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HLI Forecast Season 2010 - 2011

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Glossary

Term	Definition
AFWA	US Airforce Weather Agency
AHLU	Accumulated Heat Load Unit
AUSFC	Australian Forecast Grid
AWS	Automatic Weather Stations
BoM	Bureau of Meteorology
ºC	degrees Celsius
ENSO	The El Niño/Southern Oscillation
FSL	Forecast Systems Laboratory
GFS	Global Forecasting System
HLRI	Heat Load Recovery Index
HLI	Heat Load Index
HPC	high performance computer
IOA	Index of Agreement
Km	kilometre
M	metre
MJO	Madden-Julian Oscillation
MAE	mean absolute error
ME	Mean error
m/s	metres per second
NCAR	National Centre for Atmospheric Research
NCEP	National Center for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NVSFC	New South Wales/Victoria/South Australia Forecast Grid
QLDFC	Queensland Forecast Grid
RMSE	root mean squared error
SST	sea surface temperature
SOI	Southern Oscillation Index
TC	Tropical Cyclones
WAFC	Western Australia Forecast Grid

Executive Summary

A high resolution dynamical atmospheric modelling system was implemented as the operational Heat Load Forecast for the 2010/2011 season. A new web application was also launched where registered MLA feedlot operators could subscribe to heat load forecast products for a site specific location and have this information provided via a secure web-page interface.

There were only a small number of high heat load events this season, it appears that the movement of warm and moist tropical air masses to southern parts of the country for extended periods of time results in increased temperature and relative humidity, especially during the night-time, thereby maintaining a high HLI and restricting recovery.

The relationship between high heat load events and the various scales of motion in the atmosphere provides a new approach to the management of heat load at feedlots. Analysing the climatic drivers of high heat load events will enhance our understanding the dynamic relationship between large circulation patterns, meso-scale features, such as tropical Cyclones and local influences. To accurately predict the evolution of these dynamic systems and their influence on the HLI and AHLU a better understanding of their development, interactions and ultimately their predictability is required.

The dynamical model performed well at forecasting the location and magnitude of the synoptic features and weather patterns that influenced the development of high heat load events at the regional and local scale. The update of the GFS data stream and the subsequent initialisation change of the forecast model saw a significant improvement in delivery time and accuracy across all sites and predicted variables.

1. Introduction

During the 2009/2010 forecasting season Katestone Environmental tested a high resolution dynamical atmospheric modelling system alongside the operational statistical Heat Load Forecast. The results of this test are documented (Katestone Environmental 2010). The dynamical system was shown to provide an equivalent and at times improved forecast of Heat Load events and their duration than the statistical system. The dynamical system was implemented as the operational Heat Load Forecast for the 2010/2011 season with the statistical model running on stand-by.

The dynamic Heat Load forecasting system is run on a dedicated high performance computer (HPC) cluster developed by Katestone Environmental. The cluster handles the modelling and post-processing of forecast data before moving the data products to our onsite data store for upload to the live forecast web-page.

Along with the implementation of the operational dynamic heat load forecasting system a new web application was launched where registered MLA feedlot operators could subscribe to Heat Load forecast products for their specific location and have this information provided via a secure web-page interface. Katestone Environmental has developed a database structure and web delivery system to ensure the security of subscriber information and forecast products.

There are currently 25 subscribers to the service; this number is expected to double for the upcoming forecast season as the service was implemented late in the forecast season.

The core of the dynamical forecast is a meso-scale numerical weather prediction system, the Weather Research and Forecasting – Advanced Research and Weather (WRF-ARW) model, which is the result of a collaborative partnership, principally among the National Centre for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the National Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory, the US Air Force Weather Agency, the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration.

The WRF model is an operational weather prediction system with advanced data assimilation schemes and coupled land surface and ocean mixed layer models capable of simulating the dynamic processes that occur throughout the atmosphere, from the surface to the upper troposphere (approximately 20 km above the surface). These features are vital to the accurate prediction of the onset, magnitude and duration of Heat Load events in Australia.

2. Report Overview

Previous MLA forecast season reports have concentrated on individual locations or a selection of representative locations and the local influences of each site. While this approach provides an insight into the limitations of the models and a good benchmark for performance analysis, the underlying climatic forcings of heat load accumulation and recovery went unassessed.

The development of high heat load events is governed by the cumulative relationship implied in the HLI and AHLU equations (Gaughan *et al.* 2002) between solar radiation, wind speed, temperature, and relative humidity. These meteorological variables may be governed by the local scale features where they are measured, however they are driven by meso-scale (10 to 100's km) and synoptic scale (>1000 km) features that bring about the daily changes in weather and alternation of seasons experienced at the local scale.

It is within this framework of climatic influences that this season's heat load events have been assessed. The relationship between high heat load events and the various scales of motion in the atmosphere provides a new approach to the management of heat load at feedlots. Analysing the climatic drivers of high heat load events will enhance our understanding the dynamic relationship between large circulation patterns, meso-scale features, such as tropical Cyclones and local influences. This will significantly improve and extend the heat load forecast service by providing more accurate daily forecasts through model refinement as well as developing the ability to extend the forecast into the medium (seasonal forecasting) and long-term (climate projections).

This report presents the forecasting methodology followed by a preliminary investigation into the high heat load events that occurred during the 2010/2011 forecast period and the synoptic and meso-scale situations that interacted with these events. A summary of the forecasting performance is provided in Section 6.

3. Forecast Deployment

The Heat Load forecasts are generated by downscaling the Global Forecasting System (GFS) output from a global scale with a resolution of approximately 35 to 45 kilometres (km) to an Australian continental scale at a horizontal resolution of 27 km (Figure 1). This initial step resolves the global circulation patterns parameterised in the GFS to the synoptic features of weather systems experienced in the Australian region. This model domain is called the Australian Forecast grid or AUSFC, for short.

The next step is to downscale the AUSFC to a regional scale at a horizontal resolution of 9 km, where the influence of terrain features and regional circulation patterns become apparent. These model domains are called the Western Australia Forecast grid (WAFC), the New South Wales/Victoria/South Australia Forecast grid (NVSFC) and the Queensland Forecast grid (QLDFC). The extent of the model domains were determined by ensuring the forecast area covered the largest density of MLA registered feedlots (Figure 2) while maintaining the forecast delivery target time frame of 6 am daily.

