The Harmonized
Landsat and Sentinel-2 (HLS) Status and Plan

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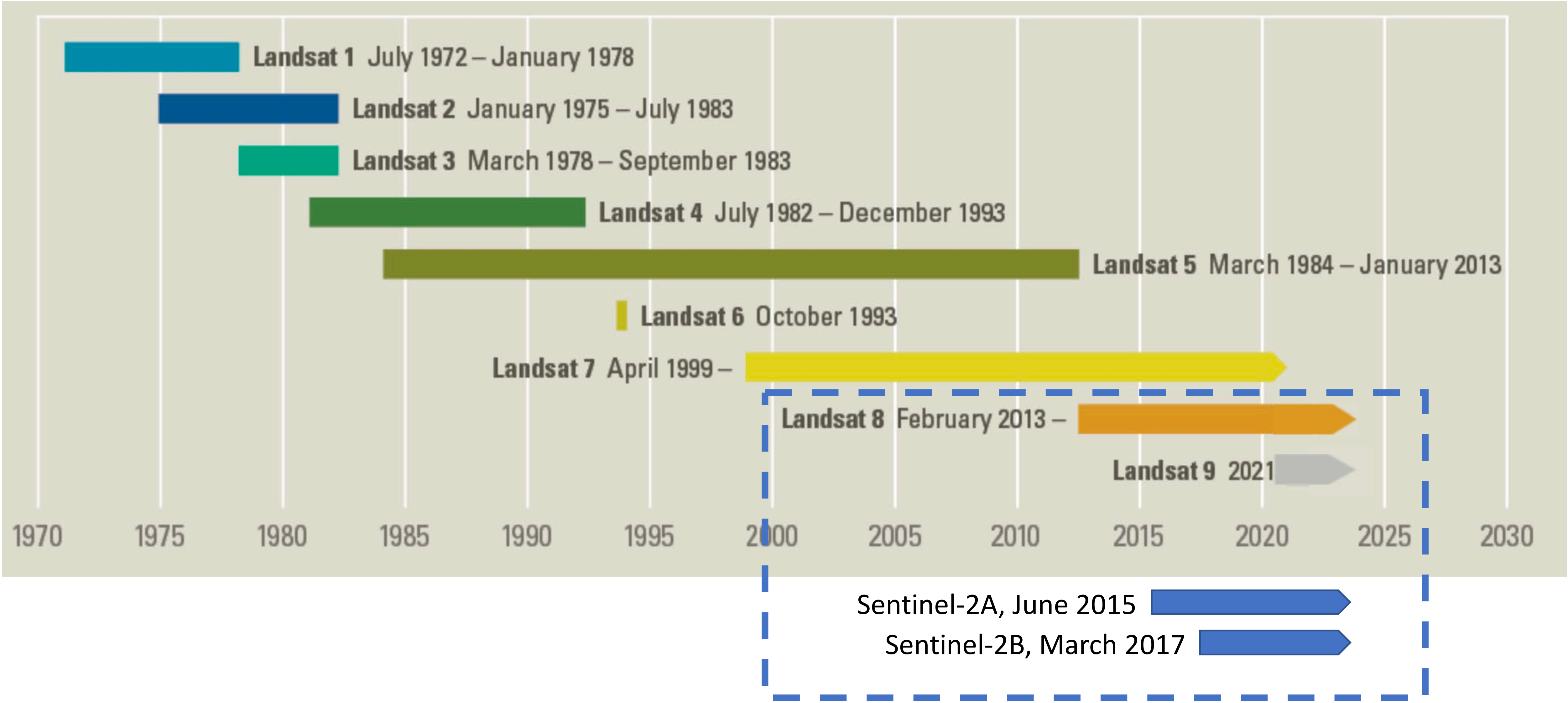
5 USGS Earth Resources Observation and Science (EROS) Center
6 NASA Goddard Space Flight Center (retired)

