1. IC5.7: Lake Effects

Instructor Notes: Welcome to AWOC Winter Track IC 5 Lesson 7: Precipitation Forcing Mechanisms and Conceptual Models. Lesson 7 will deal with aspects of lake effect snow.

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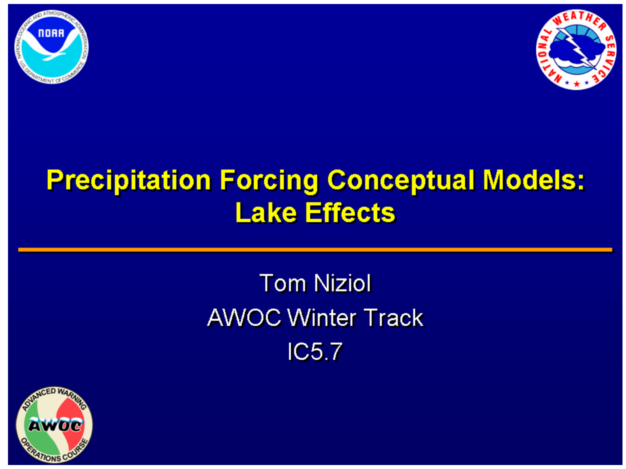

2. What Mechanisms Produce this Variety of Mesoscale Precipitation Events?

Instructor Notes: Lake and ocean effect snow bands are truly some of the most intriguing displays of winter weather. This module is not meant to provide an in-depth study of lake and ocean effect snow. Rather, it is intended to teach the basic physical processes that combine to produce these mesoscale events. The reader is encouraged however to explore other training areas, such as the MetEd NORLAT (Northern Latitudes) web site for an excellent review of the entire lake/ocean effect process. The link for the site is: http://meted.ucar.edu/norlat/snow/lake_effect/.

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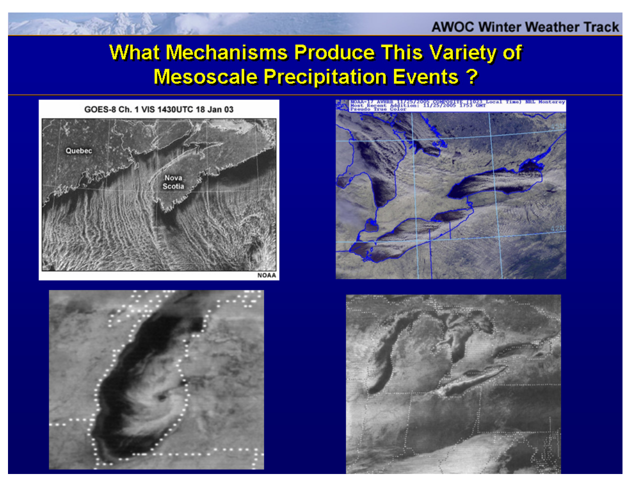

3. Lesson & Learning Objectives

Instructor Notes: Here, we will explore the reasons why lake effect and ocean effect snow bands develop, answering questions about the role that instability plays in modifying an airmass to produce clouds, the effect that frictional and thermal convergence has on snowband development, the effect that the shape and orientation of the body of water and its role in snowband production, and the role that topography has on the development of lake effect snows.

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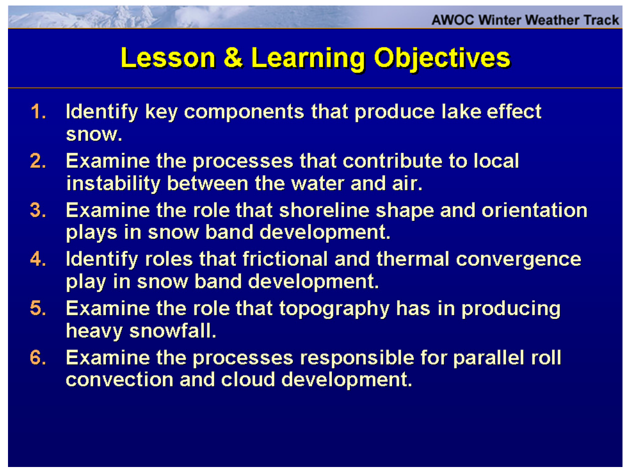

4. Performance Objective

Instructor Notes: Our performance objectives are pretty straightforward. They are to identify the conditions that are favorable for these mesoscale precipitation events, recognize patterns that may be detrimental to organized convective snows, and also understand that the role of local topography has on the location and shape of the bands.

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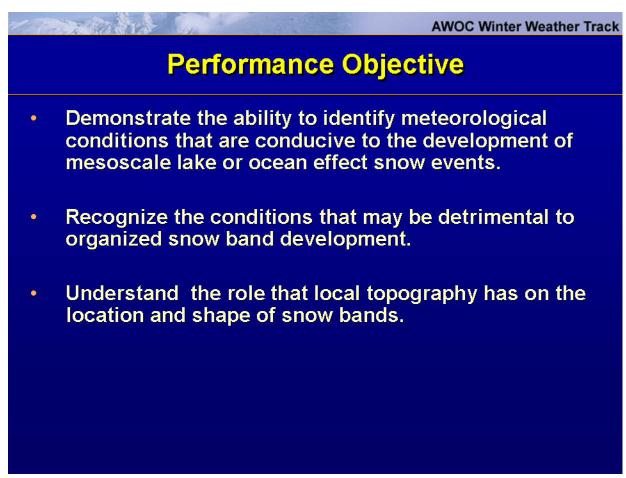

5. Ingredients-Based Forecast Approach

Instructor Notes: The development of lake effect snow, or convective snows that develop over any warm body of water in general, is (as with all precipitation mechanisms) a result of three main components: instability, moisture, and lift. In the world of lake effect snow, the first two parameters (instability and moisture) are directly linked to the modification of cold air moving across a relatively warm body of water. The third parameter (lift) is related to several other parameters including differences in frictional and thermal forcing in the vicinity of the bodies of water, as well as the surrounding topography. Together, these three parameters combine to produce a diverse array of mesoscale winter weather in select regions around the northern hemisphere.

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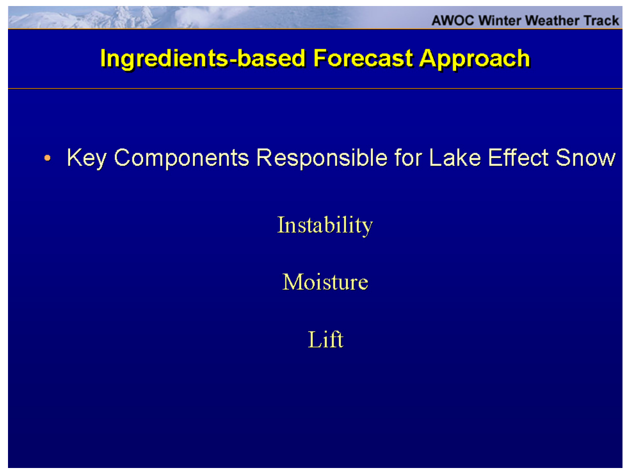

6. Local Instability

Instructor Notes: Typically, an arctic airmass is not considered to be an environment that promotes a deep layer of instability in the atmosphere. In fact, most arctic airmasses are characterized by a very shallow unstable layer that is generally capped by some sort of subsidence inversion. However, these polar or arctic airmasses do undergo significant modification when that shallow airmass crosses a warm body of water. The modification can result in increases in the depth of the unstable layer. In the next few slides, we will explore the air/water temperature difference and the depth of the unstable layer as the cold airmass crosses the warm water. We will also introduce a couple of terms that are used to help assess the local instability that is a consequence of the modification of the airmass, lake-induced CAPE and lake-induced equilibrium level.

