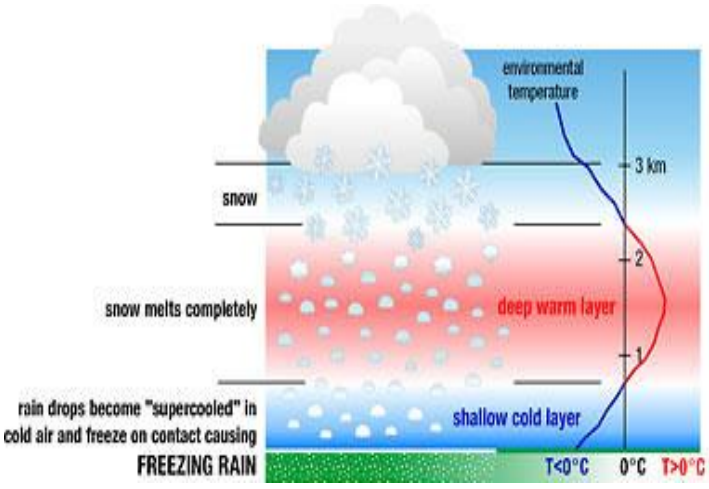


Figure 5. Freezing rain formation near a warm front.
Source

Precipitation Types

Atmospheric soundings can be very useful in determining the type of precipitation that will occur at the ground. In Figure 6, the four types of precipitation that can occur in a wintertime low-pressure system are described. As you can see, cold clouds in wintertime storms produce snow in the upper atmosphere. The precipitation type at the surface depends on the vertical air temperature profile [4].

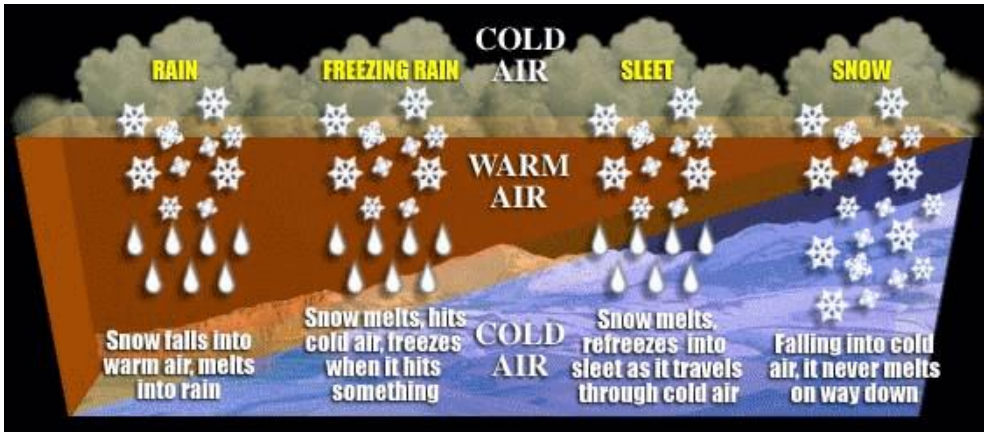


Figure 6. Precipitation types based on the vertical air temperature profile in wintertime storms.
Source

Meteorological Instruments

In winter, meteorologists are constantly searching for where the conditions come together to make an ice storm [3]. The most powerful tool at their disposal is the **weather balloon** because it can trace the vertical profile of air temperature in the atmosphere and reveal if the two criteria are present in a wintertime low-pressure system. **Rawinsondes** are sophisticated instrument packs that are attached to helium-filled weather balloons that can radio back information about the vertical temperature profile of the earth's atmosphere as they ascend.

Weather Balloons (4:21)

How to Read a Sounding (0:00-4:22)

Figure 7 shows rawinsonde data displayed on a sounding diagram. A sounding shows the vertical changes in temperature and dewpoint temperature. On this diagram, temperature is shown in degrees Celsius on the x-axis and pressure (and height) is shown on the y-axis in millibars (and kilometers). Recall, temperature and pressure typically decrease with increasing height in the atmosphere. The surface is at the bottom of the sounding near 1000 mb and at approximately 100 mb is the top of the troposphere, where the rawinsonde stopped recording data. As the rawinsonde ascends in the atmosphere, it records the air temperature (right, blue line) and dewpoint temperature (left, black line). When the temperature and dewpoint temperature line lie on top of one another (Temperature = Dewpoint Temperature), the weather balloon passed through a cloud!

