Remote Sensing of Vegetation Fires

Chris Justice

Based on Presentations from the last GOFC-GOLD Fire Implementation Team Meeting (GOFC.org), USFS SNWG and Giglio S3 Pilot

Pre-Fire > Fire > Post-Fire

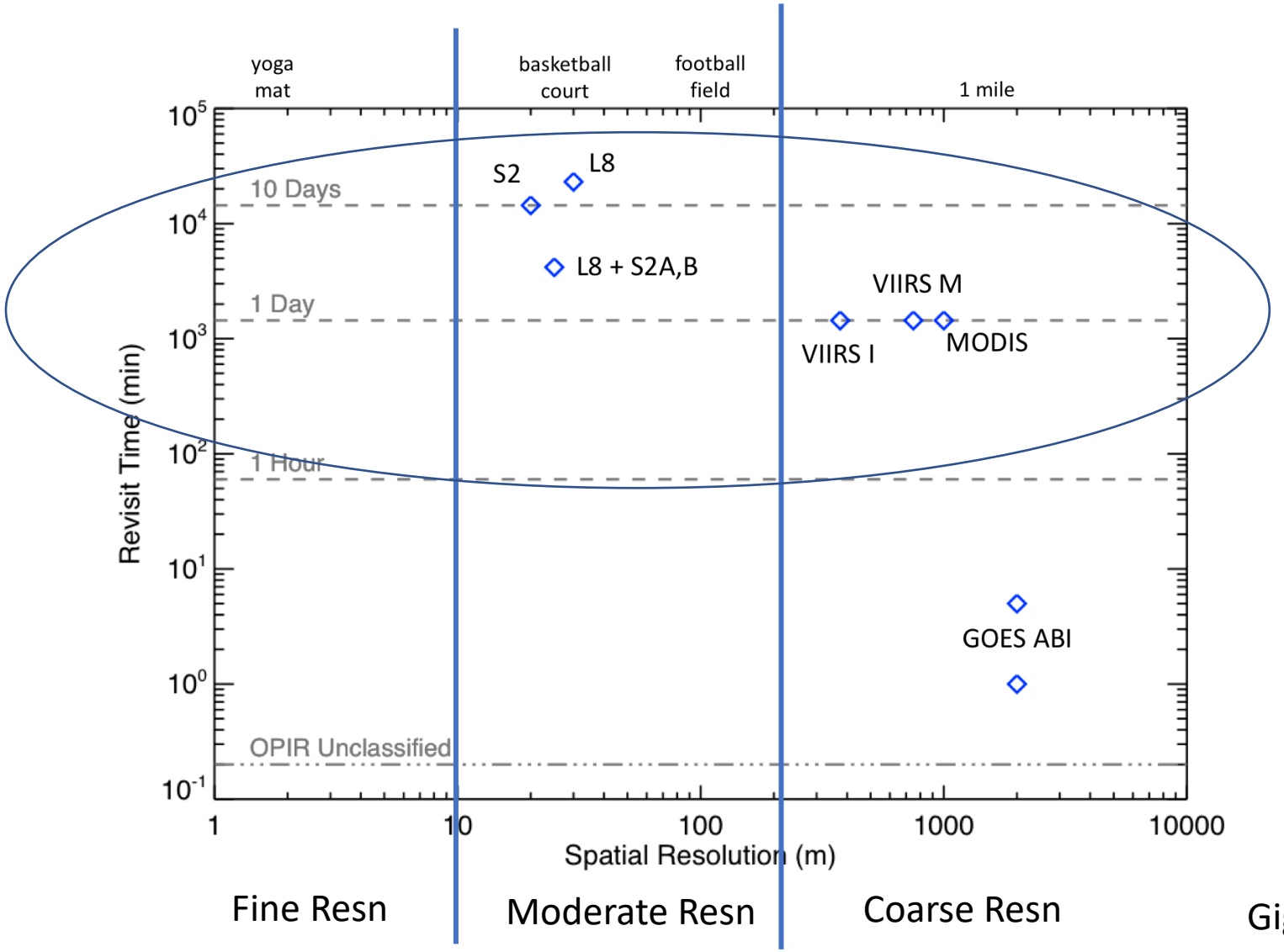
Remote sensing emphases to date

- Active Fire (Hot spots)
- Fire Radiative Power (FRP)
- Burned Area (Post Fire)

Increasing attention to other remote sensing contributions

- Vegetation Fuel Load and Composition,
- Fuel Condition (moisture content),
- Fire Behavior Modeling,
- Post-Fire Recovery,
- Smoke Composition, Transport > Air Quality > Health Impacts

Summary of Current Active Fire Sensors Revisit and Spatial Resolution



Giglio 2020

NASA EOS Moderate Resolution Imaging Spectroradiometer

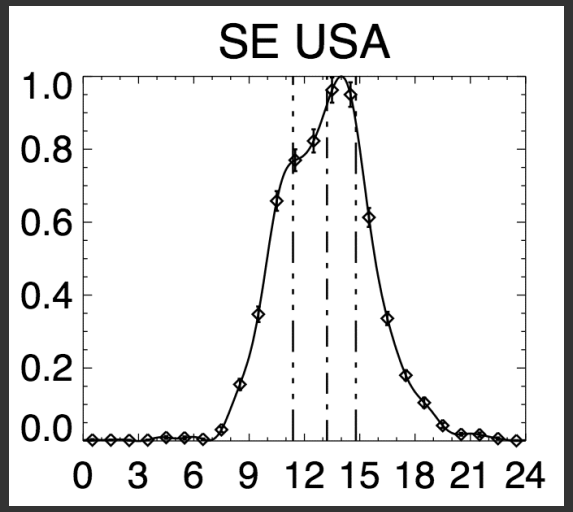
- MODIS Data Record 2000 – present
  - Terra 10:30 & 22:30 local overpass
  - Aqua 01:30 & 13:30 local overpass
- 36 spectral bands covering 0.4 to 14.4 micrometers
  - Dedicated 1 km Fire bands (sub-pixel fire detection)
    - Channel 21: 3.96 μm, ≈ 500 K saturation
    - Channel 31: 11.0 μm, ≈ 400 K saturation
    - Channel 22: 3.96 μm, ≈ 330 K saturation

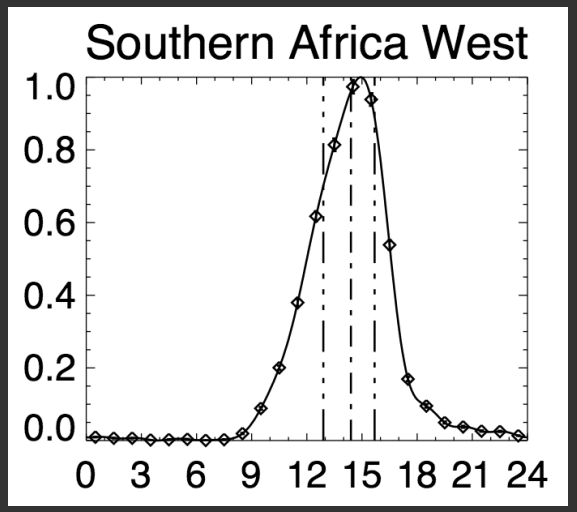
- Active Fire Algorithm
  - Look for elevated signal at 4 μm; use 11 μm channel to help exclude warm, non-fire surfaces
  - Adaptive thresholds based on local statistics so algorithm can be applied globally
  - Use additional channels to help reject false alarms
    - Small convective clouds, sun glint, land cover/vegetation boundaries, coastline, desert and other hot/reflective surfaces, urban areas

Last 7 Days of Active Fire Counts

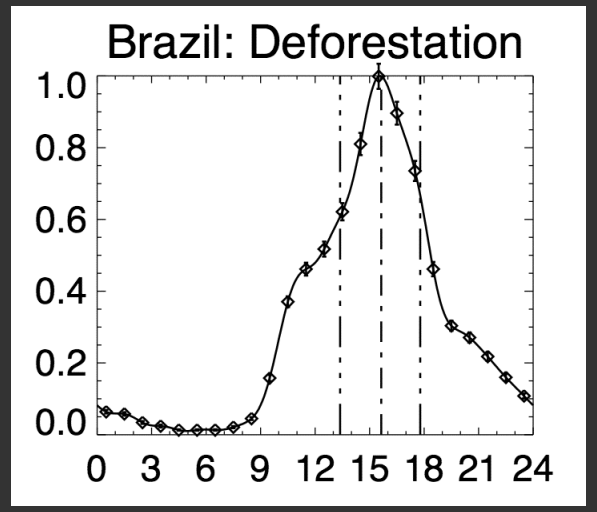
Fires in the Last 24 hours

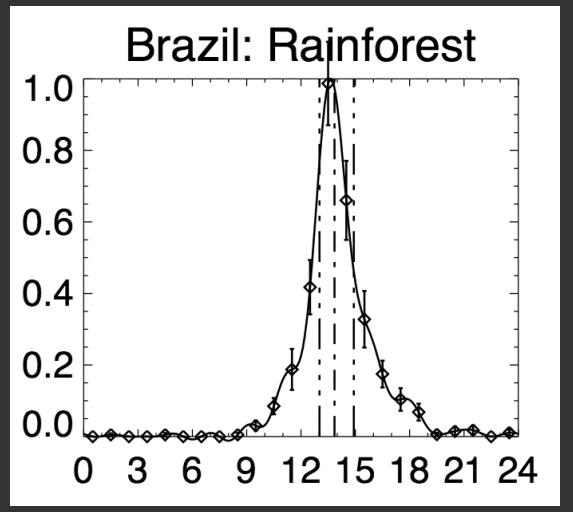
Diurnal Fire Cycle and MODIS Temporal Sampling





Local Hour

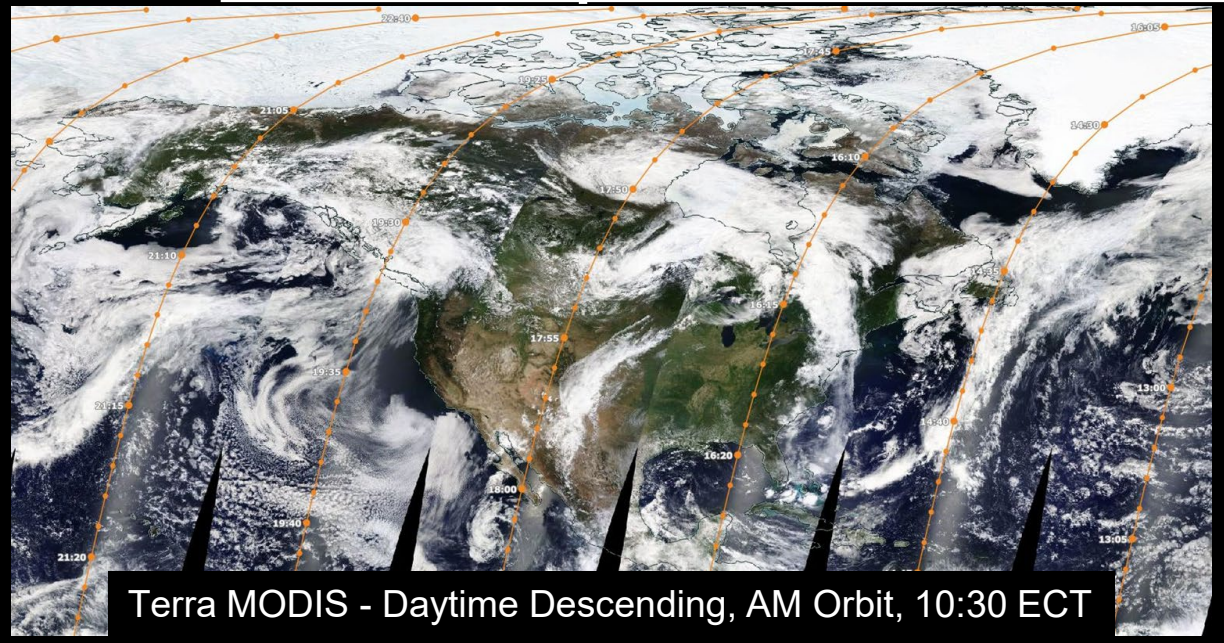




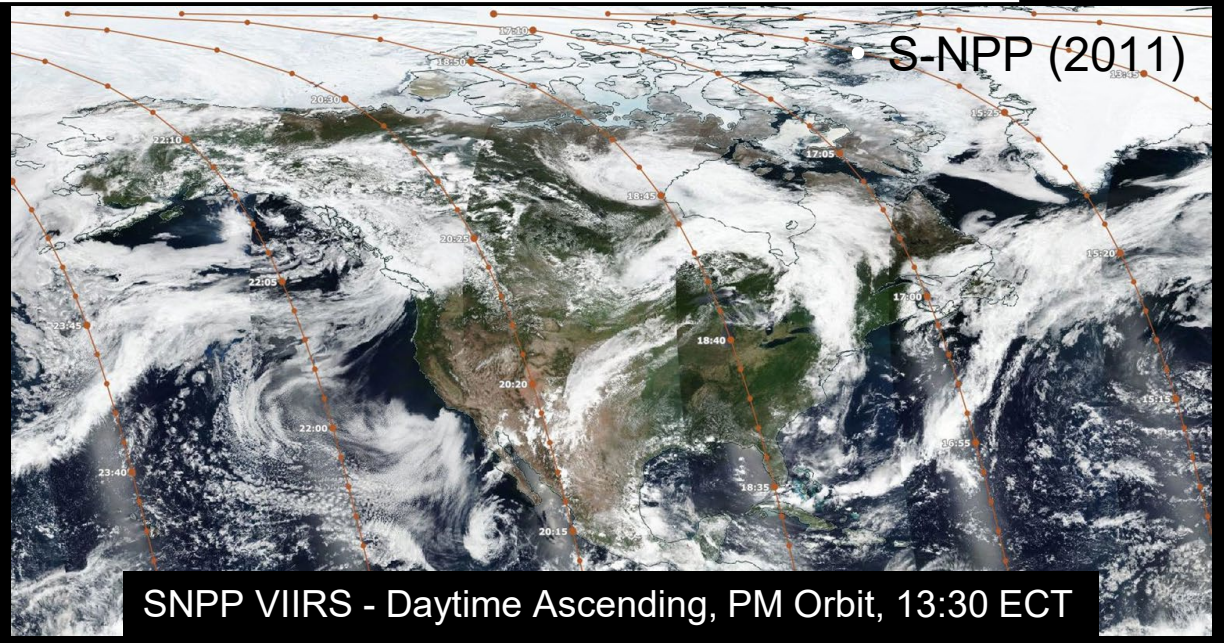
MODIS Fire Product Status – Louis Giglio (UMd)

