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Interactive comment on "InMAP: a new model for air pollution interventions" *by* C. W. Tessum et al.

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Comment: In the manuscript by Tessum et al., the authors present the development of a new modeling approach called InMAP and compare the results against WRF-CHEM. InMAP is a "expedited" approach for providing how longer term (here, annual average) pollutant concentrations will change in response to emissions changes (interventions) using an air quality modeling approach that can account for aspects of atmospheric chemistry and transport. Inputs in to InMAP come from an initial run of a more traditional air quality model, in this case WRF-Chem. The main advantages of InMAP appear to be the ability to have a variable resolution grid and more rapid execution to explore a suite of emission interventions. They evaluate the model, primarily for it's ability to recreate the results of WRF-Chem. They also use InMAP to simulate year 2005 concentrations, but that is not nearly so informative as the model is based on running WRF-Chem, first, extracting properties from there, and then assessing changes.

Thus, the performance of InMAP against the observed concentrations is likely most determined by the base WRF-Chem simulation. . ."

Response: We thank the reviewer for this comment. We agree that InMAP predictions are influenced by the underlying WRF-Chem simulation results. InMAP is designed to predict changes in concentrations, not concentrations. In this section of the paper, we are using InMAP to predict concentrations – i.e., exploring a use of the model that is outside of what the model was built to do. We considered removing this section from the paper. However, we felt it was an obvious trial case to run, and one that readers might wonder about. Our goal is to test this new model in multiple ways, and to explore how it performs under various scenarios. As InMAP is a reduced complexity model based on WRF-Chem; it is reasonable to evaluate the ability of InMAP to reproduce the predictions of the more complex model it is derived from. In fact, comparing against observed concentrations represents a test of InMAP's ability to represent a very large change in emissions (i.e., changing emissions from zero to 2005 levels), which certainly sheds useful light on the model performance. In conclusion, in the interest of sharing openly what we did and how the model performs, we elected to leave in this comparison.

Comment: ". . . and they state that "comparing InMAP against observed values represents a use of the model that is beyond what that model was designed for." (as such, maybe this part should be removed. . . it is actually misleading.)"

Response: See reply to prior comment. We feel that this information informs readers regarding InMAP's abilities. As we state in the manuscript, we compare InMAP predictions to measurements to "explore how reliably InMAP can be expected to predict larger changes in concentrations". InMAP is designed to predict marginal changes in concentrations, so testing its ability to predict the impacts of a very large change in emissions (i.e., changing emissions from zero to 2005 levels) sheds useful light on the model's performance.

Comment: General Comment: The method is rather clever, though the authors need to do a more thorough job of explaining how it is implemented before the community could become comfortable with the approach.

Response: Thank you for this suggestion. We have added explanation and clarification as described in the following responses.

Comment: Further, model evaluation should be more comprehensive given the identified potential uses (health studies associated with interventions).

Response: Thank you for this suggestion. We have added additional model evaluation as described in the following responses.

Comment: In terms of more detail on model implementation, the authors do not provide enough detail on how the time integration is conducted. What is the order of process integration? Does it matter?

Response: The order of process integration does not matter with the exception of the gas vs. particle phase partitioning for organic, nitrate, and ammonia compounds. We have edited the text of the manuscript to clarify this point.

Changes: We have added the following text: "Each process, with the exception of the instantaneous gas- vs. particle-phase partitioning of organic, nitrate, and ammonia compounds, uses an algorithm that calculates changes in concentrations based on the concentration at the beginning of the time step rather than the concentration output by other process algorithms during the same time step. Therefore, the concentrations resulting from these steps do not depend on the order of process integration. The instantaneous gas-particle partitioning, the result of which is theoretically influenced by the order of integration, is performed last."

Comment: In terms of model evaluation, it would be interesting to do traditional advection solver tests, e.g., the rotating cone, except that the advection field is reversed after a rotation (See Walcek and Aleksik, Atm. Env 1998 for tests).

Response: Our understanding is that advection solver tests are meant to evaluate algorithm performance under extreme conditions such as step changes in concentration. However, InMAP is a simplified model that is designed to predict annual average changes in concentration under annual average conditions. In general, simplified models are not recommended for use in extreme conditions. Therefore, we feel that tests of InMAP model performance under real-world conditions are more appropriate and more useful than traditional advection solver tests. Therefore, in response to this comment and others we have added a test of InMAP performance against WRF-Chem predictions for a single ground-level point emissions source of non-reactive particles. This test evaluates the combined performance of the advection, mixing, and deposition routines in InMAP. We have added this comparison to the manuscript.