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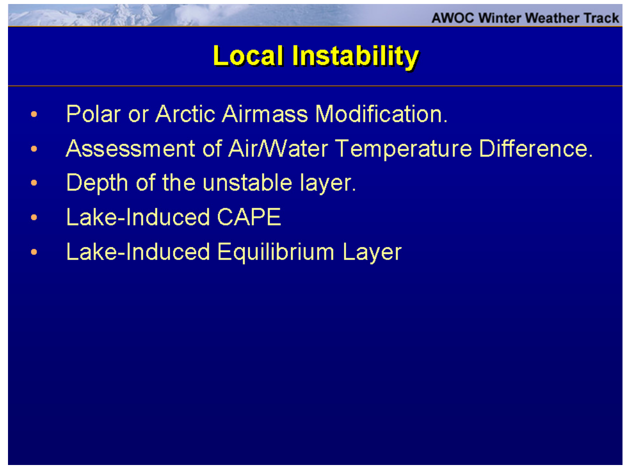

7. Assessment of Air/Water Temperature Difference

Instructor Notes: So, what are the most important parameters that define the potential for lake effect snow. The single, most important parameter that defines the potential for lake effect snow is the unstable lapse rate that is generated when cold air crosses warm water. A flux of heat and moisture from the warm lake to the cold airmass can create significant instability within the boundary layer. There is a second part to this answer, however. The depth of the cold air, defined by a capping subsidence inversion, will define the height to which convective cloud growth will occur. If there is a strong low level inversion present, then deep convective growth may not be possible. The flux of heat and moisture from the lake will modify and at times completely erode the capping inversion. It is very important, therefore, to have a good understanding of the instability and depth of the unstable layer when assessing the potential for precipitation. The modification of the lower levels of the atmosphere can be very significant at times. In the next few slides, we will look into the modification of the airmass in more detail.

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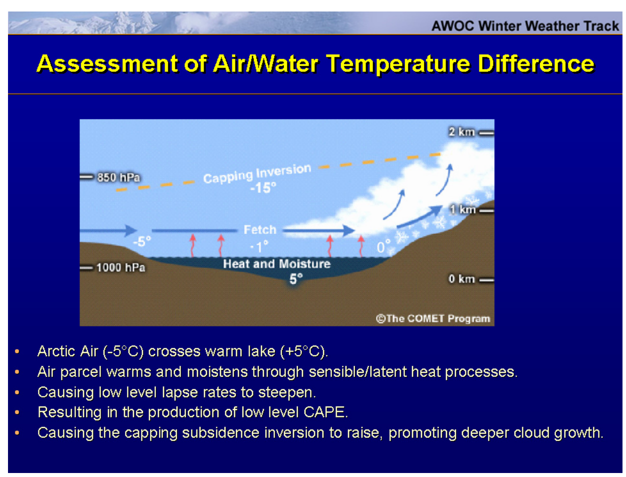
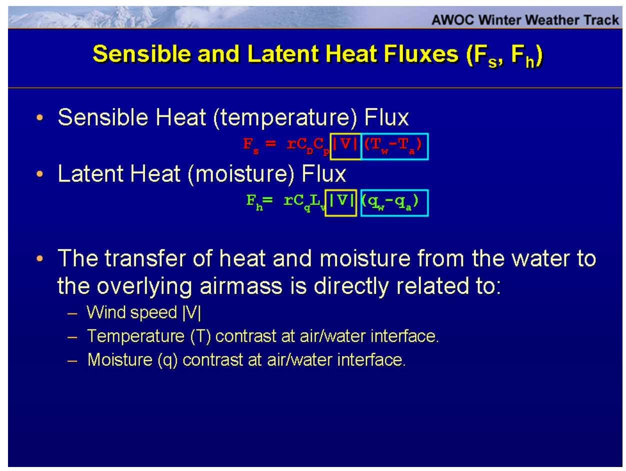


8. Sensible and Latent Heat Fluxes (Fs, Fh)

Instructor Notes: An unstable lapse rate at low levels, brought about by heating and moistening by the water below, creates an environment favorable for convection. In general, the flux of sensible and latent heat into the lower atmosphere is modulated by the wind speed over the body of water and the temperature and moisture contrast between the water and overriding airmass.

Student Notes:



9. Assessment of Air/Water Temperature Difference

Instructor Notes: Phillips showed through empirical evidence that most of the modification of a parcel's temperature occurs in the first 30 minutes or so over the lake. We further assume that most parcels spend about 1 to 3 hours traversing a typical Great Lake. This broadly suggests that the air parcels moderate about halfway (50%) between their original air temperature and the temperature of the lake. In the example, we begin with and air parcel that has a temperature of 5 degrees C and a lake temperature of 10 degrees C. If we assume about a 50% modification of surface temperature, then the air parcel reaches equilibrium at about 7.5 degrees C. Reference: PHILLIPS, DAVID W.Modification of Surface Air Over Lake Ontario in WinterMonthly Weather Review 1972 100: 662-670 Reference: PHILLIPS, DAVID W.Modification of Surface Air Over Lake Ontario in WinterMonthly Weather Review 1972 100: 662-670

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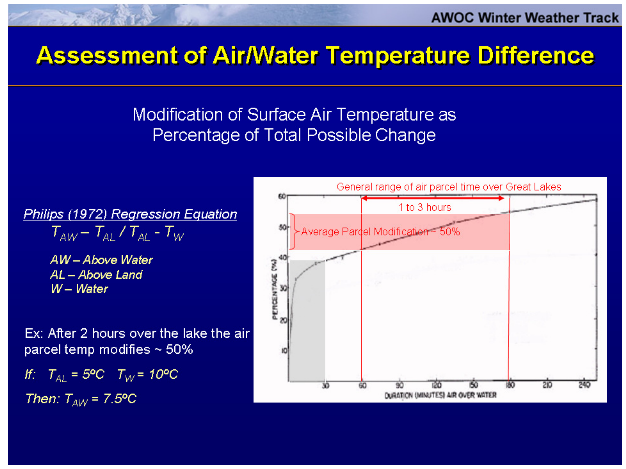
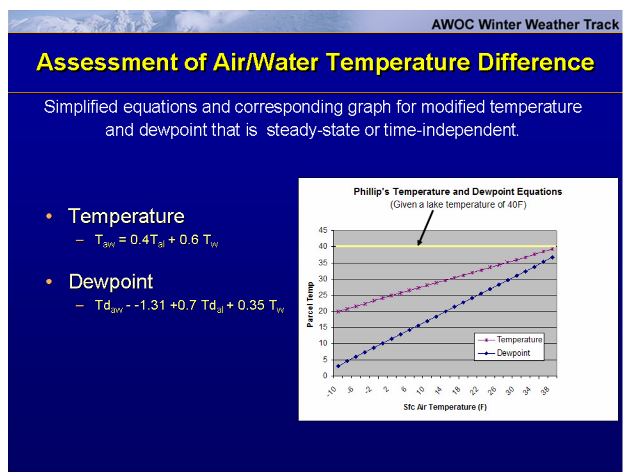


10. Assessment of Air/Water Temperature Difference

Instructor Notes: If we further assume that the air parcel reaches a steady-state at some point over the body of water, or in other words is time-independent, then the equations can be further simplified as shown. Referring to the graph, I have taken an example where the lake temperature is 40 degrees F, then plotted the modified temperature and dewpoint vs. the original parcel temperature and dewpoint. You can see that there is a much greater response (warming) of the parcel's temperature compared to the moisture response.

Student Notes:



11. Assessment of Air/Water Temperature Difference

Instructor Notes: So, based on the information we learned from the Philips studies and assumptions, let's look at an example of how much modification an air parcel might undergo. We start with a sounding over land (Buffalo, NY), and assume an air temperature of about -1 degrees C and a dewpoint of about -2 degrees C. The water temperature of adjacent Lake Erie is 11 degrees C. So, the air parcel's temperature is 12 degrees C colder than the lake temperature. Philips says that the parcel's temperature will be modified or warmed to about 5 degrees C, while the dewpoint will warm to about 1.5 degrees C. Based on the modified surface temperature and dewpoint, we end with a very unstable sounding as far as mesoscale winter convection is concerned (as shown in the following slide).

