This manuscript is an interesting study of the effectiveness of emission controls and its relation to meteorological conditions in Beijing during Olympic 2008. Based on a set of numerical experiments on emission control strategy, this study points out that meteorological conditions are at least as important as emission controls in reducing aerosol concentration during the Olympics. The authors also emphasize the dominant role of regional control in improving air quality in Beijing city. The findings are valuable for correctly evaluating the emission control efficiency during the Olympics and for policy-making of control scenario. However, the quantities analysis of the role of meteorological condition during the Olympics is still of lack. And there are some inconsistent between the topic and the experiment designs in this paper. In general, this manuscript is well presented but misses some important details (e.g. the configuration of WRF-Chem), and the simulated meteorological and emission bias need to be further discussed. Before the manuscript is suitable for publication, the listed points below should be clarified.

We thank the reviewer for the careful and comprehensive review. Following the reviewer's suggestions, we have made it clearer in the revision for the quantitative analysis of the role of meteorological condition during the Olympics (see reply to General Comment 1), and for the consistency between the topics and the experiment designs (reply to General Comments 3 and 4). We have given more detailed explanation of WRF-Chem model configuration (reply to General comment 7). We have presented evaluation of simulated meteorological conditions with observations at more sites (reply to General Comment 6). The effect of emission bias has been discussed (reply to General Comment 8).

General Comments:

1) The author gave a statement in abstract "our analysis suggests that meteorological conditions (e.g., wind direction and precipitation) are at least as important as emission controls in producing the low aerosol concentrations appearing during the Olympic period. Can the authors explain how they draw this conclusion quantitatively?

This conclusion is drawn from the budget analysis as shown in section 4.2.3 and Figure 6. For the Olympic period with low aerosol concentrations (August 11-19th), the net transport loss is 26.1 ton/day over Beijing, which indicates the favorable meteorological conditions. The emission reduction is 19.2 ton/day by comparing emission term for this period with the overall period of July-August. Considering that there are emission controls during the July-August period (e.g., 35% reduction after July 20 and 50% during the Olympics in Beijing), the emission reduction for the August 11-19th period compared to the no-control case can be larger. Even so, however, the magnitude of transport loss is still comparable to that of emission reduction. We have made it clearer in the revised manuscript.

2) The authors perform a set of numerical experiments to investigate the effectiveness of emission controls versus meteorological conditions. To ensure robust result, the well simulated meteorological condition is the pre-requisite. In my opinion, the simulation with a 36 km horizontal resolution may not sufficient to well present the complicated atmospheric circulations over the Beijing and its surrounding areas. The synoptic circulation may interact with land-sea, mountain-valley, and urban heat island *circulations. The local circulation plays an important role in determining the transport, dispersion of air pollutants. The authors are advisable to fully evaluate the simulated meteorology. In my opinion, just as what authors found in this paper, precipitation is important in wet deposition and there is underestimate of precipitation after 24 August 2008, it will be useful to use a finer horizontal resolution model (like 4km) in which cumulus parameterization could be closed. I would suggest authors to re-run the model in 4km resolution, at least for a single run with precipitation to provide enough evidence that the uncertainty from courser model resolution won't change the main result.*

We agree with the reviewer that the well-simulated meteorological condition is the pre-requisite for the robust model result. In the supplementary materials, Figure S2 is the same as Figure 4 in the paper, except that Figure S2 additionally shows daily grid-average horizontal wind speed and direction from NECP FNL reanalysis data at the lowest three layers over Beijing (Figure S2(b)). Figure S2(a) and S2(b) show that the variation of wind direction from the CTL case is similar to that from the NCEP FNL data as we expected, since the winds (U and V) are forced to NCEP FNL data through analysis-nudging. We added the above discussion in section 4.2.2.

To provide additional evidence that the uncertainty from coarser model resolution won't change the main result, following the reviewer comment, we have run the WRF model in 4 km with cumulus parameterization turned off. Figure S3 is the same as Figure 4 in the paper, except that Figure S3 additionally shows the daily grid-averaged horizontal wind speed and direction at the lowest three layers (Figure S3(b)) and daily grid-averaged precipitation rate (green line in Figure S3(c)) from the 4 km simulation and from the 36 km simulation without emission control (NO-CTL case) (purple line in

Figure S3(c)) over Beijing. Figure S3(a) and S3(b) show that the variation of wind direction from the CTL case is also similar to that from the 4 km simulation. Therefore, the relatively coarser resolution (36 km) is not going to affect our results compared with the relatively higher resolution (4 km) in terms of simulating the pollution transport surrounding Beijing. It's noteworthy that the precipitation rate from the 4 km simulation is lower than that from the CTL case and observation, although the precipitation rates from both CTL case and 4 km WRF simulation capture the main precipitation events during the Olympic Games. Since the 4 km simulation turns off the cumulus parameterization, the precipitation biases result from the microphysics scheme (i.e., Lin scheme in this study). The investigation of the sensitivity of precipitation to different microphysics schemes is beyond the scope of this paper. We have added the above discussion in section 4.2.2.

3) Authors used 2007 as the standard meteorological conditions. The representiveness is questioned. The mean of more years run are suggested to represented as the background of the meteorological condition. If the author want to evaluate the effect of meteorological condition and emission control, it is better to use the emission of 2008 in the run with meteorology of 2007 or use the emission of 2007 in the run with meteorology of 2008. There is less use to compare with No-CTL07 and No-CTL in this manuscript.

We don't intend to use the 2007 (NO-CTL07) as the standard meteorological conditions. We include the results of NO-CTL07 in Table 3 and in the text, because some measurement studies (e.g., Y. Wang et al., 2009) examined the effectiveness of emission control by comparing measured pollutant concentrations during the Olympic Games to those of the same period in 2006 and 2007 (same as NO-CTL07).

Without emission control, we would not expect much difference between the emissions in 2007 and 2008, so the NO-CTL case can represent the simulation with 2008 meteorology and 2007 emissions as the reviewer suggests. The simulation with 2008 with-control-emission and 2007 meteorology is difficult to be used for evaluating the relative effect of meteorological condition and emission control, because of interannual variability of meteorological conditions. On the other hand, following the reviewer comment, we have conducted the simulation with 2008 with-control-emission and 2007 meteorology (CTL07 case). Figure S4 shows the daily $PM_{2.5}$ from observations and the corresponding WRF-Chem simulations in CTL, NO-CTL, and CTL07 cases from July 1st to August 31st at the two sites (T1 and T2). It is shown that the $PM_{2.5}$ concentration in CTL07 case can be either higher or lower than the CTL case (2008 with-control-emission and 2008 meteorology) during July and August due to the strong interanual variability of meteorological fields.

4) There is no use to compare the results of VTL-BJ0 and VTLRD0 for the whole July and August 2008, since Beijing area is too small as compare with the whole domain, of cause the regional transport will dominate the air quality of Beijing. This is not new. It will be interested to compare the effect in the 1st, 2nd, 3rd, 4th and 5th day run under different meteorological circulation.

It's not always true that the local air quality is dominated by the regional transport. The convergence of pollutant emissions over the vast stretch of the geographically flat plains of East China makes the urban areas in China different from those in some developed countries such as the US. The emissions are more spatially spread over East China compared to the emissions over the US that are mostly isolated in urban areas (Zhao et al., 2009). One could expect that the emission reduction over a big city over the eastern US (e.g., Atlanta) would be effective enough to control the air quality there; however, even though air quality in Beijing is to a large extent influenced by the regional transport, emission control in Beijing can still be important for the reduction of pollutant concentration from our budget analysis shown in the paper.

The comparison of the results of CTL-BJ0 and CTL-RD0 for July and August 2008 in this study not only shows that the regional transport significantly affects the air quality of Beijing but also give a clear indication that the regional transport determines the daily fluctuation of $PM_{2.5}$ concentration in July and August 2008.

Although the impact of day-to-day variation of meteorological conditions on the air quality deserves investigation, this study focuses more on the comparison between effects of overall meteorological condition and emission control on the air quality.

Zhao, C., Y. Wang, and T. Zeng (2009): East China plains: A "basin" of ozone pollution, Environ. Sci. & Tech., 43, 1911–1915.

5) The authors start the simulation of WRF-Chem 2 months early than July, just want to have more realistic aerosol background. Can they verify the aerosol background is good enough?

