Statistical Science for a Better World

OCTOBER 2025

vISIon

The Magazine of
The International Statistical Institute

OFFICIAL STATS

Demography as evidence: how censuses, age structure and migration shape policy.

OPEN TOOLS

R workflows for climate evidence, with teaching resources and data.

CLIMATE ACTION

From wildfires to heat records: statistics that drive climate decisions.

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CO_2 evidence • Drought detection • Atmospheric patterns

Policies & Information

Conflicts of interest. Unless otherwise stated, authors declare no competing interests.

Submissions & enquiries. Pitches, letters and article proposals: manuele.leonelli@ie.edu.

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About *vISIon*

vISIon: The ISI Magazine is an initiative of the International Statistical Institute for accessible, rigorous writing on pressing societal issues through a data lens. Built on the society's values of professionalism, truthfulness, integrity and respect, the magazine bridges academia, national statistical offices and industry. Each issue centers on one UN Sustainable Development Goal and gathers perspectives from across ISI's seven associations. Our aim is clear, ethical communication that helps society make informed, evidence–based choices.

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President,
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Forward for the inaugural issue of vISIon

Welcome to the inaugural issue of "vISIon," the ISI Magazine!

For many years, the ISI Executives have envisioned a new communication platform for our members—a vibrant space where voices from across our society can converge to discuss important issues from statistical perspectives, share insights, and celebrate achievements. After extensive deliberations and careful planning, we are thrilled to introduce "vISIon," a magazine by the members and for the members of ISI.

The creation of "vISIon" reflects a long-overdue initiative brought to fruition under the supervision of Fabrizio Ruggeri, our incoming ISI President. I am especially pleased that we can proudly present this new publication at the 65th ISI World Statistics Congress.

We owe immense gratitude to Manuele Leonelli for stepping into the pivotal role of inaugural Editor-in-Chief. With his expertise and dedication, we have made an excellent beginning with this first issue. We are confident this magazine will continue to evolve, enriched by ongoing feedback and contributions from many of you.

Join us as we embark on this new journey. Together, we will craft a brighter vISIon for the ISI.

> *"Together, we will craft a brighter vISIon for the ISI."*

Fabrizio Ruggeri
President-Elect,
International
Statistical Institute

How we got here

Launching *vISIon*: A brief origin story

We did it! You are finally reading the first issue of vISIon: the ISI Magazine. We call it "Issue Zero" because we would like to hear ISI members' opinions on what they expect from an ISI magazine and what ISI, and especially the Editorial Board, can do to improve it and better adapt it to our community.

vISIon is the result of a long process that began many years ago with numerous documents that greatly informed our decisions. The current ISI Executive Committee shared the vision of a journal that would present scientifically sound articles, but written in a way that an educated person, not necessarily a professional statistician, could read and appreciate. We envisioned a journal that could serve as a bridge between the different statistical communities under the ISI umbrella. Topics like climate change and the impact of artificial intelligence can be approached from many angles, from official and survey statistics to environmental statistics, from the effects on business and industry to those on education, with new stochastic models and computational methods. We wanted a journal that could give voice to statisticians from all fields and around the world, in line with the spirit of the ISI. I had the privilege of leading a task force that worked to define the new ISI publication: I am very grateful to all the members for their contributions!

The current format is the result of a long process, during which several options were evaluated. The most ambitious project was to combine an app with shorter news items, linked to a website with in-depth articles, and a PDF file containing those

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articles for those who prefer this format. Unfortunately, this project was currently too expensive for the ISI, but the idea is there, and we don't know what the future holds. Ultimately, we opted for a more traditional PDF file, with the option of a website as well.

In our search for an Editor-in-Chief, we were very fortunate to find Manuele Leonelli, who accepted our invitation and immediately began working on the new magazine. We had many discussions about the magazine's character, as described above, and its sections. We agreed to involve all our associations in the Editorial Board, and Manuele did an excellent job recruiting many members, especially young people. Manuele worked as well on the magazine's format, also counting on the support of Shelley Nathoenie, Marketing and Communications Manager at the ISI Permanent Office.

A final word on the name: it was suggested by a member of the Editorial Board, and the ISI Executive Committee approved it immediately: the name says it all!

Buon viaggio (Good journey) to vISIon, Manuele and his team, and all of us!

> *"We would like to hear ISI members' opinions on what they expect from an ISI magazine."*

Manuele Leonelli
Editor-in-Chief, vISIon: The ISI Magazine

Why this magazine, why now

A statistician's take on the world's pressing challenges

We live in uncertain times, and the role of academics and scientific institutions is questioned more often, and more loudly, than before. That is exactly when we must engage more, not less. Science can sometimes feel remote or elitist; statistics is different: it is the science of learning from data to understand the world around us. Because data touch everyday life, from health and climate to education, jobs and justice, statisticians have a privileged bridge to society: we can explain assumptions, quantify uncertainty, and make trade-offs visible in plain language.

vISIon: The ISI Magazine is born with that aim. We want a platform that connects academia, national statistical offices and other public-sector producers of statistics, research institutes, NGOs and industry to offer a broad, inclusive view on pressing issues. Each issue will revolve around a single UN sustainable development goal and invite contributions from across the ISI family: methods and applications, successes and lessons learned, debates and design choices. The International Statistical Institute is uniquely placed for this work: as the international statistical society with strong ties across these communities, it is a natural home for a project that sits at the intersection of science, practice and public interest.

I am excited, humbled and proud to share this journey with an editorial board of like-minded colleagues from around the world: bringing different regions, sectors and viewpoints to the table. This truly is a blank slate: we can shape formats, tone and topics together (essays, interviews, visual explainers, short primers, even field notes). If you want to contribute, critique or suggest a direction we should cover, please reach out. The magazine will be as strong as the community that builds it.

> *"vISIon is a blank slate: Let's build it together."*

Beyond the smoke

What statistics reveal about Brazilian wildfires

Abstract. Wildfires are increasingly shaping environmental, social, and political agendas around the world. Brazil, home to six major biomes and one of the most biodiverse countries on the planet, has witnessed a worrying increase in fire activity in the last decade. Using satellite-based detections of more than 3 million fire spots recorded between 2010 and 2024, we explore temporal and geographical trends of wildfires across the Brazilian territory. Our descriptive analysis highlights strong seasonality, regional contrasts between biomes, and alarming surges in 2019–2020, particularly in the Pantanal and Amazônia. These events affect not only ecosystems and biodiversity, but also human health, livelihoods, and climate stability. We emphasize the urgent need for sustained monitoring and informed policies that connect local realities to global climate action.

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Paulo Canas Rodrigues
Professor of Statistics and Data Science at UFBA and Director of SaLLy. His work spans data science, AI, and time series forecasting. He serves as President of ISBIS, President-Elect of IASC, and Council Member of ISI, with teaching and collaborations across five continents.

> *"In a world where climate action is urgent, numbers are not just measures of destruction; they are guides for building resilience and protecting our shared future."*

In recent years, wildfires have dominated headlines across the globe: from California to Australia, from Siberia to the Mediterranean. These events are not isolated phenomena; they are symptoms of a planet under change and stress (Kumar et al., 2025; Zhu et al., 2024; Clement et al., 2024). Rising temperatures, prolonged droughts, and changes in land use are making fire seasons longer and more intense, and extreme events more regular. The consequences are immense: loss of biodiversity, destruction of property, health crises due to smoke, and massive releases of carbon into the atmosphere.

Brazil is one of the centers of this global challenge. With 15–20% of the world's known species and six ecologically distinct biomes, it plays a decisive role in regulating climate and preserving biodiversity. But Brazil is also one of the countries most affected by wildfires (Sobreira et al., 2025; de Souza Tadano et al., 2024). To understand its dynamics is to study a problem that is both local and global, and directly tied to United Nations Sustainable Development Goal 13: Climate Action.

Brazil's biomes under fire

Brazil is often called a "megadiverse" country, with its six biomes: Amazônia, Cerrado, Pantanal, Mata Atlântica, Caatinga, and Pampas. They can be briefly described as follows[1]:

- Amazônia: includes about 60% of the largest rainforest in the world, with extensive mineral reserves and 20% of the world's water availability;
- Caatinga: is in a semi-arid

[1]See also https://educa.ibge.gov.br/jovens/conheca-o-brasil/territorio/18307-biomas-brasileiros.html

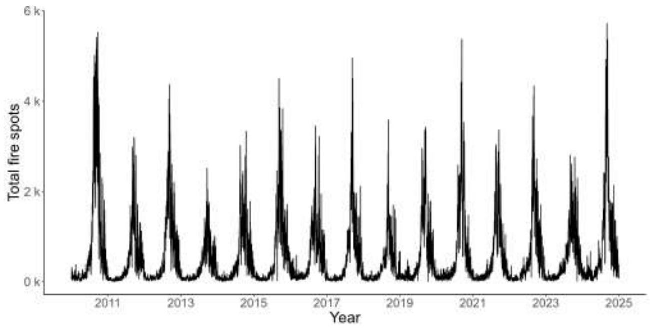

Figure 1. Daily total number of fire spots in Brazil, from the 1st of January, 2010, to the 31st of December, 2024.

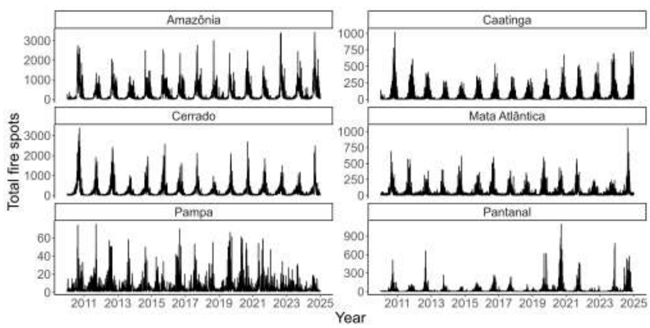

Figure 2. Daily total number of fire spots in each of the Brazilian biomes, from the 1st of January, 2010, to the 31st of December, 2024.

climate, with great biological richness and unique species;

- Cerrado: is recognized as the richest savanna in the world in terms of biodiversity, having remained unchanged until the 1950s when the federal capital was transferred to Brasília;
- Mata Atlântica: is located on the Brazilian coast, thus being the most threatened biome in the country, where only 27% of the original forest cover is still preserved;
- Pampas: is characterized by a rainy climate without a dry period and negative temperatures during the winter;
- Pantanal: is recognized as the planet's most extensive continuous floodplain.

Fires in these regions are not only ecological disasters. They disrupt the lives of millions who depend on the land for food, water, and cultural identity.

> *"Numbers alone cannot capture the full consequences. Behind each fire spot lies a story of ecological and human disruption"*

Data sources and organization

The data used in this study were obtained from the Brazilian National Institute for Space Research (INPE; Instituto Nacional de Pesquisas Espaciais; http://queimadas.dgi.inpe.br). We extracted the records in yearly batches, resulting in 15 separate files, where each row corresponds to a single fire spot.

According to the Instituto Nacional de Pesquisas Espaciais (2024), fire spots detected by satellites such as AQUA are identified on scales as small as 30 meters by 1 meter. However, because the MODIS sensors onboard AQUA and TERRA have a pixel size of approximately 1 km^2, even small burns appear to cover an entire square kilometer. In practice, a single "burning pixel" can therefore represent anything from a small to a large fire.

These observations come from satellite images collected by the AQUA M-T reference satellite, which detected more than three million fire spots over the 15-year period considered. To prepare the data for analysis, we organized and aggregated the records by date and municipality, ensuring that each fire spot was assigned to a specific day and location (Pimentel et al., 2024).

Temporal and Spatial Trends

Seasonal patterns: Figure 1 shows the daily number of fire spots in Brazil. A strong seasonal cycle is evident with peaks between August and October, coinciding with the dry season in much of the country. Outside these months, fire counts drop sharply, though sporadic events still occur.

Biomes in contrast: Breaking down the data by biome in Figure 2, we see that patterns differ across biomes. The Amazônia shows persistent fire activity year after year. The Cerrado maintains high levels of burning, reflecting agricultural pressures. The Pantanal, by contrast, is more variable, yet its 2020 spike was catastrophic, followed by a higher number of fire spots in 2024, burning large parts of the biome.

Comparing biomes fairly: Brazil's biomes differ vastly in size. Figure 3, which normalizes fire incidence per 1,000 km^2, reveals that smaller biomes such as the Pantanal and Cerrado are disproportionately affected. This emphasizes that fire risk is not just about totals, but about ecological intensity.

Who drives the totals? Figure 4 shows annual totals split by biome. Here, the Amazônia dominates, not surprisingly given its scale. But the peaks in the Pantanal and Cerrado are significant, showing that crisis points can emerge outside the rainforest.

Geographic fire spots: Figures 5 and 6 map the monthly and annual fire activity. They highlight recur-

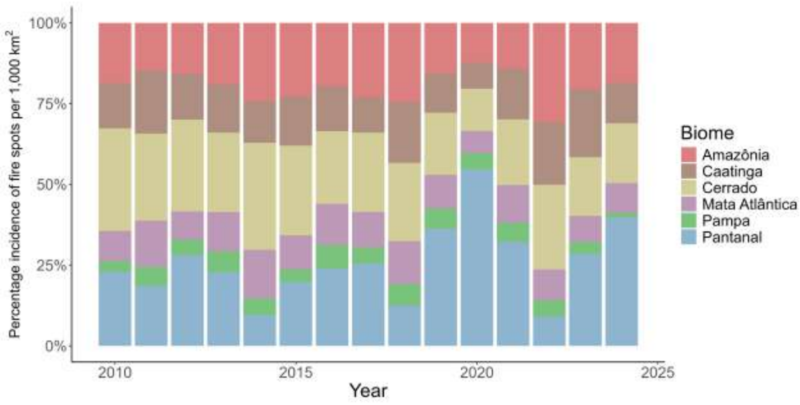

Figure 3. Percentage incidence of fire spots per thousand km^2 by biome between 2010 and 2024.

ring clusters in Pará, Mato Grosso, Acre, and Rondônia, as well as the widespread expansion of fires into the Pantanal during 2019 and 2024. These spatial patterns make it clear that fire in Brazil is not confined to remote forest, it affects many regions, often close to populated areas.

