Relating atmospheric N_2O concentration to agricultural emissions in the US Corn Belt in a meso-scale modeling framework

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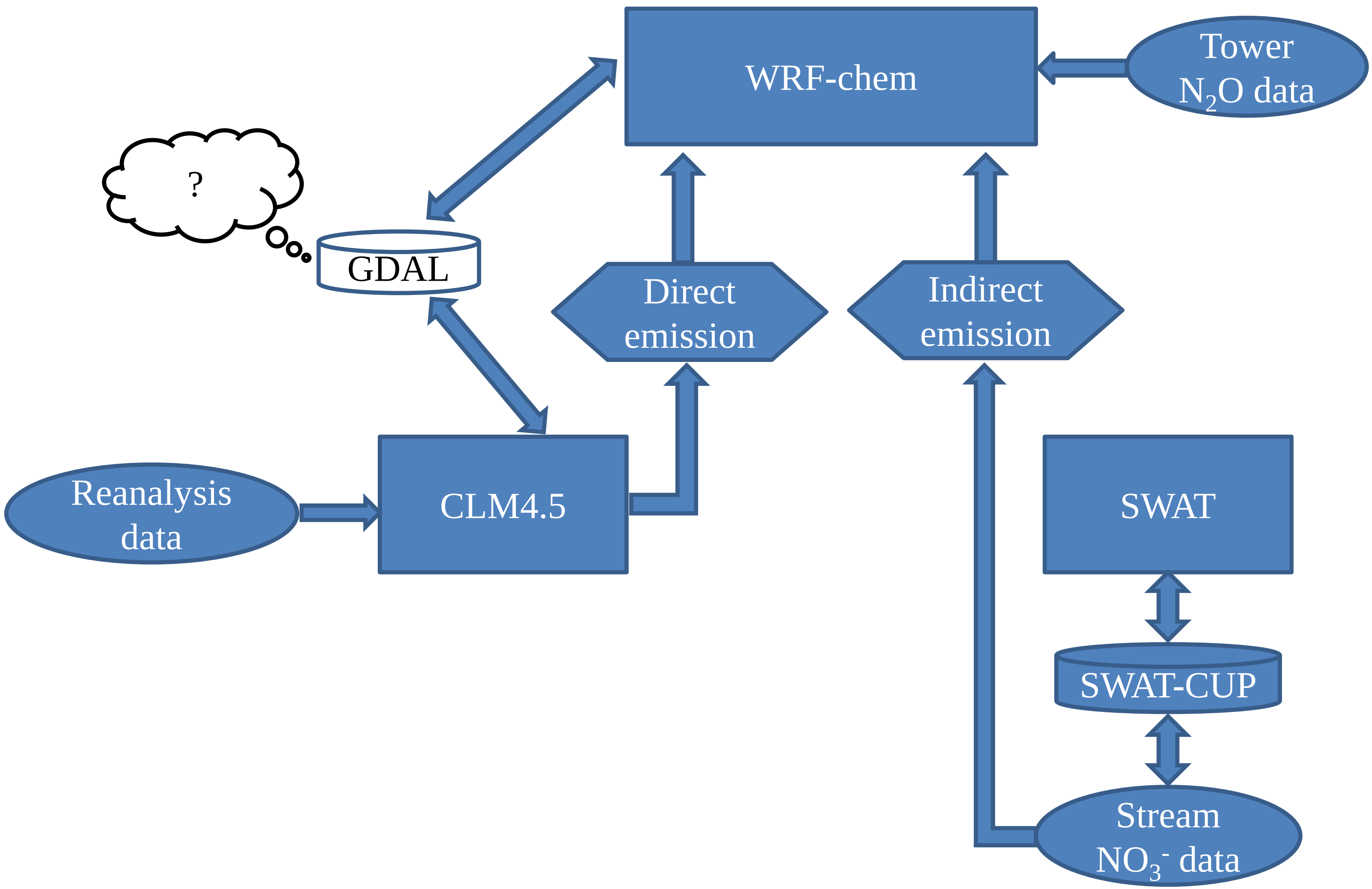
Background

- ❑ Bottom-up method
  total emission = N input or other activity data × emission factor for each pathway

- ❑ Top-down method
  total emission: determined with atmospheric N_2O mixing ratio observed on tall towers or aircraft.

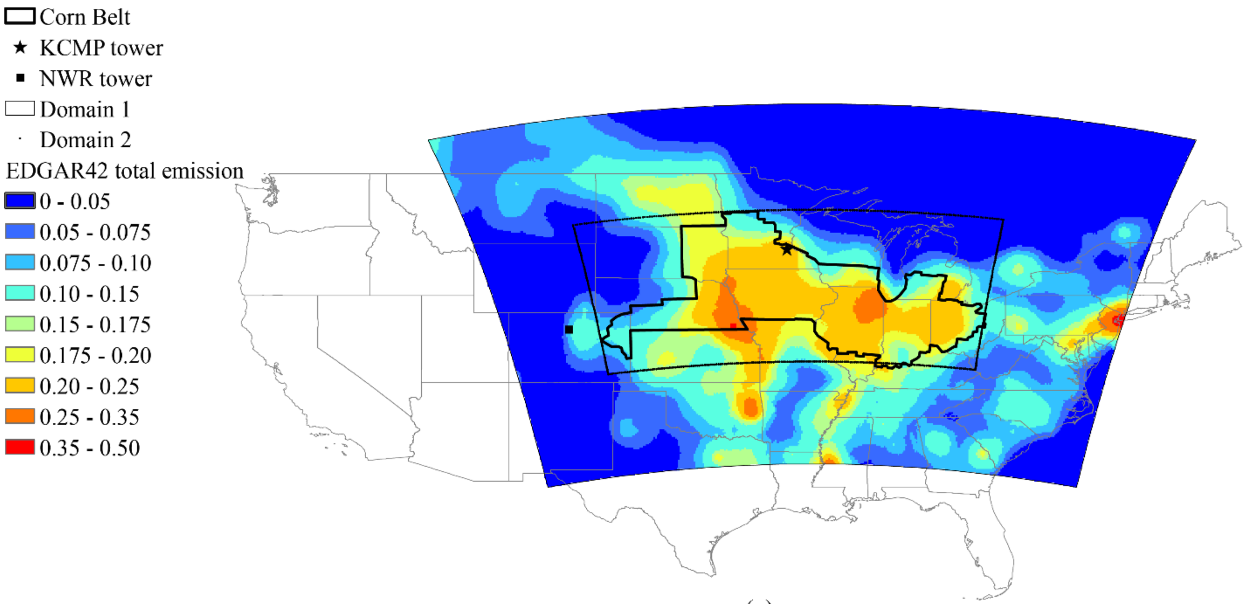
Top-down estimate >> Bottom-up estimate

Emission from headwater streams are severely underestimated

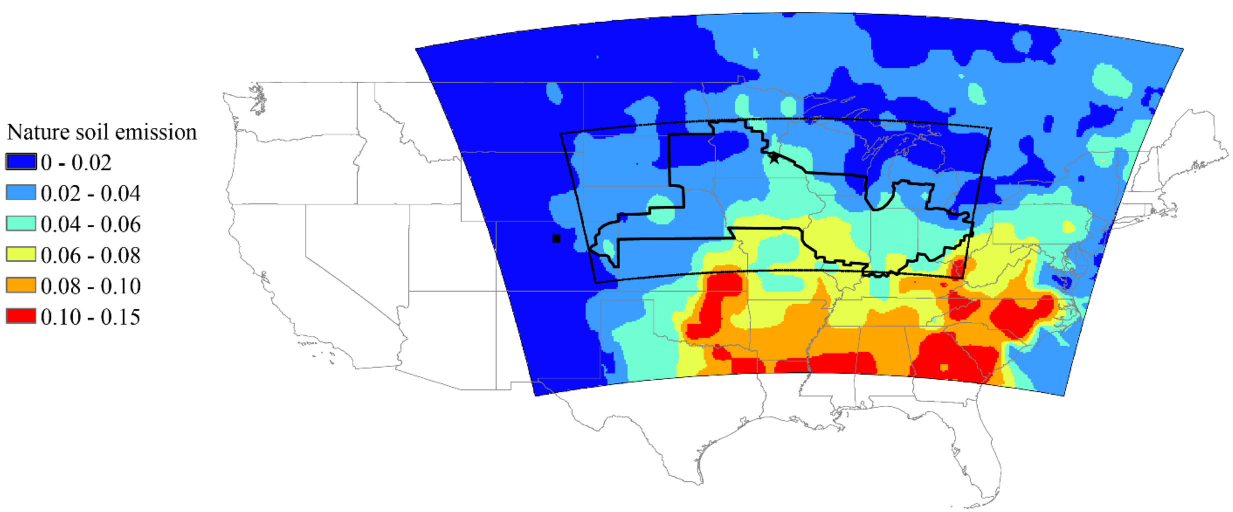


Schematic of the modeling framework

1. WRF-chem modeling and inverse analysis



(a)



(b)

Figure. Total EDGAR42 emission and nature soil emission for the study area.

1. WRF-chem modeling and inverse analysis

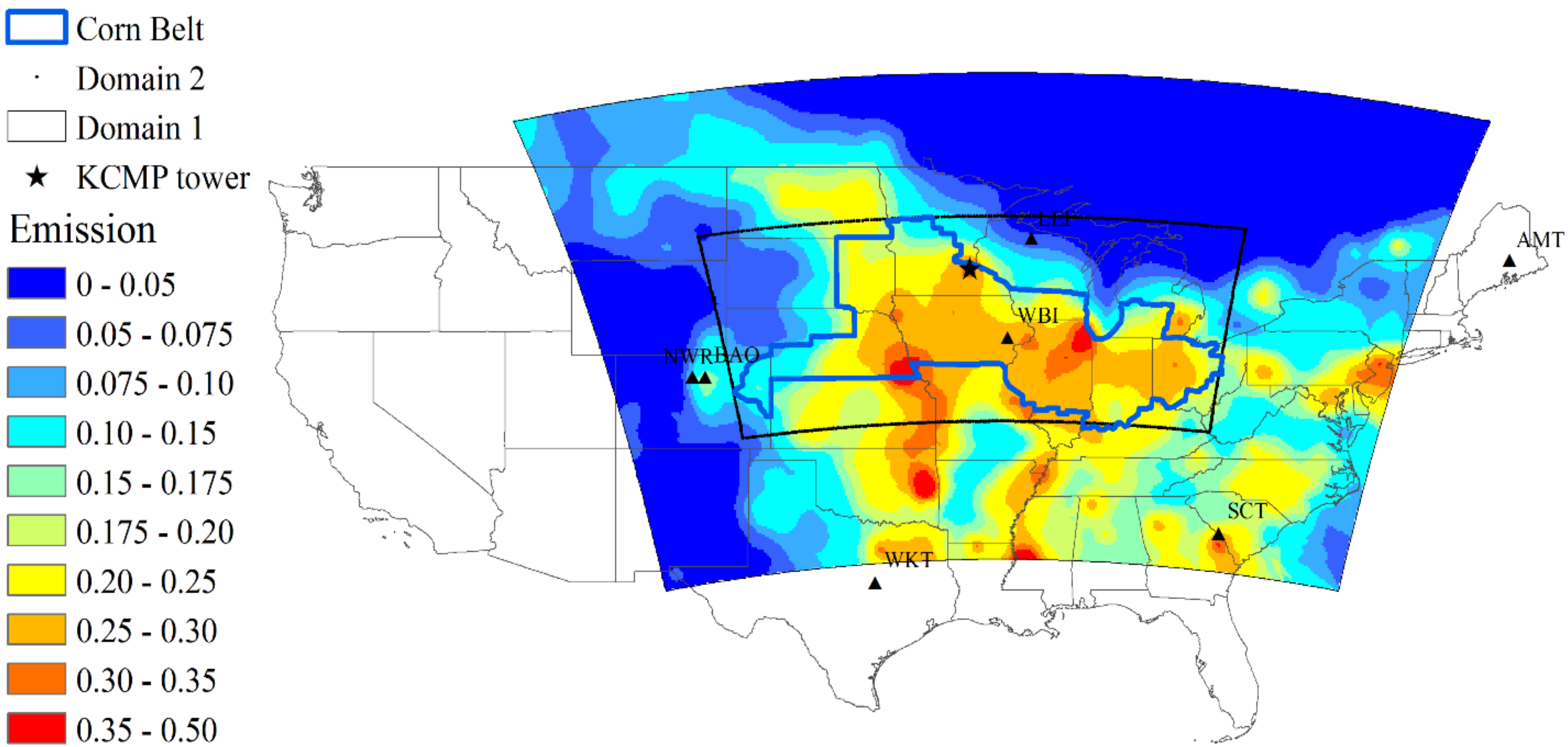


Fig. 1. Locations of the N_2O monitoring towers, scope of the Corn Belt, modeling domains, and the default N_2O emissions. Emission unit is nmol·m^{-2}·s^{-1}. KCMP – Minnesota; NWR –Niwot Ridge, Colorado.

Table. EDGAR42 N_2O emissions and EDGAR2 nature soil emission within the Corn Belt. Note: 4B + 4C_4D + 4D3 + 4F = 0.153 $nmol/m^2/s$.

