Chapter 14: Cold Waves

Teaching Tips

1. *Relate material to students' experience*

- Compare the coldest temperatures students have experienced with record low temperatures in your location and around the world.
- Have students recall the coldest conditions they have experienced. Do their assessments appear to be based on the actual air temperature, the wind chill, or some other factor?
- Provide students with "benchmark" temperatures against which the information in this chapter can be compared. These benchmarks can include the temperatures inside a refrigerator and a freezer, as well as the record low temperatures at their location. For further comparison, temperatures experienced by mountain climbers at various elevations in a standard atmosphere may be presented.
- Ask the students whether they, or any acquaintances, have ever experienced frostbite or hypothermia. What were the circumstances (air temperature, location, activity, etc.) that led to the cold-related injury?
- Have students consider the impacts of a record setting cold event at their location. What temperature range would likely be considered record setting for your location? Which devices used in their daily lives would be most likely to malfunction or become inoperative?

2. *Integrate current weather and significant events into classroom instruction*

- Access current weather information in the cold airmass formation regions of northern Canada and Siberia. Determine whether the current conditions are favorable for the formation of polar continental airmasses in these regions, i.e., are light winds and clear skies present? If not, examine NWP forecasts to see if such conditions are likely to develop.
- If the Cold Wave chapter is covered during the winter season, access current maps of wind chill temperature. (If the chapter is not scheduled for the cold season, save some cold-season wind chill maps for use with this chapter). Compare a wind chill map with the corresponding map of actual air temperatures. The difference between the two should indicate where the winds are strongest; confirm this by examining the wind reports or the sea level pressure map.
- During the current (or previous) winter, archive weather maps or other data from an actual cold wave in the central or eastern United States. Use this example to show which of the five factors listed in Chapter 14 were "contributors" to the cold waves.
- Examine soundings from a cold polar airmass, and deduce from these soundings the depth of the cold airmass. Does the depth vary among the stations within the airmass?

3. *Engage students in activities outside the classroom*

- Have students explore the impacts of cold waves on lifestyles of individuals that live in cold climates. How do people modify their lifestyles to deal with extreme cold during winter? Among the considerations are building and road construction, adaptation of automobiles and other outdoor equipment, special clothing to minimize physiological impacts, and other measures taken to prevent harm from extreme cold.

- Have students find the lowest wind chill temperature within a prescribed time period (e.g., a 24-hour period, specified in advance). Offer a reward or incentive to the student who finds the lowest confirmable value.

4. *Concepts requiring special attention*

- The cooling processes of near-surface air are often not well understood by students. The roles of horizontal temperature advection and subsidence can be placed into a framework of mechanisms by which extremely cold air forms and affects areas remote from the airmass formation region.
- The physical processes involved in heat loss from the skin may need elaboration. Distinguish the roles of conductive, radiative and latent heat losses, and indicate how each is affected by the wind speed.
- The shallowness of cold airmasses is often not appreciated by students. Use actual weather data, including soundings, to compare the horizontal and vertical extents of a cold polar airmass. Relate the vertical extent (depth) to tangible measures, such as the height of a familiar skyscraper, the elevation of mountains, or the elevations at which various types of aircraft fly.

Sample Lesson Plans

Suggested number of hour-length classes: 2

Class 1. Formation of cold waves

Primary objectives: Students should be able to:

→ identify the five key physical and dynamical processes contributing to cold air outbreaks in the central and eastern United States,

→ describe cold wave characteristics such as horizontal and vertical scales, intensity of cold, and relation to synoptic weather patterns, and

→ draw basic weather patterns that illustrate the evolution of cold waves affecting North America.

- Provide an overview of the learning objectives for today's class.
- Define "cold wave" and place cold wave temperatures in context with normal and extreme highs and lows for your local region.
- Formation of cold airmasses. Explain the physics of formation of cold polar airmasses and the conditions under which they occur.
- *Internet activity*: Use weather data to depict the horizontal and vertical structure of a cold polar airmass.
- Outbreaks of cold air into middle latitudes of North America. Introduce the five key meteorological factors leading to an extreme cold outbreak in North America east of the Rocky Mountains, emphasizing the roles of antecedent cyclones, winds, and snow cover.
- *Active learning: Exercise 14.2 – The Progression of a Cold Wave*. Helps students relate surface and upper level weather patterns during cold waves.
- *Take home activity: Exercise 14.3 – Cold Waves in North America*. Reviews basics of cold waves in a simple exercise.

Class 2. Wind Chill and Hazards of Cold Waves

Primary objectives: By the end of class students should be able to:

→ illustrate the evolution of cold waves using actual examples from North America and Europe (if Europe is covered by instructor),
→ describe cold's impacts on people in terms of wind chill and the physiology of cold,
→ explain how the polar vortex is related to cold air outbreaks, and
→ describe two ways in which future changes in global temperature can affect the occurrence of cold waves.

