climate extremes

ARC centre of excellence

ARC Centre of Excellence for Climate Extremes

ANNUAL REPORT 2017

Centre of Excellence for Climate Extremes Annual Report 2017

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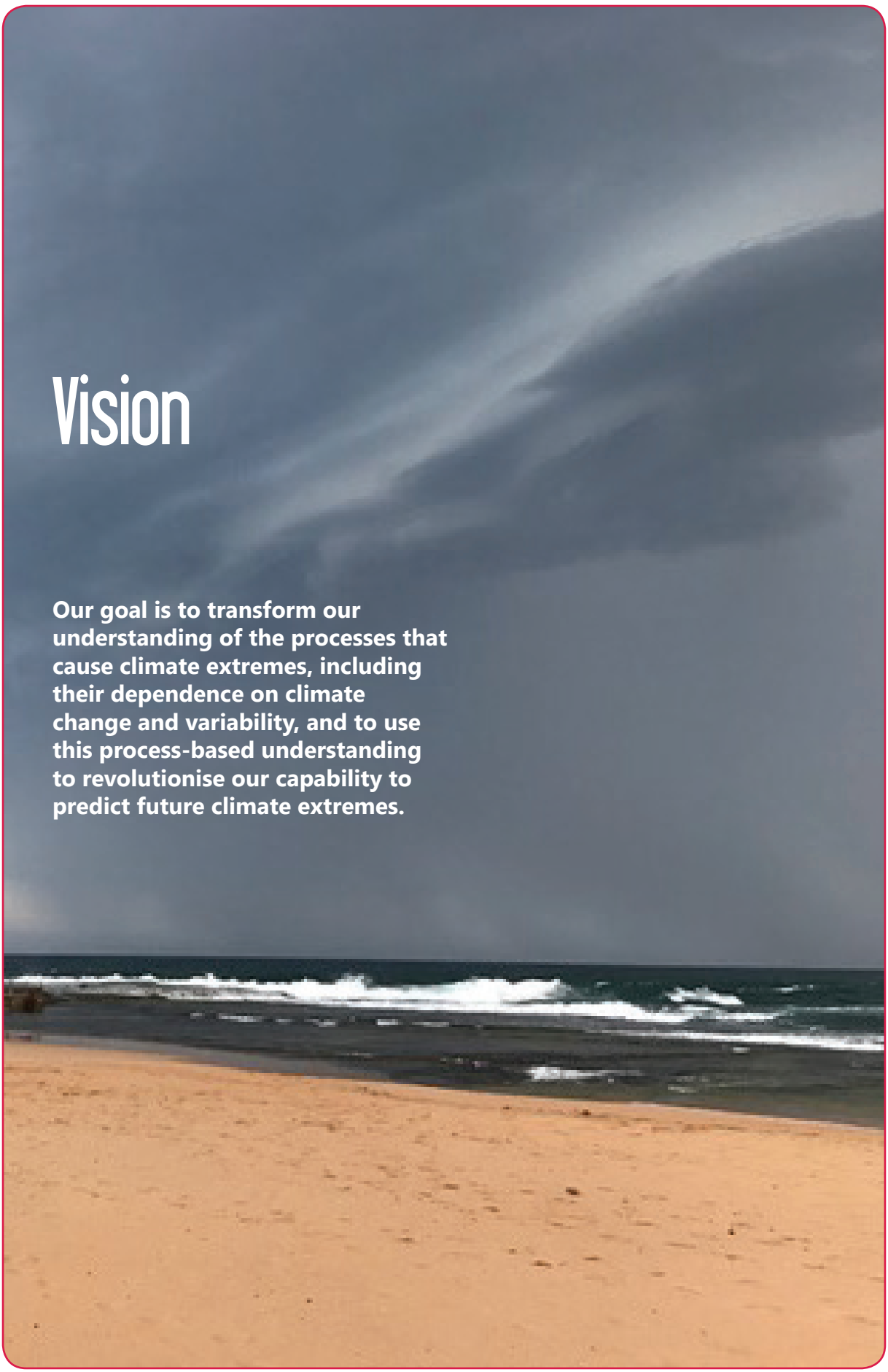
Vision

Our goal is to transform our understanding of the processes that cause climate extremes, including their dependence on climate change and variability, and to use this process-based understanding to revolutionise our capability to predict future climate extremes.



Aims and Objectives

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 aim to understand the processes causing climate extremes, build this understanding into the Australian prediction systems, and improve 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 costs 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 (WCRP) identification of climate extremes as a "Grand Challenge". This reflects the importance of extremes to society, the scientific challenges associated with their understanding and prediction, and the lack of major, coordinated activities worldwide to address them. The ARC Centre of Excellence for Climate Extremes (CLEx) therefore accepts the challenge set by the WCRP and will lead the charge on this globally significant problem.

Our efforts will focus on five key areas as set out in our strategic plan:

- **World Class Research:** we will undertake world-class research into processes that cause, amplify or prolong Climate Extremes in the past, present and future and integrate this new understanding into our national simulation systems to transform our national prediction capability;

- **An Outstanding Environment:** our Researcher Development program will provide unparalleled training and mentorship to early and mid-career researchers. We will provide a superb environment for all researchers, students, and administrative and professional staff, with a focus on diversity and inclusion.

- **Exceptional Infrastructure:** our critical infrastructure is more than high-performance computing and data – it includes the software fabric around models and the tools to use them efficiently and effectively. We have a dedicated team of computational modelling specialists to help us optimise our research performance.

- **Transformative collaboration:** we strive to achieve a rich national collaborative environment as a foundation for our research, and use that foundation to strongly contribute to national research priorities.

- **Engagement and Impact:** we engage with leading partners and stakeholders. To manage our engagement and pathways to impact strategies we have established an outreach committee to advise the Centre Executive on the development and execution of its outreach and communications strategies

Combining Australia's outstanding researchers with world-class overseas ones in CLEx will realise a unique opportunity to transform the science of climate extremes prediction. Our legacy will be a generation of outstanding graduates and early career researchers, along with scientific discovery and technical innovation that will establish Australia's leadership in climate extremes and be the envy of the international community.

Overview

The ARC Centre of Excellence for Climate Extremes (CLEx) is primarily funded by the Australian Research Council (ARC). We combine five Australian universities and a suite of outstanding national and international Partner Organisations. The establishment of the Centre – the first of its kind globally – marks a shift from investigating climate averages to a specific focus on the process-level understanding that explains the behaviour of climate extremes that directly affect Australian natural and economic systems. With this increased evidence-based understanding as our foundation, the Centre will improve our capability to predict climate extremes with the goal of reducing our national vulnerability.

CLEx was established in August 2017 with extensive investment from the ARC, the University of New South Wales, Monash University, the Australian National University, the University of Melbourne, the University of Tasmania, the Bureau of Meteorology (BoM), the New South Wales Government's Research Attraction and Acceleration Program and the New South Wales Office of Environment and Heritage. We have strong links with CSIRO and BoM, and through them with the Australian Community Climate and Earth System Simulator (ACCESS) initiative. The Centre works in partnership with the National Computational Infrastructure facility (NCI) and informs scientifically robust policy decisions via our partnerships with state and federal departments and the Earth Systems and Climate Change Hub of the National Environmental Science Programme. We have two industry partnerships already established: Risk Frontiers, an industry-funded research centre focused on risk, and the Managing Climate Variability (MCV) program, which helps link weather and climate information with the agricultural sector.

There is an increasing need to capture the behaviour of climate extremes in national prediction systems. To date, the assumption has been that models with skill in capturing the averages will have skill in capturing extremes. Evidence has emerged that disputes this assumption, leading to the need to build new mathematical models with explicit attention to the behaviour of systems under extreme conditions. CLEx will focus on the processes underlying extreme rainfall, droughts, heatwaves and cold air outbreaks. Because these are all affected by the background climate, including variability on many time scales, we will maintain research efforts on climate variability, teleconnections and climate sensitivity. Our research will be necessarily quantitative, understanding the physics, dynamics and biology of climate extremes and describing them in ACCESS. Central to our research, therefore, are the high-performance computers and data environment provided by NCI.

We aim to help reduce Australia's economic, social and environmental vulnerability to climate extremes. Climate extremes affect many facets of Australian society, including health, soil and water, agriculture, infrastructure, energy security and financial security. Our research therefore touches on many of the Federal Government's Science and Research Priorities, including its *Food, Soil and Water, Transport, Energy, Environmental Change* and *Health* priorities. By linking with Risk Frontiers we will prioritise how climate extremes affect insurance risks, and via the MCV Program we will prioritise how climate extremes affect food production.

With national and international partners, we will apply new understanding to our national prediction systems and improve predictions of climate extremes. By linking with key economic sectors we will enable better decision-making that builds increased national resilience to climate extremes and helps minimise risk to the Australian environment, society, and economy.

Director's Report

The ARC Centre of Excellence for Climate Extremes (CLEx) was formally launched on August 4, 2017. In a detailed transition plan provided to the Australian Research Council (ARC), we documented how the new research to be undertaken in CLEx would build on that achieved in the ARC Centre of Excellence for Climate System Science (ARCCSS) by transforming our focus from the climate system to how extremes behave in the climate system.

The change from averages to extremes is a change in focus; the ARCCSS maintained an exceptional research program focused on the statistics of extremes and how these changed in the observational record and in climate projections. We will now build on this effort, moving from examining extremes through a statistics lens, to using a process-based lens. Understanding why some extreme events seem to be emerging from the background state more quickly than expected necessarily requires an understanding of the mean state and of the variability implicit in the averages. This was a major focus of the ARCCSS, and it remains in CLEx as one of four major research programs — the others being drought, extreme rainfall and heatwaves & cold air outbreaks.

The move to focusing more on extremes necessitates some innovation around research infrastructure and data interrogation. Our modelling systems, used to simulate the ocean, atmosphere and land systems, need a revolution; first, to represent the key processes central to extremes events in a physically reasonable way, and second, to do this with a far higher spatial detail than previously employed. Similarly, to understand averages we could commonly condense observations or model simulations to long-term averages. If we want to understand how ocean eddies affect carbon uptake, or how land-atmosphere feedbacks intensify extreme rainfall, we will need to interrogate data in very high spatial and temporal detail.

Over the Centre's first few months we have been exploring many of these issues. How high a spatial detail is needed to simulate extremes? Can we use climate models that underpin simulations to be conducted by the Coupled Model Intercomparison Project at around 100 x 100km resolution? Or do we need to be using models at 50km, or 20km or higher? Which extremes are captured well at what resolution? Questions of these kinds provide the foundation for resolving model weaknesses and moving forward rapidly on resolving the reasons why models struggle with extreme events.

In the months since CLEx was established we have also been planning. We have advertised and filled virtually all of the research fellowships available in the Centre, attracting the best people via outstanding working conditions, superb opportunities, flexibility, and so on. We recruited for 14 research fellow positions. We are delighted to have made offers to eight women, based purely on merit. Our field, rich in Science, Technology, Engineering and Mathematics (STEM), has struggled to attract outstanding women, and while appointments at this level are not the answer to women in STEM, at least it helps increase the number of women likely to apply for permanent positions later on.

We have also been active in planning for the next seven years. We have been refining our research priorities, prioritising data sets and modelling systems, revisiting how to improve the graduate program inherited from the ARCCSS, re-engineering our website, revisiting our media strategy, and so on. It has been a busy few months but we think we are now well prepared for the arrival of most of the research fellows in the first few months of 2018.

In the remainder of this report, you will find information on how the research priorities are being refined, how we are ramping up investment in areas of need, including science, research infrastructure, and the necessary administrative systems. While it has only been a few months, we think we are already moving forward, indeed accelerating forward, in the establishment of a world-leading Centre of Excellence.

Andy Pitman

Director

ARC Centre of Excellence for Climate Extremes Strategy 2018-2024

Our Vision: We will transform our understanding of the processes that cause climate extremes, including their dependence on climate change and variability, and to use this process-based understanding to revolutionise our capability to predict future climate extremes.

Our Research Goals

- Advance our understanding of the processes involved in extreme rainfall and build this understanding into models to improve predictions
- Understand the physical mechanisms controlling the frequency, intensity and duration of heatwaves and cold air outbreaks in Australia and build this understanding into models to improve predictions
- Advance our understanding of the controls on the frequency, intensity and duration of drought in Australia in the past, present and future and improve their representation in models to improve predictions
- Discover how climate variability, climate teleconnections and climate sensitivity are related to regional climate extremes.

Our Research Strategy

- We undertake transformative blue-sky research with a critical mass of world-class climate system scientists based on a seven-year strategy
- We develop and respond to ground-breaking ideas with vigour and commitment
- We help build a national climate modelling infrastructure using our dedicated Computational Modelling Support team
- We educate the next generation of Australia's climate scientists by transforming the graduate student experience at the national scale
- We will openly collaborate nationally and internationally
- We will define overarching research questions that integrate Centre activities and strengths
- We will communicate our science to the public and to policy makers with honesty, accuracy and integrity.

Our Values

- Internationally outstanding science, published in elite journals
- An exemplar and vibrant centre, with a culture of inclusivity and equity
- A world-class education for our students and postdoctoral researchers
- Unrestricted access to our tools, data and knowledge
- Honest and clear communication of our science
- A desire to deliver more than we promise.

We are successful when:

- Our graduate students are outstanding and in demand
- We collaborate without impact from institutional barriers
- Our publications have impact on international science
- Our science is included in Australian and overseas models
- Researchers want to join our team
- Technology and data are no barrier to our science
- We communicate our science accurately, but without fear or favour.

Strategic Objectives:	World class research focused on climate extremes	An outstanding environment for all Centre activities	Exceptional research infrastructure	Transform collaboration at all scales	Research that engages and has impact
Success strategy	**Our research program**	**An outstanding culture for all**	**Our research infrastructure program**	**National climate science fabric**	**Our outreach program**
Strategic Actions we will:	1.1 Focus research on delivering four research programs: Extreme rainfall, heatwaves and cold air outbreaks, droughts and climate variability & teleconnections	2.1 Develop a researcher development program led by a Graduate Director	3.1 Establish an infrastructure team to advise on modelling and data systems	4.1 Establish structures that avoid silos and encourage cross-institutional research	5.1 Establish a knowledge brokerage team to deliver outreach programs
		2.2 Strive to reflect diversity inclusivity at all levels and actively manage well-being	3.2 Work closely with NCI to ensure our partnership is mutually beneficial	4.2 Conduct national workshops and training programs	5.2 Work with selected partner organizations to deliver bespoke research data
	1.2 An uncompromising focus on research excellence at all levels	2.3 Ensure early career representation at all levels of Centre activities	3.3 Maintain a computational modeling systems team to provide expert help	4.3 Conduct regular cross-institutional research team meetings	5.3 Develop tailored STEM educational resources for schools
	1.3 Engage nationally and internationally to ensure impact	2.4 Communicate a culture of community and belonging across the Centre	3.4 Develop components of the ACCESS model needed for our research goals	4.4 Interact with our Advisory Board on key strategic issues	5.4 Implement a media strategy, using a range of appropriate technologies
	1.4 Identify gaps in our research and attract additional funding to resolve them	2.5 Be an exemplar providing a superb environment for all students and staff	3.5 Develop a strategy for observations, models, and reanalysis data	4.5 Contribute strongly to Australia's Science and Research Priorities	5.5 Communicate our research to government, schools, businesses, etc.

Centre Structure, Governance and Management

Governance and Management

Centre Advisory Board

The Australian Research Council Centre of Excellence for Climate Extremes (CLEx) is overseen by a Board, which is chaired by distinguished scientific leader Dr Tony Press. The Centre 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 inaugural meeting of the Board is scheduled for February 2018.

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 – 2014. DrPress 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, and Australia's Commissioner for the Convention on the Conservation of Antarctic Marine Living Resources from 1998 to 2008.

Dr Helen Cleugh, Director, CSIRO Climate Science Centre

Dr Helen Cleugh is an atmospheric scientist with almost 30 years' experience combining research discovery, delivery and leadership. Her research expertise lies in quantifying the interactions between the land surface and the atmosphere, and their effects on weather, climate and hydrology; and water use and carbon uptake.

Dr Cleugh is currently the Director of the CSIRO Climate Science Centre (CSC). The CSC collaborates closely with national and international research partners to deliver knowledge and information products and services to a broad community of research and end-users.

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 1987-88. From 1998-2000 he chaired the Australian Greenhouse Office Experts Group on Emissions Trading which developed the first emissions trading system design for Australia. From 1997-2001 he was CEO of the Australian Institute of Company Directors. Ian has a particular interest in the interaction of corporate governance, corporate responsibility and sustainability.

He 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.

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 (WMO) 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.

Chris Johnston, Assistant Secretary Climate Change Policy branch, Department of the Environment and Energy

Chris Johnston is the Assistant Secretary of the Climate Change Policy branch in the Commonwealth Department of the Environment and Energy. His duties in this role include responsibility for climate change science and adaptation policy. Chris Johnston has held a number of senior positions across the Department of the Environment and Energy and the Department of Climate Change and Energy Efficiency, including in the areas of renewable energy, heritage, budget strategy and communications. He has also worked on climate change and environment policy in the Department of the Prime Minister and Cabinet.

Dr Peter May, Head of Research, Bureau of Meteorology

Now its Head of Research, Dr Peter May joined the Bureau of Meteorology (BoM) in 1990 as a research scientist, and has since overseen the development of the operational systems that underpin BoM services as well as major projects delivering climate information to the nation. He serves on a number of advisory committees and represents BoM on major national and international committees. He is presently a member of the WMO Commission of Atmospheric Science Management Committee that oversees WMO weather and environmental research coordination.

Dr Jon Petch, Head of UK Meteorological Office Science Partnerships

As Head of the UK Meteorological Office Science Partnerships, Dr Jon Petch is responsible for the UK Met Office's national and international relationships with other science organisations. Dr Petch has worked on physical modelling and parameterizations since joining the UK Met Office in 1997. From 2009, in parallel with the science research, He has also managed various science collaborations on behalf of the UK Met Office.

Dr Petch continues to carry out research in areas related to atmospheric processes and parameterizations and leads the Global Atmospheric System Studies project.

Professor Laura Poole-Warren, Pro-Vice Chancellor (Research Training) UNSW

Professor Laura Poole-Warren was appointed Dean of Graduate Research in 2010 and Pro-Vice Chancellor (Research Training) of the University of New South Wales in 2012.

Prof Poole-Warren was awarded a PhD from UNSW in 1990 and held various appointments within the university after joining the academic staff in 1995. These include Associate Dean Research Training and Associate Dean Research in the Faculty of Engineering, and Professor in the Graduate School of Biomedical Engineering.

Matt Riley, Director Climate and Atmospheric Science, Office of Environment and Heritage

Matthew Riley is Director of Climate and Atmospheric Science at the NSW Office of Environment and Heritage (OEH). He is also the Director for the NSW and ACT Regional Climate Modelling Project – NARCliM, and leads OEH's Climate Change Impacts Research Program. In addition, he also 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. He has over two decades of experience in urban meteorology, climatology and air-quality measurement.

Centre Executive

The Centre Executive is composed of the Centre Director, who carries overall responsibility for day-to-day leadership of the Centre and its research; the Deputy Director; the Chief Operations Officer; the Research Development Director; and the Manager of the Computational Modelling Support team. Each research program at the Centre of Excellence has a pair of co-leaders. An extended Centre Executive, which includes the co-leaders of each research program, meets by video conference on a monthly basis to discuss both operational and scientific matters. Every second month, the group is joined by all Chief Investigators.

Centre Committees

To maximise the Centre's effectiveness 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 the 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: Mike Roderick (ANU), Steven Sherwood (UNSW), Claire Vincent (U. Melb)

The ARC Centre of Excellence for Climate Extremes (CLEx) is committed to providing an unrivalled working environment for its students and staff. The Centre is committed to implementing measures that enhance the diversity of our staff and student populations and proactively ensure an equitable culture. To this end, the Centre has established a Diversity and Culture Committee.

The committee will provide advice and recommendations to the Centre Director and Centre Executive on matters pertaining to equity, diversity and Centre culture. The committee will also have Centre-wide initiatives and draft policies and procedures within its sphere of influence. The committee's activities will be based on research and on benchmarking of best practice in the equity, diversity and culture landscape in Science, Technology, Engineering and Mathematics (STEM) and in higher education generally.

The initial meetings of the committee were concerned with developing terms of reference and determining priorities for the committee's first 12 months. Among the terms of reference are commitments to

- develop, maintain and review an active strategy and policy on diversity, equity and culture;
- identify opportunities to improve the Centre's diversity;
- regularly report on initiatives, outcomes and ongoing concerns in respect of culture and diversity;
- provide a safe and impartial forum for Centre personnel to discuss issues around professional inequity;
- ensure diversity is reflected in invited visitors, speakers at conferences, workshops and so on; and
- recommend initiatives around Centre structure, internal communications and technology that enhance coalescence and cohesion within and across Centre nodes.

The committee is looking forward to playing an instrumental role in ensuring CLEx functions as an effective national community with a healthy, positive and collaborative culture. Respect for diversity and a commitment to equity are underpinning foundations of the Centre.

Infrastructure Committee

Chairs: Gab Abramowitz (UNSW)
Members: Nathan Bindoff (UTAS), Claire Carouge (UNSW), Dietmar Dommenget (Monash), Jason Evans (UNSW), Andy Hogg (ANU), Neil Holbrook (UTAS) and Christian Jakob (Monash)

The CLEx Infrastructure Committee's primary role is to aid the Computational and Modelling Support (CMS) team in the prioritisation and delivery of the services it provides. This includes engaging in the decision-making process 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 CLEx. The committee is also tasked with helping the CMS team allocate National Computational Infrastructure (NCI) computer and storage resources to CLEx research programs, as well as helping manage the relationship with NCI and other relevant National Collaborative Research Infrastructure Strategy capabilities.

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

The first meetings of the Infrastructure Committee have focused on

- the management of computer resource allocations across CLEx and the ARC Centre of Excellence for Climate System Science, as well as strategies for managing increased demand with finite resources as CLEx projects increase their requirements over time;

- communication of best practice 'housekeeping' guidelines for researchers to maximise available resources to active research projects; and

- developing a strategy and timeline for CMS team imbedding within research program meetings and planning.

Outreach Committee

Chair: Peter Strutton, UTAS
Members: Nerilie Abram (ANU), Julie Arblaster (Monash), Dietmar Dommenget (Monash), Jason Evans (UNSW), David Karoly (U. Melb), Alvin Stone (UNSW)

The CLEx Outreach Committee will contribute to Aim 5 of the Centre, as described in the original proposal: *To use our new knowledge and new capability to bridge from our science to impact by working with stakeholders to reduce Australia's vulnerability to climate extremes.* One important way in which the committee will do this is by advising the Centre on the design and implementation of the Knowledge Brokerage Team (KBT). The KBT will be comprised of two appointed members across UNSW and Monash, who will engage with the Centre's Media and Communications Manager, Chief Investigators, the CMS team, research fellows and PhD students. The KBT will deliver relevant outcomes to our stakeholders. These stakeholders include the federal and state governments, National Environmental Science Program hubs (Earth Systems and Climate Change Science, Clean Air and Urban Landscapes) and organisations such as Risk Frontiers and the Managing Climate Variability Program.