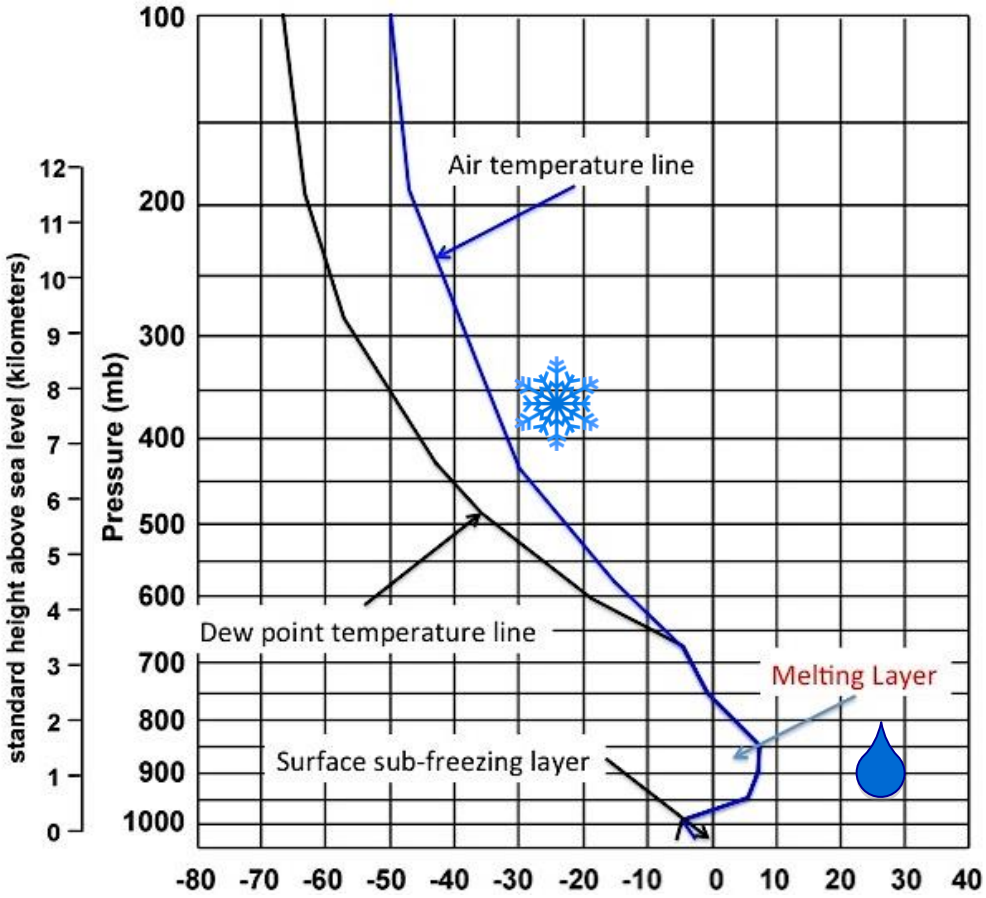


Figure 7. Air temperature and dewpoint temperature data collected from a rawinsonde displayed on a sounding diagram when conditions are favorable for an ice storm. Temperature is shown on the x-axis where 0 degrees Celsius represents the freezing line [4].

Source

Ice Storms & Soundings

If the weather balloon data shows a melting layer above a surface sub-freezing layer, like that shown in Figure 7, meteorologists watch for freezing rain conditions to develop. If the National Weather Service forecasts ¼ inch of freezing rain to form, they will issue an **ice storm warning**.

There are three things that we will look for on an atmospheric sounding to see if conditions are favorable for an ice storm:

1. The air temperature is below freezing when the blue line is to the left of 0°C, for example, between 750 mb and the top of the troposphere (100 mb). Precipitation within this cold layer of the atmosphere would fall as snow.

2. The air temperature is above freezing when the blue line is to the right of 0°C, for example, between 975 – 750 mb. This layer is referred to as a melting layer where frozen precipitation falling from above would melt into liquid rain.

