EGU General Assembly 2022

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Improving Spatiotemporal Fine Particulate Matter from a Data Assimilation Approach

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Abstract

This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

Outline

- **Research Motivation**

Part II: Assimilated Model & Scenario Setting

Part III: Major Findings

Part I: Research Framework

- **Conclusion**

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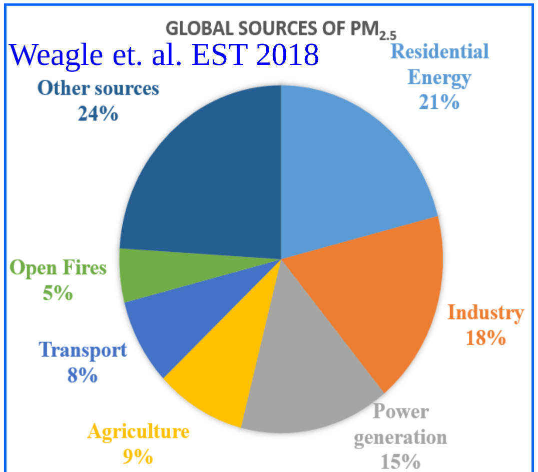
Research Motivation

- Technical guide for **Source Apportionment** of ambient ozone pollution.
- Emission control policies in the **13th Five-Year-Plan** (2016-2020).
- Atmospheric pollution **prevention and control law** of China.
- Estimated **3 million deaths** in 2014 being attributable to $PM_{2.5}$. (WHO report 2016)
- **87% of global people** reside in the areas in which the WHO air quality guideline (annual mean of 10 μg/m^3) for $PM_{2.5}$ is exceeded. (Shaddick. et. al. JRSSAS-series C, 2018)
- Satellite retrieval or statistical method? (Bi et. al. RSE 2019)
- **Air Quality Modeling**

