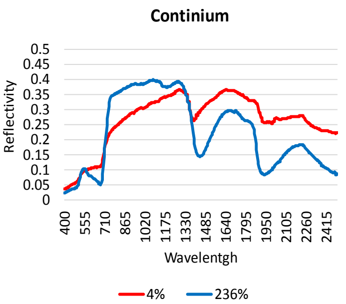
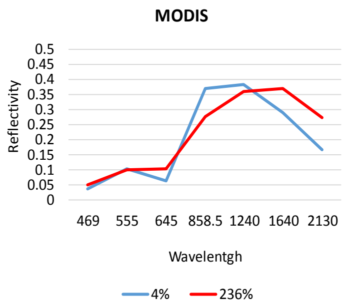
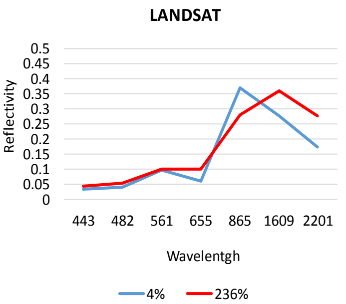
bnhcrc.com.au

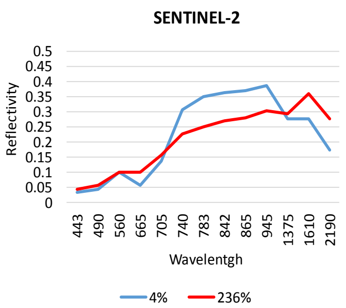
EVALUATION OF THE FEASIBILITY AND BENEFITS OF OPERATIONAL USE OF ALTERNATIVE SATELLITE DATA IN THE AUSTRALIAN FLAMMABILITY MONITORING SYSTEM TO ENSURE LONG-TERM DATA CONTINUITY

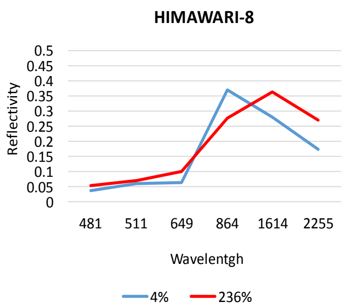
Marta Yebra, Albert Van Dijk and Geoff Cary
The Australian National University
Bushfire and Natural Hazards CRC

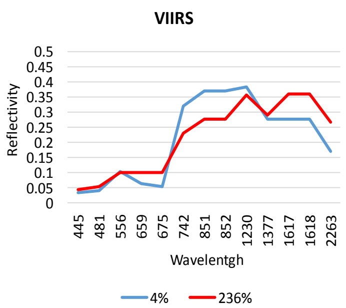












Version	Release history	Date
1.0	Initial release of document	6/12/2018

Disclaimer:
The Australian National University and the Bushfire and Natural Hazards CRC advise that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, the Australian National University and the Bushfire and Natural Hazards CRC (including its employees and consultants) exclude all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

Publisher:
Bushfire and Natural Hazards CRC

December 2018

Citation: Yebra, M., van Dijk, A. & Cary, G. (2018) Evaluation of the feasibility and benefits of operational use of alternative satellite data in the Australian Flammability Monitoring System to ensure long-term data continuity. Melbourne: Bushfire and Natural Hazards CRC.

Cover: Dry (4%) and wet (236%) vegetation spectra for the studied sensors by convolving the simulated spectra with sensor-specific spectral response functions.

TABLE OF CONTENTS

ABSTRACT

The Australian Flammability Monitoring System (AFMS) is the first, continental-scale prototype web service providing spatial information on Live Fuel Moisture Content (FMC) and landscape flammability conditions derived from satellite observations. The system uses data from the MODIS (MODerate resolution Imaging Spectrometer) instruments on board the Terra and Aqua satellites, providing estimates of FMC and flammability over a fortnight leading up to the day of interest and at 500 m spatial resolution. The Terra and Aqua satellites have already exceeded the expected lifetime and, at some point in the not-too-distant future, will become inoperative.

To support the AFMS continuity and redundancy strategy, we evaluate the feasibility and relative benefits of using alternative remote sensing imagery in the AFMS to provide finer spatial and temporal resolutions. The evaluated data sources include the geostationary Japanese Himawari-8 satellite (10min, 2km), the European Sentinel-2 (5 days, 20 m), the Landsat (16 days, 30m) and VIIRS (daily, 750 m) satellites.

