1. Diagnosing Mesoscale Internal Forcing: Frontogenesis

Instructor Notes: This is Lesson 2 in the precipitation forcing Instructional Component. You'll be listening to Phil Schumacher, the SOO at Sioux Falls, SD and Dave Schultz at NSSL. It is 29 slides long and should take 30-35 minutes to complete.

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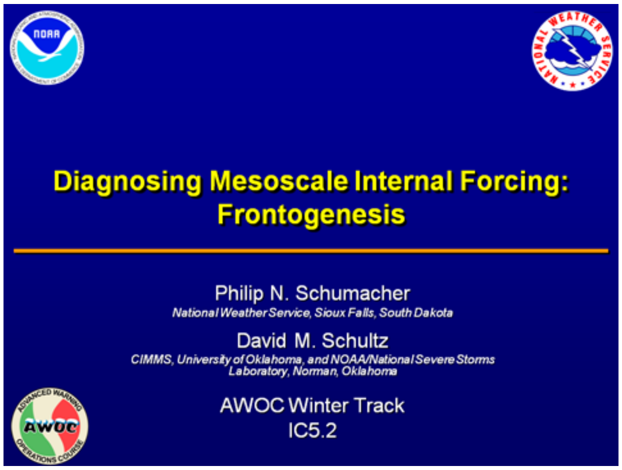

2. Learning Objectives

Instructor Notes: There are five learning objectives for this lesson. List two ways that frontogenetical circulations restore thermal-wind balance. List two types of flows favorable for Petterssen frontogenesis. Identify the difference between geostrophic frontogenesis and Petterssen frontogenesis. List two situations where differential diabatic heating can result in frontogenesis. Understand the relationship between low-level frontal circulations and upper-level synoptic-scale circulations.

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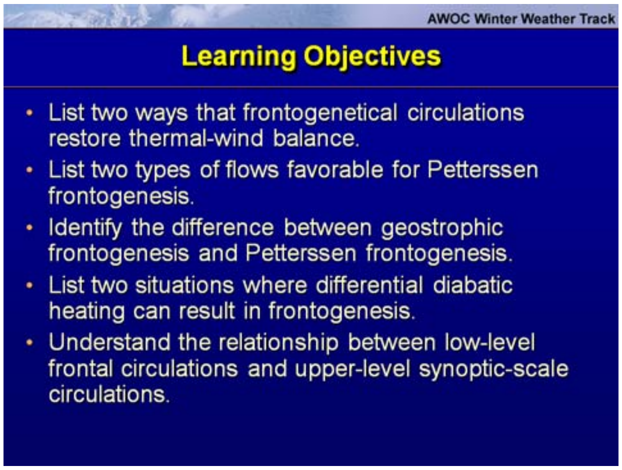

3. Performance Objectives

Instructor Notes: There are three performance objectives for this lesson. Determine which form of the frontogenesis equation available in AWIPS is most appropriate for diagnosing frontal bands. Use satellite to help identify areas where differences in diabatic heating could enhance frontogenesis. Apply the concept of coupling between upper-level waves and lower-level fronts to determine where the ascent associated with a frontal circulation may be strongest.

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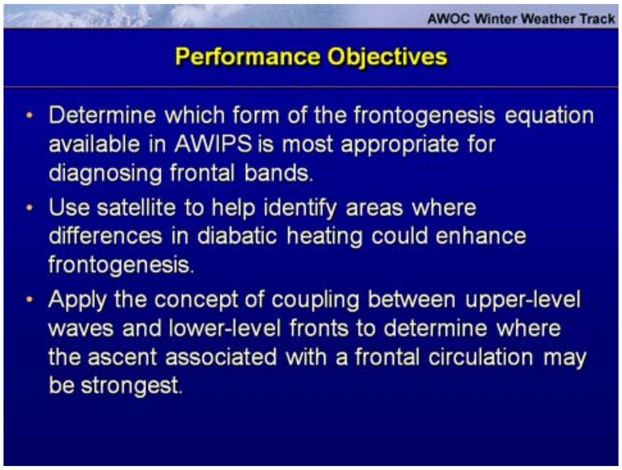

4. Frontal Circulations Produce Vertical Motion

Instructor Notes: The role of frontogenesis is to produce a direct circulation which will offset the effects of frontogenesis. The result is ascent on the warm side of the front which can produce heavy snow or rain. In some cases, very narrow and intense bands of snow (or rain) can develop. In the above case, notice that the snowband shown on radar is nearly coincident with the 700 mb frontogenesis at the same time. This snowband remained nearly stationary across South Dakota and northwest Iowa but did move north into central Iowa during the morning before becoming stationary. As a result there was a narrow band of 10 to 20 inches of snow from southeast South Dakota into east central Iowa.

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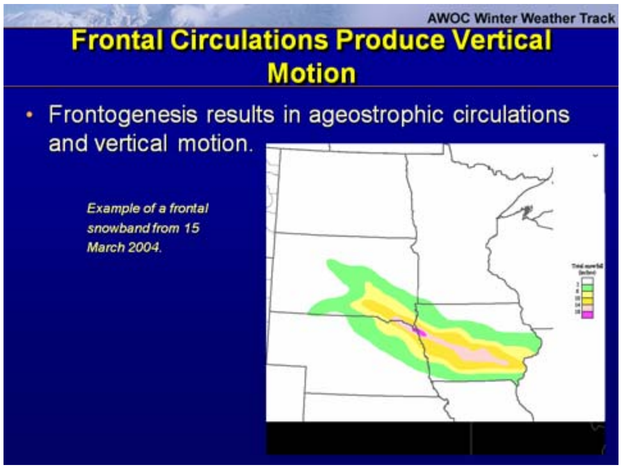

5. Thermal Wind Balance

Instructor Notes: Geostrophic theory shows that a balance exists between the vertical wind shear and the horizontal temperature gradient. The result is that the stronger the temperature gradient, the stronger the vertical wind shear must be to balance. Any forcing which disrupts this balance will produce an ageostrophic circulation which will try to restore the balance.

