Response to Referee #1:

Dear authors,

Checking your manuscript, they have come to my attention a couple of problems with the 'Code and Data Availability'.

You use here the InMAP model. In the code availability section, you mention its Github repository. This is confusing, as Github is not a suitable repository for long-term archival, and we can not accept it. However, you have archived in Zenodo the version 1.6.1 of InMAP that you use. This is fine. The problem here is that in Zenodo, you have relicensed the InMAP code under Creative Commons 4.0. CC-4.0 is compatible with the GPLv3 license of InMAP, but its use in a repository is strongly discouraged. When you submit the InMAP1.6.1 code, you can ask the Zenodo administrators to make available the GPLv3 license. Therefore, please:

- Remove the mention to the Github repository for InMAP from the 'Code and Data availability section

- Upload to Zenodo the full InMAP 1.6.1 under GPLv3

- Change the license for your version for China of the code to the original GPLv3

Best regards,

Juan A. Añel

Geosc. Mod. Dev. Executive Editor

Response: Thanks for this valuable comment. We have deleted the mention to the Github repository for InMAP from the 'Code and Data availability section'. We have re-uploaded the source code of model and changed the license into GPLv3 (available at https://doi.org/10.5281/zenodo.5111961).

Response to Referee #2:

The idea of this manuscript is of interest in the air quality modeling domain. A new reduced-complexity air quality model system called InMAP-China has been developed by linking a regional air quality model (extracting and converting parameters), a reduced-complexity air quality model, emission processing database, and a health calculation model at the resolution of 36 km, aiming at quickly quantifying the air quality and health impact in China. The total $PM_{2.5}$ concentrations together with its component and the sectoral contribution scenarios, have been assessed to evaluate the newly developed model. The manuscript has been well structured and written, just with some minor typo issues.

However, I am a little bit concerned about the benefits/advantages when developing this new proposed InMAP-China model. Firstly, the important part of the InMAP-China model is the InMAP model (a reduced-complexity model producing the pollutant concentration), which is actually under-estimating the $PM_{2.5}$ by 8.1 μg/m³ (Line 239-242). This reduced-complexity model also has difficulties in capturing the SOA (Line 335-336). The simulated concentrations will directly affect the accuracy of health calculations. On the other hand, computing power running chemical transport models is not an issue nowadays. Running it on a coarse resolution such as 36 km is remarkably faster. The running time of a CMAQ model at a resolution of 36 km is around half an hour for one-day output (varies depending on different machine cores). Running the InMAP-China model still needs the CMAQ model outputs for providing extracted parameters. So why not directly using the CMAQ model (in 36 km resolution) to produce the concentration maps for calculating the health? Although the authors mentioned in the conclusion of the manuscript (Line 341-342) that this newly developed model could be used for evaluating the effects of individual coal-fired power plants, the uncertainties of doing that are hard to quantify with 36 km resolution. Scenario settings usually using chemical transport models will not evaluate hundreds of individual power plants or hundreds of scenarios. Running only a few carefully selected representative scenarios, even with year-long simulations, is expensive using computers nowadays. It is also reasonable and doable to have more accurate results with even longer running time as pursuing science. In conclusion, the current implemented reduced-complexity model with 36 km resolution is weak in supporting the statement that it has the advantage of being time-efficient in conducting air quality predictions (Line 312-313; Line 337). The rationale/motivation for implementing the InMAP_China needs to be reconsidered.

Another important issue is about the model resolutions relating to the health calculation. It would be better if the reduced-complex model could be implemented with a CMAQ model at a finer resolution (4 km or 1 km). Existing literature shows that higher resolution concentration maps would be better for calculating health exposure in the US and Beijing. (Tao et al. 2020; Jiang and Yoo, 2018; Biggart et al. 2020). Although the authors mentioned the model resolution discussion would be in 3.3.1, there is no such a section in the manuscript at the moment.

