Development of a Landsat-8 Sentinel-2 global 30 m burned area product

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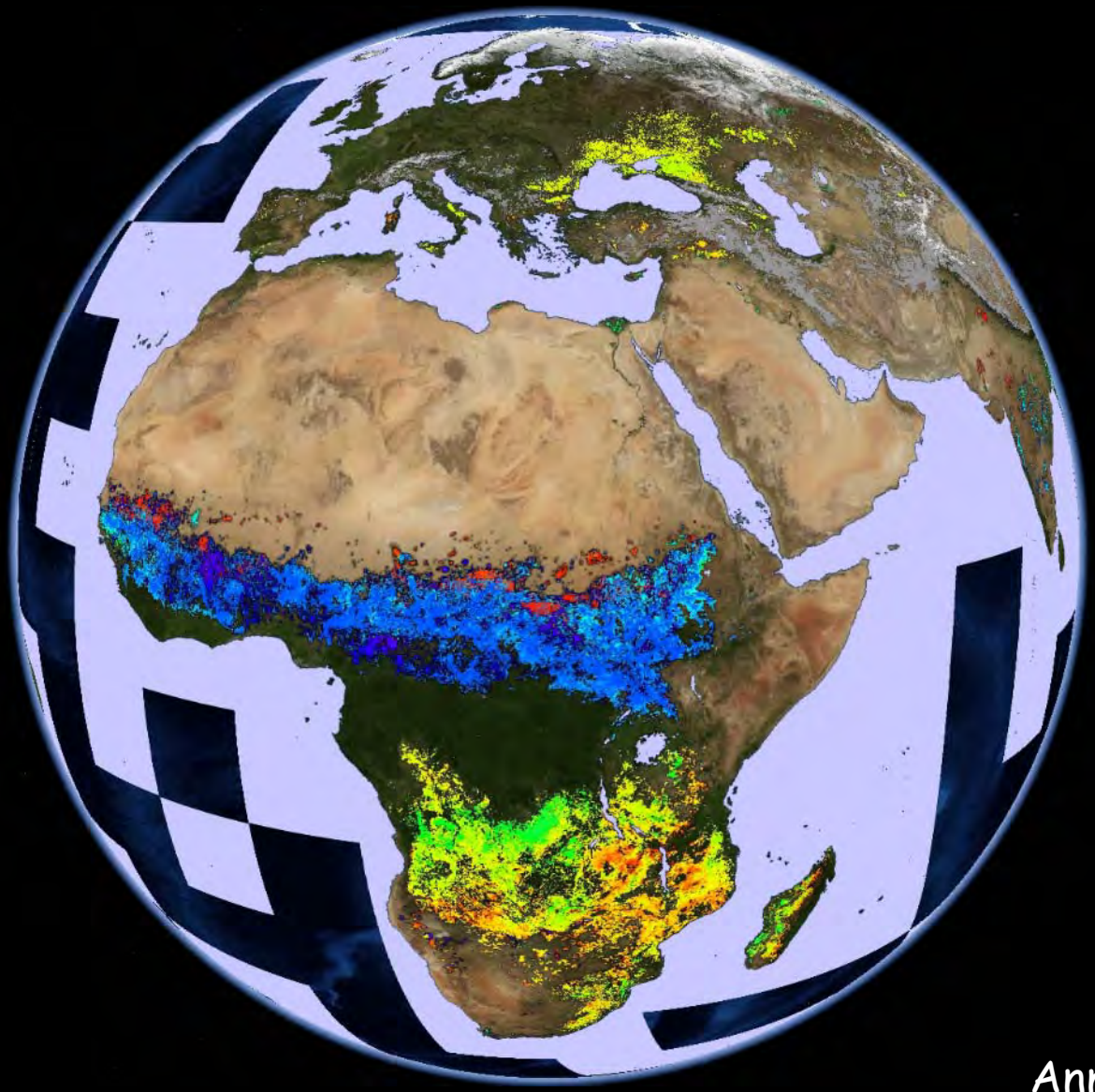
2nd GOFC GOLD FIRE IT & GWIS meeting
20-23rd November, London, U.K.

Development of a Landsat-8 Sentinel-2 global 30 m burned area product

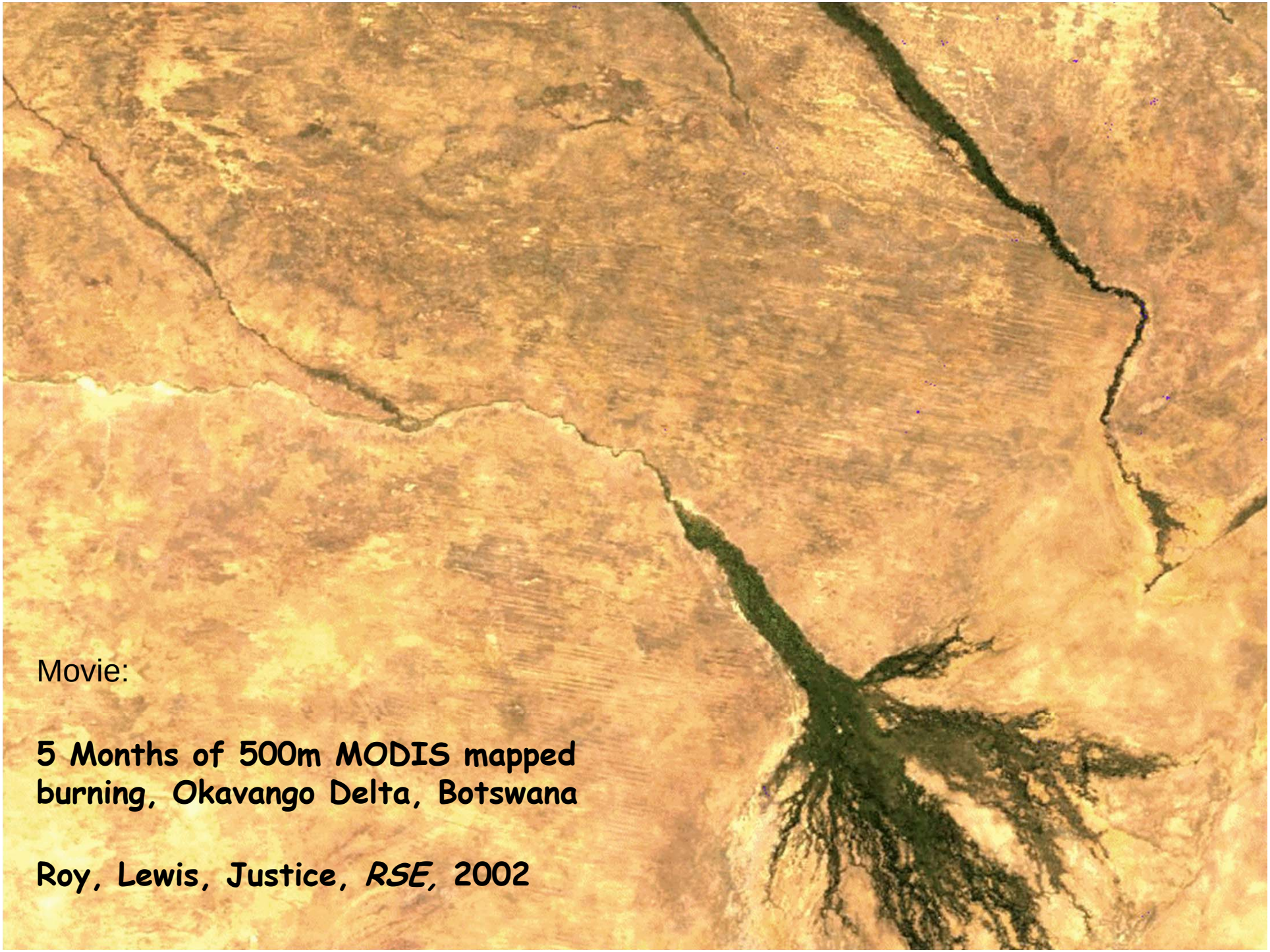
Talk Overview

- Product rationale
- Sentinel-2 & Landsat-8 Pre-Processing
- Burned area mapping algorithm
- Example 30 m burned area product results
- Validation plans

18 years of NASA systematically generated global MODIS 500 m burned area product



Annual 2001

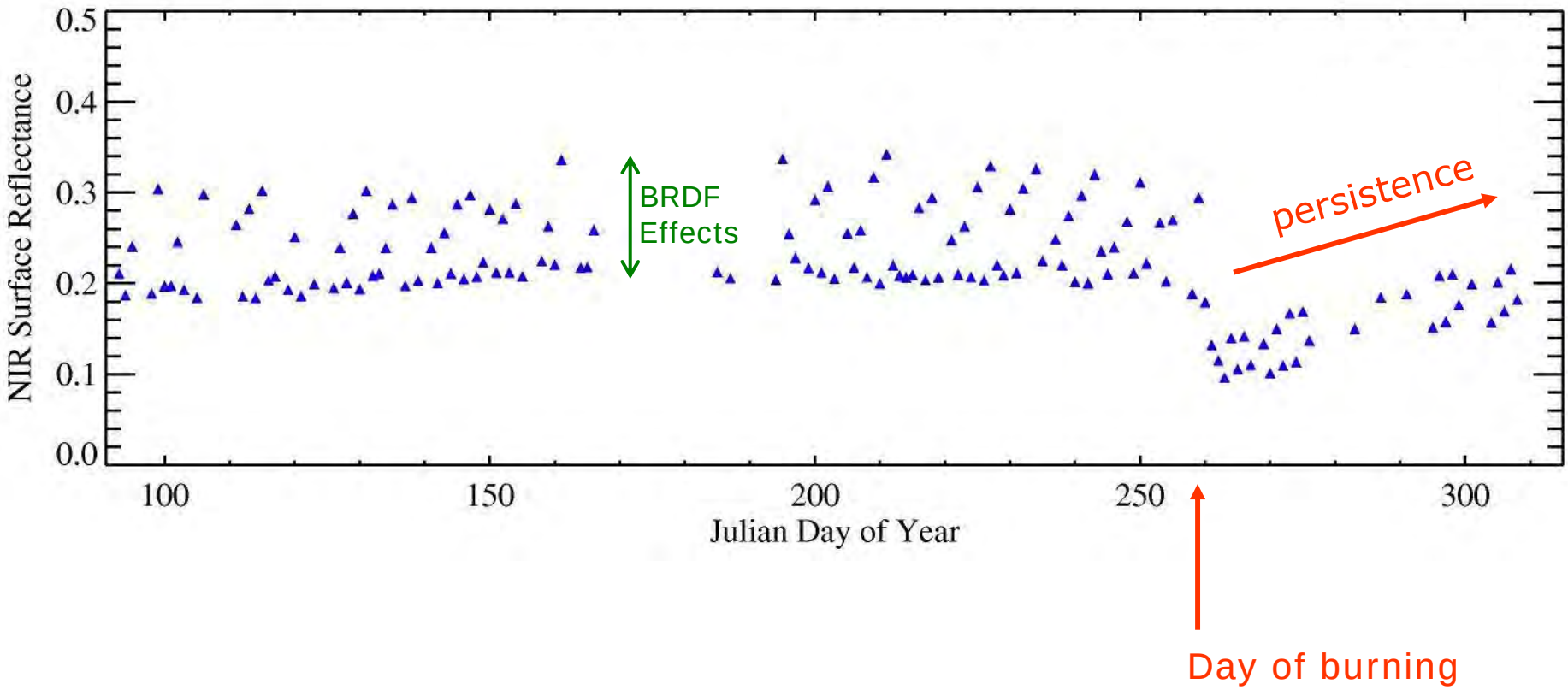


Movie:

5 Months of 500m MODIS mapped burning, Okavango Delta, Botswana

Roy, Lewis, Justice, *RSE*, 2002

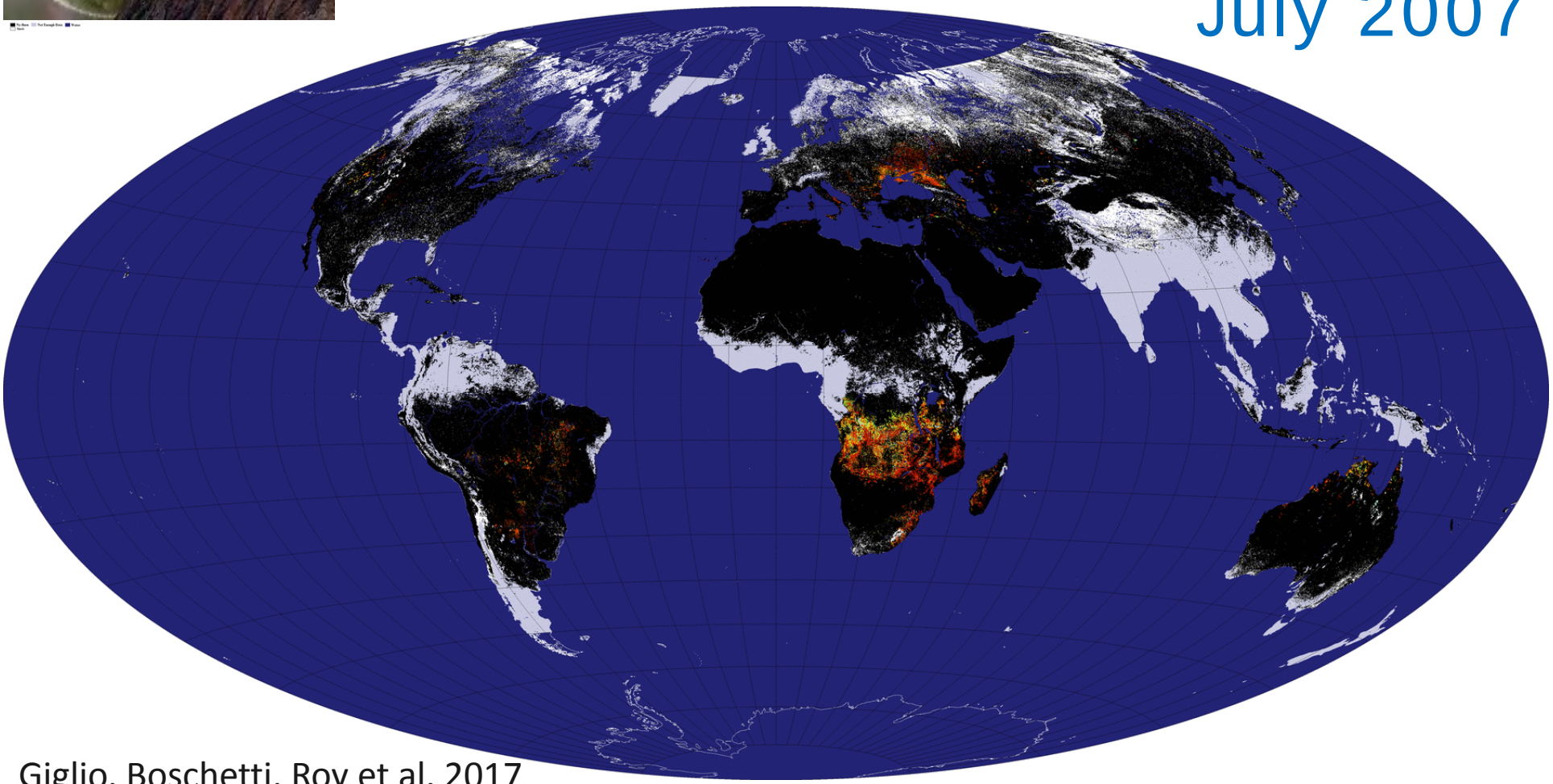
Typical MODIS 500m NIR reflectance time series




MCD45
(Collection 5.1)
Multi-temporal BRDF based
Multi-temporal VI based
with Active fire detections
MCD64
(Collection 5.1,
Collection 6)

MODIS 500m burned area C5.1 MCD45A1 (“Koala”)

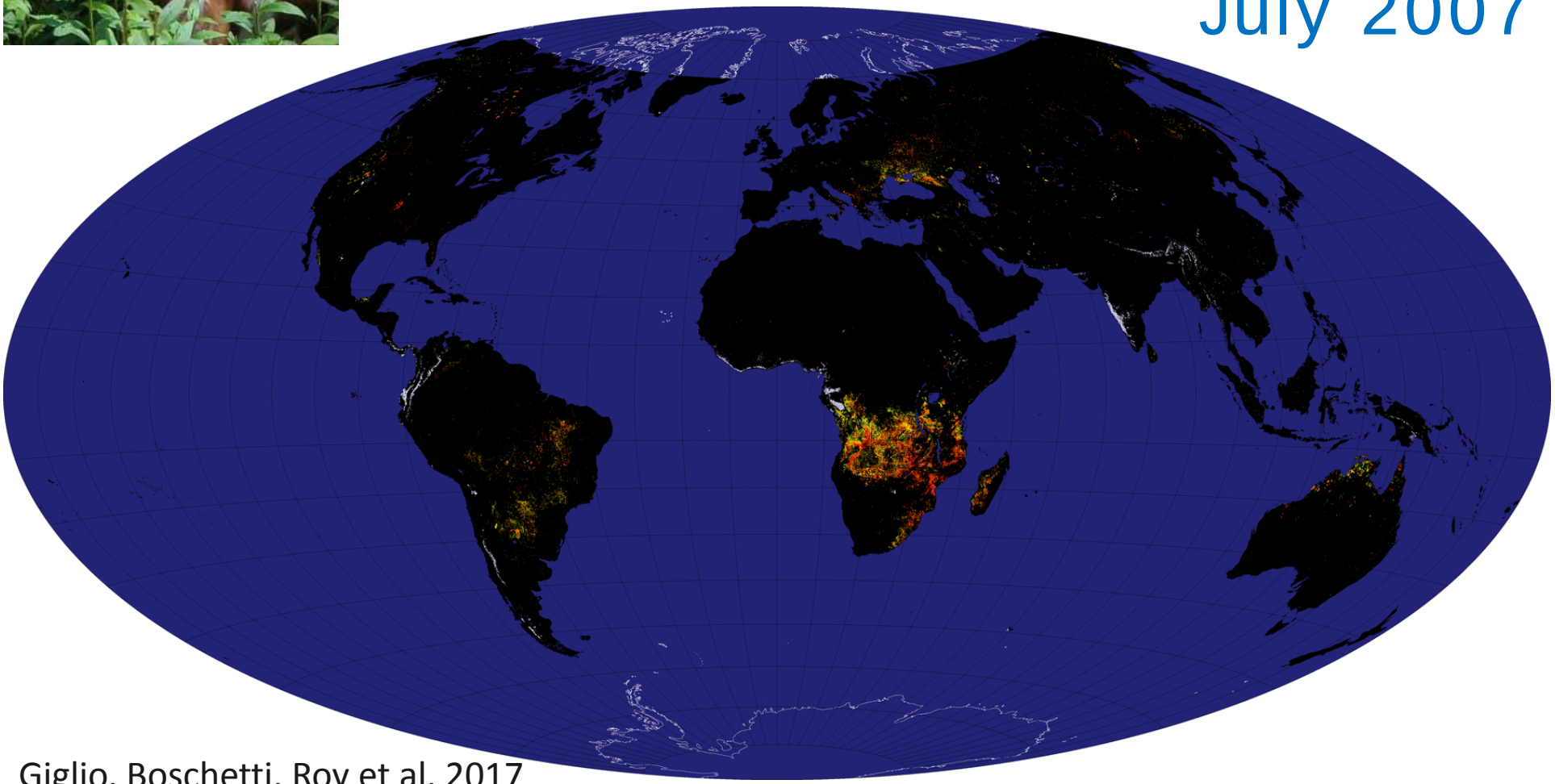
July 2007



Giglio, Boschetti, Roy et al. 2017

MODIS 500m burned area C6 MCD64A1 ("Goat")

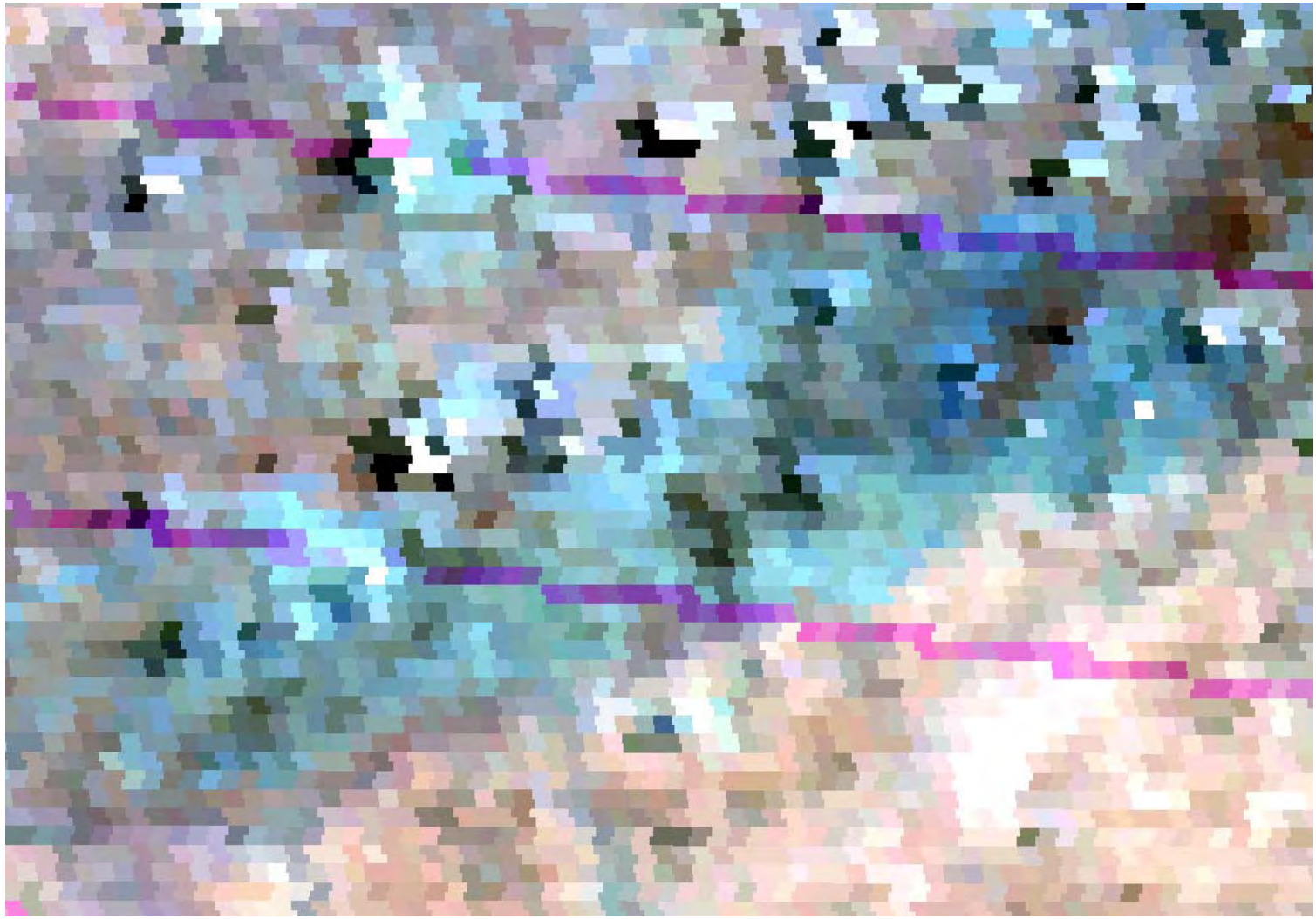
July 2007



Giglio, Boschetti, Roy et al. 2017

Chimaliro forest reserve, Malawi, September 26th 2001

MODIS 500m pixels, bands 6 (1.64μm), 5 (1.24μm), 2 (0.86μm)



31km x 23km

JOURNAL OF GEOPHYSICAL RESEARCH
Biogeosciences
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JGR

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Global burned area and biomass burning emissions from small fires

J. T. Randerson ✉, Y. Chen, G. R. van der Werf, B. M. Rogers, D. C. Morton

First published: 11 December 2012 Full publication history

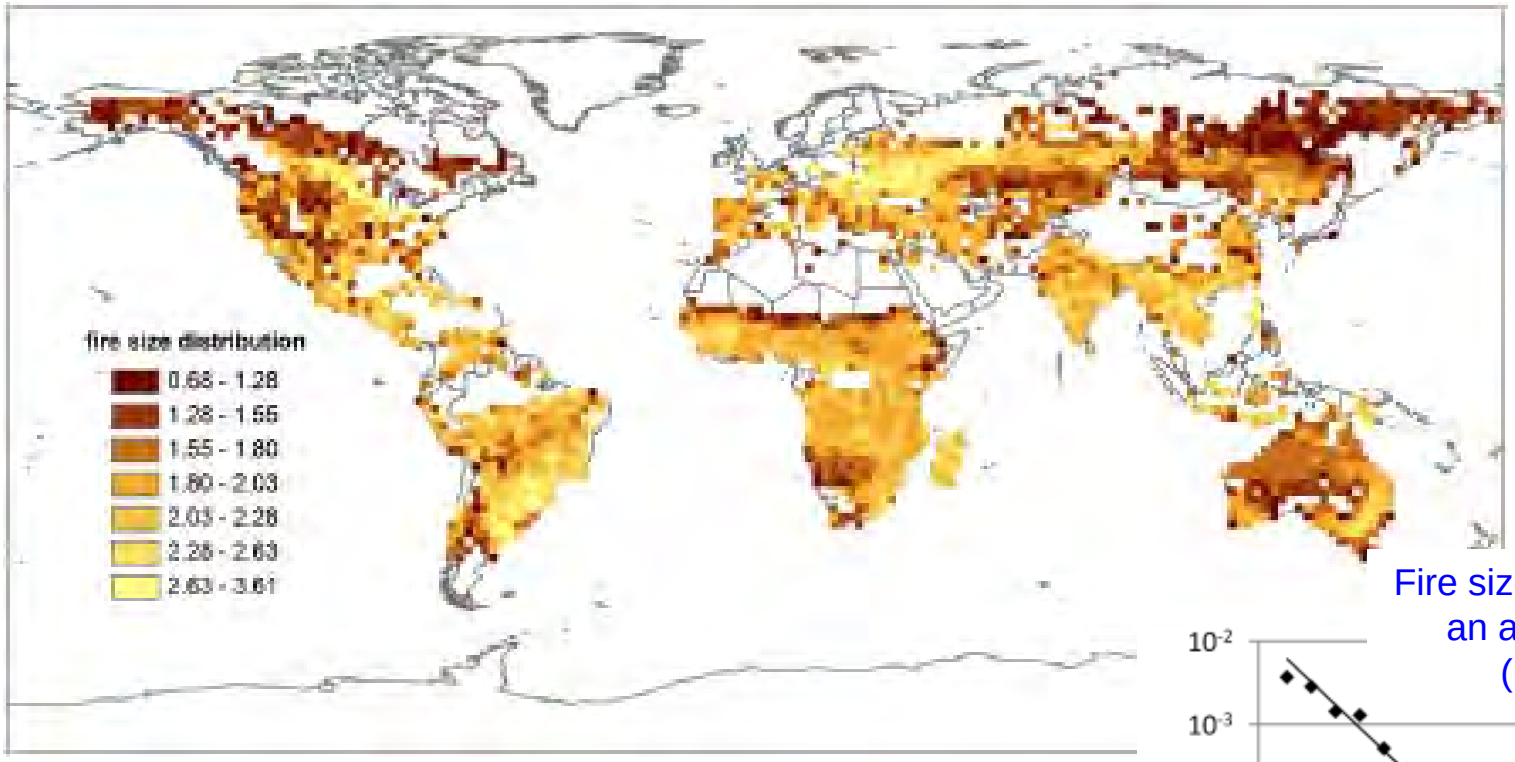
DOI: 10.1029/2012JG002128 View/save citation

Accounting for small fires increased total global burned area by ~35%, from 345 Mha/yr to 464 Mha/yr

"A formal quantification of uncertainties was not possible …"

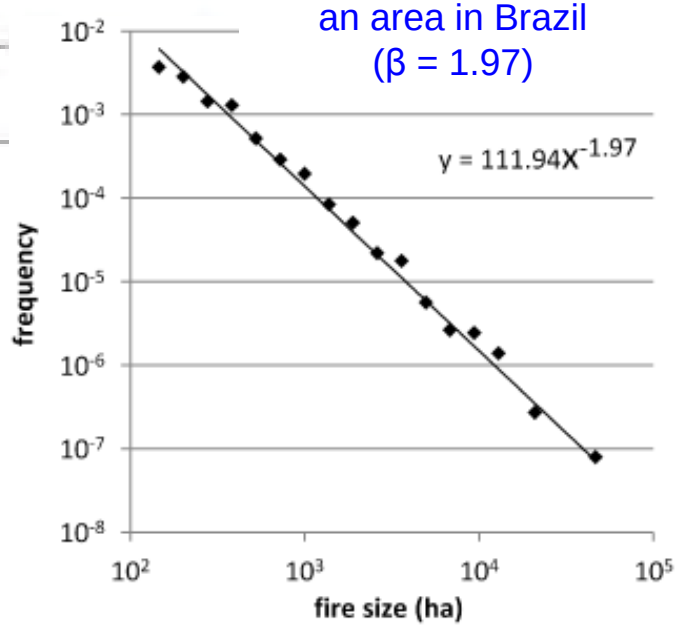
Global fire size distribution – small fires where yellow

(β power law values fitted to MODIS 500m burned area product for 2002-2010 in 2° grids)



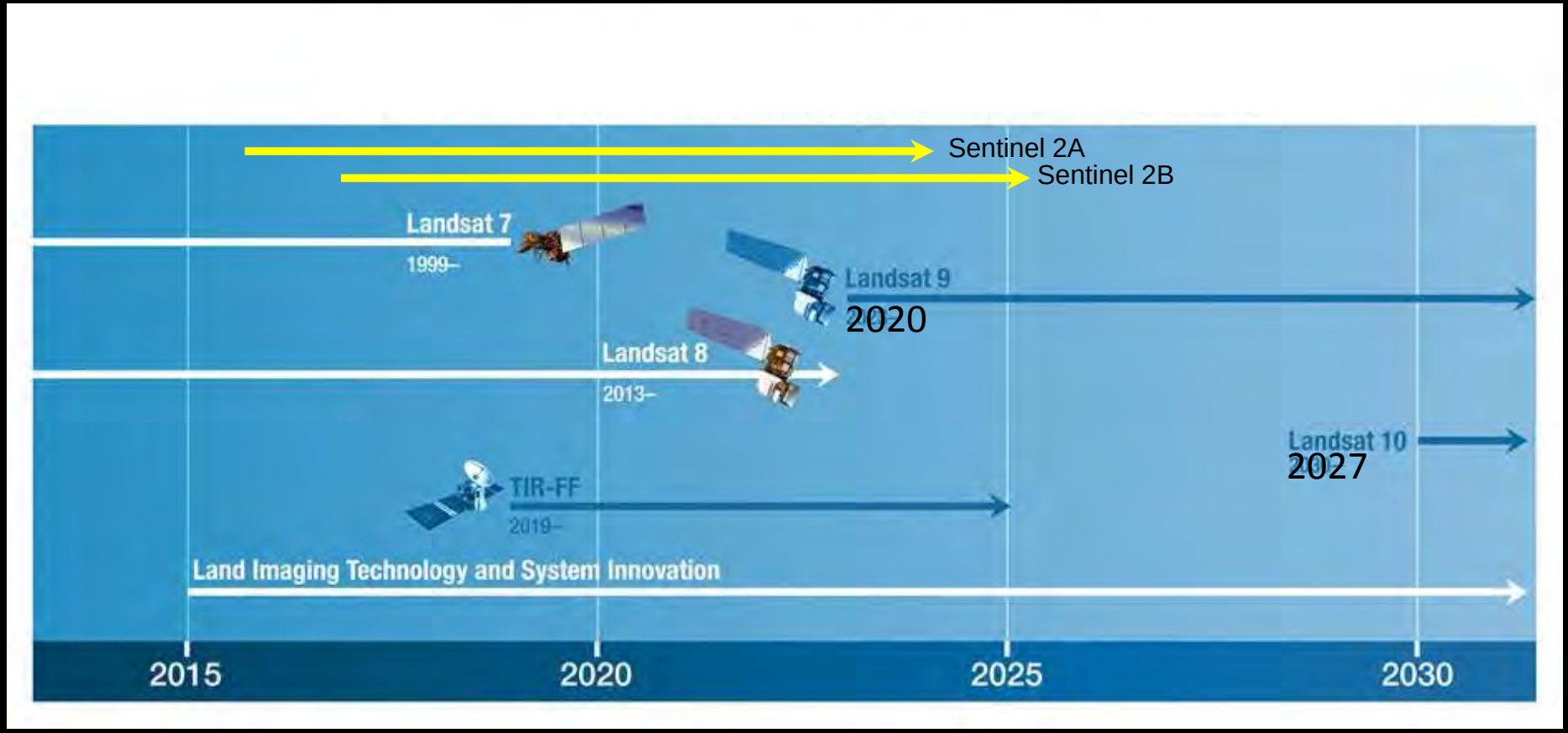
Hantson et al. 2015. *Global Ecology and Biogeography*

Fire size power-law for an area in Brazil (β = 1.97)



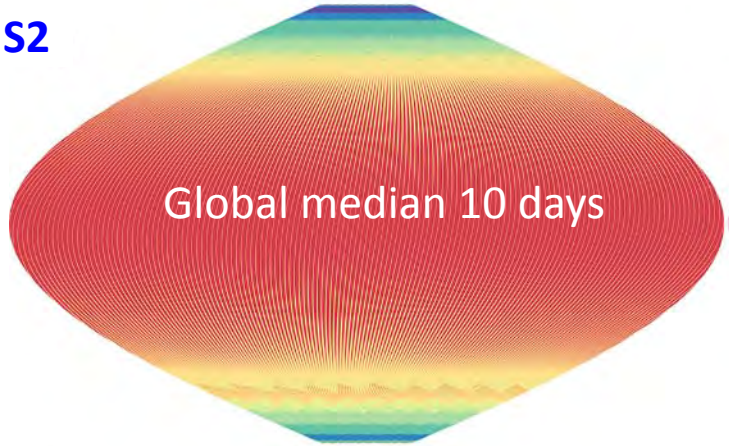
New Global moderate resolution era

Landsat 8, 9, 10

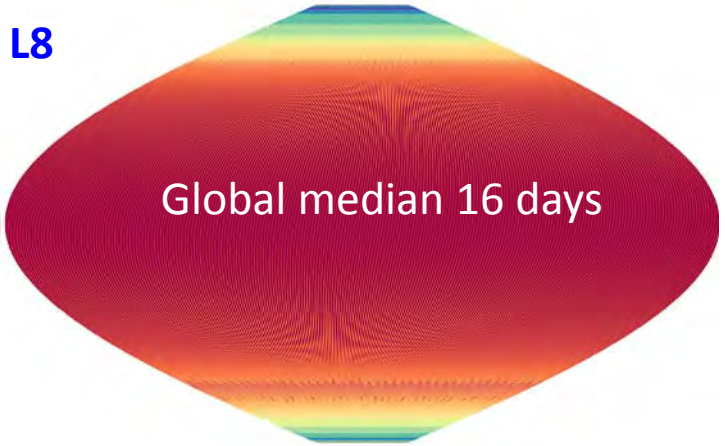


ESA Sentinel 2A & 2B

S2

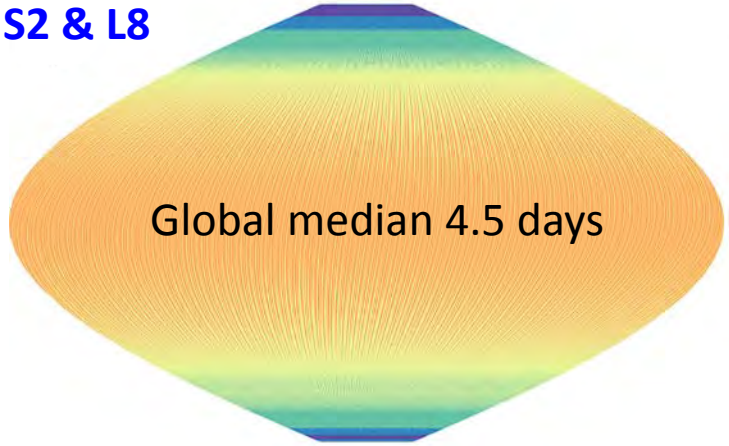


L8

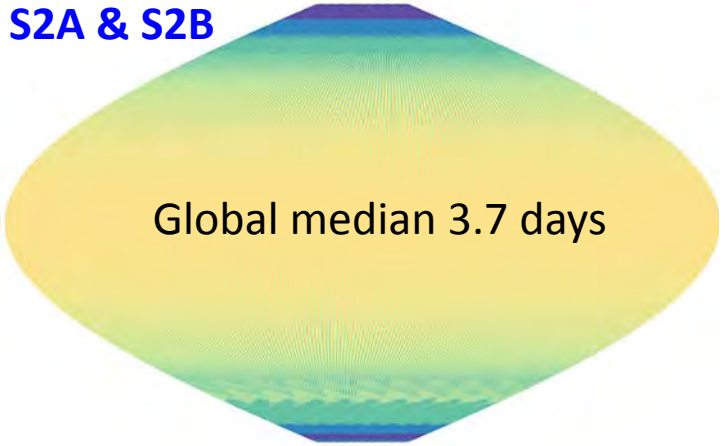


Li, J and Roy, D.P. 2017
A global analysis of
Sentinel-2A,
Sentinel-2B
and
Landsat-8
data revisit intervals
and implications
for terrestrial
monitoring,
Remote Sensing, 9,902.

