P22 Sensitivity of WRF Forecasts of Great Plains Low-Level Jets to Planetary Boundary Layer Schemes: A comparison with Lamont wind profiler data

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1. Introduction

Low level jets (LLJs) play a pivotal role in weather over the Midwest, helping to drive mesoscale convective systems that bring the region most of its rainfall, and also influencing the rapidly growing wind energy industry.

Several causes of nocturnal LLJs have been identified (see Stensrud 1996 for review). Perhaps one of the best known is the inertial oscillation. In 1957, A. K. Blackadar proposed a well-regarded theory on the formation of LLJs saying that frictional decoupling causes inertial oscillations in the early evening (Blackadar, 1957). During these early evening hours, a temperature inversion occurs and inhibits mixing, making the friction on the surface unable to affect the wind speeds aloft. This causes the wind speed to accelerate and a LLJ forms.

Bonner (1968) established criteria for the classifications of wind speed and intensity during a LLJ event. Whiteman (1997) looked at two years of LLJs in northern Oklahoma and found that LLJs occur 47% of the time during the warm season and 45% of the time during the cold season. Whiteman also noted that approximately 50% of the peak winds in LLJs occur below 500m.

Because of the very low elevation of LLJs, the best way currently to measure them is through the National Oceanic and Atmospheric Association (NOAA) Wind Profiler Network 404-mHZ radar profilers. These profilers measure wind speed between 500m and 19km, unfortunately excluding the lowest 500 m where Whiteman found many jets may peak. The goal of the present study is to use wind profiler data from Lamont, OK, a site with data available much closer to the ground, to construct a climatology of winds in LLJ events and compare it with forecasts from an ensemble of numerical weather prediction models using different Planetary Boundary Layer (PBL) schemes. This comparison will help show if any particular PBL scheme works best for capturing important characteristics of LLJs.

2. Data and Methodology

For this project, observed data was obtained from the U. S. Department of Energy's Atmospheric Radiation Measurement (ARM) project's Lamont, OK site which is equipped with a 915-mHZ wind profiler that can measure wind speeds below 500m. Using data below 2462m, with a vertical resolution of 60m, thirty cases were chosen between June 2008 and May 2010. Dates were selected for inclusion based on the presence of both strong and weak nocturnal LLJs at the site. Dates from November 14, 2008 to December 7, 2008 and from April 9, 2009 to August 13, 2009 were not used due to bad or missing data. To have a complete year of data to work with, cases were analyzed when available between June 2008 and August 2009 and then selected from November 2009 and April and May 2010. The thirty dates selected are as follows:

- June 26, 2008
- July 13, 2008
- August 4, 2008
- September 2, 3, 8, 30, 2008
- October 5, 19, 21, 2008
- December 14, 26, 2008
- February 7, 27, 2009
- March 5, 6, 19, 24, 27, 2009
- August 26, 28, 2009
- November 6, 7, 8, 9, 13, 14, 2009
- April 10, 22, 2010
- May 6, 2010

For these cases, LLJs were simulated using an ensemble of 10km grid spacing versions of the Weather Research and Forecasting (WRF) model

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and six different PBL schemes. The PBL schemes used include the Mellor Yamada Janjic (MYJ), Yonsei University Scheme (YSU), Quasi Normal Scale Elimination (QNSE), Pleim or Asymmetric Convective Model (ACM2), and the Mellor Yamada Nakanishi Nino 2.5 and 3.0 (MYNN 2.5 and MYNN3.0). The Global Forecast System (GFS) numerical weather prediction model provided the initial and lateral boundary conditions. All model simulations were initialized at 00 UTC and run for 54 hours. Comparisons between model output from the 6 different PBL scheme runs plus an ensemble mean and observed data were looked at for peak wind speed, height of the LLJ max and duration. LLJ strength and intensity was also determined and compared using the Bonner classification system as follows:

- Criteria 1 – Peak wind speed must equal or exceed 12 m/s and must decrease by at least 6 m/s by 3km
- Criteria 2 – Peak wind speed must equal or exceed 16 m/s and must decrease by at least 8 m/s by 3km.
- Criteria 3 – Peak wind speed must equal or exceed 20 m/s and must decrease by at least 10 m/s by 3km

3. Results

An example of a strong LLJ with model forecasts can be seen in Fig. 1 for the June 26, 2008 case for one hour of the time during which the LLJ event occurred. In this case, most of the PBL schemes led to a LLJ whose peak elevation was too low compared to observations. The one exception was the run using the YSU scheme. These results were common among all cases.

Using all cases, averages were determined for peak wind speed, elevation of peak wind, and duration. Table 1 shows the comparison of the six schemes to observations for peak wind speed. All six PBL schemes and the ensemble mean under-predict the observed data with the QNSE scheme performing the best, with a mean under-prediction of 3.6 m/s. The YSU scheme leads to the largest underestimate of peak speed, 6.4 m/s.

All six PBL schemes and the ensemble mean under-predicted the observed height of the LLJ wind maximum (Table 2) with the YSU scheme producing the best results with an under-prediction of only 15 m. The QNSE and MYNN predicted

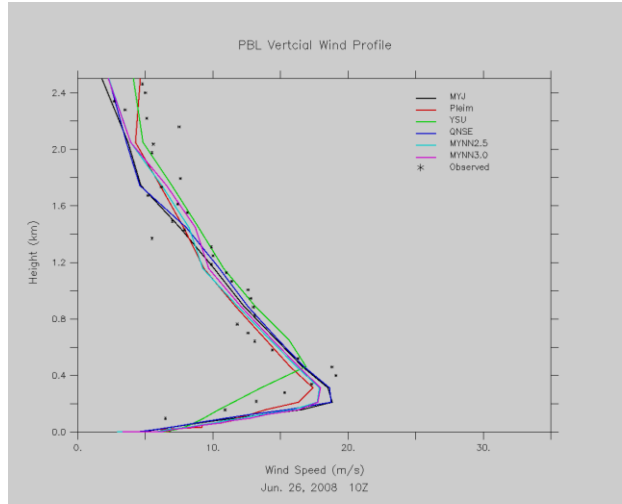

Fig. 1: Comparison of observed data from the Lamont, OK site to WRF runs with six PBL schemes at 10Z (4am CDT) June 26, 2008.

MYJ	Pleim	YSU	QNSE	MYNN 2.5	MYNN 3.0	Ensemble	OBS
19.0	18.2	16.3	19.1	18.2	17.9	18.1	22.7

Table 1: Average peak wind speed (m/s) for each PBL scheme, the ensemble mean, and the observed data from all 30 cases.

the lowest height of the maximum, an underestimate exceeding 200 m. Both for the amplitude of the peak and its height, a Wilcoxon signed-rank test showed that the behavior of the YSU scheme was significantly different from all other schemes.

MYJ	Pleim	YSU	QNSE	MYNN 2.5	MYNN 3.0	Ensemble	OBS
371.2	427.0	538.3	344.5	365.3	340.3	397.8	553.0

Table 2: Average height (m) of low level jet maximum for each PBL scheme, the ensemble mean, and the observed data from all 30 cases.

One possible reason for this difference was discovered by Shin and Hong (2011). They found that the eddy viscosity (Km) value was much larger in the YSU scheme during stable conditions than in any other PBL scheme. To determine if strong amounts of mixing (large Km) were a contributing factor to the behavior of the YSU scheme during LLJ events in the present study, the LLJ event on 24 March 2009 was examined in more detail. For this event, the YSU scheme showed little or no LLJ, while the other five PBL schemes had a distinctive LLJ feature present. The potential temperature profile at the time of maximum LLJ strength showed a stable regime in all PBL schemes, although the YSU scheme appeared to be slightly more neutral in the lowest 1000m, however the profiles were similar above that height. Finally, the Km profile (Fig. 2) for the YSU scheme had an eddy viscosity value five times larger than any other scheme. With a larger eddy viscosity, more mixing and turbulence occurred and resulted in the YSU scheme predicting a substantially weaker LLJ with a higher elevation of the maximum than the other PBL schemes. As a result, higher speeds occurred above and below the jet core, with higher momentum air being mixed closer to the surface.