The purpose for starting the simulation 2 months early (or spin up) than July is: a) to reduce the impacts of initial chemical conditions on the model simulation of aerosol which we use for analysis; b) to simulate aerosol concentrations in June. It is not the case to have more realistic aerosol background.

6) The authors present the comparison of WRF model outputs at _100 m with observed hourly wind speed, wind direction, temperature and relative humidity with observations obtained at the meteorological tower in Beijing for August 2008 (Fig. S1). As far as wind speed is concerned, the model results show frequently very higher wind speed and larger diurnal variations of wind speed compared with observations. In my opinion this seems to be poor model performance due to the coarse resolution, not "In general model simulated meteorological variables agree well with observations" as the authors state. This needs to be discussed more fully. Perhaps more observations at other sites and more meteorological parameters (e.g. precipitation, PBL) are helpful to evaluate the model results. Quantitative analysis of the model bias and the result in July should be included.

Following the reviewer comment, we change the wording on the model performance of wind speed. The large wind speed bias and too strong diurnal variations of wind speed as compared with observation are discussed in the revised manuscript. We also add more evaluation of model results (wind speed, temperature, relative humidity, and precipitation) at other sites in Beijing in both July and August in section 4.2.2 "We obtained the observation of surface Beijing meteorological condition during the Olympic Games from the internet: http://cdc.bjmb.gov.cn/gongzhong.asp?id=24 at seven sites located in Beijing. The seven sites are Changing (116.22°E, 40.22°N), Chaoyang (116.48°E, 39.95°N), Fangshan (116.00°E, 39.7°N), Haidian (116.28°E, 39.98°N), Jinhaihu (117.33°E, 40.18°N), Nanjiao (116.28°E, 39.93°N) and Shunyi (116.63°E, 40.12°N). The wind directions were only measured at the 16 directions (north, south, west, east, northwest, northeast, southeast, southwest, north-northeast, east-northeast, east-southeast, south-southeast, west-northwest, north-northwest, west-southwest, and south-southwest), so it's hard to be compared with the model results and thus not shown. Figure S5 shows the comparison of model results of both 36 km and 4 km at surface with observed hourly wind speed, temperature, relative humidity and daily precipitation rate at surface at the seven sites in July and August 2008. Generally, model can reproduce the observation at different site. It is shown that the difference between CTL case and 4 km WRF simulation is very small for wind. However, temperature from the 4 km simulation is systematically higher (especially at daytime) than that from the CTL case and observation, along with low relative humidity bias from the 4 km simulation. For precipitation, both CTL case and 4 km WRF simulation can capture the main precipitation events at each site in July and August, but underestimate observed precipitation especially for 4 km WRF simulation."

7) More details of model configuration needs to be presented. Chemical initial conditions as well as the injection method of the emission inventory should be stated clearly. Apparently these choices will affect the model result. Why authors use default boundary condition in WRF-Chem instead of the output of global model.

Following the reviewer comment, we now add more description about the model configuration in the paper. We add in section 2.3 "There is no sufficient information for calculating vertical distribution of the emissions over East Asia, thus we emitted all the emissions into the first model layer."

We add in section 2.2 "Both chemical initial and boundary conditions are from the default profiles in WRF-Chem which are the same as those in the work by McKeen et al. (2002) and are based on averages of mid-latitude aircraft profiles from several field studies over the eastern Pacific Ocean. The initial condition is not going to affect our results, since we have 1-month spin-up for simulations. There are reasons for using default boundary condition rather than the output of global model. The aerosol schemes in GCM's are different from that in WRF-Chem. The speciation uncertainty of aerosol species between GCM's and WRF-Chem is large, particularly for the dust aerosol transported from West Africa and Mid-East (not shown). In addition, the GCM's themselves can also introduce biases. On the other hand, although the default boundary condition may affect the chemical condition at the west boundary of domain (over India region), based on the size of the domain in this study, we would not expect much impact from the west boundary on the air quality in Beijing over East China during summer given the relative short lifetime of aerosols (e.g., Zhao et al., 2010). Therefore, we decided to use default boundary profiles instead of obtaining the boundary information from GCM's in this study."

We also add the references:

"McKeen, S. A., Wotawa, G., Parrish, D. D., Holloway, J. S.,Buhr, M. P., Hubler, G., Fehsenfeld, F. C., and Meagher,J. F.: Ozone production from Canadian wildfires during June and July of 1995, J. Geophys. Res., 107(D14), 4192, doi:10.1029/2001JD000697, 2002.

Zhao, C., Y. Wang, Q. Yang, R. Fu, and Y. Choi (2010): Impact of East Asia summer monsoon on the air quality over China: The view from space, J. Geophys. Res., 115, D09301, doi:10.1029/2009JD012745."

8) The model significantly overestimates the $PM_{2.5}$ concentration during the Olympic and post-Olympic period (Table 3 and Fig. 2). This positive bias may caused by the overestimated emission, which definitely affects the result "modeled concentrations of aerosol species in Beijing were decreased by 30–50% during the Olympic period" as the authors state. So the authors need to further discuss the emission uncertainties and its potential impacts on their quantitative results.

The emission uncertainties will affect the absolute values of aerosol concentration. However, it will not affect the relative change of aerosol concentration (i.e., the percentage reduction of aerosol concentration in Beijing during the Olympic period). This is because we apply the percentage reduction of emissions in the CTL case to the NO-CTL case. The high bias in $PM_{2.5}$ concentration during the Olympic and post-Olympic period is likely due to the low precipitation bias of the model. Now we add in section 4.2.1 "It is noteworthy that although the WRF-Chem simulated aerosol concentrations are higher than observations during the Olympic and post-Olympic period, this study focuses more on the relative change of aerosol concentration due to the emission control and meteorology condition. The uncertainty of emissions may affect the absolute values of aerosol concentration reduction, but not the relative change." Also we have more discussion on emission uncertainties in section 5 (Summary and Conclusions).

The biase of WRF-Chem in simulating aerosol concentrations over China deserves further investigation. We are preparing a manuscript to evaluate the WRF-Chem simulation of aerosols and fully understand and investigate its biase over China.

9) Since WRF-Chem model is a coupled model, I'd like to know if the emission control would influence the metrological condition, it will be interested to show the precipitation in NO-CTL run also.

Although WRF-Chem is a coupled model, the model simulations in this study were conducted with re-initialization of meteorological conditions every 5-day and 6-hour nudging of winds, temperature, and water vapor with NCEP FNL reanalysis data. Therefore, model simulated wind, temperature, and water vapor mixing ratio are very similar among the cases. Following the reviewer comment, we show in Figure S3(c) the precipitation rate in the NO-CTL case, which is almost identical to that in the CTL case, indicating that the difference of precipitation and other meteorological fields between the two cases with different emissions should be negligible.

Specific Comments:

1) Abstract Line 14 – "are" -> "were"

Changed.

2) Some statement should be more specify for the time scale, it is 1hour, 1 day or a month. like "Transport from the regions surrounding Beijing determines the temporal variation of aerosol concentrations in Beijing" . It the variation is in hour, day, minite or second interval.

All "temporal variation" in the text changed to "daily variation".

3) Sect. 2.2 –Land use data information should included the descriptions of the model *configuration. Reference should be added for some physical scheme.*

Following the reviewer comment, we now add in section 2.2 “The land use data used in the model are from 5-minute resolution USGS (United States Geological Survey) 24 categories data, which are derived from 1-km Advanced Very High Resolution Radiometer (AVHRR) data in a 12-month period spanning from April 1992 to March 1993 (Loveland et al. 1991, Brown et al. 1993).”

We also add references:

“Loveland, T. R., J.W. Merchant, D. O. Ohlen, and J. F. Brown. 1991. Development of a land-cover characteristics database for the conterminous U.S. Photogrammetric Engineering and Remote Sensing 57:1453–1463.

Brown, J. F., T. R. Loveland, J. W. Merchant, B. C. Reed, and D. O. Ohlen. 1993. Using multi-source data in global land-cover characterization: concepts, requirements, and methods. Photogrammetric Engineering and Remote Sensing 59:977–987.”

4) Sect 2.2 line 9, it should be (10-55N, 70-150E)

Changed.

5) P.16670, lines 27-29 – What region (just boundary condition?) are the meteorological variables nudged? The authors need to describe the nudging method. If the nudging is in 6-h interval, is there any jump in meteorological parameter?

