An Automated Operational System for Collating Field and Satellite Data for Grassland Curing Assessment

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ABSTRACT

Depending on the growth stage of grass, certain physiological characteristics, such as water content and degree of curing (senescence), determine the susceptibility of grass to ignite or to propagate a fire. Grassland curing is an integral component of the Grassland Fire Danger Index (GFDI), which is used to determine the Fire Danger Ratings (FDRs). In providing input for the GFDI for the whole state of Victoria, this paper reports the development of two amalgamated products by the Country Fire Authority (CFA): (i) an automated web-based system which integrates weekly field observations with real time satellite data for operational grassland curing mapping, and (ii) a satellite model based on historical satellite data and historical field observations. Both products combined will provide an improved state-wide map of curing tailored for Victorian grasslands.

KEYWORDS

Grassland curing, MODIS, Victoria.

INTRODUCTION

The chance of grass igniting and propagating a fire is dependent on the Fuel Moisture Content (FMC) (Cheney and Sullivan, 2008), which varies with curing (Anderson *et al.*, 2011; Anderson *et al.*, 2005; Barber, 1990; Dilley *et al.*, 2004; Paltridge and Barber, 1988; Tucker, 1977). Grassland curing is defined as the drying out of grasses and is measured as the percentage of dead grass in a grassland fuel complex (Cheney and Sullivan 2008). It is used to predict fire danger and to assist in fire management. In Victoria the Country Fire Authority (CFA) produces a weekly state-wide map of curing based on visual curing estimates from the field.

The 2009 Victorian Bushfire Royal Commission Interim Report recommended the Australasian Fire and Emergency Service Authorities Council and the Bureau of Meteorology (the Bureau) to collaborate with researchers to explore options for improving and revising fire danger indices and fire danger ratings (FDRs) (Teague *et al*., 2010). As part of this initiative, CFA established the Grassland Curing and Fire Danger Rating (GCFDR) project to obtain more accurate grassland curing information for increased accuracy of FDRs in grasslands. To improve the quality and production of weekly grassland curing maps, the main objective of the GCFDR project was to develop an automated system which integrates visually assessed field observations of curing with satellite data.

METHODOLOGIES – A HISTORICAL TIMELINE

AVHRR Satellite Imagery

Since the 1980s, the Bureau produced satellite-based maps of curing in south-eastern Australia using US National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data using two successive algorithms described in Newnham *et al.* (2010). These curing maps were initially based on an algorithm developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and CFA that used a relationship between a modified Normalised Difference Vegetation Index (NDVI) (Rouse *et al.*, 1973) and FMC (Paltridge and Barber, 1988), and a relationship between FMC and curing (Barber, 1990). The algorithm used by the Bureau was subsequently revised by CSIRO to one that directly related the degree of curing to NDVI (Dilley *et al.*, 2004). During the 1987/1988 fire season, CFA commenced the use of AVHRR to estimate curing (Garvey, 1988). The predominant limitation of this technique was consecutive weeks of complete cloud cover (Paltridge and Mitchell, 1990) resulting in no data. This was of great concern as the drying of grass can occur quite rapidly (Paltridge and Mitchell, 1990), and any rapid changes of curing may not be captured entirely by AVHRR if complete cloud cover occurs. Consequently CFA refrained from further use of AVHRR for operational support, and has since relied solely on visually assessed field observations for mapping grassland curing.

MODIS Satellite Imagery

In the late 2000s, further research was completed by the Bushfire Cooperative Research Centre (Bushfire CRC), which resulted in the development of four Australian nation-wide satellite models based on 8-day Earth Observation System

(EOS) MODerate resolution Imaging Spectroradiometer (MODIS) satellite data and field observations using a modified Levy rod method (Levy and Madden, 1933). The Levy rod method entails counting live and dead grasses that come in contact with a thin steel rod placed vertically into the ground at several points along a transect. At the completion of the Bushfire CRC research, four (best-performing) models were developed, simply named Maps A and B (Martin, 2009; Newnham *et al.*, 2010) and Maps C and D (Newnham *et al.*, 2010). These models were tested for curing assessment throughout Australia and New Zealand, and the only agency to adopt a model operationally was the NSW Rural Fire Service (RFS) with preference for Maps A and B (Newnham *et al*., 2010). The RFS accepted primarily Map B but also Map A as a curing input for the GFDI of NSW (pers. comm. Dr Simon Heemstra, Manager NSW Rural Fire Service). However, in Victoria, these models were not implemented operationally, as CFA maintained its need for weekly updates of curing. This was not possible with the chance of cloud interference, and with the processing time of MODIS data, which was in excess of a week. CFA therefore continued to rely on weekly field observations for mapping curing until an improved and a more frequently available satellite product was developed.

