Australian Government
Australian Research Council

climate extremes
ARC centre of excellence

Annual Report 2023

ARC Centre of Excellence for Climate Extremes

The ARC Centre of Excellence for Climate Extremes reduces Australia's economic, social and environmental vulnerability to climate extremes.

We do this by

- developing and leading fundamental climate science;
- improving the predictions of extreme weather and climate events;
- fostering collaborative science between five of Australia's leading universities and our Partner Organisations;
- training and investing in the climate science leaders of the future; and
- sharing our knowledge with governments, policymakers, industry and the community.

The ARC Centre of Excellence for Climate Extremes is financially supported via a Major Investment Grant (CE170100023) from the Australian Research Council (ARC). The Centre is financed and hosted by the University of New South Wales.

Collaborating institutions are Monash University, the University of Melbourne, the Australian National University and the University of Tasmania. They provide significant financial and in-kind support. The Centre also receives financial support from the NSW Research Attraction and Acceleration Program, the NSW Department of Planning and Environment and the Bureau of Meteorology.

The ARC Centre of Excellence for Climate Extremes acknowledges the Traditional Owners of Country throughout Australia. We pay our respects to Elders past and present.

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ARC Centre of Excellence for Climate Extremes Annual Report 2023

Who we are

The Australian Research Council **Centre of Excellence for Climate Extremes** is the world's first fully integrated centre focused explicitly on the understanding and prediction of climate extremes.

We research the processes causing climate extremes and build this understanding into the Australian prediction systems, thereby improving our capability to predict extremes into the future.

Climate extremes are high-impact events that can range in time scales from minutes to centuries.

They are estimated to have cost the global economy **US$2.4 trillion** between 1979 and 2012 alone.

By improving our capability to predict these extremes we will inform strategies and policies to minimise these huge sums and **reduce national and global vulnerability to climate extremes** and their potential costs.

Our unique focus is a response to the **World Climate Research Programme's identification of climate extremes as a Grand Challenge.**

This reflects the importance of climate extremes to society, the scientific challenges associated with the understanding and prediction thereof and the lack of major, coordinated activities worldwide to address them.

Thanks to a 30-million-dollar investment from the Australian Research Council (ARC) and collaboration between leading Australian and international research partners, the ARC Centre of Excellence for Climate Extremes accepts the challenge set by the World Climate Research Programme and leads the charge on this globally significant problem.

2023 in Summary

World Class Research

178
Papers Published

71%
of papers in journals with impact factor >4

13.6%
of our publications are in top 10% most cited worldwide

Outstanding Environment

14
PhD completions

70%
of PhD students attended a science or PD workshop

35
in person workshops

48%
of members are women

Exceptional Research Infrastructure

33
million SU of supercomputing time used at NCI

270
CMS tickets actioned

38
Computational modelling support drop-in sessions and presentations open to everyone in the centre

Transforming Collaboration

35
Our students come from over 27 countries

270+
hours of zoom meetings

61%
of our PhDs are international students

90%
of papers are cross institutional

Strong Engagement Beyond Academia

72+
articles and interviews by Centre Researchers

37
policy discussions and briefings to government and industry

161,000+
New website launched with over 100,000 page views

9,900+
media mentions by Centre Researchers

Winners of ARC Centre of Excellence for Climate Extremes Prizes in 2023

Director's Prize:
Sanaa Hobeichi

Best paper by a student:
Hooman Ayat

Best paper by an Early Career Researcher:
Georgy Falster

Outreach Prize:
Ruby Lieber

From the Director

Thinking back to the mid-term review, one of the key areas of advice received was to improve our external profile. One of the major achievements through 2023 was to deliver a sustained and impactful external profile strategy led by our Knowledge Brokerage team but involving a whole-of-centre approach. A key learning outcome from our efforts was a deeper appreciation of the demand for information – ranging from basic information through to technical explainers, plain-English guides to science publications and broad syntheses of major issues. The Australian Research Council Centre of Excellence for Climate Extremes (CLEX) has systematically delivered all of these, and delivery has been led in many cases by our early career researchers (ECRs). This is a new challenge for the ECRs, as traditionally they have been focused on finishing their PhD or writing papers to win a fellowship or a permanent position. Cultivating high-level communication skills in our ECRs and ensuring their efforts are public and citable via digital object identifiers (DOIs), as well as impactful, has required quite a team. So, my congratulations go to Angela Kaplish, Jonathan Brown, Alice Wilson, Georgina Harmer and, very recently, Laure Poncet for their very considerable efforts. And a reminder to all the ECRs: Add that Senate submission, Extremes report, Briefing note, media interview, magazine piece to your CVs!

Speaking of ECRs, a major outcome of Centres of Excellence is the ability to provide multi-themed training to enhance the skills and career potential of students and research fellows. Training in communications and media, writing, presentations, underpinning science, strategy, software development and so on, is beyond most groups, but CLEX has had a long-term strategy, led by Melissa Hart, to develop the talents of our ECRs. Via winter schools, workshops and one-on-one mentoring, the Centre has created a large cohort of outstanding young researchers, with sustained support from the Computational Modelling Systems (CMS) team. The CMS team has run training in Python, code management, use of the National Computational Infrastructure and so on, while simultaneously supporting major initiatives, including the Aus2200 simulations, transitioning to GPUs for machine learning and the almost impossibly hard challenge of managing petascale data for research. Further details on these activities are provided in this annual report.

I've left research until last because if you bring together outstanding researchers, with strong national and international partnerships, excellent infrastructure and active technical support, it is a given that the research will be excellent. But CLEX has exceeded even this standard, delivering a great deal of outrageously high-quality research. We have published 178 papers in 2023. Importantly, a majority of these are in hard-core-discipline journals like *Journal of Climate*, *Geophysical Research Letters*, *Journal of Geophysical Research* and so on. These are papers that form the substantive foundations for future research. A remarkable statistic is that 13.6 percent of our papers are in the top 10 percent of papers cited worldwide in all disciplines. We have also pleased our universities by publishing 23 papers in the *Nature* and *Science* stable of journals. Not surprisingly, given research at this scale and quality, the Centre has been rather swamped by awards and accolades this year, but you will need to read on to discover what those are. A personal congratulations to those recently completed PhD students – there were 14 in 2023. Completing a PhD is an enormous achievement and is never accomplished without hard work, perseverance and raw talent.

Finally, I would like to thank the Chief Investigators. The legacy of COVID-19 continues to flow through and the Chief Investigators have put in huge amounts of time to get COVID-19-affected students across the line in terms of finishing their thesis, juggling increased international commitments that have ramped up again, and organising workshops and hackathons while juggling all the usual expectations of academics. We also welcomed a new crop of Chief Investigators, post the mid-term review, who have energised many activities.

In summary, 2023 demonstrated a Centre of Excellence that undertook a wide range of excellent research, created outstanding mentoring and training opportunities for its ECRs, continued to facilitate the development of research tools and data, and can celebrate a wide range of successes. This does not happen without outstanding administration: Without Vilia Co and her excellent team many of us would simply collapse into dysfunction, so I will conclude by recognising Vilia and her team's superb contribution to the Centre through 2023.

Best wishes,

Professor Andy Pitman
Director, ARC Centre of Excellence for Climate Extremes

From the Chair of the Advisory Board

The year 2023 was one in which the Australian Research Council (ARC) Centre of Excellence for Climate Extremes reached greater heights than ever before, built on the legacies of the talented people who have contributed to and come through the Centre in the last six years. The impact the Centre of Excellence, its research and its people have had on the scientific community, policymakers, industry and the broader community has shone through, as you'll read throughout this annual report.

Over those last six years, the Centre has become a cornerstone of Australia's climate research efforts – and it's no surprise given the level of talent and innovation present at our participating universities and partners. The ARC's investment in the Centre enables the university sector to work on long-term, foundational science projects that require critical mass, and which can only be achieved by collaboration across institutions and disciplines.

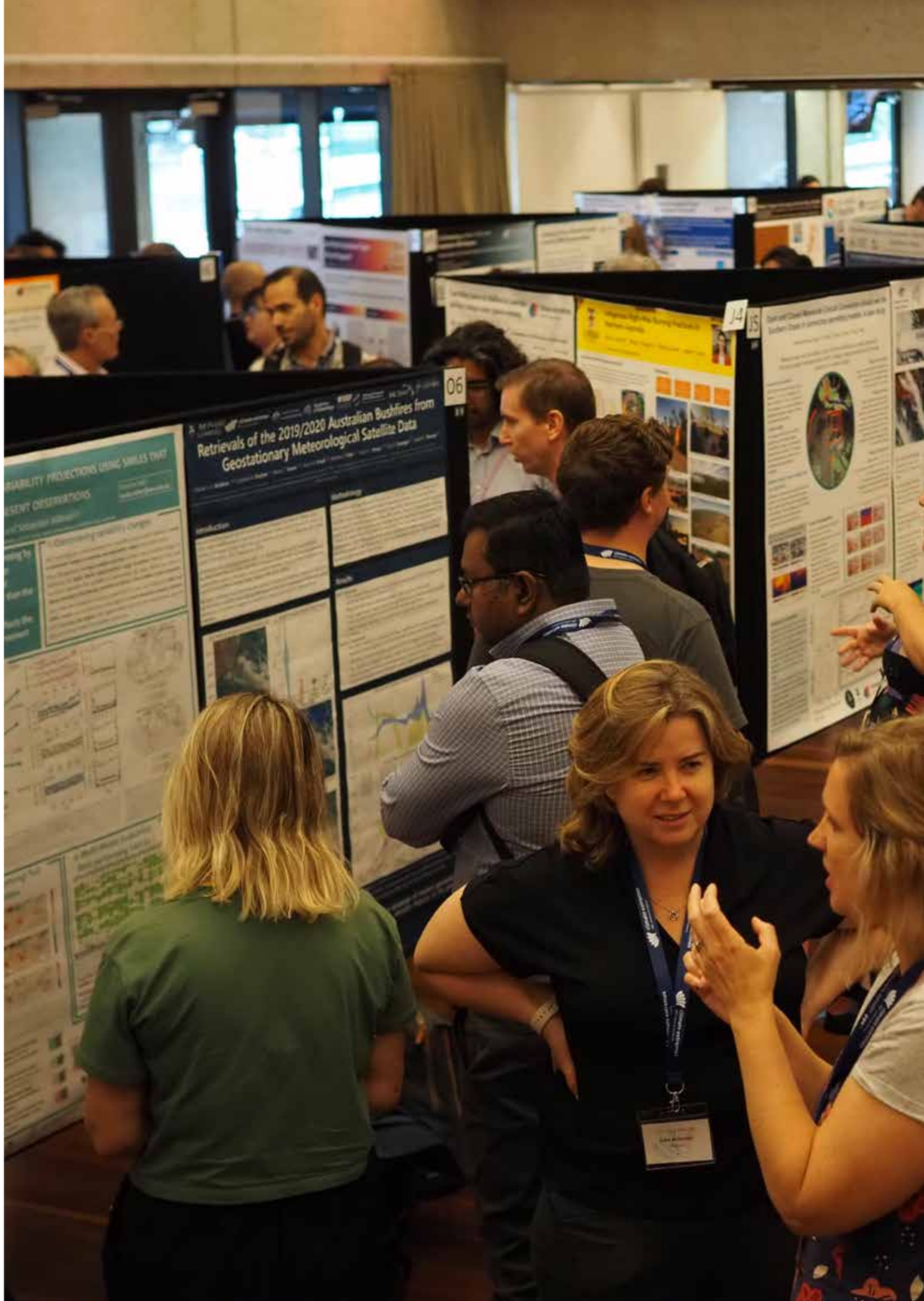
The Centre's Graduate Program has fostered the current generation of climate science leaders, and is seen in the reach of Centre researchers now working across government, industry and academia all over Australia and the world. The students currently doing research within the Centre of Excellence have bright futures, with many of them producing groundbreaking and innovative research at impressively early stages in their careers.

Our researchers have also stepped up their engagement with policymakers and the community, through presenting their research on television, radio, print and digital media, and also by engaging directly in the policy process. An impressive number of the Centre's early career researchers (ECRs) have contributed to reports, inquiries and submissions to federal and state governments, giving a strong scientific backing to smart policy decisions for the future.

In 2024, we will see a new generation of scientific discovery and leadership with the establishment of the ARC Centre of Excellence for the 21st Century Weather. In 2023 we farewelled our Chief Operations Officer, Stephen Gray, as he and Professor Christian Jakob began to establish the new Centre. I thank them for their talent and service to the ARC Centre of Excellence for Climate Extremes and I look forward to seeing what they will go on to achieve with the new Centre.

With that exciting development, the ARC Centre of Excellence for Climate Extremes still has much to do in 2024. Considering the talented ECRs we see in the Centre today, I am certain in a year's time we will have many more stories just like the ones in this report to share.

Dr Tony Press AO
Chair, ARC Centre of Excellence for Climate Extremes Advisory Board



Strategic Plan

Our Vision: Our Centre will transform the understanding and modelling of climate extremes, including their dependence on climate change and variability, to advance scientific understanding and assist decision-makers.

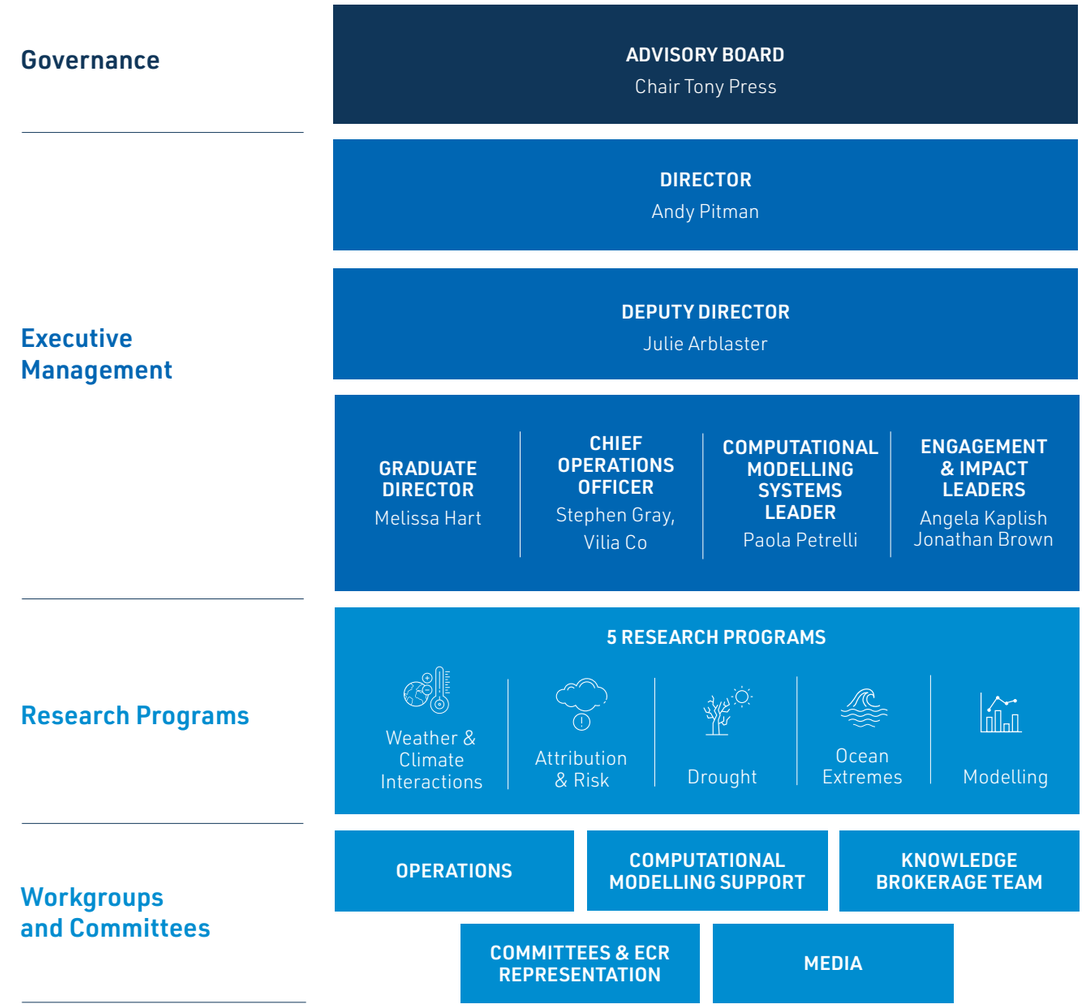
Our Research
We will be a world-leading research centre contributing a significant advancement of knowledge

Our Influence and Outreach
We will have influence and impact beyond academia to have a lasting legacy

Our People
We will demonstrate a commitment to diversity, excellence and community

Strategic Objectives	Success strategy	Strategic foci	
World class research focused on climate extremes	Our research program's success will be measured and reported via the quantity and quality of our publications	1.1	Focus on four key programs: • Weather and Climate interactions • Attribution and Risk • Drought • Ocean Extremes
		1.2	An uncompromising focus on excellence
		1.3	Leadership in national model development and collaboration
		1.4	Fundamental research into climate variability and change
An outstanding environment for all Centre activities	We will measure and report our effectiveness in achieving an exemplar environment for all students and staff	2.1	Enhanced Researcher Development Program to mentor and train the next generation
		2.2	Proactive Equity, Diversity and wellbeing initiatives
		2.3	Ensure early career representation at all levels of Centre activities
		2.4	Foster a culture of community and belonging across the Centre
		2.5	Post-COVID-19 accelerated recovery strategies
Transform collaboration at all scales	We will measure and report the breadth and depth of our collaboration	4.1	Maintain structures that avoid silos
		4.2	Conduct national workshops and training programs
		4.3	Strategic cross-institutional research team
		4.4	Interact with our Advisory Board on key strategic issues
		4.5	Post-COVID-19 accelerated recovery strategies
Exceptional research infrastructure	We will measure and report our effectiveness at maintaining research infrastructure	3.1	The Computational Modelling Systems Team provides advice on modelling and data systems
		3.2	Secure and collaborative relationships with NCI and the ACCESS NRI
		3.3	Be an exemplar for data delivery
		3.4	Develop tools for research that are sustainable beyond the Centre's lifetime
		3.5	Lead collaboration to build the next generation climate model
Research that engages and has impact	We will measure and report our effectiveness in influence and outreach	5.1	Maintain a knowledge brokerage team to facilitate stakeholder engagement
		5.2	Be an influential and dominant voice in key areas of climate extremes
		5.3	Plan and communicate for influence and impact
		5.4	Promote climate science in secondary school STEM subjects
		5.5	Post-COVID-19 accelerated recovery strategies
Identify gaps in our research, training, infrastructure, influence and outreach and seek additional funding to resolve them			

Organisational Chart



Governance, Management and Our Commitment to Equity, Diversity and Inclusion

The Australian Research Council (ARC) Centre of Excellence for Climate Extremes has a robust and efficient governance structure. Our governance model ensures participative decision-making by all Centre members, via the following: our committees for early career researchers, infrastructure, diversity and culture, seminars, and engagement and impact. Each committee presents recommendations to the Centre Executive and provides pdates to monthly Chief Investigator meetings. In addition to these internal structures, the Centre of Excellence receives guidance and strategic advice from its Advisory Board.

Centre Advisory Board

The ARC Centre of Excellence for Climate Extremes is overseen by an Advisory Board, which is chaired by distinguished scientific leader Dr Tony Press. The Centre's Advisory Board provides strategic oversight and advice to the Centre of Excellence, as well as monitoring the Centre's performance against its stated Key Performance Indicators. The Advisory Board met once in 2023, on 1 November.

Advisory Board Members in 2023

Dr Tony Press, Adjunct Professor, UTAS, Antarctic Climate and Ecosystems Cooperative Research Centre (Chair)

Dr Tony Press is an Adjunct Professor at the Antarctic Climate and Ecosystems Cooperative Research Centre, where he served as its chief executive officer from 2009 to 2014. Dr Press has had a long career in science, natural resource management, public administration and international policy.

Dr Press chaired the Antarctic Treaty's Committee for Environmental Protection (CEP) from 2002 to 2006. He was Australia's representative to the CEP and alternative representative to the Antarctic Treaty Consultative Meetings from 1999 to 2008. He was Australia's Commissioner for the Convention on the Conservation of Antarctic Marine Living Resources from 1998 to 2008.

Dr Jaci Brown, Research Director, CSIRO Climate Science Centre

Dr Jaci Brown is the Research Director for the Climate Science Centre in CSIRO's Ocean and Atmosphere Business Unit. Dr Brown's research has spanned tropical oceanography, climate projections, fisheries, high-resolution ocean defence tools and seasonal atmospheric processes in Australia. Her previous role was as a team leader in CSIRO's Agriculture and Food Business Unit. There, Dr Brown led the Weather and Climate Decisions team. This team focused on delivering actionable weather and climate knowledge to stakeholders.

Ian T. Dunlop, Independent Advisor & Commentator, Climate Change & Energy

Ian Dunlop is a Cambridge-educated engineer, formerly a senior executive in the international oil, gas and coal industries. He chaired the Australian Coal Association in 1987 to 1988. From 1998 to 2000 he chaired the Australian Greenhouse Office Experts Group on Emissions Trading, which developed the first emissions trading system design for Australia. From 1997 to 2001 Ian was chief executive officer of the Australian Institute of Company Directors. He has a particular interest in the interaction of corporate governance, corporate responsibility and sustainability.

Ian is a director of Australia 21, a fellow of the Centre for Policy Development and a member of The Club of Rome. He advises and writes extensively on governance, climate change, energy and sustainability.

Danielle Francis, Manager Liveable Communities, Water Services Australia

In her 20 years in the Australian water industry, Danielle has led communications, regulatory, pricing, stakeholder and strategy portfolios to help the industry deliver valued services to the community.

Today, as Manager, Liveable Communities at Water Services Australia, Danielle oversees work on national and regional collaboration, learning and advocacy on water security, integrated water-cycle management and climate change. She also develops initiatives to promote understanding and adoption of circular-economy principles in the water industry. In addition, Danielle leads work to promote recognition and integration of Indigenous water values and knowledge in water management and water services.

Dr Greg Holland, Willis Senior Scientist Emeritus, National Center for Atmospheric Research, Boulder, USA

Dr Greg Holland is Willis Senior Scientist Emeritus at the US National Center for Atmospheric Research (NCAR). He is also a member of the Zurich Insurance Advisory Council for Catastrophes and a key stakeholder for the European ISIpedia. Dr Holland was previously director of NCAR's Earth System Laboratory and the Capacity Center for Climate and Weather Extremes. He has served on a number of committees and review boards for the National Oceanic and Atmospheric Administration, the US National Academies and NASA, and he chaired the Tropical Meteorological Program of the World Meteorological Organization for 12 years.

Dr Holland's current research focuses on climate variability and change and its effect on weather and climate extremes. He holds a PhD in Atmospheric Science from Colorado State University. He is a fellow of both the American Meteorological Society and the Australian Meteorological and Oceanographic Society.

Professor Dane McCamey, Pro Vice-Chancellor (Research), UNSW

Professor Dane McCamey is Pro Vice-Chancellor (Research) at the University of New South Wales, Sydney. His research interest is in condensed-matter physics, in particular the role that spin (a quantum property of subatomic particles) plays in the function of optoelectronic materials and devices. His research spans from fundamental investigation of quantum properties through to applications in photovoltaics and quantum technologies. Prior to his current role, Prof McCamey was deputy dean of Research and Enterprise for UNSW Science and also served as deputy director of the ARC Centre of Excellence in Exciton Science.

Dr Jon Petch, Director, Climate and Global Dynamics (CGD) Lab, National Center for Atmospheric Research, Boulder, USA

Jon Petch is the director of the Climate and Global Dynamics (CGD) Lab at the National Center for Atmospheric Research (NCAR) in the USA. In this role, he leads a team of over 100 scientists and software engineers, overseeing diverse research in earth system science. The lab plays a crucial role in developing and supporting the Community Earth System Model (CESM), a global climate model. Jon also holds a visiting professor position at the University of Leeds, specialising in Weather and Climate Modelling, and chairs the Science Advisory Group for the US Department of Energy's next-generation earth system model program. He is involved in various international initiatives and advisory panels, showcasing his expertise in atmospheric model development and numerical experiments.