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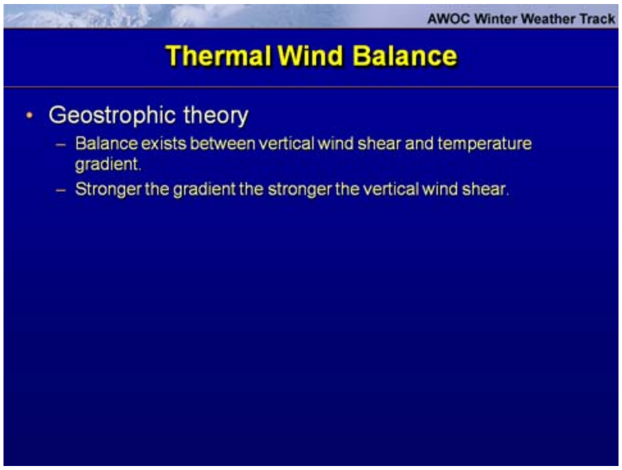

6. Fronts and the Thermal Wind

Instructor Notes: Frontogenesis examines the time rate of change of the magnitude of the temperature gradient within a parcel. An area that is frontogenetic does not necessarily mean that the thermal gradient associated within a front is necessarily strengthening. In fact, there are times when the local temperature gradient may be weakening even where there is frontogenesis. Frontogenesis only acts on the temperature gradient (i.e., there is no change in vertical wind shear). This process will produce an imbalance in the atmosphere and an ageostrophic circulation will develop.

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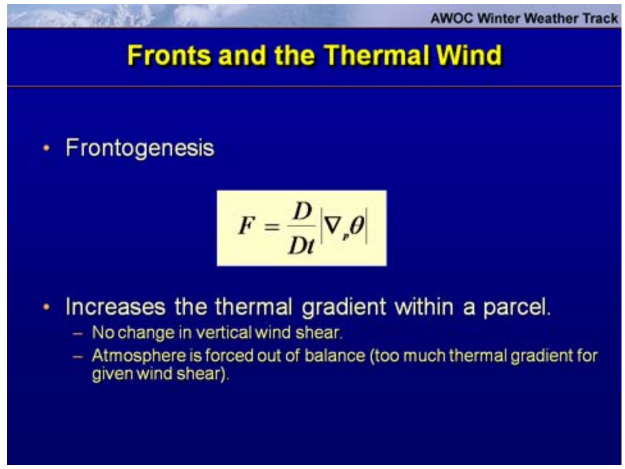

7. Frontal Circulations Act to Restore Thermal Wind Balance

Instructor Notes: A direct circulation develops which tries to restore thermal wind balance, which was disrupted by frontogenesis. The vertical portion of the circulation results in ascent in warm air and subsidence in cold air which reduces the temperature gradient. The horizontal ageostrophic flow increases the vertical wind shear. This results because the change in the geostrophic wind is directly proportional to the ageostrophic wind speed. So assuming this is an east-west front with cold air to the north, the upper branch of the circulation, which will produce ageostrophic southerly flow, increases the westerly geostrophic flow aloft. The lower branch of the horizontal circulation will produce ageostrophic northerly flow, increasing the easterly geostrophic flow at the surface.

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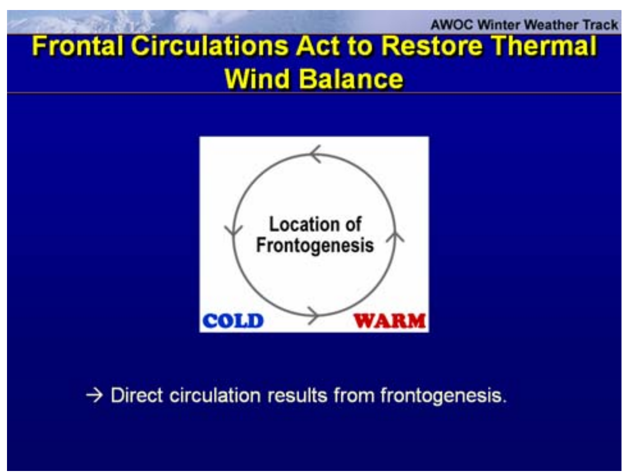


8. 1st quiz

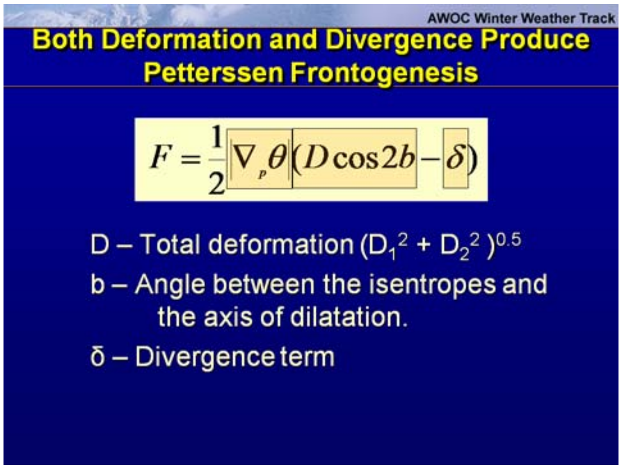
Instructor Notes:

Student Notes:

9. Both Deformation and Divergence Produce Petterssen Frontogenesis

Instructor Notes: Let's look specifically at frontogenesis and what produces changes in the temperature gradient. Note that frontogenesis is directly proportional to the magnitude of the temperature gradient. The temperature gradient is then multiplied by a quantity which is the sum of two terms. Both terms are related to the kinematics of the wind field. We'll examine each term separately in the next two slides.