LCLUC, 2-4 April 2024, Gaithersburg, MD

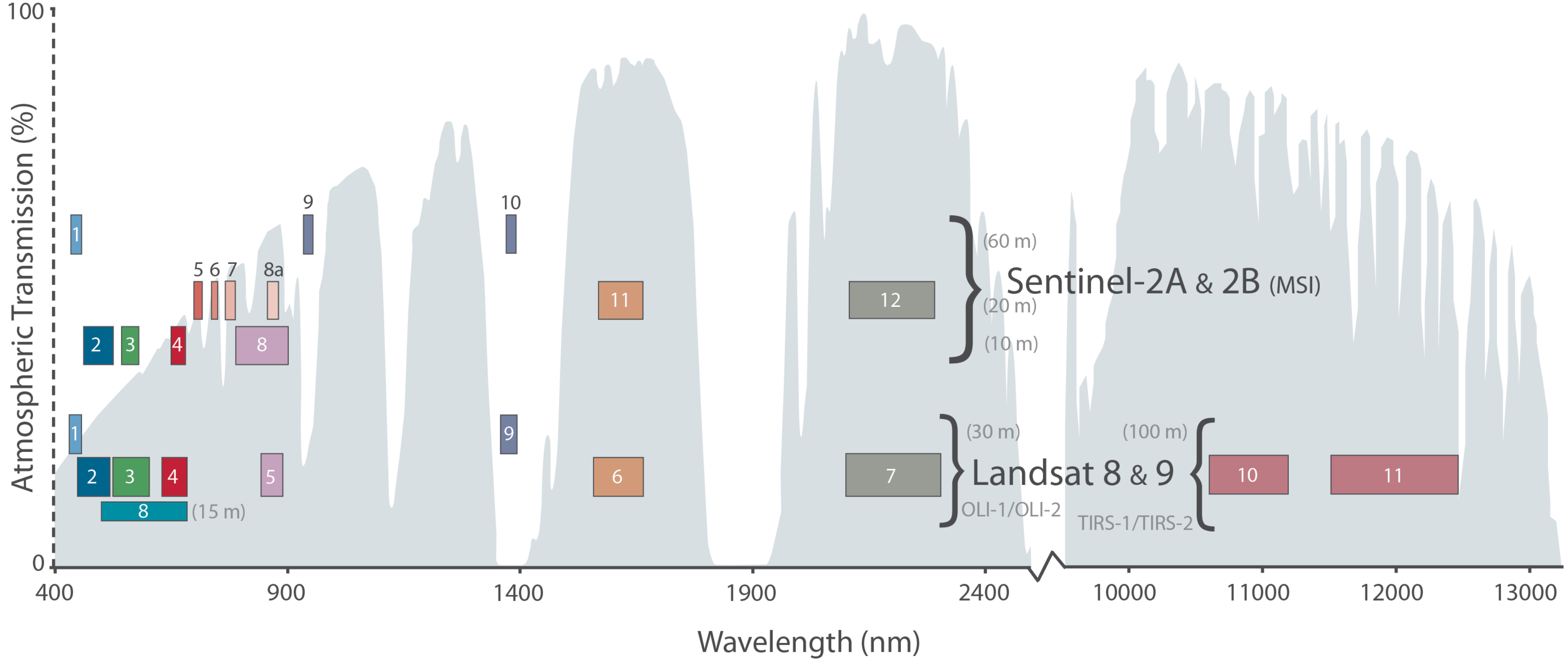
https://hls.gsfc.nasa.gov/

The Opportunity for More Frequent Observation



Adapted from: https://www.usgs.gov/media/images/landsat-missions-timeline