3. The temperature is also below freezing between the surface (1010 mb) and 975 mb. This layer is called the surface sub-freezing layer and would cause liquid rain falling from the melting layer to supercool and freeze upon contact with the ground.

Ice Storm Safety

Heavy accumulations of ice can bring down trees and topple utility poles and communication towers. Ice can disrupt electricity supply for days while utility companies repair extensive damage. In the case of an ice storm, it is important to have batteries and flashlight, candles and matches, non-perishable food, and plenty of water in your home.

Even small accumulations of ice can be extremely dangerous for driving and walking. Bridges and overpasses are particularly dangerous because they freeze before other surfaces. If you must travel during an ice storm, it is important to have food, water, and blankets in the car with you. Stay off of the roads when advised and make sure your cell phone is fully charged.

An example of how dangerous driving during an ice storm can be, watch this video of an ice storm in Portland, OR.

Portland Ice Storm (2:21)

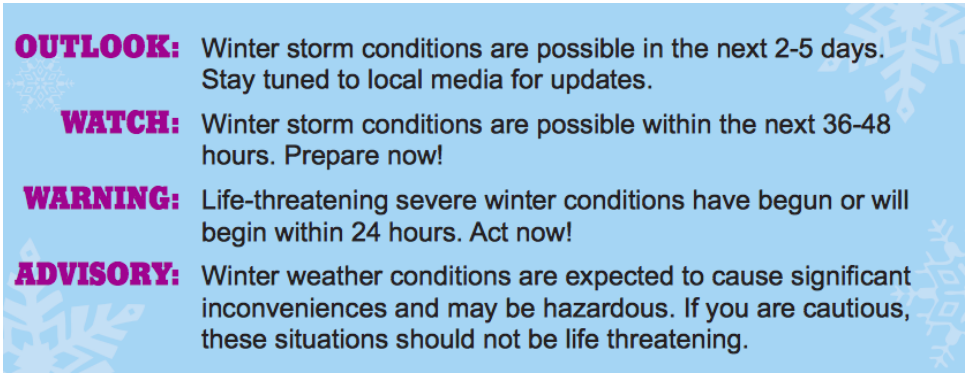


Figure 8. Criteria by which the National Weather Service distributes winter storm safety warnings.
Source

Pre-Class Activity 1, 2, 4, 5

Instructions: Before teaching about ice storms, have the students answer the questions below, followed by the scenario question for in-class discussion between you and your students.

1. Liquid water can exist below freezing (32°F / 0°C). True False

2. Freezing rain and sleet form through the same processes. True False

3. Temperature always decreases with increasing altitude. True False

4. Ice storms typically occur near
    a. a high pressure system.
    b. a cold front.
    c. a warm front.
    d. the ocean.

5. What is the name of instrument that is attached to a weather balloon to measure the vertical temperature profile of the atmosphere?
    a. Radar
    b. Satellite
    c. Radiometer
    d. Rawinsonde
    e. Barometer
    f. Rain gauge

Discussion Question: The atmosphere can produce several types of precipitation in a wintertime storm such as rain, freezing rain, sleet, and snow. How is this possible? Which weather variable that you have learned about in previous learning modules is the most important for predicting the type of precipitation that will fall at the ground?

In-Class Activity

Severe Weather Situation: Ice Storms

In this project, your group will forecast and prepare for a major winter storm that is capable of producing an ice storm. Each group member will choose one of the following roles and complete the tasks written at the end of each section.

