Hort Innovation

Final Report

Improved skill for regional climate in the ACCESS-based POAMA model

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Delivery partner:

Bureau of Meteorology

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VG13092

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Improved skill for regional climate in the ACCESS-based POAMA model VG13092

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Content

Summary

Early in 2018 the vegetable industry will have access to more accurate and more locally relevant seasonal climate outlooks from the Bureau of Meteorology - assisting with planning weeks to seasons ahead.

The Bureau is developing a new seasonal forecast system called ACCESS-S, which will replace the current system, POAMA, in 2018.

The primary aim of this project was to evaluate climate forecasts made by ACCESS-S1 (version 1) for multi-week (2-4 weeks ahead) and seasonal timescales for nine growing regions relevant to the Australian vegetable industry.

ACCESS-S1 has a number of significant enhancements over POAMA, including increased spatial resolution, improved model physics and a better representation of the climate of Australia, including over the vegetable growing regions.

ACCESS-S1 is significantly more accurate than POAMA for multi-week forecasts of rainfall and maximum (Tmax) and minimum temperature (Tmin) over the vegetable regions. On seasonal timescales the accuracy of the two systems is similar, although ACCESS-S1 outperforms POAMA for seasonal forecasts of Tmin.

The accuracy of the forecasts varies with region, time of year, variable and forecast lead time (i.e. how much advance warning). For example, the spring season tends to be the most skillful, particularly for the eastern and south-eastern vegetable regions for rainfall and Tmax. In general, forecasts for temperature are more skillful than rainfall. Early summer Tmax forecasts have good accuracy for all the vegetable regions.

Experimental forecast products based on ACCESS-S1 have been developed for the vegetable regions. The products are available to the vegetable industry via registered-user access on a Bureau research-based website (http://poama.bom.gov.au/project/hia.html). Feedback on the products is encouraged as this will help determine whether they will become fully operational Bureau products and available to all. The Bureau can also use suggestions to help tailor and guide the presentation of a product.

The project has helped to highlight that there is still scope for improvement in the accuracy of the ACCESS-S1 forecasts for the vegetable growing regions in the future. In particular, experiments have shown that initializing the forecasts with realistic soil moisture initial conditions that vary year-to-year will increase accuracy, particularly for Tmax over the eastern vegetable regions. This is being addressed in the next version of the system (ACCESS-S2).

The Bureau recommends that an update of the evaluation of forecast performance for the vegetable growing regions is undertaken when the next version of ACCESS-S is available. Improvements planned for ACCESS-S2 will lead to improvements in forecast accuracy. ACCESS-S2 will also have a larger hindcast period, enabling a more statistically robust estimate of forecast performance.

The Bureau recommends that vegetable growers trial the experimental forecast products and that future work with the industry should aim to determine the value of forecasts with respect to management decisions, such as when to plant or harvest, when to apply fertilizer and for irrigation scheduling. In addition, it is worth considering if there is a need for tailored forecast products or indices of interest to vegetable growers. Going forwards, to help farmers improve productivity and profitability, there is a need to bridge the gap between climate forecasts and on-farm business decisions.

Keywords

vegetables; managing climate variability; seasonal forecasting; climate model; ACCESS-S; environment

Introduction

Climate variability is the largest driver of annual agricultural income and production variation in Australia (Love 2005; Howden et al. 2007; Stokes and Howden 2010). The horticultural industry is no exception. Seasonal forecasts provide agricultural users with information about the expected temperature and rainfall conditions in the coming weeks to seasons, providing essential information for planning and investment decisions. Reliable multi-week and seasonal forecasts are valuable for both strategic and tactical decision-making, such as scheduling of planting and harvesting, as well as within-season decisions, such as managing irrigation demand and application of fertilizer or pesticides.

Since the introduction of the POAMA seasonal forecast system in 2013, the Bureau of Meteorology's seasonal climate outlooks have become more skillful and more useful for the agricultural sector. Recent research has also extended the Bureau's capability to include multi-week prediction, filling the gap between weather forecasts and seasonal outlooks (Hudson et al. 2011, Hudson et al. 2013). The Bureau routinely issues operational seasonal forecasts (http://www.bom.gov.au/climate/ahead) and experimental multi-week products based on the POAMA seasonal forecast system.

However, POAMA has a relatively coarse resolution (250 km^2 grid boxes) and is dated compared to forecast systems operated by the leading meteorological centers around the world. To uplift their seasonal forecasting capability, the Bureau is developing a new seasonal forecast system referred to as ACCESS-S (the seasonal prediction version of the Australian Community Climate and Earth-System Simulator). This upgrade will bring seasonal prediction into the national ACCESS modelling framework, utilising the latest local and overseas developments. One of the key partners in ACCESS is the UK Met Office (UKMO). ACCESS-S uses the latest seasonal prediction model available from the UKMO, but includes Bureau-developed enhancements to the forecast system to make it appropriate for multi-week forecasting. ACCESS-S has considerable enhancements compared to POAMA, including higher resolution of the component models and state-of-the-art physics schemes. ACCESS-S1 is planned to replace POAMA as the Bureau's official seasonal forecast system in early 2018.

Project VG13092 has focused the development and evaluation of ACCESS-S on key regions of importance to the Australian vegetable industry, with the aim of providing improved spatial and temporal forecasting for vegetable growers. It forms part of a range of projects that have been contributing to the development of ACCESS-S for multi-week to seasonal prediction. The primary objective of the project is to assess the performance of ACCESS-S1 for making multi-week and seasonal climate forecasts of rainfall and temperature for regions of interest to the vegetable industry. The results of the project will help vegetable growers understand where and when the new forecast system has accuracy and guide use of the forecasts. The work will also help guide future development and improvements of the forecast system by the Bureau. An outcome of the project is to develop and provide access to research-based experimental forecast products for the key vegetable regions, so that the industry can trial and evaluate forecasts based on ACCESS-S1.