Matthew Riley, Director, Climate and Atmospheric Science, NSW Department of Planning and Environment

Matthew Riley is Director of Climate and Atmospheric Science at the NSW Department of Planning and Environment (DPE). Matthew is also the Director for the NSW and ACT Regional Climate Modelling Project, and leads DPE's Climate Change Impacts research program. In addition, Matthew is responsible for the operation of the 43 monitoring stations of the NSW Air Quality Monitoring Network and leads the NSW Government's air quality research program. Matthew has over two decades of experience in urban meteorology, climatology and air-quality measurement.

Dr Kathryn Smith, Assistant Secretary of the National Adaptation Policy Office

Dr Kathryn Smith is Assistant Secretary at the National Adaptation Policy Office, which is part of the Climate Change Group in the Department of Climate Change, Energy, the Environment and Water. In that role Dr Smith works on climate adaptation across all governments, and is responsible for climate science coordination.

Dr Bertrand Timbal, Head of Research, Bureau of Meteorology

Dr Bertrand Timbal moved to Australia and joined the Bureau of Meteorology in 1996, after completing his PhD at the French National Met Service (Meteo-France) in 1994. After a three-year stint leading the Climate branch at the Centre for Climate Research Singapore, Dr Timbal re-joined the Bureau of Meteorology in 2020 as the General Manager for the research program, Science and Innovation Group. In this role, he leads a program of 130 scientists, support scientists and science managers delivering along the four objectives of the Bureau of Meteorology's Research and Development Plan.

Centre Executive

The Centre Executive is composed of the Centre Director, who carries overall responsibility for day-to-day leadership of the ARC Centre of Excellence for Climate Extremes and its research; the Deputy Director; the Chief Operations Officer; the Graduate Director; the Manager of the Computational Modelling Systems team; and the leaders of the Engagement and Impact team.

Each of the Centre's research programs has a pair of co-leaders who set and monitor yearly and longer-term research priorities. All Chief Investigators meet monthly to discuss Centre business and cross-nodal research activity and initiatives.

Centre Committees

To maximise the effectiveness of the ARC Centre of Excellence for Climate Extremes as a cohesive entity, we have established three key committees that report to the Centre Executive, each with an important and specific remit to enhance collaboration across the Centre and drive focus in key areas of our Centre strategy – namely, equity and diversity; outreach and pathways-to-impact; and infrastructure and technology.

Diversity and Culture Committee

Chairs: Melissa Hart (UNSW) and Stephen Gray (UNSW)

Members: Hooman Ayat (UniMelb), Isabelle Greco (UNSW), Fadhlil Rizki Muhammad (UniMelb), Andy Pitman (UNSW), Jenny Rislund (UNSW), Martin Singh (Monash) and Andrea Taschetto (UNSW)

The Centre of Excellence is committed to providing an unrivalled working environment for its students and staff. Consequently, we're implementing measures that enhance the diversity of our staff and student populations and proactively ensuring we build and maintain an equitable culture.

The Diversity and Culture Committee provides advice and recommendations to the Centre Director and Centre Executive on matters pertaining to equity, diversity and Centre culture, including mental health and wellbeing. The committee leads Centre-wide initiatives and drafts policies and procedures within its sphere of influence. The committee's activities are based on research and on benchmarking of best practice in the equity, diversity and culture landscape in Science, Technology, Engineering and Mathematics and in higher education generally.

Engagement and Impact Committee

Chairs: Angela Kaplish and Jonathan Brown (UNSW)

Members: Nerilie Abram (ANU), Ailie Gallant (Monash), Amelie Meyer (UTAS), Kim Reid (Monash), Zoe Gillett (UNSW), Alice Wilson (Monash)

The Engagement and Impact Committee at the Centre of Excellence brings together some of Australia's most talented policymakers, media and communications specialists, science communicators, content makers and designers, and more, to ensure that the essential science of climate extremes is heard by the people who need to know.

The committee advises and collaborates with the Centre's Engagement and Impact team to deliver training, resources and opportunities for Centre researchers to share their work and expertise with government, industry and the community.

Early Career Researcher Committee

Chairs: Wilma Huneke (ANU), Estefania Montoya Duque (UniMelb), Doug Richardson (UNSW), Georgy Falster (ANU)

Members: Qing Yee Ellie Ong (UNSW), Malcolm King (Monash), Yawen Shao (UniMelb), Ramkrushnbhai Patel (UTAS), Yuxin Wang (UTAS), Tahereh Alinejadtabrizi (Monash), Claire Yung (ANU), Jarrah Harrison-Lofthouse (UniMelb), Alexander Borowiak (UniMelb), Rachael Isphording (UNSW), Jiaxin Shi (UTAS), Sramana Neogi (Monash), Zijie Zhao (UTAS)

The ECR committee's mission is to facilitate, encourage, and contribute to the development of all Australian Research Council Centre of Excellence for Climate Extremes early career researchers (ECRs). The committee is composed of at least one student and at least one postdoc representative from each of the Centre's five partner institutions.

Committee members have an opportunity to:

- help shape the Centre's professional and social events to reflect their and their fellow ECRs' needs and goals;
- gain leadership experience; and
- gain insight into how the Centre operates.

Infrastructure Committee

Chair: Paola Petreli (UTAS)

Members: Gab Abramowitz (UNSW), Dietmar Dommenget (Monash), Jason Evans (UNSW), Wilma Huneke (ANU), Neil Holbrook (UTAS), Ramkrushnbhai Patel (UTAS)

The Infrastructure Committee's primary role is to aid the Computational Modelling Systems (CMS) team in the prioritisation and delivery of the services it provides. This includes facilitating discussion and decision-making around which modelling systems and data sets should be considered in or out of scope, as well as identifying emerging modelling systems or data sets that offer new opportunities for the Centre of Excellence. The committee is also tasked with helping the CMS team allocate, compute and store resources in respect to Centre research programs – particularly where there are competing requests – as well as liaise with National Computational Infrastructure and other relevant national infrastructure bodies.

These roles are intended to help maintain strong communication between Centre researchers and the CMS team, as well as support the latter in prioritising competing requests for its time.

Centre Operations Team

The transformative research that the Centre of Excellence continues to deliver is supported by a dedicated team of professional staff.

Stephen Gray (formerly chief operations officer) left the Centre in mid-2023 for a well-deserved break and to pursue new opportunities. Vilia Co, the Centre's Finance Manager, has stepped in as Chief Operations Officer.

The operations team is further comprised of Senior Project Officer Jenny Rislund (UNSW), Finance Officer Susana Widjaja (UNSW), Node Administrator Sushila Desai (UTAS), Mary Hapel (ANU), Silvana Katragadda (Monash), Taira Malby-Freckleton (UNSW) and Simon Parsons (UniMelb). In 2023, the following departed: Project Officer Ellen Hooper (UNSW), Node Administrator Sook Chor (Monash), Christine Fury (UTAS) and Carmen Tucker (ANU).

Leadership Development

We are strongly committed to providing leadership training, mentorship, guidance and opportunities for all ARC Centre of Excellence for Climate Extremes researchers, including our students and early career researchers (ECRs), along with our professional and technical staff.

Our Centre is unique among Australian Centres of Excellence in appointing a dedicated, full-time senior Graduate Director to build a fully integrated leadership and professional development program for our staff and students.

What our Centre offers far exceeds a typical 'mentoring program' in both scale and ambition. We provide bespoke, end-to-end support for our graduate students and ECRs, via the following:

- individual training-needs analyses;
- support for internships;
- a curated calendar of annual workshops, addressing both scientific and professional skills; and
- access to funding to support research visits to nodes and Partner Organisations, summer schools and other career-enhancing opportunities.

Furthermore, our students and ECRs are represented via our Early Career Researcher Committee, with an ECR representative attending Chief Investigator meetings. That committee also organises professional development and training events, including dedicated events at the national Australian Meteorological and Oceanographic Society annual meetings. It helps facilitate dedicated ECR funding applications that enable our researchers to lead small projects that expand beyond the scope of their research programs.

Our Engagement and Impact team delivers training and creates opportunities for Centre researchers and students to boost their skills in government relations, policymaking, industry engagement, science communications, media commentary, public speaking and more. The team focuses on fostering the next generation of leaders in engagement and impact through long-term skill building.

Equity, Diversity and Inclusion

Our Centre fosters a culture of diversity and inclusion

Our goal is to make the Centre of Excellence a forward-thinking organisation that enables all staff and students, regardless of background, to do their best work in a professional and compassionate environment. Our equity plan is an ambitious document to guide the Centre's efforts to fulfil our aim of being an exemplar in this space. We are serious about creating a respectful research environment for our diverse population of researchers, to ensure our staff and students can reach their full potential, and we are equally committed to making a meaningful contribution to addressing historical prejudices and inequality in Science, Technology, Engineering and Mathematics disciplines.

Research Ethics and Intellectual Property

The ARC Centre of Excellence for Climate Extremes is committed to uncompromisingly high standards of professional conduct and rigour in all activities, including all aspects of our research.

Arguably, few disciplines receive as much public scrutiny as climate science. Accordingly, climate scientists have long embraced openness, accountability and an open-source approach to their work. This ensures originality and reproducibility of research, adherence to proven methodological frameworks and rigorous data-management practices. Adherence to Findability, Accessibility, Interoperability and Reusability (FAIR) is normal practice in our field; indeed, we have been influential in driving this agenda, including in the production of recent Academy of Science reports. All new staff and students at the Centre of Excellence receive information on the ethical conduct of research as part of their Centre induction, and reminders of this responsibility are periodically circulated.

Intellectual property customarily relates to inventions as opposed to discoveries. Research in our Centre is driven by our overarching goal to better understand the physical processes in the global climate system that contribute to extremes across scales of time and space. In other words, we are a Centre of Excellence focused primarily on discovery.

Globally, the climate science community has always worked from a foundational premise that all our work is open source and shared such that others may build on work that has preceded their own, without restriction beyond the norms of attribution. Thus, code, data, models and so on are openly shared, and we benefit from this by having access to data and models that would be impossible for Australia to develop independently. By returning our contributions into that system, we provide the rationale for the rest of the world maintaining, in turn, open access to their data and models. Accordingly, we place greater emphasis on proper data management – including publishing data and code – than on traditional notions of intellectual property.

This approach to open-source development of our models and tools that assist us in interrogating model output is made explicit in the Centre's inter-institutional agreement. The agreement also offers an intellectual property framework to follow if at any point the Centre developed an invention or product that meets the standard definitions of intellectual property.

Consequently, intellectual property is a low priority in climate science – to raise this priority would break our capacity to engage internationally and access data and models developed by the climate science community. However, we recognise that around half of our graduates leave academia and research to take positions in government or industry where intellectual property considerations may be material. We are therefore developing an internal training module on intellectual property that is specific to the uniquely open-source approach taken by researchers in our field.

Chief Investigators

Director
Professor Andy Pitman AO

Professor Andy Pitman was born in Bristol and was awarded a bachelor's degree with honours in physical geography and a PhD in Atmospheric Science by the University of Liverpool, UK. He also holds a Postgraduate Certificate in Educational Leadership from Macquarie University. He has been at the University of New South Wales since 2007. He was the director of the Australian Research Council (ARC) Centre of Excellence for Climate System Science (2011 to 2017) and is now Director of the ARC Centre of Excellence for Climate Extremes.

Prof Pitman's research focus is on terrestrial processes in global and regional climate modelling, model evaluation and earth systems approaches to understanding climate change. His leadership, collaboration and research experience is extensive both nationally and internationally. Between 2004 and 2010 he convened the ARC Research Network for Earth System Science, which facilitated interaction between individuals and groups involved in climate system science.

He is a member of the Australian Community Climate and Earth System Simulator initiative, the Academy of Science's National Committee for Earth System Science and the NSW Minister for Climate Change's Science Advisory Committee. He is also heavily engaged in e-research, including most recently on the taskforce assessing the roadmap for national research infrastructure.

Internationally, Prof Pitman is closely affiliated with the World Climate Research Programme (WCRP). He was a long-term member and former chair of the WCRP's Land Committee for the Global Land Atmosphere System Study. As co-chair, he jointly led one of the first major international intercomparison exercises: the Project for the Intercomparison of Land Surface Parameterization Schemes, which is supported by the WCRP and the International Geosphere Biosphere Programme. He also sat on the Science Steering Committee of the Integrated Land Ecosystem-Atmosphere Processes Study and is currently co-coordinator of the Land Use Change: Identification of Robust Impacts project.

Prof Pitman is a regular invitee for keynote presentations and is a passionate communicator about science, contributing regularly to the media on the science of climate change. He was a Lead Author for the Intergovernmental Panel on Climate Change (IPCC) 3rd and 4th Assessment Reports, contributing to the award of the Nobel Peace Prize to the IPCC in 2007. He was review editor of the 2013 IPCC report. He has also contributed to the Copenhagen Diagnosis, an Australia-led update of the science of climate change. Prof Pitman has held editorial positions with the *Journal of Climate* and the Annals of the Association of American Geographers' *Journal of Geophysical Research-Atmospheres*, and he is currently an associate editor for the *International Journal of Climatology*.

Prof Pitman was appointed an Officer of the Order of Australia in 2019. Other awards and accolades he has received include: The Royal Society of Victoria's Medal for Excellence in Scientific Research (2019), NSW Scientist of the Year Award (2010), the Australian Meteorological and Oceanographic Society (AMOS) Medal (2009), the Dean's Award for Science Leadership at Macquarie University (2005), the Priestley Medal for Excellence in Atmospheric Science Research (2004) and the Geoff Conolly Memorial Award (2004). Prof Pitman jointly won the International Justice Prize for the Copenhagen Diagnosis (2010) and was among Sydney Magazine's list of the 100 most influential people (2010). He is a fellow of AMOS and of the American Meteorological Society.

Prof Pitman has a long track record of nurturing early career researchers and has supervised multiple PhD students through to successful completion. He has published over 200 papers in peer-reviewed journals and has authored 20 book chapters.

Deputy Director
Professor Julie Arblaster

Professor Julie Arblaster's research interests lie in using climate models as tools to investigate mechanisms of recent and future climate change, with a focus on shifts in the Southern Hemisphere atmospheric circulation, tropical variability and climate extremes. She is particularly interested in the interplay between the predicted recovery of the Antarctic ozone hole over coming decades and greenhouse gas increases in future climate projections, with its potential impacts on the surface, ocean circulation and sea ice. Her recent work has also focused on explaining extreme events in Australia, such as record-breaking temperatures and rainfall, in terms of both the role of human influences on climate and the diagnosis of the climate drivers. Prof Arblaster's research incorporates the use of observations, multi-model data sets and sensitivity experiments with a single model. Her strong collaboration with the National Center for Atmospheric Research in the U.S. and participation in various international committees and reports enhances her engagement with the latest advances in climate research internationally.

Prof Arblaster is a fellow of the Australian Meteorological and Oceanographic Society and was awarded their Priestley Medal in 2018 as well as the 2014 Australian Academy of Science Anton Hales Medal for research in earth sciences. She served as a Lead Author of the Intergovernmental Panel on Climate Change 5th Assessment Report and was on the scientific steering committee for the World Meteorological Organization/United Nations Environment Programme Scientific Assessment of Ozone Depletion. Prof Arblaster is also a member of the World Climate Research Programme Coupled Model Intercomparison Project panel and the Australian Academy of Science National Committee on Earth System Science.

Graduate Director
Associate Professor Melissa Hart

Associate Professor Melissa Hart has led and developed a national, cross-institutional graduate program which has reimagined the traditional Australian PhD. With a vital combination of breadth, depth, support and collaboration, the program has provided over 300 PhD students with the skills, knowledge and experience fundamental to developing world-leading climate science leaders equipped for employment across a range of sectors.

A/Prof Hart's leadership has been recognised via a UNSW Vice-Chancellor's Award for higher-degree research leadership and has been profiled in the Higher Education Supplement of *The Australian* newspaper. Internationally, she has represented Australia at World Meteorological Organization symposiums on challenges of contemporary meteorological education, and co-chairs the steering committee of the World Climate Research Programme training academy.

A/Prof Hart's research looks at the impact of cities on climate and climate on cities, as well as the meteorological controls on air pollution. A strong advocate for gender equity in science, she is a past chair of the Australian Meteorological and Oceanographic Society's Equity and Diversity Committee and a proud participant of the 2018 Homeward Bound Women in STEMM leadership initiative.

Professor Nerilie Abram

Professor Nerilie Abram uses paleoclimate records to study how Earth's climate has behaved in the past in order to provide a long-term perspective on recent climate change. She has a particular focus on reconstructing climate variability in the tropical Indian Ocean and Antarctica and studying how this impacts Australia's rainfall patterns. Prof Abram's work also involves proxy-model comparisons to assess forcing mechanisms behind natural and anthropogenic climate changes and to help test climate model performance in historical and last-millennium experiments.

Prof Abram holds an Australian Research Council Future Fellowship. In 2015 she received the Dorothy Hill Award from the Australian Academy of Science for her research achievements. She was a Coordinating Lead Author of the Intergovernmental Panel on Climate Change Special Report on the Ocean and Cryosphere in a Changing Climate, released in September 2019.

Professor Gab Abramowitz

Professor Gab Abramowitz's primary research interest is in evaluating computational models in climate science, ecology and hydrology. Currently his research focuses on two main areas: defining and accounting for model dependence in multi-model, ensemble climate prediction; and standardising model evaluation in land surface research. Climate research teams share literature, data sets and even sections of model code. To what extent, then, do different climate models constitute independent estimates of a climate prediction problem? What is the most appropriate statistical framework with which to define model independence? What are the implications of ignoring model dependence for future climate projection?

Prof Abramowitz is also leading the development of **modelevaluation.org**, a web application that provides automated land surface, hydrological and ecological model evaluation tools as well as observational data sets. He is a member of the Global Energy and Water Cycle Experiment Global Land-Atmosphere System Study panel.

Professor Lisa Alexander

Professor Lisa Alexander holds a BSc (Hons) and MSc in Applied Mathematics from Queens University Belfast and a PhD in Climate Science from Monash University. She previously worked as a research scientist at the UK Meteorological Office Hadley Centre, including a year on secondment at Australia's Bureau of Meteorology.

Prof Alexander's primary research focuses on understanding the variability and driving mechanisms of climate extremes. Of particular significance is her ongoing work assessing global changes in temperature and rainfall extremes, which has contributed significantly to the Intergovernmental Panel on Climate Change (IPCC) assessments.

Prof Alexander was awarded the 2011 Priestley Medal by the Australian Meteorological and Oceanographic Society (AMOS) and the 2013 Australian Academy of Science Dorothy Hill Award for her contribution to this field of research. In 2020 she became a fellow of AMOS. She has contributed to IPCC assessments in 2001, 2007 and 2021 and to the 2012 Special Report on Extremes and was a Lead Author of the IPCC's 5th Assessment Report. Prof Alexander also chairs a World Meteorological Organization expert team, is a member of the International Association of Meteorology and Atmospheric Sciences Executive Committee and sits on the Joint Scientific Committee of the World Climate Research Programme.

Professor Craig Bishop

Professor Craig Bishop completed his PhD in Applied Mathematics at Monash University. His innovative ensemble-based data assimilation and ensemble-forecasting techniques are now widely used by leading environmental forecasting agencies in several countries. Prof Bishop has held positions at the University of Reading, the NASA Goddard Space Flight Center, Pennsylvania State University's prestigious Department of Meteorology and the Marine Meteorology Division of the Naval Research Laboratory (NRL) in Monterey, California. There he garnered six outstanding-contribution awards, three NRL Alan Berman publication awards and an NRL Edison Patent Award.

Prof Bishop's positions of service to the climate and weather community include serving as co-chair of the World Meteorological Organization's Working Group on Predictability, Dynamics and Ensemble Forecasting; associate editor of the *Quarterly Journal of the Royal Meteorological Society*; and chair of the Science Steering Committee of the Joint (NASA, NOAA, US Navy, US Air-Force, National Science Foundation) Center for Satellite Data Assimilation. He was elected to the International Commission on Dynamical Meteorology in 2010 and as a fellow of the American Meteorological Society in 2012. Prof Bishop returned to Australia as Professor of Weather Prediction at the University of Melbourne, in June 2018. His research in Australia has focused on using observations to improve estimates of past, current and future weather and climate.

Professor Dietmar Dommenget

Professor Dietmar Dommenget completed his Diploma (MSc) in Physics at the University of Hamburg. He was awarded a PhD by the Max-Planck Institute for Meteorology in 2000. He joined the ECCO (Estimating the Circulation and Climate of the Ocean) project in a postdoctoral position at the Scripps Institution of Oceanography in La Jolla, California, to study the predictability of El Niño with an adjoint data-assimilation scheme. After three years in California he returned to Germany in 2003 for a fixed-term faculty position as a junior professor (lecturer) in the Meteorology department at the Helmholtz Centre for Ocean Research Kiel. Since 2010, Prof Dommenget has been at Monash University in the atmospheric and climate science group of the School of Earth, Atmosphere and Environment.

Prof Dommenget's research focuses on large-scale climate dynamics and climate modelling. He works with climate models at all levels of complexity. Most of his work centres on the development, conducting and analysis of coupled general-circulation models, but he has also developed simple conceptual models of natural climate variability. Most of his work focuses on sea surface temperature variability in the tropical and extratropical oceans.

Prof Dommenget is most widely known for his work on the interpretation of patterns and modes of climate variability. His most recent projects focus on El Niño, climate model developments and climate change. He developed a new type of climate model for the conceptual understanding of the climate response to external forcing, which is a fast and simple tool for researchers, students and the public to understand the interactions in the climate system. An outreach program based on this is called the Monash Simple Climate Model.

Professor Jason Evans

Professor Jason Evans completed his undergraduate degrees in physics and mathematics at Newcastle University in 1996 and earned his PhD in Environmental Management from the Australian National University in 2001. He then spent six years as a postdoctoral and then research fellow at Yale University in the USA. In 2007 he returned to Australia to take up a position in the Climate Change Research Centre at UNSW, where he remains today.

Prof Evans' expertise is in the area of regional climate, land-atmosphere interactions, the water cycle and climate change. His focus is on regional climate change and its impacts. His research program brings together advanced modelling tools with extensive observational data sets, with an emphasis on satellite-based, remotely sensed earth observations.

Prof Evans was a Lead Author on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems. He is on the Science Advisory Team for the Coordinated Regional Climate Downscaling Experiment, an element of the World Climate Research Programme. He was an editor of the *Journal of Climate* from 2016 to 2022. In 2020 Prof Evans was elected a fellow of the Modelling and Simulation Society of Australia and New Zealand, and in 2021 he received their Biennial Medal for outstanding contributions to modelling and simulation over a sustained period. He was also elected a fellow of the Royal Society of New South Wales, in 2021.

Associate Professor Ailie Gallant

Ailie Gallant is an associate professor in the School of Earth, Atmosphere and Environment in the Faculty of Science at Monash University. Her research focuses on drought and on precipitation variability and precipitation extremes. Associate Professor Gallant's most recent research interests include understanding what causes droughts to start and end, with a particular focus of the role of changes in weather systems during droughts.

A/Prof Gallant is a Chief Investigator for both the ARC Centre of Excellence for Climate Extremes and the upcoming ARC Centre of Excellence for the Weather of the 21st Century. She is also the Monash node lead of the National Environmental Science Program Climate Systems Hub and the Deputy Director of the Monash Climate Change Communication Research Hub.

Professor Andy Hogg

Professor Andy Hogg completed his undergraduate degree in physics at the Australian National University in 1996 and was awarded his PhD in Geophysical Fluid Dynamics from the University of Western Australia in 2002. He then spent three years as a postdoctoral fellow at the Southampton Oceanography Centre, where he developed a new, high-resolution coupled ocean-atmosphere model. In 2004 he returned to ANU to take up a position as an Australian Research Council (ARC) postdoctoral fellow. He is currently based at ANU's Research School of Earth Sciences.

Prof Hogg's research interests centre on physical processes governing the ocean and climate. His work within the ARC Centre of Excellence for Climate Extremes is focused on understanding ocean-atmosphere interactions in the Southern Ocean, particularly the exchange of heat, momentum and carbon between different components of the climate system. He plays a key role in developing tools to understand the climate system at progressively finer scales.

Prof Hogg is now Director of the Australian Community Climate and Earth-System Simulator-National Research Infrastructure, funded by the National Collaborative Research Infrastructure Strategy to develop Australia's climate modelling capability.

Professor Neil Holbrook

Neil Holbrook is Professor of Ocean and Climate Dynamics within the Institute for Marine and Antarctic Studies at the University of Tasmania (UTAS). He co-leads the ARC Centre of Excellence for Climate Extremes Ocean Extremes research program, and is the Centre's UTAS node lead.

