final report

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Updated Heat Load Index algorithm

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Executive Summary

The project was designed to develop a draft Heat Load Index algorithm, based on the surface energy balance of the feedlot. Phase 1 of the project was undertaken during the 2014/2015 summer period and consisted of:

- Collecting micro-meteorological data at UQ Gatton utilising an Eddy Covariance (EC) system to establish the heat/energy relationships between feedlot cattle and the environment
- Monitor animal health, behaviour and consumption

Unfortunately, the data to be collected on animal health, behaviour and consumption was not supplied, with the only data available from UQ being rumen temperature logs for approximately 100 animals. The micro-meteorological dataset collected by Katestone at the Gatton provides a good picture of how the environmental inputs, radiation, momentum and moisture are partitioned. However the lack of data on the cattle energy sources and sinks means the total energy balance cannot be solved and without the cattle behaviour observations and consumption rates there is no certainty whether excessive heat load was experienced during the summer period.

The EC monitoring data provided a physical explanation of the changes in the environment that appear to coincide with increases in the mean maximum herd rumen temperature (HRT) due to a transition from a hot dry climate to a hot and humid one. It also showed that these conditions will persist until the supply of water and/or water vapour is exhausted or no longer available.

Every period in the HRT dataset where the HRT stayed above the mean for more than 2 days coincided with the synoptic and micro-meteorological events described above. The limiting factor in all these events was the availability of moisture, either as water vapour or freely available water following a rain event, to drive the evaporative flux (Q_E).

While installing an EC station at every feedlot is unfeasible the data does suggest that other variables may provide a better understanding of the onset and dissipation of these conditions. For example dew point temperature, is a direct measure of the amount of water vapour present in the atmosphere and the soil/air temperature gradient can be used as a proxy for evaporative fraction (EF) under some circumstances (Gentine et al. 2007).

Phase 2 of the Project will provide the concurrent animal observations required to identify and quantify the environmental conditions that drive the onset and dissipation of heat stress events in feedlot cattle and ultimately lead to a simplified heat stress algorithm that is based on the cattle’s reaction the environmental conditions.

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Glossary

Term	Definition
°C	degrees Celsius
km	kilometre
km/h	kilometre per hour
m	metre
m/s	metres per second
m^2	square metres
Nomenclature	
Q	Energy partition
Abbreviations	
EC	Eddy covariance
EF	Evaporative fraction
SEB	Surface energy balance
UQ	University of Queensland

1. Introduction

Heat load in feedlot cattle is a function of the energy input and output called an energy balance or energy budget and is derived by the partitioning of energy in a system such that:

$$\boldsymbol{Q^*} + \boldsymbol{Q_m} = \boldsymbol{Q_H} + \boldsymbol{Q_E} + \boldsymbol{Q_G} + \Delta\boldsymbol{Q_s} \qquad \textbf{Equation 1}$$

Where, Q^* is net all wave radiation, Q_m is rate of heat production by metabolic processes, Q_H is the sensible heat flux, Q_E is the water vapour flux, Q_G is the ground heat flux and ΔQ_S is the storage of heat in the animal.

This project was designed to develop a draft algorithm, based on the surface energy balance of the feedlot. Phase 1 of the project was undertaken during the 2014/2015 summer period and consisted of:

- Collecting micro-meteorological data at UQ Gatton using an Eddy Covariance (EC) systtem to establish the heat/energy relationships between feedlot cattle and the environment
- Monitor animal health, behaviour and consumption

In order to achieve the project objective animal measurements were to be supplied by Dr John Gaugan's research group at the Gatton research feedlot. The only data that was provided by UQ was rumen temperatures at ten minute intervals for upwards of 100 cattle during the summer period. The nature of the technology used to acquire the rumen temperature necessitates that the data can be inconsistent with mixed time periods and sporadic retrieval from a random number of cattle within the feedlot herd.

Coupled with that, is the fact that the rumen temperature can be misleading following the consumption of feed or intake of water, with a typical lag of 2-3 hours following food/water intake to return to core temperature values. This can pose significant issues in establishing a cause and effect relationship with the data at hourly and sub hourly intervals without knowing the input and output of the cattle. With the limitations to data recovery and the internal variability of the dataset, we were required to coerce the rumen temperature data to be representative of the overall feedlot rumen temperature that is consistent enough for analysis with the micrometeorological dataset.

The micro-meteorological dataset collected by Katestone at the Gatton research feedlot provides a good picture of how the environmental inputs, radiation, momentum and moisture are partitioned. However the lack of data on the cattle energy sources and sinks means the total energy balance cannot be solved and without the cattle behaviour observations and consumption rates we cannot say with certainty whether excessive heat load was experienced during the summer period.

Phase 2 of the Project was designed to integrate the components of the surface energy balance (SEB), with the animal measures to trial a new heat load algorithm. As the animal data collected during phase 1 was insufficient to assess heat load in cattle these observations will be undertaken during Phase 2 alongside the SEB measurements.

This report presents results of Phase 1 of the Project. It details key findings about the environmental factors that determine the energy partitioning at the feedlot and their relationship to cattle rumen temperatures.

