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ACTIVE FIRES: EARLY FIRE DETECTION AND MAPPING USING HIMAWARI-8

Annual Report 2017-2018

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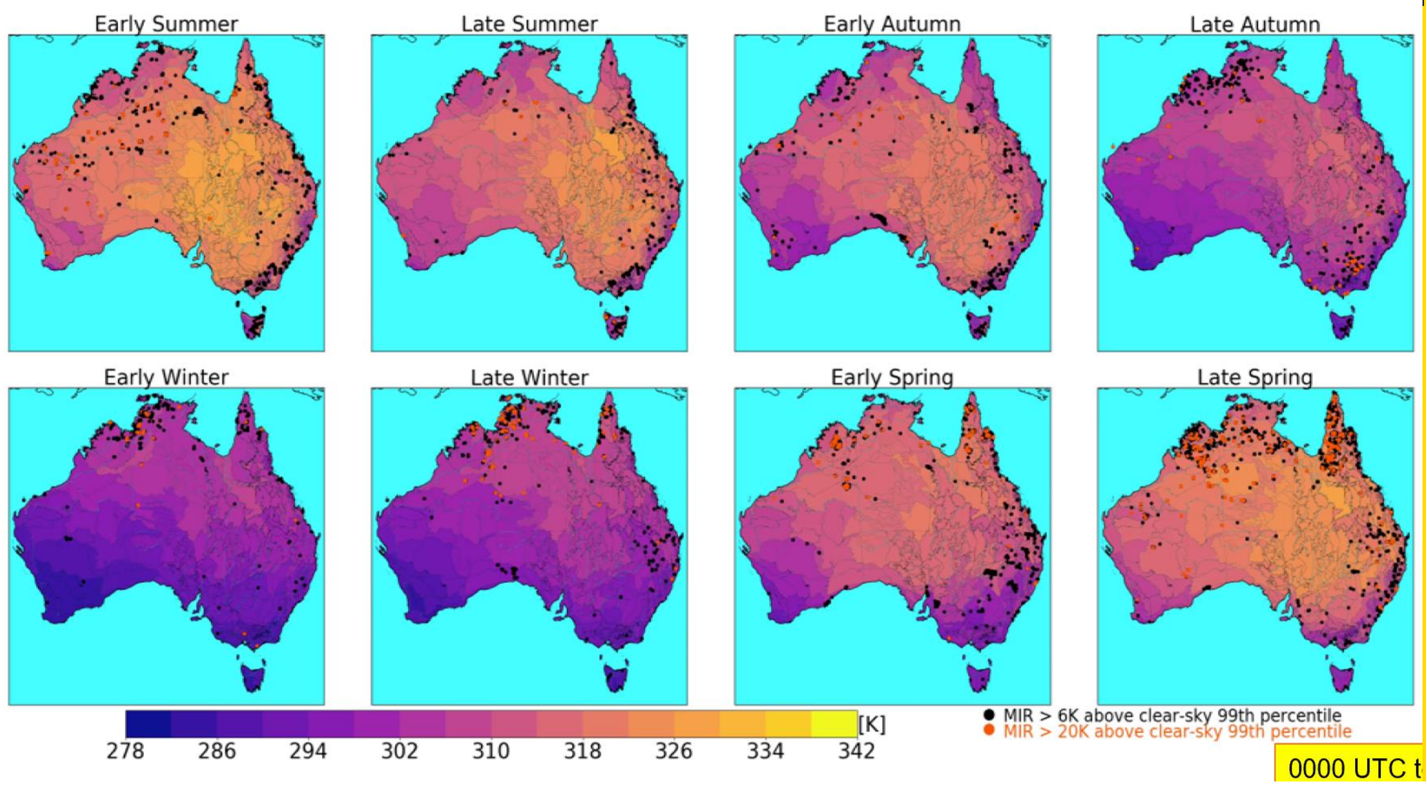
RMIT University & Bushfire and Natural Hazards CRC



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Cover: Terrestrial laser scanning data being collected for comparison with Fuels3D in Ridgeway, Tasmania.

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ACKNOWLEDGEMENTS

The project team gratefully acknowledge the assistance of end-users from the Victorian Department of Environment, Land, Water and Planning, Geoscience Australia, and in particular the New South Wales Rural Fire Service, for providing access to important datasets to allow for the intercomparison and validation of newly developed algorithms and products. Acknowledgements also go to the National Computing Infrastructure (NCI) for providing important computing resources to supporting processing of imagery and also to the Bureau of Meteorology.