Now we add the following description on nudging in section 2.2 “The winds, temperature, and moisture over the whole domain are nudged. The method of nudging (Newtonian relaxation) relaxes the model state toward the observed state by adding, to one or more of the prognostic equations, artificial tendency terms based on the difference between the two states (Stauffer and Seaman, 1990; Stauffer et al. 1991; Stauffer and Seaman, 1993). The model solution can be nudged toward either gridded analyses (analysis nudging) or individual observations (observation nudging) during a period of time. In this study, the analysis-nudging based on the NCEP FNL data is used. The simulation is nudged every 6-hour with nudging coefficients of 0.0003 for winds, temperature, and moisture."

Figure S1 is the hourly variation of meteorological fields (wind velocity, temperature, relative humidity and precipitation). It can be seen that there is no jump in these meteorological fields.

We also add three references

"Stauffer, D.R. and N.L. Seaman: Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic-scale data. Mon. Wea. Rev., 118, 1250-1277, 1990.

Stauffer, D.R., N.L. Seaman and F.S. Binkowski: Use of four- dimensional data assimilation in a limited-area mesoscale model. Part II: Effects of data assimilation within the planetary boundary layer. Mon. Wea. Rev., 119, 734-754, 1991.

Stauffer, D.R., and N.L. Seaman: Multi-scale four-dimensional data assimilation. J. Appl.Meteor., 33, 416-434, 1994."

6) Sect. 2.3 – The emission inventory is "according to the study by S.Wang et al. (2010) and personal communication with Kebin He of Tsinghua University (2011)" as the *authors states. Please briefly address the reason for the changes from the emission of S. Wang et al.*

S. Wang et al. (2010) only provided the emission reduction for Beijing during the Olympic period. We had personal communication with Dr. Kebin He of Tsinghua University (2011) to estimate the emission reduction for other period and for the surrounding area of Beijing such as Hebei province. Our estimation of emission reduction (50%) for Beijing during the Olympic period is consistent with S. Wang's result (40-60% reduction), which is mentioned in the introduction section 1.

7) Sect. 2.3 – Please briefly state how you horizontally/vertically inject the emissions (Q. Zhang et al., 2009) into WRF-Chem.

Now we add in section 2.3 "There is no sufficient information for calculating vertical distribution of the emissions over East Asia, so we emitted all the emissions into the first model layer. For horizontal distribution, the emission is interpolated from the raw data grids (0.5×0.5 degree) into our domain grids (36×36km)."

8) Sect.2.3 – The temporal variation of the emission for the simulations should be addressed. For example, how do the WRF-Chem diurnally averaged mass concentrations derived from that emissions inventory? This description needs to be added in Sect. 2.3.

Now we add in section 2.3 "We assumed no temporal variation of anthropogenic emissions in this study. Only the temporal change of emissions due to emission control is considered (e.g., emission reduction by 35% after July 20 and by 50% during the Olympics). As far as we know, the daily and diurnal emission inventory is not available over East Asia, particularly for China. We only run the model for summer time, so monthly variation is not necessary.”

9) P.16674, Line 10 – ‘(for the period of 2-10 August’ replaced by ‘(for the period 11-19 August)’

Done.

10) References - In the references list there is a paper by Q.-H. Zhang et al. (2010) (p.16681, line14) that has not yet been cited in the manuscript. Cite the paper, or delete it from the references list.

We delete it from the reference list.

11) Fig. 2. – For better comparison, the daily mean value for the simulated PM2.5 could be added in Fig. 2.

We tried to include the daily mean values in Figure 2, but it turns out that the figure becomes too busy. Therefore, we decided to only show the numbers in the table.

12) Fig. S1. – The authors are advisable to present the comparison result for the period of July-August instead of August only.

We added the 4 km simulation result in Figure S1 for comparison with CTL case with a coarser resolution. The July data from that site (Beijing Tieta at Institute of Atmospheric Physics in Beijing) is not available to us. However, for other sites, as shown in Figure S5(1)-(7) of supplementary material, we include model result (e.g., wind velocity, temperature, relative humidity, and precipitation) in comparison with observations for the whole period of July-August.

See Supplemental Figures S1-S5 below.

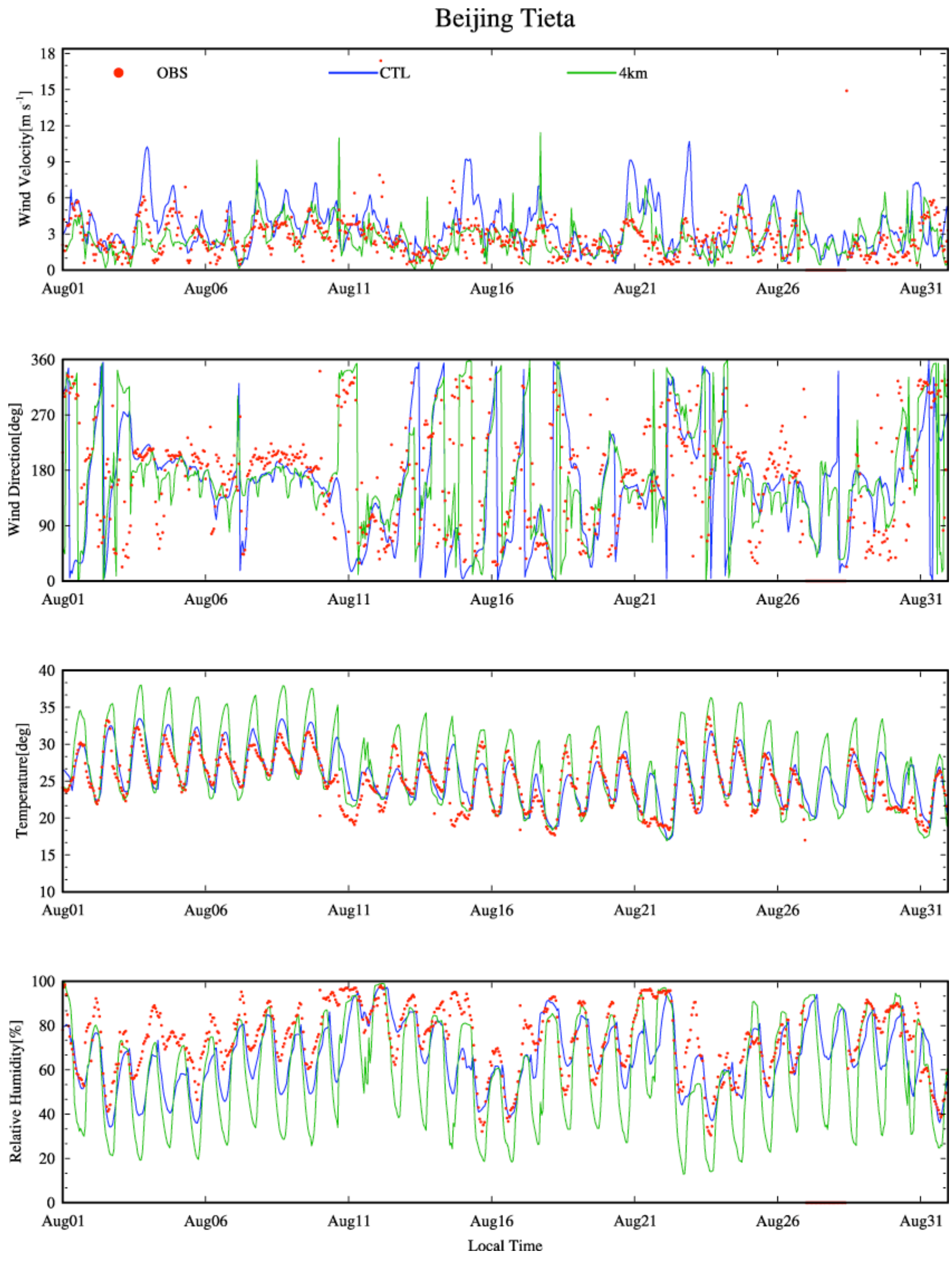


Figure S1. Comparison of model outputs at ~100 m (model level 4 from bottom) from CTL case (blue line) and 4 km WRF simulation (green line) with observed hourly wind speed, wind direction, temperature and relative humidity at the seventh platform (100 m) of the 325-m meteorological tower (116.4°E, 40°N) at the Institute of Atmospheric Physics in Beijing for August 2008.

