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The Impact of Planetary Boundary Layer Parameterization Schemes on Surface Meteorology Field and Air Pollution Concentration in WRF/CMAQ model

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- Conclusion

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Background

The Eulerian pollutants diffusion equation is :

$$\frac{\partial \overline{q_i}}{\partial t} + \bar{u}\frac{\partial \overline{q_i}}{\partial x} + \bar{v}\frac{\partial \overline{q_i}}{\partial y} + \bar{w}\frac{\partial \overline{q_i}}{\partial z} = \frac{\partial(\overline{u'q_i'})}{\partial x} + \frac{\partial(\overline{v'q_i'})}{\partial y} + \frac{\partial(\overline{w'q_i'})}{\partial z}$$

$$+S_i + R_i + \sum chemis$$

Turbulent Term
Use PBL schemes to parameterize the turbulent flux

There are two distinctive approaches to parameterize the fluxes in WRF model utilizing 12 closure schemes.

- Turbulent Closure
  - local closure
    - High-order : Parameterize the turbulent term directly
      - High-order
      - turbulent kinetic energy (TKE) closure
        Typical case : MYJ
    - Using K-theory
  - non-local closure
    - K-theory with non-local term
      Typical case: YSU
    - Transilient Turbulence Theory
      Typical case: ACM2

Specificity of YSU scheme (Hong, Noh, & Dudhia, 2006)

the turbulence diffusion equations for prognostic variables($\xi, u, v, \theta, q, q_c, q_i$) can be expressed by

$$\frac{\partial q}{\partial t} = \frac{\partial}{\partial z}\left[K_z\left(\frac{\partial q}{\partial z} - \gamma_q\right) - \overline{(w'q')_h}\left(\frac{z}{h}\right)^3\right]$$

asymptotic entrainment flux term at the inversion layer

Above the mixed layer (z >h), a local diffusion approach is applied to account for free atmospheric diffusion.

Specificity of MYJ scheme

Only local transport is allowed. The TKE (*e*) prognostic equation is expressed by,

$$\frac{\partial e}{\partial t} = -\frac{\partial}{\partial z}\left(\overline{w'e'} + \frac{1}{\rho}\overline{w'p'}\right) - \overline{w'u'}\frac{\partial u}{\partial z} - \overline{w'v'}\frac{\partial v}{\partial z} + \frac{g}{\theta_v}\overline{w'\theta_v'} - \varepsilon$$

For TKE closure schemes , the diffusivity can be commonly expressed as(Bosveld et al., 2014):

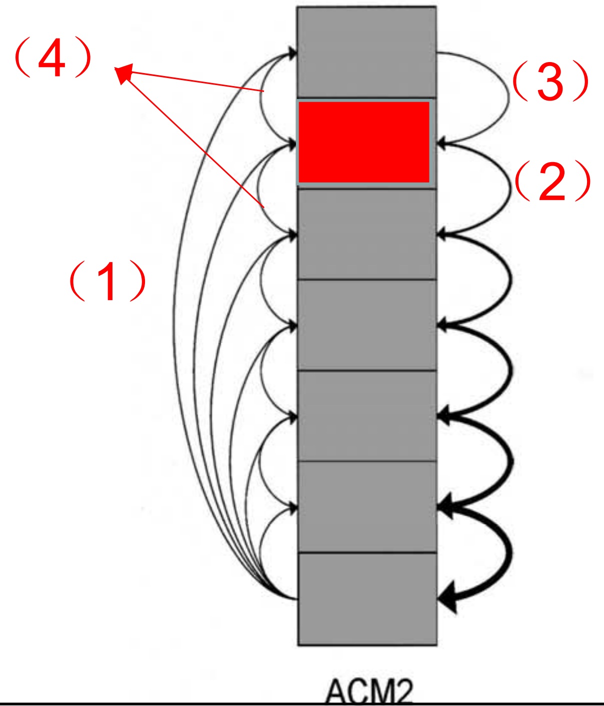
$$K = S_c \ell_m e^{0.5}$$

The TKE schemes differ in S_c and ℓ_m,and MYJ scheme is the most widely used TKE scheme.

Specificity of ACM2 scheme (Pleim, 2007)

This PBL scheme is a combination of the local and non–local mixing approach. The prognostic mean variables at layer i for ξ are given by,

$$\frac{\partial \xi_i}{\partial t} = \underset{(1)}{f_{conv} Mu \xi_i} - \underset{(2)}{f_{conv} Md_i \xi_i} + \underset{(3)}{f_{conv} Md_{i+1} \xi_{i+1} \frac{\Delta z_{i+1}}{\Delta z_i}} + \underset{(4)}{\frac{\partial}{\partial z}\left(K_\xi (1 - f_{conv}) \frac{\partial \xi}{\partial z} \right)}$$



Thus, the ACM2 is able to represent both the supergrid– and subgrid–scale components of turbulent transport in the convective boundary layer

WRF/CMAQ

Using WRF/CMAQ to evaluate the model performances of simulating pollutants by 3 widely used PBL schemes (YSU,ACM2,MYJ).

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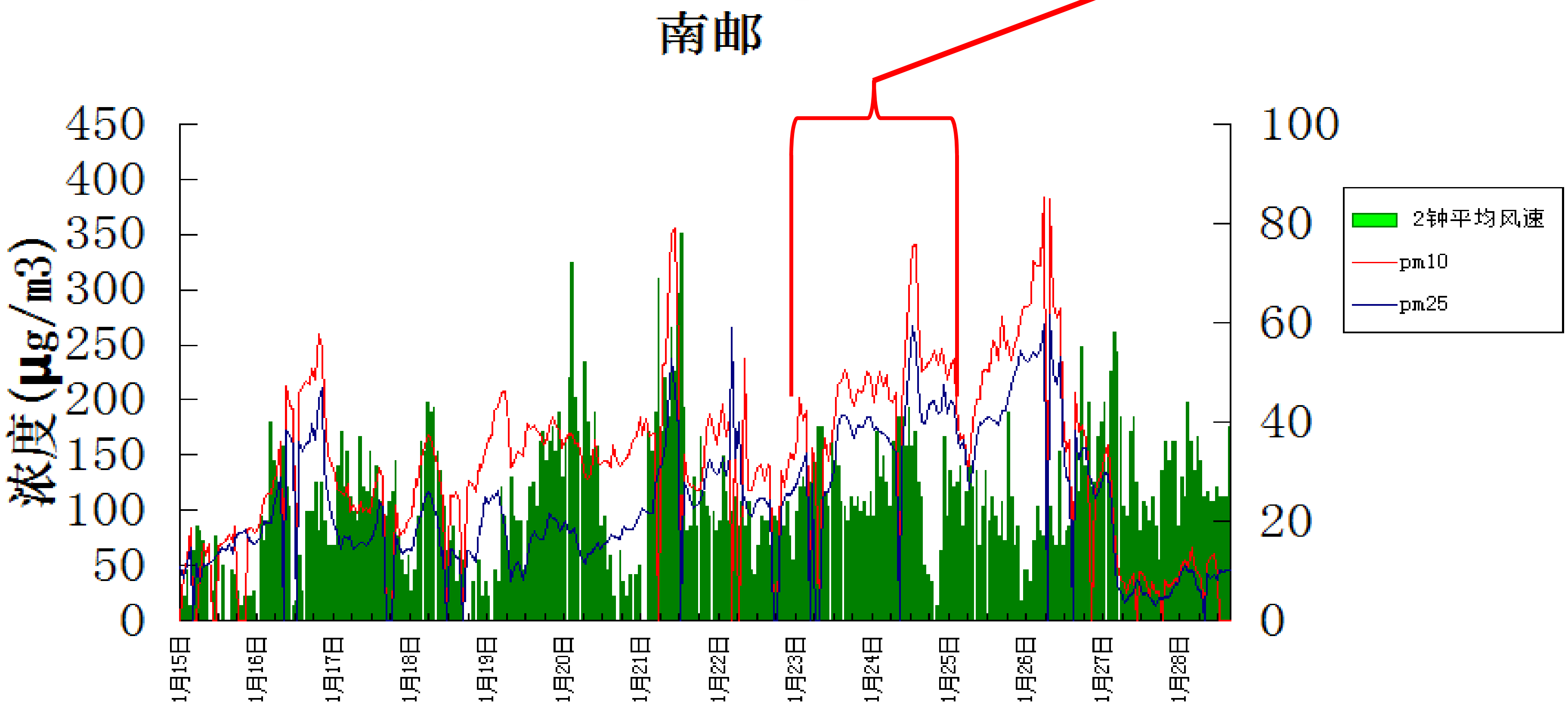
There are several heavy pollution case in Jan.2015, and we have detailed observation data during 23~25.Jan.