- Active Fire (MOD14/MYD14) + Burned Area (MCD64A1)
- Collection 6 (C6) production commenced in 2015 (AF) and 2016 (BA)
- C6 production to end December 2022
- C6 → C6.1 transition
  - Polarization correction
  - C6.1 reprocessing commenced in 2019 (now complete)
  - No change in AF product
  - Small differences in BA product
- Collection 7 planned for late 2023
- MODIS end-of-life plans being reconsidered (range 2023-2025)

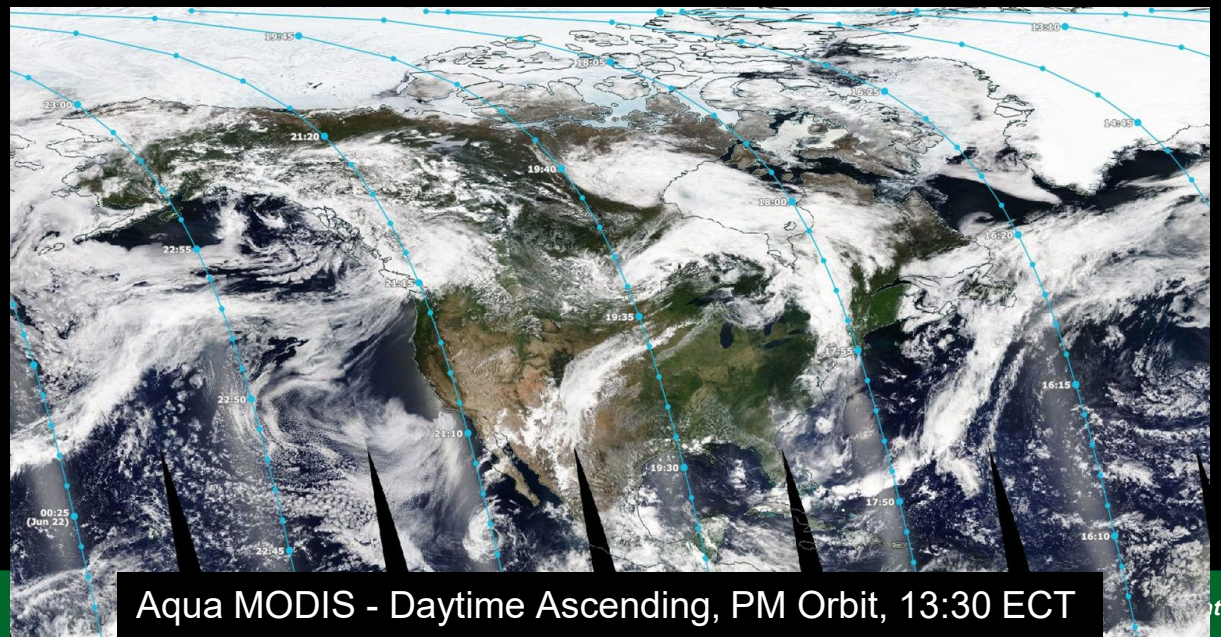
Terra/Aqua MODIS and S-NPP/NOAA-20 VIIRS



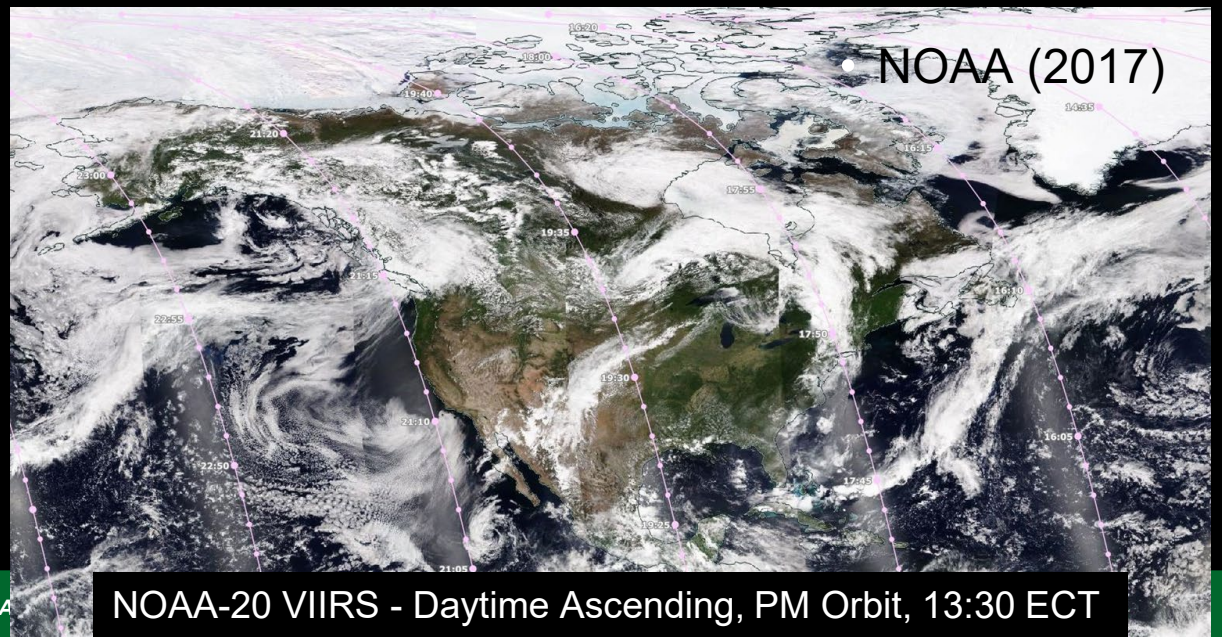
Terra MODIS - Daytime Descending, AM Orbit, 10:30 ECT



SNPP VIIRS - Daytime Ascending, PM Orbit, 13:30 ECT



Aqua MODIS - Daytime Ascending, PM Orbit, 13:30 ECT



NOAA-20 VIIRS - Daytime Ascending, PM Orbit, 13:30 ECT

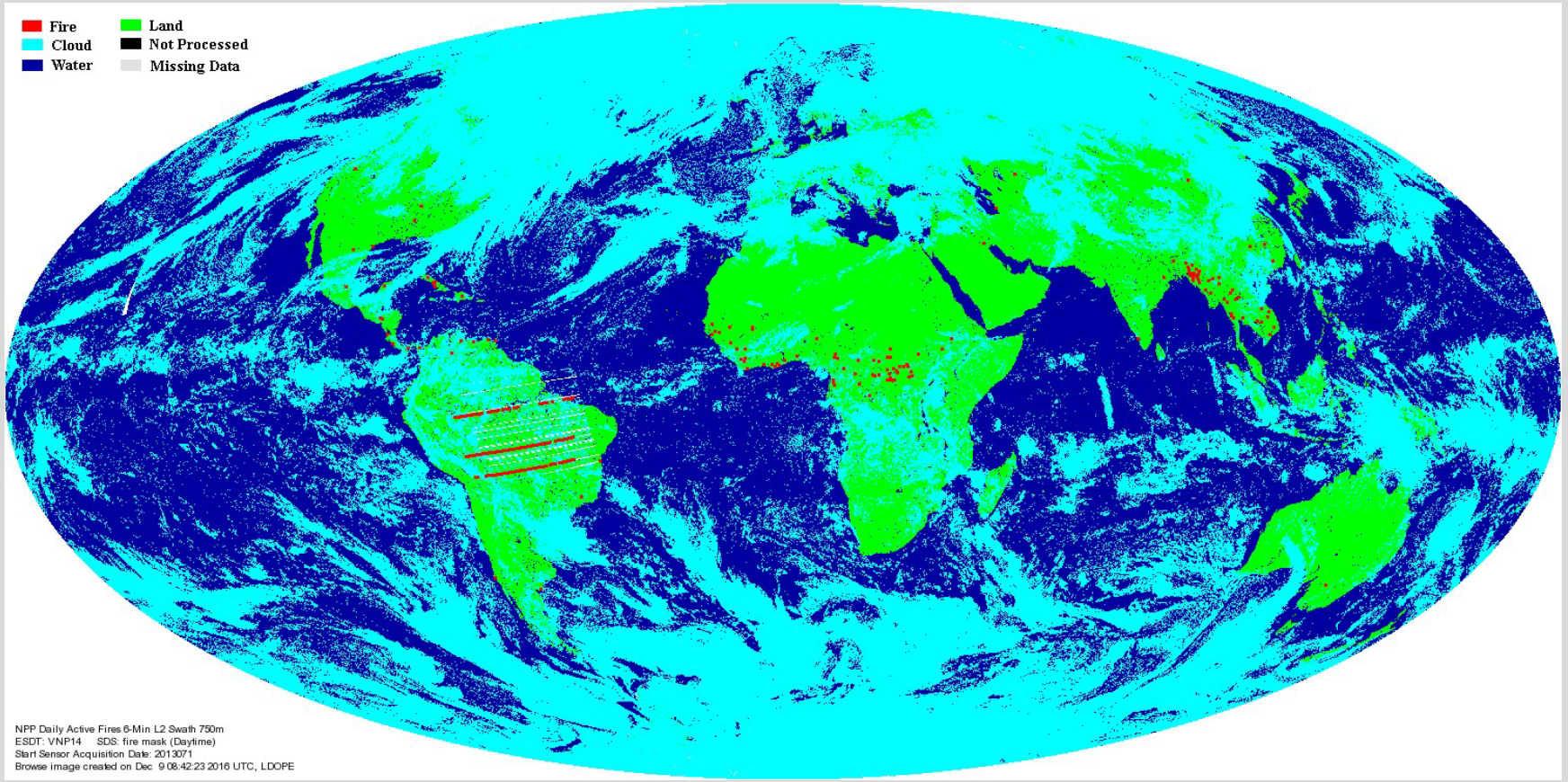
NASA VIIRS Active Fire (VNP14/VNP14IMG)

Product Overview

- Level 2 swath + Level 3 gridded
- 375-m product is a significant improvement over MODIS and is used widely
- 750-m produce retained for continuity (more like MODIS)

Limitations and Strengths

- SDR-induced bad scans in C1 product – fixed for C2 but reprocessing still pending
- No morning VIIRS overpass
- Sub-optimal M13 location (tweaked for later VIIRS)
- Responsivity across swath is much more uniform
- Unprecedented sensitivity to small fires

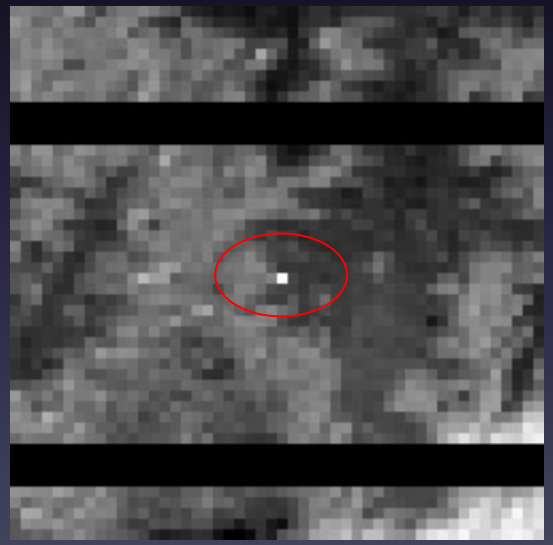


Collection-1 750-m VIIRS VNP14 active fire product

12 March 2013

Arcs of false fire pixels caused by spurious M13 scans.

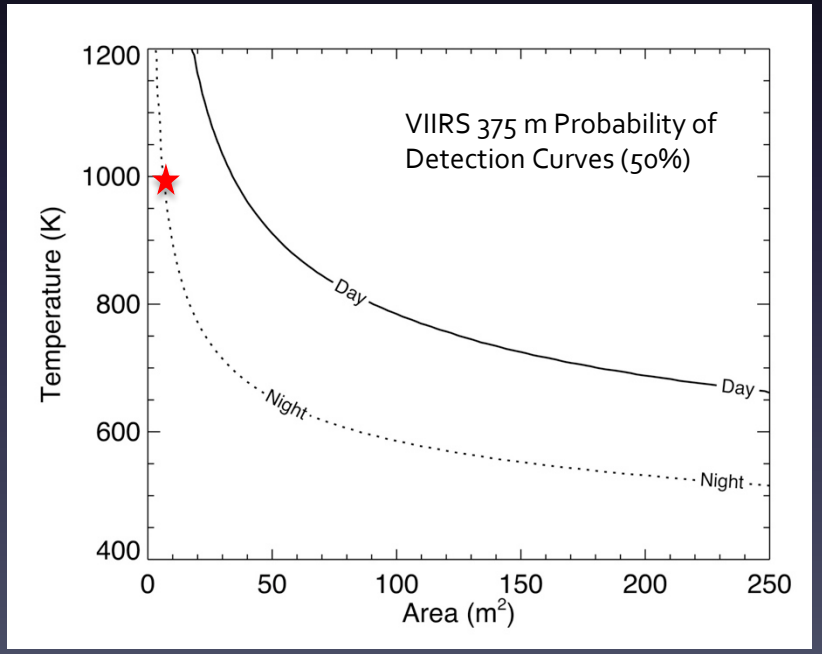
Small Fire Validation
VIIRS 375 m nighttime example in Rio de Janeiro/Brazil



Subset of VIIRS L1B data
08 July 2013 4:23 UTC (1:23am local)
Coinciding with bonfire