The Outreach Committee will ensure that the Centre maintains an effective outreach strategy by identifying opportunities and tools to engage with external groups, highlighting Centre activities and successes, and generally raising the Centre's profile. The committee will develop and implement a unified social media plan across multiple platforms and also motivate researchers at all levels to contribute to outreach, including the annual report, newsletters, the website and social media.

In the first year of CLEx, the Outreach Committee will focus on establishing the KBT and defining the way in which the committee and the KBT will work together to address the needs of stakeholders. The committee will also review the current outreach mechanisms delivered by the Centre and try to identify efficiencies in the production and dissemination of content.

Centre Business Team

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

Stephen Gray is the Centre's Chief Operations Officer and brings extensive ARC Centre of Excellence management experience to the role. He is supported by Vilia Co in the role of Finance and Resources Manager. The operations team is comprised of Events Co-ordinator Elaine Fernandes (UNSW) and Executive Assistants Jenny Rislund (UNSW), Sook Chor (Monash), Christine Fury (UTAS, 0.2FTE) Alina Bryleva (ANU, 0.4 FTE) and Karla Fallon (U.Melb 0.2FTE). Media and Communications Manager Alvin Stone (UNSW) continues his superb work of profiling the Centre's research and generously sharing his time and expertise with other communicators in the national Centres of Excellence community.

Leadership Development

As is evident from the Researcher Development Program chapter that follows, we are strongly committed to providing leadership training, guidance and opportunities for all Centre researchers, including our students and Early Career Researchers (ECRs) and our professional and technical staff. Our students and ECRs are represented via our ECR Committee, with an ECR representative attending Centre Executive meetings. Our ECR Committee also organises ECR professional development and training events, including dedicated ECR events at national Australian Meteorological and Oceanographic Society annual meetings, and helps facilitate dedicated ECR funding applications that enable our ECRs to lead small projects that expand beyond the scope of their research programs.

Equity and Diversity

The ARC Centre of Excellence for Climate Extremes fosters a culture of diversity and inclusion. Our goal is to make the Centre a progressive organisation that enables all staff and students, regardless of background, to do their best work in a professional and compassionate environment.

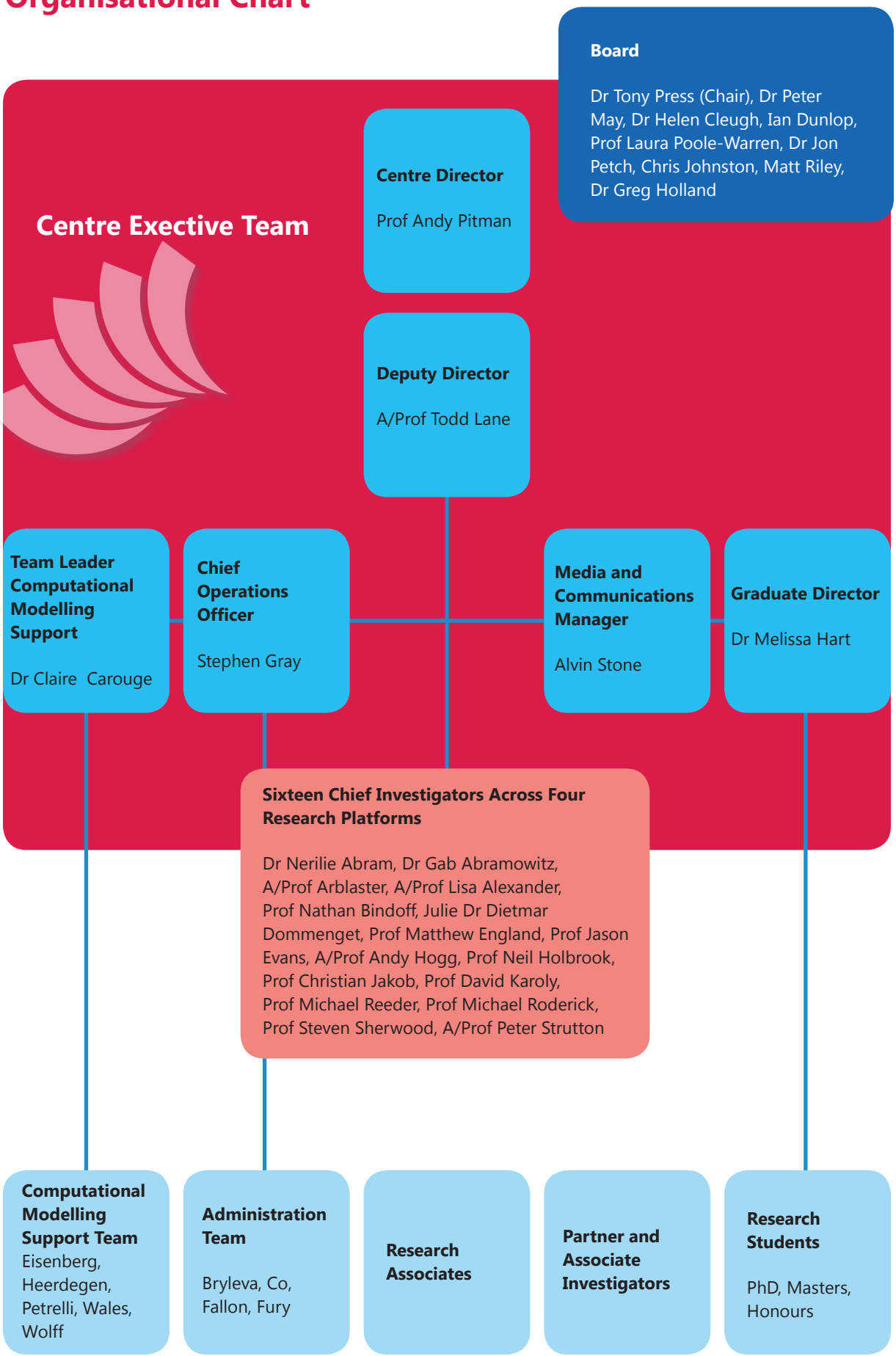
Our first significant initiative was a suite of recruitment activities for the Centre's first cohort of postdoctoral researchers. To ensure gender equity in our recruitment drive for postdoctoral researchers, the Centre reframed its recruitment process by introducing a range of strategies to address gender biases and encourage women applicants. Recruitment strategies included

- use of non-gendered language in job advertisements
- advertising targeted towards women
- ensuring diversity of interview panel members and
- compulsory implicit bias training for all interview panel members.

The gender composition of applicants throughout the recruitment process — from applications through to appointment — was tracked, and the final gender mix of eight women and six men appointed to date illustrates the success of these strategies. Dr Melissa Hart is preparing a paper for publication on the success of this recruitment strategy.

Going forward, the Centre's Diversity and Culture Committee will be working on a number of initiatives that aim to address systemic disadvantages faced by women in STEM disciplines as well as working collaboratively across the Centre to tackle challenges faced by other under-represented groups. At the time of publication, the Centre's Equity Plan was being prepared for submission to the Australian Research Council.

Organisational Chart



Chief Investigators

Prof Andy Pitman - Director

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. Prof Pitman was Head of the Department of Physical Geography at Macquarie University from 1999 to 2003 and Deputy Dean of Division from 2000 to 2003. He initiated the Climate Risk Centre of Research Excellence there before moving to the University of New South Wales in 2007 to co-direct the newly established Climate Change Research Centre.

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 Australian Research Council 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, the NSW Minister for Climate Change's Science Advisory Committee and the former Department of Climate Change Advisory Committee. In 2007 he was appointed to the Prime Minister's Science, Engineering and Innovation Council on Regional Climate Change.

Internationally, Prof Pitman is closely affiliated with the World Climate Research Programme (WCRP). He was Chair of the WCRP's Land Committee for the Global Land Atmosphere System Study from 2006 to 2008 and is now on its Science Steering Committee. 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 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 for the project Land Use Change: Identification of Robust Impacts.

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 Intergovernmental Panel on Climate Change (IPCC) Assessment Reports 3 and 4, contributing to the award of the Nobel Peace Prize to the IPCC in 2007. He has also contributed to the Copenhagen Diagnosis, an Australia-led update of the science of climate change. He has held editorial positions with the *Journal of Climate* and the Annals of the Association of American Geographers' *Journal of Geophysical Research-Atmospheres* and is currently an editor for the *International Journal of Climatology.*

Awards and accolades received by Prof Pitman include the NSW Scientist of the Year Award (2010), the Australian Meteorological and Oceanographical Medal (2009), the Dean's Award for Science Leadership at Macquarie University (2005), the Priestly Medal for Excellence in Atmospheric Science Research (2004) and the Geoff Conolly Memorial Award (2004). He 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).

Prof Pitman has a long track record of nurturing early career researchers and has supervised 10 PhD students through to successful completion, plus five masters students and a significant number of honours students. He has published more than 150 papers in peer-reviewed journals and has authored 20 book chapters.

A/Prof Todd P Lane – Deputy Director

Associate 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 2000-2002 and a staff scientist from 2003-2005. He joined the University of Melbourne in 2005, where he is now Associate Professor and Reader in the School of Earth Sciences. Between 2010-2014 he was an ARC Future Fellow.

A/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. His research within the Centre is focused on tropical convection, and he is using high-resolution cloud- and weather-prediction models to determine

the processes controlling the formation and evolution of tropical cloud systems. Of particular emphasis are convective processes in the maritime continent and the diurnal cycle of rainfall.

A/Prof Lane was the 2014-2015 President of the Australian Meteorological and Oceanographic Society (AMOS) and was Chair of the American Meteorological Society (AMS) Committee on Mesoscale Processes from 2012-2015. He is currently an editor of *Monthly Weather Review* and sits on the Advisory Board of the *Journal of Southern Hemisphere Earth Systems Science*. A/Prof Lane has received awards from AMS, the Australian Academy of Science, AMOS and NASA.

A/Prof Nerilie Abram

Associate Professor Nerilie Abram holds a bachelor of science (advanced) degree with honours from the University of Sydney and was awarded a PhD in Earth Sciences from the Australian National University in 2004. Prior to taking up her current position at ANU A/Prof Nerilie was employed as a research scientist with the British Antarctic Survey, where she held a research and managerial role in the ice-core team. She also led a multi-national effort to process and analyse a new, deep ice-core from James Ross Island. The high public profile of the British Antarctic Survey allowed her role to also involve a considerable amount of public outreach and communication.

A/Prof Abram's current pioneering research addresses the past behaviour of the Earth's climate system, and implications for anthropogenic climate change. Her outstanding research portfolio has generated unique new records of past climate and environmental impacts from regions spanning the tropics to Antarctica, plus assessments of these alongside state-of-the-art climate models. Her high-impact work has led to ground-breaking advances in understanding how climate change is affecting Southern Ocean winds, Antarctic temperatures and Australian rainfall patterns. Her 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. A/Prof Nerilie was the recipient of a QEII Fellowship upon her return to Australia in 2011 and she currently holds an ARC Future Fellowship.

Dr Gab Abramowitz

Dr Aramowitz's primary research interest is model evaluation in climate science, ecology and hydrology. Currently his research focuses on two main areas: model dependence in multi-model ensemble climate prediction and the standardisation of model evaluation in land surface research.

Climate research teams share literature, data sets and even sections of model code. Dr Abramowitz investigates questions such as the following: To what extent do different climate models constitute independent estimates of a prediction problem? What is the most appropriate statistical framework with which to define independence? What are the implications of ignoring model dependence?

Dr Abramowitz is also leading the development of the Protocol for the Analysis of Land Surface Models web application, which provides automated land-surface, hydrological and ecological model evaluation tools as well as observational data sets.

He co-chairs the Global Energy and Water Cycle Experiment Global Land-Atmosphere System Study panel, chairs the Australian Water and Energy Exchange Model Evaluation and Benchmarking working group and is a member of the Community Atmosphere-Biosphere Land Exchange Committee. He holds a PhD from Macquarie University, Sydney.

A/Prof Lisa Alexander

Associate Professor Lisa Alexander holds a Bachelor of Science and a Master of Science in Applied Mathematics and a PhD from Monash University. Between 1998 and 2006 she worked as a research scientist at the UK Meteorological Office — Hadley Centre, with a year on secondment at the Australian Bureau of Meteorology.

A/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 signifi-

cantly to the Intergovernmental Panel on Climate Change (IPCC) assessments.

She was awarded the 2011 Priestley Medal by the Australian Meteorological and Oceanographic Society and the 2013 Australian Academy of Science Dorothy Hill Award for her contribution to this field of research. She contributed to the IPCC assessments in 2001 and 2007 and to the 2012 Special Report on Extremes and was a Lead Author of the IPCC's 5th Assessment Report. A/Prof Alexander also chairs a World Meteorological Organization Commission for Climatology Expert Team and is Co-chair of the World Climate Research Programme Grand Challenge on Extremes.

A/ Prof Julie Arblaster

Julie Arblaster is an associate professor in the School of Earth, Atmosphere and Environment at Monash University, having moved there in 2016 after many years at the Australian Bureau of Meteorology and the National Center for Atmospheric Research (NCAR), in the USA, before that.

Associate Professor 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 effects on the surface, ocean circulation and sea ice. Recent work has also focused on explaining extreme events in Australia, such as record-breaking temperatures and rainfall, from a climate perspective, both in terms of the role of human influences and the diagnosis of the climate drivers.

A/Prof Arblaster's research incorporates the use of observations, multi-model data sets and sensitivity experiments with a single model. Her strong collaboration with NCAR and participation in various international committees and reports enhances her engagement with the latest advances in climate research internationally.

A/Prof Arblaster was awarded the 2014 Australian Academy of Science Anton Hales Medal for research in earth sciences and the 2018 Priestley Medal from the Australian Meteorological and Oceanographic Society. She was an active member of the World Climate Research Programme's Stratosphere-Troposphere Processes and their Role in Climate scientific steering group from 2011-2016 and served as a Lead Author of the Intergovernmental Panel on Climate Change 5th Assessment Report and was a Chapter Lead Author the latest World Meteorological Organization/United Nations Environment Programme Scientific Assessment of Ozone Depletion. She is a member of the National Climate Science Advisory Committee and the National Committee on Earth System Science.

Prof Nathanial Bindoff

Nathan Bindoff is Professor of Physical Oceanography at the University of Tasmania. Professor Bindoff is a physical oceanographer, specialising in ocean climate and the Earth's climate system, with a focus on understanding the causes of change in the oceans. He was the Coordinating Lead Author for the Oceans chapter in the Intergovernmental Panel on Climate Change (IPCC) 4th and 5th Assessment Reports (AR4 & AR5). Prof Bindoff and colleagues documented some of the first evidence for changes in the Indian, North Pacific, South Pacific and Southern oceans and the first evidence of changes in the Earth's hydrological cycle from ocean salinity.

His most recent work is on documenting the decline in oxygen content of the oceans. He has also worked in the Antarctic, to determine the total production of Adelie Land Bottom Water formation and its contribution to Antarctic Bottom Water Formation and its circulation. Prof Bindoff's group has contributed to the development of some of the largest and highest-resolution model simulations of the oceans for the scientific study of mixing in the oceans. He contributed to the IPCC's winning of the Nobel Peace Prize in 2007, shared with Al Gore, and was a Coordinating Lead Author of the Detection and Attribution chapter in the IPCC's AR5.

Prof Bindoff's current interests are primarily in understanding how the changing ocean can be used to infer changes in atmosphere and whether these changes can be attributed to rising greenhouse gases and for projecting future changes. He is also interested in the effects of changes on regional climates.

Prof Bindoff led the Climate Futures project for the study of impacts of climate change on Tasmania. He has served on 14 international committees, been the invited speaker at 22 conferences and workshops and co-chaired two workshops. He was guest editor on two special volumes of *Deep Sea Research*, and convened

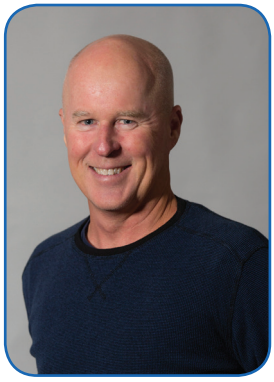
the Oceans session of the Climate Change Congress, Copenhagen, March 2009. He has published more than 100 scientific papers, seven book chapters, eight conference papers and 43 reports. He has a H index of 39 and more than 10000 citations (Google Scholar).

Dr Dietmar Dommenget

Dr Dietmar Dommenget completed his Diploma in Physics at the University of Hamburg. He started studying climate dynamics and climate model development at the Max Planck Institute for Meteorology in 1996 and finished his PhD in 2000. He joined the 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 the El Niño-Southern Oscillation in a joint observational data assimilation scheme. After three years in California he returned to Germany in 2003 for a fixed-term faculty position as a junior professor in the Meteorology department at the IFM-GEOMAR (also known as the Liebniz Institute of Marine Sciences) in Kiel. Since 2010 Dr Dommenget has been Senior Lecturer at Monash University in the Weather and Climate group of the School of Mathematical Sciences.

Dr Dommenget's research focuses on large-scale climate dynamics. 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 extra-tropical oceans. He is most widely known for his work on the interpretation of statistical patterns in climate variability. Dr Dommenget's most recent projects focus on 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.

Prof Matthew England



Professor Matthew England obtained his PhD in 1992 from the University of Sydney. He is a former Fulbright Scholar and was a postdoctoral research fellow at the Centre National de la Recherche Scientifique, France, from 1992-1994. He was a research scientist in CSIRO's Climate Change Research Program from 1994-1995 and was a CSIRO Flagship Fellow in 2005. He has been with the University of New South Wales since 1995, where he held an ARC Federation Fellowship from 2006-2010. He commenced an ARC Laureate Fellowship in 2011 and is presently Deputy Director of the UNSW Climate Change Research Centre. In 2014 Prof England was elected a Fellow of the Australian Academy of Science and in 2016 a Fellow of the American Geophysical Union.

Prof England's research explores global-scale ocean circulation and the influence it has on regional climate, large-scale physical oceanography, ocean modelling, and climate processes, with a particular focus on the Southern Hemisphere. Using ocean and coupled climate models in combination with observations, he studies how ocean currents affect climate and climate variability on time scales of seasons to centuries. His work has had significant effect on the treatment of water-mass physics in models, on the methodologies of assessment of ocean and climate models, on our understanding of large-scale Southern Hemisphere climate modes, and on the mechanisms for regional climate variability over Australia.

Prof England has served on two Prime Minister's Science, Engineering and Innovation Council expert working groups (Antarctic and Southern Ocean Science, and Energy-Carbon-Water); the Climate Variability and Predictability (CLIVAR) International Working Group for Ocean Model Development; and the ARC Earth System Science Network board. He was Co-chair of the CLIVAR Southern Ocean Region Implementation Panel 2008-2014 and is currently a member of the World Climate Research Programme/CLIVAR/Global Energy and Water Cycle Experiment Drought Interest Group.

Prof England was awarded the Land & Water Australia Eureka Prize for Water Research and the Banksia Foundation Mercedes-Benz Australian Research Award in 2008. In 2007 he received the Royal Society of Victoria Research Medal. Other awards include the Sherman Eureka Prize for Environmental Research (2006); the Australian Meteorological and Oceanographic Society

Priestley Medal (2005); the Australian Academy of Science Frederick White Prize (2004); a Fulbright Scholarship (1991-1992); and the University Medal, University of Sydney (1987).

Prof England has authored over 180 peer-reviewed journal papers. He has been a Contributing Author for two Intergovernmental Panel on Climate Change Assessment Reports and was the convening lead author of the 2009 Copenhagen Diagnosis. He has supervised more than 20 PhD students through to successful completion and taught more than 3000 undergraduate students.

He was an associate editor for *Reviews of Geophysics* 2005-2009 and an associate editor for the *Journal of Climate* 2008-2015.

Prof Jason Evans

Professor Evans has over 15 years' experience researching regional climate processes, land-atmosphere feedbacks and changes in water cycle components over land. He currently holds a professorship at UNSW and is a former ARC Future Fellow (2012) and Australian Research Fellow (2007). Prior to returning to Australia to take up his current role at UNSW, Prof Evans held a research fellow position at Yale University.

His research program brings together advanced modelling tools with extensive observational data sets, with an emphasis on satellite-based, remotely sensed earth observations. The research finds new and improved techniques to combine data with regional climate and land surface models, to help solve problems of national and international significance. Prof Evans is particularly interested in changes to the water cycle over land, largely through changes in land use and changes in climate, and how these changes influence extremes such as droughts, heatwaves and extreme precipitation.

Prof Evans is Co-chair of the Global Energy and Water Exchanges Hydroclimate Panel and Australasia region coordinator of the Coordinated Regional Climate Downscaling Experiment, both elements of the World Climate Research Programme. He is also the lead modeller on the NSW/ACT Regional Climate Modelling project. This project is producing an ensemble of regional climate projections over south-east Australia for use in impacts and adaptation research.

A/Prof Andy Hogg

Associate 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 ARC Postdoctoral Fellow. He is currently based at ANU's Research School of Earth Sciences and holds an ARC Future Fellowship.

A/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 the role of the ocean in altering the variance of modes of climate variability and the ocean's response to changes in the major climate modes. He will investigate the physical changes in Southern Ocean water-mass formation and the role of eddies and mixing in the climate system.

Due to A/Prof Hogg's unique contributions to understanding of the Southern Ocean, he was awarded the Frederick White Prize from the Australian Academy of Science in 2012, the Nicholas P. Fofonoff Award from the American Meteorological Society and the Australian Meteorological and Oceanographic Society's Priestly Award in 2015. A/Prof Hogg's publication record includes 68 scientific research papers and exhibits a flair for new and innovative research.

Prof Neil Holbrook

Professor Neil Holbrook uses his background in applied mathematics and physical oceanography, along with his expertise in ocean and climate dynamics at seasonal to multi-centennial time scales, to better diagnose the important mechanisms underpinning climate variability and climate change. His research helps to reduce the uncertainties associated with human-induced (anthropogenic) climate change, the potential risks associated

with abrupt climate change, and the likely changes in climatic extreme events, by developing a strong understanding of natural climate variability on all time scales.

Prof Holbrook's particular foci are in regional- to large-scale ocean and climate dynamics, climate change detection, attribution and risks. His research activities include the investigation of planetary scale ocean wave dynamics; interannual (in particular El Niño - Southern Oscillation) to multi-centennial scale climate variability; climate change; and dynamic/climatic influences on ocean (plankton) productivity.

Prof Holbrook also has interests in: understanding the complex feedbacks in both climate science and climate change adaptation; thermodynamic and statistical modelling of tropical cyclone genesis and intensity; and climate and vector-borne disease. His interdisciplinary interests include both observational and modelling studies. On the modelling side, he primarily works with simple- to intermediate-complexity ocean and climate dynamic, thermodynamic and ecosystem models.

Prof Holbrook is one of Australia's original National Greenhouse Advisory Committee PhD scholars and has been working in climate change science for 20 years. He has published extensively in the international literature on the ocean's role in climate, climate variability, climate extremes and climate change. Prof Holbrook was awarded leadership of Australia's National Climate Change Adaptation Research Network for Marine Biodiversity and Resources.

He is President of the International Commission on Climate of the International Association of Meteorology and Atmospheric Sciences/International Union of Geodesy and Geophysics; an associate editor of the *Australian Meteorological and Oceanographic Journal*; and a Fellow of the Australian Meteorological and Oceanographic Society.

