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Type of Project (Partners or Cooperative): Partners

Project Title: Quantifying Uncertainties of High-Resolution WRF Modeling on Downslope Wind Forecasts in the Las Vegas Valley

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Section 1: Summary of Project Objectives

Numerical simulations for severe downslope winds and trapped lee waves in Nevada's Las Vegas Valley were performed in this study (Fig. 1). One of the challenging forecasting tasks in this area is to precisely predict downslope wind events. The goal of this study was to improve model forecasts of downslope wind event intensities. This was measured by assessing different planetary boundary layer schemes in the mountain-valley region. The Weather Research and Forecasting model (WRF) was adopted for this research. The numerical experiments were constructed using two nested domains, 4 km and 1 km grid resolution. The working hypothesis was that the occurrence of low-level wind shear and surface gustiness in the Las Vegas Valley was guided by the inversion layer in the valley. The choice of boundary layer scheme and model vertical resolution will influence inversion layer height and consequently result in significant differences in surface wind and temperature forecast error below some near surface height.

Simulations of severe downslope wind events on 15 April 2008 and on 4 October 2009 were conducted. Statistical analyses of model results from three different PBL schemes and different vertical resolutions were performed. The 1 km grid spacing domain results demonstrated remarkable detail of the severe downslope winds associated with low-level wind shear and surface gustiness in the Las Vegas Valley, although the model still exhibited cold biases (~ 2 ^{o}C) in all three PBL experiments. The simulation results demonstrated that model vertical resolution was primarily responsible for the detail of the lower level wind and temperature structures. Overall, the shift in model resolution down to the meso-gamma scale is anticipated to improve the ability of forecasters to predict similar events in this region. The inverse Froude number and Froude number are two indices that may be included as the forecasting guidance for downslope winds, lee waves as well as rotors forecasting for the Las Vegas Valley. These two indices are essentially associated with the upstream atmospheric stability (i.e., *N*, Brunt-Vaisala Frequency) and low-level mean wind speed ($\overline{U}$) as well as the inversion height (z_i) in the Las Vegas Valley.

Figure 1: Topographic map of the Las Vegas Valley and surrounding areas. The peak of the Spring Mountain Range is about 11,918 ft (3,633 m).

Section 2: Project Accomplishments and Findings

Two severe downslope wind events affecting the Las Vegas Valley were investigated in this project using the Weather Research and Forecasting (WRF) model. The results affirmed the model's ability to recapture the transient nature of such events using high spatial resolution. It appears that the resonant amplification wave theory as described by Clark and Peltier (1984) is most suitable to explain these downslope winds events.

The model adequately recaptured the onset and development of the 15 April 2008 event. Downslope winds during this event reached approximately 30 m s^{-1}, which the model slightly overestimated. Figure 2 shows the 925 hPa wind and 700 hPa vertical velocity fields over the Las Vegas area. Nevertheless, this overestimation seemed to match well with station reports of wind gusts. The inverse Froude number ($\hat{h}$) for this event was about 2.75 which supported the formation of lee waves and rotors simulated by the model. The 4 October 2009 event lasted through an entire diurnal cycle, evolving with the boundary layer. The event began as terrain-generated gravity waves formed between the peaks of the Spring Mountain Range and the boundary layer inversion (~ 4000 m). As boundary layer heights decreased, gravity wave amplification on the lee slopes of the Spring Mountains began. As shown in Fig. 3, this resulted in the formation of low-level turbulence and stronger surface winds (15-20 ms^{-1}) across the lee slopes and Las Vegas Basin. The inverse Froude number and Froude number supported the trapped lee waves flow regimes simulated by the model.

The impacts of model vertical levels were assessed to determine which configuration best simulated the low-level winds. The use of high vertical resolution in the boundary layer (e.g., L61 experiment) greatly improved the surface wind forecast from the default run (L60). The lowest level in the L61 experiment adapted for this study was about 11 m, which can be directly compared with station observations (Table 1).

Planetary boundary layer (PBL) schemes were evaluated to determine which most adequately represented the 15 April 2008 event. Model temperatures and winds were validated against 20 surface station observations (Table 2). Surface sites were chosen based on wind data availability. However, not all surface stations reported at the top of the hour which caused large differences between observations and model results, as was the case with the mountain sites. Statistics calculated for the PBL schemes revealed that the MYJ and QNSE tended to underestimate valley wind speeds, while the YSU slightly overestimated (Table 3). All schemes displayed a nocturnal cold bias for temperatures, which was expected. The non-local closure PBL scheme (i.e., YSU) demonstrated the most adequate results and was selected to be the control run of this study.