Impacts on people and the environment

Numbers alone cannot capture the full consequences. Behind each fire spot lies a story of ecological and human disruption:

- Environment: wildfires destroy habitats, threaten species, and degrade soil and water systems. They release vast amounts of greenhouse gases, accelerating climate change;
- Society: smoke travels hundreds of kilometers, as seen in 2020 when fires in the Pantanal darkened skies in São Paulo, Rio de Janeiro, and Curitiba (Libonati et al., 2020). Health systems face surges in respiratory problems. Indigenous and riverine communities see their territories, food sources, and cultural heritage threatened;
- Economy: agriculture, livestock, and tourism suffer losses, with costs running into billions.

Challenges and the road ahead

The drivers of wildfires in Brazil are complex. Climate variables, especially temperature and humidity, play a decisive role. Human factors such as deforestation, farming expansion, and land-use practices amplify the risks (Pimentel et al., 2024).

Addressing the problem requires more than firefighting. It demands: (i) effective land-use policies; (ii) long-term monitoring and early warning systems; and (iii) international cooperation, since the impacts extend far beyond national borders.

For statisticians and data scientists, the challenge is to transform large datasets into insights that inform decisions. Initiatives such as INPE's satellite monitoring and MapBiomas (MapBiomas, 2023)' land-use mapping are invaluable, but their true power lies in analysis, interpretation, and communication, turning data into information, and information into action.

> *"Wildfires are not isolated phenomena; they are symptoms of a planet under change and stress"*

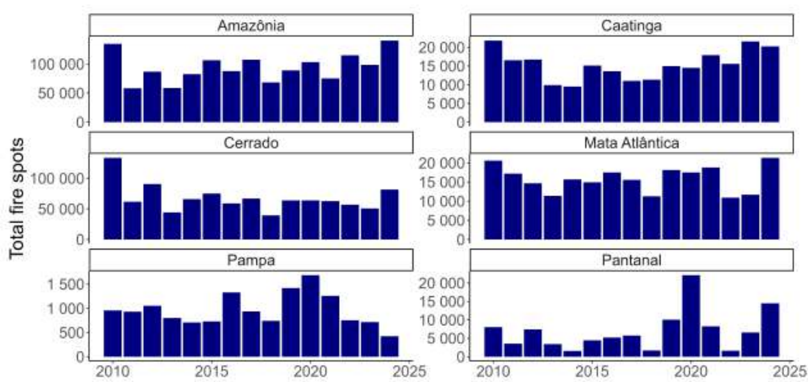

Figure 4. Total number of fire spots per year and per biome in Brazil between 2010 and 2024.

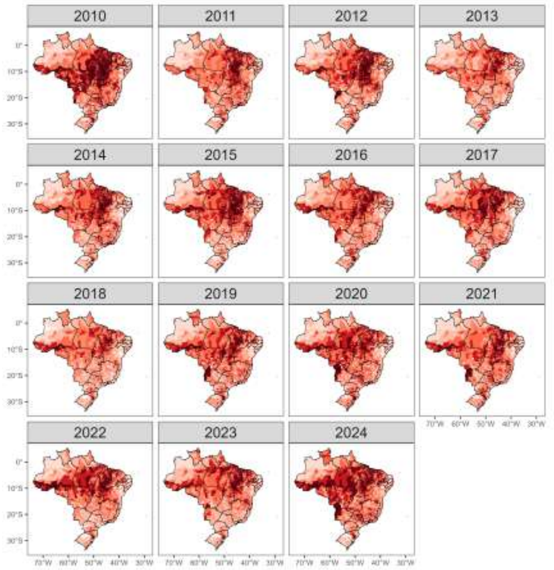

Figure 5. Heat map with the total number of fire spots per year for each of the 5,570 Brazilian municipalities between 2010 and 2024. The lines represent state borders.

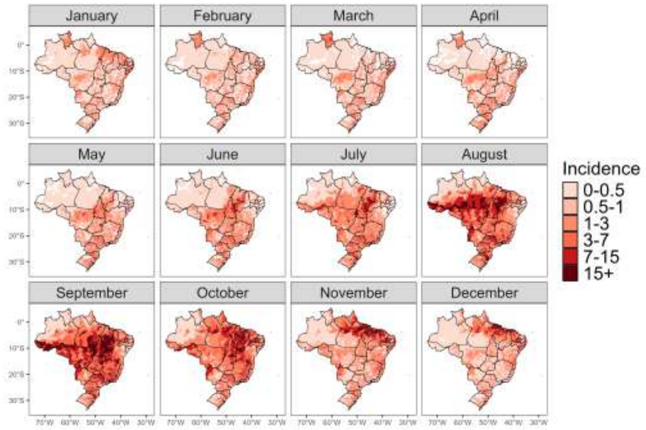

Figure 6. Heat map with the monthly average number of fire spots for each of the 5,570 Brazilian municipalities between 2010 and 2024. The lines represent state borders.

Conclusion

Wildfires in Brazil are more than environmental phenomena; they are crises that affect ecosystems, communities, and the global climate. The descriptive evidence from more than a decade of fire data reveals clear patterns of seasonality, regional vulnerability, and ecological intensity.

By looking beyond the smoke, statistics help us see both the scale of the challenge and the possibilities for change. In a world where climate action is urgent, numbers are not just measures of destruction; they are guides for building resilience and protecting our shared future.

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From metrics to meaning

Environmetrics and Sustainable Development Goals (SDGs)

Abstract. We are facing a complex and unpredictable interplay of global changes set to transform humanity and its potential in arguably an irreversible way. SDG progress is polarized, with significant disparities between the trajectories of SDG progress (metrics) and key development areas for capacity-building to effectively prepare, respond, and adapt to anticipated global change (meaning). Environmetrics is an 'n-science' that spans disciplines, institutions, and societies, and is uniquely positioned to address disparities in the SDGs. Achieving the SDGs requires practical, understandable, and trustworthy solutions, having greater flexibility, considering both AI and non-AI approaches. TIES is planning to join together with other ISI Associations in an international conference to encourage and support the exploration of new scientific avenues in AI/data science. To address the needs of early-career and youth with new knowledge and skill sets, TIES is running a mentorship and webinar program, among other communication, publication, and outreach activities. To address gaps in SDG progress, the future work of TIES needs to more effectively address regional needs and contexts. This will involve finding effective ways to transfer environmetrics knowledge, capacity, technology, and evidence-based support for policy decision-making to directly help marginalized individuals, groups, and organizations within least-developed communities.

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Humanity is at a critical juncture. We are facing a complex and unpredictable interplay of global changes set to transform humanity and its potential in arguably an irreversible way. These global risks include rapidly evolving technological advancements (e.g., big data, artificial intelligence (AI), quantum computers, and compromised encryption), alongside accelerating climate change, biodiversity decline, population increase, and resource scarcity (e.g., food and water). With the Earth under such stress, the choices we make today will not only impact future generations but may ultimately affect humanity's entire future.

Concerning climate change - under the 2015 Paris Agreement on Climate Change, 196 countries committed to limiting global warming to well below 2°C (i.e., below 1.5°C) compared to preindustrial times (1850-1900). To reach 1.5°C, the world must cut emissions to 45% below 2010 levels by 2030, and reach net-zero by 2050. This year (2025), the World Meteorological Organization (WMO) has forecasted that the annually averaged global mean near-surface temperature for years between 2025 and 2029 will range between 1.2-1.9°C higher than the average over preindustrial times (World Meteorological Organization, 2025). It is not too late to slow down future warming and prevent the worst consequences by rapidly reducing greenhouse gas emissions and implementing net-zero carbon emission by mid-century. While some effects are locked in, actions taken now will determine the severity of future impact. The United Nations (UN) Sustainability Development Goal (SDG) Goal 13 on Climate Action calls for urgent action to combat climate change and its impacts, building resilience and transitioning towards a low-carbon future[1]. This targets strengthening resilience and adaptive capacity to climate-related hazards and natural disasters through greater awareness, foresight, and early-warning. This will require integrating climate change measures into national policies, strategies, and planning, considering the needs of least developed countries, small island developing States (SIDS), women, youth, and local and marginalized communities. Keys to achieving this goal are education and ensuring human and institutional capacity (i.e., skills, knowledge, and abilities of individuals that enable them to contribute effectively to society) for timely action on climate change mitigation and adaptation.

Recent statistical modeling and analysis of global SDG progress (including Goal 13) reveals a strongly polarized global landscape or 'bipolar world', with nations specializing in specific development indicators based on their relative strengths and weaknesses (Ma et al., 2025)[2]. This involved an integrated concept of the 'SDG space of nations' as a relatedness network, for determining the relative performance and specialization patterns of 166 countries across 96 SDG indicators from 2000 to 2022. According to the Sustainability Directory, a dedicated resource within the Sustainability ecosystem, powered by advanced Large Language Model (LLM) technology, "Statistics indicate global progress on the SDGs is mixed, showing gains in some areas like poverty reduction but falling behind on many environmental and inequality targets" (Sustainability Directory, 2025). These congruent findings highlight significant disparities between trajectories of SDG progress (metrics) and key development areas (meaning). For readers interested in SDG progress in relation to their specific targets and indicators, see Our World in Data team (2023).

Environmetrics - solving complex problems

Environmetrics - as a scientific discipline that focuses on the development and application of quantitative and statistical methods to understand and solve environmental problems - is uniquely positioned to address disparities in the SDGs (El-shaarawi and Hunter, 2006)[3]. Environmetrics "goes beyond measurement and mathematics...as a unique 'n-science', a meeting ground for the ecologist, the natural and social scientist, the engineer and statistician, and ultimately the political scientist" (Hunter, 1994). The environmetrics community spans institutions (educational, local, and policy decision-making), bridges diverse scientific disciplines (including quantitative and more applied), and has an international footprint for capacity-building. A core aspect of environmetrics is strong collaboration, especially among statisticians and other scientists dealing with environmental issues (Dean et al., 2022).

> *"It is not too late to slow down future warming and prevent the worst consequences by rapidly reducing greenhouse gas emissions and implementing net-zero carbon emission by mid-century. While some effects are locked in, actions taken now will determine the severity of future impact."*

TIES - history and mission

The growth of environmetrics since the 1980's has been underpinned by The International Environmetrics Society (TIES) - first launched in Canada, and continuing since 2008, as one of seven association members of the International Statistical Institute (ISI) with membership across 150 countries[4] (Dean et al., 2022). TIES continues to foster communication, education, and capacity-building in environmetrics, with interdisciplinarity and international collaboration by design. It emphasizes effective communication and learning across disciplines and collaboration across different stages of the knowledge-action continuum, including researchers, practitioners, and decision-makers. Areas of concentration include both methodological and applied aspects, addressing climate extremes, air pollution, design of experiments, marine population dynamics and management, forest management and wildfire modeling, remote sensing, agroecosystem dynamics, animal movement modeling and invasive species, Bayesian modeling for detecting changes in ecological systems, and many more areas aligned with the SDGs. The association currently (2025) includes 211 active members from North America, Europe, Oceania, South America, Asia, and Africa, with opportunities for broader membership to join and participate individually, join a team or committee, or both. TIES organizes and facilitates both international and regional interdisciplinary conferences alongside focused research working groups to promote open scientific exchange and help train the next generation of researchers. TIES has had a longstanding, successful collaboration

[1] SDG Goal 13 on Climate Action: https://www.un.org/sustainabledevelopment/climate-change

[2] SDG Space: http://www.spacelab.team/#/SDGSpace

[3] https://www.statisticsviews.com/article/environmetrics-is-still-in-the-formation-stage-an-interview-with-walter-w-piegorsch-and-abdel-el-shaarawi/

[4] ISI Associations: https://isi-web.org/our-associations-and-committees

with the Italian environmetricians group named GRASPA (Gruppo di Ricerca per le Applicazioni della Statistica ai Problemi Ambientali) that is now a Section of the Italian Statistical Society (SIS) for Environmental Statistics, sustainability and territorial safety[5].

TIES members compiled an Environmetrics encyclopedia (see El-Shaarawi and Piegorsch, 2002) and actively publish in the dedicated Environmetrics journal (Wiley), as well as other topic-related journals. The TIES Board includes an officer for Europe, North America, and the Globe, a secretary, an officer of publications, an officer of communications, a president, a president-elect, and ex officio member from the ISI. Also, numerous activity committees oversee membership, the website, outreach and liaison, mentorship, webinars[6], and awards that include the prestigious Abdel El-Shaarawi Early Investigator's Award, TIES-Wiley Best Student Presentation and Best Paper Award (Environmetrics Journal). Scientific committees for conference organization and special lectures are also examples of activities where members can communicate and collaborate. TIES is dedicated to confronting society's most pressing environmental challenges and coordinating broader cooperative solutions and actions, rather than a nation-centric or more fragmented, orphaned approach.

"Achieving the SDGs requires practical, understandable, and trustworthy solutions. In the future, solutions may look different, being more hybrid and integrated, with greater in-built flexibility."

Recent developments

In 2023, a two-part special issue was published in the official journal of TIES (Environmetrics, Wiley), comprising a set of research articles and opinion pieces led by environmetricians who are at the forefront of the interface of statistics, AI, computer science, and environmental science. Guest editors for this special issue were TIES members, Andrew Zammit-Mangion, Wesley S. Burr, and Nathaniel K. Newlands. The issue includes works by a new generation of TIES researchers, practitioners, and decision-makers collaborating in tackling complex environmental problems and showcases the interdisciplinarity of environmetrics[7,8]

TIES also launched, in 2023, a mentoring program for early-career researchers in environmental statistics and data science, offering both academic/non-academic guidance on career development and advancement. This builds and strengthens relationships for learning and improving skills, including the design of experiments, statistical modeling and inference, data analysis, and interpretation. Mentees can also receive advice on potential directions for new research projects, literature sources, networking, professional training, and more general career guidance. Unlike research supervision, mentors provide general research or career guidance in two to four meetings annually.