Prof Holbrook is a USC/UTAS/GU Collaborative Research Network Research Leadership Fellow (Sustainability; University of Tasmania), a visiting professor at Macquarie University; and an international participant in the Southwest Pacific Ocean Circulation and Climate Experiment.

Prof Christian Jakob

Professor Christian Jakob was awarded his PhD in Meteorology from the Ludwig Maximilians University, Munich, in 2001. As a research and then 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 of the Australian Bureau of Meteorology, and since 2007 he has been a professor at Monash University. He currently is the Chair of Climate Modelling at Monash's School of Earth, Atmosphere and Environment.

Prof Jakob's experience and current interests are in the development and evaluation of the processes crucial to the energy and water cycles in global atmospheric models. Internationally, he is engaged in many scientific and collaborative activities. He is the current Co-chair of the World Climate Research Programme's (WCRP) Modelling Advisory Council. He led the prestigious Working Group on Numerical Experimentation from 2008 to 2012 and was the first university-based researcher to be appointed in that position. He was Chair of the WCRP's Global Energy and Water Cycle Experiment (GEWEX) Modelling and Prediction Panel from 2007 to 2010. Before that, Prof Jakob successfully led the GEWEX Cloud System Study, in which a group of about 150 scientists collaborated on the development and evaluation of cloud and convection representation in models. He co-led the Tropical Warm Pool International Cloud Experiment in 2006.

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.

Prof David J Karoly

Professor David Karoly gained his Bachelor of Science (Honours) in Applied Mathematics in 1976 from Monash University and was awarded his PhD in Meteorology from the University of Reading, in England, in 1980. From 1995 to 2000 he was the Director of the Co-operative Research Centre for Southern Hemisphere Meteorology at Monash University, and during 2001-2002 he was Professor of Meteorology and Head of the School of Mathematical Sciences at Monash University. From 2003-2007 he was the Williams Chair Professor of Meteorology at the University of Oklahoma. He returned to Australia in 2007 as an ARC Federation Fellow and Professor of Meteorology at the University of Melbourne – a position he held until May 2012. His current position is Professor of Atmospheric Science at Melbourne University's School of Earth Sciences.

Prof Karoly's research focuses on climate variability and climate change, including climate change, stratospheric ozone depletion and interannual climate variations due to El Niño-Southern Oscillation. He is recognised as one of the leading global experts on the dynamics of large-scale atmospheric circulation in the Southern Hemisphere and its variability. He is also recognised as a world leader in the detection and attribution of climate change, particularly at regional scales. Recently, he has been studying the effects of climate change on weather extremes and their impacts on human and natural systems.

Prof Karoly is a member of the Climate Change Authority, established in 2012 as an independent body that provides expert advice on the operation of Australia's carbon price, emissions reduction targets and other Australian Government climate change mitigation initiatives. In 2013, he became a member of the Scientific Steering Committee for the World Meteorological Organization/United Nations Environment Programme Scientific Assessment of Ozone Depletion 2014. During 2011-2012, he was a member of the Joint Scientific Committee that provides scientific oversight to the World Climate Research Programme. From 2008-2009 he was Chair of the Premier of Victoria's Climate Change Reference Group. He is also a member of the Wentworth Group of Concerned Scientists.

Prof Karoly was involved, through several different roles, in the preparation of the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report and was a Review Editor for a chapter in the IPCC 5th Assessment Report. Recent awards received include the 2014 Morton Medal of the Australian Meteorological and Oceanographic Society for "leadership in meteorology, oceanography, climate and related fields, particularly through education and the development of young scientists"; and the 2015 Royal Society of Victoria Medal for Scientific Excellence for "excellence and leadership in scientific research in the Earth sciences".

Prof 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 has also held long-term visiting positions at the National Center for Atmospheric Research (USA), the State University of New York at Albany (USA), the University of Reading (UK) and the University of Leeds (UK). His research is focused principally on weather-producing systems. However, he has published on a wide variety of topics, including fronts, tropopause folding, extra-tropical cyclones, the Madden-Julian Oscillation, Rossby waves, tropical cyclones, gravity waves, solitary waves, convection, boundary layers and bushfires. He has been the principal supervisor for more than 34 graduate students. Prof Reeder is a past President of the Australian Meteorological and Oceanographic Society (AMOS) and a winner of the Distinguished Research Award (AMOS)S) and the Loewe Prize (Royal Meteorological Society, Australia branch).

Prof Michael L Roderick

Professor Michael Roderick graduated with a Bachelor of Applied Science in Surveying from the Queensland University of Technology in 1984 and subsequently worked as a surveyor across northern Australia until 1990. He completed a Postgraduate Diploma in Geographic Information Systems at the University of Queensland in 1990. After working with the Department of Agriculture in Perth (1991-1993), he joined Curtin University. He was a lec-

turer at the School of Spatial Sciences, Curtin University of Technology, from 1993-1996 and completed a PhD in satellite remote sensing and environmental modelling at Curtin University in 1994. He joined the Australian National University as a research fellow in 1996 and currently holds a joint appointment as professor between the Research School of Earth Sciences and the Research School of Biology.

Prof Roderick's principle research interests are in environmental physics, climate science, ecohydrology (including plant-water relations), remote sensing and ecological dynamics. He has made major international contributions to understanding the water-energy-carbon linkage.

An advocate of national and international scientific collaboration, Prof Roderick co-instigated and co-organised the first international scientific meeting to address the observed decline in evaporative demand and the implications for the terrestrial water balance, hosted in 2004 by the Australian Academy of Science. He has also acted as an advisor to the US National Science Foundation's program on ecohydrology. He led the Theoretical Developments in Carbon Cycle Science program of the Cooperative Research Centre for Greenhouse Accounting from 2001-2006.

In 1999, Prof Roderick received the J.B.S. Haldane Prize of the British Ecological Society for research linking water-energy-carbon nutrients at a leaf scale, and in 2004 he received a Top100 award for his research on evaporation. He was awarded the Australasian Science Prize in 2009 for his research on evaporation and changing water availability. In 2013 Prof Roderick was awarded the John Dalton Medal by the European Geosciences Union for his groundbreaking research on trends in the water cycle. In 2015 he was elected a Fellow of the American Geophysical Union for his contributions to the science of evaporation and transpiration, including interpretation of changes in evapotranspiration under global environmental change.

Prof Roderick is also an active supervisor and mentor to emerging scientists. He is currently supervising three PhD students and has seen eight of his PhD scholars graduate since 2001.

Prof Steven Sherwood

Professor Steven Sherwood received his bachelor's degree in physics from the Massachusetts Institute of Technology in 1987. He was awarded a Master of Science in Engineering Physics from the University of California in 1991 and a PhD in Oceanography from the Scripps Institution of Oceanography, University of California, in 1995. He carried out post-doctoral research at Victoria University of Wellington (NZ) from 1996-1997 and was a research scientist at the Goddard Earth Sciences and Technology Center, USA, from 1998-2000. In 2001 he joined the faculty of Yale University, reaching the rank of professor in 2007. At the beginning of 2009 he moved to Australia, where he is currently Professor and ARC Laureate Fellow at the Climate Change Research Centre at the University of New South Wales.

Prof Sherwood is an established leader in atmospheric science. In particular, he 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 also co-authored the first US Climate Change Science Program report, Temperature Trends in the Lower Atmosphere; contributed to The Copenhagen Diagnosis update on the science in 2009 and 2011; and contributed to the National Academy of Science's *Climate Science Questions and Answers*, published in 2010. He currently serves on the editorial board of *Environmental Research Letters* and on the Steering Committee of the World Climate Research Programme's Grand Challenge on Clouds, Circulation and Climate Sensitivity.

In addition to those international activities, Prof Sherwood has co-authored over 90 papers published in peer-reviewed journals. Some of these papers have been covered extensively by the international media: for example, his 2005 paper in *Science* on atmospheric warming, which was named as one of the top 100 scientific discoveries of the year by *Discover* magazine; and his 2014 study on climate sensitivity, published in *Nature*.

Awards received by Prof Sherwood include the 2002 National Science Foundation CAREER Award and the 2005 American Meteorological Association's Clarence Leroy Meisinger Award. He was a Eureka Prize finalist in 2014. Since 2001, Prof Sherwood has given at least 60 invited presentations at scientific meetings or colloquia worldwide. His many public presentations include a briefing in the US House of Representatives, numerous television and radio appearances, and public lectures at many venues.

A/Prof Peter Strutton

Associate Professor Peter Strutton received his bachelor's degree (with first class honours) in marine science from Flinders University of South Australia in 1993. He went on to complete his PhD in Marine Science in 1998. He then left Australia to take up the positions of postdoctoral scientist and research associate with the Monterey Bay Aquarium Research Institute in California — posts he held until 2002. From 2002-2004 he was Assistant Professor with the State University of New York's Marine Sciences Research Center, and from 2004-2010 he was Assistant, then Associate Professor at Oregon State University's College of Oceanic and Atmospheric Sciences. In 2010 he returned to Australia on an ARC Future Fellowship, and since then has been Associate Professor at the Institute for Marine and Antarctic Studies, University of Tasmania.

A/Prof Strutton's research focuses on biological oceanography, and his standing as an Antarctic/Southern Ocean scientist is recognised internationally. He has considerable expertise on how modes of variability (such as the El Niño-Southern Oscillation) and internal ocean waves affect nutrients in the ocean, biological productivity and carbon exchange. Within the ARC Centre of Excellence for Climate Extremes he contributes to the Variability and Teleconnections research program. He concentrates on the drivers of observed changes in biogeochemical cycles (oxygen, carbon and nutrients).

A/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 and has co-authored two reviews of coastal Antarctic productivity. He was also an editor for the journal *Geophysical Research Letters,* where he handled 20-25 papers per month.

Graduate Director

Dr Melissa Hart

Dr Melissa Hart has used her role as Graduate Director of the ARC Centre of Excellence for Climate Extremes to lead and develop 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 120 graduate students with the skills, knowledge and experience fundamental to developing world-leading climate science researchers.

Dr Hart completed her Bachelor of Science (Honours) in 2001 and her PhD in Atmospheric Science in 2006, at Macquarie University. During her PhD studies she worked part-time at the well-respected air quality consultancy Holmes Air Sciences (now Pacific Environment).

She then spent two years as a postdoctoral researcher at Portland State University, Oregon, working on the National Science Foundation-funded FUSE (Feedback between Urban Systems and the Environment) project. This was followed by five years in a faculty position in the Department of Geography, the University of Hong Kong, China.

Dr Hart's main research focus is in the area of urban climate, in particular the effect of land use, surface characteristics and anthropogenic activities on the climate of cities, and quantification of the magnitude of the Urban Heat Island. She is also working in the area of air pollution meteorology, in particular air pollution effects from hazards-reduction burns.

Dr Hart holds an honorary position in the Department of Geography, the University of Hong Kong, and is a member of the Science Advisory Panel for Climate-Watch Hong Kong and China and of the Bureau of Meteorology's Course Advisory Committee.

Personnel

Director

Professor Andy Pitman
University of New South Wales

Deputy Director

A/Professor Todd Lane
University of Melbourne

Graduate Director

Dr Melissa Hart
University of New South Wales

Chief Operations Officer

Stephen Gray
University of New South Wales

Chief Investigators

A/Professor Nerilie Abram
ANU

Dr Gab Abramowitz
UNSW

A/Professor Lisa Alexander
University of New South Wales

A/Professor Julie Arblaster
Monash University

Professor Nathan Bindoff
University of Tasmania

Dr Dietmar Dommenget
Monash University

Professor Matthew England
University of New South Wales

Professor Jason Evans
University of New South Wales

A/Professor Andy Hogg
Australian National University

Professor Neil Holbrook
University of Tasmania

Professor Christian Jakob
Monash University

Professor David Karoly
University of Melbourne

Professor Michael Reeder
Monash University

Professor Michael Roderick
Australian National University

Professor Steven Sherwood
University of New South Wales

A/Professor Peter Strutton
University of Tasmania

Partner Investigators

Dr Sandrine Bony
LMD/CNRS (France)

Dr Elizabeth Ebert
BoM

Dr Wojciech Grabowski
NCAR (USA)

Professor Nicolas Gruber
ETH Zurich (Switzerland)

Dr Stephen Griffies
GFDL – NOAA (USA)

Dr Robert Hallberg
GFDL – NOAA (USA)

Dr Harry Hendon
CAWCR - (BoM)

Dr Anthony Hirst
CAWCR - (CSIRO)

Dr Cathy Hohenegger
MPI for Meteorology (Germany)

Dr Reto Knutti
ETH Zurich (Switzerland)

Dr Rachel Law
ACCESS (CSIRO)

Dr Gerald Meehl
NCAR (USA)

Sean Milton
Met Office (UK)

Dr Nathalie de Noblet
LMD/CNRS (France)

Professor Dani Or
ETH Zurich (Switzerland)

A/Professor Joellen Russell
University of Arizona (USA)

Dr Joe Santanello
NASA - GFSC (USA)

Professor Sonia Seneviratne
ETH Zurich (Swtzerland)

Professor Graeme Stephens
NAS - JPL (USA)

Dr Ying Ping Wang
CAWCR - (CSIRO)

Associate Investigators

Dr Markus Donat
UNSW

Professor Graham Farquhar
ANU

Dr Joelle Gergis
U.Melb

Dr Sarah Kirkpatrick-Perkins
UNSW

Dr Sophie Lewis
ANU

Dr Yi Liu
UNSW

Professor Trevor McDougall
UNSW

Dr Shayne McGregor
Monash

Dr Maxim Nikurashin
UTAS

Professor Peter Rayner
U.Melb

Dr Agus Santoso
UNSW

Dr Alexander Sen Gupta
UNSW

A/Professor Steven Siems
Monash

Professor Scott Sisson
UNSW

Dr Paul Spence
UNSW

Dr Andrea Taschetto
UNSW

Professor Kevin Walsh
U.Melb

Research Associates

Dr Martin De Kauwe
UNSW

Dr Chen Li
Monash

Computational Modelling Systems and Technical Programmers

Dr Claire Carouge
UNSW

Mr Daniel Eisenberg
UNSW

Mr David Fuchs
UNSW

Dr Aidan Heerdegen
ANU

Dr Paola Petrelli
UTAS

Dr Scott Wales
U.Melb

Dr Holger Wolff
Monash University

Professional Staff

Aline Bryleva
ANU

Sook Chor
Monash University

Vilia Co
UNSW

Karla Fallon
U.Melb

Christine Fury
UTAS

Alvin Stone
UNSW

PhD Students

Shannon Bengtson
UNSW

Shreya Dhame
UNSW

Emilio Echevarria
UTAS

Zoe Gillett
Monash

Rishav Goyal
UNSW

David Hoffmann
Monash

Sopia Lestari
U.Melb

Maxime Marin
UTAS

Josue Martinez Moreno
ANU

Roseanna McKay
Monash

Jan Jaap Meijer
UTAS

Zebedee Nicholls
U.Melb

Benjamin Price
U.Melb

Pavan Harika Raavi
U.Melb

Tony Rafter
U.Melb

Saurabh Rathore
UTAS

Manon Sabot
UNSW

Abhishek Savita
UTAS

DongXia Yang
Monash

Yifei Zhou
ANU

Masters Students

Shangyu Hu
ANU

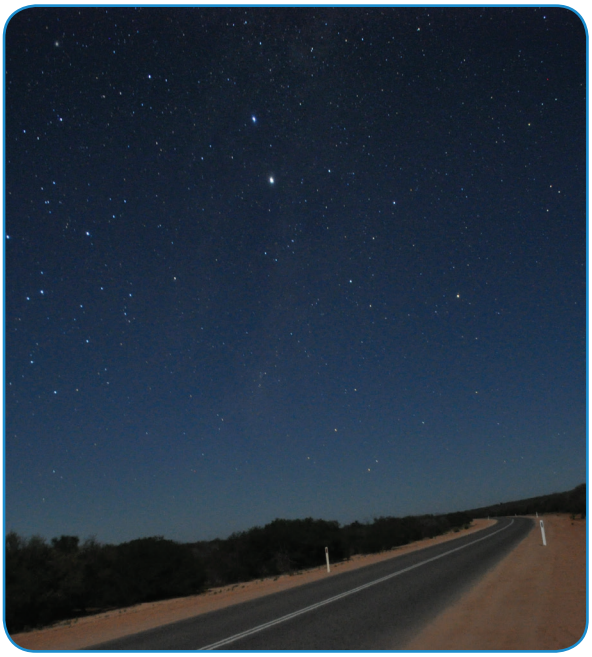
Chuang Wang
ANU

Honours Students

Emma Carroll
ANU

Yandong Lang
ANU

Research Partnerships and Engagement



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
Managing Climate Variability Program
National Computational Infrastructure
NSW Office of Environment and Heritage
Risk Frontiers

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)
NASA-Jet Propulsion Laboratory (USA)
National Center for Atmospheric Research (USA)
UK Meteorological Office (UK)
The University of Arizona (USA)

The Australian Research Council Centre of Excellence for Climate Extremes (CLEx) has a large network of Partner Organisations both in Australia and overseas. Given that our Centre was barely five months old by the end of 2017, the level of engagement by each international Partner Organisation largely reflects pre-CLEx levels of activity. We have not yet appointed the research fellows and PhD students who will visit these institutions, and our more senior researchers have not yet organised travel associated with the Centre. However, discussions on future research priorities have been ongoing, with the UK Meteorological Office and the Geophysical Fluid Dynamics Laboratory in particular, as we determine the modelling systems of choice for the future.

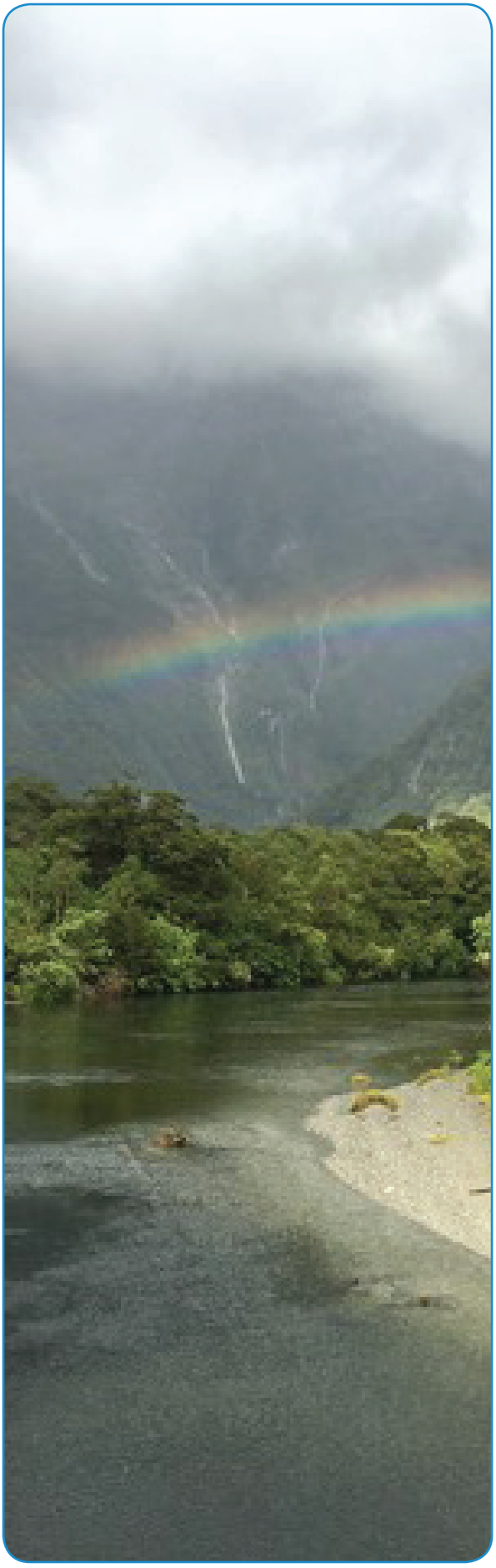
Domestically, there have been ongoing conversations with our key research partners, CSIRO and the Bureau of Meteorology (BoM). These discussions have informed our strategic and implementation plans at all levels. We have also been working closely with the National Computational Infrastructure (NCI), both in terms of operational considerations and allocation of resources, and in terms of strategic considerations linked to ongoing investment in national high-performance computing. In partnership with BoM, CSIRO and NCI, we co-developed the Climate Science Data Enhanced Virtual Laboratory (DEVL) proposal. The Climate Science DEVL was developed as a result of broad community consultation and builds on the work of the previous NCRIS NeCTAR VL and RDSI/RDS projects. University involvement in this strategic initiative would not have been feasible without the Centre of Excellence.

The development of our Knowledge Brokerage team was consciously delayed until early 2018 but the design, implementation and prioritisation of this capability has been informed through conversations with the National Environmental Science Program Earth Systems and Climate Change hub, the NSW Office of Environment and Heritage, Risk Frontiers and the Managing Climate Variability Program. We have also maintained an active dialogue with staff within the Federal Department of Environment and Energy. Although it is not a Partner Organisation, we expect that maintaining strong and open discussions will prove invaluable in the longer term, and we are delighted that the department will be represented on our Advisory Board.

We believe that in the first months of the Australian Research Council Centre of Excellence for Climate Extremes we have prepared the ground for acceleration of our national and international partnerships through 2018, and we expect to report on these outcomes next year.

Christian Jakob Presents Distinguished Lecture in Pune

CLEX Chief Investigator Professor Christian Jakob was recently invited to present the Prof. P.R. Pisharoty Distinguished Lecture to the Indian Meteorological Society in Pune. The Lecture is an annual event hosted by the Indian Institute for Tropical Meteorology (IITM) in Pune. On 14th December 2017 Christian presented his lecture on "The interaction of tropical convection with the large-scale atmosphere - New insights and modelling approaches" to an audience of about 150 meteorologists and guests. The photograph below shows Christian receiving a commemorative plaque for his lecture from IITM Director, Prof Ravi Nanjundiah. While at Pune, he also delivered a 3-day intensive training course on tropical convection and its representation in climate models to 50 students from all over India.

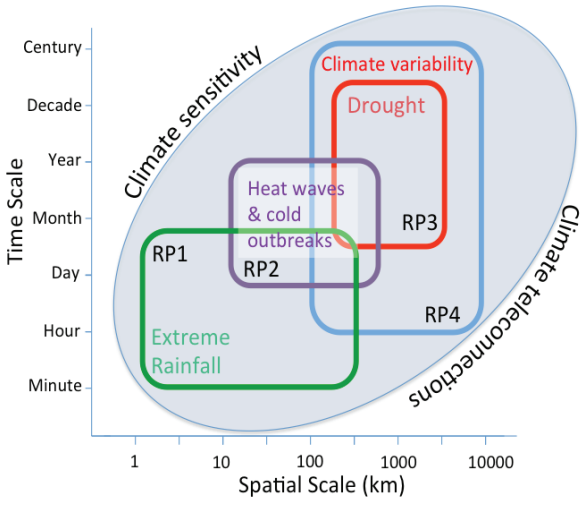


Research Overview

The ARC Centre of Excellence for Climate Extremes (CLEx) brings together four major research programs, with computational and data infrastructure and national and international partners, to form the world's first fully integrated centre dedicated to the understanding of climate extremes.

