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TECHNICAL REPORT 13

Preliminary assessment of the suitability of the Canadian WildFireSat mission for Australian Bushfire Management

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Executive Summary

The Canadian WildFireSat mission is the first satellite system specifically designed to provide timely operational fire suppression intelligence to Canadians Incident Management Teams (IMTs) at the most appropriate time of day to support operations. As such allows for tailored bushfire management outcomes which are not possible with existing multi-purpose systems. Given Australia does not have access to such tailored information, WildFireSat could provide key bushfire management information in Australia if proper mechanisms were put in place for Australia to receive WildFireSat satellite data.

This report assesses the suitability of the WildFireSat mission for Australia and identified that the current WildFireSat mission design will not have sufficient coverage in Australia and will not collect the data at Australia's peak fire activity or delivered early enough for Australian Incident Management Teams to incorporate the information in their planning reports. Additionally, WildFireSat science products would need to be evaluated and quite likely re-calibrated in Australia to increase the confidence and credibility of the products. Finally, a potential challenge is to manage the amount of raw data generated by WildFireSat for Australia.

The report concludes by giving 6 recommendations to address those issues and highlighting opportunities for Australia to collaborate on implementing those recommendations with the provision of ground stations for direct downlink, creating joined Canadian-Australian science teams and augmenting the WidFireSat fire monitoring mission with a prediction capability enabled by the Australian Ozfuel sensor allowing aspects of pre-, during- and post- fire stages to be addressed in a more integrated manner.

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1.0 Introduction

Bushfires are increasing in quantity, length, impact and intensity globally as fire activity is linked to our changing climate (Abatzoglou et al. 2019, Canadell et al. 2021). Under this situation of bushfires, land management agencies and emergency services need the best possible data to inform planning, preparedness, response and recovery activities (Australia. Royal Commission into Natural Disaster 2020).

Satellite remote sensing deals with pre-fire assessment, active fire detection, and fire effect monitoring providing critical bushfire management information (Chuvieco et al. 2020). However, most fire products currently used by fire managers in Australia and worldwide are derived from sensors that were designed for other purposes. Therefore, these satellite-derived products do not fit the spatial or temporal resolutions requirements for appropriate bushfire management activities and lack the accuracy required for decision-making. The Australian Space Agency (ASA)'s Bushfire Earth Observation Taskforce (the Taskforce) highlighted the need to provide regular, assured satellite imagery and its derived products and services to support bushfire management in Australia (Taskforce 2020). To that end, the Taskforce recommended the federal and state governments and agencies to explore opportunities that leverage and develop Australia's space industry to provide new satellite imagery capabilities, including collaboration on future platforms, to secure access to key data, address data gaps (revisit and resolution) and support the global observing system (Taskforce 2020). As part of this assessment, Australia could consider developing its own satellite capability with new satellite missions specifically designed for bushfire risk management that can deliver the required spectral, spatial, temporal and radiometric resolution and/or contribute to international missions with the same aim.

Australia's first National Space Mission for Earth Observation (EO) (NSMEO) program will see Australia design, build, and operate four new satellites to (1) improve the calibration of international operation EO missions, (2) monitor water quality, (3) map forest fuel flammability traits and (4) lightning detection and tracking. None of these missions aim is fire monitoring.

Canadian WildFireSat mission is the first satellite system specifically designed for wildfire monitoring supported by ~$170 M in government funding to the Canadian Space Agency, Natural Resources Canada and Environment and Climate Change Canada over the next 11 yr. WildFireSat will provide imagery with 400 m resolution (nadir) within 30 minutes of collection, with a significant portion of measurements occurring during their peak burn period (6 pm). With these specifications, WildFireSat will fill a gap in satellite-based wildfire monitoring data availability in Canada. The mission's objective is to provide fire situational awareness (perimeter mapping and progression, fuel consumption and carbon emissions and smoke plume dynamics) for Canada (a full list of planned science products can be found in Annex I). The provision of reliable, standardised operational fire suppression data supports a business case for developing wildfire operational systems in Canada including training of staff in the use of the products.

In principle, WildFireSat aligns well with the recommendations of the Taskforce and could provide critical fire suppression information in Australia if proper mechanisms were put in place for Australia to receive WildFireSat satellite data. Indeed, WildFireSat is highly complementary to the NSMEO's fuel flammability and lighting monitoring missions which have a greater focus on aspects of pre-fire stage. Consequently, investment by both countries can be leveraged given the Canadian government has an appetite to export WildFireSat mission internationally and bring in more partners (Joshua Johnston, Natural Resources Canada. Personal Communication). There is a unique opportunity for Australia to partner with WildFireSat and a need to develop a detailed feasibility study/business case outlining the options available and ultimately considered by the government.

This report was commissioned by SmartSat Cooperative Research Centre (CRC) and MDA space to provide an initial assessment of the feasibility of the use of the WildFireSat mission data for Australian bushfire management. Specifically, this report identifies several issues to making WildFireSat work in the Australia context to leverage decision-makers to overcome those issues. SmartSat CRC and MDA seek to understand the mission feasibility, specifically how the payload and concept of operations (ConOps) can monitor Australian bushfires. Recommendations for where MDA and SmartSat could pursue future work are provided.

This report is not comprehensive and does not include extensive consultation. It primarily considers Australia's current and anticipated capability in terms of active fire detection, surveillance, and monitoring. This assessment leverages ANU's experience and knowledge of bushfires in Australia due to A/Prof Yebra's participation in the Taskforce, the Victorian Department of Environment, Land, Water and Planning's Scientific Reference Panel and the ACT Multi Hazards Advisory Council. Knowledge from official workshops organized over the last 3 years as well as national and regional Bushfire Enquiries and recent published literature and consultation with key end users are also be used. Experts consulted in the process are listed in the acknowledgement section and mentioned as appropriate within the text.

2.0 Technical and operational challenges for active fire (hotspots) detection, surveyance, and monitoring in Australia

This section presents a high-level overview of the current use of satellite data by emergency services in Australia for fire detection, surveillance and monitoring as investigated by the Taskforce (2020) emphasizing the key technical and operational challenges that could potentially be filled in by the WildFireSat mission.

The Taskforce (2020) concluded that the spatial and temporal resolutions of current satellite sensors are unsuitable for early fire detection of small fires but are key to providing fire situational awareness (Figure 1). Providing bushfire situational awareness is especially relevant over the vast and remote rangelands and savannas of Australia (approximately 70% of Australia), therefore, most fire detection processing algorithms for widely available satellite data in Australia have been developed for monitoring or situational awareness purposes, rather than early detection.

	SUCCESSES	LIMITATIONS
DURING-FIRE: response	✓ Collaboration and sharing of resources ✓ Line scanning aircraft available to provide near-real time imagery of fires ✓ Hotspots for strategic fire mapping ✓ Weather observation ✓ Water bodies mapping for large aircraft to re-stock	× Tasking of high-resolution data via satellite too slow × Insufficient coverage of multiple large fires via airborne × Difficult to know if detected hotspots are false positives × Commercial licencing arrangement are a barrier to data sharing × Resolution & frequency of data available for tactical response

Figure 1 - Summary of the successes and limitations in preparation for the "during-fire" stage of bushfire decision-making. Source: Adapted from Taskforce (2020)

Most Emergency services Agencies in Australia use Digital Earth Australia's (DEA) Hotspots satellite product (https://hotspots.dea.ga.gov.au/). DEA Hotspots is a national bushfire monitoring system that uses satellite data to provide information about active fires using sensors onboard various satellites (Table 1). The sensors used include Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS), NOAA Advanced Very High-Resolution Radiometer (AVHRR), Suomi-NPP Visible Infrared Imaging Radiometer (VIIRS) and Himawari-8 Advanced Himawari Imager (AHI). Data from each sensor is processed with different algorithms. This data coming from various sensors is at least 17 min old and have high spatial uncertainty (1.5 km) but can be as frequent as 10 min.

Sentinel 3A/3B (S3) will be a useful addition to DEA considering that MODIS sensors will be decommissioned between 2023-2027 (NASA 2022). However, there are issues with using Sentinel 3A/3B a Fire Radiative Power (FRP) product for Australia. First, the narrow imaging swath means Australia is not covered daily and some validation work done by Geoscience Australia (GA) shows the hotspots derived from the S3 FRP product aren't accurate due to instrument saturation and algorithm limitations. Secondly, there is a delay between acquisition and data access in Australia. The Copernicus Australasia Regional Data Hub uses a dedicated link to the EU Copernicus International Partner's hub to replicate a local copy of Sentinel products within Australia. At present, the S3 fire products such as FRP are not synchronised in near-real-time (NRT) with the regional data hub, resulting in hours-old data when it is available in Australia, nullifying any advantage of close-to-real-time fire detection and situational awareness in the morning provided by Sentinel 3A/B sensors. The Hub is currently looking at a replacement platform that may improve the ability to synchronise NRT products in a timely manner (Michael Hope, Project Manager Copernicus Australasia Regional Hub, Personal Communication).

Fire managers across Australia's Tropical Savannas and Rangelands rely, almost exclusively, on satellite-based information on hotspot location (mainly accessed from the Northern Australia Fire Information (NAFI) hotspots system, https://firenorth.org.au/nafi3/) to inform them of the potential location of fires, as the distances between human habitation are in the order of 100's of kilometres. NAFI Hotspots are sourced from Landgate Western Australia (https://myfirewatch.landgate.wa.gov.au) and GA DEA Hotspots. The timeliness of the warning influences the value of the data to a range of operational activities. Although Tropical Savannas and Rangelands are sparsely populated, the Carbon Farming industry is worth millions of dollars per year, and relies on good fire management activities which, in turn, are informed by satellite imagery (Dr Andrew Edwards, Charles Darwin University, Personal communications).

Table 1: Summary of the satellites used for hotspot detection in Digital Earth Australia Hotspot System

Sensor/Instrument	Spatial resolution (m)	Temporal resolution	Equatorial pass over
MODIS TERRA	1000	Once to twice a day	10:30 and 22:30
MODIS AQUA	1000	Once to twice a day	13:30 and 01:30
VIIRS NOAA20	375	Twice a day	14:30 and 02:30
VIIRS SUOMI_NPP	375	Twice a day	13:30 and 01:30
Himawari-8	2000	10 minutes	Constant
AVHRR NOAA18	1000	Once a day	17:30
AVHRR NOAA19	1000	Once a day	14:00

One key limitation of satellite hotspot products is that it is difficult to know which hotspots are false positives and which are new fires. As with many satellite-mounted sensors, some fire areas are not picked up due to cloud cover. These factors impact decisions to redeploy resources to fight new fires when existing fires are burning. Unlike more intensely inhabited regions of Australia, in the remote rangelands, the false positives are a slightly bigger management problem than false negatives (omission is still important) as this is the only source of information and cannot be cheaply verified on the ground. Another limitation is that current hotspots derived from the different sets of existing sensors still have limited capability to map the fire front progression. The addition of Himawari-8 with 10 minutes temporal resolution is promising but it tends to detect only the larger fires and the lower spatial resolution produces hotpots kilometres in front of or behind a MODIS/VIIRS-visualised fire front. This tends to confuse fire managers until they realise it is a quite different system for more frequently updated tracking of large, fast-moving fires (Dr Peter Jacklyn, Charles Darwin University, Personal communications).

