Breeding Focus 2018 - Reducing Heat Stress

Edited by

Susanne Hermesch

Animal Genetics and Breeding Unit, University of New England, Armidale, Australia

Sonja Dominik

CSIRO Agriculture and Food, Armidale, Australia

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Animal Genetics and Breeding Unit

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Preface

“Breeding Focus 2018 – Reducing Heat Stress” is the third workshop in the series. The Breeding Focus series was developed to provide an opportunity for exchange between industry and research across a number of agricultural industry sectors. With this goal in mind, workshops have included presentations across the livestock and aquaculture industries to take participants outside their area of expertise and encouraged them to think outside the box. This year we increased the scope even further by also inviting presentations from the cropping and horticulture industries. Since the topic of heat stress has recently gained increased attention, we will discuss a wide range of aspects associated with heat stress, such as the physiology of heat stress and phenotypic indicators, genetic approaches and industry impacts.

Heat stress in animals describes a situation where an animal is exposed to high temperatures and unable to dissipate body heat, which causes an increase in body temperature. In the short term, an animal will react to heat stress with behavioural strategies (e.g. seeking shade, panting) to reduce the heat load. With prolonged excessive heat load, feed intake is reduced and production losses occur. Under extreme circumstances, excessive heat load can lead to death. In plants, heat stress can be defined as irreversible damage to plant function and development as a consequence of hot temperatures. Environmental causes of heat stress in plants and animals include high temperatures and high humidity over a long period of time, which is exacerbated by low cloud cover and high solar radiation.

With raising average temperatures, agricultural industries are faced with the challenge to manage potential impacts of heat stress on their crops, their pasture base and welfare and production of their livestock or aquaculture species. Management strategies such as shade and irrigation are effective but costly and, depending on the severity of climatic conditions, may have limited success. Susceptibility of organisms to heat stress can vary due to factors such as age and general health, but also genetic factors, such as breed or variety. Further, as we will hear during the workshop, genetic variation exists within breeds that enables genetic approaches to address heat stress in plants and animals. Selective breeding provides a long term approach that facilitates improvement of the physiology of plants and animals to cope with excessive heat load. The challenge here is to obtain cost-effective phenotypes to describe heat stress.

The chapters of this book discuss where the current climate is trending, and outlines opportunities for the crop, orchard, livestock and aquaculture industries to describe and measure heat stress, all with the focus on genetic improvement.

We would like to thank everyone who has contributed to this event for their time and effort: the authors for their contributions to the book and presentations, the reviewers who all readily agreed to critique the manuscripts. We would like to express a special thanks to Kathy Dobos for her contributions into the organisation of this workshop and the publication. Thank you!

Susanne Hermesch and Sonja Dominik
Armidale, September 2018

Climate, Weather and Water Services for Livestock Industries

Jaclyn N. Brown[1] *and Alister Hawksford*[2]

[1]Weather and Climate Decisions team, CSIRO Agriculture and Food, Hobart, TAS 7004, Australia

[2]Agriculture Program, Bureau of Meteorology, Canberra, ACT 2600, Australia

Abstract

Livestock industry researchers and service developers often use climate, weather and water data to understand and predict the impact of environmental conditions on animals (Barry *et al*., 2017). However, the wide range of data services currently available can be confusing and at times misleading, resulting in less than optimal outcomes. This chapter looks to shed some light on the range of weather and climate services available with the aim of enabling researchers and developers to deliver value to their industries. It provides background on how such services are created, some key technical considerations, and a list of currently available services from the Bureau of Meteorology, CSIRO and other sources.

Introduction

Fore note*: This chapter contains sections adapted from chapter 6.2 of Barry et al. (2017) with additions and changes made to suit the specific needs of the livestock industry.*

Heat stress on livestock is a growing problem in Australia with temperatures increasing over recent decades and further increases expected under future climate change (Nidumolu et al. 2010, 2014). Heat stress can be monitored and predicted using historical weather data and future projections. With this knowledge, adaptation strategies can be implemented on the tactical time scale (movement of cattle to shadier, cooler paddocks) and strategically (changing breeds, building shelters).