Improving the prediction of climate extremes requires integration of research across multiple spatial and temporal scales. It also requires uniting the disciplinary knowledge of ocean, atmosphere and land experts in multidisciplinary teams. Virtually every climate extreme has an imprint of interannual to decadal modes of climate variability or trends, which are strongly modulated by ocean processes. The communication of those processes to land-based climate extremes is through the atmosphere's weather systems operating on weekly to daily time scales. The land provides the local background state of surface moisture and heat, through which it can affect rainfall extremes on hourly to daily time scales or modulate heatwaves and droughts from seasons to years. Our Centre of Excellence therefore bridges time scales from many decades to minutes, and spatial scales from global to local, and within this framework we combine expertise including ocean, atmosphere and land science, with mathematics and computer science.

Each of the four CLEx research programs is therefore designed to tackle climate extremes in multidisciplinary teams, taking a multi-scale approach (see Figure). This fundamentally transforms our research from the more common approach of deeply studying phenomena in one sphere for a particular time scale. We need

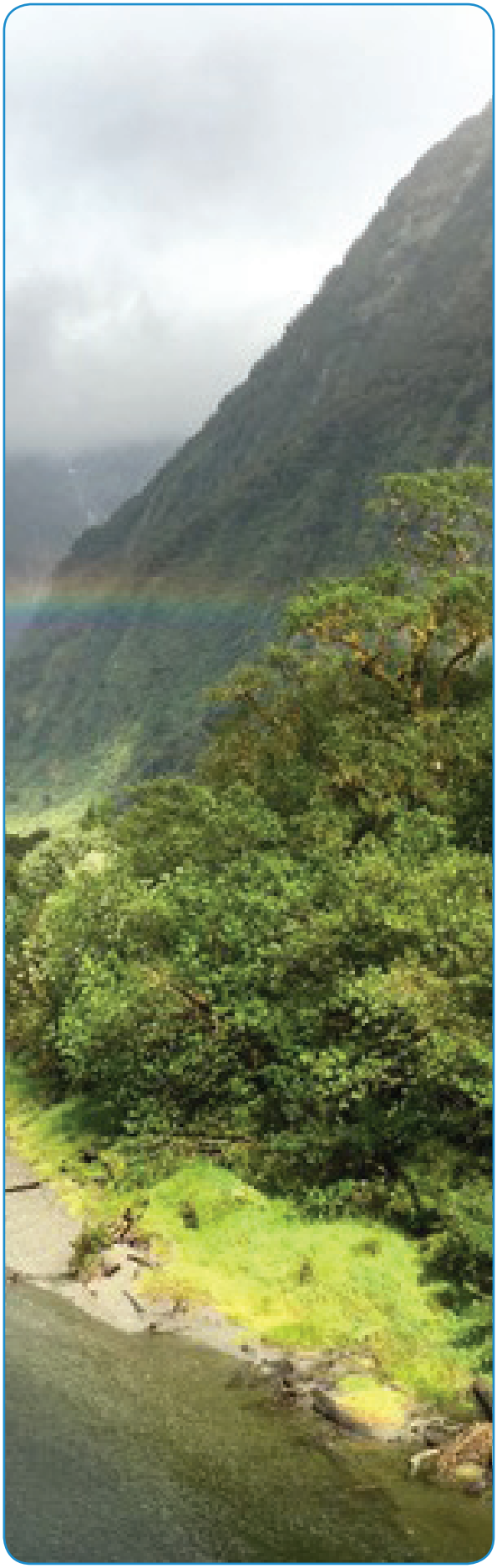


to understand what happened and, critically, why it happened. To be able to predict future climate extremes requires a deep understanding of all processes involved, sourced from a simultaneous program of research across all relevant scales and spheres. Our research programs, with their synergies across time and space, and their focus on process-level processes across spheres, will deliver this deep understanding.

You will see in the chapters that follow that in the first few months of the life of the Centre we have been working hard and systematically to embed our research direction for the years ahead. This has happened within research programs in in-depth meetings. The outcomes were then discussed among Chief Investigators to ensure integration across the four research programs and to identify synergies and address possible redundancies. The outcomes of those discussions are summarised in each of the statements of intent at the end of the following chapters. These set out the short-term goals and longer-term intents and stretch targets for our research endeavours.

Upon CLEx's commencement, we ran a very successful international recruitment campaign to attract postdoctoral research associates to work with us. We are delighted with the calibre of early career researchers we have hired from Australia and overseas, most of whom are commencing their contracts in early 2018. These young researchers will be offered more than 'just a typical postdoc'. We will discover their interests and ambitions and link them up with fellow researchers and senior leaders in the field who can help develop their scientific and professional skills. We will also challenge them to lead, to learn to resolve important problems, to reorganise their research environments to be fit for their needs, and to broaden their knowledge and skills. More details of our researcher development program can be found in a later chapter.

This first annual report does not showcase a large body of scientific output; it reflects five months of research activity from a Centre that was being established and that did not include most of the postdoctoral research associates and postgraduate students who will start in early 2018. However, this report does offer insight into significant groundwork, planning and development that will enable us to perform rigorous, collaborative and impactful research from early 2018 and then to grow that research in subsequent years.



Extreme Rainfall

Highlights and First Steps

- Successful recruitment of postdoctoral researchers to commence in 2018
- Established detailed project plans for new staff
- Preliminary investigation of changes in organised rainfall with meteorological regime in Darwin
- Collection of data sets to study variability of rainfall extremes over Jakarta.

Team

Co-leads

A/Prof Lisa Alexander
A/Prof Todd Lane

Chief Investigators

A/Prof Julie Arblaster
Prof Jason Evans
Prof Christian Jakob
Prof Michael Reeder
Prof Steven Sherwood

Partner Investigators

Dr Beth Ebert (BoM)
Dr Alain Protat (BoM)
Dr Matt Wheeler (BoM)
Dr Harry Hendon (BoM)
Dr Sandrine Bony (LMD/CNRS)
Dr Wojciech Grabowski (NCAR)
Sean Milton (Met Office UK)
Dr Jon Petch (Met Office UK)
Dr Cathy Hohenegger (MPIMET)
Dr Bjorn Stevens (MPIMET)
Graeme Stephens (NASA/JPL)

Research Staff (commencing 2018)

Martin Bergemann (U.Melb)
Malcolm King (Monash)
Sugata Narsey (Monash)
Margot Bador (UNSW)
Claire Vincent (U.Melb)

PhD Students

Sopia Lestari (U.Melb)
Pavan Harika Raavi (U.Melb)
Tony Rafter (U.Melb)
Benjamin Price (U.Melb)

Climate models predict trends in extreme rainfall over much of Australia and the surrounding regions. However, these rainfall extremes are amongst the most uncertain variables in climate model projections. The uncertainties arise because of difficulties representing rainfall in models, as most of the key processes linking changes in large-scale state to small-scale rainfall extremes are parameterized. There are also crucial gaps in our knowledge of the fundamental multi-scale processes governing rainfall extremes. Thus, the main goal of the Extreme Rainfall research program is *to improve the prediction of rainfall at all scales through fundamental advances in understanding the processes involved and to translate this understanding into the next generation of modelling systems*.

This research program will use a multi-pronged approach to meet its goals. This involves using new observational data sets, novel analysis methods and a hierarchy of models all with different resolutions and complexity. These models will include high-resolution cloud resolving and convection permitting models, single-column models, and global climate models. The Extreme Rainfall program is organised into the following four projects, each with postdoctoral researchers taking leading roles:

1.1: How do changes in the background state control extreme rainfall on the regional scale?

This project will commence by using single-column models to investigate the response of rainfall extremes to changes in the background state. The framework mimics that already attempted for large-eddy simulations, where an environment matrix is constructed, with each element of that matrix used to explore the influence of changes in dynamic and thermodynamic forcing on rainfall. Not only will this approach allow an improved understanding of these large- to small-scale relationships, when combined with observations it will also provide a framework for evaluating and improving parameterizations for climate models.

1.2: What processes underlie the spatial and temporal organisation of convective systems that lead to extreme rainfall?

Dynamical interactions along with thermodynamic and radiative feedbacks can cause convective clouds to grow in time and space and become organised. It is likely that a significant proportion of extreme rainfall can be linked in some way to convective organisation. This is especially true because the most extreme rainfall events rely on dynamical moisture convergence because the rainfall totals can exceed the total-column water amount. Yet, the processes controlling this organisation are poorly understood, and the relationships between organisational mode and extreme rainfall have not entirely been reconciled. This project will examine these organisational processes, their links to rainfall extremes and the meteorological regimes that control them.

1.3: How do tropical to mid-latitude interactions control Australia's rainfall extremes?

Recent research has identified the important dynamical links between the midlatitudes and the tropics, which help determine the behaviour of rainfall and its extremes. For example, many of the so-called bursts in the Australian monsoon have been linked to mid-latitude-derived features that help create long-lived organised convection. Moreover, interactions between the phase of the Southern Annular Mode and the El Niño- Southern Oscillation have been responsible for record rain events. These regional dynamical interactions as well as the large-scale teleconnections will be explored in this project. Specific activity and resources are linked strongly to the Heatwaves and Cold Air Outbreaks research program and to the Variability research program.

1.4: How well do climate models represent rainfall extremes and how can their simulation be improved?

Evaluating the reliability and accuracy of climate model representations of extremes is critical in order to underpin future projections. Yet, this evaluation is challenged by the mismatch between the observation networks, the size of model grids, and the highly localised and sporadic nature of some extremes. This project will begin by developing novel and innovative approaches to the assessment of rainfall extremes from climate models. It will use state-of-the-art data from radar and satellite, along with ground-based gauge observations, to assess traditional Coupled Model Intercomparison Project-style models as well as high-resolution regional climate simulations using novel extreme value statistics.

Embedded within the above projects will be numerous PhD students. A number of students have already commenced and are studying: the organisation of convection near Darwin, observations of extreme rainfall in Indonesia, and the representation of convective hazards in high-resolution climate models.

Statement of Intent for 2018

Projects	Priority	Intent
1.1	1	Investigate rainfall extremes in radar data and its links to the phase of the Australian Monsoon
1.1, 1.2	1	Develop methods to analyse rainfall extremes using a combination of gauge and radar observations over Indonesia (as part of an externally-funded PhD), with the goal of applying these methods to Australian sites
1.2	1	Explore the WRF model representation of the transition from convective (local intense) to stratiform (widespread weaker) rain
1.1, 1.2, 1.4	2	Identify and conduct high-resolution WRF and ACCESS model experiments of extreme rainfall events over Australia
1.1, 1.4	2	Use a single column version of the ACCESS model to examine the relationships between large-scale states and rainfall extremes
1.4	2	Examine extreme rainfall trends in coupled model experiments
1.3	3	Determine the links between rainfall extremes and the migration of the Australian Monsoon trough
1.3	3	Determine the links between heat waves in the south and eastern parts of the continent and enhanced rainfall in the north and west of the continent
1.1	3	Analyse the large-scale regimes responsible for rainfall extremes in the subtropics using sounding data and simulations using WRF and ACCESS
1.4	3	Evaluate climate model representation of rainfall extremes and other convective hazards with new radar and satellite observations
1.2	3	Conduct a suite of idealized model experiments to determine the fundamental processes linking convective organization to extremes.
Priority levels: 1 = to be achieved in 2018. 2 = substantial progress in 2018. 3 = progress towards in 2018		

RESEARCHER PROFILE: Dr Sugata Narsey

Sugata is tackling the challenge of understanding extreme rainfall, with a particular focus on northern Australia. Using Australia's ACCESS model in combination with satellite and radar data he will explore how extreme rainfall events are influenced by the surrounding environment and the ability of climate models to replicate this.

While the processes associated with rainfall have been extensively studied, it is not clear that the behavior of extreme rainfall events is well represented in weather and climate models. Rainfall extremes occur on a spectrum of scales ranging from local thunderstorms that may last for minutes, to widespread monsoon rainfall bursts that may last for weeks. A new dataset of radar-derived rainfall around Darwin, in combination with satellite and other observations, provides an excellent opportunity to investigate these rainfall extremes at multiple scales over northern Australia.

Sugata's previous research focused on the monsoonal rainfall bursts over northern Australia, providing a strong context in which rainfall extremes may occur in the region and the surrounding Maritime Continent. While there have been some significant advances in understanding rainfall in this region, particularly as a result of work done at the previous ARC Centre of Excellence for Climate System Science, it still remains one of the most difficult areas to accurately represent in climate models.

This work is important to Australian interests as the extreme rainfall events in this region impact the environment and people of northern Australia, as well as the agriculture and resources industries and the broader economy.

Sugata will primarily be working with the convection groups that are part of the Extreme Rainfall research program at the University of New South Wales and the University of Melbourne along with external collaborators at the Australian Bureau of Meteorology.

Heatwaves and Cold Air Outbreaks

Highlights and First Steps

- Recruited three postdoctoral researchers to begin in February 2018
- A series of heatwave event case studies have been identified for the initial focus of research
- Investigating the causes of the intensification of the East Australian Current extension and its contribution to the unprecedented 2015/16 Tasman Sea marine heatwave.

Team

Co-leads

Prof Michael Reeder (Monash)
Prof Jason Evans (UNSW)

Chief Investigators

Dr Gab Abramowitz (UNSW)
A/Prof Lisa Alexander (UNSW)
A/Prof Julie Arblaster (Monash)
Prof Neil Holbrook (UTAS)
A/Prof Todd Lane (U.Melb)
Prof Michael Roderick (ANU)
Prof Steven Sherwood (UNSW)

Partner Investigators

Prof Hoshin Gupta (University of Arizona USA)
Dr Christa Peters-Lidard (NASA-GFSC USA)
Dr Peter Stott (Met Office UK)
Prof Sonia Seneviratne (ETH Zurich, Switzerland)
Prof Reto Knutti (ETH Zurich, Switzerland)
Dr Joe Santanello (NASA-GFSC USA)
Research Staff (commencing 2018)
Dr Malcolm King (Monash)
Dr Annette Hirsch (UNSW)

Graduate Students

Maxime Marin (UTAS/CSIRO)

The weather of southern Australia is characterised by a series of migratory anticyclones, each separated by a cold front or low-pressure system. Although the focus is often placed on the fronts and cyclones as these are the rain-bearing systems, anticyclones dominate the climate of the region and are the building blocks of both heatwaves and cold air outbreaks. While it is clear that anticyclones are fundamental to both heat and cold extremes, the feedbacks that amplify average conditions to extreme conditions are far from clear. Moreover, in recent decades the intensity, frequency and duration of heatwaves has increased. Likewise, in some parts of southern Australia the wintertime cold extremes associated with frosts have been increasing.

Heatwaves are also found in the ocean. Marine heatwaves can last from several days to months and have been seen to cause substantial impacts on marine ecosystems, including tropical coral reefs through to temperate algal habitats and species. However, relatively little is known about how marine heatwaves form.

Because of the importance of atmospheric heatwaves and winter cold extremes to human health, agriculture and other aspects of human life, we will develop an understanding of these processes and mechanisms to improve how they are represented in models. Similarly, the importance of marine heatwaves to the marine ecosystems, biodiversity, fisheries, aquaculture and tourism industries motivates our research into their dynamics, causes and representation in models.

The aim of the Heatwave and Cold Air Outbreaks research program is *to explain the physical mechanisms controlling the frequency, intensity and duration of heatwaves and cold spells (in both the atmosphere and ocean) in the Australian region, in order to improve the skill of models in predicting their behaviour*.

The program is divided into four related projects:

- **2.1:** Synoptic Dynamics. How do tropical and mid-latitude weather systems affect Australian heatwaves?
- **2.2:** Role of Surface Processes. How do land processes amplify the magnitude, duration and intensity of heatwaves in Australia?
- **2.3:** Anthropogenic Influences. Can we attribute changes in heatwaves to anthropogenic influence and what are the associated physical processes?
- **2.4:** Marine Heatwaves. What processes cause marine heatwaves and cold spells in the Australian region?

2.1 and 2.2: Synoptic Dynamics and the Role of Surface Processes

Some of the work in projects 2.1 and 2.2 relies on regional-scale climate simulations to investigate the various mechanisms that can cause or amplify heatwaves. By using Community Atmosphere-Biosphere Land Exchange (CABLE) in these simulations, along with the regional Australian Community Climate and Earth System Simulator (ACCESS) model, we can link understanding to global modelling systems, including ACCESS. Currently, a small multi-physics ensemble of three Weather Research Forecasting simulations covering the Australasia region have been performed, driven by ERA-Interim reanalysis for the period 1980-2014. These simulations provide a baseline for the simulation of heatwaves. Many heatwave events occur within these long simulations. They provide the control simulation for future experiments, targeted at particular events, to quantify the role played by various aspects of the land-atmosphere system. Using back-trajectory analysis, three potential case studies have been identified: In the first, the surface heating is dominated by diabatic processes; in the second, it is dominated by adiabatic processes; while the third is close to the ensemble mean for all heatwaves in the period. An initial analysis of these simulations will lead into a broader continental focus on the processes required to capture heatwaves over the Australian continent.

Work has also progressed on how well temperature extremes can be simulated with the latest versions of CABLE coupled to the ACCESS modelling system. In the last few months of 2017 progress was made in improving the coupling of CABLE to ACCESS and in identifying possible causes for the model tendency to overstate temperature extremes. This is work-in-progress and a priority for the first few months of 2018.

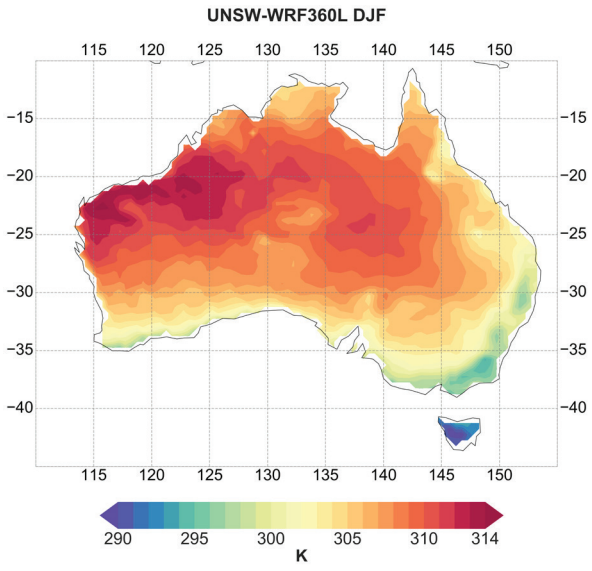


Figure 1: December-January-February maximum temperatures over Australia from one of the WRF model simulations.

2.3: Anthropogenic Influences

This project seeks to quantify how much of the observed increasing trend in heatwaves can be explained by human influence on the climate system. Using global and regional simulations, we will complete the first comprehensive sensitivity analysis using Fraction Attributable Risk attribution, with a specific focus on heatwaves. Using the same set of simulations we will examine the physical mechanisms involved in these heat extremes. We will also look at the relationship between anthropogenic ozone changes and temperature extremes.

2.4: Marine Heatwaves

This project seeks to answer important questions around process-based understanding of marine heatwaves and cold spells. Questions include the following: What physical processes cause marine heatwaves (MHWs) and cold spells (MCSs) around Australia? How important is model resolution to the timing, intensity, frequency and duration of MHW and MCS events? Can we identify mechanisms for MHW deepening? What processes cause high intensity or long duration MHW or MCS events? Which processes can be targeted to improve MHW/MCS predictability?

Statement of Intent for 2018

Projects	Priority	Intent
2.1	1	Use the existing simulations to determine the relative roles of adiabatic and diabatic processes in the dynamics of 3 typical southern Australian heat waves.
	2	Perform sensitivity model runs to identify relative roles of adiabatic and diabatic processes in the dynamics of 3 typical southern Australian heat waves.
	3	Evaluate the relative roles of adiabatic and diabatic processes in example southern Australian heatwaves and determine the relationship with wet season precipitation the over northern and western parts of the continent.
2.2	1	Perform and evaluate the climate in the ERA-Interim driven WRF runs including CABLE.
	1	Perform and evaluate the heatwaves in the ERA-Interim driven WRF runs including CABLE.
	2	Evaluate the heatwave climate in ACCESS-CABLE runs, and their relationship to physical processes in the model.
	2	Identify case studies for km-resolution simulations over key natural, agricultural and urban locations subject to heatwaves and begin simulations.
	3	Determine the processes explaining the peak temperatures over key natural, agricultural and urban locations and examine where strategies can be implemented to minimize impact.
2.3	1	Categorize noteworthy recent Australian heatwaves using a number of heatwave definitions, key features and underpinning mechanisms
	1	Determine the ability of climate models to capture the relationship between Antarctic ozone variability with Australian temperature extremes
	2	Investigate statistical methods to undertake attribution of heatwaves using one model ensemble
	2	Identify the contribution of Antarctic ozone changes to long-term trends in SH temperature extremes
	3	Applying these attribution methods to other model ensembles
	3	Comparison of attribution assessments of each heatwave across model ensembles, inclusive of each definition used and the underpinning observational/reanalysis products
2.4	1	Evaluate the large-scale mechanisms that caused the 2015/16 Tasman Sea marine heatwave.
	2	Investigate the vertical scale of marine heatwaves in the Australian region
	3	Determine the mechanisms for deepening marine heatwaves.
Priority levels: 1 = to be achieved in 2018. 2 = substantial progress in 2018. 3 = progress towards in 2018		

RESEARCHER PROFILE: Dr Annette Hirsch

It has been a bit of a round trip for Annette, who completed her PhD with the ARC Centre of Excellence for Climate System Science back in 2015 before taking a position with the IAC Land-Climate Dynamics group at ETH Zurich. She has now returned to Australia working with many familiar faces as a Research Associate in the Centre of Excellence for Climate Extremes (CLEX).

Building on her PhD and research with ETH Zurich, Annette will be exploring how we can build resilience to extreme events into cities through a better understanding of how land-atmosphere interactions change as different mitigation strategies are employed.

Using high-resolution climate models that include urban processes, she will examine how cities can expand in a way that best mitigates the impacts of heatwaves without compromising the needs of growing regions. This work is very pertinent to the expanding suburbs found on the edges of major Australian cities.

Annette's work will see her interact with multiple CLEX hubs and colleagues at CSIRO, University of Balearic Islands and ETH Zurich.

Highlights and First Steps

- Recruited two postdoctoral researchers, one starting in late 2017 and the other in February 2018
- Recruited one PhD student, who started in late 2017
- Established detailed project plans for new staff and an implementation plan
- Initiated analysis of how well the latest version of ACCESS captures extremes with the newest version of the CABLE land model.

Team

Co-leads

Prof Michael Roderick (ANU)
Prof Andy Pitman (UNSW)

Chief Investigators

A/Prof Nerilie Abram (ANU)
Dr Gab Abramowitz (UNSW)
Dr Dietmar Dommenget (Monash)
Prof Matthew England (UNSW)
Prof Jason Evans (UNSW)

Partner Investigators

Prof Hoshin Gupta (University of Arizona)
Dr Harry Hendon (BoM)
Prof Dani Or (ETH Zurich)
Prof Jonathan Overpeck (University of Arizona)
Dr Christa Peters-Lidard (NASA-GSFC)
Prof Sonia Seneviratne (ETC Zurich)
Dr Ying Ping Wang (CSIRO)

Research Staff

Dr Martin de Kauwe (UNSW)
Dr Anna Ukkola (ANU, 2018)
Nicky Wright (ANU, 2018)

Graduate Students

David Hoffman (Monash)
Manon Sabot (UNSW)
Yifei Zhou (ANU)

Droughts are common in Australia. A community perception exists that droughts are intensifying and will increase in the future. Remarkably, there is little evidence from observations or modelling to support that perception, with the exception, perhaps, of south-west Western Australia. By delivering a program of research, backed by large-scale scientific activity that integrates land, atmosphere and ocean scientists, we will understand the behaviour of droughts nation-wide. By taking this understanding through model development we will improve the prediction of the behaviour of droughts. We aim to inform decision makers on strategies to increase national resilience and assess potential mitigation strategies.