1. Meteorologist
2. Homeowner
3. Electric Operations Manager
4. City Mayor

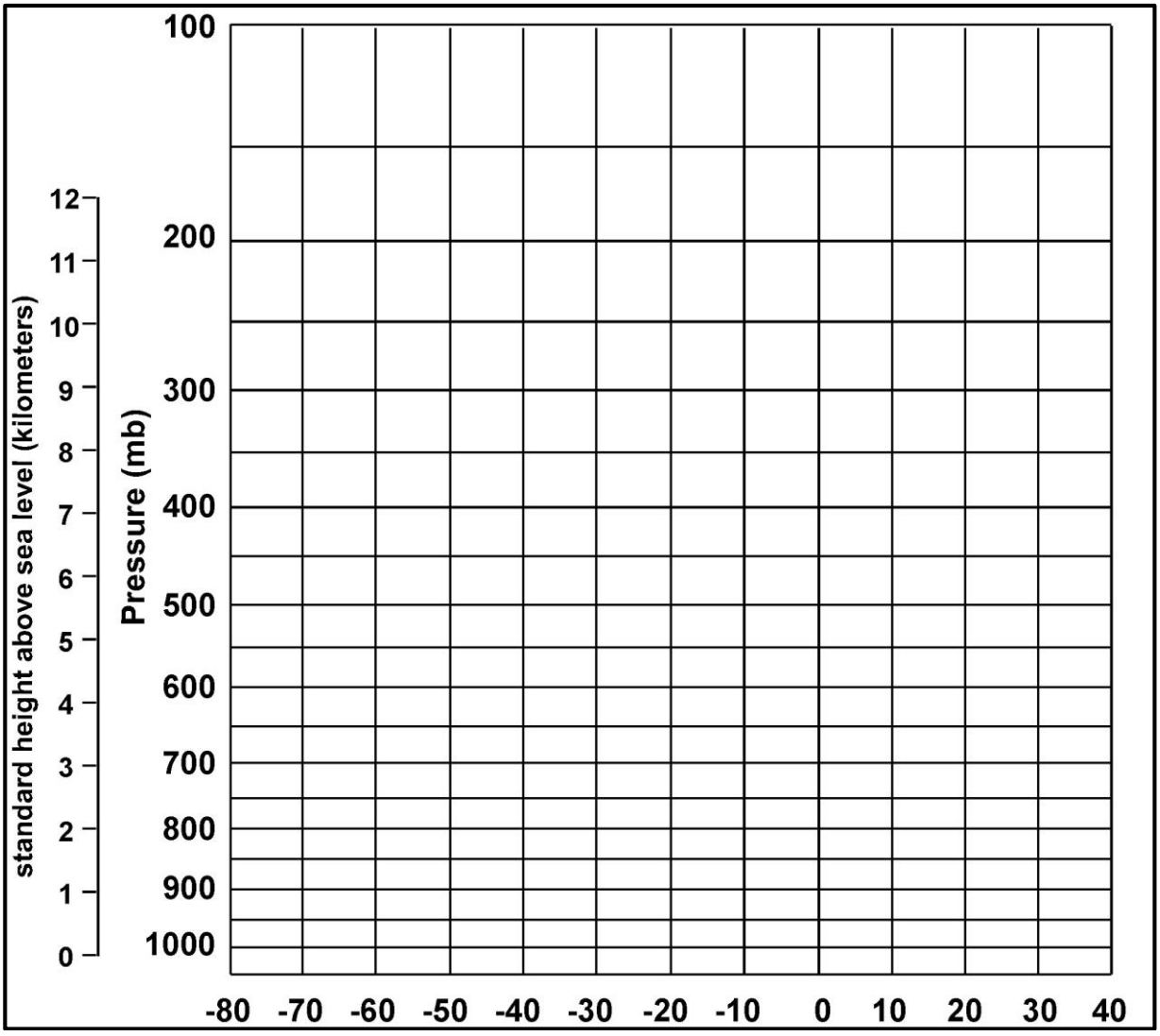
Real World Application: The Meteorologist [1]

Task #1

In mid-December 2007, a low pressure system developed east of the Rocky Mountains in the Panhandle of Texas that produced a major ice storm across central Oklahoma. Your first task as meteorologist is to draw on the blank map of the U.S. below, the position of the low pressure center (L), warm front (red line), and cold front (blue line) as they would appear for an ice storm to develop over central Oklahoma. Once you have these fronts in place, shade in the area where a band of freezing rain would form.

Task #2

If you were to launch a weather balloon into this ice storm, what might the vertical profile of the air temperature look like? On the sounding diagram below, draw this profile and label the air temperature line, surface sub-freezing layer, and melting layer.



