109

Development and verification of thermal stress forecasts for cattle in Australia's Rangelands

Cowan, T[1,2]; Hinds, E [1]; Marshall, AG[1,3]; Wheeler, MC[2]; Cobon, DH[1]

[1] Centre for Applied Climate Sciences, University of Southern Queensland, Toowoomba, QLD, Aust.;

[2] Bureau of Meteorology, Melbourne, VIC, Aust.;

[3] Bureau of Meteorology, Hobart, TAS, Aust.

Key words: cattle comfort; heat stress; chill, forecast; temperature

Abstract
The highly variable weather and climate of northern Australia can pose a significant threat to cattle and other livestock, with prolonged heat waves and sudden chill conditions known to increase mortality risk. For example, the compounding impact of high temperatures, high humidity and calm conditions led to significant cattle heat stress and dozens of animal deaths in southern Queensland in late January 2024. Conversely, the combination of flooding, low temperatures, and high winds associated with a tropical low caused thousands of cattle deaths in northern Queensland in February 2019.

Currently, the Australian Bureau of Meteorology issues national sheep graziers' alerts for potential risk of chill Test and exposure, however there are no such equivalent chill (or heat) warnings for cattle. A key objective of the Northern Australian Climate Program (NACP) is to develop prototype forecast products of thermal stress that can be utilised by livestock producers to help manage the risks posed by extreme weather and climate events.

In this research, we describe NACP's latest prototype forecast maps of the Heat Load Index (HLI) and Cattle Comfort Index (CCI), derived from the Bureau's numerical weather prediction system - ACCESS-G3. These forecasts display the predicted chill and heat conditions across Australia out to 7 days. We also assess how well the predictions of CCI performed for a extreme heat event in southern Queensland in January 2024.

Introduction
According to the Australian Bureau of Statistics in 2021, there were approximately 24.4 million dairy and beef cattle in northern Australia, with 44% (10.7 million) and 7% (1.7 million) in Queensland and the Northern Territory, respectively[16]. Cattle in Australia's far northern tropics typically encounter hot and humid wet seasons (October to April), often punctuated by monsoon bursts (Berry & Reeder, 2016). Further south, in the arid regions,

[16] https://www.mla.com.au/news-and-events/industry-news/herd-and-flock-numbers-for-each-region-released/

cattle experience hot, dry summers and cold winters. As such, Australian cattle are highly susceptible to thermal stress risk from both chill (Cowan et al., 2022) and heat stress events (Lees et al., 2019). For example, a humid-heat wave event in southern Queensland and northern New South Wales across late January 2024 (during the Australia-day long weekend) culminated in cattle deaths in feedlots across the western Darling Downs, southern Darling Downs and South Burnett regions (Condon, 2024).

The Australian Bureau of Meteorology (hereafter, the Bureau) currently provides sheep graziers' warnings for chill risk in its forecast districts (Nixon-Smith, 1972) and, during the warmer months, an Australia-wide gridded 3-day heatwave forecast service for people (Bureau of Meteorology, 2024). However, the Bureau does not officially provide gridded thermal stress forecasts for livestock. Based on an anonymous survey conducted in June 2022 with 76 beef producers across northern Australia, more than 60% of respondents expressed a desire for a cattle heat stress forecast map (Cowan et al., 2024).

As part of the Northern Australia Climate Program (NACP), researchers are developing gridded thermal stress forecast products for cattle. The NACP is funded by the red meat sector to develop innovative forecast tools to help graziers better manage drought and climate risk (Lavender et al., 2022). In this study, the first objective is to introduce the latest prototype cattle thermal stress forecasts, like the Cattle Comfort Index and Heat Load Index, developed in collaboration with the Bureau, using their deterministic 7-day numerical weather prediction system, ACCESS-G3 (Australian Community Climate and Earth-System Simulator, Global – v3). The second objective is to assess the performance of forecasts for thermal stress during the late January 2024 heatwave event in southern Queensland.

Methods

Thermal Stress Metrics

The HLI is a dimensionless measure of the instantaneous heat load in cattle, derived from the black globe temperature (which includes solar irradiance and temperature), relative humidity and wind speed (derivation in Gaughan et al., 2008). Hourly data is required to calculate the HLI, from which the Accumulated Heat Load Unit (AHLU) can be derived. When the HLI exceeds a given critical threshold value (e.g., 86 for Angus cattle, 96 for Brahman), cattle begin accumulating heat (McCarthy & Fitzmaurice, 2016). When the HLI < 77, the animals will shed their heat load, whilst the AHLU remains constant if the HLI is between 77 and the critical threshold.

