Rural R&D for Profit Program

Forewarned is Forearmed – RnD4Profit-16-03-007

Final Report

Meat & Livestock Australia

June 2017 – December 2022

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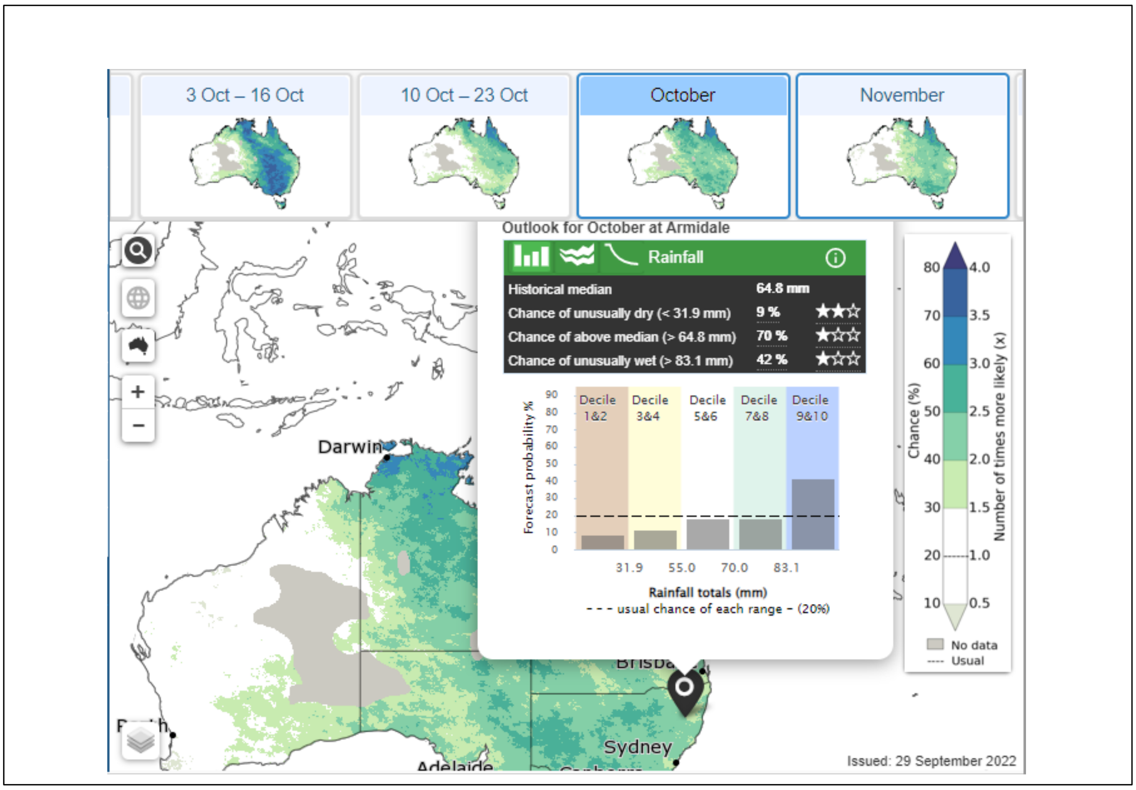


Contents

Plain English summary

Background

Australian farmers operate in one of the world's most variable climates. Climate variability and extreme climate events are key drivers of annual agricultural production and income.

The *Forewarned is Forearmed (FWFA): managing the impacts of extreme climate events* project was a long-term collaborative project funded by the Australian Government Department of Agriculture Fisheries and Forestry in the third round of the Rural Research & Development (R&D) for Profit (RRD4P) program along with significant cash and in-kind contributions from multiple Rural Research and Development Corporations (RDC's), the Bureau of Meteorology (Bureau), universities, state governments and private companies.

Objective

The objective of FWFA was on improving the forecasting of extreme weather events and equipping farmers with the information and tools needed (on multi-week and seasonal timescales) to reduce the impact of these events on farm, and on business profit.

Method

The project involved four inter-related components (called work packages). These were:

- Work Package 1: Understanding user (farmer) needs and enhancements of the climate forecast system. Lead agencies were the Bureau of Meteorology and Monash University.
- Work Package 2: Development of five new extreme event forecast products and their delivery. Lead agency was the Bureau of Meteorology.
- Work Package 3: Testing of experimental forecast products and development of sector risk management packages for climate extremes. Lead agencies were University of Melbourne (UoM), South Australian Research and Development Institute (SARDI) and University of Southern Queensland (USQ) in conjunction with Queensland Department of Agriculture and Fisheries (DAFQ).
- Work Package 4: Extension and training. Lead agencies: BCG (previously known as Birchip Cropping Group) with support from University of Melbourne / Agriculture Victoria and in collaboration with other RD&E providers.

The main industry's covered were red meat, dairy, grains, sugar and wine grapes. Support was also provided to cotton, pork and rice industries.

Following an assessment of user (farmer) needs and progressive examination of the existing forecast system (Work Package 1), the Bureau developed a series of experimental extreme event forecasts and posted them on a password protected website (Work Package 2). Industry Reference Groups (IRGs) consisting mostly of farmers, were formed for the main industry's and asked to provide feedback on each of the products (Work Package 3). These products were continually refined over the course of the project. At the same time, IRG members were asked to identify key climate extreme events of consequence in the past; evaluate associated responses to these events; and then help develop industry-specific risk management plans for these industries.

A Community of Practice (CoP) was established in 2018 (Work Package 4) to allow for members of the project team and beyond to come together, share research outcomes, tools, services etc. that relate to extreme events, as well as to gain an increased understanding as to producer needs in forecasting extreme events. It was also set up to provide the Bureau and other project partners with feedback for the newly developed forecast tools and provide training for members of the CoP so they can help facilitate the adoption of the new products amongst their networks. Monthly online meetings were held on fifty occasions with an average attendance of 16 per meeting involving researchers, extension officers, consultants, industry representatives and producers representing over 20 different organisations.

A listing of all outputs from the project can be found at https://piccc.org.au/research/project/FWFA.html. This site includes published papers, videos, webinars etc.

Results

The most popular experimental forecast products were then redesigned into operational products and publicly released on the Bureau's website. The first two products were released by the The Hon David Littleproud MP, Minister for Agriculture and Northern Australia and The Hon Sussan Ley MP, Minister for the Environment in November 2021. The next three products were released in June 2022. Since their release these new products have received over 1.34 million page views. The forecasts are based on the Bureau's seasonal forecast system and are available on the Bureau's public website for the benefit of all agriculture.

The five new operationally available forecast products can be found here http://www.bom.gov.au/climate/outlooks/#/overview/summary.

Outcomes

These new products have provided agriculture in general and farmers in particular with the first ever forecasts of rainfall and temperature extremes for the weeks to seasons ahead. The ability to provide warning of these events increases the ability to manage climate risk. While farmers were the primary intended audience, extremes maps and charts have also been provided to emergency services managers, government and elected officials especially during the 2022 La Nina flooding periods. Many of the decisions that were assisted by using the maps have inevitably assisted farmers in many and varied indirect ways (e.g. releasing water from large storages ahead of rains to reduce flooding).

As the Bureau products were publicly released late in the project, a variation to the program contract incorporated a more focused extension and communications campaign across the final 14 months aiming to deliver more presentations, webinars and legacy products. This campaign included delivery of over 20 industry talks, five webinars and videos, four farmer focussed case studies and a multiple part eLearning program (https://agriculture.vic.gov.au/support-and-resources/elearning/climate-and-weather-courses) focused around the new FWFA products.

The project has delivered a state-of-the-art forecasting service for extreme climate events via the Bureau's website. The project has improved the quality of climate and weather information available to the agriculture sector. This will improve decision-making, resilience and proactive planning for managing climate variability and change.

An independent final review concluded that *the FWFA RND4P project has been a valuable, relevant, effective, and efficient RD&E project. FWFA directly addressed each of the RND4P Program objectives and represents a practical response for the agricultural sector to better understand and adapt to a variable climate'*. It also found that 'o*verall, the project was well designed and executed with few research gaps. The FWFA project has been presented by stakeholders as a best practice example of a large and complex collaborative R&D project*.

Future research development and extension (RD&E) needs.

In relation to future research and development the project leaves a legacy of:

- Strong networks between researchers from different institutes and agricultural RDCs.
- A large set of experimental forecast products.
- A large body of scientific knowledge.
- Key insights into agricultural decision-making and the use of forecast information.

Future research, development and extension should leverage off and build on these established relationships, knowledge and insights to further refine and enhance the quality and interpretability of forecast information available to the agriculture sector. The experimental products are a key resource for future projects. In this regard and to build on the project's legacy, as there were some funds available toward the end of the project, it was decided, in conjunction with the southern NSW Innovation Hub, to contract Pinion Advisory to develop an extreme event training program for producers and advisors. This work will be completed by June 2023.

Abbreviations and glossary

Name	Abbreviation
Australian Pork Limited	APL
Bureau of Meteorology	Bureau
Community of Practice	CoP
Cotton Research and Development Corporation	CRDC
Dairy Australia	DA
Forewarned is Forearmed	FWFA
Grains Research and Development Corporation	GRDC
Industry Advisory Group	IAG
Industry Reference Groups	IRGs
Meat & Livestock Australia	MLA
Madden-Julian Oscillation	MJO
Project Leaders Group	PLG
Queensland Department of Agriculture and Fisheries	DAFQ
Research and Development	R&D
Research, Development & Extension	RD&E
Rural Research and Development Corporations	RDCs
Rural Research & Development (R&D) for Profit	RRD4P
South Australian Research and Development Institute	SARDI
Southern Annular Mode	SAM
Sugar Research Australia	SRA
University of Melbourne	UoM
University of Southern Queensland	USQ

1. Project rationale and objectives

Australian farmers and agribusiness operate in one of the most variable climates of any country in the world. Extreme climatic events (such as heatwaves, frost, heavy rainfall and extended dry) and climate variability are amongst the largest drivers of annual agricultural production and income. Several studies have concluded that further research is required to provide farmers with improved capacity to manage extreme climate and weather events.

Considerable use is made of existing weather forecast warnings (days 1–7) for extreme events, such as heavy rainfall and heatwaves. However, there is a significant gap in warnings of these extremes beyond 7-days and out to seasons ahead. Consequently, there is a significant gap in farmer's capacity for short-term proactive mitigation and response planning strategies to upcoming extremes. The Forewarned is Forearmed (FWFA) project's key aim was to start filling that gap.

The approach was that the Bureau, working with several research partners, would develop and deliver forecasts of the likelihood of climate extremes on multi-week and seasonal timescales — beyond the 7-day weather forecast. The products would be focused on heat, cold and rainfall extremes, for example, "What is the likelihood of having a decile 10 rainfall this spring?"; "What is the chance of having a heatwave in the week after next?"; "What is the chance that the upcoming month will be extremely hot?"; "What is the likelihood of having more heavy rainfall events than usual in the upcoming fortnight?". This would provide farmers with the first ever forecasts of climate extremes in the weeks to seasons ahead.

Project partners include agricultural climate and systems analysis researchers and extension experts with expertise in the dairy, beef, sheep, grains, sugar and wine industries. Partners would use Bureau outputs and work directly with farmers and farm consultants to interface the forecasts with agricultural decision-making, including developing risk management strategies.

The national project included collaboration between eight RDCs (Meat & Livestock Australia (MLA), Grains Research and Development Corporation (GRDC), Dairy Australia (DA), Agrifutures Australia, Sugar Research Australia (SRA), Cotton Research and Development Corporation (CRDC), Wine Australia, Australian Pork Limited (APL)), and had user-reference groups encompassing six industries (dairy, northern beef, southern red meat, grains, sugar and wine). While these are the main industries where direct producer involvement occurred, the outcomes of the project were extended into other agricultural industries (especially cotton, pork and rice) and beyond.

Communicating and applying climate forecasts to decision-making is an ongoing challenge, particularly given their probabilistic nature. Some of these challenges were addressed by the Round one Rural R&D for Profit Project "Improved use of seasonal forecasting to improve farmer profit". FWFA has built on that understanding. However, the key focus in FWFA was on interfacing forecasts of extremes (rather than average or median conditions) to agricultural decisions.

The overall objective of the FWFA project was to develop and deliver a state-of-the-art forecasting service for extreme climate events delivered via the Bureau website.

While structured industry engagement in projects is not new, FWFA scales this approach at a level rarely seen in Australian agriculture – with 14 project partners working together in an end-to-end approach, underpinning climate science, forecast product development, engagement with users, and the delivery and extension of a new service.

2. Method

The FWFA project was comprised of four work packages as depicted in Figure 1.

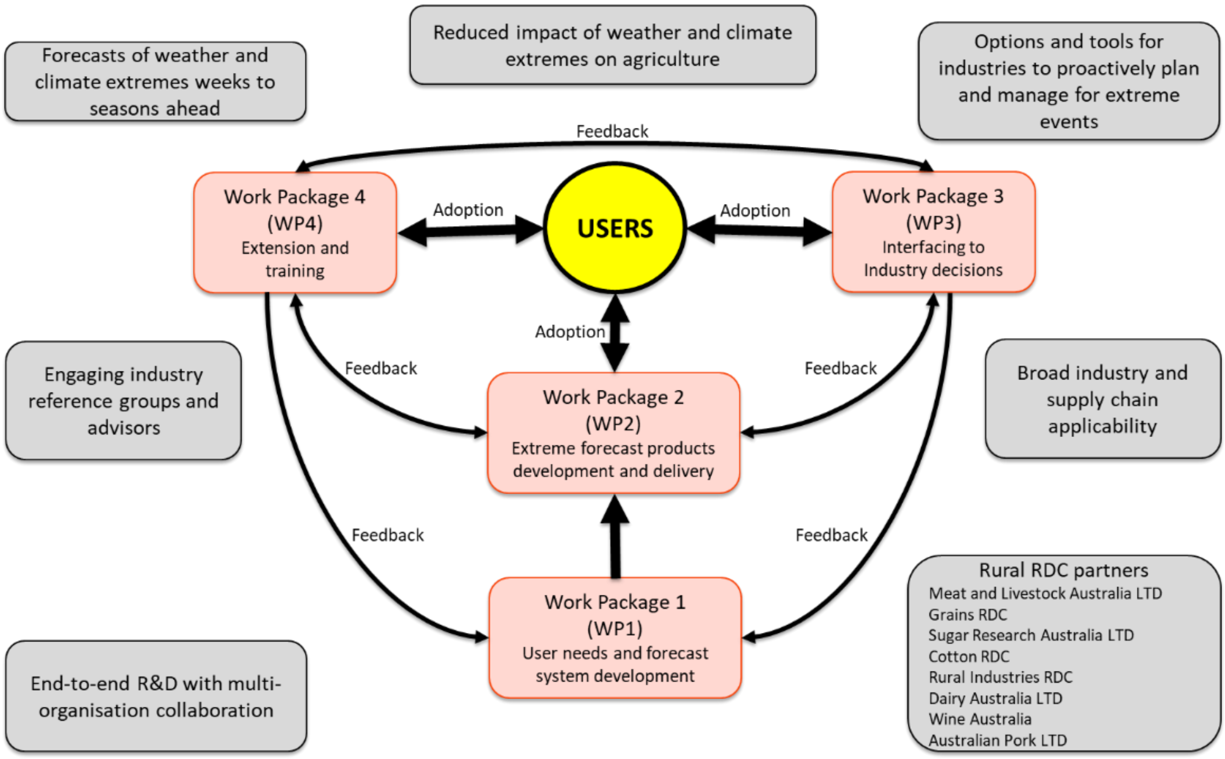


Figure 1. Overview of FWFA.