Abbreviation		Items	Emission (nmol m^{-2} s^{-1})
EDGAR42	1A1_1A2	Energy manufacturing transformation	0.00698
	1A3a_c_d_e	Non-road transportation	0.00248
	1A3b	Road transportation	0.01552
	1A4	Residential	0.00227
	1B2a_c	Oil production and refineries	0.00002
	2_3	Inudstrial process and product use	0.01388
	4B	Manure management	0.00217
	4C_4D	Agricultural soil	0.12813
	4D3	Indirect emission from agriculture	0.02215
	4F	Agricultural waster burn	0.00028
	7A	Fossil fuel fires	0
	7B_7C	Indirect emission from NOx and NH3	0.01010
	WASTER	Waste solid and wastewater	0.00388
	Total		0.208
EDGAR2	Nature soil		0.038

1. WRF-chem modeling and inverse analysis

Table 1. Model set-up used in WRF.

Basic equation	Non-hydro mode
Time-integration scheme option	Runge-Kutta 3rd order
Time step for integration	120 s
Microphysics option	WRF Single-Moment (WSM) 5-class scheme
Longwave radiation option	Rapid Radiative Transfer Model (RRTM)
Shortwave radiation option	Goddard Shortwave scheme
Cumulus option	Grell-Devenyi ensemble scheme
Boundary-layer option	Yonsei University Scheme (YSU) scheme
Surface-layer option	Monin-Obukhov Similarity scheme
Land-surface option	Community Land Model Version 4 (CLM4)

Initial and boundary conditions:

weather forecast model Global Forecast System

Model for Ozone and Related Chemical Tracers (MOZART) version 4

Experimental design

- background simulation:
  nature soil emission + EDGAR42 non-agricultural emissions for both domains
- default simulation
  nature soil emission + total EDGAR42 emission (agricultural and non-agricultural) in both domains
- scaled simulation
  <u>inner domain</u>: sum of nature soil emission, EDGAR42 non-agricultural emissions, and a multiple of EDGAR42 agricultural emissions
  <u>outer domain</u>: nature soil emission + total EDGAR42 emission

1. WRF-chem modeling and inverse analysis

Table 2. Experimental and calibrated multipliers of EDGAR42 agricultural N_2O emissions in the study. Values in brackets are the constrained agricultural emission in unit of nmol·m^{-2}·s^{-1}.

Time	June 1 – 20	August 1 – 20	October 1 – 20	December 1 – 20
Experimental multipliers	0, 1, 25	0, 1, 12	0, 1, 3	0, 1, 6
Calibrated multiples using observation at 32 m	19.0 (2.91)	9.3 (1.43)	3.4 (0.52)	3.0 (0.47)
Calibrated multiples using observation at 100 m	22.5 (3.44)	11.6 (1.77)	3.83 (0.59)	3.6 (0.55)
Calibrated multiples using observation at 185 m	28.1 (4.29)	13.0 (1.99)	4.7 (0.72)	4.3 (0.66)

1. WRF-chem modeling and inverse analysis

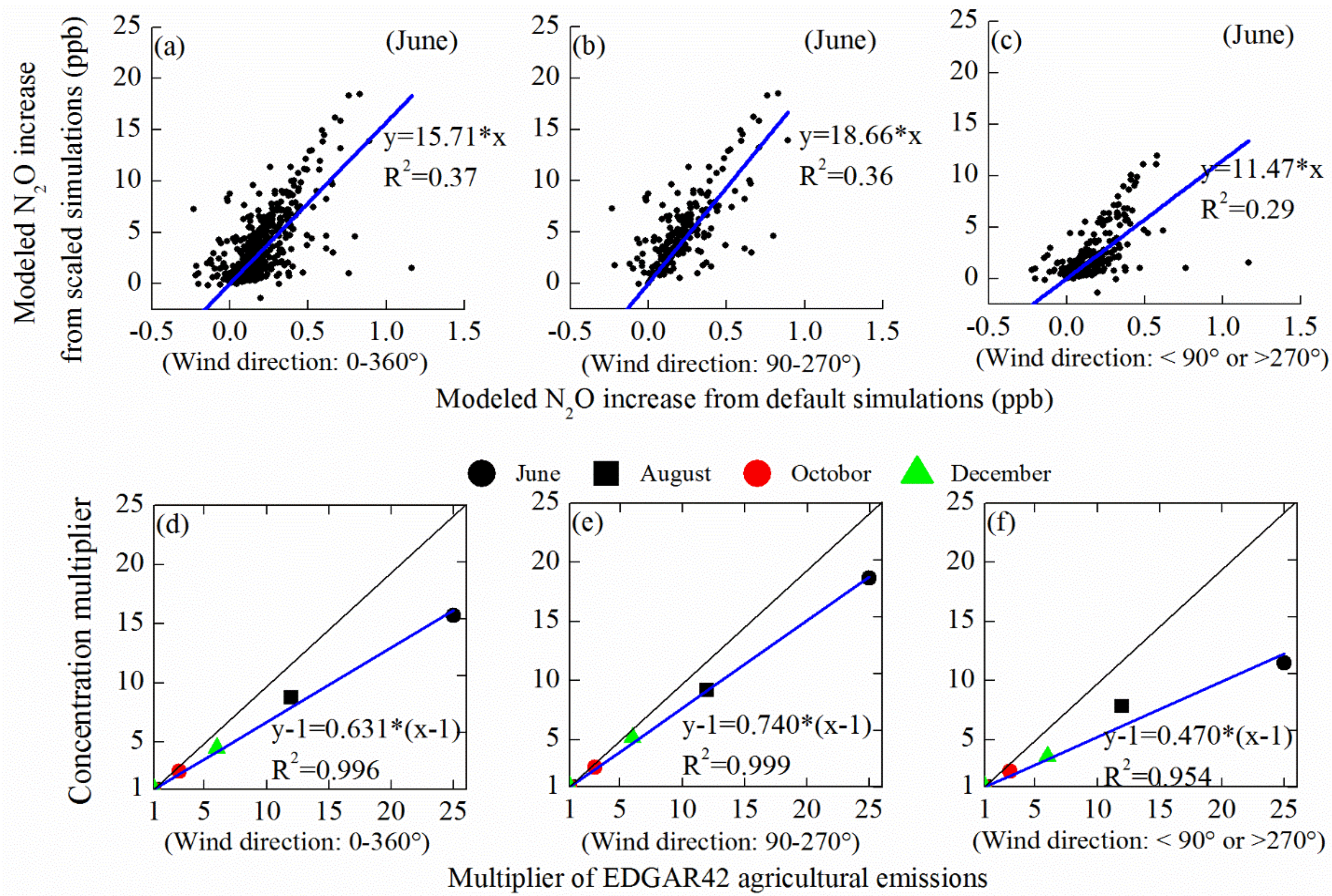
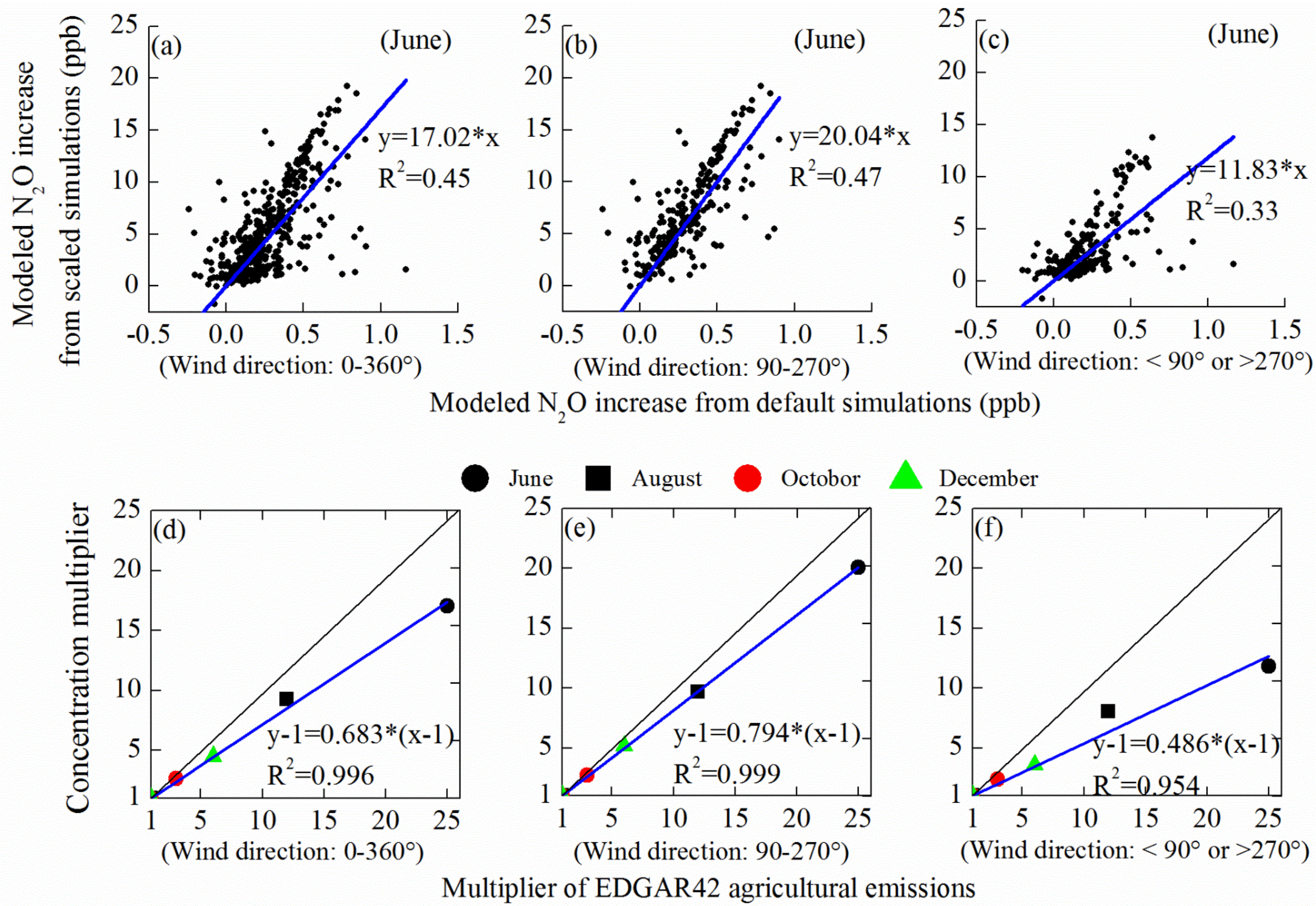
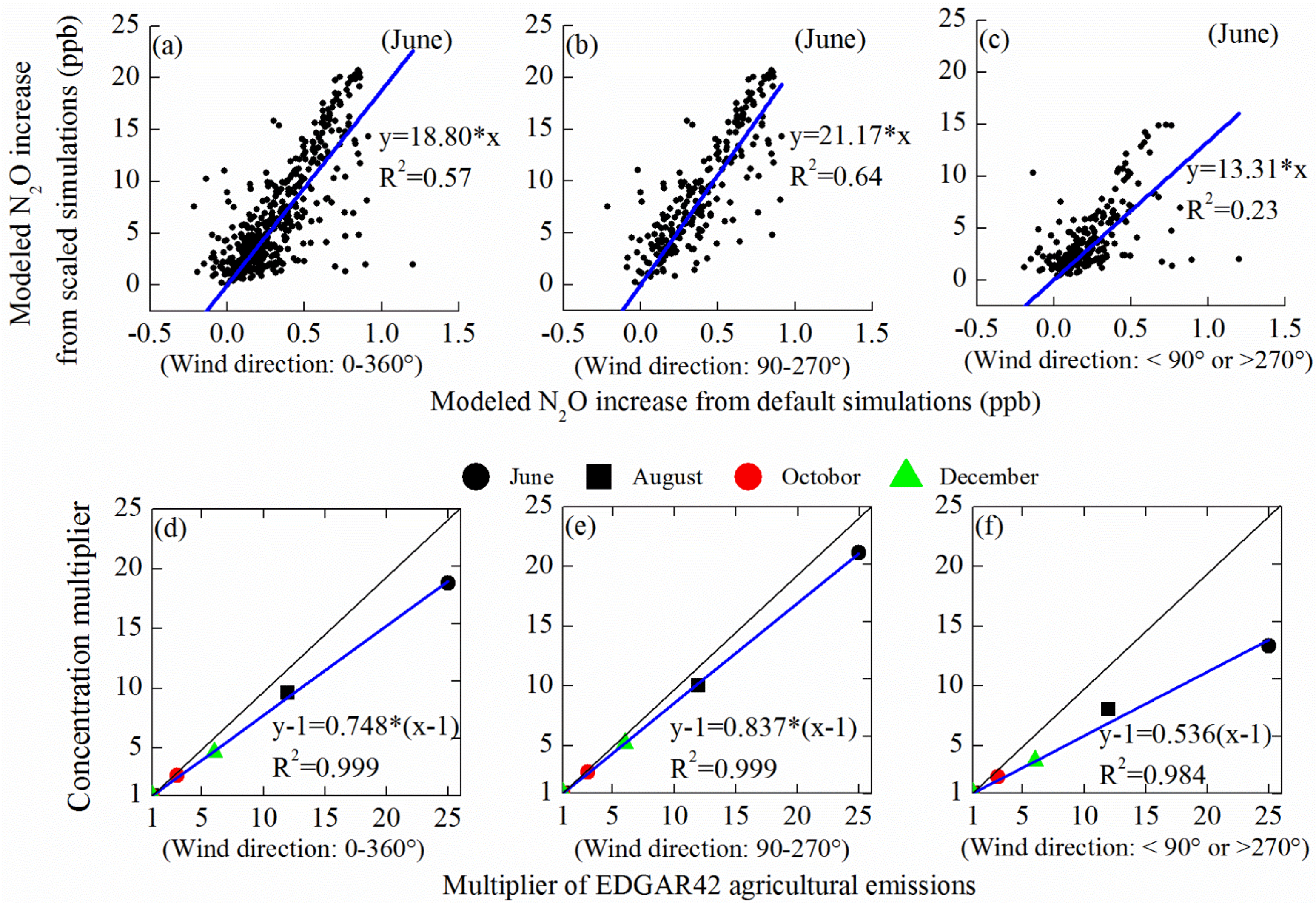


Fig. 2. Correlations between experimental multiples, wind direction, and modeled N_2O mixing ratio increases from 'default' and 'scaled' simulations at height of 185 m at the KCMP tower site. Degrees of 0°, 90°, 180°, and 270° represent north, east, south, and west winds, respectively. The regression slope in sub-figures (d) – (f) refers to the slopes as those shown in sub-figures (a) – (c).