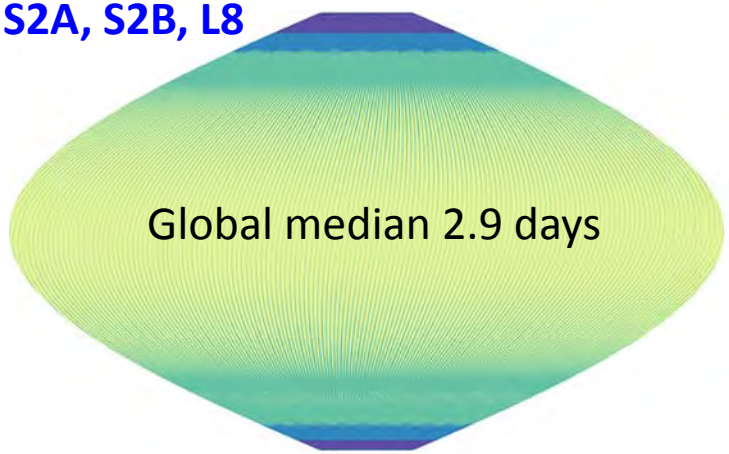
S2 & L8



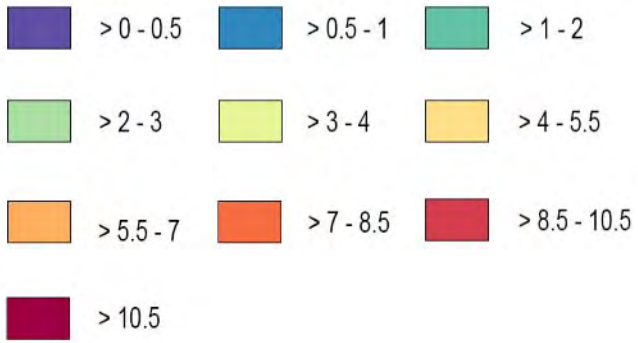
S2A & S2B



S2A, S2B, L8



Average satellite revisit interval (days)



Sentinel-2A

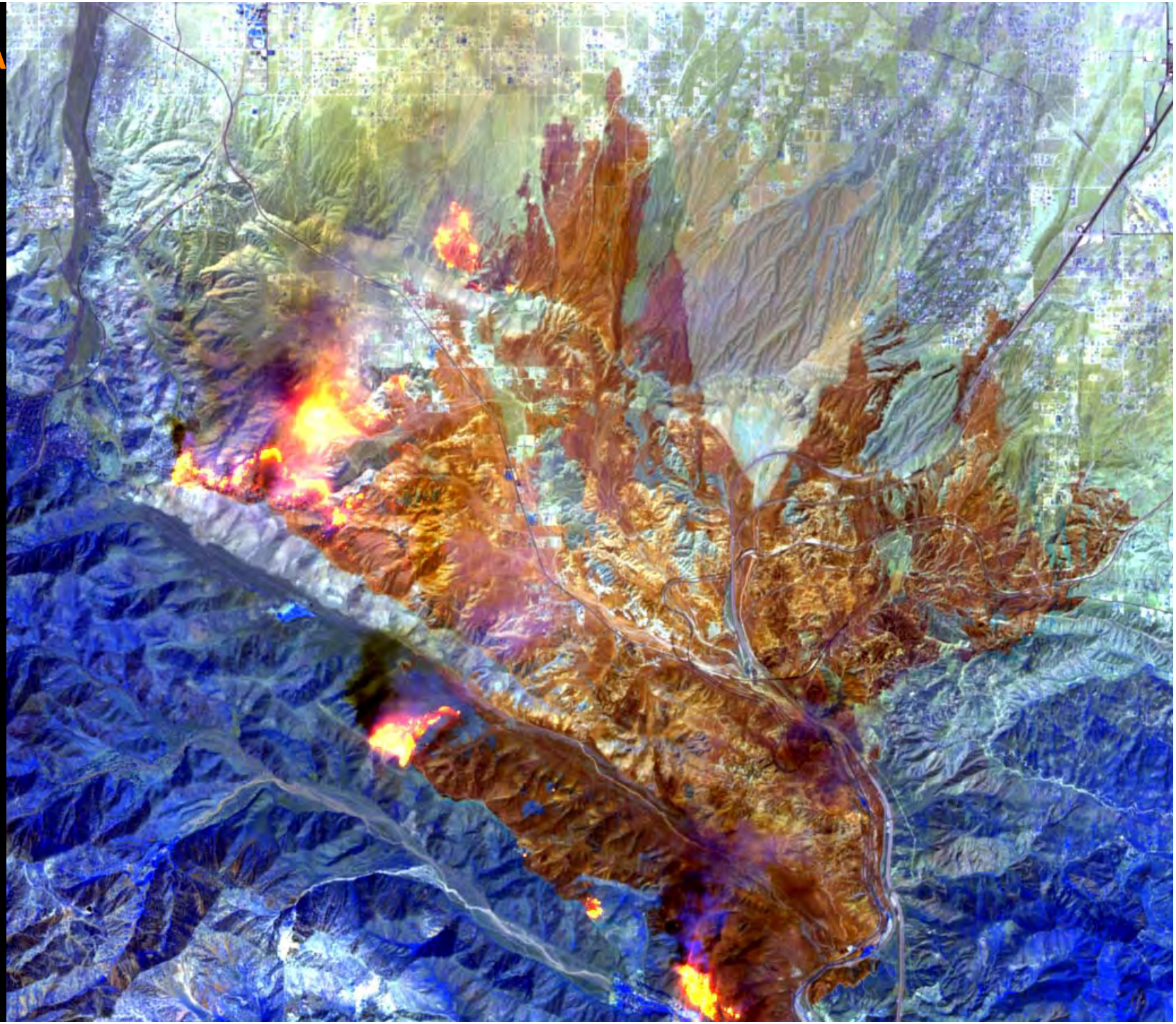
20 m

2190 nm
1610 nm
865 nm

August 17
2016

Blue
Cut fire

charred
57 square
miles, San
Bernardino
County, CA



Landsat-8

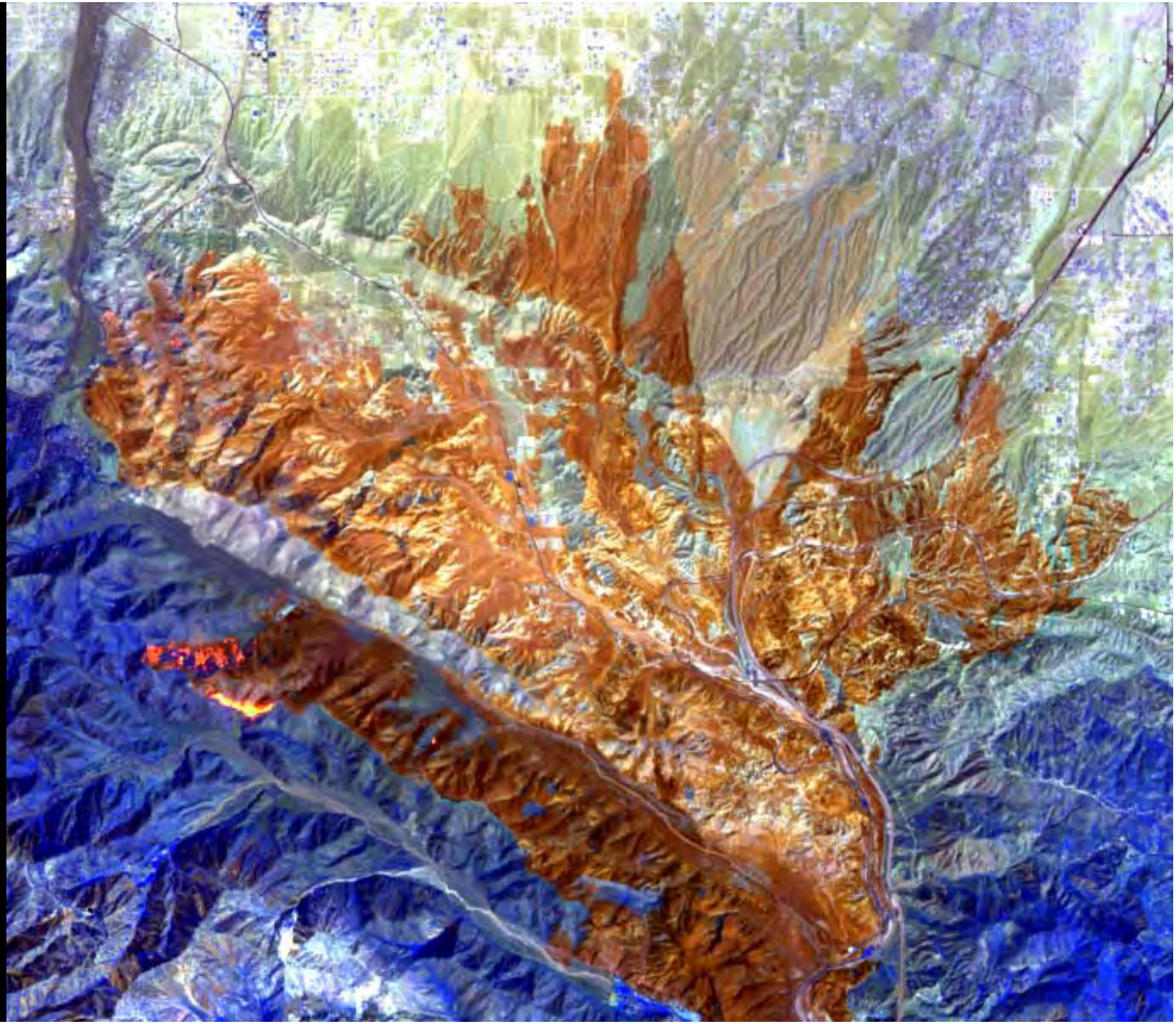
30 m

2200 nm
1610 nm
865 nm

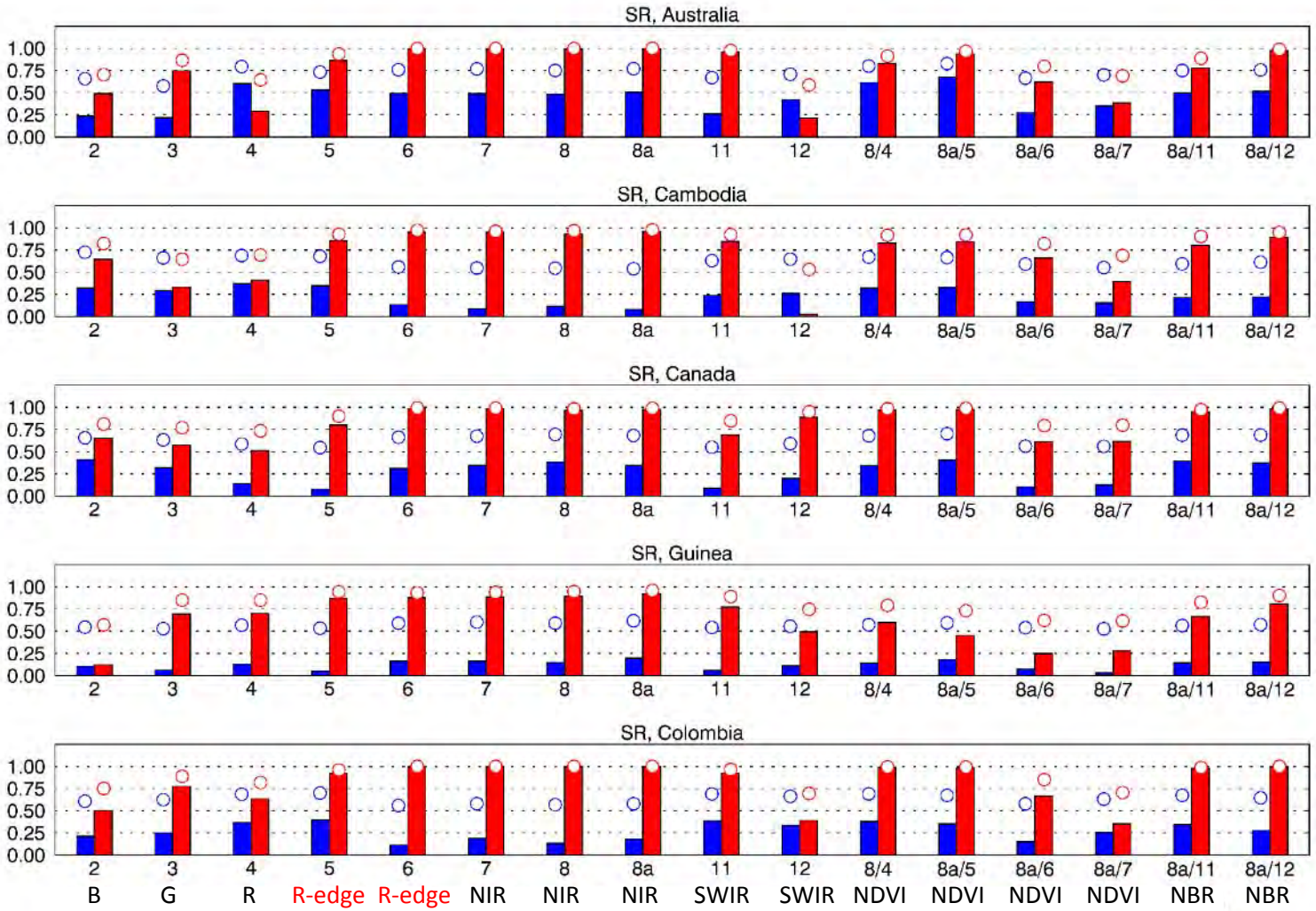
August 18
2016

Blue
Cut fire

charred
57 square
miles, San
Bernardino
County, CA



Sentinel-2 spectral bands suitable for burned area mapping (Landsat-like but also new red-edge bands)



Unburned to unburned separability (control)

Unburned to burned separability

% correct

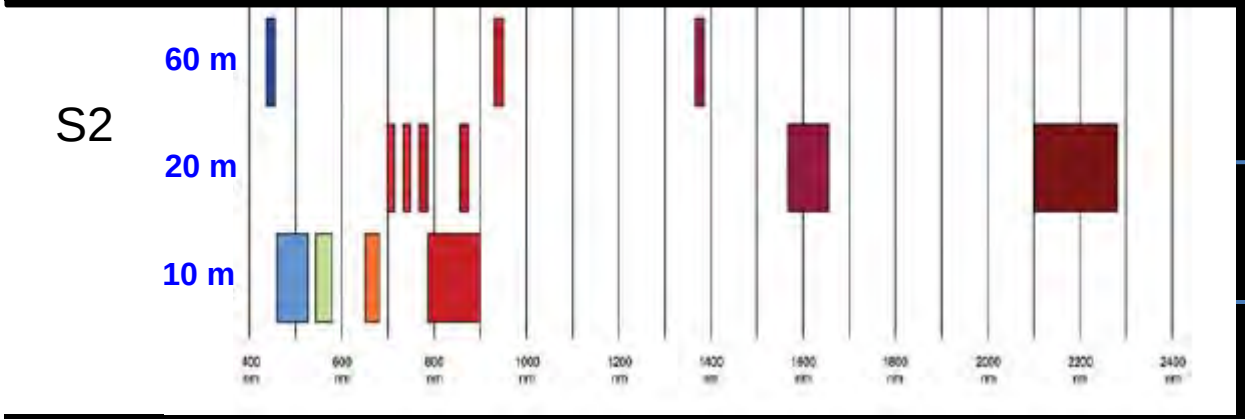
Kappa

Huang, H., Roy, D.P., Boschetti, B., Zhang, H.K., Yan, L., Kumar, S.S., Gomez-Dans, J., Li, J., 2016, Separability analysis of Sentinel-2A multi-spectral instrument (MSI) data for burned area discrimination, *Remote Sensing,* 8(10), 873.

Landsat 8 (L8) and Sentinel 2 (S2) different spectral & spatial resolutions

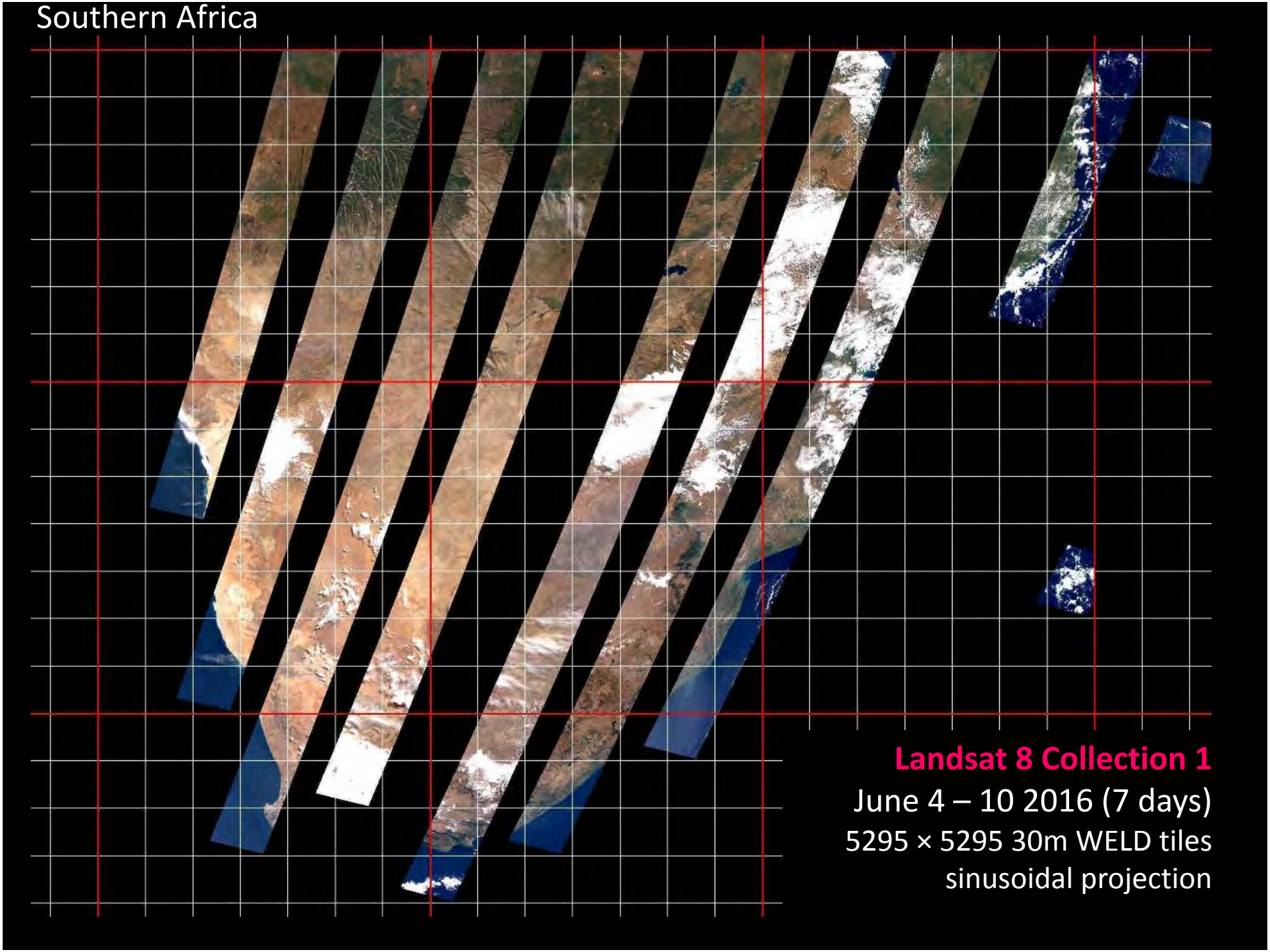
Reproject/resample each satellite sensor band independently into 30m WELD tiles

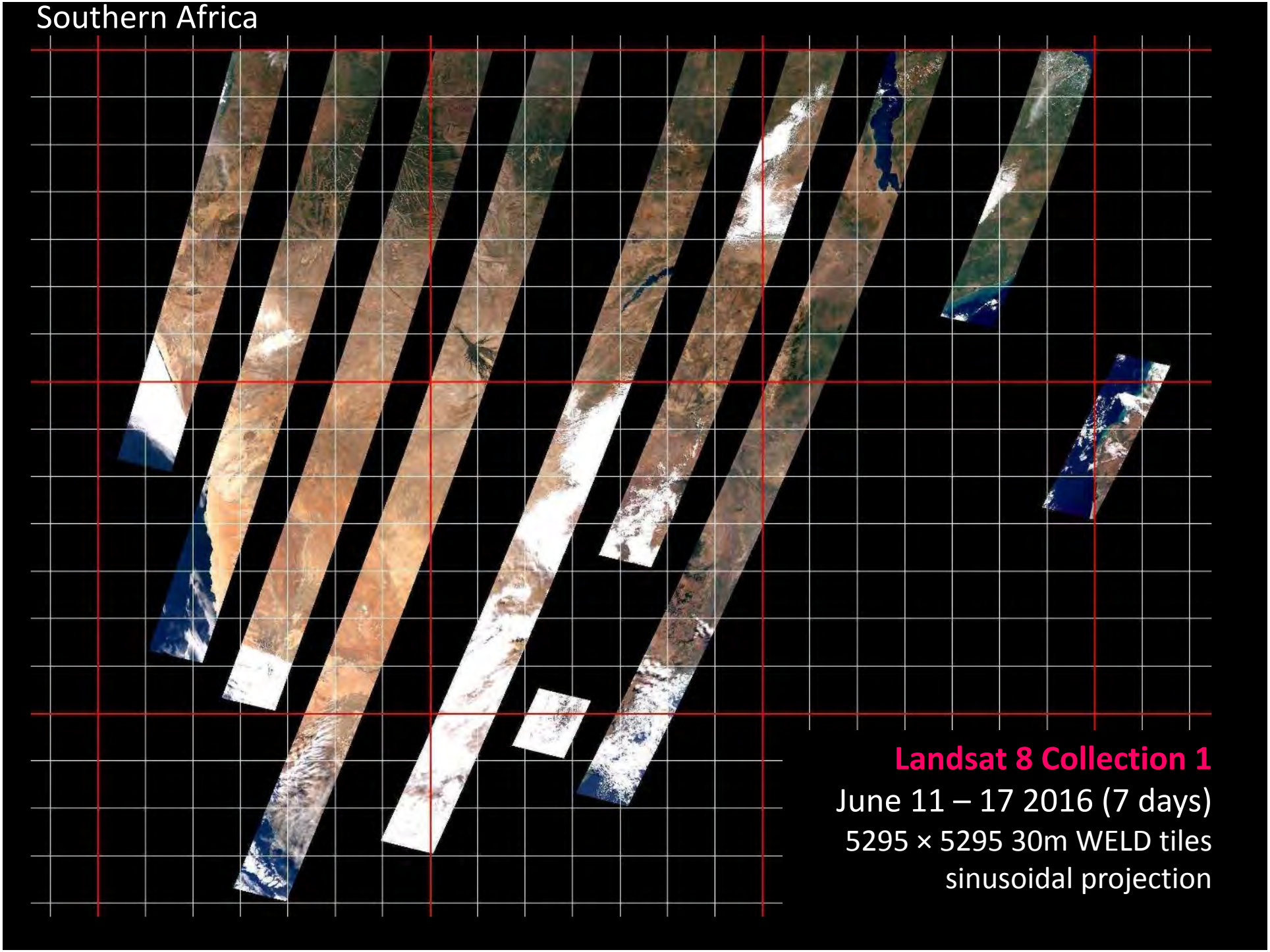
159 x 159 km
WELD tiles:

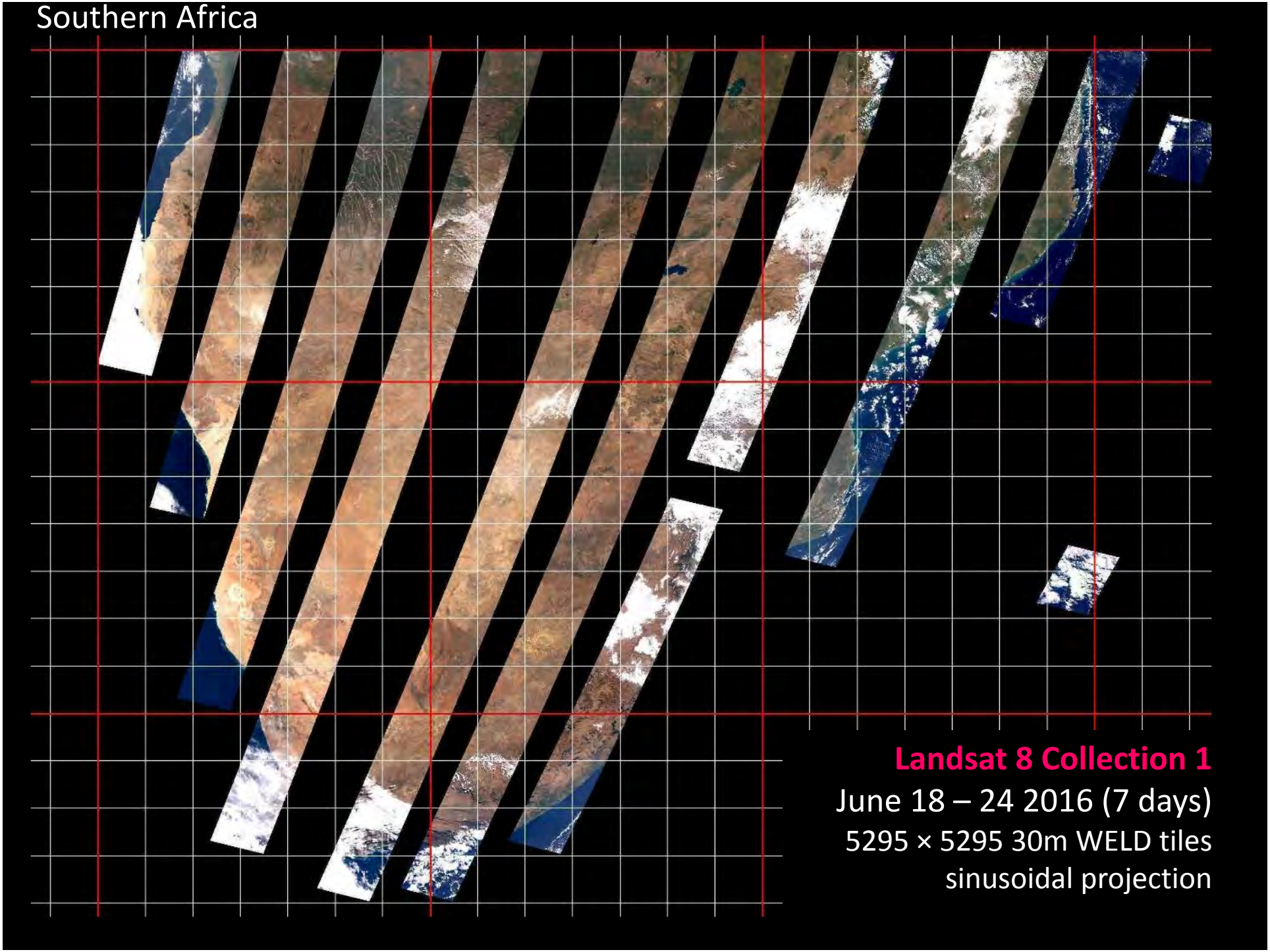


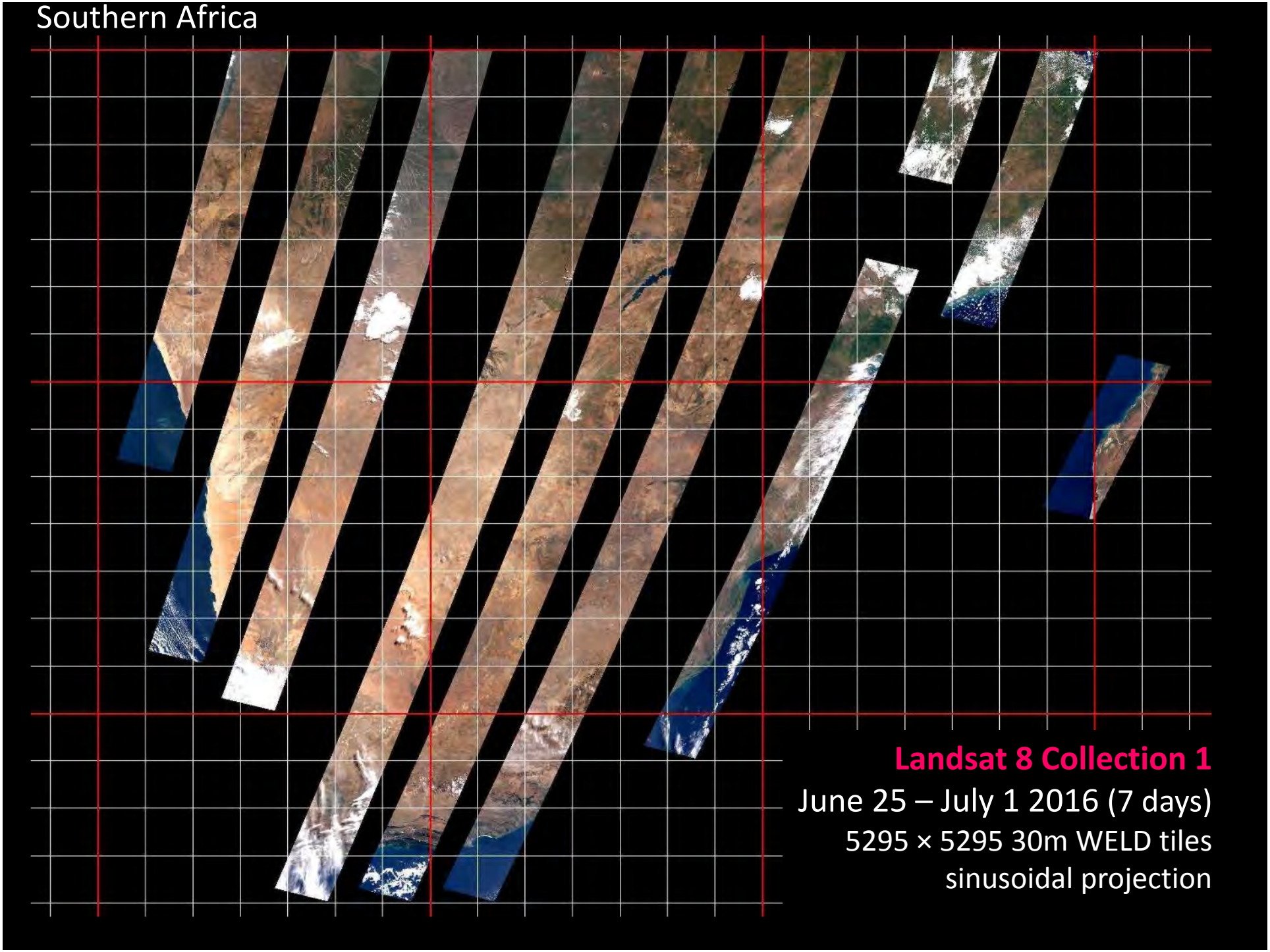
Sentinel-2 Landsat-8 Pre-Processing

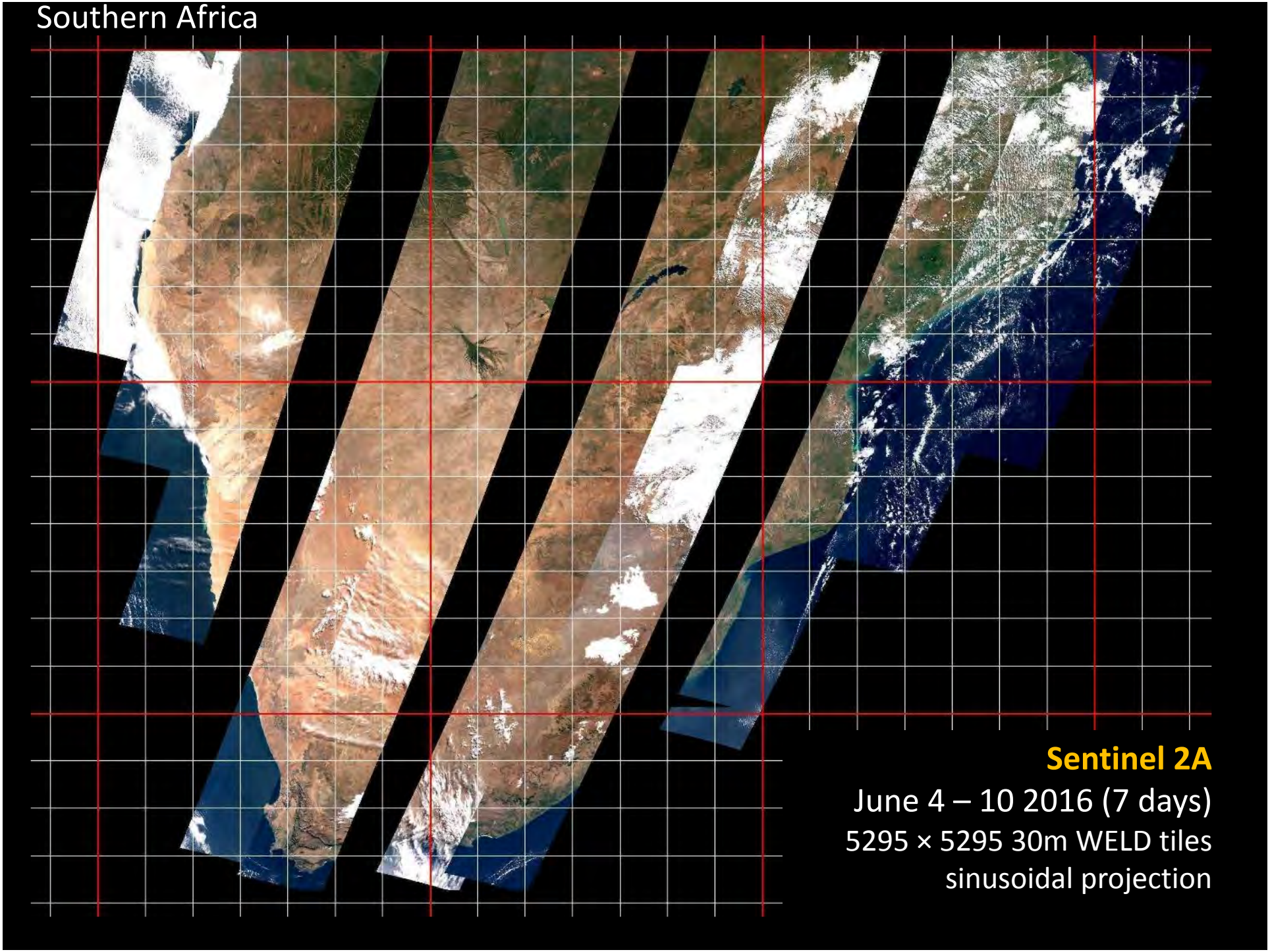
- Global WELD processing framework
  - Tiling into sinusoidal grid
  - Atmospheric correction
  - Nadir BRDF-adjusted reflectance (NBAR)
- Fix geolocation issues
  - Sentinel-2A to Landsat-8 misregistration
  - Sentinel-2A to Sentinel-2A misregistration