In situ Visual Observations

Parallel to the use of AVHRR maps from the 1980s and onwards, CFA has maintained a growing network of volunteers across Victoria who report on the state of curing during the fire season using visual observations. Compared to the Levy rod method and relative to destructive sampling, Anderson *et al.* (2005) found visual field observations to have a ±25% error, while Newnham *et al.* (2010) found this method to under-estimate curing by 11%. Additionally, while the accuracy of the visual method varies between observers, these observations are rounded to the nearest 10% (previously 5%). The visual observation method, however, has been utilised by CFA since the 1980s. The Levy rod method entails longer sampling time than visual observations, and it is not a practicable option for weekly operational use by volunteer observers. To improve the quality of the visually assessed field data, an online training package was rolled out in the 2012/2013 fire season to ensure consistent, repeatable observations. Therefore CFA relied on weekly visual observations for frequent and consistent sampling of curing throughout the fire season (which occurs from as early as October to as late as May). Weekly visual observations are collated at CFA Headquarters and are used to produce a state-wide map of curing. The curing map is delivered to the Bureau as input into the Grassland Fire Danger Index (GFDI) for Victoria. For weekly production of the curing map, the process involves a great amount of manual processing and human interaction. With the expansion of the volunteer network, the process has become time-consuming with possibility for human error. Therefore, in October 2012, a prototype automated grassland curing online system was developed, implemented and deployed operationally for the 2012/2013 fire season.

Combination of MODIS and in situ Visual Observations

Prior to the fire season of 2013/2014, the automated grassland curing system was improved and enhanced with many functions. For example, field observers are able to upload geo-referenced photos with their observations, which can be overlaid in Google Earth® for viewing by the broader public community. In addition to the weekly field observations, MODIS satellite data have been amalgamated into the system. Since October 2013, the Bureau has established a direct downlink of MODIS data, and using CFA's new satellite-curing model, MapVictoria, the Bureau has provided CFA with a rolling 8-day satellite curing product that is updated every day. This product comprises the best quality and most recent observation for every 500m pixel across the state (pers. comm. Dr Ian Grant, Satellite Specialist, Bureau of

Meteorology). The weekly field observations and the MapVictoria product are combined to provide an improved state-wide map of curing named “Victorian Improved Satellite Curing Algorithm” (VISCA). VISCA has first been used operationally for the 2013/2014 fire season, and will be used for future seasons thereafter. The entire workflow of producing VISCA has been automated and integrated into the online system.

PRELIMINARY RESULTS

To improve and automate the production of grassland curing maps for Victoria, this section of the paper describes the development of two amalgamated products: (i) an automated web-based system which integrates weekly field observations with real time satellite data, and (ii) a satellite model based on historical (MODIS) satellite data and historical field observations.

Development of an automated web-based system

Sub-systems

CFA is heavily reliant on the grassland curing observation network to provide field curing information across the state. The GCFDR project addressed an operational workflow from data collection, analysis, to a final output. The prototype system was developed to streamline the operational workflow and automate the entire process. It comprises the following sub-systems (Figure 1):

- Online Application System,
- GIS Server, and
- Database Server.

