

Interactive comment on “ModelE2-TOMAS development and evaluation using aerosol optical depths, mass and number concentrations” by Y. H. Lee et al.

Anonymous Referee #2

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This manuscript describes the implementation of a new aerosol microphysics module (TOMAS) into the ModelE2 general circulation model, contrasting in detail various aspects of the new scheme with those for the existing mass-based aerosol scheme. The paper then presents an evaluation of the ModelE2-TOMAS simulated aerosol properties against an impressive number of observational datasets covering aerosol optical properties, mass concentrations and number concentrations.

The paper is indeed appropriate for publication in GMD, and will provide a very useful reference for users of the model to understand the details of the new scheme and its expected skill against these benchmark observational datasets.

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However, although the Figures and results sections are well presented, the Abstract needs some attention and some aspects of the Introduction section require some correction which I have identified in my comments below.

As per the interactive comment from the Executive Editor, the manuscript also requires the addition at the end of the paper of a "Code availability" section giving the information of how the code for the model can be made available on request.

http://www.geoscientific-model-development.net/submission/manuscript_types.html

Overall however the paper is a worthy addition to GMD and the authors are to be commended on a very comprehensive assessment of the aerosol properties simulated by the model.

I therefore recommend the paper be published once these minor revisions have been made.

1) Title – I would suggest to replace "using" with "of simulated" which better describes the evaluation carried out in the paper

2) Authors – I was surprised to see that there were only 3 co-authors on this paper, which seemed to bring together the aerosol microphysics module, the general circulation model, use a range of emissions datasets and compare to a large number of observations. Are there any model developers or observational PIs who should also be offered co-authorship to recognise their contribution here? Does the GISS model have any "Publication Policy" to provide guidance on how best to recognise such contributions? Do the observational datasets used have any data policy about offering co-authorship? I am aware that some monitoring networks require that co-authorship be offered for publications using their observational datasets.

3) Model naming

Is there a recognised acronym for the GISS ModelE bulk aerosol scheme that could be used? In many parts of the text there is the phrase "bulk aerosol model" or "bulk

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aerosol scheme" which could usefully be abbreviated to BAM or BAS for example. Also the abstract explains that the TOMAS scheme presented is the computationally efficient 15-bin version of TOMAS. It would be useful if this was reflected in the acronym for the aerosol scheme. Is there also an existing acronym for this "fast" version of TOMAS that could be used e.g. TOMASf or TOMAS15?

A related comment is also that many of the features of the global aerosol distribution are affected by parameters within the other parts of the general circulation model, and consequently I would recommend to refer to ModelE2-BAM/ModelE2-BAS in the text describing the results and evaluation. This also goes for the microphysical scheme which I would recommend to refer to as ModelE2-TOMASf or ModelE2-TOMAS15.

It is correct to just refer to BAM or TOMAS when describing the aerosol scheme itself but when presenting aerosol properties simulated in the GCM then one could use ModelE2-BAM or ModelE2-TOMAS.

4) 1st section of the Abstract need attentions and some quantitative statements required.

The first 3 sentences of the abstract contain too much specifics and seem out of place here. The authors need to re-draft this first part of the abstract to give the overview of the aims of the paper rather than this level of detail about the new aerosol scheme. I would suggest to move the 4th sentence to instead be at the start of the abstract. Perhaps the existing first 3 sentences could even be removed – or else condensed into a single sentence giving brief general explanation of the microphysical scheme.

The sentence beginning "The TOMAS model successfully captures observed aerosol number..." and other statements would be much improved with some measures of skill against the observations. The Figures have a good set of bias and correlation measures presented and I suggest to cite some of these in the Abstract to give some quantitative metrics to back up the statements made about the model skill.

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The sentence "With TOMAS, ModelE2 has three...." seems out of place in the Abstract – suggest to remove it.

5) Merging Tables 3 and 4 together into one table for DMS, SO₂ burden & budget

I suggest to merge Tables 3 and 4 together so that the reader can easily compare the DMS and SO₂ burdens and budgets between the ModelE2 runs with the bulk and microphysical schemes.

6) 2nd paragraph of Introduction needs quite some revision.

