214

Continental-scale modelling of pasture growth with the AussieGRASS model: Learnings from 30 years of operation

Carter, JO[1]; Bruget, D[1]; Stone, G[1]

[1] Queensland Department of the Environment, Tourism, Science and Innovation

Key words: Modelling, Pasture, AussieGRASS

Abstract

The AussieGRASS model has been run operationally for Australia since 1995, with modelling outputs of current conditions and forecasts provided each month to the Long Paddock website – and is considered an 'environmental calculator' rather than just a model of pasture growth. AussieGRASS was initially built to help quantify current conditions 'relative to history' to assist with drought and seasonal conditions assessment but has since been used for many additional purposes. There have been many challenges to building and maintaining 'the operational system' – some of these challenges are summarised in this paper with regard to: input data sets (historical and current climate, climate forecasts, tree density mapping, grazing pressure, land use etc); calibration and validation (integrating field and satellite observational data sets); computation (high performance computing and storage); extension (Long Paddock web site); and human capital (staff, collaborators, and management).

Introduction

The AussieGRASS system was developed using funding provided from the Land & Water Australia (LWA) Climate Variability Program in collaboration with other states (i.e. WA, NSW, SA and NT) to extend its application from Queensland to all of Australia. The driving forces and enabling mechanisms for its establishment were: the existence of the well-calibrated GRASP pasture growth model (Rickert et al. 2000), along with (SOI-based) climate forecast systems, and land degradation of Dalrymple shire which highlighted the need to track grazing pressure and pasture growth in 'near real time' (McKeon et al. 2004), and a review of drought and drought declaration policy in Queensland (Daly 1994). Modelled pasture growth typically provides a better indication of drought than rainfall alone, as runoff, soil evaporation and other climate elements (such as atmospheric moisture content) are accounted for in the simulations.

Initially, AussieGRASS was internally funded and run for Queensland only. Funding from competitive grants followed. The first of these grants allowed field validation activities for Queensland. Once operational, various States subscribed to the AussieGRASS system along with subscriptions to the SILO climate data system. This income sustained early development, however, downsizing of state agricultural departments and Queensland and interstate departmental reorganisations made it difficult to maintain subscriptions. In addition, a global move to offer 'open data' online, ultimately ended the subscription model. For most of the 30-year period the small AussieGRASS team has undertaken a range of short duration projects, including provision of data for three federal drought schemes, climate change impacts, net primary production comparison studies, estimates of biofuel potential of pastures, livestock methane production and rangeland monitoring (Bastin 2008). Maintaining the continuity of an operational AussieGRASS system given these challenges is discussed.

Systems development has been ongoing over three decades, with many ongoing improvements in software, data, algorithms, delivery platform and information technology. This paper describes some aspects of the 30-year AussieGRASS journey; whether programming innovations and data have stood the test of time – or in what direction, with the benefit of hindsight, the modelling might best have been progressed.

Model characteristics

The AussieGRASS model runs at a daily timestep, given most field measurements occur at this time scale (e.g. pasture biomass estimates) which allows modelled and field data to be matched in time and space. Remote sensing inputs are similar, in that most imagery can be matched with a model output on the same day. A monthly time step is considered too long, as some processes (e.g. runoff) occur at much shorter time scales and pasture growth in tropical regions can be rapid. Also, measured climate data at a sub-daily timestep are largely unavailable.

Historically a 0.05-degree grid (i.e. 5 x 5 km; 25 km^2) was considered optimal given computer capacity and spatial resolution of input data. It was important to define standards for coastline masks and rules for inclusion/exclusion of coastal pixels and to ensure precise alignment of independent input layers (climate, soils, tree density, fire, flood, grazing animal density). While input layers are used at 25 km^2, most were constructed at a finer 1 km^2 resolution to facilitate future higher resolution modelling. While the model is run daily at 25 km^2 resolution we recommend that users apply outputs such as pasture growth and other variables at about 10 to 30 times the spatial and temporal run resolution.