2.5 m diameter
experimental bonfire

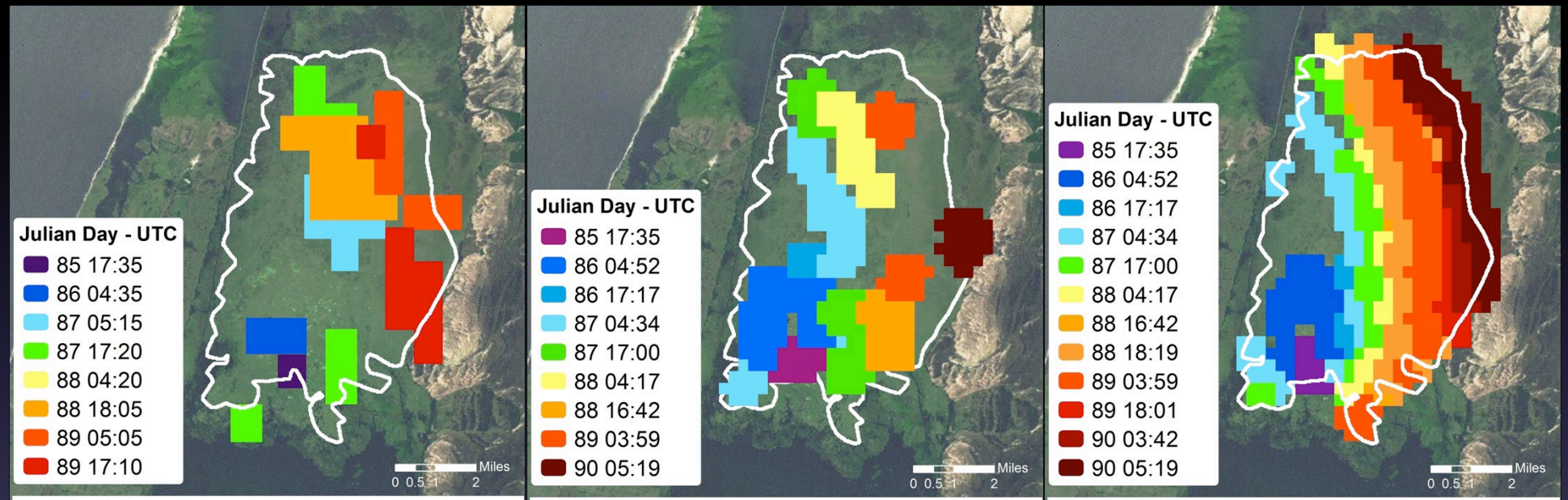
Single pixel detection
Pixel fraction containing
active fire: **0.004%**



Schroeder

MODIS 1 km × VIIRS 750 m × VIIRS 375 m Fire Data Intercomparison

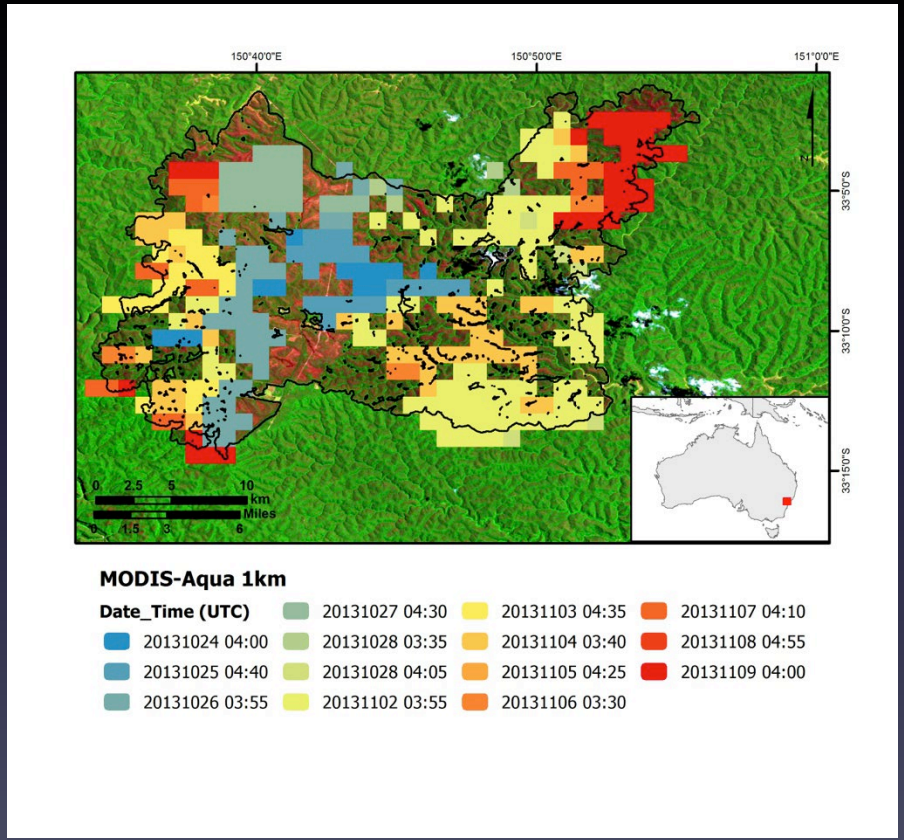
Taim Ecological Reserve, Southern Brazil (March 2013)



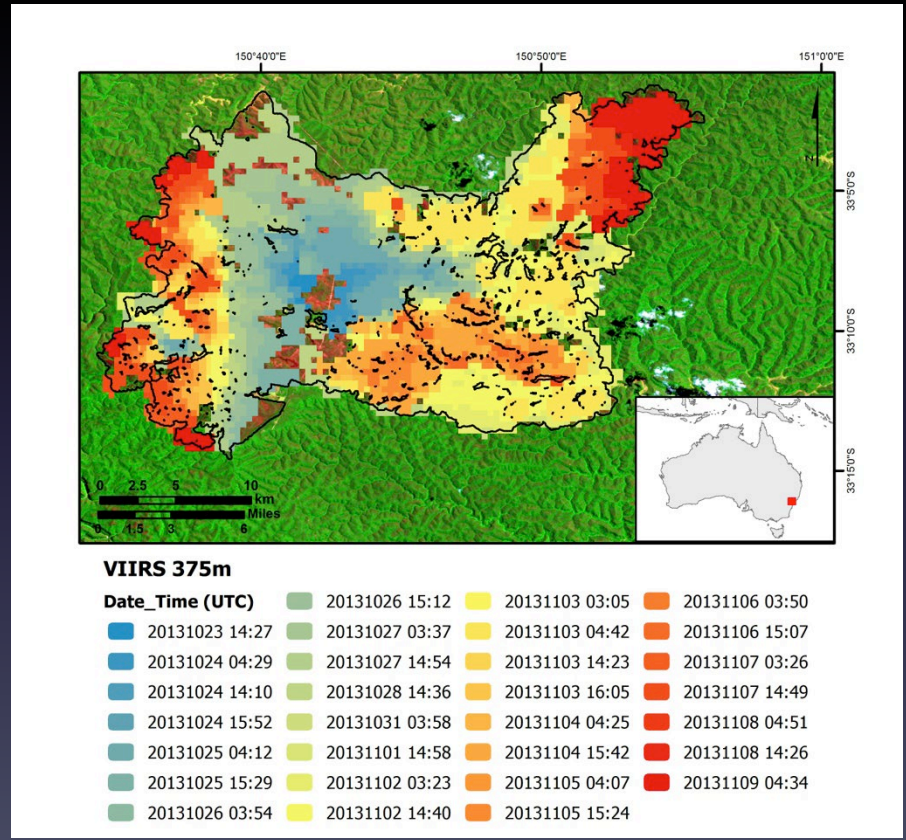
Aqua/MODIS 1 km	NPP/VIIRS 750 m	NPP/VIIRS 375 m
Pixel Area 1<>10 km²	Pixel Area 0.56<>2.5 km²	Pixel Area 0.14<>0.625 km²
Image Swath 2330 km	Image Swath 3000 km	Image Swath 3000 km

Improved Satellite Mapping of Active Fires Using VIIRS 375m Data

Aqua/MODIS 1km



S-NPP/VIIRS 375m



MODIS Burned Area Products

MCD64A1	500-m Monthly
MCD64A1-based GIS Products (SCF)	Shapefiles + 500-m GeoTIFF
MCD64CMQ (SCF)	0.25° Monthly

VIIRS Burned Area Products

VNP64A1	500-m Monthly
VNP64A1-based GIS Products (SCF)	Shapefiles + 500-m GeoTIFF
VNP64CMQ (SCF)	0.25° Monthly

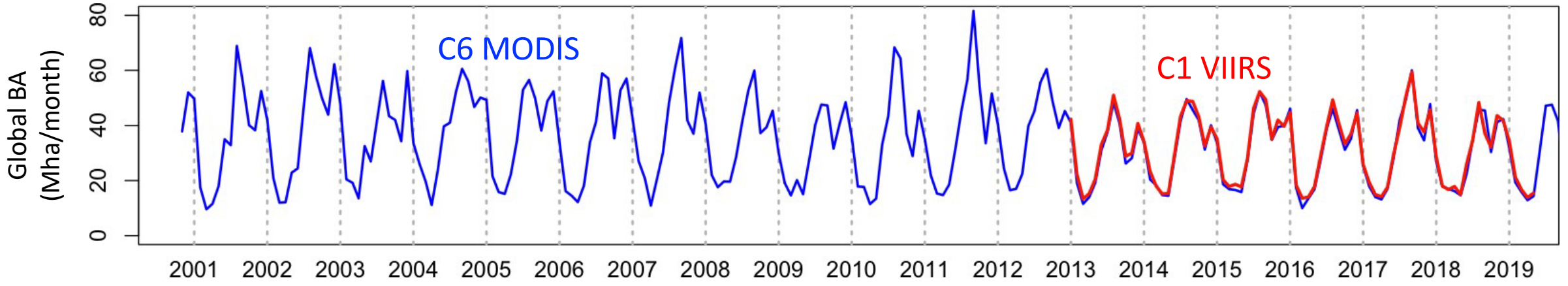
S-NPP VIIRS Burned Area (VNP64A1)

Product Overview

- Monthly global burned area with date of burn mapped to nearest day
- Adapted MODIS MCD64A1 production code to use VIIRS data
- Retained 500-m MODIS grid for compatibility
- Limited C1 release due to artifacts in C1 cloud mask (fixed for C2)

Limitations and Strengths

- No morning VIIRS overpass
- 750-m (vs. 500-m) imagery – I-bands not designed for BA mapping
- Nevertheless, highly consistent with MODIS MCD64A1 product



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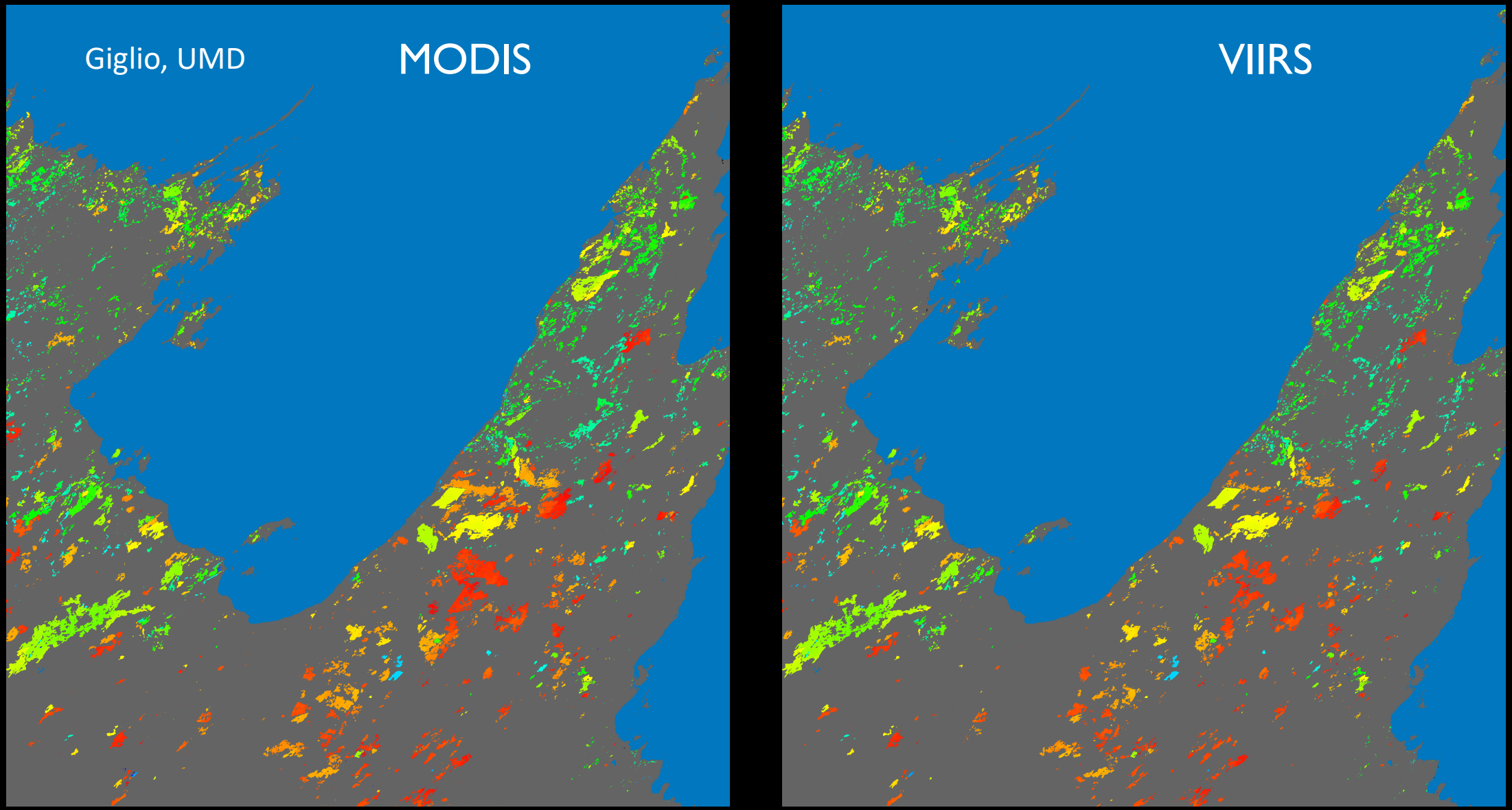
2017 Cumulative Burned Area (Northern Australia)

