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Daily Heat Load Monitoring Tool

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Executive summary

The Daily Monitoring Tool Project was separated into three distinct projects:

1. Develop and test a daily monitoring tool App.
2. Develop an alternative thermal risk assessment.
3. Review alternative forecasts.

Daily Monitoring Tool

For cattle in a feedlot their risk of heat stress changes from day to day. This is a combination of the physical properties of the animal changing (becoming acclimatised and reducing their risk and then gaining weight to become more at risk), this combined with changing weather conditions and potentially changing pen conditions results in a dynamic system that should be assessed daily to determine the risk of heat stress for a particular cattle population.

The Daily Monitoring Tool (DMT) App was developed by Katestone and available for limited testing in the 2015/16 summer. The App was designed to record the population characteristics, environmental conditions and management practices at participating feedlots. The App trial started in December 2015 with thirteen feedlots verbally agreeing to participate.

Participation by the feedlots in the use of the daily monitoring via the App was unfortunately poor. The limited data collected was analysed but it was difficult to draw any major conclusions regarding the HLI or AHLU concepts without more data. However, it is evident that more work is needed to collect sufficient observations to allow a comprehensive review of the appropriate triggers for a heat event.

Thermal Risk Assessment

An alternative method for determining the heat stress risk for a site was determined. The method incorporates cattle characteristics, feedlot management practices and the site climatology. The method is illustrated with an example, however, there are insufficient data at this stage to establish the exact form of equations and other parameter values. It is envisaged that these will be forthcoming when the data are recorded in the 2015-2016 summer season and analysed.

Long term climate datasets were also investigated to provide an alternative to sparsely located Bureau of Meteorology automatic weather stations. It was found that the risk characteristics for six representative sites obtained using the MERRA data were in agreement with those obtained using observational data. The frequency of events in the various risk categories is comparable and useable in terms of the original objectives of the RAP - that is, to determine the risk profile of a site.

Alternative forecast

The performance of K-WRF and the Bureau of Meteorology (BoM) Australian Digital Forecast Database (ADFD) system was evaluated at seventeen BoM automatic weather stations and twenty-eight feedlots that participate in the Heat Load Data Network. The results show that both systems are comparable in their performance in predicting key meteorological variables, the Heat Load Index and the Accumulated Heat Load Unit. The analysis also shows that the accuracy of both systems

suffers from the sensitivity and the interpretation of the indices themselves and to a lesser extent the accuracy of the forecast. Both systems are equally suited to form the basis for a cattle heat load early warning system.

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1. Background

The Daily Monitoring Tool Project was separated into three distinct project objectives:

1. Develop and test a daily monitoring tool App.
2. Develop an alternative thermal risk assessment and test it for specific locations across three different geographic and climatic regions.
3. Review alternative forecasts to GFS and evaluate the most suitable alternative.

The following report with address all the project objectives in separate sections.

2. Daily Monitoring Tool

The factors that go into understanding the cause of a heat event in cattle are many and without information about all the factors concurrently it is difficult to determine what the cause of an event really was. The process of undertaking daily monitoring of cattle has been extended to work as a mechanism to collect the information required to understand all the factors that contribute to the overall risk of a heat event.

For cattle in a feedlot their risk of heat stress changes from day to day. This is a combination of the physical properties of the animal changing (becoming acclimatised and reducing their risk and then gaining weight to become more at risk), this combined with changing weather conditions and potentially changing pen conditions results in a dynamic system that should be assessed daily to determine the risk of heat stress for a particular cattle population.

The Daily Monitoring Tool (DMT) was developed to record the population characteristics, environmental conditions and management practices at participating feedlots. The Tool was delivered as a mobile application (App) preloaded onto smart phones that were supplied to the participating feedlots. The data entered on the phones was synced back to Katestones' online database for storage and analysis.

The App was designed to be the focal point for integrating local observations of the weather, cattle and feedlot conditions with the predicted weather conditions. The App is a weighted aggregator of the input conditions providing a risk based approach to accurately identifying heat load events at a specific feedlot based on the local conditions observed at the time. The App provided a risk level for each population from the current day out to a seven-day lead time.

The App requires that the feedlots enter each cattle populations characteristic they wish to monitor along with their pen conditions. The Heat Load Data Network (HLDN) and the Cattle Heat Load Toolbox (CHLT) provided the observed and predicted weather conditions to the App.

2.1 Objectives

The project objective was to develop and test a daily monitoring tool App. This objective has been achieved as the App was successfully developed and tested by a number of feedlot sites over the 2015/2016 summer.

Additionally, the project proposed to analyse the data collected by the App to answer the following questions:

- Are the HLI and AHLU concepts working well?
- Are there differences in cattle behaviours between northern and southern sites for the same HLI or AHLU values?
- What factors contribute most to the risk of a heat event (management, feed, cattle type, pen conditions)?

2.2 Methodology

The App has been designed to allow feedlot operators to upload cattle data to the server at Katestone for the purposes of improving the currently available schemes for predicting heat stress in feedlot cattle and also to improve our understanding of the processes and conditions that give rise to heat stress in feedlot cattle.

The App was preloaded onto 10 Telstra 4GX BUZZ smartphones with $30 worth of data credits and mailed to 10 trial users in Queensland and New South Wales. A further 3 users were e-mail a link to download the App and install it on their own device. On receipt of the phone Katestone contacted the trial users to assist with the initial set up and configurations of their feedlots populations. Documentation on the App and its usage was also provided.