Response: We thank the referee for the valuable comments to improve our manuscript. The development of InMAP-China aims at providing an alternative to the conventional CTMs to predicting the $PM_{2.5}$ concentrations due to emission change. The loss of accuracy is unavoidable and may need to be further improved in the future study. The advantage of InMAP-China is time-efficient when it is used to quantify the contributions of multiple fine emission sources, for instance, dozens of categories of emission sources, certainly, if it is used to quantify the contributions of individual coal-fired power plants, the uncertainty is hard to evaluate and may need to be further compared with that based on conventional CTMs. In this situation, the contributions of individual emission sources are better to aggregate at the county level to reduce the uncertainty of reduced-complexity air quality models. The related descriptions have been rephrased in the fourth paragraph in the Conclusion part of this paper.

As for the model resolution, indeed, higher resolution concentration maps would be better for calculating health exposure, for instance, the cases in the US and Beijing as you mentioned. In this study, we select the 36km resolution other than 4km or 1km resolution, because the computing cost of CMAQ simulation at 4km or 1km is so huge to conduct at entire China.

More detailed points are listed below:

Response: We have followed the reviewer's suggestions and revised the manuscript. The specific comments are addressed below:

1. *Line 39-41: It seems the literature is a little bit outdated. The $PM_{2.5}$ concentrations have been decreasing in the past few years, while the O_3 pollution becomes severe (Zhao et al. 2021, Zhang et al., 2020). Li et al. (2019) showed the reduction in $PM_{2.5}$ since 2013 resulted in the increase of O_3, which became a major environmental issue in China. Please rephrase the statement based on the above findings.*

Response: Thanks for this valuable comment. We have rephrased the statement as "High $PM_{2.5}$ concentrations can be observed over eastern China from satellite observations (Xiao et al., 2020) and the $PM_{2.5}$ concentrations have been largely decreased since 2013 due to the effective control measures taken by the Chinese governments (Zhao et al., 2021)."

2. *Line 46: CTM is usually short for Chemistry Transport Model?*

Response: Thanks for your detailed comment. We have changed to utilize AQMs instead of CTM in Line 48. The phrase has been revised into “State-of-the-science three-dimensional air quality models (AQMs)”.

3. *Line 49-50: please use full names of WRF-CMAQ, WRF-Chem, and WRF-CAMx when they are firstly used in the paper, although we are quite familiar with them.*

Response: Thanks for this valuable comment. We have added the full name of the corresponding model. The sentence has been revised into “ The Weather Research and Forecasting model-Community Multiscale Air Quality Modelling System (WRF-CMAQ) (Appel et al., 2017; Chang et al., 2019), the Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) (Reddington et al., 2019), the Weather Research and Forecasting model-Comprehensive Air Quality Model Extension (WRF-CAMx) (Li et al., 2015), and the Global Adjoint model of Atmospheric Chemistry (GEOS-Chem Adjoint) (Zhang et al., 2015) were frequently used in previous studies. ”

4. *Line 53: CTM, please use a full name when you first use it in the paper.*

Response: Thanks for this valuable comment. We have changed to use AQMs and have already defined “AQMs” in Line 38.

5. *Line 54: “this challenges” should be “this challenge” or “these challenges”?*

Response: Thanks for this valuable comment. We have modified from “this challenges” into “these challenges”.

6. *Line 78: InMAP should be spelled out when it is firstly used in the paper.*

Response: Thanks for this valuable comment. The full name of InMAP is “ The intervention for air pollution model ” and has been stated in Line 84 when it is first used.

7. *Line 82: “includes” should be “including”?*

Response: Thanks for this valuable comment. We have modified it into “including”.

8. *Are there any special meanings of v1.6.1? If not, suggest using consistent InMAP-China in the manuscript instead of using both InMAP-China and InMAPv1.6.1-China (line 89 and the title?), which would be confusing readers.*

Response: Thanks for this valuable comment. The development of InMAP-China model is based on version 1.6.1 of InMAP model. We have remained consistent in the main text of the paper by using "InMAP-China" instead of InMAPv1.6.1-China. The version of the model in the title of the paper remains due to it is required to be declared according to the format statement of this journal.