A description of each of the work packages is provided below.

Work Package 1: User needs and forecast system development

Lead agency: Bureau of Meteorology and Monash University in collaboration with other RD&E providers.

Focus

This work package was research orientated and involved the following elements:

- working with key agricultural industries to understand what farmers and other members of the supply chain need (and when) in relation to forecasts of extreme weather and climate events on multi-week to seasonal timescales.
- increase the understanding of the drivers and level of predictability of weather and climate extremes - this scientific knowledge underpinned the development of new climate extreme prediction services.
- identify and reduce systematic biases that will improve the ability to predict extremes and seasonal forecasts more generally.

Work Package 2: Extreme event forecast products development and delivery

Lead agency Bureau of Meteorology in collaboration with other RD&E providers.

Focus

This work package was research and development orientated and worked with both the scientific and agricultural community to:

- develop new extreme weather/climate forecast products for use in agricultural decision-making.
- test and refine the new products generated (see also Work Package 3).
- develop and deliver at least five new products as a service to farmers that have sufficient utility and accuracy to be of value.
- increase uptake of seasonal prediction products and services for agriculture.

Work Package 3: Farmer and advisor application development

Lead agency University of Melbourne, SARDI, University of Southern Queensland in conjunction with QDAF, in collaboration with other RD&E providers.

Focus

This development-based work package linked closely with Work Packages 2 and 4 and was focussed on:

- establishing industry reference groups (IRGs) for key agricultural industries including southern red-meat, northern red-meat, dairy, wine, grains, and sugar industries (pork, rice and cotton did not have their own reference groups but their RDC was involved) to:
  - identify key climate extreme events of consequence in the past.
  - evaluate associated responses to these events.
  - develop industry-specific risk management plans for these industries.
- collecting and evaluating feedback on the products and tools produced in Work Package 2.

Work Package 4: Extension and training

Lead agency BCG, supported by Uni of Melbourne/Agriculture Victoria, in collaboration with other RD&E providers.

Focus

This work package was predominately extension based and involved the following elements:

- building on previous research to further implement Community of Practice activities to disseminate the findings of the FWFA project.
- facilitating training for new climate products.

- communicating new climate products developed through the project using existing extension avenues especially 'The Break' and other outlets.
- increasing awareness in agricultural industries of the extreme events products, risk management tools and evaluated response scenarios so as to increase uptake of extreme event products.

Project governance

There were two primary project governance groups:

Project Leaders Group (PLG) – regular liaison was undertaken with PLG members who represented all R&D provider organisations to progress the integrated implementation of the FWFA project. The PLG monitored project progress from an operational point of view.

Investor Advisory Group (IAG) – The IAG held regular meetings to oversee project progress from an investor point of view and to establish policy when needed (such as deciding which new forecast products would be operationalised). The IAG was the key decision maker for the project.

Locations

The research, development and extension activities were undertaken in partner facilities. The Bureau's Head Office in Melbourne was a key meeting place when pandemic rules allowed.

However, the actual locations of where the new forecast products could be used involved over 500 'weather stations' – see Figure 2

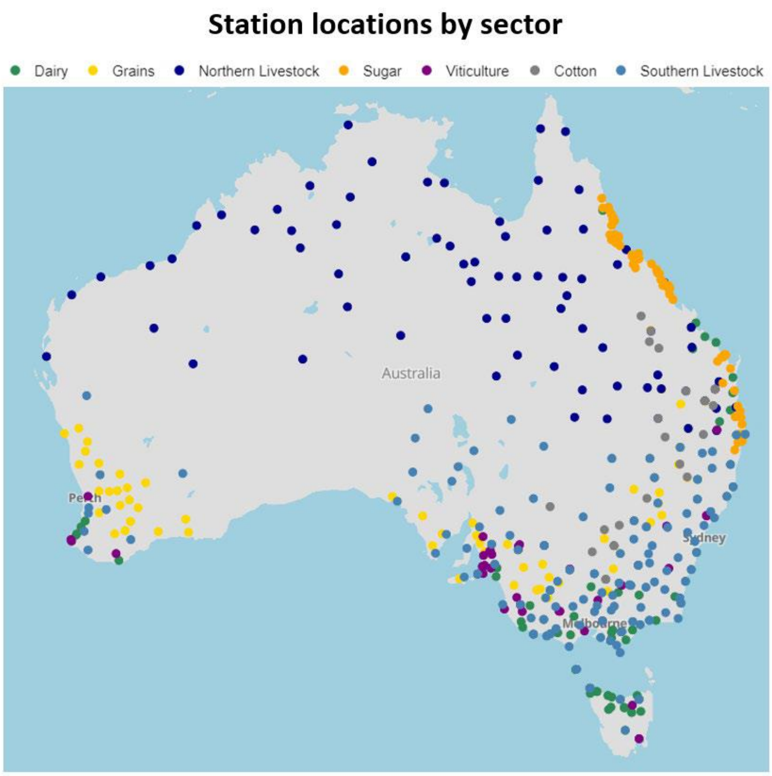


Figure 2. Map showing the set of almost 560 test weather stations used for the location-based products.

3. Project Outcomes

The outcomes of the project are summarised by each work package.

3.1 Work Package 1: User needs and forecast system development.

User needs

Nine Industry Reference Group workshops were held between October 2017 and September 2018 across Australia. The workshops were attended and coordinated by Bureau project staff together with the work package 3 researchers. Timing and locations were:

- Sugar industry, Townsville, 26 October 2017
- Red Meat industry, Charters Towers, 27 October 2017
- Red Meat industry, Longreach, 7 November 2017
- Red Meat industry, Rockhampton, 8 November 2017
- Northern Red Meat and Sugar industry Reference Groups, webinar, 11 April 2018
- Dairy reference group workshop, Melbourne, 7 June 2018
- Southern Red Meat reference group workshop, Melbourne, 22 June 2018
- Grains reference group workshop, Canberra, 17 August 2018
- Wine reference group workshop, Adelaide, 13 September 2018

The purpose of the workshops was to gather insights into the main weather and climate risks and the utility of extreme climate forecasts in the respective industries. Topics covered included primary weather/climate risks; key weather-related decisions; how might a forecast help; what actions could be taken in response to a forecast; how far in advance is information required to be able to act; and what are the critical times of year.

In addition, the workshops were used to identify cases of extreme events that had a significant impact on agricultural industries participating in the project. A spreadsheet was prepared that documented these events. The purpose of the spreadsheet was to identify possible case studies for scientific analysis, risk management, education and communication. In terms of the scientific analysis, recent events that occurred during the project (in 2019 and 2020) were used for case studies.

A user needs synthesis report was prepared (Shelley, 2018; see Appendix 7.1). The report drew together information from RRD4P Round 1 projects, information from the Reference Group workshops and additional insights from work with stakeholders as part of the Bureau's Agriculture Program regular business. This report synthesized decision points and forecasting needs of the red meat, grains, wine, dairy, sugar, rice, cotton and pork industries in managing rainfall, heat and cold weather and climate extremes in Australia. It focused on defining management actions, key regions, timescales (weeks/months/seasons) and lead times, and times of year where agricultural businesses are most impacted.

Capturing insight into user needs was an ongoing activity throughout the project.

Underpinning science

The next element of this work package was to increase the understanding of the drivers and level of predictability of weather and climate extremes. This scientific knowledge underpinned the development and communication of the extremes service.

This science was critical to understand both the Bureau's forecast system and how the main climate drivers are related to extremes over Australia. The understanding underpinned the seasonal climate service and was critical in helping to understand real-time forecasts.

An example of some of this work was the Bureau's stratospheric research that demonstrated for the first time the role that Antarctic polar vortex variations may play in predicting climate extremes over Australia up to a season in advance. The culmination of this work included two very high-profile publications in the international science community (https://www.nature.com/articles/s41561-019-0456-x and https://doi.org/10.1175/BAMS-D-20-0112.1). . In addition, all the science came to bear in winter-spring 2019, when the air above Antarctica warmed unusually and became a driver of the extremely hot and dry conditions and catastrophic fire danger that was experienced in spring of that year. Not only were the Bureau able to forecast it, but the science that had been done gave them confidence in the forecasts and an understanding of what was going on, which they were able to communicate. The communication through public mainstream media and its possible implications for eastern Australian spring climate was very effective and brought a lot of attention to the progress the Bureau were making in predictive capability that was being supported by FWFA. A Conversation article on the 2019 event, written by FWFA researchers, received over 700,000 views (https://theconversation.com/the-air-above-antarctica-is-suddenly-getting-warmer-heres-what-it-means-for-australia-123080?fbclid=IwAR3PfTz6sOqTCMq4I5-zr4g1J2Zaq7RhsjBM7Cjxf7SrxxyPedrn_uqq6l4).

The Bureau have reported significant progress with regards to rainfall, heat and cold extremes with the research showing how:

- modes of climate variability (climate drivers) such as variations in the stratospheric polar vortex, El Niño, the Madden-Julian Oscillation (MJO) and the Southern Annular Mode (SAM) influence climate extremes over Australia;
- the skill for predicting extremes varies strongly by location, season and forecast lead-time;
- timescales of predictability vary for different climate drivers;
- climate drivers influence forecast skill for rainfall and temperature extremes over Australia; and
- model errors and initialisation errors impact the prediction skill of multi-week to seasonal extremes over Australia.

This work has provided much-improved understanding of climate driver impacts on Australian climate extremes and their real-time prediction using the Bureau's ACCESS-S climate forecast system. This feeds into regular climate briefings to project partners and stakeholders, industry and government. An example of such has been the FWFA-funded monthly Bureau Climate Science updates which provided monthly climate briefings on the current state of the climate and upcoming conditions to the BCG Community of Practice (note, this was separate from the FWFA COP seminar series).

Improving the forecast system

There were two components of work which led to the development of a new sea-land breeze scheme for the model. This involved:

a) Analysis of model errors during very hot summers and how they might be reduced

This work focussed on how well the ACCESS-S model simulates hot summers. Results indicated that:

- there is a strong El Nino influence on occurrence of extreme maximum temperature seasons (top 20% events);
- when hot summers are observed, the ACCESS-S model underestimates the average maximum temperature and generally has a cold bias over parts of Australia;
- the nature of the error differs if the extreme seasons are defined for the whole of Australia compared to those defined as extreme for only the south-eastern region. This bias has serious implications for the other variables, especially the precipitation rate over Australia, and the Pacific and Indian Oceans; and
- ACCESS-S fails to accurately simulate the increased rainfall over north-eastern Australia and the adjacent ocean during heat extremes over the south-east.

The investigations showed that ACCESS-S produces forecasts of hot summers but not necessarily for the right reasons. The model fails to simulate the observed connection of hot summers in the south-east that occur when it is wet in the north of Australia, thereby missing an important mechanism that can lead to heatwaves.

b) Development of a sea-land breeze scheme to enhance or suppress convective rainfall

The analysis above demonstrated that systematic errors in rainfall over the Maritime Continent negatively affect the simulation of hot conditions (especially in summer) over south-east Australia. This was associated with a lack of convection (rainfall) over the often-complex topography of the many islands that constitute the Maritime Continent. A key reason for this shortcoming is the inability of the model to resolve sea-land breeze circulations that are responsible for a significant fraction of the rainfall in this region.

In response, the Bureau developed a parametrisation for the enhancement and suppression of convective rainfall by a sea-land-breeze system in the global atmospheric model of ACCESS-S. Sea-land-breezes are not currently present in the model and as such their impact on convective rainfall is not represented. This leads to rainfall biases in coastal locations.

The parametrisation makes use of the model's land-sea distribution to calculate a parameter that indicates the existence and strength of sea-breezes along model coastlines. This parameter can then be used to modify the likelihood of convection along coastlines.

The sea-land-breeze scheme has been stored in the code repository for the UK Met Office model and been handed to the Bureau for inclusion in their development of the next-generation seasonal prediction system in collaboration with the Met Office.

The final stage of testing the full effect of the new scheme was delayed by a longstanding computational issue introduced by the parallelisation of the model code. The issue required further assistance from the Met Office. Additionally, due to COVID-19, the postdoctoral researcher who carried out the work left Australia to be reunited with their family in Europe. At that late stage in the project, it would have been very difficult to recruit the skills required in time to carry out remaining testing.

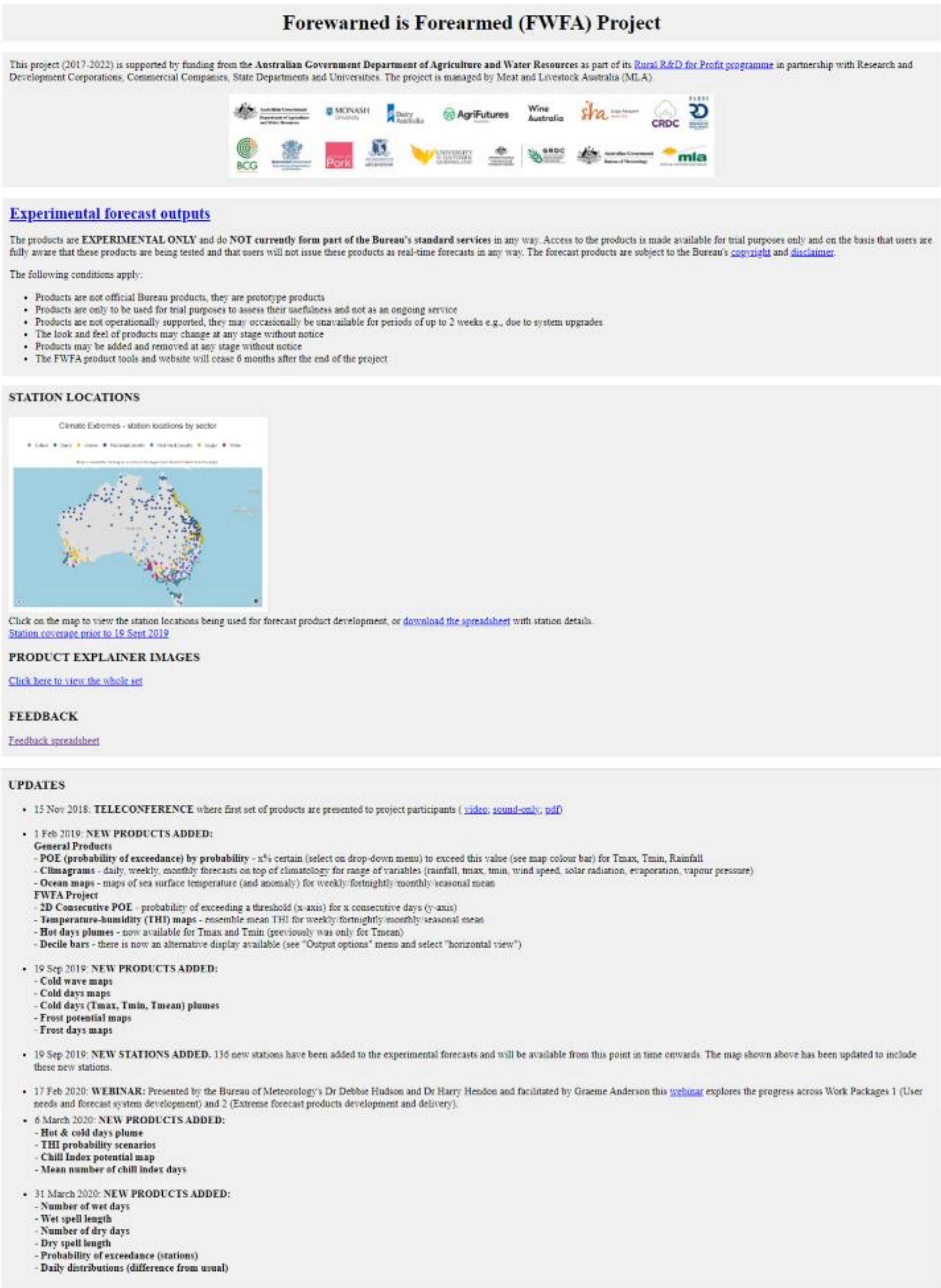
This work was a very significant foundation for catalysing ongoing model development work in this area between the Bureau and the UK Met Office. The Bureau has since picked up this work as part of their core model development, has recruited a new researcher and is now actively working with the Convection Team at the Met Office on the inclusion of the sea-breeze scheme in the new state-of-the-art convection scheme being developed for the next global model configuration. Significant progress has been made in this area.

