The City College of New York

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A high-resolution modeling study of a heat wave-driven ozone exceedance event in New York city and surrounding regions

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Presented on
Nov-30-2017

Outline

- Motivation and Objectives
- Model and Data
- Results and Discussion
- Summary
- Future work

Motivation

- O_3 is one of the major air pollutants in New York and surrounding areas.

- Heat wave is defined as the daily maximum temperature higher than 32 °C and last for more than three days , and is one of the major factors causing O_3 exceedance events (daily 8-hr max > 70 ppb) in this region.

- High temperature and relevant meteorological factors are one of the major contributors to unusually high O_3 concentrations during the heat wave events (Pu et al., 2017; Fiala, 2003; Emberson et al., 2003; Wu et al., 2017).

Motivation (cont.)

- The conventional measurements are not sufficient to quantify the impact of heat wave on ozone exceedance events, and numerical models are useful for better understanding the mechanisms for the regional transport and local chemical productions. (Eric Chaxel et al., 2009) .

- New York has complex urban terrain and easily affected by the land-sea breezes. It is important to predict O_3 exceedance events with a high-resolution numerical model which includes the urban land surface processes.

- It is critical to utilize high resolution of numerical model(s) for improving air quality forecasting in a coastal megacity like New York.

Objectives

- to improve air quality forecasting especially for ozone exceedance events with high-resolution simulations.

- to quantify the contributions of chemical reactions associated with heat waves to ozone production during a heat wave-driven ozone exceedance event.

Model and Data

❖ WRF-Chem

Table 1 Parameter settings in WRF-Chem model

Domain	1,2,3
Version	3.7.1
Time	16May 2017 to 20 May 2017
Initial Meteorological Field	Fnl (1°×1°) time: 6h 26 levels in vertical (1000hPa to 10hPa)
Horizontal Resolution	12km 4km 1.333km
P-Top	50 hPa
Horizontal Grid Point	110×85 100×73 88×61
Vertical Layers	46

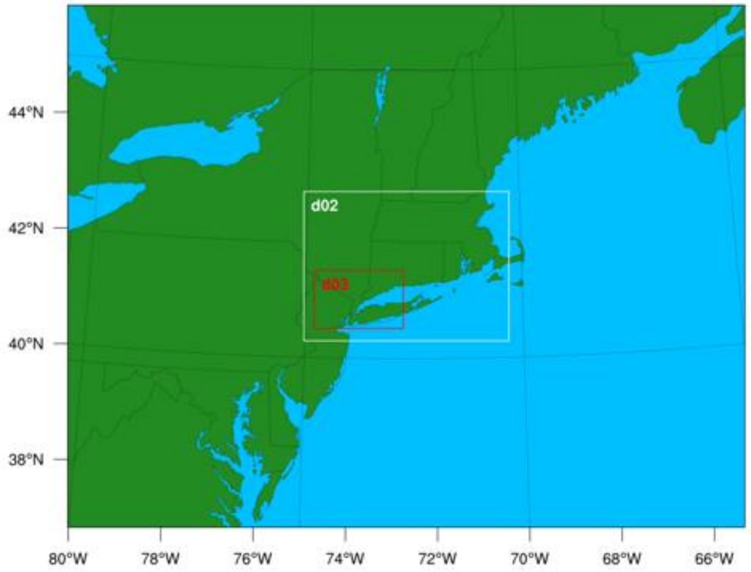


Fig. 1 Nested domains of WRF-Chem and observational sites.

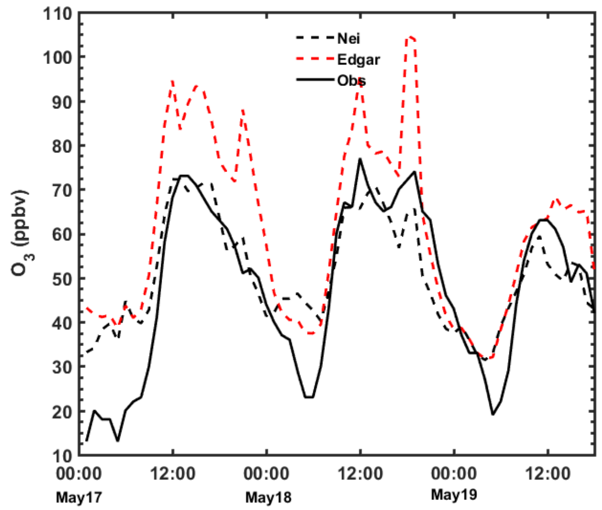
Model and Data (cont.)

- Initial and boundary conditions for chemical fields in WRF-Chem are generated from the MOZART-4/GEOS-5 simulations (http://www.acd.ucar.edu/wrf-chem/mozart.shtml)
- Meteorological ICs and BCs are from the NASA GMAO GEOS-5 simulations
- Horizontal resolution：1.9°×2.5°
- Vertical：56 layers
- Anthropogenic emissions based on David Streets' inventory for ARCTAS and the fire emissions from FINN-v1 (Wiedinmyer et al., Geosci. Model Devel, 2011).

Model and Data (cont.)

- **2011 NEI (National Emissions Inventory) emission data**
- available for the contiguous 48 state of the United States, southern Canada and northern Mexico
- Grid spacing: 4km
- NEI (Hourly emissions) different to edgar emis
  1°×1°)
- Background : Gocart
- Fire emission: Wildfire Automated Biomass Burning

  Algorithm (WF_ABBA)