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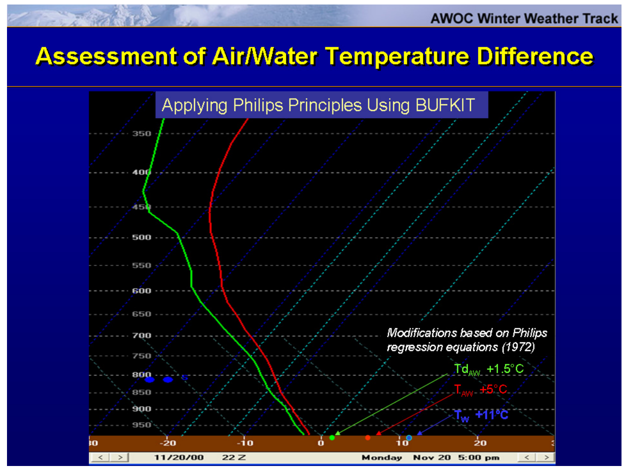
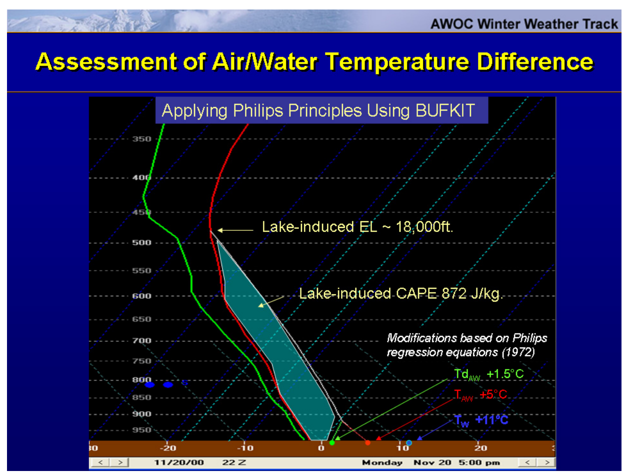


12. Assessment of Air/Water Temperature Difference

Instructor Notes: That modification of air parcel temperature and dewpoint creates a significant amount of CAPE, allowing convective cloud growth as high as 18,000ft.

Student Notes:



13. Quiz 1: Parcel Modification

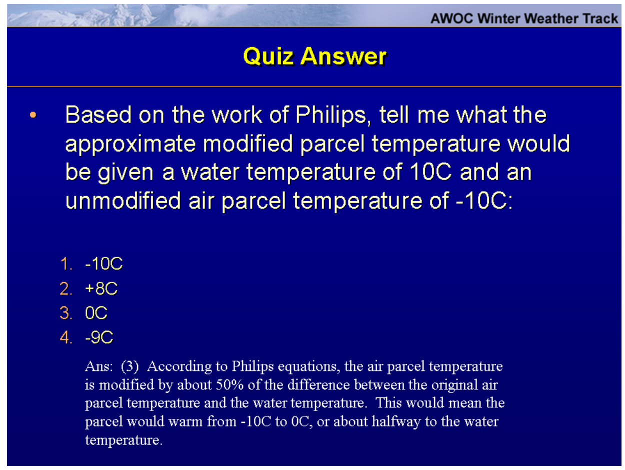
Instructor Notes: Take a moment to complete this quiz.

Student Notes:

14. Quiz 1 Answer

Instructor Notes: The correct answer is 0 degrees C.

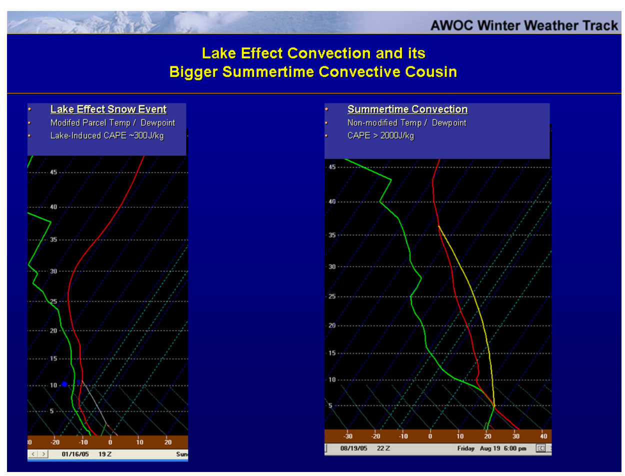
Student Notes:



15. Lake Effect vs. Summer Thunderstorm Sounding

Instructor Notes: Now, a summertime thunderstorm forecaster might say "so what?" Those convective indices are really not that impressive. As a matter of fact, let's compare a typical lake effect snow sounding (modified due to its passage over a warm lake) and a mid-latitude summer thunderstorm sounding. Can the modification of the lapse rate on such a wimpy vertical scale really have implications in the LOES environment?

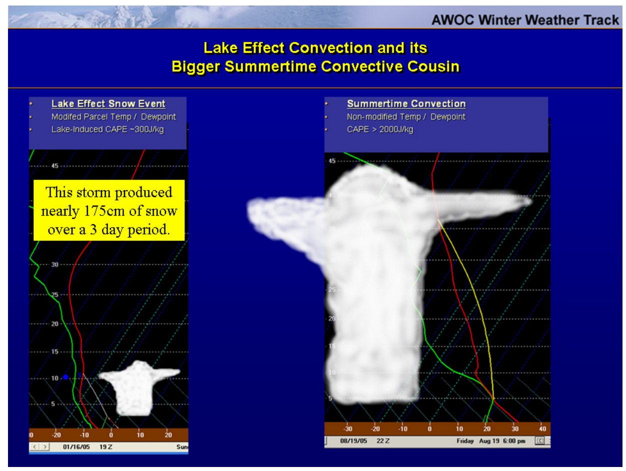
Student Notes:



16. Lake Effect Convection and its Bigger Summertime Convective Cousin

Instructor Notes: You bet it can! Although the resulting vertical scale of convection pales in comparison to summertime thunderstorms, most of the processes associated with summertime convection are there, it just happens on a smaller scale. As long as you can produce a deep enough cloud with the proper temperature and moisture structure, you can also produce respectable precipitation. Whereas LOES events are confined to a much smaller vertical scale, the temporal scale of these steady state events can last several hours and, at times, more than an entire day. As a result, precipitation totals can be impressive. In regions of deeper convection, particularly during the late fall in the Great Lakes Region, heavily rimed snow crystals and graupel can be carried a couple of kilometers into the cloud. That is high enough to produce a charge separation that leads to lightning and thunder. There is nothing like being caught outside in “thundersnow”!

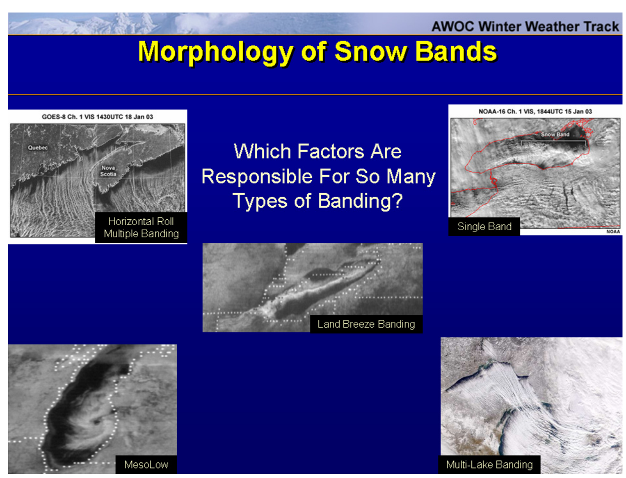
Student Notes:



17. Morphology of Snow Bands

Instructor Notes: Ok, now we have a basic understanding of the modification and resulting instability that an air parcel attains as it moves across the warm body of water. So, what mechanisms contribute to the development of so many different types of snow bands. Let’s explore that question in the next several slides.

