The authors present the contribution to ground level ozone in Phoenix from local sources in Arizona and sources in southern California. The assessment is done using the WRF-Chem coupled prognostic meteorology and chemistry modeling system. Emissions are based on 2005 National Emission Inventory. The contribution assessment is done using brute emission changes (zero out) and comparing the results to original baseline (control) simulation. All contributions are estimated using the 1.33 km domain covering southern California and Arizona to better capture air flow through important orographic features between the Los Angeles area and Phoenix area. Model application at such a fine scale to resolve important terrain features between 2 large cities to capture regional transport is useful and generally well presented in the figures. The illustration if air flow through valleys in the vertical and horizontal dimensions is particularly notable. Overall this is a good analysis characterizing local and regional contribution to Phoenix.

The authors appreciate the reviewer's comments, suggestions, and discussions. Following is a point-by-point responses.

The model results at 1.33-km suggest that WRF is adequately capturing important terrain features that channel ozone from southern California to Arizona. An interesting extension that would strengthen this manuscript would be to do a similar assessment using the 4km and possibly the 12km domain domains to see how regional ozone transport is impacted by smoothing out terrain features. The authors make a compelling case that these features are important and a fine resolution is needed to resolve the terrain, but we have not context for direct comparison with the coarser simulations.

In previous studies, Taha (2008), using MM5/CAMx, found that higher-resolution can improve model simulations on ozone concentrations in the Los Angeles area. Tie et al (2010), using WRF-Chem, found that higher-resolution improved model performance in simulating Mexico City's ozone concentrations.

To respond to the Reviewer's question, we actually have examined the effects of horizontal resolution on surface ozone concentrations. Besides CTRL runs, we have conducted two additional runs with the same model setup and configuration as the CTRL runs, but just running Domains 1, 2, and 3, whose highest resolution is 4 km. The comparisons of model performance between 1 km and 4 km resolution are listed in Table 1. The model at 1 km resolution performed better than that at 4 km resolution over all, especially for the correlation coefficients, normalized mean gross errors, mean normalized bias, and normalized mean error.

Table 1: Statistical results of hourly surface [O_3] from model simulations at 1 km and 4 km resolutions in Southern CA and Central AZ

	11-14, May 2012				16-19, July 2005			
	CA	CA	AZ	AZ	CA	CA	AZ	AZ
	1km	4km	1km	4km	1km	4km	1km	4km
Mean Bias (ppb)	-1.9	-3.4	0.6	-0.4	-2.0	-4.0	-4.8	-4.7
Normalized Mean Bias (NMB)	-7.9	-13.5	2.5	-1.7	-8.6	-16.3	-18.5	-18.4
Normalized Mean Error (%)	16.3	25.0	15.4	16.8	24.2	34.1	24.1	25.6
Mean Normalized Bias (%)	-6.7	-10.7	3.2	-1.2	-3.5	-9.7	-16.4	-18.5
Mean Normalized Gross Error (%)	16.7	24.9	15.9	17.3	23.8	34.0	24.5	26.2
Correlation coefficient	0.75	0.54	0.76	0.65	0.74	0.4	0.75	0.61
Root Mean Square Error (ppb)	16.1	19.9	15.7	15.5	22.9	30.1	15.8	17.2

The follow paragraph will be added to manuscript:

"To examine the effects of model resolution on surface ozone concentrations, we conducted two additional model runs. These two additional runs were set up and configured exactly the same as the 1.33 km runs; but, with just running WRF-Chem with Domains 1, 2, and 3, which means the highest resolution of model output is 4 km. The model performance at 4 km resolution was also validated against ozone observations and summarized in Table 1. As shown in Table 1, the model performed much better for the correlation coefficients, normalized mean gross errors, mean normalized bias, and normalized mean error at 1 km than those at 4 km. For the mean bias and normalized mean bias, the model performed better in southern California at 1 km than those at 4km, with similar performance in greater Phoenix. Therefore, we confidently conclude that WRF-Chem in its present configuration performed better at 1 km resolution than that at 4 km resolution based on the two events and 2005 NEI. Our results are consistent with previous studies (e.g., Taha 2008; Tie et al., 2010). In the following analysis and discussion, we mainly focus on the model output at 1km resolution."

The presentation of the contribution information could be presented more clearly if the contributions were shown as the difference between the baseline scenario and the sensitivity simulations. In Figure 5 and 6, the readers are left to interpret the contributions by visualizing the differences between the baseline and the simulations where emissions have been zeroed out. It would be also helpful if the authors clarify if the differences between the baseline simulation and the sum of the BEO, noAZ, and noCA should be only the chemical inflow into the 1.33 km domain or if that would include other sources of ozone. Spatial plots of contribution from southern California, Arizona, and the biogenics-only simulation would be very helpful in terms of understanding the amounts and gradient in contribution from these sources/areas when interpreting the results.

Figure 6 is replotted according to the Reviewer's suggestion.

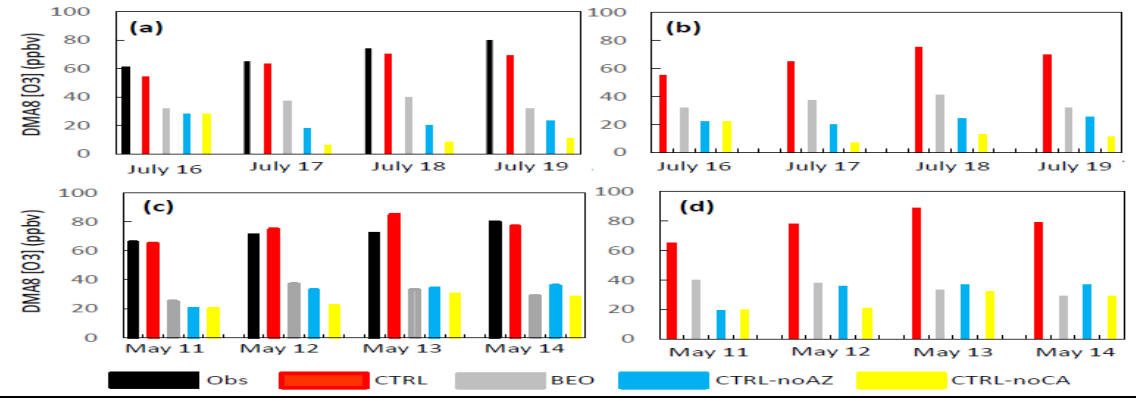

Figure 6: Mean DMA8 [O_3] in Phoenix metropolitan area from observation (Obs), simulation from CTRL runs (CTRL), BEO runs (BEO), and the relative contributions of different emission sources. CTRL-noAZ represents the modeled DMA8 [O_3] differences between CTRL run and noAZ run. CTRL-noCA displays the modeled DMA8 [O_3] differences between CTRL run and noCA run. Observation sites show in Figure 1b. (a) DMA8 [O_3] at observation sites for July 16-19, 2005, (b) the same as (a) but for that averaged from Phoenix urban grid cells. (c) and (d), the same as (a) and (b) but for the case of May 11-14, 2012.

Similar to Figure 6, the hourly ozone variations for different sites on May 14 and July 19 are also plotted as shown in Figures S4 and S5 for support materials.

A figure on DMA8 [O_3] spatial distributions for CTRL, noAZ, noCA, BEO, (CTRL-NoCA), and (CTRL-NoAZ) on July 19, 2005 is plotted and shown here. A similar figure on May 14, 2012, will be put into the supplement materials as Figure S6.

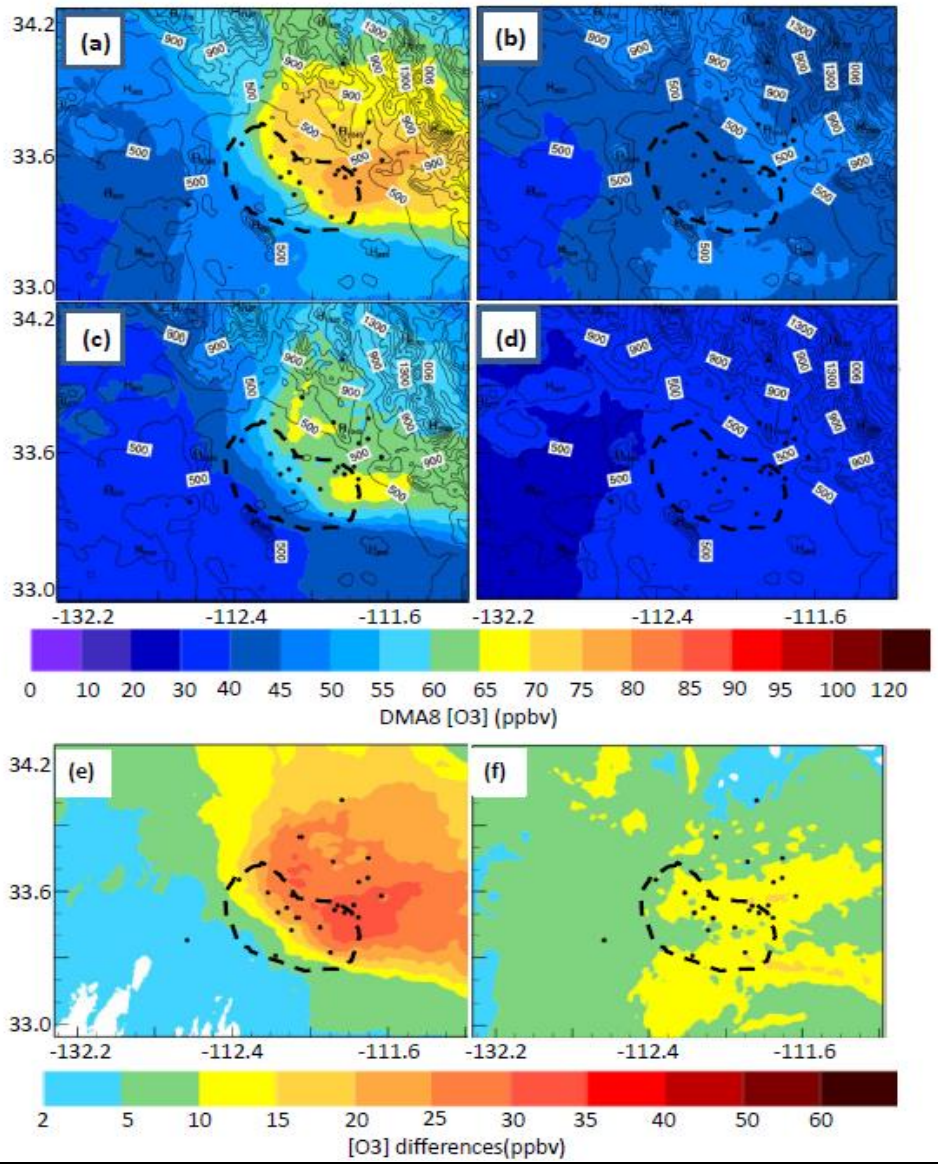

Figure 7: DMA8 [O3] spatial distributions in greater Phoenix and surround areas on July 19, 2005: (a) CTRL, (b), noAZ, (c) noCA, (d) BEO, (e) CTRL-noAZ, and (f) CTRL-noCA. Contours represent terrain elevations. Dots shows O3 observation site. Dashed-Circle indicates the approximate location of Phoenix urban area.