To get high-resolution imagery of the fire front, Australia needs to task satellites. The constraints with tasking satellites are:

- Emergency Charter relies on single locations and collecting imagery against those locations. Given that fires move too rapidly this information on single locations is not useful.
- Slow tasking and imagery receipt for satellite imagery means it is only useful for planning purposes (one to three days ahead), not for real-time decision-making.

This means that, by the time the imagery arrives to the fire managers, the firefront has significantly changed and the data becomes obsolete, highlighting the need for NRT mapping of the firefront. In certain bushfires, line-scanning aircraft are deployed to get a high-resolution overview of the fires across large burning areas (20km swaths). Helicopters are deployed for smaller area fires (1km swaths) and small drones are used to acquire imagery for a specific area in NRT (100m swaths) for tactical fire-fighting monitoring and response. However, some state emergency departments such as South Australia (SA) do not have access to aircraft for high-resolution fire front mapping and those states that have the capability do not perform a scan regularly. Line scans are used when fire behaviour is extreme, or overnight for hotspot detections (mainly 12:00 - 02:00) (Simeon Telfer, Department for Environment and Water, SA, Personal Communication).

Additionally, the piecemeal nature of existing satellite-based detection systems means that the business case for developing operational suppression systems and investing in the staff to run them cannot be made. Emergency services just go to helicopters or linescan aircraft and their systems are designed to handle the outputs of those platforms (Dr Adam Leavesley, ACT Parks and Conservations Service, Personal Communication).

3.0 Brief Summary of the Canadian WildFireSat mission

The Canadian WildFireSat mission is the first EO satellite system specifically designed for active wildfire monitoring. The satellite is expected to carry a multi-band payload covering the visible and Infrared (IR) spectrum. More specifically it will collect data in at least one band in each of the follow spectral ranges:

- Midwave Infrared (MWIR) – as narrow as possible between 3.4 μm and upper bound of 4.2 μm
- Longwave Infrared (LWIR): 10.25 – 12.45 μm
- Near Infrared: 0.75-0.95 μm
- Visible: 0.35-0.75 μm

Data will have 400 m spatial resolution (at nadir) and will be available for end users within 30 minutes of collection, with a significant portion of measurements occurring during their peak burn period. In general, Canadian boreal forests wildfire activity peaks in the late afternoon period centred around 18:00 local time known as the "peak burn period", with smouldering combustion activity overnight and in the early morning (Figure 2)

In contrast to currently available satellites which fail to observe wildfires during the most active portions of the day (table 1) WildfireSat is being designed to provide data products to fire managers in a timely matter, at a moderate spatial resolution that help managers allocate resources, inform tactics and plan operations for the upcoming hours. In addition, the moderate spatial resolution of WildfireSat provides an improvement on data products from coarse spatial resolution sensors such as Himawari-8.

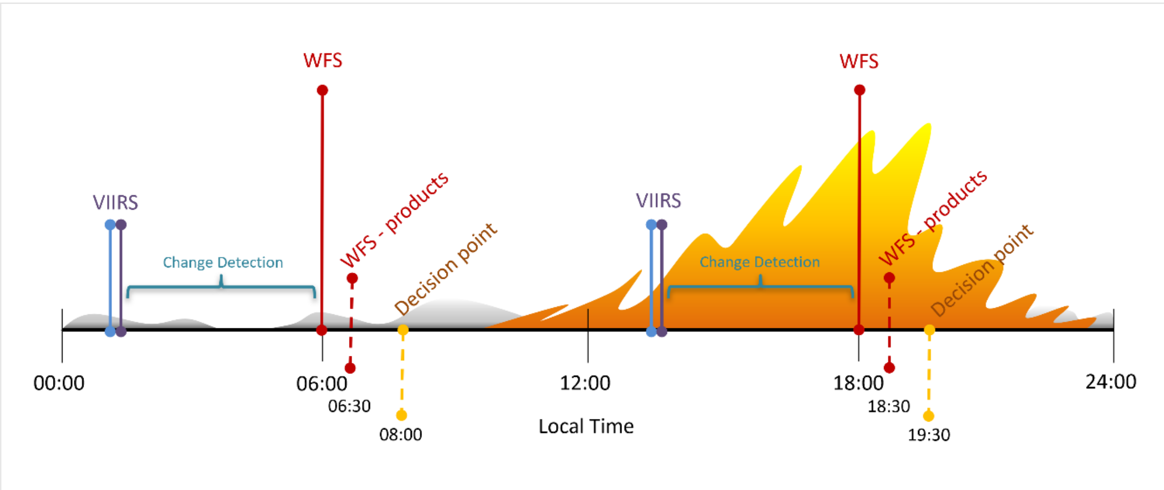

Figure 2 - Strategic active-fire satellite overpass time in relation to the diurnal wildfire activity cycle and strategic data needs for decision making in Canada. Source: Joshua Johnston, Natural Resources Canada.

The Canadian Government has budgeted for downlinks only in Canada. The Canadian ground segment characteristics WildFireSat can be accessed via this LINK. It is anticipated that the Canada Centre for Mapping and Earth Observation (CCMEO) ground segment will be the core of the WildFireSat mission. CCMEO operates three ground stations in Canada, all with X-band capabilities. This support will include Telemetry, Tracking and Control (TT&C) (commands from the Canadian Space Agency), image data downlink, data archive and dissemination of low-level products.

Value-added products, which must be created following the downlink, are expected to be generated and delivered via the Canadian Forest Service, and Environment and Climate Change Canada. These products are described in detail in Annex I, the most relevant the following:

- Calibrated Fire Radiative Power (FRP) data. FRP is the rate at which the actively burning fire is emitting radiative energy (at the time of observation) expressed in units of power (Js-1 or Watts). Through a series of airborne, ground-based and satellite data intercomparisons, FRP is well related to the rate of fuel consumption, smoke aerosol production, and trace gas release, and thus offers a direct route to quantifying the magnitude of these processes (Kaufman et al. 1998, Wooster et al. 2005).
- Hotspot data showing active fire perimeter maps twice daily for operational decisions by the Incident Management Teams (IMTs).
- Rate of Spread (ROS). Measurements and direction of spread are calculated from a time series of hotspots (including other operating systems such as VIIRS).
- Burned Area Mapping at least once per year for carbon accounting.

4.0 Summary of the Canadian WildFireSat mission

A comprehensive assessment of the suitability of the Canadian WildFireSat mission for Australian bushfire management is beyond the scope of this report as it would require additional time and resources. In consultation with MDA and Joshua Johnston (Principal Investigator of the WildFireSat mission) this report focuses on five aspects because they relate to mission design and are based on Canadian technical and operational challenges that may differ in Australia; while differing, these five areas of investigations provide higher opportunities for collaborations between the two countries.

These key focused areas investigated are:

1. **Revisit and coverage.** Evaluate the revisit times of the current WildFireSat mission in Australia and the coverage as the greater the temporal and spatial gaps in data acquisition the lower the capability of providing intelligence to maintain situational awareness during periods of escalated bushfire activity fires.
2. **Timing of acquisition.** Evaluate if the 6 am and 6 pm WildFireSat scheduled acquisition also coincides with the time of fire peak activity and key management decision-making in Australia.
3. **Downlink options and feasibility.** Evaluate if Australia is prepared to receive and store WildfireSat raw data to reduce delays in data access and processing.
4. **Science Products.** Evaluate if the WildFireSat science products apply to Australia and the feasibility of Australia producing those products in NRT.
5. **Complementarity with other planned Australian Satellite missions.** Provide an assessment on how WildFireSat complements or overlaps with other satellite missions planned in Australia.

4.1 Revisit and Coverage

The first aspect to consider is the revisit times and the coverage of the current WildFireSat mission in Australia as the greater the temporal and spatial gaps in data acquisition the lower the capability of providing intelligence to maintain situational awareness during periods of escalated wildfire activity fires.

While the majority of Canada (target area) will have a ~12 hr revisit period (6 am and 6 pm) with only occasional gaps, most of Australia will have on average, a 18-24 hr revisit period (Figure 3).

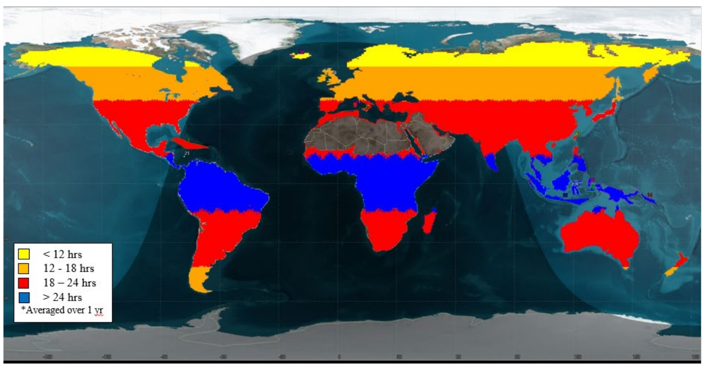

Figure 3 - Modelling for revisit times based on the updated mission requirements. The revisit times are averaged over 1 year and vary continuously with altitude. Source: Joshua Johnston, Natural Resources Canada.

More specifically, modelling done by MDA Space suggest that over a 24-hour period, a 3 spacecraft constellation mission would cover 68% of the Australian landmass using the scientific goal co-elevation angle and 76% using the limit of acceptance for the co-elevation angle (Figure 4). Modelling over 48 hours results in 86.52% and 91.66% of coverage of Australia while 72 hours are required to cover 96.9% and 98.91% of Australia under the ideal and limited scientific goal, respectively. In other words, it would take approximately 3 days to cover 98% of the Australian mainland which has limited utility for operational bushfire suppression.

The relatively poor coverage for Australia that the current WildFireSat mission will provide will be aggravated by an inherent limitation of visible and near-infrared satellite imagery to collect data on some areas and times of the day more frequently covered by cloud. Overall, in Australia, there seems to be greater cloud cover in the afternoon than in the morning (Figure 5). Across northern Australia, where most of the fires occur, cloud cover significantly increases in the afternoon and evening, especially around the Kimberley region (WA), throughout the Northern Territory, and the Cape York Peninsula (QLD) at 3 pm vs 9 am. On the other hand, northern savannas' intense afternoon fires tend to generate more smoke (Dr Peter Jacklyn, Charles Darwin University, Personal Communications). This means that the WildFireSat 6 pm scheduled visible and near-infrared data collection will be compromised by cloud cover frequently in Australia.

