Climate Systems

National Environmental Science Program

National Environmental Science Program Climate Systems Hub Attachment B: Project Plans

Project CS1.1 – Adapting to tomorrow's climate – Mission research

Project type: NESP research project •	
Project status: New project submitted for approval	
Total project budget: $515,252 (GST exclusive)	**NESP Funding:** $261,267 (GST exclusive) **Co-contributions (cash and in-kind):** $253,985 (GST exclusive)
Project start date: 01/07/2021	**Project end date**: 30/06/2022
Project Leader details:	

Project description

Project summary

The Climate Systems Hub is responsible for driving the cross-NESP Climate Adaptation Mission to improve Australia's adaptative capacity and resilience to climate change. This project establishes the Mission scope through an end-user focused and co-design approach. Using targeted scoping reviews, stakeholder engagement, partnerships and analysis of end-user needs the project will identify and prioritise adaptation research and supporting climate services, synthesis and communication and case studies to meet the aims of the Climate Adaptation Mission. It will build connections between stakeholders, Indigenous partners, scientists, and knowledge brokers to develop a program of work that is targeted, fit-for-purpose and builds on existing knowledge and capacity. It will also work to support Mission-led research in support of the other three Hubs. Outputs include: a Climate Adaptation Mission Strategic Plan, scoping of opportunities to deliver climate information, tools and decision-support, an approach to delivering pathway to impact projects and priority projects to include in RP2022.

Project description

1. What problem the projects seek to address and how it will do this.

Adaptation is about making adjustments to what we do, how we think and even social values in response to actual or expected changes in the climate. It is an ongoing process and there are no right answers. It requires access to best-available information and data starting from foundational knowledge of how climate, ecological and social systems work to regional processes and impacts. Being able to adapt to climate change relies on information to help assess risk and vulnerability, and support for making decisions. It also requires decision-support tools and examples to guide what can be a complex and socially unpalatable decision. Decision-makers in undertaking adaptation look for accessible information to understand climate change and hazards, risk assessment approaches and guidance, guidance on adaptation and resilience planning and action, evaluation of adaptation options, the use of decision support tools, guidance that informs policy and enables action through knowledge-brokering, capability building, case studies and peer learning. It is important that Australia works collaboratively here to reduce duplication and enhance impact pathways for effective delivery. The Climate Adaptation Mission provides an opportunity to bring together climate adaptation research and activities across the other three NESP hubs to build on existing work and to drive and enhance collaboration and integration of climate adaptation activities for Australia.

A successful Climate Adaptation Mission will contribute to improving Australia's adaptive capacity and resilience in response to climate change risks, particularly for environmental management.

Across the NESP program it will seek to deliver against these cross-hub outcomes:

a) adaptation decision-making is supported through delivery of fit-for-purpose data, tools and knowledge
b) management of Australia's marine and coastal environments protects ecosystems, marine life and livelihoods under a changing climate
c) Australia's terrestrial and freshwater habitats are managed to be resilient, sustainable and productive under a changing climate
d) communities are well prepared for, and adapted to, climate change.

Across the life of the Mission we will deliver adaptation focused research and outputs, synthesis and knowledge products to support adaptation, decision-support tools, accessible climate services that complement or feed into existing services and improved end-user uptake and application of evidence-based data, information and management to support climate change adaptation.

2. How the research will be undertaken, including what is in and out of scope

The Mission project will provide the over-arching framework, tools and approaches that will be adopted in all the Hubs projects. This project will be comprised of three main components:

Activity 1 Determine the scope and approach to implement a program of research, knowledge sharing and decision-support for adaptation – through a process of engagement, user needs analysis, co-design and review, this project will identify adaptation research and knowledge gaps. The engagement process will include:

- working with the Climate Systems Hub knowledge broker team, Indigenous Facilitator and Department to co-design and implement targeted stakeholder engagement
- targeted meetings and workshops with priority Divisions of the Department and in each state and territory
- an end-user needs analysis
- building collaborative links with the other Hubs and Missions.

In addition, an analysis of existing research, adaptation approaches and adaptation progress will be completed to help identify research gaps.

Identified research gaps, user needs analysis and research priorities will be used to co-develop a program logic for the Mission and in partnership with all Hubs, and to identify prioritise research needs. A monitoring and evaluation framework will be developed from the outcomes, outputs and activities in the program logic.

Activity 2 Bridging the gap between science outputs and decision-making – information gathered through stakeholder engagement and the needs analysis will be used to identify activities that can bridge the gap between climate science and adaptation. This might include:

- developing a program of synthesis and communication drawn from existing research and information to address identified knowledge gaps
- opportunities to develop decision-support and management tools
- the need to build capacity in researchers, including early career researchers, to consider stakeholder needs and adaptation outcomes in designing research projects.

We will look to develop a project approach for delivering climate information from upstream capability (e.g. research, projections) to user decisions and actions. In RP2021 the approach will be developed through scoping an initial case study focused on a common challenge (e.g. catchment flood planning). It is through these mechanisms that we will implement a process to continually identify application of the research, co-design and co-produce outcomes and link to the Hub knowledge brokering and Adaptation Mission to build effective decision support tools.

Activity 3 Engaging with Mission-led research – content experts will work to facilitate the Climate Systems Hub engagement and collaboration on research priorities of the other three Missions. In particular, they will develop evidence to support decision-making and the development of adaptation measures in each of the research areas of the Missions.

Activities that are in scope for RP2021 include: desktop reviews, stakeholder mapping, stakeholder co-design and engagement workshops (including regional workshops with state and territory partners), consultation, user needs analysis, program logic development, cross-hub collaboration and planning, research prioritisation, capacity building workshops/webcasts, synthesis and communication development, development of project approach. Development of new information through research or modelling is out of scope in RP2021.

Outputs include:

- submission of a Climate Adaptation Mission Strategic Plan

- scoping of opportunities to deliver climate information, tools and decision-support
- an approach to delivering pathway to impact projects
- identification of priority projects for inclusion in RP2022.

3. Related prior research

This project will draw extensively on past research and outputs, particularly from the Earth Systems and Climate Change Hub, to identify knowledge gaps and inform research planning. Where possible it also identify opportunities for the Hub communication team and Data Wrangler to respond to knowledge needs through synthesis and communication of existing research to meet user needs.

4. Research linkages

The key role of the Climate Adaptation Mission is to develop a cross-hub, strategic research plan to drive adaptation research and activities across the NESP program. This will include building linkages across capabilities both within NESP and outside (e.g. Australian Climate Services, Climate Services for Agriculture, Natural Disaster Management Research Centre).

5. Informing decision-making and on-ground action

While this project is focused on scoping the Climate Adaptation Mission, the long-term ambition is to improve Australia's adaptive capacity and resilience in response to climate change. That relies on delivering climate information and decision support to all levels of government, industry, communities and to land and sea managers (e.g. NGOs, Traditional Owners, farmers) to improve adaptive capacity for environmental outcomes.

Pathway to impact

This section describes how the project will inform decision making and on-ground action, and the outputs that will be delivered to research-users throughout the life of the project. This section should be populated in consultation with research end-users.

Outcomes			
• Hub-wide strategic plan (e.g. program logic, RP2022) to guide and test future research priorities • Co-designed research projects and initial collaborative partnerships • Baseline understanding of adaptation approaches, Indigenous approaches to risk and good practice in climate services.			
Research-user	**Engagement and communication**	**Impact on management action**	**Outputs**
Climate Adaptation Mission Strategic Plan			
DAWE: Environmental Science Reporting Branch; Climate Science and Services, Climate Adaptation and Resilience Division; Parks Science and Strategy Section; Biodiversity and Conservation; GBRMPA; Commonwealth Environmental Water Office (including Wetlands Branch); MDBA; Science and Management Effectiveness Section; Australian Antarctic Division NESP Hubs and Missions DISER (Agriculture Section, Emissions Reductions Research Branch, Climate Change) State/Territory governments; Local governments; Indigenous organisations; NRM Regions Australia	Targeted workshops and meetings to development and design of the program logic, program priorities, projects and outputs. Findings and outputs to be communicated via project workshops, update emails and presentations.	Details of impact will be derived through engagement and analysis of user needs. These will be clearly identified for each research project or activity. We will seek to inform and support planning for Australian Climate Services, the revised National Climate Resilience Strategy and advice to the National Climate Resilience Authority.	Co-designed, cross-hub Climate Adaptation Mission projects and development of adaptation support and management tools.
Scoping of synthesis, communication and climate service options			
DAWE: Environmental Science Reporting Branch; Climate Science and Services, Climate Adaptation and Resilience Division; Parks Science and Strategy Section; Biodiversity and Conservation; GBRMPA; Commonwealth Environmental Water Office (including Wetlands Branch); MDBA; Science and Management Effectiveness Section; Australian Antarctic Division NESP Hubs and Missions	Targeted workshops and meetings to identify opportunities to synthesis, present, collate climate science information to support decision making.	Details of impact will be derived through engagement and analysis of user needs. Any prioritised products will be co-designed with targeted users.	A scoping report highlighting opportunities to deliver climate information, tools and decision support and prioritised products. Co-designed projects to synthesis and communicate climate information.

DISER (Agriculture Section, Emissions Reductions Research Branch, Climate Change) State/Territory governments; Local governments; Indigenous organisations; NRM Regions Australia Australian Climate Services; CLEX			

Indigenous consultation and engagement

The Climate Systems Hub Research Plan outlines the history of Indigenous Engagement from our predecessor NESP Phase 1 Earth Systems and Climate Change Hub that we wish to build upon. The principles of Indigenous Engagement for individual projects such as this are outlined within the Hub's Indigenous Partnerships Strategy. We will identify and consider Indigenous research aspirations across the life of the Hub, with particular focus on the Hub's inception co-design activity (Jul-Dec 2021), and subsequent co-design implementation (Jan-Jun 2022).

This project is consistent with the Climate Systems Hub 5 Pillars of Indigenous Engagement, National First Peoples Gathering on Climate Change co-design principles, and the 3 Category Approach. Prior to co-design it is inappropriate to list actual Indigenous Cultural and Intellectual Property (ICIP) consents. As with all Climate Systems Hub projects we understand the need to identify such consents. Through actions of inclusivity we will consider opportunities for co-authorship, capacity building/training, Indigenous employment, and how ICIP and traditional knowledge will be managed.

To achieve this we will engage with the Hub's Indigenous Facilitator, alongside the broader directions of the Hub and Mission Leaders. Our project aims to align with the Hub's Indigenous Partnerships Strategy within the broader framework of the associated Knowledge Brokering, Communications, and Data Management Strategies.

Supporting the development of an Indigenous-led co-designed agenda on Climate Change Knowledge and Action

Indigenous communities across Australia are experiencing the effects of our changing climate, with changes in seasonal weather patterns, increasing temperatures, rising sea levels and changing water availability already impacting on country and people. The 2018 *National Indigenous Dialogue on Climate Change* and 2021 *First Nations Peoples gathering on Climate Change* demonstrated an overwhelming interest by Australia's First Peoples in better understanding our changing climate and what the future holds. It also highlighted the importance of an ongoing dialogue and made clear that First Peoples want to set their own agenda on climate knowledge and action. To this end, the Hub will support the organisation and delivery of the continuation of this national Gathering that allows First Nations the opportunity to do that.

Project milestones

Milestones	Due date	Responsible person
Milestone 1 – Scoping meetings with relevant sections of DAWE and states and territory representatives completed	30 Sept 2021	
Milestone 2 – Submit Climate Adaptation Mission Strategic Plan to DAWE	31 Dec 2021	
Milestone 3 – Report on options for synthesis, communication and climate service activities	31 Dec 2021	
Milestone 4 – Co-designed adaptation research plans submitted as part of RP2022 of lead Hub	31 Mar 2022	
Milestone 5 – Prioritised synthesis and communication activities submitted as projects in RP 2022 or as activities in the Knowledge Brokering or Communication Strategies	31 Mar 2022	

Data and information management

The Climate Systems Hub's Data Management Strategy details the fundamental approach to data management the hub will follow. The principles of the strategy are summarised in the following table.

Project output	Data Management and Accessibility
Data/Information product	• Research data and outputs will be well-documented according to accepted and trusted standards. A key requirement for all research products will be to follow metadata standards based on accepted best practice. • Data will be made publicly available whenever legally, ethically and contractually possible, under an open licence policy except in particular cases. A record of these exceptions will be kept, and exceptions reported periodically to the department. • Data and other research output will be stored in repositories that are accessible to end-users and other researchers, with the choice of repository based on practicalities of the data and its likely use, and stored in such a way as to endure and remain FAIR beyond the life of the project. • The project will develop its own data management plan based around the FAIR data principles, with identified data custodians responsible for managing each dataset. • Research outputs and data will be accompanied by documentation providing guidance to users on how best to make use of the data. • The nature of research outputs, their formats and repositories, will be developed through a co-design process involving stakeholders and end-users to ensure data meet their requirements and ensure data are fit-for-purpose, and will evolve through ongoing consultation. • The hub will maintain a metadata catalogue of all research data, and all metadata will be published on other public metadata catalogues. • Outputs such as websites will follow the Web Content Accessibility Guidelines (WCAG), and include an accessibility statement.
Application ready data sets	• To be published in public repositories. • Data services made available to enable ingestion into end-user models and decision-support tools.
End-user products	• Published in appropriate medium such as print or a scientific journal. • Captured in metadata catalogues. • A copy will be stored on the hub website for public access.
Raw research data	• Stored on infrastructure where generated and where they can be shared with other researchers.

Project keywords

Climate adaptation, climate services, knowledge brokering, data management for services, co-designed research

Project contacts

Researchers and other personnel

Name	Organisation	Project role	FTE

Research end-users

To be further developed as we build a stakeholder engagement plan.

Research users (program/section/branch/organisation)	Name(s)	Email (optional)

Project CS1.2 – Indigenous-led climate change knowledge and response

Project type: NESP research project	
Project status: New project submitted for approval	
Total project budget: $291,878(GST exclusive)	**NESP Funding:** $154,696 (GST exclusive) **Co-contributions (cash and in-kind):** $137,182 (GST exclusive)
Project start date:	**Project end date**: 30/06/2022
Project Leader details:	

Project description

Project summary

Climate change threatens Country and communities. This project aims to build the capacity of First Nations' organisations to care for the land and sea in a changing climate. This project scopes opportunities to build on, and further develop, the relationship of Indigenous Communities with climate researchers established through NESP Phase 1 through two activities. First is a stakeholder engagement and scoping process to identify specific knowledge gaps or needs around climate change impacts and extreme weather events on Country and their consequences – both cultural and environmental. The second pilots a collaborative research approach examining Indigenous perspectives of risk. It is expected to illuminate a broader conceptual understanding and explanation of how Indigenous perceptions of risk influence Indigenous response and adaptation priorities to climate change. This will inform the broader engagement and scoping of knowledge delivery and support for adaptation. Outcomes of the project include an interim planning workshop report, co-development of a project approach for activity 2 and project plan/s for RP2022.