These challenges motivate the main goal of the Drought research program, which is *to determine the processes controlling the frequency, intensity and duration of drought in Australia in the past, present and future.*

The Drought program is divided into four projects that are related, and linked in most cases to research programs hosted elsewhere in the ARC Centre of Excellence for Climate Extremes. Over the seven years of the Centre we will explore the following:

3.1: Large-scale Climate Processes that Influence Drought

This project is a subset of 4.2: Interannual to Interdecadal Climate Variability, which examines large-scale drivers of extremes over Australia. Drought is one example of an extreme. 3.1 brings the land surface perspective to 4.2, broadening the interdisciplinarity of this approach.

3.2: Quantifying Millennial-Scale Drought Using Observations and Models: Are Recent Changes Unusual and Are Future Projections Unprecedented?

This project will examine the baseline hydro-climatic variability over the last 2000 years for Australia and examine whether current models capture this. It will provide the baseline to ask whether projections of future droughts in Australia are unusual in the context of natural drought variability over the last 2000 years. We will use model hierarchies and observations, investigating what drought-relevant climate processes are missing from current models and how these can be resolved.

3.3: The Role of Land-Atmosphere Feedbacks During Drought Onset, Persistence and Termination

This project will examine the relative contributions of local versus large-scale processes in driving the surface drying during drought and examine whether back-trajectory modelling can quantify the relative roles of atmospheric advection and local land-atmosphere coupling during the various stages of drought development. We will determine whether the mechanisms, contributions and behaviour of droughts are properly captured in climate models.

3.4: Vegetation and Hydrology Interactions with Drought

This project will examine weaknesses relating to vegetation-hydrology interactions in land surface models and then develop and implement improved vegetation-hydrology responses to drought in Community Atmosphere-Biosphere Land Exchange (CABLE) to improve the simulation of Australian drought. We will also undertake an assessment of how significant vegetation-hydrology feedbacks are in controlling future changes in the intensity and duration of Australian droughts.

Statement of Intent for 2018

Projects	Priority	Intent
3.1	1	What controls the balances in the Australian hydrological cycle from the large atmospheric scale to the small regional land interaction
	2	Quantify how the atmospheric and oceanic teleconnections that modulate and amplify remote climate variability will change over Australia
	3	Identify the climatic conditions that characterise Australia's worst droughts, including megadroughts over SE and SW Australia, and how the duration and frequency of these events might change in the future
3.2	1	Undertake an assessment of drought metrics in existing last millennium model experiments
	1	Assess drought metrics in existing historical and 21st Century experiments, in comparison with known historical droughts
	2	Begin new multi-century experiments to test drought variability over long and pre-anthropogenic time periods
	2	Compare drought metrics in existing models with palaeoclimate evidence
	3	Assessment of drought indices in multi-century experiments run in previous year.
	3	Begin hypothesis-testing experiments to test the response of drought in models to different climate forcing scenarios.
3.3	1	Using the existing UNSW WRF ensemble runs, understand the relative roles of large scale advection and local land-atmosphere coupling on surface drying throughout the Millennium drought
	1	How does the land surface-atmosphere coupling evolve as we go into drought?
	1	Examine how well CMIP-5 models capture the characteristics of observed droughts including the Millennium drought.
	2	Perform WRF and ACCESS simulations for earlier major droughts (e.g. WWII drought).
	2	Examine the ability of WRF and ACCESS to simulate the droughts. Then analyse them to determine the relative role of advection and local coupling on the drying as the drought evolves
	2	Do land surface/climate models capture the observed behaviour of land-atmosphere coupling evolution?
	3	Compare local processes with advected processes in the context of drought
	3	Test whether new approaches to hydrology and vegetation responses to drought improve the skill in simulating observed droughts
	3	Examine how land-atmosphere coupling varies between droughts, models and resolutions
	3	Test whether new approaches to hydrology and vegetation responses to drought change future projections of droughts
3.4	1	Systematic assessment using observations of continental scale vegetation response to rainfall/drought
	1	Systematic assessment using observations of continental scale hydrologic response to rainfall/drought
	2	Assessment of how well CABLE simulates the vegetation-hydrologic response to drought
	2	Improve the representation of key vegetation-hydrology processes in CABLE to reflect new understanding of drought, and repeat model evaluation.
	3	Systematic assessment of how well we can estimate surface (vegetation-hydrologic) feedbacks to the atmosphere.
Priority levels: 1 = to be achieved in 2018. 2 = substantial progress in 2018. 3 = progress towards in 2018		

RESEARCHER PROFILE: Dr Anna Ukkola

Anna is interested in water resources and how these interact with climate and vegetation. After studying long-term changes in water resources for her PhD, her work now focuses on understanding these interactions during droughts.

Anna joins the ARC Centre of Excellence for Climate Extremes after completing her first post-doctoral appointment at the ARC Centre of Excellence for Climate System Science where she worked with the Land Surface research program where she has evaluated state-of-the-art models for droughts to better understand how droughts will evolve into the future.

Her new role will see Anna move to ANU where will analyse the role of land surface processes in controlling the characteristics of droughts in models and observations at various scales ranging from flux tower sites to regional and global scales. She will also explore vegetation responses to drought in a warming climate and how these can be better represented in models.

Climate Variability and Teleconnections

Highlights/First Steps

- Recruited five EFT postdoctoral researchers to begin in 2018
- A further 10 PhD candidates are expected to commence in 2018
- Established detailed project plans for new staff
- ENSO workshop held at UNSW in November, attracting 25 participants
- New understanding of oceanic processes relevant to climate extremes.

Team

Co-leads

Prof Matthew England (UNSW)
A/Prof Andy Hogg (ANU)

Chief Investigators

A/Prof Nerilie Abram (ANU)
A/Prof Julie Arblaster (Monash)
Prof Nathan Bindoff (UTAS)
Dr Dietmar Dommenget (Monash)
Prof Neil Holbrook (UTAS)
Prof Steven Sherwood (UNSW)
A/Prof Peter Strutton (UTAS)

Partner Investigators

Prof Steve Griffies (GFDL)
Prof Niki Gruber (ETH Zurich)
Dr Robert Hallberg (GFDL)
Dr Harry Hendon (BoM)
Dr Reto Kuntti (ETH Zurich)
Dr Simon Marsland (CSIRO)
Dr Richard Matear (CSIRO)
Dr Gerald Meehl (NCAR)
Prof Jonathon Overpeck (University of Arizona)
A/Prof Joellen Russell (University of Arizona)
Dr Bjorn Stevens (MPI)
Dr Matthew Wheeler (BoM)

Postdoctoral Researchers (commencing 2018)

Dr Ghyslaine Boschat (Monash),
Dr Navid Constantinou (ANU)
Dr Ryan Holmes (0.5 EFT)
Dr Chen Li (Monash, 2017)
Dr Amelie Meyer (UTAS)
Dr Ariaan Purich (UNSW 0.5EFT)
Dr Nicky Wright (ANU)

Research Students

Rishav Goyal (UNSW)
Josué Martìnez Moreno (ANU)
Jan Jap Mejier (UTAS)
Saurabh Rathore (UTAS)
Dongxia Yang (Monash)Taimoor Sohail (ANU)

An improved knowledge of regional and global climate extremes requires a deep process-based understanding of: (1) major coupled ocean-atmosphere modes of variability, (2) the way in which climatic signals teleconnect from one location to another, and (3) global climate sensitivity. The Variability and Teleconnections research program will discover how regional extremes are modulated by climate variability and teleconnections, and better constrain climate sensitivity via improved knowledge of ocean heat and carbon uptake and the role of human influence. We will combine observations, reanalysis products, climate models, palaeoclimate data, theory and process-based understanding to address the overarching aim *to discover how regional climate extremes are related to variability, climate teleconnections and climate sensitivity*.

This research program will combine observational data sets, a hierarchy of coupled, ocean, atmosphere and idealised models, across different resolutions and complexity, to explore the processes determining global-regional climate variability and teleconnections.

The program is organised into the following four projects, each with postdoctoral researchers taking leading roles:

4.1: Tropical Pacific Ocean-Atmosphere Circulation Changes

We will address frontier topics in tropical large-scale atmospheric circulation change research, including the following: How will the large-scale tropical ocean and atmosphere circulation change during the 21st century and what physical processes drive these changes? Are there limits in our predictive capability in these areas? How much does the spread in the simulation of modes of variability affect projections and can we improve models to reduce these biases? How robust are future predictions to these baseline model biases? How will changes in natural modes of variability alter precipitation patterns and extreme weather events? This project will improve our understanding and modelling of large-scale tropical circulation changes under anthropogenic climate change and how this will affect climate extremes.

4.2: Interannual to Interdecadal Climate Variability

This project will combine instrumental climate observations, available proxy records and sophisticated coupled climate models to advance our understanding of the overarching dynamics, trends, and variability in the climate modes that affect Australian climate extremes on interannual to interdecadal timescales. This will be done using the long-term perspective of the last 2000 years, essential for ensuring that the full range of behaviour of the various climate modes is captured, and to provide the context for assessing the significance of changes characterised in observational climate records and future climate scenarios. Key questions to be addressed include the following: How does anthropogenic climate change modulate the internally generated variability of the climate system? How does the interplay between variability in the Pacific, Indian and Southern Ocean modulate current and future climate extremes? What improvements in model physics and/or resolution are required to optimise predictability of interannual to interdecadal climate variability (including heatwaves and droughts) in climate models?

4.3: Impact of Inter-Basin and Cross-Scale Interactions and Climate Teleconnections on Extremes

Project 4.3 will combine models, observations and theory to explore the climatic teleconnections that occur across ocean basins and how these affect climate extremes over Australia. This will span inter-basin processes operating in the atmosphere, tropical-extratropical climate interactions and inter-ocean transport of climate-relevant properties, such as heat and carbon. We will examine how changes in the mean state of the Atlantic and Indian Oceans, both individually and in combination, affect the Pacific Ocean and in turn El Niño- Southern Oscillation (ENSO) teleconnections. Combining information from observations, reanalysis products and modelling will identify the underlying mechanisms modulating ENSO teleconnections over longer time scales. We will discover how different phases of the Interdecadal Pacific Oscillation modulate the effect of the tropical Pacific Ocean and ENSO on regional climate, including rainfall and drought cycles over Australia. CMIP5 climate model projections will also be analysed to estimate how teleconnections may change in a warmer climate subject to inter-model differences in the Pacific, Indian and Atlantic basins. Similar strategies will be used to examine teleconnections between the tropics and the extratropics, and how these affect climate extremes over Australia.

4.4: Southern Ocean Circulation and Biogeochemistry

The Southern Ocean is poorly observed and is the most difficult to model because extreme flows at fine scales are of first order importance to the time-mean circulation. Current-generation global models are just beginning to adequately resolve Southern Ocean extremes and the Australian Research Council Centre of Excellence for Climate System Science was at the forefront of this development. In this project, at the ARC Centre of Excellence for Climate Extremes (CLEx), we will use world class high-resolution ocean sea ice models, incorporating biogeochemistry where appropriate, to advance our understanding of the present and future circulation and oceanic carbon uptake in the Southern Ocean. We will investigate: (i) biogeo-

chemical processes that link the subtropics and tropics of both hemispheres via mode water formation; (ii) the drivers of change in the Southern Ocean, and how these changes will project onto circulation and climate in other regions; (iii) the behaviour of key phenomena, including ocean eddy fluxes, mesoscale variability and the flow over topographic features; and (iv) biological-physical coupling in the Southern Ocean and the consequences for carbon storage.

2017 Achievements

The Effects of Ozone Depletion on Climate

Associate Professor Julie Arblaster (Chief Investigator, Monash University) is an author on the 2018 World Meteorological Organization/United Nations Environment Programme Scientific Assessment of Ozone Depletion, assessments for which are carried out every four years in accordance with the terms of the Montreal Protocol. The 2018 assessment will consist of scientific chapters and a synthesis of policy-relevant information for decision makers. Julie is an author on the 'Stratospheric ozone changes and climate' chapter, which assesses our understanding of how the Antarctic ozone hole has affected our climate, including changes in rainfall, temperature, ocean circulation and sea ice, and projections for the future.

Under Julie's supervision, Zoe Gillett completed her honours degree in November 2017 at Monash University with first class honours. Her thesis, titled "Modelling the influence of the Antarctic ozone hole on Australian summer temperature variability", investigated the ability of climate models to capture the significant relationships observed between year-to-year spring Antarctic ozone variability and surface temperatures over Australia in summer. Zoe intends to enrol in a PhD program in CLEx in 2018 and will collaborate with Partner Investigators at the Bureau of Meteorology.

Associate Professor Nerilie Abram participated in Antarctic fieldwork from October 2017 - February 2018. This project was supported by the Australian Antarctic Science Program and collected a roughly 1,000year-long climate history from the remote Indian Ocean sector of Antarctica. It will provide a valuable contribution to the palaeoclimate network to be used in later years of the Centre for project 4.2.

Southern Ocean Work

The Southern Ocean controls the ocean's overturning circulation, carbon cycle and heat uptake, and hence plays a critical role in future climate scenarios. Chief Investigator Associate Professor Andy Hogg's work on Southern Ocean circulation focuses on how small-scale processes, such as convection, turbulence and eddies, alters the circulation and its variability. Ocean convection has been investigated via a novel "Direct Numerical Simulation" technique of a small-scale domain, showing how convection acts to raise the mixing efficiency in the circulation, with some regions of the ocean achieving close to the maximum possible mixing rate (Sohail et al., 2017, under review).

Ocean eddies act to moderate the effect of climate change, but understanding the cumulative effect of thousands of small eddies depends on being able to delineate and characterise eddy behaviour. With Andy, ANU PhD student Josué Martínez-Moreno has recently embarked on a project to be able to identify and characterise the behaviour of individual eddies, from either model output or satellite observations. Shown in Figure 1, below, is a snapshot in the Agulhas Current region for (a) SSH, (b) SSHa, and (c) reconstructed eddy height. Shown along the bottom panels are the corresponding kinetic energy calculated using a geostrophic approximation. This project will lead to a better understanding of the response of Southern Ocean eddies to climate change.

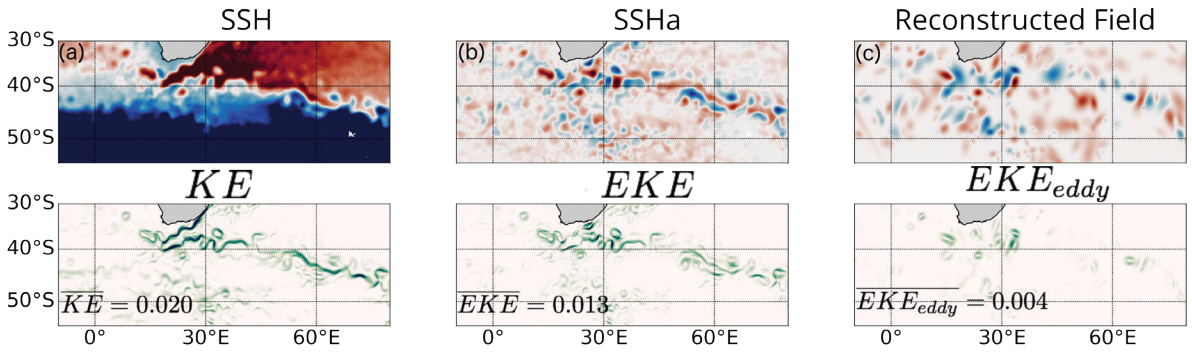


Figure 1:Snapshot in the Agulhas Current region for the fields: (a) SSH, (b) SSHa, and (c) reconstructed eddy height. Shown along the bottom panels are the corresponding kinetic energy calculated using a geostrophic approximation.

Biogeochemistry

Associate Professor Peter Strutton is a member of the Tropical Pacific Observing System 2020 (tpos2020.org) Scientific Steering Committee and Co-chair of its Biogeochemistry Task Team. The work of this committee is relevant to CLEx because the data from the observing system are used to predict and track El Niño events, validate models and feed into the climate data record of global change.

In 2018 we expect two PhD students with a focus on Southern Ocean biogeochemistry to commence with Peter at UTAS.. One will focus on using in-situ and satellite bio-optical data to track changes in tropical Pacific biogeochemistry over about the last decade. Richard Matear (CSIRO Partner Investigator) is a co-advisor. The other student will focus on biogeochemical processes in high-resolution (global) models. Initial research questions will concentrate on Southern Ocean mesoscale processes, with later expansion to lower-latitude impacts.

Marine Heatwaves

Surface waters off eastern Tasmania are a global warming hotspot, with changes here stressing the marine biodiversity, fisheries and aquaculture industries. Professor Neil Holbrook contributed to recent high-resolution ocean modelling of Tasmania's eastern shelf, which has been beneficial in characterising the interannual ocean climate variability and trends in marine heatwaves off eastern Tasmania. A decomposition of the temperature field into modes of variability has demonstrated that the East Australian Current is the dominant driver of marine heatwaves across the domain. The use of self-organising maps has also helped to identify the key large-scale oceanic and atmospheric circulation patterns relevant to the region. The research was submitted in October 2017. Zeya Li is currently a CLEx honours student working under Neil's supervision on a project titled Large-scale forcing of the 2015/16 Tasman Sea marine heatwave.

Statement of Intent for 2018

Projects	Priority	Intent
4.1	1	Characterise tropical climate variability (modes) and circulation, as potential drivers of climate extremes in Australia
	1	Assess the natural characteristics of Indian Ocean Dipole variability during the last millennium in reconstructions and simulations
	2	Perturbed physics experiments with corrected mean states to study tropical climate variability and change
	3	Analysis of tropical climate variability and change in mean state corrected coupled simulations
4.2	1	Advance a process-based understanding of the SAM via single forced experiments of a coupled climate model (ozone and GHGs)
	1	Examine the dynamics of recent and past SAM variability and trends, estimate how these have impacted climate extremes
	2	Assessment of SAM response to solar forcing scenarios in last millennium simulations
	3	Analyse evidence that the SAM mean state affected southern hemisphere temperature extremes during the last millennium
4.3	1	Analyse cross-scale interactions in the tropics, from eddy scales up to ENSO variations, and estimate the role of ocean stochastic variability in the onset of ENSO events
	1	Use CMIP5/CMIP6 simulations to estimate the way ENSO teleconnections to Australian climate extremes will be modified in the future
	2	Examine the large-scale tropical to mid-latitude forcing of marine heatwaves in the Tasman Sea
	3	Quantify tropical - extratropical interactions by studying pacemaker and partial coupled experiments forced separately in the tropics and mid- to high-latitudes
4.4	1	Begin work on framework and high-resolution ocean-sea ice model that includes biogeochemistry.
	2	Investigate how the structure of the Southern Ocean eddy field responds to changes in the SAM; and the effect of these changes on the mean ocean circulation. Compare with observations to test role of human influence of winds on eddy field.
	3	Use bio-Argo floats in the Southern Ocean to document (1) seasonal drivers of phytoplankton blooms and (2) biogeochemical signatures of eddies.
All of RP	1	Development of ACCESS coupled model correction scheme for land and ocean.
	2	Begin new last millennium simulations using Australian ESM if available, or other model if not
Priority levels: 1 = to be achieved in 2018. 2 = substantial progress in 2018. 3 = progress towards in 2018		

RESEARCHER PROFILE: Dr Ghyslaine Boschat

Ghyslaine comes to the Centre of Excellence for Climate Extremes with a research background in climate extremes, and tropical and extratropical atmospheric circulations. This background combines ideally into her research, which will focus on understanding the extratropical drivers of temperature and rainfall extremes in the Southern Hemisphere, in particular their links with the variability of the Southern Annular Mode (SAM).

SAM is the name given to north/south movement of the westerly winds that circle the Antarctic. When SAM is further to the north (in a negative phase), we see a shift northwards of a variety of weather systems. When further South (positive phase) weather systems also shift southwards. This movement has distinct impacts on the weather and climate of the Australian continent. Under global warming we are increasingly seeing a trend towards positive phases of the SAM.

Ghyslaine will be using models and observations in combination. She will use these to examine how the teleconnections and underlying physical mechanisms that result from a shifting SAM affect extreme events in the Southern Hemisphere and Australia in particular. This will also involve examining the relation between El Niño Southern Oscillation (ENSO) and SAM to understand how both may change with global warming and the impact this will have on extreme events.

Computational Modelling Support Team

Highlights

- New CMS team member Daniel Eisenberg working on CABLE integration with JULES
- Installation of UM at resolution N216, configured with GA7.1. Development of a Transpose-AMIP version and installation of SCM for the same configuration.

New Team Member Daniel Eisenberg

With the start of the ARC Centre of Excellence for Climate Extremes (CLEx), a new member has joined the Computational Modelling Support (CMS) team: Daniel Eisenberg. Daniel is based at the University of New South Wales and is now in charge of the support for the land surface model, Community Atmosphere Biosphere Land Exchange (CABLE). As part of his role, Daniel has started on a long-term project to better integrate CABLE with the Joint UK Land Environment Simulator (JULES) and the Unified Model (UM). This project aims at encouraging collaborations between CABLE and JULES developers as well as streamlining the development of the Australian Community Climate and Earth-System Simulator (ACCESS), by ensuring the link between CABLE and the UM is always maintained during future developments. The first step — on which Daniel is currently working — is to develop the JULES framework to enable running JULES and CABLE physics from the same model framework. This work is done in collaboration with the UK Meteorological Office and CSIRO.

Modelling Work

Climate Extremes are often very localised events. Even events covering extended regions or time frames often have localised triggers. As such, to model and understand climate extremes it is important to have climate models at high resolution. To provide such models to the Centre of Excellence, Dr Holger Wolff and Scott Wales have started working on the atmosphere model, UM, at resolution N216, with the latest configuration from the UK Met Office: Global Atmosphere version 7.1 (GA7.1). A first step of this project is to reproduce a previous simulation from the UK Met Office. Although we are using the same model code and the same input files, the simulations produced at the two locations are statistically different. With Joao Teixeira from the UK Met Office, we are working on understanding why. Holger and Joao have already modified the pseudo-random number generator used by the stochastic physics. This ensures both simulations use the same sequence of random numbers in their stochastic physics. It improved the comparison of the two simulations but does not completely eliminate all differences. Holger, Scott and Joao will continue to work together to understand this issue. In addition, as this work involves comparing simulations done at the UK Met Office and locally, we have now gained access to the former's archive system. This allows us to provide the Centre's researchers with copies of some of the UK Met Office's simulations — subject to its agreement.