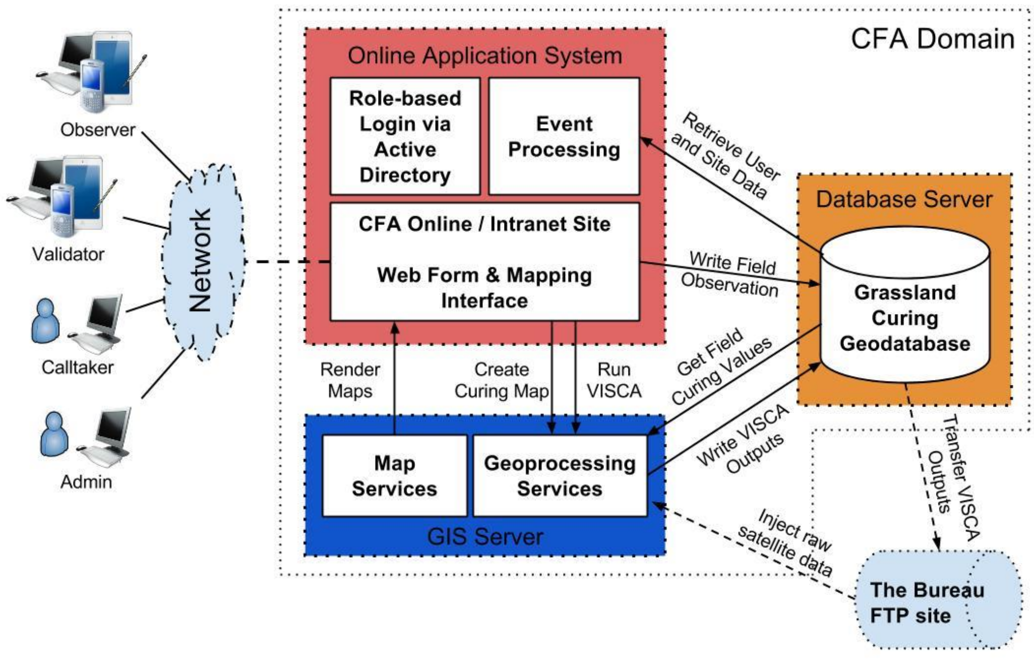

Figure 1 Overview of the design of the automated system

Online Application System

The Online Application System resides in the CFA Online website, and provides a role-based login for users to access the system via the CFA Active Directory (see Figure 1). Each role is given a different level of access to the functions of the system.

- Observers collecting field data can add and access their associated observation site(s) and report weekly observation data via the Online Application System.
- For each Victorian CFA District (see Figure 5 for district boundaries), a validator, who is usually a district-level operational manager, validates all curing values reported by observers.
- Fire and Incident Reporting System (FIRS) members are assigned the calltaker role, and assist in data entry reported from observers or validators who wish to report by phone.

- An administrator, based at CFA Headquarters, has full access to all system functions such as data validation, site and user access management, running the VISCA model and data delivery.

The Online Application System was developed to provide access from various web browsers on different platforms including desktop, tablet and smartphone. It comprises an Event Processing component (Figure 1), which mainly performs automatic email notifications for validation and data transactions such as weekly curing map distribution to the Bureau via File Transfer Protocol (FTP).

GIS Server

The Geographic Information System (GIS) Processing subsystem is powered by an ESRI ArcGIS Server 10.1, which serves a Web Mapping and Processing Service. It is accessible on the Online System for data entry. In addition, two Geo-processing web services are served from the ArcGIS Server for an administrator (via the Online System) to:

- “Run the Model” and write the VISCA output datasets to the database, and
- “Publish the Map” by generating the finalised VISCA map out of an established publishing layout template.

Database Server

The grassland curing enterprise geodatabase is established on a Relational Database Management System (Microsoft SQL Server 2008) to store all project data. It contains static datasets such as users’ login details and roles, site details, as well as dynamic information such as observations and output spatial datasets. Direct data connections were established between the database server, GIS Server and Online Application System.

Detailed Operational Workflow

The system was developed to streamline the overall workflow in operations every week during the fire season. The workflow is composed of a series of chronological processes (illustrated in Figure 2):

- Data Capture
- Data Collation
- Data Analysis and Modelling
- Data Output

These processes are described.