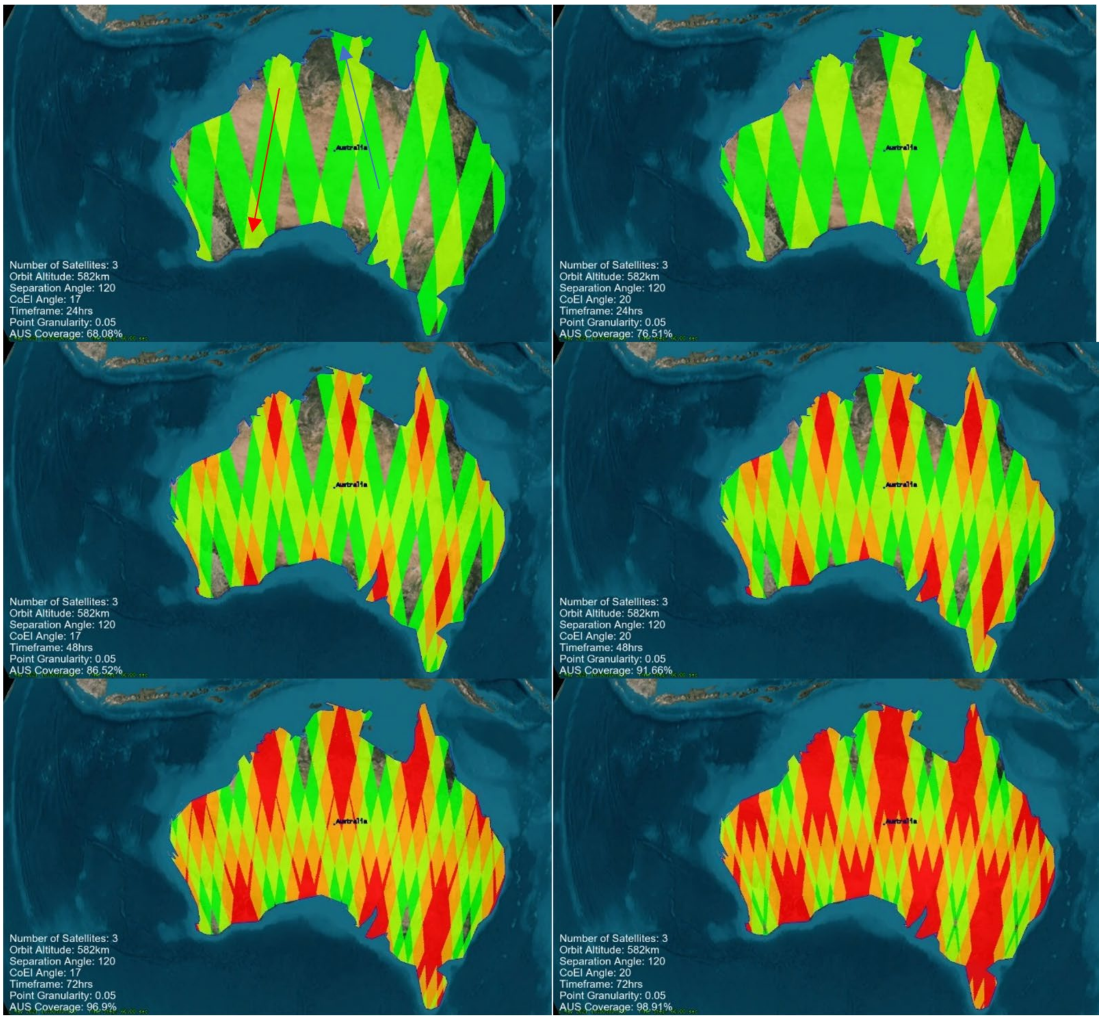

Figure 4 - Coverage plots of Australia were generated using a notional orbit of 582 km and three spacecraft for every 24 (top), 48 (medium) and 72 (bottom) hrs of coverage. Left: The 17-degree co-elevation angle (science goal) and ~325 km swath. Right: 20-degree co-elevation angle (limit of the acceptable science return) and ~385 km swath. The Blue arrow

indicates ascending swath (local time 6 am). The red arrow indicates a descending swath (local time 6 pm). Colours represent the number of times that area was covered for the time period that simulation was run Green=1, yellow = 2, Orange=3 and Red= 4. Source: Provided by MDA Space

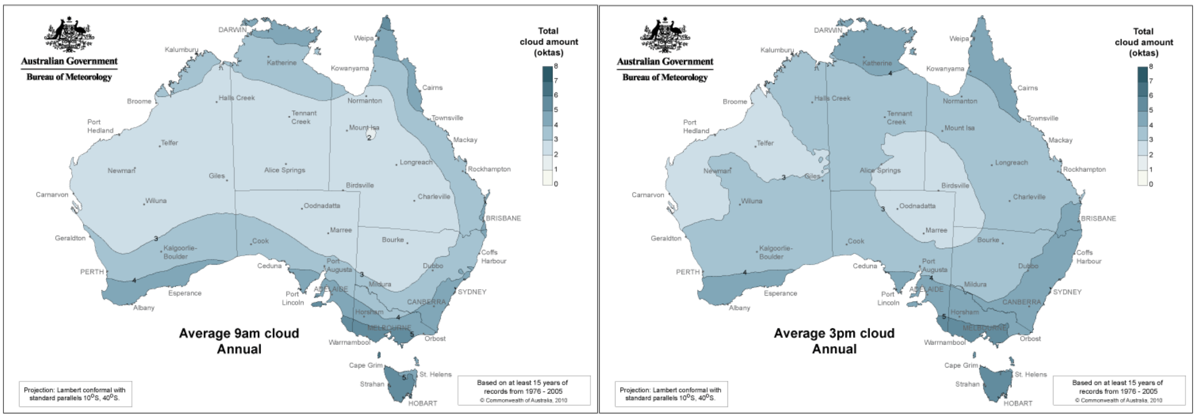

Figure 5 - Long-term (1976-2005) average cloud cover at 9am (left) and 3pm (right)

Adding spacecrafts to the constellation would result on fewer gaps between ascending or descending swaths and, consequently, there would provide additional coverage of the Australian landmass (Table 2). Adding one satellite won't make much of a difference. Even with 5 satellites, a WildFireSate constellation could not deliver a 12-hour turnaround in Australia as it would in as happens in Canada and 6 satellites would only achieve a 12-hour revisit time in 13 and 86 % of Australia with the science and limit acceptance co-elevation angels, respectively. At least 7 spacecrafts would need to be added to the constellation to deliver approximately 12 hr revisit periods across 77% of the Australian landmass. Using the current configuration of WildFireSat, a 100% coverage of Australia imaged with a 12- hour revisit time can only be achieved using 7 or more spacecrafts (Table 2).

Table 2: WildFireSat Coverage metrics for Australia

Constellation Size	Australia % coverage <12-hour revisit time	
	17 deg co-elevation angle (Science Goal)	20 deg co-elevation angle (Limit of Acceptance)
3	0	0
4	0	0
5	2.47	26.32
6	12.66	86.57
7	77.32	100
8	100	100

The % coverage indicates how much of Australia has <12-hour revisit time given the constellation size and co-elevation angle. Note that modelling is done at 582km and equally spaced satellites. For example: for a 5-satellite constellation each with 17deg coel angle, only 2.47% of AUS has a <12-hour revisit time. Source: Provided by MDA Space

The contours of the revisit time give more detail on the specific areas of Australia that will be covered by 6 or 8 hours up to +20 hours revisit times (Figure 6) or 12 hours or less revisit times (Figure7) given a constellation size and co-elevation angle. Note that the Northern Australia would require the largest constellations sizes to be capture with a revisit time of less than 12 hours under the 1 deg co-elevation angle which is the science goal.

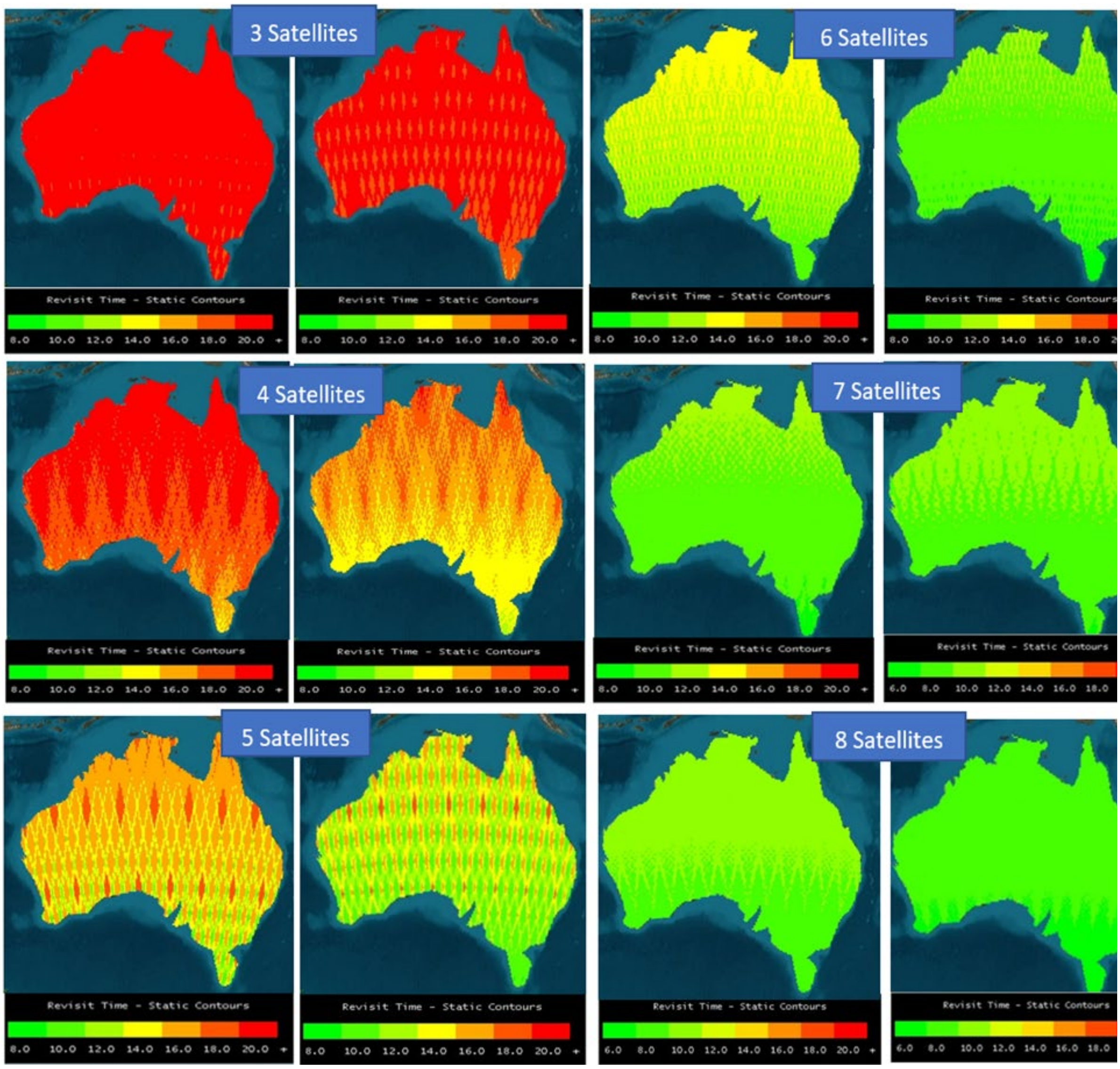

Figure 6 - Contours of the revisit times from 6 or 8 hours to 20+ hours for Australia given a constellation size (1 to 8 satellites) and co-elevation angle (LEFT: The 17-degree co-elevation angle (science goal) and ~325 km swath. RIGHT: 20-degree co-elevation angle (limit of the acceptable science return) and ~385 km swath). Note that the colour scale is not even across the images. Source: Provided by MDA