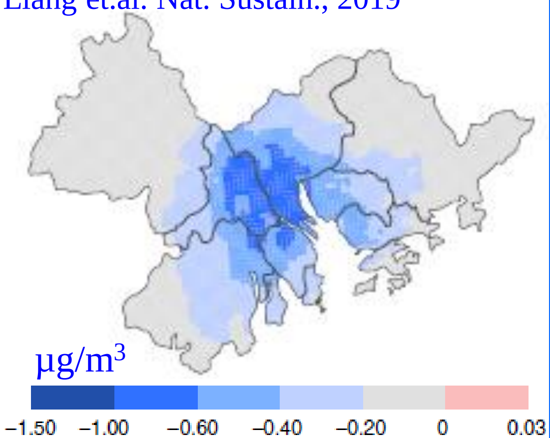
Source Apportionment



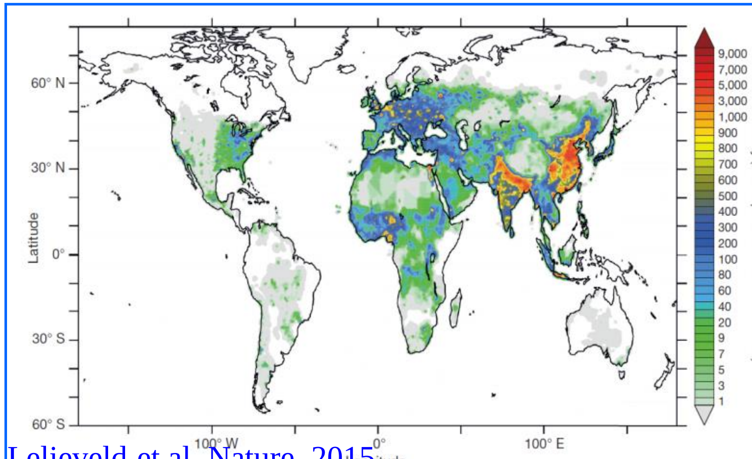
Weagle et. al. EST 2018

Policy Evaluation

Liang et.al. Nat. Sustain., 2019



Health Risks

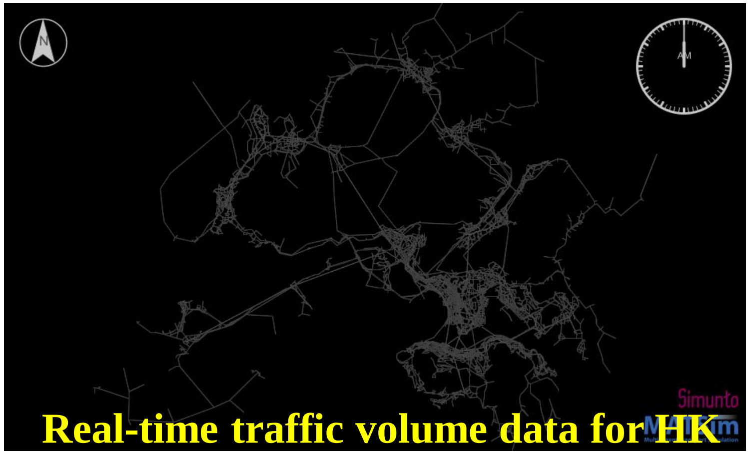


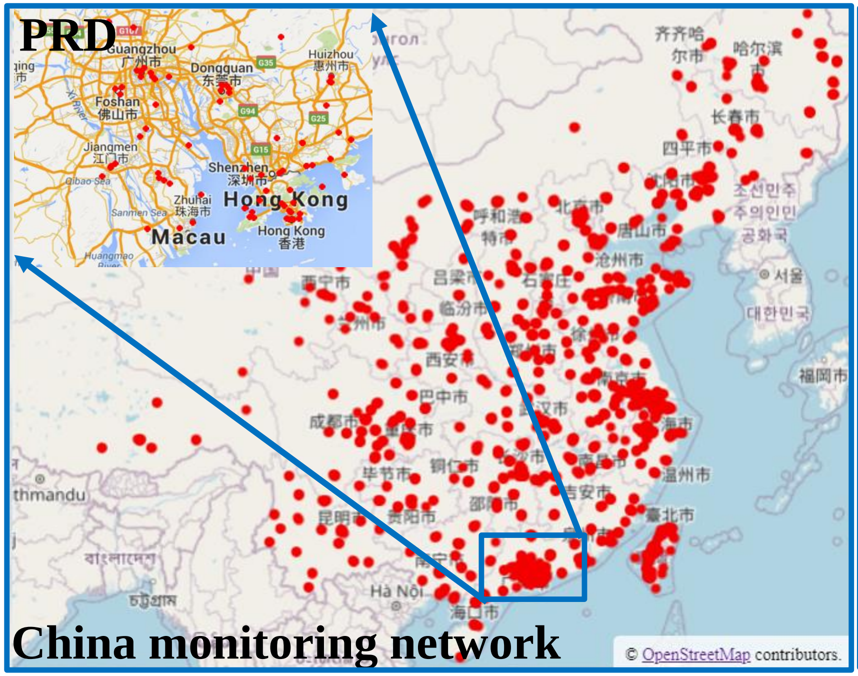
Lelieveld et.al. Nature, 2015

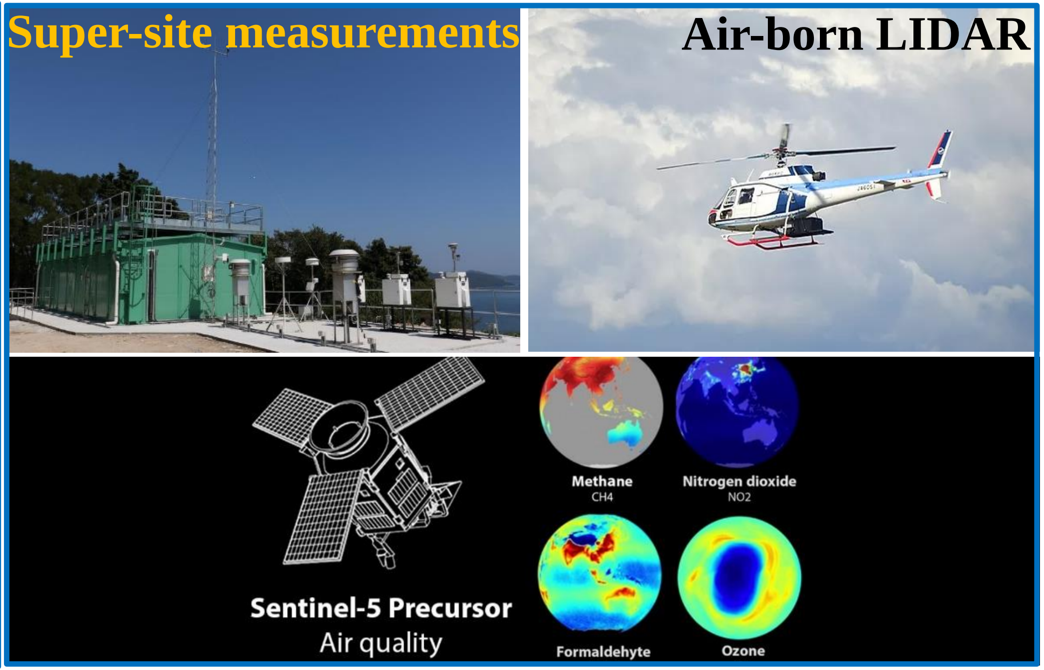
Research Motivation

- **Multi-source real-time data** offered an unprecedented opportunity to make the model validation and assimilation possible.

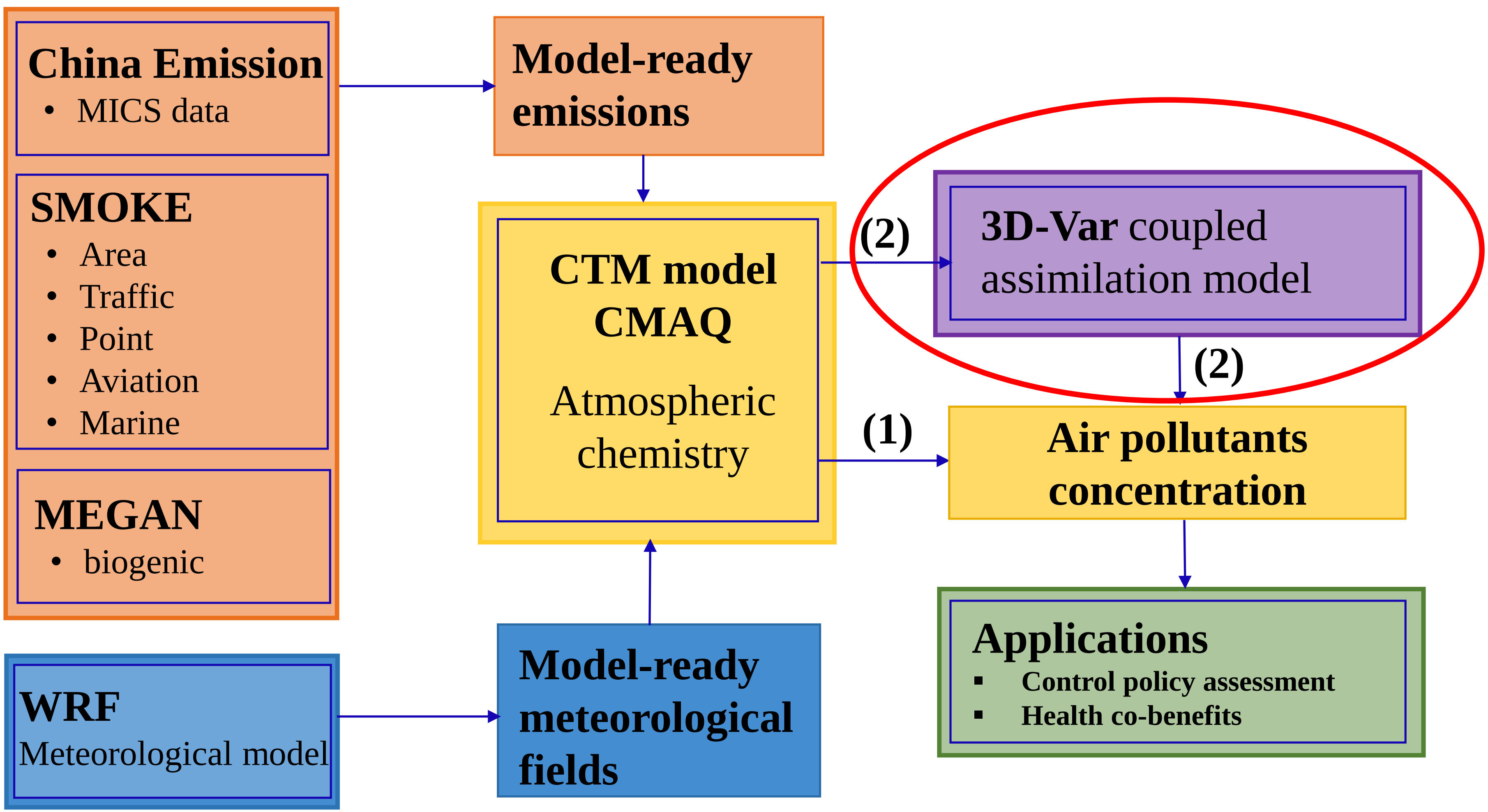
Work with Prof. Lo, H. K. in Civil, HKUST