The CCI covers both cold and heat extremes, describing an adjustment to the temperature due to changes in the relative humidity, solar irradiance and wind speed (see derivation in Wang et al., 2018). For temperatures warmer than 25°C, increases in relative humidity lead to an enhanced warming, whereas higher wind speeds will act to cool the CCI. Increased solar irradiance produces a warming effect but has less of an influence as humidity increases.

ACCESS-G3 Numerical Weather Prediction System

The Bureau's deterministic ACCESS-G3 model has a N1024 (~12 km) horizontal resolution with 70 vertical levels reaching a height of 80 km. It assimilates satellite measurements and surface observations (including 0.25° daily sea surface temperatures) at a N320 (~40 km) resolution (Bureau of Meteorology, 2019). We utilise forecasts of screen temperature and relative humidity, 10-metre winds and downwards shortwave radiation at the surface – these forecasts are generated by ACCESS-G3 at four daily initialisation UTC times: 00, 06, 12, and 18z (Zulu time) (10, 16, 22, and 04 Australian Eastern Standard Time [AEST]). For the prototype forecasts maps, we display only the 12z initialised forecasts at 3-hourly intervals, extending up to 9 days, starting from 10 AEST. In addition to CCI and HLI forecasts, we also produce forecasts for the Temperature Humidity Index (THI; a combination of temperature and dewpoint temperature; Wang et al., 2018) and AHLU, the latter calculated for five different HLI thresholds, representing different cattle breeds (e.g., 86→Angus, 96→Brahman)(Gaughan et al., 2008).

To verify these forecasts, we use observations from a network of Bureau operated Automatic Weather Stations[17]. These stations record temperature, wind speed and relative humidity. For solar irradiance observations, we rely on daily global solar exposure, derived from visible radiation measurements from geostationary satellites (Poulsen & Majewski, 2022).

Results

Gridded Thermal Stress Forecasts

An example CCI forecast for 10am AEST on 29 October 2024, is shown in Figure 1. For this forecast product, we have deliberately separated the dark reds to maroon colours (indicating heat) from the blues (indicating chill) with more neutral bland colours (indicating normal conditions). Additionally, we are currently trialling an email alert system for the THI across the northern Western Australian and Queensland Local Government Areas, as well as Northern Territory pastoral regions. The alerts are designed to notify our regional NACP extension officers (called Climate Mates) about the likelihood of extreme THI conditions over the next 1 to 5 days in their regions. The Climate Mates can then pass that information onto their network of local producers and stakeholders.

Verification of the southern Queensland heat stress event in January 2024

Next, we assess how well the ACCESS-G3 forecasts performed during a real-world cattle thermal stress event, specifically the heat conditions in southern Queensland in late January 2024, which led to reported cattle deaths across numerous feedlots (Condon, 2024). We focus on the town of Dalby in the Western Downs Region of Queensland.

It is apparent that the ACCESS-G3 forecasts did not predict the heat event at a 7–10 day lead time, as the CCI and THI were well underpredicted (Figure 2).

Closer to the event, we see the 3-5 lead time forecasts captured the diurnal cycle of the CCI and THI, however the model tended to overpredict the intensity of the heat. The reason for this is the model under-predicted the rain event on 27 January, leading to an overestimate in the solar irradiance (and underestimate in relative humidity) contribution to the CCI.

[17] http://www.bom.gov.au/climate/data/stations/about-weather-station-data.shtml