Student Notes:



18. Morphology of Snow Bands

Instructor Notes: Once boundary-layer instability over the water has been enhanced by moistening and warming, several mesoscale mechanical lifting mechanisms may help to trigger and/or enhance the convective processes. The buoyancy over the body of water contributes to horizontal roll convection, with the cloud streets lined up parallel to the prevailing flow. In addition, terrain or orographic lifting contributes significantly to snowfall production and, in some cases, channeling of flow. Differences in frictional convergence between a smooth lake surface vs. the rougher land surface (as well as differences in thermal convergence between warm bodies of water and colder adjacent land masses) also play a predominant role in snowband morphology. Finally, the shape and orientation of these bodies of water including the effects of irregular shorelines and bays and inlets also can have a profound influence on snowband development.

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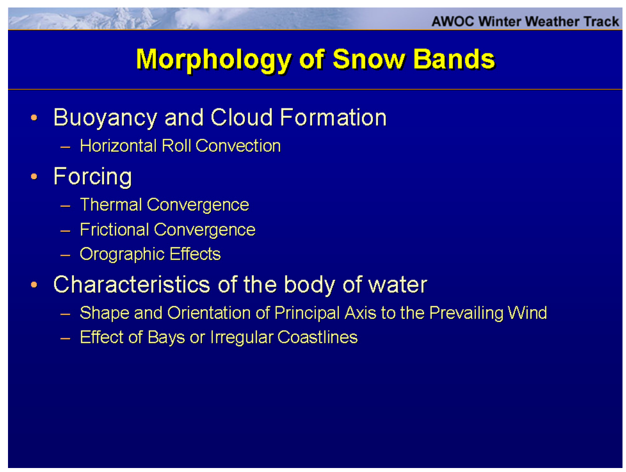
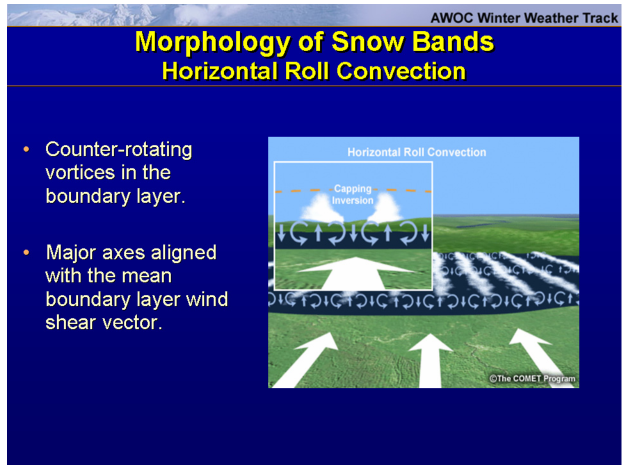


19. Morphology of Snow Bands: Horizontal Roll Convection

Instructor Notes: In a general sense, as you move cold air across a warm body of water, horizontal rolls develop aligned along the prevailing wind direction. Here, the prevailing flow within the cloud layer is into the board. This phenomenon is most often seen on large bodies of water without restricting shorelines such as the offshore portions of the Atlantic Ocean and Gulf of St. Lawrence. In addition, horizontal rolls are common on smaller bodies of water, such as the Great Lakes, when the prevailing wind is directed perpendicular to the longest axis of the lake.

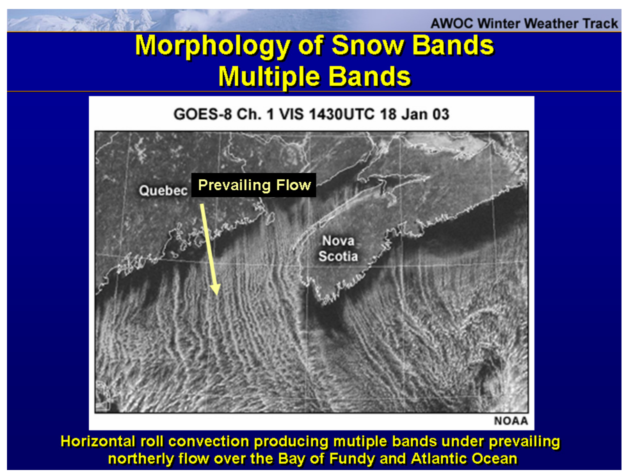
Student Notes:



20. Morphology of Snow Bands: Multiple Bands

Instructor Notes: This graphic is an example of parallel roll convection occurring in arctic northerly flow off the Canadian Maritimes over the Atlantic Ocean. Note, that when air trajectories are directed out over a broad expanse of water, such as an ocean, parallel roll convection is common. However, when the trajectory moves over smaller bodies of water, several types of bands can occur in addition to multiple streamers.

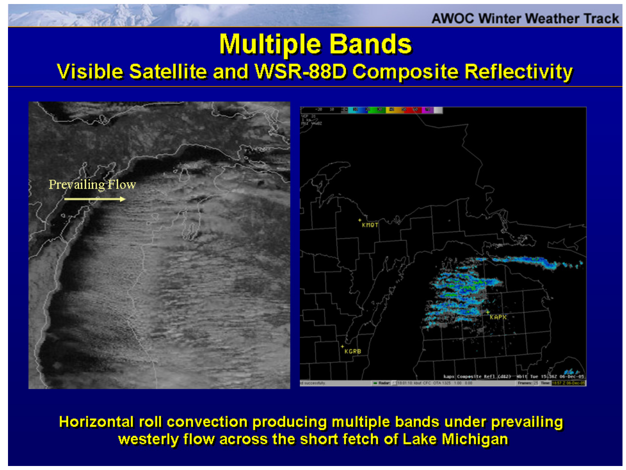
Student Notes:



21. Multiple Bands: Visible Satellite and WSR-88D Composite Reflectivity

Instructor Notes: Over bodies of water such as the Great Lakes, parallel roll convection is likely when the prevailing flow is across the shorter fetch of the lake as we see here on Lake Michigan. You can even see the banded structure in the precipitation echoes in the accompanying radar image here. These types of bands do not necessarily produce the heaviest snowfall amounts, but they can raise havoc for those travelling in the region. It is not uncommon when driving on roads that parallel the shore to drive in and out of snowfall, reducing visibilities greatly, as you cross each successive band.

Student Notes:



22. Quiz 2: Horizontal Roll Convection

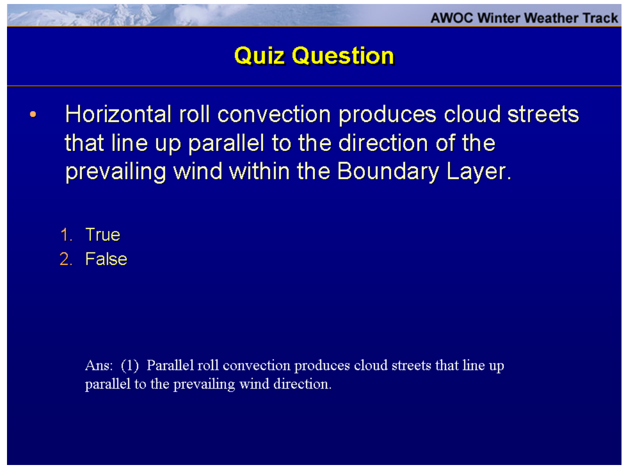
Instructor Notes: Take a moment to complete this interactive quiz.

Student Notes:

23. Quiz 2 Review

Instructor Notes: The correct answer to this question is true.

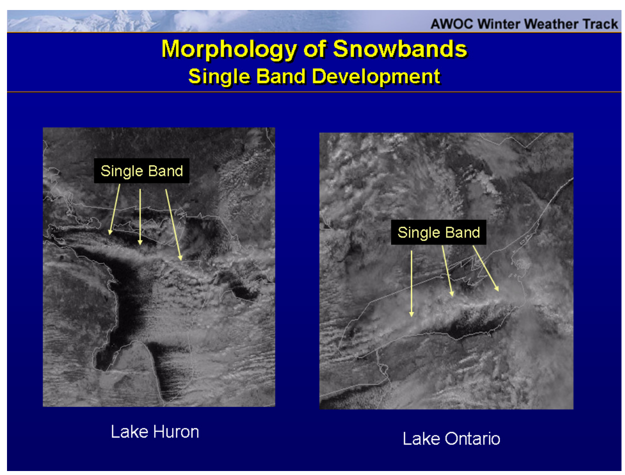
Student Notes:



24. Morphology of Snowbands: Single Band Development

Instructor Notes: When you are dealing with bodies of water that have shorelines that are parallel to one another such as several of the Great Lakes, differences in frictional and thermal properties of the shore and water combine to produce some interesting effects. Instead of several bands associated with horizontal roll convection, when winds are directed down the long fetch of lakes (with roughly parallel shores) you can end up with one, strong main band of snow.