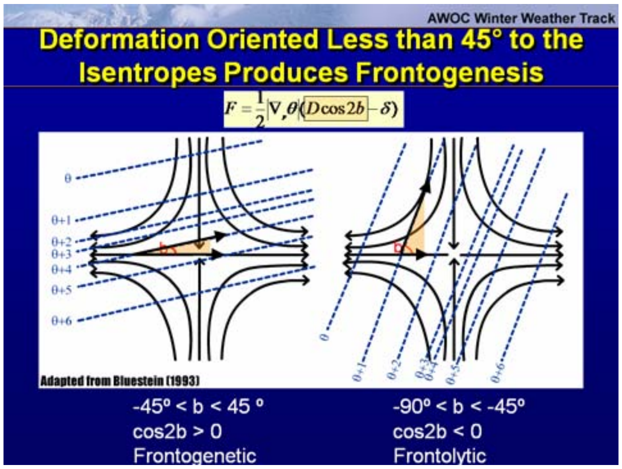
Student Notes:



10. Deformation Oriented Less than 45° to the Isentropes Produces Frontogenesis

Instructor Notes: Whether deformation is frontogenetic depends upon the orientation of the axis of dilatation with respect to the isotherms. In the diagram shown, the axis of dilatation is parallel to the x-axis. If the axis of dilatation lies within 45 degrees of the isotherms, then deformation will act frontogenetically. If the axis of dilatation is oriented more than 45 degrees from the isotherms, then deformation acts frontolytically. It should be noted that deformation is usually acting to rotate isotherms along the axis of dilatation increasing the frontogenetic forcing due to deformation.

Student Notes:



11. Convergence Always Produces Frontogenesis

Instructor Notes: Convergence will always produce frontogenesis. In the example shown, we see that convergence will act to bring isotherms together and therefore increase the temperature gradient.

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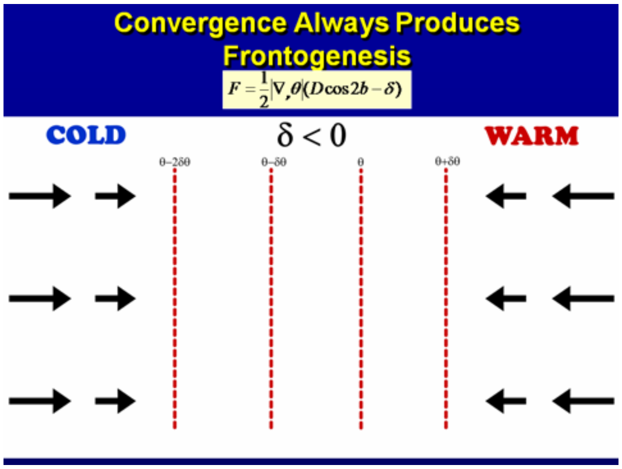

12. Divergence Always Produces Frontolysis

Instructor Notes: On the other hand, divergence always acts frontolytically. In the above example we see that divergence is acting to weaken the frontal gradient.

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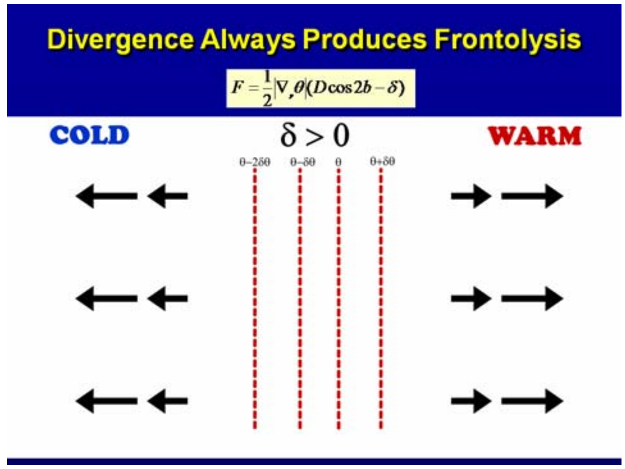

13. Fronts Form Through a Two-Step Process

Instructor Notes: Our conceptual model of how fronts are formed is that large-scale geostrophic deformation leads to frontogenesis. The vertical component of the ageostrophic secondary circulation then acts to oppose frontogenesis and weaken the temperature gradient. Meanwhile, the horizontal branch of the secondary circulation acts frontogenetically since it results in an increase in low-level convergence. In the middle of the atmosphere, the vertical branch of the circulation can offset the role of convergence while near the surface the vertical branch has little influence.

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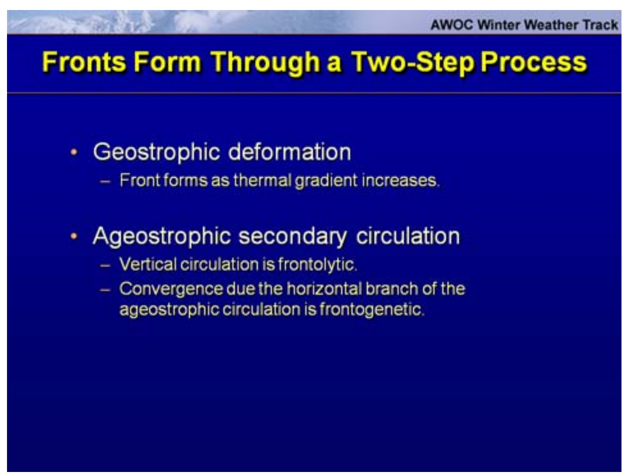

14. Avoid Using Geostrophic Frontogenesis

Instructor Notes: Although geostrophic frontogenesis is available in AWIPS, it should not be used to diagnose frontal bands. Geostrophic frontogenesis uses only the geostrophic wind, which is non-divergent. This means that divergence is not included in QG frontogenesis. Using geostrophic frontogenesis in operations ignores convergence which contributes a significant portion of the total frontogenesis especially away from cyclones. In addition, semi-geostrophic theory shows the presence of an ageostrophic cross-front wind is critical to the development of realistic looking fronts. By ignoring convergence, one misses an important ingredient to frontogenesis. We will explore this difference in the next two slides.

