APPENDIX 16

Managing Climate Variability Program V:
A Research and Development Operational Plan for 2016-17 to 2021-22

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Key groups, including key people nominated by other RDCs, have been consulted for input into the MCV5 Operational Plan. The initial consultation was by email, phone and in person, followed by a workshop at the Bureau of Meteorology in Melbourne on 27th September 2016. Peter McIntosh gave a presentation at this workshop summarising the results of the consultation to date. The following day, he summarised progress with the Operational Plan to the MCV partners at their partner meeting in Melbourne. A draft Operational Plan was then prepared with contributions from the other consultants, and this plan was distributed on 18th November to the more than 50 people consulted for further comment and feedback. The revised plan was presented to the MCV partners at a teleconference on 13th December 2016, with final comments incorporated into the final Operational Plan which was submitted on 23rd December 2016. This report is a reformatted version of the final Operational Plan.

Executive Summary

Much of Australia's agriculture is sensitive to the relatively large seasonal climate variations experienced by this country. The Managing Climate Variability (MCV) program has specialised for over 20 years in helping producers deal with seasonal variability by funding a combination of basic climate research, development, extension and communication. This Research and Development Operational Plan for the fifth round of MCV funding (2016-17 to 2021-22) describes an integrated program of project options designed to obtain the best possible outcomes for Australian agriculture. It is the result of a wide consultation process involving climate and agriculture researchers, practitioners and producers.

A few key messages emerged from the wealth of valuable information gathered. Ultimately, users want timely, accurate and easy-to-understand information about climate events that will have an impact, either good or bad, on their business. This might involve increased forecast skill at multi-week to multi-year timescales, warning of extreme temperature and rainfall events, probabilities of wet or dry seasons, and simple and familiar tools and guidance to help them make important management decisions.

To achieve this, two plans are suggested here. Plan A is based around a single large project to be submitted to round three of the Rural Research and Development for Profit (RR&D4P(r3)) Program of the Commonwealth Government, which provides excellent leverage for limited MCV funds. This project covers a wide range of topics; basic climate model improvement, evaluation, product development, operational services and delivery, farming applications, and education and training. Plan A contains smaller complementary projects to develop standard interfaces between climate model output and agricultural decisions support tools, industry studies to apply and value seasonal forecasts in selected industries, and an updated assessment of the overall value of seasonal forecast information to Australian agriculture. The latter will be important in documenting success and attracting continued funding into the future.

The integrated program delivered by Plan A is probably the best mix of projects to deliver on the MCV5 Business Case (MCV 2016). In the event that the RR&D4P(r3) proposal is not successful, Plan B has been developed to preserve as much of plan A as possible with reduced funds. The smaller projects from Plan A remain in Plan B. Additional projects are added which develop and implement the next two generations of seasonal forecast systems (ACCESS S2 and S3), explore the reasons and solutions for the systematic bias emanating from the Indian Ocean, deliver forecasts of the likelihood of frost and extreme rainfall events, and enhance the use, value, uptake and communication of forecasts. It will probably be difficult for MCV to fund all of Plan B by simply partnering with research organisations because of the reduced leverage compared to the RR&D4P program.

In the event that the RR&D4P(r3) proposal is successful, there are two further important projects that could be considered should additional funding become available. First is to increase funding for the implementation of ACCESS S2 and S3, which is not fully covered in the RR&D4P(r3) proposal. This will help these models to come on line as soon as possible. The second project involves upgrading the ACCESS land surface model to the Australian model CABLE developed specifically for Australian conditions. This is a relatively large undertaking, but would be a wise long-term investment with the possibility of improving the model substantially, particularly at farm scales.

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Background

The Managing Climate Variability Program (and its predecessor the Climate Variability in Agriculture Program) has invested in seasonal climate forecasting and variability research for the benefit of Australian agriculture since 1993. This investment has been critical in the development of the Bureau of Meteorology's seasonal forecast model, POAMA, and in the application and communication of seasonal forecasts to a wide range of agricultural enterprises across Australia. MCV funding and support has been instrumental in focusing research and development on seasonal timescales both within the BoM and in other research institutes such as CSIRO and the Universities.

The long-term value of MCV investment to Australia has been estimated to be in excess of $6 for every $1 invested (Agtrans Research 2015, and references therein). A recent report by the Centre for International Economics (CIE 2014) estimated the potential annual value of seasonal forecasts to Australian agriculture as $1.5B, or about 7% of the total industry value. The report further states that improved seasonal climate forecasts are likely to have flow-on benefits to rural communities through increased farm incomes and reduced risk and income variability.

MCV's competitive advantage and niche is in its ability to link basic climate research through development, extension and communication to on-farm application of seasonal climate forecasts. MCV has been and continues to be instrumental in bringing together researchers from various institutions to achieve this. The success of the MCV program and its investment in seasonal forecast research over many years clearly provides a strong foundation for future investment through MCV phase 5. This Operational Plan aims to optimise this investment in line with the MCV Business Case (MCV 2016)

Consultation Process

The team has consulted widely with many of the key people in the area of research and application of climate forecasts to agriculture, as well as a number of farmers from the previous MCV4 Climate Champions program (MCV 2016). The consultation has been by phone, email and face-to-face, and at two workshops held at the Bureau of Meteorology (BoM) in Melbourne. The first workshop was held on 25th August 2016, where BoM staff presented a number of project ideas to this planning team. The second workshop was held on 27th September 2016 again at BoM, where the results of the consultation were presented, BoM staff presented a modified set of project ideas for critical analysis, and then small groups were formed to develop further ideas for projects. The total number of people consulted was about 50, including groups represented by one spokesperson. A draft of this report was circulated in November 2016 for final comment by everyone who was consulted.

The MCV5 Business Case (MCV 2016) makes it clear that a substantial portion of the available funding will go to research and development of climate forecasts. This investment relies on and will build on existing investment and expertise from BoM which is Australia's sole provider in this area. Potential projects at BoM offer the greatest likely benefit, with co-engagement and co-investment from a range of partners including the Universities, and therefore proposals from BoM were subject to the greatest scrutiny through the workshop process.

Meta Questions

First, a few words about terminology; references to "climate research" and "seasonal climate" throughout this document are intended to be interpreted broadly to cover multi-week to multi-year timescales, but not weather timescales (up to 10 days) or timescales beyond a decade. References to ACCESS (the Australian Community Climate Earth Systems Simulator) generally refer to the seasonal timescale version of this system, ACCESS-S; the system actually covers timescales from weather through to climate change (see section 14).

A number of questions arose regarding the overall approach and structure that the new MCV program might have. The general view is that MCV5 needs to be very focused in order to maximize the impact of the limited funding available.

1. Should MCV fund industry-specific research? Perhaps MCV should fund more generic climate research that benefits all of agriculture and leave industry-specific applications to the individual RDCs. In practice, there may be a middle ground where the contributing partners benefit by a greater emphasis on their industries. In addition, maybe MCV could develop industry-specific projects through joint-funding with RDCs (in addition to the central pool for more basic research).

2. Related to the previous point, the question was asked about where both MCV and BoM draw the line in terms of their research and application focus. For example, the BoM would not have the resources or mandate to build industry-specific applications.

3. Is it necessary to further demonstrate the value of climate forecasts? There have been a limited number of studies over recent years estimating the value of climate forecasts to specific sections of agriculture in Australia. The MCV-commissioned CIE report (CIE 2014) used this limited information to estimate the Australia-wide value of climate forecasts to agriculture and other industries. This report was very influential, helping to secure a Rural Research and Development for Profit (RR&D4P) (DAWR 2016) project in round one for the MCV partners, and contributing to BoM being able to justify a new supercomputer. However, the report was obliged to rely on limited information, and is now three years old. Perhaps ABARES could be involved in compiling a new report.

4. Typically MCV forms partnerships with research providers on a 50/50 funding basis. However the RR&D4P programme will match MCV plus research provider funding, giving MCV increased leverage; MCV ends up contributing 25% of the project funding.

5. Should MCV fund areas where the research is fragmented between different institutions and models? How would MCV choose a winner? Would MCV perpetuate this fragmentation by providing funding?

Critical Discussion Point

In an ideal world, MCV would fund both the research to improve forecasts and the efforts to increase uptake in agriculture. In practice, MCV5 will be struggling to find the resources to fund just one of these properly.

None of the RDCs on their own are likely to fund the research needed to improve forecasts. That would seem to be the role of MCV as a consortium of climate-interested parties. That leaves individual RDCs to fund uptake and extension in their own sectors.

Perhaps a key role of MCV in addition to funding targeted climate forecast improvements is to bridge the gap between research products and industry needs. This would require making forecast information easy to use and understand, with an initial focus on the industries of the partner organizations. Effective linkage to end-users (producers and their trusted advisors) will increase the uptake and relevance of the research.

It is important to note that without MCV funding and support, there would be very little research targeted specifically at improvement of the seasonal forecast model for agriculture. MCV adds this focus for agriculture.

Summary of Key Points from Consultation

A few key points emerged during the consultation process, mentioned by quite a few respondents.

1. Users want increased forecast skill at multi-week to multi-year timescales. Forecasts of the probability (high or low) of high-impact climate events would be of most value;
2. The need for an API (Application Programming Interface) to make it easier to connect climate forecasts to biophysical models and decision-support tools. This is of particular importance given the increased focus on digital agriculture;
3. The information landscape is already very complex for producers;
4. Need more focus on agricultural applications, forecast use, communication and uptake. The interpretation of probabilistic forecasts needs careful communication;
5. Small research community – need to enhance collaboration.

These dot points are discussed in more detail below.

