

UCLA

UCLA Previously Published Works

Title

Compound weather and climate events in 2024

Permalink

<https://escholarship.org/uc/item/0v60t415>

Journal

Nature Reviews Earth & Environment, 6(4)

ISSN

2662-138X

Authors

Zscheischler, Jakob

Raymond, Colin

Chen, Yang

et al.

Publication Date

2025-04-01

DOI

10.1038/s43017-025-00657-y

Copyright Information

This work is made available under the terms of a Creative Commons Attribution-NonCommercial-ShareAlike License, available at

<https://creativecommons.org/licenses/by-nc-sa/4.0/>

Peer reviewed

Compound weather and climate events in 2024

Jakob Zscheischler^{1,2,†}, Colin Raymond³, Yang Chen⁴, Natacha LeGrix⁵, Renata Libonati^{6,7}, Cassandra D. W. Rogers⁸, Christopher J. White⁹ & Piotr Wolski¹⁰

¹ Department of Compound Environmental Risks, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

² Department of Hydro Sciences, TUD Dresden University of Technology, Dresden, Germany

³ Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles, Los Angeles, California, USA

⁴ Chinese Academy of Meteorological Sciences, Beijing, China

⁵ Earth, Ocean and Ecological Sciences Department, University of Liverpool, Liverpool, United Kingdom

⁶ Department of Meteorology, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

⁷ Instituto Dom Luiz, University of Lisbon, Lisboa, Portugal

⁸ Bureau of Meteorology, Melbourne, VIC, Australia

⁹ Department of Civil and Environmental Engineering, University of Strathclyde, Glasgow, UK

¹⁰ Climate System Analysis Group, University of Cape Town, Cape Town, South Africa

[†]e-mail: jakob.zscheischler@ufz.de

Standfirst | 2024 saw multiple high-impact compound events. Record-breaking global temperatures combined with regional weather variability to create compound floods, spatially compounding droughts and heatwaves, and hazard sequences with often devastating impacts.

Key points:

- 1) Spatially compounding droughts and fires hit southern Africa and South America, respectively, causing widespread impacts on ecosystems and human societies
- 2) Wet soils preconditioned landscapes in the US and Nepal, amplifying impacts caused by extreme rainfall events
- 3) Sequences of hazards, such as droughts or heatwaves followed by heavy rainfall, and the rapid succession of storms, led to large impacts in China, Australia and the UK

Compound weather and climate events refer to multiple drivers and hazards that combine to cause impacts on ecosystems and society¹. These drivers and hazards can combine in various ways—across time (preconditioned and temporally compounding events), across space (spatially compounding events), and/or across multiple climate variables (multivariate events) —giving rise to a myriad of possible events². Due to their complex nature, compound events are challenging to predict and often result in particularly severe impacts, as multiple adverse conditions interact and amplify each other. Climate change is already altering key variables such as temperature and precipitation, as well as the relationships between different climate factors. Systematic monitoring of when, where, and how these

events occur enhances our understanding of their dynamics and helps mitigate the risks associated with their impacts.

Here, we examine compound events that occurred in 2024 around the globe. Given the vast number of individual occurrences, we focus on a selection of particularly impactful episodes across the different compound event types .

[H1] Spatially compounding events

Spatially compounding events describe those in which multiple connected locations experience the same or different hazards in a short time period² . In the ocean, a particularly prominent spatially-compounding event was the widespread occurrence of marine heatwaves. 21% of ocean areas experienced record-breaking annual mean temperatures in 2024. These widespread marine heatwaves impacted coral reefs worldwide, with heat-stressed corals being bleached throughout the tropics, including in the western Tropical Atlantic, the eastern Tropical Pacific, Australia's Great Barrier Reef, large areas of the South Pacific, and parts of the Indian Ocean basin. Given the reefs' key role in sustaining entire ecosystems, this global bleaching event impacted economies, livelihoods, and food security.

Devastating spatially concurrent extremes also occurred over land, as epitomised by drought through much of Southern Africa . Driven by the 2023 El Niño and subsequent decreased moisture fluxes , Mozambique, Zimbabwe, southern and central Zambia, Botswana, south-eastern Angola, Namibia, southern Malawi and parts of South Africa all experienced widespread drought during their wet season in austral summer^{3,4}. Rainfall deficits were particularly severe from January to April 2024, with some regions receiving only 20-30% of their normal rainfall. Given that the region is home to approximately 135 million people, 60% of whom live in rural areas and are strongly dependent on rain-fed agriculture, this spatially extensive drought had considerable impact: crop failure and subsequent severe food shortages, limited access to clean water, disease outbreaks, and loss of livestock. However, as the event was forecasted well, some of the worst impacts could be mitigated, with pre-drought assistance reaching the most vulnerable 2 million people.