Such studies require comprehensive weather data sets which are becoming larger and more complex. The number of sources of this information is also increasing, making it harder to discern which dataset is fit for purpose. This chapter seeks to shed light on the range of available climate, weather and water data services available for the Australian continent. It does not attempt to address all available datasets or variables, but rather focuses attention on the variables likely to be impactful to those in the livestock industry.

Weather or climate?

When looking for climate, weather or water services (herein referred to simply as services) it is useful to first distinguish the difference between weather and climate. Weather is considered to be variation that occurs within days or hours whereas climate describes the longer-term patterns of weather (Barry *et al*., 2017). Climate can range from monthly time scales, such as describing the hotter-than-average temperature for July, or multi-decadal time scales, such as describing the long-term trend in decreasing rainfall in the next 50 years. Climate forecasts are typically categorised by time scales which are sub-seasonal (1 week to 3 months), seasonal (the next 12 months), multi-year to decadal (next year to next decade) and climate change (long-term changes from 30 to 100 years) (Barry *et al*., 2017).

In a nutshell, weather is defined as recent observations or soon to occur conditions within a window of approximately seven days before or after today (e.g. Did the piggery experience hot conditions yesterday? Will it get any extra hot days this week?), whereas climate is anything else (e.g. How often is the piggery exposed to hot conditions each year? How many hot days could it expect next season?).

Constructing climate, weather and water services

All services are built from the same fundamental principles of collating relevant observations, and then processing them into the type of dataset required: an observational dataset or a forecast. This section provides some background on how this is done for a range of services.

Observations – the bedrock

Observed weather data underpins all meteorological and hydrological products and is an essential component for initialising weather or climate forecasts. There are many ways in which to reprocess the observed data to provide it in the form needed for a wide range of users. Hence, historical weather data is an extremely valuable commodity for understanding our local environments and improving weather forecast skill.

Over time, there have been no fundamental changes in the types of weather data being collected; however, the measurement devices themselves have advanced to become more accurate and reliable. For example, traditional weather measuring devices included a Stevenson-screen (a white slat box that holds instruments at a standard height) with a max/min temperature, wet bulb, rain gauge, wind vane, evaporative pan, and a device to measure sunlight hours (a glass ball with a strip of paper on a mechanism). Now, weather-measuring sensors collect data automatically using electronic tipping bucket rain gauges, short-wave and long-wave radiation sensors, and ultrasonic wind sensors.

The official and co-operative weather observation networks of the Bureau of Meteorology (herein the Bureau) provide a wide range of real-time data feeds from across Australia (Figure

1). At a glance, the network contains over 2600 rain gauges, 63 radars, 685 automatic weather stations, 775 river height gauges, 200 evaporation pans, 863 anemometers (wind), 183 ceilometers (clouds), 7 satellite observing stations, 50 soil temperature probes and over 200 co-operative sites. All of these and more are managed and maintained year-round by eight manned observation hubs located in every state, contributing to more than one billion observations processed by the Bureau forecast models every day. The network has varying levels of quality and maintenance regimes, tailored for various purposes, which are captured in the metadata for every record. The spatial distribution is also broadly focused on cities and agricultural zones. For example, 69% (81%) of the time you are anywhere in Australia, you will be within 50 km (75 km) of a rain gauge connected to the Bureau network.