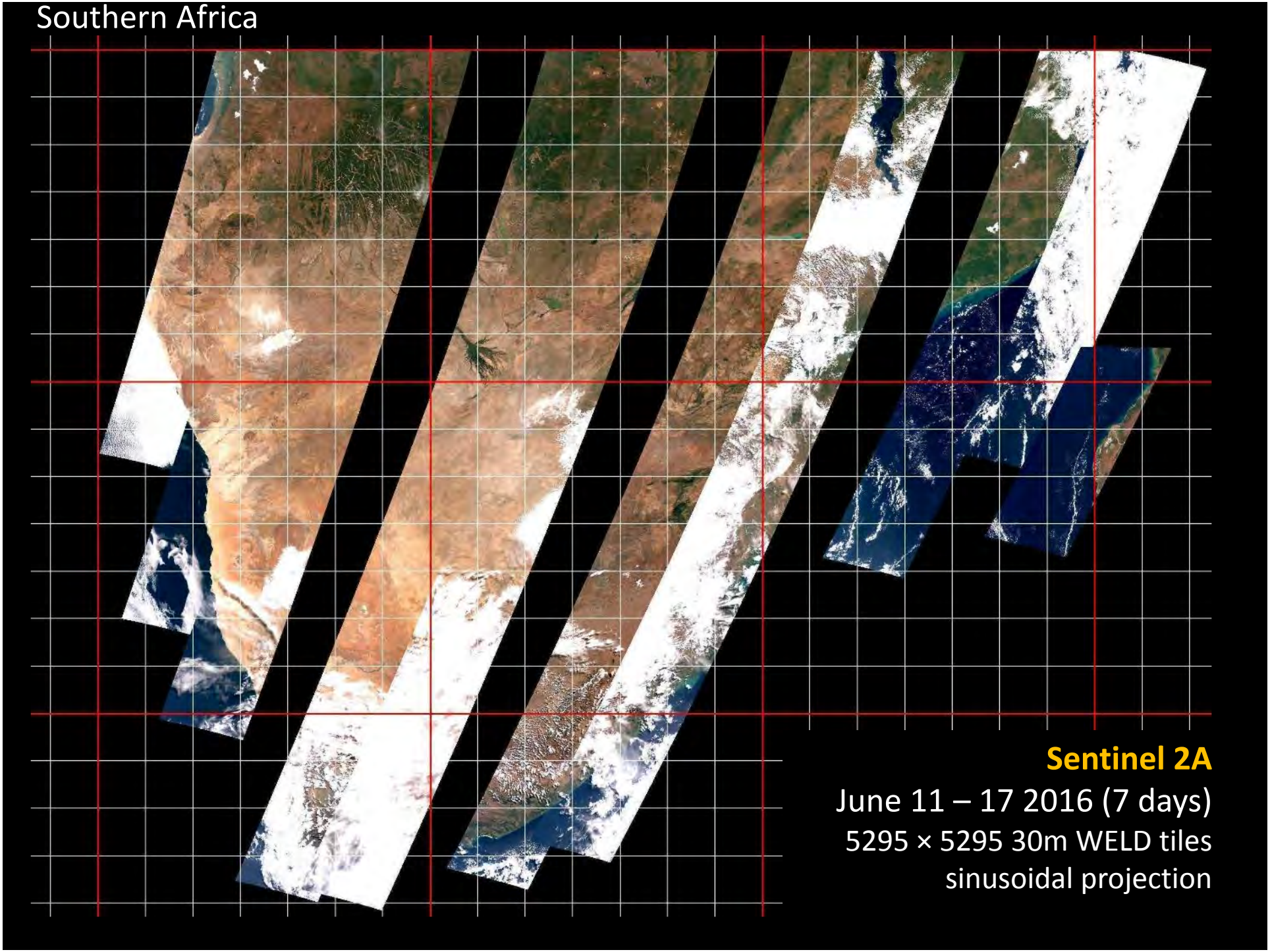

Southern Africa
Landsat 8 Collection 1
June 4 – 10 2016 (7 days)
5295 × 5295 30m WELD tiles
sinusoidal projection

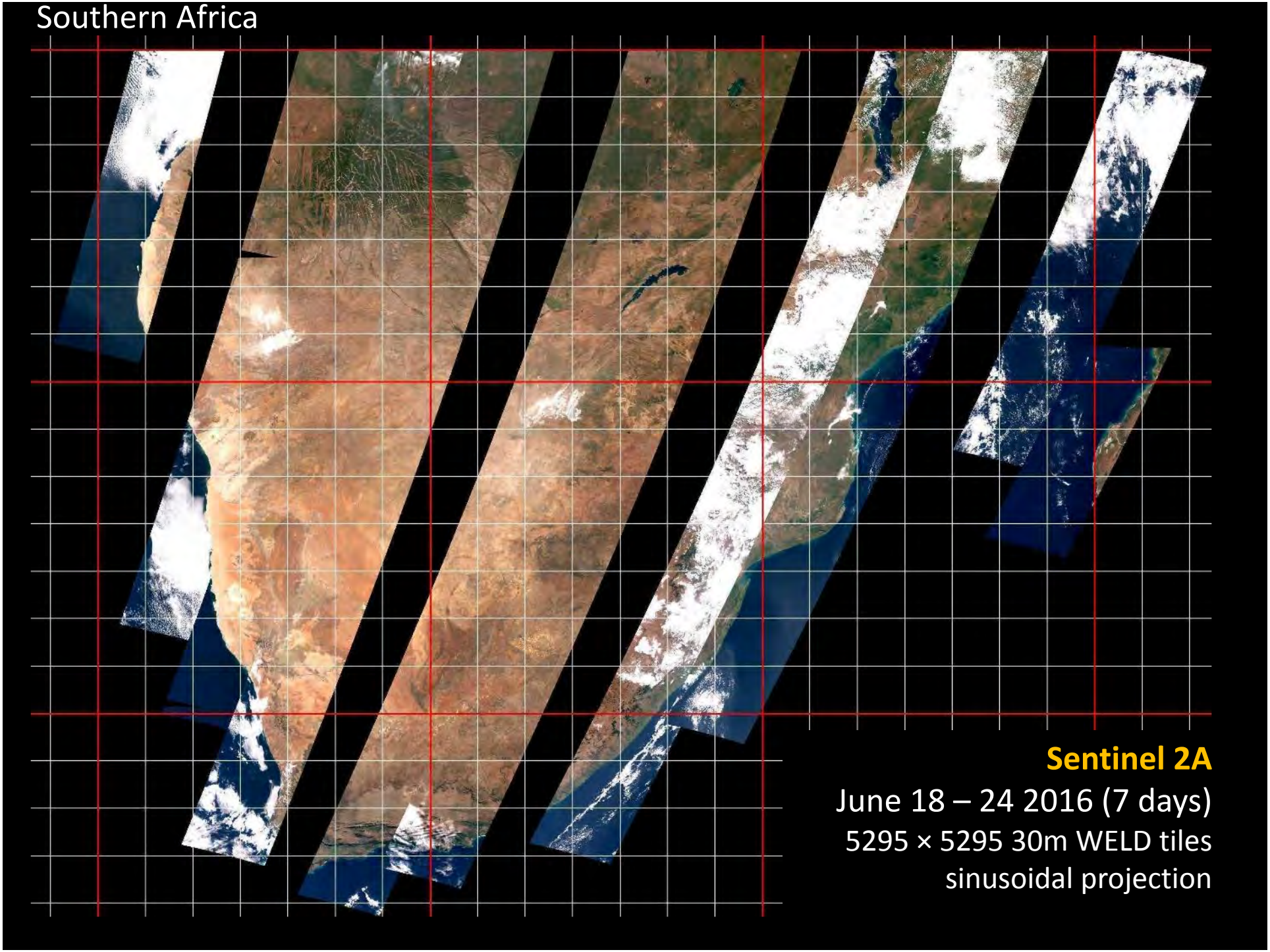

Southern Africa
Landsat 8 Collection 1
June 11 – 17 2016 (7 days)
5295 × 5295 30m WELD tiles
sinusoidal projection

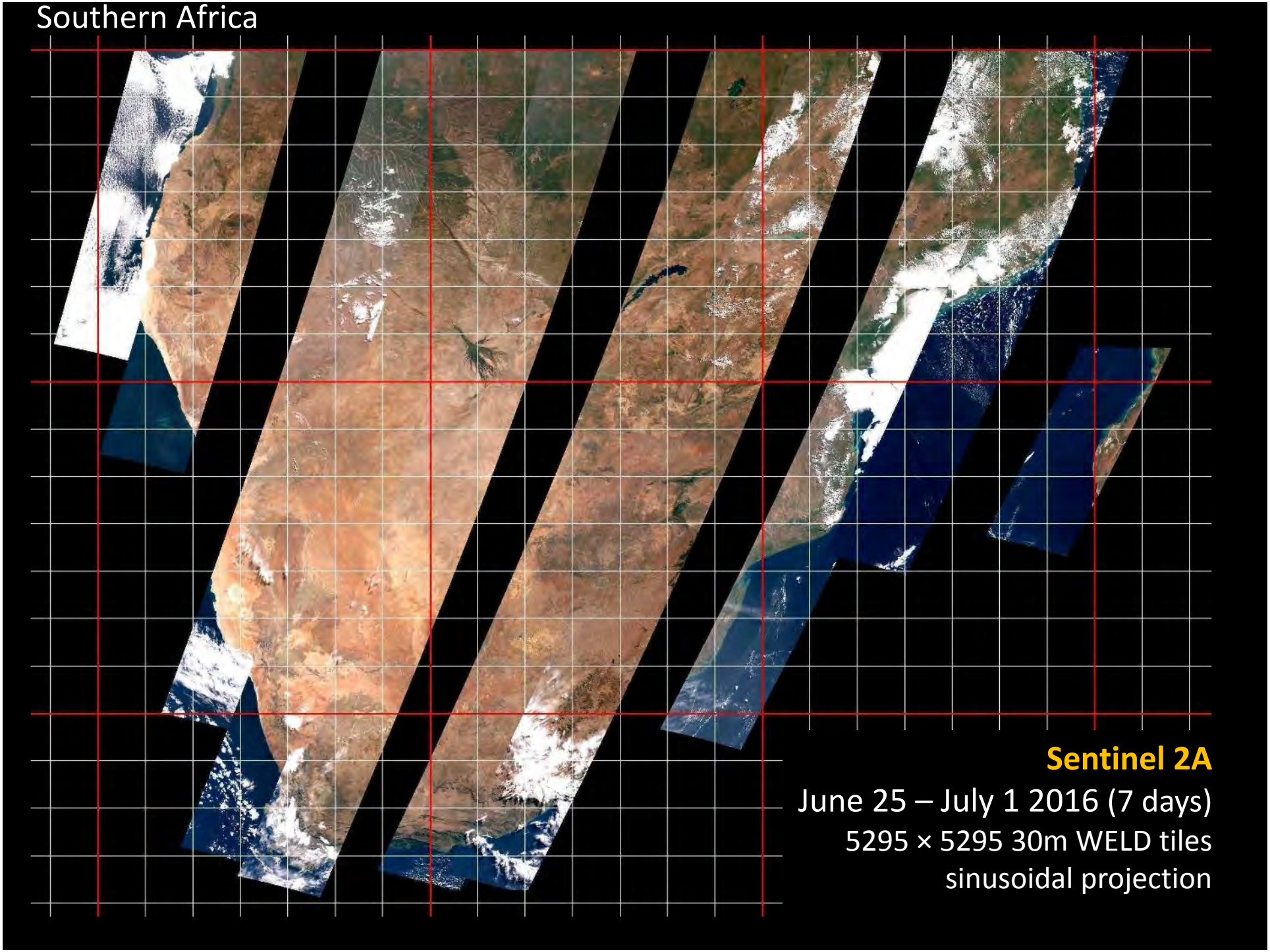

Southern Africa
Landsat 8 Collection 1
June 18 – 24 2016 (7 days)
5295 × 5295 30m WELD tiles
sinusoidal projection

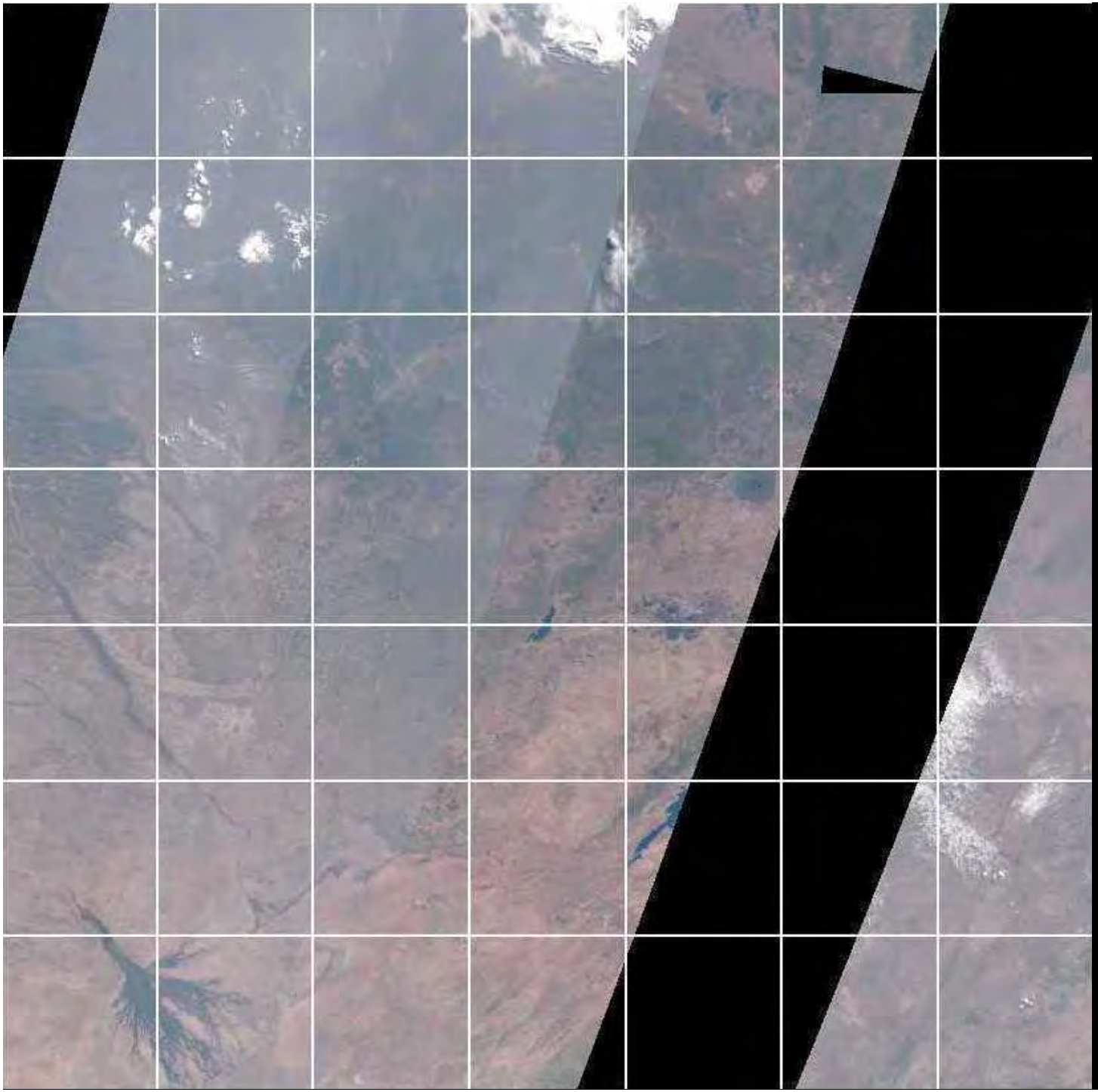

Southern Africa
Landsat 8 Collection 1
June 25 – July 1 2016 (7 days)
5295 × 5295 30m WELD tiles
sinusoidal projection


Southern Africa
Sentinel 2A
June 4 – 10 2016 (7 days)
5295 × 5295 30m WELD tiles
sinusoidal projection


Southern Africa
Sentinel 2A
June 11 – 17 2016 (7 days)
5295 × 5295 30m WELD tiles
sinusoidal projection


Southern Africa
Sentinel 2A
June 18 – 24 2016 (7 days)
5295 × 5295 30m WELD tiles
sinusoidal projection


Southern Africa
Sentinel 2A
June 25 – July 1 2016 (7 days)
5295 × 5295 30m WELD tiles
sinusoidal projection



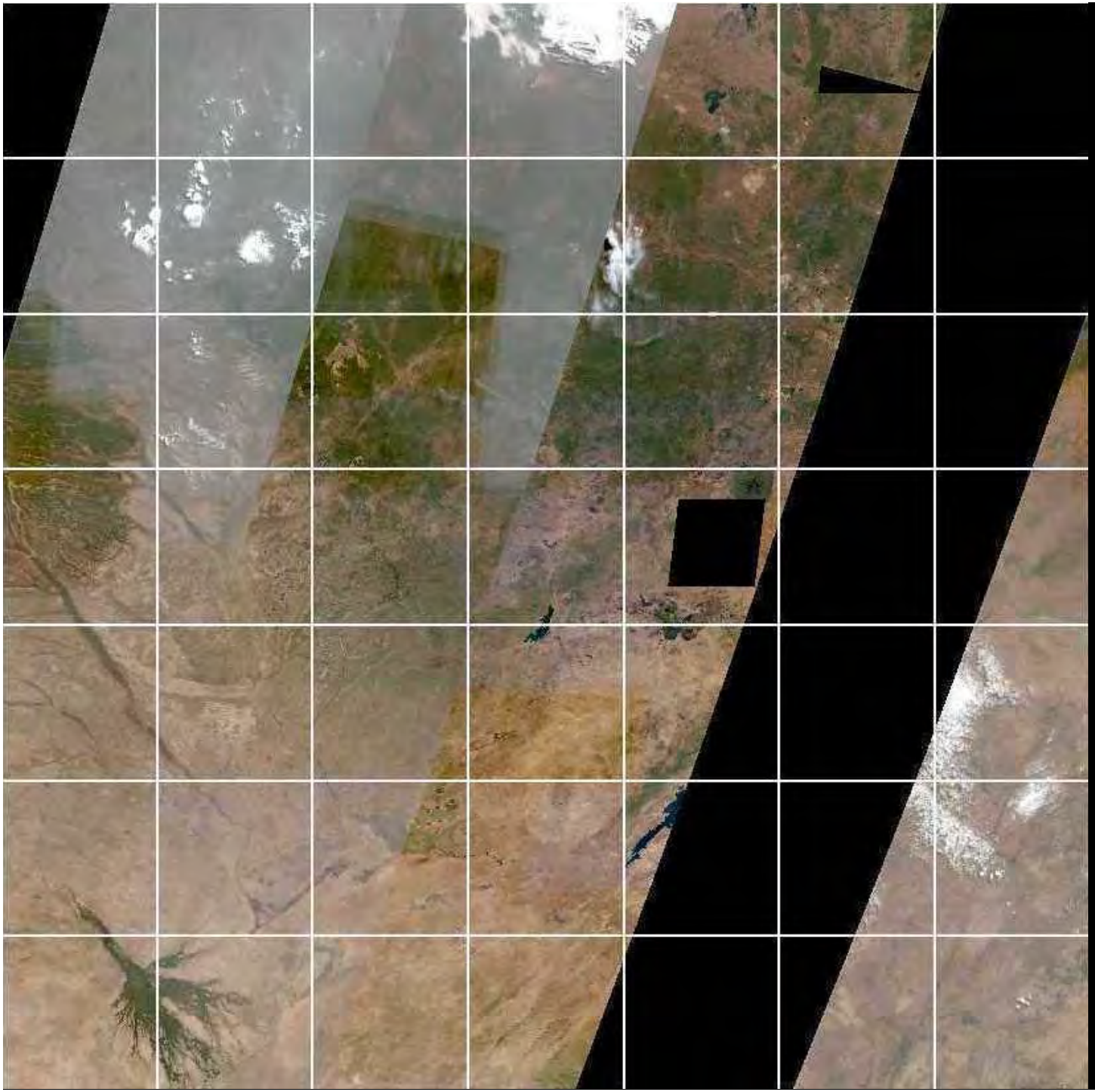
Sentinel-2A TOA reflectance

week 30
Jul. 22-28 2016

7 x 7 WELD tiles

1200 x 1200 km

MODIS tile
h20v10



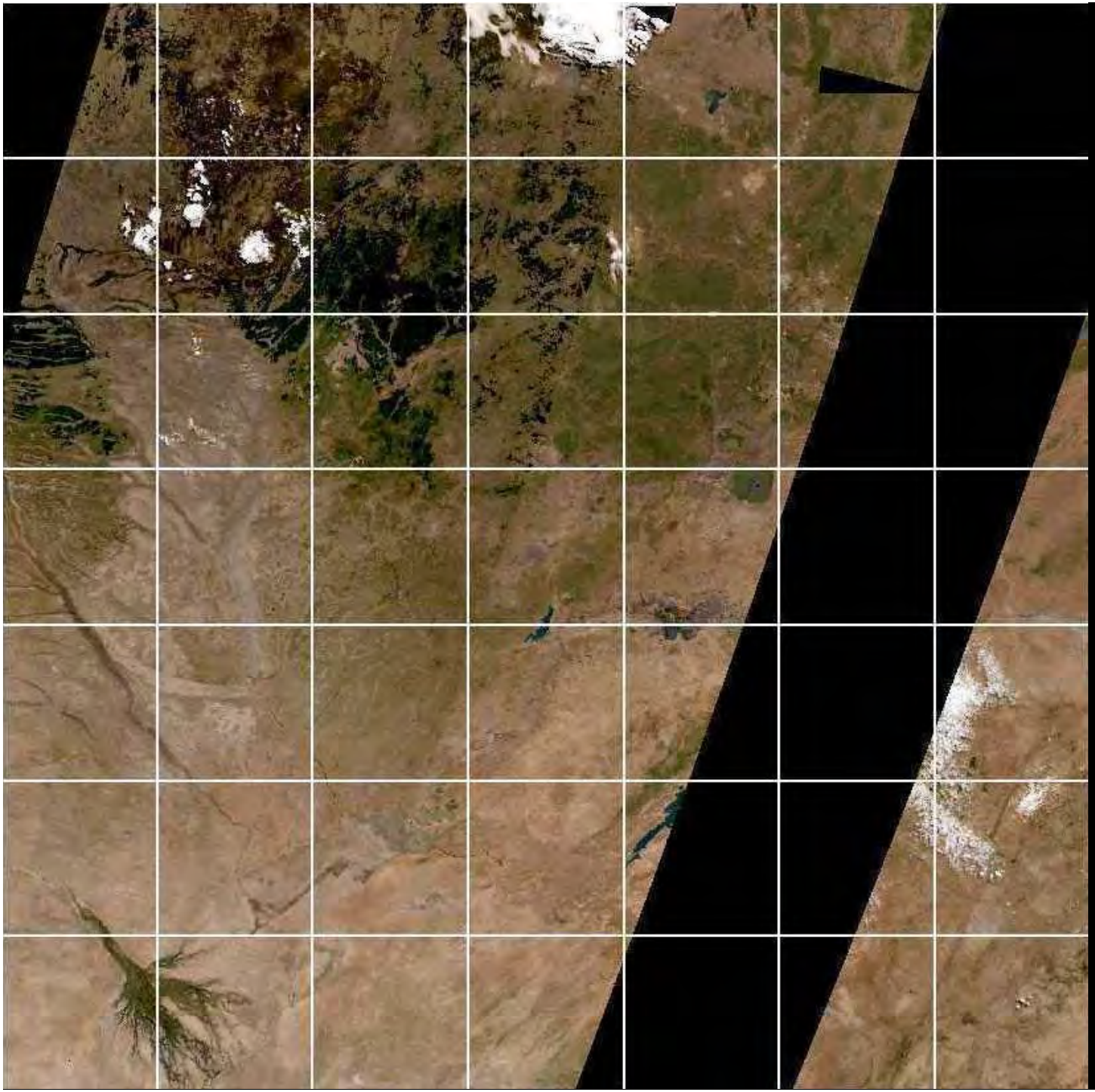
Sentinel-2A
V2.3.1
Sen2Cor
surface
reflectance

week 30
Jul. 22-28 2016

7 x 7 WELD tiles

1200 x 1200 km

MODIS tile
h20v10



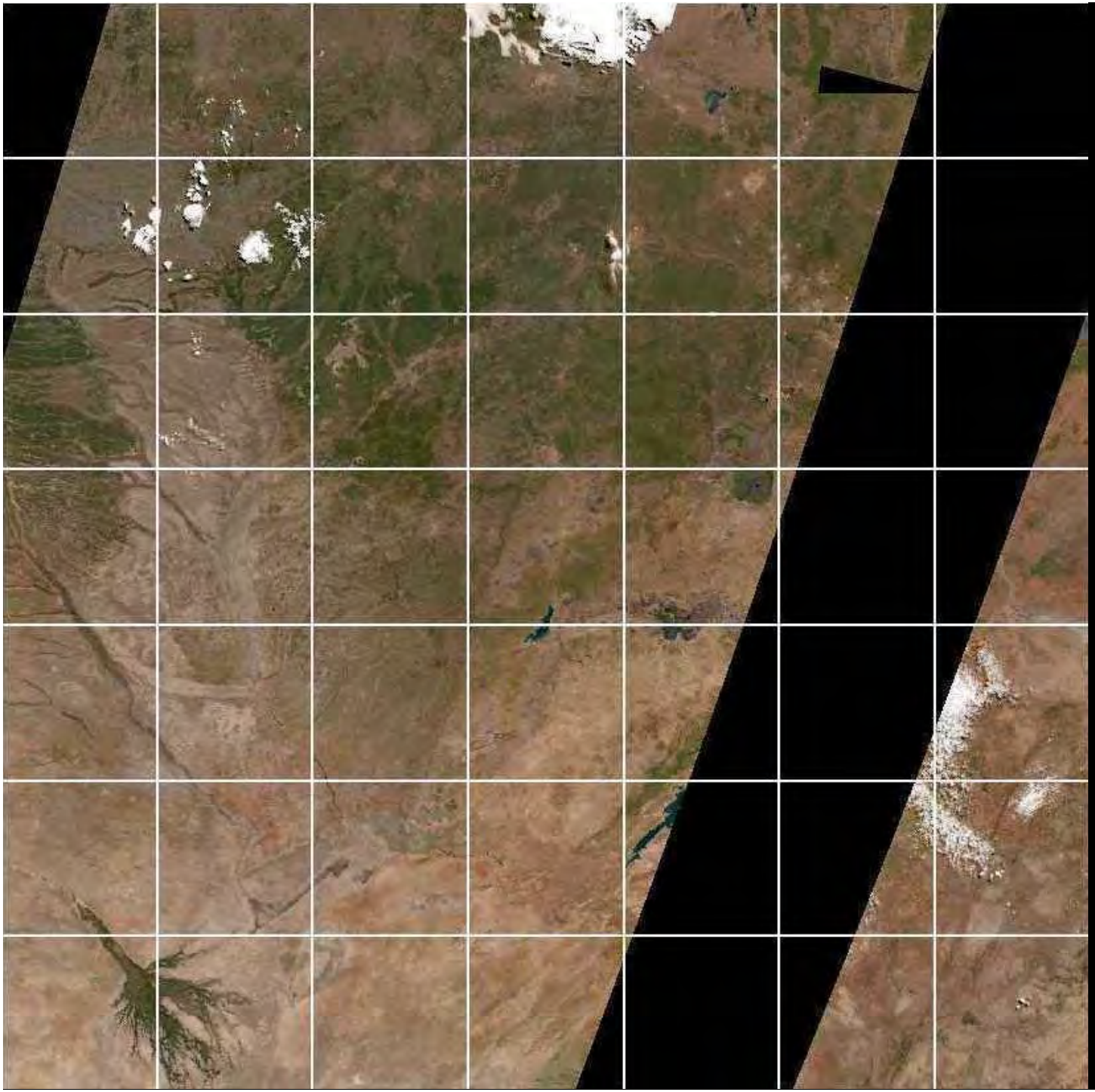
Sentinel-2A
V3.5.3
LaSRC
surface
reflectance

week 30
Jul. 22-28 2016

7 x 7 WELD tiles

1200 x 1200 km

MODIS tile
h20v10



Sentinel-2A
V3.5.5
LaSRC
surface
reflectance

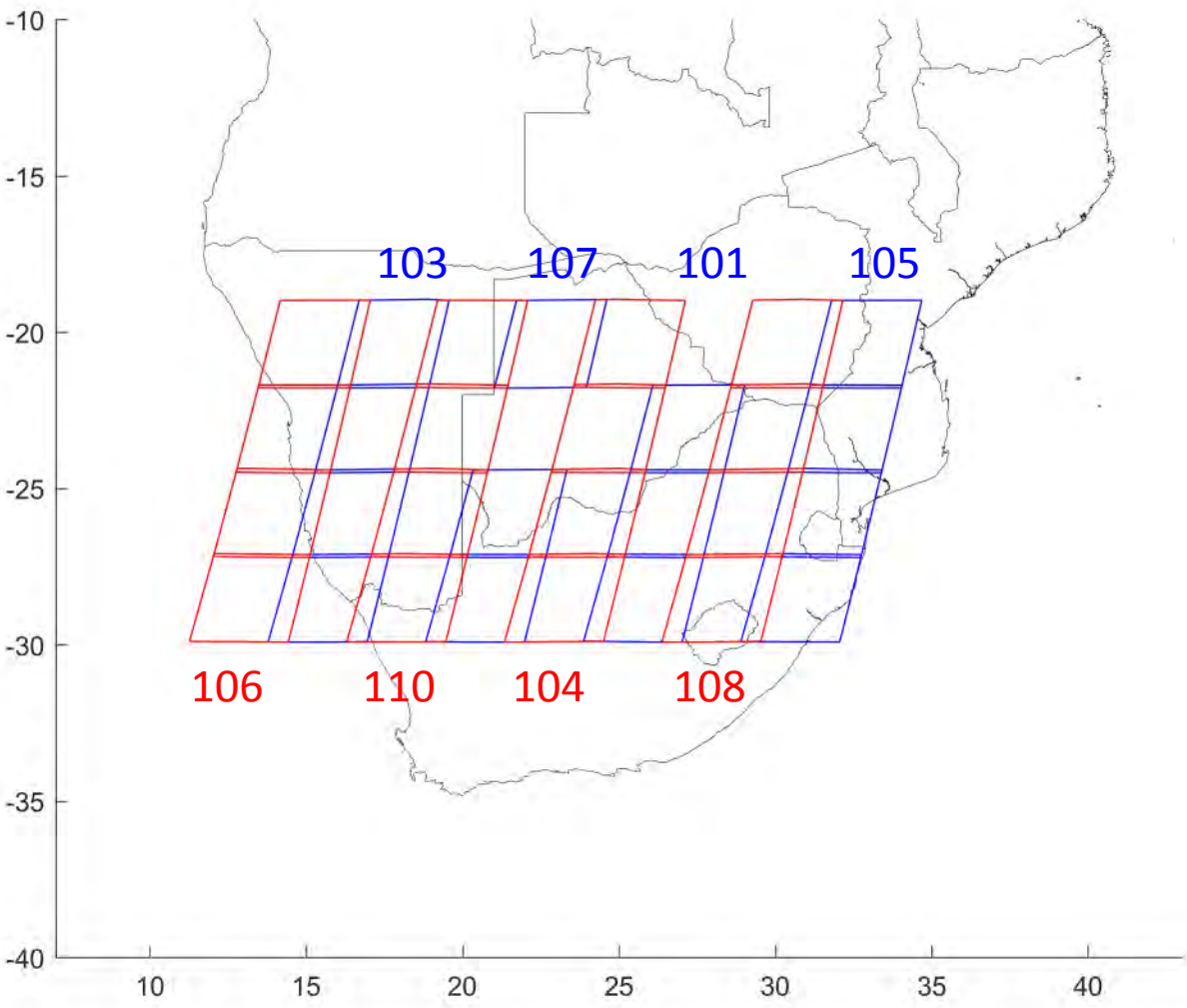
week 30
Jul. 22-28 2016

7 x 7 WELD tiles

1200 x 1200 km

MODIS tile
h20v10

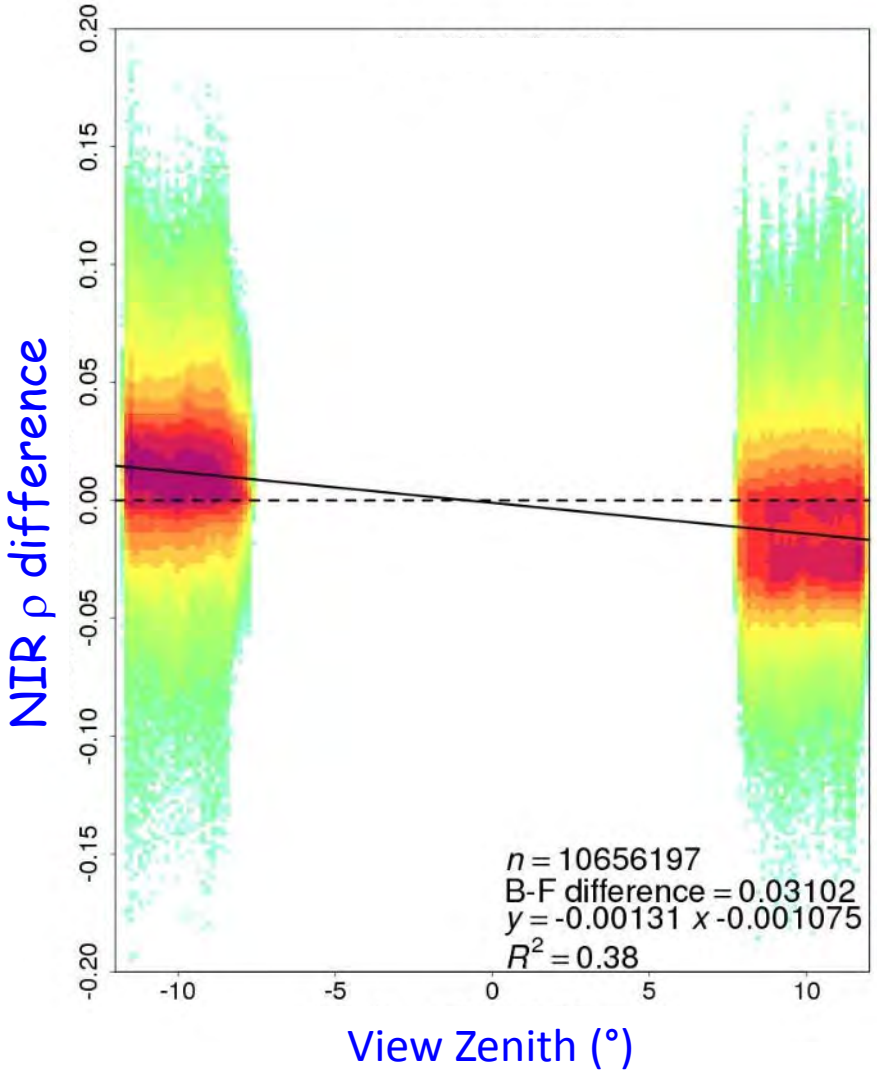
Sentinel-2A 10 days April 2016



Roy, D.P, Li, J., Zhang, H.K., Yan, L., Huang, H., 2017, Examination of Sentinel-2A multi-spectral instrument (MSI) reflectance anisotropy and the suitability of a general method to normalize MSI reflectance to nadir BRDF adjusted reflectance, *Remote Sensing of Environment,* 199, 25-38.

