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ANNUAL REPORT 2018-2019

Active fire detection using the Himawari-8 satellite

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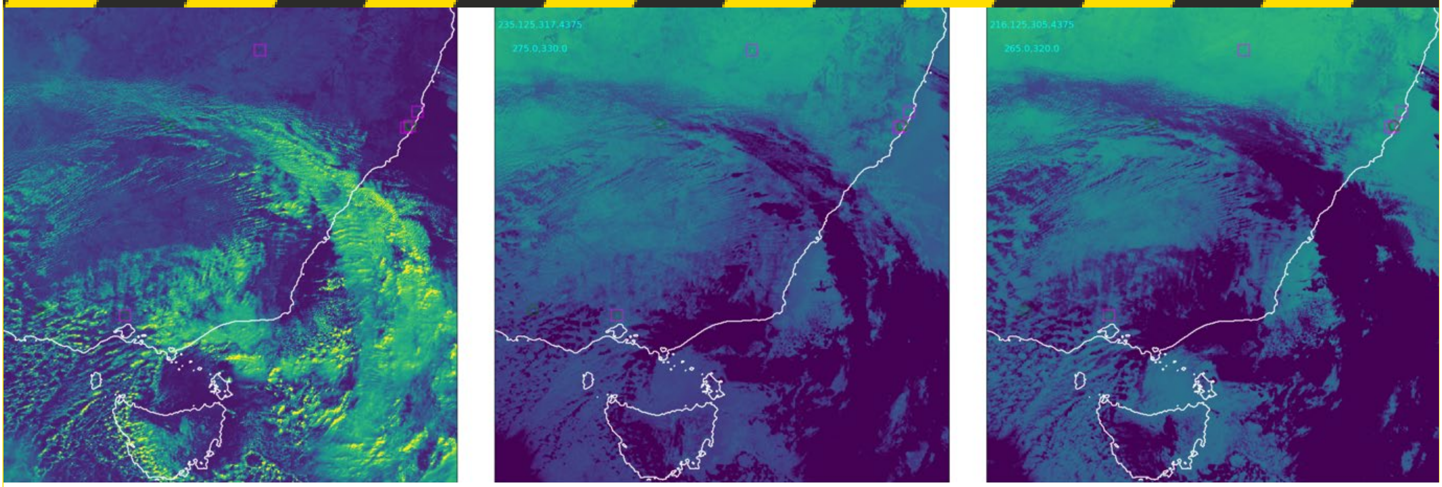

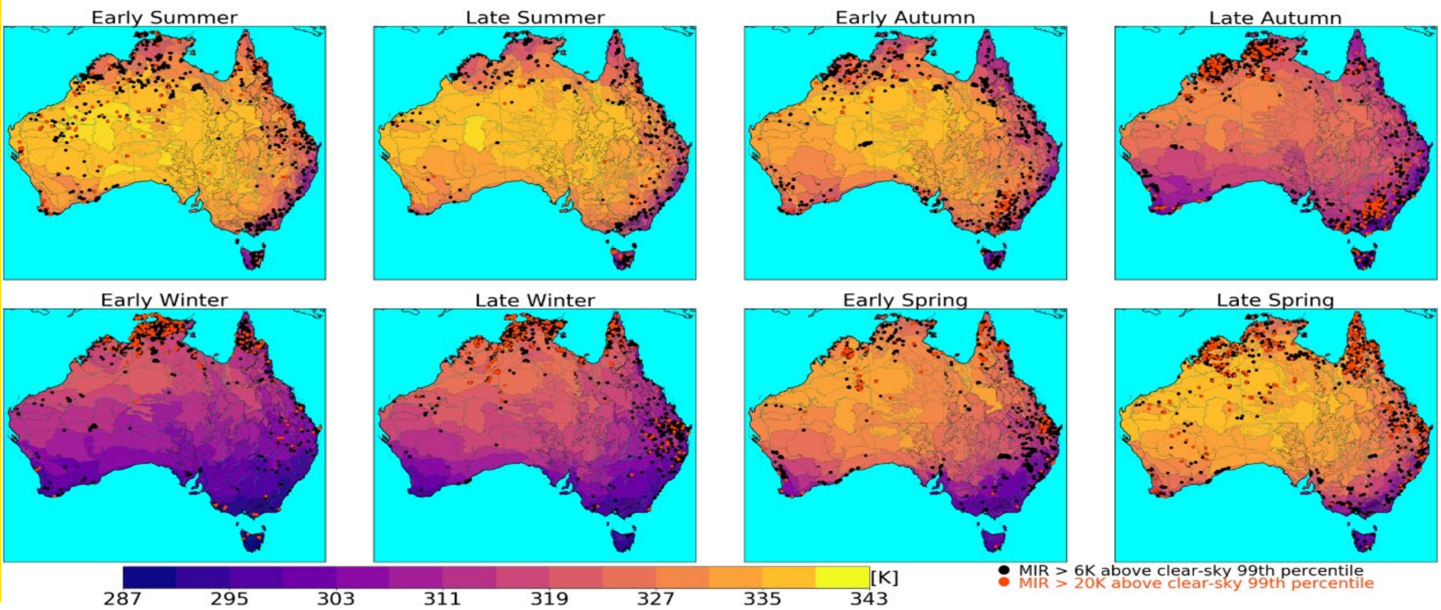

Version	Release history	Date
1.0	Initial release of document	06/04/2020

Publisher:
Bushfire and Natural Hazards CRC

April 2020

Citation: Jones S, Reinke K & Engel C (2020) Active fire detection using the Himawari-8 satellite – annual report 2018-19, Bushfire and Natural Hazards CRC, Melbourne.

Cover: 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.

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ACKNOWLEDGMENTS

The project team gratefully acknowledge the assistance of end-users from across Australia including the Victorian Department of Environment, Land, Water and Planning, Geoscience Australia, and in particular the New South Wales Rural Fire Service, for supporting and hosting a near-real time trial of the new Himawari-8 hotspot algorithm. Acknowledgements also go to the National Computing Infrastructure (NCI) and RMIT (EOS) for providing important computing resources to support rapid processing of imagery and also to the Bureau of Meteorology for the immediate access to Himawari-8 imagery. Each of these agencies' contributions facilitated timely improvements to the algorithm, and enabled the practical and scientific merits of the solution to be demonstrated.

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? One aspect of evaluation is how does the algorithm, and implementation of the algorithm as a processing chain, perform under operational circumstances. To this end, an end-user trial was hosted by NSW RFS for the near-real time implementation of the new AHI hotspot algorithm.

Highlights of 2018 – 2019 have included:

- Five peer-reviewed, international journal publications.
- A Himawari-8 cloud mask is implemented and assessed based on published international literature for suitability in Australia. Significant limitations on fire detection reliability leads to new cloud-independent method for improved detections.
- 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.
- Two project PhD students completed.
- End-user trials for near-real time testing of algorithm completed and ongoing since 2019 with rollouts planned for other states.

END-USER PROJECT IMPACT STATEMENT

Brad Davies, *Rural Fire Service, NSW*

´As a way of accelerating this exciting research toward industry utilisation, the NSWRFS proposed to the research team a real-world 'live' trial of the experimental satellite fire detection algorithm under development. The RMIT project leaders were keen to pursue the NRT trial to identify opportunities to refine their work in a practical setting, as well as obtain real-world performance data. The RFS invested the time and expertise to incorporate RMITs work into existing systems so it can run in parallel with currently operational satellite detection systems. Early industry utilisation has become a very important step in the research programme itself. That is, using an incomplete product in a trial within an agency prior to the conclusion of the research project has enabled the research team to develop, troubleshoot, and refine their work.´

INTRODUCTION

This project is a critical part of the BNHCRC's value to the broader Australian government. The government run Sentinel Hotspots application is used by all levels of government, private sector, researchers and the public. This project will assist the Australian government to develop and validate Himawari-8 as a data source for the Sentinel Hotspots application. Our vision is to create a world leading approach to monitor fire activity. To achieve this, we propose the use of remote sensing technologies for active fire detection and monitoring.

This project is a critical part of the BNHCRC'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. 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 into the future.

The aim this project is to next generation, remote sensing satellite information to enhance Australia's operational capabilities and information systems for bushfire monitoring across a range of spatial scales and landscapes. Ultimately the outcomes of this research will enable measures of active fires in terms of areal extent and magnitude, which in turn will have the potential to inform decisions about bushfire response, fuel hazard management and ecosystem sensitivity to fire; during fire events and post - fire rehabilitation efforts.

