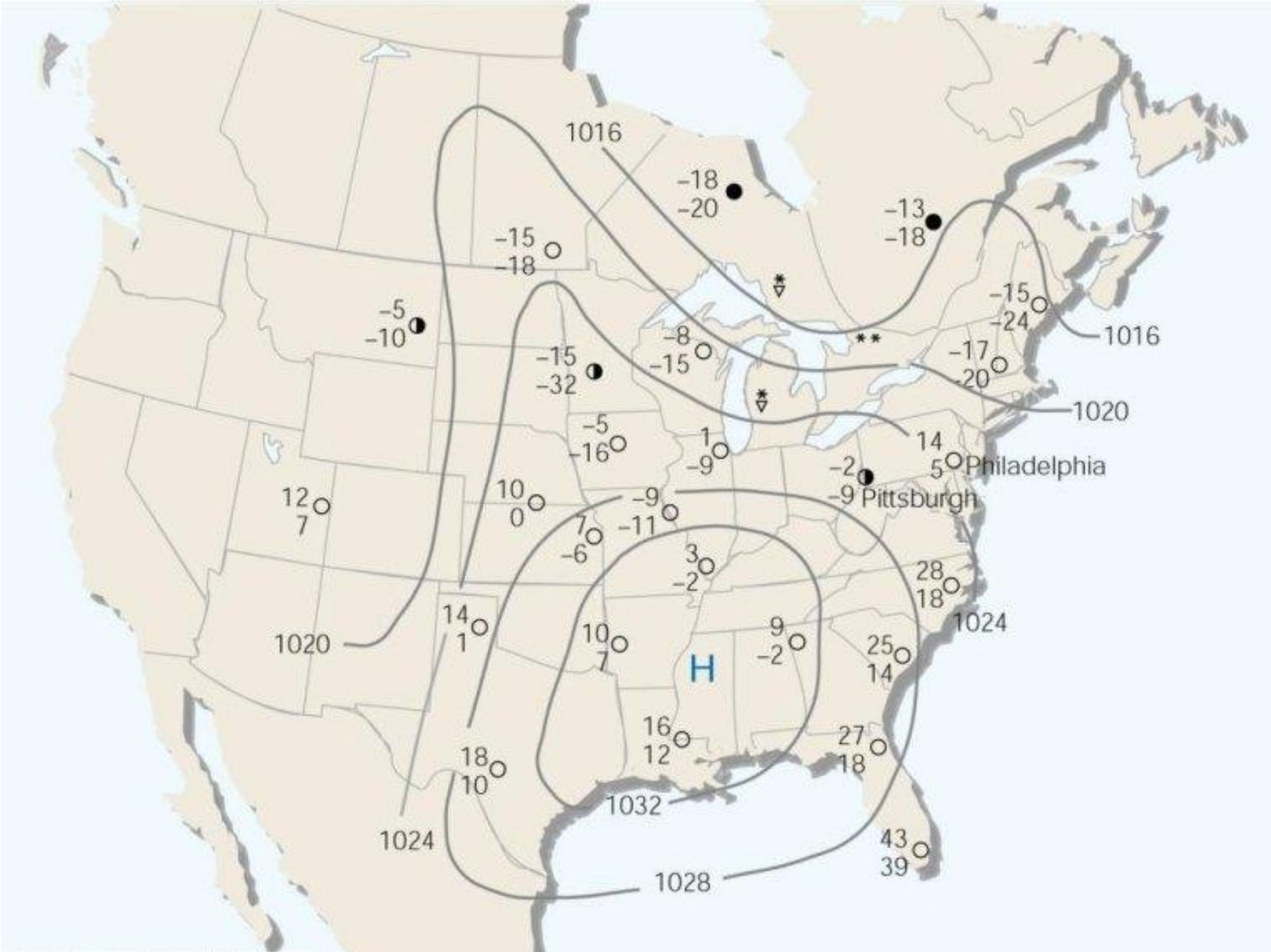
Air Masses, Fronts, and Middle-Latitude Cyclones

Outline

- Air Masses
  - cP, cA, mP, mT, cT
- Fronts
  - Stationary, cold, warm, occluded
- Middle-Latitude Cyclones
  - Factors in their development

Air Masses

- **Air Mass** – an extremely large body of air whose properties of temperature and humidity are fairly similar in any horizontal direction at any given latitude.
  - Air masses may cover thousands of square kilometers.
  - Part of weather forecasting is a matter of determining air mass characteristics, predicting how and why they change, and in what direction the system will move.



Here, a large, extremely cold water air mass is dominating the weather over much of the United States. At almost all cities, the air is cold and dry. Upper number is air temperature (°F); bottom number is dew point (°F).

Source Regions

- **Source Regions** – are regions where air masses originate. In order for a huge air mass to develop uniform characteristics, its source region should be generally flat and of uniform composition with light surface winds.
  - The longer air remains stagnant over its source region, the more likely it will acquire properties of the surface below.
  - Best source regions are usually dominated by High Pressure [e.g. ice and snow covered arctic plains and subtropical oceans and desert regions.]
  - *Are the middle latitudes a good source region???*

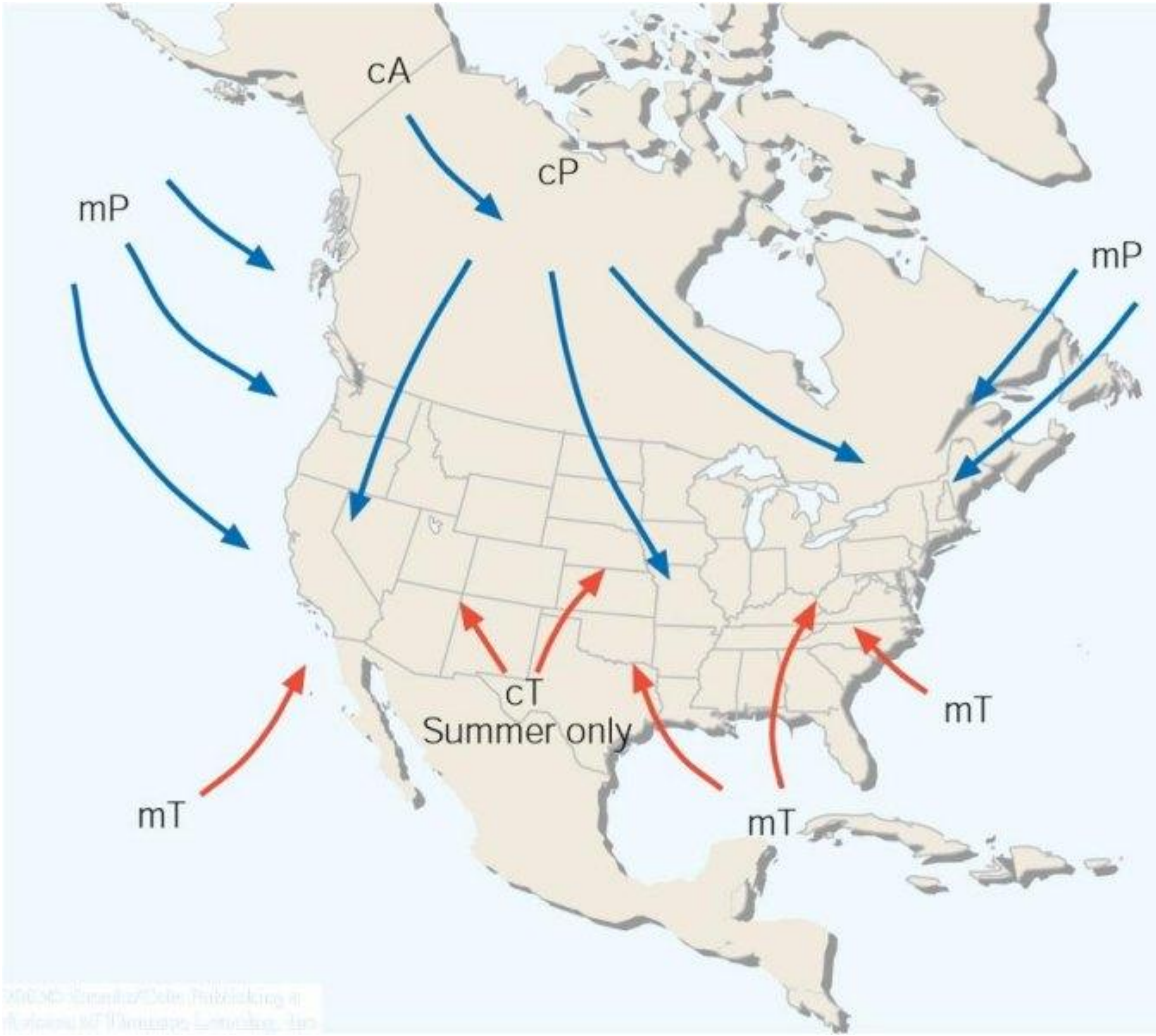
Classification

- Air masses are grouped into four general categories according to their source region
  - **Polar** (P) are air masses that originate in polar latitudes
  - **Tropical** (T) are air masses that form in warm tropical regions
  - **Maritime** (m) are air masses that originate over water (moist in the lower layers)
  - **Continental** (c) are air masses with a source region over land (dry)

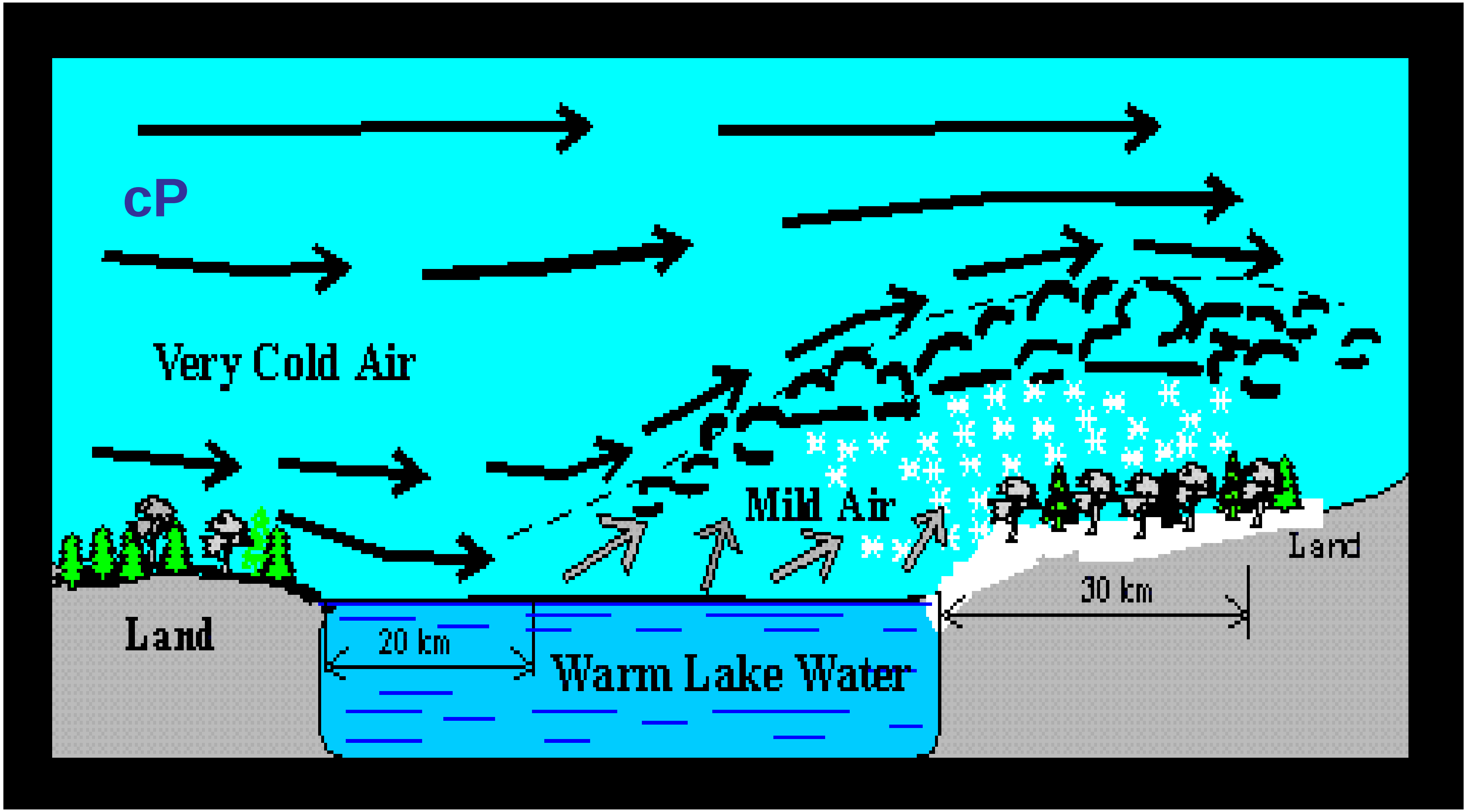
Air Mass Classification/characteristics

- **cP** – Continental Polar air mass. Cold, dry and stable.
- **cT** – Continental Tropical air mass. Hot, dry, stable air aloft, unstable air at the surface
- **cA* – Continental Artic. Extremely cold cP air mass
- **mP** – Maritime Polar air mass. Cool, moist, unstable.
- **mT** – Maritime Tropical air mass. Warm, moist, usually unstable.
- **mE* – Maritime Equatorial. Extremely hot humid air mass originating over equatorial waters.

Air mass source regions and their paths.



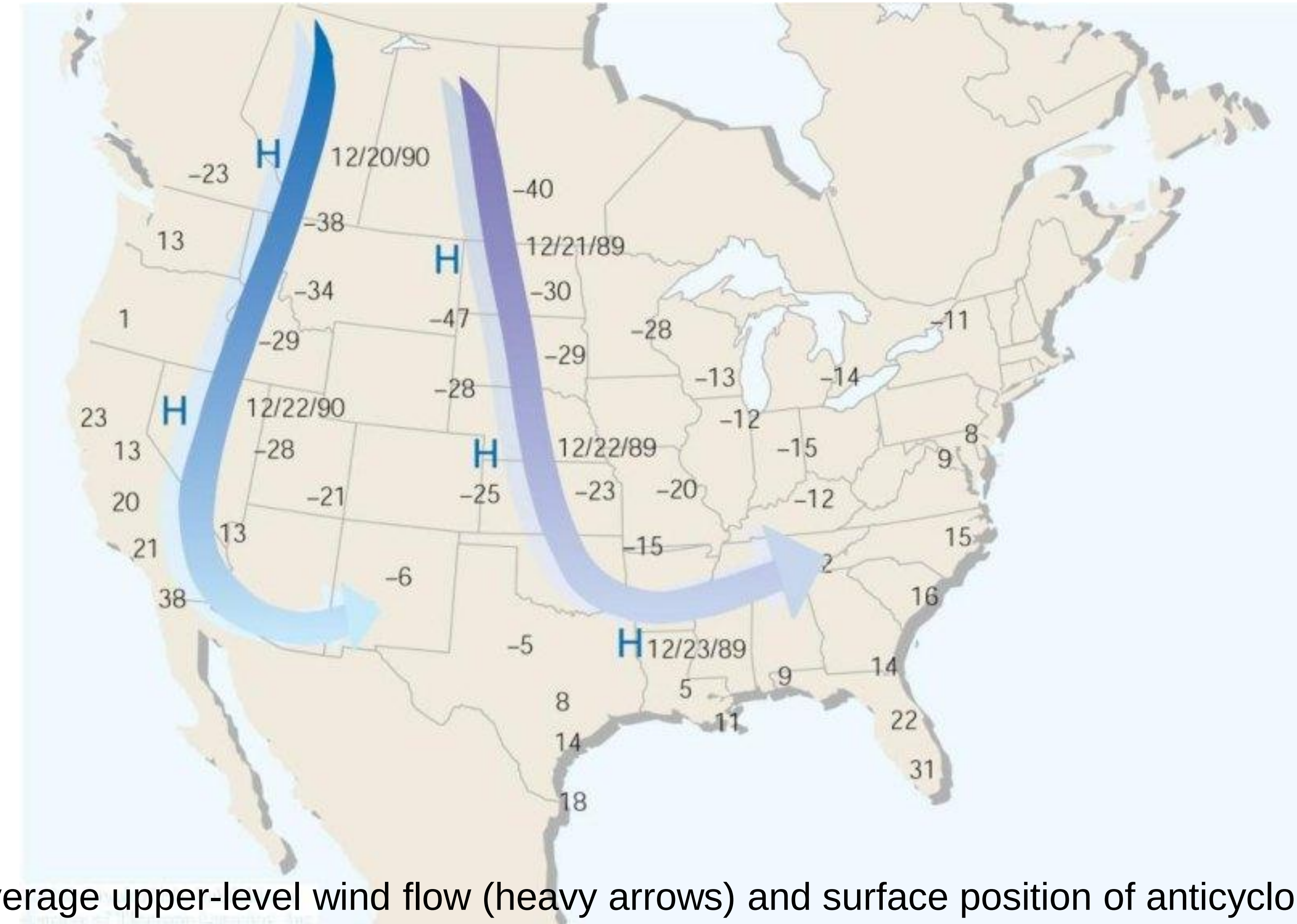
Lake Effect Snows



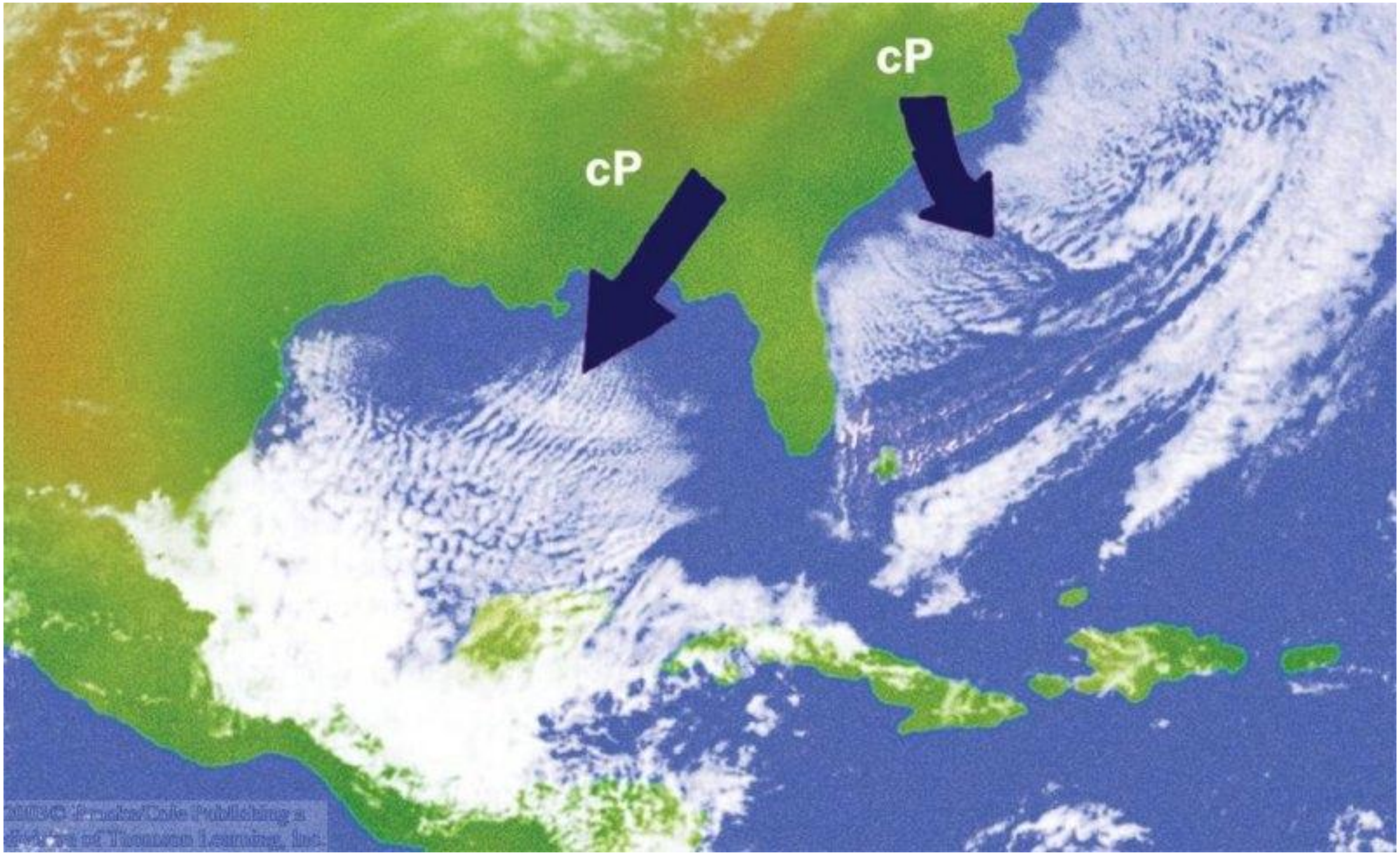
For more on lake effect snow see text pg 204

cP

- cP and cA air masses bring bitterly cold weather to the US in the winter.
- Originate over ice and snow covered regions of N. Canada and Alaska where long clear nights allow for strong radiational cooling of the surface. Air becomes cold and stable. Little moisture in source region makes this air mass relatively dry. Eventually a portion of this air mass breaks away and moves southward as an enormous shallow high pressure area.
- As air moves southward it is modified. Temperatures moderate as it moves south.



Average upper-level wind flow (heavy arrows) and surface position of anticyclones (H) associated with two extremely cold outbreaks of arctic air during December. Numbers on the map represent minimum temperatures (°F) measured during each cold snap.