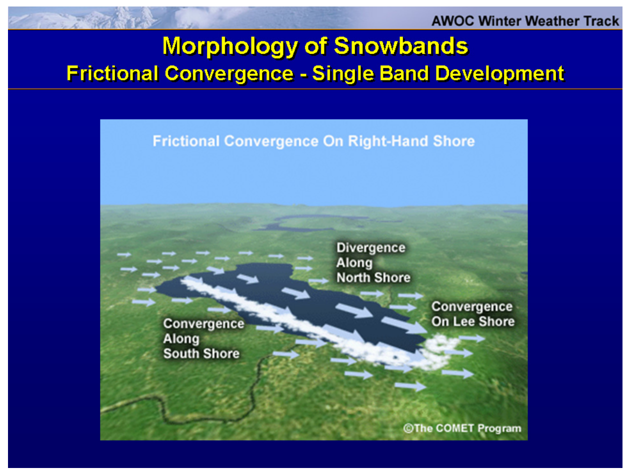
Student Notes:



25. Morphology of Snowbands: Frictional Convergence - Single Band Development

Instructor Notes: Surface winds moving over water experience very little frictional drag. So, wind speeds are relatively higher than those over land surfaces where hills, vegetation, and even large buildings can reduce wind speed. As a result, fast-moving air over the water converges into slow-moving air over the land, creating a zone of frictional convergence and lift near the leeward shore. The opposite effect occurs along the windward shore, resulting in surface frictional divergences and subsidence. In addition, the winds over land are slowed to a greater extent by friction resulting in a larger leftward deflection across isobars towards lower pressure than that occurring over the water. Therefore, when winds are directed parallel to the long fetch of a body of water, relative to the prevailing low-level wind flow, frictional convergence is favored near the right-hand shoreline, and this can be the dominant factor in creating a single band of convection near the shore. Over time this band may propagate inland away from the original zone of convergence.

Student Notes:



26. Morphology of Snowbands: Frictional Convergence - Single Band Development

Instructor Notes: An additional source of convergence and lift is brought about by the land breeze generated by the thermal gradient between the lake and adjacent land areas. On elliptically shaped bodies of water, or those with parallel shorelines over a narrower portion of the lake, the relatively warm, the moist environment over the water contributes to the formation of a “mesolow” that enhances the convergence of cooler land breezes over the water body. The cooler land breeze helps to lift the unstable air over the water, and this lifting can be particularly significant in cases where land breezes from opposite shores converge in the vicinity of the mesolow. In environments with strong, prevailing synoptic-scale flow, the effect of the land breeze is overshadowed a bit by the prevailing wind, but it still exists.

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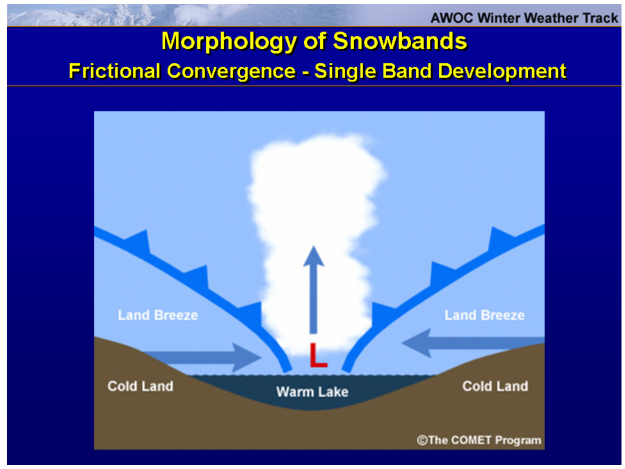
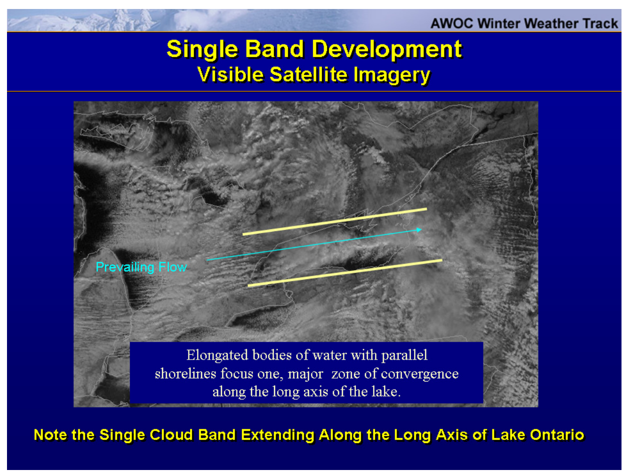


27. Single Band Development: Visible Satellite Imagery

Instructor Notes: So, let's go back to one of our single band satellite images and look at it more closely in relationship to its orientation and shape with the two parallel shores of lake Ontario. The combination of frictional and thermal convergence when prevailing flow is parallel to the long axis of an elliptically shaped body of water will produce a single, strong convergence zone and snow band over the lake.

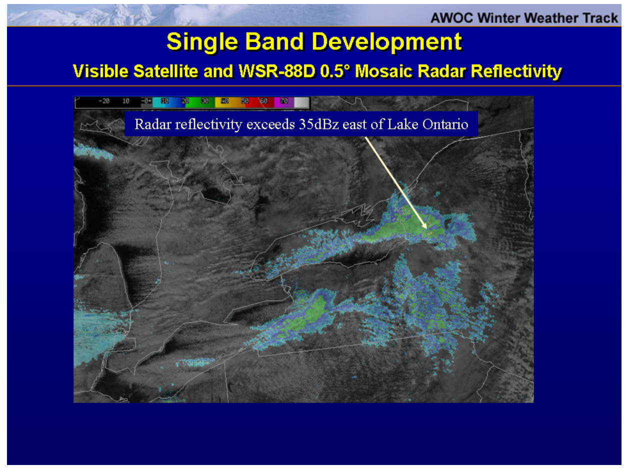
Student Notes:



28. Single Band Development: Visible Satellite and WSR-88D 0.5 Degree Mosaic Radar Reflectivity

Instructor Notes: Here you can see the actual precipitation echoes associated with the cloud band. The single band of snow that is generated in this fashion can produce extreme snowfall rates in excess 4 inches per hour at times. They also are often accompanied by lightning and thunder.

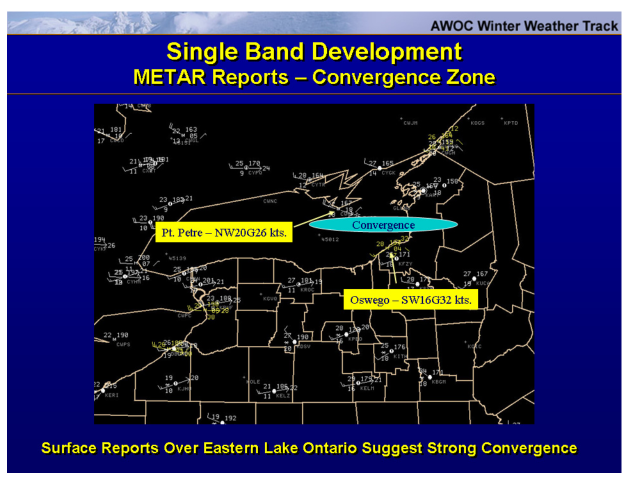
Student Notes:



29. Single Band Development: METAR Reports - Convergence Zone

Instructor Notes: As noted, the combination of frictional and thermal convergence when prevailing flow is parallel to the long axis of an elliptically shaped body of water will produce a single, strong convergence zone over the lake. Here you can see the effect that this environment has on opposite shores of the lake. Check out the wind direction and speed on the north shore of Lake Ontario at a place Called Pt. Petre. We have NW wind at 20 (with gusts to 26) kts. Now, just a few miles away, along the south shore of the lake, Oswego is reporting a SW wind of 16 (with gusts to 32) kts. Over a distance that spans less than 40 nm., there is nearly a 90 degree wind shift with significant wind speeds, producing a narrow, strong zone of convergence leading to impressive vertical motions out over the lake.