Prof Holbrook's research concentrates on developing process-based understanding and improved knowledge of the predictability of ocean and climate extremes, focusing on marine heatwaves (MHWs) – the ocean analogue of atmospheric heatwaves that can have devastating impacts on life in the sea. Prof Holbrook has been a critical player in pioneering our understanding of marine heatwaves. He designed and led the first global assessment of the drivers of marine heatwaves, which elucidates the potential predictability of enhanced or suppressed MHW likelihoods associated with large-scale climate modes. The outcomes of this research have set the baseline for future studies of MHW processes and predictability and led to a follow-up article advancing the thinking around MHW processes, predictability and prediction. Recently, Prof Holbrook led a study of MHW impacts/projections in the tropical western and central Pacific Island nations and their communities. He co-leads an international Working Group on MHWs and is also a member of the international Climate Variability and Predictability Research Focus on Marine Heatwaves in the Global Ocean.

Prof Holbrook is an elected fellow of the Australian Meteorological and Oceanographic Society and an associate editor of the *Journal of Southern Hemisphere Earth Systems Science*. He is a former president of the International Commission on Climate of the International Association of Meteorology and Atmospheric Science/International Union of Geodesy and Geophysics (2011 to 2019) and an associate editor of the *Journal of Climate* (2006 to 2008). He also led Australia's National Climate Change Adaptation Research Network for Marine Biodiversity and Resources (2009 to 2013).

Prof Holbrook is recognised as a Clarivate Highly Cited Researcher (2021 to 2023) and was named on the Reuters list of 1000 most influential climate scientists (2021).

Dr Yi Huang

Dr Yi Huang is a senior lecturer in climate science at the School of Geography, Earth and Atmospheric Sciences, the University of Melbourne. Her research seeks to address some of the fundamental yet climatically important questions that underpin the understanding of atmospheric processes, Earth's energy budget and the water cycle. For example: How do clouds and precipitation modulate the Earth's climate system? What processes control the properties of clouds and precipitation? How do these processes differ geographically? Dr Huang addresses these questions through a combination of targeted field observations, remote-sensing data (including machine learning), deep theoretical understanding and high-resolution numerical modelling. Ultimately, her work aims to harness the critical knowledge that will help improve weather and climate predictions at multiple scales.

Dr Huang's main research interests are Southern Hemisphere meteorology and cloud and precipitation physics. Her projects involve the employment of in-situ/aircraft measurements, remote-sensing (space-borne and ground-based) observations, historical observations, reanalysis data sets and state-of-the-art numerical simulations, in order to understand clouds and precipitation generated by the Southern Hemisphere extratropical weather systems, how they link to Australian rainfall (including extremes), and how they differ from their Northern Hemisphere counterparts (such as the North Atlantic and North Pacific oceans). In addition, Dr Huang has developed interest and expertise in boundary layer meteorology, air-sea Interaction, and mountain meteorology (for example, orographic precipitation across south-eastern Australia). She has also conducted applied research in collaborations with several domestic industry partners, including Snowy Hydro and Hydro Tasmania.

Professor Christian Jakob

Professor Christian Jakob was awarded his PhD in Meteorology from the Ludwig Maximilians University, Munich, in 2001. As a research and senior research scientist for the European Centre for Medium-Range Weather Forecasts from 1993 to 2001, he worked on the development and evaluation of the model representation of clouds, convection and precipitation. From 2002 to 2007 he was senior and principal research scientist at the Bureau of Meteorology, and since 2007 he has been a professor at Monash University. Currently he is the Chair of climate modelling at Monash's School of Earth, Atmosphere and Environment. He is also the Director of the ARC Centre of Excellence for the Weather of the 21st Century.

Prof Jakob's interests are in the development and evaluation of the processes crucial to the energy and water cycles in global atmospheric models. He is also interested in better understanding how our weather is going to change as the planet warms. Internationally, Prof Jakob has been engaged in many collaborative scientific activities. He is a past co-chair of the World Climate Research Programme's (WCRP) Digital Earths Lighthouse Activity and the WCRP Modelling Advisory Council (2012 to 2017). He led the Working Group on Numerical Experimentation (2008 to 2012) and was chair of the WCRP's Global Energy and Water Cycle Experiment's Modelling and Prediction Panel from 2007 to 2010.

In recognition of his prominent position in the climate science field, Prof Jakob was a Lead Author for the Intergovernmental Panel on Climate Change 5th Assessment Report, Working Group 1. In 2016 his research was recognised via the Ascent Award of the American Geophysical Union's Atmospheric Sciences Section, and in 2017 he was elected a fellow of the Australian Meteorological and Oceanographic Society (AMOS). He was awarded the AMOS Morton Medal in 2018.

Prof Jakob departed the ARC Centre of Excellence for Climate Extremes in mid-2023 to lead the ARC Centre of Excellence for the Weather of the 21st Century, which will begin operations in early 2024.

Professor Todd Lane

Professor Todd Lane was awarded his PhD in Applied Mathematics from Monash University in 2000, having completed his bachelor's degree in 1997. He was a postdoctoral fellow with the National Center for Atmospheric Research (USA) from 2000 to 2002 and a staff scientist there from 2003 to 2005. He joined the University of Melbourne in 2005, where he is now a professor and Head of the School of Geography, Earth, and Atmospheric Sciences. Between 2010 and 2014 he was an Australian Research Council Future Fellow.

Prof Lane's primary research focus is on atmospheric processes. He is internationally recognised as an expert on tropical thunderstorms, atmospheric waves and turbulence. He has made important contributions to many aspects of mesoscale meteorology, convective cloud dynamics and high-resolution atmospheric modelling. Prof Lane's research at the ARC Centre of Excellence for Climate Extremes is within the Weather and Climate Interactions research program, where he conducts research on extreme rainfall and fronts. He uses high-resolution regional atmospheric models to determine the mesoscale processes controlling extremes to help better understand and predict them.

Prof Lane has held numerous leadership positions, including president of the Australian Meteorological and Oceanographic Society (AMOS) (2014 to 2015), chair of the American Meteorological Society's (AMS) Committee on Mesoscale Processes (2012 to 2015) and editor of *Monthly Weather Review* (2016 to 2018). He has received awards from AMS, the Australian Academy of Science and NASA and is a fellow of AMOS.

Dr Nicola Maher

Dr Nicola Maher completed her PhD at the University of New South Wales in September 2016. She was then awarded an Alexander von Humboldt Postdoctoral Fellowship to move to Germany to work at the Max-Planck Institute for Meteorology. In this position, Dr Maher was the manager of the institute's Grand Ensemble and used Single Model Initial-Condition Large Ensembles (SMILEs) to understand and disentangle uncertainty in climate projections. In 2020 she accepted a Cooperative Institute for Research in Environmental Sciences Visiting Postdoctoral Fellow position at the University of Colorado, Boulder, USA. Since June 2023 she has been a research fellow at the Australian National University.

Dr Maher's research investigates drivers of observed climate change and projected changes in climate models. She is interested in large-scale modes of variability, such as the El Niño Southern Oscillation (ENSO). In Boulder, her research largely focused on the impacts of ENSO on North America and how ENSO might change in the future. She is similarly interested in understanding how variables such as temperature and precipitation – with its potential impacts on global population – may change in the future. Dr Maher has worked on understanding uncertainties in climate model projections, largely using SMILEs. Her current research focuses on understanding the dynamics, impacts and future projections of variability in the Pacific Ocean.

For her PhD thesis, entitled "Natural drivers of interannual to decadal variations in surface climate", Dr Maher won the Uwe Radok Award for the best PhD thesis awarded in 2016 in Australia in the fields of meteorology, oceanography, glaciology or climatology. In 2023 she won an Australian Research Council Discovery Early Career Researcher Award.

Dr Amelie Meyer

Dr Amelie Meyer completed her PhD in 2014 at the University of Tasmania, on the topic of circulation, mixing and internal waves in the Southern Ocean.

Dr Meyer then worked as a postdoctoral fellow at the Norwegian Polar Institute in Tromsø, Norway, on changing ocean-ice interactions in the Arctic. She is currently a senior research fellow at the University of Tasmania, where she has been granted an Australian Research Council Discovery Early Career Researcher Award.

Dr Meyer works on climate variability, polar science and ocean circulation to look at how and why polar regions are influenced by climate. To understand polar oceans, Dr Meyer collects scientific observations in the Arctic and Antarctic. This work has taken her to remote places where she has spent a total of 180-plus days working both on research ships and on the ice.

Dr Meyer is a strong advocate for science communication and outreach. In 2019 she was awarded the Tasmanian Young Tall Poppy Science Award and the ARC Centre of Excellence for Climate Extremes Director's Prize.

Dr Negin Nazarian

Dr Negin Nazarian is a Scientia senior lecturer at UNSW's School of Built Environment and a fellow at the City Futures Research Centre in Sydney. As an urban climatologist, Dr Nazarian evaluates the ways the built environment interacts with the climate, and in return, how urban dwellers are affected by this interaction. She is a graduate of the University of California, San Diego and, before joining UNSW in 2020, was the Science, Mathematics, and Research for Transformation (SMART) Scholar at the MIT-led group in Singapore.

Dr Nazarian leads the Climate-Resilient Cities (CRC) research lab, a multidisciplinary group focused on the pressing challenges of urban climate (particularly urban heat exposure and ventilation). The lab uses a range of established and emerging methods such as climate modelling, environmental sensing and IoT technologies. CRC's research is focused on two streams: a) high-resolution microscale climate modelling and urban canopy parameterizations for mesoscale schemes, and b) urban climate informatics for enhancing personal heat exposure assessments.

Associate Professor Sarah Perkins-Kirkpatrick

Associate Professor Sarah Perkins-Kirkpatrick completed her PhD at the University of New South Wales in 2010. She has previously held an Australian Research Council (ARC) Discovery Early Career Researcher Award and an ARC Future Fellowship. She is currently an associate professor at UNSW Canberra, at the Australian Defence Force Academy.

A/Prof Perkins-Kirkpatrick's work investigates trends in heatwaves globally and in Australia, as well as exploring the role of human activity behind such trends. She is currently focusing on comprehensive methods of attributing heatwaves to climate change, and how we might be able to attribute the health impacts of heatwaves to climate change.

A/Prof Perkins-Kirkpatrick was the recipient of the 2013 Young Tall Poppy Award, the 2014 Director's Prize from the ARC Centre of Excellence for Climate System Science and the 2016 Australian Meteorological and Oceanographic Society (AMOS) Early Career Researcher Award. In 2016 she was named one of 'UNSW's 20 rising stars who will change the world', and in 2021 she won the Australian Academy of Science Dorothy Hill Medal, as well as the AMOS Communications and Outreach Award.

Professor Michael Reeder

Professor Michael Reeder completed a PhD in Applied Mathematics at Monash University, before holding postdoctoral positions at the University of Munich (Germany) and the NASA Goddard Space Flight Center (USA). He subsequently returned to Monash University as a member of staff, rising through the ranks to professor.

Prof Reeder's research is focused principally on the dynamics of weather-producing systems. He has published on a wide variety of topics, including fronts, tropopause folding, extratropical cyclones, Rossby waves, heat waves, tropical cyclones, gravity waves, solitary waves, convection, boundary layers, the Hadley and Walker circulations, the Madden-Julian Oscillation and bushfires. He has been the principal supervisor for more than 50 graduate students.

Prof Reeder is a fellow and past president of the Australian Meteorological and Oceanographic Society (AMOS). He is a winner of the AMOS Zillman Medal and the Loewe Prize (Royal Meteorological Society, Australian Branch), and he has given the AMOS Clarke Lecture.

Dr Kate Saunders

Dr Kate Saunders is a lecturer in the Department of Econometrics and Business Statistics at Monash University. Her primary focus is on statistical modelling of climate extremes, and understanding how the probability of extreme events might be influenced by natural variability and climate change. Other interests include statistical post-processing of meteorological forecasts, quality control of meteorological data and how to estimate the risk posed by compound weather events.
Dr Saunders' research improves our understanding of the probability of extreme climate/weather events and helps us to make informed decisions about natural disaster risk.

Dr Callum Shakespeare

Dr Callum Shakespeare was awarded his PhD from the Department of Applied Mathematics and Theoretical Physics at the University of Cambridge, in 2015. Since that time he has worked at the Australian National University, initially as a postdoctoral fellow before becoming a continuing academic in 2023. Dr Shakespeare currently leads the Climate and Fluid Physics research group and the Climate and Fluid Physics Laboratory at the ANU.

Dr Shakespeare's research spans oceanography, atmospheric science and air-sea interactions, using a combination of mathematical theory, numerical modelling and laboratory experiments. He is particularly well known for his theoretical work on fine-scale ocean processes such as submesoscale eddies, fronts and internal waves. Dr Shakespeare also leads the ANU's core 2nd year Climate Science course and convenes the ANU Research School of Earth Sciences honours program.

Professor Steven Sherwood

Professor Steven Sherwood was awarded his PhD in Oceanography from the Scripps Institute of Oceanography, University of California, in 1995. He carried out postdoctoral research at Victoria University of Wellington (NZ) from 1996 to 1997 and was a research scientist at the NASA-Goddard Earth Sciences and Technology Centre from 1998 to 2000. In 2001 he joined the faculty of Yale University, where he later rose to the rank of professor. At the beginning of 2009 he moved to Australia, where he is a professor at – and former director of – the Climate Change Research Centre at the University of New South Wales.

Prof Sherwood has made significant contributions to the understanding of moisture-related processes in the atmosphere. His areas of study include atmospheric humidity; convective systems; interactions between clouds, air circulation and climate; remote sensing of storms; and observed warming trends.

Prof Sherwood was a Lead Author of the chapter on Clouds and Aerosols in the 2013 Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report, Working Group I, and a Contributing Author to the IPCC's previous report in 2007. He currently serves on the review board of the journal *Science* and co-chairs the World Climate Research Programme's Lighthouse Activity on Safe Landing Climates.

Dr Martin Singh

Dr Martin Singh is a senior lecturer in the School of Earth, Atmosphere and Environment at Monash University. He obtained his PhD from the Massachusetts Institute of Technology and was a postdoctoral researcher at Harvard University before his appointment at Monash in 2017.

Dr Singh's research interests are in atmospheric dynamics and climate change. He is particularly interested in the influence of cloud and precipitation processes on atmospheric circulations of a wide range of spatial scales. Understanding the role of such moist processes in determining the climate is an important step toward predicting the possible impacts of human-induced global warming.

Professor Peter Strutton

Professor Peter Strutton received his bachelor's degree with honours in marine science from Flinders University of South Australia, in 1993, and went on to complete his PhD in Marine Science in 1998. He then left Australia to take up a postdoctoral research position with the Monterey Bay Aquarium Research Institute in California – a post he held until 2002. From 2002 to 2004 he was assistant professor with the State University of New York's Marine Sciences Research Centre, and from 2004 to 2010 he was assistant, then associate professor at Oregon State University's College of Oceanic and Atmospheric Sciences.

In 2010 Prof Strutton returned to Australia on an Australian Research Council (ARC) Future Fellowship and since then has been associate professor then Professor at the Institute for Marine and Antarctic Studies, University of Tasmania.

Prof Strutton's research focuses on biological oceanography and his standing as an Antarctic and Southern Ocean scientist is recognised internationally. He has considerable expertise on how modes of variability – such as El Niño and internal ocean waves – affect nutrients in the ocean, biological productivity and carbon cycling. In the ARC Centre of Excellence for Climate Extremes, Prof Strutton contributes to the Ocean Extremes research program. He is contributing to projects in the area of ocean variability – physical, biological and chemical. He concentrates on the drivers of observed changes in biogeochemical cycles, including oxygen, carbon and nutrients, with a recent and continuing focus on eddies.

Prof Strutton is an experienced supervisor and mentor of early career researchers. He currently oversees two postdoctoral researchers and several PhD and honours students. He has an extensive publication record that spans work on Antarctica to the tropical Pacific and the Labrador Sea. He is a past editor for the journal *Geophysical Research Letters* and a former leader of the Bluewater and Climate Node for Australia's Integrated Marine Observing System. Prof Strutton has also served on the scientific steering committee and Biogeochemistry Task Team for the redesign of the Tropical Pacific Observing System (tpos2020.org).

Associate Professor Andrea Taschetto

Associate Professor Andrea Taschetto is based at the Climate Change Research Centre, University of New South Wales.

A/Prof Taschetto investigates the mechanisms by which the oceans affect global and regional climate, using observations and numerical models. Her work looks at the impact of sea surface temperature variability on precipitation over Australia and elsewhere. She is particularly interested in the mechanisms of the different types of El Niño Southern Oscillation; specifically, how these influence atmospheric circulation, interact with other oceanic basins and affect extreme events such as droughts and heavy rainfall.

A/Prof Taschetto was awarded the Australian Academy of Science Dorothy Hill Award in 2016 for her contribution to the climate science field. She was awarded an Australian Research Council (ARC) postdoctoral fellowship in 2010 and an ARC Future Fellowship in 2016. She was a council member of the Australian Meteorological and Oceanographic Society and is currently a member of the Climate Variability and Predictability Pacific Regional Panel and Tropical Basin Interactions Research Foci.

Dr Anna Ukkola

Dr Anna Ukkola is a senior lecturer at the University of New South Wales.

Dr Ukkola's research focuses on understanding the effects of climate change, human activities and increasing atmospheric CO2 on vegetation and water resources. In particular, she is interested in how the frequency and intensity of drought is changing in Australia and globally. Her research combines climate and land surface modelling with observations, including remote sensing, hydrological and climate data and flux tower measurements. Currently, Dr Ukkola is working on an Australian Research Council Discovery Early Career Researcher Award project to explore whether more realistic land surface processes improve operational seasonal predictions of drought.

Dr Claire Vincent

Dr Claire Vincent is a senior lecturer in the School of Geography, Earth and Atmospheric Sciences at the University of Melbourne. She completed her PhD at the Technical University of Denmark in 2010, where she examined the mesoscale variability of wind resources. Prior to this, Dr Vincent worked at Australia's Bureau of Meteorology, first as a forecaster and then on a project to verify near-surface winds from mesoscale modelling.

Dr Vincent's research interests include tropical weather and climate variability, extreme rainfall and the variability of renewable energy resources. She is particularly interested in the different scales of variability in the weather and climate system, and the ways in which these scales interact.

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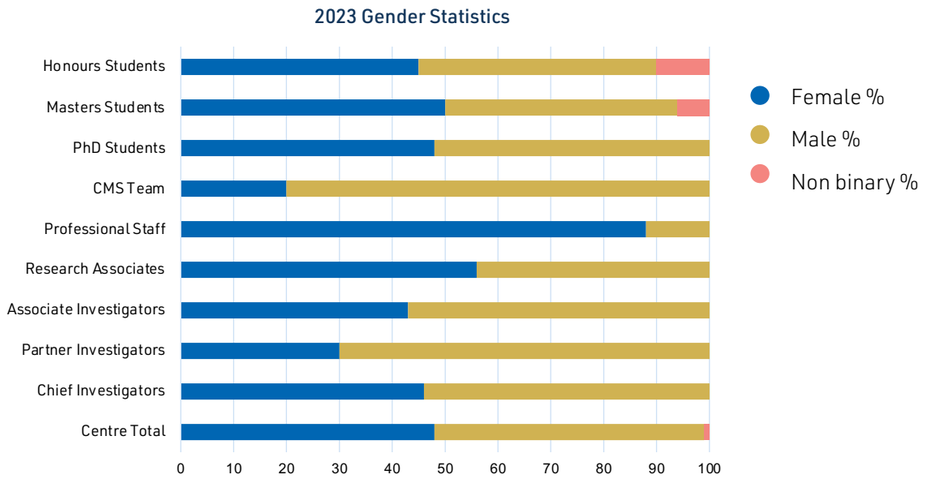
2023 Gender Metrics



The ARC Centre of Excellence for Climate Extremes is committed to creating a diverse and equitable working environment. Since the commencement of the Centre, we have increased the proportion of women Chief Investigators from 22 percent to 46 percent. This is a notable achievement in the physical climate sciences. We are training the next generation of research associates (56 percent women) in a wide range of scientific, professional and leadership skills to provide them with a strong foundation to become the leaders of tomorrow in whatever sector they choose for their future careers.

Our Partners

Administering Institution

The University of New South Wales

Collaborating Institutions

The Australian National University

Monash University

The University of Melbourne

The University of Tasmania

Australian Partner Organisations

Bureau of Meteorology

CSIRO

National Computational Infrastructure

NSW Department of Planning, Industry and Environment (formerly OEH)

Risk Frontiers

Sydney Water

International Partner Organisations and Collaborators

ETH Zurich (Switzerland)

Geophysical Fluid Dynamics Laboratory (USA)

LMD – Centre National de la Recherche Scientifique (France)

Max-Planck Institute for Meteorology (Germany)

NASA-Goddard Space Flight Center (USA)

National Center for Atmospheric Research (USA)

UK Meteorological Office (UK)

The University of Arizona (USA)

The ARC Centre of Excellence for Climate Extremes has a large network of Partner Organisations, both in Australia and overseas. Each of our partners was carefully chosen for the expertise and resources they contribute to the overall research and outreach objectives of the Centre and the climate research community at large. Our Partner Organisations enable us to collaborate on cutting-edge science and model development and to advance our engagement and impact ambitions.

Climate science leaders of the future

Researcher Development Program

The ARC Centre of Excellence for Climate Extremes Graduate and Researcher Development Program further develops national capacity in climate science by training and mentoring the next generation of researchers. It equips them with the intellectual and technical capacity required to take on the research challenges of the future.

The Researcher Development Program includes fundamental research and communication skills, professional development, mentoring and leadership opportunities, and it involves all Centre of Excellence researchers.

The program complements opportunities offered at our university Partner Organisations. Within this Researcher Development Program is a program of tailored research training for postgraduate and honours students, which forms our Graduate Program.

Both these programs are coordinated by our Graduate Director, Associate Professor Melissa Hart, who also acts as a point-of-contact, advisor and advocate for the Centre's students and postdoctoral researchers.

Winter School 2023

Our winter schools are the cornerstone of our Graduate Program. We want to graduate students who not only have highly specialised knowledge in their own area of research but also a broad understanding of the discipline as a whole. Our winter schools provide this opportunity. The theme of the winter school changes each year, and shifts from broader, relevant-to-everyone topics, to more focused topics requiring prerequisite knowledge.

This year the winter school topic was **Observations in the Climate System**. It is a topic that is vitally important to all in the climate sciences. The vast majority of us use observations in some way, but few have a comprehensive understanding of what observations are collected, how they are collected, how they are used to create the gridded products we use in our research, or how they are used to inform climate models. Thus, the Winter School 2023 provided an overview of all of this and more, including visiting some key climate observation labs – the University of Tasmania Institute for Marine and Antarctic Science ice core lab and the Marine National Facility research vessel, the RV Investigator.

Science Fundamentals Lectures

In addition to our winter schools, the Centre of Excellence also runs regular Science Fundamentals online lectures, to provide vital breadth of knowledge.

This year, the lectures are being facilitated by Centre postdoctoral researcher, Dr Hooman Ayat. Dr Ayat surveyed our Centre students and early career researchers to gather which topics they would like to be covered in these lectures.

The use of statistics in the climate sciences was one of the topics most requested, and thus Chief Investigator Dietmar Dommenget offered a five-session statistics course for all Centre researchers. This course was offered in a flipped classroom mode whereby participants watched short lecture-style videos beforehand, providing time for detailed discussion during our online sessions.

Have you ever wondered how you apply for a PhD?

In Australia, you need to first find a supervisor willing to support your PhD application, which can be a daunting prospect. Our researchers receive many of these requests each week and the quality of the email greatly impacts a prospective candidate's chances of a positive response.

Our Graduate Director, Associate Professor Melissa Hart, has provided advice on **How to cold e-mail for a PhD**, which was published in *Nature* in the careers section. Her key piece of advice: 'A cold email might seem like an intimidating prospect with little chance of success, but if it is written with care and personalised it can open doors that you might not even have known were there.'

Undergraduate Scholarships

In late 2023 we welcomed our next batch of undergraduate scholars to the Centre. These scholarships provide outstanding undergraduate students with an introduction to both the Centre and climate extremes research. Students were situated at our node universities and national Partner Organisations and undertook a six-week project, supervised by our postdoctoral researchers, which gives them vital supervisory and research leadership experience. Almost half of our undergraduate scholars continue on to further study with us, and some even publish their projects in international journals.

