DIFFICULTIES WITH CLASSIFYING AND ANALYZING THE LOW LEVEL JET IN A CONVECTION ALLOWING ENSEMBLE

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ABSTRACT

Common in the Great Plains, the low level jet can have important implications for storms and convective systems as it can increase heat, moisture, and vertical wind shear after sunset. Criteria created by William Bonner in 1968 have been used in numerous studies in the past five decades, and are still commonly used today. As convection allowing models become more accurate and more important in forecasting today, the relationship between the LLJ and storms can be analyzed to provide further knowledge into the impacts the LLJ may have on severe weather. This study used data from the NSSL Experimental Warn-on-Forecast System for ensembles for May 16th, 2017 to see if the Bonner criteria would be a suitable classification method for a typical severe weather event in the Great Plains. Results show that for cases with a strong background wind field such as the one examined in this study, the use of Bonner's criteria prevents a spatially coherent jet from being classified due to a lack of wind shear. Therefore, a different method of classifying the low level jet is required to analyze the low level jet and storms in a convection allowing ensemble.

1. INTRODUCTION

The nocturnal low level jet (LLJ) is a low-level wind maximum common to the Great Plains of the United States (Bonner 1968, Whiteman et al. 1997, Shapiro 2016). The LLJ is a large scale feature that can be hundreds of kilometers wide and up to 1000 km long (Bonner et al. 1968), with a vast majority of LLJs being southerly (Bonner 1968).The wind maximum is typically found within the lowest 1km above ground level (AGL), and most frequently the maximum is found between 300-600m AGL (Whiteman et al. 1997). LLJ formation is most common between the months of April and September (Bonner 1968, Jiang et al. 2007) and wind speeds in the jet core often reach speeds greater than 20 ms^{-1} (Parish 2016). In fair weather conditions, the LLJ typically develops after sunset, reaches its greatest intensity a few hours after midnight, and then begins to dissipate in the early morning hours of the following day (Shapiro 2016). This development occurs with the decoupling of surface winds from the rest of the atmosphere (Bonner 1968) as the temperature inversion that is characteristic of the nocturnal boundary layer acts to inhibit turbulence and vertical mixing in the overnight hours (Werth et al. 2011).

The LLJ has important implications for the Great Plains region. Increased low-level wind speeds and shear can be hazardous for airplanes on takeoff and landing (Blackadar 1957), is associated with the rapid spreading of wildfires (Barad 1961), and can impact the growing industry

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of renewable wind energy (Storm et al. 2009). With respect to meteorological phenomena, the LLJ has garnered a lot of attention due to its ability to increase heat and moisture transport (Means 1952, Bonner 1966), which can lead to a destabilization of the atmosphere. The nocturnal timing of the jet bringing this destabilization can help storms maintain themselves after sunset when surface CAPE would typically be decreasing. The inherent increase in low-level wind shear with the LLJ also leads to a large increase in storm relative helicity (SRH) (Maddox 1993). With the increase in use and importance of convection allowing models (CAMs) in severe weather forecasting, the relationship between the LLJ and storms in the models needs to be assessed in order to see how their interaction is depicted and what implications this has for the model forecast. In order to properly study this interaction, a good method needs to be determined for correctly classifying the LLJ in a CAM.

2. BONNER CRITERIA

This study examines the use of the Bonner (1968) criteria for the classification of the LLJ in a convection allowing ensemble. Bonner created his criteria from a 2-year climatology of low level wind data from 47 stations across the United States. The criteria were created subjectively, described by Bonner as a "reasonably stringent set of criteria which would still leave a large enough sample of jet observations to give some statistical validity to the study". These criteria have been used in numerous studies since their development and are still widely accepted today.

Taking from Blackadar (1957), Bonner sets the upper boundary for the wind maximum of a LLJ as 1.5 km AGL. Bonner (1968) then creates three different classifications for the LLJ based on both wind speed (12, 16, and 20 ms^{-1}) and speed shear (6, 8, and 10 ms^{-1}) relative to the next highest minimum, or the 3 km AGL level, whichever is lower. A summary of the Bonner criteria can be seen in Table 1. Whiteman et al. (1997) took notice that Bonner's criteria were not exclusive, meaning that a LLJ that meets Criteria 3 would be classified as a 1, 2, and 3 level jet. This study follows the modifications of Berg et al. (2015) in interpreting the criteria as mutually exclusive, so that a wind profile meeting criterion 3 is only denoted as meeting criterion 3.