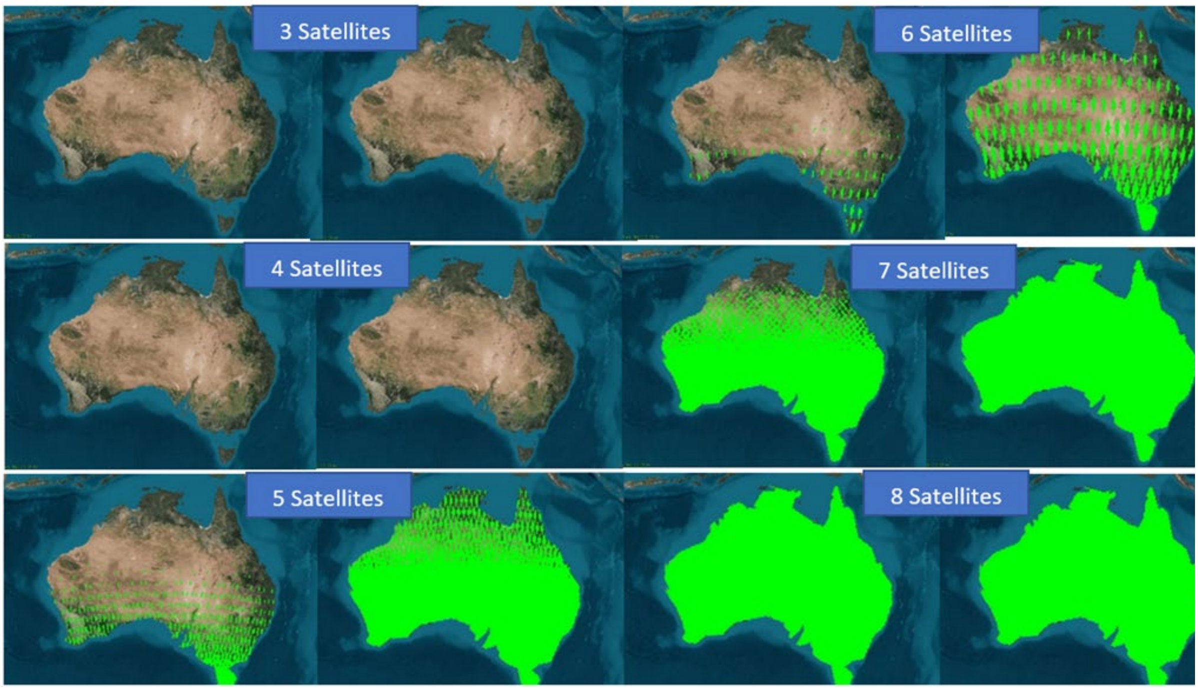

Figure 7 - Australian regions where there is a 12 h or less revisit time (green). LEFT: The 17-degree co-elevation angle (science goal) and ~325 km swath. RIGHT: 20-degree co-elevation angle (limit of the acceptable science return) and ~385 km swath. Source: Provided by MDA

4.2 Timing of acquisition

The second aspect to consider is if the 6 am and 6 pm scheduled acquisition coincide with the time of fire peak activity in the Canadian boreal forest and if key management decision-making fits Australia's needs.

Based on a study by Chatzopoulos-Vouzoglanis (2022) during the Southeast Australian Black Summer Fires, FRP and the number of hotspots were considered indicators of peak fire activity. FRP peaked typically around 3 pm with the number of hotspots increasing in the evening. This holds under various stratifications and fire detection algorithms and sensors (Figures 8,9). It's worth noting that (i) the increase in hotspots in the evening can be due to the sensitivity of detections between the day versus night algorithm; (ii) The Biogeographical Region and Individual Geostationary HHMMSS Threshold (BRIGHT) v1.84 (Day and Night) (Engel et al. 2021) uses different algorithms for night and day conditions; the times when the algorithm changes from dawn to dusk(and viceversa), therefore, show lower accuracies than other times and (iii) the study was taken during the Black Summer and was heavily impacted by clouds and smoke, therefore, limiting the capability of satellite detections (A/Prof Karim Reinke, RMIT University, Personal Communication).

Expanding Chatzopoulos-Vouzoglanis (2022) 's study of the diurnal cycles to the whole of Australia for July 2019 and January 2020 and in woodlands and forests (Chatzopoulos-Vouzoglanis, K. et al, under review) we can see that for the south of Tropic of the Capricorn, fire intensity is at its lowest range around 5 am (local time) and then peaks around 3 pm during Summer (January) with fire intensity reaching its lowest intensity around 7 am, peaking around 1 pm during Winter (July). North of the Tropic of Capricorn, fire intensity appears to peak around 1 pm regardless of the season and reaches its lowest intensities between 6- 7 am. It's worth noting that the observations were limited to January and July data only, representing the two ends of the northern fire season, and as before, the reliability of observations decreases during algorithm switch between dawn and dusk.

Plucinski (2014) investigated the timing of vegetation fires around the city of Perth (Western Australia) using records of fires burning in vegetation obtained from the Department of Fire and Emergency Services (DFES) for three metropolitan management regions. He concluded that the ignitions profiles have an hourly profile that reflects fire danger and fuel availability with a peak around 4-5 pm, slightly lagging peak Forest Fire Danger Index/Grassland Fire Danger Index (Figure 10).

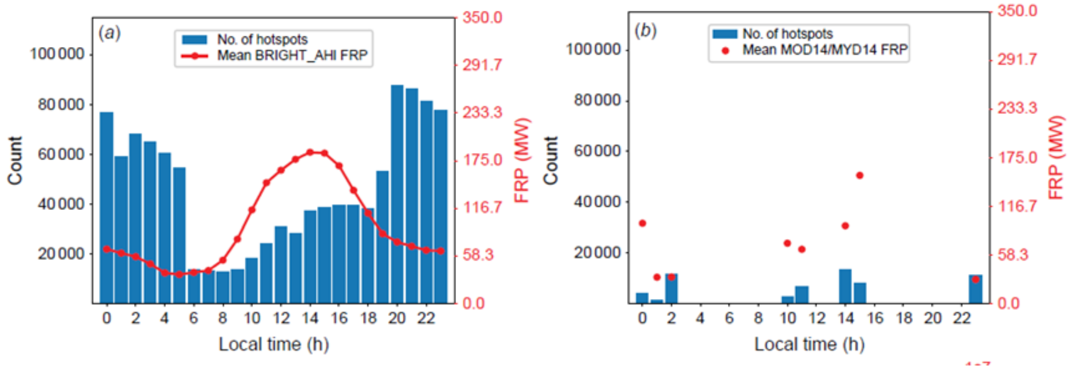

Figure 8 - Aggregated diurnal cycles of hotspot numbers overlayed by mean FRP for the Biogeographical Region and Individual Geostationary HHMMSS Threshold (BRIGHT) v1.84 (Day and Night) algorithm (Engel et al. 2021) (a) and MOD14/MYD14 (b) sensors. The data are grouped in hourly intervals and represent the entirely of the Black Summer fires (November 2019-March 2020). Source: Chatzopoulos-Vouzoglanis (2022)

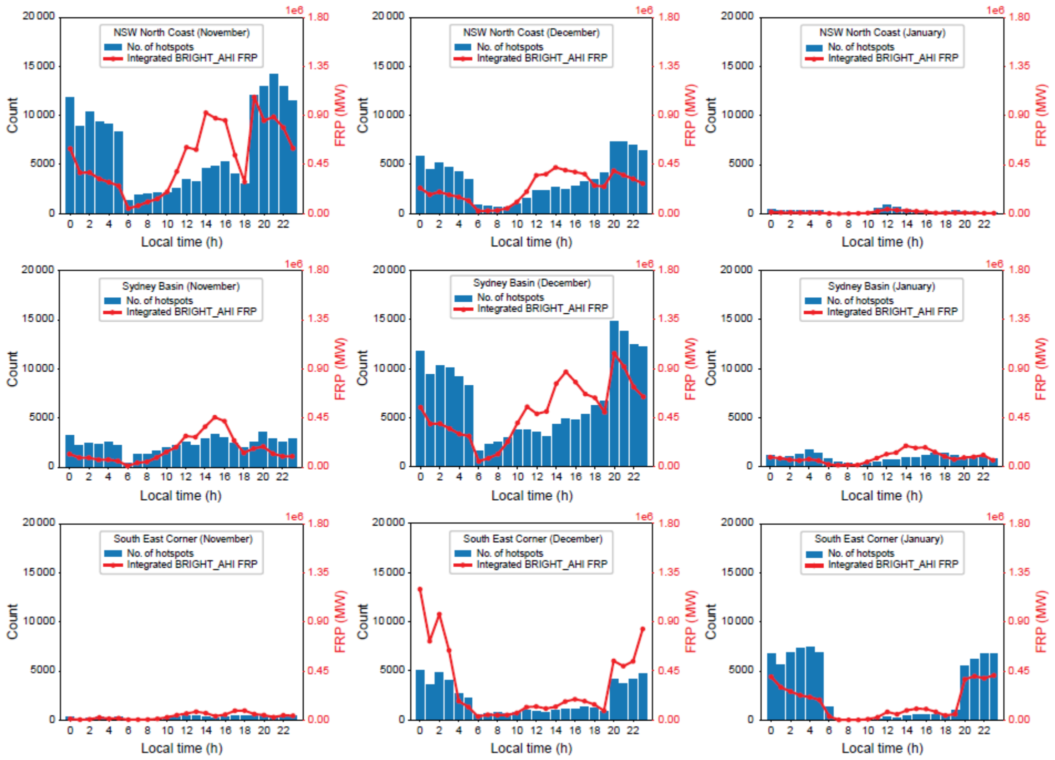

Figure 9 - Aggregated diurnal cycles of Integrated FRP form Himawari-8 (red line with dots) over the numbers of hotspots (blue bars) between November 2019 and January 2020 for the three bioregions, following a north to south latitudinal gradient (NSW North coast – top row; Sydney Basin – middle row; South East Corner – bottom row). From left to right the progression depicts the temporal change (November- January, while from top to bottom spatial change (bioregions from north to south). Source: Chatzopoulos-Vouzoglanis (2022)

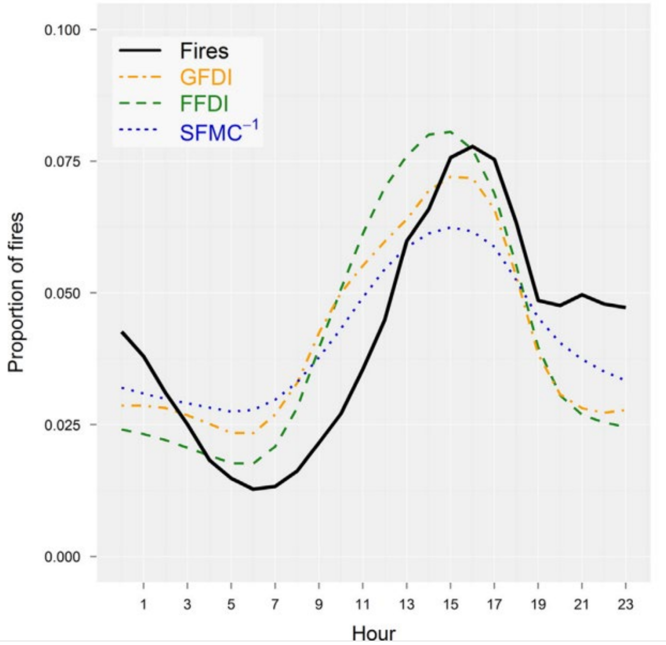

Figure 10 - Hourly profile of fires for all-cause types compared with profiles for Grassland Fire Danger Index (GFDI) and Forest Fire Danger Index (FFDI) and inverse Surface Soils Moisture Content (SFMC) of the litter layer used to indicate the availability of the fuel for ignition. Source: (Plucinski 2014)

Based on these studies, Australia's peak fire activity apers to be 1 to 4 hours earlier than the 6 pm peak of fire activity observed in Canada, depending on the location in Australia and the time of the year.

In terms of the acquisition of the data to be available by the time key management decisions need to be made in Australia, the standard shift cycles are from 8 am – 8 pm or 6 am – 6 pm (Figure 11). This is based on historical preference, and to try and give crews the best chance of doing a handover during daylight when fire behaviour is hopefully moderated (Simeon Telfer, Department for Environment and Water, SA, Personal Communications). According to the current situation and for intelligence to be incorporated into an Incident Action Plan (IAP), it needs to be received and interpreted by 5 am or 4/5 pm which is the time when the IAP needs to be completed, preferably sooner.

According to the key management decision points in most of Australia, the products need to be on the hands of the Incident Management Team one or two hours earlier than what has been scheduled for Canada, that is between 3-5am, or 3-5pm Australian time

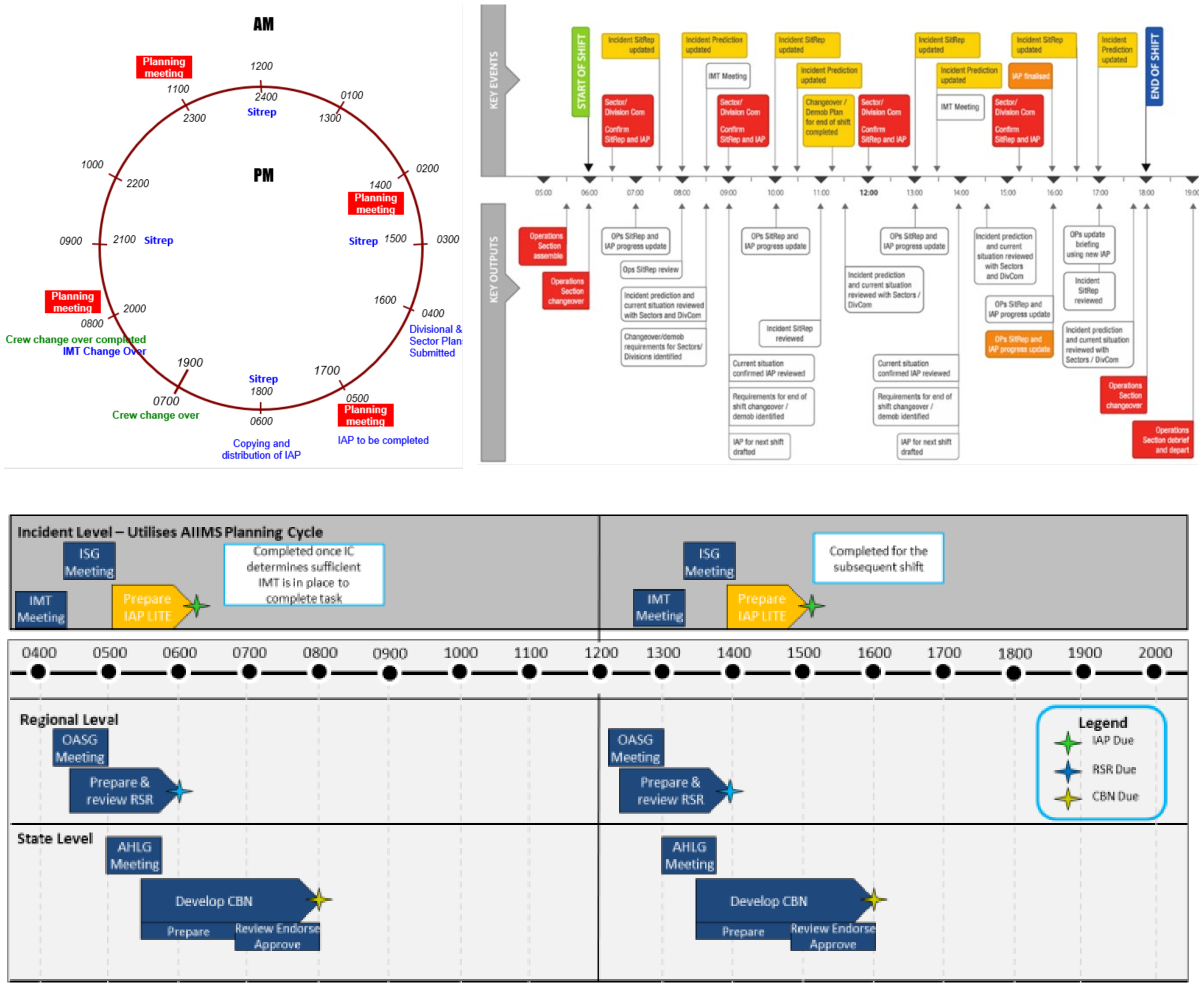

Figure 11 - Incident Management Team Planning Cycle clock for South Australia (upper Left) and New South Whales, Australian Capital Territory and Victoria (upper right) and Western Australia (bottom). Source: Country Fire Service. Level 3 Incident Management Guidelines; NSW Planning Officer Training Handbook and WA Incident Management Guidelines. Note that the detailed planning cycle for QLD was not resourced on time for the delivery of this report but following the advice from the other jurisdictions will work for Queensland Fire Emergency Service (Andrew Sturgess, Ex- Manager of Queensland Fire and Emergency Services, Current Technical Director Fire Technology at RedEye)

In the Northern Territory, many cattle ranchers, Indigenous rangers and park rangers that manage these fires frequently consult NAFI and other websites to obtain information on the fire fronts and the fire breaks they are heading towards. The web-based maps help them decide if, when, and how, to respond to a wildfire. The late morning information (currently coming from Terra passes) plays an important role in this decision-making – it not only fills a key gap in the day but around 80% of the burnt area mapping uses the clearer morning imagery from Terra's MODIS sensor. Another aspect to consider is knowing where fires are heading in the morning also allows time for backburns to be implemented before the hotter and more dangerous afternoon conditions arrive (Jacklyn 2022).

6 am and 6 pm acquisitions are not considered ideal to support fire management in the northern savannas as it takes a few hours and a bit of wind for the fires to flare up enough to be visible by the coarser thermal sensors but before 6 pm cloud will often have developed. Therefore, the clearest view of the ground when hotspots are most detectable is mid-morning (Andrew Edwards, Charles Darwin University, Personal Communication).

4.3 Downlink

This section presents an assessment of the Australian downlink options for the Canadian WildFireSat mission. For Australia to benefit from this mission's data, the data must be downlinked in near real-time (< 30 minutes). As such, there is a need to downlink Australian data whilst the satellite is over Australia, implying the use of an Australian ground station. Several options were identified and are presented and assessed below. This section was produced by UNSW Canberra Space on a best effort basis and does not constitute a full assessment of WildFireSat downlink options in Australia. As such:

- Options and providers listed have not been consulted in the making of this report.
- UNSW Canberra Space does not have any affiliation with the options and providers listed in this report. UNSW Canberra Space contracts Cingulan Space to provide ground station services in support of the RAAF M2 mission (https://space.skyrocket.de/doc_sdat/raaf-m2.htm)
- This report is based on UNSW Canberra Space's best knowledge at the time of writing. Accuracy and/or completeness are not guaranteed.
- This report does not constitute legal or professional advice. Persons rely upon this publication entirely at their own risk and must take responsibility for assessing the relevance and accuracy of the information in relation to their circumstances.

4.3.1 Assumptions

Several assumptions were made for the purposes of this document. Some assumptions are based on the "WildFireSat External Ground Station Requirements Infosheet" (Annex II), while other assumptions are based on team experience and knowledge. The assumptions directly derived from the Infosheet are:

- The spacecraft has direct broadcast capability in X-Band.
- The orbit is a 650 km Sun-synchronous Orbit (SSO), 1800h LTAN.
- Supporting antenna require a G/T of > 25.4 dB/K.
- Daily data volume of 33.6 GB/day for one spacecraft (only Australian data is downlinked), based on the example data volume calculation presented in the Infosheet.
- The spacecraft downlink data rate is 128 Mbps.

Assumptions based on UNSW Canberra Space's experience:

- A single spacecraft. If a constellation of three spacecraft is launched, we assume they will be evenly distributed over the orbit plane to improve revisit times. Each spacecraft will be far enough away from others in the constellation that they are independent for the purpose of this report. As such, data volumes, imaging times, contact times, and operating costs should be scaled up by the number of spacecrafts in the constellation. No other scaling limitations exist for small (<5 spacecraft) constellations in the same orbital plane.
- The use of a steerable (electrically or mechanically), isoflux, or wide-beam antenna is assumed. This allows simultaneous payload operation and data downlink to Australia.
- The spacecraft operates in nadir-pointing, with a sensor on the nadir face. The sensor does not have a significant look away from the nadir axis.

Elements to consider in future work:

- Data latency estimates consider time from image generation to arrival at the Data Processing and Archiving System (DPAS). They do not account for time spent processing the data inside the DPAS, or for dissemination to product consumers.
- Power and pointing aspects were not considered in this report; the satellite was assumed to be power positive and in a constant nadir configuration.

4.3.2 Australian data volume estimation

The longest strip-length over Australia is approximately 3,900 km long, which is transited by the spacecraft in approximately 520 seconds. This is comparable with the 500 second Canada overpass given in the Infosheet. The longest overpass will generate 8.32 GB of data (at 16 MB/s), which must be downlinked inside the pass to meet the data latency requirement. Simulating the satellite's orbit gives a histogram of Australian imaging strip-lengths (measured in seconds), shown in Figure 12. The upper-bound of 520 seconds given in Figure 12 is consistent with the approximate strip-length calculation performed above. Table 3 presents the assumptions and calculations of the maximum daily and yearly data volume generated by WildFireSat over Australia.