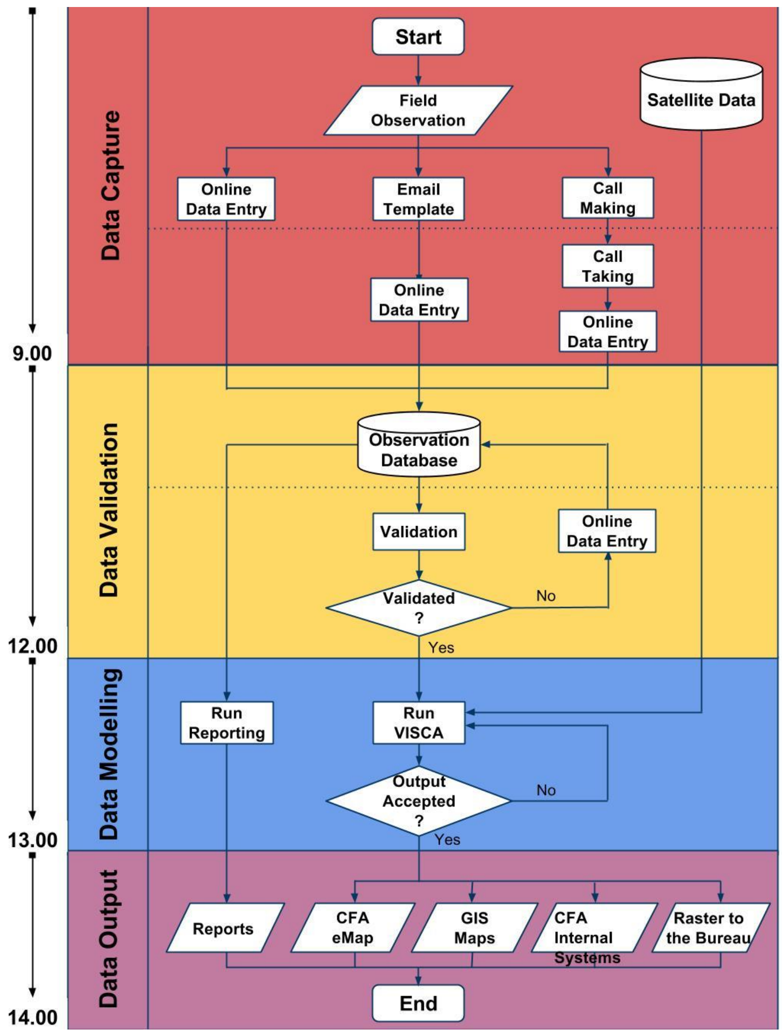

Figure 2 Grassland Curing Workflow

Data Capture

Every week throughout the fire season, field observers report observation details of their associated sites including grassland curing, height, cover, rate of drying, as well as weekly rainfall either directly through the online system data entry form (Figure 3) or via email or phone. All data are captured and stored in the grassland curing database.

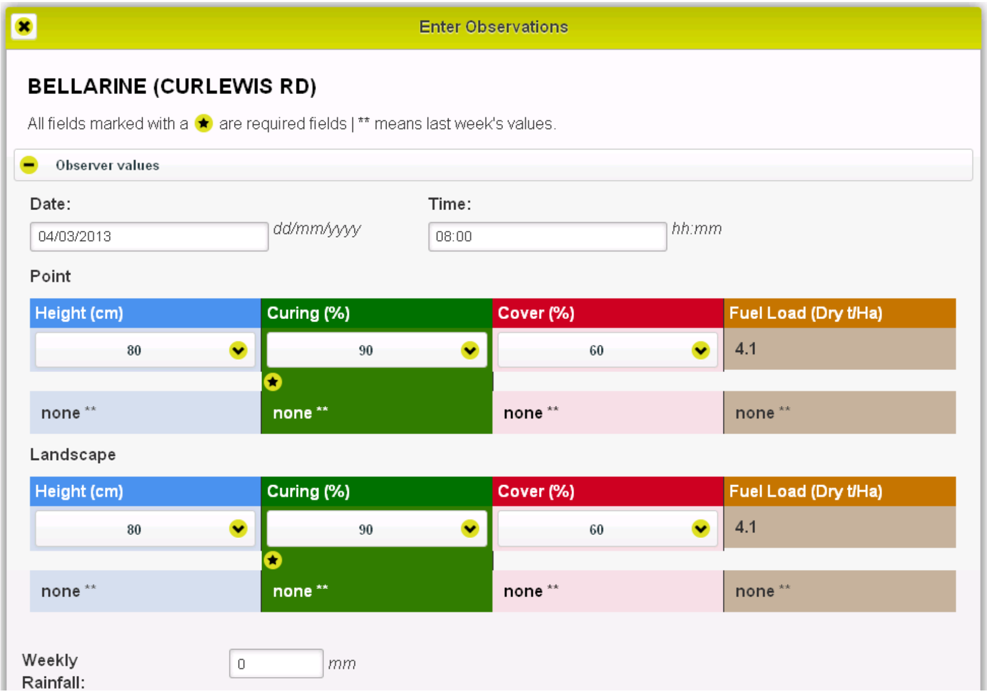

Figure 3 Example of a Data Entry Form (at the Bellarine field site, southern Victoria)

Data Collation

Once field curing values have been reported, the values are validated by CFA operational managers in each CFA district. Validation can be processed using the online system data validation form (Figure 4) or over the phone.