Katestone engaged a computer design company (Zone 4) to develop the framework and App user interface. A set of wireframes were created based documentation provided to Zone 4 by Katestone. The wireframes included all critical user interaction points, data entry stages and the steps that link them together that will be included in the final App.

The App is designed to work with the existing CHLT system; any user wishing to use the App will need to be already registered with CHLT. The App's login process is integrated into the existing Katestone: chlt.katestone.com.au membership database. The App passes the user details to the membership database for verification of the user.

More detail regarding the App Structure and functionality can be found in Milestone Report 5.1.

2.3 Results

The App trial started in December 2015 with thirteen feedlots verbally agreeing to particulate. All sites were provided with access to the App along with an introductory letter and users guide.

Unfortunately, uptake of the tool was limited to less than half of the participating feedlots and of those that did enter data only one entered data consistently (Feedlot 186) and one only when the status was not normal, i.e. feed drop or panting scores above 1, (Feedlot 178). Several factors may explain why the App did not receive as much uptake as envisaged. These are:

- Delayed delivery of the App to users, Apple software verification, Android and Windows Phone compatibility issues delayed the launch of the trial until mid December
- Users required more training to setup the App and become proficient users

- Doubling up of work load at the feedlot, users had to use the App as well as filling out their internal monitoring requirements and using the CHLT web service
- WIFI connectivity was an issue at some feedlots (pers.comms)

The 2015-16 season was not very active, most feedlots reported no heat events throughout the season (pers.comms and 2015/16 EOS survey results).

From the limited datasets retrieved from the App trial it is difficult to make any major conclusions about the HLI and AHLU in setting a realistic threshold for identifying cattle heat load events.

Consultation with feedlots during the season, and review of the data collected as part of this trial, indicates that there are some problems with the AHLU benchmark of 50 units correlating with a high probability of cattle experiencing a heat event. While the HLI appears to represent the general environmental conditions small deviations in the HLI can cause significant ramifications to the AHLU.

This is most evident at Feedlot 186 (see Figure below), located in north western QLD. The AHLU (as calculated from onsite AWS) indicates that extreme prolonged heat load events occurred through the majority of January and February. The events identified from the AHLU do not coincide with the entries in the daily observations; except for the February 4 2016 (10-20% pant score 1).

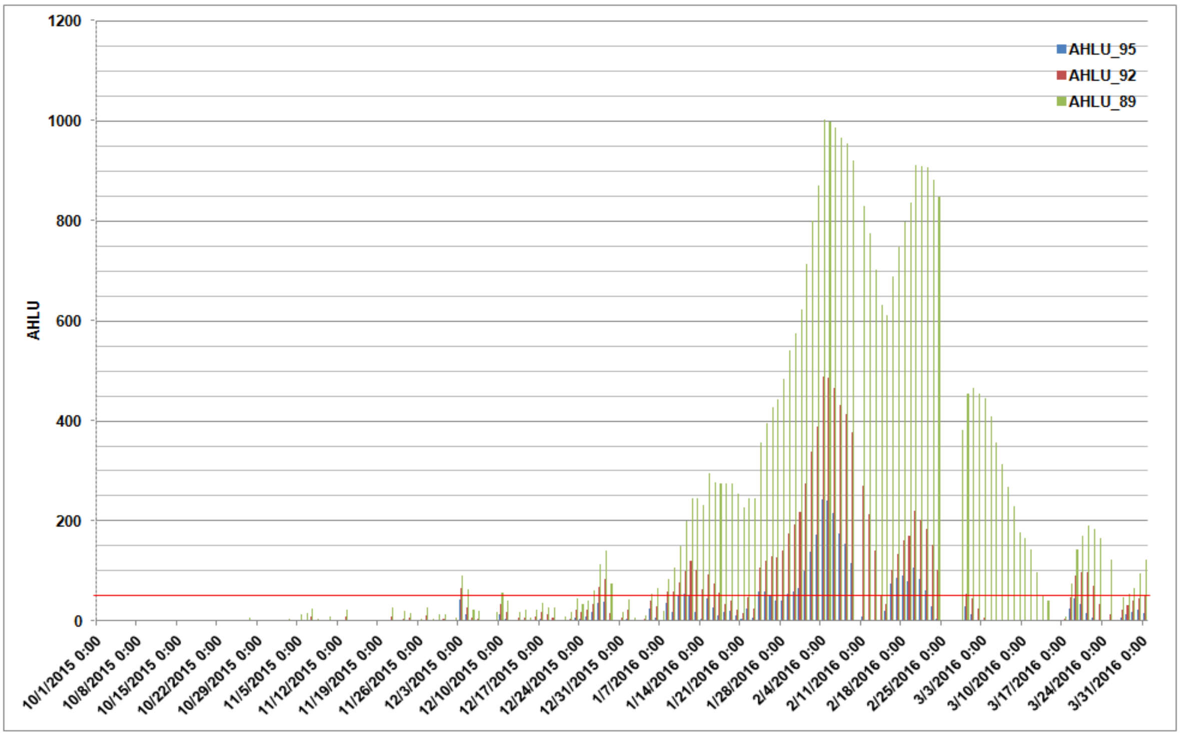

Figure 1 **Feedlot 186 calculated AHLU 95, 92 and 89 from onsite measurements. Red horizontal line indicates the high alert threshold for issuing the automated alerts in the CHLT service**

A similar situation occurred at Feedlot 178 located in southeast QLD, where several AHLU events over 50 were measured at the site but cattle observed minimal heat accumulation with less than 10% of the population showing pant scores of 1-2.

