Natural Resources Canada | Ressources naturelles Canada

BULLETIN 93

Frontline EXPRESS

Canadian Forest Service – The Great Lakes Forestry Centre

Wildfires from Space: a synthesis of satellite missions for active fire monitoring

INTRODUCTION

Satellites have been used for fire monitoring for over 40 years (Wooster et al., 2021). The well-known MODIS instruments that drove the uptake of satellite data in operational fire management are nearing end-of-life, with significant implications for the systems and people that rely on those data (Frontline Express 92). Earth observation (EO) data from satellites play an important role in providing intelligence to fire management decision makers (Johnston et al. 2020). The use cases can be organized by four stages of fire monitoring: pre-fire inventory, active fire monitoring, post-fire assessment, and multi-scale synthesis (Crowley at al. 2022).

The purpose of this report is to provide a synthesis of the current and future EO satellite missions that can (or will) provide freely available data for active fire detection and monitoring, and to raise awareness of missions that can be used in place of MODIS. Knowledge of aspects such as the spatial resolution, timing and frequency of observations, and data latency are key to planning for use of these data in operational fire management.

TYPES OF ORBITS

Of the biggest distinctions between types of EO satellites used for wildfire applications is whether they are in a polar or geostationary orbit (Figure 1). Polar orbiting satellites (e.g., satellites with the VIIRS instruments) orbit the earth on a nearly North-South axis, passing close to the Earth's poles. Most polar orbiting satellites used for active fire monitoring are also in sun synchronous orbits (i.e., they pass over the same ground location at the same local time each day at ~600-800 km altitude). Geostationary satellites, such as GOES-16 and GOES-18, are positioned directly above the equator at a much higher altitude (~36,000 km) than polar orbiting satellites. The geostationary orbit means that they appear stationary relative to the Earth's surface, and therefore maintain a consistent view of the same surface locations**.**

Geostationary satellites have a higher temporal resolution (i.e., more frequent imaging) than polar orbiting satellites and so provide more detail on the diurnal fire cycle. **Unfortunately, due to Canada's northerly location, the spatial resolution of geostationary imagery in Canada is very coarse, and the Earth's surface is viewed at an at an extremely oblique angle** (Figure 1).

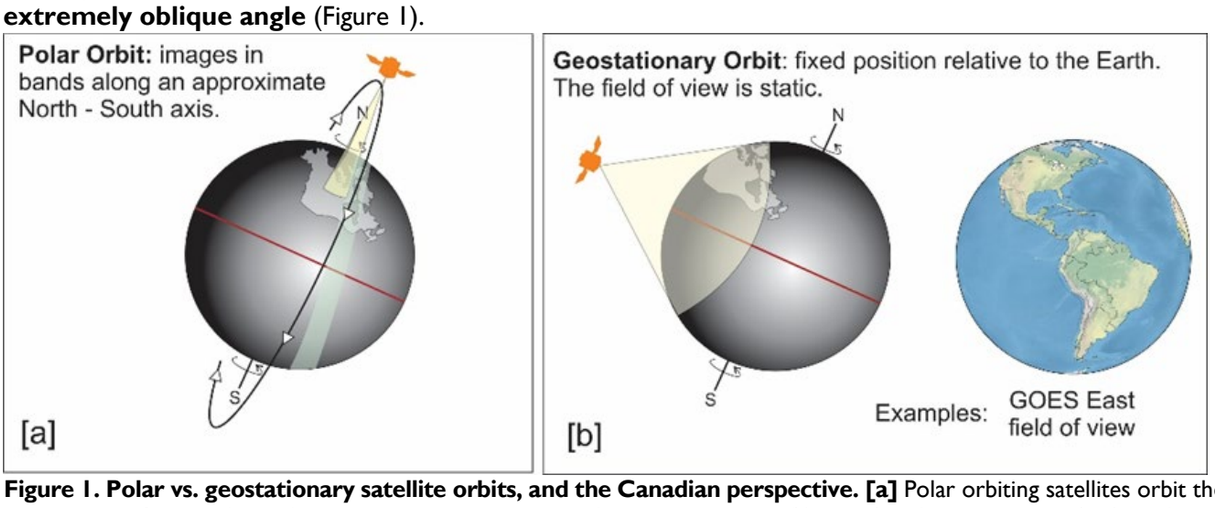

Figure 1. Polar vs. geostationary satellite orbits, and the Canadian perspective. [a] Polar orbiting satellites orbit the Earth on a nearly North-South axis passing close to the poles and provide a small number (4 to ~10, latitude dependent) of relatively high resolution (≤ 1km^2) observations of Canadian locations each day. **[b]** Geostationary satellites provide observations every 10-15 minutes for the full 'Earth disk', but spatial resolution decreases rapidly away from the centre of the image due to the angle at which the sensor views the Earth, and the Earth's curvature.