Task #3

As a meteorologist, it is important that you learn to properly convey weather information to the general public. Your task is to create a 5-minute weather broadcast, like you might see on the Weather Channel, describing how an ice storm forms. Remember that your classmates will not know much about what you have just learned so be sure to address the following topics in your broadcast:

1. Convey statistics about ice storms in the U.S. (fatalities, car crashes, etc.)
2. Share some of the facts about water
3. Explain what supercooled water is and how it forms.
4. Explain where ice storms form in a low pressure system.
5. Define an ice storm warning from the NWS and issue your warning for this case.
6. Explain the "melting layer" and "surface sub-freezing layer"
7. Show your maps/diagrams from "Task #1" and "Task #2"
8. Show pictures from this event, which can be found at ***NWS Photos***

Build this weather broadcast using presentation software (like PowerPoint) and be sure to supplement everything you discuss with images and videos. Your teacher has access to several videos and pictures of ice storms so make sure to use your teacher as a resource as well as the Internet. Be sure both informative and entertaining!

December 10, 2007 Ice Storm in Oklahoma
Source

Real World Application: Homeowner

Discussion Questions

1. You are sitting in your living room watching TV, and a winter storm warning has just been issued for Norman, OK by the National Weather Service on the news. What resources should you gather to prepare yourself and your home for the storm over the next few days?

2. An ice storm is expected to affect your area for 2-3 days causing power outages across Oklahoma. It is a good idea to go to the store to gather supplies you might not otherwise have in your house. What items do you buy to prepare to not have power for several days?

3. You are a doctor at a nearby hospital and cannot miss a day of work. An ice storm is issued for the next few days and you are scheduled to work. You must decide what the best way of transportation to get to work safely is. If you decide to drive in the ice storm, what kind of clothing, supplies, and precautionary measures do you take to ensure your safety?

Task

Based on your ideas from the above discussion questions, create a survival plan for your home in order to prepare beforehand, appropriate actions to take during an ice storm, and deal with the aftermath. Things to consider:

- You may not be able to leave your house during the storm or immediately afterwards
- The resources you will need while you are stuck in your home
- The potential for a power outage, frozen pipes, etc.
- Proper maintenance of sidewalks and driveways
- Possible damage caused by the storm, such as downed trees or branches on your property
- Clean-up of ice and tree branches

Icing and tree damage in Moore, OK on December 10, 2007
Source

Real World Application: Electric Operations Manager

Discussion Questions

1. You are the operations manager for a major electric supply company in Oklahoma. There are over 100,000 homes and businesses without power. Because driving is very hazardous during the storm, you cannot send employees out to safely return power to your customers. As the manager, you are receiving phone calls with complaints.

    a. Do you send out employees to return power regardless of the road conditions?

    b. What is your plan once the roads are safe to travel on and how do you explain this to the unhappy customers?

2. After the storm, there is high demand to get power back up and running as quickly as possible. It is your job to ensure that you have enough employees, and that you keep them both safe and satisfied.

    a. How will you prioritize *when* and *where* to dispatch your employees, and why?

3. What actions will you take to ensure your business's recovery and customer satisfaction?

Task

As the electric operations manager, your employees have to be out on the road during and after the blizzard. Create a company plan for ice storms to ensure your employees' safety and customer satisfaction. Assume some employees will encounter treacherous driving conditions during and after the storm. Things to consider:

- Hypothermia
- Hunger
- Dehydration
- Not being able to see in the dark
- Potential car problems
- Blocked roads from fallen trees

Real World Application: City Mayor of Norman, OK

Discussion Questions

1. You are the mayor of Norman, OK and the National Weather Service has just informed you of an ice storm expected to last 2-3 days.

    a. What guidelines and suggestions should you give to your citizens, and how are you going to communicate this information?

2. Emergency services such as hospitals and police officers will need to be available to the citizens during and after the ice storm.

    a. How will you make sure that these services will be kept up and running, in spite of limited people and resources due to poor road conditions?

3. Consider now that the ice storm has passed, and many frustrated citizens have contacted you about various problems, such limited accessibility to roadways due to downed trees. Many city employees have been working overtime to maintain the city roads and cleanup.

    a. Given the situation, what can you do to please the citizens and properly compensate city employees?

