final report

Project code: B.FLT.4004

Prepared by: Esteban Abellán, Christine Killip, and Shelby Cunliffe
Weather Intelligence Pty Ltd

Date published: 16 April 2019

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 1961
NORTH SYDNEY NSW 2059

Heat Load Index Forecast Season 2018-2019

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

Executive summary

Heat stress in feedlot cattle can have a deleterious effect on cattle performance and in extreme cases lead to cattle death. The National Feedlot Accreditation Scheme requires that feedlots have a heat stress management plan in place to cope with weather events that can lead to excessive heat loads. The Cattle Heat Load Toolbox, developed by Katestone and now operated by Weather Intelligence (a Katestone Company), alerts feedlot operators of impending adverse weather conditions that could lead to excessive heat load in feedlot cattle.

The toolbox is web based and provides access to weather and heat load forecasts out one week and risk assessment programs. The service is underpinned by over 17 years of research into cattle heat load funded by Meat and Livestock Australia (MLA). The Cattle Heat Load Toolbox brings all this research together and uses a world class weather forecasting system to generate accurate forecasts across Australia. This service provides useful and practical information to help feedlot operators manage heat stress in cattle through advanced warning of adverse conditions. Thus, allowing operators time to undertake appropriate actions to mitigate the risk of heat stress when alerted.

Katestone has been providing this service for over 12 years and in that time the service has grown from 16 to 347 forecast locations (including 66 public sites). The forecast for the service is generated using the Weather Research & Forecasting model. The system is monitored by Weather Intelligence scientists throughout the summer season and assessed for performance in predicting the location, magnitude and duration of heat load events. The system has proven to accurately predict these key features and alert the relevant operators of the impending situation.

There are currently 591 subscribers, 274 user sites (271 feedlots and 3 abattoirs) registered to use the forecasting service, covering nearly a million head of feedlot cattle across Australia. This season saw 3 new feedlots register for the service.

Feedlot Operators subscribe to the service free of charge and request a forecast for their feedlot. Subscribers also define risk alert levels suitable to their feedlot management and cattle type and condition through the Risk Assessment Program. Alerts are sent daily by email or SMS to designated recipients (e.g. site managers, veterinarians).

The service provides early warning of potential major heat load events and rapid changes in the HLI through the automated alerts system and regular updates on the web site.

Overall the system performed well in predicting the HLI on an hour by hour basis for much of the forecast period. Feedback from the end of season survey indicates that there is a high level of satisfaction with the forecast accuracy, from most respondents in the survey.

A separate project to update the RAP, a tool used to assess the long-term risk of heat events at individual sites, was also undertaken. Following a detailed verification study and consultation with an ALFA working group it was decided to keep the current RAP until further research is completed. A summary of the work undertaken is presented in this report.

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1 Project objectives

The Cattle Heat Load Toolbox (**Error! Reference source not found.**) was developed to assist in warning feedlot operators of impending adverse weather conditions that could lead to excessive heat loads (and potential mortality) for feedlot cattle. The objectives of the project are to:

1. Provided a daily forecast of heat load to the Australian feedlot sector, incorporating:
    a. Continuous monitoring of infrastructure to ensure the security and continued provision of the service.
    b. Timely update of the forecasts, plus review of forecast delivery and performance on a daily basis.
    c. Ongoing integration of new subscribers into the HLDN, plus regular checks with existing users to ensure everything is functioning correctly.

2. Undertaken upgrades to the service and ancillary aspects of the CHLT to:
    a. Re-order the RAP so that it better reflects the climatic heat load risk associated with a particular site.
    b. Update the data that underpins the RAP housed within the CHLT.

2 Service Use

A total of 591 subscribers, 274 user sites (271 feedlots and 3 abattoirs) are currently registered for the CHLT (Fig. 1). The decrease in the number of subscribers during the 2017-18 season is explained by the database clean up that was carried out at the beginning of that season. Sites with no users associated with the site were removed from the system.

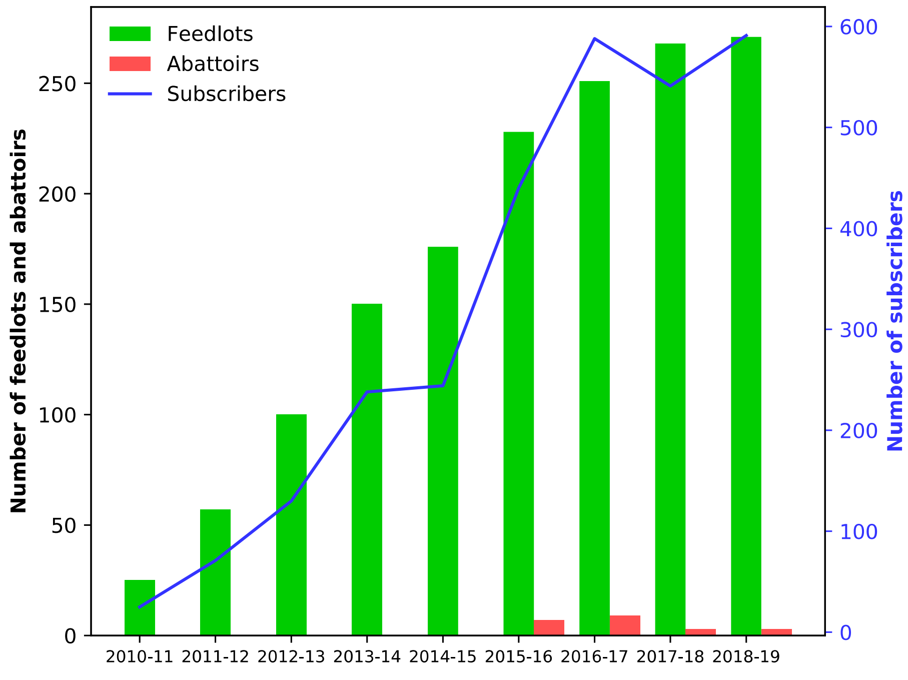


Fig. 1 Uptake of the CHLT service since its launch in 2010-11

There are now 52 feedlots participating in the Heat Load Data Network (HLDN) and 55 onsite weather stations. There are 3 feedlots that have 2 weather stations. The HLDN integrates the onsite weather station data into the CHLT system every hour (if the data is available), initialising the predicted AHLU from the measured data. However, most sites upload the weather data every 4, 6 or 24 hours. HLDN data is also displayed on the feedlots CHLT My Site page. The observations of the current day are proceeded by the forecast for the balance of the day. The user can also check the observations for the last 7 days and the forecast for the next 7 days (including the current day). The facility to download all observations as a file is also available.

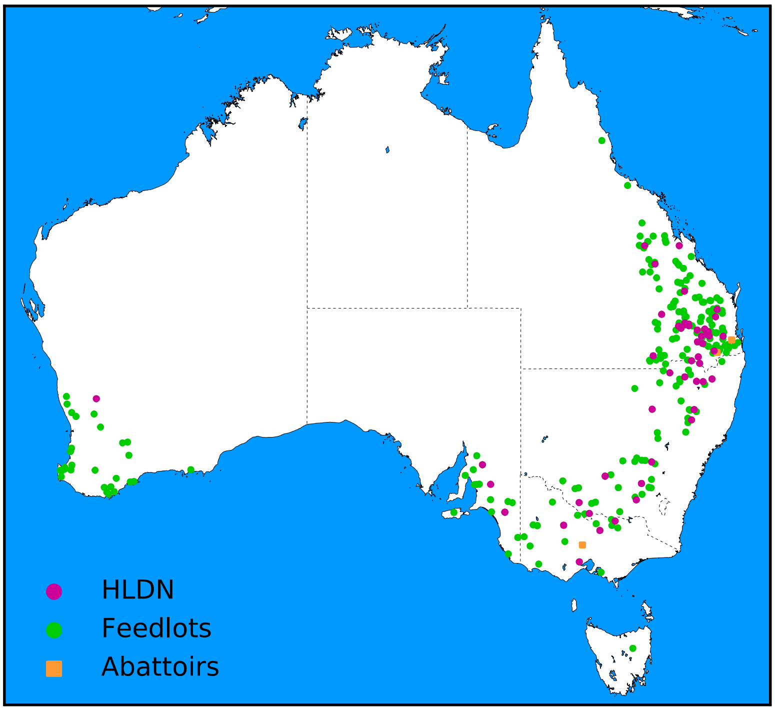


Fig. 2 Location of subscriber feedlots and HLDN participants

3 Methodology

3.1 Forecasting Service

3.1.1 Overview

There are three parts to a successful early warning system:

1. Accurate weather forecast
2. Appropriate triggers that are relevant to the local climate and represent conditions that are conducive to heat stress in lot fed cattle
3. Communication of the warnings via an appropriate media

The following schematic presents an overview of the CHLT system (Fig. 3). The blue areas represent the global input from weather stations and models. These data are not gathered or generated directly by Weather Intelligence. The purple represents the local weather forecast, generated by Weather Intelligence every day. The red box indicates the areas of research that need to go into developing a robust system. The grey box represents the input from feedlot weather stations (HLDN). And finally, the delivery of the information is represented in green and shows the web site and alerts.

3.1.2 The Weather Models

The two weather forecasting models utilised by Weather Intelligence are an implementation of the Weather Research and Forecasting – Advanced Research and Weather (WRF-ARW) model (K-WRF), as a primary forecast, and the Australian Digital Forecast Database (ADFD), as a backup system.

Katestone's implementation of the WRF model (K-WRF) is initialised daily producing a 7-day forecast at an hourly time step. The modelling domain extends from 105°E to 160°E and 8°S to 45°S encompassing a significant portion of the oceans to better resolve the generation of tropical weather systems (Fig. 4). The resolution of the model is 12 km, meaning that data is generated at 12 km spacing over a 23,436,000 km^2 area. K-WRF receives its initial and boundary conditions (IBCs) from the GFS model, which already contains data assimilated from the Australian WMO monitoring sites, as well as satellite and upper air soundings. The model also incorporates a detailed land surface model that accounts for soil type, moisture content, porosity and vegetation type and density (Fig. 5).

The ADFD operates continuously as an alternative weather forecasting product. It contains the official BOM weather forecast elements produced from multiple models and they are controlled by the Bureau's operational meteorologists. As K-WRF system, ADFD covers a 7-day period and provides hourly data. The ADFD has a horizontal grid resolution of 3 km for Victoria and Tasmania, and 6 km for the remainder of Australia. Unlike K-WRF model, ADFD does not make solar radiation data available to the public, therefore a clear-day assumption is considered to estimate solar radiation.

In the event of a K-WRF failure, the ADFD forecast is utilised for the morning forecast. This includes the website update and alerts and the source of forecast is also noted on the website.

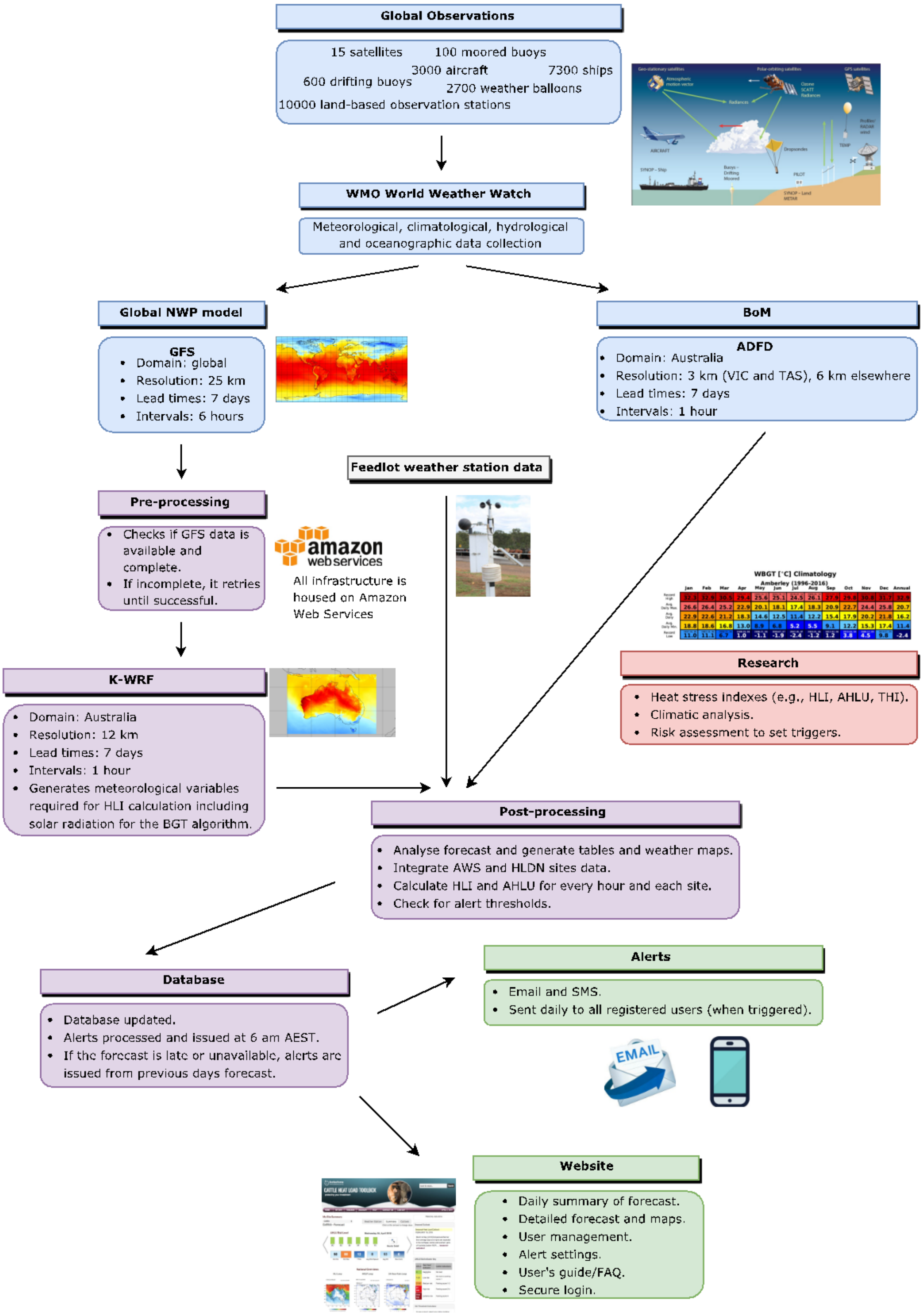


Fig. 3 Overview of the current process to deliver a forecast to CHLT

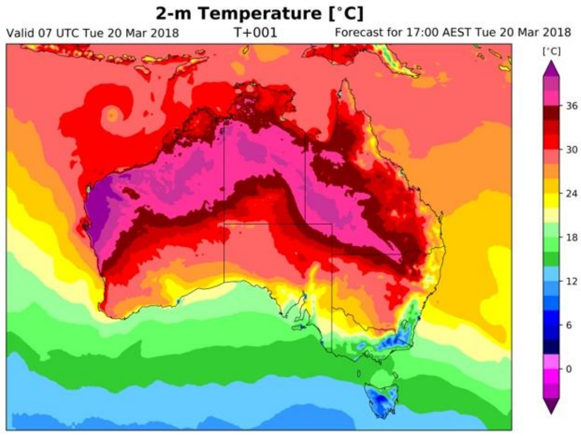


Fig. 4 **K-WRF forecast domain**

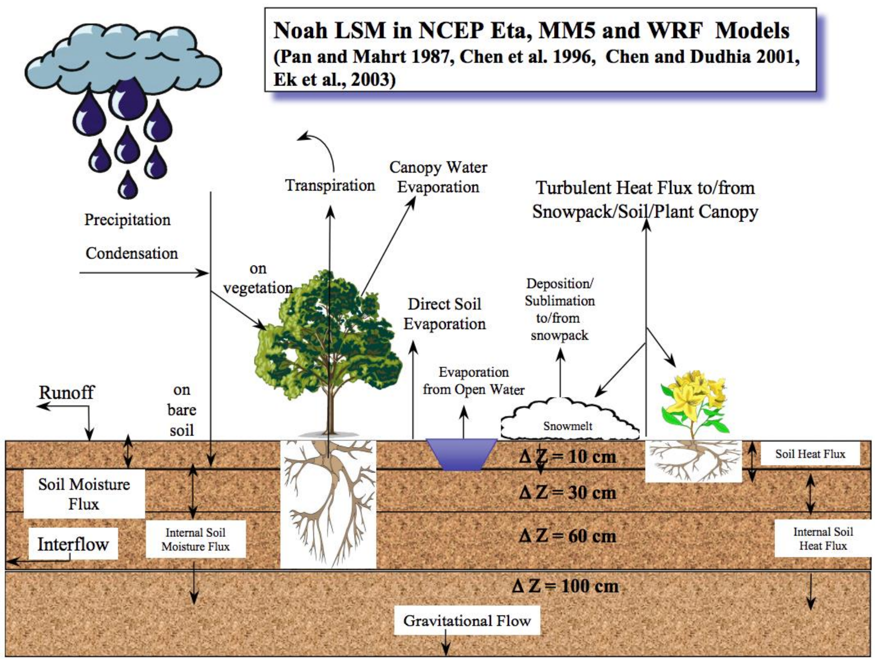


Fig. 5 **Schematic of the Noah Land Surface Model used in the K-WRF system**

3.1.3 Heat Load

There are many climatic conditions that may predispose feedlot cattle to high body heat loads, including:

- A recent rain event
- A high ongoing minimum and maximum ambient temperature
- A high ongoing relative humidity
- An absence of cloud cover with a high solar radiation level

- Minimal air movement over an extended period (4-5 days)
- A sudden change to adverse climatic conditions

It is usually a combination of some of these conditions that leads to an excessive heat load event, which may result in cattle deaths if conditions persist for a few days.