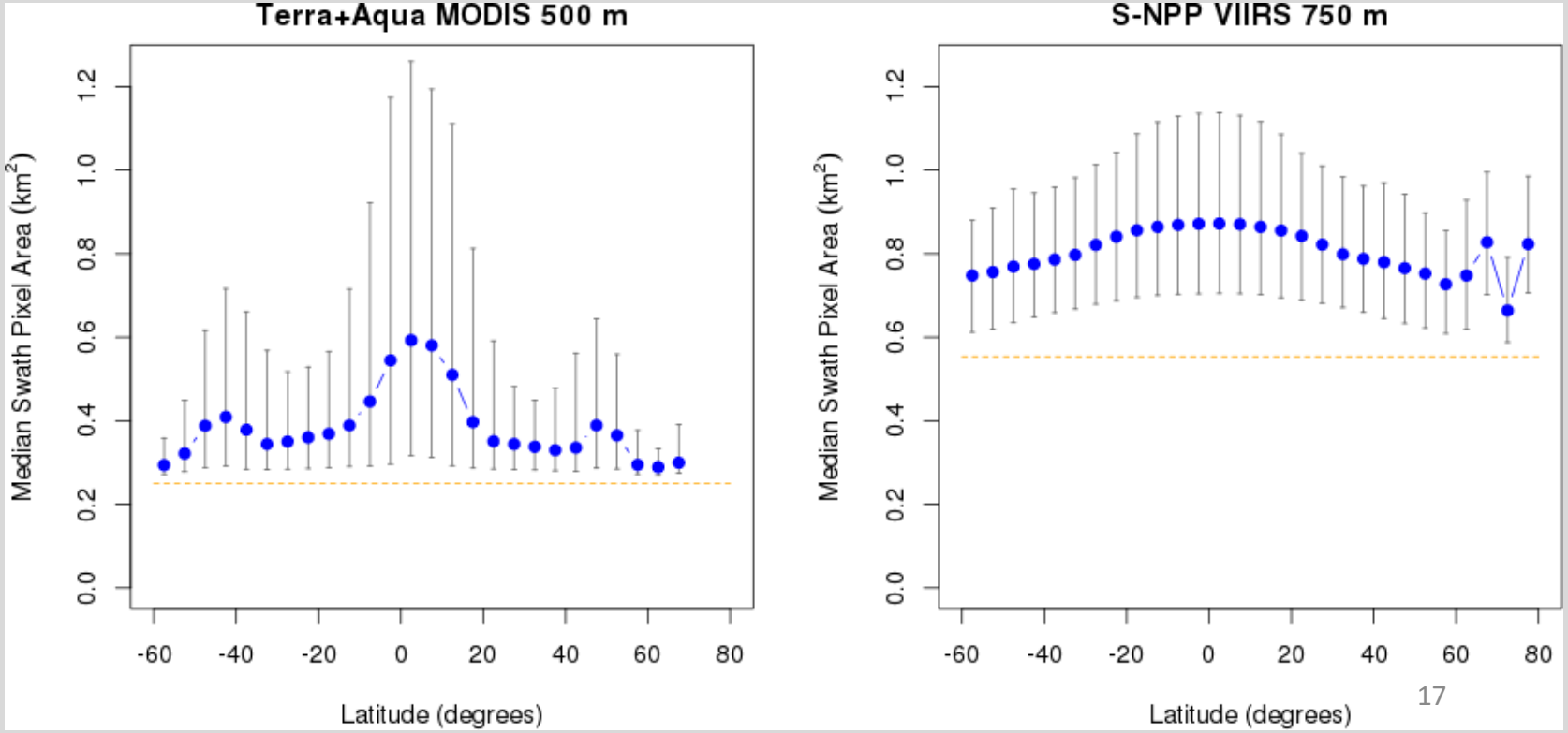


Giglio, UMD

Status of S-NPP/NOAA-20 VIIRS Burned Area

- Improve product fidelity by combining S-NPP and NOAA-20 VIIRS observations
- Analogous to combining Terra and Aqua MODIS observations
- Improve MODIS continuity
- NOAA-20 VIIRS “hooks” in code
- Post-C2 (C3?) VNP64A1 product

Multiple VIIRS ➔ Effective resolution of 750-m VNP64A1 burned area product much closer to effective resolution of 500-m MODIS burned area product in tropics. Effective MODIS resolution remains significantly better at high latitudes, however.



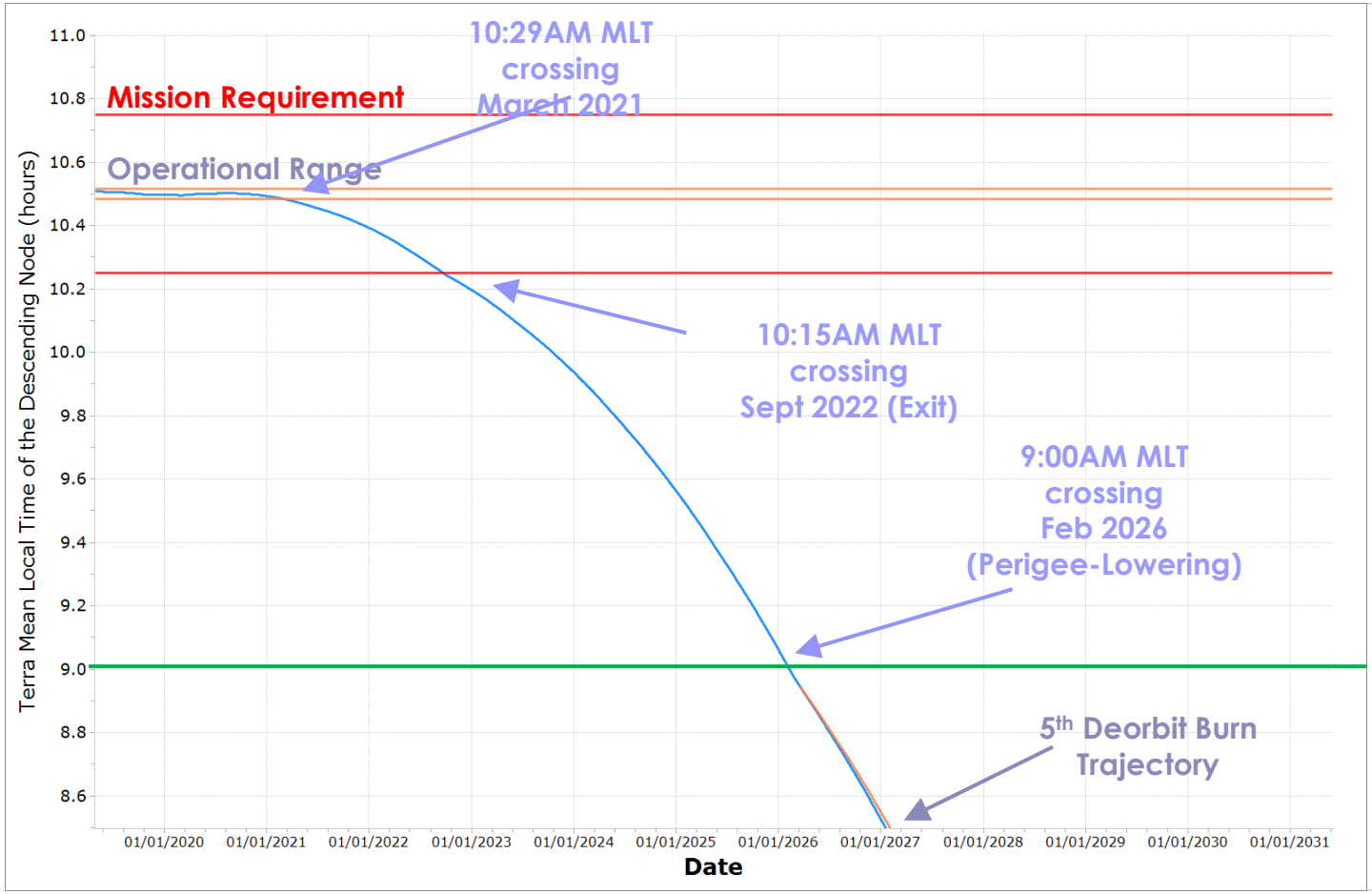
Summary - NASA VIIRS Fire Product Status

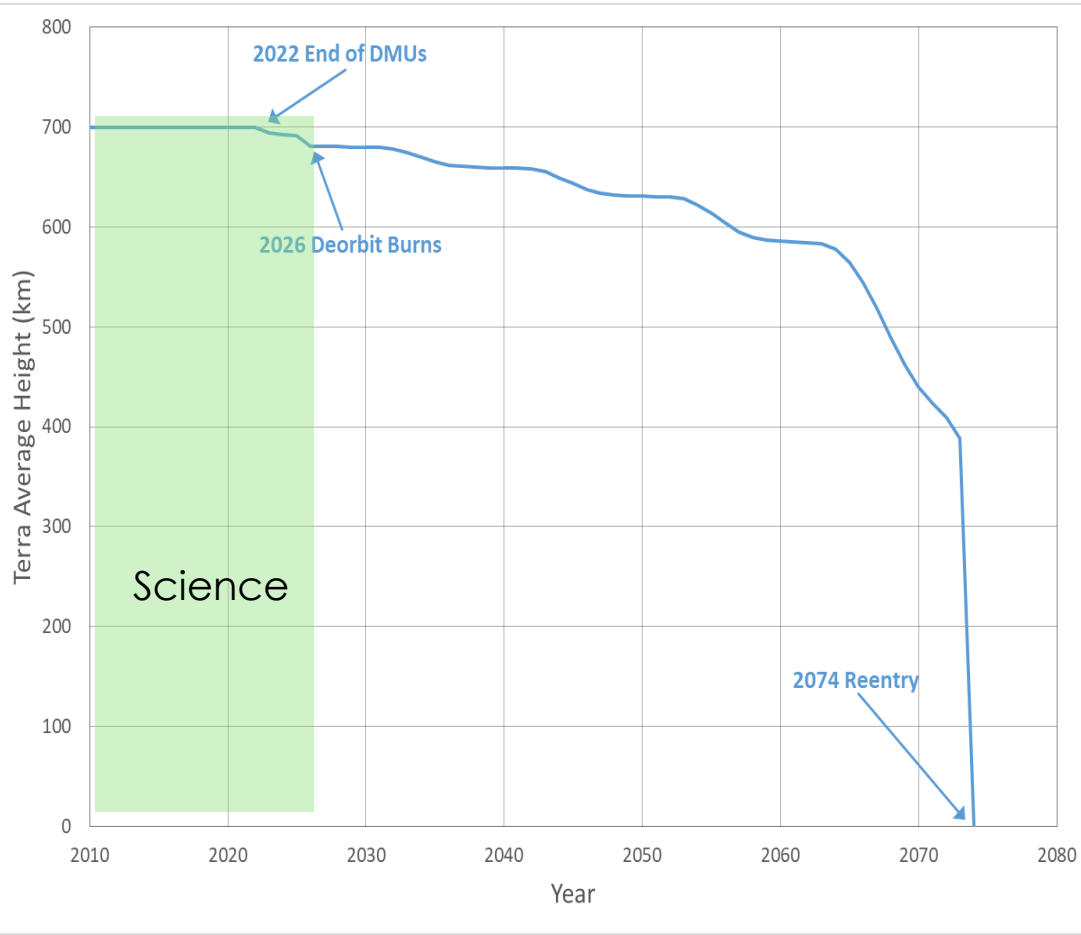
- Active Fire: 375-m VNP14IMG + 750-m VNP14
- Burned Area: “500-m” VNP64A1
- Collection 1 remains current long past its expected lifetime
- Significant improvements made for Collection 2
  - NOAA-like SDR ➔ NASA Level 1B transition
- Collection 2 Land reprocessing massively delayed

Terra – End of Life Planning

Constellation exit assumed to be required when crossing time reaches 10:15 am

Passivation currently planned at 9 am crossing time (the EO-1 limit)





Decommissioning Plan	MLT Violation (10:29AM)	MLT Violation (10:15AM)	Exit Year	De-orbit Burns (#)	Apogee at Depletion (km)	Perigee at Depletion (km)	Crossing time 9:00AM MLT	EOM to Reentry (years)	Reentry Date
Baseline	**Mar 2021**	**Sept 2022**	**2022**	**5**	**691.1**	**667.0**	**2026**	**43**	**2069**

Terra and Aqua Missions – Current Status

- Still collecting valuable data, but…
  - Both are aging spacecrafts
  - Number of spacecraft anomalies is increasing
  - Increasingly expensive to operate (~$90 million/year)
- Both no longer have necessary fuel to maintain altitude and tight crossing times
- Both are currently exiting their respective constellations and their local-crossing times are drifting earlier (Terra) and later (Aqua) in the day
- End of science data collection/end of mission schedule
  - Terra - December 2023
  - Aqua - August 2023

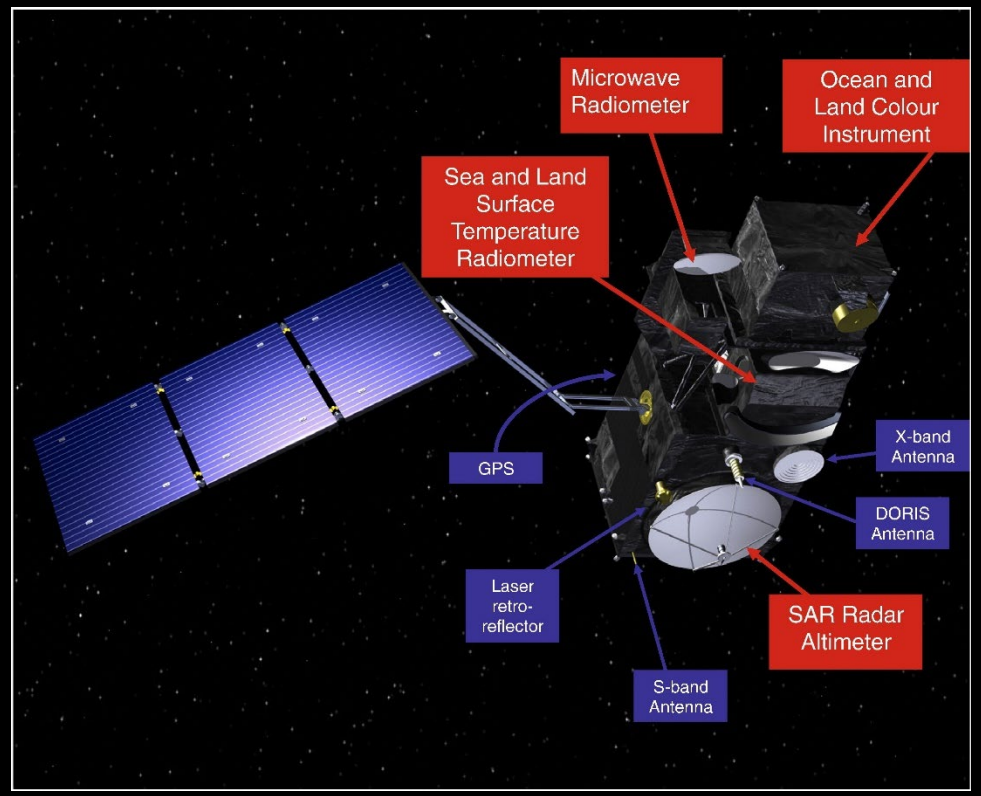
Observation and Product Continuity

- Aqua MODIS PM observation and product continuity assured through VIIRS
  - NOAA-20 / JPSS-1 (2017)
  - NOAA-21 / JPSS-2 (November 2022)
  - JPSS-3 (2027)
  - JPSS-4 (2032)
- No NASA or NOAA missions to provide AM observation and product continuity for Terra MODIS