The following sections describe the background, research approaches, key milestons, a utilisation study and outputs of our Himawari-8 active fire detection research.

BACKGROUND

Fire over Australia is a continuing natural hazard that needs to be monitored. Frequently and accurate monitoring of fires, particularly over such a large land-mass, is complex particularly when using satellite data to highlight likely locations of fires. Humans can subjectively use satellite-data to detect fires, but automated detection of fires is more efficient, the algorithms more reliable, and the results can be more communicatable and archivable. Automated fire detections from polar-orbiting satellites such as MODIS and VIIRS are currently used via the Sentinel website.

In October 2014, the Japanese Meteorological Service launched a new geostationary satellite that has the potential to detect fires over all of Australia every 10-minutes. The Himawari-8 satellite orbits centered on 140.7°E, with Australia located well within its full-disk area. The Japan Meteorological Service, in co-operation with the Bureau of Meteorology, gratiously make Himawari-8 observations available to Australian researchers. Himawari-8 observes 16 channels, ranging from visible to infrared, with spatial resolutions from 500m to 2000m, taking full-disk scans every 10-minutes. With such a wealth of information suddenly available, the question becomes: is it possible to use Himawari-8 satellite data to automatically detect fires over Australia every 10-minutes?

Himawari-8 does have the remote-sensing channels required to detect active fires but developing a fire dectection algorithm for Himawari-8 data is complex. Fires radiate strongly in the middle-infrared channel (MIR). They radiate so strongly that even fires taking up a small fraction of a pixel can raise the pixel MIR value. But, a raise in the MIR value is hard to determine without a fixed pre-fire or "background" value. Pre-fire or "background" MIR values change due to diurnal and meteorological fluctuations. And to complicate matters futher, reflected sunlight from clouds can also raises MIR values. The complexity of detecting fires in satellite data increases further when the pixel size increases (i.e. from 1000m to 2000m). Satellite pixels represent observations over an area. The physical properties of an area may be uniform, but they may also be discontinuous; fire and non-fire; cloud and non-cloud. Larger pixels may not be able to resolve these small-scale physical processes. Instead these processes become "blurred" along with the other data, altering the dominant value proportionally. This "blurring" of small-scale processes presents a challenge, and some fires may present as relatively small-changes in non-stationary datasets.

New approaches are required to efficiently detect active-fires using the Himwari-8 satellite data. Existing active-fire detection algorithm tailored to polar-orbiting algorithms rely on the higher-resolving power of those datasets. The polar-orbiting fire detection algorithms allow for *some* residual noise due to unresolved processes, but the amount of unresolved processes is assumed to be small. Increasing the amount of unresolved processes may cause the algorithm to become ddegraed. Existing geostationary algorithms, like WF-ABBA, cope with unresolved processes by adding in numerical weather prediction information. Numerical weather prediction information is complex, undergoes frequently updates and is difficult to source in real-time. The aim of this project is to create new Himawari-8 active-fire detection algorithms that can cope with unresolved processes while not using additional numerical weather prediction information.

RESEARCH APPROACHES

STATISTICAL 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.