3. METHODOLOGY

This study examines the case of May 16th, 2017 using data from the NSSL Experimental Warn-on-Forecast System for ensembles (NEWS-e). NEWS-e is run on a nested 3 km grid spacing with a mesoscale parent 3 km grid, in a domain that changes by day based on the event. Observations of horizontal wind, pressure, temperature, and dewpoint temperature are assimilated into the ensemble hourly, while radar reflectivity and velocity data from WSR-88Ds within the domain are assimilated using an ensemble Kalman filter (EnKF) every 15 minutes (Skinner et al. 2016). On the hour, 180-minute storm-scale forecasts are issued, while on the half-hour, 90-minute storm-scale forecasts are issued, each with a 5 minute output. NEWS-e is comprised of 18 forecast ensemble members with three different planetary boundary layer (PBL) schemes (Wheatley et al. 2015).

The case of May 16th, 2017 was chosen for the numerous supercells that moved across

Bonner Low Level Jet Criteria		
	Speed (m/s)	Shear (m/s)
Criteria 1	12	6
Criteria 2	16	8
Criteria 3	20	10
• Wind maximum below 1.5 km AGL • Strong shear to the next highest minimum or the 3 km AGL level, whichever is lower.		

Table 1. A summary of the Bonner criteria

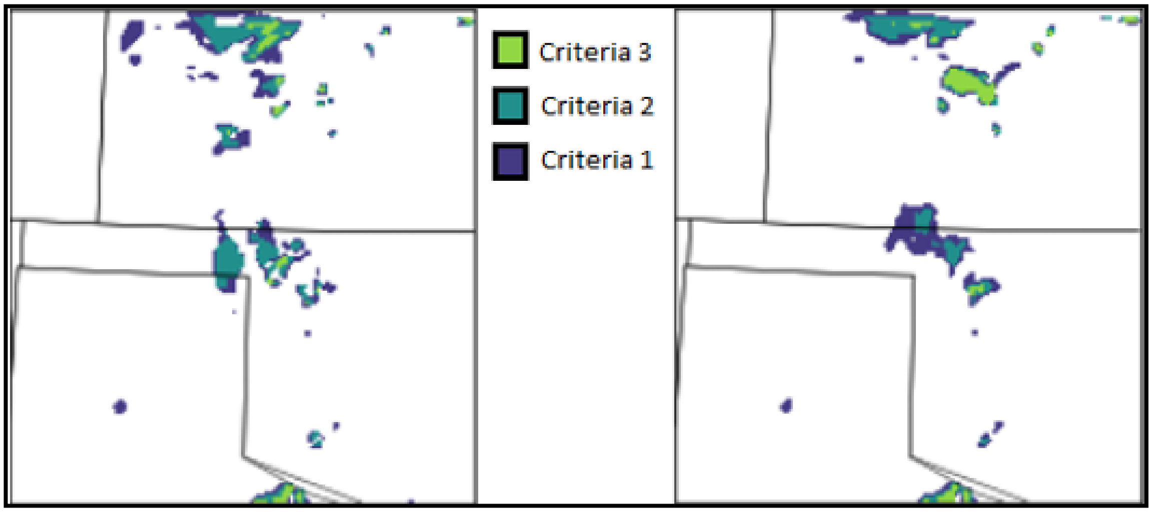

Figure 1. A side by side panel comparing jet classification by using the actual wind maxima/minima (left) and classification by using model levels 7 and 12 as proxies (right).

much of the given NEWS-e domain (Texas Panhandle and Oklahoma). These storms produced severe winds and hail, as well as a few tornadoes. For the purpose of this study, May 16th was a good case because these storms remained present and active across the 0000 UTC time line, when the LLJ would be expected to develop/intensify.

Of the 18 forecast members, the researchers used Members 1, 10, and 18, each with a different PBL scheme: YSU, MYJ, and MYNN, respectively. The 2200, 2300, and 0000 UTC 180-minute NEWS-e forecasts were examined in this research, providing data out to 0300 UTC. At each point in the domain, the jet is classified according to the speed and shear criteria set by Bonner.

Classifying the jet by calculating the wind speed at the exact maxima and the shear from that maxima to the exact minima or the 3 km level per the Bonner Criteria proved to be difficult, time consuming, and prone to errors. As a solution, the authors used model level 7 and model level 12 as proxies for the height of the actual maxima and minima, respectively. Model level 7 was chosen as a proxy for the maxima because it is the level where the maxima were most often found, and on average the height of level 7 in the domain was 859.6m AGL, slightly higher than where LLJ maxima are most frequently located, but is still well below the 1.5 km upper boundary set by Bonner. Level 12 was chosen as the proxy for the minima because it was the level where the minima were most often found, and the level had an average height of 2436.4m AGL, below the 3 km level set by Bonner.