Figure 1 Surface temperature forecast from GFS 35 km and WRF-ARW 27 km

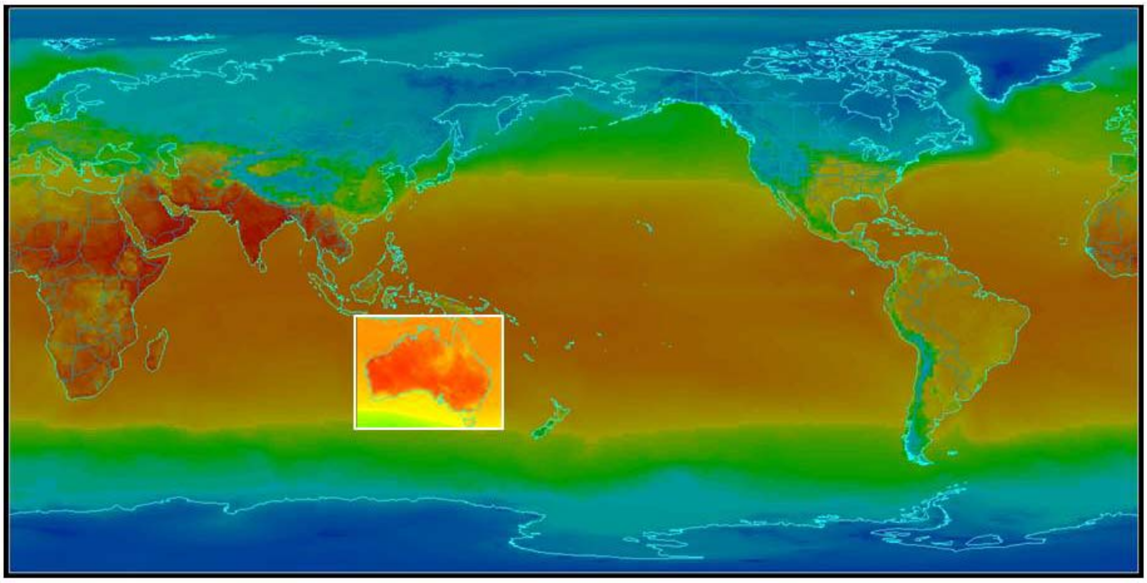
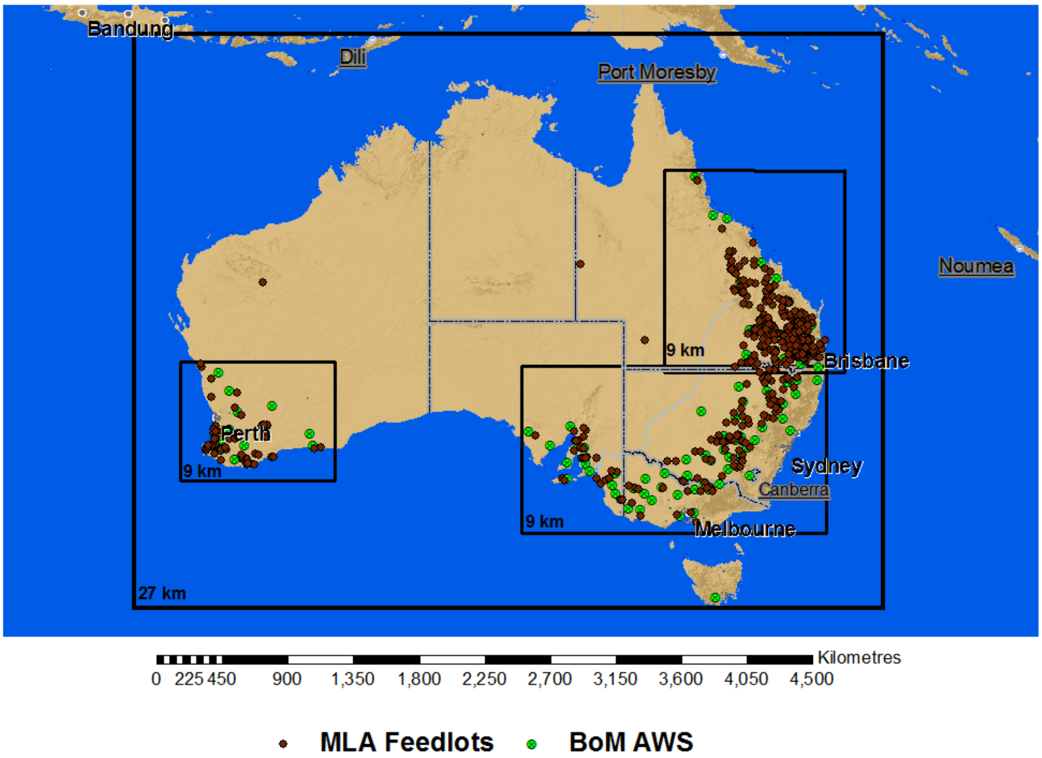


Figure 2 Map projection of forecast domains, BOM automatic weather stations and MLA registered feedlots



The target time frame for forecast delivery was largely met throughout the forecast season, with only minor interruptions to delivery due to external connection issues, which had a cascade effect ultimately leading to extended processing times. One major interruption was during the catastrophic flooding experienced in South East Queensland in early January 2011 which lasted for several days.

Katestone Environmental recognises that interruptions to the service are detrimental to the operation of MLA registered feedlots. We have since implemented an upgrade pathway for our internal and external network connectivity and improvements to model configuration and hardware specifications. We are also implementing a rostering system to provide a better seven day per week operation of the service.

The GFS modelling system used to initialise the Katestone forecasting models was upgraded in January to include a refined horizontal resolution of approximately 27 km and the time step decreased to 3 hours from the previous 6 hourly output. The update also saw the inclusion of new data assimilation streams from satellite based observations. The changes to the GFS allowed Katestone Environmental to download the GFS 0600 model run for daily initialisation. Previous runs where reliant of the GFS 1800 model run from the previous day. During the forecasting interception due to the floods the Katestone forecasting models were reconfigured to take advantage of the considerable improvement provided by the GFS. The performance analysis of both initialisation schemes are shown in Section 6.

4. Climatic Drivers for High HLI

The MLA heat load forecast service becomes operational on October 1 and runs through to March 31 each year. The service covers the shoulder season of Spring, all of Summer and the onset of Autumn, which was designed to coincide with hottest periods of the year that could have the most deleterious impact on feedlot cattle. This period also coincides with some of the most active and dynamic meteorological conditions experienced on the Australian content.

The El Niño/Southern Oscillation (ENSO) is known to have significant impacts on the Australian climate, particularly on rainfall, tropical cyclone formation and the onset of the Australian monsoon (Sturman and Tapper 1996). The monsoon is a region of low pressure that typically sits to the north of Australia and moves south during the summer months drawing warm moist tropical air onto the continent along with heavy rains and the occasional tropical cyclone. The location of the monsoon trough is linked to the location of the sub-tropical ridge, a region of high pressure that sits to the south of the continent during the summer months. The relative position and intensity of these two features is one factor driving the movement of warm moist tropical air into the southern reaches of the continent.

The Australian monsoon has an active and a break phase, where the active phase tends to bring heavy rains and movement of the trough poleward, while the break phase tends to bring lighter rains and a retreat of the trough towards the equator. This motion is thought to be influenced by the Madden-Julian Oscillation (MJO) an eastward pulse of convection that occurs on average every 30 to 90 days and tends to coincide with the active phases of the monsoon. The interaction between the ENSO, the monsoon and the MJO tends to dominate the meteorology in the tropics and is largely responsible for heavy rains and the poleward migration of tropical air masses which generally bring warmer temperatures and high levels of relative humidity to the tropics, sub-tropics and at times to the mid-latitudes.

Associated with these tropical features are the East Coast trough and the West Coast trough which form in a north-south orientation. These troughs develop as the surface heats up and a shallow low pressure system becomes centre in the Pilbarra region (West Coast trough) and the Cloncurry region (East Coast trough). The positioning and intensity of these features mark the intersection of coastal ocean air masses and inland air masses, affecting the conditions experienced on either side of these features.

For example as the West Coast trough moves inland it initiates the sea breeze so sought after in southern Western Australia, while locations to the east of the trough will experience temperatures upwards of 40 °C. The West Coast trough is also associated with the formation of a Northwest cloud band which draws moist tropical air from the Indian Ocean across the continent bringing heavy rains and increased temperatures to the south and eastern parts of the country.

The dynamic relationship between the different scales of atmospheric motion is what alters the conditions experienced at any given location. The features and patterns described above are thought to be some of the driving factors that determine whether the accumulation of heat load will persist and where recovery is likely. Although the models can simulate most of these features quite well, variations in position and magnitude at this large scale can cause significant variability in conditions at the local scale. To accurately predict the evolution of these dynamic systems and their influence on the HLI and AHLU a better understanding of their development, interactions and ultimately their predictability is required.

5. Forecast Season Summary

5.1 Synoptic Drivers

The summer season of 2010/2011 was not an average season. Weather across the country was influenced by one of the strongest La Niña event on record. Figure 3 shows the 30 day rolling Southern Oscillation Index (SOI) from January 2009 to August 2011 the complete record extends to 1876. The SOI is a measure of the intensity of the ENSO phenomenon where values of greater than +8 represent La Niña conditions, values less than -8 represent El Niño conditions and values that lie between +8 and -8 are considered neutral. The SOI is derived from the pressure difference between Tahiti and Darwin.

Figure 3 Southern Oscillation Index running average for January 2009 to August 2011