Development of climate data and other inputs

Climate data is perhaps the greatest challenge for modelling pasture growth, as plant growth models require a minimum set of daily input data. Ideally it is useful to be able to run the model back in time so comparisons with historical climate events (e.g. Australian 1901-1903 drought period and 1890s floods) can be made. Note, these historical events are still the most severe events experienced in some parts of Australia. It is also useful to examine the historical impacts of total grazing pressure on land degradation processes (e.g. McKeon et al. 2004). Quantitative drought evaluation to inform government policy necessitates a near real time supply of climate data for AussieGRASS model outputs. AussieGRASS evolved from ‘hand punching’ data to videotext and eventually internet File Transfer Protocol (FTP). Climate data interpolation algorithms and data quality control were implemented into the SILO system (Jeffrey et al. 2001). Gridded data sets were built and made available to the science community long before such data sets were available from the Bureau of Meteorology (BoM). The advantage of this ‘in-house’ climate data system is that it can be closely coupled to AussieGRASS in a shared computing environment where additional quality assurance analyses can occur. There is also the potential to add additional climate data to the system (especially rainfall). In recent times we have supplemented BoM rainfall data with rainfall observations from the Queensland flood warning network, as well as from our own network of about 30 grazing properties.

In addition to being able to run in ‘near real time’, the system needs to be able to re-run when additional rainfall data arrives in the system (especially from volunteers providing hard copy records). In Australia, data from only about 50% of rainfall stations are available in the first days of the new month, so the modelling system needs to be re-run and updated, typically four times a month. It is also useful to have climate forecast data at climate change and seasonal forecast time scales, as these forecasts combined with 'initial conditions' (typically soil moisture, nitrogen status and ground cover), can be used to estimate future pasture conditions.

Until recently, seasonal forecasts were generated from statistical systems that produced a set of 'analogue' years based on climate indicators such as the SOI. Analogue year systems are relatively easy to implement given access to a climate data archive. In the last decade or so gridded climate data from weather models has started to become available – and while these new data sources appear to be beneficial, they entail significant overheads as data needs to be bias-corrected and downscaled, automatically downloaded, resized to the user's grid dimensions and formatted.

Climate data quality and availability has declined since ~ 1970's due to a reduction in measurement sites. For example, both pan evaporation and cloud cover (a solar radiation proxy) have caused issues due to a lack of detection and slow switch over to satellite radiation estimates. Other important variables such as estimated total grazing pressure also present challenges as the Australian Bureau of Statistics (ABS) no longer collects annual agricultural statistics. Remote sensing is used for tree density inputs as well as fire scar data for biomass resets and the Landsat archive provides green and dry cover time series to assist model calibration.

Data formats and processing

An early decision in development of the AussieGRASS framework, derived from the group's experience in remote sensing, was to process data as raster grid cells rather than polygons. Initially we used formats from an older remote sensing package DSIMP but when this platform became obsolete, we developed our own data format designed to minimise storage and file upload time. A range of raster manipulation tools was developed inhouse for post processing (e.g. calculation of percentiles). While initially essential, this system has become limiting as NetCDF is becoming a global standard for climate and some ecological data. The SILO climate data is now produced in NetCDF format and the AussieGRASS model can input and output directly in NetCDF format, avoiding file conversion when using climate forecasts – in hindsight, a direction that could have been pursued much earlier.

The AussieGRASS model is highly optimised for a High-Performance Computing (HPC) environment and runs each pixel every day, reading and writing daily grids for the model extent rather than running each pixel for the duration of the simulation then moving to the next pixel which requires disassembly and reassembly of gridded input (especially climate data) and assembly of many small files to generate output maps. In the HPC environment efficient use of resources such as caching of input data in RAM disk rather than reading from spinning disk can reduce run times by more than 5%. There are very significant speed gains to be made in code optimisation. In particular, the layout of data in memory is critical in multi-threaded systems and memory access needs to be kept local to each thread. In addition, data arrays in memory need to be structured such that the next needed variables are close, so that caching is effective. We found that memory reorganisation could improve processing times by a factor of 8 or more.

Automation and diagnostics

Automation is essential especially when the system is run by a small team. The AussieGRASS operational system has been almost fully automated since inception. Model runs and post processing are instigated automatically. To deliver in 'policy' time often requires running on weekends and public holidays as well as having a system that copes with staff being on leave (with ability to remotely access the system). Despite automation, we believe it is important to have a minimum of 2-3 dedicated staff available to cope with any problems that emerge, monitor progress and fix issues. AussieGRASS has produced monthly outputs within a few days of the end of each month for about 30 years (with the longest outage being about 10 days due to a climate data system rebuild). Operations are designed to be largely fail-safe. For example, if the input data does not arrive there is a fall back to long-term average climate or secondary data sources.

