High resolution simulations of boundary layer behavior in California’s Owens Valley using the WRF-ARW model during T-REX 2006

Mr. Robert E. Dumais, Jr.*
Dr. Teizi Henmi (Ret)
U.S.Army Research Laboratory
Dr. Edward Colon
SAIC/NCEP.
Dr. Sen Chiao
Florida Institute of Technology

1. Introduction

The recent Terrain-induced Rotor Experiment (T-REX) field campaign (Grubišić, 2006), held during the spring of 2006 in the Owens Valley of California, has provided researchers in a number of atmospheric science fields with a wealth of data that characterizes atmospheric boundary layer (ABL) structure and evolution in complex terrain regions. The primary focus of T-REX was to observe and study the highly perturbed lee wave/boundary layer/rotor system common in the spring throughout the Owens Valley.

The substantial volume of in-situ data obtained from the T-REX suite of meteorological instruments also afforded the U.S. Army Research Laboratory (ARL) the opportunity to study conditions that are unique to nocturnal stable atmospheric boundary layers that develop over rift valleys. The main goals of the ARL research are to: 1) examine the nocturnal low-level jet formation under quiescent boundary layer conditions within the Owens Valley; 2) characterize the role of surface heating/cooling and its effect on inversion layer variations within the Owens Valley; 3) evaluate planetary boundary layer parameterizations at high spatial resolution.

We recently employed the Weather Research and Forecasting (WRF) Advanced Research WRF (ARW) model (Skamarock et al, 2005) to run high resolution simulations of ABL conditions associated with (1) Enhanced Observation Periods (EOPs) 4 and 5 (April 28-30) which were characterized by quiescent large-scale meteorological conditions and (2) Intensive Observation Period (IOP) 13 (April 15-17, 2006) in which robust lee wave/rotor activity over the Owens Valley was observed.

Our analysis efforts to date have focused upon EOP 4 -5 case study results, and we will discuss this case study in this paper. EOP 4 was noted for a moderately strong nocturnal downvalley wind regime, while EOP 5 experienced a strong downvalley wind regime. Therefore, our natural interest in terms of analysis has centered upon the WRF-ARW reproduction of these flows. This includes not only investigating the downvalley surface flows themselves, but also aspects of the associated nocturnal low level jet (

---

* Corresponding author address : Robert E. Dumais, Jr., U.S. Army Research Laboratory, White Sands Missile Range, NM 88002-5501; e-mail: rdumais@arl.army.mil

LLJ) in the valley, the depth and evolution of the nocturnal inversion, distributions of temperature and moisture in the valley, the evolution and spatial distribution of evening drainage flows near the valley side walls, and any impact of larger-scale forcing.

It was initially thought, based upon initial National Center for Atmospheric Research (NCAR) Integrated Sounding System–Multiple Antenna Profiling Radar (ISS MAPR) observations (http://www.eol.ucar.edu/rtf/facilities/iss/) , that a three-layer nocturnal wind structure above the valley floor similar to that noted in EOP 2 (Daniels et al,2006) was also present throughout both EOP 4 and 5. However, upon closer look of the quality-controlled profiler data and after examining concurrent soundings taken by the University of Leeds at the Independence Airport, it is currently thought that the profiler results in the upper levels of the valley were contaminated in both EOP 4 and 5 by the presence of nocturnal migratory birds. (Schmidli, 2007).

Our WRF-ARW simulations also compare the two primary available model ABL schemes: one involving local closure (Mellor-Yamada-Janjic, MYJ) and the other non-local closure (Yonsei State University, YSU) parameterizations. Surface and vertical sounding measurements used to validate our simulation results have so far been derived from the Desert Research Institute's (DRI) Automated Weather Stations (AWS) and the NCAR ISS-MAPR. Additional upper air measurements used have been those of the University of Leeds special soundings.

The results of our forecast analyses will later be compared with results obtained from other research groups modeling T-REX ABL structure and evolution during EOP and IOP phases, yielding a clearer picture of how model ABL parameterizations (along with other selectable configuration and namelist run-time options) impact the accuracy of high-resolution simulations under the unique conditions of such rift valley environments.