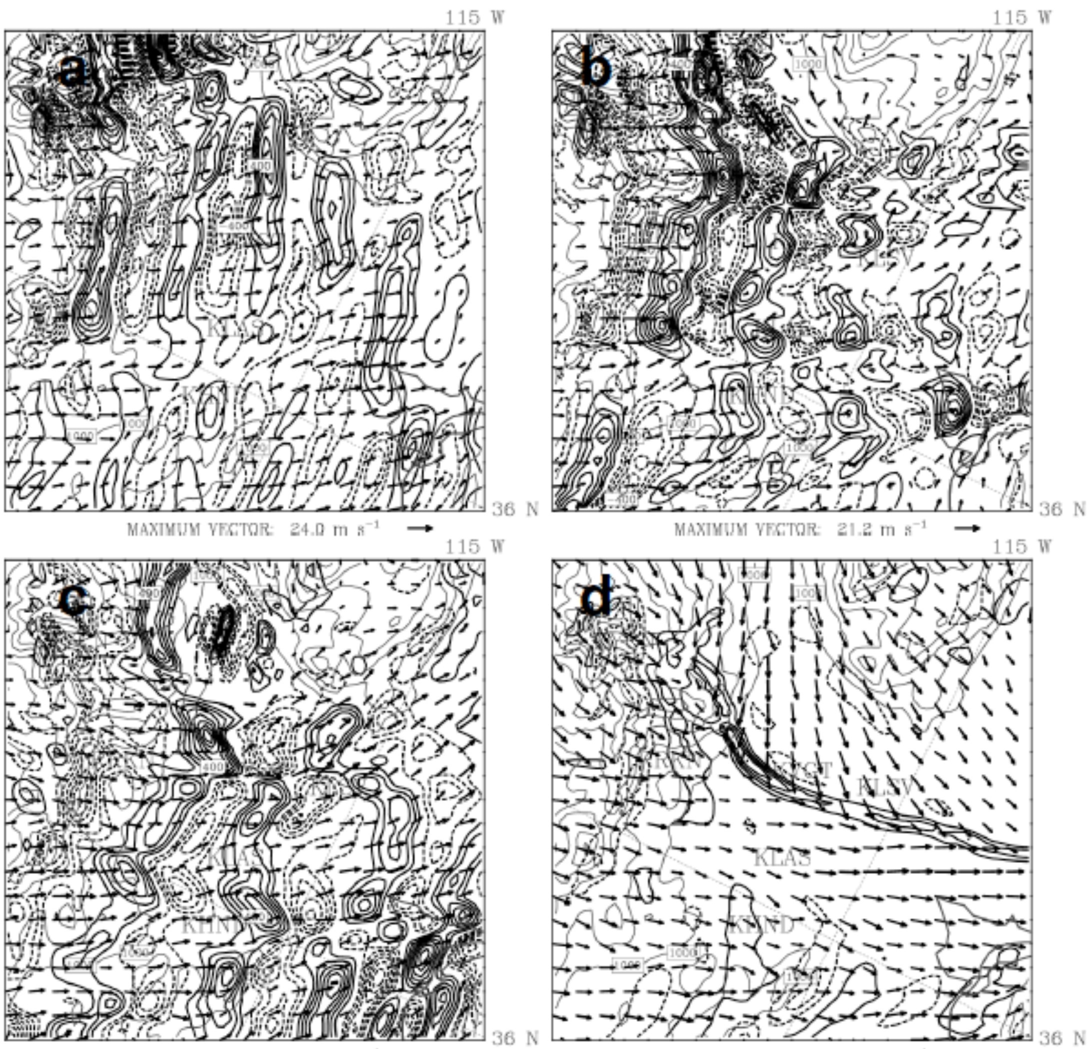

Figure 2: The simulated wind vectors at 925 hPa and vertical velocity at 700 hPa (interval = 100 cm s^{-1}) from the 1km domain valid at (a) 0600 UTC 15 (b) 1200 UTC 15, (c) 1800 UTC 15, and (d) 0000 UTC 16 April 2008.