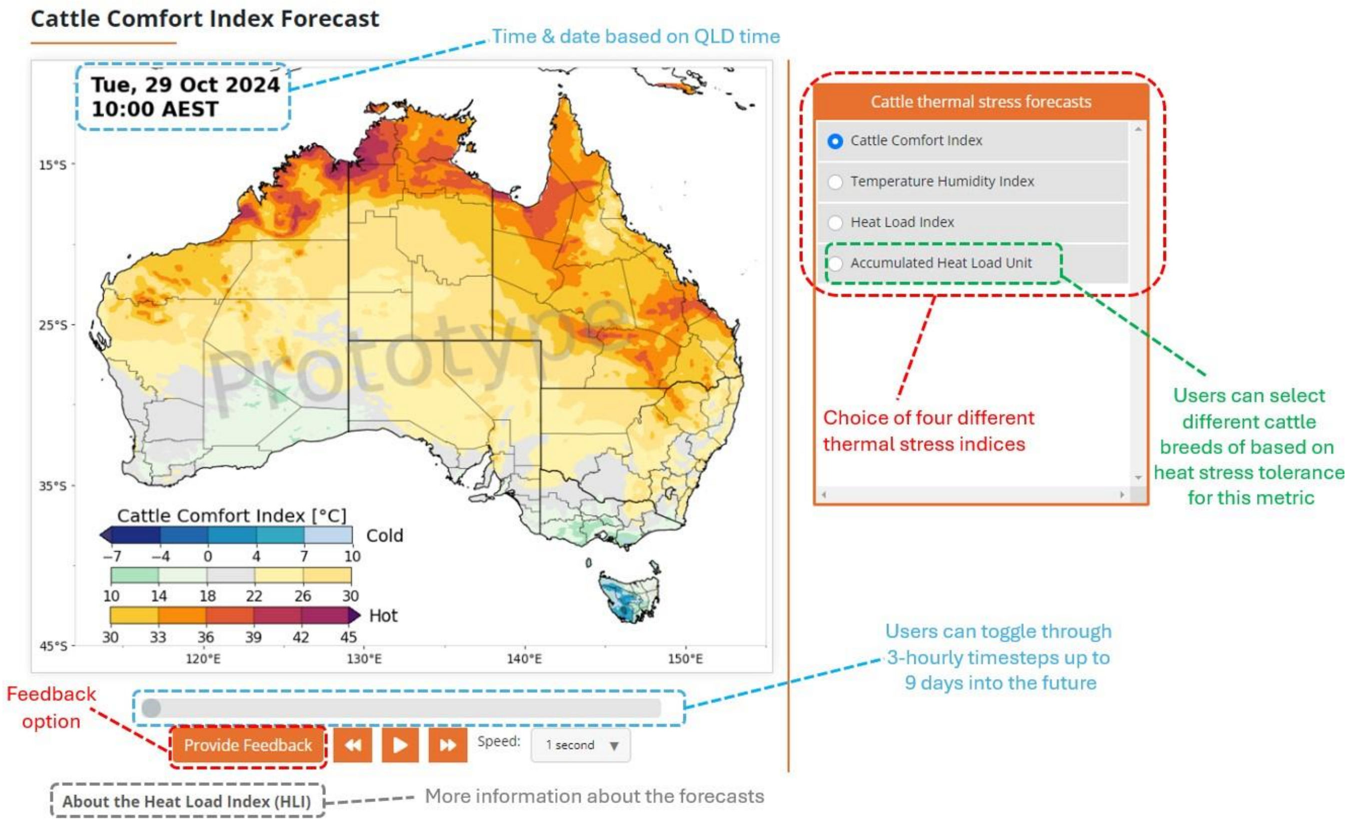

Figure 1: Example of a Cattle Comfort Index (CCI) forecast map from the Bureau's ACCESS-G3 numerical weather prediction system. This forecast is taken from https://nacp.org.au/cattle_thermal_stress_forecasts.

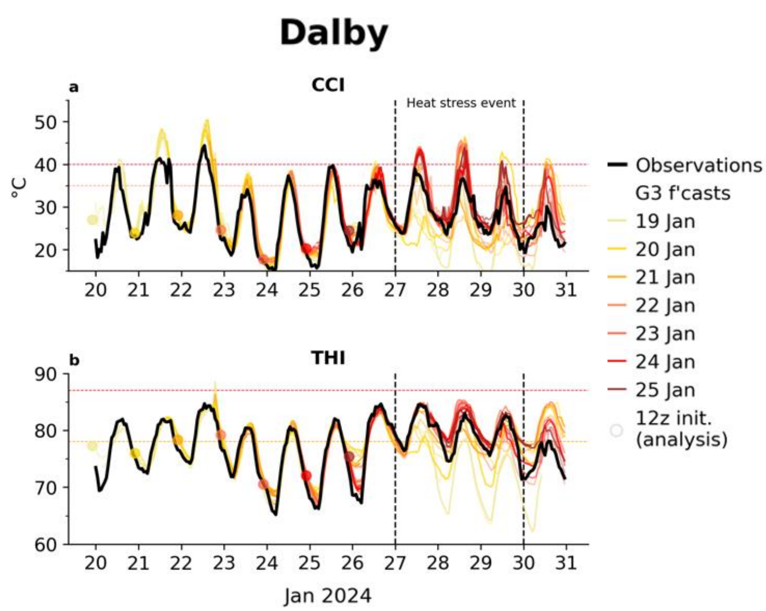

Figure 2: Observed heat stress event (black lines) in Dalby, Queensland (27.16°S, 151.26°E) in late January 2024, as indicated by (a) the Cattle Comfort Index (CCI) and the Temperature Humidity Index (THI). The coloured lines (yellow to red) show the ACCESS-G3 forecasts from 19-25 January. Circles indicate the model forecast initialisation at 12z each day (e.g., 10pm local time).

Discussion

This paper has introduced a suite of cattle thermal stress forecast products, based off the Bureau's deterministic numerical weather prediction model, ACCESS-G3. Initial verification results suggest that forecast skill is relatively good up to 5 days, however beyond that lead time, wind and relative humidity become harder to predict, and hence, Cattle Comfort and Heat Load indices show greater divergence from observations. There is scope to expand these forecast products to include other indices such as the Livestock Chill index, which would be of value for sheep/wool producers in central/northern Queensland. Other improvements could include using higher resolution modelling, such as the Bureau's ACCESS-City models, that are centred over metro regions at a 1.5 km horizontal resolution. The NACP team are also exploring ways to enhance forecast visualisations on the product website, including the potential for users to zoom in on a region of interest. This would improve the accessibility and utility of forecasts. Future NACP research will target the defining of heat and chill thresholds for cattle under Australian climate conditions, noting that temperatures in the cooler months are not as severe as in Europe or North America, however cattle can still be significantly impacted.

Acknowledgements

This work is funded by Meat & Livestock Australia, the Queensland Government through the Drought and Climate Adaptation Program, and the UniSQ through the Northern Australia Climate Program. We thank Dr Rajashree Naha and Dr Ghyslaine Boschat for providing helpful feedback on an early manuscript draft.

References

Berry, G. J., & Reeder, M. J. (2016). The Dynamics of Australian Monsoon Bursts. *Journal of the Atmospheric Sciences*, *73*(1), 55–69. https://doi.org/10.1175/JAS-D-15-0071.1

Bureau of Meteorology. (2019). *APS 3 upgrade of the ACCESSG/GE Numerical Weather Prediction system, NOC Operations Bulletin Number 125*. http://www.bom.gov.au/australia/charts/bulletins/opsbull_G3GE3_external_v3.pdf

Bureau of Meteorology. (2024). Heatwave Service Level Specification.

Condon, J. (2024). Oppressive long-weekend weather leads to feedlot mortalities. *Beef Central*. https://www.beefcentral.com/news/oppressive-long-weekend-weather-leads-to-feedlot-mortalities/

Cowan, T., Wheeler, M. C., Cobon, D. H., Gaughan, J. B., Marshall, A. G., Sharples, W., McCulloch, J., & Jarvis, C. (2024). Observed climatology and variability of cattle heat stress in Australia. *Journal of Applied Meteorology and Climatology*, *63*, 645–663. https://doi.org/10.1175/JAMC-D-23-0082.1

Cowan, T., Wheeler, M. C., Day, C. D. B., Nguyen, H., & Cobon, D. (2022). Multi - week prediction of livestock chill conditions associated with the northwest Queensland floods of February 2019. *Scientific Reports*, *12*(5907), 1–13. https://doi.org/10.1038/s41598-022-09666-z

Gaughan, J. B., Mader, T. L., Holt, S. M., & Lisle, A. (2008). A new heat load index for feedlot cattle. *Journal of Animal Science*, *86*(1), 226–234. https://doi.org/10.2527/jas.2007-0305

Lavender, S. L., Cowan, T., Hawcroft, M., Wheeler, M. C., Jarvis, C., Cobon, D., Nguyen, H., Hudson, D., Sharmila, S., Marshall, A. G., de Burgh-Day, C., Milton, S., Stirling, A., Alves, O., & Hendon, H. H. (2022). The Northern Australia Climate Program: Overview and selected highlights. *Bulletin of the American Meteorological Society*, *103*(11), E2492–E2505. https://doi.org/10.1175/BAMS-D-21-0309.1

Lees, A. M., Sejian, V., Wallage, A. L., Steel, C. C., Mader, T. L., Lees, J. C., & Gaughan, J. B. (2019). The Impact of Heat Load on Cattle. *Animals*, *9*(6). https://doi.org/10.3390/ani9060322

McCarthy, M., & Fitzmaurice, L. (2016). Heat load forecasting review. *Meat and Livestock Australia*, 1–74.

Nixon-Smith, W. F. (1972). The forecasting of chill risk ratings for new born lambs and off-shears sheep by use of a cooling factor derived from synoptic data (Bureau of Meteorology Working Paper No. 150).

Poulsen, C., & Majewski, L. (2022). Gridded satellite solar observations project: Implementation of Heliosat-4 and the application of bias correction. *Bureau Research Report No. 062*, 1–48.

Wang, X., Bjerg, B. S., Choi, C. Y., Zong, C., & Zhang, G. (2018). A review and quantitative assessment of cattle-related thermal indices. *Journal of Thermal Biology*, *77*, 24–37. https://doi.org/https://doi.org/10.1016/j.jtherbio.2018.08.005