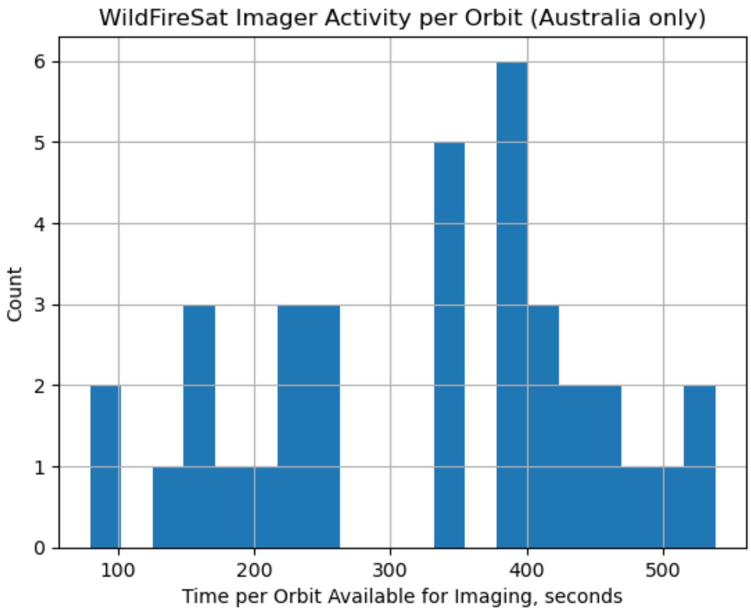

Figure 12 - Distribution of the duration of Australian imaging passes with "no imaging' passes removed, simulated for 50 days.

Table 3: Data volume estimation.

Parameter	Value	Comment
A. Daily imaging time (s)	2,100	Maximum amount of Australian imaging performed in a 24-hour period (simulation, Figure 2).
B. Payload data rate (MB/s)	16	Given in the Infosheet.
C. Data generated per day (GB/day)	33.6	A x B
D. Data generated per year (TB/year)	12.3	C x 365

The SSO orbit and Australia's non-polar location mean that Australia is only visible in approximately 4 orbits per day, with the satellite completing 15 orbits per day in total. Figure 2 gives the distribution of the time spent imaging Australia each day in a 50-day orbit simulation, with the upper-bound determining the value of parameter A in the data volume estimate (Table 1).

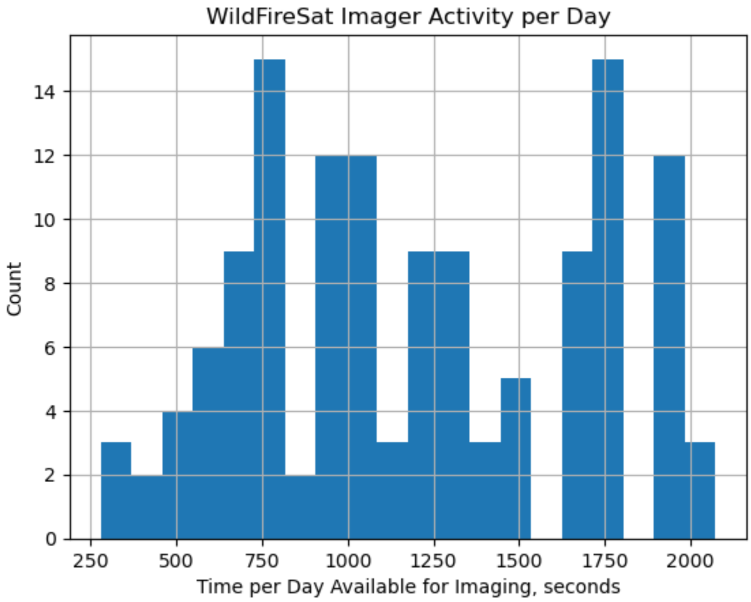

Figure 13 - Time spent imaging Australia per day, simulated for 50 days.

4.3.2.1 Data latency estimation

The data latency requirement for WildFireSat mission can be met by ensuring that ground station coverage exists for the entirety of the area to be imaged, and that the data downlink rate is at least the payload output data rate. The first condition can be met with ground station site selection, discussed below. The second condition is satisfied by the nominal system design presented in the Infosheet, where the data downlink rate of 128 Mbps is equal to the payload output data rate of 128 Mbps.

As such, Australian ground stations can be used to always meet the data latency requirement, and a detailed analysis is not required.

4.3.2.2 Australian ground station position

For the purposes of this analysis, we assume that ground stations can be accessed at the following locations:

1. Alice Springs, Northern Territory
2. Perth, Western Australia
3. Darwin, Northern Territory
4. Sydney, New South Wales
5. Hobart, Tasmania

These locations represent generally the existing location of Australian stations. They should be interpreted as prototypical examples, and not as specific site recommendations. Visibility of the ground station from the spacecraft, with a 5-degree elevation mask, is shown in Figure 14.

A single station solution will meet Australia's needs for direct broadcast reception from WildFireSat. A multiple station solution will also meet Australia's needs and provide excess capacity which may be used to downlink other mission data; for example, to ensure data archive completeness, or to provide additional ground segment redundancy

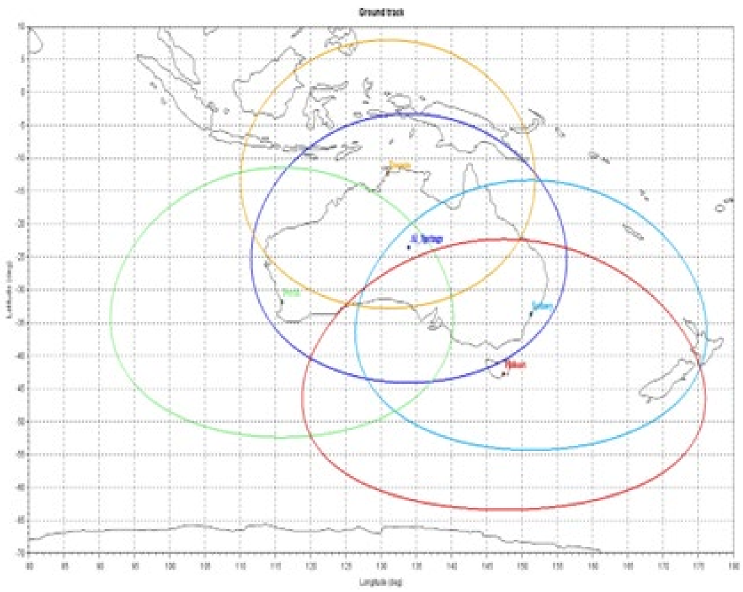

Figure 14 - Australian ground station coverage regions, 5-degree elevation mask.

Bushfire monitoring over the entirety of Australia is desired, with the east and west coast setting a lower bound on useful coverage. The following section explores which ground station locations meet different user needs.

1. **Alice Springs, Northern Territory**
   An Alice Springs station covers all of mainland Australia, and as such, allows for near real-time monitoring of all of Australia. There is partial coverage over Australia; this need could be met with the addition of another east coast/Tasmanian station, or further communication link analysis that results in the elevation mask being lowered to 4 degrees (from the 5 degrees used in Figure 14).
2. **Perth, Western Australia**
   A ground station in Perth provides sufficient coverage of the west coast but does not provide coverage over the east coast. As such, this station must be paired with a Hobart or Sydney station to provide adequate coverage.
   We do not recommend pairing with an Alice Springs station due to the significant coverage overlap; if Alice Springs is used, then it is better paired with an east coast station to provide whole-of-Australia coverage.
3. **Darwin, Northern Territory**
   A ground station in Darwin does not provide adequate coverage of Australia's population centres on the east and west coasts. This station is best used to provide coverage to countries to Australia's north, if Australia wishes to extend bushfire monitoring capability to its international partners. This station can be used to extend the Australian network but should not form the Australian network itself.
4. **Sydney, New South Wales**
   A ground station in Sydney provides sufficient coverage of the east coast but does not provide coverage over the west coast. As such, this station must be paired with a Perth station to provide adequate coverage. Alternatively, this station can be paired with Alice Springs to provide complete coverage, and significant coverage overlap.
5. **Hobart, Tasmania**
   A ground station located in Hobart provides coverage for only the east coast population centres. This station is best used to provide Tasmanian coverage with an Alice Springs station providing coverage for the remainder of Australia.

Otherwise, this station should be combined with both a Sydney and Perth station. Over-coverage will result in lower ground station utilisation, and lower financial efficiency. Benefits of over-coverage include increased redundancy and robustness to single-site downtime.

4.3.2.3 Implementation options

The following ground station implementation options were considered, based on what is currently available in Australia. These options are:

A. Government in-kind contribution
B. SmartSat CRC furnished ground station
C. Commercial existing ground station providers

Lower maturity/higher technical risk options such as optical communications and medium earth orbit (MEO) relay stations were not considered, particularly as these options would require changes to the WildFireSat satellite platform. All cost estimates are provided in Australian dollars.

A. Government in-kind contribution

Applicability to the WildFireSat mission and availability - Various Australian government organisations (Geoscience Australia, Bureau of Meteorology, CSIRO) operate ground stations in support of foreign earth observation space missions. These stations currently support missions such as the Landsat 8, Landsat 9, NOAA 18, NOAA 20, and NovaSAR-1. Locations include Alice Springs, Hobart, Learmonth, Crib Point, and Shoal Bay. X-Band is generally available.

Technical assessment - The stations mentioned in previous section have antennas in the range of 3 to 9 metres. These antennas have suitable G/T figures and can likely support downlink at rates greater than 128 Mbps.

Cost estimate - As Government assets, it may be possible for access to these stations to be provided as Australia's in-kind contribution to this mission.

B. Commercial providers (exclusive access)

Applicability to the WildFireSat mission and availability - The SmartSat CRC could purchase a ground station and organise to have it hosted at a commercial ground station hosting facility. A commercial facility normally provides security, site services, monitoring, and maintenance. Co-locating ground stations at a facility allows the costs of the above services to be shared across all users, which results in lower pricing relative to an owned-and-operated station. The ground station could be shared with other missions that have downlink technical specifications similar to that of WildFireSat.
Implementation options include:

- The Centre for Appropriate Technology Satellite Enterprises (CfAT Satellite Enterprises) offer ground station hosting capability at Alice Spring.
- Nova Systems offer ground station hosting at Peterborough, South Australia.
- Capricorn Space offer ground station hosting at Mingenew, Western Australia.
- Cingulan Space offer ground station hosting at Yass, New South Wales.
- SSC Space Australia offer hosting services at the Yarragadee Tracking Facility, Western Australia.
- Pivotel may offer hosting services on the east coast.

Technical assessment - Furnishing a ground station requires the customer to present a ground station for installation at the host site. The host site may consult with the customer to design an appropriate solution. As such, we assume that any solution for this option will meet the technical needs and will be located per the positioning recommendations in the Australian ground station position section above.

Cost estimate - The capital cost of provisioning a ground station is likely to be A$200k to A$1M. This option is well-suited to operating multiple missions where the above costs can be shared, with the station being operated at high utilisation. It is less suited to a single mission or satellite, as utilisation of the station will be low whilst capital and operating costs remain high. The operational cost for a hosted solution is likely to be A$100k/year to A$200k/year.

C. Commercial providers (time-share)

Applicability to the WildFireSat mission and availability - Ground stations in Australia are made available via many different commercial providers. Some providers are Australian owned, whereas others may be the Australian arm of an international corporation. Time-share ground stations are typically costed on a “per minute” or “per pass” basis.