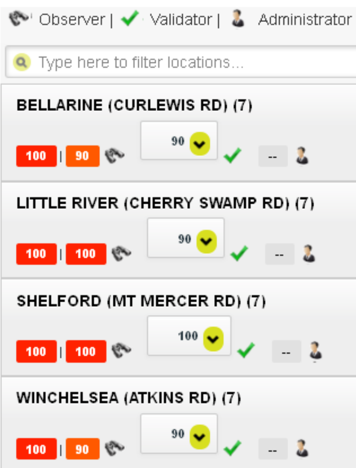

Figure 4 Example of a Data Validation Form (for District 7, southern Victoria)

When curing values from all districts have been validated, an administrator at CFA Headquarters can run the VISCA model by triggering a Geoprocessing service (Figure 1) via the Online Application System. At this stage of the processing, the model creates a GIS file locating all point curing values across the state (as shown in Figure 5). This file is stored in the Grassland Curing geodatabase and can be viewed on the Online Application System for the administrator to check for quality assurance.

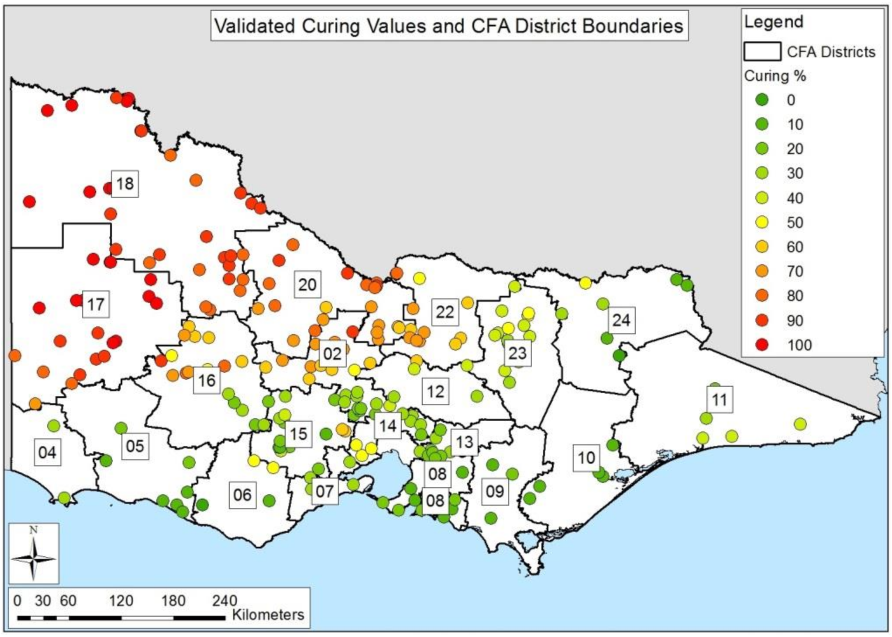

Figure 5 Map of Validated (Point) Curing Values for November 19th 2012 and CFA District Boundaries.

Development of a Satellite Model

Synchronising Satellite and Field Observations

With extensive coverage of state-wide point curing data (Figure 5), the integration of satellite data further improves the spatial resolution of the state-wide curing map. The MODIS Surface Reflectance Product, MOD09A1, has a 500m spatial resolution and comprises historical records dating back to the year 2000. The Bureau can now provide this product as rolling 8-day composites every day. MOD09A1 comprises seven bands, shown in Table 1. These spectral bands are sensitive to certain biophysical changes of vegetation such as cellular structure, changing levels of chlorophyll content, cellulose content and water content, all of which can be used to infer curing. In order to develop a MOD09A1-based model, MOD09A1 time-series, archived and processed by Paget and King (2008), were compared against field observations of curing from 2005 to 2013. Observations were taken from 211 field sites throughout Victoria as shown in Figure 5.