EXECUTIVE SUMMARY

Satellite sensors are an important source of observations of fire activity in the landscape, and the advent of recent geostationary satellites such as Himawari-8 provide earth observations every 10-minutes. This near-real time data provides opportunities for new and improved fire detection algorithms. Early fire detection algorithms that take advantage of such high frequency observations, and that are primed for Australian landscapes, are developed under this project.

The fitness for purpose of new data products forms part of the development phase. How well do they perform? What are their limitations? What are their advantages for observing fire under different fire scenarios and in different landscapes? This also demands understanding such outputs in the context of data sources and procedures that are currently in operation. Complementing this evaluation into performance is the development of new methods that take into account comparing high temporal frequency + low spatial resolution geostationary outputs with low temporal frequency + moderate spatial resolution low earth orbiting outputs.

Highlights of 2017 – 2018 have included:

- Best session presentation awarded at the 38th Asian Conference of Remote Sensing (Space Applications – Touching Human Lives), Disaster and Risk Reduction, for the presentation "Large Area Validation of Himawari-8 Active Fires Products".
- Four peer-reviewed, international journal publications.
- A Himawari-8 cloud mask is implemented and assessed based on published international literature for suitability in Australia.
- Three active fire algorithms developed for Himawari-8; (1) temporal fitting for early fire detection, (2) statistical driven detections using Australian IBRA regions for early fire detection and (3) fire activity monitoring and mapping at improved spatial resolutions.
- New postdoctoral research fellow joins the RMIT team.
- End-user trials for near-real time testing of algorithm planned for early 2019.

INTRODUCTION AND BACKGROUND

Emerging earth observation technologies designed for monitoring fire and its effects, combined with the ubiquitous nature of remote sensing means there is an ongoing requirement to develop new fire detection algorithms that take advantage of new developments in earth observations, and understand the fitness for purpose of new data products.

The advent of the new geostationary satellite, Himawari-8, online in 2016 has meant that the entire continent of Australia is observed every 10 minutes. This provides a new opportunity for wildfire surveillance, bringing with it the need to re-think and re-explore the way in which fire detection algorithms have been traditionally designed. The outcomes of the project to build the capacity for new fire information that complements existing, and next generation, remote sensing satellite information thereby enhancing Australia's operational capabilities and information systems for bushfire monitoring and mapping. Ultimately the outcomes of this research will enable measures of fire activity to be made which in turn have the potential to inform or support efforts in prediction and monitoring, including bushfire response planning and fire rehabilitation efforts.

This project is a critical part of the BNH CRC's value to Geoscience Australia and the broader Australian government. The Sentinel Hotspots application is used by all levels of government, private sector, researchers and the public – this system would not be trusted by those parties without sound validation. This project will continue to assist the Australian government in developing and validating the capability of the Himawari-8 data source to Sentinel Hotspots program. Further, the project will assist in the ongoing improvement of vital bushfire information acquired through state-of-the-art remote sensing technology as needed by fire and emergency management now and in the future.

The following sections describe the rationale, method and preliminary findings and outputs for the implemented Himawari-8 cloud mask, early fire detection and fire line mapping algorithms.

