Talking points for cyclogenesis life cycle

1. Title
2. Learning objectives
3. Before we begin discussing extra-tropical cyclogenesis, it's important to understand the various components of flow, usually referred to as conveyor belts when discussing cyclogenesis. We present a conceptual diagram, produced by COMET, of the conveyor belts associated with extra-tropical cyclogenesis. Ahead of the cold front in the warm sector, the warm conveyor belt transports warm air poleward from lower to upper-levels. As the cyclone evolves, you may observe a branch of the warm conveyor belt peel off in a cyclonic direction towards the surface low. This is typically referred to as the secondary warm conveyor belt, and once the system is occluded is generally referred to as the TROWAL airstream or trough of warm air aloft. Note that this airstream does not ascend as high in the vertical as the anticyclonic branch of the warm conveyor belt that is typically caught up in westerlies aloft. The cold conveyor belt originates north of the warm front and transports cold air from lower to mid-levels in a generally poleward direction towards the surface low. The dry conveyor belt, or dry slot is a region of subsidence behind the cold front that is composed of 2 branches as shown. This region typically is characterized by warmer brightness temperatures in water vapor imagery.
4. Early in the life cycle of extra-tropical cyclogenesis an upper level trough approaches a frontal band. The shaded blue region in the conceptual diagram represents clouds as they might be observed on IR satellite imagery. Red lines correspond to 500 mb heights and cyan arrows represent the approximate upper level jet position. When analyzing cyclogenesis, it's important to identify the various conveyor belts and understand how they are evolving. At this time period, we identify the warm conveyor belt easily since its associated with a region of clouds and probably precipitation in the vicinity of the frontal band. As cyclogenesis begins, the middle and upper cloud deck associated with the warm conveyor belt takes on a crescent shape. This pattern is usually called the baroclinic leaf. The baroclinic leaf is situated largely on the cold side of the frontal band, but within the warm conveyor belt whose origin lies at low-levels on the warm side of the front. Now, study the 3 water vapor bands for this cyclone over China using imagery from the Himawari satellite as proxy data for GOES-R. Keep in mind that cold cloud tops will look the same across the 3 bands since the weighting function peaks at cloud top, where the 3 water vapor bands add value is in regions of clear sky. In the case of cyclogenesis, this would be the dry slot region. During the baroclinic leaf phase we can see a region of subsidence as indicated by relatively warmer brightness temperatures south of the baroclinic leaf. With current GOES water vapor imagery (which would correspond closely to the 7.0 micron mid level water vapor band on Himawari), we look for trends in the dry slot (that is, a warming trend, and/or increasing areal coverage of warmer brightness temperatures) to indicate trends in the cyclogenesis evolution. With GOES-R, you will have 3 channels that have weighting function profiles at different levels to provide a 3-dimensional perspective of the cyclogenesis process. Now, you might begin looking for increasing subsidence manifested by warming brightness temperatures in the dry slot at 7.3 microns, then monitor for increasing depth of the subsidence region at 7.0 microns, and finally at 6.2 microns. Not only can you

assess trends in the areal coverage of subsidence, but now the depth of it as well by using the 3 water vapor bands in tandem.

