Talking points for VISIT teletraining session:
Cyclogenesis: Analysis utilizing Geostationary Satellite Imagery

1. Title slide
2. Objectives
3. Early cyclone model by Bjerknes and Solberg (1922). Based primarily on surface data with some sounding information at lower levels. Middle and upper troposphere data not available at this time.
4. Modern concept of cyclogenesis. Modern theory stresses the interaction of upper and lower tropospheric features.
5. Wide frontal cloud band with cold tops - cyclogenesis begins in the vicinity of a pre-existing frontal band as upper level trough approaches. Red lines are 500 mb height. Cyan arrows represent a schematic of the approximate location of upper level jet. Shaded blue indicates cloud cover as might be observed in IR imagery. Frame 2) Water vapor example of schematic.
6. Baroclinic leaf phase - this pattern represents the beginning of the cyclogenesis process. The term Warm Conveyor Belt (WCB) is introduced. Warm Conveyor Belt here as defined by Harrold (1973) as a flow of high theta-w air that ascends as it advances poleward ahead of the cold front. It often produces precipitation.
7. Barolinic leaf phase (jet structure) - An S shaped area begins to develop in the WCB. Upper level short wave interacts with surface front leading to surface pressure falls and increasing vertical motions. The result is increasing thermal advection, rising air and an expanding cloud shield ahead of the region of the developing surface low, and an increase the upper level wind speeds. Frame 2) Water vapor example of schematic. Example shows drier air at mid-upper levels to the southwest of the develop baroclinic leaf where subsidence is occurring. Warming is south of the inflection point. If this were not the case, cyclogenesis would most likely not occur.
8. Incipient position of the surface low
9. Schematic accompanying description on previous slide
10. Development of warm and and cold conveyor belts - formal definitions
11. Warm and cold conveyor belts - schematic from Carlson 1980
12. Baroclinic leaf advanced phase.
13. Advanced leaf phase - described in previous 2 slides. Frame 2) Water vapor example of schematic
14. Evolution to the comma shape
15. Fully developed comma cloud - Schematic accompanying description on previous slide. Frame 2) Water vapor example of schematic
16. Basic review slide - shows emerging CCB in IR imagery as well as the developing cusp, Water Vapor shows position of surface low at various stages as well as the WCB/CCB in mature system.
17. Occlusion begins - As system occludes cold and warm air begin to mix and sfc low begins to fill. Upper level wind speeds decrease poleward of the center. Frame 2) Water vapor example of schematic
18. Surface low begins to fill
19. Basic cyclogenesis - diagrams from Bader illustrating material just covered

20. Water Vapor loop of first segment (17:30 UTC (14 Mar) - 15:30 UTC (15 Mar). Baroclinic leaf with dry slot to its southwest is developing.
21. Loop of Water Vapor imagery, 300 mb isotachs and wind barbs from AVN – times are 18:00 UTC (14 Mar) - 06:00 UTC (16 Mar). Note jet max associated with the WCB. Jet maximum associated with short wave trough can be seen approaching from the west. The two jet max's can still be easily identified. Often times the area of developing cyclogenesis is associated with the phasing between two jets. Draw a line from the right rear quadrant of the eastern jet to left front quadrant of the western jet. The key on the water vapor imagery is the beginning of a new dry slot on or near this line.
22. Water Vapor loop of second segment (16:00 UTC (15 Mar) - 13:30 UTC (17 Mar). Notice the new area of drying associated with the phasing jets expands and basic cyclogenesis begins shortly thereafter.
23. IR imagery superimposed on AVN model fields, where yellow is MSLP and cyan is 500 mb height. Note that the primary extra-tropical cyclone matures and the surface pressure (model-derived) drops fastest in this case as the "cusp" phase is reached. This matches the earlier conceptual model discussion. Note also that the shortwave to the west intensifies and develops a surface low. The model position appears to be significantly off.
24. Visible imagery 17:45 UTC (16 March) - 02:00 UTC (17 March). Shadows reveal the emerging CCB and the limiting streamline in the easternmost system. Also note cellular cumulus behind the cyclone in the cold sector. The secondary system to the west is developing in this cooler air. This type of cyclogenesis – called Cold Air – will be addressed later.
25. Summary of basic cyclogenesis
26. Variations in cyclogenesis - listed. Terminology varies by author (Bader's terminology in parentheses).
27. Split flow with basic cyclogenesis - Introduction
28. The forecaster should note the WCB in the central Pacific (northwest of Hawaii). Notice the indentations in the WCB near the end of this loop with a small area of cold cloud tops just north of the largest indentation.
29. GMS (Japanese Geostationary Satellite) view of the longwave trough, the WCB (just observed, and a shortwave trough approaching from the west.
30. GOES-10 view of WV imagery with AVN generated 300 mb isotachs and wind barbs. Loop runs from 03:00 - 12:00 UTC, 24 Oct 1997. Note the jet max approaching from the west is moving southward with a diffluent region to its east. This is the region of maximum vorticity advection. Note also that this is the area where the two jets are phasing. Northeast of there the winds are westerly.
31. There are 3 regions where baroclinic leafs appear to be developing. Question) Which area would be a threat to forecasters in the northwestern United States? Answer is C to be shown in the next several slides.
32. IR imagery superimposed on AVN model fields, where yellow is MSLP and cyan is 500 mb height. A cyclone develops on the southern end near region B and moves southward. Note this low is vertically stacked and will probably weaken soon. Meanwhile in region C a baroclinic leaf develops. This potential cyclone is in westerly flow and is the one most likely to affect the United States. The model fails to find a surface low during this period.