Sentinel-2A 10 days April 2016

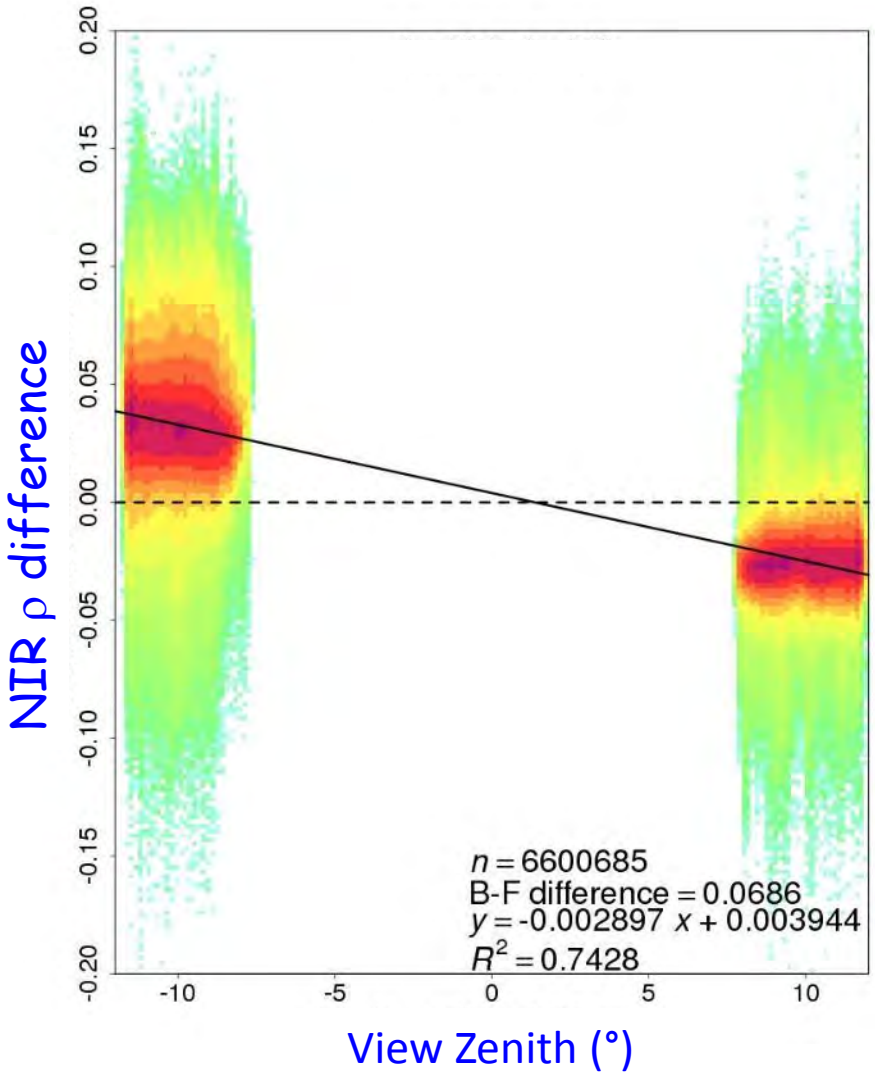
Swath overlap NIR ρ difference V view zenith

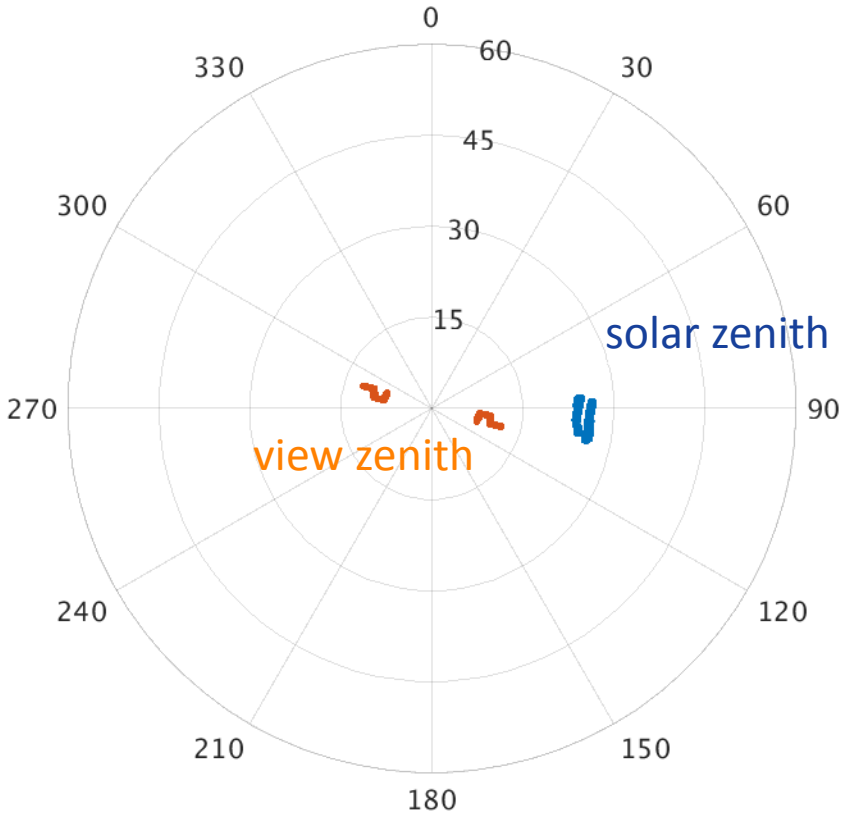


Sentinel-2A 10 days January 2016

(Solar Principal Plane)

Swath overlap NIR ρ difference V view zenith

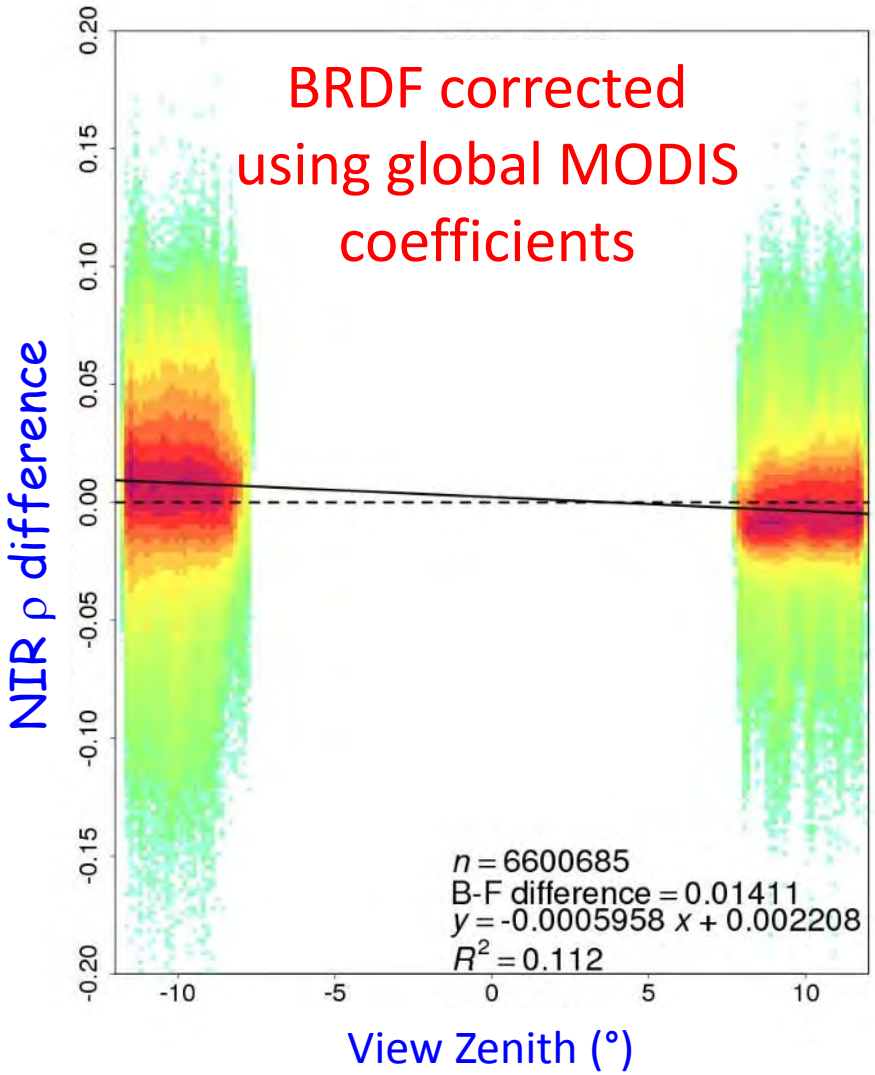


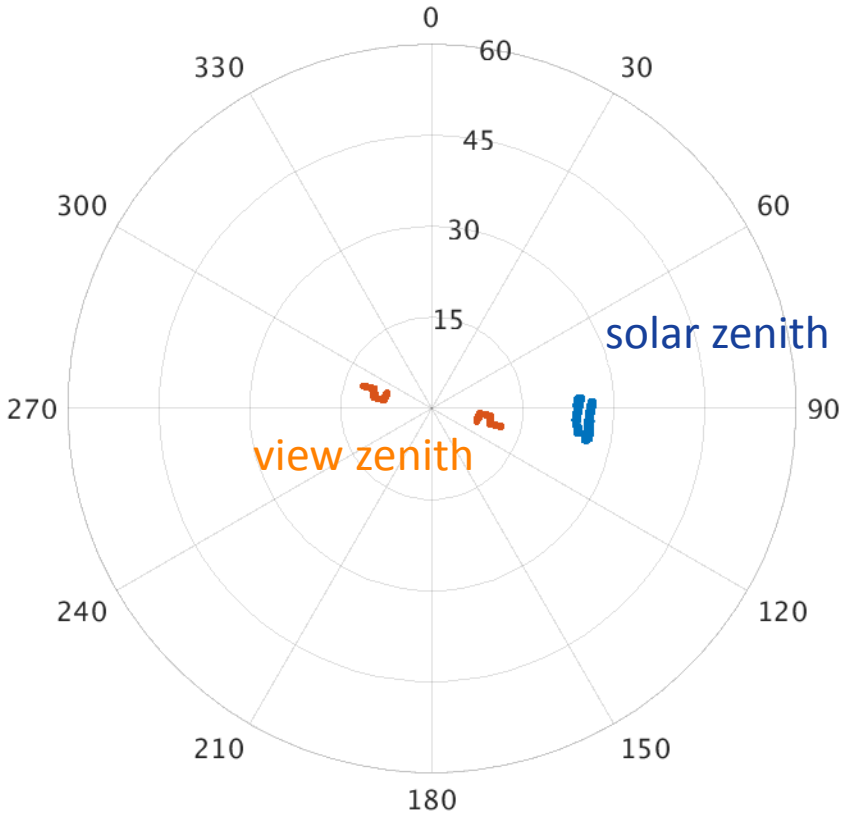


Sentinel-2A 10 days January 2016

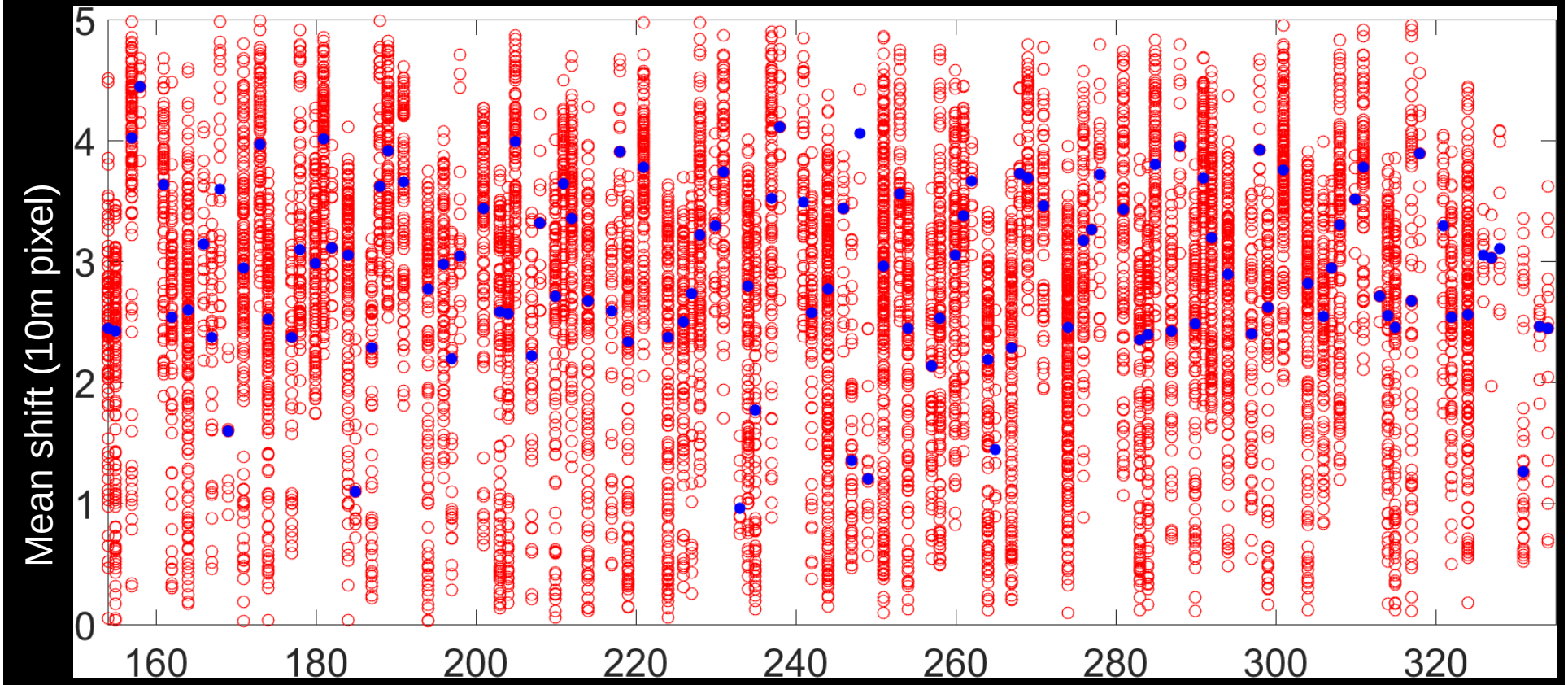
(Solar Principal Plane)

Swath overlap NIR ρ difference V view zenith



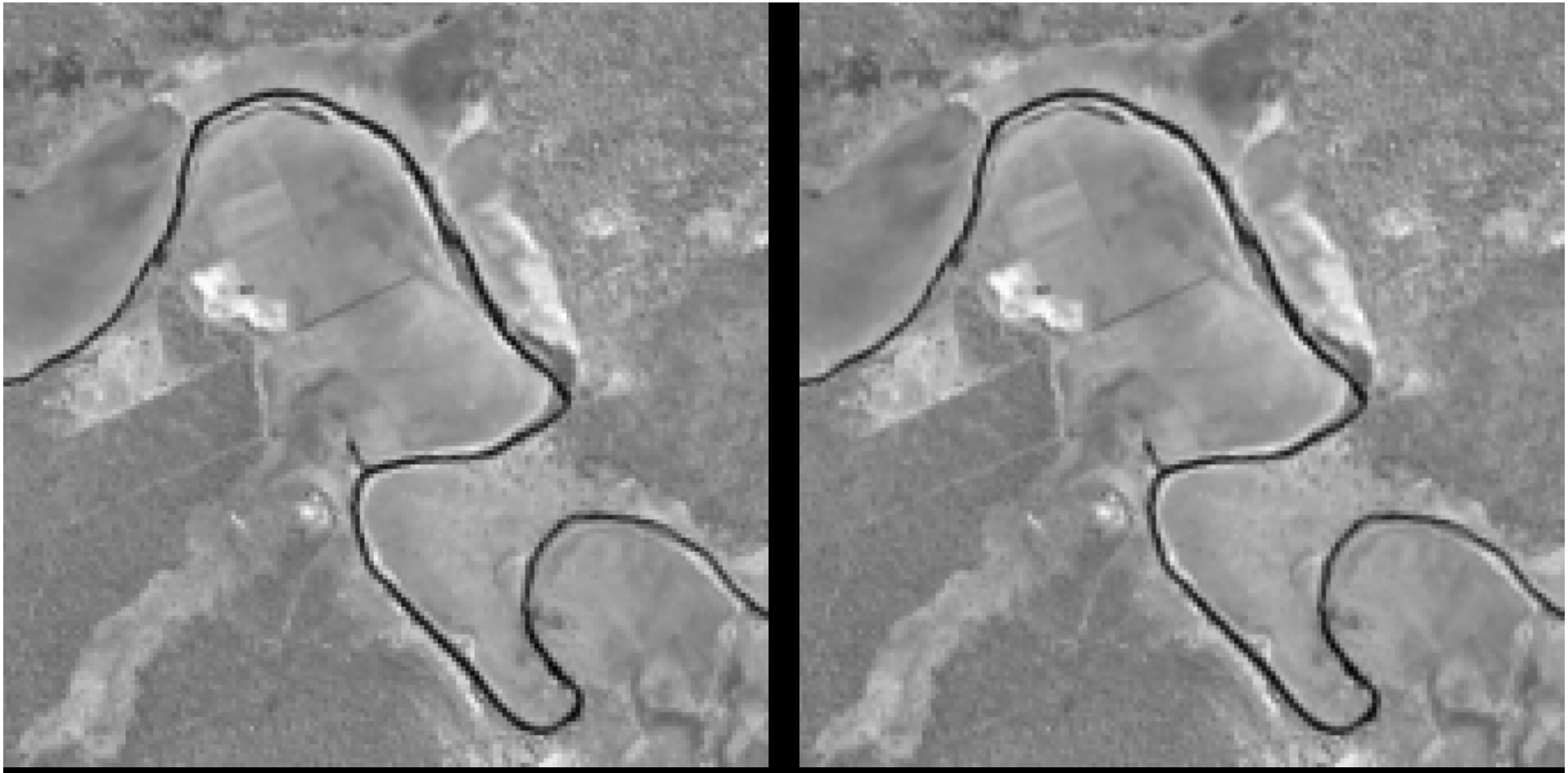


Landsat 8 <-> Sentinel 2
misregistration characterization (10m), UTM 35



Yan et al. 2017

μ = 2.761, σ = 1.075, max = 4.990 (10m pixels) (4,574 matched image pairs)



Original

Registered

Landsat 8 Collection 1

June 3 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

Registered

Sentinel 2A

June 2 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

Registered

Sentinel 2A

June 12 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

Registered

Sentinel 2A

June 22 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

Registered

Sentinel 2A

July 2 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

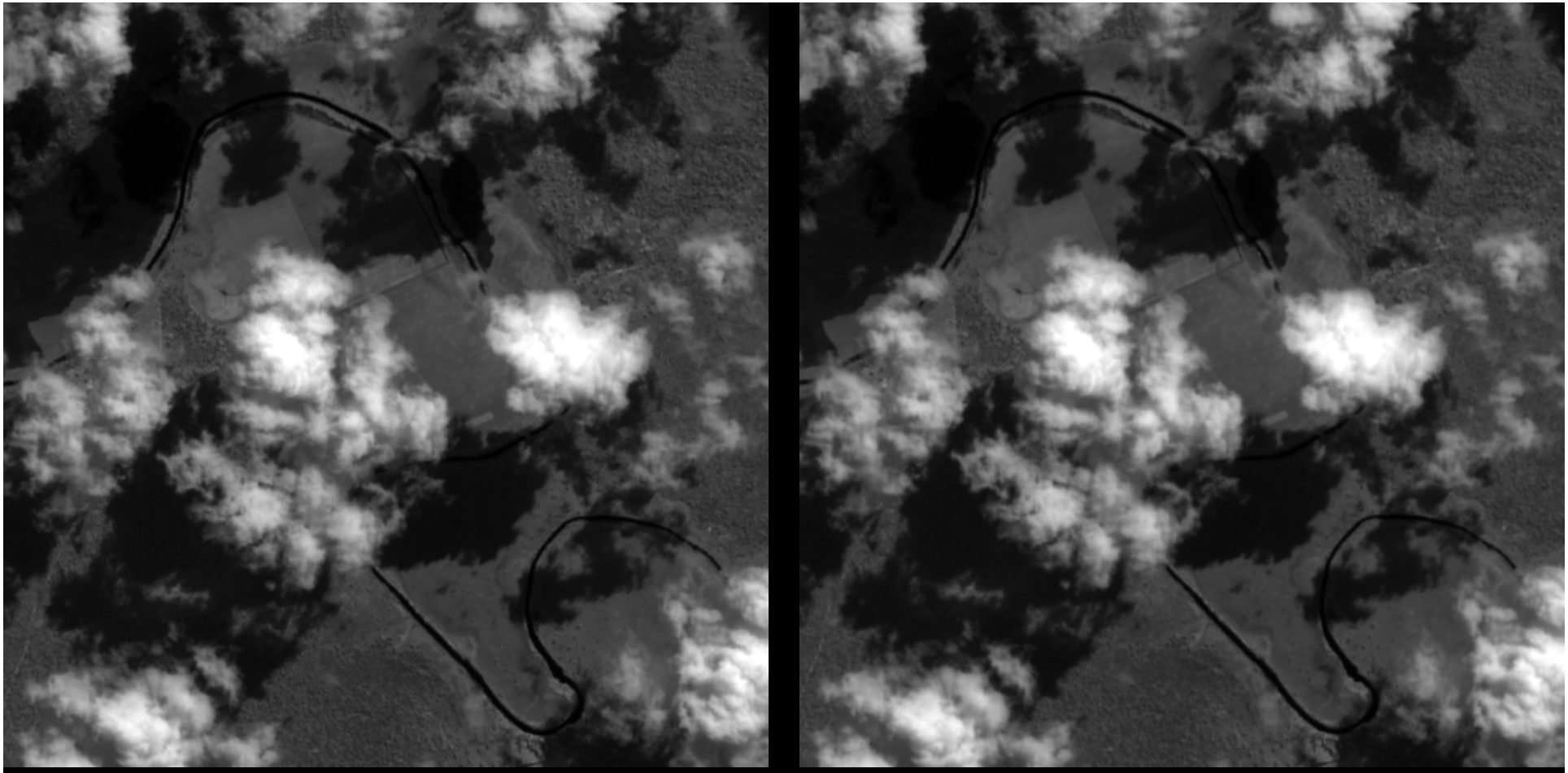
Registered

Landsat 8 Collection 1

July 5 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR



Original

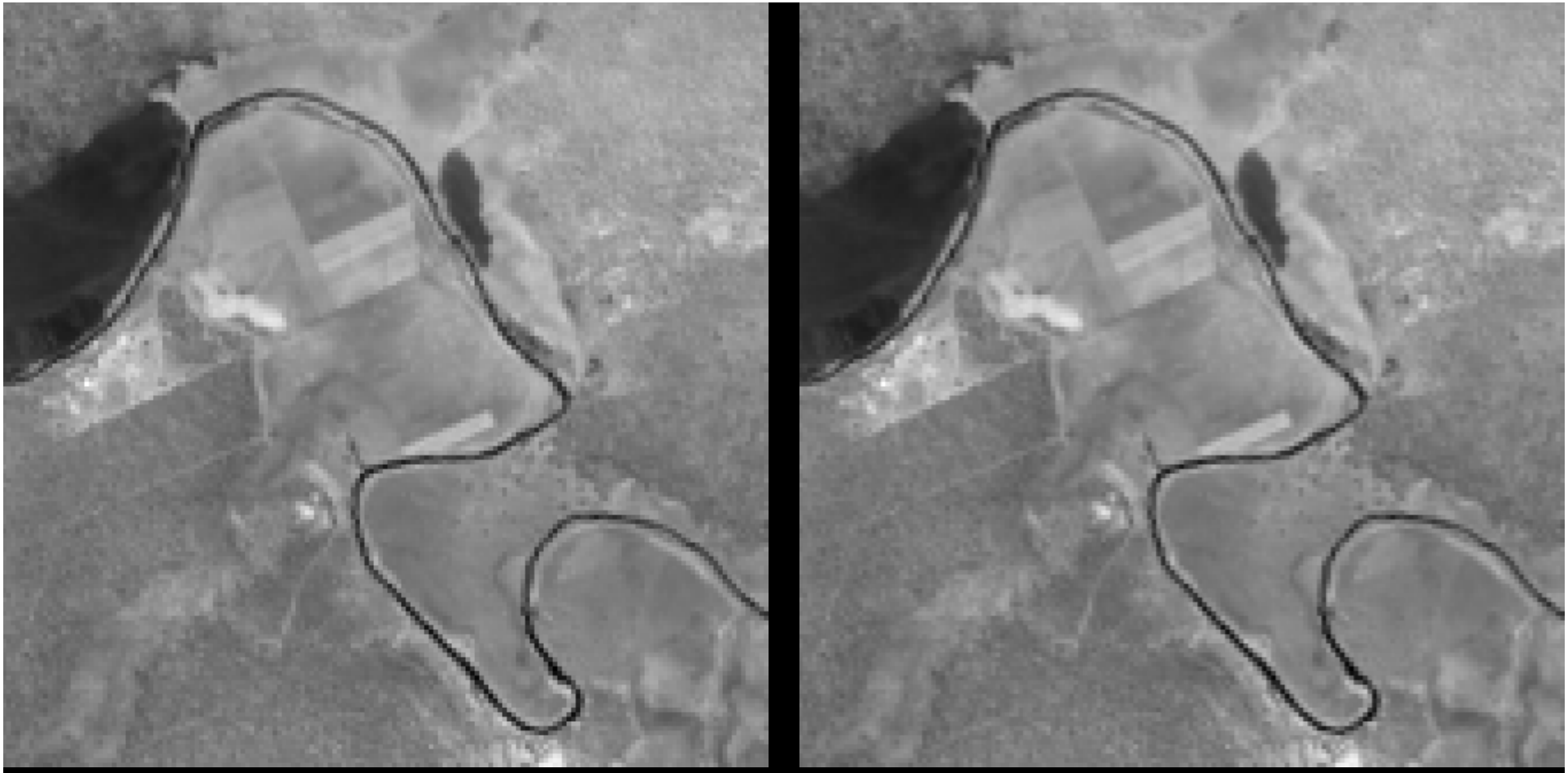
Registered

Sentinel 2A

July 12 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR



Original

Registered

Landsat 8 Collection 1

July 21 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

Registered

Sentinel 2A

July 22 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

Registered

Sentinel 2A

August 1 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

Registered

Landsat 8 Collection 1

August 6 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

Registered

Sentinel 2A

August 11 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

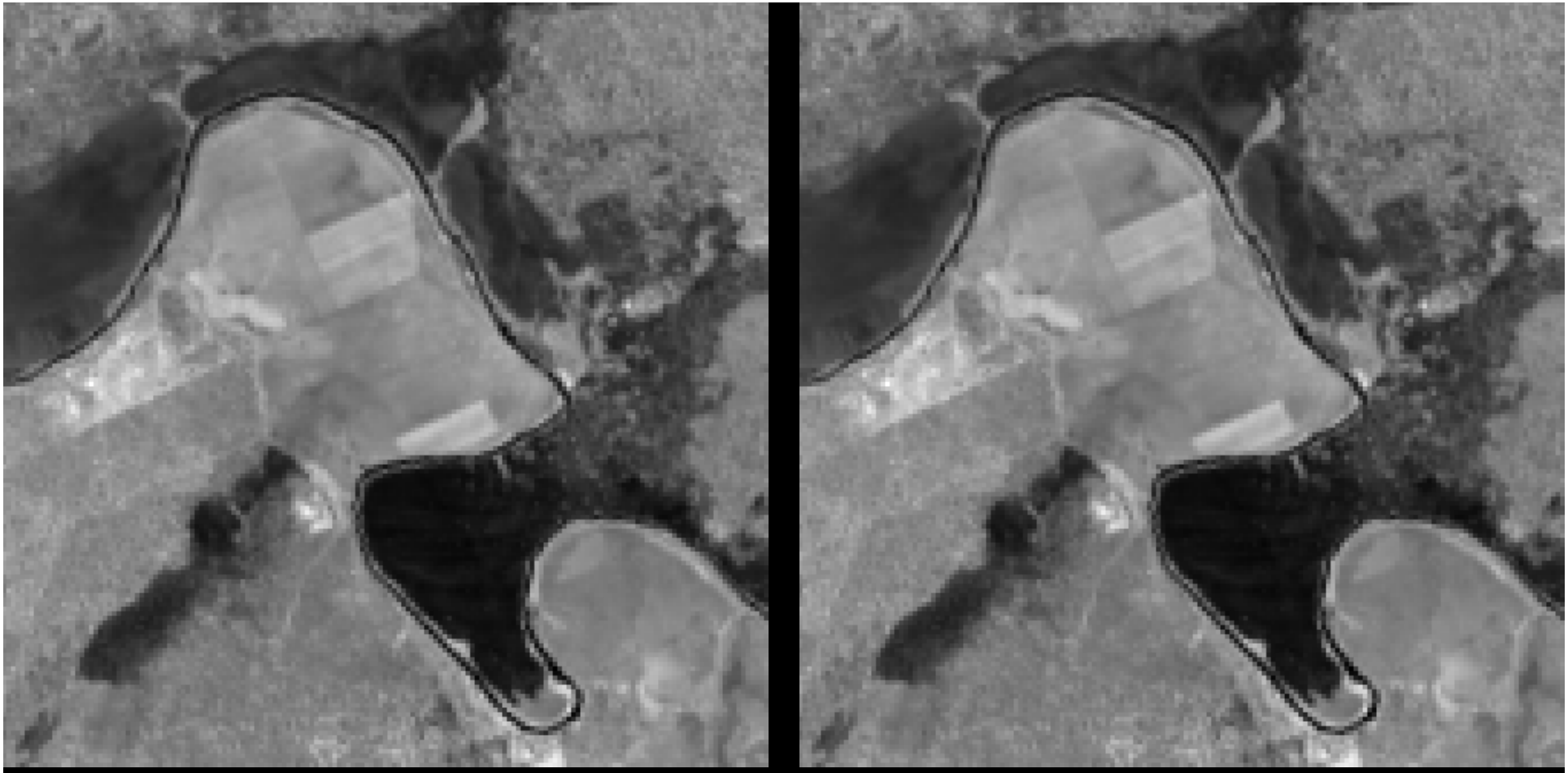
Registered

Sentinel 2A

August 21 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR



Original

Registered

Landsat 8 Collection 1

August 22 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

Registered

Sentinel 2A

August 31 2016

Copperbelt Provence, Zambia

500 × 500 10 m pixels, NIR

Original

Registered

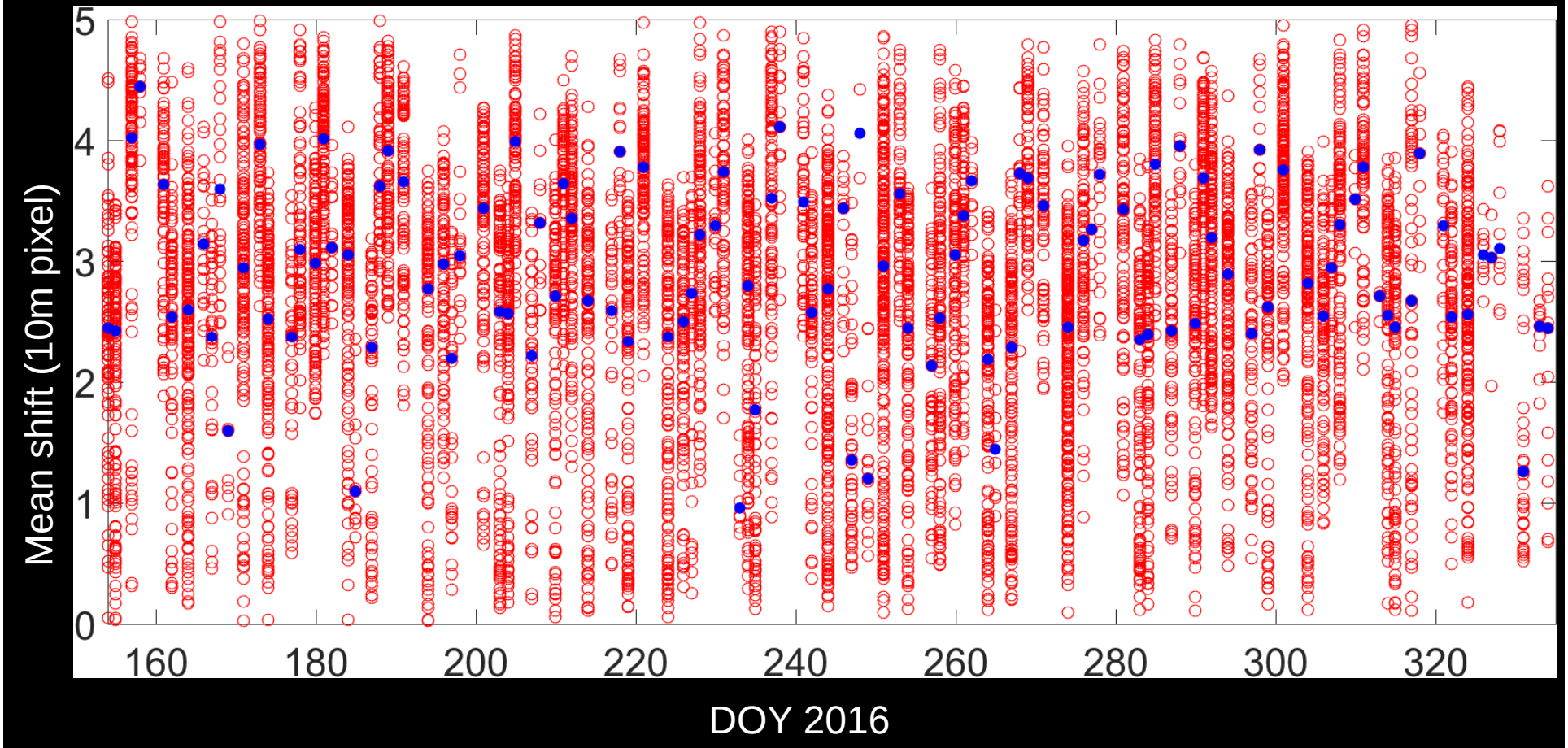
Landsat 8 Collection 1

September 7 2016

Copperbelt Provence, Zambia

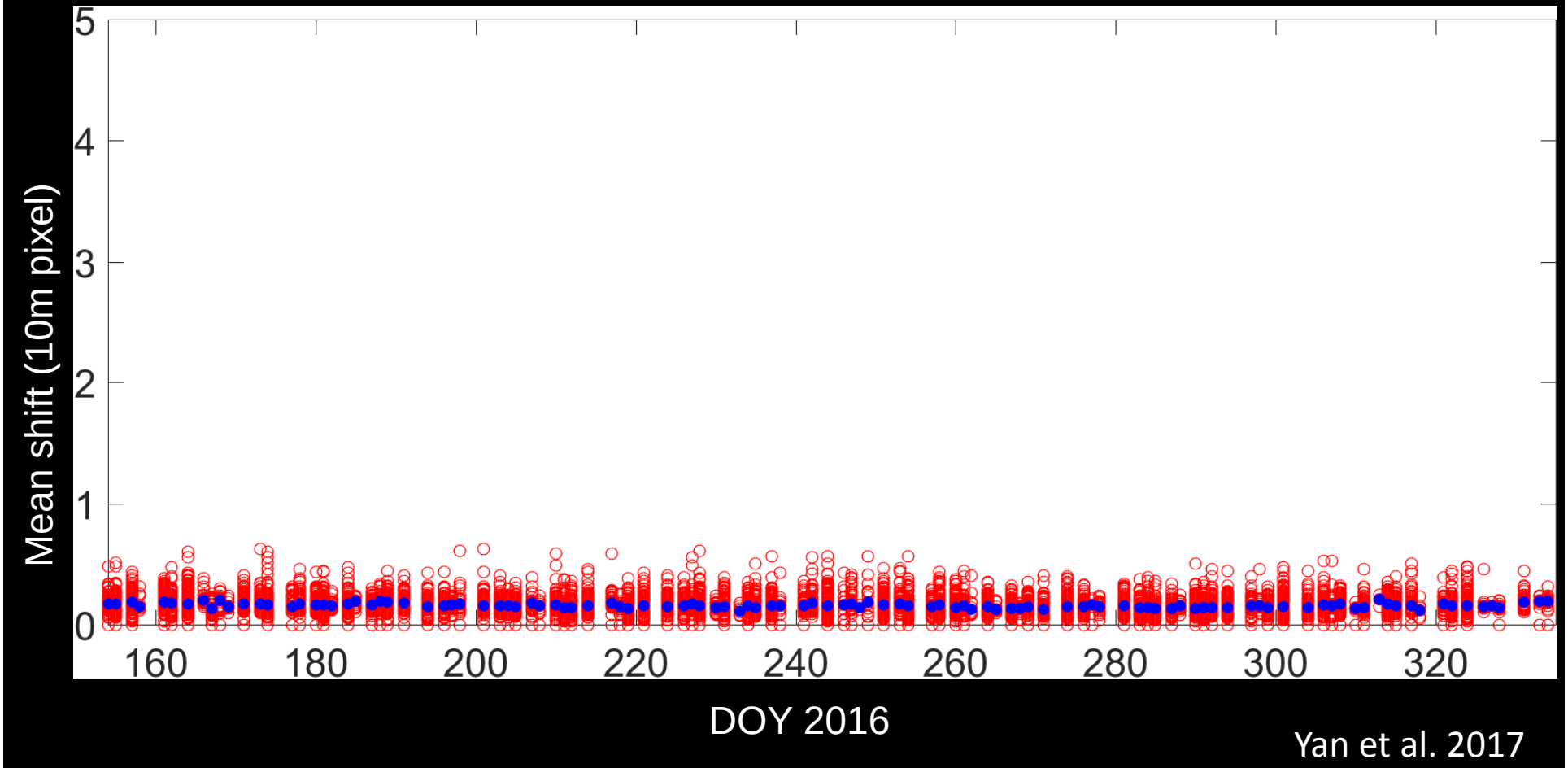
500 × 500 10 m pixels, NIR

Landsat 8 <-> Sentinel 2
misregistration characterization (10m), UTM 35



μ = 2.761, σ = 1.075, max = 4.990 (10m pixels) (4,574 matched image pairs)