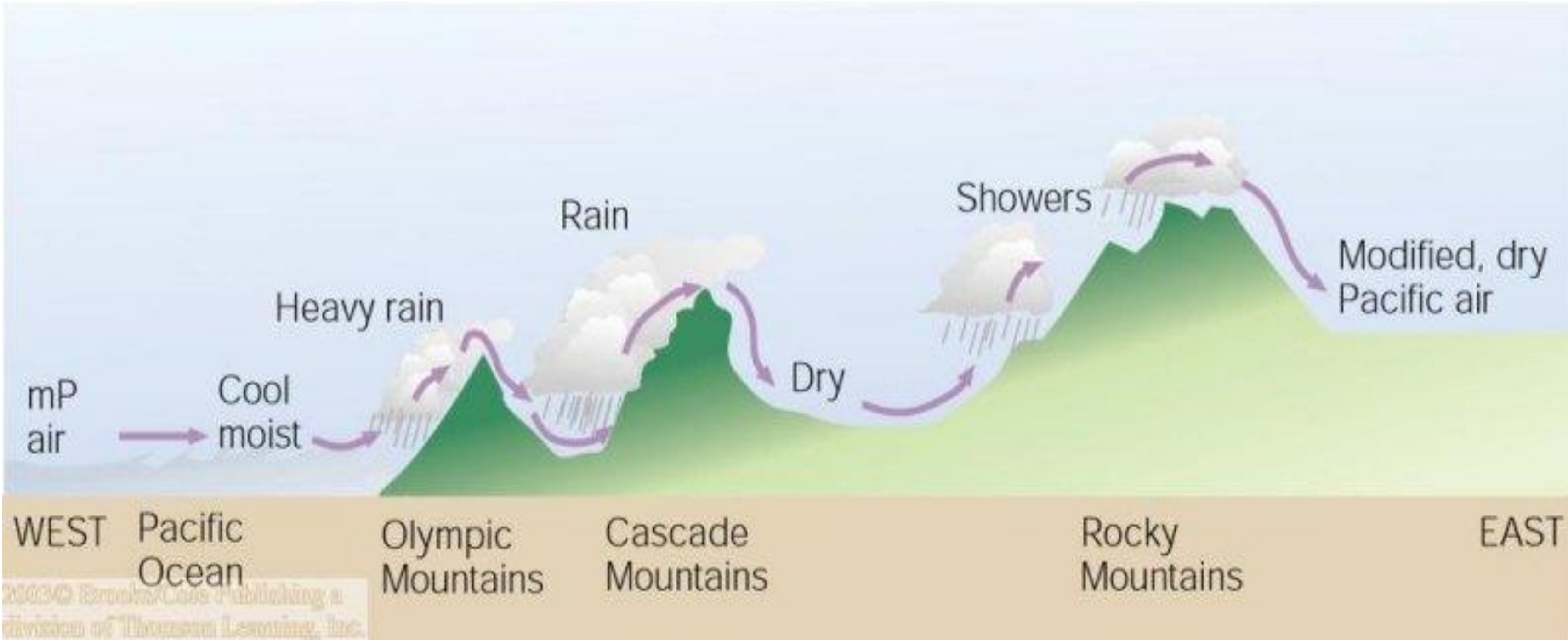
Visible satellite image showing the modification of cP air as it moves over the warmer Gulf of Mexico and the Atlantic Ocean.

mP

- cP air originating over Asia and frozen polar regions is carried eastward and southward over the Pacific Ocean by the circulation around the Aleutian Low.
- Ocean water modifies the cP air by adding warmth and moisture creating mP air.
- mP air is cool and moist, but is modified as it moves from Pacific over the Rockies and into plains.

mP

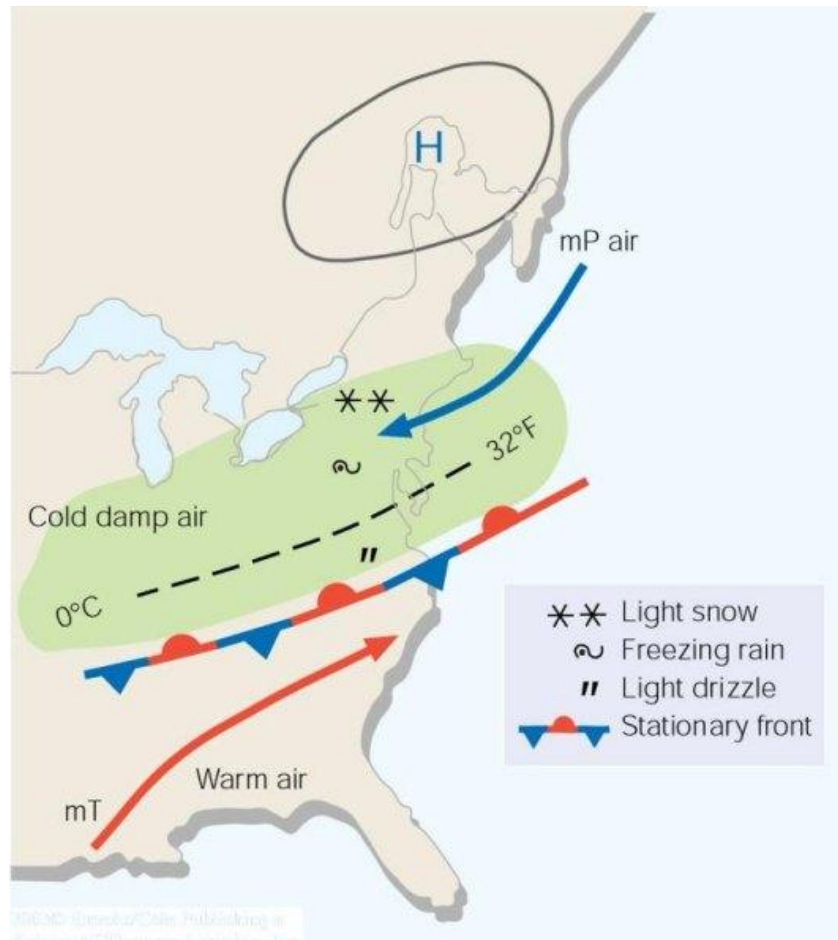
A winter upper-air pattern that brings mP air into the west coast of North America. The large arrow represents the upper-level flow. Note the trough of low pressure along the coast. The small arrows show the trajectory of the mP air at the surface. Regions that normally experience precipitation under these conditions are also shown on the map. Showers are most prevalent along the coastal mountains and in the Sierra Nevada.



- After crossing several mountain ranges, cool moist mP air from off the Pacific Ocean descends the eastern side of the Rockies as modified, relatively dry Pacific air.

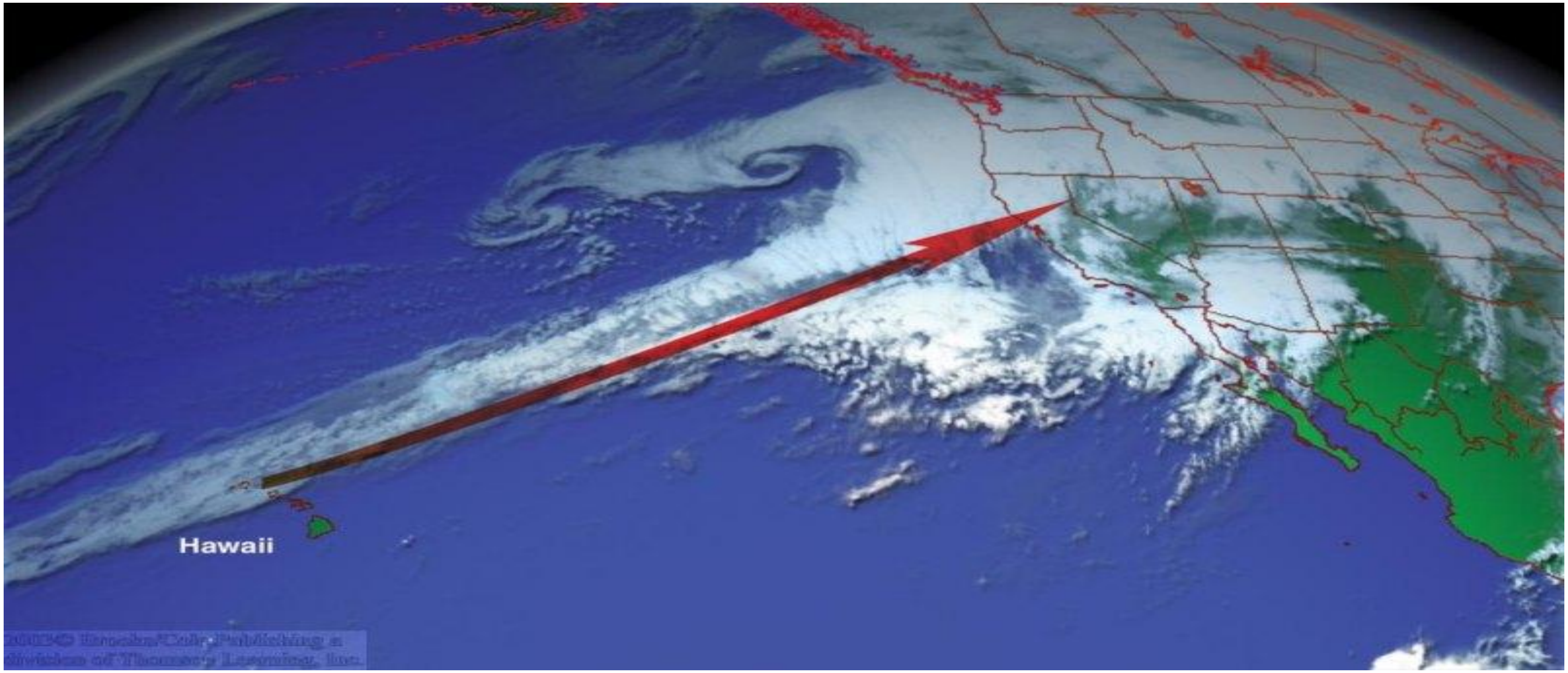
mP

- Along the east coast, mP orginates in the North Atlantic as cP air moves southward some distance of the Atlantic coast.
- Winter and early spring surface weather patterns that usually prevail during the invasion of mP air into the mid-Atlantic and New England states. (Green-shaded area represents precipitation.)
- Atlantic mP is usually colder than Pacific mP air. Atlantic mP air is much less common.



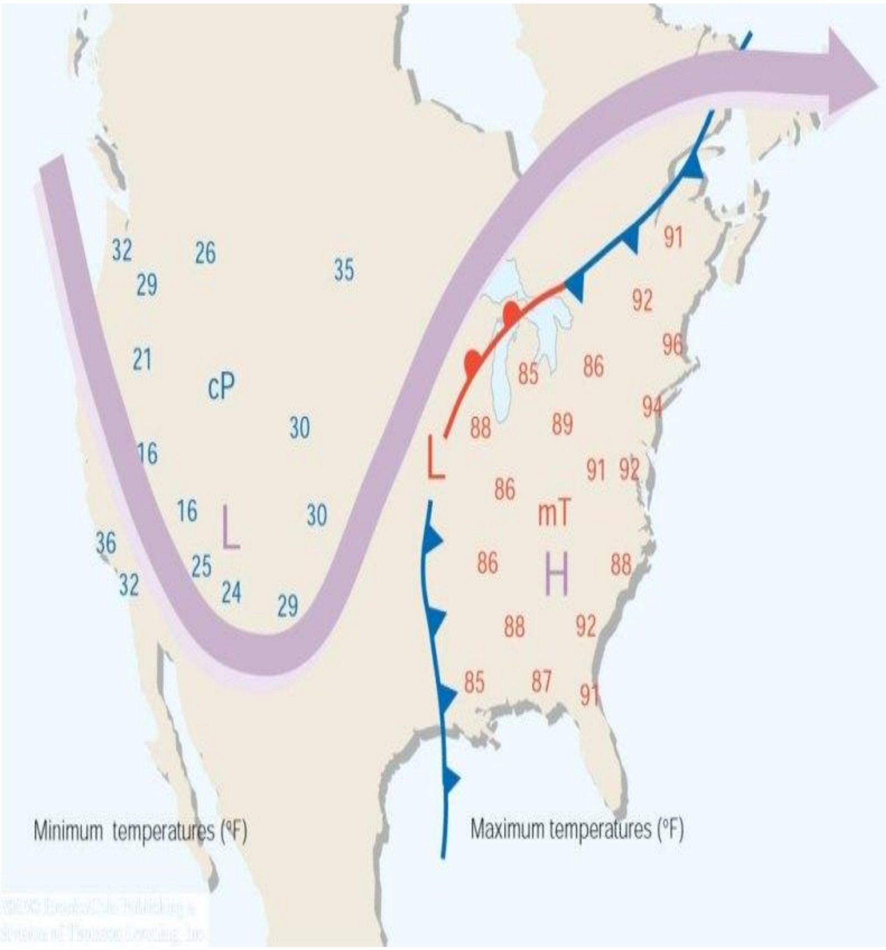
mT

- Wintertime source region for Pacific Maritime Tropical air mass is the subtropical east Pacific Ocean.
- Must travel many many miles over the ocean before reaching the California coast.
- Warm, moist air masses that produce heavy precipitation. Warm rains can cause rapid snow melt leading to disastrous mud slides.
- mT air that influences the weather east of the Rockies originates over the Gulf of Mexico and Caribbean Sea.



- An infrared satellite image that shows subtropical (mT) air (heavy red arrow) moving into northern California on January 1, 1997. The warm, humid airflow (sometimes called "the pineapple express") produced heavy rain and extensive flooding in northern and central California.

mT

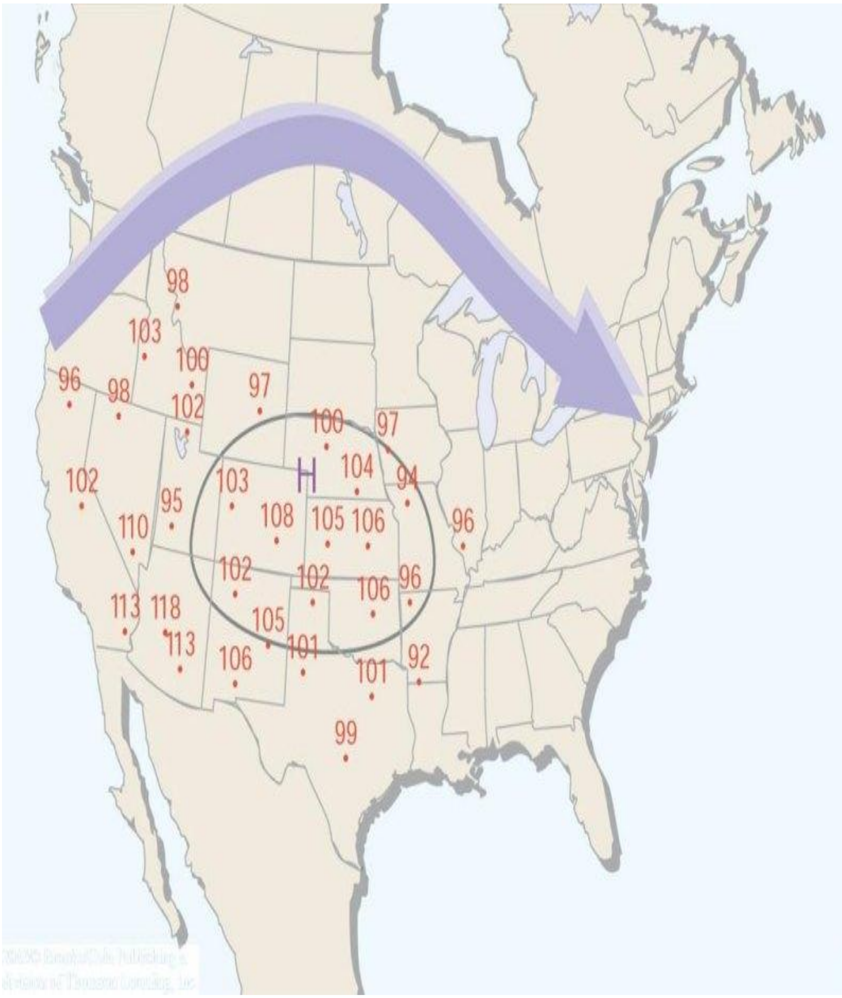


- The surface low-pressure area and fronts are shown for April 17, during an unseasonably hot spell in the eastern portion of the United States. Numbers to the east of the surface low (in red) are maximum temperatures recorded during the hot spell, while those to the west of the low (in blue) are minimums reached during the same time period. The heavy arrow is the average upper-level flow during the period. The faint L and H show average positions of the upper-level trough and ridge.

cT

- The only real source region for this hot dry continental tropical air mass in North America is found during the summer in Northern Mexico and the adjacent arid southwestern United States.
- Hot, dry, unstable. RH<10% in the afternoons, frequent dust devils during the day.
- **Air mass weather** – Persistent weather conditions brought about when an air mass controls the weather in a region for some time.

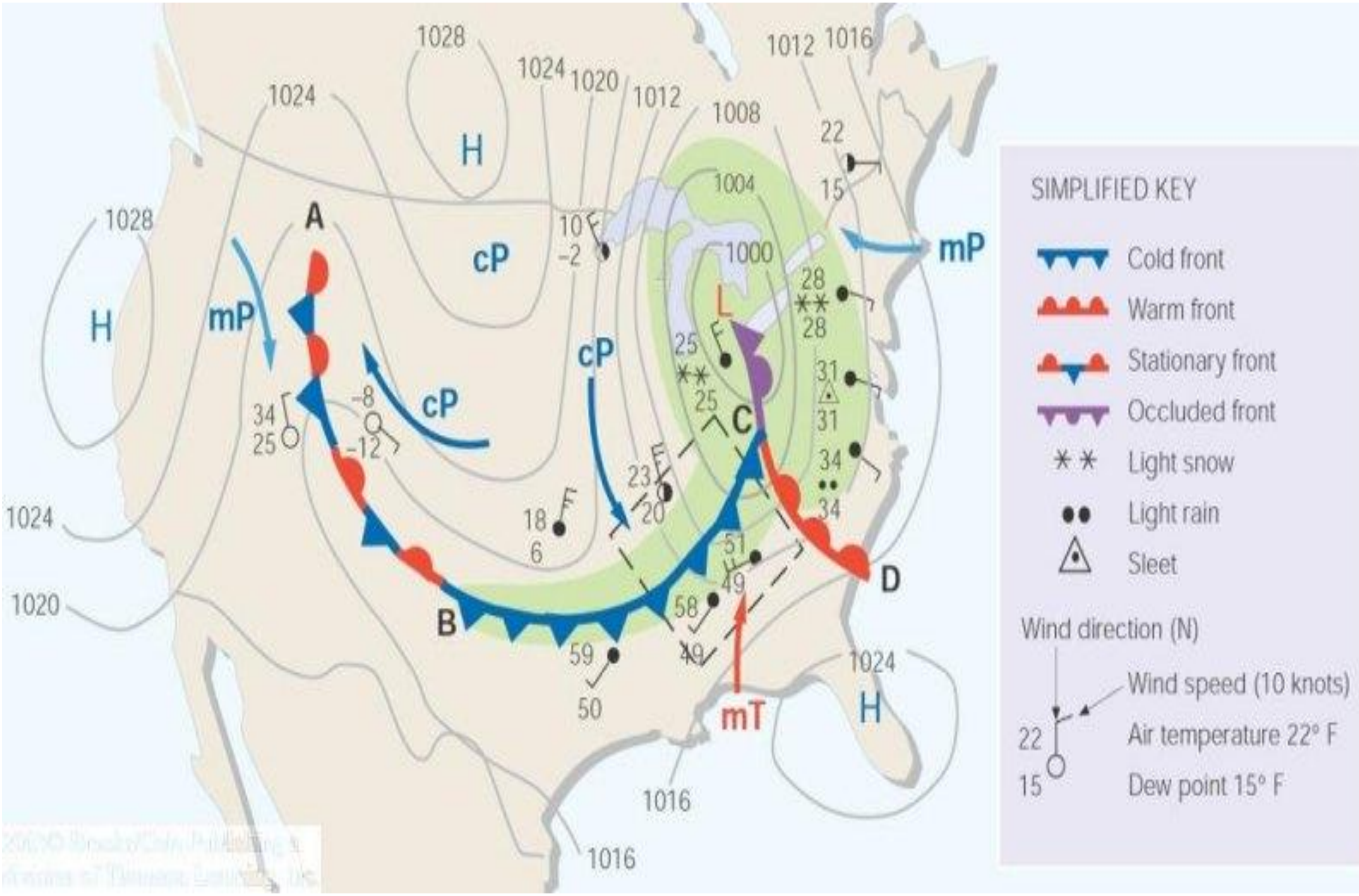
cT



- During June 29 and 30, 1990, continental tropic air covered a large area of the central and western United States. Numbers on the map represent maximum temperatures (°F) during this period. The large H with the isobar shows the upper-level position of the subtropical high. Sinking air associated with the high contributed to the hot weather. Winds aloft were weak with the main flow shown by the heavy arrow.

Fronts

- A **front** is a transition zone between two air masses of different densities. Since density differences are most often caused by temperature differences, fronts usually separate air masses with contrasting temperatures. Often they will also have contrasting humidities as well.
- Fronts have horizontal and vertical extent. The upward extension of a front is referred to as the *frontal surface* or *frontal zone*.



A weather map showing surface-pressure systems, air masses, fronts, and isobars (in millibars) as solid gray lines. Large arrows in color show air flow. (Green-shaded area represents precipitation.)

Stationary Front

- A front with *essentially no movement*
- Drawn as alternating red and blue line. Semicircles face toward colder air on the red line and triangles point toward warmer air on the blue line.
- Winds tend to blow parallel to a stationary front.
- If either a cold or warm front stops moving, it becomes a stationary front

Cold Front

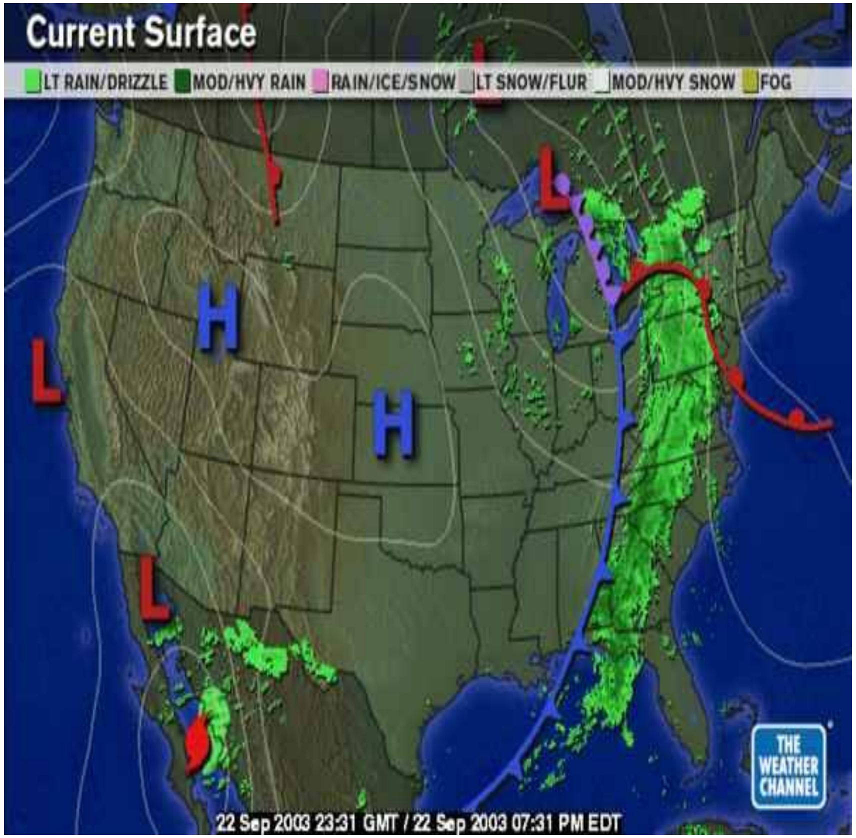
- Represents a zone where cold, dry stable polar air is replacing warm moist unstable tropical air.
- Drawn as solid blue line with the triangles along the front showing its direction of movement.