Results at 100 m



Results at 32 m

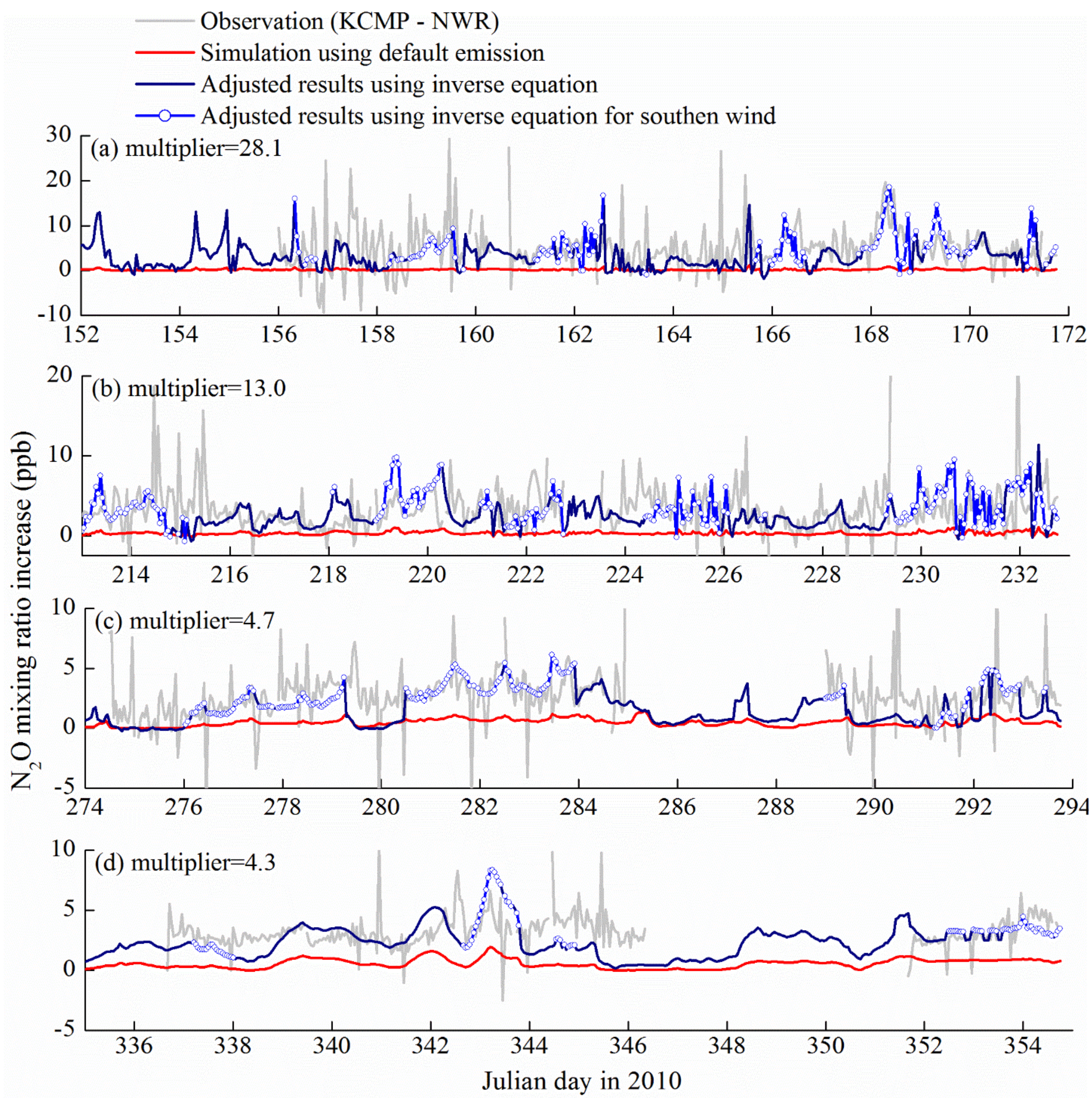
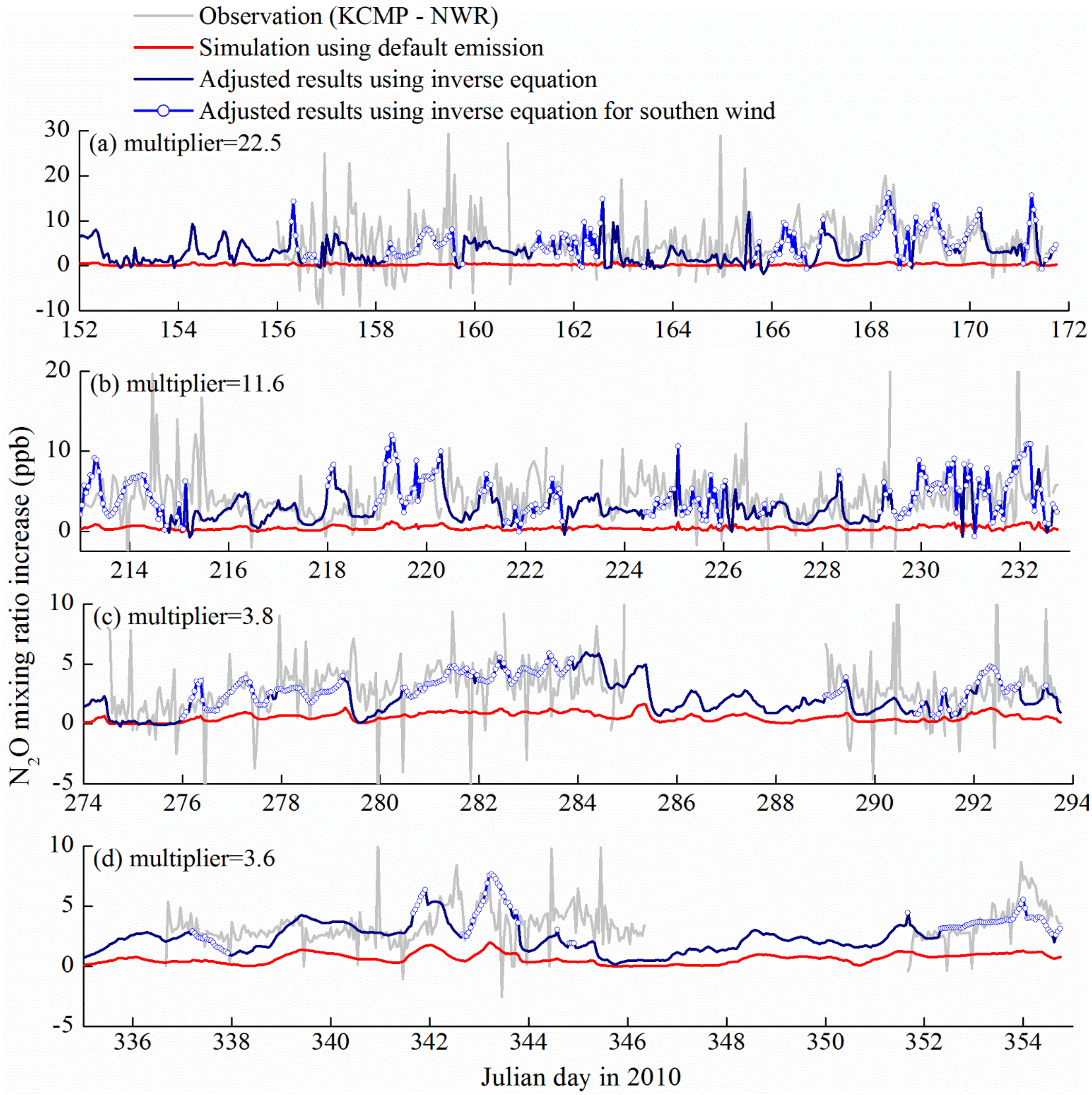
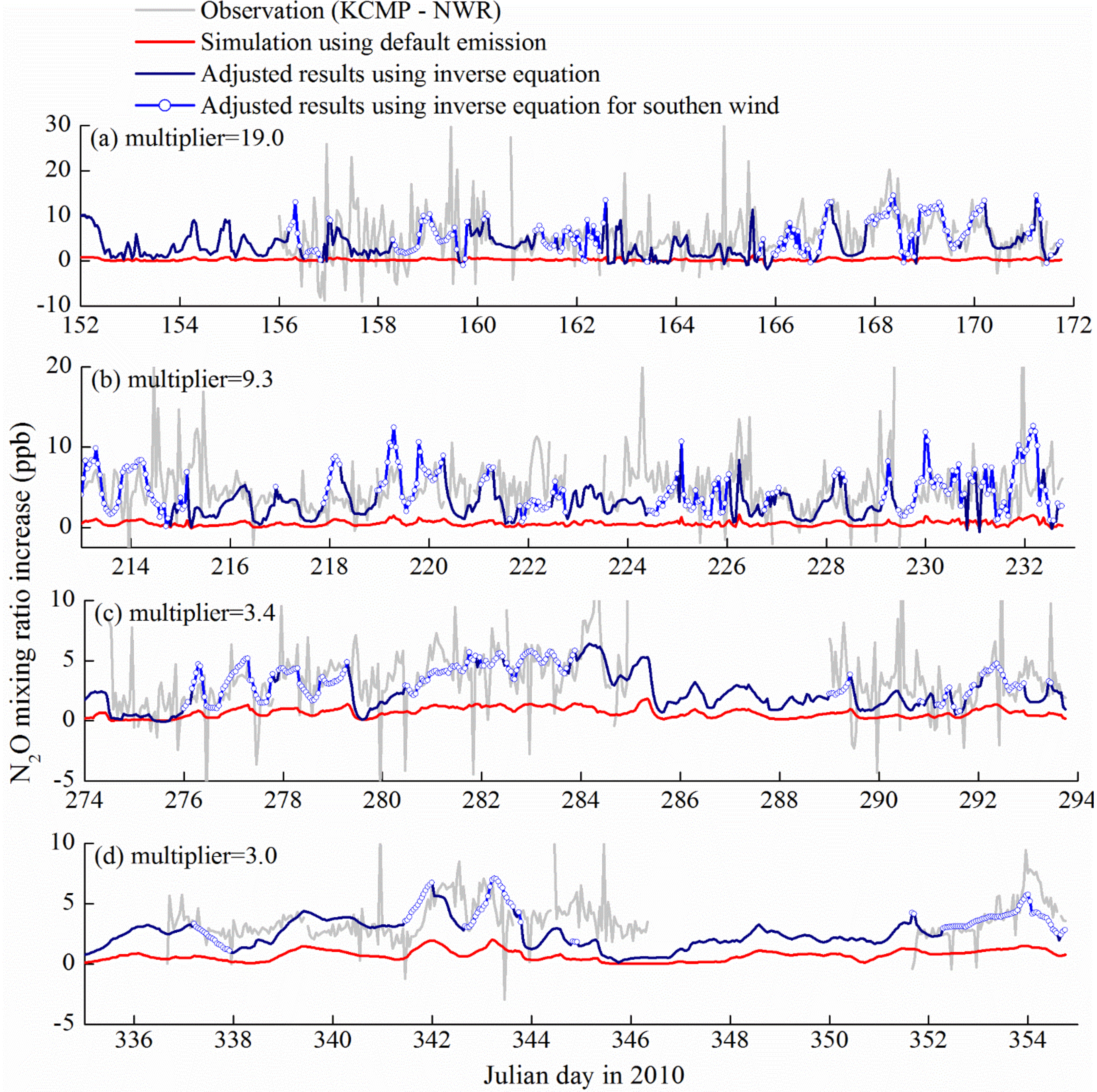


Fig. 3 . Observed (grey lines), modeled (red lines), and the scaled (blue and navy blue lines) N_2O mixing ratio increases at the KCMP tower site. The modeled increases (red lines) are the values from 'default simulation' subtracted by values from 'background simulation'. Results in this figure are for the height of 185 m.