Climate extremes research in 2023

The following chapters outline just a fraction of the exceptional research undertaken by scientists at the Australian Research Council Centre of Excellence for Climate Extremes.

Weather and Climate Interactions Research Program

The climate is the aggregate of individual weather systems. From this perspective, weather systems are the building blocks of the climate. Of course, the connection is not one way, since the frequency and amplitude of various weather systems are themselves modulated by climate.

The Weather and Climate Interactions research program investigates climate, and especially climate extremes, through a weather lens. In this pursuit, our work focuses on the physical mechanisms responsible for extreme weather in the tropics and extratropics and the effect of climate change on these mechanisms. Understanding how the weather changes as the world warms, and especially how extreme weather changes, is an important part of how climate change affects people, the economy and the environment.

Project 1

Fronts are perhaps the only weather systems implicated in heat, wind and precipitation extremes. To illustrate this point, consider the following:

- The most catastrophic fires in recent history in southern Australia have been associated with extreme but shallow dry cold fronts that form along the southern coastline
- Melbourne's record maximum temperature preceded the passage of the extreme cold front on Black Saturday
- Frontal systems commonly provide the uplift needed to produce extreme precipitation.

Our research into extratropical extremes is guided by the overarching question:

What controls the strength, frequency and path of fronts in the Australian extratropics, and how do these factors affect extremes?

Project 2

Tropical lows are among the most important rain-bearing weather systems in the northern half of the continent. For example, in northern Australia, around half of all summertime rainfall is associated with them. Moreover, tropical lows are commonly implicated in rainfall extremes – the east-coast flooding of 2021 being a recent catastrophic illustration. These considerations motivate our second overarching research question:

What causes the long-lived, heavy rains in tropical and subtropical Australia?

2023 Update
High-Resolution Simulations

During the first half of 2023, researchers at the ARC Centre of Excellence for Climate Extremes made terrific progress in developing a very high-resolution regional model over Australia. The model, called AUS2200, is a configuration of the Australian Community Climate and Earth-System Simulator at 2.2 kilometres.

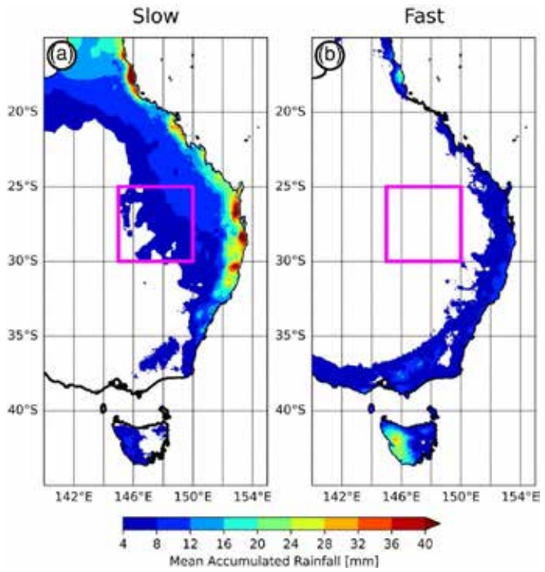
The development has been especially exciting for the Weather and Climate Interactions research program. We organised two hackathons to analyse the AUS2200 runs. The first hackathon was part of a program retreat (in Flinders, Victoria) and focused on a simulation of the February 2022 Lismore floods. The second was a larger gathering that attracted researchers from all of the Centre's research programs and the Bureau of Meteorology.

We now have an AUS2200 simulation of the following events: the 2022 NSW/QLD floods; three Madden-Julian Oscillation events, sampled across different phases of the El Niño Southern Oscillation; and extreme wildfire weather (Black Summer 2019/2020, Black Saturday 2009, Canberra Fires 2003, Ash Wednesday 1983 and Ash Wednesday 1980). Dr Yi Huang and Dr Hooman Ayat have been instrumental in the development of the model and have led the subsequent analysis.

These simulations will underpin much of the research planned in the Weather and Climate Interactions program in 2024. For example, the simulations are being used to unravel the complex relationships between weather fluctuations on a weekly to monthly scale and the influence of mountains on rainfall at a local scale – among many other things!

Research Snapshot
Heavy rain in subtropical Australia

In the late summer and autumn of 2022, heavy rain and floods caused havoc along the coastal margins of southern Queensland and northern New South Wales. Motivated by the events of that year, Dr Michael Barnes led a more general study on the causes of heavy rainfall in the region. This work has recently appeared in *The Quarterly Journal of the Royal Meteorological Society*. Dr Barnes and his colleagues (Dr Malcolm King, Professor Michael Reeder and Professor Christian Jakob) found that heavy rainfall along the subtropical eastern seaboard almost always followed the same meteorological script: large undulations in the jet stream (known as Rossby waves) produce slow-moving, upper-level low-pressure systems (known as "coherent cyclonic potential vorticity anomalies") together with moist onshore easterlies. Because the upper-level low-pressure systems move slowly, they remain in the area for days, continually lifting moist air to make clouds and produce copious rain.



Barnes, M.A., King, M., Reeder, M. & Jakob, C. (2023) The dynamics of slow-moving coherent cyclonic potential vorticity anomalies and their links to heavy rainfall over the eastern seaboard of Australia. *The Quarterly Journal* of the Royal Meteorological Society, 149, 2233–2251. https://doi.org/10.1002/qj.4503

Research Snapshot
Communicating climate change and extreme rain

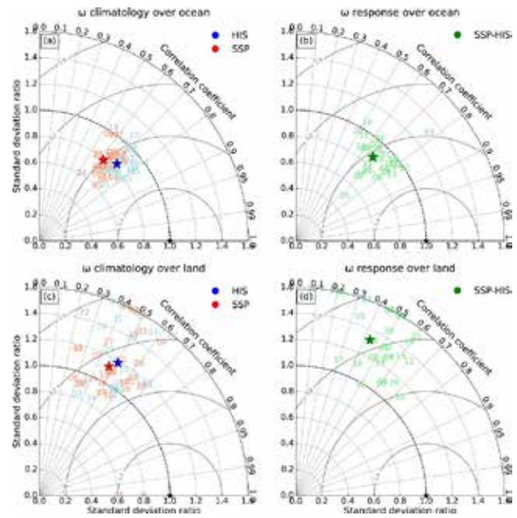
Dr Andrew King, Dr Kim Reid and Dr Kate Saunders published a study about communicating the link between climate change and extreme rain events. Climate change is altering many aspects of the world around us and, when extreme events occur, climate change is often blamed in public discourse. This paper discusses why care must be taken in drawing a link between climate change and extreme rain events. In particular, long-duration extreme rainfall, often associated with river flooding, is usually related to persistent atmospheric moisture transport and stalled weather patterns. The climate change link with multi-day extreme rainfall is less clear than it is for sub-daily events where intensification is found almost everywhere. The paper gives guidance on how scientists discuss climate change and extreme rainfall in the aftermath of extreme events.

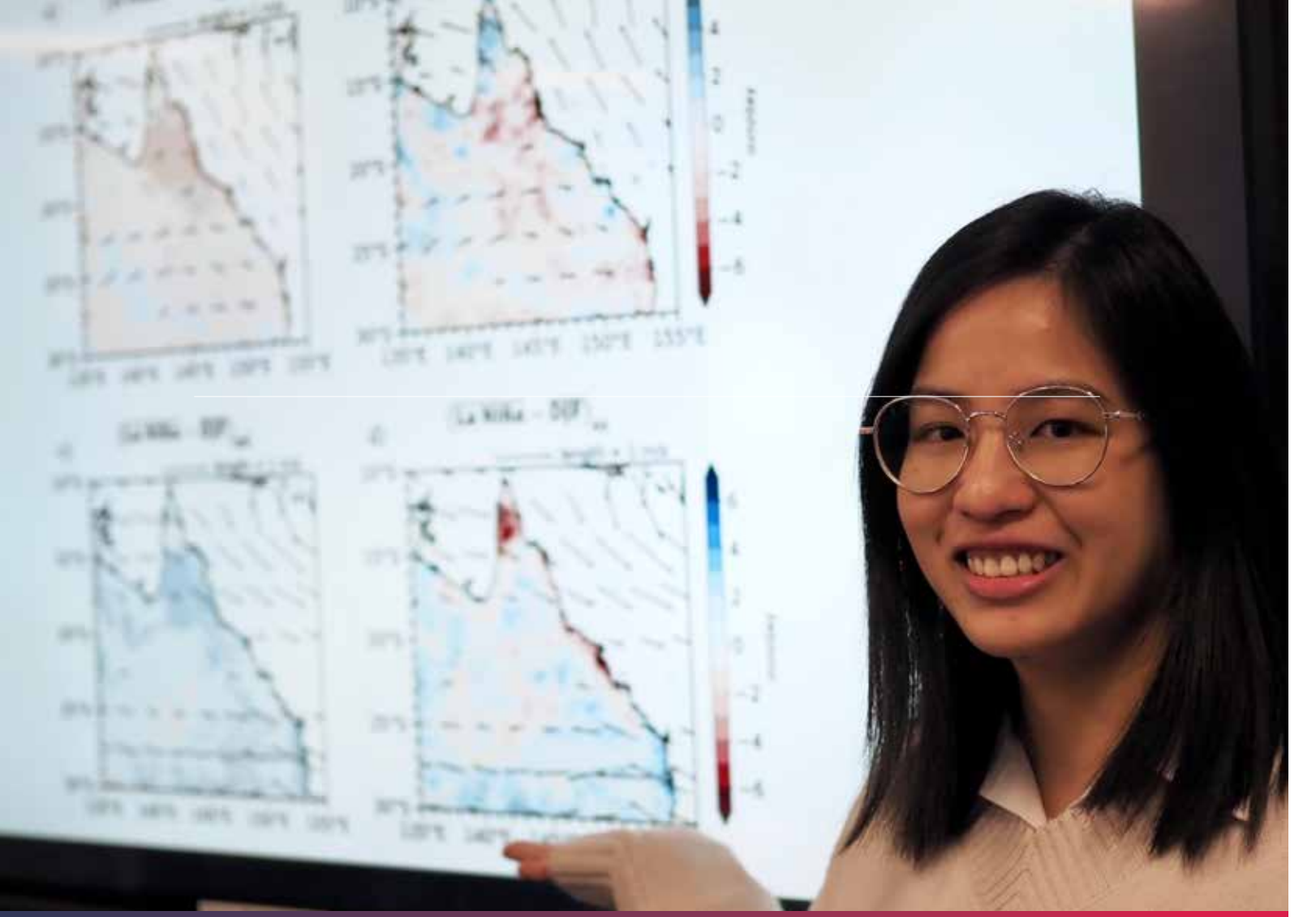
King, A.D., Reid, K.J. & Saunders, K.R. Communicating the link between climate change and extreme rain events. *Nature Geoscience* 16, 552–554 (2023). https://doi.org/10.1038/s41561-023-01223-1

Research Snapshot
What's weakening the tropical winds?

In their recent research, PhD student Chen-Shuo Fan and Professor Dietmar Dommenget asked the question: why is the tropical circulation (winds) weakening? Using many climate models – such as the Coupled Model Intercomparison Project 6 (CMIP6) model – they found that the tropical circulation weakened by about 10 to15 percent over the 21st century. Moreover, they found the primary cause for this weakening was that the tropopause was rising. (The tropopause is the boundary between the lowest layer of the atmosphere, called the troposphere, and the next layer of the atmosphere, called the stratosphere.) The researchers argue that this deepening of the troposphere slows the circulation, which is important, as our weather is confined to the troposphere.

Fan, C-S. & Dommenget. D. The weakening of the tropical circulation is caused by the lifting of the tropopause height. *Climate Dynamics* (2023) https://doi.org/10.1007/s00382-023-06909-1





Early Career Researcher: Thi Lan Dao – University of Melbourne

Researcher Thi Lan Dao grew up in a coastal city in Vietnam. There, she saw first-hand the severe damage to local communities from tropical cyclones and heavy rainfall. Reflecting on her experiences growing up, she says it inspired her to use science to help communities deal with these extremes.

"From that moment I felt I wanted to learn to help predict and understand weather, and to improve projections so that we can reduce the damage from extreme events."

In 2023, Thi Lan published a study on the combined effects of the El Niño Southern Oscillation and the Madden-Julian Oscillation on mean and extreme rainfall in Queensland. Although these two phenomena are relatively well understood on their own, their combined influence is less well understood. Thi Lan's research showed that even though there is less rainfall overall in most parts of Queensland during El Niño, the effect of the Madden-Julian Oscillation is greater during El Niño than La Niña. This means that the Madden-Julian Oscillation can bring important rainfall during otherwise dry periods.

Dao, T. L., C. L. Vincent, and T. P. Lane, 2023: Multiscale Influences on Rainfall in North-east Australia. *Journal of Climate*, 36, 5989–6006, https://doi.org/10.1175/JCLI-D-22-0835.1

Weather and Climate Interactions 2024 Statement of Intent	
Whole-of-research program activities	• Finalise a paper documenting the 2022 heavy rainfall across eastern Australia and review what is known about the physical processes responsible.
Project 1 activities What controls the strength, frequency and path of fronts in the Australian extratropics, and how do these factors affect extremes?	• Evaluate the ACCESS regional 2.2 km (AUS2200) case-study simulations of 2019/2020 summer • Investigate the fire-weather dynamics of Ash Wednesday front with ACCESS regional 2.2 km (AUS2200) simulations • Evaluate summertime extreme mesoscale drying in ERA5 and construct a climatology • Investigate the northward progression of fronts in connection to the termination of heatwaves and the initiation of monsoon bursts.
Project 2 activities What causes the long-lived, heavy rains in tropical and subtropical Australia?	• Investigate the morphology and life cycle of Rossby-wave breaking and their connection to slow-moving vortices and extreme rainfall • Investigate how well the morphology and life cycle of Rossby-wave breaking and slow-moving vortices are represented in CMIP6 models • Establish the variability/co-variability of ENSO/IOD and MJO in long historical data and examine composite large-scale variability over tropical Australia • Assess northern Australia rainfall variability under different climate modes using pacemaker experiments or CMIP models, to help answer 'what should be expected in a warmer world' • Diagnose the thermodynamic and dynamic drivers of large-scale rainfall variability • Analyse the relationship between wildfire, ENSO and climate change in CMIP6 simulations • Investigate the 2016 early June rainfall along the Australian east coast using ACCESS regional 2.2 km (AUS2200) simulations – and available observations – to identify the role of synoptic, mesoscale and orographic processes in driving the extreme rainfall • Complete an investigation of diurnal cycle of clouds and precipitation over north Queensland during the coral bleaching season under different wind regimes • Complete an investigation of local rainfall responses to MJO using ACCESS regional 2.2 km (AUS2200) simulations and available observations • Investigate the temporal distributions of heavy precipitation events over southeast Australia. Do they consist of single pulses of heavy precipitation, complex multiple periods of heavy falls, or some other temporal modulation? What are the main determinants of these characteristics? • Use the Australian unified radar archive and other rainfall data sets to construct a climatology of rainfall extremes over Australian major cities for various spatial scales of extreme • Characterise the large-scale environmental conditions associated with precipitation extremes at different scales over Australia.
Engagement activities	• Apply stakeholder indices to Queensland mean and extreme rainfall and variability with ENSO / MJO / IOD • Write a Briefing note on MJO-ENSO impact on extreme rainfall • Write a Briefing note on slow-moving vortices and extreme rainfall.

Attribution and Risk Research Program

The Attribution and Risk research program improves the understanding of changes in climate extremes, such as heatwaves, extreme rainfall and droughts. It is clear that anthropogenic climate change is already influencing some aspects of these extremes and will continue to do so in the future. Attributing the cause of these changes and assessing their future risk is key to reducing the vulnerability of our natural and economic systems to these extreme events.

In this program we assess and improve the quality of our observations, our process understanding and the capability of our models to simulate extreme events. We also develop new methods using machine learning, an untapped tool in this area with game-changing potential.

Project 1

How do the relative roles of large-scale, regional and local-scale processes and their interactions shape Australian extremes and govern their changes?

Project 2

Can machine learning/ statistical approaches be used to improve the representation of scale interactions, processes and projection of the risk of extremes?

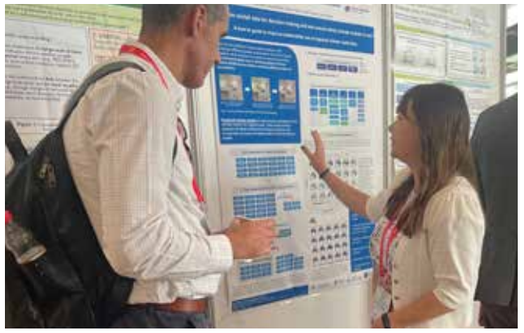
2023 Update

The Attribution and Risk research program at the ARC Centre of Excellence for Climate Extremes has continued its work on understanding the processes responsible for climate extremes in Australia, along with developing advanced statistical tools to improve our modelling and assessment of risk. This included a workshop in March focusing on rainfall extremes, with a day dedicated to understanding the meteorology and climate of several major flooding events that caused substantial damage and insurance losses across different regions of eastern Australia in 2022.

Other activities of note were our contributions to the experimental design of AUS2200 simulations, our production of Briefing notes on both detection and attribution in general and attribution of extreme events in the Australian region – and our investigations into how machine learning could cut the cost of downscaling global climate models.

We continued to build relationships with industry, through webinars and discussions with the agriculture, adaptation and finance sectors. We have also contributed to many high-level scientific meetings, such as those held by the **Joint Scientific Committee of the World Climate Research Programme**. Several Centre members were involved in the organisation of the **WCRP Open Science conference** in Rwanda, including Chief Investigators Associate Professor Sarah Perkins-Kirkpatrick and Dr Negin Nazarian, who led concept papers on event attribution and climate information for a resilient society respectively.

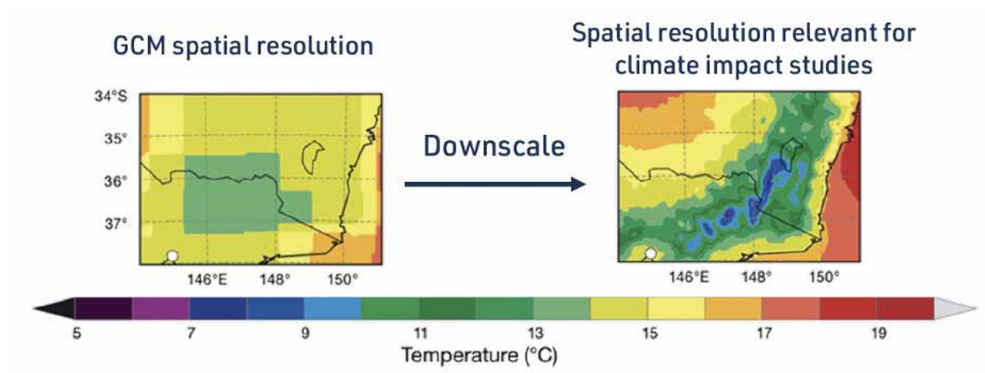
Our Attribution and Risk research program leads, Professor Lisa Alexander, Professor Julie Arblaster and A/Prof Sarah Perkins-Kirkpatrick, Chief Investigators, Dr Nicola Maher and Dr Negin Nazarian, and Professor Steven Sherwood, all played key roles at the WCRP Open Science Conference, including convening sessions and giving keynote presentations. Numerous associate investigators, postdoctoral researchers and PhD students also attended the conference and presented posters and talks. An "Australia booth" showcasing many of the Centre's Briefing notes added to the Centre's major presence at the conference. A Kigali Declaration will be issued as an outcome of the conference, with contributions from all participants.



Research Snapshot

Dr Sanaa Hobeichi produced a **Briefing note on machine learning** and how it could be used to improve the way in which we get finer-scale resolution data from our coarser-scale global models. Machine learning is a subfield of Artificial Intelligence that focuses on building algorithms that can learn and apply what has been learnt autonomously. The Briefing note was built on a **research article in *Earth's Future***, in which Dr Hobeichi outlined how her methodology could produce high-resolution climate projections from a larger number of global models, enabling uncertainty quantification, and so better support for resilience and adaptation planning.

Hobeichi, S., Nishant, N., Shao, Y., Abramowitz, G., Pitman, A., Sherwood, S., et al. (2023). Using machine learning to cut the cost of dynamical downscaling. *Earth's Future*, 11, e2022EF003291. https://doi.org/10.1029/2022EF003291

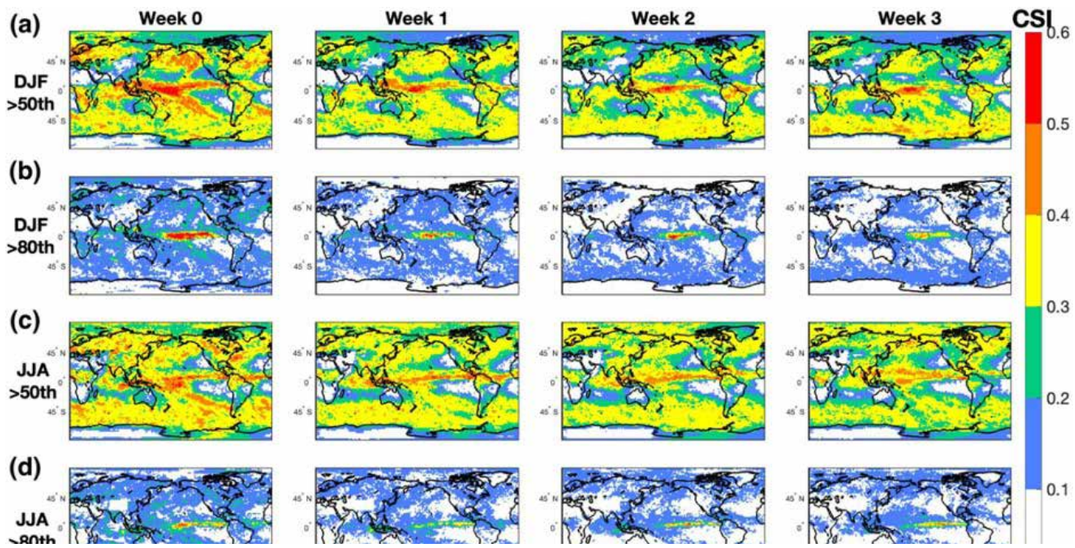


Research Snapshot

Dr Kim Reid had a busy 2023. In addition to collaborating on several publications and leading a paper on the Australian rainfall extremes of 2022, she published a study on how we can enhance the skill of multi-week forecasting of rainfall.

Atmospheric water vapour is often better represented in models than rainfall, which is patchy and sporadic and therefore difficult to predict. Since atmospheric water vapour is a key ingredient in rainfall, Dr Reid's study tested whether it could be used as a proxy for rain using the Bureau of Meteorology's multi-week forecasting model, the Australian Community Climate and Earth-System Simulator-S2. She found that in some locations, using the atmospheric water vapour to predict rainfall instead of the model rainfall itself, actually led to improved forecasting skill. This method may help enhance the predictability of heavy rainfall events up to one month in advance.