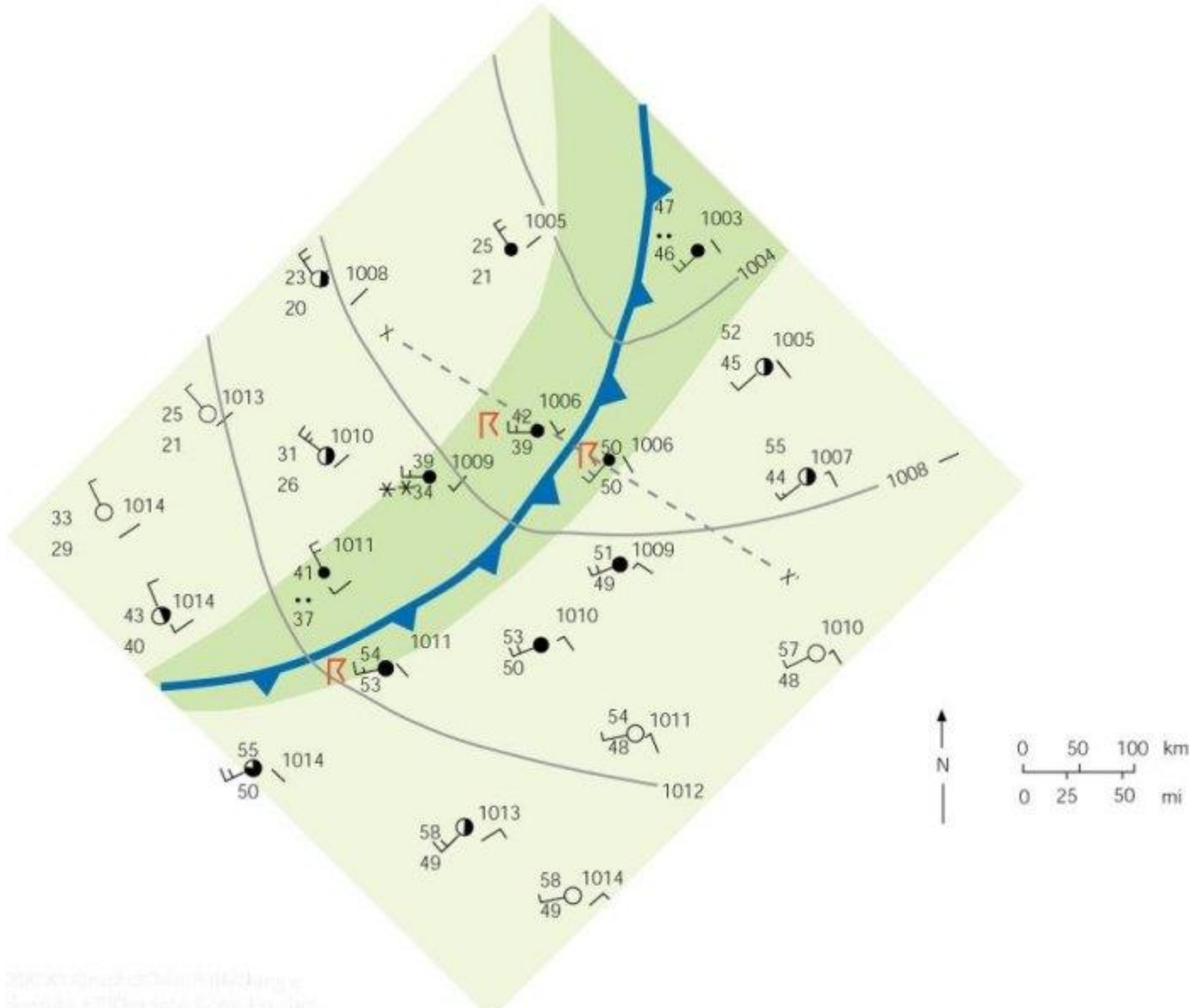
Criteria for locating a front

- Sharp temperature changes over a relatively short distance
- Changes in the air’s moisture content (changes in dew point)
- Shifts in wind direction
- Pressure and pressure changes
- Clouds and precipitation patterns.
- Fronts lie in a trough

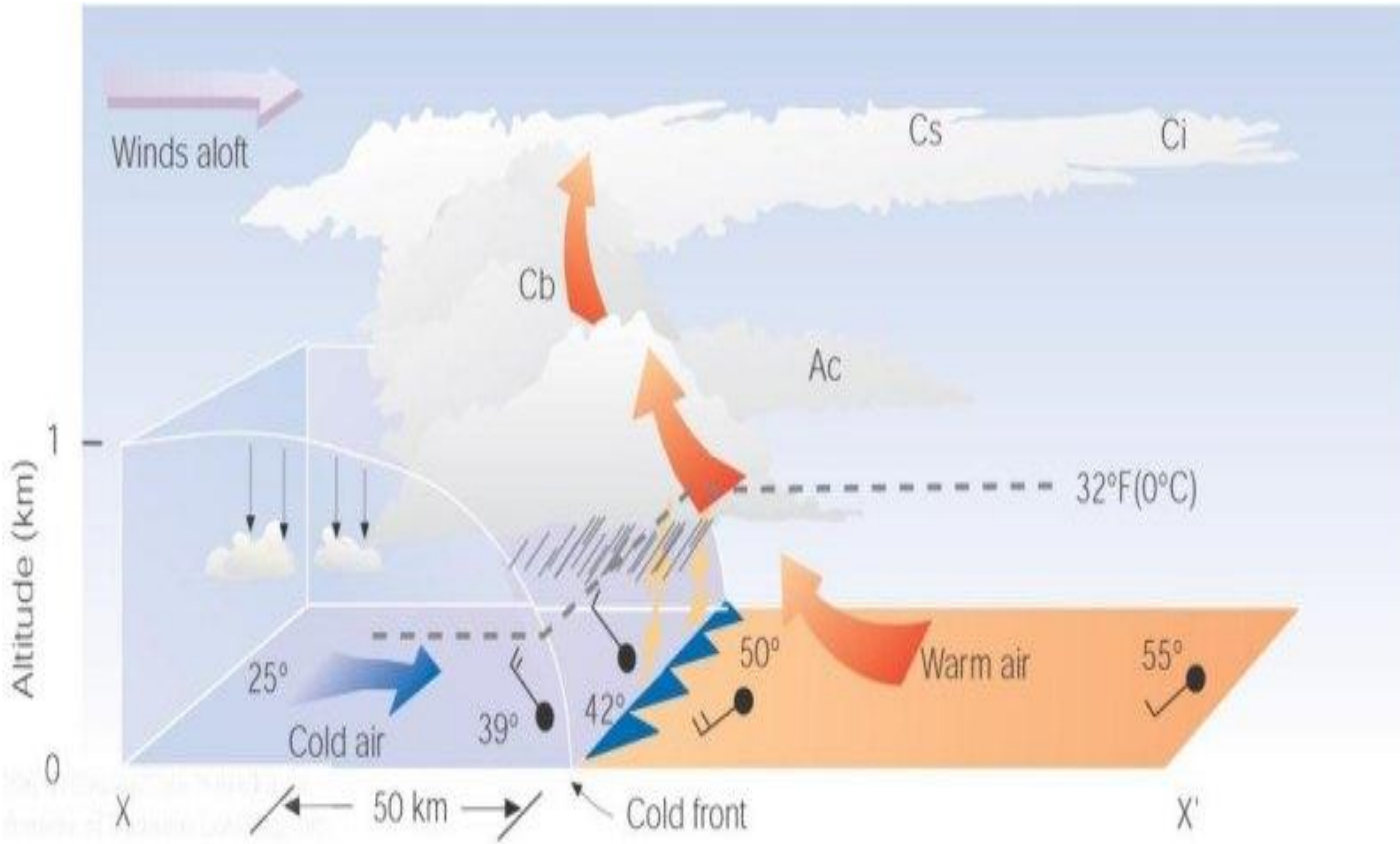
What is a Trough?

- A trough is an elongated area of low pressure
- Isobars kink as they cross cold fronts
- Wind shifts occur from one side of a front to the other
- Lowest pressures are usually recorded just as a front passes. Pressure falls in advance of a cold front and rises behind a cold front





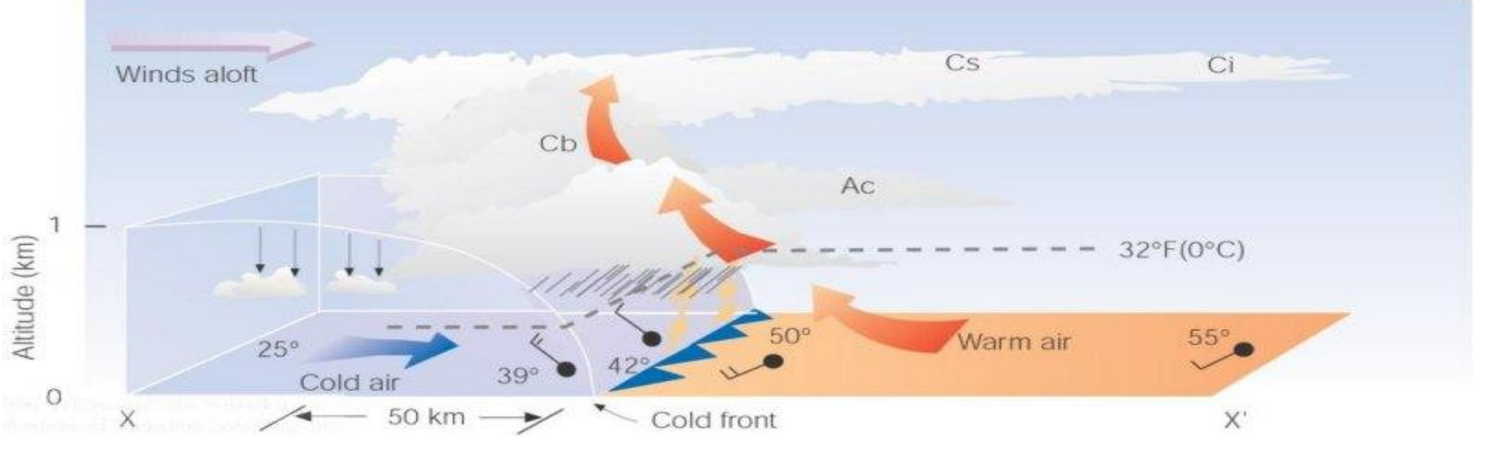
A closer look at the surface weather associated with the cold front situated in the southeastern United States in the previous figure. Gray lines are isobars. Dark green shaded area represents precipitation.



A vertical view of the weather across the cold front in the previous figure, along the line *X-X′*.

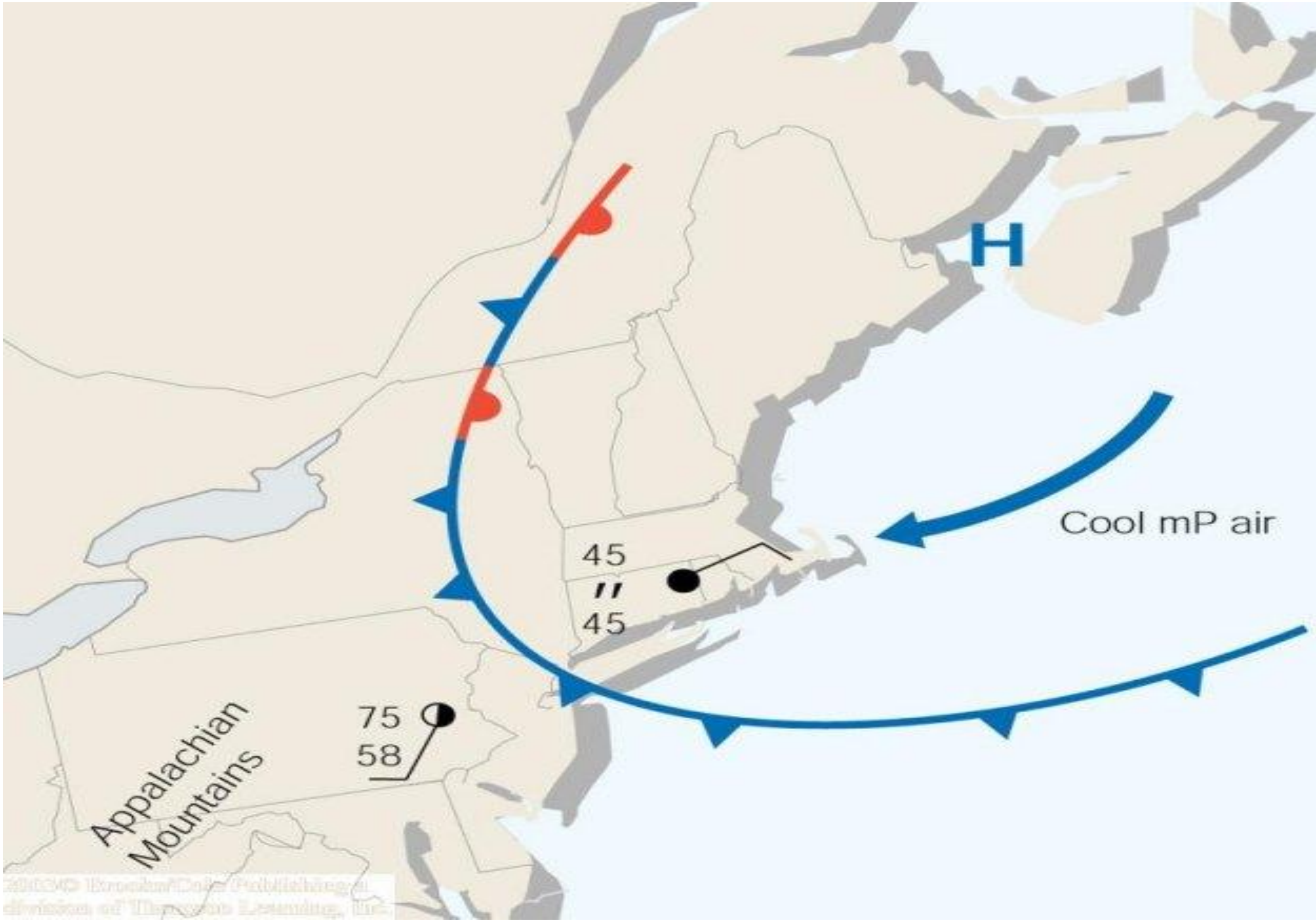
Slope of a cold front

- The leading edge of the front is steep
- Steepness due to friction
- Air aloft pushes forward blunting the frontal surface
- Distance from leading edge of front to cold air =50 km. But the front aloft is about 1 km over our head. Thus it is said to have a slope of 1:50
- This is a fast moving front. Slow moving fronts have less slope



Typical weather with a cold front

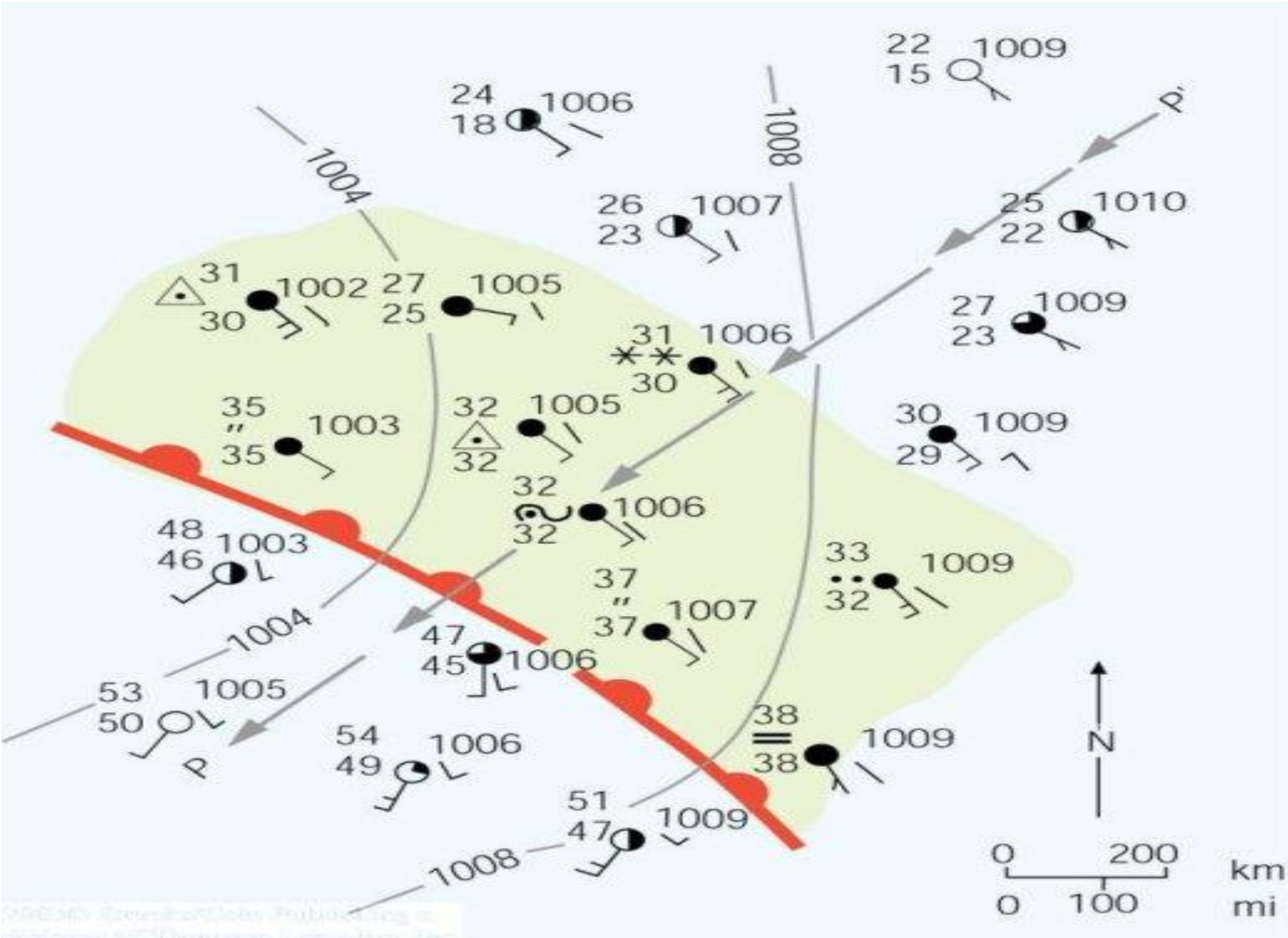
- Winds shift from S or SW to W or NW
- Temperature – warm before drops at front and keeps dropping
- Pressure – Falls steadily before, minimum at FROPA, rises after
- Precipitation – Showers before; heavy precip at front, TSTMS, snow; precip decreases then clearing
- Visibility – Hazy before; poor at front; improving after
- Dewpoint – High before; sharp drop at FROPA; lowering after



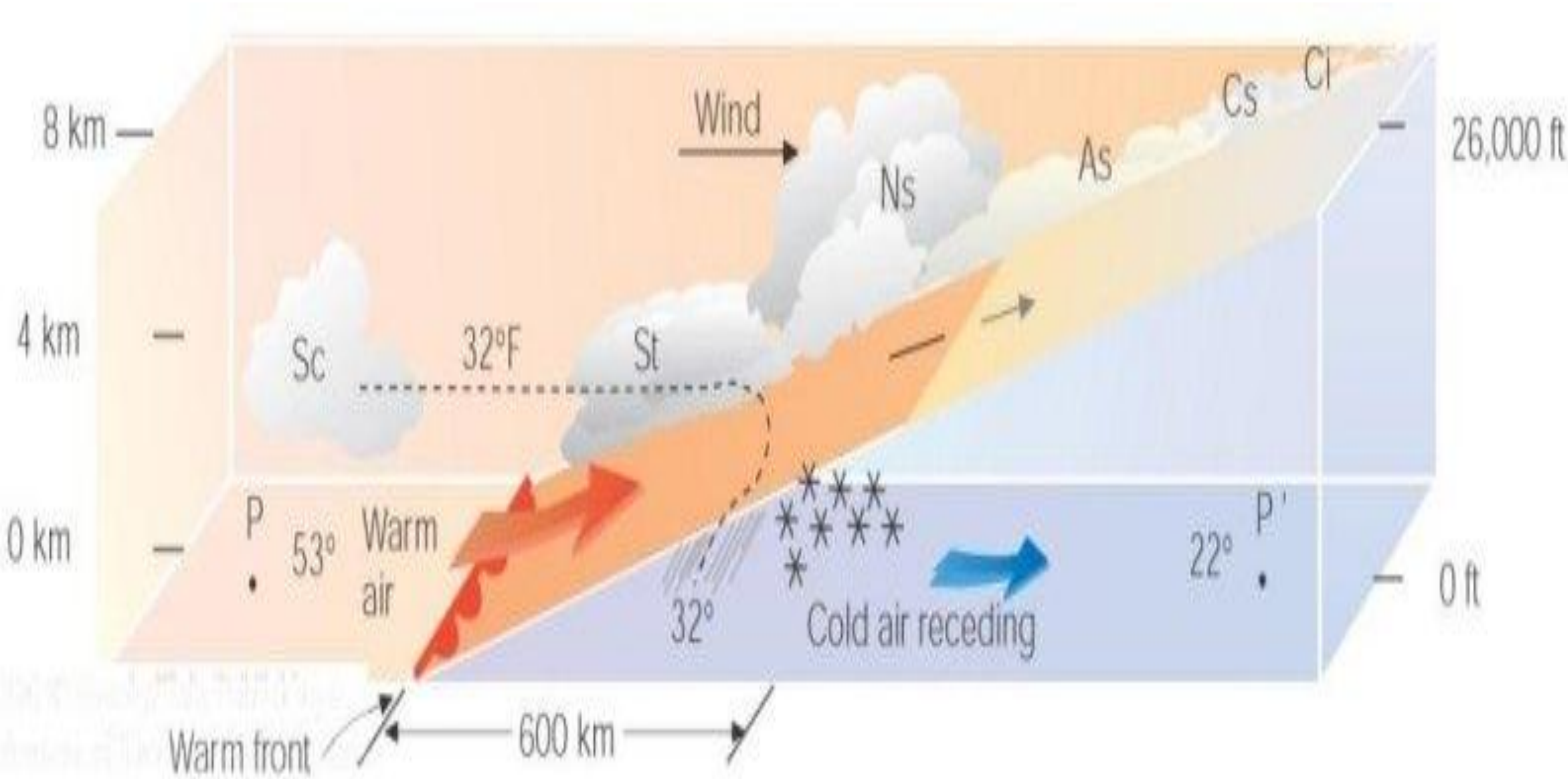
A "back door" cold front moving into New England during the spring. Notice that, behind the front, the weather is cold and damp with drizzle, while to the south, ahead of the front, the weather is partly cloudy and warm

Warm Fronts

- A warm front is a front that moves in such a way that warm air replaces cold air
- Depicted by solid red line with half circles pointing into the cold air
- Average speed of movement = 10 kts (half the speed of an avg cold front)
- **Overrunning** – rising of warm air over cold; produces clouds and precipitation well in advance of the front’s surface boundary
- Average slope is 1:300



Surface weather associated with a typical warm front. Gray lines are isobars. (Green-shaded area represents precipitation.)