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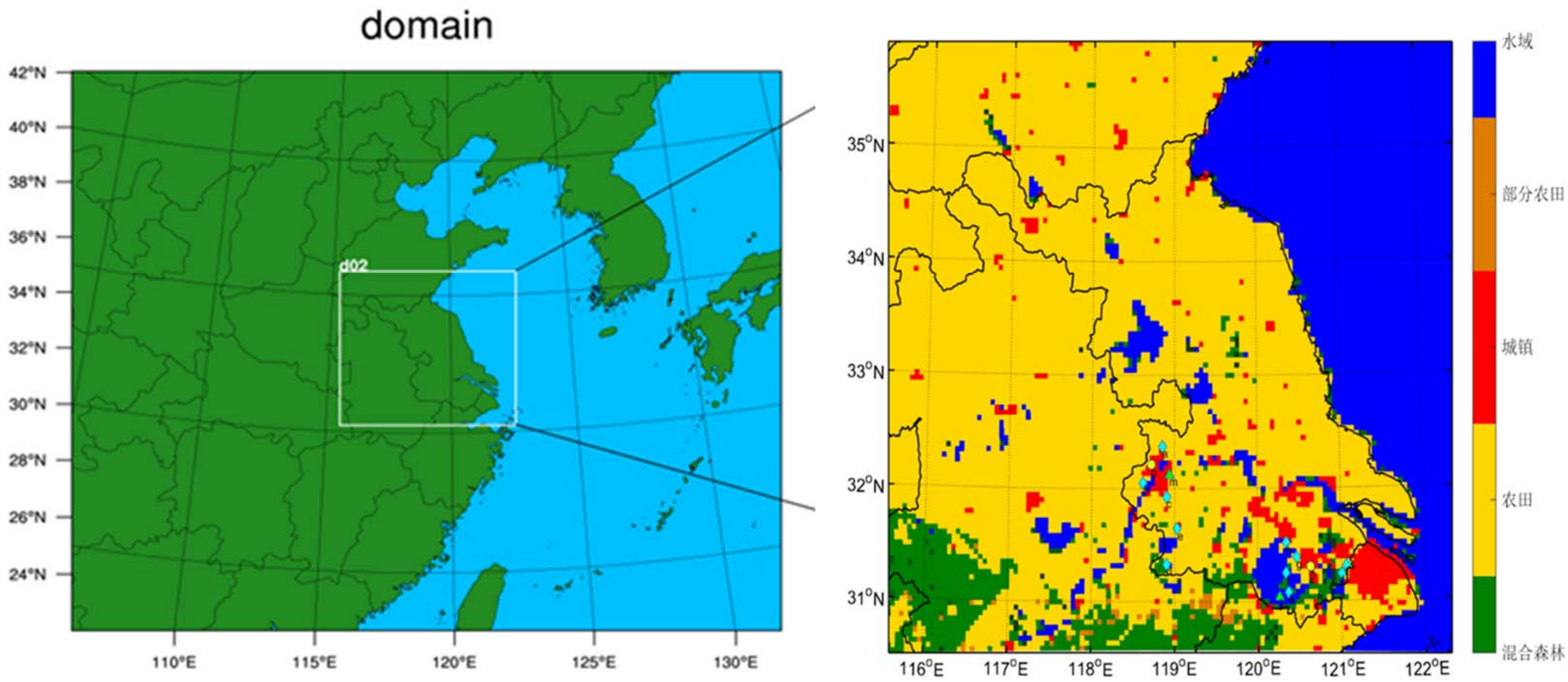
Simulation Characteristics

Domain Num.	1	2
Period	**0800 23.Jan 2015 ~ 0800 25.Jan 2015(LST)**	
Initial condition meteorology	NCEP(6h , 1°)	
Domain center location	33.0° N，119.0° E	
Initial condition chemistry	Spin-up by YSU scheme	
Vertical level	52	
Horizontal grid	WRF：180 × 150； CMAQ：160 × 130	WRF：150 × 150； CMAQ：130 × 130
Horizontal resolution	15km	5km
Time step	60s	
Other options	Default	


domain
d02
42°N
40°N
38°N
36°N
34°N
32°N
30°N
28°N
26°N
24°N
110°E
115°E
120°E
125°E
130°E
35°N
34°N
33°N
32°N
31°N
116°E
117°E
118°E
119°E
120°E
121°E
122°E
水域
部分农田
城镇
农田
混合森林

Meteorological station distribution

Number	City	Station Number	Longitude	Latitude	Observations
(a)	Nanjing	58235	118.51	32.22	pressure, temperature, wind components, wind direction, relative humid
(b)		58237	118.35	32.04	
(c)		58238	118.54	31.56	
(d)		58339	118.54	31.2	
(e)		58340	119.02	31.39	
(f)	Suzhou	58349	120.34	31.25	
(g)		58352	120.46	31.39	
(h)		58353	120.34	31.52	
(i)		58356	121.00	31.24	
(j)		58358	120.26	31.04	
(k)		58359	120.37	31.08	
(l)		58377	121.06	31.31	

Tethersonde station distribution

Number	Station	Longitude	Latitude	Observation
(m)	Nanjing Nanyou	118.94	32.12	Height, temperature ,wind speed , wind direction, relative humid
(n)	Suzhou Dongshan	120.26	31.04	

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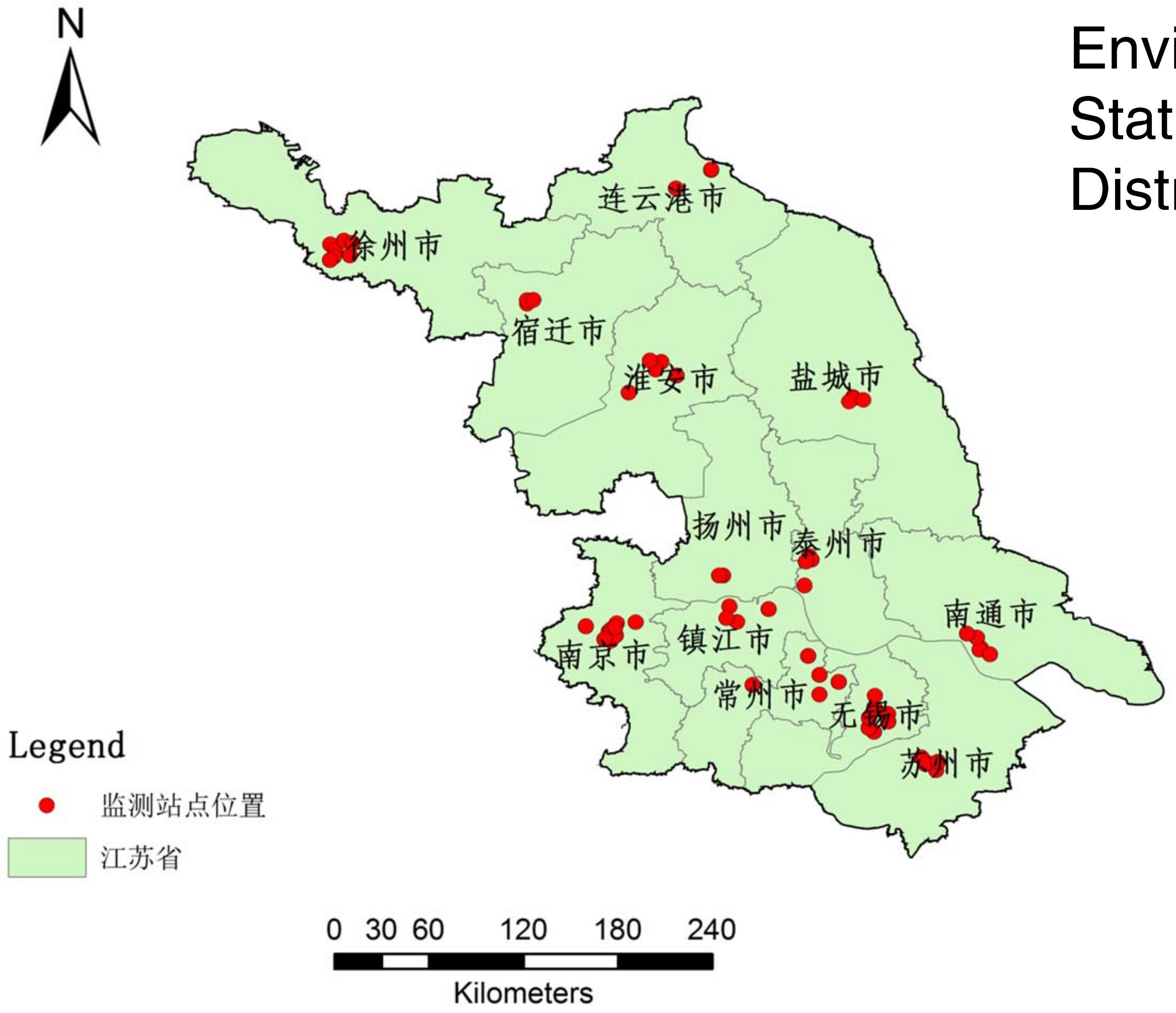
Environmental Station Distribution



Results and discussion

- Surface Meteorological variables validation
  - Surface meteorological variables
  - Tethersonde profile

- Air Pollutants simulation comparison
  - Gaseous pollutants
  - Particulate pollutants
  - Case Analysis