Results and discussion

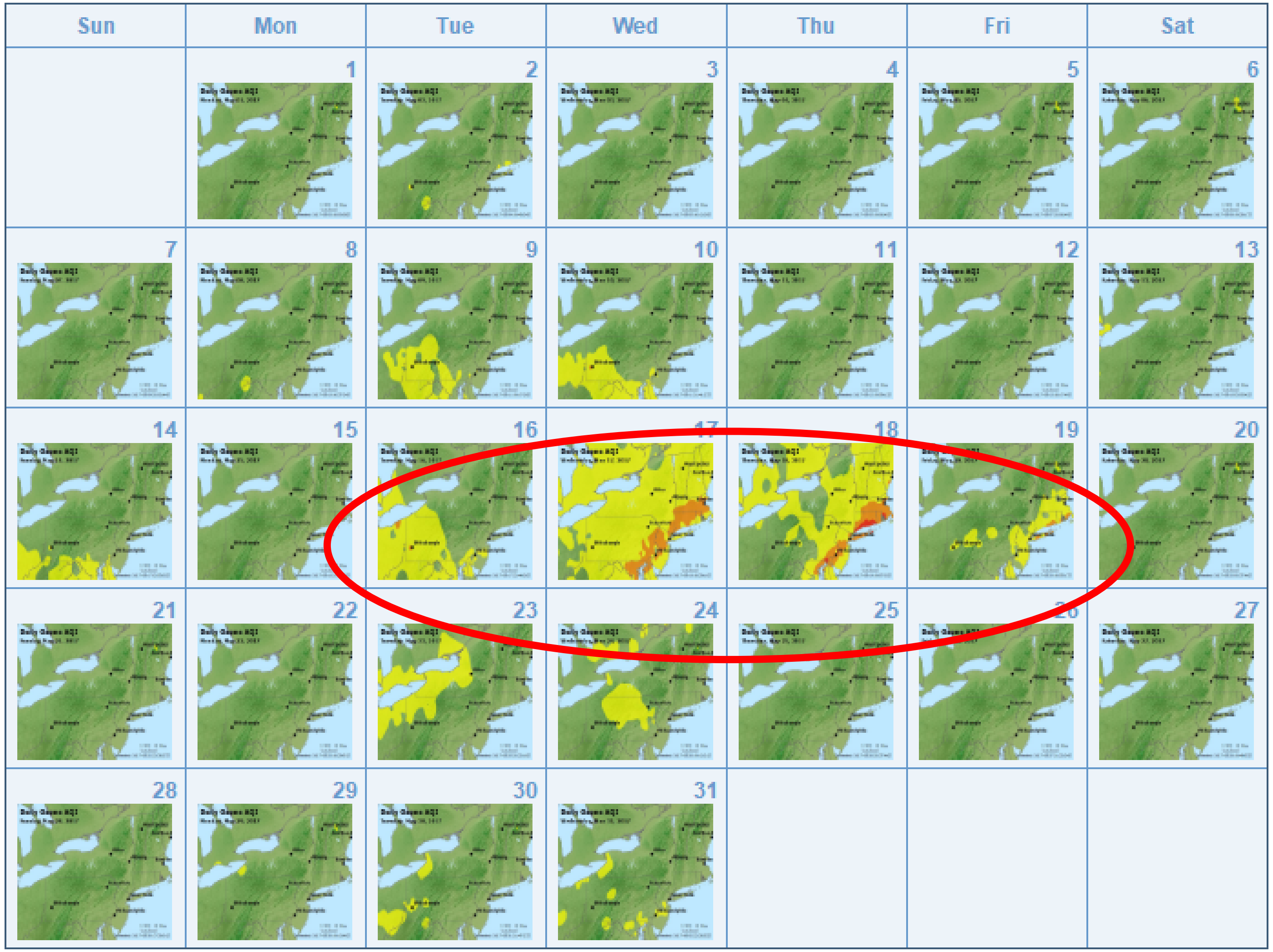


Fig.2 Monthly overview of ozone AQI over New York-Pennsylvania-New Jersey in May 2017 （data access: Environmental Protection Agency, US）.

Results and discussion

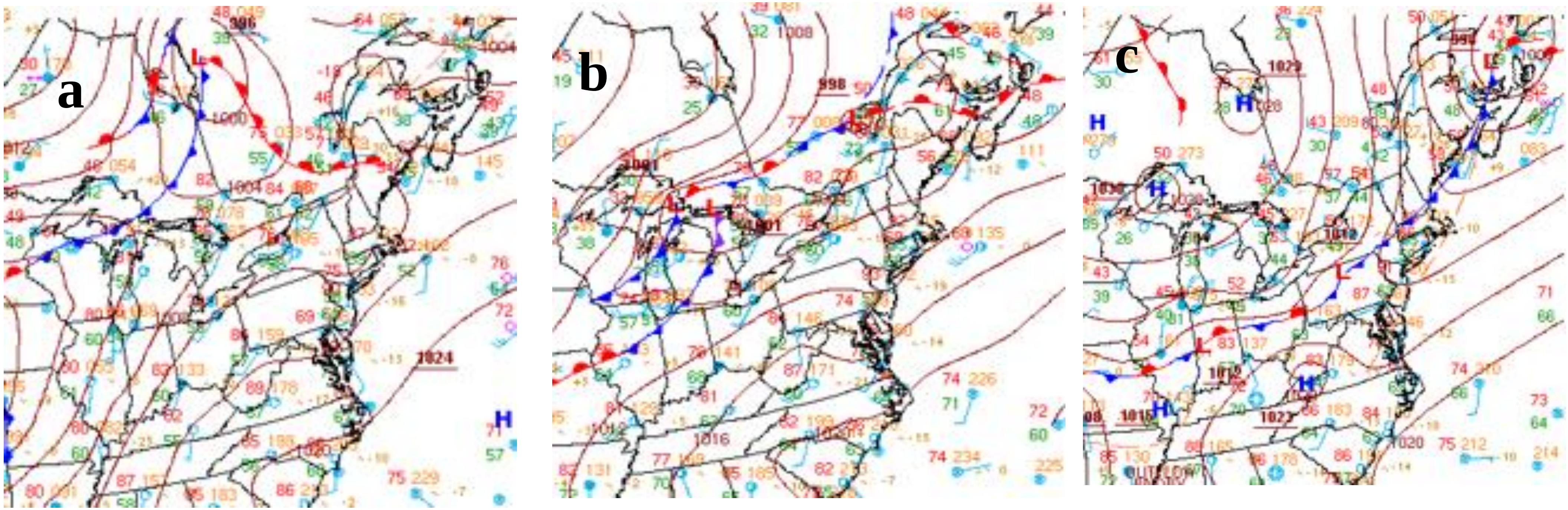


Fig. 3 Surface weather chart at 1400 LST on May 17-19 2017 (from NOAA North American analysis).

Controlled by the high pressure system and influenced by winds from ocean during the heat wave.

WRF/Chem-predicted T_2

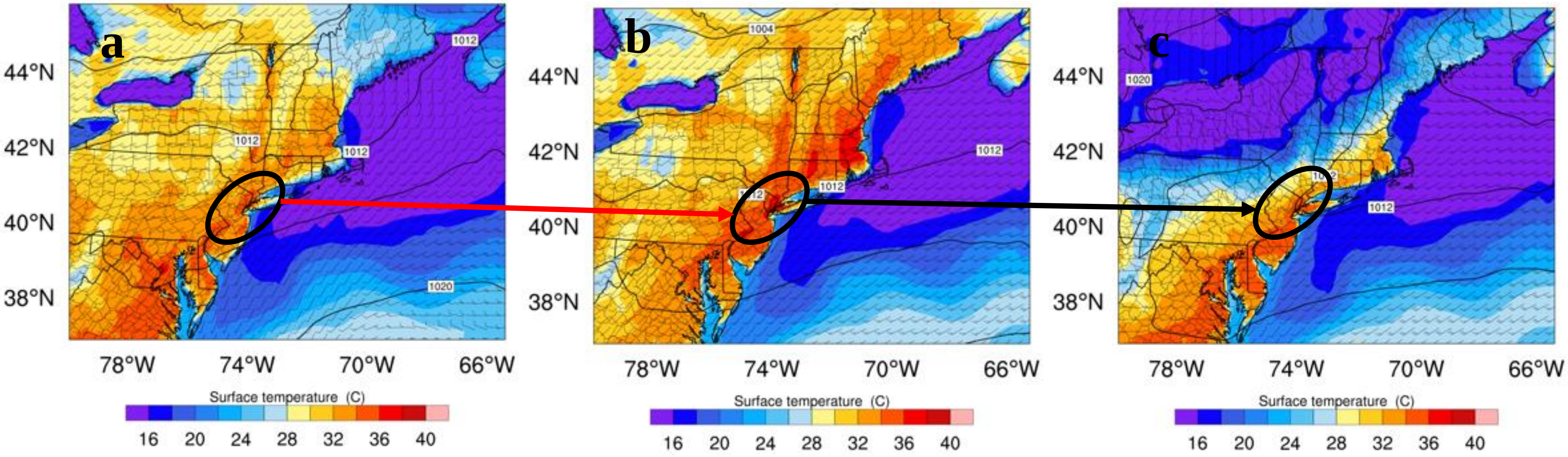


Fig.4 Predicted T_2 at 14 EST on May (a) 17, (b) 18, and (c) 19, 2017.

Surface temperature exceeded 36°C on May 18 in New York, which is consist with the area of high ozone concentrations.

Evaluations of WRF/Chem-predicted O_3

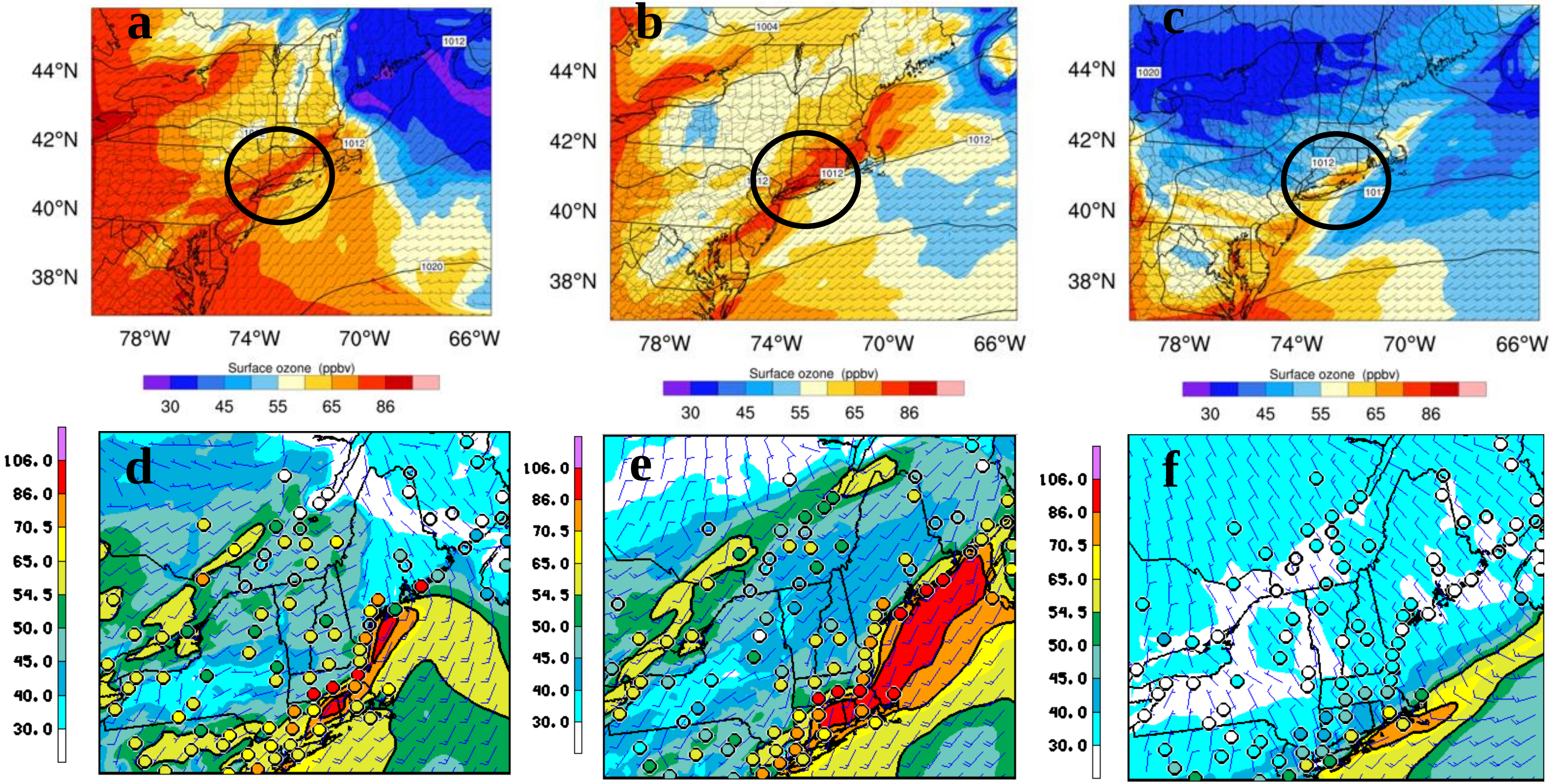
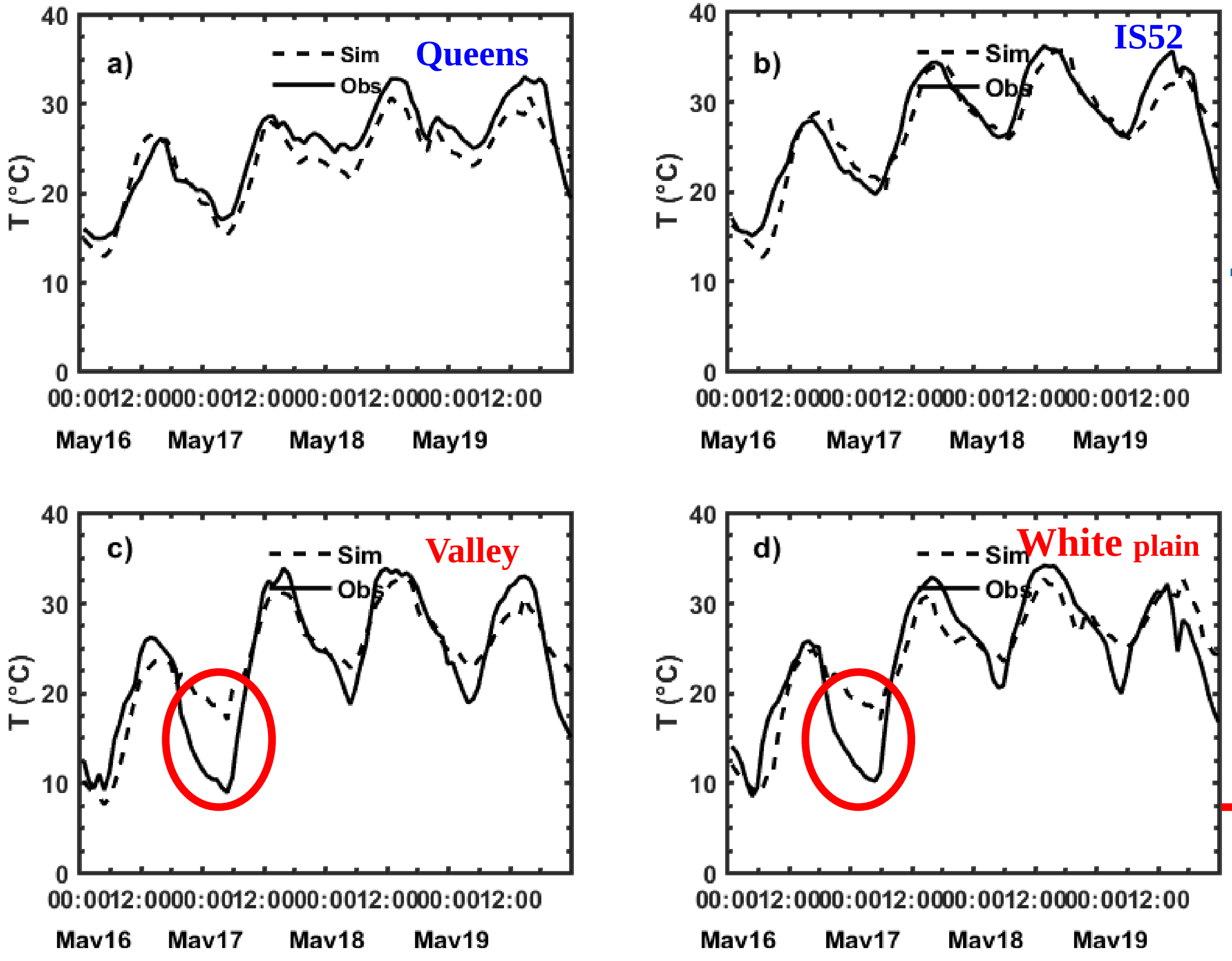


Figure 5. Comparisons of WRF/Chem simulated surface O_3 with the NOAA NMMB-CMAQ products and AirNow observational data on May 17-19, 2017 (a-c: WRF/Chem; d-f: NMMB-CMAQ; dotted points: AirNow)

WRF/Chem simulated T_2



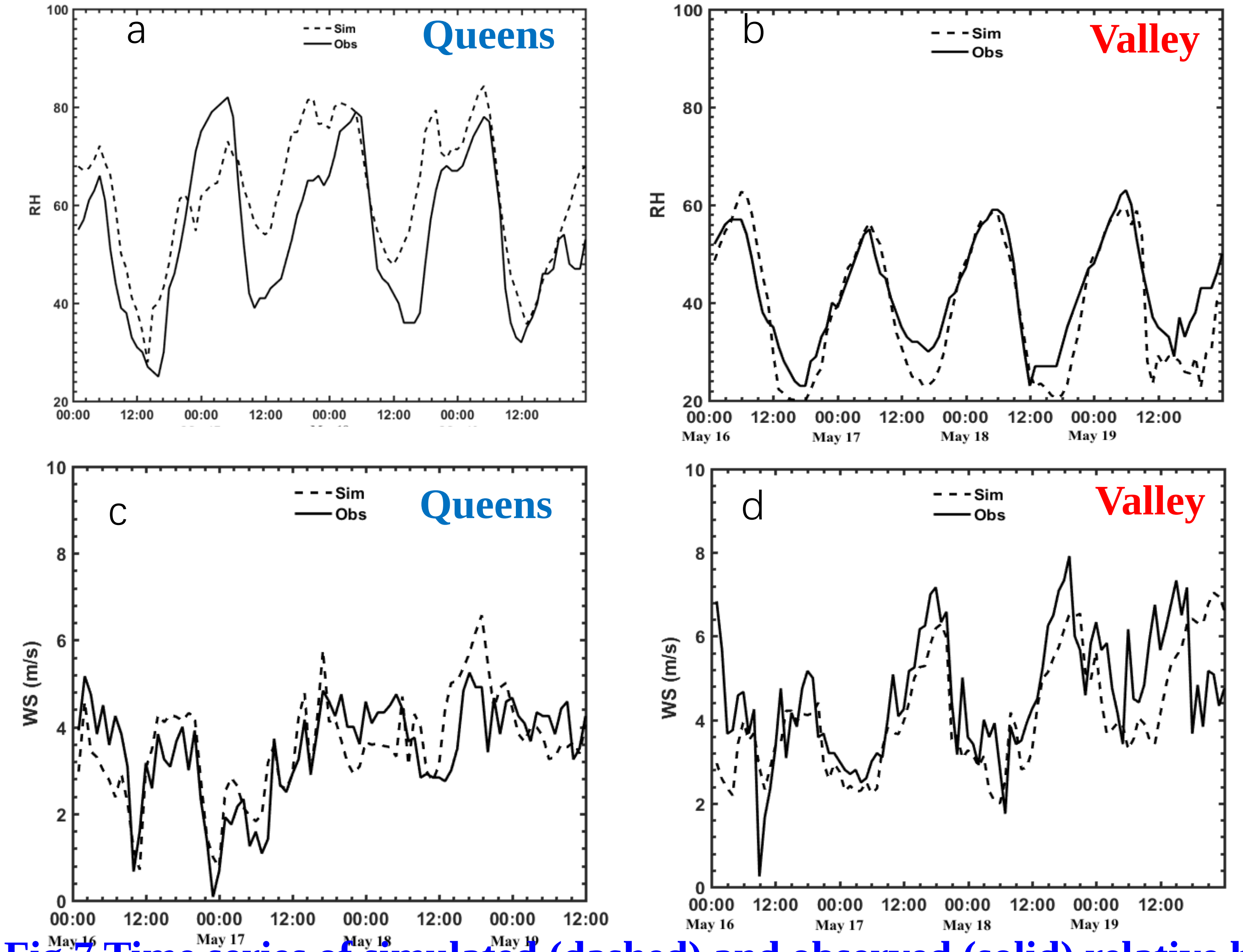
A heat-wave event occurred on May17. and the model overestimates the nighttime minimal at rural sites.

urban

rural

Fig.6 Time series of simulated (dashed) and observed (solid) surface temperature(°C) at a) Queens, b) IS52, c)Valley, d) White plain.

WRF/Chem simulated RH and WS



The RH was increased greatly and weak-moderate levels wind speeds at urban sites during heat wave event.

Fig.7 Time series of simulated (dashed) and observed (solid) relative humidity at a) Queens, b) Valley and wind speed c)Queens, d) Valley.

Statistical evaluations of T_2, RH, and WS

Tab 2. The correlation coefficient, root-mean-square and mean bias errors of measured and predicted at New York (p<0.0001)

	R	RMSE	MB
T(Queens)	0.94	2.22	-1.42
T(IS52)	0.94	2.22	-1.42
T(valley)	0.88	3.64	0.56
T(white plains)	0.86	2.2	-1.42
RH(Queens)	0.81	11.8	7.5
RH(valley)	0.93	6.1	-2.9
WS(Queens)	0.76	0.82	0.05
WS(valley)	0.66	1.3	-0.5

Over-predictions in urban areas
under-predictions in rural areas.

Evaluation of predicted NOx

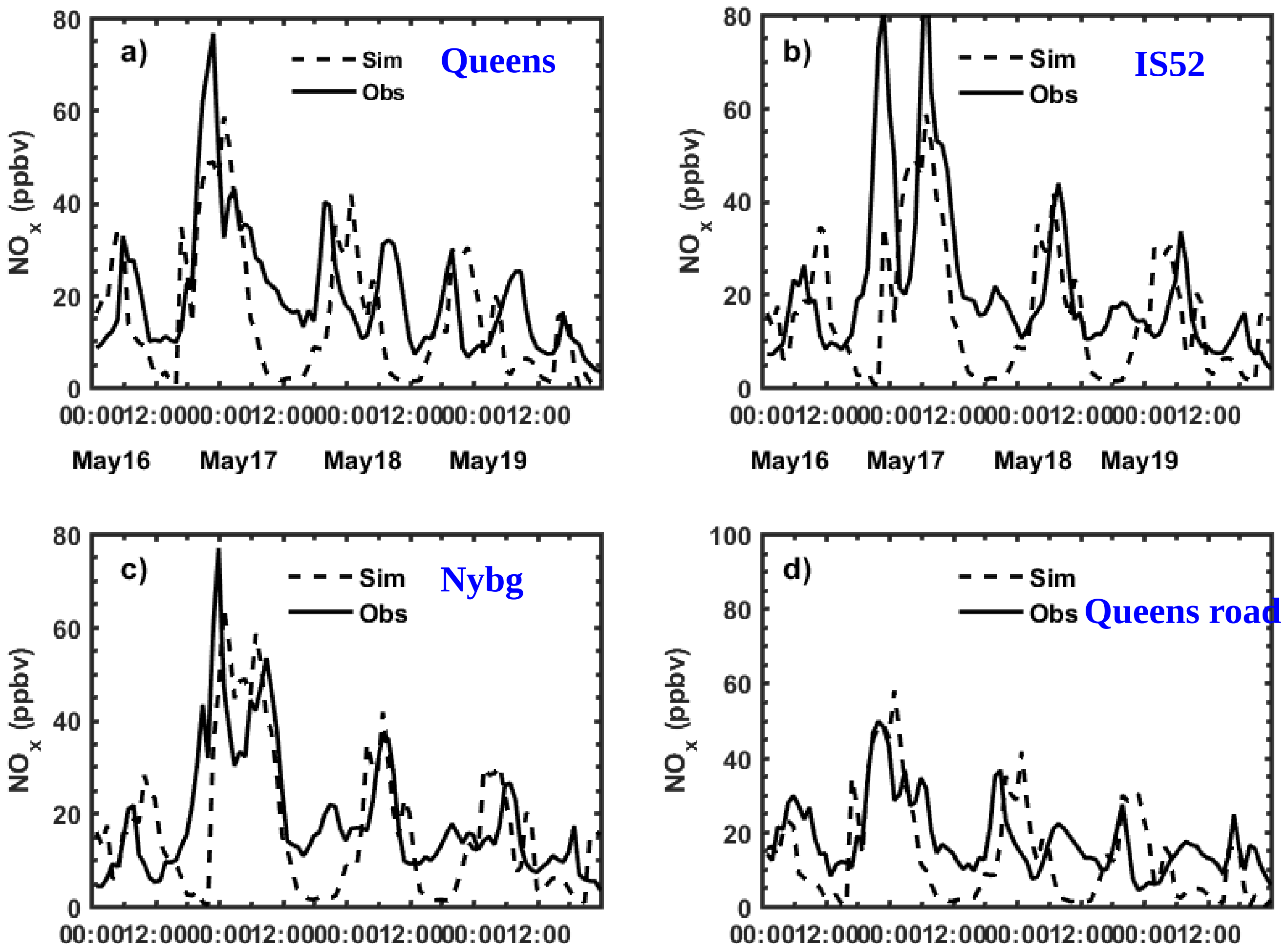


Fig.8 Time series of simulated (dashed) and observed (solid) surface NO_x (ppbv) at a) Queens, b) IS52, c)Nybg, and d) Queens road

Statistical evaluations of NOx

Tab 3. The correlation coefficient, root-mean-square and mean bias errors of measured and predicted at New York ($p<0.0001$)

	R	RMSE	MB
NO_X(QUEENS)	0.57	13.78	-4.83
NOx(IS52)	0.5	20.27	-8.47
NO_X(nybg)	0.64	15.29	-3.54
NO_X(queens road)	0.55	13.98	-4.83

Under-predicted NOx !

A comparison of simulated O_3 with observations

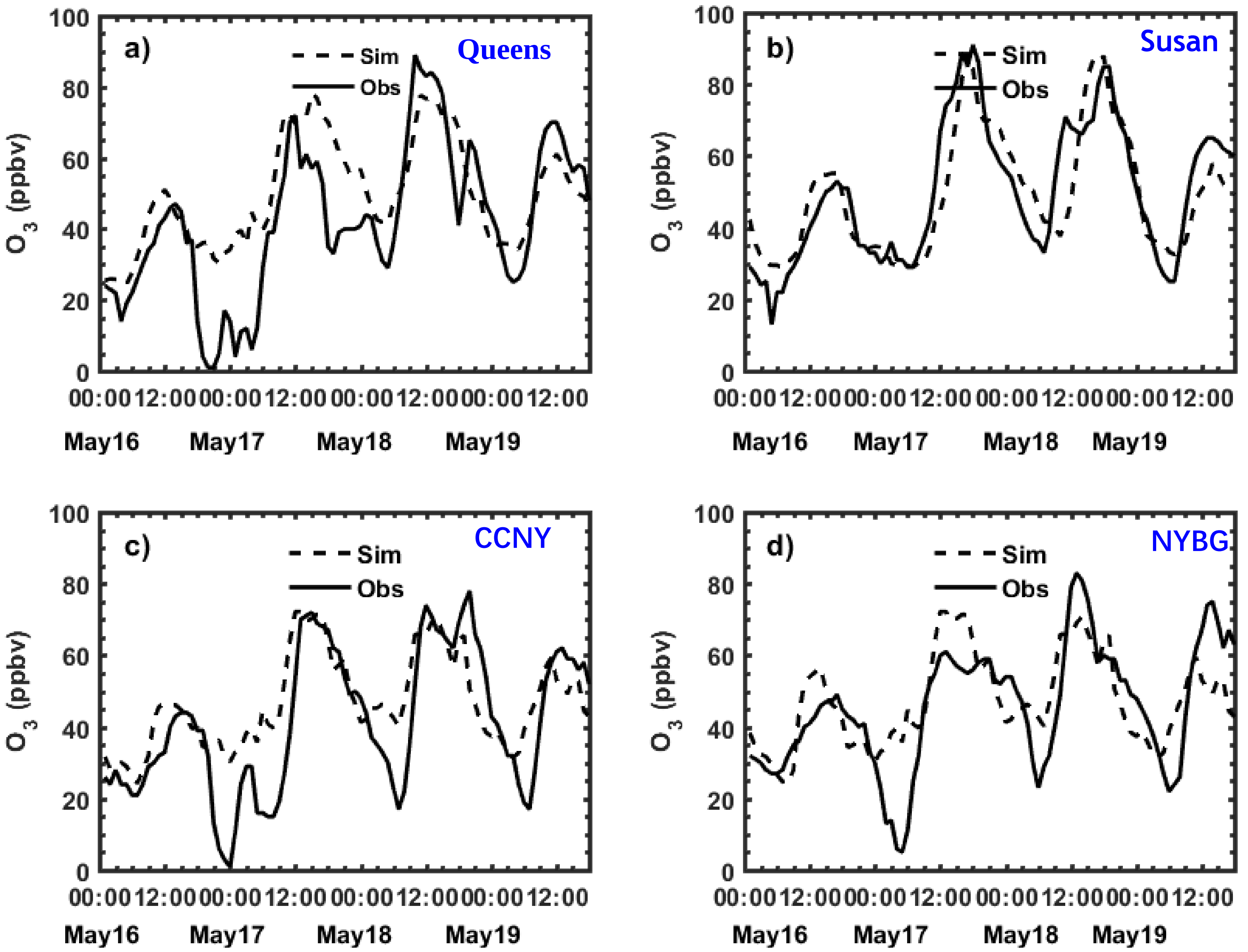


Fig.9 Time series of simulated (dashed) and observed (solid) surface O_3 at a) Queens, b) Susan, c) CCNY, and d) NYBG.

WRF/Chem captures the general shape of the diurnal cycle of ozone with minima in the early morning and maxima in the afternoon

A comparison of simulated O_3 with obs (cont.)

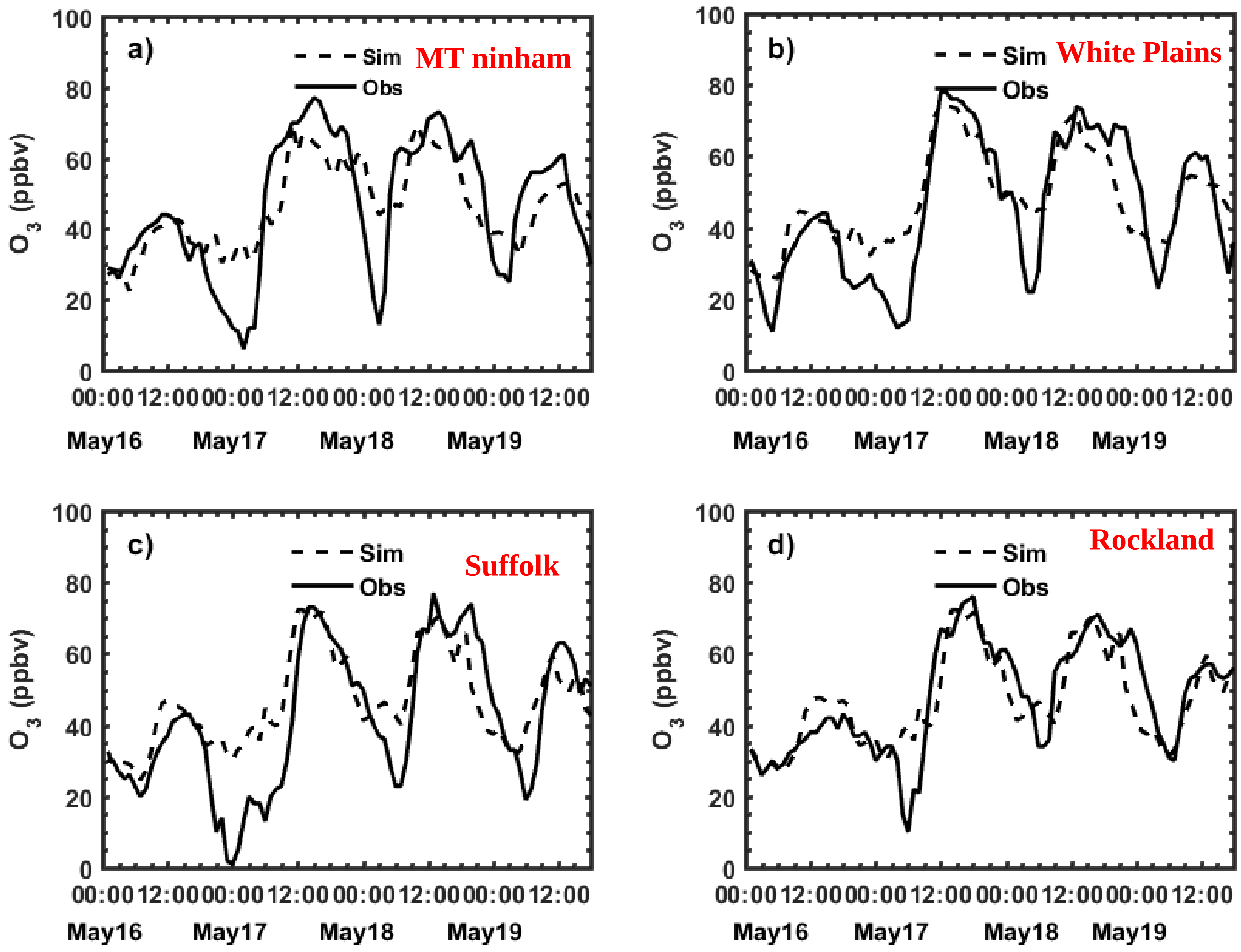


Fig.10 Time series of simulated (dashed) and observed (solid) surface O_3 at a) MT Ninham, b) White Plains, c) Suffolk, and d) Rockland.

A comparison of simulated O_3 with obs (cont.)

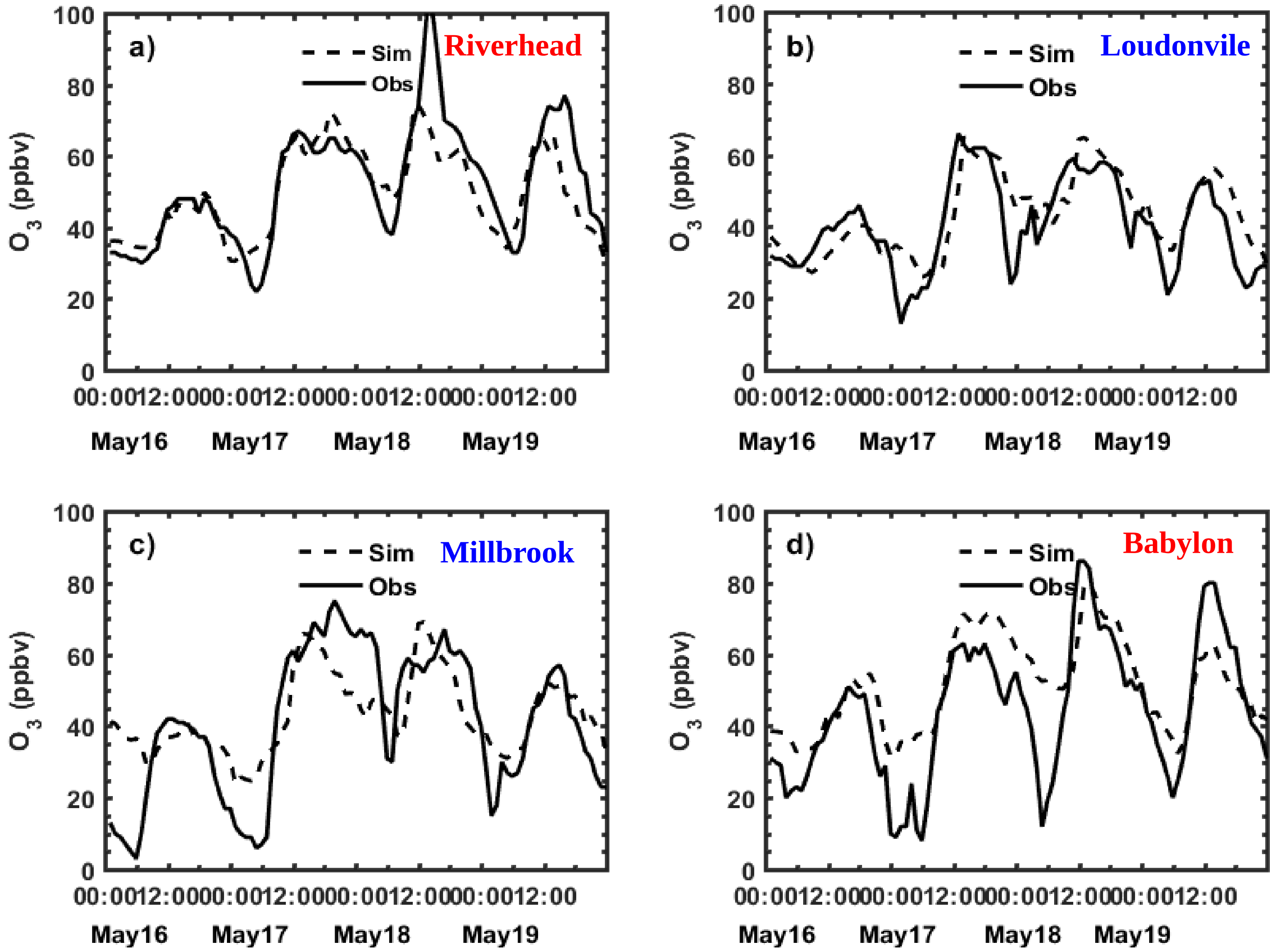


Fig.11 Time series of simulated (dashed) and observed (solid) O_3 at a) Riverhead, b) Loudonvile, c) Millbrook, and d) Babylon.

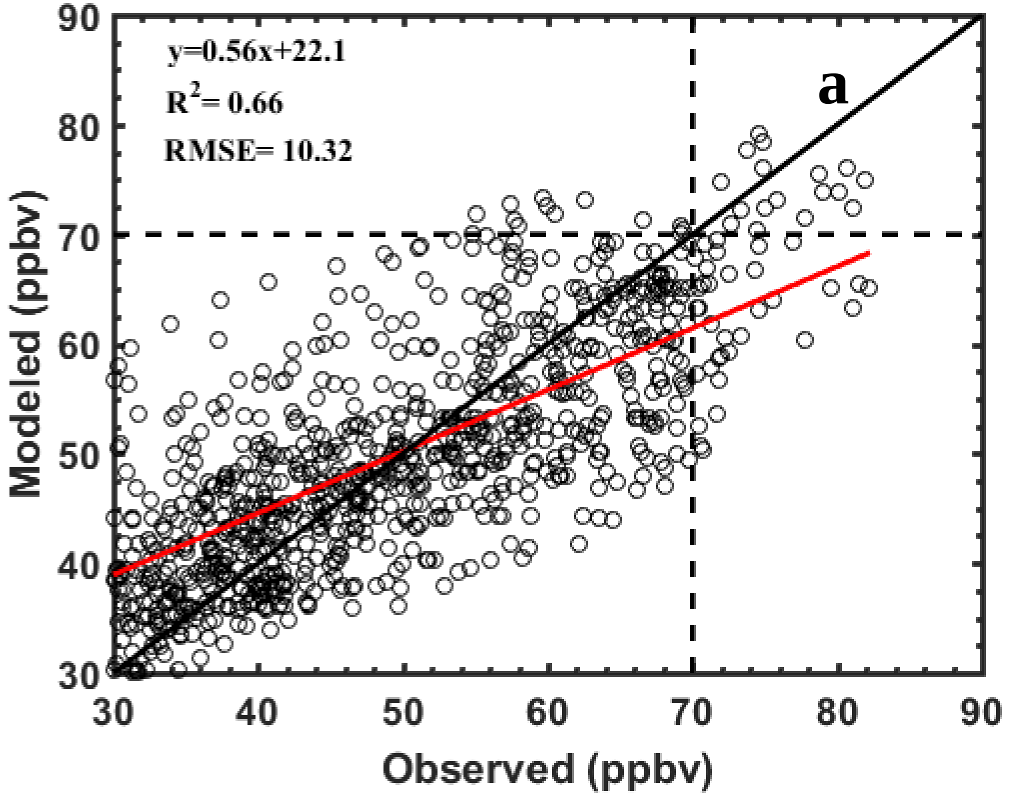
The model over-predicted at nighttime and captured the ozone peak quite well.

Statistical evaluations of O_3 predictions

Tab 4. The correlation coefficient, root-mean-square and mean bias errors of measured and predicted at New York ($p<0.0001$)

	R	RMSE	MB
Queens	0.78	14.8	7.23
Susan	0.86	9.5	-0.54
Ccny	0.78	13.2	5.35
NYBG	0.7	12	2.06
MT Ninham	0.82	11.56	0.6
White plains	0.86	10.57	2.46
Suffolk	0.81	-7.23	-0.72
Rockland	0.83	12.27	-0.61
Riverhead	**0.84**	**9,43**	**-2.32**
Loudonvile	**0.77**	**8.6**	**2.9**
Millbrook	**0.77**	**13.6**	**2.1**
babylon	**0.81**	**8.17**	**-2.32**

Evaluations of daily 8-hr max O_3 predictions



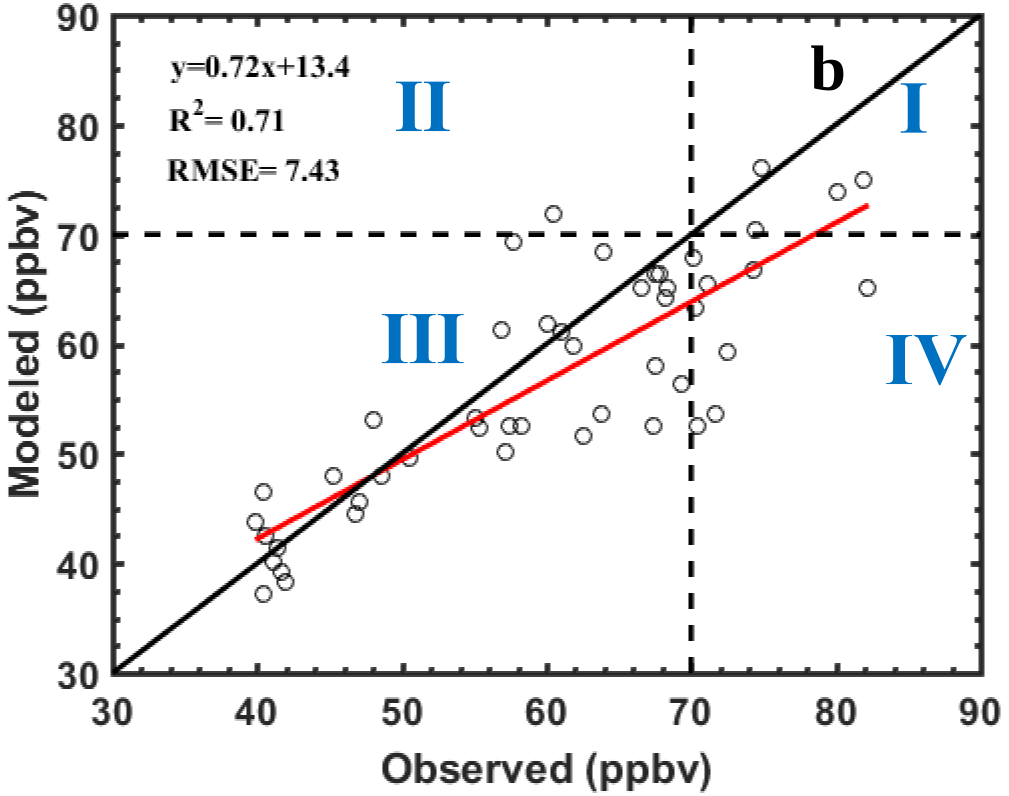


Figure 12. Scatter plot of the simulated vs. observed (a) 8-h average and (b) daily daily 8-hr maxima O_3 on May 17-19 2017 (Note: exceedance thresholds: 70 ppbv)

Over-predcited at low concentration (<50.0 ppbv) but under-predicted at high concentrations (> 50.0 ppbv)

Evaluations of daily 8-hr max O_3 predictions

- Ⅰ ：a forecast 8 h exceedance (>70 ppbv) that did occur
- Ⅱ : a forecast 8 h exceedance that did not occur
- Ⅲ : a forecast 8 h nonexceedance that did occur
- Ⅳ : a nonforecast 8 h exceedance that did occur

$$FAR=\left(\frac{II}{I+II}\right)\cdot 100\% = 2\%$$ (False alarm ratio)

$$CSI=\left(\frac{I}{I+II+IV}\right)\cdot 100\% = 31\%$$ (Critical success index)

FAR : the percentage of times an exceedance was forecast when none occurred
CSI : how well forecasted and measured exceedances were predicted

Results: backscatter Lidar

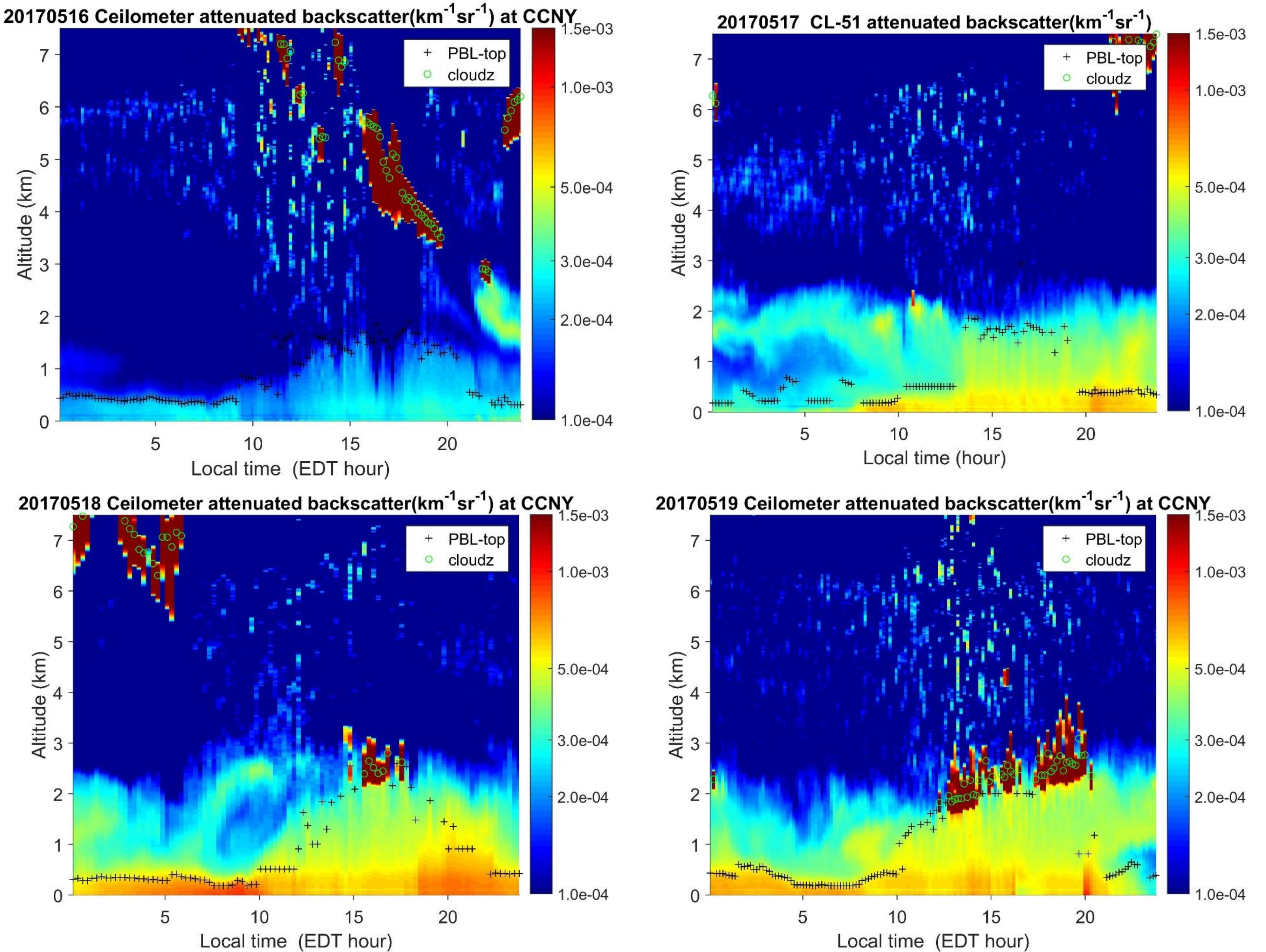
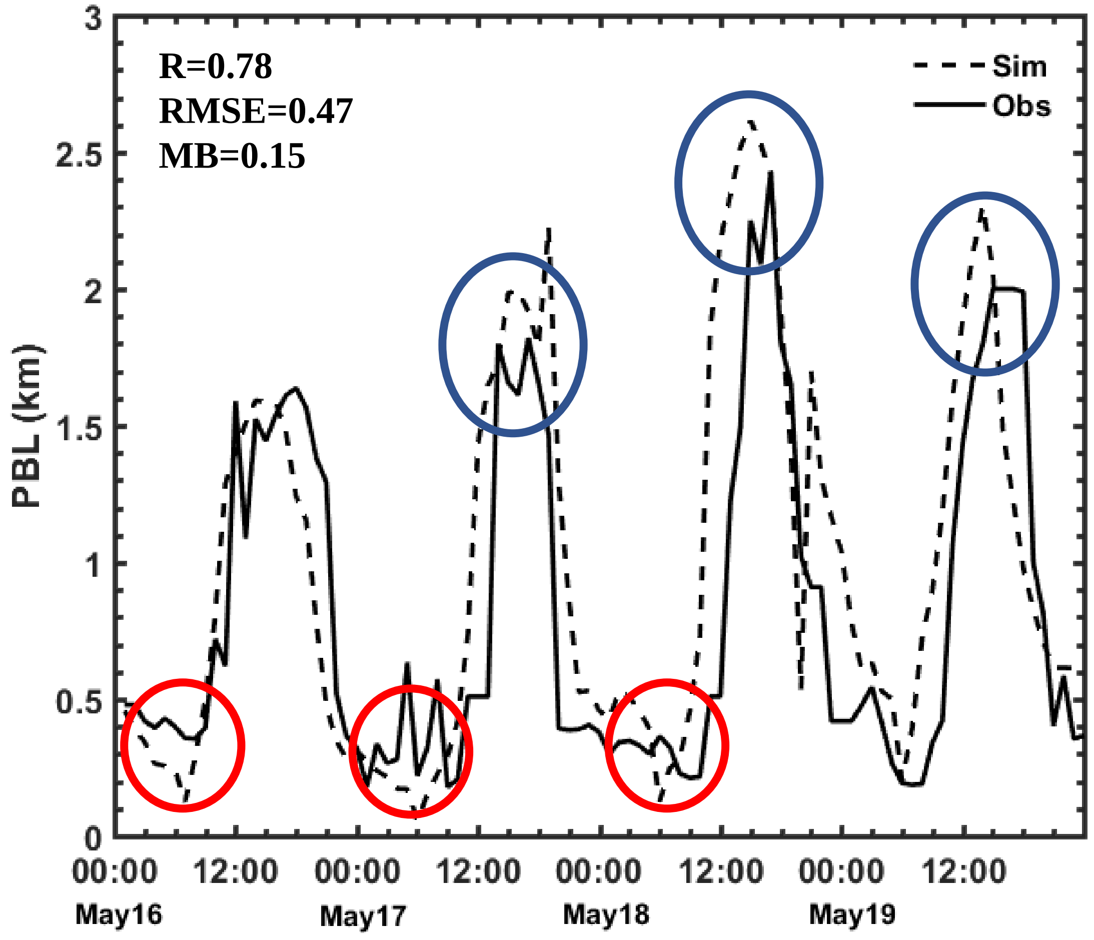


Fig 13. Spatial and temporal distribution of observed daily mean attenuated backscatter index at CCNY during May 16-19 2017 (Black cross: PBL height)

Results: planetary boundary layer



Underestimated at nighttime (cause ozone over-predictions)

Overestimated at daytime (under-predictions of ozone)

Fig.14 Time series of simulated (dashed) and observed (solid) planetary boundary layer height (km) at CCNY

Results: Statistical surface tem and ozone

Tab 5 Comparisons of daily 8-hr max and mean value of ozone and temperature at 12 stations

	O_3(mean)	O_3(max)	T(max)
16	**31.7 (26-39)**	**44**	**26.9**
17	**45.7 (38-56)**	**66**	**31.2**
18	**56.7 (52-64)**	**73**	**34.4**
19	**46.5 (42-53)**	**63**	**34.1**
16	**31.8 (26-37)**	**43**	**25.9**
17	**46.1 (41-50)**	**59**	**33.3**
18	**54.3 (48-61)**	**66**	**33.9**
19	**41.6 (36-47)**	**53**	**32.5**

25 ppbv

29 ppbv

7.5°C

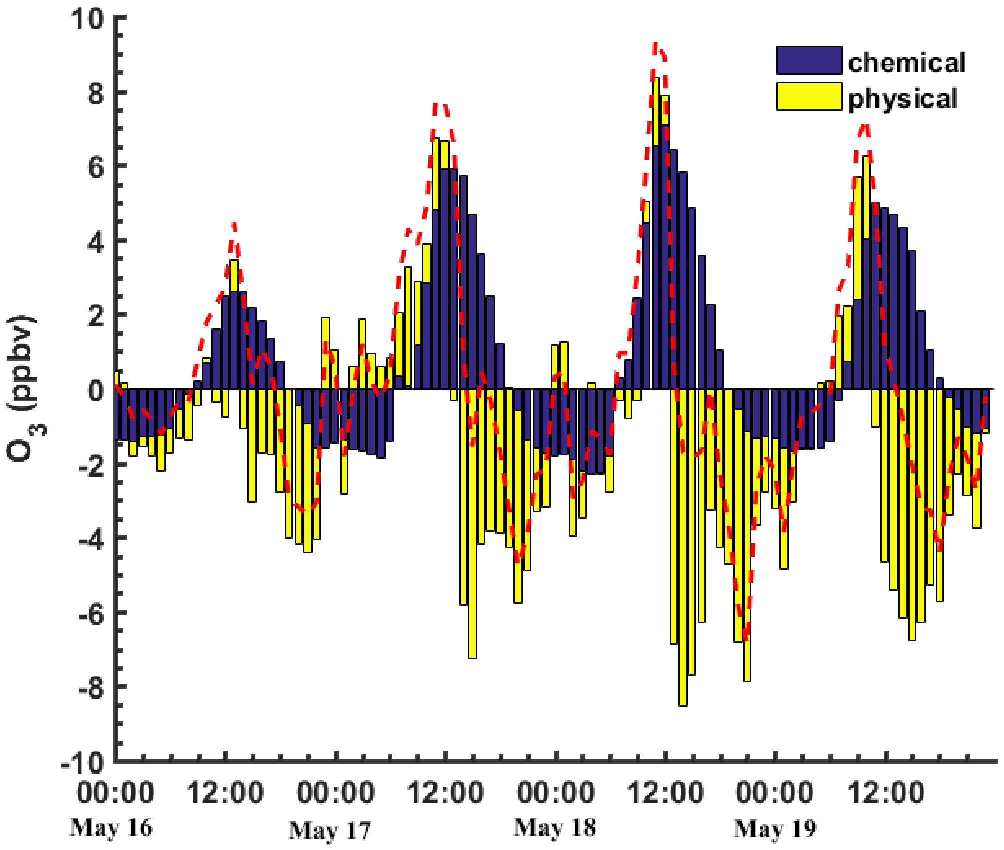
22.5 ppbv

23 ppb

8°C

Increase in O_3 in urban areas is higher than that in rural areas

Process analyses of O_3 change



The chemical production is increased gradually

Chemical contribution
16th: 13.7 ppbv
17th: 34.1 ppbv
18th: 39 ppbv
19th: 29.8 ppbv

Fig 15 O_3 change due to chemical reactions and physical transport in the surface layer at 12 sites on May 16-19, 2017 (Red dashed line: net change)

Summary

A high-resolution model WRF/Chem was successful to simulate the meteorological fields, NOx, and O_3 during a heat wave driven ozone exceedance event in New York and surrounding areas.

The daytime underestimation of O_3 is mainly attributed to the over-predicted boundary layer height and underestimated ozone precursors (e.g., Nox). The overprediction of nighttime O_3 is attributed to a high vertical mixing coefficient, underestimated boundary layer in the model.

The process analyses show the chemical production increased gradually and was the biggest contributor (i.e., 39 ppbv) to the ozone exceedance event during the heat wave related event.

Future work

- To develop a manuscript.
- To investigate the impact of long-range transport on the wildfire associated severe ozone pollution episode.
- To compare high resolution(1.3km) WRF/Chem simulations with the NOAA NMMB-CMAQ products (12km) for evaluating the impact of high resolution simulations on air quality forecasting, especially for the sea-breeze related air pollution events.



Thanks