Spectral and Spatial Similarity
Between Landsat-8/9 and Sentinel-2A/2B

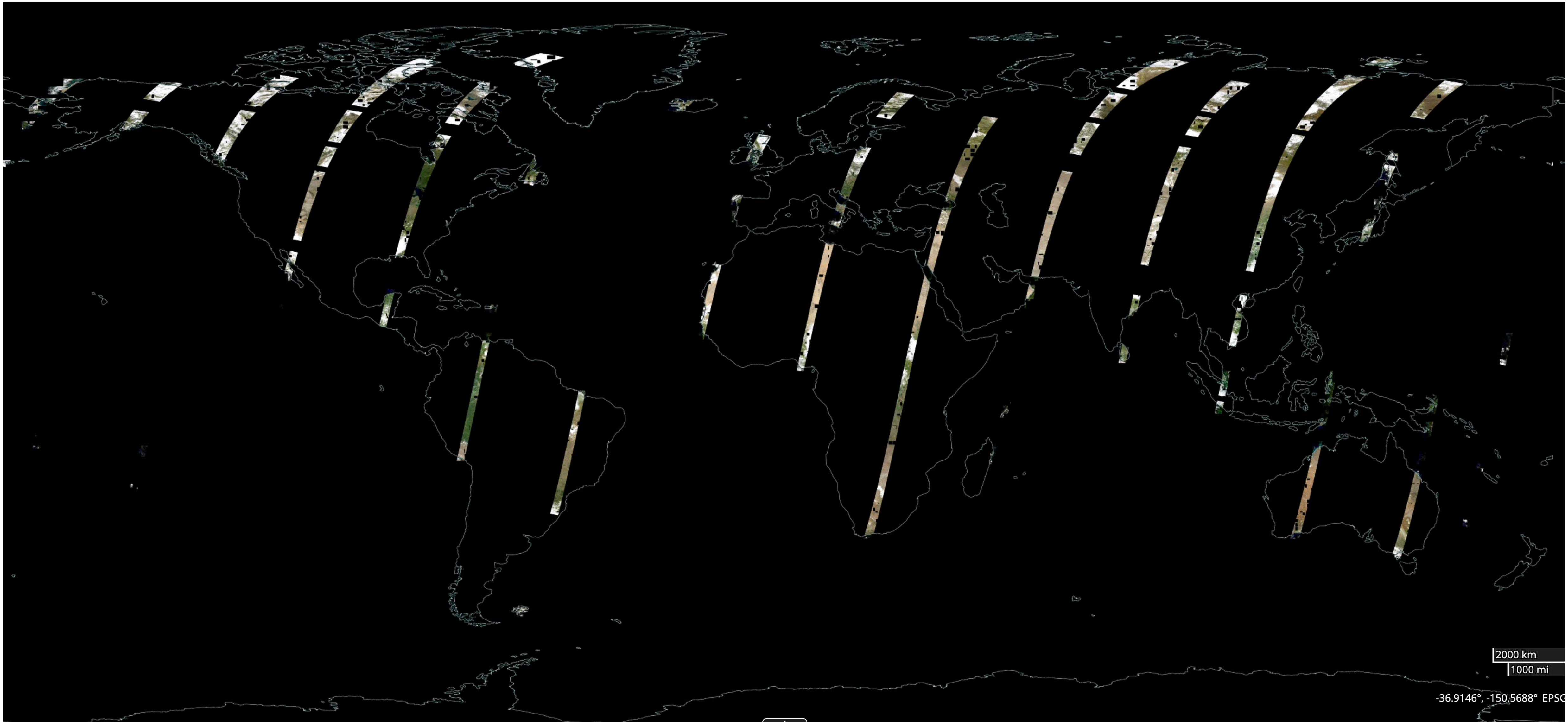


Landsat-8/9: 30m

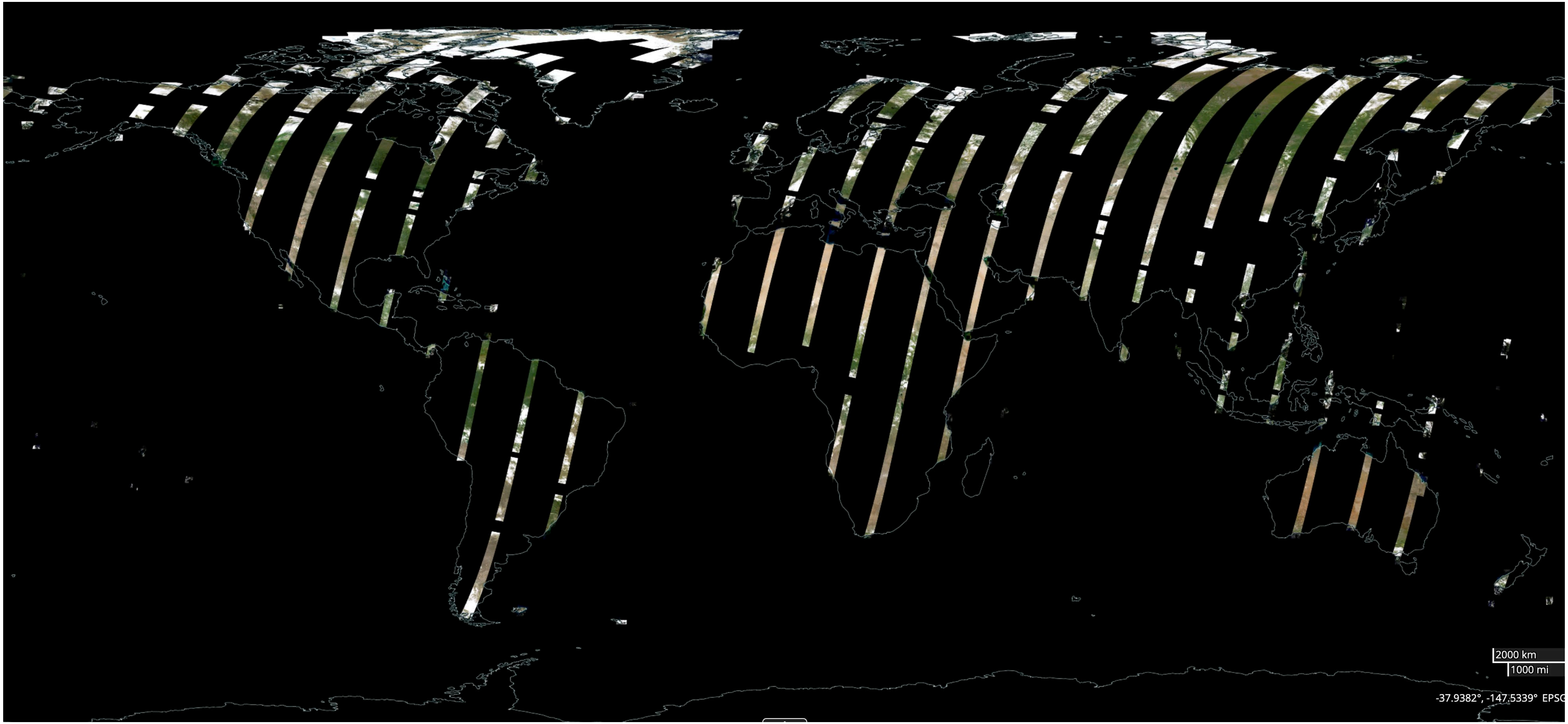
Sentinel-2: 10/20/60m

Sun-synchronous, similar morning equatorial overpass time