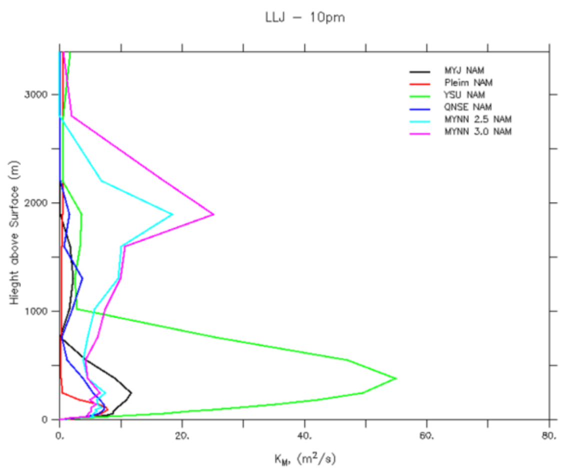

Figure 2: Eddy viscosity as a function of height during the LLJ peak on March 24, 2009 at 10pm LST. Each line represents a different PBL scheme; MYJ (Black), MYNN 2.5 (Cyan), MYNN 3.0 (Magenta), Pleim or ACM2 (Red), QNSE (Blue), and YSU (Green).

The average duration of the simulated LLJ events was between 10.3 and 10.6 hours for all schemes, values matching rather closely the observed value of 11.1 hours (not shown).

The observed data and model output also was broken down into the Bonner classification criteria (shown earlier). First, for Bonner Criteria 1, all schemes except YSU over-predicted the average peak wind speed, although amounts were less than 2 m/s, and all schemes except MYJ over-predicted the average height of the LLJ maximum (Table 3). The average duration was under-predicted by the schemes for this criterion, by as much as 6 hours for Pleim.

	Avg Peak Wind Spd	Avg Height of LLJ Max	Avg Duration
MYJ	15.2m/s	270.0m	7.7hrs
Pleim	14.5m/s	490.0m	5.3hrs
YSU	13.7m/s	583.3m	5.7hrs
QNSE	15.8m/s	463.3m	8.0hrs
MYNN2.5	15.1m/s	436.7m	8.0hrs
MYNN3.0	14.3m/s	403.3m	8.0hrs
Ensemble	14.6m/s	441.1m	7.1hrs
OBS	13.9m/s	366.7m	11.3hrs

Table 3: Bonner Criteria 1 averages

For Bonner Criteria 2 (Table 4), the schemes performed opposite to that of Bonner Criteria 1, under-predicting the average peak wind speed by roughly 2-4 m/s, and average height of LLJ maximum by 50-250 m. The duration, however, was over-predicted by the schemes, often by around 2 h.

	Avg Peak Wind Spd	Avg Height of LLJ Max	Avg Duration
MYJ	19.4m/s	365.0m	12.0hrs
Pleim	18.1m/s	414.0m	11.9hrs
YSU	17.7m/s	538.0m	11.6hrs
QNSE	19.0m/s	352.0m	12.0hrs
MYNN2.5	18.3m/s	373.0m	12.0hrs
MYNN3.0	17.8m/s	373.0m	11.9hrs
Ensemble	18.4m/s	402.5m	11.9hrs
OBS	21.7m/s	592.0m	10.2hrs