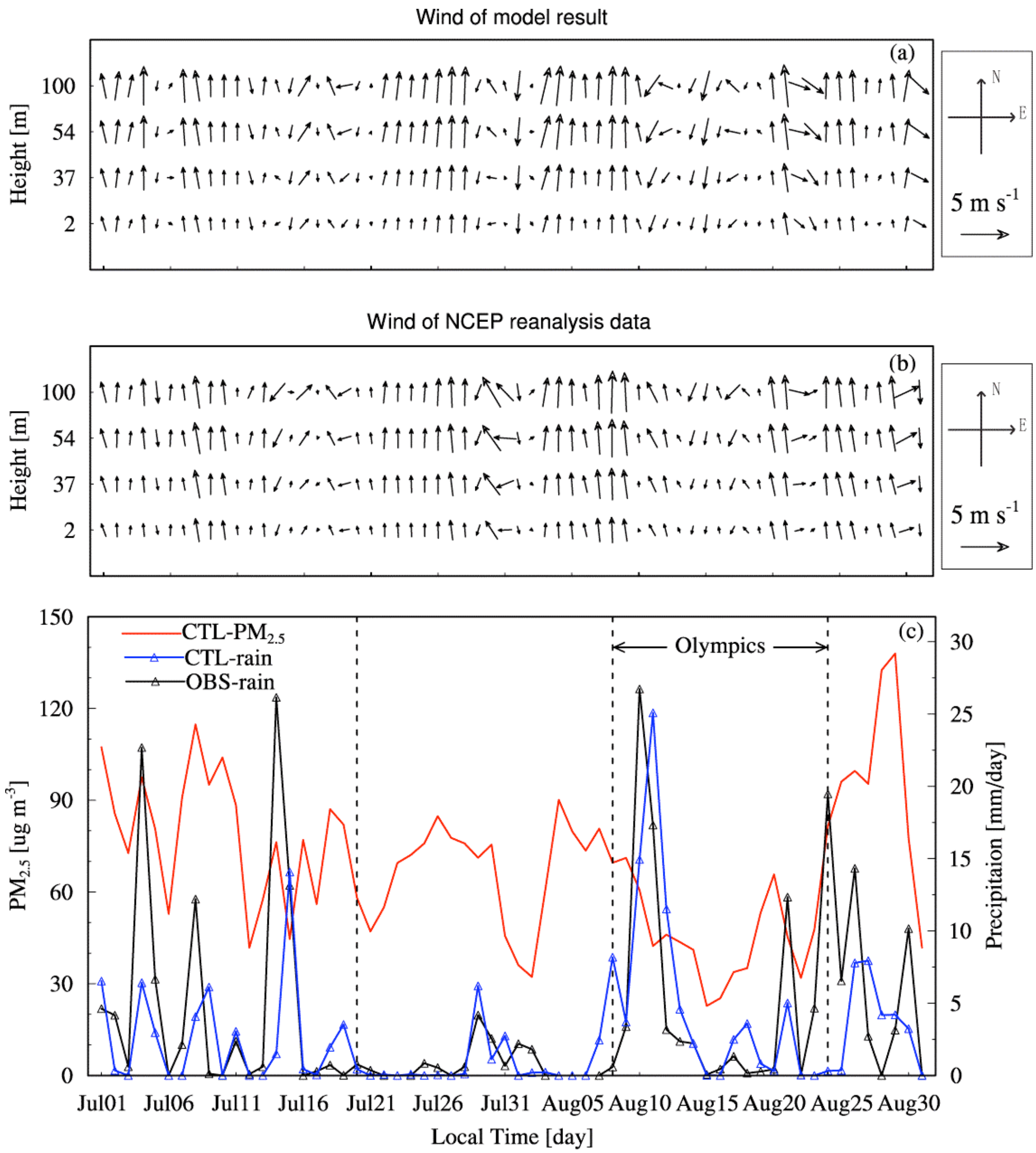


Figure S2. Time series of (a) daily mean and grid averaged horizontal wind speed and direction from CTL case at the lowest three layers over Beijing, (b) daily mean and grid averaged horizontal wind speed and direction from NECP FNL reanalysis data at the lowest three layers over Beijing, and (c) daily mean and grid averaged $PM_{2.5}$ concentration, daily sum and grid averaged precipitation rate from CTL case and observation over Beijing from July 1st to August 31st. Direction of arrows in (a) and (b) denotes the direction of horizontal wind and the length of arrows denotes wind speed.

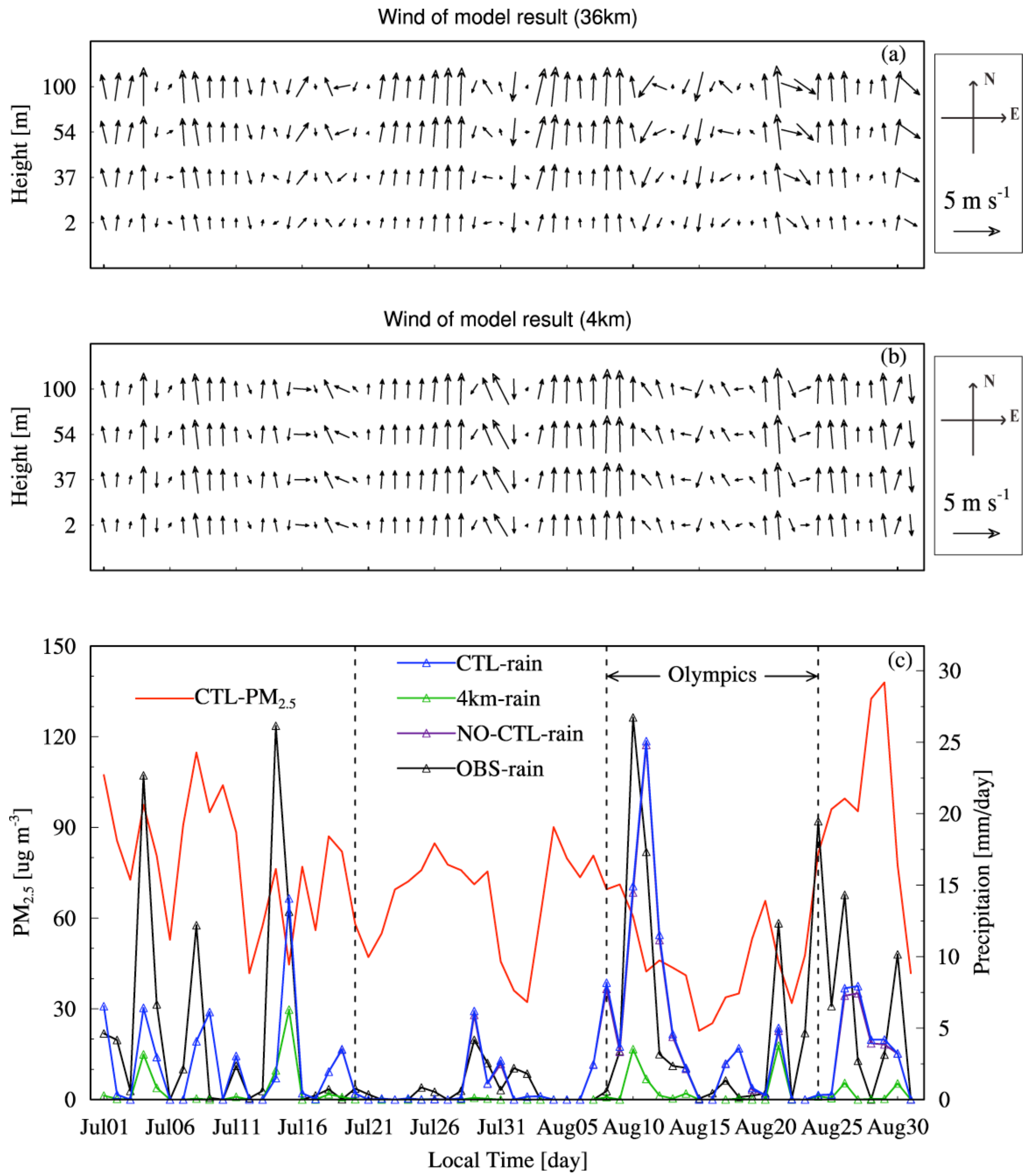


Figure S3. Time series of (a) daily mean and grid averaged horizontal wind speed and direction from CTL case at the lowest three layers over Beijing, (b) daily mean and grid averaged horizontal wind speed and direction from 4 km model simulation at the lowest three layers over Beijing, and (c) daily mean and grid averaged $PM_{2.5}$ concentration, daily sum and grid averaged precipitation rate from CTL case, NO-CTL case, 4 km model simulation and observation over Beijing from July 1st to August 31st. Direction of arrows in (a) and (b) denotes the direction of horizontal wind and the length of arrows denotes wind speed. The two lines of precipitation rate from CTL and NO-CTL in (c) are almost coincided with each other.