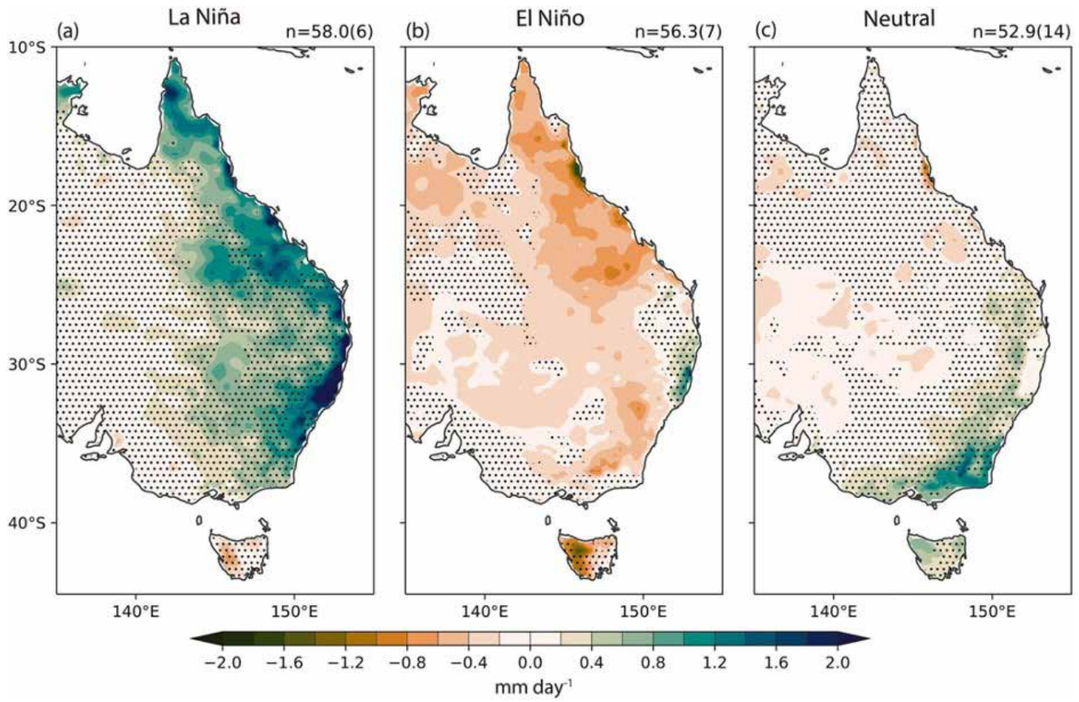
Reid, K.J., Hudson, D., King, A.D., Lane, T.P. & Marshall, A.G. (2023) Atmospheric water vapour transport in ACCESS-S2 and the potential for enhancing skill of subseasonal forecasts of precipitation. *The Quarterly Journal* of the Royal Meteorological Society, 1–13. https://doi.org/10.1002/qj.4585



Research Snapshot

Dr Zoe Gillett examined the links between large-scale circulation associated with El Niño-Southern Oscillation and weather in east Australia. The study looked at days when a cyclone was present over eastern Australia during El Niño and La Niña years. During La Niña, the cyclones co-occurred, with a high-pressure system to the south-east of Australia in the Tasman Sea resembling the high pressure centre from an ENSO-induced Rossby wave train. This circulation setup favours northeasterly winds that direct tropical moisture from the tropical Pacific Ocean to east Australia, which, combined with updraft, increases rainfall in east Australia.

Gillett, Z. E., Taschetto, A. S., Holgate, C. M., & Santoso, A. (2023). Linking ENSO to Synoptic Weather Systems in Eastern Australia. *Geophysical Research Letters*, 50(15), e2023GL104814. https://doi.org/10.1029/2023GL104814



Early Career Researcher: Phuong Loan Nguyen – UNSW

Dr Phuong Loan Nguyen submitted her thesis on understanding precipitation over Monsoon Asia in observations and climate models and is now working as a postdoctoral research fellow at UNSW. She says:

"Doing my PhD thesis at the ARC Centre of Excellence for Climate Extremes was an amazing yet challenging journey. Overcoming challenges, including completing much of my PhD off-campus, even overseas, and welcoming and caring for a small child, added unique experiences to this journey. Despite this, with the support of the Centre, I developed a deep understanding of rainfall extremes over south-east Asia in observations and regional climate models, along with notable computational and analysis skills enhanced by the graduate training programme.

Transitioning into the next phase of my career, I hope to leverage those skills to better inform decision-making processes related to climate risk."

Nguyen, PL., Bador, M., Alexander, L.V. et al. Selecting regional climate models based on their skill could give more credible precipitation projections over the complex South-east Asia region. *Climate Dynamics* 61, 3431–3452 (2023). https://doi.org/10.1007/s00382-023-06751-5

Attribution and Risk 2024 Statement of Intent	
Whole-of-research-program activities	• Hold 2024 Attribution and Risk workshop in conjunction with a potential review paper on compound events • Finalise a paper documenting the 2022 heavy rainfall across eastern Australia (joint with Weather and Climate Interactions research program).
Project 1 activities How do the relative roles of large-scale, regional and local-scale processes and their interactions shape Australian extremes and govern their changes?	• Analyse the ACCESS regional 2.2 km (AUS2200) Coral Sea experiments for understanding the 2022 extreme rainfall events • Investigate temporal clustering of extreme rainfall in Eastern Australia • Finalise a paper on trends and projections in East Australian atmospheric moisture flux • Analyse and publish ACCESS pacemaker experiments (joint with Drought research program) • Examine future risk of heatwaves in comparison to historical events • Analyse projections of heatwaves in millennial ACCESS climate stabilisation runs • Understand future survivability limits in Australia due to extreme heat and humidity conditions.
Project 2 activities Can machine learning/statistical approaches be used to improve the representation of scale interactions, processes and projection of the risk of extremes?	• Explore value of Generative Adversarial Networks (GANs) for representing statistics of extreme events in projections • Explore generalisation/extrapolation properties of different machine learning downscaling techniques • Quantify the information that large-scale predictors provide about rainfall.
Engagement activities	• Continue engagement with AON, Australian Actuarial Society and the agriculture community • Develop an Extremes Dashboard embedded into climdex.org • Contribute to concept papers and decisions coming out of the World Climate Research Programme's Open Science Conference.

Drought Research Program

The Drought research program at the ARC Centre of Excellence for Climate Extremes is focused on understanding what determines the onset, persistence and termination of drought. We are particularly interested in understanding this for the recent (2017 to 2019) NSW drought and into the future.

Project 1

What determines the onset, persistence and termination of drought?

Large-scale climate modes, such as El Niño and positive Indian Ocean Dipole events, are often linked to increased drought risk in parts of eastern Australia. However, the weather processes connecting these broad-scale distant features to local rainfall are unclear.

Project 2

Why did the 2017 to 2020 drought in eastern Australia develop and what made it so impactful?

This case study has focused the combined efforts of the Drought research program with a diversity of research being done to define the characteristics, the small- and large-scale drivers, and the predictability, of the Tinderbox Drought (the 2017 to 2020 NSW drought). For example, did interactions between the land and the atmosphere intensify the hot and dry extremes towards the end of the Tinderbox Drought and also during Australia's Black Summer fire disaster that punctuated the end of this severe drought?

2023 Update

After a particularly wet couple of years in Australia, the Bureau of Meteorology declared an El Niño in September 2023. Understanding the link between El Niño and drought is a major research focus in the Drought program. Centre researchers have been busy communicating the impact of El Niño to the Australian community and policy makers and explaining why El Niño can be a challenge to predict.

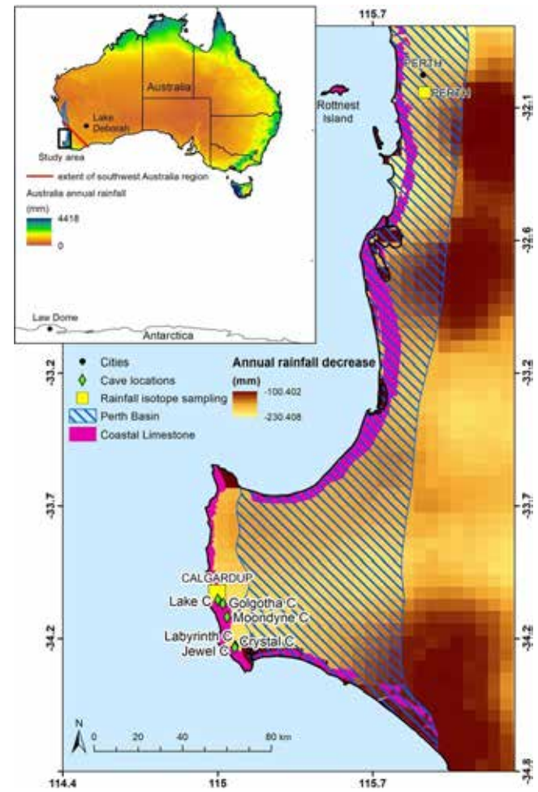
Centre researchers also invested much effort into understanding the 2017 to 2020 NSW drought, which we named the "Tinderbox Drought". This drought devastated rural communities and culminated in the Black Summer bushfires. Understanding past events such as this drought will help us better prepare for future droughts. A special issue of the journal *Climate and Weather Extremes*, focused on the Tinderbox Drought, has been underway throughout 2023 and that special issue brings together a cross-section of the research focused on improving our understanding of the drought.

Research Snapshot

Centre Chief Investigator, Professor Nerilie Abram, contributed to a study on understanding groundwater recharge in south-western Australia. This area of Australia is particularly affected by reduced rainfall caused by human activities. Recent shifts in rainfall patterns have slowed the recharge of groundwater reserves, risking water supply to local communities. By analysing changes in cave stalagmites, the researchers showed that the decline in groundwater recharge over recent decades is unprecedented in the past 800 years. This points to an increasing impact of climate change on water availability in this region.

To further investigate how water availability has changed over many years, Centre researchers created computer simulations of the climate that go back a thousand years. These extended simulations help scientists get a clearer picture of how the climate and water resources change on their own, without any human impact. This understanding helps them predict what could happen as the climate gets warmer. These simulations will contribute to a major international modelling effort to understand past climate variations.

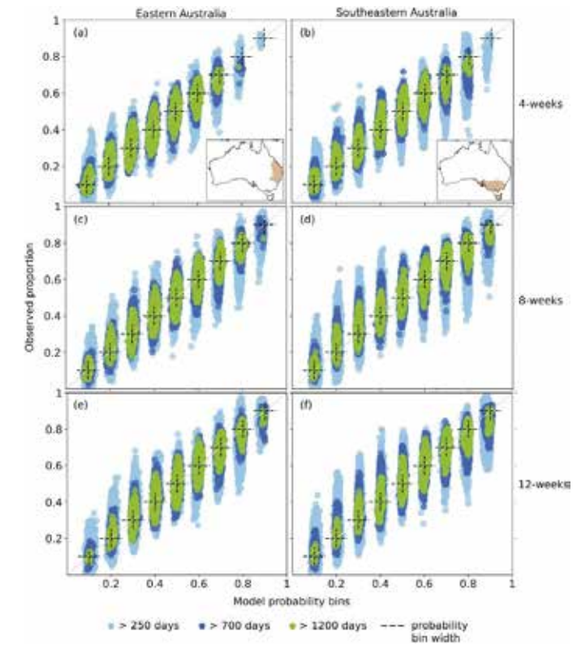
Priestley, S.C., Treble, P.C., Griffiths, A.D. et al. Caves demonstrate decrease in rainfall recharge of south-west Australian groundwater is unprecedented for the last 800 years. *Communications Earth & Environment* 4, 206 (2023). https://doi.org/10.1038/s43247-023-00858-7



Research Snapshot

While predicting when droughts will begin is important, equally important is understanding when a drought will end. Centre postdoctoral fellow Dr Anjana Devanand led a study that developed a method to predict the chance that a drought will end in the next four, eight or 12 weeks. For any location in south-east Australia that is currently in drought, the method uses a logistic regression model to take the current conditions and determine the likelihood that the drought will end according to the historical record. The study found that the state of large-scale climate modes in the tropical Pacific Ocean (El Niño-Southern Oscillation) and tropical Indian Ocean (Indian Ocean Dipole) could alter the chances of a drought ending by up to 20 percent. During ongoing droughts, estimates of drought recovery within sub-seasonal timescales are valuable for risk management, particularly within the agricultural and water resource sectors

Devanand, A., J. P. Evans, G. Abramowitz, S. Hobeichi, and A. J. Pitman, 2023: What is the probability that a drought will break in Australia? *Weather and Climate Extremes*, 41, 100598, https://doi.org/10.1016/j.wace.2023.100598.



Early Career Researcher: Dr Georgy Falster – Australian National University

Dr Georgy Falster worked with colleagues from Washington University in St. Louis, University of Hawaii and the University of California to conduct research into the Pacific Walker Circulation (the atmospheric part of the El Niño Southern Oscillation – a major influence on droughts and rainfall), using data collected by scientists all over the world.

The research, published in *Nature*, found that the Pacific Walker Circulation has changed its behaviour in the industrial era – in ways that the researchers didn't expect. They also found that volcanic eruptions can cause an El Niño-like weakening of the Pacific Walker Circulation.

"I was very interested in science from a young age and I've always been very interested in the natural world" says Dr Georgy Falster.

"Even if there's just a little bit of information stored up in an ice core from Antarctica or a tree from China, we can extract that and use that to help us figure out how the Pacific Walker Circulation has changed. I take many data sets that have been produced by different scientists all over the world, over many years, and put those into a big pool of data to see what new things I can pull out."

Falster, G., Konecky, B., Coats, S. et al. Forced changes in the Pacific Walker circulation over the past millennium. *Nature* 622, 93–100 (2023). https://doi.org/10.1038/s41586-023-06447-0

Drought 2024 Statement of Intent	
Whole-of-research-program activities	• Produce synthesis paper: characterising past and future drought in Australia (past droughts, how bad can droughts get, how does climate change alter risk) • Conduct Pacemaker experiments to understand the role of ocean dynamics in drought development.
Project 1 activities What determines the onset, persistence and termination of drought?	• Examine the changing rates of drought termination • Investigate past drought trends and their drivers • Quantify future drought changes across multiple projections • What are the worst droughts we could get, and why do they happen? • Implement lateral flow in soil column and explore the influence on land/atmosphere coupling • Establish characteristics of Australian multi-year droughts in observations and in large ensemble simulations.
Project 2 activities Why did the 2017 to 2020 drought in eastern Australia develop and what made it so impactful?	• Coordinate a special issue in *Weather and Climate Extremes* on the Tinderbox Drought
Engagement activities	• Prepare an industry and government symposium on Drought in Australia • Write a series of Briefing notes on drought • Continue industry engagement in Drought program meetings.

Ocean Extremes Research Program

Marine heatwaves and mesoscale (~10–100 kilometres) ocean physics have a profound impact on the marine environment. They affect ocean physical properties like temperature, mixing, eddies and fronts. These processes in turn affect plant and animal physiology and nutrient availability, with consequences at all levels of the ocean food chain. Marine heatwaves also interact with atmospheric physics, while ocean biology and chemistry is at the core of the carbon cycle, with consequences for future climate trajectories. The Ocean Extremes research program at the ARC Centre of Excellence for Climate Extremes answers the following questions:

Project 1

Marine heatwaves: How can we best model and predict marine heatwaves?

Project 2

Biogeochemistry: What are the current and future roles of mesoscale physics and biogeochemistry in the climate system?

2023 Update

The Ocean Extremes program has had several PhD completions in 2023, highlighting the energy, productivity and global reach of our student cohort.

Dr Nicholas Pittman used a combination of observations and models to investigate variability in the **flow of carbon through the equatorial Pacific**. Dr Pittman is now working at **Emmi**, a company that helps investors understand the carbon footprint of their portfolio.

Dr Guillaume Liniger investigated the biological productivity of one of the ocean's most extreme environments – **Antarctic polynyas** – and has now taken up a research position at the Monterey Bay Aquarium Research Institute in California, working in the **global biogeochemical Argo project**. Dr Clara Vives also used biogeochemical Argo floats in her work on **Southern Ocean plankton blooms**, and she is now a research associate at the University of Copenhagen. Dr Stephy Libera submitted her PhD thesis in April, and flew straight to Belgium to begin a postdoctoral research position at Universitè Catholique de Louvain. Dr Libera's PhD work on sea ice/ocean interactions is highly relevant to recent Antarctic marine heat waves.

Dr Zeya Li examined sea surface temperature anomalies and marine heatwaves along both Australia's east and west coasts and the eastern Pacific rim in terms of El Niño Southern Oscillation modulation. As a recent graduate, she is now working for CSIRO in Perth on machine learning techniques to improve marine heatwave prediction.

Our ongoing students continue to make important contributions to the field. Denisse Fierro-Arcos combined physical and biological observations and modelling results for ecological applications, including sharing her code. Catherine Gregory investigated and identified important atmospheric drivers of Tasman Sea marine heatwaves as a step toward better understanding subseasonal-to-seasonal time scale marine heatwave predictability. Yuxin Wang has examined the predictability of marine heatwaves off Western Australia and found that the positive Indian Ocean Dipole and La Niña provide multi-month lead time predictability for this region.

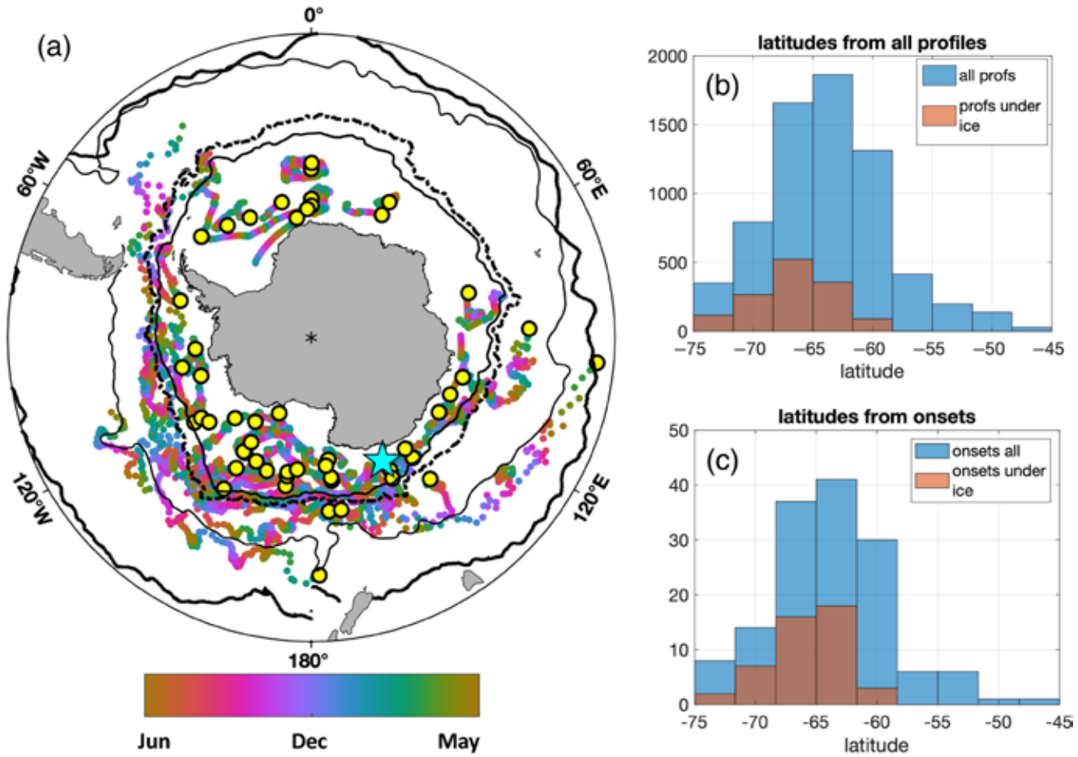
Our research associates and senior researchers have also been productive in both the science and policy realms. Examples include publishing in discipline journals on Indian Ocean eddies and **Southern Ocean carbon cycling**, producing a Briefing note on ocean biogeochemistry, contributing to submissions to the Australian Government Climate Change Authority and sharing our analysis tools with the climate science community.

A Centre-sponsored and targeted marine heatwave workshop involving 12 expert participants from Australia and overseas was held at Moreton Island, Queensland, from 23–25 May 2023. The overall workshop aim was to address the question: *What are the key mechanisms and scales that will improve knowledge of marine heatwave predictability and prediction?* The workshop explored dynamically characterising marine heatwaves, the importance and types of subsurface marine heatwaves and the essential ingredients of a good marine heatwave forecast.

Research Snapshot

For the last year and final chapter of her PhD, Dr Vives was at the University of Copenhagen in Denmark. Her PhD was focused on understanding how plankton blooms vary across the Southern Ocean – where plankton blooms means intense accumulations of the photosynthetic, microscopic plants at the base of the marine food chain. They are crucial for ecosystem health, including the abundance of krill and whales, and they play a significant role in the uptake of carbon by the ocean. Dr Vives used Biogeochemical-Argo floats to show that seasonal changes in light and sea ice are major causes of variability in the timing of these blooms. But the answer differs depending on whether we measure the bloom using chlorophyll or carbon or nitrogen as an indicator. This has important implications for how we observe Southern Ocean biology, but also tells us how plankton physiology operates in the extreme environment of the Southern Ocean. In the final part of her PhD research, Dr Vives again used biogeochemical-Argo floats to see how measures of ocean productivity change depending on the subsurface distribution of plankton and if they accumulate in dense layers near nutrient sources around 100 metres depth. At the University of Copenhagen Dr Vives is using her Centre of Excellence training to study how Greenland glacier sediments can be used for ocean enrichment and ocean alkalinity enhancement.

Vives, C.R., Schallenberg, C., Strutton, P.G. and Boyd, P.W. (2023), Biogeochemical-Argo floats show that chlorophyll increases before carbon in the high-latitude Southern Ocean spring bloom. *Limnology and Oceanography Letters*. https://doi.org/10.1002/lol2.10322



Early Career Researcher: Yuxin Wang – University of Tasmania

Yuxin Wang is a PhD student at the University of Tasmania, working on seasonal to interannual time scale predictability of marine heatwaves. In the first stage of her PhD, Yuxin focused on marine heatwaves off the Western Australia coast. Utilising a computationally cheap yet robust empirical dynamical model – a linear inverse model – Yuxin investigated the role of El Niño Southern Oscillation and Indian Ocean Dipole modes as predictors of enhanced likelihood of marine heatwaves off Western Australia. Yuxin's second stage PhD work involves the application of an intermediate-complexity model – a reduced-gravity (first baroclinic mode shallow water) model – to unravel whether the mechanisms underlying the identified precursors that trigger marine heatwaves along the Western Australian coast could be attributed to oceanic Rossby and Kelvin waves. While a complicated, fully coupled model (for example, a general circulation model) might provide a more accurate simulation, this simpler model provides insight into the dominant dynamical mechanisms at play and that inform potential predictability of marine heatwaves in the region.

Wang Y, NJ Holbrook and JB Kajtar, 2023: Predictability of marine heatwaves off Western Australia using a linear inverse model. *Journal of Climate*, 36, 6177–6193, https://doi.org/10.1175/JCLI-D-22-0692.1

Ocean Extremes 2024 Statement of Intent	
Whole-of-research-program activities	• Conduct 2024 Ocean Extremes research-program-focused workshop • Analyse ocean mesoscale features in observations and models and determine their contribution to marine heatwaves and ocean biogeochemistry.
Project 1 activities How can we best model and predict marine heatwaves?	• Improve understanding of marine heatwave dynamics, processes and predictability • Analyse and compare Lagrangian and Eulerian approaches • Submit three collaborative papers for peer-review and publication (culmination of work undertaken and post-2023 Centre Marine Heatwave Workshop): – Dynamical characterisation of marine heatwaves – What are the ingredients of a good marine heatwave forecast? – Lifting the lid on subsurface marine heatwaves.
Project 2 activities What are the current and future roles of ocean physics and biogeochemistry in the climate system?	• Develop techniques to quantify biogeochemical structures in mesoscale ocean features such as fronts and eddies using observational and reanalysis data sets • Quantify impacts of Southern Ocean standing meander changes on local fluxes of carbon, heat and nutrients.
Engagement activities	• Contribute to the Centre for Climate Extremes Report 2024 • Submit Conversation articles and/or press releases associated with papers and projects • Centre Briefing notes: Consider (1) marine heatwaves, (2) biogeochemical modelling, (3) dust, iron and productivity.

Modelling Research Program

Climate models are the main tool available to climate scientists around the world to predict future changes in the ocean-atmosphere-land system, and these are widely used to study climate processes. Climate modelling also underpins much of the research performed throughout the ARC Centre of Excellence for Climate Extremes. The Modelling research program improves Australia's climate model, the Australian Community Climate and Earth System Simulator (ACCESS), for the benefit of the research and prediction across our Centre and across the nation.

PROJECT 1: AUS2200

High-resolution regional atmospheric modelling

AUS2200 is a community-based project that aims to develop high-resolution regional modelling capacity at 2.2km grid spacing across Australia and surrounding ocean using ACCESS. The project provides a common platform that facilitates research and model-development activities that advance scientific understanding of important atmospheric processes across a wide range of scales, from continent-wide to kilometre. The project monthly meetings, led by Centre Chief Investigator Dr Yi Huang, are regularly attended by Centre researchers and colleagues from the Bureau of Meteorology, National Computational Infrastructure and the AESS.

Over the past year, major optimisation efforts led by the Computational Modelling Support team have led to significant improvements in the model's computational performance and efficiency, with the speed of the modelling workflow being improved by a factor of 10, from three model days per day to over 30. A number of community-driven pilot projects have been conducted during 2022 to 2023, wherein AUS2200 simulations are used to investigate a range of high-impact extreme weather events across Australia.