RESEARCH APPROACH

IMPLEMENTATION OF A HIMAWARI-8 CLOUD MASK FOR AUSTRALIA

Rationale

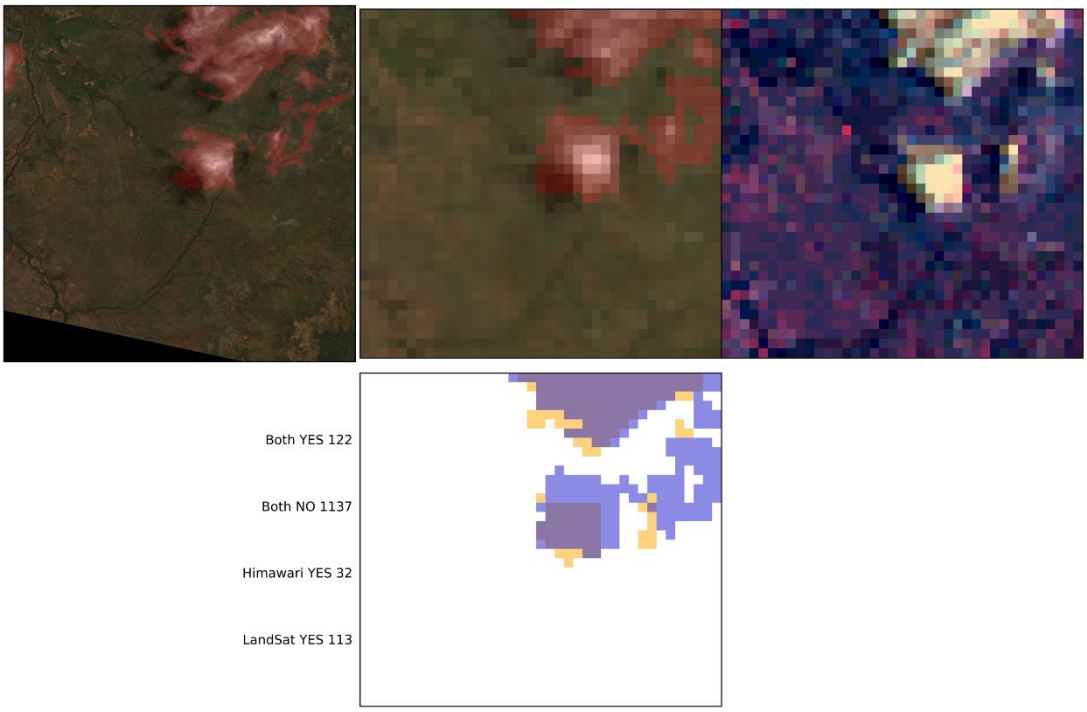
Fires when viewed from space produce positive anomalies in middle Infrared (MIR) satellite channel data. But, in order to correctly and accurately identify if a MIR value is a positive "anomaly", researchers try to capture the "normal", or "background" MIR value. Capturing a "normal" clear-sky MIR distribution is non-trivial because MIR values are sensitive to *both* thermal radiation *and* solar radiation reflected from clouds. Therefore, to capture a "normal" clear-sky MIR distribution it is important to remove data containing clouds. Imprecise assumptions regarding thresholds that delineate clear- from cloudy-sky can lead to either clouds getting into the dataset or more than necessary clear-sky or fire pixels being left out of the dataset. Cloud-contaminated datasets have the potential to have lower the "background" TIR and higher "background" MIR expected values. A lowered background TIR value could lead to more pixels being deemed as fires, and an increased background MIR could lead to more fire-pixels being treated as clear-sky pixels. Therefore, it is important to pre-process image datasets for cloud as accurately as possible.

Method and Results

For the initial implementation of a cloud mask for Himawari-u, the work by fire-detection researchers (Xu et al., 2010) was used. The Xu et al. (2010) cloud mask over land uses Visible, Mid-Infrared and Thermal-Infrared Satellite Channels, along with solar information to delineate between daytime and night-time areas. The algorithm conducts six tests to decide on the likelihood of a satellite pixel containing cloud. An example output is shown in Figure 1. On the left is the LandSat true color + cloud mask (red), in the middle is the same information but on the coarser Himawari projection, and on the right is the Himawari (modified true color) and its cloud mask (orange). Below, the LandSat cloud mask (blue) is overlaid on the Himawari cloud mask (orange). Statistics on the side of the legend show the number of pixels having cloud in both, neither, or only one of the Himawari and Landsat cloud masks. (Note: The LandSat dataset has a much higher spatial resolution than the Himawari dataset. Therefore, the LandSat cloud mask was re-gridded from its native resolution to the coarser Himawari grid resolution before conducting the comparison.)

In the Figure 1 example, the LandSat and Himawari cloud masks compare favourably. However, it is important to note that the results were limited to northern Australian case studies and the suitability of the Xu et al. (2010) cloud masking algorithm declined in coastal and southern areas of Australia and this is likely due to the original algorithm being calibrated and validated in equatorial environments. Examination of outputs using the published Xu et al. (2010) albedo threshold identified as too low for the Himawari Satellite across the Australian continent.