Note: Some instructors choose to limit the discussion to North America only. In this case, proceed to **Wind Chill.

- Review cold waves in North America by going over *Active Learning Exercise* 14.3 as a class.
- Extreme cold in Europe and Asia. Cold waves in Europe: provide an overview of geography of Eurasia, discuss the formation of Siberian airmasses, and the relation of cold waves to the atmospheric circulation over the North Atlantic.
- Define the North Atlantic Oscillation and provide examples of its two phases.
- Compare and contrast North American and European cold waves.
- *Internet activity*: current airmasses over Siberia
- **Wind Chill. Define, briefly discuss the origins and need for wind chill index, and work through examples of how to determine wind chill equivalent temperature.
- Provide an overview of the physiological aspects of cold, frostbite, and hypothermia.
- *Internet activity:* NWS Hazards Statistics website, examine recent distributions of cold-related fatalities
- Define cold wave warnings and advisories; discuss protective measures people can take to reduce the impacts of cold.
- *Active learning: Exercise 14.1 – Wind Chill Temperature*. Helps students become familiar with the wind chill chart.
- *Query the class*: Stimulate a discussion about society's changing vulnerability to extreme cold.
- Cold waves and global climate change. Emphasize links back to chapter 5 and the uncertainty around cold wave frequency and severity with global climate models.

ANSWERS TO QUESTIONS IN TEXTBOOK

CHECK YOUR UNDERSTANDING 14.1

1. What are the major impacts of cold waves?
   A. Loss of vegetation, damage to buildings and other infrastructure, human suffering including fatalities and injuries.

2. Why is the phrase "cold wave" used in connection with a cold-air outbreak?
   A. The "cold" portion refers to the unusually low temperatures and the "wave" references the wave pattern of upper atmospheric flow that creates the severe surface conditions.

3. What are three factors that favor the formation of the coldest airmasses over high latitudes?
   A. (1) long nights (2) light winds (3) clear skies, also strong inversions

4. What is a typical depth of a polar airmass?
   A. One to several kilometers

CHECK YOUR UNDERSTANDING 14.2

1. List factors that favor the intensification of an upper-air ridge over western North America.
   A. Warm air east of a strong cyclone over the Pacific flows northward, warming the lower troposphere and shifting the jetstream to higher latitudes. (2) the flow associated with strong cyclones originating east of the Rockies or along the East Coast transports cold air southward, deepening an upper-air trough over the eastern portion of the continent.

2. What is the most common wind direction at the jetstream level above a North American polar airmass?
   A. Northwesterly winds.

3. What is the channeling effect?
   A. The enhancement of southward or southeastward flow of cold air west of a low pressure center on the plains due to blocking by the Rocky Mountains.

4. What five factors contribute to the development of major cold waves over the central and eastern United States?
   A. (1) surface high over northern Canada or Alaska (2) ridge over western North America (3) movement of airmass southeastward with subsidence (4) enhancement of southward transport of cold air over the Plains by a cyclone to the east, (5) extensive snow cover.

CHECK YOUR UNDERSTANDING 14.3

1. What is the relation between the coldest Siberian air and nearby mountains?
   A. The nearby mountains trap the cold air in Siberia and they also prevent warmer air over the ocean from penetrating into Siberia

2. From which direction does Europe receive its coldest airmasses?
   A. From the east

3. Which pressure centers are involved in the North Atlantic Oscillation?
   A. The subpolar low near Iceland and the subtropical high near the Azores

CHECK YOUR UNDERSTANDING 14.4

1. What is the wind chill temperature?
   A. The equivalent temperature that human skin senses due to heat loss caused by the combined effects of both cold and wind.

2. Explain the difference between a wind chill advisory and a wind chill warning.
   A. An advisory is issued when conditions are dangerously cold and a warning is issued when the cold is life-threatening.

3. Will global climate change mean the end to cold waves?
   A. No.

TEST YOUR UNDERSTANDING

1. Which region of the United States suffers the greatest losses from cold waves? Why?
   A. Southern states of the U.S. People are not as used to extreme cold and some do not have the resources available to protect themselves and property from the hazards that accompany cold waves.

2. Explain why airmasses that develop over Canada are colder than airmasses that form over the Arctic Ocean.
   A. Leads, or cracks, in the sea ice release heat from the ocean, raising the air temperature over the Arctic Ocean.

3. What is the ideal trough-ridge pattern of the jetstream for the development of polar airmasses?
   A. A trough over the central part of North America and a ridge over western North America.

4. Explain how a cyclone over the Gulf of Alaska can intensify a ridge over western North America.
   A. Air flows counterclockwise around the cyclone. This results in southerly flow off the western coast of North America, transporting warmer air northward. Warm air intensifies the ridge.

5. What causes cold polar airmasses to typically move southeastward over North America?
   A. Two factors: (1) tendency for denser fluid (cold air) to sink and spread and (2) movement of airmass in response to stronger steering winds in middle and upper troposphere.