The system produces many log files and emails signifying the success or otherwise of completed tasks. These often help to diagnose any potential problems. Furthermore, additional ancillary model outputs are generated such as plant nitrogen status for rapid diagnostic examination. Along with the biophysical model code, there is a large amount of coding that supports model calibration and validation. This calibration and validation coding and data preparation programming represents the bulk of the total coding effort in the modelling system (Table 1).

Modelling Outputs

Success in modelling relies on providing useful and accessible information. The Long Paddock website (Stone et al. 2019) has been the key delivery website and has evolved over time. We believe that it is a significant advantage to have a recognisable brand and web presence that is enduring, rather than being lost amongst ever changing general government web platforms. In addition, autonomous website control allows rapid updating and fixing of issues that would otherwise be someone else's low priority. Ability to rapidly produce test web pages within an operational environment and fully automated product uploads/reloads are essential. In the early stages of the AussieGRASS development we used a specialist extension officer to extend the AussieGRASS and the Long Paddock website across Queensland and Australia. In recent years there has been no major nation-wide extension effort, and we largely rely on users outside Queensland, finding their own way to the website. A key part of the websites success has been due to the team's efforts in marketing the Long Paddock product suite at field days and workshops.

The product package from AussieGRASS includes a range of grazing and fire related products typically made available as relatively simple to understand maps and tables. Products are made available in different formats such as PDF files, GeoTIFF, and text files and are named systematically such that automated retrievals of data from the web site are possible. Information is generated as actual amounts and percentiles (of various duration) to display current conditions relative to history. While many drought products use complicated indices, we have chosen percentiles as most likely to be understood by our general audience and we support the maps with a video explaining percentiles tailored to landholders. Perhaps the most challenging issue in regards percentiles is the most appropriate baseline period to use.

Results

As a regional to national scale product AussieGRASS remains useful after 30 years and currently contributes to the national AADI program (Hughes *et al*. 2025), revised Queensland drought analysis, daily calculation of fuel loads for fires and information for plague locust modelling. A 1 km resolution version of AussieGRASS that improves accuracy of tree-grass competition is in pre-production testing, as are climate change runs to 2100 with 3 scenarios and 15 models. Its companion product FORAGE, which is designed for paddock to property-scale application, uses the same data, pasture model, computing infrastructure and website with shared 'team effort', to generate about 50,000 property scale reports per year. The SILO climate data system continues to produce ready to use climate data for a large user community.

Discussion

There are many reasons for the success and endurance of the AussieGRASS product, however, the most important to us seem to be: (a) tight integration of the modelling system with climate and other data inputs and a web-based front end, all largely under a single supportive management structure; (b) strong focus on usable products that serve a variety of users; (c) systems designed for both broadscale and property applications; (d) concentration on gathering and using a broad range of calibration and validation data sets and (e) adequate base funding to maintain computing and data infrastructure and a small number of long serving staff who apply the skills of systems analysis to provide an operational and enduring service. Challenges remain, however, as continuing deterioration of climate monitoring and agricultural statistics, broad-scale species change (e.g. Buffel grass invasion) and lack of fire and woody density clearing maps pre-1980s all present formidable challenges.

Table 1. Characteristics of the AussieGRASS system.