location puts it towards the edge of the GOES-16 and GOES-18 fields of view, where the spatial resolution is very low (~8-32km2 location dependent; Hall et al., 2019). This makes it challenging to detect actively burning fires in Canada using GOES, and this problem is compounded as you move further north. In Canada, there is therefore an increasing reliance on polar orbiting satellites for fire intelligence.

Despite its widespread integration into operational fire management tools, MODIS is not part of an 'operational' meteorological satellite programme (i.e., there are no plans for direct replacements of MODIS) and will cease to operate by 2026 at the latest (see Frontline Express 92). This will have considerable implications for wildland fire management users of the MODIS active fire products. MODIS users should consider whether the satellite systems described below are suitable MODIS-replacements for their needs.

SUMMARY OF SATELLITE SYSTEMS

The following provides a point-in-time summary of the characteristics of existing and future civil (government) space agency satellites systems relevant for wildland fire monitoring in North America that will provide freely available data. Information was compiled from the CEOS Database (http://database.eohandbook.com/), WMO OSCAR (https://space.oscar.wmo.int/), and space agency websites. The rapidly expanding commercial EO sector is also beginning to provide novel, paid-for fire intelligence products for wildland fire management. We do not discuss commercial solutions here, as these companies typically do not openly provide detailed information about their technology and methods and we do not want the inclusion (or omission) of specific commercial satellite systems and products to be interpreted as an expression of support, or lack thereof.

Please note, satellites with a direct broadcast capability can reduce data latency further than is listed here, but these direct broadcast data may only be available for limited regions or specific end users. Overpass times and revisit frequency listed below are reported for locations at the equator unless otherwise stated, as is standard in the EO community. In Canada, overpass times are likely to be ± 2 hours of this time, and revisit frequency will also be higher due to the increasing convergence of satellite orbital tracks towards the poles.

Polar Orbiting Satellite Missions

Instrument and Lead Space Agency: MODIS (MODerate-Resolution Imaging Spectroradiometer) – NASA

Satellites: Terra (1999-2026 or sooner) Aqua (2002-2026 or sooner)
Spatial resolution for active fire: 1km
Approx. overpass times and revisit frequency: Terra: 10:30 and 22:30 daily, Aqua: 13:30 and 01:30 daily.
Data Latency for general users: Near real time data: <30 minutes, **Science quality data**: 2-3 months.

Data sources	Other information
Near real time data: NASA LANCE FIRMS (hotspot product): https://firms.modaps.eosdis.nasa.gov/ LANCE Worldview and Rapid Response (Swath-based products): https://earthdata.nasa.gov/lance **Science quality data:** Many repositories of standard ('science') quality data exist. See the MODIS Collection 6 Active Fire Product User's Guide for details.	MODIS active fire products are mature and widely used in both the scientific and wildland fire management communities. However, these instruments are close to end of life (2023-2026, exact end-of-life TBC) and as of 2022, changes in how Aqua and Terra are operated will impact fire detection, with potentially serious implications for operational use of these products. See ***Frontline Express 92*** for further details. No direct replacement for MODIS is planned. **Core science reference**: Giglio et al. (2016).

Instrument and Lead Space Agency: VIIRS (Visible Infrared Imaging Radiometer Suite) - NOAA and NASA

Satellites: SUOMI-NPP (2011-2026); NOAA-20 (2017-2027); NOAA-21 (2022-2028); JPSS-3 AKA NOAA-22 (2026-2033); JPSS-4 AKA NOAA-23 (2031–2038)
Spatial resolution for active fire: 375m
Approx. overpass times and revisit frequency: SUOMI-NPP: 13:30 & 01:30 daily; NOAA-20: 13:55 & 01:55 daily; NOAA-21: 13:05 and 01:05 daily; JPSS-3 and -4 will have similar overpass times (~13:30/01:30) to earlier satellites in the series.
Data Latency for general users: Near real time data: <30 minutes, **Science quality data**: up to 2-3 months.