6. Prior to a severe cold wave, a strong surface cyclone moves across the central and eastern United States. Explain the role of the surface cyclone in the development of the cold wave.
   A. The cyclone often produces snowfall which acts to maintain the cold through radiative processes. The cyclone also helps create a strong pressure gradient to its west, which helps transport the cold air southward.

7. How can the temperature of a polar airmass warm as it migrates from Canada into the contiguous United States?
   A. Compressional warming due to subsidence

8. What is the role of the Rocky Mountains in the occurrence of a cold wave in the central United States?
   A. The mountains force the cold air to remain in the central portion of the U.S. by channeling it along the east side of the range.

9. Why is snow cover called “nature’s refrigerator”?
   A. Snow cover is bright white and reflects much of the incoming solar radiation. This prevents the radiation from melting the snow and eventually warming the air temperature. Snow also radiates infra-red radiation readily, further cooling the air.

10. What two factors help explain why Siberian wintertime temperatures are extremely cold?
    A. (1) The large distance to the nearest unfrozen ocean and (2) the presence of mountains to the east and south, which block warmer air from moving into the area

11. Why do cold polar airmasses generally move westward over Europe?
    A. The coldest air is found in Siberia. When pressure patterns and associated westerly winds weaken over the Atlantic, cold air from Siberia can move westward into Europe.

12. Where do the Northern Hemisphere’s coldest airmasses develop during winter.

A. Siberia

13. What happens to the North Atlantic surface pressure pattern prior to a cold outbreak in Europe?
A. The subpolar low near Iceland and the subtropical high near the Azores weaken at the same time, resulting in high pressure from Siberia moving eastward into Europe.

14. Explain how the North Atlantic Oscillation plays a role in Europe's episodes of extremely cold weather.
A. West-to-east airflow over Europe weakens during the negative phase of the North Atlantic Oscillation, enabling a pool of cold Siberian air (low temperatures, high-surface pressure) to migrate westward over Europe.

15. Discuss the two ways in which wind enhances loss of heat from the skin.
A. Wind removes the insulating layer of warm air adjacent to skin, resulting in additional heat loss. Wind also increases evaporation of moisture from skin, resulting in additional heat loss.

15. Why is the phrase "Beast from the East" used by residents of Great Britain during winter?
A. The coldest airmasses that affect Great Britain arrive from the east.

16. How did scientists in Antarctica obtain estimates of the wind's effect on heat loss?
A. They measured the time required for the cooling and freezing of known volumes of water starting at various temperatures.

17. Name at least one important factor that the wind chill index does not take into account.
A. Sunshine and moisture from snow melting on the skin are two factors.

18. Suppose a thermometer is held outside in a strong wind. After the thermometer has equilibrated, does it show the actual temperature or the wind chill temperature? Why?
A. It shows the actual air temperature. A thermometer cannot detect wind chill temperature because, unlike the human body, it does not generate heat internally to be lost at its surface. The wind chill temperature only is a measure of rate of heat loss from a body, not the actual temperature.

19. How would you expect the wind chill to differ from the actual air temperature during the formation of a polar airmass?
A. During the formation of a polar airmass the wind chill and the air temperature would be similar. Airmass formation requires light winds.

20. Discuss how wind chill warnings and advisories are influenced by geographic location.
A. Warnings and advisories are issued to help protect people. Those persons who live in areas more vulnerable to extreme cold will have wind chill warnings and advisories issued at higher temperatures than for regions where cold temperatures are more commonplace.

21. Would you expect Australia to be affected by cold waves during the Southern Hemisphere winter? Why or why not?
A. No. The whole of Australia is surrounded by ocean at a relatively low latitude. There is no good source region for extremely cold air to develop.

22. What is the "polar vortex" and how is it related to cold air outbreaks?
A. The polar vortex is a band of strong winds in the stratosphere located in middle to high northern latitudes during winter months. When the polar vortex is disrupted by the jet stream,

it becomes unstable and lobes of extremely cold air separate from the main vortex. These lobes of cold air propagate downward, contributing to the strength of cold waves.

23. Will global warming end the occurrence of cold waves? Explain.
    A. No. In a warmer world, cold air outbreaks into middle latitudes may become less frequent and less intense, but the atmospheric circulation will occasionally develop patterns that transport polar air southward. The transported polar will be much colder than average for the mid-latitude location.

TEST YOUR PROBLEM-SOLVING SKILLS

1. Air cools primarily by a net loss of infrared energy, and it warms primarily by a gain of energy from solar radiation. (Much of the solar radiation is absorbed by the ground and then conducted to the air, but the source is still the sun's energy – see Chapter 5). Suppose for simplicity that the loss of infrared energy, by itself, causes the air near the ground to cool by 5ºF per day. Suppose also that the solar radiation, by itself, warms the air by 0.25ºF per day for each degree latitude south of 65ºN. (North of 65ºN, the heating by sunlight is negligible during winter.) Assume that there is no horizontal or vertical wind to change the air's temperature.
   (a) As you go south from 65ºN, at which latitude do you cross from a zone of net cooling to a zone of net warming?