This year, to strengthen and promote research on environmental issues and climate change in Latin America and the world, TIES is jointly organizing an International Conference (LACSC-TIES-EnviBayes-EnvrASA) on Statistics, Data Science, and Computing for the Environment and Climate Change in Mexico City (in the third quarter of 2026) with the Latin American Regional Section of the International Association for Statistical Computing (IASC-LARS ISI), Mexican Association of Statistics Asociación Mexicana de Estadística (AME), International Environmetrics Society (TIES ISI), Section on Environmental Sciences of the International Society for Bayesian Analysis (EnviBayes ISBA), and Section on Statistics and the Environment of the American Statistical Association (ENVR ASA). The effort to broaden TIES collaboration with other ISI Associations is a new direction for expanding collaboration and relationships to address crucial SDG gaps, and to expand interdisciplinary knowledge exchange. As raised by Esterby (2018), who has explored the character, contributors, and evolution of past TIES conferences, "It remains to be seen if TIES conferences continue into the future...where being small has helped to preserve some of the character of the conferences, or perhaps, other modes of communication will transform the conferences but retain the feature of providing a home for environmetricians.". The challenge ahead is clear: to preserve the character and effectiveness of past TIES conferences, while expanding networking and collaboration, membership, and opportunities for members, particularly in AI/data science.

Challenges and future directions

In Europe, environmental statistics faces the dual challenge of responding to highly diverse regional contexts while ensuring harmonized analyses across often fragmented national data systems. Within this complex landscape, TIES plays a vital role by fostering scientific collab-

[5] https://graspa.org/
[6] TIES Webinars: https://www.environmetrics.xyz/
[7] Part 1: https://doi.org/10.1002/env.2787
[8] Part 2: https://doi.org/10.1002/env.2788

oration and methodological innovation, contributing to the development of robust statistical tools that support environmental monitoring and policy-making at the European level. Looking ahead, there are significant opportunities for TIES to enhance its impact by consolidating interdisciplinary networks, promoting open data initiatives, and training a new generation of statisticians equipped to address emerging challenges, such as climate adaptation, biodiversity loss, and sustainable resource management.

From a broad disciplinary standpoint, environmetrics is far from immune to the ongoing advances in AI; indeed, its exposure may be greater than that of many adjacent scientific domains. The remarkable success of deep neural networks in operational weather forecasting has rekindled a longstanding debate: What is the comparative merit of physically based models - those founded on the conservation of mass, momentum, and energy—versus empirical, data-driven formulations such as Gaussian processes? Recent developments in physics-informed neural networks provide a compelling answer. These hybrid frameworks demonstrate that physical principles and statistical learning need not be viewed as competing paradigms. Rather, they can be integrated to yield models that are simultaneously predictive, computationally efficient, and scientifically interpretable. This synthesis not only enhances forecast accuracy but also deepens our understanding of the underlying environmental processes.

The implications of AI extend well beyond modeling. The emergence of large language models (LLMs), for instance, signals a transformation in how environmetrics research may be communicated to decision-makers and the public. Such tools have the potential to translate complex probabilistic assessments of risk and articulate the inherent variability of climate systems in language accessible to non-specialists, thereby supporting more informed policy formulation and societal engagement. Camps-Valls et al. (2025) discuss the hurdles of dealing with limited data, integrating real-time information, and deploying understandable models, all crucial steps for gaining stakeholder trust and meeting regulatory needs.

Achieving the SDGs requires practical, understandable, and trustworthy solutions. In the future, solutions may look different, being more hybrid and integrated, with greater in-built flexibility. Such flexibility could enable linking research findings into operational products that track and communicate uncertainty more effectively. Communicating risk and uncertainty to the public needs greater attention to combat misinformation related to environmental issues and challenges. This is also necessary to retain and expand the relevance of environmetrics for the public good and to achieve the SDGs. Greater efforts to involve youth in a new TIES Youth Section could help TIES provide support and opportunities for new generation of envirometricians with new ways of thinking, new skills sets, and different support needs. TIES has a prominent role in bringing meaning to the SGD goal metrics. Future directions for TIES could focus collective efforts on regional contexts and needs, including environmental problems in least developed countries and their impact on marginalized groups and communities. In this way, TIES would become a beacon encouraging broader environmetrics awareness, education, and technology-transfer.

Acknowledgements

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Statistical analysis of record-breaking temperatures

Is there evidence of climate change?

Abstract. Climate change impacts are often assessed through averages, but extremes events cause the most severe consequences. Traditional methods for studying extremes face challenges, whereas record-breaking events offer a simpler, more communicative, and statistically robust approach to evaluate deviations from a stationary climate. The aim of this work is to review statistical tools for analyzing record-breaking temperatures and to demonstrate how they can objectively assess evidence of climate change in their occurrence. The tools are based on hypothesis testing to determine whether observed record-breaking temperatures are consistent with a stationary climate or with a global warming scenario. These tests exploit the probabilistic properties of record-breaking events in i.i.d. sequences, evaluating whether the probability of a record at time t equals $1/t$ or exceeds it. Additionally, information from four types of records (forward/backward, upper/lower) is combined, yielding more powerful tests to detect the effects of global warming. Finally, results for 40 daily temperature series in Spain over the period 1960–2021 are presented. They reveal a significant climate change impact in the number of record-breaking temperatures, with the effect being neither spatially uniform nor homogeneous throughout the year.

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Climate change is often communicated through averages such as mean global temperatures or average rainfall patterns. Concerning temperatures, the IPCC (Lee et al., 2023) has documented with high confidence that measurable warming trends on mean temperatures are being observed across the globe. However, the extremes, the most intense and rare events, are the ones that often leave the most serious consequences on societies and ecosystems. Heatwaves and unprecedented daily temperature values can lead to devastating impacts: excess mortality, agricultural loss, infrastructure breakdowns, and ecosystem stress. Despite of this, fewer works have examined the impact of climate change on the tails of the temperature distribution and extreme events. Probably because the analysis of extremes, by definition rare, is methodological more complicated.

A first challenge in the study of extreme events is the definition itself, since a general operative definition does not exist. Different approaches to define extremes are found in the literature. The two most commons are, block maxima and EOT (Excess Over Threshold) approaches. In the first one, the maxima in a period of time, for example a year, are defined as extremes, while in the second any value over an extreme threshold is considered as extreme. Both are powerful but require substantial modeling assumptions and involve complex estimation of tail parameters, which can be sensitive to small sample sizes.

Another concept related to the tails of a distribution and extremes are record-breaking events. They are a valuable metric for assessing the impact of climate change on the upper tail of the temperature distribution. More precisely, the frequency of calendar-day records is a commonly used metric to this end used by many national meteorological institutes such as AEMET or the US National Oceanic and Atmospheric Administration, and also by the Copernicus Climate Change service. The calendar day records are defined as the record-breaking events in each of the 365 time series corresponding to each day of the year. The use of this metric shows important advantages beyond traditional approaches. One of them is their strong communicative value. The occurrence of a record always have a high impact in the media. Furthermore, they present important methodological advantages. First, the definition of records is based on the values within each time series. This allows for a more 'fair' comparison between series from different locations or times of the year, without requiring standardization. Second, the occurrence of records in i.i.d. series follows well-known probabilistic properties that do not depend on the underlying distribution of the variables. In a stationary climate, daily temperatures can be considered an i.i.d. series. These probabilistic properties allow us to compare observed record-breaking temperatures with their expected occurrence under stationarity.

Once, the interest of the study of record-breaking temperatures is established, the question that arises is whether the observed record-breaking temperatures are consistent with a stationary climate. The aim of this work is to show statistical methods which offer us invaluable help to answer this question in an objective way.

Definition and probabilistic properties of records

Given a series of variables (X_t), we say that X_i is an upper record, if $X_i > \max_{t<i}(X_t)$. Then, we can use a series of binary variables to characterize the occurrence of records in that series: $I_1 = 1$ and for $t > 1$

$$I_t = \begin{cases} 1 & \text{if } X_t \text{ is a record.} \\ 0 & \text{if } X_t \text{ is not a record.} \end{cases}$$

From these binary variables, we can also define the series of the cumulative number of records up to time t, $N_t = \sum_{i=1}^{t} I_i$.

As previously mentioned, one of the advantages of records are the probabilistic properties they have in continuous i.i.d series of random variables (the so called *classical record model*). The two following properties are of great importance in practice because they hold regardless of the distribution of (X_t), provided the series is i.i.d.

Property 1. (I_t) are mutually independent variables with distribution Bernoulli(p_t) where,

$$p_t = P(I_t = 1) = 1/t, \quad t = 1, 2, \ldots$$

Property 2. The asymptotic distribution of N_t, number of records up to time t, when $t \to \infty$, is Normal $N_t \sim N(\mu_t, \sigma_t)$ where

$$\mu_t = \sum_{i=1}^{t} \frac{1}{i} \quad \sigma_t^2 = \sum_{i=2}^{t} \frac{1}{i}\left(1 - \frac{1}{i}\right).$$

Testing the stationarity assumption

The previously described properties are very useful for studying whether climate change affects the upper tail of the temperature distribution, and specifically the occurrence of upper records. In a stationary climate, the daily temperature series for each calendar day can be regarded as a sequence of continuous i.i.d. random variables. This implies that, by comparing the observed behavior of temperature records with the well-known expected behavior in i.i.d. sequences, we can detect deviations and thereby formulate a hypothesis test.

More precisely, we define a test to study the following hypotheses. Given

$$p_t = P(I_t = 1)$$

$$H_0: \quad p_t = 1/t, \quad \text{for } t = 2, \ldots, T.$$
$$H_1: \quad p_t > 1/t \quad \text{for at least one } t.$$

Note that H_1 corresponds to a series of variables with an increasing trend (global warming), which leads to a higher probability of record occurrences.

Assuming that we have M (≥ 1) i.i.d. series of length T, $(X_{t1}), (X_{t2}), \ldots, (X_{tM})$, mutually independent, we could define as a reasonable statistic, just the total number of records observed in the M series in the observed period of length T,

$$\mathcal{N} = \sum_{m=1}^{M} \sum_{t=1}^{T} I_{tm}.$$

This statistic assigns the same weight to a record occurring at time $t = 3$ as to one at time $t = 30$, even though the latter provides stronger evidence of deviation from stationarity, since its probability of occurrence is much lower ($1/30$ versus $1/3$). A simple way to improve the statistic is to weight each record by its occurrence time, for example, using $w_t = t$.

$$\mathcal{N}_w = \sum_{m=1}^{M} \sum_{t=1}^{T} w_t I_{tm}.$$

Cebrián et al. (2022) found that the best election of the weights is $w_t = t^2/(t-1)$, since it provides an unbiased UMP test. Under H_0, $\mathcal{N}_w$ is asymptotically Normal when $M \to \infty$.

However, they also found that the power of the resulting test may be low if M is not sufficiently large. This is because the samples provide limited information, as the number of records is generally small. A way to address this is to increase the information about the tails by considering other types of records and combining information from all of them. This is possible because, given a single series of variables, we can define four types of records: upper and lower records in the original series $X_1, X_2, \ldots, X_T$, and upper and lower records in the backward series $X_T, X_{T-1}, \ldots, X_1$ (see Figure 1). In an i.i.d. series, the indicators of the four types of records, $I_t, I_t^L, I_t^B, I_t^{BL}$, follow the same Bernoulli$(1/t)$ distribution, since lower records have the same probabilistic properties as upper records.

> *"However, the extremes, the most intense and rare events, are the ones that often leave the most serious consequences on societies and ecosystems."*

Further, by combining information from the four types of records, we can define test statistics to study various hypotheses. The null hypothesis H_0 always assumes that records occur in an i.i.d. series, but different alternative hypotheses H_1 can be considered by assigning positive or negative coefficients to each type of record. For example, for testing the effect of an increasing trend in the upper tail, we consider $\mathcal{N}_u = \mathcal{N}_w - \mathcal{N}_w^B$, and for the effect of an increasing trend in both tails,

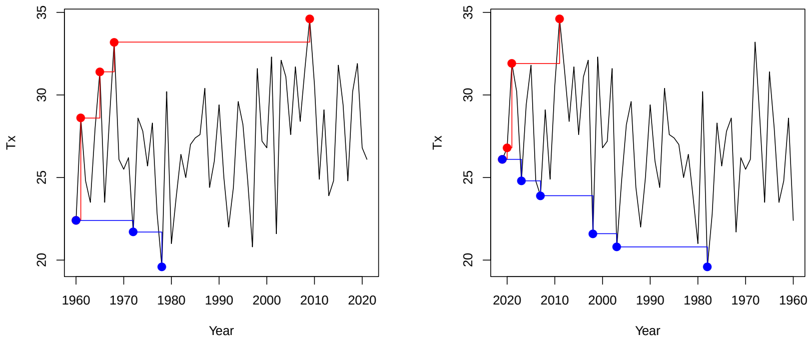
$$\mathcal{N}_{both} = \mathcal{N}_w - \mathcal{N}_w^L - \mathcal{N}_w^B + \mathcal{N}_w^{BL}.$$

It can be shown that, under the null hypothesis and assuming the M series are mutually independent, $\mathcal{N}_u$ and $\mathcal{N}_{both}$ follow an asymptotic Normal distribution as $M \to \infty$ (Cebrián et al., 2022). A simulation study further demonstrated that these tests have a high power for $M \geq 15$ even when the underlying trend is weak. If the M series available are not mutually independent, the distribution of the statistics and the corresponding p-values can instead be obtained using a permutation approach (Castillo-Mateo et al., 2023b).

Implementation

In order to implement this test, M (≥ 1) serially uncorrelated series of length T, $(X_{t1}), (X_{t2}), \ldots, (X_{tM})$, that are mutually independent are required. In the context of a study assessing the effect of global warming on record-breaking daily temperatures, the calendar-day records provide 365 series corresponding to each day of the year, which, under the null hypothesis of no climate change, are i.i.d. series. The issue is that temperature series from consecutive days are highly dependent, so the 365 series are not mutually independent even under the null. However, a subset of M^* independent series can be obtained by selecting series that are sufficiently separated in time, by ten days or even less, yielding more than 36 mutually independent series, and typically around 70.