33. Water Vapor loop (03:00 UTC (24 Oct) - 00:00 UTC (25 Oct). Note the region of drying to the west/southwest of the developing baroclinic leaf in region C. Remember that dry air developing south of the inflection point is another sign that cyclogenesis will most likely occur. Southern cyclone remains less intense, most likely because northern system is cutting off the cold air.
34. Water Vapor loop (03:00 UTC (24 Oct) - 19:00 UTC (26 Oct) showing the full sequence of split flow cyclogenesis in this example. We observed an increasing number of indications in the imagery that cyclogenesis would most likely occur. There was strong upper support (dual jets), development of a baroclinic leaf, a developing dry slot south of the incipient position. Finally, we note an indentation that developed along the baroclinic leaf just east of the dry slot. Note that the southern system occludes completes, remains small and drifts southwest. The northern system intensifies as illustrated in basic cyclogenesis discussed earlier. It makes landfall at the end of the loop.
35. Cold air cyclogenesis – Introduction to cold air cyclogenesis
36. GOES-10 view of WV imagery with AVN generated 300 mb isotachs and wind barbs. Loop runs from 12:00 UTC (27 Nov 1997) - 12:00 UTC (28 Nov 1997). Note trough over Gulf of Alaska, a WCB on the east side of this trough, and a jet maximum on the west side. In the center of the trough GOES WV imagery shows a comma cloud associated with a shortwave trough.
37. Water Vapor loop (10:30 UTC (27 Nov) - 18:45 UTC (28 Nov). Loop shows the short wave trough developing and intensifying between the two jets, entirely within the cooler air west of the WCB. When developing systems remain west of the WCB, we call this Cold Air Cyclogenesis.
38. IR imagery (from 12:00 UTC, 27 Nov through 15:00 UTC 28 Nov) superimposed on AVN model fields, where yellow is MSLP and cyan is 500 mb height. Model underplays the intensity of the development – model seems to have "fallen behind" on system development. 500 mb trough amplifies substantially as cyclone develops.
39. Instant Occlusion Cyclogenesis – Introduction.
40. Secondary warm conveyor belt - recent modification to earlier work by Carlson. Flow of air in CCB indicated by dashed arrows
41. GOES-8 Water Vapor loop (03:15 UTC – 23:45 UTC, 24 Jan 2000). Loop shows apparent cold air cyclogenesis over the southeastern U.S. in the early part of the loop, BUT convection develops between the WCB and the intensifying cyclone. When this occurs the cyclone can draw air from the warm sector via a secondary WCB. The cyclogenesis occurs more rapidly and the system becomes more intense.
42. IR loop from 02:45 UTC - 22:01 UTC 24 Jan 2000. Different perspective of the instant occlusion. Note emersion of the CCB over Georgia and South Carolina.
43. In Stream Cyclogenesis – Introduction
44. GOES-10 Water Vapor loop (12:00 UTC 19 Nov. – 12:00 UTC, 21 Nov 2001). Loop shows a family of cyclones developing along the north side of a zonal jet (in-stream).
45. IR imagery (from 12:00 UTC, 19 Nov through 12:00 UTC 21 Nov) superimposed on AVN model fields, where yellow is MSLP and cyan is 500 mb height. Compare the development of the surface lows with the satellite imagery and assess how the AVN is handling each system.
46. AWIPS case studies introduction
47. Introduction to 24 February 1999 case for Boston (BOX) CWA