2. ARL WRF-ARW Modeling during T-REX 2006.

Throughout the active phase of the 2006 T-REX (Mar-Apr), ARL (with support from the Army High Performance Computing Research Center) along with other various modeling groups (Naval Research Laboratory, National Oceanic and Atmospheric Administration's Global Systems Division, and the National Weather Service Office in Las Vegas) generated daily mesoscale model forecasts that were placed on the web at NCAR (http://catalog.eol.ucar.edu/cgi-bin/trex/model/index). ARL executed the WRF-ARW in a triple nest configuration (18km/6km/2km) with 40 vertical levels (to 10 mb), using National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) (Kanamitsu, 1991) initial and lateral boundary conditions, and generating 48 h forecasts based daily at 1200 UTC. Subsequent to T-REX 2006, ARL than reran each case in a double nest (with two-way feedback) configuration (3 km/1 km) from the NCEP ETA-based North American Model (NAM) (Black, 1994) 12 km initial and lateral boundary conditions. Again, 40 vertical levels were applied, but this time to only a top of 50 mb.

Another reason that special attention has been paid by ARL to the simulations generated during T-REX EOPs is that some of the ARL effort has been supported by an ARL and Defense Threat Reduction Agency (DTRA) stable boundary layer program. Numerous statistics and graphical products have been generated by ARL for both the 2 km (and the subsequent 1 km) WRF-ARW results, and these are in the process of being compiled into a publication. EOPs 4 and 5 were selected for the current case study, due to the high fidelity 1 km results obtained previously, and due to the strong nocturnal downvalley flow patterns observed by the DRI mesonet, University of Leeds soundings, and the ISS MAPR in the Owens Valley during that period. An example of the WRF-ARW multinest results from the EOP 4 and 5 MYJ simulation (surface wind directions) are shown in Figure 1, compared to DRI mesonet observations at site 13.

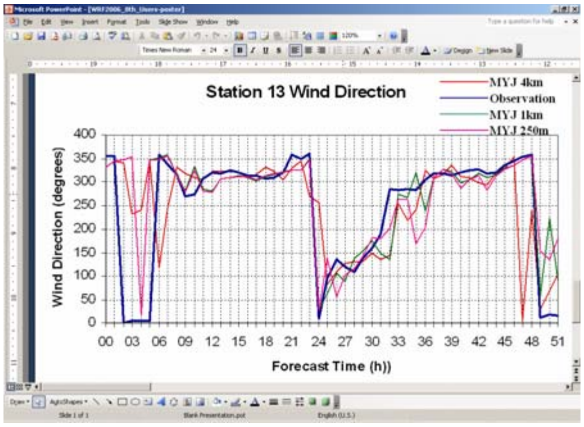

Figure 1. WRF-ARW surface results compared to DRI mesonet observation site 13- MYJ-run wind direction.

3. WRF-ARW Model Configuration for EOP 4/5 Case Study

In order to better simulate the significant diurnal flow features in the Owens Valley throughout EOPs 4-5, the WRF-ARW was run in a triple (one-way) nesting configuration of 4 km, 1 km, and 250 m grid spacing. Horizontal dimensions of 121x121 were used for each nest (Figure 2). In the vertical dimension, 50 levels and a top of 50 mb were used. In order to simulate the entire EOP 4 and 5 period, a 51h forecast period was selected spanning 1800 UTC Apr 28- 2100 UTC Apr 30. No data assimilation was used, and NCEP NAM 12 km gridded fields provided the initial and lateral boundary conditions for the outer nest. Additionally, two simulations were run to compare differences in PBL schemes, one using YSU and the other MYJ. The other namelist physics remained fixed between the simulations, and are listed in Table 1.

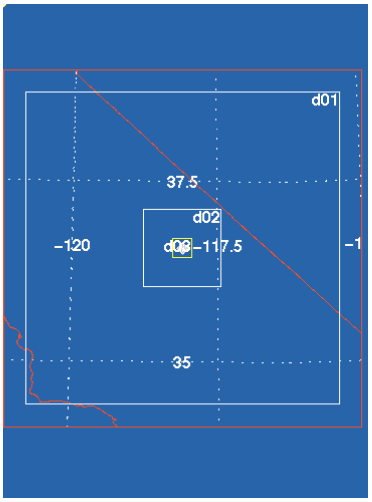

Figure 2. ARL WRF-ARW nest configuration for EOP 4/5 high resolution model runs.

