Final report

Feedlot Heat Load Forecasting Service FY23 to FY27

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Abstract

This report encompasses the progress towards the third milestone of delivering the MLA Feedlot Heat Load Forecasting Service, and completion of the system delivery and evaluation against pilot sites.

The main objective is to complete the development and launch the Feedlot Heat Load Forecasting Service, and assess suitability against the initial 14 pilot reference sites. Managing the impact of hot weather is of increasing importance due to the changing global environment and consumer expectations.

It is a critical element of Australia's National Feedlot Accreditation Scheme.

The Service is being delivered using standard software development practices and incorporating advanced peer-reviewed algorithms.

The deliverables of this milestone are included within and where appropriate as appendices to this document.

The project has been delivered in line with the previously agreed expectations.

Executive summary

Background

This project has been commissioned to develop a new next generation heat load indexation tool to assist feedlot farmers in proactively managing heat stress in their livestock. The tool will be used to provide advanced weather forecasting, daily and weekly alerting for heat load events, and other management tools for climate events.

Objectives

By the date agreed, MistEO will deliver;

(1) a new feedlot heat load forecast service web interface including user registration portal, GPS coordinate nomination, heat load threshold calculator, historical risk documentation, and MLA heat load management publications.
(2) A forecast service that incorporates the most accurate weather forecast service considering WRF and ADFD forecast data, and other feasible sources.
(3) A daily heat load forecast service (7-day horizon) to up to 500 NFAS accredited feedlots utilising the HLI and AHLU algorithms (Gaughan et al. 2008) as part of (1).
(4) Annual communications and service support program
(5) Annual milestone report to MLA

Methodology

There are three parts to the early warning system, such as accurate weather forecasting, appropriate triggers or limits which need to be which could be considered to be adverse, and communication of the warning via appropriate media. The following two sections are showing the overall methodology for forecasting the weather variables and calculating the Heat Load Index.

Results/key findings

The performance of the forecasts have been assessed against the observations taken from 4 benchmark locations located in different territories. Following the benchmark comparison it was observed that the accuracy of the system is in line with agreed expectations.

Benefits to industry

The feedlot industry in Australia will be able to benefit from a more up to date and accurate heat load indexation service than previously available, with an increased feature set due to increased investment in heat load and climate event management tools

Future research and recommendations

Future research could be conducted incorporating advanced IoT device integration such as mistEO's proprietary collars, the incorporation computer vision data to further support accurate heat load indexation and more accurately assessing the impact of heat and climate events on livestock.

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1. Background

1.1 Purpose and Description

Meat & Livestock Australia is committed to progressive research and development to enable Australian feedlot producers to manage excessive heat load. Heat load is known to negatively impact cattle health, welfare and productivity. Managing the impact of hot weather is of increasing importance due to the changing global environment and consumer expectations. It is a critical element of Australia's National Feedlot Accreditation Scheme.

Heat waves are a significant concern for lot fed cattle in Australia. They occur where maximum ambient conditions are above a certain threshold for a number of successive days (typically 3-5) or with rapid onset of extreme temperature/humidity. The ability to forecast heat wave events has enabled livestock producers to implement mitigation strategies to prepare for adverse heat load events. Heat load is the cumulative effect of animal factors (such as genotype, coat type, coat colour, diet type, diet composition, body condition) and environmental conditions that affect the thermal comfort of animals. Cattle may accumulate heat during the day (rise in body temperature) and dissipate that heat at night. If there is insufficient cooling at night cattle enter the following day with accumulated heat load.