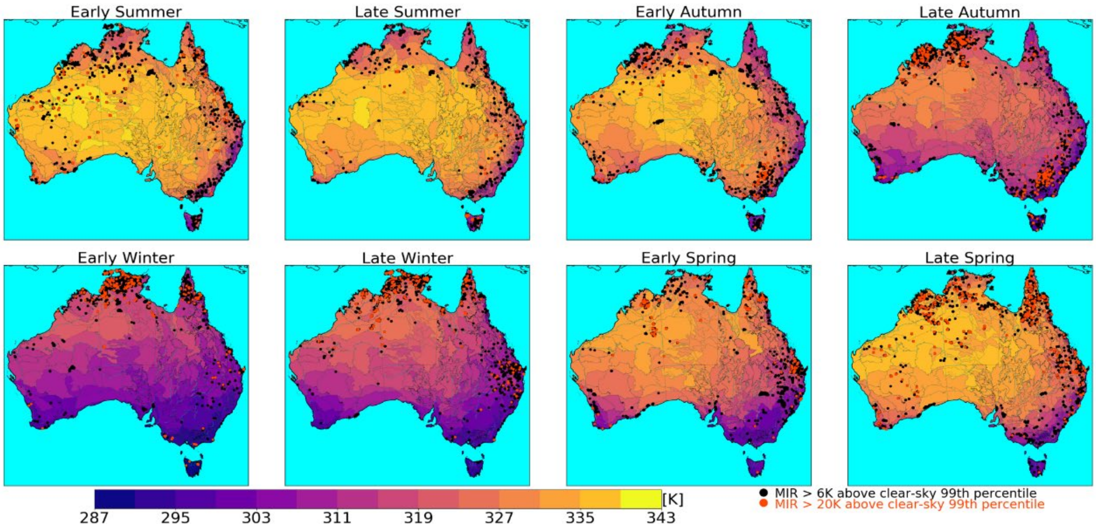

FIGURE 2 SUB-SEASONAL AND IBRA REGION CLEAR-SKY MIR DISTRIBUTION 99TH PERCENTILE VALUES ON BACKGROUND PLOT, WITH SUSPECT HOTSPOTS WITH MIR VALUES 6K AND 20K ABOVE THE CLEAR-SKY MIR 99TH DISTRIBUTION VALUE.

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).

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 1 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 2 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.

MULTI-RESOLUTION FIRE LINE PRODUCT FOR EARTLY FIRE DETECTION

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. Overall this 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

Cloud-mask datasets for cloud-dependent algorithms implemented and supporting PhD student submissions and publications. Implementation of a cloud-mask (highlighting reliability issues with the published cloud-mask algorithm for fire detection) and review of existing satellite-based fire detection techniques leads to the development of a new approach for Himawari-8 imagery. Key steps involved:

- Proposal of new fire detection technique for Himawari-8
- Implementation of new technique
- Test technique on full-year dataset over all of Australia
- Analysis of output and revision / minor tweaks
- Present new algorithm at AFAC.
- Implement data processing chain from satellite data ingestion from BoM through to delivery to end-user agency.
- Set up NSW RFS trial and receive feedback.
- Modify algorithm.
- Validate old and new algorithm.
- Prepare original algorithm paper for publication, and begin extensive validation work for second paper for publication.

UTILISATION AND IMPACT

SUMMARY

RMIT hotspots were made available to NSW RFS in near real-time. The real-time trial led to further improvements to the RMIT algorithm, and NSW RFS had a chance to become more familiar with the RMIT hotspots and Himawari-8 data.

REGIONAL TRIAL

RMIT used Himwari-8 data made available by the Bureau of Meteorology, from February 2019 to May 2019, to deliver active-fire hotspots to NSW RFS in near real-time. Processing time for the algorithm from the receipt of the Himawari-8 imagery through to final hotspot delivery was typically 2 minutes.

Extent of use

- RMIT delivered active-fire hotspots to the NSW RFS in near real-time.
- Feb 2019 to May 2019 (and beyond).
- NSW RFS made active-fire hotspots available to operational users via a graphical interface that included both location and timing information.
- The hotspots were used in an exploratory fashion.
- RMIT also monitored hotspots in a more localized way.

Utilisation potential

- Hotspots available from Himawari-8 <u>every 10 minutes, 24 hours a day</u>.
- Highlights areas with anomalous MIR values over NSW.
- For detection, monitoring and fire-fighting purposes.

Utilisation impact

- Changes to the algorithm.
- Changes to the outputs (extra info, plus “clouds”).
- The RMIT hotspots were made available to NSW RFS in almost at the same time the Himawari-8 became available, with a roughly minute delay beyond the Himawari-8 latency. This was achieved using modest computing resources, highlighting the potential for RMIT hotspots to be used in a operational setting time-wise.
- Demonstrated feasibility of algorithm.
- Allowed NSW RFS to start thinking of how to best use such data volumes.

NEXT STEPS

Update the output (format, attribution) in consulation with NSW RFS.

Joint RMIT and NSW RFS AFAC presentation and paper.

Publications + Conferences.

Expand the trial to other regions

Back-run the trial algorithm over a large time-period (12 months) for additional validation.

PUBLICATIONS LIST

PEER-REVIEWED JOURNAL ARTICLES

1 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.

2 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), pp.877-885.

3 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.

4 Jones, S., Hally, B., Reinke, K., Wickramasinghe, C., Wallace, L. and Engel, C., 2018, July. Next Generation Fire Detection from Geostationary Satellites. In *IGARSS 2018-2018 IEEE International Geoscience and Remote Sensing Symposium* (pp. 5465-5468). IEEE.

5 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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