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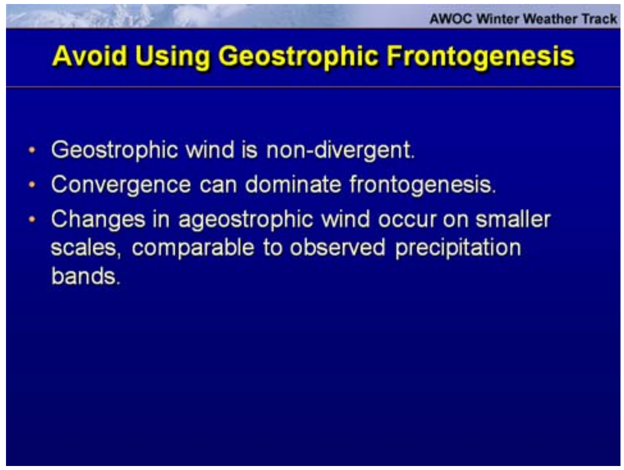

15. comparing total, geostrophic frontogenesis

Instructor Notes: The above example shows a case where the total and geostrophic frontogenesis are not coincident. The geostrophic frontogenesis is maximized over southeast Minnesota while the total frontogenesis is maximized over eastern South Dakota. Notice that this maximum is collocated with the maximum in convergence. In this case, the divergence term of the frontogenesis equation is dominant.

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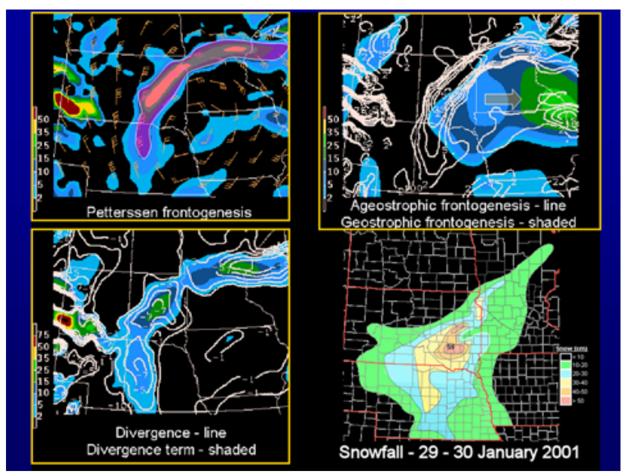
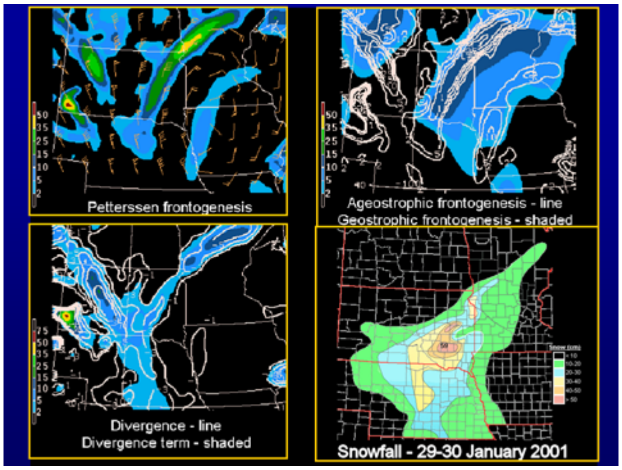


16. Geostrophic vs total wind

Instructor Notes: As the front continues to develop, the total frontogenesis and QG frontogenesis are nearly coincident in eastern South Dakota. However, the total frontogenesis is much stronger and more narrow due to the frontogenesis of the ageostrophic wind. While frontogenesis has developed in the western Dakotas, it was not associated with significant precipitation. The heaviest snowfall, up to 2 feet, was coincident with the location of the Petterssen frontogenesis. Much of this snow fell before the QG frontogenesis was maximized across eastern South Dakota and central Nebraska. Using geostrophic frontogenesis would have resulted in missing potential for a significant snowfall event over Nebraska, South Dakota and Minnesota and anticipating the sharp gradient on the northwest side of the low.

Student Notes:



17. F-vectors are Closely Related to Petterssen Frontogenesis and Q-vectors.

Instructor Notes: You may be familiar with Q-vectors. Q-vectors calculate the effect that the geostrophic wind is having on the flow. Specifically, the orientation of Q points in the same direction as the low-level branch of the secondary circulation, and the magnitude of Q is proportional to the magnitude of this branch. Through the QG omega equation, the divergence of Q can be used to diagnose the forcing for vertical motion. One partitioning of the Q-vector yields Qn and Qs. Qn is the component of the Q-vector normal to the local orientation of the isentropes. Qs is the component of the Q-vector parallel to the local orientation of the isentropes. Thus, Qn represents the frontogenesis due to the geostrophic wind alone. As we previously argued, this is generally inappropriate for ascertaining frontal circulations. In AWIPS, you may find some functions called F-vectors. F-vectors have two components: Fn and As. F-vectors are the total-wind generalization of Q-vectors and the magnitude of Fn is the same as Petterssen frontogenesis. While no similar expression relating F-vectors to forcing for vertical motion (as in the Q-vectors in QG theory), the divergence of F-vectors can be used to diagnose the forcing for vertical motion due to the total wind. Thus, Fn and its divergence are the preferred methods for diagnosing frontal circulations, not Qn and its divergence. Because F uses the total wind, the convergence field is much noisier than seen with Q-vector convergence. Therefore forecasters should look for temporal continuity in the divergence of Fn and overlay frontogenesis in order to help identify areas where there is persistent forcing for ascent.