It is noteworthy that series from different calendar days do not share the



b

Figure 1. Definition of the four types of records in a series: upper and lower (red and blue in the left plot) and upper and lower in the backward series (red and blue in the right plot).

same distribution, as the distribution for August 1 is not the same as that for December 1. However, this is not an issue, since the M series are not required to have identical distributions, given that the probabilistic properties of the occurrence of record-breaking events are the same for any distribution.

In some cases, we may be interested in analyzing not the entire year, but a specific season or even a single month. In such instances, obtaining a sufficiently large number of independent series by extracting subsets from the available data can be challenging (approximately 90 series for a season or 30 for a month). In these situations, the permutation approach remains valid, allowing the tests to be applied effectively

All the described tests, together with some others and additional graphical tools, can be implemented using the R package *RecordTest* (Castillo-Mateo et al., 2023a), which is freely available on CRAN.

Spain as a case-study

We analyze daily maximum temperatures from 40 Spanish stations, recorded from 1960 to 2021 (downloaded from the ECA webpage, original source AEMET), selected for the quality, completeness, and homogeneity of the series across the study area.

> *"The accelerated pace of record-breaking events underscores the urgency of implementing both mitigation and adaptation strategies."*

As an illustration, we apply the proposed tests to investigate the presence of global warming effects, an increasing trend, in the upper tail of temperature distribution. Since we analyze 40 series simultaneously, the resulting p-values are adjusted using the Benjamini–Yekutieli procedure to account for multiple dependent comparisons (Benjamini and Yekutieli, 2001). To study whether the impact of climate change is homogeneous throughout the year or not, the tests are carried out, first for the entire year and then separately for each season. The adjusted p-values for each location are shown in the maps presented in Figure 2. In these maps, strongly significant results (p-values < 0.05) are shown in red, moderately significant ones ($0.05 \leq$ p-value < 0.1) in gray, and non-significant results (p-values ≥ 0.1) in blue.

The results show that the effects of global warming are neither homogeneous across seasons nor spatially uniform. The influence of climate change on the occurrence of record-breaking temperatures is significant throughout most of Spain, with the exception of some coastal areas, particularly in the north. Summer is the most affected season, showing significant effects across nearly the entire country except for limited areas along the northern coast. In contrast, autumn is the least affected season, with the strongest impacts along the eastern area.

Discussion and conclusions

An important conclusion from this work is that statistical tools, such as the proposed hypothesis testing for record-breaking events, are essential for objectively quantifying the effects of global warming. In particular, they make it possible to measure the occurrence of records over time, capture both intra-annual and spatial variability, and assess deviations from a stationary climate. It is important to note that a deviation from a stationary climate does not imply an increase in the number of record-breaking events, but rather that these events are occurring at a rate higher than expected under stationarity.

From a climatic perspective, the analysis for Spain over the period 1961–2021 leads to the following conclusions: (i) The number of record-breaking temperatures has increased significantly compared to the expected number under a stationary climate, in most regions of Spain; (ii) This increase is not spatially homogeneous: it is more pronounced in inland areas than along the coast, and stronger along the Mediterranean coast compared to the Atlantic. The increase is also not uniform throughout the year, with the most pronounced rise occurring in summer.

Once the effect of climate change on the occurrence of record-breaking temperatures is objectively established, more relevant questions arise. Addressing these questions requires additional statistical tools within the framework of spatio-temporal models (Castillo-Mateo et al., 2025). Such models are particularly useful for predicting the occurrence of records at unobserved spatial locations, producing maps of relevant summary measures, and quantifying the uncertainty associated with those predictions.

Finally, it is important to emphasize the utility of these statistical

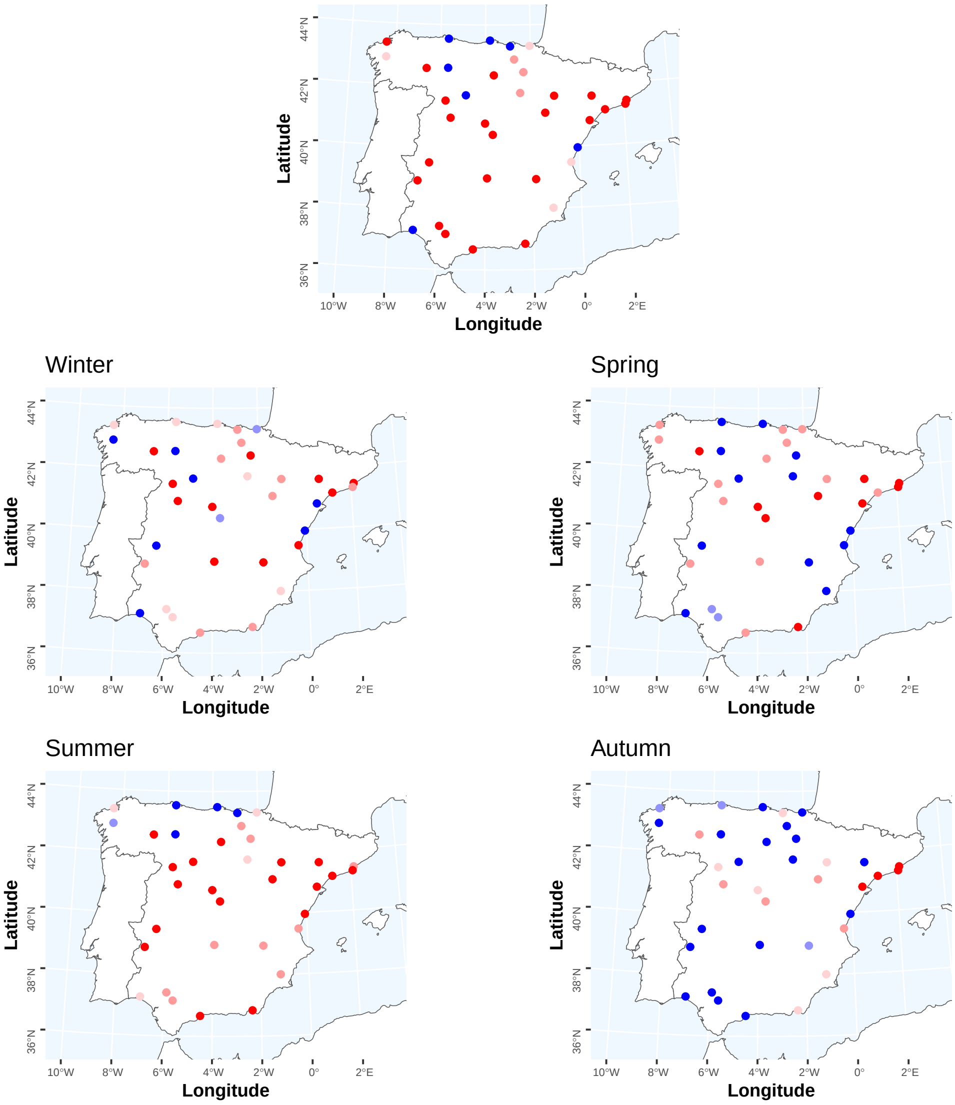


Figure 2. Adjusted p-values for assessing the effect of global warming on the upper tail of daily temperature, computed annually and by season; p-values < 0.05 (red), $0.05 \leq$ p-value < 0.1) (gray), p-values ≥ 0.1 (blue).

tools and results for guiding climate adaptation at both national and regional levels, informing public health preparedness, and supporting decisions on infrastructure resilience investments. The accelerated pace of record-breaking events underscores the urgency of implementing both mitigation and adaptation strategies. In this context, record-based monitoring provides a transparent, interpretable, and statistically rigorous approach for tracking the evolving climate and effectively communicating its impacts to policymakers and the public.

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Have humans caused the current climate crisis?

Investigating CO_2 data throughout the Earth's history

Abstract. Climate change poses an existential threat to mankind and the planet, with effects that reach far beyond rising temperatures, encompassing complex and interrelated phenomena. We showcase ways to engage students in exploring and visualizing climate change data, using the freely accessible CODAP software to foster statistical literacy and critical thinking.

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Throughout Earth's long history, it has gone through cycles of ice ages and warm periods. But is today's rapid warming part of a natural pattern—or is it something new, caused by human action? This question is one of the key topics of the educational project *Educational Strategies for Environmental Literacy*[1] (short: EduS4EL) that invites students and the general public to explore the relationship between carbon dioxide (CO_2) levels and global temperatures, melting of glaciers and sea level rise. This exploration is carried out through an analysis of freely accessible, real-world climate data. While carrying out this analysis the learners strengthen their belief in the fundamental role of reliable data and the institutions that provide them. In interviews after interventions students confirmed their faith in statistical data and stressed their relevance[2]. We find these opinions particularly important in times like ours, when autocratic governments tend to reduce the role of official, independent statistical institutions. Developed and tested in various college and high school settings, the materials presented here guide learners investigate a key scientific and societal issue: the anthropogenic (human-made) rise in CO_2.

For decades, scientists have warned that climate change — driven largely by greenhouse gas emissions — is a serious global threat. Its impacts are already visible: shrinking glaciers, melting sea ice, rising sea levels, longer and more intense heatwaves, and shifts in the ranges and behavior of plants and animals. Extreme weather events are becoming more frequent (see the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[3]).

CO_2 plays a vital role in Earth's climate system. It traps heat in the atmosphere, helping to maintain an average surface temperature of about 16°C—warm enough to sustain life. But when atmospheric CO_2 increases, so does the planet's temperature. The science is clear: human activities such as burning fossil fuels, industrial production, transportation, and heating are the main drivers of this increase. Yet, some skeptics argue that current changes might simply reflect natural fluctuations seen in Earth's past. Can these doubts be refuted by data?

Teaching material including a lesson plan and links to data, free software for analysis are freely accessible (Biehler et al., 2025; Engel et al., 2022) that guide learners to explore the following key questions: (i) How has atmospheric CO_2 evolved over geological time? (ii) What does the data tell us about the connection between CO_2 levels and global temperatures? (iii) What evidence supports the claim that the recent CO_2 spike is caused by human activity?

By digging into the data, learners can uncover for themselves what makes today's climate change different—and why it matters.

The data

CO_2 concentrations obtained from Antarctic ice cores (Vostok ice core) or directly in the atmosphere (Keeling curve) serve as the data basis.

These data are suitable for analyzing the CO_2 concentration over time because ice cores in places of perpetual frost are regarded as archives for climate data. Snow accumulates there very slowly, and an ice core composed of many layers of snow contains a long, accurate record of temperature and atmospheric composition over many millennia because the air bubbles trapped in the ice are small samples of the ancient atmosphere. By analysing air bubbles in the ice, it is possible to reconstruct the atmospheric composition at different times, including CO_2 content, methane content and other greenhouse gases. These air bubbles are trapped in the ice when it formed and give an indi-

[1] https://edus4el-ludwigsburg.eu

[2] https://www.youtube.com/watch?v=QxDIAVqDJOQ&list=PL39Ajv9z7W_LxRpGyyU6ohBvQHUjL1MtS&

[3] https://www.ipcc.ch

cation of the atmospheric CO_2 concentration at that time. Between 1970 and 1995, Russian and French teams drilled to a depth of 3623 meters at Vostok Station in Antarctica, generating data that reconstructed the CO_2 concentration in the atmosphere and the temperature at Vostok for the last 420,000 years. CO_2 is measured in parts per million by volume (ppmv), which is the number of CO_2 molecules per million molecules of dry air. The Vostok ice core data consists of two time series: CO_2 and temperature, with the temperature given as a deviation from the modern surface temperature average of -55.5 degrees Celsius at Vostok.

In order to be able to adequately assess the current fluctuations in temperature and CO_2 content with regard to the last few millennia, it is necessary to look at current data from our time. Another well-known dataset relating to the CO_2 concentration in the atmosphere serves this purpose. In 1958, Charles David Keeling began CO_2 measurements on the mountain Mauna Loa, Hawaii, which have been carried out regularly ever since. The Mauna Loa Observatory is located at an altitude of 3397 meters above sea level and is one of the most important atmospheric research facilities due to the strong marine inversion layer at this location. Measuring at this altitude not only minimizes the influence of vegetation and human activity on the measurements, but also allows a clear separation between the polluted, lower parts of the atmosphere and the much cleaner troposphere[4]. For Potsdam climate researcher Stefan Rahmstorf, the Mauna Loa data set (together with the Vostok data set) is one of the five most important data sets in climate research[5]. Harvard science historian Naomi Oreskes even describes the Keeling Curve derived from this data as "one of the most important works of the 20th century"[6].

"We find these opinions particularly important in times like ours, when autocratic governments tend to reduce the role of official, independent statistical institutions."

Data analysis

Visualizing and analyzing climate data requires appropriate software tools. A powerful and versatile option is the statistical computing environment R (see Guimarães et al., 2022; Ridgway, 2022, for an R-based analysis of climate data). However, the choice of software should be guided by the learners' prior knowledge and experience. For beginners, the freely available educational platform CODAP offers a user-friendly entry point and enables immediate hands-on exploration.

A useful starting point for analysis is the visualization of the Mauna Loa CO_2 data, which invites the first guiding question: Have there been historical periods of rising atmospheric CO_2 levels that cannot be attributed to human activity? Figure 1 presents monthly mean values of atmospheric CO_2 concentrations (in ppm) measured in the troposphere from 1958 to 2025.

Figure 1 reveals a clear trend for the period from 1958 to 2025:

- Atmospheric CO_2 concentrations have steadily increased from approximately 310 to 420 ppmv over the span of 65 years.
- Superimposed on this long-term trend are regular annual fluctuations, which are essentially seasonal in nature. These variations can be attributed to plant photosynthesis. During spring and summer, vegetation absorbs CO_2 more actively, reducing atmospheric concentrations. In contrast, during winter, photosynthetic activity declines, resulting in less CO_2 uptake and higher atmospheric levels.