At the same time, the role played by initial conditions is crucial to successfully represent real climate extreme events in model simulations. To achieve this, researchers are using reanalysis data sets to drive their climate models over a few days. Scott and Holger have

now created a utility that allows any researcher to start a simulation with the UM model using the GA7.1 configuration initialised from the ERA-Interim product (European Reanalysis Interim). This can be done for any date from 1979 to 2015. The same utility can be used to create initial conditions for other versions of the UM model.

Finally, some analyses of local atmospheric processes, land processes or land-atmosphere interactions do not necessitate a full global model. In some cases, it is much easier and much more efficient to work with one column of atmosphere and land. For these reasons, Scott has started work on getting the Single Column Model from the UM working at NCI with the latest configuration from the UK Met Office.

CMS Team Member Profiles

Dr Claire Carouge
Computational Modelling Systems Leader

Dr Claire Carouge is the leader of the Computational Modelling Systems (CMS) team at the Australian Research Council Centre of Excellence for Climate Extremes. She coordinates the efforts of the team members distributed over the five nodes of the Centre.

In parallel, Claire provides the modelling support for the Weather Research and Forecasting (WRF) atmospheric regional model and the CSIRO Atmosphere, Biosphere and Land Exchange (CABLE) land surface model at the Centre of Excellence. As such, she has coupled CABLE to WRF via the integration of CABLE into the Land Information System (LIS). She has also developed new diagnostics in WRF required for simulations for the Coordinated Regional Downscaling Experiment. She now maintains, keeps up-to-date and documents a stand-alone modified WRF model and the CABLE-LIS-WRF coupled model.

Claire is also developing a proper suite of tests for CABLE in collaboration with the CABLE development team at CSIRO. She supports researchers using and developing the CABLE and WRF models at the Centre. Claire was awarded a PhD in Atmospheric Sciences from Université Pierre et Marie Curie (Paris, France) in 2006.

Danny Eisenberg
Computational Modelling Support

Danny Eisenberg is a software developer who completed his BSc (Computer Science) in 1996. In his current role with the ARC Centre of Excellence for Climate Extremes (CLEx), based at the University of New South Wales, Danny is responsible for supporting the land surface model, the Community Atmosphere Biosphere Land Exchange model (CABLE). Danny is working collaboratively with the UK Meteorological Office and CSIRO to better integrate CABLE with the Joint UK Land Environment Simulator and the Unified Model.

Prior to joining CLEx, Danny worked at the UNSW Climate Change Research Centre on a project related to the Protocol for the Analysis of Land Surface Models web application, which provides automated land surface, hydrological and ecological model evaluation tools as well as observational data sets. Danny has also worked for many years as a rabbi, specialising in adult Jewish education.

Dr Aidan Herdeegen
Computational Modelling Support

Dr Aidan Heerdegen is a computational scientist with a background in physical chemistry, with experience supporting research in climate modelling and statistical analysis of climate data. Aidan is primarily responsible for supporting the use and development of ocean simulation codes within the Australian Research Council Centre of Excellence for Climate Extremes. His current major focus is the development of a new, high-resolution (1/10°) global ocean model configuration in collaboration with the Consortium of Ocean Sea Ice Modelling in Australia.

Aidan has a Bachelor of Science (Honours) in Physics and Chemistry from Massey University (NZ) and a PhD from ANU. He is based with the Climate Fluid Physics group, Research School of Earth Sciences, ANU, and joined the Computational Modelling Systems team in 2014.

Dr Paola Petrelli
Computational Modelling Support

Dr Paola Petrelli is the data manager of the Australian Research Council Centre of Excellence for Climate Extremes (CLEx)). Before commencing in her current role, she managed oceanographic and climate data sets for the Tasmanian Partnership for Advanced Computing, acquiring extensive experience in web services and software used by the earth science research community. She received a PhD from the University of Siena (Italy) in 2005.

Paola sets the Centre data strategy and provides advice on data management practices. She leads the data collaborations with our Partner Organisations and the National Computational Infrastructure (NCI) to manage shared data resources. Paola represents the Centre of Excellence in the Coupled Model Intercomparison Project - Phase 6 technical and climate data set committees. An important part of her role is to publish CLEx data and metadata on public repositories such as the NCI data services, the Earth System Grid Federation and the Australian National Data Service's Research Data Australia. Contact her if you need advice for your

data management plan and to access, download, store, share and/or publish data. She can also provide advice with any aspect of data policy, such as licensing, rights and retention requirements.

Scott Wales
Computational Modelling Support

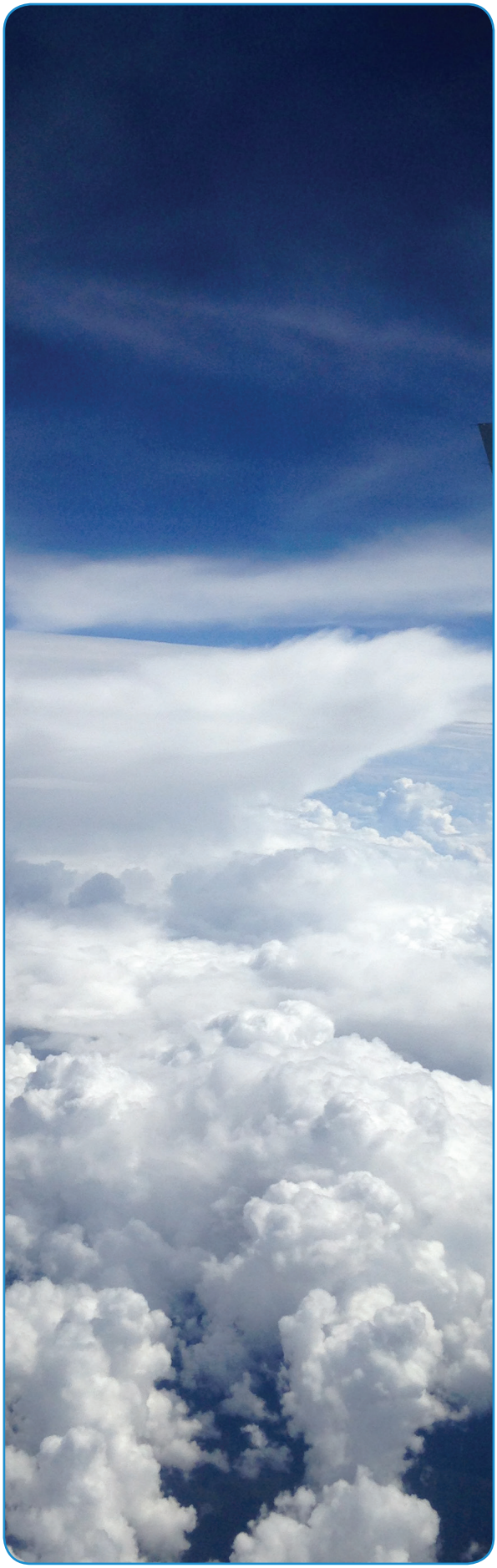
Scott Wales supports the researchers at the Australian Research Council Centre of Excellence for Climate Extremes who work with the Unified Model (UM), the atmospheric component of the Australian Community Climate and Earth System Simulator (ACCESS) model. He helps researchers to understand, run and modify the model and works with our Partner Organisations to make their model configurations usable on the National Computational Infrastructure supercomputers.

Scott also works closely with leaders across the ACCESS community, providing technical advice and helping to develop and maintain the infrastructure needed to run the model at NCI — such as the Accessdev and Subversion servers. He also works with our partners at the UK Meteorological Office on collaborative development across the entire UM partnership.

Scott has experience in a variety of different computational modelling techniques, including numerical atmospheric models, cosmological N-body simulations, and stochastic partial differential solvers. He has a Bachelor of Science (Honours) in Physics from the University of Queensland.

Dr Holger Wolff
Computational Modelling Support

Dr Holger Wolff has a background in physics. After graduating from the University of Hannover, he successfully completed a PhD in Quantum-Atom Optics at Swinburne University in Melbourne, with a focus on micro-fabrication of atom chips for Bose-Einstein-Condensate Experiments. Following the PhD, Holger worked with CSIRO as a programmer for atmospheric modelling for three-and-a-half years. He joined the Australian Research Council Centre of Excellence for Climate System Science in November 2013, and continues to support the climate research community in Australia with the ARC Centre of Excellence for Climate Extremes.



ENSO Workshop

A workshop on El Niño – Southern Oscillation (ENSO) dynamics was held 20 – 21 November 2017, at UNSW, hosted by the ARC Centre of Excellence for Climate Extremes.

The workshop was attended by 25 ENSO researchers and forecasters, the majority of whom are members of the Centre of Excellence. We also had a number of attendees from the Bureau of Meteorology (BoM) and other institutions, including CSIRO, UNSW, Monash, University of Tasmania and ETH Zurich.

The two-day workshop was filled with animated discussions on how ENSO works and what influences its dynamics and predictability. Given the strong and often severe effects of ENSO globally and on Australia, advancing our understanding of ENSO dynamics is essential for improved seasonal climate predictions and future projections.

The idea of arranging the workshop was raised by Dr Harry Hendon (BoM) during a NESP project meeting in June 2016. Dr Hendon realised the necessity to bring together Australian experts in the field to discuss the pertinent issues, to clarify and formulate a plan on how to address them, and how to enhance collaboration across the extended network of the Centre.

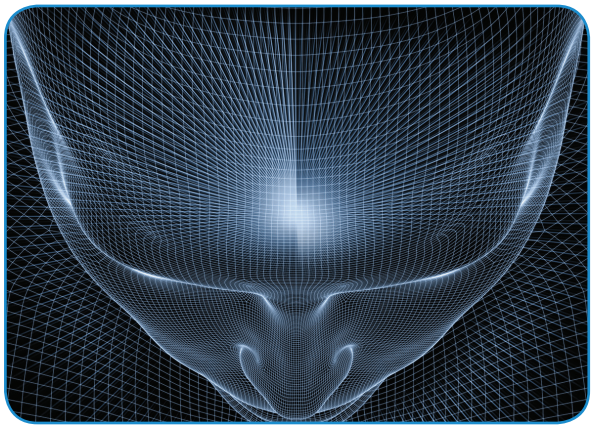
The meeting was timely, as the last ENSO workshop was held in February 2015 when the world was expecting a big El Niño that did not eventuate. The El Niño instead materialised in the second half of 2015, emerging as a particularly strong one. The 2015/16 El Niño can be considered as the first extreme El Niño of the 21st Century with interesting characteristics that are distinct to the previous extreme El Niños in 1982 and 1997.

The interesting case of the 2015/16 El Niño initiated the workshop discussions (Agus Santoso, Guomin Wang, Esteban Abellan), followed by an informative talk on the operational forecast of the 2014-2017 ENSO events (Felicity Gamble). This was then followed by a series of discussions on ENSO predictability (Eun-Pa Lim, Jing-Jia Luo, Sonja Neske), response to greenhouse warming (Dietmar Dommenget, Scott Power, Agus Santoso), and various modelling aspects of ENSO (Harun Rashid, Neil Holbrook, Ryan Holmes, Andrea Taschetto).

Day two of the workshop opened with discussions on mechanisms of decadal variability and ocean heat uptake, as they are linked to ENSO dynamics (Matt England, Shayne McGregor, Ryan Holmes, Maurice Huguenin). Also relevant to understanding ENSO dynamics is the interplay of ENSO with large-scale modes of variability (Pandora Hope) and impacts on weather (Acacia Pepler), emphasising the importance of ENSO prediction, which was also highlighted in the second day discussion (Hanh Nguyen). Technical issues on statistical analysis and ways to better capture ENSO variability (Harry Hendon, Arnold Sullivan) were also covered. The workshop then proceeded with an entertaining and insightful summary of international workshops, focussing on the 'ENSO Complexity' workshop in held Busan, South Korea October 2017. It was agreed that the Busan workshop was a very productive and successful meeting resulting in a review paper submitted to Nature journal. Our own ENSO workshop was wrapped up with a list of outcomes, recommendations, and future research directions that are being written up as a formal report.

The workshop organisers thank the ARC Centre of Excellence for Climate System Science for its support; Vilia Co, Jenny Rislund, Bronwen Smith for their help on logistics, to ensure the workshop ran smoothly; Alvin Stone for setting up and maintaining the workshop website; and certainly all of the participants, presenters, and note takers (Leela Frankcombe, Hanh Nguyen), as well as Tropical Green for their help with catering.

Researcher Development Program



The ARC Centre of Excellence for Climate Extremes (CLEx) researcher development program and its related graduate program will further develop national capacity in climate science by training and mentoring the next generation of researchers. It will equip them with the intellectual and technical capacity required to take on the research challenges of the future.

A strategic objective of the Centre of Excellence is to transform graduate education in climate science at the national scale. The CLEx researcher development and graduate programs extend beyond the reach of single universities and will develop national capacity in climate science by training and mentoring the next generation of researchers. It will equip them with the intellectual and technical capacity required to take on the research challenges of the future.

Our students are enrolled at one of our five universities; however they are often supervised across universities, and/or co-supervised by researchers from the CSIRO, Bureau of Meteorology, or one of our international Partner Organisations. Most students are involved in collaborative projects that span across our universities, Partner Organisations, and often our research programs. We provide generous travel support for our students to visit our national and international partners.

The researcher development program will foster fundamental research and communication skills, professional development, mentoring and leadership opportunities, and will involve all Centre researchers. The program will complement opportunities offered at the Centre nodes.

The researcher development program consists of three pillars – science fundamentals, communication, and professional development.

- **Science fundamentals** provides annual, graduate-level climate science winter schools and a library of online resources, which includes the following: virtual lectures, expert seminar series, grant and fellowship writing support, technical training in key models and programming languages, and data management skills.

- **Communication** includes training in scientific paper writing, publishing and profile building, and media and presentation skills.

- **The professional development** component will involve formal mentoring and leadership opportunities for researchers. Early- to mid-career researchers will have opportunities to co-lead research programs and to lead research and outreach activities.

Within the researcher development program we provide tailored research training for postgraduate and honours students which forms our graduate program. Within the first six months, the Centre has attracted 21 new graduate students. These students come from a variety of undergraduate backgrounds, including mathematics, physics, engineering, and environmental sciences, and come to us with a varying range of skills and knowledge. Therefore, components of the graduate program will be tailored to individual student needs. Each incoming student undertakes an individualised training-needs analysis to assess their skills and knowledge base. This reveals the skills and knowledge they need to acquire for successful completion of their project and to prepare for their future careers.

These programs are coordinated by our Graduate Director, Dr Melissa Hart, who is also the primary point of contact, advisor and advocate for the Centre's students and early career researchers.

Melissa was busy throughout 2017 welcoming our new students. She ensured they were able to feel welcome and to actively participate in the Centre's annual workshop held in conjunction with the ARC Centre of Excellence for Climate System Science, in Canberra, in November. In the first half of 2018 our new students and research associates will have opportunities to be involved in writing workshops, technical skills training and a winter school on the science of climate extremes.

In the pages that follow you will have a chance to read about the work of a selection of students who have recently commenced postgraduate studies with CLEx.

Selected Student Profiles

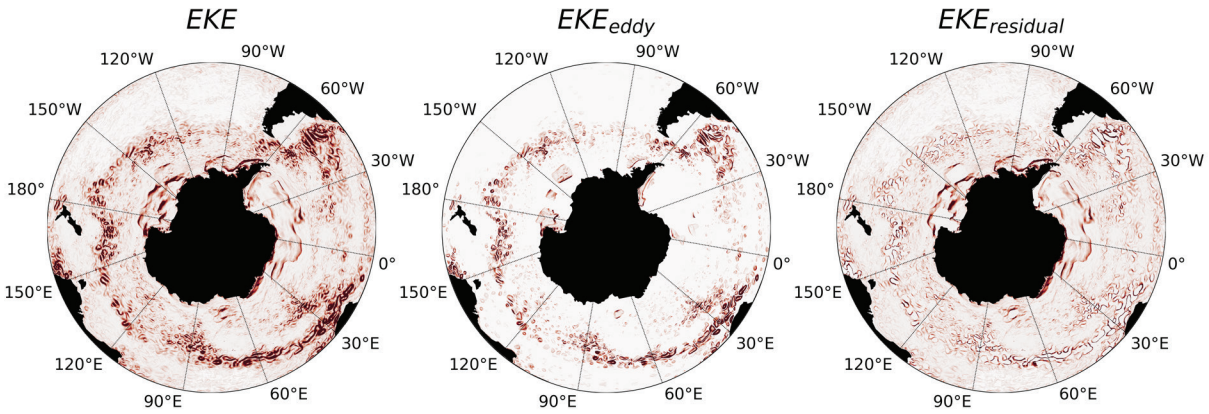


Figure: First implementation of the decomposition algorithm to extract EKE, EKE$_{eddy}$ and EKE$_{residual}$ in the Southern Ocean, using the geostrophic velocity obtained from the SSH field of a numerical simulation (ACCESS-OM).

Josué Martinez Moreno, PhD Student, ANU

Who in CLEx are you working with?

My primary supervisor is Andrew Hogg, and my associate supervisors are Adele Morrison, Andrew Kiss and Matthew England.

Tell us a little about your background, how did you get here?

In June 2017, I finished my undergraduate bachelor degree under the advice of Prof Angel Ruíz. My undergraduate thesis was titled "Pollution scenarios in the Gulf of Mexico by the river plume of the Coatzacoalcos river". The main goal of this research project was to understand and predict possible trajectories of passive particles and a scenario of the pollutant dispersion caused by the river plume of the Coatzacoalcos River.

Tell us a little about your project/planned project.

It has been pointed that mesoscale eddies constitute one of the principal components of the oceanic energy balance. Its variation may influence the regulation of the Earth's weather and climate change. One of the principal components in the oceanic energy budget is the Kinetic energy (KE), which can be split into the mean kinetic energy (MKE) and the eddy kinetic energy (EKE). However, one difficulty in determining the role of eddies in the oceanic transient adjustment to climate change is the lack of a process-based definition of EKE and EAPE. So, the aim of this study is to propose a new way to decompose KE according to different ocean processes.

What opportunities are you hoping the Centre of Excellence can offer you?

I would like to learn and interact as much as I can. It looks like the Centre of Excellence will provide a lot of opportunities to grow and learn while I am developing my own research.

What are your hopes/plans for after you graduate?

A short-term goal will be obtaining a postdoctoral position related to projections of climate change, modifying the oceanic energy budget. My final goal would be to find an academic position, where I could continue in the fields of physical oceanography, climate change or pollution.

Benjamin Shroeter, PhD Student, UTAS

Who in CLEx are you working with?

I work most closely with Professor Nathan Bindoff, who supervises me alongside Dr Phil Reid (BoM) and Dr Kelvin Michael (IMAS).

Tell us a little about your background, how did you get here?

After my undergraduate studies in Canberra, I had a brief stint in the private sector before moving to Melbourne and starting a Master of Information Technology alongside full-time employment as a software engineer with the Bureau of Meteorology. Later, I worked for satellite operations as a scientific programmer, where I worked with Artificial Neural Networks for precipitation nowcasting. During this time, I spent four months in Christchurch for a Postgraduate Certificate in Antarctic Studies (culminating in a trip to the ice) before embarking on a PhD at the Institute for Marine and Antarctic Studies in Hobart. Nowadays, I work full time with the Bureau on Numerical Weather Prediction (NWP) development for the National Operations Centre while completing my PhD part time, from Hobart.

Tell us a little about your project/planned project.

My project, titled Towards improved modelling of the high southern latitudes, investigates the performance of the Australian Global NWP model, ACCESS-G, south of 50S. By establishing a performance baseline and identifying systemic model biases in the region, we aim to better understand the physical processes driving model skill. In doing so, we seek to address opportunities for model development through an improved representation of Antarctic physics and processes that may be applied to improve forecast accuracy necessary for logistics, operations and personnel safety.

What opportunities are you hoping the Centre of Excellence can offer you?

The opportunities for which I am most appreciative are the conferences and workshops hosted and supported by the Centre. For students, these opportunities are invaluable experiences, putting us in contact with leading minds and affording us the ability to showcase our own contributions. If it weren't for the generous support of our affiliate bodies, these opportunities would otherwise be difficult to come by.

What are your hopes/plans for after you graduate?

My immediate plans are to remain in Hobart and continuing to operate in the NWP space, doing what I enjoy.

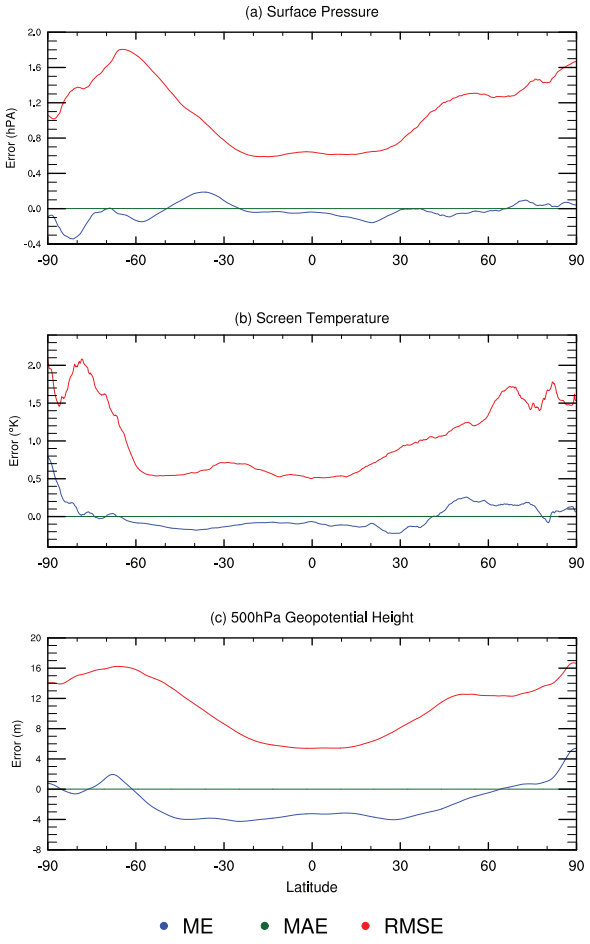


Figure: ACCESS-G annual error metrics plotted as latitudinal averages for all analysis times (0, 6, 12, 18Z) and for all forecast horizons (12, 24, 36, 48hrs) between 01/04/2016 and 31/03/2017).

Manon Sabot, PhD Student, UNSW

Who in CLEx are you working with?

My main supervisor is Prof Andy Pitman, and Dr Martin De Kauwe is my co-supervisor. As part of the UNSW Scientia initiative, I also have a "career mentor": Dr Melissa Hart. As my interests lie in the processes that control the vegetation response to drought, I hope to build future collaborations at the interface of the Drought and the Heatwave research programs in CLEx.

Tell us a little about your background, how did you get here?

I did a BSc in Physics at the University of Brest, France, which led to an MSc in Ocean, Atmosphere, Climate, and Space Observations at the Université Pierre et Marie Curie (UPMC), Paris.

Despite growing up by the sea, I was always more interested in climate-ecosystems interactions on land, so I ended up with an MSc in Climate, Land Use, and Ecosystem Services from UPMC and AgroParisTech.

The French system is such that we undertake several internships throughout university. After graduation, one of these internships turned into a job at the Max Planck Institute for Meteorology, Hamburg. There, I worked on questions of climate and forest management.

Tell us a little about your project/planned project.