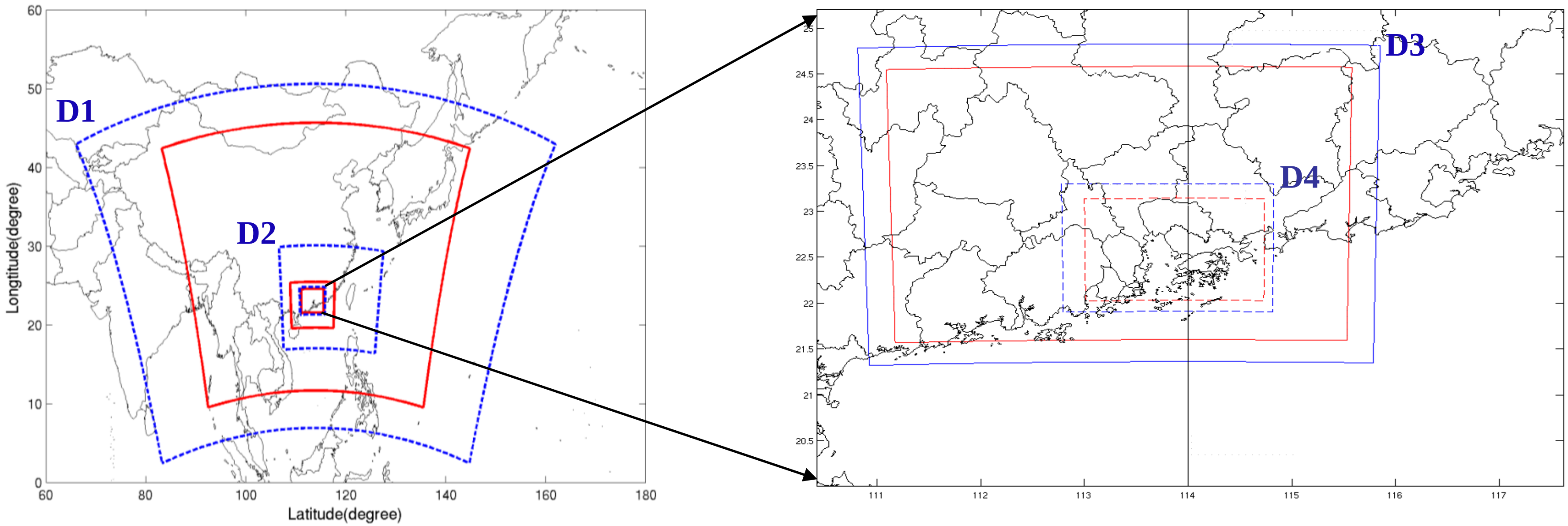


Part I: Research framework



Domain setting of the system

- **Larger WRF domain could minimize the boundary effects of meteorological parameters on CMAQ grid.**

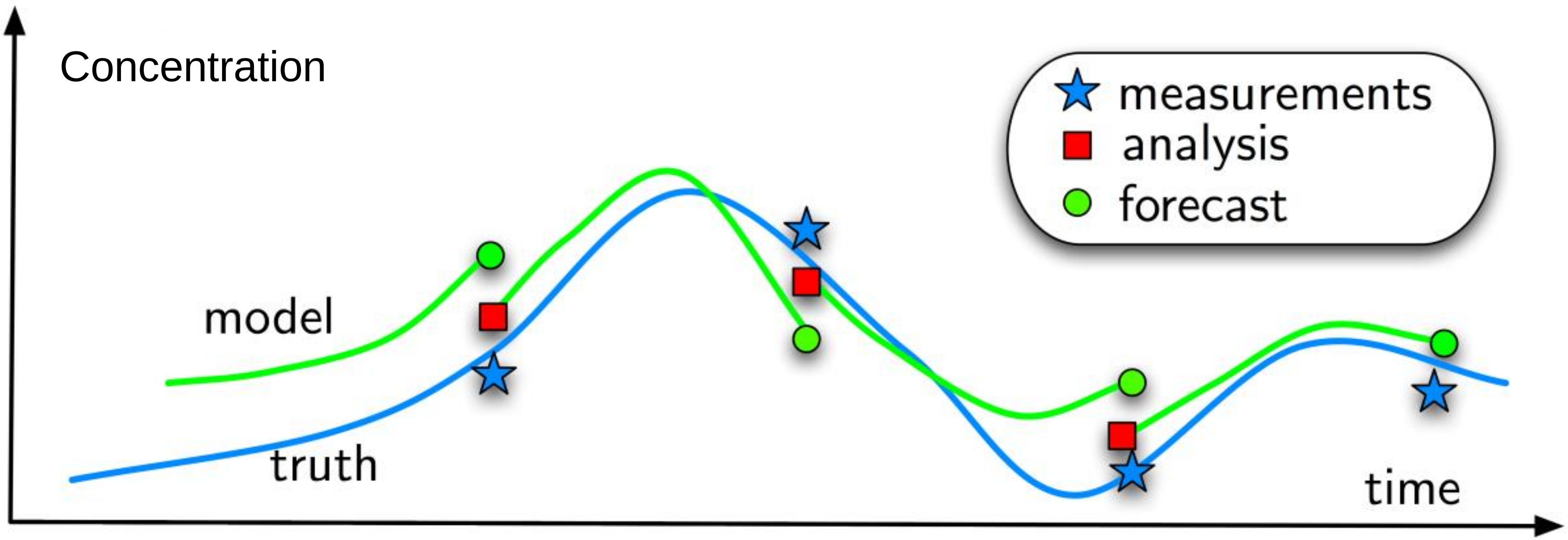


Parameter	Value
Projection	Lamber-Conformal
Alpha	250°N
Beta	40°N
X center	114°E
Y center	28.5°N

Domain	Geographical coverage	WRF grid (km)	CMAQ grid (km)	Resolution (km)
D1	China and Japan	7641 x 4968	4914 x 3726	27
D2	Southeast China	2007 x 1467	882 x 666	9
D3	Guangdong	516 x 390	456 x 330	3
D4	Hong Kong	214 x 163	179 x 125	1

Part II: 3D-Var model coupled a fusion system

Theory of the 3D-VAR model



$$J(\boldsymbol{x_a}) = \frac{1}{2}(\boldsymbol{x_a} - \boldsymbol{x_b})^T \boldsymbol{B}^{-1}(\boldsymbol{x_a} - \boldsymbol{x_b}) + \frac{1}{2}(\boldsymbol{y_0} - \mathcal{H}(\boldsymbol{x_a}))^T \boldsymbol{R}^{-1}(\boldsymbol{y_0} - \mathcal{H}(\boldsymbol{x_a}))$$

$\boldsymbol{x_a}$ is the vector of analysis; $\boldsymbol{x_b}$ is the background; $\boldsymbol{y_0}$ is the observation vector