We use Radiative Transfer Models to build a database of simulated spectra for the different studied sensors and corresponding to different FMC conditions. The database is then used to test the suitability of the different sensor to retrieve FMC based on their different spectral characteristics and goodness of retrieval (e.g. r^2 and RMSE between retrieved and modelled).

VIIRS obtained the highest accuracy retrieval (r^2=0.8, RMSE=19%, n=6178) followed by Sentinel-2 (r^2=0.8, RMSE=23, n=6178), Landsat-8 (r^2=0.8, RMSE=24, n=6178) and Himawari-8 (r^2=0.7, RMSE=24, n=6178). These results were expected as VIIRS has a larger number of sensor bands (5 bands) in the Short Wave Infrared (SWIR) followed by Sentinel-2 (3 bands), Landsat and Himawari-8 (two bands each).

VIIRS, therefore, is likely the best candidate to ensure the AFMS website data provision continuity. Sentinel-2 (3 bands) and Himawari-8 are the best second and third candidates that obtain similar accuracies while increasing the spatial (Sentinel-2, 20m) and temporal (Himawari-8, 10 minutes) resolutions of the products displayed in the AFMS.

Future work will focus on integrating estimates from these different data sources to better support a range of fire management activities such as prescribed burning and pre-positioning of firefighting resources and inform the future National Fire Danger Rating System.

END USER STATEMENT

INTRODUCTION

The Fuel Moisture Content (FMC) of live bushfire fuel affects fire danger and fire behaviour, as it strongly influences the key components of flammability including ignitability, fire sustainability and combustibility (Anderson 1970). Spatially comprehensive and temporally frequent estimates of FMC should be a fundamental component of fire danger rating systems in support of a wide range of fire risk management and response activities, such as prescribed burning and pre-positioning firefighting resources.

The Australian Flammability Monitoring System (AFMS) (Yebra et al. 2018) is the first, continental-scale prototype web service providing spatial information on:

- Live FMC, in kg water per kg dry matter, expressed as a percentage.
- Uncertainty in the FMC values, in the same units.
- A Flammability Index (FI), providing a relative measure of fuel flammability between 0 and 1.
- Soil moisture content near the surface (0-10 cm), in m^3 water per m^3 of soil volume).
- Soil moisture content in the shallow soil (10-35 cm), in the same units.

The AFMS allows users to visualise and interpret information on the above information as maps or graphs for any part of Australia. Data can be compared to preceding years or downloaded for further analysis.

The FMC and Flammability are derived from Moderate Resolution Imaging Spectroradiometer (MODIS) observations available at a resolution of 500 m and a 4-day time step (Yebra et al. 2018). Flammability is an index that is calculated using empirical relationships between historical FMC and the occurrence and spread of bushfires. At each time step, the values are derived from observations during the previous eight days (Yebra et al. 2018).

The soil moisture data are produced by the Bureau of Meteorology's JASMIN modelling system (Dharssi and Vinodkumar, 2017), also developed as part of the BNHCRC research program. They are available at 5 km resolution and daily time step.

The AFMS is already providing useful insights into landscape dryness and flammability to assist fire and land managers with resource allocation for fire protection and response, improved awareness of fire hazard to people and property, as well as to assist on scheduling planning and prevention activities. However, the Terra and Aqua satellites that carry MODIS have already exceeded the expected lifetime and, at some point in the not-too-distant future, will become inoperative.

Each remote sensing application has its own unique spatial, temporal and spectral resolution requirements which need to be appreciated but also budget limitations. MODIS temporal and spatial resolutions are still too coarse to support certain fire management decisions. For example, the system cannot track diurnal changes in fuel moisture conditions and have limited applicability for targeted fire management activities in heterogeneous terrain.

To support the AFMS continuity and redundancy strategy, and better fit its information to purpose, we evaluate the feasibility and relative benefits of using alternative remote sensing imagery in the AFMS.