Recent major meteorological, hydrological, and ecological droughts affecting Australia, the Amazon and North America have had considerable impacts on ecosystems, human populations and economic systems. With climate change, increases in temperature and large uncertainties in the response of rainfall are widely expected to exacerbate the incidence of drought. It is commonly believed that droughts will increase in both magnitude and frequency. Remarkably, the evidence to support this projected increase is equivocal. To determine whether the risk of drought will increase, major improvements in our understanding of land-atmosphere interactions is crucial. My project explores land-atmosphere feedbacks at times of drought and the implications for the future, with a focus on how we represent the impact of drought on the vegetation in state-of-the-art climate models. In the absence of the exact process understanding, I am interested in how optimization approaches can provide useful mechanistic understanding and help to understand and represent those impacts.

What opportunities are you hoping the Centre of Excellence can offer you?

The first thing I expect is a healthy and positive work environment, which the Centre and the CCRC have proven really good at creating. In the years to come, I am hoping to make the best out of the Centre's connections to relevant research institutions in Australia and abroad.

What are your hopes/plans for after you graduate?

I believe there is a need to better communicate the findings of our research to policy and decision makers. I would really like to help facilitate that link, but whether I'd be doing that in an academic environment is for the future to decide. Three years is a long way to go!

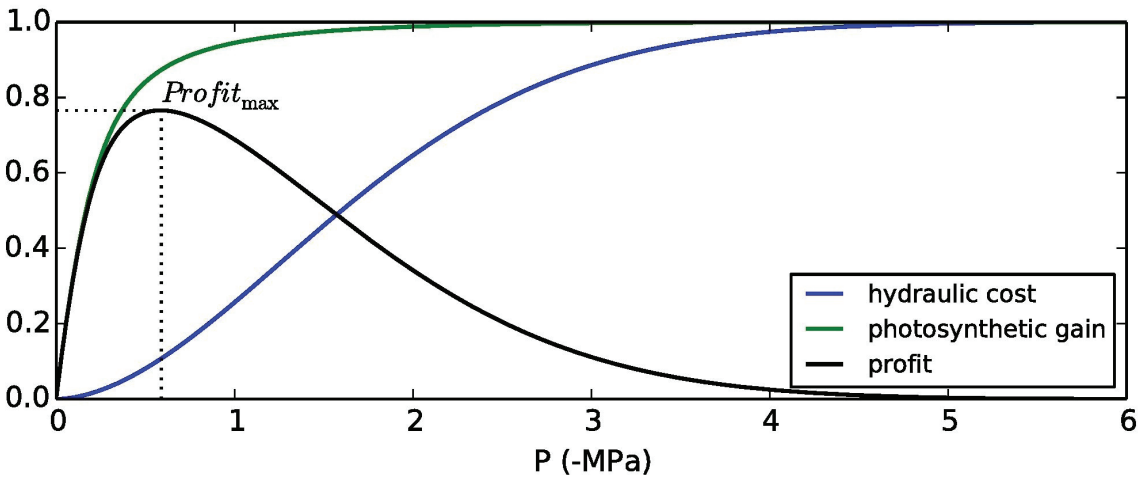


Figure: Optimization model of photosynthetic gain versus hydraulic cost for plants. The profit curve represents the tradeoff between transpiration and carobon assimilation. The optimal tradeoff occuring when the profit is maxium. Reproduced from Sperry et al., 2017

Roseanna McKay, PhD Student, Monash University

Who in CLEx are you working with?

I work with Dr Julie Arblaster and Dr Dietmar Dommenget from CLEx, as well as Dr Pandora Hope from the Bureau of Meteorology.

Tell us a little about your background, how did you get here?

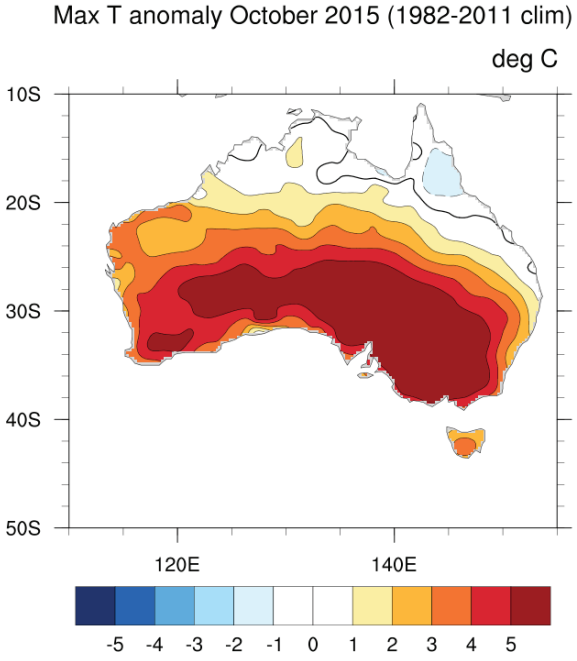
I did my undergraduate degree at the University of Tasmania and majored in applied mathematics and physics. In 2013 I joined the Bureau of Meteorology and completed the Bureau's Graduate Diploma of Meteorology before becoming a weather forecaster in Adelaide for three years. I started my PhD, back in March because I wanted to learn more about how our climate is changing, and to learn how to help others understand how climate change will affect them.

Tell us a little about your project/planned project.

I am looking at spring heat extremes in Australia, and investigating a teleconnection back to the Indian Ocean. The aim is to understand how this teleconnection works, by using seasonal prediction models (POAMA and potentially ACCESS-S), and how it may be changing as the world warms. Hopefully this will lead to hot springs being better predicted into the future.

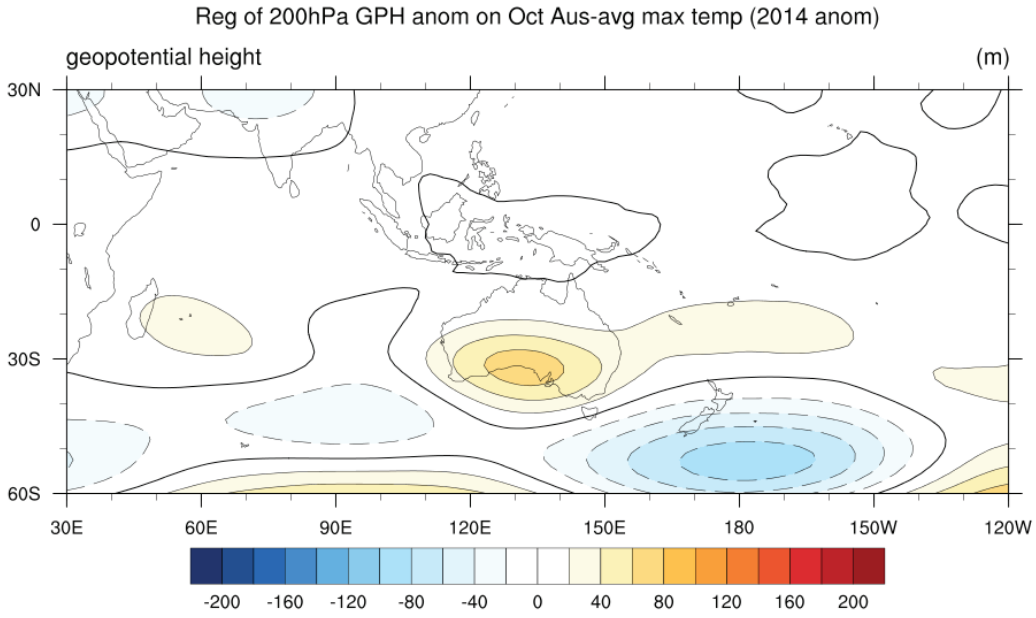
What opportunities are you hoping the Centre of Excellence can offer you?

I think the Centre offers excellent opportunities to meet and discuss my work with researchers with a range of experience — from ECRs to world leaders — so I can really benefit by incorporating their advice into my own research. I really love the opportunities to visit other nodes, attend more conferences and workshops, practise public speaking and poster-making skills, and learn a host of skills relevant to research that will be a great help through my candidature.



What are your hopes/plans for after you graduate?

I hope when I graduate that I can find a career where I can help communicate what is happening with climate change to the wider community, and continue to research the changes that are impacting Australian seasons and weather so that forecasts can be improved.



Sopia Lestari,
Phd Student, University of Melbourne

Who in CLEx are you working with?

I am a PhD student in the first year, at the School of Earth Sciences, University of Melbourne, working with David Karoly, Andrew King and Claire Vincent from Uni. Melb, and Alain Protat from the Bureau of Meteorology.

Tell us a little about your background, how did you get here?

I have been working as a junior climate researcher-government officer at the Agency for the Assessment and Application of Technology, in Jakarta, Indonesia, for seven years, managing rainfall and weather radar data. I have been analysing rainfall extremes, in particular, in Indonesia with the collaboration of the Japan Agency for Marine-Earth Science and Technology (, Japan. I am eager to develop my skills and my knowledge about rainfall extremes by pursuing a higher degree (a PhD) in Australia, since we have a collaboration with some institutions and universities in Australia under the Year of Maritime Continent project, 2017 to 2019.

Tell us a little about your project/planned project.

My PhD project aims to understand the variability of rainfall extremes in Jakarta and surroundings and to observe the dominant factors, namely remote and local forcings affecting these extremes in line with the CLEx project.

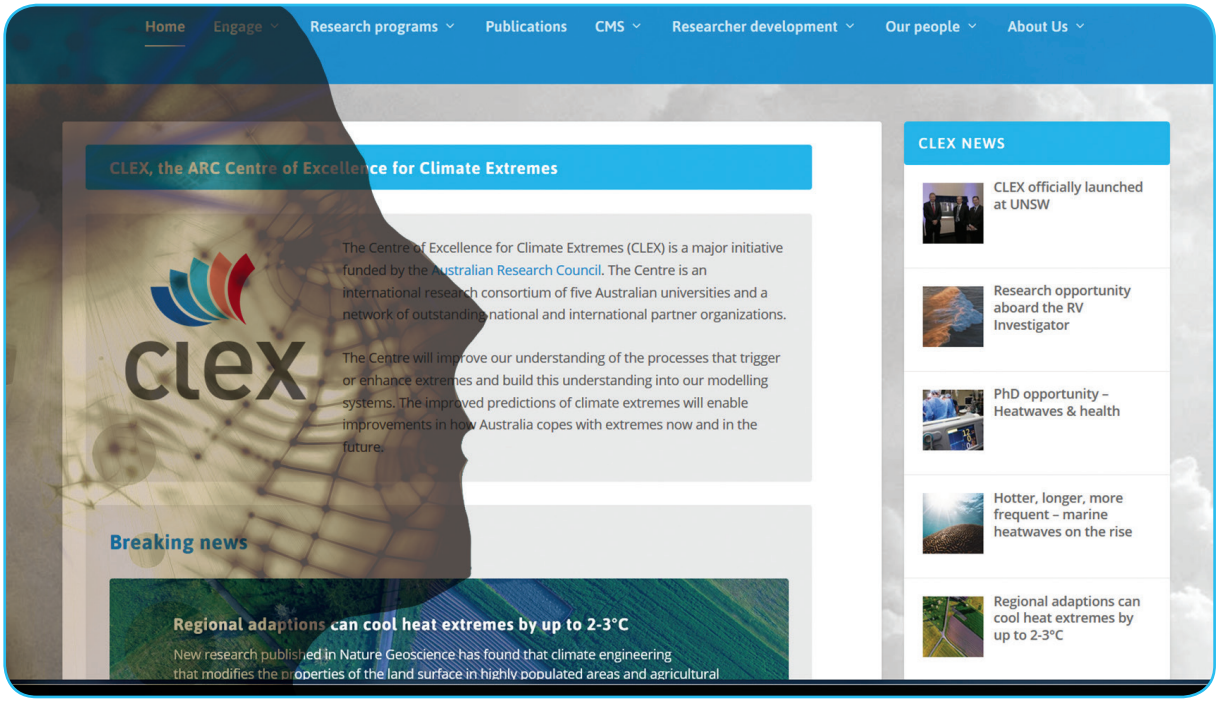
What opportunities are you hoping the Centre of Excellence can offer you?

Being a member of this project, I hope it could widen opportunities to meet students and scientists from other universities/institutions to share ideas as well as build a connection with them. In addition, joining many seminars/schools/workshops held by CLEx, or getting seminar information through the CLEx mailing list, will be also beneficial for supporting my thesis project.

What are your hopes/plans for after you graduate?

After graduating with a PhD, I expect to maintain connections and collaborate with CLEx members, in particular, who work on climate in the Maritime Continent.

Media and Communications



The first six months of the ARC Centre of Excellence for Climate Extremes (CLEx) has been focused on foundational work to set it up for the years ahead. This has included developing branding, building a professional website, making media aware of the new Centre, putting in place social media policies and platforms, creating an enhanced internal communications platform, and developing a long-term strategy for training of Centre staff.

This strong focus on putting down a solid internal and external communications platform is based on our experience with the ARC Centre of Excellence for Climate Systems Science (ARCCSS). With ARCCSS we hit the ground running and added in different components around its media program, on the fly, as they were required. With the new Centre, we can put in place proven strategies and add new foundational structures to enhance even further the communication between nodes, and outwards.

CLEx also offers us new challenges. Its extended focus into the effects of extremes on economies, industry and environment means this Centre of Excellence will have to develop links with industry leaders, peak bodies, niche media outlets and policymakers. This will require establishing links with key influencers in these areas, to get our work in front of policymakers at all levels of government and industry.

Our communications strategy is built around a three-tier foundation: internal communications, media training and resource building, and external communications. The first two foundations feed directly into the third and will be a key part of our goal to work on improving the skills of young researchers, so they can become the public voices of the future.

Website

The website is detailed separately because it reflects and enhances all three of the aforementioned foundations — which is why there has been a strong focus on developing it not just as an outward expression of the Centre but as an internal repository of resources and a reporting tool.

The website has been designed to make adding multimedia components relatively simple, giving us the opportunity to create interactive pages and active visuals. It will host a blog platform for students and other researchers to share experiences along with tips and resources. These will also help the Media and Communications Manager to identify promising public science communicators. The website will include a section for media training, where tips and resources will be made available.

The website is, of course, the public face of the Centre. However, research has shown us that many Centres of Excellence experience high bounce rates. With this in mind, we will examine how to create pages that are both useful and engaging, so the public stays. We will be exploring housing automatically-updated climate metrics, resource pages for school students, video explainers and podcasts. Sharing stories via social media will be a simple one-touch process.

A section of the website will be password protected, where useful assets for researchers, students, technical staff and professional staff will be made available.

Media and Communications Foundations

Foundation 1: Internal Communications

The aim of this strategy is to ensure that the five Centre of Excellence nodes are consistently engaged. This not only helps in sharing research but also enables the Media and Communications Manager to identify and act on a broad range of opportunities.

With this in mind, we have identified node communication leads who will also engage with our social media strategy. There will be monthly meetings with these leads and the Media and Communications Manager, social media Key Performance Indicators will be put in place, and there will be weekly interaction through an emailed Weekly Update to all nodes and our Partner Organisations. These will all feed into the quarterly newsletter.

This structure means that all five Centre nodes will interact around communication matters on at least a weekly basis, and probably more. Once this is up-and-running, it will also allow us to develop our alumni network and to highlight visitors of note.

Foundation 2: Media Communications and Training Resources

Few graduate courses have media training for scientists, and there is simply no time for honours students to do this kind of training. Thus, we train our PhD students from scratch.

We are developing a structured media training program for our students and researchers and providing them with a variety of related resources. Currently we have a half-day course on preparing for media and the interview process and will be adding further modules over the coming year. Resources will be available on our website.

Intriguingly, there is no formal course for designing academic posters, despite their importance as generators of peer interaction at national and international conferences. We have designed a regular course that creates a simple process for producing posters. Again, resources will be made available on our website.

Foundation 3: External Communications

We envisage a strong internal communications culture designed designed to alert us to stories and opportunities that will allow us to be active outward communicators of our research and to engage with public discussion around climate extremes. The training in external communications will also allow younger researchers to take advantage of opportunistic media coverage.

Our audience includes key stakeholders, partners, national and international peer groups, future students, the general public, industry leaders and policymakers. The aim is for the Centre of Excellence to be seen as a key authority in the area of climate extremes.

To do this we aim to strengthen relationships with existing media and establish new connections to niche and industry, target key influencers through our social media brands, and create attractive and useful reasons for users to regularly engage with our website. To accomplish this, we will

- become more regular users of Wolters Kluwer CCH, which sends media releases to politicians and the Canberra press gallery;
- develop strong relationships and write articles for industry-based outlets;
- increase our activities with online media outlets like *The Conversation, Climate Central* and *RenewEconomy*;
- form partnerships with multimedia experts/media to produce videos and podcasts; and
- produce more shareable multimedia assets.

Our social media presence will be focused on the established forms of social media with deep penetration: Twitter and Facebook. We will have administrators at every node and a strategy to time posts to hit media personalities, influential peers and others who need to engage with the science.

There will be an area on the website dedicated to prospective students that will also feature the activities of our current students. The highly successful graduate program developed by Dr Melissa Hart will figure in much of the media around our students.

At the time of writing we are already seeing the first fruits of this focus on foundations, with a *Sydney Morning Herald* editorial specifically highlighting CLEx in January 2018. This was followed by the wide reporting of two of our first papers, and stories in the broadcasting, online and print realms highlighting our expert commentary.

With these foundations slotting in to place, we expect very positive results for the Centre of Excellence in 2018.

Alvin Stone
Media and Communications Manager

Prizes, Outreach and Engagement

Prizes, Awards, Elections and Citations

Alexander, L. 2017/18 WMO Commission for Climatology Outstanding Service Award

Arblaster, J. 2017 AMOS Priestley Medal

Arblaster, J. Contributing author, Chapter 3, IPCC Special Report on Oceans and Cryosphere

Bindoff, N. IPCC First IPCC Lead Author Meeting for Special Report on the Ocean and Cryosphere in a Changing Climate

Bony, S. Gérard Mégie Prize by the French Academy of Sciences

England, M. 2017 Sydney Institute of Marine Science Emerald Award for contributions to our knowledge of the ocean's role in climate

England, M. 2017 Tinker-Muse Prize for Science and Policy in Antarctica

Evans, J. 2017 Amos Priestley Medal

Griffies, S. Nominated Fellow of the American Geophysical Union

Jakob, C. Named as a Fellow of AMOS

McDougall, T. NSW Premier's Prize for Excellence in Mathematics, Earth Sciences, Chemistry and Physics

Government and Industry Engagement

Pitman, A. Briefing to the Department of the Environment and Energy on the NCRCIS ACCESS initiative

Pitman, A. Briefing to an investor group of superannuation companies, organised by Credit Suisse - Melbourne

Public Talks and Community Engagement

England, M. SIMS Foundation Dinner, "Antarctic change and what it means for Australia's coastline"

Pitman, A. Max Planck Institute for Meteorology, "Drought in climate models: What can we do about the uncertainty in climate projections?"

Editor Roles

Abram, N. Chief Editor, *Climate of the Past*

Alexander, L. Editor-in-Chief, *Weather and Climate Extremes*

Evans, J. Associate Editor, *Journal of Climate*

Hogg, A. Editor, *Geophysical Research Letters*

Jakob, C. Associate Editor, *Journal of Climate*

Karoly, D. Chief Editor, *Australian Meteorological and Oceanographic Journal*

Lane, T. Editor, *Monthly Weather Review*

Lewis, S. Inaugural Editor, *Journal of Southern Hemisphere Earth System Science*

Pitman, A. Associate Editor, *International Journal of Climatology*

Saenko, O. Editor, *Journal of Climate*

Santoso, A. Associate Editor, *Journal of Climate*

Sherwood, S. Editor, *Environmental Research Letters*

International Committee Memberships

Alexander, L. GEWEX Scientific Steering Group

Alexander, L. Scientific Steering Committee of the International Geosphere-Biosphere Programme (IGBP) Analysis, Integration and Modelling of the Earth System (AIMES) project

Arblaster, J. Author, Chapter 5, 2018 WMO/UNEP Scientific Assessment on Ozone Depletion

Bindoff, N. CLIVAR Science Steering Group, 2014-2017

Bindoff, N. Royal Society of New Zealand Marsden Fund Committee for Earth Science Panel, 2014-2017

Jakob, C. Attended WCRP JSC meeting and reported on the WCRP Model Advisory Council

Jakob, C. Chaired the 6th Session of the WCRP Modelling Advisory Council, Reading, UK

Karoly, D. External Advisory Board, European Climate and Weather Events: Interpretation and Attribution (EUCLEIA) project

Karoly, D. Scientific Steering Committee, WMO/UNEP Scientific Assessment of Ozone Depletion 2018

Karoly, D. External Advisory Board, European Prototype demonstrator for the Harmonisation and Evaluation of Methodologies for attribution of extreme weather Events (EUPHEME) project

Lane, T. American Meteorological Society Committee on Mesoscale Processes

Lane, T. Council of the International Forum of Meteorological Societies

Lane, T. WMO's Monsoon Panel Expert Team on Severe Monsoon Weather

Santoso, A. CLIVAR Pacific Panel

Monash PhD student Vidhi Bharti and University of Adelaide Prof. Murray Hamilton preparing the UAVs for a test flight on the Macquarie island. La Astrolabe ship floating in the background (Nov 28, 2016; Photo Courtesy - Stuart Henderson, ARPANSA)

Sherwood, S. Steering Committee of the WCRP Grand Challenge on Clouds, Circulation and Climate

Strutton, P. Steering Committee for the Tropical Pacific Observing System 2020 (tpos2020.org). Also Chair of the TPOS2020 Biogeochemistry Task Team

Walsh, K. WMO Expert Team on Climate Impacts on Tropical Cyclones

Australian Committee Memberships

Abram, N. National Committee for Earth System Science

Arblaster, J. National Climate Science Advisory Committee

Arblaster, J. National Committee for Earth System Science

Hart, M. Chair - AMOS Equity and Diversity Committee

Karoly, D. Board, Tipping Point Australia

Karoly, D. Wentworth Group of Concerned Scientists

Lane, T. Advisory Board, *Journal of Southern Hemisphere Earth Systems Science*

Lane, T. National Councillor and immediate past President of the Australian Meteorological and Oceanographic Society

Lane, T. Advisory Board, *Journal of Southern Hemisphere Earth Systems Science*

Phillips, H. Elected Chair of the Tasmanian Regional Centre of AMOS

Pitman, A. National Committee for Earth System Science

Pitman, A. Monash Foundation Scholarships

Pitman, A. National council, AMOS

Sen Gupta, A. National Committee for Earth System Science

Sherwood, S. Australian Academy of Science meeting (invited as external member)

Strutton, P. Co-lead of Bluewater and Climate Node of Australia's Integrated Marine Observing System

Publications

The ARC Centre of Excellence for Climate Extremes (CLEx) commenced operations on 4 August, 2017. Given the time spans involved in manuscript preparation and the peer review process, only a small amount of our initial work had made it to press by the end of the year.