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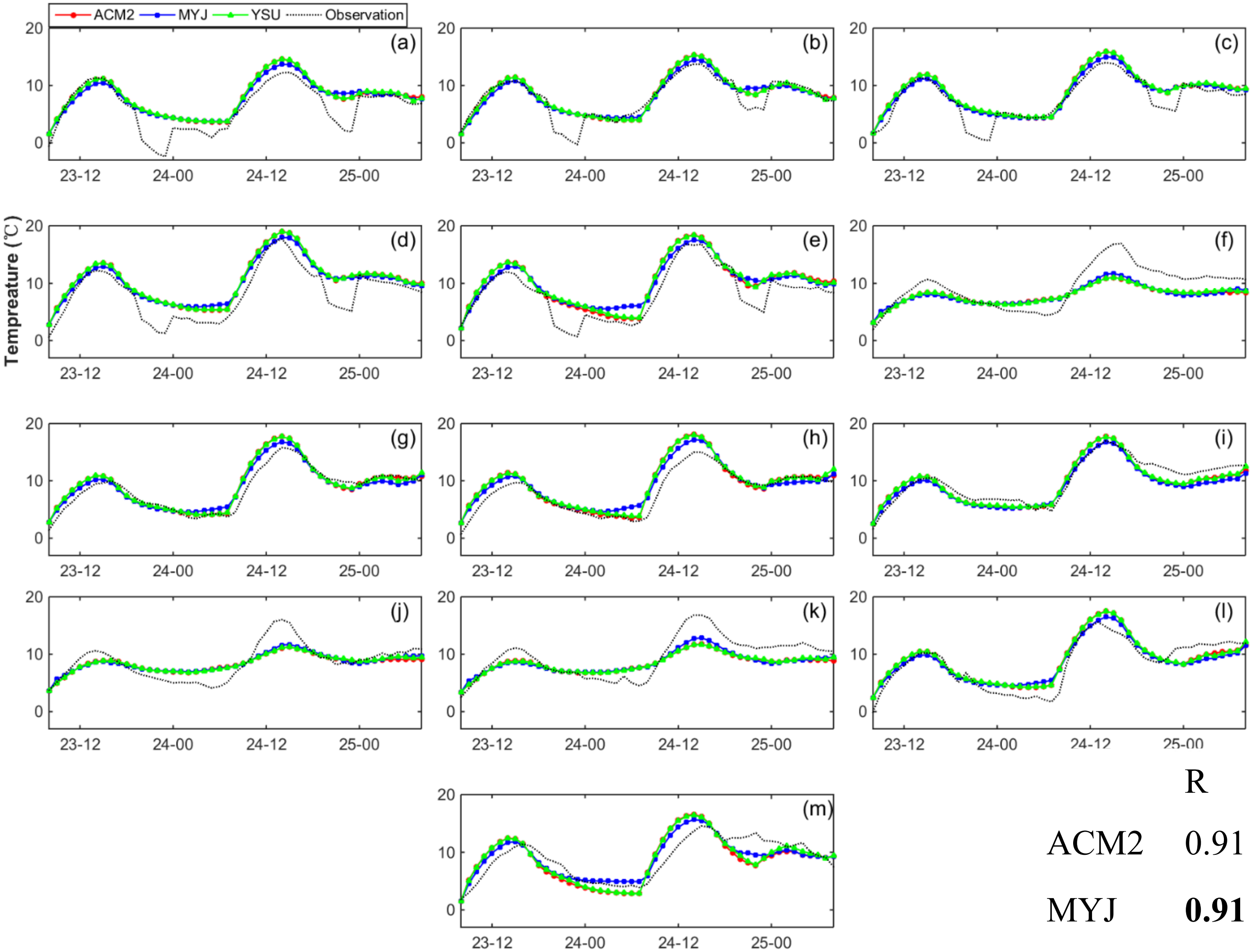
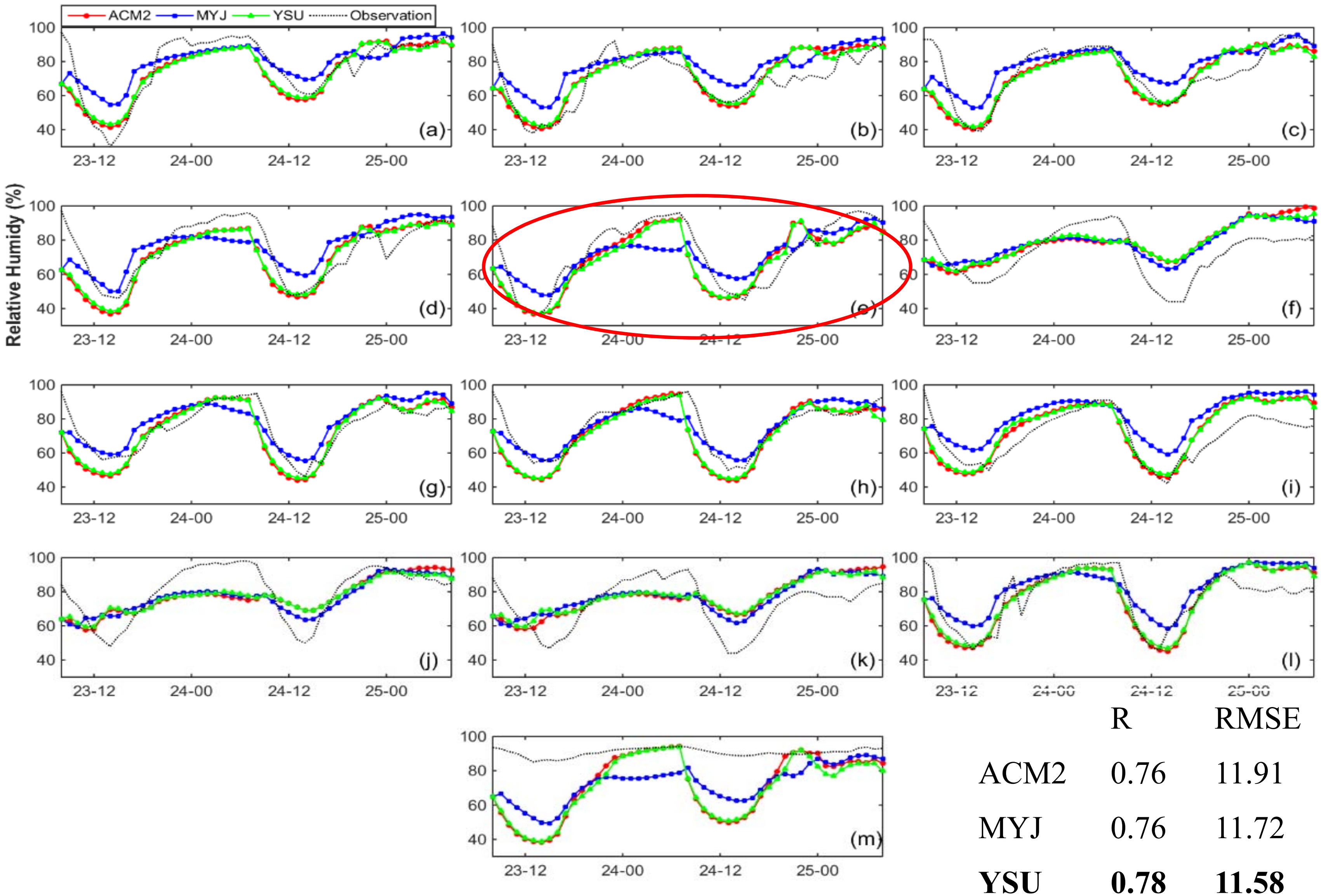
Surface Temperature at 2m