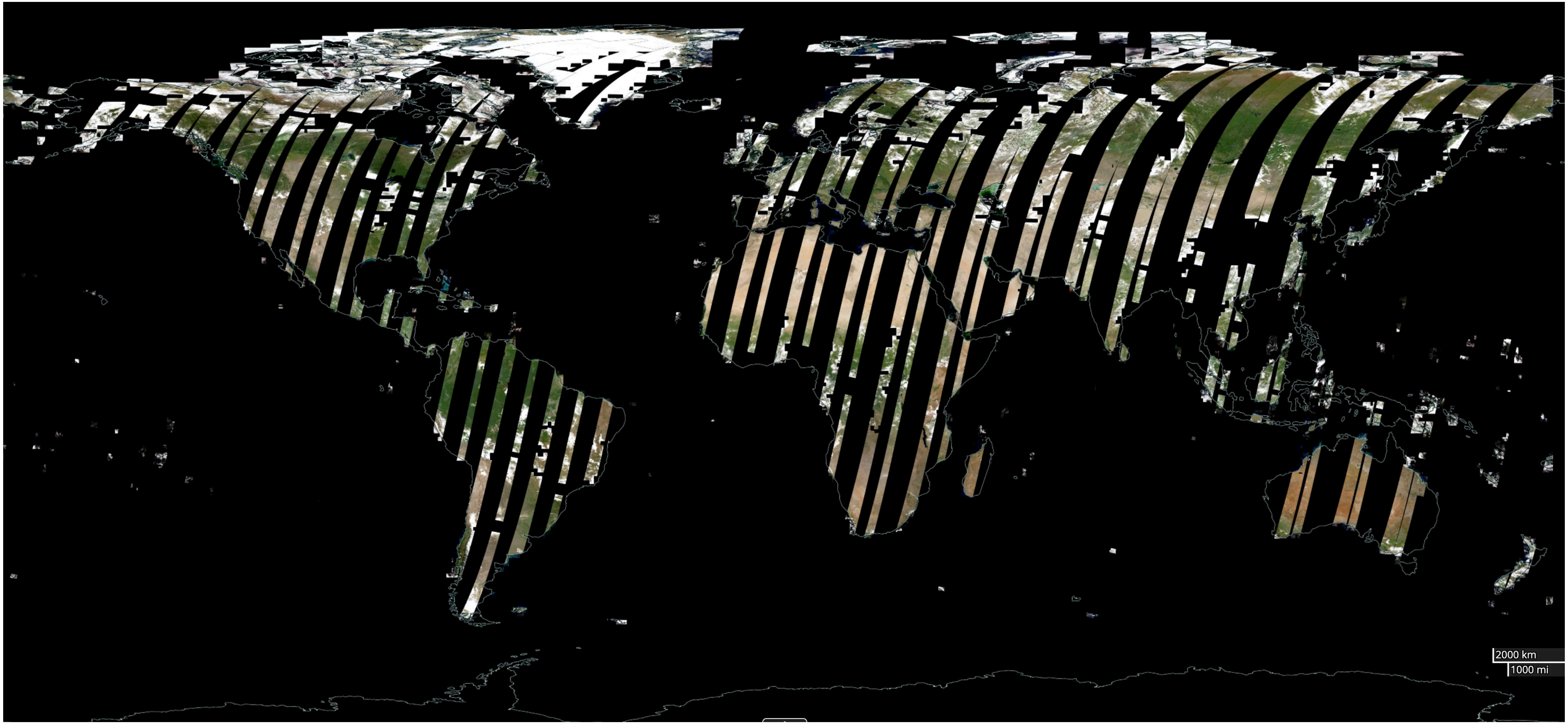
24 hours of Landsat 8



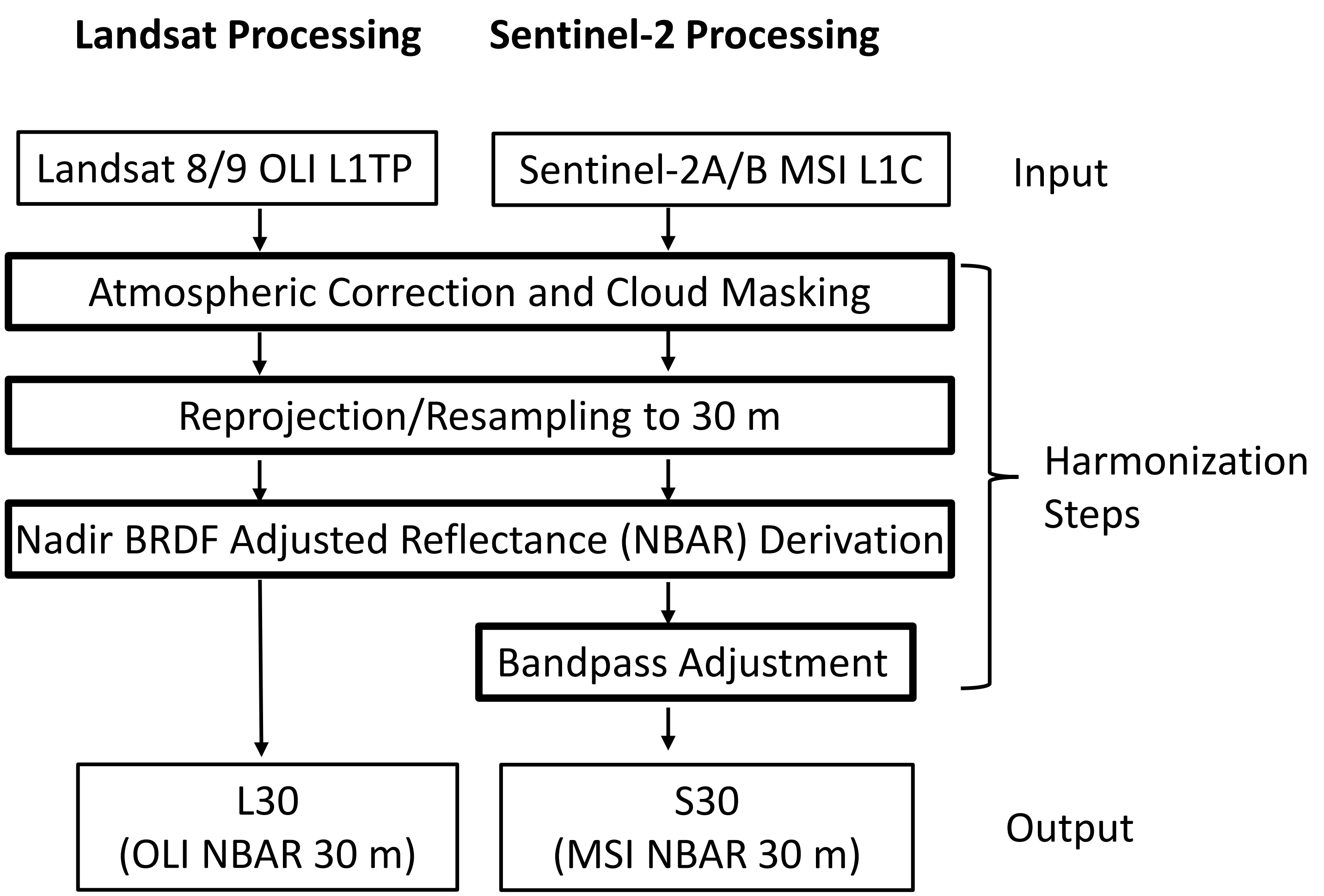
24 hours of Landsat 8 + Landsat 9



24 hours of Landsat 8 + Landsat 9 + Sentinel-2A + Sentinel-2B



The HLS Processing Steps



Atmospheric Correction: Land Surface Reflectance Code (LaSRC)

Originally by: Eric Vermote

Adapted by: USGS for operational use

Ancillary data: MODIS derived spectral band ratios, water vapor, and ozone.

Now transition to VIIRS based water vapor and ozone.

