Response to Referees for "Simulations of a cold –air pool associated with elevated wintertime ozone in the Uintah Basin, Utah" by E.M. Neemann et al. 2014

Reviewer comments are in italics. Responses are underlined.

Anonymous Referee #1
Received and published: 9 July 2014

General Comments:

This manuscript (i.e., Neemann et al., 2014) investigated a 6-day cold-air pool episode associated with elevated wintertime ozone in Utah using WRF-CMAQ simulations. This work is important to understand the elevated wintertime ozone episodes. The main weakness of this paper is lack of analysis of vertical profiles of chemical species. Thus I recommend revision before it can be accepted for publication.

Author Response: The authors thank Referee 1 for the thorough and insightful review. We have responded to each comment below. We summarize the changes made to the document below:

Specific Comments:

Given the boundary layer vertical structure playing a critical role for ozone accumulation for the selected episode, vertical profiles of chemical species (including O3 precursors and O3) need to be presented. For example, such profiles need to be added into the current Fig. 6.

Author Response: We agree with both referee 1 and 2 that the ozone, VOC, and NOx profiles are very important (and would be useful to show in Fig. 6). However, the work presented here was conducted primarily to improve the meteorological modeling of these CAP episodes in the Uintah Basin, with the preliminary CMAQ O_3 simulations presented to illustrate the impact of the meteorology on the general spatio-temporal ozone evolution. This study is part of a special issue that will include the aforementioned vertical profiles of chemical species in other papers within the special issue, for example, vertical profiles pertaining to the episode we modeled are included by Oltmans et al. (2014). Simulations using the CMAQ and WRF-Chem modeling frameworks to model ozone are an area of active research by many UBWOS scientists. Other scientists will be presenting detailed analyses of the vertical profiles of ozone and various chemical species that those groups collected over both the 2011-2013 and 2013-2014 winters.

Cross section of O3 in Figure 15 might be better to put along with vertical cross section of potential temperature in Figure 12. By doing so, the readers can immediately see the impact of cold pool on O3 accumulation.

Author Response: We liked this idea and aredid this figure with ozone data shown. Unfortunately, the cross-section of ozone at the time of the CAP tilting described in this figure did not effectively illustrate the impact of CAP on ozone accumulation since it was 11 pm MST.

Also the authors might consider adding O3 contours in Figure 10, similar as the current Fig. 16c. probably remove the current black lines in Figure 10 since color shade is enough.

Author Response: Agreed. We have added O_3 contours as well as cloud water and ice content in response to reviewer 3 to Fig. 10 (which is now Fig 9 in the revised manuscript) and removed most of the black lines (left thin ones at 5 K intervals to help highlight the theta contours) as suggested. Doing this allowed presentation of O_3 for the NONE case in addition to the FULL case. We did not compute ozone for the BASE simulation and therefore Fig. 9a does not show ozone. In addition, by compressing the information from Fig 16c into Fig 9b, we have removed Fig. 16c from the paper.

"Liquid-phase low stratus and fog are represented by aqua/green colours (e.g., southern ID and portions of western and central UT) while the yellow/orange colours evident in the basin are typically associated with ice-phase stratus and fog". Such information needs to be given using a color bar in the Figure.

Author Response: We have added a colored-coordinated legend that correspond to pertinent features in Fig 5a and b.

AGL and above sea level are mixed in the text, e.g., "lowest 300m is capped by increasing potential temperature on 4 February below 1800m (Fig. 6a and c). The strong stability extends upwards to 2750m".

Author Response: The text is changed to reflect that all heights are in MSL unless specifically referenced as AGL. AGL references are only used in 4 instances where it is necessary to convey near-surface vertical extent.

"The mixed layer is shallower on the 5th (Fig. 6b) with lower relative humidity within the CAP". I don't read this in Fig. 6. Relative humidity exceeded 100% on both 4th and 5th

Author Response: We agree this text was misleading and have clarified the text to point out the slightly lower RH in the upper portions of the boundary-layer CAP, which indicates the lack of cloud cover on that day: "The observed mixed layer was shallower the following day as a result of thinner surface ice fog (Fig. 4b) with ~10% lower relative humidity within the upper portions of the CAP."