B is the Background Error Covariance (BEC) matrix

R is the Observation Error Covariance (OEC) matrix

$\mathcal{H}$ is the observation operator

Scenario setting

Scenarios	Assimilation cycles	Description
NotDA	No assimilation	Base control: spinning up for 10 days and digesting the initial conditions from the previous-cycle simulation.
H24DAPM	UTC 12:00	On the basis of the control case, assimilating $PM_{2.5}$ data once a day.
H06DAPM	UTC 12:00, 18:00, and 00:00, 06:00 the next day	On the basis of the control case, assimilating $PM_{2.5}$ data four times a day.
H6DAPSN	UTC 12:00, 18:00, and 00:00, 06:00 the next day	On the basis of the H06DAPM case, assimilating $PM_{2.5}$, SO_2, and NO_2 simultaneously.
H6DAPSNO	UTC 12:00, 18:00, and 00:00, 06:00 the next day	On the basis of the H06DAPM case, assimilating $PM_{2.5}$, SO_2, NO_2, and O_3 simultaneously.
H6DAALL	UTC 12:00, 18:00, and 00:00, 06:00 the next day	On the basis of the H06DAPM case, assimilating $PM_{2.5}$, SO_2, NO_2, O_3, PM_{10} and CO simultaneously.

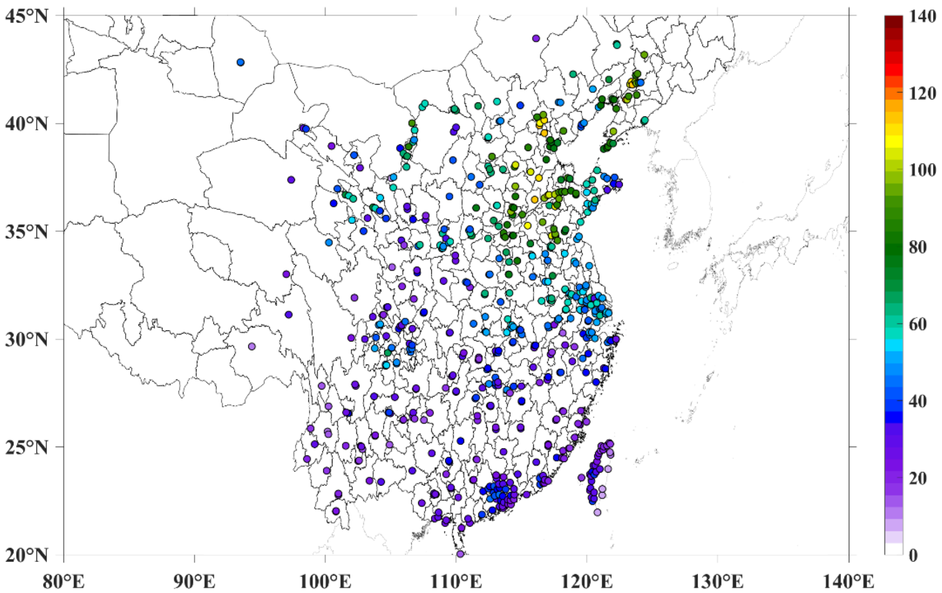
Observations and the base model simulation in November

China observation stations (Observations of **584 stations** were assimilated after **cleaning >1600 stations** data.)

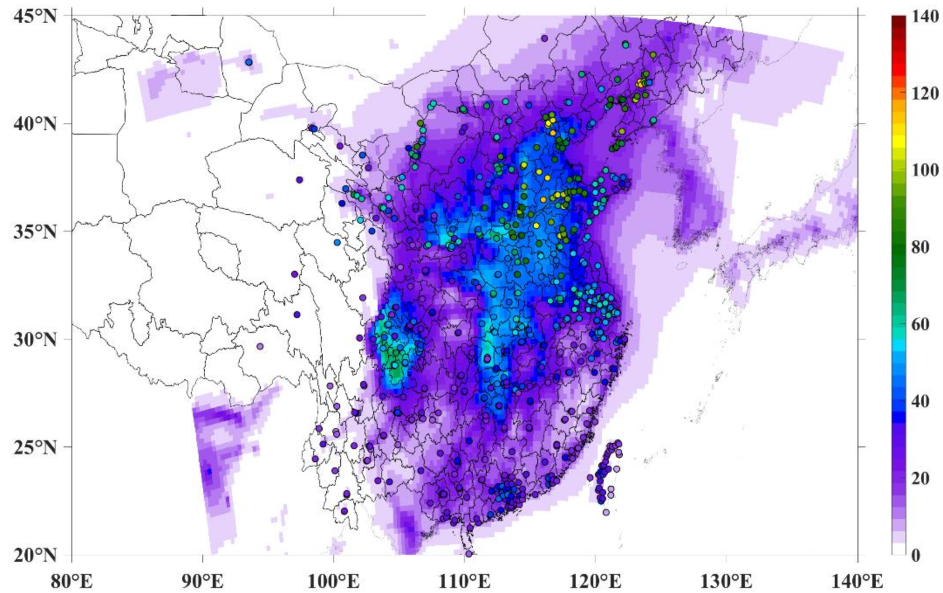
- Averaging the points within the same grid squares
- Setting concentration thresholds for different pollutants
- Checking data continuity

Model simulation on top of the observations.