Before

After

Cloud Masking and Dilation of Cloud/Cloud Shadow

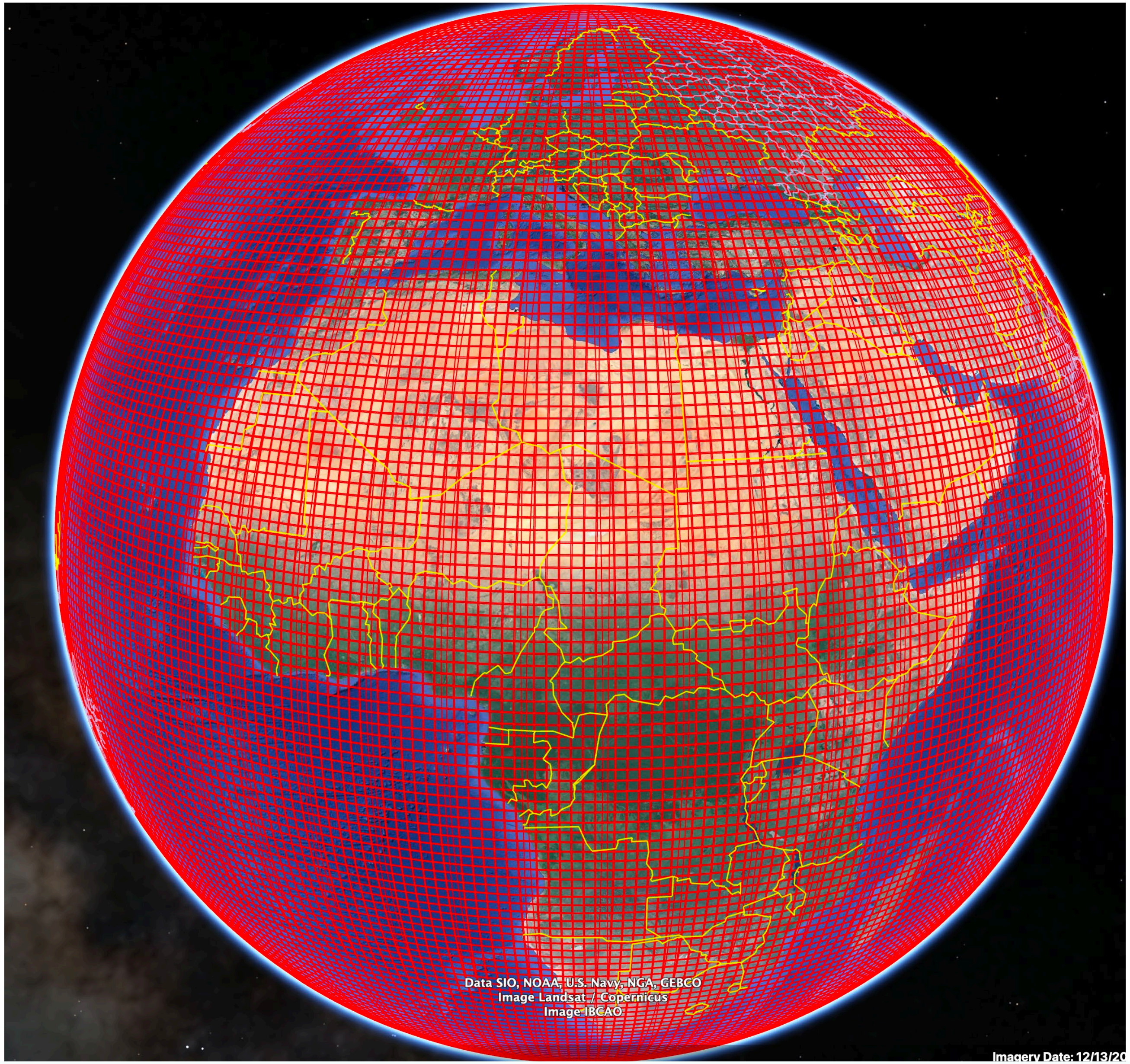
Dilation in yellow

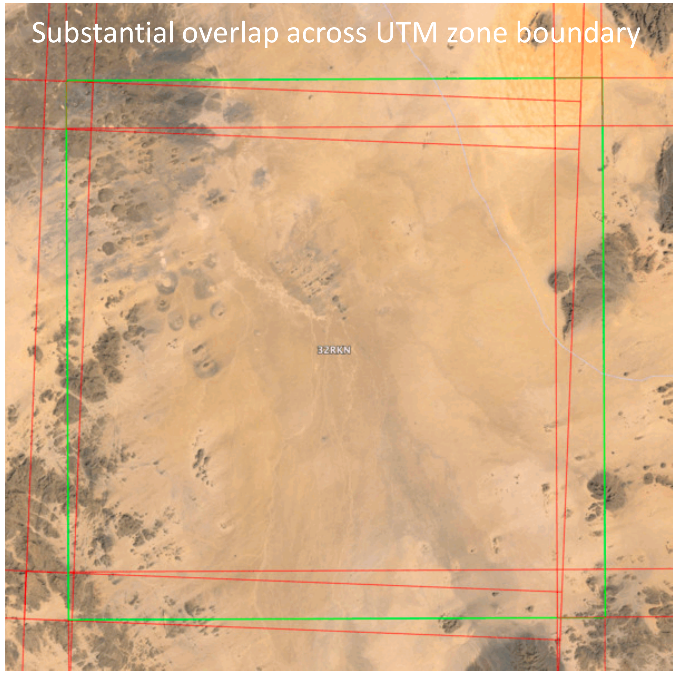
Qiu, Shi, Zhu, Zhe &He, Binbin. Fmask 4.0: Improved cloud and cloud shadow detection in Landsats 4-8 and Sentinel-2 imagery. RSE, vol. 231, p. 111205

QA band contains LaSRC aerosol levels and Fmask results

Bit number	Mask name	Bit value	Mask description