   A. $5ºF/day - (x º \text{ lat.})(0.25º/day) = 0$, where x = # of degrees lat. south of 65ºN

   $x = 5.0/0.25 = 20^º \rightarrow$ net warming occurs south of $65^º - 20^º = \underline{45^ºN}$

   (b) If an airmass is initially at a temperature of 0ºF at a latitude of 50ºN, and there is no wind to remove the air from its location, how long would it take that air to cool to -40ºF (ºC), a typical temperature of polar continental air?
   A. At 50ºN, net cooling rate = -5ºF/day + 15(0.25ºF/day) = -1.25ºF/day
   so cooling to –40ºF requires -40ºF/(-1.25ºF/day) = <u>32 days</u>

   (c) Suppose now that a surface high-pressure center develops, and the air slowly sinks at a rate of 250 meters per day. Recalling the dry adiabatic lapse rate, how would the answers to (a) and (b) change?
   A. Sinking at 250 m/day → warming by (0.25 km/day)(10ºC/km) = 2.5ºC/day
   = 4.5ºF/day
   in (a), need to go south by only 2º lat → 63ºN
   in (b), temperature changes by -1.25ºF/day + 2.5ºF/day → warming,
   <u>so air will never reach –40ºF</u>

2. You have been ice fishing in a warm heated shelter in the exact center of a lake with a 1-mile radius. While you were fishing, the leading edge of a polar airmass arrived, dropping the temperature to -10°F (-22°C). To make matters worse, the wind is now blowing from the

north at 20 mph. Unfortunately, your car is parked on the north shore of the lake. Fortunately, the lake is surrounded by trees that reduce the wind speed in the trees by 50% from the speed over the frozen lake. You can walk or run at any speed up to 5.4 mph (11 min per mile). If you are to avoid frostbite, what is the safest route to your car? Why? (Hint: When walking or running against the wind, your speed must be added to the wind speed. Use this fact, together with the frostbite times that accompany the wind chill chart).

A. Standing on lake, -10ºF, 20 mph → wind chill T_{wc} = -35ºF (30 min to frostbite)
Standing in trees, -10ºF, 10 mph → wind chill T_{wc} = -28ºF
Option 1: Run straight north to car (1 mile):
Wind speed = 25 mph, T_{wc} = -37°F, time to frostbite = 10 min,
running time (1 mile) = 11 min. Will experience frostbite.
Option 2: Run south (1 mile), then run ½ circle through trees to car (3.14 miles)
Wind speed = 15 mph, T_{wc} = -32°F, time to frostbite = 30 min,
running time (4.14 miles) = 45.4 min. Will experience frostbite.
Option 3: Run east or west (1 mile), then ¼ circle through trees to car (1.57 miles)
Wind speed = 20 mph (15 mph in trees), T_{wc} = -35°F, time to frostbite = 30 min,
running time (2.57 miles) = 28.2 min. Avoids frostbite (barely). Best option.

3. Consider a hypothetical polar airmass having a depth D and a surface air temperature of -30ºC
(-22ºF). In the lowest third of this airmass, there is a strong inversion with the temperature increasing upward at 3ºC per 100 m. In the remainder of the depth D, the temperature decreases with elevation at 0.5ºC per 100 m. Suppose that this airmass then moves up against a large mountain range in which the lowest point is Gonner Pass (elevation = 1800 m). The temperature at Gonner Pass is -20ºC (-4ºF) prior to the arrival of the polar airmass.

(a) If D = 2 km, what will be the temperature in the polar airmass at elevations of 1 km, 2 km and 3 km?

A. T = -30ºC + 1/3 D (30ºC/km) + (h – 1/3 D)(-5ºC/km)
If D = 2 km:
At h = 1 km, T = -30ºC + 2/3 km (30ºC/km) + 1/3 km (-5ºC/km) = <u>-11.7ºC</u>
At h = 2 km, colder by 5ºC → <u>-16.7ºC</u>
At h = 3 km, " " " → <u>-21.7ºC</u>

(b) Will the polar airmass spill through Gonner Pass to the other side of the mountains?

A. At 1800 m, $T_{polar\ airmass}$ = -15.7ºC, which is warmer than –20ºC,
so <u>polar airmass will not spill through Gonner Pass</u>

(c) How do your answers to (a) and (b) change if the temperature in the inversion layer increases at only 1ºC per km?