The authors compared a plan view of jet classifications using the actual maxima/minima and a plan view using model level 7/level 12 (Figure 1). Though some small differences exist between the two methods, it was determined the proxies were accurate enough for use in this research. Additionally, many checks were performed throughout the research to ensure that using different model levels as proxies would not have an impact on the results.

Using these proxies, this study compares plan views of the classified LLJ according to Bonner with plan views of the actual wind speed at model level 7 and the actual shear from model level 7 to level 12. The speed, shear, and jet classifications were averaged over one hour, centered on a specific hour. For example, with the 2200 UTC model run, the 2300 (0000) UTC average wind speed, shear, and jet classification were computed by taking an average of each five minute output from 2230 (2330) UTC to 2330 (0030) UTC. The authors also make use of the 40 dBZ threshold to locate where storms exist in the domain.

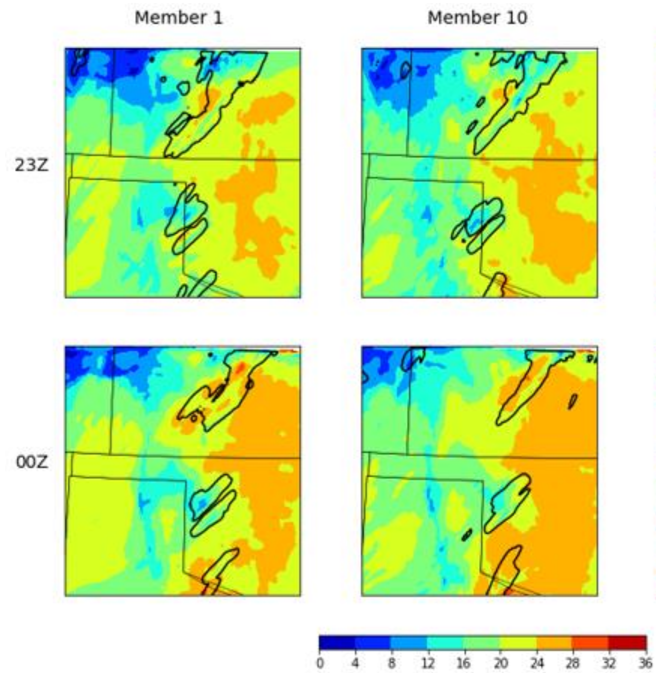

Figure 2a. 2200 UTC Run Level 7 wind speed averaged over one hour centered on 2300 (0000) UTC for each member. Black contour outlines the 40dBz reflectivity for the same time.

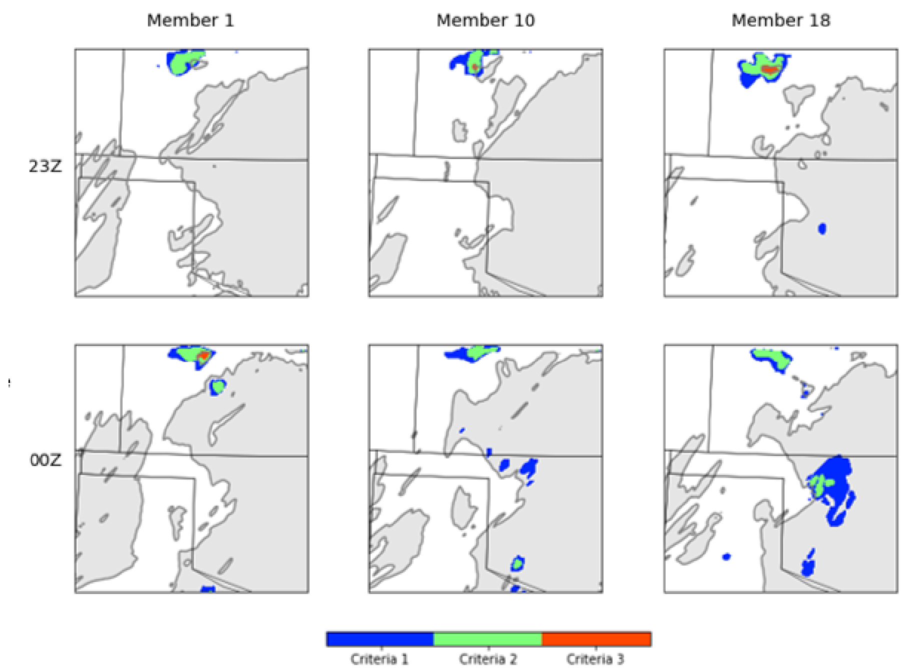

Figure 2b. 2200 UTC Run jet classification according to the Bonner criteria, taken from wind speeds at model levels 7 and 12 averaged over one hour centered on 2300 (0000) UTC for each member. The gray shaded area represents where wind speeds >= 20 ms^{-1}