5. In this loop of the mid level water vapor band at 7.0 microns which is close to what you have now with current GOES water vapor imagery, we see an approaching upper level trough impinging on a frontal zone. Along the frontal zone we see widespread cloud cover associated with the warm conveyor belt. During the loop we observe the evolution of a crescent shape, indicating baroclinic leaf development, with a region of subsidence south of it as indicated by warming brightness temperatures.
6. Next we'll discuss where the surface low is forming or will form soon by looking at the incipient position. In the conceptual diagram, notice where the change in curvature along the western edge of the warm conveyor belt where the crescent shape exists, this is referred to as the inflection point. Next, draw a line perpendicular to the surface front through the inflection point. The surface low often forms within two degrees of latitude from the intersection of the line and the surface front, which corresponds to the red circle depicted in our conceptual diagram. This technique works well in the absence of terrain, lee cyclone effects will not work well with this technique so be aware of terrain.
7. As we advance in time to the so called advanced leaf phase of cyclogenesis evolution. The northern and western part of the baroclinic leaf develop into a comma shape. The upper level jet is near the northern edge of the warm conveyor belt. As the wave deepens, the surface low position moves poleward relative to the upper cloud deck, deepens and the cold cloud shield expands in areal extent.
8. In the animated 7.0 micron imagery, note the development of a comma shape. The cold cloud shield continues to expand in areal extent. Also, the dry slot continues to expand in areal extent. One of the signs to look for in continued cyclogenesis evolution is an inflection point that develops along the eastern portion of the dry slot. Soon after we observe this inflection point, the dry slot begins to intrude northeastward, resulting in the cusp which will discuss next.
9. During the comma cloud phase, we observe the emergence of a relatively low cloud deck on the northwest flank of the cyclone wrapping cyclonically towards the surface low. This is the cold conveyor belt. The dry slot intrudes from the southwest, cutting off the westward cloud protrusion from the main body of the cloud shield. A cusp may appear at the end of the comma head. The cusp is located near the upper level low and usually indicates the cutoff low is at least 500 mb deep. The surface low continues to move cyclonically towards the upper low, in fact when you observe a cusp, draw a line from the end of the cusp to the edge of the warm conveyor belt, this is where the surface low most likely exists. In the 3 water vapor bands, note the cold conveyor belt is associated with relatively warmer cloud top temperatures with the cusp at the tip, and the dry slot wrapping around it.
10. In the animation of the mid level water vapor band at 7.0 microns, note the emergence of the lower level clouds associated with the cold conveyor belt. At the end of that region we observe the cusp, which forms as the dry slot intrudes from the southwest. Remember the surface low will exist approximately east of the cusp along the western edge of the warm conveyor belt.
11. I want to briefly the discuss the IR imagery at 10.4 microns, this corresponds to the last frame in the water vapor loop we just looked at. The IR imagery is good for looking at colder cloud tops

associated with the warm conveyor belt, however if we're interested in the lower level clouds such as those associated with cusp development at the end of the cold conveyor belt, it may be more difficult to identify the cusp compared to the water vapor imagery.

12. The next phase of cyclogenesis is the onset of the occlusion process and generally indicates a mature cyclone. The cusp begins to wrap around the system, with the resulting position of the surface low wrapping cyclonically back towards the upper low in a system relative sense. The cyclone center begins to cutoff from the warm sector, indicating the occlusion. At this point the secondary warm conveyor belt is generally referred to as the TROWAL. Typically the surface low is at or near maximum intensity around or slightly after this time.
13. Here is the corresponding animated imagery with the 7.0 micron band. Note the well defined subsidence region associated with the dry slot. Keep in mind the position of the surface low pivots around with the cusp so that initially the low is northeast of the cusp along the warm conveyor belt and by the end of the loop is almost due north of the cusp since the surface low is moving cyclonically towards the center of the upper low.
14. In the later stages of the evolution of the extra-tropical cyclone, temperature advection decreases as the surface low begins to fill as warm and cold air mix. The system may still be quite intense at this time, but will begin the process of weakening from this point forward. The surface low continues to spiral around perpendicular to the cusp until it eventually becomes aligned with the upper low, indicating the system has become vertically stacked.
15. As we look at the animation of the 7.0 micron mid level water vapor band. We see a mature cyclone with a large shield of cold cloud tops. Well defined conveyor belts. In fact, notice how much larger in areal extent the dry slot is at this point compared to early in the life cycle. This relative trend in the dry slot appearance can be used not only in single channel time trends but also multi-channel time trends to assess the depth of the dry slot. The cyclone in its mature phase should have the most well defined dry slot signature.
16. This is a conceptual diagram of the so called basic type of cyclogenesis. There are a number of different variations in types of cyclogenesis. Once you gain skill at understanding the various conveyor belts and their evolution. You can adapt your understanding with the satellite imagery to the different types of cyclogenesis.
17. There are a number of new bands on GOES-R that will aid in analysis of cyclogenesis. One of them is the 9.6 micron ozone band. This band is sensitive to stratospheric intrusions of ozone, which in the case of extra-tropical cyclogenesis indicates high potential vorticity. This slide illustrates an important point regarding new bands on GOES-R. Although they may be able to detect certain things (in this case, ozone), they may not necessarily be useful by themselves, but may be very useful when combined with other channels as a product. Note that the 9.6 micron band by itself in a color table we typically use with IR channels does not show any indications of the high ozone air associated with the stratospheric intrusion. However, in the RGB Air Mass product the stratospheric intrusion of higher ozone can be clearly seen in the red shading. The RGB product makes use of other bands, in addition to the 9.6 micron band in a way to bring out the signal we wish to see, which in this case is the high ozone concentration.