According to ongoing temperature analyses conducted by NASA's Goddard Institute for Space Studies (GISS), the average global temperature has risen by at least 1.1° C since 1880. Most of this warming has occurred since 1975, at an estimated rate of 0.15 to 0.20° C per decade[7]. GISS compares model calculations from five leading scientific institutions, and although there are some differences in detail, the overall temperature curves are remarkably consistent. This consistency is reflected in the title of one of their graphics: "A world of agreement: Temperatures are rising." While the global mean temperature is a useful indicator—particularly when formulating climate targets—it is important to note that warming is not evenly distributed across the globe. To account for this, the GISS website provides statistical world maps that visualize regional temperature differences.

As a next step, we examine historical CO_2 and temperature data. This perspective allows us to address a common objection to the theory of anthropogenic climate change—namely, that the Earth has always experienced natural cycles of warming and cooling, along with fluctuations in atmospheric CO_2 levels. These historical glacial–interglacial cycles are primarily attributed to variations of the Earth's orbit around the Sun, known as Milankovitch cycles. The increased solar radiation during these periods leads to a rise in global temperatures, which subsequently triggers a release of CO_2 into the atmosphere. The resulting increase in CO_2 further amplifies the warming through positive feedback.

To assess whether the current CO_2 concentrations measured at Mauna Loa fall within the natural range of such historical fluctuations, we turn to the Vostok dataset, which provides long-term records of temperature and CO_2 levels. These data originate from ice cores drilled in Antarctica and serve as one of the most important archives of Earth's paleoclimate.

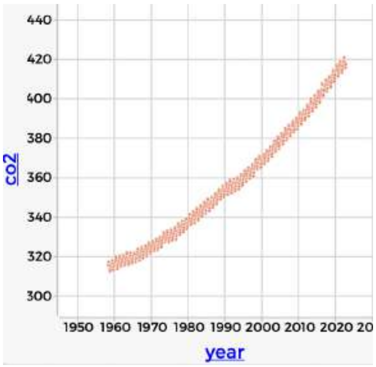

Figure 1. Monthly mean value of CO_2 content in ppm in the earth's atmosphere, measured on Mauna Loa, Hawaii, between 1958 and 2025.

[4] https://gml.noaa.gov/obop/mlo/
[5] https://www.pik-potsdam.de/~stefan/5datasets_rahmstorf.pdf
[6] https://www.advancedsciencenews.com/science-of-the-2010s-the-urgency-of-climate-change
[7] https://earthobservatory.nasa.gov/world-of-change/global-temperatures

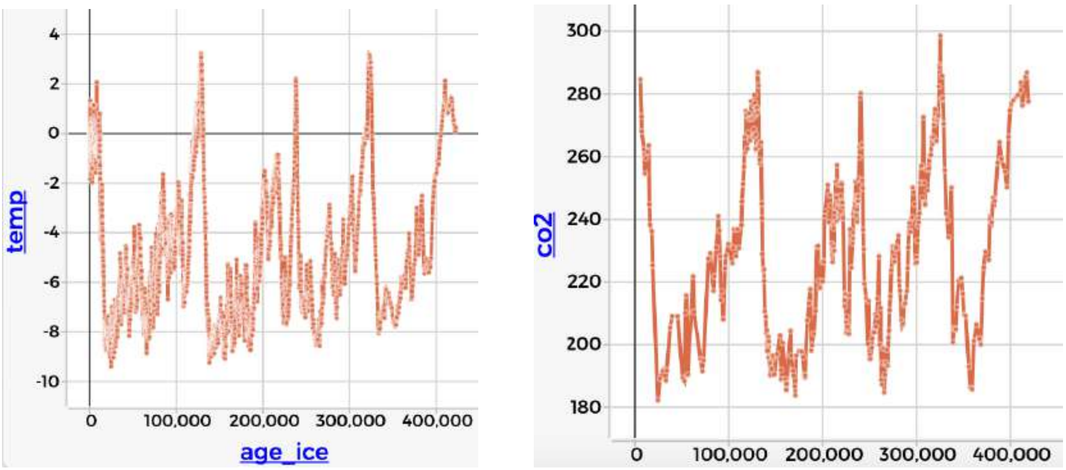

Figure 2. Ice age (in years) and temperature deviations (defined as temperature deviation in degree Celsius from the modern mean value of $-55°$ C) (right), ice age and co2, i.e. CO_2 content of the earth's atmosphere, measured in ppmv (left). Note the orientation of the horizontal axis as a reversed time axis, i.e. 100,000 means 100,000 years ago.

> *"Yet, some skeptics argue that current changes might simply reflect natural fluctuations seen in Earth's past. Can these doubts be refuted by data?"*

Figure 2 displays deviations in local temperature from the modern mean of $-55°$ C at the Vostok site, covering the past 420,000 years of Earth's climate history. The data reveal recurring temperature swings of up to 12° C, which climate scientists interpret as indicative of changes in global average temperature. Establishing a precise correlation between local and global temperatures, however, requires the use of climate models. The graph also depicts atmospheric CO_2 concentrations (in ppmv) over the same period, providing an opportunity to analyze the long-term relationship between CO_2 levels and temperature.

The graphs in Figure 2 demonstrate that

- Earth's temperature has always undergone periodic fluctuations—commonly referred to as ice ages. These are understood to be driven primarily by Milankovitch cycles, which describe variations in Earth's orbital characteristics.
- Similarly, atmospheric CO_2 concentrations have varied significantly over geological timescales, typically ranging between 180 and 300 ppmv.
- A clear connection between temperature fluctuations and CO_2 levels is evident in the parallel structure of the two curves. Periods of high CO_2 concentrations correspond with higher temperatures, while lower CO_2 levels align with cooler climatic phases. This correlation suggests a close relationship between greenhouse gases and global temperature, although the precise mechanisms of interaction remain an active area of scientific research[8].
- It is also notable that transitions between temperature and CO_2 minima and maxima span several thousand years, typically between 7,000 and 11,000 years. However, due to the large timescale of 420,000 years presented in the graph and the compressed horizontal axis, these gradual changes may misleadingly appear as abrupt shifts at first glance.

In the next step, we bring together the two datasets—Vostok and Mauna Loa—to compare corresponding findings. Each dataset reveals its own characteristic development. The Vostok ice core data show a cyclical pattern of temperature and CO_2 concentrations spanning hundreds of thousands of years (Figure 2), whereas the Mauna Loa Observatory data, beginning in 1958, display a continuous and accelerating upward trend in atmospheric CO_2, albeit with seasonal fluctuations (Figure 1).

The critical insight emerges when the two datasets are taken together (Figure 3). Although they were collected at entirely different locations using different methodologies, climate researchers regard them as fully comparable[9]. This synthesis reveals a striking anomaly: the recent increase in atmospheric CO_2 levels far exceeds the historical range of natural fluctuations. While past variations ranged between approximately 180 and 300 ppmv, CO_2 levels have risen by more than 100 ppmv in just the past 65 years, starting from an already elevated baseline.

This dramatic and unprecedented rise does not align with the cyclic patterns observed throughout Earth's climatic history. The contrast becomes especially evident when considering the scale of change: past increases occurred gradually over millennia, whereas the recent rise has taken place within a single human lifetime.

The combined representation of the data in Figure 3 provides compelling evidence that the rise in atmosphericCO_2 concentrations since 1958 cannot be attributed to natural geological fluctuations. Historically, CO_2 levels varied between 180 and 300 ppmv, with cyclical changes occurring roughly every 100,000 years. In stark contrast, the Mauna Loa data

[8] https://www.mpg.de/16166855/den-ursachen-von-eiszeiten-auf-der-spur

[9] https://keelingcurve.ucsd.edu/2014/03/20/how-are-ice-core-data-and-mauna-loa-atmospheric-data-made-comparable/

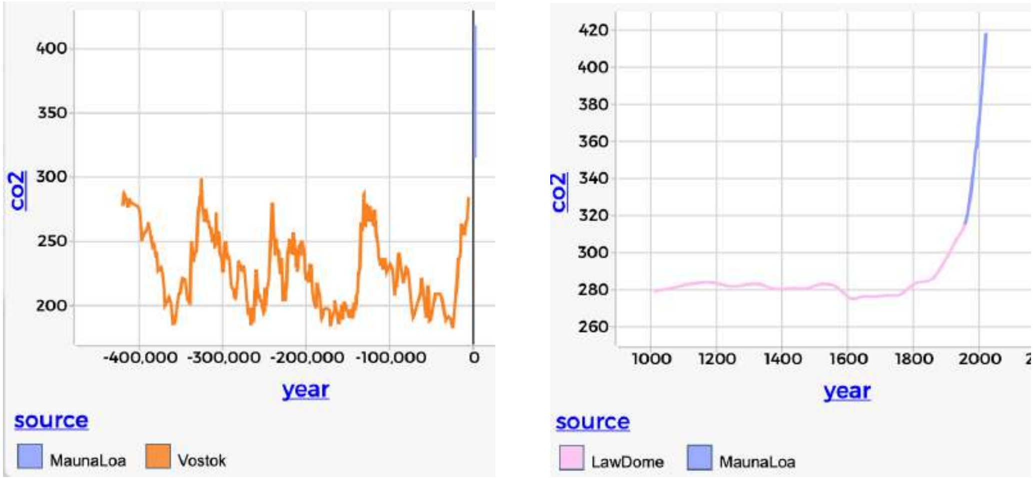

Figure 3. Left: Vostok CO2 and Mauna Loa data in one graph. On the time scale, the Mauna Loa data are now very close together and lie far above the values of the Vostok data. Right: Data from Law Dome ice core drilling and Mauna Loa data.

show a rise from approximately 320 to 420 ppmv within just 65 years—a rate of change unprecedented in the geological record.

This development indicates that Milankovitch cycles alone are no longer sufficient to explain the current trend. In contrast, the sources of anthropogenic CO_2 emissions—such as industry, transportation, and building heating—are well understood. When energy is generated through the combustion of fossil fuels, significant amounts of CO_2 are released into the atmosphere, contributing directly to the observed increase in concentration (see, e.g., Our World in Data[10]). The conclusions drawn from the Mauna Loa data are further supported when correlated with CO_2 measurements from other ice cores. One notable example is the Law Dome ice core in Antarctica, which provides high-resolution records of atmospheric CO_2 and temperature from the years 1010 to 1975, with data points at five-year intervals. These data are also accessible through the Environmental Systems Science Data Infrastructure for Climate Research[11]. Figure 3 (right part) presents a combined visualization of the Law Dome and Mauna Loa CO_2 datasets. Remarkably, the CO_2 curve from the Law Dome record merges almost seamlessly into the Mauna Loa curve, providing a compelling continuity between reconstructed historical data and modern atmospheric measurements. This smooth transition not only confirms the reliability and comparability of ice core–derived data with direct atmospheric observations, but also strengthens the interpretation that the sharp rise in CO_2 levels is a recent phenomenon, closely correlated with the onset and expansion of industrialization.

Conclusion

Extensive measurements and model-based projections leave no doubt that modern civilization emits far more CO_2 than natural ecosystems can absorb. While a few graphs alone cannot replace decades of comprehensive climate research, they offer a powerful entry point for understanding the evidence. In education, it is crucial to present this evidence without oversimplifying complex climate dynamics and to emphasize that the scientific consensus rules out non-anthropogenic explanations for the recent rise in atmospheric CO_2. The historical and current data and visualizations used in this unit reflect core components of the scientific process – an approach that must be defended despite currently growing tendencies to downplay or dismiss it. The critical message is this: rising CO_2 levels are directly driving the increase in global average temperatures, with consequences already visible worldwide. Urgent action, especially a substantial reduction in global CO_2 emissions, is essential to mitigate future risks and protect the planet for generations to come.

Instructional materials

Detailed teaching materials from EduS4EL for use in classroom are freely accessible through https://edus4el-ludwigsburg.eu/publications/.

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"The critical message is this: rising CO_2 levels are directly driving the increase in global average temperatures, with consequences already visible worldwide."

[10] https://ourworldindata.org/co2-and-greenhouse-gas-emissions

[11] https://doi.org/10.3334/CDIAC/ATG.011

metR: An R package for analysis and visualization of meteorological fields

Abstract. The metR package provides specialized tools for meteorological data analysis and visualization within the R programming environment. Built on tidy data principles and integrated with ggplot2, metR addresses common challenges in atmospheric science by offering functions for NetCDF data handling, statistical analysis methods like Empirical Orthogonal Functions, derivative calculations on spherical grids, and advanced visualization capabilities for scalar and vector fields. The package bridges the gap between domain-specific meteorological tools and the broader R data science ecosystem, enabling atmospheric scientists to leverage modern statistical workflows while maintaining access to specialized atmospheric science methods.

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Meteorological data analysis presents unique challenges that require specialized computational tools. However, while leveraging domain-specific tools can result in speed and efficiency gains, by using non-standard data structures and methods, it isolates the data and analysis from the wider community of statistical software. The metR is an R (R Core Team, 2025) package developed to bridge this gap by providing tools for reading meteorological data as a tidy data.frame, ensuring seamless integration with the existing R data science workflow while addressing the specific needs of the atmospheric science community.

Core Features and Functionality

metR provides robust data input capabilities through the `ReadNetCDF()` function. Unlike basic NetCDF readers, `ReadNetCDF()` returns tidy data.table (Barrett et al., 2025) objects with proper dimensions and intelligent handling of multi-dimensional arrays.

Besides returning a tidy data.table, this function also provides extensive subsetting capabilities:

- Index-based subsetting, such as selecting the first 10 timesteps
- Value-based subsetting, such as selecting data between 10°S and 10°N
- Disjoint selection for non-contiguous regions
- Multi-file processing with parallel processing

The package also includes several statistical and mathematical operations commonly used in atmospheric sciences.

Empirical Orthogonal Functions (EOF): The EOF( ) function performs Principal Component Analysis on meteorological fields, supporting both standard and rotated EOF analysis. It handles complex spatiotemporal data structures and provides confidence intervals through bootstrap sampling. The implementation is optimized for large datasets using the irlba package (Baglama et al., 2022) when appropriate.