4. Discussion

ARL has completed a pair of high resolution simulations of the period spanning EOP 4 and 5 of T-REX 2006, encompassing 51 h between 1800 UTC Apr 28- 2100 UTC Apr 30. Initial ARL focus has been on analysis of results from the 1 km (second) nest, although some attention has also been paid to both the outer (4 km) and inner (250 m) nest outputs. The simulations differed only in that one used the YSU PBL namelist option, while the other the MYJ.

WRF-ARW Namelist Options
Lin microphysics
No cumulus parameterization
Dudhia short wave radiation
RRTM long wave radiation
NOAH land surface model
conventional terrain averaging in WRFSI
Runge-Kutte 3rd order dynamics
Diff_opt=1 (2nd order diffusion on coordinate surfaces)
Km_opt=4 (horizontal Smagorinsky 1st order closure)
5th order horizontal advection of momentum & scalars
3rd order vertical advection of momentum and scalars

Table 1. Options selected in namelist for ARL's WRF-ARW high- resolution EOP 4-5 model run.

Using a variety of free public-domain graphical display packages, plots for both simulations and all WRF-ARW nests continue to be generated, examining features both at the surface and aloft. These include detailed cross section analyses, both zonal and meridional. In addition, numerous special observations collected during the 2006 T-REX (surface mesonet, wind profiler, soundings, etc.) are being collected and processed for use in verifying the results of the model simulations and for producing comparisons.

Most of the observational comparisons for the EOP 4-5 high-resolution runs are in the process of being generated at ARL, and are not shown in this paper. Initial findings do seem to show that both model PBL options (YSU and MYJ) generally reproduced well, although with differences, the diurnal temperature, moisture, and flow evolution of the EOP 4 and 5 period, particularly the downvalley flows and low-level jet structure (20-30 knots) observed at night and in the early morning hours just above the valley floor (Figures 3-8). Overall, the MYJ comparisons do appear superior, however. In both the YSU and MYJ runs, the forecasts tend to degrade some after about 30 h, particularly for surface moisture/dewpoint (which seem to be possible phasing errors). We are currently comparing these results to those of our previous double nest (3km, 1km) configuration, to see if some of these later forecast period discrepancies might be due more to the large-scale forcing via the NAM. Continued focus will be on the differences in downvalley flow evolution between the YSU and MYJ runs (particularly in the early evening transition hours) and on the general overall structure of the wind and thermodynamic fields both near and well above the Owens Valley floor.

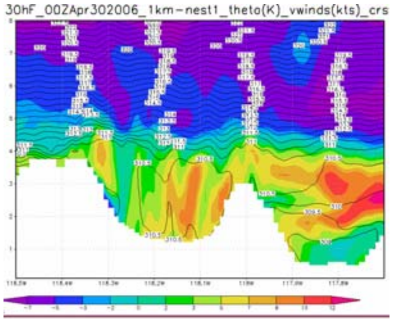

Figure 3. Zonal cross section at 36.81 deg N, valid 2006 Apr 30 00 UTC after 30 h, with blue/purple representing northerly v-wind comp (WRF-ARW 1 km nest 2- MYJ option)

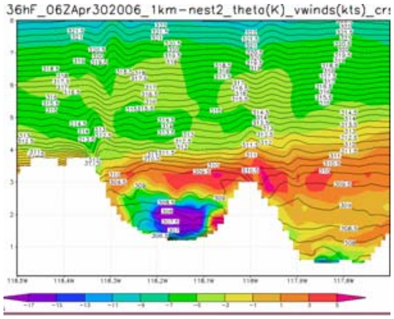

Figure 4. Same as Fig 3, but valid 2006 Apr 30 06 UTC after 36 h.

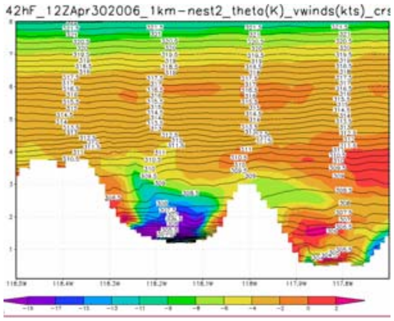

Figure 5. Same as Fig 3, but valid 2006 Apr 30 12 UTC after 42 h.