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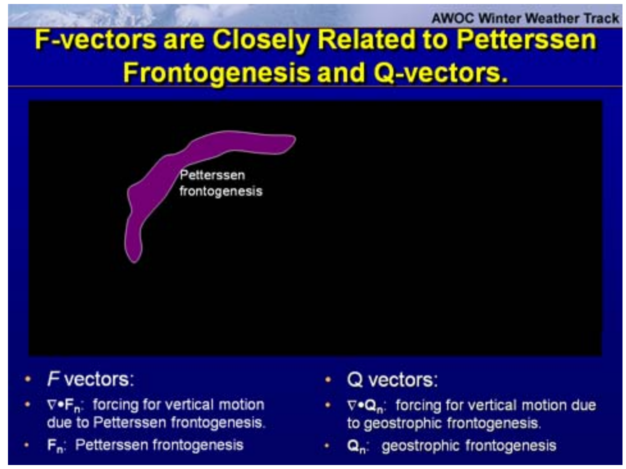

18. 2nd quiz

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

Student Notes:

19. To Diagnose Mesoscale Processes, Use Frontogenesis Calculated with the Total Wind.

Instructor Notes: In this example, the warm air is located to the north and west of the 850 mb frontogenesis. The Fn vector convergence is located to the warm side of the frontogenesis maximum and along the gradient in frontogenesis. So at 850 mb, the largest lift would be extending from central South Dakota into central Minnesota. As one goes higher into the atmosphere, the ascent would slope to the southeast. Therefore, because of the sloped ascent of a frontal circulation, it is critical to determine what level is most appropriate to examine frontogenesis when determining where the heaviest precipitation will be located. We will discuss selection of levels to examine frontogenesis later in this lesson and also in Lesson 3.

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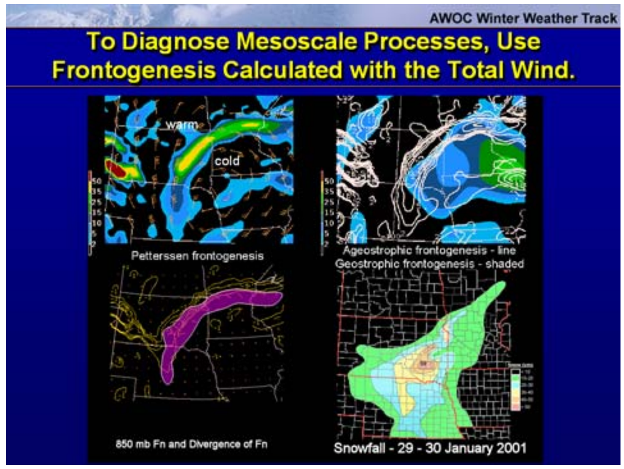
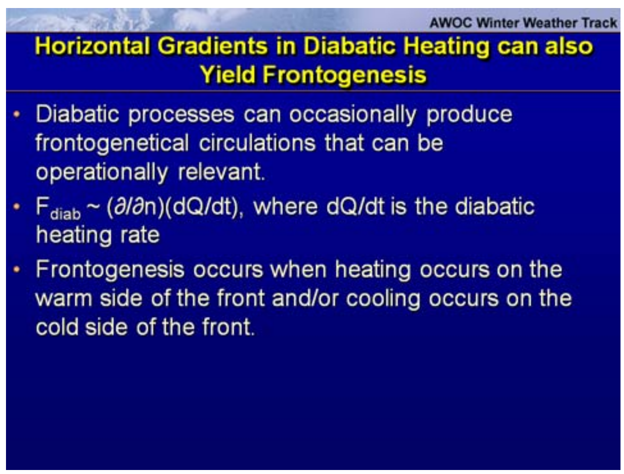


20. Horizontal Gradients in Diabatic Heating can also Yield Frontogenesis

Instructor Notes: Note that n is in the cross-front direction. We can produce a conceptual graphic.

Student Notes:



21. Examples of Diabatic Effects on Frontogenesis

Instructor Notes: The sensible heating from the water on the warm side of the Gulf Stream can enhance fronts moving offshore. The low clouds behind cold fronts can reduce the diurnal temperature range, and clear skies ahead of the front can increase the diurnal temperature range. In this situation, vertical motion along the front can be enhanced during the daytime when the front is increasing in intensity and minimized during the night when the front is decreasing in intensity. As shown by Markowski et al. (1998), cloud boundaries can be another region where frontogenesis can occur.

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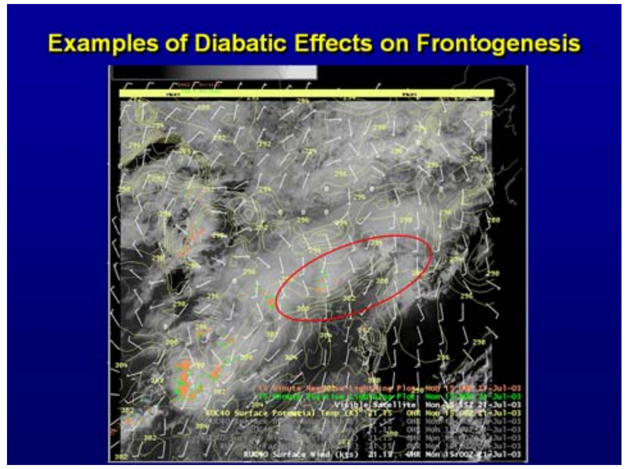