Derivatives and Gradients: The `Derivate()` function computes finite difference derivatives with support for spherical coordinates, boundary conditions, and multi-dimensional fields. This is essential for calculating quantities like vorticity, divergence, and temperature gradients.

Geostrophic Wind Calculation: `GeostrophicWind()` computes geostrophic winds from geopotential height fields, accounting for the Coriolis effect and spherical geometry.

Thermodynamic Functions: A comprehensive family of thermodynamic functions implements computations based on the ideal gas law, adiabatic processes, Clausius-Clapeyron equation, and other fundamental atmospheric relationships. These functions allow computation of variables like density, pressure, and temperature from other relevant state variables. For example, `metR::IdealGas(p = 101300, t = 293)` returns the density of air at sea level and room temperature.

metR extends ggplot2 (Wickham, 2016) with specialized geoms and stats designed for meteorological data:

Enhanced Contour Plotting: `geom_contour_fill()` and `geom_contour2()` provide filled contours with advanced features including:

- Function-based break determination using `MakeBreaks()`
- Support for unequal breaks between facets
- Kriging interpolation for sparse or irregular data
- Circular boundary conditions for global datasets
- On-the-fly reprojection of contours to different coordinate systems
- Automatic labeling of contour levels

Vector Field Visualization: `geom_streamline()` creates streamlines through Euler integration, while `geom_arrow()` displays vector fields with proper scaling and meteorological conventions. These functions support wrapping for global datasets and custom arrow styling.

Specialized Scales: The package includes meteorological-specific scales such as `scale_longitude()`, `scale_y_level()` for pressure levels, and `scale_divergent()`

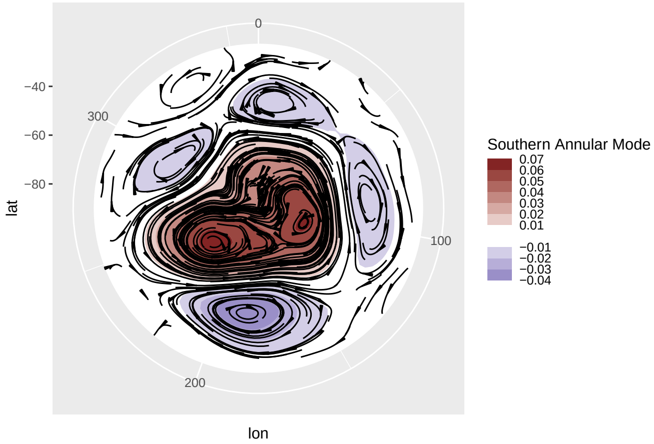

Figure 1. Leading EOF of 700 hPa geopotential height anomalies south of 20°S. Streamlines show the geostrophic wind.

Listing 1. Example metR workflow to compute the Southern Annular Mode pattern (output shown in Figure 1).

```
library("data.table", "ggplot2", "metR")

geopotential <- ReadNetCDF("geopotential_height.nc",
                          subset = list(lat = c(-90, -20), lev = 700))
geopotential[, gh := Anomaly(gh)*sqrt(cos(lat*pi/180)),
             by = .(lon, lat, month(date))]
sam <- EOF(gh ~ lat + lon | date, data = geopotential, n = 1)

sam$left[, c("u", "v") := GeostrophicWind(gh/sqrt(cos(lat*pi/180)),
                                          lon, lat)] |>
  ggplot(aes(lon, lat)) +
  geom_contour_fill(aes(z = gh/sqrt(cos(lat*pi/180)), fill = after_stat(level)),
                    binwidth = 0.01, breaks = AnchorBreaks(0, exclude = 0),
                    xwrap = c(0, 360)) +
  geom_streamline(aes(dx = dlon(u, lat), dy = dlat(v)),
                  L = 80, skip = 3, xwrap = c(0, 360)) +
  scale_fill_divergent_discretised(name = "Southern Annular Mode") +
  coord_polar()
```

for diverging color schemes common in atmospheric visualization.

Example Workflow

A typical metR workflow that demonstrates the package's integrated approach is shown in Listing 1 whose output is shown in Figure 1. The following example visualises the Southern Annular Mode (SAM, Limpasuvan and Hartmann, 1999) by first reading geopotential height data, subsetting to latitudes south of 20°S at the 700 hPa level. It computes monthly anomalies weighted by the square root of the cosine of latitude to account for area differences. The SAM is then identified as the leading Empirical Orthogonal Function, with its spatial pattern represented by the left singular vectors. Since this represents a geopotential height field, the code uses `GeostrophicWind()` to estimate the associated circulation and visualizes it using streamlines.

Conclusion and Future Development

The metR package has been well received in the atmospheric science community. With over 20,000 monthly downloads according to CRAN logs, its design philosophy of integrating specialized meteorological methods with modern R workflows has proven successful in numerous research applications, from climate analysis to synoptic meteorology.

Current development focuses on implementing NetCDF file output capabilities, performance improvements in key operations. The package's open-source nature and active community ensure continued evolution to meet the changing needs of atmospheric scientists working in R.

Availability

The metR package is available on CRAN and GitHub (https://github.com/eliocamp/metR) under the GPL-3 license. Comprehensive documentation and examples are available at https://eliocamp.github.io/metR/.

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Using the SPIChanges R package at the heart of the Amazon rainforest

Abstract. The SPIChanges R package is designed to improve the use of the Standardized Precipitation Index (SPI) under changing climate conditions. The objective of this study is to demonstrate the SPIChanges package´s applicability. It was applied to daily precipitation data from a location at the heart of the Amazon rainforest. The results allowed us to conclude that the package enhances drought assessment under the current global climate change conditions.

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Graciela da Rocha Sobierajski
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Letícia Lopes Martins
Researcher at the Agronomic Institute of Campinas, specializing in hydrology and climate-risk analytics.

Climate change has increased drought frequency in many regions worldwide. The SPIChanges R package was developed by Blain et al. (2025) to detect changes in precipitation patterns and quantify their impact on drought occurrence. This study demonstrates the package's applicability and provides guidance for interpreting its results.

Methodology

The package was applied to daily precipitation data from Manaus, Brazil (2000–2025), obtained from the MERGE product (Rozante et al., 2020). The core methodological step of the package is to compare the cumulative probability of an observed precipitation amount calculated from stationary and non-stationary versions of the same parametric distribution. The package fits up to 16 increasingly complex gamma-based models. Further methodological details are provided in Blain et al. (2025).

Model Description

The package's algorithm can be summarized in three main steps:

1. Calculate the Standardized Precipitation Index (SPI) and cumulative probability: The stationary two-parameter gamma distribution is fitted to estimate SPI values and cumulative probabilities of each rainfall amount.
2. Fit time-varying distributions: The non-stationary gamma distributions are fitted to the precipitation series. The best-fitting model is selected using the second-order Akaike Information Criterion.
3. Estimate cumulative probabilities under climate change: The selected non-stationary model is used to estimate time-varying cumulative probabilities, which are compared with the stationary estimates from step 1. This comparison indicates whether the frequency of drought events has increased or decreased over time.

Implementation

The package aggregates daily data into a quasi-weekly time scale, which divides each month into four periods.

The code reported in Listing 1 aggregates the daily precipitation into a 4–quasi-weekly time scale, which corresponds to a backward-looking moving rolling window of one month.

Results

The `model.selection` component of `results` (Table 1) presents the best gamma-based model for each quasi-weekly period in Manaus. The `Changes.Freq.Drought` component of `results` shows how the time-varying parameters of Model 3 impacted drought frequency in Manaus. For example, it shows how such changes affected the climatologically expected precipitation (Table 2). This output field also shows how this climate change affected drought occurrence

Listing 1. Example SPIChanges workflow to detect changes in drought frequency

```r
# installing and loading the package
if (!require(SPIChanges))
  install.packages("SPIChanges")
library(SPIChanges)

# Load daily rainfall data for Manaus
rain <- read.csv("Manaus_prec.csv", sep = ",", header = TRUE)

rain.ts <- TSaggreg(rain[, 2], start.date = "2000-01-01", TS = 4)

# Detect changes in drought frequency
results <- SPIChanges(rain.at.TS = rain.ts, only.linear = "No")
```

in terms of their frequency (Table 3).

Table 1. Best gamma-based model by quasi-weekly period in Manaus.

Month	quasiWeek	model
1	1	1
1	2	1
1	3	1
1	4	1
2	1	1
2	2	1
2	3	1
2	4	1
3	1	1
3	2	1
3	3	1
3	4	1
4	1	1
4	2	1
4	3	1
4	4	1
5	1	1
5	2	1
5	3	1
5	4	1
6	1	1
6	2	1
6	3	1
6	4	1
7	1	1
7	2	1
7	3	1
7	4	1
8	1	1
8	2	1
8	3	1
8	4	1
9	1	1
9	2	1
9	3	3
9	4	1
10	1	1
10	2	1
10	3	1
10	4	1
11	1	1
11	2	1
11	3	1
11	4	1
12	1	1
12	2	1
12	3	1
12	4	1

Table 2. Expected precipitation (mm).

StatNormalRain	NonStatNormalRain
50.62	40.43

Table 3. Change in drought occurrence frequency expressed as a percentage.

ChangeMod	ChangeSev
17.65	16.87

Discussion

For 47 quasi-weekly periods, the stationary gamma distribution was the best-fitting model, suggesting no climate trend (Table 2). A non-stationary model (Model 3) was selected in the 35th quasi-week, which indicates a linear change in the dispersion of the precipitation frequency distribution. The `Changes.Freq.Drought` field indicated that this linear change is the result of a shift toward drier conditions in the precipitation values accumulated from the 2nd quasi-week of August to the third quasi-week of September. This statement is based on the fact that the climatological expected precipitation (*StatNormalRain* and *NonStatNormalRain*) for this period decreased over time (Table 2). Additionally, the expected frequency of moderate to extreme *ChangeMod*) and severe to extreme *ChangeSev*) droughts (Table 3) increased over the last 26 years in the location of the Amazon rainforest.

Conclusion

The SPIChanges package models changes in drought frequency under the current climate change conditions. The package enhanced drought assessment in a location situated at the heart of the Amazon rainforest, by showing increases in drought frequency during the end of austral winter and the beginning of spring seasons.

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The overlooked science of understanding the world: Demography

Abstract. Can demography explain China's economic growth? Can it shed light on the challenges faced by African nations? Why do Canada and Luxembourg actively promote immigration? In 2023, Canada reached a historic population milestone of 40 million for the first time.

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Can demography explain the rapid economic growth of China over the past few decades, as well as the recent economic slowdown? Can it help explain the struggles in Africa? Is demography a contributing factor to explain the conflicts in the Middle East? What insights can the average age of a country's population offer? Numerous socio-economic phenomena and political situations can be analyzed and predicted through demographic studies. Surprisingly, the array of tools that most pundits rely on rarely seems to incorporate this vital perspective.

Demography is the scientific study of (human) populations, providing essential information about neighborhoods, workplaces, cities, countries, continents, and the entire world. Understanding the gender distribution and socio-economic characteristics of a specific population is crucial for grasping their fundamental needs and the trajectory they are likely to follow. The availability of more disaggregated data enhances our understanding of these dynamics.

One-child policy in China

The one-child policy in China was an initiative implemented from 1979 to 2015, aimed at curbing the country's population growth by limiting many families to a single child. While assessing the ethical implications of this policy is beyond the scope of this article, the one-child policy did contribute to China's rapid economic growth over the past few decades. Many countries have transitioned from a scenario characterized by high birth rates and high infant mortality rates to one with low birth rates and reduced infant mortality rates. Between the two scenarios, countries experienced high birth rates and low infant mortality rates, often resulting in larger families. This is known as the (first) demographic transition.

Those large families can pose significant challenges to a country's socio-economic conditions. This is the current reality in many African nations. Rapid and excessive population growth can result in issues related to food and water distribution, job scarcity, and inadequate infrastructure. In contrast, China's demographic transition was one of the fastest in history, largely due to the implementation of the one-child policy, which led to a markedly different developmental trajectory. While this process took over a century in Europe, China achieved it in approximately 30 years.

"Numerous socio-economic phenomena and political situations can be analyzed and predicted through demographic stud- ies. Surprisingly, the array of tools that most pundits rely on rarely seems to incorporate this vital perspective."

Study of (human) populations

Birth, immigration, emigration, and death are the primary variables in demography. Intuitively, birth and immigration contribute to population growth, while emigration and death result in a decline in population. Most demographic data is derived from census information, making it a crucial aspect of the field of demography.

In theory, censuses take place worldwide once a decade during the first week of November in years ending in '0' or '1'. The census questionnaire remains largely consistent across different countries. A census is a systematic process for acquiring, recording, and analyzing information about the members of a specific population. The United Nations offers recommendations that include official definitions, classifications, international practices, guidelines, simultaneity, and defined periodicity, as well as topics to be addressed in the census.

In the growth economics model, which earned Robert Solow a Nobel prize in 1987, the economist demonstrated that population growth plays a central role in economic growth. Demography serves as a vital tool for understanding reality and formulating long-term policies for success. The Solow model is characterized by capital accumulation, population growth, and productivity. In simple terms, a larger population results in more housing, more vehicles, more food, and more job opportunities.

In Western countries...

Why do Canada and Luxembourg—two of the wealthiest countries in the world—encourage immigration? In many Western nations, there is considerable debate surrounding immigration. In 2023, Canada reached a historic population milestone of 40 million for the first time, largely due to its generous immigration policies rather than its birth rate. The government's plan aims to increase the population to 100 million by 2050. Similarly, Luxembourg also offers substantial incentives for both natality and immigration.

Other countries may be less enthusiastic about immigrants, yet maybe they have every reason to welcome them. Today, many countries are facing the so-called second demographic transition, characterised by very low birth rates—fewer than two children per couple, less than enough to maintain the population—and low mortality rates. These conditions have significant implications. The population decrease leads to economic decline, as fewer people result in diminished demand for cars, apartments, and food.

