Atlantic Salmon Aquaculture Subprogram: Forecasting ocean temperatures for salmon at the farm site

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2010/217. Atlantic Salmon Aquaculture Subprogram: Forecasting ocean temperatures for salmon at the farm site

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OBJECTIVES:

1 Generate site specific seasonal water temperature statistical forecasts for three nominated farm sites.

2 Generate and test the skill of dynamical regional ocean forecasts using the BOM seasonal prediction model (POAMA)

3 Undertake cost-benefit analysis of the value of these short-term predictions for the salmon industry

OUTCOMES ACHIEVED TO DATE

Development of seasonal water temperature forecasting methods for the farmed salmon industry allows future planning and risk management against predicted environmental conditions. Monthly forecasts were delivered for the period September 2010 to March 2011, for four sites. These forecasts can be used to inform a wide range of tactical farm management decisions, and represent an investment in best practice for the industry – as occurs for a number of land-based farming operations. The cost of forecasts is very low in real terms, and relative to the potential benefit. The salmon industry has indicated that these forecasts can inform planning for the coming months, and offer considerable returns in cost savings relative to the investment. Delivery of forecasts in the coming years is now possible, and the individual salmon companies are deciding on their on-going operational requirements for the coming year.

Many marine businesses, including aquaculture, are impacted by environmental conditions at a range of time scales. Information about the future weather or climate conditions, commonly called forecasting, is useful for risk management, business planning, and if used correctly, improving overall business performance, leading to increased profitability. Recent partnerships with the Tasmanian salmon industry have raised awareness about the potential impacts of climate change, and in particular, warm summers are a potential risk. This risk can be managed if information about the future were available. There are a range of operational decisions that could be modified on the basis of forecasts of environmental conditions. Advances in seasonal ocean forecasting –information about the ocean state at a time scale of weeks to months – means such warning is now possible. Marine applications currently in operational use in the Australian region include forecasts of coral reef bleaching and tuna fishing zones. Inshore regions are considered more challenging than for open ocean situations, however, preliminary analyses some years ago, suggested that useful forecasts for south-east Tasmanian waters were possible.

In this project we respond to calls from industry to develop and deliver forecasts of water temperature at salmon farms around Tasmania. The primary goal was to provide forecasts at lead times of up to four months.

We examined several approaches to delivery of seasonal forecasts of water temperature for the Tasmanian salmonid industry. Data on water temperature at the farm sites was provided and varied in length. Both statistical (Objective 1) and dynamical (Objective 2) forecasting approaches were tested for skill and accuracy, using historical hindcasting. Longer time series are expected to provide more robust statistical forecasts. We also developed a generic cost-benefit model to evaluate the economic benefit to farms that used the forecasts.

A statistical approach based on time series analysis of historical and recent data from each of four farm sites was used to deliver monthly forecasts of average monthly temperature. A total of seven monthly forecasts (Sept 2010 to March 2011) were delivered for each site. The accuracy of forecasts was greatest for the Tasman site (mean difference between forecast and actual observation over all lead times of 0.28°C), followed by Dover (mean difference between forecast and actual observation over all lead times of 0.3°C), Huon (mean difference between forecast and actual observation over all lead times of 0.45°C), and Macquarie Harbour (mean difference between forecast and actual observation over all lead times of 0.62°C). The forecasts for the year 2010-11 correctly predicted above or below average temperatures for all lead times 100% of the time for Tasman, 87% for Dover, 80% for Huon, and only 60% for Macquarie Harbour.

The exploration of dynamical forecasting based on the Australian Bureau of Meteorology (BOM) seasonal forecast model; Predictive Ocean Atmosphere Model for Australia (POAMA). This state-of-the-art seasonal to inter-annual seasonal forecast system is based on a coupled ocean/atmosphere model and ocean/atmosphere/land observation assimilation systems, and used for coral bleaching and tuna habitat forecasting in other regions of Australia. We evaluated the potential for forecasting water temperatures using the dynamical model to project regional temperatures and then down-scaled these to the farm site. The forecasting of average regional temperature around Tasmania generally showed good skill for up to three months into the future, during both summer and winter months, although as expected, skill declined with increasing lead time. Measured sea surface temperature anomaly (SSTA) values at the farms and the observed regional Tasmanian SSTA index (ITAS) were strongly correlated for 1991-2010, with $r = 0.76$ and $r = 0.83$ for Huon and Dover, respectively. The high correlations between the regional index and the farm data indicated that the index is a useful predictor of farm conditions. The model demonstrates useful skill up to lead-times of 1-2 months throughout the year. Overall, the forecast skill for ITAS, coupled with the observed relationship between ITAS and the farm locations, resulted in a lower skill in predicting conditions at the farm sites. However these results still show the model has useful skill in predicting farm temperatures within the upcoming season (e.g. a forecast could be skilful for December when issued 1 October).

The final element of the project, determining the economic value of seasonal forecasts to the salmon companies was not completed at the time of this final report. A generic cost-benefit model has been developed, and discussed with companies at the information session on the project. Despite initial agreement, the economic data to populate the model and explore the adaptation options has not been forth coming from the salmon companies. Confidentiality and cooperation was agreed, however, and so we hope to pursue this further in future.

Overall, the project has successfully demonstrated and delivered useful forecasts that we anticipate companies will demand in subsequent years. To go without this information, now that it is available, is like wearing a blindfold on a cliff-top night foray.

KEYWORDS: seasonal forecasting, operational management, cost-benefit analysis

2. Acknowledgments

This project was completed with the cooperation of the TSGA and member companies, and funded by CSIRO Climate Adaptation Flagship, Bureau of Meteorology, and the FRDC through the Tactical Research Fund. Preparation of the final report was aided by Toni Cracknell.

3. Background

Information about the future will be useful if decisions can be modified on the basis of that information. For a range of industries, environmental conditions can impact on business activities and hence profitability. Information about the future weather or climate conditions, commonly called forecasting, is useful for risk management, business planning, and if used correctly, improving overall business performance.

Weather forecasting is widely used by Australians for planning activities on time scales from hours to days. Climate forecasting is being used to plan infrastructure, coastal planning and long term industry changes at time scales of decades to centuries. Between these two extremes, is seasonal forecasting, which aims to deliver information at a time scale of weeks to months. In aquaculture for example, there are operational decisions that are made at a range of time scales, and some of these decisions could be modified on the basis of environmental conditions (**Figure 1).**

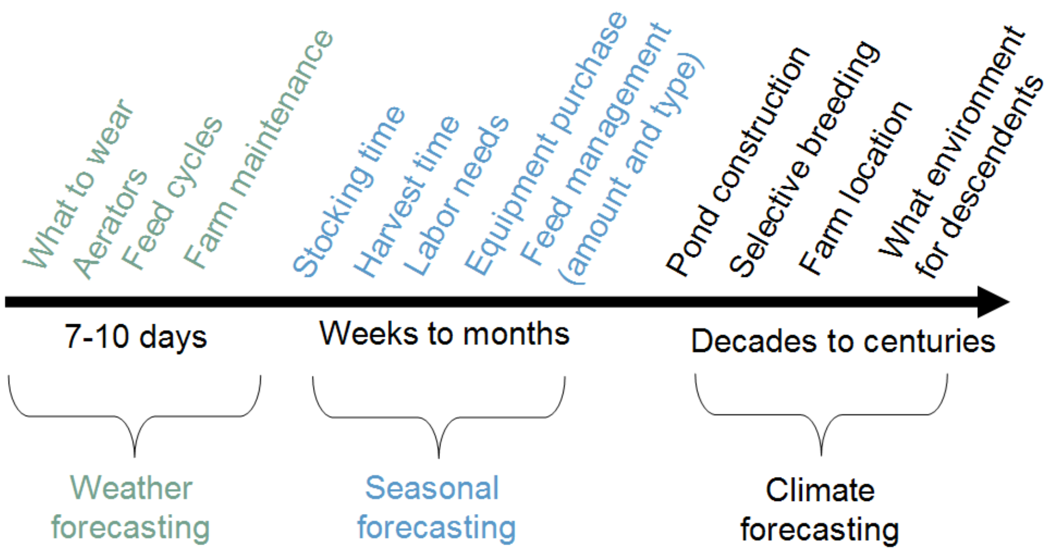


Figure 1. Information on future environmental conditions can be delivered at a range of timescales, and the appropriate time scale depends on the lead time for the decision that is to be supported.

There are a range of forecasting methods, which can be qualitative or quantitative. Experienced individuals use qualitative forecasting for informing decision making: a simple look skyward can allow a forecast about the potential for rain in the coming hours. At longer time scales, useful forecasts will probably be based on quantitative approaches.

Quantitative forecasts are generally grouped into two categories: statistical or dynamical. Statistical methods typically use historical (time series) data as the basis of estimating future outcomes, and can range from the simple (e.g. average temperature for the next January based on the previous set of Januarys) to the complex (e.g. autoregressive integrated moving average (ARIMA) model, which is a generalization of an autoregressive moving average (ARMA) model). Statistical relationships could exist between atmospheric or oceanic indicators and local variables, or between local variables at two points in time, and thus form the basis for prediction.

Dynamical forecasting methods for marine applications are based on global atmospheric and oceanic circulation models. In this project, we used the Australian Bureau of Meteorology (BOM) seasonal forecast model. The Predictive Ocean Atmosphere Model for Australia (POAMA) is a state-of-the-art seasonal to inter-annual seasonal forecast system based on a coupled ocean/atmosphere model and ocean/atmosphere/land observation assimilation systems (http://poama.bom.gov.au/about_poama2.shtml). Extensive analysis have been done of the capability of the POAMA system for regional forecasting of climate in the south east of Australia and in the subtropical Indian Ocean. These analyses have demonstrated that regional seasonal forecasts for Australia from POAMA have skill equivalent to, or better than, the current statistical approaches.

Seasonal forecasts from dynamical ocean-atmosphere models of high risk conditions in marine ecosystems can be very useful tools for managers, allowing for proactive management responses. The Australian Bureau of Meteorology's seasonal forecast model POAMA is currently used to produce operational real-time forecasts for coral bleaching risk on the Great Barrier Reef (GBR) (Spillman and Alves 2009; Spillman et al. 2011). These forecasts provide an early warning of potential bleaching risk prior to summer, which allows reef managers to both focus monitoring programs and implement strategies to minimise bleaching damage, as well brief government. POAMA forecasts are also used in the management of multi-species long-line fisheries on the east coast of Australia (Hobday et al., 2011). Ocean temperature forecasts are combined with a statistical southern bluefin tuna habitat model to produce experimental habitat maps for fisheries authorities to use in regulating fishing effort.

This project was in response to request from salmon companies and the Tasmanian Salmonid Growers Association (TSGA) to provide short-term ocean forecasts for Tasmanian farm sites. It follows from informal requests over the past years from various companies to provide predictions of ocean water temperatures for the coming months. Industry discussion subsequently endorsed this project for TRF funding.

Forecasts of ocean conditions around Tasmania that can be utilised by managers of salmon aquaculture farms can be used to as a warning of extreme conditions (e.g. hot summers) but operationally can also allow management of feed composition, stocking densities and freshwater bathing, all of which enhance farm production in a variable climate. Improved management of marine resources, with the assistance of such forecasts tools, is also likely to enhance their resilience and adaptive capacity under climate change (Hobday and Polaczanska 2010; Marshall et al. 2011).

4. Need

Salmon aquaculture in Tasmania, Australia, is a growing industry and important regional employer, worth millions of dollars to the state's economy. It also has been identified as an industry vulnerable to climate change (Hobday et al. 2008). Salmon are kept in sea cages for the final two years of production, with fish health strongly influenced by ocean conditions. Growth is coupled with water temperature, with salmon grown towards their upper thermal limit in summer (Battaglene et al. 2008). Under climate change however, this upper thermal limit is predicted to be exceeded more frequently (Battaglene et al. 2008) which could result in degraded fish health, increased disease outbreaks and mortality. Anticipation of potentially stressful ocean conditions would allow proactive farm management, minimising of the impacts of extreme warm temperatures and enhancing industry resilience under climate change.

This TRF project was initiated in response to requests from salmon companies to provide short-term ocean forecasts for Tasmanian farm sites. With this information, farm managers can plan environment-dependent operations in the upcoming months, such as stocking rates, feed management, disease treatments, and staffing levels for cage maintenance.

5. Objectives

The TRF funding covered the first objective, while internal CSIRO and BOM funding contributed to the second and third objective.

1. Generate site specific seasonal water temperature statistical forecasts for three nominated farm sites.
2. Generate and test the skill of dynamical regional ocean forecasts using the BOM seasonal prediction model (POAMA)
3. Undertake cost-benefit analysis of the value of these short-term predictions for the salmon industry

6. Methods

Objective 1 and 2 are to develop and deliver forecasts for future water temperatures to the farm sites. As described in the background (**Section 3)**, seasonal forecasting can be based on statistical or dynamical methods, or a combination of the two. In this project we considered both approaches, as outlined in **Figure 2**. Both approaches required local temperature data, as recorded on the farms.

Salmon farm data

Farm data was supplied by several salmon farms around Tasmania (Fig. 1a). Monthly temperature data was available for varying lengths of time which will impact on the statistical approaches to forecasting. Data coverage for Huon and Dover farms was for 1991-2010, Tasman was for 1997-2010 and Macquarie Harbour was for 2006-2010. Data coverage through the month also varies for some sites. Finally, we note that the quality of the data varied over time due to issues such as lost loggers, substitution and combination of data from two sites into a single record. Issues of quality control of the farm data should be addressed by the salmon companies, and here we were forced to assume the data correctly represented the local conditions at the farm site for the reported temporal period.

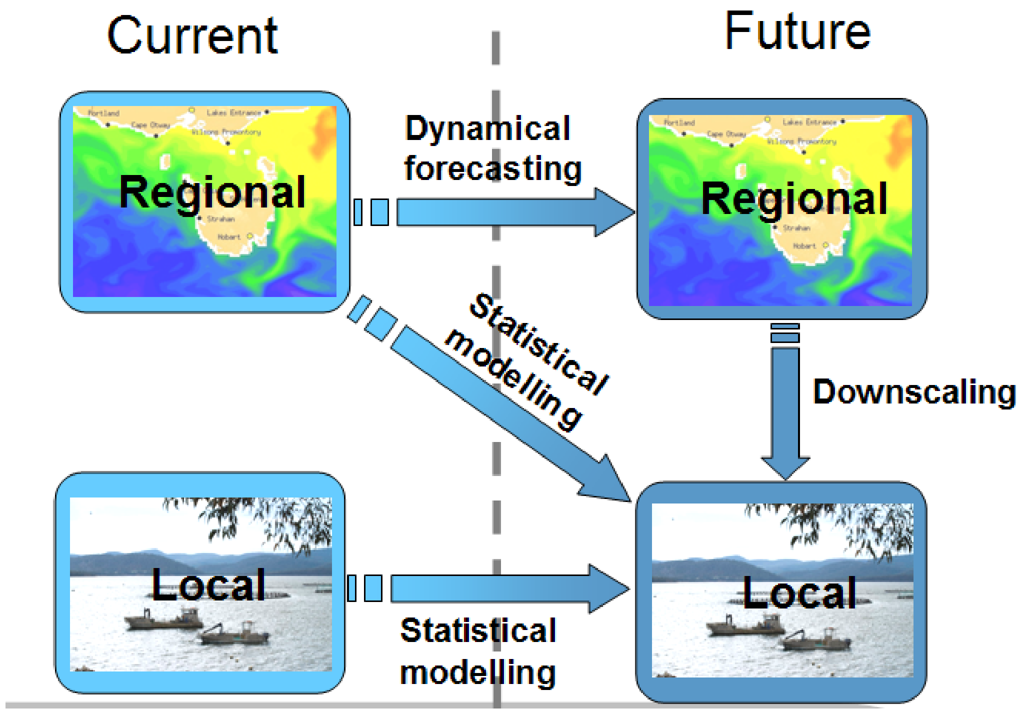


Figure 2. Methods for forecasting local conditions at the farm site. The "operational method" used to deliver the forecasts is via local information from the current period used to project temperatures at the local scale in future.

6.1 Statistical forecasts

Three statistical approaches were explored, although only one was selected for delivery of operational forecasts.

6.1.1 Approach 1: simple correlative patterns at the farm sites

The first approach involved a search for relationships between peak summer temperatures and temperatures in the preceding spring, based on correlative statistics (**Appendix 3**). This analysis showed that for the south-east sites, warm summers are broadly preceded by warm winters and springs. Correlations between peak summer temperatures at Dover and those in preceding months are significant for August, November and January. However, the variance accounted for is small (< 33%) suggesting the preceding months provide at best only a rough indication of summer peak temperatures, using correlative statistics. This approach is described in **Appendix 3**, was not considered useful for development of forecasts, and is not discussed further in this report.

6.1.2 Approach 2: large scale drivers of farm water temperatures

The second approach involved exploration of large scale climate signals and long-term patterns in the farm data. In a potentially changing climate, with superimposed decadal oscillations in water temperatures, it is possible that current conditions do not have a precedent within the limited time scale of data from the farm sites. However, local conditions, particularly water temperatures, are likely to be influenced by conditions at the regional level, which in turn may be conditional upon global or hemispheric changes. The larger scales provide context to the patterns at smaller scales. Trends in the southern hemisphere from the long-term data sets available from international projects were investigated. The preliminary analysis showed that the Southern Hemisphere temperature trend over the past several decades has not been as great as that in the Northern Hemisphere, but it does display similar overall trends and some cyclical behaviour (**Figure 3)**. The most recent trend (last decade) appears to be a respite from the rise of the past several decades, with evidence of a slight decline.

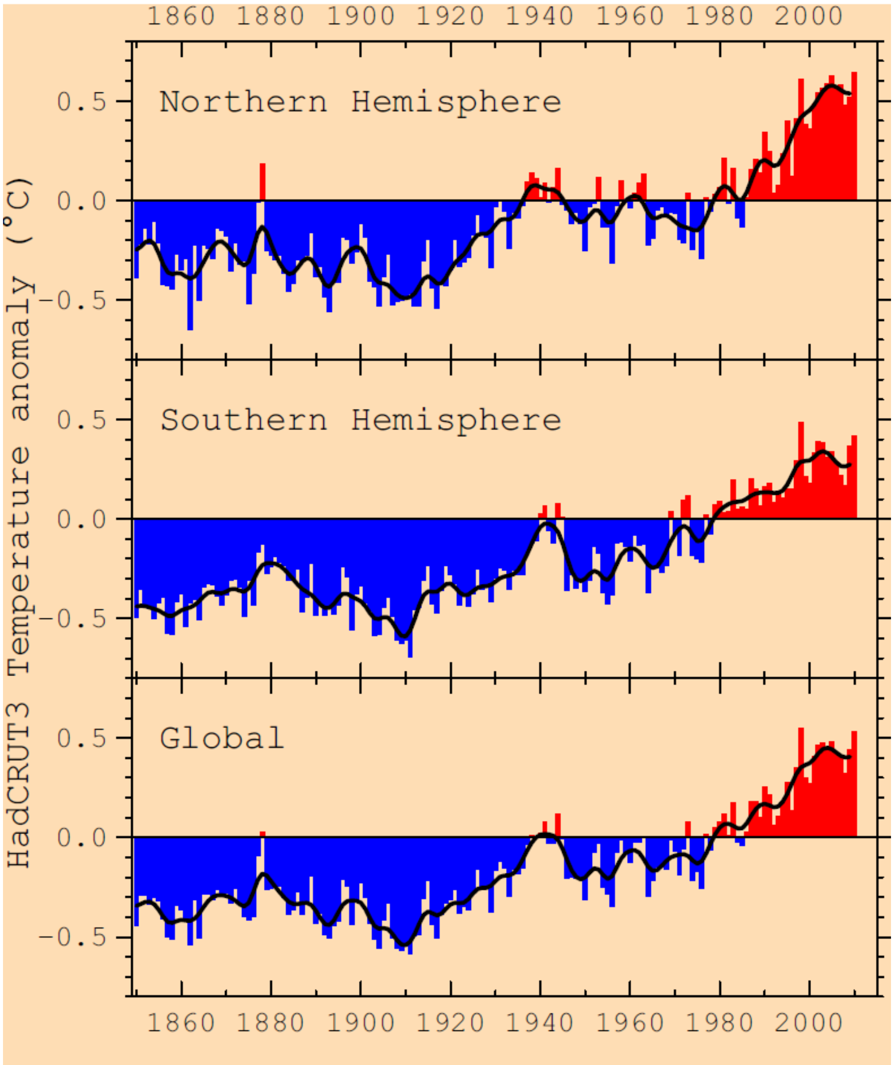


Figure 3. Annual temperature and smoothed trends for the global, northern and southern hemispheres, from the Climate Research Unit (http://www.cru.uea.ac.uk/) for the variance-adjusted version of combined land and marine (sea surface temperature) temperature anomalies, denoted: HadCRUT3v.

We examined the data for the Southern Hemisphere in greater detail in an attempt to project the future trends and cycles out to periods of two years (**Appendix 4**). Over the next two years, Southern Hemisphere temperature anomalies are projected to remain at the higher end of the observed range before declining. Bearing in mind the observation that peaks in southern Tasmania may follow peaks in this time series, this hypothesis warrants much more scrutiny than was possible in this project. This preliminary exploration of the hemispheric patterns and trends does suggest that a more detailed modelling exercise be conducted in order to determine whether hemispheric signals can be used to foretell significant climate-related events in southern Tasmania. There are cycles and quasi-cycles at a whole range of scales but within a limited window (in space and time) a reduced number may be dominant. The ability to identify and track these events offers hope for projecting climate trends at least a number of years ahead. This approach is described in **Appendix 4**, but was not considered useful for development of seasonal forecasts at this time, and is not discussed further in this report.

6.1.3 Approach 3: statistical time series forecasting

The final statistical approach was based on time series analysis, using the Holt-Winters and seasonal ARIMA techniques. The structured exponential smoothing approach of Holt-Winters assumes a decomposition of the time-series into a level, a slope and a seasonal pattern which can vary with time (via exponential decay parameters which are estimated by the algorithm, which give more weight to recent data). We also supplement these analyses with seasonal ARIMA (auto-regressive "integrated" moving-average) models which can provide longer and somewhat more stable projections using state space models. This method is similar to the Holt-Winters analysis, but the trends in the current year can depend on trends in previous years. We do not discuss the technical details of these methods but instead will rely upon their statistical predictive and projection measures to determine the most suitable projections. Some of the early reports were delivered with both methods, however, we judged the seasonal ARIMA approach to be structurally preferable to that of the Holt-Winters, and simplified the forecasts delivered to the salmon companies to this single method during the latter months of forecast delivery.

Forecast skill

The skill of the forecasts was evaluated with anomaly plots (**Figure 4)**. Above (below) average forecasts for a month at various lead times that were matched with above (below) average observations for the same month indicate the forecast approach was skillful. Mismatches between forecast and observations indicate poor skill. The overall percentage of correct forecasts was evaluated as "total correct/total".

Accuracy was assessed as the absolute difference in the observed and forecast temperature values for each lead time for each site.

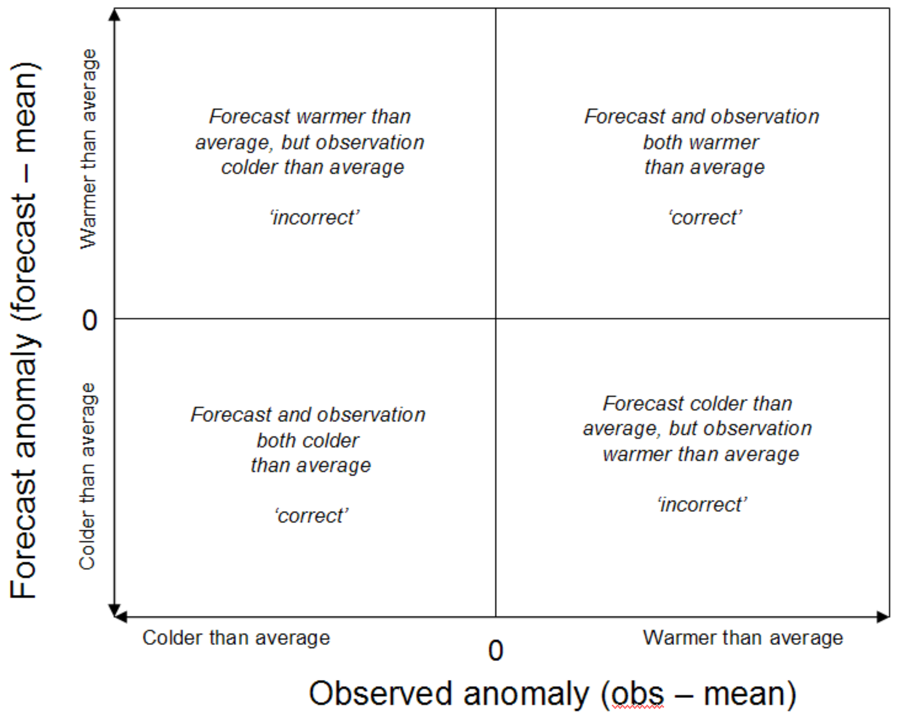


Figure 4. Example anomaly plots for evaluating forecast skill. The correct forecasts are when the observations and the forecast were in agreement, while "incorrect" is when the forecast did not match the observations.

6.2 Dynamical forecasts – POAMA-based approach

In this component of the study (Objective 2) we evaluated the potential for forecasting water temperatures using the dynamical model to project regional temperatures and then downscale these to the farm site (**Figure 2).** We focused on the Huon and Dover farm sites as the time series of temperature data were the longest.

Each dataset was scaled by removing the long-term monthly mean ocean temperatures for 1991-2010 for each farm to create temperature anomalies to allow for comparison. The two farms were strongly correlated with one other (r = 0.885).

Model description

The Predictive Ocean Atmosphere Model for Australia (POAMA; version 2) is a global coupled ocean-atmosphere ensemble seasonal forecast system developed jointly by the Australian Bureau of Meteorology and CSIRO Division of Marine and Atmospheric Research. The forecast system consists of a coupled ocean-atmosphere model and data assimilation systems for the initialisation of the ocean, land and atmosphere. Further details can be found in Spillman and Alves (2009) and Spillman (2011).

A thirty member ensemble of retrospective forecasts (hindcasts) was generated by starting the model thirty times on the first day of each month for 1982-2010, initialised only with data available before the start date and running forward in forecast mode for nine months. Each of the thirty forecasts is initialised using a slightly different set of ocean initial conditions from the POAMA Ensemble Ocean Data Assimilation System (PEODAS). The use of a forecast ensemble provides some indication of the possible spread or uncertainty in the future evolution of the climate system and allows for probabilitic forecasts. Ensemble members are averaged to give the overall ensemble mean forecast.

POAMA monthly modelled sea surface temperature (SST) values were scaled by first removing the model monthly climatology to create model anomalies (SSTA). The model climatology is the long-term monthly mean ocean temperatures for 1991-2010, computed relative to start month and lead-time for the model (Spillman and Alves 2009). Lead-time is defined as the time elapsed between the model start date and the forecast date, i.e., if the start date is 1 February 2010 and the forecast is for April 2010, the forecast lead-time is 3 months, while the forecast, for February 2010 is defined as lead-time 0 months. A regional Tasmanian SSTA index (ITAS) was also calculated by averaging SSTA values over the region 40-44 S and 142-151 E (Fig. 1b). This index was shown to be highly correlated with the surrounding area, indicating it suitability as an index representative of regional conditions.

Model Skill

To assess the accuracy of the POAMA temperature forecasts, model skill is calculated by correlating model SSTA ensemble mean values with observed monthly SSTA values in both space and time (Spillman and Alves 2009). The observation dataset used was the PEODAS reanalysis, which incorporated satellite and in situ data over the hindcast period. Generally forecast accuracy is highest for lead-time 0 months and decays as forecasts predict further into the future (i.e. increasing lead-time). In addition to anomaly correlations the probabilistic skill of the model was also assessed using all thirty ensemble members and temperature terciles as appropriate thresholds. Probabilistic verification is an important complement to any deterministic verification, and provides a useful and quantitative way to measure uncertainty (Kirtman, 2003). Relative Operating Characteristic (ROC; Mason and Graham, 1999) curves and debiased Brier Skill Scores (BSSD; Mason and Stephenson 2008) were calculated to assess the useful skill of probabilistic forecasts, with all grid points in the Tasmanian (ITAS) region contributing to the statistics. These skill scores are commonly used verification measures in weather and seasonal forecasting (Spillman et al. 2011).

6.3 Economic cost-benefit analysis

The third objective was to estimate the value of the forecasts to the salmon industry. If forecast information is used correctly, it should allow greater benefits when a good environmental year is identified early (and occurs), and reduce losses when a bad year is forecast (and occurs) (**Figure 5**).

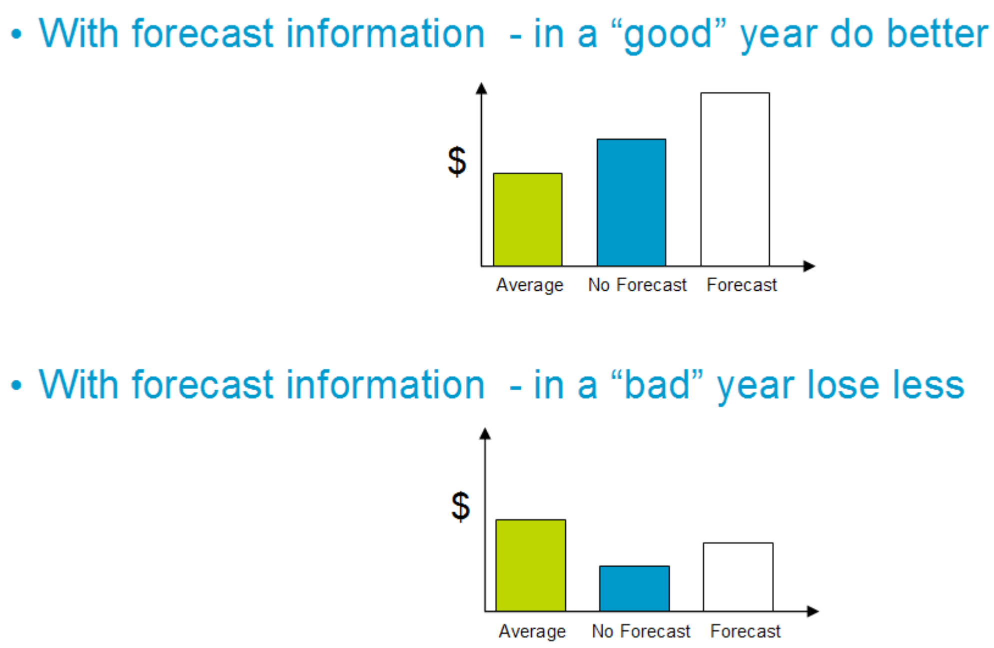


Figure 5. Economic return from using forecast information in a good year should be higher than the average year, and higher than without using a forecast. In a poor environment, the return may still be lower than the average, but will be higher than would have occurred if no forecast were available.

