nature portfolio

# Research Briefing template

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The Briefing will not be peer-reviewed but, in consultation with you, it will be robustly edited for scientific clarity, language, consistency and house style to maximize its accessibility. You will receive an edited Word file for approval prior to production, in which you will see the comments from a referee and/or editor to be included in the Briefing.

**TITLE:** The title should be different to that of the research paper, highlight the key findings and be short and accessible [**90 characters max**]

**The elusive role of dynamics in mid-latitude winter precipitation under climate change**

**This is a summary of**: Gu, L. *et al*. Uncertain dynamic response of mid-latitude winter precipitation. *Nature* https://doi.org/10.1038/xxxx (2026)

**News & Views:** if your article is also covered in a News & Views we will link to it here https://doi.org/10.1038/xxxx

**STANDFIRST: brief summary**
Please add one to two sentences that succinctly summarize what has been achieved. **[50 words max]**

This study disentangles anthropogenic forced thermodynamic and dynamic contributions to mid-latitude winter precipitation trends from internal variability using climate model experiments and statistical learning. Thermodynamic effects are largely consistent between models and observations, but whether circulation changes are forced or unforced remains uncertain.

**SECTION 1: The question (please <u>leave title</u> most relevant to your work and delete the others)**
Please add four to five sentences giving some introduction and context to the work. What is the historical context? If you are answering a question or solving a problem, what is it and why is it of academic or societal importance? Keep in mind that you are trying to help academics in other disciplines appreciate the big picture significance of <u>why</u> you have undertaken this research project. **[120–150 words]**

Understanding changes in precipitation is critical for society and ecosystems[1]. The importance of human-induced climate change and unforced internal variability in determining mid-latitude winter precipitation trends is well established, yet discrepancies persist between observed and simulated trend patterns[2,3]. Some studies have attributed these discrepancies to unforced internal variability[4], whereas others point to deficiencies in current climate models that may underestimate the circulation response to anthropogenic forcing[5]. These contrasting interpretations highlight the need for new methodological approaches and a comprehensive assessment of mid-latitude winter precipitation trends. Understanding whether circulation-induced winter precipitation trends are forced or unforced is key for improved near-term future projections: If past circulation trends were partly forced, historical trends will likely continue; whereas if past circulation trends were unforced, a reversal of the circulation-induced trend components may have to be expected.

**SECTION 2: The discovery (please <u>leave title</u> most relevant to your work and delete the others)**
**Paragraph 1:** What form did your investigation take? What experiments/observations/analyses did you perform, and why were they suited to the goals of the work? Here you are trying to help the reader understand the rationale for the specific approach that you have adopted. **[100–150 words]**
**Paragraph 2:** What did you find? What immediate conclusions can you draw from these findings? **[100-150 words]**

This study disentangles anthropogenic forced thermodynamic and dynamic contributions to mid-latitude winter precipitation from internal variability. Two complementary approaches were used. First, a statistical learning framework trained on pre-industrial simulations from CMIP6 archive was used to estimate circulation-induced precipitation. The trained model was applied to reanalysis datasets (ERA5, JRA3Q, NCEP), CMIP6 output and the 100-member CESM2 large ensemble to infer thermodynamic and dynamic contributions in observations and models. The forced circulation response was estimated by averaging across ensemble members. Second, CESM2 experiments were conducted in which horizontal winds were nudged to isolate thermodynamic and dynamic effects. Atmospheric circulation was constrained either to (i) model-derived states from fully coupled CESM2 simulations with external forcing, and to (ii) observation-based states from ERA5. The two independent methods enable the separation of thermodynamic and dynamic contributions to precipitation in both observations and models, and facilitate comparison between statistical learning and physical climate model experiments.

Thermodynamic precipitation trends derived from climate models agree generally with those from reanalysis, suggesting that climate models capture the thermodynamic component of observed changes. By contrast, simulated dynamic trends barely encompass observation-based estimates in regions where circulation dominates precipitation trends, such as Southern Europe (SEU). This points to limitations in the representation of large-scale circulation patterns that caused precipitation changes. Further extracting the simulated forced dynamic components from the models' dynamic trends reveals that it is weak and uncertain across statistical learning and climate model experiments (Fig. 1). In SEU, although the forced dynamic trend accounts for only 10% of the full ERA5-based dynamic trend, climate models consistently simulate a circulation-induced drying pattern.

**SECTION 3: The implications (please leave title most relevant to your work and delete the others)**

**Paragraph 1:** Are there broader implications or applications of your findings? If so, what are they? **[ 50–100 words]**

**Paragraph 2:** What are the obvious limitations or caveats; what does this research <u>not</u> allow you to say? **[50-100 words]**

**Paragraph 3:** What are the obvious next questions/steps to take this further/ aspects of the research to strengthen? What do you hope or plan to do next? **[30–50 words]**

Winter precipitation trends over the Northern Hemisphere mid-latitudes have received increasing attention in recent years. For example, Vicente-Serrano et al.[4] reported winter precipitation in SEU dominated by variability in the North Atlantic Oscillation. However, the spread of simulated dynamic trends over SEU from climate models barely capture the observed trends. Climate models simulate a consistent forced dynamic contribution, albeit the circulation-induced drying in SEU is weak compared to the observed trend. Under future scenarios of increasing anthropogenic forcing, we find a continued circulation-induced drying trend in SEU, which closely resembles current observed trend patterns. This finding supports the interpretation that climate models may underestimate the magnitude of the forced dynamic contribution.