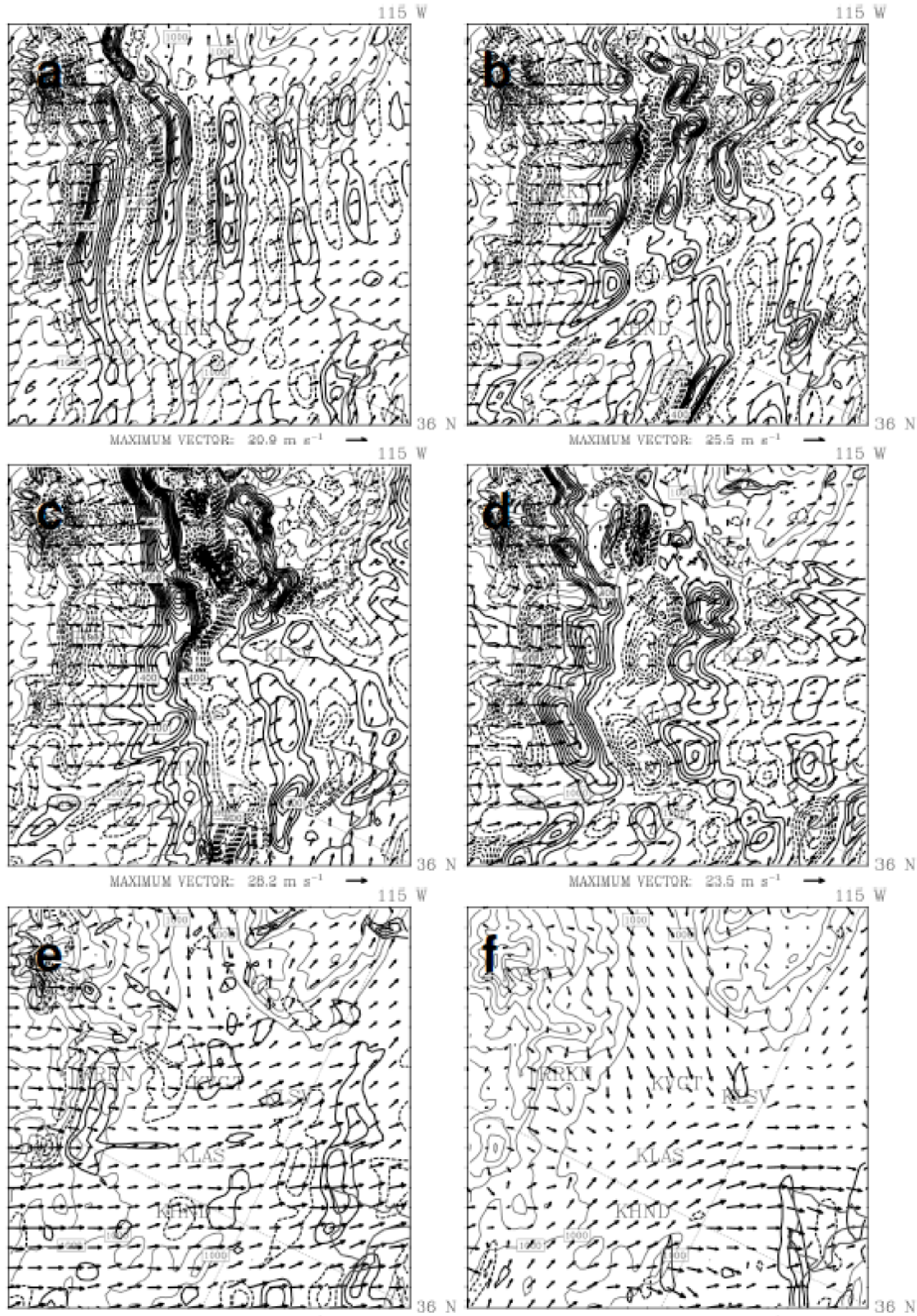

Figure 3: The simulated wind vectors at 925 hPa and vertical velocity at 700 hPa (interval = 100 cm s^{-1}) from the 1km domain valid at (a) 0000 UTC 04, (b) 0600 UTC 04, (c) 1200 UTC 04, (d) 1800 UTC 04, (e) 0000 UTC 05 and (f) 0600 UTC 05 Oct 2009.