3.2 Work Package 2: Extreme event forecast products development and delivery

The project involved extensive consultation with industry reference groups and project partners during the forecast product development to provide ideas for product development and to gain feedback on the appearance, utility and interpretation of the experimental forecast products developed.

A research project website for the experimental forecast products was developed (Fig. 3). This website was password protected and available to project partners, IRGs and others (at the discretion of project leaders). It will continue to be available until June 2023. Details are as follows:

- The experimental forecasts are hosted on a special web interface (Fig. 4) which was designed for the project to enable viewing of the forecasts in the trialling and testing phase.
- The forecasts were updated daily in real-time.
- More than 27 products were developed during the project. Table A1 (see Appendix 7.2) lists the experimental products. Some products were more general, and applicable to rainfall, heat and cold extremes, such as the Decile Bars (i.e., counted as one product). Whereas some were specific to either rainfall, heat or cold extremes, such as the rainfall probability of exceedance curves. The product development was done in a co-design approach with partners and users, with the aim of eventually converging on the final products to be made operational. The experimental products were developed in phases over a few years, with feedback gathered at various intervals.
- Each product was accompanied by an "explainer" which described the product and aided interpretation for the trialling phase (e.g., Fig. 5).
- The location-based products were tested and trialled using ~560 weather stations (Fig. 2). The location of these stations was determined in consultation with project partners and industry reference groups. It was vital for the trialling of the products that producers were able to relate the chosen forecast location to conditions on their own farm.



Forewarned is Forearmed (FWFA) Project

This project (2017-2022) is supported by funding from the **Australian Government Department of Agriculture and Water Resources** as part of its Rural R&D for Profit programme in partnership with Research and Development Corporations, Commercial Companies, State Departments and Universities. The project is managed by Meat and Livestock Australia (MLA).

Experimental forecast outputs

The products are **EXPERIMENTAL ONLY** and do **NOT currently form part of the Bureau's standard services** in any way. Access to the products is made available for trial purposes only and on the basis that users are fully aware that these products are being tested and that users will not issue these products as real-time forecasts in any way. The forecast products are subject to the Bureau's copyright and disclaimer.

The following conditions apply:

- Products are not official Bureau products, they are prototype products
- Products are only to be used for trial purposes to assess their usefulness and not as an ongoing service
- Products are not operationally supported, they may occasionally be unavailable for periods of up to 2 weeks e.g., due to system upgrades
- The look and feel of products may change at any stage without notice
- Products may be added and removed at any stage without notice
- The FWFA product tools and website will cease 6 months after the end of the project

STATION LOCATIONS

Climate Extremes - station locations by sector

Click on the map to view the station locations being used for forecast product development, or download the spreadsheet with station details.
Station coverage prior to 19 Sept 2019

PRODUCT EXPLAINER IMAGES

Click here to view the whole set

FEEDBACK

Feedback spreadsheet

UPDATES

- 15 Nov 2018: **TELECONFERENCE** where first set of products are presented to project participants (video; sound-only; pdf)
- 1 Feb 2019: **NEW PRODUCTS ADDED:**
  General Products
  - **POE (probability of exceedance) by probability** - x% certain (select on drop-down menu) to exceed this value (see map colour bar) for Tmax, Tmin, Rainfall
  - **Climagrams** - daily, weekly, monthly forecasts on top of climatology for range of variables (rainfall, tmax, tmin, wind speed, solar radiation, evaporation, vapour pressure)
  - **Ocean maps** - maps of sea surface temperature (and anomaly) for weekly/fortnightly/monthly/seasonal mean
  FWFA Project
  - **2D Consecutive POE** - probability of exceeding a threshold (x-axis) for x consecutive days (y-axis)
  - **Temperature-humidity (THI) maps** - ensemble mean THI for weekly/fortnightly/monthly/seasonal mean
  - **Hot days plumes** - now available for Tmax and Tmin (previously was only for Tmean)
  - **Decile bars** - there is now an alternative display available (see "Output options" menu and select "horizontal view")
- 19 Sep 2019: **NEW PRODUCTS ADDED:**
  - **Cold wave maps**
  - **Cold days maps**
  - **Cold days (Tmax, Tmin, Tmean) plumes**
  - **Frost potential maps**
  - **Frost days maps**
- 19 Sep 2019: **NEW STATIONS ADDED.** 136 new stations have been added to the experimental forecasts and will be available from this point in time onwards. The map shown above has been updated to include these new stations.
- 17 Feb 2020: **WEBINAR:** Presented by the Bureau of Meteorology's Dr Debbie Hudson and Dr Harry Hendon and facilitated by Graeme Anderson this webinar explores the progress across Work Packages 1 (User needs and forecast system development) and 2 (Extreme forecast products development and delivery).
- 6 March 2020: **NEW PRODUCTS ADDED:**
  - **Hot & cold days plume**
  - **THI probability scenarios**
  - **Chill Index potential map**
  - **Mean number of chill index days**
- 31 March 2020: **NEW PRODUCTS ADDED:**
  - **Number of wet days**
  - **Wet spell length**
  - **Number of dry days**
  - **Dry spell length**
  - **Probability of exceedance (stations)**
  - **Daily distributions (difference from usual)**

Figure 3. A screenshot of the FWFA research project website for the experimental products

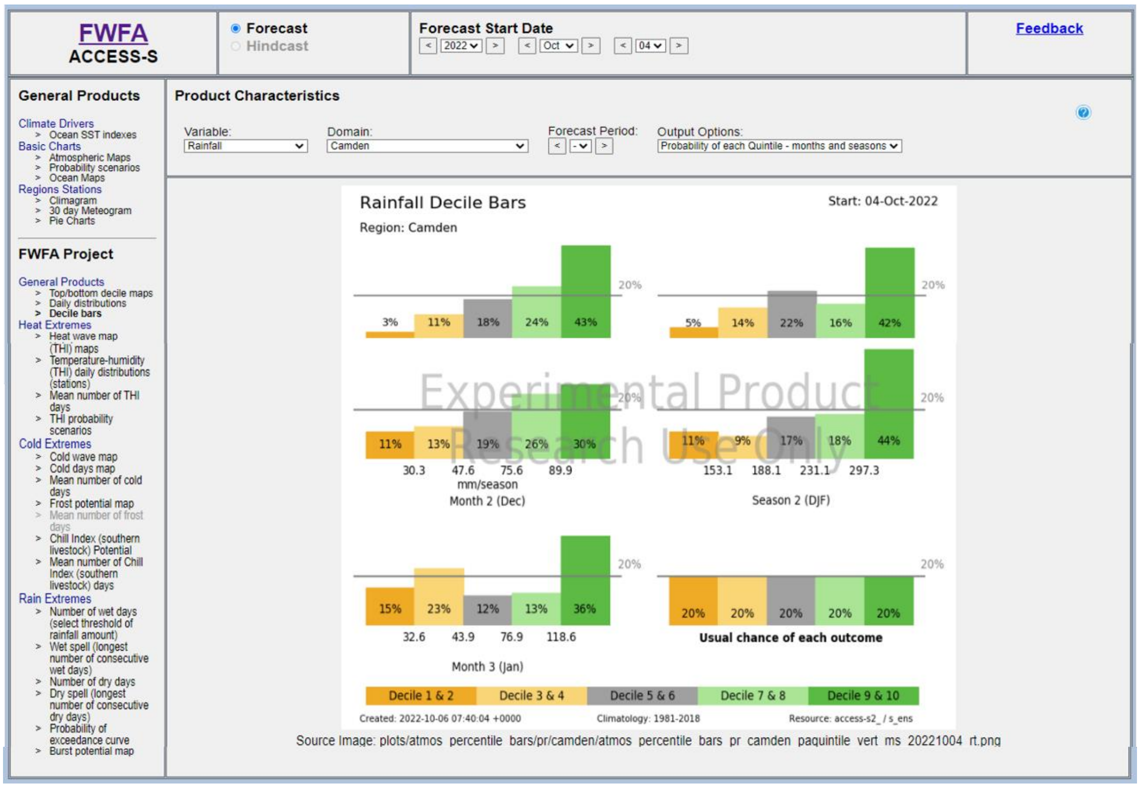


Figure 4. A screenshot of the website hosting the experimental forecast products

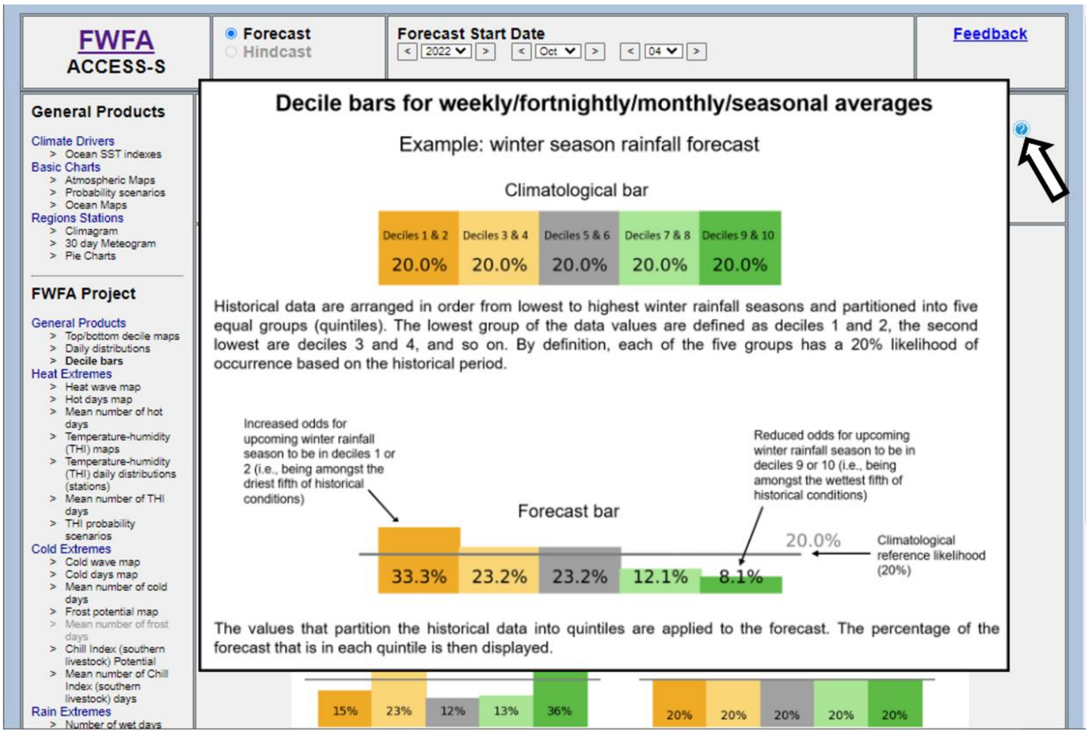


Figure 5. A screenshot of the experimental forecast webpage showing that for any given forecast product there is an accompanying "explainer" (click on the information button)

Feedback on the experimental products:

The feedback on the experimental products was achieved through various channels, but primarily via direct feedback from project partners, through targeted workshops/webinars with the industry reference groups, as well as webinars coordinated by the FWFA COP. The feedback was essential to:

- Provide ideas for product development.
- Facilitate the decisions of which forecast products would transition to become official Bureau products.
- Improve the interpretability and understanding of a product, including the required supporting information (particularly if destined to become an official Bureau product).
- Improve the display of the product (particularly if destined to become an official Bureau product).

The feedback on the experimental products was entered into a spreadsheet and responses from the Bureau were provided against each item (see also 3.3.2).

Five experimental products were selected to become official Bureau products. They were:

1) Extremes maps: showing the chance of having very wet, dry, hot or cold conditions.
2) Decile bars for locations: showing the shift in the probabilities compared to usual across five categories for rainfall, maximum and minimum temperatures.
3) Climagrams for locations: timeseries graphs showing the forecast of rainfall totals, maximum and minimum temperatures respectively for the coming weeks and months.
4) Rainfall probability of exceedance curves for locations: graphs showing the probability of exceeding a range of rainfall amounts.
5) Rainfall burst maps: showing the chance of exceeding 3-day rainfall accumulation amounts.

These are described in more detail later.

Selection of the official FWFA products was a project-wide decision, ratified by the project's IAG. From feedback on the experimental products, and in selection of the five products, it became clear that:

- There was a desire for *forecast information across all timescales*, with little preference for one timescale overall. Practical decisions are being made at a range of timescales. Users want information across daily, weekly, monthly and seasonal timescales, and do not obviously distinguish between "weather" and "climate". This is reflected in all the products, except the burst-potential maps, being offered for spans covering weeks to seasons.
- There was a strong preference for *location-based products*. Hence, there was significant effort in ensuring that location-based products, used experimentally at specific locations, became available across the entire Australian continent.
- The need for *map-based products* was also recognised, such as the extremes maps and the rainfall burst maps. As one of the IRG members commented "Maps are great for an overview, especially for graziers who may be considering other regions for agistment, choosing areas to target for sales, and trying to pick market trends." Maps also put into context whether local- or regional-scale impacts are likely and can help interpretation of confidence in a forecast (e.g., when located in the middle of a region of the "same colour" compared to when located on the edge). In addition, many managers are working for large companies (e.g., Treasury Wine Estates for viticulture) and dealing with production across large areas of Australia.