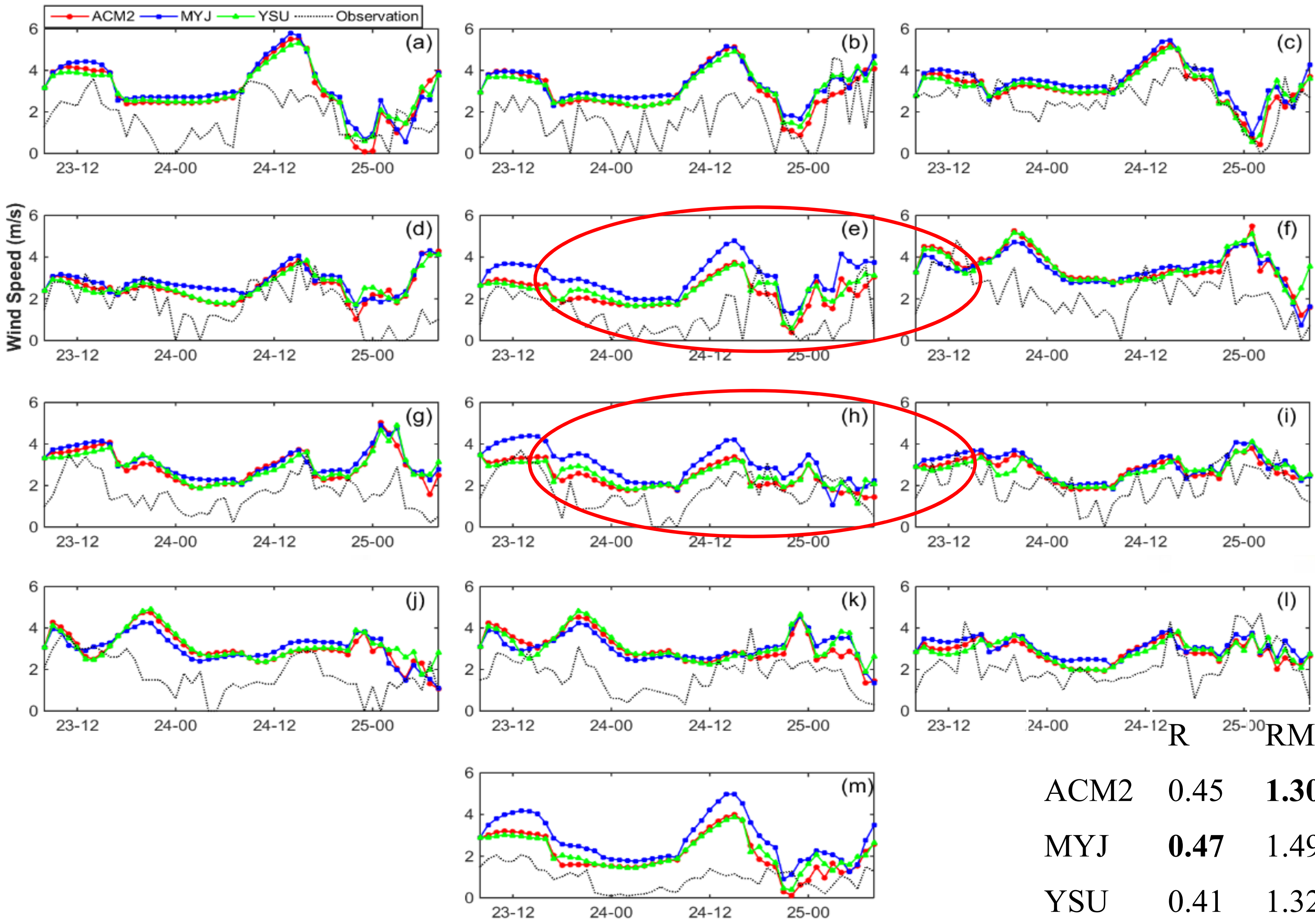
	R	RMSE	E	I
ACM2	0.91	2.08	0.26	0.89
MYJ	**0.91**	**1.95**	**0.26**	**0.90**
YSU	0.91	2.06	0.26	0.89

Surface Relative Humid at 2m



	R	RMSE	E	I
ACM2	0.76	11.91	0.12	0.14
MYJ	0.76	11.72	0.14	0.76
YSU	**0.78**	**11.58**	**0.12**	**0.80**

Surface Wind Speed at 10m



	R	RMSE	E	I
ACM2	0.45	**1.30**	**1.05**	**0.55**
MYJ	**0.47**	1.49	1.29	0.51
YSU	0.41	1.32	1.12	0.53

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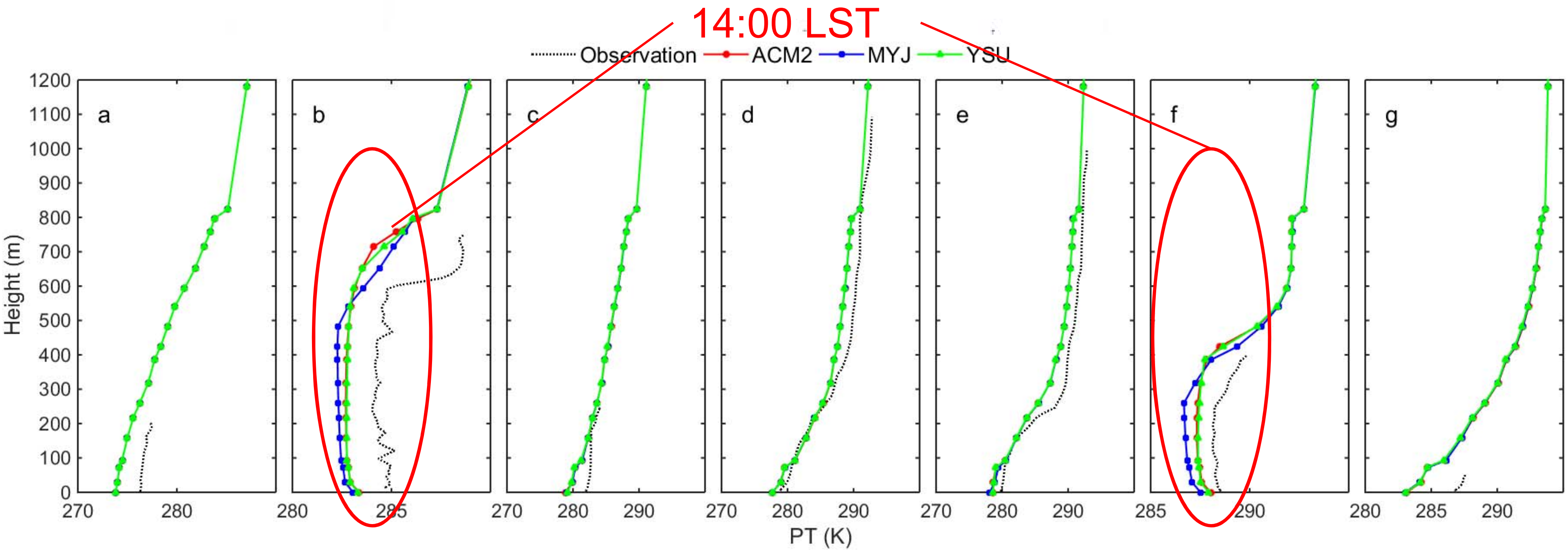
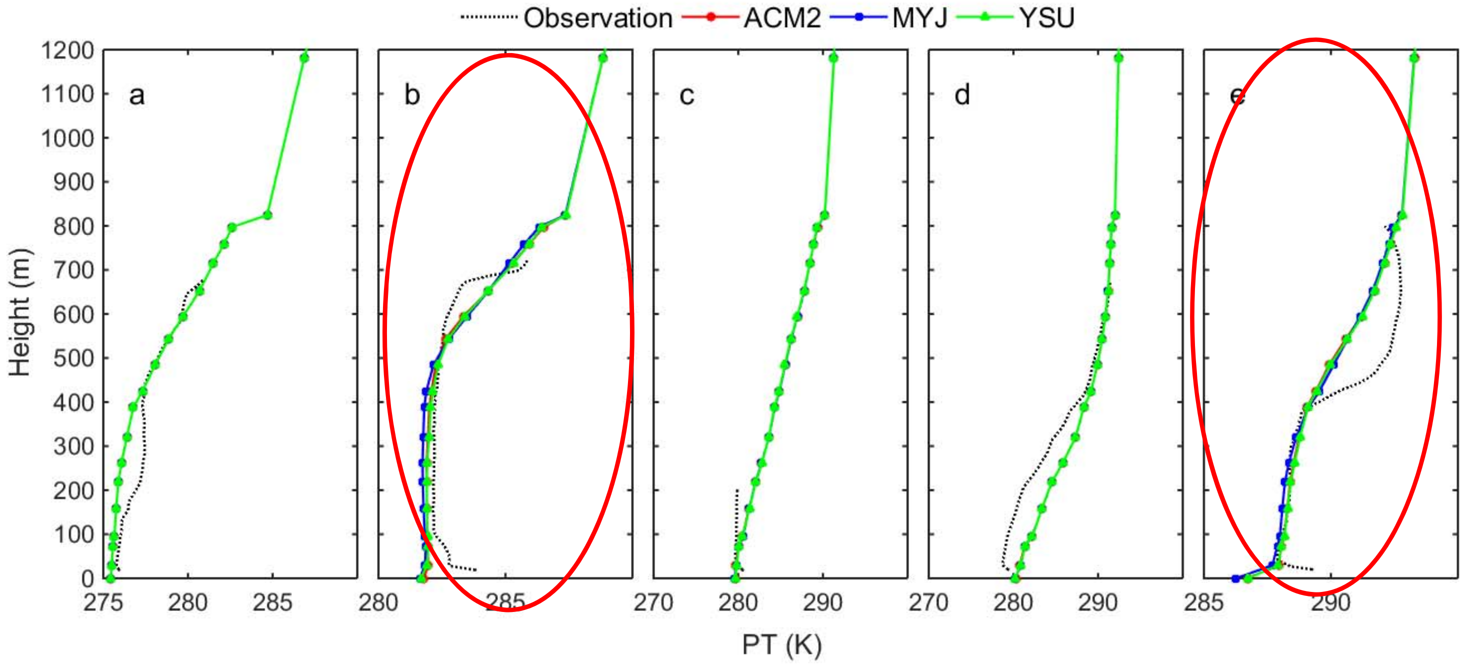
Potential Temperature Profile