The Heat Load Index (HLI) model and the Accumulated Heat Load Unit (AHLU) were developed by monitoring panting scores of commercial feedlot cattle across a range of sites in Australia and the United States and have been utilised by the Australian feedlot industry since 2008 to forecast and manage heat load. Calculation of the Heat Load Index (HLI) requires ambient temperature (TA; °C), relative humidity (RH; %), wind speed (WS; m/s) and black globe temperature (BGT; °C). Of these, TA, RH and WS are routinely measured by the majority of weather stations. Although sensors for measuring BGT exist, these are not normally included as part of the standard weather station and must be ordered from a suitable supplier. In the absence of a BGT sensor, the BGT can be inferred from measurements of TA and solar radiation (SR; W/m2). The methods for calculating the HLI are all publicly available. The Accumulated Heat Load Unit (AHLU) represents the amount of heat accumulated in cattle over a period of time. The rate of accumulation depends on the current HLI value and the thresholds used. Large HLI values result in a more rapid increase in AHLU, conversely, low HLI values result in a decrease of the AHLU (i.e. the cattle cool down and recover). The base threshold occurs at a HLI value of 86 (base AHL). This threshold is based on a healthy Black Angus steer, 80 days on feed without access to shade. The threshold is adjusted on the basis of breed type, access to shade, and days on feed (see Gaughan et al. 2008 for details).

2. Objectives

By the date agreed, MistEO will deliver the following objectives. This list has been adjusted given the consent to commercialise the solution being received by MistEO.

(1) a new feedlot heat load forecast service web interface including user registration portal, GPS coordinate nomination, heat load threshold calculator, historical risk documentation, and MLA heat load management publications.

(2) A forecast service that incorporates the most accurate weather forecast service considering WRF and ADFD forecast data, and other feasible sources.

(3) A daily heat load forecast service (7-day horizon) to up to 500 NFAS accredited feedlots utilising the HLI and AHLU algorithms (Gaughan et al. 2008) as part of (1).

(4) Annual communications and service support program which includes:
    a. annual pre-season training webinar (planned for October each year)
    b. pre-season newsletter to registrants (planned for October each year
    c. issue of daily alert for accumulated heat load to nominated users (by 6 AM AEDT)
    d. end of season survey (planned for April each year).
    e. service support (business hours for Eastern timezones)

(5) Annual milestone report to MLA that contains:
    a. a. Annual suitability assessment of weather forecasting service to minimise mean and linear bias of observed vs. predicted weather indices contributing to the Heat Load Index.
    b. Number of registered feedlots and aggregated usage statistics
    c. Number of registered individual users, and aggregated usage statistics
    d. Number of alerts issued to registered feedlots in each state by HLI threshold

3. Methodology

3.1 Overview

There are three parts to the early warning system, such as accurate weather forecasting, appropriate triggers or limits which need to be which could be considered to be adverse, and communication of the warning via appropriate media. The following two sections are showing the overall methodology for forecasting the weather variables and calculating the Heat Load Index.

3.2 Weather Model

For weather forecasting, mistEO uses the Weather Research and Forecasting - Advanced Research and Weather (WRF-ARW) model. The WRF-ARW is suitable for a broad range of forecasting ranging from a few meters to thousands of kilometers.

For weather forecasting, initial and boundary conditions are taken from the Global Forecasting System (GFS) model, which contains data assimilated from the weather stations, upper air soundings as well as satellite data. WRF-ARW contains a Land Surface Model which is important for forecasting at the earth's surface. The complete workflow of the forecasting and Heat Load Calculations are given in **Figure 3.2.1** below.