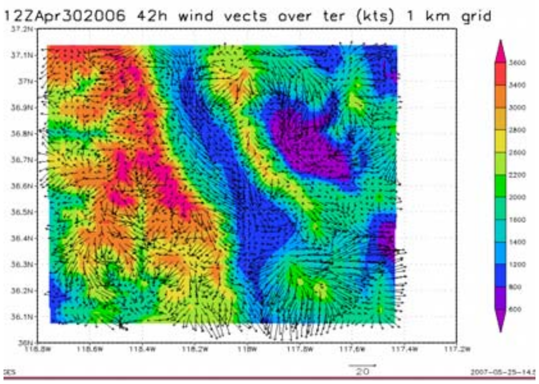

Figure 6 . Surface 10 magl wind vectors (kts) Plotted over shaded terrain (m), valid 2006 Apr 30 12 UTC after 42 h (WRF-ARW 1 km nest 2- MYJ option).

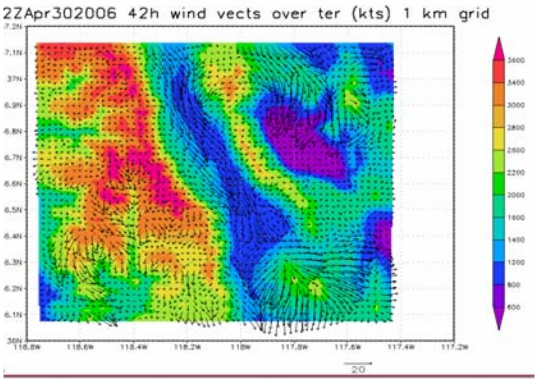

Figure 7. Same as Fig 6, but for YSU.

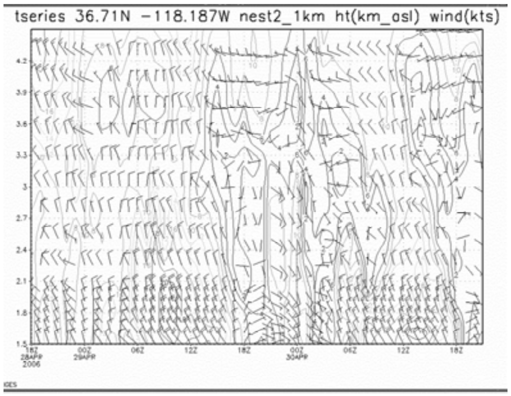

Figure 8. Time/height series of winds (kts) near Independence , CA (WRF-ARW 1km nest 2- MYJ option) with height axis in km asl.

5. Acknowledgements

The authors would like to thank both the Army's Major Shared Resource Center and the Army High Performance Computing Research Center (including Network Computing Services, Inc) for the use of their high performance computers. They would also like to thank Dr. Jim Doyle (NRL), Dr. Tina-Katopodes-Chow (U. California-Berkeley), Dr. Juerg Schmidli and Dr. Jimy Dudhia (NCAR), and Dr. Steve Koch (NOAA GSD) for their useful suggestions and ideas.

6 . Refererences

Black, T., 1994: The new NMC mesoscale Eta model: description and forecast examples. Wea. and Forecasting, 9, 265--278.

Daniels, M.H., Chow, F.K., and G.S. Poulos. 2006. Effects of soil moisture initialization on simulations of atmospheric boundary layer evolution in Owens Valley. Paper 7.2. 12th Conference on Mountain Meteorology, Amer. Meteor. Soc., 8 pages.

Grubišić, V., and J. D. Doyle, 2006: Terrain-induced Rotor Experiment, Invited Talk, AMS 12th Mountain Meteorology Conference, Santa Fe, Amer. Meteor. Soc.

Kanamitsu, M., J.C. Alpert, K.A. Campana, P.M. Caplan, D.G. Deaven, M. Iredell, B. Katz, H.-L. Pan, J. Sela, and G.H. White, 1991: Recent changes implemented into the global forecast system at NMC. Wea. and Forecasting, 6, 425-435.

Schmidli, J., 2007: Personal Communication. NCAR, May 2007.

Skamarock, W.C., J.B. Klemp, J. Dudhia, D.O. Gill, D.M. Barker, W. Wang, J.G. Powers, 2005: “A description of the Advanced Research WRF version 2”. National Center for Atmospheric Research Technical Note, NCAR/TN-468+STR, Mesoscale and Microscale Modeling Division, June 2005, 100 pp.