However, the observed dynamic trends reflect the combined effects of forced response and internal variability. As observations represent a single realization, the forced component cannot be directly isolated. We therefore cannot exclude the possibility that internal variability in observations coincidentally resembles the forced dynamic response. Despite this uncertainty, our results show that a reliable representation of large-scale circulation is key for robust regional precipitation projections.

Further research is planned to conduct nudged circulation experiments with high-resolution weather forecast models, such as ECMWF's Integrated Forecasting System (IFS), in order to better constrain the magnitude of the forced circulation response to anthropogenic forcing at the global scale.

**There is some flexibility with the word limit for each section; together sections 1, 2 and 3 should not exceed 650 words**

**SIGNING OFF**

Please 'sign off' the final paragraph (which will appear on the first page of the briefing) with the names of the researchers (**2 max**) that completed this template, in the following format:

**Lei Gu[1] & Sebastian Sippel[2]**
[1]University of Oxford, Oxford, United Kingdom
[2]Leipzig University, Leipzig, Germany

**Institution name, Town or City, Country.** Please include only one (current, at the time of publication) institution/affiliation per person.

**SECTION 4: Behind the paper**

This is an informal section that will be boxed-off on the second page of the briefing and signed with the initials of the researchers completing the template. Here, please provide some more personal insights into how the research was carried out. For instance, how did the research question come about? How difficult was it to get the research funded? Were there any serendipitous experiments that changed the direction of, or accelerated, the research? What did you consider to be the most important experiment in the research? Was there a certain moment in the project that was most exciting, thrilling, defining or encouraging? How did collaborations come about? What was the most difficult period of the research? Please 'sign off' the final paragraph with the initials of the researcher that wrote this (it must be one of the researchers listed above). **[150 words]**

My interest in precipitation began during my PhD research, when I became fascinated by the interplay between internal variability and external forcing, and the thermodynamic and dynamic drivers of precipitation changes under global warming. After publishing related work in *Nature Communications* in 2023 (<u>doi:10.1038/s41467-023-39039-7</u>), I was keen to explore these questions further. This opportunity arose when Sebastian Sippel and Reto Knutti launched a project – "Constraints on near-term warming projections via distributionally robust statistical and machine learning" (COPE). I was lucky to join the Climate Physics group at ETH Zurich, where I learned to combine statistical learning with physically based climate model simulations to disentangle thermodynamic and dynamic contributions to precipitation changes – and, more importantly, how to approach scientific questions with passion and persistence. After completing this project, I moved to Oxford to join Predictability of Weather and Climate group led by Timothy Palmer and Antje Weishiemer, where we are continuing this line of research using high-resolution weather forecast models from ECMWF. Exploring the Earth system and its circulation responses remains endlessly fascinating, and I look forward to continuing this journey – following these evolving patterns together with colleagues at ETH and Oxford.

## REFERENCES

A maximum of **5 references** can be cited. In addition to primary papers, please consider citing associated protocols, preprints and key reviews, to enable researchers to further their reading.

All references must be **numbered and cited sequentially** (using a superscript number) in the following order: main text, then figure legend. The numbered references should be listed at the end of the summary in the format: 1. Author, A. B. & Author, B. C. *Nat. Cell Biol*. **6**, 123–131 (2001).


[1] Sarojini, B. B., Stott, P. A. & Black, E. Detection and attribution of human influence on regional precipitation. *Nat. Clim. Change* **6**, 669–675 (2016).

[2] Simpson, I. R. et al. Confronting Earth System Model trends with observations. *Sci. Adv.* **11**, eadt8035 (2025).

[3] Shaw, T.A. *et al*. Emerging climate change signals in atmospheric circulation. *AGU Adv*. **5**, p.e2024AV001297. (2024).

[4] Vicente-Serrano, S. M. *et al.* High temporal variability not trend dominates Mediterranean precipitation. *Nature* **639**, 658–666 (2025).

[5] Blackport, R. & Fyfe, J. C. Climate models fail to capture strengthening wintertime North Atlantic jet and impacts on Europe. *Sci. Adv.* **8**, eabn3112 (2022).


## FIGURE

Please suggest one or two panels from the figures in your paper that best illustrate your findings. Please note that the Research Briefing figure can contain **no more than two panels from the main manuscript figures**: the panels must be the same as those in the main paper, and cannot be from the extended data or supplementary information. The Research Briefing figure will be sized to fit into about 115mm width x 85mm height; please keep this in mind when selecting your panels, as overly large, text-heavy or complex panels might not fit. The suggested figure should be sent as an editable ai file with the completed template.

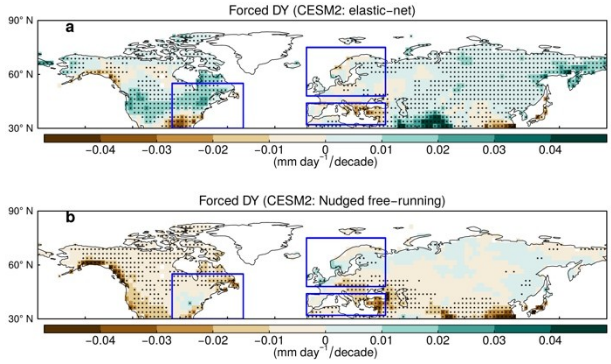


**FIGURE 1 Anthropogenic forced dynamic precipitation trends in winter (1950–2022). a,** Anthropogenic forced dynamic (DY) precipitation changes estimated using the statistical learning model on CESM2 large ensemble. **b**, As in **a**, but derived from CESM2 nudged experiments. Forced thermodynamic precipitation changes are first estimated from three paired nudging simulations; and the forced dynamic component is then obtained by subtracting the forced thermodynamic changes from the CESM2 large ensemble mean.

## EXPERT OPINION

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