Project description

1. What problem the projects seek to address and how it will do this.

First Nations Peoples in Australia have been responding to climate variability and environmental change for millennia, and have a lot to teach us about caring for Country. With climate change threatening Country and communities, First Nations' organisations need the best-available climate change science to supplement traditional knowledge and help them care for the land in a changing climate. Collaboration between First Nations Peoples and the Earth Systems and Climate Change (ESCC Hub) resulted in innovative ways of developing and using climate change science to make it relevant and accessible to all peoples. A co-design process underpinned much of the work, and helped build strong relationships with stakeholders that will benefit future climate adaptation projects. In NESP Phase 2 we look to build on these relationships, expand our sharing of climate knowledge and explore opportunities to support Indigenous-led adaptation projects.

Indigenous Peoples bring a particular perspective of climate risk related to their individual socio-economic, historical, political, cultural and environmental circumstances. Their strong perception is that human health is connected to environmental health. As a result, their perceptions are often specific to communities and their cultures, places and regions with distinctive community values, resource and policy circumstances. Indigenous Peoples have also expressed their desire to understand climate change, how it may affect the environment, access and rights to lands and waters, customary practices and culturally important species, infrastructure, health and access to services, and how they might respond. Responding to climate change is about managing risk. Understanding risk perceptions can set the foundation for new pathways of research collaboration, better tailored climate science and information to enable risk reduction responses and to build adaptive capacity and agency to plan for climate change.

Our goal is to improve the participation, inclusion and leadership of Indigenous Peoples in understanding and applying climate information to manage and protect their traditional lands and seas, now and in the future.

2. How the research will be undertaken, including what is in and out of scope

Activity 1: Supporting the development of an Indigenous-led co-designed agenda for climate change knowledge and action

In this activity we will look to build on and further develop the relationship of Indigenous communities with climate researchers established through planning for and delivering the 2021 National First

Peoples Gathering on Climate Change. The approach, process and protocols used in co-designing and co-delivering the Gathering will underpin scoping next steps, broadening stakeholder engagement and expanding focus to understanding climate risk and adaptation approaches. The work of NESP Phase 1 identified priorities for future research including bio-cultural renewal, monitoring of seasonal indicators, impacts on water cycles/flows, water rights and access, impacts of resource extraction, governance and institutional responses and cumulative impacts. In RP2021 we will look to prioritise opportunities for future activities. In particular, this next phase of collaboration and engagement will work to identify specific gaps or needs in the impact of a changing climate and extreme weather events on Country and their consequences – both cultural and environmental. Discussions will also include sustainable, preventative and adaptive practices. Steps include seeking interest among established collaborators, establishing a planning group and/or steering committee and running an interim planning workshop.

In this second NESP hub, we look to extend the collaborative approach of the Gathering to foster Indigenous-led, end-to-end approaches to including climate consideration in planning for Country. We will look for case studies to demonstrate the approach and build capacity. In a continuation of the collaboration with the Butchulla Aboriginal Corporation and the Queensland Government, we will co-design a case study that delivers climate science information and data and includes traditional knowledge insights into World Heritage property risk assessment and adaptation plans and activities. We have also begun engaging with the Traditional Owner groups in the Northern Peninsula Area (NPA) of Queensland to socialise the idea of undertaking a second case study with this group.

A journal paper plan that reports on the outcome of the 2021 Gathering is planned. This will involve inviting contributing authors and lead authors to collaborate and provide text, co-developing the structure and analysis.

Output: Interim workshop report, journal paper plan and team, scoping of case study partnerships, contribute project plan to RP2022.

Activity 2: Indigenous perspectives of risk

This activity pilots an approach to collaborative research that will support Indigenous-led climate knowledge and action. It seeks to improve the inclusion and participation of Indigenous Peoples in understanding and using climate information to manage and protect their traditional lands and seas, under an increasingly uncertain and changing climate. It focuses on identifying the opportunities and roles of traditional knowledge and western science in a two-way knowledge sharing and learning. A central tenet of the approach is the protection of traditional knowledge in climate-related partnerships.

We trial multiple case studies, or place-based partnership approach to focus on Indigenous perspectives of risk. The approach was initiated in the ESCC Hub's Indigenous perspectives of risk project in Shark Bay with Malgana Aboriginal Corporation. This activity builds on the initial work and extends it through growing existing partnerships and investing in additional partnerships for on-ground application of Indigenous-led climate knowledge and action.

Our approach brings to the fore the question of how and under what conditions improved understanding of risk enables preparation for risk reduction actions tailored to particular natural, social and institutional settings. This will be achieved through an Indigenous-led, co-designed research process, two-way sharing of western and Indigenous perceptions of climate risk and learning across the project case study partners. The two-way learning approach can inform each partner's understanding of the impacts of climate change. The adoption of an Indigenous-led process will ensure that the project focus is relevant to the local groups; the research process is governed by local decision-making structures; and that the project addresses key risk issues for land and sea management. The place-based approach drives the discussion of climate risk from the local

institutional, environmental, cultural and social contexts to the wider influences that affect capacities and resources to respond to a changing climate.

The use of a comparative case study analysis can help answer questions about how to account for differences in perspectives of risk, and articulate and tailor information to particular contexts. It is expected to illuminate a broader conceptual understanding and explanation of how Indigenous perceptions of risk influence Indigenous response and adaptation priorities to climate change. The broader cross learnings can then support the application of the research findings to other Indigenous groups across the Country to improve the participation and inclusion of Indigenous peoples in understanding and using climate information for the management and protection of their traditional lands and seas.

In RP2021 we take forward the recommendation from the Shark Bay workshop to begin the co-design process of scoping and implementing the case study. We will also develop a framework for further case study selection in partnership with our case study communities. We will consider a mix of cross-Hub projects as well as projects underway by Hub researchers and their collaborators. Briefings and engagement with Indigenous communities and stakeholders involved in Activity 1 will inform that scoping and engagement process.

Outputs: Co-development of a case study approach with a minimum of two Indigenous Traditional Owner groups, co-developed framework for identification of additional case study communities, submission of project plan for RP2022

3. Related prior research

We will continue to build on the strong relationships between Hub researchers and Indigenous Communities that were developed in the ESCC Hub. Our successful partnerships with Malgana Peoples of Shark Bay and Butchulla people of K'gari (Fraser Island) in the ESCC Hub place our team in good stead to continue our project collaborations with these Indigenous research partners and the state collaborators.

4. Research linkages

We will look to build linkages with other Hubs and Missions to build on existing relationships where possible, and to support our case study communities to address value sets associated with their perspectives of local risk (e.g. species response to climate changes).

5. Informing decision-making and on-ground action

Ultimately, this project is working to build capacity in Indigenous communities to understand their climate risk and plan how to respond in a way that is locally appropriate and relevant. It will also provide capacity development within the research community, Hubs, Missions and government stakeholders in using Indigenous perspectives of risk and land management practices in adaptation planning.

Pathway to impact

This section describes how the project will inform decision making and on-ground action, and the outputs that will be delivered to research-users throughout the life of the project. This section should be populated in consultation with research end-users.

Outcomes			
Our goal is to improve the participation, inclusion and leadership of Indigenous peoples in understanding and applying climate information to manage and protect their traditional lands and seas, now and in the future.			
Research-user	**Engagement and communication**	**Impact on management action**	**Outputs**
DAWE: Climate Science and Services, Climate Adaptation and Resilience Division (DAWE), Parks Science and Strategy Section, Biodiversity and Conservation, Commonwealth Environmental Water Holder (incl. MDBA, Wetlands Section), GBRMPA	Findings and outputs to be communicated via project updates (e.g. Hub Newsletter), emails and presentations.	Inform approaches to adaptation policy and action for Australia's First Nations people and communities.	Project progress report
State and territory governments	Findings and outputs to be communicated via project updates (e.g. Hub Newsletter), emails and presentations.	Inform approaches to adaptation policy and action for Australia's First Nations people and communities.	Project progress report
Local government	Findings and outputs to be communicated via project updates (e.g. Hub Newsletter), emails and presentations.	Inform approaches to adaptation policy and action for Australia's First Nations people and communities.	Project progress report
Traditional Owner groups	Identification of steering committee and project partners. Engagement through workshops and Traditional Owner meetings of case study groups. Findings and outputs to be communicated via targeted emails and a webinar.	Begin identifying knowledge needs and sharing information	Report summary/ webinar. Interim planning workshop. Plan for case study development.
NGOs	Findings and outputs to be communicated via project updates (e.g. Hub Newsletter), emails and presentations.	Inform approaches to partnering with Australia's First Nations people and communities to co-manage land for adaptation.	Report summary/ webinar

Indigenous consultation and engagement

The Climate Systems Hub Research Plan outlines the history of Indigenous Engagement from our predecessor NESP Earth Systems and Climate Change Hub that we wish to build upon. The principles of Indigenous Engagement for individual projects are outlined within the Hub's Indigenous Partnerships Strategy and will underly this project.

This project is consistent with the Climate Science Hub 5 Pillars of Indigenous Engagement, National First Peoples Gathering on Climate Change co-design principles, and the 3 Category Approach. Prior to co-design it is inappropriate to list actual Indigenous Cultural and Intellectual Property (ICIP) consents. As with all Climate Systems Hub projects we understand the need to identify such consents. Through actions of inclusivity, we will consider opportunities for co-authorship, capacity building/training, Indigenous employment, and how ICIP and Traditional knowledge will be managed.

To achieve this, we will engage with the Hub's Indigenous Facilitator, alongside the broader directions of the Hub and Mission Leaders. Our project aims to align with the Hub's Indigenous Partnerships Strategy within the broader framework of the associated Knowledge Brokering, Communications, and Data Management Strategies.

Supporting the Development of an Indigenous-Led Co-designed agenda on Climate Change Knowledge and Action

Indigenous communities across Australia are experiencing the effects of our changing climate, with changes in seasonal weather patterns, increasing temperatures, rising sea levels and changing water availability already impacting on country and people. The 2018 *National Indigenous Dialogue on Climate Change* and 2021 *First Nations Peoples gathering on Climate Change* demonstrated an overwhelming interest by Australia's First Peoples in better understanding our changing climate and what the future holds. It also highlighted the importance of an ongoing dialogue and made clear that First Peoples want to set their own agenda on climate knowledge and action. To this end, the Hub will support the organisation and delivery of the continuation of this national Gathering that allows First Nations the opportunity to do that.

Project milestones

Milestones	Due date	Responsible person
Milestone 1 – Co-development of a case study approach with a minimum of two Traditional Owner groups (Activity 2)	Due 1 Jan 2022	
Milestone 2 - Journal paper plan and team	30 March 2022	
Milestone 3 - Co-developed framework for identification of additional case study communities (Activity 2)	30 March 2022	
Milestone 4 - Submission of project plan/s for RP2022	30 March 2022	
Milestone 5– Interim workshop report (Activity 1)	30 March 2022	

Data and information management

The Climate Systems Hub's Data Management Strategy details the fundamental approach to data management the hub will follow. We will appoint a data management contact. The principles of the strategy are summarised in the following table:

Project output	Data Management and Accessibility
Data/Information product	• Research data and outputs will be well-documented according to accepted and trusted standards. A key requirement for all research products will be to follow metadata standards based on accepted best practice. • Data will be made publicly available whenever legally, ethically and contractually possible, under an open licence policy except in particular cases. A record of these exceptions will be kept, and exceptions reported periodically to the department. • Data and other research output will be stored in repositories that are accessible to end-users and other researchers, with the choice of repository based on practicalities of the data and its likely use, and stored in such a way as to endure and remain FAIR beyond the life of the project. • The project will develop its own data management plan based around the FAIR data principles, with identified data custodians responsible for managing each dataset. • Research outputs and data will be accompanied by documentation providing guidance to users on how best to make use of the data. • The nature of research outputs, their formats and repositories, will be developed through a co-design process involving stakeholders and end-users to ensure data meet their requirements and ensure data are fit-for-purpose, and will evolve through ongoing consultation. • The hub will maintain a metadata catalogue of all research data, and all metadata will be published on other public metadata catalogues. • Outputs such as websites will follow the Web Content Accessibility Guidelines (WCAG), and include an accessibility statement.
Application ready data sets	• To be published in public repositories. • Data services made available to enable ingestion into end-user models and decision-support tools.
End-user products	• Published in appropriate medium such as print or a scientific journal. • Captured in metadata catalogues. • A copy will be stored on the hub website for public access.

Project keywords

Traditional Owners, risk perspectives, traditional knowledge, adaptation, managing Country and Sea

Project contacts

Researchers and other personnel

Name	Organisation	Project role	FTE

Co-contributors

Name	Organisation	Contribution

Research end-users

Research users (program/section/branch/organisation)	Name(s)	Email (optional)

Project CS1.3 – Regional knowledge for local action

Project type: NESP research project	
Project status: New project submitted for approval	
Total project budget: $1,788,220 (GST exclusive)	**NESP Funding:** $866,883 (GST exclusive) **Co-contributions (cash and in-kind):** $921,337 (GST exclusive)
Project start date: 01/09/2021	**Project end date**: 30/06/2022
Project Leader details:	
Project Leader details:	

Project description

Project summary

Modelling projections provide plausible scenarios of Australia's future climate. It is essential that projections are supported by the best available science, are up-to-date, credible and in a useable format to support decision-making. This project builds on research performed in NESP Phase 1 Earth Systems and Climate Change Hub (ESCC), on projections and hazards. We will work closely with stakeholders to scope and prioritise projections work. During this co-design process the project team will identify key specific end-users and work with them to determine their climate projection information needs, how climate projections information can be improved to best help them answer policy and management questions. It will also identify priority areas for improving modelling performance.

Project description

1. What problem the project seeks to address and how it will do this.

Modelling projections provide for future planning, including about the average climate and extreme hazards in our warming world. Projections provide essential information about climate hazards and allows scientists and decision-makers to contemplate impacts and adaptation responses. Projections and scenarios are an essential tool but there are numerous variations of how they can be constructed (e.g. choice of model, time scale, spatial scale etc) and produced (e.g. time-series, probabilities, thresholds, maps, visualisations etc). Some model variables are better simulated than others and we can have greater confidence or precision in some projections (e.g. temperature) than others (e.g. rainfall). Users increasingly look for projection information that is coordinated and up-to-date with recent improved understanding of climate processes and drivers (e.g. findings of NESP Phase 1 ESCC projects, CMIP6 projections). There is also an increasing appetite for climate information that is designed to suit user needs – a bottom-up approach designed with specific challenges or sectors in mind. This includes a desire for guidance on choice of data sets, understanding of model assumptions and appropriate modelling scale to apply in decision-making.

In this project we will work closely with stakeholders to scope and prioritise projections work. During this co-design process the project team will identify key specific end-users and work with them to determine their climate projection information needs, how climate projections information can be improved to best help them answer policy and management questions. It will also identify priority areas for improving modelling performance.

2. How the research will be undertaken, including what is in and out of scope

The project will link with other research efforts across the wider research community and activities through engagement activities and knowledge brokering. This will include undertaking research with strong links to other Hubs & Missions (such as Resilient Landscapes Hub for fire hazards, coastal impacts for storm hazards, Sustainable Communities and Waste Hub for heat island effect, etc.). During the scoping phase of our co-design process, we will work these users to determine tailored research to meet user needs, with a focus on activities that facilitate strong links with end user and next user groups, to enable the effective uptake of the project research outputs to inform decision-making and on-ground action.

Large-scale production of new downscaled projections is **out of scope** as the Australian Climate Services will now perform this role.

Activity 1: Co-design and prioritisation of projects for RP2022

In this activity we will scope and prioritise gaps and opportunities to meet knowledge needs, and identify partnerships to co-design individual priority projects for RP2022. Stakeholders will be identified in partnership with the knowledge brokering team. The activity will be informed by:

- the state of play, current progress and impact of research, and outcomes in climate projections science
- an analysis of research gaps
- understanding and informing Hub outcomes reflected in the Hub's program logic
- nominating a project co-design lead to work closely with the Hub's knowledge brokering team
- participating in Hub-wide workshops and engagement to identify and prioritise user needs and opportunities.

We will also look to build cross-hub collaborative opportunities. For example, we have identified an opportunity to work with the Sustainable Communities and Waste Hub to trial very high resolution (~1km) simulations of heatwave events in an urban area (e.g. Sydney) to identify primary mechanisms (e.g. building type, density) that cause and modify heatwave intensity at the city scale. Identified opportunities will be co-designed for consideration in RP2022.

Output: Short synthesis report on where the science of projections has come from and future opportunities, submission of co-designed project plans to RP2022.

Activity 2: Outreach – toward targeted projection approaches and products

Working with the Mission lead, knowledge brokers, Indigenous Facilitator and stakeholders we will scope and review what questions might be addressed by improved projection products - both technical improvements and in outreach products. Options to improve current projection include:

- accounting for model independence and uneven sampling of climate sensitivity
- projections expressed as a probability (e.g. the probability of temperatures exceeding x degrees at a fixed pint in time) using multiple sources of evidence
- combining downscaled projections with Global Climate Model (GCM) projections to improve confidence in projections of extremes and hazards
- investigating improvement of statistical methods that address model bias to create seamless projections that are consistent with observations and reanalyses
- development of output products that are internally consistent for multiple hazards (e.g. tell story of both flood risk and fire risk rather than handling separately)
- improved understanding of climate change and hazards, including for key phenomena such as bushfires, tropical cyclones, thunderstorms and associated weather extremes (connecting to CS projects 1.4 & 1.5).

In developing enhanced projections methods, we will focus on rainfall extremes and associated hydrological hazards (e.g. flood risk factors) building on Electricity Sector Climate Initiative (ESCI) and ESCC extreme weather projections for storm types. We will develop a synthesis of current knowledge and methods as well as the future directions that could be taken to underpin conservation management, water management and catchment planning.

We will work closely with states and territories undertaking downscaling experiments, the Australian Climate Services and the Department to explore options for improved output products and projection approaches as part of the national effort in coordinating the downscaling activities across the Australia. We will also seek to identify opportunities for Hub projects and partnerships to co-design and co-produce projections that deliver to needs.

In addition to technical approaches, we will look at co-developing and testing approaches to communicating projection outputs. In RP2021 we will pilot and test the use of a 'storylines' approach with key users (e.g. Indigenous communities) as an appropriate way to communicate scenarios of future change. This approach communicates projected changes together with the drivers of change to present a cohesive story of the future.

Output: Short report or briefing note that scopes future development of projection products and the role of the Hub in that, synthesis report providing state-of-play in projections associated with rainfall extremes, case study of trialling a storyline approach.

Activity 3: Causes and characteristics of future change including hazards

This activity uses opportunities to analyse projection approaches and analysis of hazards that builds on the work of NESP Phase 1 and new CMIP6 projections data. These analyses provide foundations for future projection outputs and products as described in activities 1 and 2.

Outputs: In RP2021 we are focused on producing follow-up analysis of hazards (outputs1- 3) and assessing projection and model methods arising from NESP Phase 1 ESCC research (outputs 4-6).

1) Inclusion of updated tropical cyclone projections (based on CMIP6 GCMs) in the ESCC cyclone portal for access by decision-makers in cyclone prone regions. A supporting analysis by an analysis of tropical cyclone projections detailing extreme wind gust return periods and regional changes in guidance material and draft peer-reviewed paper.
2) Draft report on extreme fire weather conditions, built on previous ESCC methods for modelling extreme fire conditions in Australia and considering knowledge from other regions of the world.
3) Analyse the influence of upper-tropospheric troughs on climate hazards and projected future changes to inform weather forecasting communities (e.g. AFAC, BoM). Draft peer reviewed paper ready for submission.
4) Expanding on the approach developed in NESP Phase 1 ESCC (Realised Added Value) to determine where downscaled projections added value to GCM results with respect to rare extremes. Analysis to be submitted as a journal article (draft completed for review), to inform all sector groups for future planning.
5) Modelling assessment methods applied to the new CMIP6 projections data to compare to past modelling efforts. This would include intercomparison of CORDEX-CMIP6 simulations to determine opportunities for future modelling improvements. Results would be released in a report (draft completed for review) tailored to next users who wish to utilise CORDEX data.
6) Analysis of methods to quantify model independence and implications for model choice when building climate projection ensembles. Briefing note or workshop to inform next-users producing down-scaled projections.

3. Justification of foundational science

A proportion of the work in this project is targeted at improving the precision of projections, validating and applying new progress in model techniques and outputs (e.g. new generation CMIP6 models) to ensure access to best available information and developing approaches that can be applied to problems in ways that best address challenges. It includes the time-consuming, but essential process of quality control to ensure projections are credible and reliable as well as accessible. It is also necessary to keep projections up to date with advances in understanding in complex climate processes and phenomena such as fire-weather and super-cell thunderstorms.

4. Related prior research

We build on prior NESP Phase 1 ESCC Hub Projects 5.3 (projections) and 5.5 (weather hazards), and the development of Climate Change in Australia (CCiA).

5. Research and NESP linkages

The project will link with other research efforts across the wider research community and activities through engagement activities and knowledge brokering. This will include undertaking research with strong links to other Hubs and Missions (e.g. Resilient Landscapes for fire hazards, coastal impacts for storm hazards).

6. Informing decision-making and on-ground action

Projection information is widely used by all sectors. We would look to target our outputs to environmental problems and will work with potential users in the Australian Climate Service, Great Barrier Reef Marine Park Authority (GBRMPA), National Parks, World Heritage, state and territory governments as well as end user sector groups such as land managers, health providers, local governments.

Pathway to impact

This section describes how the project will inform decision making and on-ground action, and the outputs that will be delivered to research-users throughout the life of the project. This section should be populated in consultation with research end-users.

Outcomes			
Underpinning science, development and improvement of climate projection information and approaches that is coordinated and up-to-date to address needs of users in managing the environment.			
Research-user	**Engagement and communication**	**Impact on management action**	**Outputs**
Climate Science and Services, Climate Adaptation and Resilience Division (DAWE)	Collaborate to identify potential users, identify knowledge needs, priority development of projections approaches and products Findings and outputs to be communicated via project workshops, project update emails and presentations	Inform coordination of national projection and downscaling effort	Short synthesis report on where the science of projections has come from and future opportunities Submission of co-designed project plans to RP2022
Other CS projects and other Hubs (links through threatened species; coastal)	These project and Hubs will be contacted during the early stages of this project to scope and coordinate activities, identify partnership opportunities and where appropriate co-design project proposals	Identify opportunities and limitations to use projection information	Co-designed project plans submitted to RP2021 Report on extreme fire weather conditions Synthesis report providing state-of-play in projections associated with rainfall extremes Case study of trialling a storyline approach
Australian Climate Service (ACS)	Consultation and meetings to identify needs. Engaged in the development and design of project outputs. Briefings of research progress and findings	Identify future research directions and approaches to downscaling and projection work	Short synthesis report on where the science of projections has come from and future opportunities Peer reviewed papers providing analysis of projection approaches and underpinning science
State and territory government groups	Will be communicated with through this project to determine how to best coordinate activities	Input to future research directions to meet knowledge needs	Co-designed project plans submitted to RP2022 Short synthesis report on where the science of projections has come from and future opportunities
Environment sector (GBRMPA, AIMS, National Parks/World Heritage)	Will be communicated with through this project to determine how to best coordinate activities	Input to future research directions to meet knowledge needs	Report on extreme fire weather conditions Synthesis report providing state-of-play in projections associated with rainfall extremes Case study of trialling a storyline approach

Indigenous consultation and engagement

The Climate Systems Hub Research Plan outlines the history of Indigenous Engagement from our predecessor NESP Earth Systems and Climate Change Hub that we wish to build upon. The principles of Indigenous Engagement for individual projects such as this are outlined within the Hub's Indigenous Partnerships Strategy. We will identify and consider Indigenous research aspirations across the life of the Hub, with particular focus on the Hub's inception co-design activities (Jul-Dec 2021), and subsequent co-design implementation (Jan-Jun 2022).

This project is consistent with the Climate Science Hub 5 Pillars of Indigenous Engagement, National First Peoples Gathering on Climate Change co-design principles, and the 3 Category Approach. Prior to co-design it is inappropriate to list actual Indigenous Cultural and Intellectual Property (ICIP) consents. As with all Climate Systems Hub projects we understand the need to identify such consents. Through actions of inclusivity, we will consider opportunities for co-authorship, capacity building/training, Indigenous employment, and how ICIP and traditional knowledge will be managed.

To achieve this, we will engage with the Hub's Indigenous Facilitator, alongside the broader directions of the Hub and Mission Leaders. Our project aims to align with the Hub's Indigenous Partnerships Strategy within the broader framework of the associated Knowledge Brokering, Communications, and Data Management Strategies.

In this project we will investigate the opportunity to co-develop projection storylines with Indigenous partners. We will also support the Indigenous-led climate change knowledge and response project (CS1.2) through participating in knowledge sharing and learning as required.

Project milestones

Milestones	Due date	Responsible person
Milestone 1 Short synthesis document released on where the science of projections has come from and future opportunities	Due 30/10/2021	
Milestone 2 Short report or briefing note that scopes future development of projection products and the role of the Hub; Progress report (written or verbal) to DAWE on peer reviewed papers and associated analysis	Due 31/12/21	
Milestone 3 Contribute projections research project co-design outcomes to submission of draft RP2022 and Hub Annual Progress Report under direction of Hub and Mission Leaders	Due 31/03/22	
Milestone 4 Briefing note or workshop to inform next-users producing down-scaled projections	Due 30/06/22	
Milestone 5 Synthesis report providing state-of-play in projections associated with rainfall extremes	Due 30/06/22	
Milestone 6 Report on extreme fire weather conditions	Due 30/06/22	
Milestone 7 Case study reporting on trial of a storyline approach to projections	Due 30/06/22	
Milestone 8 Four peer reviewed papers drafted ready for review	Due 30/06/22	

Data and information management

The Climate Systems Hub's Data Management Strategy details the fundamental approach to data management the hub will follow. Samuel Bell will be the project data management contact. The principles of the strategy are summarised in the following table.

Project output	Data Management and Accessibility
All data/Information products	• Research data and outputs will be well-documented according to accepted and trusted standards. A key requirement for all research products will be to follow metadata standards based on accepted best practice. • Data will be made publicly available whenever legally, ethically and contractually possible, under an open licence policy except in particular cases. A record of these exceptions will be kept, and exceptions reported periodically to the department. • Data and other research output will be stored in repositories that are accessible to end-users and other researchers, with the choice of repository based on practicalities of the data and its likely use, and stored in such a way as to endure and remain FAIR beyond the life of the project. • The project will develop its own data management plan based around the FAIR data principles, with identified data custodians responsible for managing each dataset. • Research outputs and data will be accompanied by documentation providing guidance to users on how best to make use of the data. • The nature of research outputs, their formats and repositories, will be developed through a co-design process involving stakeholders and end-users to ensure data meet their requirements and ensure data are fit-for-purpose, and will evolve through ongoing consultation. • The hub will maintain a metadata catalogue of all research data, and all metadata will be published on other public metadata catalogues. • Outputs such as websites will follow the Web Content Accessibility Guidelines (WCAG), and include an accessibility statement.
Application ready data sets	• To be published in public repositories. • Data services made available to enable ingestion into end-user models and decision-support tools.
End-user products	• Published in appropriate medium such as print or a scientific journal. • Captured in metadata catalogues. • A copy will be stored on the hub website for public access.
Raw research data	• Stored on infrastructure where generated and where they can be shared with other researchers.

Project keywords

Projections; hazards; downscaling; scenarios; tailored products; extremes; climate risks; climate change

Project contacts

Researchers and other personnel

Name	Organisation	Project role	FTE

Research end-users

Research users (program/section/branch/organisation)	Name(s)	Email (optional)
Science and Climate Services, Climate Adaptation and Services Branch		
ACS - Australian Climate Services: next user for improved projections methods and downscaling including for various hazard types		
FAIR – Federated Climate Data		
Climate Adaptation and Resilience Division (DAWE)		
Parks Australia (DAWE)		
Queensland North Assessments Branch (DAWE)		
The State of the Environment Report team		

Project CS1.4 – Understanding climate variability

Project type: NESP research project	
Project status: New project submitted for approval	
Total project budget: $1,510,260 (GST exclusive)	**NESP Funding:** $728,706 (GST exclusive) **Co-contributions (cash and in-kind):** $781,554 (GST exclusive)
Project start date: 01/09/2021	**Project end date**: 30/06/2022
Project Leader details:	

Project description

Project summary

Australia’s climate variability and extreme climate conditions impact all sectors and ecosystems, as well as the day-to-day activities and wellbeing of all sectors of society. In recent decades, the characteristics and predictability of the climate processes that drive this variability have changed, and research, some of which resulting from NESP Phase 1 ESCC Hub projects, highlights that these changes will continue in the future as the world continues to warm. While many advances in climate science have been made in recent years, a lot of these advances have focused on understanding and projecting the impacts of drivers of Australian climate variability and extremes in isolation. However, several questions remain open regarding Australia’s climate future, including how these drivers combined to influence each other and Australian climate in the future. This project will utilise outputs from the next generation of climate models to take the next step in answering some of the remaining questions around climate variability and extremes by analysing observational data and climate model output, as well as running climate model simulations. This project will enhance the understanding of the climate system processes and provide us with better tools to improve modelling and projections of key variables such as Australia's temperature and rainfall. We will also contribute to the development of climate change data and information, informing decision makers across Australia to develop adaptation and management plans for the future.

Project description

1. What problem the project seeks to address and how it will do this.

Climate variability and change vary across Australian regions, and from season to season. Several large-scale climate phenomena strongly influence Australian climate variability. They are the El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Southern Annular Mode (SAM), the Australian monsoon, and the Madden Julian Oscillation (MJO). The physical processes driving these phenomena are complex and occur on a wide range of timescales and spatial scales. Additionally, against the backdrop of these evolving complex processes is a global climate that varies on all time scales that also includes emerging rare phenomena (e.g. Antarctic stratospheric variability) that can fuel extreme events and hazards. Because of the complexity of these climate drivers, previous research has focused mainly on studying one or two of these processes in isolation. Our understanding of the role of these large-scale processes has greatly improved. However, recent research from NESP Phase 1 ESCC Hub showed that the interaction of two or more processes can create dramatic weather conditions and seasonal forecasts (for example, the co-occurrence of El Nino and positive IODs, 2 years in a row, set the very hot and dry conditions which exacerbated the severity of the fires experienced in 2019). Studies have also shown that variability in the various tropical oceans are signals of variability in the tropical Atlantic and Indian oceans and can be fed back to the Pacific via large scale atmospheric circulation patterns, and vice versa. For example, there is evidence that ENSO variability that normally starts around spring is linked to Atlantic variability in winter. These climate drivers are, at least in part, predictable. By better understanding these large-scale climate phenomena, and how they interact with each other and other climatic processes across multiple spatial and temporal scales, we can provide valuable information about the chances of related extreme event occurrences.

This project aims to take the next step in answering some of the open questions faced in climate variability, change and extremes research relevant to decision making for Australia’s future. In particular we begin investigations of how large-scale climate processes evolve and interact with each other across multiple spatial and temporal scales. The aim is to build a better understanding of how these large-scale processes, and as a consequence climate variability, will change in response to increased global warming.

2. How the research will be undertaken, including what is in and out of scope

Activity 1: Co-design and prioritisation of research projects for RP2022

As foreshadowed above, there are many directions to investigate the understanding of not only climate drivers, but importantly the implications of the interaction of these drivers could take. In RP2021 we will scope options for future research and linkages across the NESP program. This will include exploring existing research gaps and options to refine approaches, identification of linkages with other Hubs and identify needs of key users. Possible areas for advancement include:

- strengths and weaknesses of the newest generation of climate models in simulating these climate phenomena and their underlying processes, including identifying regions where these processes are well-simulated and where models agree on projections of future climate
- projected changes of El Niño Southern Oscillation and Indian Ocean Dipole by understanding how sources of uncertainty in climate models can be improved
- understanding of the current capability of climate models to simulate climate drivers
- how to improve the representation of ENSO and IOD in climate models with a focus on improving ACCESS (CM2 and ESM versions)
- better understanding of the interactions between the IOD and other climate modes (I.e. ENSO), and their response to greenhouse warming
- re-evaluation of projections from CMIP6 models, particularly with regards to ENSO, IOD, and their interactions
- better understanding of causes and predictability, including decadal predictability, of extreme ENSO events
- improve understanding of decadal variability and trends.

Together with the knowledge brokering team we will work with key stakeholders to identify priority knowledge and research needs and how understanding of climate processes and drivers can directly inform decision-making as well as improving models and projections.

This project has developed a relationship with Damian Morgan-Bulled from the Yorta Yorta Nation Aboriginal Corporation and Jason Wilson (Yauwaalaraay/Euahlay People) and through the ESCC Hubs National First Peoples Gathering on Climate Change. It will continue to strengthen these relationships, and along with Hub's Indigenous Facilitator, will continue to explore the opportunity of an Indigenous–led co-design activity for RP2022

Output: Project plans for RP2022 that are integrated across the Hub or NESP program and delivering through a value chain to address user needs.

Activity 2: Continued outreach and synthesis

Through NESP Phase 1 ESCC Hub outreach efforts, the opportunity to increase understanding of climate drivers and processes among stakeholders to support decision-making was identified. In this activity we will work with stakeholders and user groups to identify and co-develop updated climate information in formats best suited to their needs. For example, we could produce information products showing how the climate drivers such as ENSO, SAM, IOD interact and what this means for regions across Australia. The format will be determined in consultation with users, but could include a synthesis report, regional briefings or webinars. A short synthesis report will be produced on where the science has come from and future opportunities for research will be produced. It will consider how cases studies might be used test the application of this research.

Output: Short synthesis report, an outreach product (format to be determined through user engagement).

Activity 3: Understanding large-scale climate drivers, their teleconnections, interactions and their changes in a warming world.

We will investigate the strengths and weaknesses of the newest generation of climate models (CMIP6) in simulating climate phenomena and their underlying processes. This includes identifying regions where these processes are well-simulated and where models agree on projections of future climate. In particular, will use ACCESS (see project CS1.7) to run experiments that explore the interaction between the Atlantic and Pacific oceans, to help improve model biases. We will also aim to constrain projected changes of El Niño Southern Oscillation and Indian Ocean Dipole by understanding how sources of uncertainty in climate models can be improved. This work aims to improve our understanding of the current capability of climate models to simulate these crucial climate drivers. The long-term outcome of this work is improved scenarios of how the climate will change. The outputs will guide future development of climate models and climate projections.

The research will be conducted by analysing a combination of the new generation of climate models (CMIP6 – including the two Australian ACCESS models), observational data, and running climate experiments. Our research findings will be submitted to peer-reviewed journals and presented at conferences/workshops as opportunities arise.

Output: New findings will be synthesised into a plain-language summary report for stakeholders. The outputs will guide future development of climate models and climate projections, through engagement with C1.7 and C1.3.

3. Justification of foundational science

Understanding the physical processes behind large-scale climate drivers and how they interact has been the longstanding goal of climate scientists around the world. With the added complexity of unprecedented climate change, it is crucial that we understand how the drivers of Australian climate will change in response to global warming. Knowing how key variables like rainfall and temperature will fluctuate and change in various regions is the basis of policy planning and decision-making. Current projections and information based on previous research, provides a range of future scenarios that can be difficult to plan to. In some regions, for example, plausible scenarios of rainfall change include both drier or wetter conditions. While we can respond to climate change with current projections, increased precision of projections will help iteratively refine adaptation responses and improve efficiencies in actions.

It may not be easy to draw a direct line between foundational research and policymaking, however the pursuit of fully understanding the climate system is a mammoth task faced being tackled piecemeal by every climate scientist around the world. It is important to keep in mind that every advancement in understanding is a step towards i) better representation of physical processes in the models, which then leads to ii) more reliable and accurate climate projections, which leads to iii) better decision making and a more informed public. Ultimately, we aim to contribute to a society, nation, and world which is prepared for the climate “code red for humanity” (U.N. Secretary-General António Guterres, 2021).

4. Related prior research

This project follows closely from the work done in projects 2.2 and 5.2 of the ESCC Hub in NESP Phase 1 (‘Understanding climate variability and change – past, present and future’). These projects investigated understanding the major climate drivers impacting Australian climate – their processes, interactions, representation in climate models, and how they may change under global warming. These projects also explored flash drought in Australia (when, why, how it happens). Another key output of these projects was progress in extreme event attribution research. New methods were

developed for event attribution and work was started to integrate the event attribution system into ACCESS-S2, which is a first step to an operational event attribution system. This work was the result of CMIP3 and CMIP5 analysis. The new generation of climate models and data (CMIP6) now available (including models which show significant improvement in some areas) provides an opportunity to update the findings. In particular consideration of ENSO/IOD, for which there have been improvements in simulation of Pacific variability. Further, with the addition of climate models with large ensembles of simulations there is much greater ability to extract robust insights into the interactions of climate modes, and climate extremes.

5. Research and NESP linkages

This project is closely linked with ACCESS development (CS1.7), oceans (CS1.6) and climate projections (CS1.3) work of the Climate Systems Hub.

6. Informing decision-making and on-ground action

The Hub research program will be developed in partnership with key stakeholders and end-users to ensure pathways to impact are clearly established and user requirements are addressed. This scoping phase of the co-design process will be used to establish partnerships with stakeholders to co-produce and deliver the project. Once applications of the Hub's research outputs are identified, the Hub research program will adapt its research products and/or co-design tools to enable those applications by working with partners, Hub knowledge brokering and the Adaptation Mission. It is through these mechanisms that we will implement a process to continually identify application of the research, co-design and co-produce outcomes and link to the Hub knowledge brokering and Adaptation Mission to build decision support tools.

Pathway to impact

This section describes how the project will inform decision making and on-ground action, and the outputs that will be delivered to research-users throughout the life of the project. This section should be populated in consultation with research end-users.

Outcomes			
This project will improve the ability to manage the impacts of climate change through better understanding of climate variability and extremes such as drought and floods on urban and natural ecosystems and threatened species in the Australian landscape. It will be measured by the uptake of the information in impact risk, planning and adaptation assessments.			
Research-user	**Engagement and communication**	**Impact on management action**	**Outputs**
Climate Adaptation and Services Branch, DAWE, State Governments and other CS Hub projects	Engagement with users to understand their needs around understanding the interactions between the large-scale process that drive Australia's climate	Produce Information products showing how the climate drivers such as ENSO, SAM, IOD interact and what this means for regions across Australia. This is very important for management action as it will provide a better understanding of how these processes will change over time and the impact of that on the extreme weather events	Information products
Australian Climate Services (David Jones)	Co-design the research undertaken in output 3	Input to future research directions to meet knowledge needs	Provision of projects outputs for the development of the projections
Yorta Yorta Nations Aboriginal Corporation (Damian Morgan-Bulled)	Continue developing the relationship with Damian Morgan-Bulled to extend activities		
Yauwaalaraay/Euahlay Nation (Jason Wilson)	Continue developing the relationship with Jason Wilson to extend activities		
Projects C1.3 and C1.7		Input to future research directions to meet knowledge needs	Provision of projects need to check outputs for the development of the ACCESS model

Indigenous consultation and engagement

The Climate Systems Hub Research Plan outlines the history of Indigenous Engagement from our predecessor NESP Earth Systems and Climate Change Hub that we wish to build upon. The principles of Indigenous Engagement for individual projects such as this are outlined within the Hub's Indigenous Partnerships Strategy. We will identify and consider Indigenous research aspirations across the life of the Hub, with particular focus on the Hub's inception co-design activity (Jul-Dec 2021), and subsequent co-design implementation (Jan-Jun 2022).

Some of the project team members have developed a relationship with Damian Morgan-Bulled from the Yorta Yorta Nation Aboriginal Corporation through the National First Peoples Gathering on Climate Change. It will continue to strengthen this relationship and, along with Hub's Indigenous Facilitator, will continue to explore the opportunity of an Indigenous–led co-design activity for RP2022

This project is consistent with the Climate Science Hub 5 Pillars of Indigenous Engagement, National First Peoples Gathering on Climate Change co-design principles, and the 3 Category Approach. Prior to co-design it is inappropriate to list actual Indigenous Cultural and Intellectual Property (ICIP) consents. As with all Climate Systems Hub projects we understand the need to identify such consents. Through actions of inclusivity, we will consider opportunities for co-authorship, capacity building/training, Indigenous employment, and how ICIP and traditional knowledge will be managed.

Project milestones

Milestones	Due date	Responsible person
Milestone 1 - Project plans for RP2022 are integrated across the Hub or NESP program and deliver through a value chain to address user needs	Due 30/03/2022	
Milestone 2- Information products using existing data and research from ESCC Hub describing the interactions between large scale climate processes	Due 31/03/22	
Milestone 3- Outputs for model and projections development delivered to the relevant next users	Due 30/06/22	

Data and information management

The Climate Systems Hub's Data Management Strategy details the fundamental approach to data management the hub will follow. We will appoint a data management contact. The principles of the strategy are summarised in the following table:

Project output	Data Management and Accessibility
Data/Information product	• Research data and outputs will be well-documented according to accepted and trusted standards. A key requirement for all research products will be to follow metadata standards based on accepted best practice. • Data will be made publicly available whenever legally, ethically and contractually possible, under an open licence policy except in particular cases. A record of these exceptions will be kept, and exceptions reported periodically to the department. • Data and other research output will be stored in repositories that are accessible to end-users and other researchers, with the choice of repository based on practicalities of the data and its likely use, and stored in such a way as to endure and remain FAIR beyond the life of the project. • The project will develop its own data management plan based around the FAIR data principles, with identified data custodians responsible for managing each dataset. • Research outputs and data will be accompanied by documentation providing guidance to users on how best to make use of the data. • The nature of research outputs, their formats and repositories, will be developed through a co-design process involving stakeholders and end-users to ensure data meet their requirements and ensure data are fit-for-purpose, and will evolve through ongoing consultation. • The hub will maintain a metadata catalogue of all research data, and all metadata will be published on other public metadata catalogues. • Outputs such as websites will follow the Web Content Accessibility Guidelines (WCAG), and include an accessibility statement.
Application ready data sets	• To be published in public repositories. • Data services made available to enable ingestion into end-user models and decision-support tools.
End-user products	• Published in appropriate medium such as print or a scientific journal. • Captured in metadata catalogues. • a copy will be stored on the hub website for public access.
Raw research data	• Stored on infrastructure where generated and where they can be shared with other researchers.

Project keywords

Climate variability, modes of variability, climate drivers, climate teleconnections, droughts

Project contacts

Researchers and other personnel

Name	Organisation	Project role	FTE

Co-contributors

Name	Organisation	Contribution

Research end-users

Research users (program/section/branch/organisation)	Name(s)	Email (optional)

Project CS1.5 – Preparing for emerging climate extremes

Project type: NESP research project	
Project status: New project submitted for approval	
Total project budget: $1,140,825 (GST exclusive)	**NESP Funding:** $577,907 (GST exclusive) **Co-contributions (cash and in-kind):** $562,918 (GST exclusive)
Project start date: 01/07/2021	**Project end date**: 30/06/2022
Project Leader details:	

Project description

Project summary

“Before anything else, preparation is the key to success” – Alexander Graham Bell

Extreme climate events such as heatwaves, heavy rainfall events and droughts have huge impacts on Australia’s communities, natural environment and economic resources. Studies show that some types of extreme events have been and are expected to increase as a result of global climate change. Understanding the character, causes, and risks of occurrence of these extreme events is important for policymakers, planners, and land managers, to allow them to better plan for and respond to current and future extreme events. The project will address this need by undertaking fundamental and applied studies on current and future climate extremes in Australia and by delivering the findings in an accessible and usable manner to the users. This may include contributions to the development of relevant data and information, enabling decision makers across Australia to develop risk assessment tools, adaptation, and management plans for the future. We will work with selected users to identify and implement research priorities, wherever possible, building on existing science and other research activities. The outcomes will improve Australia’s preparedness for and recovery from extreme events.

Project description

1. What problem the project seeks to address and how it will do this.

The impacts of climate extremes are evident across Australian regions. To help Australians build resilience and preparedness for such events, there are at least four themes of knowledge that are needed by policymakers, planners, and land managers: the characteristics, the causes, the predictability/likelihood of, and the impact or risk from an extreme climate event. Secondly, we need to ensure the knowledge products developed by the researchers are relevant and usable.

Our current understanding on some types of extreme events (e.g. flash drought and bushfires) has greatly improved through NESP Phase 1 and other research activities. However, there are still many outstanding questions in extremes research relevant to decision making for Australia’s future, according to the learning from NESP Phase 1 and our initial literature review and initial engagement with some users. For instance, what is the relevant drought information required by selected sectors or users; what are the current and future characteristics and lifecycle of drought that we need to manage; what is the probability and the consequence of two or three types of extreme events occurring simultaneously or consecutively (e.g. flash drought together with heatwaves; seasonal drought followed by bushfires, then followed by flood); what is the probability of exceeding thresholds with/without human forcing on an extreme events?

The project will address the above two problems by: (i) enhancing our current understanding of the characteristics (including trends and projected changes), the causes, the predictability and the impact or risk of an extreme climate event; (ii) contributing to the development and delivery of relevant data and information required by selected users to inform, for instance, their risk assessment management plans current and future climate extremes in Australia.

2. How the research will be undertaken, including what is in and out of scope.

Activity 1: Scoping and co-design of research projects

This activity will identify user needs, prioritisation and co-design for projects relevant to climate extremes. We will do this in RP2021 through reviewing existing information and other research activities conducted elsewhere as well as engaging with selected users, together with the knowledge brokering team. As part of this, we will refine scope and research approach, including refining stakeholders/users list and forms of engagement.

Some possible research areas to address each of the aforesaid needs are described in Activity 3 below. This initial list will underpin the co-design conversations, and help elucidate the pathways that further research may follow in order to achieve value and impact for stakeholders.

Output: Project plans for RP2022 that integrate understanding and implementing that knowledge of climate extremes across the Hub or NESP program and delivering through a value chain to address user needs.

Activity 2: Ongoing outreach to facilitate the dissemination and use of research products

We will produce outreach products such as synthesis report, article or webinar summarising research findings to date, focused on climate extremes. The products can be tailored to support the Climate Adaptation Mission and other research users (stakeholders). Previous experience from NESP Phase 1 has shown that there is significant media interest in these topics, allowing the research findings to inform the general public as well.

We will also provide data or information developed to date to inform guidance to users as opportunity arise. For instance, in RP2021 we will provide drought projections data developed under NESP Phase 1 to Drought Resilience Self-Assessment Tool (DR-SAT) Project funded by DAWE. The extreme event attribution information can be disseminated to DAWE, insurance groups, agricultural and finance sector.

Output: Outreach products (format and number of products to be determined through user engagements).

Activity 3: Research on character, causes, and risks of occurrence of extreme events

Following Activity 1 (scoping and co-design), we will conduct research building on existing science (including those obtained through NESP Phase 1) to enhance our understanding of: the character of extreme events (including trends and projections), their causes (including attribution study), and risks of occurrence (in the current and future period).

Initial list of research areas, to underpin the co-design conversations, includes:

- define standard metrics for characterising key extremes events, including refining understanding of what is relevant drought information required for selected sectors or end-users (e.g. environment finance, and research), building on work in NESP Phase 1
- examine characteristics and lifecycle of drought, including its spatial variability, onset, and duration
- assess links between large scale circulation and drought characteristics, and predictability of drought archetypes
- assessment of the links between large scale circulation and drought; predictability of heat-wave and drought archetypes; understand model's simulation of drought and seasonal extremes
- continue the attribution work that was started in NESP Phase 1 - setting up ACCESS-S2 model system and building up diagnostic and analysis tools
- use attribution methods developed in NESP Phase 1 to analyse CMIP5/6 output to determine probability of exceeding thresholds with/without human forcing (temperature, etc)
- continue analysis begun in NESP Phase 1 on quantifying the impact of anthropogenic forcing in the observed multi-decadal changes in rainfall over Australian regions
- understand the change in likelihood of occurrence of record-breaking heatwaves
- investigate flash drought and associations with heatwaves as contributing processes and as a compound event, building on work under NESP Phase 1 (project 5.2)
- advance analysis for current and future risk of low rainfall and high temperature compound events, which has started in NESP Phase 1 (project 5.2)

- understanding of changes to drought hazard under climate change and what the bio-physical and/or socio-economic impacts of these changes. This is needed to develop an integrated modelling framework to estimate projected drought or heat impacts, as part of our effort in improving drought and heat-stress projections developed under NESP Phase 1 (project 5.2 and 5.4).

This research will be conducted by analysing a combination of observational data and climate models (CMIP5 and CMIP6, including the Australian ACCESS models). We will also engage with complementary research activities conducted elsewhere (e.g. Australian Climate Services (ACS), Climate Services Australia (CSA), DR-SAT, which are funded by DAWE) where possible.

Improving the above-mentioned understanding will help to 'future proof' Australia in the context of the changing nature of extreme events

Output: In RP2021 we focus on continuing work that was started in NESP Phase 1. New findings will be synthesised into a plain-language summary report for stakeholders, as opportunity arise. Specific outputs arelisted below:

1. Peer review paper on attribution of long-term dry; Data on probability of exceeding heat extremes for use in attribution studies.
2. Draft report on preliminary findings on drought archetypes in Australia and links to large-scale circulation.
3. Provision of drought projections data developed through NESP1 and guidance to end-users as opportunity arises.
4. Presentation on a scoping study on flash drought and heatwaves.

3. Justification of foundational science

The impact from climate extremes have been and will continue to be most devastating to the environment and community. As a result, there is an unpresented and increasingly high demand for information on current and future risks of extreme events. Our past experiences in working closely with users (e.g. through NESP Phase 1 ESCC Hub) suggest that users often require information which is not available yet partly due to limitations in the science. The fundamental and applied research in this Project will help researchers to meet such demands and to address existing knowledge gaps.

At this stage, we consider learnings from NESP Phase 1 ESCC Hub as a basis, but also weave in how co-design might direct future foundational research.

4. Related prior research

All project Activities (including research) will build on work that was done in the ESCC Hub of NESP Phase 1, particularly projects 5.2 and 5.4. It will also build on the most updated observational data and model simulations (e.g. CMIP5 and CMIP6) available to date. The IPCC sixth assessment report had a strong focus on both attribution and regional drought and provides another source of knowledge of the wide range of international research on which to build the work in this project.

5. Research and NESP linkages

This project is closely linked with the Adaptation Mission, variability (CS1.4), climate projections (CS1.3) work of the Climate Systems Hub. Through the Adaptation Mission and the co-design process we will work with other NESP Hubs to determine how the work under this project can support their research.

6. Informing decision-making and on-ground action

The Hub research program will be developed in partnership with key stakeholders and end-users to ensure pathways to impact are clearly established and user requirements are addressed. This co-design phase will be used to establish partnerships with stakeholders to co-produce and deliver the project. Once applications of the Hub's research outputs are identified, the Hub research program will adapt its research, research products and/or co-designed tools to enable those applications by

working with partners, Hub knowledge brokering team and the Adaptation Mission. Findings from the Adaptation Mission will also inform us as to the conduits via which the research can be applied, such as through adaptation services or Australian Climate Service. It is through these mechanisms that we will implement a process to continually identify application of the research, co-design and co-production outcomes to enable decision makers across Australia to develop risk assessment tools, adaptation, and management plans to best minimise future climate risk.

Pathway to impact

This section describes how the project will inform decision making and on-ground action, and the outputs that will be delivered to research-users throughout the life of the project. This section should be populated in consultation with research end-users.

Outcomes			
Immediate outcome: Enhanced understanding informing policy makers, planners and land managers to allow them to better plan for and respond to current and future extreme events. Long-term outcome: Improved Australia's preparedness for and recovery from extreme events			
Research-user	**Engagement and communication**	**Impact on management action**	**Outputs**
Climate Services for Agriculture (Lynette Bettio, Mahesh Prakash)	Engaged in the development and design of the program logic, program priorities, project and outputs. Findings and outputs to be communicated via project workshops, quarterly project update emails and presentations	Identify future research directions and approaches Data and information (e.g. on drought projection and extreme events attribution) are incorporated into the ACS platform	Outreach products (e.g. presentation, workshop participation, data, approach to undertake attribution study) as appropriate and needed Provision of drought projections data and guidance to end-users as opportunity arises
Australian Climate Service (ACS, David Jones)	Collaborate to identify potential users, identify knowledge needs, research priority, and research synergy, together with knowledge broker team Briefings of research progress and findings	Identify future research directions and approaches Data and information on climate extremes enable decision makers across Australia to develop risk assessment tools, adaptation, and management plans for the future	Outreach products (e.g. presentation, workshop participation, data, approach to undertake attribution study) as appropriate and needed Peer review paper on attribution of long-term dry events.
Climate Science and Services, Climate Adaptation and Resilience Division (DAWE) (Will Howard)	Collaborate to identify potential users, identify knowledge needs, and research priority, together with knowledge broker team Findings and outputs to be communicated via project workshops, project update emails and presentations as opportunity arise.	Inform coordination of national policy and/or research effort on extreme events research	Outreach products (e.g. presentation and briefing) as opportunity arise and/or upon request
NACP (Matt Wheeler)	Collaborate to identify potential users, identify knowledge needs, and research priority, together with Knowledge Broker team Findings and outputs to be communicated via project workshops, project update emails and presentations as opportunity arise	Identify future research directions and approaches Data and information on climate extremes enable decision makers across Australia to develop risk assessment tools, adaptation, and management plans for the future	Preliminary report/presentation on a scoping study on flash drought and heatwaves

Drought & Climate extremes resilience tool (DR-SSAT) (Stephanie Downes)	Findings and outputs to be communicated via project workshops, quarterly project update emails and presentations	Data/knowledge resulted from the research included in the DR-SAT tool	Datasets on historical and projected changes of droughts for Australia

Indigenous consultation and engagement

The Climate Systems Hub Research Plan outlines the history of Indigenous Engagement from our predecessor NESP Earth Systems and Climate Change Hub that we wish to build upon. The principles of Indigenous Engagement for individual projects such as this are outlined within the Hub's Indigenous Partnerships Strategy. We will identify and consider Indigenous research aspirations across the life of the Hub, with particular focus on the Hub's inception co-design activities (Jul-Dec 2021), and subsequent co-design implementation (Jan-Jun 2022).

This project is consistent with the Climate Science Hub 5 Pillars of Indigenous Engagement, National First Peoples Gathering on Climate Change co-design principles, and the 3 Category Approach. Prior to co-design it is inappropriate to list actual Indigenous Cultural and Intellectual Property (ICIP) consents. As with all Climate Systems Hub projects we understand the need to identify such consents. Through actions of inclusivity, we will consider opportunities for co-authorship, capacity building/training, Indigenous employment, and how ICIP and Traditional knowledge will be managed.

To achieve this, we will engage with the Hub's Indigenous Facilitator, alongside the broader directions of the Hub and Mission Leaders. Our project aims to align with the Hub's Indigenous Partnerships Strategy within the broader framework of the associated Knowledge Brokering, Communications, and Data Management Strategies.

In this project we will investigate the opportunity to co-develop understanding of drought characteristics with Indigenous partners. We will also support the Indigenous-led climate change knowledge and response project (CS1.2) through participating in knowledge sharing and learning as required.

Project milestones

Milestones	Due date	Responsible person
Milestone 1 Plan for outreach products scoped and confirmed with key users	Due 30/11/21	
Milestone 2 Progress Report to CS Hub	Due 30/12/21	
Milestone 3 Project plans contributed to RP2022	Due 30/3/2022	
Milestone 4 Synthesis and communication products available on the CS website	Due 30/6/2022	
Milestone 5 Draft peer review paper on attribution of long-term dry; Provision of drought projections data and presentation on drought characteristics; Presentation on a scoping study on flash drought and heatwaves; Data on probability of exceeding heat extremes	Due 30/6/2022	

Data and information management

The Climate Systems Hub's Data Management Strategy details the fundamental approach to data management the hub will follow. Gen Tolhurst will be the project data management contact. The principles of the strategy are summarised in the following table

Project output	Data Management and Accessibility
All data/Information products	• Research data and outputs will be well-documented according to accepted and trusted standards. A key requirement for all research products will be to follow metadata standards based on accepted best practice. • Data will be made publicly available whenever legally, ethically and contractually possible, under an open licence policy except in particular cases. A record of these exceptions will be kept, and exceptions reported periodically to the department. • Data and other research output will be stored in repositories that are accessible to end-users and other researchers, with the choice of repository based on practicalities of the data and its likely use, and stored in such a way as to endure and remain FAIR beyond the life of the project. • The project will develop its own data management plan based around the FAIR data principles, with identified data custodians responsible for managing each dataset. • Research outputs and data will be accompanied by documentation providing guidance to users on how best to make use of the data. • The nature of research outputs, their formats and repositories, will be developed through a co-design process involving stakeholders and end-users to ensure data meet their requirements and ensure data are fit-for-purpose, and will evolve through ongoing consultation. • The hub will maintain a metadata catalogue of all research data, and all metadata will be published on other public metadata catalogues. • Outputs such as websites will follow the Web Content Accessibility Guidelines (WCAG), and include an accessibility statement.
Application ready data sets	• To be published in public repositories. • data services made available to enable ingestion into end-user models and decision-support tools.
End-user products	• Published in appropriate medium such as print or a scientific journal. • Captured in metadata catalogues. • A copy will be stored on the hub website for public access.
Raw research data	• Stored on infrastructure where generated and where they can be shared with other researchers.

Project keywords

Projections; extremes; drought; compound extreme events; hazards; quantifying climate risk; climate change.

Project contacts

Researchers and other personnel

Name	Organisation	Project role	FTE

Co-contributors

Name	Organisation	Contribution

Research end-users

Research users (program/section/branch/organisation)	Name(s)	Email (optional)
Climate Adaptation and Resilience Division (DAWE)		
ACS - Australian Climate Services: next user for improved projections methods and downscaling including for various hazard types		
Climate Services for Agriculture		
Drought Resilience Self-Assessment Tool (DR-SAT)		
Parks Australia (DAWE)		
Queensland North Assessments Branch (DAWE)		
Biodiversity Conservation Division (DAWE)		
The State of the Environment Report team (DAWE)		

Project CS1.6 – The changing ocean’s coastal and climate impacts

Project type: NESP research project	
Project status: New project submitted for approval	
Total project budget: $689,377 (GST exclusive)	**NESP Funding:** $364,998 (GST exclusive) **Co-contributions (cash and in-kind):** $324,379 (GST exclusive)
Project start date: 01/09/2021	**Project end date**: 30/06/2022
Project Leader details:	

Project description

Project summary

This project builds on our fundamental understanding of the ocean, its dynamics, and its role in Australian climate. In RP2021, we will work with the NESP team and stakeholders to identify priority research and information needs, scope and co-design projects and identify opportunities for collaboration. We will also focus on short-term work to continue improving ocean and coastal observational products and synthesis and communicate understanding and capability in identifying ocean change role on climate and coastal impacts. We will also continue to foster and leverage international partnerships and developments to support Australian applications.