Changes: We have added an evaluation of InMAP performance for a single point source of non-reactive particles and a corresponding discussion to the manuscript.

Comment: The current model evaluation also should provide more information on if there are regional/temporal differences in the errors, as those can be important in heath studies.

Response: This is an important comment. Figure 5 in the manuscript shows model performance by region. As discussed in the manuscript, annual average exposure to PM2.5 is the main driver of health effects from air pollution, and InMAP is an annual-average model. Since InMAP does not compute temporally explicit results, it is not possible to perform temporally explicit error calculations.

Comment: Further, how well does the model do at capturing the impact of changing point source impacts, e.g., from power plants. Is the behaviour of InMAP the same as WRF-Chem. It would be of interest if the sulphur dioxide and sulphate changes were the same.

Response: All of the emissions scenarios that we test contain a combination of mobile, industrial, agricultural, and electric generation (i.e., power plant) sources. We have added a series of appendix figures describing the major types of emissions contributing to each scenario and containing scenario-specific concentration patterns and performance results. We have also added the evaluation of the performance of InMAP vs. WRF-Chem for a single nonreactive point source as described above.

Changes: We added a series of appendix figures describing the major types of emissions in each scenario and giving scenario-specific statistics and concentration patterns, as well as a corresponding discussion. We additionally added a single-point performance evaluation and corresponding discussion.

Comment: They should include a table of their assessment of how InMAP recreates the concentration changes from WRF-Chem for each of the eleven scenarios they have conducted. How this should be given is a plot of Delta(C)InMAP vs. Delta(C)WRF-Chem, for each of the major species of interest (ozone, sulphate, nitrate, black carbon, organic carbon, nitrogen dioxide), along with the regression information (slope, correlation). That would appear to be the most telling approach to assess how well their approach works.

Response: We thank the reviewer for this suggestion. For spatially averaged concentrations, the requested plots are included in Figures 3-5. In response to this comment and others, we have also added a series of figures that include the requested information for grid-cell specific comparisons as well as the spatial patterns in InMAP and WRF-Chem concentration predictions for each scenario. We did not include these results in table format because we feel that the plots allow for easier interpretation of the results than tables do in this case, but we do include the data used to make the plots in figures 3-5 as supporting data.

Changes: We added a series of figures describing the major types of emissions in each scenario and scenario-specific statistics and spatial concentration patterns, as well as a corresponding discussion.

Comment: Their evaluation also does not link to the recent air quality model evaluation

in Europe being conducted as part of the AQMEII initiative.

Response: The AQMEII initiative does investigate model skill in reproducing short-term changes in concentrations, but it is not able to separate changes caused by emissions, which are the focus of InMAP, with changes caused by other factors such as meteorology. Because AQMEII focuses on model ability to predict total ambient concentrations rather than the annual average changes in concentrations that InMAP focuses on, the AQMEII data and results are of limited applicability to this manuscript.

Comment: Specific Comments: Equation 1 should be set up to account for the multipollutant mixtures in the atmosphere. R should explicitly include gas-particle partitioning, and given that they are including aerosols, something about aerosol growth should be included/mentioned. Dry deposition is a boundary condition.

Response: To respond to this comment we have reformatted Equation 1 to clarify that there are multiple pollutants in the model and that chemical reactions transfer mass from one specie to another. We have also added text to clarify that InMAP assumes particle size and density to be constant. We agree that dry deposition is a boundary condition. However, wet deposition is not a boundary condition. Therefore, we left the d term which represents both wet and dry deposition in Equation 1.

Changes: We added text "InMAP assumes atmospheric particle diameter and density—which it only uses to calculate dry deposition rate—to be constant at 0.3 um and 1830 kg m-3, respectively." We also edited Equation 1 as described above.