"This figure depicts the spatial distributions of DMA8 [O_3] for different emission scenarios on July 19, 2005. The CTRL run indicates that the higher [O_3] occur in the northeastern urban perimeter, which is

consistent with previous studies (e.g. Lee and Fernando 2013). The effects of SoCal emissions and AZ local emissions on DMA8 [O_3] are location-dependent. The case of May 14, 2012, is also examined (see Figure S6) and a similar distribution as Figure 7 is found but it differs in magnitude."

More emphasis is needed throughout the manuscript that these impacts are based on the 2005 National Emission Inventory (NEI)and emissions have changed since 2005 in both California and Arizona. Also notable emissions in these areas may be changing at different rates (e.g., more aggressive emission control programs in one place compared to the other, higher rate vehicle fleet turnover in one area compared ti the other, etc.). It would be ideal if the most recently available NEI was used to support this analysis, but in place of that the authors could strengthen the manuscript by providing a comparison of anthropogenic emissions in southern California and Phoenix that were used in this modeling assessment and the emissions for these areas from the 2011 NEI. This would be the best alternative to using newer emissions as part of the modeling since the authors correctly note(page 8270 Lines 16-22) that making emissions adjustments to the 2005 NEI such that the model estimates of o3 match observations does not provide a better estimate if episode specific emissions but compensates for other model specific formulation deficiencies. The authors should also discuss any implications of 2005 vs 2011 emissions comparison to the relative contributions of Arizona and California emissions to Phoenix ozone concentrations. If the emission comparison between 2005 and 2011 suggests that the relative influence if emission from these two regions has changed in the past 10 years, appropriate caveats should be added to the abstract and conclusion sections.

Thanks for the comments and suggestions. Lines 16-22 on Page 8270 are removed. Emission changes are discussed:

"The emission comparisons between the South Coast Air Basin, California and Maricopa County, Arizona for years 2005 (red) and 2011 for Maricopa County and 2012 for South Coast Airshed (blue). Relative to 2005, anthropogenic emissions of CO, NOx, and VOC are reduced 40-50% in 2012 in the south coast airshed, California, explaining why the [CO] and [NOx] were overestimated. However, the changes in Maricopa County are not significantly except CO from Mobile."

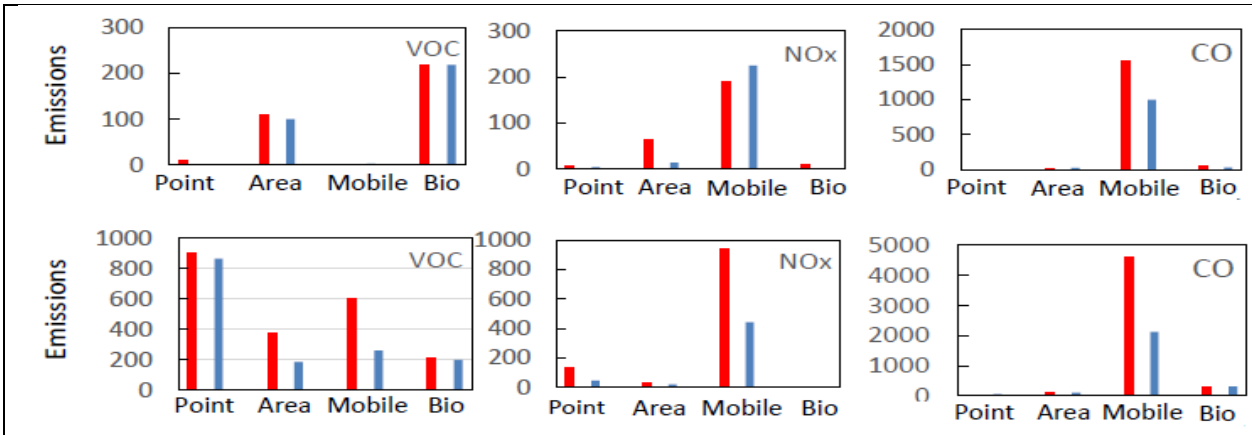

Figure S2: Emission (Ton per day) comparisons in Maricopa County (top panel), Arizona, and South Coast Airshed (bottom panel), California, between 2005 (red) and 2011(blue) for Maricopa County and 2012(blue) for South Coast Airshed. In South Coast Airshed, emissions from Mobile in 2012 are reduced significantly (40-50%), relative to 2005. The emission variations can explain why WRF-Chem overestimated the ozone precursors in the May 2012 case. In Arizona, CO emissions from mobile are reduced. NOx emissions are reduced for area sources but actually increase for mobile sources.

"South Coast emission data are downloaded from http://www.arb.ca.gov/app/emsinv/fcemssumcat2013.php.

Maricopa County emission data are downloaded from http://maricopa.gov/aq/divisions/planning_analysis/emissions_inventory/Default.aspx ."

The caveat that "the results are based on NEI 2005" is also added in the abstract and conclusion.

The U.S. Environmental Prediction Agency has published modeling guidance in 2007 (U.S. Environmental Protection Agency, 2007) and more recently at the end of 2014 (U.S. Environmental Protection Agency, 2014) that should be used place of older guidance from 1991. As noted in the 2007 and 2014 modeling guidance documents U.S. EPA has no criteria for "acceptable" model performance (U.S. Environmental Protection Agency, 2007, 2014). The Agency recommends comparing model performance results (performance metrics such as bias, error) to those estimated in other similar contemporary model applications. The authors note quite a few relevant modeling studies done for the southwest U.S, in the introduction section so the most relevant model performance would be to compare the results here to those studies where possible. Additionally, in the absence of the relevant contemporary studies, model performance results here could be compared to recent review paper (Simon et al, 2012) that compiled model performance statistics for regional and local scale O3 and PM2.5 photochemical model simulations.

Thank you for the comments.

"Table 1 presents the statistics of comparisons of surface ozone concentrations between the model and observations in southern California (total 46 sites) and greater Phoenix area (total 24 sites), respectively. These statistics shown in Table 1 are widely used in evaluating model performance (Simon et al., 2012). Our statistics are comparable with those from previous studies in the two regions. For example, in southern California, the mean biases, RSME and correlation coefficients shown in Table 1 are comparable with those from Huang et al.(2013, their Table 3) and Chen et al. (2013, their Tables 2 and 3). Furthermore, the mean normalized bias and mean normalized gross error are comparable with those from Taha (2008, in his Table 2). In greater Phoenix, these statistics are generally comparable with those from Lee et al. (2007), and Li et al. (2014)."

Since the goal of these simulation is to assess interstate transport from California to Arizona and that could take several days, the episodes seems rather short especially when combined with exclusion of only a single day at the beginning of the episode for spin-up. Are these periods of elevated ozone only for a single day or would it be possible to relax some of the episode criteria and include more days in the analysis?

A: In the manuscript, most of the figures (such as Figures 2, 3, 4, 5, 6, 7, 8, 10 and 11), analysis, and discussion are based on multiple days or multi-day means. In Figures 9, 12 and 13, which show specific time periods in a single day, we mainly want to show the transport of the front , because, compared with other days, this day has an especially clear frontal movement.

Some additional information regarding the methodology would be useful. Was the analysis nudging used for any of the domains in WRF? If so, which domains and which variables where nudged (above and below PBL?). What us the vertical grid structure used in the analysis? Was the MOZART simulation for 2005 or some other year?

The relevant information will be added in the text.

"In addition, analysis nudging is applied for the meteorological fields (U, V, T, GPH, and Q) above the PBL in the outer most domain for the first 24 hours."

"The vertical configuration of the model comprised 41 vertical layers: The lowest 15 layers are within 1500 m a.g.l. and the first half-vertical layer above ground level is 12.5 m. a.g.l."

The atmospheric chemical boundary and initial conditions are obtained from MOZART-4/GEOS-5 (http://www.acd.ucar.edu/wrf-chem/mozart.shtml) for the 2012 case and from MOZART-4/NCEPT42 for the 2005 case (Emmons et al., 2010).

I appreciate that this suggestion generally outside of the scope of this project, but since the authors made effort to model Phoenix at 1,33km grid resolution it would be interesting if some information could be presented about the urban gradients and variability in ozone on these episode days. Are local emissions features seen in the model results (e.g., large point sources, highways etc.)? Spatial plots for the metropolitan area for baseline simulation and the sensitivity simulations showing contribution from southern California and Arizona could be of interest.

A spatial distribution plot for July 19, 2005, has been plotted as shown in the second figure in this response) and the other plot for May 14, 2012, Figure S6) is put into supportive materials. Due to diffusion, dispersion, and advection, the plots still cannot resolve these local emission features, even at 1.33 km resolution, partly because our 1.33-km grids with their emissions had to be interpolated from the 4 km NEI-2005.

The ozone gradients and variability at the metropolitan scale can be clearly seen (the second Figure of this response, and Figure S6).

Figure 1. The lower panel is nicely presented. However, the political boundaries are hard to make out.

Thank you. Figure 1 is re-plotted.

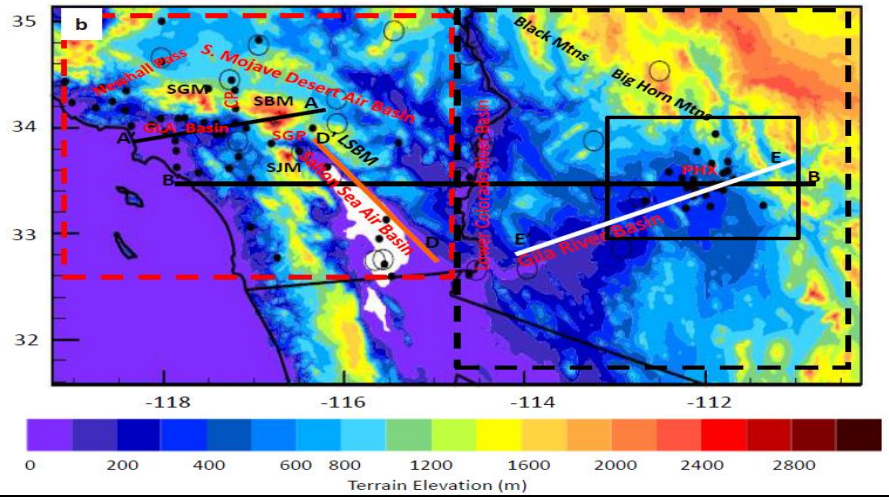

Figure 1b: Terrain elevations (m).