The following providers of time-share ground station access currently operate in Australia:

- Amazon Web Services (AWS) Ground Station
- Microsoft Azure Orbital Ground Station
- Viasat Real-Time Earth
- RBC Signals
- Kongsberg Satellite Services (KSAT)
- Leaf Space
- Infostellar
- ATLAS Space Operations

Note that some of the above providers resell ground stations hosted by the companies listed in the subsection on *Applicability to the WildFireSat mission and availability*, or act as brokers for individual ground stations. Most stations are located on the east and west coasts. There may be time-share capability located in central Australia.

Technical assessment - X-Band is well-supported by Australian commercial providers.

Cost estimate - Capital costs are non-existent as the user does not take on ownership of the ground station. There may be some upfront costs in the areas of on-boarding and spectrum management, however these are not expected to be significant (< $50k). Typical costs are around $5/minute to $15/minute, with a pass lasting around 15 minutes (2 minutes of setup, 11 minutes of tracking, and 2 minutes of teardown). On-demand pricing can be more expensive, with a spending commitment often allowing reasonable discounts.

D. SmartSat CRC furnished ground station

Applicability to the WildFireSat mission and availability - The SmartSat CRC or another consortium partner could procure a ground station specifically to participate in this mission. This ground station would be located to provide the greatest coverage of bush-fire prone areas of Australia and have capabilities that would allow it to receive the direct broadcast data. The ground station could be shared with other missions that have downlink technical specifications like WildFireSat.

The consortium would own the land the station is operated on. Otherwise, a commercially hosted option is given in Option B. Commercial Providers.

Technical assessment - Furnishing a ground station requires the customer to present a ground station for installation at the host site. As such, we assume that any solution for this option will meet the technical needs and will be placed per the positioning recommendations in the Australian ground station positioning section.

Cost estimate - The land for the ground station either needs to be acquired or rented. This is site-specific and is not included here. The capital cost of provisioning a ground station is likely to be $500k to $2M. Additional funding should be set aside for staffing and maintenance, which may present as an operating expenditure of $100k/year to $200k/year and $100k/year respectively.

This option is well-suited to operating multiple missions where the above costs can be shared, with the station being operated at high utilisation. It is not well-suited to a single mission or satellite, as utilisation of the station will be low whilst capital and operating costs remain high. The operational cost for a hosted solution is likely to be $100k/year to $200k/year.

4.3.2.4 Summary and comparison of all the options

Table 4 presents a summary of the Australian downlink options for the WildFireSat mission that were considered in this report.

Table 4: Summary of the Identified Options

Criteria		Government provided (A)	Exclusive access (B)	Time-share access (C)	Owned (D)
Applicability (yes/no)		Yes	Yes	Yes	Yes
Availability	Likely	Yes	Yes	Unlikely	
Data latency		Near real-time	Near real-time	Near real-time	Near real-time
Daily downlink capacity	Sufficient, fixed	Sufficient, fixed	Sufficient, scalable	Sufficient, fixed	
Cost estimate (capital)		In-kind	$200k to $1M	$50k	$500k to $2M
Cost estimate (operational)	In-kind	$100k/year	$130k/year	$100k/year to $200k/year	

Australia is well-suited to receiving direct broadcast information from WildFireSat in near real-time, for the purpose of monitoring bushfires in Australia.

A time-share ground station solution (Option C) appears to be optimal, as it provides lower capital and operational costs, and allows for ground station access to be scaled to meet the benefit Australia derives from the mission. It is likely that time-share capability is available at Alice Springs.

If time-share ground stations are not available at Alice Springs, then the fall-back recommendation is either a hosted station at Alice Springs, or time-share access to an east coast and a west coast site.

4.3.2.5 Future Work

A detailed communication link budget should be developed, informed by the WildFireSat spacecraft specifications, and the capabilities of candidate ground station systems. This will validate assumptions made about the system design for the purpose of this analysis.

Whether Australian ground stations connect to an Australian DPAS, or into the WildFireSat mission DPAS is an open question. Integrating with the WildFireSat DPAS will result in cost savings, and better integrate Australia with its mission partners. Hosting an Australian DPAS may be more expensive but will result in a sovereign capability and provide opportunities for Australia to gain DPAS experience.

A preliminary assessment of the implementation options and their geographical availability has been presented in this report. A detailed assessment of the options available at each recommended ground station position should be conducted to ensure that an appropriate service is available, prior to finalising the ground segment design.

The X-Band spectrum has heritage for use by earth observation missions in Australia. Discussions with the Australian Communications and Media Authority (ACMA) should be entered into to ensure spectrum availability and any specific geographical restrictions. There are allocations from 8025 MHz to 8400 MHz for earth observing missions (space to earth) in the Australian Table of Allocations and the ITU Radio Regulations Table of Allocations that are appropriate for use by this mission.

4.4 Science Products

All WildFireSat products and algorithms will be publicly available (Joshua Johnston, Natural Resources Canada, Personal Communication). For Australia to benefit from NRT capability the raw data from the sensor (L0) would need to be downlinked to Australian ground stations (see previous section) and be transmitted to a specialist team in Australia for processing and evaluation. This section assesses the applicability of the WildFireSat science products to Australia and the feasibility of Australia producing those products in NRT.

On the first aspect, information on the specific algorithms that will be used to derive the WildFireSat products was not available so only high-level comments and considerations to make sure the algorithms are suited for Australia can be made at this stage.

- Calibrated FRP data. The FRP data generated by WildFireSat must be correlated with ground data to ensure reliability and accuracy. It is expected that some of the algorithms used to derive FRP would need to be fine-tuned to Australia's conditions (e.g., different coefficients might be needed for the radiative functions).
- Hotspot data showing active fire perimeter maps. This information is very important to fire managers and the timeliness of this data is a critical factor in its utility, so these data need to be delivered to fire managers as quickly as possible (ideally within 30 minutes of data collection and before IAP). It is also expected that the algorithms for hotspot detection will need to be tuned to Australia.
- Rate of Spread (ROS). Measurements and direction of spread will be calculated from a time series of hotspots (including other operating systems such as VIIRS). ROS measurement is driven by fine spatial and appropriate temporal resolutions with low data latency. The WildFireSat spatial resolution would be sufficient to have an idea of the ROS of large fires, but the temporal resolution will be insufficient for a very detailed estimation of the ROS. However, ROS estimates can provide a useful indication at the time the different EO satellites overpast if the data latency is lower than 30 minutes (Figure 2).
- Burned Area Mapping: Data is needed at least once per year for carbon accounting but there is value to fire monitoring if it is possible to complement hotspot data with weekly moderate-resolution burned area mapping to track fire growth between observations. Consequently, mapping burned areas on a weekly basis could be a good addition.

In conclusion, most WildFireSat science products will need to be evaluated and quite likely re-calibrated in Australia to increase the confidence and credibility of the products.

Regarding data processing, Australia has a demonstrated capability that can handle and support the data processing requirements of these products (Held 2012). Downstream development is part of the ASA's Communications Technologies and Services (Agency 2020) and the Earth Observation from Space (Agency 2021) Roadmaps meaning that the Australian government wants users to create products that make use of EO time-series. GADI is one of the most powerful computer systems on the planet. Hosted by the National Computational Infrastructure in Canberra, GADI provides processing and storage services to a wide range of projects ranging from health to physics, and from astronomy to earth sciences. The Pawsey Supercomputing Centre is another example of processing and storage capabilities. A joint venture between CSIRO, the Western Australian and Federal Governments, and universities, it is one of two Tier-1, High-Performance Computing facilities in Australia. These systems can easily handle the pre-processing, storage, and use stages of the WildFireSat mission.

GA DEA is at the leading edge of EO product development. Focusing on Australia, but applicable worldwide, DEA creates, tests, and distributes continental-scale satellite imagery and products that have a wide range of applications. DEA is part of Australia's digital infrastructure, and it's designed to store, process, and facilitate the analysis of EO data. Most DEA products are based on Landsat imagery and leverage the 30 yearlong archives and the 8–16-day revisit time. DEA is also adding Sentinel 2 imagery to the catalogue and new products are being developed based on the higher spatial and temporal resolution. The DEA team has a proven track record of creating high-quality products for different industries. While adding a new stream of data is not simple, DEA has the knowledge, experience, and capabilities to create innovative products that benefit private and public stakeholders across Australia and elsewhere. Therefore, DEA could be in a position to store and process WildfireSate L0 data and generate and deliver a range of science products.

4.5 Complementarity with other Australian Satellite missions planned

Despite current limitations, Australia increasingly depends on EO imagery and data to inform bushfire management activities. The Australian government and several associated organisations such as the ASA and GA are showing an increased interest in domestically developed technologies for use on the National Space Mission for Earth Observation (NSMEO), including bespoke optical instruments for EO operating in the visible and infrared (VIS/NIR/SWIR) spectrum. There are several missions in the planning phase in Australia to provide continental-scale information to managers, practitioners, and end users. This section evaluates how WildFireSat relates to those missions and ASA's strategy for satellite EO.

Australia's first National Space Mission for EO (NSMEO) program will see Australia design, build, and operate four new satellites (LINK).

- Satellite cross-calibration radiometer (SCR) - Geoscience Australia- SCR will be a hyperspectral imaging spectrometer to provide the gold standard for radiometric cross-calibration among commercial and government EO data sets. – Phase A study finalised and published (Space 2022b)
- National water quality monitoring – Aquawatch Australia (CISRO and SmartSat CRC) (SmartSat 2021) is a program to monitor inland and coastal water quality from the ground and form space combing sensor data to create information products for the benefit of various downstream users.
- National bushfire fuel flammability monitoring – Ozfuel - with international scalability (Space 2022a)
- Operational meteorological data collection, including a satellite lightning sensor in geostationary orbit, currently conducting a pre-phase A.

None of the Australian planned missions overlaps with WildFireSat science objectives. Instead, WildFireSat is highly complementary to the NSMEO's fuel flammability monitoring mission and satellite lightning sensor.

OzFuel is a bushfire prevention satellite mission that will monitor forest fuel flammability providing critical geospatial input to be used by local and state authorities for tactical fire operations, planning and mitigation activities (instead of giving information of active fire. Detailed Ozfuel mission concept and feasibility assessment and initial cost estimation can be found in UNSW Canberra Space (2022a). The study concluded that the Ozfuel mission concept is technologically feasible and could be developed by leveraging the existing technical capability within Australia and the global space community. The Ozfuel programme development schedule is 36 months and will create opportunities to partner on domestic and international fire monitoring and prevention missions. The costing analysis on the perceived work and expenses shows that the mission as envisioned would cost approximately AUD 9M. Alternative spacecraft platform providers (other than Skycraft) and launch providers may offer lower costs for Ozfuel's mission but such options have not been extensively explored. There are opportunities to explore the Ozfuel sensor to be hosted on WildFireSat.

The future satellite lightning sensor in geostationary orbit in Australia will provide an earlier indication of lightning strikes in near real-time. Both Ozfuel and lighting sensors are focused on 'Pre- to Early Fire' phases and would be highly complementary to WildFireSat satellite data for on-ground targeted resource deployment. Integrating information from WildFireSat, Ozfuel and the lighting sensor will allow aspects of pre-, during- and post-fire stages to be addressed in a more integrated manner.