METHODS

SATELLITE DATA

Any remote sensing application has unique resolution requirements and, thus, the trade-off between spatial, temporal and spectral resolution as well as associated cost need to be reconciled for the selection of satellite images candidates to replace MODIS in the AFMS. The current system provides daily estimates of flammability and moisture conditions at 500m resolution. Higher temporal resolution systems (e.g. Himawari-8, 10 minutes) can track changes in FMC within a day (Quan *et al.* 2018), but at a lower spatial resolution (2km), that might not be suitable for some situations (e.g. identify soft control lines based on fuel moisture differentials in heterogeneous and mountainous locations). In contrast, high spatial resolution sensors (e.g. SPOT <10m) may estimate FMC even of individual tree crowns but at a low temporal resolution (15 days to monthly depending on cloud coverage) and at a high cost.

In addition to temporal and spatial resolution and cost, another important factor to consider when it comes to selecting a sensor to retrieve FMC is its spectral resolution. To retrieve FMC accurately, the sensor requires enough narrow bands in the Near Infrared (NIR) and, more importantly, the Short Wave infrared (SWIR) region of the solar spectral domain. In the SWIR and NIR water has a direct effect on spectral reflectance through absorption of radiation. Depending on plant tissue water content, the reflectance is thus reduced to a varying extent within the water absorption features centred on 970, 1200, 1450, 1940, and 2500 nm (Yebra *et al.* 2013) (Figure 1). However, changes in leaf pigment concentrations and leaf internal structure co-vary with FMC, and also produce changes in visible and NIR reflectance that may be correlated with FMC (Fig. 3). When plants are under water stress, depletion of chlorophyll may produce a decrease in reflectance in the visible bands, especially in the red end of the visible spectrum. When leaves wilt during dehydration and senescence, many of the reflective interfaces of leaves are eliminated as internal air space is reduced and cell walls come together, which reduces NIR reflectance (Knipling, 1970).

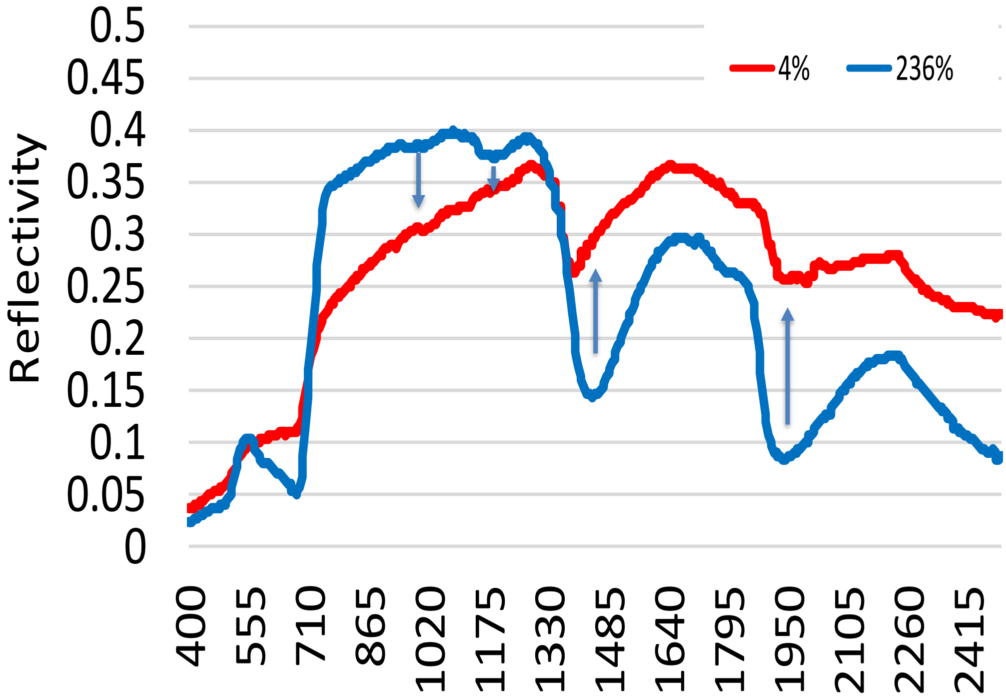


FIG. 1. SIMULATED REFLECTANCE CURVES, OR SPECTRAL SIGNATURES, OF VEGETATION WITH DIFFERENT FMC (%) PROVIDE THE KNOWLEDGE BASE FOR LIVE FMC INFORMATION EXTRACTION.