9. *Line 102; 103: repeat "Figure 1 shows the model framework", please rephrase the statement.*

Response: Thanks for this valuable comment. We have deleted the repeated sentence.

10. *Table 2: Please adjust the format to make the table clearer.*

Response: Thanks for this valuable comment. We have adjusted the Table.

11. *Line 231-232: please indicate clearly how the InMAP-China model simulates the $PM_{2.5}$ concentrations? What are the inputs and outputs for different scenarios? In table 3, please indicate clearly which version of CMAQ results are used to extract and convert the parameters for InMAP-China.*

Response: Thanks for this valuable comment. We have revised the descriptions in this part as " The emission inputs for these ten simulations have been presented in Table 3. The annual averaged physical and chemical process parameters are calculated based on the output variables of the WRF-CMAQ model, which has already been mentioned in Section 2.1.2. Based on the above input, the particle continuity equations are solved in InMAP-China to obtain the annual averaged $PM_{2.5}$ concentrations at the steady-state of the atmosphere. The equation is presented in Formula 1.

$$\frac{\partial C_i}{\partial t} = \nabla(D\nabla C_i) - \nabla(\vec{v}C_i) + \sum_{j=1}^{n} R_{ij} + E_i - d_i \qquad (2\text{-}1)$$

where C_i is the concentration of one of n model pollutant species, D is a molecular diffusion coefficient (neglected here as a negligible source of chemical transport in the atmosphere compared to advection), $\vec{v}$ is the wind vector, R_{ij} is the net formation rate of species i from species j, E_i is pollutant emission and d_i is pollutant removal via wet and dry deposition.

In order to make a comparison with the InMAP-China simulations, eleven CMAQ simulations are performed under the same emission inputs. The hourly $PM_{2.5}$ concentrations simulated by CMAQ in 2017 are averaged to obtain the annual averaged

$PM_{2.5}$ concentrations. Due to limited computational resources, each simulation is conducted for four representative months (January, April, July, and October) in 2017."

The version of the CMAQ model is 5.2 and has been declared in Table 3.

12. *For the $PM_{2.5}$ component evaluation, it could be understood that comparing the InMAP-China results with the CMAQ model (figures S4-S7) is a good way. But, if possible, comparing the $PM_{2.5}$ component simulations of InMAP-China model with the observational component measurements would give more confidence in the newly developed model.*

Response: Thanks for this valuable comment. For the evaluation of the $PM_{2.5}$ component, we tried to collect the data of the observational component measurements, however, we merely collected the data at several cities (Beijing city for the entire year and three other cities for several months), it is difficult to acquire the completed data of more monitory stations in 2017. Therefore, to understand the performance of $PM_{2.5}$ components, we decide to compare it with that predicted by the CMAQ model for the evaluation.

13. *Line 209: It seems there is no section 3.1.3 for discussing the effects of the model spatial resolution on $PM_{2.5}$ concentration predictions, although the authors mentioned here.*

Response: Thanks for this valuable comment. We have deleted this statement.

14. *Line 396 and 399: keep using a consistent format for journal titles. Other places: Line 411; 417, 420, 450 …… Please check all the reference formats to meet the journal requirement.*

Response: Thanks for this valuable comment. The format of the Journal titles in the reference has been revised to remain consistent format, which can be seen in Line 396, Line 399, Line 411, Line 417, Line 420, and Line 450.

Response to Referee #3:

This is a one-stop modeling tool development to study various pollution scenarios and associated mortality rates. This is a well written document and easy to follow. I see that the authors have put in a significant effort to make this tool functional. This work will provide a foundation for the InMAP-China model for future work to be conducted.

The main objective was to develop a tool for a faster turn-around time estimating mortality rate as the end point topic. However, the authors need to add some discussions as to how fast this new tool is as compared to CMAQ model operating at the same grid resolutions. It was not clear to me as to (1) what was the grid spacing used in the WRF-CMAQ model and (2) what were the computational speeds of each models-e.g., CMAQ vs InMAP-China. Though authors used the coupled WRF-CMAQ model, it is possible to estimate CPU time used up for CMAQ alone. If authors wanted to minimize computational burden of InMAP-China, then why not limit vertical layers to top of PBL and provide top boundary conditions to speed up computations? Just have fewer layers in the PBL and none in the free troposphere!