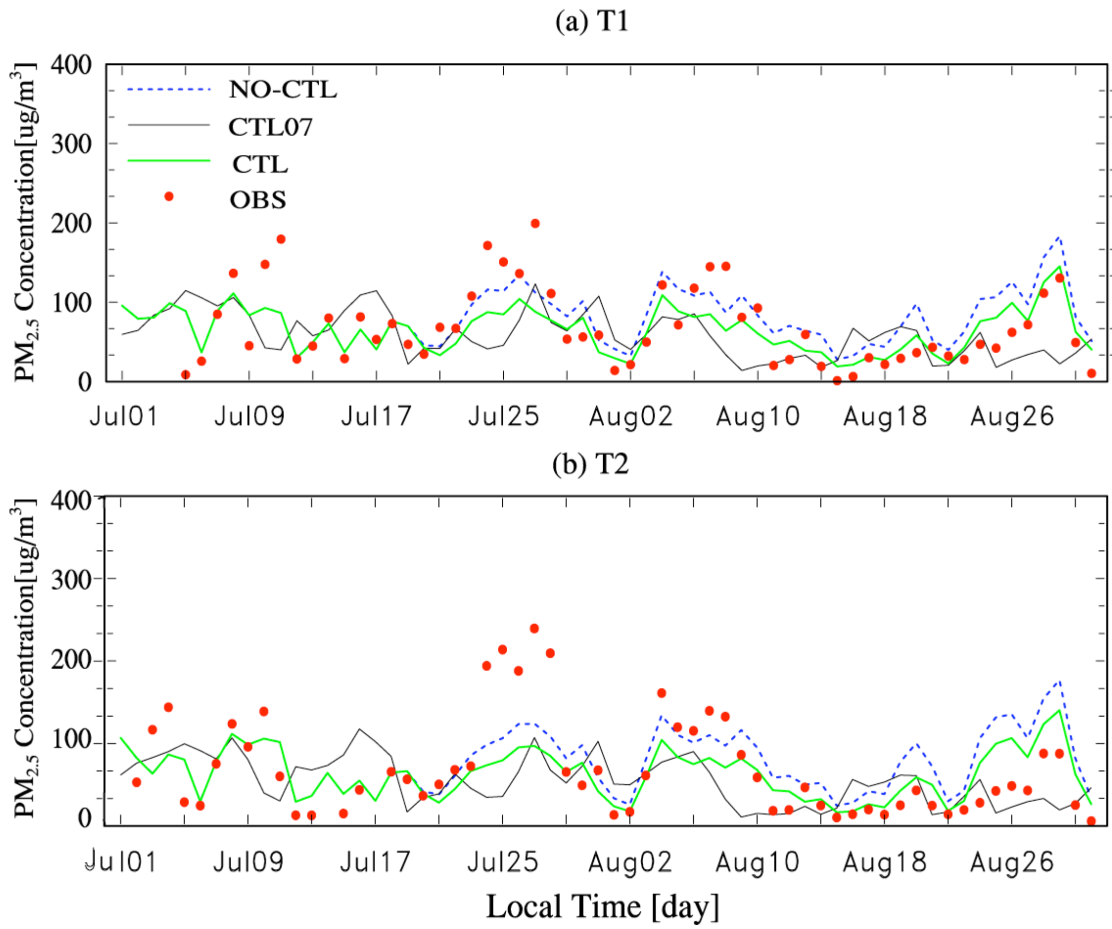


Figure S4. Daily PM2.5 from observations and the corresponding WRF-Chem simulations in CTL, NO-CTL and CTL07 cases from July 1st to August 31st at the two sites (T1 and T2).