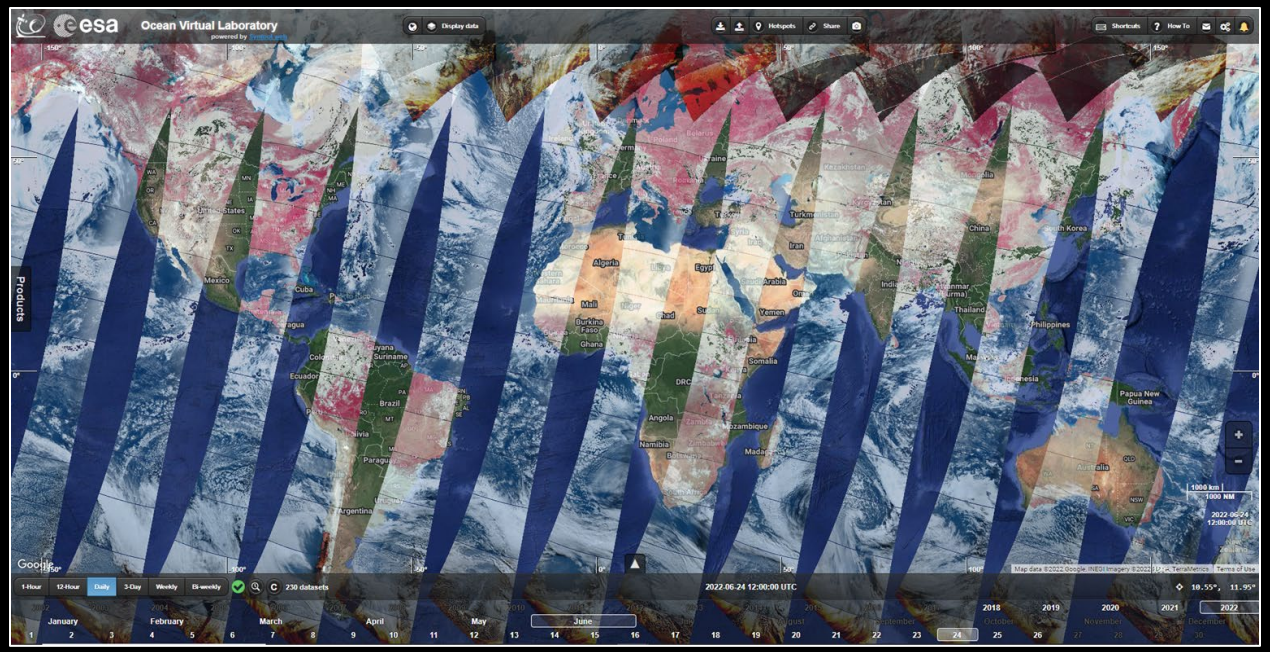
Options for Developing MODIS AM Continuity

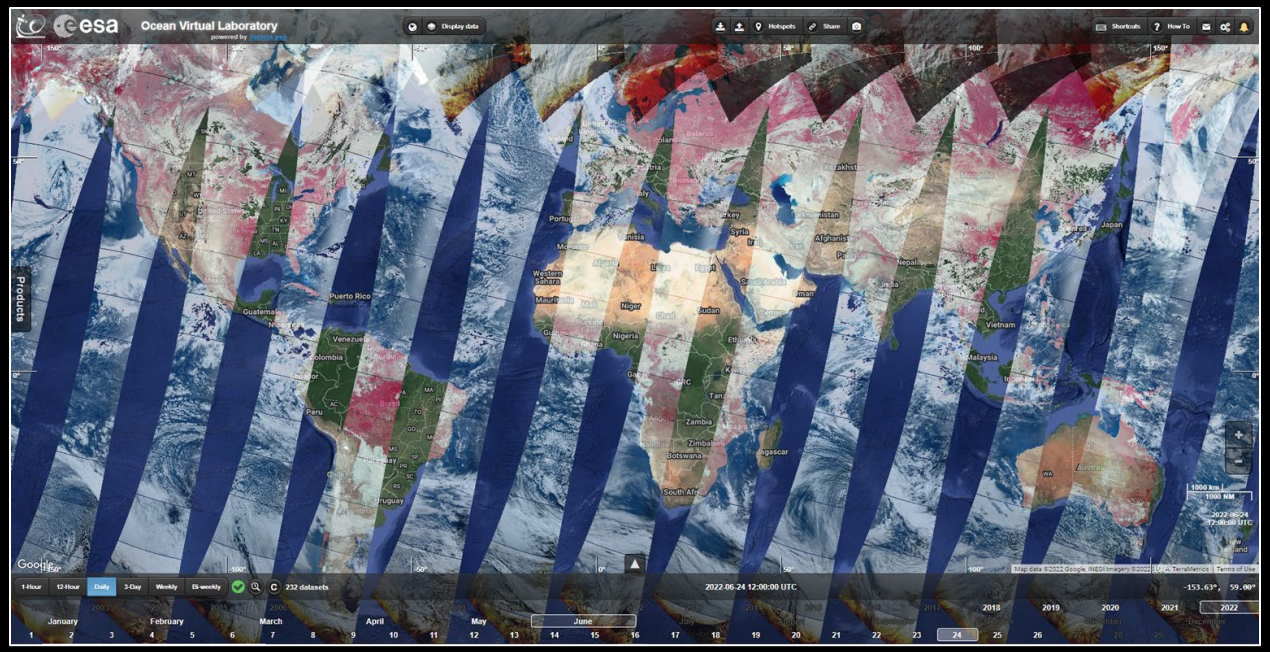
1. Sentinel 3 OLCI / SLSTR - European Space Agency (ESA)

- Sentinel 3 mission consists of two identical, concurrently operating platforms
  - Sentinel 3A / 3B
- Ocean and Land Color Instrument (OLCI)
  - 1,270 km swath
  - 21 bands (VIS / NIR) at 300m resolution
- Sea and Land Surface Temperature Radiometer (SLSTR)
  - 1,400 km swath
  - 6 bands (VIS, SWIR) at 500m and 5 bands (MWIR, LWIR) at 1km resolution



SLSTR Daily Coverage Example





Sentinel 3A and 3B SLSTR daytime swath coverage for June 24, 2022

	Constellation configuration	Revisit at equator	Revisit for latitude > 30°
SLSTR dual view (day and night)	One satellite	< 1.8 days	< 1.5 days
	Two satellites	< 0.9 days	< 0.8 days

Global coverage revisit times for SLSTR

Options for Developing MODIS AM Continuity

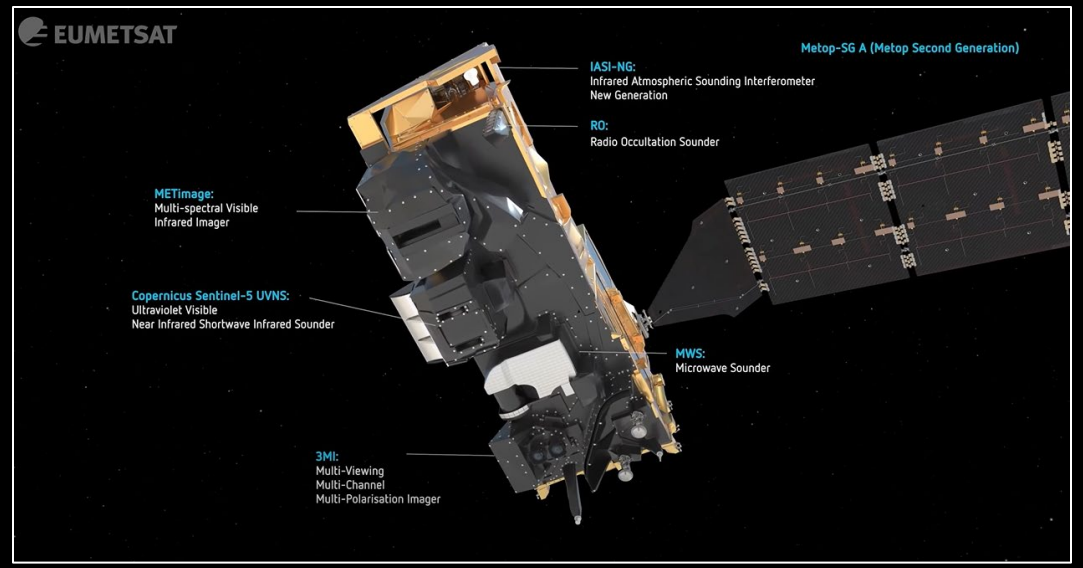
1. Sentinel 3 OLCI / SLSTR - European Space Agency (ESA)

- Sentinel 3 series is planned for operation through 2031 with a 10 am overpass
  - Sentinel 3A (2016)
  - Sentinel 3B (2018)
  - Sentinel 3C (2023)
  - Sentinel 3D (2025)
- NASA GSFC receives a S3 data feed from ESA
- NASA is evaluating “Tier 1” S3 land products (surface reflectance, active fires, land surface temperature)
  - ESA Synergy Surface Reflectance product under-performs compared to MODIS surface reflectance product (Vermote et al.)
  - ESA / EUMETSAT Fire Detection and Fire Radiative Power product evaluation is planned

Options for Developing MODIS AM Continuity

2. MetOp-SG / METimage - EUMETSAT

- METimage, a VIIRS-like instrument
  - 2,670 km swath
  - 20 bands (VIS / NIR / SWIR / TIR) at 500m resolution
  - 9.30 am overpass
  - Temporal resolution / revisit time will be very similar to MODIS and VIIRS
- MetOp-Second Generation mission anticipated to begin in early 2024



Options for Developing MODIS AM Continuity

2. MetOp-SG / METimage - EUMETSAT

- The MetOp-SG series is planned for operation from 2024-2040s with a 9:30 am overpass
  - MetOp SG A1 (2024)
  - MetOp SG A2 (2031)
  - MetOp SG A3 (2038)
- NASA is seeking to establish partnership to access METImage data and conduct instrument calibration after launch
- NASA is seeking to develop and generate ‘Tier-1’ Land Products from METimage test data

Summary Recommended NASA Actions

2023

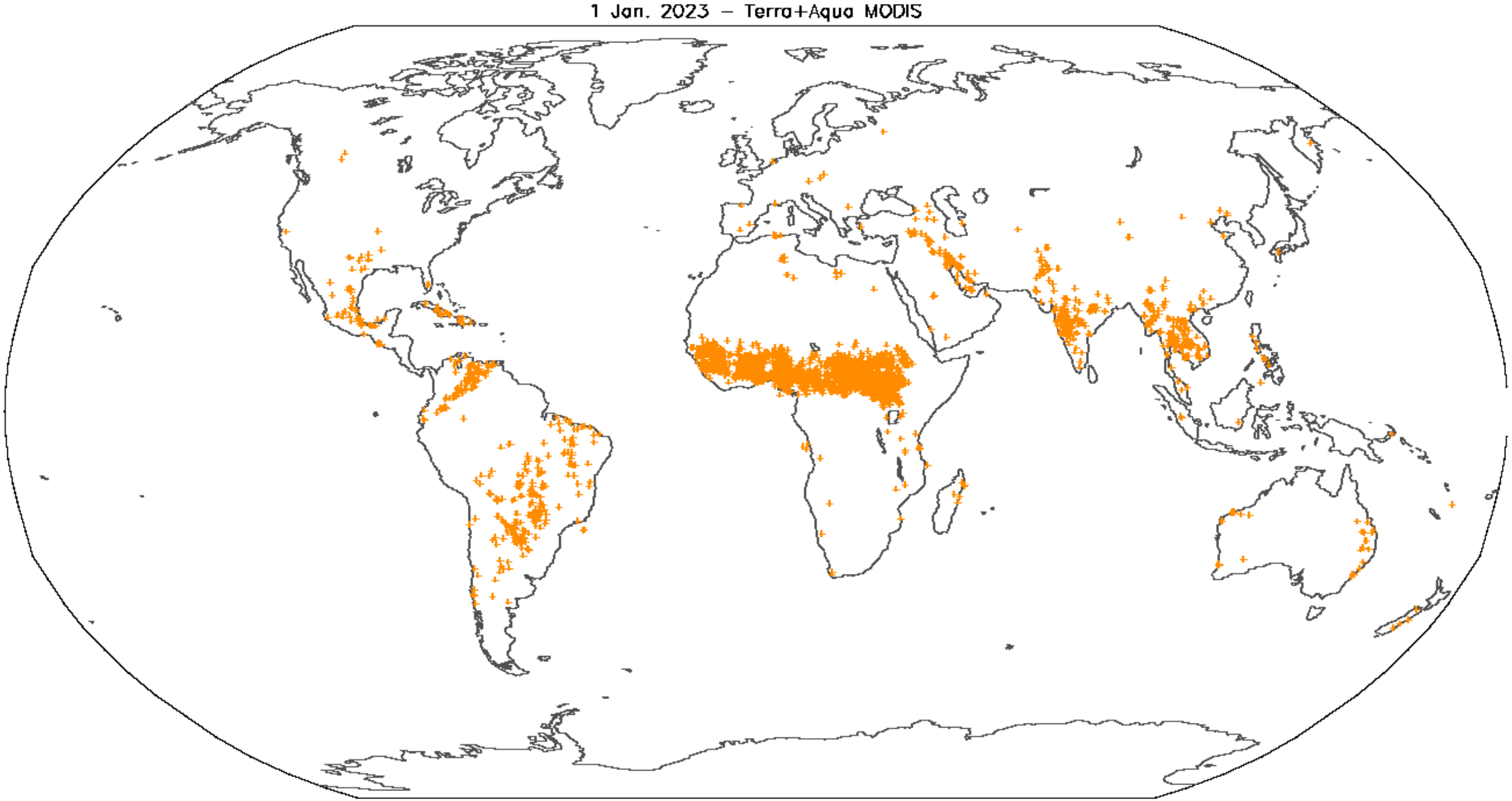
1. Evaluate Sentinel 3 Fire Detection and Fire Radiative Power product performance compared to Terra MODIS product
2. Complete the preparation of Sentinel 3 ‘Tier-1’ Land Products as an interim solution to data continuity if MODIS Terra data is discontinued
3. Discuss with European partners plans for access, download and storage of METimage Level 1 data
4. Adapt and generate NASA ‘Tier-1’ Land Products from METimage using test data
5. Adapt the Land Products that will require combining VIIRS and METimage data (e.g., Burned Area, Albedo, LAI / FPAR, Snow and Ice) using test data

