

Supplementary information for
Wind-Aware, Time-Scale Adaptive PM_{2.5} Spatiotemporal
Forecasting with Spatial Regularization

Guyu Zhao^{a,b}, Shuo Zhang^{a,b}, QiMing Liu^{a,b} and Hongdou He^{a,*}

^aSchool of Information Science and Engineering, Yanshan University, Qinhuangdao

^bThe Key Laboratory for Software Engineering of Hebei Province, Qinhuangdao

*Corresponding Author

He Hongdou, E-mail: hhd@ysu.edu.cn

Table S1. Parameter Explanations for the PM_{2.5} Prediction Model. This table lists the input parameters used in the PM_{2.5} concentration prediction model and provides a brief explanation of their impact on air quality.

Table S2. Optimal parameter values used in the experiments.

Table S3. Air Quality Level Classification Based on the "Technical Regulations for Ambient Air Quality Index"

Table S4. Sensitivity Analysis of the Neighborhood Size k in kNN Graph Construction

Fig.S1. Distribution of Stations in the Beijing-Tianjin-Hebei Region.

Fig.S2. Time Convolution Block structure

Fig.S3. Comparison of city-level MAPE for hourly PM_{2.5} forecasts in the BTH region.

Fig.S4. Contour maps comparing PM_{2.5} forecasts at different lead times with ground-truth observations. Results are shown for 1h, 6h, 12h, and 24h forecasts across cities in the BTH region under varying pollution levels.

Table S1. Parameter Explanations for PM2.5 Prediction Model

Parameter	Explanation
AQI (Air Quality Index)	A single numerical indicator that integrates multiple pollutant concentrations (e.g., PM _{2.5} , PM ₁₀ , O ₃) to represent overall air quality. It helps track general pollution levels and provides indirect insights into PM _{2.5} trends.
CO (Carbon Monoxide)	Concentration of Carbon Monoxide, mainly from vehicle exhaust and combustion sources. CO often co-occurs with PM _{2.5} in urban areas, indicating shared emission origins.
NO ₂ (Nitrogen Dioxide)	A reactive nitrogen gas produced mainly by fossil fuel combustion. It is a precursor to secondary particulate formation and correlates with traffic-related PM _{2.5} emissions.
O ₃ (Ozone)	A secondary pollutant formed through photochemical reactions involving NO _x and VOCs. Ozone levels influence the oxidative environment and the formation of secondary PM _{2.5} .
PM ₁₀ (Particulate Matter 10)	Particulate matter with diameter $\leq 10\mu\text{m}$, which includes PM _{2.5} . PM10 trends often move with PM2.5 and can indicate broader particle pollution.
PM _{2.5} (Particulate Matter 2.5)	Fine particulate matter with diameter $\leq 2.5\mu\text{m}$. It poses significant health risks and is the core target variable in the prediction model.
SO ₂ (Sulfur Dioxide)	A gaseous pollutant from industrial processes and coal combustion. SO ₂ can react in the atmosphere to form sulfate particles, contributing to PM _{2.5} levels.

t2m (2-meter Temperature)	Near-surface air temperature at 2 meters. It influences atmospheric mixing, stability, and chemical reaction rates, all of which affect PM _{2.5} dynamics.
d2m (2-meter Dew Point Temperature)	Dew point temperature at 2 meters, reflecting ambient humidity. High dew points are associated with enhanced aerosol hygroscopic growth and secondary PM formation.
V10 (10-meter North-South Wind Component)	Meridional (north-south) wind component at 10 meters altitude. It affects pollutant transport and regional dispersion of PM _{2.5} .
u10 (10-meter East-West Wind Component)	Zonal (east-west) wind component at 10 meters altitude. Together with V10, it determines wind-driven horizontal movement of air pollutants.
tp (Total Precipitation Rate)	Total precipitation rate in millimeters per hour. Rainfall helps remove PM _{2.5} from the air through wet deposition.
sp (Surface Pressure)	Surface atmospheric pressure, indicating synoptic weather conditions. It influences boundary layer height and the vertical mixing of pollutants, thus affecting PM _{2.5} accumulation.

Table S2. Optimal parameter values used in the experiments.

Hyperparameters	Values
Training epoch	100
Input sequence length	168
Hidden dimension	64
Mid-layer channel	32
Number of heads	4
Window size	8
Distance-decay temperature	6.0
Wind-bias scale	0.5
Time-decay temperature	12.0
Number of experts	4
Top-U temperature	0.5
Entropy-reg weight	0.01
Number of prototypes	50
Cluster-softmax temperature	1.0
Dynamic-adj temperature	0.5
Static-dynamic fusion α init	0.1
Laplacian-reg weight	0.1
Learning rate	1e-4
Weight decay	1e-3

Table S3. Air Quality Level Classification Based on the "Technical Regulations for Ambient Air Quality Index"

Level	PM2.5 concentration range ($\mu\text{g}/\text{m}^3$)
Excellent	0-35
Good	36-75
Light Pollution	76-115
Moderate Pollution	116-150
Heavy Pollution	151-250
Severe Pollution	>250

Table S4. Sensitivity Analysis of the Neighborhood Size k in kNN Graph Construction

K	1h		6h		12h		24h	
	MAE ↓	RMSE ↓	MAE ↓	RMSE ↓	MAE ↓	RMSE ↓	MAE ↓	RMSE ↓
2	4.637	7.300	8.932	13.568	11.056	16.985	13.057	19.677
4	4.614	7.181	8.387	13.065	10.769	16.152	12.896	19.333
6	4.635	7.204	8.654	13.548	11.036	16.835	13.202	19.712
8	4.659	7.259	8.854	13.882	11.532	17.002	13.636	20.051

