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 it's 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 off the eastern seaboard. 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 or only low clouds. 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. The water vapor bands can indicate trends in the cyclogenesis evolution via the dry slot, that is, a warming trend, and/or increasing areal coverage of warmer brightness temperatures. Typically, you will observe 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. The most intense cyclones typically have a well defined dry slot at 6.2 microns. Assess trends in the areal coverage of subsidence as well as the depth of it by using the 3 water vapor bands in tandem.

5. In this loop of the 3 water vapor bands along with the air mass RGB, we see an approaching upper level trough impinging on a frontal zone over the southeast. 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 4 panel display, 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 a segment of the dry slot. Soon after we observe this inflection point, the dry slot begins to intrude northward, resulting in the cusp which we'll discuss next.
9. During the comma cloud phase, we observe the emergence of a cloud deck on the northwest flank of the cyclone wrapping cyclonically towards the surface low. This is the cold conveyor belt, which consists of low-level clouds at the leading edge as we'll see later in a zoomed in IR loop. The dry slot intrudes from the south or 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. This is a zoomed in animation of the low level water vapor band at 7.3 microns. Cusp development occurs at this region, which forms as the dry slot intrudes from the south / southwest. Remember the surface low will exist approximately east of the cusp along the western edge of the warm conveyor belt.
11. An animation of the IR imagery at 10.3 microns clearly shows the emergence of the lower level clouds associated with the cold conveyor belt on the south to southeast flank of the developing cusp.

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. 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 7.3 micron band, we'll point out the location of the features we'll be discussing on the next slide. During this loop we see the cusp as well as the onset of the occlusion process. 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 east/northeast of the cusp along the warm conveyor belt and by the end of the loop is north/northeast of the cusp since the surface low is moving cyclonically towards the center of the upper low.
14. Here are corresponding static images with annotations, the earlier image is on the left with a later image on the right. Note how the surface low pivots cyclonically in a system relative sense back towards the upper low. The incipient position of the surface low is located along a segment of a line of convection. We're inferring that the convection must be developing along the frontal zone, most likely a segment of the occluded front.
15. 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. Note the occluded front in our conceptual diagram. 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.
16. As we look at the 4 panel animation, we see a mature cyclone with a large shield of cold cloud tops and 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. The lower right panel shows the air mass RGB product. The red colors that we see in the later portion of the loop indicates high ozone air associated with a stratospheric intrusion, a signature of high potential vorticity.
17. 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.
18. It's important to focus on the components of extra-tropical cyclogenesis in GOES water vapor imagery so for the next case we'll look at a long loop of the 7.0 micron band. Early in the loop we observe an intense jet streak moving southeastward into the southeast U.S., as it pivots northeastward the warm conveyor belt offshore develops considerable convection, this is associated with the warm conveyor belt. Shortly afterwards, we observe a cyclonic branch of the warm conveyor belt peel back to the northwest in Virginia and West Virginia, this is usually referred to as the secondary warm conveyor belt. The strong jet streak continues to move

northeastward leaving in its wake multiple vorticity maxima from Ohio to the Washington DC area and later further northeast. This is referred to as the shear zone and we'll illustrate these in static images on the next slide. Near the end of the loop, we see cusp development east of Maryland as the system further intensifies.