"Data collected from ozonesondes and tethersondes during February 2013show that the vertical extent of maximum ozone concentrations was typically limited to 1700m m.s.l. and below, or in the lowest 200–300m of the boundary layer (Schnell et al.,2014). A gradient in concentrations was noted above this level, with ozone concentrations returning to background 03 levels above 1900m m.s.l. (Karion et al., 2014)." Such vertical structure of O3 needs to be presented along with vertical profiles of meteorological variables.

Author Response As discussed earlier, we agree that vertical structure of ozone is important. However, these profiles during the CAP event modelled in this paper will be presented in other papers within the ACP special issue (e.g. Oltmans et al. 2014), such that this information will be readily accessible for intercomparison with our model results.

Table 2 is confusing. How many simulations are conducted? 3? 4?

Author Response: We agree that Table 2 was confusing and we have modified it in response. Only 3 simulations were conducted and we have simplified Table 2 so that the FULL simulation is no longer duplicated in the Table.

"Most schemes generally allow too much turbulent mixing, which results in boundary layers that are too deep (Holtslag et al., 2013). While the MYJ PBL scheme was ultimately selected for this study, the Asymmetric Convective Model, Grenier-Bretherton-McCaa, and Bretherton-Park PBL schemes were also tested in addition to the Yonsei University (YSU) scheme with and without the Jimenez surface layer formulation and updated stability functions (Jimenez et al., 2012). The MYJ was chosen since it best represented the combination of moisture, stability, and temperature". This gives an impression that all the PBL schemes except MYJ give too much turbulent mixing, which might not be true [Hu et al., 2013].

Author Response: We have modified the text so that it does not give the impression that all PBL schemes except MYJ give too much turbulent mixing. Our understanding is that generally all schemes including MYJ are somewhat overdispersive in stable PBL situations (Baklanov et al. 2011, Holtslag et al, 2014, etc). We have modified the above statement to the following (and also added the useful information found in the Hu et al. 2013 reference):

"PBL schemes have difficulties handling low clouds, vertical temperature profiles, 2 m temperatures, and mixing in stably stratified conditions (Reeves et al., 2011; Shin and Hong, 2011; Zhang et al., 2013). Many schemes typically allow too much turbulent mixing in stable conditions, which results in boundary layers that are too deep (Holtslag et al., 2013). While the MYJ PBL scheme was ultimately selected for this study, the Asymmetric Convective Model, Grenier-Bretherton-McCaa, and Bretherton-Park PBL schemes were also tested in addition to the Yonsei University (YSU) scheme with and without the Jimenez surface layer formulation and updated stability functions (Jimenez et al., 2012). The MYJ was chosen because in simulating this particular CAP it best represented the combination of moisture, stability, and temperature characteristics that were observed in the Uintah Basin for the simulated period. Further testing of PBL schemes performance in the presence of high wind speeds above the stable PBL are also needed (e.g., Hu et al. 2013 found that modifications to the YSU nighttime velocity scale improved the simulations). "

Zhang et al. [2013] is more appropriate for the statement of "PBL schemes have difficulties handling 2m temperatures, and mixing in stably stratified conditions"

Author Response: We have added this reference.

"The warm air aloft (700hPa temperatures between -7 and 0°C) overtopping

very cold low-level air (diurnally ranging between -18 and -5°C) resulted in a strong capping inversion within the basin." This is an important mechanism for the confined cool pool formation [Lu and Zhong, 2014]. It is better to show such information in a figure (i.e., vertical profile of temperature)

Author Response: We have clarified this description and now introduce Fig. 4 earlier (sounding profiles) in our discussion of the cold pool evolution to give a Figure to go with the description.

Figures need improvement, e.g., Figure 2.

Author response We have worked to improve most of the Figures (2 Figures were removed from the paper during the revision process as requested by reviewers). A summary of changes to the Fig. is given below:

All Figures: Tick marks have been changed to 00:00 MST (midnight).

Fig 2. Rescaled so that (a) and (b) were the same size. Added red box in (a) that corresponds to region in (b). Added legend text and scale to (a) and (b)

Fig. 3. Added legend text (surface albedo and snow depth). Increased size of a-c lettering and increased size of image to improve print quality.

Fig. 4. Increased size of font on vertical and horizontal axes.

Fig. 5. Included legend for satellite images as requested.

Figs. 7 and 8. Added legend text (Temperature, Longwave Difference and 2-m Temperature Difference).