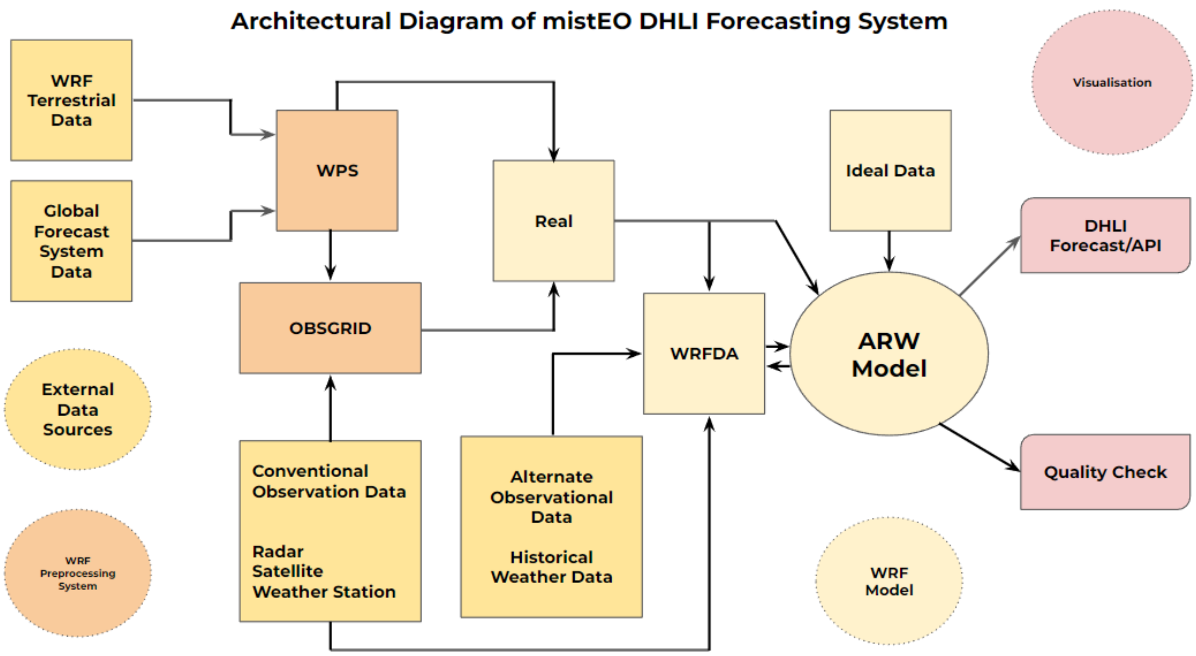


Fig.3.2.1

WRF model is initialized using GFS forecast data, and forecasting the weather for 7 days at an hourly time step. The model domain extends from 102°E to 167°E and from -5°S to 47°S encompassing Australia, at a resolution of 27 km. All the subscriber feedlots and HLDN participant locations are covered using two domains of resolution of 9km each, as shown in **Figure 3.2.2** below.

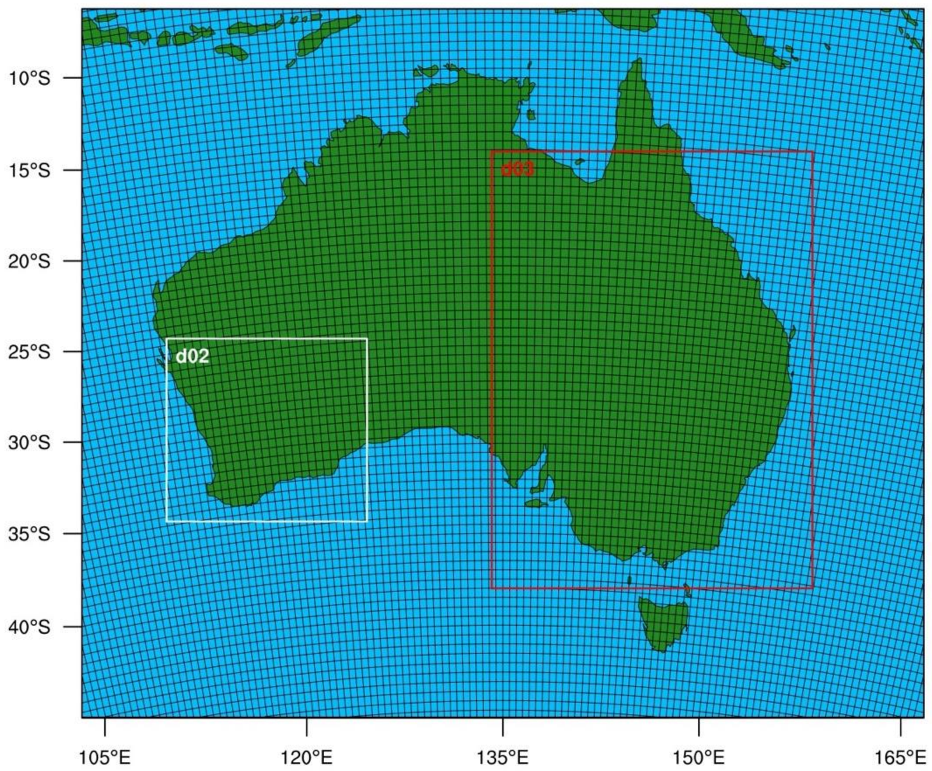


Figure 3.2.2 - Weather Forecast Domain

3.3 Heat Load Index

The performance of the model forecast is reviewed at the benchmark AWS sites. These locations are Bureau of Meteorology(BOM) sites that do not record Black Globe Temperature (BGT) measurements or solar radiation. As such these variables are not included in the performance analysis. Henceforth, the solar radiation parameter for the calculation and analysis of BGT is taken from the reanalysis dataset (ERA 5 - Copernicus Reanalysis).