Landsat 8 <-> Sentinel 2
misregistration characterization (10m), UTM 35
after partial-orbit based registration



Yan et al. 2017

μ = 0.161, σ = 0.076, max = 0.624 (10m pixels) (4,574 matched image pairs)

Prototyping a Landsat-8 Sentinel-2 global burned area product

- Algorithm concept
- S2-L8 combined results


D. Roy

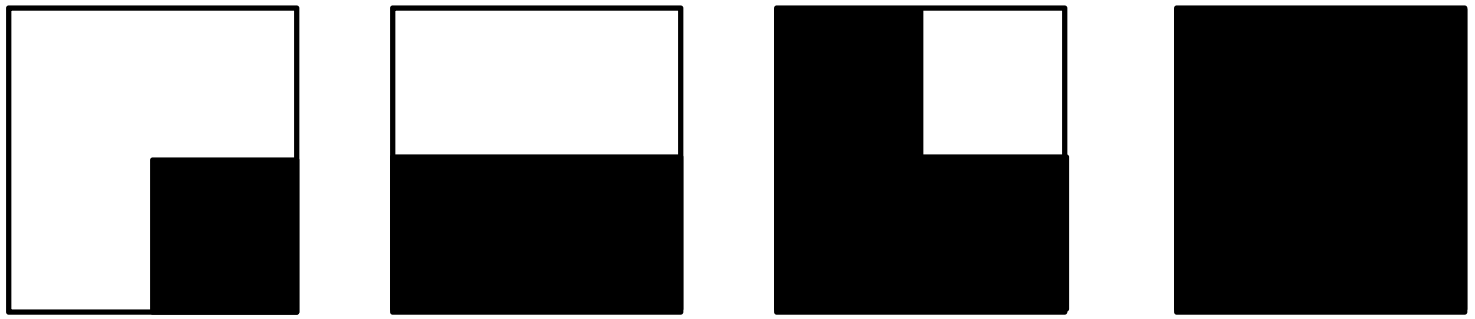

Burned pixel is a mix of burned and unburned stuff
AND the burned stuff has different reflectance
D. Roy

To first order the change in reflectance due to burning is dependent on the fraction of area burned *f* and combustion completeness *cc*

Luigi Boschetti

Linear spectral Mixture: Burning

Fraction of pixel area burned $0 \leq f \leq 1$



f = 0.25 0.50 0.75 1.0

Linear mixture model:

$$\rho = f\,\rho_B + (1-f)\,\rho_{UB}$$

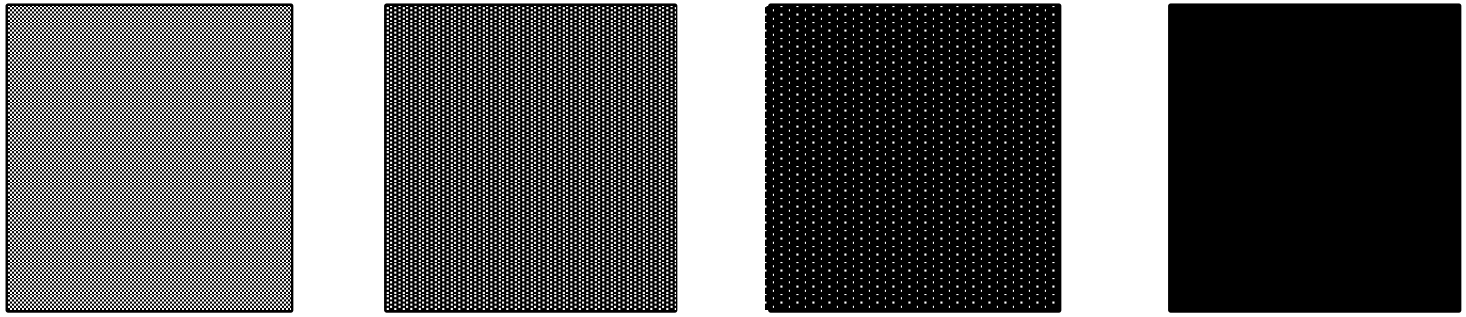
Reflectance of pixel in some band

Reflectance of pixel if it was *all* burned

Reflectance of pixel if it was *all* unburned

Linear spectral Mixture: Burning

Combustion completeness $0 \leq cc \leq 1$



cc = 0.25 0.50 0.75 1.0

Linear mixture model:

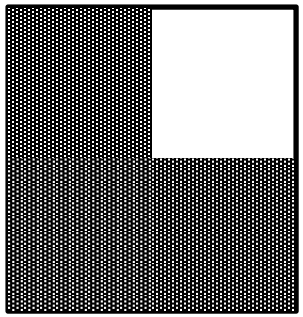
$$\rho = cc\ \rho_{\underline{B}} + (1-cc)\ \rho_{\underline{UB}}$$

Reflectance of pixel in some band

Reflectance of pixel if it was *all* burned

Reflectance of pixel if it was *all* unburned

Spectral Mixture: Burning



Combining the two linear mixture equations for a generic pixel with fraction of area burned f and combustion completeness cc:

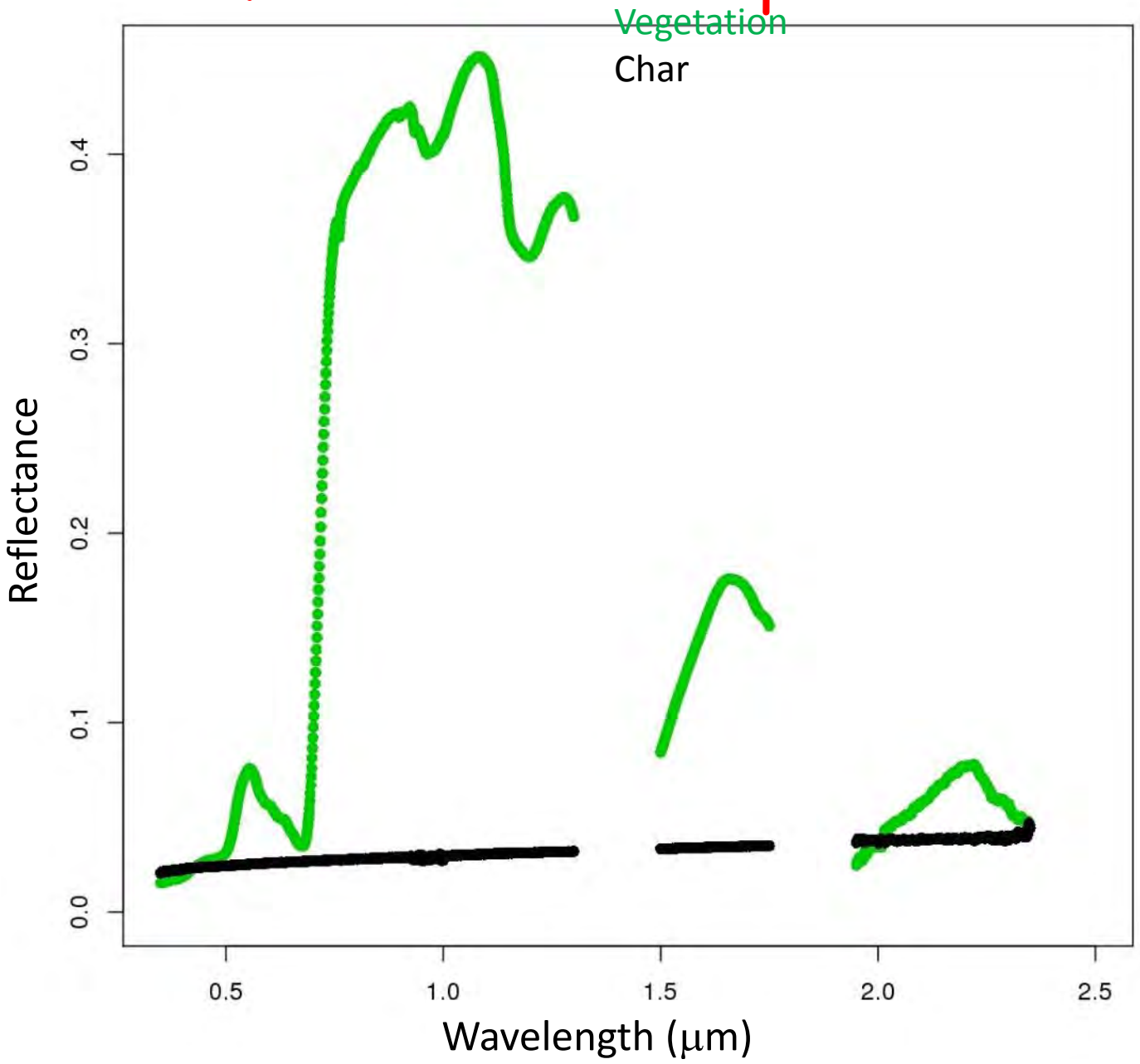
$$\rho = f\,\rho_B + (1-f)\,\rho_{UB}$$
$$\rho_B = cc\,\rho_B + (1-cc)\,\rho_{UB}$$

$$\rho = f\,cc\,\rho_B + f(1-cc)\,\rho_{UB} + (1-f)\,\rho_{UB}$$

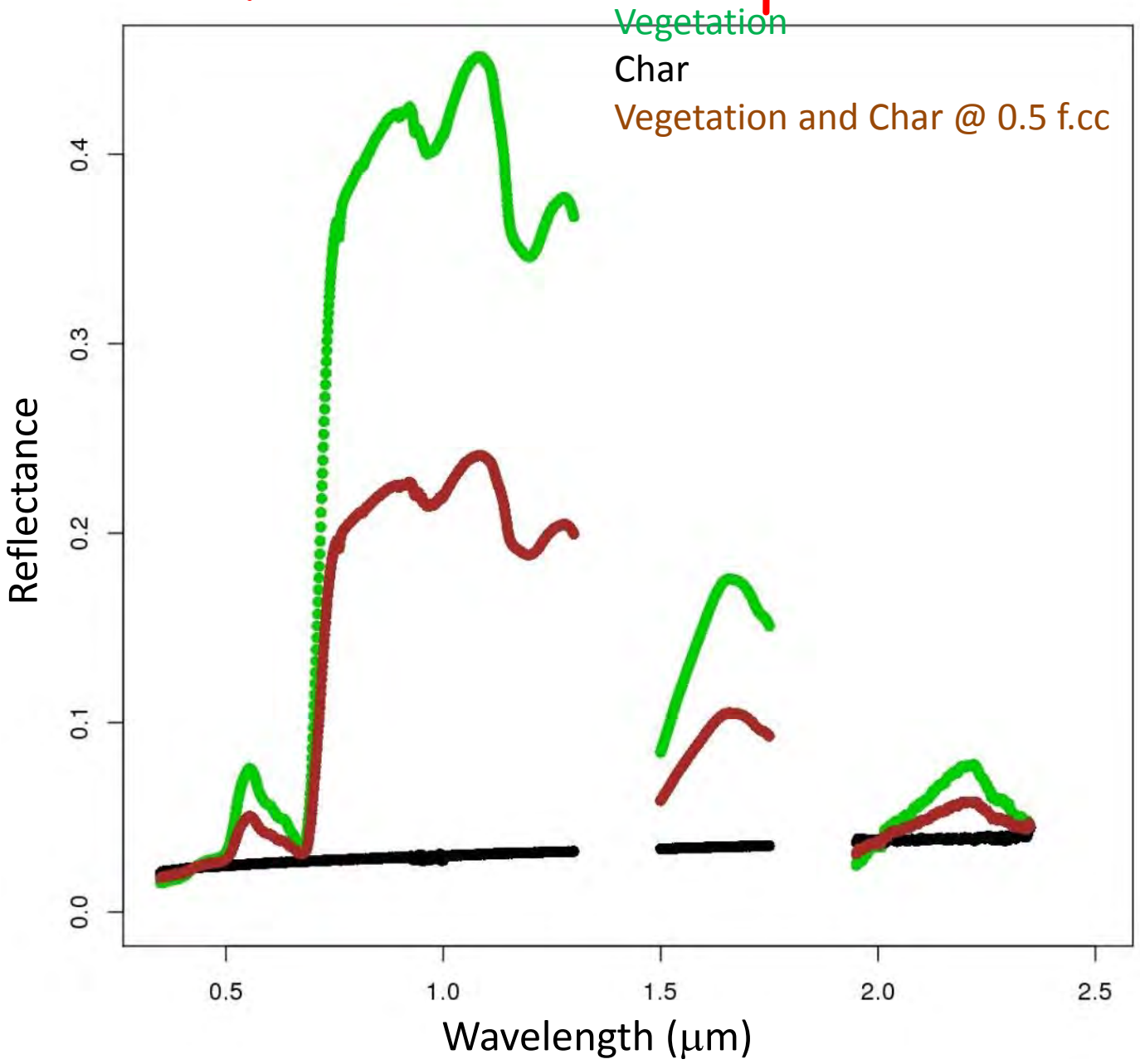
$$\boxed{\rho = (1-f\,cc)\,\rho_{UB} + f\,cc\,\rho_B}$$

Roy, D, Landmann, T (2005) Characterizing the surface heterogeneity of fire effects using multi-temporal reflective wavelength data. *International Journal of Remote Sensing* 26, 4197-

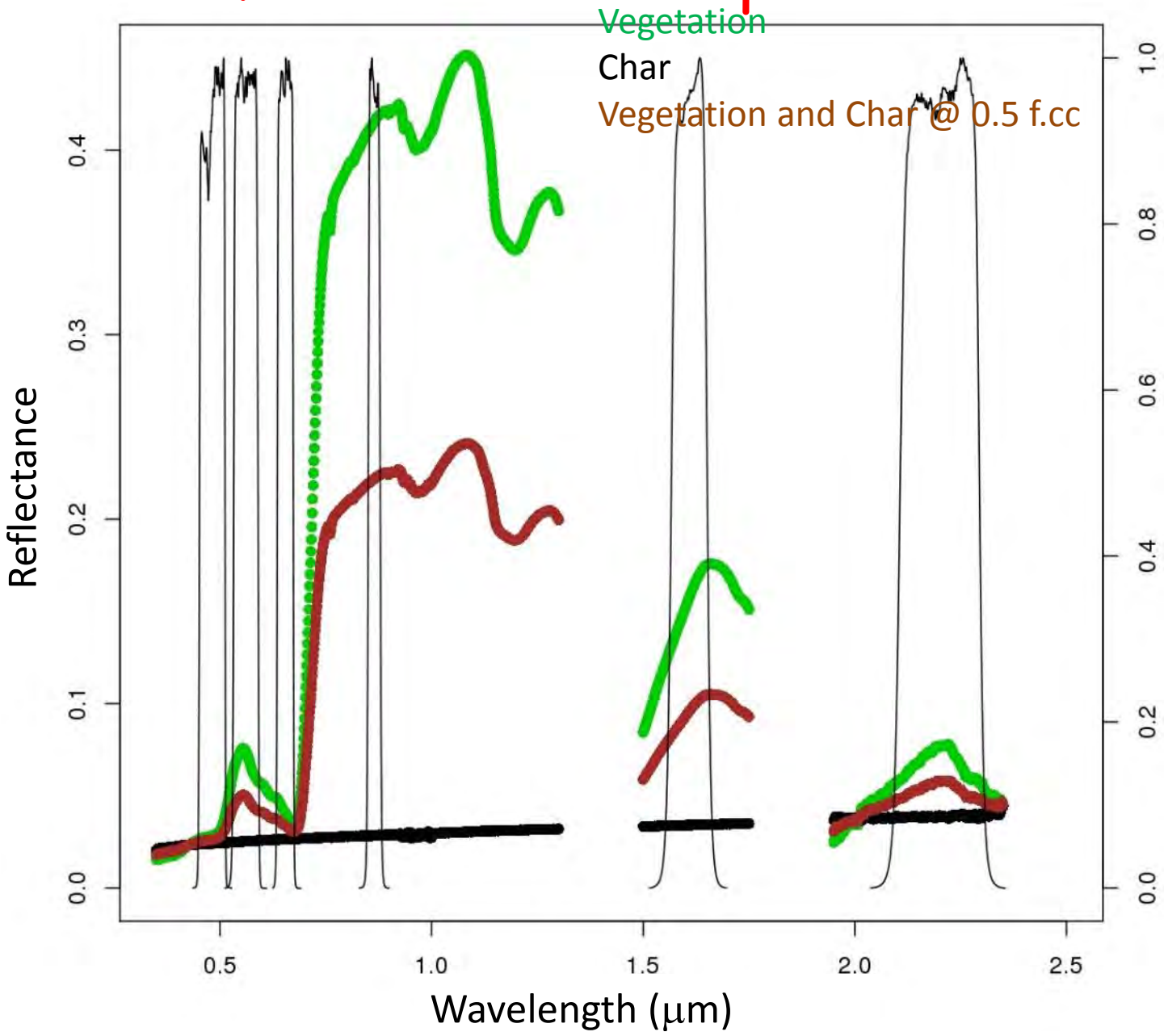
Derive synthetic training data using f × cc model & spectra

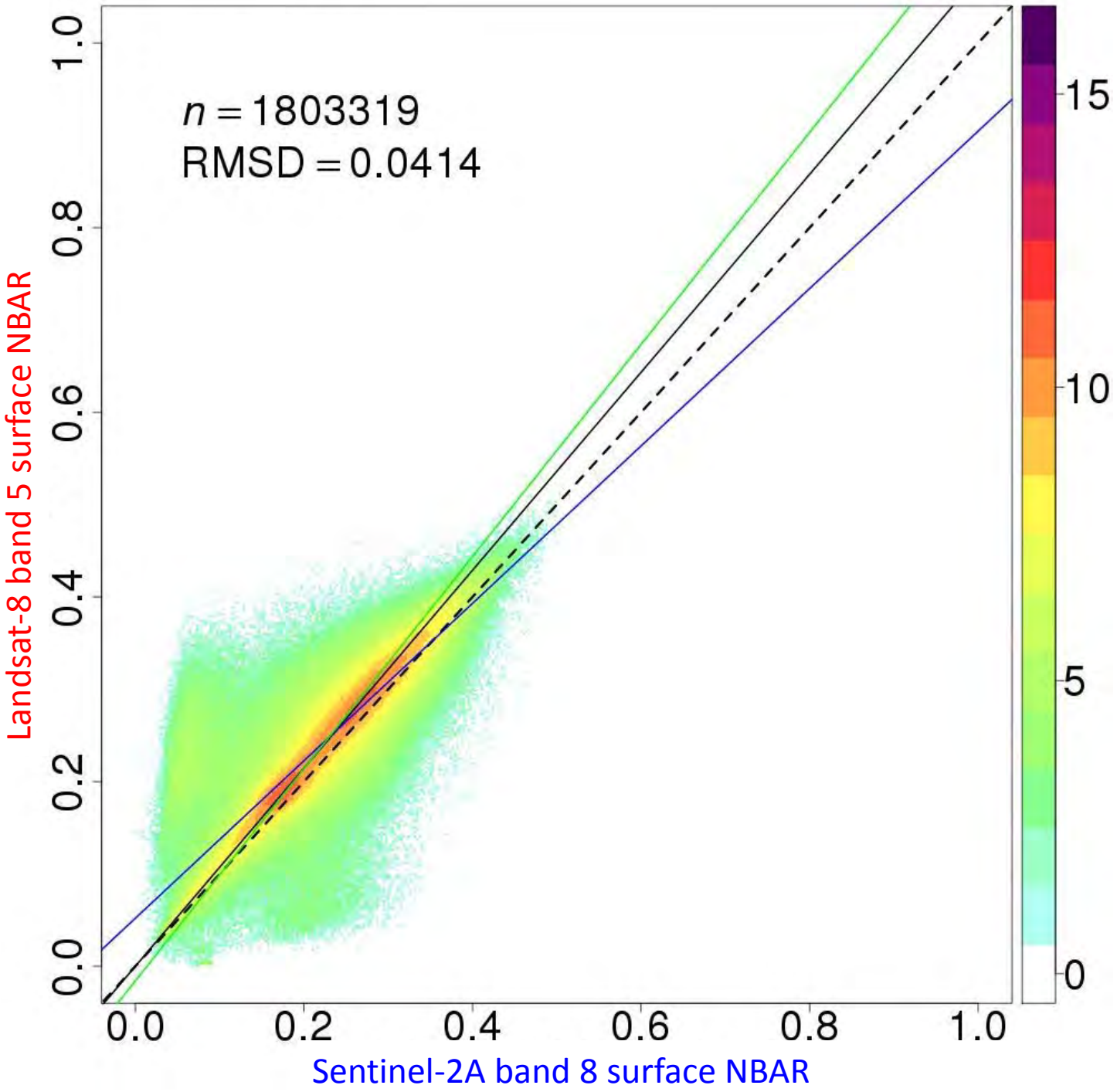


Derive synthetic training data using f × cc model & spectra



Derive synthetic training data using f × cc model & spectra



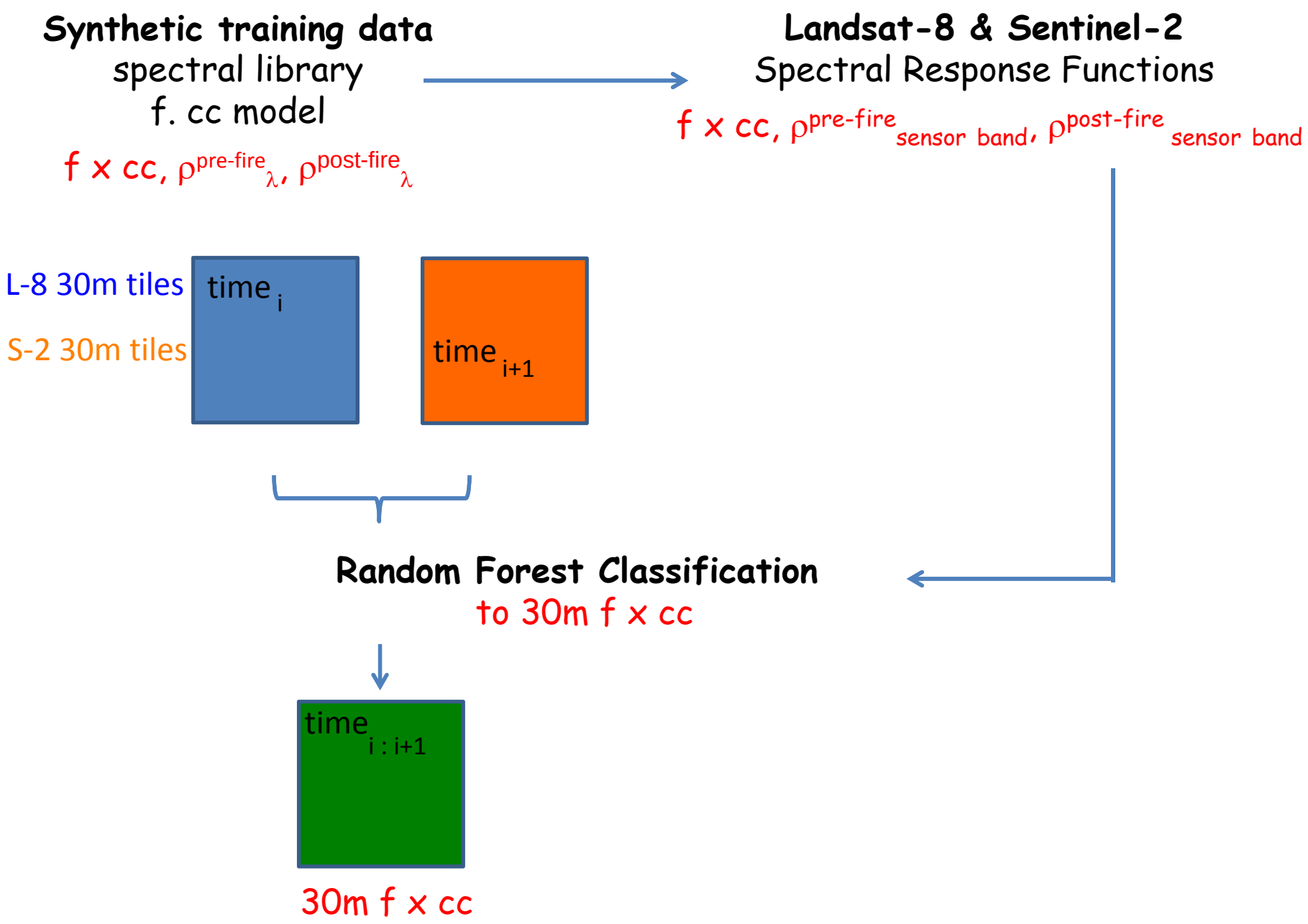


Landsat-8

Sentinel-2A

NIR statistical calibration

Zhang et al., Characterization of Sentinel-2A and Landsat reflective wavelength and normalized difference vegetation index differences, *RSE*, Submitted


Synthetic training data
spectral library
f. cc model
f x cc, ρ pre-fire λ, ρ post-fire λ
Landsat-8 & Sentinel-2
Spectral Response Functions
f x cc, ρ pre-fire sensor band, ρ post-fire sensor band
L-8 30m tiles
S-2 30m tiles
time i
time i+1
Random Forest Classification
to 30m f x cc
time i : i+1
30m f x cc