Comment: They present an interesting comment "InMAP's advection scheme accounts for variability in wind direction. For instance, for a location where wind travels West at 5 m/s and East at 5 m/s the other half of the time, InMAP's advection calculation in each time-step would include wind traveling both West and East at 2.5 m/s." Thus, it would seem that this would act as diffusion in the end. Now, let's think of an example that the wind coms from the NW at 5 m/s half the time and from the SE at 5 m/s the other half. If there was a point source in a grid, the impact of that point source should be along a NW-SE line. However, it would seem that in the current implementation, the point source would be diffused, and it is not apparent to me that you would retain the directionality. For the simple case they mention, what is the equivalent diffusivity (I calculate it to be U(dx): if this is true, this should be discussed in the text)?

Response: We have added text to the manuscript to point out this limitation of our modeling approach. We have also redesigned the advection scheme into explicit advective and diffusive components, which should serve to additionally clarify this limitation.

Changes: We redesigned the InMAP advection scheme to explicitly contain advective and diffusive components, and updated the "Advection" manuscript section (as well as other related parts of the manuscript and figures) to reflect the changes. We also added the text: "As shown above, to represent temporally-variable advection in an annual average modelling framework, InMAP splits advective transport into three steps, one of which is advective in nature and two of which are diffusive in nature. One result of this is that in some cases information regarding transport direction may be lost. For instance, an extreme case were wind travels from the Northwest half of the time at 2 m/s and from the Southeast the other half of the time at 2 m/s would be represented by InMAP as advection at 0 m/s and diffusive mixing equally in all directions at $\sqrt{2}$ m/s."

Comment: It is a bit discomforting to have an empirical factor (FA in eqn 3) that, so far as I can tell, has no fundamental basis. In essence, doesn't this just make up for dividing the velocities by 2 because, on average, flows are 50% from each direction? Would this have to be re-determined for each application or is there some more general foundation for the choice.

Response: In response to this comment and others we have redesigned the advection scheme as described in the manuscript. The new advection scheme no longer contains an empirical correction factor.

Changes: We changed the advection scheme in InMAP and updated the manuscript accordingly.

Comment: In their appendix A, they should include OSAT and PSAT that have been implemented in CAMx.

Response: We do include a discussion of particle source apportionment. In response to this comment we have added text to clarify that PSAT is an example of source apportionment. We have not mentioned OSAT, which is used for ozone, because InMAP does not predict ozone concentrations.

Changes: We added the text "One example of a source apportionment tool is the Particle Source Apportionment Tool (PSAT)".

Comment: They also make an interesting comment about reduced form models "For this reason, these methods generally are not amenable to use by non-experts." Is this approach amenable to use by non-experts (particularly since it doe use an empirical adjustment factor)?

Response: Yes: a goal of InMAP is to be amenable to use by non-experts after the initial setup and testing is complete for a given spatial and temporal domain. The initial setup and testing would be done by an expert. (As mentioned above, in response to this comment and to others, we redesigned the InMAP advection scheme so that it no longer uses an empirical correction factor.)

Changes: We made changes to the InMAP so that it no longer contains empirical coefficients, and updated the relevant sections of the text and figures to reflect the changes.

Comment: In the end, the authors present a new and potentially clever and interesting approach.

Response: We thank the reviewer for this comment.

Comment: There is still much to be done to provide the community comfort on whether the results are reasonable and could be used to assess interventions similar to those proposed. They need to further explore and communicate the limitations.

Response: We have added additional discussion of model limitations and additional model evaluations and results as described above. We look forward to continuing to explore the use of InMAP in future research.

Comment: The minimum that needs to be done before it can be reconsidered for acceptance: 1. In their test case, show what happens to the ozone, SO2 and sulphate plumes due to an individual power plant in the WRF-Chem and InMAP cases.

Response: We thank the reviewer for this comment. As several of the scenarios that we tested are dominated by emissions from power plants, we have responded to this comment by including more information about how InMAP performs in those specific scenarios in a set of Appendix figures. We have also added a new model evaluation of model performance in a scenario with emissions from a single point source. InMAP does not make predictions of ozone concentrations.

Changes: We added a series of appendix figures describing the major types of emissions in each scenario and giving the spatial patterns of concentrations in each scenario and scenario-specific statistics, as well as a corresponding discussion. We also added a performance evaluation for emissions from a single source of non-reactive particles and a corresponding discussion.

Comment: 2. Do a more detailed comparison of the WRF-Chem and InMAP 12 km applications to assess the ability of InMAP to capture the impacts of changing mobile source emissions, e.g., plot and provide performance data on the change of concentrations on a grid-by-grid basis.