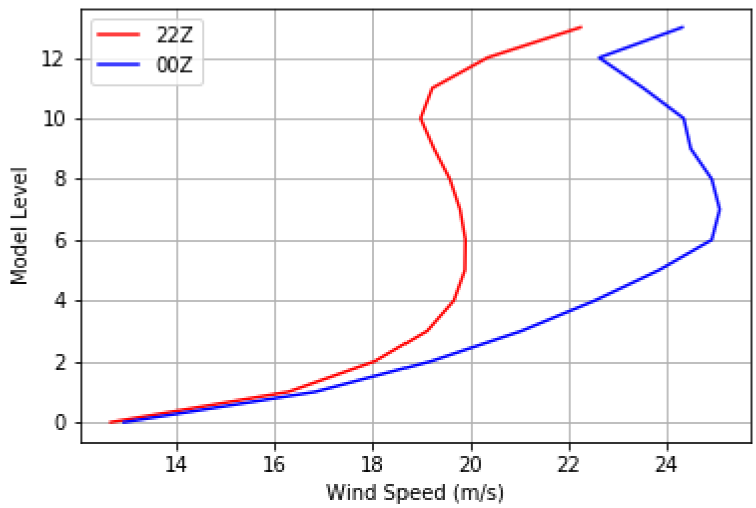

Figure 3. 2200 UTC Run at a point in the domain not classified as a LLJ according to the Bonner criteria.

3. RESULTS

a. 2200 UTC Run

Figure 2a displays the average level 7 wind speed for 2300 and 0000 UTC. The figure shows that for both times, all three members have wind speeds greater than 12 ms^{-1} – the threshold to meet speed criterion 1 – in nearly the entire domain. However, when the jet classification is displayed as in Figure 2b, it can be seen that very little of the region is classified as a Bonner low level jet. With the speed criteria being met, the cause of the lack of jet classification is a lack of wind shear. To explain this missing shear criteria, Figure 3 shows a vertical wind profile taken from a point with >= 20 ms^{-1} winds that was still not classified as a jet in Member 1. While the low level wind maximum increased from ≈20 ms^{-1} at 2200 UTC to ≈ 25ms^{-1} at 0000 UTC, the strong winds above the maximum prevent the shear criteria from being met.

Figures 2a and 2b also begin to show some variability between the members. Member 18 has stronger wind speeds than Members 1 and 10. Member 18 also has a small region classified as a LLJ in Northwest Oklahoma, whereas Members 1 and 10 do not.

b. 2300 UTC Run

Figure 4a shows the wind speed increasing with time from 0000 to 0100 UTC, as all three models show >= 24 ms^{-1} winds in the latter time. Even with wind speeds exceeding the highest criterion set by Bonner (20 ms^{-1}) in nearly the entire eastern half of the domain for both times, the Bonner LLJ classifications in Figure 4b show that the wind profiles must still lack the necessary wind shear in much of the region.

The 0100 UTC jet classification does show an increase in area classified as a Bonner LLJ from 0000 UTC, especially in Member 18, but much of the region remains unclassified.

Member differences are becoming even more pronounced in this run, especially between Members 1 and 18. At 0100 UTC, member 18 has a relatively large area in North Central Oklahoma where the wind field is meeting Bonner's criterion 3, but member 1 still has almost no points classified as a Bonner LLJ in this area, even with the strengthening wind speeds.

c. 0000 UTC Run

Figure 5a shows another increase in wind speed from 0100 to 0200 UTC, with wind speeds reaching >=32 ms^{-1} in all three members for the latter time. The reflectivity contour is overlaying a region where wind speeds are lower than their surroundings, indicating that the storms are having a modifying effect on their environment. This modifying effect can be also seen in Figures 5b and 5c, where the environments surrounding the storms do not meet the Bonner criteria and have a lack of wind shear, appearing as a hole in an otherwise sheared and mostly LLJ classified region.