Methodology

Assessment of forecast performance of ACCESS-S1, focussing on vegetable growing regions, is targeted at users and applications scientists. The analysis highlights times of year and regions where the forecasts are most or least accurate. It also facilitates identifying errors and potential model improvements which will ultimately lead to providing improved forecasts in regions of interest for vegetable growers.

Experimental forecast products have been developed for the key vegetable regions. They are available in real-time for trial, evaluation and feedback by vegetable growers.

Horticulture regions

The definition of the vegetable regions for the project was done in consultation with Will Gordon (Industry Services Manager, HIA). Nine regions were defined and are shown in Figure 1. These regions are defined on the 0.25° (~25 km) AWAP (Australian Water Availability Project) observations data grid (Jones et al. 2009). The POAMA model has a course resolution grid, approximately 250 km, and some of these regions are represented by only one or two POAMA grid-boxes. Owing to the grid resolution and configuration, Tasmania is not represented as land in POAMA. This means that for the Devonport Region the grid boxes from POAMA are classified as sea-points. In contrast, the 60 km resolution ACCESS-S model represents Tasmania as land and with sufficient detail to adequately cover the Devonport Region and other agricultural zones. The respective model grid boxes are weighted depending on their contribution to a given region. These weights are used when creating the average skill for a given region.

Figure 1: The nine horticulture regions used in the study.

Forecast Systems

POAMA-2 is the system that currently produces the Bureau's operational seasonal climate outlooks (http://www.bom.gov.au/climate/ahead/), but it remains experimental for forecasts on the multi-week timescale. For full details of the model, data assimilation and ensemble generation refer to Hudson et al. (2013).

ACCESS-S1 will be the next version of the seasonal forecast system, and is scheduled to replace POAMA as the Bureau's official system in early 2018. The system has considerable enhancements compared to POAMA, including higher vertical and horizontal resolution of the component models and state-of-the-art physics parameterisation schemes. Table 1 highlights some of the key model differences between POAMA-2 and ACCESS-S1. ACCESS-S1 is based on the UK Met Office GloSea5-GC2 seasonal prediction system, but has enhancements to the ensemble generation strategy to make it appropriate for multi-week forecasting, and has a larger ensemble size to better represent uncertainty. Full details of the ACCESS-S1 system are provided in Hudson et al. (2017a,b).

Table 1: Some of the key model differences between POAMA-2 and ACCESS-S.

	POAMA-2	ACCESS-S
Atmospheric model	Bureau Atmospheric Model (BAM) ~10 years old	Latest UKMO atmospheric model (Global Atmosphere 6.0, Unified Model) which is part of the UKMO coupled model GC2.
Atmospheric resolution	Horizontal: 250 km (T47) Vertical: 17 levels (does not extend into the stratosphere)	Horizontal: 60 km in the mid-latitudes (N216) Vertical: 85 levels (extending into the stratosphere)
Land surface model	Simple bucket model for soil moisture and 3-layers for soil temperature.	State-of-the-art land surface model (Global Land 6.0; Joint UK Land Environment Simulator; JULES) with 4 soil levels. Sophisticated representation of soil and surface hydrology and of fluxes of heat and moisture within the soil and to the atmosphere. It is part of the UKMO coupled model GC2.
Ocean model	Modular Ocean Model (MOM version 2). ~13 years old	Latest European ocean model (Global Ocean 5.0; Nucleus for European Modelling of the Ocean; NEMO ORCA25) which is part of the UKMO coupled model GC2.
Ocean resolution	Horizontal: ~200 km x 100 km Vertical: level thicknesses range from 15 m near the surface to almost 1000 m near the bottom	Horizontal: 25 km Vertical: level thicknesses range from 1 m near the surface to about 200 m near the bottom (6000 m depth)
Sea ice model	No sea ice model (climatological sea ice is prescribed).	Latest sea ice model developed by the USA and UK (Global Sea Ice 6.0; Los Alamos sea ice model; CICE) which is part of the UKMO coupled model GC2.
Model Physics	>10 years old	Latest from UKMO and collaborators

Forecast performance evaluation

The performance of POAMA-2 and ACCESS-S1 for forecasting rainfall, maximum (Tmax) and minimum (Tmin) temperature on timescales beyond that of a typical weather forecast has been evaluated for the horticulture regions. Specifically, we have assessed the accuracy of forecasts for fortnight 1 (comprises weeks 1 and 2 of the forecast); fortnight 2 (comprises weeks 2 and 3 of the forecast); fortnight 3 (comprises weeks 3 and 4 of the forecast); upcoming months and upcoming seasons. For the seasonal forecasts, the perfomance of 0-month lead and 1-month lead forecasts are assessed. The lead time refers to the time between the forecast initialisation and the forecast period of interest. For example, for a 0-month lead forecast of the Dec-Jan-Feb season the forecast is initialised on 1 December, whereas a 1-month lead forecast for the same season is initialised on 1 November. Evaluation of performance is based on a set of hindcasts — forecasts that are generated retrospectively for a period in the past — and the forecasts are compared with the observed outcome. The hindcast period for ACCESS-S1 is 1990-2012, and includes an 11-member ensemble (i.e. multiple forecasts generated for the same time to span uncertainty) from the 1st, 9th, 17th, and 25th of every month. The same hindcast period from POAMA is used for comparisons between the two systems.

To assess the performance of the forecasts, the correlation between the ensemble mean forecast and the observations is used (Hudson et al. 2017a). The forecasts are compared with the observations, as provided by the AWAP gridded datasets (Jones et al. 2009). The focus of the evaluation is for the nine vegetable growing regions (Figure 1). The evaluation was undertaken for both a preliminary and the final version of ACCESS-S1.