Data sources	Other information
Near real time data: NASA LANCE FIRMS (hotspot product): https://firms.modaps.eosdis.nasa.gov/ LANCE Worldview and Rapid Response (Swath-based products): https://earthdata.nasa.gov/lance **Science quality data:** Many repositories of standard ('science') quality data exist. See the VIIRS Active Fire Product User's Guide for details.	VIIRS active fire data extends back to 2012, and is now widely used instead of (or to supplement) MODIS Aqua data products in scientific and operational applications. Unlike MODIS, VIIRS instruments are an integral part of an operational EO mission (JPSS), and so VIIRS active fire data should be reliably available until the late 2030s. Unlike MODIS, VIIRS is only planned to provide afternoon (~13:30) and late night (~01:30) data. **Core science reference:** Schroeder et al. (2014).

Instrument and Lead Space Agency: SLSTR (Sea and Land Surface Temperature Radiometer) - ESA

Satellites: Sentinel 3A (2016-2026); Sentinel 3B (2018-2028); Sentinel 3C (2024-2034); Sentinel 3D (2028-2038)
Spatial resolution for active fire: 1km
Approx. overpass times and revisit frequency: When data from two Sentinel-3 satellites are combined, data are available daily at 10:00 and 22:00.
Data Latency for general users: Near real time data: < 3 hours, **'Non-time critical' data:** < 1 month.

Data Sources	Other information
Near real time data: Provided by EUMETSAT https://navigator.eumetsat.int/product/EO:EUM:DAT:0207 **'Non-time critical' data**: https://scihub.copernicus.eu/dhus/#/home	For thermal EO monitoring applications (e.g. fires, sea/land surface temperature) the Sentinel-3 SLSTR mission is becoming the de facto replacement for MODIS Terra due to a similar morning overpass time and instrument capabilities. The Sentinel-3 SLSTR active fire products are relatively new. While these products adequately capture fire activity in most situations, some known data quality issues exist that have yet to be resolved, and products should be interpreted with care by users. For further details of outstanding considerations, see Xu and Wooster (2023) and EUMETSAT (2023). **Core science reference:** Xu and Wooster (2023).

Instrument and Lead Space Agency: WildFireSat - CSA

Satellites: Multi-satellite constellation (2029-2034)
Spatial resolution for active fire: 300-400m
Approx. overpass times and revisit frequency: ~18:00 and 06:00 daily in Canada and the USA.
Data Latency for general users: Near real time data: < 30 minutes.

Data sources	Other information
Fire products (hotspot and fire intelligence products) will be available from the Canadian Wildland Fire Information Framework (CWFIF). Imagery will be available from Earth Observation Data Management System (EODMS: https://www.eodms-sgdot.nrcan-rncan.gc.ca/index-en.html)	Developed specifically to meet Canadian fire manager needs, providing fire intelligence products during peak burning conditions in boreal regions to end users with low latency (<30minutes). For more information, see **https://cfs.nrcan.gc.ca/publications?id=40873** **Core science reference:** Johnston et al (2020).

Instrument and Lead Space Agency: OLI (Operational Land Imager) – NASA/USGS

Satellites: Landsat 8 (2013-2023); Landsat 9 (2021-2026)
Spatial resolution for active fire: 30m
Approx. overpass times and revisit frequency: When both Landsat-8 and 9 are combined, data from are available approximately every 8 days at ~10:00.
Data Latency for general users: Near real time data: 30- 60 minutes

Data sources	Other information
Near real time data: NASA LANCE FIRMS ('curated' hotspot product): https://firms.modaps.eosdis.nasa.gov/	High spatial resolution allows more detailed monitoring of fire fronts than using MODIS or VIIRS data. Low temporal resolution (8 days rather than sub-daily for VIIRS, SLSTR & MODIS) means that for many fires, Landsat active fire products are unlikely to be available. **Core science reference:** Schroeder et al. (2016).

Instrument and Lead Space Agency: MSI (Multi-Spectral Instrument) - ESA

Satellites: Sentinel 2A (2015-2025); Sentinel 2B (2017-2027); Sentinel 2C (2024-2034); Sentinel 2D (2028-2038)

Spatial resolution for active fire: Anticipated that 20m resolution fire products will be derived from short-wave infra-red imagery.