Other spatially-compounding events occurring in 2024 include: Concurrent widespread floods caused by Storm Boris in mid-September in central Europe (affected countries include Austria, Czech Republic, Poland, Romania, Slovakia, Germany, Hungary) which caused 27 fatalities and an estimated total damage of 4.2 billion Euros. Extensive river and wetland flooding across northern South Sudan contributed to internal displacement of more than 350,000 people and an accelerating cholera outbreak. (

[H1] Preconditioned and multivariate events

Preconditioned events are those whereby a hazard has an impact (or an amplified impact) owing to pre-existing conditions in the area². They can combine with multivariate events, which refer to those where multiple drivers or hazards combine to cause an impact . Such events were seen across South America in 2024: widespread record-breaking high temperatures co-occurred with extremely dry conditions,

with strong winds and available fuel subsequently supporting devastating fires in many regions . For instance, fast-moving fires in central and southern Chile in February were characterized as a 1 in 30-year event⁵, affecting 40,000 people, destroying 7000 homes and killing 130—the worst natural disaster in the country since the 2010 earthquake. In Bolivia, the country's most uncontrolled fire season ever recorded burned over 15 million hectares, releasing around 100 megatons of carbon and affecting more than 65,000 families, including traditional and Indigenous populations. In the Brazilian Pantanal, the largest wetlands in the world, exceptional wildfire conditions occurred in June rather than mid-September , burning 44 0,000 hectares (five times the historical average) in that month—an event expected to occur once every 35 years⁶ .

Notable preconditioning can also occur on the opposite end of the hydroclimatic spectrum. Indeed, several factors compounded to make September 2024's Hurricane Helene a >US\$100-billion disaster and the deadliest mainland-US tropical cyclone since 2005⁷ . In the days leading up to landfall, a stalled cold front plus orographic forcing drew tropical moisture northward, leading to heavy antecedent precipitation (100-250mm) and saturated soil moisture over the southern Appalachian Mountains. Hurricane Helene's passage over the region 24-36 hours later caused an additional 150-300 mm of rain to fall across inland portions of North Carolina, Virginia and Tennessee, a multi-day precipitation total whose estimated recurrence interval is more than 1,000 years. The sequence triggered record-breaking fluvial flooding along with landslides and debris flows. Extensive damage to the infrastructure network in narrow flood-stricken valleys complicated evacuation, response and recovery efforts, and entirely isolated some communities. Emphasizing the unexpectedness and accentuating the toll of this combination of hazards⁸, uptake of flood- and earth-movement insurance in the most affected inland areas was <1% of homes.

Other 2024 preconditioned and multivariate compound events include: Wet soils at the end of the monsoon season combined with extreme rainfall on September 26-28 and led to flash floods in Nepal that caused 244 fatalities and severely disrupted infrastructure. Cyclone Chido, which entered the Mozambique Channel on 14 December featured compound wind and precipitation extremes that caused at 172 fatalities in Mozambique, Mayotte and Malawi and destroyed thousands of homes.

[H1] Temporally compounding events

Temporal compounding considers hazardous events in a particular region that occur in quick sequence, exacerbating effects compared to a single event² . A rapid succession of storms is one such example , the impacts of which can be particularly severe⁹, as apparent in the UK during 2024. In January, for instance, there was a cluster of three storms: Storms Henk, Isha and Jocelyn. Storm Henk brought strong winds with gust up to 81mph and heavy rain on 2 January, which compounded an already wet period from late 2023, causing power outages for 38,000 properties, and severe road and rail transport disruptions from flooding. Storms Isha and Jocelyn (21–24 January) then arrived in quick succession, driven by a powerful jet stream, with Isha with gusts up to 99mph prompting extensive amber warnings and a rare overnight red warning for wind in Scotland. An additional storm cluster also occurred in late November and early December with Storms Bert, Conall and Darragh. Storm Bert (22–25 November) was the UK's first designated 'multi-hazard' storm, bringing strong winds, heavy rain and snow, with over 150mm of precipitation falling in the wettest upland areas resulting in localised flooding and

fatalities. Storm Darragh followed just two weeks later, worsening flood concerns, causing multiple deaths, and leaving 2.3 million customers without power.

Temporal compounding events also consider hazard sequences swinging from one extreme to the opposite, as with heavy rainfall to heavy drought--so-called whiplash events¹⁰. This sequencing was observed in major cropland regions between the Yellow-River and Huai-River in China during early summer 2024. In May-June, the region received less than 50% of their normal precipitation, with many meteorological stations observing record low levels since 1961. However, these drought-hit regions were suddenly inundated with 400-600 mm in during the 20 days of July (a doubling to quadrupling of the normal amount) when the major rainband moved northward and stayed nearly stationary. This drought-heavy rainfall combination overwhelmed the coping capabilities of farmers, with maize and rice yields amongst the most affected. Such whiplashes between dry and wet conditions are expected to intensify with climate change¹⁰.