Spatial map of monthly averaged OBS for $PM_{2.5}$



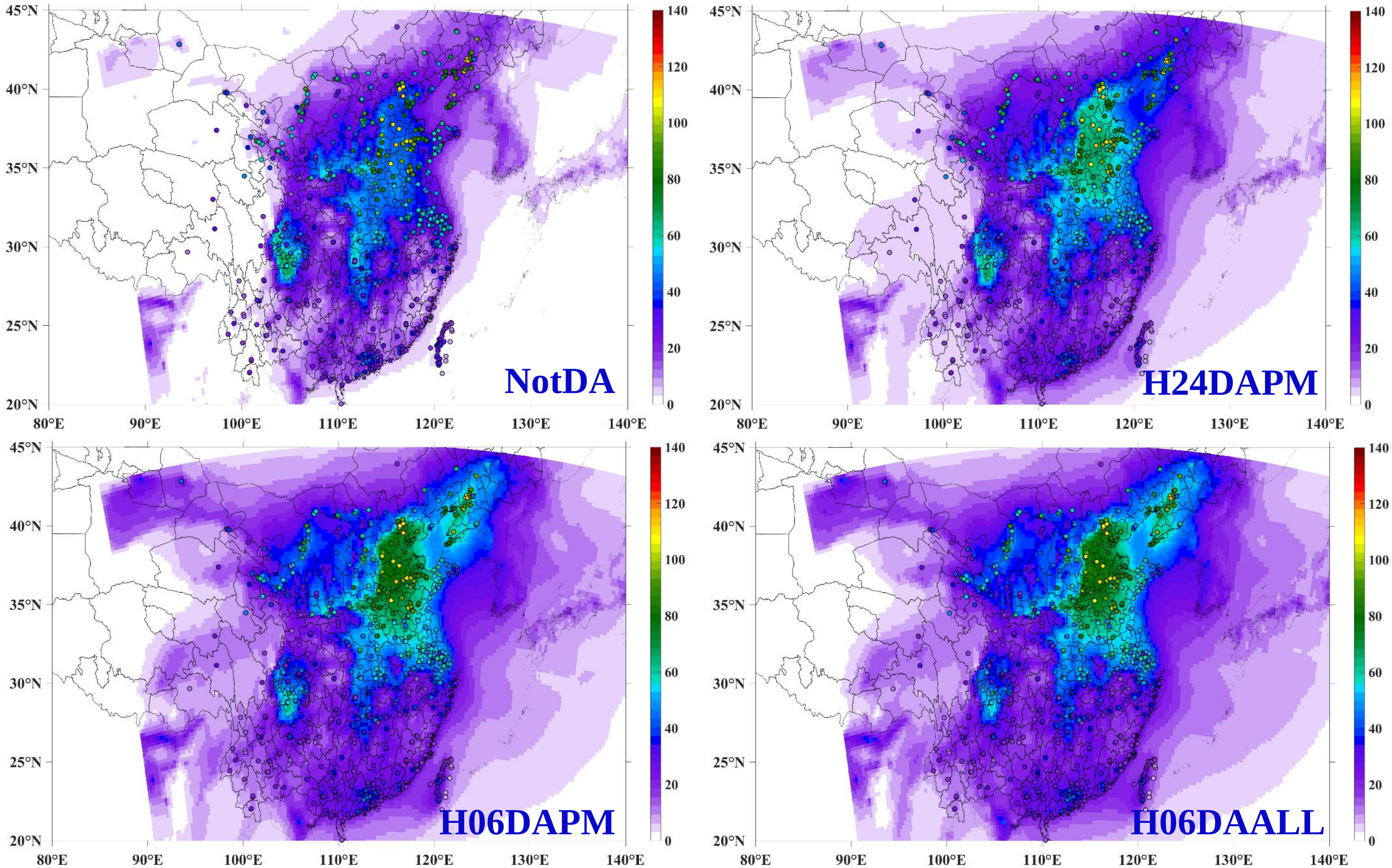
Model simulated monthly averaged $PM_{2.5}$



Part III: Assimilated monthly mean spatial maps of $PM_{2.5}$

- All the assimilation scenarios improved the model simulations.
- The H06DAPM outperformed the H24DAPM.
- The simulation in the PRD region differed less, possibly because the localized EI was adopted.
- The H06DAALL case is more or less the same with the H06DAPM case.

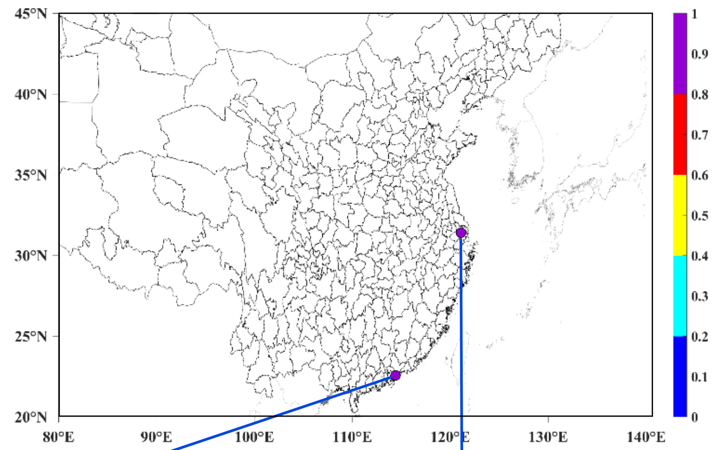
November

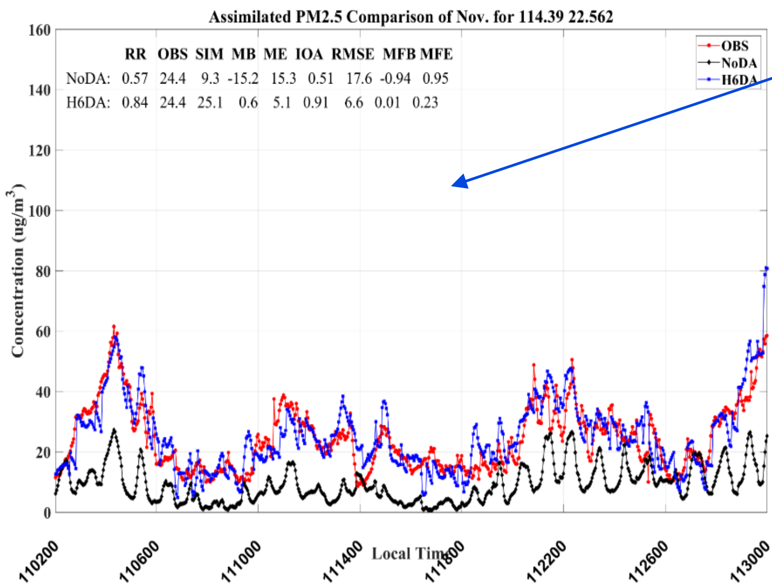


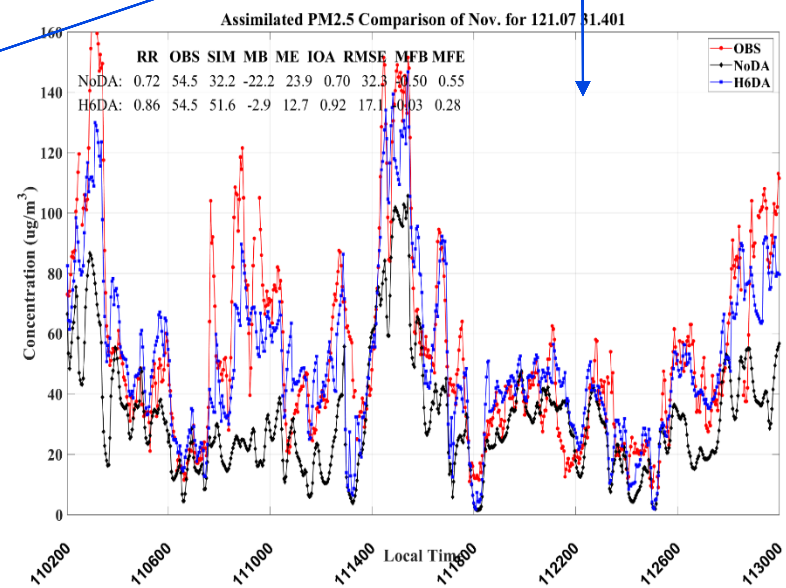
Time series plots and statistical matrix