Ongoing Evaluation of SLSTR Active Fire Data

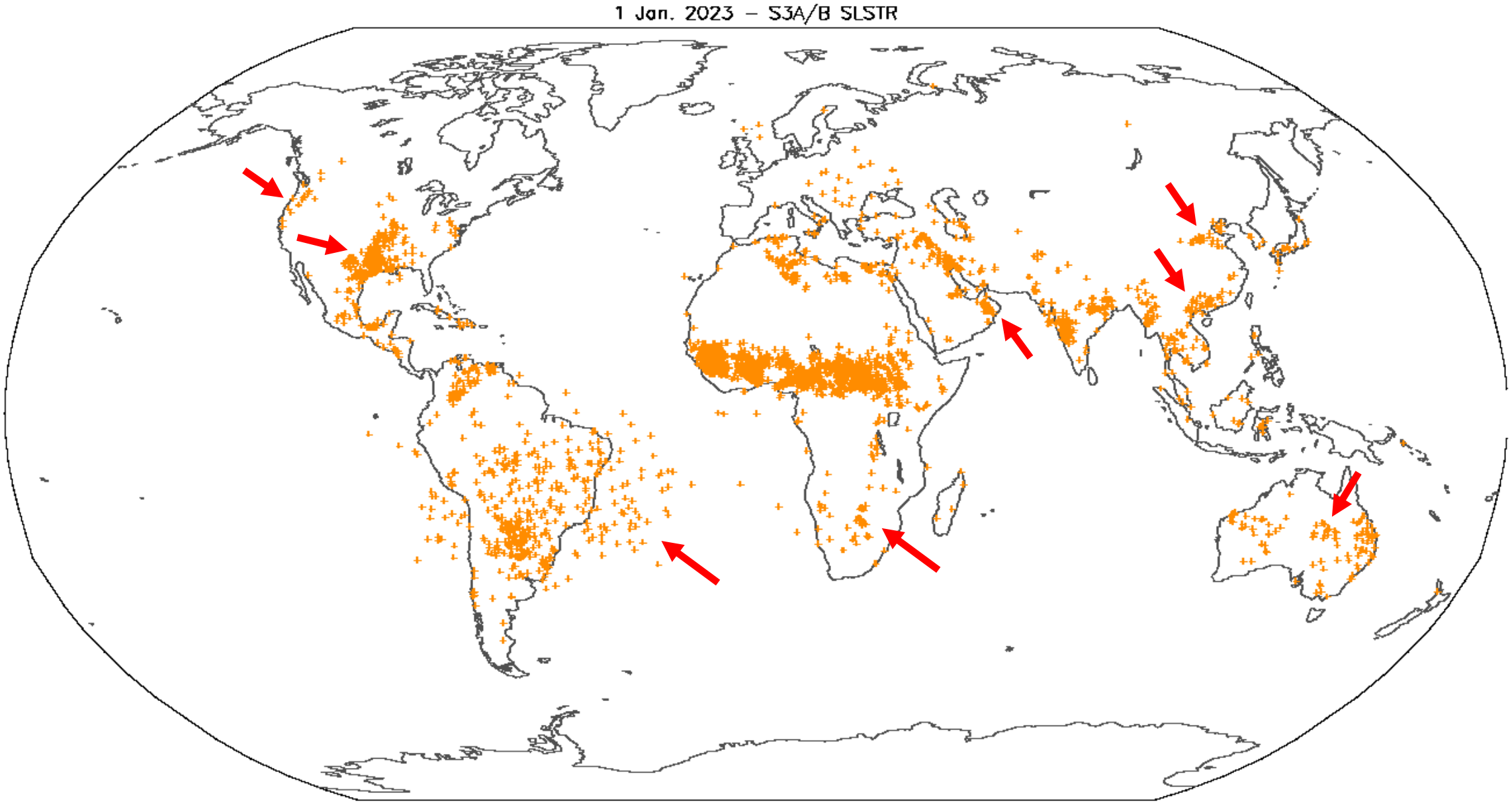
- Each SLSTR reports ∼3× as many fire pixels as Terra MODIS
  - Higher sensitivity, especially at night
    - Constrained pixel growth (conical scan)
    - Wavelength: 3.74 µm MWIR channel vs. 3.96 µm for MODIS
  - Higher false alarm rate, especially along cloud edges + SAA
    - MWIR/LWIR misregistration + wavelength
- Additional assorted practical (but manageable) product discrepancies
- Preliminary Evaluation and Comparison Underway

1 Jan. 2023 **Terra+Aqua MODIS**

Fire Pixels



1 Jan. 2023 **S3A+S3B SLSTR NRT** Fire Pixels

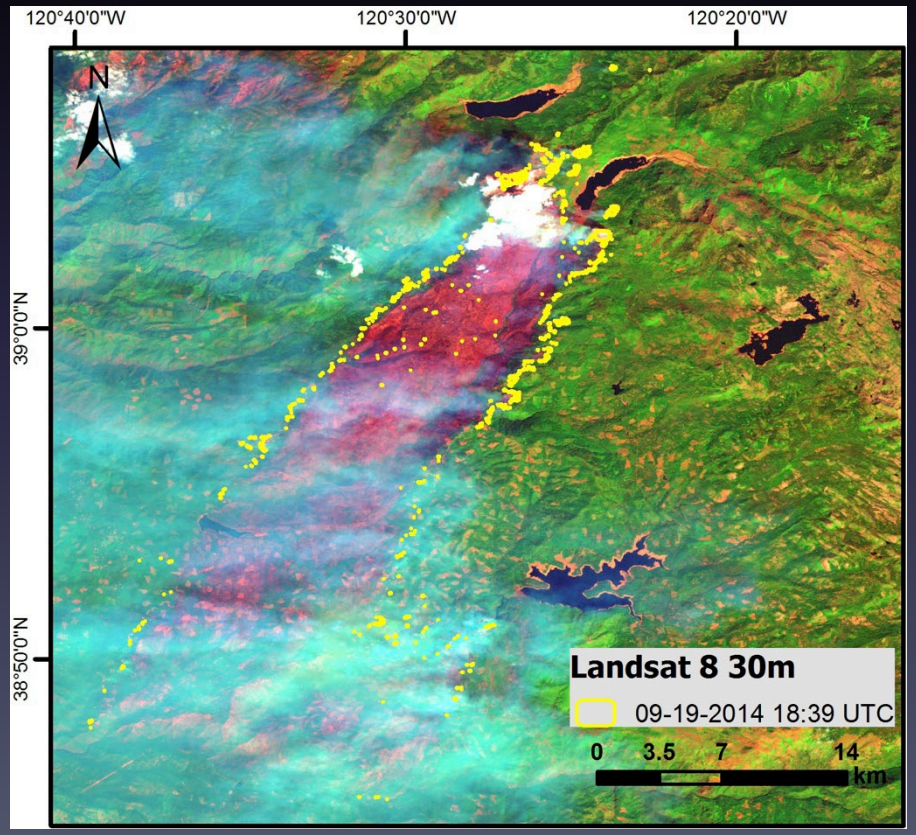


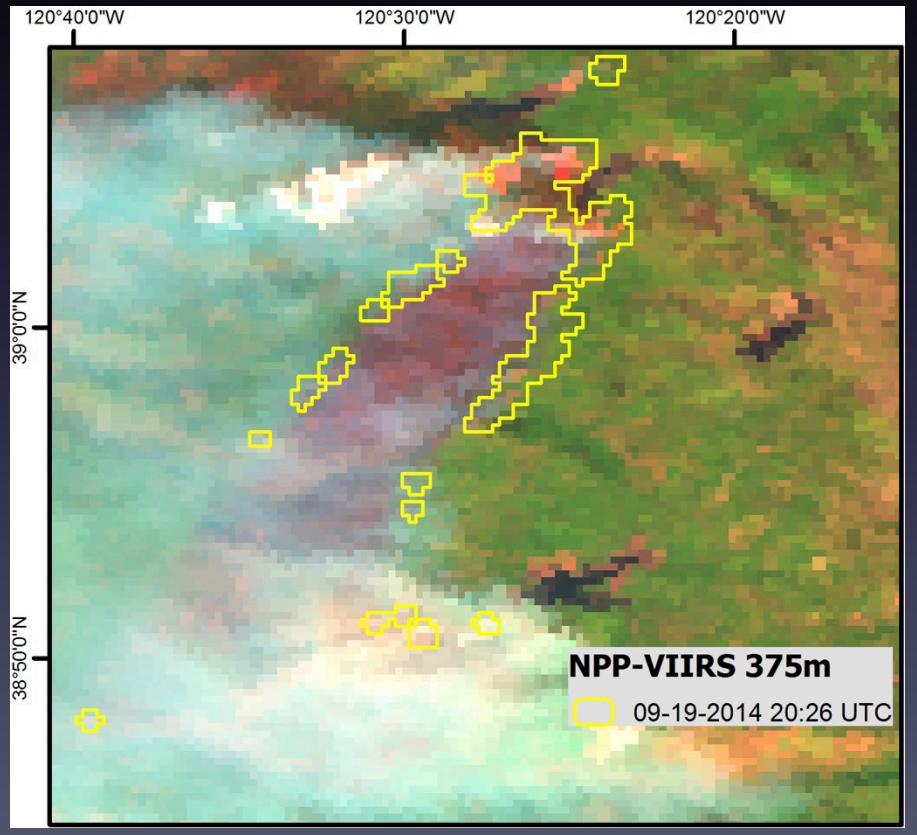
The Landsat-8 30 m Active Fire Detection Data

Pros:
Uses OLI Shortwave Infrared Channel
>150x more information per unit area than VIIRS 375 m
>1000x more information per unit area than MODIS 1km

Cons:
Limited coverage (16 day-interval)

Potential:
Launch of other similar sensors could greatly increase data availability in the future (2-3 years)
Near real-time data processing/distribution being explored





Landsat 8 OLI Fire Detection

Table 1. List of 30 m resolution Landsat-8/OLI channels used in the active fire detection algorithm, and their primary application.

OLI channel	Wavelength (μm)	Application
1	0.43–0.45	Active fire detection & water mask
2	0.45–0.51	Water mask
3	0.53–0.59	Water mask
4	0.64–0.67	Water mask
5	0.85–0.88	Active fire detection & water mask
6	1.57–1.65	Active fire detection & water mask
7	2.11–2.29	Active fire detection, water mask & temporal analysis

Schroeder et al. 2016

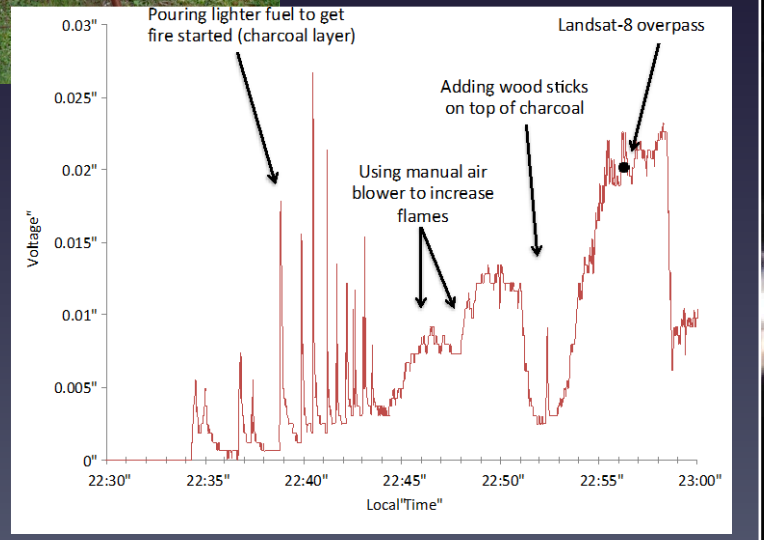
Very Small Fire Validation
Landsat-8 nighttime example in Greenbelt/USA