Table 1 First seven MODIS Spectral Bands (NASA, 2013)

Band	**Spectral region**	**Wavelength (nm)**
1	red	620 – 670
2	near infrared (NIR)	841 – 876
3	blue	459 – 479
4	green	545 – 565
5	near infrared (NIR)	1 230 – 1 250
6	short wave infrared (SWIR)	1 628 – 1 652
7	short wave Infrared (SWIR)	2 105 – 2 155

A Victorian Curing Model - "MapVictoria"

Using the synchronised field and satellite data, an extensive number of vegetation indices and multiple linear regressions (MLRs) were modelled and tested for their correlative power against observed curing values. The best performing model comprises a MLR using two vegetation indices: NDVI and GVMI, displayed in Table 2. The model was simply named MapVictoria.

Table 2 Vegetation Indices

Vegetation Index	**Formulae**	**Reference**
NDVI Normalised Difference Vegetation Index	$NDVI = \frac{(Band2 - Band1)}{(Band2 + Band1)}$	Rouse *et al.*, 1973
GVMI Global Vegetation Monitoring Index	$GVMI = \frac{(Band2 + 0.1) - (Band6 + 0.02)}{(Band2 + 0.1) + (Band6 + 0.02)}$	Ceccato *et al.*, 2002

Using field and satellite data from 2005 to 2013, Figure 6 plots observed curing (from the field) against predicted curing (estimated by MapVictoria). Supposing that observed curing has 0% error; the model was evaluated using the Root Mean Square Error (RMSE), the Mean Absolute Error (MAE) and the Mean Bias Error (MBE) (Willmott, 1982). The MapVictoria model estimates curing with an accuracy of ±11.02% (MAE). However, observed curing does not have a 0% error, but an error of up to ±25% (Anderson et al., 2005). Field observations are rounded at 10% intervals and in some cases 5%, resulting in 5 or 10% gaps in the data. Thus, the overall error of the model cannot be accurately determined. While high scatter is evident in the data, the model exhibits a slope of best fit of 0.8061, and tends to over-estimate (by 11%) at low levels of curing and under-estimate (by 11%) at high levels of curing. This is consistent with the Bushfire CRC models (Newnham *et al.*, 2010).

Having said this, the model exhibits no bias (0% MBE), and the model exhibits a lower RMSE (of 13.86%) than any other model tested in this analysis.

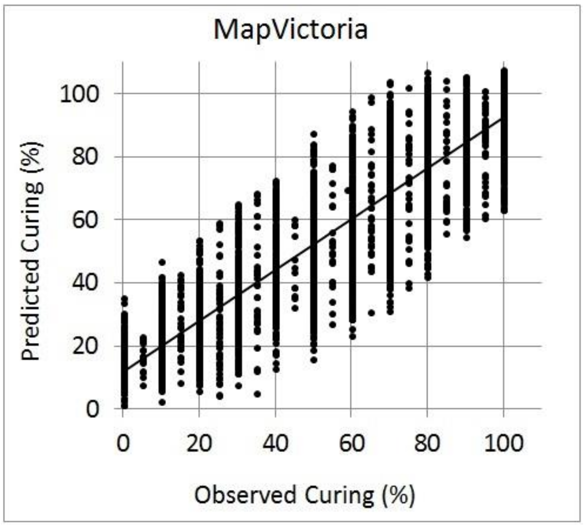

Figure 6 Predicted Curing (estimated by MapVictoria) against Observed Curing (visual observations from the field).

Since MapVictoria and the nation-wide models are all based on MOD09A1 data, it was of interest to compare the derivation of all models. Maps A and B are derived from 210 Levy rod observations from 21 field sites across Australia (Martin, 2009), and Maps C and D are derived from 343 Levy rod observations collected from 25 field sites across Australia (Newnham *et al.*, 2010). MapVictoria, on the other hand, is derived from a total of 3,938 (visual) observations collected from 211 sites across Victoria. This extensive coverage of data across the state gives confidence in using the MapVictoria model in Victoria as it is tailored specifically for Victorian grasslands.

Masking out of Water-bodies and Forests

While the measure of curing focuses on grasslands alone, curing estimates over water and forest are not valid. Therefore, preceding the calculation of curing in real time, water-bodies are masked out using a modified approach of Xiao et al. (2006). The masking of tree cover, on the other hand, does not require as frequently updated information. Tree cover is therefore masked out using a static VicMap Vegetation Dataset (Department of Environment and Primary Industries).

