Earth Systems and Climate Change Hub

National Environmental Science Programme

Industry engagement to identify climate sensitive decisions on multi-year timescales:

TasLab Engage Final Report

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1. Introduction

Climate conditions such as temperature, wind and rainfall influence the operations and subsequent profitability of many Australian industries, including agriculture, horticulture, energy and water resources. Having advance knowledge of the climate, on timescales relevant to operational decisions, may therefore assist in operations planning for these industries, potentially providing the ability to identify periods of increased profitability or risk. Timescales of interest may include days, months, seasons, years and beyond. Daily to ~10-day weather forecasts (also called 'predictions') and monthly to seasonal climate forecasts have been available operationally for many years via a variety of sources, including Australia's Bureau of Meteorology (BOM). For periods out to ~100 years into the future, climate change projections are available through initiatives like 'Climate Change in Australia'.

Bridging the gap between seasonal forecasts and climate change projections are forecasts on the annual, multi-year and decadal timescale (Figure 1). Forecasting on these timescales is a relatively new research area globally and as such forecasts have only more recently become available, in particular through the World Meteorological Organisation's (WMO) Annual-to-Decadal Climate Prediction Centre. The CSIRO, via the Decadal Climate Forecasting Project (DCFP), are delivering forecasts on the multi-year to decadal timescale, providing Australia's contribution to the WMO's centre.

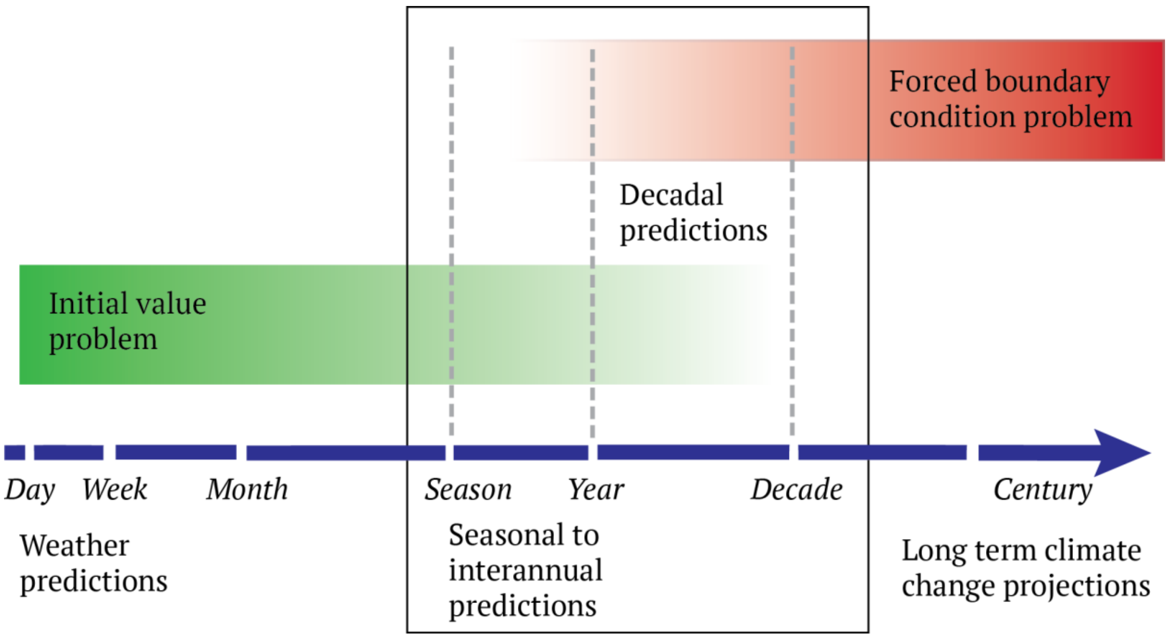

Figure 1: Decadal predictions in the context of short term weather and seasonal predictions and long term climate change projections (Source: https://www.wcrp-climate.org/grand-challenges/gc-near-term-climate-prediction). Note that 'prediction' and 'forecast' are synonymous terms.

Beyond the development of a forecast model and the delivery of long-range forecasts, the DCFP aims to:

- Undertake fundamental scientific research to identify and understand the ocean and atmospheric processes giving rise to predictability in key climate variables (e.g. temperature, rainfall) on the annual, multi-year and decadal timescale, which includes characterising long-term variability in these variables; and
- Advance the utility of climate forecasts by closely integrating forecast skill evaluation to specific applications (e.g. evaluating how well the model forecasts key climate variables) and determining useful ways to present forecast information.

These aims clearly rely on stakeholder engagement, particularly to understand the types of climate variables of relevance to stakeholders, the timescales of importance to operational decisions and to determine ways in which long-range forecasts might be incorporated into operations.

The National Environmental Science Program's Earth System and Climate Change Hub's TasLab Engage case study was developed to contribute to fulfilling DCFP's aims. Engagement, to better understand stakeholder needs regarding annual, multi-year to decadal predictions, will be integral in informing future directions of the DCFP.

TasLab Engage particularly focused on engaging Tasmanian-based stakeholders because of the broad range of industries based in the region (e.g. hydropower generation, Antarctic operations, emergency services, agriculture, aquaculture, forest management) and the highly variable climate across the state (Hill et al., 2009; Pook et al., 2010; Tozer et al., 2018). We think of Tasmania as a 'laboratory' for climate research, information and applications.

2. Project summary

The objectives of TasLab Engage were to:

1. Identify groups within Tasmania interested in exploring the climate sensitivities of their specific industry.
2. Engage with these groups via face-to-face meetings.
3. Identify the climate sensitivities of the relevant industries, particularly on the annual, multi-year to decadal timescales, and the operational decisions made on these timescales.
4. Produce an associated list of climate variables/indices that address these climate sensitivities.
5. Provide preliminary analysis of the historical annual to decadal variability of the relevant climate indices using observational climate data.

This report summarises activities undertaken as part of the National Environmental Science Program Earth System and Climate Change Hub's (NESP ESCC) TasLab Engage case study, including outcomes of and recommendations stemming from the activities, and the impact of TasLab Engage on the DCFP and the broader decadal forecasting community.

The TasLab Engage project team comprised members of CSIRO's Decadal Climate Forecasting Project (DCFP), the ESCC Hub and the University of Tasmania. As mentioned above, the project activities were designed to contribute to the DCFP's goals of advancing the utility of multi-year to decadal forecasts (which they are delivering) in Australian industry; and undertaking fundamental research into the predictability of annual to decadal variability in important climate variables. To that end, four Tasmanian-based industry stakeholders - Antarctic operations, wine producers, hydropower generation and emergency services - were engaged to elicit the climate sensitivities and climate information needs of their industry, focusing on the annual, multi-year to decadal timescale.

None of the stakeholders interviewed explicitly use forecasts beyond the seasonal timescale. However, all the stakeholders interviewed have a set of decisions they make, or have the potential to make, on annual to multi-year timescales, indicating the potential utility of long-range forecasts for these industries. It should be noted though that multi-year forecasts might be suited to some industries more than others. For example, those in more reactive industries, like the emergency services, may find multi-year forecasts less useful. Indeed, each industry, and the stakeholders within those industries, have different complexities. It is clear that one-on-one engagement between forecast generators and users is crucial to understanding the complexities and climate information needs of individual industries.

Interviewed stakeholders articulated a list of key variables that influence their operations. A preliminary analysis was undertaken to identify any long-term variability in a subset of these variables. The analysis indicated that all variables exhibit some annual and decadal variability e.g. alternating years of high and low temperatures. The outcomes of TasLab Engage provides focus for DCFP's activities. Several recommendations for the DCFP stemmed from this project, which will assist the DCFP in achieving the goals listed above.

Recommendation 1: The DCFP should include assessment of the stakeholder relevant climate variables in their routine forecast skill assessments.

Recommendation 2: The DCFP should continue engaging one-on-one with the stakeholders to explore where any areas of multi-year forecast skill identified in the relevant climate variables could be used in stakeholder decisions. This may also involve identifying ways to communicate forecast skill (where it is present) and uncertainty clearly.

Recommendation 3: The DCFP should conduct detailed exploration of the processes giving rise to the multi-year to decadal variability and predictability in the stakeholder relevant climate variables.

Recommendation 4: The TasLab Engage project team should interview a broader cross section of stakeholders and industries both within and outside of Tasmania to provide a more extensive Australian industry perspective on the utility of multi-year to decadal climate forecasts.

3. Project activities

TasLab Engage launch

TasLab Engage was launched via a brief presentation at the inaugural Tasmanian Climate Symposium held in Hobart on 14 November 2018. The Symposium was organised by Hydro Tasmania and the Tasmanian Climate Change Office and featured presentations by local scientists and an industry focused panel. Many representatives from local industry groups were in attendance.

Industry survey

As part of the TasLab Engage launch, a short survey was prepared and distributed (Appendix A) at the Tasmanian Climate Symposium. A key aim of the survey was to elicit stakeholders interested in further correspondence. Survey questions focused on identifying the types of climate information that are used in stakeholder operations (e.g. variables and timescales). We received no survey responses during the event and only two following the event. We subsequently approached the two respondents – State Emergency Service (SES) and Redbank Farming – to take part in TasLab Engage interviews.

Stakeholder interviews

In addition to the SES and Redbank Farming, we approached Hydro Tasmania, Australian Antarctic Division (AAD), Tasmania Fire Service and Tasmanian Institute of Agriculture (TIA) to take part in interviews. These additional stakeholders were approached based on either discussions at the Tasmanian Climate Symposium, discussions at the NESP ESCC Hub 2019 Science Symposium and Annual Workshop or a previous relationship due to other existing projects with the stakeholders.

Of the six stakeholders approached, four agreed to participate in TasLab Engage interviews: the SES, Hydro Tasmania, TIA and the AAD. We note that the SES and TIA have broad interests but our focus as part of TasLab Engage was on the Flood Policy Unit and the wine industry, respectively. We targeted representatives of each organisation who understand the operations of their specific organisation.

Semi-structured stakeholder interviews were conducted during August 2019. A list of questions was drafted prior to the interviews (Appendix B). The questions were designed to guide and stimulate discussion and were not necessarily all asked during the interviews. The project team undertaking the interviews comprised members of the DCFP, NESP ESCC Hub and the University of Tasmania.

Historical analysis of key variables

An outcome of the stakeholder interviews was a list of climate variables/indices that influence stakeholder operations (Table 1). Based on this list we performed a historical analysis on one selected variable for each stakeholder. The analysis was designed to put the variables of interest, including extreme values, in an annual and decadal context. This fits the notion that in climate forecasting (including seasonal, annual to decadal forecasting), it is not possible to forecast individual daily or multi-day extreme events (e.g. heatwaves). Rather, the aim is to identify and forecast periods in time or certain climate regimes that are more or less favourable for the development of these types of extreme events (e.g. a year that is more favourable to the development of heatwaves). This analysis contributes to DCFP's aim of characterising long-term variability in climate variables relevant to stakeholder operations.

As part of the analysis we:

- identified the mean daily values (or values for a selected percentile) recorded in the season of interest across each year and each decade of the analysis period.
- extracted the number of days per year and per decade above a selected extreme threshold (e.g. a temperature threshold indicative of heatwave days).

A key result of the analysis was that all selected variables exhibit interannual to decadal variability. Importantly, even in the presence of warming trends in the temperature-based variables, interannual variability is an important feature.

Full results and discussion of the analysis are presented in Appendix C.

4. Stakeholder engagement outcomes

Introduction to stakeholders

Australian Antarctic Division (AAD)

The AAD is a part of the Australian Government's Department of Agriculture, Water and Environment and is responsible for Australia's activities in the Australian Antarctic Territory and the Southern Ocean. The AAD leads Australia's Antarctic Program. The AAD operate three stations in eastern Antarctica (Casey, Davis, Mawson) and one on sub-Antarctic Macquarie Island, which are accessed via ship or plane primarily during the October to March period. Aviation and shipping thus dominate operations planning. The ice runway at Wilkins Aerodrome (near Casey) is built each season and serves as an Antarctic terminal for intercontinental flights. Each summer there are intercontinental and intracontinental flights, transferring passengers to, from and within Antarctica. Additionally, each station is resupplied most summers via the Aurora Australis icebreaker (soon to be replaced by the Nuyina icebreaker).

State Emergency Service (Flood Policy Unit)

The SES provide emergency response services across the year in Tasmania for severe storms and floods, road crash rescue, and a range of other general rescue and community support roles via volunteers. Additionally, they provide community education programs around emergency event preparedness. Our discussion with the SES focused on operations related to flood response.

Tasmania Institute of Agriculture (Wine industry)

TIA is a research institute at the University of Tasmania specialising in agriculture and food research. TIA, via its Horticulture Centre, has expertise in viticulture and wine chemistry. We focused discussion around the Tasmanian wine industry and the decisions vineyard managers make during the growing season and across years. There are seven major wine growing regions across Tasmania, primarily located around the major cities of Hobart and Launceston.

Hydro Tasmania

Hydro Tasmania is Australia's leading producer of renewable energy, primarily through hydropower. Hydro Tasmania operate 30 hydropower stations across six water catchments, primarily located in western Tasmania. Hydro Tasmania provides electricity to Tasmania and exports electricity to mainland Australia via the Basslink undersea cable, selling into the National Electricity Market (NEM).

Key climate variables and analysis summary

Table 1 presents the key climate variables that influence stakeholder operations identified during the TasLab Engage stakeholder interviews.

Table 1: Climate variables that influence stakeholder operations, including the timescales of interest and how they impact operations. The variables selected for further analysis are marked with an asterisk *.

Stakeholder	Key climate variables	Timescales of interest	Operations affected
AAD	Sea ice extent & thickness particularly around Mawson and Davis stations	Hourly, daily, monthly, seasonal, year-to-year	Affects shipping operations, potential to impact multi-year projects
	Wilkins runway temperature*	Daily, seasonal	Affects timing of runway opening and closing, potential to impact multi-year projects
	Wind at all stations	Hourly, daily	Affects aviation and day-to-day station operations
	Clouds at all stations	Hourly, daily	Affects aviation operations
	Blizzards at all stations	Hourly, daily	Affects aviation and day-to-day station operations
SES (flood service)	Extreme rain events across Tasmania*	Hourly, daily, seasonal	Potential to cause flooding
	Streamflow	Hourly, daily	Monitor for flooding
	Tides and swell around Tasmania	Hourly, daily	Potential to cause coastal infrastructure damage
	High winds around Tasmania	Hourly, daily	Potential to cause infrastructure damage
	Cutoff low pressure systems	Hourly, daily	Associated with significant rainfall events in highly populated eastern Tasmania
TIA (wine industry)	Temperature in wine regions in Tasmania and mainland Australia, including growing degree days	Daily, seasonal, annual	Influences timing of crop growth, fungicide purchasing
	Rainfall in wine regions in Tasmania and mainland Australia	Daily, seasonal, annual	Too much rain during flowering can cause fungal infection, fungicide purchasing, may influence irrigation allocation purchasing
	Extreme rainfall	Hourly, daily	Potential to cause crop damage
	Bushfires in Tasmania and the mainland	Any time	Causes significant crop damage, including smoke taint
	Hail	Hourly, daily	Potential to cause crop damage
	Frosts*	Daily	Potential to cause crop damage
Hydro Tasmania	Rainfall in western Tasmania	Daily, seasonal, annual, multi-year	Influence storage levels in Hydro catchments
	Extreme wet and dry periods	Seasonal, annual, multi-year	Influence storage levels in Hydro catchments
	El Niño Southern Oscillation and Indian Ocean Dipole phases	Seasonal, annual, multi-year	Perception that these processes influence seasonal rainfall variability in Hydro catchments
	Heatwaves in Melbourne*	Daily, multi-day	Influence energy pricing

Common stakeholder themes

The common themes identified across all four stakeholders are:

Timescales of interest:

- Extremes are important – extreme rainfall and temperature events (e.g. heatwaves, frosts, very dry seasons/years) on different timescales have the greatest impact on operations.

Climate information use:

- None of the stakeholders currently use forecasts on the annual to decadal timescale, some use seasonal forecasts and all use daily weather forecasts.
- Historical (observational) climate information relevant to their region/industry is used in operations.
- Anecdotes related to past extreme events/years guide current practice.

Potential utility of multi-year to decadal forecasts:

- All stakeholders have a clearly articulated set of decisions they make on multi-year timescales.

Individual stakeholder summaries

We now provide stakeholder specific answers to the following key questions, which expand upon the common themes presented above:

1. What weather/climate information do they currently use?
2. What decisions do they make (or have the potential to make if suitable information is available) on the annual, multi-year and decadal time timescales?

Answers to these key questions provide the DCFP with information regarding the stakeholder's familiarity with climate forecasts, the incorporation of forecast information into the operations decision-making process and the scope for the stakeholders to use long-range predictions. In addition to answers to the above questions, we present examples of how the long-range predictions might be useful to current operations.

Australian Antarctic Division

1. Over the summer season the AAD use daily-to-5 day weather forecasts provided by the BOM. They don't use climate forecasts at present, and therefore are not familiar with the formats that forecasts are presented in. Any seasonal to multi-year planning is done based on their knowledge of the climatology of the region. While they don't use climate projections it was noted that the projection of increased sea ice around East Antarctica outlined in the

IPCC Fifth Assessment Report convinced them to increase the ice breaking capacity of the new Nuyina icebreaker.

2. Year-to-year the AAD make decisions regarding aviation and shipping operations. That is, they have a relatively predictable annual cycle in regard to when the aviation (e.g. when they start building Wilkins runway, when they close the runway over summer) and shipping (i.e. when each station is resupplied each summer) programs commence and cease each year. They also regularly have multi-year projects (e.g. million year ice core project, rebuilding of Macquarie station, planning of Davis rock runway) that require long term planning.

Sea ice affects AAD shipping operations, particularly around Mawson station. Challenges occur when the sea ice does not behave as expected. For example, over the last decade there have been some years when sea ice around Mawson has not broken up when expected. Too much sea ice prevents timely resupply as the ice breaker cannot get close enough to the station. The ultimate risk of too much sea ice is being unable to reach the station to resupply and provide personnel. If this were to occur there is a risk of having to close the station. Other options, like fuel drops via helicopter, are uneconomical.

Multi-year forecasts of likely sea ice conditions around Mawson may be beneficial for AAD operations planning. For example, if more extensive and thicker sea ice is forecast for the next two years, the AAD may choose to resupply the station in the current season with enough fuel to cover the following years.

State Emergency Service (Flood Policy Unit)

1. The SES use BOM weather forecasts and extreme weather warnings. They also use BOM seasonal forecasts and seem satisfied with the existing format of this information. At the moment they do not use climate forecasts beyond the seasonal timescale. They have been using 2100 climate projections to produce a state-wide strategic flood map indicating current flood risks and risks out to 2100 (i.e. 1%, 2% and 5% Annual Exceedance Probabilities for current period and projections for 2100).
2. The SES are a reactive organisation and hence the hourly/daily timescale is particularly important for their operations. On a longer timescale (e.g. annual to multi-year) they plan volunteer recruitment and mobilisation and community education programs (e.g. what to do in the event of flooding, insurance education).

If the SES received a forecast of wetter than normal conditions for a particular region over the next few years, this may compel them to focus their recruitment and education programs on that region. Beyond this, long-range forecasts may provide limited use for the SES given that their primary operations are on the relatively short timescales (i.e. responding to flooding).

Tasmania Institute of Agriculture (Wine industry)

1. Vineyard managers typically use BOM weather and seasonal forecasts to guide daily to seasonal tasks. Climate projections of warmer temperatures (and the already experienced warming trend in temperatures in Tasmania) have also guided planting over the past few years and driven the success of recent seasons, noting that once vineyards are planted, they are difficult to change. Forecasts on an annual to multi-year timescale are not currently used.
2. On a year-to-year basis vineyard managers will make decisions about irrigation (they pay for water allocations each year) and when to buy and apply fungicide spray.

Fungicide purchase is impacted by predicted rainfall, as very wet weather can encourage fungal growth, increasing the need to spray. There are limited stocks of spray each season across Australia and availability of spray is dependent on demand in other parts of Australia. Tasmania is at some disadvantage because the spray season is typically later than most of Australia. This means there is a risk that only a limited amount of spray is available when it is needed in Tasmania.

A multi-year forecast of wetter than normal conditions in Tasmania and/or mainland Australia may guide a vineyard manager to purchase fungicide earlier than normal in anticipation of increased need to spray and limited stock availability in the next few years.

Hydro Tasmania

1. Hydro Tasmania use BOM seasonal forecasts. They note that the forecasts are given as the probability of exceeding the median, but they do not find this format useful in their activities as they are impacted most by extreme events (e.g. extreme dry periods). They did note, however, that the recent positive Indian Ocean Dipole (IOD) and associated drier spring forecast compelled them to hold back energy generation. Hydro Tasmania also use historical climate data to drive their simulations, while climate projections are used to guide their long-term scenario modelling. Spot energy traders additionally use daily BOM forecasts.
2. Hydro Tasmania use simulations that run out several years to operate their system. These simulations take into account historical climate data and projected energy prices. Network maintenance (e.g. taking certain storages offline for maintenance) is also planned years ahead and generally occur on a 5 year (small storages) and 10 year (large storages) basis.

Annual to multi-year forecasts could potentially guide Hydro Tasmania's energy/water simulations. If a forecast indicated dry conditions next year, Hydro Tasmania may hold water back in their storages this year instead of using it to generate electricity in the current period. This means that more water will be available in the following dry years, which may help mitigate the risk of not meeting irrigation allocation demands (which may increase in dry years), environmental flow levels and local electricity requirements. Alternately, a forecast of wetter than average conditions in the coming years may influence their maintenance planning schedule, which can have lead times up to five years.

Outages during very wet periods are not desired as this causes delays to the maintenance schedule, which may mean that they are not able to take advantage of good conditions for generating electricity.

Summary and recommendations

All stakeholders make (or have the potential to make) decisions on the annual, multi-year and decadal timescale, though long-range forecasts might be suited to some industries more than others. For example, Hydro Tasmania already run multi-year simulations that guide their operations and have an established multi-year maintenance program. These systems would therefore likely benefit from advanced knowledge of climate conditions over the coming years. On the other hand, most of the operations undertaken by the SES occur on shorter timescales, suggesting that long-range forecasts are less useful. That said, there is some potential for multi-year climate information to guide SES volunteer recruitment and community education programs.

We summarised the climate variables relevant to stakeholder operations in Table 1 and provided a preliminary analysis of the annual to decadal variability in selected variables in Appendix C.

The **first recommendation** stemming from TasLab Engage is for the DCFP to include assessment of the stakeholder relevant climate variables (Table 1) in their routine forecast skill assessments.

The **second recommendation** is for the DCFP to continue engaging one-on-one with the stakeholders to explore where any areas of multi-year forecast skill identified in the relevant climate variables could be used in stakeholder decisions. This activity may also include exploring the manner in which to deliver climate forecasts and their associated skill (where it is present) to stakeholders. If forecast skill and uncertainty can be communicated clearly, then decadal forecasts may be taken up more quickly by industry. This contributes to DCFP's goal of advancing the utility of climate forecasts in industry.

The **third recommendation** is for the DCFP to conduct detailed exploration of the processes giving rise to multiyear variability and predictability in the stakeholder relevant climate variables. This will contribute to the DCFP's broader goal of undertaking fundamental scientific research to identify and understand the ocean and atmospheric processes giving rise to predictability on the annual, multi-year and decadal timescale, and shape this for maximal national benefit.

The **fourth recommendation** is for the TasLab Engage project team to interview a broader cross section of stakeholders and industries both within and outside of Tasmania. This will provide a more extensive Australian industry perspective on the utility of decadal climate predictions. Stakeholders within the fire service (e.g. Tasmanian Fire Service) would be of interest given the significant impacts of bushfires on other industries like the wine industry, as discussed above.

5. TasLab Engage impact story

DCFP impacts

The outcomes of TasLab Engage were presented to the DCFP via a seminar in September 2019. The seminar highlighted the decisions each stakeholder makes on the multi-year to decadal timescale, indicated the variables that are most relevant to each stakeholder and discussed the recommendations stemming from this study. The outcomes of TasLab Engage provide focus for DCFP's activities. For example, we have identified the climate variables that the DCFP should include in their forecast skill assessments (i.e. assessments of how well the model forecasts the climate). The outcomes additionally provide further impetus for existing initiatives within the DCFP (e.g. DCFP's focus on sea ice prediction).

A tangible example of the impact of TasLab Engage on the DCFP can be seen through an existing project with Hydro Tasmania. As part of the project the DCFP is delivering multi-year forecasts and investigating the application of forecast information to a toy Hydro Tasmania system model. TasLab Engage has contributed knowledge around the important influence of temperature variability in Melbourne on Hydro Tasmania's operations. As a result, the DCFP will include assessment of their skill in the forecasting temperatures in Victoria in their work program and include Melbourne temperatures in their system model simulations.

TasLab Engage has additionally provided the means for the DCFP to build a network of climate information users, which can assist in the development of industry specific skill metrics and operations-suitable forecast formats as the DCFP progresses. The co-production of decadal forecast knowledge between the DCFP and industry stakeholders, particularly given the relative infancy of the field, is an important step in maximising the utility of DCFP's forecasts and increasing the uptake of decadal information by stakeholders. Stakeholders who are better able to utilise decadal climate information will be better placed to consider climate in their mid to longer term business operations and risk assessment planning tools. This may ultimately lead to Australian industries who are better prepared to manage the risks and impacts of a changing climate.

International impacts

On a global level, the DCFP is involved in the WMO's World Climate Research Program's Decadal Climate Prediction Project. The project aims to investigate the potential to make skilful forecasts on the annual, multi-year and decadal timescales, with some focus on the application of the forecasts to societal needs. The outcomes of TasLab Engage have the potential to provide guidance to this international project, and the broader international decadal prediction community, around societally-relevant variables. For example, a representative from the DCFP will be presenting at the international Workshop on Societally-Relevant Multi-Year Predictions, which is sponsored by the World Climate Research Program. A key focus of the workshop is the identification of user requirements for multi-year predictions, which the outcomes of TasLab Engage clearly contribute to.

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Appendix A

TasLab Engage Survey

How can climate information aide your business, industry, or organisation?

This survey has been developed by the Decadal Climate Forecasting Project at CSIRO as part of the TasLab initiative. We want to better understand how climate information could better support you. This short survey will help us connect with you and your needs.

*** 1. Please provide your name:**

☐

*** 2. Who are you representing (organisation)?**

☐

*** 3. Write a short description of what you do and your role in your organisation?**

☐

*** 4. What kinds of weather data (information over the next two weeks) and climate data (information longer than 2 weeks away) are relevant to your operations? (select all that apply)**

☐ Rainfall
☐ Temperature
☐ Wind
☐ Sunshine
☐ Storms
☐ Other
☐ I don't believe any are relevant

*** 5. What time periods are you interested in for most planning decisions you make? (select all that apply)**

☐ Daily
☐ Weekly
☐ Monthly
☐ Seasonal
☐ Annual
☐ Decade
☐ 30 years or longer

*** 6. Do you use climate forecasts for your decisions?**

☐ Yes
☐ No

*** 7. If you don't use climate forecasts for your decisions, why not?**

☐ Unavailable
☐ Unreliable
☐ Not suited to my operations
☐ Other

*** 8. What is the longest planning horizon that you typically consider in managing your operation?**

- ☐ Daily
- ☐ Weekly
- ☐ Monthly
- ☐ Seasonal
- ☐ Annual
- ☐ Decade
- ☐ 30 years or longer

*** 9. Are your operations sensitive to climate extremes?**

- ☐ Yes
- ☐ No

*** 10. What kinds of climate extremes are of interest to your operations? (select all that apply)**

- ☐ Flood
- ☐ Fire
- ☐ Drought
- ☐ Storms
- ☐ Heatwaves
- ☐ Frost
- ☐ Hail
- ☐ Extreme winds
- ☐ Calm days
- ☐ Storm surges

*** 11. Please provide your email if you'd like to receive further correspondence**

Please return to: carly.tozer@csiro.au

Appendix B

Interview questions

1. Describe what you do, what is your industry about?
2. What are some of the weather and climate strengths of your region for your industry?
3. What are some of the weather and climate challenges of your region for your industry?
4. Do you currently use climate forecasts and/or climate projections in your operations?
5. If so, how? If not, why?
6. Do you see climate extremes or changes in average climate as being of most concern/risk to your operations?
7. What do you do during the year? (Walk us through what happens month by month during a typical year as part of your workflow). Annual cycle.
8. What decisions do you make during a year as part of your workflow? Can you identify some of the key decision points in your annual workflow?
9. What are the types of climate information you think about in making these decisions?
10. Can you describe a good year from the point of view of your operations? And what made it a good year?
11. Can you describe a bad year from the point of view of your operations? And what made it a bad year?
12. What are the risks that you protect against?
13. How do your work plans change year to year?
14. What do you do in the current year with next year and subsequent years in mind?
15. Are there multi-year climate risks for your operations and what are they?
16. Can we map out a 10 year calendar?
17. Suppose you knew (for certain) we were entering 3 years of drought/wet/hot/cold from next year, what decisions would you make now to prepare for it?
18. Suppose that there was a 60% chance of 3 years of drought/wet/hot/cold from next year, would you still take the same actions?
19. What would be the worst case scenario if you made a choice based on a forecast and that forecast ended up being wrong?
20. What are the sources of climate and weather information that you currently use (all

timescales)?

21. Do you use a form of climatology in planning your work? (What are your expectations based on historical climate for your area)
22. Does any of the information you use pertain to multi-year timescales?
23. What are the gaps in the information?
24. What climate indices would be most useful and at what timescales?
25. Would you use a forecast for these indices if you knew it was better than climatology most of the time?
26. If yes, when would you want to see that forecast issued?
27. In what format do you currently use climate information? Should it be formatted differently?
28. Subset of ensemble forecast information presented in different formats, ask how they understand each. E.g. chocolate wheels (pie diagrams), cumulative plumes, tercile/above-below median,
29. Are you interested in further engagement?

Appendix C

Historical data analysis

As indicated in Section 3, we performed an analysis on a climate variable that influences the operations of each stakeholder. Table 2 indicates the variables selected and the associated data availability. We provide further discussion around the chosen variables, seasons and regions below.

Table 2: Details for selected variables. Note that ACORN-SAT refers to the BOM’s high quality Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) (Trewin, 2012).

Stakeholder	**Variable and region**	**Season**	**Data Source**	**Data availability**
AAD	Maximum temperature at Wilkins Aerodrome	Summer	Japanese 55-yr Reanalysis	1/1/1958-30/06/2018
SES	Extreme rainfall in Hobart	Autumn	BOM station 94029	1/1/1900-31/5/2019
TIA	Minimum temperature in Launceston	Spring	BOM (ACORN-SAT) station 91311	2/1/1910-31/5/2019
Hydro	Maximum temperature in Melbourne	Summer	BOM (ACORN-SAT) station 86071	1/1/1910-5/1/2015

We extracted daily data for the variables listed in Table 2. It is important to note that from the perspective of climate forecasting (including seasonal, annual to decadal forecasting), it is not possible to forecast individual daily or multi-day extreme events (e.g. heatwaves). Rather, the aim is to identify and forecast periods in time or certain climate regimes that are more or less favourable for the development of these types of extreme events (e.g. a year that is more favourable to the development of heatwaves). Here we attempt to put the variables of interest, including extreme values, in an annual and decadal context, providing a preliminary analysis of the annual to decadal variability in these daily variables. With this in mind, we performed the following analyses:

1. We identified the mean daily values (or values for a selected percentile) recorded in the season of interest across each year and each decade of the analysis period.
2. We extracted the number of days per year and per decade above a selected extreme threshold (e.g. a temperature threshold indicative of heatwave days). These are considered ‘extreme days’.

AAD - Wilkins summer temperatures

Wilkins Aerodrome serves as the Australian Antarctic terminal for intercontinental flights. The Aerodrome is located approximately 70km inland of Casey research station. Flights occur during October to March each year. For six weeks over summer the runway closes due to sub-surface melt. Runway ice temperatures are recorded every day at different levels below the surface. These measurements guide decisions on when to close and reopen the runway. Around 10 years of in-situ daily data for Wilkins Runway is available (pers. comm. Robb Clifton), which provides limited opportunity to explore annual to decadal variability in summer temperatures. Given this we use the Japanese 55-year Reanalysis (JRA) dataset, which provides global climate data on a 1.25°x1.25° grid (i.e. approximately 140 km x 140 km) for 1958 to present-day. We extracted daily maximum surface air temperature data at the grid cell encompassing Wilkins Aerodrome (66.7°S, 111.5°E).

In Figure 2a we present the mean daily summer temperature occurring in each year and each decade across the 1959 to 2018 period, noting that 1958 was excluded because it featured only part of summer. There is clear interannual variability evident in the temperature record with the mean greater in some years compared to others (Figure 2a). Additionally, there appears to be a general positive trend in mean temperatures across the record in concert with decadal-scale variability (i.e. dips in the temperature occur in the 1990s and 2010s). Figure 2b presents the number of days above the 90th percentile daily summer temperature (-0.4°C) per year and per decade. This threshold is not necessarily representative of the threshold used in practice to determine when Wilkins Runway should close and reopen each summer but provides some indication of how the frequency of extreme threshold exceedances might change year-to-year and across decades. In line with variability in the mean temperatures (Figure 2a), there is a general increase in the number of days above the threshold across the record, peaking in the 2000s, before decreasing in the recent decade. The summers of 2005 and 2006 were particularly warm with around a third of summer days in these years exceeding the -0.4°C threshold. One might expect that in summers such as 2005 and 2006, Wilkins Runway may have needed to close for longer periods of times, noting that regular passenger flights to Wilkins did not commence until summer 2008 (i.e. Dec 2007-Feb 2008).

Overall, surface temperatures at Wilkins Aerodrome (as represented by the JRA gridded data) exhibit annual to decadal variability. One might expect ice temperatures to show similar variability. This means there are likely years and decades with higher daily temperatures than others, which may have implications for aviation operations at Wilkins Aerodrome. For example, if a summer of above average maximum temperature was forecast then this may mean that Wilkins runway will be closed earlier and for longer that summer. This would likely result in a reduced number of intercontinental flights being undertaken, which would impact the AAD’s ability to transfer personnel.

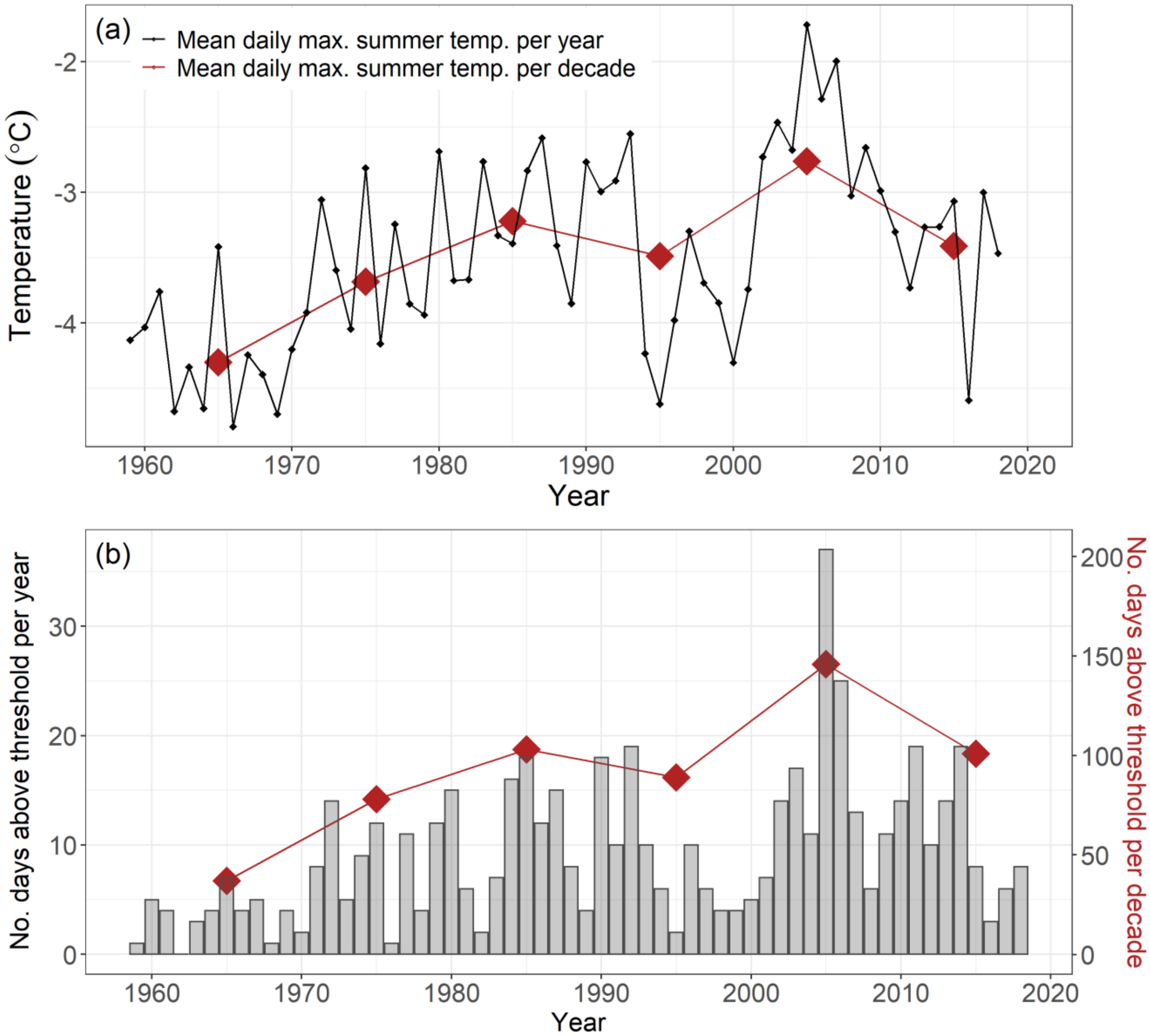

Figure 2: (a) Mean daily maximum summer temperature per year and per decade for the JRA grid cell encompassing Wilkins Aerodrome. (b) No. of days above 90th percentile summer temperature (-0.4°C) per year and per decade, where the 90th percentile value is calculated across the historical record. Note the red diamonds sit in the middle of the decade they represent e.g. the red diamond at 1965 represents the 1960-1970 decade.

Advanced knowledge of a warmer than usual summer, through the provision of decadal climate predictions, may provide important input into AAD decisions around changes to their typical aviation and shipping operations and allow planning for alternate means of transporting personnel to Antarctica.

SES Flood - Rainfall extremes in eastern Tasmania

In autumn 2018 Hobart experienced an extreme 1-day rainfall event that caused flooding, strong winds, infrastructure damage and major disruption across the capital city, leading to $100 million in insurance claims (Cooper 2019). The SES responded to more than 180 requests for assistance in the Greater Hobart area as a result of the event (https://www.ses.tas.gov.au/one-year-on-from-extreme-weather/). Characterising extreme daily rainfall on an annual and decadal is challenging given its relatively erratic nature (e.g. in comparison to daily temperature). Nonetheless, we present the maximum daily autumn rainfall amounts recorded in Hobart each year and the 99th percentile autumn rainfall per decade (Figure 3a) along with the number of days per year and decade greater than the 99th percentile autumn rainfall amount.

Figure 3a indicates the marked interannual variability in maximum rainfall amounts. The record is punctuated by 3 events that recorded more than 100 mm of rainfall in 1 day (1909, 1960, 2018). Events of this magnitude are clearly rare (i.e. 3 in 120 years). On the decadal timescale the 99th percentile rainfall level oscillates between around 20-30 mm. Figure 3b indicates that events greater than the long term 99th percentile value (22.9 mm) do not occur each year. It is also not often that multiple extreme rainfall days occur each autumn i.e. only 28 autumns out of the 120 year record feature multiple days exceeding the 22.9 mm threshold. A clustering of high rainfall events in one autumn period may make recovery efforts more challenging. The number of daily rainfall extremes recorded has reduced over the past two decades (Figure 3b).

If climate forecasts for years of extreme rainfall for specific regions could be provided to the SES, they may be able to focus their recruitment and education plans, in anticipation of increased risk of flooding in those areas.

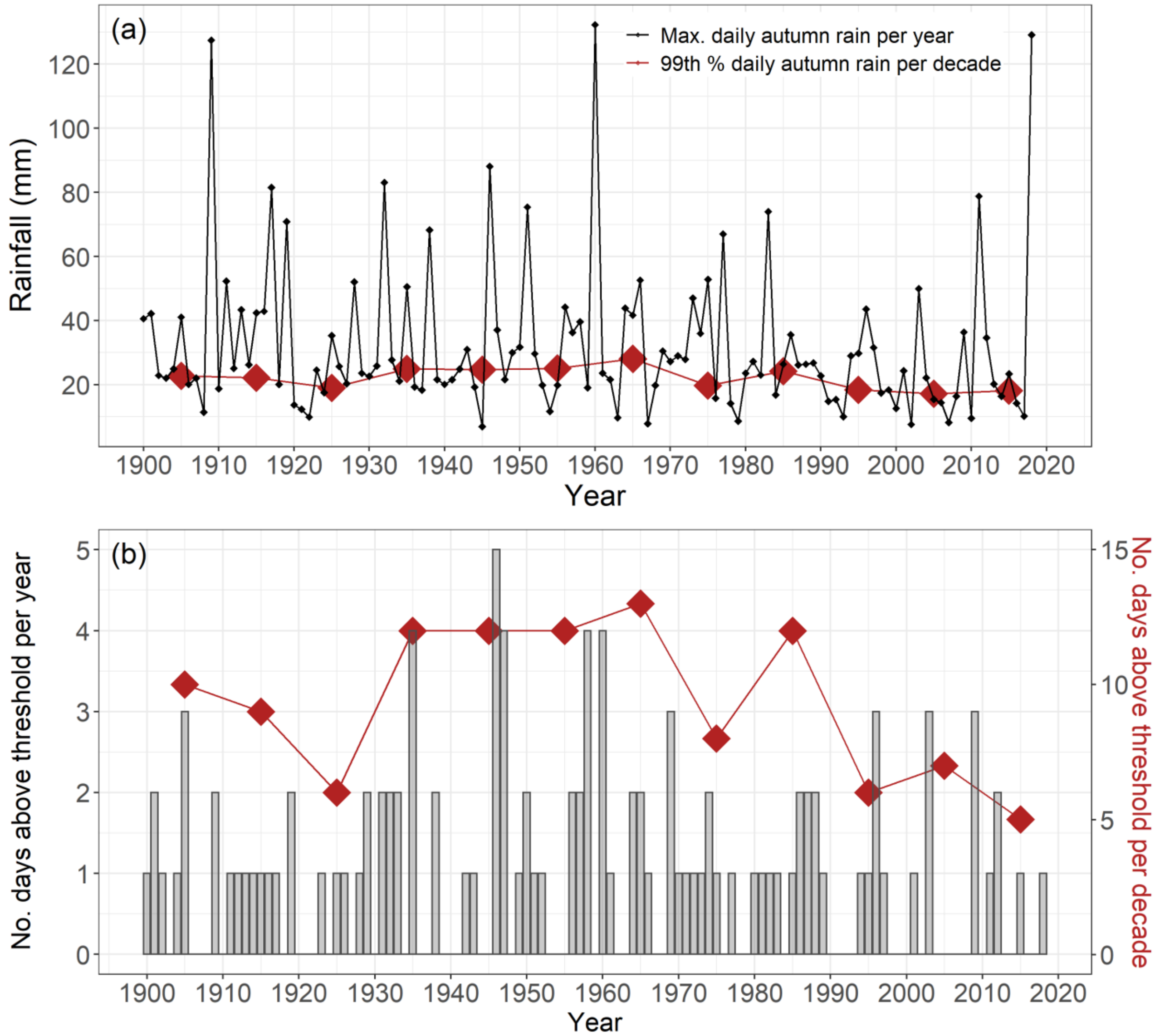

Figure 3: (a) Maximum daily autumn rainfall per year recorded in Hobart and 99th percentile autumn rainfall per decade. (b) No. of days above 99th percentile autumn rainfall (22.9 mm) per year and per decade where the 99th percentile value is calculated across the historical record. Note the red diamonds sit in the middle of the decade they represent e.g. the red diamond at 1915 represents the 1910-1920 decade.

Wine industry - Frosts in southeast Tasmania

Frosts during spring can damage plant cells potentially resulting in significant crop losses. We assessed the interannual to decadal variability in minimum spring temperature and days below 0°C, which we use as an indicator of frost. Our region of interest is the Tamar Valley, home to Tasmania's largest wine district. In Figure 4a we present the mean minimum spring temperatures recorded at Launceston, located within the Tamar Valley. Figure 4a indicates that there has been interannual variability in the mean minimum temperatures, and that these annual oscillations occurred in concert with a warming trend from the 1960s. The warming trend is clearly evident in the decadal record, whereby the mean spring temperature remained steady at around 4.5°C until 1960, but increased until the 1980s before steadying again from the 1990s to present.

In Figure 4b we present the number of days below 0°C for each year and decade, which clearly shows that there are a greater number of days below 0°C prior to 1960. The number of days below 0°C decreases in line with the increasing mean minimum temperatures presented in Figure 4a. From the 1980s onward the number of frost days per decade is relatively constant (around 45 days each decade), but there is substantial year-to-year and multi-year variability in the number of days below 0°C.

A forecast of a year with increased frost risk may motivate a vineyard manager to invest in frost warning systems and adopt other adaptation mechanisms (e.g. sprinkler systems) ahead of time.

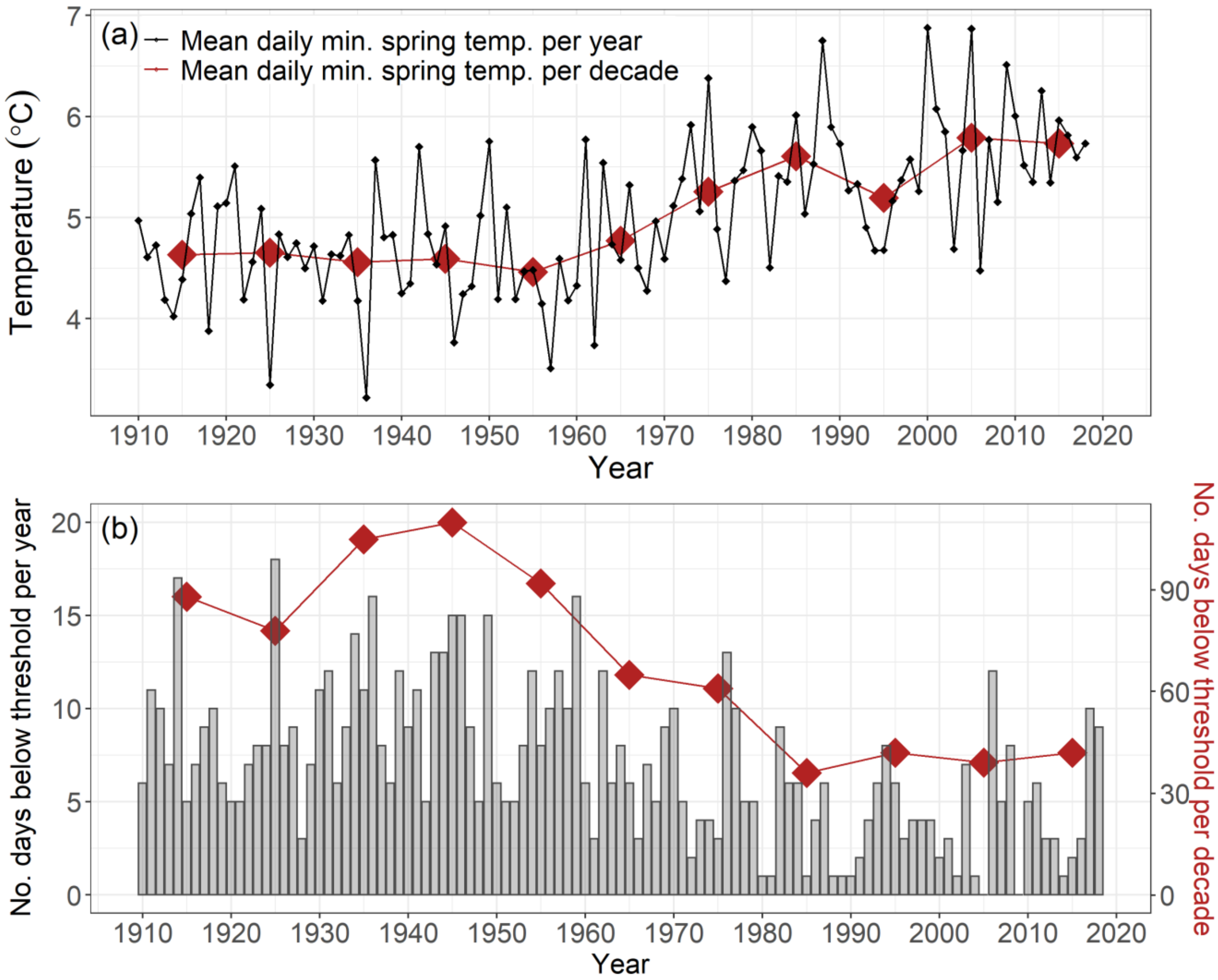

Figure 4: (a) Mean daily minimum spring temperature per year and per decade in Launceston (ACORN-SAT 91311). (b) No. of days below 0°C per year and per decade. Note the red diamonds sit in the middle of the decade they represent e.g. the red diamond at 1915 represents the 1910-1920 decade.

Hydro Tasmania - Melbourne heat waves

Summer heatwaves in Melbourne lead to high demand for power and therefore drive energy pricing, which influences Hydro Tasmania’s operations. We assessed the annual to decadal variability in mean maximum summer temperatures in Melbourne (Figure 5a) and the variability in the number of days above the 95th percentile summer maximum temperature (37.3°C), which we classify as heatwave days (Figure 5b).

Figure 5a indicates that the decadal mean maximum summer temperature was relatively steady from 1910 to the 1990s at around 25.5°C, before increasing from the 1990s to present. Despite the apparent increasing temperature trend post-1990s, this period featured the 3 lowest mean maximum summer temperatures across the record (i.e. 1992, 1996 and 2002).

Most summers recorded at least 1 day above 37.3°C, with the greatest number of heatwave days occurring in the summers of 1951, 1968 and 1981 with 13 days exceeding the 37.3°C threshold (Figure 5b). On the decadal timescale, there are oscillating peaks and troughs in heatwaves days per decade, with the greatest number of heatwave days occurring in the 1960s and the lowest in the 1970s.

Provision of multi-year to decadal climate predictions may assist HydroTas with planning and operations on a multi-year basis. For example, a forecast of increased heatwave risk in Melbourne for the coming year might compel Hydro Tasmania to hold water in their storages this year so that they can generate more electricity next year when electricity prices would likely be higher.

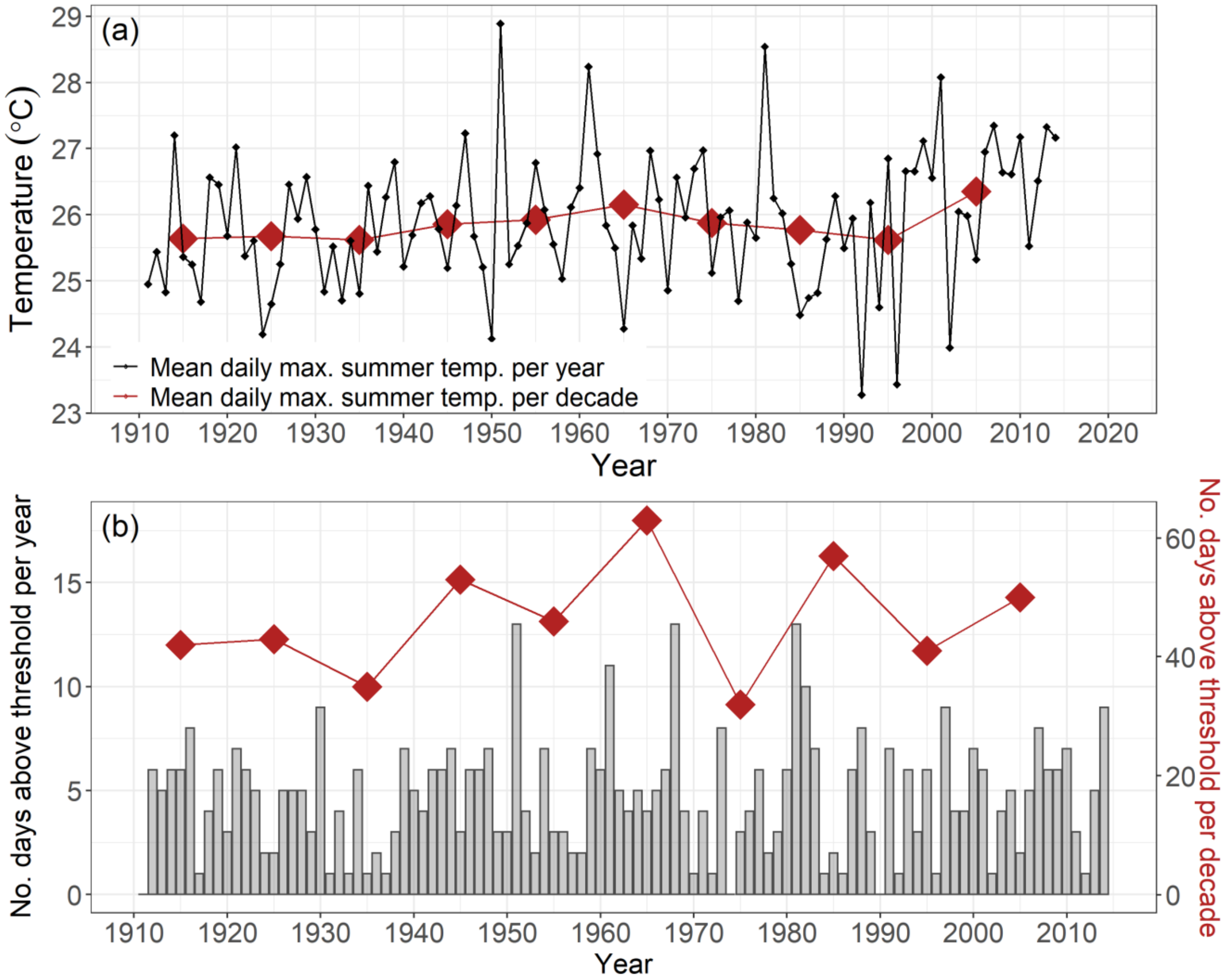

Figure 5: (a) Mean daily maximum summer temperature per year and per decade in Melbourne (ACORN-SAT 86071). (b) No. of days above the 95th percentile summer maximum temperature (37.3°C) per year and per decade where the 95th percentile is calculated across the historical record. The red diamonds sit in the middle of the decade they represent e.g. the red diamond at 1915 represents the 1910-1920 decade. Note that the record ceases in 2014 so no decadal record is presented for 2010-2019.

Data analysis summary

The above analysis suggests that there is interannual to multi-year variability in all variables of interest. Even in the presence of a warming trend in temperature (noting that we did not undertake formal trend analysis) interannual variability is an important feature. For example, the 3 lowest mean maximum summer temperatures in Melbourne (i.e. 1992, 1996 and 2002) occurred in concert with a warming trend. Additionally, decadal variability may also be a feature of these variables e.g. the apparent peaks and troughs in decadal heatwave counts in Melbourne. Identification of the underlying patterns (i.e. the variability) in these climate variables is the first important step towards being able to predict these variations.

From this preliminary analysis, next steps might involve:

- Further exploration into annual and decadal patterns of the selected variables (e.g. formal trend and changepoint analysis).
- Identification of the atmospheric and oceanic processes driving rainfall and temperature patterns (e.g. is there a common way in which the climate system sets itself up when temperatures are lower in Melbourne?). We note past research has found that heatwaves, frosts and wet and dry daily to multi-day events across southern Australia are associated with atmospheric features, including cutoff lows and blocks and also large-scale atmospheric features called 'wave trains' (e.g. Risbey et al. 2018; Tozer et al. 2018). These wave trains comprise a series of alternating low and high pressure systems that travel across the Southern Hemisphere. Current work within CSIRO's DCFP is focusing on identifying the links between these wave trains and oceanic features (e.g. the El Nino Southern Oscillation), which tend to have longer lead times than atmospheric features.
- Determining if there is predictability in any of interannual and decadal patterns identified.
- Assessing whether our climate models simulate the relevant features i.e. if the models can't capture the relevant atmospheric and oceanic features, it is unlikely that forecasts coming out of the model will provide any skill (Tozer et al., 2020).
- Assessing existing literature related to the above points.

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