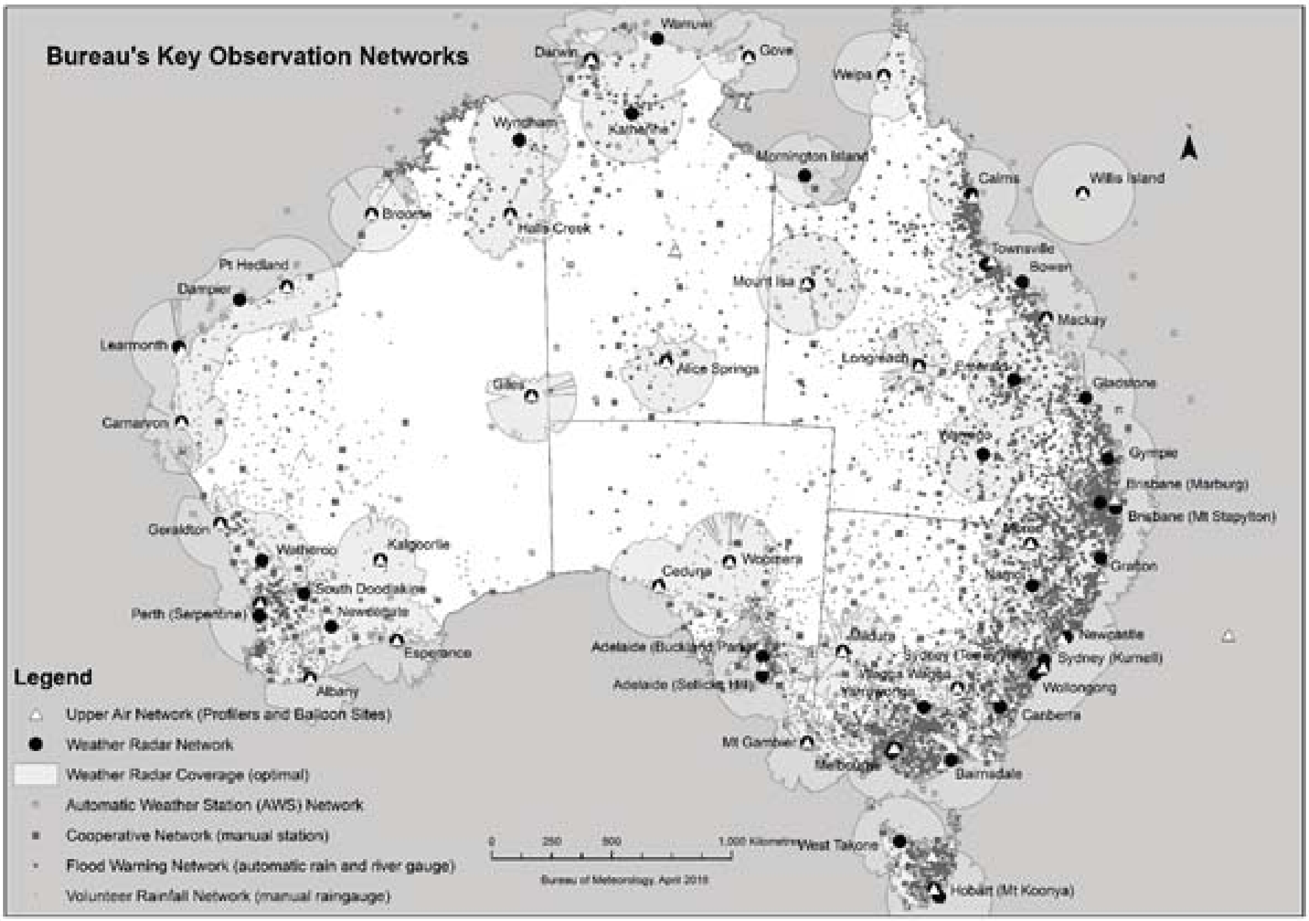

Figure 1. A snapshot of the Bureau's key observation networks

Beyond the official Bureau network of weather stations there are many private weather stations and networks collecting data. These are primarily installed to assess conditions at the paddock scale or where complex topography also comes into play – for example, a paddock on one side of a mountain will have very different weather to that recorded on the other side. Techniques are now being designed to add these third-party networks to the Bureau suite to both improve the national modelled observations and to take existing weather forecasts and records and calibrate them to the paddock of interest where sufficient weather records are available.

Gridded products of historical weather have been developed to help us study climate changes throughout Australia. To obtain a grid of historical weather information, point observations are used and then varying techniques such as interpolations or dynamic models can be used to 'fill in the gaps'. Scientific Information for Land Owners (SILO – service available from https://legacy.longpaddock.qld.gov.au/silo/) and the Australian Water Availability Project (AWAP – service available from http://www.bom.gov.au/climate/maps/) are examples of these products available for Australia (see "Other technical service considerations" below for more details).

Forecasts – pushing observations into the future

Any forecast product is generated by considering the relationships between known observations over time, and uses physics to project those relationships into the future. These projections are generated by complex computer models run on supercomputers around the world.