- There was a strong desire for visualising the forecast as a *time-series for a given location.* This was clear from the popularity of the climagram product. This enables a clear view of what is coming over the time horizon rather than having to look at multiple maps.
- There was a desire for a *range of complexity* of information and the degree of complexity required was dependant on the user. A comment from the Grains IRG was that they may use simpler products for a "quick-look" summary of the forecasts, but that for a business decision they would then want to have as much information as possible, such as shown in the rainfall Probability of Exceedance Curves. Many of the FWFA products are relatively complex and often require some initial explanation. Based on the range of feedback received, the understanding of the products varies considerably. The following three comments from IRG members provide an indication of some of the range in responses:
  - "If the information is presented with too much complexity growers will be turned off."
  - "I am fine with the presentation of most products and would not like things 'dumbed down' too much."
  - "Now that I am starting to understand how to read the products, I am quite comfortable with the current displays."

Once a product was selected for operations, feedback from internal testing, project partners and IRGs informed the refinement of the appearance and interpretation of the selected products. Feedback was sought through webinars, meetings and surveys (e.g., http://piccc.org.au/research/project/FWFA_Forum.html).

Required changes to the front-end (website) were undertaken to host the new products and display them in accordance with agreed visualisation and functionality, including supporting information such as forecast accuracy, period climatology and product explanation.

Code and data used in the experimental version were further developed and optimised to ensure that the operational process ran smoothly and expeditiously across the entire Australian continent for the location-specific products so as not to cause delay. Data not previously presented on the experimental site (such as accuracy and climatology) were prepared and included in the operational process.

Work was done to ensure that the product generation code had been peer reviewed, had suitable unit tests, was thoroughly documented, had an archived code-history and met Bureau computing requirements for deployment into the Bureau production environment.

The code was migrated into the Bureau's production supercomputing environment, while ensuring all data-feeds and transfer processes were robust and maintained the agreed level of service.

The operational forecasts were delivered on the Bureau public webpage, with salient messages about the extremes forecasts from now on included in successive outlook summaries.

<u>Operational products</u>:

The five official Bureau products:

The five new forecast products provide producers and advisors with information to improve resilience and productivity and are available on the Bureau's website. Users can select any location to view its chance of unseasonal and extreme temperature and rainfall for the weeks, months, or seasons ahead.

The first two products were released to the public in November 2021 and the final three in June 2022. The new forecast products are:

Product 1: Extremes Maps

Maps of the chance of having extreme (deciles 1&2 and deciles 9&10 respectively) rainfall, maximum and minimum temperature for the weeks to seasons ahead.

The extremes maps show the chance of having extreme rainfall, extended dry periods, and unusually high or low maximum and minimum temperatures for the weeks, months and seasons ahead (e.g., Fig. 6). These maps are a natural extension of the Bureau's already available probability of above median maps and show the chance of having unusual wet, dry, hot or cold conditions. For these maps "extreme" has been defined as being amongst the driest, wettest, hottest or coldest 20% of periods (weeks/months/seasons) from the climatological (historical) period (i.e., deciles 1 & 2 (bottom 20%) or deciles 9 & 10 (top 20%)).

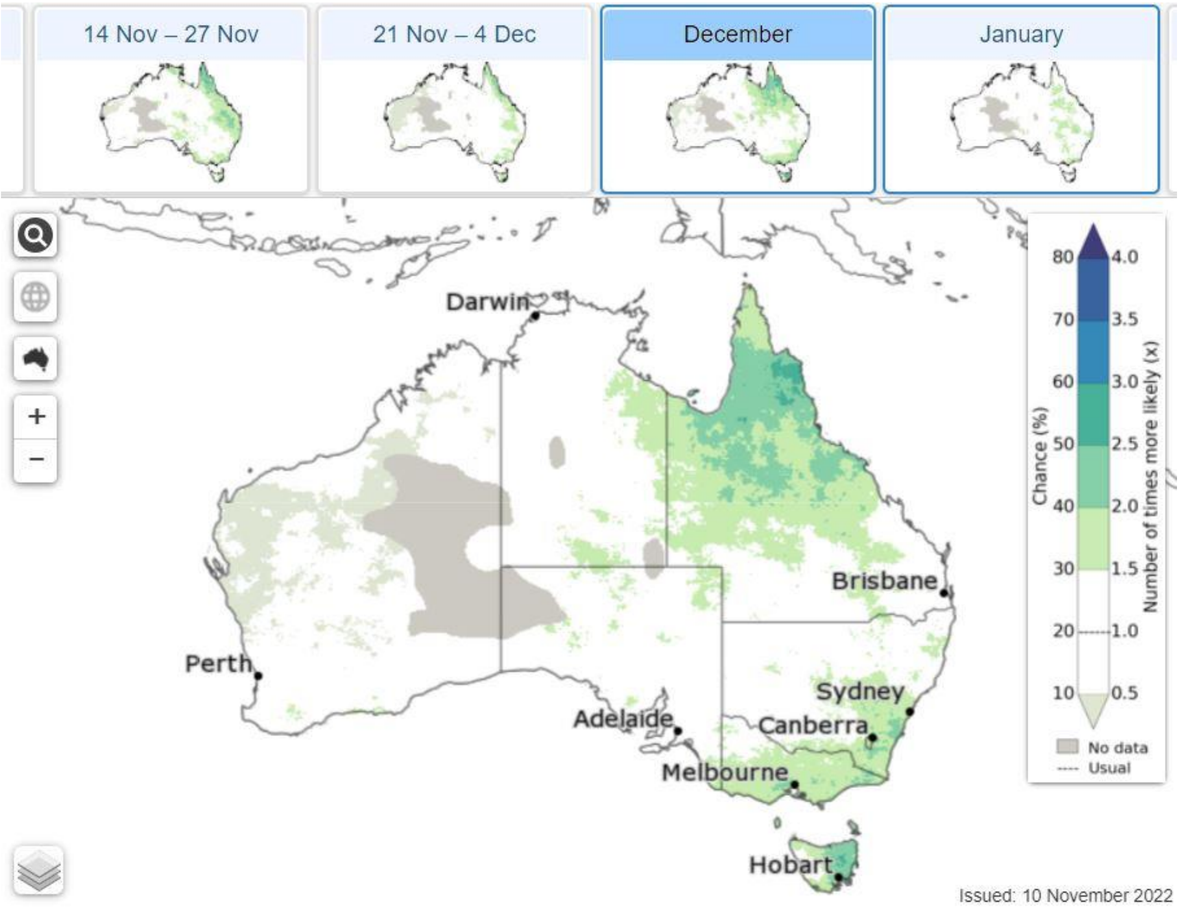


Figure 6. Example of an extreme map: Chance of unusually high rainfall for the next calendar month. This map shows the chance of having rainfall totals in highest 20% of the historical range (decile 9 and 10) in the month of December 2022. Issued 10 November 2022.

The extremes maps are accompanied by maps of forecast skill and the climatological (historical) extreme threshold (i.e., 20th or 80th percentile value) for the particular period under scrutiny are also available from the website (e.g., Fig. 7).

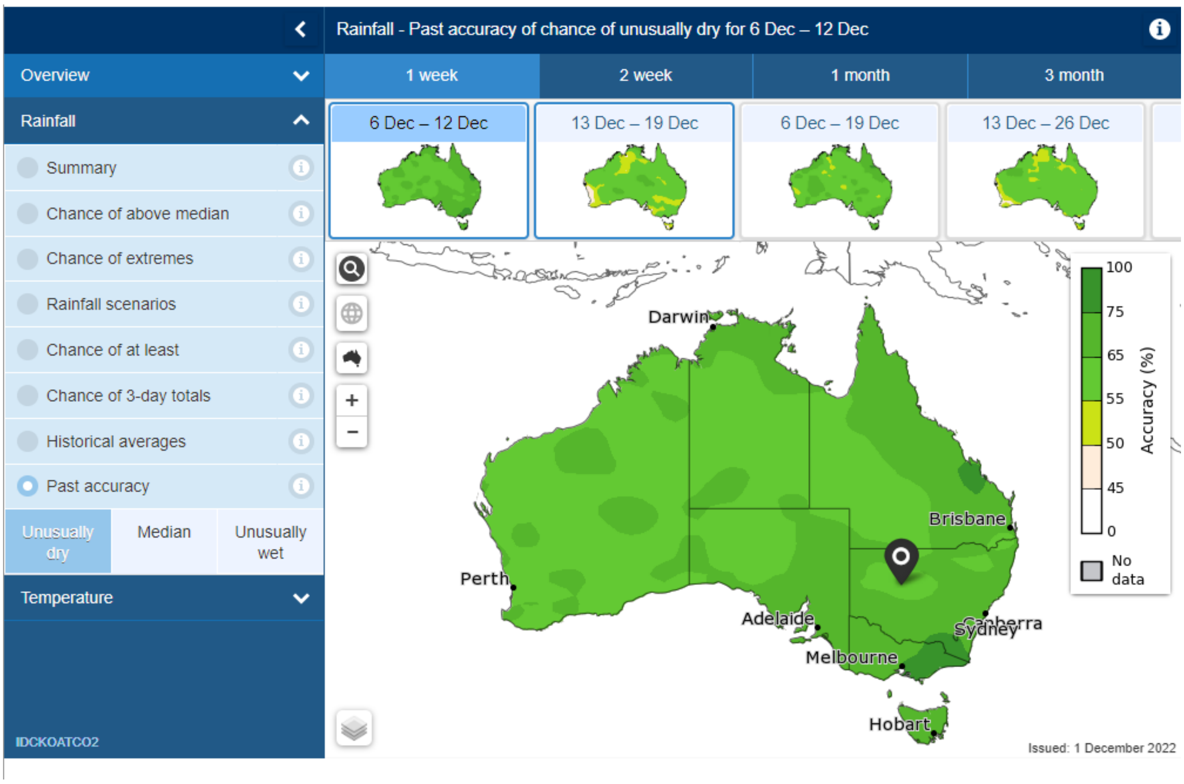


Figure 7. Example of a skill map (top) and a historical threshold map (bottom) for rainfall. The skill map is showing the past accuracy of forecasts of the chance of unusually dry conditions (i.e., being in the bottom 20% of historical conditions) for the week of the 6-12 December. The threshold map is showing the 20th percentile threshold value (calculated over 1981-2018) for the week of the 6-12 December.

Product 2: Decile Bars

Location-based graphs of the chance of being in any of the climatological quintiles for rainfall and temperature (minimum and maximum) for the weeks to seasons ahead.

The decile (or quintile) bars are location-based bar charts for any location in Australia displaying the likelihood of rain/temperature being in each of 5 climatological ranges (i.e., the likelihood of being in the lowest to the highest 20% of historical records, and indicate the shift in the probabilities compared to usual across the five categories (quintiles). These are displayed in a pop-up window for a selected location, activated when the location is clicked on, or searched for from an outlook map (e.g., Fig. 8). They are available for rainfall and maximum and minimum temperatures for the weeks, months and seasons ahead. These were one of the most popular products that arose from consultation with producers and advisors, given that they are location-based, show changes relative to what is usually expected across a range of categories and is relatively easy to understand.

An indication of the model skill for each forecast is also included in the display by way of a star-rating (Fig. 8).

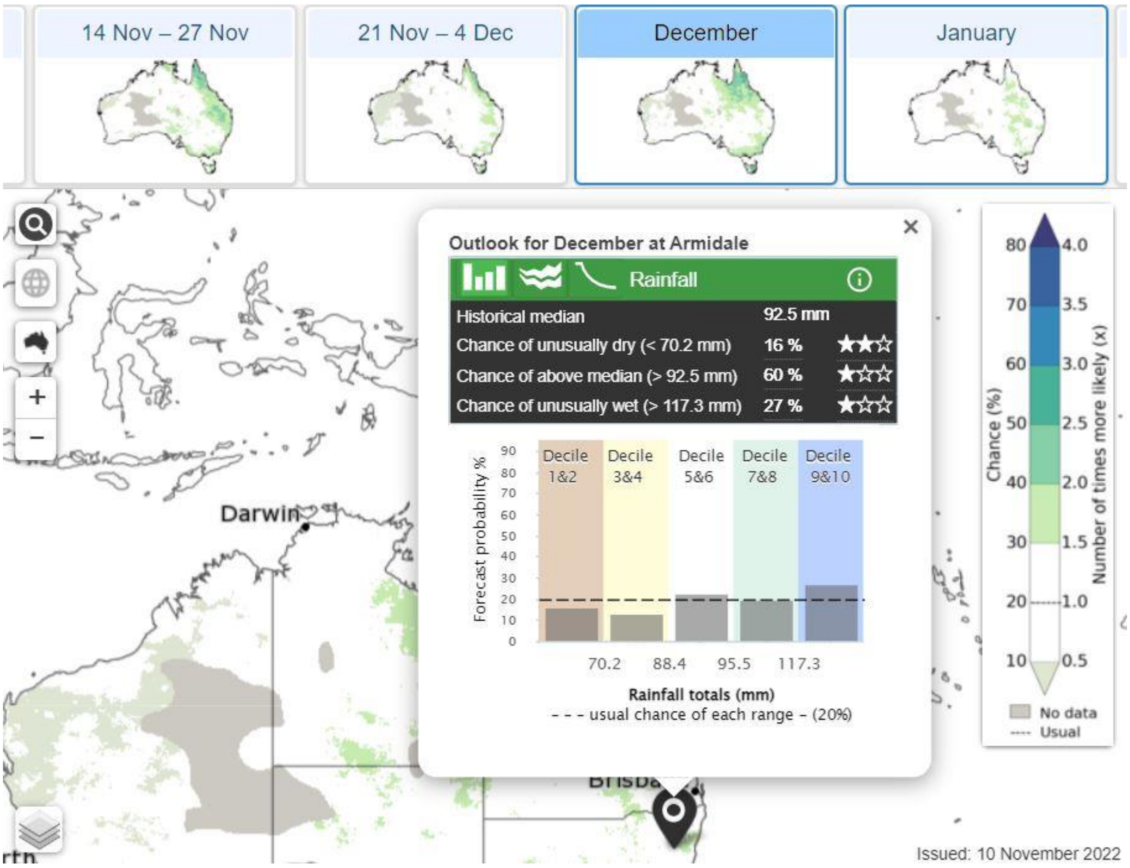


Figure 8. Example of the decile bars showing the rainfall forecast for Armidale, NSW for the month of December (generated on 10 November 2022). The forecasts show the probabilities across five different quintile ranges. The long-term average probability ("usual chance") for each category is 20% and the forecasts show the shift in the odds compared to usual.

Product 3: Climagrams

Location-based graphs of the time series of forecast rainfall and temperature (maximum and minimum) for coming weeks and months.

The climagrams are location-based rainfall and temperature time series graphs for any location in Australia. These are weekly and monthly recent observations showing the forecast of rainfall totals, maximum and minimum temperatures respectively for the coming weeks and months (e.g., Fig. 9). They also appear on the pop-up window for a given location. Past observations are also shown on the graph. Insight from producers and advisors really drove the creation of this product due to the strong desire to visualise the forecast as a time-series for a given location (rather than having to look at multiple maps).

An indication of the model skill for each forecast is also included in the display by way of a star-rating (Fig. 9).

Figure 9. Example of a climagram. The timeseries of observed (solid line) and forecast (box plots) rainfall (y-axis) for consecutive weekly periods (x-axis) for Armidale. The box plots indicate the range in the expected outcomes from the forecasts. The background colour indicates the historical quintile ranges.

Product 4: Rainfall Probability of Exceedance

Location-based graphs of the chance of exceeding rainfall totals for weeks to seasons ahead.

The Probability of Exceedance (POE) forecasts are location-based graphs displaying the probability of a comprehensive range of rainfall amounts for the coming weeks to seasons (e.g., Fig. 10). These appear on the pop-up window. They are probably the most complex of the new products. However, once understood, through the consultation process with producers and advisors, the overwhelming feedback was that this product is valuable and will allow users to delve deeper into the forecast information.

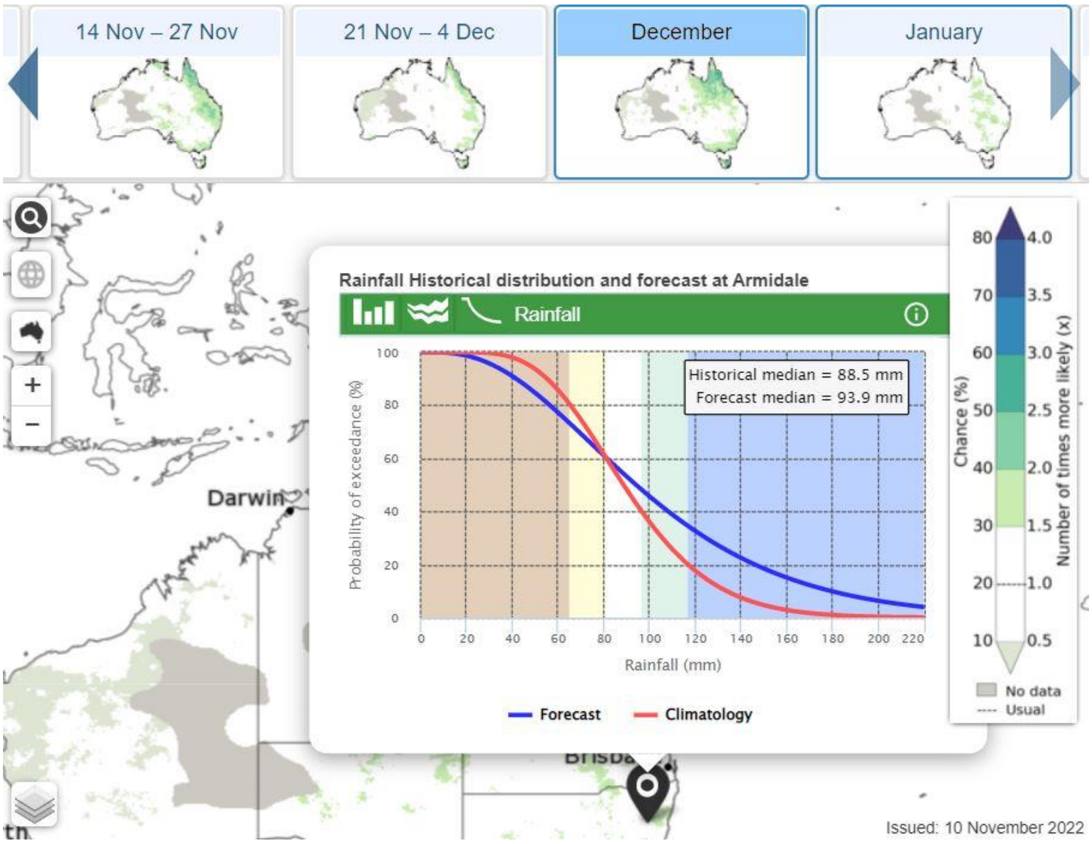


Figure 10. Example of a Probability of Exceedance forecast for rainfall, showing the forecast (blue) and usual conditions (red) for Armidale during the month of December 2022. The curves give the probability (y-axis) of experiencing different thresholds of rainfall (x-axis).

Product 5: 3-day Rainfall Accumulation (or "burst")

Maps of the chance of having specified 3-day rainfall accumulations in the weeks to fortnights ahead.

The 3-day rainfall accumulation (or "burst") maps show the chance of having events where 3-day rainfall totals ranging from 15 mm to 75 mm are exceeded in the weeks and fortnights ahead (e.g., Fig. 11). This product provides more information about the distribution of rainfall within a period. For example, there is a big difference in the impact of having a week of light rainfall each day compared to a burst of rainfall over 3-days. This product was particularly popular with northern producers to, for example, indicate the prospect of achieving "green date" conditions in upcoming weeks.

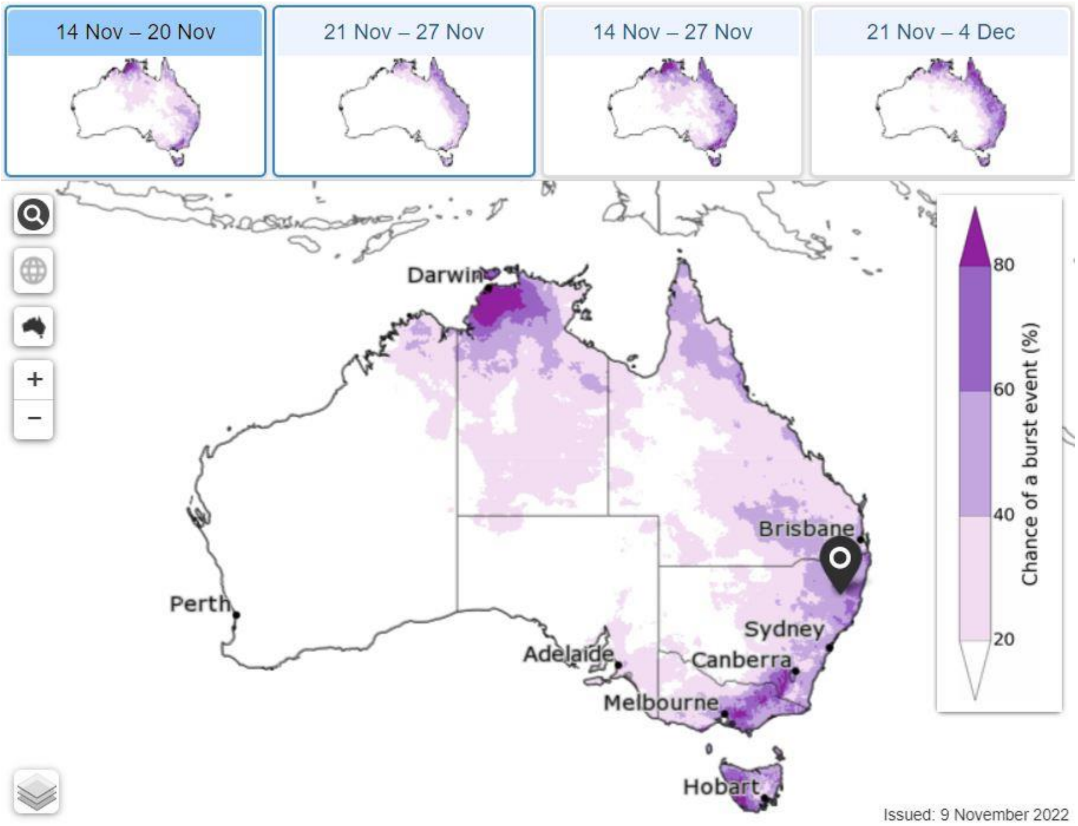


Figure 11. Example of the 3-day rainfall accumulation (burst) product. The map shows the probability of receiving an intense "burst" of rainfall over a short period of time. This is showing the chance of at least 25 mm within 3 days during the period 14 November to 20 November 2022. The forecast was issued 9 November.

3.3 Work package 3: Farmer and advisor application development

Work package 3 involved several facets.

3.3.1 Establish industry reference groups

As noted above, IRGs were formed for southern red meat, northern red meat, grains, wine grapes and sugar. These were managed by project partners in University of Melbourne, SARDI and University of Southern Queensland (with QDAF).

The role of the IRG member was to participate and contribute to FWFA with the aim of representing the views of dairy producers / southern red-meat producers / northern red meat producers / wine grape producers / grain producers and sugar producers around extreme climate and weather events. More specifically they had a role in identifying likely on farm impacts, prioritising the extreme events risks of most consequence to their industry, contributing to an extreme events risk management framework for their industry as well as providing feedback to the Bureau on their forecasting products usefulness and applicability to their respective industry.

A structured and iterative consultation process involving the IRG was undertaken to:

a) Identify the extreme events of greatest consequence to their industry (first face-to-face workshop);
b) Identify appropriate response scenarios to each identified extreme event (scheduled virtual meetings and email); and
c) Evaluate the products and tools produced by Bureau (scheduled real-time sessions, resources made available on web and facilitation of surveys and web forums).

Industry workshops were held face to face for the IRGs across 2017, 2018 and 2019. During 2020 to 2022 workshops were almost exclusively by zoom / Teams due to the COVID-19 pandemic. Participation and contribution of the IRG members varied throughout the project with COVID-19 limiting face to face meetings which were more effective than webinars and online meetings. A small number of IRG members continued to provide feedback throughout the project.

In northern Australia, an important source of feedback was provided through the Northern Australia Climate Program (NACP) network of Climate Mates and their producer clients in the red-meat industry, and the Drought and Climate Adaptation Program (DCAP) network of sugar industry clients.

3.3.2 Facilitate IRGs to provide feedback to the Bureau

Over the course of the project as the Bureau developed experimental forecast products, the IRGs were engaged to provide feedback on each product (see section 3.2). Most of these 'feedback sessions / meetings' were done digitally due to the pandemic which was less than optimal.

Once experimental products were selected as recommendation by the PLG to be operationalised, a meeting of the IAG was called to consider that recommendations. All PLG recommendations were accepted by the IAG. During the development of operational products further meetings of PLG members and IRG participants were held to get further feedback on the look and feel of the operational products. The Bureau took this feedback on board and came back with final products which, as noted earlier, were released in November 2021 and June 2022.

In the north, external to the IRG activities other events (workshops, multi-topic days, webinars) were conducted by NACP and DCAP where FWFA products were discussed and feedback collected and provided to the Bureau.

3.3.3 Produce an extreme event risk management framework

Work package 3 research partners have contributed to industry specific and generic risk management packages for extreme climate events. This work was led by SARDI.

The process taken was to look at key questions of identifying risks, matching risks to climate and weather information and then conducting Decision Analysis. The process used was:

1. **Start by listing the main risks from climate**

   Begin by identifying and prioritising the key weather and climate risks for different enterprises. The FWFA project had lists generated by IRGs for grains, red meat, dairy, wine and sugar. It had also developed simple worked examples from grains, dairy, sheep and sugar industries.

2. **Then match the risks to information on climate extremes**

   Different risks require specific climate information at a range of time periods from weeks, months, seasons and years. Feedback on information gaps is important. In recent times the Bureau of Meteorology has issued forecasts on more time periods, updated more often.

3. **If necessary, use Decision Analysis for extra insights**

   When a climate risk is matched to climate information, the decision can be obvious. Sometimes a climate risky decision is difficult even with a forecast that shifts the odds to wetter/drier or warmer/cooler. Decision Analysis is an applied economic tool to deal with decisions where 1) the outcome matters to the decision maker and 2) information is incomplete. The following is a worked example of Decision Analysis for the grains and dairy industry.

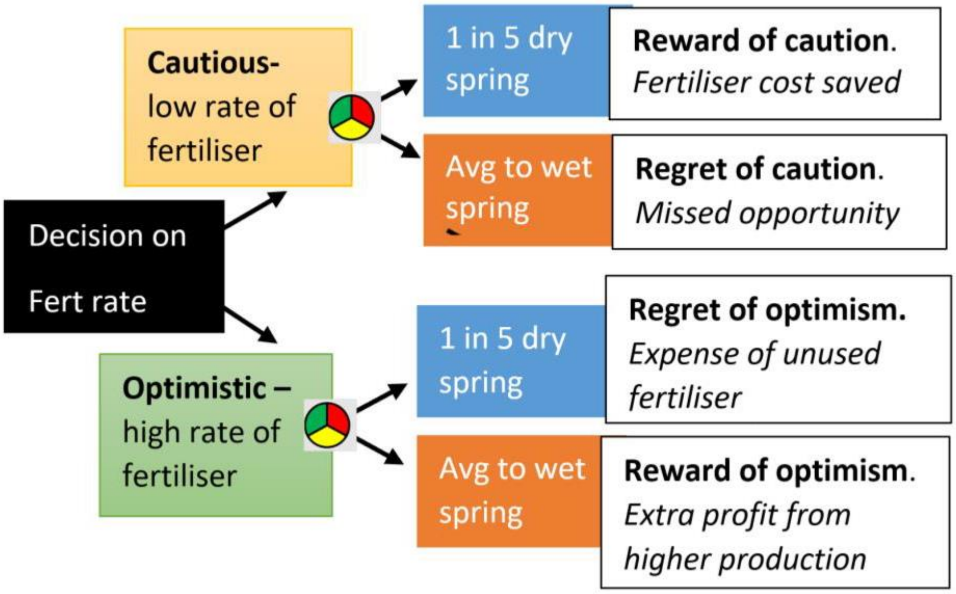


Figure 12: Worked examples of these sort of tools were provided to the relevant RDC's.

In addition to industry sector risk management strategies, the project, led by SARDI also developed a generic climate risk decision analysis. A copy of this is at Attachment 2 to this report.

3.4 Work package 4: Extension and training

Measurable impacts of extension occur over significant time and rely on focused strategies and investment.

Work Package 4 was to deliver FWFA extension and training which as it turns out, within the timeframe, was not an insignificant challenge given the first two Bureau products were operational just over a year before project end (November 2021) and the final three only six months (July 2022) before the end of the project.

As a part of project activities, a Community of Practice (CoP) was established by BCG in 2018 to allow for members of the project team and others to come together, share research outcomes, tools, services etc. that relate to extreme events, and gain an increased understanding as to producer needs in forecasting extreme events. It was also set up to provide the BOM and other project partners with feedback on the newly developed forecast tools and provide training for members of the CoP so they can help facilitate the adoption of the new products amongst their networks.

Monthly online meetings were held on fifty occasions with an average attendance per meeting of 16 researchers, extension officers, consultants, industry representatives and producers representing over 20 different organisations. In conjunction with these meetings, monthly Bureau webinars were also held to help build seasonal climate forecasting and extreme event knowledge amongst the climate community.

In the last 12 months of the project the UoM subcontracted the Agriculture Victoria Team and BCG to further deliver against Work Package 4 using their extensive experience and existing networks. Given the release times of the Bureau products, variations to partner contracts incorporated a more focused extension and communications campaign across the final months of the project. This arrangement delivered further webinars, farmer talks, FWFA eLearn online, case studies, and increased social media and online material and legacy products.

As the Bureau products were developed, the AgVic team brought them directly into their presentations/discussion. As an example, by December 2022 Graeme Anderson and Dale Grey had spoken with over 3,441 farmers and 4,350 advisors across 160 events to southern producers (note these numbers will be underestimated as not all counts were recorded). In addition the AgVic team has developed an eLearning course which is housed on the Victorian Government's Department of Jobs, Precincts and Regions (DJPR) site (https://agriculture.vic.gov.au/support-and-resources/elearning/climate-and-weather-courses) and will grow in promotion and distribution in 2023. In the north, during 2022 alone, USQ and DAFQ staff spoke to well over 1,000 producers / advisors at a range of events where FWFA products were highlighted.

These numbers do not include the attendees and viewers of webinar/video and recording products. From the Excel listing attached to this report, over 21,300 viewers have either attended live (791) or viewed recordings (20,590) regarding the FWFA products and research. Note around 85% of online views are attributed to the Bureau product launch video in 2022 and the latest Climate and Water Outlooks video (29/12/2022) using the new FWFA Tools. This relates to 59 online recordings and includes project specific webinars, Community of Practice meetings and some industry webinars. Again, this will be undercounted as other industry activities in the south have not been reported/captured.

BCG supported a further two Community of Practice meetings in early 2022 and then focussed on supporting the social media promotion across the Climate Kelpie Facebook, Twitter and website. In addition, the FWFA project and outputs featured highly across editions of Climate Kelpie News (in 2022 alone with over 6,000 opens) with 16 focussed articles published on the Climate Kelpie Website blog.

BCG has also produced three farmer-focused case studies based on the FWFA Project products. These will be disseminated in early 2023 and accessible via the Climate Kelpie and UoM PICCC websites. To date, beyond 2022 the Climate Kelpie website will no longer be maintained as it has not been taken on by another organisation.

In the final months of the project a 'FWFA mini-conference' was held so as to achieve two aims:

- To expose FWFA legacy items (forecast products, risk management packages, videos etc) to a broader audience; and

- To discuss where these legacy items may reside in future and how they potentially link with other climate related initiatives such as AgriClimate Outlooks and Climate Services for Agriculture.

The mini conference was highly successful and formed the basis of ongoing discussions.

A listing of all outputs from the project can be found at https://piccc.org.au/research/project/FWFA.html. This site includes published papers, videos, webinars etc.

To further build on the project's legacy items, and as there were still some funds available toward the end of the project, it was decided, in conjunction with the southern NSW Innovation Hub, to contract Pinion Advisory to develop a training program for producers and advisors. This work will be completed by June 2023.

3.5 Achievement against project objectives

The following briefly reports against the project's key performance indicators. It should be read in conjunction with sections 3.1, 3.2, 3.3 and 3.4.

KPI description	Progress achieved against KPI
KPI Progress update of the PLG and IAG (Activity 2)	☒ Achieved ☐ Partially achieved ☐ Not achieved This KPI has been achieved. **Project Leaders Group (PLG)** – There has been regular liaison with and between PLG members (from all research and extension provider organisations) to progress implementation of the FWFA project. Due to COVID restrictions there have been no face-to-face meeting of the PLG since the 10 March 2020 meeting, except for the December 2022 mini FWFA conference. Over the project period focus has been placed on: • Updates from all work package partners • Engagement of IRG's • Discussion around and recommendations to the IAG on the preferred experimental products to be operationalised • Input into the design of operational products • Progress with risk management frameworks and extreme event scenarios – both generic and industry specific **Investor Advisory Group (IAG)** – The IAG held specific meetings over the course of the project to consider new Research & Development (R&D) projects and make selections of which products to operationalise. The IAG approved all five forecast products to be operationalized by the Bureau.

KPI description	Progress achieved against KPI
KPI Update on project communication and extension outputs (Activity 3)	☒ Achieved ☐ Partially achieved ☐ Not achieved This KPI has been achieved. Without doubt, the biggest communication and extension event over the period was Ministers David Littleproud and Sussan Ley (Minister for Agriculture and Northern Australia and Minister for the Environment respectively) publicly announcing the release of the FWFA Products on the Bureau of Meteorology's Climate Outlooks webpages on 1 November 2021. This event was supported by FWFA partners and received significant national media coverage. Since their release there have been over 1.34 million page views of the new FWFA products. There have been: • Fifty Community of Practice meetings • Dozens of scientific papers produced (see Attachment 1 – Outputs and legacy items) • Countless webinars conducted talking about experimental and operational forecast products (see http://piccc.org.au/resources/videos-webinars/) • Hundreds of presentations to scientific audiences and farmers • Significant social media listings • The production of nine short explanatory videos • Development of case studies and blogs on the climate kelpie website The University of Melbourne has developed a web page that lists resources for public FWFA output – publications and media: https://piccc.org.au/resources/research-publications/FWFA_publications (note this does not include links to unlisted recordings such as the FWFA CoP sessions).
KPI Provide a report detailing progress against Activities 5.1	☒ Achieved ☐ Partially achieved ☐ Not achieved This KPI has been achieved as detailed below: Work Package 1 has managed this KPI (BUREAU, Monash Uni). **Activities 5.1: The Grantee must undertake research activities to understand user needs for extreme climate forecasts and forecast system development**

<table>
<tr><th>KPI description</th><th>Progress achieved against KPI</th></tr>
<tr><td></td><td> including identification of key risks for each industry and identifying response scenarios.
Understanding user needs – the requirement to understand user needs was completed with the publication of the User Needs Analysis (Milestone 4) – attached to this report as Appendix 7.1. However, we continued to get feedback on user needs over the life of the project through Industry Reference Group meetings (IRGs).
2. Undertaking research to extend the capability of ACCESS-S to accurately forecast extremes, including:
I. research into how large-scale drivers influence extreme climate events
II. using case studies of extreme events to inform the analysis
III. reducing known biases
IV. reviewing past reports on industry forecasting needs.
Research - A summary of the work undertaken in this component of the project was reported by Professor Christian Jakob (Monash University) to a 2021 Community of Practice webinar (see https://youtu.be/-vqxW0TXsdA). Some of the analysis that has been undertaken to improve extreme seasonal climate forecasts includes:

Identified the role of the MJO for driving weekly mean rainfall extremes by season.
Demonstrated the capability of the ACCESS-S1 system to simulate MJO-induced variations.
Forecast skill for weekly mean rainfall extremes in weeks 2 and 3 was shown to be enhanced in some regions when the MJO was strong and in certain phases.
Maps of expected enhancements of skill when the MJO is strong can be used by end-users to enhance confidence in the forecasts.
Development of sea-breeze parametrisation.
Developed offline version of the parametrisation.
Testing and tuning of the new parametrisation.
</td></tr>
<tr><td>KPI 10.5 A report detailing progress against Activities 5.3</td><td> ☒ Achieved
☐ Partially achieved
☐ Not achieved
This KPI has been achieved. </td></tr>
</table>

KPI description	Progress achieved against KPI
	Work Package 3 (UoM, SARDI, USQ) has managed this KPI **Activities 5.3: The Grantee must develop relevant farmer and advisor risk management packages across multiple industries for extreme climate events. This will require:** **1. Interacting with industry reference groups (see 5.1) identifying key risks for each industry and testing products developed in activity 5.2 to identify appropriate response scenarios and provide feedback to refine the products** **2. Analysing response scenarios to develop a risk management framework and toolkits on a multiple industry basis; presenting the extreme event tools to the Community of Practice and other audiences identified in Activity 3.** Achieved – industry specific risk management packages have been delivered to MLA, GRDC, DA, Wine Australia and SRA. A generic risk management package was also developed (attached to this final report). In addition, SARDI and the University of Adelaide recently developed and tested an interactive Climate Risk Management package.
KPI 10.6 a report on progress with specific communication and extension activities (5.4) including Community of Practice and existing extension networks	☒ Achieved ☐ Partially achieved ☐ Not achieved This KPI has been achieved. Work package 4 (BCG, Agriculture Victoria) has managed this KPI. In recent months, as mentioned above, the University of Melbourne was appointed to coordinate a new extension and communication program. **Activity 5.4: The Grantee must implement a range of communication and engagement activities delivered through a variety of existing channels, including the Community of Practice facilitated by the Birchip Cropping Group (BCG); existing RDC extension networks; and Bureau regional stakeholder networks.** There has been continuing publicity about the project through papers and presentations made by provider partners and contributing organisations to meetings, workshops and conferences. The FWFA Community of Practice (CoP) held 50 webinars over the course of the project. There have also been monthly webinars by the Bureau of Meteorology (managed by BCG) to provide an in-depth analysis of the drivers behind recent conditions and what to expect heading into the following months. There are 113 members on the attendee list with an average of 24 attendees (mostly climate science communicators).

KPI description	Progress achieved against KPI
	A listing of presentations and publications over the period is provided in section 5 below.

3.6 Contribution to program objectives

The objectives of the Rural R&D for Profit program are to realise significant productivity and profitability improvements for primary producers, through:

- generating knowledge, technologies, products or processes that benefit primary producers
- strengthening pathways to extend the results of rural R&D, including understanding the barriers to adoption
- establishing and fostering industry and research collaborations that form the basis for ongoing innovation and growth of Australian agriculture.

The FWFA project achieved these objectives by developing five new forecast products of extreme climate events and making them public on the Bureau's website. As noted earlier, since their first release in late 2021, over 1.34 million views have been made on these products. The Bureau's website allows for a direct route to market. The key now will be for new climate initiatives such as AgriClimate Outlooks (https://www.aginnovationaustralia.com.au/news/$19m-investment-to-bolster-australian-agricultures-climate-resilience) and Climate Services for Agriculture (https://www.agriculture.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/climate-services) to keep promoting those products for use by agricultural practitioners.

In addition, an enduring legacy from the project is the fostered collaborations (see section 4) that have been developed and will surely lead to future joint work.

4 Collaboration

The FWFA project was based on a strong collaborative framework. Partners who provided cash and / or in kind were the Bureau, University of Melbourne, University of Southern Queensland, SARDI, Agriculture Victoria, DAFQ, BCG and RDCs in MLA, SRA, GRDC, Wine Australia, DA, CRDC, APL and Agrifutures Australia.

These organisations were represented on the PLG and / or on the IAG. Many of these organisations had not worked together before, but many are now highly likely to collaborate in future projects.

The following table provides an indication of the level of collaboration brought about by the program from the perspective of the University of Melbourne. Other partners could provide a similar matrix of collaborations.

Table 1. Forewarned is Forearmed Project – collaborative relationships and organisations.

Organisation	Innovation	Will continue
DJPR Agriculture Victoria (Partner)	Subcontracted to them as part of FWFA. UoM has a strong record and relationship of collaboration with the Ag Vic Team. The general sharing and learning in climate variability and the FWFA output is especially important for future consistency and progress in innovation.	Highly likely e.g. Drought Hubs
BCG (Partner)	Subcontracted to them as part of FWFA. As with the Ag Vic Team, UoM has a strong record and relationship of collaboration with the Birchip Cropping Group.	Highly likely
SARDI (Partner)	Focused collaboration with SARDI (specifically Peter Hayman) on the development of the FWFA generic risk management product. This has been a great learning curve with progressive discussions and work which will flow through to the way producers' approach and make decisions about climate risks.	Likely
Dairy Australia (DA) (Partner)	UoM (PICCC) has an established history collaborating with DA. In this project the collaborative continuity was challenged due to multiple DA personnel and structural changes	Highly likely
MLA (Partner)	A lead organisation on this project MLA oversaw all reporting and as a rep for the Southern Red Meat Industry UoM could run a variety of risks prototypes and discussions by Doug McNichol until his departure.	Highly likely
Bureau (Partner)	This is the first project where UoM (PICCC) has worked directly with staff from the Bureau and arguably builds a new strategic alliance to develop further projects.	Likely
USQ (Partner)	Less collaboration and involvement with northern partners during this project.	Possible
DAFQ (Partner)	Less collaboration and involvement with northern partners during this project.	Possible
Industry reference groups members – farmers (VIC, NSW, WA)	The collaboration with individual producers has been amazing throughout the FWFA Project. Enabling the option for end users to access and give feedback on experimental and operational forecast products including collaborating with the Bureau has been very valuable and	Likely through other projects

	is likely to be taken up as a model for future product development. The risk work with the IRG members meant we were getting first-hand, robust information to feed into frameworks and response scenarios.	
Fonterra, Parmalat & NORCo (External)	Access to 17 years of milk record data for specific heat stress periods which was then collated into a database for analysis of financial impacts on farm and costing of specific heat stress management options. Increase inter-industry collaboration: while corporate confidentiality of the data from each of these collaborators exists, these collaborations enable an element of external collaboration and agreement (between essentially competitors). Enabling these interactions benefits all parties.	Possible through other projects
Sheep CRC (External)	UoM initiated collaboration with the Sheep CRC, specifically with respect to their Ag360 (ASKBILL) tool (with a view to look at whether the tool may extend to the dairy and beef industries and used as a risk management tool for the FWFA project).	Early in project, sporadic
AGBU UNE (External)	Breeding stakeholders' discussion and presentation. This has opened an opportunity for UoM (PICCC) to be part of the breeder network discussions.	Likely
National Australia Bank (External)	Ongoing discussions and interest in this project to explore risk management frameworks for agriculture. Likely this will contribute to future financial development in the climate risk on farm in these organisations.	Highly likely
Rabobank (External)	Ongoing discussions and interest in this project to explore risk management frameworks for agriculture. Likely this will contribute to future financial development in the climate risk on farm in these organisations.	Highly likely

5 Extension and adoption activities

Please see section 3.4

6 Lessons learnt

At the conclusion of the project, project members developed a paper on lessons learnt. A copy of the paper is included as Appendix 7.3. In summary, key lessons learnt included:

- The project benefited from extreme climate events that occurred during the project (e.g. 2022 floods) and a growing interest in information from climate science. The project worked with this broader trend in interest and made a modest contribution to it.
- Generic forecast products answered most of the climate risks raised by industry.
- Layering detail or added complexity can be effective.
- A positive unintended consequence of FWFA forecasts is improved understanding of probabilistic forecasts.
- The skill of forecasts remains a challenge.
- Moving from i) awareness to ii) understanding climate drivers to iii) understanding probabilities to iv) using probabilities in decision making is hard work – but we have made some progress.
- Communication should have been more clearly built into the design and funding of the project.

The other key finding arising from the project was the difficulty of receiving broad-based feedback on complex issues via digital means of communication. Face to face meetings are likely to have been far more engaging.

7 Appendix - additional project information

7.1 User needs analysis

Shelley document – attached.

7.2 Listing of experimental products developed

Table A1: Experimental forecast products developed during the project for heat, cold and rainfall extremes.

Product	Variable	Lead time	Description
General (heat, cold and rainfall)			
Top/bottom quintile (maps)	Maximum temperature (Tmax), Minimum temperature (Tmin), Rainfall	Weeks to seasons ahead	Maps of the probability of being in the top/bottom quintile for Tmax/Tmin/rainfall for a given lead time.
Climagrams (stations)	Tmax, Tmin, Rainfall	Daily, weekly and monthly	Box-plot timeseries of upcoming days, weeks, or months showing the range of possible outcomes.
Decile/quintile bars (stations)	Tmax, Tmin, Rainfall	Weeks to seasons ahead	Bars showing the forecast probability for each of the 5 (quintile) categories (i.e., the categories include the following deciles: 1+2, 3+4, 5+6, 7+8, 9+10). The climatological expected probability in each category is 20%. The forecast product shows where there is a reduced/increased likelihood for a given category.
Pie charts (stations)	Tmax, Tmin, Rainfall	Weeks to seasons ahead	Three-category pie charts showing the probability for each tercile (e.g. showing probability of being drier, near-normal or wetter than usual. Similarly, for Tmax and Tmin).
Daily distributions (stations)	Tmax, Tmin, Rainfall	Weeks to seasons ahead	The forecast shows the distribution of daily (number of days) of various Tmax/Tmin/rainfall totals from the forecast for a given period. The product also shows what is normally expected at the given time of year (climatology), thus highlighting any shifts compared to climatology.

Heat Extremes			
Heatwave maps	A heatwave is defined as 3 or more consecutive days exceeding the 90th percentile of daily mean temperature.	Weeks to fortnights ahead	Maps of the probability of having a warmwave/heatwave in a given period. (Note: the heatwave is defined using a seasonally varying threshold – this will, for example, pick up warm waves in the winter half of the year)
Hot days probability maps	Daily Tmax above the 90th percentile of daily Tmax. Also available for daily Tmin and Tmean	Weeks to seasons ahead	Chance of having more than the usual number of hot days (or nights) in a given period. (Note: a hot day is defined using a seasonally varying threshold – this will, for example, pick up hot days in the winter half of the year)
Number of hot days	As above	Weeks to seasons ahead	Number of hot days (or nights) in the period (from the ensemble mean). The days do not need to be consecutive.
Hot days plume (stations)	Daily Tmean	Daily out to 30 days	This product shows the daily forecast plume of Tmax out to 30 days. The plume shows the spread (10th, 25th, median, 75th, 90th percentiles of the forecast ensemble) of the forecast ensemble members and highlights (in orange) when the forecast exceeds the climatological (long-term) 90th percentile.
Temperature-humidity maps	Daily Tmax (T_max), 9am vapour pressure (VP_9am) and 3pm vapour pressure (VP_3pm).	Weeks to seasons ahead	Maps showing the THI expected (ensemble mean). The temperature-humidity index (THI) is of general interest to livestock industries and is used for warnings in the Dairy Industry. THI = T_max + 0.36 * T_d + 41.2 • T_d is the daily dew point temperature • T_d = (234.5 * ln(VP / 6.112)) / (17.67 - ln(VP / 6.112)) VP is the mean of the 9am and 3pm VP

Temperature-humidity distributions (stations)	As above .	Weeks to seasons ahead	The forecast product will allow users to identify specific THI thresholds of interest (e.g., when THI>78, milk production is seriously affected). The forecast shows the distribution of daily THI data from the forecast for a given period. The forecast product also allows the user to compare the forecast with what is normally expected for the daily distribution of THI at the given time of year (climatology), thus highlighting if there are any shifts compared to climatology. THI is defined as above.
Temperature-humidity probability of exceedance scenarios	As above	Weeks to seasons ahead	The average THI over the period that has a 25% (or 50% or 75%) chance of occurring. THI is defined as above.
Mean number of THI days	As above	Weeks to seasons ahead	Maps show the expected number (ensemble mean) of mild, moderate, high or severe THI days in the forecast period: Moderate (>72), high (>78), severe (>82) THI is defined as above.
Cold extremes			
Coldwave maps	A coldwave is defined as 3 or more consecutive days less than the 10th percentile of daily mean temperature.	Weeks to fortnights ahead	Maps of the probability of having a cool/coldwave in a given period. (Note: the coldwave is defined using a seasonally varying threshold – this will, for example, pick up "cool waves" in the summer half of the year)
Cold days probability maps	Daily Tmax below the 10th percentile of daily Tmax.	Weeks to seasons ahead	Chance of having more than the usual number of cold days (or nights) in a given period. (Note: a cold day is defined using a seasonally varying threshold – this will, for example, pick up cold days in the summer half of the year)

	Also available for daily Tmin and Tmean		
Number of cold days	As above	Weeks to seasons ahead	Number of cold days (or nights) in the period (from the ensemble mean). The days do not need to be consecutive.
Cold days plume (stations)	Available for daily Tmean, Tmin, Tmax	Daily out to 30 days	This product shows the daily forecast plume of Tmax, Tmin or Tmean out to 30 days. The plume shows the spread (10th, 25th, median, 75th, 90th percentiles of the forecast ensemble) of the forecast ensemble members and highlights (in blue) when the forecast is less than the climatological observed 10th percentile.
Frost potential maps	Daily Tmin	Weeks to fortnights ahead	Chance of having at least one frost in the forecast period. The forecast is based on the minimum temperature being below a given threshold (<2deg; <0deg; <-2deg; or <-5deg). These thresholds have been chosen to indicate days when the temperature may be suitable for frost formation. It is called "frost potential" because frost may or may not form on these days, depending on other factors, such as wind, local topography and humidity
Number of frost days	Daily Tmin	Weeks to seasons ahead	Expected number of frosts in the forecast period (ensemble mean). The forecast is based on the minimum temperature being below a given threshold. The thresholds are defined as noted above.
Chill Index Potential (southern livestock)	Daily mean temperature, rainfall and wind speed	Weeks to fortnights ahead	Maps showing the chance of having at least one mild/moderate/high/severe Chill Index day in the forecast period. Chill Index (Carter et al. 2019) is defined as the potential heat loss in kJ/m2/hr, and is given by: C = (11.7 + 3.1v0.5) (40-T) + 418(1-e-0.04x) + 481 • v is the mean daily wind velocity (m/sec), • T is the average daily temperature (degC) • x is the daily rainfall (mm). The forecast is based on the Chill Index being above a given threshold. Here we are plotting the probability of at least one day of mild, moderate,

			high or severe Chill Index from the range of outcomes, where: Mild (> 900), moderate (> 1000), high (> 1100), severe (> 1200)
Mean number of Chill Index days (southern livestock)	Daily mean temperature, rainfall and wind speed	Weeks to seasons ahead	Maps show the expected number (ensemble mean) of mild, moderate, high or severe Chill Index days in the forecast period. Chill index is defined as above.
Rainfall Extremes			
Number of wet days (select threshold of rainfall amount)	Daily rainfall totals	Weeks to seasons ahead	Maps of the number of "wet days" in the forecast period (ensemble mean), where what is counted as "wet" can be selected from a drop down menu (i.e. daily rainfall >0.2mm, >5mm, >10mm, >15mm, >25mm or >50mm).
Longest wet spell (number of consecutive wet days)	Daily rainfall totals	Weeks to seasons ahead	Maps showing the length of the longest wet spell in the period, where a wet day is >0.2 mm of rain. Here we are using the *median* of the longest wet spell from the range of outcomes.
Number of dry days	Daily rainfall totals	Weeks to seasons ahead	Maps of the number of "dry days" in the forecast period, where a dry day is <0.2 mm of rain Here we are using the *median* number of dry days from the range of outcomes.
Longest dry spell (number of consecutive dry days)	Daily rainfall totals	Weeks to seasons ahead	Maps showing the length of the longest dry spell in the period, where a dry day is <0.2 mm of rain. Here we are using the *median* of the longest wet spell from the range of outcomes.
Probability of exceedance curves for stations	Rainfall totals over a period	Weeks to seasons ahead	Probability of exceedance (POE) curves for rainfall totals in a given period. Curves for the forecast POE (black) and the usual POE (i.e., climatology; grey) are shown. The rainfall threshold is shown on the x-axis, and the associated probability of exceeding that threshold on the y-axis.
Rainfall burst (3-day accumulations)	3-day rainfall accumulations	Weeks to fortnights ahead	Maps showing the chance of exceeding 3-day rainfall totals, ranging from 15 mm to 75 mm.

7.3 Lessons learnt

Some lessons learned on use of FWFA forecasts for information for managing climate extremes. January 2023.

Peter Hayman (SARDI) and Ann-Maree Graham (U Melbourne) acknowledging input and notes from Graeme Anderson and Dale Grey (AgVic), David Cobon (USQ) and Andrew Watkins (Bureau).

The Forewarned is Forearmed project was an important step in a broader program of work that delivers climate information to the agricultural sector.

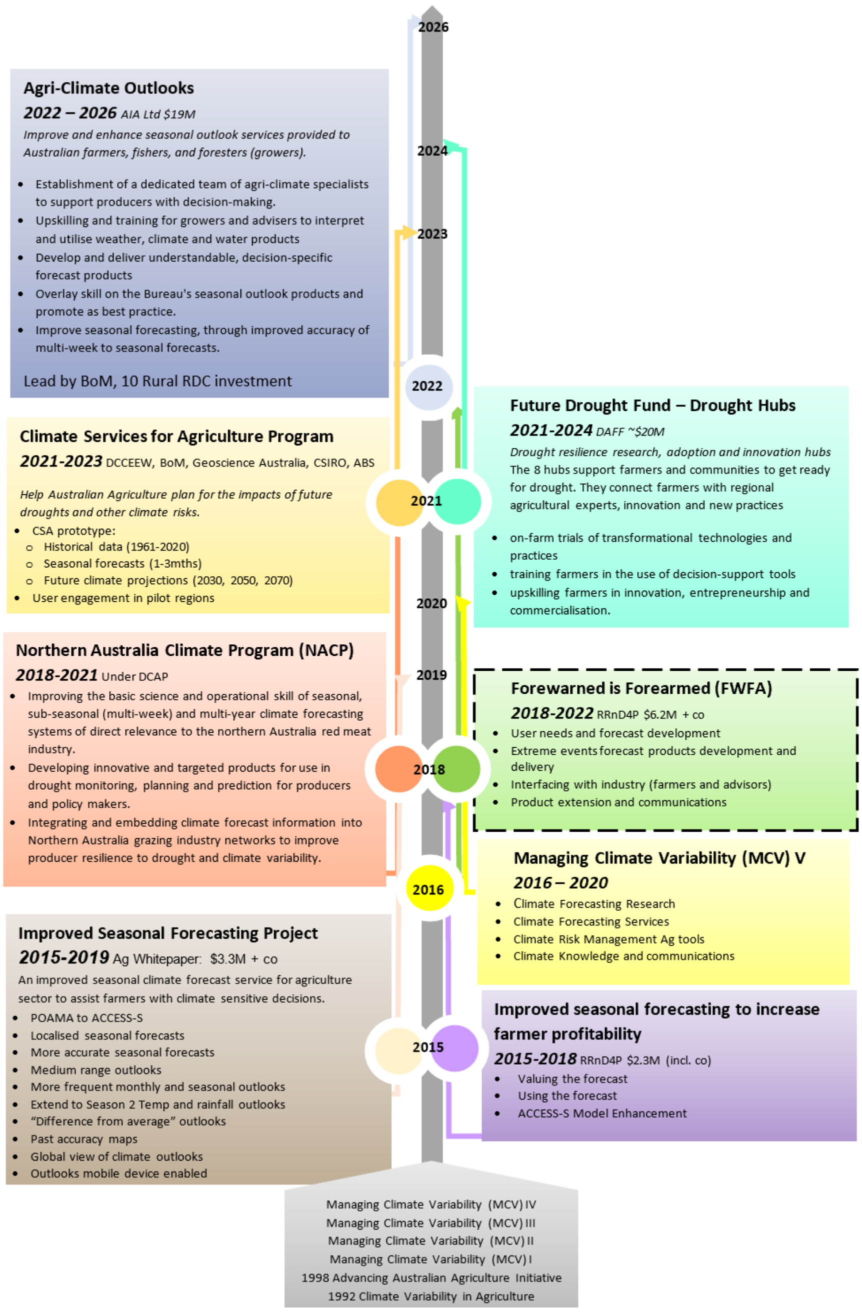


Figure 7.1: Timeline of projects and programs that preceded and overlapped FWFA (graphic prepared by Ann Maree Graham).

Lessons learned/observations.

1) **The project benefited from extreme climate and a growing interest in information from climate science. We worked with this broader trend in the interest and made a modest contribution.**

As observed by Andrew Watkins, Technical Lead - Extended Prediction at Bureau of Meteorology, there was an initial concern that products such as maps of increased chance of extreme deciles would be white (no data) most of the time. This didn't happen. The maps showed vivid colours forecasting increased chances of very wet conditions. The spring and early summer of 2022 were extremely wet and consistent with the forecasts. During the life of the project, members of the Industry Reference Groups (IRGs) experienced drought, floods, wet harvests, inaccessible roads, bogged pastures, heat and frost.

Extreme climate events affecting agriculture have always been newsworthy with ingredients of dramatic images, records being broken and relatable stories of human suffering, resilience and heroism. Although not a new development, climate science is increasingly becoming part of the narrative. This applies to the attribution of extreme events to climate change and the use of extreme events to argue for more action on reducing emissions. There is also a substantial appetite in Australian agricultural industries and media to understand the science behind climate variability. For example, the very dry winter and spring of the strongly positive Indian Ocean Dipole (IOD) in 2019 which followed dry conditions and failed crops in 2017 and 2018. This led to the outlook for a positive IOD in 2020. In 2022 the very wet winter and spring are widely linked to the triple La Niña. As discussed later, the research and article on sudden stratosphere warming in August 2019 generated a large amount of interest in the media, especially the article in The Conversation.

This increase in extremes has further developed awareness of climate drivers and seasonal forecasts in most Agricultural industries. Although difficult to attribute to FWFA, the funding, the resources, meetings with industry and linking of industry to Bureau climate scientists helped increase the awareness and understanding of climate drivers. The monthly Bureau climate science updates as part of the community of practice have been very important as a two-way flow of information.

2) **Generic forecast products answered most of the climate risks raised by industry**

Although each agricultural industry and region tends to see themselves as unique, there is much in common when it comes to climate and weather risks. Unsurprisingly, risks were aligned or similar between dairy and southern red meat, or between grains and wine grapes. More surprisingly was that across all industries the basic climate risks were similar (too much rain, too little rain, too hot, too cold). Furthermore, while the context of a decision such as the rate of nitrogen fertiliser to add to a grain crop differs from deciding on a stocking rate, both decisions involve adjusting inputs to match the coming season. Likewise, the decision to provide additives to feed for dairy cows before a heat event is the same essential decision as irrigating a grape vine before a heat event or spraying a grain crop with a fungicide before a wet spring. Most decisions are variants on 1) adjusting inputs to match the downside risk and upside opportunity of the coming season (N fertiliser/stocking rate) or 2) spending money to protect crops and animals from an adverse climate event (prevent downside risk).

While impact models have their place and can incorporate antecedent conditions such as stored soil moisture or standing feed, it is useful to separate the forecast signal from the process of modelling crop and pasture growth or the impact on animal productivity. An advantage of multiweek forecasts of rain and temperature is that farmers and advisers can add their unique context and interpretation. The discussion on generic forecasts is further addressed under accuracy (lesson 5 below).

3) Layering detail or added complexity can be effective (walking up Figure 1).

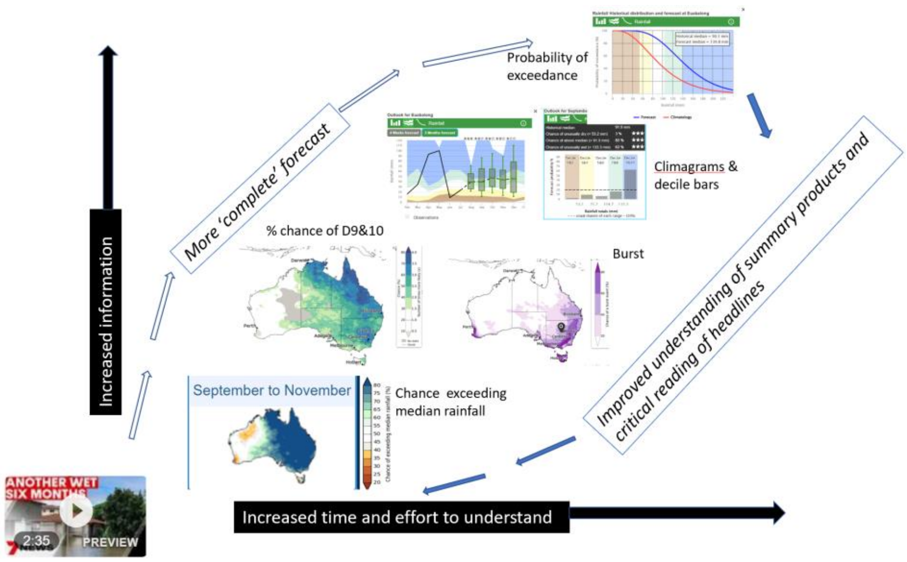


Figure 7.2. Increasing time and cognitive effort to understand the forecast product (x axis) is rewarded with a more complete forecast (y axis).

The FWFA products span a level of detail. Accessing this extra detail requires time and cognitive effort. Maps require a quick glance from users. Most users will be looking at a location or region and the map shows whether they are in the centre or edge of the forecast signal. The location specific products (quintile bars, climagrams and POE) include probability on one axis and amount (mm or degrees C on the other axis). This provides an opportunity to check the likelihood of different thresholds which is likely to be beneficial at specific times such as harvest or shearing.

The concept of a more complete forecast comes from US Academy of Science report (2006) “Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts”. This report argues that no forecast is complete without a description of its uncertainty. If we accept that the plume is the forecast, there is information for decision makers in both the direction of the plume (wetter, drier, warmer or cooler) and the dispersion of the plume (narrow dispersion vs wide dispersion). The climagrams with box plots against the background of climatology show the signal and dispersion. A common observation is that the dispersion of ensemble runs is close to the climatological dispersion after a fortnight.

Products such as the climagram also show the variation in each month. For example a 3 month outlook can be due to most of the wetter signal in only one month, especially if it is the first of the three months.

The colour scheme for the rainfall quintiles (blue D9&10, green D7&8, white D5&6, yellow D3&4 and brown D1&2) adds to the intuitive appeal of the products. The consistent use of colours between the climagram, the decile bars and the probability of exceedance improves learning.

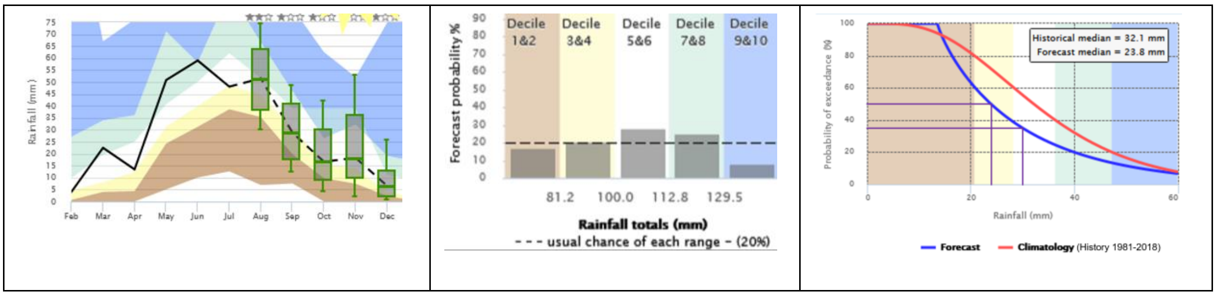


Figure 7.3. Example of monthly climagram, quintile bars and probability of exceedance.

Explaining these products as the 99 ensemble runs is a useful way to convey the information. A phrase used in extension by Dale Grey (AgVic) is that the model will always be right.

This fits the argument of Gigerenzer (2003) that when users have different interpretations of "30% chance of rain" (30% of area, 30% of time) it is not because they don't understand probabilities. Rather it is because we haven't communicated what the percent chance is referring to. It might be clearer if we said 30% of model runs showed rain at this location and 70% didn't.

4) **A positive unintended consequence of FWFA forecasts is improved understanding of probability (walking back down Figure 2)**

A benefit of the effort to understand the quintile bars, climagrams and POE (going up Figure 2) is a clearer understanding of the concept of "Above Median" in the maps in the standard Bureau outlook, or even being a more informed user of media headlines.

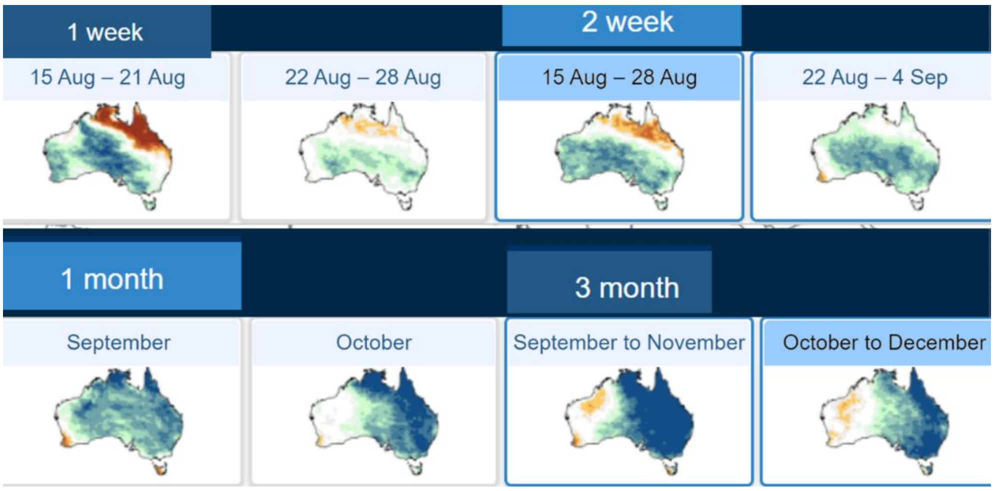


Figure 7.4. Ribbon of maps showing percent chance of above median for coming weeks, fortnights, months and seasons.

While it is common to critique the percent chance of above median maps, they do offer an opportunity for busy users to assess the direction of the forecast signal (dry or wet) and the strength of the forecast signal (coloured map vs white map). Important feedback from the grains industry was that it was useful to know "nothing to see here" and this this was one of the attractions of the pie charts.

5) **The skill of forecasts remains a challenge**

Consistent feedback from IRGs is that the skill of the forecast is a barrier to use. Members of the IRG who followed the products most closely, provided some of the strongest feedback on the issue of skill. Resources from FWFA contributed to underlying climate science, but most of the resources were in product development. As we progress up Figure 1, there is a more complete forecast, but there is no improvement in the underlying skill.

At the start of the project a view was expressed that the generic products would not have uptake compared to forecasts that were run through models to provide impacts such as sheep blowfly strike, pasture growth, crop yields, grape development. Some of the impact models have been most developed in the grains industry through crop modelling. Nevertheless, a clear message from the grains IRG was "just give us better seasonal rainfall forecasts…. running poor forecasts through a wheat model doesn't help". The argument was that farmers can work out what a wet or dry spring means on their farm. Furthermore, if the problem is that as humans we tend to think of single futures and struggle to imagine multiple futures, impact modelling can reinforce a single future.

Generic seasonal forecasts of rain in the next three months that are roughly right, are more valuable than specific impact forecasts that are precisely wrong. This might be a false dichotomy, but the fact remains that running a forecast through a crop or livestock model doesn't improve the underlying accuracy of the forecast.

6) Moving from i) awareness to ii) understanding climate drivers to iii) understanding probabilities to iv) using probabilities in decision making is hard work – but we have made some progress

In the previous RR&D4P project, respondents were asked to estimate the change over the last five years in 1) awareness, 2) understanding of climate drivers and 3) understanding of probabilistic seasonal climate forecasts. Awareness of forecasts was ranked higher than understanding of climate drivers with the understanding of probabilities consistently ranked as the lowest.

The two social science surveys as part of the FWFA project (Taylor et al 2021, Kuehne (2022) indicated that awareness of forecasts is increasing along with understanding of basic climate drivers. There are products on probabilities (eLearning prepared by Ag Vic and Adelaide Uni products in development). NACP has an excellent video and SARDI has industry updates that include different ways of communicating probability, some of which have worked.

Communicating probabilities continues to be hard work. As indicated in lesson 4, one of the benefits the project focusing on extremes is a reminder that the plume is the forecast. FWFA products such as the quintile bars seems to be a particularly useful way to communicate probabilities (Graeme Anderson pers comm, Peter Hayman pers experience).

A further step is moving from understanding probabilities to using probabilities in decision making. This is a harder but rewarding area, as it provides a reason for understanding probabilities and a framework to use probabilities in decision making.

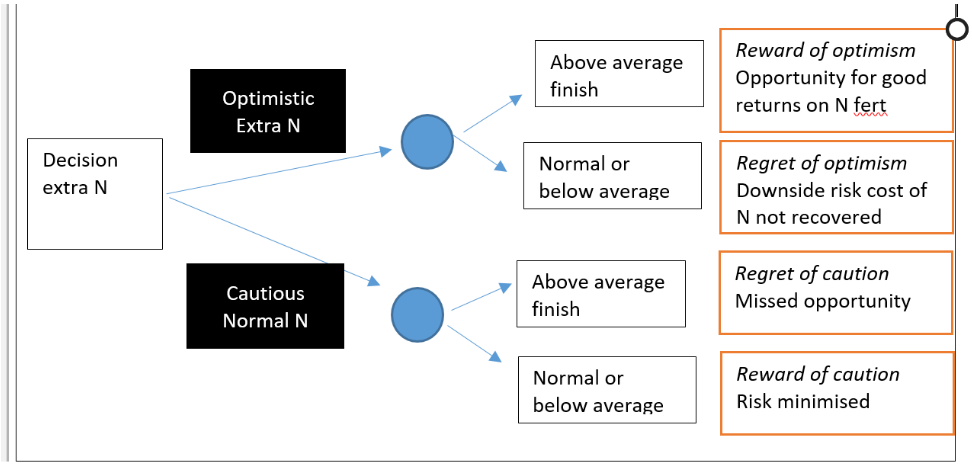


Figure 7.5: Worked example of decision analysis for the grains industry.

7) **Communication should have been more clearly built into the design and funding of the project.**

The five new FWFA Products became publicly available late in the project, leaving a short project time period to undertake extension and sharing to increase public awareness – this task will need to be embedded into the future projects and ensure Bureau (CSA) and AIA (Agri-Climate Outlooks) play a role to promote the FWFA products amidst the new project outreach.

We may have undersold the climate research side of FWFA. Peer reviewed publication outputs from the project are impressive. We could have enhanced communications around this work? To encourage the flow through to the lay person. As per point 1 "**Growing interest in information on climate extremes,** the FWFA research could have been translated to the common vernacular. An article in The Conversation Sept 2019 is a lay translation of work out of the FWFA project published by the Bureau in Nature October 2019. The popular article has had almost 1M accesses compared with the ~4K of the scientific article. Given the increased appetite for climate science in the general public, there are opportunities to communicate more widely by requiring the related delivery of a popular article translating the research.

Extension of the products will take a considerable while to move through the community of users and therefore it would currently not be a 'good measure' of communication about the products. The question that remains is, did the project do enough to communicate these products? In November 2021 and July 2022, media releases and Ministerial announcements were made, webinars coincided with the public launch, online publications picked up and wrote about the releases, information was sent out to large networks and more recently online information sessions have been convened. The Bureau has communication KPIs and stats to indicate the circulation of this information. However anecdotal evidence appears to indicate that some people who should be aware of the products are not. While it is useful to have the products as part of the main Bureau outlook maps, many users are unaware that they can look at point data showing climagrams, decile bars and probability of exceedance from this map.

As the Managing Climate Variability (MCV) era comes to a close, it's critical that across the agriculture/climate community we recognise the three core elements for improved climate risk management in Australia:

1. Better forecasts (models, weather, multiweek, seasonal, climate change)
2. Better understanding of forecasts (climate literacy of users & forecast products)
3. Farm risk management & adoption (strategies, tactics, tools to better manage risks both with and without forecasts).

Recommendations

1. Build on the growing interest and understanding of climate science concepts in the broader community (e.g. widespread interest in the triple La Nina).
2. Ensemble modelling conveys that the plume is the forecast. The uncertainties captured in the spread of the plume need to be clearly communicated. Although disappointing that the climagram shows the spread of the box plot returns to climatology beyond a fortnight, this is important information.
3. Following from above, although the FWFA products visually show the level of skill/accuracy, the project work has not included improving the accuracy of the forecast. This remains an issue for end users.
4. This project has worked on ways to convey probabilities, continued extension and communication in this area will strengthen this broader understanding.
5. Future research projects producing journal articles may benefit from having a parallel delivery on their subject published in popular publications (e.g. The Conversation) to extend circulation of information and results.

7.4 Project, media and communications material and intellectual property

The primary output from the project are the five new forecast products that are hosted on the Bureau's website. They are publicly available.

A detailed listing of all project outputs – publications, webinars, social media etc is attached to this milestone report.

7.5 Equipment and assets

No equipment was purchased by the project. In terms of assets see section 7.4.

7.6 Monitoring and evaluation

The final project evaluation is attached to this report as Attachment 3. In summary, '*the independent final review concluded that the FWFA RND4P project has been a valuable, relevant, effective, and efficient RD&E project. FWFA directly addressed each of the RND4P Program objectives and represents a practical response for the agricultural sector to better understand and adapt to a variable climate'*. It also found that '*overall, the project was well designed and executed with few research gaps. The FWFA project has been presented by stakeholders as a best practice example of a* *large and complex collaborative R&D project*.

7.7 Budget

Attached to this final report.