Published

De Kauwe, M.G., Medlyn, B.E., Knauer, J., Williams, C.A., 2017. Ideas and perspectives: how coupled is the vegetation to the boundary layer? Biogeosciences 14, 4435–4453. https://doi.org/10.5194/bg-14-4435-2017

Williams, P.D., Alexander, M.J., Barnes, E.A., Butler, A.H., Davies, H.C., Garfinkel, C.I., Kushnir, Y., Lane, T.P., Lundquist, J.K., Martius, O., Maue, R.N., Peltier, W.R., Sato, K., Scaife, A.A., Zhang, C., 2017. A Census of Atmospheric Variability From Seconds to Decades. Geophys. Res. Lett. 44, 2017GL075483. https://doi.org/10.1002/2017GL075483

In Press at 31 Dec 2017

Evans, J.P., Kay, M., Prasad, A., Pitman, A., 2018. The resilience of Australian wind energy to climate change. Environ. Res. Lett. 13, 024014. https://doi.org/10.1088/1748-9326/aaa632

Fiddes, S.L., Woodhouse, M.T., Nicholls, Z., Lane, T.P., Schofield, R., In press. Cloud, precipitation and radiation responses to large perturbations in global dimethyl sulfide. Atmos. Chem. Phys. Discuss. In press. https://doi.org/10.5194/acp-2017-1141

Hobeichi, S., Abramowitz, G., Evans, J., Ukkola, A., 2018. Derived Optimal Linear Combination Evapotranspiration (DOLCE): a global gridded synthesis ET estimate. Hydrol. Earth Syst. Sci. 22, 1317–1336. https://doi.org/10.5194/hess-22-1317-2018

Klein, T., Zeppel, M.J.B., Anderegg, W.R.L., Bloemen, J., Kauwe, M.G.D., Hudson, P., Ruehr, N.K., Powell, T.L., Arx, G. von, Nardini, A., In Press. Xylem embolism refilling and resilience against drought-induced mortality in woody plants: processes and trade-offs. Ecol Res 1–17. https://doi.org/10.1007/s11284-018-1588-y

Knauer, J., Zaehle, S., Medlyn, B.E., Reichstein, M., Williams, C.A., Migliavacca, M., De Kauwe, M.G., Werner, C., Keitel, C., Kolari, P., Limousin, J.-M., Linderson, M.-L., 2018. Towards physiologically meaningful water-use efficiency estimates from eddy covariance data. Glob Change Biol 24, 694–710. https://doi.org/10.1111/gcb.13893

Oliver, E.C.J., Lago, V., Hobday, A.J., Holbrook, N.J., Ling, S.D., Mundy, C.N., 2018a. Marine heatwaves off eastern Tasmania: Trends, interannual variability, and predictability. Progress in Oceanography 161, 116–130. https://doi.org/10.1016/j.pocean.2018.02.007

Seneviratne, S.I., Phipps, S.J., Pitman, A.J., Hirsch, A.L., Davin, E.L., Donat, M.G., Hirschi, M., Lenton, A., Wilhelm, M., Kravitz, B., 2018. Land radiative management as contributor to regional-scale climate adaptation and mitigation. Nature Geoscience 11, 88–96. https://doi.org/10.1038/s41561-017-0057-5

Open Access

CLEx requires authors of papers attributed to the Centre to ensure they are compliant with their own institutional procedures for ensuring published research is deposited into an institutionally sanctioned open-access repository. Authors must adhere to publisher's copyright stipulations regarding embargo periods but are encouraged to upload pre-print versions of their manuscripts to institutional repositories prior to the lifting of embargo periods, where this is permissible and practicable.

2017 Key Performance Indicators

Performance Measure	Reporting interval	Target 2017	Achieved 2017
Number of research outputs	Annually		
Journal articles		10	2
Book chapters		2	0
Software modules published		2	2
data sets published,		2	2
social media@facebook posts		52	0 (1)
social media via Centre website updates		25	25
Science explainer videos		1	1
Quality of research outputs	Annually		
Percentage of publications in journals with impact factors greater than 2.0		80	100
Percentage of publications in journals with impact factors greater than 4.0		60	50
Number of papers in journals with impact factors greater than 10		2	0
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		1	0
Computational skills workshops/tutorials		3	1
Science fundamentals workshops		1	
Leadership and professional development workshops		1	1
Communications/writing workshops		1	1
Number of centre-wide virtual lectures/seminars		5	2
Percentage of students/ECRs attending researcher development activities		90%	74%
Number of workshops/conferences held/offered by the Centre	Annually		
National workshop		1	1
International conference/workshop		1	1
Topical/Research Program workshops		3	1
Number of additional researchers working on Centre research	Annually		
Postdoctoral researchers		7	2
Honours students		0	2
HDR students		5	22
Associate Investigators		24	24
Graduate Student Training	Annually		
Number of PhD completions		0	0
Number of Masters by Research completions		0	0
Number of Honours student completions		0	2
Percentage completing PhD students submitting within 4 years (FTE)		-	-
Number of mentoring programs offered by the Centre 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.	Annually and at mid-term review	1	1
Number of presentations/briefings	Annually		
To the public		5	2
To government		5	1
To industry/business/end-users		5	1
To non-government organisations		5	0
To professional organisations and bodies		5	0
Number of new organisations collaborating with, or involved in, the Centre	Annually	0	0

Performance Measure **Additional CLEx-specific Performance Measures:**	Reporting interval	Target 2017	Achieved 2017
Equity and Diversity Initiatives	Annually		
Percentage of female graduate students		50%	33%
Percentage of female research fellows		50%	50%
Percentage of senior female research fellows		50%	n/a (2)
Percentage of Centre leaders who are female		50%	27% (3)
Percentage of administration team who are female		50%	88%
Percentage of board members who are female		50%	22%
Percentage of keynote speakers at workshops and conferences who are female		50%	50%
Computational Modelling Support	Annually		
New/refined/enhanced software modules for the climate models developed and served to the community.		2	2
New/refined/updated software tools for data analysis developed and served to the community.		2	1
New/refined/updated data sets served to the community.		2	2
Monthly bulletin to all researchers on CMS-related updates		6	5
Explainer videos on key CMS issues		2	2
Percentage of students with cross node and/or partner organisation supervision	Annually	50 %	43%
Percentage of students/ECRs making a research visit to other nodes and/or Australian partner organisations	Annually	50%	9% (4)
Student / ECR internships in industry/government		0	0
Percentage of students/ECRs making a research visit to international partner organisations or organisation with a collaborative relationship	Annually	15	
Number of undergraduate summer scholarships offered	Annually	0	0
Regular Research Program videoconference meetings p/a	Annually	3	
Media KPIs	Annually		
Media Releases		5	2
Website – Unique Hits		15000	3878
Website – Page Views		20000	8050
Stories in media		100	
Social Media – Twitter (followers)		50	104
Social Media – Facebook (followers)		50	n/a (1)
Knowledge Brokerage Team	Annually and at mid-term review		
Establishment of significant partnerships		2	0
Data sets provided to stakeholders		1	0
Strategic advice provided to stakeholder		1	0
Demonstrated examples of model improvements available for use in national modelling systems	Annually and at mid-term review	1	

Footnotes

1: We elected to maintain a single ARCCSS-branded Facebook profile during the 12 month overlap period between the two centres. There were periodic posts regarding CLEx on the ARCCSS Facebook page.

2: No Senior Research Fellows appointed in 2017

3: Centre leaders defined as Directorate, RP co-leads, COO, Graduate Director and CMS Team Leader

4: Graduate students affiliated to CLEx are all in the first months of their candidature and still settling in. For most this means that research visits to other nodes would be of limited vale at this early stage.

Financial Statement

Executive Summary

The Australian Research Council Centre of Excellence for Climate Extremes (CLEx) 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 2017, CLEx received $5,771,392 (103%) income compared to the full-year budget of $5,582,171. In terms of the Centre's expenditure, $263,777 (6%) was spent compared to the full-year budget of $4,237,746. This was due to the late commencement start date and delays in personnel appointments.

In 2017, personnel accounted for the highest proportion of expenditure of $176,462 (67%), followed by travel expenditure of $43,667 (18%). Overall, the Centre's cash balance in 2017 is $5,507,614.

Financial Management and Performance

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

The Centre meets its reporting requirements to the ARC by submitting the annual Centre Outputs and Detailed Income and Expenditure report. The Centre also meets all other reporting obligations set by Partner Organisations that provide financial support.

2017 Income

Cash income totalled $5,771,392 from all sources. The Centre derived its income from the ARC, participating universities, the Bureau of Meteorology (BoM), the NSW Office of Environment and Heritage (OEH) and the NSW Department of Industry Research Attraction and Acceleration Program (RAAP). Income is summarised by source in detail in the tables that follow.

1: Australian Research Council Funding

The Centre received indexed income from the ARC of $4,415,250. This was distributed to the institutions in accordance with the inter-institutional agreement and was used for payroll, scholarships, consumables, equipment, materials, maintenance and travel.

2: Government Funding

2.1 Bureau of Meteorology

BoM committed $10,000 in year one of the Centre's operations. This cash contribution was targeted at PhD top-up scholarships for students working collaboratively with BoM.

2.2 NSW Office of Environment and Heritage

The cash investment from OEH 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 $100,000 in 2017.

2.3 NSW Department of Industry RAAP

RAAP funding is invested 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 $143,000 in 2017

3: Collaborating Organisation Funding

Cash contributions to the Centre of Excellence from the Administering Organisation and the Collaborating Organisations amounted to $1,103,142, as follows:

$454,479	UNSW
$112,706	ANU
$158,947	University of Melbourne
$133,204	University of Tasmania
$243,806	Monash University

4: In-kind Contributions

In-kind support totalled $2,221,887 in 2017. The Centre is grateful for $1,312,069 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 $909,818. Again, this was mainly personnel time. The actual in-kind was lower than budgeted, due to the Centre's late commencement date compared to full-year budget.

Organisation	In-kind Budget $	In-kind Actual $
ANU	725,047	228,357
BOM	135,966	56,653
CSIRO	308,000	128,333
LATMOS CNRS/INSU/IPSL	13,400	5,583
Max Planck Inst. for Meteorology	45,000	18,750
Met Office UK	150,000	62,500
Monash	622,656	169,051
NASA Goddard Space Flight Centre	38,361	15,984
NASA Jet Propulsion Lab	50,200	20,917
NCAR	101,981	42,492
NCI	825,300	343,875
NOAA	30,000	12,500
OEH	312,785	130,327
Risk Frontiers Grp	42,000	17,500
Swiss Federal Inst of Tech	79,000	32,917
UMEL	674,521	167,766
University of Arizona, USA	79,085	21,488
UNSW	1,439,672	616,530
UTAS	458,757	130,365
TOTAL	**6,131,730**	**2,221,887**

2017 Leverage

The Centre's 2017 cash income of $5,771,392 and in-kind support of $2,221,887 total $7,993,279, with ARC funding accounting for $4,415,250 of the total income. The Centre's leverage of $3,578,029 equates to $1.81 of external funding and in-kind contributions for each $1.00 received from the ARC.

2017 Expenditure

In 2017 the Centre expended $263,777, analysed below:

Personnel (including on-costs)	$176,462	67%
Scholarships	$17,064	6%
Equipment and Maintenance	$6,182	2%
Consumables and Events	$20,402	8%
Travel	$43,667	18%

2017 Income Vs Expenditure

Income and Expenditure is based on cash and is derived from the institutions' general ledgers. The Collaborating Organisations certify income and expenditure by formally acquitting all grants as at 31 December, 2017.

The Centre's cash expenditure of $263,777 was below income of $5,771,392 by $5,507,615.

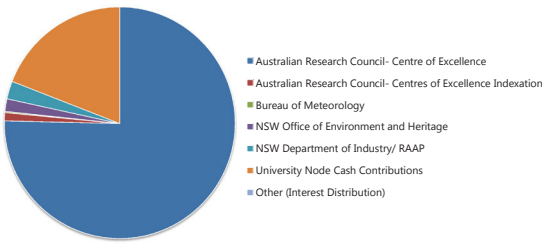
The Centre will carry over a balance of $5,507,615 to 2018. The carry-over by institution is as follows:

University of New South Wales	$2,414,323	surplus
Australian National University	$602,547	surplus
University of Melbourne	$691,697	surplus
University of Tasmania	$658,582	surplus
Monash University	$1,140,896	surplus

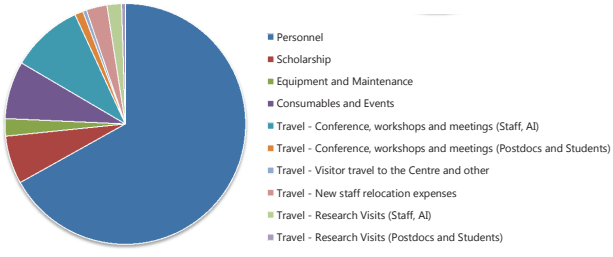
In summary, as at 31 December, 2017, the financial position for the life of CLEx after its first year of operation is as follows:

Total Cash Income	$5,771,392
Total Expenditure	$263,777
Surplus carried forward to 2018	**$5,507,615**

Income by Source



Expenditure



Income & Expenditure Forecast

	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	4,250,000	4,300,000	4,300,000	4,300,000	4,300,000		30,050,000
Australian Research Council- Centres of Excellence Indexation	65,250	0	0	0	0	0	0		65,250
Bureau of Meteorology	10,000	20,000	30,000	30,000	30,000	20,000	20,000		160,000
NSW Office of Environment and Heritage	100,000	100,000	100,000	100,000	100,000	100,000	100,000		700,000
NSW Department of Industry/ RAAP	143,000	0	0	0	0	0	0		143,000
University Node Cash Contributions	1,103,142	1,244,050	1,243,798	1,236,879	1,227,652	1,227,635	1,227,635		8,510,791
Other (Interest Distribution)	0	0	0	0	0	0	0		-
Total	**5,771,392**	**5,614,050**	**5,623,798**	**5,666,879**	**5,657,652**	**5,647,635**	**5,647,635**	**0**	**39,629,041**
2. ARC Expenditure	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**TOTAL**
Personnel	114,662	3,308,493	3,333,354	3,348,677	3,358,536	3,360,528	3,360,922	2,325,899	**22,511,072**
Scholarship	6,358	252,783	252,783	252,783	252,783	252,783	252,783	174,936	**1,697,991**
Equipment and Maintenance	0	108,000	15,000	40,000	15,000	15,000	15,000	10,381	**218,381**
Consumables and Events	16,369	179,619	243,543	195,311	202,292	200,299	199,905	138,343	**1,375,680**
Travel - Conference, workshops and meetings (Staff, AI)	12,634	308,352	308,352	308,352	308,352	308,352	308,352	213,392	**2,076,135**
Travel - Conference, workshops and meetings (Postdocs and Students)	0	99,633	99,633	99,633	99,633	99,633	99,633	68,950	**666,745**
Travel - Visitor travel to the Centre and other	1,336	105,517	105,517	105,517	105,517	105,517	105,517	73,022	**707,460**
Travel - New staff relocation expenses	0	0	0	0	0	0	0	0	-
Travel - Research Visits (Staff, AI)	0	64,289	64,289	64,289	64,289	64,289	64,289	44,490	**430,222**
Travel - Research Visits (Postdocs and Students)	1,341	64,289	64,289	64,289	64,289	64,289	64,289	44,490	**431,564**
Total	**152,701**	**4,490,973**	**4,486,758**	**4,478,849**	**4,470,688**	**4,470,688**	**4,470,688**	**3,093,904**	30,115,249
3. Nodes Expenditure	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**TOTAL**
Personnel	65	416,064	479,345	489,454	473,195	478,015	504,377	329,395	**3,169,910**
Scholarship	10,706	389,406	389,819	373,113	416,116	420,771	420,771	274,794	**2,695,496**
Equipment and Maintenance	6,182	31,303	21,343	35,853	27,353	27,353	20,853	13,619	**183,861**
Consumables and Events	4,575	13,978	14,911	18,347	18,294	23,695	23,571	15,394	**132,765**
Travel - Conference, workshops and meetings (Staff, AI)	12,901	204,957	204,957	204,957	204,957	204,957	204,957	133,852	**1,376,497**
Travel - Conference, workshops and meetings (Postdocs and Students)	2,969	78,988	73,988	67,988	73,988	78,988	67,988	44,401	**489,298**
Travel - Visitor travel to the Centre and other	0	23,007	19,377	20,106	24,467	24,467	20,106	13,131	**144,661**
Travel - New staff relocation expenses	7,354	11,000	0	20,000	16,000	6,000	0	0	**60,354**
Travel - Research Visits (Staff, AI)	5,132	29,000	29,000	29,000	29,000	29,000	29,000	18,939	**198,071**
Travel - Research Visits (Postdocs and Students)	0	9,000	9,000	9,000	9,000	9,000	9,000	5,878	**59,878**
Total	**49,885**	**1,206,704**	**1,241,741**	**1,267,818**	**1,292,370**	**1,302,247**	**1,300,624**	**849,402**	**8,510,791**
4. Others	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**TOTAL**
Personnel	61,192	100,000	100,000	100,000	100,000	100,000	100,000	181,808	**843,000**
Scholarship	0	20,000	30,000	30,000	30,000	20,000	20,000	10,000	**160,000**
Equipment and Maintenance	0	0	0	0	0	0	0		-
Consumables and Events	0	0	0	0	0	0	0		-
Travel - Conference, workshops and meetings (Staff, AI)	0	0	0	0	0	0	0		-
Travel - Conference, workshops and meetings (Postdocs and Students)	0	0	0	0	0	0	0		-
Travel - Visitor travel to the Centre and other	0	0	0	0	0	0	0		-
Travel - New staff relocation expenses	0	0	0	0	0	0	0		-
Travel - Research Visits (Staff, AI)	0	0	0	0	0	0	0		-
Travel - Research Visits (Postdocs and Students)	0	0	0	0	0	0	0		-
Total	**61,192**	**120,000**	**130,000**	**130,000**	**130,000**	**120,000**	**120,000**	**191,808**	**1,003,000**
5. Summary Income Vs. Expenditure / Carry Over	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**TOTAL**
ARC									
Total Income	4,415,250	4,250,000	4,250,000	4,300,000	4,300,000	4,300,000	4,300,000	0	**30,115,250**
Total Expenditure	152,701	4,490,973	4,486,758	4,478,849	4,470,688	4,470,688	4,470,688	3,093,904	30,115,249
Income less Expenditure	4,262,549	-240,973	-236,758	-178,849	-170,688	-170,688	-170,688	-3,093,904	**0**
Nodes									
Total Income	1,103,142	1,244,050	1,243,798	1,236,879	1,227,652	1,227,635	1,227,635	0	**8,510,791**
Total Expenditure	49,885	1,206,704	1,241,741	1,267,818	1,292,370	1,302,247	1,300,624	849,402	**8,510,791**
Income less Expenditure	1,053,257	37,346	2,057	-30,939	-64,718	-74,612	-72,989	-849,402	**0**
Other									
Total Income	253,000	120,000	130,000	130,000	130,000	120,000	120,000	0	**1,003,000**
Total Expenditure	61,192	120,000	130,000	130,000	130,000	120,000	120,000	191,808	**1,003,000**
Income less Expenditure	191,808	0	0	0	0	0	0	-191,808	**0**
Carry over surplus / deficit	**5,507,614**	**-203,627**	**-234,702**	**-209,788**	**-235,407**	**-245,300**	**-243,677**	**-4,135,114**	**0**

2017 Cash Income & Expenditure

	UNSW	ANU	U.Mel	U.Tas	Monash Uni	Total $	FY Budget
1. Cash Income							
Australian Research Council- Centre of Excellence	1,805,380	544,916	548,321	538,105	913,278	4,350,000	4,350,000
Australian Research Council- Centres of Excellence Indexation	65,250					65,250	0
Bureau of Meteorology	10,000					10,000	10,000
NSW Office of Environment and Heritage	100,000					100,000	100,000
NSW Department of Industry/ RAAP	143,000					143,000	0
University Node Cash Contributions	454,479	112,706	158,947	133,204	243,806	1,103,142	1,122,171
Other (Interest Distribution)						0	0
Total	**2,578,109**	**657,622**	**707,268**	**671,309**	**1,157,084**	**5,771,392**	**5,582,171**
2. ARC Expenditure							
Personnel	62,370	31,354	4,273	8,291	8,375	114,662	2,104,420
Scholarship	0	6,358	0	0	0	6,358	157,783
Equipment and Maintenance	0	0	0	0	0	0	152,000
Consumables and Events	16,369	0	0	0	0	16,369	172,475
Travel - Conference, workshops and meetings (Staff, AI)	4,675	3,898	4,061	0	0	12,634	306,516
Travel - Conference, workshops & meetings (Postdocs & Students)	0	0	0	0	0	0	92,289
Travel - Visitor travel to the Centre and other	0	1,336	0	0	0	1,336	67,297
Travel - New staff relocation expenses	0	0	0	0	0	0	0
Travel - Research Visits (Staff, AI)	0	0	0	0	0	0	64,289
Travel - Research Visits (Postdocs and Students)	0	0	0	0	1,341	1,341	64,289
Total	**83,413**	**42,946**	**8,334**	**8,291**	**9,716**	**152,701**	**3,181,356**
3. Nodes Expenditure							
Personnel	607	0	0	0	0	607	183,457
Scholarship	0	10,706	0	0	0	10,706	345,343
Equipment and Maintenance	55	0	3,378	0	2,749	6,182	37,982
Consumables and Events	2,809	0	117	0	1,108	4,033	12,635
Travel - Conference, workshops and meetings (Staff, AI)	9,642	0	3,259	0	0	12,901	199,957
Travel - Conference, workshops & meetings (Postdocs & Students)	936	1,120	913	0	0	2,969	70,988
Travel - Visitor travel to the Centre and other	0	0	0	0	0	0	22,027
Travel - New staff relocation expenses	0	303	0	4,436	2,616	7,354	36,000
Travel - Research Visits (Staff, AI)	5,132	0	0	0	0	5,132	29,000
Travel - Research Visits (Postdocs and Students)	0	0	0	0	0	0	9,000
Total	**19,181**	**12,129**	**7,667**	**4,436**	**6,472**	**49,885**	**946,390**
4. Partner Organisations							
Personnel	61,192					61,192	100,000
Scholarship	0					0	10,000
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 & meetings (Postdocs & Students)	0					0	0
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**	**0**	**0**	**0**	**0**	**61,192**	**110,000**
5. Summary Income Vs. Expenditure / Carry Over							
ARC							
Total Income	1,870,630	544,916	548,321	538,105	913,278	4,415,250	4,350,000
Total Expenditure	83,413	42,946	8,334	8,291	9,716	152,701	3,181,356
Income less Expenditure	1,787,217	501,970	539,987	529,814	903,562	4,262,549	1,168,644
Nodes							
Total Income	454,479	112,706	158,947	133,204	243,806	1,103,142	1,122,171
Total Expenditure	19,181	12,129	7,667	4,436	6,472	49,885	946,390
Income less Expenditure	435,298	100,577	151,280	128,768	237,334	1,053,257	175,781
Partner Organisations							
Total Income	253,000	0	0	0	0	253,000	110,000
Total Expenditure	61,192	0	0	0	0	61,192	110,000
Income less Expenditure	191,808	0	0	0	0	191,808	0
Carry over surplus / deficit	**2,414,323**	**602,547**	**691,267**	**658,582**	**1,140,896**	**5,507,615**	**1,344,425**

Australian Government

Australian Research Council

UNSW SYDNEY

Australian National University

MONASH University

THE UNIVERSITY OF MELBOURNE

UNIVERSITY of TASMANIA