Monthly averaged statistical matrix (584 monitoring stations)

PM2.5 November	CORR	MB	IOA	RMSE	MFB	MFE
NotDA	0.4	−21.18	0.54	37.52	−0.4	0.59
H24DAPM	0.52	−13.36	0.65	30.42	−0.23	0.45
H6DAPM	**0.61**	**−7.36**	**0.72**	**25.33**	**−0.1**	**0.37**
H06DAALL	**0.62**	**−7.03**	**0.73**	**24.9**	**−0.1**	**0.41**







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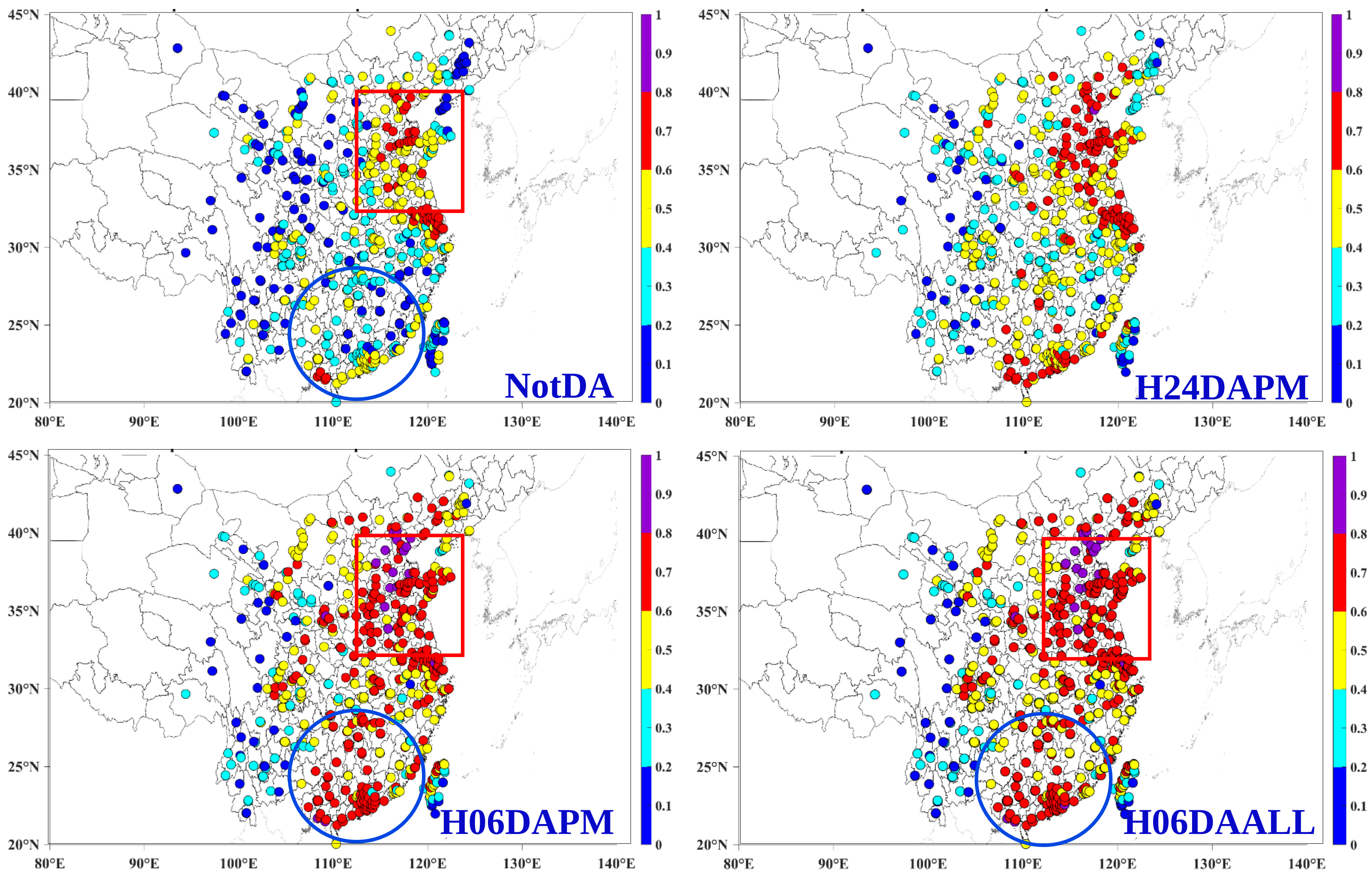
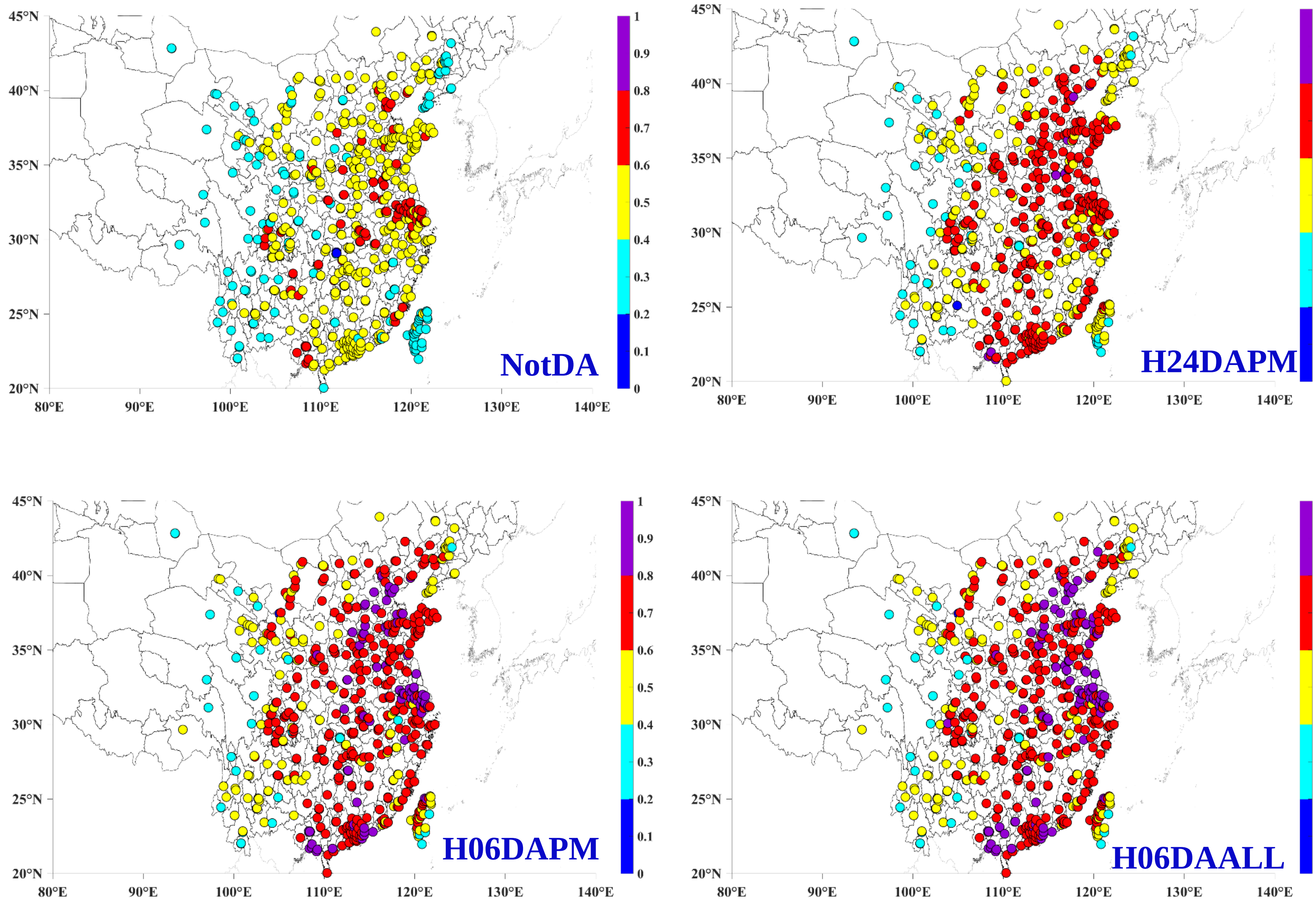
Spatial distribution of the correlation for $PM_{2.5}$