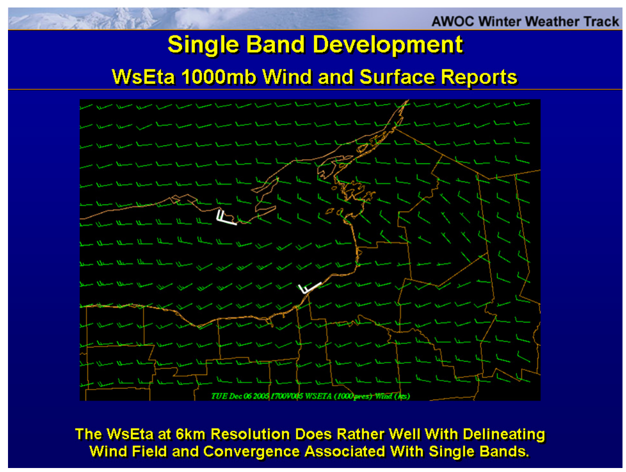
Student Notes:



30. Single Band Development: WsEta 1000 mb Wind and Surface Reports

Instructor Notes: So let's take this a step further and see if we can diagnose the environment around one of these strong single bands of snow. Here, we are looking at output from one of our higher resolution numerical models to diagnose that same convergence zone. This graphic is from a 6-km version of the Workstation Eta model. I overlaid the approximate locations of the two observations we referred to in the last slide in white onto the model 1000mb wind forecast taken at the same time of the observations. It looks like the model did a relatively good job at picking out that convergence zone. But what kind of convergence are we seeing within that zone over the lake

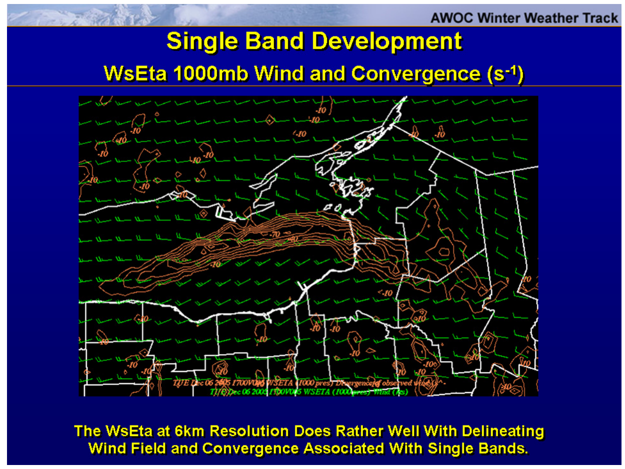
Student Notes:



31. Single Band Development: WsEta 1000 mb Wind and Convergence (s^-1)

Instructor Notes: Now, we overlay the model 1000mb convergence field produced by those winds and you have some idea of the type of lift that is occurring out over the lake.

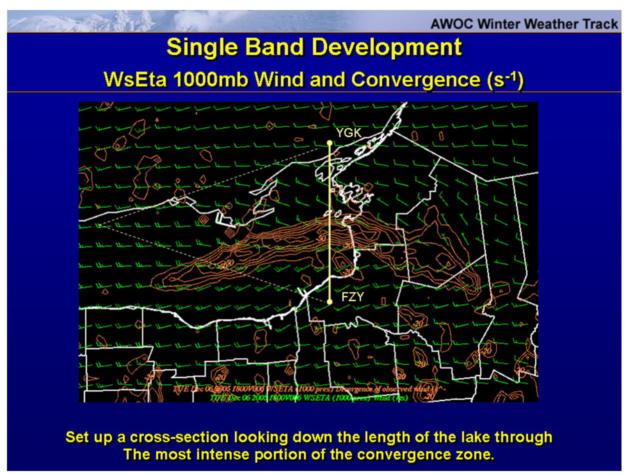
Student Notes:



32. Single Band Development: WS ETA 100mb wind & convergence

Instructor Notes: I want to take this one step further and try to give you a better idea of the vertical and horizontal scales of the convection. So, we will draw a cross-section through the model snow band at the east end of the lake as shown by the line. In the next slide, you will be viewing the cross-section from the west end of Lake Ontario, looking down the long fetch of the lake with the north shore on the left-hand side and the south shore on the right.

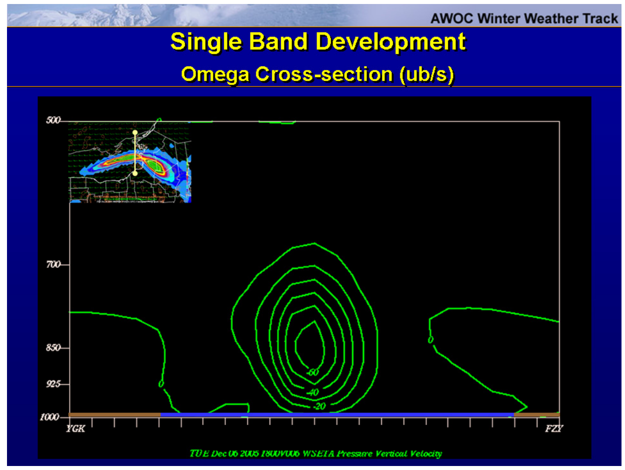
Student Notes:



33. Single Band Development: Omega Cross-Section

Instructor Notes: This graphic is the omega field that represents the lake effect snow band out over the east end of the lake. Note: the depth of the omega field is only up through about 700mb with the max somewhere around the 850mb level. The horizontal scale of the omega field is on the order of only about 15 miles in width. If you want to diagnose the vertical motion field in such lake effect convection, it is often better to look at vertical motion fields well below 700mb, typically in the range of 900 to 850mb.

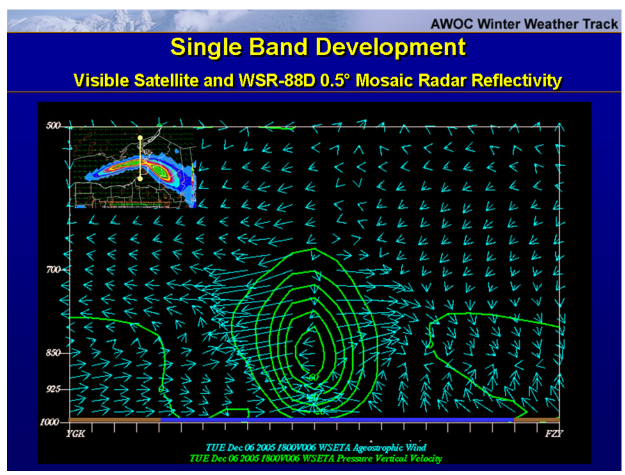
Student Notes:



34. Single Band Development: Visible Satellite and WSR-88D 0.5 Degree Mosaic Radar Reflectivity

Instructor Notes: To complete the understanding of the type of circulation that this environment produces, we overlay the ageostrophic wind onto the circulation. Doing so clearly shows the low-level convergence and midlevel divergence associated with the snow band.