In Figure 5b, an increase in the total area classified as a Bonner LLJ can be seen in all three members from 0100 to 0200 UTC. However, there

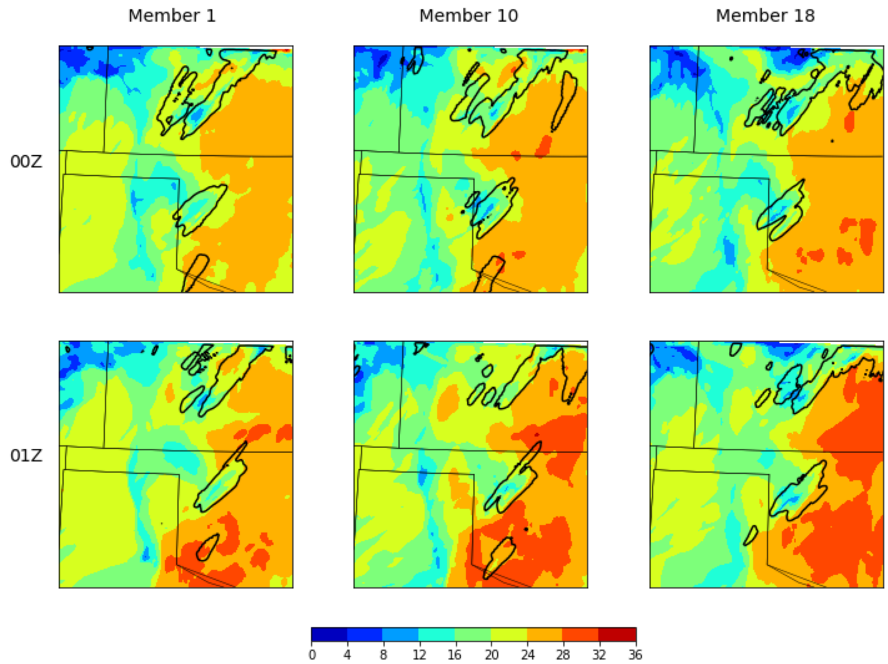

Figure 4a. 2300 UTC Run Level 7 wind speed averaged over one hour centered on 0000 (0100) UTC for each member. Black contour outlines the 40dBz reflectivity for the same time.

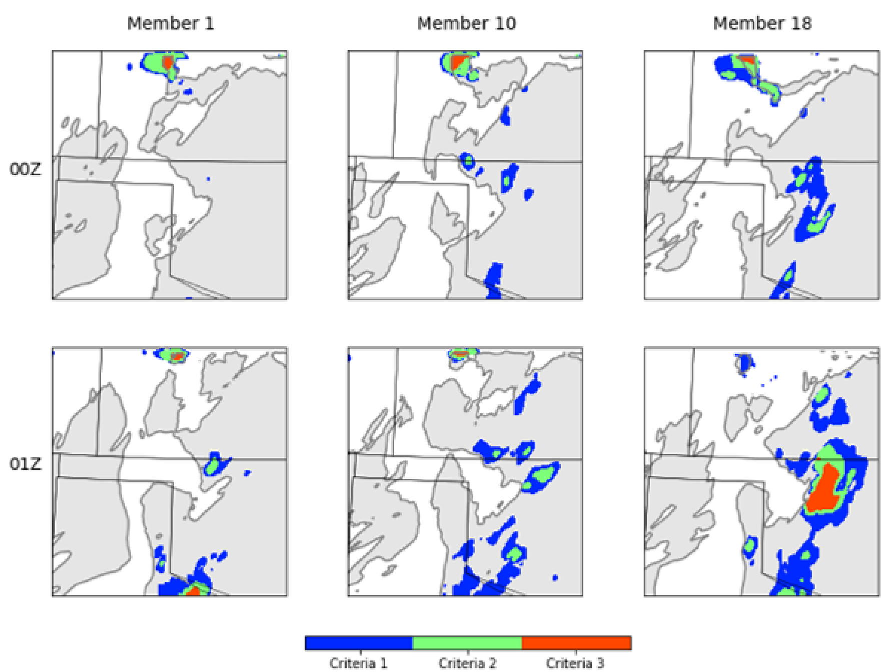

Figure 4b. 2300 UTC Run jet classification according to the Bonner criteria, taken from wind speeds at model levels 7 and 12 averaged over one hour centered on 0000 (0100) UTC for each member.

still is a lacking of a spatially coherent LLJ, especially in Members 1 and 10. While Member 18 has a larger region classified as a LLJ, this still does not display the large-scale feature described by Bonner et al. 1968. Still, similar to previous runs, the area with wind speeds strong enough to meet Bonner criterion 1 (12 ms^{-1}) is much larger than the area actually classified as a LLJ, displaying that the wind shear is what is limiting jet classification in many of the profiles.