FIGURE 1 EXAMPLE LANDSAT/HIMAWARI CLOUD MASK COMPARISON SHOWING GOOD



SPATIAL AGREEMENT (BOTH YES = DARK PURPLE, BOTH NO = WHITE, HIMAWARI-8 YES = LIGHT PURPLE AND LANDSAT YES = YELLOW).

Initial results were found to be suitable for use over northern Australia but were significantly compromised in southern parts of the continent. The work by Xu et al. (2106) was based on thresholds developed on equatorial environments, and therefore not suited across an entire continent such as Australia. It is proposed that a dynamic albedo threshold would produce a more reliable and accurate cloud mask.

Outputs

- Python code implementing the Xu et al. (2010) algorithm and applied to Himawari-8 imagery for 2016.
- Accuracy assessment of Himawari-8.
- Revision and recommendations to Xu et al. (2010) algorithm for Australian conditions across the continent.

DEVELOPMENT AND POTENTIAL OF A TIME-SERIES APPROACH FOR EARLY FIRE DETECTION

Rationale

Fire detection and monitoring relies on an accurate estimate of the background temperature of a fire's location. This cannot be directly measured from the pixel signal due to obscuration caused by the infrared emission of fire. Previous methods of background temperature estimation have relied on using a target's adjacent background conditions in a contextual manner to estimate this temperature. This method can be used effectively for background estimation in ideal conditions, but deteriorates when exposed to ephemeral factors such as cloud cover and smoke, and in areas of land surface heterogeneity. Identification of these locations and conditions of poor background temperature recovery have led to investigations of the use of multi-temporal data for background temperature estimation, which when matched with signal fitting and smoothing techniques can lead to a more robust method of temperature estimation than via context.

Method and Results

Multi-temporal methods of estimation utilise the pixel's time series history to make inferences about its current behaviour. These can be as simple as looking at the same time for a number of days and making a temperature estimate based upon this, but in reality there are a number of periodic signals which make up the temperature signal of a location over a period of time. The largest influence over background temperature is time of day - incident solar radiation not only increases radiation through reflectance during the daytime, but also increases thermal emission from the surface through convection. These two components make up a strong diurnal signal which is exhibited by almost all cloud-free land surface pixels. Given that solar radiation has such a strong influence, it follows that we may be able to use this underlying signal to provide temperature estimations of a pixel when an obscuring factor is present, such as cloud or fire.

Multi-temporal temperature estimations at pixel level suffer from similar problems to the use of single-timepoint contextual methods, in that obscuration by cloud in particular makes temperature recovery difficult. In some areas, periodic cloud cover can completely inhibit the use of temperature data during critical times for fire activity. The Broad Area Training method provides a more robust method of temperature estimation by using land surface areas at similar latitudes to provide a version of the expected diurnal signal of a pixel. This signal can then be scaled using the pixel's immediate history to reflect the current conditions of the pixel, and subsequently then used for background temperature prediction.

The Broad Area Training method for fire background temperature estimation has been assessed both for reliability and robustness as compared to other background estimation methods, and for its general applicability for fire detection as part of a simple thresholding method. The general applicability of the method for temperature estimation looked at the BAT technique for general applicability and performance over Australia, in comparison to both contextual temperature estimates and per-pixel multi-temporal estimation. The study found an overall increase in estimation effectiveness compared to per-pixel multi-temporal methods, and increased robustness to incidences of cloud (see Table 1).

TABLE 2 COMPARISON OF FITTING TECHNIQUES TO BRIGHTNESS TEMPERATURES RECORDED

BY THE AHI SENSOR USING RMSE AFTER ELIMINATING INCIDENCES OF CLEAR SKY PROBABLY (CSP) OF LESS THAN ONE FROM THE EVALUATION (FROM HALLY ET AL. (2017)).

Fitting technique	**RMS Error (K)**				
Incidences of CSP < 1	≤ 10	$11-30$	$31-50$	$51-70$	> 70
Pixel-based training	0.78	1.01	2.28	3.25	10.40
BAT (30 days)	0.94	0.94	1.11	1.48	4.19
BAT (10 days)	1.15	1.21	1.40	2.10	6.31
Contextual temperature	0.33	0.42	0.41	0.40	0.42
Number of samples	*903*	*741*	*768*	*851*	*2345*

The BAT method was also extended into a study which pitted the use of simple thresholds for thermal anomaly identification against commonly used fire products in part of Northern Australia (Hally et al. 2018). Fire locations were identified using a burned area product, and the associated active fires were examined using both LEO fire products, such as VIIRS VNP14 and MODIS MxD14, against thresholds above estimated background temperature using AHI imagery. The study showed an increase of fire detections overall when using the AHI imagery, with low omission rates and improvements in time of fire detection (see Table 2).