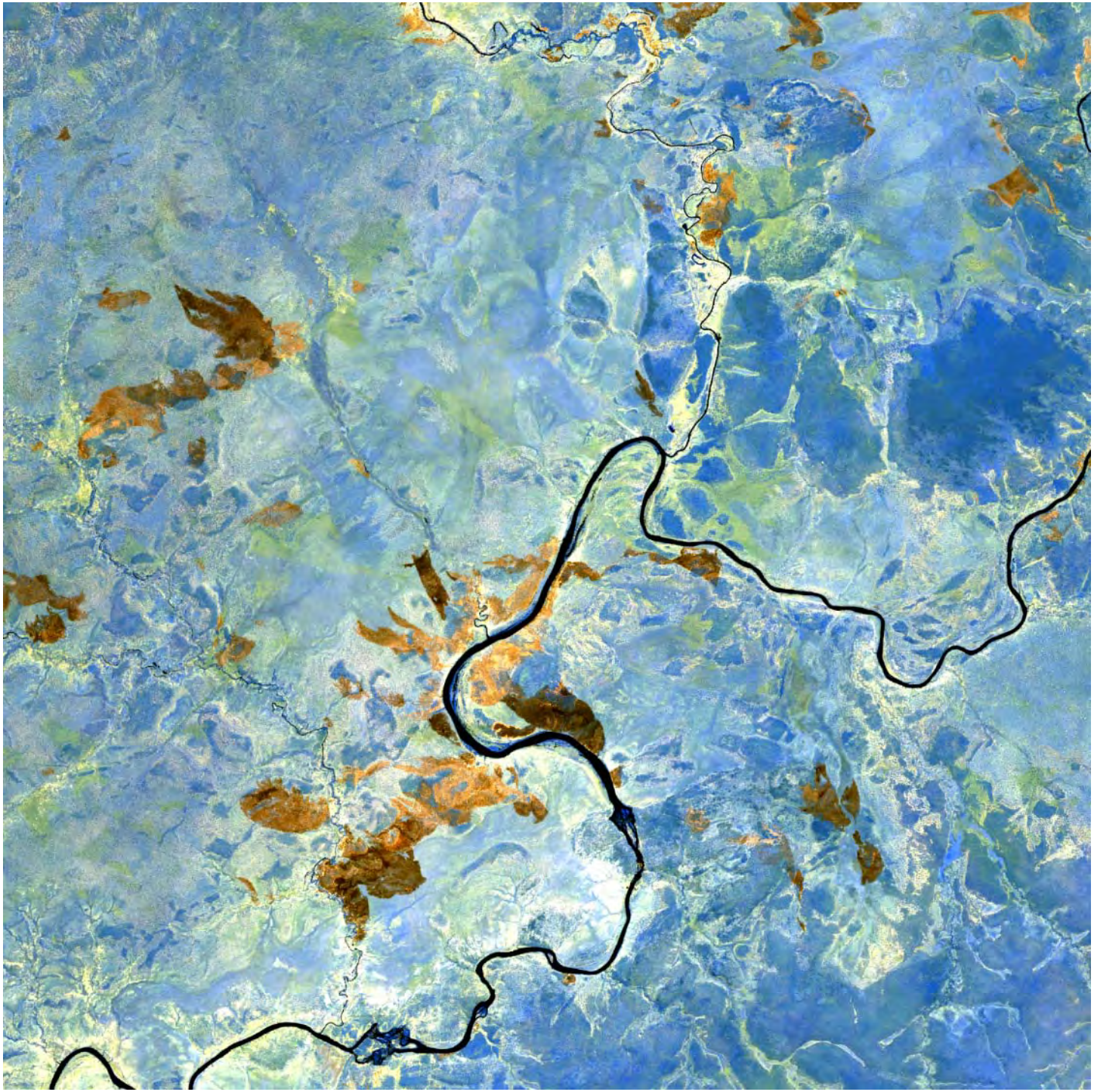
Sentinel-2A

Kafue
National park,
Zambia

Day 154 2016

2000 x 2000 30m
pixels

false color surface
NBAR



Landsat-8

Kafue
National park,
Zambia

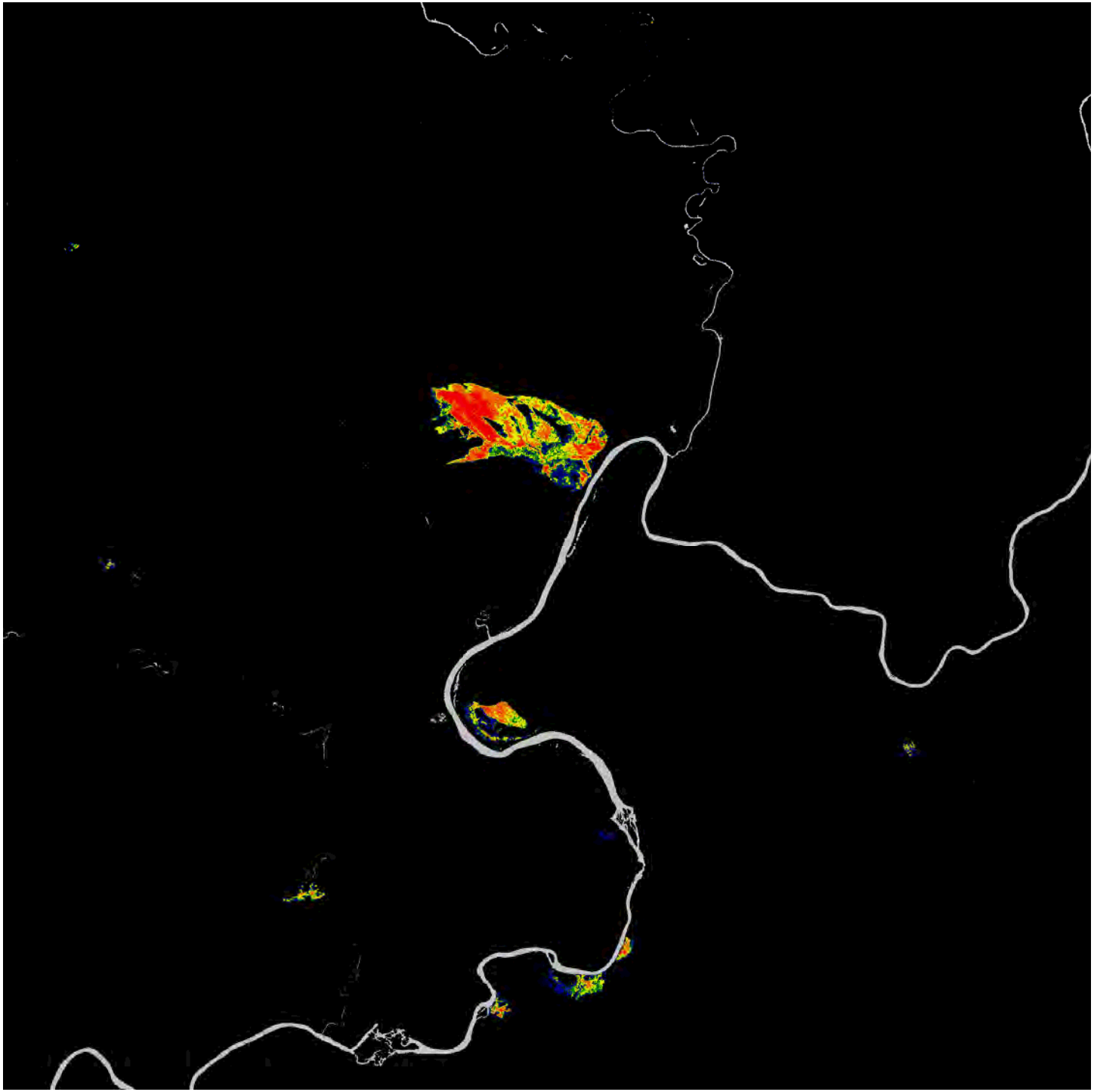
Day 155 2016

2000 x 2000 30m
pixels

false color surface
NBAR

f x cc

day 154 -> 155



2000 x 2000 30m pixels

Landsat-8

Kafue
National park,
Zambia

Day 155 2016

2000 x 2000 30m
pixels

false color surface
NBAR

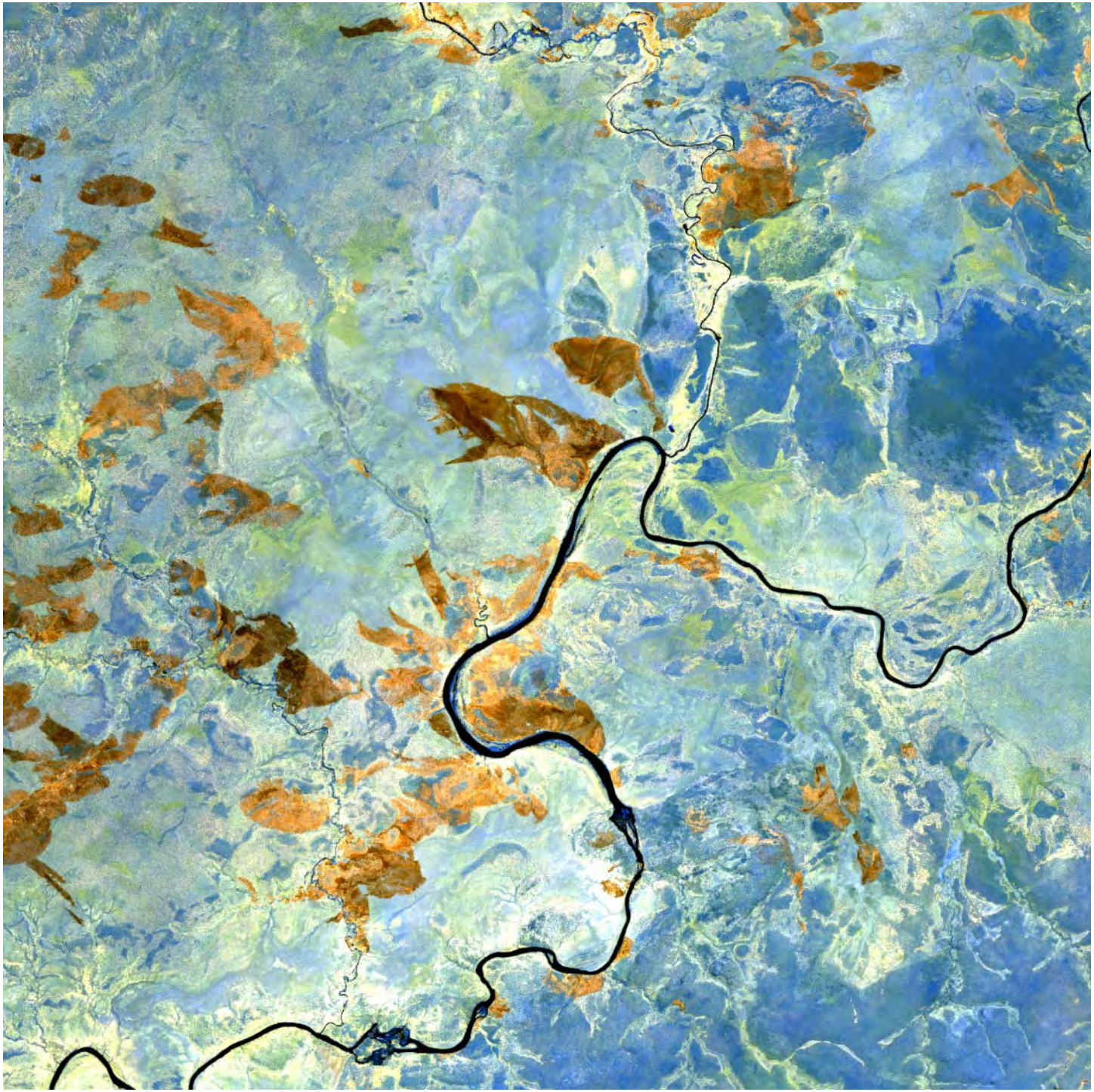
Sentinel-2A

Kafue
National park,
Zambia

Day 164 2016

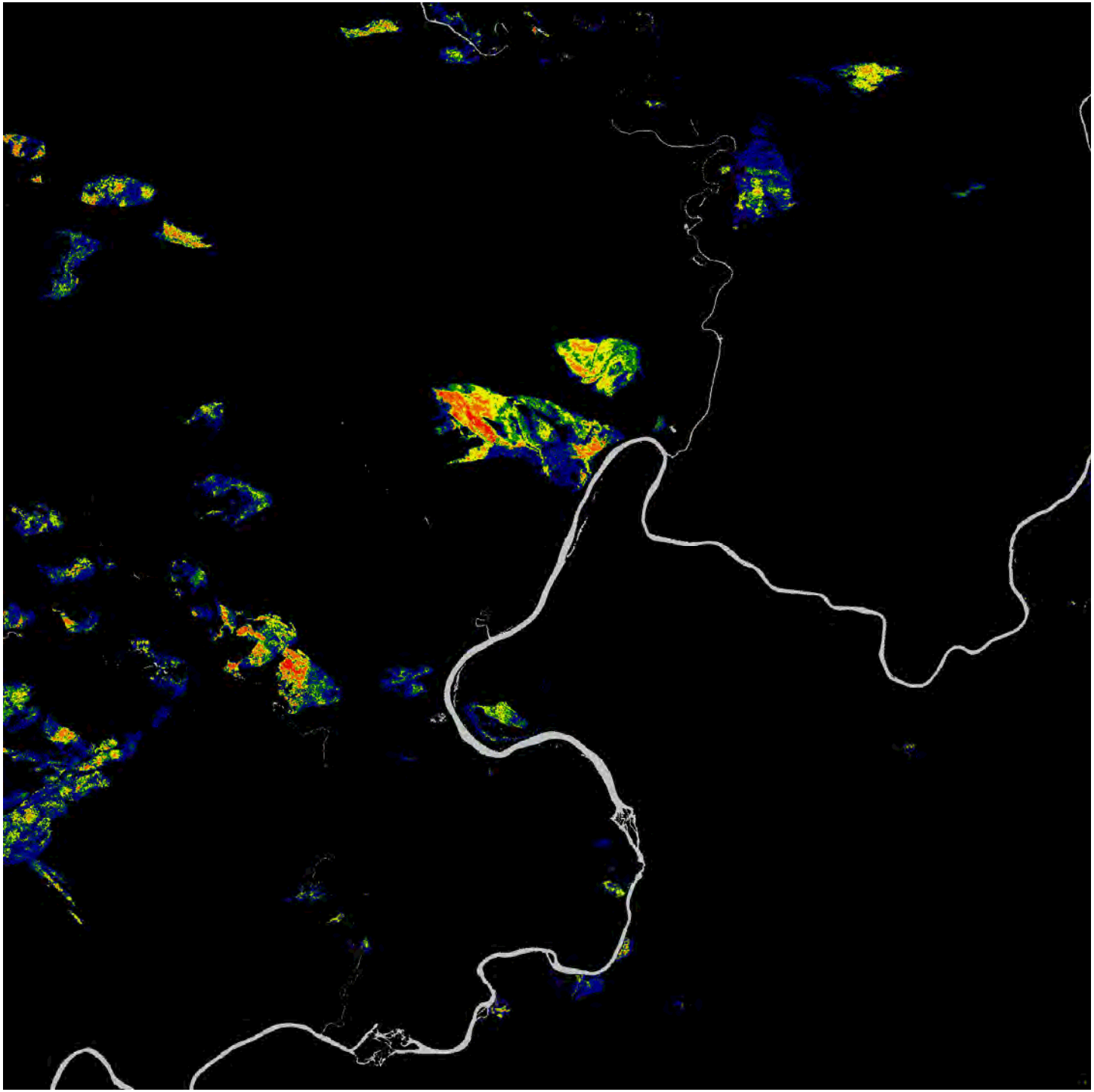
2000 x 2000 30m
pixels

false color surface
NBAR

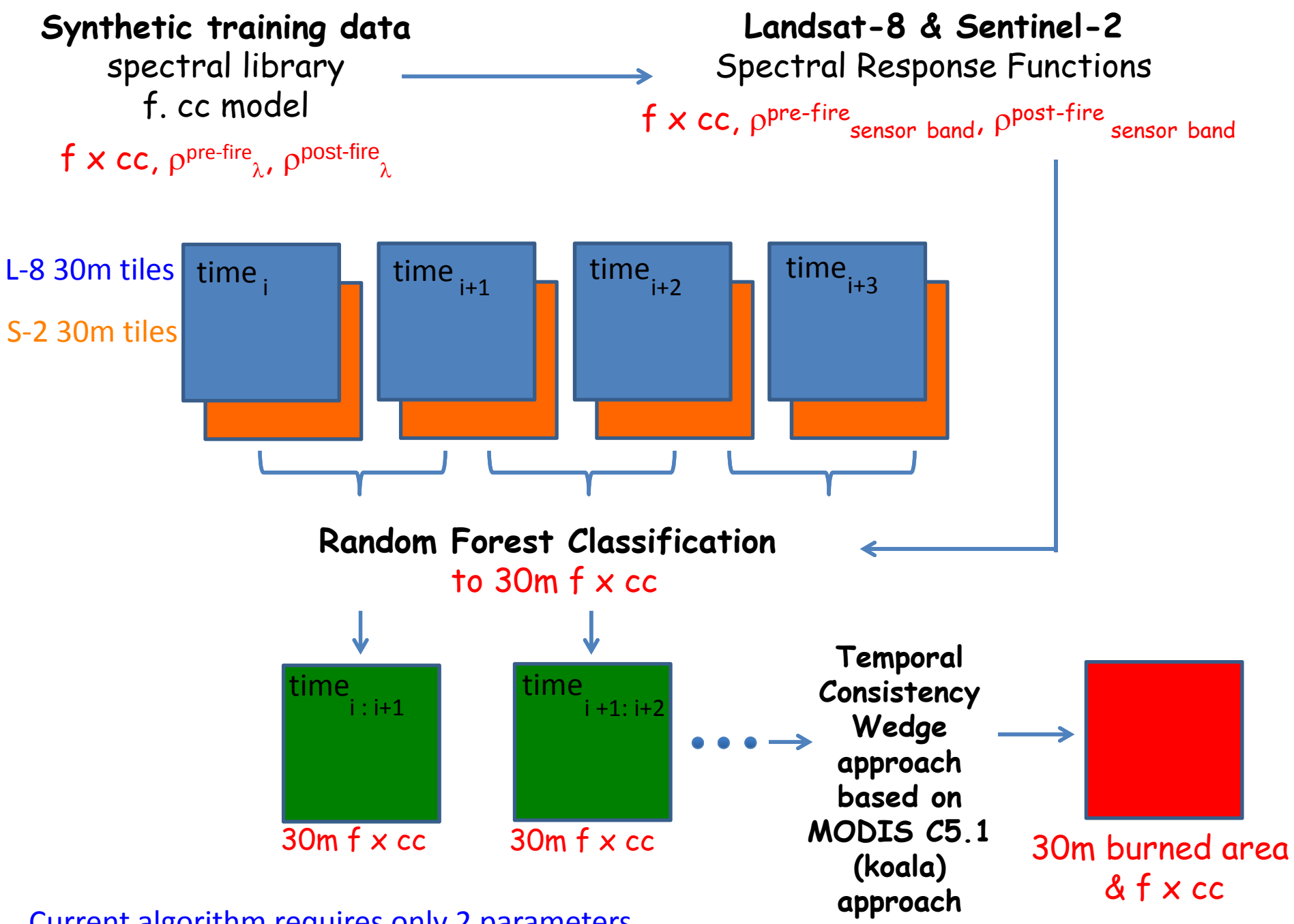


f x cc

day 155 -> 164



2000 x 2000 30m pixels


Synthetic training data
spectral library
f. cc model
f x cc, ρ pre-fire λ, ρ post-fire λ
Landsat-8 & Sentinel-2
Spectral Response Functions
f x cc, ρ pre-fire sensor band, ρ post-fire sensor band
L-8 30m tiles
S-2 30m tiles
time i
time i+1
time i+2
time i+3
Random Forest Classification
to 30m f x cc
time i : i+1
time i +1: i+2
30m f x cc
30m f x cc
Temporal Consistency Wedge approach based on MODIS C5.1 (koala) approach
30m burned area & f x cc
Current algorithm requires only 2 parameters