Nanyou station,(a) 08:00 23.Jan, (b)14:00, (c)20:00, (d) 02:00 24.Jan, (e)08:00 ,(f)14:00, (g) 20:00



Dongshan station,(a) 08:00 23.Jan, (b)14:00, (c)20:00 (d)08:00 24.Jan ,(e)14:00

No much differences

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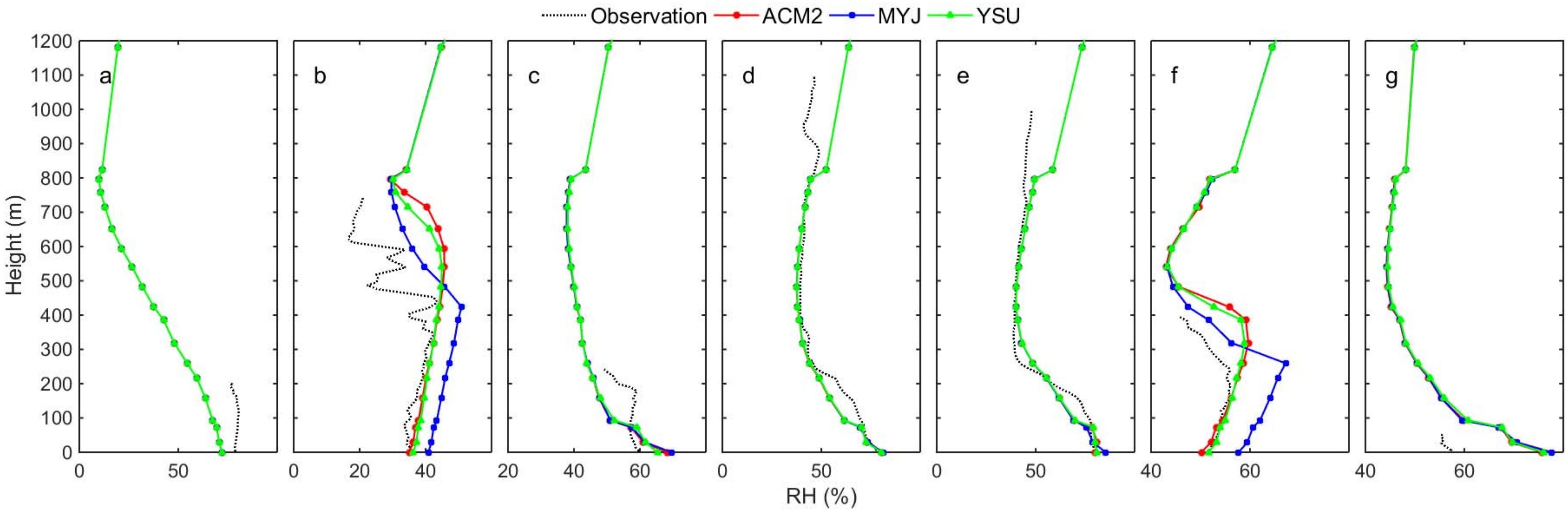
Relative Humid Profile



Nanyou station,(a) 08:00 23.Jan, (b)14:00, (c)20:00, (d) 02:00 24.Jan, (e)08:00 ,(f)14:00, (g) 20:00

Similar to potential temperature profile

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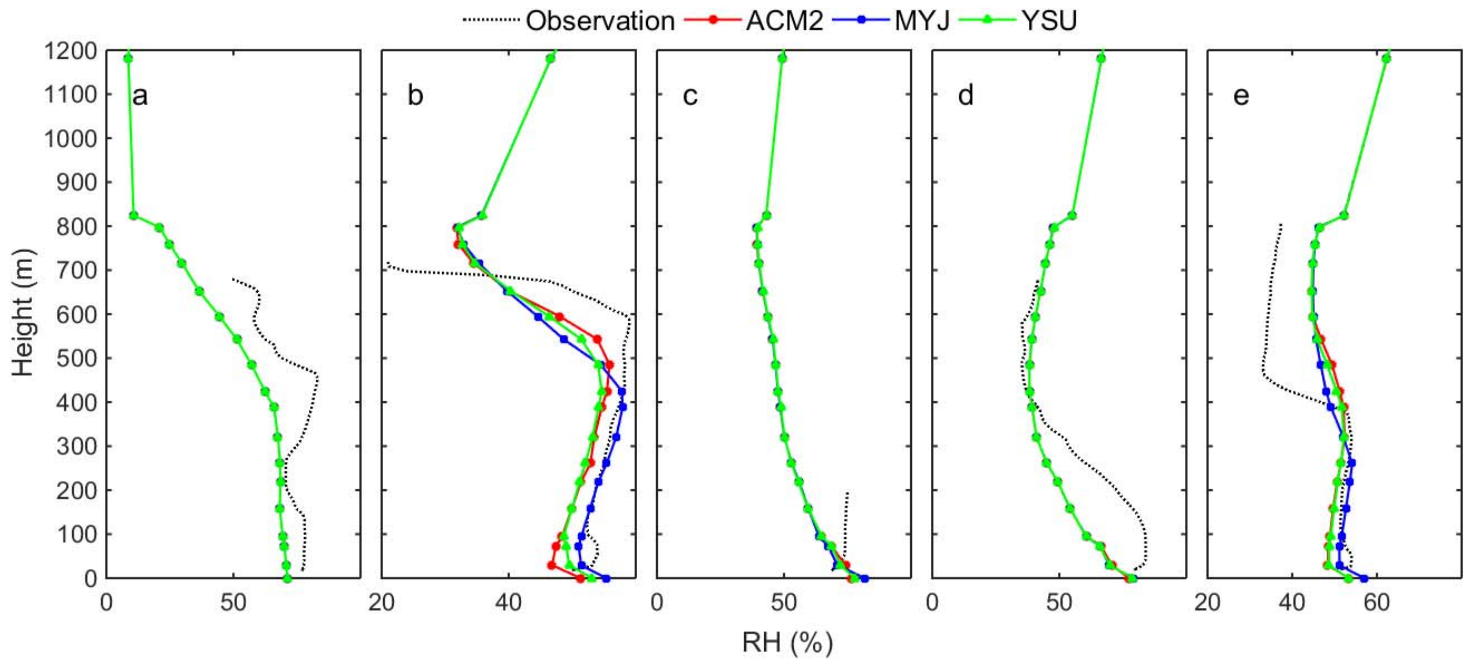

Dongshan station,(a) 08:00 23.Jan, (b)14:00, (c)20:00 (d)08:00 24.Jan ,(e)14:00

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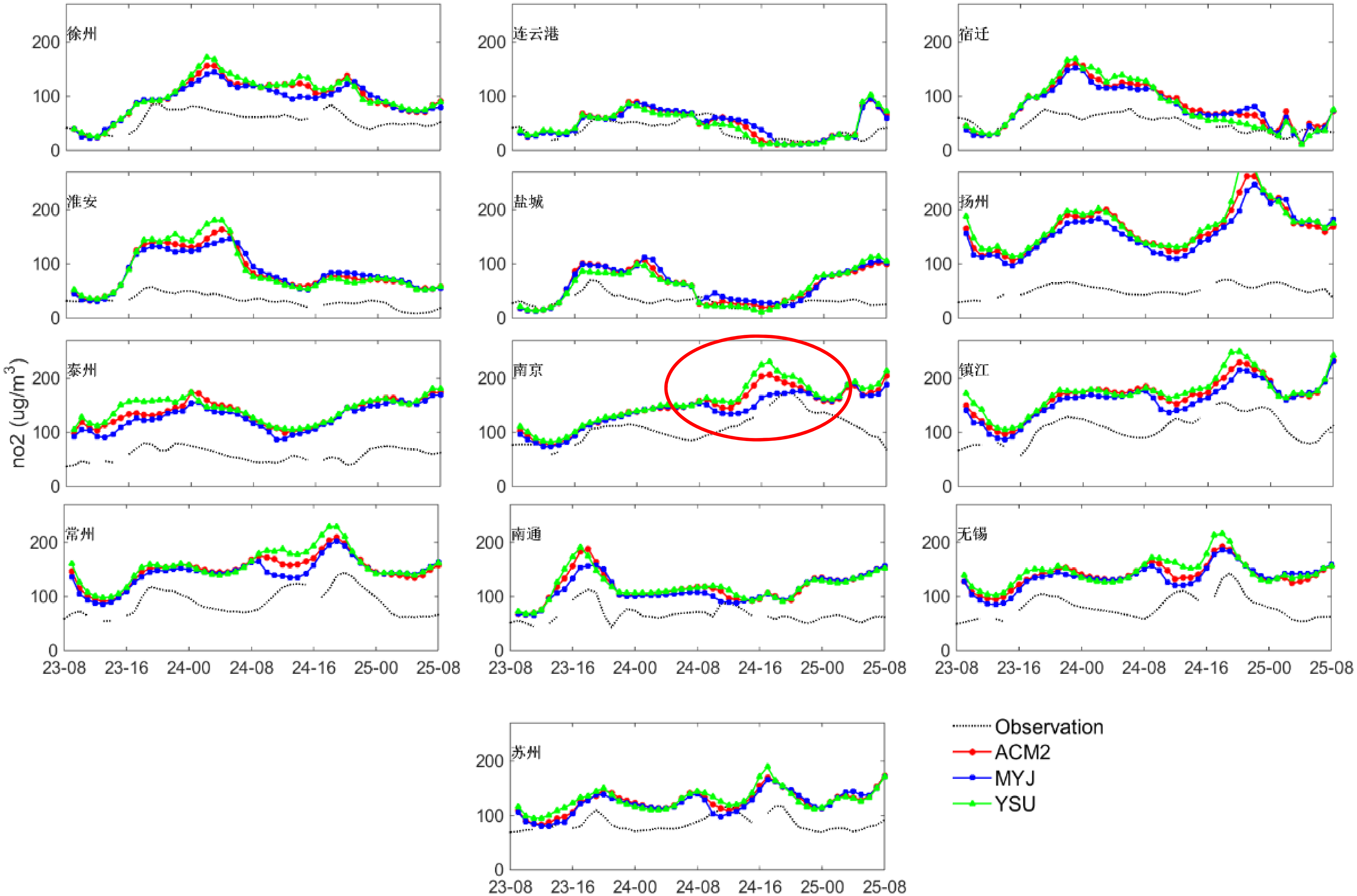
NO_2 Concentration