Approx. overpass times and revisit frequency: When data from two Sentinel-2 satellites are combined, data are available every 5 days at the equator (2-3 days at mid latitudes) at ~10:30 (in Canada: ~12:00).

Data Latency for general users: Imagery available between 6 hours and ~2 days from capture, on Sci-hub.

Instrument and Lead Space Agency: METimage - ESA

Data sources	Other information
Level 1-2 imagery (***not*** fire products): from https://scihub.copernicus.eu/	At the time of writing no public, freely available, global active fire products are operationally produced for Sentinel-2, but they are expected to be released in the near future (late 2023+). Some fire agencies (e.g. BC Wildfire in Canada) produce local experimental products internally for a non-public audience, and other Sentinel-2 products are available commercially. Sentinel-2 active fire products have similar applications to Landsat fire products due to a similar spatial resolution and revisit frequency. **Core science reference:** No fire product documentation available yet.

Instrument and Lead Space Agency: METimage - ESA

Satellites: METOP-SG A1 (2024-2032); METOP-SG A2 (2031-2039); METOP-SG A3 (2038-2046)

Spatial resolution for active fire: 500m.

Approx. overpass times and revisit frequency: 09:30 and 21:30, daily.

Data Latency for general users: Near real time data**:** Unknown at the time of writing.

Data sources	Other information
Unknown at the time of writing.	At the time of writing little is known about the development of future METimage active fire products. METimage may be able to provide VIIRS-like active fire hotspots at a similar overpass time to Terra MODIS. The midwave infrared channel may however have a low saturation point, and therefore cannot be used to derive fire radiative power (FRP). More information on METOP-SG A mission is available at: https://www.eumetsat.int/metop-sg **Core science reference:** No fire product documentation available yet.

GEOSTATIONARY SATELLITE MISSIONS

Instrument and Lead Space Agency: ABI (Advanced Baseline Imager) - NOAA

Satellites: GOES-16; GOES-17; GOES-18

Spatial resolution for active fire: 2km to 10s of kms, location dependent.

Approx. overpass times and revisit frequency: Imagery of the entire Americas every 10 to 15 minutes.

Data Latency for general users: Near real time data: 20- 30 minutes.

Data sources	Other information
NASA LANCE FIRMS (NOAA FDC and KCL/IPMA products): https://firms.modaps.eosdis.nasa.gov/	Useful for providing high temporal resolution data over the USA and Southern Canada, GOES data becomes increasingly unreliable for fire detection with increasing latitude. ***See (Frontline Express 92)*** for more details on the use of geostationary imagery in Canada. Several different fire products are available (NOAA FDC and KCL/IPMA) for the GOES satellites via FIRMS, each with pros and cons described in detail in the FIRMS FAQ.

ACKNOWLEDGEMENT

This note was produced in support of the Committee on Earth Observation Satellites (CEOS) Working Group Disasters Wildfire Pilot (https://ceos.org/ourwork/workinggroups/disasters/wildfire-pilot/) and Canada's WildFireSat Mission (https://www.asc-csa.gc.ca/eng/satellites/wildfiresat/).

Authors: Mark C. de Jong and Colin B. McFayden

Reviewers and contributors: **Natural Resources Canada, Canadian Forest Service** - Alan S. Cantin; Morgan A. Crowley; Timothy J. Lynham; Joshua M. Johnston; Lynn Johnston; Dan Thompson; Anna Turbelin; **British Columbia Ministry of Forests, Wildfire Service** - Ash Richardson; **Yukon, Wildland Fire Management Branch** - Mike Smith; **Canadian Space Agency** - Denis Dufour; and **NASA** - Douglas Morton.