Figure 2-4: There is a lot of useful information presented in these time series plots. However, the information is difficult to differentiate. Perhaps using different line types (dashed etc) could help make these easier to interpret or presenting the information as a time series of blox plots.

Figure 2, 3, and 4 are re-plotted. The data are hourly data and make it hard to plot a extremely clear time series.

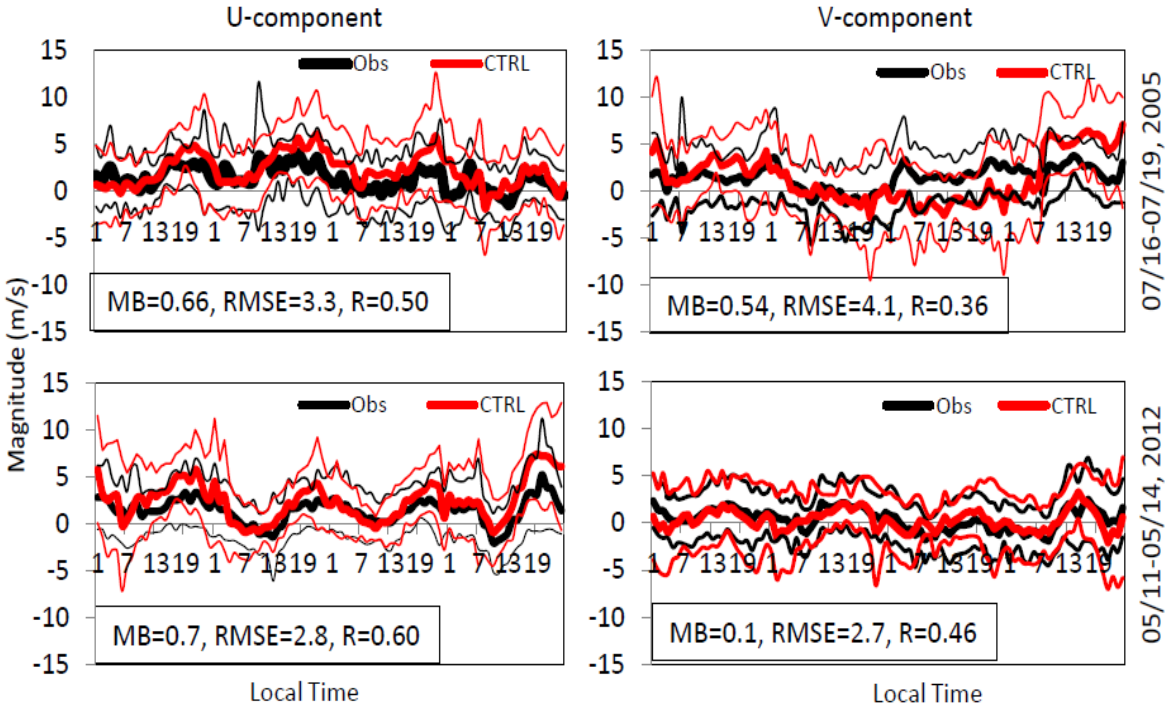

Figure 2: Surface wind comparisons between simulations (bold-red) and observations (bold black). There are totally 20 sites, including those in CA and AZ with locations shown in Figure 1b as circles. The variation ranges of simulation and observation are correspondently labeled by thin-red-line and thin-black-line, respectively. Mean Biases (MB), RMSE and correlation coefficient (R) are labeled also. CTRL represents WRF-Chem control run.

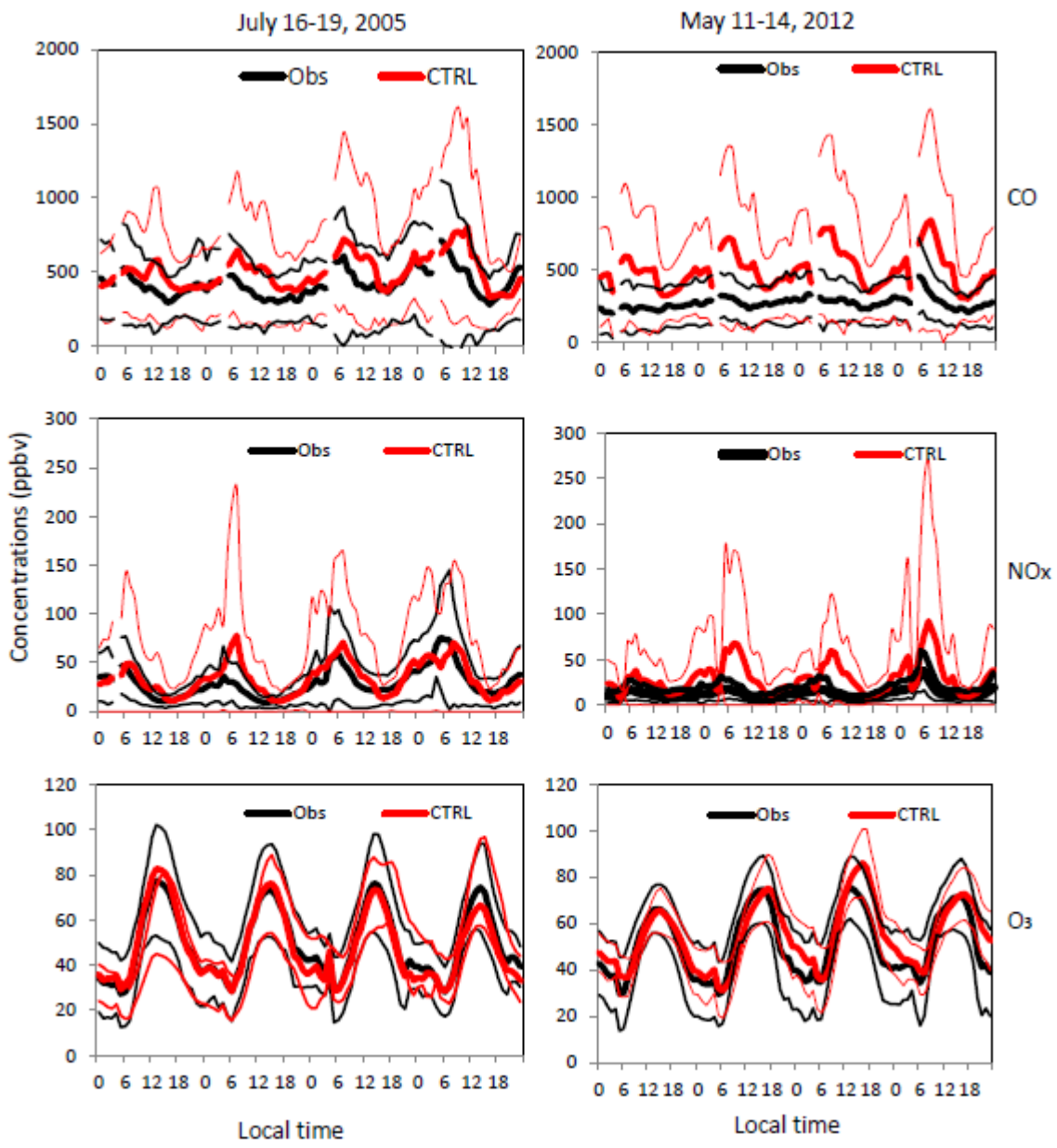

Figure 3: The comparisons of CO, NOx, and O_3 concentrations between observations (bold black) and simulations (bold red) in Domain 4. There are 23 sites for NOx, 20 sites for CO, and 65 sites for O_3 observations during the study time periods. The locations are shown in Figure 1b. The variation ranges of simulation and observation are correspondently labeled by thin-red-line and thin-black-line, respectively. Missing observation time (4:00 local time) is masked in the figure. CTRL represents WRF-Chem control run.

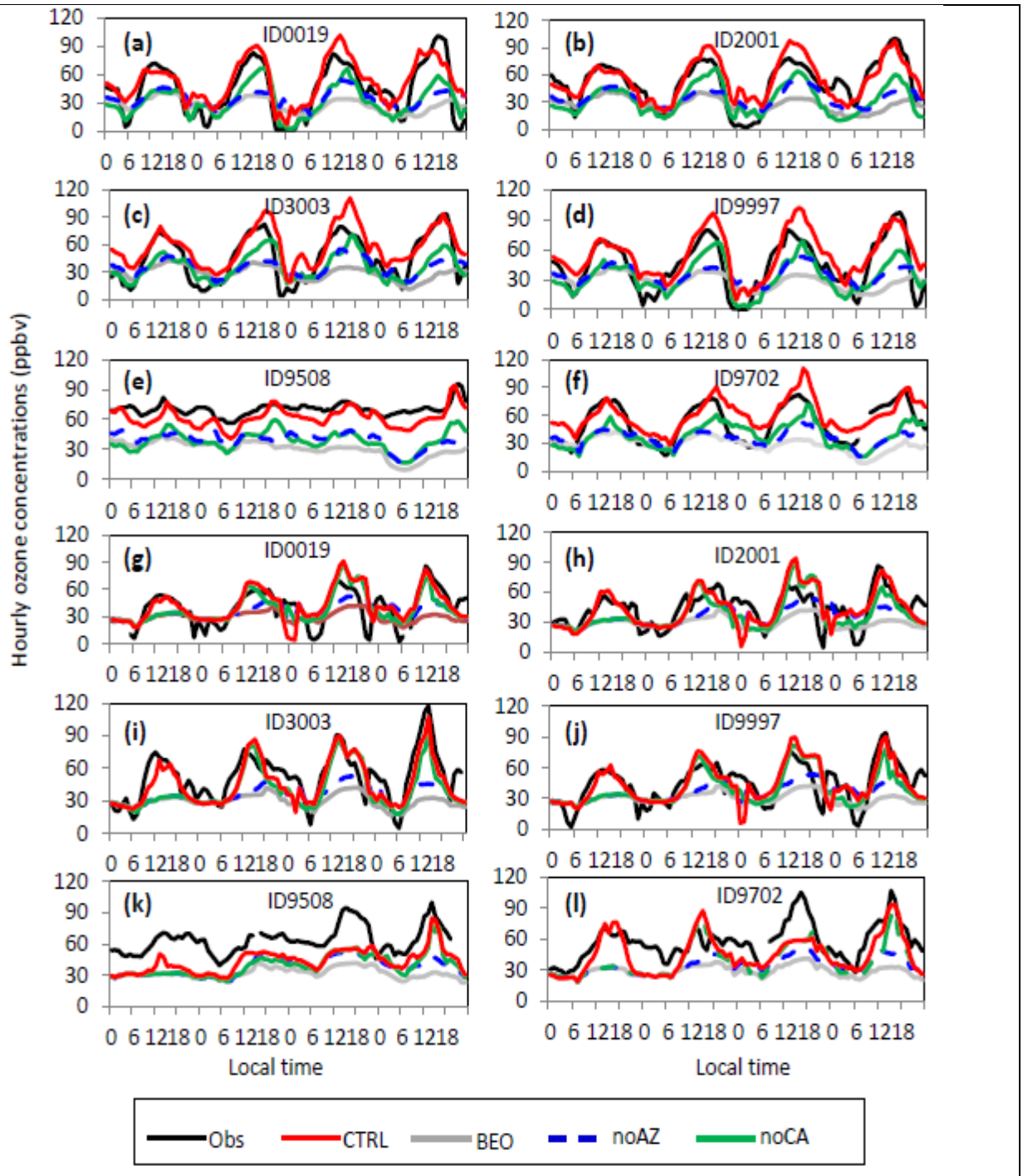

Figure 4: Relative contributions of different emission scenarios to [O_3] at observation sites in Phoenix metropolitan area and surrounding rural areas. The dates are May 11-14, 2012 (Figure 4a-4f) and July 16-19, 2005(Figures 4g-4l). Idxxxx corresponds to the EPA AIRS site number in Maricopa County, Arizona. Black line indicates the [O_3] observation. Red line represents the simulated [O_3] for the CTRL run. Dashed-blue line shows the [O_3] for the noAZ run. Green line displays the [O_3] for the noCA run. Gray line is the [O_3] for the BEO run.

Figure 6. This may be easier for those less familiar with the material to interpret if there were only 3 sets of bars: observation, baseline (control) total, and then a stacked bar showing the contributions from BEO, noAZ, and noCA in different color.

Figure 6 is replotted in response to reviewer.

Due to non-linear interactions among chemistry, emissions, physics and dynamics and/or due to the uncertainties of the emissions and models themselves (Kwok et al., 2014). The stacked bars wouldn't work because the differences are not additive.

Figures 7, 8, 9, 11, and 12: These are really nice Figures. On some of them, the political boundaries are a little hard to see. It would be really interesting to see comparable Figures with the 4 km and maybe the 12 km simulations to see how the lack of orographic resolution impacts these features (could be put in supporting information to avoid large re-writes to the manuscript).

The spatial figures are replotted (Figure 9) and the political boundaries are much clearer now. Relevant 4-km resolution plots are analyzed and some examples are shown here (details on Figure S7, S8, S9, S10, and S11 will be shown as supportive materials).

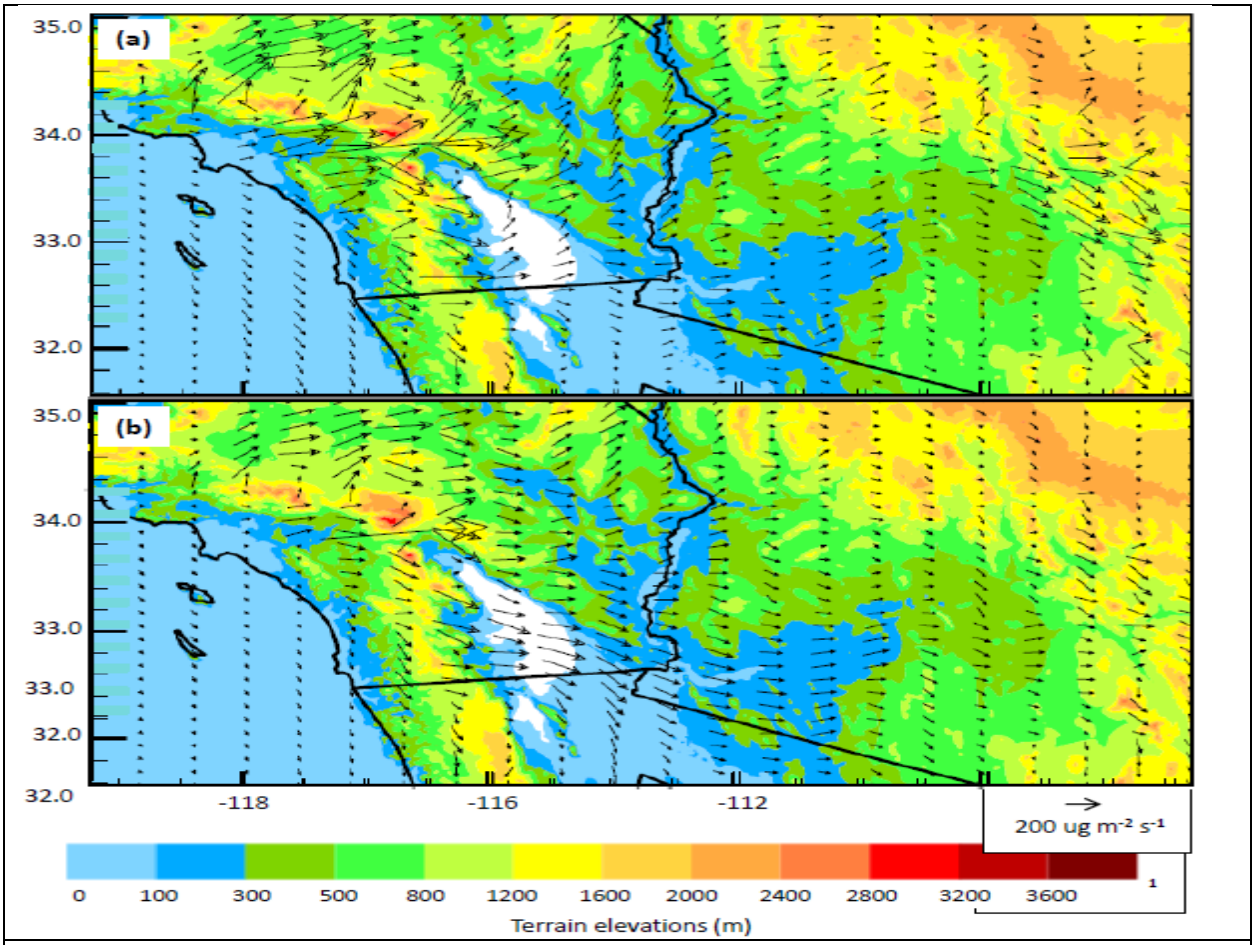

Figure 9: Integrated fluxes of ozone differences (CTRL-noCA) from surface to 1400 m above ground-level: (a) average from 18Z to 02Z, July 16 to July 20, 2005, and (b) average from 03Z to 17Z, July 16 to July 20, 2005

Figure 12 and Figure 13 are the same.

Thank you and now corrected (now Figure 13).

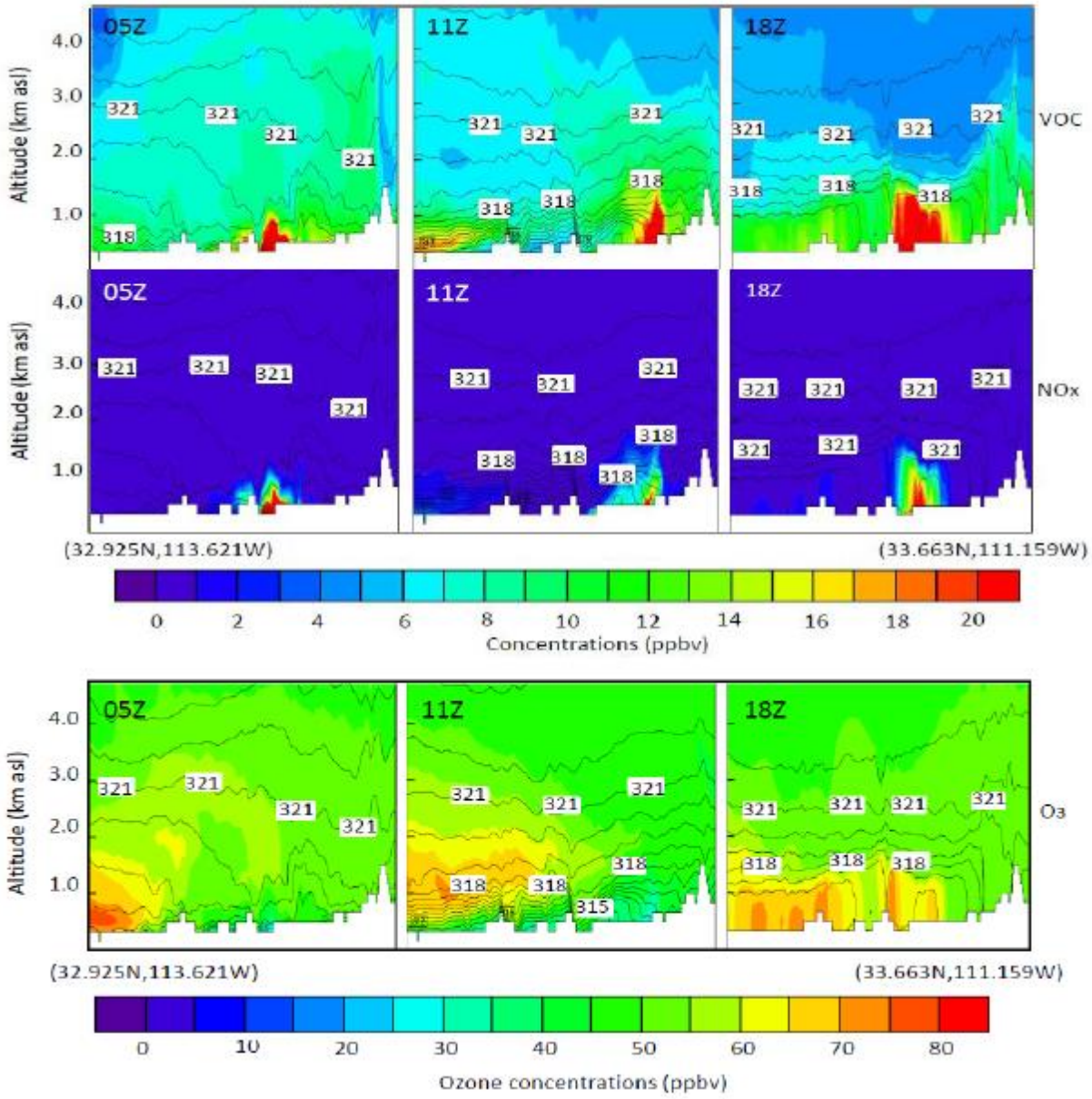

Figure 13: The vertical distribution of VOC (top), NOx (middle), and O_3 (bottom) along the cross-section D'D (shown in Figure 1b) in Gila River Basin, Arizona at 05Z, 11Z, and 18Z, July 18, 2005. Contours are potential temperature with 1-K interval.

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Supportive Materials

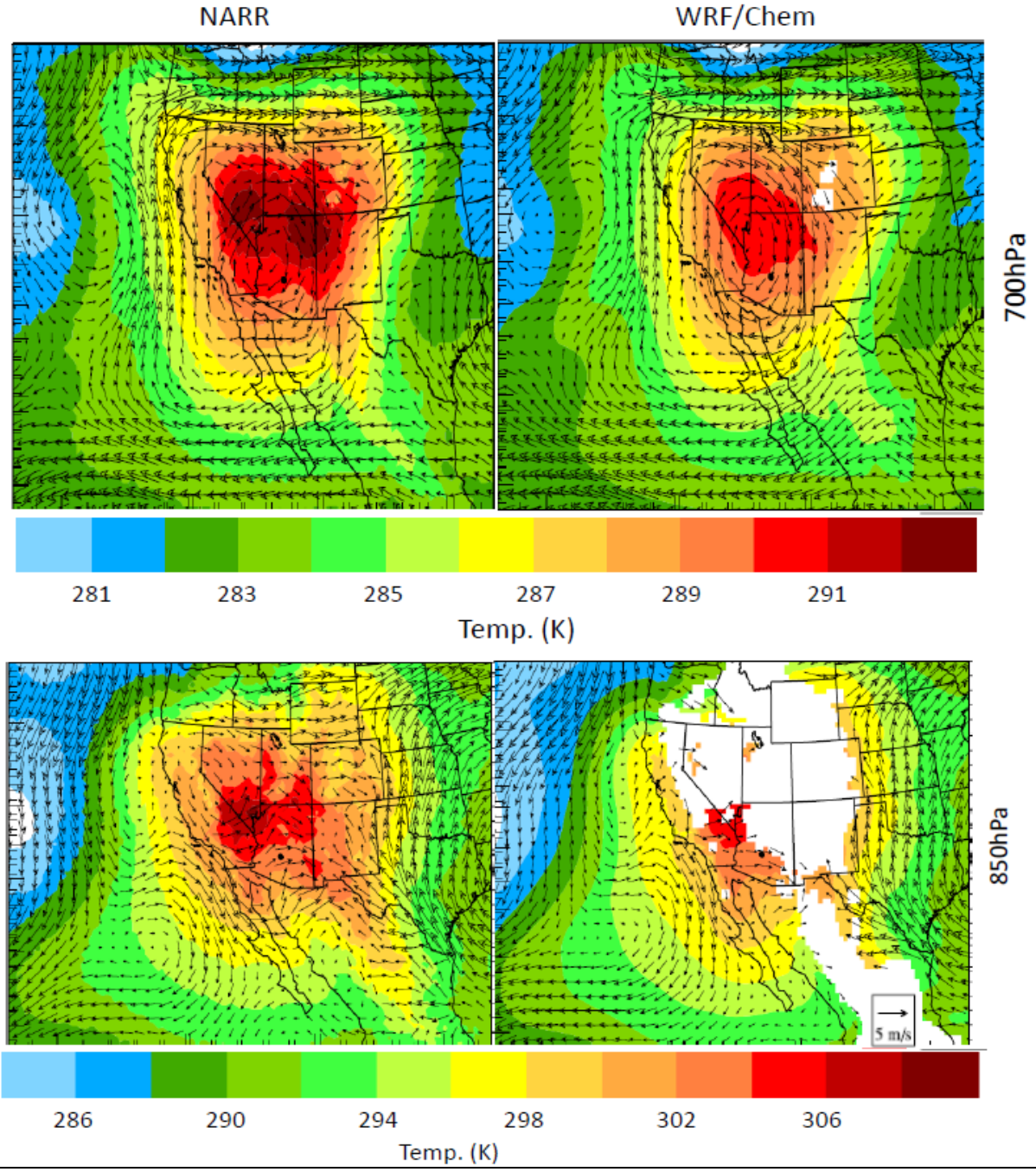

Figure S1: Averaged wind and temperature comparisons at 700 hPa and 850 hPa between WRF-Chem simulations and NARR data. The data are averaged from 16-19, July 2005. The masked areas in right column are the locations where terrain elevations are higher than the heights of 850 hPa (lower right) and 700 hPa (upper right). WRF-Chem simulations match the wind and temperature patterns of NARR data in general. In addition, at 850 hPa, there are westerly winds between southern California and Central Arizona in both sources.

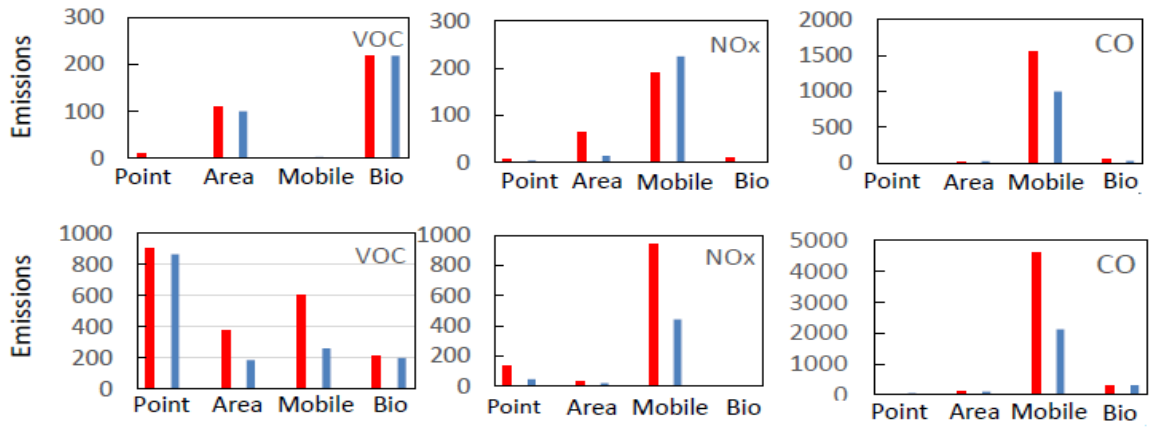

Figure S2: Emission (Ton per day) comparisons in Maricopa County (top panel), Arizona, and South Coast Airshed (bottom panel), California, between 2005 (red), and 2011(blue) for Maricopa and 2012 for South Coast. In South Coast Airshed, emissions from Mobile in 2012 are reduced significantly (40-50%), relative to 2005. The emission variations can explain the reasons of WRF-Chem overestimated the ozone precursors in May 2012 case. In Arizona, CO emissions from mobile are reduced. NOx emissions are reduced from Area but increased from Mobile.

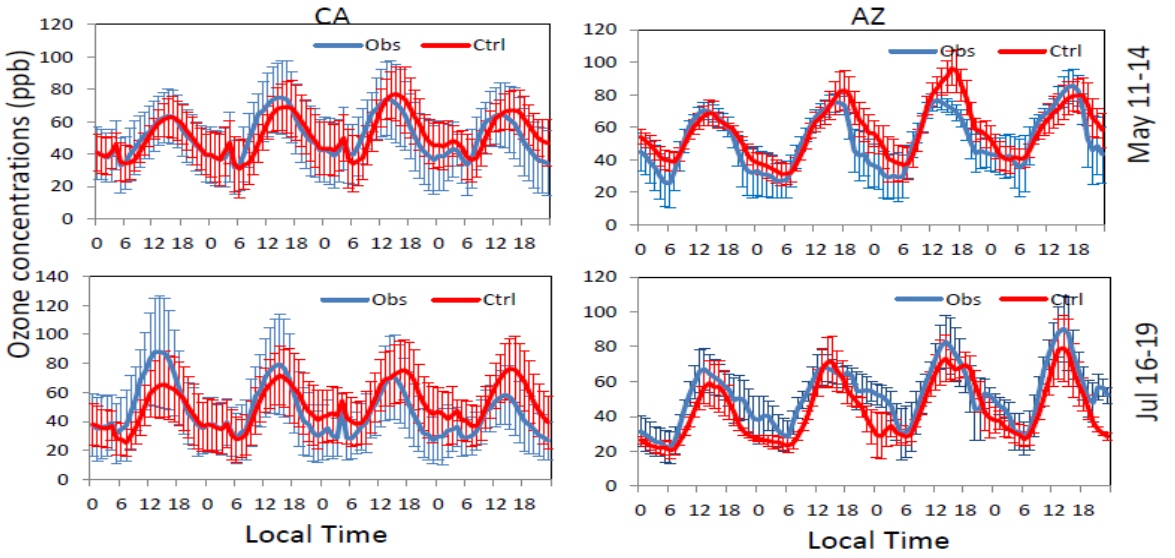

Figure S3: Ground-level ozone concentration comparisons between observations (blue) and simulations (red) in southern California and greater Phoenix, Arizona. The observation sites are labeled in Figure 1b (solid dots). There are about 46 sites for ozone observation in southern California and 24 sites in Greater Phoenix. Ctrl represent WRF-Chem CTRL run.

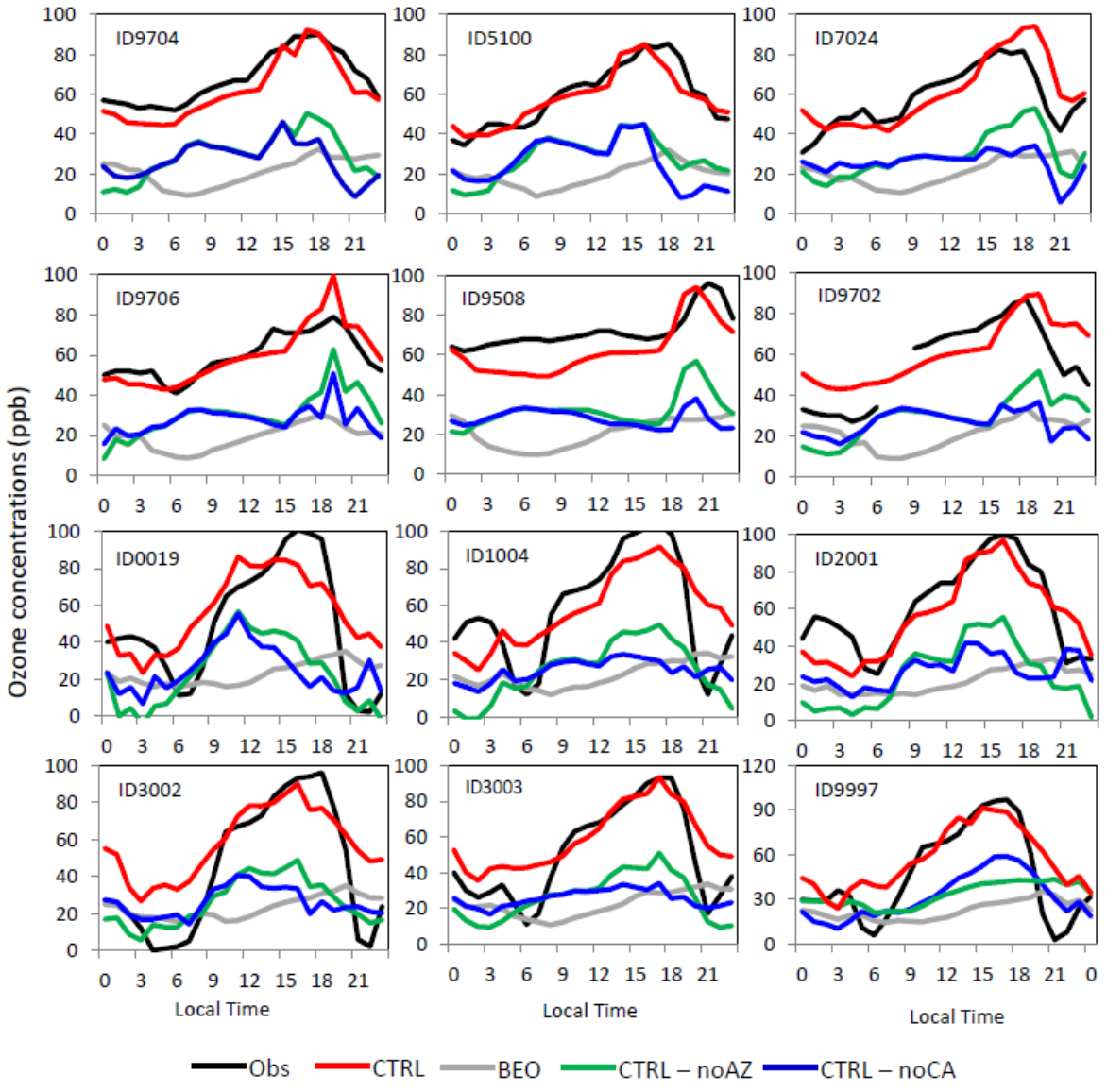

Figure S4: Relative contributions of different emission sources to ozone concentrations ([O_3]) at observation sites in Phoenix metropolitan area and surround rural. The date shown in the figure is May 14, 2012. Idxxxx indicates the site EPA AIRS number. The county number is 013, and state number is 04. In Figure, black line indicates the ozone observation. Red line represents the simulated ozone concentrations from CTRL run. Green line shows the [O_3] differences between CTRL run and noAZ run. Blue line displays the ozone concentration differences between CTRL run and noCA run. Gray line is the ozone concentrations from BEO run.

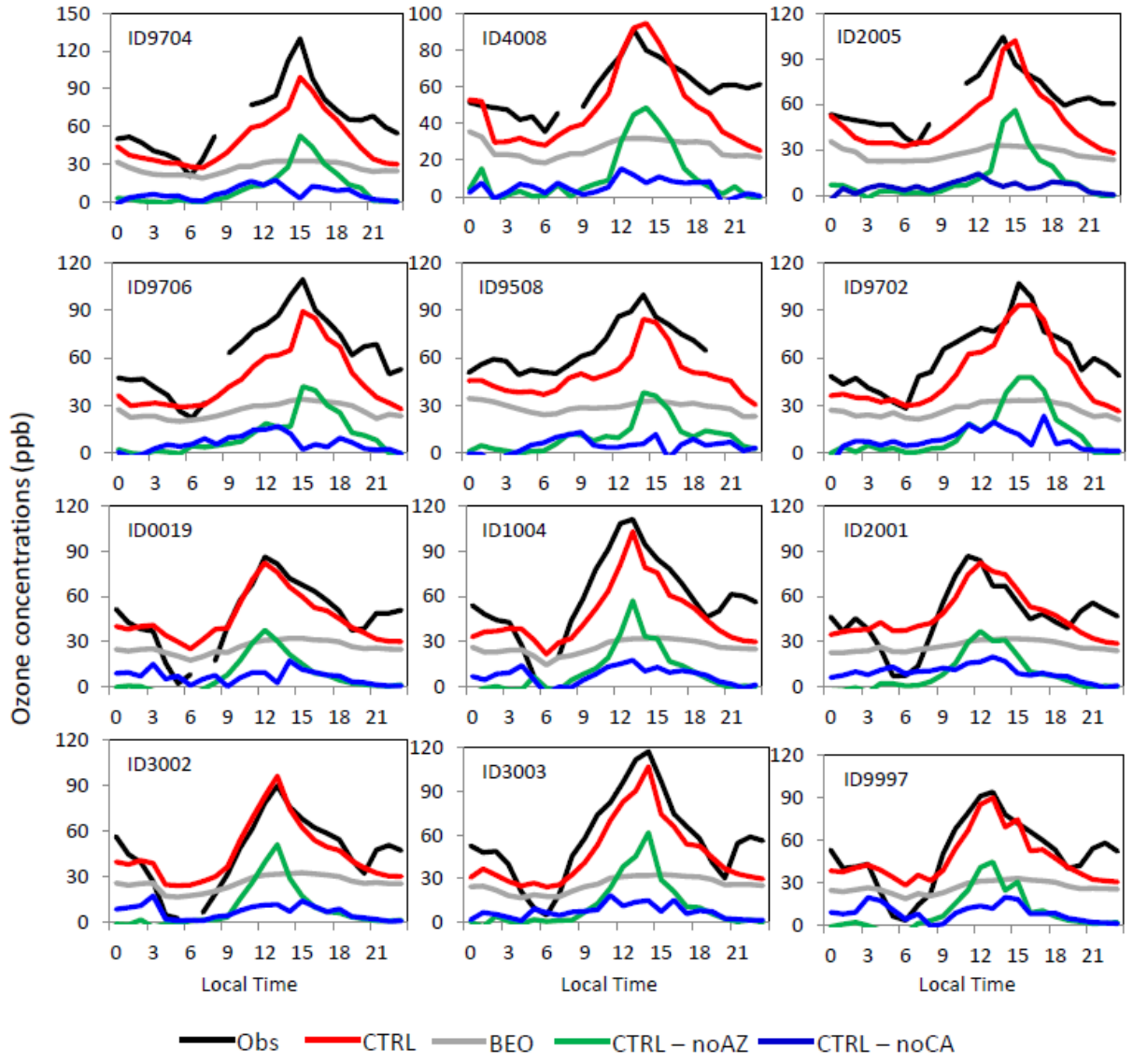

Figure S5: Relative contributions of different emissions sources to [O_3] at observation sites in Phoenix metropolitan area and surround rural. The date shown in the figure is July 19, 2005. Idxxxx indicates the site EPA AIRS number. The county number is 013, and state number is 04. In Figure, black line indicates the ozone observation. Red line represents the simulated [O_3] from CTRL run. Green line shows the ozone concentration differences between CTRL run and noAZ run. Blue line displays the ozone concentration differences between CTRL run and noCA run. Gray line is the ozone concentrations from BEO run.

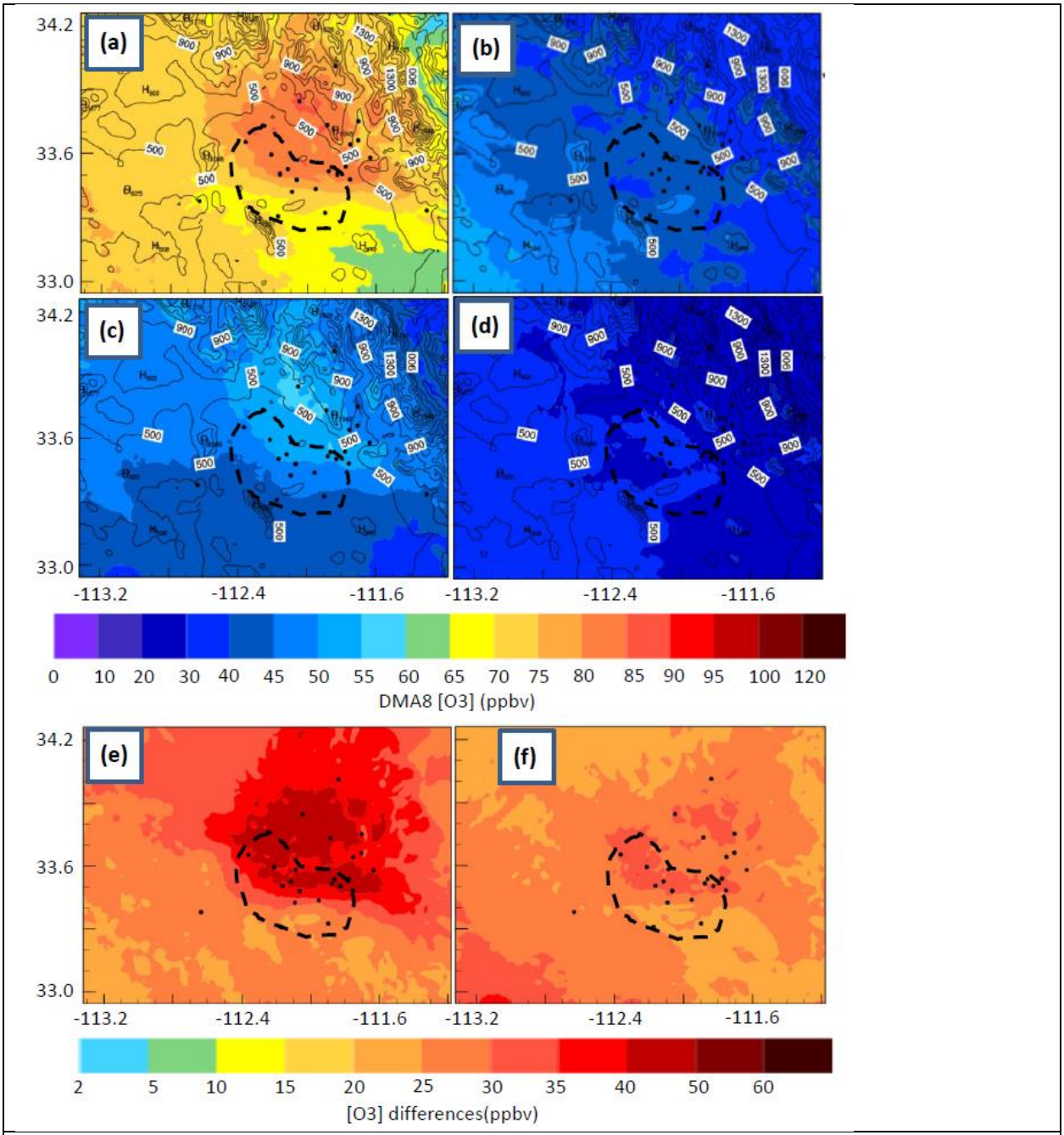

Figure S6: DMA8 [O_3] spatial distributions in greater Phoenix and surround areas on May 14, 2012: (a) CTRL, (b), noAZ, (c) noCA, (d) BEO, (e) CTRL-noAZ, and (f) CTRL-noCA. Contours represent terrain elevations. Dots shows O_3 observation site. Dashed circle indicates the approximate location of Phoenix urban area.

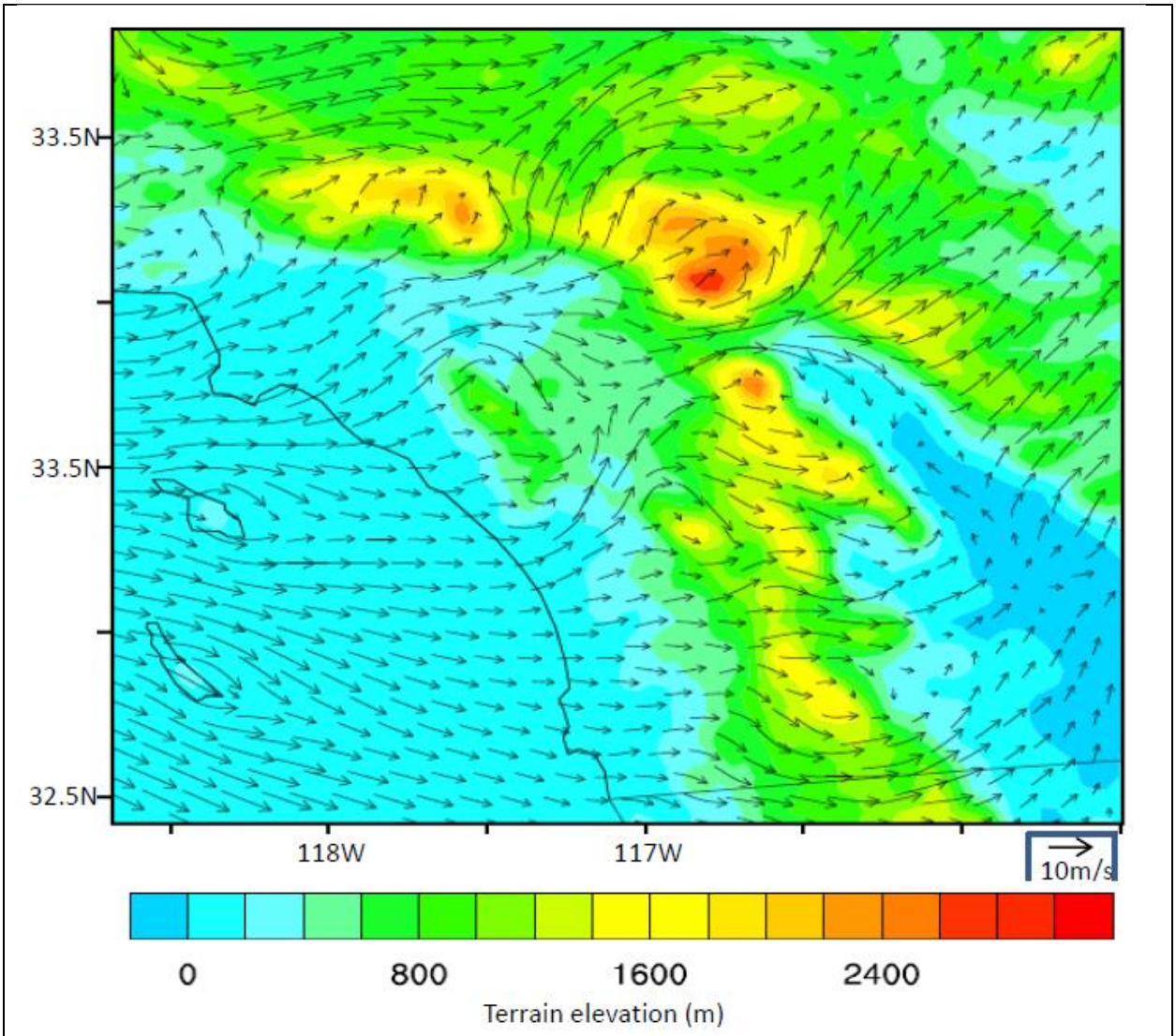

Figure S7: Day time mean of wind field vectors at 30 m a.g.l. from 4 km resolution run. Data are averaged over day time from July 16-20, 2005. There are the same patterns between Figure S7 and Figure 8 (shown in the ACPD manuscript) in general. However, there are differences in Salton Sea Airshed and Mojave Desert Airshed.

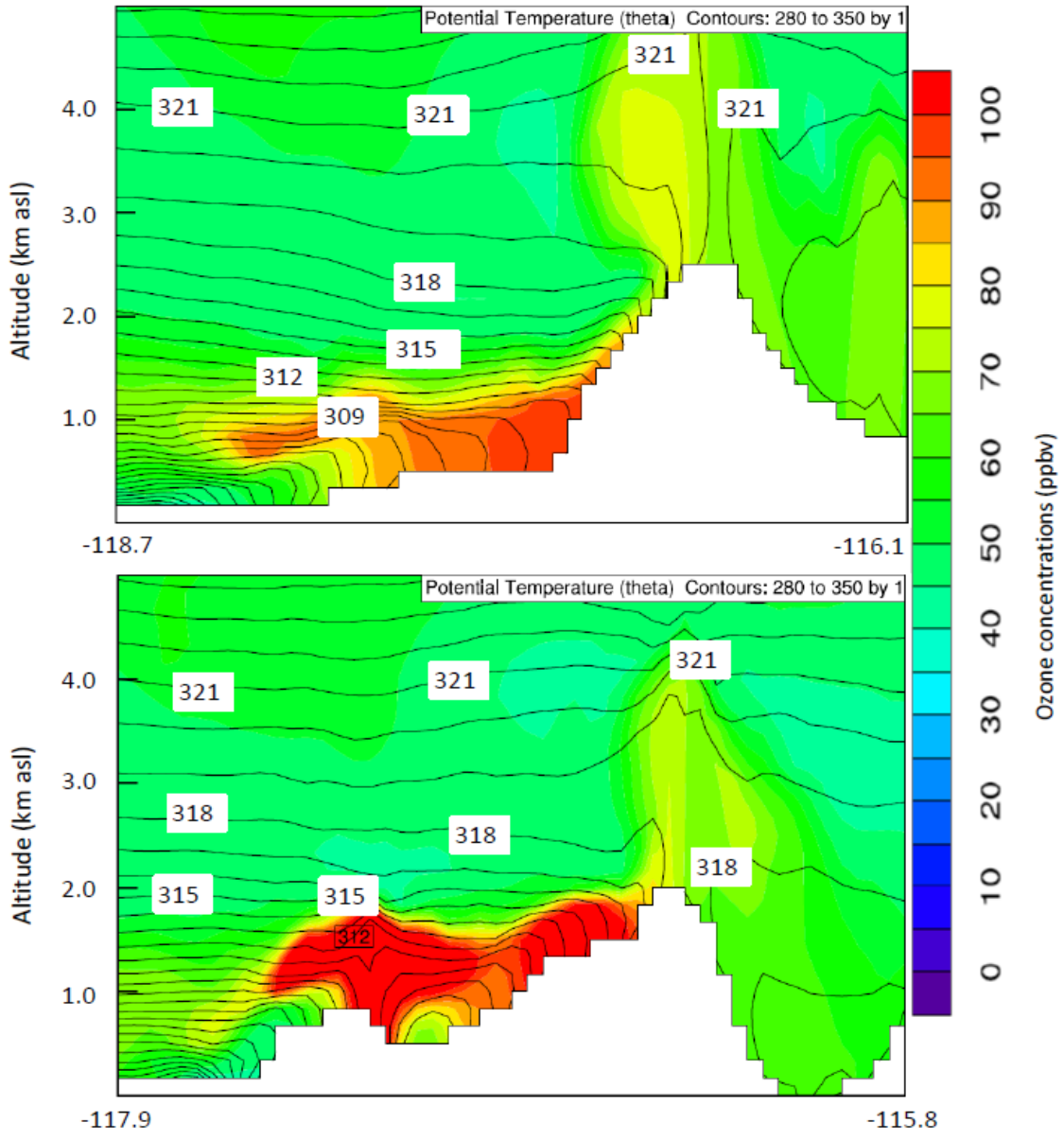

Figure S8: Vertical distributions of ozone along cross-section Lines A'A (top) and B'B (bottom) shown in Figure 1 at 22Z of July, 17, 2005. The contours are potential temperature starting at 280K with 1-K interval. Figures are plotted based on 4 km resolution run. Comparing Figure S8 with 1-km run (Figure 9 in corresponding ACPD manuscript), the Mountain Chimney Effect looks weaker at 4 km resolution than that at 1 km resolution.

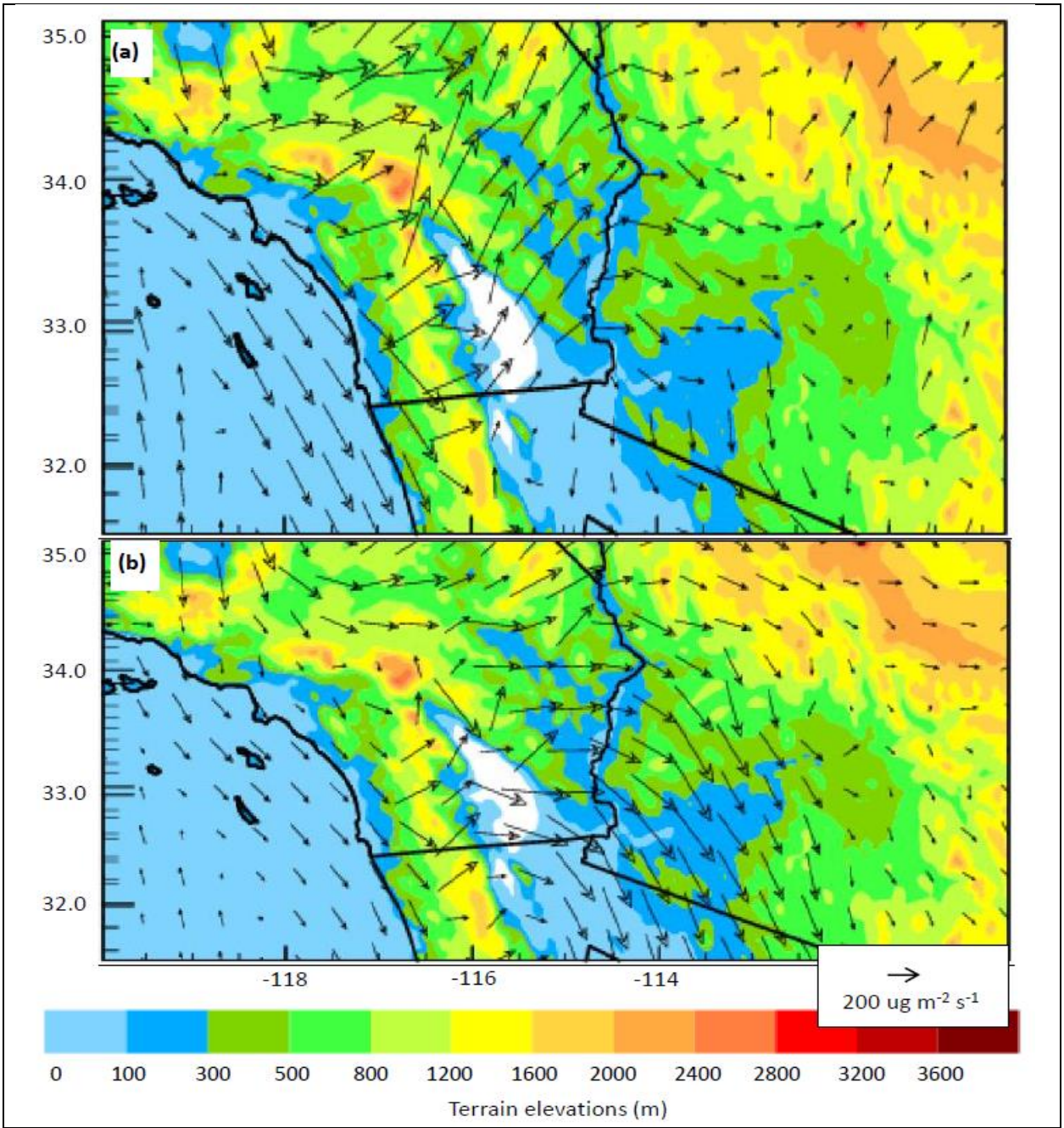

Figure S9: Integrated ozone transport flux differences (CTRL-noCA) from surface to 1400 m above ground-level: (a) average from 18Z to 02Z, July 16 to July 20, 2005, and (b) average from 03Z to 17Z, July 16 to July 20, 2005. Figures are based on 4 km resolution run. Comparing Figure S9 with 1 km run (Figure 11 in the ACPD manuscript), the Pass Channel Effect is much weaker at 4 km than that at 1 km both daytime and night time. In addition, the transport patterns are slightly different between 1km results and 4 km results.

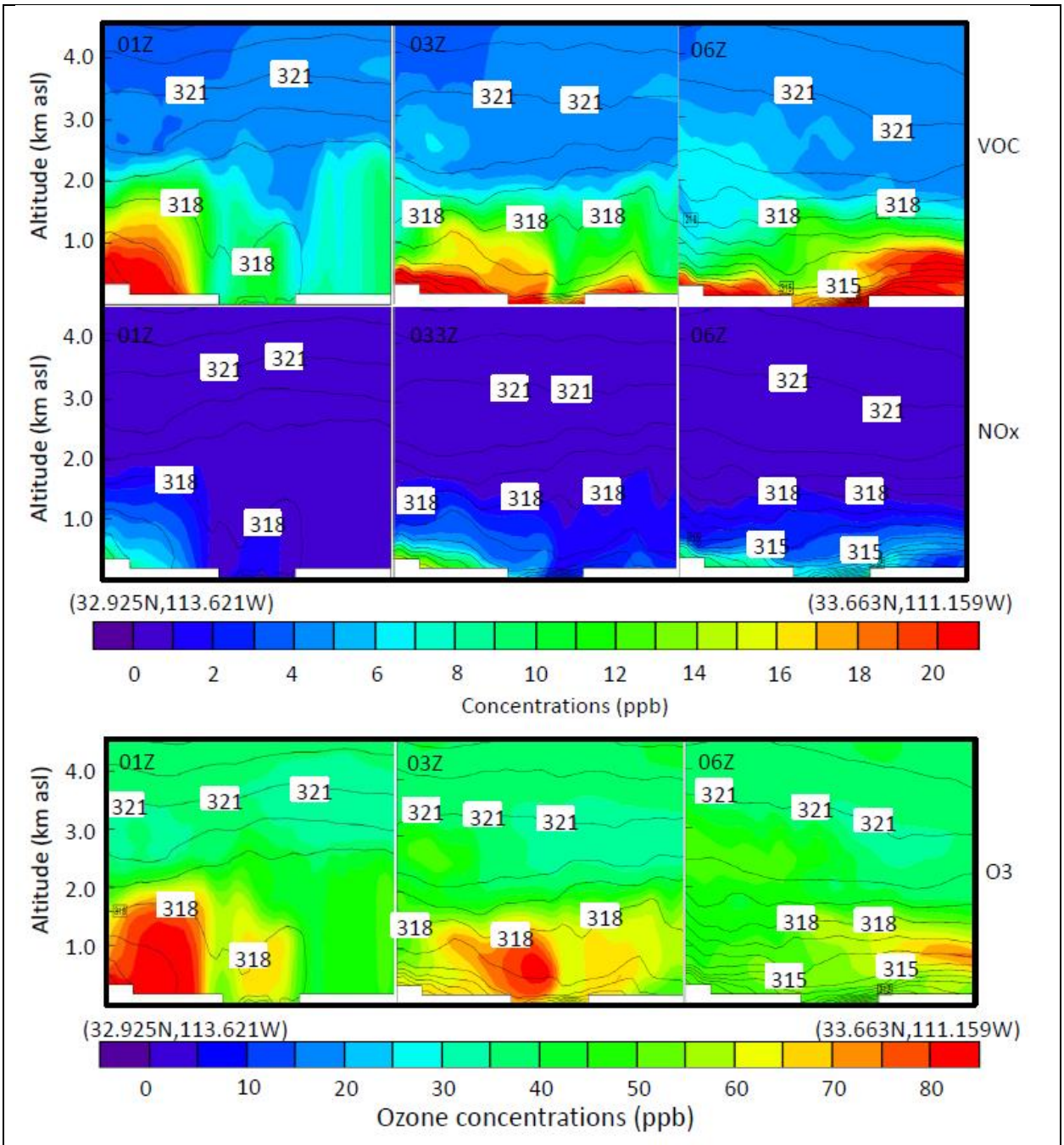

Figure S10: The vertical distribution of VOC (top), NOx (middle), and O_3 (bottom) along the cross-section D'D (shown in Figure 1) in Salton Sea Basin at 01Z, 03Z, and 06Z, July 18, 2005. Contours are potential temperature with 1-K interval. Data are from 4 km run. In comparing Figure S10 with 1 km run Figure (Figure 12 in the ACPD manuscript), the vertical distributions are over all similar but differences in detail at fine scales.

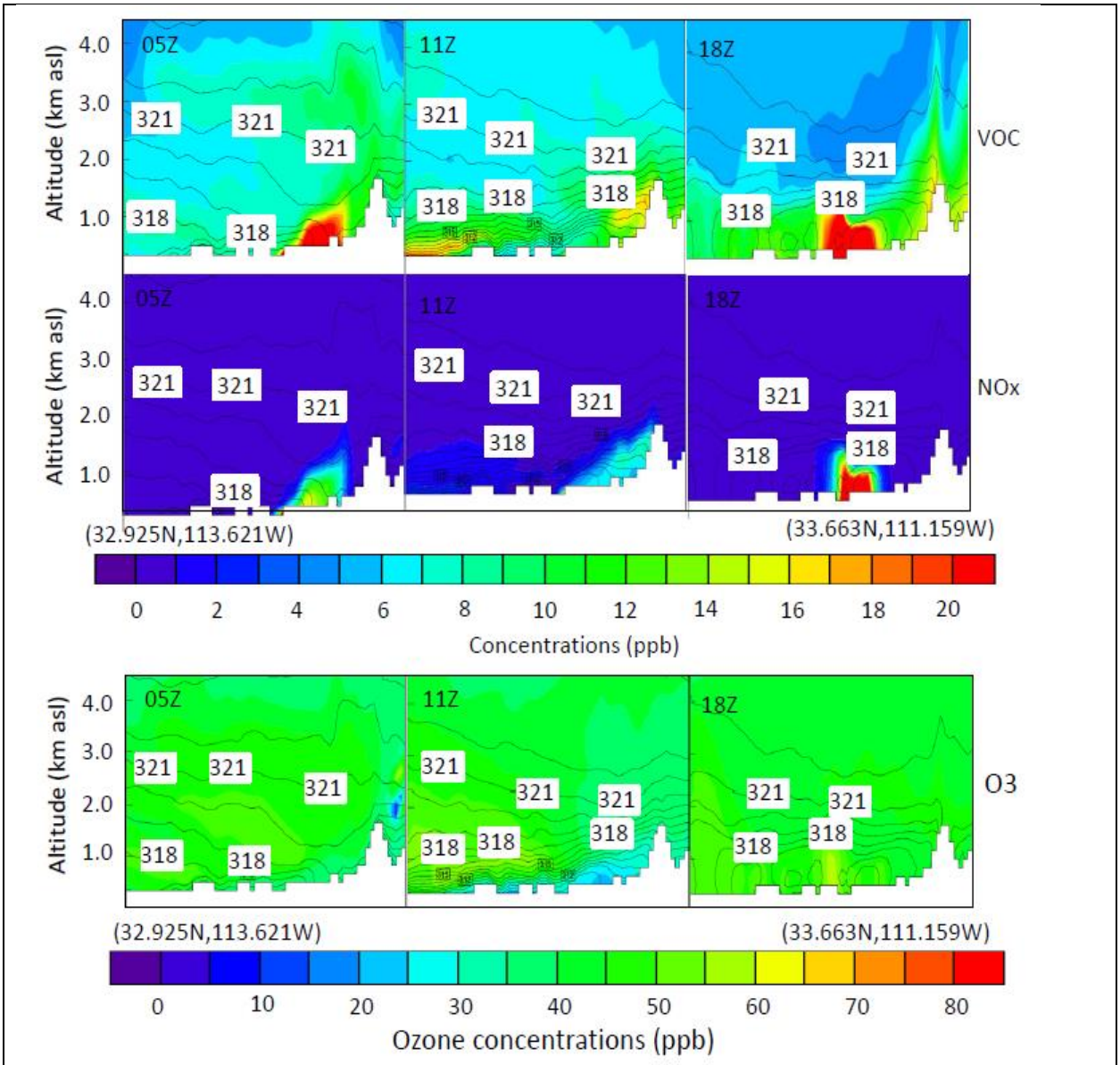

Figure S11: The vertical distribution of VOC (top), NOx (middle), and O_3 (bottom) along the cross-section D'D (shown in Figure 1) in Gila River Basin, Arizona at 05Z, 11Z, and 178Z, July 18, 2005. Contours are potential temperature with 1-K interval. Data are from 4 km resolution model run. In comparison Figure S11 with 1 km model run Figure (Figure 13 in ACPD manuscript), ozone concentration at 4 km resolution is much weak.