Given that a forecast may provide options for management, that will have different costs and benefits, we were interested in determining what value seasonal forecasts might bring to the salmon industry. The economic benefits and costs for different management strategies can be evaluated using a common tool: cost-benefit analysis (CBA).

Our goal in using CBA was to identify the suite of management options that would offer the greatest net economic benefit to the company. This method compares the long term net economic benefits (total costs plus benefits) of different management approaches. The option with the highest net economic benefit will be the preferred option.

There are several limitations and difficulties when using CBA (Norman-Lopez 2011), however, for this project, the relevant ones are;

1. The data required to produce a CBA can be costly and time-intensive: CBA is often costly and time-intensive if a full-scale analysis is required. A specific area can be analysed instead to reduce costs and time spent through careful consideration of the areas that are most likely to be substantial or particularly relevant to a particular issue – in this case the environment.
2. The quality of the results depend on the quality of the data: Inaccurate input data will bias to the results.

A generic cost-benefit model was developed for the salmon industry so that the economic effects of forecasted (and realised) changes in seasonal sea surface temperatures could be determined. A number of different scenarios and different farming locations in Tasmania were incorporated and additional scenarios providing for changes in market prices were also included. The scenarios included cases where the season would be warmer than usual, colder than usual and average. Thus, the forecasts would allow the famer to use the warm or cold scenario, rather then the average in planning the year. The weight of fish would be modelled using a logistic growth function, and projected changes in temperatures were expected to affect the time when the fish would be introduced in cages, the weight of fish at time t, the fish value and the time period to harvest the fish. Exogenous price changes were also expected to impact the value and the time period when fish would be harvested. The analysis was constructed in an excel spreadsheet where the farmers primary objective was assumed to be the maximisation of net present value at each rotation. Hence, fishers would harvest as soon as the salmon's relative weight was equal to the cost of waiting (the sum of the real interest rate, mortality of the fish, and the opportunity cost of not substituting the fish for younger faster growing fish). The relative advantage of being able to correctly select the warm and cold years can be derived, illustrating the benefits for the industry for using seasonal forecasts rather than expecting and planning based on an average year. An example of the data needed from salmon companies to complete this analysis is shown in **Table 1**.

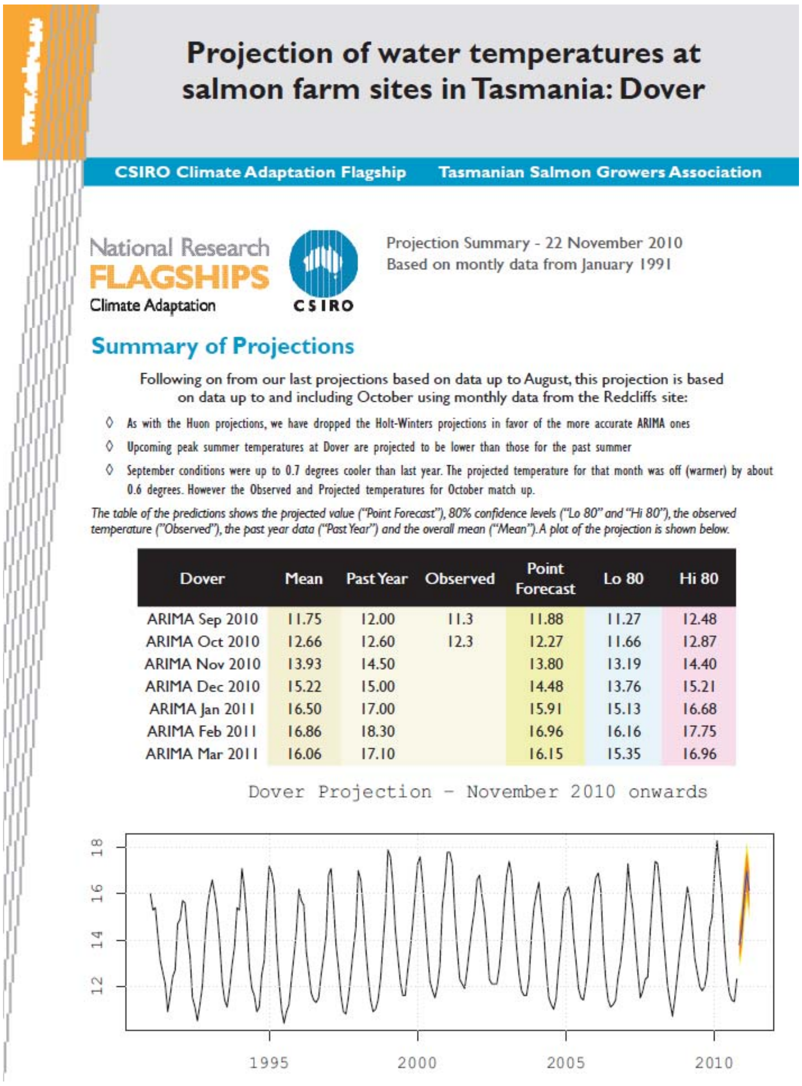
Table 1. Economic information required to complete the cost benefit analysis for salmon companies using seasonal forecasts.

Category of information	Information on costs/processes required for analysis	Additional information
Production cycle length and capacity of pens	Month of transfer of smolts from hatcheries into sea pens Length of time in sea pens Month of transfer of salmon into larger sea pens Length of time in larger sea pens before harvest Dimension and capacity of small and larger sea pens Initial number of fish in small and larger sea pens Target size before removing fish from small and large sea pens	
Smolts and larger fish operating expenses	Feeds (Different types of feeds, Quantity/day (kg), Cost($)/Tonne)	Time of year (e.g. month), SST, or other reasons, that lead to a switch between different feeds
	Bathing of fish (No of baths in different seasons, No of different workers per bath, Maintenance cost of bathing system)	Reasons for changing the bathing of fish seasonally
	Net management (biofouling) (cleaning boats used in different seasons, No of different workers/bath and season, maintenance and operating costs of onshore cleaning facilities)	Impacts from biofouling from changes in SST
	Fallowing (distance travelled/week, fuel costs/week, No of different workers)	Changes in fallowing in different seasons
Other operating expenses	Fuel and oil, repairs and maintenance, electricity, water supply or pumping licenses, aquaculture licenses, chemicals(cleaning,medical), insurance, other costs	
Capital items	Land and building facilities Boats bathing system, Automated feeder, Net washer, Others Smolt and larger pens (floating cages, inner and outer nets, lighting, other) Other infrastructure(generators, pumps, harvesting and diving equipment, workshop tools and equipment)	Information required for each of the capital items specified (Total Cost, Year of Purchase, Life (Years), Salvage value)

7. Results and Discussion

7.1 Statistical forecasts

The first and most important objective of this project was met. Seasonal forecasts of water temperature at the farms were delivered for four sites (instead of the agreed three sites) for the months of September 2010 to March 2011. These were based on the statistical time series approach forecast approach (**Section 6)**, and an example is provided in **Figure 6**, and all forecasts are attached as **Appendix 5**. Each forecast was emailed to the participating companies, and the single page provided information for the months ahead, as well as the previous year, the long-term average and the observations for the year to date.



Projection of water temperatures at salmon farm sites in Tasmania: Dover

CSIRO Climate Adaptation Flagship   Tasmanian Salmon Growers Association

National Research FLAGSHIPS Climate Adaptation   CSIRO

Projection Summary - 22 November 2010
Based on montly data from January 1991

Summary of Projections

Following on from our last projections based on data up to August, this projection is based on data up to and including October using monthly data from the Redcliffs site:

- As with the Huon projections, we have dropped the Holt-Winters projections in favor of the more accurate ARIMA ones
- Upcoming peak summer temperatures at Dover are projected to be lower than those for the past summer
- September conditions were up to 0.7 degrees cooler than last year. The projected temperature for that month was off (warmer) by about 0.6 degrees. However the Observed and Projected temperatures for October match up.

The table of the predictions shows the projected value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). A plot of the projection is shown below.

Dover	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80
ARIMA Sep 2010	11.75	12.00	11.3	11.88	11.27	12.48
ARIMA Oct 2010	12.66	12.60	12.3	12.27	11.66	12.87
ARIMA Nov 2010	13.93	14.50		13.80	13.19	14.40
ARIMA Dec 2010	15.22	15.00		14.48	13.76	15.21
ARIMA Jan 2011	16.50	17.00		15.91	15.13	16.68
ARIMA Feb 2011	16.86	18.30		16.96	16.16	17.75
ARIMA Mar 2011	16.06	17.10		16.15	15.35	16.96

Figure 6. An example forecast issued for November 2010 for the site at Dover (Redcliffs). The point forecast is the estimate from the statistical model, while the observed value shows the performance of previous forecasts.

The skill of the statistical forecasts for the period September 2010 to March 2011 varied between sites (**Figure 7**). It was a cooler than average year, and so the forecasts were all generally predicting a cooler year, as was observed. The skill was highest for the Tasman site, with all forecasts matched with corresponding observation months agreeing in sign (cooler than average forecasts were in agreement with cooler than average observations) (**Table 2)**. The agreement was 87% for Dover, followed by 80% for Huon and 60% for Macquarie Harbour. These relative rankings were also reflected in the accuracy of the forecasts, with over all lead times, the Tasman forecasts were an average of only 0.28°C from the observed value in the corresponding month, while for Macquarie Harbour, forecasts were on average different by 0.62°C (**Table 2)**. Dover and Huon were an average of 0.30°C and 45°C from the observed temperatures. The differences were greatest at long lead times (3-4 months), and least at the 1 month lead time.

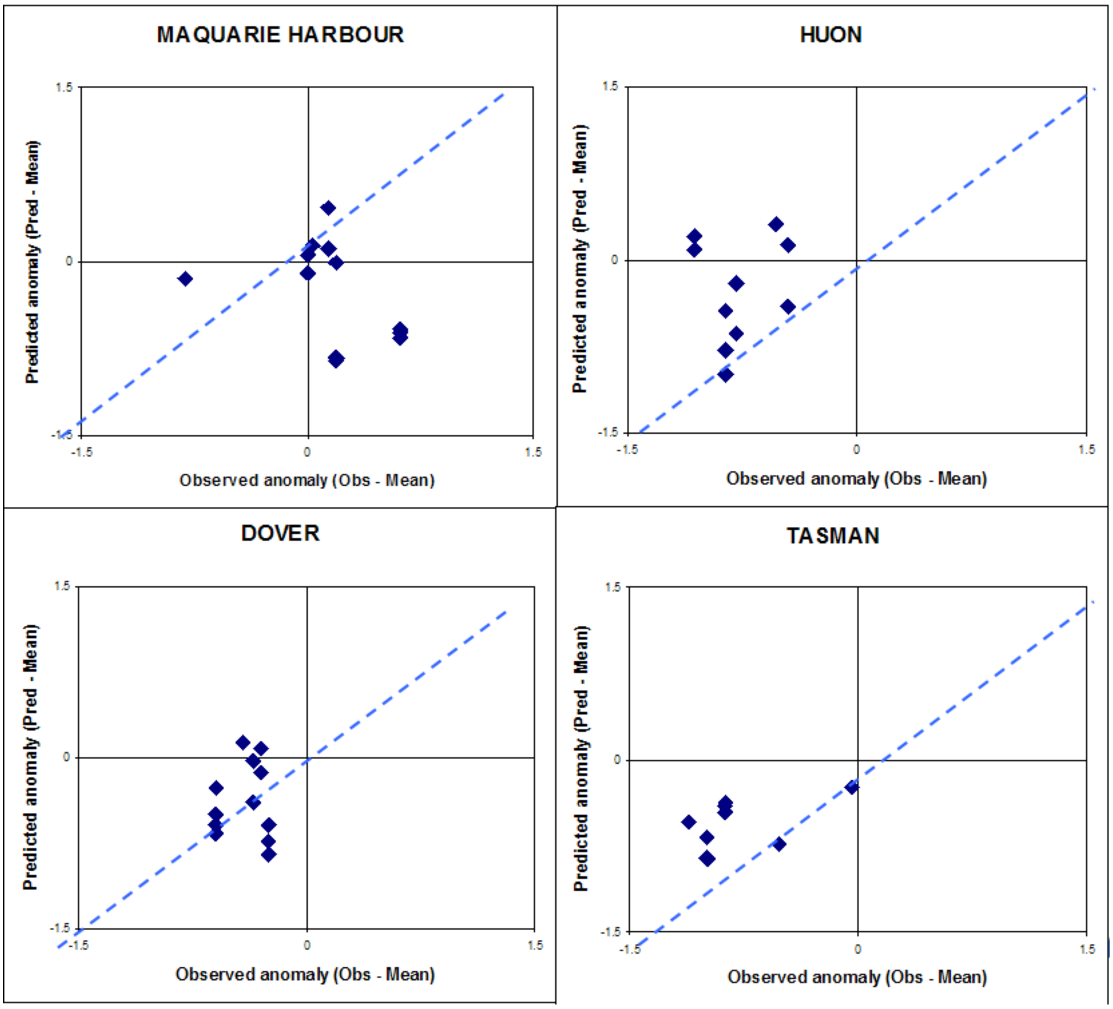


Figure 7. Skill plots for the forecasts delivered in this project for the months September 2010 to March 2011, for the four sites, at all lead times.

Table 2. Skill and accuracy of forecasts for the period September 2010 and March 2011, for all lead times.

Site	Skill (%)	Average difference between forecast and observed temperature (°C)
Dover	87	0.30
Huon	80	0.45
Macquarie Harbour	60	0.62
Tasman	100	0.28

The skill of the statistical forecasts based on historical reanalysis (i.e. using data from previous years to predict each month in previous years) showed the similar variation between sites. For example, at a lead time of one month the skill for Huon is better forecasting one month ahead to December (i.e. a forecast in November for December) than in September, as indicated by the scatter of points (**Figure 8**). At a lead time of one month for the Tasman site, skill was good for most months, and particularly for February (**Figure 9).** At Macquarie Harbour site, which has the least years of data (2006-2010) the skill is poor in all months (**Figure 10).** At Dover skill is good in all months, and actually highest in winter months (**Figure 11).**

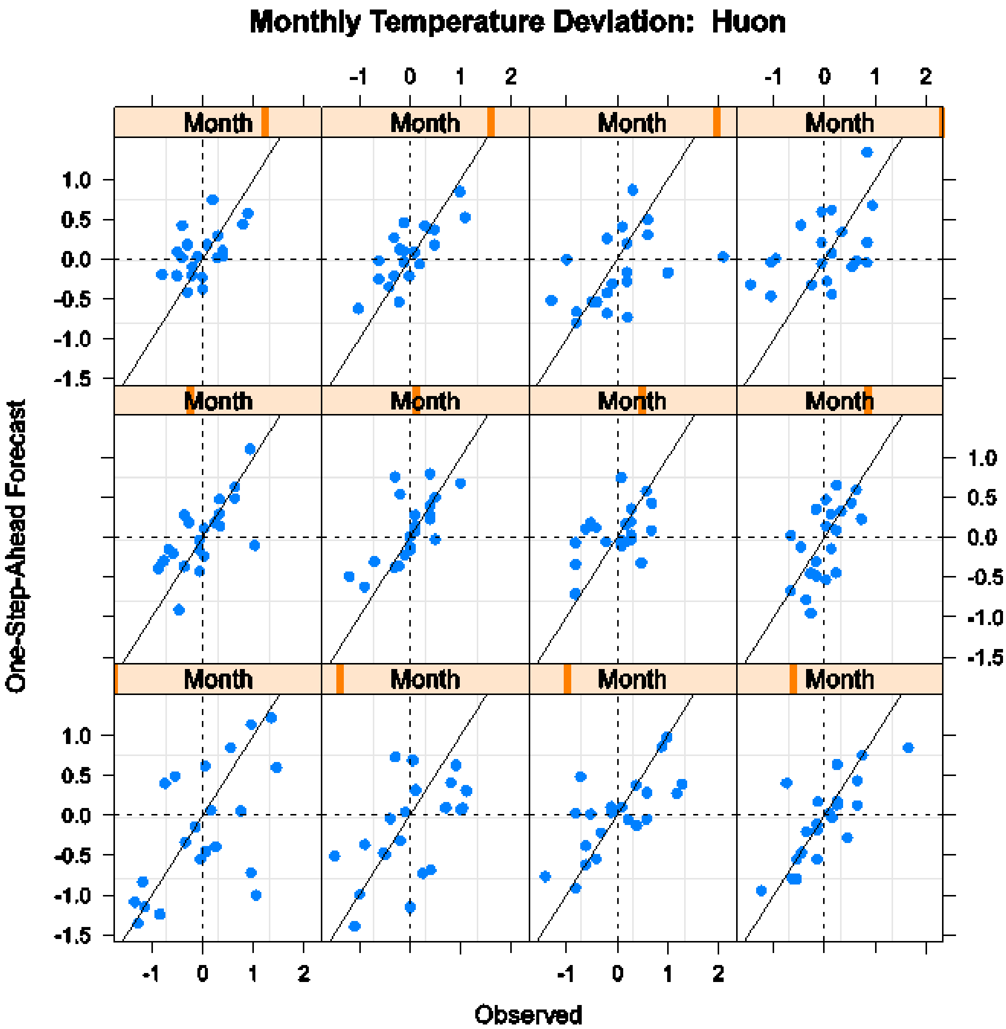


Figure 8. Hindcast skill plots for 1 month lead time forecasts for each month of the year for the Huon site. The subplots correspond to January in the upper left, and December in the lower right.

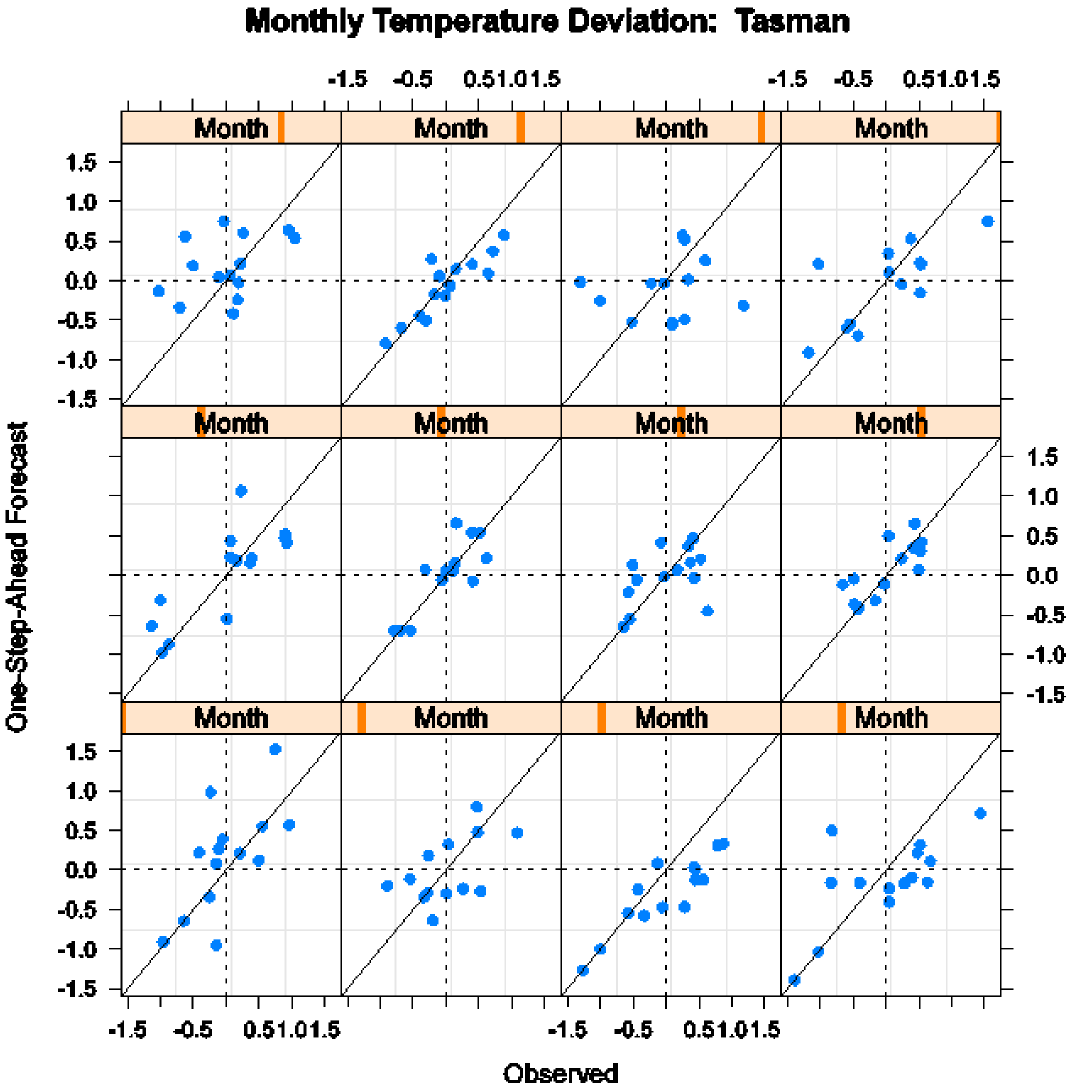


Figure 9. Hindcast skill plots for 1 month lead time forecasts for each month of the year for the Tasman site. The subplots correspond to January in the upper left, and December in the lower right.

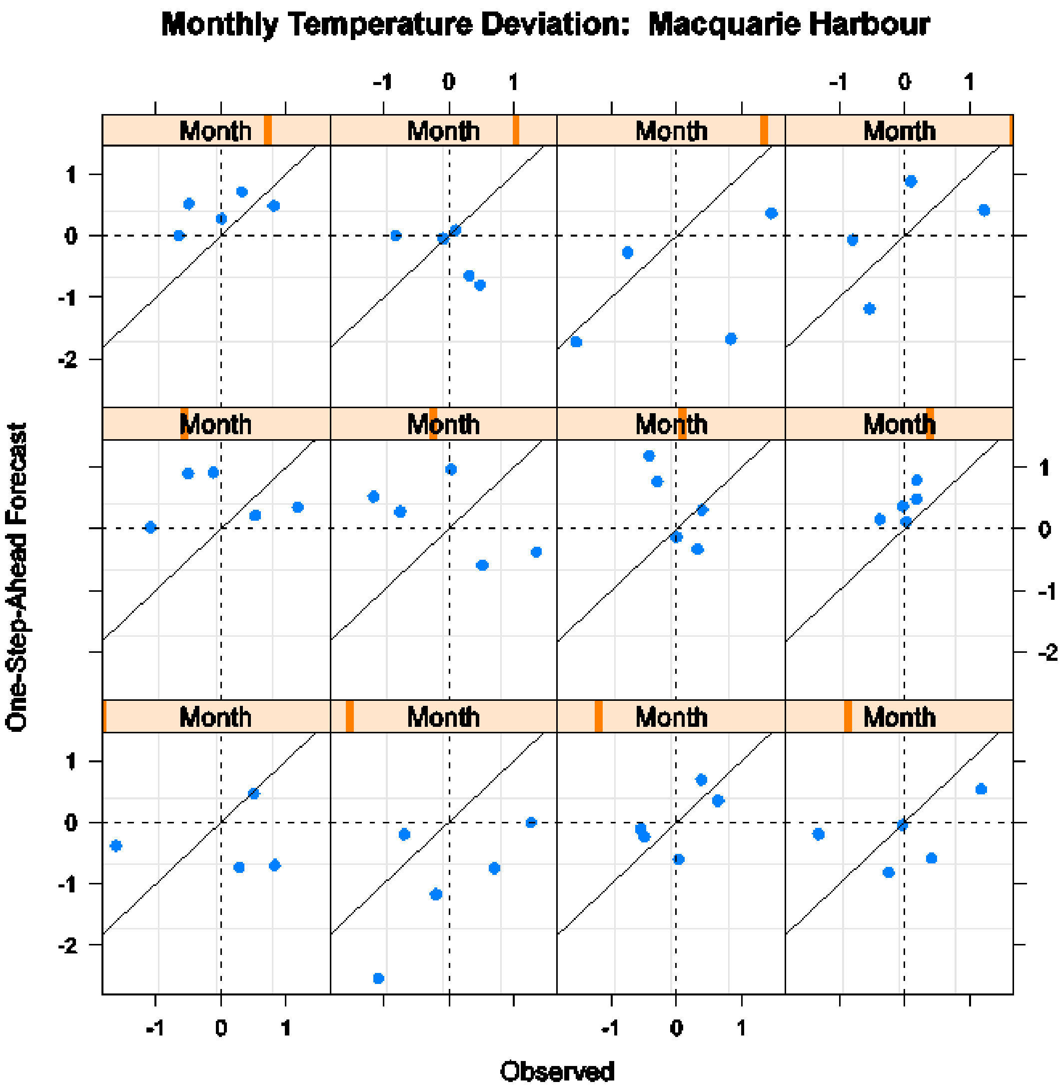


Figure 10. Hindcast skill plots for 1 month lead time forecasts for each month of the year for the Macquarie Harbour site. The subplots correspond to January in the upper left, and December in the lower right.

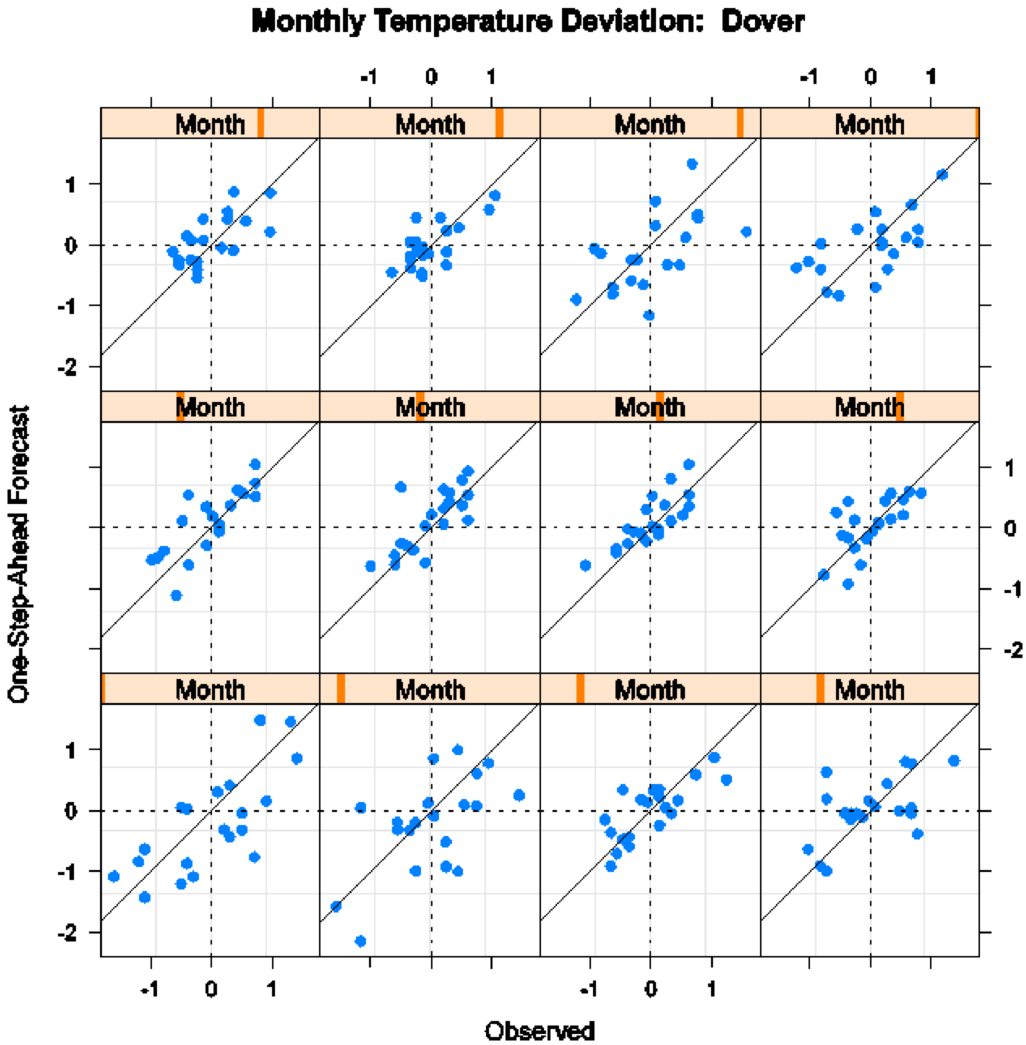


Figure 11. Hindcast skill plots for 1 month lead time forecasts for each month of the year for the Dover (Redcliff) site. The subplots correspond to January in the upper left, and December in the lower right.

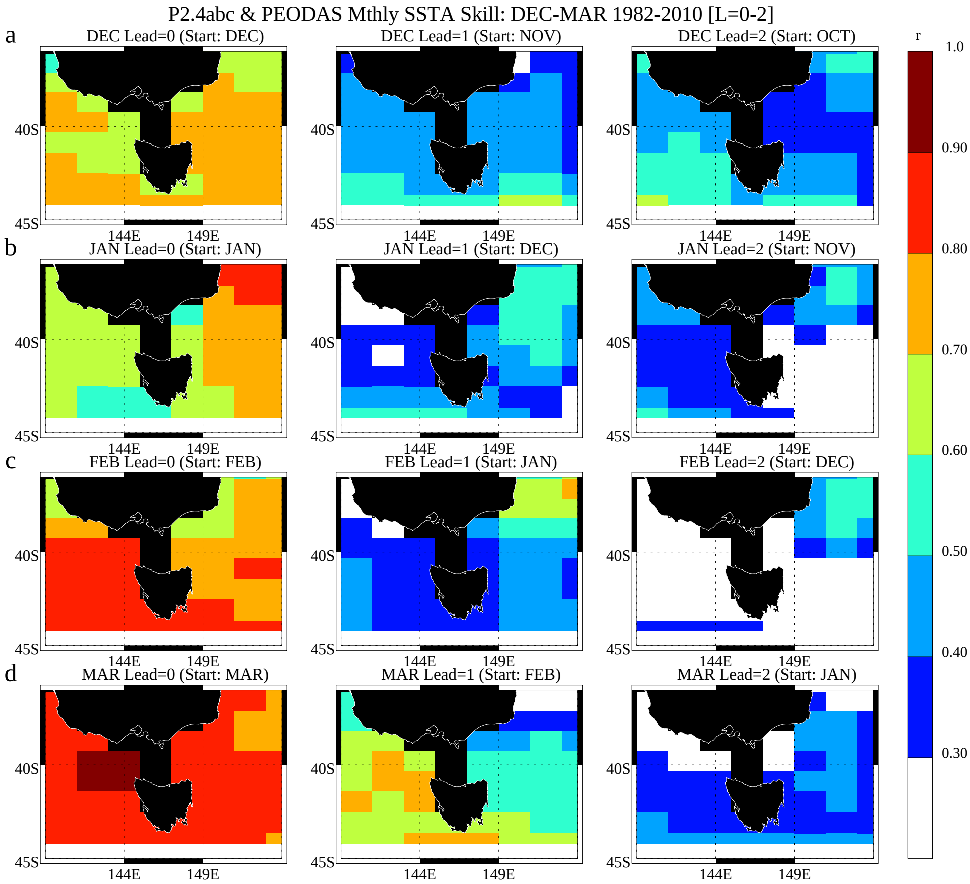
Overall, the statistical approaches can provide useful forecasts for three of the four sites, despite the limitations in the specific tools, which include constant seasonal patterns, and failure to deal with anomalous months. Dynamical models offer the prospect of overcoming these issues, and we present results in the next section.

7.2 Dynamical forecasts

Regional Model Skill

POAMA SSTA forecasts around Tasmania generally show good skill for up to three months into the future, during both summer and winter months. Correlations of monthly model forecasts of SSTA with observations for 1991-2010 around Tasmania are shown in **Figure 12**. The model has highest skill for all summer months at leadtime 0 months (e.g. forecast for December issued on 1 December) and is highest for the three month period NDJ

(November, December, January) and FMA (February-March-April). Forecast skill decays with leadtime and is lower at lead times of 2 months (e.g. forecast for December issued on 1 October), particularly for February. Model skill in the cooler months (June, July, August, September) is useful and higher at all lead-times than during the summer months.



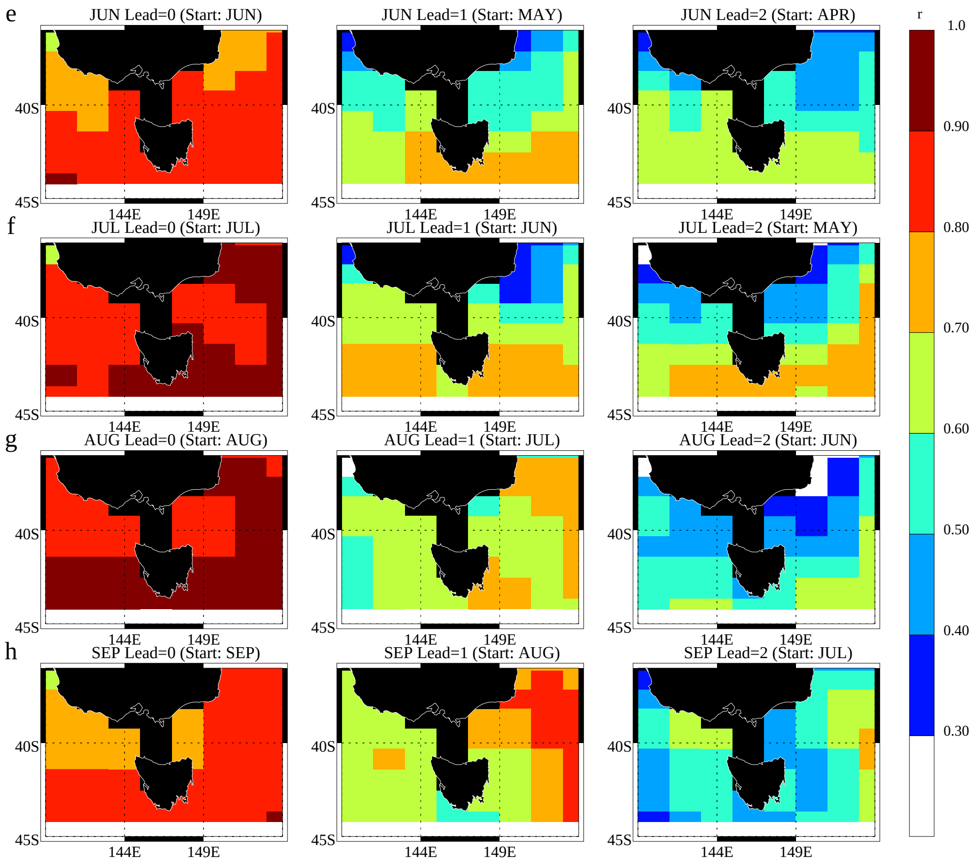


Figure 12. Correlations between monthly mean POAMA SSTA forecasts and PEODAS around Tasmania for summer months (a) December, (b) January, (c) February, (d) March and winter months (e) June), (f) July, (g) August and (f) September 1991-2010 at 0, 1 and 2 month lead-times.

Farm forecast skill

Measured sea surface temperature anomaly (SSTA) values at the two farm sites and the observed regional Tasmanian SSTA index (ITAS) were strongly correlated for 1991-2010, with r = 0.76 and r = 0.83 for Huon and Dover, respectively (**Figure 13**).

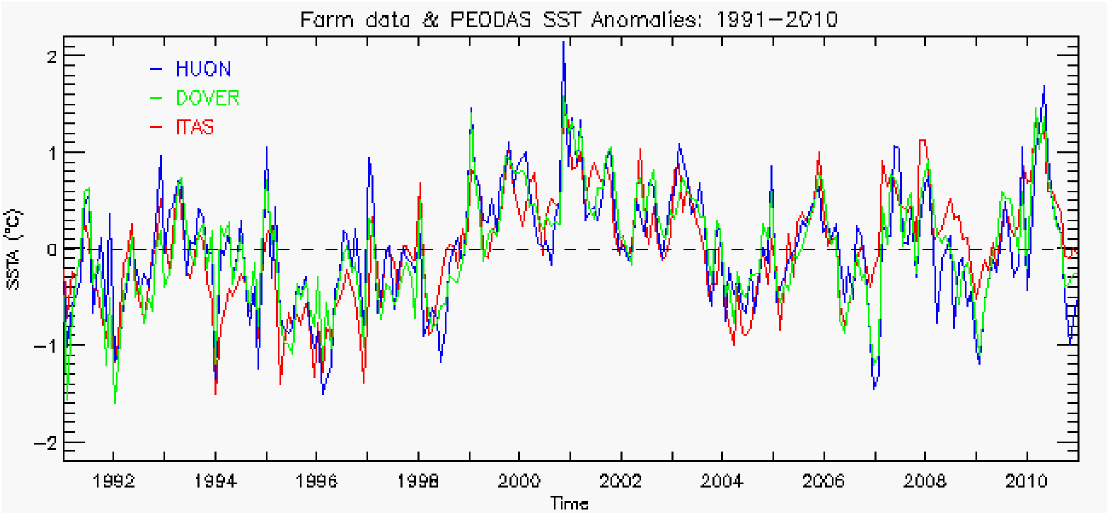


Figure 13. Monthly SSTA values for the Huon and Dover farms, together with ITAS values derived using PEODAS, for 1991-2010.

The high observed correlations between the regional index and the farm data indicates that the index is a useful predictor of farm water conditions. Forecasts skill for the index was then calculated to see whether POAMA could predict ITAS, and thus SSTA at Huon and Dover farms. Model skill in predicting ITAS using PEODAS as observations is shown in **Figure 14** for all months in the full hindcast set (1982-2010).

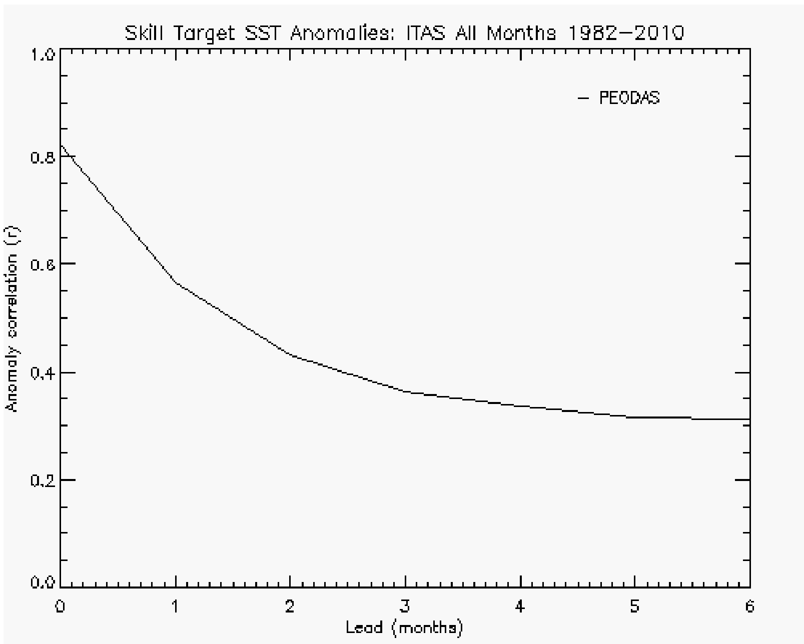


Figure 14. Skill of POAMA predictions for ITAS (ensemble mean) for all months 1982-2010 at lead-times of 0-6 months.

The model demonstrates useful skill up to lead-times of 1-2 months throughout the year. The forecast skill for ITAS, coupled with the observed relationship between ITAS and the farm locations, would result in a lower skill in predicting conditions at the farm sites. However these results still show the model has useful skill in predicting farm temperatures within the upcoming season e.g. a forecast could be skilful for December when issued 1 October.

Thus, dynamic models can be used to forecast for inshore regions, and in future years will complement the statistical approaches developed (see **Section 9, Further Development).** To generate predictions of absolute temperatures for each farm, model sea surface temperature anomaly (SSTA) values can be added to the derived farm climatologies, resulting in numbers comparable to the statistical forecasting methods.

7.3 Economic cost-benefit analysis

A generic cost-benefit model was developed, and discussed with companies at the information session on the project. Despite initial agreement, the economic data to populate the model and explore the adaptation options has not been forth coming from the salmon companies. As such, this objective, funded by CSIRO, was not achieved. Confidentiality and cooperation was agreed, however, and so we hope to pursue this further in future.

8. Benefits

The salmon companies are the direct beneficiaries of this research – it was commissioned to deliver forecasts for surface water temperatures for the coming months, and we delivered these forecasts, along with estimates of accuracy.

The component of the project (Objective 3) to determine the cost-benefit of the forecasts has not proceeded as planned, in part due to the commercial nature of the economic information needed to determine the value. We continue to pursue this analysis, but expect the value to far outweigh the cost. Anecdotal feedback from the companies suggests that the potential value of wise use of a forecast could be in the order of A$1-2 million per year per company.

9. Further Development

Operational forecasts based on the statistical and dynamic approaches can now be delivered to farm sites in the south-east of Tasmania for ongoing years. Our ability to forecast water temperatures at Macquarie Harbour was less impressive, and without further R&D to also include tidal flushing, wind mixing, freshwater inputs, and air temperature influences, will be of limited value as currently projected. It may be useful to couple the forecasting with the industry-commissioned Macquarie Harbour hydrodynamic model to further understand the physical drivers. Operational forecasts can be delivered for the south-east of Tasmania, based on methods developed in this project. We should also note that with more time and effort we can investigate potentially more robust projection approaches - which will be a part of ongoing CSIRO investment in this area.

In future years, we will also work to deliver ensemble forecasts which can be used as a measure of confidence in projections (**Figure 15).**

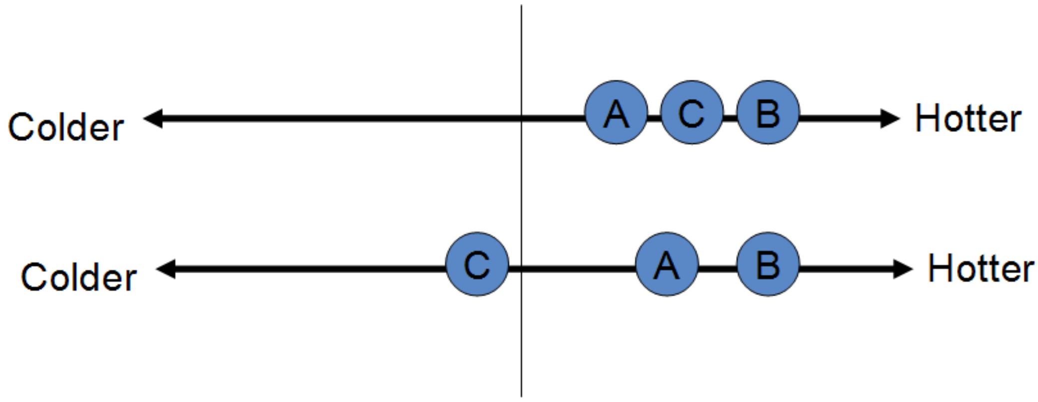


Figure 15. An example of multiple forecasts. In the upper case, the three forecasting methods have all suggested that the future period will be hotter than normal, with method B indicating the warmest period. In the lower case, method C forecasts cooler conditions, while methods A and B forecast a warmer period.

Given the planned salmon expansion in Macquarie Harbour, development of successful seasonal forecast methods in this region may be important in the near future. This will require additional research effort to determine the predictive capability based on a combination of water and air temperatures, and rainfall/stream flow. This would be a considerable challenge, and may not yield improved results, as forecasting rainfall and air temperature at seasonal scales is extremely difficult.

It is important to note that seasonal forecasts are not always correct; a warmer January may be forecast the previous October, but a colder one may eventuate. Measures of skill, such as forecasts are correct in projecting above average conditions in 9 out of 10 years are useful measures of forecast quality. Determining the pay-off time for following the forecasts may be an important consideration, and should be determined in the coming years, as a decision support tool (Peter McIntosh et al. unpublished paper: seasonal forecasting for agriculture).

Finally, exploratory analyses also suggest that statistical forecasts for longer time periods (1-2 years) might be possible given the long term cycles in the southern hemisphere. This could be pursued in future depending on industry interest.

10. Planned outcomes

Monthly site-specific projections were delivered to companies from Sept 2010 to March 2011. The forecasts delivered to salmon companies allowed farm-based decision making to account for expected temperatures in the months ahead.

It is expected that companies with the ability to plan for the future and modify their decisions based on environmental information will consider using forecasts as part of their standard operation procedure.

Advice from the Tasmanian Salmonid Growers Association (May 23, 2011) regarding continued central funding for these forecasts is that:

- Industry agreed that any further investment into seasonal forecasting should be undertaken as a commercial contract between CSIRO and interested companies.

- Thus, Industry agreed that this activity should be approached as a consultancy not R&D.

We are now in the process of planning for forecast delivery for the coming years with individual companies.

This project attracted considerable attention during the year. A press release around the time of the CRRSPI conference (Feb 2011) generated media interest and community profile for the salmon industry. This was pre-approved by Peter Horvat (FRDC) and the salmon companies ahead of time. Presentations on the forecasting aspects of the project have been made at a number of conferences, and generated considerable interest:

- CCRSPI Conference 2011 (Melbourne, Feb, 2011)
- Australian Seafood Industry and Climate Change Symposium (Brisbane, March 2011)
- Australian Marine Sciences Association Annual Conference (Perth, July 2011)
- Australian Prawn and Barramundi Farmers annual meeting (Sydney, August 2011)

Extension of these forecasting approaches to other aquaculture industries (e.g. prawn) is also in the planning phase, and we expect that many forward thinking businesses will soon consider seasonal forecasts as essential as weather forecasting. At the time of writing, a proposal to develop seasonal forecasting for the tropical prawn aquaculture industry has just been funded.

11. Conclusion

The objectives of the project were met from the perspective of the salmon companies, in that forecast method was developed, and forecasts were delivered for four sites every month between September 2010 and March 2011. These forecasts were one-page summaries, emailed to the company representatives each month.

The selected method for delivery of forecasts was based on a statistical time series approach, which showed good skill for the three south-east Tasmania sites, and poorer performance for the Macquarie Harbour site. This should lend confidence for continued use of ocean forecasts in south-east Tasmania.

This project was designed to compare several forecasting methods. Each approach has its own advantages and disadvantages. Statistical methods are computationally simpler, but forecasting skill can be weaker due to climate-related trends in both predictors and predicted climate elements. The dynamical approach is potentially the best tool for making seasonal predictions as it simulates the physical relationships that make each year's seasonal conditions unique. Dynamic approaches also (in principle) have the ability to cope with changes in variables as climate change occurs. The major disadvantage is that they require complex computational methods and resources, and remain sensitive to errors in the initial conditions for calculation. Using an operational climate forecasting model (POAMA) overcomes this disadvantage from the perspective of the industry, as constant improvement to the model is being undertaken by the BOM.

In future, forecasts from both statistical and dynamical approaches can be delivered to the salmon industry, and the skill of each model compared, before the user makes a decision to modify a decision based on the forecasts.

The project also intended to estimate the value of these forecasts to the industry; however, this element was not completed and the value cannot be determined at this time. Individual companies may choose to undertake their own value analysis.

Overall, this project completed the method development and delivery of seasonal forecasts for surface water temperature forecasts for the salmon industry, at lead times of up to four months. These forecasts provide an unprecedented opportunity for the managers of the farm sites to adjust their plans and strategies based on anticipated future environmental conditions.

12. References

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13. Appendix 1: IP

The IP arising from this project is the property of CSIRO and the BOM. The FRDC TRF funded component was for delivery of forecasts (**Objective 1)**. This report is suitable for public distribution.

14. Appendix 2: Staff engaged on the project

CSIRO staff engaged on the project

Alistair Hobday

Vincent Lyne

Ron Thresher

Donna Hayes

Ana Norman-Lopez

BOM staff engaged on the project

Claire Spillman

15. Appendix 3: Simple statistical relations

Preliminary statistical analysis of temperature variability at the Southern Tasmanian salmon farms sites

Ron E. Thresher

Introduction

In 2003, V. Lyne and R. Thresher undertook a brief consultancy with Tassal to determine if the high summer temperatures then being recorded at the salmon farms would continue, and if peak summer temperatures could be predicted from either or both a combination of oceanographic and farm data. The project developed along two lines: Lyne examined the larger scale oceanographic settings, and in particular the role of episodic warming due to poleward extension of the East Australian Current (EAC) down the east coast of Tasmania on temperatures experienced at the fish farms, and Thresher focussed more on the farm data themselves, to determine if there was any internal consistency and inertia to the temperatures that could be used to forecast summer peaks.

Statistical analysis of the farm data, though sparse for most sites, indicated

1. temperatures tended to peak in February, and there was a strong correlation between annual degree days experienced at a farm and the mean February water temperature at that farm;
2. regression analyses showed a correlation between summer peak (February) temperatures and those the preceding September, essentially late winter/early spring; and
3. the predictability of the September water temperatures was greatly enhanced if odd and even numbered years were treated separately. For both odd and even years, the regressions between September and following February temperatures were almost straight lines, suggesting a predictability of summer peak temperatures from those in early spring to within a fraction of a degree.

Discussions with industry suggested there was no operational reason why the odd and even numbered years differed, nor did the alternation fit unambiguously with well-known biennial atmospheric variability (the Quasi-Biennial Oscillation). In the end, it was suggested that the difference between groups of years might relate to alternating effects of a warm EAC and a cold Zeehan Current influence, the interface of which is near the Huon farm sites. Alternatively, the apparent pattern, though statistically very strong, could have been an artefact of the less than 20 years of total data then available, and hence simply due to chance.

This sub-project re-examines the farm data, now up-dated to 2010, and tests the robustness of the early spring predictor of peak summer temperatures.

Data sources

Temperature data at the farms were provided in Excel format by Tassal, and reflect temperatures recorded daily at a depth of 5 m.

Maria Island temperature and salinity records were provided by Dr. Ken Ridgway (CSIRO MAR). Temperatures at Rottnest Island were courtesy of Dr. Ming Feng (CSIRO MAR); gaps in the record were filled by interpolation by V. Lyne. Air temperature and rainfall records for Hobart are from the Australian Bureau of Meteorology (Hobart Monthly Climate Bulletins).

1. Regional coherence of the temperature data

Long-term data are available from 4 sites: Nubeena, Huon, Dover and Macquarie Harbour. Inter-annual differences among sites in winter (July) and early summer (December) temperatures are compared in Figure 1. December was used in this analysis, rather than February, because February data have not been collected in recent years at Huon.

The time series are too short (particularly Macquarie Harbour) to justify a clustering or some other statistically based grouping analysis, but it is clear from examining the data that there are strong similarities among sites in their patterns of summer and winter temperatures. December temperatures are strongly correlated among all four sites, including Macquarie Harbour. The pattern of inter-annual differences in July temperatures is similar for Huon, Dover and Macquarie Harbour, but slightly different for Nubeena. The data suggests that in a cluster analysis, the two SE and the west coast site would group tightly, whereas Nubeena would be similar, but a slight outlier.

The conclusion reached from this analysis is that temperature variability at these sites is dominated by a large scale, regional signal, on to which is superimposed local variability. The average correlation among sites in December accounts for 58.5% of the inter-annual variability, suggesting that local effects and measurement error account for the remaining 41% of the signal; in July, the regional signal accounts for 38.8% of the variance, the bulk being local effects and/or error.

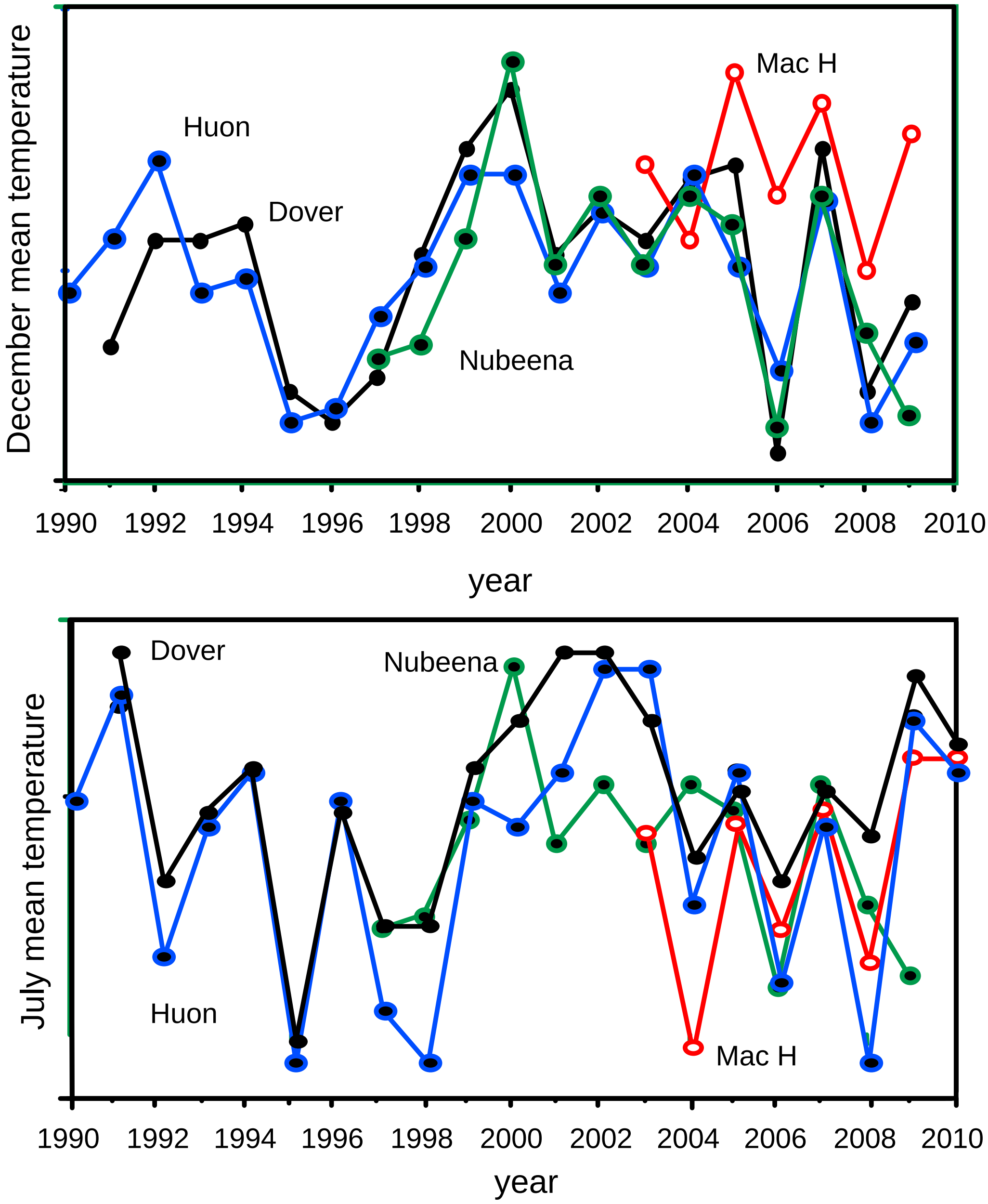

Figure 1. Comparison of year-to-year differences in winter (July) and early summer (December) temperatures at farm sites in Nubeena, Huon, Dover and Macquarie Harbour.

2. Comparison of regional signal with long-term oceanographic and climate signals

In the earlier analysis, Lyne and Thresher speculated that inter-annual variability in farm temperatures resulted at least in part from shifts in water masses around Tasmania, and in particular the extent to which the warm EAC extended southwards along the east coast of Tasmania.

To test this idea further, I compare summer peak (February) temperatures in Dover, the site for which we have to longest February time series, to inter-annual differences in water temperatures at the CSIRO Maria Island monitoring station, temperatures at the Rottnest Island monitoring station off Western Australia, and a local climate signal – air temperatures at Hobart. Maria Island temperatures correlate with poleward extent of the EAC; Rottnest temperatures similarly correlate with the strength of the Leeuwhin Current, which is the source of the cold Zeehan Current that affects SW Tasmania.

Correspondence between the Huon/Dover February temperatures and February temperatures at Maria Island, Rottnest and the February mean air temperature in Hobart are shown in Figs 2-4. The Dover peak water temperatures tend to correlate with water temperatures at Maria Island ($r = 0.48$, $n = 16$ years, $p = 0.059$) and Rottnest ($r = 0.53$, $n = 14$ years, $p = 0.053$), but correlate by far most strongly with Hobart air temperatures ($r = 0.83$, $n = 18$ years, $p < 0.0001$)(Figure 5). The apparent influence of the MI temperatures on Dover can perhaps be explained by a weak correspondence between Hobart February air temperatures and the MI February water temperatures ($r = 0.29$, $n = 40$ years, $p = 0.74$). The correlation between Hobart air temperatures and Rottnest temperatures are wholly non-significant ($r = 0.07$, NS). There is a weak suggestion (Figure 2) that the MI signal has a stronger influence on peak summer temperatures at Nubeena than it does on other sites.

Graphic analysis indicates that the relationship between Maria Island and Rottnest Island temperatures, on the one hand, and those in February at the Dover farm site, on the other, is strongest if the comparison is based on February oceanographic data, i.e., there is no indication that the Dover temperatures are a lagged response to temperature variability earlier in the year.

The data suggest that 1) predicting summer water temperatures at Dover, and regionally, is tantamount to predicting Hobart summer mean air temperatures, and 2) the effects of regional oceanographic features, such as the Zeehan Current and the EAC, are secondary to atmospheric effects. Figure 5 implies that if you could forecast Hobart February air temperatures accurately, then you could further predict, to about 0.5ºC accuracy, summer peak water temperatures at the farms.

Hobart February rainfall does not correlate with February water temperatures at Dover, not does it contribute significantly to the regression against Hobart air temperature when included using multiple regression.

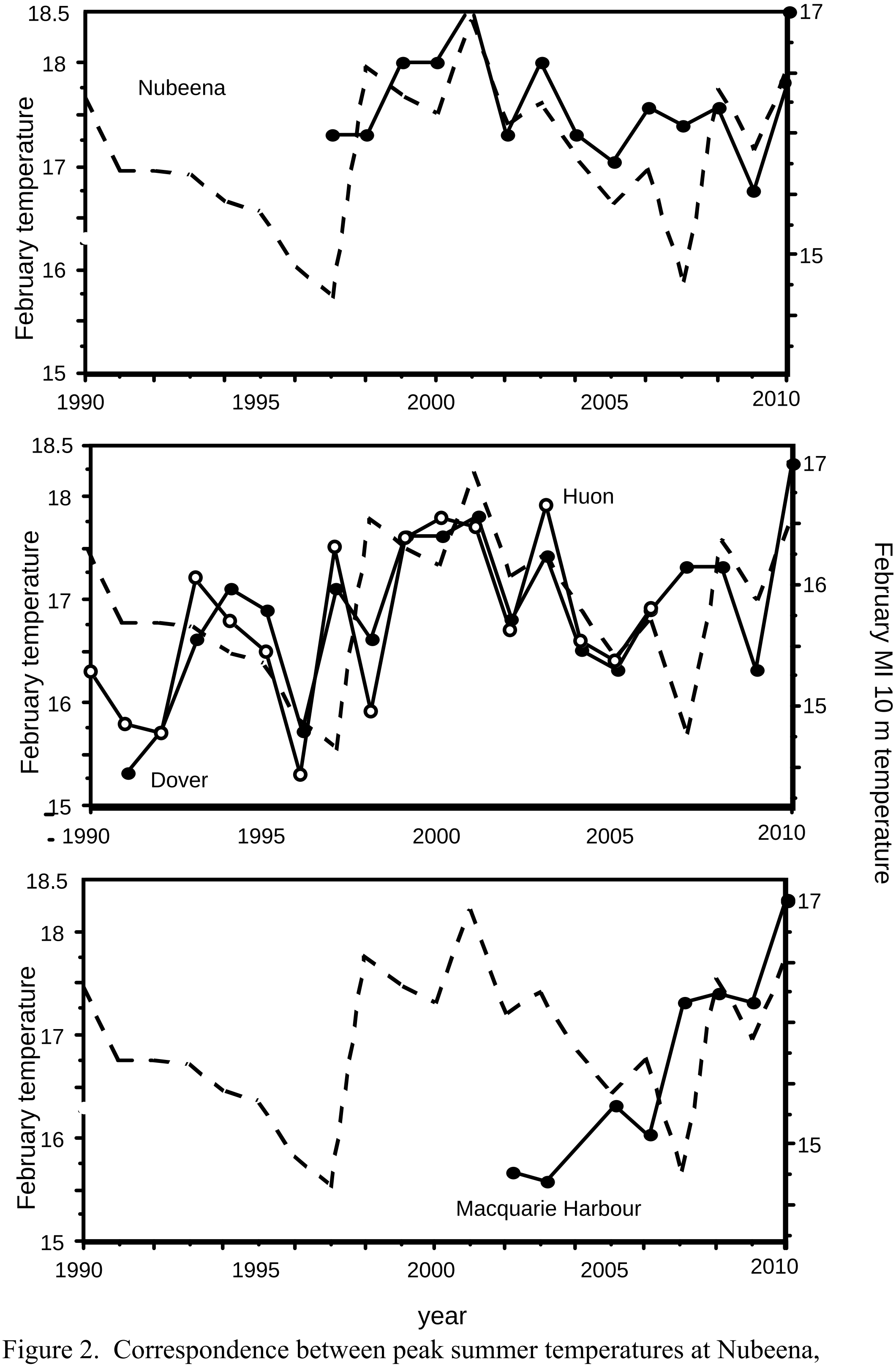

Figure 2. Correspondence between peak summer temperatures at Nubeena, Dover/Huon and Macquarie Harbour and summer (February) temperature at the Maria Island monitoring station (dashed lines).

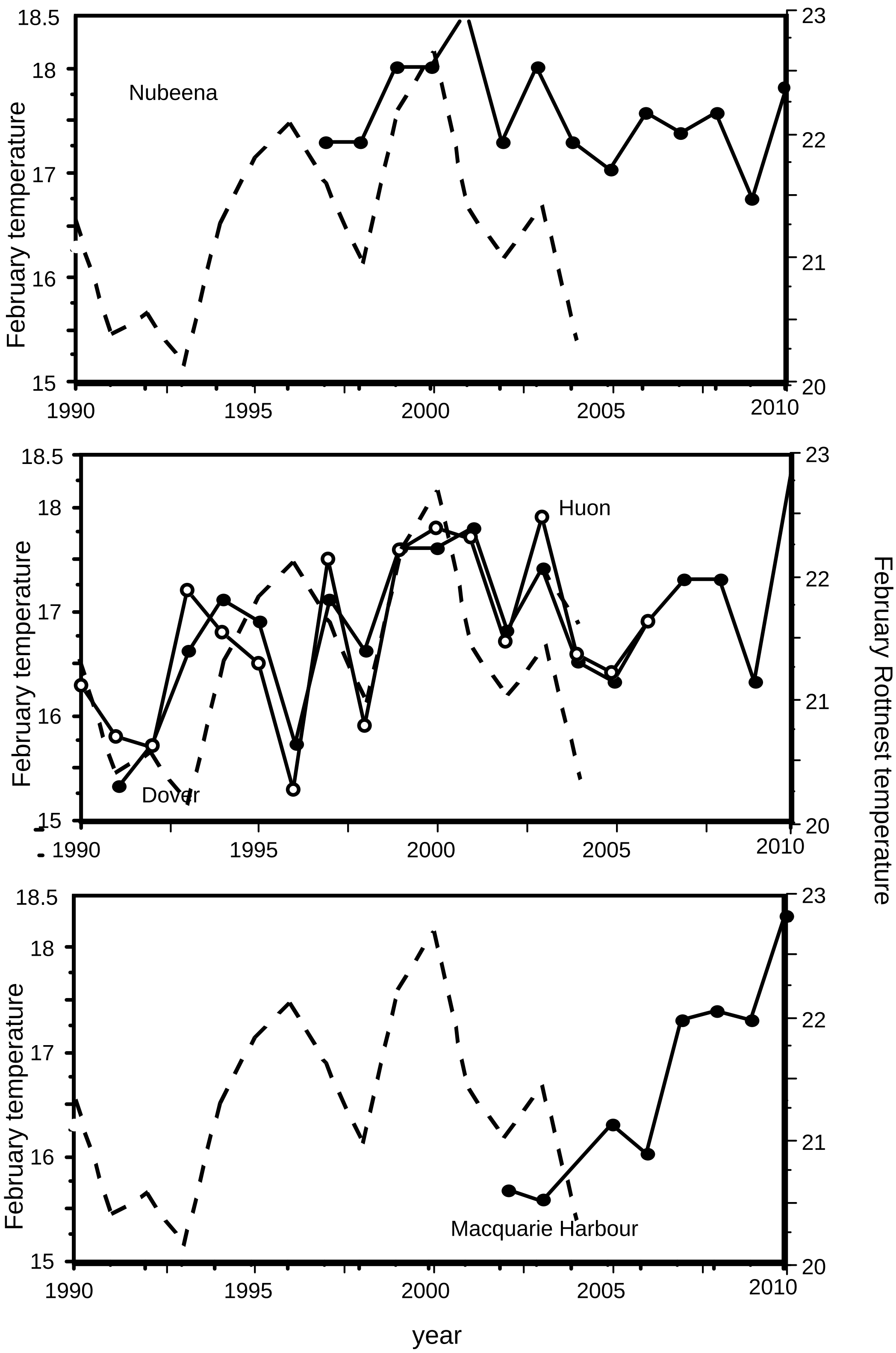

Figure 3. Correspondence between peak summer temperatures at Nubeena, Dover/Huon and Macquarie Harbour and summer (February) temperature at the Rottnest Island monitoring station (dashed lines).

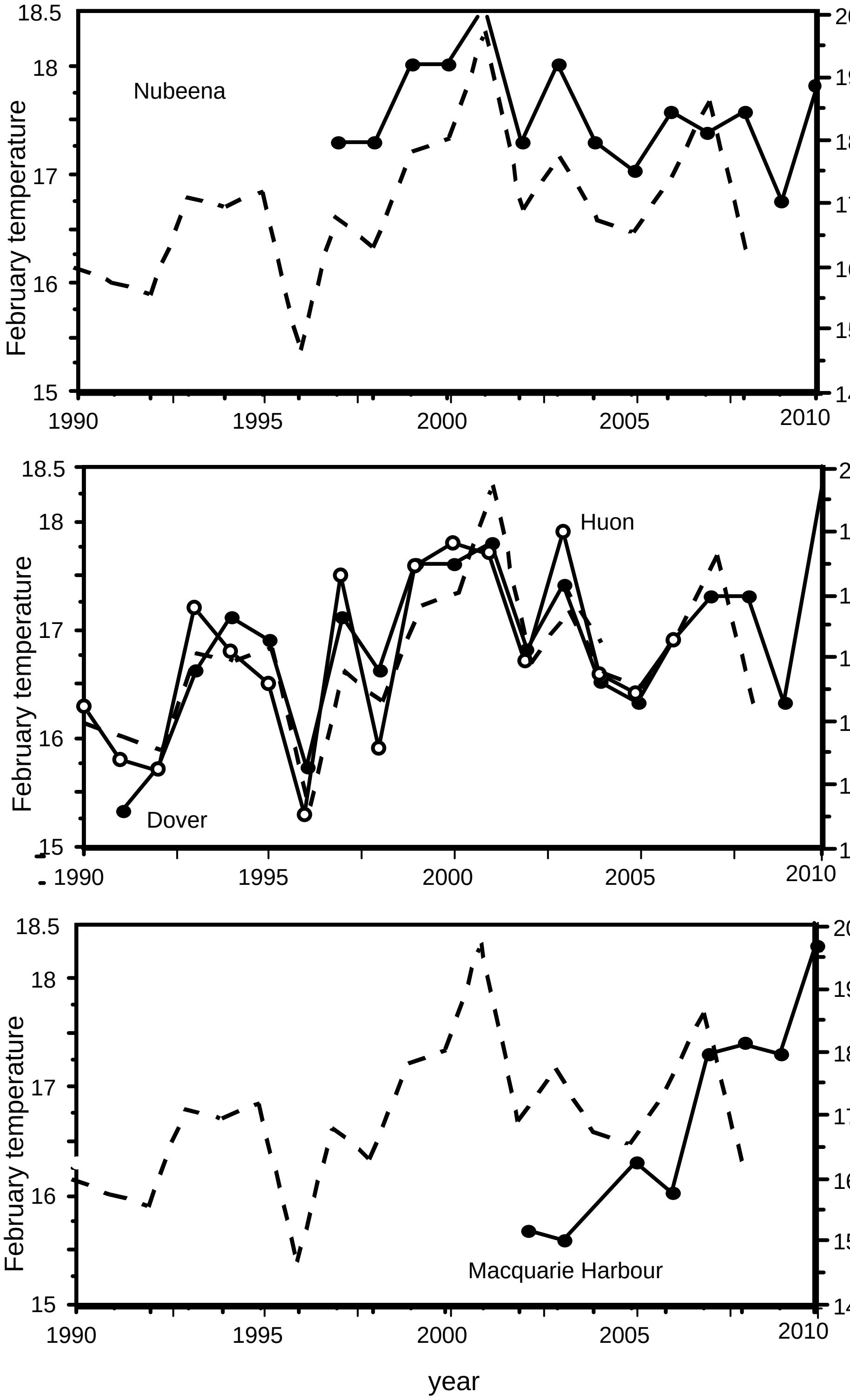

Figure 4. Correspondence between peak summer temperatures at Nubeena, Dover/Huon and Macquarie Harbour and summer (February) monthly mean air temperature at Hobart (dashed lines). Air temperatures from published BOM records.

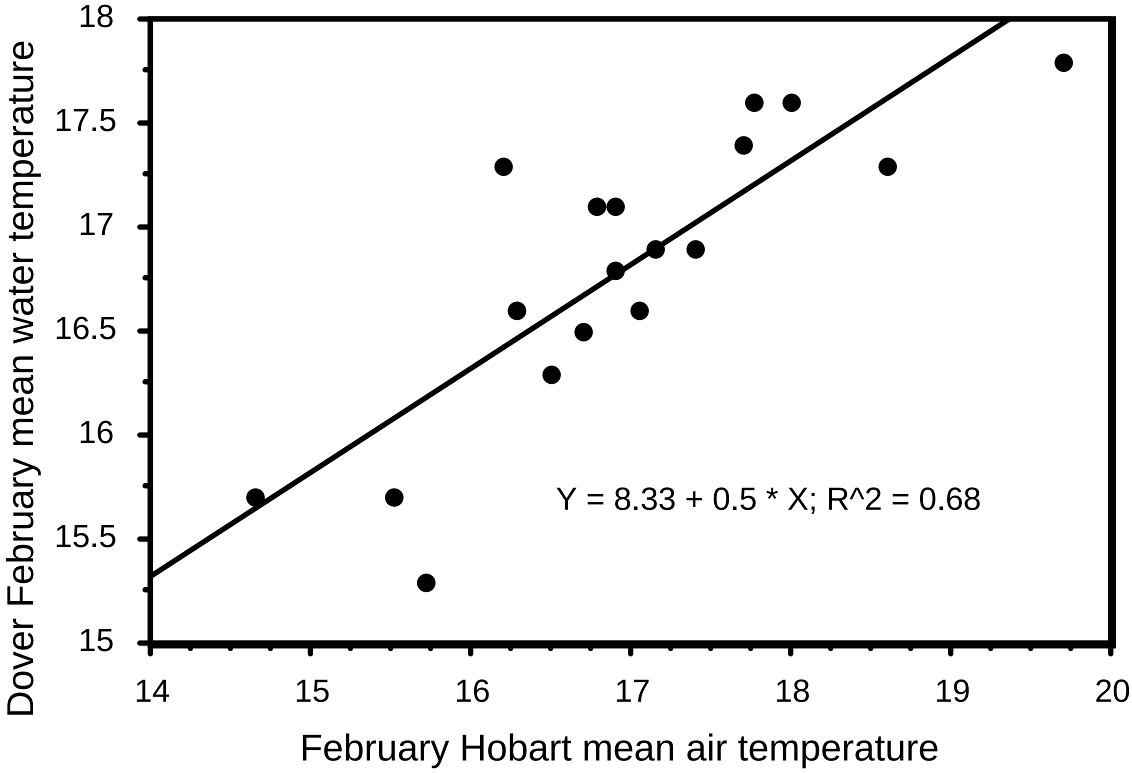

Figure 5. Regression between Hobart February mean air temperatures and February mean water temperature at the Dover farm sites. The correlation accounts for 68% of the variance in water temperature and implies a predictive accuracy of about 0.5º over a range from about 14-20º. Data for 2009 and 2010 are not included in the analyses, as BOM did not publish monthly mean temperatures for those years.

3. Predicting seasonal peak temperatures based on trends in farm temperatures

Short-term predictability can be based on either inertia in the system, process understanding or both. I test for the former by comparing peak summer (February) temperatures at Dover with those over the preceding 7 months, to determine if unusually warm, or cool, summers are first indicated earlier in the season.

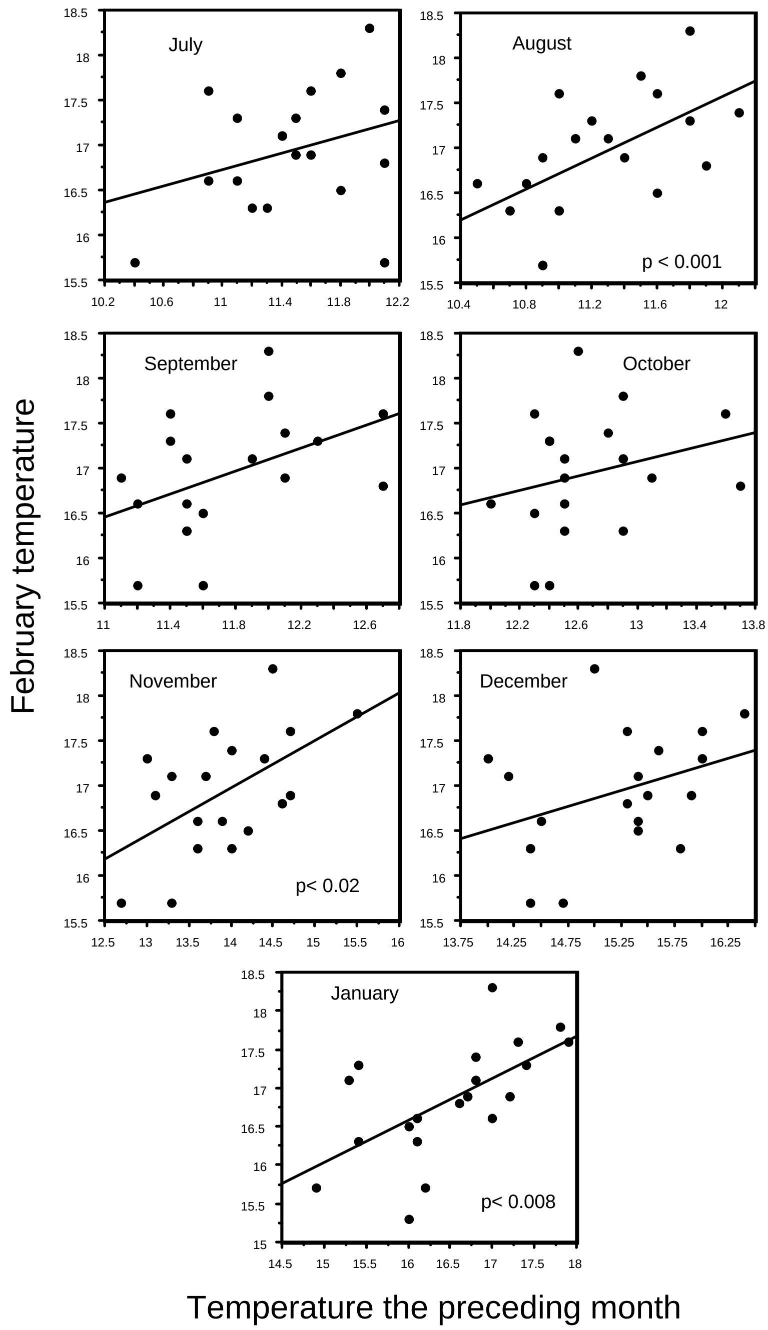

Figure 6. Regressions between peak summer temperatures (February) at Dover, and temperatures for each of the preceding 7 months at Dover.

Regressions between February temperatures at Dover and those in the preceding months are shown in Figure 6. Regressions are significant for three months: August, November and January, though for all months there is a tendency for warm summers to be paralleled by higher temperatures in the preceding late winter and spring. Predictability is relatively poor, however, with temperatures in January, for example, still only accounting for 37% of the variance in February temperatures. Essentially, temperatures early in the year can indicate whether there is likely to be a warm or cool summer, but the regression is not precise enough to say how warm or cool it will be.

Adding February water temperatures at Maria Island or Rottnest to the regression of August temperatures at Dover against those in February did not significantly improve the regression (and would be of limited value for a prediction in any case). To test whether an odd/even year split enhanced predictability, I regressed August temperature against temperatures the following February for Nubeena, Huon and Dover split by odd and even years (Figure 7). The odd/even split is a significant predictor only for Huon, is a trend only (p = 0.12) for Dover, and is wholly non-significant at Nubeena.

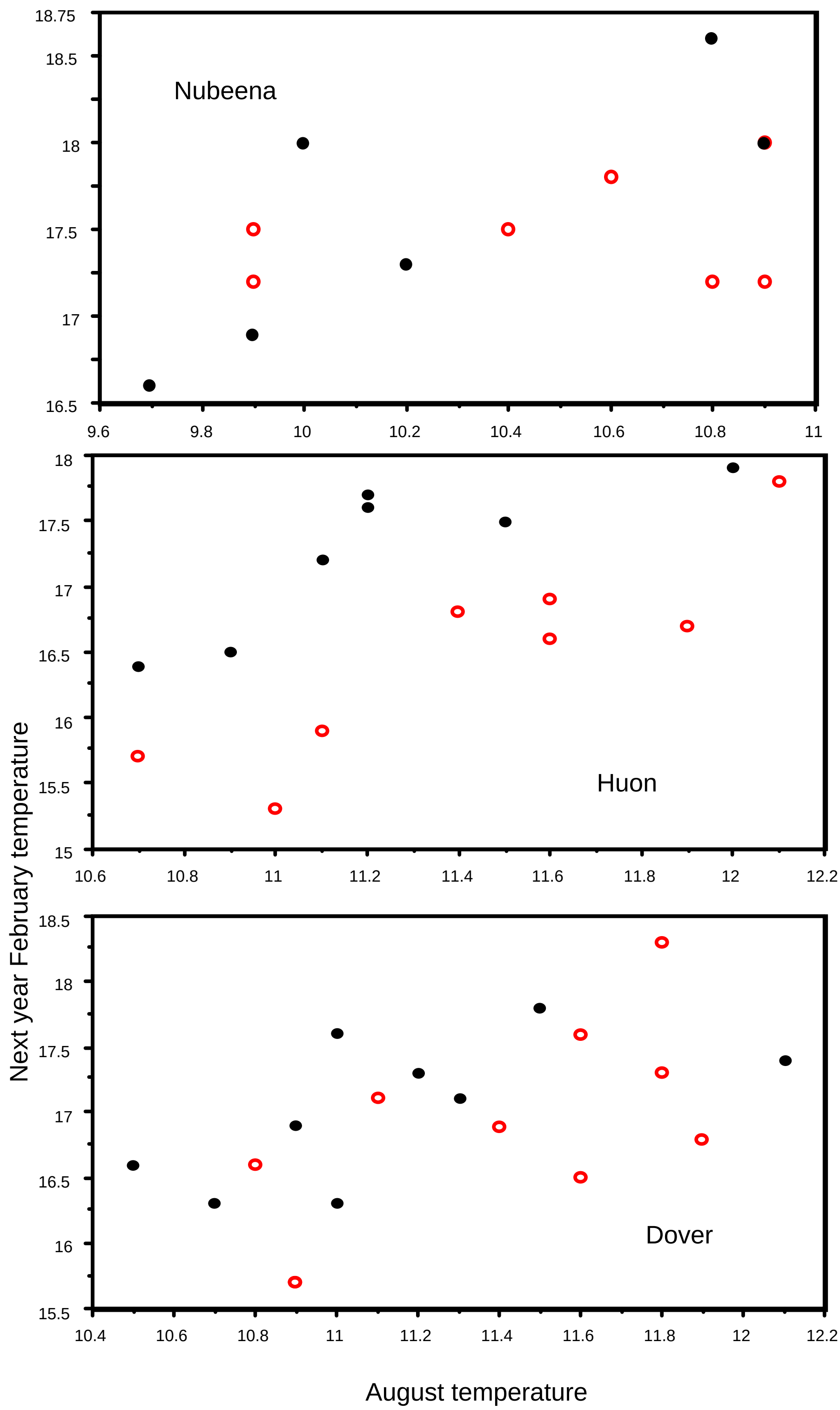

Figure 7. Regression between August water temperatures each year and water temperatures the following February, at Nubeena, Huon and Dover, split into odd (open circle) and even (closed symbols) years.

Conclusions

1. Differences between years in summer and winter temperatures tend to vary in parallel across the four main study areas (Nubeena, Huon, Dover and Macquarie Harbour). This suggests that temperatures are determined mainly by a regional factor, rather than those specific to each site. Regression analysis suggests that the regional factor accounts for about 60% of the variance in the summer (December) temperature, but only about 40% of the winter (July) signal.
2. Peak summer (February) temperatures at the sites with the longest data records (Huon and Dover) tend to vary among years with summer temperatures at Maria Island and Rottnest Island. These are, respectively, indicators to the strength of the East Australian and Leeuwin Currents. However, by far the best correlate of summer water temperatures is February mean air temperature in Hobart. This implies that the dominant factor determining farm temperatures is atmospheric, rather than oceanographic, and that predicting peak summer temperatures at the farms equates to predicting summer temperatures for Hobart.
3. Within years, warm summers are broadly preceded by warm winters and springs. Correlations between peak summer temperatures at Dover and those in preceding months are significant for August, November and January. However, the variance accounted for is small (< 33%) suggesting they provide at best only a rough indication of summer peak temperatures.
4. There remains a tendency for the SE farm sites (Huon and Dover) for regressions to split significantly between odd and even numbered years. The reason for this split remains obscure, on which basis it is not likely to be a safe predictor.

16. Appendix 4: Operational statistical forecasting

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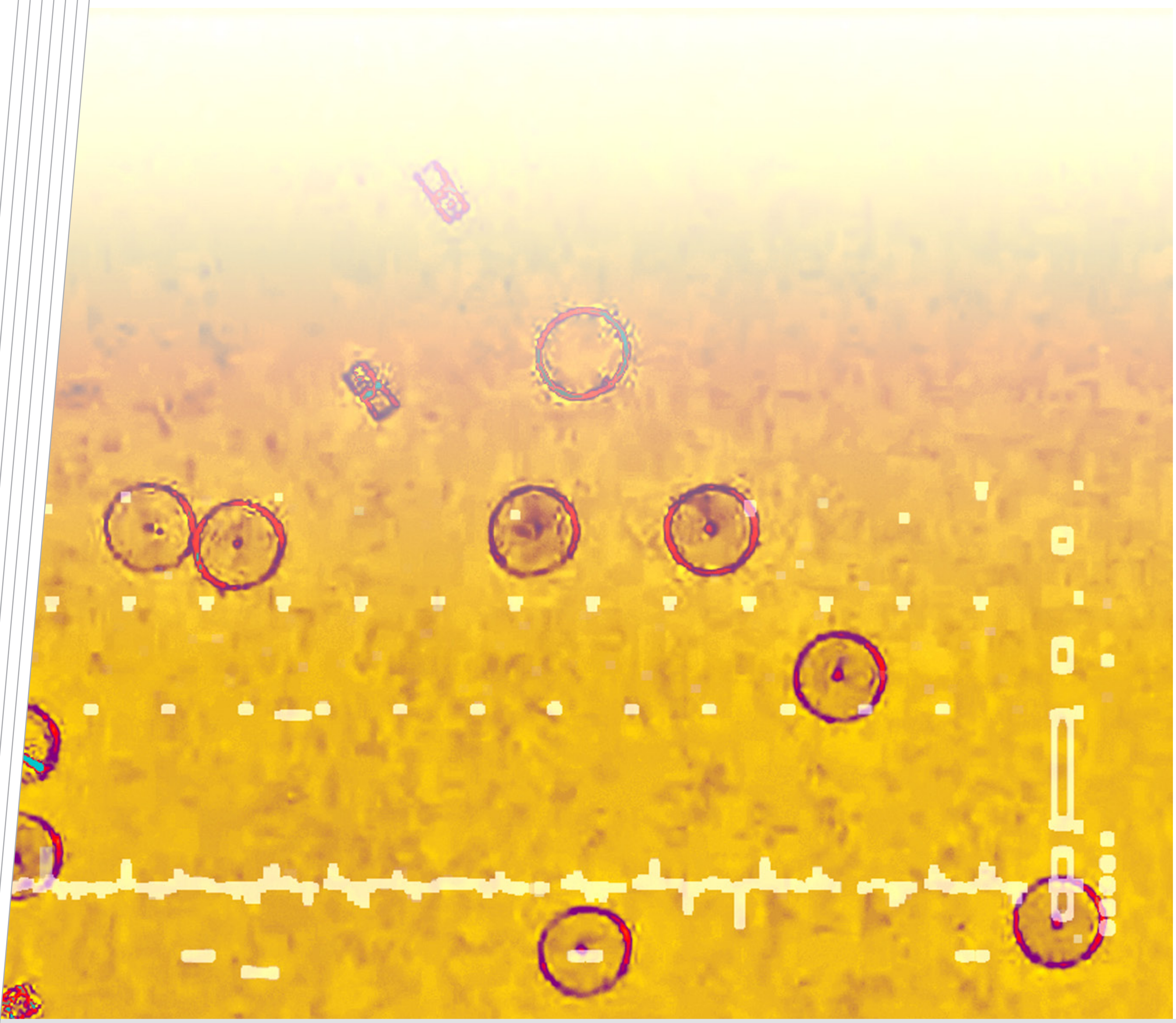

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Projection of water temperatures at salmon farm sites in Tasmania: Preliminary analyses

Project Team: ***Vincent Lyne, Donna Hayes, Roger Scott, Alistair Hobday, Ron Thresher***

CSIRO Marine & Atmospheric Research
CSIRO Climate Adaptation Flagship

Background

This project is part of the response to a request from the Tasmanian Salmon Growers Association to provide short-term projections of water temperatures at three Tasmanian farm sites. Projections are required at lead times of up to four months based on existing statistical tools. The overall project (of which this project is a part) will investigate additional forecast methods that are of interest to CSIRO. CSIRO will provide assessments of these as a separate report.

Thus, the ambit of this project is to restart and update seasonal projections of water temperatures at three farm sites (Dover, Tasman Island and Macquarie Harbour) using existing techniques (i.e., with minimal investment in investigating other techniques - which are to be conducted in the companion CSIRO project to this). Projections are required up to 4 months in advance with assessments of statistical deviations.

A key requirement for this project is provision of the projections as rapidly as possible, which in turn requires data from farm sites, the Bureau of Meteorology (BoM) and the CSIRO Remote Sensing Facility to be accessed as quickly as possible. As we write this report, data from the BoM was received on the 20th September, along with the processed satellite image data. To being with, we analysed data for the Dover farm site as it was one of the first sites for which we obtained data. Other farm site data have been received and we will process and analyse these in due course. However, given the urgency of the project, the results for the Dover site as well as the more generic global and regional analyses are provided here as a heads-up on the preliminary projections. We stress again that these analyses are preliminary and based on existing statistical tools.

Analytical Approach and Data

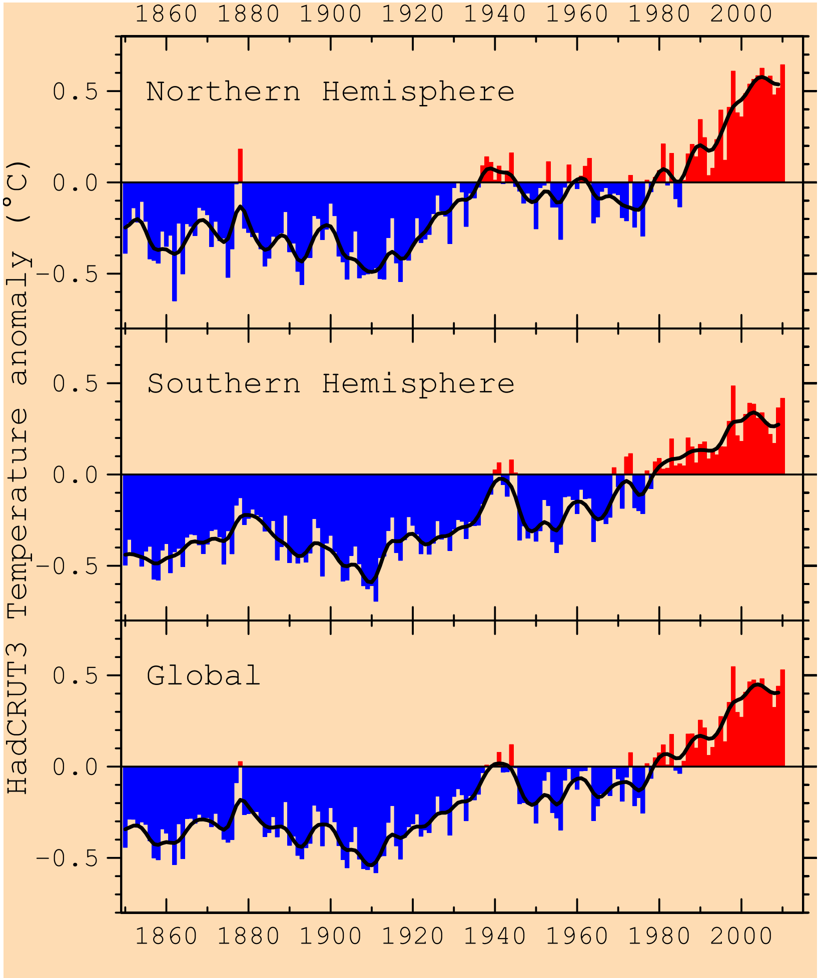
The analytical approach adopted in the past relied upon pattern matching combined with time-series forecasting techniques. In a potentially changing climate, with superimposed decadal oscillations in water temperatures, it is possible that current conditions do not have a precedent within the limited information accessible from the farm sites. However, local conditions, particularly water temperatures, are likely to be influenced by conditions at the regional level, which in turn may be conditional upon global or hemispheric changes. Our analytical strategy was to conduct a nested set of assessments of trends at three different scales: hemispheric, regional and local (farm site). The larger scales provide context to the patterns at smaller scales. For this project the trends in regional and local scales are of prime interest but we first investigate the trends in the southern hemisphere from the long-term data sets available from international projects.

As in the past, our time-series analysis strategy is based on the established structured exponential smoothing approach of Holt-Winters which assumes a decomposition of the time-series into a level, a slope and a seasonal pattern which can vary with time (via exponential decay parameters which are estimated by the algorithm). We also supplement these analyses with seasonal ARIMA (auto-regressive "integrated" moving-average) models which can provide longer and somewhat more stable projections using state-space models. We will not discuss the technical details of these methods but instead will rely upon their statistical predictive and projection measures to determine the most suitable projections. We should also note that with more time and effort we can investigate potentially more robust projection approaches - which should be part of the subject of the CSIRO component of this overall project.

Global Data

A variety of global temperature datasets are currently available. We used the global/hemispheric datasets from the Climate Research Unit (http://www.cru.uea.ac.uk/) for the variance-adjusted version of combined land and marine (sea surface temperature) temperature anomalies, denoted: HadCRUT3v. Trends of the temperature anomalies shown below display a number of key features:

- similarities and some significant differences in the patterns for the Northern and Southern hemisphere.
- relative to the chosen baseline (1961 - 1990), the South has been cooler overall than the North
- likewise, since 1980, the rate of temperature increase over the past few decades is less than that seen in the North
- these are possibly a consequence of the greater relative ocean surface area in the South compared to the North (the oceans offering greater heat (enthalpy) absorption, and hence inertia)
- both series appear to show cyclical perturbations superimposed on the trend; with the South showing more damped ones - possibly from the greater inertia of its water masses
- over the past decade or so, the seemingly relentless rise in temperature has abated to a plateau, or a slight decrease
- there's less evidence of the cyclical behaviour (but it's still there) during the increasing phase



The key message from this is that the Southern Hemisphere temperature trend over the past several decades has not been as great as that in the Northern Hemisphere, but it does display similar overall trends and some cyclical behavior. The most recent trend (last decade) appears to be a respite from the rise of the past several decades, with evidence of a slight decline. In the following section we examine the data for the Southern Hemisphere in greater detail in an attempt to project the future trends and cycles.

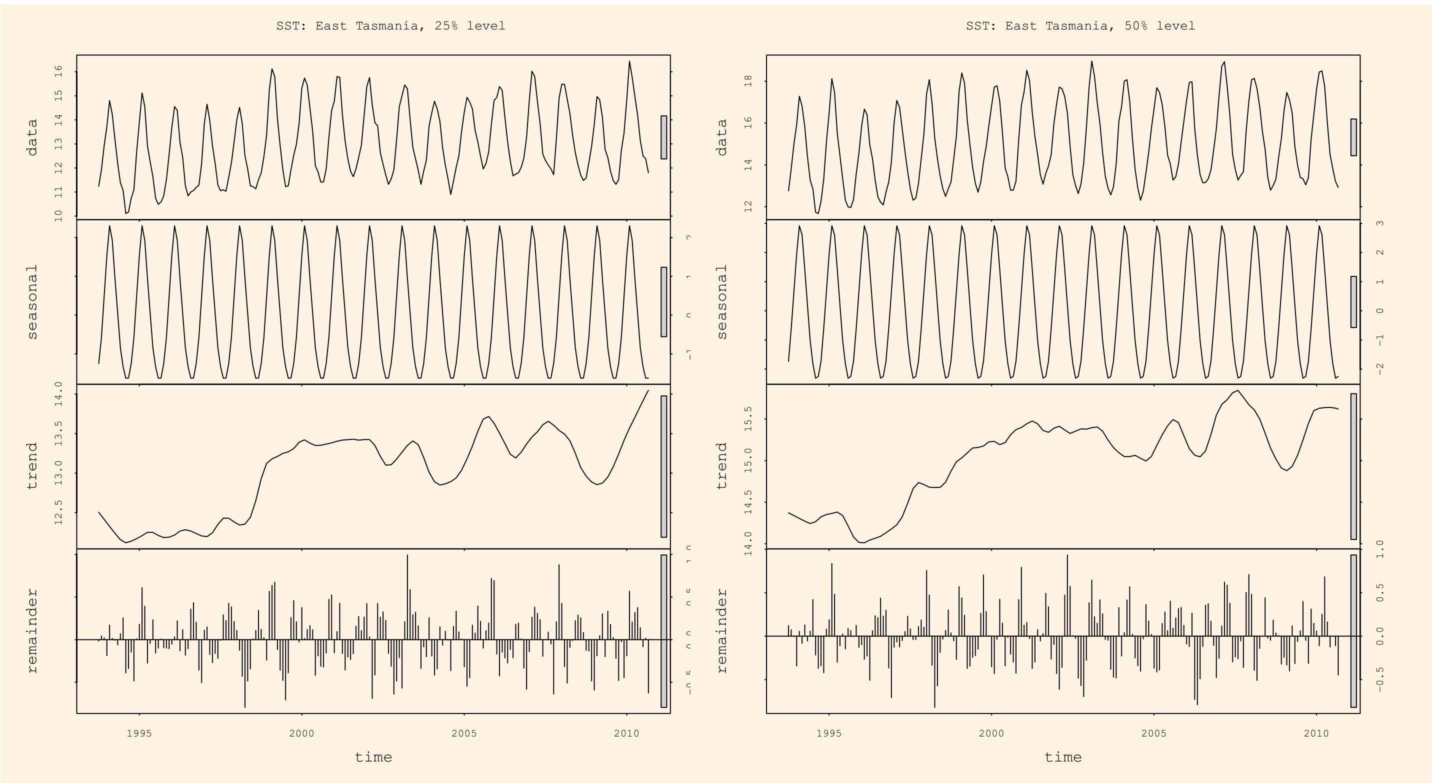
Regional Data

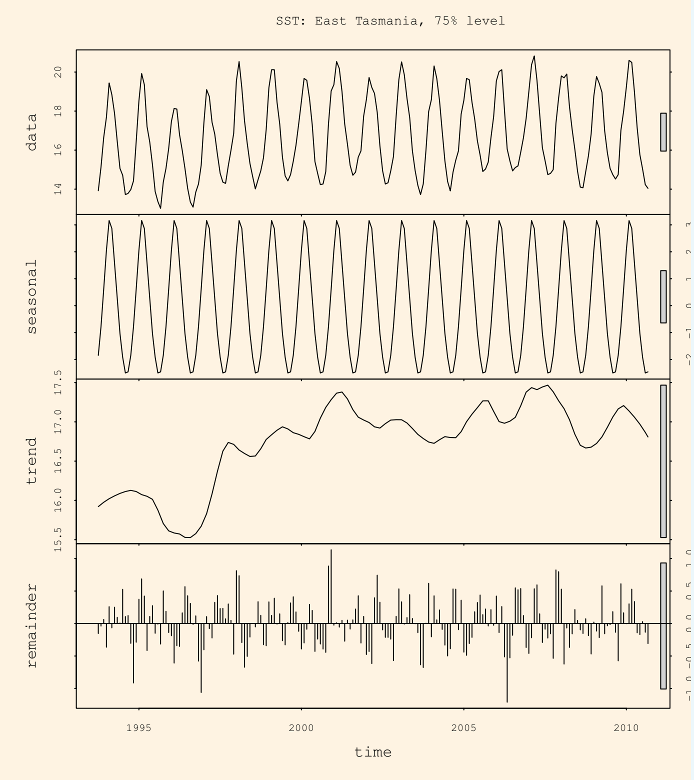
Sea surface temperature (SST) data were obtained from the CSIRO Marine & Atmospheric Research Remote Sensing Facility. Raw data were processed by (histogram) filtering out anomalies across a moving 15-day window and subsampling every 6 days. In the past we used one region extending from 140.17 to 154.18 longitude, and -36.75 to -46.95 latitude, at a resolution of 0.03 degrees. With the requirement to project temperatures for Macquarie Habour, we split the region into an east extending from 147 to 154.18 longitude (same latitude range as past), and a west extending from 140 to 146 longitude. Dates for the filtered image records were set at the mid-point of the filtering window.

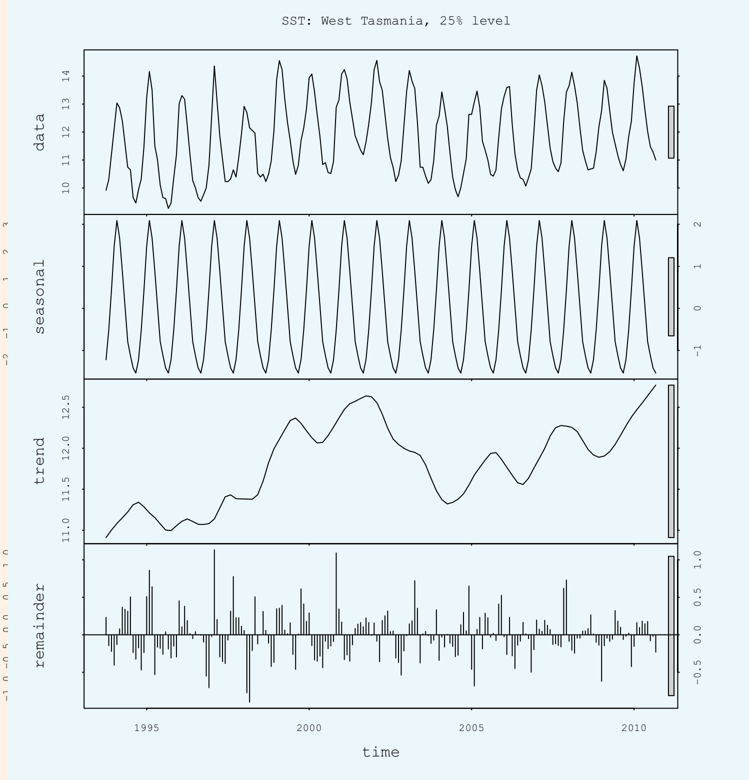
For each region, monthly quantile statistics were computed at the 25%, 50% (median) and 75% levels; these representing respectively the cooler, median and hotter waters of the region. In the east, the farm sites should be situated more in the cooler part, while Macquarie Habour in the west should be situated more in the median band. The monthly series extends from October 1993 to August 2010 (with a couple of records in September 2010).

Exploratory analyses were conducted by decomposing the time-series into trend, seasonal and residual components. Various models were assessed to investigate their abilities in modelling and projecting these components.

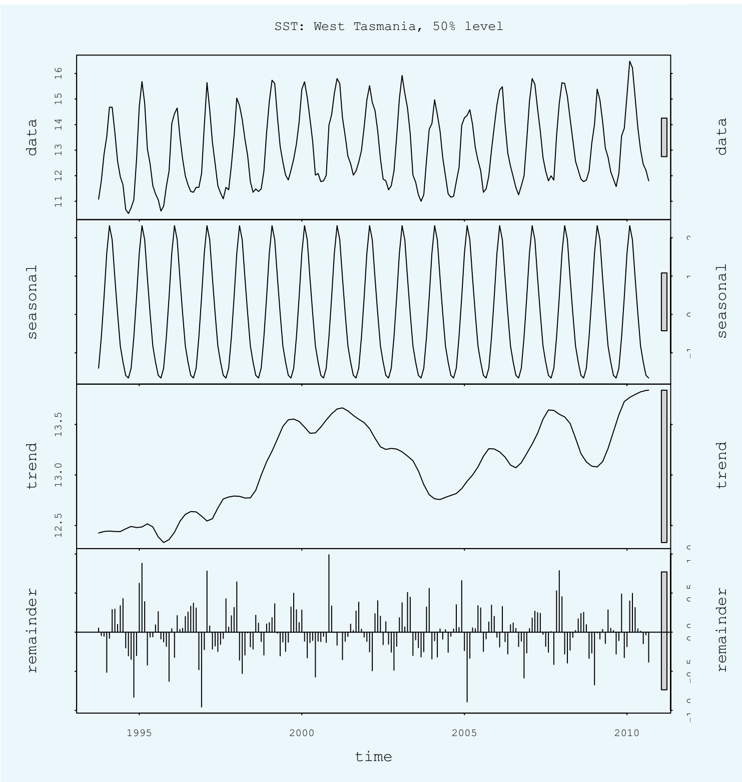
Decompositions of the SST time-series are shown in the following plots for the east coast (25%, 50% and 75% levels) and then the west coast. In each set of plots, the top plot is the monthly data, followed by the seasonal pattern, the trend and then the residual. The bars on the right provide a comparative scale representing the same change in temperature. The decomposition procedure used is not sophisticated enough to allow for changing seasonal patterns and non-stationary residuals, so this is a quick-look at the data to determine the major trends and patterns. Overall, while the trend for the east coast appears similar, there is an abrupt change evident in the latter part of the 1990 decade; with the change seeming to occur earlier (one to two years) for the 75% and 50% series than the 25% where the change occurs in the late 1990's (noticeably more abrupt change). The tail end of the trends show a sharp rise for the 25%

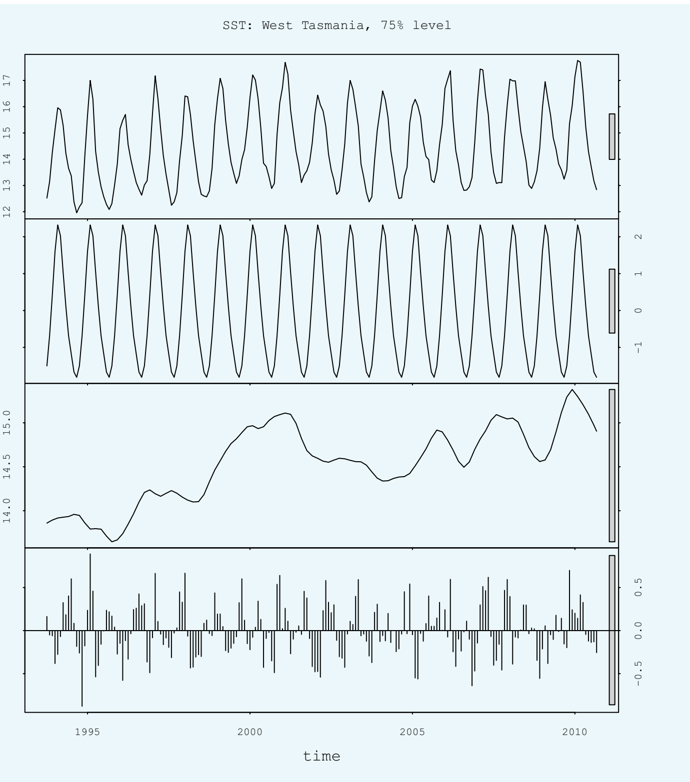






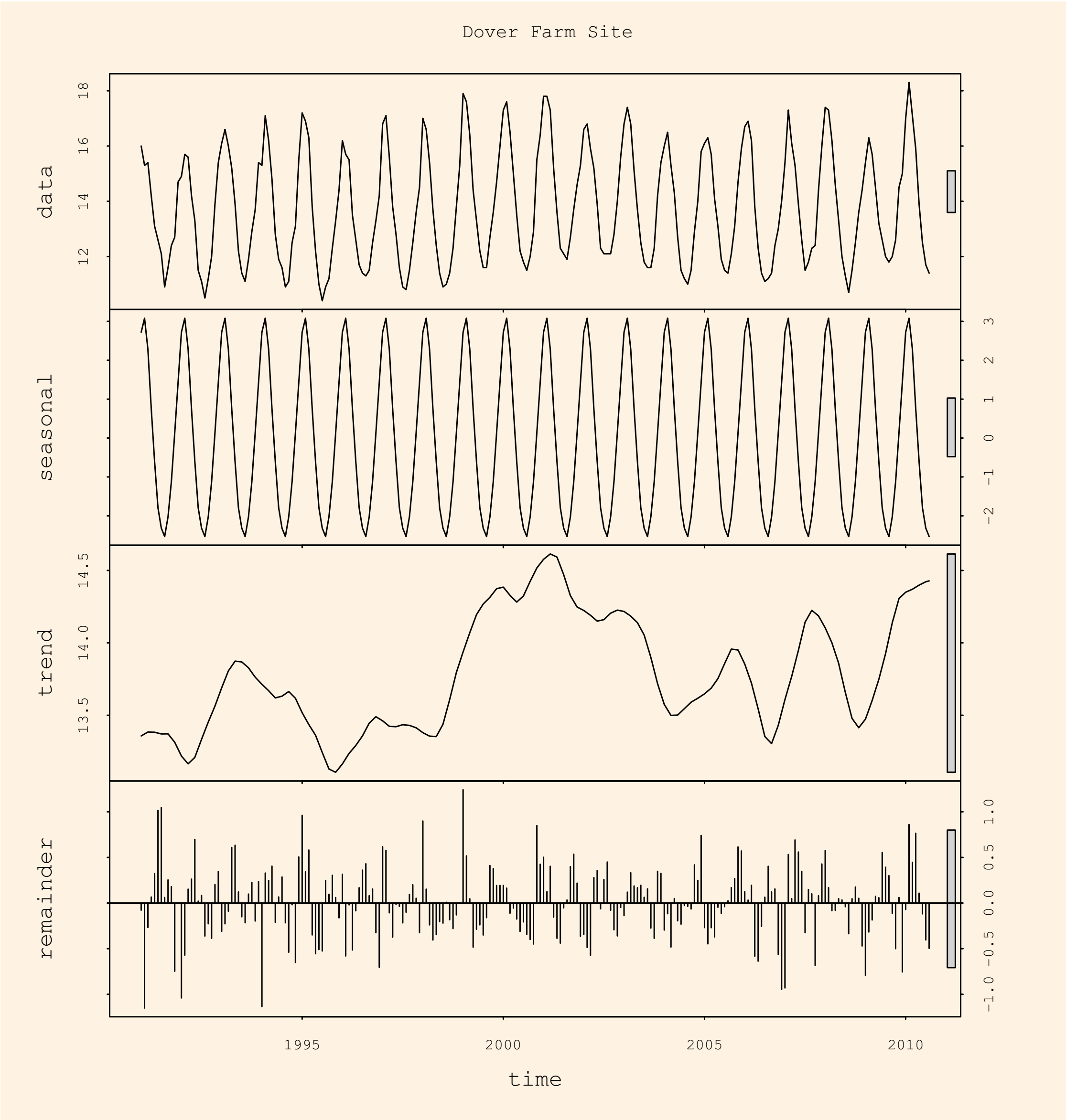
series, while the 50% is leveling off and the 75% is in decline. These observations suggest that the trends in the warm and cooler water masses are not in phase (in fact the 25% and 75% may be out of phase at the tail end), and that warming changes are not uniform. The patterns in the west coast are more akin to strong cycles at a couple of scales superimposed on an increasing trend. A peak warming is centred roughly around 2000, or later. By contrast the east coast warming about this period is more sustained. As with the east coast, the tail-end trends are similar (warming 25% series, levelling 50% and declining 75%). Clearly, there are suggestions of cycles and lagged responses so much more insights are possible from these data than is possible in this project.





Dover Farm Site Data

For the Dover farm site, Tassal provided monthly, and daily, data from the beginning of 1991 up till the end of August 2010. A decomposition of the time series, shown below, has a trend that somewhat resembles the pattern seen in the west coast 25% series. The tail-end is still at an incline but not as steep as the increasing trend over the past few years. Exploratory analyses of the trend show cyclical behaviour at a range of time scales (up to about 3 years). Seasonal ARIMA (SARIMA) modelling (details to follow



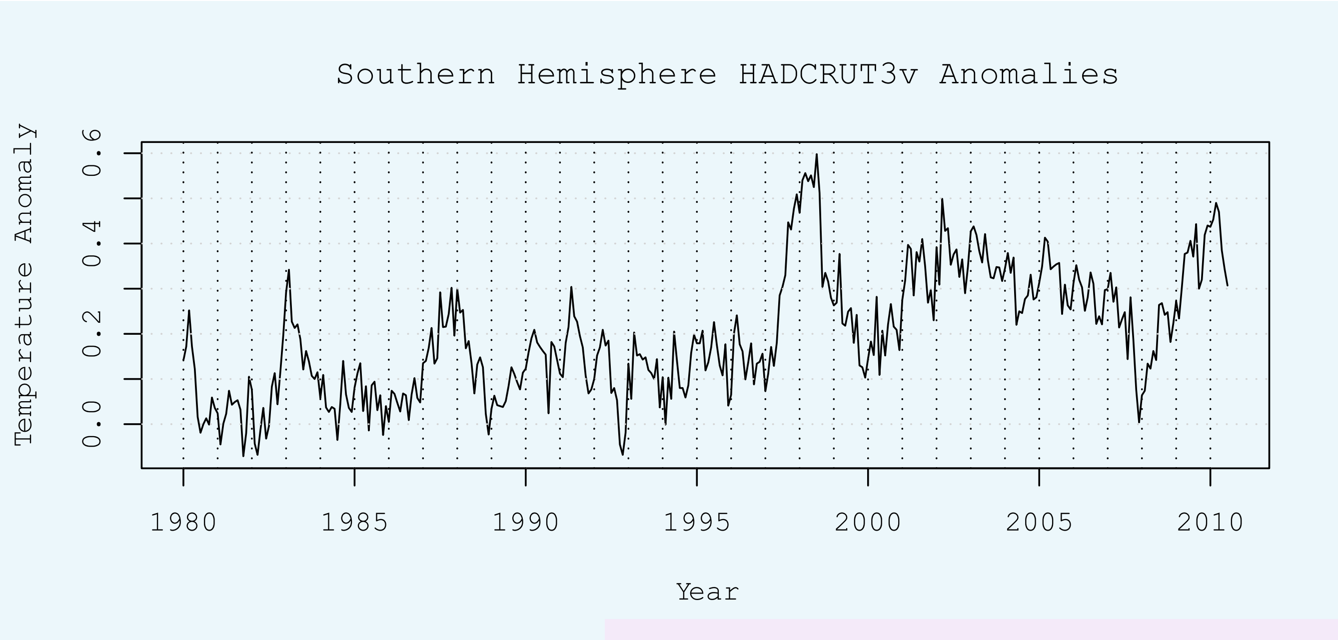
later) suggests strong seasonal auto-correlation between years (about -0.6, which suggests a flip in decay behaviour - damped cyclical decay), and up to at least 3 years moving average dependence (meaning that part of the current seasonal signal is a linear combination of corresponding seasonal signals from the past 3 years). The ARIMA models suggest that the trend is predictable but the model is a rather complex one so some caution is required in projecting the model into the future (years ahead). For the current project, the trend suggests that the underlying baseline is at the upper end of the pattern observed over the whole record, and comparable to the highs seen in the early 2000's.

Projections

Hemispheric Projections

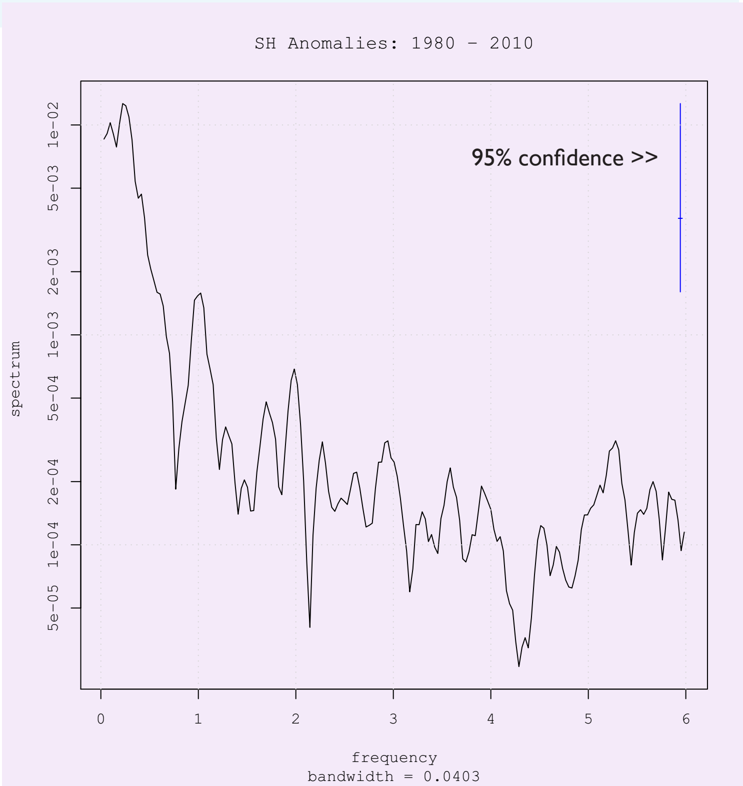
We examine firstly the southern hemisphere record for global indicators that might be relevant to understanding the warming experienced in south eastern Tasmanian waters in the late 1990's, and the projection of the climate phase that may be relevant in understanding the future years ahead.

The time series of Southern Hemisphere temperature anomalies from the 1850 is far too complex for us to even attempt to model in this project. The spectrum of cycles increases with the period from about 2 years (seasonal anomalies deleted in the record) up to the longest cycle possible with the length of the record (period of half the record length). No peaks stand out, so there's a complex of cycles and quasi-cycles interacting. On the other hand, if we focus on a narrower window of the record, not all cycles will

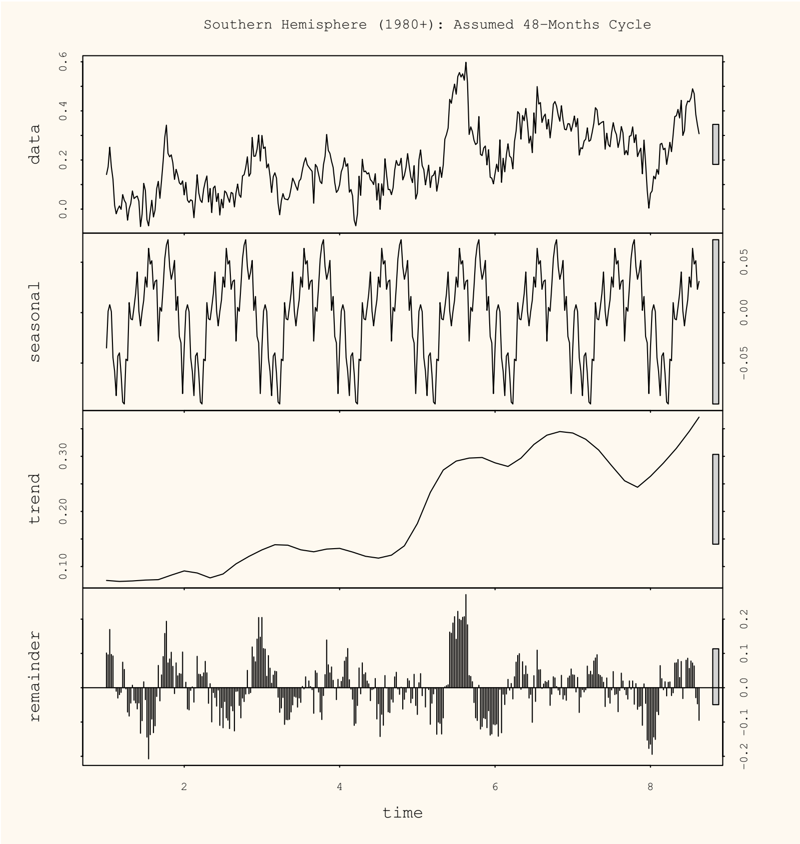


be present and we may have some hope of resolving the pattern. With that in mind, we plot above the record for the HADCRUTv3 time-series of monthly temperature anomalies from 1980 up to August 2010.

Some quasi-cycles of several years duration are apparent superimposed on a longer term trend. The spectra (smoothed - shown on the right) has peaks at about 6 and 3 years (at frequency = 1 and 2 respectively). Although, of course, most of the variability is at the longest scale (the trend).

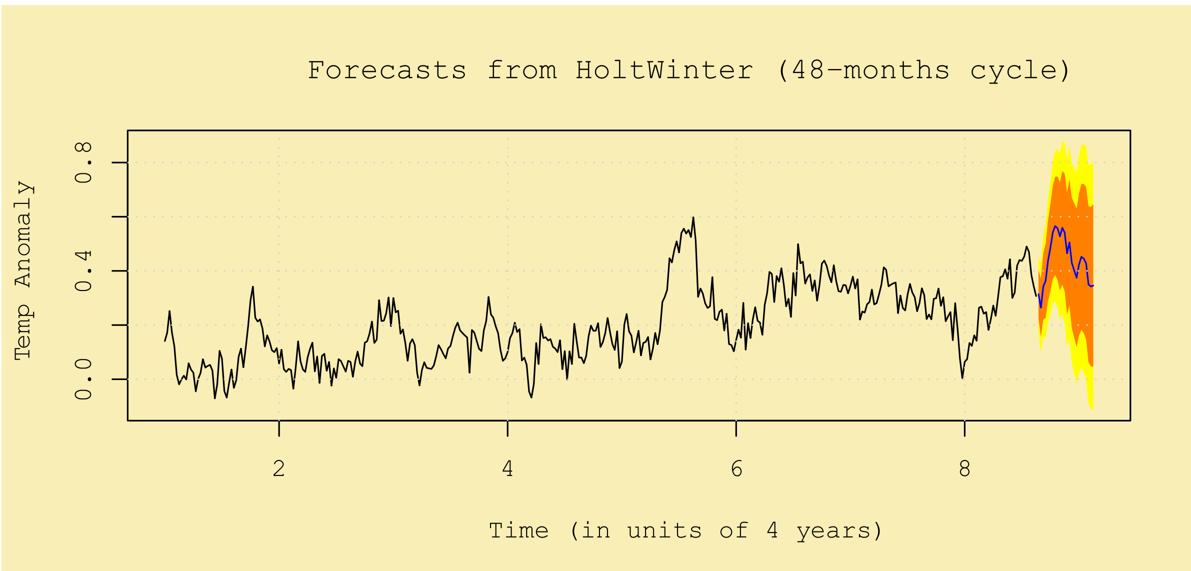


To examine the trend and cycles, we decomposed the series assuming a cycle period of 4 years - as shown in the plot below. A complex repeating cycle is decomposed along with a trend (the trend is relatively robust to the assumed period of the cycle), and significant residuals, so the decomposition is inadequate in resolving the patterns. Peaks in the cycle also do not always line up with the observed peaks leading to high residuals. Despite this, the final peak at the tail-end appears to line up well.



The trend shows a "jump" at about 1996 (note peak in the raw data is at July 1998) , and this combines with the peak in the cycle that apparently led to the observed peak in 1998. Note that the observed peaks in the regional SST occurred at about 2000 or so, a few years later. Thus, it would be worthwhile to investigate the use of the hemispheric trends (or perhaps trends from other regions in the southern hemisphere) to provide context for trends likely to emerge off southern Tasmania a few years in advance. - an exciting possibility.

In attempting to project the series out to a few years, we tested the Holt-Winters algorithm as well as the seasonal ARIMA models. Both had difficulty fitting the series. The Holt-Winters forecasts for 2-years ahead together with confidence bands (approximate one and two standard deviations) are shown below:

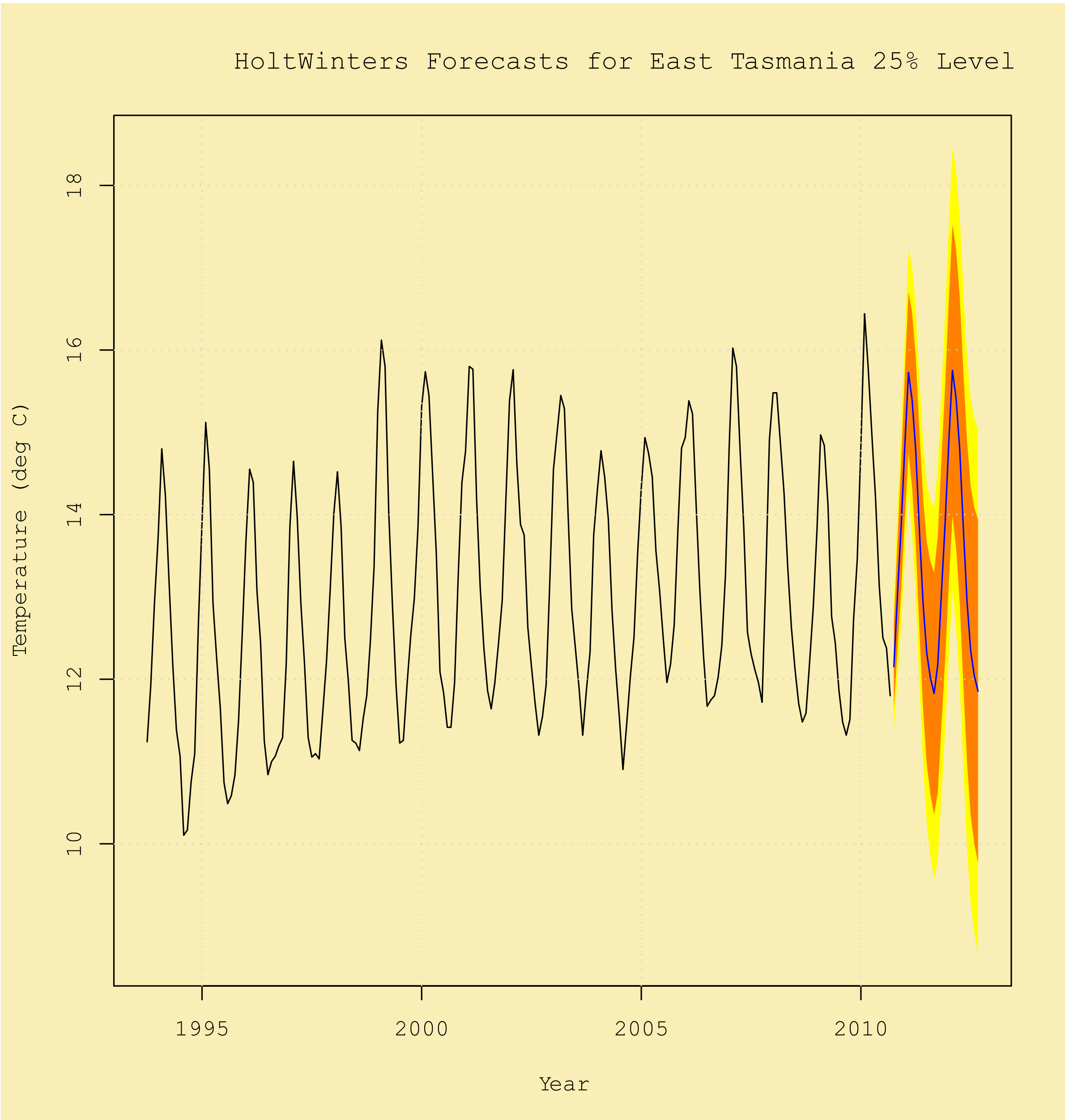


Over the next two years, Southern Hemisphere temperature anomalies are projected to remain at the higher end of the observed range before declining. Bearing in mind the observation that peaks in southern Tasmania may follow peaks in this time-series, this hypothesis warrants much more scrutiny than is possible in this project. We conclude the analysis of the hemispheric patterns and trends by recommending that a much more detailed modelling exercise be conducted in order to determine whether hemispheric signals can be used to foretell significant climate-related events in southern Tasmania. There are cycles and quasi-cycles at a whole range of scales but within a limited window (in space and time) a number may be dominant. The ability to identify and track these events offers hope for projecting climate trends at least a number of years ahead.

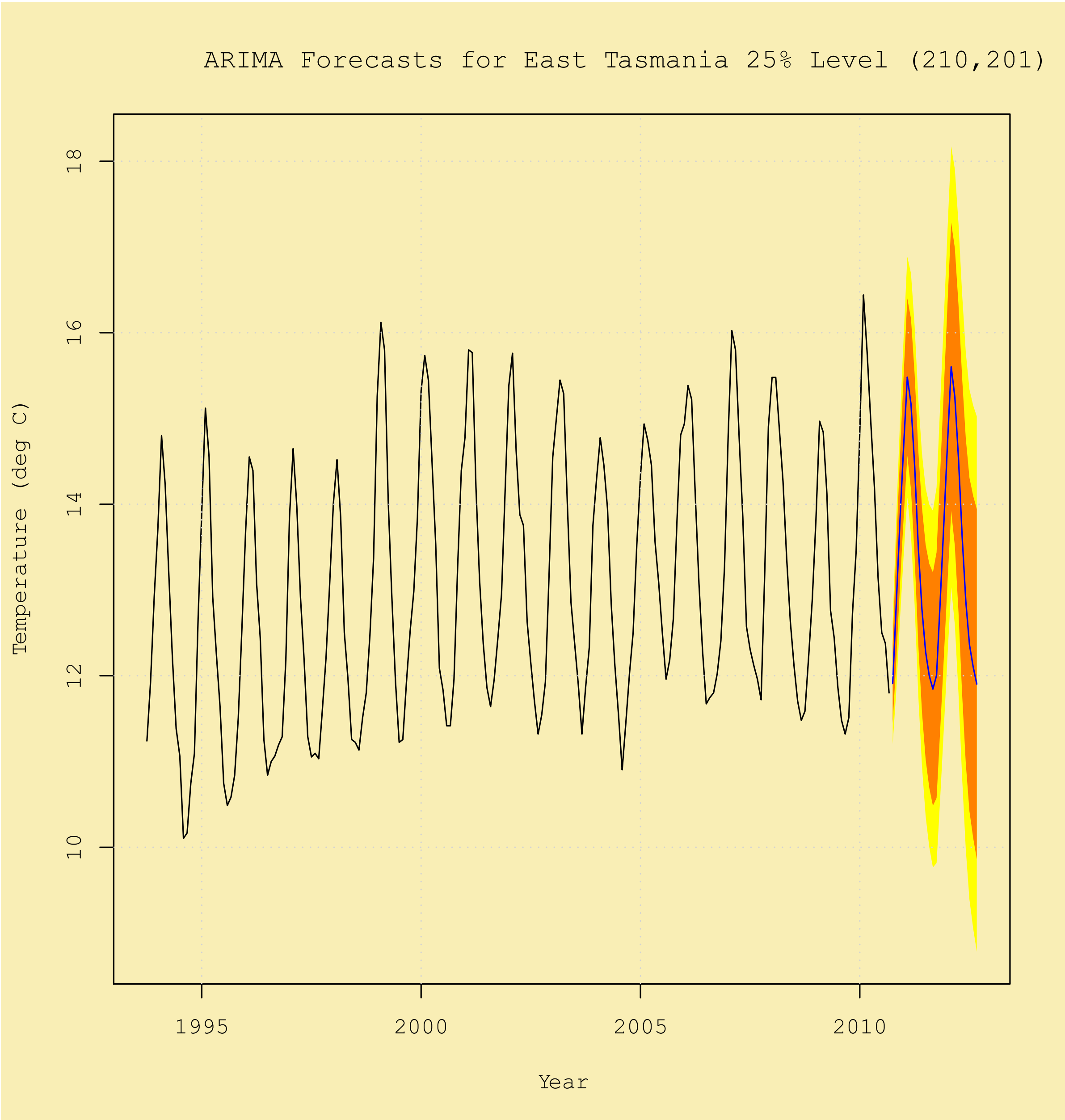
Regional Projections

For the regional analysis, we use the eastern Tasmania 25% satellite SST series. The Holt-Winters projection shown below suggests, compared to the past year, cooler peak summer temperatures for the next two years; and winter minima that are about as warm. Residuals from this forecast (not shown) are marginally significant at lag correlations of up to 3 months (suggesting problems in fitting the seasonal signal), and at lags of 14 months or greater (very marginal - indicating slight problem in dealing with inter-annual variability). Note wider confidence bands for the second year projection.

The seasonal ARIMA forecasts of the best fitting model (with one level of differencing, 2-months auto-



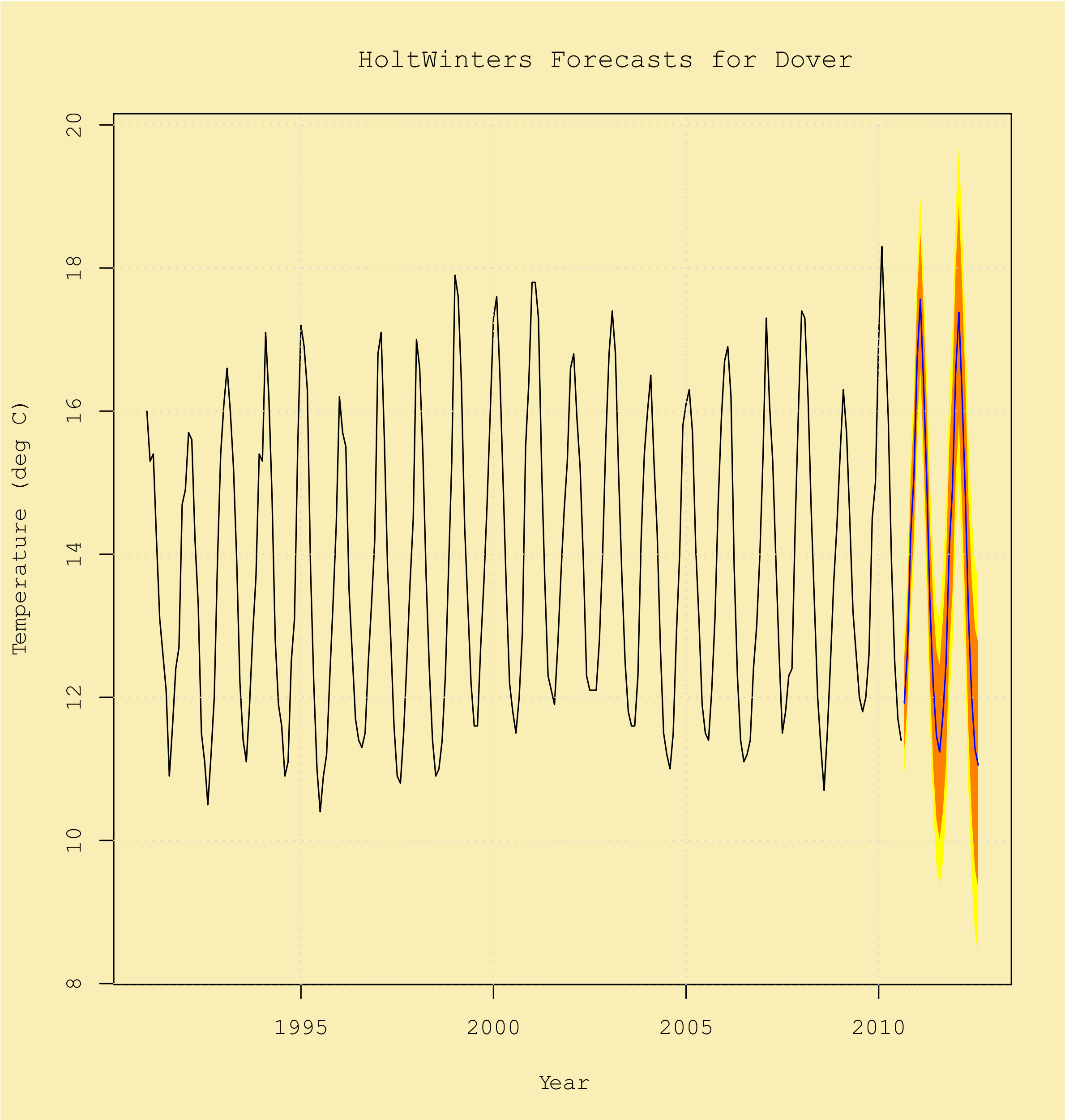
regression, two-seasons auto-regression and one-season moving average) shows a similar projection but with slightly lower summer peaks. The residual auto-correlation is just above significance at 5 months and at 12 months. The ARIMA models appear to provide lower projections than the Holt-Winters, but the residual statistics tend to be in favor of the seasonal ARIMA model.s We conclude that at a regional level,



the coolest waters off eastern Tasmania are projected to peak at temperatures lower than the past year, but the winter minimum is expected to be about as warm.

Dover Farm Site Projections

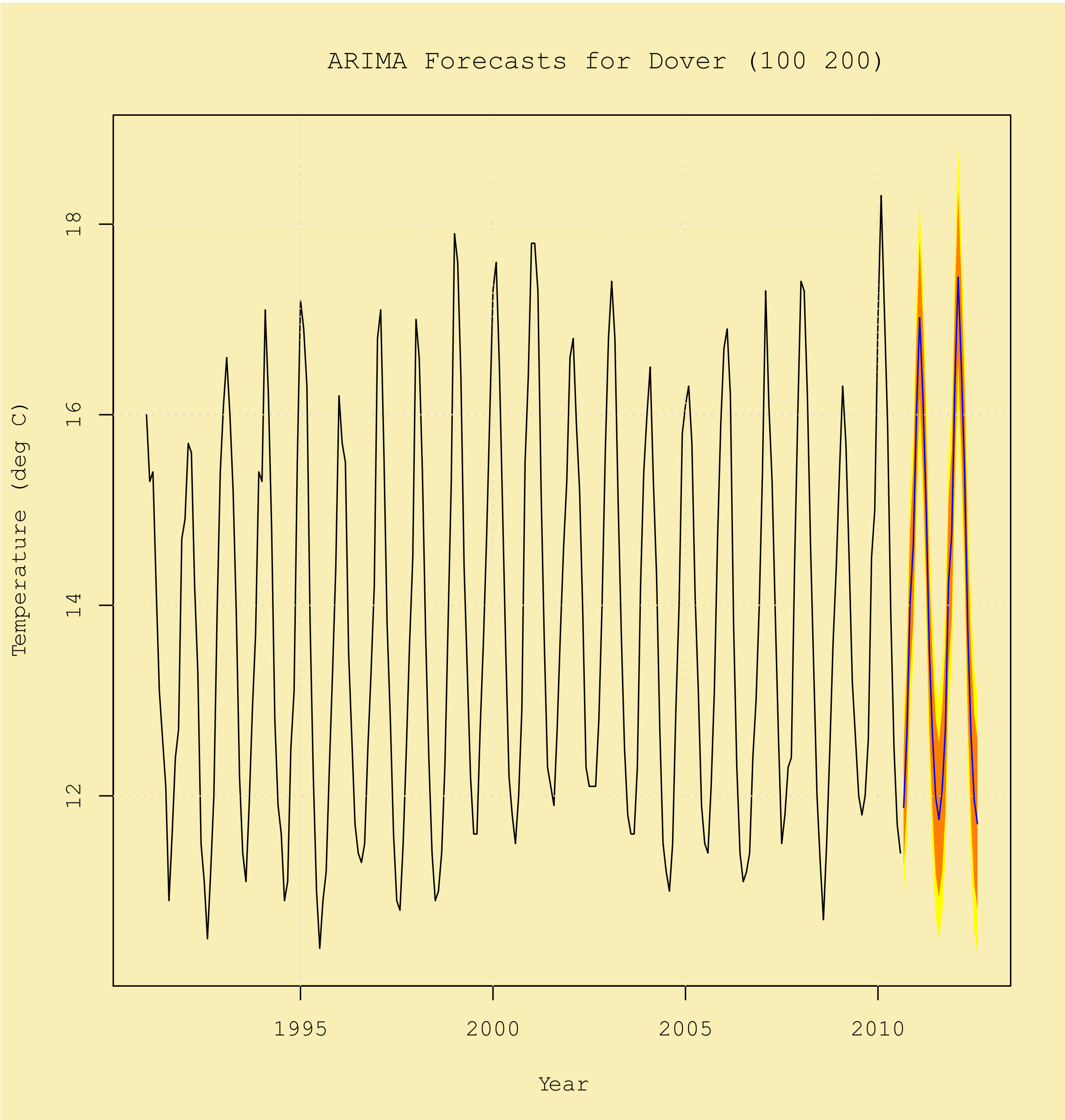
Following the same process as the regional projection, the Holt-Winters projection for the Dover monthly temperatures is shown below. Cooler summer and winter temperatures are projected, but the projection has marginally significant residuals at lag correlations of up to 5 months (with the exception of the 2-month lag).



A table of the predictions out to March 2011 is provided below with columns for the projected value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), and the 95% confidence levels ("Lo 95" and "Hi 95"). Almost all projected months are at or above the means computed over the time-series.

	Point Forecast	Lo 80	Hi 80	Lo 95	Hi 95	Mean
Sep 2010	**11.92**	11.28	12.56	10.94	12.90	***11.75***
Oct 2010	**12.66**	11.95	13.38	11.57	13.76	***12.66***
Nov 2010	**14.27**	13.49	15.06	13.08	15.46	***13.92***
Dec 2010	**15.11**	14.27	15.94	13.82	16.39	***15.22***
Jan 2011	**16.72**	15.83	17.62	15.35	18.09	***16.50***
Feb 2011	**17.56**	16.61	18.51	16.11	19.01	***16.86***
Mar 2011	**16.39**	15.39	17.39	14.87	17.92	***16.06***

Projections from the best seasonal ARIMA model are shown below. The projected peak is below that from the past year (and lower even than the second year's projection). Winter minima are warmer by comparison. The residuals from this model (a single auto-regressive term for the series and two for the



season) are not significant out to lags of two years, so we have greater confidence in these projections than the Holt-Winters. These projections are about the same as, or lower than the mean (slightly above for Sep and Feb)

	Point Forecast	Lo 80	Hi 80	Lo 95	Hi 95	Mean
Sep 2010	**11.87**	11.27	12.48	10.95	12.80	***11.75***
Oct 2010	**12.63**	11.90	13.36	11.52	13.74	***12.66***
Nov 2010	**14.01**	13.24	14.79	12.82	15.20	***13.92***
Dec 2010	**14.67**	13.83	15.42	13.40	15.84	***15.22***
Jan 2011	**16.00**	15.19	16.81	14.77	17.24	***16.50***
Feb 2011	**17.02**	16.21	17.83	15.78	18.26	***16.86***
Mar 2011	**16.19**	15.38	17.01	14.95	17.43	***16.06***

Final Remarks

Using our best available statistical tools, and within the limited time-frame for this project, our best estimates of the forthcoming summer conditions are:

1. Upcoming peak summer temperatures are projected to be lower than those for the past summer
2. Upcoming winter minimum temperatures are projected to be about the same or warmer
3. Regional projections are also similar with cooler summers, and winters about the same as last year
4. Considerable uncertainty surrounds the analyses of the Southern Hemisphere patterns and trends, but the best estimate show a warming pulse over the past few years. Our best guess, and we stress that it is only a guess, is that the warming pulse may flow through to regional and local conditions in the next few years. This uncertainty needs to be investigated and resolved if we are to progress in our projections of future conditions..

Acknowledgements

We thank the companies involved for their help in providing data from the farm sites. Funding for the project was provided through the Tasmanian Salmon Growers Association, and through the CSIRO Climate Adaptation Flagship. VL wishes to acknowledge those who have been unable to access him whilst he disappeared into this project.

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CSIRO and the Flagships program

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills. CSIRO initiated the National Research Flagships to address Australia's major research challenges and opportunities. They apply large scale, long term, multidisciplinary science and aim for widespread adoption of solutions.

17. Appendix 5: Individual forecasts

The following pages contain the individual forecasts for each site for the months September 2010 to March 2011.

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Projection of water temperatures at salmon farm sites in Tasmania: Dover

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation

CSIRO

Projection Summary - 22 September 2010
Based on montly data from January 1991

Summary of Projections

Using our best available statistical tools, and within the limited time-frame for this project to date, our best estimates of the forthcoming summer conditions at the Dover salmon farm site are that:

- ◊ Upcoming peak summer temperatures at Dover are projected to be lower than those for the past summer
- ◊ Upcoming winter minimum temperatures at Dover are projected to be about the same or warmer
- ◊ Regional projections are also similar with cooler summers, and winters about the same as last year
- ◊ Considerable uncertainty surrounds the analyses of Southern Hemisphere patterns and trends, but the best estimate show a warming pulse over the past few years. Our best guess at this stage of the project is that the warming pulse may flow through to regional and local conditions in the next few years.

We used two methods (Holt-Winters and ARIMA) that provide good fits to the available data. The ARIMA estimates tend to be lower than the Holt-Winters and we will assess their respective prediction skill as the season progresses. For the moment, we are recommending the Holt-Winters projections be used. Full details of the methods are provided in a companion report that also assesses regional and global trends. The table of the predictions shows the projected value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the 95% confidence levels ("Lo 95" and "Hi 95"), the past year data ("Past_Year") and the overall mean ("Mean").

Dover	Mean	Past_Year	Point Forecast	Lo 80	Hi 80	Lo 95	Hi 95
ARIMA Sep 2010	11.75	12.00	11.88	11.27	12.48	10.95	12.80
ARIMA Oct 2010	12.66	12.60	12.63	11.91	13.36	11.52	13.75
ARIMA Nov 2010	13.93	14.50	14.01	13.24	14.79	12.83	15.20
ARIMA Dec 2010	15.22	15.00	14.63	13.83	15.42	13.41	15.85
ARIMA Jan 2011	16.50	17.00	16.00	15.20	16.81	14.77	17.24
ARIMA Feb 2011	16.86	18.30	17.02	16.21	17.83	15.78	18.26
ARIMA Mar 2011	16.06	17.10	16.19	15.38	17.01	14.95	17.44
ARIMA Apr 2011	14.53	15.90	15.07	14.26	15.88	13.83	16.31
HW Sep 2010	11.75	12.00	11.92	11.28	12.56	10.94	12.90
HW Oct 2010	12.66	12.60	12.67	11.95	13.38	11.57	13.76
HW Nov 2010	13.93	14.50	14.27	13.49	15.05	13.08	15.46
HW Dec 2010	15.22	15.00	15.11	14.27	15.94	13.82	16.39
HW Jan 2011	16.50	17.00	16.72	15.83	17.62	15.35	18.09
HW Feb 2011	16.86	18.30	17.56	16.61	18.51	16.11	19.01
HW Mar 2011	16.06	17.10	16.39	15.40	17.39	14.87	17.92
HW Apr 2011	14.53	15.90	15.02	13.97	16.07	13.42	16.62

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Projection of water temperatures at salmon farm sites in Tasmania: Dover

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 22 November 2010
Based on montly data from January 1991

Summary of Projections

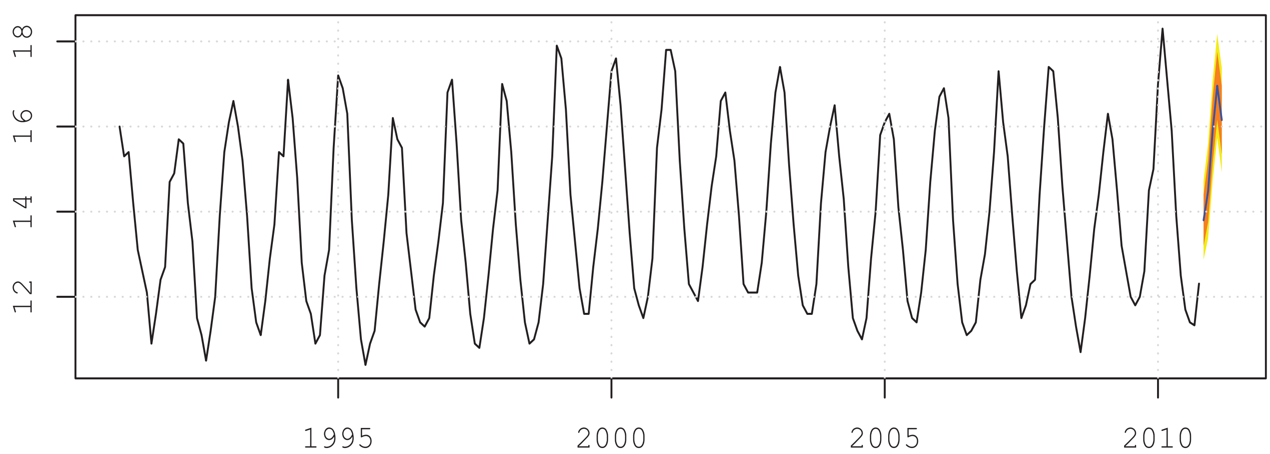
Following on from our last projections based on data up to August, this projection is based on data up to and including October using monthly data from the Redcliffs site:

- ◊ As with the Huon projections, we have dropped the Holt-Winters projections in favor of the more accurate ARIMA ones
- ◊ Upcoming peak summer temperatures at Dover are projected to be lower than those for the past summer
- ◊ September conditions were up to 0.7 degrees cooler than last year. The projected temperature for that month was off (warmer) by about 0.6 degrees. However the Observed and Projected temperatures for October match up.

The table of the predictions shows the projected value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). A plot of the projection is shown below.

Dover	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80
ARIMA Sep 2010	11.75	12.00	11.3	11.88	11.27	12.48
ARIMA Oct 2010	12.66	12.60	12.3	12.27	11.66	12.87
ARIMA Nov 2010	13.93	14.50		13.80	13.19	14.40
ARIMA Dec 2010	15.22	15.00		14.48	13.76	15.21
ARIMA Jan 2011	16.50	17.00		15.91	15.13	16.68
ARIMA Feb 2011	16.86	18.30		16.96	16.16	17.75
ARIMA Mar 2011	16.06	17.10		16.15	15.35	16.96

Dover Projection – November 2010 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Dover

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation

CSIRO

Projection Summary - 7 December 2010
Based on montly data from January 1991

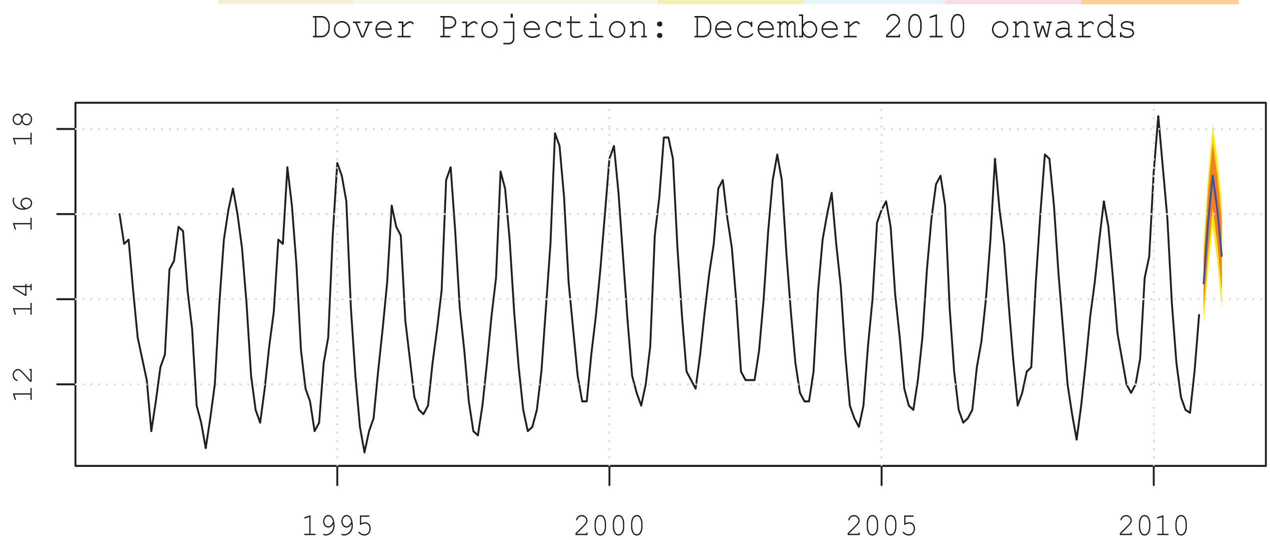
Summary of Projections

Following on from our last projections based on data up to October, this projection is based on data up to and including the 28th November using monthly data from the Redcliffs site:

- ◊ As with the Huon projections, we have dropped the Holt-Winters projections in favor of the more accurate ARIMA ones
- ◊ Upcoming peak summer temperatures at Dover are projected to be lower than those for the past summer
- ◊ As with the past few months, conditions in November were cooler than last year and cooler than the mean. The projected temperature for that month was off by less then 0.2 degrees.

The table of the predictions shows the projected value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). A plot of the projection is shown below. The Score is calculated as the deviation of the Point Forecast from the observed, scaled by the Mean for that Month.

Month	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Sep 2010	11.75	12.00	11.33	11.88	11.27	12.48	0.95
Oct 2010	12.66	12.60	12.31	12.27	11.66	12.87	1.00
Nov 2010	13.93	14.50	13.63	13.80	13.19	14.40	0.99
Dec 2010	15.22	15.00		14.37	13.77	14.97	
Jan 2011	16.50	17.00		15.83	15.1	16.56	
Feb 2011	16.86	18.30		16.90	16.13	17.68	
Mar 2011	16.06	17.10		16.11	15.32	16.91	



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Projection of water temperatures at salmon farm sites in Tasmania: Dover

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 10 January 2011
Based on montly data from January 1991

Summary of Projections

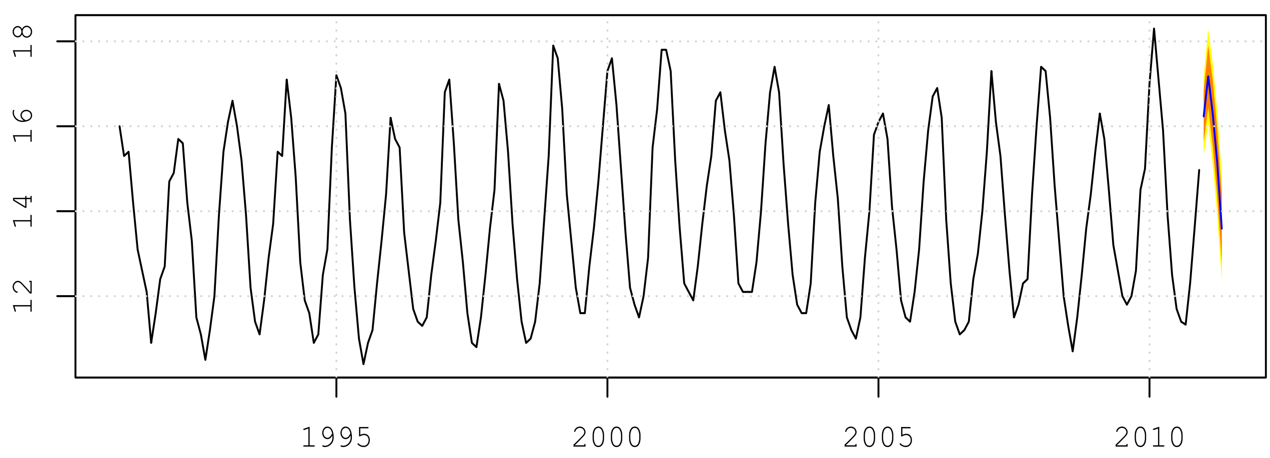
This projection is based on data up to and including the 31 December 2010 using monthly data from the Redcliffs site:

- ◊ Upcoming peak summer temperatures at Dover are still projected to be lower than those for the past summer, but projections are revised upwards from those supplied in December (for example by 0.4 degrees for the January projection, and less for the other months).
- ◊ As with the past few months, conditions in December were slightly cooler than last year and about the same as the mean. The projected temperature for that month was off by 0.6 degrees; with the Observed value being at the upper end of the 80% confidence band.

The table of the predictions shows the projected value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). A plot of the projection is shown below. The Score is calculated as the deviation of the Point Forecast from the observed, scaled by the Mean for that Month.

Month	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Sep 2010	11.75	12.00	11.33	11.88	11.27	12.48	0.95
Oct 2010	12.66	12.60	12.31	12.27	11.66	12.87	1.00
Nov 2010	13.93	14.50	13.63	13.80	13.19	14.40	0.99
Dec 2010	15.22	15.00	14.97	14.37	13.77	14.97	0.96
Jan 2011	16.50	17.00		16.23	15.63	16.84	
Feb 2011	16.86	18.30		17.17	16.45	17.9	
Mar 2011	16.06	17.10		16.3	15.52	17.07	

Dover Projection: January 2011 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Dover

CSIRO Climate Adaptation Flagship   Tasmanian Salmon Growers Association

National Research FLAGSHIPS Climate Adaptation   CSIRO

Projection Summary - 7 February 2011
Based on montly data from January 1991

Summary of Projections

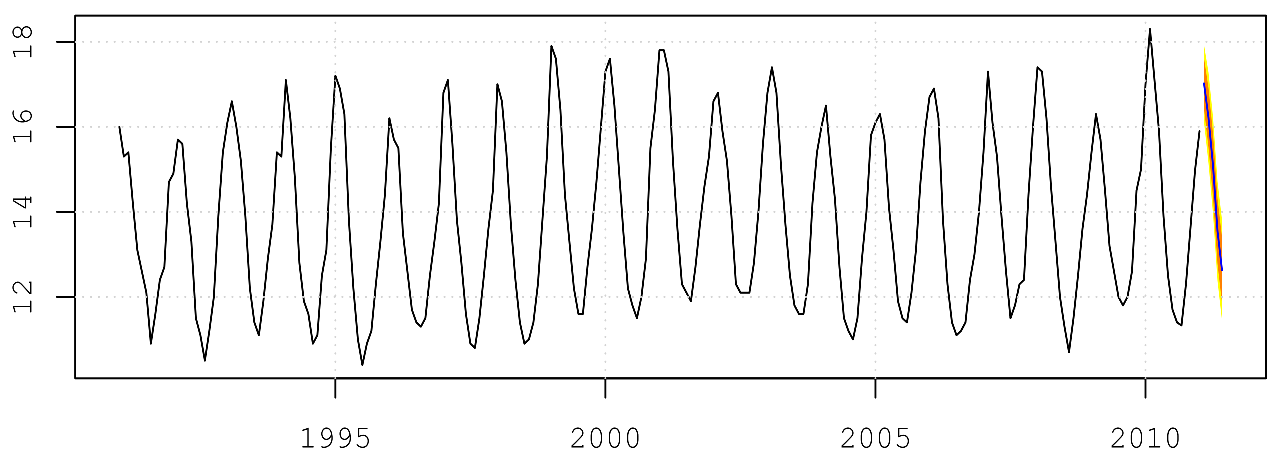
This projection is based on data up to and including the 31 January 2010 using monthly data from the Redcliffs site:

- Upcoming peak summer temperatures at Dover are still projected to be lower than those for the past summer, but slightly warmer than the Mean.
- As with the past few months, conditions in January were slightly cooler than last year and the Mean. The projected temperature for January was warmer by just over 0.3 degrees after it was revised upwards by about 0.4 degrees last month.

The table of the predictions shows the projected value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). A plot of the projection is shown below. The Score is calculated as the deviation of the Point Forecast from the observed, scaled by the Mean for that Month.

Month	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Sep 2010	11.75	12.00	11.33	11.88	11.27	12.48	0.95
Oct 2010	12.66	12.60	12.31	12.27	11.66	12.87	1.00
Nov 2010	13.93	14.50	13.63	13.80	13.19	14.40	0.99
Dec 2010	15.22	15.00	14.97	14.37	13.77	14.97	0.96
Jan 2011	16.50	17.00	15.90	16.23	15.63	16.84	0.98
Feb 2011	16.86	18.30		17.02	16.43	17.62	
Mar 2011	16.06	17.10		16.21	15.51	16.91	

Dover Projection: February 2011 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Dover

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 11 March 2011
Based on montly data from January 1991

Summary of Projections

This projection is based on data up to and including February using monthly data from the Redcliffs site:

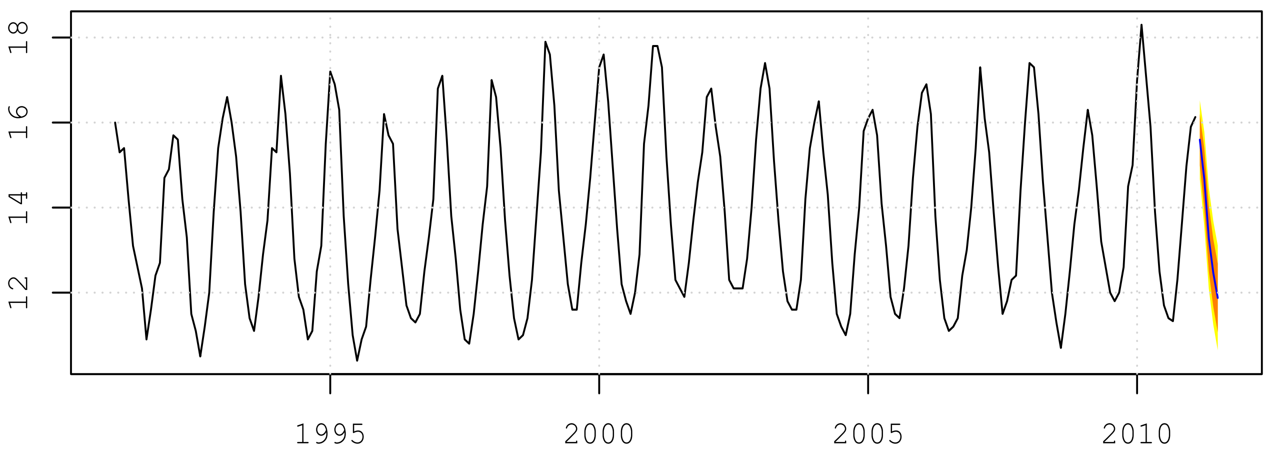
◊ As with the past few months, conditions in February were cooler than last year and the Mean. The projected temperature for February was warmer by almost 0.9 degrees.

◊ The projected temperature for March has been revised downward.

The table of the predictions shows the projected value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). A plot of the projection is shown below. The Score is calculated as the deviation of the Point Forecast from the observed, scaled by the Mean for that Month.

Month	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Sep 2010	11.75	12.00	11.33	11.88	11.27	12.48	0.95
Oct 2010	12.66	12.60	12.31	12.27	11.66	12.87	1.00
Nov 2010	13.93	14.50	13.63	13.80	13.19	14.40	0.99
Dec 2010	15.22	15.00	14.97	14.37	13.77	14.97	0.96
Jan 2011	16.50	17.00	15.90	16.23	15.63	16.84	0.98
Feb 2011	16.86	18.30	16.13	17.02	16.43	17.62	0.95
Mar 2011	16.06	17.10		15.60	14.99	16.20	

Dover Projection: March 2011 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Huon

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 22 September 2010
Based on montly data from January 1990 (derived from Tassal and Huon Aquaculture data)

Summary of Projections

Using our best available statistical tools, and within the limited time-frame for this project to date, our best estimates of the forthcoming summer conditions at the Huon salmon farm site are that:

- ◊ Overall, the ARIMA projections show cooler peak summer (Feb-Mar) temperatures (cooler than the Holt-Winters) compared to last year but warmer winters
- ◊ Taken together, our best estimates of the upcoming summer ranges from similar to cooler than last summer peak temperatures
- ◊ Data for the Tassal and Huon Aquaculture sites need to be monitored over the coming months to update these forecasts which are based on an amalgamation of incomplete records
- ◊ Projected August temperatures should be assessed, along with any data on September, to determine the relative accuracy of the two projections.

We used two methods (Holt-Winters and ARIMA) that provide good fits to the available data. The ARIMA estimates tend to be lower than the Holt-Winters and we will assess their respective prediction skill as the season progresses. For the moment, we are recommending the Holt-Winters projections be used. Full details of the methods are provided in a companion report that also assesses regional and global trends. The table of the predictions shows the projected value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the 95% confidence levels ("Lo 95" and "Hi 95"), the past year data ("Past_Year") and the overall mean ("Mean").

Huon	Mean	Past_Year	Point Forecast	Lo 80	Hi 80	Lo 95	Hi 95
ARIMA Aug 2010	11.37	11.40	11.68	10.98	12.38	10.61	12.76
ARIMA Sep 2010	11.73	11.40	11.93	11.11	12.75	10.68	13.18
ARIMA Oct 2010	12.56	12.30	12.36	11.50	13.21	11.05	13.66
ARIMA Nov 2010	13.90	14.90	14.03	13.16	14.89	12.70	15.35
ARIMA Dec 2010	15.16	14.70	14.72	13.85	15.60	13.39	16.06
ARIMA Jan 2011	16.44	16.51	16.04	15.16	16.91	14.70	17.37
ARIMA Feb 2011	16.79	17.83	16.85	15.98	17.73	15.51	18.19
ARIMA Mar 2011	15.92	17.10	15.90	15.03	16.77	14.56	17.24
HW Aug 2010	11.37	11.40	11.79	11.06	12.52	10.67	12.90
HW Sep 2010	11.73	11.40	12.11	11.32	12.91	10.90	13.33
HW Oct 2010	12.56	12.30	12.78	11.92	13.64	11.47	14.09
HW Nov 2010	13.90	14.90	14.60	13.69	15.52	13.20	16.01
HW Dec 2010	15.16	14.70	15.34	14.37	16.31	13.85	16.82
HW Jan 2011	16.44	16.51	16.87	15.84	17.90	15.30	18.44
HW Feb 2011	16.79	17.83	17.73	16.65	18.80	16.08	19.38
HW Mar 2011	15.92	17.10	16.67	15.54	17.80	14.94	18.40

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Projection of water temperatures at salmon farm sites in Tasmania: Huon

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 21 November 2010
Based on montly data from January 1990

Summary of Projections

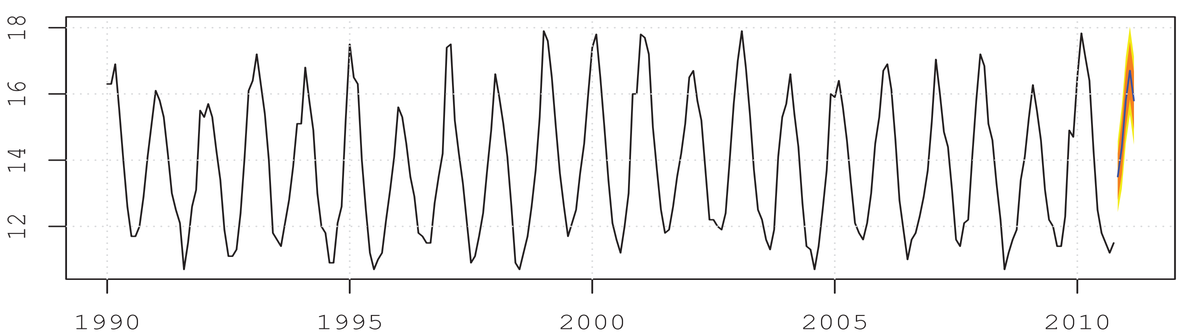
Following on from our last projections based on data up to July, this projection is based on data up to and including October using monthly data from the the Huon Smolt sites (Killala and Brabazon Point):

- ◊ From the two projection methods used, we have dropped the Holt-Winters method as the ARIMA method was more accurate. We have also provided in the Table below the Lower and Upper bounds for the 80% confidence intervals (these are narrower than the 95% ones).
- ◊ Cooler conditions than last year are still being projected.
- ◊ The observed October monthly temperature is the coolest on record - in fact 0.4 degrees cooler than the lowest previously recorded (in 2008). The projection for this month was warmer by just over 0.4 degrees.
- ◊ The algorithm projected warmer conditions than observed for August to October so there is currently a persistent bias in the projections compared to the observed. The algorithm is however adjusting to the unusually cooler conditions which are near the lower 80%.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). Point forecasts from November onwards are the projections based on data up till October. A plot of the projection is shown below.

Huon	Mean	Past_Year	Observed	Point Forecast	Lo 80	Hi 80
ARIMA Aug 2010	11.37	11.40	11.5	11.68	10.98	12.38
ARIMA Sep 2010	11.73	11.40	11.2	11.82	11.11	12.52
ARIMA Oct 2010	12.56	12.30	11.5	11.92	11.22	12.62
ARIMA Nov 2010	13.90	14.90		13.50	12.80	14.20
ARIMA Dec 2010	15.16	14.70		14.38	13.57	15.20
ARIMA Jan 2011	16.44	16.51		15.82	14.96	16.67
ARIMA Feb 2011	16.79	17.83		16.71	15.84	17.57
ARIMA Mar 2011	15.92	17.10		15.80	14.93	16.67

Huon Projection - November 2010 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Huon

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 13 December 2010
Based on montly data from January 1990

Summary of Projections

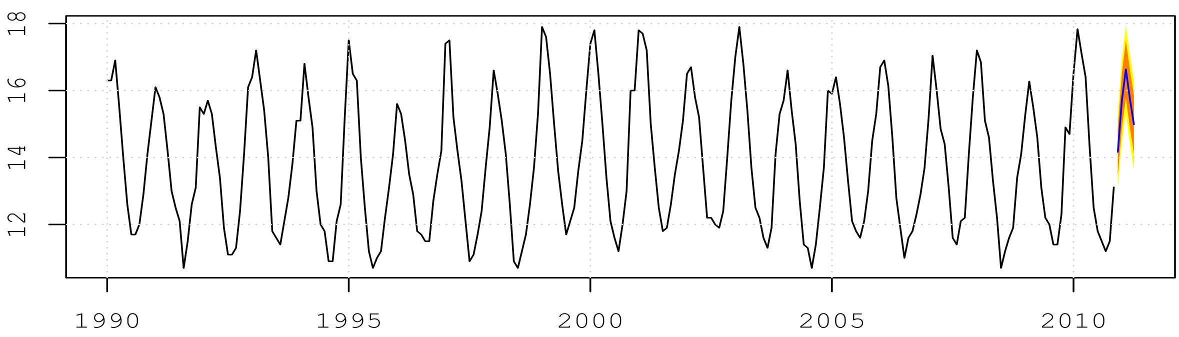
This projection is based on data up to and including November using monthly data from the the Huon Smolt sites (Killala and Brabazon Point):

- ◊ Cooler conditions than last year are still being projected.
- ◊ The observed November monthly temperature is cooler than the mean by almost 0.8 degrees, and almost 1.8 degrees cooler than last year. As with the past month, the projection for this month was warmer by about 0.4 degrees.
- ◊ The warmer bias in the projections compared to the observed. still persists.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). Point forecasts from December onwards are the projections based on data up till November. The Score is calculated as the deviation of the Point Forecast from the Observed, scaled by the Mean for that Month. A plot of the projection is shown below.

Month	Mean	Past_Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug 2010	11.37	11.40	11.50	11.68	10.98	12.38	0.98
Sep 2010	11.73	11.40	11.20	11.82	11.11	12.52	0.95
Oct 2010	12.56	12.30	11.50	11.92	11.22	12.62	0.97
Nov 2010	13.90	14.90	13.11	13.50	12.80	14.20	0.97
Dec 2010	15.16	14.70		14.17	13.47	14.87	
Jan 2011	16.44	16.51		15.69	14.87	16.51	
Feb 2011	16.79	17.83		16.63	15.78	17.49	
Mar 2011	15.92	17.10		15.76	14.89	16.63	

Huon Projection: December 2010 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Huon

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

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CSIRO

Projection Summary - 10 January 2011
Based on montly data from January 1990

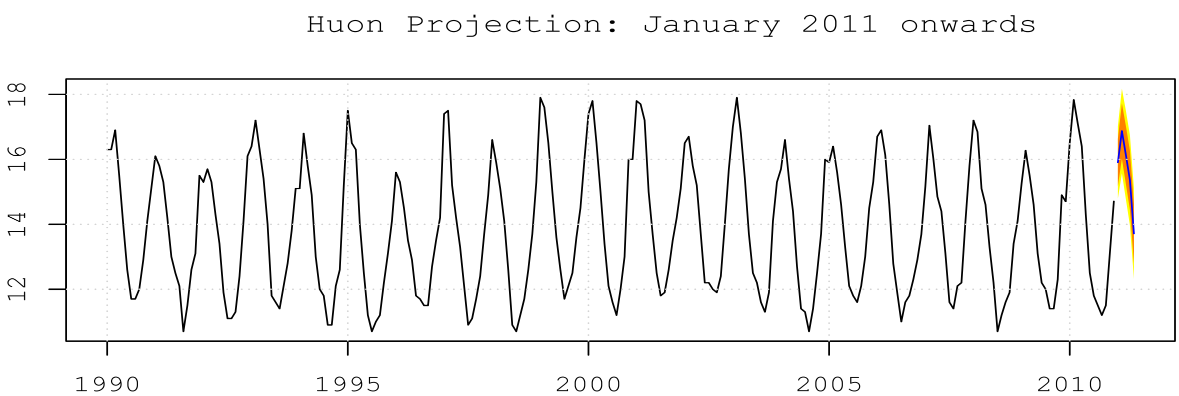
Summary of Projections

This projection is based on data up to and including December 2010 using monthly data from the the Huon Smolt sites (Killala and Brabazon Point):

- ◊ Cooler conditions than last year are still being projected but projections are slightly higher than the mean for February and March.
- ◊ The Observed December monthly temperature was almost equal to that last year. In contrast to the past month, the projection for December was cooler by 0.54 degrees. Projections for the upcoming months have been revised upward compared to those supplied last month.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). The Score is calculated as the deviation of the Point Forecast from the Observed, scaled by the Mean for that Month. A plot of the projection is shown below.

Month	Mean	Past_Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug 2010	11.37	11.40	11.50	11.68	10.98	12.38	0.98
Sep 2010	11.73	11.40	11.20	11.82	11.11	12.52	0.95
Oct 2010	12.56	12.30	11.50	11.92	11.22	12.62	0.97
Nov 2010	13.90	14.90	13.11	13.50	12.80	14.20	0.97
Dec 2010	15.16	14.70	14.71	14.17	13.47	14.87	0.96
Jan 2011	16.44	16.51		15.90	15.18	16.63	
Feb 2011	16.79	17.83		16.87	16.02	17.72	
Mar 2011	15.92	17.10		16.13	15.24	17.02	



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Projection of water temperatures at salmon farm sites in Tasmania: Huon

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 7 February 2011
Based on montly data from January 1990

Summary of Projections

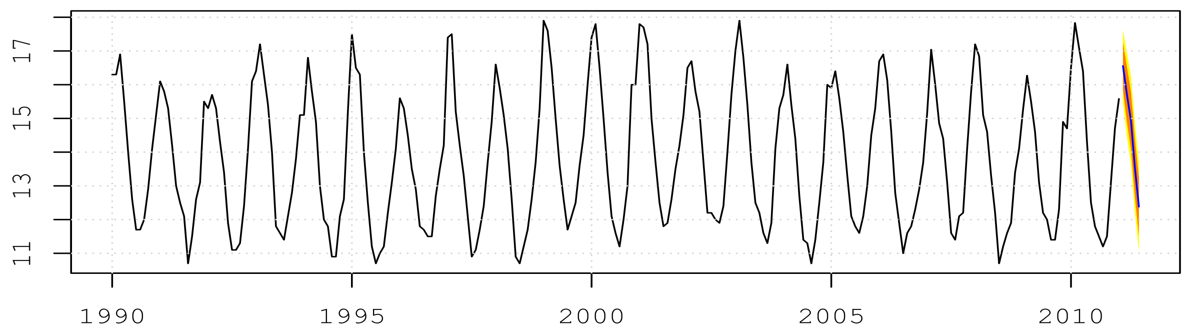
This projection is based on data up to and including January 2010. As the Huon smolt site data for Killala and Brabazon Point were not available for January, we used the Roaring site data from Huon Aquaculture.

- ◊ Cooler conditions than last year are still being projected and projections are slightly lower than the mean for February and March.
- ◊ The Observed January monthly temperature was cooler than the projection, and we are uncertain how much, if any, of the deviation is due to differences between the smolt sites and the Roaring site.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). The Score is calculated as the deviation of the Point Forecast from the Observed, scaled by the Mean for that Month. A plot of the projection is shown below.

Month	Mean	Past_Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug 2010	11.37	11.40	11.50	11.68	10.98	12.38	0.98
Sep 2010	11.73	11.40	11.20	11.82	11.11	12.52	0.95
Oct 2010	12.56	12.30	11.50	11.92	11.22	12.62	0.97
Nov 2010	13.90	14.90	13.11	13.50	12.80	14.20	0.97
Dec 2010	15.16	14.70	14.71	14.17	13.47	14.87	0.96
Jan 2011	16.44	16.51	*15.58*	15.90	15.18	16.63	0.98
Feb 2011	16.79	17.83		16.56	15.86	17.26	
Mar 2011	15.92	17.10		15.71	14.89	16.52	

Huon Projection: February 2011 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Huon

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 11 March 2011
Based on montly data from January 1990

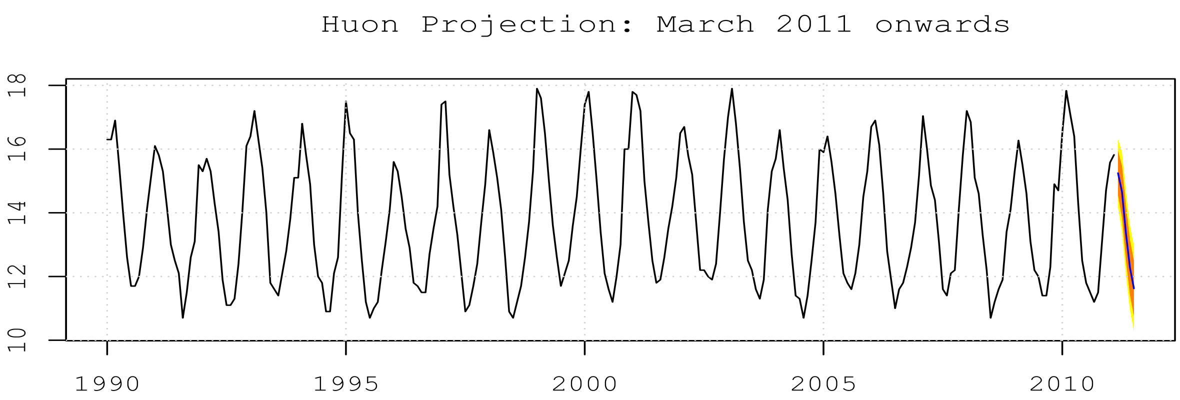
Summary of Projections

This projection is based on data up to and including February 2010. As the Huon smolt site data for Killala and Brabazon Point were not available for January, we used the Roaring site data from Huon Aquaculture.

- ◊ Cooler conditions prevailed over February and the projection is for that trend to persist through March.
- ◊ The Observed February monthly temperature was cooler than the projection and his led to a doward correction for the March projection.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). The Score is calculated as the deviation of the Point Forecast from the Observed, scaled by the Mean for that Month. A plot of the projection is shown below.

Month	Mean	Past_Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug 2010	11.37	11.40	11.50	11.68	10.98	12.38	0.98
Sep 2010	11.73	11.40	11.20	11.82	11.11	12.52	0.95
Oct 2010	12.56	12.30	11.50	11.92	11.22	12.62	0.97
Nov 2010	13.90	14.90	13.11	13.50	12.80	14.20	0.97
Dec 2010	15.16	14.70	14.71	14.17	13.47	14.87	0.96
Jan 2011	16.44	16.51	*15.58*	15.90	15.18	16.63	0.98
Feb 2011	16.79	17.83	*15.82*	16.56	15.86	17.26	0.96
Mar 2011	15.92	17.10		15.25	14.55	15.95	



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Projection of water temperatures at salmon farm sites in Tasmania: Macquarie Harbour

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 22 September 2010
Based on montly data from February
2006 for the Table site

Summary of Projections

Using our best available statistical tools, and within the limited time-frame for this project to date, our best estimates of the forthcoming summer conditions at the Macquarie Harbour salmon farm site are that:

- ◊ The time series at Macquarie Harbour is relatively short and inter-annual variability in the seasonal signal is high
- ◊ Broad structural features in the Strahan Aerodrome correspond to the Table site temperatures where they overlap
- ◊ Cooler summer peak temperatures are projected for next year
- ◊ At a regional level we find that the Strahan temperature signal most closely reflects that seen in the west SST series at the 75% level - meaning that temperatures reflect the warmest ocean conditions off west coast of Tasmania. This offers some hope of using SST to assist in predicting the trend at the farm site

We used two methods (Holt-Winters and ARIMA) that provide good fits to the available data. The ARIMA estimates tend to be lower than the Holt-Winters and we will assess their respective prediction skill as the season progresses. For the moment, we are recommending the Holt-Winters projections be used. Full details of the methods are provided in a companion report that also assesses regional and global trends. The table of the predictions shows the projected value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the 95% confidence levels ("Lo 95" and "Hi 95"), the past year data ("Past_Year") and the overall mean ("Mean").

M Habour	Mean	Past_Year	Point Forecast	Lo 80	Hi 80	Lo 95	Hi 95
ARIMA Sep-10	11.27	10.61	11.12	9.90	12.34	9.25	12.98
ARIMA Oct-10	12.77	13.28	13.23	11.85	14.62	11.11	15.35
ARIMA Nov-10	15.57	17.03	15.63	14.20	17.05	13.44	17.81
ARIMA Dec-10	16.52	16.62	15.94	14.50	17.38	13.73	18.14
ARIMA Jan-11	17.81	18.63	16.98	15.54	18.43	14.78	19.19
ARIMA Feb-11	18.70	19.97	18.71	17.27	20.16	16.50	20.92
ARIMA Mar-11	17.23	17.87	16.96	15.52	18.41	14.75	19.17
ARIMA Apr-11	14.64	15.82	15.04	13.59	16.48	12.83	17.25
HW Sep-10	11.27	10.61	11.61	10.29	12.94	9.59	13.64
HW Oct-10	12.77	13.28	13.65	12.30	15.00	11.59	15.72
HW Nov-10	15.57	17.03	16.53	15.16	17.91	14.44	18.63
HW Dec-10	16.52	16.62	16.89	15.49	18.28	14.76	19.02
HW Jan-11	17.81	18.63	18.38	16.96	19.79	16.21	20.54
HW Feb-11	18.70	19.97	19.78	18.34	21.22	17.58	21.98
HW Mar-11	17.23	17.87	17.94	16.48	19.40	15.70	20.17
HW Apr-11	14.64	15.82	15.81	14.33	17.30	13.55	18.08

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Projection of water temperatures at salmon farm sites in Tasmania: Macquarie Harbour

CSIRO Climate Adaptation Flagship Tasmanian Salmon Growers Association

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 22 November 2010
Based on montly data from February 2006 for the Table site

Summary of Projections

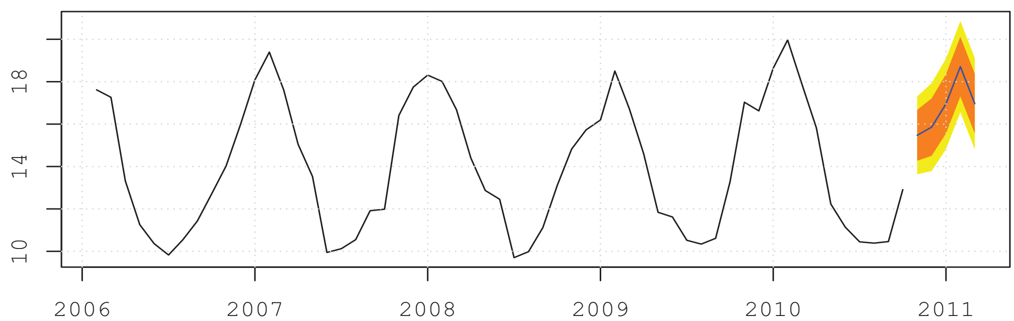
Following on from our last projections based on data up to August this projection is based on data up to and including October using monthly data from the Table site in Macquarie Harbour:

- From the two projection methods used, we have dropped the Holt-Winters method as the ARIMA method was more accurate. We have also provided in the Table below the Lower and Upper bounds for the 80% confidence intervals (these are narrower than the 95% ones). A projection for August is included in the Table below (based on data up to July).
- Cooler conditions than last year are still being projected.
- The observed September monthly temperature is relatively cool (coldest on the record was 10.43 in 2006). The projection for this month was warmer by 0.66 degrees.
- Projections for August and October match the observed temperature well.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). Point forecasts from November onwards are the projections based on data up till October. A plot of the projection is shown below.

M Habour	Mean	Past_Year	Observed	Point Forecast	Lo 80	Hi 80
ARIMA Aug-10	10.36	10.34	10.39	10.50	9.26	11.73
ARIMA Sep-10	11.27	10.61	10.46	11.12	9.90	12.34
ARIMA Oct-10	12.77	13.28	12.91	12.88	11.67	14.10
ARIMA Nov-10	15.57	17.03		15.47	14.27	16.67
ARIMA Dec-10	16.52	16.62		15.86	14.50	17.21
ARIMA Jan-11	17.81	18.63		16.96	15.56	18.35
ARIMA Feb-11	18.70	19.97		18.71	17.30	20.12
ARIMA Mar-11	17.23	17.87		16.96	15.55	18.37

Macquarie Habour Projection – November 2010 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Macquarie Harbour

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation

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Projection Summary - 11 December 2010
Based on montly data from February 2006 for the Table site

Summary of Projections

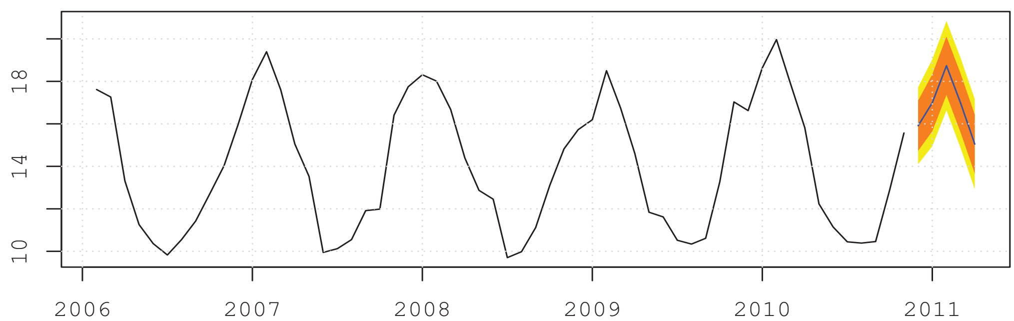
This projection is based on data up to and including November using monthly data from the Table site in Macquarie Harbour:

- As with the other sites, we have dropped the Holt-Winters method as the ARIMA method was more accurate.
- Cooler conditions than last year are still being projected, but we note the warm Observed conditions in early December (not shown), which are not projected to continue.
- The observed November monthly temperature is equal to the mean and cooler than last year. The projection for this month was cooler by 0.1 degrees.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). Point forecasts from December onwards are the projections based on data up till November. The Score is calculated as the deviation of the Point Forecast from the Observed, scaled by the Mean for that Month. A plot of the projection is shown below.

Month	Mean	Past_Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug-10	10.36	10.34	10.39	10.50	9.26	11.73	0.99
Sep-10	11.27	10.61	10.46	11.12	9.90	12.34	0.94
Oct-10	12.77	13.28	12.91	12.88	11.67	14.10	1.00
Nov-10	15.57	17.03	15.57	15.47	14.27	16.67	0.99
Dec-10	16.52	16.62		15.91	14.73	17.10	
Jan-11	17.81	18.63		16.99	15.65	18.33	
Feb-11	18.70	19.97		18.74	17.36	20.11	
Mar-11	17.23	17.87		16.98	15.59	18.36	

Macquarie Harbour Projection: December 2010 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Macquarie Harbour

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 10 January 2011
Based on montly data from February 2006 for the Table site

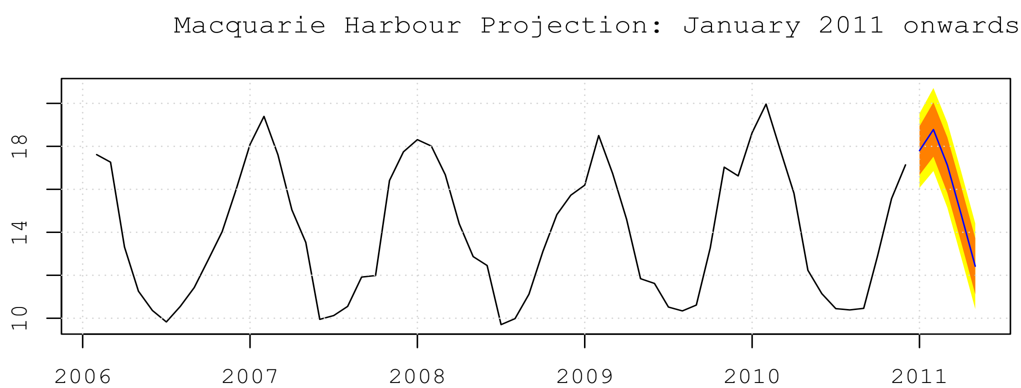
Summary of Projections

This projection for Macquarie Harbour is based on data from the Table site up till the 9th December when the logger broke loose. The rest of the month was based on data from the Liberty site and we made no allowance for site differences in the projections.

- ◊ Cooler conditions than last year are still being projected, and about equal to the Mean.
- ◊ The Observed December average was much higher than the projection (the worst projection for all the sites and months so far). We ssupect local influences at play that need to be resolved to improve the projections.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). The Score is calculated as the deviation of the Point Forecast from the Observed, scaled by the Mean for that Month. A plot of the projection is shown below.

Month	Mean	Past_Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug-10	10.36	10.34	10.39	10.50	9.26	11.73	0.99
Sep-10	11.27	10.61	10.46	11.12	9.90	12.34	0.94
Oct-10	12.77	13.28	12.91	12.88	11.67	14.10	1.00
Nov-10	15.57	17.03	15.57	15.47	14.27	16.67	0.99
Dec-10	16.52	16.62	17.14	15.91	14.73	17.10	0.93
Jan-11	17.81	18.63		17.80	16.67	18.93	
Feb-11	18.70	19.97		18.78	17.52	20.05	
Mar-11	17.23	17.87		17.12	15.83	18.42	



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Projection of water temperatures at salmon farm sites in Tasmania: Macquarie Harbour

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 02 February 2011
Based on montly data from February 2006 for the Table site

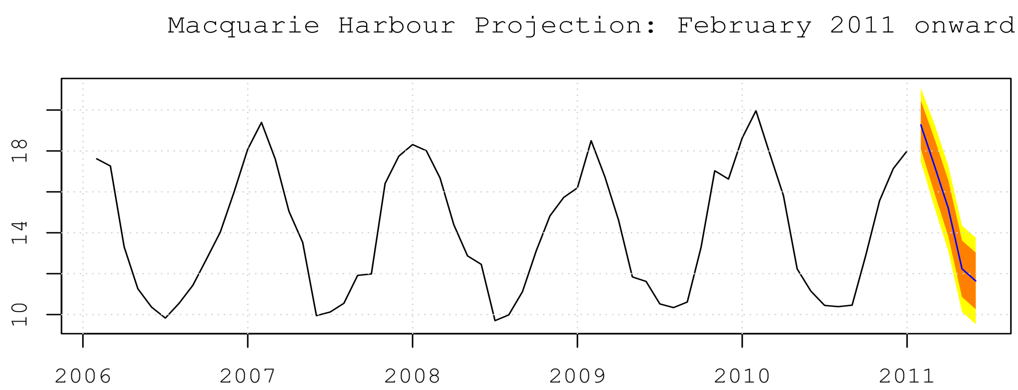
Summary of Projections

This projection for Macquarie Harbour is based on data from the Table site. Unfortunately the logger at the Table site became flooded at some point during the month so data from the Liberty Point site was substituted.

- ◊ Cooler conditions than last year are still being projected, and 0.58 degrees warmer than the Mean.
- ◊ The Observed January average matched the Point Forecast well, despite the deviation seen in the previous month (December).

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). The Score is calculated as the deviation of the Point Forecast from the Observed, scaled by the Mean for that Month. A plot of the projection is shown below.

Month	Mean	Past_Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug-10	10.36	10.34	10.39	10.50	9.26	11.73	0.99
Sep-10	11.27	10.61	10.46	11.12	9.90	12.34	0.94
Oct-10	12.77	13.28	12.91	12.88	11.67	14.10	1.00
Nov-10	15.57	17.03	15.57	15.47	14.27	16.67	0.99
Dec-10	16.52	16.62	17.14	15.91	14.73	17.10	0.93
Jan-11	17.81	18.63	18.00	17.80	16.67	18.93	0.99
Feb-11	18.70	19.97		19.28	18.1	20.46	
Mar-11	17.23	17.87		17.27	15.94	18.6	



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Projection of water temperatures at salmon farm sites in Tasmania: Macquarie Harbour

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

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Projection Summary - 11 March 2011
Based on montly data from February 2006 for the Table site

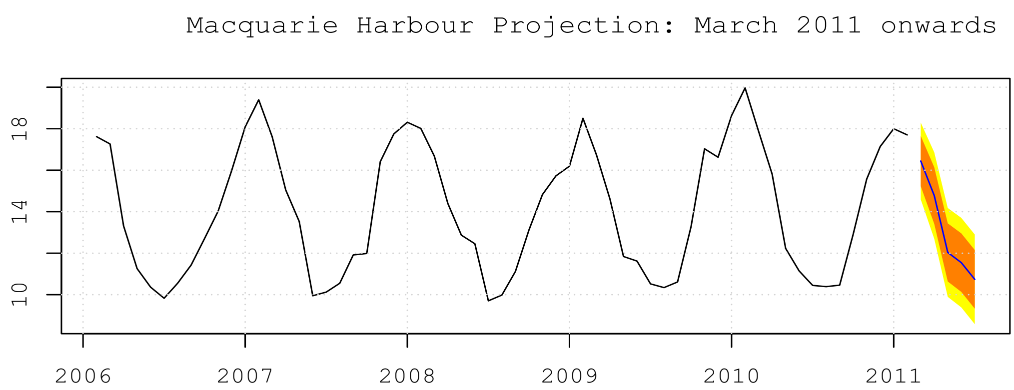
Summary of Projections

This projection for Macquarie Harbour is based on data from the Table site. Unfortunately the logger at the Table site became flooded at some point during the month so data from the Liberty Point site was substituted.

- Cooler conditions than last year and the Mean are being projected.
- The Observed February was well below the projected and well below the Mean. This was the worst projection on record for all sites and months.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). The Score is calculated as the deviation of the Point Forecast from the Observed, scaled by the Mean for that Month. A plot of the projection is shown below.

Month	Mean	Past_Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug-10	10.36	10.34	10.39	10.50	9.26	11.73	0.99
Sep-10	11.27	10.61	10.46	11.12	9.90	12.34	0.94
Oct-10	12.77	13.28	12.91	12.88	11.67	14.10	1.00
Nov-10	15.57	17.03	15.57	15.47	14.27	16.67	0.99
Dec-10	16.52	16.62	17.14	15.91	14.73	17.10	0.93
Jan-11	17.81	18.63	18.00	17.80	16.67	18.93	0.99
Feb-11	18.70	19.97	17.70	19.28	18.1	20.46	0.92
Mar-11	17.23	17.87		16.44	15.23	17.65	



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Projection of water temperatures at salmon farm sites in Tasmania: Tasman

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 22 November 2010
Based on montly data from January 1997

Summary of Projections

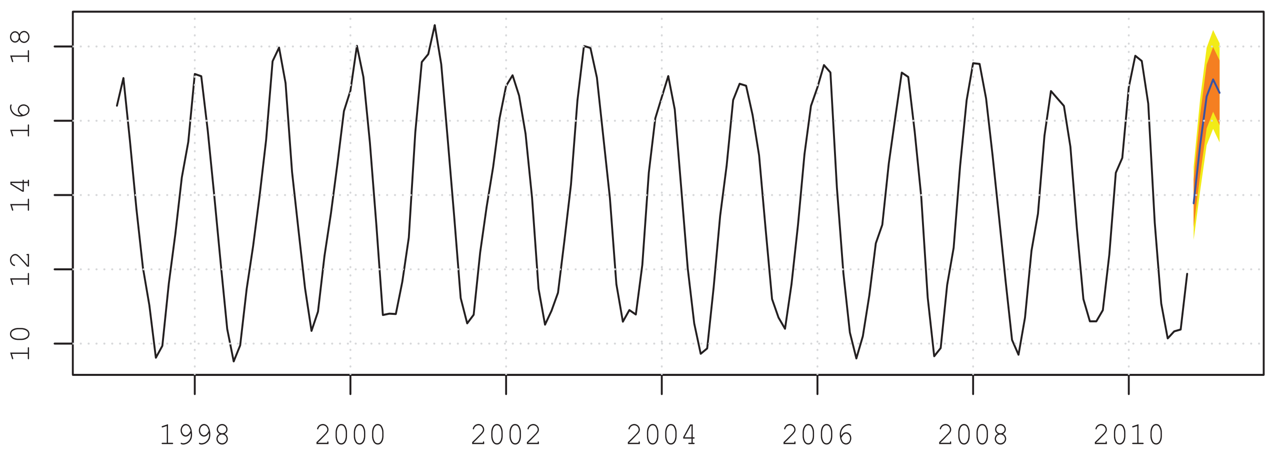
This is our start of the projections for the Tasman site (Nubeena: Creesses and Badger) using data supplied by Tassal. The series begins from January 1997. The key points of the projections are:

- Overall cooler conditions than last year are projected. Observations from August to October are also cooler, particularly September which is the coolest on record (by about 0.4 degrees).
- Withe the exception of the very cool September, projections are within 0.2 degrees for the one-month ahead forecast. The September projection was warmer by just under 0.6 degrees.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). Point forecasts from November onwards are the projections based on data up till October. A plot of the projection is shown below.

Dover	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80
ARIMA Aug 2010	10.37	10.60	10.33	10.13	9.49	10.77
ARIMA Sep 2010	11.49	10.90	10.38	10.95	10.31	11.59
ARIMA Oct 2010	12.87	12.40	11.88	12.01	11.37	12.66
ARIMA Nov 2010	14.51	14.60		13.78	13.13	14.42
ARIMA Dec 2010	16.03	15.00		15.35	14.54	16.16
ARIMA Jan 2011	17.05	16.90		16.65	15.79	17.51
ARIMA Feb 2011	17.49	17.75		17.11	16.24	17.98
ARIMA Mar 2011	16.74	17.61		16.75	15.88	17.62

Tasman Projection - November 2010 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Tasman

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 7 December 2010
Based on montly data from January 1997

Summary of Projections

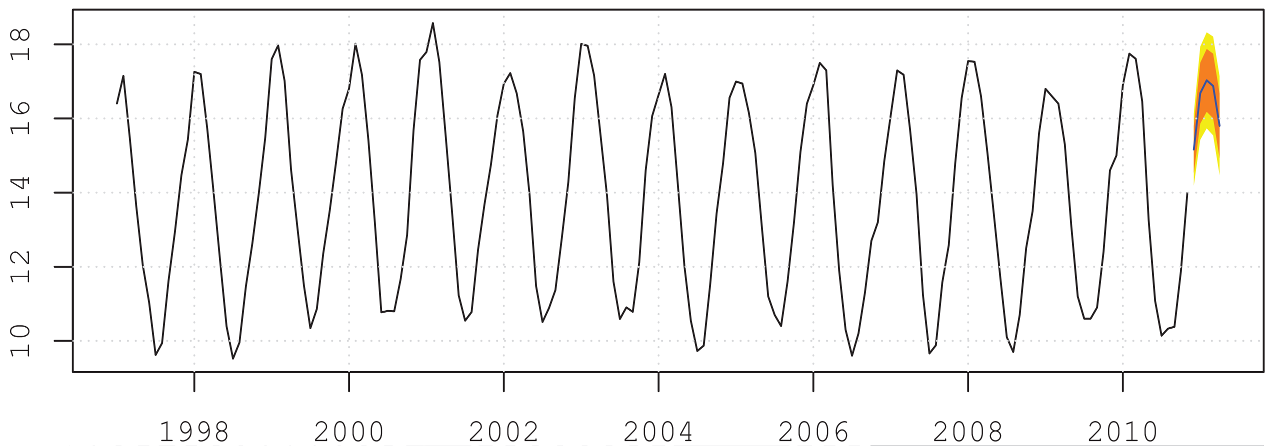
Projections for the Tasman site (Nubeena: Creesses and Badger) are presented using data supplied by Tassal up till November 2010. The series begins from January 1997. The key points of the projections are:

- ◊ Similar conditions to last year are projected over the next two months but heading into a cooler summer.
- ◊ Projected November conditions were slightly cooler than observed, but tracking well apart from the very cool observed September.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). Point forecasts from November onwards are the projections based on data up till October. A plot of the projection is shown below. The Score is calculated as the deviation of the Point Forecast from the observed, scaled by the Mean for that Month.

Month	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug 2010	10.37	10.60	10.33	10.13	9.49	10.77	0.98
Sep 2010	11.49	10.90	10.38	10.95	10.31	11.59	0.95
Oct 2010	12.87	12.40	11.88	12.01	11.37	12.66	0.99
Nov 2010	14.51	14.60	13.99	13.78	13.13	14.42	0.99
Dec 2010	16.03	15.00		15.16	14.52	15.8	
Jan 2011	17.05	16.90		16.68	15.86	17.51	
Feb 2011	17.49	17.75		17.03	16.18	17.88	
Mar 2011	16.74	17.61		16.88	16.01	17.75	

Tasman Projection: December 2010 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Tasman

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

National Research FLAGSHIPS Climate Adaptation CSIRO

Projection Summary - 10 January 2011
Based on montly data from January 1997

Summary of Projections

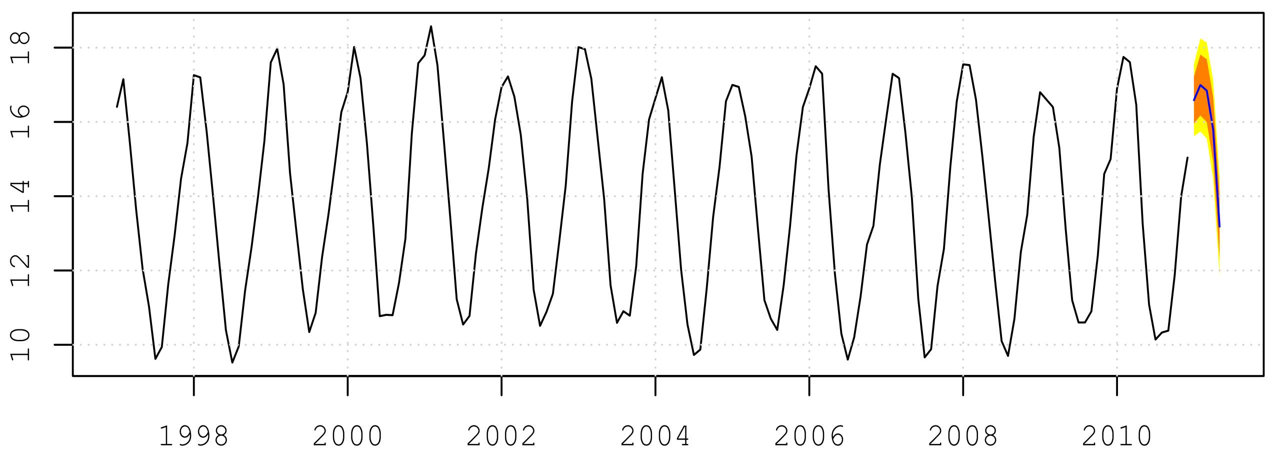
Projections for the Tasman site (Nubeena: Creesses and Badger) are presented using data supplied by Tassal up till December 2010. The series begins from January 1997. The key points of the projections are:

- ◊ Slightly cooler conditions than last year are projected over the next three months.
- ◊ Projected December conditions were slightly warmer than observed, but tracking well apart from the very cool observed September.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). A plot of the projection is shown below. The Score is calculated as the deviation of the Point Forecast from the observed, scaled by the Mean for that Month.

Month	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug 2010	10.37	10.60	10.33	10.13	9.49	10.77	0.98
Sep 2010	11.49	10.90	10.38	10.95	10.31	11.59	0.95
Oct 2010	12.87	12.40	11.88	12.01	11.37	12.66	0.99
Nov 2010	14.51	14.60	13.99	13.78	13.13	14.42	0.99
Dec 2010	16.03	15.00	15.04	15.16	14.52	15.80	0.99
Jan 2011	17.05	16.90		16.59	15.95	17.22	
Feb 2011	17.49	17.75		16.99	16.17	17.81	
Mar 2011	16.74	17.61		16.84	16.00	17.69	

Tasman Projection: January 2011 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Tasman

CSIRO Climate Adaptation Flagship   Tasmanian Salmon Growers Association

National Research FLAGSHIPS Climate Adaptation   CSIRO

Projection Summary - 7 February 2011
Based on montly data from January 1997

Summary of Projections

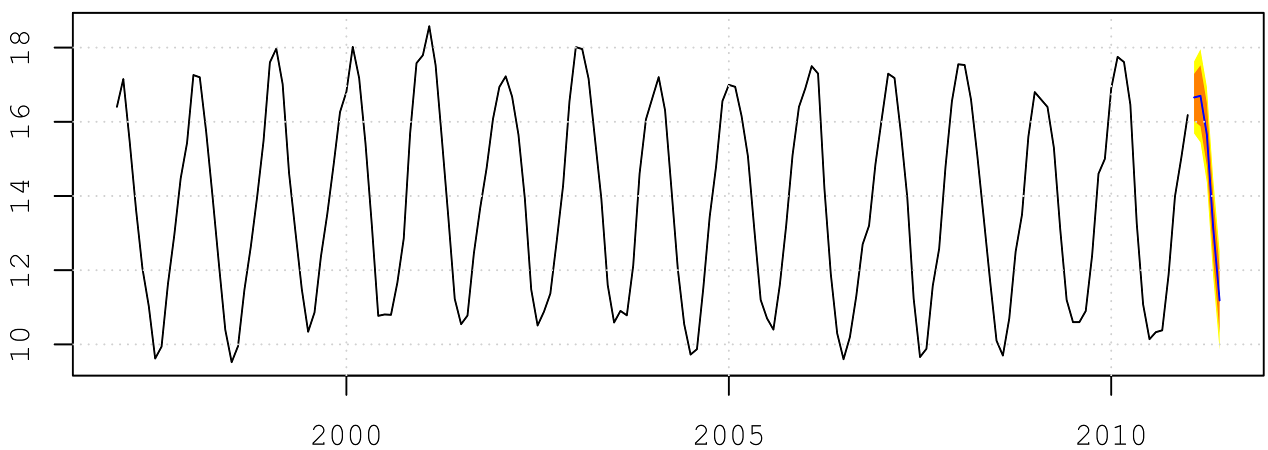
Projections for the Tasman site (Nubeena: Creesses and Badger) are presented using data supplied by Tassal up till January 2011. The series begins from January 1997. The key points of the projections are:

- ◊ Cooler conditions than last year and the Mean persisted, and this is also the projected trend for February.
- ◊ Projected January conditions were slightly warmer than observed, but tracking well apart from the very cool observed September.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). A plot of the projection is shown below. The Score is calculated as the deviation of the Point Forecast from the observed, scaled by the Mean for that Month.

Month	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug 2010	10.37	10.60	10.33	10.13	9.49	10.77	0.98
Sep 2010	11.49	10.90	10.38	10.95	10.31	11.59	0.95
Oct 2010	12.87	12.40	11.88	12.01	11.37	12.66	0.99
Nov 2010	14.51	14.60	13.99	13.78	13.13	14.42	0.99
Dec 2010	16.03	15.00	15.04	15.16	14.52	15.80	0.99
Jan 2011	17.05	16.90	16.18	16.59	15.95	17.22	0.98
Feb 2011	17.49	17.75		16.66	16.02	17.29	
Mar 2011	16.74	17.61		16.70	15.88	17.52	

Tasman Projection: February 2011 onwards



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Projection of water temperatures at salmon farm sites in Tasmania: Tasman

CSIRO Climate Adaptation Flagship **Tasmanian Salmon Growers Association**

Projection Summary - 11 March 2011
Based on montly data from January 1997

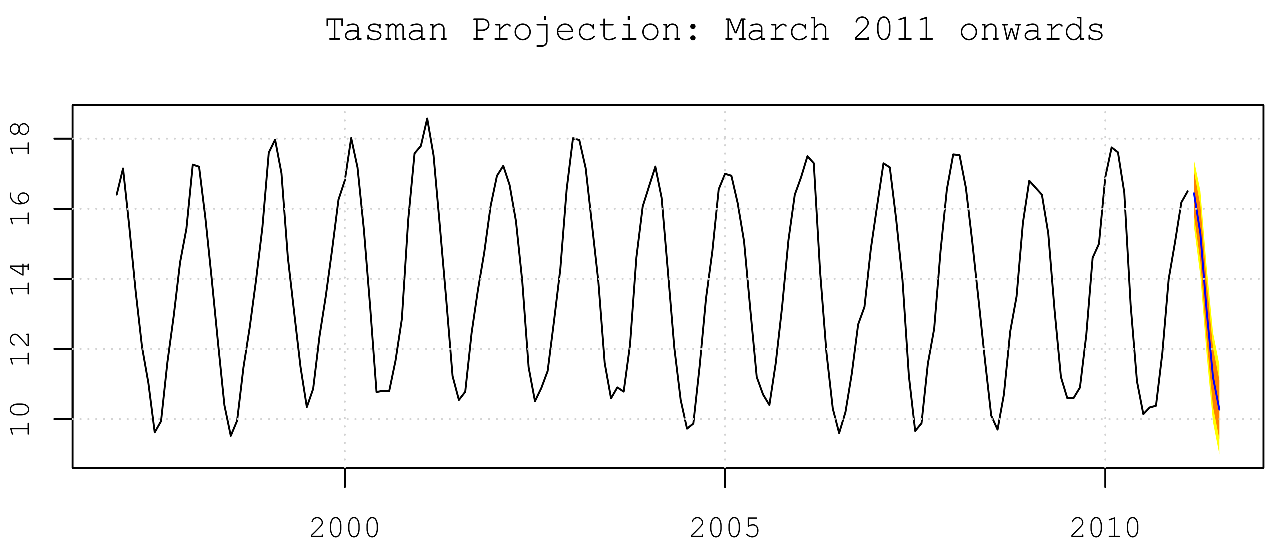
Summary of Projections

Projections for the Tasman site (Nubeena: Creesses and Badger) are presented using data supplied by Tassal up till January 2011. The series begins from January 1997. The key points of the projections are:

- ◊ Cooler conditions than last year and the Mean persisted - in line with the projection.
- ◊ The cooler conditions are projected to extend into March.

The table of the predictions shows the projected one-month ahead value ("Point Forecast"), 80% confidence levels ("Lo 80" and "Hi 80"), the observed temperature ("Observed"), the past year data ("Past Year") and the overall mean ("Mean"). A plot of the projection is shown below. The Score is calculated as the deviation of the Point Forecast from the observed, scaled by the Mean for that Month.

Month	Mean	Past Year	Observed	Point Forecast	Lo 80	Hi 80	Score
Aug 2010	10.37	10.60	10.33	10.13	9.49	10.77	0.98
Sep 2010	11.49	10.90	10.38	10.95	10.31	11.59	0.95
Oct 2010	12.87	12.40	11.88	12.01	11.37	12.66	0.99
Nov 2010	14.51	14.60	13.99	13.78	13.13	14.42	0.99
Dec 2010	16.03	15.00	15.04	15.16	14.52	15.80	0.99
Jan 2011	17.05	16.90	16.18	16.59	15.95	17.22	0.98
Feb 2011	17.49	17.75	16.50	16.66	16.02	17.29	0.99
Mar 2011	16.74	17.61		16.44	15.82	17.06	



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