- Vertical view of clouds and precipitation across the warm front in Fig. 8.15 (the previous figure), along the line P-P'.

Typical weather with a warm front

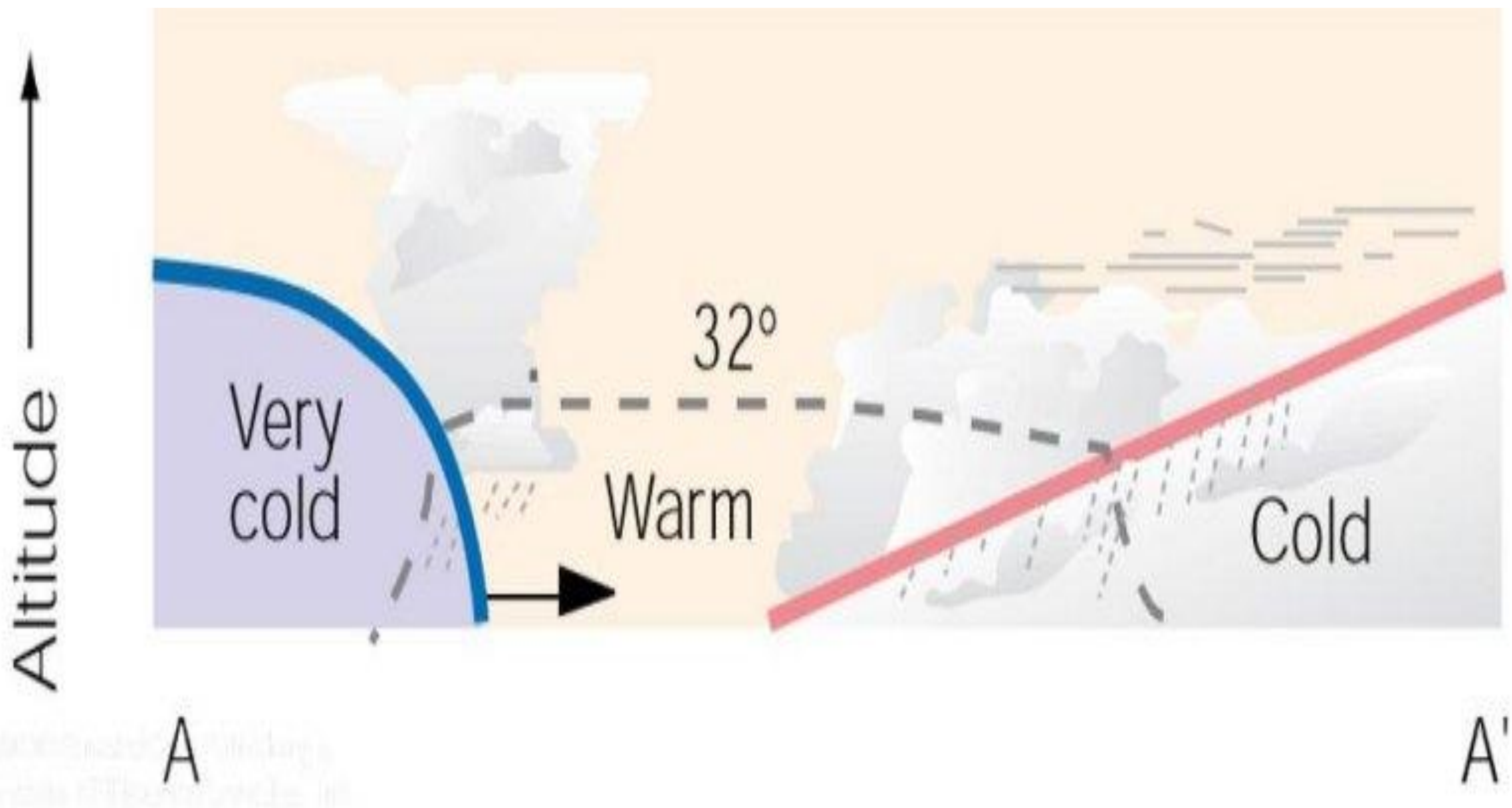
- Winds before (S or SE); variable at front; S or SW after FROPA
- Temperature – cool to cold before; rising at FROPA; Warmer then steady after
- Pressure – Usually falling before; steady at FROPA; slight rise then falling after
- Clouds Ci, Cs, As, Ns, St, Fog, occasional CB before; Stratus with the front; clearing with scattered SC after
- Precipitation – light to mod Rain, snow, sleet, or drizzle (with showers in summer) before; Drizzle at FROPA; little to no precip after FROPA
- Dew point – steady rise before FROPA; Steady with FROPA; Rise then steady after FROPA

Occluded Fronts

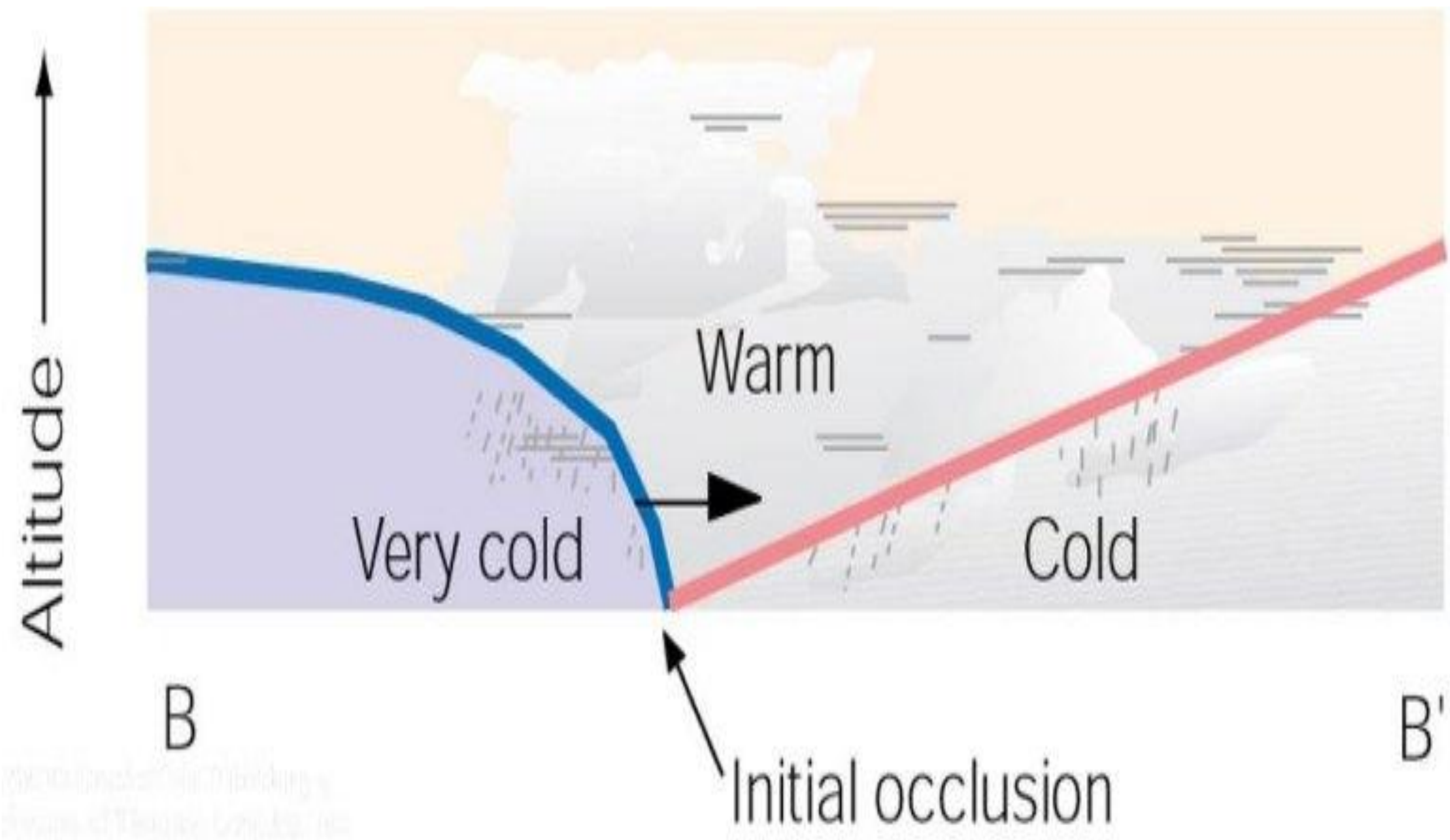
- When a cold front catches up to and overtakes a warm front, the frontal boundary created between the two air masses is called an **occluded front** or simply an **occlusion**
- Represented as a solid purple line with alternating cold front type triangles and warm front half circles
- Two types: Warm and cold occlusions; cold occlusions most prevalent in the Pacific coastal states; warm occlusions occur when the milder, lighter air behind a cold front is unable to lift the colder heavier air off the ground and instead rides up along the sloping warm front

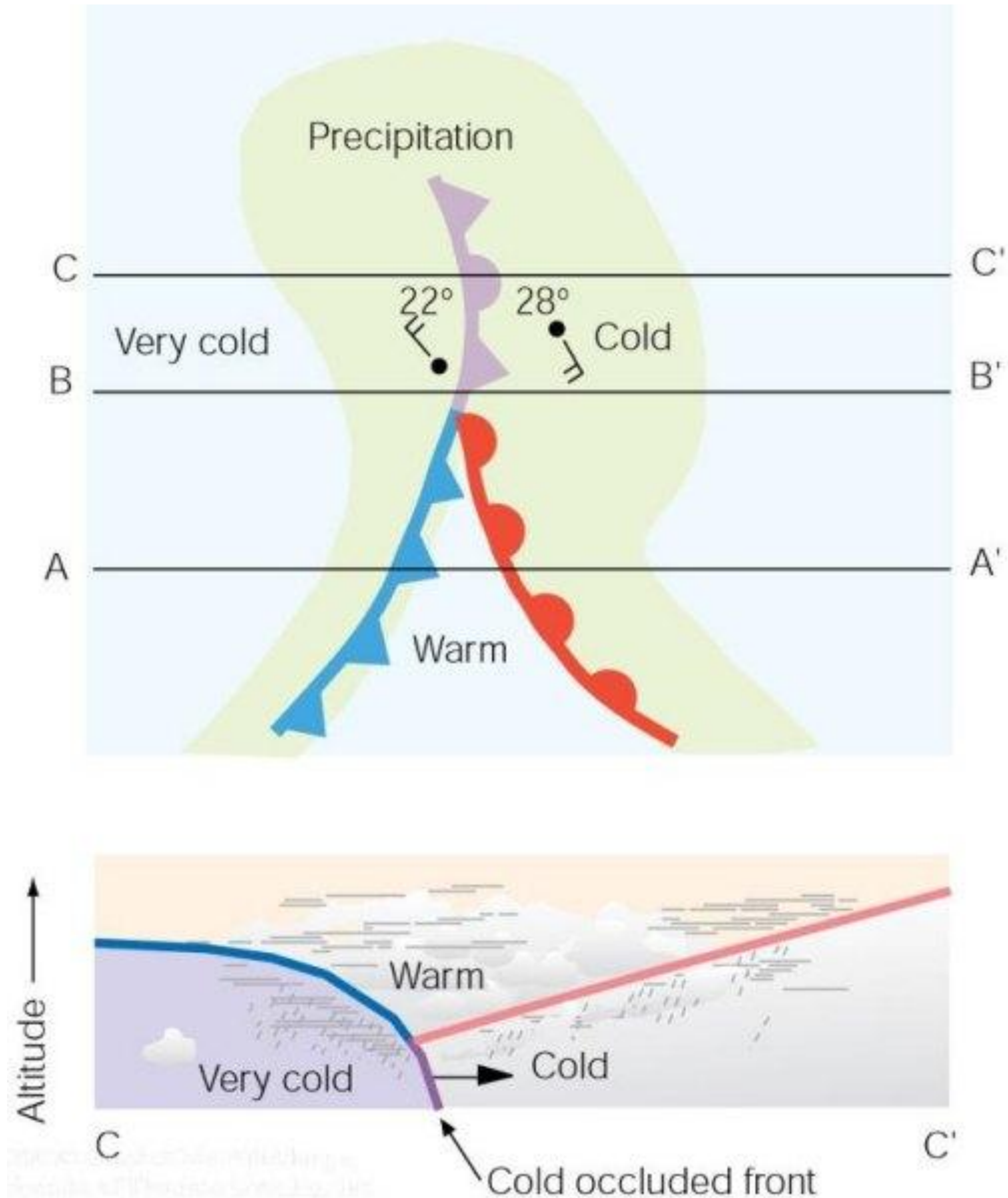
The formation of a cold-occluded front.

The faster-moving cold front...



...catches up to the slower-moving warm front...

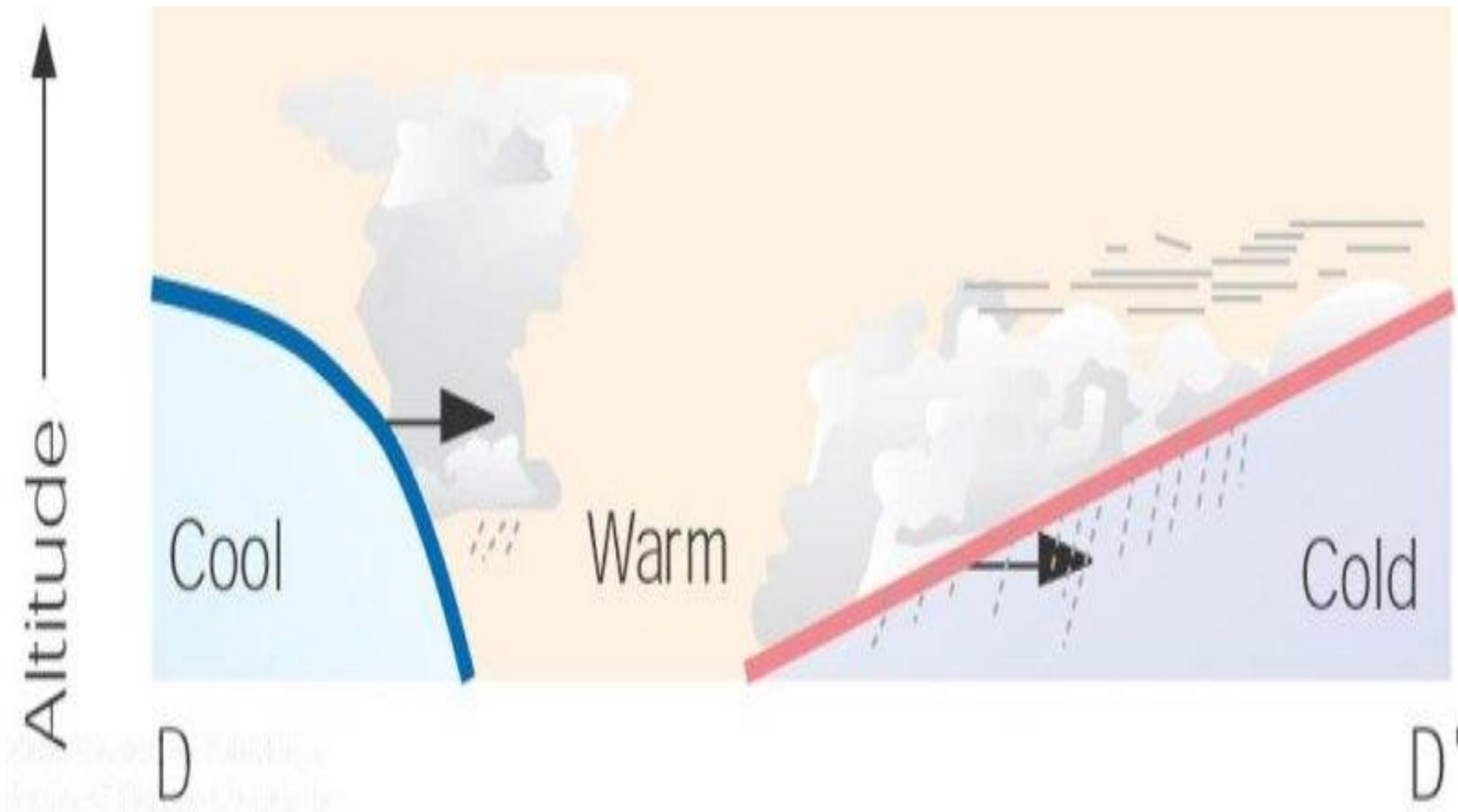




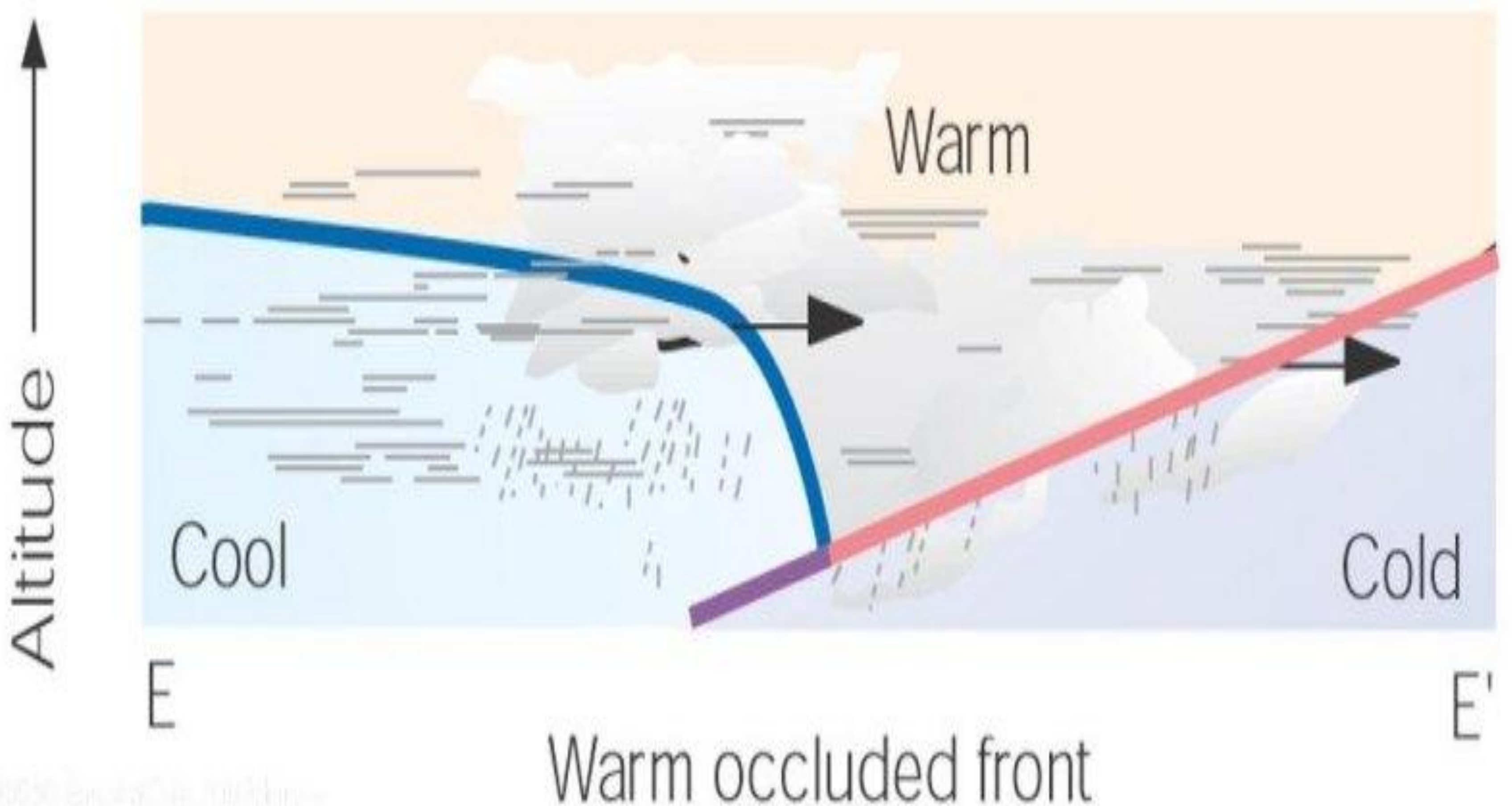
...and forces it to rise off the ground. (Green-shaded area represents precipitation.)