In the absence of measured BGT, a quantified relationship between BGT, ambient temperature (T), and solar radiation (SR) is used. Here solar radiation is taken from reanalysis data.

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

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

For the BGT & HLI calculation, negative temperature observations are neglected.

The HLI Calculation consists of two sets of equations , HLI will be taken as HLI(high) when the BGT exceeds above 25°C and HLI will be considered as HLI(low) when the BGT drops below 25°C

HLI_High (BGT>25) = 8.62 + (0.38 x Relative Humidity) + (1.55 x BGT) - (0.5* Wind Speed) + EXP(2.4-Wind speed)

HLI_Low(BGT<25) = 10.66 + (0.28 x Relative Humidity) + (1.3 x BGT) - Wind Speed

4. Results (to-date)

4.1 Forecast Verification

The performance of the forecasts have been assessed against the observations taken from 14 benchmark locations located in different territories. **Table 4.1.1** describes the details and **location** of the benchmark sites.

Sl. No.	Site	Lat	Lon	WMO Code	State
1	Albury	-36.06	146.95	95896	NSW
2	Amberley	-27.62	152.71	94568	QLD
3	Armidale	-30.52	151.61	95773	NSW
4	Charlton	-36.28	143.33	94839	VIC
5	Clare High School	-33.82	138.59	95667	SA
6	Emerald	-23.56	148.17	94363	QLD
7	Griffith	-34.24	146.06	95704	NSW
8	Hay	-34.54	144.83	94702	NSW
9	Miles	-26.65	150.18	95529	QLD
10	Moree	-29.48	149.84	95527	NSW
11	Oakey	-27.40	151.74	94552	QLD
12	Roma	-26.54	148.77	94515	QLD
13	Tamworth	-31.07	150.83	95762	NSW
14	Warwick	-28.20	152.10	94555	QLD

Table 4.1.1 - Feedlot locations

The performance of the forecast is reviewed at the weather station 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. The solar radiation parameter for the calculation and analysis of BGT is taken from reanalysis dataset(ERA 5 - Copernicus).

In the absence of measured BGT, a quantified relationship between BGT, ambient temperature (T) and solar radiation (SR) is used. Here solar radiation is taken from reanalysis data.

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

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

For the BGT & HLI plotting -ve temperature is considered as 0°C, as

because the equation contains square root terms.

For the HLI Calculation two sets of equations are used, HLI will be taken as HLI(high) when the BGT exceeds above 25°C and HLI will be considered as HLI(low) when the BGT drops below 25°C

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

Frac High = 1/(1 + e-((BGT-25)/2.25))

HLI = (Frac High * HLI High) + ((1 - Frac High) * HLI_Low)

4.2 Model Validation

For the model verification part the weather observations from 01st January 2023 to 9th March 2023 are taken in every hour interval and validated with the model forecast for the same period. The HLI and other parameters time series performance(Observation Vs Model) for the station Tamworth is presented below.

Heat Load Index

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

- Root Mean Square Error(RMSE)
- Mean Absolute Error(MAE)
- BIAS
- Correlation Coefficient(CO)

HLI Error Matrix Tables

Day 1 : (24 * 1) Hours

Sl. No.	Station	HLI RMSE	HLI MAE	HLI BIAS	HLI CO
1	Albury	6.57	5.70	-5.37	0.96
2	Amberley	4.55	3.34	-2.62	0.95
3	Armidale	3.39	2.63	-0.89	0.96
4	Charlton	4.19	3.37	-2.93	0.97
5	Clare High School	4.54	3.71	-2.85	0.97
6	Emerald	5.79	4.99	-4.82	0.97
7	Griffith	4.07	3.22	-2.25	0.97
8	Hay	3.66	2.97	-2.13	0.97
9	Miles	5.61	4.46	-3.97	0.96
10	Moree	3.68	2.82	-0.18	0.97
11	Oakey	4.09	3.01	-1.77	0.96
12	Roma	4.05	3.21	-2.32	0.97
13	Tamworth	4.02	3.01	-2.00	0.96
14	Warwick	5.33	4.09	-3.57	0.95
	Average	**4.54**	**3.61**	**-2.69**	**0.96**

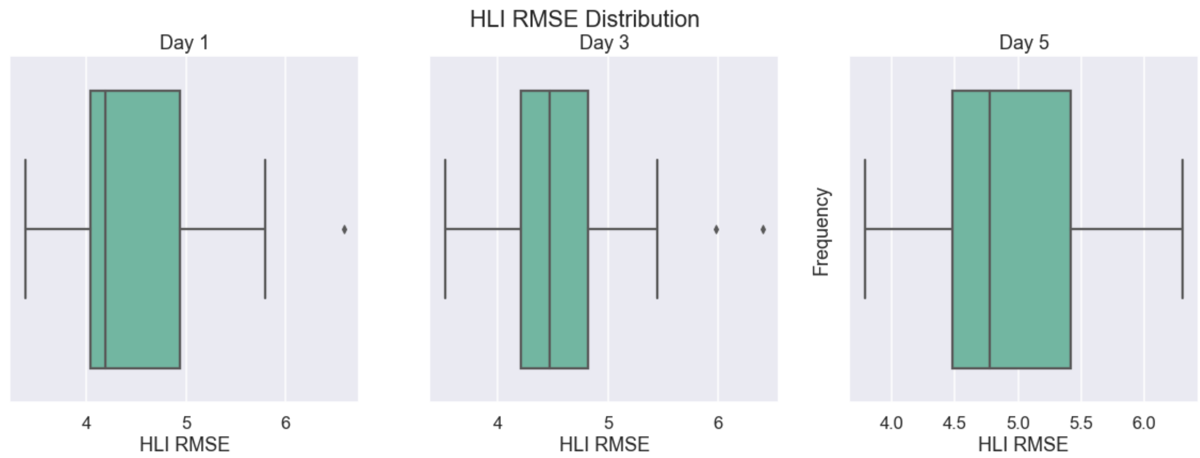
Day 3 : (24 * 3) Hours

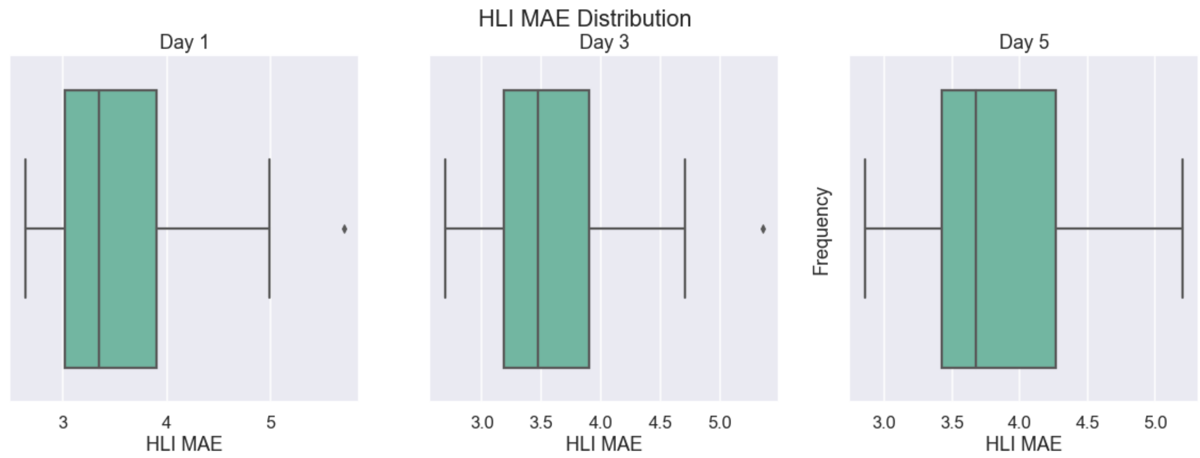
Sl. No.	Station	HLI RMSE	HLI MAE	HLI BIAS	HLI CO
1	Albury	6.40	5.36	-4.85	0.95
2	Amberley	4.60	3.38	-2.43	0.95
3	Armidale	3.52	2.69	-0.60	0.95
4	Charlton	4.35	3.47	-2.77	0.97
5	Clare High School	4.97	4.01	-2.97	0.96
6	Emerald	4.63	3.79	-3.54	0.97
7	Griffith	4.24	3.29	-1.92	0.97
8	Hay	3.96	3.13	-1.93	0.97
9	Miles	5.98	4.70	-3.99	0.94
10	Moree	4.05	3.06	-0.04	0.96
11	Oakey	4.38	3.23	-1.75	0.95
12	Roma	4.47	3.50	-2.28	0.96
13	Tamworth	4.17	3.07	-1.45	0.96
14	Warwick	5.44	4.18	-3.49	0.94
	Average	**4.65**	**3.63**	**-2.43**	**0.96**

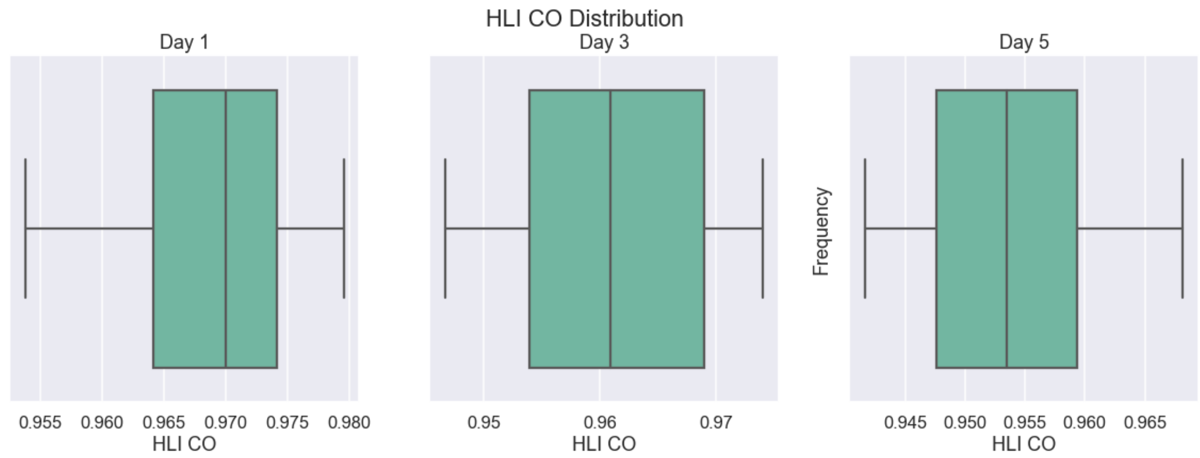
Day 5 : (24 *5) Hours

Sl. No.	Station	HLI RMSE	HLI MAE	HLI BIAS	HLI CO
1	Albury	6.30	5.20	-4.45	0.94
2	Amberley	4.77	3.54	-2.50	0.94
3	Armidale	3.78	2.85	-0.49	0.94
4	Charlton	4.62	3.67	-2.60	0.96
5	Clare High School	5.19	4.17	-2.86	0.96
6	Emerald	5.74	4.54	-4.23	0.94
7	Griffith	4.53	3.49	-1.63	0.96
8	Hay	4.32	3.38	-1.62	0.96
9	Miles	6.14	4.84	-3.91	0.94
10	Moree	4.38	3.30	-0.08	0.95
11	Oakey	4.67	3.47	-1.82	0.94
12	Roma	4.86	3.77	-2.21	0.95
13	Tamworth	4.42	3.27	-1.33	0.95
14	Warwick	5.63	4.35	-3.57	0.942
	Average	**4.95**	**3.85**	**-2.38**	**0.95**

Box plots comparing several verification methods and statistics of HLI forecasts averaged across the 14 benchmark sites and for the validation period(01st January 2023 - 09th March 2023) is given below







5. Success in meeting the milestone

5.1 Milestone Objectives

#	Description / Criteria	Current Status
3A	Annual suitability assessment of weather forecasting service to minimise mean and linear bias of observed vs. predicted weather indices contributing to the Heat Load Index.	Completed – Section 4 of this report
3B	Number of registered feedlots and aggregated usage statistics	Currently 3 registered feedlot is actively using the system and evaluating it
3C	Number of registered individual users, and aggregated usage statistics	Currently 10 registered individual users
3D	Number of alerts issued to registered feedlots in each state by HLI threshold	Multiple alerts issued across all pilot feedlots
3E	End of user season survey results	Verbal feedback has been received on a weekly basis from pilot feedlots, awaiting further pilot feedlots to be enrolled in the pilot

6. Future Research and Recommendations

6.1 IoT Device Integration

Cattle collars equipped with sensors and monitoring technology offer many opportunities to help farmers and ranchers monitor the heat stress of their livestock. Here are some of the key benefits:

- Early Detection of Heat Stress: Cattle collars can provide real-time data on the body temperature of the animal, and behaviour (standing/lying) allowing farmers to detect the onset of heat stress early and take appropriate measures to prevent it from becoming severe. This is particularly important in hot and humid environments, where heat stress can quickly become a serious health issue for the animal.
- Improved Animal Welfare: By monitoring the body temperature and behaviour of the animal, cattle collars can help farmers identify individual animals that are at higher risk of heat stress and take steps to mitigate the risk. This can include providing shade, increasing airflow, and providing access to cool water.
- Increased Productivity: Heat stress can significantly impact the productivity of cattle, causing a reduction in milk production, weight gain, and fertility. By monitoring the temperature and other physiological parameters of the animal, cattle collars can help farmers optimize the environment and management practices to maintain the productivity of the herd.
- Data-Driven Decision Making: Cattle collars can generate a wealth of data on the health and behavior of the animals, providing farmers with valuable insights into the performance of their herd. This data can be used to optimize feeding and breeding programs, reduce disease incidence, and improve overall herd management.

6.2 Computer Vision Data

Computer vision technology offers several opportunities for monitoring the heat stress of cattle. Here are some of the key benefits:

- Non-Invasive Monitoring: Computer vision technology enables non-invasive monitoring of cattle, which is particularly important for assessing heat stress. This technology can capture images of the animals in real-time, without the need for physical contact, which reduces stress and potential injuries in cattle.
- Detection of Early Signs of Heat Stress: Computer vision technology can detect early signs of heat stress in cattle by analyzing their behavior and physiological parameters such as respiration rate, panting, and sweating. By detecting these signs early, farmers can take measures to reduce heat stress, such as providing shade and cooling systems, before it becomes a severe health issue.
- Automated Monitoring: Computer vision technology can be used to automate the monitoring of cattle, which reduces the labor required for monitoring and can provide continuous monitoring of the herd. This can be particularly beneficial in large-scale livestock operations where manual monitoring is not feasible.
- Data-Driven Decision Making: Computer vision technology can generate a wealth of data on the behavior and physiology of cattle, providing farmers with valuable insights into the health and well-being of their herd. This data can be used to optimize herd management

practices, improve feed and water management, and reduce the incidence of heat stress and other health issues.

7. References

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Acronyms

GFS	Global Forecast System
WRF	Weather Research Forecast
WPS	WRF Preprocessing System
ARW	Advanced Research WRF
WRFDA	WRF Data Assimilation
API	Application Programming Interface
d01	Domain 1
d02	Domain 2
d03	Domain 3
d04	Domain 4
Lat	Latitude
Lon	Longitude
WMO	World Meteorological Organization
WA	Western Australia
NT	Northern Territory
T	Temperature
SR	Solar Radiation
BGT	Black Globe Temperature
HLI	Heat Load Index
AHLU	Accumulated Heat Load Unit
DHLI	Dairy Heat Load Index
HLDN	Heat Load Data Network
RMSE	Root Mean Square Error
MAE	Mean Absolute Error
CO	Correlation Coefficient