Taking into consideration the above criteria, we selected as potential good successors of MODIS the sensors on board the geostationary Japanese Himawari-8, the European Sentinel-2, the Landsat-8 and VIIRS satellites. These satellites have onboard sensors with different resolutions (Table 1). These sensors provide finer spatial or temporal resolutions or both that the currently used MODIS satellite.

TABLE 1. SUMMARY OF THE SENSORS EXPLORED IN THIS STUDY. AMONG SEVERAL SPECTRAL BANDS AVAILABLE THE ONES SELECTED HERE ARE THOSE THAT RELEVANT TO FMC RETRIEVAL ALGORITHM.

			Spectral resolution			
Satellite Sensor	Spatial resolution (m)	Temporal resolution	Spectral range (µm)	Multi-spectral Bands	Year Launch	Designed Life (Years)
MODIS	500	1-2 days	458-2155	7	2000	5
Landsat-8 OLI	30	16 days	433-1390	8	2013	6
VIIRS	750	Daily	4412-2250	10	2011	7
Himawari-8	2000	10 minutes	470-2256	6	2014	15
Sentinel-2A/2B MSI	20	5 day	442-2202	13	2017	12

RADIATIVE TRANSFER FORWARD MODELLING

Too gain insights into any differences between the studied sensors in the ability to retrieve FMC due only to their spectral resolution differences, we build a Look-up Table (LUT) containing 6179 simulated reflectance values from 400nm to 2500nm corresponding to different FMC values, as explained in Yebra *et al.* (2018).

The studied sensors band reflectance values were derived by calculating the simulated spectra with sensor-specific spectral response functions as

$$\overline{\rho_{band}} = \frac{\int_{band\ \lambda\ \min}^{band\ \lambda\ \max} S_{band}\,(\lambda)\rho(\lambda)d\lambda}{\int_{band\ \lambda\ \min}^{band\ \lambda\ \max} S_{band}\,(\lambda)\rho(\lambda)d\lambda} \quad \text{Equation 1}$$

Where ρ_{band} is the simulated reflectance for a specific sensor's band, $S_{band}(\lambda)$ is the sensor spectral response function for the band, and $band_{\lambda min}$ and $band_{\lambda max}$ are the minima and maximum wavelengths where $S_{band}(\lambda)$ is greater than zero, and $\rho(\lambda)$ is the simulated spectral information for a given spectrum.

RETRIEVAL OF FMC

The methodology to derive FMC using the simulated spectra for the different sensors studied is based on the LUT inversions. All simulated reflectance in the LUT were subsequently compared to each simulation (taken as the reflectance observations) using the spectral angle (SA) (Equation 2)

$$SA(v,w) = \cos^{-1}\left[\frac{\sum_{i=1}^{m} v_i w_i}{\sqrt{\sum_{i=1}^{m} v_i^2}\sqrt{\sum_{i=1}^{m} w_i^2}}\right] \quad \text{Equation 2}$$

where v and w are each simulated reflectance considered as an m-dimensional vector, with m being the number of bands considered.

Bands located in the blue region were discarded because variation in FMC has no effect in blue wavelengths (Bowyer and Danson, 2004) whereas measurement errors are greater than in longer wavelengths (Roy et al., 2014 and references therein). In addition to the spectral bands, the Normalized Difference Infrared Index, (NDII, Hardisky *et al.,* 1983) was also computed and included in the vectors v and w. Finally we removed band in the SWIR to verify the sensitivity of these bands to the retrievals.

Similarly to Yebra *et al.* (2018), the SA values for the simulated spectra from the LUT were ranked by their similarity to each simulated spectrum. Rather than adopting only a single 'optimal' result, we tested the sensibility of the different sensors to the number of best solutions selected by taking as a solution the average of a larger ensemble of 'near optimal' RTM results of variable size (from 1 to the total number of simulations). Root Mean Square Error (RMSE) and correlation coefficient between retrieved and simulated FMC was used to evaluate the sensibility.