The calculation of HLI requires Relative Humidity (RH) expressed as a percentage, Wind Speed (WS) in m/s and Black Globe Temperature (BGT) in °C. HLI is calculated as a composite of HLI_{low} and HLI_{high}, with a weighting factor determined as a function of the difference in the calculated BGT and a threshold of 25°C (Gaughan et. Al 2002). A blending function was introduced as a result of an analysis of data over time, wherein it was evident that large jumps in HLI could occur under some circumstances when the BGT passes through 25°C – for example from 24.9°C to 25.1°C (B.FLT.0357).

In equation form, HLI_{LOW} and HLI_{HIGH} are calculated as follows, noting that exp is the exponentiation function:

$$HLI_{low} = 1.3 * BGT + 0.28 * RH - WS + 10.66$$

$$HLI_{high} = 1.55 * BGT + 0.38 * RH - 0.5 * WS + \exp(2.4 - WS) + 8.62$$

The weighting factor is calculated and used as:

$$FRAC_{high} = \frac{1.0}{(1.0 + \mathrm{e}^{-\frac{BGT - 25.0}{2.25}})}$$

$$HLI = \left(FRAC_{high} * HLI_{high}\right) + (\left(1 - FRAC_{high}\right) * HLI_{low})$$

It is also worth noting that if any calculation of HLI yields a value less than 50, this value must be set to 50, as the dissipation of heat does not increase below this point.

The use of BGT in calculating the HLI, rather than ambient temperature, takes into account radiation effects as well as air temperature. Although sensors for measuring BGT exist, these are not included as part of the standard weather station and must be ordered from a suitable supplier. In the absence of measured BGT, a quantified relationship between BGT, ambient temperature (T) and solar radiation (SR) can be used. Here solar radiation can either be a measured value or a calculated value.

BGT can be calculated from T and SR using the following equation (noting that log is the logarithm function using base-10):

$$BGT = 1.33 * T - 2.65 * \sqrt{T} + 3.21 * \log(SR + 1) + 3.5$$

Accumulated Heat Load Units (AHLU) has been developed to give some indication of the amount of heat that is accumulated by an animal when it is exposed to environmental conditions that are above its ability to maintain thermo-neutral conditions.

For every hour that an animal is above its threshold HLI value, it will gain heat. This additional heat load accumulates over time and is reflected as an increase in body temperature. It is a normal physiological response for animals to gain heat during the day and dissipate this accumulated heat to the environment at night. If the animal cannot dissipate this accumulated heat overnight, the animal carries a heat load into the following day.

This makes the animal more susceptible to the effects of subsequent heat load. The three aspects that determine the potential for excessive heat load in feedlot cattle include time, intensity, and the opportunity to dissipate heat.

The following variables are required to calculate the AHLU:

- the HLI,
- upper (UL) and lower (LL) limit of the thermal neutral zones, and
- interval (in hours) between successive HLI estimates (Δt).

LL is fixed at 77, while UL is a variable dependent on the HLI value at which stock begins to accumulate heat. This depends on the stock characteristics, location, and management practices including mitigation measures.

The equation for calculating AHLU is as follows:

$$AHLU_{current} = AHLU_{previous} + BALANCE$$

If the HLI is less than LL ($HLI \leq 77$), then the heat is dissipated at half the rate of accumulation (the difference between HLI and LL). If the HLI falls between the LL and UL, then heat is neither dissipated nor accumulated. If the HLI is greater than UL, heat is accumulated.

In equation form, the $AHLU_{current}$ is calculated as:

$$HLI \leq 77 \xrightarrow{yields} AHLU_{current} = AHLU_{previous} - \Delta t * \frac{77 - HLI}{2}$$

$$77 < HLI < UL \xrightarrow{yields} AHLU_{current} = AHLU_{previous}$$

$$HLI \geq UL \xrightarrow{yields} AHLU_{current} = AHLU_{previous} + \Delta t * (HLI - UL)$$

AHLU values do not go below zero. If any calculation results in an AHLU value below zero, it is set to zero.

Sites connected to the HLDN are initialised from AHLU calculated from data collected at local AWS, which theoretically would result in a more accurate AHLU forecast. The same holds true for BOM sites. Sites which do not have an integrated AWS are initialised from the previous day's AHLU forecast.

3.1.4 Delivery

3.1.4.1 Forecast Generation

The sequence of steps that must be completed for the forecast to be delivered (as outlined in Fig. 3); from data retrieval and pre-processing to forecast computation and post-processing is monitored between the hours of 6 am and 9 pm, 7 days a week.

Once the forecast is generated a daily checklist is completed. These checks include but are not limited to:

- Alerts triggered successfully.
- K-WRF, GFS, ACCESS, ECMWF comparison.
- Weather systems analysis and comparison to satellite observations.
- Hot spot identification and analysis.
- Performance analysis versus observations (magnitude and timing).

3.1.4.2 Website and database administration

The CHLT system is administered and maintained by a system administrator. The system administrator maintains the integrity and security of the cloud-based infrastructure. There are three nodes within the HPC facility that require administration and maintenance:

1. Computational node - Core activities are data retrieval, pre-processing and forecast computation
2. Database node - Core activities are post processing, data storage and data availability to the web server
3. Web node - Core activities are website delivery, user information management, web security

The system administrator also maintains the CHLT website and includes:

- Registering new subscribers.
- Checks their coordinates are valid.
- Configures site specific forecast in the model.
- Maintenance of the CHLT web site and associated databases.
- E-mail and SMS alert functions.
- Daily monitoring and maintenance of computer systems including weekends and holidays.
- Online and phone support for registered users during regular office hours (8 am to 5 pm).

Maintenance and update of the FAQ page.

3.1.4.3 Onsite AWS Integration

The Heat Load Data Network (HLDN) allows feedlots to send in their weather station data our servers and include these data in their site-specific forecast for the AHLU. To date 55 sites are operational.

The AWS integration requires continuous monitoring of data quality, as spurious data entering the system can adversely impact the prediction of risk and degrade confidence in the system. The integration step involves calculating the AHLU for all thresholds from the onsite data and initialising the predicted AHLU from the last available time step in the observations.

An automated data quality check is initiated at the integration step that flags spurious data and issues an internal alert to manually quality assure the offending dataset. Our experience indicates that the spurious data is either due to damage to the sensor, i.e. lightning strike, or changes to the data format following a system update by the AWS provider.

In the event, spurious data is flagged the following process is initiated:

1. Lead meteorologist/Senior Data Analyst alerted
2. Data extracted for manually QA
3. AWS owner notified of issue and solution if known
4. If solution is unknown
    a. AWS taken offline
    b. AWS owner contacted, and solution identified
5. If solution is still unknown
    a. AWS supplier contacted, and solution identified
    b. AWS reinstated to operations

3.1.4.4 Alerts

The alerts, for a user selected HLI Threshold value, used in the system are:

- AHLU event today: AHLU > 50 units for today
- AHLU event tomorrow: AHLU > 50 for tomorrow and AHLU = 0 for less than 6 hours
- Extended AHLU event: AHLU > 50 units for more than 3 consecutive days
- Incomplete night time recovery: AHLU = 0 for less than 6 hours for more than 3 consecutive days in 7 day forecast period
- Rapid HLI change: change in HLI > 40 units over 4 hours

Alerts are processed every morning during the period 1 October – 31 March and issued around 6.30 am AEST.

3.2 RAP

The Risk Analysis Tool (RAP) was developed in 2005 for the purpose of obtaining the risk profile of a heat event for the Australian Feedlot industry. The risk that is calculated by the RAP consists of the probability of occurrence of specific heat events at the specified site (All BOM weather station sites). These heat events are classified in terms of their duration (in days) and the daily maximum AHLU value. The classifications are: Medium Risk, (AHLU between 21 and 50), High Risk (AHLU between 51 and 100) and Extreme Risk (AHLU greater than 100). For example, the probability of Extreme Risk events of three day duration is one event in two years. The output is displayed to the user with no interpretation of the acceptability of the predict risk level.

The RAP is available for anyone to use on the Cattle Heat Load Toolbox website.

MLA/ALFA has identified some key areas that needs further refinement and improvement to the current RAP tool. The purpose of the improvements is:

- To simply the user interface, making it easier for a feedlot operator to use
- To remove several user driven variables from the tool to make it simpler to run and remove ambiguity and interpretation by the user
- The proposed changes will also improve the quality and consistency of the tool
- The overall improvements to the RAP will also mean that it will be easier for setting an industry accepted and auditable level of Heat Load risk for feedlots.

Working with MLA and ALFA the RAP was redesigned to deliver a simple more prescriptive process to allow users to assess their risk of a heat event at their feedlot.

Key features include:

- Auditable process for NFSA officers
- Removal of unwanted mitigation factors in risk assessment
- Removal of “number of events” and replace with predetermined risk categories (Low, Moderate and High) for each month
- Display of cattle risk

- Display of shade and unshaded pen risk
- Acknowledgement process for user to agree to terms and conditions of use (and basic requirements for a class 1 feedlot with respect to management of heat)
- Preselection of suitable climate data for each assessment
- Generation of a detailed RAP report that is stored in the system and lodged with the auditors

A schematic of the RAP process is presented in Fig. 6.

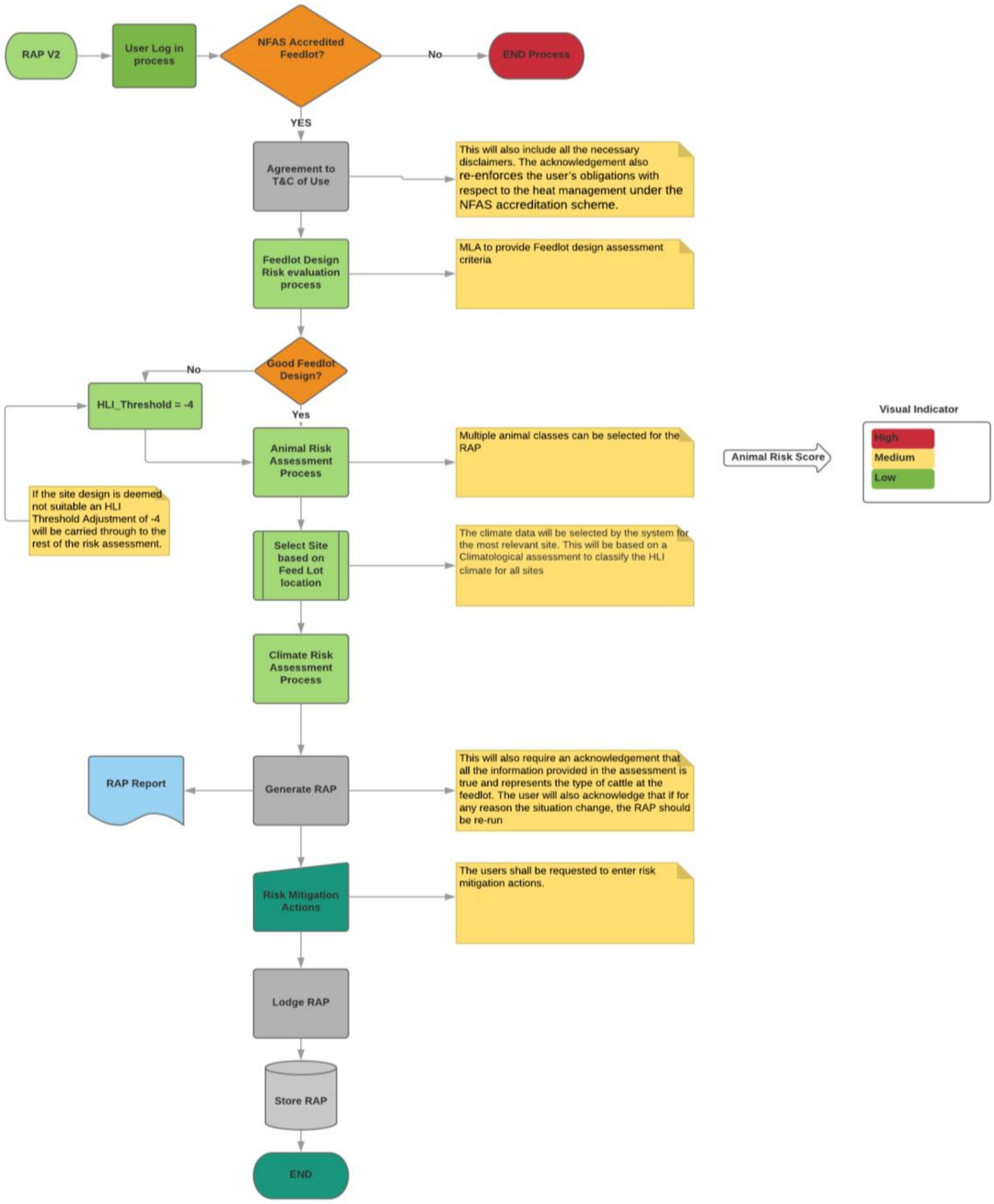


Fig. 6 Schematic of the Beta RAPV2 process

4 Success in meeting the Milestone

The CHLT was operational for the full season with alerts sent out daily from 1 October 2018 to 31 March 2019. The following sections present a summary of the season including:

- General climatic conditions and heat load
- Delivery of alerts
- Web site statistics
- An overview of the performance of the forecasts, and
- Feedback from the users via the end of season survey.

A Beta version of the upgraded RAP was delivered for consideration by the ALFA committee in October 2018 along with the first verification report. Following considerable consultation with the RAP working group and generation of multiple verification reports it was concluded that the proposed new RAP method was not providing consistent and defensible results. Screenshots of the Beta RAP are presented in Section 3.2 and the final verification report is presented in Appendix B.

4.1 Season Overview

4.1.1 Weather and Climate Review

4.1.1.1 Temperature and Rainfall

2018 was Australia's third-warmest year on record (the national observational dataset commences in 1910). Australia's area-averaged mean temperature for 2018 was 1.14˚C above the 1961-1990 average. Both maximum and minimum temperatures were warmer than average, leading to the 2nd- and 11th-warmest on record, respectively. Regarding rainfall, nationally-averaged rainfall for 2018 was 412.8 mm, 11% below the 1961-1990 average, making it Australia's 39th-driest year in a record spanning 1900 to present.

Focusing on the 2018-19 season (from October 2018 to March 2019), temperatures were above average for the majority of Australia (Fig. 7). Nationally, summer 2018-19 was the warmest summer on record. It was exceptionally warm across NSW, VIC, WA, and NT. The delayed onset of the monsoon, and generally weak monsoonal activity across northern Australia outside of northern QLD, facilitated the build-up of heat over the continent during early summer. Persistent slow-moving blocking high pressure systems over the Tasman Sea and a notable absence of strong cold fronts in the south maintained the persistent heat. A number of significant fires also occurred during the season. In QLD fires associated with the extreme heatwave were active across the east of the state from late November and continued into December.

The 2018-19 season rainfall was below average for most of Australia (Fig. 8 left). For the nation as a whole, it was the seventh-driest summer on record, despite very heavy rain in parts of northern QLD. In Darwin, monsoon onset did not occur until 23 January, which is nearly a month later than usual. In the south of the country, long-lived blocking high pressure systems over the Tasman Sea and a lack of strong cold fronts contributed to below average rainfall.

In stark contrast to most of the rest of Australia, several intense rainfall events contributed to above average rainfall along the northeast coast, northern interior and northwest of QLD. Severe tropical cyclone Owen caused flooding on the east of QLD's Cape York Peninsula in mid-December and contributed to thunderstorms over south-eastern Australia. From 24 January to early February, an active monsoon trough and a slow-moving monsoonal low produced extremely heavy rainfall over tropical QLD. The system produced 11 consecutive days of heavy rain in some areas. For example, Townsville Aero received 1339.8 mm in 11 days.

Comparing rainfall of this season to the previous season (2017-18), a dramatic decrease is observed across northwest of Australia, southeast corner of QLD and northeast region of NSW, whereas a significant increase occurred in some areas of QLD as mentioned above (Fig. 8 right).