Response: We thank the referee for the valuable comments to improve our manuscript. We have followed the reviewer's suggestions and revised the manuscript. The specific comments are addressed below:

Thanks for this valuable comment. (1) The grid spacing used in the WRF-CMAQ model is 36km and it is already presented in Table S2. (2) The vertical layers in this study are 14 layers ranging from the surface to the tropopause. If we further reduce the vertical layer, the computation is expected to be speeded up. However, it is limited to reduce the total consumed time, especially when conducts a lot of simulations. InMAP-China simplifies the physical and chemical process in $PM_{2.5}$ simulations and reduces the running time to approximately one hour to simulate the annual averaged $PM_{2.5}$ concentrations. The high efficiency in $PM_{2.5}$ simulations promotes us to develop the version of the reduced-complexity air quality model in China.

The total CPU time to conduct the $PM_{2.5}$ simulation for the entire year in 2017 using the conventional CMAQ model is about 1460 core*hours and the total CPU time to predict $PM_{2.5}$ concentrations in 2017 using InMAP-China model is 24 core*hours. In the InMAP-China simulation, the annual averaged air pollutants concentrations are solved based on the particle continuity equation, while the hourly concentrations need to be solved using the CMAQ model.

It is kind of a weak point that InMAP-China depends solely on WRF-CMAQ simulations. It will be a great service to the CTM community had the authors tested and evaluated the InMAP-China using the GEOS-Chem modeling platform since it uses *a very coarse grid resolution plus it is global. Thus, in that case, the newly developed tool could be used for any region or country of choice without any major effort. This seemed to be truly a missed opportunity for now, but it is not too late I believe for the authors.*

Response: Thanks for this valuable comment. That's a great idea to develop the reduced-complexity air quality model using the GEOS-Chem modeling platform on a global scale. The original research group who developed the InMAP (for the United States) has already focused on this topic to develop a global reduced complexity air quality model. If it is finished, the modeling tool can be expected to be used in other regions on a global scale.

Reason(s) for under-predictions over southern China are not speculated or explained – or I could not find those reasons.

$PM_{2.5}$ under-predictions are about -23%, a large bias given the magnitude of the $PM_{2.5}$ concentrations over China and is being attributed to using a different chemical mechanism as compared to CMAQ. What were the reasons for NOT using CMAQ chemical mechanism in the InMAP-China model beside computational constraints? For demonstration, one additional simulation using the CMAQ chemical scheme would have shed more light on this matter.

Response: Thanks for this valuable comment. In the InMAP-China, the chemical process is simplified as mentioned in Text 1 in the main part of this paper. The way to deal with chemical mechanisms in InMAP-China is simplified, which is based on the concentration results derived from the CMAQ model. To be more accurate to present, the corresponding sentence has been modified into "the uncertainty of the simplification of chemical process in the InMAP-China".

Text 1 The simplification of chemical reactions is different among pollutants. For NO_x, NH_3, and volatile organic compound (VOCs) precursors, the annual averaged gas-particle partitioning is adopted and calculated before using the output concentrations of species from CMAQ. For SO_2 pollutants, the annual oxidation rate of two major conversion pathways for SO_2 is calculated using concentrations of hydroxyl radical (HO) and hydrogen peroxide (H_2O_2) in CMAQ, and the conversion is estimated in InMAP-China.

Authors stated that advection was weakened due to averaging wind vectors. I am not sure why authors could not average zonal and meridional wind components separately and then re-compute the vertical wind to maintain mass balance. If this is what was *done, then it should be stated accordingly and, in that case, averaging impacts should be minimal in my opinion since each wind component is processed separately.*

Response: Thanks for this valuable comment. The zonal and meridional wind components are averaged separately in this model, the weakening effects of wind components refer to the offset of the opposite directions in the annual average process to obtain the annual wind speed.