	R	RMSE	E	I
ACM2	**0.61**	59.0	**0.98**	**0.42**
MYJ	0.44	**53.7**	0.91	0.41
YSU	0.61	60.3	0.98	0.42



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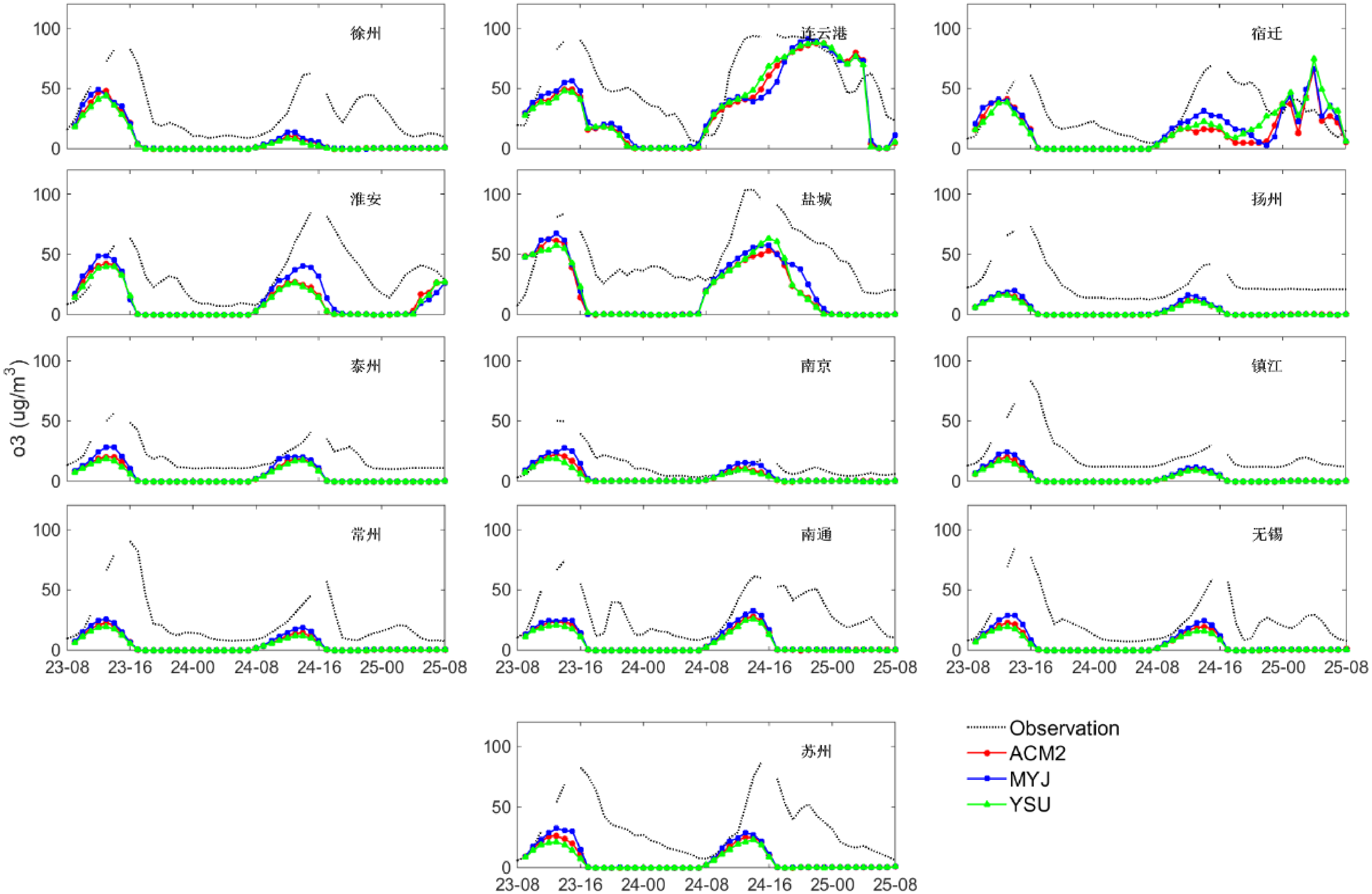
	R	RMSE	E	I
ACM2	0.53	27.1	0.81	0.53
MYJ	**0.76**	**23.3**	**0.80**	**0.62**
YSU	0.73	25.3	0.83	0.57

O_3 Concentration



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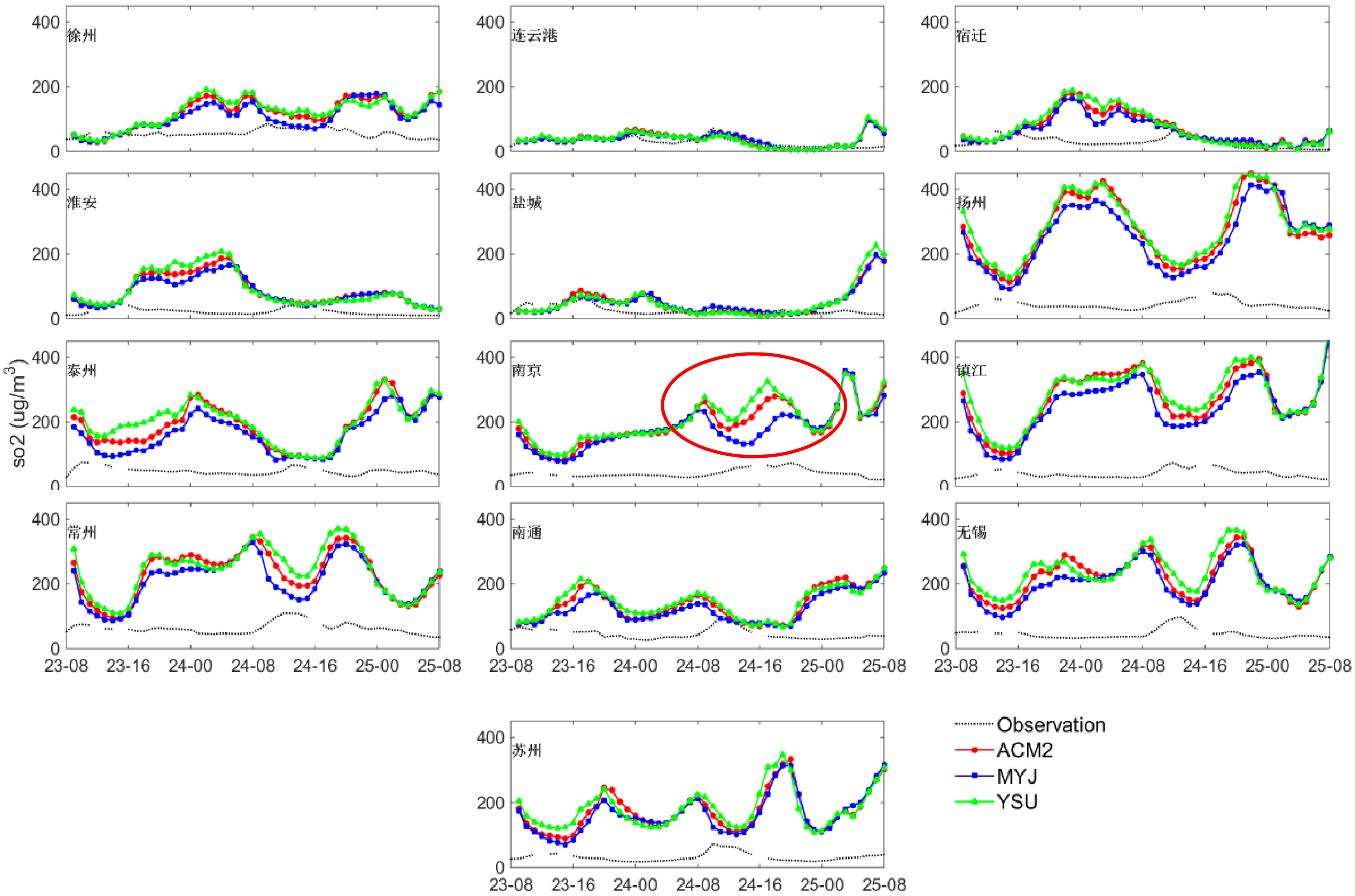
SO_2 Concentration