Further details of the methodology can be found in Shi et al. (2016) and Hudson et al. (2017a).

Research-based experimental forecast products

Pie chart and histogram forecast products have been developed for rainfall, Tmax and Tmin for multi-week and seasonal forecast timescales. The software development included data processing and calibration of the forecast ensemble; automating the process for updating products as new forecasts become available; generating the visual display of the forecast product, and designing the website. The forecasts are based on 99-member ensembles.

The pie charts show the likelihood that temperatures (either Tmax or Tmin) will be cooler, near normal or warmer than usual for a particular forecast lead time and region (similarly for rainfall i.e. drier, near normal or wetter than usual). They are available for forecasts of Week 2, Fortnight 2 (week 2+3), Fortnight 3 (week 3+4), Month 1, Month 2 and Season 1 for each vegetable region.

The histograms show the distribution of forecast daily values within the selected forecast period (e.g. for temperature, it shows the number of days that are likely for specific temperatures). The forecast distribution is shown in yellow and is plotted on top of the distribution that is usually expected on average for that time of year (i.e. climatology) which is shown in grey. By comparing the forecast distribution with the background climatological distribution one can see how the forecast period differs from the long term climatology. Forecasts are available for Week 2, Week 3, Fortnight 1 (week 1+2), Fortnight 2 (week 2+3), Fortnight 3 (week 3+4), Month 1, Month 2, Month 3, Season 1 and Season 2 for each vegetable region.

Outputs

- Oral presentation: Hudson, D. 2015. Forearmed is forewarned: seasonal forecasting for horticulture. National Horticulture Convention, Gold Coast, 26 June.

  Debra Hudson was invited to present at the 2015 National Horticulture Convention. The presentation can be viewed on YouTube: https://www.youtube.com/watch?v=nma3dLaI8bk

- "Weather the storm with the latest technology" In: *Vegetables Australia*. January/February 2015, p30-31

  This article in Vegetables Australia describes the research project.

- Shi, L., Hudson, D., Alves, O., Young, G., MacLachlan, C., 2016. Comparison of GloSea5-GC2 skill with POAMA-2 for key horticultural regions. *Bureau Research Report*, No. **13**. Bureau of Meteorology, Australia (Available at: http://www.bom.gov.au/research/research-reports.shtml).

  This science report compares the performance of multi-week and seasonal forecasts from POAMA for the horticulture regions with a preliminary version of ACCESS-S1 called GloSea5-GC2.

- Hudson, D., Shi, L., Alves, O., Zhao, M., Hendon, H.H., Young, G., 2017. Performance of ACCESS-S1 for key horticultural regions. *Bureau Research Report*, No. **20**. (Available at: http://www.bom.gov.au/research/research-reports.shtml).

This science report assesses the performance of multi-week and seasonal forecasts for the horticulture regions from the final configuration of ACCESS-S1.

- Experimental forecast products are available for trial, evaluation and feedback by the vegetable industry: http://poama.bom.gov.au/project/hia.html

  Experimental forecast products for the vegetable regions, based on BoM's new seasonal prediction system ACCESS-S1, are available via registered-user access on a BoM research-based website (http://poama.bom.gov.au/project/hia.html). Note that experimental forecasts do not form part of the Bureau's operational product set —they are not in production, not supported, and have not gone through the level of assurance required of operational products. While they may be available in real-time, continuity of service is not guaranteed – they may be unavailable for a few days at a time or even weeks on some occasions. They are intended for research purposes and for trial of new products by users that are party to an agreement with the Bureau.

- Debra Hudson presented to the HIA Vegetable Strategic Investment Advisory Panel on the project outputs and outcomes (24 August 2017). In addition, there was a session facilitated by BoM's new Agriculture Program (Luke Shelley and Alister Hawksford) devoted to discussing weather and climate related needs and constraints facing vegetable growers and how BoM might best meet the needs of horticulture in the future.

- Article submitted to AUSVEG for publication in one of their newletters or magazines describing the outcomes of the project and the experimental forecast products.

Outcomes

This project has led to an improved and documented understanding of the performance of ACCESS-S1 for multi-week and seasonal forecasting for primary regions of importance to vegetable growers. ACCESS-S1 will provide the vegetable industry with more locally relevant and accurate forecasts compared to POAMA. Two scientific reports published from the project, Shi et al. (2016) and Hudson et al. (2017), show detailed results of the evaluation of POAMA-2 and ACCESS-S1. Key results are summarized here.

Experimental forecast products based on ACCESS-S1 have been developed and are available for trial by vegetable growers (detailed below).

<u>ACCESS-S1 compared to POAMA</u>

The most obvious improvement of ACCESS-S1 over POAMA-2 is more locally relevant forecasts for vegetable growers. In ACCESS-S1 the atmosphere and land model resolutions are 60 km, compared to 250 km in POAMA-2, which means that local effects are better captured. At this higher resolution the model can better represent Australian topography (Figure 2) and average climate patterns (e.g., Figure 3). For example, ACCESS-S1 can differentiate between the climates of western and eastern Tasmania, whereas Tasmania is not resolved as land in POAMA-2. ACCESS-S1 also better represents the Great Dividing Range, which plays a key role in influencing the spatial distribution of rainfall.

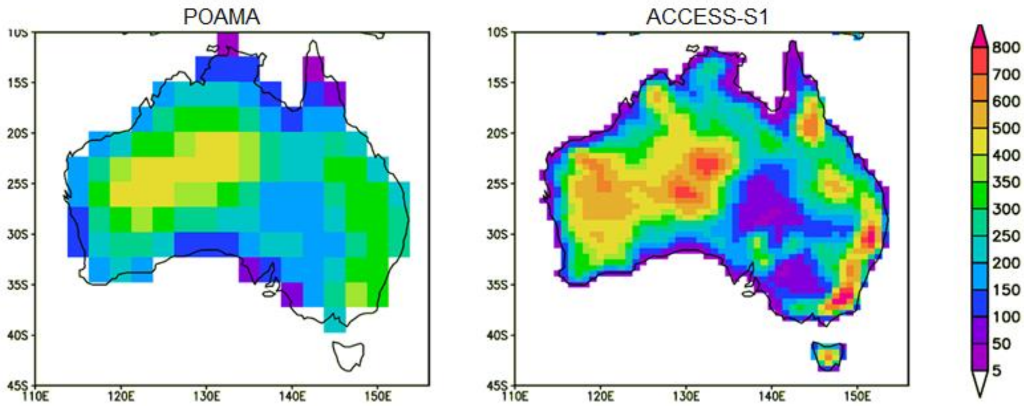

Figure 2: Height (m) of the topography from POAMA-2 (left) and ACCESS-S (right). The size of the pixels on the maps is indicative of the respective model grids.

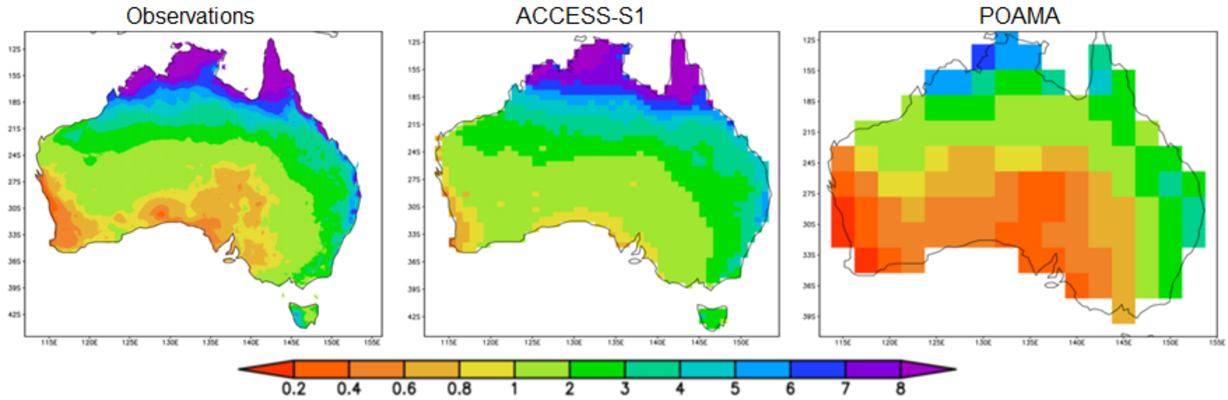

Figure 3: Mean rainfall (mm/day) for the summer season (Dec-Jan-Feb) from AWAP observations (left), ACCESS-S1 (middle) and POAMA-2 (right).

Figure 4 summarizes the comparison between ACCESS-S1 and POAMA-2 across all vegetable regions and for all times of year. It is clear that ACCESS-S1 is much better than POAMA-2 for multi-week forecasts (out to month 1). On seasonal timescales the performance of the two systems is similar.

There are regional and seasonal variations in performance. In particular, POAMA outperforms ACCESS-S1 for forecasts of Tmax for seasonal forecasts of late autumn through to late winter for the eastern regions (particularly Bowen and Bundaberg) (discussed further in the "Discussion and Evaluation" section), and ACCESS-S1 outperforms POAMA for seasonal forecasts of Tmin, particularly for Bowen, Bundaberg, Sydney and Carnarvon. Other research has also shown that compared to POAMA-2, ACCESS-S1 better predicts the important drivers of Australian climate variability, namely the El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Southern Annular Mode (SAM) and Madden-Julian Oscillation (MJO) (Lim et al. 2016; Hudson et al. 2017b).

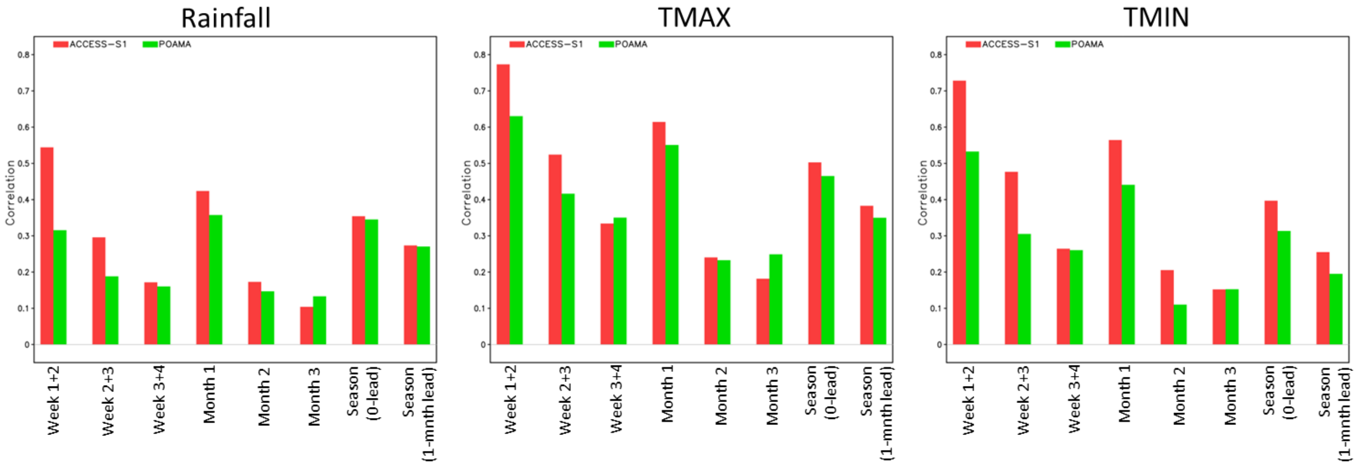

Figure 4: Correlation skill (y-axis, 0.1 interval) for all horticulture regions and times of year for forecasts at different timescales and lead times (x-axis, i.e. forecasts for fortnight 1 (weeks 1+2), fortnight 2 (weeks 2+3), fortnight 3 (weeks 3+4), month1, month 2, month 3, a season at 0-months lead and a season at 1-months lead) from ACCESS-S1 (red) and POAMA (green) for rainfall (left), Tmax (middle) and Tmin (right). The analysis is for all forecasts initialized on the 1st of every month in the period 1990-2012.

<u>ACCESS-S1 performance</u>

The following summarizes the evaluation of ACCESS-S1 in more detail. Season names are represented with the first letter of each month e.g. Dec-Jan-Feb season is DJF. Figure 5 shows the results for 0-month lead seasonal skill.

For forecasts of seasonal mean rainfall:

- For the eastern (Bowen, Bundaberg, Sydney) and south-eastern (Werribee, Mildura, Devonport, Adelaide) regions, forecasts of spring rainfall (ASO and SON) are generally skillful and perform better than for other seasons.
- For the two western Australian regions (Carnarvon and south-western WA), there is some skill for forecasting early spring (ASO) rainfall at short lead times, particularly for Carnarvon, but less so for spring (SON) rainfall at longer leads.
- The Carnarvon region, in the north-west, has good skill for the short-lead predictions of all the seasons (i.e., FMA, MJJ, ASO and NDJ).
- For summer rainfall, the two northern regions of Carnarvon and Bowen exhibit good skill for forecasts of early summer (NDJ) rainfall. Carnarvon also has good skill for summer (DJF) rainfall at the longer lead time, but the skill for summer (DJF) rainfall for Bowen drops off markedly.
- The skill for forecasts of early winter (MJJ) (at 0-month lead) and winter (JJA) (at 1-month lead) rainfall is in general poor, apart from the early winter (MJJ) forecast for Carnarvon.
- Forecasts of early autumn (FMA) rainfall at short lead times are skillful for Carnarvon and reasonably skillful over the southern regions of Sydney, Mildura and Adelaide.

For forecasts of seasonal mean Tmax:

- In general Tmax forecasts are more skillful than rainfall.

- All regions exhibit skill for seasonal forecasts of the spring (SON) season at a 1-month lead time, with the eastern regions (Bowen, Bundaberg, Sydney) showing the highest skill.
- Forecasts of early summer (NDJ) exhibit good skill for all the vegetable regions. However, the skill drops away markedly for the longer lead time forecasts for summer (DJF), particularly for the southern regions (Werribee, Mildura, Devonport and Adelaide).
- There is notably poor (negative) skill for the eastern vegetable regions (Bowen, Bundaberg and Sydney) for forecasts of early winter (MJJ) and winter (JJA) Tmax.

For forecasts of seasonal mean Tmin:

- In general, the skill for Tmin is less than that for Tmax.
- The skill tends to drop away sharply for 1-month lead seasonal forecasts of Tmin compared to the 0-month lead forecasts
- The northern regions (Bowen, Bundaberg and Carnarvon) have good skill for short lead forecasts of early spring (ASO). This season is less skillful for the more southern vegetable regions.
- The northern regions (Bowen and to a lesser degree the Bundaberg and Carnarvon) have reasonable skill for short lead forecasts of early winter (MJJ). Skill for this season is particularly poor for the south-eastern mainland regions.
- The southern vegetable regions exhibit good skill for forecasts of early summer (NDJ) and early autumn (FMA).
- For the 1-month lead forecasts there is good skill for forecasts of winter (JJA) for the north eastern regions (Bowen, Bundaberg) and for summer (DJF) for the western regions (south western WA, Carnarvon) and the Sydney region.

For forecasts of multi-week rainfall, Tmax and Tmin i.e., for fortnight 1, fortnight 2 (weeks 2+3) and fortnight 3 (weeks 3+4) of the forecast:

- The skill in fortnight 1 is high for all regions and variables.
- There is a clear reduction in skill with forecast lead time, i.e. going from fortnight 1 to 3.
- Beyond fortnight 1, the multi-week forecasts of rainfall are more skillful in the winter half of the year compared to the summer half of the year in virtually all the regions. In contrast, for Tmax and Tmin the skill tends to be higher in the summer half of the year compared to the winter half, particularly for the southern regions for Tmin and the eastern regions for Tmax.
- The skill for the Tmax multi-week forecasts in particular, is high in all regions and lead times.

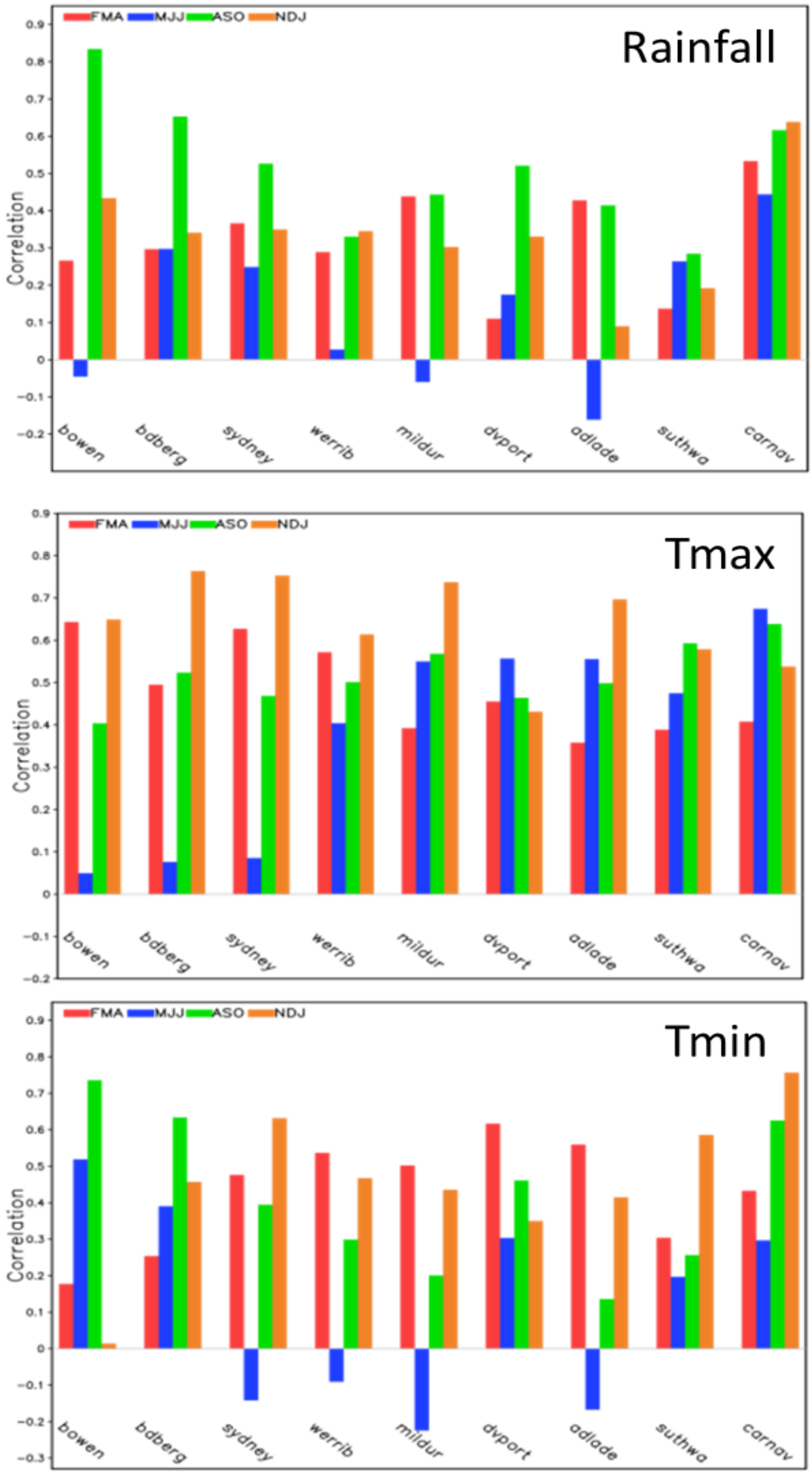

Figure 5: Correlation skill for 0-month lead forecasts of seasonal mean rainfall anomalies for the Feb-Mar-Apr (red), May-Jun-Jul (blue), Aug-Sep-Oct (green) and Nov-Dec-Jan (orange) seasons. Skill is shown for the horticulture regions (Figure 1), indicated from left to right: Bowen, Bundaberg, Sydney Basin, Werribee/Cranbourne/Gippsland; Mildura; Devonport; Adelaide Plains; south western WA and Carnarvon. Statistically significant correlations exceed 0.4 (at the 95% confidence level, n=23).

Research-based experimental forecast products

Experimental forecast products have been developed for the nine regions and are available at http://poama.bom.gov.au/project/hia.html for trial and feedback by vegetable growers.

Pie charts show the likelihood that temperatures (either Tmax or Tmin) will be cooler, near median or warmer than usual for a particular forecast lead time and region. For rainfall, the pie charts show the likelihood that the region will drier, near median or wetter than usual for the forecast period. See Figure 6 for an example.

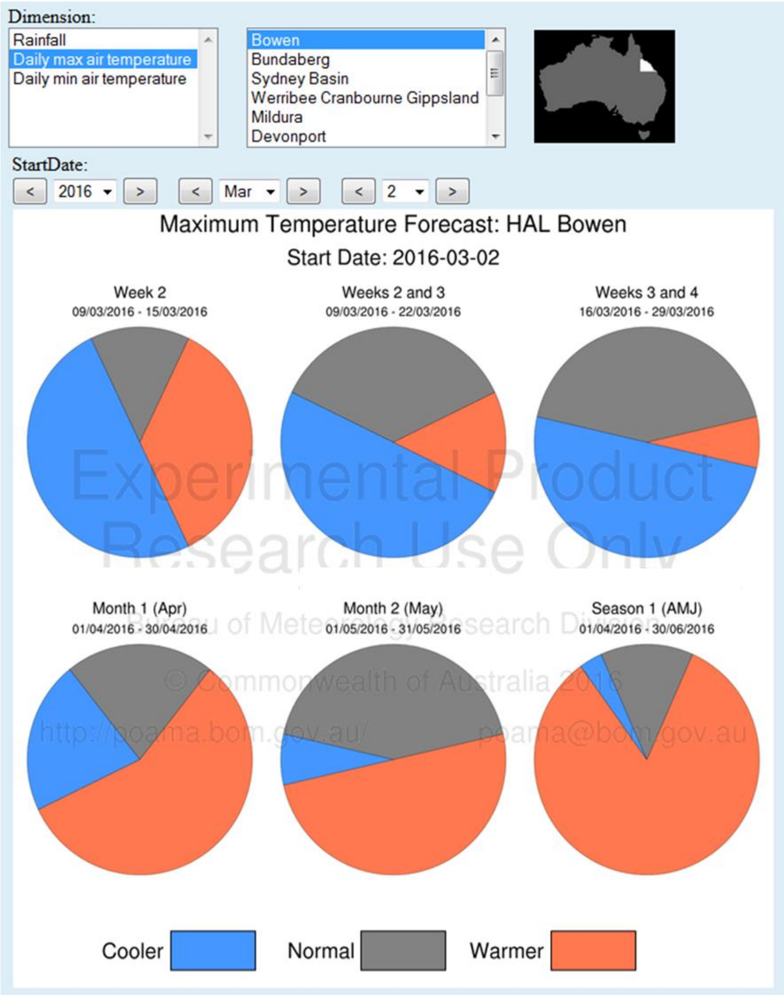

Figure 6: An example of the pie chart forecast product, showing the forecast for Tmax for the Bowen region for a forecast issue date of 2 March 2016. This forecast is suggesting that there is an increased chance that it will be cooler than normal in the upcoming weeks in March (i.e. week 2, week 2+3, week 3+4), but that for the upcoming months (April, May) and season (AMJ) the odds favour warmer than normal conditions.

The histograms show the distribution of forecast daily values within the selected forecast period (e.g. for temperature, it shows the number of days that are likely for specific temperatures). The forecast distribution is shown in yellow and is plotted on top of the distribution that is usually expected for that time of year (climatology) which is shown in grey. By comparing the forecast distribution (yellow) with the background climatological distribution (grey), the user can see how the forecast period differs from the long term climatology. See Figure 7 for an example.

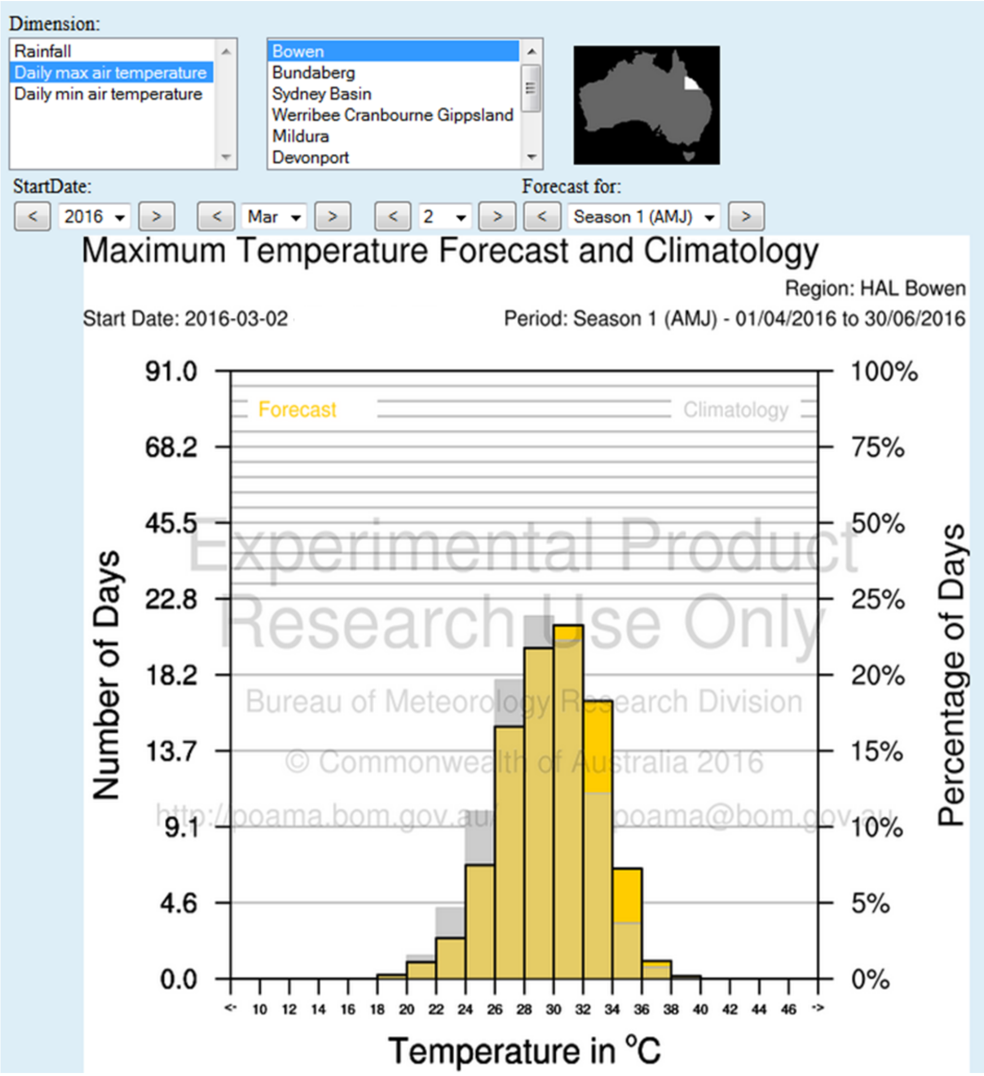

Figure 7: An example of the histogram forecast product, showing the forecast for the upcoming season for Tmax for the Bowen region for a forecast issue date of 2 March 2016. The forecast distribution (yellow) compared to the climatology distribution (grey) suggests that there will be more days than normal that have temperatures over 30 degrees.

<u>Use of the experimental forecast products</u>

The forecast products are subject to the Bureau's copyright and disclaimer, and are for registered users only (they are not to be distributed) and available on the basis that users are fully aware that these products are being tested and that users will not issue these products as real-time forecasts in any way.

Experimental forecasts do not form part of the Bureau’s operational product set —they are not in production, not supported, and have not gone through the level of assurance required of operational products. While they may be available in real-time, continuity of service is not guaranteed – they may be unavailable for a few days at a time or even weeks on some occasions. They are intended for research purposes and for trial of new products by users that are party to an agreement with the Bureau.

Evaluation and discussion

There are a number of significant improvements of ACCESS-S1 over POAMA-2 that will benefit the vegetable industry. ACCESS-S1 will provide the vegetable industry with more locally relevant and accurate forecasts compared to POAMA. However, the project has helped to highlight that there is still scope for further improvement in the skill of the ACCESS-S1 forecasts for the vegetable growing regions in the future. Some of the identified shortfalls in ACCESS-S1 include:

- Weak/deficient teleconnections between ENSO, the IOD and the SAM and Australian rainfall respectively over eastern and south eastern regions, particularly in the winter half of the year (Lim et al 2016). This is thought to be related to rainfall errors over the tropical Indian Ocean. Reducing this error will be a priority of the Bureau's future model development for improving forecast skill in subsequent versions of ACCESS-S.
- Initialization of the forecasts with climatological soil moisture (as done by the UKMO), rather than realistic soil initial conditions that vary year-to-year. Initializing using climatology impacts negatively on the skill of the multi-week (from week 4) and seasonal forecasts, particularly for Tmax over eastern Australia and to a lesser degree on Tmin over south-eastern Australia for forecasts in early winter and winter. The next version of ACCESS-S (version 2) will not be reliant on the UKMO initialization strategy; instead the Bureau's data assimilation will be used, whereby the land surface will be initialized with realistic initial conditions. Experiments have shown that this should noticeably improve the skill of these forecasts in ACCESS-S2 compared to ACCESS-S1, particularly for the eastern and southern vegetable growing regions and particularly for Tmax.

A caveat of the current study is the relatively small sample size (n=23 years) used for the evaluation of forecast performance. A period of 23 years is typically too short to obtain statistically reliable results, particularly for aspects of the prediction system that are inherently noisy, such as for forecasts of relatively small regions of Australian climate (in contrast to less noisy, more large-scale aspects like ENSO). A long enough hindcast set is necessary for including sufficient cases of the low frequency influences on Australian climate, like the different phases of ENSO, and for knowing how the skill may vary based on the state of these climate drivers.

The forecast skill shown in this study is the average skill over the whole 23 year period, but the skill is not uniform across all years. There will be times when the forecast will be more skillful than others e.g., forecasts are usually more skillful during El Niño and La Niña years than in neutral years. The size of the hindcast period for ACCESS-S1 is limited due to the availability and reliance on the UKMO's initial conditions. However, for ACCESS-S2 a longer hindcast set is planned, spanning at least 30 years.

The evaluation of forecast performance has focused on key regions of importance to vegetable growers. However, forecast skill is not the same as forecast value. A forecast has value if it leads to better decision-making. "Value" depends on how well the forecast system can make predictions, but it also depends on the nature of the management decision, the risk profile of the decision-maker, whether or not action can be taken on the basis of a forecast given a certain amount of advance warning, and the user's costs and losses associated with taking or not taking action.

To get optimal use out of climate forecasts, there is a need to partner with the vegetable industry to determine the level of skill that is useful and what management decisions could be made on the basis of the forecasts at their given level of skill. There may be different climate related risks and management decisions at different times of the year for each region and crop. The key question is whether the forecasts lead to better decision-making.

This project has provided a valuable basis for a new 4-year research project (started August 2017) funded under the Queensland Drought and Climate Adaptation Program 2, designed to improve drought preparedness and resilience for Queensland producers (https://www.daf.qld.gov.au/environment/drought/dcap/about-dcap). The project, entitled *The Use of Bureau of Meteorology Multi-Week and Seasonal Forecasts to Facilitate Improved Management Decisions in Queensland's Vegetable Industry,* involves adding two further regions, the Lockyer Valley and the Granite Belt, to the experimental forecast products developed in this project, and will trial the forecast products with producers to enhance farm management decision making in the Queensland vegetable industry.

Recommendations

Two sets of recommendations have emerged that are aimed at 1) interaction with users and 2) underpinning scientific research:

1) Interaction with users:

- Trial the experimental forecast products with vegetable growers. Growers are encouraged to provide feedback through the email address supplied on the products website. Feedback will facilitate these products eventually being made fully operational, supported Bureau products and available to all. The Bureau can also use suggestions to help tailor and guide the presentation of a product, so that it is clear, understandable and useful for farmers.
- Work with vegetable growers to determine the level of skill that is useful and what management decisions could be made on the basis of the forecasts at their given level of skill.
- Determine if there is a need for tailored forecast products or indices of interest to vegetable growers (e.g. the likelihood of temperatures exceeding a threshold).

2) Scientific research:

- Update the evaluation of forecast performance for the vegetable growing regions when the next version of ACCESS-S is available. Development of ACCESS-S version 2 is already underway. ACCESS-S2 will include the BoM's ensemble generation and data assimilation system and will not be reliant on the UKMO initialization strategy. Improvements to the way that the land surface is initialized in the forecasts should lead to improvements in forecast skill, particularly for the eastern and southern vegetable growing regions and particularly for Tmax. ACCESS-S2 will also have a larger hindcast period, enabling a more statistically robust estimate of the skill and an investigation of how the skill changes according to the state of key climate drivers, such as ENSO.

Scientific refereed publications

Shi, L., Hudson, D., Alves, O., Young, G., MacLachlan, C., 2016. Comparison of GloSea5-GC2 skill with POAMA-2 for key horticultural regions. *Bureau Research Report*, No. **13**. Bureau of Meteorology, Australia (Available at: http://www.bom.gov.au/research/research-reports.shtml).

Hudson, D., Shi, L., Alves, O., Zhao, M., Hendon, H.H., Young, G., 2017. Performance of ACCESS-S1 for key horticultural regions. *Bureau Research Report*, No. **20**. (Available at: http://www.bom.gov.au/research/research-reports.shtml).

Intellectual property/commercialisation

No commercial IP has been generated in this project.

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