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# Intercomparison of air quality simulations in 2019 using three chemical transport models

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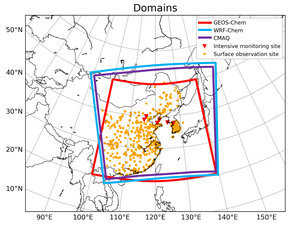
## Introduction

- Exposure to ambient $PM_{2.5}$ caused about 2.9 to 4.2 million deaths from 2010 to 2017 and air pollution was ranked the fifth among the global mortality risk factors (Cohen et al., 2017; HEI, 2019), the mortality attributable to air pollution is expected to continue to dominate in Asia at about 75% among the mortality factors by 2050 (Lelieveld et al., 2015).
- Major East Asian countries have implemented strong air pollution control policies over the past decades, the concentration level is still higher than these in other areas or compared to the internationally recommended values (Zhang et al., 2019; Trnka, 2020; Bae and Kim, 2022).
- Chemical transport model (CTM) can be a powerful tool for understanding the physical and chemical processes that affect air pollution, as an approach using multiple models can increase the reliability of the model, it is widely used to understand air pollution problems.
- However, existing CTMs have their own inherent bias errors in the model system, model results are also different depending on the region or period. Therefore, it can be seen that a common understanding of the performance and uncertainty of each model and further efforts to improve the modeling system are important.
- In this study, we compared the air quality simulation results by CMAQ, WRF-Chem and GEOS-Chem models in Northeast Asia including China and Korea for the months representing each season in 2019. And we also analyzed the factors that show performance differences between models.

## Methodology

### ◆ Configuration of CTMs



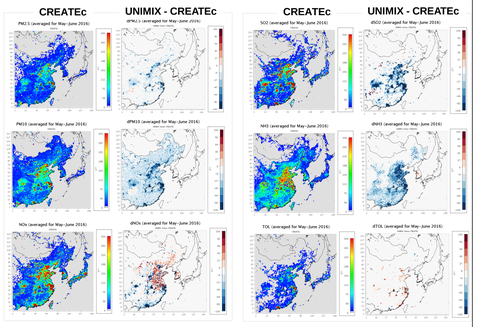

[ Modeling domains and observation site ]

[ Input options of participating models ]

| | CMAQ | WRF-Chem | GEOS-Chem |
|---|---|---|---|
| Version | 5.2 | 3.9.1 | 13.3.3 |
| Horizontal Resolution | 9 X 9 km | 9 X 9 km | 0.25° X 0.3125° |
| Grid number | 431 X 394 | 451 X 428 | 129 X 121 |
| Vertical levels | 23 | 43 | 47 |
| Boundary layer | YSU | YSU | Nonlocal PBL mixing |
| Anthropogenic emissions | UNIMIX2019 | | |
| Biogenic emission | MEGANv2.1 | MEGANv2.0 | MEGANv2.1 |
| Aerosol | AERO6 | 4 bins-MADE-VBS | Hodzic+aging |
| Gaseous chemical mechanism | CB6R3 | RACM | GEOS-Chem v13.3.3 |
| Biomass burning emission | Not used | Not used | GFED4 |

[ Observation locations ]

| | | Site name | Longitude | Latitude |
|---|---|---|---|---|
| GTS & ASOS | China | Beijing | 116.283 | 39.933 |
| | | Baoding | 115.567 | 38.85 |
| | | Dalian | 121.633 | 38.9 |
| | | Changdao | 120.717 | 37.9333 |
| | Korea | Baengnyung | 124.712 | 37.974 |
| | | Seoul | 126.966 | 37.571 |
| Intensive monitoring sites | China | Beijing | 40.042 | 116.419 |
| | | Baoding | 38.858 | 115.486 |
| | | Dalian | 38.886 | 121.577 |
| | | Changdao | 38.189 | 120.746 |
| | Korea | Baengnyung | 37.9647 | 124.634 |
| | | Seoul | 37.6098 | 126.9348 |

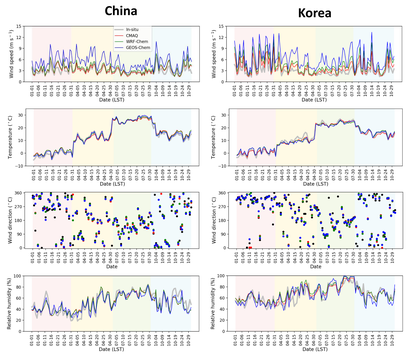



[ UNIMIX2019 emission inventory ]