	R	RMSE	E	I
ACM2	-0.07	139.2	3.56	0.15
MYJ	-0.1	118.3	3.05	0.18
YSU	0.06	139.0	3.53	0.18



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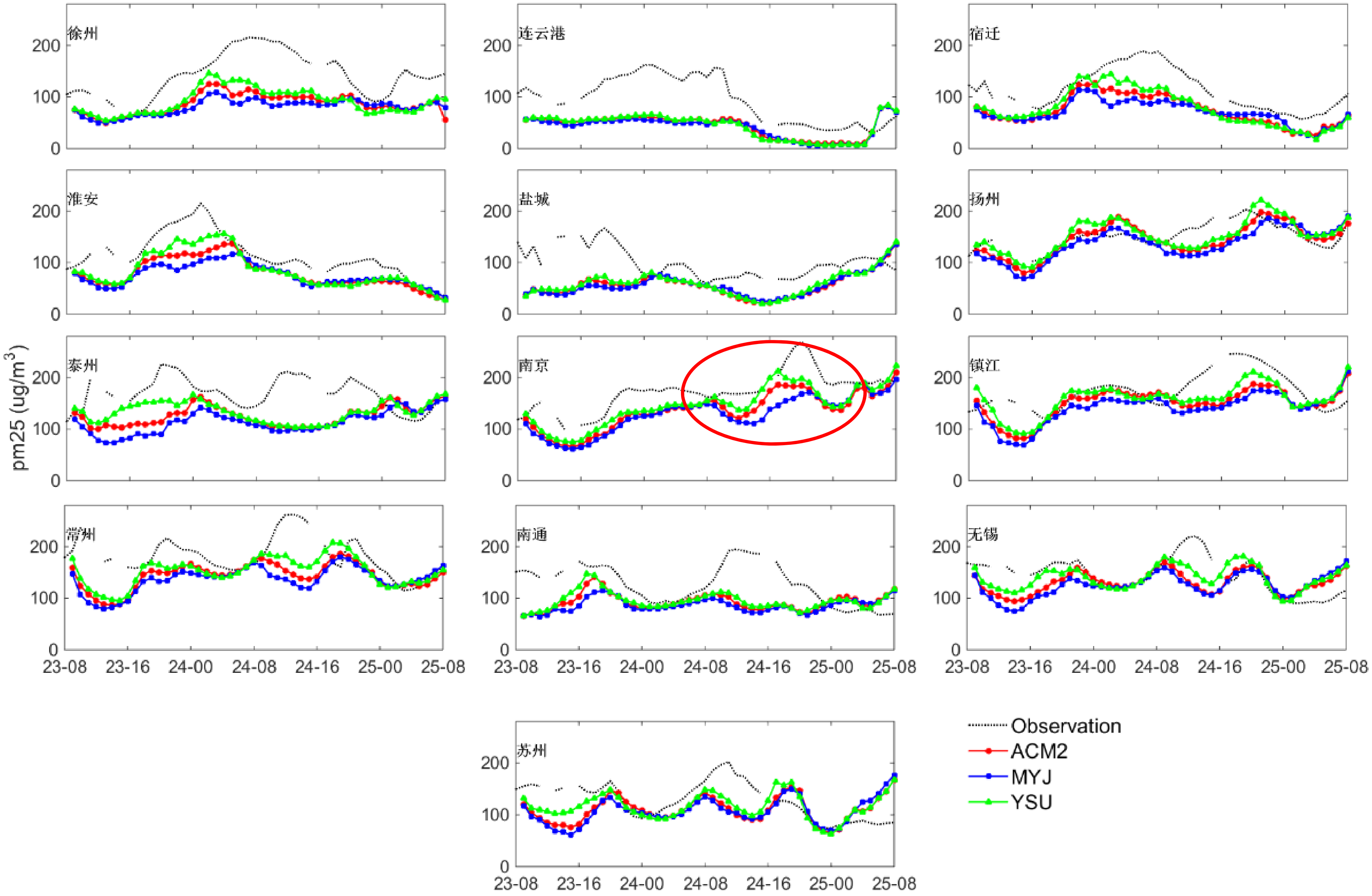
PM2.5 Concentration

	R	RMSE	E	I
ACM2	0.43	47.2	0.29	0.58
MYJ	0.30	55.8	0.33	0.49
YSU	**0.53**	**43.6**	**0.28**	**0.62**



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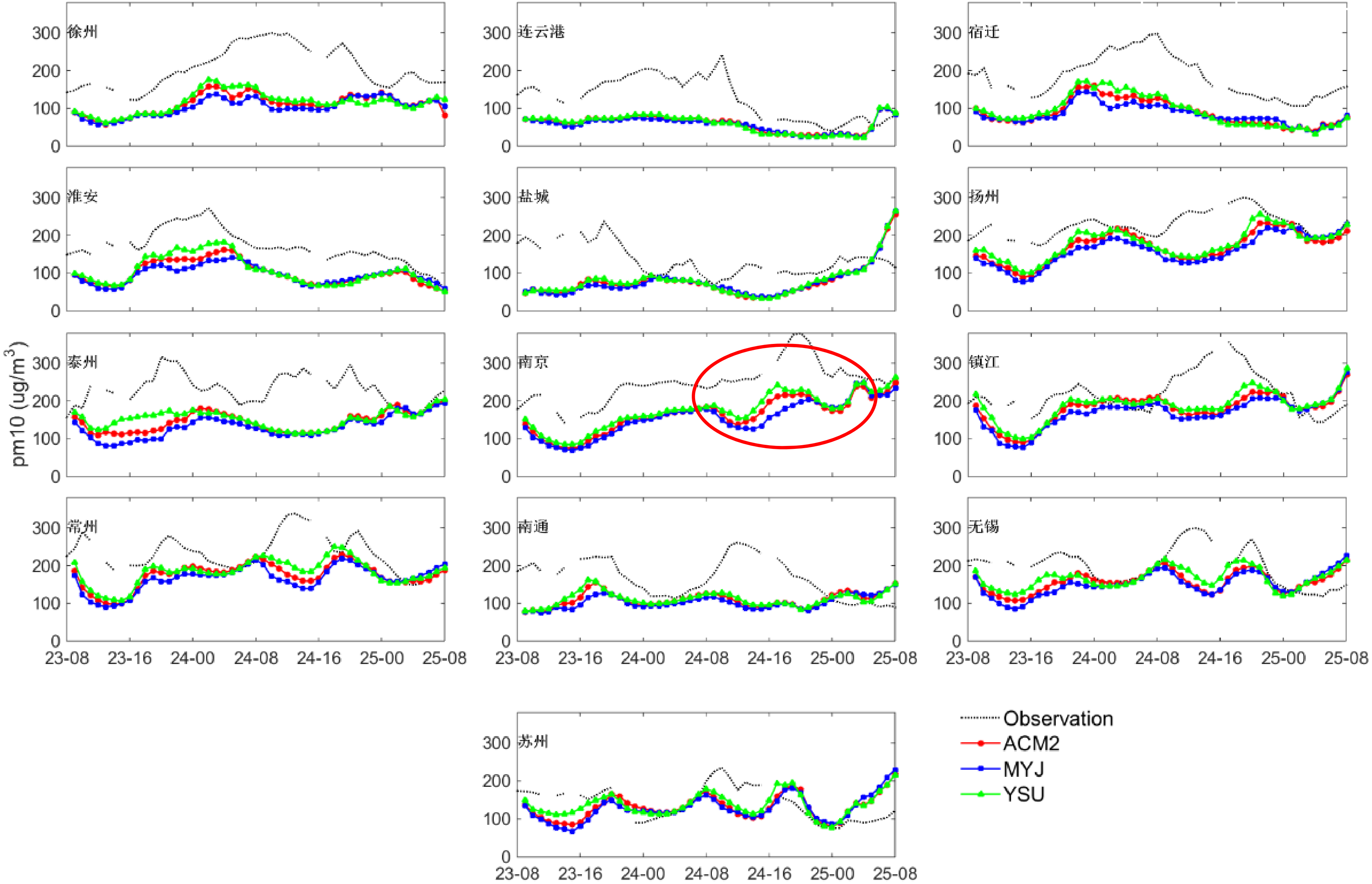
PM10 Concentration

	R	RMSE	E	I
ACM2	0.29	80.4	0.35	0.47
MYJ	0.17	90.8	0.40	0.42
YSU	**0.40**	**76.3**	**0.34**	**0.50**



Case Analysis:

For Nanjing station, there are obvious differences during 0800 24.Jan to 1800 24.Jan.