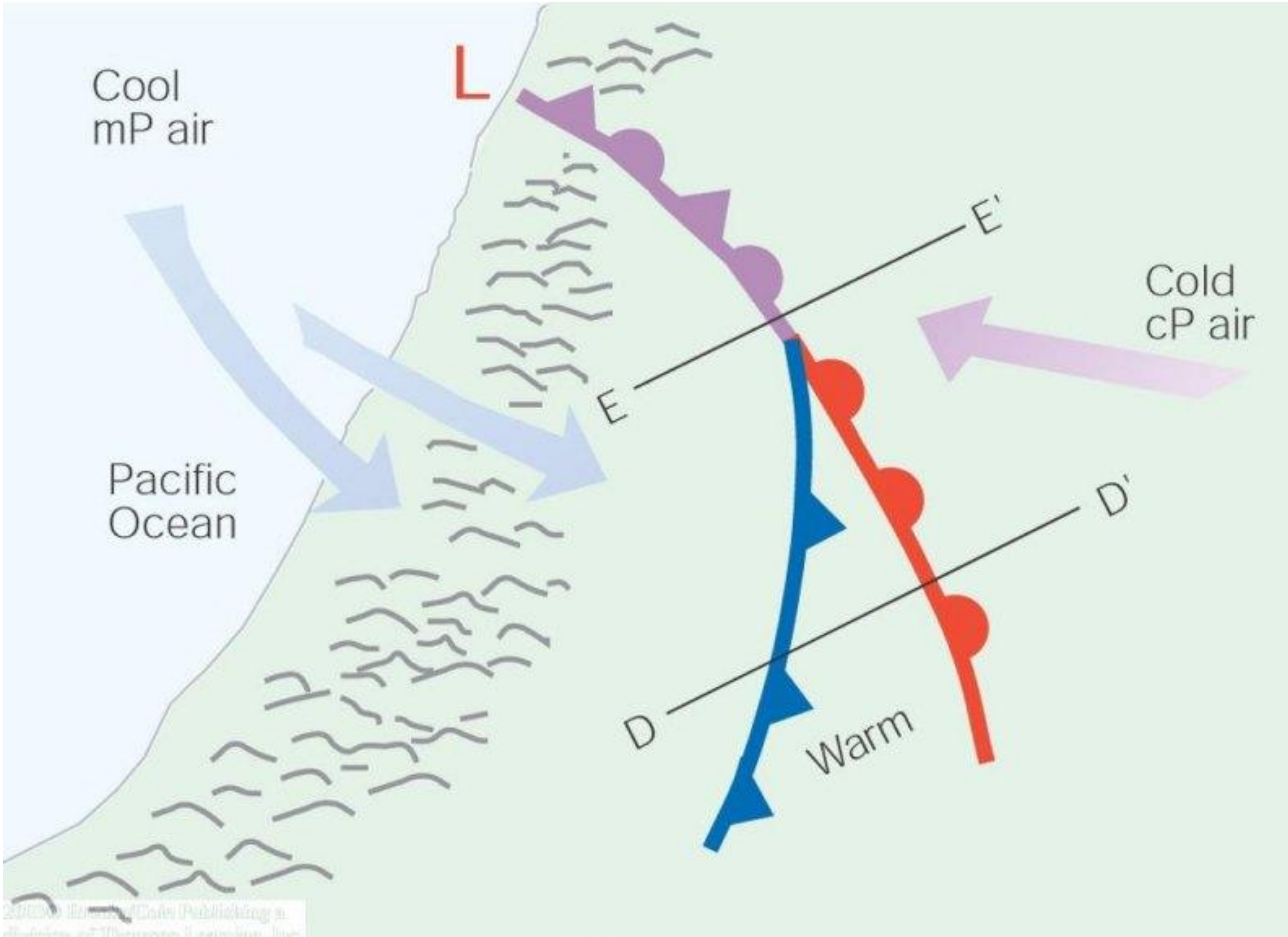
The formation of a warm-type occluded front.

The faster-moving cold front in this figure..

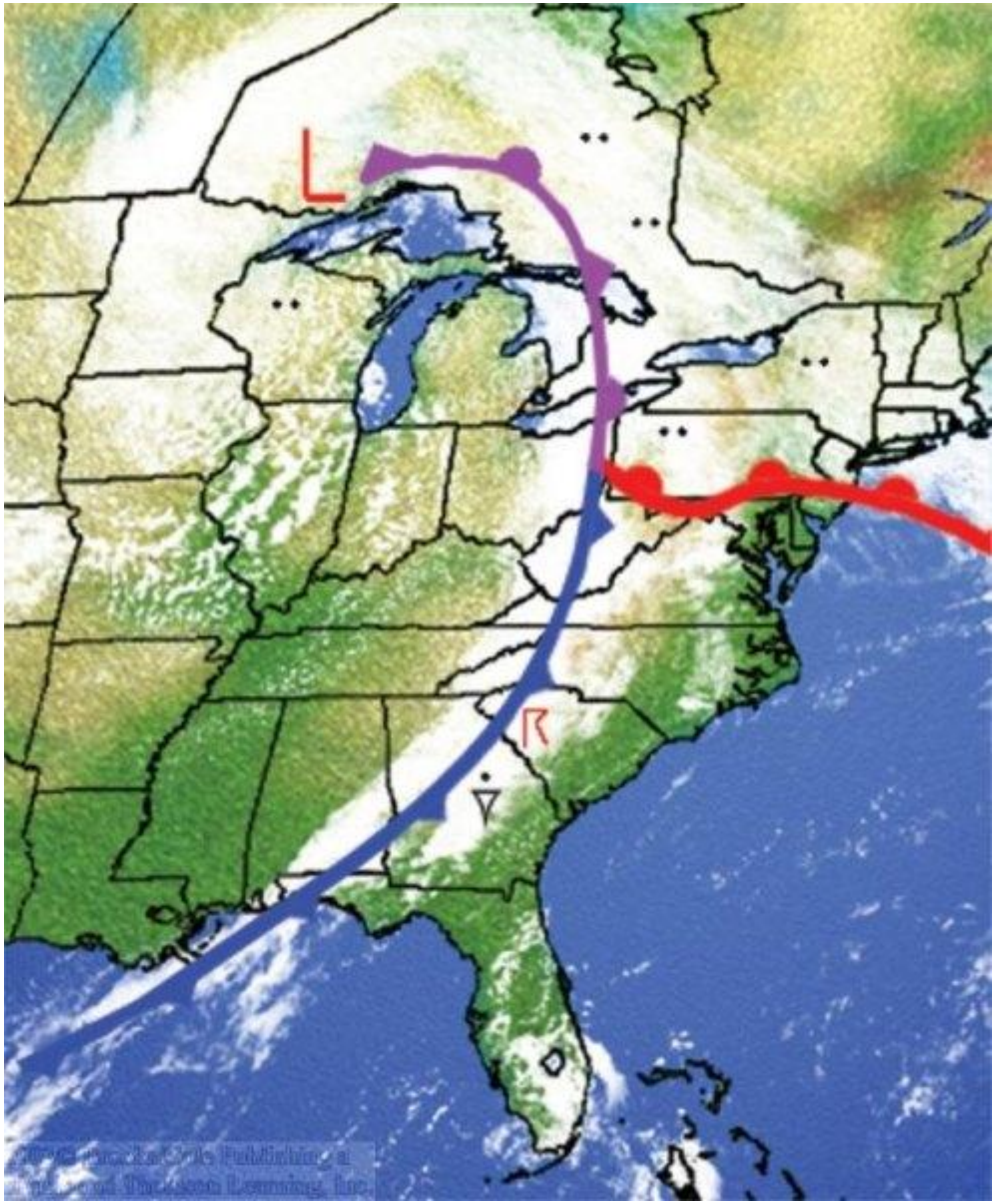


...overtakes the slower-moving warm front in this figure.





The lighter air behind the cold front rises up and over the denser air ahead of the warm front. Here is a surface map of the situation.



A visible satellite image taken on May 22, 2001. Superimposed on the photo is the position of the surface cold front, warm front, and occluded front. Precipitation symbols indicate where precipitation is reaching the surface.

Typical weather with an occluded front

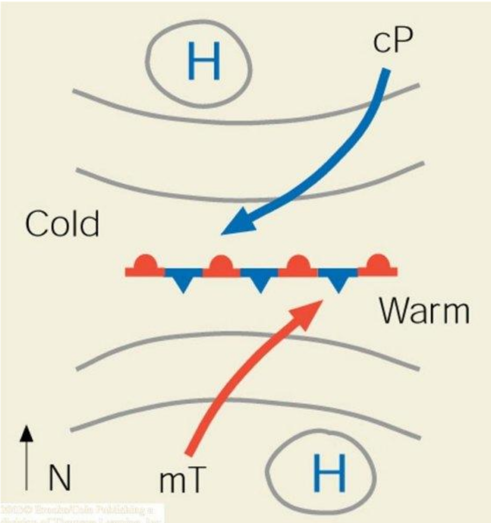
- Winds – E, SE, or S before; variable at FROPA; W or NW after
- Temperature (Cold type) – Cold or cool before; dropping with FROPA; Colder after
- Temperature (Warm type) – Cold before; Rising with FROPA; Milder after.
- Clouds – Ci, Cs, As, Ns before, Ns, Tcu, Cb with FROPA; Ns, As or scattered Cu after
- Precipitation – All intensities before; during and after followed by clearing
- Dewpoint – steady before; slight drop with FROPA, slight drop after but may rise a bit if warm occlusion

Polar Front Theory

- Developed by Norwegian scientists (Bjerknes, Solberg, Bergeron)
- Published shortly after WW I
- Polar front theory of a developing wave cyclone
- Working model of how a mid-latitude cyclone progresses through stages of birth, growth, decay.
- Today the work has been modified to serve as a convenient way to describe the structure and weather associated with migratory storm systems.

Polar Front Theory

- Bet you cannot stand the suspense!
- Cannot wait another minute longer…
- OK here it is …
- Steady now, you are about the leave the world of the common person and join the elite world of the “informed”
- More Cocktail conversation



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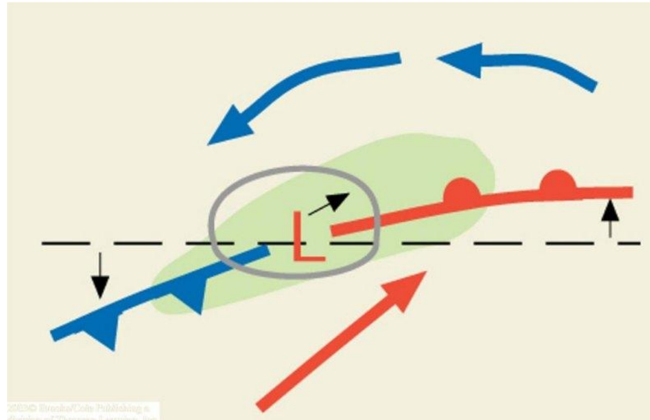

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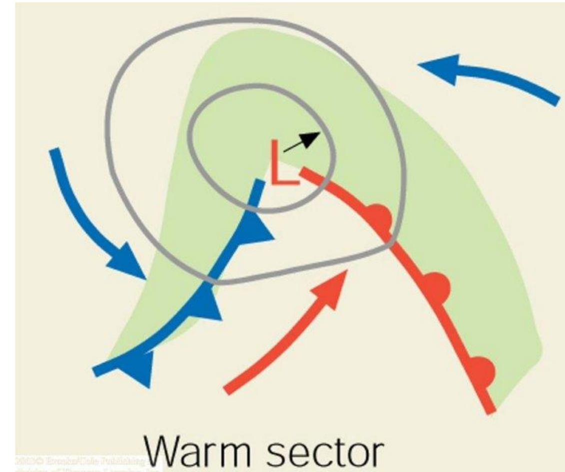

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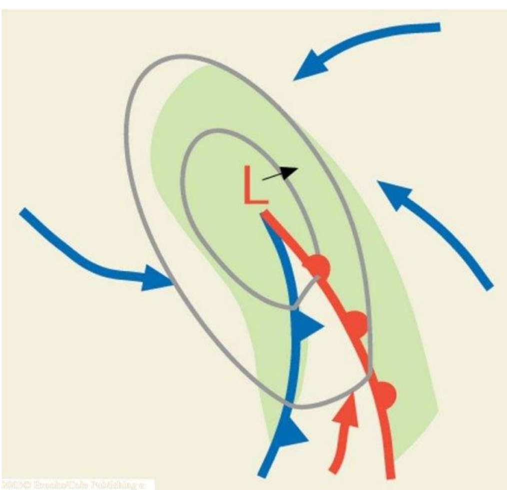

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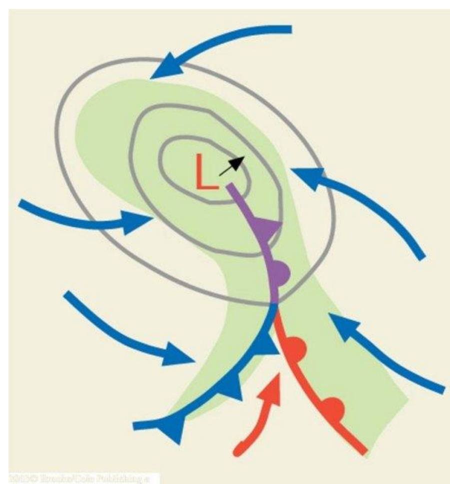

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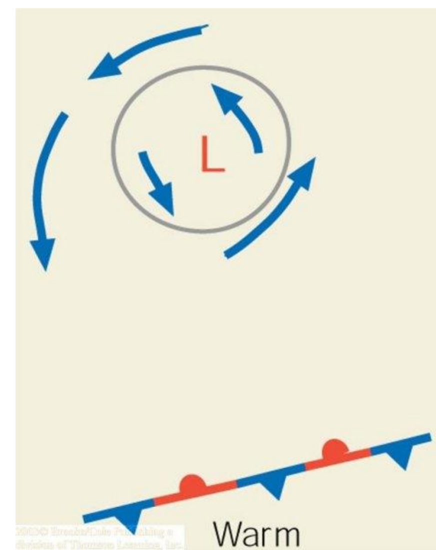

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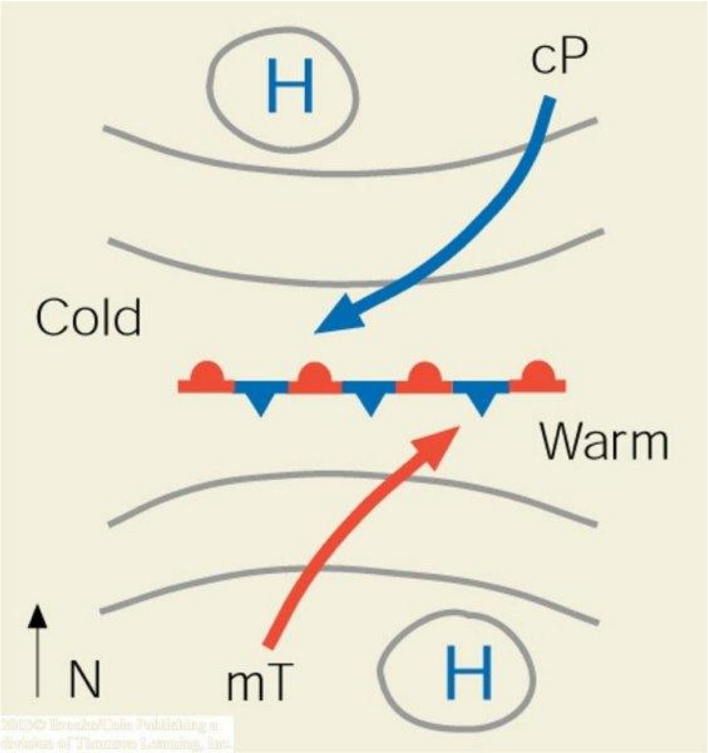
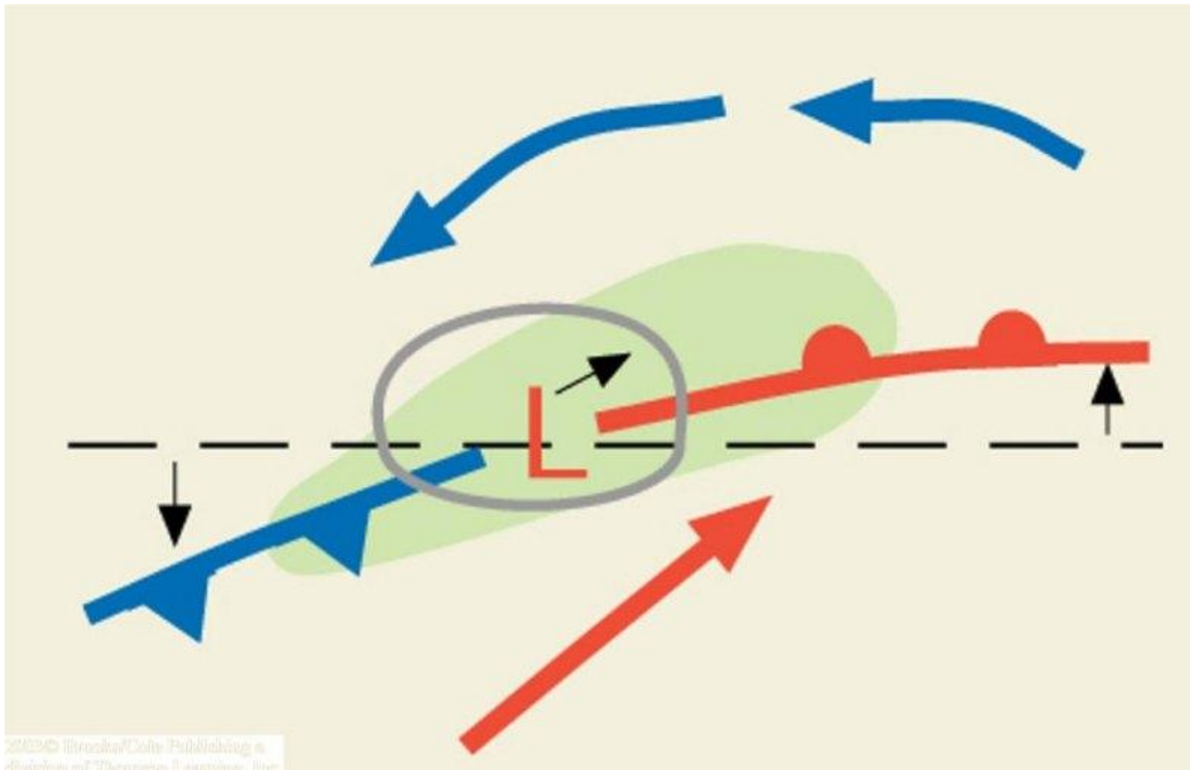
Step One



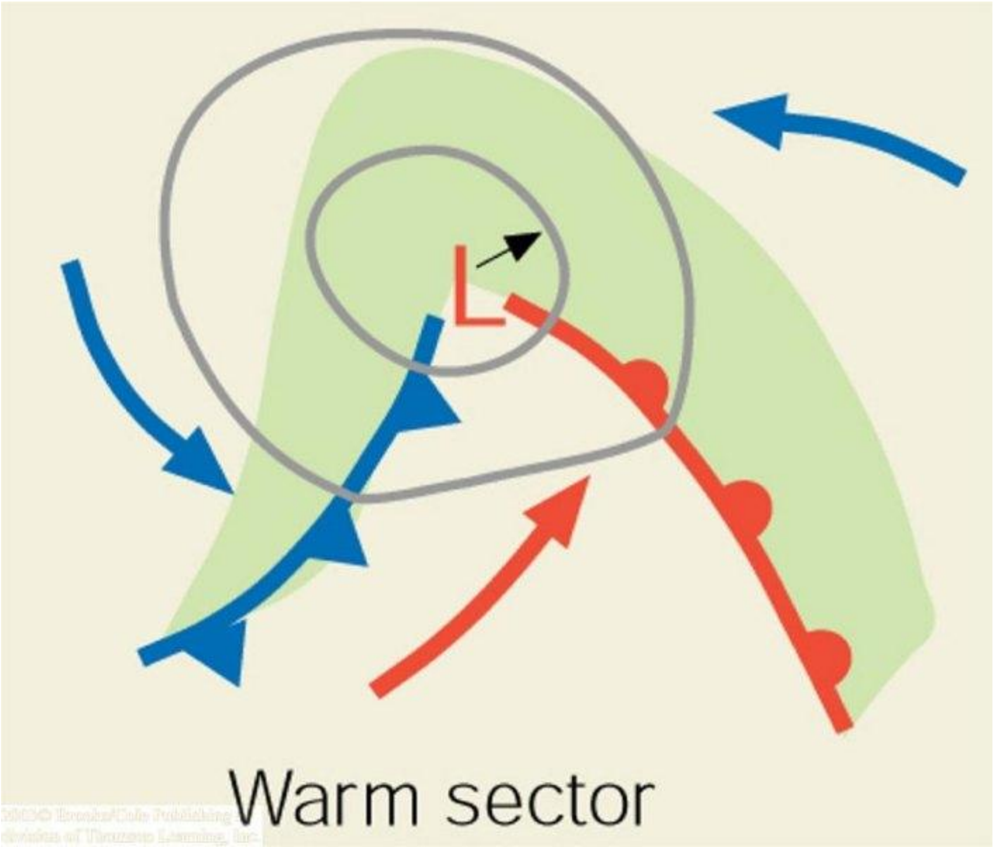
A segment of the polar front as a stationary front. (Trough of low pressure with higher pressure on both sides. Cold air to the North, warm air to the south. Parallel flow along the front.