22. Upper-Level Circulations can Affect the Depth of the Low-Level Frontal Circulation.

Instructor Notes: In 1982, Shapiro used a conceptual model to show that the location of an upper-level jet relative to a low-level frontal circulation can play a critical role on whether a deep tropospheric circulation develops or not. In the example on the left, the exit region of the jet crosses over the surface front. The result is that the ascending branch of the indirect circulation of the jet is coincident with the ascending branch of the direct circulation associated with the front. This coincidence produces deep convection over the surface front. On the right side, the jet does not cross the surface front. As a result the descending branch of the indirect circulation is located over the ascending brand of the direct circulation of the front near the surface boundary. This suppresses convection and one is left with shallow lift along the surface boundary. However, notice that as one continues to the left and deeper into the cold air the ascending branch of the indirect jet circulation is collocated with the ascending branch of the frontal circulation. This does produce deep lift well behind the surface front and, were this winter, one could imagine a band of heavy snow developing in that area.

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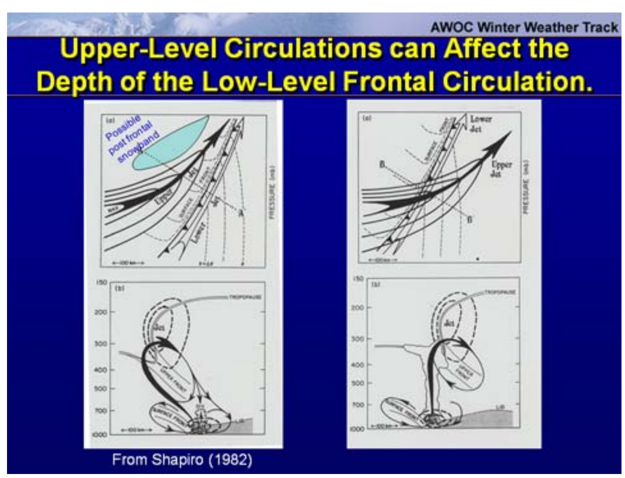

23. Coupling of Upper- and Lower- Level Tropospheric Jet-Front Systems

Instructor Notes: Hakim and Keyser (2002) ran a theoretical model to test this conceptual model of Shapiro (1982). To simplify the problem, Hakim and Keyser have frontogenesis located near the surface and frontolysis (to represent the exit region of a jet) aloft. This condition does not produce a realistic frontal circulation that extends well behind the front. What it does show is that the location of the forcing with respect to each other is critical. In the uncoupled case, we see that the ascending branches are separate and the low-level frontal circulation remains shallow, while in the coupled case both ascending branches are coincident and a much deeper ascent is observed. This illustrates how critical the location of the upper wave can be to development of intense frontal circulations.

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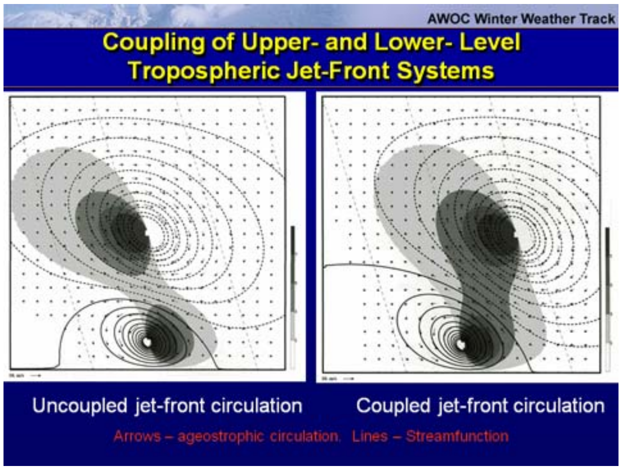

24. PV Anomalies and Frontogenesis

Instructor Notes: Upper waves also impact low-level wind field and thermal field. Recall from Lesson 1 that potential vorticity anomalies act like magnetic fields, their impact extends well beyond the level where they are located. This can increase the deformation and divergence in the presence of a front. One way to examine this impact is to invert potential vorticity to look at the wind field due only to an anomaly located near the tropopause. While the exact details of this process are beyond this talk, realize that when one inverts you only recover the non-divergent portion of the wind field. The role of convergence in frontogenesis will be missed.

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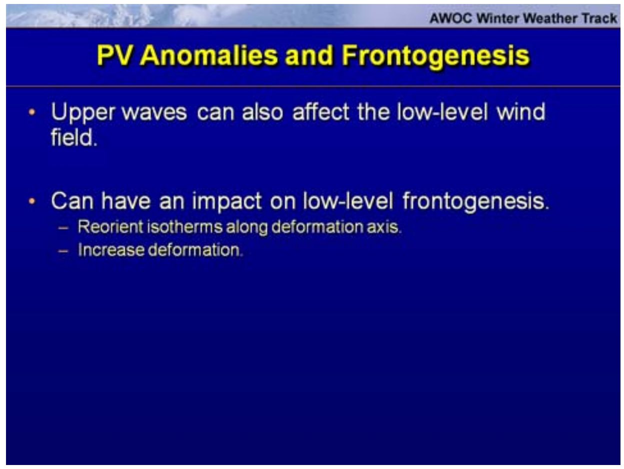

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25. 1200 UTC 30 Dec. 1993
0000 UTC 31 Dec 1993

Instructor Notes: Morgan (1999) split PV anomalies between upper-level, midlevel (diabatically produced), and surface anomalies (coincident with cold and warm temperature anomalies). We will examine the role of the upper anomaly. The graphic on this slide examines a deepening cyclone over New England. In the 250 to 500 mb layer (top) one can see a positive PV anomaly over New York and a negative anomaly over the Canadian maritimes. Both anomalies translate northeast in 12 hours. The resultant thermal and wind field (bottom) induced by these two anomalies shows that there is enhanced frontogenesis near the thermal ridge over New England which extends south along the cold front. The impact on frontogenesis increases 12 hours later over the Canadian maritimes. In this case the interaction of the two PV anomalies results in frontogenesis develop within a trowal and enhances snowfall in eastern New England and the maritimes.