4.5.1 Key closely related research initiatives in Australia

Optus Bushfire Research Centre of Excellence - The Optus Bushfire Research Centre of Excellence at ANU aims to develop an innovative national system to detect bushfires as soon as they start and put them out within minutes using a layered approach that combines sensors on different platforms including satellites, long-endurance remotely piloted aerial systems (drones), cameras on fire towers and ground sensors (Yebra et al. 2021, Yebra et al. 2022). One of the main projects of the Centre is a comprehensive five-year evaluation of methods and technologies for rapid detection and location of small fires and determining the situations under which each technology overperforms or complements each other. To that aim, the team will be performing some experimental burns and coordinating with local fire and land management agencies to collect observations during prescribed burns.

WildFireSat science team could be part of such an evaluation that can support its calibration and validation activities facilitating the team access to prescribe and experimental fires.

SmartSat CRC project: Real-Time Fire Analytics - This project proposes a satellite system of systems encompassing geostationary, polar orbiting and aerial based sensors for real time fire landscape attribution. The project will design and deliver a data and platform ecosystem to allow autonomous real time information on fire to be detected, processed and delivered to end users.

This project is presented as two elements:

1. design and implementation of a data and platform ecosystem that will enable fire surveillance in real time from geostationary, polar-orbiting and aerial platformed sensors. This system of systems approach will allow for the best available information to always be provided.
2. derivation of autonomous AI algorithms for the real time surveillance of fires and its attribution (e.g. burn severity, FRP etc.)".

WildFireSat could be part of this data and platform ecosystem.

5.0 Conclusions and Recommendations References

Australians use EO data to support bushfire emergency management activities. EO data is derived from sensors that were designed for purposes other than wildfire monitoring, therefore there are currently no sensors dedicated to monitoring active fires in Australia. Moreover, Australia does not have yet access to regular, assured and accurate satellite imagery and fire-derived products and services for fire monitoring.

Some of the key technical and operational challenges of the use of EO for fire monitoring could be addressed by the WildFireSat mission. This report has identified several issues that prevent the full utility of the future WildFireSat mission for operational monitoring of Australian bushfires and proposes some recommendations on what needs to be done rather than how it should be done to overcome those challenges and get access to WildFireSat data and products in the future in a timely, regular and assured manner.

Issue 1 - The current WildFireSat mission design will not have sufficient coverage in Australia.

Recommendation 1 - A comprehensive assessment could explore what orbital requirements are ideal for additional spacecraft to add coverage/revisit for Australian.

Issue 2 - The timing of the acquisition of WildFireSat data is not ideal for Australia.

- Australia's peak fire activity is between 1-5 pm which is earlier than the 6 pm peak of fire activity reported in Canada.
- Australian Incident Management Teams need the information to complete their planning reports by 4-5 pm

Recommendation 2 - Options need to be explored to collect the data before 6 am and 6 pm.

Issue 3 - WildFireSat data will be more useful for Australia if provided on a timely, regular and assure basis.

Recommendation 3 - Agreements would need to be put in place for Australia for the direct downlink of the data.

Recommendation 4 - Collaboration between the wildfiresat science team and a range of Australian stakeholders is needed to ensure NRT data and products are developed and available for Australia and elsewhere.

Issue 4 - WildFireSat science products would need to be evaluated and quite likely re-calibrated in Australia to increase the confidence and credibility of the products.

Recommendation 5 - Joint Canada-Australia Science teams could collaborate with the Optus Bushfire Research Centre of Excellence and GA to support calibration/validation activities.

Issue 5 - WildFireSat focus on active fire evolution and could be augmented by a prediction capability enabled by the Ozfuel sensor allowing aspects of pre-, during- and post-fire stages to be addressed in a more integrated manner

Recommendation 6.1 - Explore opportunities for a collaborative effort between Canada and Australia to launch a satellite for the dual purpose of forest fuel monitoring and fire detection to address the bushfires, challenge more comprehensively.

Recommendation 6.2 - Explore an inter-agency level establishment of a virtual observatory for fire prevention and detection observatory including WildFireSat (fire detection and progression) and OzFuel (fuel flammability monitoring going into the season and for fire behaviour analysis during fires)

6.0 Acknowledgements

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Appendix A

Acronyms and Abbreviations

Acronym	Definition
ACMA	Australian Communications and Media Authority
AHI	Advanced Himawari Imager
AWS	Amazon Web Services
ANGSTT	Australian National Ground Segment Technical Team
ANU	Australian National University
ASA	The Australian Space Agency
AVHRR	Advanced Very High-Resolution Radiometer
CCMEO	Canada Centre for Mapping and Earth Observation
ConOps	Concept of operations
CRC	SmartSat Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEA	Digital Earth Australia
DFES	Department of Fire and Emergency Services Western Australia
DPAS	Data Processing and Archiving System
EO	Earth Observation
FRP	Fire Radiative Power
GA	Geoscience Australia
GADI	National Computational Infrastructure's newest supercomputer
IAP	Incident Action Plan
KSAT	Kongsberg Satellite Services
MEO	Medium earth orbit
MODIS	Moderate Resolution Imaging Spectroradiometer
NRT	Near-real-time
NAFI	Northern Australia Fire Information
ROS	Rate of Spread
SCR	Satellite cross-calibration radiometer
SSO	Sun-synchronous Orbit
S3	Sentinel 3

TT&C	Telemetry, Tracking and Control
VIIRS	Visible Infrared Imaging Radiometer
WMO	World Meteorological Organization

Appendix B

WildFireSat Science Products.

Table 1:Tier 1 - Satellite L1B data

Product	Outputs
Cloud mask	Mask of cloud contaminated pixels
Contextual Fire Detection	Mask of fire effected pixels, and confidence, false positive rejection
Characterisation	FRP (MW) Effective Fire Area (ha) Effective Fire Temp (K)
AI Detection*	Cloud mask: Mask of fire effected pixels, and confidence, false positive rejection

Table 1: Tier 2 - Data synthesis with VIIRS

Product	Outputs
Clustering of fire pixels	Differentiation of pixels contributing to a single fire or adjacent fires (similar the M3 CWFIS product)
Rate and Direction of Spread	Mean ROS (m/min) over the afternoon period. Generalized mean direction of travel for all moving regions of the perimeter
Fire Intensity	Mean FI (kw/m) for the subpixel perimeter.
Burned Area Map	Map of disturbed forest area
Fire Severity Map	Map of relative severity of fire effected area
Smoke plume ID	Re-characterisation of portions of the cloud mask as smoke.
Fire Arrival Time Map	Burned area map tagged with the first satellite observation of each cell. Similar to Parks day of burn map, possibly omitting interpolation.

Table 3: Tier 3 - T1, T2 + ancillary data and models

Product	Outputs
Proximity and threat to interface	Distance to values and estimated time of arrival at the interface zone. Based on observed rate and direction of spread from Tier 2, and national WUI maps
Fire Growth Model (FGM) projection	This could be using Bigfoot, or local agency FGM, or BurnP3, (TBD)
Fire Growth Model data assimilation	R&D required – open FGM which can update coefficients in spread equations based on observations
Fuel grid verification	Local to the FGM AOI
Risk/threat	Where this fire falls in the context of risk assessment (e.g. how it ranks on a relative scale)
Torchlight trigger point	Automated approval of Torchlight deployment

Suppression potential/effectiveness	Map of potential suppression method options based on observed fire behaviour (i.e. can we action this fire?)
Land surface change	Vector or raster representation of land surface change (e.g., Lake ice cover, vegetation change, etc.)

Appendix C

WildFireSat External Ground Stations Requirements Infosheet

DRAFT

WildFireSat External Ground Station Requirements Infosheet

This document contains an initial set of assumed requirements known at this time to allow external satellite antenna receiver operators the opportunity to prepare to receive and store WildFireSat (WFS) raw data for their region of interest. These assumptions and requirements will evolve as the mission moves through all phases. Downlink parameter assumptions are based on a single satellite, however, it should be noted that the baseline Canadian operational mission design includes 3 identical satellites. The operational mission will be the full 3 satellite constellation and downlinking should be considered as 3x the baseline single satellite parameters below. Final parameters for the mission will be solidified following Phase-B in 2024.

This document does not discuss production of data products, which must be executed following downlink.

Anticipated Launch: Late 2027/Early 2028
Commissioning period: 4 months
Lifetime: 5 years
Contact: nrcan.wildfiresat.rncan@canada.ca

Technical requirements for standard downlink

The following section contains information on WildFireSat downlink characteristics to enable external ground stations to fully support image data acquisition. It is not anticipated that TT&C support will be required for external stations.

The following table contains required parameters for a ground station to be able to support WildFireSat X-Band downlinks, as well as an example of maximum expected data volume. This table is not complete and will be updated once parameters are verified.

Assumed WildFireSat Baseline Downlink Parameters (X-Band only)

Orbit	650 km altitude, sun-synchronous, 18h00 LTAN
Number of channels	One
Downlink frequency	TBD end of phase B
Polarization	RHCP
Minimum G/T	25.4 dB/K
Downlink Rate	128 Mbps
Modulation Schema	TBD end of phase B
Data Volume Example	500s overpass of Canadian AoI – single satellite
IR (MWIR + LWIR) Data	3.2MB/images/s = 6.4MB/s
VIS + NIR Data	9.6MB/image/s

Total Data Volume	16MBs = 128Mbps = ~8GB

Canadian ground segment characteristics

It is anticipated that the CCMEO ground segment will be the core for the WildFireSat mission. This support will include TT&C (commands from CSA), image data downlink, data archive and dissemination of low level products. Value added products are expected to be delivered via CFS and ECCC. CCMEO operates three ground stations in Canada, all with X-band capabilities. The following table lists the base physical and technical characteristics of the CCMEO antenna systems. All antennas are 13m and from L3Harris (formerly L3Datron).

CCMEO Antenna Parameters

Physical Characteristics	
Reflector	13 m diameter
Operating Temperature	-40 C to +50 C (-50 C for Inuvik)
Operating Wind	96 km/h
Survival Wind	193 km/h
Velocity	Azimuth: 12 deg/sec minimum Elevation: 7.5 deg/sec minimum Third Axis: 5 deg/sec maximum
Acceleration	Azimuth: 10 deg/sec2 maximum Elevation: 10 deg/sec2 maximum
Tilt Axis	7 deg from vertical
X Band Characteristics	
Frequency Range	8.0 to 8.5 GHz
Polarization	Data: RCHP and LHCP (simultaneous) Track: RCHP/LHCP (switch selectable)
System G/T (8 GHz at 5 deg elevation, clear sky)	> 37.4 dB/K
System Beamwidth	0.19 deg nominal
X-Band Converter	
Input Frequency	8.0 to 8.5 GHz
IF Outputs	Data: 720 MHz Track: 720 MHz
Bandwidth (1 dB)	500 MHz minimum (Data and Track)
Gain (RF to IF)	Data: 26 dB nominal Track: 29 dB nominal
Noise Figure	Data: 18 dB maximum Track: 14.5 dB maximum

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