Important highlights include a research project led by Dr Hooman Ayat, with AUS2200 simulations used to investigate the role of frontal dynamics in the 2019/2020 Black Summer megafire event in south-east Australia. Moreover, AUS2200 simulations of the 2022 NSW/QLD extreme rainfall event were examined in two hackathons organised by the Weather and Climate Interactions research program during February and March 2023. With a focus on initial evaluation of the simulations, the hackathons were attended by over 20 early career researchers across several universities, plus members of the Computational Modelling Support team and colleagues from the Bureau of Meteorology.

PROJECT 2: ACCESS-CM2-025

Developing Australia's coupled modelling capacity.

The recent focus of Australia's coupled model development is to increase model grid resolution. The coupled model combines an ocean, sea ice, atmosphere and land component. The current generation of the coupled model has a 1° resolution, which equates to approximately 100 kilometres distance between neighbouring grid points. Many processes occurring in the climate system are not captured with such a model grid. A new, developed-model configuration has an increased grid resolution for the ocean component (0.25°). Current work evaluates the model performance compared to observations, as well as the previous and coarser model, and uses the information to improve various details in the configuration.

2023 Update

The Modelling program works closely with the newly established Australian Earth System Simulator (AESS) to achieve its goals. The AESS established a new Earth System Modelling Community Working Group which is co-led by Centre researcher, Associate Professor Shayne McGregor, and meets fortnightly. The group brings together Australian scientists interested in climate modelling and provides a platform for exchange, networking, and teamwork to advance Australia's modelling capability.

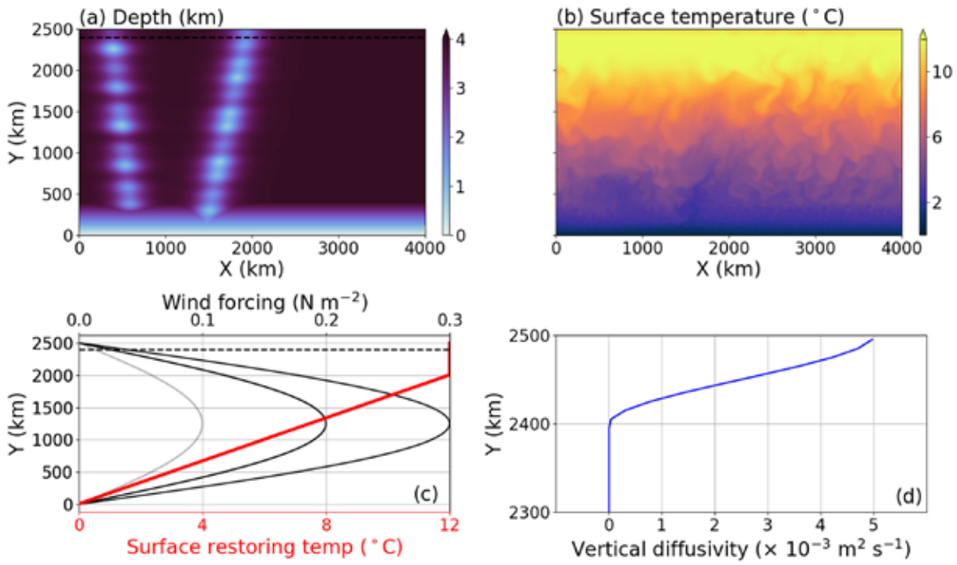
The Modelling program has put together an overview on climate modelling which is now online on the Centre's website for anyone interested. The overview is a great resource for the non-research audience to learn about climate models and their different types, as well as the role of the Coupled Model Intercomparison Project for the Intergovernmental Panel on Climate Change reports.

Additionally, a set of Briefing notes has been published that highlight research performed using particular model configurations. These Briefing notes highlight the work by postdoctoral researchers from the Centre and cover the land (Dr Mengyuan Mu), atmosphere (Dr Hooman Ayat) and ocean (Dr Wilma Huneke).

Research Snapshot

Centre researcher Dr Luwei Yang led a study on the role of ocean waves in the response of the Southern Ocean to changes in westerly winds. The westerly winds over the Southern Ocean have been increasing over the last few decades and it is important to understand how this increase in the winds affects the global ocean circulation. The largest current on Earth, the Antarctic Circumpolar Current, is situated in the Southern Ocean, and observations as well as modelling work have indicated that the current strength is insensitive to the increased winds. The study by Yang et al., however, points out that the previous work has not included a certain type of oceanic waves, lee waves, and that these have the ability to change the current's response to winds. The findings of the study suggests that future modelling work should take the effect of lee waves into account in order to achieve a more accurate understanding of how the global ocean circulation responds to climate change.

Yang, L., Nikurashin, M., Hogg, A. M., & Sloyan, B. M. (2023). Lee waves break eddy saturation of the Antarctic Circumpolar Current. *Geophysical Research Letters*, 50, e2023GL103866. https://doi.org/10.1029/2023GL103866



Early Career Researcher: Hannah Dawson – University of New South Wales

Hannah Dawson, who is a PhD student with the Centre, has published a study in the *Journal of Geophysical Research: Oceans* on the pathways and time scales of connectivity around the Antarctic continental shelf. The Antarctic margin covers a small area of our planet, but the ocean dynamics in the region play an enormous role in the climate system. The movement of water affects the distribution of heat, freshwater, nutrients and biological organisms, with impacts on the Antarctic Ice Sheet stability, oceanic heat and carbon uptake, as well as ecosystems. Yet, the pathways and strength of ocean currents are poorly understood. Hannah and her co-authors made use of high-resolution model output and combined it with a particle tracking algorithm to constrain pathways and time scales of connectivity around the Antarctic continent. A commentary piece published in the same journal highlights the great work by Hannah and puts the results into a global context.

Dawson, H. R. S., Morrison, A. K., England, M. H., & Tamsitt, V. (2023). Pathways and timescales of connectivity around the Antarctic continental shelf. *Journal of Geophysical Research: Oceans*, 128, e2022JC018962. https://doi.org/10.1029/2022JC018962

Modelling 2024 Statement of Intent	
Whole-of-research-program activities	• Provide modelling and model-analysis tools • Provide bespoke model experiments to support the research activities throughout the Centre community.
Project 1 activities Global Coupled Modelling	• Run a new, 500-year simulation with ACCESS-CM2 at 0.25° ocean resolution with improved eddy at high latitudes • Run an Antarctic freshwater forcing experiment with ACCESS-CM2 at 1° ocean resolution as a contribution to the international Southern Ocean Freshwater Release Model Experiments Initiative.
Project 2 activities Atmospheric Regional Modelling	• Continue to improve the AUS2200 modelling suite, with progress towards greater flexibility and efficiency • Develop the ability to choose boundary conditions from ERA5, ERA5LAND and/or BARRA(-2) with flexible domain size and time frame • Document the model and experiment set-up • Run the model for key 2019/2020 weather events and possibly for the full year of 2019 (with support from the CMS team and ACCESS-NRI) • Develop a platform/system to capture, advertise, document and evaluate available cases through engagement with the wider community.
Project 3 activities Land Surface Modelling	• Continue joint development of JULES-and-CABLE modelling framework and benchmarking platform (modelevaluation.org) with the UK Met Office.
Engagement activities	• Deepen the collaboration between the ACCESS-NRI initiative and the Centre • Conduct hackathon on model evaluation in preparation for CMIP7. Continue collaboration between the Centre, CSIRO and ACCESS-NRI.

Computational Modelling Systems

2023 Update

The Computational Modelling Systems team provides technical support with climate models configuration, data analysis and data management to researchers in the ARC Centre of Excellence for Climate Extremes. The team provides support via a helpdesk and runs a weekly CodeBreak online session. The CodeBreak includes short training sessions on a variety of topics and offers an opportunity for the team to work one-on-one with the researchers, solving their coding issues. Blog posts, training and other documentation are other ways the team supports the community: These are important to answer frequently asked questions efficiently and quickly.

Highlights in 2023 include work on high-resolution atmospheric simulations using the Australian Community Climate and Earth System Simulator (ACCESS) atmosphere-land coupled model.

This work generated several simulations of extreme weather events whose output is now available to the Centre researchers and students for analysis. The data will be published in the next few months using a new version of the ACCESS post-processor tool, on which the team has also been working in the last few months.

Another important project was the integration of a groundwater module in the Community Atmosphere Biosphere Land Exchange (CABLE) model. This is now completed and ready to become part of the official CABLE version.

All of these projects are part of our collaboration with the ACCESS National Research Infrastructure (ACCESS-NRI).

Finally, the team continues working on several data projects and collaborations to improve resources to manage and access climate data sets. Our focus for the coming year will be to ensure that all our training, data and code work developed across several years will be properly documented and, where possible, maintained past the Centre's lifespan.

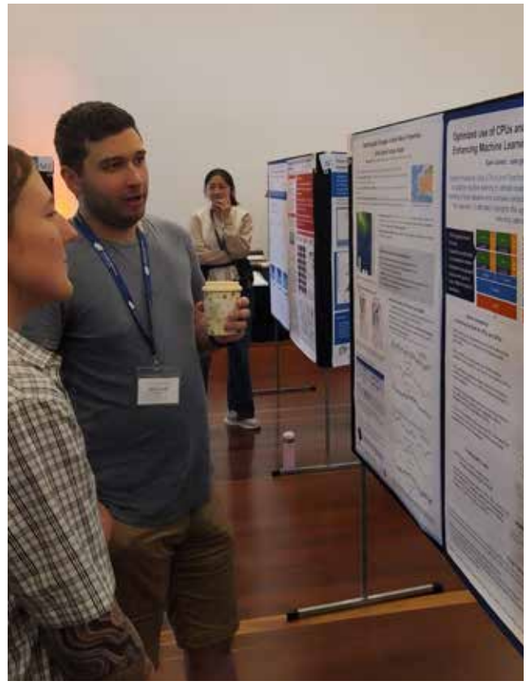
Whilst the running time improved, there was still the challenge of procuring enough computing time allocation to perform the simulations. In March we learned about the STRESS2023 initiative at the NCI. This is an allocation to run large-scale workflows on the new Sapphire Rapids nodes, just recently added to the Gadi NCI server. This gave Dale a chance to put in an application to participate using the future simulations planned for AUS2200 as a use case. We were granted 10 MSU worth of computer time. To put it in perspective: This is nearly double what the entire Centre of Excellence gets allocated every quarter of the year.

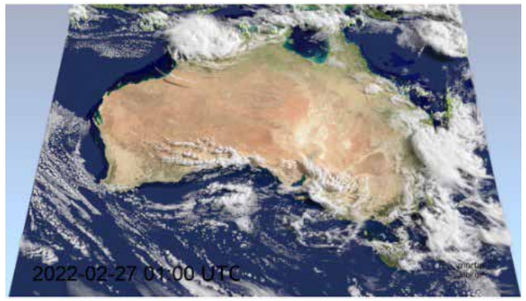
A list of simulations covering extreme weather events was agreed with the Weather and Climate Interactions program group. These included a series of bushfires, the 2022 northern NSW floods, an extreme East Coast Low event and a complete Madden-Julian Oscillation cycle under El Niño, La Niña, and Neutral phases.

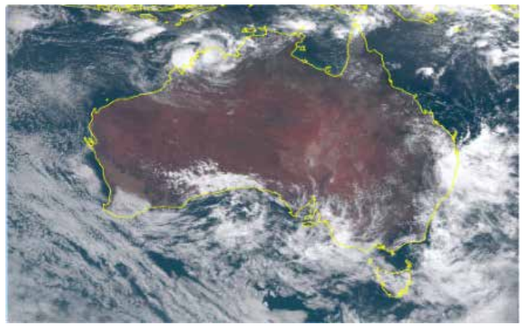
The resulting data will lead to a deeper understanding of extreme weather phenomena over Australia, including a more rigorous evaluation of the scientific accuracy of the AUS2200 model than previously possible. These model simulations also tested the performance and behaviour of the Unified Model on the new Sapphire Rapids nodes, with a final modelling speed of 54.5 days in 24 hours. This provided insight on the effective use of NCI facilities for Unified Model users with immediate implications for the Bureau, CSIRO and Centre climate researchers.

Highlights
Modelling extreme weather events in Australia at 2.2km resolution

Last year, the **Weather and Climate Interactions** research program prepared a high-resolution regional atmosphere simulation of Australia and the surrounding ocean to enable modelling of extreme weather in unprecedented detail. Dale Roberts' major optimisation efforts made it practical to run this AUS2200 model configuration over longer time periods, with the speed of the modelling workflow being improved by a factor of 10, from three model days per day to over 30.







The picture (courtesy of the Weather and Climate Interactions program) shows some preliminary results from the Brisbane flood simulations against a high-resolution Himawari satellite image.

Generating user-friendly ACCESS model output

Paola Petrelli and Sam Green created a new ACCESS Model Output Post-Processor (MOPPeR), a Python-based tool designed to convert the ACCESS model output to a Climate Model Intercomparison Project 6 (CMIP6)-compliant format. It produces data which is easier to use and well documented, as well as performing calculations for derived variables.

ACCESS-MOPPeR started as an upgrade of the APP4, which was used to process model output for CMIP6 experiments. This was a powerful tool but it was built for specific ACCESS configurations. The new tool can be customised more easily to work for different model configurations. The first published version was, in fact, used to produce output for the AUS2200 simulations.

All ACCESS-MOPPeR package dependencies have been upgraded, which resulted in a faster, more reliable code. The mapping between raw model output and compliant output is now much more flexible and automated. The tool can also be customised to produce output conformant to different standards – including, but not limited to, CMIP6 and potentially CMIP7. An important design feature is that the mapping functionality can be used independently of the file processing; so potentially to aid separate tasks, like data cataloguing.

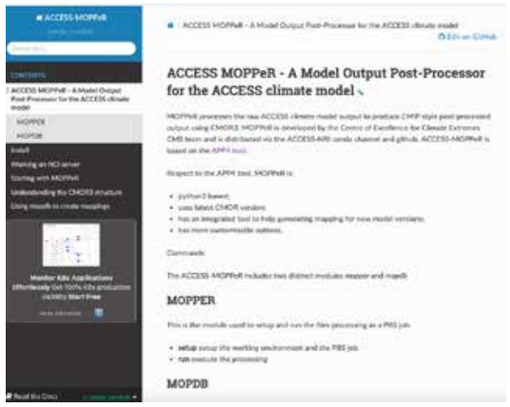
The tool is hosted in the ACCESS-NRI Github organisation. Throughout the development phase we have kept in touch with key people in the NRI, so as to facilitate its use across the ACCESS community.

CABLE groundwater module integration

Ramzi Kutteh completed the integration of the groundwater component of CABLE developed by Dr Mengyuan Mu four years ago. During this time the CABLE code went through a significant refactoring, and for this reason the integration was structured in two phases.

The first involved implementing Dr Mu's work into a version of CABLE just preceding refactoring of the code. The first phase, including extensive testing, corrections and validation by Dr Mu, was successfully completed around May 2023. In addition, a set of notes, tables and diagrams detailing the changes made in the first-phase code was prepared for future reference.

The second phase of the project involved integration of the code resulting from the first phase into the current (as of June 2023) CABLE version. The coding aspect of this second phase was completed in early September 2023, followed by successful testing and debugging. As with the first, this phase is also accompanied by extensive documentation. Some of this has contributed to the important project of improving the CABLE documentation, led by Dr Claire Carouge from ACCESS-NRI.



Connecting climate science to Australians & beyond

What is Engagement and Impact at the ARC Centre of Excellence for Climate Extremes?

Climate science is a fundamental part of protecting and improving the resilience of communities from the extremes of climate change.

Floods, fires, heatwaves, storms, rising oceans – **extreme events** – will become more widespread with every fraction of warming.

Climate scientists are being asked for help and advice by governments, industry and decision-makers to prepare for the decades to come. We need to be able to look ahead and plan for the future.

The Engagement and Impact team at the ARC Centre of Excellence for Climate Extremes brings together some of Australia's most talented policymakers, media and communications specialists, science communicators, content makers, designers and more, to ensure that the essential science of climate extremes **is heard by the people who need to know**.

We train researchers in engagement and impact skills so they can be recognised by decision-makers as: Trusted, Respected, Legitimate, Credible, Reputable

Researchers achieve this by:

- providing expert comment to international and Australian media;
- making submissions to government inquiries and processes;
- producing, and appearing in, web and social media content;
- meeting with decision-makers directly, to educate them about climate science; and
- producing resources for school teachers to incorporate climate science into their syllabi.

The Engagement and Impact team provides the training, structure and support that enables Centre researchers to undertake these activities now and well into the future.

Case Study:
Collaborative Science and Communications

When Dr Georgy Falster had a paper accepted in the prestigious journal, *Nature*,

… the Engagement and Impact team at the ARC Centre of Excellence for Climate Extremes snapped into action to help the early career researcher prepare for the paper's release.

Lead Knowledge Broker Angela Kaplish and Communications and Media Advisor Jonathan Brown conducted an extensive pre-interview with Dr Falster at the Australian National University to collect content and ascertain her goals for communicating the research. Four goals were identified:

- Construct effective analogies and plain-English explanations for the concept of the Pacific Walker Circulation
- Communicate research findings that multi-year La Niña and El Niño events could become more common in future
- Highlight the international and collaborative nature of the research
- Highlight Dr Falster's passion for teaching.

Following the pre-interview, the Engagement and Impact team produced **a web article and video** to explain – in advance of the paper's publication – what the Pacific Walker Circulation is, in order to prime audiences and to secure search-engine rankings for the term.

The Knowledge Brokerage team produced a briefing for policymakers to explain the implications of the research, and the Communications and Media Advisor collaborated with the Nature press office and press offices of the Australian National University, Washington University in St Louis, University of Hawaii, Manoa, and the University of California, Santa Barbara.

Two media releases and web articles were produced – one highlighting the key findings of the paper and a second, human-interest story highlighting Dr Falster's passion for collaborative science.

The results of the Engagement and Impact team's strategies were:

- The "What is the Pacific Walker Circulation?" article is now the third-ranked article for the search term (above Wikipedia)
- The research paper was ranked in the top five percent of all research outputs scored by Altmetric
- Dr Falster received over 330 mentions in Australian media
- Dr Falster was commissioned to produce an article for The Conversation
- The research was highlighted in the US National Research Foundation's October research news.

Most importantly, the Centre's Engagement and Impact team focused on supporting Dr Falster's long-term skills and confidence for communicating her research in future.

Case Study: Researchers Contributing to policy

In 2023, researchers at the ARC Centre of Excellence for Climate Extremes contributed to over 14 policy submissions for federal and state inquiries.

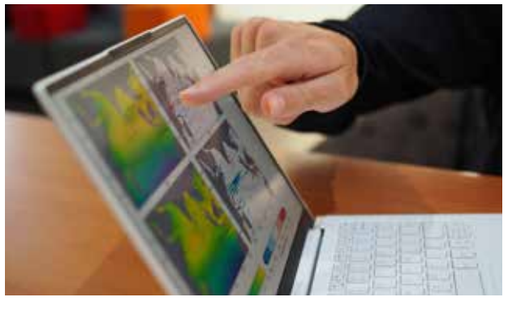
Topics covered were wide-ranging:

- Australia's emissions reduction targets
- Diversity in Science, Engineering, Technology, Mathematics
- The National Health and Climate Strategy
- The impact of severe weather events on Australia's roads
- Climate-related financial disclosure
- and more.

Impressively, the Centre's early career researchers have been some of the strongest contributors to policy submissions, setting themselves up as key scientific advisors for Australian governments into the future.

The Centre's contributions have also led to researchers appearing at a number of government inquiries/hearings in 2023 to offer further advice to decision-makers and highlighting their views and expertise.

The Engagement and Impact team plays a vital role in identifying opportunities for researchers, coordinating policy submissions, teaching and mentoring researchers to write effective policy submissions and ensuring researchers' policy work is seen by decision-makers.



What is a poilicy submission?

Policy submissions give experts, advocates and lobbyists an opportunity to participate in the decision-making process by providing advice and recommendations to government and regulatory bodies.

Policy submissions are often made in response to issues, policy proposals or reports established by governments/ parliaments or as a requirement of legislation.

Writing policy submissions is a key skill for researchers to ensure quality scientific advice is taken into consideration as governments and policymakers create and monitor laws in relation to climate, weather and the related fields of science.

Case Study: Learning in Real Media Environments

The ARC Centre of Excellence for Climate Extremes has made a concerted effort in 2023 to ensure that researchers gain long-term communications and media skills that last well into their future careers.

Rather than focus on low-value and short-term media opportunities, the Centre has focused on building structure and skills for researchers.

This has been achieved in three primary ways:

Collaborative Practice Content

Utilising **climateextremes.org.au** and the Centre's social media channels, the Engagement and Impact team has used these platforms to help researchers practise their skills as science communicators.

Researchers might collaboratively write an article with the Engagement and Impact team or be filmed for a video explaining their research. The Centre has focused on using these opportunities primarily as a means to teach effective science communication skills.

Researchers engage in a collaborative drafting and editing process which includes receiving feedback on their work, and eventually leads to publication on the Centre's website and social media platforms.

Setting up Researchers with Long-term Structures and Relationships

Researchers have been supported to use services such as the Australian Science Media Centre (ASMC) to maintain an ongoing presence in the Australian media.

The ASMC holds a database of scientists made available for Australian journalists. The service is independently funded by Australian universities to identify media opportunities and support Australian research and scientists.

By setting up Centre of Excellence researchers through this service, researchers have ongoing opportunities and media support for the long-term. Some 21 of our researchers were listed in the ASMC's database in 2023.

The Engagement and Impact team has complemented these opportunities by providing one-on-one mentoring, practice sessions and media commentary feedback to help early career researchers engage with the media.

Media Training in Real Studio Environments

Partnering with Humdinger Studios based in Melbourne, the Centre of Excellence tailored a science communications training course that utilised a real TV and podcast studio.

In 2023, over 30 Centre researchers had the opportunity to be interviewed in a real TV studio and to practise sharing their personal stories and research for public audiences.

'I had a lot of fun recently doing some media training! I'll be better prepared for any future media interview now... these kinds of opportunities are what makes working at the ARC Centre of Excellence for Climate Extremes so great' – Dr Doug Richardson

The training provided a safe, "fish-out-of-water" opportunity whereby researchers could get a feel for the environment of a TV and podcast studio, without the pressure of "going live".

A number of researchers from the training sessions have since gone on to do live TV and radio appearances, including with Weekend Sunrise on Channel 7 and the ABC News Channel.

What's Ahead

Engagement and Impact Strategy 2022 to 2024

In 2022 and 2023 the Engagement and Impact team at the Centre of Excellence changed significantly, with four new engagement and impact experts coming into the organisation and the previous team departing for new opportunities. Building on the previous team's strategy, the new team refocused the Centre's activities to build a long-lasting legacy for the Centre and its experts.

Engagement and Impact Team 2022 to 2024

Purpose

- **Invest in long term skills.** We can provide access to and support the development of skills in engagement and impact through practical actions and examples.
- **Create opportunities.** We will create platforms, publications and opportunities for Centre experts to showcase their research and be recognised for their engagement and impact skills.
- **Boost confidence.** We will help Centre researchers to feel confident engaging with Government, policy makers, media and industry and how they can do small actions to make their communications more impactful.
- **Celebrate the Centre and our people**. As the Centre comes to a close we will make sure our people and their research is celebrated and recognised.

Our Support

- We will refine the previous Engagement and Impact team's priorities, meeting our promises to our funders, partners and community, while re-focusing on the most effective use of our skills and resources.
- Researchers will have increased their confidence in how to engage in their work and make an impact with stakeholders so that they can continue to show the impact of their research well into the future.
- Researchers can take forward a body of engagement activities and material which exhibits and highlights their skills at the end of the Centre.
- We will provide and prioritise activities that cement the Centre's long term legacy.

Priorities 2022 to 2024

Influential Voices	Creating a profile for the Centre and its researchers to be known as: Trusted, Respected, Legitimate, Credible, Reputable.
Research Engagement	Build ties and connections with government, industry and policymakers. Create writing skills opportunities through everg reen content, reactive content and media skills.
Schools Engagement	Climate classrooms workshops + educational resources.

Case Study: Briefing Notes

The ARC Centre of Excellence for Climate Extremes produced a number of high impact Briefing notes in 2023, garnering global attention for the Centre's research and researchers.

What is a Briefing note?

A Briefing note is a targeted publication produced by the Centre of Excellence to educate and inform a specific audience about a scientific question or concept.