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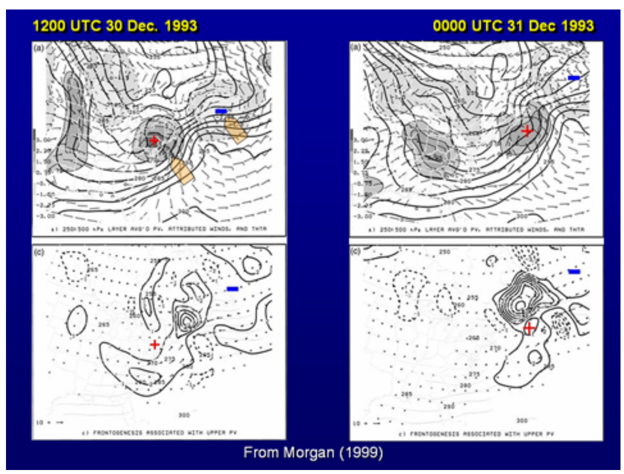

26. 400–300-mb PV, and 950-mb Moisture Convergence

Instructor Notes: On April 30, 2001, a small area of severe convection developed from northeast Nebraska into southeast Minnesota. This resulted from an interaction between a PV anomaly moving across South Dakota and a surface convergence boundary over northwest Iowa. The shaded image shows the PV anomaly as a darkening area over South Dakota. Also overlaid is the wind convergence at 950 mb. As the upper wave approaches eastern South Dakota, the convergence increases and narrows across eastern Nebraska, western Iowa, and southern Minnesota.

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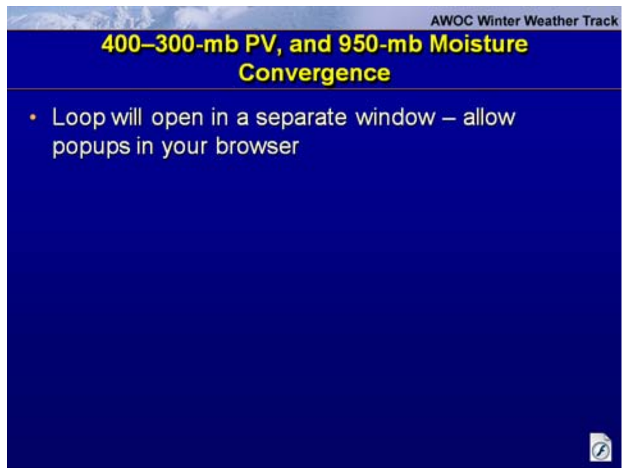

27. Example – 30 April 2001Visible Satellite and Observations

Instructor Notes: This loop (which shows up in a separate window...make sure your popup blocker is turned Off) shows the visible satellite imagery and observations from 30 April 2001. The orange X is the approximate location of the center of the PV anomaly and the dashed red line is the convergence boundary. Notice that as the PV anomaly approaches, the convergence line slowly progresses to the northwest. The winds in portions of northwestern Iowa shift to the southeast and accelerate to 10 to 15 knots. Across southeast South Dakota, the winds became northwest and increased over 10 kts as well. The result was increased surface convergence and with the low surface stability severe surface-based convection developed over northwest Iowa. We believe that the approach of the PV anomaly not only induced lift near the surface boundary but may have induced more convergence flow near the boundary.

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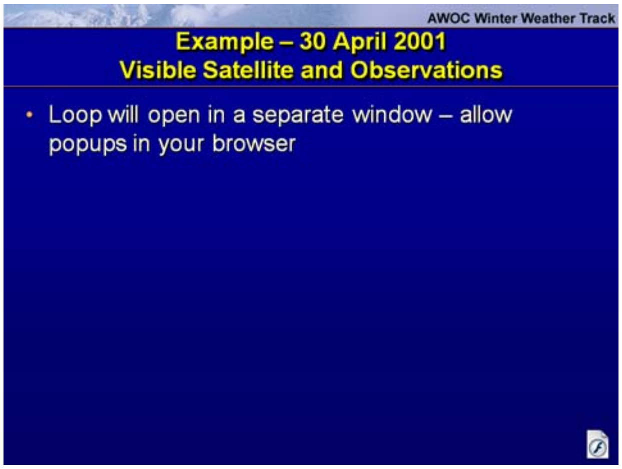

28. Use Q-vectors as Means to Identify the Impact of PV Anomalies on Low Level Fronts

Instructor Notes: One of the most difficult decisions for a forecaster is to determine what level to examine frontogenesis. We saw from Hakim and Keyser (2002) that the location of the upper-level anomaly with respect to the low-level anomaly was critical to determine whether a coupled circulation will develop. To apply this idea, overlay the upper-level Q-vector convergence, which examines the role of the synoptic-scale upper-level wave and then frontogenesis at different levels. Noting where the frontogenesis is generally collocated with the Q-vector convergence can help you decide what level to examine. In most cases, there will be a 50 – 100 mb layer that may apply. While the example only shows a snap shot from one time, one would generally want to examine the Q-vector convergence and frontogenesis through the entire event to see how both evolve. Note that the 850 mb frontogenesis is located well south of the axis of Q-vector convergence. At the same time both 700 mb and 650 mb are nearly located along the axis of Q-vector convergence. They remain nearly coincident with the strong Q-vector convergence through the event and either level would be a good choice. This process will still not tell you how broad or narrow the frontal band will be. This topic will be examined in Lesson 3. In addition, Lesson 4 will provide more examples of the role of the upper level wave in enhancing frontal circulations and IC 6 will discuss a methodology for determining the potential for frontal bands.