Results in this figure are for the height of 100 m



Results in this figure are for the height of 32 m

1. WRF-chem modeling and inverse analysis

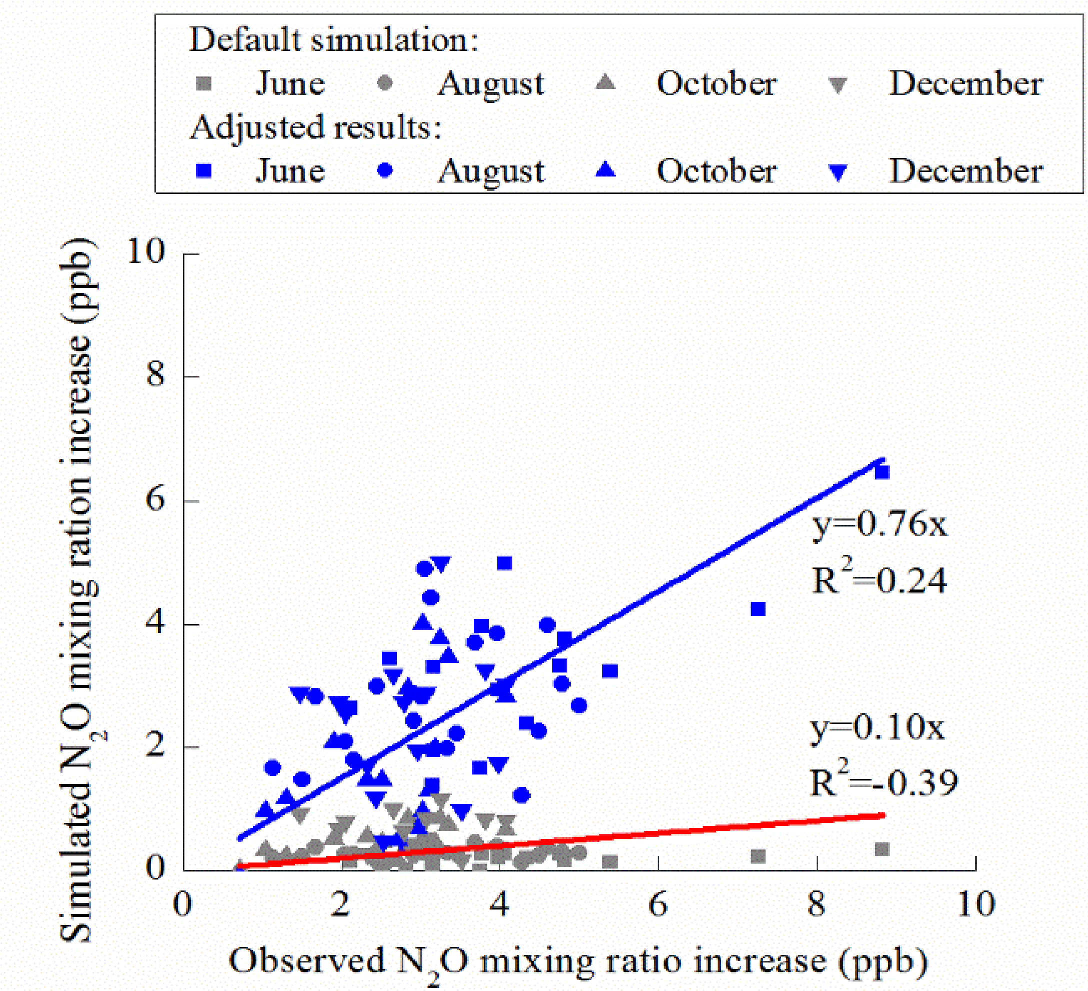


Fig. 4. Correlations between the observed and scaled daily N_2O mixing ratio increases at the KCMP tower site. Results in this figure are for the height of 185 m.

1. WRF-chem modeling and inverse analysis

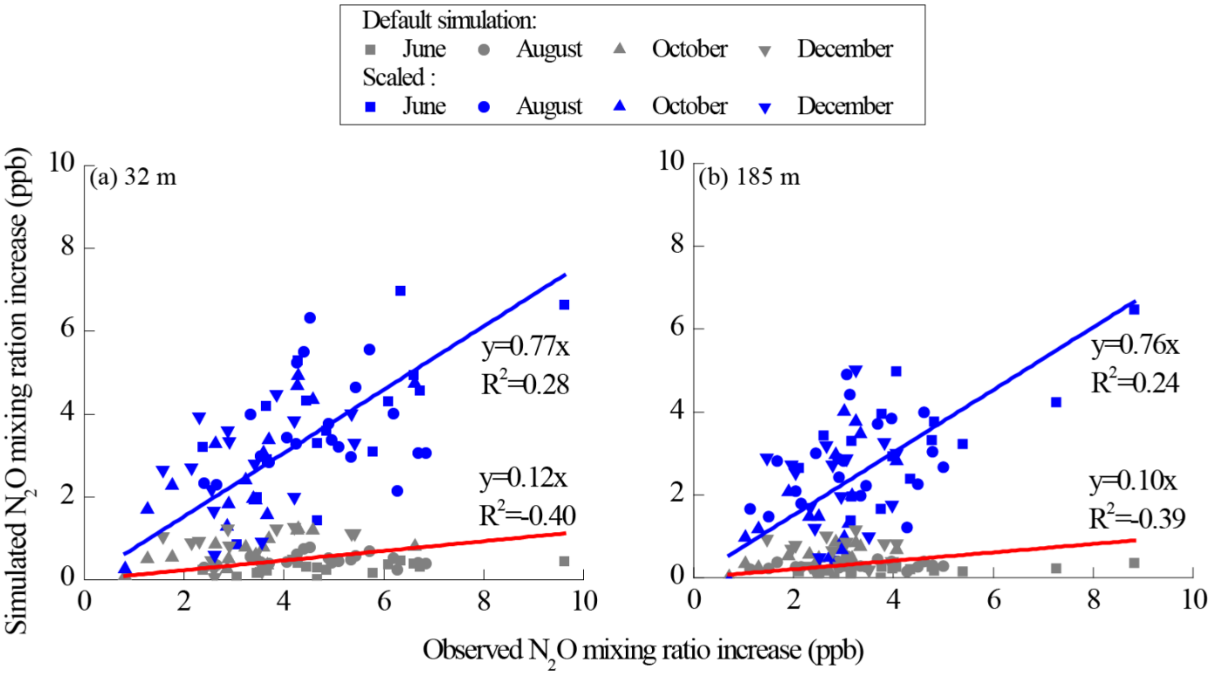


Fig. Correlations between the observed and scaled daily N2O mixing ratio increases at the KCMP tower site.

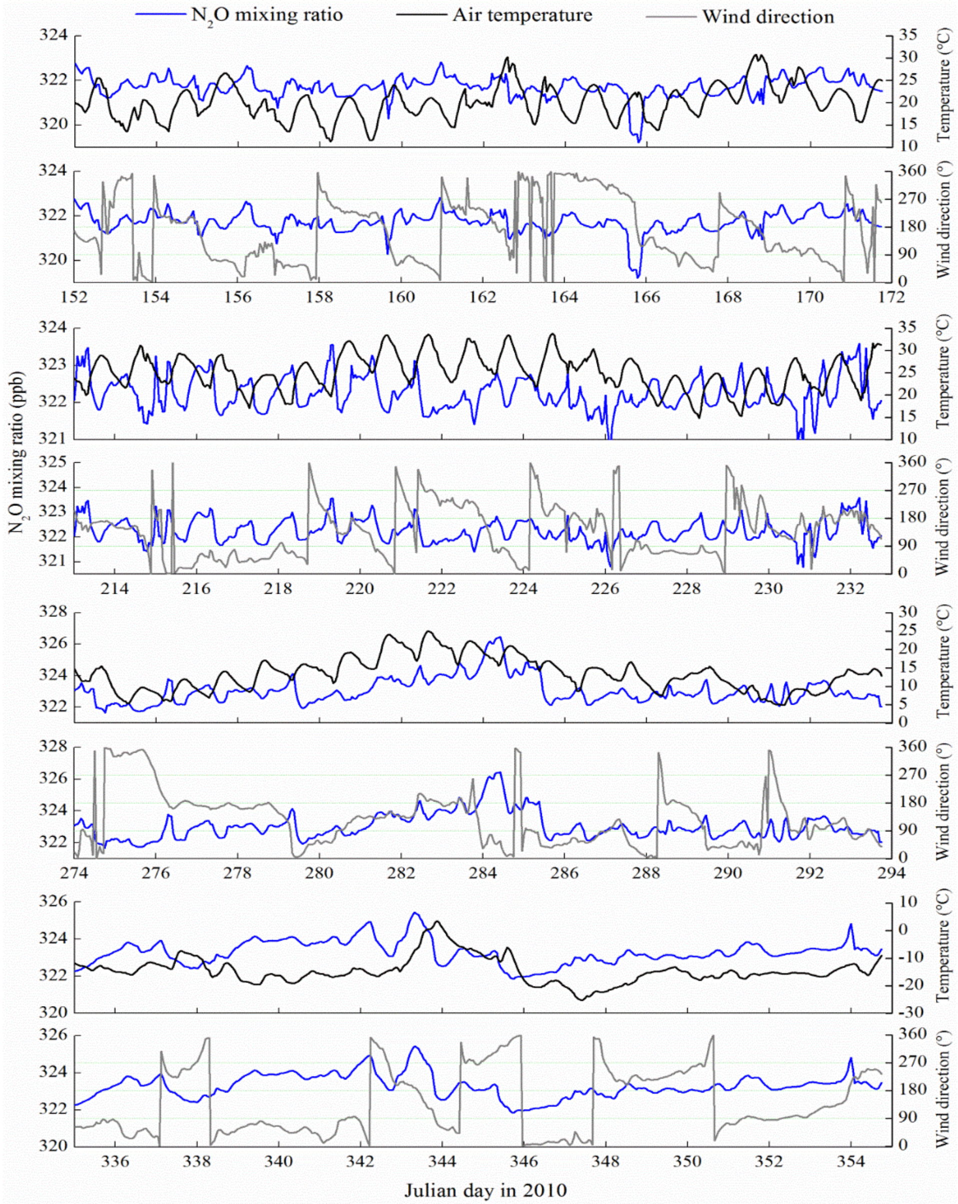


Figure. Correlations between simulated air temperature, wind direction, and N_2O mixing ratio at height of 100 m at KCMP tower site.

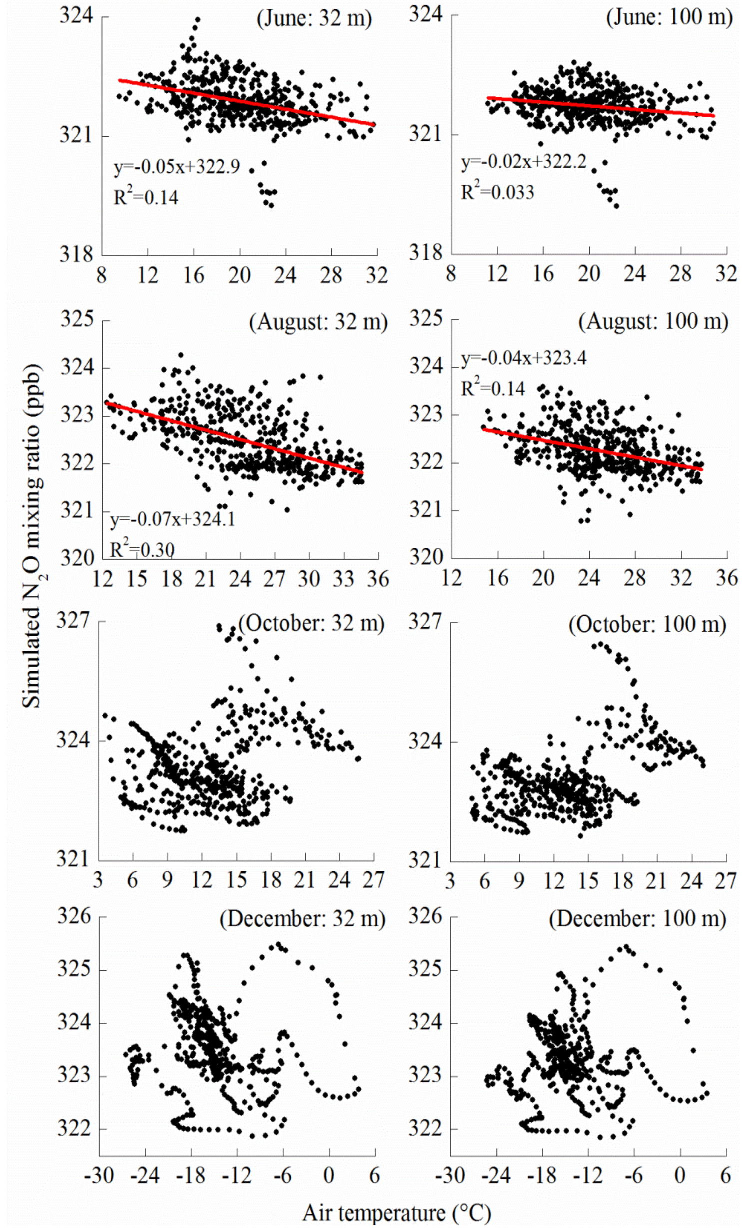


Figure. Scatter plot between simulated air temperature and N_2O mixing ratio at the KCMP tower site.