Victorian Improved Satellite Curing Algorithm

The satellite model is adjusted with weekly field observations (shown in Figure 5) to produce a finalised map named VISCA. To find a field value for every 500m pixel, the state is divided into regions; derived from spatial patterns from the most recent MODIS satellite image (the MapVictoria model). The median field curing value is calculated from all sites within each region within a given distance. This creates a temporary layer, named “fieldmap”, comprising a field curing value for every 500m pixel across the state. The MapVictoria values are then adjusted by the “fieldmap” values, with greater weighting for pixels closer to the field site locations. The model then processes a final map with a 3,000m spatial resolution, the required cell size for Graphical Forecast Editor (GFE) input in Victoria. The finalised map, VISCA, is stored as GIS data in the Grassland Curing geodatabase.

Once the finalised dataset (now VISCA) has been created (see an example in Figure 7), a Geoprocessing service (Figure 1) automatically generates a weekly map with VISCA set in an established template. The map is published on the CFA Grassland Curing website for all stakeholders to view. The map is also fed as an additional layer into the Victorian Emergency Map (eMap), which provides real time data for emergency management support. Finally, the Event Processing component of the Online System (Figure 1) automatically sends the VISCA dataset to the Bureau via a FTP site. It is then fed into the GFE and is utilised to calculate the GFDI for Victoria.

The GFDI values are used to calculate Fire Danger Ratings in the north-western part of the state.

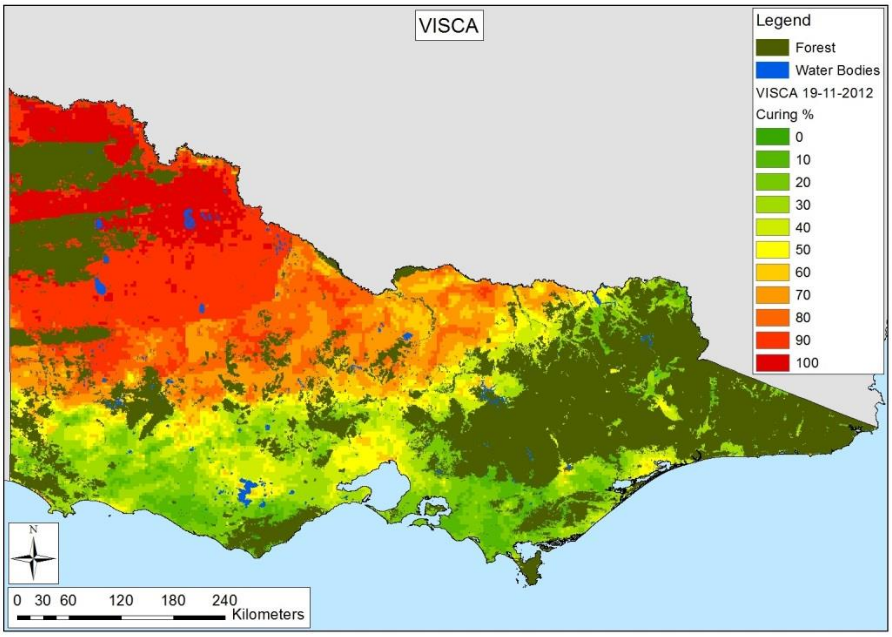

Figure 7 Example of the Finalised Curing Product - VISCA, November 19th 2012

CONCLUSIONS

For improvement of current fire danger calculations of grasslands in Victoria, CFA has developed an automated web-based system combining satellite data with visually assessed field observations of curing. Using an extensive network of 150+ field observers, CFA receives reliable state-wide information of curing every week throughout the fire season. Automation has dramatically minimised the amount of manpower required to collate field observations from across the state. These observations are used to adjust a new satellite model (MapVictoria), tailored specifically for Victorian grasslands. The combined product, named VISCA, is an improved grassland curing input for the GFDI, and hence FDRs. VISCA provides more accurate information for the declaration of the fire danger period at a municipal level, declaration of total fire bans, determination of fire suppression difficulty, fire preparedness and community warnings.