TABLE 3 DETECTION RESULTS OF THE THRESHOLDING ALGORITHM ON 150 FIRE INCIDENTS IN EACH DETECTION GROUPING PER TEMPERATURE THRESHOLD. DETECTIONS OCCUR WHERE AT LEAST ONE BRIGHTNESS TEMPERATURE MEASUREMENT EXCEEDS THE FITTED BRIGHTNESS TEMPERATURE BY THE SELECTED THRESHOLD. SYNCHRONOUS FIRE DETECTIONS ARE CLASSIFIED AS WHERE AN ANOMALY DETECTED BY ONE OR BOTH OF THE ACTIVE FIRE PRODUCTS HAS AT LEAST ONE CORRESPONDING DETECTION FROM THE THRESHOLD ALGORITHM WITHIN TWENTY MINUTES OF THE LEO (FROM HALLY ET AL. (2018)).

Group\Threshold	2 K		3 K		4 K		5 K	
n=150 for all	Detected	Synchronous	Detected	Synchronous	Detected	Synchronous	Detected	Synchronous
Burned area only	75.3%	N/A	63.3%	N/A	56.0%	N/A	50.0%	N/A
VIIRS AF only	95.3%	38.7%	88.0%	27.3%	84.7%	22.0%	77.3%	17.3%
MODIS AF only	97.3%	60.7%	97.0%	58.0%	91.3%	52.7%	86.0%	48.0%
Both AF products	99.3%	68.0%	98.3%	58.7%	92.0%	51.3%	89.3%	46.0%

Outputs

- Hally, B., Wallace, L., Reinke, K., Jones, S. and Skidmore, A., 2018. Advances in active fire detection using a multi-temporal method for next-generation geostationary satellite data. *International journal of digital earth*, pp.1-16.
- Hally, B., Wallace, L., Reinke, K., Jones, S., Engel, C. and Skidmore, A., 2018. Estimating Fire Background Temperature at a Geostationary Scale—An Evaluation of Contextual Methods for AHI-8. *Remote sensing*, *10*(9), p.1368.

DEVELOPMENT AND POTENTIAL OF A STATISTICS APPROACH FOR EARLY FIRE DETECTION

Rationale

Clear-sky satellite observations are linked to variables such as daytime radiation, atmospheric conditions and the underlying landscape characteristics. The amount of incoming radiation and hence heating of the ground can vary with time of day, season, proximity to the equator or pole, and weather conditions. Landscape conditions can vary greatly across the Australian-continent. Hence not all areas of Australia can be representative of each other.

Statistical estimations increase in accuracy when the errors are small or the sample size is larger. The Himawari sensor has fixed accuracy specifications, and Himawari started archiving data in 2015. These cannot be changed. To increase the accuracy of the active fire detection we can increase the sample area upon which the statistics are based. Normally-distributed populations have samples that are drawn from one single population. Variations in the underlying population can lead to a non-normal statistics and therefore inaccurate statistical estimations. To increase the sample size without distorting the statistic, we can group regions in terms of pixels that are representative of each other.

Method and Results

Biogeographic regions are regions of land that are representative of each other in terms of certain biological, ecological and climatic conditions. Version 7 of the Interim Biogeographic Regionalization for Australia has broken up Australia in 89 regions and 419 sub-regions. These 419 sub-regions can be used to group representative areas of satellite data. In this work, an IBRA sub-region specific dynamically-varying definitions of clear-sky albedo, MIR and TIR was created. These "clear-sky" albedo, MIR and TIR definitions were used to detect potential fires in Himawari data. Albedo, MIR and TIR clear-sky values differed greatly between IBRA sub-regions, and within individual sub-region sub-seasons and is illustrated in Figure 2.

Single, Australia-wide clear-sky MIR, TIR and albedo estimates cannot not reflect this level of spatial and seasonal variability. Dynamic characterization of clear-sky conditions for MIR, TIR and albedo, however, can be achieved across IBRA sub-regions and for different seasons. These dynamic clear-sky statistics can be used to form a simple fire hotspot algorithm that preliminary findings show have substantially lower rates of commission errors than the currently available WF-ABBA algorithm, and are comparable to currently operational satellite-based hotspots.