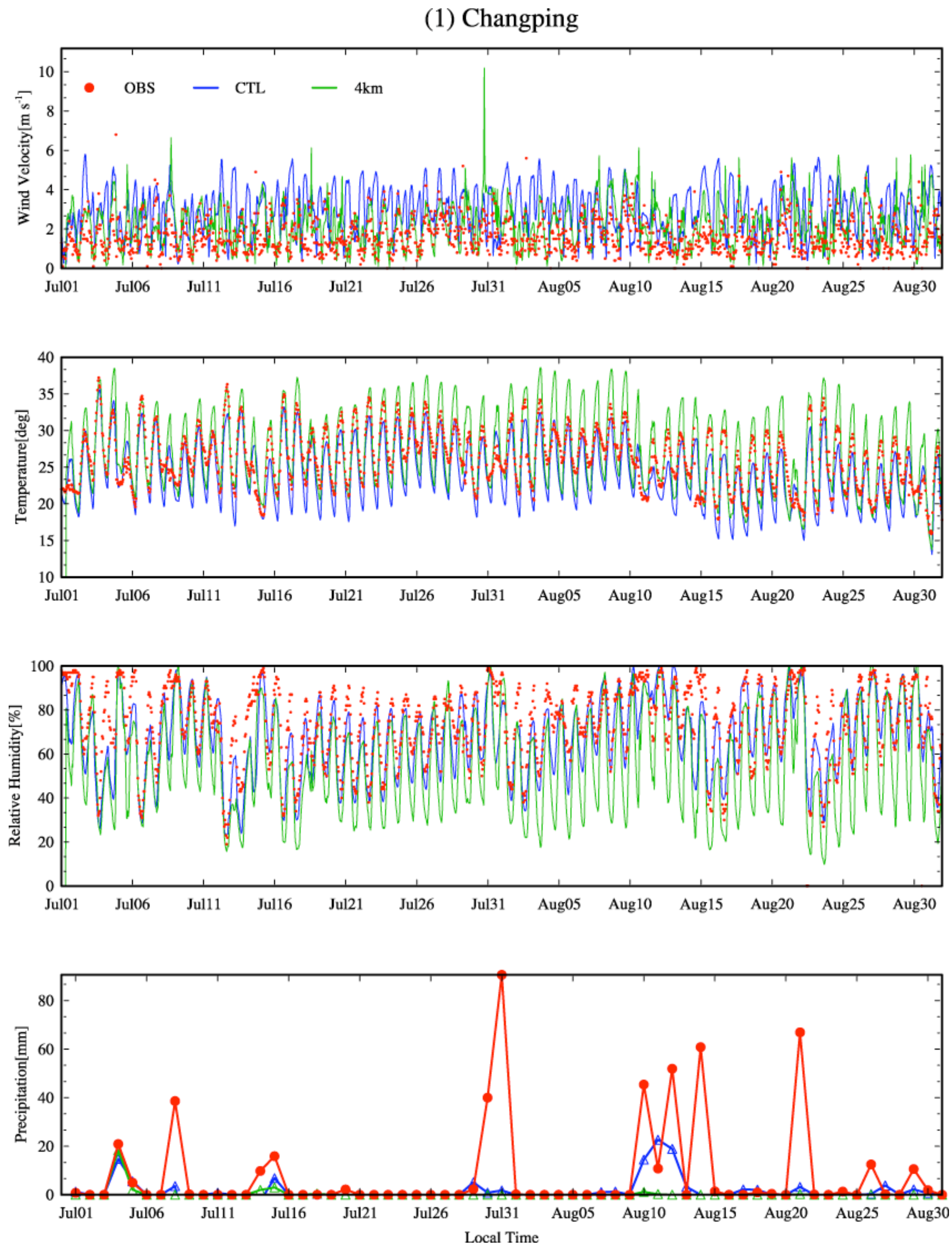
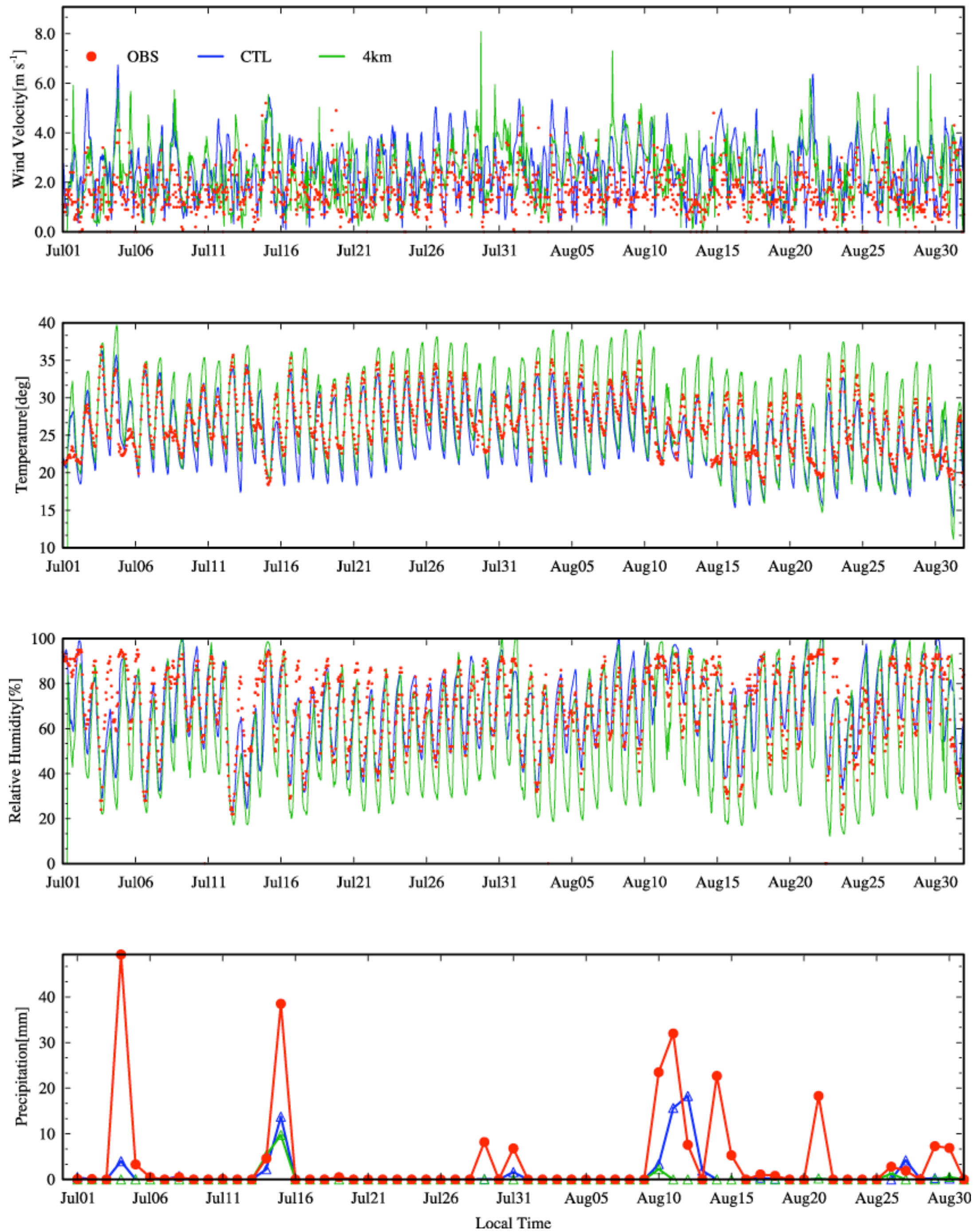
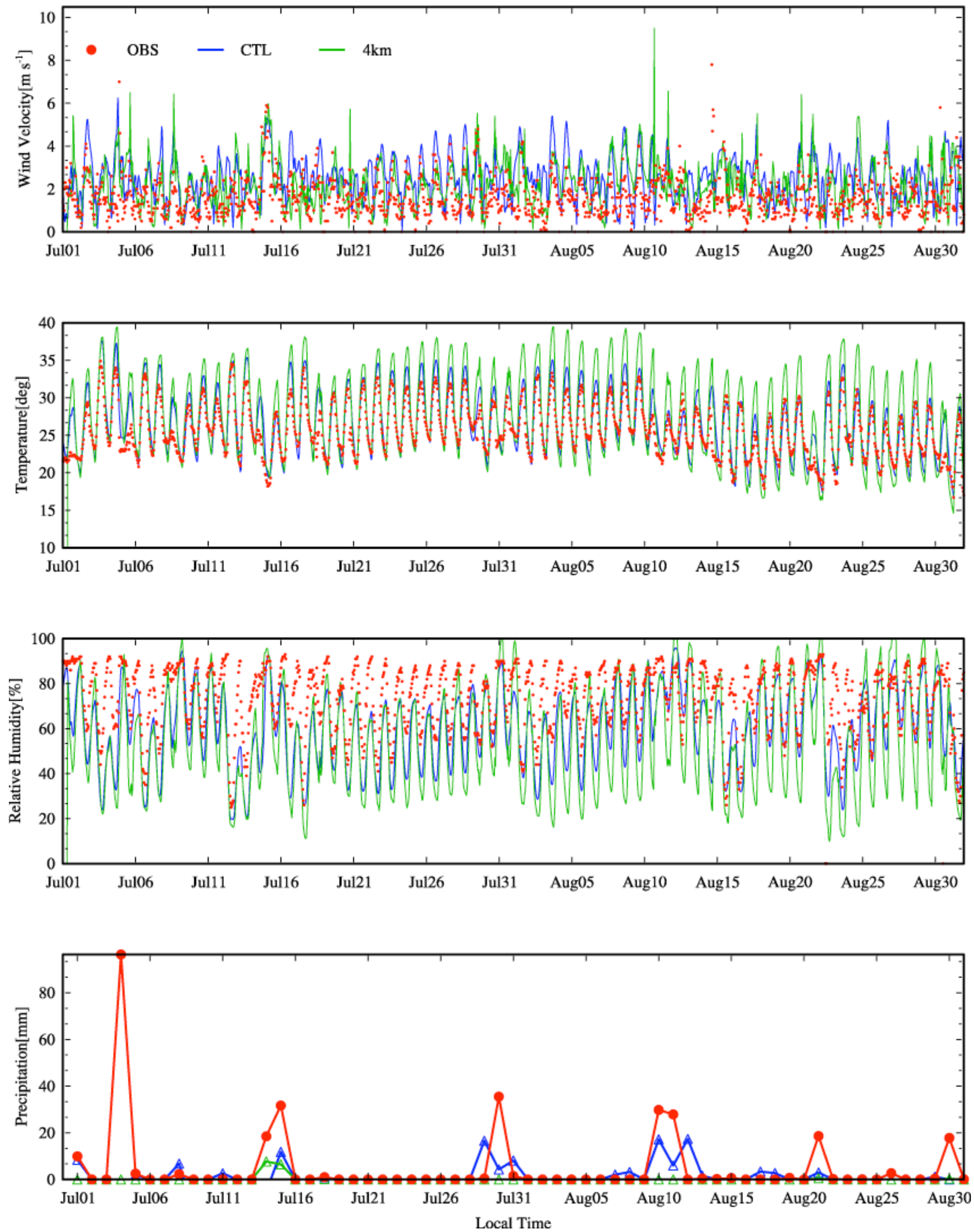


Figure S5 (1)-(7). Comparison of model outputs at surface with observed hourly wind speed, temperature, relative humidity and daily precipitation rate at surface at seven sites in Beijing.