Fig. 9. We added 03 contours to Fig 9b and c in the revised manuscript and removed most of the black lines associated with potential temperature (left a few thin ones at 5 K intervals to help highlight the theta contours).

Fig. 11. We added legend text (Wind Speed, etc) and added Another time to show changes in CAP depth on the western slope.

Fig. 13. We added color-scale to Fig. 13a as requested by reviewer 2 to make spatial ozone variations more visually obvious.

Fig. 14. We added legend text (ozone) and compressed the old Fig 16a and b into Fig 14e and f

Author Response: The Hu et al. 2013 and Zhang et al. 2013 papers were added to the reference list

Hu, X. M., P. M. Klein, and M. Xue (2013), Evaluation of the updated YSU planetary

boundary layer scheme within WRF for wind resource and air quality assessments, J Geophys Res-Atmos, 118(18), 10490-10505, doi 10.1002/Jgrd.50823.
Lu, W., and S. Zhong (2014), A numerical study of a persistent cold air pool episode in the Salt Lake Valley, Utah, Journal of Geophysical Research: Atmospheres, 119(4), 2013JD020410, 10.1002/2013JD020410.
Zhang, H. L., Z. X. Pu, and X. B. Zhang (2013), Examination of Errors in Near-Surface Temperature and Wind from WRF Numerical Simulations in Regions of Complex Terrain, Weather Forecast, 28(3), 893-914, Doi 10.1175/Waf-D-12-00109.1.

Author Response: we have also added the following new references regarding UBWOS work that were recently submitted to ACPD Uintah Basin Special Issue:

Lee, L., Wooldridge, P. J., Gilman, J. B., Warneke, C., de Gouw, J., and Cohen, R. C.: Low temperatures enhance organic nitrate formation: evidence from observations in the 2012 Uintah Basin Winter Ozone Study, Atmos. Chem. Phys. Discuss., 14, 17401-17438, doi:10.5194/acpd-14-17401-2014, 2014.

Li, R., Warneke, C., Graus, M., Field, R., Geiger, F., Veres, P. R., Soltis, J., Li, S.-M., Murphy, S. M., Sweeney, C., Pétron, G., Roberts, J. M., and de Gouw, J.: Measurements of hydrogen sulfide (H_2S) using PTR-MS: calibration, humidity dependence, inter-comparison and results from field studies in an oil and gas production region, Atmos. Meas. Tech. Discuss., 7, 6205-6243, doi:10.5194/amtd-7-6205-2014, 2014.

Warneke, C., Veres, P. R., Murphy, S. M., Soltis, J., Field, R. A., Graus, M. G., Koss, A., Li, S.-M., Li, R., Yuan, B., Roberts, J. M., and de Gouw, J. A.: PTR-QMS vs. PTR-TOF comparison in a region with oil and natural gas extraction industry in the Uintah Basin in 2013, Atmos. Meas. Tech. Discuss., 7, 6565-6593, doi:10.5194/amtd-7-6565-2014, 2014.

Oltmans, S. J., Karion, A., Schnell, R. C., Pétron, G., Sweeney, C., Wolter, S., Neff, D., Montzka, S. A., Miller, B. R., Helmig, D., Johnson, B. J., and Hueber, J.: A high ozone episode in winter 2013 in the Uinta Basin oil and gas region characterized by aircraft measurements, Atmos. Chem. Phys. Discuss., 14, 20117-20157, doi:10.5194/acpd-14-20117-2014, 2014.

Ahmadov, R., McKeen, S., Trainer, M., Banta, R., Brewer, A., Brown, S., Edwards, P. M., de Gouw, J. A., Frost, G. J., Gilman, J., Helmig, D., Johnson, B., Karion, A., Koss, A., Langford, A., Lerner, B., Olson, J., Oltmans, S., Peischl, J., Pétron, G., Pichugina, Y., Roberts, J. M., Ryerson, T., Schnell, R., Senff, C., Sweeney, C., Thompson, C., Veres, P., Warneke, C., Wild, R., Williams, E. J., Yuan, B., and Zamora, R.: Understanding high wintertime ozone pollution events in an oil and natural gas producing region of the western US, Atmos. Chem. Phys. Discuss., 14, 20295-20343, doi:10.5194/acpd-14-20295-2014, 2014.