- Data for $PM_{2.5}$ for the 1467 China sites (CNEMC) and the 295 Korean sites (NIER) at surface, and for air pollutants (Sulfate ($SO_4^{2-}$), Nitrate ($NO_3^-$), Ammonium ($NH_4^+$), Organic aerosol (OA), and Elemental carbon (EC)) at intensive monitoring sites were used for model evaluation.
- Three chemical transport models (CTMs) participated in this study and were used to conduct air quality simulations focusing on PM2.5 and major chemical compositions for January, April, July, and October, 2019 representing the season.
- The modeling emission inventory (UNIMIX2019), which reflects the 2019 air pollution emission from anthropogenic sources in China and Korea, was used for all three CTMs to increase the reliability of the multi-model experiment in 2019.

## Results

### ◆ Result 1: Evaluation of meteorological variables




[ Timeseries between simulated and observed meteorological variables at near-surface ]

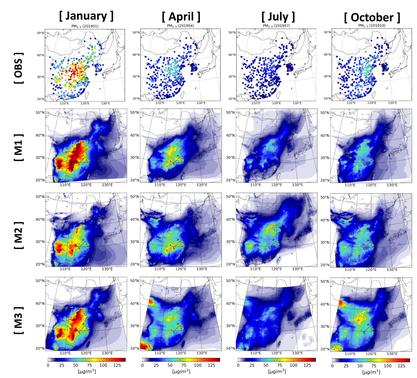
- As a result of the analysis of ground weather maps, it was found that in July 2019, there was a significant presence of clouds, haze, and precipitation.
- The evaluation of the meteorological fields was conducted at intensive monitoring sites.
- For wind speed, the GEOS-Chem model tended to overestimate, and a relatively low correlation coefficient was observed in July.

| | | | R | NMB | RMSE |
|---|---|---|---|---|---|
| Wind speed | China | M1 | 0.90 | 11.18 | 0.66 |
| | | M2 | 0.92 | 22.28 | 0.85 |
| | | M3 | 0.92 | 80.65 | 2.64 |
| | Korea | M1 | 0.84 | 27.26 | 1.38 |
| | | M2 | 0.82 | 57.26 | 2.29 |
| | | M3 | 0.78 | 114.53 | 4.09 |
| Temperature | China | M1 | 0.99 | 4.43 | 1.81 |
| | | M2 | 0.99 | 5.76 | 1.51 |
| | | M3 | 1.00 | 3.18 | 0.99 |
| | Korea | M1 | 0.99 | -3.48 | 1.63 |
| | | M2 | 0.97 | -0.34 | 2.23 |
| | | M3 | 0.97 | -1.68 | 2.47 |

*M1 : CMAQ, M2 : WRF-Chem, M3 : GEOS-Chem

### ◆ Result 2 : Evaluation of $PM_{2.5}$ surface concentration

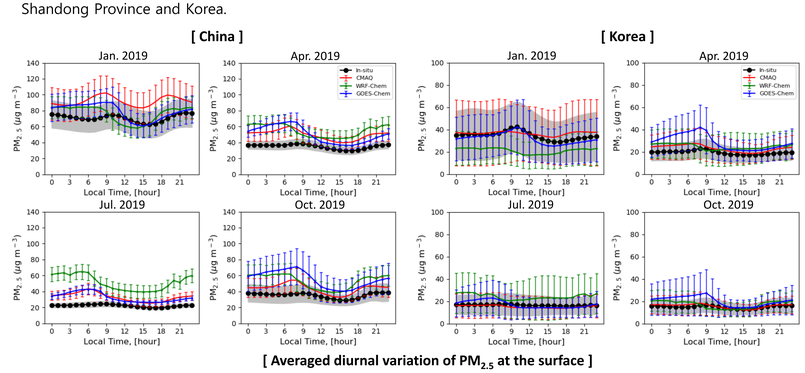
- Observed and Simulated monthly $PM_{2.5}$ concentration at the surface




| | | China | | Korea | |
|---|---|---|---|---|---|
| | | R | NMB(%) | R | NMB(%) |
| 201901 | M1 | 0.66 | 28.08 | 0.87 | 7.31 |
| | M2 | 0.49 | 6.58 | 0.84 | -37.61 |
| | M3 | 0.63 | 9.79 | 0.86 | -6.08 |
| 201904 | M1 | 0.56 | 40.25 | 0.68 | 18.50 |
| | M2 | 0.45 | 55.82 | 0.66 | 26.72 |
| | M3 | 0.56 | 41.67 | 0.64 | 47.42 |
| 201907 | M1 | 0.51 | 45.63 | 0.72 | -7.08 |
| | M2 | 0.46 | 127.01 | 0.69 | 48.30 |
| | M3 | 0.42 | 44.91 | 0.74 | 5.18 |
| 201910 | M1 | 0.54 | 22.89 | 0.65 | 4.82 |
| | M2 | 0.47 | 49.31 | 0.57 | 15.04 |
| | M3 | 0.53 | 55.58 | 0.66 | 35.63 |