19. This static image from 2 different times allows you to focus in on some of the features we just discussed, and I'll allow you to see the loop once again after this slide. In the upper left is the earlier image, with a clear defined dry slot annotated in the blue oval, the warm conveyor belt in the red oval and the secondary warm conveyor belt in the yellow oval. Typically the secondary warm conveyor belt is referred to as the TROWAL after occlusion begins. In the lower right, we have an image from a later time. The shear zone is left over after the initial jet streak moves quickly northeastward off the eastern seaboard. The jet results in strong speed shear and associated vorticity maxima elongated downstream. The shear zone is a common place to find heavy precipitation, we'll look at the observed precipitation map on the next slide. Finally, the green oval indicates the second jet streak that comes along, moves northeastward and later leads to cusp formation east of Maryland, further intensifying the system.
20. Now that we've discussed the location of the various signatures, study the loop once again to follow these features along in the animation. I also provided the observed precipitation through 12Z March 21, this was a heavy snow event in the Washington DC region. *15 second pause*.
21. This loop covers a nor'easter event on 7 March 2018. We're looking at 2 of the 3 GOES water vapor bands with GOES imagery on the top row and the corresponding bands of synthetic imagery from the NSSL WRF on the bottom row. When analyzing a cyclogenesis event, it's important to focus on the various components of cyclogenesis, for example the warm conveyor belt, dry slot or jet streaks that come in to intensify the system. One of the important aspects of this particular cyclone was the development of a TROWAL airstream which shows itself as a region of convection that develops east of New Jersey. This convection fills in between the warm conveyor belt offshore and the surface low along the coast. Once the convection fills in with its associated TROWAL airstream, this allows more unstable air from the warm sector to feed into the surface low, intensifying it and leading to more hazardous weather in general. This could have been analyzed with traditional model fields of RH, potential temperature and so forth but we can formulate our conceptual model in a more efficient way since we can conceptualize what is going on in GOES imagery based on our experience of satellite imagery interpretation and compare that with an integrated perspective of model output.
22. Looking at some other imagery for the same case on 7 March 2018, the top 2 rows are useful for assessing stratospheric intrusion of ozone associated with high potential vorticity. We already discussed the utility of this earlier with the air mass RGB shown in the upper left, but it can also be diagnosed with the differential water vapor RGB product shown in the upper right. Very dry mid to upper level air is depicted in bright orange colors. In the bottom panels we can see the development of the convection associated with the TROWAL airstream in the IR and visible bands as we discussed in detail on the previous slide. These features are adequately sampled with the full disk imagery as shown here, next we'll consider some applications of 1-minute imagery.

23. Here's the 1-minute imagery for the same case zoomed in over the surface low where we can see an eye like feature clearly in the visible imagery. 1-minute imagery can be useful in analyzing extra-tropical cyclogenesis for smaller scale features, such as transitory small scale circulations, low-level jets such as a sting jet and the development of convection as we've been discussing with the TROWAL airstream. The day cloud phase distinction RGB is useful for convective initiation since the transition from light blue colors to green colors signifies glaciation at cloud top, and as the clouds continue to grow deeper in the vertical they will appear yellow to reddish in color.
24. Time for an interactive exercise. This is GOES-16 CONUS sector imagery at 15-minute temporal resolution showing the water vapor bands along with IR imagery at 10.3 microns. Your task is to see what components of cyclogenesis previously described you can identify in this animation. Also, try using the incipient position technique discussed earlier to infer the position of the surface low. I'll give you some time for analysis and then I'll provide a summary on the next slide.
25. I added the GFS 0 or 3 hour MSLP and surface winds onto the 6.2 micron loop in the lower left to assist us in the position of the low, with the caveat that the surface low is over water. Early in the loop, we see a well-defined warm conveyor belt east and northeast of a dry slot. North of that we see a broad region of easterly flow resulting from a combination of the cold conveyor belt and likely TROWAL that develops during the loop. Early in the loop we see indications of a circulation in west central Pennsylvania that loses its identity during the loop. The MSLP analysis from the GFS shows this is a surface low that merged with the coastal low, which became the dominant surface low during the animation. In the water vapor bands, this circulation seemed to evolve into the leading edge of the cusp. Identification of the cusp is key to the incipient position technique in inferring the surface low position. The leading edge of the cusp are lower-level clouds, meaning 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 edge of the warm conveyor belt which in this case is the boundary between the dry slot and clouds, oriented almost east-west. Along the edge of the warm conveyor belt is the inferred position of the surface low, which the GFS seems to have a good representation of in this case. Note that the surface low deepens soon after we see cusp development. Remember that the surface low will pivot cyclonically back towards the upper low in a system relative sense as the system progresses.
26. Summary