Briefing notes can be tailored for many different audiences and purposes.

The Engagement and Impact team works with researchers to tailor content for their target audience, to produce high-quality imagery and to design and distribute the Briefing notes to audiences.

Preparing Australia and the World for El Niño

The most successful Briefing note of 2023 was led by early career researcher Ruby Lieber. **"What is El Niño's impact on Australia's weather and climate?"** was the most popular article on climateextremes.org.au, with over 8000 page-views and linked to over 200 websites. It was quoted in an El Niño explainer article produced by ***The Sydney Morning Herald*** and ***The Age*** and was referenced in ***The Washington Post***. Ruby also appeared as an expert on Channel 7's Weekend Sunrise program to explain the El Niño phenomenon for the Australian community.

Ruby is now recognised as one of Australia's most effective new science communicators on the El Niño phenomenon.

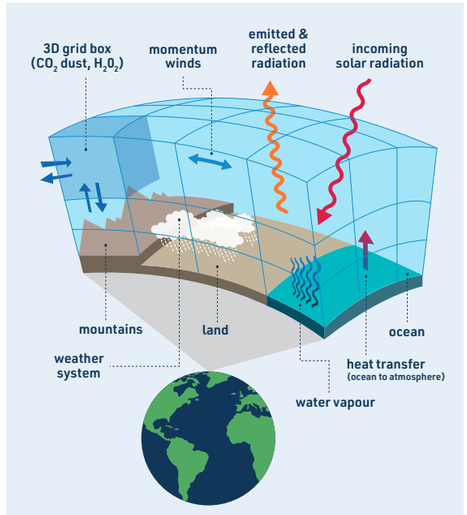
Explaining Climate Modelling for Different Audiences

One of the major projects for the year was a series of Briefing notes and web articles explaining climate models to different audiences.

The Centre's **climate modelling hub** explained the concepts behind climate models for three different audiences: **climate model beginners, climate model stakeholders** and **climate model experts**.

These were underpinned by the Briefing notes **"Climate modelling – an overview"**, **"A closer look at climate modelling"** and three climate modelling related research briefings produced by early career researchers.

The Engagement and Impact team worked with researchers over a number of months to tailor the content for different audiences and levels of scientific literacy, producing high-quality designs and a glossary to help the community understand climate modelling terminology.



Australian Research with Global Reach

The Centre's Briefing notes and reports were also featured on a stall at the World Climate Research Programme conference in Kigali, Rwanda, and web traffic to the Centre's Briefing notes came from countries all over the world, including the United States, United Kingdom, India, China, France and more.

2024 – Providing Skills and Support for the Future of Climate Science

To leave a long-term and lasting legacy for the ARC Centre of Excellence for Climate Extremes, the new Engagement and Impact team is focusing on long-term skills and support for researchers in 2024.

Engaging in the policy process

Centre of Excellence researchers have and will continue to submit to government and industry inquiries – learning about policy processes and translating science for decision-makers. The Engagement and Impact team will also continue producing the Centre's highly regarded Briefing notes and reports to assist policymakers in understanding the science of climate extremes.

Highlighting early career researchers

The Centre will continue to publish a range of written and video profiles of early career researchers, teaching them how to be interviewed, promote themselves and prepare for media opportunities as their careers develop.

Long-term media skills and opportunities

The Centre has partnered with the Australian Science Media Centre (AMSC) and Science Media Exchange to provide ongoing media opportunities, often leading to multiple Centre researchers appearing in stories together, providing diverse perspectives on climate science. Twenty-one Centre experts provided regular media commentary through the ASMC in 2023.

Training workshops and one-on-one support

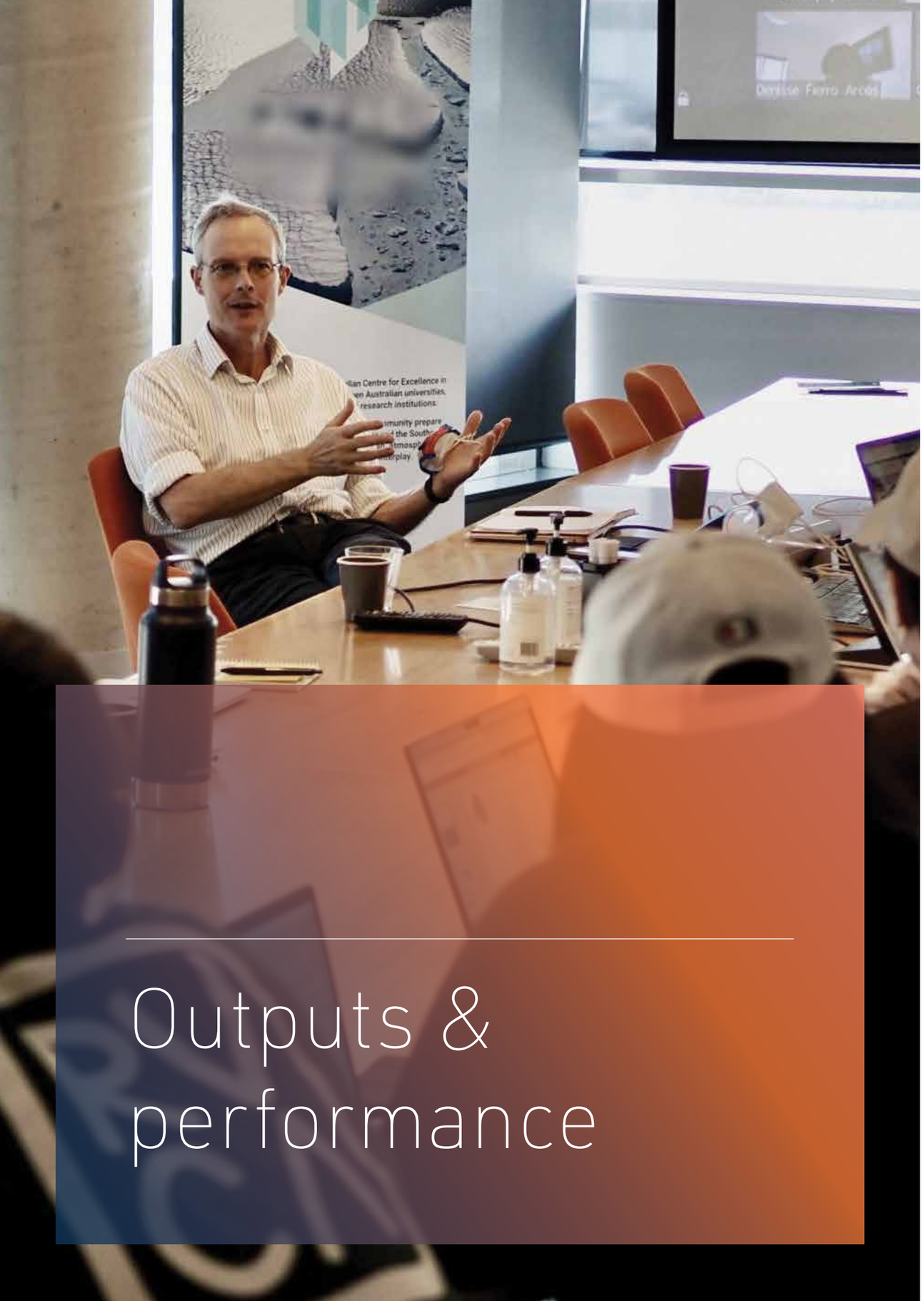
The Engagement and Impact team has delivered media training, career development and more. The team has also provided one-on-one support to Centre researchers at all levels, doing everything from assisting senior researchers to prepare for high-level Government consultations, through to holding coaching sessions for students doing their first-ever media appearances. In 2024, the team will build on these training workshops and one-on-one support.

Design, imagery and boosting climate science

The Centre's graphic designer, Georgina Harmer, is assisting researchers in communicating their research through effective design. This will be achieved through the development of a range of templates – for posters, Powerpoint presentations and social media. Custom and tailored designs are also created for the Centre's larger reports, such as the annual report and the State of Extremes report. The team will continue to assist the Centre of Excellence in communicating scientific concepts effectively.

Teaching climate science in schools

The Centre's highly successful Climate Classrooms program will continue in 2024, led by Dr Sanaa Hobeichi (a former maths teacher and now one of the Centre's most valued researchers) and the Monash Climate Change Communication Research Hub.



Outputs & performance

Publications

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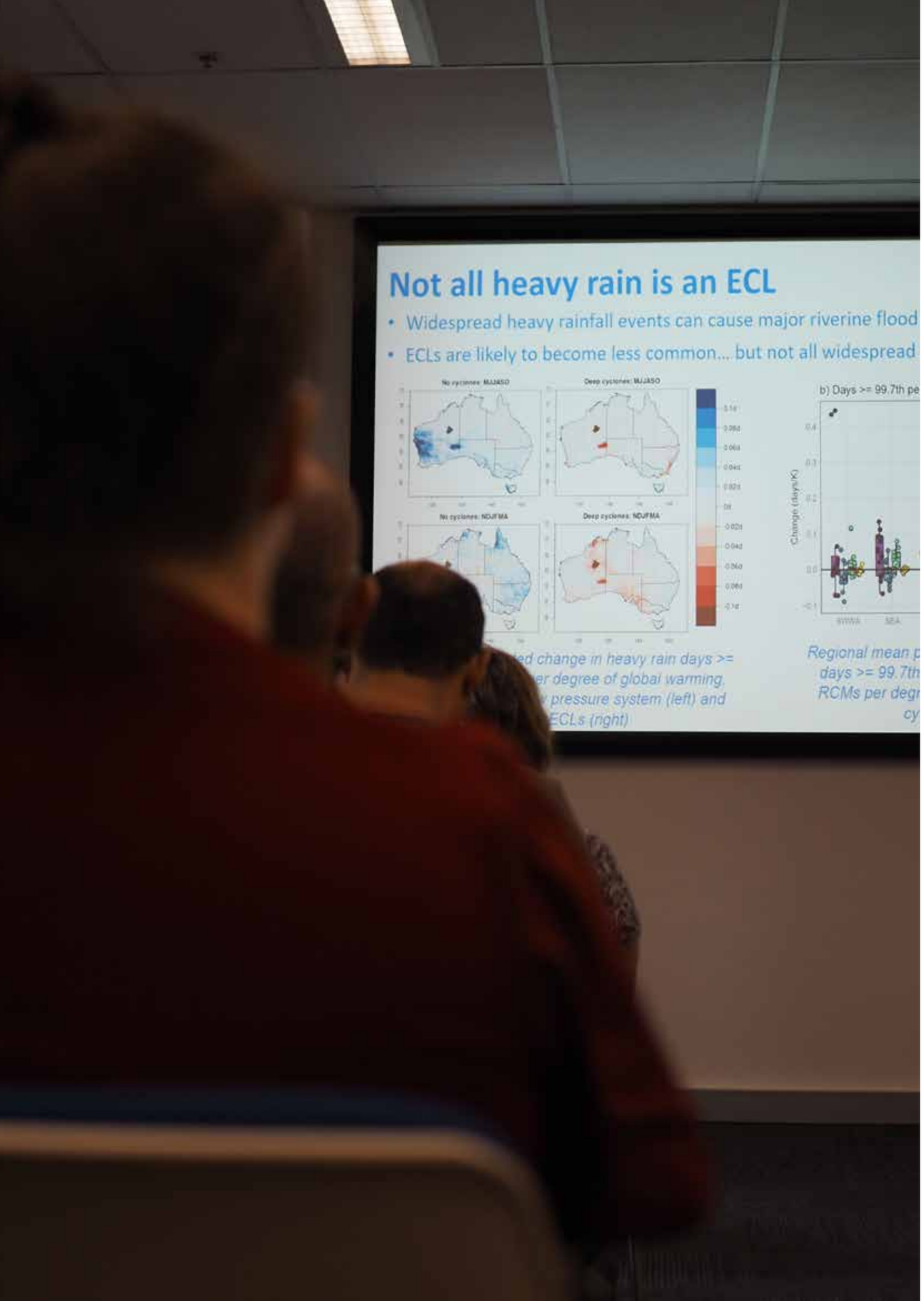

Impact, Engagement, Awards and Service

Prizes and Awards

Ayat, Hooman: 2023 CLEX prize for best paper by a student

Falster, Georgy: 2023 CLEX prize for best paper by an early career researcher

Gallant, Ailie: 2023 AMOS Outreach Award

Goyal, Rishav: AMOS Uwe Radok award for best PhD thesis

Hobeichi, Sanaa: 2023 CLEX Director's prize for the most outstanding contribution to the Centre

Kim, Youngil: Dean's Award for Outstanding PhD Theses Round 2 2023

Lieber, Ruby: 2023 CLEX Engagement and Impact prize

Liqui Lung, Franciscus: Best student poster – CLEX Annual Workshop 2023

McDougall, Trevor: NSW Scientist of the Year

Montoya Duque, Estefania: 2023 Royal Society of Victoria Young Scientist Research Prizes, second place in Earth Sciences

Nazarian, Negin: Awarded Timothy Oke Award 2023 for her work and leadership in urban climate research

Ortiz Guzman, Valentina: Best student poster – CLEX Annual Workshop 2023

Poddar, Shukla: ARC PGC research candidate award for promoting climate change awareness in the energy sector

Press, Tony: Awarded Officer of the Order of Australia (AO)

Quail, Katie: Best student poster – CLEX Annual Workshop 2023

Raupach, Tim: Outstanding poster award at the World Climate Research Programme Open Science Conference

Roughan, Moninya: Royal Society of New South Wales Clarke Medal

Saunders, Kate: Finalist Natural Hazards Research Australia Disaster Challenge

Sengupta, Aditya: Ocean Society of India's PG Dissertation Award at OSICON-23

Shakespeare, Callum: Awarded the Nicholas P. Fofonoff Award by the American Meteorological Society

Sherwood, Steven: AOGS Distinguished Lecture in Atmospheric Sciences

Engagement with Industry and Government

Abram, Nerilie: Guest speaker/panellist at Climate Forum event at Parliament House

Abramowitz, Gab; Kaplish, Angela; Pitman, Andy: Submission to NSW government inquiry on Net Zero Future bill 2023 Arblaster Julie; Reid, Kimberley: Provided evidence at the hearings for the Victorian Parliament's Inquiry into the 2022 Flood Event in Victoria

Arblaster, Julie; Kaplish Angela; Pitman, Andy; Pathmeswaran, Charuni; Wilson; Alice: Submission to the Department of Health and Aged Care on the National Health and Climate Strategy consultation

Evans, Jason: Provided evidence at the hearings for the Victorian Parliament's Inquiry into the 2022 Flood Event in Victoria

Evans, Jason: Presented about climate projections at the "Catastrophe and Reinsurance Symposium"

Falster, Georgy: Participated in ECN submission to Climate Change Authority issues paper

Gallant, Ailie: Briefing on climate change and extremes to the Westpac Board of Executives

Hobeichi, Sanaa: Presentation to Risk Frontiers: "Advancing Drought Prediction using Machine Learning and Drought Impact Reports" at their Annual Seminar

Hobeichi, Sanaa: Gave a seminar to the Bureau of Meteorology Data Science and Emerging Technologies Team on the use of machine learning to reduce the cost of dynamical downscaling

Hobeichi, Sanaa: Expert advice to farmers/growers and Hort Innovation on the potential of AI to enhance weather forecasting and make it suitable for farm use

Hobeichi, Sanaa: Gave a seminar at CSIRO Aspendale on the use of machine learning to reduce the cost of dynamical downscaling

Holgate, Chiara: Attended Institute for Water Futures seminar on Murray-Darling Basin governance in a changing climate and organised follow-up engagement

Huneke, Wilma: Collaborated on a submission to the Issues Paper on Setting, tracking and achieving Australia's emissions reduction targets by the Climate Change Authority

Kaplish, Angela; Wilson, Alice; Pitman, Andy: Submission to House of Representatives Committee Inquiry into the implications of severe weather events on the national regional, rural and remote road network

Kaplish, Angela; Wilson, Alice; Pitman, Andy: Submission to federal government Department of Industry Battery Strategy Consultation

Kaplish, Angela: Briefed Climate Salad representative on what activities the Centre does and relevance to their community of members

Kaplish, Angela: Discussion with 'The Policymaker' publication to determine how and where the Centre can contribute to policy discussions

Kaplish, Angela and Pitman, Andy: Meeting with Federal National Wetlands Director to advertise the drought symposium and ask for potential speakers

Kaplish, Angela; Pitman, Andy; Wilson, Alice: Briefing on research to the Federal Department of Agriculture, Fisheries and Forestry (DAFF) on Clex research and our ability to help covering modelling and drought

Kaplish, Angela and Wilson, Alice: Introductory discussion with NAB on historical data for flooding for probability of default

Kaplish, Angela: Discussions with Commonwealth Environmental Water Policy section on requirements of climate considerations in formulating upcoming renewed policy settings

Kaplish, Angela: Comments to National Climate Risk Assessment team on the National climate risk assessment strategy early draft

Kaplish, Angela: Climate Change Authority Director of Agriculture, Land and Waste – regarding submission and carbon sequestration work

Kaplish, Angela and Pitman, Andy: Discussion with Parks Australia on using climate model projections data

Kaplish, Angela: Meeting with Federal Wetlands section Climate adaptation representative on their use of climate scenarios

Kaplish, Angela: Discussion with Climate Change Authority Climate Science Team on requirements for next progress statement to Parliament as well as general climate science information requirements

Kaplish, Angela; Sherwood, Steven; Wilson Alice; Nazarian, Negin: Introductory meeting with Federal Department of Health on climate impacts on health

Kaplish, Angela: Discussion on requirements for Climate Science with the National Adaptation Policy Office

Kaplish, Angela: Attendance and advertising of Centre information and research to National Climate Projection committee working group 3, with Federal and state and climate agency stakeholders

Kaplish, Angela: Preview of Weather and Climate Extremes report to Climate Change Authority. Interested in Attribution information

Kaplish, Angela: Discussion with Federal Water Division on review of science-based policy

Kaplish Angela; Jakob, Christian; Pitman, Andy: Discussion with Infrastructure Victoria on the work of the Centre and the vulnerability of assets to climate extremes

Kaplish, Angela and Pitman, Andy: Consultation on climate related financial disclosure

Kaplish, Angela: Advised the Department of Climate Change Energy, Environment and Water on contacts for uncertainty and climate and comms materials for the WCRP conference in Rwanda

Kaplish, Angela: Meeting with Danielle Francis, Policy Director at Water Services Association of Australia regarding Clex drought research and symposium

Kim, Youngil and Evans, Jason: Invited talk to the Centre for Climate Research Singapore (CCRS), a part of the Meteorological Service Singapore (MSS), titled "Comprehensive Bias Correction of Regional Climate Model Boundary Conditions for Simulation of Hydrologic Extremes"

Lane, Todd: Briefing to the AFAC Climate Change Group on Extreme Event Attribution

Outputs & performance | Impact, Engagement, Awards and Service

Patel, Ramkrushnbhai: Submission to the Climate Change Authority Issues paper: Setting, measuring and achieving Australia's emissions reduction targets

Patel, Ramkrushnbhai: Submission for the Climate Change Amendment (Duty of Care and Intergenerational Climate Equity) Bill 2023

Pitman, Andy: Presented the latest science linked to fire and flood in the context of climate change to the NSW Independent Planning Authority

Pitman, Andy: Briefed the Reserve Bank and APRA on climate projection science

Pitman, Andy: Invited keynote speaker at the Australian Hydrographers Association 2023 Conference, "Three aspects of high-quality hydrological data we need"

Pitman, Andy: Briefed representatives from the CBA on strategies to manage climate risk

Pitman, Andy; Abramowitz, Gab: Gave evidence at a hearing for the inquiry into the Climate Change (Net Zero Future) Bill 2023, Parliament House, Sydney

Pitman, Andy: Invited by the National Research Infrastructure Advisory Group to attend the Environment and Climate presentations by ARDC, TERN and IMOS and provide expert commentary

Pitman, Andy: Presented to the senior executive of Transport for NSW on the use of climate projections to assess risk to infrastructure

Pitman, Andy: Joined Dr Tanya Fielder and presented to the Auditing and Assurance Standards Board and the Australian Accounting Standards Board on Climate modelling in Financial Reporting

Pitman, Andy: Letter/email submission to Treasury regarding Climate-related financial disclosure

Pitman, Andy: Briefed Chief Investigators from the ARC Centre of Excellence for Innovations in Peptide and Protein Science on mid-term review experiences and strategies

Quail, Katie: Presented research findings to the First Nations Clean Energy Network policy working group

Raupach, Tim: Presented a briefing on hail and climate change to Suncorp

Raupach, Tim: Provided a briefing on hail proxy trends to Aon as part of the Aon and CCRC Climate Advisory Council

Raupach, Tim: Provided a briefing on current work on hail trends using environmental proxies to risk and reinsurance company Guy Carpenter

Raupach, Tim: Provided a briefing on current work on hail and climate change in Australia to Tony Hirst at the Australian Climate Service

Raupach, Tim: Briefing on hail work and possible collaborations to Finity Consulting

Raupach, Tim: Delivered a webinar on hail hazard changes across Australia to the Insurance Council of Australia for a session titled "industry leading research" Raupach, Tim; Alexander, Lisa: Provided briefings to the Actuaries Institute Climate & Sustainability Working Group

Reid, Kimberley: Contributed to submission to the Climate Change Authority on setting Australia's emissions reduction targets

Richardson, Doug: Discussed linkages between weather and power systems with Powerlink

Richardson, Doug: Invited presentation at Bureau of Meteorology R&D Workshop titled "The risk to global coffee supply from synchronous climate hazards"

Richardson, Doug: Presented energy-climate work to CSIRO and explored opportunities for collaboration

Santoso, Agus: Meeting with CBA climate risk team to provide latest update on science

Short, Ewan: Organised/facilitated presentation by, and group discussion with, Salome Hussein from Risk Frontiers

Taschetto, Andrea: Presentation at the Risk Frontiers Seminar Series "All about El-Niño– what it is and what to expect"

Ukkola, Anna: Presentation at Engineers Australia Hydrology and Water Resources Symposium on a climate science perspective on drought

Wilson, Alice: Submission to Select Committee on Australia's Disaster Resilience Wilson, Alice; Barnes, Michael: Submitted to Inquiry on 2022 Victorian floods

Wilson, Alice; Hart, Melissa; Arblaster, Julie; Hobeichi, Sanaa; Singh, Martin; Muhammad, Fadhlil Rizki; Greco, Isabelle; Kaplish, Angela: Submission to the Department of Industry, Science and Resources on 'Pathway to Diversity in STEM Review draft recommendations'

Public Talks and School Outreach

Abram, Nerilie: Attended Climate Crisis Advisory Group: public meeting on "Emerging tipping points in Antarctica"

Alexander, Lisa: Interview with Year 8 students at Marist Sisters College Woolwich which appeared in their newsletter under "STEM CORNER: Highlighting Successful Women in STEM"

Arblaster, Julie: Participated in Quad Fellowship Summit panel on 'Propelling sustainable climate solutions' at Melbourne Connect on 9 June

Brown, Josephine and Sengupta, Aditya: Ran work experience (year 10) session 'Understanding climate change and predicting earth's future warming'

Gallant, Ailie: Science activities with Foundation students at Rangeview Primary School for Science Week

Greco Isabelle and Rey-Costa, Elona: Part of the Powerhouse Museum's Climate Cafe event, sharing our work with other young people working in climate science and with members of the general public attending

Greco, Isabelle: Presented a brief summary of work on severe hail research at Future Science Talks Sydney to a scientific and public audience

Greco, Isabelle: Presentation about severe hail to a general audience at Pint of Science at Ashfield Bowling Club

Greco, Isabelle: Presentation at Women in Data Science Event, introducing research and sharing views on what we could do to better engage diverse genders in science

Greco, Isabelle: Ran an activity teaching children conditional probability and participated scientific outreach at the Queers in STEM NSW Family Day at the Australian Museum

Greco, Isabelle: Presented a summary of research to an academic audience at the pride@UTS event 'Things that Flow'

Greco, Isabelle: Ran an interactive lesson for Skype a Scientist with 30 Grade 5 students in Singapore on the role of technology in creating and resolving the climate crisis

Greco, Isabelle and Ipshording, Rachael: Delivered a session on using climate data in schools to a group of teachers as part of UNSW's Data to Discovery program

Greco, Isabelle: Skype a Scientist presentation to Grade 10 students in Pathankot about weather, climate change, and adaptation and mitigation

Greco, Isabelle: Presented on a panel at the both local and international 'Do the Maths' events discussing a career in mathematics/science

Greco, Isabelle and Ipshording, Rachael: Lead students in a UNSW SciX Project exploring weather and air quality around Sydney

Hobeichi, Sanaa and Sherwood, Steven: Organised a Machine Learning workshop day at the ACCESS-NRI workshop

Hobeichi, Sanaa: Presented at DARE (ARC Training Centre in Data Analytics for Resources & Environments) on Climate Downscaling

Hobeichi, Sanaa; Poddar Shukla; Shao, Yawen: Ran an in-person Climate Classrooms workshop at Monash University in partnership with the Monash Climate Change Communication Research Hub

Huang, Yi: Gave an Open Day expert talk for the School of Geography, Earth and Atmospheric Sciences "How do clouds help regulate the climate over the Great Barrier Reef?"