When using forecast information, it is important to understand the two types of forecasts and the expected skill (reliability) of that forecast. As the time scale of a forecast increases, so does the uncertainty, which necessitates differences in the styles of forecast services (Barry *et al*., 2017). Weather forecast models are more often deterministic (single value) than probabilistic (range of possible outcomes), as compared to climate models that are more probabilistic than deterministic. As such the information obtained from each is often used in different ways. For example, a heat load index service for the next week is likely to contain a single value for each day, whereas a heat load index service for the next season is likely to contain tens or hundreds of possible values for each day which indicate the spread of likely outcomes.

The skill of any forecast is measured by the past accuracy of that forecast service. As a generalised rule of thumb, a deterministic forecast could currently be expected to be reliable out to no further than seven days. Probabilistic forecasts are more complex, but generally gain skill as they are averaged over longer periods of time. Hence, skill will vary depending on the variable, location, time of year, spatial/temporal averaging, and the lead time of the service. This is an important consideration when generating any type of probabilistic forecast product.

Weather forecasts

In Australia, operational weather forecasting is provided by the Bureau which also enables third parties to develop and maintain forecast services. They run a range of models under the name Australian Community Climate and Earth-System Simulator (ACCESS – http://www.bom.gov.au/nwp/doc/access/NWPData.shtml). To create its official forecasts, the Bureau combines each of these models with the major international deterministic forecasting models, weighted according to recent and historical performance, to create a consensus forecast twice per day. Forecasting staff in each state office then use local knowledge and experience to fine tune the final product. This final forecast grid is known as the Australian Digital Forecast Database (ADFD, service available from http://www.bom.gov.au/australia/meteye/) and is used to generate the official forecasts seen all throughout Australia. This consensus approach is internationally recognised as best practice (Engel and Ebert, 2012).

Climate forecasts

For many operational decisions, including stocking rates and pasture management, forecasts are needed for the next six months. One way to do this is to generate **statistical outlook models** using past climate records. Analogue years are chosen from the past according to larger climate states such as El Nino Southern Oscillation (ENSO).

In recent years **dynamical seasonal climate models** are becoming skilful enough to be used in agricultural decision making (Rodriguez *et al*., 2018, Brown *et al*., 2018). These models are similar to weather forecasting models which take current observations from around the globe and use physics to predict how they will change into the future. However, climate models are run at a lower spatial resolution and provide predictions for up to nine months ahead. Unlike weather forecasts, however, they provide a probabilistic picture of the future that must be interpreted accordingly.

We are now at a cross roads in the statistical vs dynamical model approaches for climate forecasting in agriculture. Both methods have their advantages and are increasingly being combined to provide indications of the unfolding seasonal climate. ACCESS-S is the latest climate model out of the Bureau, developed in partnership with the UK Meteorological Office. ACCESS-S will operate at a higher resolution (60 km) than its predecessor POAMA-2 (250 km) and will incorporate the latest developments from local and overseas sources. General climate information will be soon available from this model on the Bureau's website (http://www.bom.gov.au/climate/outlooks). Detailed daily output from this model will be available in hindcast mode (historical forecasts) or as an operational real-time forecast (updated daily), suitable for generating tailored agricultural forecast services such as pasture growth scenarios or the likelihood of heat stress.

Climate change projections

Even longer forecasts that reach out to multi-year, decadal or climate change scales use similar dynamical models, with changes to the way they are tuned. Recently, CSIRO has invested significantly in developing climate forecasts on the multi-year to decadal time scale with the development of the CAFÉ model. This model uses novel techniques for initialisation to push the boundaries of predictability into the decadal time scale (https://research.csiro.au/dfp/about/).

Climate change forecast information – looking at the next 30 to 100 years – includes extra elements of uncertainty. We don't know which emissions scenario we will track over the coming decades and models must therefore provide answers to a range of possible outcomes. Extra complexity is added as ongoing research can sometimes be contradictory on how the major climate features such as El Niño might change (if at all) under these future scenarios (Brown *et al*, 2015, Chen *et al*., 2017, Collins *et al*., 2010). Nevertheless, there is certainty around factors such as increases in global temperature and sea level rise that are valuable for agricultural policy decision makers across a range of industries.

Runs of climate change models are accessible through international data portals or via Australian databases. The raw output is stored on the National Computing Infrastructure (http://nci.org.au/). A more user-friendly approach to viewing future climate scenarios for Australia can be found on the Climate Change in Australia website (https://www.climatechangeinaustralia.gov.au/en/) or the Consistent Climate Scenarios portal (https://data.qld.gov.au/dataset/consistent-climate-scenarios).