This research highlights the sensitivity of flow over mountains to a number of variables. Boundary layer scheme appears to be a critical factor affecting the accuracy of wind forecasts in this turbulent environment. Besides that, the resolution of the model vertical levels is also an important factor for better forecasting of near-surface wind and temperature. The setting of vertical levels in this study demonstrated the value of using high, near-surface vertical resolution to improve the forecasts. The model recreated Aircraft Meteorological Data Relay (AMDAR) data very well, which also validated quality of the AMDAR data. The major differences of these two events in terms of downslope wind, lee waves, as well as rotors forecasting in the Las Vegas Valley were the upstream atmospheric stability and low-level mean wind speed as well as the inversion height in the valley.

The model, however, still exhibited the cold bias overall. Further investigation should be conducted on how to improve land use, soil moisture and snow cover (if any) initialization, as they have been shown to impact results. Also, the sensitivity of radiative schemes may need to be examined to further eliminate the cold bias in the model. Based on the findings in this paper, the NWS Las Vegas Forecast Office mesoscale model now runs the YSU scheme with increased vertical resolution in the boundary layer. The improved wind forecasts from this configuration are important for issuing public warnings and watches for high winds as well as forecast products for aviation such as TAFs. Nevertheless, long-term verifications of model performance are still needed.

Level (from bottom)	**Vertical configurations**		
	L60	**L61**	**L137**
1	21.5	11.1	28.8
2	90	33.2	84.8
3	183.1	57	140.7
4	301.2	81.8	196.5
5	449.3	108.3	252.2
6	636.7	136.2	307.9
7	865.4	165.4	363.4
8	1064	195.9	418.9
9	1213	227	474.6
10	1363.8	259.4	530.2

Table 1: The height in meters of the lowest 10 terrain-following vertical levels for the three vertical configurations tested, L60, L61, and L137, at KLAS.

Surface Observation Stations

Station	Latitude	Longitude	Elevation (m)
Station 44	36.668	-116.017	1123
Mercury	36.661	-116.005	1120
Desert Rock	36.624	-116.019	1007
Indian Springs	36.574	-115.676	963
Nellis Range	36.54	-115.537	938
Yucca Gap	36.437	-115.331	969
Kyle Canyon	36.265	-115.609	2195
CW4221 North Las Vegas	36.244	-115.205	671
Nellis Air Force Base	36.233	-115.033	570
Pahrump	36.221	-115.995	805
North Las Vegas Airport	36.212	-115.196	672
Red Rock Canyon	36.135	-115.43	1145
Las Vegas	36.114	-115.148	620
CW3746 Las Vegas	36.113	-115.054	515
Blue Diamond Ridge	36.08	-115.39	1475
McCarran International Airport	36.079	-115.155	663
CW7282 Henderson	36.039	-115.094	609
Mountian Springs	36.031	-115.517	1707
Arden	36.029	-115.226	740
Henderson Executive Airport	35.973	-115.134	760

Table 2: List of surface observation stations

All Station (20)

	Surface Temperature			Surface Wind Speed		
Model Run ID	Mean Bias	RMSE	Corr	Mean Bias	RMSE	Corr
YSU 60 levels	-2.24	2.51	0.923	3.83	5.70	0.323
QSNE 61 levels	-2.44	2.65	0.934	0.48	4.21	0.251
YSU 61 levels	-2.18	2.46	0.920	1.47	4.12	0.281
MYJ 61 levels	-2.57	2.83	0.941	0.63	4.09	0.278
YSU 137 levels	0.09	1.87	0.923	3.63	5.70	0.268

Valley Stations (16)

	Temperature			Wind Speed		
Model Run ID	Mean Bias	RMSE	Corr	Mean Bias	RMSE	Corr
YSU 60 levels	-2.17	2.46	0.923	2.74	4.73	0.324
QSNE 61 levels	-2.44	2.65	0.934	-0.27	4.14	0.277
YSU 61 levels	-2.09	2.37	0.929	0.68	3.98	0.292
MYJ 61 levels	-2.57	2.83	0.940	-0.05	4.05	0.303
YSU 137 levels	0.29	1.89	0.916	2.71	4.76	0.262

Mountain Stations (4)

	Temperature			Wind Speed		
Model Run ID	Mean Bias	RMSE	Corr	Mean Bias	RMSE	Corr
YSU 60 levels	-2.50	2.70	0.924	7.92	9.33	0.316
QSNE 61 levels	-2.46	2.66	0.934	3.31	5.97	0.155
YSU 61 levels	-2.56	2.80	0.886	4.44	6.11	0.240
MYJ 61 levels	-2.59	2.82	0.945	3.20	5.79	0.184
YSU 137 levels	-0.73	1.79	0.951	7.11	9.22	0.291

Table 3: Model output statistics compared to surface station observations from 06-23 UTC 15 April 2008.