Step Two



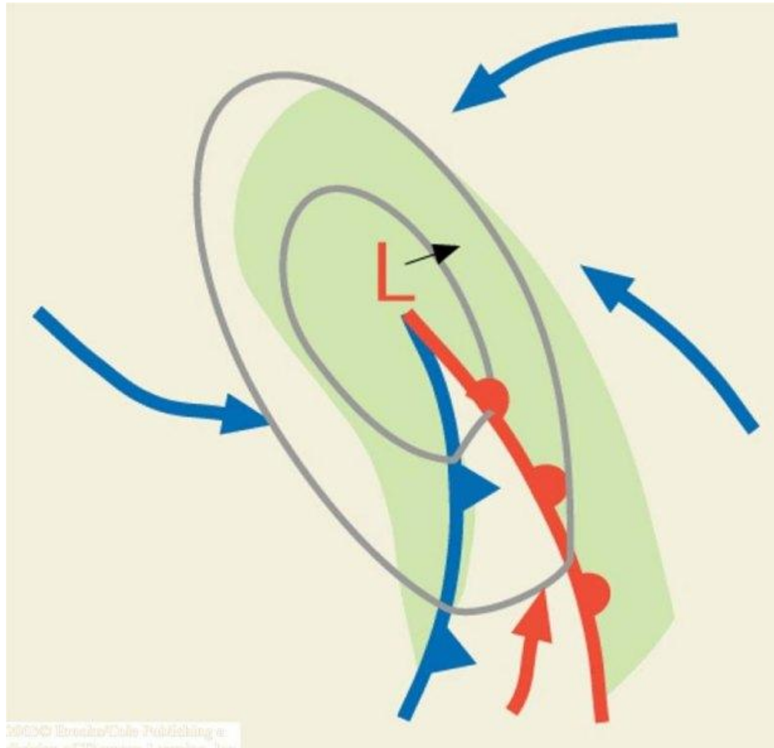
Under the right conditions a wavelike kink forms on the front. The wave that forms is known as a frontal wave. Wave cyclone – an extratropical cyclone that forms and moves along a front. The circulation of winds about the cyclone tends to produce a wavelike deformation on the front

Step Three



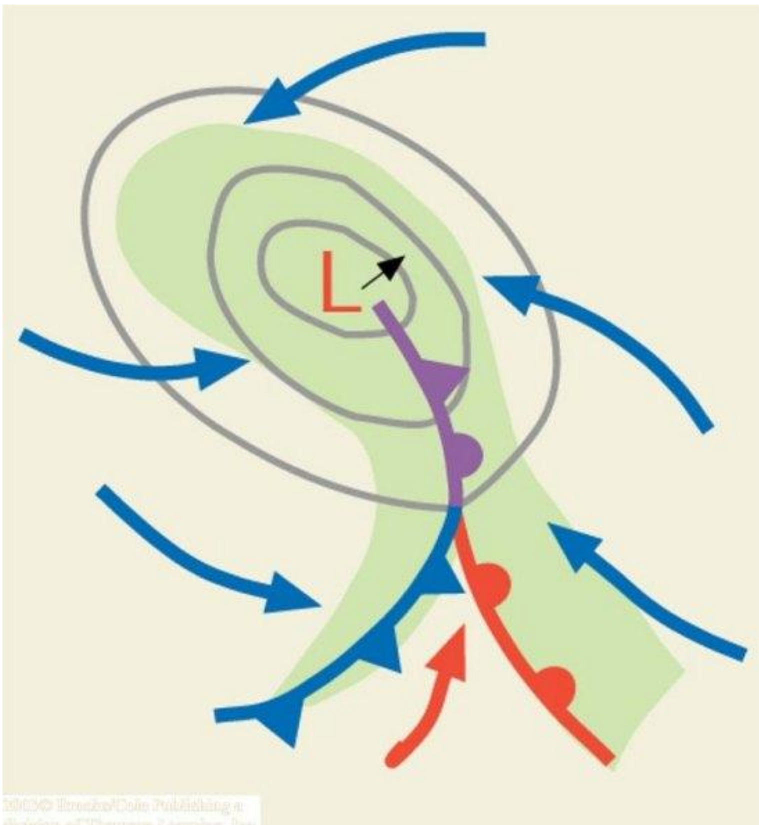
Steered by the winds aloft, the system typically moves east or northeastward and gradually becomes a fully developed open wave in 12 to 24 hours. **Open wave** – the stage of development of a wave cyclone where a cold front and a warm front exist, but no occluded front. The center of lowest pressure in the wave is located at the junction of two fronts.

Step Four



Central pressure is now lower, several isobars encircle the wave. The more tightly packed isobars create a stronger cyclonic flow, winds swirl counterclock-wise and inward toward the low’s center. Energy for the storm is derived rising warm air and sinking cold air transforming potential energy to kinetic energy (energy of motion). Condensation supplies energy in the form of latent heat. Converging surface winds produce an increase of kinetic energy. The cold front advances on the warm front…

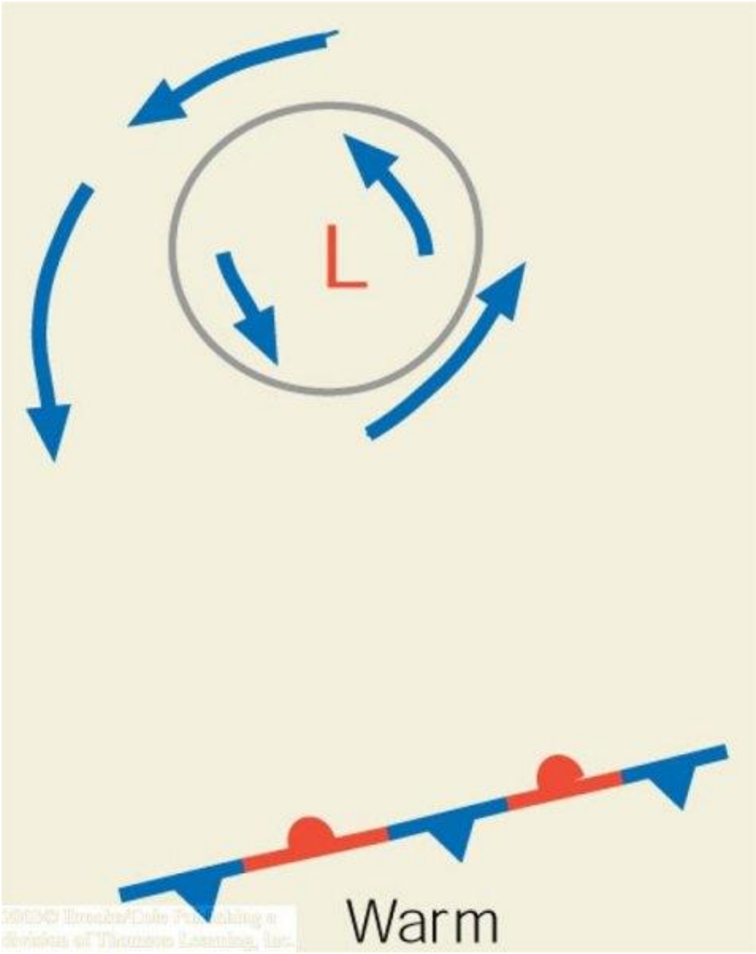
Step Five



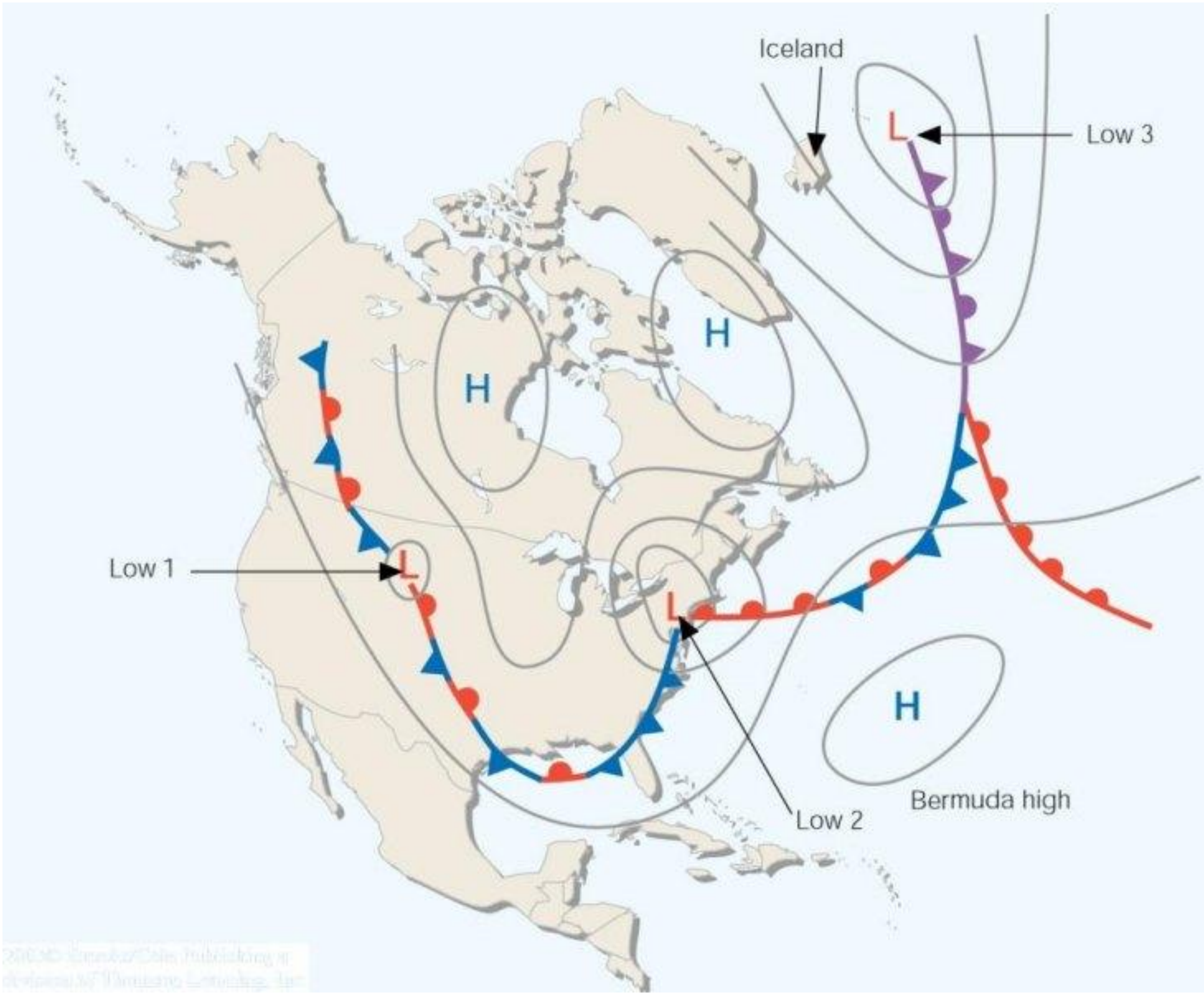
As the open wave moves eastward, central pressures continue to decrease, and the winds blow more vigorously. The faster-moving cold front constantly inches closer to the warm front, squeezing the warm sector into a smaller area. Eventually the cold front overtakes the warm front and the system becomes occluded. The storm is usually most intense at this time, with clouds and precip covering a large area.

Step Six

- The intense storm from step five gradually dissipates, because cold air now lies on both sides of the cyclone. Without the supply of energy provided by the rising warm, moist air, the old strom system dies out and gradually disappears. Occasionally, however a new wave will form on the westward end of the trailing cold front.
- **The entire life cycle of a wave cyclone can last from a few days to over a week.**

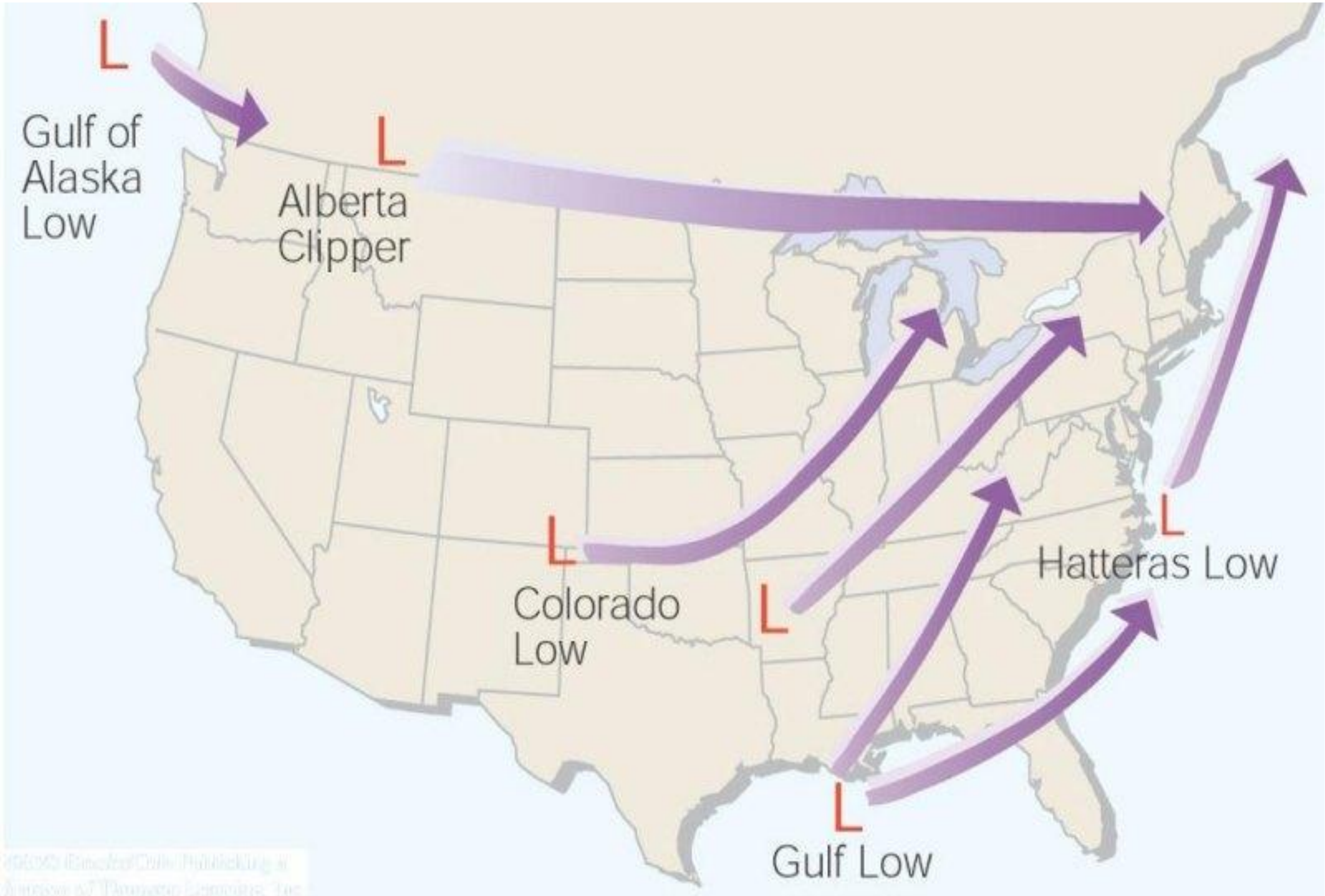


A series of wave cyclones (a "family" of cyclones) forming along the polar front

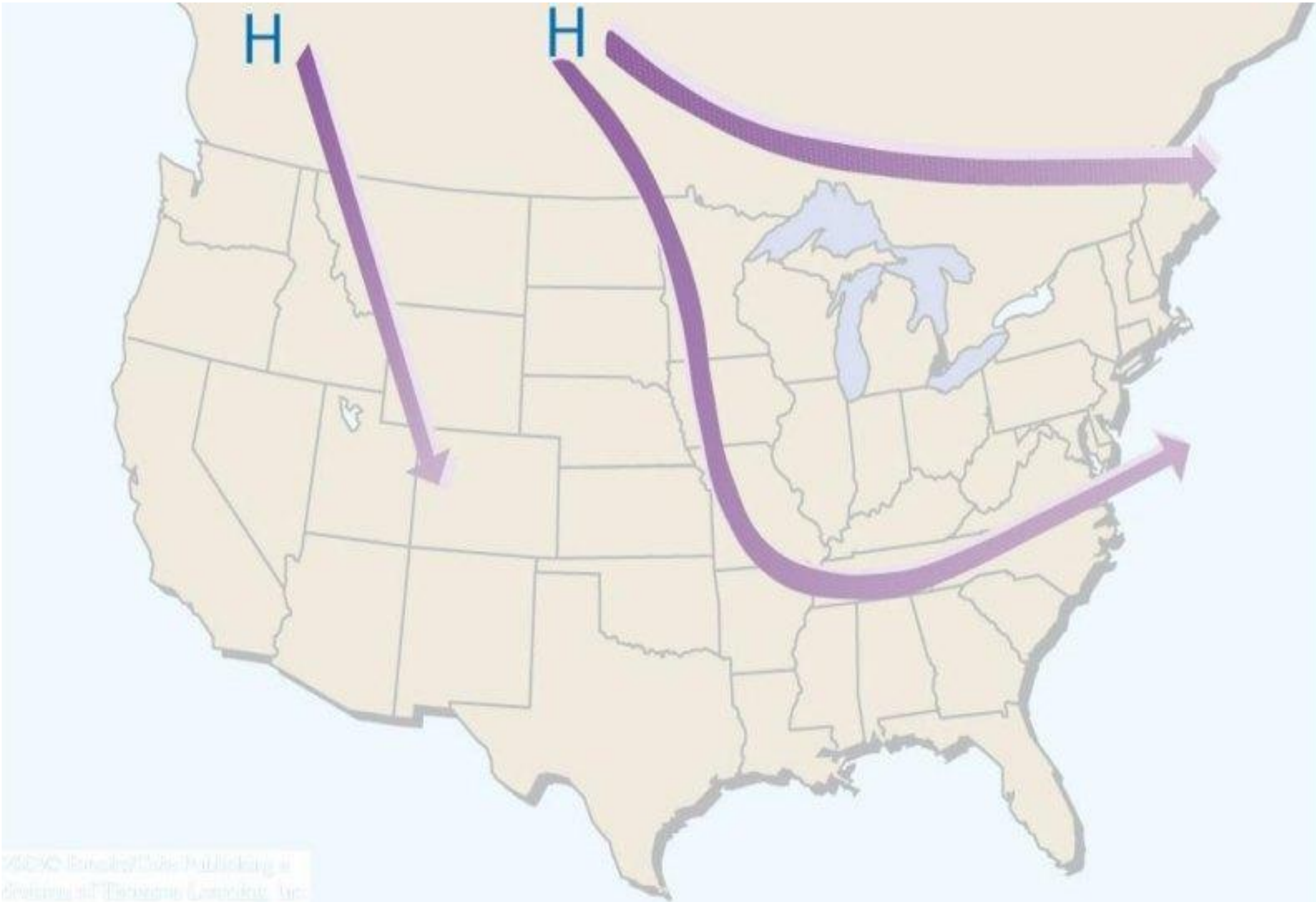


Where do mid-latitude cyclones tend to form?

- **Cyclogenesis** – any development or strengthening of a mid-latitude cyclone
- Here in the US there are regions that show a propensity for cyclogenesis, including the eastern slopes of the Rockies, where a strengthening of developing storm is called a **lee-side low** because it is forming on the leeward side of the mountains.
- Additional areas include Great Basin, Gulf of Mexico, Atlantic Ocean-east of the Carolinas



Typical paths of winter mid-latitude cyclones. The lows are named after the region where they form.



Typical paths of winter anticyclones

Northeasters

- Storms that form along the eastern seaboard of the United States and then move northeastward.
- This causes northeasterly winds along the coastal areas.
- These Nor’easters usually bring heavy snow or sleet and gale force winds which frequently attain maximum intensity off the coast of New England.
- See details of December 1992 Nor’Easter in your text on page 223

Developing Mid-Latitude Cyclones and Anticyclones

- **Convergence** – The piling up of air or the atmospheric condition that exists when the wind cause a horizontal net inflow of air into a specified region
- **Divergence** – the spreading out of air or the atmospheric condition that exists when the winds cause a horizontal net outflow of air from a specific region

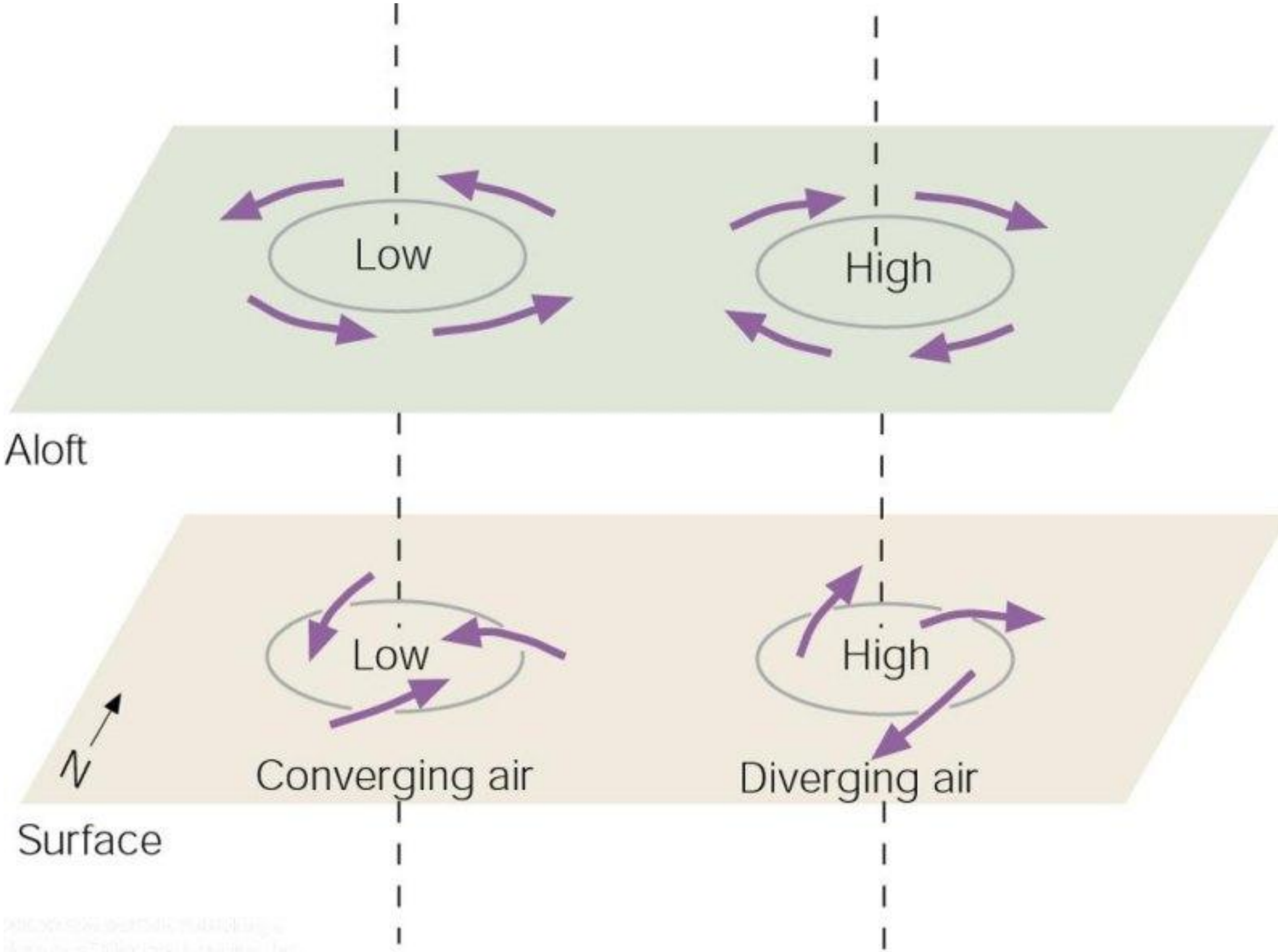
Developing Mid-Latitude Cyclones and Anticyclones

Thermal pressure systems are shallow and weaken with increasing elevation.