Temporally compounding hazards can also consist of different hazard types. For example, increased atmospheric instability and moisture availability during some heatwaves can subsequently intensify extreme rainfall¹¹. This temporal sequence was observed in southeastern Australia toward the end of 2024, affecting the major cities of Sydney, Melbourne and Canberra which account for ~42% of Australia's population. The region witnessed heatwave conditions in November followed by an outbreak of severe storms with heavy rainfall and damaging wind gusts. The event was most severe over eastern New South Wales, where the heatwave persisted from 23-29 November, with extreme rainfall (>99th percentile) following on 30 November-1 December. The event also affected the state of Victoria, but with a shorter heatwave (21-24 November) and less severe rainfall (27 November). Property damage occurred due to flooding and strong winds.

Other temporally-compounding events include: Sequences of heavy rainfall during different stages of the growth cycle caused substantial drops in crop production in many parts of Europe. Successive rounds of thunderstorms led to flooding across the US Upper Midwest in June, including a partial dam failure when dead trees — killed by a preceding drought — clogged a spillway.

[H1] Summary

Compound weather and climate events were ubiquitous in 2024. They were driven in large part by extremely high temperatures at the global scale, high atmospheric moisture capacity (and related vapor-pressure deficit) and a decaying strong El Niño. 2024 was the hottest year on record and harbinger of a 1.5°C world¹². Compound events that feature extremely high temperatures as one of the drivers or hazards – like spatially concurrent heatwaves, compound hot-dry events and widespread wildfires – are more likely to occur under such conditions. Continuing climate change will lead to even more such events in the future, while a generally intensified hydrological cycle will also render co-occurrences and sequences with other hazards such as heavy precipitation and widespread droughts more likely. The diversity in scales, involved variables, and relevant interactions, as well as the devastating impacts caused by most events, highlights the urgent need to better understand, model and predict compound events in a changing climate.

References

1. Zscheischler, J. *et al.* Future climate risk from compound events. *Nat. Clim. Change* **8**, 469–477 (2018).
2. Zscheischler, J. *et al.* A typology of compound weather and climate events. *Nat. Rev. Earth Environ.* **1**, 333–347 (2020).
3. Kimutai, J. *et al.* El Niño key driver of drought in highly vulnerable Southern African countries. (2024) doi:10.25561/110770.
4. Manatsa, D., Mushore, T. & Lenouo, A. Improved predictability of droughts over southern Africa using the standardized precipitation evapotranspiration index and ENSO. *Theor. Appl. Climatol.* **127**, 259–274 (2017).
5. Kimutai, J. *et al.* Despite known coastal cooling trend, risk of deadly wildfires in central Chile increasing with changing land management in a warming climate. (2024) doi:https://doi.org/10.25561/109375.
6. Barnes, C. *et al.* Hot, dry and windy conditions that drove devastating Pantanal wildfires 40% more intense due to climate change. (2024) doi:https://doi.org/10.25561/113726.
7. Thiem, Haley & Lindsey, Rebecca. Hurricane Helene’s extreme rainfall and catastrophic inland flooding. (2024).
8. Heinrich, D., Stephens, E. & Coughlan de Perez, E. More than Magnitude: Towards a multidimensional understanding of unprecedented weather to better support disaster management. *Water Secur.* **23**, 100181 (2024).
9. de Ruiter, M. C. *et al.* Why We Can No Longer Ignore Consecutive Disasters. *Earths Future* **8**, e2019EF001425 (2020).
10. Swain, D. L. *et al.* Hydroclimate volatility on a warming Earth. *Nat. Rev. Earth Environ.* **6**, 35–50 (2025).

11. Sauter, C., Catto, J. L., Fowler, H. J., Westra, S. & White, C. J. Compounding Heatwave-Extreme Rainfall Events Driven by Fronts, High Moisture, and Atmospheric Instability. *J. Geophys. Res. Atmospheres* **128**, e2023JD038761 (2023).
12. Bevacqua, E., Schleussner, C.-F. & Zscheischler, J. A year above 1.5 °C signals that Earth is most probably within the 20-year period that will reach the Paris Agreement limit. *Nat. Clim. Change* 1–4 (2025) doi:10.1038/s41558-025-02246-9.