Nanyou station was selected to study further.

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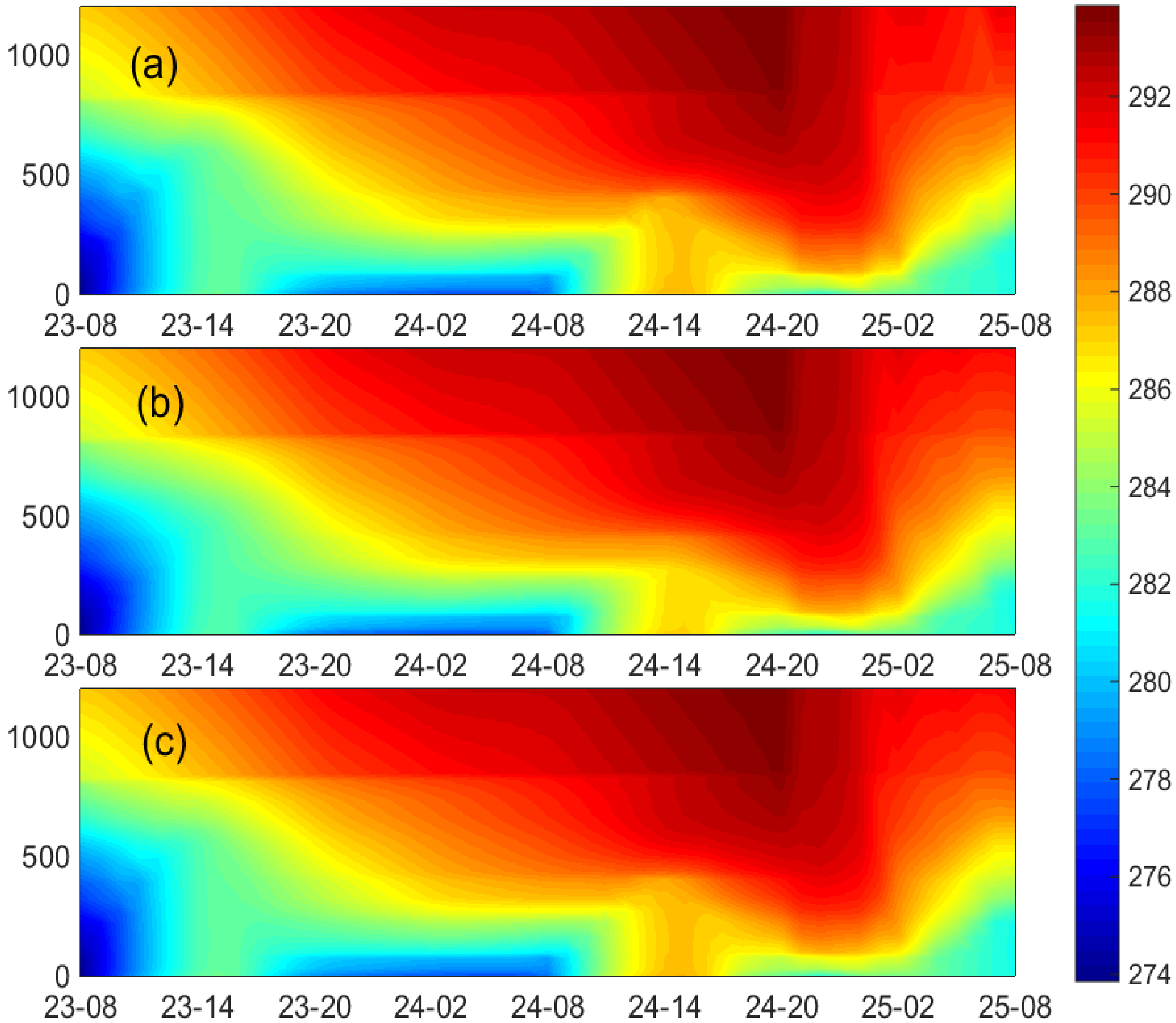

Virtual potential temperature versus height and time
(a)ACM2 ,(b)MYJ ,(c)YSU

Non–local schemes have the highest PBLH and virtual potential temperature with a little breakthrough to the inversion layer.

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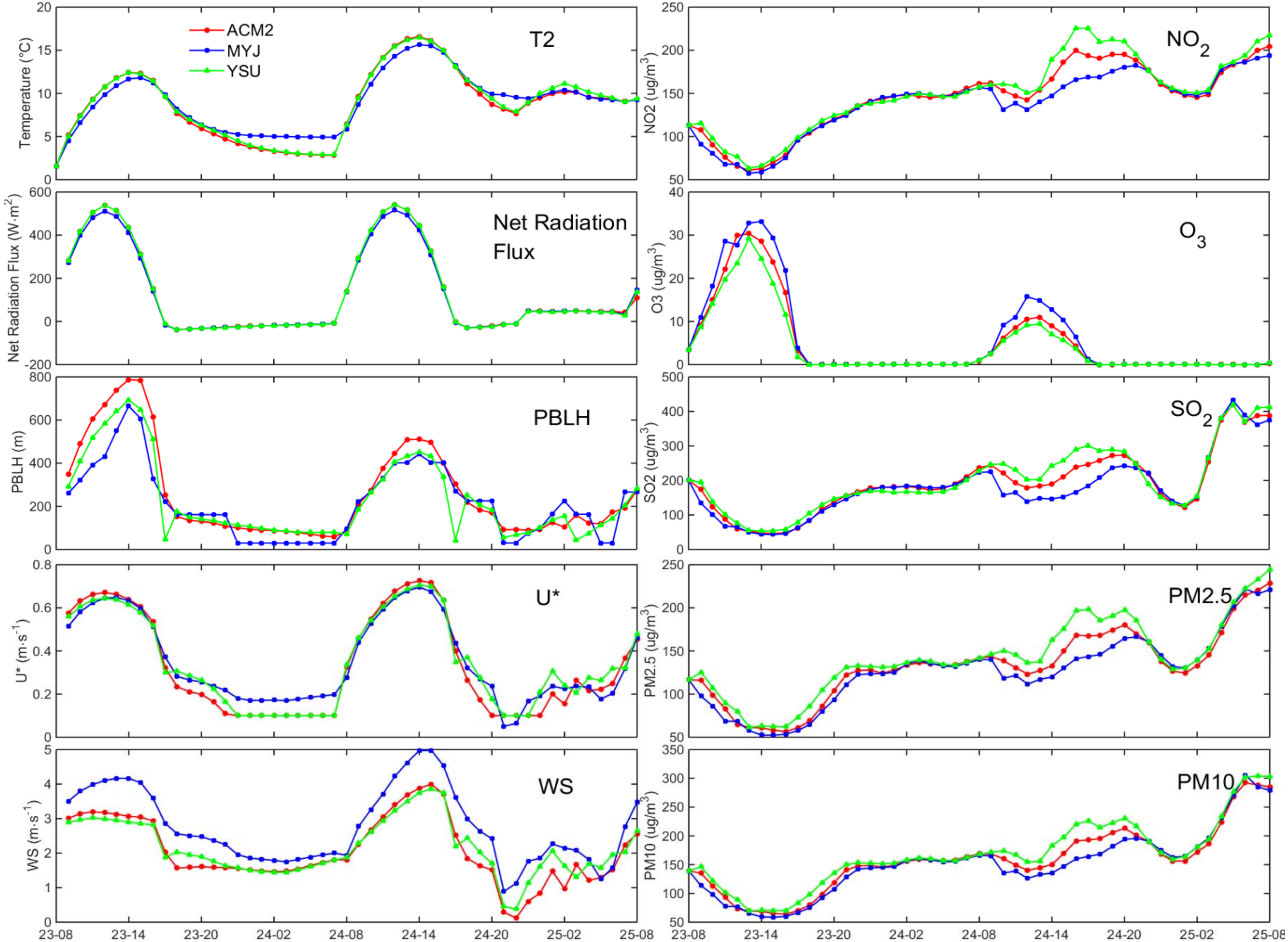
Nanyou station results compare



The main differences are reflected in PBL Height , u* and wind speed ,where wind speed plays the most significant role.

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Conclusion

- As can be seen from the current study, the simulation results of different PBL schemes have a more significant differences when temperature is relatively high. The PBL schemes affect turbulence diffusion and PBL height as well as pollutants concentration.

- This case indicates that vertical turbulence mixing mechanism differs in PBL schemes, where MYJ scheme has the weakest mixing effect during noon, leading to a lower PBL height. However MYJ scheme also has the maximum wind speed, thus simulating a lowest pollution concentration. Meanwhile, YSU and ACM2 not differ greatly.

- The pollutant emission source used in this study results in a lower O_3 ,PM2.5 and PM10 simulation concentration , but a obviously higher NO_2 and SO_2 simulation concentration . In the latter part of the study, we should change the emission source.

- This study only analysis a single heavy pollution case of 23.Jan 2015 to 25.Jan 2015. Whether the preliminary conclusions can be applied to other weather condition still needs a further discussion.

Thanks !