ACRONYMS AND INITIALISMS

ABI	Advanced Baseline Imager
CSA	Canadian Space Agency
ESA	European Space Agency
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EO	Earth observation
FIRMS	Fire Information for Resource Management System
FRP	fire radiative power
GOES	Geostationary Operational Environmental Satellites
MODIS	Moderate Resolution Imaging Spectroradiometer
MLT	mean local overpass time
MSA	Multi-Spectral Instrument
NASA	National Aeronautics and Space Administration
NASA LANCE	NASA's Land, Atmosphere Near real-time Capability for EOS
NOAA	National Oceanic and Atmospheric Administration
NRT	Near real time
OLI	Operational Land Imager
SLSTR	Sea and Land Surface Temperature Radiometer
USGS	United States Geological Survey
VIIRS	Visible Infrared Imaging Radiometer Suite

REFERENCES

Crowley, M.A.; Stockdale, C.A.; Johnston, J.M.; Wulder, M.A.; Liu, T.; McCarty, J.L.; Rieb, J.T.; Cardille, J.A.; White, J.C. 2023. Towards a whole-system framework for wildfire monitoring using Earth observations. Glob. Change Biol. 29, 1423–1436. https://doi.org/10.1111/gcb.16567

EUMETSAT (2023) Sentinel-3 Product Notice – SLSTR Level-2 Near Real Time (NRT) Fire Radiative Power (FRP). [Online]. Accessed 2023/06/09. Available from: https://www-cdn.eumetsat.int/files/2021-11/Sentinel-3%20Product%20Notice%20%E2%80%93%20SLSTR%20Level-2%20Near%20Real%20Time%20Fire%20Radiative%20Power_PB2.80_v1.pdf

Giglio, L.; Schroeder; W.; Justice, C.O. 2016. The collection 6 MODIS active fire detection algorithm and fire products. Remote Sens. Environ. 178, 31–41. https://doi.org/10.1016/j.rse.2016.02.054

Hall, J.V.; Zhang; R.; Schroeder, W.; Huang, C.; Giglio, L. 2019. Validation of GOES-16 ABI and MSG SEVIRI active fire products. Int. J. Appl. Earth Obs. Geoinformation 83, 101928. https://doi.org/10.1016/j.jag.2019.101928

Johnston, J.M.; Jackson, N.; McFayden, C.; Ngo Phong, L.; Lawrence, B.; Davignon, D.; Wooster, M.J.; van Mierlo, H.; Thompson, D.K.; Cantin, A.S.; Johnston, D.; Johnston, L.M.; Sloane, M.; Ramos, R.; Lynham, T.J., 2020. Development of the User Requirements for the Canadian WildFireSat Satellite Mission. Sensors 20, 5081. https://doi.org/10.3390/s20185081

Schroeder, W.; Oliva, P.; Giglio, L.; Csiszar, I.A. 2014. The New VIIRS 375m active fire detection data product: Algorithm description and initial assessment. Remote Sens. Environ. 143, 85–96. https://doi.org/10.1016/j.rse.2013.12.008

Schroeder, W.; Oliva, P.; Giglio, L.; Quayle, B.; Lorenz, E.; Morelli, F. 2016. Active fire detection using Landsat-8/OLI data. Remote Sens. Environ., Landsat 8 Science Results 185, 210–220. https://doi.org/10.1016/j.rse.2015.08.032

Wooster, M.J.; Roberts, G.J.; Giglio, L.; Roy, D.; Freeborn, P.; Boschetti, L.; Justice, C.; Ichoku, C.; Schroeder, W.; Davies, D.; Smith, A.; Setzer, A.; Csiszar, I.; Strydom, T.; Frost, P.; Zhang, T.; Xu, W.; de Jong, M.; Johnston, J.; Ellison, L.; Vadrevu, K.; McCarty, J.; Tanpipat, V.; Schmidt, C.; San-Miguel, J. 2021. Satellite remote sensing of active fires: History and current status, applications and future requirements. Remote Sens. Environ. 267, 112694. https://doi.org/10.1016/j.rse.2021.112694

Xu, W.; Wooster, M.J. 2023. Sentinel-3 SLSTR active fire (AF) detection and FRP daytime product - Algorithm description and global intercomparison to MODIS, VIIRS and landsat AF data. Sci. Remote Sens. 100087. https://doi.org/10.1016/j.srs.2023.100087

CONTACT INFORMATION

Great Lakes Forestry Centre
1219 Queen Street East
Sault Ste. Marie, ON P6A 2E5 Canada
Telephone: 705-949-9461
E-mail: wildfiresat-gardefeu@nrcan-rncan.gc.ca
Web site: nrcan.gc.ca/forests/research-centres/glfc/13459

Aussi disponible en français sous les titre : ***Nouvelle Express, Bulletin No 93.***

ISSN 1496-7847 (Print) ISSN 1496-7855 (Online)