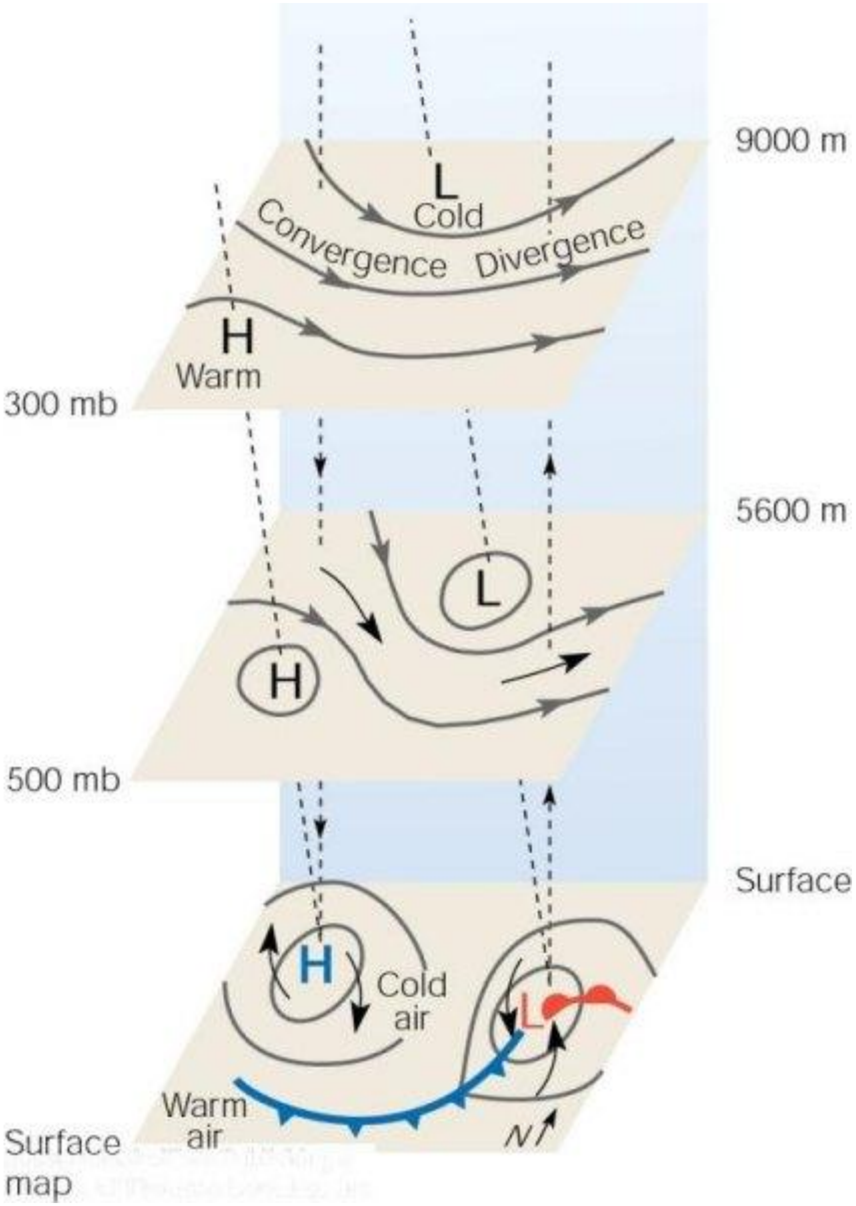
- Developing surface storm systems are deep lows that usually intensify with height
- Therefore, a surface low pressure area will appear on an upper level chart as either a closed low or a trough.

Developing Mid-Latitude Cyclones and Anticyclones

- Suppose an upper level low is directly above the surface low. Significant convergence does not occur in a low aloft as it does at the surface (no friction aloft). A low that is not supported by some divergence aloft will dissipate
- Same is true for a high pressure system; divergence at the surface needs some support from convergence aloft to survive



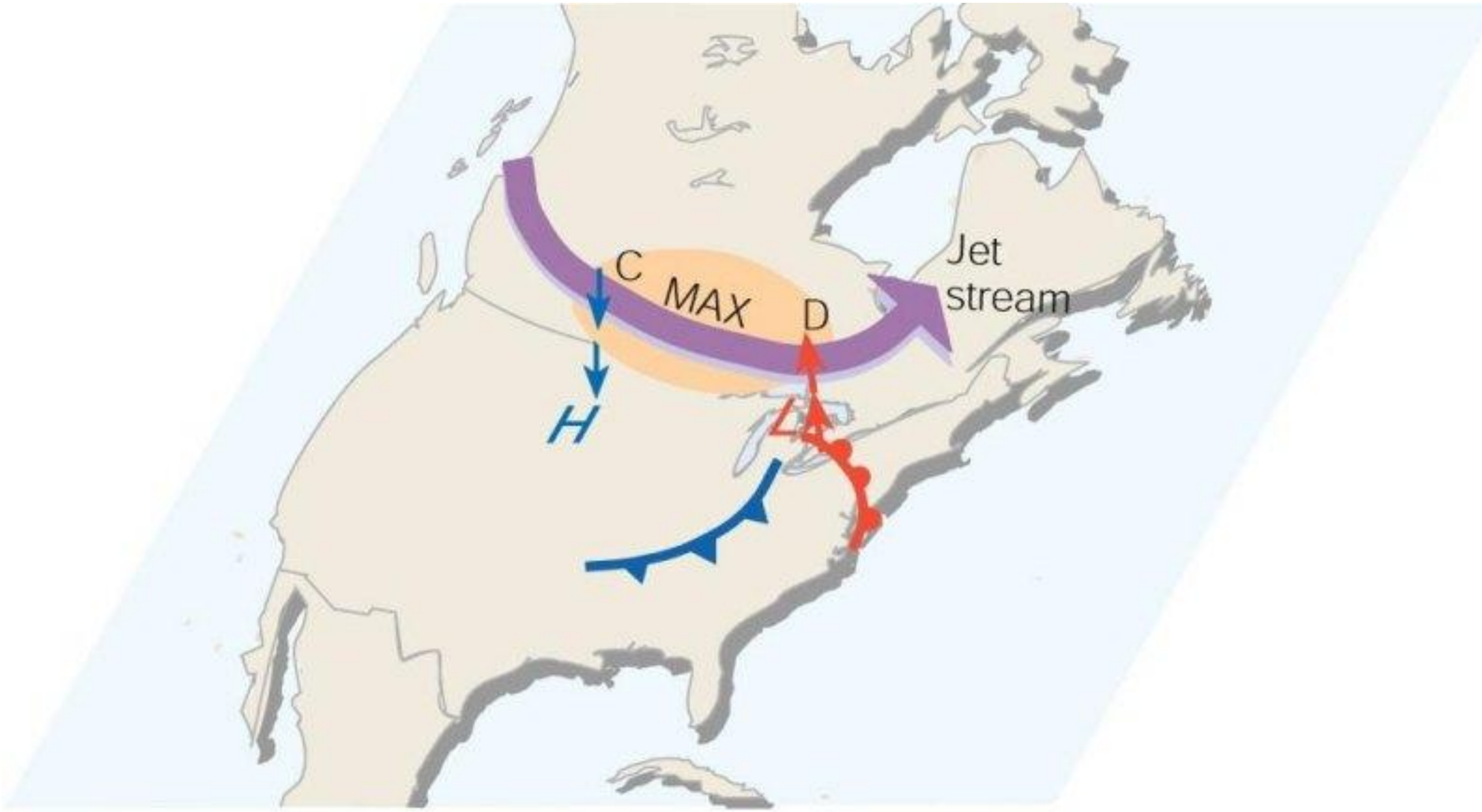
If lows and highs aloft were always directly above lows and highs at the surface, the surface systems would quickly dissipate.



An idealized vertical structure of cyclones and anticyclones.

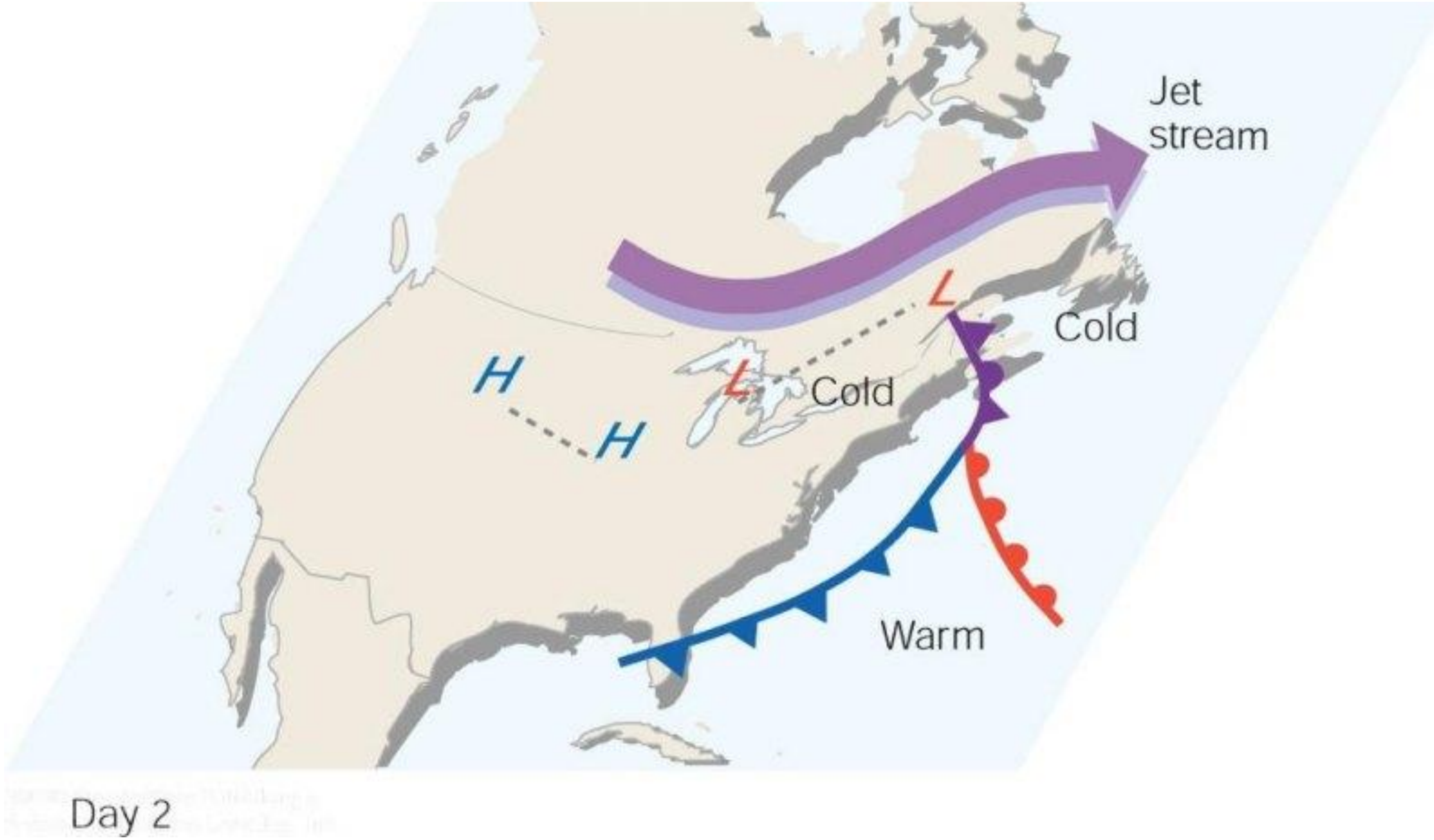
Jet Streams and Developing Mid-latitude Cyclones

- Jet streams play an additional part in the formation of surface mid-latitude cyclones and anticyclones.
- When the polar jet stream flows in a wavy west to east pattern, deep troughs and ridges exist in the flow aloft.
- Jet maxima or jet streaks produce regions of strong convergence and divergence along the flanks of the jet.



Day 1

As the polar jet stream and its area of maximum winds (the jet streak, or MAX). Swings over a developing mid-latitude cyclone, an area of divergence (*D*) draws warm surface air upward, and an area of convergence (*C*) allows cold air to sink. The jet stream removes air above the surface storm, which causes surface pressures to drop and the storm to intensify.

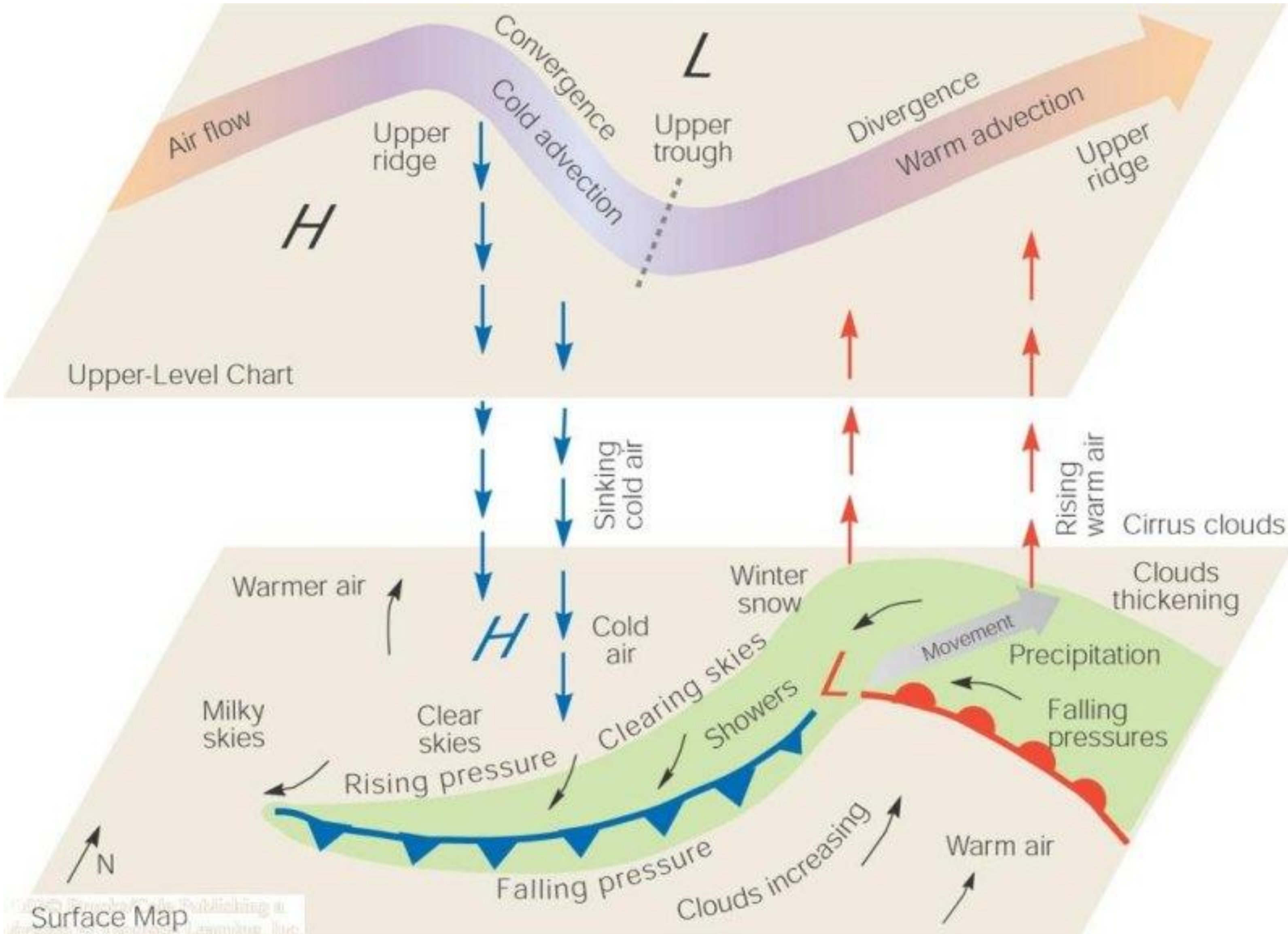


When the surface storm moves northeastward and occludes, it no longer has the upper-level support of diverging air, and the surface storm gradually dies out.

Water vapor satellite image showing a jet streak (heavy arrow) situated off the coast of Southern California.

Upper level Support

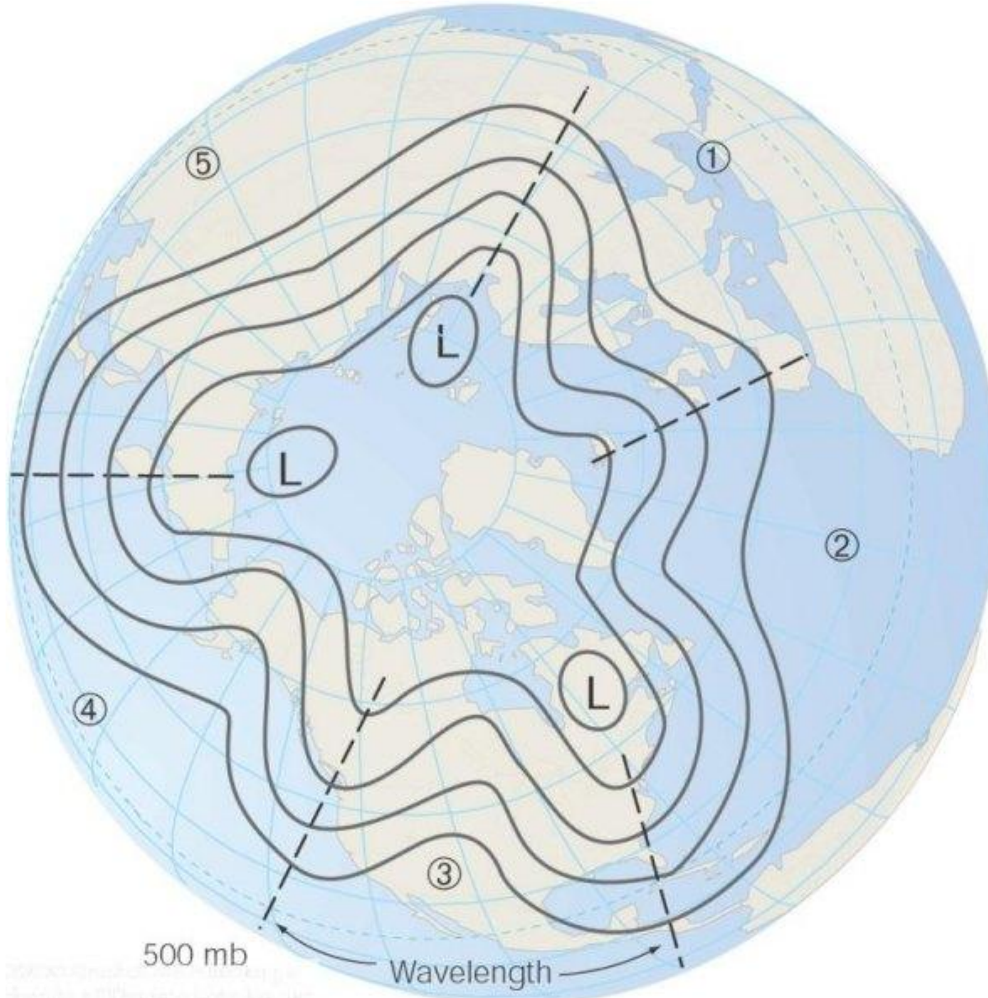
- Upper air support – For a storm to intensify an upper level counterpart – a trough of low pressure that lies to the west of the surface low is necessary.
- At the same time, the PFJ must form into waves and swing slightly south of the developing storm. When these conditions exist, zones of convergence and divergence along with rising and sinking air provide energy conversions for the storms growth.



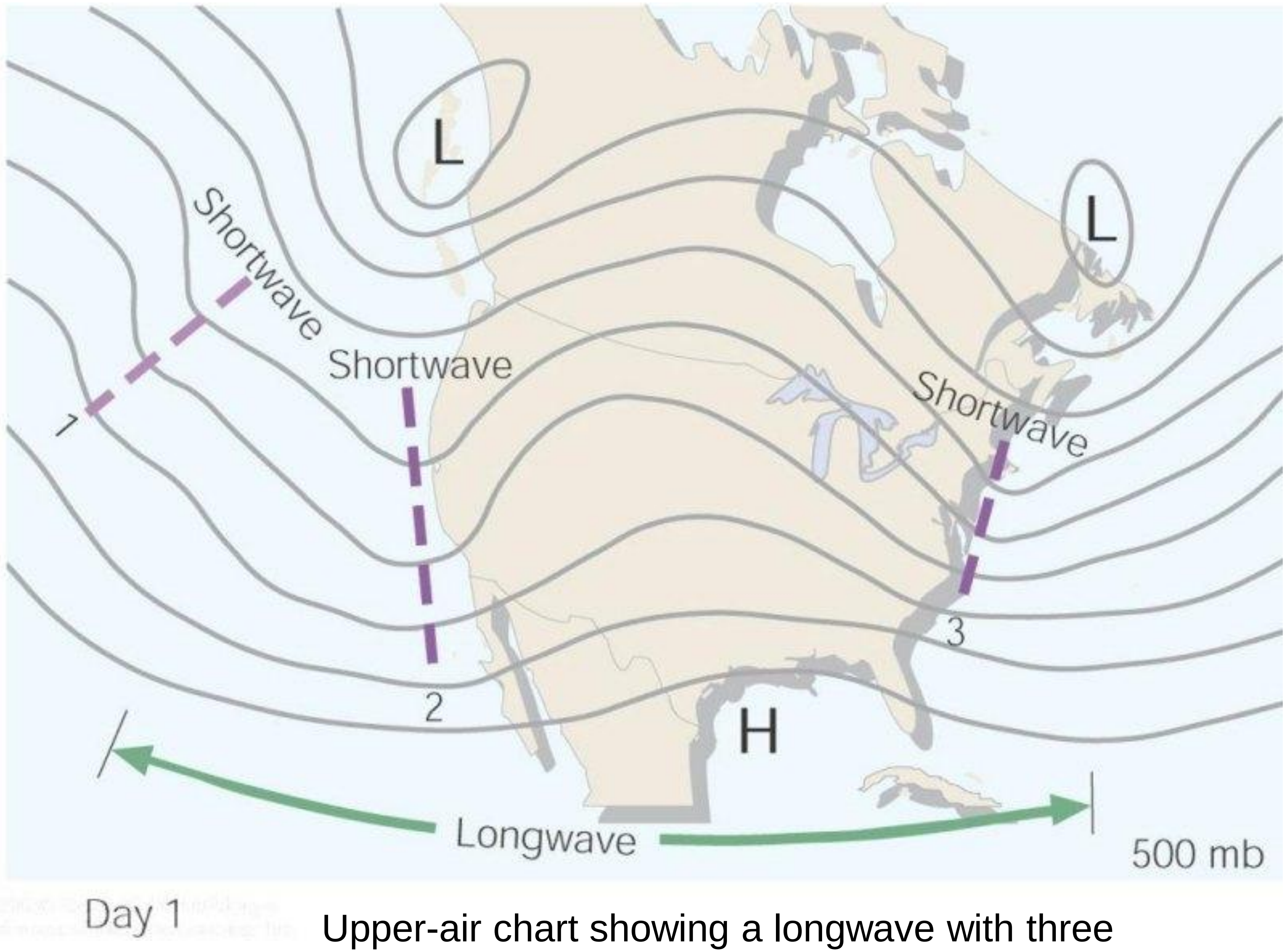
Summary of clouds, weather, and vertical motions associated with a developing wave cyclone.

Long waves and Short Waves

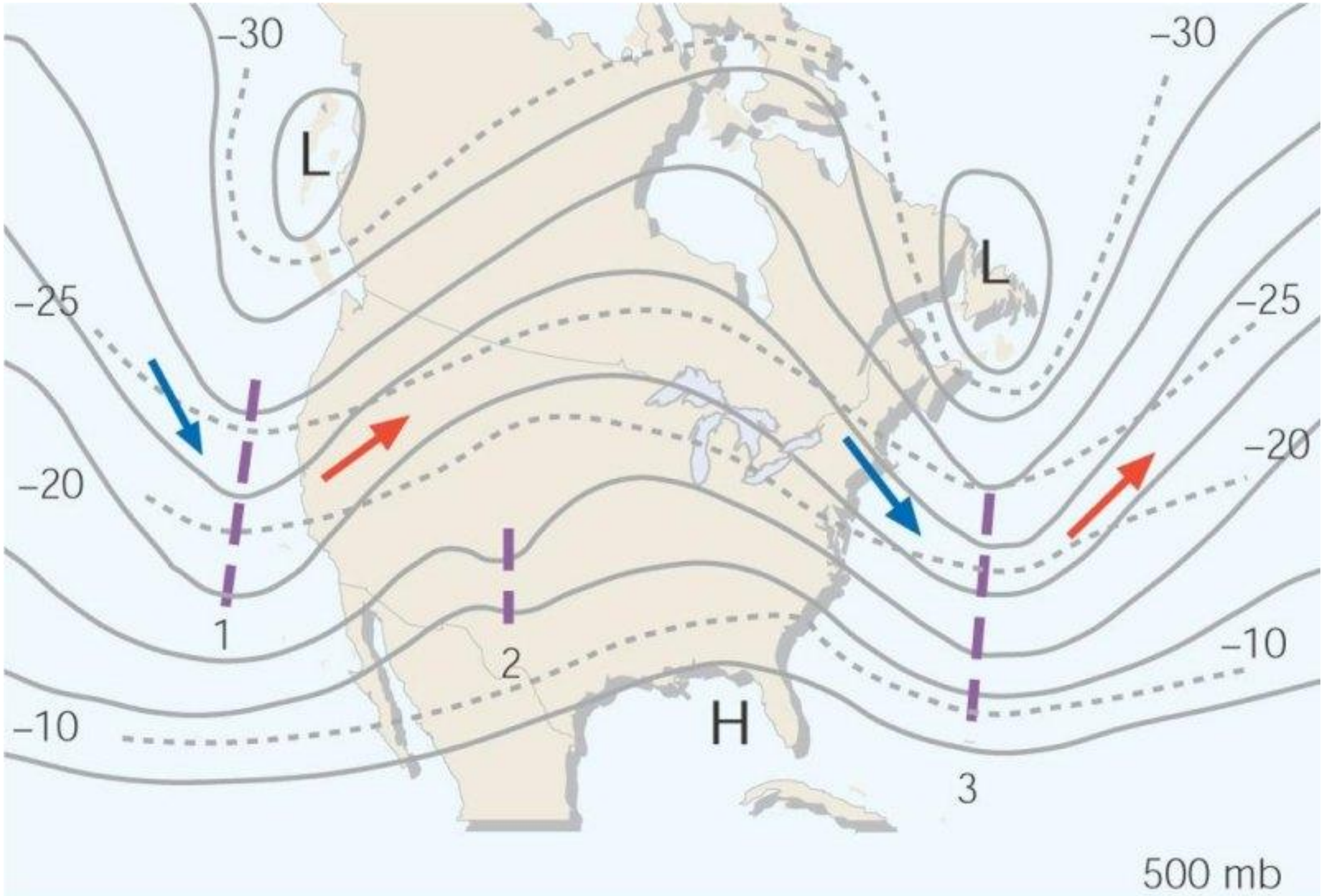
- **Long waves** – a wave in the major belt of westerlies characterized by a long length (thousands of km) and significant amplitude. *Rossby Waves*
- **Short Waves** – a small wave that moves around longwaves in the same direction as the air flow in the middle and upper troposphere. *Shortwave troughs*



A 500-mb map of the Northern Hemisphere from a polar perspective shows five longwaves encircling the globe. Note that the wavelength of wave number 3 is greater than the width of the United States. Solid lines are contours. Dashed lines show the position of longwave troughs.

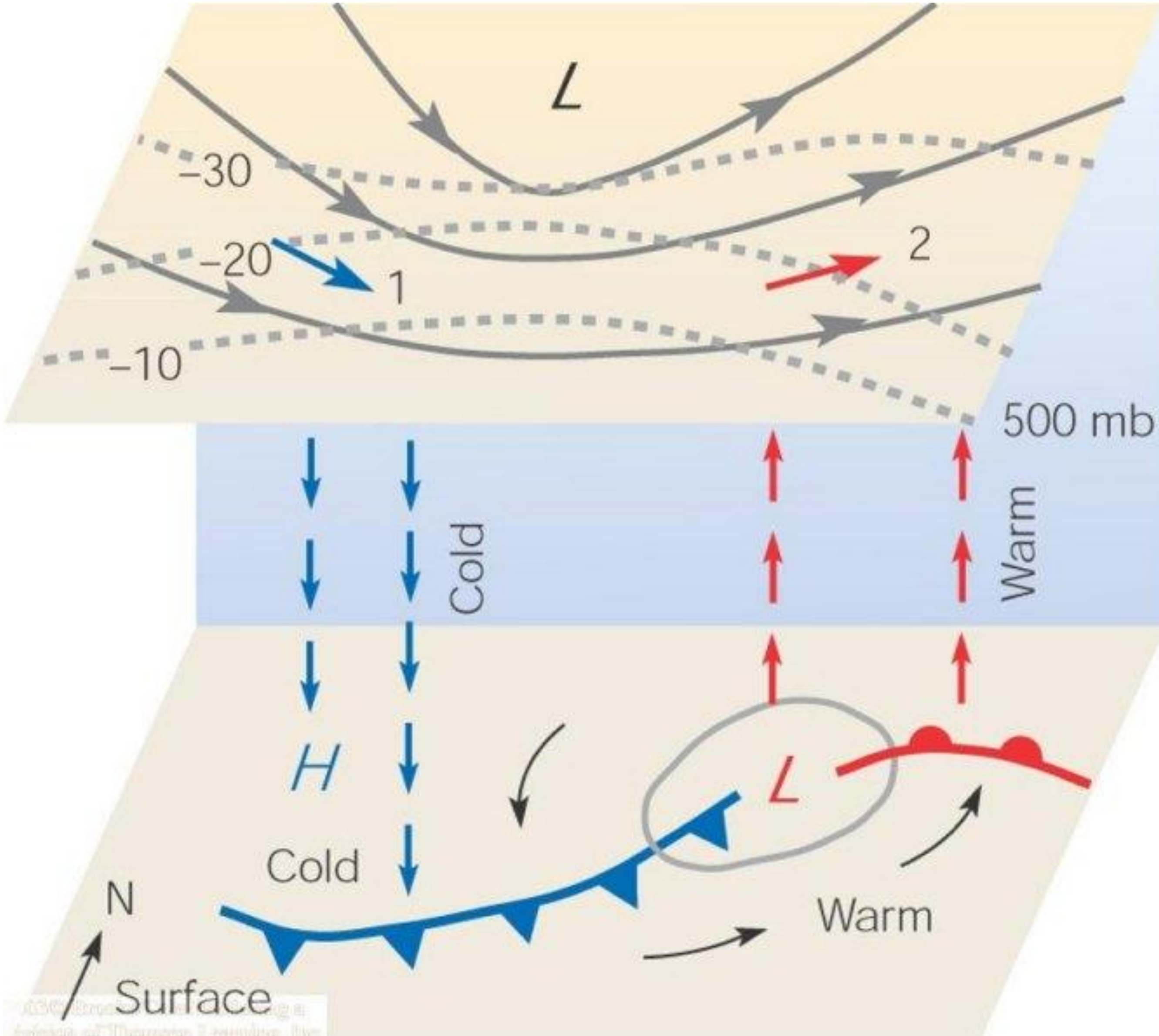


Upper-air chart showing a longwave with three shortwaves (heavy dashed lines) embedded in the flow.



Day 2 (24 hours later)

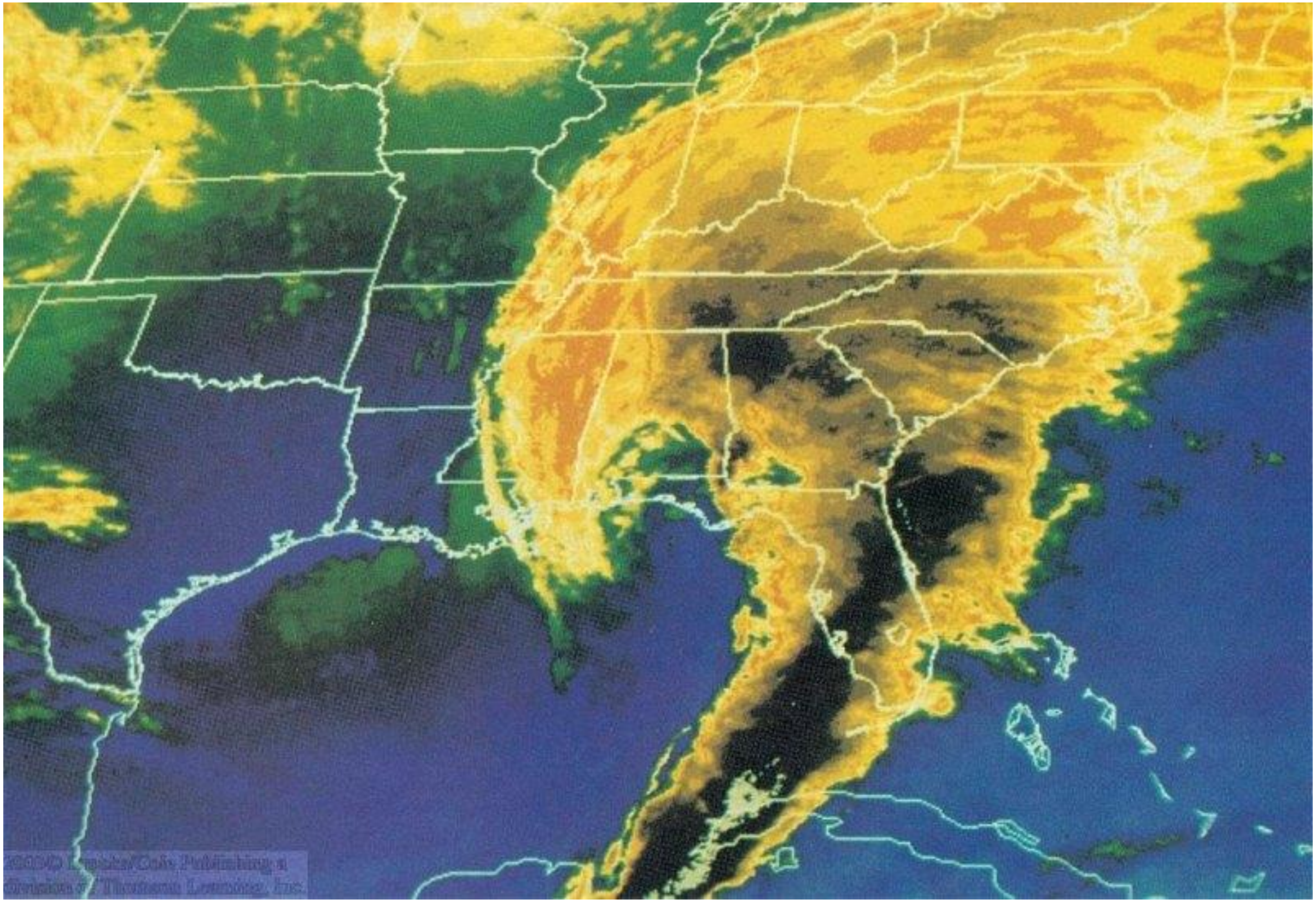
Twenty-four hours later the shortwaves have moved rapidly around the longwave. Notice that the shortwaves labeled 1 and 3 tend to deepen the longwave trough, while shortwave 2 has weakened as it moves into a ridge. Notice also that as the longwave deepens in diagram, its length actually shortens. Dashed lines are isotherms in °C. Solid lines are contours. Blue arrows indicate cold advection and red arrows warm advection.



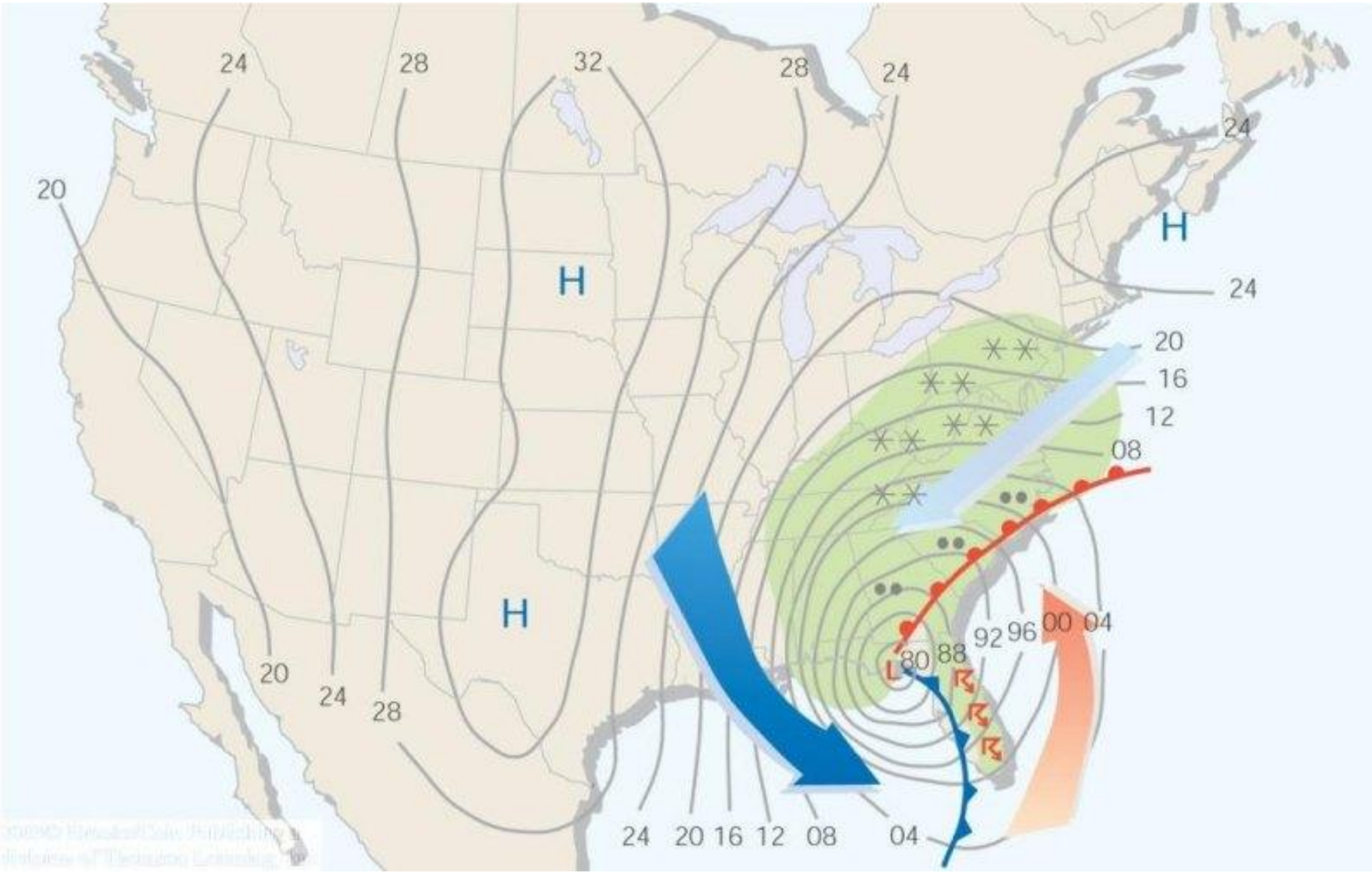
A shortwave (not shown) disturbs the flow aloft, initiating temperature advection. The upper trough intensifies and provides the necessary vertical motions (as shown by vertical arrows) for the development of the surface cyclone.

What happens when it all comes together just right!

- Storm of the Century
- Approx. 270 people killed, 48 at sea, three times greater than the death toll for Hurricanes Hugo and Andrew
- Asheville airport closed for three days. Every airport on east coast was closed for some period of time
- 160 people rescued at sea
- Mount Mitchell- 50 inches of snow 14 ft drifts
- Myrtle Beach had 90 mph winds
- Temperature reached 2 F in Asheville

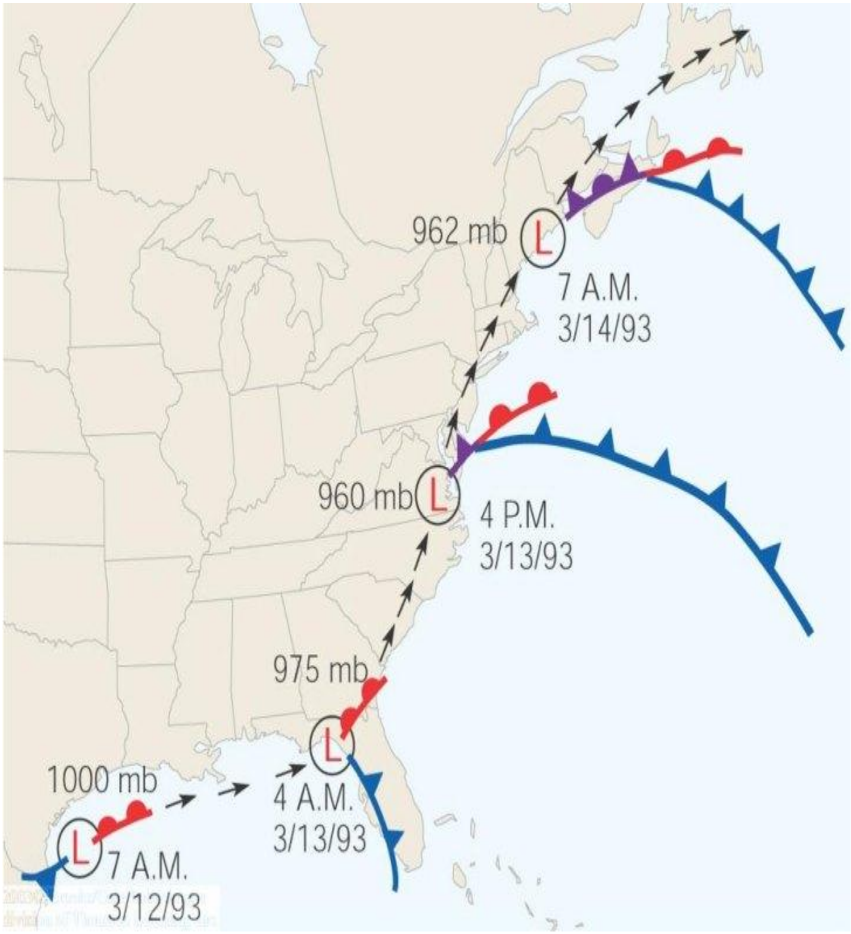


A color-enhanced infrared satellite picture that shows a developing wave cyclone at 2 A.M. (EST) on March 13, 1993. The darkest shades represent clouds with the coldest and highest tops. The dark cloud band moving through Florida represents a line of severe thunderstorms. Notice that the cloud pattern is in the shape of a comma.



Surface weather map for 4 A.M. (EST) on March 13, 1993. Lines on the map are isobars. To obtain the proper pressure in millibars, place a 9 before those readings of 96 or lower, and place a 10 before those readings of 00 or higher. Green shaded areas are receiving precipitation. (The large orange arrow represents warm humid air and the warm conveyor belt. The light blue arrow represents cold moist air and the cold conveyor belt; the dark blue arrow represents cold dry air and the dry conveyor belt.)

Storm of the Century



The development of a wave cyclone into the ferocious storm of March, 1993. A small wave in the western Gulf of Mexico intensifies into a deep open-wave cyclone over Florida. It moves northeastward and becomes occluded over Virginia where its central pressure drops to 960 mb (28.35 in.). As the occluded storm continues its northeastward movement, it gradually fills. The number next to the storm is central pressure in millibars. Arrows show direction of movement. Time is Eastern Standard Time (EST).