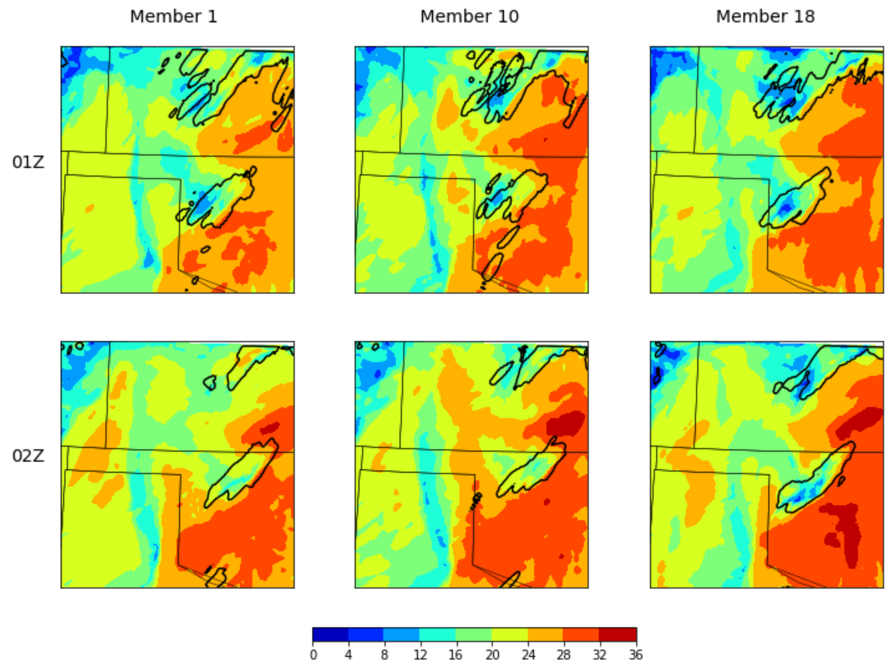

Figure 5a. 0000 UTC Run Level 7 wind speed averaged over one hour centered on 0100 (0200) UTC for each member. Black contour outlines the 40dBz reflectivity for the same time.

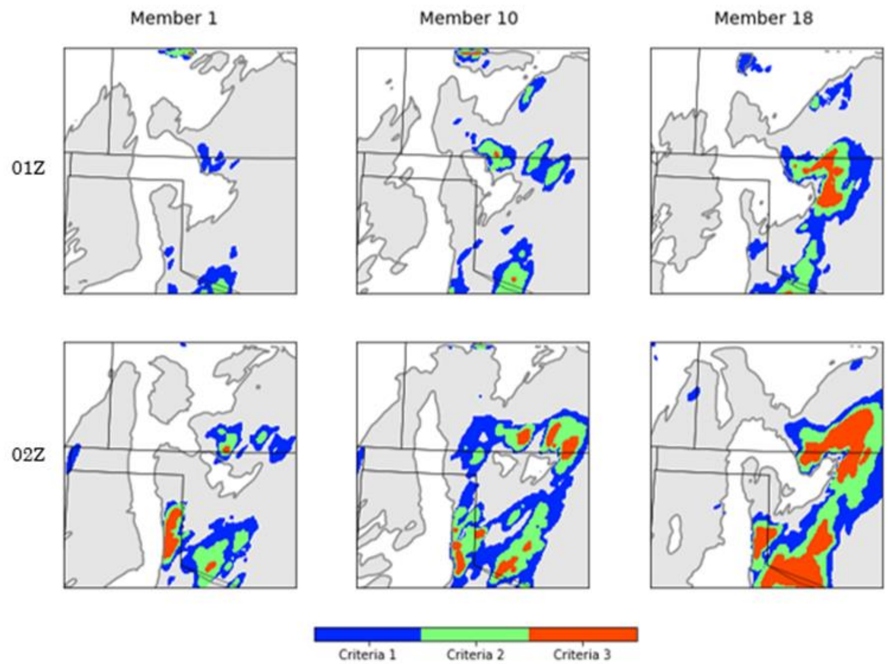

Figure 5b. 0000 UTC Run jet classification according to the Bonner criteria, taken from wind speeds at model levels 7 and 12 averaged over one hour centered on 0100 (0200) UTC for each member.

Figure 5c displays the average wind shear valid for 0100 and 0200 UTC, with the black contour outlining the areas where a LLJ wind profile is classified according to the Bonner Criteria. This contour follows exactly along the 6 ms^{-1} shear contour, displaying that with the strong winds at this time, jet classification is being completely determined by wind shear.