> *"Politics, as well as economics, is profoundly affected by demographic changes. Can demography help us understand the current situation in Israel?"*

Can we apply this reasoning to Europe? Europe has the lowest birth rate and oldest population in the world. We recall that at one time in our families, some generations had ten siblings. The varying immigration laws and the ongoing debate surrounding them unfortunately do not contribute positively to the growth of the European economy.

Is demography a factor in the conflicts in the Middle East?

Politics, as well as economics, is profoundly affected by demographic changes. Can demography help us understand the current situation in Israel? The complex circumstances in Israel can be partly attributed to demographic factors. After the Second World War, Israel's population was predominantly composed of individuals from Europe, with only a small number of Orthodox Jews. Due to their limited numbers, Orthodox Jews were exempted from military service for religious reasons. However, in the last two decades, Israel's population has undergone significant transformations. The number of Orthodox Jews has increased dramatically, driven by a high birth rate influenced by religious practices. Consequently, there has been a recent decision to draft ultra-Orthodox individuals for military service. Additionally, other demographic groups distinct from the founders have also expanded, including Jewish immigrants from Russia and various Arab countries. This diverse composition of the Jewish population has significantly influenced domestic politics.

Demography is a powerful, yet often underappreciated, tool for predicting future global challenges. Many economic situations and geopolitical issues can also be clarified through demographic analysis. The average age of a population provides insights into its attitudes toward war, risk, and entrepreneurship. Generally, a younger population is more inclined to embrace change than an older one.

> *"Demography is a powerful, yet often underappreciated, tool for predicting future global challenges. Many economic situations and geopolitical issues can also be clarified through demographic analysis."*

Philippines

Mapping optimism in the pearl of the orient seas

Abstract. The Philippines is well known for its natural beauty and cultural richness, but equally noteworthy is the resilience and optimism of its people. While tourist destinations often capture the spotlight, what truly stands out is how Filipinos adapt and thrive in the face of challenges. In this article, we collaborate with OCTA Research Group, one of the private polling institutions in the country, to examine their recent survey data. Through visualization and analysis, we explore the patterns and nuances of Filipino optimism, highlighting how statistics can shed light on the social fabric of a nation. Beyond these insights, this article also aims to demystify the process of building statistical indices—illustrating how simple survey responses can be transformed into meaningful indicators that help us understand society at large.

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The Philippines, known as the “Pearl of the Orient Seas”, earned this title not only because of its strategic location but also due to its breathtaking natural landscapes, vibrant culture, and pristine waters. Tourism has long been a cornerstone of its economy, serving as both a driver of growth and a mirror of the nation’s resilience. In 2024, the Philippine Statistics Authority (PSA) reported that Tourism Direct Gross Value Added (TDGVA) reached PHP 2.35 trillion, an 11.2% increase from the previous year. The sector accounted for 8.9% of the country’s Gross Domestic Product (GDP) and provided livelihoods for about 6.75 million Filipinos[1]. These figures highlight not only the industry’s critical role in economic recovery but also its expanding capacity to sustain communities and promote national identity.

Beyond its economic impact, Philippine tourism thrives on diversity. Spread across more than 7,600 islands, the country offers an array of attractions—from white-sand beaches and mountain landscapes to centuries-old heritage towns and vibrant cultural festivals. This demonstrates that the Philippines is more than just its stunning coastlines. It also boasts unique land formations and a cultural depth that reflects centuries of history and tradition.

Equally important are the cultural values that enrich the visitor experience and define the nation’s identity. Among these, Filipino hospitality stands out. In 2012, Forbes Magazine recognized Filipinos as some of “the friendliest people in the world,” ranking them first in Asia (Greenfield, 2012). Beyond their warm smiles, Filipinos are also celebrated for their resilience (Lagon, 2024), a quality that continues to spark reflection and debate among the people themselves. Increasingly, this resilience has been linked with optimism, a social resource that shapes both everyday life and national outlook. Unlike natural landscapes or cultural landmarks, optimism is less visible yet it plays an equally important role in how Filipinos face challenges and look toward the future. To better understand this side of Filipino identity, we use survey data

[1]https://psa.gov.ph/statistics/tourism

that reflects public sentiment. In this article, we work with OCTA Research Group, a leading private polling institution, to visualize and analyze Filipino optimism using results from their nationwide Tugon ng Masa survey.

Data on Optimism

This study draws on data from OCTA Research Group's Tugon ng Masa (Responses of the Masses) survey, an independent, non-partisan nationwide poll designed to capture Filipino public sentiment. The stratified multi-stage probability sampling survey was conducted nationwide from August 28 to September 2, 2024, through face-to-face interviews. The sample size was 1,200 probability-selected respondents aged 18 years and above from all economic class homes. The overall sample for the Philippines carries a $\pm 3\%$ margin of error at the 95% confidence level. The article's analysis is primarily for the purpose of visualization and does not aim to serve as a regional index of optimism.

A stratified multi-stage probability sampling design was employed. The number of sample barangays[2] (a total of 240) was distributed among the 17 regions proportional to population size. In each sample barangay, five probability respondents were selected. The sampling schemes for the National Capital Region (NCR) and the rest of the Philippines varied slightly. For NCR, 60 barangays were selected proportional to the city/municipality's population, with interval sampling used to draw the five sample households. For the rest of the country, cities/municipalities were first allocated and selected, followed by the proportional selection of barangays within them. In all areas, the final selection of the adult respondent within the household was randomly chosen using a probability selection table.

A specific protocol was implemented to ensure gender balance (half male, half female), where only male family members were prelisted for odd-numbered questionnaires and only female members for even-numbered ones. The research methodology further ensures data quality. The questionnaire was prepared in Filipino with an English translation and translated into various local languages for regional use, including Bicol, Cebuano, Ilocano, and Ilonggo. Field interviewers underwent extensive face-to-face and online training, and the data gathering was strictly monitored through field supervision, observation (12% of interviews), and spot checking (21% of unsupervised interviews) to ensure data integrity. The survey's key questions focused on optimism and perceptions of well-being, with the central item asking respondents: "Do you believe your quality of life will improve in the next six months?"

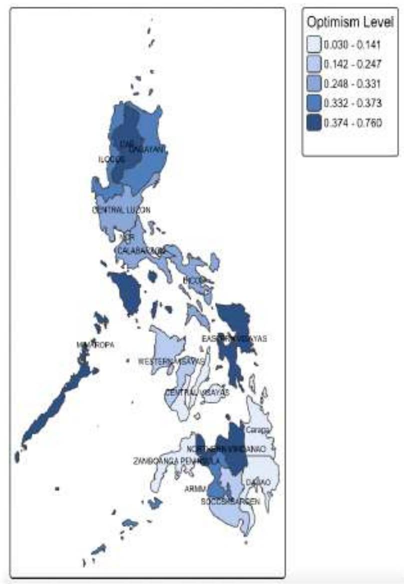

Figure 1. Regional weighted proportion of Filipino's perspective on optimism.

The latest data from the "Tugon Ng Masa" survey conducted in December 2023 shows that 49% of adult Filipinos are optimistic that their quality of life will improve in the next six months. This is 15% higher than the October 2023 survey, suggesting a growing sense of hope and economic confidence among the population. The weighted regional proportion of Filipino's perspective on optimism is shown in Figure 1. Regional findings reveal interesting variations, with optimism being highest in the MIMAROPA (51%) and lowest in Caraga (3%). We note that while data are available at the regional level, the survey was primarily designed to yield national estimates. As a result, the regional margins of error may be as high as 30%. Beyond simple regional comparisons, the data can be subjected to Spatial Autocorrelation Analysis (Moran's I) to determine if optimism is clustered geographically. Finding positive spatial autocorrelation would indicate that optimism in one barangay is influenced by the sentiment in neighboring areas, suggesting the role of local government performance, community support networks, or localized economic booms (e.g., proximity to new infrastructure projects). We then obtained the global Moran's I (Bivand et al., 2008) for regional weighted proportions of the Filipino's perspective on optimism (see Figure 2). Through Monte Carlo simulation, we do not find evidence to support the presence of spatial autocorrelation, i.e., the Moran's plot in Figure 2 presents a horizontal line, or no spatial autocorrelation.

Moving forward...

To further enhance the rigor and insight of such studies, several improvements could be considered. The first essential step is the implementation of a proper and statistical-way index assessment. Instead of relying solely on the question "Do you believe your quality of life will improve

[2]The barangay historically known as the barrio, is the smallest administrative division in the Philippines.

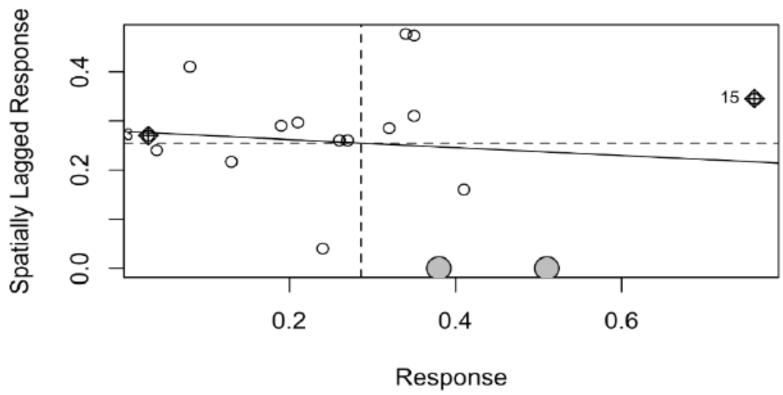

Figure 2. Moran's plot for Regional weighted proportion of Filipino's perspective on optimism

in the next six months?" which measures directional expectation, a statistically sound National Optimism Index (NOI) should be constructed. This index would follow established econometric techniques, such as Principal Component Analysis (PCA) or Factor Analysis, to combine multiple variables into a single, comprehensive score. The index should include the directional expectation question alongside other metrics, such as: a) a retrospective question (e.g., "Do you believe your quality of life has improved in the last six months?"), b) a perception of national economic outlook (e.g., "Do you believe the Philippine economy will improve?"), and c) a measure of personal financial security (e.g., job security or ability to meet monthly expenses). The final index score would then be normalized (e.g., scaled from 0 to 100 or represented as a net balance score, subtracting pessimists from optimists) to facilitate time-series and cross-regional comparisons. Good methodological references for this approach include the work of Nardo et al. (2008) on constructing consumer sentiment indices, as well as the established frameworks used by prominent global pollsters like Eurobarometer or the Michigan Consumer Sentiment Index (MCSI). This multi-faceted approach transforms the data from a simple poll result into a robust sociological indicator.

To further improve the survey, particularly the sampling and questionnaire design, several measures should be considered. While the current sample size of 1,200 is adequate for a national estimate ($\pm 3\%$ error margin), achieving more precise estimates for sub-regions like the Cordillera Administrative Region (CAR) or the smallest regions requires either oversampling in these areas or adopting a more granular stratification to ensure all 17 regions achieve an error margin below $\pm 8\%$. Furthermore, the questionnaire itself could be enhanced by including open-ended questions to capture the reasons for optimism or pessimism—a qualitative layer that adds depth to the quantitative results. This mixed-methods approach would allow the study to correlate "what" Filipinos feel (the index score) with "why" they feel it (free-response answers on job prospects, anti-corruption efforts, etc.). Finally, adopting a panel design—interviewing the same respondents over multiple survey waves—would enable researchers to track changes in individual optimism, offering powerful insights into the long-term drivers of resilience and economic behavior.

Other spatial analyses may also be considered in this kind of dataset as the geographical granularity of the survey opens opportunities for advanced geospatial analysis, such as, Geographically Weighted Regression (GWR). GWR allows the identification of regional-specific drivers of optimism. For instance, in agricultural regions, optimism might be highly correlated with crop yield and farmgate prices, while in Metro Manila, the primary driver might be wage growth and commuting time. This contrasts with traditional Ordinary Least Squares (OLS) regression, which assumes relationships are constant across the country. Through these spatial methods, the study can provide policymakers with tailored, evidence-based recommendations for different geographic contexts.

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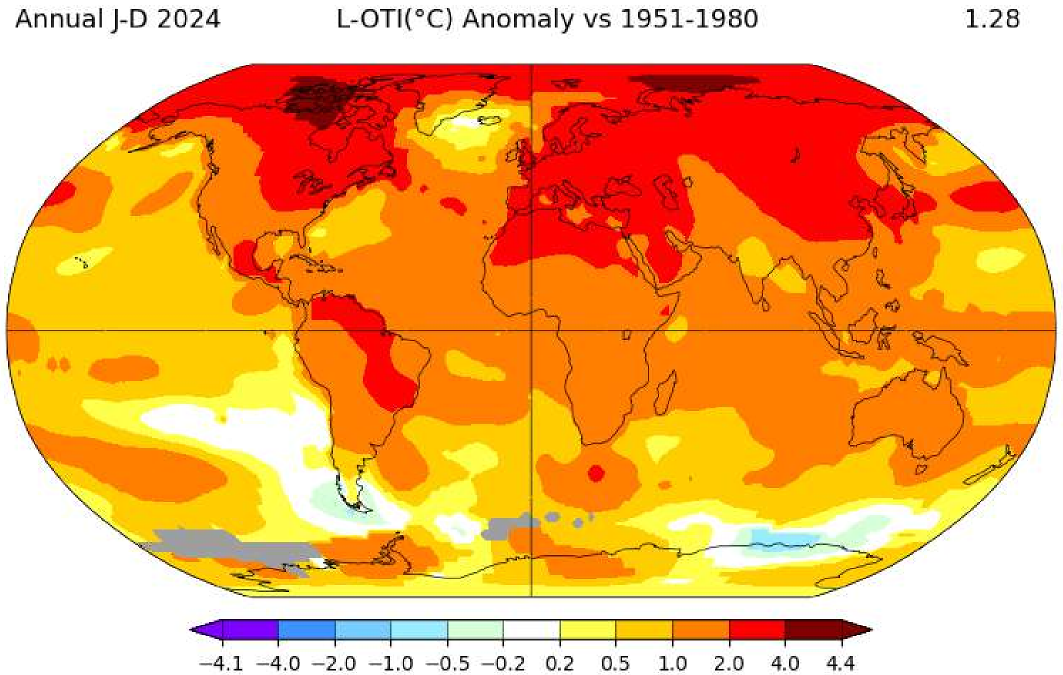
Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., and Giovannini, E. (2008). *Handbook on Constructing Composite Indicators: Methodology and User Guide.* OECD Publishing.