2. Data collection

2.1 Eddy covariance

The micro-meteorological monitoring was conducted by an Eddy Covariance (EC) method. This method is by far the most robust as the method measures the individual turbulent eddies that are responsible for the transport of heat and moisture within the boundary layer by resolving the partition pathways of heat and moisture at a very high resolution and is the ideal method for this project.

The EC system was purchased from Campbell Scientific and installed at the UQ Gatton research feedlot on October 16 2013 and removed on April 30 2014. A high resolution krypton-hygrometer was also loaned from CSIRO to record the moisture fluxes. The EC system recorded the following variables:

- Temperature
- Relative humidity
- Wind speed and wind direction as U and V components
- Vertical velocity
- Water vapour
- Black globe temperature
- Soil temperature
- Downwelling shortwave radiation
- Downwelling longwave radiation
- Upwelling shortwave radiation
- Upwelling longwave radiation
- Ground heat flux
- Latent heat flux
- Sensible heat flux

The temperature, water vapour and vertical velocity were recorded every 0.1 seconds to capture the structure of turbulent eddies. Turbulence is the mechanism by which energy is transferred from one surface to another. In this context it refers to the transfer of heat and moisture to/from the surface and atmosphere. Here Equation 1 is reworked without the sources and sinks for the cattle:

$$\boldsymbol{Q}^{*} = \boldsymbol{Q_H} + \boldsymbol{Q_E} + \boldsymbol{Q_G} + \Delta\boldsymbol{Q_s} \qquad \textbf{Equation 2}$$

such that Q_m is removed and ΔQ_s is inserted, in reference to the energy partitioned in to the ground surface. The data is then represented as an hourly average sensible heat flux (Q_H), latent heat flux (Q_E), ground flux (Q_G), ground storage (ΔQ_s) and net all wave radiation (Q^*).

The EC system allows us to describe the environment in a physically meaningful and consistent way, such as a hot and dry or cool and wet environment. In the hot and dry environment Q_H will be dominant at the expense of Q_E, whereas in an environment with lots of available water Q_E will dominate at the expense of Q_H. A simple diagnostic for determining the type of environment is the Bowen ratio:

$$\boldsymbol{\beta = \frac{Q_h}{Q_e}}$$ **Equation 3**

Where a Bowen ratio of less than 1 indicates that Q_E (i.e. evaporation / evapotranspiration) is dominant while a ratio greater than 1 indicates a warmer and drier climate and Q_H is dominant. Table 1 shows the typical Bowen ratios observed for a range of surface types.

Table 1 Typical Bowen ratio values for a range of surfaces

Type of surface	Range of Bowen ratios
Desert	>10
Semi-arid landscapes	2.0-6.0
Temperate rainforests	0.4-0.8
Tropical rainforests	0.1-0.3
Tropical oceans	<0.1
Reproduced from Sturman and Tapper 1996, page 310 table 10.1	

The Bowen ratio was calculated for the UQ Gatton research feedlot and is presented in Table 2. The data indicates that on average the feedlot would fall within the semi-arid landscape with a Bowen ration of 6.3 and a range of 4.3 to 11.6. The variability in the Bowen ratio can be seen in Figure 2. The higher the Bowen ratio is the greater the contribution of Q_H, meaning a hotter and drier environment. The lower the Bowen ratio is indicates that more energy is being partitioned into Q_E than was previously the case. This means that the environment is getting more humid. While Q_H is still the dominant energy sink during these periods, the small increases in Q_E create a hot and humid environment as opposed to a hot and dry one.

Table 2 Bowen ratios calculated at the UQ Gatton research feedlot

Location	Range of Bowen ratio	Average Bowen ratio
UQ Gatton test feedlot	4.3-11.6	6.3