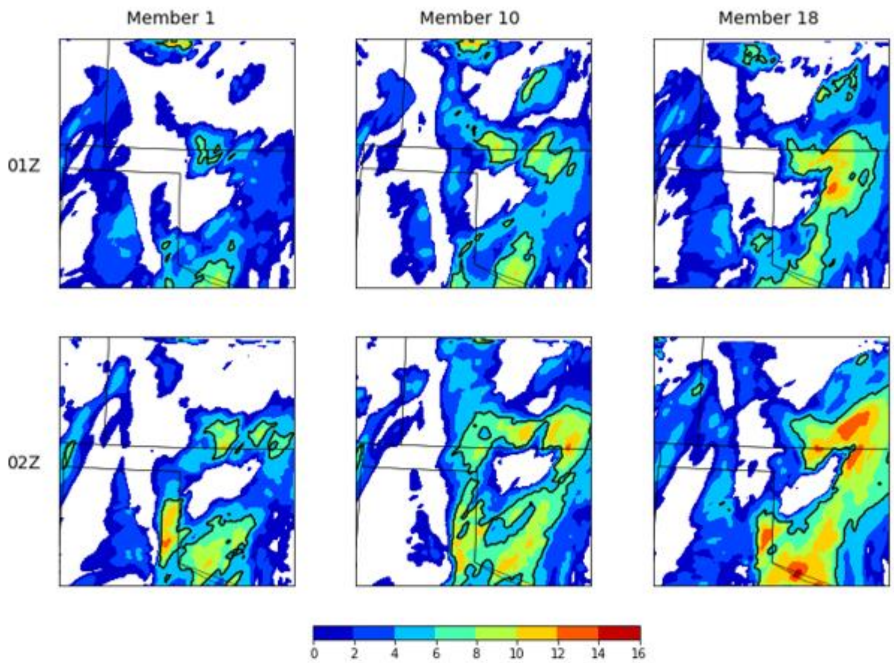

Figure 5c. 0000 UTC Run wind shear from level 7 to level 12, averaged over one hour centered on 0100 (0200) UTC for each member. Black contour outlines where the Bonner LLJ criteria is met.

Figures 5a, 5b, and 5c also display even greater differences between ensemble members than in previous runs. While the members all display similar reflectivity, especially for 0200 UTC, their wind speeds at model level 7 and therefore their resulting jet classification have some major differences. Member 18 still has the strongest winds and the largest area classified as a LLJ, whereas Member 1 especially has a noticeably smaller region classified as a LLJ.

Another interesting difference between the three members is how the winds at level 7 appear to recover after the storms pass through. In Figure 5a at 0200 UTC, Member 10 has the strongest wind speeds through the center of the domain, with a North-South oriented tongue of winds with speeds >= 24 ms^{-1} just west of the storms that recently passed through, whereas Members 1 and 18 do not have this feature. The implications of these stronger wind speeds west of the storms can be seen in Figure 5b, where Member 10 has Bonner LLJ profiles all of the way along the Oklahoma/Texas Panhandle border, intersecting the Oklahoma panhandle, and extending northward into Kansas, whereas the other two members do not.

4. CONCLUSIONS

One important takeaway from this research is the pronounced differences between the three different members handling of the LLJ. With each member using a different PBL, it is not surprising that there is noticeable variability between the members as the LLJ is closely tied to the nocturnal boundary layer, and despite these differences, conclusions can still be drawn from what was found in this study.

The lack of a spatially coherent LLJ classified by Bonner is controlled by the shear criteria. On May 16th, 2017, there was a strong background wind field present. The May 17th 0000 UTC rawinsonde launch over central Oklahoma from the Norman National Weather Service office found a 35 kt wind at 850mb, and a 55 kt wind at 700mb. This strong synoptically forced wind field made the shear criteria difficult to meet even with a strong low level wind maximum present. Therefore, using the Bonner Criteria in these highly non-quiescent conditions led to the under classification or no classification of the LLJ at many points in the model grid, where a subjective assessment by the authors deemed there likely was a LLJ present.