RESULTS AN DISCUSSION

A dry and a wet spectrum simulated for the different studied sensors is presented in Figure 2. Sensors onboard Sentinel-2 and VIIRS present more bands in the SWIR region than MODIS, Landsat-8 and Himawari-8.

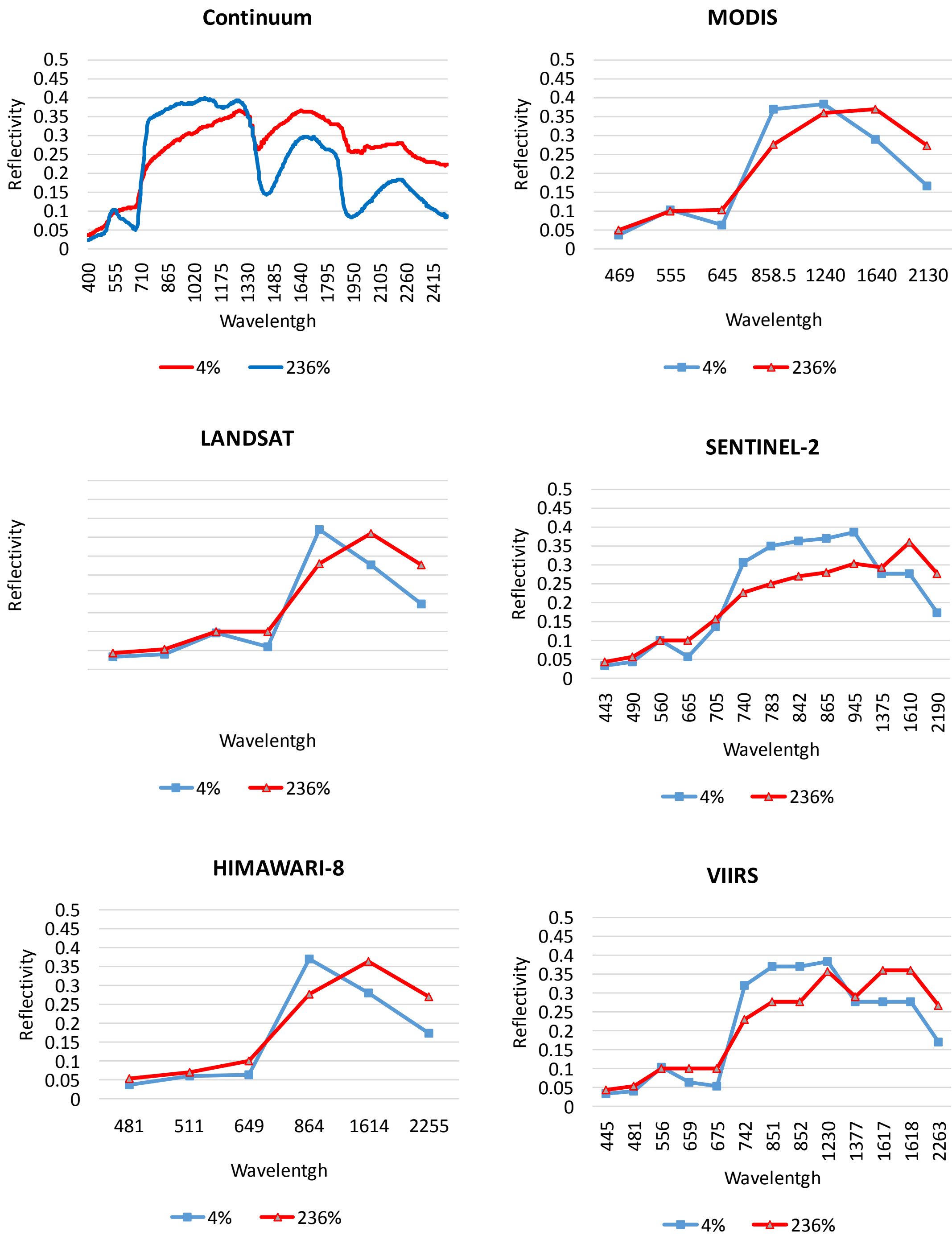


FIGURE 2. DRY (4%) AND WET (236%) VEGETATION SPECTRA FOR THE STUDIED.

The median of the corresponding FMC values from the 1 to 6179 most similar spectra in the LUT show that VIIRS is less sensitive to changes in the number of solutions selected from the LUT (Fig. 4).

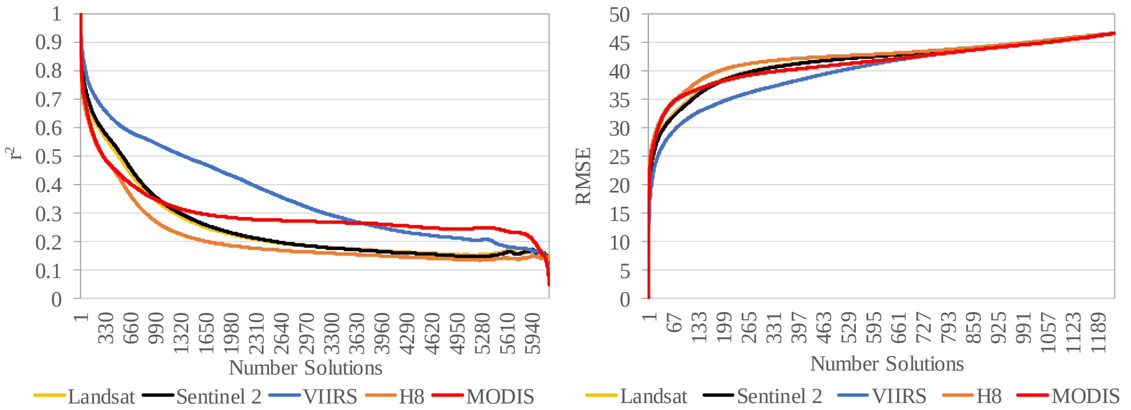


FIGURE 4. R² (LEFT) AND RMSE (RIGHT) VALUES BETWEEN SIMULATED AND ESTIMATED FMCVALUES AS A FUNCTION OF THE NUMBER OF SELECTED SPECTRA IN THE LUT.

VIIRS obtained the highest accuracy retrieval (r^2=0.8, RMSE=19%, n=6178) followed by Sentinel-2 (r^2=0.8, RMSE=23, n=6178), Landsat-8 (r^2=0.8, RMSE=24, n=6178) and Himawari-8 (r^2=0.7, RMSE=24, n=6178). These results were expected as VIIRS has five bands in the Short Wave Infrared (SWIR), which are key for water content estimation, followed by Sentinel-2 (3 bands), Landsat and Himawari-8 (two bands each). The accuracies highly decreased when removing the SWIR bands for the inversion (Table 3). VIIRS, therefore, is likely the best candidate to ensure the AFMS website data provision continuity.

TABLE 2. QUANTITATIVE MEASURES OF MODEL INVERSION PERFORMANCE IN RETRIEVING FMC USING DIFFERENT SENSORS.

RMSE, ROOT MEAN SQUARE ERROR; RMSES, RMSE SYSTEMATIC; RMSEU, RMSE UNSYSTEMATIC. 40 SOLUTIONS

Sensor	Slope	intercept	R²	RMSE	RMSEs	RMSEu	n
Landsat-8 OLI	1.2	-21	0.8	24	7	23	6178
Sentinel-2A/2B MSI	1.2	-22	0.8	23	7	21	6178
VIIRS	1.2	-18	0.8	19	6	18	6178
Himawari-8	1.2	-19	0.7	26	6	25	6178
MODIS	1.14	-16	0.7	24	5	24	6178

TABLE 3. QUANTITATIVE MEASURES OF MODEL INVERSION PERFORMANCE IN RETRIEVING FMC USING DIFFERENT SENSORS.