Subject	**Comment**
Time Step	Daily to match satellite and ground measurements, aim to approach reality at monthly time scales, capture runoff and erosion events. Also, matches available climate data.
Calibration spin-up	Approximately 30 years to equilibrate pasture biomass especially for slow growing arid zone species (e.g. *Triodi*a spp).
Spin-up operational	Model is run forward from 1890; state variables are saved, then last 2-3 years are updated with each model run to ingest updated rainfall and climate data. Then forecasts are run with best estimates of initial conditions.
Calibration	PEST optimisation package and manual calibration (which may include many variables).
Output timing	Run at day 1-3 each month; update runs about every 10 days to capture updating rainfall data, daily for fuel loads.
Output variables	Most model variables can be output if desired, input variables for checking, absolute values, counts > threshold.
Output method	Data grids for daily, monthly, annual, selected date, to match observations, ascii files to match single point observation, various diagnostic tables for running in single pixel mode.
Data formats	Internal Drought Research Raster (in-house, binary run length encoded), NetCDF. Outputs GeoTIFF, PDF, ASCII tables. (maps with colour blind and other accessibility features)
Post processing	Percentiles of various durations; monthly to 30 years, maps, time series plots, probabilities, anomalies.
Automation	Linux ‘cron’ automation utility starts (various model runs, fuel loads, 1 km experimental, several seasonal forecasts, post processing to percentiles, map generation, archiving, placement on Long Paddock).
Time duration	1880-1890 spin-up, 1890-today, 3 months ahead, standard 18 months ahead for both weather model climate and statistical forecasts. 1975-2015 climate change baseline, current to 2100 for climate change.
Spatial resolution	Projection geographic, 5 km version (pixel size 0.05 degrees; grid extent -10^0S, -44^0S; 112^0W, 154^0W) and 1 km version (pixel size 0.01 degrees; similar grid extent).
CO_2 effects	Can be fixed concentration, historical timeseries, or represent CO_2 associated with climate change forecasts (i.e. Shared Socioeconomic Pathways).
Climate inputs	Daily rainfall, Tmax, Tmin, vapour pressure, solar radiation, potential evaporation (wind optional).
Additional inputs	Fire scars (1-3 days), total grazing pressure (annual, 6 animal types), floods from Landsat water masks, ocean mask.
Satellite calibration/validation	(Initially NOAA AVHRR NDVI) Landsat main source of calibration data (all scenes in Australia for fractional green and total cover), ancillary; GRACE soil moisture, OCO_2 chlorophyll fluorescence, CO_2, Scimachy CH_4, AMSR surface soil moisture, Sentinel 1 G0 backscatter for soil moisture., ERS2 radar altimeter backscatter.
Site based calibration /validation	TSDM > 600,000 observations, pasture N concentration, soil nitrate, soil moisture, pasture utilization, grass basal area, live weight gain, erosion, runoff, tree litter fall and mass, grass litter, grass root mass, ground cover, pasture growth.
Inputs static	Soils type and soil parameters, pasture community map, tree density map.
Coding	Main model code Fortran 90 (~ 31K lines), post processing shell scripts and plotting (R), python, (~17K lines). Data preparation e.g. total grazing pressure (shell, python, Fortran 90 (> 85K lines), calibration/ validation, etc (> 172K lines)

Acknowledgements

We acknowledge the many staff who have contributed to the AussieGRASS project over many years.

References

Bastin G and the ACRIS Management Committee (2008). ‘Rangelands 2008‘Taking the Pulse’, published on behalf of the ACRIS Management Committee by the National Land & Water Resources Audit, Canberra.

Carter JO, Hall WB, Brook KD, McKeon GM, Day KA, Paull CJ (2000). Aussie Grass: Australian Grassland and Rangeland Assessment by Spatial Simulation. In '*Applications of seasonal climate forecasting in agricultural and natural ecosystems*'. (Eds GL Hammer, N. Nicholls, C. Mitchell) pp 329-347. (Springer: Dordrecht).

Daly JJ (1994) 'Wet as a shag, dry as a bone: drought in a variable climate' (Queensland Department of Primary Industries information series, QI93028).

Hughes N, Gaydon D, Gupta M, Schepen A, Tan, P, Brent G, Bellew S, Turner A, Sharman C, Taylor P, Carter J, Bruget D, Hochman Z, Searle, R, Song Y, Horan H, Mitchel P, Beletse Y, Holzworth D, Guillory L, Brodie C, McComb J, Singh R, (2025). Monitoring agricultural and economic drought: the Australian Agricultural Drought Indicators (AADI) *Natural Hazards and Earth System Sciences* (submitted).

Jeffrey SJ, Carter JO, Moodie KB, Beswick AR (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modelling and Software.* 16/4. 309-330

McKeon G, Hall W, Henry B, Stone G & Watson I (eds) (2004). 'Pasture Degradation and Recovery in Australia's Rangelands: Learning from History' (Department of Natural Resources Mines & Industry, Queensland Government).

Rickert KG, Stuth JW, McKeon GM (2000). Modelling pasture and animal production In. 'Field and Laboratory Methods for Grassland and Animal Production Research'. (Eds LT Mannetje, RM Jones), pp. 29-66 (CABI publishing: New York).

Stone G, Dalla Pozza R, Carter J, McKeon G (2019). Long Paddock: climate risk and grazing information for Australian rangelands and grazing communities. The Rangeland Journal 41, 225–232.