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

Partnerships between university researchers and the NWS operational forecasters are of paramount importance. It is with these relationships that new operational strategies to better forecast and model our high impact weather may be developed. Specifically, the relationship between Florida Tech and the NWS Las Vegas has fostered a study to investigate the effects topography has on downslope wind and lee waves locally across the county warning area and surrounding areas. That said, further investigation and better, high-resolution modeling could be employed to identify the effect of downslope wind events in the Las Vegas Valley. Further studies, on phenomena such as rotors, may help to identify the causative effects specific wind flow patterns may initiate, assisting operational forecasters with advancing lead time on those high impact weather events.

Section 4: Benefits and Lessons Learned: University Partner Perspective

The collaboration between Florida Tech and the NWS Las Vegas office provides an important benefit to advance our understanding of the processes of fine scale circulations as well as the lower boundary forcing (i.e., topography) over the Las Vegas valley. One graduate student (Andre Pattantyus) who was partially supported by this project had completed his M.S. thesis in July 2010, and now is continuing on to get his Ph.D. Through the onsite visit we were able to further understand the needs from the operational perspective. We were able to tailor this research project to better fit into the needs from the NWS Las Vegas. In the near future, we will further investigate rotor cloud events in the Las Vegas valley region. The partnership indeed provides my institution the opportunity to contribute to our discipline in a significant way.

Section 5: Publications and Presentations

<u>*Referred Journal and Proceedings*</u>:

Pattantyus, A., S. Chiao, and S. Czyzyk, 2010: Improving High-Resolution Model Forecasts of Downslope Winds in the Las Vegas Valley. J. Applied Meteorology and Climatology, conditionally accepted, major revision.

Pattantyus, A., S. Chiao, and S. Czyzyk, 2010: Numerical model forecasting of downslope winds in the Las Vegas Valley. Proceedings of the 5th International Symposium on Computational Wind Engineering, Chapel Hill, NC, May 23-27, 2010.

Pattantyus, A., and S. Chiao**,** 2010: Numerical studies of convective and stable boundary layer evolution in mountainous regions. Proceedings of the International Symposium for the Advancement of Boundary Layer Remote Sensing (ISARS), Paris, France, June 28-30, 2010.

<u>*Conference Presentation:*</u>

Pattantyus, A., S. Chiao, S. Czyzyk, and M. Staudenmaier, 2011: Downslope Wind Forecasts in a Mountainous Region: Assessing Uncertainty in High-Resolution Modeling over the Las Vegas Forecast Zone. The 24th Conference on Weather and Forecasting /20th Conference on Numerical Weather Prediction, Seattle, WA, January 23-27, 2011.

Pattantyus, A., and S. Chiao, 2010: Numerical model forecasting of downslope winds in the Las Vegas Valley. Florida Academy of Sciences Annual Meeting, Ft. Pierce, FL, March 19-20.

<u>*Thesis:*</u>

Pattantyus, A., 2010: Numerical Investigations of Mountain Flows in the Las Vegas and Owens Valleys. Florida Institute of Technology, M.S. Thesis, pp. 92.

Section 6: Summary of University/Operational Partner Interactions and Roles

The Florida Institute of Technology and NWS Las Vegas office interacted on this project constantly. For the past year and a half we have had phone conferences as well as email exchanges. An onsite visit was conducted in August 2010. We presented the findings from this research as well as to discuss the strategy about the model configuration. That is one of the important tasks of this project. In addition to onsite visit, we were able to present results at international conferences (see Section 5). The graduate student who was partially supported by this grant defended his M.S. thesis successfully in July 2010. A manuscript has been reviewed and is conditionally accepted in the Journal of Applied Meteorology and Climatology. Both university and operational partners share the authorship of these publications. The partnership of FIT and NWS Las Vegas will lead to better understand the fundamental scientific as well as forecasts issues in simulating high impact weather events.