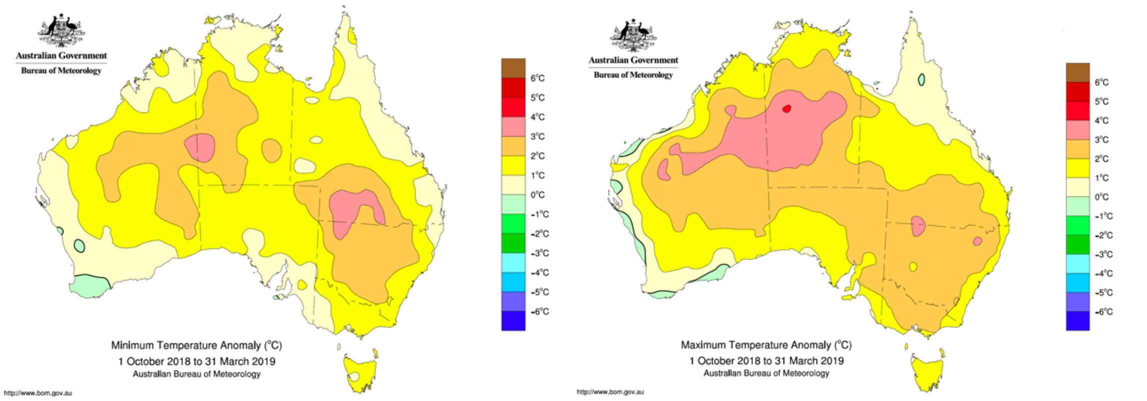


Fig. 7 Minimum (left) and maximum (right) temperature anomaly during the 2018-19 season

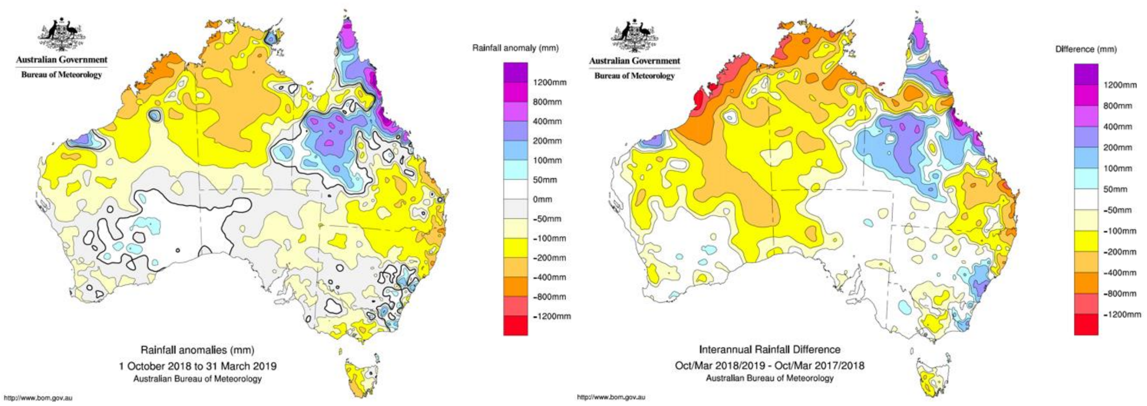


Fig. 8 Rainfall anomalies during the 2018-19 season (left) and the difference between this season and last season (right)

4.1.1.2 Climate Drivers

Australia's weather is influenced by many climate drivers. A brief description and their impacts on the 2018-19 season is given here.

4.1.1.2.1 El Niño-Southern Oscillation

El Niño-Southern Oscillation (ENSO) is arguably the most important global climate pattern affecting extreme weather conditions. It is characterized by two phases: warm phase (El Niño) and cold phase (La Niña). An El Niño event occurs when sea surface temperatures in the central and eastern tropical Pacific Ocean become substantially warmer than average, and this causes a shift in atmospheric circulation. As a result, the heavy rainfall that usually occurs to the north of Australia moves to the central and eastern parts of the Pacific basin. Therefore, an El Niño event is usually associated with drier conditions over eastern parts of Australia. Conversely, the enhanced trade winds during La Niña events lead to cooling of the central and eastern tropical Pacific Ocean and heavy rainfall can occur to the north of Australia.

In order to monitor ENSO events, two main indexes are utilized: Niño-3.4 and SOI, measuring changes in the ocean and the atmosphere, respectively. The Niño-3.4 index refers to the observed sea surface temperatures within a region of the central and eastern equatorial Pacific, whereas SOI takes the difference of atmospheric pressure between Darwin and Tahiti. After one of the strongest El Niño events in 2015-16, oceanic and atmospheric indicators reflected neutral state throughout the 2016-17 season (Fig. 9 top). A weak and short-lived La Niña event occurred during the 2017-18 season and ENSO indicators eased back to neutral levels over the second half of 2018. Despite the warming in sea surface temperatures since mid-2018, atmospheric indicators of ENSO such as cloudiness, trade winds and the SOI did not responded and have mostly remained neutral (Fig. 9 bottom).

Therefore, it is suggested that ENSO had negligible or relatively little effect on Australian rainfall patterns over this season.

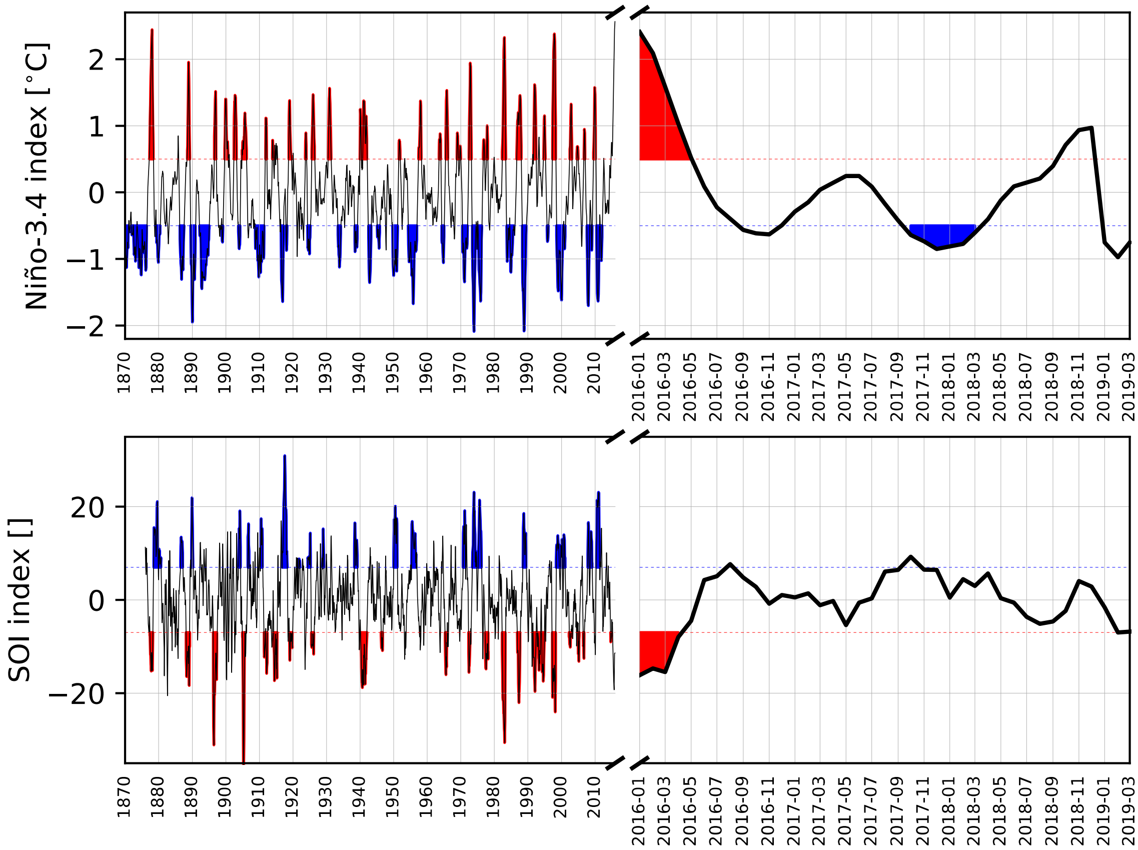


Fig. 9 **Time series of Niño-3.4 index and SOI, Red (blue) shaded areas indicate El Niño (La Niña) events. Data source: NOAA and BOM**

4.1.1.2.2 Indian Ocean Dipole

Indian Ocean sea surface temperatures impact rainfall and temperature patterns over Australia. Sustained changes in the difference between sea surface temperatures of the tropical western and eastern Indian Ocean are known as the Indian Ocean Dipole (IOD). Being one of the key drivers of Australia's climate, IOD can have a significant impact on agriculture since the events generally coincide with the winter crop growing season. Neutral IOD phase means that water from the Pacific flows between the islands of Indonesia, keeping seas to Australia's northwest warm. Positive IOD phase, i.e. with cooler than normal water in the east and warmer than normal in the west, implies less moisture than normal in the atmosphere to the northwest of Australia, resulting in less rainfall and higher than normal temperatures over parts of the country during winter and spring. However, negative IOD phase, i.e. with warmer than normal water in the east and cooler than normal in the west, leads to above-average winter-spring rainfall over parts of southern Australia.

A positive IOD event began in early September 2018, as indicated by positive values of Dipole Mode Index (DMI) and decayed by early summer (Fig. 10). Therefore, neutral conditions persisted during most of the 2018-19 season, which resulted in the IOD having little influence on Australian climate from December to April.

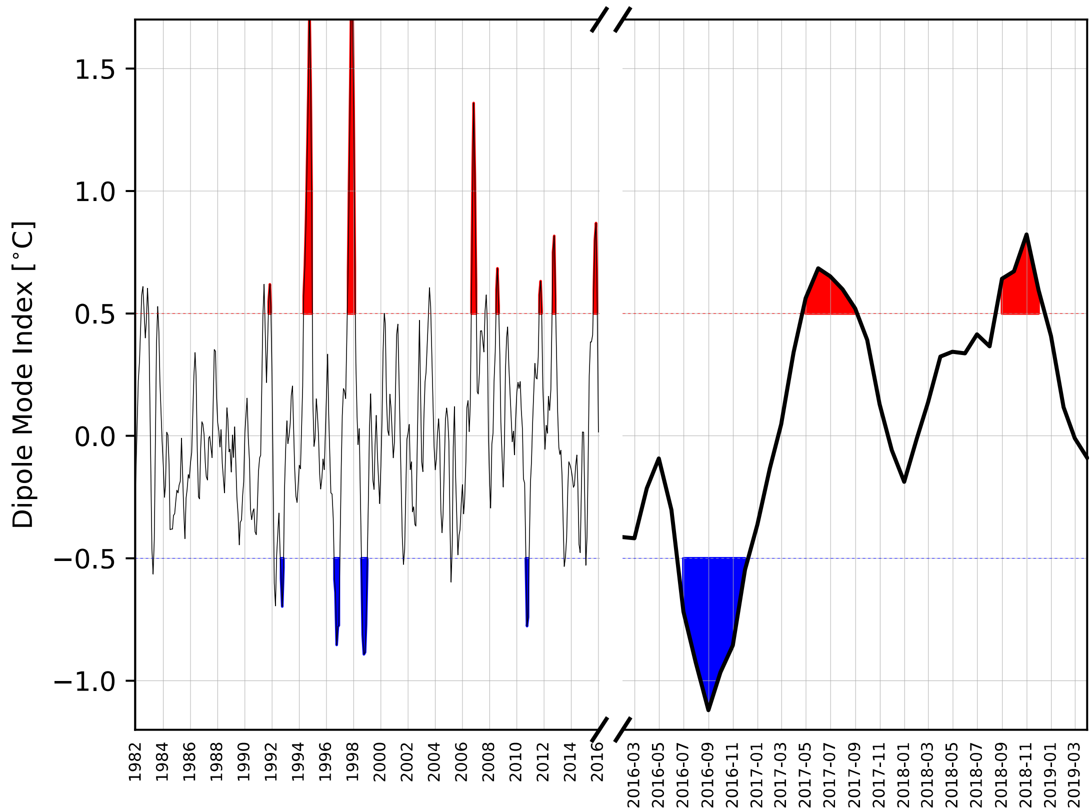


Fig. 10 **Time series of Dipole Mode Index. Red (blue) shaded areas indicate positive (negative) IOD events. Data Source: NOAA**

4.1.1.2.3 Southern Annular Mode

The Southern Annular Mode (SAM) describes the north-south movement of the westerly wind belt that circles Antarctica, dominating the middle to higher latitudes of the southern hemisphere (Ho et al. 2012). The changing position of the westerly wind belt influences the strength and position of cold fronts and mid-latitude storm systems, and it is an important driver of rainfall variability in southern Australia. In a positive SAM event, the band of westerly winds contracts towards Antarctic. This results in weaker than normal westerly winds and higher pressures over southern Australia, restricting the penetration of cold fronts inland. Conversely, a negative SAM indicates that the band of westerly winds expands towards the equator. This shift in the westerly winds leads to more low-pressure systems over southern Australia.

A high positive SAM dominated during the 2018-19 season, starting from mid-2018 (Fig. 11). This might explain the decreased rainfall observed in parts of southern Australia, particularly in VIC and TAS (Fig. 8 left).

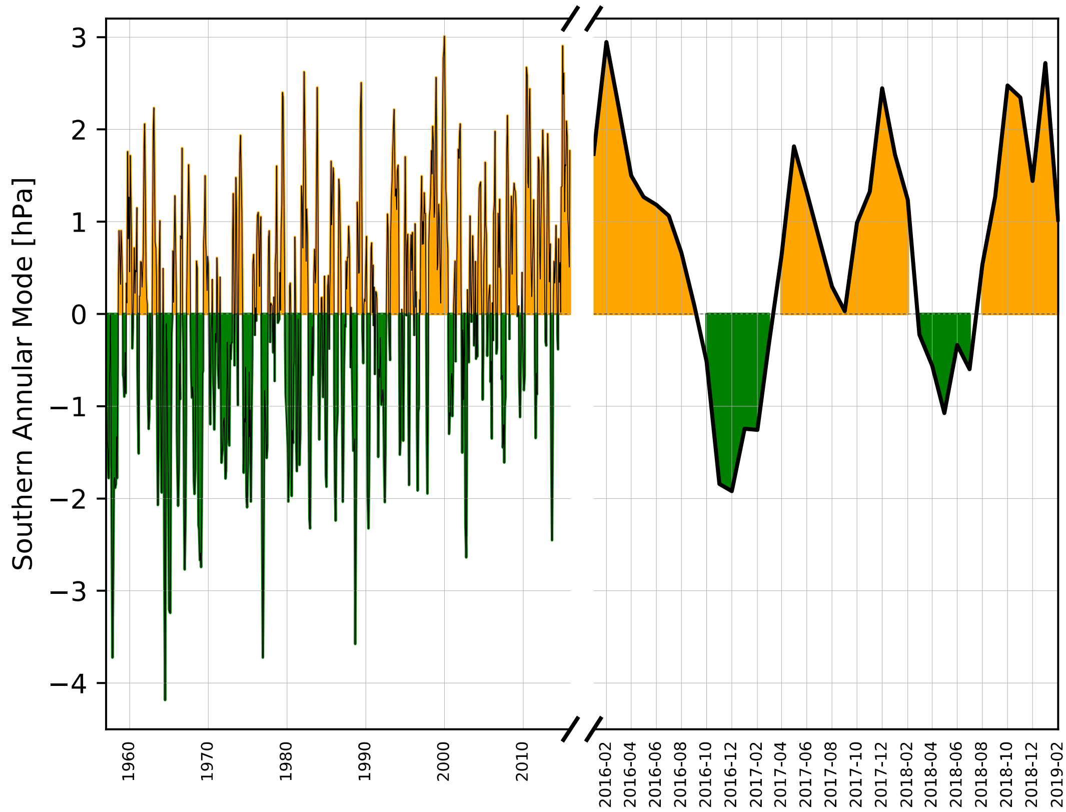


Fig. 11 Time series of Southern Annular Mode

4.1.1.3 Tropical Cyclones

There were 8 Tropical Cyclones (TC) during the forecast period within the Australia region, which is below the long-term average (10 TCs), although only 6 had an effect upon the Australian mainland (**Error! Not a valid bookmark self-reference.**). Only TC Owen, which was categorised as severe, impacted on feedlot areas over northern QLD due to steady rainfall over this region in early December. Innisfail recorded a daily total of 149 mm of rain on 15 December. However, HLI values remained below 90 during this episode.

Table 1 Tropical cyclones in the Australian region between October 2018 and March 2019

Date	Name	Category	Region
29 Nov – 17 Dec	Owen	3	QLD, NT
26 Dec – 9 Jan	Penny	2	QLD
19 – 30 Jan	Riley	3	WA
7 – 22 Feb	Oma	2	QLD, NSW
15 – 26 Mar	Trevor	4	QLD, NT
18 – 31 Mar	Veronica	4	WA

4.1.1.4 Heat Load

The daily average HLI anomaly[1] derived from observations at the 17 benchmark locations (section 4.1.4.1) for the 2018-19 season is shown in Fig. 12. Most of the sites exhibit, as expected, some fluctuations of HLI between above and below average throughout the 6-month period. Interestingly however, sites in VIC and NSW (Fig. 17) show much above average HLI values in December and January, whereas the rest of the benchmark locations display HLI values around the climatology, or even below average part of this 2-month period. Katanning HLI remained close to normal values for this season.

The weekly average daily maximum HLI derived from observations for all sites is presented in Fig. 13. For most of the sites, HLI peaks between mid-January and early February. Not surprisingly, Yanco, Hay, and Griffith had similar maximum HLIs due to their proximity Fig. 17). Interestingly, mid-latitude sites show a clear seasonal cycle of HLI with a dramatic decrease after their peak (for instance, Yanco, Hay, Griffith, Albury, Charlton, and Clare High School), whereas most QLD sites exhibit slight or non-existent decline of HLI during the second half of the 6-month period.