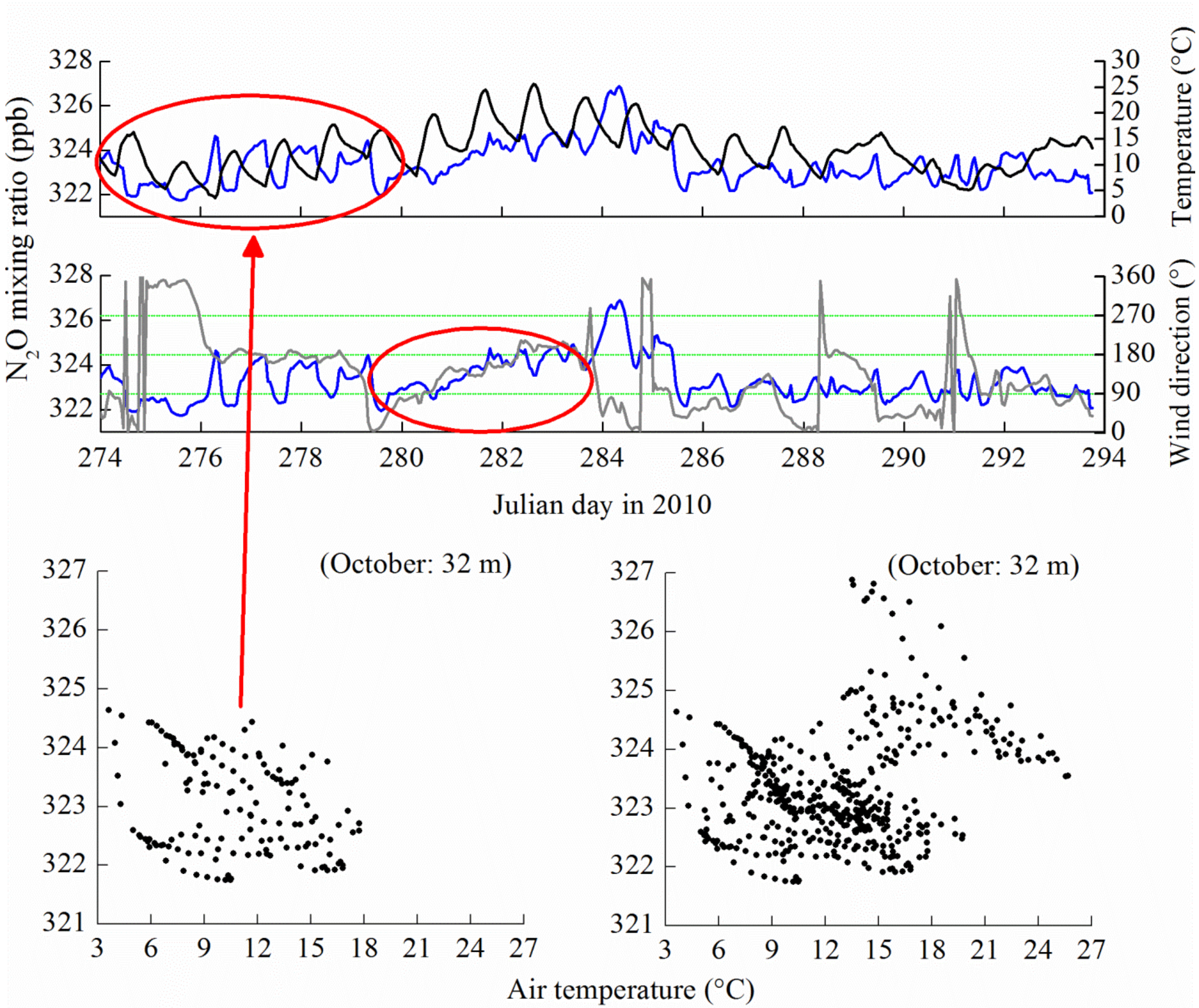


Figure. Correlations between simulated air temperature, wind direction, and N_2O mixing ratio at height of 32 m at the KCMP tower site in October.

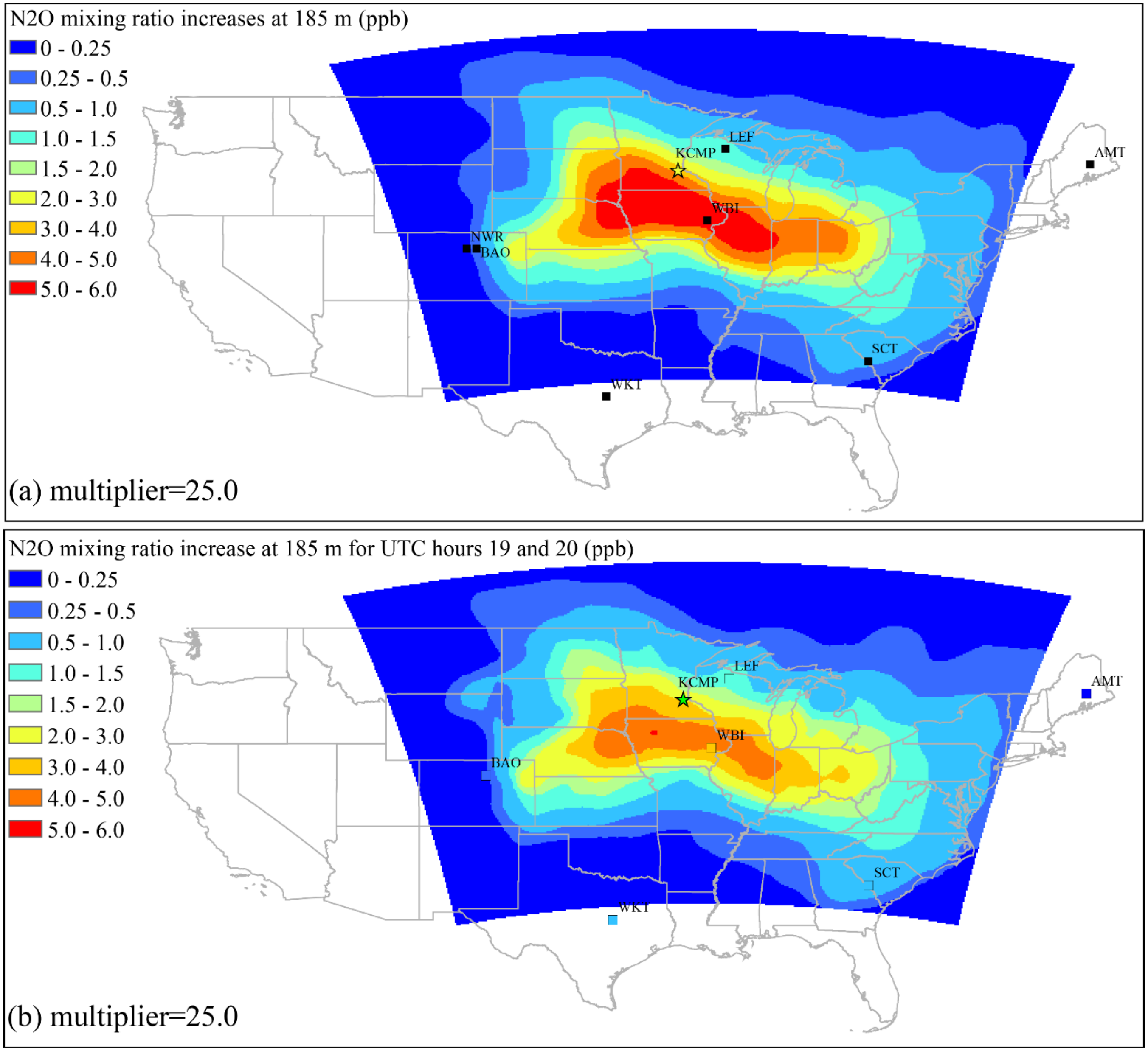


Fig. 5. Spatial characteristics of the mean values of the modeled N_2O mixing ratio increases during June 1st – 20th. In sub-figure (a), the averages of the entire modeling period; (b) the modeling results are for hours 19 and 20 (UTC), the observations – illustrated using colors in the filled squares, are for hour 19 and / or 20 (UTC). BAO is the background site for WBI, LEF, SCT, AMT, and WKT.

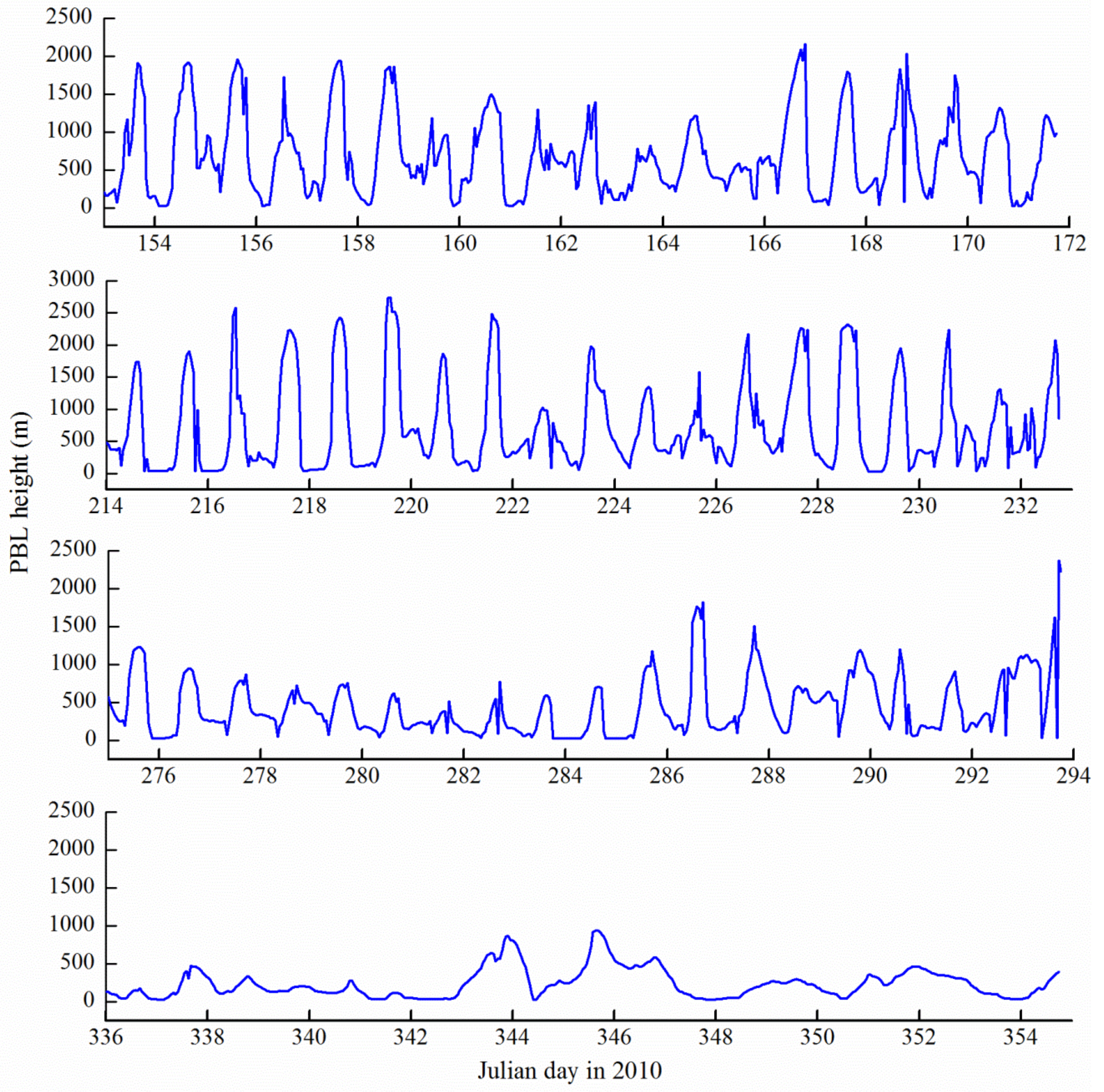


Figure. Simulated mixing heights for different periods.