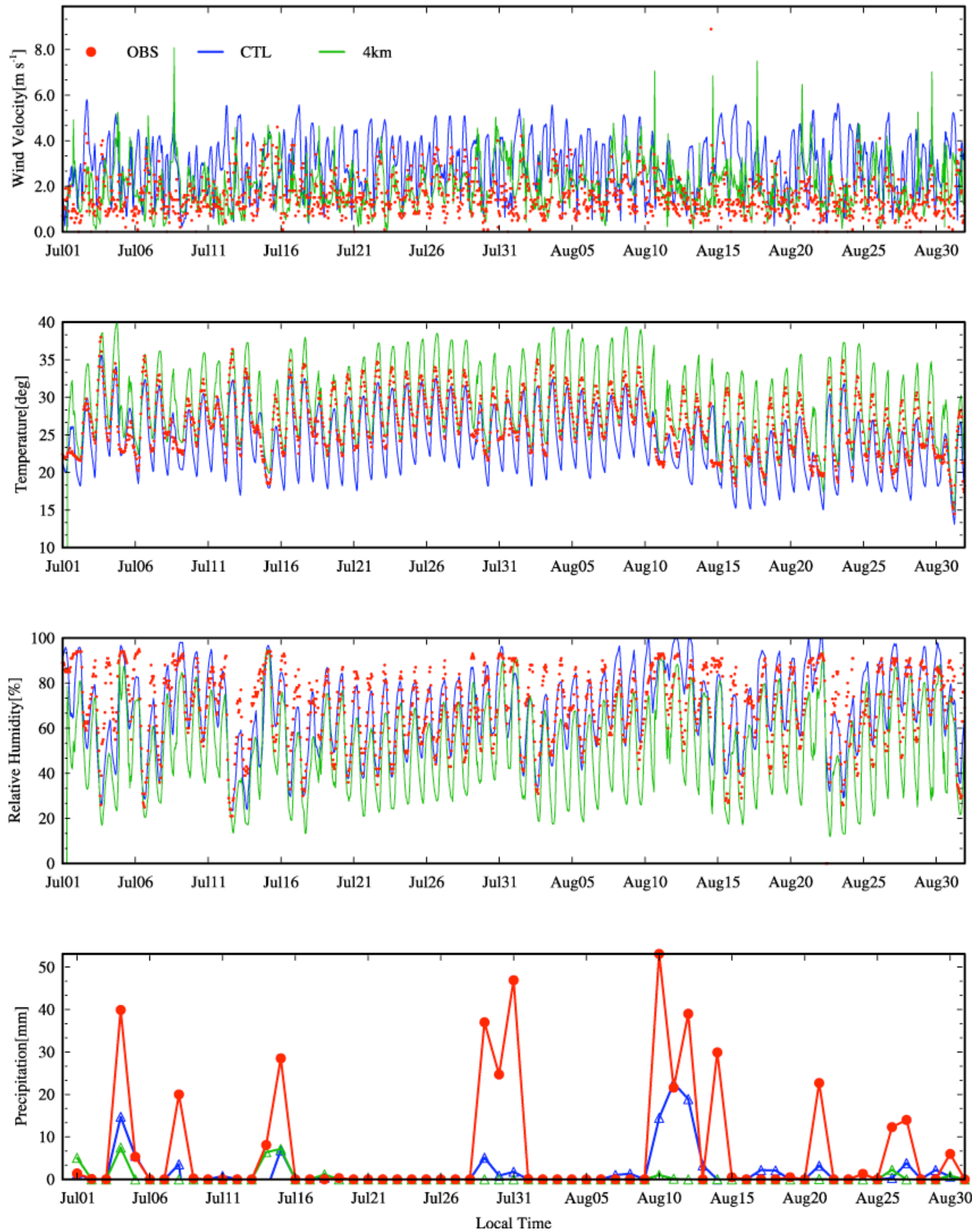
(2) Chaoyang


OBS
CTL
4km
Wind Velocity[m s-1]
Temperature[deg]
Relative Humidity[%]
Precipitation[mm]
Jul01
Jul06
Jul11
Jul16
Jul21
Jul26
Jul31
Aug05
Aug10
Aug15
Aug20
Aug25
Aug30
Local Time

(3) Fangshan

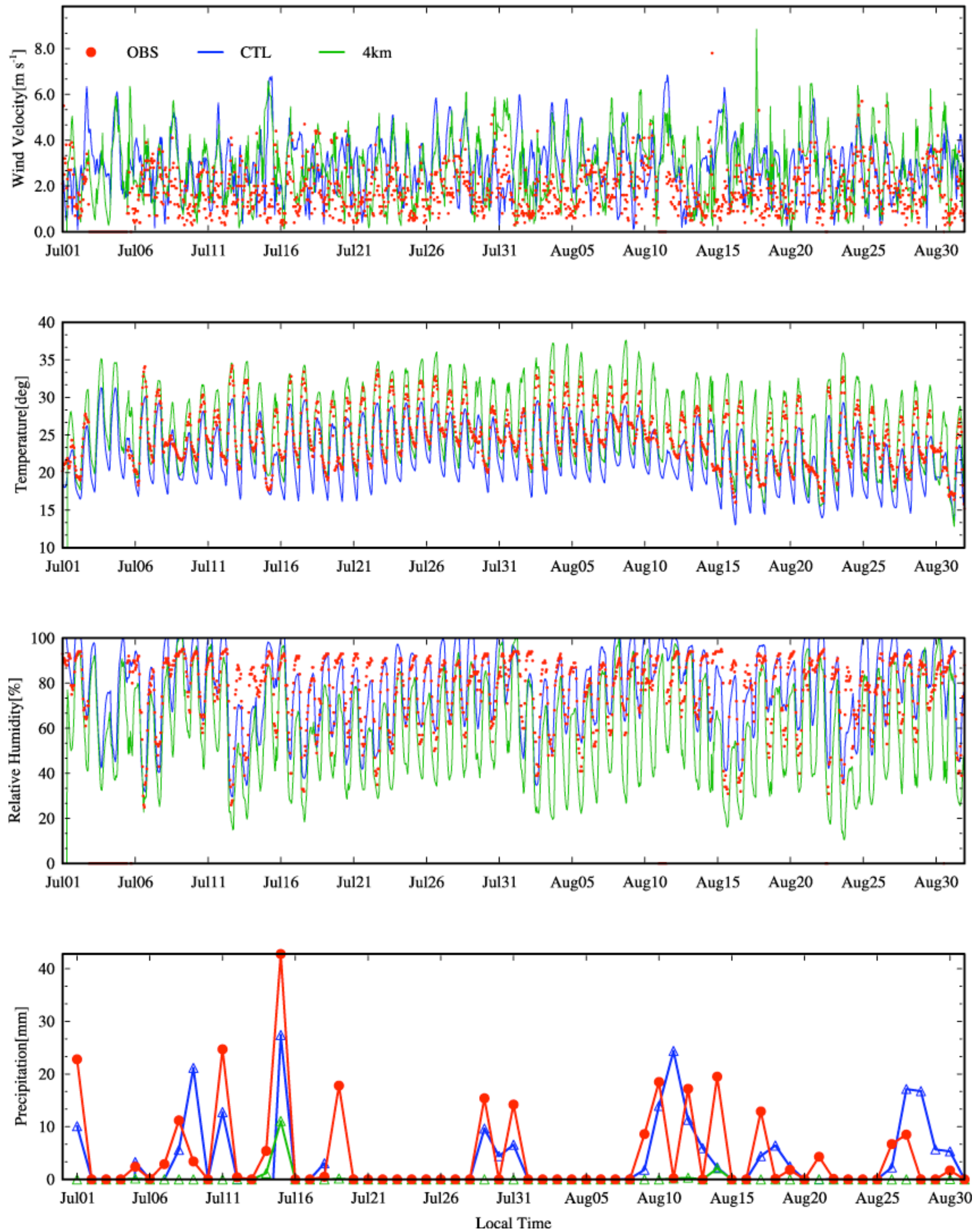

OBS
CTL
4km
Wind Velocity[m s-1]
Temperature[deg]
Relative Humidity[%]
Precipitation[mm]
Jul01
Jul06
Jul11
Jul16
Jul21
Jul26
Jul31
Aug05
Aug10
Aug15
Aug20
Aug25
Aug30
Local Time