18. This is a loop of the RGB air mass product which really brings out the high potential vorticity region associated with the stratospheric intrusion of high ozone. This product will have multiple uses in analyzing cyclogenesis, including different air masses.
19. What about higher temporal resolution imagery that will be available for GOES-R? Typically we don't think of higher resolution imagery being used in analyzing cyclogenesis. There aren't too many 1-minute imagery events available for winter time cyclones, since 1-minute imagery is generally called for warm season convection. However, 1-minute imagery will likely be available for significant winter storms on GOES-R so what uses can it have other than just providing better continuity? As proxy for GOES-R we make use of GOES-14 SRSOR 1-minute IR imagery for an event from February 2016. On the synoptic s scale, the development of a warm conveyor belt is clearly visible. In current/past GOES imagery this would've been our primary focus and the same conclusions would've been reached. However, in the 1-minute imagery we're able to observe a number of transitory features that appear/disappear. In this animation, there are 2 regions of cyclonic vorticity in Colorado. These circulations had bursts of higher reflectivity on radar and associated localized higher snowfall rates.
20. Later in the same cyclone, the warm conveyor belt covers a large region from Texas to Colorado. It peels cyclonically towards the Front Range of Colorado (moving almost due west). During this period, heavy snow occurred over northern and northeast Colorado. Along the western edge of the warm conveyor belt we observe ripples that may be the result of shearing instability along this interface. We see a quasi-stationary deformation zone left in the wake of one of the earlier small scale circulations. In east central Colorado see a ripple develop along the edge of the warm conveyor belt that evolves into the appearance of transverse bands. These may exist further north as well under the cloud deck and we're just able to see them at this location. The transitory circulations in the previous slide and the features we pointed out here are examples of new features you may see in the 1-minute imagery since 1-minute imagery was typically not available for winter storms in the past. Are these features important to weather at the surface, in other words for operational applications? This is an open question for many of these features and in fact an opportunity for research that can lead to potential operational applications. The significance of these features may become more apparent to you as you integrate the GOES-R imagery with information from other high temporal resolution observational datasets. The key here is to keep an open mind when viewing 1-minute imagery and as you gain experience in looking at more events, you may discover useful new applications.
21. Time for an interactive exercise. In this case over the Pacific with imagery from the Himawari satellite we have the 3 water vapor channels at and the IR band at 10.4 microns. I'll give you some time to study the loop, then on the next slide I'll provide a static image of the last time frame so you can identify where the surface low can be inferred by the incipient position technique we discussed earlier.
22. Here is a static image, I'll provide some time for you to identify where the surface low can be inferred.
23. Now we'll discuss the incipient position technique for this case. Remember the feature to look for is the cusp, and keep in mind these are low-level clouds. Since they are low-level clouds, the cloud tops are relatively warm in the IR imagery, so it may be easier to use a blend of the 3

water vapor channels. Identify the bottom of the cusp, and imagine a line perpendicular from that point to the western edge of the warm conveyor belt. Along the edge of the warm conveyor belt is the inferred position of the surface low. This is over the ocean so we would expect this technique to work well, and have greater value since there are limited surface observations.

24. Summary