Huang, Yi: Year 10 student experience talk at the University of Melbourne

Ipshording, Rachael and Greco, Isabelle: UNSW Gateway Winter On-Campus Mini-Lecture: Co-taught two engaging, 45-min 'Weather and Climate' lectures to prospective undergraduate students

Kaplish, Angela: Talk to Centres of Excellence forum on Knowledge Broking and Government Relations

Kaplish, Angela and Brown, Jaci: Career in Climate talk to NESP Climate College Forum

Lane, Todd and King, Andrew: Facilitated panel discussion (Lane), panel member (King). 'Carbon in the atmosphere: Is it all bad news?' at the University of Melbourne

Lieber, Ruby; Borowiak, Alexander; Harrison-Lofthouse, Jarrah: Participated in a panel event at Theatre Works Explosives Factory on climate change and art

Lieber, Ruby and Brown, Josephine: Public talk titled "Oh boy, here comes El Niño!" for the Science Festival Masterclass series organised by the University of Melbourne

Patel, Ramkrushnbhai: Participated in Curious Climate Schools Tasmania Q&A

Pathmeswaran, Charuni: Talk on co-occurring terrestrial and marine heatwaves at the Pint of Science Festival

Quail, Katie: Invited to present research at the Digital Grid Future Institute's public event on 'Unexplored Aspects of the Energy Transition' held on campus at the University of New South Wales

Reid, Kimberley: Visited McClellan College to talk about being a scientist with disadvantaged high school students

Short, Ewan and Vincent, Claire: Running a tupperware fluid tank experiment, and describing introductory geophysics to high school students

Stewart, Kial: Ran a laboratory tour for the National Indigenous Summer School Program at the Australian National University

Stewart, Kial: Ran a laboratory tour for Indigenous students from the Ngaanyatjarra Lands School, Western Australia

Stewart, Kial: Ran a laboratory tour for the Earth & Environment Science Olympiad Program at Australian National University

Stewart, Kial: Ran a laboratory tour for the National Youth Science Forum at the Australian National University

Stewart, Kial: Ran a laboratory tour for Radford College Canberra at the Australian National University

Stewart, Kial: Led laboratory tours and ran an all-day session for an ACT STEM in Primary Schools outreach program

Stewart, Kial: Delivered two presentations and ran a laboratory session at Marist College Canberra

Taschetto, Andrea: Panel participation at the NSWAdapt Forum 2023 – "The new frontier of climate adaptation and impacts science" at the University of Technology

Vincent, Claire: Ran two workshops with high-school students as part of 'The Science Experience' program

Scientific Leadership and Editorships

Abram, Nerilie: Chair, National Committee for Antarctic Research

Abram, Nerilie: Member, External Advisory Board European DEEPICE project

Abram, Nerilie: Member, advisory board ANU Institute for Climate Change

Abram, Nerilie: Co-editor in Chief, Climate of the Past

Abram, Nerilie: Member, National Committee for Antarctic Science

Abram, Nerilie: Member, Australian Antarctic Science Council

Abram, Nerilie: Member, Climate Crisis Advisory Group

Abram, Nerilie: Member, International Liaison Committee Oldest Ice project

Abram, Nerilie: Australian Delegate to Scientific Committee for Antarctic Research

Abramowitz, Gab: Member, Australian Museum Climate Solutions Centre Advisory Group
Abramowitz, Gab: Member, scientific reference panel for private company XDI / Climate Risk Engines

Abramowitz, Gab: Member, GEWEX Global Land/ Atmosphere System Study (GLASS) Panel

Alexander, Lisa: Co-chair, WMO Expert Team on Climate Information for Decision-making

Alexander, Lisa: Member, WCRP Joint Steering Committee

Alexander, Lisa: Member at Large, International Association of Meteorology and Atmospheric Science Executive Council

Alexander, Lisa: Editor in Chief, Weather and Climate Extremes

Arblaster, Julie: Member, National Committee for Earth System Science

Arblaster, Julie: Member, Coupled Modelling Intercomparison Project (CMIP) panel

Ashcroft, Linden: Ordinary member, AMOS National Council

Brown, Josephine: Chair, Australian Meteorological and Oceanographic Society Expert Group on Climate Variability

Evans, Jason: Member, WCRP CORDEX Science Advisory Team

Hart, Melissa: Elected co-chair WCRP Academy Steering Group

Hart, Melissa: Member, Australian Museum Climate Solutions Centre Advisory Group

Henley, Benjamin: Executive Domain Editor, WIREs Climate Change

Huang, Yi: Co-chair, ACCESS-NRI Atmospheric Modelling Working Group

Huang, Yi: Editorial board of Atmospheric Chemistry and Physics

Meyer, Amelie: Associate Editor at Journal of Geophysical Research Oceans

Meyer, Amelie: Member, International SCOR working group 'Analysing ocean turbulence observations to quantify mixing (ATOMIX)'

Meyer, Amelie: Member, Antarctic Women's Network

Perkins-Kirkpatrick, Sarah: Editor, Weather and Climate Extremes

Perkins-Kirkpatrick, Sarah: Co-Chair, Early Career Scientist Committee, International Association of Meteorology and Atmospheric Sciences

Pitman, Andy: Member, National Committee for Earth System Science

Pitman, Andy: Member, International J. Climatology International Editorial Board

Pitman, Andy: Member, TERN Science Advisory Committee

Reid, Kimberley: Co-chairing of the ACCESS NRI Forecasting and Prediction Working Group

Santoso, Agus: Editor, Journal of Climate

Sengupta, Aditya and King, Andrew: Selected for the Fresh Eyes on CMIP initiative in the Model Evaluation Subgroup

Sen Gupta, Alexander: Member, National Committee for Earth System Science

Sherwood, Steven: Co-Chair, WCRP Safe Landing Climates Lighthouse

Sherwood, Steven: Member, WCRP Grand Challenge on Climate Sensitivity steering committee

Sherwood, Steven: Review editor, Science

Strutton, Peter: Member, International Biogeochemical Argo Mission Team

Strutton, Peter: Member, Tropical Pacific Observing System Scientific Advisory Committee

Taschetto, Andrea: Member, CLIVAR Pacific Region Panel

Taschetto, Andrea: Member, CLIVAR Tropical Basin Interactions Working Group

Taschetto, Andrea: Associate Editor, Journal of Southern Hemisphere Earth System Science

Taschetto, Andrea: Guest Associate Editor of Frontiers in Climate – Dynamics and Impacts of Tropical Climate Variability: Understanding Trends and Future Projections

Taschetto, Andrea: Review Editor of Frontiers in Climate – Predictions and Projections

Vincent, Claire: Member of the National Academy of Science National Committee for Earth System Science

Vincent, Claire: Member, ACCESS-NRI Scientific Advisory Committee

Zika, Jan: Member, National Committee for Earth System Science

2023 KPIs

Performance measure		Target 2023	Achieved 2023
1. Number of research outputs	Annually		
Journal articles		150	178
Book chapters		5	4
Software modules published		2	18
Data sets published		2	12
Facebook posts		52	157
Centre website updates		25	202
LinkedIn posts		15	336
Science explainer videos		2	21
2. Quality of research outputs	Annually		
Percentage of publications in journals with impact factors greater than 2.0		80	97%
Percentage of publications in journals with impact factors greater than 4.0		60	75%
Percentage of publications in journals with impact factors greater than 10		10	13%
3. Number of conferences held/offered by the Centre	Annually		
National workshop		1	1
International conference/workshop		1	1
Topical/Research program workshops		3	5
Teacher workshop with training material kit		1	1
4. Number of training courses held/offered by the Centre	Annually		
Professional development training in gender equity and diversity		1	1
Professional training for ECRs in engaging with government and decision makers		2	2
Computational skills workshops/tutorials		3	6
Science fundamentals workshops		1	10
Leadership and professional development workshops		1	4
Communications/writing workshops		1	5
Number of centre-wide virtual lectures/seminars		5	50
Percentage of students/ECRs attending researcher development activities		90%	70%
5. Number of additional researchers working on Centre research	Annually		
Postdoctoral researchers		2	8
Honours students		10	9
HDR students		10	20
Associate investigators		5	2
6. Student Completions	Annually		
Number of PhD completions		14	14
Number of Masters by Research completions		4	2
Number of Honours student completions		10	5
Percentage completing PhD students submitting within 4 years (FTE)		100%	100%

Performance measure		Target 2023	Achieved 2023
7. Number of mentoring programs offered by the Centre	Annually		
We have an integrated researcher development program for HDR students and early-mid career researchers. It includes a personalised skills needs assessment and induction, an annual calendar of workshops and training opportunities, an annual winter school covering science fundamentals, cross-node and partner organisation supervision, and a mentoring circle initiative involving all centre researchers and students allowing a range of mentoring and networking opportunities.		1	1
Percentage of ECRs and HDR students with a completed training needs analysis template		100%	100%
8. Number of presentations/briefings	Annually		
To the public		10	44
To government		10	33
To industry/business/end users		5	18
To non-government organisations		5	7
To professional organisations and bodies		5	9
9. Number of new organisations collaborating with, or involved in, the Centre	Annually	1	0
10. Gender profile by cohort (female/male/any gender)	Annually	F:M:Any	
Graduate students		40:40:20	48:51:1
Research fellows		40:40:20	56:44
Senior research fellows		40:40:20	46:54
Centre leaders		40:40:20	60:40
Administration team		40:40:20	88:12
Advisory board members		40:40:20	46:54:00
Keynote speakers at workshops and conferences		40:40:20	50:50

Performance measure		Target 2023	Achieved 2023
ARC Centre of Excellence for Climate Extremes Specific KPIs			
11. Computational Modelling Support	Annually		
Supported climate models served to the community		15	18
New/updated/supported environment for data analysis served to the community		5	10
New/refined/updated data sets served to the community.		8	11
Monthly bulletin to all researchers on CMS-related updates		11	11
Training material produced and delivered		15	35
Percentage of compute time allocation used		95%	97%
12. Researcher Development Program	Annually		
Percentage of students with cross node and/or partner organisation support and project input		80	75%
Student / ECR internships in industry/government		2	1
Percentage of students/ECRs making a research visit to other nodes and/or Australian partner organisations		50	18%
Percentage of students/ECRs making a research visit to international partner organisations or organisation with a collaborative relationship		30	11%
Number of undergraduate summer scholarships offered		15	13
Regular Research Program videoconference meetings p/a		10	30
Media KPIs	**Annually**		
Media releases		15	24
Website – unique hits		40,000	63,168
Website – page views		50,000	161,323
CLEX media mentions		300	9,985
Social media – Twitter (new followers)		600	284 (1)
Social media – Facebook (new followers)		400	49 (2)
Social media – LinkedIn (new followers)		80	653
Additional pathways to impact	**Annually**		
Establishment of significant partnerships			
Data sets provided to or updated for stakeholders		3	10
Briefing notes published		8	11
Number of research program meetings with stakeholder focus		8	12
Tailored advice provided to stakeholders		5	26
Demonstrated examples of model improvements available for use in national modelling systems		2	2

(1) Twitter/X is an unstable/unethical platform now.
(2) Facebook severely limits reach unless you pay. The cost benefit is not strong enough.

2023 Financial Statement

Executive Summary

The ARC Centre of Excellence for Climate Extremes formally commenced operations on 4 August 2017. The Centre's financial affairs are conducted within the established procedures, controls and delegations of the relevant universities, and as set out by the Australian Research Council (ARC). This statement provides an analysis of the income and expenditure of the Centre of Excellence.

In 2023, the Centre received $6,015,079 (100%) income compared to the full-year budget of $6,003,548. In terms of the Centre's expenditure, $7,298,661 (97%) was spent compared to the full-year budget of $7,529,902.

In 2023, personnel accounted for the highest proportion of expenditure of $5,295,239 (73%), followed by travel expenditure of $1,017,889 (14%). Overall, the Centre's cash balance in 2023 is in deficit by $1,283,583.

Financial Management and Performance

Quarterly financial reporting monitors institutional income and expenditure against the Centre-wide budget. The Centre's Finance Officer prepares consolidated financial statements for review by the Chief Operations Officer and the Director. The Centre-wide finances are discussed at Centre Executive meetings, and financial statements are tabled at Centre Advisory Board meetings.

The Centre meets its annual reporting requirements to the ARC and meets all other reporting obligations set by Partner Organisations that provide financial support.

2023 Income

Cash income totalled $6,015,079 from all sources. The Centre derived its income from the ARC, participating universities, the Bureau of Meteorology, the NSW Department of Planning and Environment (DPE), and the NSW Department of Industry Research Attraction and Acceleration Program (RAAP). Income is summarised by the source in detail in the tables that follow.

1: Australian Research Council Funding

The Centre received indexed income from the ARC of $4,885,419. This was distributed to the institutions following the inter-institutional agreement and was used for payroll, scholarships, consumables and events, equipment and maintenance and travel.

2: Government Funding

2.1 Bureau of Meteorology

The Bureau committed $20,000. This cash contribution was targeted at PhD top-up scholarships for students working collaboratively with the Bureau.

2.2 NSW Department of Planning and Environment

The cash investment from DPE is specifically intended to support pathways-to-impact by supporting an improved understanding of climate extremes in NSW and by making this knowledge available to the community and decision-makers in the form that they need. The Centre received 3 years (2021-2023) of funding totalling $325,000.

2.3 NSW Department of Industry RAAP

RAAP funding invests in appointing a Research Fellow to focus on high-resolution modelling of processes relating to climate extremes (e.g. hail, drought processes, vegetation-climate extremes, etc.). The Centre received $142,143 in 2023.

3: Collaborating Organisation Funding

Cash contributions to the Centre of Excellence from the Administering Organisation and the Collaborating Organisations amounted to $955,984 as follows:

UNSW	$336,191
ANU	$77,431
University of Melbourne	$132,456
University of Tasmania	$157,216
Monash University	$252,690

4: In-kind Contributions

In-kind support totalled $8,512,191 in 2023. The Centre is grateful for $6,272,864 of in-kind contributions, provided by the Administering Organisation and the Collaborating Organisations. The contributions are primarily personnel-related and consist of the apportioned salary, on-costs and burdens of faculty members and other university staff members who contribute towards the Centre. Partner Organisations provided additional in-kind contributions of $2,239,327. Again, this was mainly personnel time.

Organisation	In Kind Budget	In Kind Actual
Bureau of Meteorology	159,524	143,572
CSIRO	367,500	344,121
ETH Zurich	65,317	65,317
Geophysical Fluid Dynamics Laboratory	30,000	30,000
LMD – Centre National de la Recherche Scientifique	13,400	13,400
Max-Planck Institute for Meteorology	20,000	20,000
Monash University	855,431	1,414,320
NASA-Goddard Space Flight Center	44,605	44,605
National Center for Atmospheric Research	128,155	128,155
National Computational Infrastructure	892,000	892,000
NSW Department of Planning, Industry and Environment	312,785	312,785
Risk Frontiers	45,000	45,000
The Australian National University	741,685	829,753
The University of Arizona	50,372	50,372
The University of Melbourne	923,049	954,533
The University of New South Wales	1,976,032	2,528,630
The University of Tasmania	465,623	545,629
UK Meteorological Office	150,000	150,000
TOTAL	7,240,477	8,512,191

2023 Leverage

The Centre's 2023 cash income of $6,015,079 and in-kind support of $8,512,191 total $14,527,270 with ARC funding accounting for $4,885,419 of the total income. The Centre's leverage of $9,641,850 equates to $1.97 of external funding and in-kind contributions for each $1.00 received from the ARC.

2023 Expenditure

In 2023 the Centre expended $7,298,661, analysed below:

Personnel (including on-costs)	$5,295,239	72.6%
Scholarships	$500,991	6.9%
Equipment and Maintenance	$44,844	0.6%
Consumables and Events	$439,699	6.0%
Travel	$1,017,889	13.9%

2023 Income Vs Expenditure

Income and Expenditure are based on cash and is derived from the institutions' general ledgers. The Collaborating Organisations certify income and expenditure by formally acquitting all grants as of 31 December 2023.

The Centre's cash expenditure of $7,298,661 was above income of $6,015,079 by $1,283,583.

The Centre will carry over a deficit balance of $1,283,583 to 2024. The carry-over by institution is as follows:

University of New South Wales	$727,510	deficit
Australian National University	$143,165	deficit
University of Melbourne	$63,768	deficit
University of Tasmania	$65,363	surplus
Monash University	$414,504	deficit

In summary, as at 31 December, 2023, the financial position for the life of ARC Centre of Excellence for Climate Extremes after its seventh year of operation is as follows:

Total Cash Income	$6,015,079
Total Expenditure	$7,298,661
Deficit carried forward to 2024	$1,283,583

Finance Tables

Cash Income & Expenditure

	2017–2023 Actual						Budget / Forecast	
1. Cash Income	2017	2018	2019	2020	2021	2022	2023	2024	TOTAL
Australian Research Council- Centre of Excellence	4,350,000	4,250,000	4,250,001	4,300,000	4,300,000	4,300,000	4,400,001	0	30,150,001
Australian Research Council- Centres of Excellence Indexation	65,250	128,456	211,645	295,388	378,106	420,210	485,419	0	1,984,474
Bureau of Meteorology	10,000	20,000	30,000	30,000	30,000	20,000	20,000	0	160,000
NSW Department of Planning and Environment	100,000	100,000	100,000	165,000	300,000	25,000	0	0	790,000
NSW Department of Industry/ RAAP	143,000	143,000	142,857	143,000	143,000	143,000	142,143	0	1,000,000
University Node Cash Contributions	1,103,142	1,285,737	1,253,234	1,236,647	1,600,020	1,111,724	955,985	174,684	8,721,174
Other (Interest Distribution)	0	15,871	19,146	3,087	696	4,770	11,531	0	55,101
Department of Agriculture, Water and the Environment			4,523		4,000	4,000			12,523
Sydney Water Corporation	0	200,000	0	0	0	0	0	0	200,000
Total	5,771,392	6,143,064	6,011,406	6,173,122	6,755,822	6,028,704	6,015,079	174,684	43,073,272

2. ARC Expenditure	2017	2018	2019	2020	2021	2022	2023	2024	TOTAL
Personnel	114,662	1,941,921	3,354,377	3,350,987	2,992,974	3,418,564	5,236,236	5,336,994	25,746,715
Scholarship	6,358	90,723	158,714	191,388	217,551	311,788	483,134	402,575	1,862,231
Equipment and Maintenance	0	5,105	33,216	12,814	3,500	4,202	20,379	53,000	132,217
Consumables and Events	16,369	165,632	160,379	110,198	128,817	297,141	342,573	524,991	1,746,099
Travel – Conference, workshops and meetings (Staff, AI)	12,634	133,395	210,647	48,557	10,454	142,930	348,682	303,063	1,210,362
Travel – Conference, workshops and meetings (Postdocs and Students)	0	40,497	178,653	49,316	26,531	208,137	344,713	199,386	1,047,233
Travel – Visitor travel to the Centre and other	1,336	38,236	31,324	22,335	0	5,966	35,812	65,519	200,529
Travel – New staff relocation expenses	0	0	0	0	0	0	11,009	0	11,009
Travel – Research Visits (Staff, AI)	0	9,585	34,451	7,153	-2,004	12,647	10,863	26,072	98,767
Travel – Research Visits (Postdocs and Students)	1,341	380	3,484	1,802	0	5,783	12,175	54,345	79,311
Total	152,701	2,425,476	4,165,244	3,794,550	3,377,822	4,407,159	6,845,575	6,965,946	32,134,472

3. Nodes Expenditure	2017	2018	2019	2020	2021	2022	2023	2024	TOTAL
Personnel	65	311,556	615,789	475,725	603,844	92,194	-303,296	465,460	2,261,336
Scholarship	10,706	61,092	132,039	120,983	105,712	185,892	7,857	205,547	829,828
Equipment and Maintenance	6,182	48,972	46,325	17,274	41,776	29,054	24,465	28,298	242,346
Consumables and Events	4,575	43,568	53,831	48,424	43,636	87,644	97,127	130,401	509,205
Travel – Conference, workshops and meetings (Staff, AI)	12,901	49,055	67,758	21,570	14,943	84,552	96,053	137,438	484,269
Travel – Conference, workshops and meetings (Postdocs and Students)	2,969	60,341	104,294	18,986	13,011	178,416	146,450	225,515	749,982
Travel – Visitor travel to the Centre and other	0	9,570	41,971	9,881	0	0	2,580	78,000	142,002
Travel – New staff relocation expenses	7,354	55,163	22,719	2,193	37,490	29,628	4,881	0	159,428
Travel – Research Visits (Staff, AI)	5,132	8,979	22,952	4,320	-2,677	11,965	4,672	29,500	84,843
Travel – Research Visits (Postdocs and Students)	0	10,981	13,860	8,446	1,296	-4,750	0	24,174	54,007
Total	49,885	659,276	1,121,538	727,802	859,030	694,595	80,787	1,324,333	5,517,245

	2017–2023 Actual		
4. Others	2017	2018	2019
Personnel	61,192	192,341	272,939
Scholarship	0	10,000	14,000
Equipment and Maintenance	0	0	0
Consumables and Events	0	0	0
Travel – Conference, workshops and meetings (Staff, AI)	0	0	0
Travel – Conference, workshops and meetings (Postdocs and Students)	0	0	523
Travel – Visitor travel to the Centre and other	0	0	0
Travel – New staff relocation expenses	0	0	0
Travel – Research Visits (Staff, AI)	0	0	0
Travel – Research Visits (Postdocs and Students)	0	0	0
Total	61,192	202,341	287,462

5. Summary Income Vs. Expenditure / Carry Over	2017	2018	2019
ARC			
Total Income	4,415,250	4,378,456	4,461,646
Total Expenditure	152,701	2,425,476	4,165,244
Income less Expenditure	4,262,549	1,952,980	296,402
Nodes			
Total Income	1,103,142	1,285,737	1,253,234
Total Expenditure	49,885	659,276	1,121,538
Income less Expenditure	1,053,257	626,461	131,696
Other			
Total Income	253,000	478,871	296,526
Total Expenditure	61,192	202,341	287,462
Income less Expenditure	191,808	276,530	9,064
Carry over surplus / deficit	5,507,614	2,855,971	437,162

2017–2023 Actual				Budget / Forecast	
2020	2021	2022	2023	2024	TOTAL
338,433	260,881	334,287	362,299	195,067	2,017,440
10,000	79,000	34,000	10,000	35,000	192,000
0	0	0	0	0	–
0	0	0	0	0	–
0	0	0	0	0	–
0	0	7,661	0	0	8,184
0	0	0	0	0	–
0	0	0	0	0	–
0	0	0	0	0	–
0	0	0	0	0	–
348,433	339,881	375,948	372,299	230,067	2,217,624

2020	2021	2022	2023	2024	TOTAL
4,595,388	4,678,106	4,720,210	4,885,419	0	32,134,474
3,794,550	3,377,822	4,407,159	6,845,575	6,965,946	32,134,472
800,838	1,300,284	313,051	-1,960,156	-6,965,946	2
1,236,647	1,600,020	1,111,724	955,985	174,684	8,721,174
727,802	859,030	694,595	80,787	1,324,333	5,517,245
508,845	740,990	417,129	875,198	-1,149,649	3,203,928 [1]
341,087	477,696	196,770	173,674	0	2,217,624
348,433	339,881	375,948	372,299	230,067	2,217,624
-7,346	137,815	-179,178	-198,625	-230,067	0
1,302,337	2,179,089	551,003	-1,283,583	-8,345,662	3,203,930

(1) The remainder of the program will be finalised using organisational funds

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