[1] The HLI anomalous values are calculated by subtracting the monthly climatology to the actual value. In order to smooth the data, 6-day moving averages are shown.

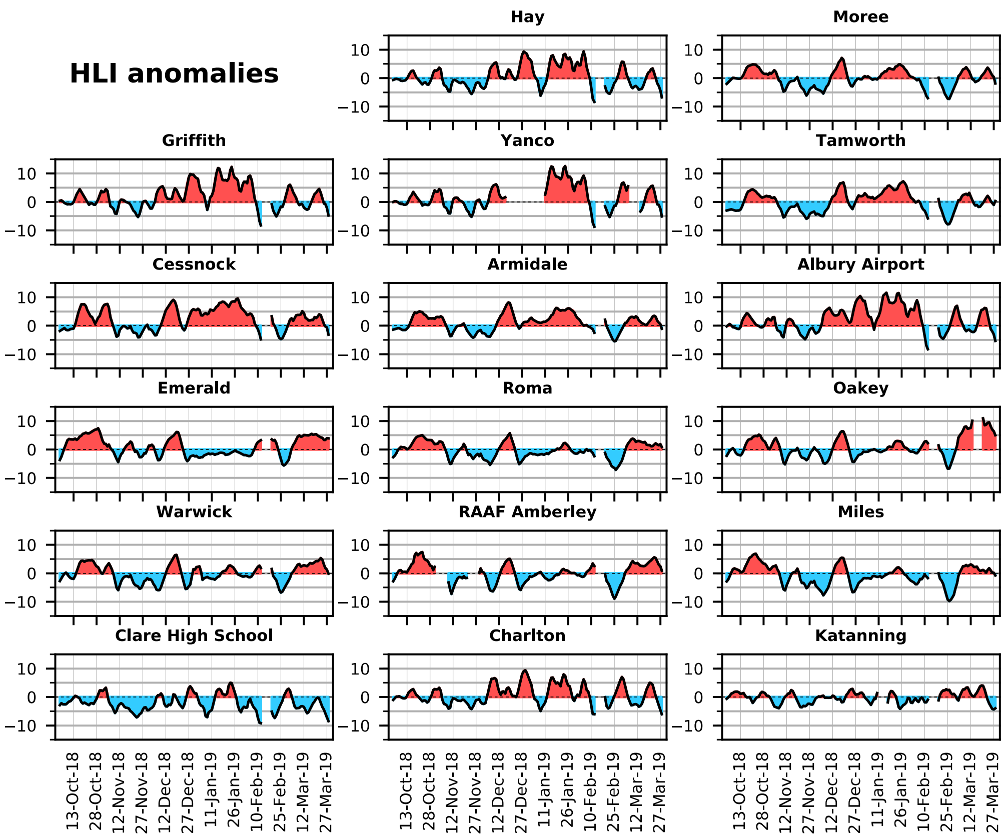


Fig. 12 Daily average HLI anomaly for the 17 benchmark locations. Note that red (blue) shades are used to denote higher (lower) HLIs values than usual

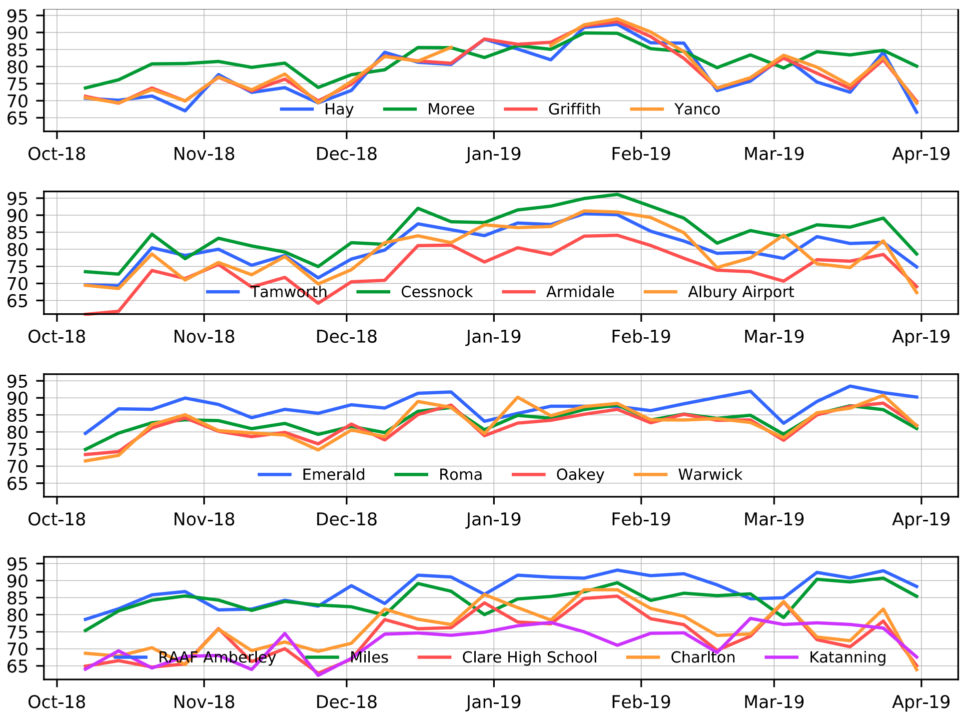


Fig. 13 Weekly average of daily maximum HLI for the 17 benchmark locations

4.1.2 Automated alerts

A total of 7,871 emails and 2,879 SMS alert messages were issue during the 2018-19 summer forecast period, with a peak number of email and SMS alerts sent in January (Fig. 14). The breakdown of alerts by type for each month is also shown in this figure. Alerts for extended AHLU event and for today-tomorrow comprise most of the alerts. There were only 85 alerts, which represents less than 1% of total alerts, for Rapid HLI change. Unlike last season, in which there was none incomplete recovery alert triggered, this type of alert was activated 6 times at Wirreanda and Korunye Park feedlots, both near Adelaide.

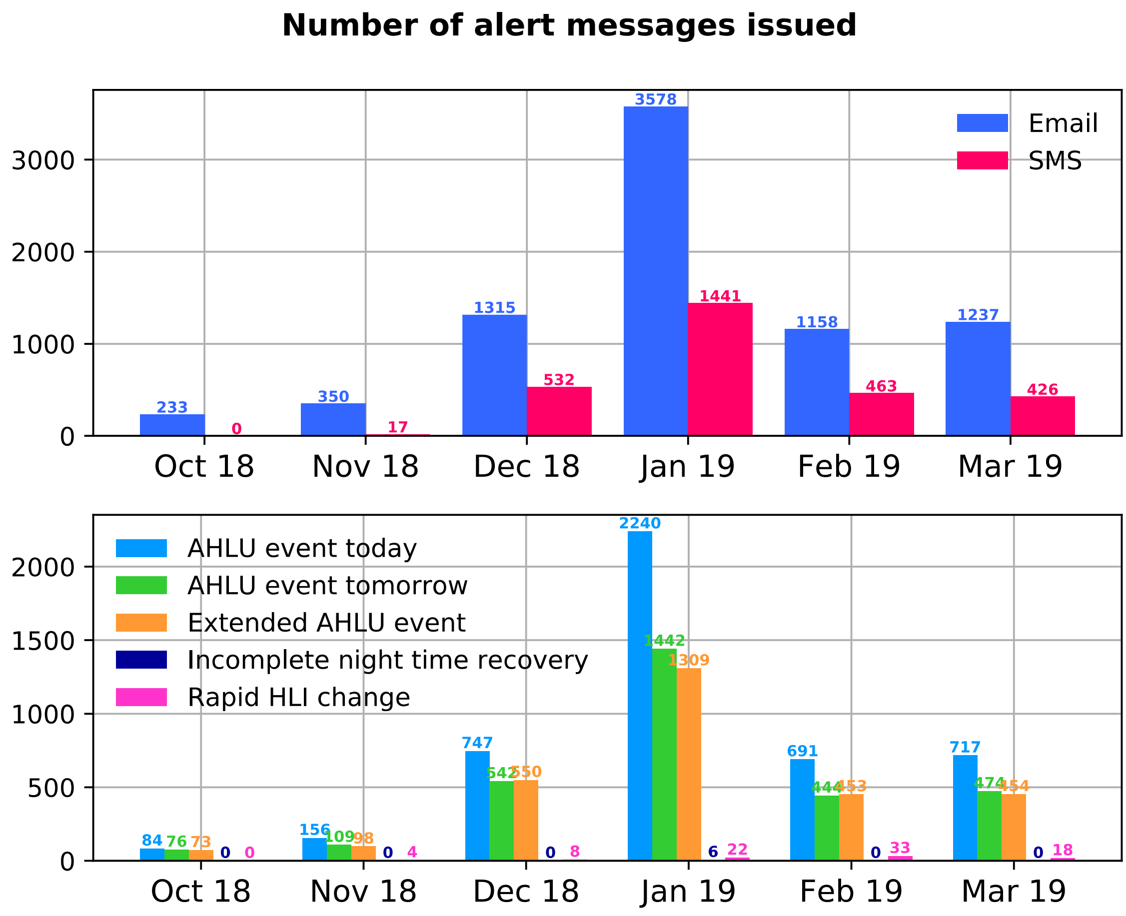


Fig. 14 Number of alerts sent by alert and notification types during the 2018-19 season

4.1.3 Web site statistics

The distribution of the CHLT website traffic by state is shown in Fig. 15. Queensland accounts for 50% of the site overall traffic, followed by NSW (21%) and VIC (16%). The remaining 13% is made of WA (7%), South Australia (4%), Australian Capital Territory (.5%), Tasmania (.5%) and Northern Territory (0.5%). The number of users decreased from 1,814 during the 2017-18 season to 1,735 during the current season, representing a decrease of 2.7%.

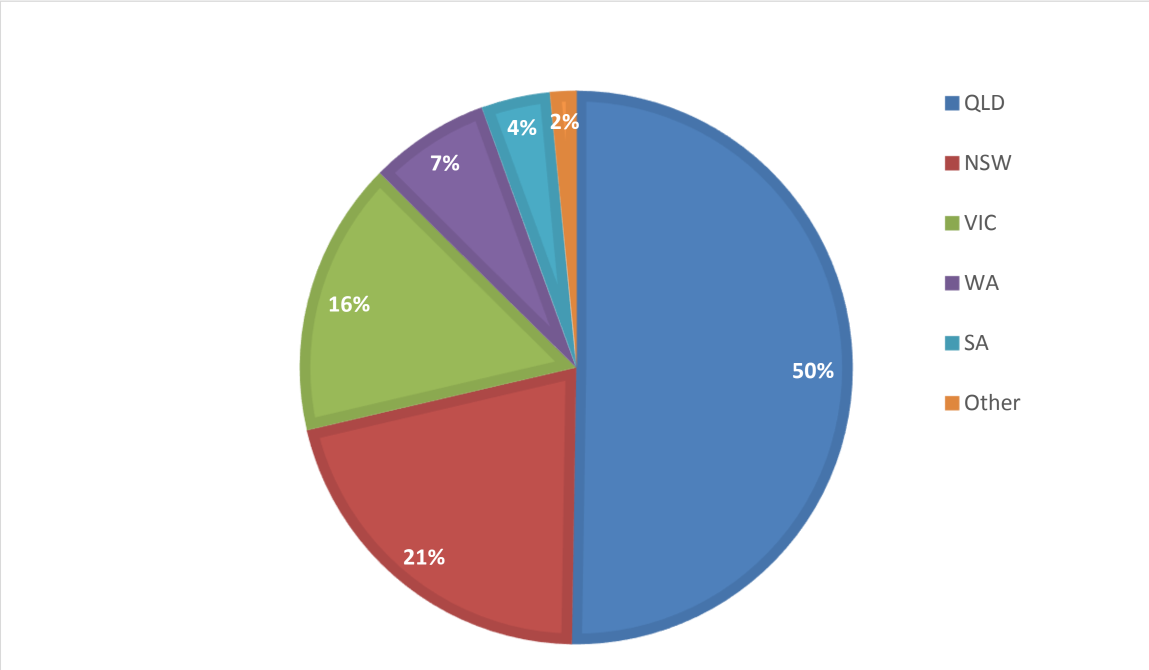


Fig. 15 CHLT website traffic by state during this season

The top 10 webpages are shown in Table 2. The "My Site" and "Homepage" are the top two web pages. This is to be expected as they are the landing pages for the public and subscribers accessing the http://chlt.katestone.com.au/. The "RAP calculator" is the next most visited page accounting for 3.5% of the sites traffic. This page lead to the "Major town forecast", which accounts for approximately 2.5%. The "Toolbox", "Registered Observations", "HLI calculator", "Manage Alerts", and Site specific pages represent less than 2% each.

Table 2 Top 10 webpage as percentage of site traffic for the period 1-Oct-2018 to 31-Mar-2019

Web page	% Site Traffic
Homepage	23%
My Site Summary	19%
RAP calculator	3.5%
Major town forecast	2.5%
Toolbox	2%
My Site Summary – Registered Observations	1.1%
HLI calculator	1%
Manage alerts	1%
My Site Summary – Registered Forecasts – Site 259	0.8%
Public Forecasts – Gympie	0.8%

Fig. 16 shows the distribution of devices accessing the CHLT website. Most users (71.5%) access the service from a desktop computer, followed by mobile phones (26%) and tablets (2.5%). This constitutes a 2.65% decrease in the amount of desktop traffic, a 27% increase in the amount of mobile phone usage and a 43% decrease in tablet usage.

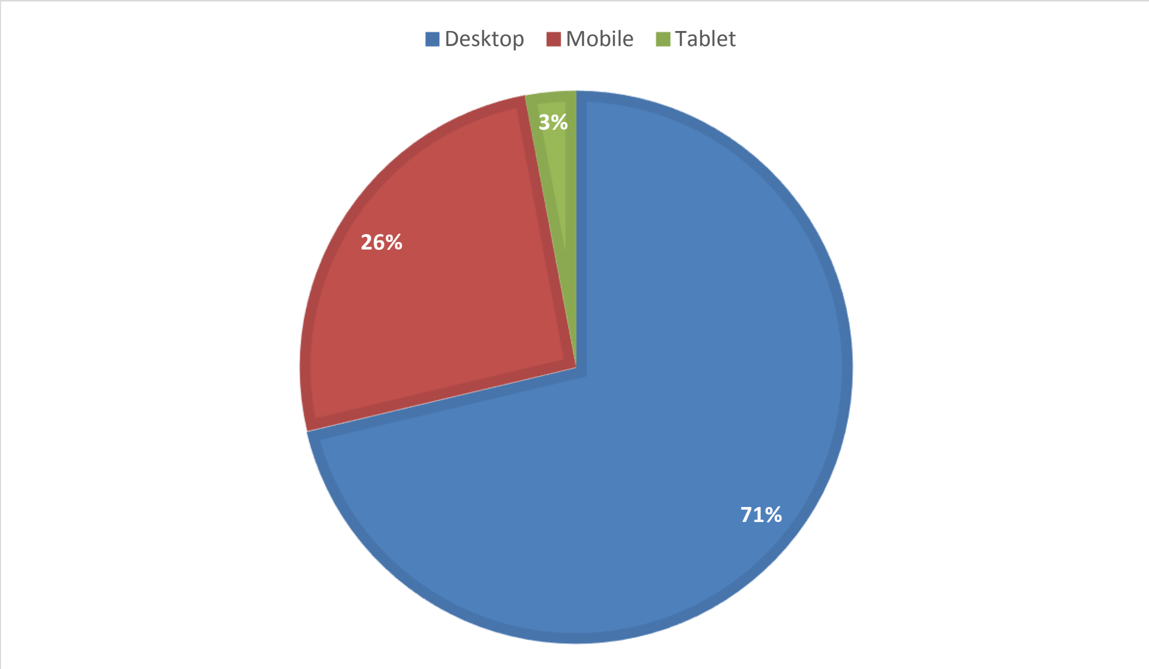


Fig. 16 Distribution of devices accessing the website

4.1.4 Service performance

4.1.4.1 Benchmark locations

The performance of the forecasting service has been assessed against the 17 benchmark locations. Most of these sites have been included in the forecast service since its inception and provide a good measure of the forecasts performance over the years. Fig. 17 and Table 3 describe the benchmark locations.