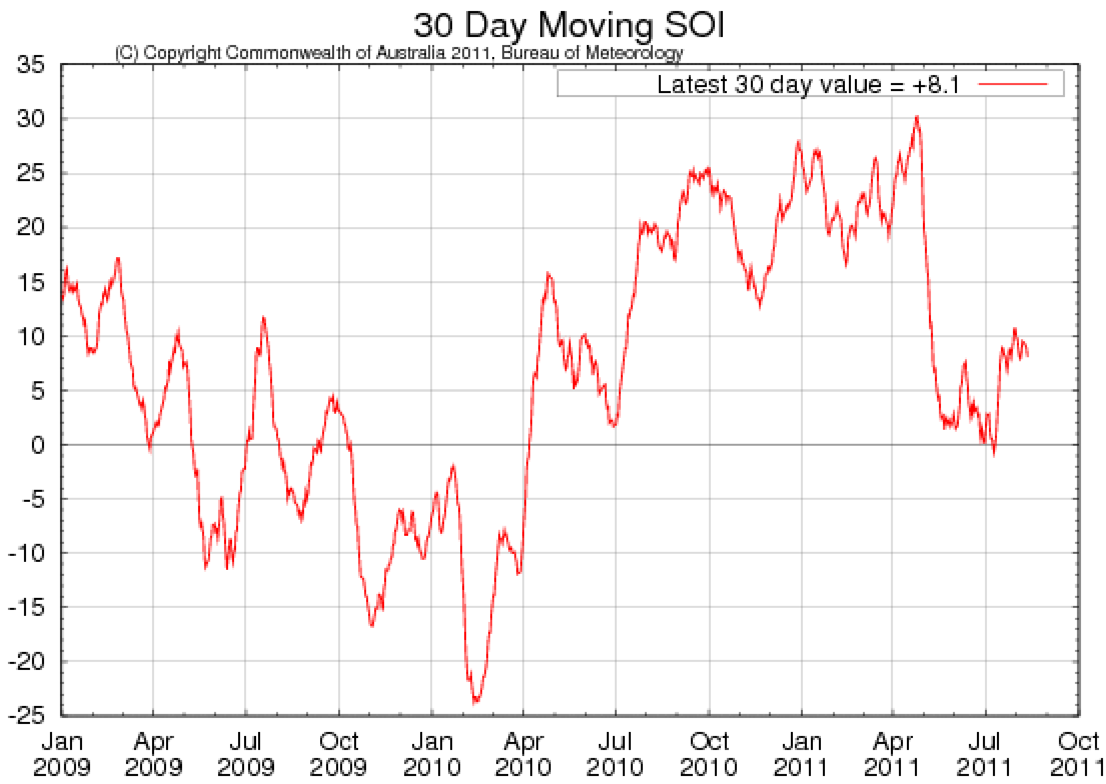


Figure 4 shows the climatological average and the 2010/2011 average positions of the monsoon trough, sub-tropical ridge and the east coast and west troughs. The 2010/2011 average position of the east and west coast troughs do not appear to be significantly different from the climatological mean. However the position of the monsoon trough and sub-tropical ridge is slightly further south than average. There is also distinct westerly skew to the positioning of the monsoon trough, which may be attributed to number of cyclones that formed along the west coast.

It was the second wettest summer on record for Australia. Maximum temperatures were generally cooler than normal whilst overnight minima were mostly above normal. Significant rainfall and flooding occurred over large parts of eastern and northern Australia, most notably the Queensland and Victoria floods in January 2011. These features and weather patterns are typical of La Niña conditions.

Figure 4 December 2010 to March 2011 average sea level pressure indentifying the location of the monsoon trough and sub-tropical ridge

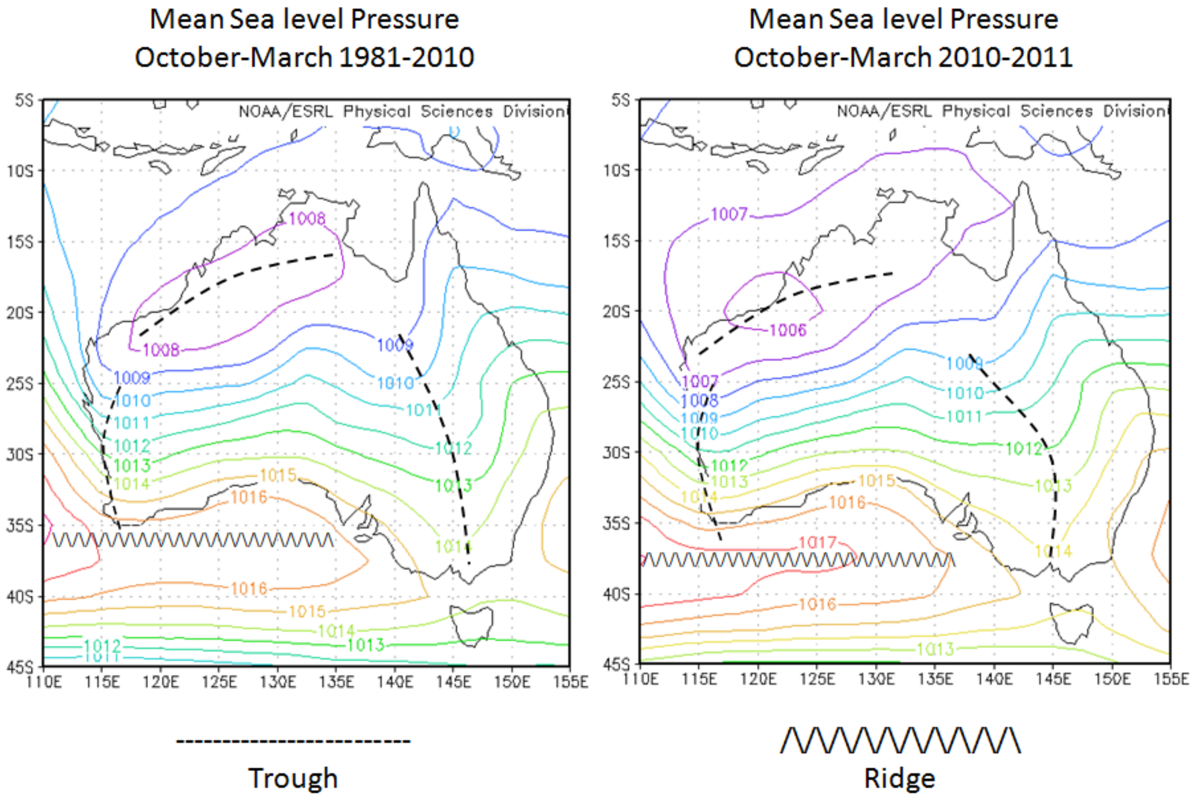


Image provided by Physical Sciences Division, Earth System Research Laboratory, NOAA, Boulder, Colorado, from their Web site at http://www.esrl.noaa.gov/psd/.

The effect these synoptic and global features may have on the accumulation of heat load in cattle is currently unknown. There were only a small number of high heat load events during the forecast period. Most events were diffuse in the respect that only a few locations within each forecast domain experienced prolonged periods of high HLI. In order to assess the influence of synoptic features on the evolution of high heat load events a novel technique was developed by Katestone Environmental to investigate the distribution of HLI events at multiple scales, from the continental to the regional down to the local scale of individual sites.

5.2 Identifying High Heat Load Events

During the 2010/2011 forecast season three continent wide high heat load periods were identified. These periods were:

- 26 January 2011 to 08 February 2011
- 15 February 2011 to 21 February 2011
- 25 February 2011 to 02 March 2011

These periods were identified by calculating an average heat load recovery index for all sites based on a re-analysis of Bureau of Meteorology (BoM) automatic weather stations (AWS) for the forecast period, November 2010 to March 2011. The heat load recovery index (HLRI) is calculated by subtracting the calculated HLI from the minimum recovery threshold of 77 HLI units and averaging the remainder across all sites resulting in a mean hourly HLRI. Extended periods without recovery are then extracted by low pass filtering the hourly HLRI into three and six day window, this can be reduced or increased to any time window that is desired. The HLRI is expressed by

$$HLRI = \frac{1}{t_d}\sum_{t=1}^{t_d}\left(\frac{\sum_{n=1}^{N}(77 - HLI_n(t))}{N}\right)$$

where t is the base time step of the data set, in this case one hour, t_d is the time window in hours, such that three days equals 72 hours, N is the total number of sites, n represents each individual site and HLI is the heat load index for each site.

A minimum and maximum recovery threshold is proportional to the minimum heat load accumulation value assigned to cattle type and condition, where a heat load accumulation threshold of 83 has a recovery threshold of -6 and 21 on the HLRI scale, these values correspond to heat loading during the daytime (negative value) and the amount of recovery during the night (positive value). To accumulate heat load the HLRI must be below both recovery thresholds for that cattle type. The length of time and magnitude of the exceedence below these criteria represents the severity of the event. Table 1 provides guidance on the relevant recovery thresholds.

Table 1 Heat load recovery scale by accumulation threshold

HLI accumulation value	$HLRI_{min}$	$HLRI_{max}$
95	-18	9
92	-15	12
89	-12	15
86	-9	18
83	-6	21
80	-3	24

The HLRI scale was developed as a means of identifying periods where the HLI was above the HLI accumulation value without any recovery for the forecast season. Figure 5 shows the heat load recovery index averaged for all sites. Recovery thresholds have been plotted for minimum HLI accumulation value 83. Two periods are evident where the recovery threshold exceeds its range and a third is very close to the threshold. To draw out these patterns the data is low pass filtered for a 3 day and six day window (Figure 6). The minimum recovery threshold for the filtered data can be defined by the sum of the $HLRI_{min}$ and $HLRI_{max}$. The banded regions coincide with the high heat load events experienced across the continent and circled areas are localised regional events. The HLRI was also calculated for each state to confirm the interpretation of the Australia wide HLRI.