Response: In response to this comment and others, we have added a series of appendix figures showing grid-cell-by-grid-cell spatial patterns and performance statistics for each scenario.

Changes: As requested, we added a series of appendix figures describing the major types of emissions in each scenario and giving the spatial patterns of concentrations

in each scenario and scenario-specific statistics. We discuss those results in the main text.

Comment: 3. Follow the behaviour of the emissions of a point source in a windfield that is diagonal to the grid, but like they discuss, goes in one direction 50% of the time and in the other direction 50% of the time. Without those it should not be accepted. Other issues are above, and the results of those tests may indicate other issues to address.

Response: As described above, we have added text to the manuscript describing what would happen in the scenario described in this comment, and identifying it as a limitation of the model. Additionally, we have redesigned the advection scheme to make clear that it is both advective and diffusive.

Changes: We added the text: “As shown above, in order to represent temporally-variable advection in an annual average modelling framework, InMAP splits advective transport into three steps, one of which is advective in nature and two of which are diffusive in nature. One result of this is that in some cases information regarding transport direction may be lost. For instance, an extreme case were wind travels from the Northwest half of the time at 2 m/s and from the Southeast the other half of the time at 2 m/s would be represented by InMAP as advection at 0 m/s and diffusive mixing equally in all directions at $\sqrt{2}$ m/s.”

Comment: 1. Does the paper address relevant scientific modelling questions within the scope of GMD? Does the paper present a model, advances in modelling science, or a modelling protocol that is suitable for addressing relevant scientific questions within the scope of EGU? Yes 2. Does the paper present novel concepts, ideas, tools, or data? Yes

Response: No response

Comment: 3. Does the paper represent a sufficiently substantial advance in modelling science? Unclear at this time. More evaluation is required.

Response: As discussed above, we have added substantial additional evaluation and evaluation results to the manuscript. We will continue to use and test the model in ongoing research.

Comment: 4. Are the methods and assumptions valid and clearly outlined? No. . . see the review.

Response: We have increased the clarity of the descriptions the methods, and re-designed the advection solver as described above.

Comment: 5. Are the results sufficient to support the interpretations and conclusions? No. . . See the review.

Response: As discussed in comments above, in response to comments from this reviewer we have added multiple additional examples of model evaluation.

Comment: 6. Is the description sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? In the case of model description papers, it should in theory be possible for an independent scientist to construct a model that, while not necessarily numerically identical, will produce scientifically equivalent results. Model development papers should be similarly reproducible. For MIP and benchmarking papers, it should be possible for the protocol to be precisely reproduced for an independent model. Descriptions of numerical advances should be precisely reproducible. Very close. Could be better.

Response: We have added additional model description in response to the above comments.

Comment: 7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution? Yes 8. Does the title clearly reflect the contents of the paper? The model name and number should be included in papers that deal with only one model. Yes

Response: No response.

Comment: 9. Does the abstract provide a concise and complete summary? Too much time is spent on unnecessary material (background) without getting to the important/novel aspects of the model and the results.

Response: We appreciate that this reviewer would prefer more details on the model itself and less information on the rationale for why we developed the model in the first place. Other readers may have different preferences. Throughout the manuscript we have added many new details on the model itself, as requested by the reviewer. A manuscript describing a new model should include a rationale for creating a new model, and a description of needs that are not being met by existing models. The background material in our manuscript is necessary for understanding why several important details of InMAP are set up the way that they are.

Comment: 10. Is the overall presentation well structured and clear? Reasonable. For exceptions see the review.

Response: We have improved the clarity of the manuscript in response to the comments above.

Comment: 11. Is the language fluent and precise? Yes

Response: No response.

Comment: 12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used? Not totally, see the review.

Response: We have improved our mathematical representations in response to the comments above.

Comment: 13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? Reasonable. See the review.

Response: We thank the reviewer for this comment.

Comment: 14. Are the number and quality of references appropriate? Yes

Response: No response

Comment: 15. Is the amount and quality of supplementary material appropriate? For model description papers, authors are strongly encouraged to submit supplementary material containing the model code and a user manual. For development, technical, and benchmarking papers, the submission of code to perform calculations described in the text is strongly encouraged. The supplementary material could be extended to provide additional performance information.

Response: We have added additional performance information to the manuscript.

Interactive comment on Geosci. Model Dev. Discuss., 8, 9281, 2015.