Task

You have been asked to be interviewed by a local news station. Prepare a skit that you will present to your class. Brainstorm creative ideas as group, and then select two students to act out the skit. One student will act as the interviewer and ask the mayor questions, and another student will act as the mayor and respond to the questions. Things to consider:

- How the mayor kept citizens informed
- Ice cleanup, road maintenance, and tree removal on roadways
- Damage to the city's infrastructure
- Monitoring city resources such as electricity

Take Home Assignment

Part 1. Multiple Choice (Circle One) 2, 4

1. When pure water remains in its liquid form below freezing temperatures, it is called
    a. sleet
    b. supercooled
    c. sub-melting
    d. snow
    e. ice

2. A warm front occurs when
    a. warm air overruns cold air
    b. warm air overruns more warm air
    c. cold air overruns warm air
    d. warm becomes more dense than cold air

3. In order for freezing rain to form, which of the following is not necessary?
    a. A low pressure
    b. A melting layer above the surface
    c. A surface sub-freezing layer
    d. Blizzard conditions
    e. Falling supercooled water

4. Which two devices are used to measure the vertical temperature profile of the atmosphere?
    a. An airplane and barometer
    b. An airplane and anemometer
    c. A weather balloon and barometer
    d. A weather balloon and rawinsonde
    e. A thermometer and barometer

5. Which of the following will the National Weather Service issue if an ice accumulation is forecasted to exceed ¼ inch in the next 24 hours?
    a. Freezing Rain Outlook
    b. Freezing Rain Watch
    c. Freezing Rain Warning
    d. Freezing Rain Alert

Part 2. Winter Weather [6]

Instructions: Visit the National Weather Service homepage and answer the following questions.

NWS Homepage

The map is shaded according to current watches, warnings, and advisories followed by a listing of each and its location. Using the legend of colors below the map, answer the following questions. You may click on the links or locations on the map for more information.

1. Are there currently any Freezing Rain Warnings in the United States?

2. If so, in which states are they occurring?

3. Click on the Freezing Rain Warning link below the map and read the first entry. Summarize the report and the weather conditions that are expected for that region.

   Location:

   Weather Conditions:

4. Choose a location where a winter weather event is occurring (Freezing Rain Warning, Winter Storm Warning, Freeze Warning, Winter Weather Advisory, or Winter Storm Watch). Click the map to zoom in, and then again to get the exact location's current weather conditions. Record the following for that location:

   Location:

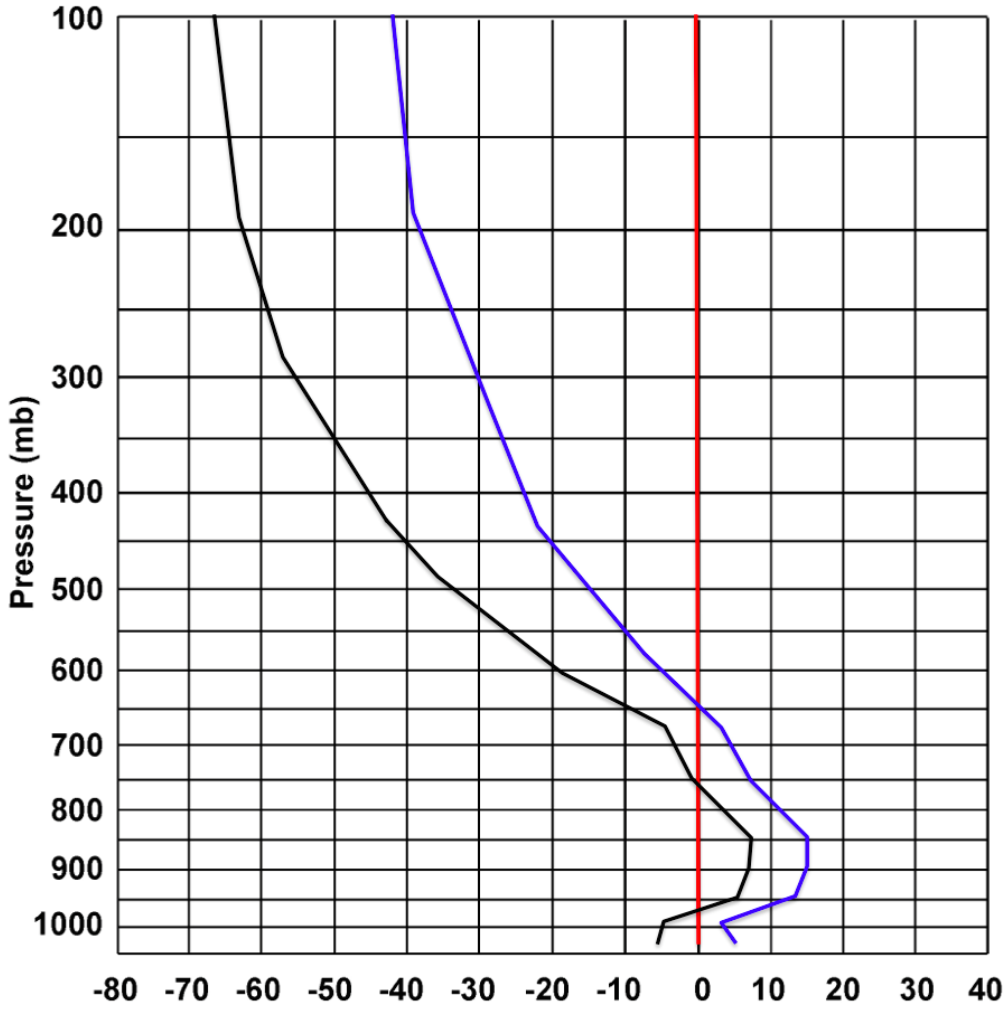
   Temperature:

   Wind Speed:

   Precipitation/Cloud Cover:

Part 3. Atmospheric Soundings 2, 6

Instructions: Using the following sounding to answer the questions below. Temperature is shown on the x-axis in degrees Celsius and the pressure is shown in millibars. The blue line represents the air temperature. The black line represents the dewpoint temperature. The red line represents the freezing line (0 ^{o}C).



1. What is the name of the instrument pack that records the vertical temperature profile?

2. At what pressure level does the sounding begin?

_____ mb

3. What is the air temperature at 650 mb?

_____ ^{o}C

4. At which pressure level does the air temperature equal -30 ^{o}C?

_____ mb

5. Is there a melting layer on the sounding? If so, circle it and label it on the sounding.

Yes No

6. Is there a surface sub-freezing layer? If so, circle and label it on the sounding.

Yes No

7. Is this sounding favorable for freezing rain?

Yes No

8. If not, what type of precipitation would expect to fall at the surface?

a. Snow b. Sleet

c. Rain d. I expect freezing rain to fall

Student Evaluation 2, 4, 5

Instructions: After completing the lesson on ice storms, please have the students answer the following questions below.

1. Which of the following is not true about supercooled water?
    a. Supercooled water is liquid water that exists at temperatures below freezing.
    b. Supercooled water is pure water that occurs in the liquid state below 32^{o}F.
    c. Supercooled water requires a surface or impurity to freeze upon.
    d. Supercooled water can occur in clouds below -60^{o}C.

2. A band of freezing rain occurs _____ with respect to the center of wintertime low pressure system.
    a. behind the warm front
    b. behind the cold front
    c. north of the warm front
    d. north of the cold front

3. Freezing rain requires
    a. wind speeds that exceed 35 mph
    b. a warm melting layer above the surface
    c. surface temperatures below freezing
    d. a surface to freeze upon

4. A freezing rain warning is issued by the NWS when
    a. freezing rain occurs for more than 6 hours.
    b. freezing rain, sleet, or snow occurs for more than 24 hours.
    c. an ice accumulation is forecasted to exceed ¼ inch.
    d. an ice accumulation is forecasted to exceed 0.01 inch.
    e. all of the above