A. At h = 1 km: T =-30ºC + 1/3 D (1ºC/km) + (h – 1/3 D)(-5ºC/km) = <u>-33ºC</u>
At h = 2 km: Colder by 5ºC → <u>-38ºC</u>
At h = 3 km: " " " → <u>-43ºC</u>
At 1.8 km, $T_{polar\ airmass}$ = -37ºC, colder than -20ºC; <u>air will spill through Gonner Pass</u>

4. A strong polar airmass 2000 miles in diameter is centered over Yellowknife in northwestern Canada at noon on Sunday. The airmass is moving at 30 mph directly toward St. Louis,

Missouri. Create a meteogram (use qualitative axis labels rather than distinct values) to indicate the behavior of the following variables over the next four days at St. Louis:

(a) Temperature
(b) Dewpoint temperature
(c) Surface pressure
(d) Wind direction
(e) Wind speed
(f) Wind chill temperature

A. Travel time to St. Louis for leading edge of cold airmass: 2000 mi/30 mph = 67 hrs
Near end of 3rd day (at 67 hours, or shortly after 7 am Wednesday), St. Louis will experience the following:
(a) Temperature will start to drop and will continue to drop
(b) Dewpoint temperature will start to drop and will continue to drop
(c) Surface pressure will start to rise and will continue to rise
(d) Wind direction will shift to northwest or north
(e) Wind speed will likely be strong (20 to 30 mph) with wind speed increasing relative to speeds prior to 7 A.M. Wednesday
(f) Wind chill temperature will drop dramatically (colder and windier)

Test Bank Questions

TRUE/FALSE

1. Cold waves generally affect a much larger area compared to other winter hazards such as blizzards and ice storms.
   True
2. It is estimated that the average number of fatalities in the United States attributed to cold waves in on the order of 600 per year, according to the Centers for Disease Control and Prevention.
   False
3. The greatest direct economic losses from cold waves are experienced by the agricultural sector.
   True
4. The northern United States is most vulnerable to cold waves because buildings are not designed for extreme cold, nor are residents generally equipped to deal with cold conditions.
   True
5. The most meaningful measure of a cold wave's impact is the actual air temperature at the surface.
   False
6. The Northern Hemisphere's coldest airmasses form over the Arctic Ocean.
   False

7. The “wave” in a cold wave comes from the strong ocean waves that develop in response to the cold.
   False
8. Airmasses over land in the Arctic tend to be colder than airmasses over the Arctic Ocean.
   True
9. Leads in sea ice release heat into the atmosphere preventing the most extreme cold airmasses from developing.
   True
10. Surface high-pressure systems that form in the Arctic tend to strengthen with height.
    False
11. Temperature inversions are rarely associated with cold polar airmasses.
    False
12. By insulating the ground, snow cover reduces the intensity of cold air outbreaks.
    False
13. A northward flow of maritime air into Alaska favors the build-up of a ridge over northwestern North America.
    True
14. During a cold wave, air normally flows southeastward into the central United States.
    True
15. Cooling is enhanced in cold polar high-pressure areas by clear skies, which increase the loss of radiational energy.
    True
16. The core of a cold air outbreak is usually a region of subsidence aloft and associated adiabatic warming.
    True
17. High-pressure centers over northern Canada and Alaska intensify only if the curvature effect favors convergence in the jetstream aloft.
    False
18. The Rocky Mountains play an important role in channeling the cold air from high latitudes into the central United States.
    True
19. Airmasses forming over northern Asia are generally not as cold as those forming over northern Canada.
    False
20. Europe’s winters are relatively mild for its latitude because the prevailing airflow is from the Atlantic Ocean.
    True
21. The wind chill temperature does not depend on the air’s moisture content.
    True

22. The recent revision of the calculation of the wind chill index generally produces lower (colder) values than the older formulation.
False

23. If you are standing in direct sunshine, you will feel warmer than the wind chill temperature implies.
True

24. The criteria for the issuance of a Wind Chill Advisory by the National Weather Service vary with location and time of year.
True

25. Severe cold in the central United States is more likely to occur if an extensive snow cover has built up during the preceding weeks.
True

26. Global climate change may cause an increase in frequency of cold waves in specific areas of the world even if the global mean temperature increases.
True

27. An upper-air trough over the western United States helps to steer cold airmasses.
False

28. Cold waves generally affect a much smaller area compared to other winter hazards such as blizzards and ice storms.
False

29. According to the Centers for Disease Control and Prevention, in an average year there are no fatalities in the United States due to extreme cold.
False

30. According to the Centers for Disease Control and Prevention, in an average year several thousand persons die due to extreme cold.
False

31. Fatalities in the U.S. due to extreme cold are typically less than 100, according to the Centers for Disease Control and Prevention.
False