48. Eta 300 mb Height and isotachs from 12:00 UTC 24 February forecast through 18:00 UTC 25 February 1999. Broad trough off the east coast of the U.S. with an elongated jet streak off the southeast coast. Loop shows a developing trough over the BOX CWA with jet maxima on either side of the trough. There may be potential for the two jets phasing offshore.
49. Eta 500 mb Height and isotachs from 12:00 UTC 24 February forecast through 18:00 UTC 25 February 1999. Notice the embedded shortwaves, one of which becomes a negatively tilted trough centered on the BOX CWA by the next morning.
50. GOES-8 Water Vapor loop (00:15 UTC – 13:32 UTC, 24 Feb 1999). Note the WCB off the coast of the Atlantic seaboard and the circulation over the Carolinas. Also notice the digging jet over the Dakotas.
51. Eta 300 mb Height and isotachs. 12:00 UTC 24 February. There are three jets of concern. One is southeast of Nova Scotia, the other is off the coast of Georgia with another over Iowa. Be sure to be aware that the two eastern jets could phase offshore and affect the Boston CWA. The jet to the west seems to be digging and may sharpen the trough. The satellite imagery shows a deeper trough than indicated by the Eta initial analysis.
52. Eta 500 mb Height and vorticity from 12:00 UTC 24 Feb 99. Forecast out to 06:00 UTC 25 Feb. Water vapor image underlaid with initial analysis to illustrate that the vorticity centers are not necessarily associated with the circulation center of the developing cyclone. Vorticity centers can be generated by both circulations and speed shears associated with jet streaks. They should not be used to track/forecast the circulation center unless one can clearly separate the two effects. Notice also that the amplitude of the trough is underdone in the initial analysis.
53. SST analysis 24 February 1999. Shows a strong temperature gradient associated with the Gulf stream that is oriented northeast to southwest. NWS offices in North Carolina use the SST's as input to the Atlantic Surface Cyclone Intensification Index (ASCII) to forecast cyclone intensification: http://nwsilm.wilmington.net/science/ascii/ascintro.html
54. Eta MSLP, precipitation, and surface winds from 12:00 UTC 24 Feb through 06:00 UTC 25 Feb. Forecast indicates the low will stay well off coast but deepen to 999 mb by 18:00 UTC the next morning. The forecast precipitation begins at 06:00 UTC 25 February 1999 but the most intense precipitation stays well offshore in the model. Even though the minimum central pressure is not very low, the high pressure to the north is quite strong (1036 mb). The pressure gradient is therefore quite strong. The strong high also plays a role in the postion/movement of the low.
55. GOES-8 Water Vapor loop (14:00 UTC 24 Feb – 02:32 UTC 25 Feb 1999). Deep convection is observed developing behind the WCB as the system moves over the region of maximum SST gradient of the Gulf Stream. Notice convection is also beginning to develop on the south end of the system, east of Florida, between the WCB and the cyclone. This should be a warning flag that the system may soon be drawing warm air from the warm sector (i.e. instant occlusion). Trough has developed a negative tilt and is amplifying partly in response to the jet over the midwest.
56. GOES-8 Water Vapor loop (02:32 UTC – 14:30 UTC 25 Feb 1999). Deep convection expands as the system begins to draw unstable air from the warm sector. As the convection moves on shore, heavy snow begins in eastern MA.
57. GOES-8 Water Vapor image 12:00 UTC 25 Feb 1999 overlaid with 24 hr forecast of the Eta MSLP. Bold white "L" shows low circulation as seen in animated water vapor

imagery. This position matches the expected position from the conceptual model being northeast of the end of the cusp. Eta forecast low position is too far south. Also the forecast trough was not as sharp as what actually occurred. A secondary WCB developed and the system was able to access more unstable air than expected. The result was deep, convective snow showers over land.