Improved Forecast Skill

As a prelude to discussing the improvement of forecast skill, it would be prudent to be aware of "naïve demand". Everyone wants better skill, but there is already value to Australian agriculture with the existing skill (Asseng, et al. 2012). Seasonal forecasts will never be perfect due to the chaotic nature of the climate system (Shukla 1998), and individual forecasts can be wrong. However, the long-term guidance is ultimately valuable in much the same way as a 70/30 biased coin might come down tails occasionally but in the long run would make you money. It is also important to have realistic expectations about what is possible in terms of increased skill. For example, improving rainfall skill in climate models has been called a "wicked problem"; there are multiple factors that interact in complicated and non-obvious ways.

The desire for increased skill spans a number of dimensions; lead-time, forecast period, time of year, which variable is forecast, and region.

Three regions emerged as requiring the most work; southwest Western Australia (SWWA), Queensland and Tasmania. A locally-developed statistical seasonal forecast (SSF) (DAFWA 2016) in SWWA is considered to be more useful than POAMA in that region, and so SSF is used by DAFWA in their agricultural applications. DSITI in Queensland use a range of statistical and dynamical forecasting systems including POAMA, although use of POAMA is at present limited. POAMA has little skill in Tasmania because the relatively old atmospheric model component has ocean where Tasmania should be. In addition, the coarse resolution of POAMA assigns just four ocean-model grid points as land to simulate Tasmania. There is no chance of representing the important topographic effects at this resolution.

ACCESS-S version 1 will improve forecast skill in SWWA for temperature but not so much for rainfall, and will improve all variables in Tasmania. ACCESS-S1 will also improve skill in Queensland for all variables at short multi-week timescales, but will decrease skill for maximum temperature in particular at longer timescales. This is understood to be due to the climatological initialization of the land surface that is currently part of the model as obtained from the UK Met Office. Experiments using realistic land initial conditions indicate a substantial improvement over much of the country, and these improvements are scheduled to be included in ACCESS-S2.

Increased skill was indicated as being desirable at a wide range of timescales, from multi-week (just beyond the weather timescale) to multi-year (e.g. runs of good or bad years). It was suggested that multi-week forecasts in particular are important for a range of tactical on-farm decisions, but that more work is needed on how best to make use of them. The idea of forecasting regime transition probabilities was also raised in the context of multi-year forecasts. For example, the transition to wetter conditions in 2016 after the El Nino in 2015 is more predictable than the onset of an El Nino, which was expected in 2014 but eventuated in 2015.

It was suggested that a range of skill measures be considered beyond simple correlation, such as statistical sharpness and reliability. A focus on non-ENSO years was also recommended as a way of improving the model further, since the strong ENSO years are most accurately forecast but don’t always coincide with drought years.

Climate is the average of weather. While weather cannot be predicted accurately beyond 10-14 days, climate models work by simulating weather systems as they are affected by large-scale climate drivers. For example, a wet seasonal forecast for south-east Australia would be a consequence of the model generating more rain-bearing fronts and cutoff lows and/or wetter instances of these weather systems. Alternatively the spatial location of weather systems might be moved by climate drivers. The conclusion is that it is important that the models simulate the statistics of key weather systems accurately.

Two key weather features that emerged in consultation were the long-wave trough and east-coast lows (ECLs). The long-wave trough might not be considered a classic weather system, but it is important in steering rain-bearing fronts and lows as they approach Western Australia. It will also have an effect on downstream regions of southern Australia. ECLs can develop rapidly off the east coast of Australia and bring strong winds and extreme rainfall to the coastal regions where the sugar industry in particular can be strongly affected.

Diagnosing why a model has inadequate skill in a particular region is not as easy as might be expected. There is no knob in the model that can be adjusted to alter rainfall in SE Queensland, for example. Climate models are global, and they are globally connected by planetary-scale oceanic and atmospheric processes such as Rossby waves. Altering convection in the Indian Ocean can affect rainfall over SE Australia. These remote influences are called teleconnections, and they are fundamental to the way climate drivers affect local rainfall and temperature.

The speed and direction of propagation of Rossby waves and other important dynamical processes are determined by key aspects of the mean state of the model, such as the vertical temperature gradient or the north-south structure of the zonal winds in the sub-tropical jet. The underlying shape and location of key climate drivers can also contain errors, such as the westward bias of the western Pacific warm pool experienced by almost all climate models which shifts ENSO to the west compared to observations.

Mean-state bias in climate models could be considered both the most important issue to address and the hardest. There is still a great deal of “dynamical detective” work to be done to determine the causes of mean-state errors and correct them. These errors tend to arise within a few days after the model starts which means that an “initial tendency analysis” can be conducted relatively cheaply in terms of computer time. These errors also tend to be “stubborn”, in that changing key aspects of the model might have little effect. The problem would appear to be complex and globally connected. Note that there are errors in the variability of models as well as errors in the mean. For example, ACCESS-S1 has an Indian Ocean Dipole (IOD) that is too strong, although the associated rainfall over Australia is too weak.

The starting point for any model forecast is called the initial condition. It involves estimating the global atmospheric, oceanic, land surface and sea-ice state from observations. Regardless of the number of observations, the initial condition will never be known perfectly. Small errors here can grow to large uncertainty in the forecast in future months due to chaos. To estimate this uncertainty, an ensemble of initial conditions is generated and many forecasts are made. It is generally the case that the spread of forecasts for a single year will be less than the spread of observed outcomes over many years, in which case the forecast has useful predictive skill.

POAMA is a relatively old model that “bats above its weight” because it has a very good initialization and ensemble generation scheme developed by CSIRO and BoM. The new model, ACCESS-S1, inherits an inferior scheme from the UK Met Office, and this cannot be changed for the first version. Even so, on most measures ACCCESS-S1 will be superior to POAMA. It is planned to incorporate a fast-track and updated version of the POAMA initialization scheme into ACCESS-S2, and the full version into ACCESS-S3. Both S2 and S3 will, as part of this process, have an improved land surface initialization scheme. This has already been shown to improve forecast skill over much of Australia, particularly for maximum temperatures over Queensland.

One of the hardest physical parameterizations to get right in any atmospheric model is the convection and rainfall process. This is particularly important in the tropics because there is a lot of energy involved, and because a significant amount of this energy can be carried away from the tropics by Rossby waves to affect mid-latitude weather. Furthermore, convection and rainfall over tropical ocean regions form part of the large-scale ocean-atmosphere feedback processes that are ENSO and the IOD.

The round one RR&D4P(r1) project (DAWR 2015) has a sizeable component looking at convection and rainfall, and it is anticipated that advances will be incorporated into ACCESS-S3. However, more research is needed in the related area of cloud parameterization. Clouds act to trap heat and reflect sunshine, and are an integral part of the climate system, particularly in the tropics and over the southern ocean.

Quite a number of respondents mentioned the importance of forecasting extreme weather and climate events. These events include heat waves, large-area frosts, floods and extended dry periods, and there are many derived indices designed to capture the importance of these and other events to agriculture on a range of timescales. Extreme events can have a big impact on production and generate a great deal of (generally negative) publicity. It has been suggested that an increased focus on extreme events, or maybe climate and weather that is “out of the ordinary”, would be of most use to agriculture as well as attracting support from Government and other funding sources. Furthermore, such an approach might help reduce the information overload that many farmers complain of. As one workshop participant put it, “Only annoy me when there’s something to say!”

It is important to acknowledge that not all extreme events will have a practical management response no matter how well they are forecast. However, new technologies may emerge as forecasts improve (e.g. LED temperature indicators in cherry crops to guide mixing of warm air down to ground level by helicopters). Accurate forecasts of short to medium term rainfall will remain of great practical use.

Although much of the research effort within Australia and from MCV has been directed towards POAMA and now ACCESS, it is important to remember that there are other reputable climate models run by various research institutes internationally. Forecast errors tend to be uncorrelated between models despite the occasional common problem (such as the western Pacific warm pool bias), and so an ensemble of forecasts from a range of models is more accurate than an ensemble from any individual model. The BoM, through their ENSO wrap-up, and the Victorian Department of Agriculture, through their Fast Break newsletter (Agriculture Victoria 2016), survey eight models including POAMA. Common advice given by climate advisors is to look for consistency across this range of models. If they all give roughly the same message then this forecast should be considered as being more reliable than if the models disagree. A consistent forecast can be of value in informing management decisions, whereas an inconsistent forecast would likely lead to decisions based on long-term risk management and non-climate factors.

Although MCV is committed to supporting development of ACCESS, when considering projects that incorporate forecast information into tools for advisors and producers it might be prudent to ensure that a range of reputable models are represented.

Digital Agriculture and APIs

Many of the people consulted mentioned the rise of digital agriculture and the importance of integrating climate forecasts with this new technology. An example would be an automatic irrigation system in the sugar industry that allocates water based on in-situ measurements of soil moisture and crop demand combined with multi-week forecasts of temperature and rainfall.

Many respondents also mentioned the need for application programming interfaces (APIs) which make it easy to incorporate climate model forecasts into existing biophysical models and agricultural decision support tools. One of the very few examples is Yield Prophet Lite, an IOS and web app that accesses the latest growing season rainfall forecast, suitably calibrated and downscaled to a user’s location, using a single internet command (BCG 2016).

Raw seasonal climate model output is complicated to use and understand for many reasons. Furthermore, each climate model will have a different output format, range of variables, measurement units and underlying assumptions about the ensemble structure. The output can consist of many terabytes of data stored across multiple files. Extracting a time series forecast at a single point using standard web access protocols such as OPeNDAP can take tens of minutes. This is far too long to be used in an app where the expectation is that results will be returned within a few seconds.

An API is an agreed set of functions and procedures that allows a particular agricultural application (such as APSIM or AussieGRASS) to easily access climate forecasts on a range of space and time scales in a format that the application already understands. The data must be able to be quickly downloaded over the internet, and be up-to-date. Different applications will require different APIs, but much of the infrastructure and computer code will be in common. APIs relevant to the industries of the contributing partners to MCV would be developed first.