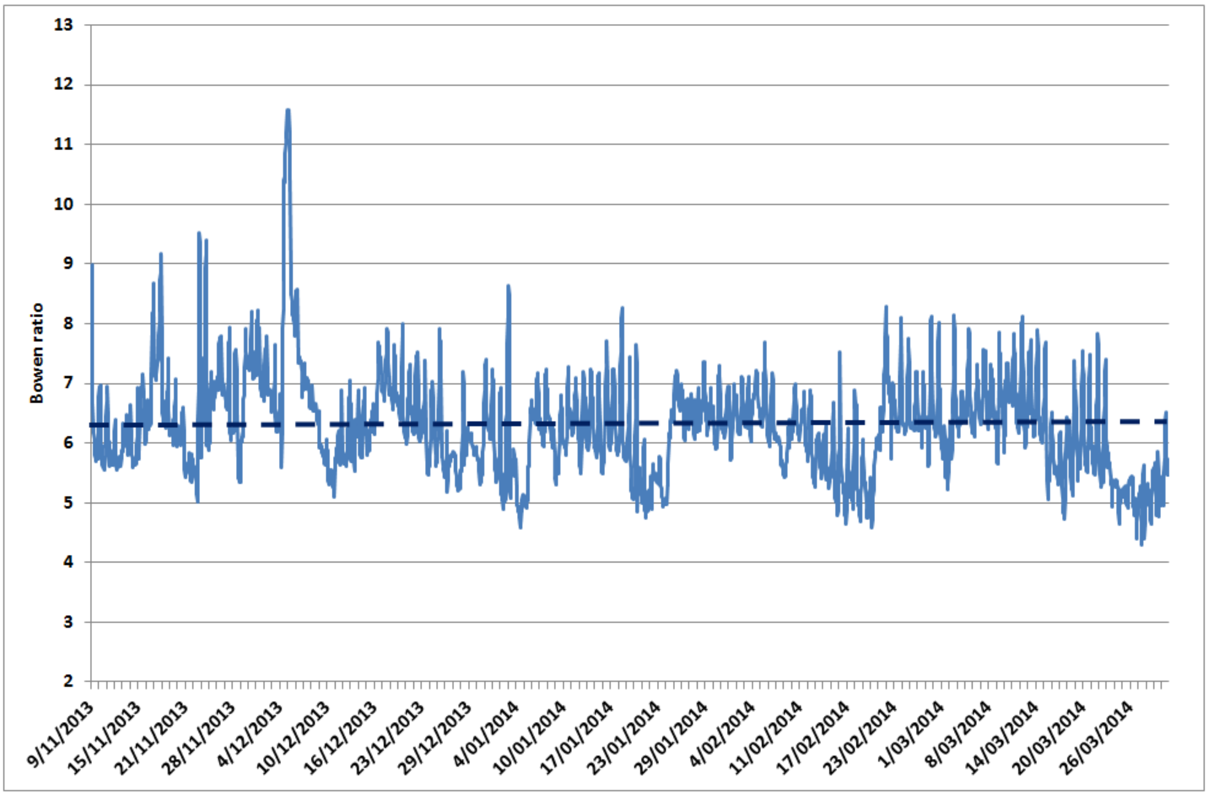

Figure 1 **Bowen ratio calculated at the UQ Gatton research feedlot. The dashed line indicates the average Bowen ration for the monitoring period.**

This increase in Q_E partitioning is only small compared to the overall energy distribution; however it can have a significant impact on the environment the cattle are acclimatised too. In order to draw out this relationship the evaporative fraction (*EF*) was calculated as:

$$\boldsymbol{EF = \frac{Q_e}{Q_h + Q_e}}$$ **Equation 4**

This diagnostic variable provides a measure of how much Q_E is contributing to overall energy flux density. The higher the *EF* value is; the greater contribution of Q_E to the environment. By this measure we are able to clearly identify periods of increased Q_E and therefore the hot and humid environmental condition. Most notably between

- December 20 2013 and January 6 2014
- January 17 2014 and January 23 2014
- February 11 2014 and February 21 2014
- March 16 2014 and March 28 2014

There was also a period of rapid fluctuations early in the data set between November 10 and December 12. These periods appear short lived, not lasting for more than a day or two in either direction.

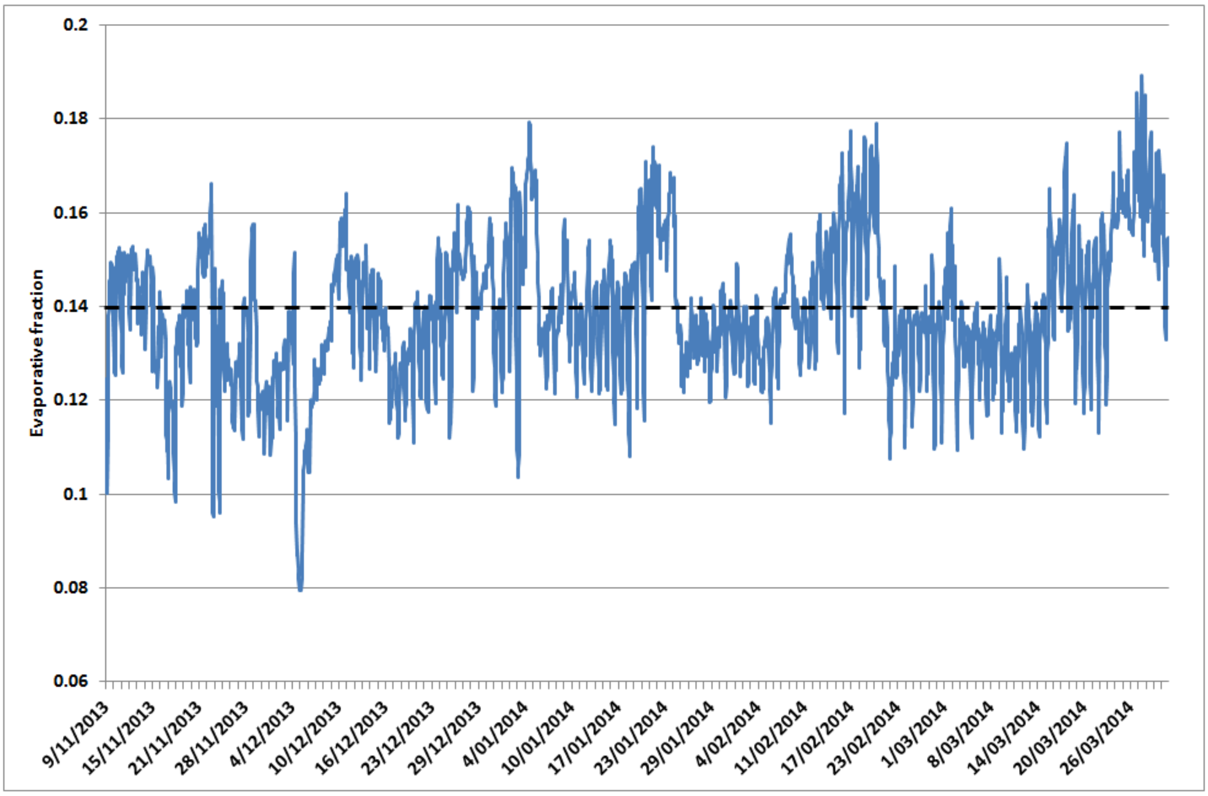

Figure 2 **Evaporative fraction (*EF*) calculated at the UQ Gatton test feedlot. The dashed line indicates the average Bowen ration for the monitoring period.**

2.2 Rumen temperature

The rumen temperature was measured using a wireless rumen bolus that transmits the temperature every 10 minutes to a server located at the feedlot. Individual cattle respond to heat in different ways based on their physiology, breeding and behavioural habits, as such looking at one steer or only a handful can bias the data. To overcome this we calculated the average hourly maximum temperature from the bolus data set to derive a herd mean maximum rumen temperature (HRT).

The hourly HRT for the period is shown in Figure 3, the dashed line is the average HRT over the period (39.5 °C). Several periods stand out showing a ramping up of the HRT over several days. These are especially evident on January 3 2014 to January 7 2014 and February 14 2014 to February 21 2014. There are also some periods in the HRT dataset that show slight elevations near the end of December and the end of January. These periods are not as pronounced as previous events but they do appear as periods that are above the mean HRT.

Other periods of note are around mid-March where the HRT drops significantly below the mean for the rest of the period with only a few rapid increase near the end of the data set. These particular events are interesting to note for further investigation as they may have links to cattle acclimatisation processes or changes in consumption. Without the concurrent behavioural response data this is only speculative. As such, the period from March 9 2014 onwards has been excluded from the analysis.

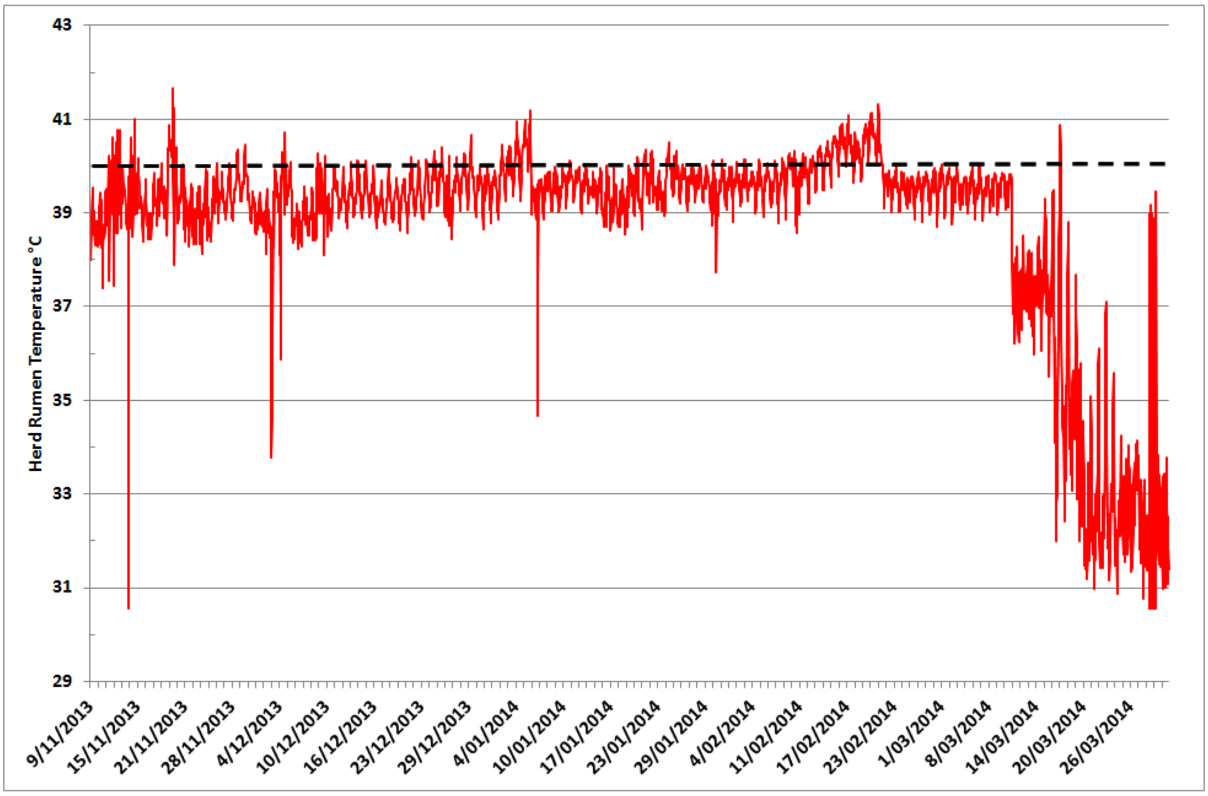

Figure 3 **Mean maximum herd rumen temperature (HRT) recorded at UQ Gatton research feedlot**

3. Analysis

The EF and HRT time series were normalised to a mean of 0 and a standard deviation of 1 so as to enable comparison at the same scale (Figure 4). The normalised time series show that the ramping up of the HRT and the EF coincide in time with the EF leading the HRT by about 12 hours.

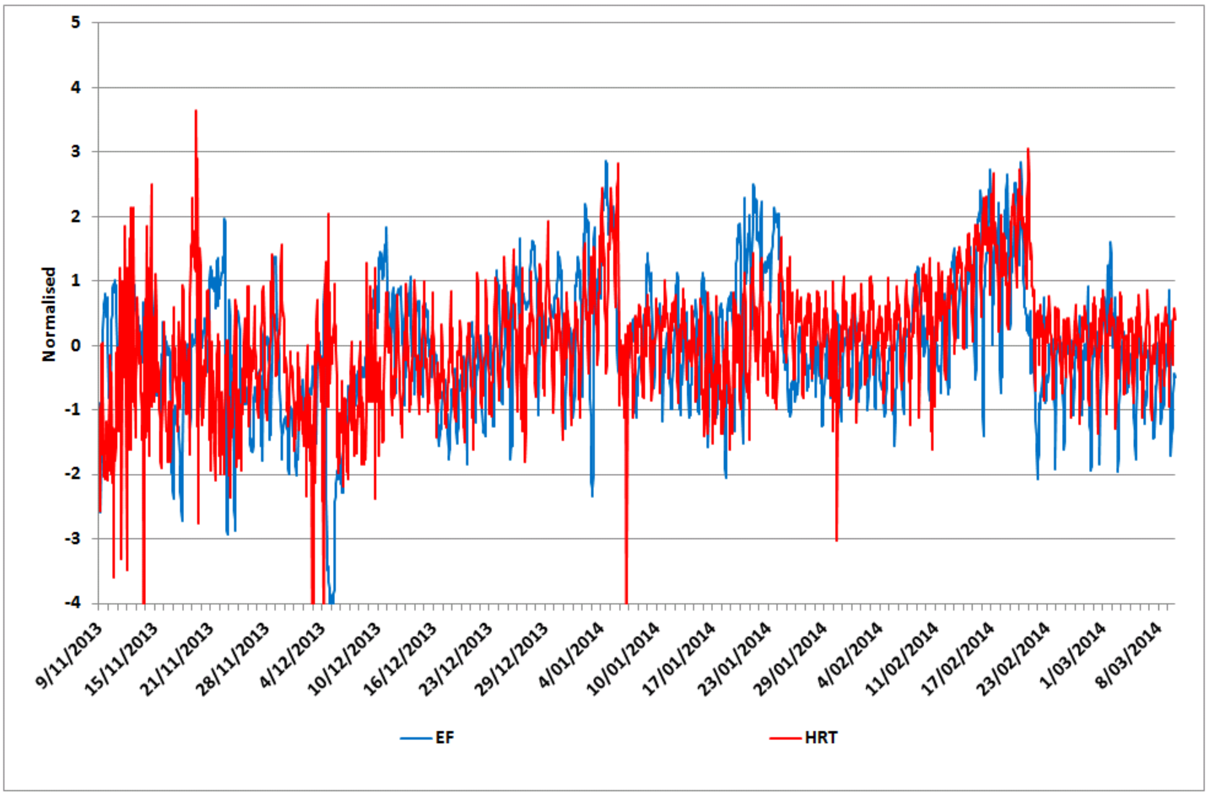

Figure 4 **Normalised evaporative fraction (EF) and herd rumen temperature (HRT)**

During these ramping up periods more energy is being partitioned into Q_E than during other periods in the data set when the HRT is not elevated. This local increase in Q_E creates a hot and humid environment that persists for several days and is usually followed by a rapid decrease in the HRT and EF. This is particularly evident during the February 2014.

3.1 February 2014

February 11 to 22 saw a series of complex low pressure systems and associated troughs forming along the tropical northern reaches of Australia and extending diagonally across Queensland. These troughs persisted until February 22 where a high pressure system in the Australian Bight extended a ridge into southeastern Australia (Figure 5).

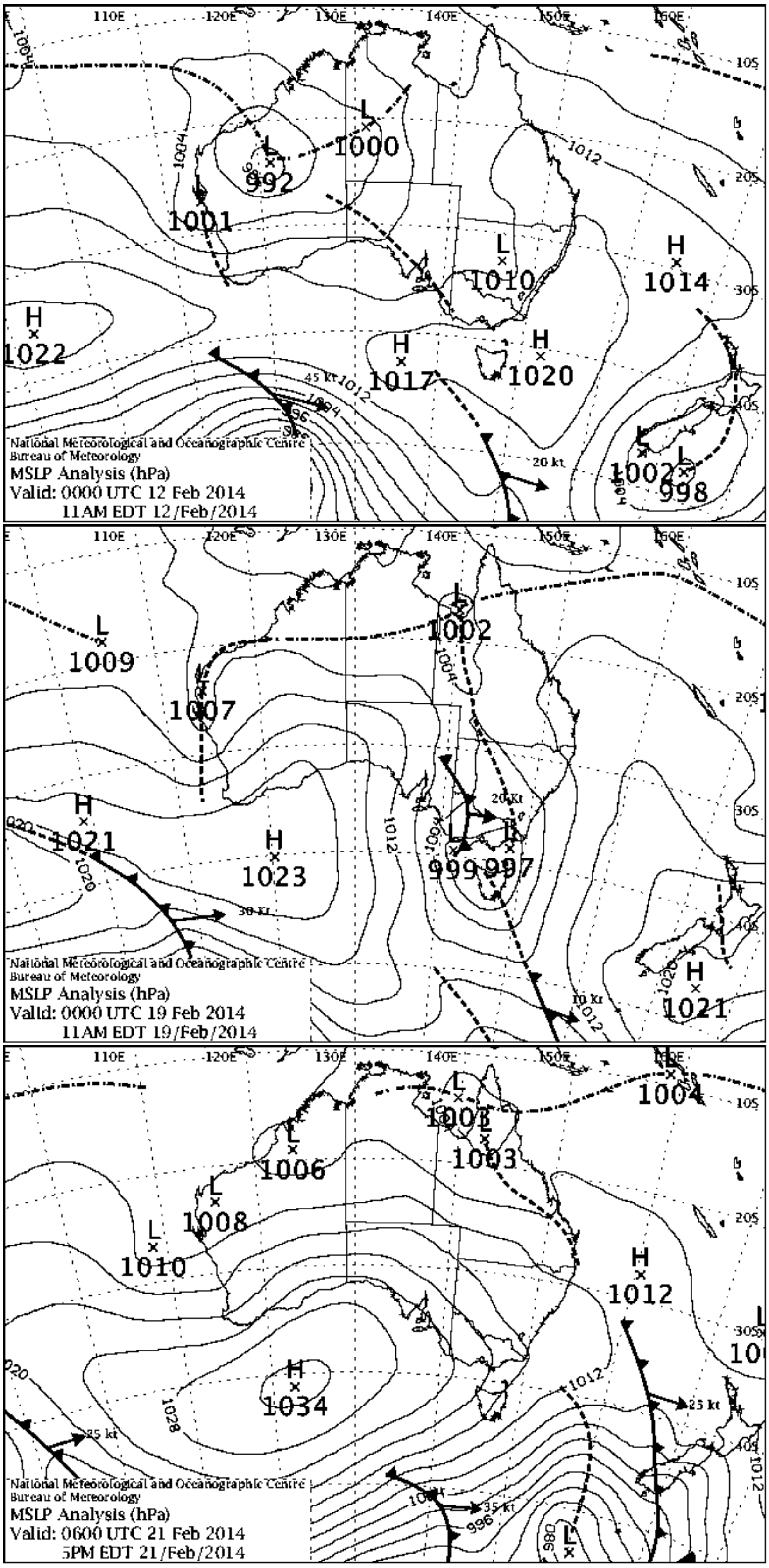

Figure 5 **Synoptic mean sea level analysis charts**

The local environmental conditions observed at the UQ Gatton research feedlot are a direct result of these synoptic features. As the inland trough develops across the interior of Queensland, hot, moist air is funneled down from the tropics into southeast Queensland along a north to westerly wind.

The transport of hot humid air persists until the ridge from the Bight moves the trough out to sea replacing the north westerly winds with a north easterly wind around February 21 2014. The effect these synoptic features have on the local environment is seen in the EF diagnostic dropping off abruptly on February 21 as the transport of water vapour from the tropics is shut off (Figure 6).

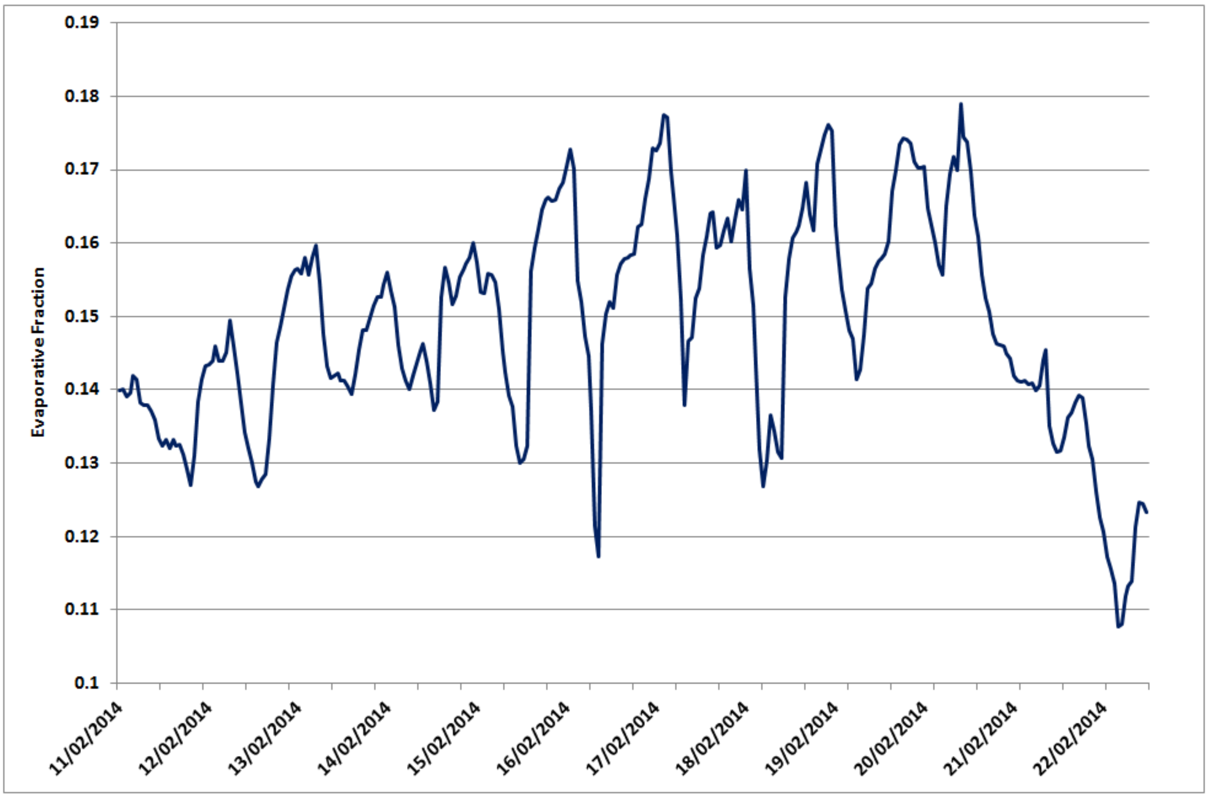

Figure 6 **Evaporative fraction at UQ Gatton**

In the context of the surface energy balance, more water vapour entering the system means more energy is being partitioned into the evaporative flux (Q_E). This causes the environment to transition from a hot and dry climate to a hot and humid climate and, if these conditions persist, will ultimately produce rain or at the extreme end a convective storm.

This period culminated in minor rain events on February 18 2014 where 1.4 mm of rain and February 22 2014 where 0.2 mm was recorded at the BOM operated Gatton monitoring station. While they are only small amounts of rain, they do add to the total available water for Q_E to continue to operate above its usual range, thereby maintaining the hot and humid climate.

During this time we also observed an increase in the ground heat flux (Q_g). Significantly Q_g is a net source of energy into the system when its values are positive, which is usual for daytime periods. This period saw Q_g continue to be a net source after sunset driving Q_E into the night. Thereby the stored energy in the ground surface is being released into the overlying atmosphere and used to evaporate any available soil moisture and surface water. This particular energy balance signature is what keeps the environment hot and humid into the night (Figure 7).

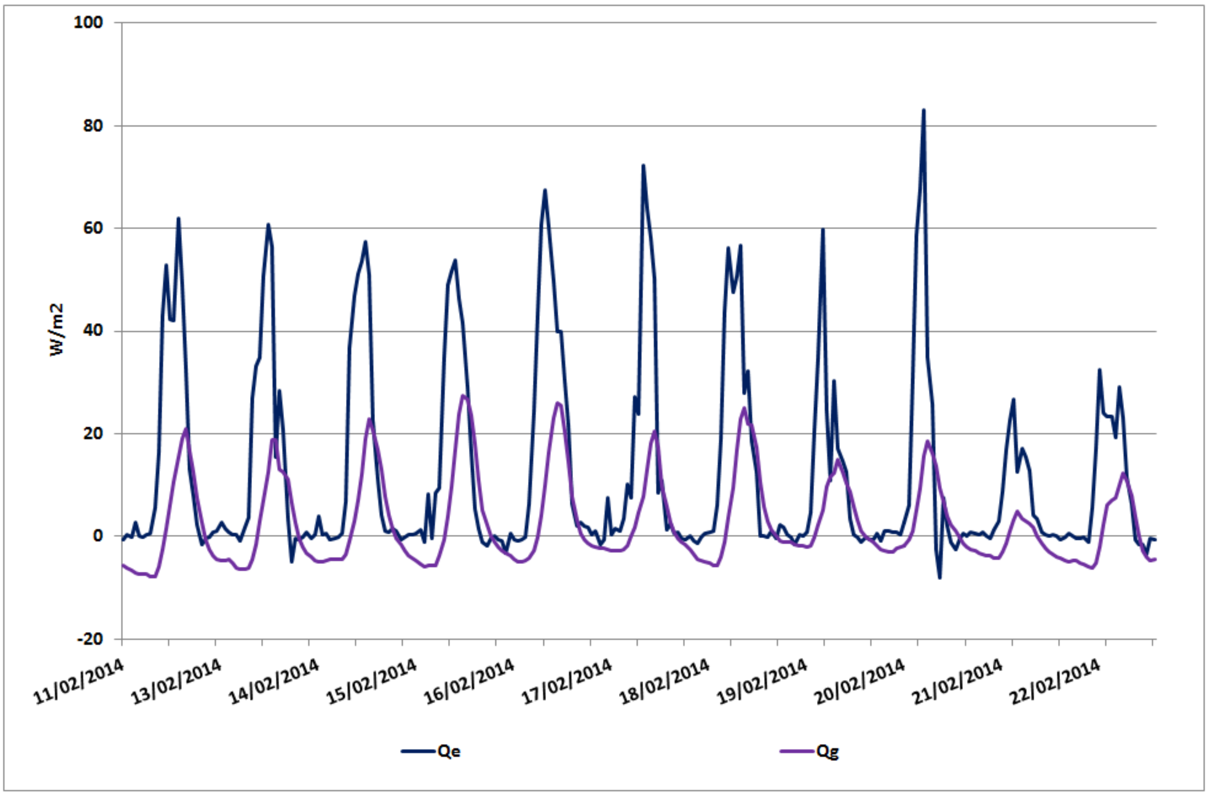

Figure 7 **Evaporative flux (Qe) and ground heat flux (Qg) at UQ Gatton**

The HRT is shown to follow this trajectory with what appears to be a lag period of about 12 hours. Interestingly we can identify in the HRT time series the rain event on the 18th where we see a reduction in the HRT followed by an increase over the following days as Q_E begins to ramp up again (Figure 8)

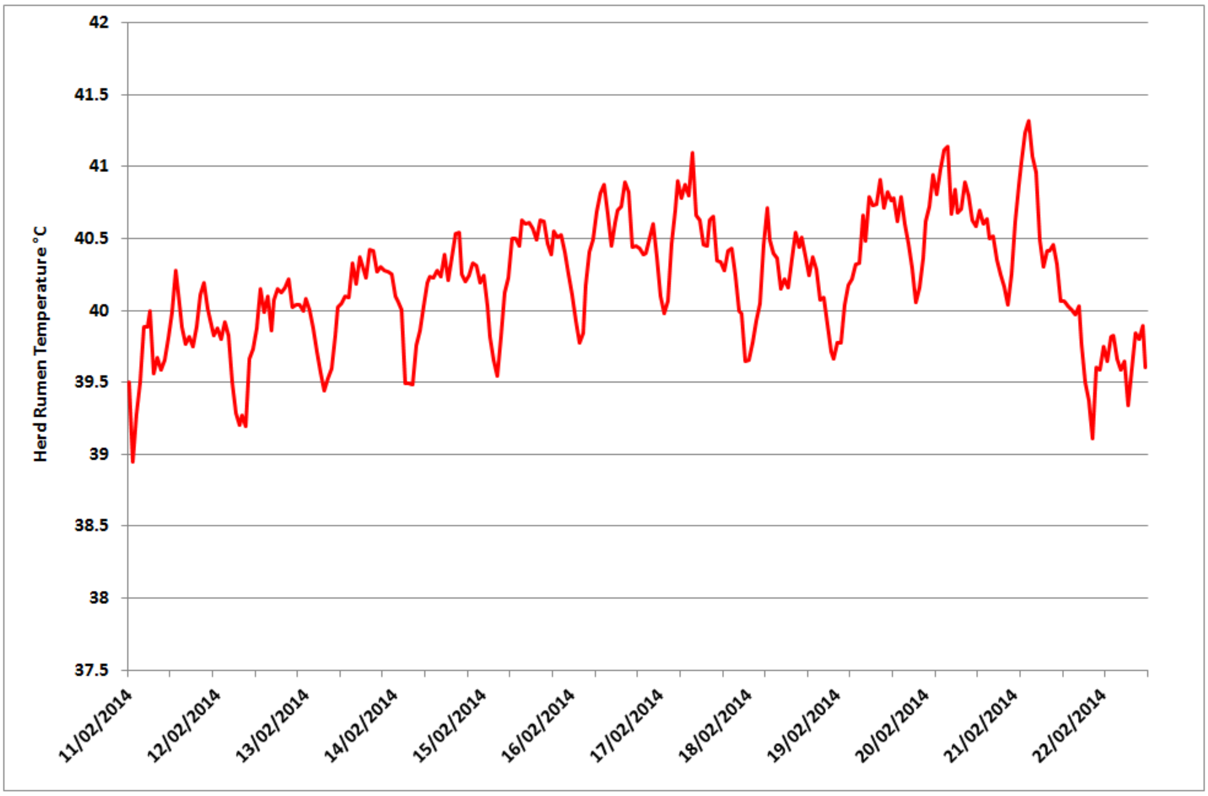

Figure 8 **Herd rumen temperature at UQ Gatton test feedlot**

4. Conclusions

The EC monitoring data provided a physical explanation of the changes in the environment that appear to coincide with increases in the mean maximum herd rumen temperature (HRT) due to a transition from a hot dry climate to a hot and humid one. It also showed that these conditions will persist until the supply of water and/or water vapour is exhausted or no longer available.

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While installing an EC station at every feedlot is not feasible, the data does suggest that other variables may provide a better understanding of the onset and dissipation of these conditions. For eaxmple dew point temperature, is a direct measure of the amount of water vapour present in the atmosphere and the soil/air temperature gradient can be used as a proxy for EF under some circumstances (Gentine et al. 2007).

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5. References

Gentine, P., Entekhabi, D., Chehbouni, A., Boulet, G., Duchemin, B. 2007. "Analysis of evaporative fraction diurnal behavior", *Agricultural and Forest Meteorology*, 143, 13-29.