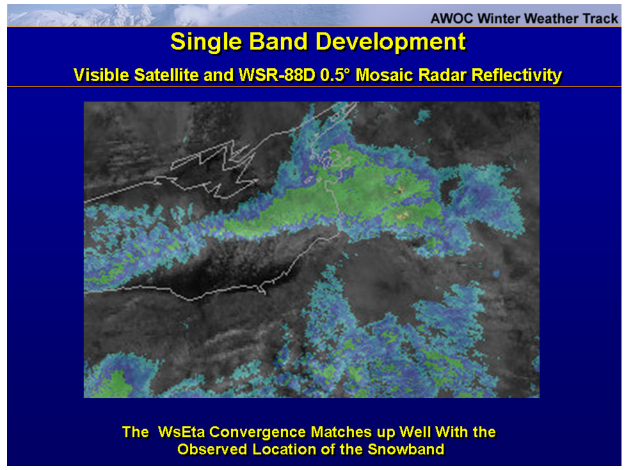
Student Notes:



35. Single Band Development: Visible Satellte and WSR-88D 0.5 Degree Mosaic Radar Reflectivity

Instructor Notes: Here is the actual radar/satellite image from that same timeframe. The Workstation ETA (WsEta) model did a pretty good job at capturing the mesoscale circulation responsible for the development of this single band of heavy snow. This band produced over 2 feet of snow.

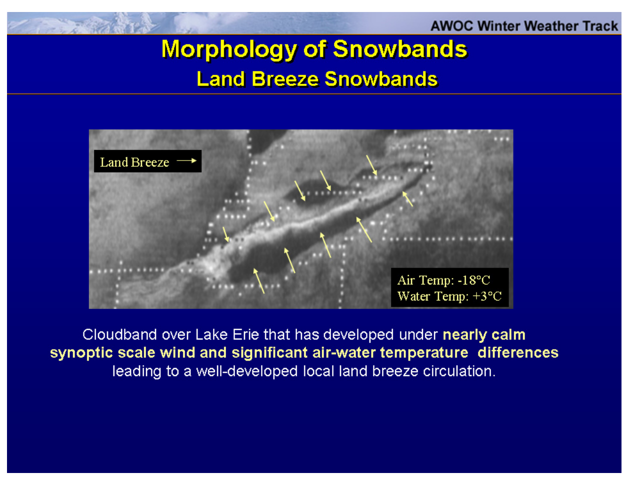
Student Notes:



36. Morphology of Snowbands: Land Breeze Snowbands

Instructor Notes: This example may look like another wind parallel, single band of snow. However, it formed under different circumstances and is generally much weaker than the single band that we just looked at. If the prevailing flow is very weak and the air-lake temperature difference is significant, there is little contribution from differential frictional convergence; rather, thermal convergence is the main player. In this situation, a well-defined land breeze circulation develops that produces a weak convergence zone over the lake. The resulting snowband may take on the configuration shown, in which the snowband parallels the shore.

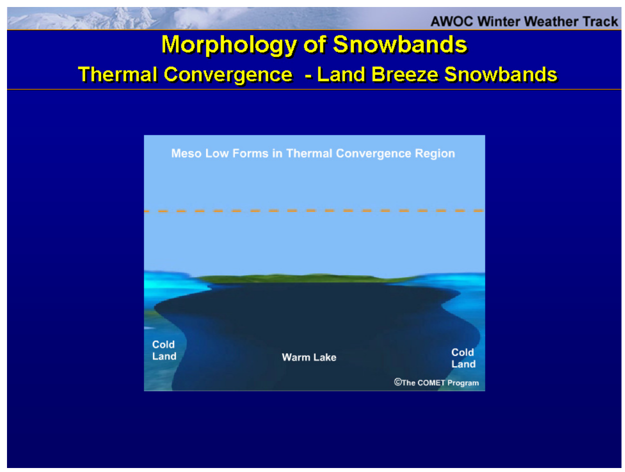
Student Notes:



37. Morphology of Snowbands: Thermal Convergence - Land Breeze Snowbands

Instructor Notes: In these types of bands, the predominant mechanism responsible for the location and shape of the snow band is the land breeze generated by the thermal gradient between the lake and adjacent land areas. The relatively warm, moist environment over the water contributes to the formation of a "mesolow" that enhances the convergence of cooler land breezes over the water body. The cooler land breeze helps to lift the unstable air over the water. This lifting can be particularly significant in cases where land breezes from opposite shores converge in the vicinity of the mesolow.

Student Notes:



38. Land Breeze Snowbands

Instructor Notes: At times, the position of this band may be near the shoreline, similar to the location of the band created by frictional convergence, when the larger-scale background flow forces the convergence zone closer to the leeward shore. This suggests that in certain instances multiple convergence mechanisms may be working in concert to enhance the lifting. These types of bands generally do not produce the snowfall amounts that accompany single, wind parallel bands forced by thermal and frictional convergence. Why not? Answer the quiz question next to find out…

Student Notes:

39. Quiz 3: Snowbands

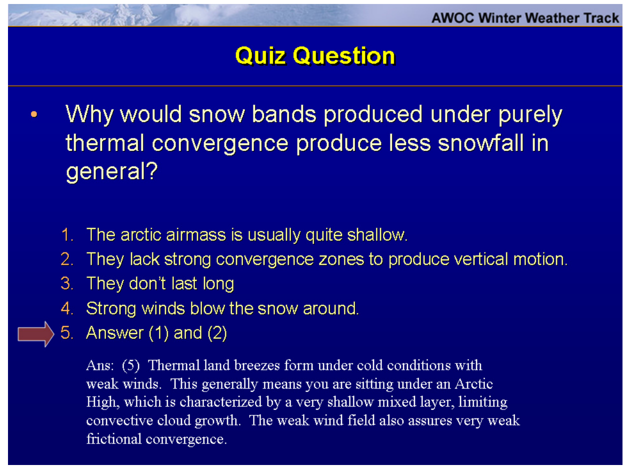
Instructor Notes: Take a moment to complete this quiz.

Student Notes:

40. Quiz 3 Review

Instructor Notes: The correct answer is both #1 and #2.

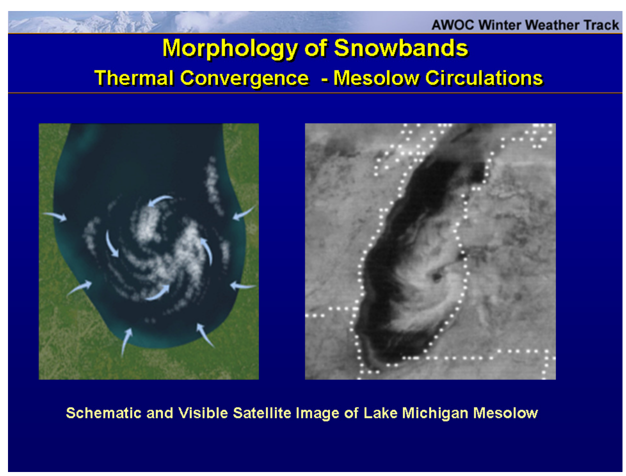
Student Notes:



41. Morphology of Snowbands: Thermal Convergence - Mesolow Circulations

Instructor Notes: In cases where the shoreline takes on a bowl-shaped or more circular configuration, the thermal convergence cab actually produce a rotational circulation or a mesolow. Once again, the type of weather system that typically produces pure, thermal convergence due to weak synoptic-scale wind and very cold temperatures is generally an arctic high, which is capped by a strong subsidence inversion, limiting convective cloud growth and snowfall.

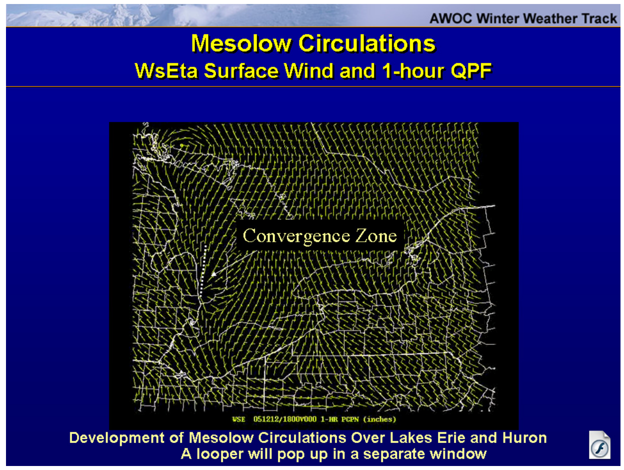
Student Notes:



42. Mesolow Circulations: WsEta Surface Wind and 1-Hour QPF

Instructor Notes: Here is a movie of the Workstation Eta (WsEta) running at 6-km resolution under very weak synoptic-scale flow and significant temperature difference between the land and water. Pay attention to the southern end of Lake Huron, where a land breeze convergence zone has developed along the west shore of the lake. As we move forward in time in one-hour increments, you will see the plume of precipitation and the associated convergence zone move north, develop a “spin” off the thumb of Michigan, and finally develop into a mesolow out over the relatively bowl-shaped portion of the lake. You can even see a mesolow briefly develop on Lake Erie, where the “bowl-shaped” north shore may be responsible for a “spin-up” too.