Ideally, the output from multiple seasonal prediction systems would be available through each API, increasing the ensemble size substantially and therefore improving the statistical reliability of the information by averaging across different models. This might be a stretch objective given the large amounts of data in different formats associated with overseas models, but it would be a highly-desirable product not only for research and development in Australia but throughout the world.

An additional function of an API could be to calculate derived variables that are not routinely produced by climate models but are useful in agricultural applications. For example, in the grazing industry a growth index is more valuable than simple forecasts of rainfall and temperature (McIntosh, Ash and Stafford-Smith 2005).

The provision of suitable APIs to industry researchers may also help overcome some of the barriers to uptake of forecast information by making it easy and familiar. One possible delivery mechanism would be through SILO, where data from past years and forecasts from future ensemble years would be available in a seamless fashion.

Finally, it is important to give thought to the design of APIs so that they need as little modification as possible over time. It would not be desirable to have to repeat this process over and over again, although at the same time it will not be possible to define rigid standards that cannot change.

Information Overload

There were quite a number of comments about the complexity of the information landscape for producers and their advisors. There are 46 decision support tools listed on the Climate Kelpie web site (MCV 2016) alone after a rigorous selection procedure. In addition to these tools, climate and weather information is available on a wide variety of web sites both within Australia and overseas. However, very few of the decision support tools incorporate climate forecasts.

The general consensus seemed to be that producers don't need more tools, but rather that climate forecasts should be incorporated into existing tools so that this additional information could be utilized in a familiar setting.

Most decision support tools appear to focus on a single management decision, such as fertilizer application or stocking rate. While it is important initially to fully understand the impact and value of these individual decisions, ultimately a farmer is operating in a complex decision-making environment and juggling many factors. It would be useful to have more complex multi-decision support tools, perhaps based on existing and well-understood tools, where a manager can look at the potential consequences of a set of management decisions compared to a different set. This sort of A/B comparison would help reduce the complexity of decision making, and increase learning about the interaction between various decisions. As part of a GRDC-funded national project, DAFWA are developing just such a tool for the grains industry that could act as a prototype and test bed in this area, particularly with the addition of climate forecasts through a suitable API.

Maintain Focus on Agricultural Applications, Use and Communication

The current MCV5 business plan suggests allocating 35% of funds to improving the forecast, and another 30% to valuing the forecast. The remainder is allocated to using and communicating the forecast. A number of people have raised the importance of maintaining a focus on application and extension of climate information and use to ensure that the benefits of new research flow through to end users.

The concern was raised that Australia is losing people who can communicate climate forecasts to producers, perhaps due to reduced funding in this area. The possibility was raised that climate forecast information is losing focus compared to all the other factors that a producer has to consider.

The question was asked earlier in this report as to whether MCV should focus more on research that has an industry-wide application, leaving industry-specific work to the relevant RDCs. This is particularly relevant when there is a relatively small pot of money to be allocated. On the other hand, the contributing partner RDCs may feel that they are supporting non-contributing RDCs.

One possible resolution to these issues is to allocate resources to making forecast information easily available for use in industry-specific work through development of the appropriate APIs. The MCV contributing partners would obtain an advantage for their investment by having their APIs developed first.

The issue of forecast interpretation and commentary to translate complex technical information for general use was mentioned a number of times. If this is done well it can build user trust and increase uptake of climate forecasts.

Enhance Collaboration and Community

It is generally acknowledged that Australia has a relatively small research community in climate and agriculture and that for the most part it would be advantageous to encourage collaboration rather than competition. The second consultation workshop highlighted the need to establish a community around the development of the ACCESS model. It would be beneficial to enhance communication between the small number of groups working on ACCESS, perhaps through a shared web site and regular workshops. It is not clear that this is the responsibility of MCV, and there are moves within the ACCESS community itself to enhance communication and collaboration. However, as a major stakeholder, MCV should at least have some input into this. More generally, it would be desirable to increase the collaboration and communication between all researchers and practitioners in climate and agriculture. It may be that the Community of Practice (CoP), which is managed by the Birchip Cropping Group as part of the RIRDC-managed RR&D4P(r1) project, could assist with this objective.

A second area where collaboration and communication would be advantageous is in multi-year forecasting. At the moment there are separate groups in CSIRO, BOM and DSITI pursuing different aspects of this important problem. At the very least MCV should keep a watching brief on this rapidly-developing area of research.

A third area where there are different groups working in potentially-different directions is that of land-surface and soil-moisture modelling. ACCESS-S1 uses JULES, the UKMO land-surface scheme. There are plans to change the way this is initialized, but the basic model is likely to be retained. Australia (CSIRO and Universities) has developed a land-surface model called CABLE, which is generally thought to be superior to JULES for Australian conditions. There may be advantages to incorporating this model into ACCESS in the medium term. The Australian Water Availability Project (AWAP) soil moisture product is based on CABLE (Bureau of Meteorology 2016). The BoM has developed a statistical scheme called AWRA (Bureau of Meteorology 2016), and is pursuing a relatively large project to conduct soil moisture mapping and forecasts over Australia. The shape of this project is being refined, but it is not clear which land-surface scheme it would use, and whether this would benefit ACCESS. Furthermore, a number of people (including some farmers) have noted that they don't need a gridded soil moisture product because they measure the soil moisture on their farm. To summarize, it seems likely that soil moisture modelling and mapping is another area that MCV could keep a watching brief on for the moment.

Summary of Other Points from Consultation

Communication

1. There is concern that many farmers are still not aware of POAMA. The counter point is that awareness of seasonal forecasts products is more important than awareness of how they are produced or particular products;

2. There are a lot of POAMA-based experimental products available on the BoM web site but protected by a password because they are not considered operational. A lot of this information would be valuable to producers right now;

3. It remains important to communicate that forecast skill varies by season, region, ENSO state and other factors;

4. Much more communication is required on the use and value of imperfect forecasts;

5. It is not enough to present the mean value of a forecast. The spread contains much more useful information, and reinforces the probabilistic nature of climate forecasts;

6. A good approach might be to present probabilistic information to farmers (with adequate explanation) and let them decide on their own risk profile. Different farmers have different levels of acceptable risk;

7. The Break and The Fast Break newsletters give a valuable interpretation of the forecast from a range of models;

8. Do we give producers the best management decision, or let them work it out (in conjunction with other factors) from forecasts of rainfall etc.? The latter approach seems preferable, giving the producer engagement in and ownership of the decision.

9. We now have tools to contextualize climate information to end users (e.g. Yield Gap Australia, YPLite, CliMate). There is low-hanging fruit here.

Intellectual Property (IP)

The ownership and control of IP in research projects can inhibit research and cause delays in the application of knowledge to agriculture. It is important to compare the value of research IP to RDCs with the value to industry of the research. For example, there have been ongoing issues between CSIRO and GRDC over IP related to APSIM for more than 8 years. The question is whether this has benefited the grains industry in the long run?

BoM have restrictions on the use of raw POAMA forecast data; it can be used for research purposes only. The reason for this is not so much related to IP as to BoM not being able to guarantee the provision of raw POAMA data in an operational commercial environment. This has not prevented free tools, like Yield Prophet Lite (which depends on raw POAMA forecasts), being made available to the public. The situation will become a little trickier when it comes to paid tools. The BoM is aware of the issue. The solution will depend on decisions made about data provision in a necessarily secure environment, and the resources required to support the associated infrastructure.

Other Points Raised from Consultation

In no particular order:

1. State and national yield prediction is desirable particularly from an industry and value chain perspective. While this is now technically feasible, there is still a lot of research to do on the best ways to drive agricultural models with the output of forecast models. Yield Gap Australia (CSIRO and GRDC 2016), for example, is a possible template for the delivery of national predictions.

2. One way of getting some focus on a large task is to ask where and when climate forecasts make a difference. Even if a forecast is skilful, there may not be an appropriate response in terms of a management decision. For example, a frost forecast after planting is difficult to take advantage of;

3. There is a need to explore further the barriers to uptake of climate information and ways to break down those barriers through additional social science research;

4. Are there institutional barriers to the uptake of climate forecasts? For example, if RDCs are not supporting and promoting the use of climate forecasts, will their industry get the message that they are not useful?

5. There are many advantages to ensuring that WA grains researchers are included as part of MCV5. A strong connection between grains research in the east and west of Australia allows sharing of knowledge and experience for the benefit of the national grains industry. WA is strongly affected by the long-wave trough which guides weather systems towards or away from the coast, but can also influence the downstream southern states. Research on representation of the long-wave trough in models could have widespread impact. DAFWA have considerable experience in connecting climate forecasts to end-users, although they use a statistical forecast scheme that is somewhat more skilful than POAMA in SWWA. They are developing a prototype of a multi-decision support tool for management scenario testing that could incorporate ACCESS forecasts, but also be widely applicable across the Australian wheat industry. WA is a major wheat producer, growing 36% of the Australian wheat harvest on average.

6. MCV could support the development of an accredited course for agricultural/climate advisors ("train the trainer"). There are very few people in Australia qualified to provide education spanning agriculture and climate.

7. When considering the value of climate forecasts, it is important to consider the whole value chain (e.g. sugar mill scheduling, storage, transport) as well as producers.

8. What is the benefit/cost ratio for improving climate forecasts compared to using the existing skill?

9. It is much more valuable to provide decile information about a forecast than above/below median.

10. A number of people are using YPLite just to get to the decile forecasts at the end. There is a possible project here to put the time-evolution of decile forecasts on the web complete with error bars and start-time averaging with lagged ensembles to improve forecast stability and reliability.

Project Ideas from Consultation

This section describes a number of ideas for projects that have evolved through the consultation process. These ideas have led to the development of two possible pathways for investment in Research and Development for MCV5 as discussed in the following section 9. Each plan is based on a limited set of projects arising out of these ideas. The projects are described in section 10.

The first nine of the ideas in this section were discussed and developed at the second workshop at BoM on 27 September 2016. Break-out groups for each idea were tasked with describing what success would look like, and to undertake a SWOT analysis (strengths/weaknesses/opportunities threats) to the extent that time permitted. The remainder of the ideas have emerged through the overall consultation process and from the review panel, and are in a more general format.