RMSE, ROOT MEAN SQUARE ERROR; RMSES, RMSE SYSTEMATIC; RMSEU, RMSE UNSYSTEMATIC. 40 SOLUTIONS-NO SWIR BANDS

Sensor	Slope	Intercept	R²	RMSE	RMSEs	RMSEu	n
Landsat-8 OLI	1	-8	0.3	40	1.7	40	6178
Sentinel-2A/2B MSI	1.2	-20	0.4	35	5	35	6178
VIIRS	1.1	-14	0.3	38	3	38	6178
Himawari-8	1	-5.4	0.2	42	0.9	42	6178
MODIS	1	-11.2	0.2	42	2	42	6178

Single-sensor monitoring systems are constrained by their inherent data characteristics in the spectral, spatial and temporal domains. Consequently, Sentinel-2 and Himawari-8 are the best second and third candidates that obtain similar accuracies than VIIRS while increasing the spatial (Sentinel-2, 20m) and temporal (Himawari-8, 10 min) resolutions of the products displayed in the AFMS. Himawari-8 can track diurnal changes in FMC, which is essential for early warning, especially in fuel types, including grasslands that exhibit strong diurnal FMC fluctuations. All these data is easily accessible vie the National Computing Infrastructure but it is at different levels of processing in terms of atmospherically corrections and cloud masked. While Landsat-8 is fully corrected and masked, Sentinel-2 and Himawari-8 data is currently in a row format.

CONCLUSIONS AND RECOMMENDATIONS

The current AFMS relies on MODIS instruments on board the Terra and Aqua satellites. However, the expected lifetime of the Terra and Aqua satellites has already been exceeded, and at some point, in the not-too-distant future, they will become inoperative. To support an AFMS continuity strategy we have to evaluate the feasibility and relative benefits of using alternative satellites. The most promising candidate data source is VIIRS satellite (750m, daily). Sentinel-2 (20m, 5 days) and Himawari-8 (2km, 10 min) can also ensure continuity at the same time than provide finer spatial and temporal resolutions.

Future work will focus on integrating estimates from these different data sources to better support a range of fire management activities such as prescribed burning and pre-positioning of firefighting resources and inform the future National Fire Danger Rating System.

REFERENCES

Anderson, H.E. (1970). Forest fuel ignitibility. Fire Technology, 6, 312-319

Bowyer, P., & Danson, F. M. (2004). Sensitivity of spectral reflectance to variation in live fuel moisture content at leaf and canopy level. Remote Sensing of Environment, 92, 297–308.

Dharssi, I., and Vinodkumar, 2017, JASMIN: A prototype high-resolution soil moisture analysis system for Australia, Research Report No. 026, Bureau of Meteorology. http://www.bom.gov.au/research/publications/researchreports/BRR-026.pdf

Hardisky, M.A., Klemas, V., & Smart, R.M. (1983). The Influence of Soil-Salinity, Growth Form, and Leaf Moisture on the Spectral Radiance of Spartina-Alterniflora Canopies. Photogrammetric Engineering And Remote Sensing, 49, 77-83

Knipling, E. B. (1970). Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Remote Sensing of Environment, 1, 155–159.

Quan, X, He, B., Yebra, M., Liu, X., Zhang, X. Retrieval of Fuel Moisture Content from Himawari-8 product: Towards real-time wildfire assessment. International Geoscience and Remote Sensing Symposium, 2018, Valencia (Spain).

Roy, D.P., Wulder, M.A., Loveland, T.R., C.E, W., Allen, R.G., Anderson, M.C., Helder, D., Irons, J.R., Johnson, D.M., Kennedy, R., Scambos, T.A., Schaaf, C.B., Schott, J.R., Sheng, Y., Vermote, E.F., Belward, A.S., Bindschadler, R., Cohen, W.B., Gao, F., Hipple, J.D., Hostert, P., Huntington, J., Justice, C.O., Kilic, A., Kovalskyy, V., Lee, Z.P., Lymburner, L., Masek, J.G., McCorkel, J., Shuai, Y., Trezza, R., Vogelmann, J., Wynne, R.H., & Zhu, Z. (2014). Landsat-8: Science and product vision for terrestrial global change research. Remote Sensing of Environment, 145, 154-172

Yebra, M., Chuvieco, E., Danson, M., Dennison, P., Hunt, E.R, Jurdao, S., Riano, D., Zylstra, P, 2013. A global review of remote sensing of live fuel moisture content for fire danger assessment: moving towards operational products. Remote Sensing of Environment.136, 455-468.

Yebra, M., Quan, X., Riano, D., Rozas-Larraondo, P., van Dijk, A., Cary, G.J. A fuel moisture content and flammability monitoring methodology for continental Australia based on optical remote sensing. Remote Sensing of Environment. 212:260-272.