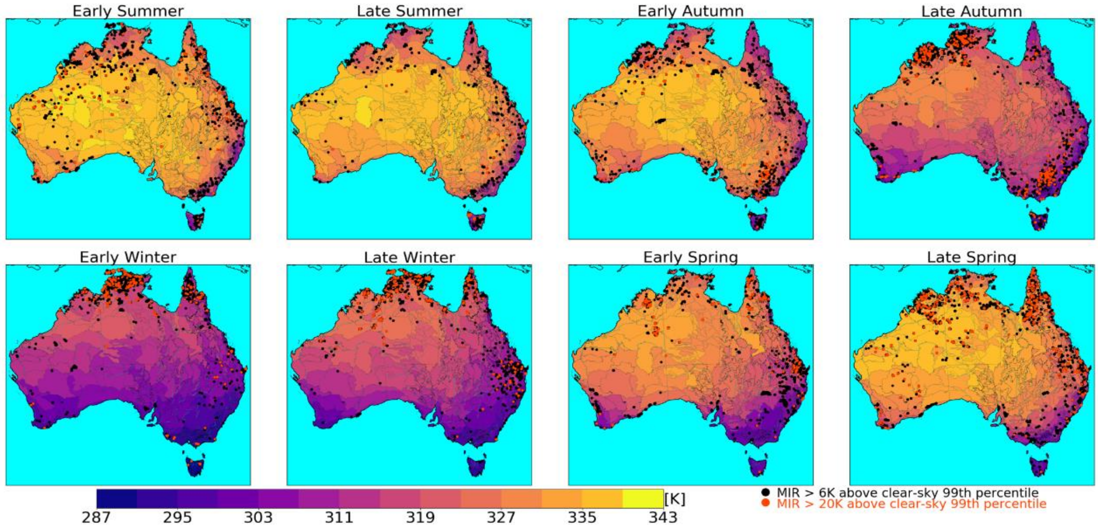


Figure 2. Sub-Seasonal AND IBRA REGION clear-sky MIR DISTRIBUTION 99th percentile VALUES on BACKGROUND PLOT, WITH SUSPECT HOTSPOTS WITH MIR VALUES 6K and 20K ABOVE the CLEAR-SKY MIR 99th DISTRIBUTION VALUE.

Outputs

- Engel, C., Jones, S. and Reinke, K., 2018. Performance of fire detection algorithms Using Himawari-8, in *Research Proceedings from the Bushfire and Natural Hazards CRC and AFAC conference*. 9pp (non-peer reviewed).

DEVELOPMENT AND POTENTIAL OF A MULTI-RESOLUTION FIRE LINE PRODUCT.

Rationale

AHI-FSA (Advance Himawari Imager - Fire Surveillance Algorithm) is a new wildfire surveillance algorithm that uses three independent threshold conditions to MIR, NIR and RED channels to detect fire-line pixels, and in doing so can map fire activity from a spatial resolution of 2km x 2km to 500m x 500m. This has potential benefits to fire detection using geostationary satellites which suffer from coarse spatial resolutions. Combined improvements in spatial resolution and high frequency of observations have the potential to provide information on fire activity in near-real time.

Method and Results

In the AHI-FSA, a potential fire day image is compared to a non-fire day image that is a cloud and fire free composite image with the same timestamp as the fire day. These two images form the basis of implementing the conditions that result in fire line activity. The three conditions are designed to detect thermal anomalies, changes in vegetation cover due to fire, and the edge between smoke and non-smoke pixels. The first condition is the "MIR condition" where thermal anomalies are detected using a contextual based approach. Outputs from "MIR condition" are the first layer of data available for fire surveillance named AHI-FSA 2 km detections. The second layer of data available through AHI-FSA is the AHI-FSA 500m fire-line pixels. AHI-FSA 500m fire-line pixels are detected when all three AHI-FSA conditions are satisfied.

AHI-FSA was intercompared against LEO hotspot products and Landsat-8 burnt scars using case study fires as well as an annual data set. Initially, case study fires over the northern grass/woodlands of Australia was used for intercomparison where there is a relatively high number of wildfire activity in this region, as well as being an area well documented in the remote sensing of fire literature.