1. ACCESS S2/S3 build

    Development

1. Implement past MCV improvements in ACCESS-S2/3

2. E.g. Coupled assimilation + ensemble generation - fast-track version in ACCESS-S2 and full version in ACCESS-S3

3. Includes land surface initialisation + sea ice initialisation

    Evaluation for MCV

1. Evaluation of forecast accuracy for regions/products relevant to MCV

2. Identification and evaluation of major busts/failures relevant to MCV users

3. Use this information to inform use of forecasts (e.g. better quantification of expected reliability or reduced limit of predictability) and/or future development (e.g. if model/initialisation problems)

    Products and applications

4. Develop and evaluate skill for new agricultural products (e.g. growing season 6-month outlooks, growing degree days)

5. Utilise new calibrated forecasts at 60km

6. Develop variables required for agricultural models, calibrated to 5km (using quantile mapping) over Australia (co-investment with other groups)

7. Enable other MCV research projects to utilise the 5km calibrated forecasts from the research server.

Success

1. Having ACCESS-S2/S3 running operationally in the shortest possible time.

Outputs

1. Knowledge (reports) on busts, failures and successes.

2. APIs linked to standard ACCESS-S outputs

3. Evaluation of ACCESS-S against POAMA outputs for agriculture

4. Evaluation of ACCESS-S against SSF for use in WA

Strengths

1. Team effort and coordinated approach

2. Building on existing models and knowledge

Weakness

1. Resolution of WA or other areas may still not be adequate

2. Systematic bias – Indian Ocean

Explore the cause of the biases

1. Explore the link between atmospheric model errors and Indian Ocean Bias

2. Leverage existing RR&D4P(r1) project – convection (e.g. could focus on cloud errors)

3. Explore the possibility of ocean model error – mixing, Indonesian Throughflow

Explore improvements

4. From existing RR&D4P(r1) project

5. From UKMO – new and old developments

6. From other groups – e.g. Ocean modellers in France

7. Local development

Implement improvements

8. Test improvements in coupled forecasts

9. Implement in next operational system

Outputs

10. Substantial reduction in rainfall bias (quantify?)
11. Improved depiction of IOD and impacts on Australian climate
12. Increased skill at longer lead times in southern and eastern regions in the cool season
13. Better interaction between ENSO and IOD (broader benefits)

Strengths

1. Interactions with other research agencies (UKMO, Monash, BoM, NESP)
2. Over a longer timeframe this can leverage other projects and diagnostic capability (e.g. existing RR&D4P(r1) project on convection)
3. Benefits regions of Australia where agriculture is important industry.

Weaknesses

1. Don't know what to do – trial and error
2. POAMA will provide only vague guidance – it's a different model
3. High-risk but high-reward
4. Extreme rainfall and frost

Heat extremes

1. Extend the previous MCV heat extremes project

Extreme Rainfall

1. Develop set of extreme rainfall products (e.g. Decile probabilities)
2. Evaluate the accuracy
3. Provide trial real-time products

Frost

1. Understand drivers of frost and cold waves and their representation in ACCESS-S
2. Determine potential products
3. Evaluate ACCESS-S accuracy
4. Provide trial real-time products

Success

1. Small suite of skilful forecast products (e.g. heatwave, frost potential, heavy rainfall, cold)
2. Increased understanding of drivers of extreme events on multi-week and seasonal timescales
3. Enhanced partnerships

4. Reduced impact of extremes on agriculture
5. Improved communication to stakeholders

Outputs

1. Trial real-time forecast products of extremes (e.g. heatwave, frost potential, heavy rainfall, cold)

Strengths

1. Partnerships/co-funding/leveraging skills and capacity
2. High impact
3. Concrete skill for some extremes
4. Changing the risk

Weaknesses

1. Often can't act (no management response possible)
2. Misinterpretation of forecast/extreme
3. Poor/limited skill for some extremes
4. Small ensemble size
5. Limitations of sampling (rare events)

6. Land surface

This project would assess the possible replacement of the UK Met Office land surface model (JULES) with the locally-developed model (CABLE). CABLE has been developed for Australian conditions, in particular the semi-arid sub-tropical agricultural regions not found in Europe where JULES has been developed.

1. Understand role of land surface in multi-week to seasonal forecasts (e.g. especially role for extreme events)
2. Evaluate the initialisation of the land-surface from the coupled assimilation (compare to offline run of Jules)
3. Investigate potential benefits from further improvements in land initialisation
4. Evaluate the skill in predicting land surface temperature and moisture, and improvements in predicting rainfall and temperature extremes from ACCESS-S
5. Develop/evaluate land-surface moisture forecast products at 60km
6. Investigate potential to calibrate this to 5km AWAP using quantile mapping
7. Evaluate the suitability of land surface forcing fields to drive agricultural applications models (60 and 5km)

8. Provide land surface forcing fields in a format suitable to agricultural researchers

9. Link to potential RR&D4P project on local level soil moisture analyses and prediction

Outputs
1. Improved accuracy of forecasts (e.g. particularly Tmax in Qld, but overall too) at multi-week to a few months through better land surface initialization

Strength
2. We know the problem

Weakness
3. Quantifying importance (spatially & temporally dependent)

Opportunities
4. Soil moisture decision support system (DSS)

5. Irrigation/runoff DSS

6. Increased confidence in seasonal forecasts

Threat
1. Multiple land surface schemes

2. Multi-year prediction
1. Potential for multi-year prediction – is there skill for extended prediction of ENSO

2. Case studies – ability to predict La Nina following EL Nino (including back to back)

3. Case studies – ability to predict potential for El Nino onset a few years out

4. Evaluate potential benefits of multi-year prediction

5. Advise extension of ACCESS-S into longer lead times (e.g. 1-3 years)

6. BoM ~0.5 FTE with limited case studies and evaluation of UKMO – strategic investment

7. Looking for external support to produce more substantial study using several user relevant case studies

Success
8. Significant value add from predictions over historical scenarios

9. Models can predict changes in state (ENSO, IOD phase)

Outputs
1. Shifts in probability distribution over 3 years

2. Skill for models with this job?

Strength

1. Better communication combined with historical scenarios (e.g. what happened after previous El Nino)

Weaknesses

2. Predictability barrier limits skill?
3. Is there added value (how does a farmer respond?)
4. Multiple sources (could be a strength)
5. Needs persistence in seasonal drivers (is there enough?)

Discussion added after workshop - How to focus collaboration in this space?

There are three groups known to be addressing multi-year forecasting within Australia:

1. NESP/CSIRO (Terry O'Kane, James Risbey and others): Research incorporating new ideas about multi-year predictability into the GFDL coupled model has recently been substantially expanded, with CSIRO committing 15 full-time research positions over the next decade to model development and coupled data assimilation within the ACCESS framework, process studies, and verification and processing of ocean observations. CSIRO is also coordinating with the BoM and will provide underpinning science for future developments in multi-year prediction and coupled data assimilation for the ACCESS-S system.
2. BoM (Oscar Alves): Planning experiments running ACCESS-S beyond one year
3. QDMC/USQ/DSITI (Jozef Syktus): Investigate the climatological drivers, length, duration, frequency and spatial extent of multi-year droughts from historical records. This analysis will provide a baseline quantification of the risk of multi-year drought to inform climate risk management by stakeholders.

These are different and complementary approaches. It is important the main players communicate regularly. Perhaps MCV could fund an annual workshop.

Application Programming Interface

An API (Application Programming Interface) connects different models together using an agreed method and format in a way that is simple, fast and well-documented. The SILO climate database is a good example. It takes raw station observations of meteorological variables over time, fills temporal gaps by interpolation from neighbouring stations or using climatology, interpolates to the location requested and produces data files that are in a range of formats for commonly-used agricultural applications. SILO has been called a foundational data set, and its importance to agricultural research in Australia over many years cannot be overestimated.

This project would do the same for the output from climate models. Initially it would focus on ACCESS and provide output in formats suitable for the major decision support tools used by the MCV partner industries. Eventually it would seamlessly encompass a range of credible climate models and provide output in a wide range of agro-specific formats.

There are five main challenges to solve here:

1. Decide on the most appropriate way to produce a suitable ensemble of climate forecast data from the raw ensemble data across multiple models. Even within a single model such as ACCESS, there will be different ensemble numbers at different timescales.

2. Calibration of the output to remove model bias. This must be model, location and season specific.

3. Downscaling of the variables. The effects of topography must be taken into account, as well as the effect of averaging over a model grid box (the so-called “drizzle problem”).

4. Ease of access – there are web protocols such as REST and SOAP that are relevant here.

5. Speed of access. Extracting time series from operational meteorological data centres can involve striding across thousands of files, which cannot occur rapidly with protocols such as OPeNDAP. Accessing data from overseas models adds an extra layer of complexity and time overhead. A decision support tool requires results almost instantly. A lengthy delay is very likely to inhibit uptake. To address this it may be necessary to invest in appropriate infrastructure.

It is likely this project would require ongoing support to ensure uninterrupted service in the event of changes in climate models, and to allow the addition of new decision support tools (although ideally any new tool would be coded to use an existing format). Maintaining a set of updated documentation will also be an important task.

Outcome

1. Substantially increased uptake of seasonal forecasts in a range of tools and industries

Strengths

2. Popular idea during consultation

3. Good support from a number of research organizations

4. Proof-of-concept exists

Weaknesses

1. Does this satisfy RDC's desire for industry-specific research?

2. Would require good communication and documentation to prevent misuse

Opportunity

3. Easy path to mainstreaming climate forecasts in agriculture

Threats

4. Is CSIRO heading in a similar direction?

5. Will require ongoing maintenance.

(Note added as a result of a review of the first draft: the word "threat" here is used in the sense of a SWOT analysis. It would not be desirable for MCV and CSIRO independently to develop an API for seasonal climate forecasts. CSIRO has indicated that they strongly support the development of an API because it would be of enormous value to their agricultural research. CSIRO would gladly consult and collaborate in the development of this interface.)

6. Enhancing ACCESS community

A number of different research institutes and teams are working on various aspects of the ACCESS model at different timescales. There are real synergies to be obtained by bringing these researchers together into a community to share knowledge and techniques. The Community of Practice (CoP) that has been set up as part of the existing RR&D4P(r1) project could play an important role here in maintaining communication between groups and facilitating knowledge-sharing workshops.

1. ACCESS or MCV community? Ag communities + forecast providers

2. Common metrics

3. Methodologies shared

4. Data standards

5. Communication forum (e.g. seasonal outlook, community of practice, Fast Break, Landline?)

6. Site for accessing data and information (e.g. Climate Kelpie). Bring together what exists now.

7. Capacity development (develop educational material, training opportunities)

8. Who is missing (apart from BoM, CSIRO, Unis, State Ag Depts) – ABARES, DAWR, RDCs.

Output

1. Increased collaboration and knowledge sharing between researchers using ACCESS based on shared methods and data handling

Strength

2. Synergies obtained through knowledge sharing and data standards

Weakness

3. Knowledge already shared sufficiently without MCV funding

4. Using and valuing forecasts, uptake and communication

Success

1. Increase in use and trust of climate forecasts in agricultural decision-making

Output

2. Commentary behind the forecasts (TV, radio, web)
3. Yield Prophet Lite pilot deciles
4. Historical phase e.g. ENSO, IOD, year after El Nino.
5. CliMate as a vehicle?
6. User market research
7. SAM page or tool for Australian context

Strengths

1. YP – choice for user styles
2. BoM outlook products getting better (video, IOD, ENSO etc)

Weaknesses

1. Critical to identify users (define specific target)
2. Defined roles e.g. BoM national, who does state, regions?
3. Do we have benchmark data on users of seasonal outlooks (e.g. percentage of farmers using BoM 3 month outlooks)?

4. Multi-week forecasts

Forecasts at multi-week timescales span the gap between weather forecasts (up to 10 days) and seasonal forecasts (more than a month). Such forecasts are generally quite skilful provided the model initialization and ensemble generation methods are adequate (such as in POAMA). Multi-week forecasts are of considerable use to end-users to enable planning beyond the weather timescale for important operations such as sowing and harvesting. This idea is about the development of forecasts of agriculturally-relevant variables on multi-week timescales, together with the probabilities of important weather events such as east-coast lows (ECLs) and the key multi-week climate driver SAM (southern annular mode).

Outputs

1. Tailored prediction of products (8-28 days)
2. Variables (rainfall, Tmax, evapotranspiration, soil water etc)
3. Forecasts of ECLs and SAM

Strengths

1. Forecast is already done
2. High farmer uptake
3. Demonstrated skill

Weaknesses

1. Accuracy difficult
2. Communication and interpretation (not a weather forecast)

Opportunities

1. Links to community and emergency services
2. Links to forecasts on other timescales

Threats

1. Expectation management
2. Focus of MCV charter

Soil Water – 'Rain in the bank'

This is a large program being developed jointly by BoM and the University of Melbourne, and it is still evolving. It currently consists of 10 integrated research, development and extension projects. The main output will be an operational system to provide a gridded analysis of current root zone soil water, and forecast values three or more months in advance.

The ability to take soil moisture observations and infuse them into a modelling system is complex and the science is uncertain. The project would almost certainly produce a useful product, but it is not clear that it would lead to any improvement in decision making by farmers. The models do not produce directly "actual soil moisture". The model output would need to be translated into something useful. Farmers tend to know their soil moisture fairly well at the start of the growing season, together with their soil's water holding capacity, and this information is specific to the paddock scale.

There are a number of land surface schemes being used in Australia at the moment. The agreed national land model is CABLE. The current land model in ACCESS is JULES, which comes with the UK Met Office version of ACCESS. The BoM run a statistical system called AWRA. Furthermore, CSIRO already provides gridded soil moisture through AWAP. Ideally this large program will unify the current fragmented land surface modelling scene in Australia, but it is not clear at the moment if the program is structured to achieve this.

Review paper on model mean-state errors

Reducing mean-state errors in the forecast model has the potential to lead to a substantial improvement in forecast skill. While the major mean-state errors can be quantified, it is very difficult to assign fundamental causes and remedies for specific errors. The large-scale circulation patterns and global propagation of planetary waves in these global coupled ocean/atmosphere/sea-ice/land surface models make the diagnosis of the causes of mean-state errors difficult. If a significant cause is identified (e.g. tropical convection) it can be very difficult to change this part of a model to improve the mean state and not have negative impacts on some other important quantity (such as variability). Sometimes, the model errors can be stubborn; significant model changes might make little difference.

This is a high risk and high reward area of research. One way for MCV to address this is to commission a scientific review paper by a senior climate scientist to bring together all the research on reducing mean-state errors in global climate models. Such a review paper, completed in the course of a year, could inform MCV investment in this area as well as increase awareness of the issue and current state of knowledge amongst key stakeholders. The down side to this approach is that it would delay this important research by a year, although it would presumably be better targeted. It might also be the case that key climate model scientists are already sufficiently aware of the research into model mean-state errors that such a review would be considered unnecessary.

High impact climate and weather (RR&D4P(r3) proposal)

This idea is an alternative to the first 5 ideas (and maybe others), covering much of what needs to be done but with a slight change of emphasis. It is particularly aimed towards obtaining funding from the RR&D4P program. It would involve BoM, CSIRO, CoECSS, CoECE, SARDI and potentially others.

Extreme events are generally high impact and high visibility. It would therefore be sensible to address these explicitly. Extreme events occur on timescales from days to years. Extreme weather events can cause daily flooding, frost, heat stress, high winds and coastal erosion. Extreme climate events are associated typically with droughts on monthly to multi-year timescales. Tropical cyclones could also be considered here.

This would be a relatively large undertaking with 6 components:

1. Underpinning science and system improvement
    1. Understanding drivers and predictability
    2. Improving the model and ensemble structure
    3. Reducing the Indian Ocean bias
2. Evaluation
    1. Which regions and timescales have skill
    2. Role of land-surface
3. Product development
    1. Stakeholder engagement for product prioritization (e.g. with CoP group)
    2. Drought indices, rainfall risk, heat/cold/frost events, tropical cyclones
    3. Decile forecasts (SILO stations or 5km grid popup)
4. BoM services and data delivery
    1. Operational products
    2. BoM services
    3. Operational data server
5. Applications
    1. CSIRO/SARDI/DPIs/Unis etc
6. Education and training
    1. User engagement/workshops
    2. Education on how to use forecast to best manage risk
    3. BoM/CSIRO/DPI extension officers
    4. Training the trainers

Decile forecast web site

Farmers are saying they want more than above/below median rainfall forecasts. Yield Prophet Lite has implemented a binned decile rainfall forecast that has proved popular and easy to understand. In fact, a number of people are putting dummy values into the app just to get to the forecast probabilities at the bottom of the second page. This project would build a simple web site that delivered a decile rainfall or temperature forecast at a requested SILO station. It would improve on the YPLite forecast by using a lagged ensemble of 5 or 7 start dates to improve forecast reliability and reduce forecast changes from time to time, and would also develop a method for indicating how accurate the forecast probabilities have been historically. One final addition would be the evolution of forecast probabilities over the last few months, or from the start of the growing season.

Output

1. web site to deliver a decile rainfall or temperature forecast at a requested SILO station, including forecast evolution and historical skill

2. Update CIE valuation report

It has been said that a MCV competitive advantage is in demonstrating industry value and success. This has been very valuable over the years.

The first CIE report (CIE 2014) on the value of seasonal forecasts, commissioned by MCV, showed a substantial benefit to farmers and to Australia from seasonal climate forecasts. This report was influential in many ways, for example, contributing to the agricultural white paper that provided additional funding for seasonal forecasting to BoM. However, the report concludes:

"While it is clear the benefits of improved seasonal climate forecasts is (sic) significant for the agriculture sector, further work is needed to be able to fully quantify these benefits in a comprehensive manner. Future work should endeavour to fill the gaps in the current literature – particularly the value of seasonal forecasts to livestock operations and a wider range of management practices."

It might be advantageous for the long-term funding of climate research for agriculture for MCV to consider either an update to the first CIE report based on more recent information, or to commission a project to do the research necessary to better quantify the benefit and value of climate forecasts to agriculture.

Industry studies incorporating economic assessment

As noted under idea 14, there is a lot of benefit that can come from an assessment of the economic value of seasonal climate forecasts to agriculture. The CIE report (CIE 2014) made an excellent first attempt at such an assessment, but was hampered by a lack of specific economic studies across a range of industries such as livestock. This project would develop a range of small industry studies to assess the economic importance of seasonal climate forecasts that could feed into an updated valuation report as outlined in idea 14.

For the grains industry, there is a lot of knowledge that could be shared between the east and west of the country. In WA, POAMA is not generally used due to its reduced skill there, although studies have shown the forecast can still be valuable. Instead, DAFWA has developed its own statistical seasonal forecast (SSF) system that has somewhat better skill than POAMA. Forecasts are presented through a locally-developed web site that could be used in other states. With the advent of ACCESS-S, it is likely that DAFWA will once again consider using a dynamical forecast system, perhaps initially in conjunction with SSF. A model ensemble system could even be considered, combining ACCESS-S and SSF. In terms of management tools, DAFWA are currently experimenting with a composite tool that allows testing of multiple management decisions at once. This tool would benefit from the addition of seasonal climate forecasts from ACCESS-S. It would also help researchers across the country start thinking and experimenting with the more complex management environment of a real world farm.

For the extensive rangelands grazing industry, there is a lot of innovative work that is possible in terms of using a seasonal forecast most effectively. There are a couple of studies that show that it is better to forecast pasture growth or live-weight gain rather than rely simply on rainfall. It should be possible to provide spatial maps of pasture growth, for example, over most of Australia, updated according to the latest forecast. In northern Australia it may also be valuable to simply forecast the onset of the wet season. Studies of the economic value of such forecasts would be of immense interest.

The cotton industry has a number of climate sensitivities; for irrigated cotton it is the temperature at the start and end of the growing season, while for the expanding dryland cotton industry, rainfall forecasts are most important. Again, an evaluation of the best ways to use forecast information, and the associated economic benefits, would be very useful.

There are similar projects that could be envisioned for horticulture, viticulture and sugar, all of which can be climate sensitive.

All these industry studies would feed into an updated economic assessment of the value to Australia of seasonal climate forecasts, and in addition should enable an assessment of the incremental value of further investment in seasonal climate research.

Discussion: Plan A and Plan B

There are many worthy ideas and projects that would be of benefit to Australian agriculture and deserve funding by MCV. However, with limited funds, MCV will need to choose a limited set of projects to have the maximum impact consistent with the requirements of the funding partners.

There appear to be two possible funding pathways:

1. Support a relatively large RR&D4P(r3) proposal, which would cover a broad range of research to maximize the chance of success, but which would leave less than half of the available MCV funding for a few additional projects through collaboration and partnering with the usual research institutions;

2. Support a well-chosen and balanced set of collaborative projects to cover the key requirements to emerge from the consultation.

Plan A: RR&D4P(r3) + API + industry studies and valuation

Idea 12 on High Impact Climate and Weather is particularly designed as a project for the RR&D4P funding source. It focuses on high impact and high visibility events for agriculture. It covers a very wide range of research, encompassing much of idea 1, all of ideas 2 and 3, and most of ideas 8, 9 and 13. This pathway has the advantage of leveraging MCV funds at 25/75 rather than the usual 50/50 and is in line with the research priorities for MCV5.

The additional projects to be funded outside the main project may need to be smaller in size. One would be designed to increase the utility and uptake of existing and future seasonal forecasts through the development of standard interfaces between forecasts and agricultural tools. This will also act to enhance collaboration and community across Australia’s small agricultural and climate research effort. A range of industry studies are recommended to continue MCV-funded work on using seasonal forecasts for the benefit of Australian agriculture.

These studies will benefit from and provide a test bed for the standard interfaces developed. In addition, information about the value of seasonal forecasts obtained from these studies will enable an updated assessment of the benefit of climate forecasts to Australian agriculture. Such an assessment will be invaluable in securing future funding for additional work in this area.

Plan A could, then, consist of the following projects (numbering refers to descriptions contained in the following section 10, and the ideas on which the projects are based are indicated in parentheses):

1. 10.1 - High Impact Climate and Weather (idea 12 including part or all of ideas 1, 2, 3, 8, 9 and 13) through RR&D4P(r3);
2. 10.2 - Application Programming Interface (API) (idea 6);
3. 10.3 - Industry studies incorporating economic assessment (idea 15);
4. 10.4 - Update CIE valuation report (idea 14).

It must be emphasised that this plan does not cover all of ideas 1, 8, 9 or 13. Furthermore, it does not encompass any of ideas 4, 5, 7, 10 or 11. It is the opinion of the authors that if more funding were to become available that idea 1 contained within project 10.1 would benefit from additional resources, and idea 4 could become an additional project (10.9 – Land Surface) worthy of substantial funding after due consideration of a range of complex issues.

Plan B: As much of Plan A as possible

The projects contributing to Plan A represent a balanced body of work encompassing the research and development needed to improve seasonal forecasts, through the connection, application and communication of seasonal forecasts to a range of industries, and culminating in an assessment of the increased value to Australian agriculture. In the event that the RR&D4P(r3) proposal is not successful, it is still desirable to try and achieve as much of the same work as possible.

With this in mind, a desirable set of projects for plan B is:

1. 10.5 – ACCESS S2/S3 build (idea 1);
2. 10.6 – Systematic bias in the Indian Ocean (idea 2);
3. 10.7 – Frost and extreme rainfall (idea 3);
4. 10.8 – Using and valuing forecasts, uptake and communication (idea 8);
5. 10.2 - Application Programming Interface (API) (idea 6);
6. 10.3 - Industry studies incorporating economic assessment (idea 15);
7. 10.4 - Update CIE valuation report (idea 14).

If more funding was available, then idea 4 is also considered to be of high priority as an additional project (10.9 – Land Surface)) after due consideration of a range of complex issues.

Other considerations

There has been much discussion about project 10.9 which involves substantial work on understanding the land surface modelling component of ACCESS. This project would assess the possible replacement of the UK Met Office land surface model (JULES) with the locally-developed model (CABLE). CABLE has been developed for Australian conditions, in particular the semi-arid sub-tropical agricultural regions not found in Europe where JULES has been developed. Replacing JULES with CABLE is not a trivial task, and would require substantial research and additional computing. In addition, there are wider implications because ACCESS is used for numerical weather prediction (NWP) by the BoM, and climate change forecasting by CSIRO. In the opinion of experts in land surface modelling, on timescales of 1-2 years JULES will be fine, but on longer timescales it is desirable to move to CABLE. One possible pathway is for the Australian developers of CABLE to work with the UK Met Office to incorporate the best parts of CABLE into the UK Met Office model (on which ACCESS is based). However, this might take 10 years to achieve. The alternative is for MCV to seek additional funds to fund project 10.9 after negotiating agreement with BoM, CSIRO and the Universities to overcome any complexities in implementing a unified approach.

Idea 5 (multi-year) is considered to be of lower priority for MCV at the moment, partly because CSIRO is committing substantial resources to the fundamental research, partly because the value of multi-year forecasts is yet to be demonstrated, and partly because the research community in Australia lacks a unified approach, making it difficult to decide which group to back. However, it is worth MCV keeping a watching brief in this area, perhaps with a view to funding a project to demonstrate the value of such forecasts. Idea 7 (enhancing ACCESS community) is being pursued by the research community itself and requires no funding from MCV. Idea 10 (Soil water) is large, complex and ambitious, but it is not clear what benefit it would bring to farmers who already measure their own soil water, and they also have access to crop models driven by seasonal forecasts (e.g. Yield Prophet). Idea 11 (mean-state review paper) is considered to be unnecessary given that climate researchers are generally familiar with the limited knowledge in this field. Idea 13 (decile forecast web site) is relatively small and is most likely to be undertaken by BoM as part of their operational forecast delivery.

Project Summaries for recommended projects

1. High Impact Climate and Weather (Plan A)

Key Research Questions;

For the key high impact climate and weather events affecting Australian agriculture, determine for a relevant range of locations and times:

1. Drivers/causes/sources
2. Potential predictability
3. Current predictability
4. Model deficiencies leading to low predictability
5. Model improvements to give the best increase in predictability

The project will also determine optimum ways to deliver the relevant information on climate and weather extremes to end users through BoM services, applications, user engagement, workshops and education of extension personnel.

Outputs and Benefits

This project will deliver scientific reports addressing the dot points above. It will also deliver research and operational products of use and value to the scientific and end-user communities.

The benefits will include increased trust in model forecasts due to increased skill and better understanding of model limitations. This will lead to increased uptake and use of forecasts by industry with an associated increase in production value and a decrease in climate-related risk.

Approximate Cost

About one half of the MCV5 budget, which is then leveraged through collaborator funding and again through the RR&D4P program.

Recommended Approach

Once high impact events have been defined, and the drivers and predictability investigated, the key model deficiencies should become clear. The likely areas for model improvement at the moment are initialization, ensemble generation, Indian Ocean bias and the land surface scheme. Other important areas may become apparent.

Product development and delivery will require close collaboration between BoM services and external agencies with greater knowledge in this area. Operational delivery is probably best achieved through BoM. Education and training will involve individual industries determining their most appropriate channels.

Recommended Groups

BoM, CoECSS (Monash, Melb., UNSW), CoECE, CSIRO, SARDI, State DPIs

2. Application Programming Interface (API) (Plans A & B)

Key Research Questions

To make detailed climate forecast information available quickly and easily for use in agricultural decision support systems, web tools and apps.

Outputs and Benefits

The output would be a data delivery system that provides climate model output in exactly the format required by existing agricultural decision support tools. The system will be very easy to use and provide data fast enough to drive mobile applications where a response is expected within seconds. The system will be capable of providing data from a range of climate models, but would focus on ACCESS-S in the first instance.

Approximate Cost

2 FTE (full-time equivalent) total spread over 1 or 2 years, plus ongoing support of 0.1 FTE

Recommended Approach

There are five main challenges to solve here:

1. Decide on the most appropriate way to produce a suitable ensemble of climate forecast data from the raw ensemble data across multiple models. Even within a single model such as ACCESS, there will be different ensemble numbers at different timescales.

2. Calibration of the output to remove model bias. This must be model, location and season specific.

3. Downscaling of the variables. The effects of topography must be taken into account, as well as the effect of averaging over a model grid box (the so-called “drizzle problem”).

4. Ease of access – there are web protocols such as REST and SOAP that are relevant here.

5. Speed of access. Extracting time series from operational meteorological data centres can involve striding across thousands of files, which cannot occur rapidly with remote data access protocols such as OPeNDAP. Accessing data from overseas models adds an extra layer of complexity and time overhead. A decision support tool requires results almost instantly. A lengthy delay is very likely to inhibit uptake. To address this it may be necessary to invest in appropriate infrastructure.

It would be desirable to explore synergies and learnings from existing climate projection research where there is experience in providing application-ready information. It might be possible to establish a seamless approach that spans all the relevant timescales.

Recommended Groups

BoM/Square V/State Departments of Agriculture/SARDI/CSIRO

CSIRO (through Agriculture and the new data innovation research unit Data 61) have expressed strong support for this project, a willingness to consult and collaborate on the development of APIs, and a desire to use the interfaces developed in their agriculture applications.

Industry studies incorporating economic assessment (Plans A & B)

Key Research Questions

In a range of climate-sensitive industries (grazing, cotton, sugar, horticulture, viticulture etc.), what is the best way to combine seasonal climate forecast information with key industry management decisions to obtain the desired outcomes (increased income, reduced risk and volatility, increased sustainability and environmental outcomes etc.)? In the grains industry, what lessons, tools and information can be shared between researchers in the east and the west to the benefit of all? Are there forecast systems, decision support tools and communication web sites that provide useful and valuable information in one region that could be easily and usefully adopted by the other region? Can ACCESS-S forecasts be used in existing tools in the west? Can decision support and forecast display tools developed in the west be usefully adopted in the east? What are the issues in using model-derived ensemble forecast data to drive agricultural models such as APSIM? For the extensive rangelands grazing industry, what variables would be best to forecast, and what management decisions can best be made based on a forecast? Similar questions can be framed for cotton, sugar, horticulture and viticulture.

Outputs and Benefits

Advances in forecast skill and value, decision support and forecast presentation will be made more rapidly by adopting existing and proven tools rather than re-inventing them. A more uniform approach to presenting information to agriculture Australia-wide will increase uptake and reduce confusion. Each region stands to benefit in terms of increased production and reduced climate-related risk by the adoption of known and proven tools.

Approximate Cost

Average of 2 FTE per each industry study (spread over 2 or 3 years)

Recommended Approach

It is likely that each industry will need a tailored approach to combining seasonal forecasts and existing management decisions and tools. Incorporating ACCESS-S forecasts into existing tools and displays could be achieved through existing or new APIs. A comparison of different methods to predict outputs would be informative. In the grains industry, where there is already a number of studies linking a single management decision to a forecast, tools containing multiple management decisions could be trialled to explore the interactions between different decisions to more closely simulate real-world conditions.

Recommended Groups

DAFWA, BCG, BoM, CSIRO, UNSW DPI, DSITI, USQ, SARDI, Vic DPI=

Update CIE Valuation Report (Plans A & B)

Key Research Questions

Obtain updated and more comprehensive estimates of the value of seasonal climate forecasts to Australian agriculture. Estimate the value of multi-year forecasts, or conversely, the skill needed for multi-year forecasts to be of value.

Outputs and Benefits

The output would be an authoritative report that demonstrated the value of climate forecasts to Australian agriculture. The benefit would be widespread in terms of enhanced uptake of forecasts, and increased support for climate forecasts leading to increased funding. The next generation of supercomputers needed to improve climate forecasts would be obtained sooner, leading to increases in skill at a faster rate, and therefore increased value. There is a snowball effect here, which is why keeping this information updated and scientifically defensible is important.

Approximate Cost

0.5 FTE total spread over 6 months to one year

Recommended Approach

Since the previous CIE report, there has been some more research on the value of climate forecasts to agriculture in specific case studies. Methods for scaling up this limited information to larger areas are needed. Additional value studies might also be necessary using novel methodologies.

Recommended Groups- ABARES or CIE

ACCESS S2/S3 build (Plan B)

Key Research Questions

How to implement and operationalize ACCESS S2 and S3 in the shortest possible time to have the best possible skill for Australian agriculture? How best to evaluate forecast accuracy, quantify forecast skill for users, and identify areas for future model improvement?

Outputs and Benefits

6. S2 and S3 running operationally as soon as possible
7. Knowledge (reports) on busts, failures and successes.
8. APIs linked to standard ACCESS-S outputs
9. Evaluation of ACCESS-S against POAMA outputs for agriculture

Approximate Cost

6-9 FTE total comprising 2-3 FTE per year for 3 years plus suitable operating for workshops, travel and publishing

Recommended Approach

Development

10. Implement past MCV improvements in ACCESS-S2/3
11. E.g. Coupled assimilation + ensemble generation - fast-track version in ACCESS-S2 and full version in ACCESS-S3
12. Includes land surface initialisation + sea ice initialisation

Evaluation for MCV

13. Evaluation of forecast accuracy for regions/products relevant to MCV
14. Identification and evaluation of major busts/failures relevant to MCV users
15. Use this information to inform use of forecasts (e.g. better quantification of expected reliability or reduced limit of predictability) and/or future development (e.g. if model/initialisation problems)

Products and applications

16. Develop and evaluate skill for new agricultural products (e.g. growing season 6-month outlooks, growing degree days)
17. Utilise new calibrated forecasts at 60km
18. Develop variables required for agricultural models, calibrated to 5km (using quantile mapping) over Australia (co-investment with other groups)
19. Enable other MCV research projects to utilise the 5km calibrated forecasts from the research server.

Recommended Groups

BoM/CoECSS (Monash, Melb., UNSW)

Systematic bias - Indian Ocean (Plan B)

Key Research Questions

What are the causes of the systematic model errors associated with the Indian Ocean? Is it the atmosphere, ocean or the coupling between them? What can be learned from other research groups about this problem?

Outputs and Benefits

20. Substantial reduction in rainfall bias
21. Improved depiction of IOD and impacts on Australian climate
22. Increased skill at longer lead times in southern and eastern regions in the cool season
23. Better interaction between ENSO and IOD (broader benefits)
24. Increased forecast skill over large regions of agricultural land influenced by the Indian Ocean

Approximate Cost

3-4 FTE total spread over 2-3 years plus suitable operating

Recommended Approach

Explore the cause of the biases

25. Explore the link between atmospheric model errors and Indian Ocean Bias
26. Leverage existing RR&D4P(r1) project – convection (e.g. could focus on cloud errors)
27. Explore the possibility of ocean model error – mixing, Indonesian Throughflow

Explore improvements

28. From existing RR&D4P(r1) project
29. From UKMO – new and old developments
30. From other groups – e.g. Ocean modellers in France
31. Local development

Implement improvements

32. Test improvements in coupled forecasts
33. Implement in next operational system

Recommended Groups

BoM/CoECSS(Monash, Melb., UNSW)

Frost and extreme rainfall (Plan B)

Key Research Questions

How are frost and extreme rainfall events defined in a way that is meaningful to end-users? What are the drivers of these extreme events? How well does the model represent these drivers? How well does the model predict the likelihood of these extreme events? How best to communicate forecasts of extreme events to end-users?

Outputs and Benefits

34. Small suite of skilful forecast products (e.g. heatwave, frost potential, heavy rainfall, cold)
35. Increased understanding of drivers of extreme events on multi-week and seasonal timescales
36. Reduced impact of extremes on agriculture
37. Improved communication to stakeholders

Approximate Cost

2-3 FTE total spread over 2-3 years plus suitable operating

Recommended Approach

Heat extremes

38. Extend the previous MCV heat extremes project

Extreme Rainfall

39. Develop set of extreme rainfall products (e.g. Decile probabilities)
40. Evaluate the accuracy
41. Provide trial real-time products

Frost

42. Understand drivers of frost and cold waves and their representation in ACCESS-S
43. Determine potential products
44. Evaluate ACCESS-S accuracy
45. Provide trial real-time products

Recommended Groups

BoM/CoECSS (Monash, Melb., UNSW)

Using and valuing forecasts, uptake and communication (Plan B)

Key Research Questions

Existing climate forecasts contain useful and valuable information for much of the Australian agricultural region. New models that will come on line soon will improve skill and value further. How can the uptake, use and trust of existing and future climate model information be increased? What is the best way to establish successful two-way communication with end-users? How can this information best be applied in commercial agriculture?

Outputs and Benefits

Outputs could be:

1. Training course to "train the trainers" to develop a skilled group of educators/communicators that bridge the gap between agriculture and climate;
2. Single aggregating web site to bring together all the ag/climate knowledge;
3. Commentary behind the forecasts (TV, radio, web);
4. Yield Prophet Lite deciles available everywhere and at any time, together with skill and reliability indications;
5. Put climate forecasts into the app "CliMate" (if not happening already).

The benefits of increased uptake and smart use of climate forecasts would be increased gross margins, increased industry efficiency, and increased resilience to climate-related risks.

Approximate Cost

3 FTE total spread over 3 years plus suitable operating

Recommended Approach

1. MCV work with a University or relevant training body to develop a training course focussed on climate forecasting for agriculture;
2. Review of research into barriers to uptake of climate forecasts;
3. Development of aggregating web site and strong promotion of its use;
4. Development of a commentary (BoM or Vic DPI), YPLite deciles (BCG/Square V) and CliMate.
5. Develop an effective communication strategy to establish two-way dialogue between researchers and end-users.

Collaboration or integration with existing social research projects at DSITI/QDMC should be explored.

Recommended Groups

Universities, State Departments, BoM

Land Surface (Plans A & B)

Key Research Questions

Incorporate the CABLE land-surface model into ACCESS-S for use on timescales from NWP through seasonal and multi-year timescales.

Evaluate and refine relevant modules included in CABLE, such as irrigation and ground water, for daily to multi-year timescales.

Examine and develop relevant modules representing crops into CABLE for daily to multi-year timescales.

Feed land surface model developments back to the UK Met Office for inclusion into future versions of ACCESS-S.

Develop an ensemble initialisation system for soil moisture for CABLE within ACCESS-S.

Outputs and Benefits

CABLE has been developed by Australians for Australian conditions. The UK Met Office model, JULES, is not well suited to our conditions, for example the nature of Australian droughts, and the intensity of Australian heatwaves. There are many Australian researchers already working on CABLE-related science, and long term development of the model builds on this large and expert community. JULES is unlikely to be modified for Australian conditions because this offers no return for the UK Met Office.

The benefit would be a land-surface model that is better suited to Australian conditions and therefore contributes to more accurate forecasts. The model would be more easily modified and tailored for local conditions as the local research effort grows and makes progress. Another benefit would be the collaboration between research groups (e.g. BoM, Universities, CSIRO) all working on the same model.

Outputs would be increasingly-skilful forecasts at times and in areas that are limited by the current land-surface model, land-surface model outputs that are tailored to local requirements, and a strengthening of the partnership with the UK Met Office through genuine two-way collaboration.

Approximate Cost

12 FTE total spread over 3 years, of which half is comprised of BoM and CoECE commitments of 1 FTE per year each (see below), plus suitable operating.

Recommended Approach

(a) BoM makes a commitment to implementing CABLE into the seasonal prediction system over a defined time period (say 3 years)

(b) MCV invest in 2 x FTE for 3 years, one with BoM and one with the new Centre of Excellence for Climate Extremes (CoECE)

(c) BoM commits a matching FTE to focus on this specific problem (e.g. ensemble soil moisture initialisation)

(d) CoECE commits 1 FTE to match - either science or technical or in combination

(e) CoECE advertises a PhD scholarship on this specific topic.

(f) BoM provides a suitable version of the prediction system at NCI as a system for collaboration, and jointly with the CoECE appropriate computational resources and technical expertise are committed.

Recommended Groups

BoM, Universities (particularly UNSW, Monash), CSIRO, CoECE

Group	Key People	Main Topics
Agriculture Victoria	**Graeme Anderson**	**Services and support for the farming sector**
ANU	**Andy Hogg**	**Part of CoECSS**
Centre of Excellence for Climate System Science (CoECSS or CoE)	**Andy Pitman** **Christian Jakob**	**Fundamental climate system science related to climate processes**
Birchip Cropping Group (BCG)	**Chris Sounness**	**Application and communication of seasonal climate forecasts. Yield Prophet. YPLite.**
Bureau of Meteorology	**Oscar Alves** **Neil Plummer**	**Development of seasonal forecast models. Delivery of seasonal forecast information.**
CSIRO Agriculture & Food	**Jaci Brown** **Steve Crimp**	**Application of seasonal forecasts to agriculture.**
CSIRO Climate Centre/NESP	**James Risbey** **Terry O'Kane**	**Development of multi-year forecasts.**
DAFWA	**Art Diggle** **Meredith Guthrie** **Fiona Evans**	**Research and development for WA's agriculture and food sector. Run the statistical seasonal forecast (SSF) system**
Melbourne University	**David Karoly**	**Part of CoECSS**
Monash University	**Christian Jakob**	**Part of CoECSS**
NESP Earth Systems and Climate Change Hub	**Helen Cleugh**	**Inform policy and management decisions predominantly on multi-year and longer timescales.**
NSW DPI	**Jason Crean**	**Strategic science which underpins the growth, sustainability and biosecurity of primary industries in NSW.**
Qld DSITI	**Ramona Dalla Pozza** **Ken Day (SPOTA)**	**Climate and weather research, social research. Statistical seasonal forecasting (SPOTA).**

Queensland Drought Mitigation Centre	**Roger Stone** **Jozef Syktus**	**Conduct monitoring and engage in climate research to find out more about what drives drought. Baseline quantification of the risk of multi-year drought.**
SARDI	**Peter Hayman**	**Research and development for SA's primary industries**
Tasmanian Institute of Agriculture (TIA)	**Holger Meinke**	**Use of seasonal forecasts for pasture growth (e.g. dairy).**
University of NSW	**Andy Pitman**	**Part of CoECSS**
University of Tasmania	**Nathan Bindoff**	**Part of CoECSS**
UNSW Climate Change Research Centre (CCRC)	**Steven Sherwood** **Matt England**	**Wide range of climate topics**
USQ International Centre for Applied Climate Sciences (ICACS)	**Roger Stone**	**Climate science and its application to agriculture**

References

Agriculture Victoria. *The Fast Break, The Very Fast Break newsletters.* 2016. http://agriculture.vic.gov.au/agriculture/farm-management/newsletters-and-updates/the-break,-the-fast-break-and-the-very-fast-break-newsletters (accessed December 21, 2016).

Agtrans Research. "Economic impact assessment of prospective investment in phase V of the Managing Climate Variability Program." Report to MCV, 2015.

Asseng, S., P.C. McIntosh, G. Wang, and N. Khimashia. "Optimal N fertiliser management based on a seasonal forecast." *European Journal of Agronomy* 38 (2012): 66-73.

BCG. *Yield Prophet Lite.* 2016. http://www.yieldprophet.com.au/yplite/ (accessed October 24, 2016).

Bureau of Meteorology. *About Australian Water Resources Assessments.* 2016. http://www.bom.gov.au/water/awra/ (accessed December 12, 2016).

—. *About the ACCESS model.* 2016. http://www.bom.gov.au/australia/charts/about/about_access.shtml (accessed December 12, 2016).

—. *Climate Maps - Australian Water Availability Project.* 2016. http://www.bom.gov.au/jsp/awap/ (accessed December 12, 2016).

CAWCR. *Australian Community Climate and Earth Sytems Simulator.* 2016. http://www.csiro.au/en/Research/OandA/Areas/Assessing-our-climate/CAWCR/ACCESS (accessed December 12, 2016).

CIE. *Analysis of the benefits of improved seasonal climate forecasting for agriculture.* Canberra: Managing Climate Variability, 2014.

CSIRO and GRDC. *Yield Gap Australia.* 2016. http://www.yieldgapaustralia.com.au/wordpress/ (accessed December 8, 2016).

DAFWA. *Seasonal Climate Information.* 2016. https://www.agric.wa.gov.au/drought/seasonal-climate-information (accessed October 24, 2016).

DAWR. *Approved projects - Round 1.* 2015. http://www.agriculture.gov.au/ag-farm-food/innovation/rural-research-development-for-profit/approved-projects (accessed December 21, 2016).

—. *Rural Research and Development for Profit.* 2016. http://www.agriculture.gov.au/ag-farm-food/innovation/rural-research-development-for-profit (accessed October 24, 2016).

McIntosh, P.C., A. Ash, and M. Stafford-Smith. “From Oceans to Farms: The Value of a Novel Statistical Climate Forecast for Agricultural Management.” *Journal of Climate* 18 (2005): 4287-4302.

MCV. *Business Case for Investment 2016-2020.* Managing Climate Variability Program, 2016.

—. *Climate Kelpie.* 2016. http://www.climatekelpie.com.au/ (accessed October 24, 2016).

—. *MCV Climate Champion Program.* 2016. http://www.climatekelpie.com.au/farmers-managing-risk/climate-champion-program (accessed December 21, 2016).

Shukla, J. “Predictability in the Midst of Chaos: A Scientific Basis for Climate Forecasting.” *Science* 282 (1998): 728-731.

Stone, Roger C, Graeme L Hammer, and Torben Marcussen. “Prediction of global rainfall probabilities using phases of the southern oscillation index.” *Nature* 384 (1996): 252-255.

Acronyms

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ACCESS	Australian Community Climate Earth System Simulator
ANU	Australian National University
API	Application programming interface
APSIM	Agricultural Production Systems Simulator
ARC	Australian Research Council
AWAP	Australian Water Availability Project

BoM	Australian Bureau of Meteorology
CAWCR	Collaboration for Australian Weather and Climate Research
CIE	Centre for International Economics
CoECSS	Centre of Excellence for Climate System Science
CoECE	Centre of Excellence for Climate Extremes
CoP	Community of Practice (part of the RR&D4P(r1) project)
CVAP	Climate Variability in Agriculture Program (forerunner to MCV)
DAFWA	Department of Agriculture and Food WA
DAWR	Australian Government Department of Agriculture and Water Resources
DSITI	Qld. Department of Science, Information Technology and Innovation
DSS	Decision Support System
ECL	East-coast low-pressure system
ENSO	El Nino Southern Oscillation
FTE	Full-time equivalent (measure of employment)
ICACS	USQ International Centre for Applied Climate Sciences
IOD	Indian Ocean Dipole
NESP	National Environmental Science Program
NWP	Numerical Weather Prediction
OPeNDAP	Open-source Project for a Network Data Access Protocol
POAMA	Predictive Ocean Atmosphere Model for Australia
QDMC	Queensland Drought Mitigation Centre
RDC	Research and Development Corporation

RIRDC	Rural Industries Research and Development Corporation
RR&D4P	Rural Research and Development for Profit
SAM	Southern Annular Mode
SARDI	South Australian Research and Development Institute
SPOTA-1	Seasonal Pacific Ocean Temperature Analysis version 1
Square V	Software design company responsible for Yield Prophet and YPLite
TIA	Tasmanian Institute of Agriculture
UKMO	UK Met Office
USQ	University of Southern Queensland
YPLite	Yield Prophet Lite

Explainer – What is ACCESS?

ACCESS is the Australian Community Climate Earth System Simulator. It is a national approach to the prediction of weather and climate on timescales from days to centuries. It involves collaboration between the Bureau of Meteorology, CSIRO, and a number of Australian Universities, principally through the ARC Centre of Excellence for Climate System Science. ACCESS uses component models sourced mainly from the UK Met Office (UKMO), the Geophysical Fluid Dynamics Laboratory (GFDL) in the USA, and some versions use the Australian-developed CABLE model for land surface processes.

In practice, ACCESS involves at least three separate modelling structures:

1. ACCESS for weather forecasting: this model uses the UKMO atmosphere model driven by observed surface conditions over the land and ocean. It has a number of configurations with different spatial resolutions for different purposes (Bureau of Meteorology 2016).
2. ACCESS-S for seasonal forecasting: version S1 of this model uses the UKMO coupled ocean/atmosphere/land/sea-ice model/assimilation/initialization system. Later versions will use developments of the POAMA assimilation/initialization scheme.
3. ACCESS for climate change: this model uses the UKMO atmosphere coupled to the GFDL ocean model and, in recent versions, the Australian land surface model CABLE. It has been the basis for Australia’s contribution to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (CAWCR 2016)