32. Cold waves can, and do, cause fatalities.
True

33. While cold waves cause inconvenience for many people, they do not result in loss of life in the United States.
False

34. Strong winds are good for the formation of very cold airmasses because they mix up the cold and warm air.
False

35. North America's coldest airmasses form over the Canada.
True

36. Leads in the Arctic Ocean prevent the air temperature over the ocean from becoming as cold as the air over continental Canada.
    True
37. The "wave" in a cold wave comes from the pattern in the jetstream flow.
    True
38. Severe cold in the central United States is more likely to occur if an extensive snow cover has built up during the preceding weeks.
    True
39. A wind chill warning is issued when extreme cold is occurring or threatens the region under the warning.
    True
40. A wind chill watch is issued when extreme cold is occurring or threatens the region under the warning.
    False
41. A wind chill advisory is issued when the wind chill temperature will be sufficiently low that, if caution is not exercised, the cold could lead to life-threatening situations.
    True
42. The wind chill temperature does not depend on the air's moisture content.
    True
43. Global warming may cause an increase in frequency of cold waves in specific areas of the world.
    True
44. Cold waves will cease to be a weather hazard in the future because global warming is increasing the Earth's air temperature.
    False
45. A continuation of Earth's present warming trend through the 21st Century would not completely eliminate cold waves.
    True
46. The frequency of cold waves will most likely increase because of if present warming trends continue.
    False
47. As climate changes over the 21st Century, the locations most frequently affected by cold waves may change.
    True

MULTIPLE CHOICE

1. Which of the following regions of the United States most commonly experiences cold waves?
    (a) Northern Plains
    (b) West Coast

(c) East Coast
(d) South

A: (a) Northern Plains

2. Which of the following regions of the United States is most vulnerable to cold waves?
   (a) Northern Plains
   (b) West Coast
   (c) East Coast
   (d) South

A: (d) South

3. Which of the following statements regarding cold waves is not true?
   (a) Cold waves generally affect much larger areas than other winter weather events.
   (b) Approximately 600 deaths per year are attributable to hypothermia in the United States.
   (c) Cold-related deaths in the United States occur disproportionately among the young, in the North, and among females.
   (d) The greatest direct economic losses from severe cold result from damage in the agricultural sector

A: (c) Cold-related deaths in the United States occur disproportionately among the young, in the North, and among females.

4. Which of the following statements regarding cold waves is not true?
   (a) The actual temperatures during record-setting cold outbreaks are far warmer in the southern states than in the northern states.
   (b) The South is especially vulnerable to cold waves because many buildings are not designed for extreme cold.
   (c) The economic losses from cold waves from broken water pipes and commercial slowdowns are relatively low.
   (d) Heating costs in the residential and commercial sectors are directly impacted by cold waves.

A: (c) The economic losses from cold waves from broken water pipes and commercial slowdowns are relatively low.

5. The formation of an abnormally cold airmass requires which of the following?
   (a) sharp temperature gradients
   (b) a strong jetstream aloft
   (c) strong winds
   (d) (a), (b) and (c) are all correct
   (e) None of the above are correct.

A: (e) None of the above are correct.

6. Which of the following does not favor cooling of air in the lower troposphere?
   (a) dense fog
   (b) light winds
   (c) long nights

(d) clear skies

A: (a) dense fog

7. The core of a cold wave at the surface is what type of pressure system?
   (a) strong high-pressure
   (b) weak high-pressure
   (c) strong low-pressure
   (d) weak low-pressure

A: (a) strong high-pressure

8. Which of the following is <u>not</u> a favored region for cold airmass formation?
   (a) northern Scandinavia
   (b) northern Canada
   (c) Siberia
   (d) Alaska

A: (a) northern Scandinavia

9. When a cold polar airmass is found over a land surface, what is its typical depth?
   (a) less than 1 km
   (b) 1 to 3 km
   (c) 3 to 6 km
   (d) more than 8 km

A: (b) 1 to 3 km

10. Which statement best describes "leads"?
   (a) openings in stratocumulus clouds within polar airmasses.
   (b) streamers of wind-blown snow that are carried over bare ground.
   (c) openings in a sea ice cover, exposing unfrozen ocean water to cold air.
   (d) cool airmasses that are preceded by extremely cold outbreaks of polar air.

A: (c) Openings in a sea ice cover, exposing unfrozen ocean water to cold air.

11. The surface high-pressure systems that form under cold dense airmasses _____with height and are characterized by _____in the lowest several hundred meters
   (a) weaken; channeling
   (b) weaken; temperature inversions
   (c) strengthen; channeling
   (d) strengthen; temperature inversions

A: (b) weaken; temperature inversions

12. Why do strong winds typically initiate a cold-air outbreak in middle latitudes?
   (a) rapid equatorward motion minimizes the warming en route
   (b) the strong winds minimize frictional heating of the air
   (c) strong winds indicate that the air originated in the upper troposphere, where the air is very cold
   (d) strong winds enhance evaporation of ice crystals and raindrops, cooling the air by the consumption of latent heat

A: (a) rapid equatorward motion minimizes the warming en route

13. During a cold outbreak over eastern North America, the axis (centerline) of an upper-air _____would most likely be found over the _____.
    (a) trough; Rocky Mountains
    (b) ridge; Rocky Mountains
    (c) trough; West Coast
    (d) ridge; East Coast

A: (b) ridge; Rocky Mountains

14. Which of the following is not a contributor to the southward plunge of cold airmasses into the central United States?
    (a) The cold air is very dense.
    (b) The air has little moisture content.
    (c) Steering winds in the middle and upper troposphere.