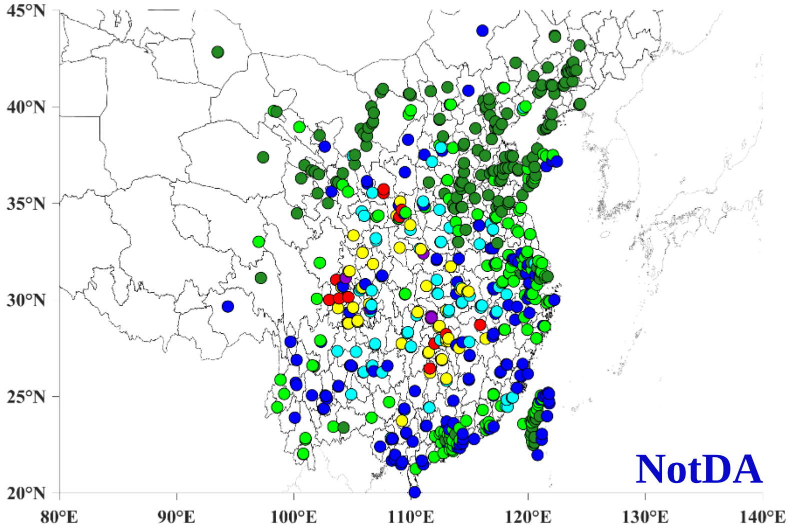
- The H06DAPM **(red square)** could improve model even the base model has already got a good correlation (0.6-0.8).
- The worse the base model performs **(blue circle),** the larger the improvement gained (0.4-0.6).
- The city-clusters tend to have a greater improvement than the boundary region.

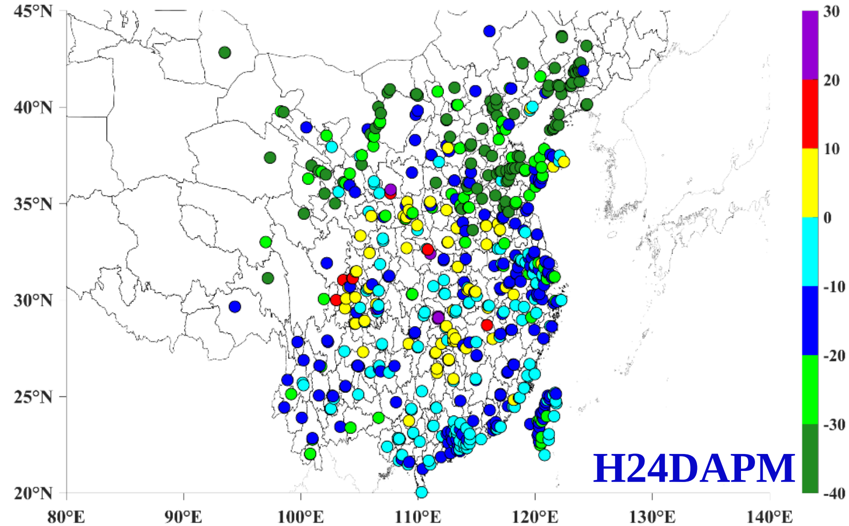


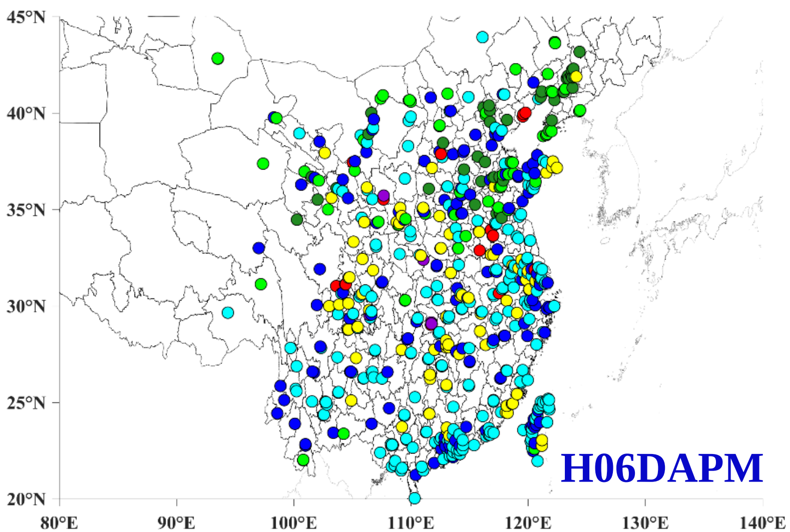
Spatial distribution of the IOA for $PM_{2.5}$