(4) Haidian



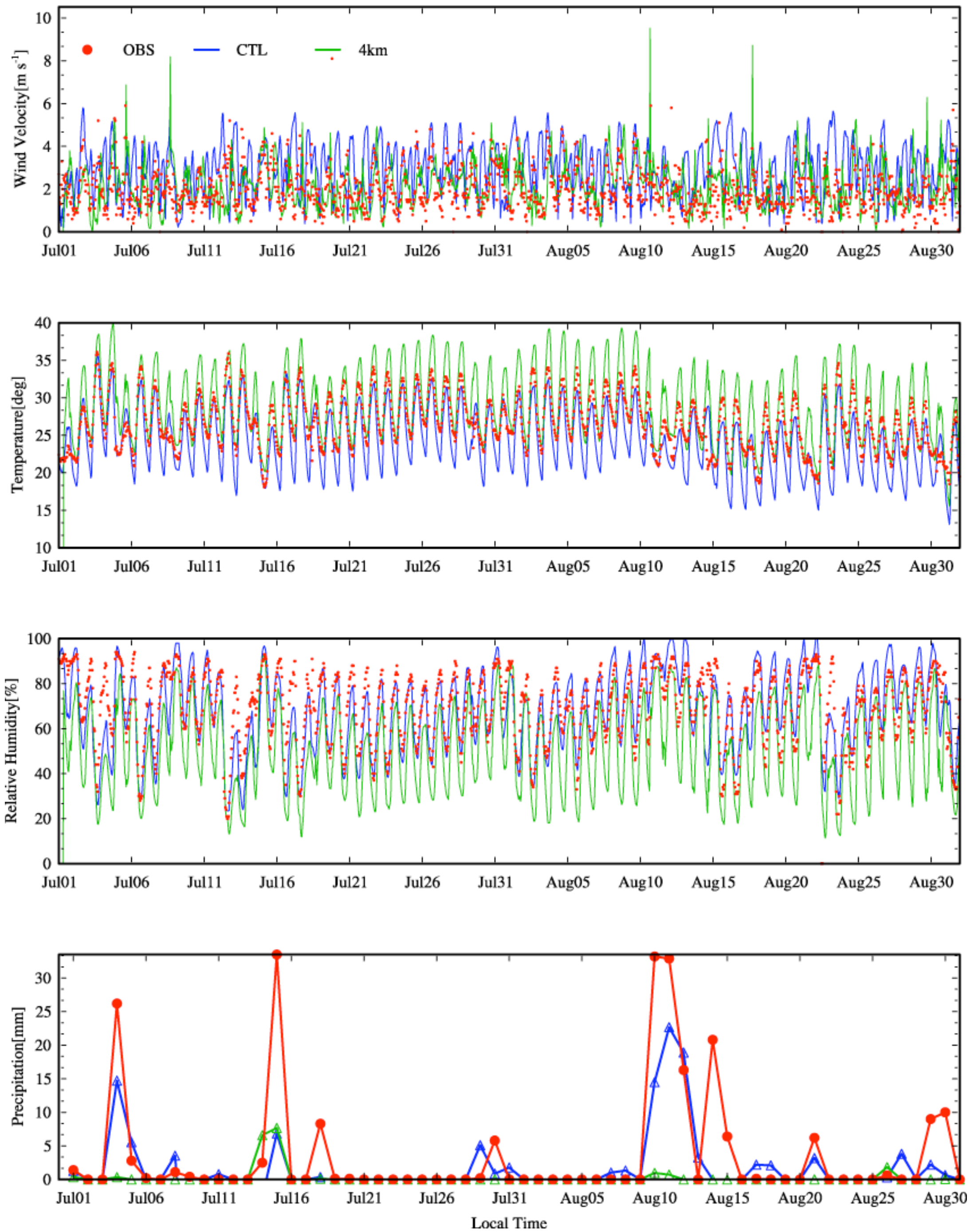
OBS
CTL
4km
Wind Velocity[m s⁻¹]
Temperature[deg]
Relative Humidity[%]
Precipitation[mm]
Jul01 Jul06 Jul11 Jul16 Jul21 Jul26 Jul31 Aug05 Aug10 Aug15 Aug20 Aug25 Aug30
Local Time

(5) Jinhaihu



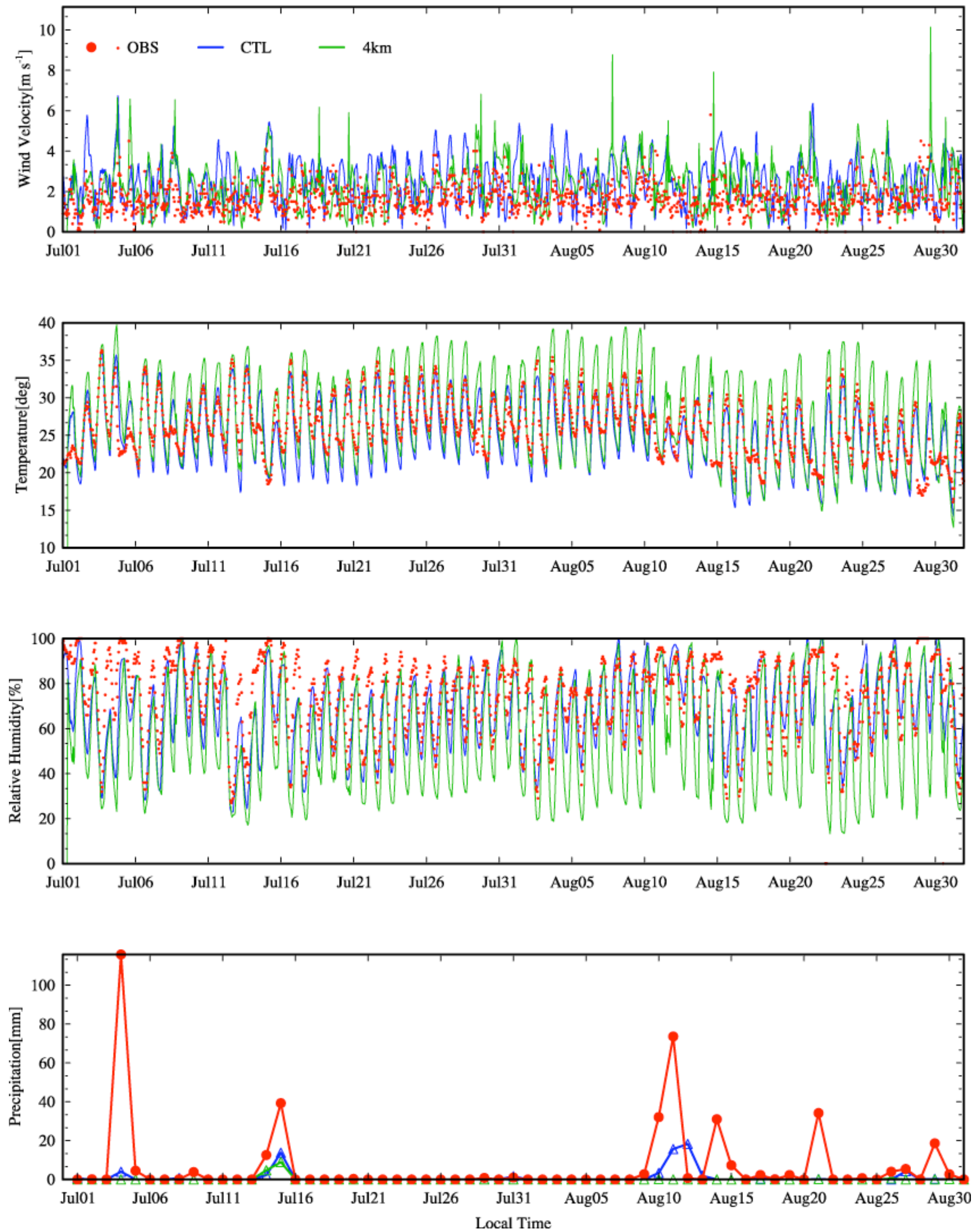
OBS
CTL
4km
Wind Velocity[m s-1]
Temperature[deg]
Relative Humidity[%]
Precipitation[mm]
Jul01
Jul06
Jul11
Jul16
Jul21
Jul26
Jul31
Aug05
Aug10
Aug15
Aug20
Aug25
Aug30
Local Time

(6) Nanjiao



OBS
CTL
4km
Wind Velocity[m s-1]
Temperature[deg]
Relative Humidity[%]
Precipitation[mm]
Jul01
Jul06
Jul11
Jul16
Jul21
Jul26
Jul31
Aug05
Aug10
Aug15
Aug20
Aug25
Aug30
Local Time

(7) Shunyi



OBS
CTL
4km
Wind Velocity[m s-1]
Temperature[deg]
Relative Humidity[%]
Precipitation[mm]
Jul01
Jul06
Jul11
Jul16
Jul21
Jul26
Jul31
Aug05
Aug10
Aug15
Aug20
Aug25
Aug30
Local Time