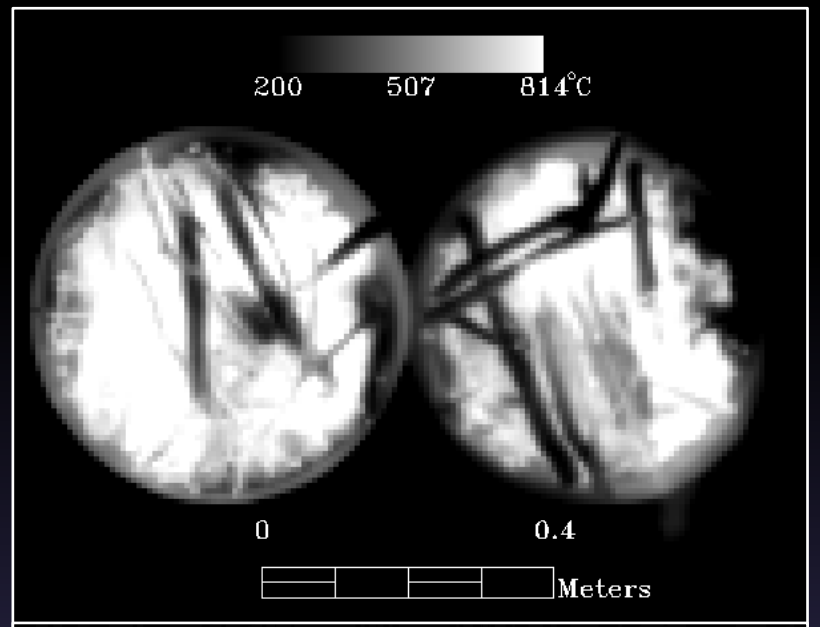
04 April 2015
10:56pm local

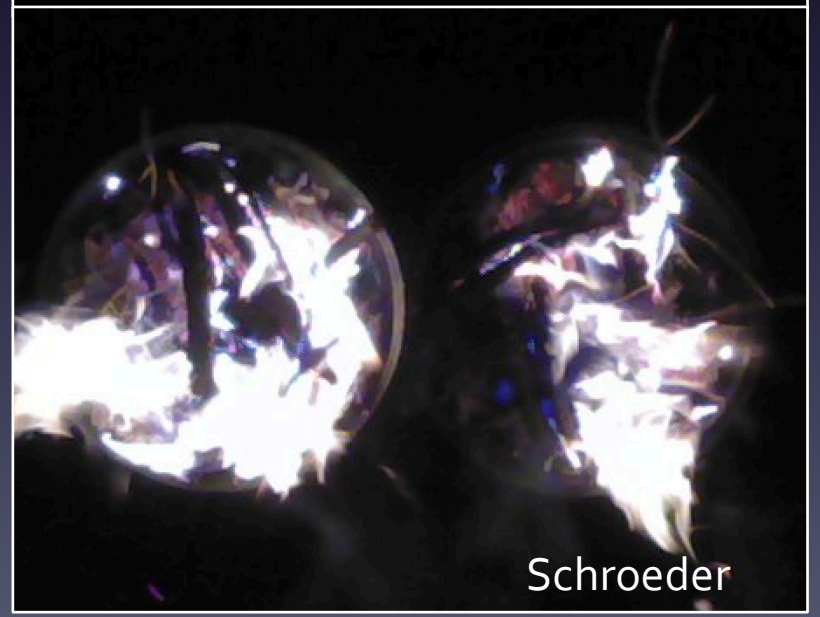
FLIR camera and dual-band radiometer mounted to 5 m telescoping tower overlooking grill fire

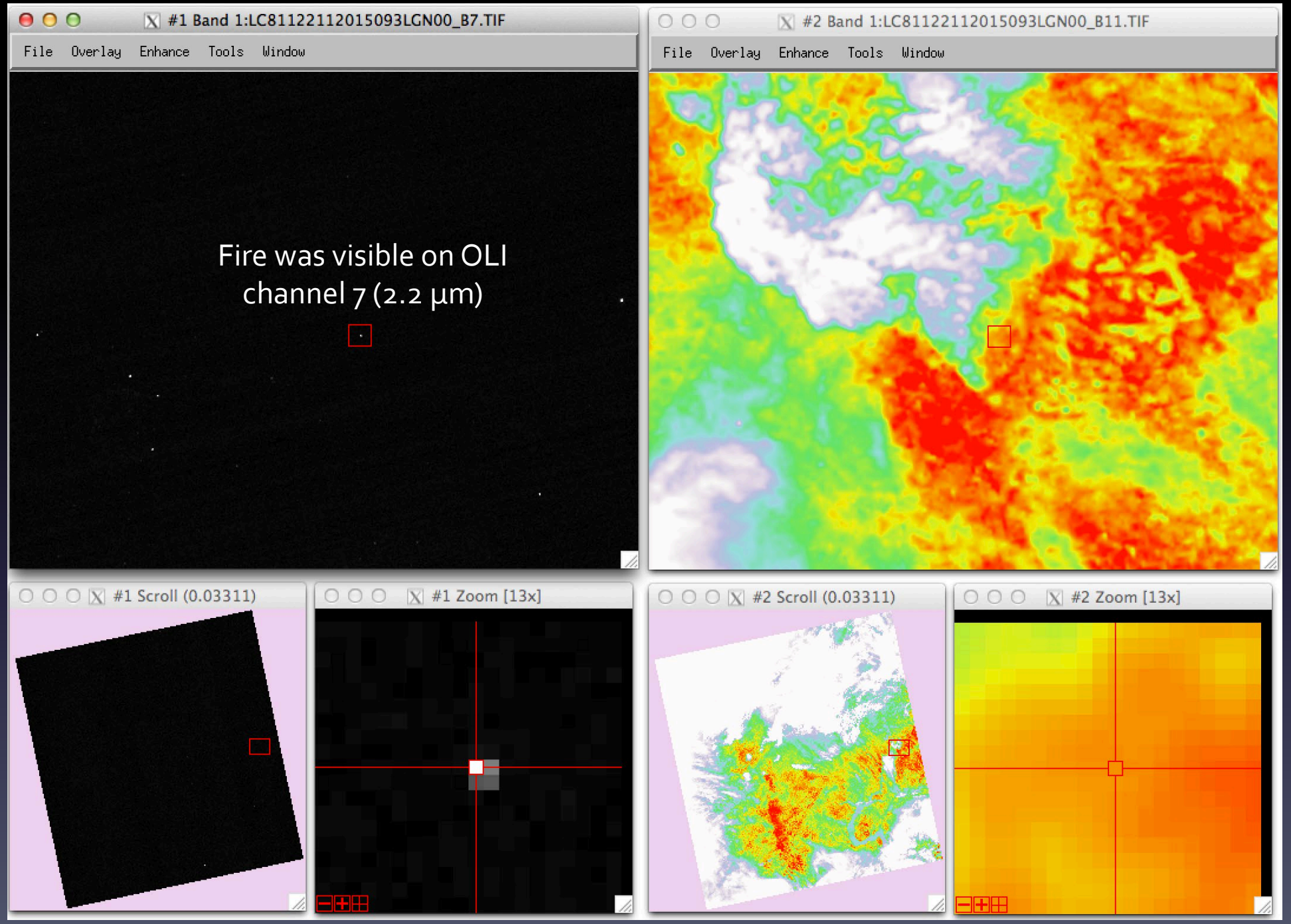
Effective area (combined): 0.5 m²

Lon: 76.870° W
Lat: 39.009° N







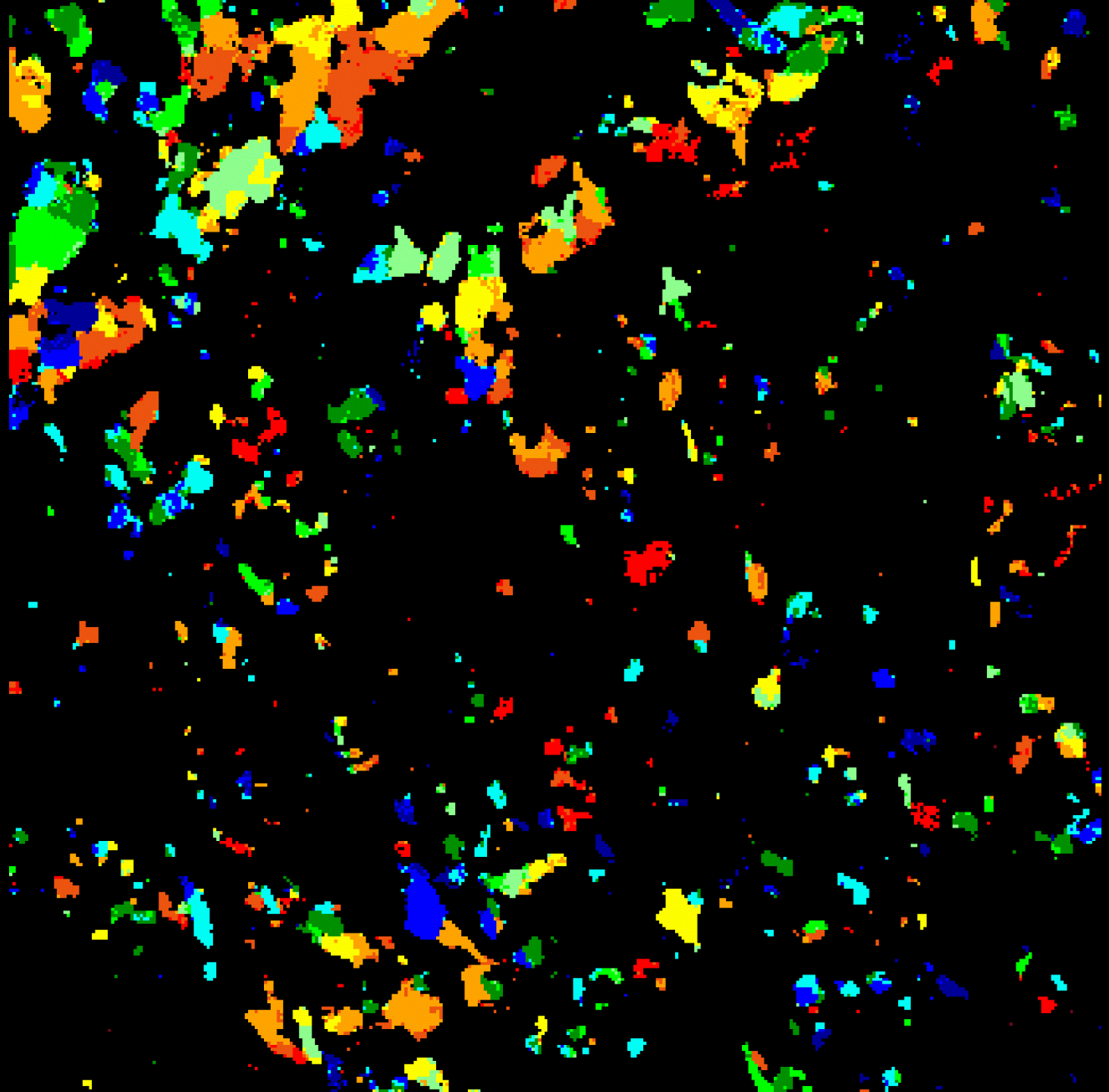

#1 Band 1:LC81122112015093LGN00_B7.TIF
File Overlay Enhance Tools Window
Fire was visible on OLI
channel 7 (2.2 µm)
#2 Band 1:LC81122112015093LGN00_B11.TIF
File Overlay Enhance Tools Window
#1 Scroll (0.03311)
#1 Zoom [13x]
#2 Scroll (0.03311)
#2 Zoom [13x]