ACKNOWLEDGEMENTS

The authors acknowledge Dr Edward King and Mr Matt Paget (CSIRO) for historical mosaiced (MOD09A1) satellite data, Dr Musa Kilinc (Monash University) for assistance with statistical analyses, Dr Glenn Newnham (CSIRO) for remote sensing assistance, Dr Ian Grant (the Bureau) for reviewing the manuscript, for remote sensing assistance, and for operational satellite data processing. The authors would also like to thank Dr Paul Loto'aniu and Mr David Howard (the Bureau) for implementing much of the near-real time MODIS processing system. Last but not least, the authors thank Mr Tom Sanderson (CFA) for spatial systems and database assistance and CFA Online Services for ICT Support.

REFERENCES

Anderson SAJ, Anderson WR, Hollis JJ, Botha EJ (2011) A simple method for field-based grassland curing assessment. *International Journal of Wildland Fire* **20** (6):804-814.

Anderson SAJ, Anderson WR, Hines F and Fountain A (2005) Determination of field sampling methods for the assessment of curing levels in grasslands, Bushfire CRC Unpublished Report (Christchurch, NZ).

Barber J (1990) Monitoring the Curing of Grassland Fire Fuels in Victoria, Australia with sensors in satellites and aircraft - A Country Fire Authority study in Remote Sensing (Melbourne, VIC).

Ceccato P, Gobron N, Flasse S, Pinty B and Tarantola S (2002) Designing a spectral index to estimate vegetation water content from remote sensing data Part 1: Theoretical approach. *Remote Sensing of Environment* **82**(2-3): 188-197.

Cheney P and Sullivan A (2008) 'Grassfires - fuel, weather and fire behaviour. Second Edition.' (CSIRO Publishing: Melbourne).

Dilley A, Millie S, O'Brien D and Edwards M, (2004) The Relation between Normalized Difference Vegetation Index and Vegetation Moisture Content at three grassland locations in Victoria, Australia. *International Journal of Remote Sensing* **25**(19): 3913 - 3928.

Garvey M (1988) Country Fire Authority and remote sensing. CFA internal report (Melbourne, VIC)

Levy EB and Madden EA (1933) The point method of pasture analysis. *New England Journal of Agriculture **46***, 267-279.

Martin DN (2009) 'Development of satellite vegetation indices to assess grassland curing across Australia and New Zealand.' PhD Dissertation, RMIT University, Melbourne, Australia

NASA (2013) National Aeronautics and Space Administration Goddard Space Flight Center - MODIS Specifications. Available at http://modis.gsfc.nasa.gov/about/specifications.php.

Newnham GJ, Grant IF, Martin DN, Anderson SAJ (2010) Improved Methods for Assessment and Prediction of Grassland Curing - Satellite Based Curing Methods and Mapping. Published Report, Bushfire CRC Project A1.4, Melbourne, Australia. Available at www.bushfirecrc.com/managed/resource/a1-4_final_report.pdf.

Paget MJ and King EA (2008) MODIS Land datasets for the Australian region - CSIRO Marine and Atmospheric Research Internal Report No. 004. Available at https://lpdaac.usgs.gov/lpdaac/products/modis_policies

Paltridge GW and Barber J (1988) Monitoring Grassland Dryness and Fire Potential in Australia with NOAA/AVHRR Data. *Remote Sensing of Environment* **25**(3): 381-394.

Paltridge GW and Mitchell RM (1990) Atmospheric and Viewing Angle Correction of Vegetation Indices and Grassland Fuel Moisture Content Derived from NOAA/AVHRR. *Remote Sensing of Environment*, **31**: 121-135.

Rouse JW, Haas RW, Schell JA and Deering DH (1973) Monitoring vegetation systems in the great plains with ERTS. Proceedings of the Third ERTS Symposium Vol 1 (Washington DC).

Tucker CJ (1977) Spectral estimation of grass canopy variables. *Remote Sensing of Environment* **6**(1): 11-26.

Teague B (The Hon. AO), McLeod R (AM), and Pascoe S (AM) (2010) The 2009 Victorian Bushfires Royal Commission final report. Available at www.royalcommission.vic.gov.au/Commission-Reports/Final-Report.

Willmott CJ (1982) Some comments on the evaluation of model performance. *Bulletin of the American Meteorological Society* **63**, 1309-1313.

Xiao X, Boles S, Frolking S, Li C, Babu JY, Salas W and Moore B (2006) Mapping paddy rice agriculture in South and Southeast Asia using multi-temporal MODIS images. *Remote Sensing of Environment* **100**(2006): 95-113.