The paper uses a regional modeling system to simulate ozone in the vicinity of Phoenix and perform a series of sensitivity studies to determine the relative contributions of local and distance sources on ozone in Phoenix. While the tools used are not novel and the model simulates processes that have been discussed previously in the literature(e.g., mountain-chimney effect), what is different about this paper is how the model has been used to simulate the regional scale transport from California to Phoenix at high-spatial resolution encompassing this region. In this way, the effects of the complex terrain in California on the winds and transport are represented in a realistic way. The paper definitely demonstrates the importance of distant sources on local air quality. Overall, the methods used are sound and the discussion on the results is well organized, but some additional discussion is needed to clarity important missing information.

The authors appreciate the reviewer's comment and suggestions. Following is point-by-point response.

General Comments:

Although I found the model performance for the surface stations credible, there is no evolution of the model aloft. The authors presents several figures on transport aloft, but their analysis relies totally on the model. Including some observations aloft would have strengthened the author's assertions regarding transport. At a minimum, the authors should include some sort of analysis of the performance of the wind and temperature aloft. I understand there may be no data available on ozone and the other chemical species aloft for the two case studies chosen. The authors should at least discuss the fact that many, many air quality campaigns have been sampled ozone and other trace gasses aloft. It is reasonable to expect that at least some of these cases may have been suitable to study transport to Phoenix. Perhaps some discussion at the end of the manuscript could be added to state what sort of data is needed to further refine the analysis and better quantify the relative role of local and distant emission sources on concentrations in Phoenix.

Thanks for the suggestion and comments.

"The wind and temperature comparisons between WRF-Chem in Domain 1 and NARR data are examined. Generally, the simulations are consistent with NARR data in patterns and magnitudes for the two cases. More specifically, there were continuous, westerly winds between southern California and central Arizona for both NARR and simulations at 850 hPa. Figure S1 is the example of the comparison of wind and temperature at 850 hPa (bottom panel) and 700 hPa (top panel) for the average of July 16-19, 2005."

The relevant discussions for vertical distributions for trace gasses:

"In past decades, there were a few field experiments conducted to measure the vertical distributions of meteorological fields and trace gasses in southern California (e.g., the southern California Air Quality Study in 1987 [Lawson, 1990]; the southern California Ozone Study in 1997[Groes and Fujita, 2003] and CALNEX-2010[www.esrl.noaa.gov/csd/calnex/]) as well as in Phoenix area (e.g., Phoenix Air Flow Experiment II in 1998 [Fast et al. 2000; Nunnermacker et al., 2004]). Some of the events during the experiments have been used to address ozone transport (e.g., Huang et al. 2013; Langford et al., 2010) from the southern California coast. No aloft measurements could be found for May 2010 that would be of help in the present model performance evaluation. In addition, satellite-retrieved data may also be used to demonstrate the vertical distributions and even distant transport (e.g., Huang et al., 2013), although these data exhibit limitations for air quality studies such as coarse-resolution, accuracy, etc. (e.g., Bowman, 2013). To quantitatively examine the transport and vertical distribution from

southern California coasts to Phoenix, field observations, especially measurements aloft, along the inland California desert region and within western Arizona are needed."

Another area that needs additions discussion is the general meteorological conditions during the two cases and whether they are common or not. I assume that both of these periods are mostly sunny conditions? If this was for some other location, clouds would likely affect photochemistry at least somewhere in the domain. It is possible that there are mostly clear skies in the cases. Normally some sort of evaluation of cloudiness is needed as well in the simulation because of its affect on photochemistry.

Thanks for pointing this out.

"For both events, the synoptic weather in southern California and south-central Arizona was nearly calm, clear, and sunny with light westerly winds within the lower troposphere for the time periods discussed in this manuscript, based on NARR 3-hourly data. In addition, these two events represent pre-monsoon season and monsoon season, respectively, two typical climate circulations (Adams and Cowrie, 1997) during the ozone season.

The model (WRF-Chem) is initialized four days prior to each episode, with the data of the first 24-hours being discarded. 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."

Specific Comments:

Page 8362, Line 5: Change "Control" to "control"

Changed.

Page 8362, Line 7: Add "US" to Environmental Protection Agency.

Added.

Page 8366, Line 9: The authors should include which version of WRF-Chem is being used.

Added in the text. WRF-Chem version 3.5.1 is used.

Page 8367: Lines 9-11: I do not think acronyms are needed for these areas are needed since they are not used that often and there is already plenty of acronyms in the text.

The acronyms are removed from the text.

Page 8369: Line 10: which observations are being referred to? Are these all the stations shown in Figure 1b? Please be specific.

Added in the text: Circles in Figure 1b.

Page 8370: Lines 3-5: The authors do not mentioned whether data assimilation is used in the present simulations or not. So, I have to assume that it is not and that NARR influences the model simulation only through initial and boundary conditions. The domain is rather large, so the model could drift over a four-day simulation period. Given that the focus of this paper is transport from California to Phoenix and much of that transport is aloft, it would be useful to have some sort of evaluation of the model performance aloft.

Thanks for the suggestion and comments.

"The model (WRF-Chem) is initialized four days prior to each episode with the data of the first 24hours discarded. 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 wind and temperature comparisons between WRF-Chem in Domain 1 and NARR data are also examined. The simulations are consistent with NARR data in patterns and magnitudes for the two cases, in general. More specifically, there were continuous, westerly winds between southern California and central Arizona for both NARR and simulations at 850 hPa. Figure S1 is the example of the comparisons of wind and temperature at 850 hPa (bottom panel) and 700 hPa (top panel) for the average of July 16-19, 2005."

Page 8370: Line 6: As with Table 1, I would find 2 figures more useful. One showing the results for southern California and the other for those around Phoenix. The point of this paper is showing contributions of pollutants from California transported to Arizona, so knowing the model performance in the sources region is critical.

Table 1 is revised based on two air sheds separately.

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

A figure for ozone concentration variation in south California and greater Phoenix is added as figure S3.

"Figure S3 shows [O_3] time series separately for southern California and greater Phoenix, corresponding statistics are shown in Table 1. In checking Figure 3, and Figures S2 and S3, although the NEI-2005 over-estimated CO and NOx emissions in 2012 in the south coast airshed, California, causing [NOx] and [CO] to be over-estimated as well, the ozone simulations nonetheless appear to be quite acceptable. One explanation could be that this airshed is categorized as a VOC-limited ozone environment. Under this condition, ozone concentrations are restrained by VOC concentrations. In other words, reducing NOx fails to reduce ozone concentrations (e.g.,Taha et al., 1998) and the same is also found in Phoenix area(Fast et al., 2000, Lee and Fernando, 2013), which can partly explain why the modeled [O_3] matched the

observations, even though the modeled [NOx] and [CO] are highly overestimated in the May case."

Page 8370, Line 16-22: I understand the authors are trying to note the NEI05 emissions for their May 2012 case will be problematic, I find the justification about the reductions used in other studies is pointless since they do not try to adjust the emissions anyway. Those studies may use different reductions but none of them are likely be "corrected" since the model is not a prefect representation of real conditions. What they are simply doing is adjusting the emissions to best fit the model to observation.

Line 16-22 are removed from the text. Instead, emission changes are discussed and a figure (Figure S2) is added:

"Figure S2 shows the emissions between the South Coast Air Basin, California and Maricopa County, Arizona for 2005 and 2011 for Maricopa County and 2012 for South Coast airshed. Relative to 2005, anthropogenic emissions of CO, NOx, and VOC are reduced about 40-50% in 2012 in the south coast airshed, California. Therefore, the NEI 2005 over-estimates [CO] and [NOx]."

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

Page 8371, Line 2: The authors need to state how many stations are included in the analysis. Are these only for Phoenix or for a larger region? They should refer to Figure 1. Also, it would be useful to segregate the statistics for those around Phoenix and those in southern California.

The number of sites used has been added in the text. Table 1 and Figure S3 show the results of greater Phoenix and southern California, separately.

Page 8371, Line 14: Change "concentrations" to "ozone concentrations". The NOx and CO for the 2012 case are much higher than observed, however, So, despite errors, in precursor emissions, ozone still fails into the range of accepted EPA criteria?

Thanks for the comments.

"Figure S3 shows [O_3] time series separately for southern California and greater Phoenix, corresponding statistics are shown in Table 1. In checking Figure 3, and Figures S2 and S3, although the NEI-2005 over-estimated CO and NOx emissions in 2012 in the south coast airshed, California, causing [NOx] and [CO] to be over-estimated as well, the ozone simulations nonetheless appear to be quite acceptable. One explanation could be that this airshed is categorized as a VOC-limited ozone environment. Under this condition, ozone concentrations are restrained by VOC concentrations. In other words, reducing NOx fails to reduce ozone concentrations (e.g.,Taha et al., 1998) and the same is also found in Phoenix area(Fast et al., 2000), which can partly explain why the modeled [O_3] matched the observations, even though the modeled [NOx] and [CO] are highly overestimated in the May case."

Page 8373, Lines 24-26: I am not convinced of this statement. This simulation includes ozone from the boundary condition that varies in time as well. So the authors have not separate out just the biogenic contribution. There is some diurnal variability seen in the time series that does suggest a biogenic effect, however.

These sentences are revised:

"Figure 6 demonstrates the following important results: (1) the impact of AZ emissions on DMA8 [O_3] in the Phoenix area is greater than that of the SoCal's; (2) even so, SoCal emissions increase DMA8 [O_3] in the Phoenix area by up to 30 ppbv, though this is day and case dependent; **(3) the DMA8 [O_3] from the BEO experiment are in excess of 30 ppbv, including the contributions of biogenic emissions and lateral boundary transport. Based on the diurnal variation shown in Figures 4 and 5, and Figures S4 and S5, [O_3] due to biogenic emissions could be 10-17 ppbv. In other words, the contribution of BEO emissions to Phoenix DMA8 [O_3] cannot be ignored despite the region's aridity and relative lack of dense forests. Note that all of these results are based on the US EPA 2005 National Emission Inventory."**

Page 8375, Line 6: The authors mention the height of model level 5m and 17, but do not mention what the height is for level 13.

Level 13 is about 1100 m a. g. l. and added in text.

Page 8379, Line 16: Change "EPA" to "the US EPA"

This sentence is removed from the revision version.

Figure 10: include the date of the plots.

The date is added in the caption.

Dereferences:

Adams, D., and Cowrie, A.: The North American monsoon, BAMS, 78(10), 2198-2213,1997.

Bowman, K.: Toward the next generation of air quality monitoring: Ozone, Atmos. Environ., 80, 571-583, 2013.

Cores B., and Fujita, E.: Overview of the 1997 southern California ozone study (SCOS97-NARSTO), Atmos. Environ.,37,3-26.doi:10.1016/S1352-2310(03)00379-0., 2003.

Fast J., Doran J., and Shaw W.: The evolution of the boundary layer and its effect on air chemistry in the Phoenix area, J. Geophys. Res., 105(D18), 22833-22848, 2000.

Huang, M., Bowman, K., Carmichael, G., Pierce, B., Worden, H., Lou, M., Cooper, O., Pollack, I. Ryerson, T., and Brown, S.: Impact of Southern California anthropogenic emissions on ozone pollution in the mountain states: Model analysis and observational evidence from space, J. Geophys. Res-Atmos., 118, 12784-12803, 2013.

Langford A., Senff C., Alvarez R., Banta R., and Hardesty R.: Long-range transport of ozone from the Los Angeles Bsin: A case study, *Geophys. Res. Lett*, **37**, L06807,doi:10.1029/2010GL042507, 2010.

Lawson D.: The southern California air quality study, J. Air Waste Manage. Assoc., 40,156-165, 1990.

Nunnermacker L., Weinstein-Lloyd J., Kleinman L., Daum P., Lee Y., Springston S., Klotz P., Newman L., Neuroth G., and Hyde P.: Ground-based and aircraft measurements of trace gases in Phoenix, Arizona (1998), Atmos. Environ., 38, 4941-4956, 2004.

Lee S., and Fernando H.: Dispersion of an urban photochemical plume in Phoenix metropolitan area, *Atmos. Environ*., **80,** 152-160, 2013.

Taha H., Konopacki S, and Akbari H.: Impacts of lowered urban air temperature on precursor emission and ozone air quality. J. Air Waste Manage. Assoc., 48, 860-865, 1998.

Supportive Materials

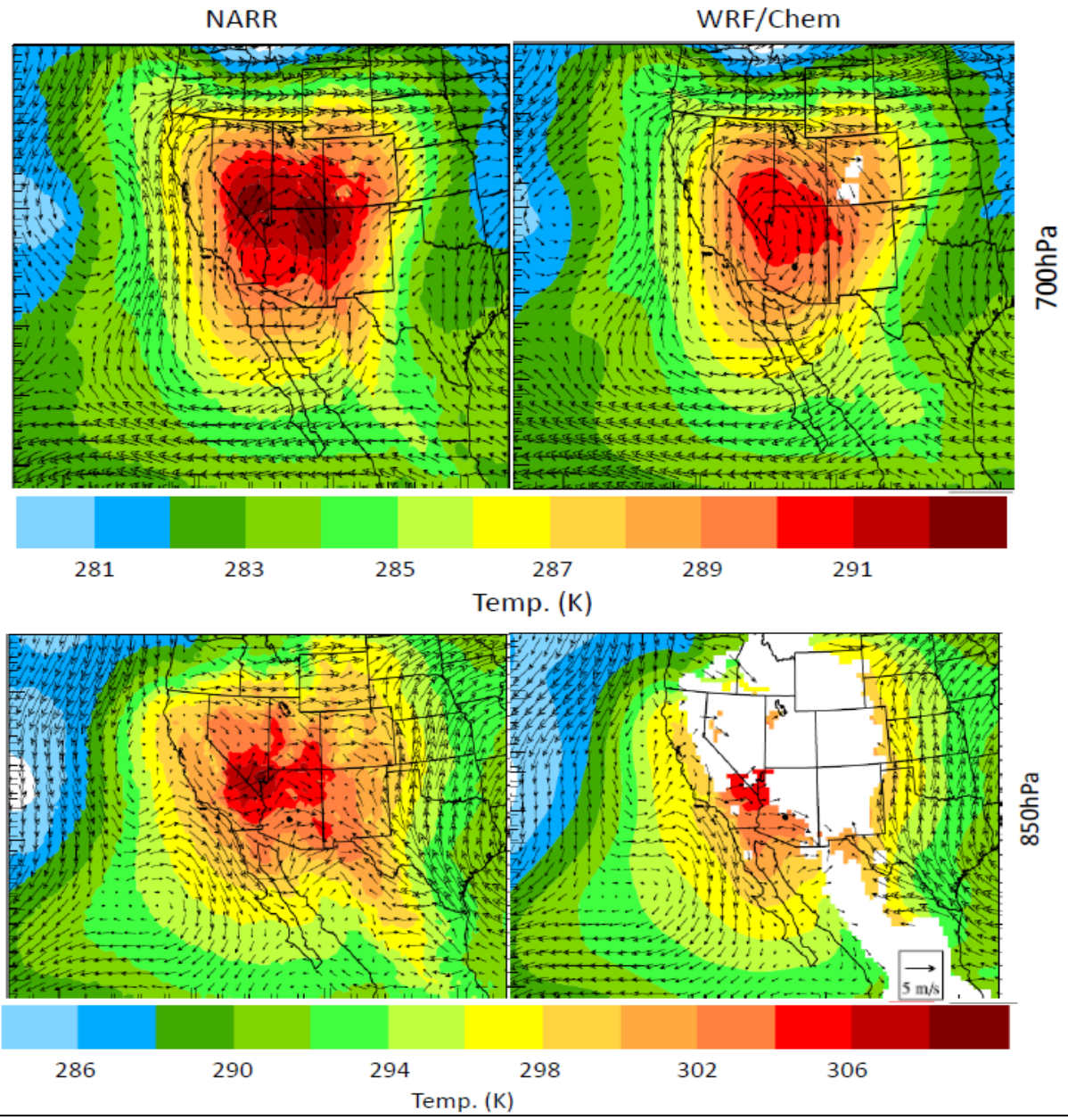

Figure S1: Averaged wind and temperature comparisons at 700 hPa and 850 hPa between WRF-Chem simulations and NARR data. The data are averaged from 16-19, July 2005. The masked areas in right column are the locations where terrain elevations are higher than the heights of 850 hPa (lower right) and 700 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.

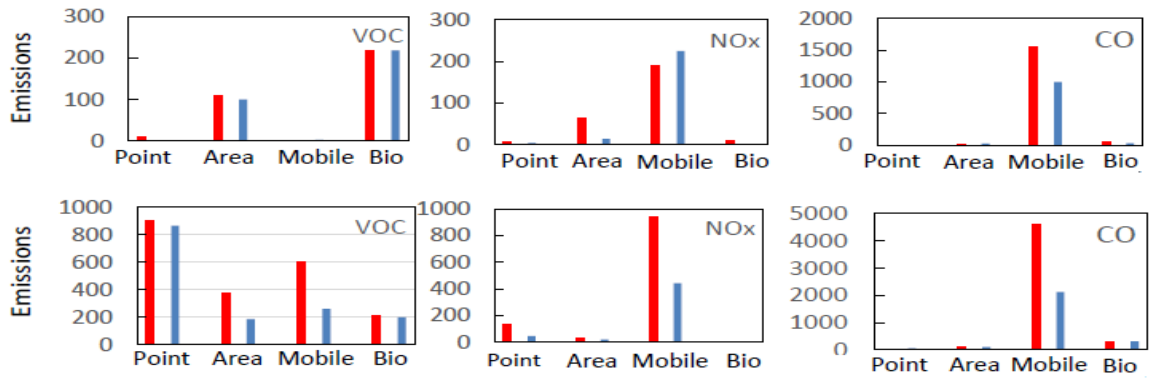

Figure S2: Emission (Ton per day) comparisons in Maricopa County (top panel), Arizona, and South Coast Airshed (bottom panel), California, between 2005 (red), and 2011(blue) for Maricopa and 2012 for South Coast. In South Coast Airshed, emissions from Mobile in 2012 are reduced significantly (40-50%), 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.

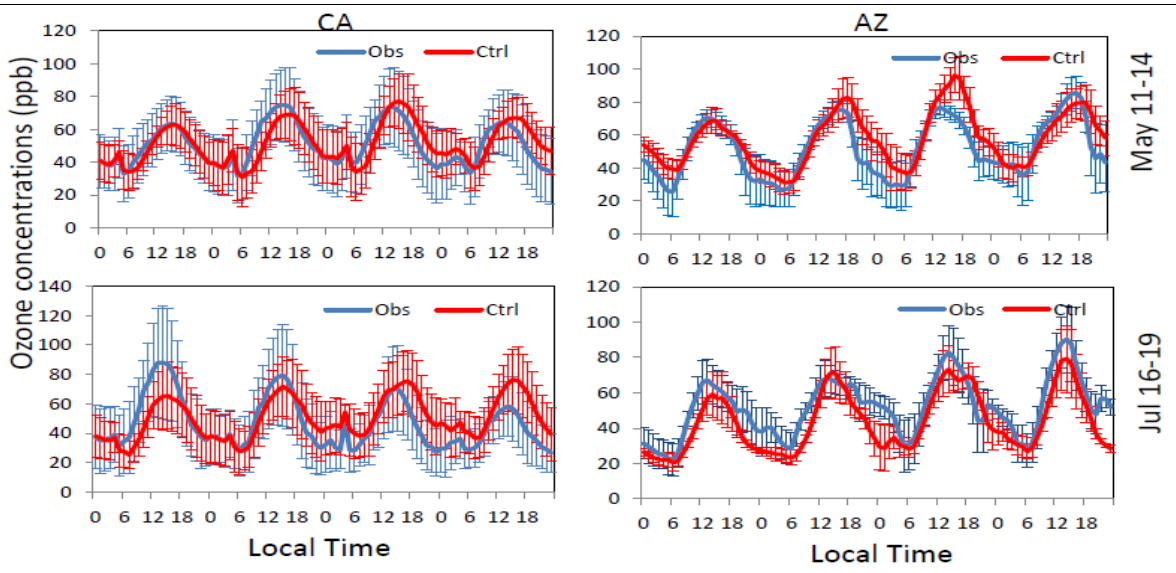

Figure S3: Ground-level ozone concentration comparisons between observations (blue) and simulations (red) in southern California and greater Phoenix, Arizona. The observation sites are labeled in Figure 1b (solid dots). There are about 46 sites for ozone observation in southern California and 24 sites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

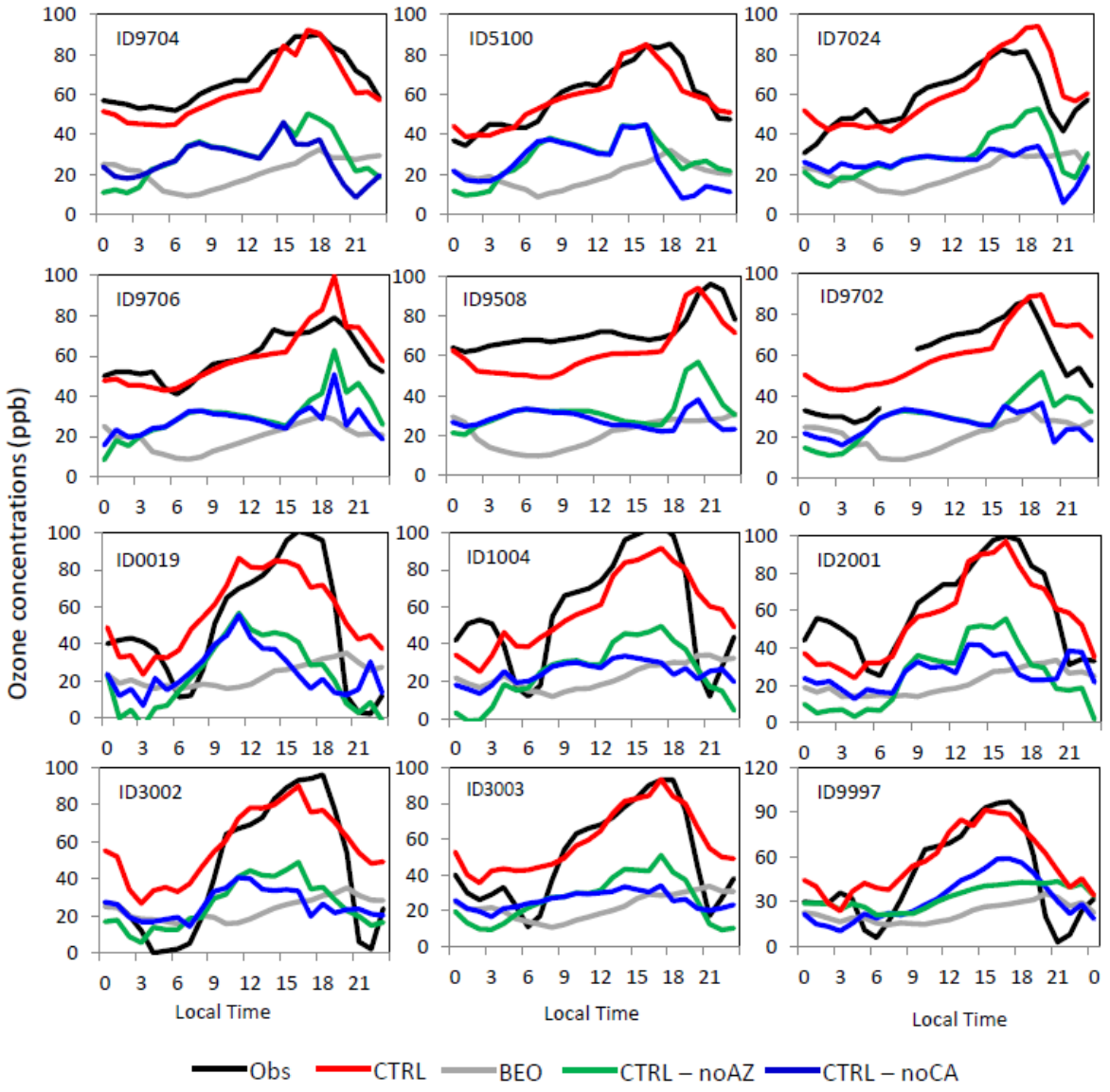

Figure S4: Relative contributions of different emission sources to ozone concentrations ([O_3]) at observation sites in Phoenix metropolitan area and surround rural. The date shown in the figure is May 14, 2012. Idxxxx indicates the site EPA AIRS number. The county number is 013, and state number is 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.

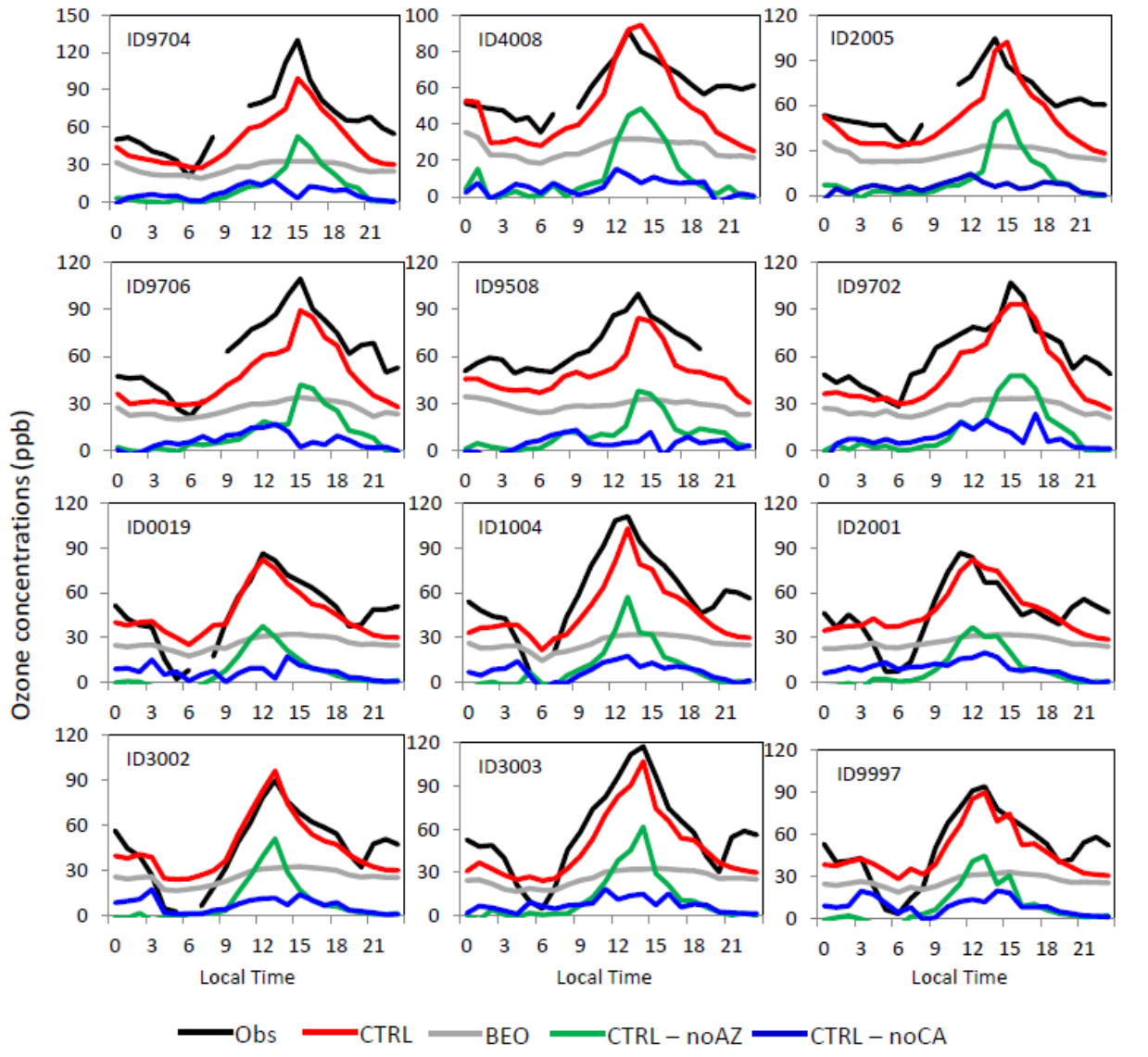

Figure S5: Relative contributions of different emissions sources to [O_3] at observation sites in Phoenix metropolitan area and surround rural. The date shown in the figure is July 19, 2005. Idxxxx indicates the site EPA AIRS number. The county number is 013, and state number is 04. In Figure, black 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.

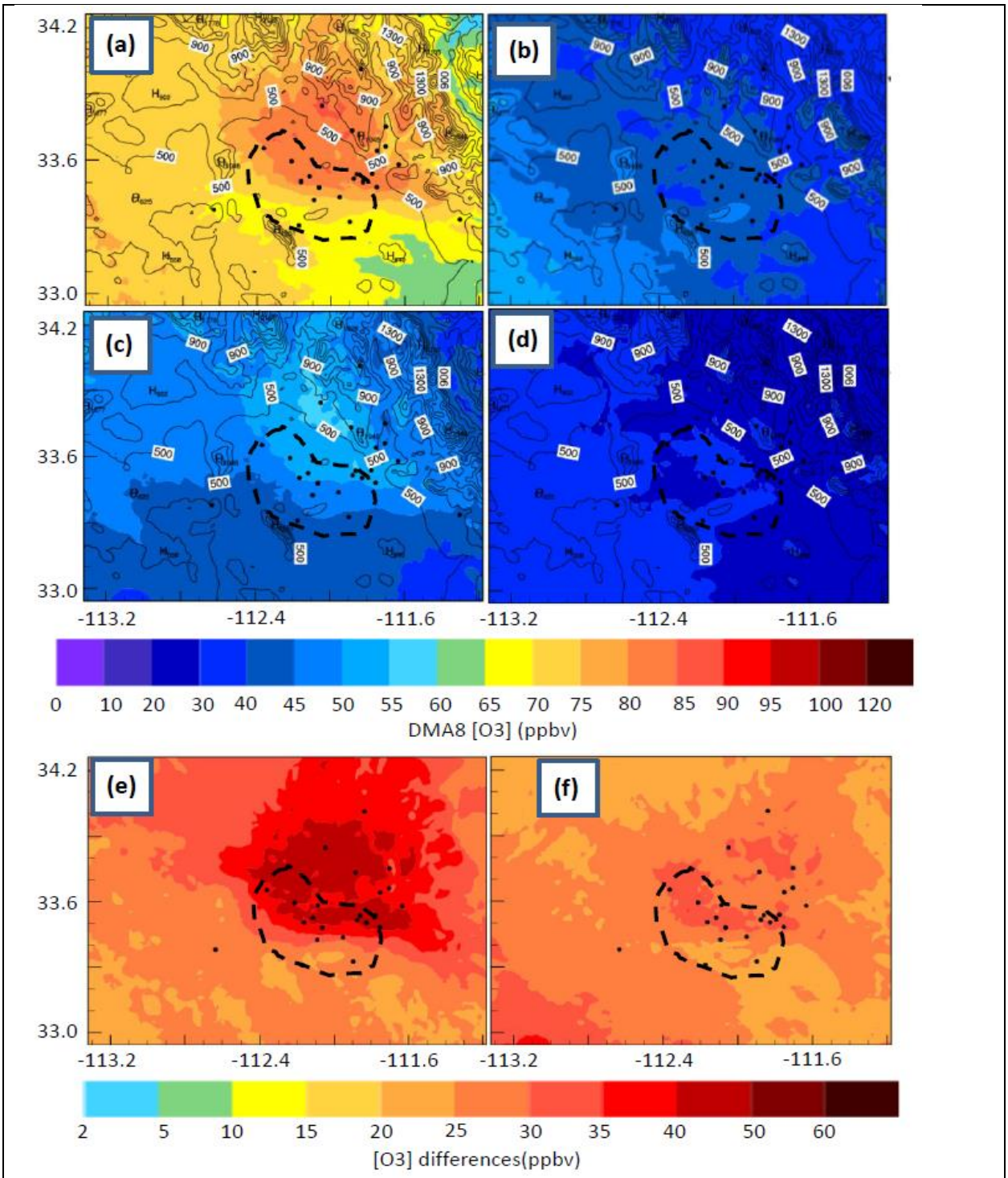

Figure S6: DMA8 [O_3] spatial distributions in greater Phoenix and surround areas on May 14, 2012: (a) CTRL, (b), noAZ, (c) noCA, (d) BEO, (e) CTRL-noAZ, and (f) CTRL-noCA. Contours represent terrain elevations. Dots shows O_3 observation site. Dashed circle indicates the approximate location of Phoenix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

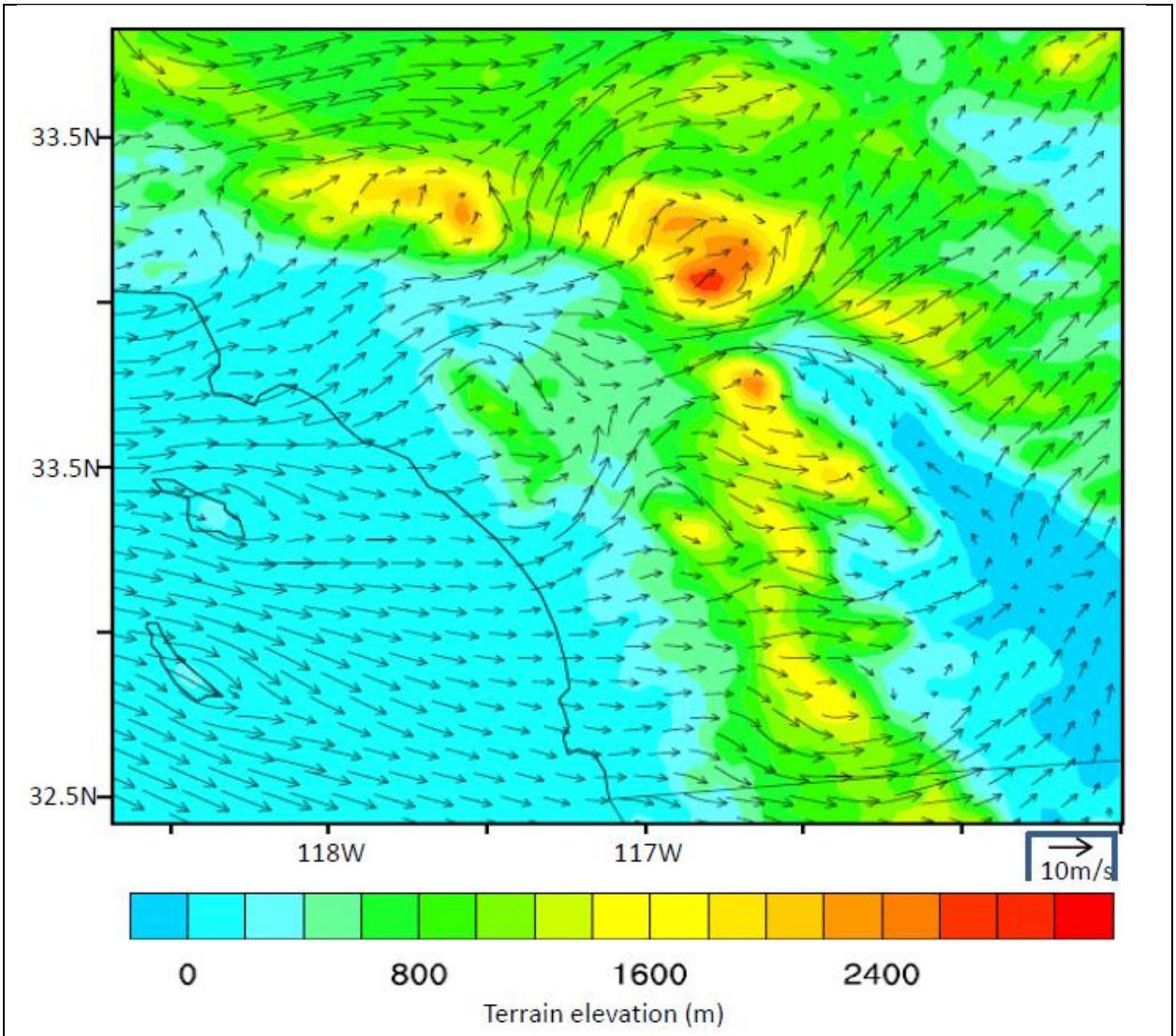

Figure S7: Day time mean of wind field vectors at 30 m a.g.l. from 4 km resolution run. Data are averaged over day time from July 16-20, 2005. There are the same patterns between Figure S7 and Figure 8 (shown in the ACPD manuscript) in general. However, there are differences in Salton Sea Airshed and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

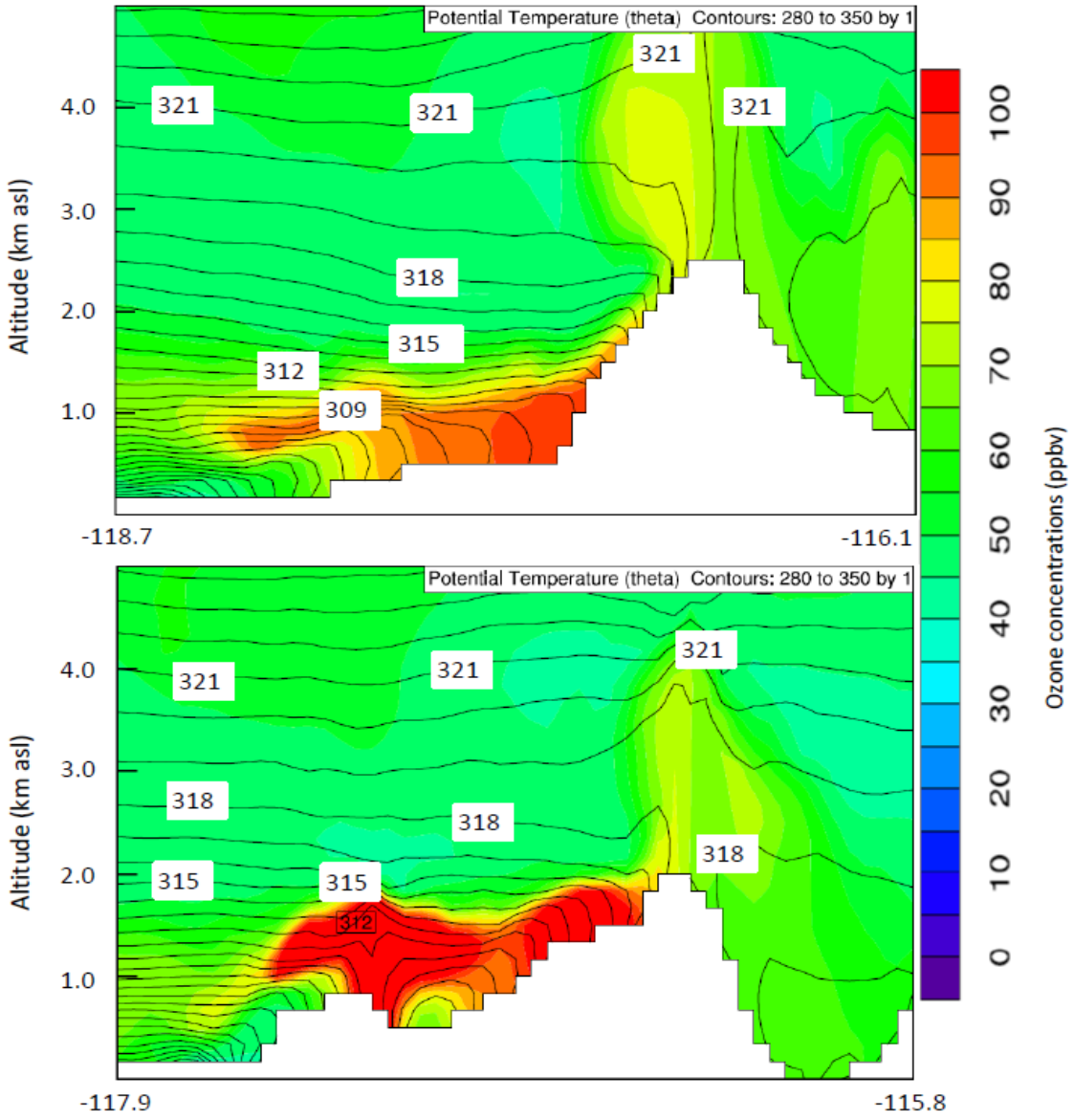

Figure S8: Vertical distributions of ozone along cross-section Lines A'A (top) and B'B (bottom) shown in Figure 1 at 22Z of July, 17, 2005. The contours are potential temperature starting at 280K with 1-K interval. Figures are plotted based on 4 km resolution run. Comparing Figure S8 with 1-km run (Figure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

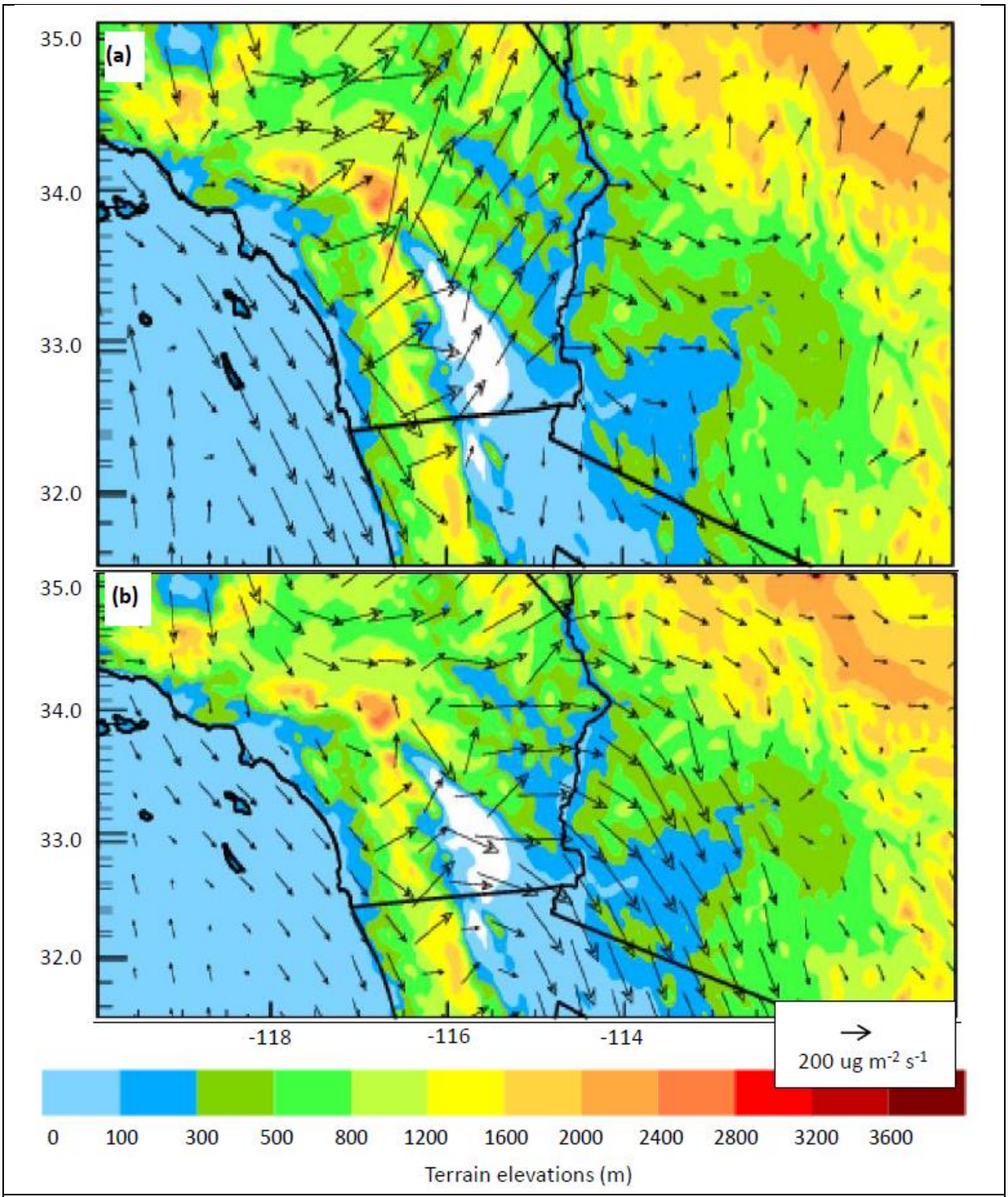

Figure S9: Integrated ozone transport flux differences (CTRL-noCA) from surface to 1400 m above ground-level: (a) average from 18Z to 02Z, July 16 to July 20, 2005, and (b) average from 03Z to 17Z, July 16 to July 20, 2005. Figures are based on 4 km resolution run. Comparing Figure S9 with 1 km run (Figure 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.

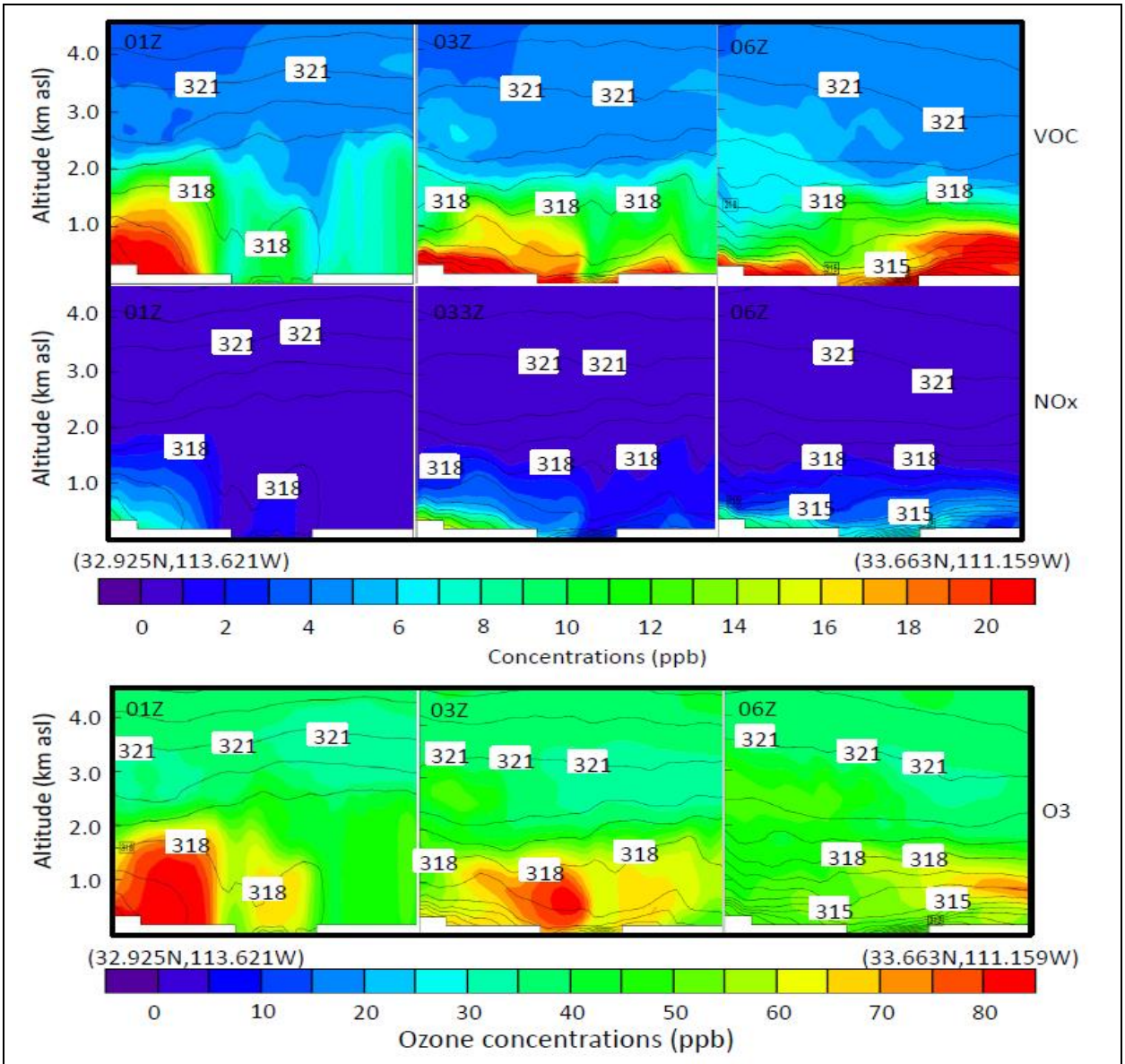

Figure S10: The vertical distribution of VOC (top), NOx (middle), and O_3 (bottom) along the cross-section D'D (shown in Figure 1) in Salton Sea Basin at 01Z, 03Z, and 06Z, July 18, 2005. Contours are potential temperature with 1-K interval. Data are from 4 km run. In comparing Figure S10 with 1 km run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

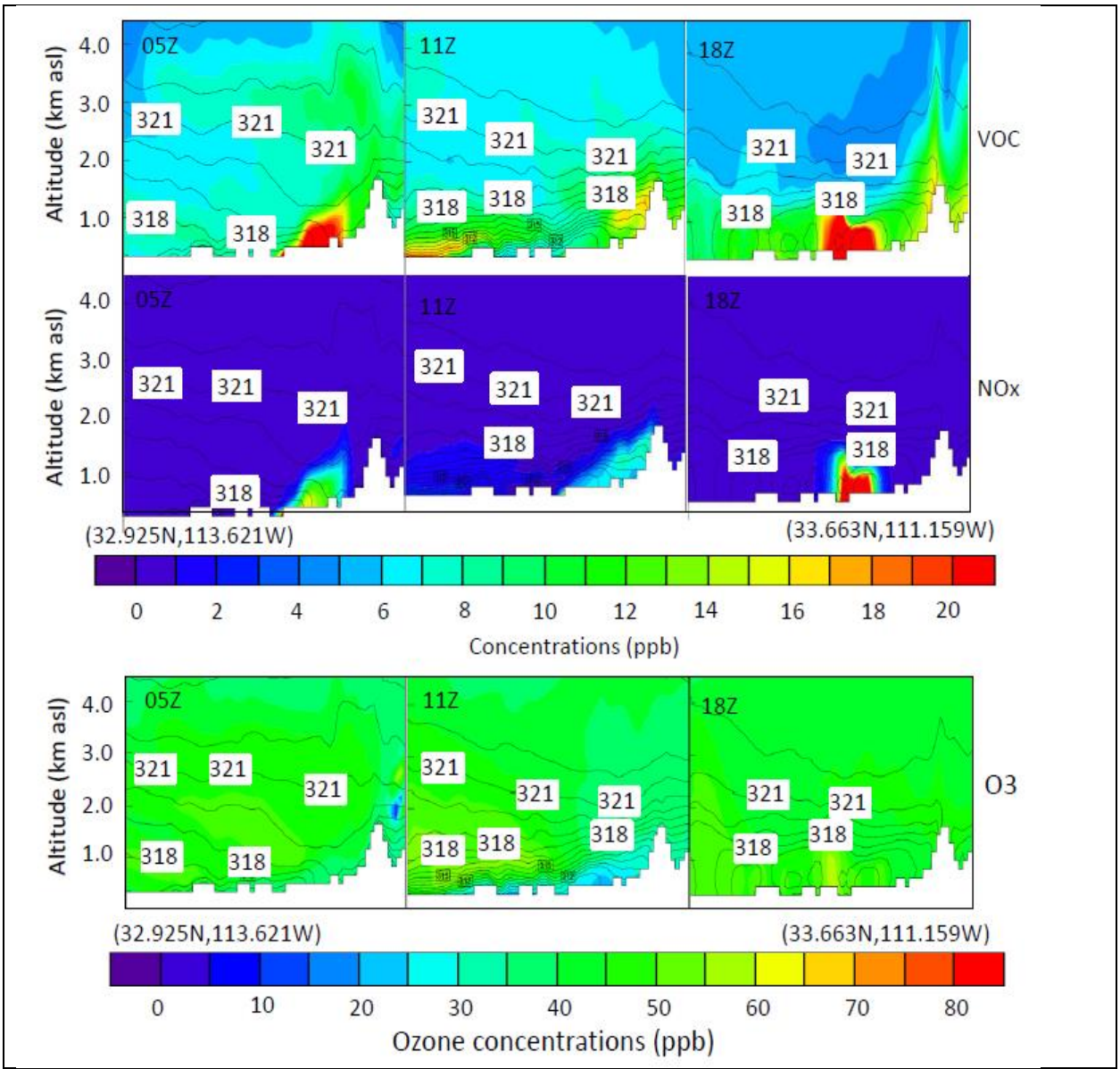

Figure S11: The vertical distribution of VOC (top), NOx (middle), and O_3 (bottom) along the cross-section D'D (shown in Figure 1) in Gila River Basin, Arizona at 05Z, 11Z, and 178Z, July 18, 2005. Contours are potential temperature with 1-K interval. Data are from 4 km resolution model run. In comparison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