58. Observed snowfall amounts for the event.
59. Summary of 24 February 1999 case - Several factors came together for Instant Occlusion cyclogenesis. The SST gradient on the north wall of the Gulf stream provided latent heat release and the dual jet structure with development occurring between the two jets was key. The southern jet was too far south in the Eta, which caused the model to not capture this development as accurately. The Eta was playing “catch up” much of the time for this event, it was too slow to capture the rapid development and, more importantly, too far offshore (south and east).
60. Introduction to 10-11 April 2001 case for Goodland (GLD) CWA
61. Eta 500 mb height (yellow contours in dm) and vorticity (solid shading) from 00:00 UTC forecast through 18:00 UTC 11 April 2001. A four corners upper low is forecast to move northeast towards Kansas and deepen.
62. Eta 850 mb height (green contours in dm), isotherms (red) and wind barbs same times as previous slide. Notice the strongest warm advection is northeast of the advancing low.
63. Water Vapor loop from 21:00 UTC (10 April) through 02:00 UTC (11 April) 2001. The WCB is located from southwest Texas northeastward into Iowa. Upper low is located over the 4 corners region. Initially appears to be cold air cyclogenesis, but notice the signs of developing convection along the Kansas/Colorado border. Recall that developing convection between the WCB and the upper low is an indicator of Instant Occlusion cyclogenesis.
64. Eta 6 hour forecast CAPE valid at 06:00 UTC 11 April 2001. We want to check to see if conditions are favorable for the development of a secondary warm conveyor belt which would transition the system from a cold air type of cyclogenesis to the more significant instant occlusion type of cyclogenesis. The two ingredients to consider are instability and if the area of interest is in the jet exit region (recall slide 40 mentions this is important for the development of the secondary warm conveyor belt). The instability shows that indeed there is sufficient instability for convection develop betwen the warm conveyor belt and the upper low in Colorado, in the next slide we will assess if this area is in the jet exit region.
65. Eta 300 mb height (green contours dm), isotachs (dashed yellow in knots) at 000:00 UTC 11 April 2001. The deep convection in Kansas has developed ahead of the 300 mb jet maximum. The developing convection on the KS/CO border occurs in the exit region of the jet.
66. Water Vapor loop from 02:00 UTC through 11:00 UTC (11 April) 2001. Confirms instant occlusion cyclogenesis. Recall that the developing cyclone will now be accessing the more unstable air from the warm sector. Note that system seems to be moving along Eta predicted track as we saw earlier.
67. MSAS MSLP and surface wind analyses from 00:00 UTC through 11:00 UTC 11 April 2001. Note the MSLP begins falling most rapidly around 05:00 UTC as the instant occlusion takes place. As the secondary WCB feeds warmer air into the system, vertical motions increase and MSLP decrease. Note that this is also the time when the left front

quadrant of the 300 mb jet moves over the area, and the time when the upper low moves out of the Rockies. This provides additional forcing via the development of a lee trough. Also, notice the error in the position of the low on the MSAS MSLP analysis. On the water vapor loop in the previous slide we saw the cusp in east central Colorado around 06:00 UTC which would place the surface low in northwest Kansas. The MSAS MSLP analysis between 05:00 and 07:00 UTC showed it southwest of the location given in the WV imagery. Surface observations showed that the low was indeed in southeast Colorado as the MSAS analysis showed. There are two reasons for the discrepancy. First, the stretching of vorticity associated with a column of air as it moves from the higher alpine regions to the plains causes the low to form in the vicinity of maximum vorticity stretching. Second, the downslope winds associated with this new low will cause an area of warm advection, south of the surface low circulation. These two factors cause the surface low to be a little further south than what was expected from water vapor imagery analysis alone.

68. Summary of 10-11 April 2001 case
69. Summary