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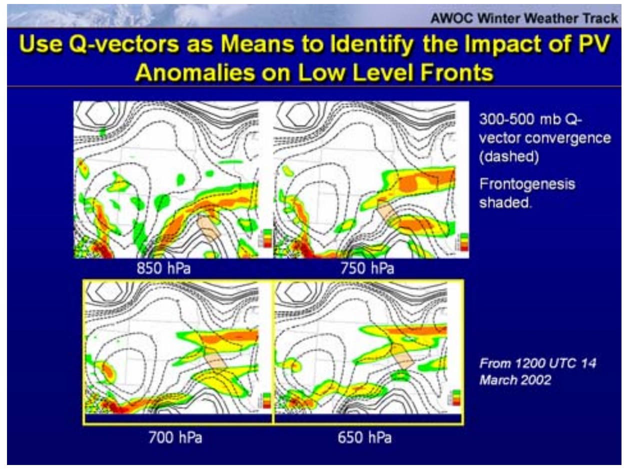

29. ic5 lesson2 query 3

Instructor Notes:

Student Notes:

30. Conclusion

Instructor Notes: In conclusion, frontal circulations arise as the atmosphere attempts to restore thermal wind balance. Frontogenesis acts to increase the thermal gradient while not changing the vertical wind shear. Therefore an ageostrophic circulation will develop. The horizontal portion of the circulation will act to increase the vertical wind shear while the vertical portion of the circulation will act to weaken the thermal gradient. When calculating horizontal frontogenesis, deformation and convergence both can act to increase the thermal gradient within a parcel.

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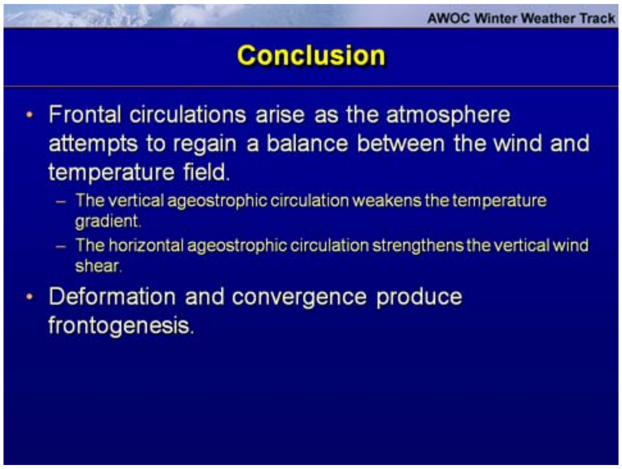

31. More Conclusions

Instructor Notes: While both Petterssen and geostrophic frontogenesis are available in AWIPS, it is critical the Petterssen frontogenesis is used. The geostrophic form of frontogenesis does not include convergence since the geostrophic wind is non-divergent. This will result in a calculation which is broader and weaker than using the total wind. Differences in diabatic heating, such as land vs. water surface or clear vs. cloudy skies, can also result in frontogenesis and, given time, produce a frontal circulation. Finally, upper-level PV anomalies can have large effect on frontal circulations. First, PV anomalies are also associated with ageostrophic circulations. These circulation can act to enhance or inhibit the updraft associated with a frontal circulation. Therefore being aware where superposition of frontal circulation and synoptic-scale wave circulations can help identify locations where frontal bands are most likely to develop. Second, PV anomalies can influence the low-level wind field. This can mean increased or decreased deformation along a thermal gradient which can impact frontogenesis. By changing the deformation near a boundary, a PV anomaly may also change the strength of a frontal circulation.

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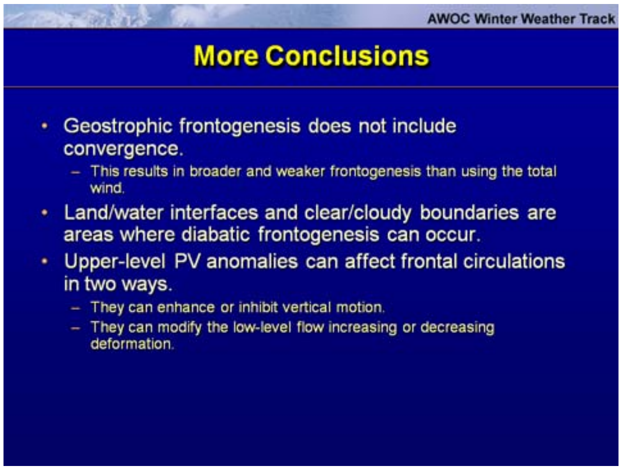

32. References

Instructor Notes: This slide contains a list of references mentioned during this presentation.

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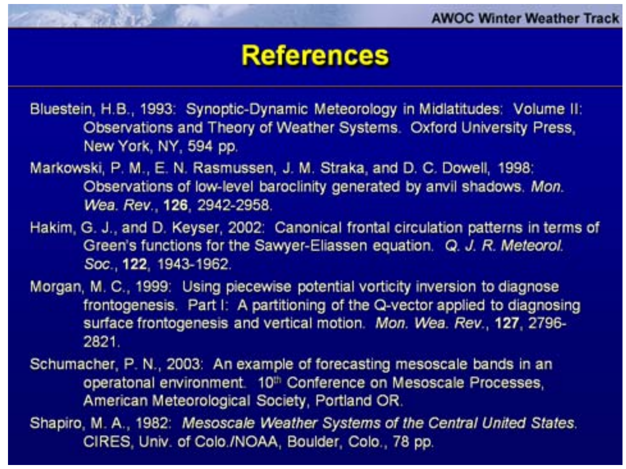

33. Have any Questions????

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: