Response to Referee 1

Referee 1 in black, and response in blue.

I recommend this paper be accepted, subject to addressing the following concerns:

Yes, the paper shows that the emulator can produce output for some variable that are linearly related to forcing. But I think the entire project needs to be framed more clearly. Some of these points are addressed in the discussion, but they need to be added to the abstract. What can the emulator not do? What is its purpose? Because it does not include a seasonal cycle in the resulting maps of temperature and precipitation, it cannot be used for many potential impacts of climate change that matter, such as food production and water resources. It cannot simulate monsoon impacts. It cannot simulate the diurnal cycle, which is important for many impacts, including agriculture and tropospheric ozone. It does not include downward diffuse vs. direct radiation, or UV. And because the two GCMs used as examples differ quite a bit in some aspects, any actual use of the emulator would require multiple climate models so as to add a probability distribution to the resulting emulated climate.

- We have now added more framing in the abstract, introduction, and discussion to clarify that this emulator's purpose is to aid in exploration of SAI scenarios, especially those which are uncoordinated or otherwise highly dynamic, and that it is intended to work in concert with the eventual running of a full Earth System Model if one desired a more detailed assessment of any particular scenario's impacts.

Will it be possible to also emulate impacts of SRM in addition to the standard climate variables of temperature, precipitation, and evaporation? What would it take? And can the authors add warnings about the usage of emulators prominently in their abstract and introduction?

- A methods subsection, results, and discussion of an example of expanding SRM to another climate variable (September Sea Ice extent) has now been included, in addition to a new co-author, Ali Akherati.
- Warnings about emulator usage and how an emulator is not a substitute for an Earth System Model, have been included into the abstract and introduction.

The way the emulator works is to include CO_2-equivalent and SO_2 time series of forcing, but no mention is made of tropospheric aerosols, land use, and other forcings included in SSPs. How are they handled?

- All SSP forcing from Riahi et al. (2027) has now been included, including tropospheric aerosols but excluding land use changes.

Please also address the 40 comments in the attached annotated manuscript.

- The 40 comments have been addressed further in this response.

Technical issues:

Cider is not brewed. It is fermented. So the title to section 2 needs to be changed. See the comments in the attached annotated manuscript.

- Section 2's title changed to Making CIDER (Methods)

Your model nomenclature is confusing. You have CESM2(WACCM), CESM2-WACCM6, and CESM2. Are these all the same? Then use the same notation. The same for UKESM1 and UKESM1.0.

- Nomenclature made consistent - the two models are referred to as CESM2-WACCM6 and UKESM1.

There are several acronyms that are not defined.

- Acronyms have now been defined before use.

You use "validation" multiple times, when you mean "evaluation." "Validation" means that you are proving that the model works, that it is valid.

- Validation changed to evaluation throughout the paper.

Multiple references in the text do not use parentheses around the years.

- Parentheses added to references in text.

Further Comments

1. Line 8: Or evaluate?
    - Validate changed to evaluate.
2. Line 15: You cannot cool temperatures. You can cool physical things, like the air. Do you mean "reduce?"
    - Cool changed to reduce.
3. Line 17: increasing
    - Increases changed to increasing.
4. Line 17: Earth's
    - The earth changed to Earth.
5. Line 17: providing
    - Provides changed to providing.
6. Line 18: This word has a specific IPCC meaning. Change to "reduce" or "ameliorate"
    - Mitigate changed to Ameliorate.
7. Line 31: Brody et al, 2024
    - Brody, Zhang et al. 2025 changed to Brody et al. 2025.
8. Line 43: al.
    - al changed to al.
9. Line 44: al.
    - al changed to al.
10. Line 55: by whom? What about those who desire looking at impacts
    - Primary desired features changed to a subset of features.

11. Line 57: et
    - et. changed to et
12. Line 64: prove that it is valid?
    - We moved this section into where we introduce Sect. 3, and we changed validate to evaluate.
13. Line 70: Brewing CIDER
    - Section title changed to Making CIDER
14. Line 72: Also needs other forcing, from GHGs, tropospheric aerosols and other things
    - Included other anthropogenic forcings.
15. Line 80: variable
    - Variables changed to variable, and examples given.
16. Line 81: What about SSP forcing from tropospheric aerosols and land use?
    - Other SSP forcing from Riahi et al. (2027) is included, including tropospheric aerosols but excluding land use.
17. Line 91: Define acronym and what it is
    - A subsection defining climate models is now included at the start of Section 2.
18. Line 97: *q(t)*
    - Italicized.
19. Line 99: *t*
    - Italicized.
20. Line 100: *t*
    - Italicized.
21. Line 106: *x* (and the rest of the variables)
    - All further variables italicized.
22. Line 113: (1998)
    - Replaced with a different source, since we are now including all anthropogenic forcings and this formulation is no longer used.
23. Line 119: [no indent]
    - Indent removed
24. Line 123: ESM
    - Earth System Model changed to ESM
25. Line 125: but does the assumption still hold here?
    - Changed the sentence to instead point to Sect. 3, where the assumption is shown to hold.
26. Line 162: Define
    - Defined (now in Section 2.1)
27. Line 165: define
    - Defined (now in Section 2.1)
28. Line 172 : (2023)
    - Added parentheses
29. Line 175: Southern Hemisphere
    - Southern Hemisphere capitalized.
30. Line 191: e.g.,
    - Comma added.

31. Table 1: Define acronyms. What are UKESM1 and CESM2?
    - Definitions added in table description.
32. Line 204: Figures have to be numbered in order of usage in the paper. Where are Figs 2-4?
    - Removed the mention, since Figure 5 appears in Section 3 anyways.
33. Line 255: southern hemisphere
    - Southern Hemisphere capitalized.
34. Line 256: remove As a note
    - As a note removed.
35. Line 263: remove (CIDER)
    - Removed (CIDER).
36. Line 264: remove (SAI)
    - Removed (SAI).
37. Line 291: cannot
    - Changed can’t to cannot.
38. Line 291: behavior
    - Changed behaviour to behavior.
39. Line 295: made
    - Changed they make to made.
40. Line 295: are not
    - Changed aren’t to are not.

Response to Referee 2

Referee 2 in black, and response in blue.

Farley et al. present in their manuscript CIDER, which is a climate emulator designed to emulate regional and global responses to a SAI deployment. The emulator is trained by using existing simulations from two Earth System models and is then evaluated with a novel climate model simulation scenario of a multi-actor uncoordinated SA deployment. Their results show that CIDER can be used to estimate multiple climate variables of interest and thus can be a valuable tool for exploring the climate implications of various deployment scenarios.

General comments:

The study by Farley is quite interesting and the presented emulator is a quite impressive tool. This study certainly deserves to be published, but the manuscript currently lacks clarity and needs major revisions. First of all, it did not become clear to me what the main purpose of this study is. Is it the presentation of the climate emulator itself or the validation of the climate emulator. The intention or purpose of this study should be clearly communicated in the manuscript.

- Additional framing has been added in the abstract and introduction, and the word validation is avoided. The purpose of this paper is to present a novel climate emulator, including evaluation of its performance on data outside of the training set.

The current version of the manuscripts lacks important information on the model simulations. Farley et al. refer to other publications, however, they cannot expect that every referee or reader reads three additional papers to understand what actually has been done in this study. Therefore, some repetition of information is unavoidable. For example, the simulation runs used for training and validation should be shortly described, e.g. the information should be added for which time period the simulations have been performed and what set-up has been used.

- Descriptions of the simulations used have been added, the model setups have been expanded and made into their own subsection, and descriptions of the time periods used have been added.

Specific comments:

P3, L71: How many years have been used or are needed for training?

- The amount of years used for training (35 years) has been added.

P3, L74: Which one or two climate models? Are you referring here to specific climate models or do you mean one or to models in general?

- Clarification has been added here, and a subsection on the specific climate models used has been added to the beginning of Sect. 2.

P3, L77ff: Which algorithm has been used for training? How does the input data for CIDER look like (e.g. dimension?)

- Clarification has been added to Step 1, and we also added a pointer to a new subsection about the emulator's form and algorithm.

P3, L80: "computes global mean climate variables"? How have these been computed? Which physics are behind these computations? Has a model been used?

- Clarification has been added onto step 2 specifying how the computation is handled, as well as a pointer to a new subsection on emulator form for more details.

P4, L90-92: I cannot follow you what actually has been done here.

- The unclear section of the text has been reworded to be more clear.

P4, L94: What is the impulse response?

- A segment on what the impulse response is and how it applies to the emulator has been added.

Section 2.1: It would be quite helpful if Section 2.1 could be split into two or three subsections to be more concise.

- Section 2.1 has been split – details on the internal workings of the emulator have been separated into their own subsection.

P6, L135: How many years have been used for training?

- Information about how many years have been used and how many are needed has been added.

P6, L136: What exactly do you mean with simulation types? Simply to different simulations (set-ups)?

- The word *type* has been replaced with the more accurate word *set*.

P6, L157-P7, L168: Move this paragraph higher up. This actually should be the first subsection in Section 2 since the description of the used climate models is essential for understanding what you have done.

- This paragraph has been moved to the start of Section 2 and made its own subsection.

P7, L168: The abbreviation PI has not been introduced.

- PI has been introduced earlier in the paragraph.

P7, L172: For which years has the simulation been performed? Provide this information as well as the most important settings used.

- Years and reference to model settings has been added.

P7, !79: Are these the training scenarios or has all this done in one scenario? I thinks it needs to be more clearly be pointed out what has been done.

- The words “in this scenario” have now been added.

P8, Table 1: Are the latitudes given here the latitudes where SO2 has been injected? More details should be added in the table so that the reader can understand what has been done without reading three other papers. Last row: Add also here more information than just referring to Sect. 2.3.

- A column describing each simulation set has been added, and column headers have been changed for clarity.

P9, L205: Do you mean AOD, temperature and precipitation are shown in Sect. 3, but evaporation only in Appendix A1? Could this be more clearly stated?

- This statement has been clarified.

P9, L206: In Fig. 2 time series are shown. This should be mentioned in the text and also what time period is shown should be mentioned.

- Time series has been mentioned in description and in the text.

P9, L207: validation of what?

- The word validation has been removed in favor of a description of how CIDER is evaluated.

P9, L207: Which SAI scenarios have been considered should be explicitly be mentioned.

- The considered SAI scenarios are now explicitly mentioned.

P10, Figure 10 caption: How can this be an average over 2020-2039 when a time series is shown?

- The description has now been reworded for clarity.

P11, Figure 3: What is meant with SE normalized?

- Description of what is meant with SE-normalized has been added to the figure’s caption.

P11, Figure 3 caption: Which simulation period has been considered?

- Description of considered simulation period has been added to the figure’s caption

P12, Figure 4 caption: It should be clearly mentioned in the caption that time series are shown.

- A mention of time series and years included has been added to the caption.

P13, Figure 5 caption: Mention that a time series is shown.

- A mention of time series and years included has been added to the caption.

P14, Figure 6 and Figure 6 caption: Description in the caption and lines shown in the legend do not agree.

- The caption has been changed to reflect what is in the figure and legend.

P14, L262: This is rather a discussion than a conclusion section.

- Section title has been changed to discussion and conclusions.

P15, L271-278: This is a very important point and should be much earlier in the manuscript be mentioned. I would suggest to move this (or additionally mention this) In the introduction.

- This point is now additionally mentioned in the abstract and introduction.

P17, L344-346: This does not belong to the conclusion section and should rather be provided in the code and data availability section.

- These lines have been moved to the code and data availability section.

P17, L347: Since this section is a discussion a short conclusion section summarizing the major results should be added.

- The choice was instead made to retitle the section to discussion and conclusions.

P19, L352 and L353: doubling of “assisted in”.

- Doubling has been removed.

Technical corrections:

P2, L66-69: Section should be abbreviated as Sect.

- Section is now abbreviated as Sect. throughout the paper.

P5, units: Check the Copernicus style for units, e.g. mm/day is written as mm day -1 and no dots are used between units.

- Units have been changed to match Copernicus style.

P7, L183: Temperature -> temperature

- Temperature has been decapitalized.

P12, L246: Section should be abbreviated as Sec. (unless it appears at the begin of the sentence). The same holds for Figure which should be abbreviated as “Fig.”.

- Section has been abbreviated as Sect., and Figure, Fig.

P13, L248: Add “Fig.” before %b, 5c, 5d and 5f.

- Fig. has been added.

P15, L291: can’t -> cannot

- Can’t has been changed to cannot.

References: Check the reference style for Copernicus publication, to my knowledge journal names should be abbreviated.

- The Copernicus BibTeX style file is already used.