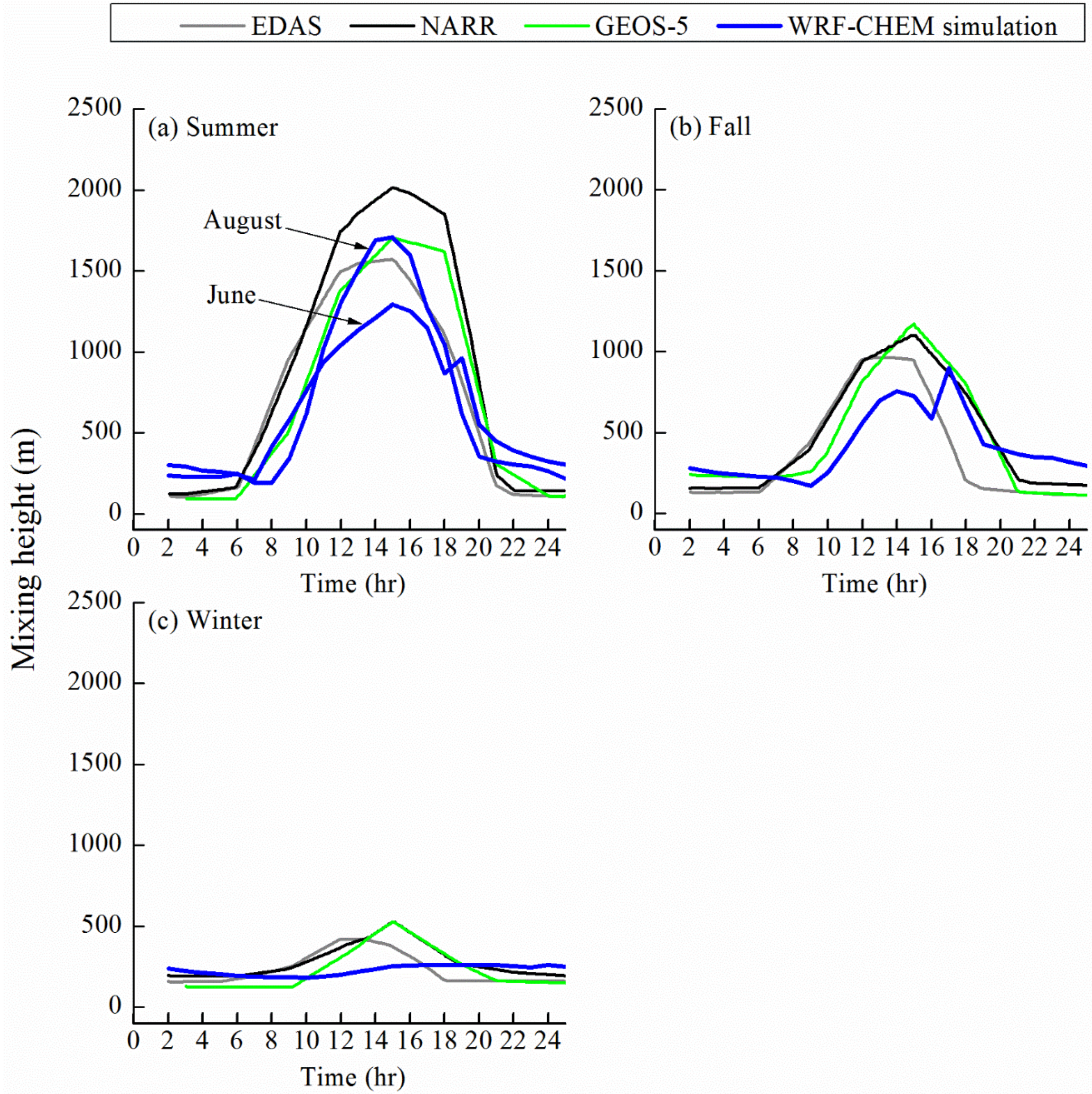


Fig. 6. Simulated mixing height at the KCMP tower site in the present study (blue lines) and in Kim et al. (2013) (grey, black, and green lines). “EDAS” and “NARR” represent the mixing heights calculated by the STILT model using the meteorological data sets of “Eta Data Assimilation System” and “North American Regional Reanalysis”, respectively, and “GEOS-5” is the mixing height used to drive the GEOS-Chem model in Kim et al. (2013).

Key findings:

- The simple inverse analysis method based on the WRF-Chem modeling in the present study could be used to do the inverse analysis for N_2O emission within the Corn Belt.
- The agricultural N_2O emissions within the Corn Belt was clearly underestimated in the EDGAR42 database for all four periods from June to December, which is needed to be scaled up to at least 19 folds during the emission peak month – June, 2010.
- The dynamics of the monitored high-resolution N_2O mixing ratio at the KCMP tower site, which were influenced by diffusivity and wind direction, could be captured and reproduced by the WRF-Chem. The diffusivity affected the N_2O mixing ratio dynamics more in June and August than that in October and December, while wind direction influenced the dynamics more in October and December than that in June and August.
- The spatial patterns of the influences of the Corn Belt on the atmospheric N_2O mixing ratios during the emission peak month – June, 2010 could be perfectly captured by WRF-Chem model, and the Corn Belt-induced N_2O mixing ratio increase at height of 300 m is larger than 1 ppb during June 2010 within a scope that is larger than the Corn Belt itself.

2. CLM single-point mode modeling

Table. Land cover for the simulated grid (~5km × 5km).

PFT number in CLM4.5	PFT name	Percentage of PFT in the modeling grid (%)
0	Bare Ground	1.9
1	Needleleaf evergreen tree – temperate	2
7	Broadleaf deciduous tree – temperate	8
13	Unmanaged crop	45
15	C_3 Unmanaged Irrigated Crop	3
17	Rainfed Corn	16
18	Irrigated Corn	3
19	Rainfed Temperate Cereals	7
23	Rainfed Soybean	11
24	Irrigated Soybean	1
-	Urban area	2.1

2. CLM single-point mode modeling

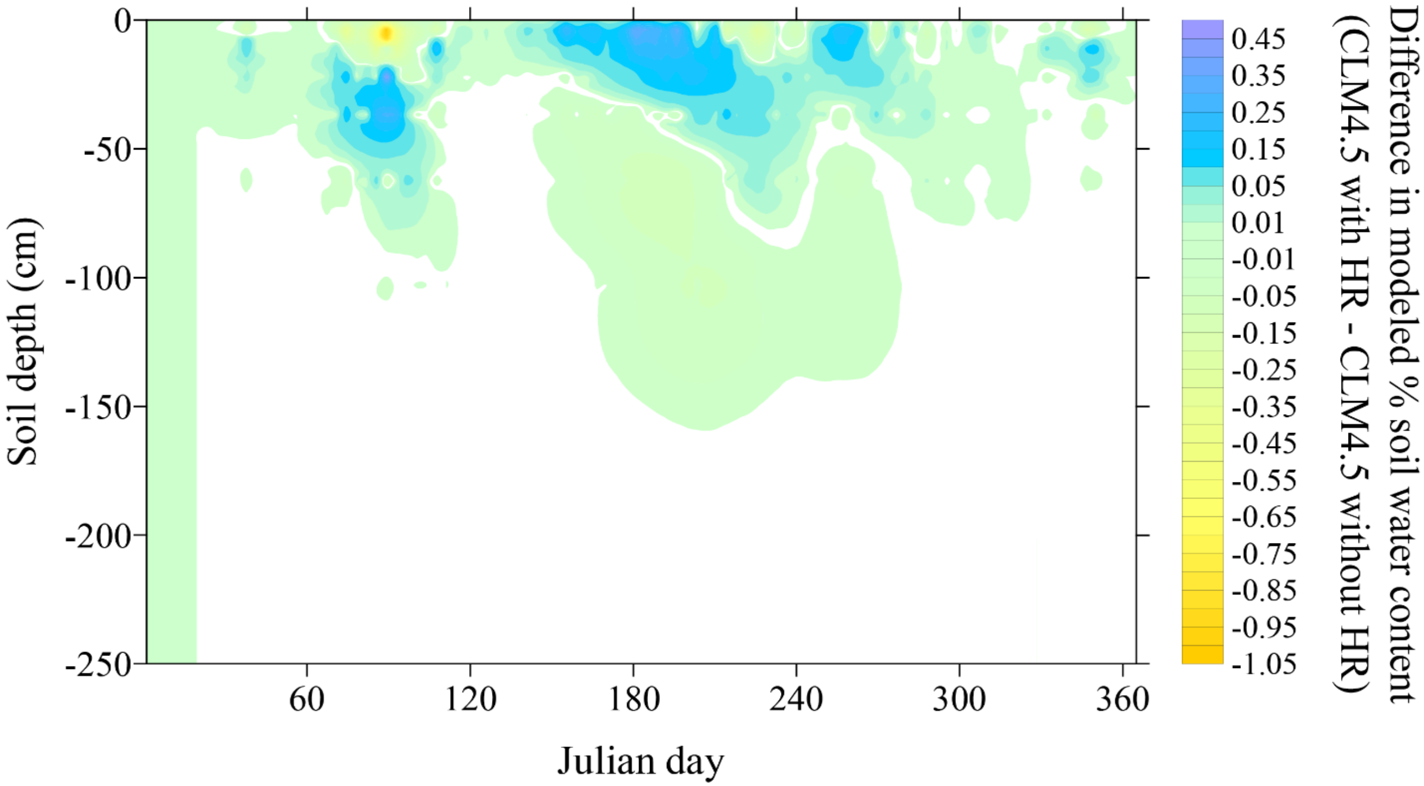


Figure. Modeled HR flux, as represented by the amount of soil moisture given or received per day, for the rainfed Corn column. Results shown here are the averaged values for Julian days over the entire simulation period (2005-2012). Hydraulic descent – plant root transfers soil water from shallower to deeper soil layers, could be found during Julian days 60-120; Hydraulic lift- plant root lifts soil water from deeper to shallower soil layers, could be found during Julian days 150-210.

2. CLM single-point mode modeling

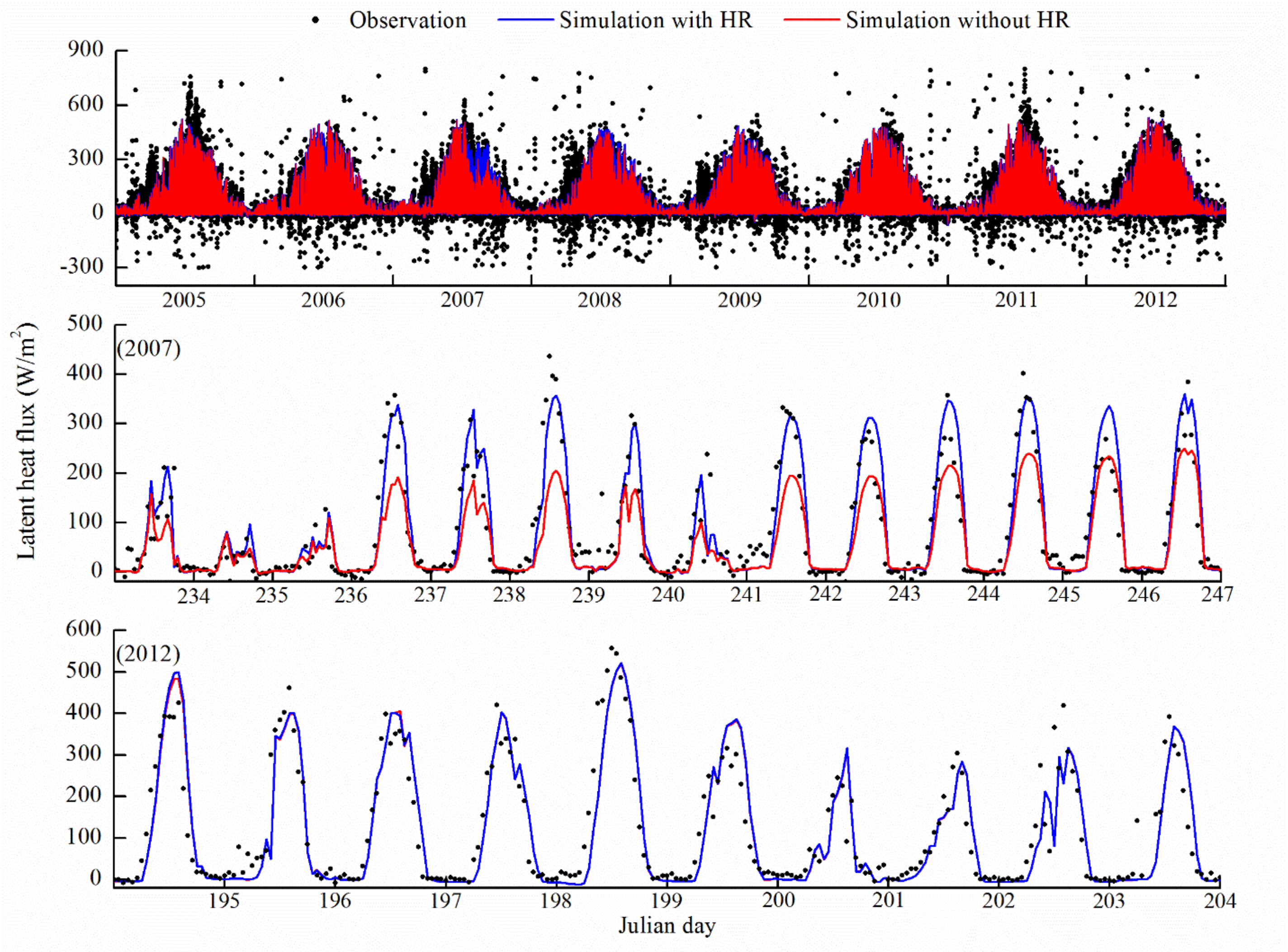


Figure. Observed and modeled hourly latent heat flux (evapotranspiration).

2. CLM single-point mode modeling

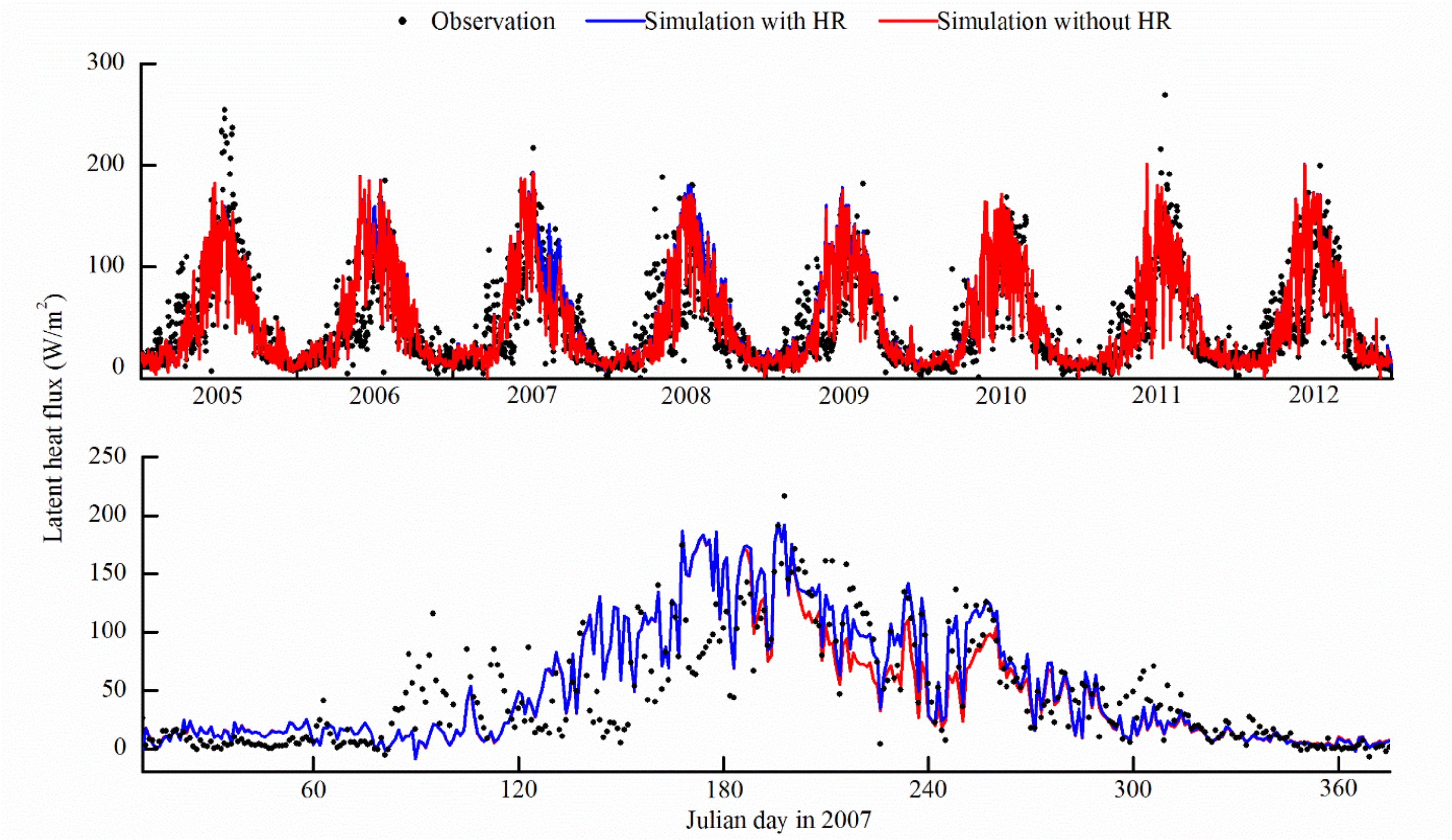


Figure. Observed and modeled daily latent heat flux (evapotranspiration).

2. CLM single-point mode modeling

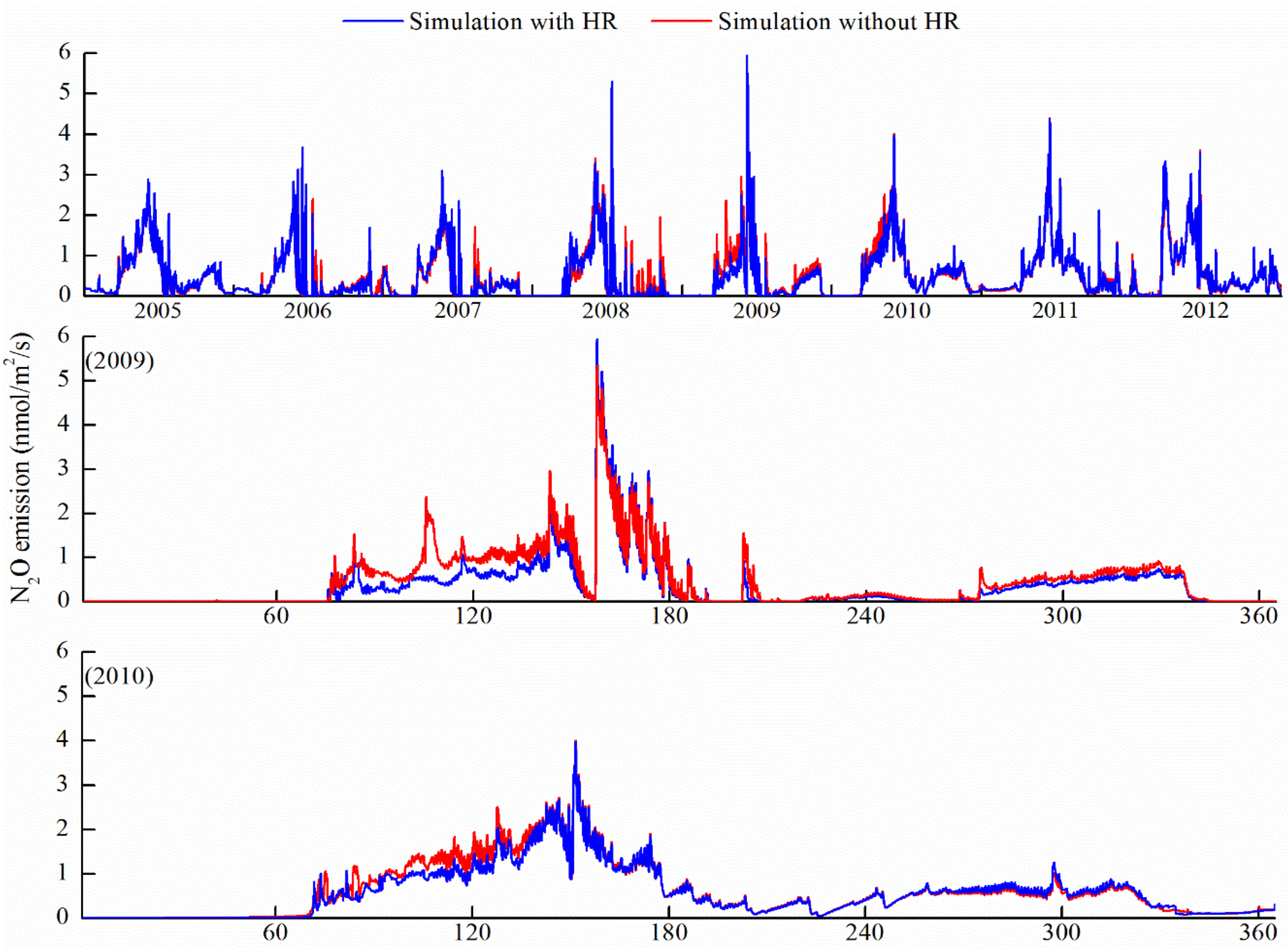


Figure. Observed and modeled N_2O emission.

3. SWAT modeling

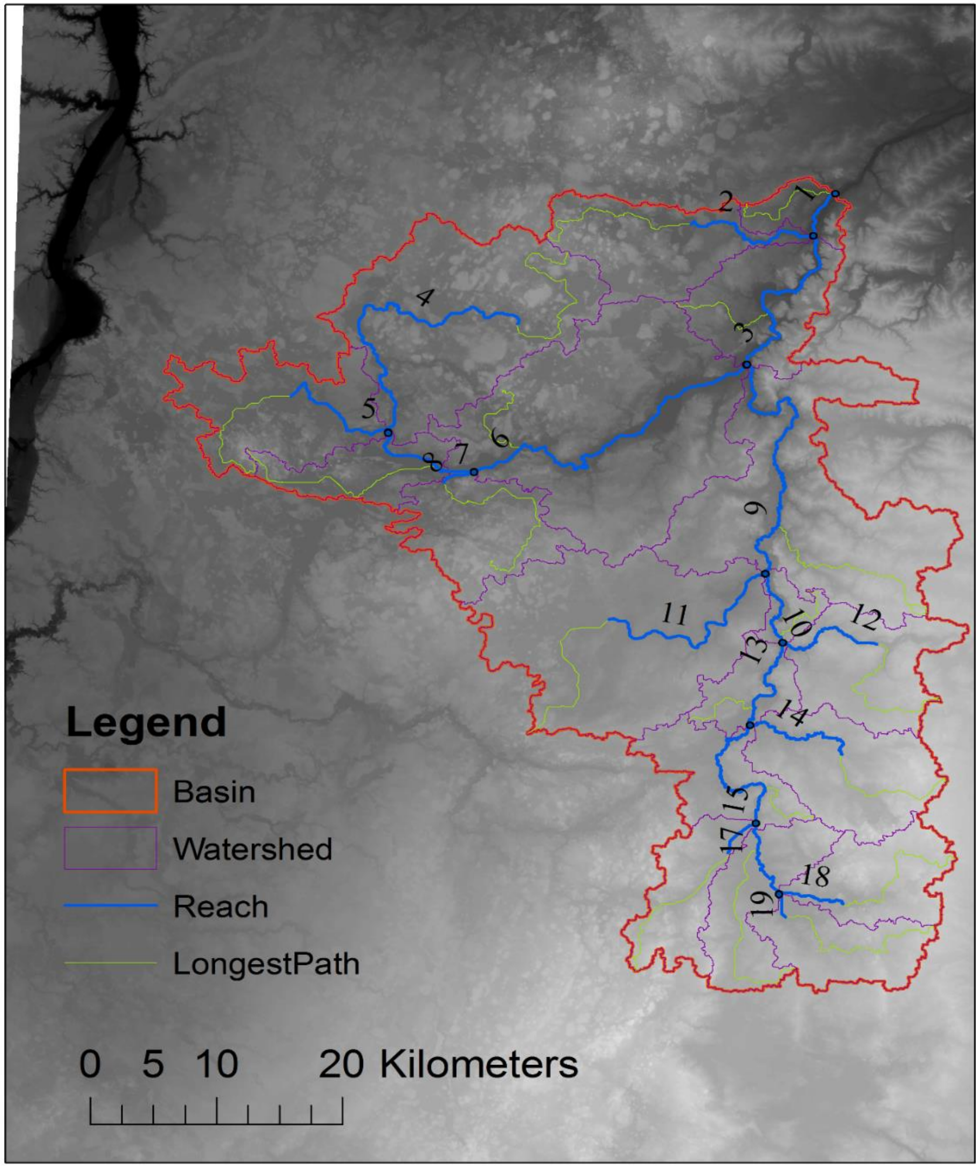


Figure. Watershed delineation. DEM data (background figure) are taken from the National Elevation Dataset at a resolution of 30 meters.