Table 4: Bonner Criteria 2 averages

	Avg Peak Wind Spd	Avg Height of LLJ Max	Avg Duration
MYJ	20.2m/s	410.9m	10.5hrs
Pleim	19.7m/s	441.3m	10.4hrs
YSU	16.7m/s	548.1m	10.4hrs
QNSE	20.5m/s	369.1m	10.4hrs
MYNN2.5	19.7m/s	400.0m	10.5hrs
MYNN3.0	19.3m/s	358.1m	10.5hrs
Ensemble	19.4m/s	421.3m	10.5hrs
OBS	25.8m/s	575.0m	12.0hrs

Table 5: Bonner Criteria 3 averages

For Bonner Criteria 3 (Table 5) the schemes under-predicted average peak wind speed, average height of LLJ maximum, and average duration. Wind speeds were typically underestimated by 6 m/s, except for YSU, which was closer to 9 m/s.

Finally, the frequency of the hour in which the peak wind speed from the nocturnal LLJ event occurred was also examined (Fig. 3).

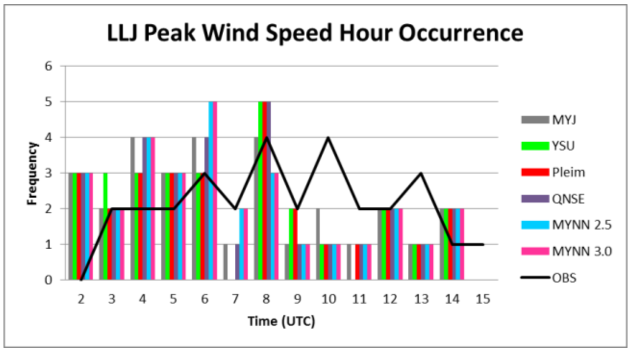

Fig. 3: Hourly occurrence at which the maximum wind speed occurred for both simulations and observed data. Observations are given with the black line while each bar represents a different PBL scheme; MYJ (Gray), MYNN 2.5 (Cyan), MYNN 3.0 (Magenta), Pleim or ACM2 (Red), QNSE (Blue), and YSU (Green).

All schemes showed the peak wind speeds likely occurring in the late night hours up until around 06-08 UTC, while the observations showed the peak wind speed more likely to occur a little later, with twin peaks at 08 and 10 UTC.

4. Summary and Conclusions

WRF simulations of LLJs using 6 different PBL schemes were compared to observations from the Lamont, OK wind profiler. Average peak wind speeds and the height of the LLJ wind maximum are under-predicted by all ensemble members, although the underprediction of height is noticeably less with the YSU scheme. Differences between the YSU scheme and the other five were found to be statistically significant and are likely related to much larger eddy viscosity values under stable conditions for YSU. It appears substantial improvements are still needed in models to improve forecasts of peak LLJ winds and elevation of the jet. However, duration of the modeled LLJ events agreed rather well with observed data.

Application of the Bonner Classification revealed some differences in behavior based on the type of event. Peak wind speed and height of LLJ maximum were over-predicted by most schemes for Bonner Criteria 1, with duration under-predicted by almost 4 hours. For Bonner Criteria 2, peak wind speed and height of jet were under-predicted, but duration was overpredicted. For Bonner Criteria 3, the models under-predicted both the average height of the LLJ maximum and average duration, and under-predicted the average wind speed with a larger difference than Bonner Criteria 1 or 2. Finally, we found the models were a few hours too early with peak wind speeds.

Overall, the results suggest substantial differences in the simulation of LLJs depending on which PBL scheme is used, and no one scheme performs much better than any other. Future work should examine how these errors in LLJ forecasts may affect forecasts of MCSs.

5. Acknowledgments

NSF funded the BioGeosciences REU summer program in which this research began. Partial funding was supplied by DOE grant #13-450-141201, Ames Laboratory Project 290-25-09-02-0031, ERPC grant #400-60-12, and NSF grant ATM-0848200 with funding from ARRA 2009.

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