Preliminary results showed AHI-FSA was able to detect a single VIIRS hotspot, 40% of the time over the Northern Australian woodland. Schroeder et al. (2014) demonstrated VIIRS hotspots were able to detect fires 0.01 ha in size at 800k with 50% confidence suggesting AHI-FSA could be detecting much smaller fires compared to 14 ha (375 m x 375 m) VIIRS single hotspots ground resolution. Case study fires demonstrated the improved fire surveillance capabilities of AHI-FSA 500 m fire-line pixels. Continuously tracking fire movement, every ten minutes, AHI-FSA 500 m demonstrated 25% Australia wide commission error when intercompared to VIIRS hotspots. Over Northern Australia, this figure was 7% intercompared to Landsat-8 burnt scars suggesting correct detection by AHI-FSA. AHI-FSA 500 m tend to have high omission error when compared to near synchronous LEO hotspots. However, when a daily temporal window is considered lower omission error is observed; AHI-FSA 500 m reported a low 7% omission error compared to MODIS in the Northern Australia when daily composite was used. Over all resust demonstrated AHI-FSA can be used for wildfire surveillance in remote parts of Australia where resources can only be deployed for a hand full of high-risk fires. AHI-FSA can be used to identify fires that are rapidly developing, suddenly changing direction and moving toward settlements and fires that gradually dying down.

Outputs

- Wickramasinghe, C., Wallace, L., Reinke, K. and Jones, S., 2018. Implementation of a new algorithm resulting in improvements in accuracy and resolution of SEVIRI hotspot products. *Remote Sensing Letters*, 9(9), 877-885.
- Wickramasinghe, C., Wallace, L., Reinke, K. and Jones, S., 2018. Intercomparison of Himawari-8 AHI-FSA with MODIS and VIIRS active fire products. *International Journal of Digital Earth*, pp.1-17

KEY MILESTONES

Key milestones for Active Fires are summarized according to: development of the algorithms, supporting products and intercomparison methods, and end-user trials.

Two algorithms have been developed and evaluated in case study situations. The next phase examines these across longer time periods and over greater areas. As part of the validation process, a new approach was developed to derive errors of omission and commission with algorithm outputs. This was necessary to facilitate the comparison of hotspot products that are created from sources with very different spatial resolutions and temporal frequencies.

Both the time-series based fire detection algorithm and multi-resolution fire line mapping algorithm required a cloud mask for implementation of each algorithm, and also to perform an accuracy assessment. In Australia, an accurate cloud mask for Himawari-8 was not available. Without a cloud mask it is not possible to implement the algorithms or undertake a thorough validation analysis. As a result, the literature was reviewed and a publication by Xu et al. (2010) was implemented to generate the necessary cloud mask. This was implemented for 2016 Himawari-8 data. Further analysis showed a decreasing reliability in the cloud mask along coast areas and in southern Australia. However, it was an improvement on what was currently available.

Resulting from the analysis into the implementation of a cloud mask was a second, new fire detection algorithm based on regional and seasonal statistical thresholds. The advantage of this approach is it does not rely on a cloud mask, rather embedding these types of anomalies within the algorithm process itself. Preliminary results with low earth orbiting satellite hotspot products are favourable, and comparisons with WF-ABBA indicate this new algorithm significantly improves in reducing false alarms, a well-known issue with WF-ABBA.

Planning is under way with NSW RFS, with data support from the Bureau of Meteorology, for a near real time trial of the new detection algorithm in early 2019. The scope of the trial and metrics for capturing performance are being developed in partnership with end-users.

UTILISATION OUTPUTS

Utilisation outputs to date consist of:

- AHI cloud mask code based on Xu et al. (2010) and assessment of utility in Australia applied to 2016 data
- two AHI early fire detection algorithms
- one fire mapping algorithm at two spatial resolutions (2km, 500m)
- new approach for the intercomparison of high frequency + low spatial resolution satellite products with low frequency + high spatial resolution satellite products
- demonstration of performance of algorithms against other operational fire products

PUBLICATIONS LIST

- Hally, B., Wallace, L., Reinke, K., Jones, S. and Skidmore, A., 2018. Advances in active fire detection using a multi-temporal method for next-generation geostationary satellite data. *International journal of digital earth*, pp.1-16.
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