Table 3 Geographical information and WMO code of the benchmark locations analysed

Site Name	Lat	Lon	WMO code	State
Hay	-34.54	144.83	94702	NSW
Moree	-29.48	149.84	95527	NSW
Griffith	-34.24	146.06	95704	NSW
Yanco	-34.62	146.43	95705	NSW
Tamworth	-31.07	150.83	95762	NSW
Cessnock	-32.78	151.33	95771	NSW
Armidale	-30.52	151.61	95773	NSW
Albury Airport	-36.07	146.95	95896	NSW
Emerald	-23.56	148.17	94363	QLD
Roma	-26.54	148.77	94515	QLD
Oakey	-27.4	151.74	94552	QLD
Warwick	-28.2	152.1	94555	QLD
RAAF Amberley	-27.62	152.71	94568	QLD
Miles	-26.65	150.18	95529	QLD
Clare High School	-33.82	138.59	95667	SA
Charlton	-36.28	143.33	94839	VIC
Katanning	-33.68	117.6	94641	WA

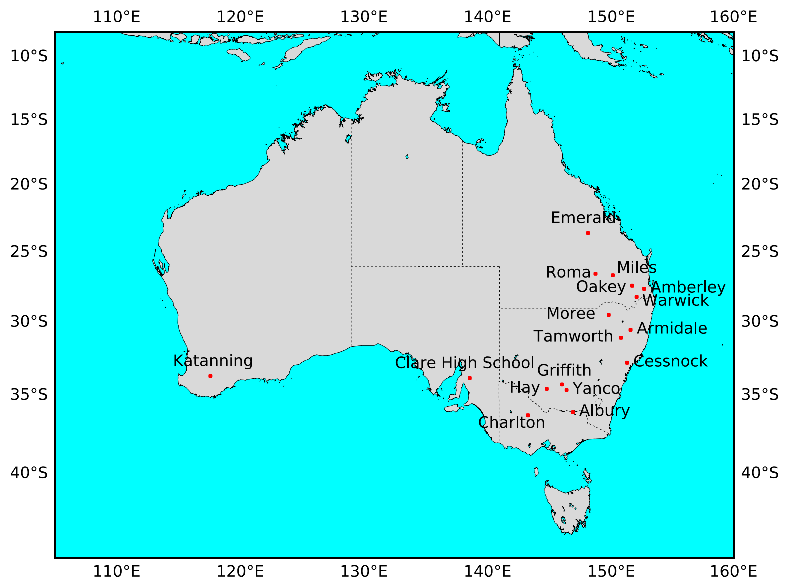


Fig. 17 Map of the 17 benchmark sites

4.1.4.2 Results

The performance of the forecast is reviewed at the AWS sites identified above. These locations are Bureau of Meteorology sites that do not record Black Globe Temperature (BGT) measurements or solar radiation. As such these variables are not included in the performance analysis. Temperature, humidity and wind speed are reviewed for forecasting ability as is the HLI and AHLUs. The HLI and AHLU performance analysis is presented here. The parameters that are used to assess the performance of the system are in Appendix A.

4.1.4.2.1 Heat Load Index

Fig. 18 shows the progression of the forecast performance since the 2005-06 season for the 17 benchmark locations. In particular, it represents the Root Mean Square Error (RMSE), which is the average magnitude of the forecast error being 0 the perfect score. As expected, the 3-day lead time RMSE has been lower than that for the 1-day lead time although their difference was much higher during the first years in contrast to the last years.

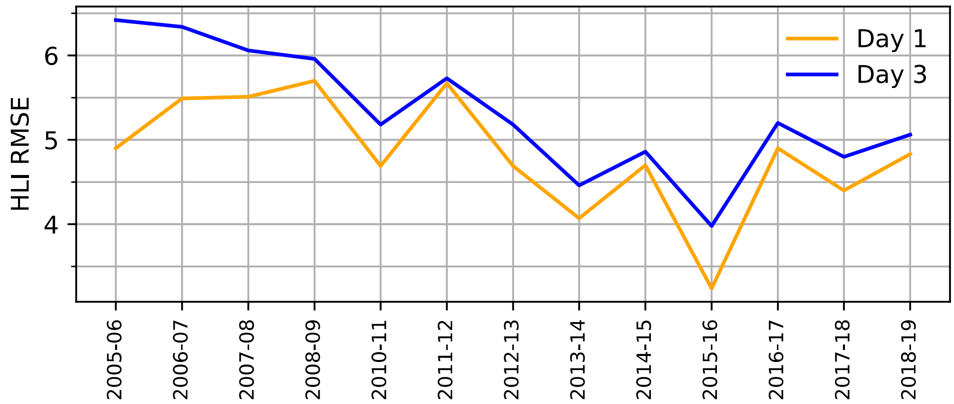


Fig. 18 HLI RMSE averaged seasonally (from 1-Oct to 31-Mar) and across the 17 benchmark sites throughout 13 seasons

Focusing on the 2018-19 season, the first 3 days of the forecast exhibit similar values of RMSE followed by a gradual increase for the 4-day, 5-day and 6-day lead time, and finally an abrupt increase for the 7-day out forecast (Fig. 19). This decrease in model efficiency with increase in lead time can be explained by increase in uncertainty. We point out that RMSE puts greater influence on large errors than smaller errors, but it does not indicate the direction of the deviations.

To further verify the model performance, other continuous scores have been considered:

- Mean Absolute Error (MAE): it measures the average magnitude of the errors without considering their direction, as RMSE, but it is not a quadratic scoring rule. Rather, MAE is a linear score, which means that all the individual differences are weighted equally in the average. Both the MAE and RMSE can range from 0 to ∞, and they are negatively-orientated scores (i.e., the lower values, the better).

- Mean Error (ME): it indicates the average direction of error, but it does not indicate its magnitude. As it does not measure the correspondence between forecasts and observations, it is possible to get a perfect score (0) for a bad forecast if there are compensating errors.

- Bias (BIAS): it compares the average forecast magnitude to the average observed magnitude. As ME, it does not measure the correspondence between forecasts and observations, and therefore errors can cancel out.

- Correlation Coefficient (CC): it measures the linear association between forecast and observation. Visually, the correlation measures how close the points of a scatter plot are to straight line. Ranging from -1 to 1, the CC is positive when higher (lower) forecast values tend to be associated with higher (lower) observed values whereas CC is negative when higher (lower) forecast values tend to be associated with lower (higher) observed values.

- Refined Index of Agreement (rIOA): this index, developed by Willmott et al. (2011), indicates the sum of the magnitudes of the differences between the model-predicted and observed deviations about the observed mean relative to the sum of the magnitudes of the perfect-forecast and observed deviations about the observed mean. A value of rIOA of 0.5, for example, indicates that the sum of the error-magnitudes is one half of the sum of the perfect-model-deviation and observed-deviation magnitudes. Thus, rIOA is a measure of how well each time step (hour) performance is compared to the average of the observations.

The MAE indicates that the average difference between the forecast and the observed HLI is from roughly 3 units for 1-day lead time to 4 units for 7-day lead time (Fig. 19b). Furthermore, the fact that RMSE indexes are not much larger than MAE indexes (only 2 HLI units) suggests a similar magnitude error in the forecast. In other words, very large errors are unlikely to have occurred. The overall negative values of ME (Fig. 19c) along with a general BIAS < 1 (Fig. 19d) imply that HLI tends to be under-forecast.

Consistent with the results described above, the very high CCs represent positive and very strong correlation between forecast and observed values with an obvious poorer performance for the 7-day lead time (Fig. 19e). Finally, the close values of rIOA to 1 indicate a very good agreement between the variation of predicted and observed values at different time steps (Fig. 19f).

Overall the performance of the operational forecasts in predicting the HLI on an hour-by-hour basis is good. We found that forecast skill is extremely high out to 3 days, followed by high skill the following 3 days.

It is also worth noting that as the data is paired in time the forecast can be an hour or two behind or ahead of the environment, causing a disparity in the dataset where the observed HLI is higher than predicted at any given hour. This can be caused by the movement of weather features, such as a trough, across the monitoring point. For instance, the model may move the trough over a region at 7 am, whereas in reality the trough crossed that point at 9 am. These small variations at the hourly scale can cause large variations in the HLI. In this aspect, a review of daily AHLU via the contingency tables (as presented in the following section) overcomes some of the minor discrepancies by interpreting hourly data.

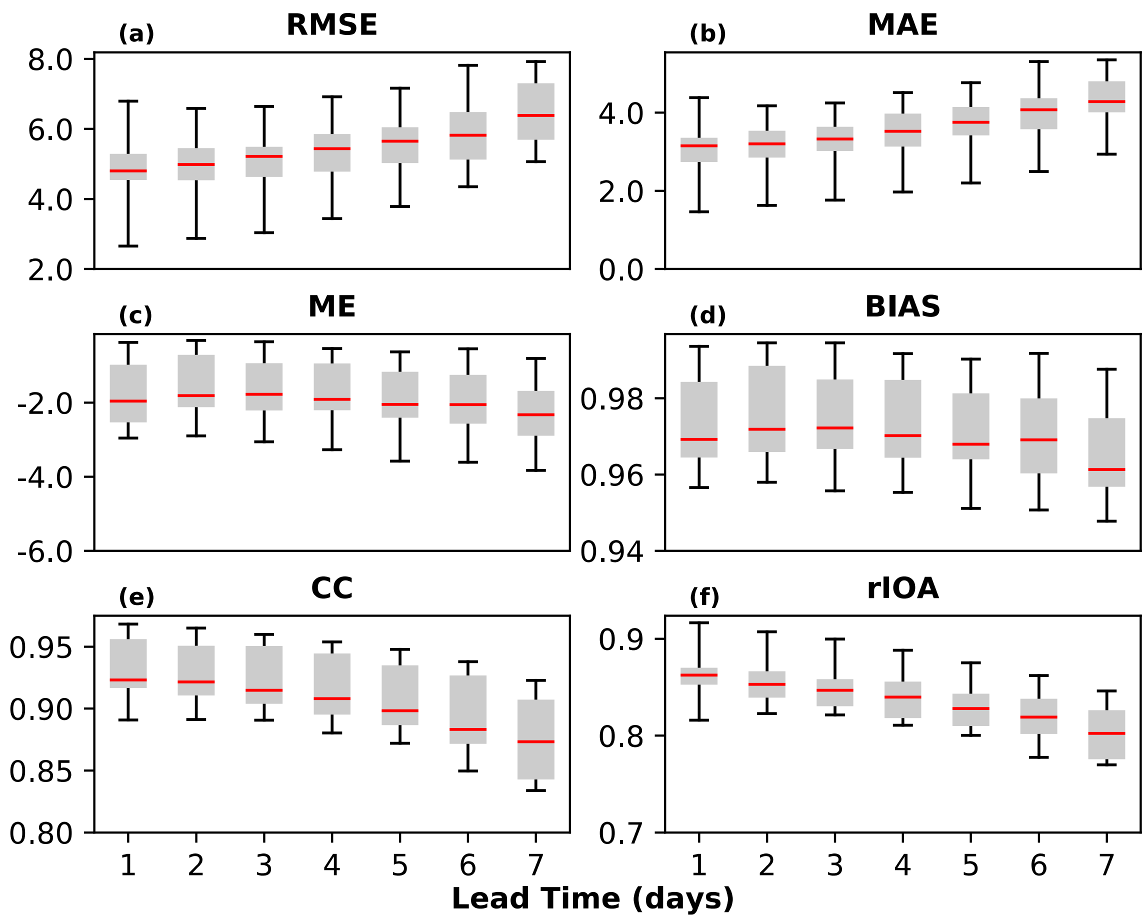


Fig. 19 **Box plots comparing several continuous verification methods and statistics of HLI forecast averaged across the 17 benchmark sites and for the 2018-19 season. The bottom and top of the box show the 25th and 75th percentiles, respectively; the red line represents the median and the lower and upper whiskers are the minimum and maximum, respectively. A brief description of these indices is given in Section 5.3.1**

4.1.4.2.2 Accumulated Heat Load Units

A number of categorical statistics of AHLU contingency tables are analysed in this section. Among the metrics, the contingency table (Wilks, 2006) is extensively used in evaluation studies. The contingency table metrics describe whether forecast AHLU hits or misses the observed AHLU and leads to false forecast relative to observations.

Table 4 **Contingency table. A perfect forecast system would produce only “hits” and “correct negatives”, and no “misses” or “false alarms”**

	Observed: YES	**Observed: NO**
Forecast: YES	hits	false alarms
Forecast: NO	misses	correct negatives

Based on the contingency table, several metrics are defined as follows:

- Accuracy: it gives an indication of what fraction of the forecasts were correct. Ranging from 0 to 1, 0 means no skill and 1 is the perfect score.
- Bias (or frequency bias): it measures the ratio of frequency of forecast events to the frequency of observed events. Therefore, it indicates whether the forecast system has a tendency to underforecast (BIAS<1) or overforecast (BIAS>1) events. The bias ranges from 0 to infinite, being 1 the perfect score.
- Probability of Detection (POD) or hit rate: it answers the question: what fraction of the observed “yes” events were correctly forecast? The POD is very sensitive to the climatological frequency of the events and it is a good measure for rare events. The POD ranges from 0 to 1; 0 indicates no skill and 1 indicates perfect score.
- Probability of false detection (POFD) or false alarm rate: it answers the question: what fraction of the observed “no” events were incorrectly forecast as “yes”. The FAR ranges from 0 to 1; 0 indicates perfect score.
- False Alarm Ratio (FAR): it tells what fraction of the predicted “yes” events actually did not occur (i.e., were false alarms. As POD, FAR is very sensitive to the climatological frequency of the event. As POFD, the FAR ranges from 0 to 1 and 0 indicates perfect score.
- Threat Score (TS) or critical success index: it indicates how well the forecast “yes” events correspond to the observed “yes” events. Thus, it can be thought of as the accuracy when correct negatives have been removed from consideration. It depends on climatological frequency of events, with poorer scores for rarer events.

Figures Fig. 20-Fig. 25 show the above metrics including all benchmark locations for the forecast season for 1-day through to 6-day forecast AHLU. The accuracy index indicates that above 85% of all risk levels forecasts were correct for the 6-day period, with a better fraction of correct forecasts for high and extreme events than medium- and low-risk levels. This is a consequence of most cases for high and extreme events have a large number of "correct negatives". The better accuracy for higher AHLUs can be also explained by this lack of observed events. As expected, the accuracy decreases gradually with increasing lead time, except for high AHLUs in which the forecast can be considered almost perfect for all lead times.

The BIAS shows that, in general, the forecast risk is more than the observed risk (overforecast) for 1-day out whereas the opposite (underforecast) is found for the rest of the lead days. Note that BIAS cannot be computed if there are no observed events. POD index varies from near 1 for high AHLUs to around 0.5 for low AHLU and extreme risk events. This poor skill for extreme risk events and low AHLUs is explained by the sensitivity of this metric to missed events and hits only (climatology frequency of the events). As for BIAS, POD is not calculated if there are no observed events.

The POFD, which is conditioned on observations rather than forecasts, exhibits values near 0, which means that false detection (number of false alarms in relation to all non-observed events) in the forecast is rare. The FAR, which is conditioned on forecasts rather than observations and it is a measure of reliability, indicates a steady growth as lead time progresses. For instance, FAR values at around 0.3 during the last days of forecast for AHLU80 mean that in roughly 30% of the forecast risk level, the level was not observed. This is consistent with the positive BIAS described above and it could be improved by under forecasting. Finally, the fact that TS does not consider correct negative forecast, it shows a lower score than the rest of the metrics.

Overall, hits and correct negative events are much larger than misses and false alarms as indicated at the top of each figure, which results in an excellent forecast.

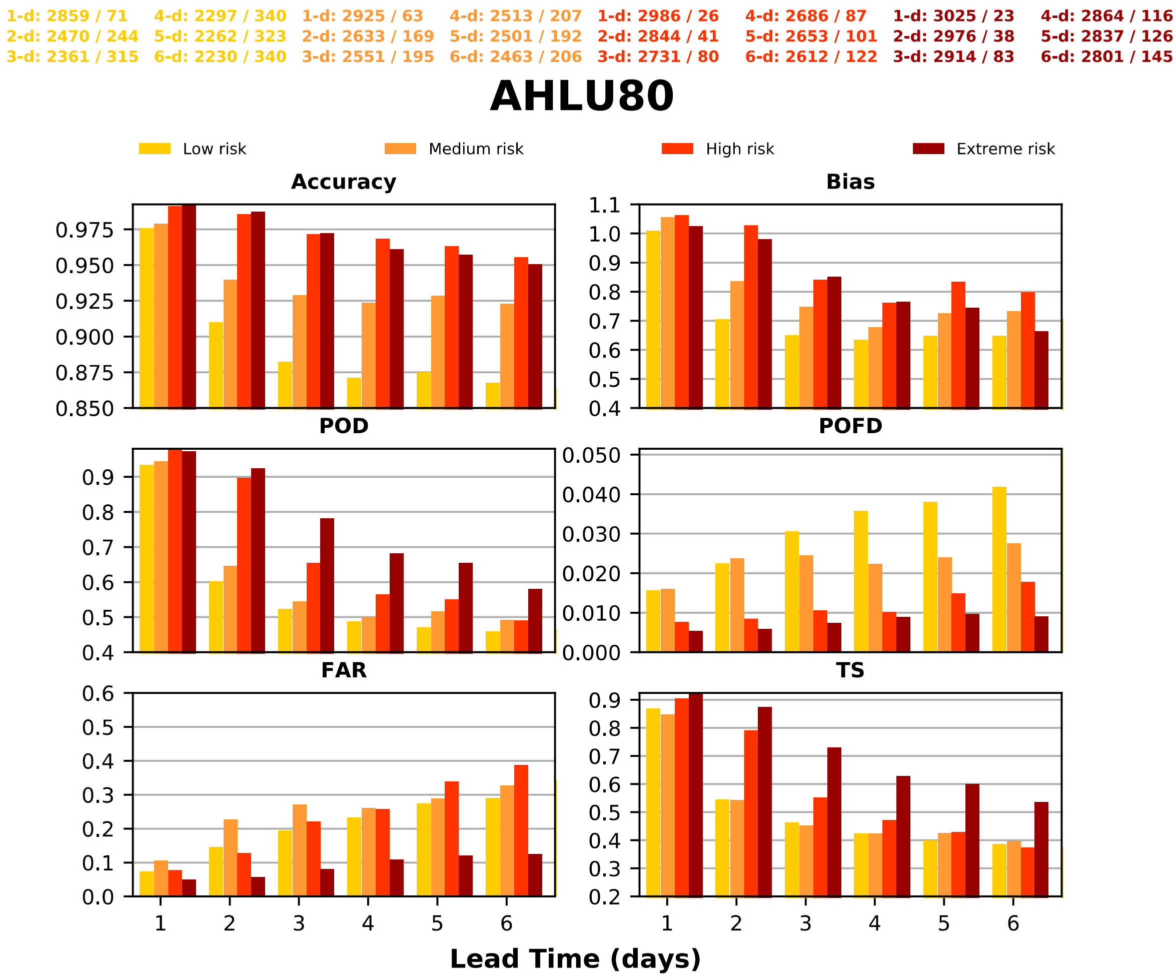


Fig. 20 Measures derived from the AHLU80 contingency table across the benchmark locations and the 2018-19 season

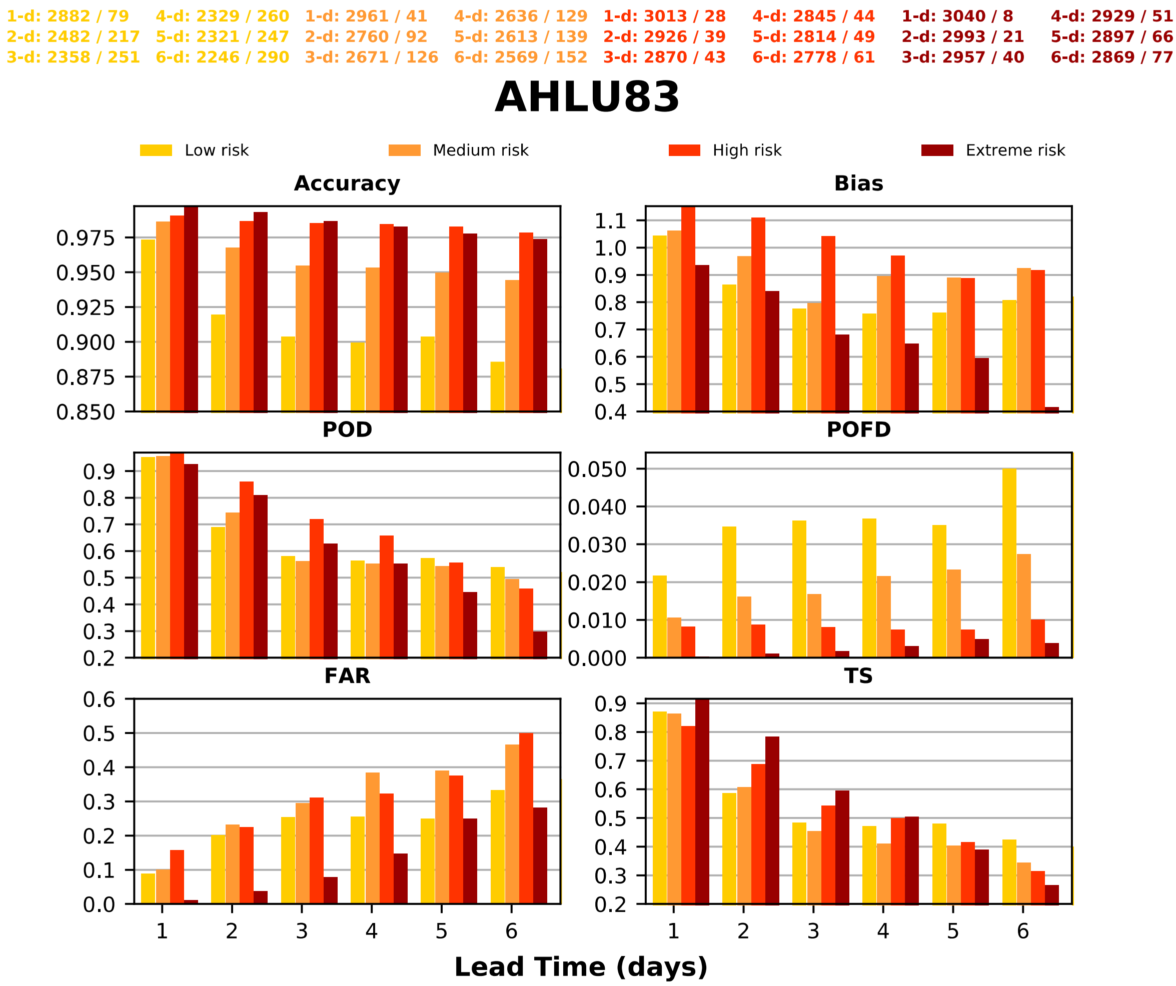


Fig. 21 Measures derived from the AHLU83 contingency table across the benchmark locations and the 2018-19 season

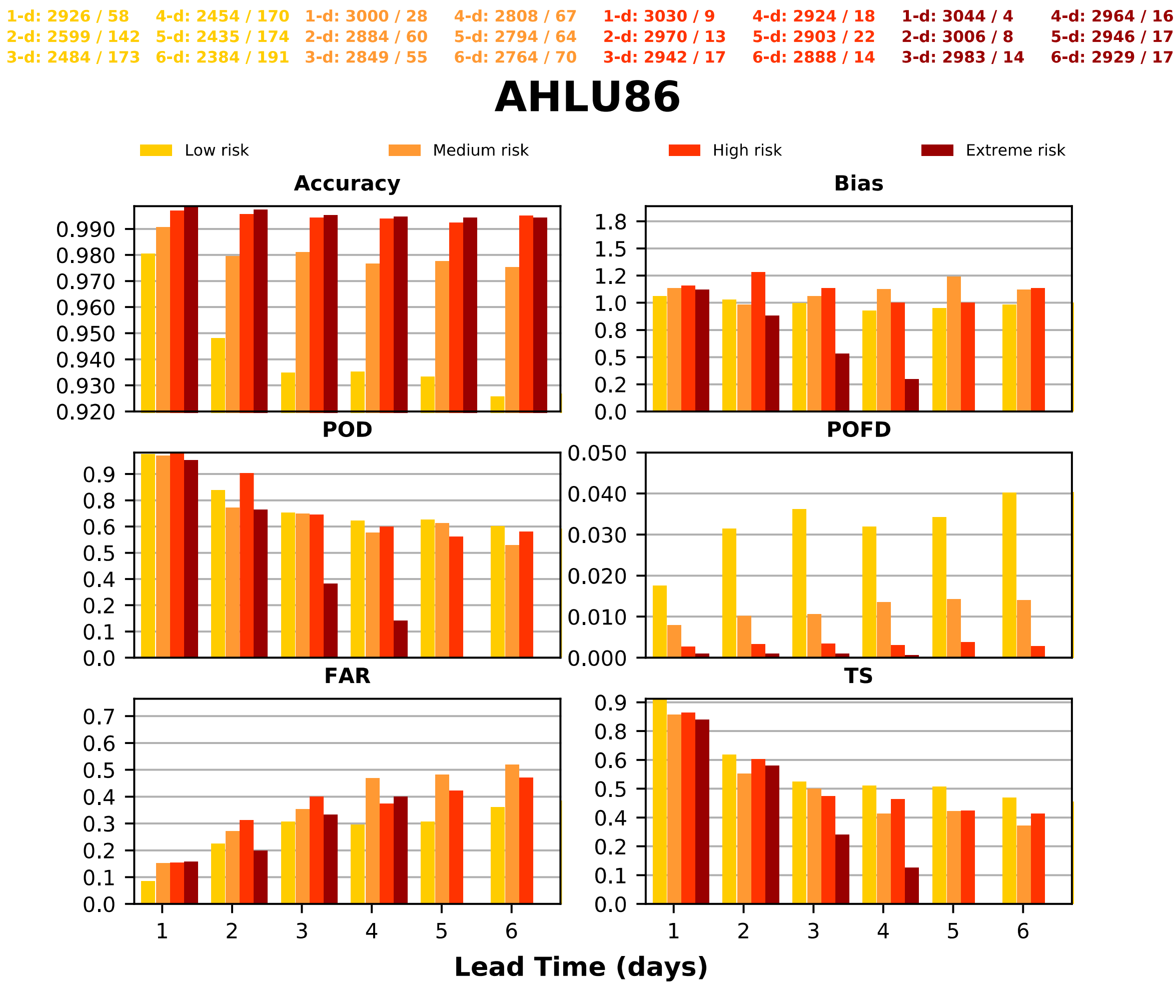


Fig. 22 **Measures derived from the AHLU86 contingency table across the benchmark locations and the 2018-19 season**

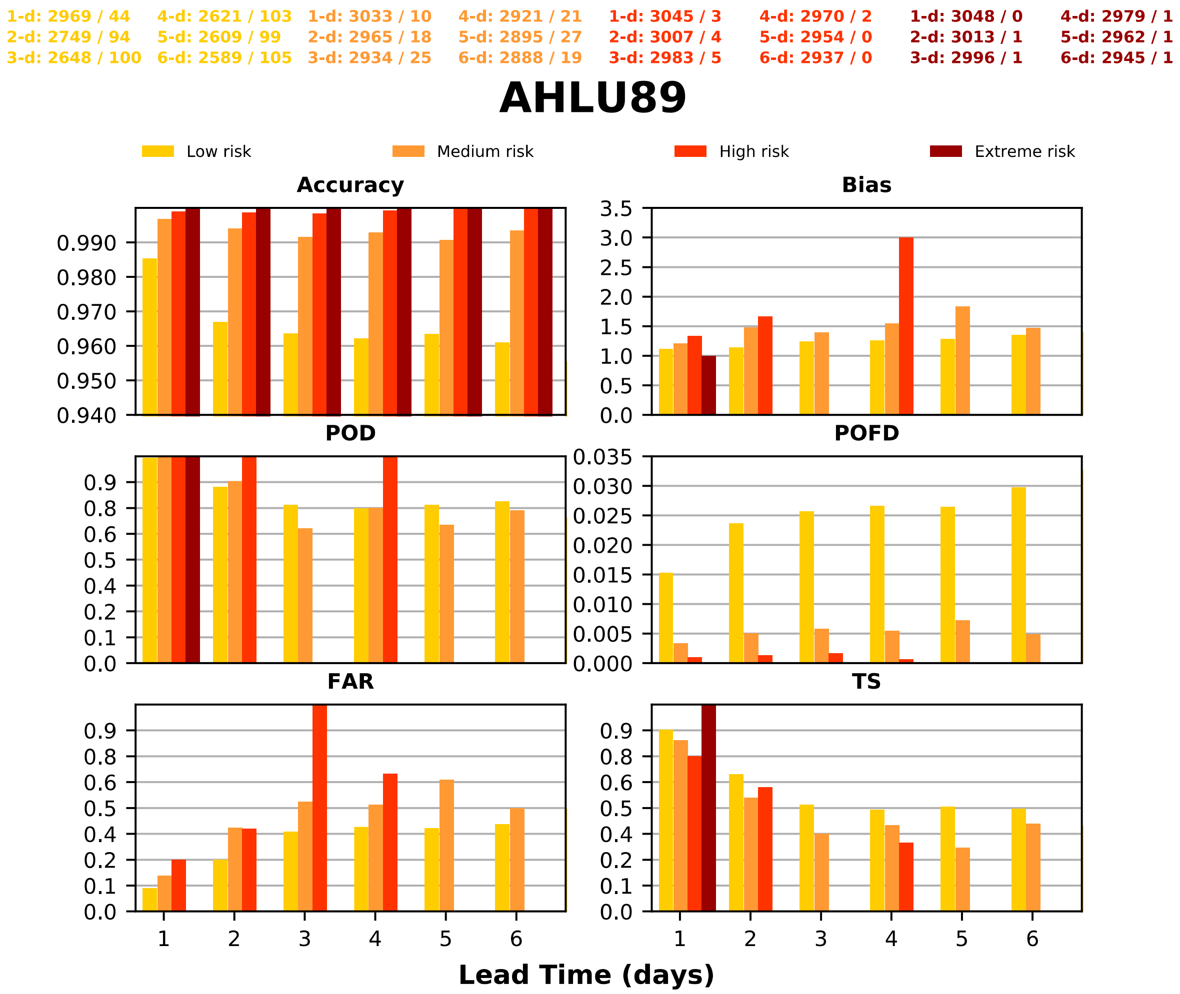


Fig. 23 Measures derived from the AHLU89 contingency table across the benchmark locations and the 2018-19 season

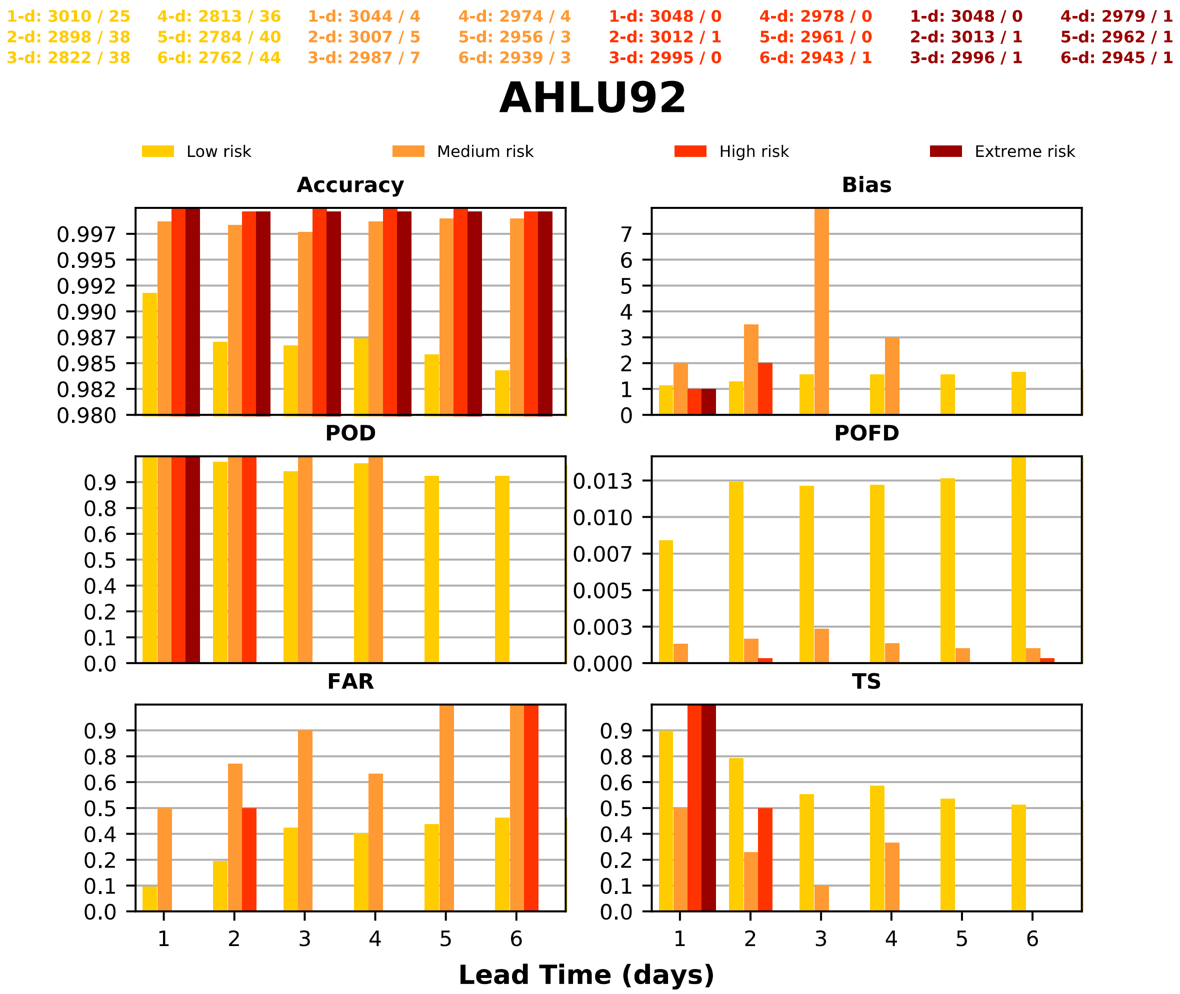


Fig. 24 Measures derived from the AHLU92 contingency table across the benchmark locations and the 2018-19 season

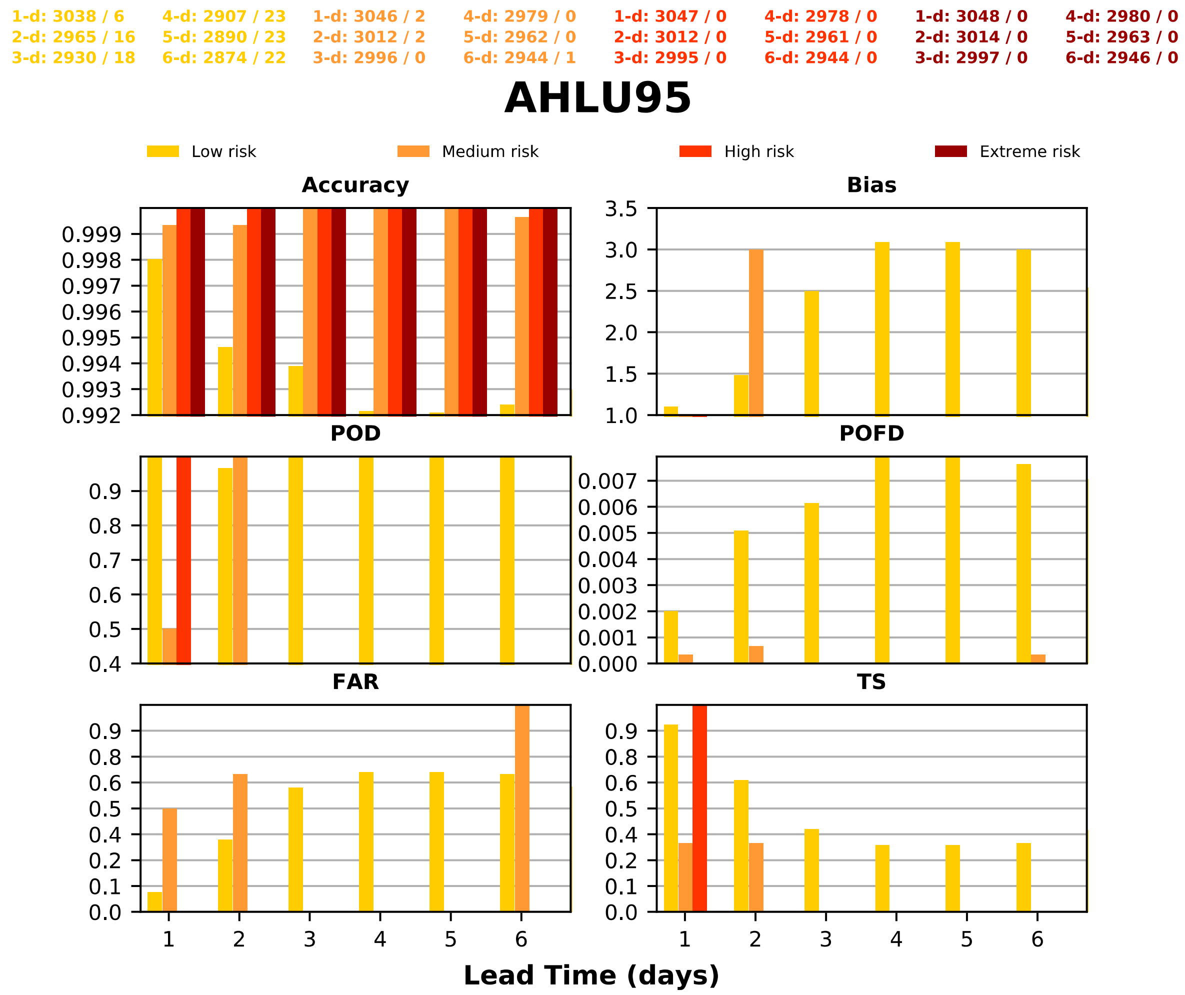


Fig. 25 **Measures derived from the AHLU95 contingency table across the benchmark locations and the 2018-19 season**

4.1.5 User Survey

At the end of this season, a survey was sent out to all CHLT subscribers. The subscribers were invited to comment on the accuracy of the forecast and other aspects of the service. The survey received a total of 75 responses, representing 92 feedlots. Users, such as nutritionists or veterinarians, may be associated with more than one site. It is not possible to ascertain which feedlot subscribers where referring to in the survey if they are subscribed to multiple sites.

Fig. 26 shows the breakdown of respondents by state. Half of respondents are from Queensland followed by New South Wales and Victoria, which account for 33% and 6%, respectively. Western and South Australia represent 4% only, whereas Tasmania has the lowest proportion of respondents.

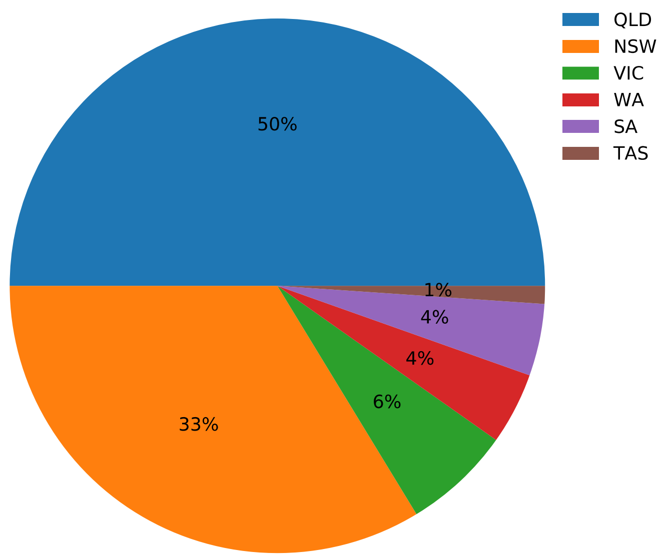


Fig. 26 **Percentage of survey respondents according to the state where their feedlots are localised**

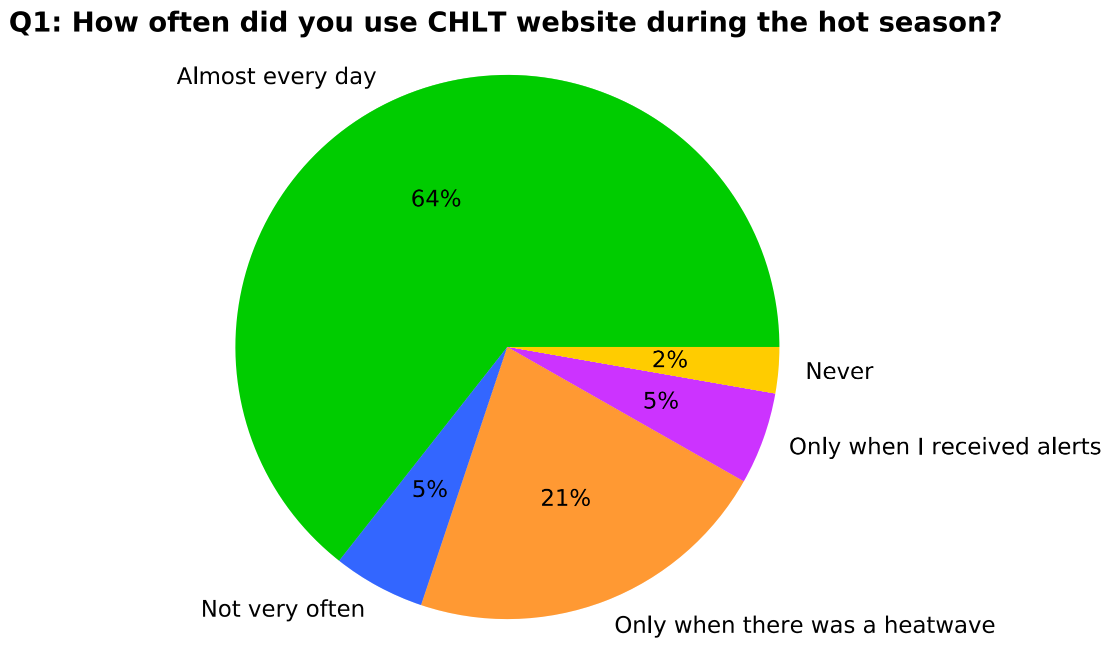


Fig. 27 **Responses to question 1 of the end of season survey**

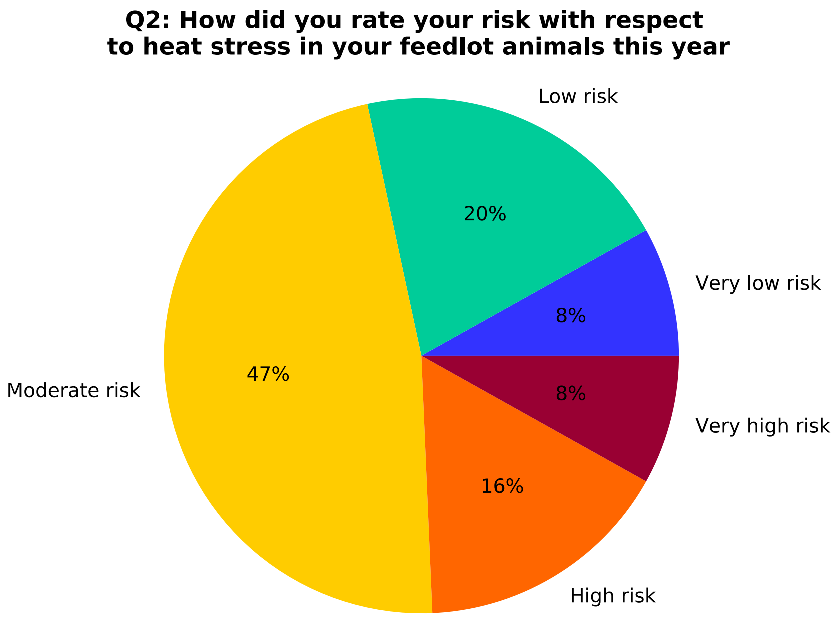


Fig. 28 Responses to question 2 of the end of season survey

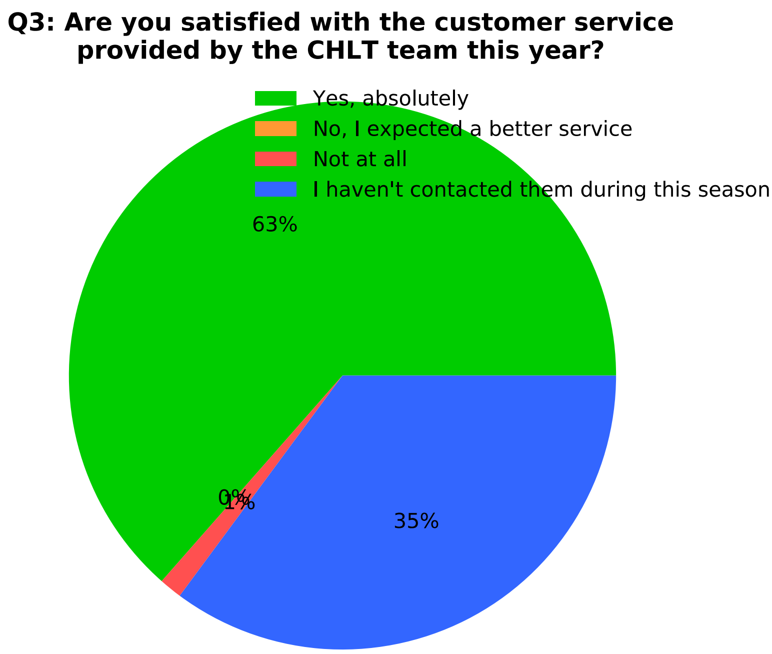


Fig. 29 Responses to question 3 of the end of season survey

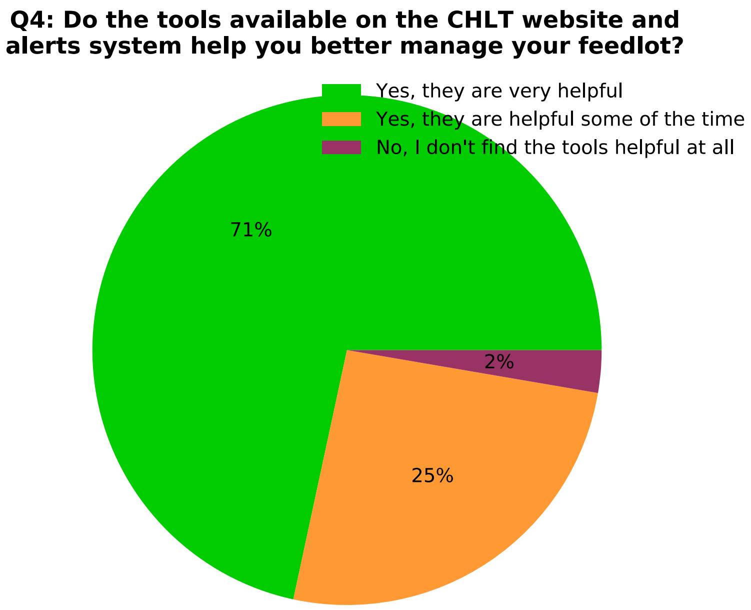


Fig. 30 Responses to question 4 of the end of season survey

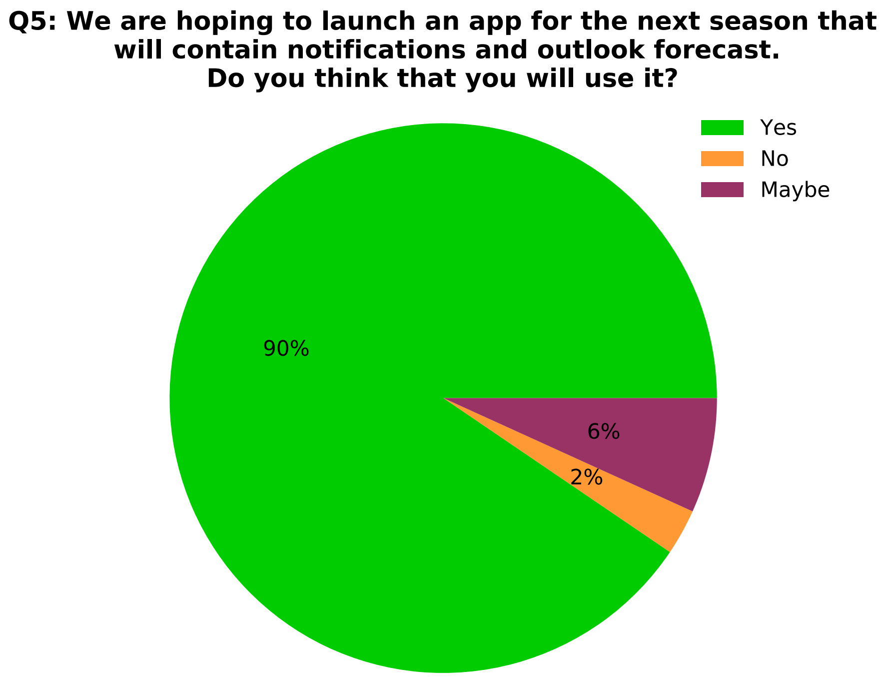


Fig. 31 Responses to question 5 of the end of season survey

Table 5 Additional comments of the end of season survey

Q6. If there is something specific you would like to communicate with the team, please add your comments here:		
Answer Options		**Response Count**
Comments:		19

Number	**Comments:**
1	Peechelba HLI forecasts are consistently about 10 units below the actuals we experience. Would be good to get this more accurate.
2	humidity is a major issue after a rain event when heat is prevalent. Is there anyway humidity can be highlighted to the same effect as heat.?
3	Make the weekly forecast so it can be downloaded to a PDF.
4	re smartphone app - In transit app that delivers animal welfare outcomes - measuring heat load, monitoring livestock, tracking locations and animal temperament during transit - fit to load?, tracking, density, etc. all this information will be accessed via app on a load-by-load basis. *(name and email address)*
5	It may be something i am doing wrong on my end but, when we print an outlook for some reason there is no colour on the print out. i think the colour really helps staff that need to look at the outlook, because they can identify a heat period easier, when they just don't have time to look online.
6	We don't seem to be getting any closer to an accurate forecast maybe not using the best BOM forecast for this area.
7	i think making and app with heat load and CHLT would make it a lot more easy to use on day to day basic
8	The feedlot is in voluntary suspension
9	We are unable to use the Site Glen Innes Airport this year to do our RAP analysis which has meant we need to use another site that is not reflective of our feedlots temperature profile. This was mentioned to Katestone at the beginning of the season.
10	I would like to be able to print out the day results/ ie just for Tuesday , so I can show other staff and also keep it for records, etc
11	Still some issues later in the season regarding accuracy of forecast on a short term basis. Would be great to be able to reforecast during the day as actual data becomes available.
12	We are very low risk in Northern Tasmania and don’t use the site much as it does not really relate to Tasmania's low risk.
13	Keep up the good work. Thank you.
14	When i go into 'my site' in Cattle Heat load, there is a blank space below heading i have to scroll down to find 'my site summary'. i believe there used to be a weather

	map here... at the moment it is simply a big white space of nothing. Can you fix this heading into next summer? Thank you
15	The heat load tool is getting better however we saw symptoms of heat load our standard 86's in week 12 that were not forecast. We are at Maude NSW.
16	we found that forecasting was a lot more accurate this year than in previous years
17	Capacity to include an additional warning relating to rapid rise in AHL, e.g. +30 units within 1 or 2 hours in combination with warning related to exceeding threshold HLI may assist in identifying risks associated with rapid onset heat load conditions. Would like to extend special thanks to Katestone team for collecting and sending data request during time when the rest of the country was in cruise control. It was greatly appreciated and assisted directly with understanding situation.
18	Thanks for your help in the industry, it has become a very valuable management tool.
19	Thank you ... i think this is a very valuable resource.

The end of season survey indicated:

- Almost two thirds of respondents use the CHLT website almost every day during the hot season. One-quarter check on the website only when there is a heatwave or when they have received alerts (Fig. 27   Responses to question 1 of the end of season survey).
- Almost half of the participants perceived moderate risk of heat stress in their feedlot animals during this season, while around 20% rated as low and high risk (Fig. 28).
- Considering the customers who have contacted us at some point this season, everyone, except for one, are very happy with the level of service they received from the team this season. (Fig. 29).
- A large proportion of respondents (up to 71%) find the tools available on the CHLT website and alerts system helpful for a better management of their feedlot whereas only 2% do not find the tools useful (Fig. 30).
- The vast majority (up to 90%) would use an App if it was available and only 2% would not (Fig. 31).

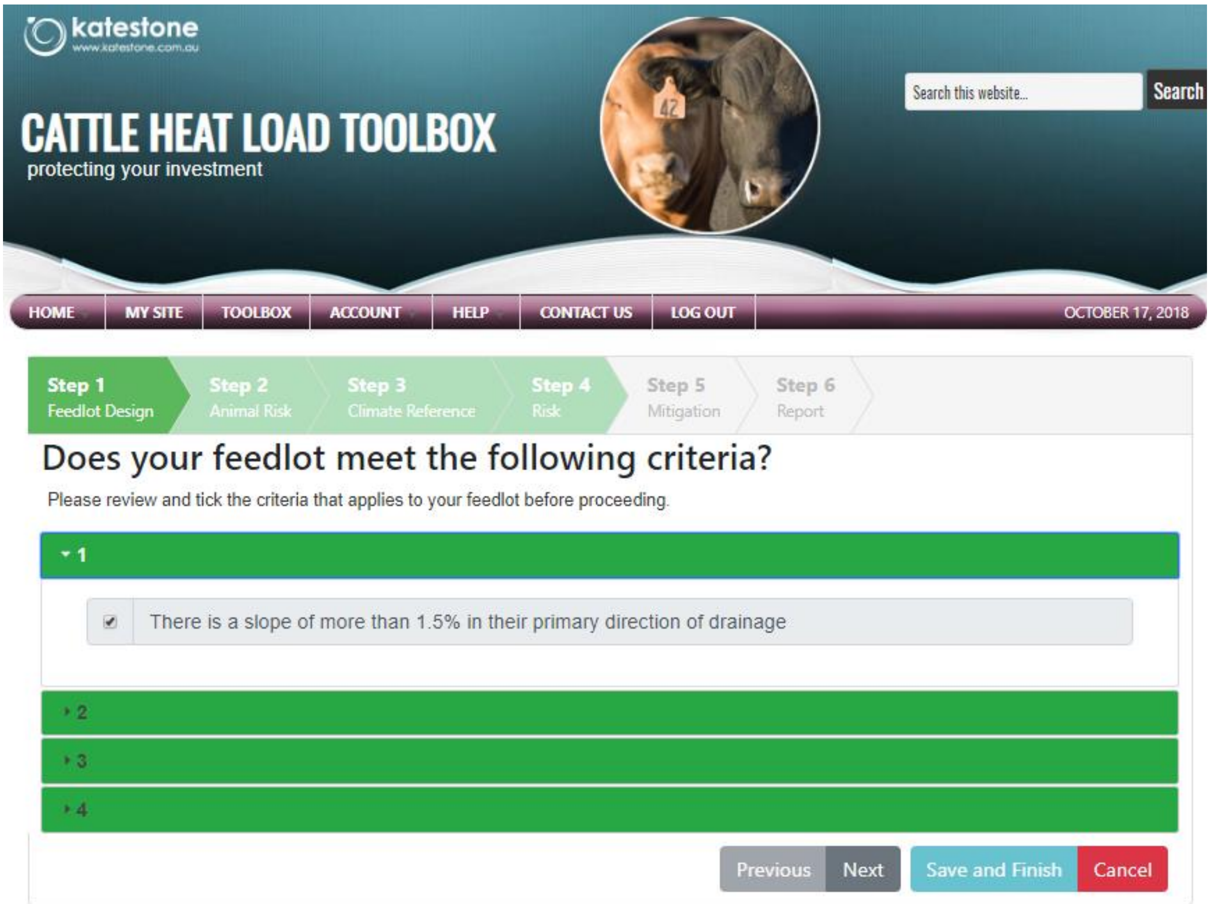
Other comments (

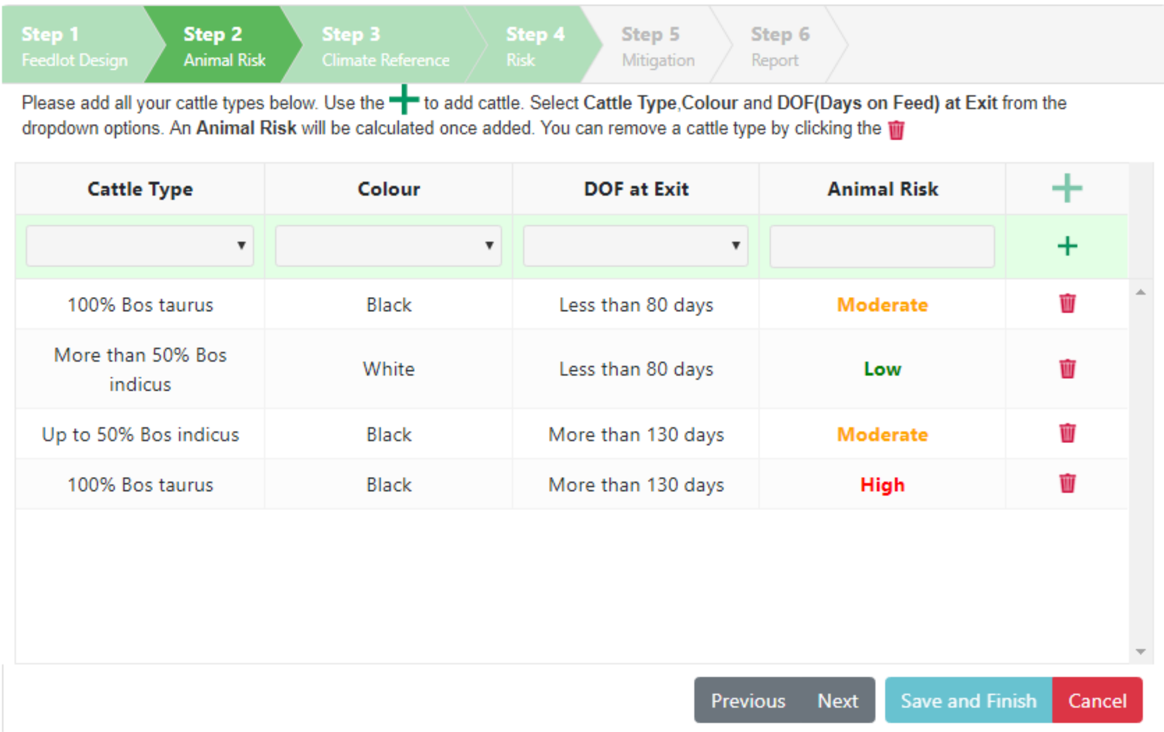
- Table 5):
    - Some comments are related to printing out the forecast. For instance, some suggested having a PDF version to download the weekly forecast or having the option of printing out one day only.
    - Additional alerts considering a rapid increase in AHLUs.
    - As expected, some comments highlighted the disagreement sometimes between observations and forecasts.

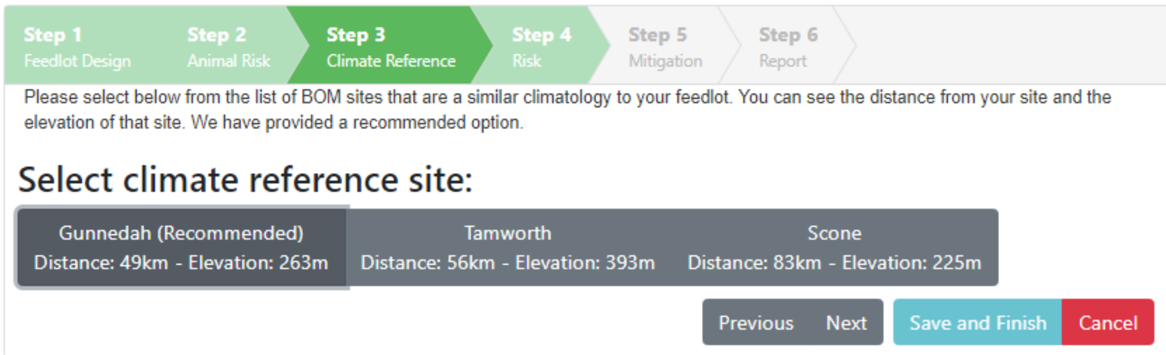
Overall, the survey results indicate that most users are well satisfied with the service provided by team this season. However, we received some comments that help us to determine the weaknesses of CHLT so that we can improve the product for the next seasons. Regarding CHLT availability, in the last newsletter we emphasized that the website is active throughout the year, although alerts are only sent from October to March.

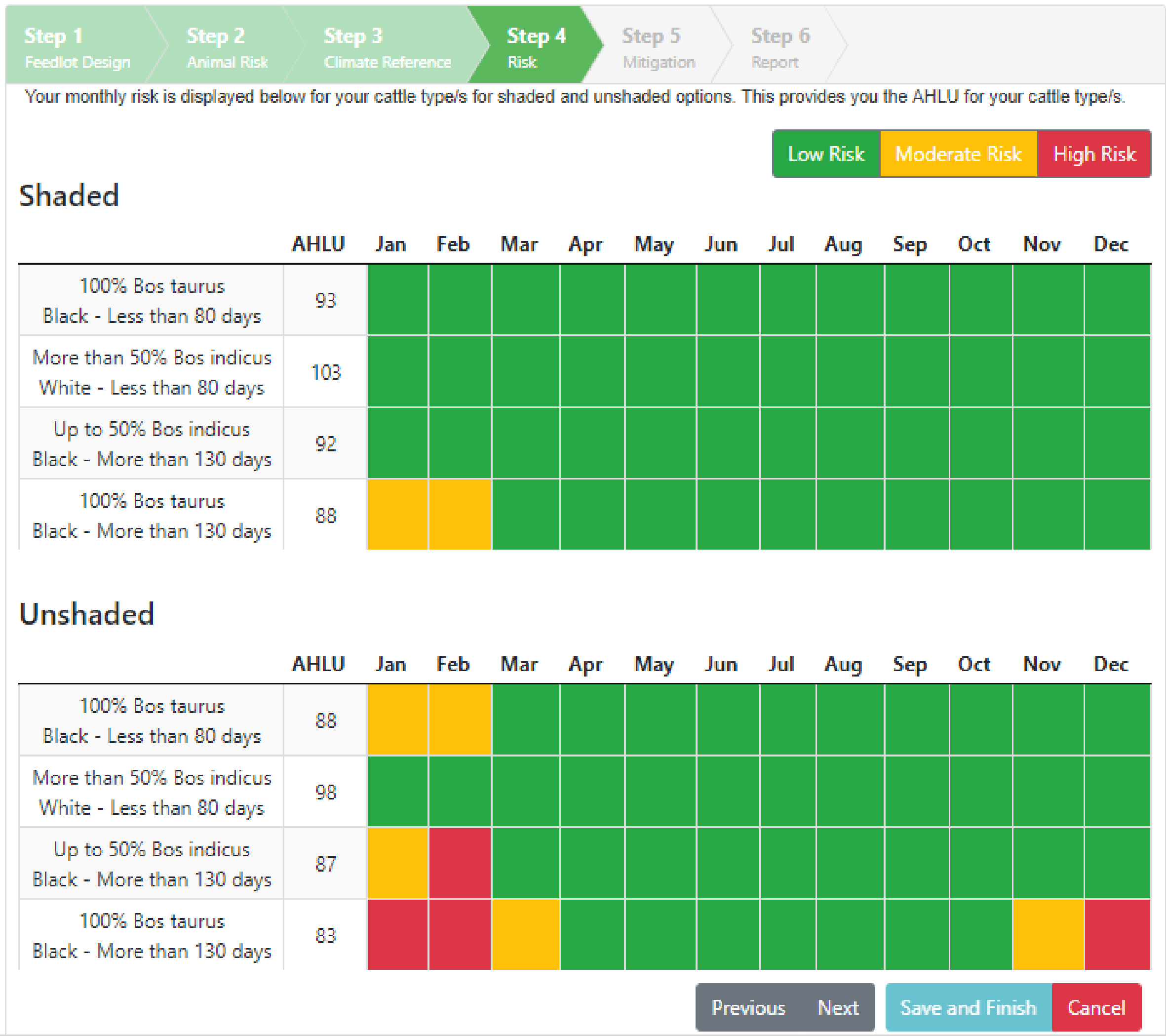
4.2 RAP Upgrade

Screen shots of the Beta Version of the new RAPV2 are presented below.






Step 1
Feedlot Design
Step 2
Animal Risk
Step 3
Climate Reference
Step 4
Risk
Step 5
Mitigation
Step 6
Report
Please select below from the list of BOM sites that are a similar climatology to your feedlot. You can see the distance from your site and the elevation of that site. We have provided a recommended option.
Select climate reference site:
Gunnedah (Recommended)
Distance: 49km - Elevation: 263m
Tamworth
Distance: 56km - Elevation: 393m
Scone
Distance: 83km - Elevation: 225m
Previous
Next
Save and Finish
Cancel


Step 1
Feedlot Design
Step 2
Animal Risk
Step 3
Climate Reference
Step 4
Risk
Step 5
Mitigation
Step 6
Report
Your monthly risk is displayed below for your cattle type/s for shaded and unshaded options. This provides you the AHLU for your cattle type/s.
Low Risk
Moderate Risk
High Risk
Shaded
AHLU Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
100% Bos taurus Black - Less than 80 days 93
More than 50% Bos indicus White - Less than 80 days 103
Up to 50% Bos indicus Black - More than 130 days 92
100% Bos taurus Black - More than 130 days 88
Unshaded
AHLU Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
100% Bos taurus Black - Less than 80 days 88
More than 50% Bos indicus White - Less than 80 days 98
Up to 50% Bos indicus Black - More than 130 days 87
100% Bos taurus Black - More than 130 days 83
Previous
Next
Save and Finish
Cancel

Step 6 is a report presenting the results of the RAP.

5 Conclusions

The CHLT service has become an integral part of heat load management at Australian Feedlots. The number of subscribers and feedlots that are registering for the service continues to grow every year. Overall the user base is satisfied with the delivery and performance of the service.

Although the 2018-19 season saw above average temperatures over much of Australia, the HLI values were close to average in Queensland. The extremely dry 2018 that preceded the current season also had a big impact on cattle market.

The rapid change in the HLI alert threshold has not been adequately investigated and events may be missed or misinterpreted. This alert threshold needs further developed to allow a more accurate warning of these type of events.

Several subscribers have requested that a mobile phone friendly version of the CHLT service be provided. Given the increase in users accessing the service through mobile devices it would be prudent to implement this change soon.

The forecast performance for prediction of HLI was comparable to the last five. The volatility of the HLI algorithm has been shown in previous studies (B.FLT.0392), indicating that a near perfect forecast can still produce an error of 5 to 7 HLI units, which is similar to the RMSE for a 3-day forecast.

Overall the variability in the predicted HLI is within the known error bounds of the HLI algorithm. Nonetheless, subscribers are questioning the accuracy of the forecast and how to further improve the information received onsite.

The success of the overall system depends on the underlying research to determine a robust assessment of heat risk. The currently model is extremely sensitive to the assumptions and small changes in meteorological conditions. For this reason the roll out of a new Risk Assessment Process was delayed until further work can be undertaken.

6 Bibliography

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7 Appendix A – Evaluation Parameters

Methods for forecasts of continuous variables:

- Root mean square error: $RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2}$
- Mean absolute error: $MAE = \frac{1}{N}\sum_{i=1}^{N}|F_i - O_i|$
- Mean error: $ME = \frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)$
- (Multiplicative) bias: $Bias = \frac{\frac{1}{N}\sum_{i=1}^{N} F_i}{\frac{1}{N}\sum_{i=1}^{N} O_i}$
- Correlation coefficient: $r = \frac{\sum(F-\bar{F})(O-\bar{O})}{\sqrt{\sum(F-\bar{F})^2}\sqrt{\sum(O-\bar{O})^2}}$
- Refined index of agreement: $rIOA = \begin{cases} 1 - \frac{\sum|F_i - O_i|}{2\sum|O_i - \bar{O}|}, \; when \; \sum|F_i - O_i| \leq 2\sum|O_i - \bar{O}| \\ \frac{2\sum|O_i - \bar{O}|}{\sum|F_i - O_i|} - 1, \; when \; \sum|F_i - O_i| > 2\sum|O_i - \bar{O}| \end{cases}$

Methods for dichotomous (yes/no) forecasts:

- Accuracy: $Accuracy = \frac{hits + correct\ negatives}{total}$
- Bias: $Bias = \frac{hits + false\ alarms}{hits + misses}$
- Probability of detection: $POD = \frac{hits}{hits + misses}$
- Probability of false detection: $POFD = \frac{false\ alarms}{correct\ negatives + false\ alarms}$
- False alarm ratio: $FAR = \frac{false\ alarms}{hits + false\ alarms}$
- Thread score: $TS = \frac{hits}{hits + misses + false\ alarms}$