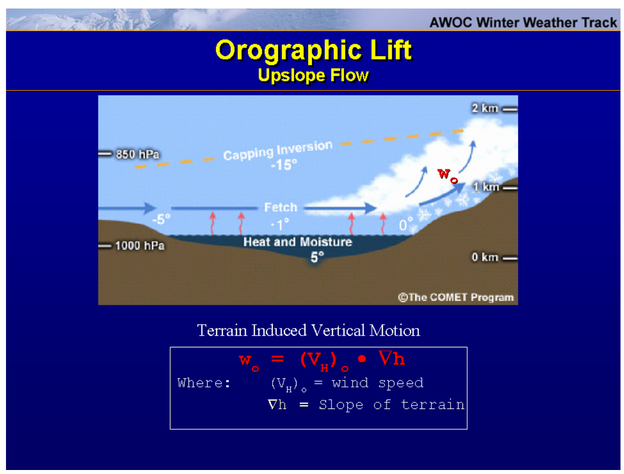
Student Notes:



43. Orographic Lift: Upslope Flow

Instructor Notes: Our final ingredient in producing lift is the effect that the topography of the region downwind of the lake has on snow production. As shown in the formula, terrain induced vertical motion is a direct result of wind speed and the slope of the terrain and (as we will see in following slides) there is a surprising amount of lift that can occur as a consequence of orographic features downwind of many lakes.

Student Notes:

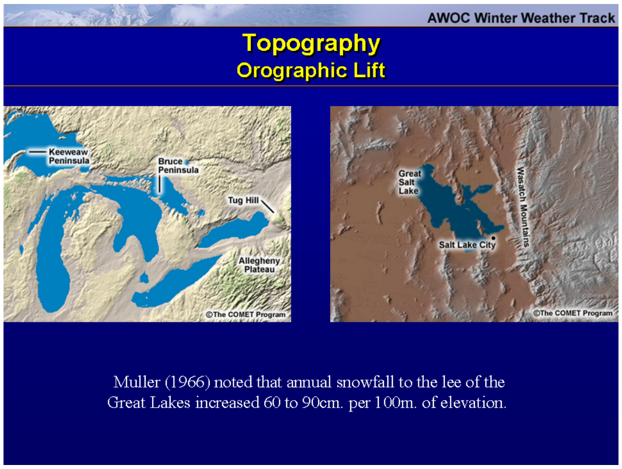


44. Topography: Orographic Lift

Instructor Notes: As snow bands encounter the higher elevations downwind of the lakes, snowfall is enhanced by an increase in the vertical motion produced by the flow.

This effect can be significant, especially when taken over an entire winter season. Muller (1966) noted that annual snowfall to the lee of the Great Lakes increased 60 to 90 cm per 100 m of elevation. In addition, the topography downwind of the body of water can help channel lake effect snow bands. As an example, the region around the Great Salt Lake where alternating north-south ridges and valleys to the southeast of the lake channel the flow. Reference: Muller, Robert, A. 1966. Snowbelts of the Great Lakes. Weatherwise 19, No. 6 (Dec. 1966): 248-55.

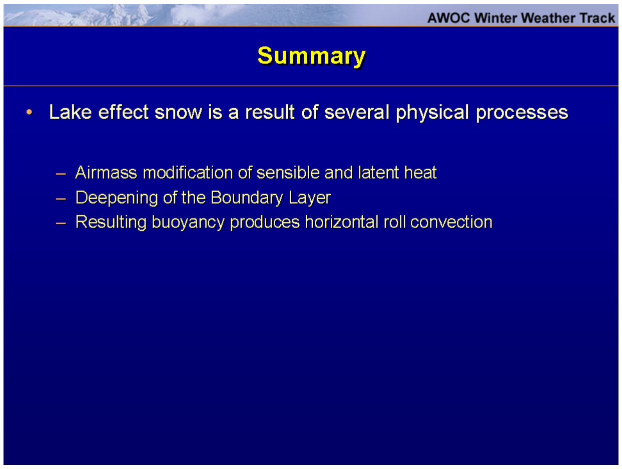
Student Notes:



45. Summary

Instructor Notes: So, in summary, there are several physical processes that contribute to the formation of these mesoscale snow storms, including: the modification of the airmass due to the release of sensible and latent heat as the cold air crosses the warm water, the deepening of the boundary layer from the modification of the lower atmosphere, and the development of convective rolls as the buoyancy of the airmass increases.

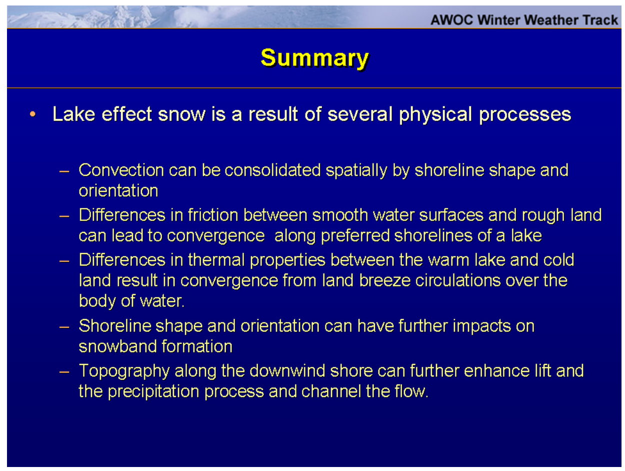
Student Notes:



46. Summary

Instructor Notes: In addition, under conditions such as parallel shorelines on some lakes, the roll convection can be consolidated into one particular band. Frictional effect between land and water will produce preferred areas of convergence. Thermal differences between land and water will create preferred areas of convergence as well. The shape and orientation of the shoreline itself will also contribute to preferred areas of band development. Finally, topography will further enhance lift and precipitation production while also helping to channel flow in some situations.

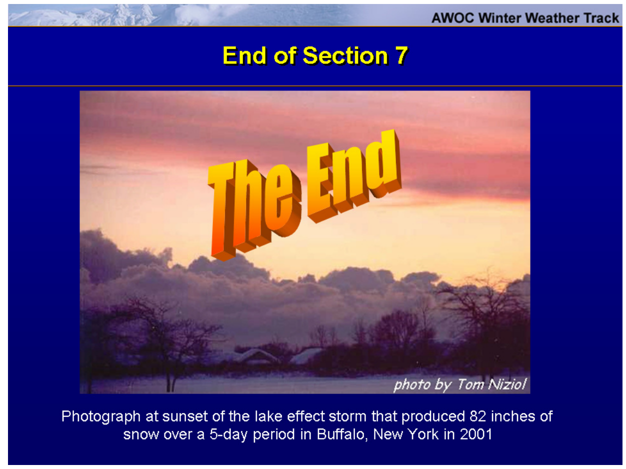
Student Notes:



47. End of Section 7

Instructor Notes: I hope you enjoyed a brief look at the physical processes that contribute to the development of lake snows. Other components of these mesoscale features that we were not able to discuss here, are addressed in other parts of AWOC's Winter Weather Course. I will also point you to the COMET NORLAT or Northern Latitudes web page (available off the MetEd web site) for a more in-depth discussion of lake effect snow.

Student Notes:



48. Have Any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

Student Notes: