

Author Response to Anonymous Referee #2

Manuscript: egusphere-2025-6301

Revised title: Antarctic Sea-Ice Anomalies and Global Hazard-Event Records: An Exploratory Analysis, 2010–2024

Dear Anonymous Referee #2,

We sincerely thank you for your careful, critical, and detailed assessment of our manuscript. Your comments identified fundamental problems in the original submission, including unsupported global-event claims, the short observational record, inadequate treatment of common climate drivers, weak justification of the exponential model, conflation of regional evidence with global event records, and serious reference-list problems. We have therefore undertaken a substantial rewrite rather than a limited textual revision.

The revised manuscript has been reframed as an exploratory observational analysis of statistical co-variation. The title, abstract, introduction, methods, results, conceptual framework, discussion, and conclusions have all been rewritten. The revised line numbers cited below refer to the clean revised manuscript. Our point-by-point responses follow the summary of major revisions.

Major revisions

- **Causal interpretation removed.** The manuscript now consistently uses terms such as statistical association, co-variation, synchronization and conceptual pathway, and explicitly states that the results do not establish direct causal attribution.
- **Statistical analysis strengthened.** The exponential curve is retained only as a descriptive comparison. Linear fitting is now the primary model-form check, supplemented by Pearson correlation, Spearman rank correlation, detrended-residual correlation, leave-one-out sensitivity analysis and Benjamini–Hochberg false-discovery-rate adjustment.
- **Data object and scope clarified.** The China National Climate Center dataset is described as a record of major hazardous weather and climate events, not a complete objective census of all global extremes. Regional SIC maps are used only as contextual illustrations, whereas basin-wide annual mean SIE is the statistical predictor.
- **ENSO and SAM roles redefined.** ENSO is treated as a first-order quantified climate background. SAM is discussed only as a literature-supported potential co-modulating factor because it is not independently included in the quantitative tests.
- **Mechanistic discussion rebuilt.** The former causal mechanism narrative and unsupported numerical claims have been removed. The new framework separates plausible physical pathways, event-level statistical association and common modulation, and explicitly identifies the analyses needed for future attribution.
- **References re-audited.** The problematic, unverifiable, irrelevant or misapplied references identified by Reviewer 2 have been corrected or removed, and Antarctic-specific literature recommended by the reviewer has been added.

Point-by-Point Response to Anonymous Referee #2

R2.1 Global-event claims exceed the available evidence

Reviewer comment: *It is an extraordinary claim that the number of global, rather than regional or Southern Hemisphere, extremes might be modulated to a meaningful extent by Antarctic SIE, and the evidence presented is far insufficient.*

Response: We agree that the original global-modulation claim was not supported. The revised manuscript no longer claims that Antarctic SIE controls or meaningfully modulates the global occurrence of extreme events. The statistical outcomes are now defined as the recorded annual frequencies of major hazardous weather and climate events under a consistent reporting scheme, rather than an objective census of all global extremes. The Introduction states that regional mechanisms must not be extrapolated into global causal claims and describes the global relationship as an open question. The seven categories are retained for transparent comparison, but the interpretation is explicitly hierarchical: extreme heat and cold waves show the more robust statistical associations; floods, rainstorms and typhoon-storm events show intermediate exploratory associations requiring cautious interpretation, with the detrended relationships for floods and rainstorms weakening markedly; tornadoes and blizzards are weak or unstable and are not used as primary physical evidence.

Revised manuscript: Introduction, Lines 36–61; data limitations, Lines 86–107; Results, Lines 219–226 and 227–287; Discussion, Lines 383–436.

R2.2 Exponential model and short sample

Reviewer comment: *Section 3.2 uses correlations between global-extreme indices and SIE through an exponential regression model. There are only 14 years of data, and the justification for choosing an exponential relationship is weak.*

Response: We agree that the exponential model cannot serve as the sole foundation for interpretation. The revised manuscript states explicitly that the dataset contains 15 annual observations, from 2010 through 2024 inclusive. The exponential fit is now used only as a descriptive curve for comparison with a possible nonlinear form and does not imply an assumed exponential climate response. We added a linear fit for every event category and use the linear-fit P values as the primary multiple-testing set. We further added Pearson correlation, Spearman correlation, detrended-residual correlation, leave-one-out sensitivity and FDR correction. Results are interpreted only as statistical associations.

Revised manuscript: Methods, Lines 120–139; Results, Lines 193–226; Table 1A–B, Lines 205–218.

R2.3 Correlation is not causation; ENSO may affect both SIE and event indices

Reviewer comment: *Statements such as “the reduction in SIE is likely a significant driver” assume that SIE drives an impact and ENSO modulates it. A more plausible first-order argument is that ENSO modulates both SIE and many of the global extreme-event indices. The ENSO–sea-ice literature is insufficiently cited.*

Response: We agree and removed the driver language. ENSO is now treated as a first-order quantified climate background that may co-vary with both Antarctic sea ice and event-generating conditions. SAM is treated only as a literature-supported potential co-modulating factor because it was not independently included in the quantitative tests. The revised framework therefore does not place sea ice at the beginning of a one-way causal chain. We also added relevant ENSO–SAM–Antarctic sea-ice literature, including Wang et al. (2023), Liu and Zhu (2024) and Wang et al. (2025). Because the 15-year annual record does not permit comprehensive multivariable causal identification, we state this limitation directly rather than claiming that ENSO or SAM has been statistically controlled.

Revised manuscript: Introduction, Lines 62–71; Data sources, Lines 92–97; Section 3.3.1, Lines 289–323; Conclusions, Lines 453–477.

R2.4 Literature review, reference validity and mechanistic overstatement

Reviewer comment: *Several references do not appear to exist; other references are misrepresented or refer to the Arctic while the Antarctic is discussed. The mechanistic discussion assumes causation, makes unsupported statements as fact and is overly long. The statement that warming propagation “resulted” in a 37% increase in global extreme heat misrepresents the cited work.*

Response: We acknowledge the seriousness of this concern. We conducted a reference-by-reference audit of the items identified by the reviewer. Unverifiable, irrelevant, inappropriate or misapplied references were removed; incorrect entries were corrected; and Antarctic-specific studies were added. The unsupported quantified statements concerning albedo change, radiative absorption, local warming rate, baroclinicity, jet displacement, event duration and the alleged 37% causal increase were deleted. The former mechanistic narrative was replaced by a shorter conceptual-pathway discussion. Each event category is now discussed in conditional language, with explicit attention to regional controls, shared climate backgrounds and the analyses required for future testing.

Revised manuscript: Introduction, Lines 54–71; Section 3.3, Lines 288–436; reference list, Lines 498–572.

R2.5 Narrowing the scope and focusing on physically plausible linkages

Reviewer comment: *The manuscript should select indices for which strong physical arguments exist, focus on those linkages, and consider ENSO/SAM as possible drivers rather than merely modulators.*

Response: We narrowed the interpretive scope rather than deleting the systematically compiled event categories. Retaining all seven categories enables a transparent comparison and shows that the evidence is not uniform. Only extreme heat and cold waves are presented as relatively strong statistical associations. Floods, rainstorms and typhoon-storm events are classified as intermediate exploratory associations that require cautious interpretation; the detrended relationships for floods and rainstorms weaken markedly. Tornadoes and blizzards are labelled weak or unstable and are not used as primary support for the conceptual framework. ENSO is now treated as a shared first-order climate background, and SAM is not described as a regulatory variable quantitatively identified by this study.

Revised manuscript: Results, Lines 219–287; Section 3.3.1, Lines 289–323; synthesis, Lines 426–436.

R2.6 Lag expectation and identification of propagation

Reviewer comment: *If Antarctic SIE is claimed to have driven the extremes, would a lag be expected? Are there ways to identify the propagation of the warming effect?*

Response: The revised manuscript no longer claims that SIE drove the recorded events. We did not add a lagged-regression claim because the annual sample contains only 15 observations; applying one- or two-year lags would further reduce the effective sample and multiply the number of tests. Instead, we explicitly identify lagged-correlation diagnostics, wave-activity-flux analysis, reanalysis-based circulation diagnosis and numerical sensitivity experiments as necessary next steps for testing timing and propagation. This limitation is stated in the abstract, the conceptual framework, the extreme-heat discussion and the conclusions.

Revised manuscript: Abstract, Lines 21–24; framework, Lines 319–323; extreme-heat discussion, Lines 351–355; Conclusions, Lines 470–477.

Reference-list issues raised by Reviewer 2

R2.R1 Ayres et al.: incorrect DOI.

Response: Corrected. The revised reference is Ayres, Screen, Blockley and Bracegirdle (2022), Journal of Climate, 35, 4665–4685, DOI 10.1175/JCLI-D-21-0918.1. It is used to support the coupled atmosphere–ocean response to Antarctic sea-ice loss and its possible links with Southern Hemisphere circulation adjustment.

Revised manuscript: Introduction, Lines 28–30 and 54–61; References, Lines 499–500.

R2.R2 Crosta et al.: incorrect DOI.

Response: Removed. The associated claim concerning marginal-zone uncertainty was not essential to the revised analysis and has been deleted.

Revised manuscript: The former Crosta citation and related statement no longer appear.

R2.R3 Cvijanovic and Caldeira (2015): DOI points to another article and the named article appears not to exist.

Response: Removed in full. The revised manuscript does not use this reference or the direct-driver statement it was cited to support.

Revised manuscript: The former citation in Section 3.2 has been deleted; revised Section 3.2 begins at Lines 175–178 with exploratory wording.

R2.R4 Dou and Zhang: incorrect DOI.

Response: Removed. The ENSO–sea-ice discussion has been rewritten using verifiable Antarctic-specific literature.

Revised manuscript: Revised ENSO discussion, Lines 62–71 and 289–306.

R2.R5 He et al.: AGU abstract is not an appropriate reference.

Response: Removed. No conference abstract is used to support the revised mechanism discussion.

Revised manuscript: The former citation no longer appears.

R2.R6 Hrudya et al.: DOI points to another paper and the named paper appears not to exist.

Response: Removed in full.

Revised manuscript: The reference and all associated claims have been deleted.

R2.R7 Jeromsen et al.: irrelevant and not used in the text.

Response: Removed from the reference list.

Revised manuscript: The reference no longer appears.

R2.R8 Ji et al.: DOI is invalid and the paper appears not to exist.

Response: Removed. The sentence claiming that atmospheric propagation resulted in a 37% increase in global extreme-heat frequency has also been deleted.

Revised manuscript: Revised extreme-heat discussion, Lines 331–355.

R2.R9 Komatsu et al., “Antarctic sea ice loss amplifies polar boundary layer convection...”: appears not to exist.

Response: Removed in full. The revised oceanic pathway is supported only by references retained after the audit.

Revised manuscript: Revised cold-wave and Southern Ocean discussion, Lines 364–382.

R2.R10 Osborne et al.: irrelevant or unused.

Response: Removed. The exponential model is no longer justified by a general optimisation reference; it is explicitly described as a descriptive comparison rather than a mechanistic model.

Revised manuscript: Methods, Lines 125–139.

R2.R11 Rantanen et al., “Arctic amplification...”: DOI invalid or misapplied.

Response: Removed. The unsupported quantitative statements about a 15% reduction in baroclinicity and a specific jet-displacement amplitude have also been deleted.

Revised manuscript: Revised extreme-heat discussion, Lines 331–355.

R2.R12 Zhang et al., “SAM negative phase...”: DOI invalid and the paper appears not to exist.

Response: Removed. The revised manuscript cites verified, directly relevant studies for SAM, Antarctic sea ice and Southern Hemisphere circulation, including Wang et al. (2023), Eabry et al. (2024), Schroeter et al. (2023), and Zhang et al. (2024) where appropriate.

Revised manuscript: Introduction, Lines 62–71; Section 3.3, Lines 289–306 and 364–436; References, Lines 521–523, 552–553, 559–560 and 567–569.

Specific comments from Reviewer 2

R2.S1 Use of quotation marks for emphasis

Response: The three examples identified by the reviewer—“small perturbations trigger large responses”, “stable-then-declining”, and “decreasing SIE leads to increased frequency of extreme events”—have been removed or rewritten as normal prose. Quotation marks are no longer used as a general emphasis device.

Revised manuscript: Methods, Lines 120–139; Results, Lines 149–169 and 175–226.

R2.S2 Regional results are emphasized but not used in the correlation analysis

Response: We now state explicitly that SIC maps are illustrative regional background only, whereas annual mean basin-wide SIE is used in the statistical analysis. No regional SIC result is presented as direct evidence for global-event attribution.

Revised manuscript: Data sources, Lines 81–85; Results, Lines 159–169; Figure 2 caption, Lines 171–174; Conclusions, Lines 438–445.

R2.S3 Selective and Arctic-focused literature; missing Antarctic studies

Response: The Arctic or misapplied references have been removed. We added the two Antarctic studies recommended by the reviewer: Ayres et al. (2022) and Hay and Kushner (2024), together with additional Antarctic-specific literature. The revised Introduction distinguishes evidence for regional Southern Hemisphere responses from unsupported global causal generalization.

Revised manuscript: Introduction, Lines 47–61; References, Lines 499–500 and 529–530.

R2.S4 Original Lines 16–17 and 46–47: unclear whether SIC decreases are new results or literature statements

Response: The revised manuscript separates these functions. The abstract reports the study’s representative spatial result. The Introduction cites previous studies for regional Antarctic sea-ice variability. The Methods state that SIE is used for interannual correlation analysis and SIC only for representative spatial illustration.

Revised manuscript: Abstract, Lines 13–18; Introduction, Lines 31–42; Data sources, Lines 81–85.

R2.S5 Original Lines 55–63: conflation of regional links and globally distributed events

Response: The revised Introduction now separates established or plausible regional Southern Hemisphere responses from the unresolved question of global recorded-event frequency. It explicitly warns against extrapolating local mechanisms into global causal claims.

Revised manuscript: Introduction, Lines 36–61.

R2.S6 Original Lines 64–66: unsupported statement that existing research confirms a link with global extreme weather

Response: The statement has been removed. It is replaced by language stating that the global recorded-event relationship remains an open question and that current evidence mainly supports potential teleconnections or physical links to specific regional extremes.

Revised manuscript: Introduction, Lines 43–61.

R2.S7 Original Lines 70–72: Josey et al. (2024) does not support western tropical Pacific temperature and typhoon-frequency claims

Response: The unsupported typhoon claim and numerical percentage have been deleted. Josey et al. (2024) is now used only to support the anomalously low Antarctic sea ice in 2023 and the associated regional sea-ice background; it is no longer cited for western tropical Pacific SST or typhoon-generation frequency.

Revised manuscript: Introduction, Lines 36–40; Results, Lines 155–158; revised reference entry, Lines 533–534.

R2.S8 Original Line 86: unexplained “West Antarctic rainstorm”

Response: This phrase and the associated unsupported regional claim have been removed.

Revised manuscript: The revised aims at Lines 72–79 contain no such claim.

R2.S9 Original Line 92: unexplained negative correlation and unsupported claim about CMIP models

Response: The statement has been removed. The revised text no longer asserts that CMIP models reproduce a general negative correlation between Antarctic sea ice and global extremes.

Revised manuscript: Introduction and aims, Lines 43–79.

R2.S10 Original Line 120: ambiguous “This data”

Response: The data sources and statistical object are now named explicitly: NSIDC SIE/SIC, China National Climate Center monthly major-event records, and NOAA/NCEP NEPI and NCPI indices. A dedicated subsection explains event aggregation and reporting limitations.

Revised manuscript: Data sources and event compilation, Lines 81–107.

R2.S11 Original Line 125: percentages are SIE changes, not SIC changes

Response: Clarified. The equations now define SIEDN as the daily SIE anomaly percentage relative to the 1981–2010 daily SIE median, and SIEYN as the annual mean SIE anomaly percentage. SIC is separately described as a spatial illustrative field.

Revised manuscript: Data sources, Lines 81–85; equations and definitions, Lines 108–119; Table 1 note, Lines 208–218.

R2.S12 Original Line 323: ENSO–sea-ice literature should be cited

Response: Added and integrated. The revised manuscript cites Wang et al. (2023) for combined ENSO–SAM effects on seasonal Antarctic sea ice, Wang et al. (2025) for the 2021–2023 three-year La Niña background, and Liu and Zhu (2024) for a modelled Antarctic sea-ice–ENSO pathway.

Revised manuscript: Introduction, Lines 62–71; Section 3.3.1, Lines 289–306; References, Lines 538–539 and 559–563.

R2.S13 Mechanistic discussion comments were not exhaustive

Response: We treated this as a request for comprehensive reconstruction rather than isolated edits. Section 3.3 has been rewritten throughout. Unsupported quantitative statements and deterministic causal wording from the original manuscript have been removed, regional controls are specified for each event category, and the framework is explicitly presented as a conceptual interpretation.

Revised manuscript: Section 3.3, Lines 288–436; Figure 8 caption, Lines 357–363.

R2.S14 Original Line 526: unsupported claim of being the first to quantify the “El Niño + negative SAM” effect

Response: The novelty-priority claim has been deleted. The revised manuscript states that combined ENSO–SAM phases are already known to affect seasonal Antarctic sea ice and cites Wang et al. (2023). It also states repeatedly that SAM is not independently quantified in this study.

Revised manuscript: Introduction, Lines 62–71; Data sources, Lines 92–97; Section 3.3.1, Lines 298–306; Conclusions, Lines 453–460.

We thank you again for your detailed and critical assessment. Your comments led us to reframe the study, strengthen the statistical evaluation, rebuild the conceptual framework, and complete a reference-by-reference audit. We respectfully submit the revised manuscript for renewed consideration.

Sincerely, Shulin Tang and Yaozong Zhang