A: (b) The air has little moisture content.

15. What role do East Coast cyclones play during the development of cold waves that affect the eastern United States?
    (a) Cold air is pulled southward at low levels behind the cyclone.
    (b) The southward movement of cold air west of the cyclone intensifies the upper-level trough over eastern North America.
    (c) Snow cover is often made more extensive.
    (d) Both (a) and (c) are correct.
    (e) (a), (b), and (c) are all correct.

A: (e) (a), (b), and (c) are all correct.

16. An early sign that a major cold outbreak is in store for the central and eastern United States is a strong surface high over what region?
    (a) the West Coast
    (b) Scandinavia
    (c) Labrador
    (d) Alaska

A: (d) Alaska

17. Which of the following would you not expect to find in association with a cold air outbreak east of the Rockies?
    (a) strong northwest winds
    (b) a ridge over the West Coast
    (c) extensive snow cover in Canada
    (d) upward vertical motion over southern Canada

A: (d) upward vertical motion over southern Canada

18. Over northern Asia, the formation of cold airmasses is enhanced by:
    (a) the large distance to the nearest unfrozen ocean
    (b) the absence of mountain barriers to the south and east

(c) Both (a) and (b) are correct.
(d) None of the above are correct.

A: (a) the large distance to the nearest unfrozen ocean

19. Which statement about the spatial extent of cold waves is correct?
    (a) Strong cold waves can extend as far south as Texas and northern Mexico
    (b) Deep cold airmasses can spill over the Rocky Mountains into the Great Basin
    (c) In rare cases, cold airmasses can spill westward over the Sierra Nevada into California
    (d) (b) and (c) are correct.
    (e) All of the above statements are correct.

A: (e) All of the above statements are correct.

20. Which of the following is <u>not</u> a key environmental factor that contributes to a cold wave in the central or eastern United States?
    (a) extensive snow cover over central North America
    (b) channeling of the cold-air pool by the Rocky Mountains.
    (c) the buildup of a ridge in the jetstream over western North America
    (d) rapid cooling of the air near the surface and convergence aloft downstream of the ridge
    (e) unusually high dew point temperatures to over the central United States

A: (e) unusually high dew point temperatures over the central united States

21. Europe's coldest airmasses arrive from which direction?
    (a) north
    (b) south
    (c) east
    (d) west

A: (c) east

22. Several days prior to a major cold outbreak in Europe, there is typically a _____ of the surface _____ gradient over the North Atlantic.
    (a) strengthening; pressure
    (b) weakening; pressure
    (c) strengthening; temperature
    (d) weakening; temperature

A: (b) weakening; pressure

23. The rate of conductive heat loss from an object is proportional to the gradient of _____ between the object's surface and the surrounding air.
    (a) wind
    (b) pressure
    (c) temperature
    (d) None of the above

A: (c) temperature

24. What is the term used to describe the effect of temperature and wind on the rate at which exposed flesh will cool?
    (a) wind chill factor
    (b) wind chill index
    (c) virtual temperature
    (d) apparent temperature

A: (a) wind chill factor

25. If the wind chill temperature is –25 ºF (–32 ºC), in approximately how many minutes will exposed skin suffer frostbite?
    (a) 1 minute
    (b) 15 minutes
    (c) 30 minutes
    (d) 60 minutes

A: (c) 30 minutes

26. The thresholds used for cold wave warnings:
    (a) are the same for each region.
    (b) are the same for each season.
    (c) are defined by precise temperatures.
    (d) are defined by precise wind chills.
    (e) None of the above are correct.

A: (e) None of the above are correct.

27. Which of the following decades had the fewest extremely cold days in the central United States?
    (a) 1920s
    (b) 1950s
    (c) 1980s
    (d) 1990s

A: (b) 1950s

28. The highest sea level pressures ever recorded in the contiguous United States:
    (a) are higher than 1050 mb.
    (b) have occurred during extreme cold outbreaks.
    (c) were recorded in Montana and adjacent states.
    (d) Both (b) and (c) are correct.
    (e) (a), (b) and (c) are all correct.

A: (a), (b) and (c) are all correct.

29. Which state holds the record for the lowest surface air temperature ever recorded in the United States?
    (a) Alaska
    (b) Montana
    (c) North Dakota
    (d) Minnesota
    (e) Maine

A: (a) Alaska

30. Which of the following combinations is most conducive to the occurrence of extremely cold surface temperatures?
    (a) cloudy sky, snow-covered ground, strong winds
    (b) cloudy sky, snow-covered ground, light winds
    (c) clear sky, snow-covered ground, light winds
    (d) clear sky, snow-free ground, strong winds
    (e) clear sky, snow-free ground, light winds

A: (c) clear sky, snow-covered ground, light winds

31. If the air temperature is 5°F, the wind speed is 25 mph, and the wind chill equivalent temperature is –17°F, what temperature will a thermometer read?
    (a) 25°F
    (b) 5°F
    (c) –8°F
    (d) –17°F