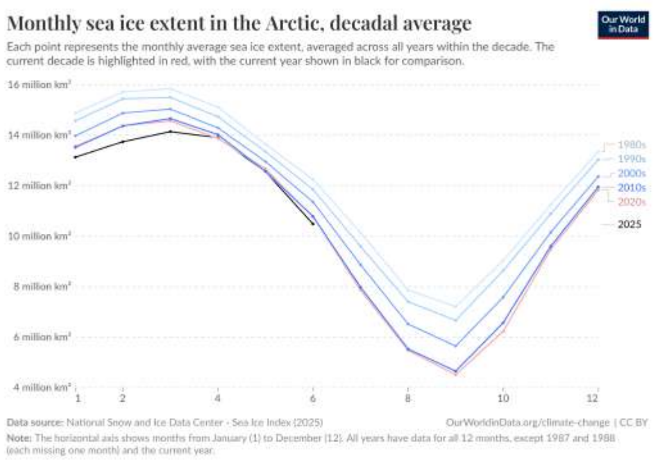
OUR WORLD IN DATA

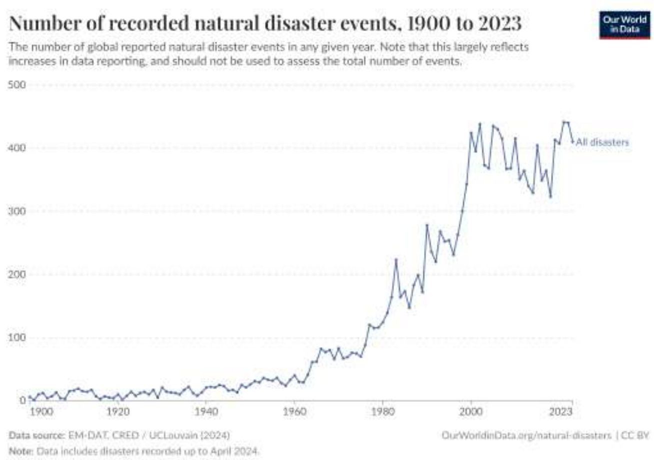
Global temperature anomalies 2024



Source: NASA GISS — GISTEMP v4 Global Maps (https://data.giss.nasa.gov/gistemp/maps/). Public domain.
What this shows: Annual (Jan–Dec) 2024 surface temperature *anomalies* vs the 1951–1980 mean, combining land (GHCNv4) and sea (ERSSTv5); 1200 km smoothing; Robinson projection.

Impacts & risks snapshot





Data & Visualization Sources for Climate

- **NASA GISTEMP v4 — Global Maps:** https://data.giss.nasa.gov/gistemp/maps/
- **Our World in Data — Climate Change:** https://ourworldindata.org/climate-change
- **WMO — State of the Global Climate:** https://public.wmo.int/en/our-mandate/climate
- **Copernicus C3S — Climate Indicators:** https://climate.copernicus.eu/climate-indicators
- **NOAA Climate — Dashboards:** https://www.climate.gov
- **Global Carbon Project — Global Carbon Budget:** https://globalcarbonbudget.org
- **UNFCCC — GHG Data Interface:** https://di.unfccc.int *and* **NDC Registry:** https://unfccc.int/NDCREG
- **WRI Climate Watch — Country & sector GHGs:** https://climatewatchdata.org
- **NASA Sea Level Change — Observations/Projections:** https://sealevel.nasa.gov

COMMUNITY CORNER

International Prize in Statistics 2025: Grace Wahba

The International Prize in Statistics is a biennial global honour celebrating a single major achievement with broad, lasting impact across science and society; the 2025 prize is presented at the World Statistics Congress in The Hague.

Grace Wahba (University of Wisconsin–Madison) is recognised for foundational advances in smoothing splines and reproducing-kernel Hilbert space theory (including the Representer Theorem) and for generalised cross-validation (GCV), which underpin modern nonparametric regression and numerous machine-learning applications. Her ideas continue to shape kernel methods and remain central to contemporary statistical learning.

Mahalanobis International Award 2025: Víctor Manuel Guerrero Guzmán

The ISI's Mahalanobis International Award recognises exemplary contributions to statistics in developing countries—spanning research, leadership, and institution-building that strengthen statistical systems and inform evidence-based policy.

Víctor Manuel Guerrero Guzmán (ITAM, Mexico) is honoured for influential work in time-series analysis and forecasting and for advancing official statistics across Latin America, including innovations in seasonal adjustment, temporal disaggregation, rapid estimation, and trend–cycle analysis. He has strengthened statistical institutions through sustained leadership and training, translating rigorous methods into policy-relevant indicators. His mentorship has helped build capacity across the region and fostered a vibrant community of practice.

Jan Tinbergen Award 2025: Tarikul Islam

The ISI's Jan Tinbergen Award recognises outstanding work by young statisticians and includes an invitation to present at the ISI World Statistics Congress.

Tarikul Islam (University of Dhaka, Bangladesh) is recognised for *"Causal Inference with Misclassified Exposure: Correcting the IPW Estimator,"* introducing a principled correction to inverse-probability weighting for exposure misclassification. Addressing a frequent challenge in administrative and survey data, his approach improves the credibility of causal conclusions in real-world evaluations. In line with the 2025 theme "Statistical Systems," the work advances robust, scalable practice in official statistics.

Other Awards & Recognitions

- **Founders of Statistics Prize 2025** — **Trevor Hastie** & **Hui Zou**, for "*Regularization and Variable Selection via the Elastic Net*" (JRSS B, 2005).
- **David Cox Medal for Statistics (inaugural, 2025)** — **Eric Tchetgen Tchetgen** (proximal/IV causal inference); **Nancy Zhang** (statistical genomics); **Richard Samworth** (shape-constrained methods & change-point analysis).

- **IAOS Young Statisticians Prize 2025** — **1st:** **Hanan Ather**, "*LLM-Assisted Record Linkage*"; **2nd:** **Francesco Ortame** & **Francesco Isidori**, "*Statistical Frameworks for Reliable ML Predictions and Inference*"; **3rd:** **Maynard A. T. Acosta**, **Joermine E. P. Robredo** & **Naha M. T. Bañoc**, "*Real-time Monitoring of HFCE Using Google Trends*"; **Special commendation:** **Achmad F. B. Firmansyah**, "*Modernizing Harvested Paddy Areas Estimation via Satellite Imagery & ML*".
- **Florence Nightingale Award 2024 (IBS/CWSD)** — **Winner: Ulrich Kemmo Tsafack**, "*Tri-level Variable Selection for Ultra-high Dimensional Multi-omics*"; **Runner-up: Diribsa Tsegaye Bedada**, "*Handling Missing Data in HIV Studies with Survey Weights*"; finalists recognised.
- **Hannan Medal 2025 (Australian Academy of Science)** — **Noel Cressie**, for seminal contributions to spatial & spatio-temporal statistics and environmental applications.
- **TIES Best Paper Award 2024** — **Derek Tucker** & **Drew Yarger**, "*Elastic functional changepoint detection of climate impacts from localized sources*".
- **SAE Award 2025** — **Ray Chambers** (Small Area Estimation Award) for outstanding contributions to SAE research and practice.
- **IASS recognitions** — **Isabel Molina** elected Corresponding Member (Royal Academy of Exact, Physical & Natural Sciences of Spain); **Natalie Shlomo** received the 2025 ESRA Outstanding Service Award.
- **Rao Prize Conference 2025 (Penn State)** — Rao Prize: **Trevor Hastie**; Lecturers: **Martin Wainwright** (P. R. Krishnaiah), **Hui Zou** (C. G. Khatri).

Newly Elected ISI Members 2025

Join us in welcoming the newest members of the ISI community.

- David Gunawan (*Australia*)
- Rafael De Souza (*Brazil*)
- F. Richard Guo (*China*)
- Xinhong Yang (*China*)
- Anita Harmina (*Croatia*)
- Sara Taskinen (*Finland*)
- Phillip Yam (*Hong Kong*)
- Enrico Ivaldi (*Italy*)
- Antonietta Mira (*Italy*)
- Takayuki Abe (*Japan*)
- Jae Keun Yoo (*Korea*)
- Carlo Cavicchia (*Netherlands*)
- Janet van Niekerk (*Saudi Arabia*)
- Bojana Milosevic (*Serbia*)
- Shih–Feng Huang (*Taiwan*)
- Stefan Sperlich (*Switzerland*)
- Kiros Berhane (*United States*)
- Matias D. Cattaneo (*United States*)
- Shanshan Ding (*United States*)
- Jianhua Hu (*United States*)
- Tang Lu (*United States*)
- Wang Zhu (*United States*)

Upcoming Webinars

- **23 Oct 2025** — One World Extremes Seminar: *Graphical models for infinite measures with applications to extremes*.
- **29 Oct 2025** — IASS Webinar 57: *Sampling for Business Surveys at Statistics Canada* (Waksberg Award Lecture).
- **17 Dec 2025** — IASS Webinar 59: *Some History of the Use of Models in Survey Sampling*.

Calls for Papers & Special Issues

- **JDSSV (IASC)** — Open call for submissions: ML/statistical learning, visualization & verbalization, visual analytics, big-data infrastructures, interactive learning, advanced computing. *iasc-isi.org*
- **Environmetrics — Special Issue**: *Modern Methods and Applications of Spatio-Temporal Statistics*. **Deadline: 28 Dec 2025**.
- **Environmetrics — Special Issue**: *Extreme Processes and Their Impact on Hazards and Risks*. **Deadline: 30 Sep 2026**.
- **Stochastic Processes and their Applications — Special Issue**: *From linguistics to neuroscience, non-Markovianness & Context Tree Models — A tribute to Antonio Galves*. **Deadline: 31 Dec 2026**.

66th ISI World Statistics Congress
11–15 July 2027 · Busan, South Korea

The 66th ISI World Statistics Congress will bring together statisticians and data scientists from across academia, official statistics, central banks, the private sector, and beyond to exchange knowledge, explore new developments, and build lasting connections.

Busan, a dynamic coastal city known for its cultural richness and warm hospitality, offers an inspiring setting for learning, collaboration, and exchange. Working closely with our Korean colleagues, we're preparing an inclusive, welcoming experience for all participants.

The programme will feature insightful sessions on emerging trends, opportunities for hands-on learning, and spaces to connect and collaborate. ISI and its Associations are made by, not only for, their members, and your participation helps shape the future of statistics.

More info: https://www.isi-next.org/conferences/isi-wsc2027/

5th ISI Regional Statistical Conference 2026
03–05 June 2026 · Valletta, Malta

Join us at the University of Malta for the 5th ISI Regional Statistical Conference, the first held in Europe. Expect invited and contributed sessions spanning statistics and data science, including intersections with AI, with an emphasis on ethical, sound methods and effective social impact.

Meet fellow statisticians and data scientists, enjoy three days of discussions and networking, and discover Malta's rich history and culture in the heart of the Mediterranean.

Deadlines: *Invited Paper Sessions* (*IPS*): 1 Nov 2025; *Contributed Paper Sessions* (*CPS*): 15 Dec 2025.

More info: https://www.isi-next.org/conferences/isi-rsc-malta-2026/

Calendar of Conferences & Workshops

- **4–7 Nov 2025** — LACSC 2025 (IASC-LARS), *Valparaíso, Chile.*
- **5–7 Nov 2025** — EESW25 (European Establishment Statistics Workshop), *Rome, Italy.*
- **24–26 Nov 2025** — uRos 2025 (Use of R in Official Statistics), *Bucharest, Romania.*
- **1–2 Dec 2025** — 4th Workshop on Methodologies for Official Statistics (IASS), *Rome, Italy.*
- **2–6 Mar 2026** — XVII CLAPEM 2026 (Bernoulli Society/SLAPEM/LARC), *Montevideo, Uruguay.*
- **13–16 Jun 2026** — IMS Asia Pacific Rim Meeting (IMS-APRM), *Hong Kong, China.*
- **15–19 Jun 2026** — Stochastic Processes and their Applications (SPA 2026), *Ithaca, NY, USA.*
- **12–17 Jul 2026** — ICOTS 12 (IASE), *Brisbane, Australia.*
- **24–28 Aug 2026** — European Meeting of Statisticians (EMS 2026), *Lugano, Switzerland.*
- **11–15 Jul 2027** — 66th ISI World Statistics Congress (WSC 2027), *Busan, South Korea.*

The ISI Mission

Established in 1885, the ISI is a non-profit, non-government organisation with members in over 150 countries. Our mission is to promote the understanding, development, and good practice of statistics worldwide by fostering knowledge, sharing best practices, and creating opportunities to network. Since 1947, the ISI has held Special Consultative Status with the UN Economic and Social Council, enabling participation in the UN Statistical Commission and related activities. The ISI network spans most national statistical offices, international organisations, and professional societies around the world.

Join the ISI

We welcome members who share our mission of *Statistical Science for a Better World*. The ISI unites statisticians and data scientists across sectors and regions, including students and early-career members. As a member, you gain recognition, community, up-to-date knowledge, discounts, and a growing international network. Membership runs from 1 January to 31 December.

Become a member

Existing or former members: log in to the Membership System with your email (reset password if needed) to renew, reinstate, or add memberships. For assistance: isimembership@isi-web.org.

ISI Journals

International Statistical Review

The flagship journal of the International Statistical Institute and its Associations, publishing broad-interest work in statistics and probability: reviews and expository pieces, statistical computing and graphics, statistics education, and applications across sectors.

Stat

An ISI–Wiley journal for rapid, high-quality dissemination of new theoretical, methodological, and applied results. Compact articles with fast decisions, supported by online materials (data, code, graphics, and media) across all areas of statistics and allied quantitative fields.