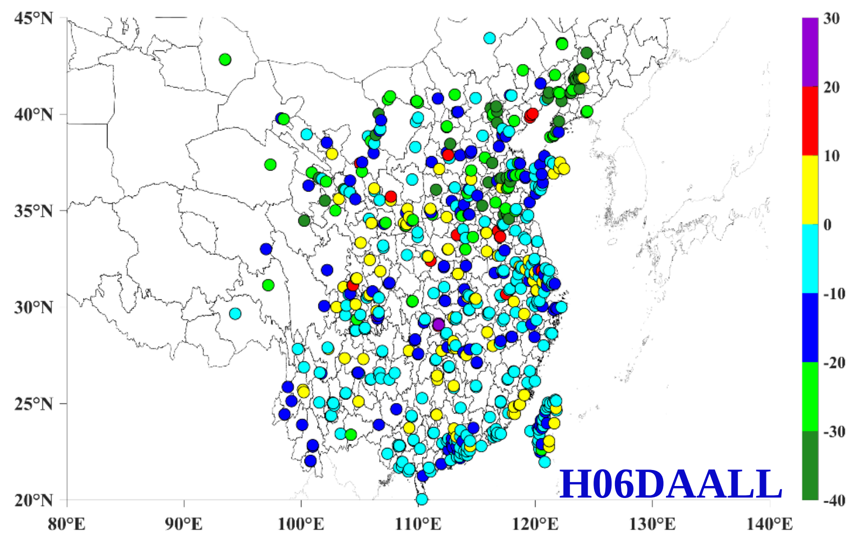


Spatial distribution of the MB for $PM_{2.5}$









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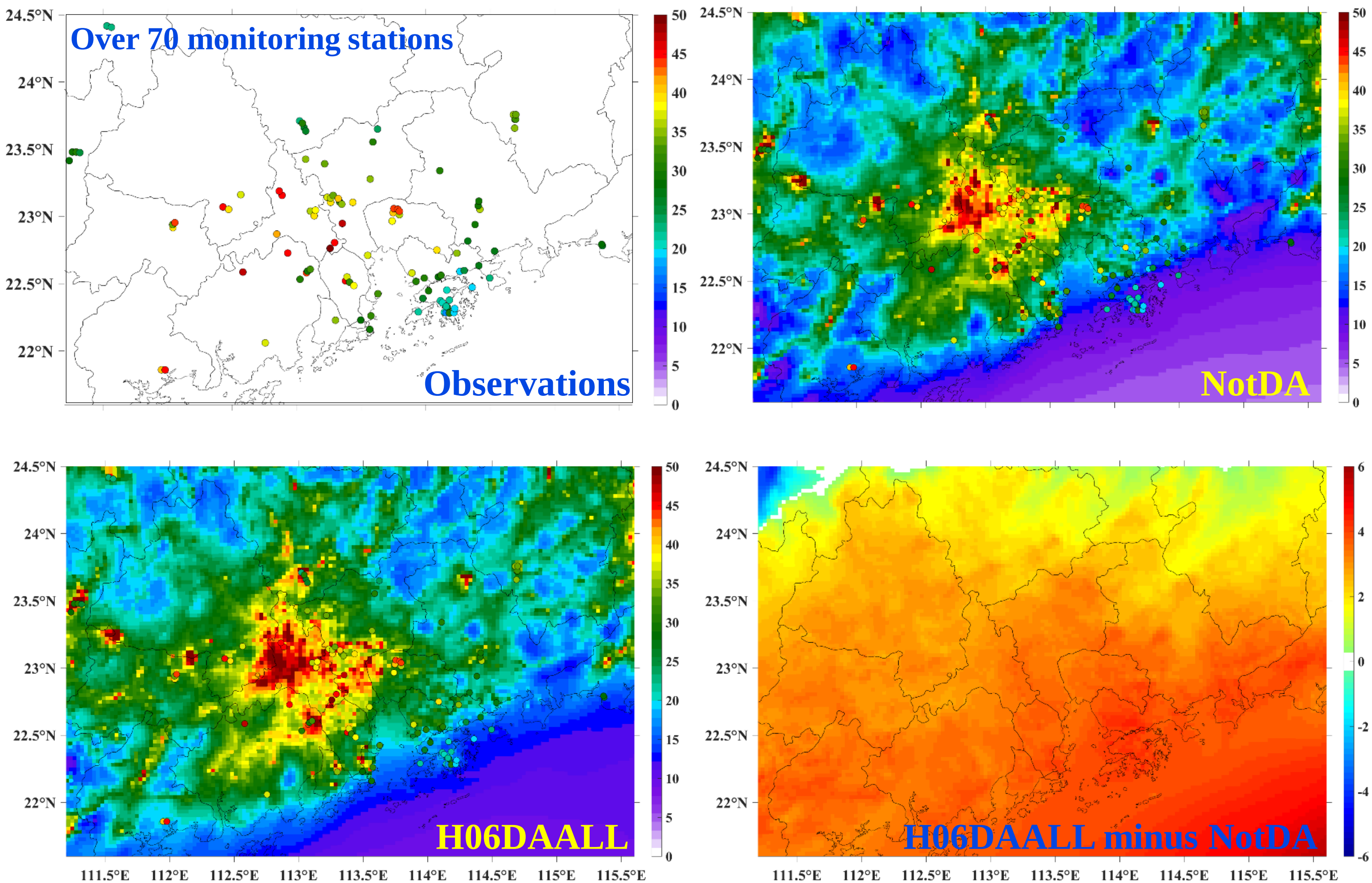
Assimilation improvement for the innermost $PM_{2.5}$

- **Assimilating** the air pollutants in the **outermost domain** (Domain 1) brought **substantial increases** in predicted $PM_{2.5}$ in the **innermost domain** (Domain 3) **by around 2-4 μg/m³** for November in the PRD region.
- The potential reason is the north-easterly wind bring the pollutants along with the coastal line.



Conclusion

- **A novel 3D-Var approach** coupled with the CMAQ model assimilation system for improving model bias was constructed for the whole of China and the targeted PRD region.
- Sensitivity analysis scenarios were carried out to evaluate the **impact of the data assimilation frequency** on the benefits of assimilation.
- **Assimilating the air pollutants in the outermost domain** brought substantial improvement of the $PM_{2.5}$ model simulations for the innermost domain**, offering an alternative method** to the existing domain-wide data fusion algorithms.
- **The north-easterly wind bring the air pollutants** along the **coastal line** to the PRD water, so as to lift up the domain-wide assimilated air pollutants during the domestic-heating season.
- **Multiple assimilations** of different pollutants, including $PM_{2.5}$, SO_2, NO_2, O_3, PM_{10}, and CO, confirm the effectiveness of the proposed data assimilation system in different geographic areas.

Thank you!

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[1] **Zhang, X.,** Fung, J. C. H.*, Lau, A. K. H., Zhang, S., & Huang, W. (2021). Improved modeling of spatiotemporal variations of fine particulate matter using a three-dimensional variational data fusion method. ***Journal of Geophysical Research: Atmosphere.***