A: (b) 5 ℉

32. Which of the following is *not* a major impact of cold waves?
    (a) injuries
    (b) fatalities
    (c) loss of vegetation
    (d) damage to buildings
    (e) decrease in gasoline production

A. (e) decrease in gasoline production

33. Which of the following regions of the United States suffers the greatest losses from cold waves?
    (a) Midwest
    (b) New England
    (c) Desert southwest
    (d) Southern states
    (e) Northern plains states

A. (d) Southern states

34. Which of the following regions of the United States most commonly experiences cold waves?
    (a) Northern Plains
    (b) West Coast
    (c) East Coast
    (d) South

A. (a) Northern Plains

35. Which of the following states is most vulnerable to cold waves?
    (a) Ohio

(b) Vermont
(c) Colorado
(d) Wyoming
(e) Louisiana

A. (e) Louisiana

36. Which of the following states is most vulnerable to cold waves?
(a) Illinois
(b) Montana
(c) Arkansas
(d) Wisconsin
(e) Pennsylvania

A. (c) Arkansas

37. Which of the following states is most vulnerable to cold waves?
(a) Maine
(b) Oregon
(c) Florida
(d) Kentucky
(e) North Dakota

A. (c) Florida

38. Which of the following states is most vulnerable to cold waves?
(a) Iowa
(b) Michigan
(c) Alabama
(d) New York
(e) South Dakota

A. (c) Alabama

39. Which of the following states is most vulnerable to cold waves?
(a) Texas
(b) Indiana
(c) Vermont
(d) Wyoming
(e) Pennsylvania

A. (a) Texas

40. Which of the following is <u>not</u> a factor that favors the formation of the coldest airmasses over
(a) high latitudes?
(b) long nights
(c) strong winds
(d) clear skies

A. (c) strong winds

41. Which of the following is not a factor that favors the formation of the coldest airmasses over high latitudes?
    (a) strong temperature inversions
    (b) long nights
    (c) light winds
    (d) cloudy skies

A. (d) cloudy skies

42. The formation of an abnormally cold airmass requires which of the following?
    (a) sharp temperature gradients
    (b) a strong jetstream aloft
    (c) strong winds
    (d) (a), (b) and (c) are all correct
    (e) None of the above are correct.

A. (e) None of the above are correct.

43. What is the term used to describe the flow in the middle and upper troposphere that has the strongest influence on surface conditions (such as cold wave out outbreaks and thunderstorms)
    (a) gustnado
    (b) steering flow
    (c) friction flow
    (d) adiabatic flow
    (e) rear inflow jet

A. (b) steering flow

44. What term describes the enhancement of southward or southeastward flow of cold air west of a low pressure center on the plains due to blocking by the Rocky Mountains.
    (a) cyclonic effect
    (b) adiabatic effect
    (c) curvature effect
    (d) channeling effect
    (e) geostrophic effect

A. (d) channeling effect

45. Which statement best describes “leads”?
    (a) openings in stratocumulus clouds within polar airmasses.
    (b) streamers of wind-blown snow that are carried over bare ground.
    (c) openings in a sea ice cover, exposing unfrozen ocean water to cold air
    (d) cool airmasses that are preceded by extremely cold outbreaks of polar air.

A. (c) openings in a sea ice cover, exposing unfrozen ocean water to cold air

46. What season is wind chill factor most important?
    (a) spring
    (b) summer
    (c) autumn

(d) winter

A. (d) winter

47. A medical condition in which a person's body temperature is lowered to the point where it can be life threatening
    (a) hypothermia
    (b) hyperthermia
    (c) frostbite

A. (a) hypothermia

48. What is a medical condition in which the affected part of the body is frozen?
    (a) hypothermia
    (b) hyperthermia
    (c) frostbite

A. (c) frostbite

49. If the air temperature is 0°F, the wind speed is 20 mph, and the wind chill equivalent temperature is –22°F, what temperature will a thermometer read?
    (a) 0°F
    (b) 2°F
    (c) 30°F
    (d) –22°F

A. (a) 0°F

50. If the air temperature is -15°F, the wind speed is 30 mph, and the wind chill equivalent temperature is –46°F, what temperature will a thermometer read?
    (a) 30°F
    (b) -15°F
    (c) –45°F
    (d) –46°F

A. (b) -15°F

51. If the wind chill temperature is –25 ºF, in approximately how many minutes will exposed skin suffer frostbite?
    (a) 5 minutes
    (b) 10 minutes
    (c) 30 minutes
    (d) more than 30 minutes

A. (c) 30 minutes

52. If the wind chill temperature is –70 ºF, in approximately how many minutes will exposed skin suffer frostbite?
    (a) 5 minutes
    (b) 10 minutes
    (c) 30 minutes
    (d) more than 30 minutes

A. (a) 5 minutes