3. SWAT modeling

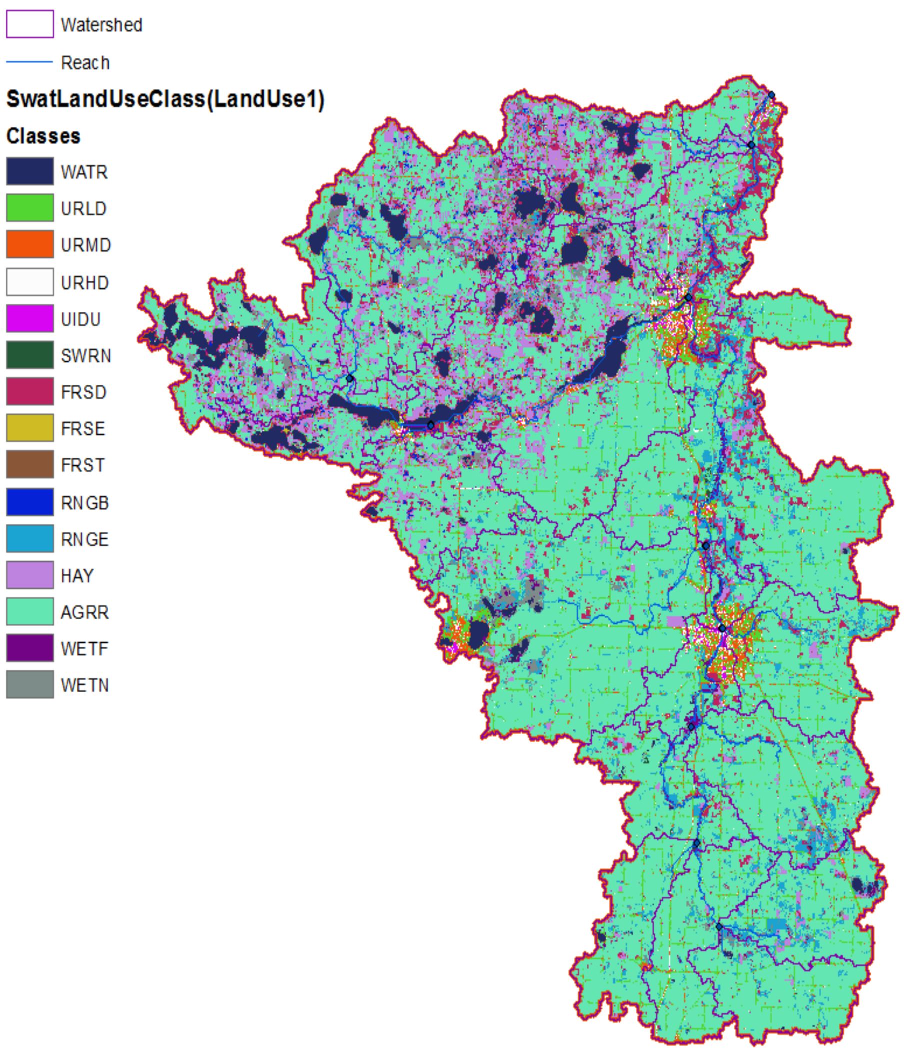


Figure. Land cover data for the model come from the 2001 National Land Classification Dataset (NLCD), 2011 Edition, amended 2014.

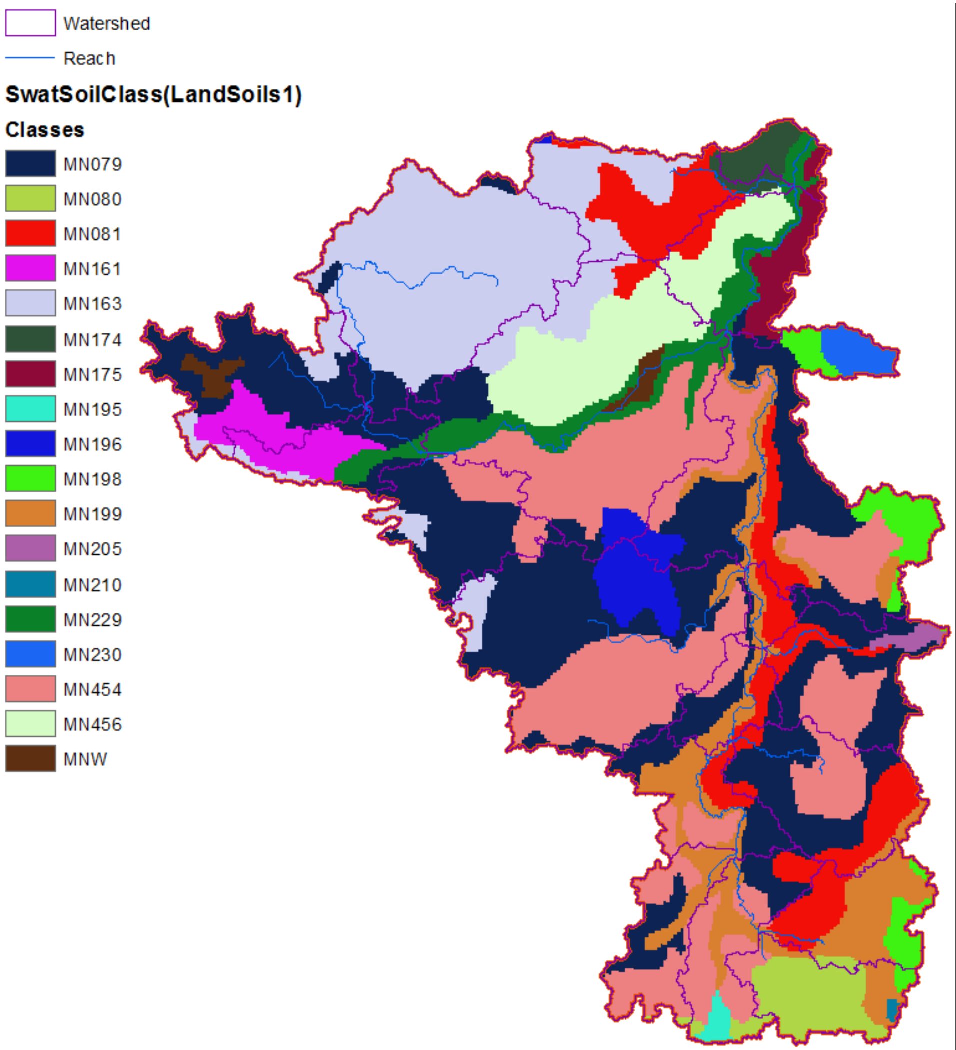


Figure. Soils data are from the STATSGO state soils coverage (USDA, 1991) distributed with ArcSWAT.

3. SWAT modeling

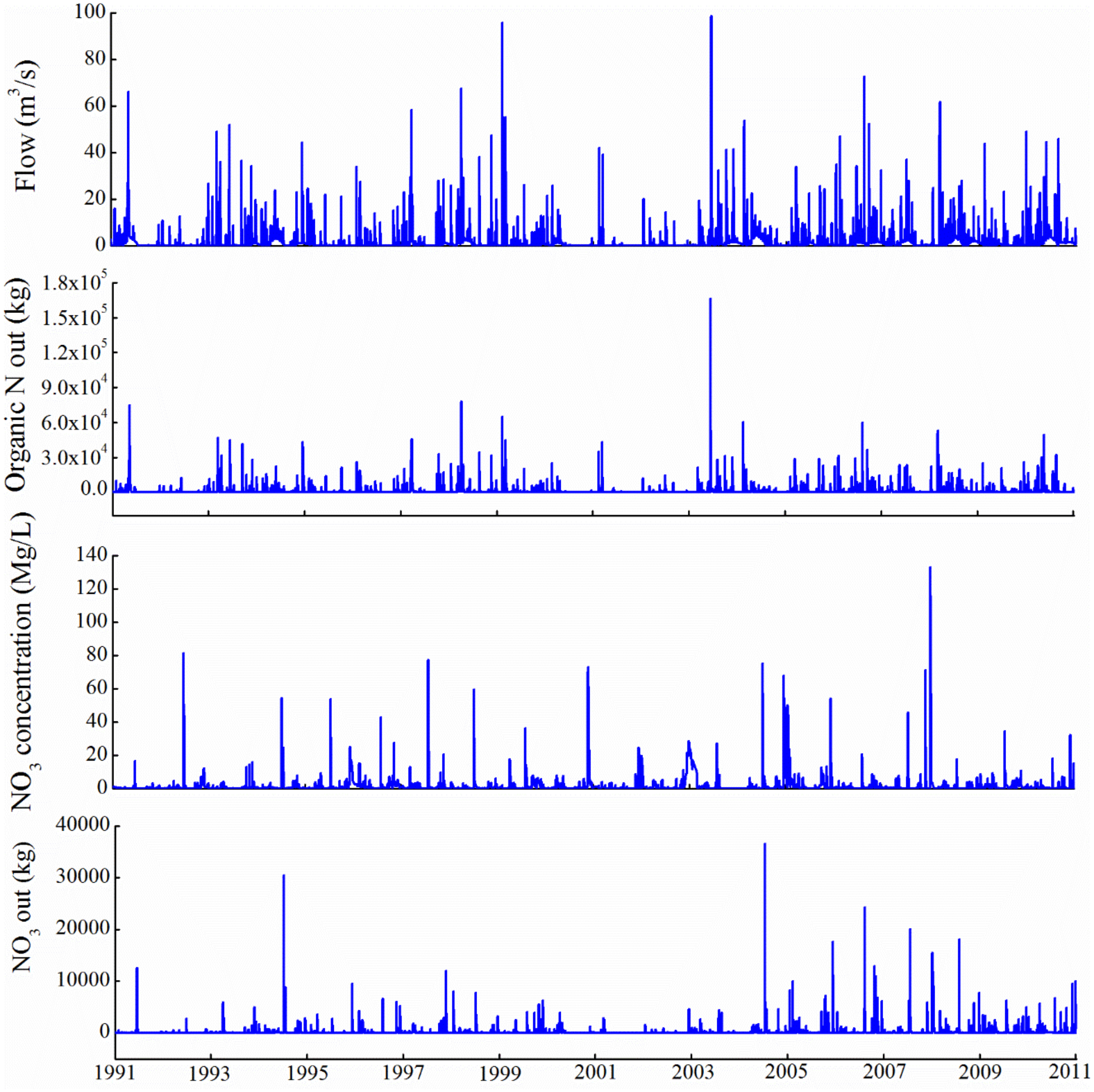


Figure. Results for all years for Reach #11 in the first figure.

3. SWAT modeling

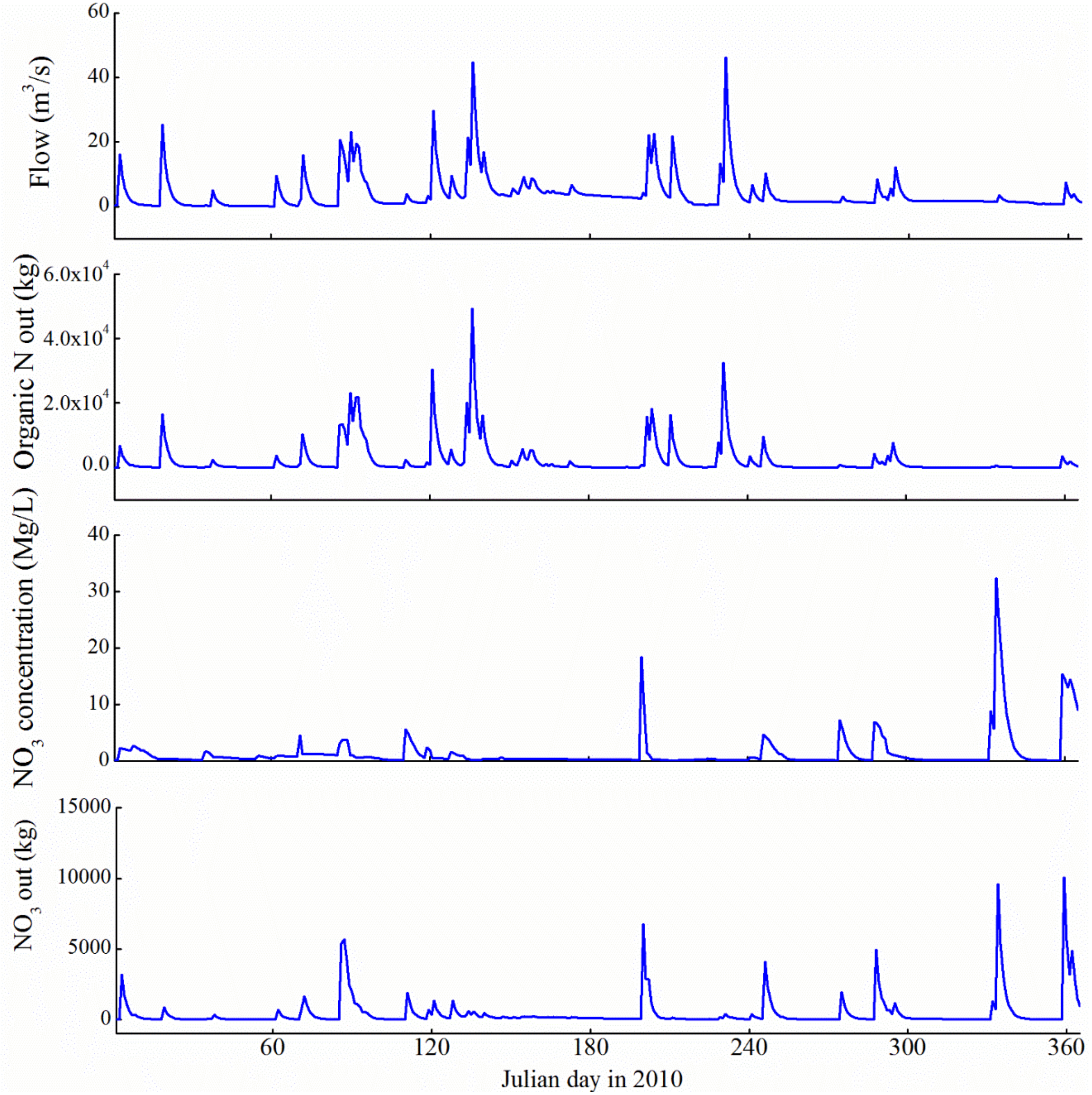


Figure. Results for year 2010 for Reach #11 in the first figure.

谢谢大家！