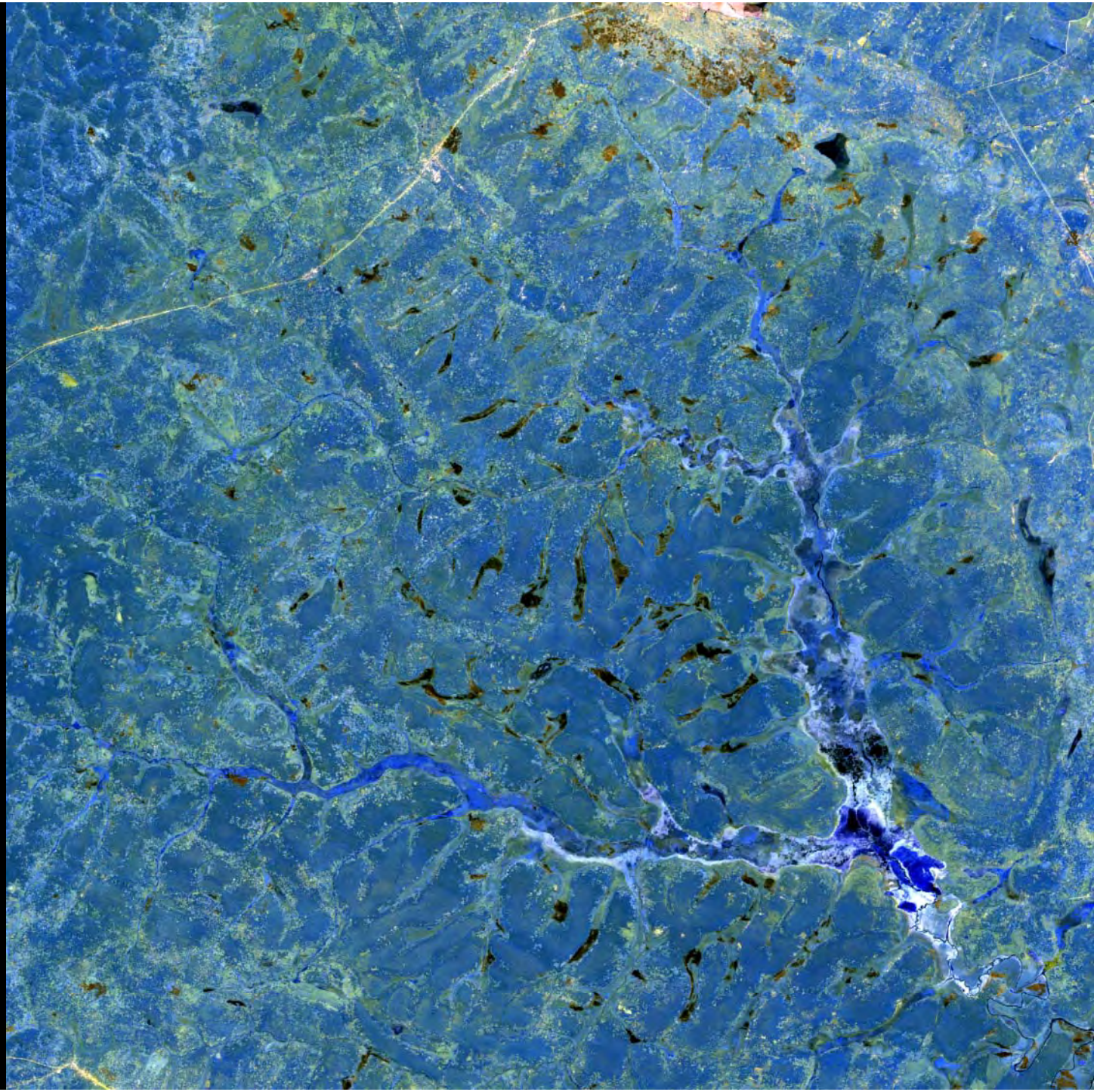
Sentinel-2A

Day 154 2016

2190 nm
1610 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



Landsat 8

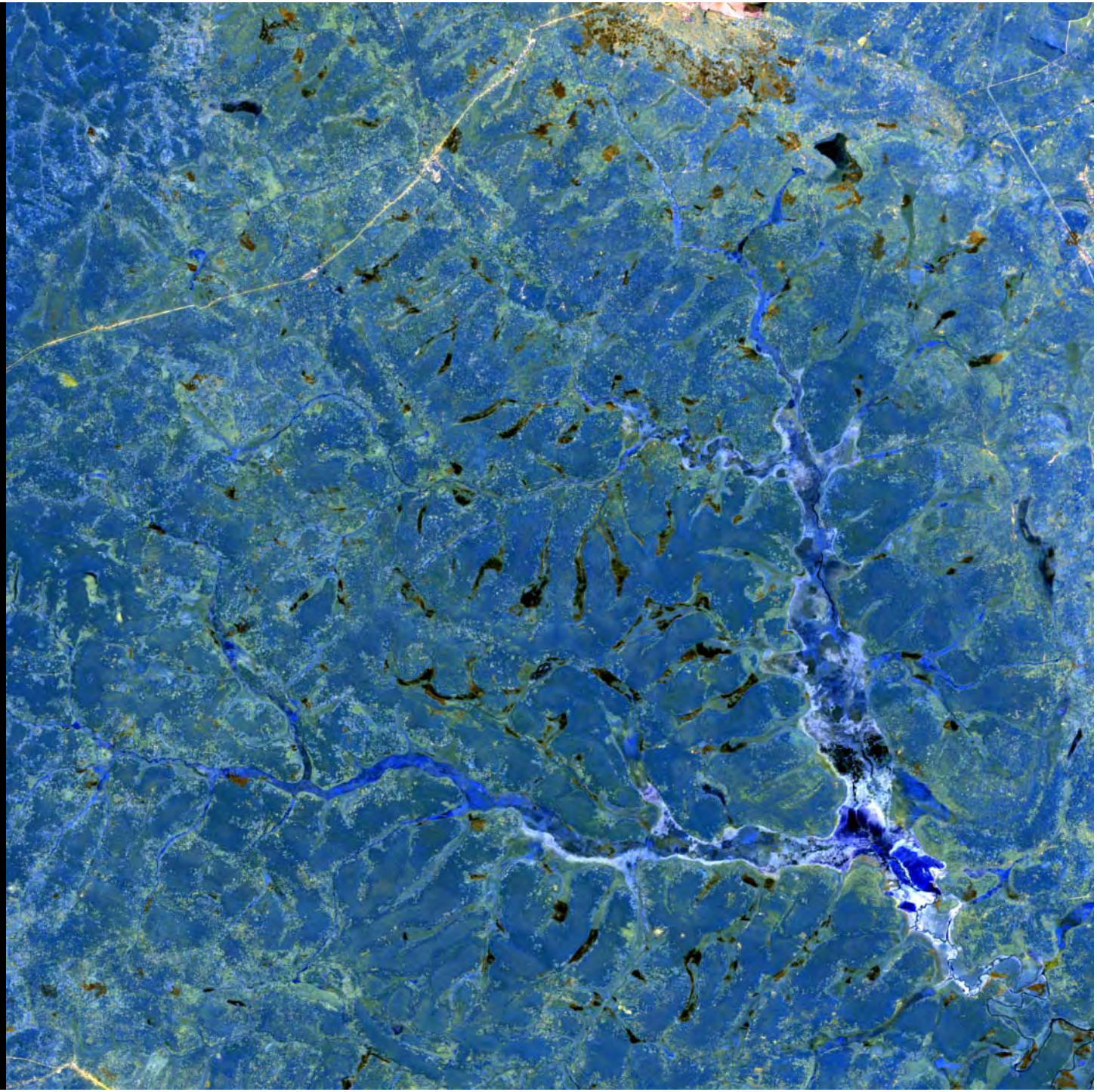
collection 1

Day 155 2016

2200 nm
1600 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



Sentinel-2A

Day 164 2016

2190 nm
1610 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence

Landsat 8

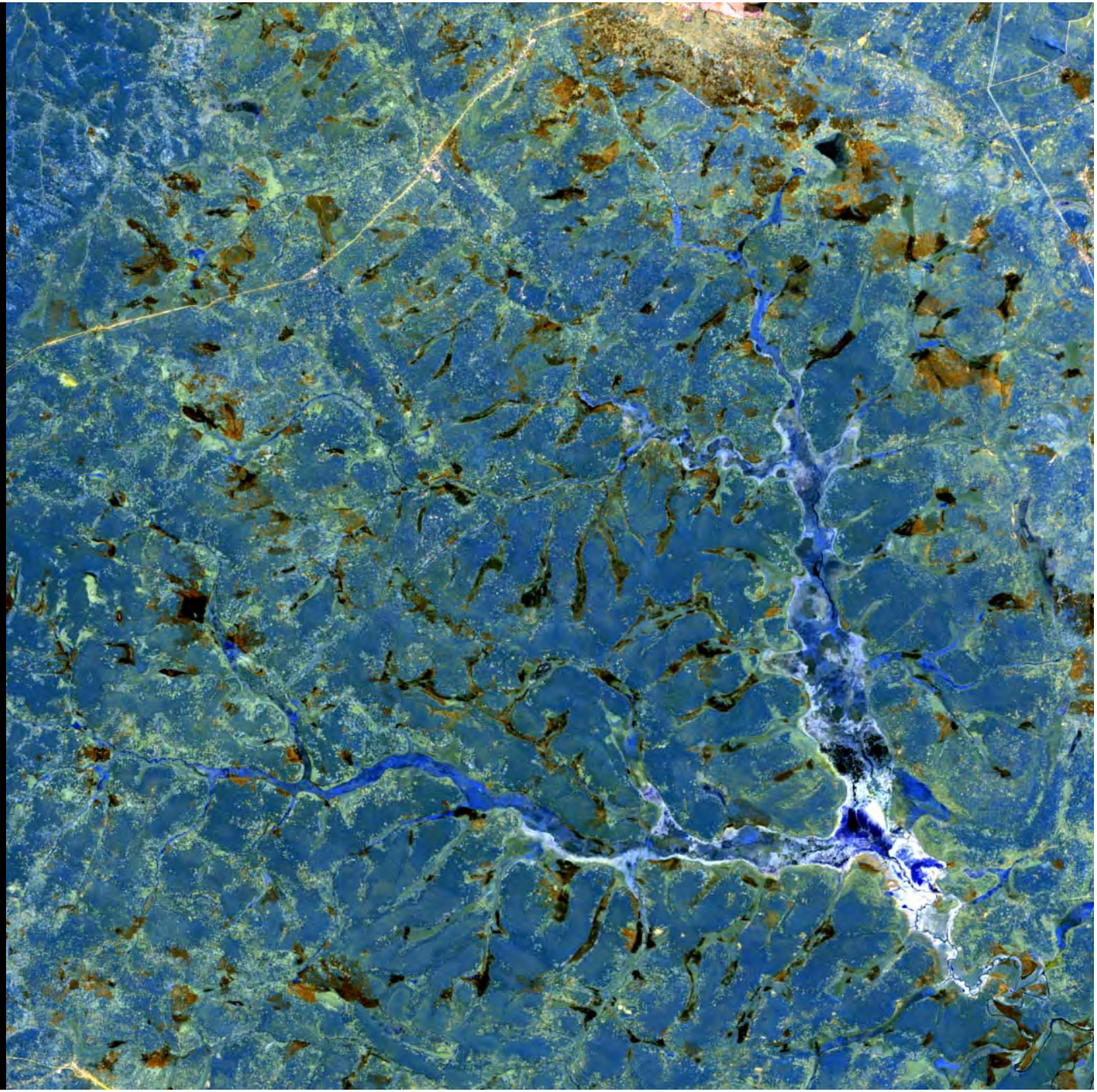
collection 1

Day 171 2016

2200 nm
1600 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



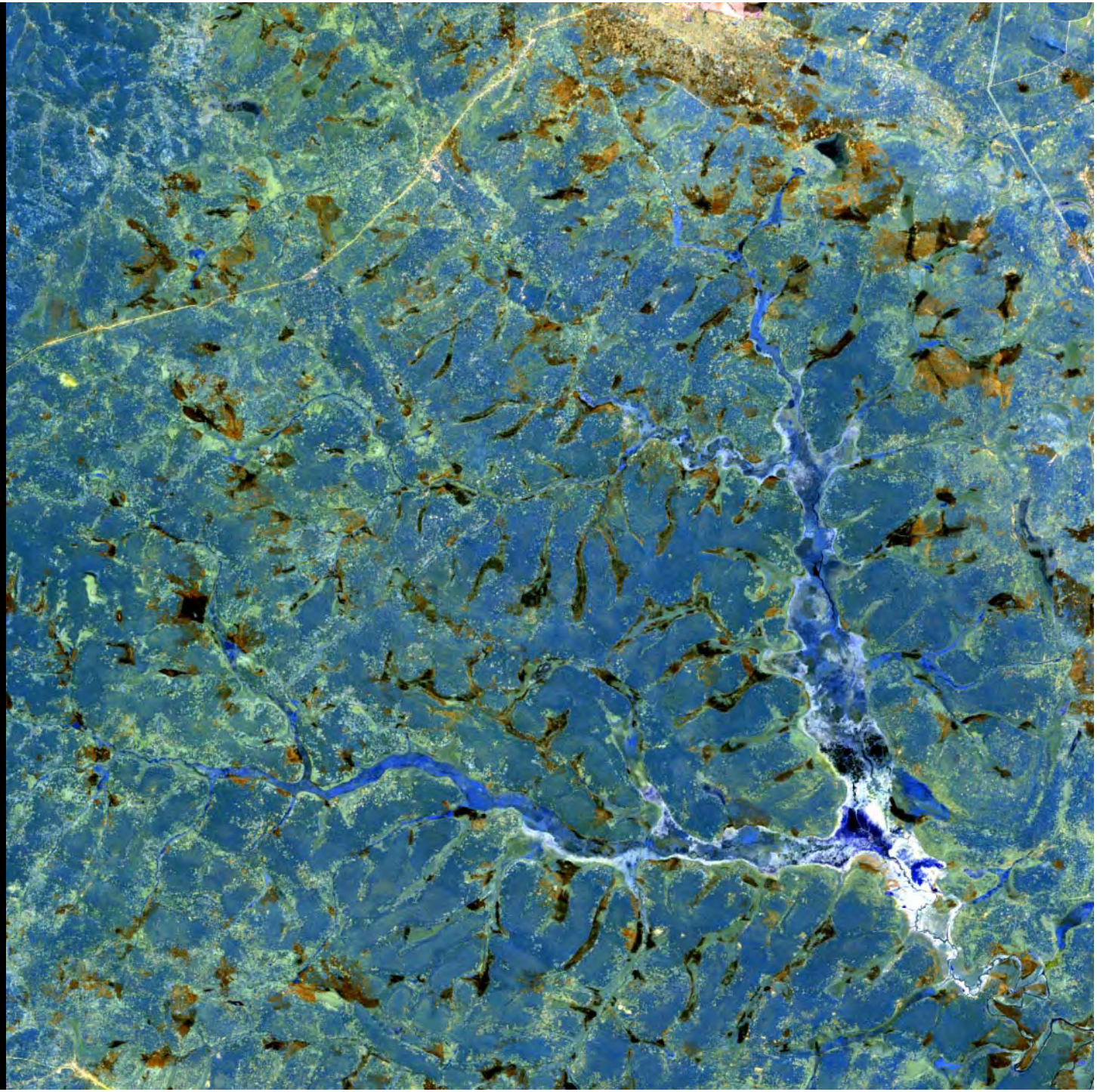
Sentinel-2A

Day 174 2016

2190 nm
1610 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



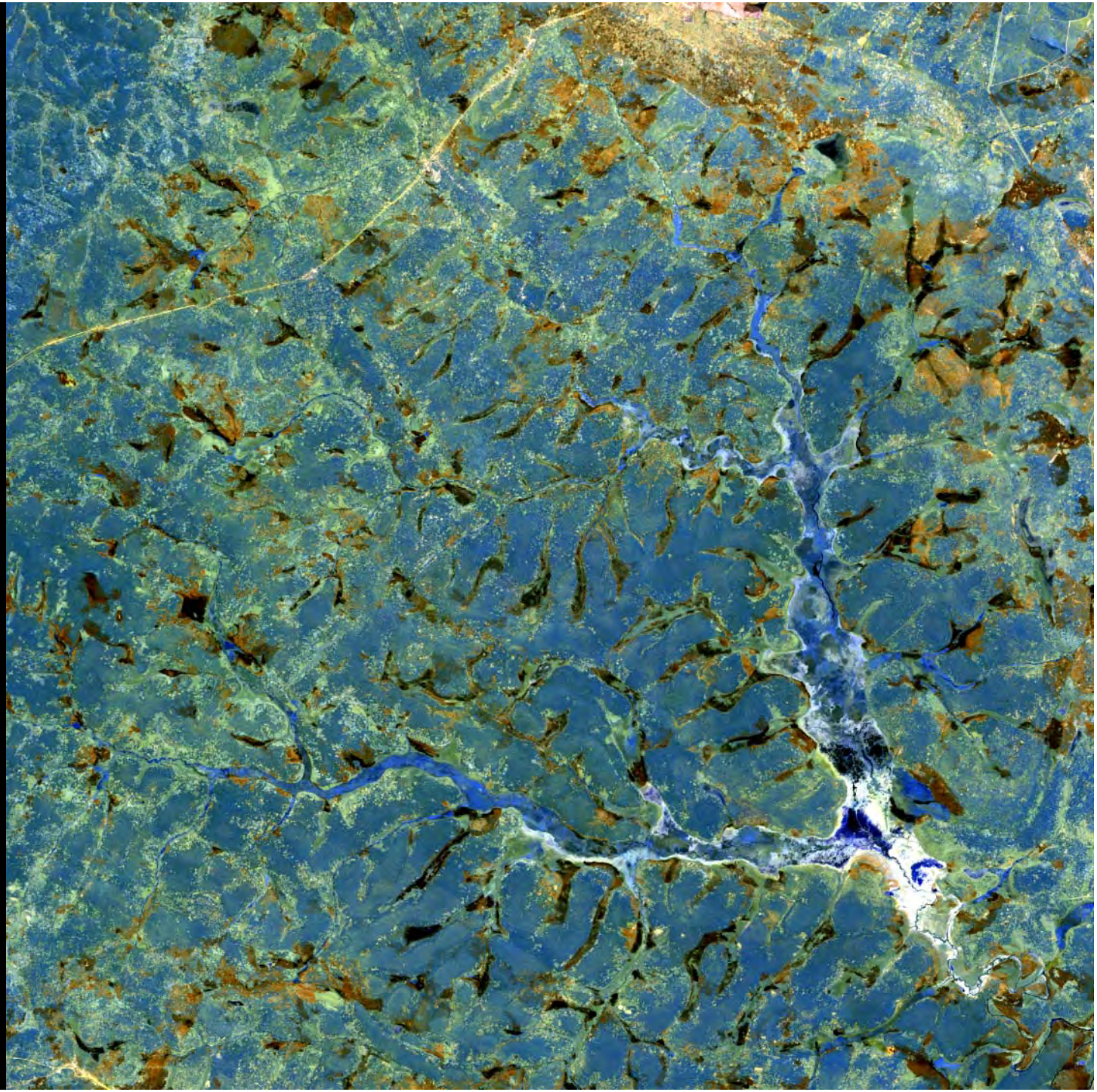
Sentinel-2A

Day 184 2016

2190 nm
1610 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



Landsat 8

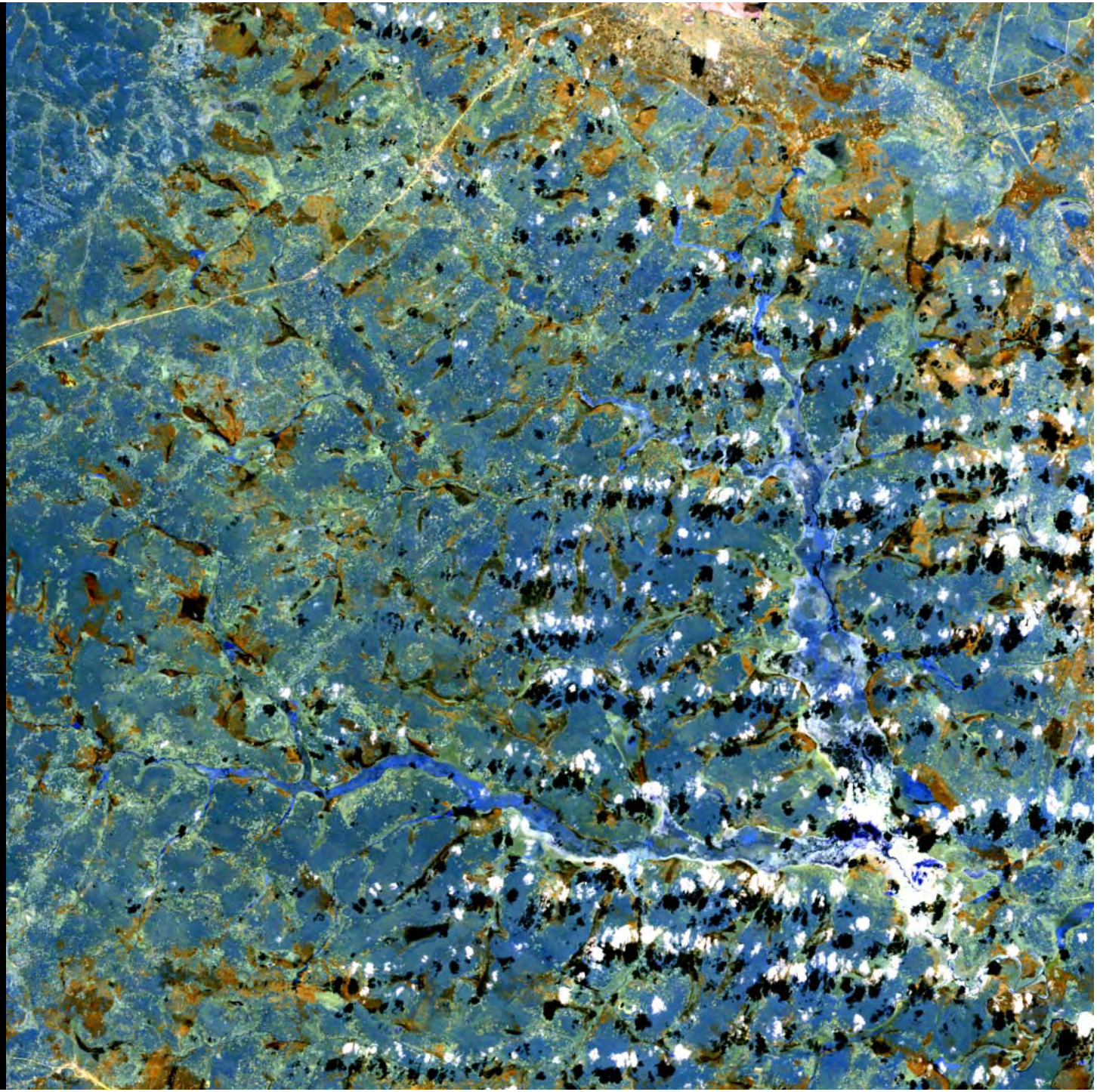
collection 1

Day 187 2016

2200 nm
1600 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



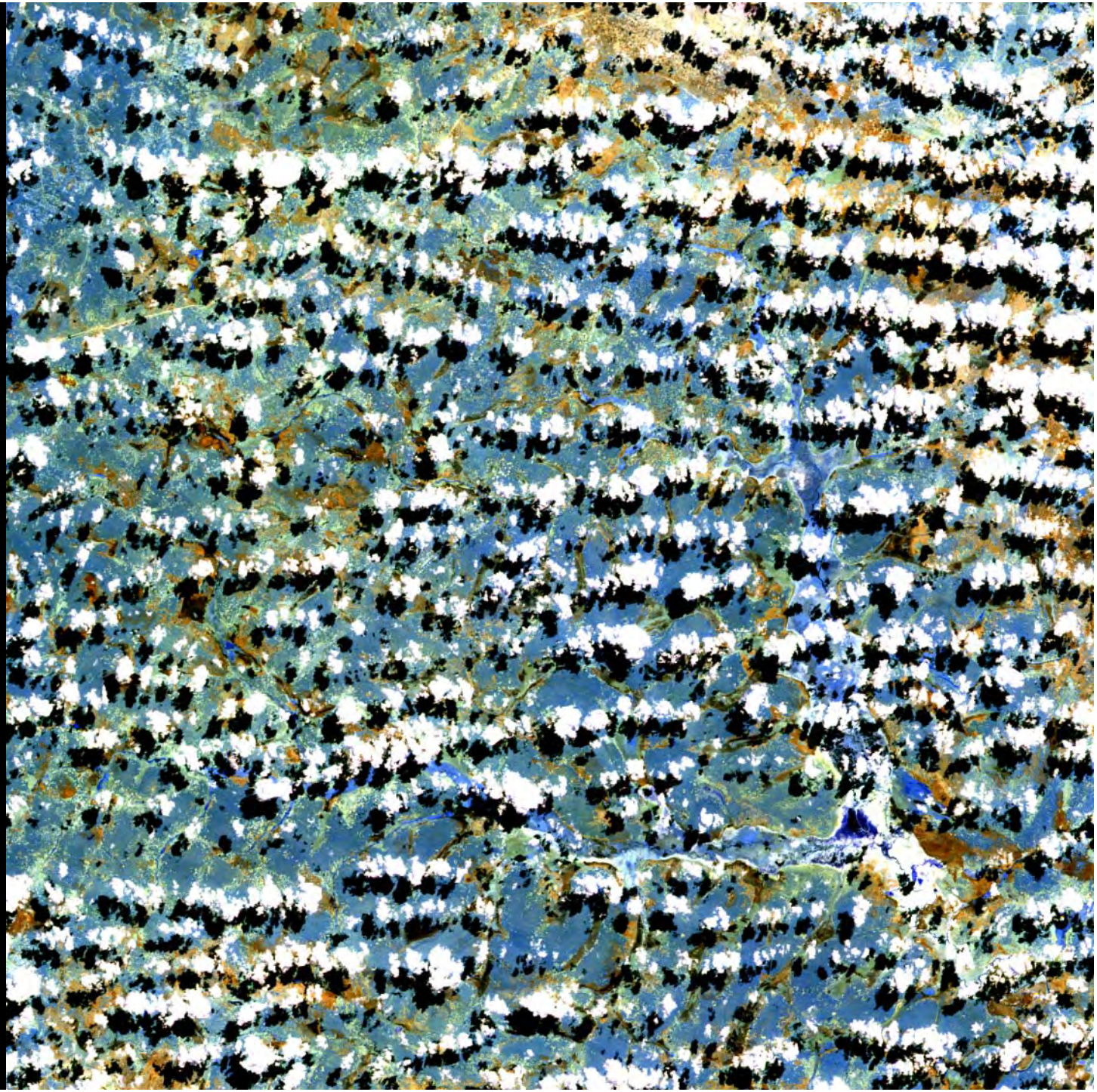
Sentinel-2A

Day 194 2016

2190 nm
1610 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



Landsat 8

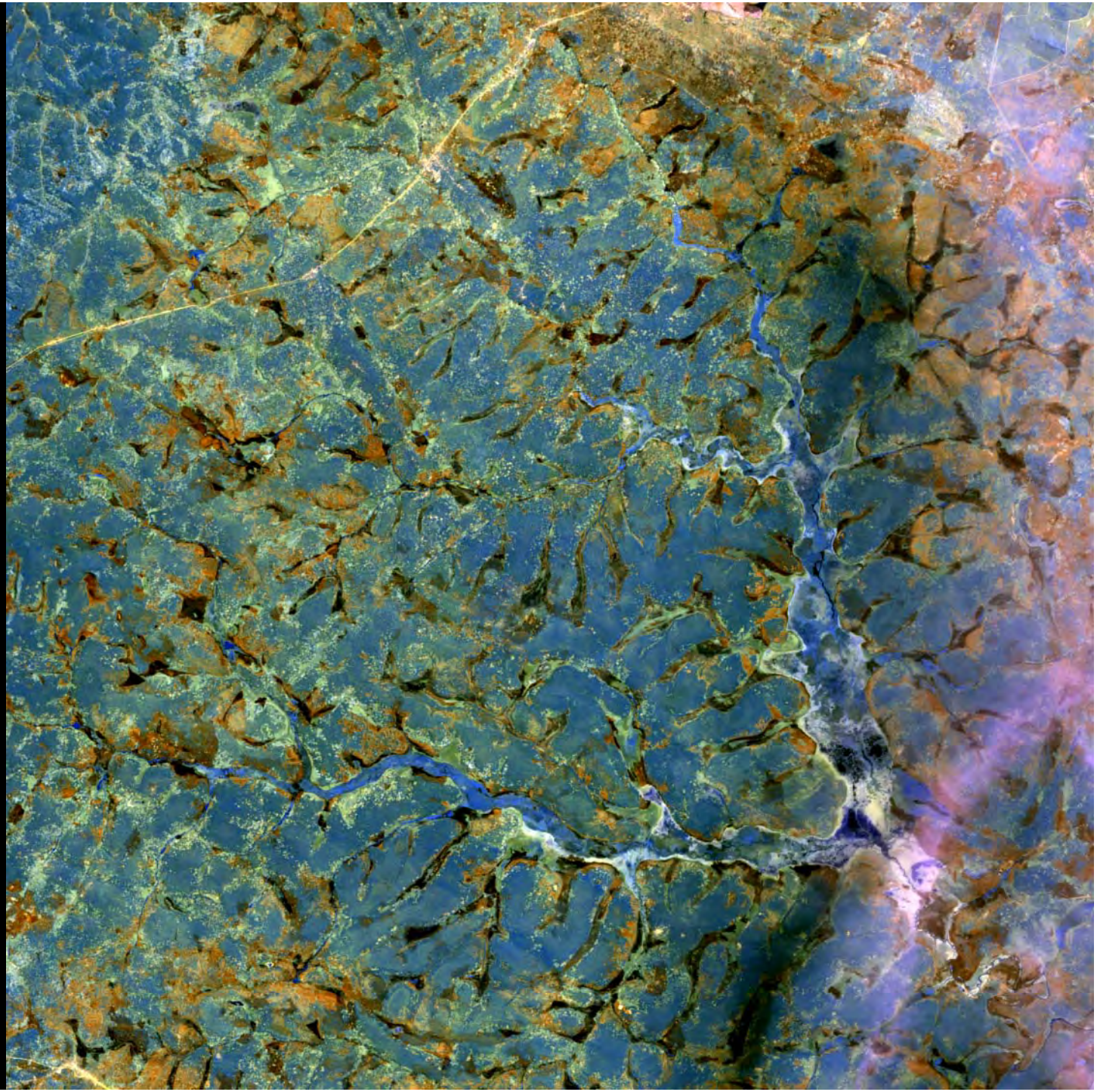
collection 1

Day 203 2016

2200 nm
1600 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



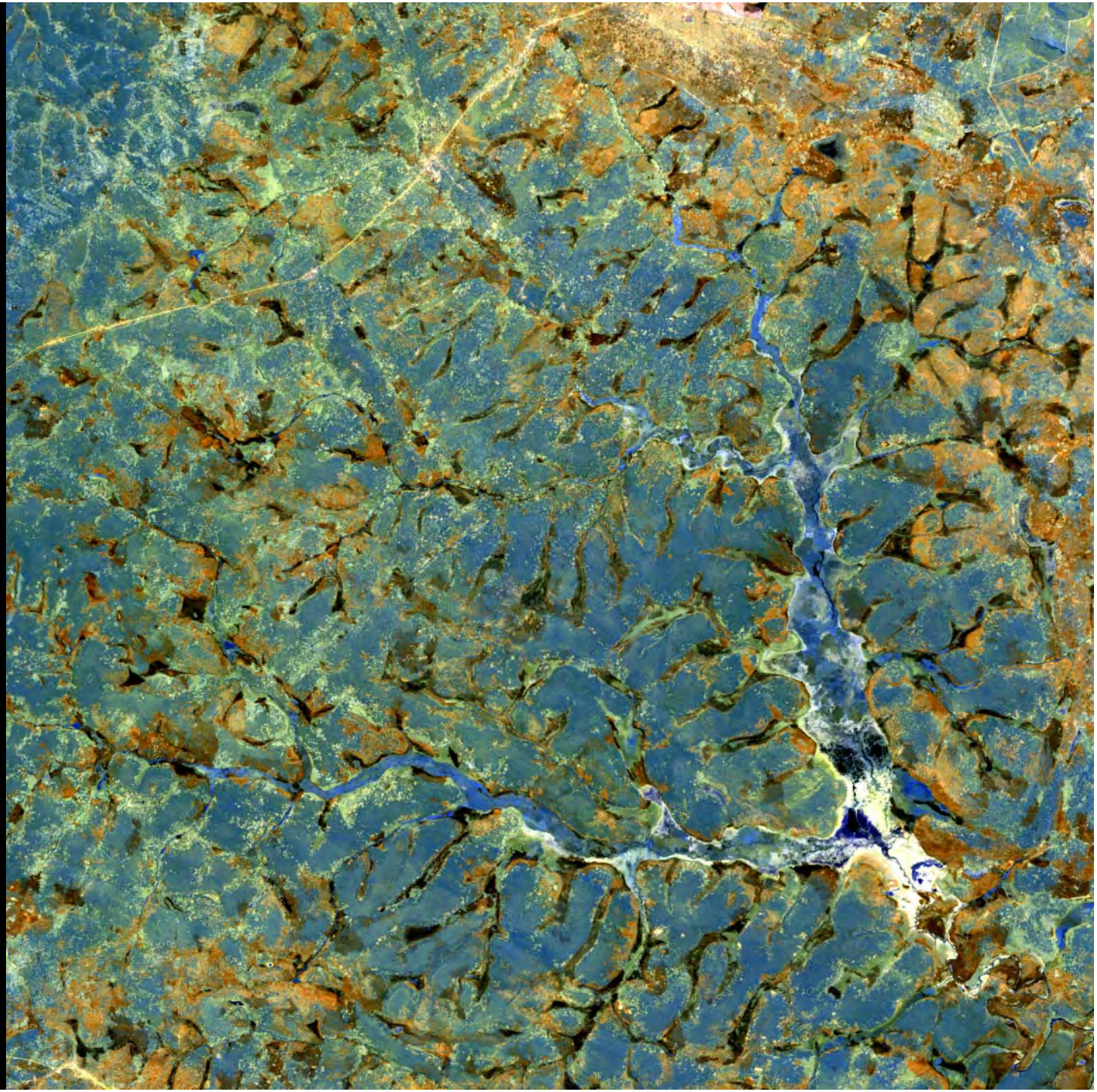
Sentinel-2A

Day 204 2016

2190 nm
1610 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



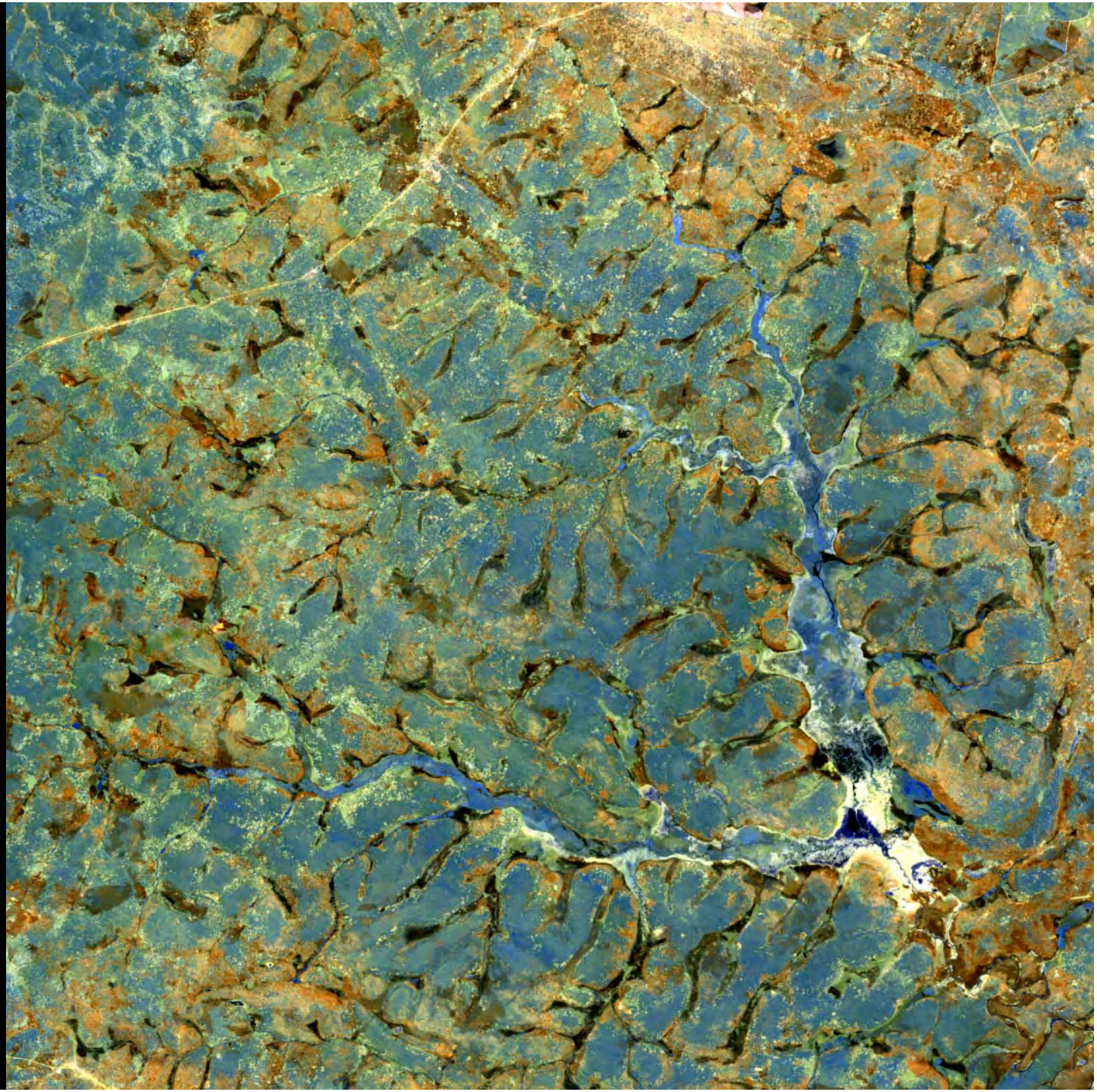
Sentinel-2A

Day 214 2016

2190 nm
1610 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



Landsat 8

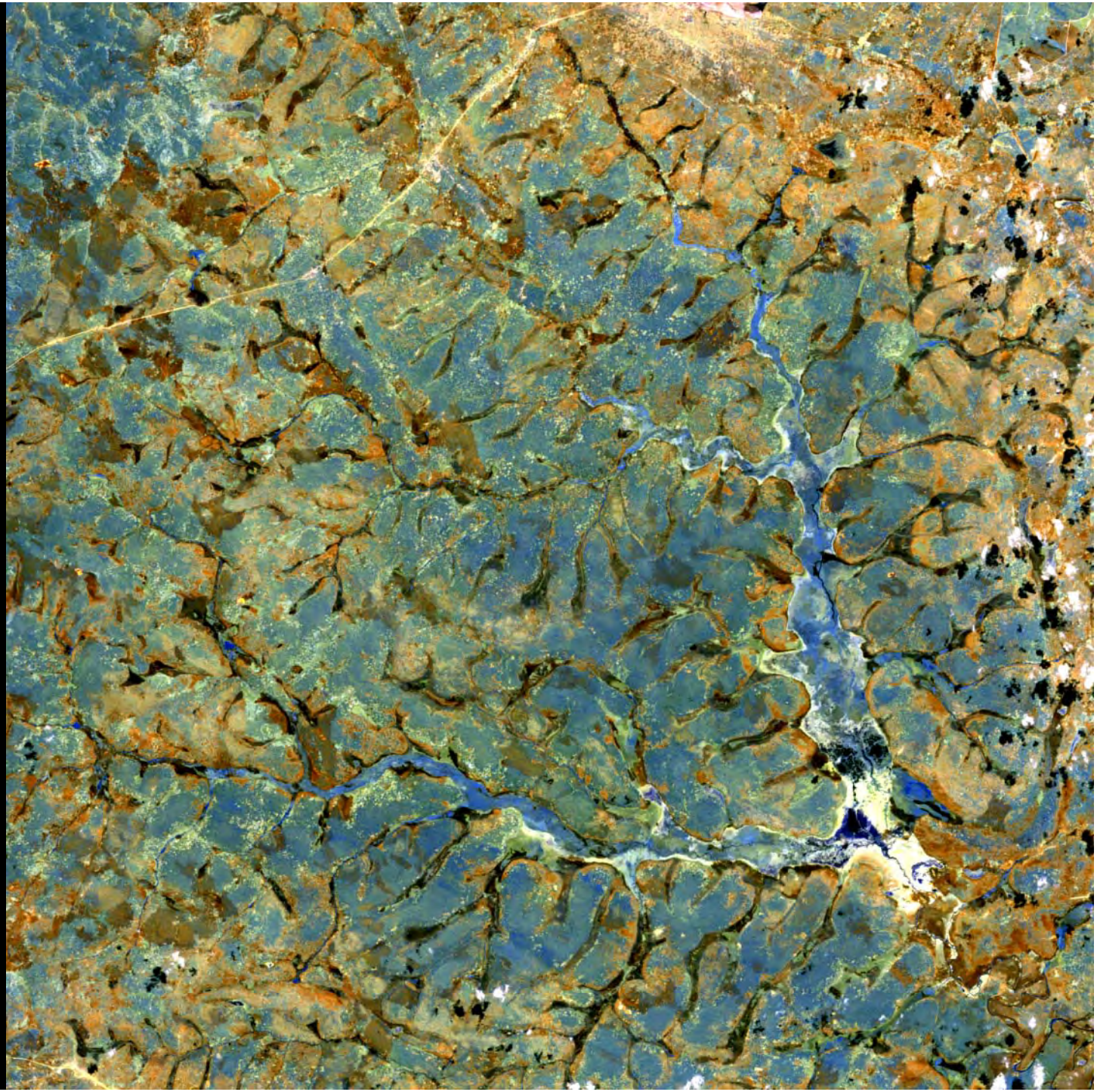
collection 1

Day 219 2016

2200 nm
1600 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



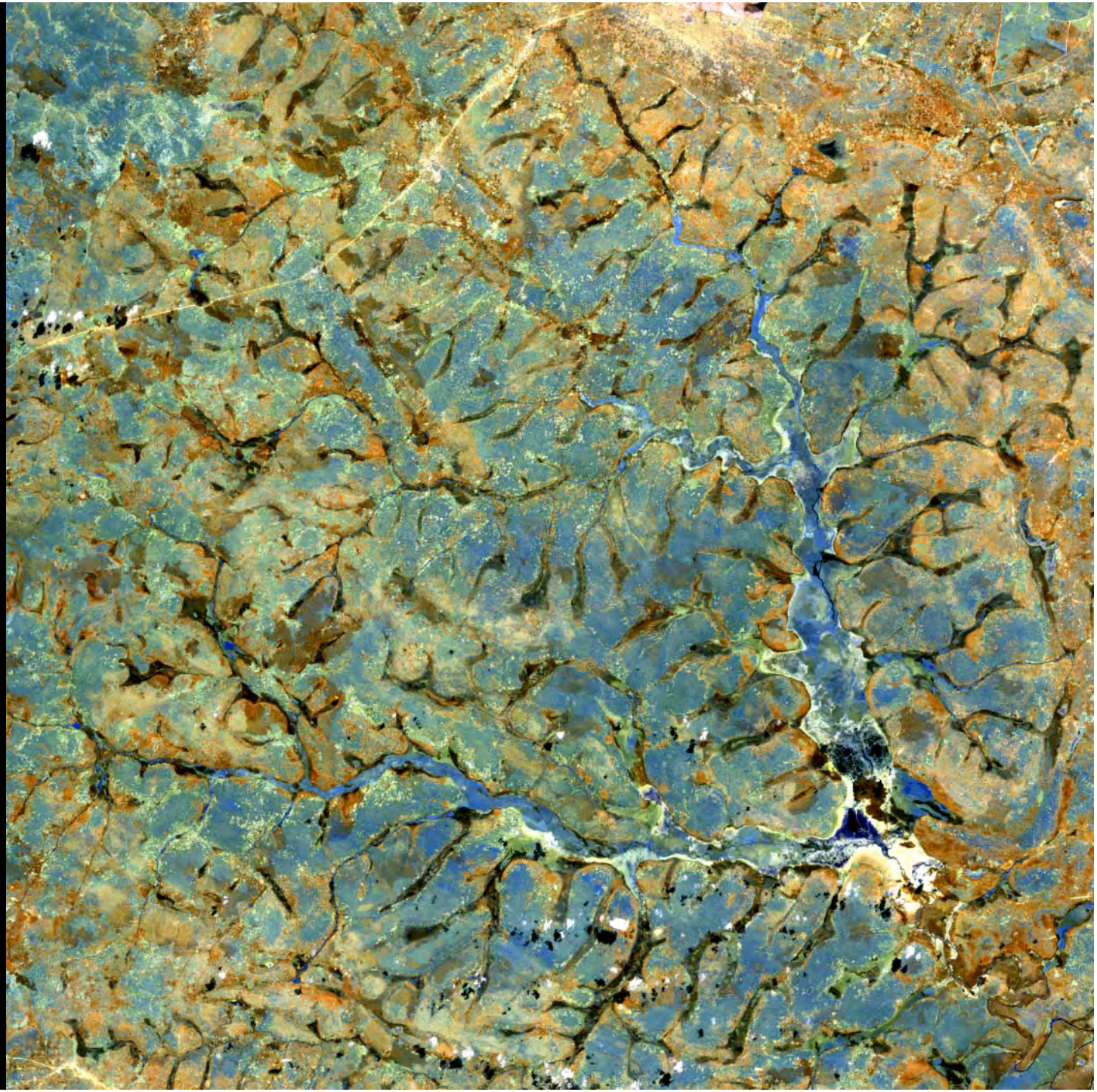
Sentinel-2A

Day 224 2016

2190 nm
1610 nm
865 nm

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



Landsat 8

Sentinel-2A

wedge method

Burned area & f.cc

days 154-224

(13 images)

f.cc < 0.2

0.2 ≤ f.cc < 0.4

0.4 ≤ f.cc < 0.6

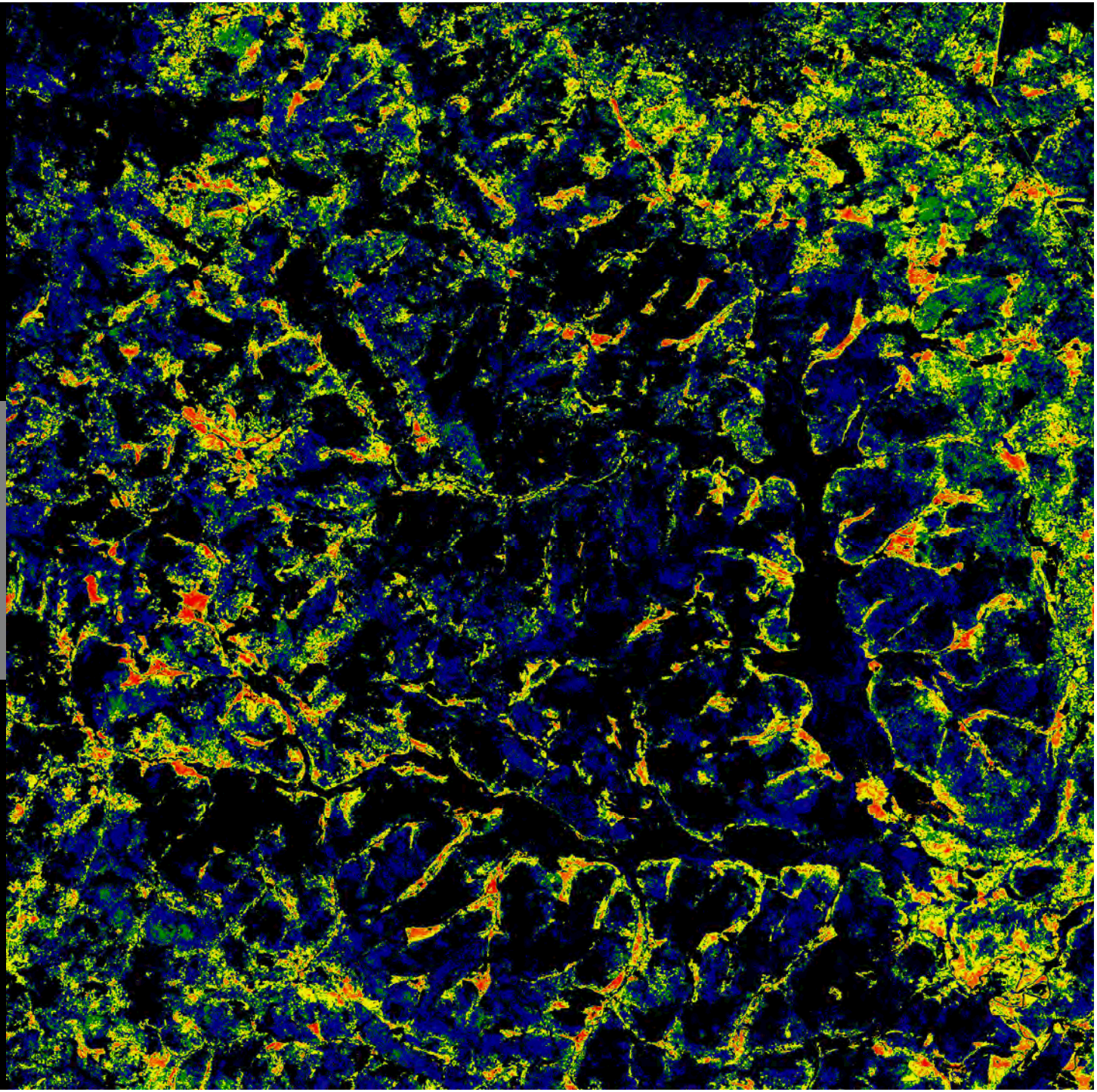
0.6 ≤ f.cc < 0.8

0.8 ≤ f.cc < 0.9

0.9 ≤ f.cc < 1.0

2000 x 2000
30m pixels

Zambia,
Copperbelt
Provence



Landsat 8

Sentinel-2A

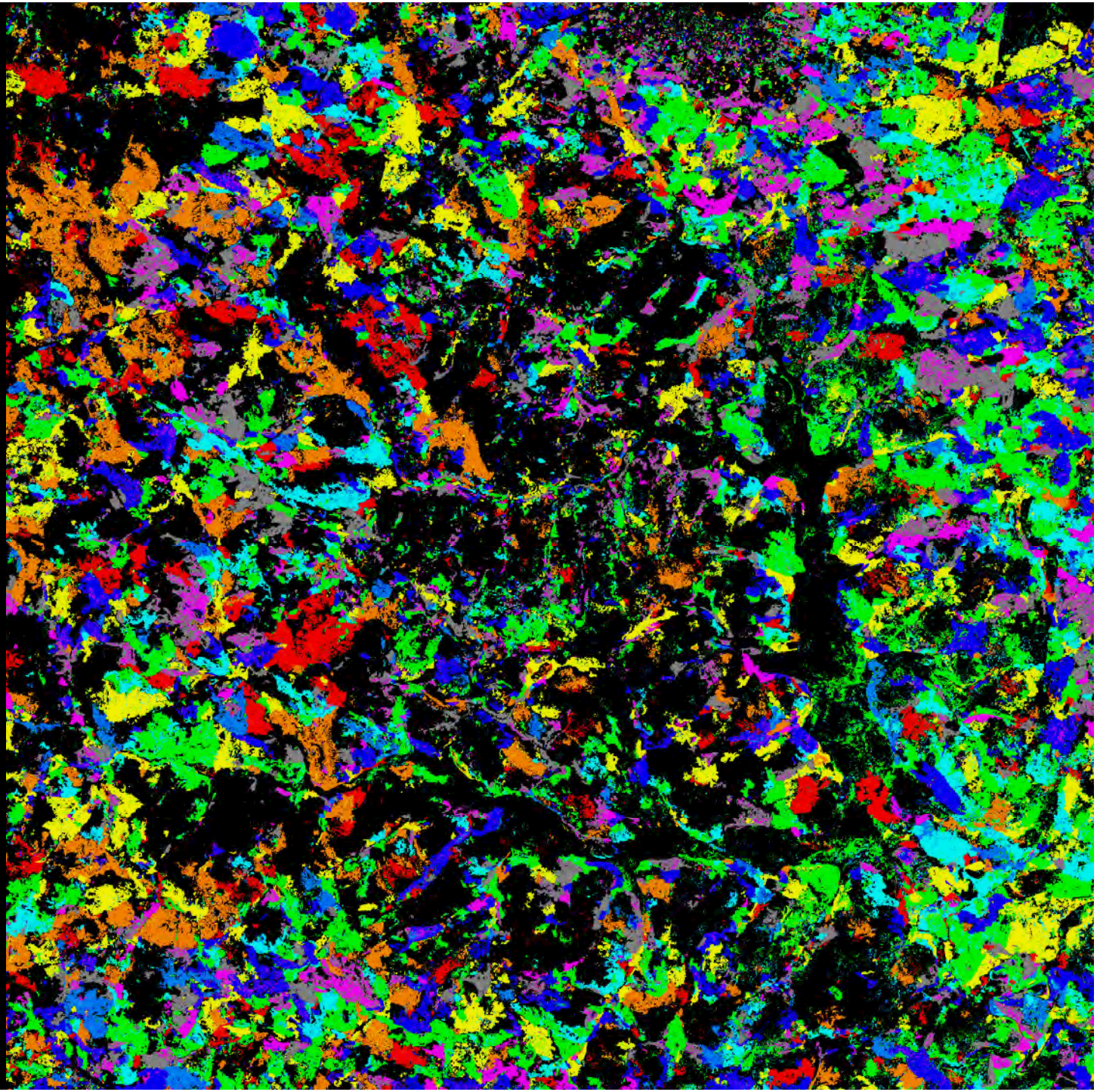
wedge method

Day of burning

(minus 154)

1≤days ≤5
6≤days ≤10
11≤days ≤15
16≤days ≤20
21≤days ≤25
26≤days ≤30
31≤days ≤35
36≤days ≤40
41≤days ≤45
46≤days ≤50
51≤days ≤55
56≤days ≤60
61≤days ≤65
66≤days ≤70

Zambia,
Copperbelt
Provence



MODIS 1km

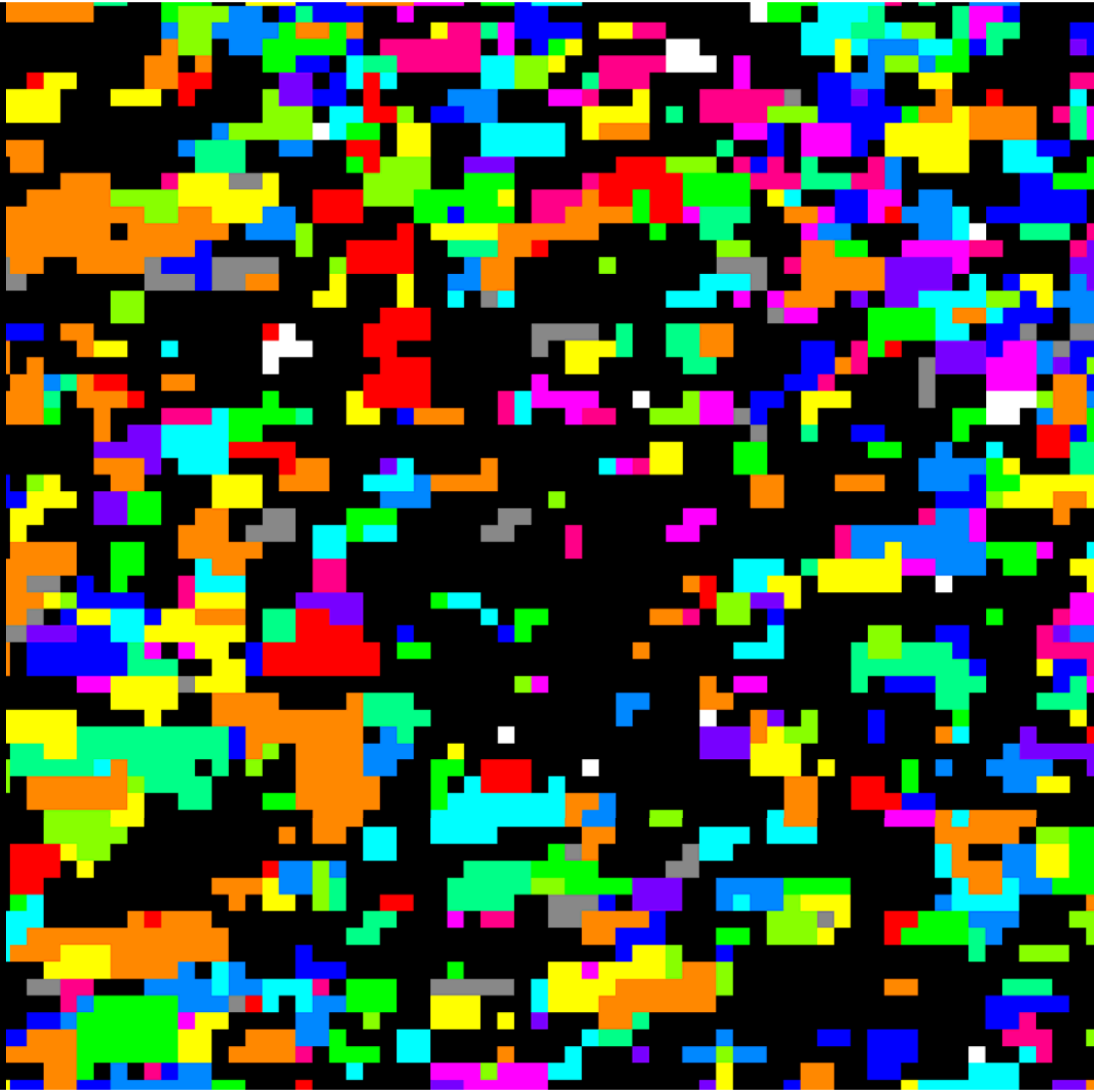
active fire detections

Day of detection

(minus 154)

1≤days ≤5
6≤days ≤10
11≤days ≤15
16≤days ≤20
21≤days ≤25
26≤days ≤30
31≤days ≤35
36≤days ≤40
41≤days ≤45
46≤days ≤50
51≤days ≤55
56≤days ≤60
61≤days ≤65
66≤days ≤70

Zambia,
Copperbelt
Provence



Landsat 8

Sentinel-2A

wedge method

Burned area & f.cc

days 154-224

(13 images)

f.cc < 0.2

0.2 ≤ f.cc < 0.4

0.4 ≤ f.cc < 0.6

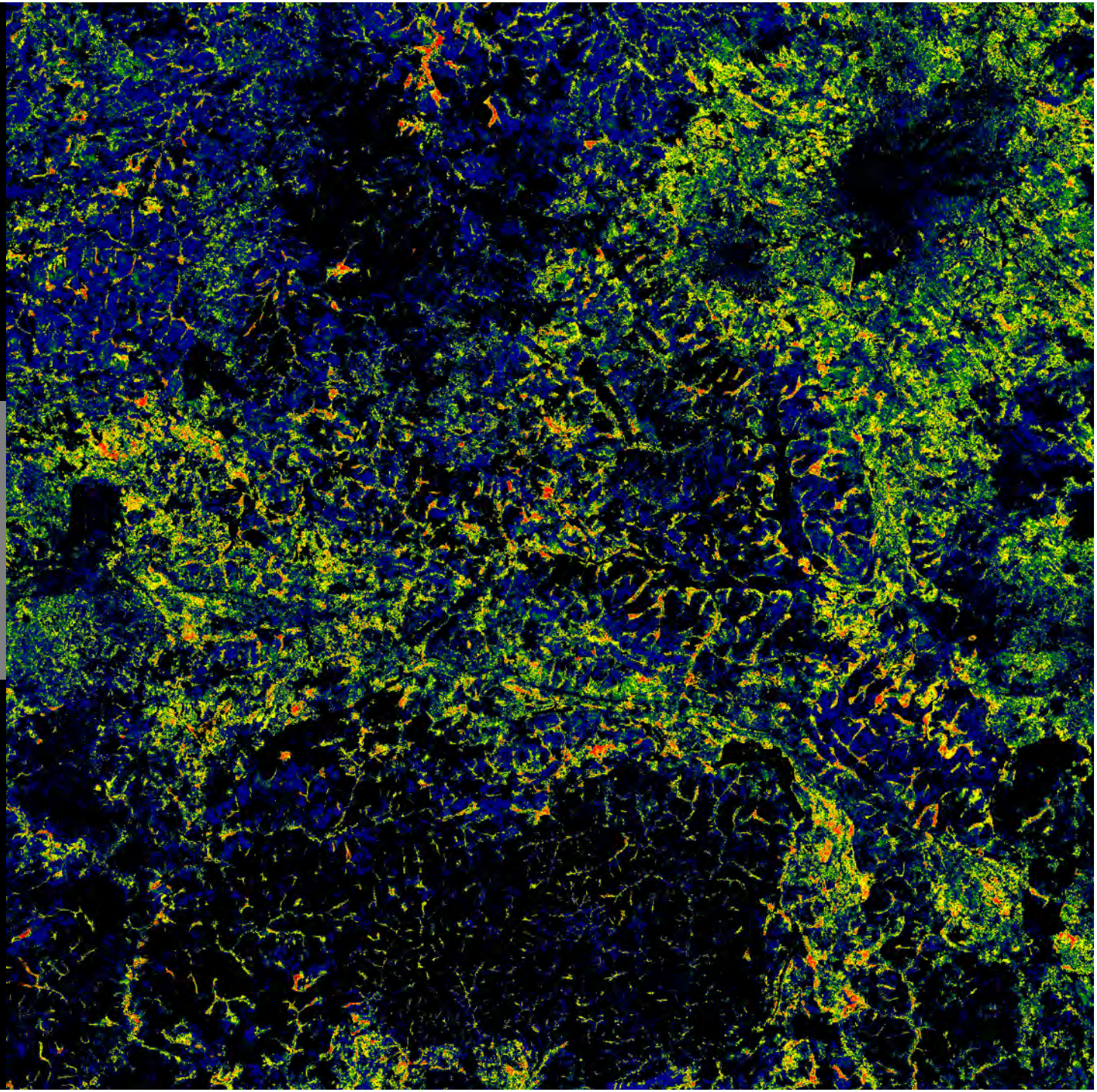
0.6 ≤ f.cc < 0.8

0.8 ≤ f.cc < 0.9

0.9 ≤ f.cc < 1.0

5295 x 5295
30m pixels
(158 x 158 km)