Figure 5 Average heat load recovery index for all sites

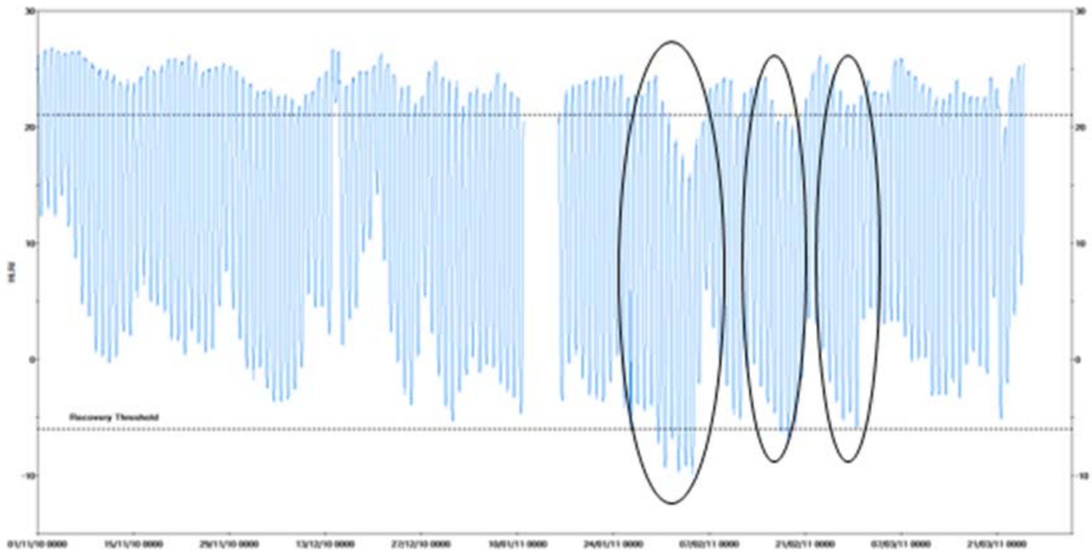
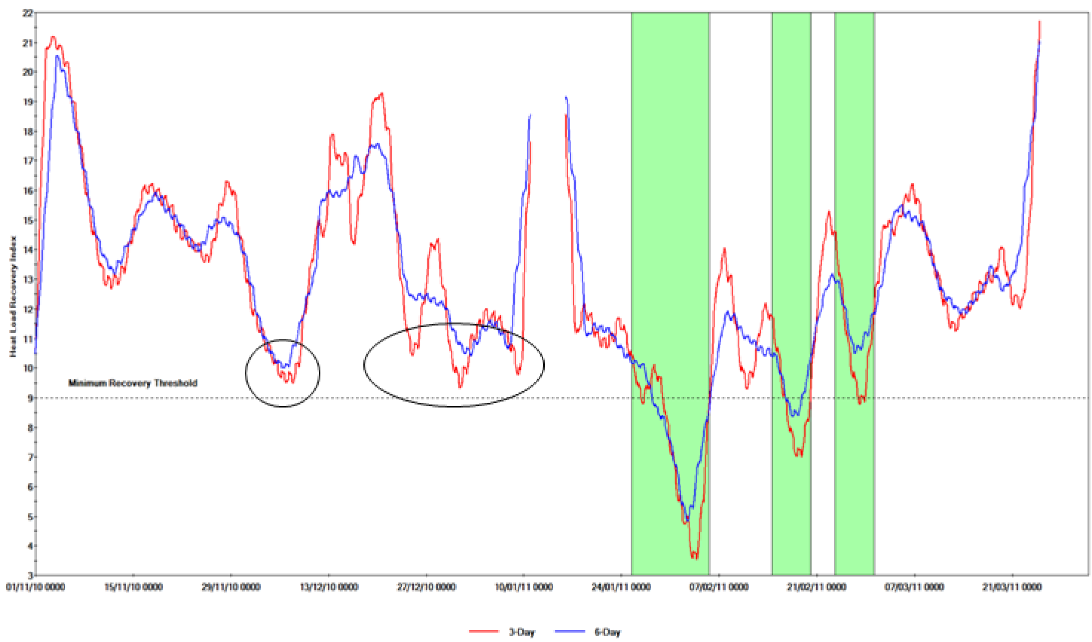


Figure 6 Low pass filtered heat load recovery index. Banded regions are significant at a continental scale. Circled areas are localised regional events



5.3 High Heat Load Events

5.3.1 26 January 2011 to 04 February 2011 - Continental

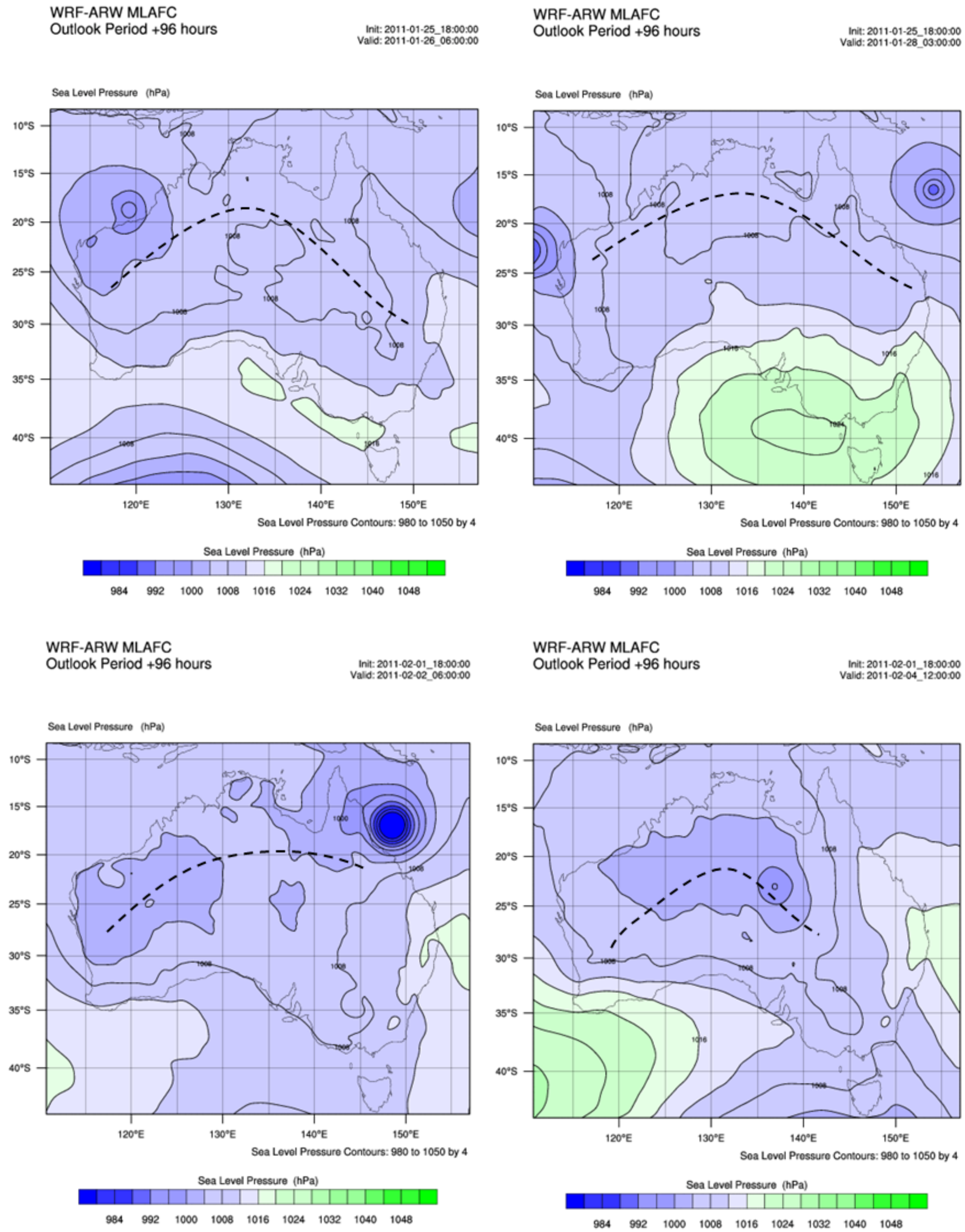
5.3.1.1 Synoptic situation

This period was very active across much of Australia with a typically complex and rapidly evolving synoptic situation. Three tropical cyclones (TC) formed and impacted on the Australian coast during this period; Severe TC Bianca, TC Anthony and Severe TC Yasi. Severe TC Bianca crossed the south west coast of WA as an extra tropical-TC on 30 January, the same day that TC Anthony crossed the north QLD coast. Severe TC Yasi crossed the north QLD coast on 03 February. The overall synoptic pattern throughout this period showed a rapid succession of high pressure and frontal systems transiting south of the continent. The east and west coast troughs, typical for this time of year, were present. At times these were augmented by surface troughs forming over central parts of the country. A strong and persistent ridge was evident along much of the east coast for the period.

5.3.1.2 Influence at feedlots

Only five locations where unaffected during this period, four in Western Australia (Wandering, Katanning, Esperance and Bridgetown) and the one site in Tasmania (Warra) the remaining 86 sites experienced a prolonged period of elevated HLI. The mean day time temperature across all sites peaked at 34 °C with mean minimum night time temperatures of 20 °C, relative humidity also increased on average to 85% during the day and 50% at night. Compared to the a mean day time temperature of 32 °C and 17 °C at night with mean a relative humidity of 73% during the day and 37% at night in the days preceding the event. This period saw the HLI exceed 100 units and remained above 85 during the night at some locations.

Figure 7 AUSFC sea level pressure forecast January 26, 28 and February 2, 4 2011. Dashed line indicates location of monsoon trough

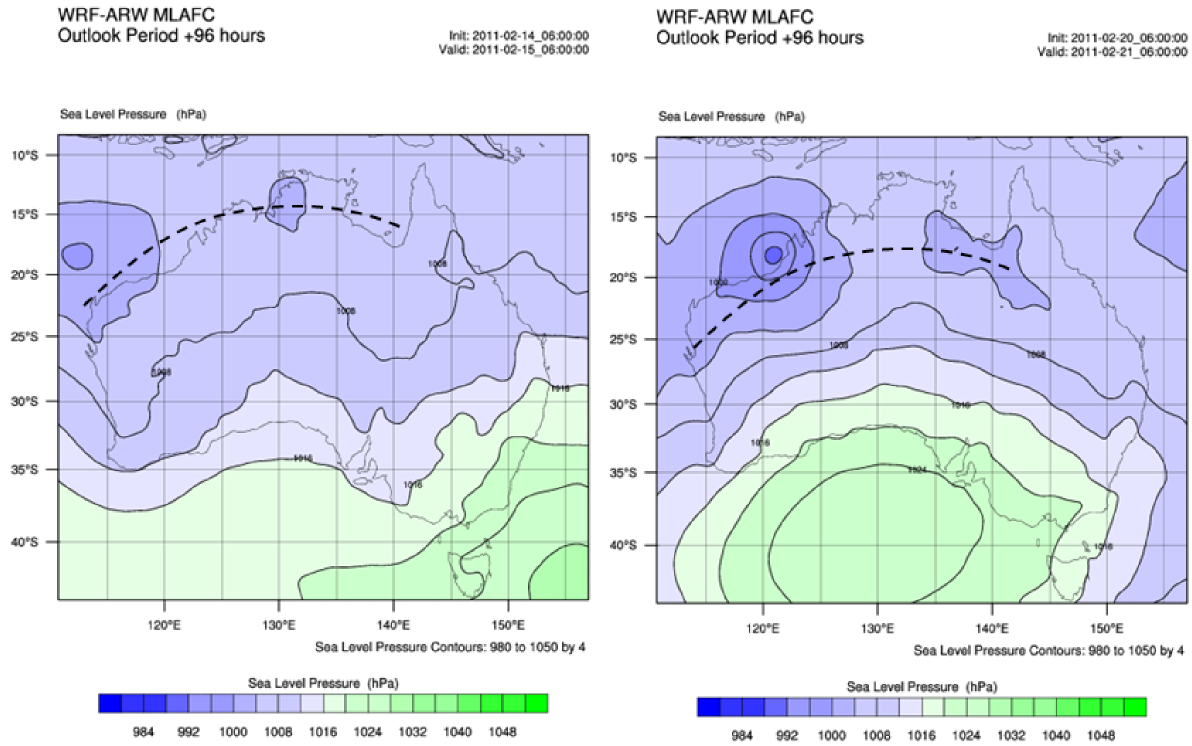


5.3.2 15 February 2011 to 21 February 2011- Continental

5.3.2.1 Synoptic situation

During this period TC Carlos was active off the WA coast. It was downgraded to a low pressure system near the WA south coast on 26 February. Once again the overall synoptic pattern throughout this period showed a rapid succession of high pressure and frontal systems transiting south of the continent. The west coast trough was present as expected, however, the east coast trough appeared less defined early in the period than in the previous state wide heat load event. Persistent ridging from high pressure systems in the Tasman Sea was evident along much of the east coast. The monsoon trough was active over northern parts of Australia before moving south over inland northern Australia, joining with the east and west coast troughs. Once again the monsoon trough was further south than is typical for this time of year. This pattern will typically bring a warmer air mass to the region, resulting in an increase in temperatures.

Figure 8 AUSFC sea level pressure forecast for February 15 and 21 2011. Dashed line indicates location of monsoon trough



5.3.2.2 Influence at feedlots

This event mainly affected locations in Queensland, NSW, and WA. Locations in Victoria and South Australia were largely unaffected due to the high pressure system that was moving into the bight during this time. The mean day time temperature across all sites peaked at 28 °C with mean minimum night time temperatures of 20 °C, relative humidity also increased on average to 90% during the day and 60% at night. Compared to the a mean day time temperature of 26 °C and 16 °C at night with mean a relative humidity of 80% during the day and 45% at night in the days preceding the event. This period saw the HLI exceed 105 units and with only a few hours below 65 during the night at some locations.

5.3.3 26 February 2011 to 2 March 2011 - Continental

5.3.3.1 Synoptic situation

This period was a continuation of the February 15-21 event. There were three days of recovery between events as the system passed through the region. This period was less intense than the preceding event as the low pressure systems to the west and east of the continent decayed and the monsoon trough returned to its mean summer position.

5.3.3.2 Influence at feedlots

This event mainly affected locations in Queensland and NSW. Locations in Victoria and South Australia and WA were largely unaffected as the tropical air mass had already been moved out of these areas. The temperature, relative humidity and HLI profiles were very similar to the previous event although less intense and affecting fewer locations. The most affected sites where the northern feedlots and those further inland, these sites recorded higher temperatures and relative humidity than the coastal sites most likely due to the retreat of the monsoon trough back to its mean northern position.

5.3.4 4 December 2010 to 8 December 2010 – South Australia

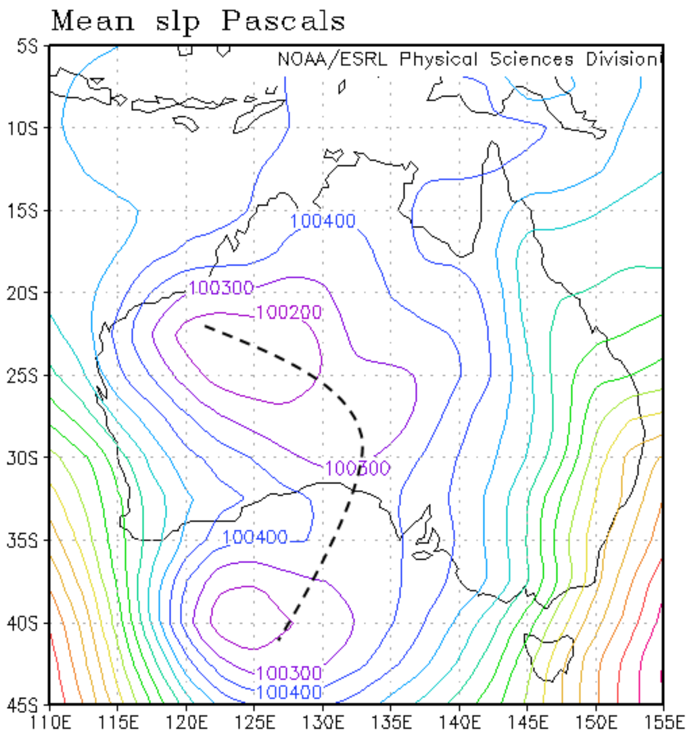
5.3.4.1 Synoptic situation

A complex of tropical low pressure systems (the monsoon trough) migrated south; bringing warm humid tropical air into the bight, this feature is known as a northwest cloud band (Figure 9). This system persisted for several days before a large high pressure moved into the southern tip of Western Australia pushing the monsoon trough back to its northerly position.

5.3.4.2 Influence at feedlots

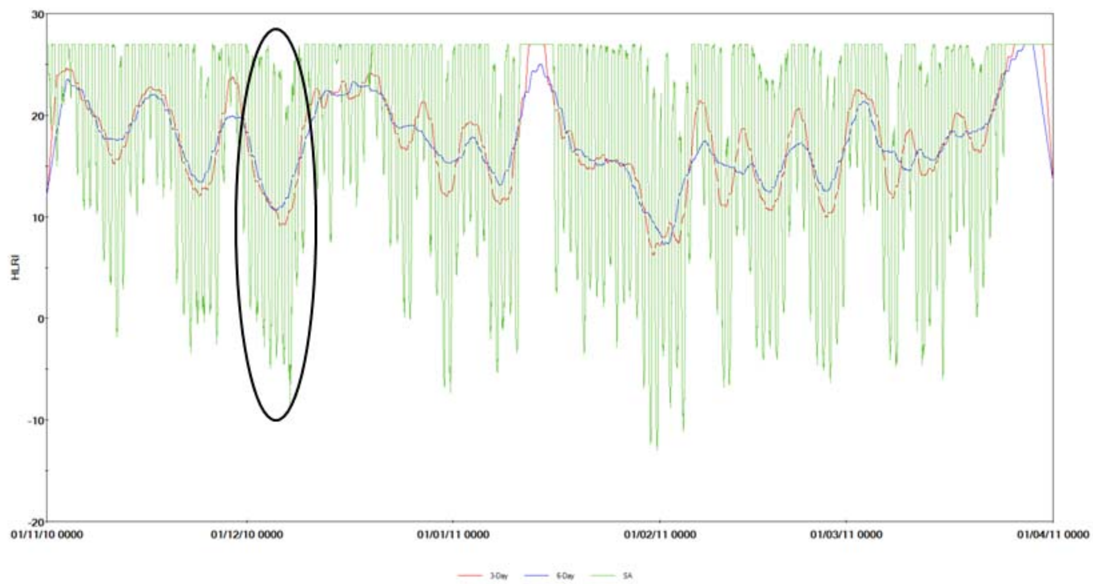
During this period average day time temperatures were up to 35 °C and night time temperatures did not drop below 20 °C. Relative humidity averaged 90% during the day decreasing to 50% during the night coupled with generally light to moderate winds (< 3.5 m/s). These conditions persisted for several days causing an accumulation of heat load in this region as night time recovery was limited (Figure 10).

Figure 9 Sea level pressure averaged over the period December 04-08 2010 Dashed line indicates location of the trough



Note: The AUSFC time series data for this period has been analysed it is only the gridded dataset that was not available for this period. *Image provided by Physical Sciences Division, Earth System Research Laboratory, NOAA, Boulder, Colorado, from their Web site at* *http://www.esrl.noaa.gov/psd/*.

Figure 10 Average, 3 day and 6 day filtered heat load recovery index for all South Australian forecast sites



5.3.5 23 December 2010 to 26 December 2010 – Western Australia

5.3.5.1 Synoptic situation

A series of high pressure systems transiting the Southern Ocean into the Tasman Sea extended weak ridging across south and east Australia. However this period was dominated by a complex series of surface troughs and lows which formed over areas of Victoria, NSW, QLD, NT and WA. The monsoon trough was defined over the Top End for much of the period. The monsoon trough also interacted with the surface troughs over inland QLD and WA. Toward the end of the period the monsoon trough becomes more defined, stretching across inland northern Australia (Figure 11).

5.3.5.2 Influence at feedlots

During this period average day time temperatures were up to 35 °C and night time temperatures did not drop below 20 °C. Relative humidity averaged 90% during the day decreasing to 50% during the night coupled with generally light to moderate winds (1.5 to 4.5 m/s). These conditions persisted for several days causing an accumulation of heat load in this region as night-time recovery was limited (Figure 12).

Figure 11 Sea level pressure averaged over the period December 23-26 2010 and January 3-6 2011. Dashed line indicates location of the trough

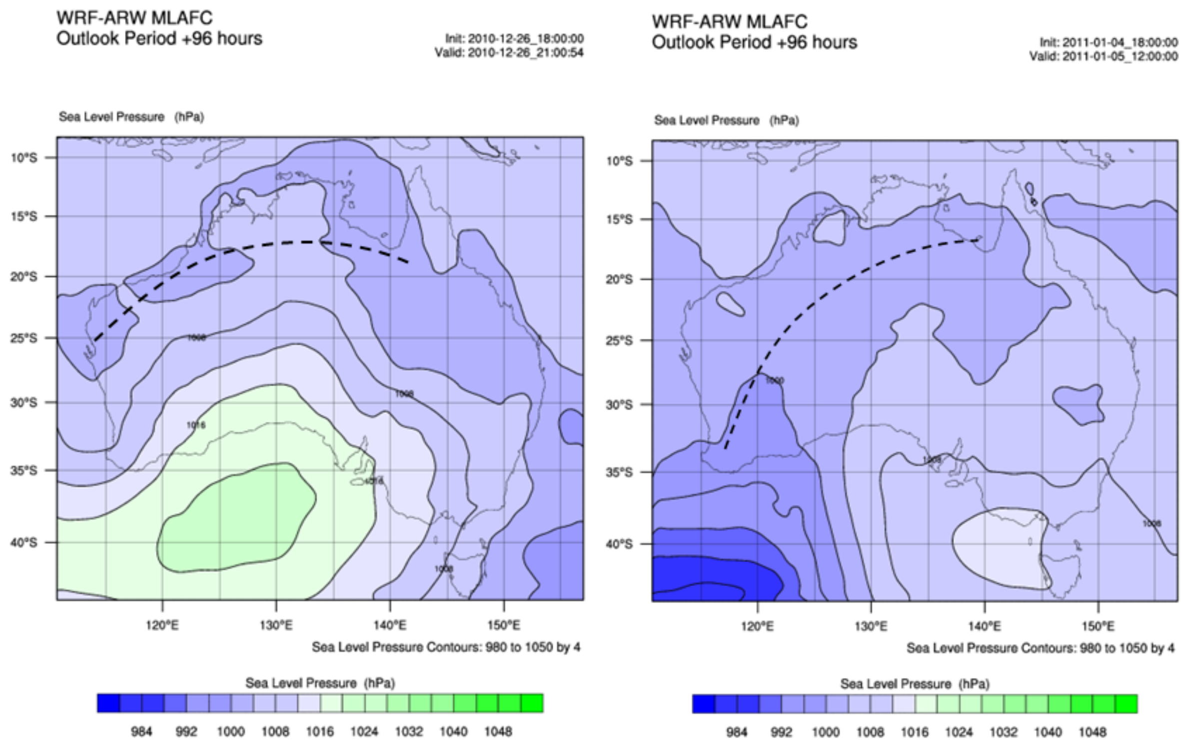
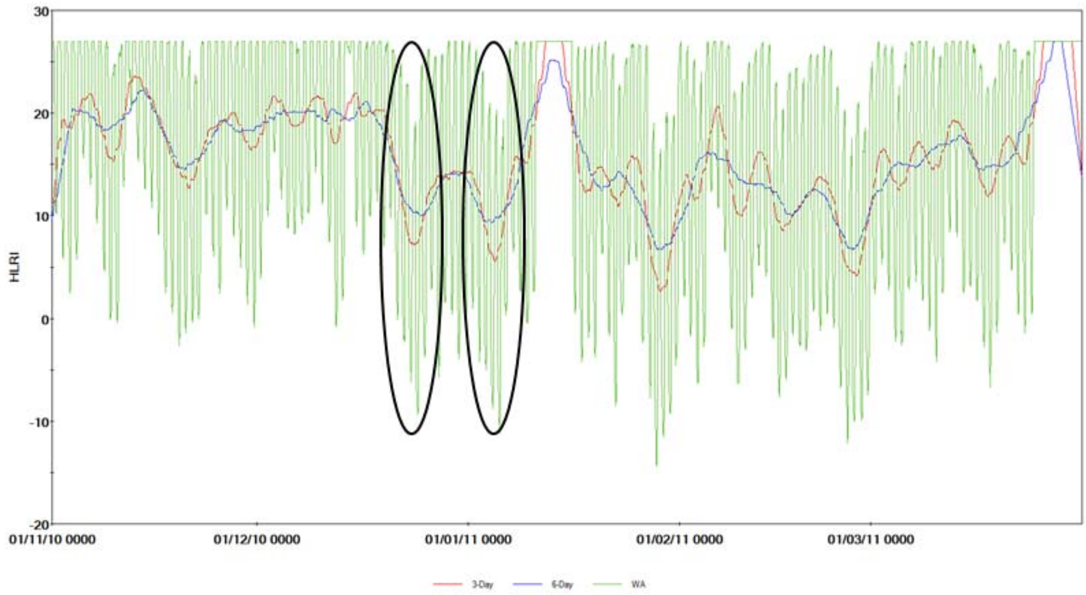


Figure 12 Average, 3 day and 6 day filtered heat load recovery index for all Western Australia forecast sites



6. Forecast performance

6.1 Performance Measures

The index of agreement (IOA) is the ratio of the total RMSE to the sum of two differences:

- The difference between each prediction and the observed mean
- The difference between each observation and observed mean.

The IOA is a good measure of model performance in that it compares each individual hour against the mean of the observations, such that if the predicted and observed values vary at different scales or rates a poor agreement will result (< 0.6). Where an IOA of 1 indicates perfect agreement or both the predicted and observed vary about the mean at the same scale and rate. The 0600 model initialisation saw a significant improvement in the IOA for all variables (Figure 13). The predicted HLI saw the greatest improvement ranging between 0.82 and 0.95.

The root mean squared error (RMSE) can be described as the standard deviation of the difference for hourly prediction and observation pairings at a specific point which measures the average magnitude of the error. The difference between forecast and corresponding observed values are each squared and then averaged over the sample. Finally, the square root of the average is taken. Since the errors are squared before they are averaged, the RMSE gives a relatively high weight to large errors. This means the RMSE is most useful when large errors are particularly undesirable. Overall, the RSME is a good overall measure of model performance.

The mean absolute error (MAE) measures the average magnitude of the errors in a set of forecasts, without considering their direction. It measures *accuracy* for continuous variables. Expressed in words, the MAE is the average over the verification sample of the absolute values of the differences between forecast and the corresponding observation. The MAE is a linear score which means that all the individual differences are weighted equally in the average. The MAE and the RMSE can be used together to diagnose the variation in the errors in a set of forecasts. The RMSE will always be larger or equal to the MAE; the greater difference between them, the greater the *variance* in the individual errors in the sample. If the RMSE=MAE, then all the errors are of the same magnitude.

6.2 Results

During the period from November 1 to March 31 the model performed well overall, there was significant variability in the error between regions and forecast day. A significant overall improvement in the forecast was observed after January with a decrease in variability between regions and forecast day, with only the fourth day of the forecast showing signs of divergence.

The changes made the GFS and the initialisation time frame improved forecast delivery time by 25% and showed significant improvement in the accuracy of the forecast (Figure 13). The improvements showed an overall decrease in error for all meteorological variables and the HLI. The results of the performance analysis are summarised here, complete performance tables for each site for the model are provided in Appendix A.

Figure 13 Index of Agreement for relative humidity, wind speed, temperature and HLI

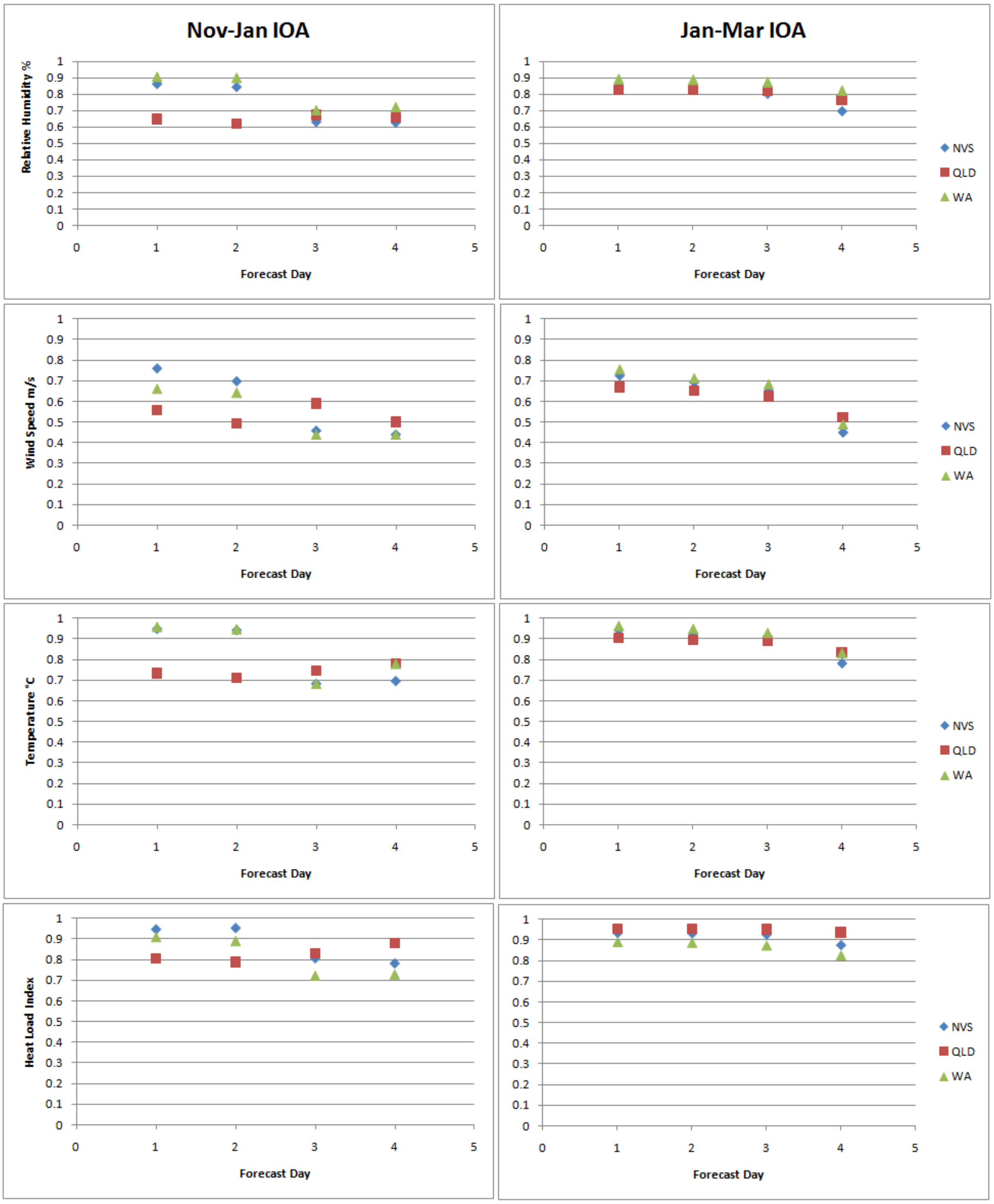


Figure 14 Root mean squared error for relative humidity, wind speed, temperature and HLI

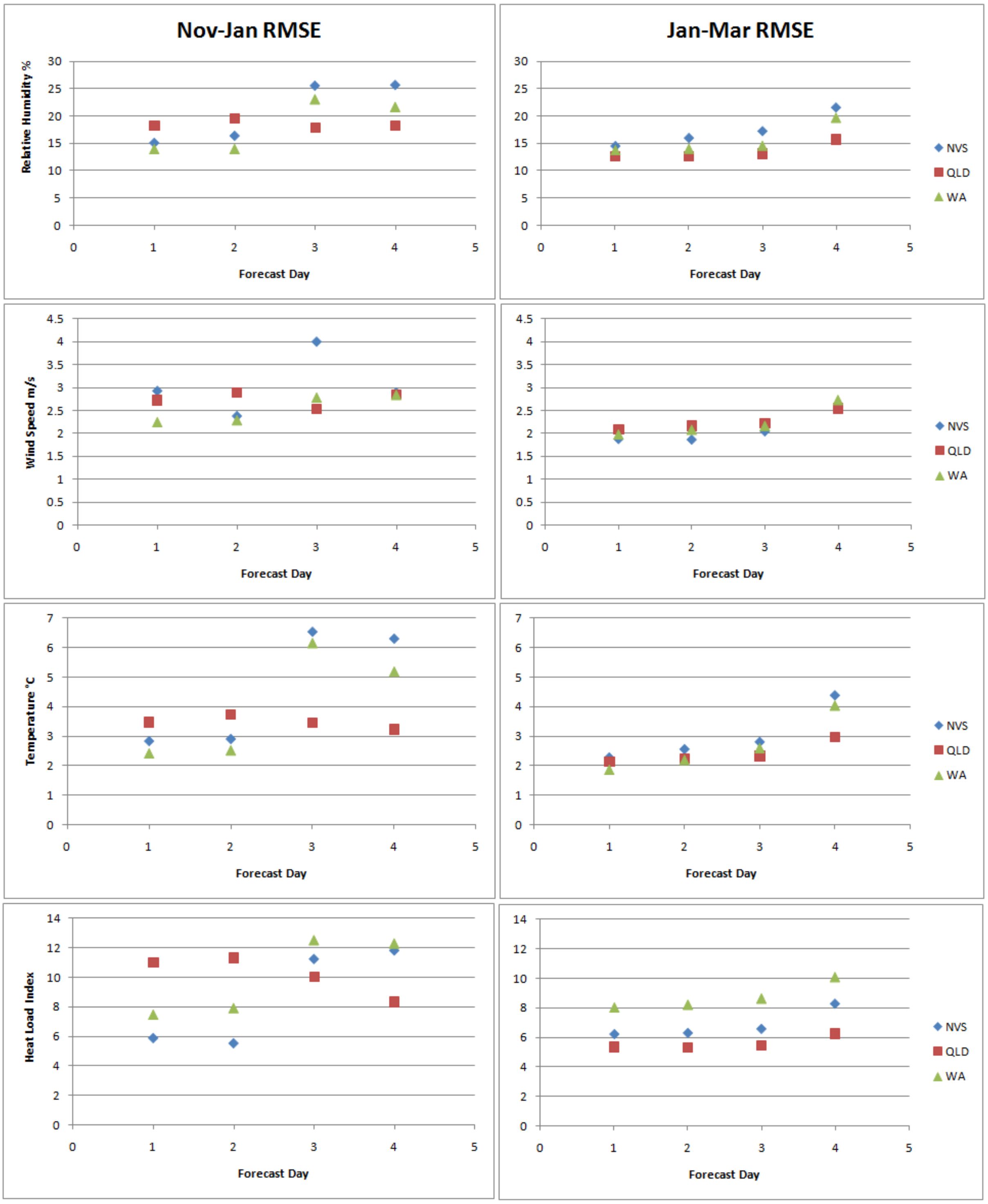
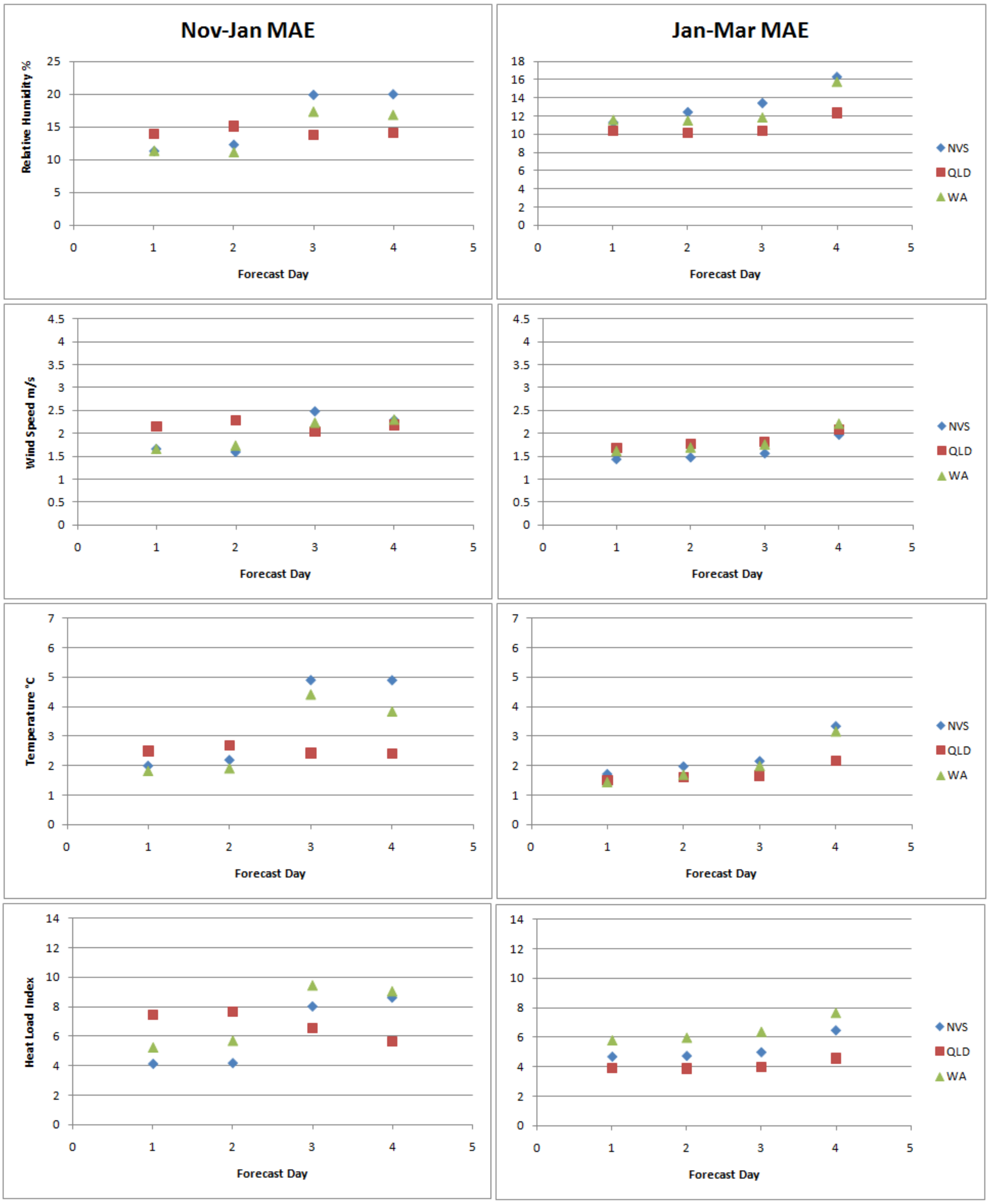


Figure 15 Mean absolute error for relative humidity, wind speed, temperature and HLI



The model tends to over-predict relative humidity across all locations, this leads to a general over-prediction of the HLI by up to 10 HLI units with an average error of ±5 HLI units. The variability in relative humidity predictions is thought to be dependent on the models inability to resolve the local scale (< 5 km) land use characteristics, such as a soil types ability to retain and transfer water. These parameters affect the development of the boundary layer and hence the conditions experienced within it.

While the model calculates soil moisture content and evapotranspiration from vegetation, observations of these variables are not currently available for feedlots or the more remote areas of the Australian continent at a resolution suitable for comparison with or inclusion in the model. On site meteorological data and surface characteristics, such as albedo, leaf area index, surface roughness and deep soil moisture content from feedlots and forecast locations should improve the accuracy of relative humidity predictions and hence improve the HLI predictions.

Overall the modelling system performed very well, accurately predicting the onset, magnitude and duration of high heat events at all sites.

7. Conclusions

There were only a small number of high heat load events this season, at the broad scale it appears that the movement of warm and moist tropical air masses to southern parts of the country for extended periods of time results in increased temperature and relative humidity, especially during the night-time, thereby maintaining a high HLI and restricting recovery.

The synoptic patterns exhibited during these high heat load events indicate that fluctuations in the position of the monsoon trough and relative position of the sub-tropical ridge could play a significant role in the development of heat load events at both the regional and continental scale. It was also shown that on a regional scale the proximity and location of Tropical Cyclones to either coast can modulate the flow of air masses and cause localised heat load events further afield than where their impacts are usually felt. The development of a Northwest cloud band was also linked with a high heat load event localised around the South Australian Feedlots.

These features are well known aspects of the Australian climate (Sturman and Tapper 1996) however the dynamic interaction between localised heat load events, meso-scale features such as Tropical Cyclones and the synoptic scale movements of the monsoon trough and Sub-tropical ridge is poorly understood.

The dynamical model performed well at forecasting the location and magnitude of the synoptic features and weather patterns that influenced the development of high heat load events at the regional and local scale. The update of the GFS data stream and the subsequent initialisation change of the forecast model saw a significant improvement in delivery time and accuracy across all sites and predicted variables.

8. Recommendations

The forecast systems configuration, physics and dynamics are constantly under review and finetuned as required during operation. This is known as the model optimisation process and is a fundamental aspect of numerical weather prediction and the delivery of the heat load forecast service. Further improvements to the modelling system can be achieved through onsite meteorological measurements at feedlots that have subscribed to the site specific service. This will enable a performance analysis to be conducted for these locations as well as aiding in the refinement of model parameterisations.

Updates to model configuration are recommended to take advantage of the increased resolution of the GFS T574 model run. The GFS T574 provides analysis at a resolution of 27 km, equivalent to the current AUSFC grid. It is recommended that the AUSFC grid be refined to approximately 11km ±3 km and expanded to encompass the Timor Sea, Arafura Sea and Coral Sea in the tropics and the Tasman Sea and Southern Ocean in the mid latitudes. This will improve the models parameterisation and prediction of convective cell development, particularly in the tropics and associated weather patterns. Daily sea surface temperature (SST) observations are now available at a resolution suitable for assimilation in the modelling system. Previously SST was initialised from the models onboard climatology. Katestone Environmental has been testing the SST update cycle outside of the forecast season with impressive results and recommends initialising all forecasts with these data.

Further study is required to conclusively link the formation and movement of synoptic and meso-scale features to local, regional and Australia wide heat load events. In particular the potential effects of climate variability (both short and long term) on these synoptic scale phenomena and what this means to the industry on a regional and local scale.

It is recommended that a heat load climatology be developed for Australia in order to identify the links between ENSO, phases in the monsoon, tropical cyclones and local conditions. This will extend the analysis presented here by identifying key aspects of the climate that drive the development of high heat load events in association with conditions at the local scale. The climatology will increase our understanding of the dynamic relationship between the multiple scales of atmospheric motion and their influence on local conditions increasing the efficiency of the model optimisation process.

A climatology of heat load will also enable the development of seasonal forecasting tools, such as an updated RAP that accounts for ENSO phases and intensity. There is also the potential for climate projections of medium to long term climate variability and the impact it may have on feedlot development and management.

9. References

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