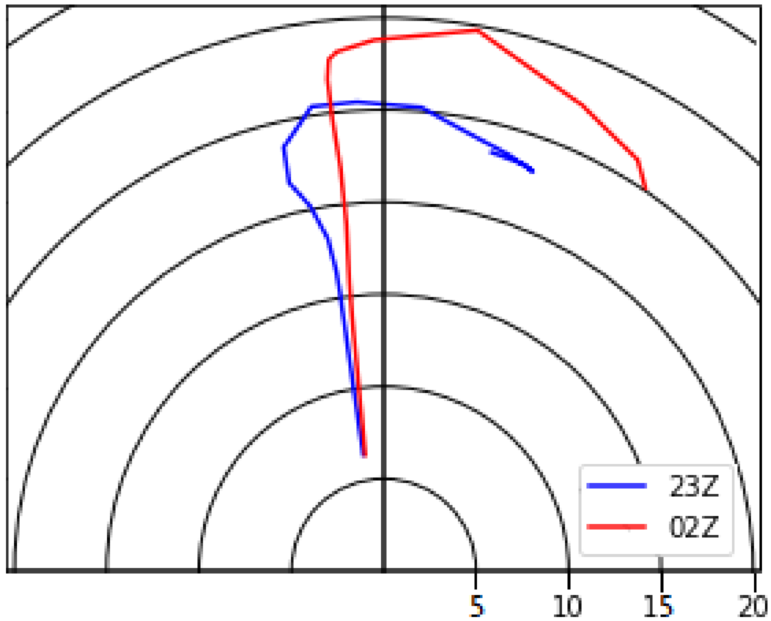

Figure 6. Member 18 2300 UTC Run hodograph at 2300 and 0200 UTC.

With the Bonner criteria not being suitable to identify the LLJ in this case, a different method for classifying the jet in non-quiescent conditions needs to be developed in order to study the relationship between the jet and storms in a CAM.

The authors briefly discussed other possible methods that may be beneficial in future studies of classifying the LLJ in a CAM for cases with a strong background wind field. One possible method is to use an increase in SRH over time as a criterion. Since Maddox illustrated that the LLJ can significantly increase SRH, this parameter could be considered in addition to wind speed when classifying a jet in non-quiescent conditions. Figure 6 shows a hodograph at a point that was not classified as a LLJ per the Bonner criteria. The lengthening/widening of the hodograph from 2300 to 0200 UTC demonstrates that the SRH is

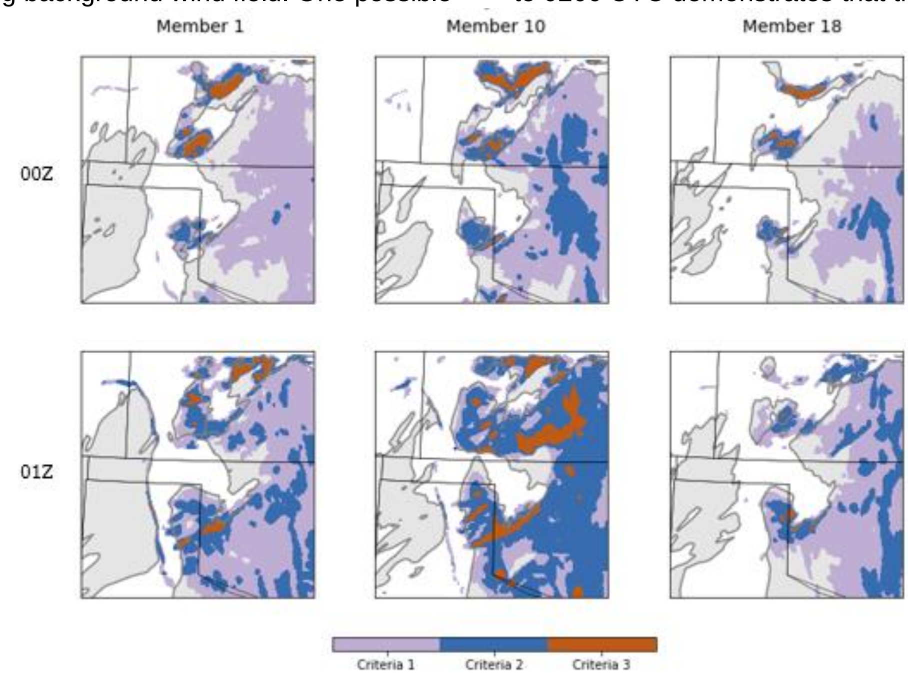

Figure 7. 2300 UTC Run wind shear from level 7 to level 2, averaged over one hour centered on 0100 (0200) UTC for each member.

increasing over this time period. Another possible method would be to create a shear criterion for *below* the wind maxima rather than above. Taking the shear as the difference between the wind speed at model level 7 and level 2 (mean height ≈ 80m AGL), a more spatially coherent jet is seen as in Figure 7. The values for shear criteria 1, 2, and 3 were arbitrarily picked for this specific case (9 m/s, 12 m/s, and 15 m/s respectively), and the speed criterion were held constant from Bonner's method. Future work compiling a severe weather LLJ climatology could help to determine proper values for these criterion if this is a suitable method of classifying a LLJ in such cases.

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