For Feedlot 400 the daily monitoring indicated that this feedlot did not experience any heat load events over the monitoring period. All the cattle were healthy and there was only one population with a feed drop of 10% and this coincided with the processing within the last 2 days. There were only two periods in the daily observations were the panting score was above zero, only reaching 1.

2.4 Discussion

The daily monitoring tool was designed to answer the following questions:

Q: Are the HLI and AHLU concepts working well?

A: From the limited datasets retrieved and in consultation with Feedlots during season, we can see that there are serious flaws in the AHLU concept. While the HLI appears to represent the general environmental conditions small deviations in the HLI can cause significant ramifications to the AHLU. This is most evident at Feedlot 186, which is located north western QLD. The AHLU indicated that a prolonged extreme heat load event was occurring for most of the season, when the site did not experience any heat events. A similar situation occurred at Feedlot 178 located in southeast QLD, where several extreme events are depicted in the data, when no events occurred.

Q: Are there differences in cattle behaviours between northern and southern sites for the same HLI or AHLU values?

A: Not enough data was retrieved from this project to provide any insights.

Q: What factors contribute most to the risk of a heat event (management, feed, cattle type, pen conditions)?

A: Not enough data was retrieved from this project to provide any insights.

More data about cattle behaviour and responses to the environment are required to ascertain the influence cattle source location and the key risk factors that drive heat stress in cattle.

2.5 Recommendations

The concept of daily monitoring has its merits, evidenced by most feedlots having an internal daily monitoring procedure. The App was a first pass at formalising the daily monitoring procedures into a risk based approach to managing cattle heat stress, where on the ground observations of environmental and cattle conditions takes precedence over calculated variables and passive sensors (AWS data). These data are important but should not outweigh what is physically being observed by a knowledgeable and experienced operator. The App is the focal point for the operator to input their observations along with the forecast and onsite weather station data to make informed decisions about cattle management. Feedback from participants, illustrates this interaction;

> "*The app worked well, it told me what was going on and when things were looking bad. It was great to have on hand while out checking the bunks and captured enough information to make informed decisions. There were issues with connecting to the internet as we don't have Wifi onsite and I would have liked to see some of the weather forecast displayed on it, such as likelihood of rain.*" (Trial participant)

From the limited data collected and other feedback from the feedlots this season, it appears that the AHLU risk levels are not representing the observations of cattle experiencing heat events. Using a daily monitoring tool as a means of mass collection of data from multiple climatic regions, with multiple cattle types and feedlot setups can provide invaluable data to help build a more robust set of risk factors. More data about cattle behaviour and responses to the environment are required to ascertain the influence cattle source location and the key risk factors that drive heat stress in cattle.

The use of an App may not have suited the audience and this should be considered in future use. Alternative methods of collecting the data (e.g. via a data portal on the current CHLT web site) should be investigated.

3. Thermal Risk Assessment

The current Risk Analysis Program (RAP 2004), used by feedlots to understand their risk of a heat event, has been operating for over ten years. This project assessed options to upgrade the program to allow for better sources of meteorological data and a new risk assessment method.

The current program has a number of short comings, the main one is the inconsistent data set used to arrive at the statistics for the sites included in the final product. The data sets range in lengths from less than five to over ten years. In order to faithfully capture the risk profile for a site, the largest dataset possible should be used. The varied range in datasets and short period of data may have resulted in inconsistent risk assessments between sites and potentially risk levels for some sites are not fully representative of the true situation. In this project, the MERRA data set are investigated for suitability to use in a risk analysis program.

An alternative method for determining the heat stress risk for a site was also investigated. The method incorporates cattle characteristics, feedlot management practices and the site climatology.

3.1 Objectives

The project objective is to test an alternative data source and methodology for assessing heat risk at feedlots across Australia. The majority of Australia's feedlots are in remote and rural regions without representative long-term data sources. To address this Katestone reviewed available model reanalysis datasets that could be used as proxy observations for any feedlot in Australia and compared the data to observations. A new risk assessment methodology was also investigated.

3.2 Methodology

The project followed a four-step approach to achieve the project objectives. These were:

Step 1 - Investigate alternate climate data sources and calculate HLI and AHLU for 3 locations (aim for 20 years + datasets)

Step 2 - Test alternate climate data, determine risk and compare to RAP 2004 for different climatic locations

Step 3 - Define questionnaire for basic thermal risk assessment

Step 4 - Produce alternative risk assessment

The detailed methodology and analysis can be found in Milestone Report 2.2.

3.3 Discussion

The MERRA data set was analysed to ascertain whether it would be a suitable replacement for the observational data used in the RAP 2004. Advantages of the MERRA data set are that a large selection of parameters are available on an hourly basis for a period of at least twenty years. In addition, since MERRA data are gridded, meteorological data for any location on the Australian continent can be extracted, whereas RAP 2004 was limited to locations hosting a Bureau of Meteorology Automatic Weather Station.

The RAP analyses were carried out using a subset the MERRA data for six representative sites in the RAP 2004 suite of sites. The subsets spanned the same time interval as the available Bureau of Meteorology data, ensuring that the resulting statistics represented the same time periods. Analyses included (i) the generation of the corresponding statistics used in the RAP 2004 so that direct comparison of the risk profiles can be made and (ii) the development of an algorithm to generate the relative risk ranks of the sites. The rankings were carried out for both the MERRA data set and the Bureau of Meteorology observational data set. The Spearman Rank Correlation Coefficient (McClave and Dietrich, 1994) was used to ascertain how consistently the sites were ranked.

Examination of the RAP risk profiles indicated that both data sets produced risk profiles that agree in ascertaining risk profile of a particular site. Both data sets ranked the site risk levels consistently as indicated by a Spearman Rank Correlation Coefficient value of 96%.

An alternative scheme was outlined for evaluating the monthly risk profile for feedlot sites. The scheme incorporates parameters pertaining to the meteorology, cattle type and feedlot management practices. The methodology is based on standard risk assessment procedures used in government and industry.

The method of Deciles used by the Bureau of Meteorology was used to classify the probability and ranking of the hazard. A risk level was obtained by means of a questionnaire which was then used to generate a mapping function that mapped a hazard level to a corresponding consequence.

The method was illustrated with an example. The hazard used in the example was the HLI, though it must be emphasised that if it proves inadequate, it can easily be replaced by a more suitable parameter. Also, the consequence levels used were those used in industry. A more suitable measure can be used if appropriate. A similar argument can be made for the questionnaire.

3.4 Recommendations

An alternative method for determining the heat stress risk for a site was determined. The method incorporates cattle characteristics, feedlot management practices and the site climatology. The method is illustrated with an example, however, there are insufficient data at this stage to establish the exact form of equations and other parameter values. It is envisaged that these will be forthcoming when the data are recorded in the 2015-2016 summer season and analysed.

Long term climate datasets were also investigated to provide an alternative to sparsely located Bureau of Meteorology automatic weather stations. It was found that the risk characteristics for six representative sites obtained using the MERRA data were in agreement with those obtained using observational data. The frequency of events in the various risk categories is comparable and useable in terms of the original objectives of the RAP - that is, to determine the risk profile of a site.

4. Alternative forecast data and performance

The CHLT forecasting service relies on the availability of a global forecast to initialize the boundary conditions for the K-WRF Australian forecast model. The current system utilizes the Global Forecast System (GFS) a weather forecast model produced by the National Centers for Environmental Prediction (NCEP) of the United States.

One of the key performance areas for the CHLT service is reliability of the service to deliver a forecast and issue alerts by 6 AM Australian Eastern Standard Time (AEST) daily during the operational forecast season (October to March). Delivery issues have been encountered over the past few years with the reliability of Australia's internet infrastructure, particularly in the Milton Business district and Brisbane CBD. Notwithstanding extreme weather events, such as floods and Ex-Tropical Cyclones, internet connectivity has played a role in the delay of GFS retrieval from overseas based servers, such as those that house the GFS datasets.

Therefore, to ensure the reliability of the forecast delivery, alternative sources of global forecasts need to be investigated. Katestone undertook a review of available global and Australian forecast data sets to determine the most appropriate source to test against the current GFS-KWRF forecast system.

Katestone identified two sources of alternate data for supplying the forecast weather information for the CHLT service:

- The Australian Digital Forecast Database (ADFD)
- The ACCESS-G weather forecast model as the boundary conditions for the K-WRF system

During the course of the project Katestone relocated all CHLT services to the Amazon Web Services (AWS) infrastructure based in Sydney. Since the move the reliability of the GFS-KWRF system has been exceptional, with zero downtime and zero delays. The improved infrastructure at the AWS data centre with direct backbones to the US, has reduced download times 10-fold making bandwidth issues and the need to source data locally less important. The ACCES-G model can still be considered as a valid boundary condition to initialise K-WRF, but would be best served if it was included in an ensemble forecasting system alongside the GFS-KWRF implementation.

This changed the scope of the project as we no longer needed to balance the requirements of data retrieval times and data reliability with the potential to improve the overall system. As such testing, the ACCESS-G model as boundary conditions to WRF was no longer required. The focus of the project moved to review the performance of a totally independent forecasting service (ADFD) which does not require running K-WRF. This has the benefit of cutting down on computational time and potentially operational costs in the long term.

4.1 Objective

The objective for this project was to review alternative forecasts suitable to be used as a data source for the CHLT and to evaluate the most suitable alternative.

4.2 Methodology

The ADFD was compared against the current K-WRF system for 17 benchmark sites and 28 Feedlots that are participating in the Heat Load Data Network (HLDN). The Benchmark sites will provide a direct comparison of the ADFD with K-WRF with respect to the past 10 years of CHLT operational service, these benchmarks are the same ones used in the end of CHLT season analysis.

The Benchmark sites will only be assessed for predictive performance on temperature, relative humidity, wind speed and HLI. The BGT is not included in this analysis as it must be calculated from a clear sky solar radiation assumption for each benchmark site and does provide a true indication of performance.

The HLDN sites provide us with a unique opportunity to investigate the performance of the K-WRF and the ADFD at non-BoM monitoring locations and for the first time a direct investigation of the black globe temperature (BGT) algorithm that is used in both K-WRF and the ADFD against measured BGT's in the field. The analysis of the HLDN sites included temperature, relative humidity, wind speed, BGT and HLI.

Performance of K-WRF and the ADFD was assessed against the performance benchmarks listed in Table 1.

Table 1 Performance benchmark guidelines

Measure	HLI	T	RH	WS
IOA	>0.9	>0.7	>0.7	>0.6
MAE	<6	<2	<10	<2
BIAS	±2	±1	±5	±1
RMSE	<6	<2	<15	<2

4.3 Results

The ADFD and KWRF predictions for HLI, temperature, relative humidity and wind speed were statistically evaluated against the measured variables at the BoM Benchmark locations and HLDN sites. All results are presented in Milestone Report 5.2. The results for HLI only are presented below for the Benchmark locations and HLDN sites.

The results are presented here as the aggregate median across all locations, individual results are provided in Section 4 of Milestone Report 5.2, with the highest and lowest scoring locations providing the bounds of the forecast distribution for day 1 to day 7 of the forecast period. The Analysis period is from October 1 2015 to March 31 2016. The Index of Agreement (IOA), Root Mean Squared Error (RMSE), Bias and Mean Absolute Error (MAE) are presented for HLI below.

4.3.1. Benchmark sites

The aggregate ADFD and KWRF meet the performance benchmark for the HLI across all metrics. Both systems have outliers that exceed the performance benchmark but only marginally. The IOA for the HLI remains above 0.9 for the entire analysis period and for each day of the forecast (Figure 2). The RMSE, Bias and MAE all show a similar trajectory over the 7 days of the forecast, gradually declining in performance as the forecast extends into the future. Both systems tend to under predict the HLI by 2-3 units in the first 4 days of the forecast. Overall the ADFD is shown to slightly outperform KWRF, particularly near the end of the forecast period.

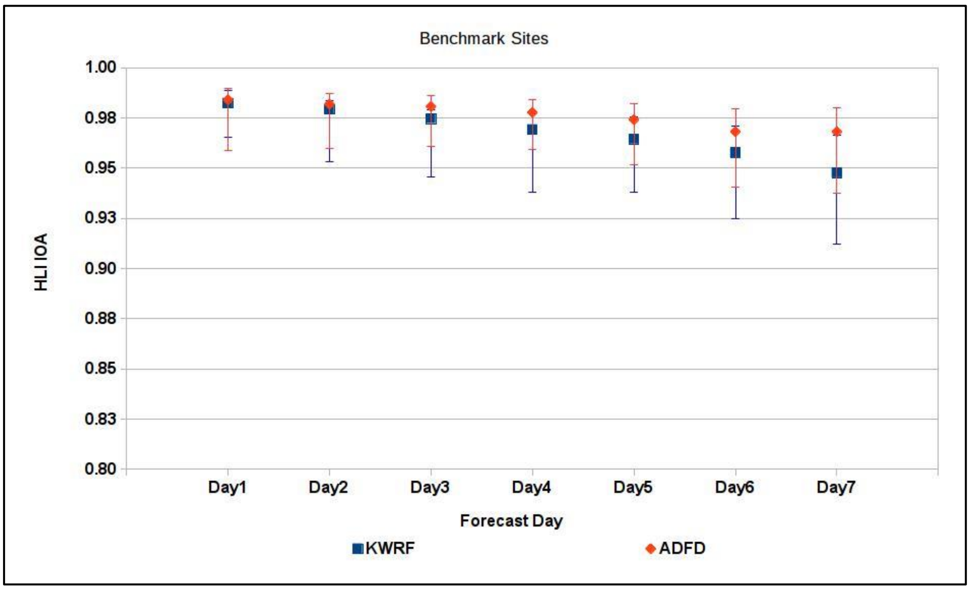

Figure 2 Aggregate HLI Index of Agreement (IOA) for KWRF and ADFD against Benchmark Sites

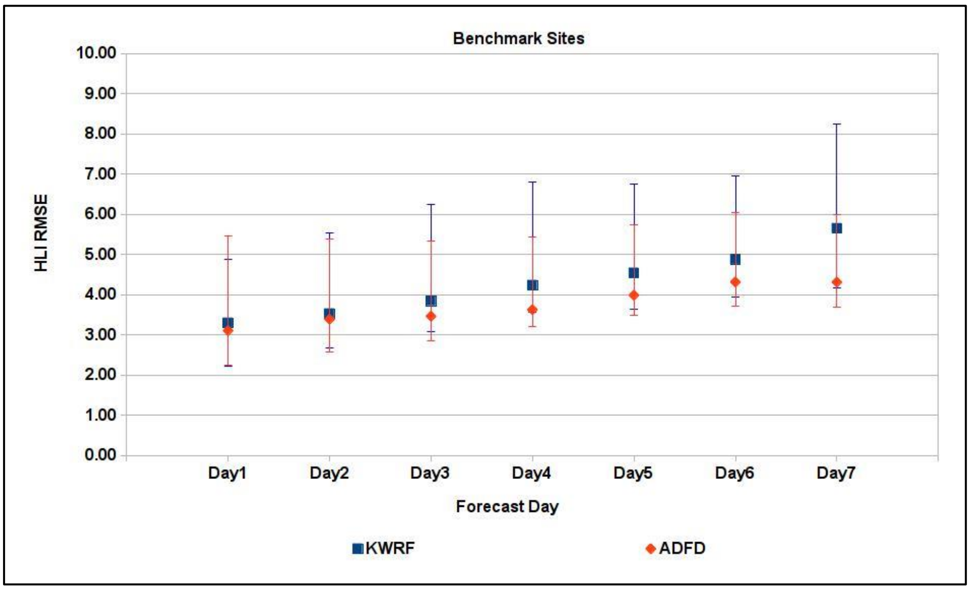

Figure 3 Aggregate HLI Root Mean Square Error (RMSE) for KWRF and ADFD against Benchmark Sites

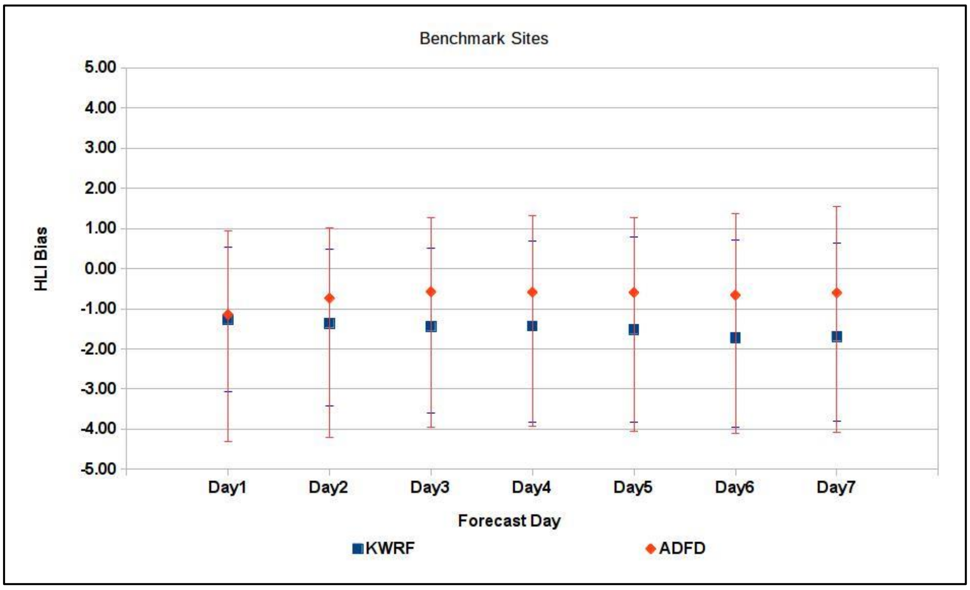

Figure 4 **Aggregate HLI Bias for KWRF and ADFD against Benchmark Sites**

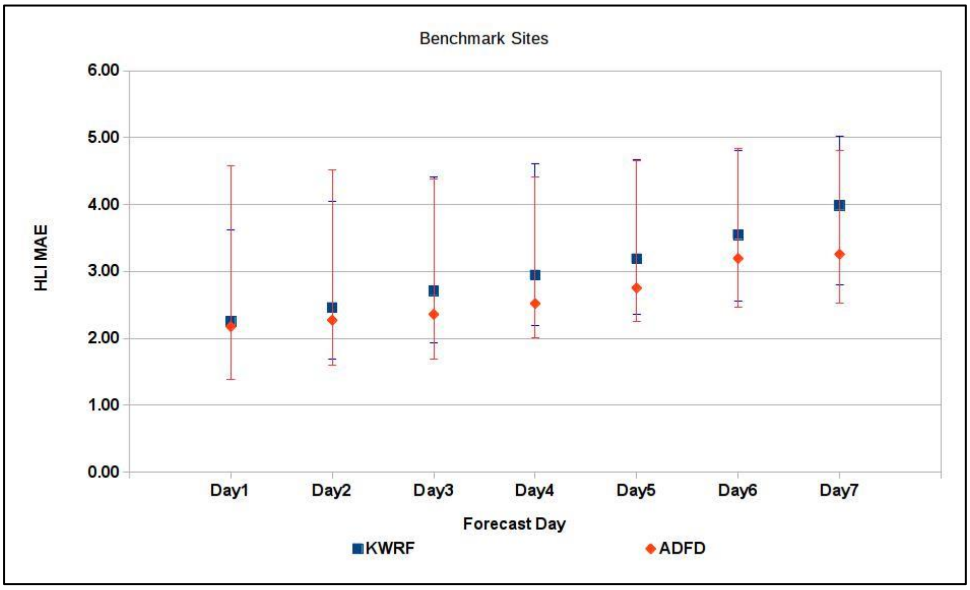

Figure 5 **Aggregate HLI MAE for KWRF and ADFD against Benchmark Sites**

4.3.2. Heat Load Data Network Feedlots

The aggregate ADFD and KWRF meet the performance benchmark for the HLI IOA and MAE up to day 6 and day 7 of the forecast. The RMSE for both systems is only slightly higher than the benchmark both hovering around 7 until day 6 and 7. Both systems have outliers that exceed the performance benchmark. The RMSE, Bias and MAE all show a similar trajectory over the 7 days of the forecast, gradually declining in performance as the forecast extends into the future.

Both systems tend to under predict the HLI by 6 units throughout the forecast, negative bias, however the spread of the distribution indicates that both system can over predict the HLI by a similar amount (Figure 8).

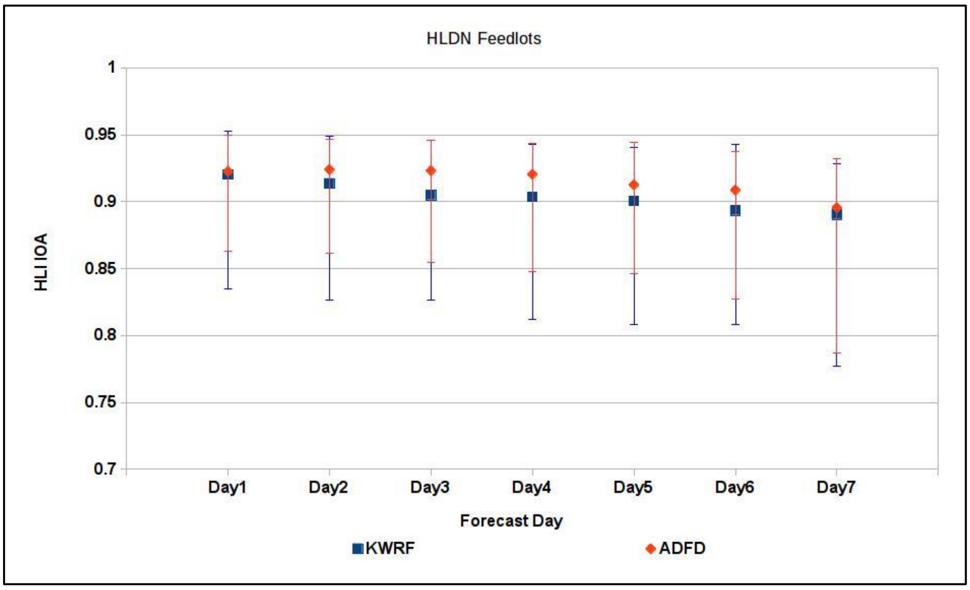

Figure 6 **Aggregate HLI Index of Agreement (IOA) for KWRF and ADFD against HLDN Feedlot weather stations**

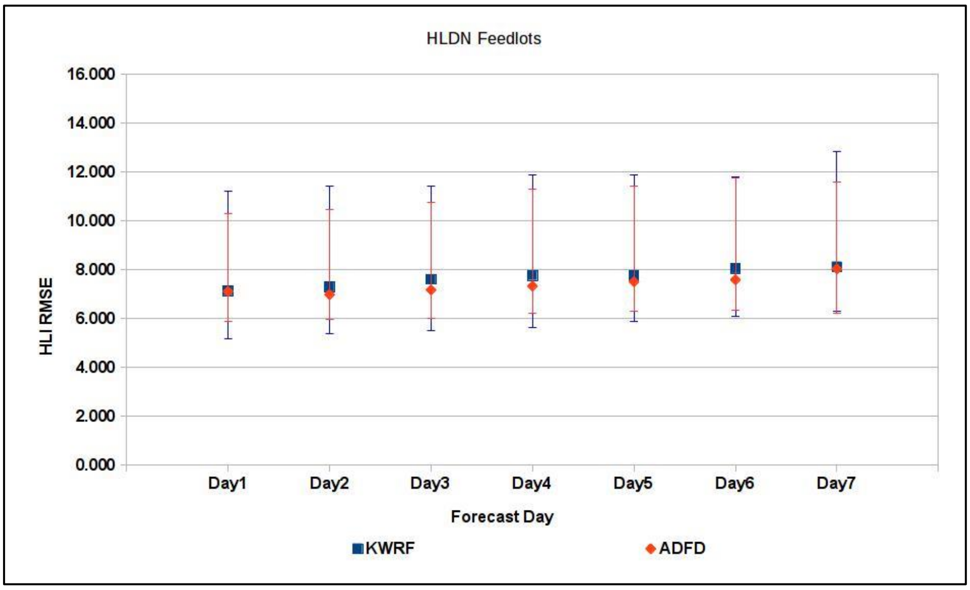

Figure 7 **Aggregate HLI Root Mena Square Error (RMSE) for KWRF and ADFD against HLDN Feedlot weather stations**

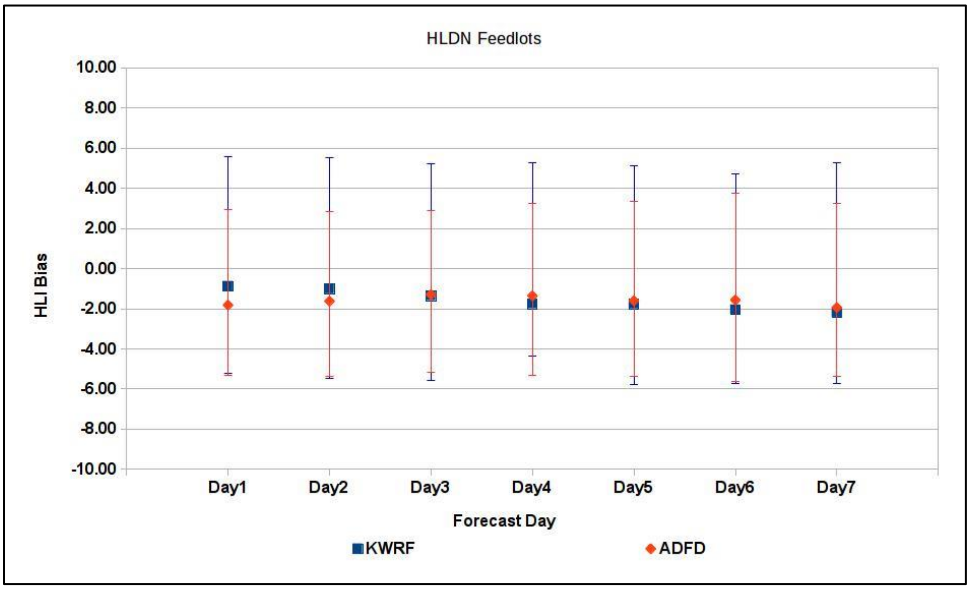

Figure 8 **Aggregate HLI Bias for KWRF and ADFD against HLDN Feedlot weather stations**

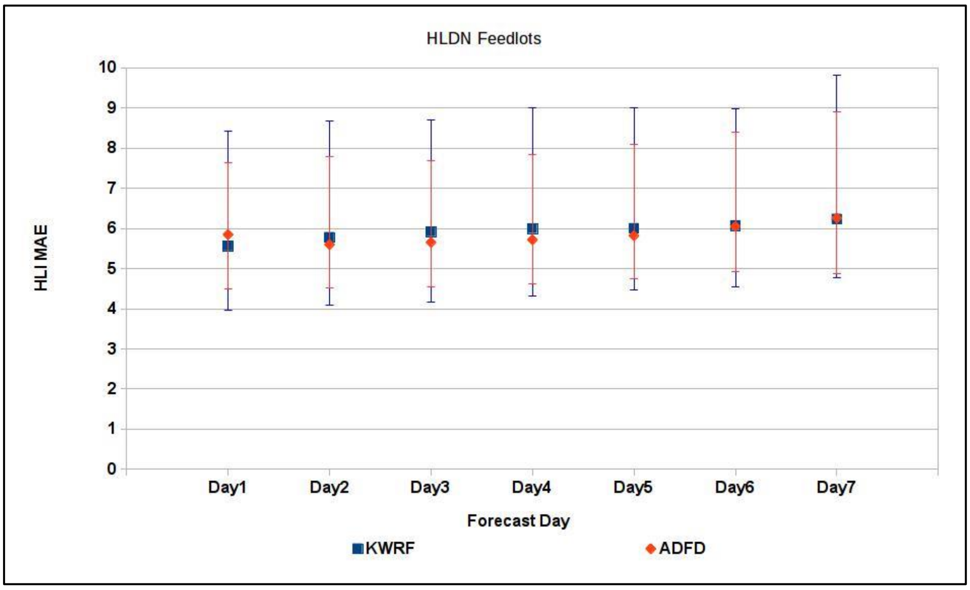

Figure 9 **Aggregate HLI Mean Absolute Error (MAE) for KWRF and ADFD against HLDN Feedlot weather stations**

4.4 Discussion

The ADFD and KWRF systems have been shown to perform equally well at the Benchmark Sites and the HLDN Sites. Both systems have similar error trajectories through time and show similar magnitudes of error. There is essential no statistical difference between the two data sources for any of the meteorological variables or the HLI.

Interestingly the clear sky assumption used in the ADFD did not provide any better or worse performance in regard to the calculated BGT. This may be due to the large sample size, where singular events are essentially averaged out of the analysis. As the BGT is integral to the HLI further investigation into the derivation of the variable and its use in predicted heat load in cattle is required.

The analysis showed that both systems produced large errors in predicting the relative humidity at the HLDN feedlots. Initial thoughts on the reason for this is the highly modified land use around a feedlot, whereas the models, both KWRF and ADFD rely of land surface schemes that identify a region by its soil type and land cover, i.e. sandy loam and grasslands. The implications of land use modifications on the local micro climate are currently unknown and warrant further investigation.

As both data sources performed to a high level and neither can be said to outperform the other the only separation between the two comes down to availability, cost and avenues for improvement.

The ADFD and KWRF both cover a 7 day period and provide hourly data. The ADFD incorporates model, data assimilation and human forecast interpretation from the BoM. This means that the ADFD data should be in line with the official BoM forecast for regions that receive official BoM forecasts. The ADFD is also provided at a higher horizontal resolution, 6 km by 6 km compared to KWRF's current horizontal resolution of 12 km by 12 km.

However, the ADFD does not provide any solar radiation variables, meaning that these would need to be calculated in post processing. The ADFD is made available between 6 AM and 7 AM AEST and does not adjust its delivery schedule with day light savings. Those sites working off day light savings time, will not receive any information until 7 or 8 am. This time frame does not include any post processing time, updating databases and issuing alerts, as such delivery times could extend to 9 am. This all assumes that the ADFD is complete and delivered on time. Alternatively, the forecast issued 12 hours previous could be used.

As the ADFD is an aggregation of the BoM forecast service there can be significant inconsistencies at State boundaries where the variable fields are merged together. Essential different forecast centres may have a different interpretation of the variable field further away from population centres and near state borders where each centres area of responsibility ends. For example, Figure 10 shows the ADFD forecast temperature grid for June 15 2014. There is up to an 8°C temperature difference along the state boundary between South Australia and Victoria. This pattern is visible to some extent along all the State and Territory boundaries.

Figure 10 ADFD temperature forecast grid for South Australia and Victoria on June 15 2014. The state line is evident by the 8°C difference

4.5 Recommendations

The ADFD was shown to offer no statistical advantage over the KWRF system. The issues with the prediction of the HLI and heat stress in general is a matter of interpretation and application of the data to feedlot specific conditions, both environmental and cattle specific. Forecast accuracy eventually reaches a point of diminishing returns, both systems predict temperature and wind speed to a high degree of accuracy. Relative humidity predictions perform better at the Benchmark sites than at the HLDN Feedlots, this may be due to the models inability to represent the land surface interactions within a feedlot as opposed to a grassland.

5. Bibliography

McClave, J.T. and F.H. Dietrich 1994, *Statistics,* Macmillan Publishing Company, Englewood Cliffs, NJ 07632, ISBN 0-02-379211-6

Fairbanks, M, Tennant, D, Dracup, M, Beard, D, & Cramb, J 2011, 'What are rainfall deciles', Farmnote 56/2005, September 2011, Department of Agriculture and Food (Government of Western Australia)

Katestone 2015, Milestone 2.1 Daily Heat Load Monitoring Tool – Thermal Risk Assessment. Prepared for Meat and Livestock, Katestone Environmental, August 2015.

Katestone 2015, Milestone 3.2 Daily Heat Load Monitoring Tool – Alternative Forecast Evaluation. Prepared for Meat and Livestock, Katestone Environmental, October 2015.

Katestone 2016, Milestone 5.1 Daily Heat Load Monitoring Tool – Evaluation of data collected from Daily Monitoring Tool. Prepared for Meat and Livestock, Katestone Environmental, May 2016.

Katestone 2016, Milestone 5.2 Daily Heat Load Monitoring Tool – Evaluation of alternative forecast service performance. Prepared for Meat and Livestock, Katestone Environmental, May 2016.