This para mentions 3 categories of aerosol microphysics model – moment, modal and sectional. But I'm a bit puzzled by what is meant by "moment". It is said that "moment-based methods track lower-order (radial) moments of a size distribution." My understanding of aerosol microphysics models is that they can be categorized as either modal and sectional. And that the radial moment tracked by the scheme then describes which variables are treated prognostically by the model. Both modal and sectional schemes can be either single-moment or double-moment. TOMAS is a double-moment sectional scheme for example. I'd recommend the authors re-write this paragraph with this classification. I would remove the text "moment, " from the 1st sentence and replace "In general, moment-based methods track lower-order (radial) moments of a size distribution, and modal-based methods.." with "Modal methods...". Suggest then to replace "represent a mode" with "represent a subset" later in that sentence.

In the 3rd sentence suggest to replace "predicting the amount of" with "representing" and re-write the last 2 sentences explaining that one can have single-moment, double-moment or triple-moment schemes with reference to existing models which have these approaches.

7) Introduction 3rd para – 1st sentence – further to my recommended changes above here I suggest to replace the existing text "(i.e. zeroth moment)" with "(i.e. zeroth radial moment)" and replace the existing text "mass (i.e. 1st mass moment)" with

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"mass (i.e. third radial moment)". The current text is confusing because the sentence could confuse the reader with the use of mass moments. My suggested revised text just refers to radial moments as they are the usual one referred to in terms of size distributions.

8) Introduction 3rd para – 3rd sentence – as per my comment 6) I suggest here to not consider moment methods separately from modal and sectional methods. Suggest to replace "The modal and the moment-based approaches are..." with "Modal approaches are...."

9) Introduction 4th para – I'd suggest to reword the sentence beginning "Despite the accuracy..." – perhaps shorten that sentence to instead say: "Despite the accuracy in predicting aerosol microphysical processes, the original version of TOMAS has a heavy computational burden." Then in the sentence after that I'd suggest to replace "more computationally efficient" with "less computationally expensive configurations..".

10) Introduction 5th para – the 1st sentence beginning "Since uncertainties..." seemed out of place here. I'd suggest to start that para with the current 2nd sentence changing the start of it from "Therefore, here we..." to "Here, we... I think the current 1st sentence would fit well at the end of the paragraph changing the start of it from "Since uncertainties in..." with "We also note however that uncertainties in...". I would also reword from the current "...come from not only aerosol modelling itself but..." with "come not only from aerosol modelling but..." and finish the sentence after the text boundary layer, and advection)" – delete the text "it is important to include the improvements in both aerosol modelling and the other parts of GCM." as that's implied already in the rest of that sentence.

11) Introduction 6th para – suggest to replace "that has a goal of understanding" with "which aims to understand"

12) Introduction 6th para – suggest to shorten substantially the sentence beginning "The model description...." to instead simply say something like "Here we give a de-

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tailed description of ModelE2-TOMASf and evaluate simulated aerosol mass, number and optical depth against those from ModelE2-BAM (Schmidt et al., 2014) and observations." The sentence afterwards should have a citation for the expected paper if it is already well advanced in its preparation. If not then the sentence should be removed. With that re-worded sentence the next sentence beginning "In this paper, as a comparison with TOMAS, we include..." can be deleted.

13) Introduction 6th para – Be clear when you're referring just to a description of the aerosol scheme and where it's describing the full model ModelE2-TOMAS. For example in the sentence beginning "Section 2...." when you say "including the bulk aerosol model" I suggest you say here the bulk aerosol scheme".

14) Introduction 6th para – Insert "the" between "design of" and "simulations".

15) Introduction 6th para – sentence beginning "Section 5.." can be made shorter and easier to read by deleting "the" between "presents" and "global budgets" and replacing "and the evaluation of the TOMAS and bulk aerosol scheme model..." with "and evaluates ModelE2-TOMAS and ModelE2-BAM..."

16) Section 2 – 1st para – suggest not to begin a sentence with "The newest version of" as this will rapidly become not the case as time passes... Also this sentence is clumsily worded and makes this whole para difficult to read. Suggest to re-write that sentence to instead be something like "In this section we briefly describe ModelE2 (Schmidt et al., 2014), the GISS climate model used to perform simulations for the Coupled Model Intercomparison Phase 5 (CMIP5)". Suggest to refer here to Taylor et al. (2012) when CMIP5 is mentioned. With this re-wording the later sentence "A brief description of ModelE2 is given here." can be deleted.

17) Section 2 1st para – the Prather (1986) paper is missing in the References – please add.

18) Section 2 1st para – replace "hydroscopic" with "hygroscopic".

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19) Section 2.1 title – this para is not really describing the bulk aerosol scheme but rather the way it is implemented within ModelE2. Suggest to change the title to "Implementation of the bulk aerosol scheme in ModelE2" or "ModelE2-BAS description" or similar.

20) Section 2.2 last sentence – reference is missing for "(2002)" – also the authors need to add sentence giving brief explanation of this – cloud droplet number concentration as a function of aerosol number or mass?

21) Section 3 title – again this section is describing the overall model not just the TOMAS aerosol microphysics scheme. As in my comment 19) I suggest to have this section as "Implementation of TOMASf aerosol microphysics scheme into ModelE2"

22) Section 3 1st para – 1st sentence – see my comment 7) above I suggest to refer to radial moments only throughout to avoid confusion. Suggest to replace the existing text "(i.e. 0th moment)" with "(i.e. zeroth radial moment)" and replace the existing text "mass (i.e. 1st mass moment)" with "mass (i.e. third radial moment)".

23) Section 3 1st para – 3rd sentence – suggest to replace "the TOMAS model tracks ten quantities for each size bin..." with "ten quantities are tracked for each size bin..."

24) Section 3 1st para – that 3rd sentence is very long and needs to be re-written as at least 2 sentences. Also please clarify what is meant by "the ammonium mass is diagnosed in each size bin based on sulphate mass..." Later in that sentence you mention that the scheme tracks aerosol ammonium so is it transported or diagnosed? Please take care with the wording here when revising the manuscript.

25) Section 3 1st para – you say "TOMAS uses a moving sectional approach to treat water uptake" – Please can you clarify this – I assume this moving sectional approach deals with the aerosol dynamics. Isn't that moving sectional approach based on dry size – what is meant here? Please re-word to clarify.

26) Page 5839 line 1 – insert "alternative" between "Several" and "nucleation schemes".

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27) Page 5839 line 6 – you have already introduced the faster configuration of TOMAS on page 5835 so you don't need this wording here – please reduce this sentence. I have also suggested to give it a name such as "TOMASf" or "TOMAS15". So please replace "With the development of computationally efficient TOMAS models (i.e. Fast TOMAS), the TOMAS microphysics module became more flexible...." with something like "As well as being computationally faster, the development of TOMASf (see section 1) also made the scheme more flexible...."

28) Page 5839 lines 10 to 12 – this sentence says "TOMAS" much too many times. Suggest to delete the "compared to the original TOMAS" at the end as that's implicit in the wording already – then can delete "in TOMAS" after "lower size cutoff" – again it's clear already you're referring to TOMAS.

29) Page 5839 lines 12-19 – these sentences would be much better illustrated in a Figure showing the different size bin configurations across the size spectrum. Perhaps they don't even need to be shown at all? Is this already described elsewhere in another paper?

30) Page 5839 line 21 to 23 – this para needs some rewording – the current text says "condenses" but the sentence describes aqueous sulphate production so condensation is not the right term. Suggest to change

"First, the TOMAS model condenses the sulphuric acid formed from aqueous oxidation by hydrogen peroxidized (H_2O_2) directly onto sulphate aerosols in ambient air..."

with

"First, ModelE2-TOMAS adds sulphate mass produced in the aqueous phase directly to the bin-resolved sulphate mass in ambient air...."

31) Page 5839 line 25 – replace "...sulphate formed from aqueous oxidation should release to the air only when the cloud water evaporates" with "...sulphate formed in the aqueous phase will only be released as interstitial aerosol when the cloud water

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evaporates".

32) Page 5839, line 28 – replace "For in-cloud scavenging, modified Kohler theory is used..." with "Modified Kohler theory is used..." – this sentence is referring to activation not in-cloud scavenging.

33) Page 5839, line 29 – "for activation of each size section..." somewhere in this para the kappa values used for each component need to be given.

34) Page 5840, line 1 – suggest to replace "activate and are subject to" with "activate (i.e. contribute to cloud droplet number) and which are subject to..."

35) Page 5840, lines 3-7 – this sentence needs to be clarified – is this referring to scavenging or activation or both? Also replace "hopple" with "Hoppel".

36) Page 5840, within the description of ModelE2-TOMAS there is no mention of how aerosol-radiation interactions (i.e. aerosol direct radiative effects) are represented. Do the size-resolved aerosol information feed into aerosol scattering and absorption in the ModelE2 radiative transfer model? There needs to be at least a sentence or two describing what is done here.

37) Page 5840, section 4 title – suggest to replace "Simulation setup" with "Description of the simulations"

38) Page 5840 line 18 – replace "2000" with "year-2000" and replace "CMIP5" with "ACCMIP".

39) Page 5840 lines 21-22 – give the original reference for continuous volcanic emissions from GEIA – is it the Andrea & Kasgnoc (1998) dataset that you mean here?

40) Page 5842 – title for section 4.2 – suggest to change to "The ModelE2-TOMAS run setup"

41) Page 5842 – line 2 – please give reference for the MERRA re-analysis fields.

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42) Page 5842 – lines 14-18 – reword this sentence to make it easier to read. Suggest to replace "Note that an emission size distribution used for the biofuel emissions is generally the same" with "Note that although the emissions size distribution for biofuel emissions are generally assumed to be the same.." and delete "as their burning materials are the same". Then replace ", but our model assumes the.." with ", in the ModelE2-TOMASf run we assume the ..." and replace "follow the fossil fuel because the CMIP5 emissions does not..." with "follow the finer fossil fuel size settings because the ACCMIP emissions do not..."

43) Page 5842 – line 22 – replace "sulphate and carbonaceous aerosols" with "primary sulphate and carbonaceous emissions" so it is clear that you mean the assumed size for the emissions.

44) Page 5842 – line 23 – here you give the Lee et al. (2013) reference for GISS-TOMAS but earlier in the manuscript you cite Lee and Adams (2010) for GISS-TOMAS – which is the best one to refer to – presumably the same?

45) Page 5843 – lines 1-2 – delete the sentence beginning "Whereas the GISS-TOMAS does not...." – you've already said that in point 1).

46) Page 5843 – line 2 – suggest to replace "Additionally the" with "Note also that the" – that reads better in my opinion.

47) Page 5843 – lines 6-8 – Presumably this info is for SO2 emissions here right? If so please put this information into Table 3 rather than writing it as a sentence.

48) Page 5843 – lines 12-13 – replace "and thus they are excluded" with "and is therefore not received by any of the TOMAS size bins."

49) Page 5843 section 4.3 title – suggest to change to "The ModelE2-BAS run setup" or similar.

50) Page 5843-5844 section 4.3 1st sentence – the 1st half of this sentence can be deleted as you've already explained earlier in the article and so I suggest to start this

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as "To compare to the ModelE2-TOMAS run, we also ran the ModelE2-BAS model nudged to the same MERRA reanalysis meteorology with 3 years spin-up."

51) Page 5844 section 4.3 2nd sentence – suggest to replace "The natural emissions and emissions-relevant setup are not necessarily the same between the bulk and TOMAS models. This is because we maintain..." with "However, the natural emissions and associated settings are not always the same between the two models because we chose to maintain...."

52) Page 5844, line 5 – Suggest to replace "Here, we note that the differences..." with "To assist the interpretation of the results, we briefly summarize the differences...."

53) Page 5844, line 14 – insert "whereas ModelE2-TOMAS assumes only 1%" after "(Dentener et al., 2006)".

54) Page 5845, lines 13-14 – suggest to replace "In case of the bulk aerosol model in ModelE2.." with "For ModelE2-BAS.." or similar acronym.

55) Page 5845, line 16 – delete "newer".

56) Page 5845, line 20 – replace "in both models." with "in both simulations."

57) Page 5846, line 7 – why are the H₂SO₄ and SOA precursor gas budgets in the text rather than in a Table. It would be much better to tabulate them alongside the DMS and SO₂ in Table 3.

58) Page 5846, lines 10-11 – is this the same for the bulk aerosol scheme? How is SOA handled? State if this is the same or not in the text.

59) Page 5846, lines 13-14 – "and OH and NO₃ concentrations" – state in brackets whether these oxidants are interactive or prescribed.

60) Page 5847, line 2 – But what about the chemical sinks. That authors should comment here. Do the ModelE2-TOMAS and ModelE2-BAS have the same approach for oxidants and hence the same chemical sinks? This should be stated here as it could

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make a big difference.

61) Page 5848, line 10 – replace "that the model does not capture" with "that neither of the simulations is able to capture".

62) Page 5849, line 8 – add "in ModelE2-TOMAS" after "98% of the total deposition"

63) Page 5849, line 13-17 – rewrite this sentence to shorten it. How about Note that the GISS-E2-R-TOMAS simulation used for ACCMIP is almost identical model except for the"

64) Page 5850, lines 11-12 – "has a significantly faster removal rate and increases the mean value" – is this for dust or for sea-salt – or for both – please clarify in that sentence.

65) Page 5850, line 14 – Another issue is that, for components in the coarse part of the particle size range, some of the variation between the models for burden and lifetime can be explained by differences in the upper size cut-off used in the models. Please add a sentence at the end of this para noting this in the interpretation.

66) Page 5850, line 19 – insert "and much lower than the AeroCom median value" after "than in the TOMAS model."

67) Page 5850, line 22 – insert "and a factor of two lower than the AeroCom mean after "compared to TOMAS".

68) Throughout results sections replace TOMAS with ModelE2-TOMAS.

69) Page 5853, lines 11 to 14 – I don't understand why there is such a big difference between the surface SO₄ in the 2 model runs in these SH marine regions. Is this related to the differences in the treatment of aqueous sulphate production and wet removal between the ModelE2-BAS and ModelE2-TOMAS runs?

70) Page 5854, line 18 – insert "for both models" after "severe underprediction"

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71) Page 5855, lines 1-4 – the observations at Heimaey, Iceland show a big peak in June or so that is not seen in other months – what is the cause of the higher dust emissions here? Are there papers that have attributed this to a spike in emissions from certain sources? Add reference to these.

72) Page 5855 line 10 – you state this may be showing the dust emission are too low – but could it alternatively (or as well as) be that there is too rapid removal in the model? If so insert "or the removal timescale is too fast" after "are too low".

73) Page 5857 lines 28-29 – "indicating a possibility of aerosol emissions being underestimated in these regions". That's a bit speculative. Couldn't it also be that something in the model that could be causing the bias? You need to give a bit more to back up your statement here. Are there references which have also shown this similar bias in other models?

74) Page 5858 line 28 – replace "In contrary" with "By contrast"

75) Page 5859 line 4 – "undeprediction" → "underprediction".

76) Page 5859 line 18 – "particles with diameters" → "particles with dry diameters" in both CN3 and CN10 definitions. That's certainly how its measured – please can you confirm whether your model values are based on dry or wet diameter.

77) Page 5859 line 22 – I would delete the word "obviously" – it is worth stating this – it may not be obvious to some readers.

78) Page 5859 lines 26-28 – you can see this in the ratio of CN3 to CN100. For the base case, CN3 is about a factor of 40 higher than CN100 and only about a factor 6 higher in the surface layer. In the LowNUC and NoNUC these ratios shift substantially. Worth stating this in the text.

79) Table 9 – suggest to delete the 1st column "Emission rate". You don't refer to these values in the text and it is not obvious why the values are given here.

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80) Page 5860 – line 1 – you have "Aerosol number burdens" but the values are given in particles per cm³ which suggests they are concentrations not burdens. Burden implies it's a column-integrated property which would have be given per unit area rather than per unit volume. Please give a different term.

81) Page 5860 – lines 17-19 – Change "Obviously when turning nucleation off, CN3 is very close to CN10" to "When nucleation is switched off CN3 is very close to CN10 near to the surface (Figure 19 g and h)." Again this is not necessarily obvious to the reader – it is worth stating.

82) Please add labels a), b), c) ... to all Figures with more than 1 panel so that it is possible to refer to them in the text. Figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26 and 28.

83) Page 5860, line 19 – insert "primary" between "anthropogenic" and "emissions" – I'm assuming that's what was intended here.

84) Page 5861, lines 2-3 – You say "Rather suprisingly, dust particles in our model contribute to CN100 quite significantly" – why is that surprising? It is not obvious to the reader why that is surprising. You should explain why it is surprising or else delete the sentence.

85) Page 5861, line 22-24 – the use of whisker lines in Figure 21 is confusing. The reader will assume that the circle in the centre of the whisker is the one to refer to. I would suggest that the circle should be showing the BASE case – you could then have one vertical whisker down from that with two horizontal whiskers indicating the 2 sensitivity runs. Please change Figure 21 accordingly.

86) Page 5861 line 25-29 – the BASE run seems to high according to the Figure with the LowNuc in much better agreement at some sites. Please can you comment on this in the text.

References:

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Andres, R. and Kasgnoc, A.: A time-averaged inventory of subaerial volcanic sulfur emissions, *J. Geophys. Res.-Atmos.*, 103, 25251–25261, 1998.

Taylor, K. E., Stouffer, R. J., and Meehl, G. A.: An overview of CMIP5 and the experiment design, *B. Am. Meteorol. Soc.*, 93, 485–498, 2012.

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