Second Review of "The interaction of Solar Radiation Modification with Earth System Tipping Elements" (egusphere-2023-1753) for Earth System Dynamics

General comments:

The authors have substantially revised this manuscript, tightening the writing & structure and reducing repetition throughout, and in my view, it has improved considerably as a result. In particular, the authors have caveated their summary of overall SRM effectiveness for CTPs more thoroughly, emphasising the uncertainties brought by non-temperature drivers in the abstract, introduction, and discussion (while the counter-point made that this could also make SRM more effective, not only less, is fair enough too). The additional figures and tables are useful, better helping to demonstrate tipping dynamics, how SRM might intervene in these dynamics, and the paper's results. Table 1 has also improved with the addition of more explicit discussion of drivers, effectiveness, and confidence throughout, making it easier to discern key points. Other points raised, for example the ocean temperature focus for marine ice sheets, or current general circulation / Earth system model limitations, have also been clarified, and the authors have justified their selection of systems to consider in this paper.

Beyond minor further suggestions, my main remaining comments concern the subtleties of categorising tipping in the Himalaya-to-Sundarbans (HTS) hydro-ecological system. While I appreciate the value of looking at HTS as an integrated socio-ecological system likely featuring localised tipping points, I am not yet convinced that it can be categorised as a regional/impact tipping element by the rationale of AM22 (even as a highly uncertain one) without a clear mechanism for shared tipping dynamics at the system rather than subsystem level beyond a common threshold. For comparison, warm-water coral reefs are classed as regional elements because there's evidence for a bleaching frequency threshold beyond which recovery is prevented and localised die-off becomes inevitable, with widespread mortality across the same biome/ecosystem functional group occurring at similar warming levels. Similarly, while Amazon rainforest dieback due to moisture recycling failure is also localised, it can trigger further dieback across much wider parts of the same system via that process, and is all one biome/functional group. In contrast, HTS covers multiple biomes/ecosystem functional groups, with the default likelihood being that different habitats that may tip are likely to tip due to different dynamics at different levels of climate change/degradation. It's still fine to include HTS in the paper though, but I think it either needs a little more justification as to how systemic tipping might emerge at the integrated system level, or a little more clarification that it's socio-ecological system with localised tipping, which this paper is suggesting as a potential element but is still a valuable case-study for considering SRM impacts on even if not.

Specific comments (by line no.):

23: I think "could" or "is likely" rather than just "is" is more appropriate here, given most of the evidence comes from simulations.

38: A comma has escaped.

47: Should "reverse" be here as well (along with avoid/postpone)?

61: "stop increasing" would be smoother than "stop to increase".

130: "tipping elements" would be more consistent terminology than "earth systems" here, or Earth subsystems to differentiate from the Earth system as a whole.

144: Insufficient SRM possible/used is also highly relevant for only postponing tipping.

175 / Table 1: The table is much improved, but I had to repeatedly look back at caption to remind myself of what each letter meant in the second column. A simpler approach to consider might be pluses and minuses, e.g. - for worsen, ~ for negligible, + for partial compensation, ++ for effective compensation, and +++ for overcompensation (however, that'd mean +/-s for both driver and compensation direction, so that might be too confusing...), or just abbreviations e.g. over, part, etc. Also, I assume bolding for drivers means primary drivers, but I don't think this is stated (and is missing e.g. for MSC driver or HTS driver/reversibility). I was going to ask too whether it'd might make more sense to have Table 1 plus its description (lines 194-205) after Section 5 instead, but on reflection I can see it can be argued either way which makes more sense to the reader. Finally, I broadly agree with the categorisations, though I'd query a few of the overall ones, such as whether HTS should be U-P (as the uncertain effect of SAI on monsoons could be critical), whether AR should be U-P or W-P (as evidence / GCMs remain limited, and while I agree it works better in east than west, there remains an uncertain risk of bringing west to point of bistability instead), whether SPG should be U-E (as no driver has an N or W, but there are few studies), and whether BPF should be P-E (as studies find reduced permafrost loss, but not totally countered, albeit potentially improvable via SAI strategy).

Fig. 3: I believe the compensations here are the overall compensation judgments in Table 1 (rather than temperature alone), but would be useful to state in the legend or caption for clarity.

222-244 & 286-287: This is indeed the IPCC AR6 summary, but the nature of confidence language makes it sound less compelling than I think the evidence suggests (especially from palaeo studies) - AR6 for example reported several studies where total loss committed at 2-3°C (ch.9-pg.78). As such, so that it doesn't sound like tipping is unlikely (rather than uncertain) below 3C, if space allows I'd suggest clarifying that this is specifically the IPCC AR6 assessment and briefly mentioning that some studies do find evidence for past collapse within this range.

323: Double citation.

385: Pedantic, but "like the Greenland Ice Sheet" to be specific to the icy bit of Greenland.

402-403: Should clarify the temperature level in G3 for unfamiliar, i.e. 2020 levels I believe. Also, maybe better to have this sentence integrated in to paragraph above rather than free-floating?

574-575: Some caveats on phrasing here, as while we do refer to this as a "global/core tipping *element*", referring to a "global tipping *point*" in a permafrost context can be misread, as it is often associated with the idea of a runaway warming threshold in the permafrost carbon feedback at the global scale (which the recent assessment by Nitzbon et al. this year [https://www.nature.com/articles/s41558-024-02011-4] is clear in ruling out). Nitzbon et al. also assess the Yedoma scenario as unlikely (although they do support localised abrupt thaw as tipping, albeit without a specific threshold warming level), which is worth mentioning here for context. Lastly, more accurate to say "becomes more widespread at" rather than "could occur at", given some abrupt thaw is already happening (our threshold estimate here is for when localised tipping becomes regionally/globally widespread in a near-synchronous manner, as for coral reefs).

598-599: Do you mean less effectively than limiting GMT through zero emissions?

655-669 / Fig. 4: (6) is not explicitly labelled in caption (e.g. before "It sinks along the shelf edge").

680: I think until after 2100 would be more accurate

709: Anthropogenic global warming, for clarity (as can't rule out palaeo warming events triggering circulation collapse).

722: Not a major issue, but is this the first time this compensation language is used in main text outside of table 1? It's useful, but feels like could be more consistent throughout if used.

885: GHGs are defined in Intro, so no need to redefine here.

1161: Relevant here is this recent paper, also in this SI: https://esd.copernicus.org/articles/15/671/2024/esd-15-671-2024.html

1196: Phytoplankton are indeed under-studied on this, but corals & symbiont algae are relevant here (statement is equivalent for all though).

1232-1234: I think this should be caveated more upfront here, making it clearer that you are advocating this system as being a plausible candidate for a tipping element for the first time here, with this section making the case for it being a tipping element as well as SRM's likely impact on it. Otherwise, as phrased it to me it can be read as saying it's already been established as plausible, which I don't think is the case yet. You should also rephrase the part in parentheses, as to me it implies that we suggest HTS as a candidate regional/impact element in AM22, rather than the category of regional/impact element being proposed in AM22.

1239-1242: I think this is a good framing and caveat, as much like some threshold-free systems are considered in this paper the HTS doesn't need to be a tipping element per se to be considered, and there is value in considering SRM's affect on tipping cascades in socio-ecological systems. As it stands though, I personally don't think sufficient evidence is presented for tipping to be likely at the integrated system level, but that doesn't mean it shouldn't be discussed.

1246-1251: The key difference between heterogeneity in HTS vs Amazon/corals is that shallow tropical coral reefs and the Amazon rainforest (NB, we consider the Amazon *rainforest* to be the tipping element, not the whole Amazon *basin*, as it shares a common tipping dynamic within same biome) are all the same biome/ecosystem functional group, whereas HTS integrates quite different biomes. Furthermore, the evidence presented for alternative states emerging are to me all evidence of ecosystem state change under continued pressure, but insufficient for full regime shifts to a new and self-sustaining alternative state. A degraded ecosystem can be quasi-stable under sustained pressure, but to prove it's in an alternative state / system attractor in a dynamical systems sense (the theoretical underpinning to tipping points), one would have to demonstrate that feedbacks exist that would maintain this new state even if the pressure relented, instead of allowing recovery to an original-like state (albeit with some adaptive differences between original and recovered state, as per Holling's ecological rather than engineering resilience). Invasive species are a candidate driver in this sense (e.g. cited in GTPR23 as playing a role in localised tipping in savannah/dryland ecosystems), though whether it could act as a driver at the integrated system level for the HTS rather than some specific habitats within it is harder to see.

1259-1261: Good to be thinking about the alternative state would be (bearing in mind need for additional dynamical evidence mentioned above) – would low diversity grasslands be expected across all topography though, given the spatial and climatic heterogeneity?

1264-1266: For HTS to be considered one integrated tipping element (in line with AM22/GTPR definitions, at least), I think the tipping dynamic for it either needs to be a process spanning and involving all of these sub-systems, or be the same tipping dynamic in each of them but with near-synchronous thresholds. As it stands it feels more like tipping is possible within each HTS ecological,

agricultural, and human sub-system without a clear common tipping dynamic or threshold across them all, with correlation in their degradation/tipping more likely to be due to sharing common drivers in warming and habitat loss/degradation rather than direct causation between them. This is to some extent true of coral tipping too, as tipping dynamics are localised to each reef rather than spanning the whole element, but the reason we grouped those as a tipping element anyway is that they share a common specific tipping dynamic (i.e. bleaching recurrence leading to mass mortality) with likely regionally-to-globally similar warming thresholds (i.e. ~1.5C) leading to near-synchronous tipping across the whole biome/functional group. Ideally then there'd be some discussion of whether there's a specific process that could feasibly span across the whole HTS system and precipitate tipping in its subsystems at approximately the same level of climate change, or highlight this as a gap to explore in future before HTS can be considered as a regional tipping element.

1276-1278: As above, are these drivers for tipping in each HTS sub-system, or for integrated HTS system as a whole?

1294: Are the Western Ghats part of HTS as defined? The west coast of India seems a bit far removed from Himalaya-to-Sundarbans. (Eastern Ghats would make more sense, but even they don't quite make it to edge of GBM drainage basin).

1321: Suggest changing "Earth System" to "climate", as the Earth system view is that climate, biological, and human dimensions are all aspects of the overall Earth system they are all a part of.

1351: AM22 not necessarily the best citation on this – we compiled more evidence & papers on boreal tipping dynamics in the GTPR23 biosphere chapter: https://global-tipping-points.org/section1/1-earth-system-tipping-points/1-3-tipping-points-in-the-biosphere/

1359, 1363 & Table 1: Permafrost "melting" should be permafrost thawing for accuracy.

1394: Cite Table 1 here as discussing results it summarises (could arguably have table here rather than up top too, but I can see arguments for placement at either place).

1398-1399: Sentence a bit fragmented here, and probably need to clarify for readers why AMOC can overcompensate in previous sentence but not compensating here.

1400: And for some elements, we're not fully sure of the relative importance of different drivers yet either.

1448: I like this uncertainty typology, makes discussion very clear.

Table 1 & Supp. Info.: SPG is misspelled as SGP in several places (e.g. SI line 18, 74; Table1 SPG row evidence strength column), so need to check through for that.

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