[ Spatial distribution of Simulated monthly $PM_{2.5}$ concentration and Performance statistics of $PM_{2.5}$ at the surface ]

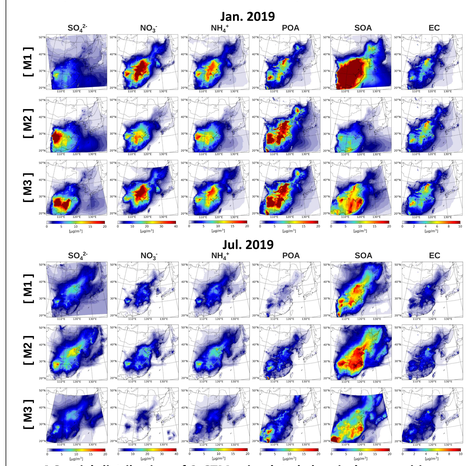
- In January, the NMBs of CMAQ, WRF-Chem, and GEOS-Chem were 28.08%, 6.58%, and 9.79%, respectively, with CMAQ showing the largest overestimation.
- In July, the bias of WRF-Chem was about 3 times higher than that of other models. In October, performance of $PM_{2.5}$ simulated by CMAQ was better than others. The bias of GEOS-Chem was relatively large in mainland China around Shandong Province and Korea.



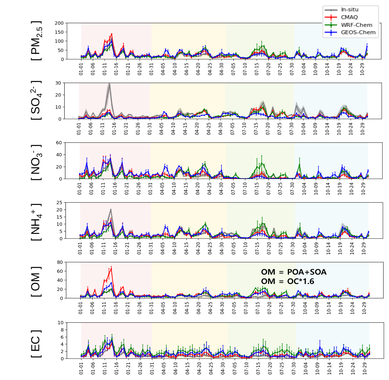

[ Averaged diurnal variation of $PM_{2.5}$ at the surface ]

### ◆ Result 3 : Analysis of $PM_{2.5}$ and chemical compositions

- Spatial distribution and chemical species

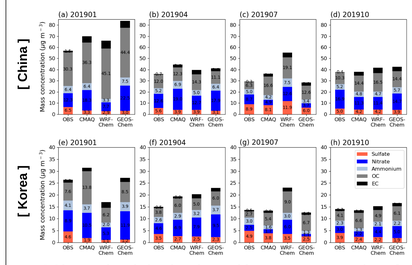



[ Spatial distribution of 3 CTMs-simulated chemical compositions in January and July 2019 ]




[ Time series of observed and simulated daily mean concentration in Korea ]

- The concentrations of the major chemical composition that contribute to the total $PM_{2.5}$ mass concentration was different.




[ Observed and simulated monthly mean concentration of major $PM_{2.5}$ chemical components ]

- WRF-Chem simulated higher SO42- concentration than other models in all seasons.
- In summer, the relative humidity was very high, and there were very many clouds, and haze or precipitation continued from mid-July.
  ⇒ We are looking into the causes of the overestimated concentration of each component in summer.
- Although all CTMs used the same anthropogenic emissions inventory, CMAQ simulated lower POA concentrations in all seasons than those of other models.
- The discrepancy is associated with the different treatments of secondary organic aerosol (SOA) production.
  ⇒ CMAQ includes new pathway for potential combustion secondary organic aerosol (pcSOA) (Murphy et al., 2017)

## Summary & Future works

- In this study, the seasonal prediction performance of $PM_{2.5}$ and major particulate matter (sulfate, nitrate, ammonium, organic carbon, and elemental carbon) simulated by three CMTs was evaluated in China and Korea.
- The concentrations of $PM_{2.5}$ were typically higher during winter compared to summer, and the CTMs showed good performance in predicting these seasonal variations. However, there were discrepancies in the simulation results of $PM_{2.5}$ between the models due to the different chemistry settings.
- The results of these multi-model intercomparisons will be helpful in the future research to increase understanding of the differences between the simulated results by muti-CTMs in Northeast Asia and to seek the ways to improve the model prediction performance.

## Reference & Acknowledgement

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