Other technical service considerations

Resolution

While the underpinning physics of weather and climate forecast models is the same at each time scale, the structure of the spatial grids and time steps alters. We can expect as computing power increases into the future, that the grid size and time step will decrease, bringing greater resolution to forecasts.

At the weather time scale, forecast grids are often of the order of 12–25 km with 70 vertical levels into the atmosphere and a time step of 6 hours. These models generate forecasts out to 10 days. Climate models need to be run for longer periods and so must make sacrifices in resolution and time step to account for the larger computational cost. These generally extend out to 6 months at daily 60–100 km resolution. Climate change models run for the next 100 years and have spatial resolutions of around 100 km.

Depending on the area of interest, it may be suitable to select a coarser spatial resolution to reduce computational costs or gain longer forecast lead times. For example, low lying regions with minimal topography may not gain much from higher resolution temperature grids as it is unlikely to vary much. However, regions of highly variable terrain will experience large fluctuations in temperature between the top and bottom of valleys. Hence, it is important to consider the target area when considering which service to use, particularly in the case of inter-paddock heat variability.

Interpolation method

Weather and Heat stress can vary across individual paddocks. Knowledge of typical heat stress pattern throughout the farm allows for adaptive measures to be put in place ahead of heat events. In general, services look to provide temporally and spatially continuous information for any point in Australia over a grid but not at the paddock level. Paddock scale information necessitates estimating values where data is not available through time (e.g. due to a period of faulty equipment), or through space (e.g. temperature measured at the farmhouse, but an estimate is needed for the back paddock). This requirement is more frequently met through the creation of gridded datasets.

These grids are generated using a variety of methods under two broad umbrellas: statistical interpolation; or dynamical modelling. It is important to understand the differences in methods used to ensure the dataset is fit for purpose. Statistical interpolation employs methods such as splines, which are useful to those who want to maintain the values of known points, or kriging, which won't necessarily maintain known values, but can better estimate directional momentum (Prim, A 2018). Statistically interpolated grid services are computationally cheap and as such are common. Dynamically modelled services on the other hand are computationally expensive as they relate multiple variables through space and time to produce a physically consistent estimate of conditions at a point. This generally makes dynamically generated services better suited to applications such as heat load or pasture growth which require multiple variables, as those variables will be consistent.

Available data services

This section provides lists of currently available data services for climate, weather and water, with a focus on gridded datasets which best meet agricultural requirements. Most services will contain a wide range of variables suited to livestock applications, such as: rainfall; temperature; humidity; wind; soil moisture; solar radiation; etc. Links to further information are provided, though it is recommended that anyone using such services first contact Agriculture@bom.gov.au and/or the provider to discuss the application of the data and ensure it is fit for purpose. Note that many services are cost-recovered.

Climate services

Table 1. Key climate data services. Adapted from Barry et al. (2017).

TYPE	MODEL OR DATA	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	INTERPOLATION METHOD	LINKS (FURTHER INFORMATION, SERVICES AND/OR DATA SOURCES)
Historical observations	**AWAP (Bureau)**	5 km	Daily, monthly	Kriging	http://www.bom.gov.au/climate/maps/ http://www.bom.gov.au/climate/data-services/maps.shtml
	BARRA (Bureau, available 2018)	12 km or 1.5 km for selected regions	Daily, hourly, 10-minute	Dynamical model	http://www.bom.gov.au/research/projects/reanalysis/
	SILO (DSITI)	5 km grid or stations	Daily	Spline	https://legacy.longpaddock.qld.gov.au/silo/
	Climate Data Online (Bureau)	Stations	Daily, monthly	n/a	http://www.bom.gov.au/climate/data/
Sub-seasonal to seasonal forecasts (next month to 12 months)	**POAMA (Bureau, to be decommissioned in 2018)**	250 km	Daily	Dynamical model	http://www.bom.gov.au/climate/outlooks/#/overview/summary/ http://www.bom.gov.au/climate/data-services/maps.shtml
	ACCESS-S (Bureau, available 2018) ***ACCESS-S downscaled and calibrated version***	60 km *5 km*	Daily	Dynamical model	http://www.bom.gov.au/climate/outlooks/#/overview/summary/
Multi-year to decadal forecasts (next year to next 10 years)	**CAFÉ (CSIRO)**	250 km	Daily	Dynamical model	https://research.csiro.au/dfp/
Climate change forecasts (out to next century)	**CMIP5**	Typically ~100 km		Dynamical model	https://cmip.llnl.gov/cmip5/ https://www.climatechangeinaustralia.gov.au/en/ https://data.qld.gov.au/dataset/consistent-climate-scenarios

Weather services

Table 2. Key weather data services. Adapted from Barry et al. (2017).

TYPE	MODEL OR DATA	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	INTERPOLATION METHOD	LINKS
Recent observations – within 24 hours	**Automatic weather stations (Bureau)**	Stations	Daily, hourly, minute	n/a	http://reg.bom.gov.au/reguser/reguser.shtml
	Radar (Bureau)	Range: 64km, 128km, 256km, and 512km	Six or ten minutes	n/a	http://www.bom.gov.au/australia/radar/ http://reg.bom.gov.au/reguser/reguser.shtml
Weather forecasts – next 7 days	**ACCESS-C (Bureau, capital cities and surrounds)**	4 km	Hourly	Dynamical model	http://reg.bom.gov.au/reguser/reguser.shtml
	ACCESS-TC (Bureau, relocatable tropical cyclone regions)	12 km	Hourly	Dynamical model	http://reg.bom.gov.au/reguser/reguser.shtml
	ACCESS-R (Bureau, Australian region and surrounds)	12 km	Hourly and 3-hourly	Dynamical model	http://www.bom.gov.au/australia/charts/viewer/index.shtml http://reg.bom.gov.au/reguser/reguser.shtml
	ACCESS-G (Bureau, global)	25 km	3-hourly and 6-hourly	Dynamical model	
	ADFD (Bureau, multi-model forecaster edited consensus product)	6 km (3 km for Vic/TAS)	Hourly, 3-hourly and daily	Dynamical model	http://www.bom.gov.au/australia/meteye/ http://reg.bom.gov.au/reguser/reguser.shtml

Water services

Table 3. Key water data services. Adapted from Barry et al. (2017).

TYPE	MODEL OR DATA	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	INTERPOLATION METHOD	LINKS
Observations	**AWRA-L (Bureau)**	5 km	Daily	Water balance model driven by AWAP rainfall	http://www.bom.gov.au/water/landscape
	Water Data Online (Bureau)	Stations	Site dependent	n/a	http://www.bom.gov.au/waterdata/
Seasonal forecasts (next month to 6 months)	**AWRA-L (Bureau, trial available 2018)**	5 km	Daily	Water balance model driven by ACCESS-S rainfall	awrams@bom.gov.au

Choosing a service that is fit for purpose

As discussed in this chapter, there are a wide range of climate, weather and water data services available to the livestock industry. The challenge to researchers and developers lies in selecting the service that is best suited to the requirements of the target industry or desired service. This chapter has provided an overview of how such services are generated, the key considerations for selecting a dataset, and a range of further information resources. However, it should be noted that this is not an exhaustive list, nor does it highlight all potential pitfalls.

The Bureau has recently implemented an Agriculture Program in alignment with its new strategy. The role of this team is to deliver value to the agriculture sector by acting as facilitators of weather, climate and water information. We welcome the chance to assist you if needed with accessing any of the listed data services. We also offer help in understanding and interpreting weather and climate information. This is undertaken in a truly agnostic manner, with the mandate to simply create impact and value. As such, the Agriculture Program is a source of unbiased advice for each point of the agriculture sector value chain (researchers, farmers, processors, transporters, marketers, service providers, etc.)

The Bureau Agriculture Program works in close collaboration with CSIRO, and particularly the Weather and Climate Decisions Team. This team is passionate about finding ways to translate weather and climate decisions into actionable knowledge. They connect deep domain knowledge in Agriculture with the challenges of weather and climate. More information is available from Jaclyn.Brown@csiro.au.

The Bureau asks to hear more about your opportunity(ies) to create value. Contact Agriculture@bom.gov.au.

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