Project description

1. What problem the project seeks to address and how it will do this.

Australia's coasts are dynamic zones shaped by interactions between the ocean, land and atmosphere processes. On the coast side, rainfall and temperature influence the surface and sediment movement on the coast, while ocean temperature, waves, tides, ocean currents and wind all contribute energy to form and shape our coastlines. The ocean, while impacting directly on the coasts through inundation and sea level rise, is also critically important to our climate system and can influence rainfall, moisture and temperature patterns over the land interior. The ocean is a key climate component that plays an influential role in extreme El Niños and La Niñas, tropical cyclone activity, drought, and extreme rainfall.

There are three areas where ocean dynamics and processes drive climate variability and change and that impact society and the environment. First, is the link between ocean changes and key modes of climate variability that drive Australia's climate. Main drivers include: the El Niño/Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM)). Central to this is understanding the ocean's role in the global energy budget, driven by the uptake, storage and redistribution of heat by the ocean. The ocean currently stores over 90% of the excess heat in the climate system. Second is the direct impact on the ocean of increased heat storage, including rising sea levels, marine heatwaves, and marine ecosystem changes (e.g. phenology, species changes). Finally, is the direct impact of waves, sea-levels and boundary current variability on coastal erosion and inundation.

This project looks at these key impacts through ocean processes and linkages, focusing in RP2021 on building on existing information and data to improve accessibility and scope methods and priorities for future work.

2. How the research will be undertaken, including what is in and out of scope.

Activity 1: Co-design and prioritisation for RP2022

This activity is focused on contributing to the strategic planning of the Climate Systems Hub around ocean and coastal processes research. We will scope options for future research and linkages across the NESP program. This will include exploring existing research gaps and options to refine approaches, identification of linkages with other Hubs and identify needs of key users. Examples of future research gaps include the following:

- Investigate boundary current variability and exchanges between the deep ocean and coastal environments, and their role in sea level rise and extreme events, including marine heatwaves, and impact on marine ecosystems.

- Quantify regional patterns of change in ocean heat uptake and freshwater distribution in the Pacific, Indian and Southern Oceans and the ocean processes driving this change.
- Investigate ocean-atmosphere exchanges that drive the redistribution of heat and freshwater by the Indo-Pacific and Southern Ocean circulation for improved climate predictions, projections and climate service information.
- Further develop sea level reconstruction methods to incorporate methodological improvements, and the higher resolution Sentinel satellite data.
- Investigate vertical land movement on coastal tide gauges using the network of permanent Global Positioning System (GPS) data, other geodetic techniques and improved Global Isostatic Adjustment models.
- Lengthen tide records through digitisation and reconstructing past sea level trends to better understand how sea levels are changing globally and regionally as well as enabling the development of improved historical sea level reconstructions for use when delivering sea level projection information.
- Research on the relationship between modelled wave climates and shoreline position measured through high resolution satellite imagery (e.g. WorldView-2 imagery) to assess the relationship between modelled wave fields and shoreline change.
- Developing techniques to predict shoreline change at regional scales.
- Analysing downscaled ocean model outputs to provide more detailed understanding of circulation change around Australia.

The project will appoint a subject expert co-design lead who will work with the knowledge brokering team, Indigenous facilitator and Adaptation Mission in engaging with the NESP Hubs and Missions, key stakeholders and potential end-users in co-designing a program-level strategic research framework to identify and prioritise research projects. Identified priority research projects will then be co-designed with key stakeholders and partners to inform RP2022.

Output: Identify and co-design priority research project/s for RP2022.

Activity 2: Delivery of ocean and sea level rise observational-based data products

Utilising a combination of observational data and climate model output, this activity is focused on the synthesis and delivery of higher-level derived products to support both future NESP research and the wider Australian community.

Outputs: In RP2021 we are focused on four outputs:

- 2012-2019 Eastern Australian Current (EAC) volume, heat and salinity transport time series. This high-level product targets knowledge gaps identified in the Earth Systems and Climate Change (ESCC) Hub synthesis of project 5.7, assembling this data will help understand changes in the EAC and the influence on weather and climate across the full spectrum from daily to interannual and multidecadal time scales. We will investigate opportunities for the data to answer climate-related questions such as 'what do changes in East Australian Current (EAC) variability mean for regional fish recruitment and stocks?'
- Quality control and update of altimeter and tide gauge record – quality control and processing of satellite altimetry data will help us track ongoing sea level change. Digitising of old paper records to build records back in time enables broader understanding of past sea-level change. We will continue our work on the newly digitised Williamstown record, only the second gauge in Australia now to have digitised hourly records extending to pre-1900. We will work with the Bureau of Meteorology to ensure that the product complies with their protocols to ensure its

inclusion into their ANCHORS database for quality-controlled tide gauge data. This data is used to monitor changing frequency of extreme sea level/inundation events to help councils/government prioritise adaptation/land-use planning and being located on Australia's south coast, complements the long records in existence for Fremantle (1885-) and Fort Denison (1912-), particularly for understanding changes in the meteorological drivers of extremes.

- Update of information associated with the Canute sea-level rise calculator webtool – The foundational data for the Canute webtool includes extreme sea level event statistics and sea-level rise projections. Through the stakeholder consultation process, we will seek feedback for how Canute can be strengthened to better meet stakeholder needs and as new datasets become available, they need to be incorporated into Canute (e.g. IPCC 6th assessment report sea-level rise projections).
- Gridded observational marine heatwave statistics around Australia (1982-2020) - Making data from the ESCC Hub project 5.8 report of marine heatwave statistics publicly available and accessible.

The project team will look to submit at least five manuscripts to peer-reviewed journals arising from ongoing analysis of project work under the ESCC Hub. And a short technical report summarising progress. Papers will focus on identifying the key oceanic and atmospheric processes that control pathways to the deep ocean for heat as a result of global warming and how this varies across time and from region to region.

Activity 3: Continue to foster and leverage international partnerships

Australia plays an important role in international ocean process science. In this project we will continue to engage in relevant international programs as established under ESCC. This is important to leverage international developments for Australian applications including ocean observing systems and the Canute 3 platform. Activities include:

- contributing to international efforts to design national and international ocean observing networks and to develop research-quality datasets
- maintaining leadership of World Meteorological Organization (WMO) Coordinated Ocean Wave Climate Project (COWCLIP)
- continuing to co-chair the World Climate Research Program (WCRP) Grand Challenge on Sea Level Rise
- maintaining leadership roles in Global Ocean Observing Systems (GOOS) panels and platforms, Ocean Decade and the Climate and Ocean: Variability, Predictability and Change (CLIVAR) project which is one of the four core projects of the WCRP
- maintaining and developing the Canute3 webtool developed under ESCC Hub NESP Phase 1 to incorporate up-to-date analysis and datasets on sea level projections, extreme sea levels (e.g. return periods of extreme coastal water levels including tides, storm surges and waves under different sea level rise scenarios) to provide a delivery pathway for coastal extremes information nationally.

Out of scope: Coastal coupled wave and hydrodynamic simulations under current and future climate conditions will be undertaken as part of the Australian Climate Service (ACS). However, outputs from those efforts such as national coupled wave and hydrodynamic modelling over historical and future time periods will be used for research in NESP in coming years and analysis of those outputs will be provided into tools such as Canute3.

3. Justification of foundational science

Reliable global CO_2 emission targets, and Australia's emission policy and mitigation and adaptation actions, are dependent on understanding the ocean's role in the global energy budget that is driven by the uptake, storage and redistribution of heat by the ocean. More reliable predictions and projections are expected from increased knowledge of the ocean – enabling informed national scale responses to changes in climate and facilitating substantial return on investment through reducing climate impacts risks to marine ecosystems, fisheries and aquaculture, agriculture, and water and health management systems.

4. Related prior research

The above research activities will build on work undertaken in the NESP Phase 1 Earth Systems and Climate Change Hub projects 5.7 and 5.8.

5. Research and NESP linkages

The research outputs will be of direct relevance to the Climate Adaptation Mission, NESP Phase 2 Marine and Coastal Hub, Protected Places Mission, Threatened Species and Ecological Mission and Sustainable Communities and Waste Hubs. The information produced by the project will inform and guide ACS and Commonwealth, State and Local initiatives and projects.

6. Informing decision-making and on-ground action

The co-design phase of the project will identify user requirements and establish the pathway to impact for the research topics within the scope of this project. This will enable Hub researchers to tailor their research outcomes to end-user needs. For some products, the pathway to impact is clear. For example, the records of observed ocean circulation, heat content and sea level changes and associated analysis are used in State of the Climate and Environment reporting and IPCC Assessment and Special reports.

Pathway to impact

This section describes how the project will inform decision making and on-ground action, and the outputs that will be delivered to research-users throughout the life of the project. This section should be populated in consultation with research end-users.

Outcomes			
Better understanding of the ocean's role in the global energy budget is needed to inform Australia's emission policy, mitigation and adaptation actions. Research on sea levels, waves, sea level extremes, marine heatwaves, and coastline change are topics of significant societal importance. Coastal-based research builds on ocean observations and process-based understanding to ensure information is translated and delivered with maximum impact to coastal sectors and practitioners.			
Research-user	**Engagement and communication**	**Impact on management action**	**Outputs**
Climate Science and Services, Climate Adaptation and Resilience Division (DAWE)	Engage in co-development of project design and priorities	The project plan will be targeted to meet key stakeholder needs	Priority research and information needs
CLEX, COSIMA, ARC funded ocean and climate researchers	Engage in the development and design of national and international ocean observing networks	Observing networks that are collaboratively and efficiently designed to maximise return on investment	Ocean observational data products for use by Climate Extremes CRC, AAPP, NESP Climate Systems projects
Government research institutions (CSIRO, BoM, AIMS, AAD)	Findings and outputs to be communicated via project workshops, scientific research papers, provision of datasets and presentations Input to ANCHORS dataset	Datasets used to understand impact on coastal and marine ecology	Identify and co-design priority research project/s for RP2022
NESP Marine and Coastal Hub	Findings and outputs to be communicated via project workshops, scientific research papers, provision of datasets and presentations	Datasets used to understand impact on coastal and marine ecology	Identify and co-design priority research project/s for RP2022
Australian Climate Services Bluelink	Findings and outputs from coastal research activities including how coastal satellite observations can inform coastal change will lead to new methods of developing future coastal hazard layers	Provision of improved coastal hazard information will inform decision making	Research papers that provide observational validation of new methods for coastal hazard assessment and global best practice in developing sea level projections
State and territory governments	Engage in identification of knowledge needs Identify opportunities for collaboration	Improved planning for coastal hazards Identification of marine heatwave hazards Input to downscaled modelling	Co-designed project outputs Improved information in CANUTE for planners

Additional outputs

1) International science planning and program input to leverage investment and analysis of oceans surrounding Australia.

Indigenous consultation and engagement

The Climate Systems Hub Research Plan outlines the history of Indigenous Engagement from our predecessor NESP Earth Systems and Climate Change Hub that we wish to build upon. The principles of Indigenous Engagement for individual projects such as this are outlined within the Hub’s Indigenous Partnerships Strategy. We will identify and consider Indigenous research aspirations across the life of the Hub, with particular focus on the Hub’s inception co-design activity (Jul-Dec 2021), and subsequent co-design implementation (Jan-Jun 2022).

This project is consistent with the Climate Science Hub 5 Pillars of Indigenous Engagement, National First Peoples Gathering on Climate Change co-design principles, and the 3 Category Approach. Prior to co-design it is inappropriate to list actual Indigenous Cultural and Intellectual Property (ICIP) consents. As with all Climate Systems Hub projects we understand the need to identify such consents. Through actions of inclusivity, we will consider opportunities for co-authorship, capacity building/training, Indigenous employment, and how ICIP and Traditional knowledge will be managed.

To achieve this, we will engage with the Hub’s Indigenous Facilitator, alongside the broader directions of the Hub and Mission Leaders. Our project aims to align with the Hub’s Indigenous Partnerships Strategy within the broader framework of the associated Knowledge Brokering, Communications, and Data Management Strategies.

Project milestones

Milestones	Due date	Responsible person
Milestone 1 Written plan for CANUTE updates developed with stakeholders	Due 30/10/2021	
Milestone 2 Progress report on Activity 2	Due 31/12/21	
Milestone 3 Submission of paper on EAC variability and dynamics Production of EAC transport time-series	Due 31/12/21	
Milestone 4 Short report on analysis of 2012-2019 Eastern Australian Current (EAC) volume, heat and salinity transport time series	Due 31/12/21	
Milestone 5 Contribute Ocean and Coastal Climate Processes co-design outcomes to submission of draft RP2022 and Hub Annual Progress Report under direction of Hub and Mission Leaders	Due 31/03/22	
Milestone 6 Updates made to CANUTE as determined through consultation	Due 30/06/22	
Milestone 7 Quality control and update of altimeter and tide gauge record for Williamstown completed	Due 30/06/22	
Milestone 8 Short report or briefing note on gridded observational marine heatwave statistics around Australia (1982-2020)	Due 30/06/22	
Milestone 9 International science planning and program input reported to CS Hub and DAWE	Due 30/06/22	

Data and information management

The Climate Systems Hub's Data Management Strategy details the fundamental approach to data management the hub will follow. The principles of the strategy are summarised in the following table

Project output	Data Management and Accessibility
All data/Information products	• Research data and outputs will be well-documented according to accepted and trusted standards. A key requirement for all research products will be to follow metadata standards based on accepted best practice. • Data will be made publicly available whenever legally, ethically and contractually possible, under an open licence policy except in particular cases. A record of these exceptions will be kept, and exceptions reported periodically to the department. • Data and other research output will be stored in repositories that are accessible to end-users and other researchers, with the choice of repository based on practicalities of the data and its likely use, and stored in such a way as to endure and remain FAIR beyond the life of the project. • The project will develop its own data management plan based around the FAIR data principles, with identified data custodians responsible for managing each dataset. • Research outputs and data will be accompanied by documentation providing guidance to users on how best to make use of the data. • The nature of research outputs, their formats and repositories, will be developed through a co-design process involving stakeholders and end-users to ensure data meet their requirements and ensure data are fit-for-purpose, and will evolve through ongoing consultation. • The hub will maintain a metadata catalogue of all research data, and all metadata will be published on other public metadata catalogues. • Outputs such as websites will follow the Web Content Accessibility Guidelines (WCAG), and include an accessibility statement.
Application ready data sets	• To be published in public repositories. • Data services made available to enable ingestion into end-user models and decision-support tools.
End-user products	• Published in appropriate medium such as print or a scientific journal. • Captured in metadata catalogues. • A copy will be stored on the hub website for public access.
Raw research data	• Stored on infrastructure where generated and where they can be shared with other researchers.