Experimental Burned Area Product using HLS Data

David Roy, MSU

Burned Area

Day of burning
MODIS
500m MCD64
July 2016



0-2
3-5
6-8
9-11
12-14
15-17
18-20
21-23
24-27
28-31

Angola,
Lunda Sul
Province

159 x 159 km

Roy,
MSU

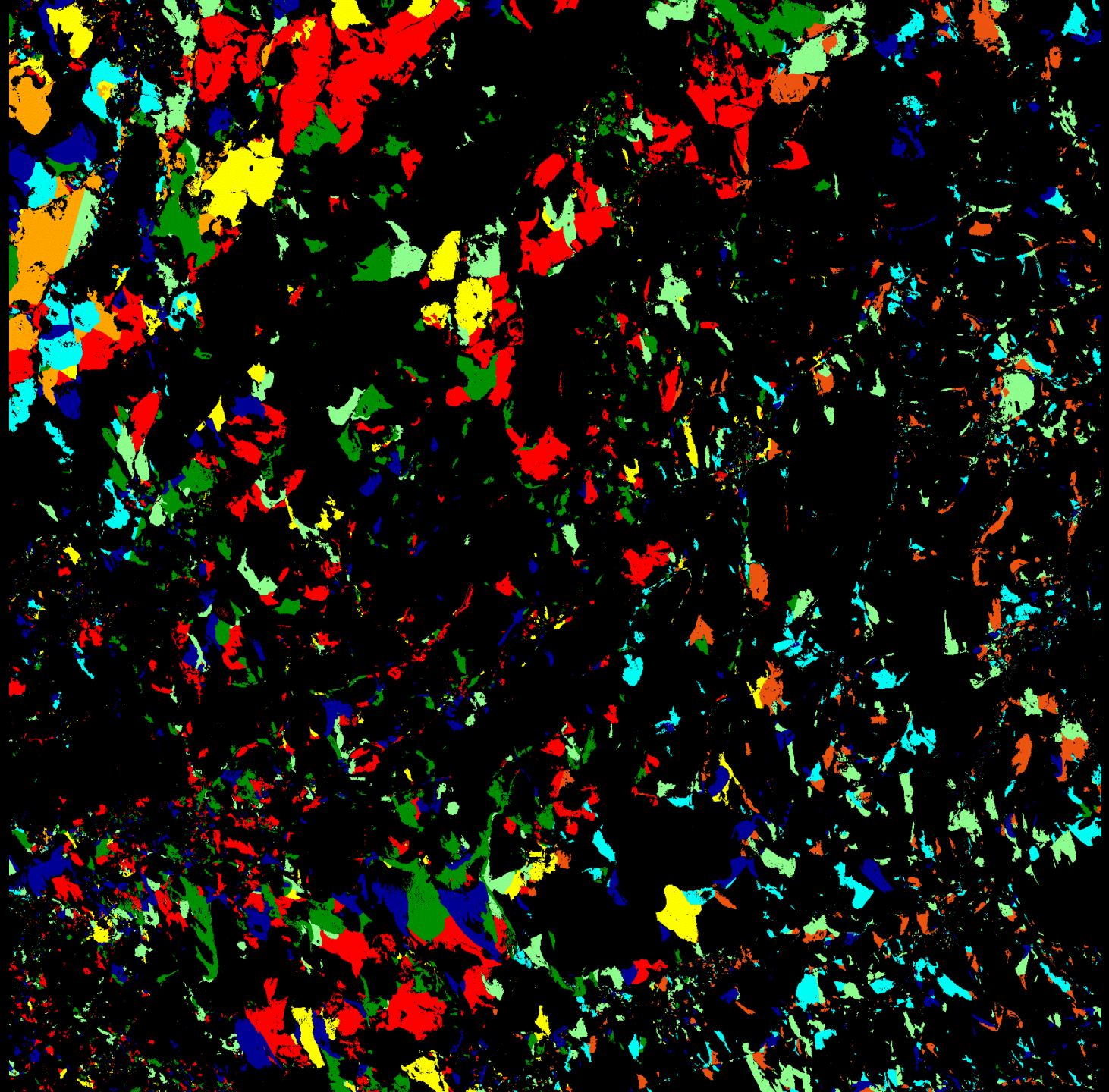
R

Day of burning

30m Sentinel-2

Landsat-8

July 2016

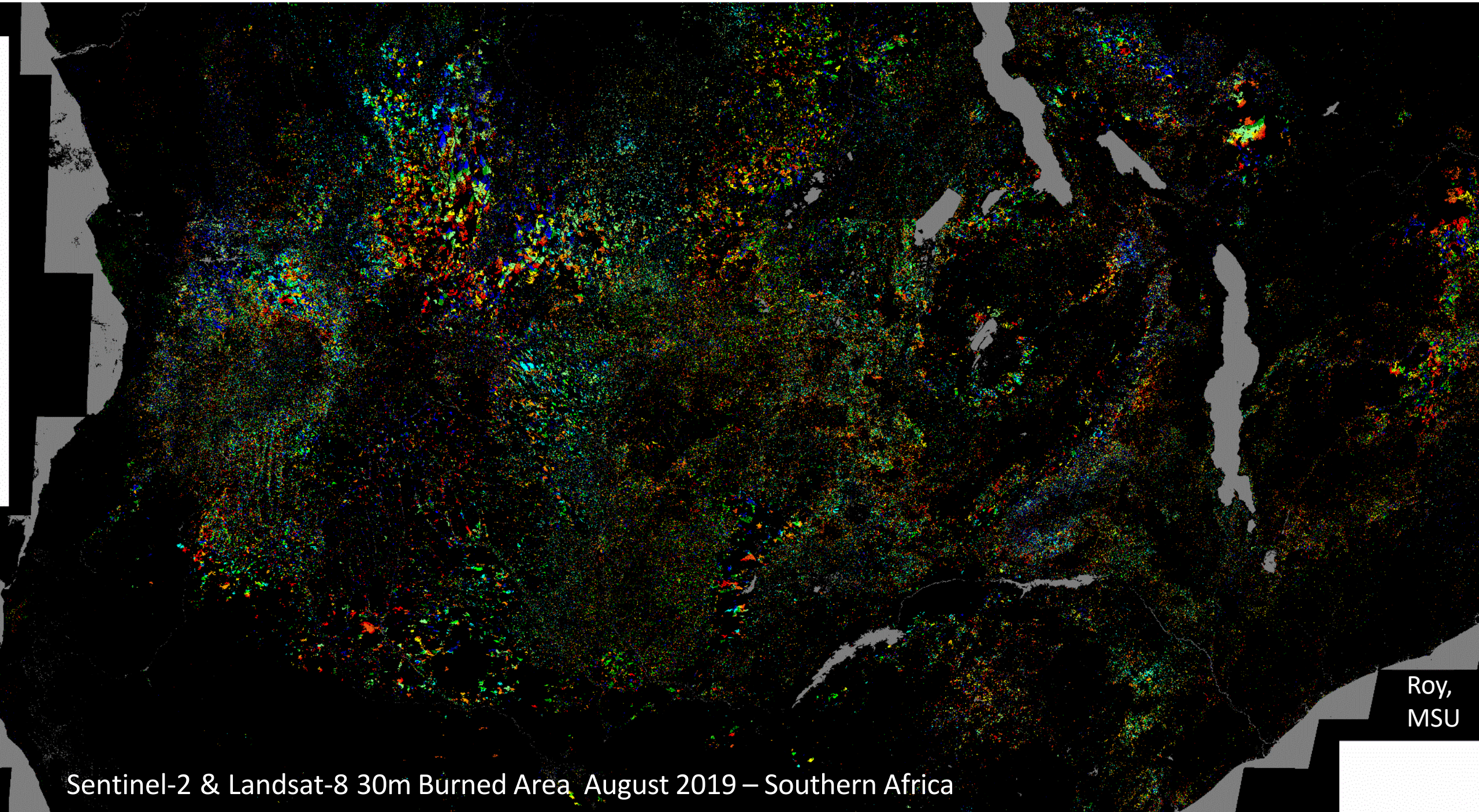


0-2
3-5
6-8
9-11
12-14
15-17
18-20
21-23
24-27
28-31

Angola,
Lunda Sul
Province

159 x 159 km

Roy,
MSU



Sentinel-2 & Landsat-8 30m Burned Area August 2019 – Southern Africa

Some Very Large Numbers

- US Federal wildfire suppression costs in the United States have spiked from an annual average of about $425 million from 1985 to 1999 to $1.6 billion from 2000 to 2019.
- 2019/2020 California Emergency Fund suppression costs $1.04 billion (Calfire)

$450 Billion	**$100 Billion**	**$14 Billion**
Cost of long-tern health exposures related to US wildfires from 2008 to 2012, according to an EPA report	Overall cost of 2017 California wildfire season, estimated by Headwaters Economics.	Headwaters estimate of the cost of fire suppression and insurance claims for property loss in the 2017 wildfire season.

California 2020.
Worst Fire Season in Ca history

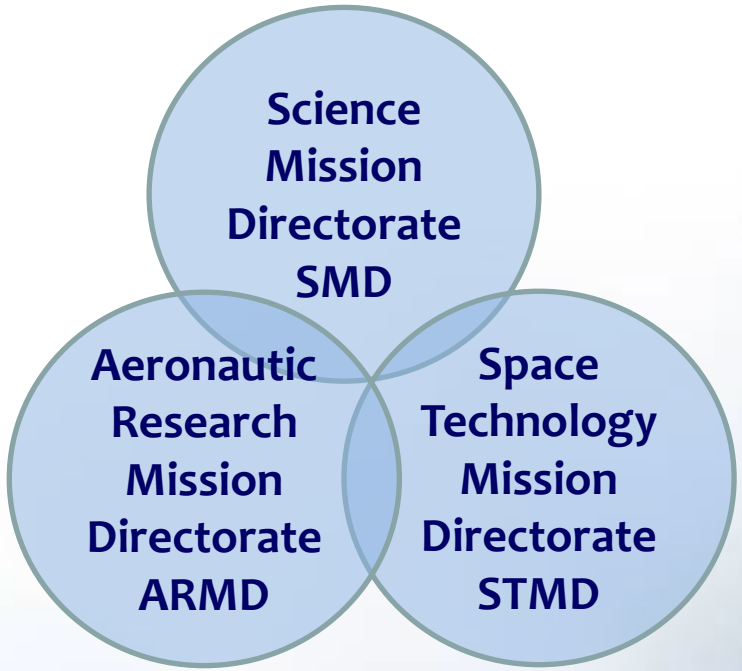
NASA's New Wildland Fire Earth Observation Science & Applications Program Developments: "FireSense"

A NASA-WIDE APPROACH

A NASA Wildfire Research, Development, and Technology Transition Program

A Whole of NASA Solution (ARMD,SMD,STMD)

To advance our nation's ability to predict and manage wildfires and mitigate their impacts



NASA is working with the Wildfire community to provide science and technology infusion to develop strong foundations upon which that community can advance their management capabilities; a five-year NASA-wide program

User Engagement Workshop
Wildfire Management Challenges, Gaps & Barriers

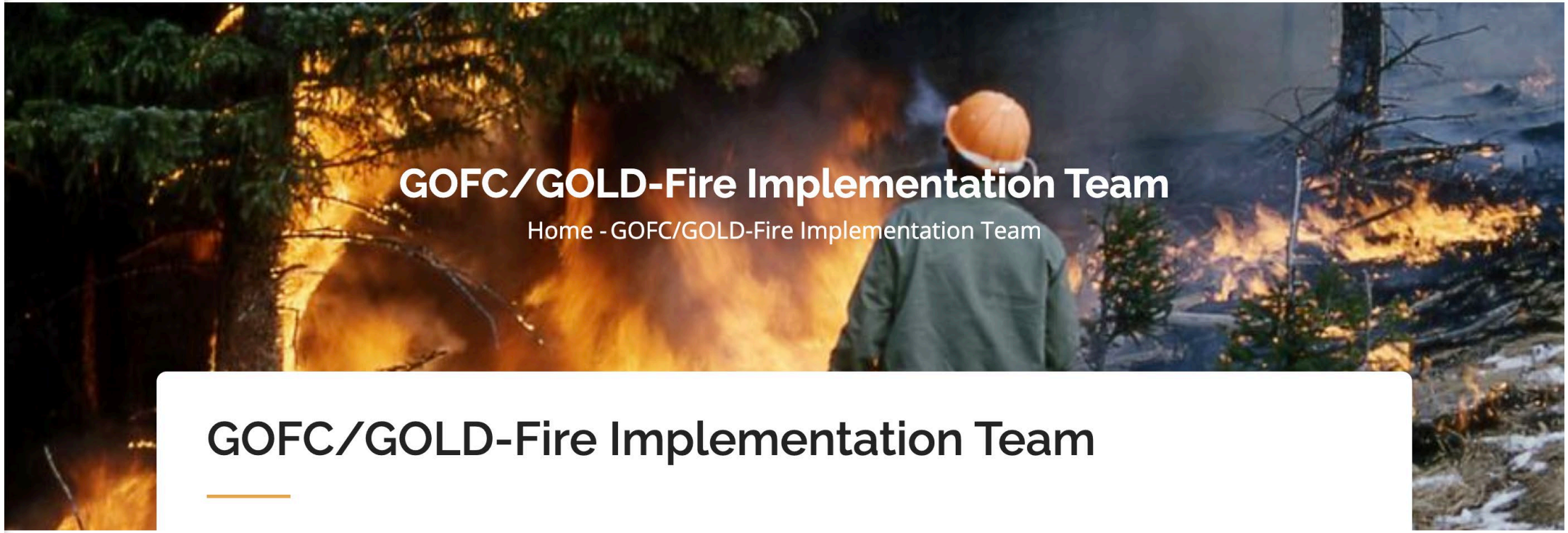
Detection Tracking, Surveillance, and Prediction

- Surveillance - infrequent high spatial resolution satellite (LEO) or aircraft observations miss much of the fire progression; more frequent coarse resolution satellite (GEO)
- Fire detection and location accuracy is not always precise enough
- Few reliable models for tracking and predicting fire progress
- Better sensing is needed, difficult to observe through clouds and at night
- Data and model fusion is limited, need for an integrated observing system
- Lack of miniaturized sensor for UAS
- Rogue drone operations result in grounding of aerial fire suppression missions

Multi-Agency Planning

- Multi-agency collaboration for resource and technology roadmap needs to be improved
- Budgets to support forest management and strategic planning are often redirected in season for tactical firefighting (limits adoption of new research and tools in fire management).

GOFC-GOLD
Global Observations of Forest Cover and Land Use Dynamics



GOFC/GOLD-Fire Implementation Team

GOFC/GOLD (Global Observations of Forest and Land Cover Dynamics) is a project of the Global Terrestrial Observing System (GTOS) program, which is sponsored by the Integrated Global Observing Strategy (IGOS). The main goal of GOFC/GOLD is to provide a forum for international information exchange, observation and data coordination, and a framework for establishing the necessary long-term monitoring systems.

The GOFC/GOLD-Fire Mapping and Monitoring Theme seeks to refine and articulate the international observation requirements and encourage the best possible use of fire products from existing and future

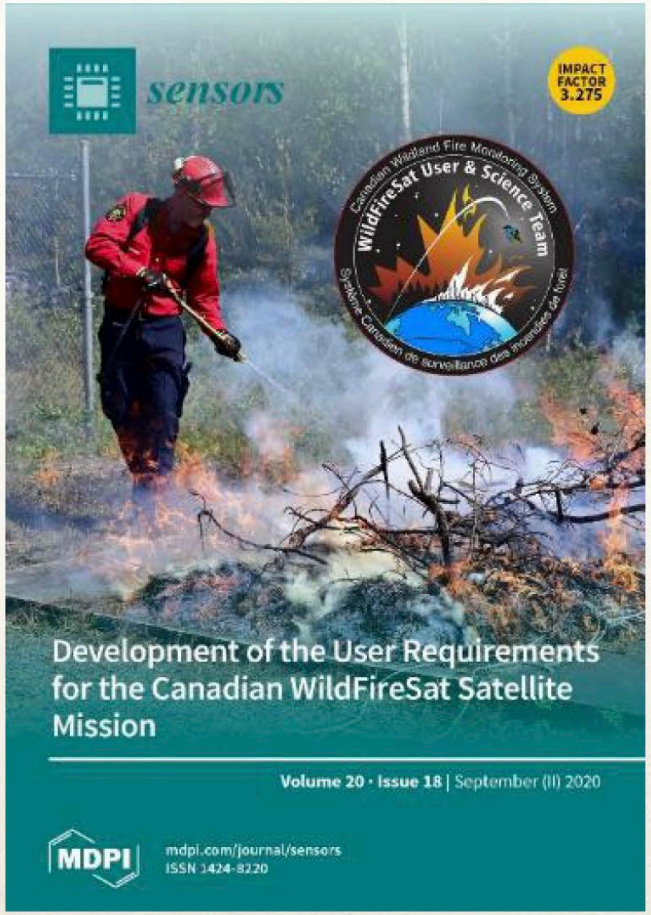
WildFireSat

Key Features:

- VIS/NIR (200 m)
- MWIR/LWIR (400 m);
- Daily peak burn overpass;
- FRP optimised;
- Detection capacity at 15 x 15 m fire;
  - *open canopy (Johnston et al, 2018)
- 30 min data latency.

Fire Monitoring Capability:

- Near-real-time data delivery;
- Early detection (remote access fires);
- Active perimeter mapping and progression;
- Perimeter mapping of ROS (m min^{-1}) when combined with VIIRS (Johnston, 2016);
- Perimeter mapping of FI (kW m^{-1}), (Johnston et al, 2017);
- Mapping of Fuel Consumption (kg m^{-2});
- Near-real-time measurements of carbon emissions and smoke plume dynamics.



(Johnston *et al*, 2020)