Zambia,
Copperbelt
Provence



Landsat 8

Sentinel-2A

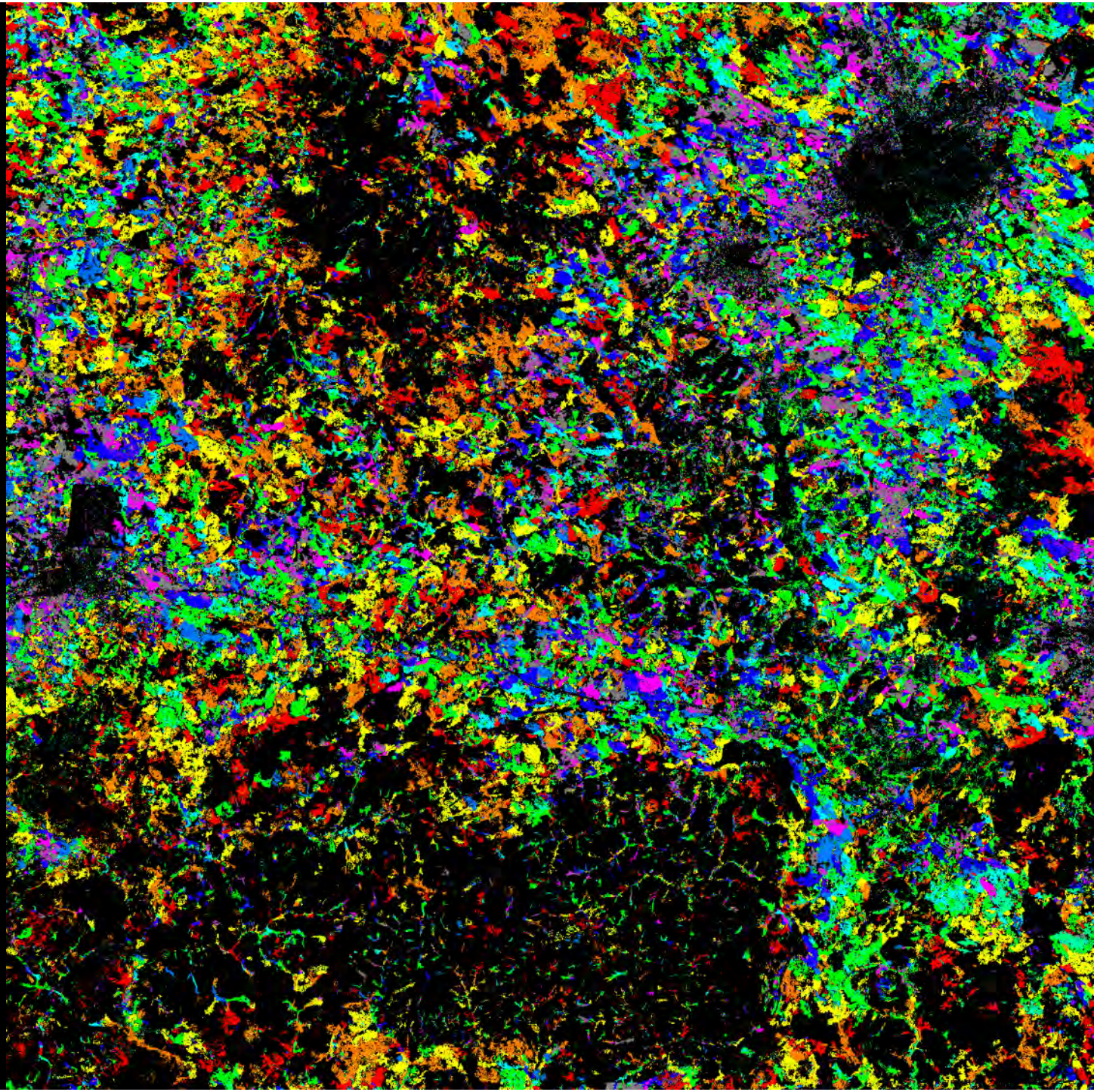
wedge method

Day of burning

(minus 154)

1≤days ≤5
6≤days ≤10
11≤days ≤15
16≤days ≤20
21≤days ≤25
26≤days ≤30
31≤days ≤35
36≤days ≤40
41≤days ≤45
46≤days ≤50
51≤days ≤55
56≤days ≤60
61≤days ≤65
66≤days ≤70

Zambia,
Copperbelt
Provence



MODIS 1km

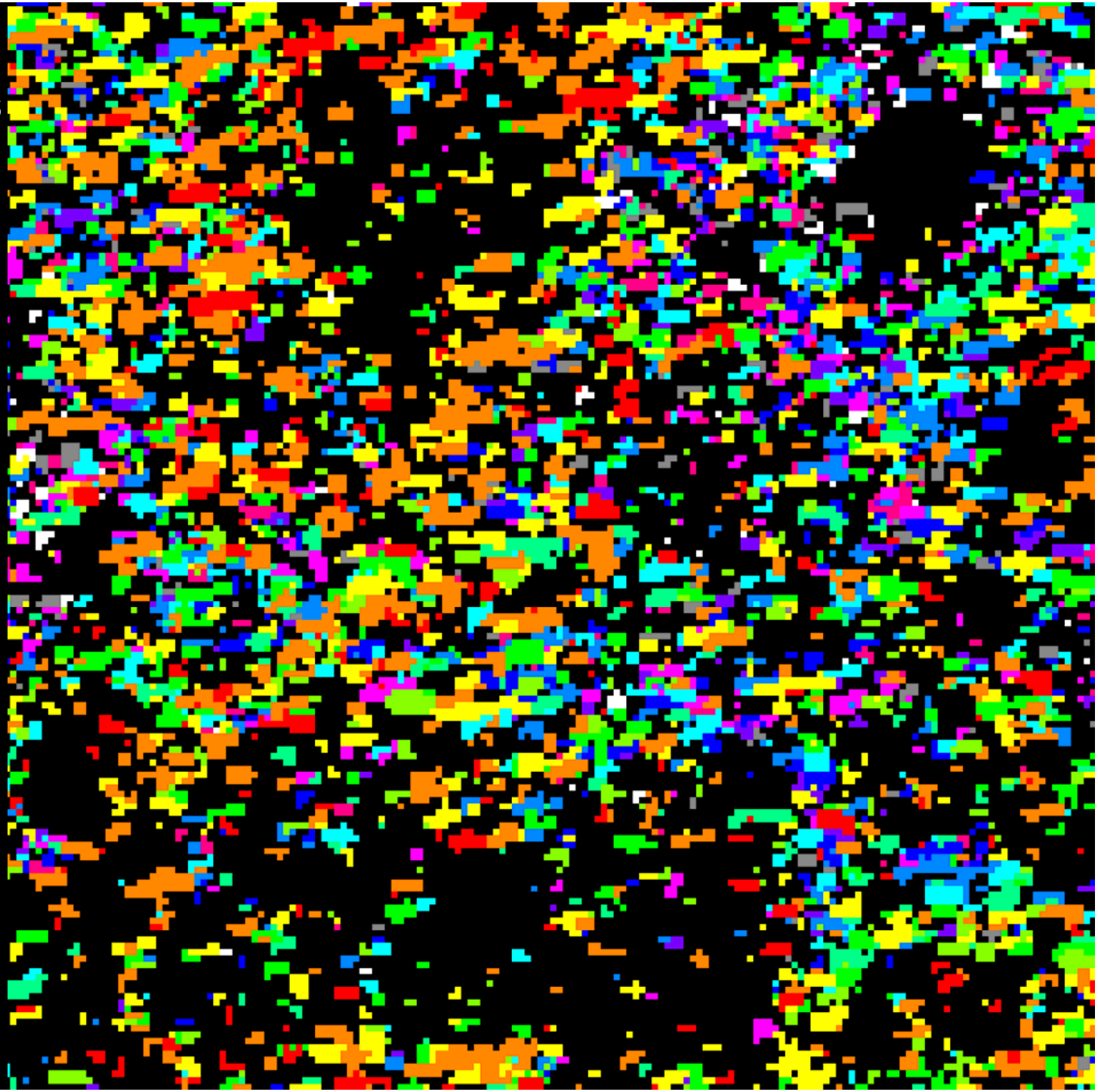
active fire detections

Day of burning

(minus 154)

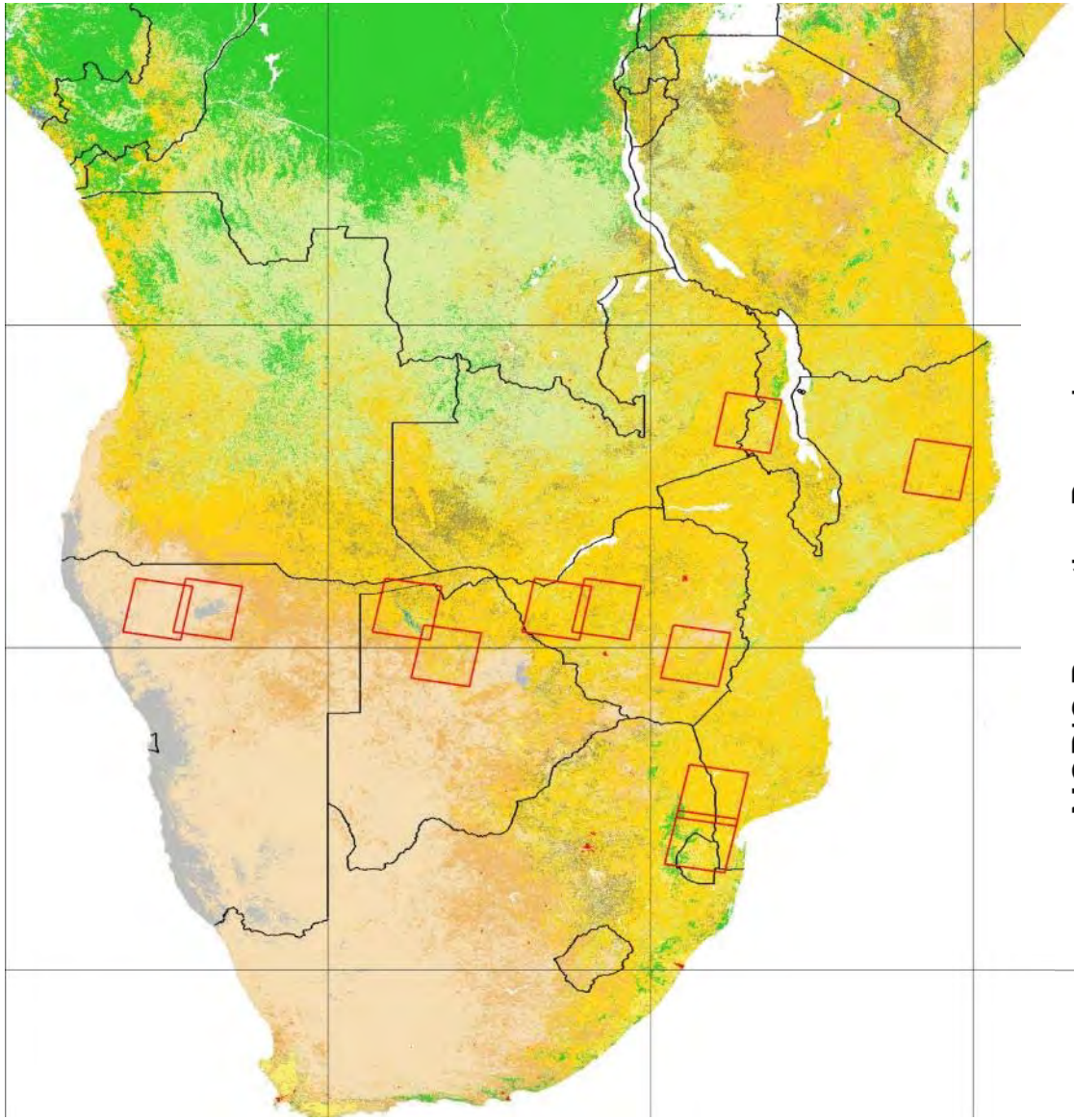
1≤days ≤5
6≤days ≤10
11≤days ≤15
16≤days ≤20
21≤days ≤25
26≤days ≤30
31≤days ≤35
36≤days ≤40
41≤days ≤45
46≤days ≤50
51≤days ≤55
56≤days ≤60
61≤days ≤65
66≤days ≤70

Zambia,
Copperbelt
Provence

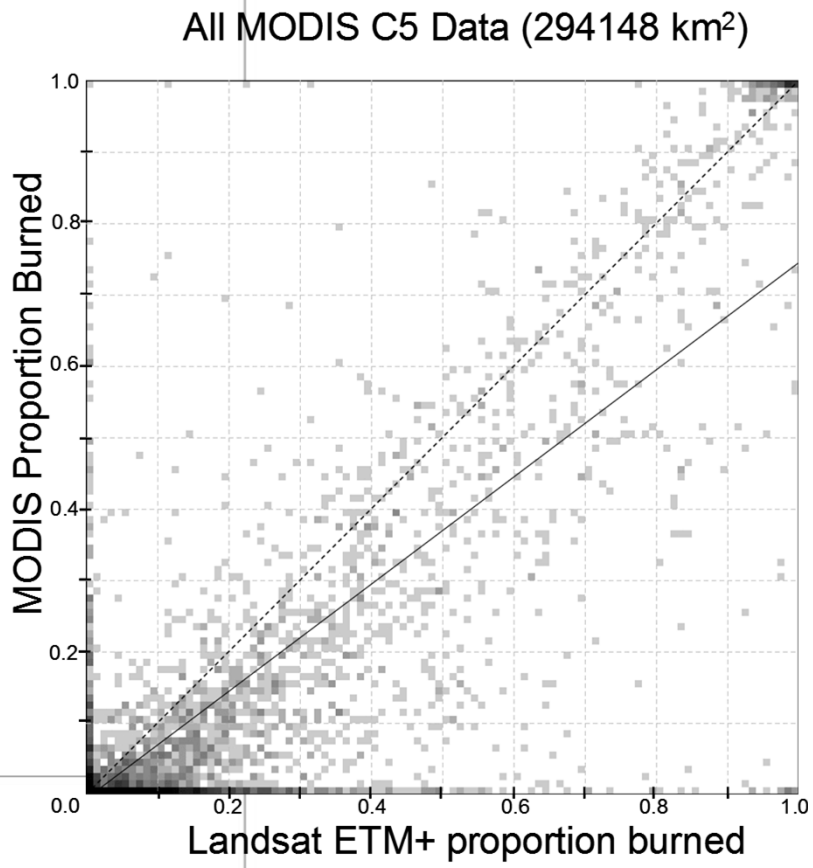


Validation

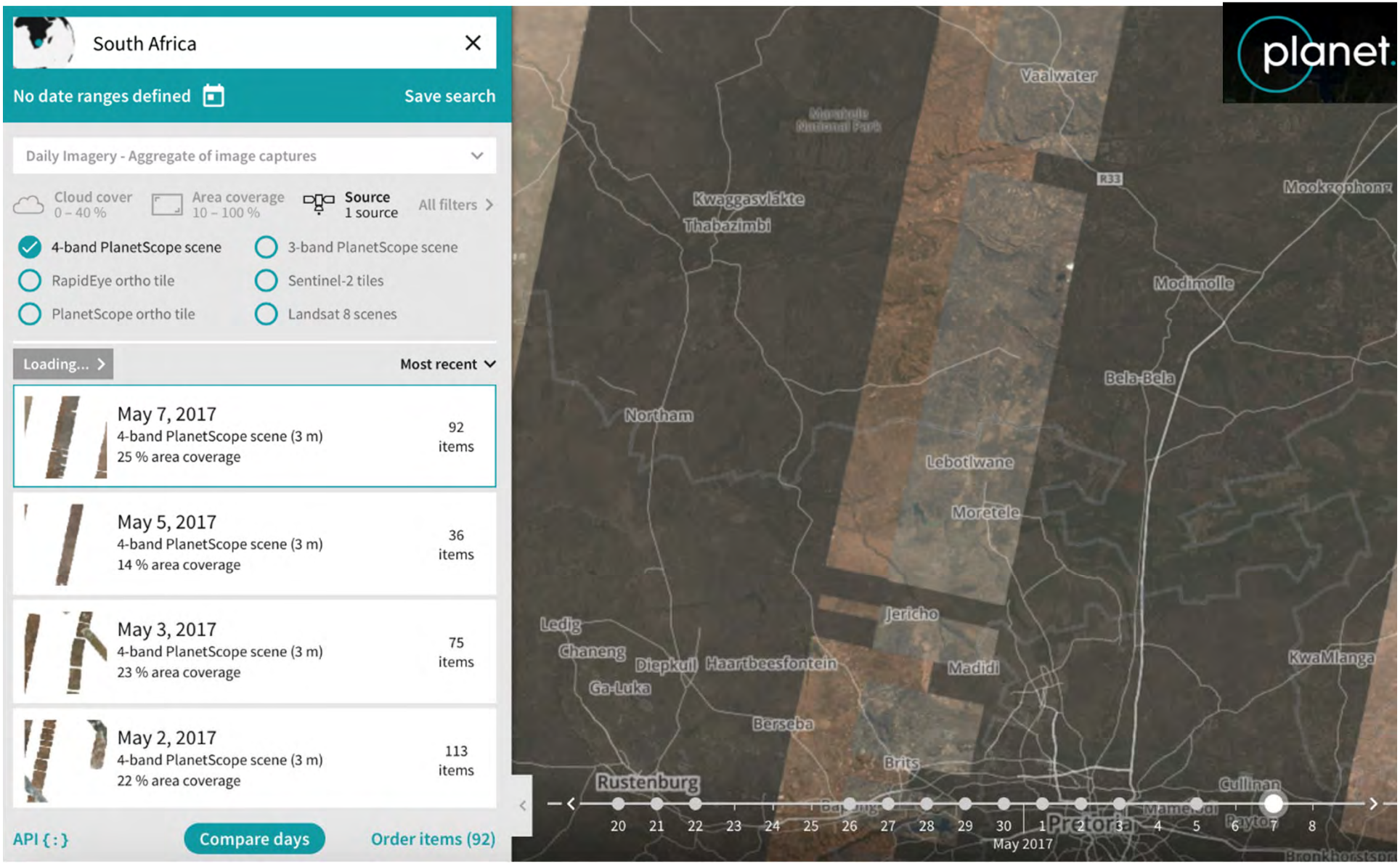
Previously MODIS 500 m burned area validation by comparison with 2-date Landsat interpreted burned maps



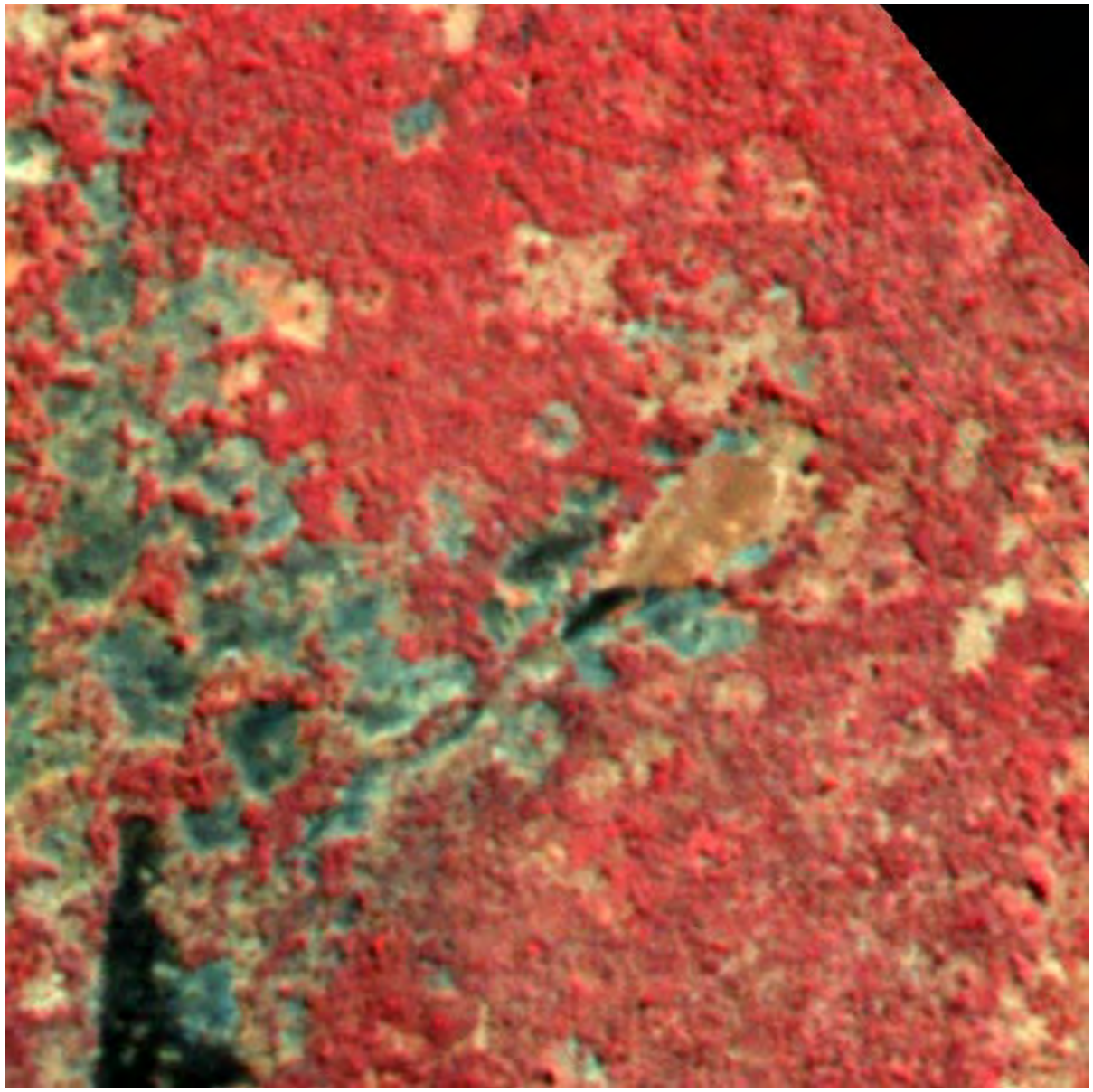
Roy, Frost, Justice, Landmann, et al., 2005, The Southern Africa Fire Network (SAFNet) regional burned area product validation protocol, *International Journal of Remote Sensing,* 26, 4265-4292.



Validate 30m Landsat-8 Sentinel-2 burned area & f using commercial multi-date interpreted high resolution data



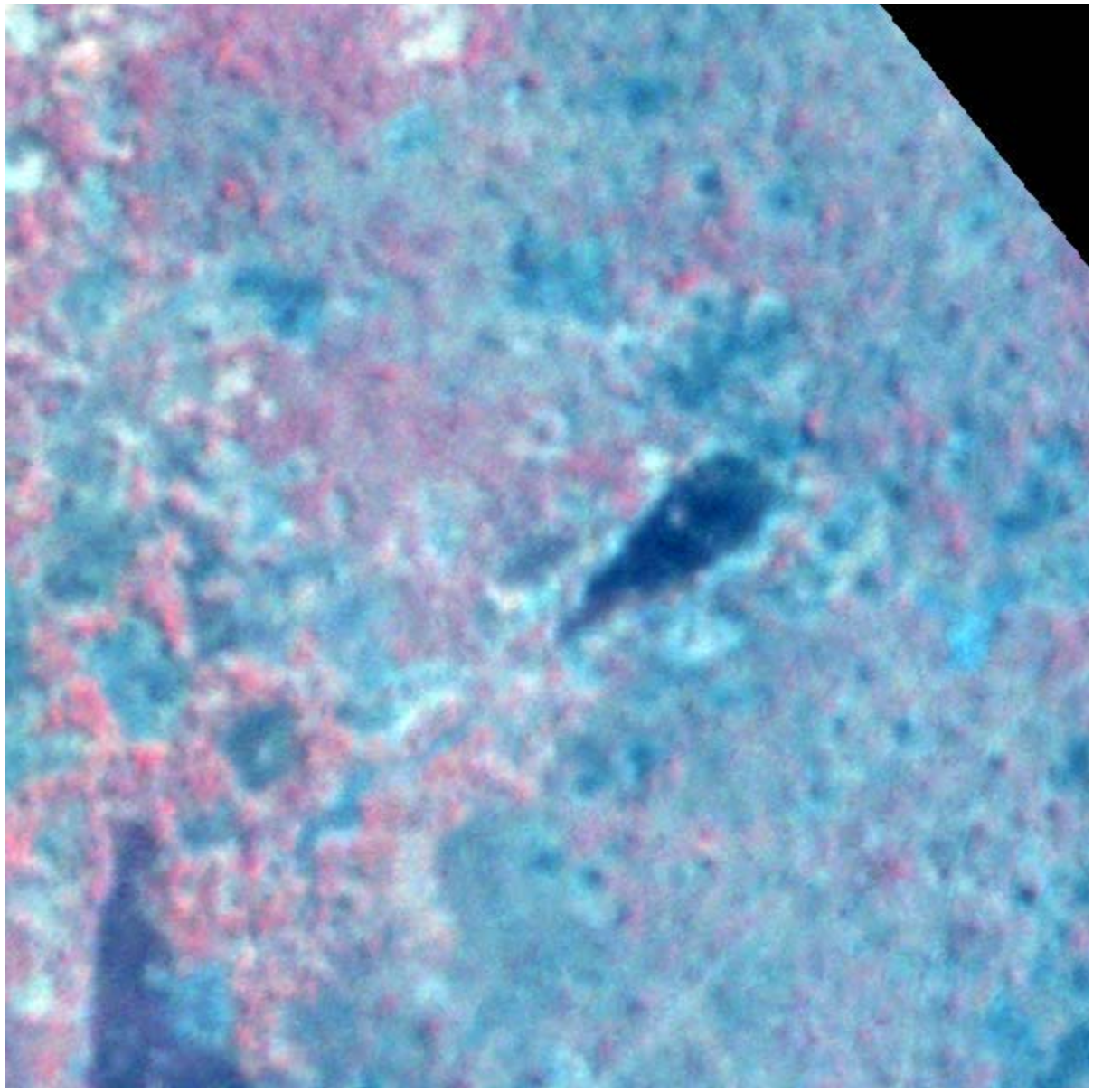
600 × 600 3 m pixels (1.8 km × 1.8 km)



Somewhere in Zambia

July 18th 2016

600 × 600 3 m pixels (1.8 km × 1.8 km)



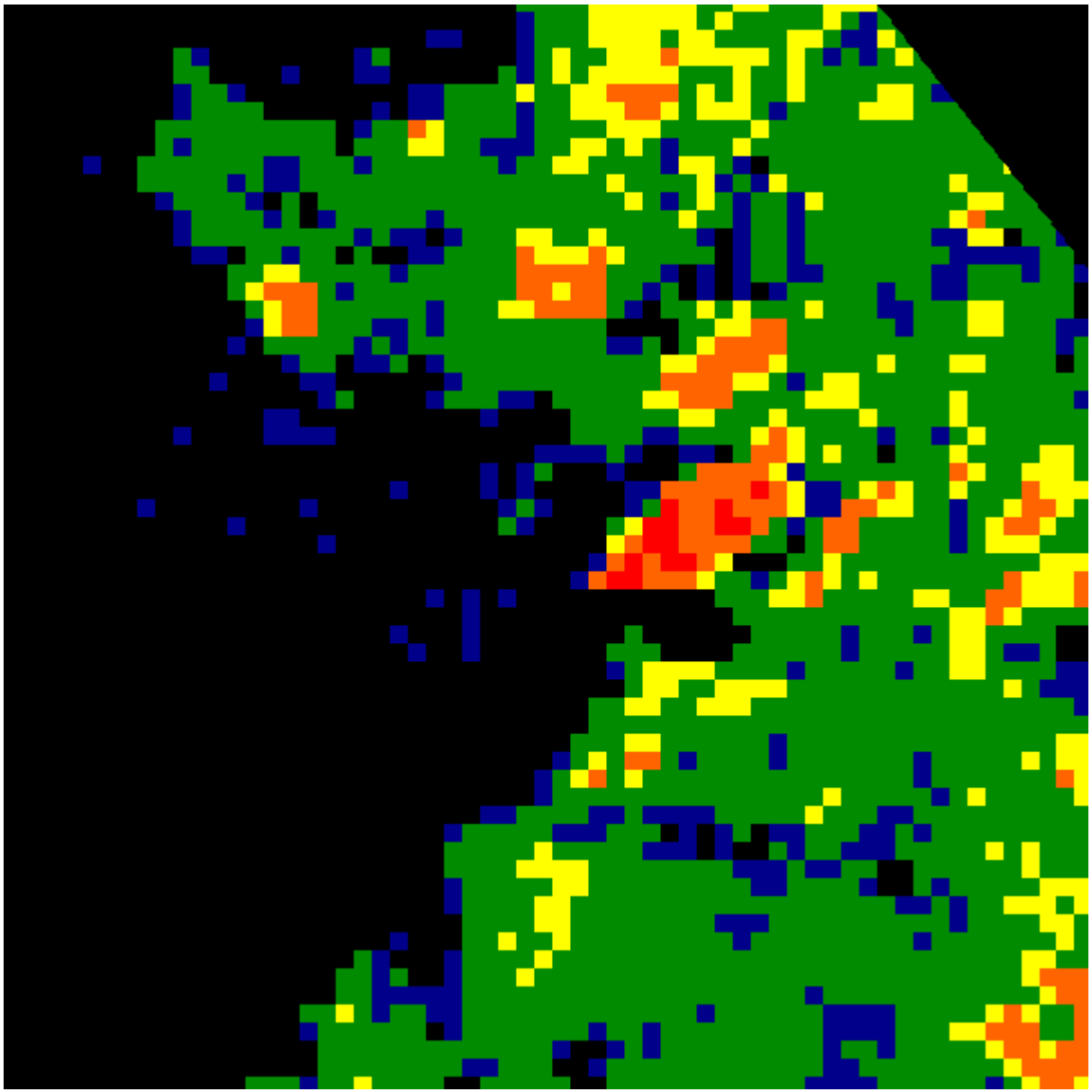
Somewhere in Zambia

August 18th 2016

60 × 60 30 m pixels (1.8 km × 1.8 km)

S2A/L8

f x cc

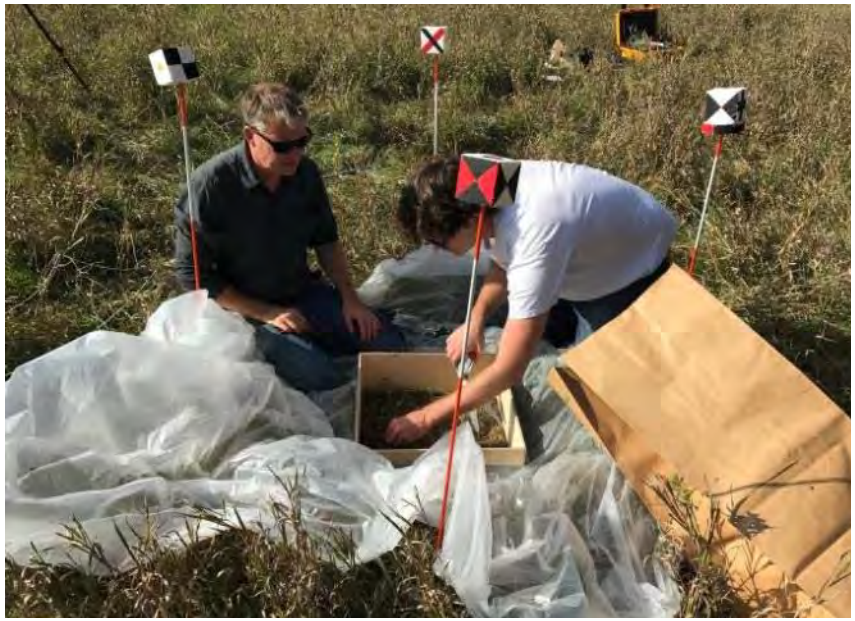


Somewhere in Zambia

July – August 18th 2016

CC estimation by *in situ* biomass measurement pre-post fire very time consuming

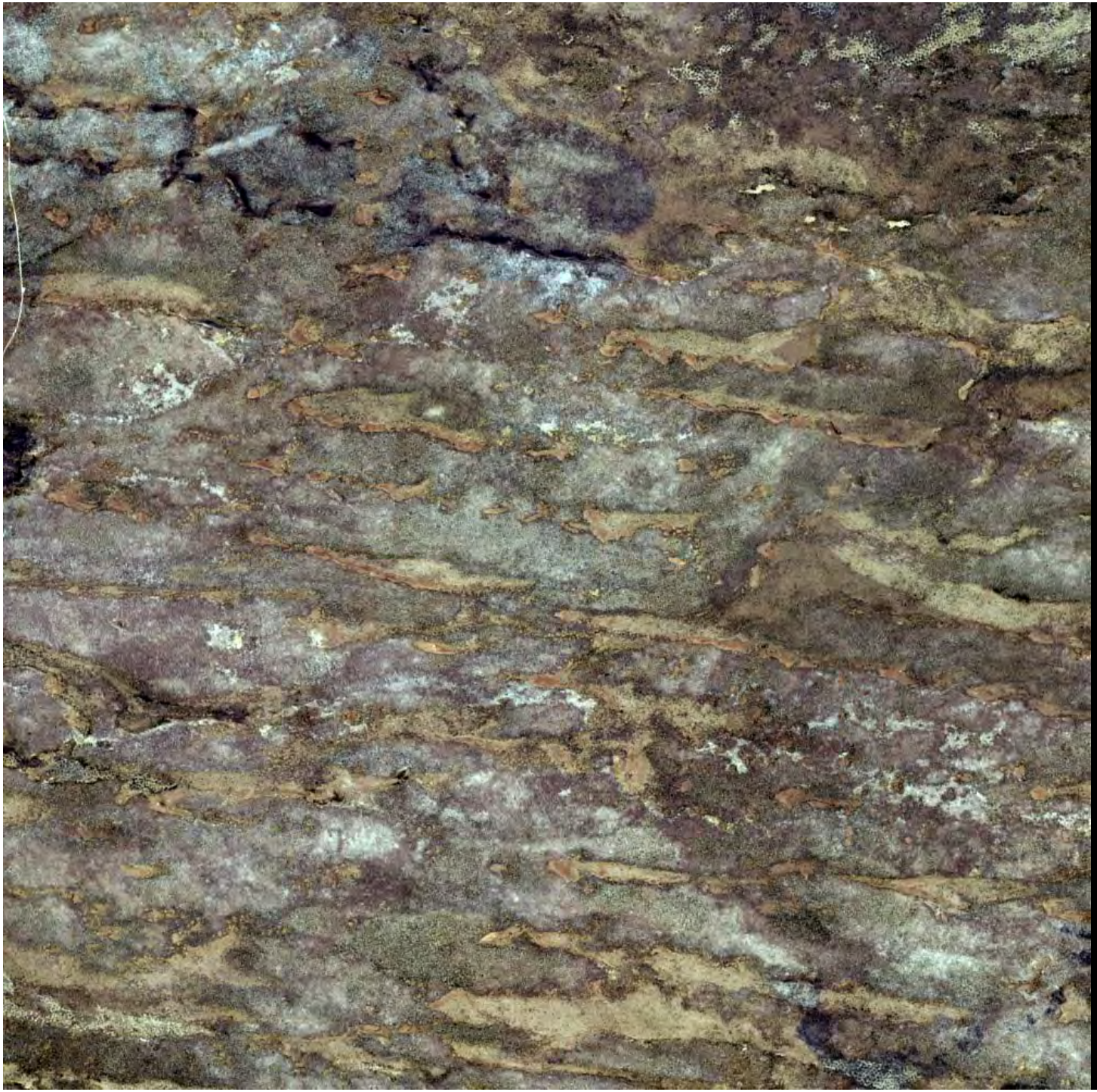
Validate *cc* using high speed, low-cost, highly portable Terrestrial Laser Scanner ?



Cooper, S.D., Roy, D.P., Schaaf, C.B., Paynter, I., 2017, Examination of the potential of Terrestrial Laser Scanning and Structure-from-Motion photogrammetry for rapid nondestructive field measurement of grass biomass, *Remote Sensing*. *9* (6), 531.

Summary

- New global burned area mapping capability
  - Exciting ! Moving from MODIS to Landsat resolution burned area products
  - Combined Landsat-8 / Sentinel-2 data provide needed higher temporal resolution data with improved quantization and signal/noise characteristics over heritage Landsat
- Major R&D effort on Sentinel-2 and Landsat-8 pre-processing
  - Registration, BRDF correction to NBAR, among sensor calibration
  - several papers from my group please see http://globalmonitoring.sdstate.edu/faculty/roy/roy.html
- Prototype automated burned area algorithm developed
  - applied to NBAR surface reflectance gridded WELD tile time series
  - only 2 parameters (search duration = 30 days, max gap = 10 days)
  - map 30m burned area + sub-pixel fraction (f) x combustion completeness (cc)
- Next steps:
  - Algorithm paper in preparation
  - Multi-year Africa registered Landsat-8 and Sentinel-2A WELD tiled surface NBAR
  - Add Sentinel-2B
  - Validation with commercial data (burned area, f) & Terrestrial Laser Scanner (cc), field campaign in South Africa planned



Landsat-8 OLI

30m true color reflectance

July 21st 2014

The effects of burned areas may persist on the landscape

Angola
north of
Mucusso National Park

30 x 30 km

Landsat-8 OLI

30m true color

Reflectance

August 6th 2014

The effects of burned areas may persist on the landscape

Angola
north of
Mucusso National Park

30 x 30 km

Landsat-8 OLI

30m true color

Reflectance

August 6th 2014

Active fire detections

Angola
north of
Mucusso National
Park

30 x 30 km

Kumar & Roy, 2017, International Journal of Digital Earth