Project keywords

Ocean Processes, hydrological cycle, sea-level rise, marine heatwaves, coastal extremes, shoreline change

Project contacts

Researchers and other personnel

Name	Organisation	Project role	FTE

Research end-users

Research users (program/section/branch/organisation)	Name(s)	Email (optional)
Climate Science and Services, Climate Adaptation and Resilience Division (DAWE)		
CLEX, COSIMA, ARC funded ocean and climate researchers.		
Government research institutions (CSIRO, BoM, AIMS, AAD)		
NESP Marine and Coastal Hub		
Australian Climate Services		
Bluelink		
State and territory governments		
Wetlands Section (DAWE)		
Parks Australia (DAWE)		
Queensland North Assessments Branch (DAWE)		
State of the Environment Report team (DAWE)		

Project CS1.7 – Modelling the future

Project type: NESP research project	
Project status: New project submitted for approval	
Total project budget: $1,448,911 (GST exclusive)	**NESP Funding:** $754,054 (GST exclusive) **Co-contributions (cash and in-kind):** $694,857 (GST exclusive)
Project start date: 01/07/2021	**Project end date**: 30/06/2022
Project Leader details:	

Project description

Project summary

Climate models are an invaluable tool for understanding past, current and future climates. Climate models are the means by which information on future climate is generated, packaged into climate projections and utilised by Australian decision-makers to inform policies and management options. To serve this purpose Australia has made a long-term investment into the Australian Community Climate and Earth System Simulator (ACCESS). It brings together the land, ocean, ice, atmosphere and biosphere to explore the integrated response of different social and economic futures and what this means for Australia's variable and changing climate. This project hands over existing climate modelling capability to a new National Research Infrastructure. It engages through co-design to define future directions and applications for ACCESS in consultation with research users and stakeholders. It builds on prior research with larger sets of experiments, and provides a significant and policy-relevant new experiment of a near-future global climate that exceeds Paris Agreement targets before returning below those thresholds.

Project description

1. What problem the project seeks to address and how it will do this.

Climate and Earth System Models, such as ACCESS, are a fundamental tool for improving our understanding of the earth system and for providing quantitative information about future climate in response to changes in human-induced and natural activities. This project maintains existing ACCESS capability and coordinates co-design of future ACCESS work. In the last 18 months major emitting nations across the globe are committing to net zero emissions towards the mid-century in an effort to keep global average surface temperatures below a 2°C warming above preindustrial levels (Paris Agreement). The pathway to limiting global warming to below 2°C will very likely include a temporary exceedance of this temperature target (overshoot). We will explore the impact and implications of a temperature overshoot/recovery on the Australian region.

2. How the research will be undertaken, including what is in and out of scope

There are 3 in scope research activities for this project in RP2021:

Activity 1: Outreach to ACCESS-NRI

The Department of Education, Skills and Employment (DESE) National Collaborative Research Infrastructure Strategy (NCRIS) has recently announced a National Research Infrastructure (NRI) for ACCESS. This project will support formation of the ACCESS-NRI by providing the two versions of ACCESS submitted to the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project phase 6 (CMIP6). These two versions represent a baseline for current state-of-science of the ACCESS climate modelling effort. They capture over a decade of prior research investment, and will seed the future global climate modelling development of the ACCESS-NRI.

Output: Deliver entry level CMIP ACCESS model configurations to ACCESS-NRI.

Activity 2: Co-design and prioritisation for RP2022

The co-design process will: (i) maintain engagement with the ACCESS community via, e.g. the existing program of 'ACCESS Science Days' and; (ii) identify research users and stakeholders needs and priorities through engagement and building of partnerships through workshops facilitated by Hub knowledge brokering experts to ensure the involvement of the Australian research community. Workshop participation will focus on the design and selection of new model experiments and needs for model development.

Output: Identify and co-design priority research project/s for RP2022.

Activity 3: Foundational science and tangible outputs

(i) Our understanding of climate models and outputs increases when we run multiple simulations, with minor perturbations, of the same experiment, e.g. the historical period already observed, or low and high future emissions scenarios. in response to a request from the Australian Climate Service (ACS) we will run such so-called “ensemble” experiments to generate better inputs to develop regional downscaling by ACS. The new large ensemble set will be used to separate the anthropogenic climate change signal from internal climate variability.

(ii) We also propose a new ACCESS experiment. The pathway to limiting global average surface warming below 2°C could include a temporary exceedance of this temperature target (overshoot). We will use the standard CMIP6 overshoot scenario (SSP5-3.4-OS) to create ACCESS outputs that allow scientific exploration of this increasingly possible and policy-relevant future.

(iii) Analysis of Australian climate in existing ACCESS simulations including the reversibility of the climate/carbon cycle, land-based carbon mitigation, tropospheric ozone, climate drivers and climate change responses to support intra-hub projects. The testing and evaluation of new features of model components from national and international ACCESS partners remains a fundamental science activity.

Output: Larger experimental ensembles including for the new overshoot/recovery experiment.

Out-of-scope: Development of new model configurations is not considered for RP2021.

3. Justification of foundational science

Climate and Earth System Models, such as ACCESS, are a fundamental tool for improving our understanding of the earth system and for providing quantitative information about future climate in response to changes in anthropogenic and natural activities. The CMIP6 models are the primary source informing our understanding of future climate. They underpin the projections of future climate assessed by the Intergovernmental Panel on Climate Change (IPCC), which in turn influence policy such as the United Nations Framework Convention on Climate Change CoP-21 Paris Agreement. This project continues Australia’s contribution to this important international effort.

4. Details of related prior research

ACCESS climate modelling was a significant activity in the NESP Phase 1 Earth Systems and Climate Change (ESCC) Hub. Those efforts provided Australia’s climate modelling contributions to the WCRP/CMIP6. The CMIP6 models underpin the plausible scenarios of future climate and their impacts as assessed by the recent IPCC sixth assessment report. The larger experimental ensembles build on past work based on the small ensemble available at the time.

Through the support of the ESCC Hub two ACCESS versions were developed, evaluated, submitted to CMIP6 and released to the community. They can now be readily deployed for new experiments. ACCESS simulations performed under these previous projects will also be used in this work to support further analysis.

5. Research and NESP linkages

This project will focus on planning how the ACCESS model will meet the needs across the NESP portfolio through (a) interpretation and provision of model outputs, (b) running standardised and tailored simulations and (c) enhancing the model’s capability. The co-design process will engage with next users within and beyond the Hub to help determine future priorities across these three areas.

The large ensemble of simulations proposed in this work will meet the expressed needs of other Climate Systems Hub projects: “CS1.3 Regional knowledge for local action”, “CS1.4 Understanding of

climate variability", "CS1.5 Preparing for emerging climate extremes". The overshoot scenario and analysis of carbon and climate reversibility is of particular interest for project "CS1.8 Australia's carbon stocktake."

ACCESS simulation results will also support the newly formed multi-agency Australian Climate Service (ACS), and CSIRO projects such as the Towards Net Zero Mission and Hydrogen Energy Systems Future Science Platform. This project also supports Australia's involvement in an international model consortium, the UK Met Office led Unified Model partnership,

6. Informing decision-making and on-ground action

ACCESS modelling underpins the work of other projects that aim to provide information to decision makers, both within the Climate Systems Hub and outside the Hub. For example, ACCESS simulation results are the basis for downscaling and regional projections at various temporal and spatial scales which directly inform policy and decision makers, e.g. through planned work of the ACS.

Pathway to impact

This section describes how the project will inform decision making and on-ground action, and the outputs that will be delivered to research-users throughout the life of the project. This section should be populated in consultation with research end-users.

Outcomes
A key outcome of this project is scoping of future research for RP2022 based on the co-design process. This will determine future ACCESS model development and applications based on end-user and stakeholders needs. Since ACCESS underpins research within the Hub, across Hubs and other projects, the co-design process will include next users from all of those projects. ACCESS ensemble simulations will be used within ACS, CLEX and the University of Queensland for downscaling and assessment of extreme events which will then inform decision makers about possible climate impacts on Australian regions. Large ensembles are required to identify appropriate individual ensemble members for downscaling but also to identify and robustly sample extreme events such as heatwaves, droughts and floods. Large ensembles allow for a more accurate sampling of the entire distribution, including the tails where the extreme events occur. Analysis of the ACCESS overshoot scenario simulations by hub users, research partners and the wider community will show if exceeding a certain temperature threshold might lead to an irreversible loss of Australian ecosystems and their services. Analysis of the reversibility of the climate and carbon cycle by researchers within this project will identify which processes cannot be reversed and what this means at a broader scale for Australia's ecosystems and their services. Research on land-based carbon mitigation and the impact of soil phosphorus availability on future land carbon sinks will highlight Australia's potential in natural solutions for carbon dioxide removal and how this will assist our pathway in reaching Net-Zero emissions. Simulation results from the 2°C overshoot scenario, the climate and carbon cycle reversibility analysis and research on land-based carbon mitigation can inform the (emissions) pathway Australia chooses to follow, especially when ecosystem services such as food production are found to be at risk.

Research-user	**Engagement and communication**	**Impact on management action**	**Outputs**
NCRIS ACCESS-NRI	Engagement in discussions and planning of ACCESS-NRI via ACCESS Oversight Committee and ACCESS Science Days	Facilitates uptake of ACCESS models by research community	Provide entry-level CMIP6 configurations of ACCESS-ESM1.5 and ACCESS-CM2
Australian Climate Service University of Queensland Department of Environment and Science, Queensland Government	Engaged in decision about ideal ensemble size and which scenarios to run Communicate release and publication of ensemble members from ACCESS simulations through meetings and emails	ACCESS ensemble will be used for downscaling to provide better information of climate impacts on regional Australia	ACCESS ensemble data sets published for CMIP6 on Earth Systems Grid Federation (ESGF) Conference or workshop presentation on large ensemble analysis
Australian Research Council Center of Excellence for Climate Extremes (CLEX)	Communicate release and publication of ensemble members from ACCESS simulations through meetings and emails	ACCESS ensemble will be used to analyse extreme events such as drought and rainfall and how this might change in the future	ACCESS ensemble data sets published for CMIP6 on ESGF Conference or workshop presentation on large ensemble analysis
Australian Research Council COSIMA Linkage Project	Attendance at weekly ocean modelling meetings. Communication of relevant ocean and coupled modelling analysis	Facilitates uptake of ACCESS models by research community	ACCESS ensemble data sets published for CMIP6 on ESGF

CS Hub projects: 1.3 Regional knowledge for local action 1.4 Understanding climate variability 1.5 Preparing for emerging climate extremes	Engaged in decision about ideal ensemble size and which scenarios to run Communicate release and publication of ensemble members from ACCESS simulations through meetings and emails.	ACCESS ensemble will be used for downscaling to provide better information of climate impacts on regional Australia.	ACCESS ensemble data sets published for CMIP6 on Earth Systems Grid Federation (ESGF). Conference or workshop presentation on large ensemble analysis.
CS hub project 1.8 Australia's land and ocean carbon and acidification	Communicate results from reversibility analysis through meetings and hub reports Engage in discussion about implications of results for Australian carbon stocks	Research findings will inform about potential risks and implications of following a pathway that heavily relies on carbon dioxide removal	Journal paper draft on carbon cycle and climate reversibility
CS hub project 1.8 Australia's land and ocean carbon and acidification	Communicate results through meetings, workshops, conferences and regular hub reports	Research will highlight the potential of land-based carbon mitigation in Australia. This will assist in assessing Australia's potential for carbon dioxide removal, which is important for the overall goal in reaching Net-Zero emissions	Journal paper draft on land-based carbon mitigation and impact of soil phosphorus availability on Australian carbon sinks
UK Met Office	Communicate findings through emails and meetings	ACCESS latest climate model will be used to test the new UM physics for the Indo-Pacific and Australia regions with an aim of improving the climate predictability of Australia	Scientific presentations to UK Met Office colleagues through GC4, Convection (CoMorph) and IndoPacific Working Groups
NARCLIM – Kathleen Beyer DPIE/ACT	Communicate release and publication of ensemble members from ACCESS simulations through meetings and emails	ACCESS ensembles available to project	ACCESS ensemble data sets published for CMIP6 on ESGF
DAWE CSIRO/CSC CLEX BoM	Engagement in co-design process and co-production process Communicate via workshops, quarterly project updates, emails and presentations	The research plan will define future developments and applications for ACCESS and how this will benefit end users and decisions makers	Co-designed research plan RP2022

Indigenous consultation and engagement

The Climate Systems Hub Research Plan outlines the history of Indigenous Engagement from our predecessor NESP Earth Systems and Climate Change Hub that we wish to build upon. The principles of Indigenous Engagement for individual projects such as this are outlined within the Hub's Indigenous Partnerships Strategy. We will identify and consider Indigenous research aspirations across the life of the Hub, with particular focus on the Hub's inception co-design activity (Jul-Dec 2021), and subsequent co-design implementation (Jan-Jun 2022).

This project is consistent with the Climate Science Hub 5 Pillars of Indigenous Engagement, National First Peoples Gathering on Climate Change co-design principles, and the 3 Category Approach. Prior to co-design it is inappropriate to list actual Indigenous Cultural and Intellectual Property (ICIP) consents. As with all Climate Systems Hub projects we understand the need to identify such consents. Through actions of inclusivity, we will consider opportunities for co-authorship, capacity building/training, Indigenous employment, and how ICIP and traditional knowledge will be managed.

To achieve this, we will engage with the Hub's Indigenous Facilitator, alongside the broader directions of the Hub and Mission Leaders. Our project aims to align with the Hub's Indigenous Partnerships Strategy within the broader framework of the associated Knowledge Brokering, Communications, and Data Management Strategies.

Project milestones

Milestones	Due date	Responsible person
Milestone 1 – Contribute to mid-term 6-month inception co-design phase report to DAWE/NESP team under direction of Hub and mission leaders. [e.g. identification of place in program logic, engagements with DAWE research needs, further outreach activities, stakeholders engaged, process for research prioritisation]	30 Sept 2021	
Milestone 2 – Contribute to final 6-month inception co-design phase report to DAWE/NESP team under direction of Hub and mission leaders. [e.g. refinement of place in program logic, engagements with DAWE research needs, further outreach activities, stakeholders engaged, research prioritisation for RP2022]	31 Dec 2021	
Milestone 3 – Contribute ACCESS co-design outcomes to submission of draft RP2022 and Hub Annual Progress Report under direction of Hub and Mission leaders	31 March 2022	
Milestone 4 – Contribute to final RP2021 co-design report of DAWE/NESP team under direction of Hub and Mission leaders	30 Jun 2022	
Milestone 5 - Additional ensemble members and other simulations for both ACCESS model versions performed and datasets published under CMIP6 on ESGF	30 Jun 2022	
Milestone 6 – ACCESS CMIP6 entry-level configurations provided to ACCESS-NRI	30 Jun 2022	
Milestone 7 – Study results and paper drafts available. Results presented at workshops and conferences	30 Jun 2022	

Data and information management

The Climate Systems Hub's Data Management Strategy details the fundamental approach to data management the hub will follow. The principles of the strategy are summarised in the following table:

Project output	Data Management and Accessibility
All data/information products	• Research data and outputs will be well-documented according to accepted and trusted standards. A key requirement for all research products generated by the hub research will be following metadata standards based on accepted best practice. • Data will be made publicly available whenever legally, ethically and contractually possible, under an open licence policy except in particular cases. A record of these exceptions will be kept, and exceptions reported regularly to the Department. • Data and other research output will be stored in repositories that are accessible to end-users and other researchers, with the choice of repository based on practicalities of the data and its likely use, and stored in such a way as to endure and remain FAIR well beyond the life of the project. • The project will develop its own data management plan, with identified data custodians responsible for managing the data. • The nature of research outputs, their formats and repositories, will be developed through a co-design process involving stakeholders and end-users to ensure data meet their requirements and are fit-for-purpose, and will evolve through ongoing consultation. • Research outputs and data will be accompanied by documentation providing guidance to users on how best to make use of the data. • The hub will maintain a metadata catalogue of all research data, and all metadata will be published on other public metadata catalogues. • Outputs such as websites will follow the Web Content Accessibility Guidelines (WCAG), and include an accessibility statement.
ACCESS model simulation results	• All simulation results contributing to CMIP6 will be submitted to the Earth Systems Grid Federation (ESGF), where data are freely available to all interested parties.
Scientific publications and reports	• Publications and reports will be made available through the CS hub website and/or appropriate peer-reviewed scientific journals.

Project keywords

Climate modelling, Earth system modelling, ACCESS, future projections, global climate

Project contacts

Researchers and other personnel

Name	Organisation	Project role	FTE

Research end-users

Research users (program/section/branch/organisation)	Name(s)	Email (optional)
DAWE NESP		
DAWE Climate Adaptation and Resilience Division		
Parks Australia		
DAWE QLD North Assessments Branch		
DAWE SOE team		
UK Met Office Indo-Pacific PEG		
UK Met Office UM development		
QLD University		

Project CS1.8 Australia’s land and ocean carbon and acidification

Project type: NESP research project	
Project status: New project submitted for approval	
Total project budget: $698,867 (GST exclusive)	**NESP Funding:** $370,400 (GST exclusive) **Co-contributions (cash and in-kind):** $328,467 (GST exclusive)
Project start date: 01/09/2021	**Project end date**:30/06/2022
Project Leader details:	

Project description

Project summary

Australia's oceans and land play a key role in offsetting Australia's greenhouse gas emissions. This project builds on our understanding of contemporary and future carbons sinks and budgets on land and in the ocean to produce a spatial representation of Australia's carbon budgets. Maps showing spatial variation in carbon sources and sinks will inform governments, at all levels, about the magnitude of carbon stocks and their vulnerability to climate change and variability, along with the capacity to enhance these stocks to meet current and future emission targets. This project will also inform the vulnerability of the oceans to increasing acidification, the direct result of the uptake of anthropogenic carbon. Our analysis will consider how ocean acidification varies and the risks associated with variability along Australia's east coast. It will contribute to understanding and projecting marine impacts and commercial consequences. We will also engage with a range of stakeholders to consider future research and knowledge delivery priorities and opportunities for cross-hub collaborations.

Project description

1. What problem the projects seek to address and how it will do this.

Parties to the Paris Agreement, including Australia, aim to keep global average temperatures well below 2^{o}C, and pursue efforts to stay below 1.5 ^{o}C. To achieve this target, net zero emissions must be reached by mid-century. This will be achieved by balancing sources of carbon emissions and capture and storage of carbon – the global carbon budget. Australia's commitment to the Paris Agreement and long-term emissions reduction policies relies on understanding and accounting for carbon sources and sinks. Our understanding continues to evolve, but significant gaps persist. There remains limited understanding of the potential of land and oceans to take-up carbon, the relative role and dynamics of anthropogenic versus natural sources and sinks, and how climate change will impact the capacity and permanence of carbon sinks to store carbon.

As well as being the most significant greenhouse gas contributing to human-induced global-warming, carbon also has direct, chemical impacts on our environment. The world's oceans have absorbed around a third to a half of carbon dioxide released through human activities, but have experienced detectable changes in ocean acidification as a direct result. Ocean acidification poses significant and very long-lasting risks to the viability and productivity of marine ecosystems and the important (ecosystem) services they provide. Declines of marine species and ecosystems has the potential to impact important economic activities including fisheries, tourism and coastal protection. To date, focus has been on long-term changes, but ocean variability on shorter timescales (analogous to marine heatwaves) has the potential to have very significant impacts on marine ecosystems but are less well understood or characterised.

This project continues to build the picture of the fate of carbon emissions, both on land and in the ocean. It builds on methods used in NESP Phase 1 to develop a terrestrial carbon budget, and introduces consideration of ocean carbon capture and impacts.

2. How the research will be undertaken, including what is in and out of scope

The project will undertake three activities in RP2021.

Activity 1: Scoping and planning carbon related research for the Climate Systems Hub

This activity is focused on contributing to the strategic planning of the Climate Systems Hub around carbon research. We will scope options for future research and linkages across NESP. This will include exploring existing research gaps and options to refine approaches, identification of linkages with other Hubs and identification of the needs of key users. Examples of future research gaps include:

- insights into where, how much and how current land and marine carbon stocks might be vulnerable under future climate change, and to explore the potential of different regions and domains for enhanced carbon sequestration
- bringing together normally siloed research on land-based carbon sources and sinks to include the ocean carbon budget, thereby expanding the carbon budget to the Australian domain
- investigating how calcification of reef-building organisms might impact marine habitats, wave movement and storm surge.

The project will appoint a subject expert co-design lead who will work with the knowledge brokering team, Indigenous facilitator and Adaptation Mission in engaging with the NESP Hubs and Missions (particularly with Resilient Landscapes Hub, and Marine and Coastal Hub), key stakeholders and potential end-users in co-designing a program-level strategic research framework to identify and prioritise research projects. Identified priority research projects will then be co-designed with key stakeholders and partners to inform RP2022. A key component of consultation will be the planning and execution of a number of consultation meetings with relevant federal government departments and state and territory governments.

Output: Identify and co-design priority research project/s for RP2022.

Activity 2: Mapping carbon budgets for Australia

We extend and build on work undertaken in NESP Phase 1 to continue to update and refine the carbon budget for Australia's land ecosystems (including carbon fluxes from coastal ecosystems) for the last decade. Calculations will include all major anthropogenic and natural fluxes for the most recent decade for which data is available. Bringing together the carbon budget will involve collaborating with the National Carbon Accounting System (NCAS) team from Department of Industry, Science, Energy and Resources (DISER) to integrate anthropogenic fluxes and universities and international partners to estimate other fluxes. This will be integrated with our own biogeochemical modelling capability developed in the Earth Systems and Climate Change Hub to estimate natural fluxes. The results will be spatially represented on maps to help policy-makers identify priority areas for investment and management for carbon benefits.

The resulting Australian analysis will also contribute to global greenhouse gas budgets (the Global Carbon Project) and the global stocktake under the Paris Agreement.

Providing information for project-level carbon accounting is out of scope as this is already done by the National Carbon Accounting team and the Clean Energy Regulator.

Output: Continental land carbon budget maps of the net carbon balance for the most recent decade over Australia.

Input to the global assessment Regional Carbon Cycle Assessment and Processes (RECCAP-GCP) as part of the Global Carbon Project

Activity 3 Ocean carbon uptake and acidification

We will pilot an assessment of variability and change in ocean carbon uptake and ocean acidification using existing observations and high-resolution model projections. The assessment will focus on characterising long and short-term variability in the Coral and Tasman Seas. This variability is very significant due to its strong influence on conditions along the entire eastern Australian coast. The potential for impacts on coral reefs, fisheries and tourism are of considerable concern and ocean acidification will plan an increasingly important role in this as the ocean continues to take up carbon.

Output: Assessment and spatial analysis of ocean acidification in the Coral Sea and Tasman Seas for source waters for East Australia, including a short technical report.

3. Related prior research

This project builds on existing capacity to develop greenhouse gas budgets for Australia and globally, and the modelling capacity to explore the evolution of land carbon sinks – developed in part through the ESCC Hub – to develop a spatial analysis of the carbon budget. We also use existing data and model projections to develop the ocean acidification assessment.

4. Research linkages

We will build linkages with the Resilient Landscapes Hub and Marine and Coastal Hub to consider the role of land-based carbon mitigation projects, vegetation restoration and fire management for their role in determining the future of aboveground biomass carbon sinks. Likewise, we will work closely with the Marine and Coastal Hub to connect understanding of ocean acidification variability, marine carbon cycle feedbacks, impacts on reef building organisms, waves, and potential of blue carbon in terms of carbon budget (including non-carbon greenhouse gases) and ecosystem services.

5. Informing decision-making and on-ground action

Interest in understanding where and what sources and sinks of carbon exist, comes from all levels of government seeking to reduce emissions and meet mitigation targets. It also comes from big corporations investing in carbon offsets. The results of Activity 2 will provide information to better develop large scale mitigation portfolios relying on carbon sinks. Activity 3 will contribute to our understanding of marine ecosystem resilience and impacts on commercial activities.

Pathway to impact

This section describes how the project will inform decision making and on-ground action, and the outputs that will be delivered to research-users throughout the life of the project. This section should be populated in consultation with research end-users.

Outcomes			
Enhanced understanding of the magnitude and permanence of Australia's carbon sinks and stocks in response to climate change and variability. Essential for reporting carbon budgets and potentially enhancing capacity to enhance these stocks to meet current and future emission targets, at the State and Federal Government levels. Understanding the changes in recent past and future changes in ocean acidification, central to informing and adapting to marine impacts and the commercial consequences of acidification around Australia; critical for natural resource managers at all levels including (but not limited to) the Great Barrier Reef, commercial fin and shellfish, maricultural and Indigenous rightsholders.			
Research-user	**Engagement and communication**	**Impact on management action**	**Outputs**
National Inventory Systems and International Reporting – DISER Contact: Rob Sturggis (head branch), Max Collett (manager of the Land Sector Carbon Modeling) State and territory governments climate change policy and information representatives	Consultation to define overall components of the carbon budgets to maximise its value, and data contributions from the national carbon accounting system (anthropogenic emissions)	Identified capacity and reliability of land carbon sinks and provide insights for long term policy on carbon abatement	Continental land carbon budget with maps of the spatial distribution of the net carbon balance for the most recent decade
Regional Carbon and Processes Assessment (RECCAP) Contact: Global Carbon Project, Ben Poulter (NASA); UNFCCC Global stocktake process	Align contribution to the requirements of international assessments: RECCAP2 and the UNFCCC Global Stocktake	Contribution to global stocktake to assist UNFCCC to track progress towards the goal of reaching net zero emissions	Draft manuscript intended for submission in peer review journal as a contribution to RECCAP2, and data in the required formats as a contribution to the global stocktake
NESP Phase 2 Marine and Coasts Hub	Observed changes in ocean chemistry around Australia	Contribution to Australia's reporting on SDGs to the UN	Identify and co-design priority research project/s for RP2022 Draft manuscript intended for submission in peer review journal on ocean acidification in the coral sea and Tasman Seas source waters for the East Australia

Indigenous consultation and engagement

The Climate Systems Hub Research Plan outlines the history of Indigenous Engagement from our predecessor NESP Earth Systems and Climate Change Hub that we wish to build upon. The principles of Indigenous Engagement for individual projects such as this are outlined within the Hub’s Indigenous Partnerships Strategy. We will identify and consider Indigenous research aspirations across the life of the Hub, with particular focus on the Hub’s inception co-design activity (Jul-Dec 2021), and subsequent co-design implementation (Jan-Jun 2022).

This project is consistent with the Climate Science Hub 5 Pillars of Indigenous Engagement, National First Peoples Gathering on Climate Change co-design principles, and the 3 Category Approach. Prior to co-design it is inappropriate to list actual Indigenous Cultural and Intellectual Property (ICIP) consents. As with all Climate Systems Hub projects we understand the need to identify such consents. Through actions of inclusivity, we will consider opportunities for co-authorship, capacity building/training, Indigenous employment, and how ICIP and traditional knowledge will be managed.

To achieve this, we will engage with the Hub’s Indigenous Facilitator, alongside the broader directions of the Hub and Mission Leaders. Our project aims to align with the Hub’s Indigenous Partnerships Strategy within the broader framework of the associated Knowledge Brokering, Communications, and Data Management Strategies.

Project milestones

Milestones	Due date	Responsible person
Milestone 1 Scoping meetings with relevant sections of DAWE, DISER, State and territory representatives, Marine and Coasts Hub completed	1/12/2021	
Milestone 2 Co-designed adaptation research plans submitted as part of RP2022	31/03/2021	
Milestone 3 Continental land carbon budget maps of the net carbon balance for the most recent decade over Australia	31/03/2022	
Milestone 4 Contribute to the global assessment Regional Carbon Cycle Assessment and Processes of the Global Carbon Project	30/06/2022	
Milestone 5 Short technical report of analysis assessment and spatial analysis of ocean acidification in the Coral Sea and Tasman Seas	30/06/2022	

Data and information management

The Climate Systems Hub's Data Management Strategy details the fundamental approach to data management the hub will follow. The principles of the strategy are summarised in the following table:

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Application ready data sets	• To be published in public repositories. • data services made available to enable ingestion into end-user models and decision-support tools.
End-user products	• Published in appropriate medium such as print or a scientific journal. • Captured in metadata catalogues. • A copy will be stored on the hub website for public access.
Raw research data	• Stored on infrastructure where generated and where they can be shared with other researchers.

Project keywords

Carbon cycle, climate change and variability, restoration, resilience, ecosystem services, ocean acidification, greenhouse gases.

Project contacts

Researchers and other personnel

Name	Organisation	Project role	FTE

Research end-users

Research users (program/section/branch/organisation)	Name(s)	Email (optional)
NESP/Science Partnerships		
Climate Adaptation and Resilience Division (DAWE)		
Wetlands Section (DAWE)		
Queensland North Assessments Branch (DAWE)		
State of the Environment Report team (DAWE)		