5. Liquid water is less dense than ice. T F

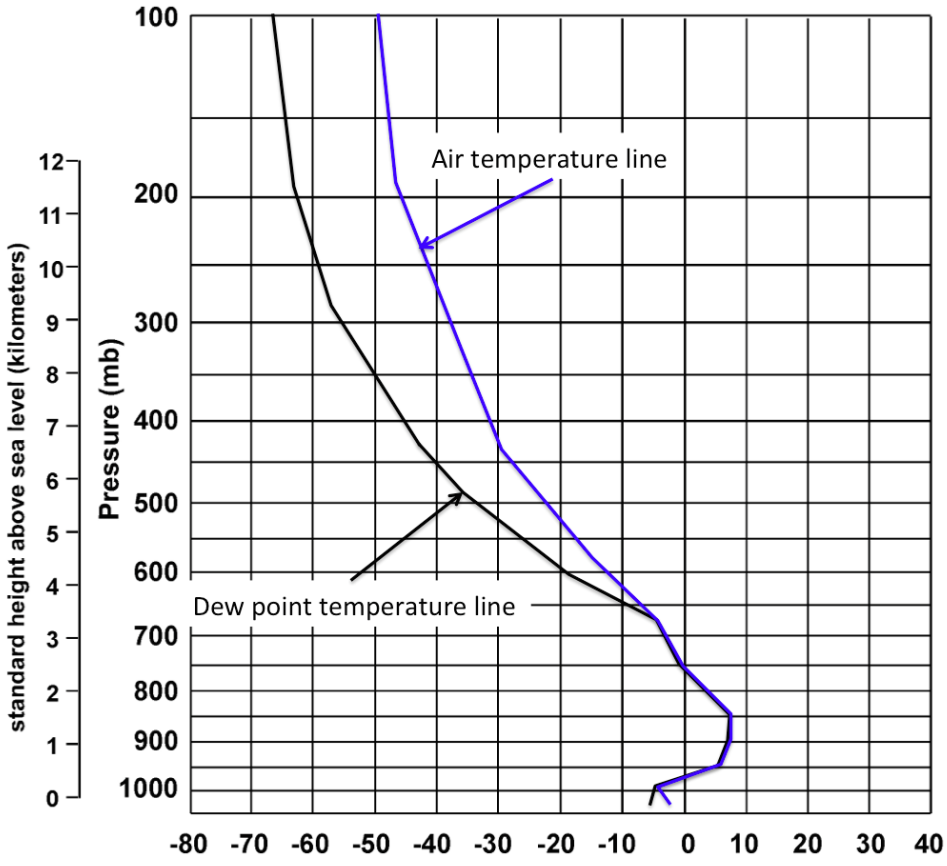
6. The molecular structure of ice is hexagonal. T F

7. Pure water is able to remain a liquid at temperatures below freezing. T F

8. Dust is an excellent surface by which water is able to freeze upon. T F

9. Briefly describe the difference between sleet and freezing rain. How does each type of precipitation form?

10. What is the difference between the air temperature and dewpoint temperature at the surface?



a. 0 ºC
b. 4 ºC
c. 10 ºC
d. 15 ºC

Common Core State Standards (CCSS) Initiative
To learn more, visit http://www.corestandards.org

Next Generation Science Standards (NGSS)
To learn more, visit http://www.nextgenscience.org

The following standards are met in this learning module:

1. **NGSS.MS-ESS2.5**

MS-ESS2-5. Weather and Climate
Provide evidence for air pressure systems and resulting weather conditions.
Lecture: Introduction & Ice Storms; Pre-Class Activity; In-Class Activity: Meteorologist

2. **CCSS.ELA-LITERACY.RST.6-8.4**

Grade 6-8: Science and Technical Subjects
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific science or technical context relevant to grades 6-8 texts and topics.
Lectures: Bolded text; Pre-Class Activity; Student Evaluation; Take Home Assignment: Part 1 & 3; Student Evaluation

3. **NGSS.MS-ESS3-2**

MS-ESS3-2. Human Impacts
Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.
Lecture: Meteorological Instruments

4. **NGSS.MS-ESS2-5**

MS-ESS2-5. Weather & Climate (DCI ESS2.C)
The complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns.
Lecture: Freezing Rain, Precipitation Types & Meteorological Instruments; Pre-Class Activity; Take Home Assignment: Part 1; Student Evaluation;

5. **CCSS.ELA-LITERACY.RST.6-8.8**

Grade 8: Science and Technical Subjects
Distinguish among facts, reasoned judgment based on research findings, and speculation in a text.
Pre-Class Activity; Student Evaluation

6. **CCSS.ELA-LITERACY.RST.6-8.3**

Grade 6-8: Science and Technical Subjects
Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.
Take Home Activity: Part 2 & 3

7. **CCSS.ELA-LITERACY.RST.6-8.7**

Grade 6-8: Science and Technical Subjects
Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).
Video lectures