Fig.S1. Distribution of Stations in the Beijing-Tianjin-Hebei Region

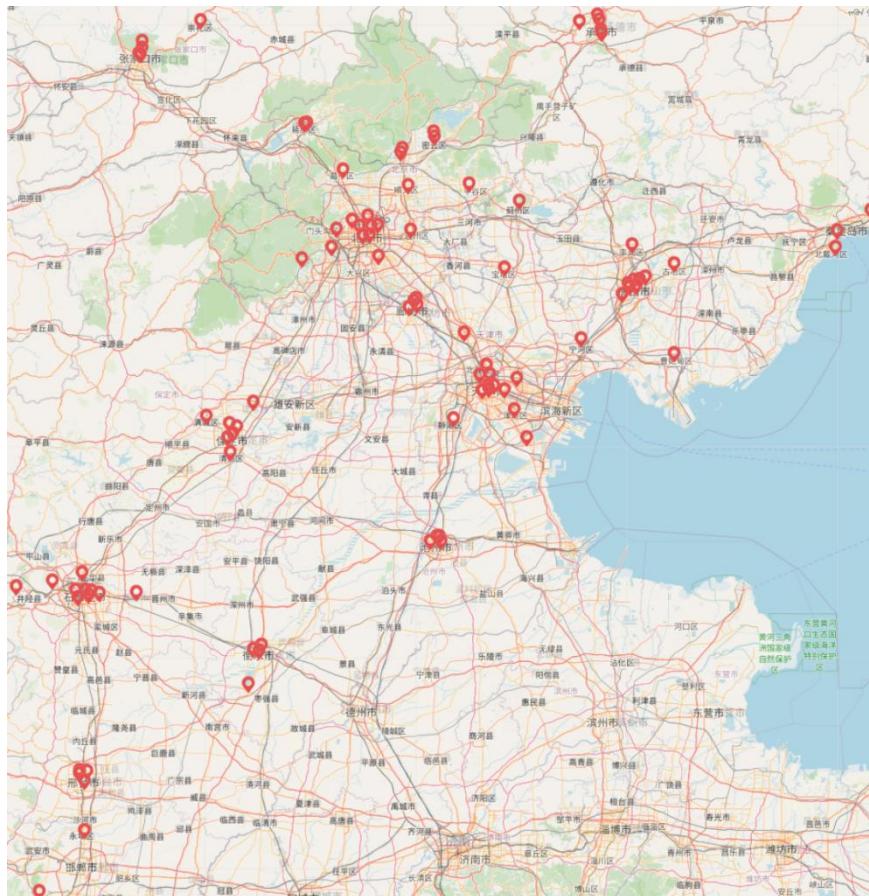


Fig.S2. Time Convolution Block structure

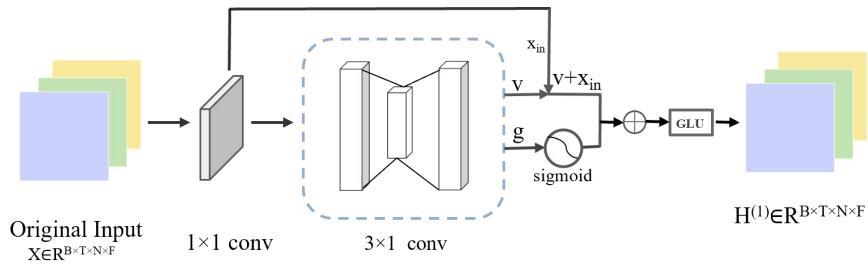


Fig.S3. Comparison of city-level MAPE for hourly PM_{2.5} forecasts in the BTH region.

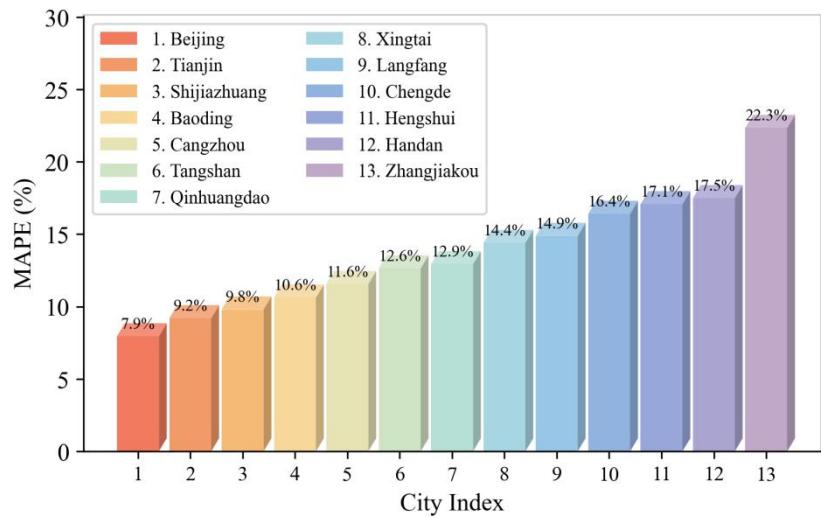


Fig.S4. Contour maps comparing PM_{2.5} forecasts at different lead times with ground-truth observations. Results are shown for 1h, 6h, 12h, and 24h forecasts across cities in the BTH region under varying pollution levels.