End matter

Acknowledgements

J.Z. acknowledges the Helmholtz Initiative and Networking Fund (Young Investigator Group COMPOUNDX, Grant Agreement VH-NG-1537) and the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003469 (XAIDA). Y.C. acknowledges the National Natural Science Foundation of China (42375041) and China Meteorological Administration (CMA) Youth Innovation Team (CMA2024QN06). C.J.W. was supported by the European Union's Horizon Europe through the 'Multi-hazard and risk informed system for enhanced local and regional disaster risk management (MEDiate)' project under grant agreement No 101074075. C.J.W. wishes to thank Emily Wallace and Helen Roberts, both UK Met Office, for their constructive discussions relating to the 2024 UK storm sequences. C.D.W.R. is supported by funding from the Australian Climate Service. R.L. acknowledges the Brazilian National Council for Scientific and Technological Development (Cnpq - grants 311487/2021-1 and 443285/2023-2) and Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ grant E-26/200.329/2023).

Competing interests

The authors declare no competing interests.

Publishers note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Figure

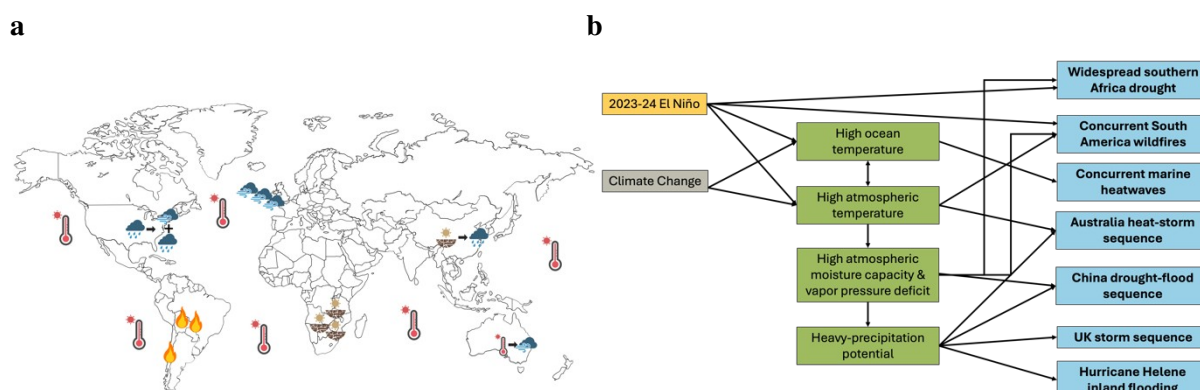


Figure 1. **Global-scale drivers combined with local weather variability to create compound events in the ocean and on all continents.** **a** | Examples of compound events in 2024 . **b**, The mechanisms through which the 2023-2024 El Niño and ongoing climate change caused various compound events in 2024. Green boxes indicate drivers, blue boxes indicate hazards . While there are some common drivers at the larger scale, how compound events play out at the local scale is highly context dependent, often overwhelming response capacities.

Instructions for panel a

Global oceans

Throughout 2024: Spatially concurrent marine heatwaves

Impacts: coral bleaching

Southern Africa

Jan-Apr 2024: Spatially concurrent droughts across multiple countries

Impacts: crop failure, loss of livestock, food shortage, disease outbreaks

Central Europe:

Sep 2024: Spatially concurrent floods

Impacts: 27 fatalities, 4.2 billion Euros economic damage

Chile

Feb 2024: extreme wildfires facilitated by dry, hot and windy conditions

Impacts: 130 fatalities, 40,000 people affected, 7000 homes destroyed

Bolivia

Jul-Oct 2024: extreme wildfires facilitated by dry, hot and windy conditions

Impacts: 15 Mio hectares burnt, 65,000 households affected

Brazil (Pantanal)

Jun 2024: extreme wildfires facilitated by dry, hot and windy conditions

Impacts: 440,000 hectares burnt

North Carolina, East Tennessee, southwestern Virginia, US

Sep 2024: Hurricane Helene drops extreme amounts of rain on preconditioned wet soil

Impacts: >200 fatalities, >US\$100 billion in economic damages

Nepal

Sep 2024: flash floods caused by extreme rainfall on preconditioned wet soil

Impacts: >200 fatalities, >1,200 houses destroyed, critical infrastructure damaged

Mozambique Channel

Dec 2024: Compound wind and precipitation extremes associated with Cyclone Chido

Impacts: >150 fatalities in Mozambique, Mayotte and Malawi, thousands of homes destroyed

UK

Jan 2024: Storm cluster Henk, Isha and Jocelyn

Nov-Dec 2024: Bert, Conall and Darragh

Impacts: fatalities, blackouts, severe road and rail transport disruptions

Croplands between Yellow-River and Huai-River

May-Jul 2024: extreme drought followed by heavy rainfall

Impacts: damaged crops#

South-east Australia

Nov-Dec 2024: heatwave followed by heavy rainfall

Impacts: damaged property

Upper Midwest US

Jun-Jul 2024: drought followed by heavy rainfall

Impacts: flooding, partial dam failure

South Sudan

Aug-Dec 2024: heavy rainfall, high Lake Victoria water levels

Impacts: >1M people affected, crop and livestock losses, food shortage, cholera outbreak