7-6	aerosol level	11	High aerosol
		10	Moderate aerosol
		01	Low aerosol
		00	Climatology aerosol
5	Water	1	Yes
		0	No
4	Snow/ice	1	Yes
		0	No
3	Cloud shadow	1	Yes
		0	No
2	Adjacent to cloud/shadow	1	Yes
		0	No
1	Cloud	1	Yes
		0	No
0	Cirrus	Reserved, but not used	NA

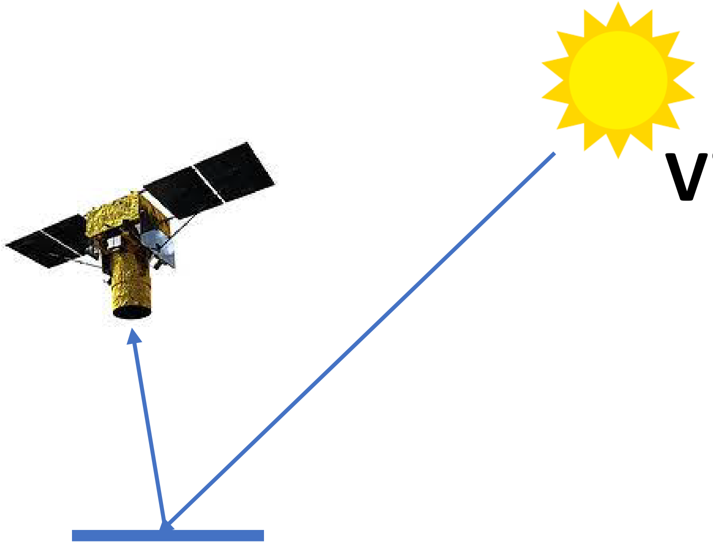
HLS Adopts the Military Grid Reference System (MGRS) Based Grid Used by Sentinel-2

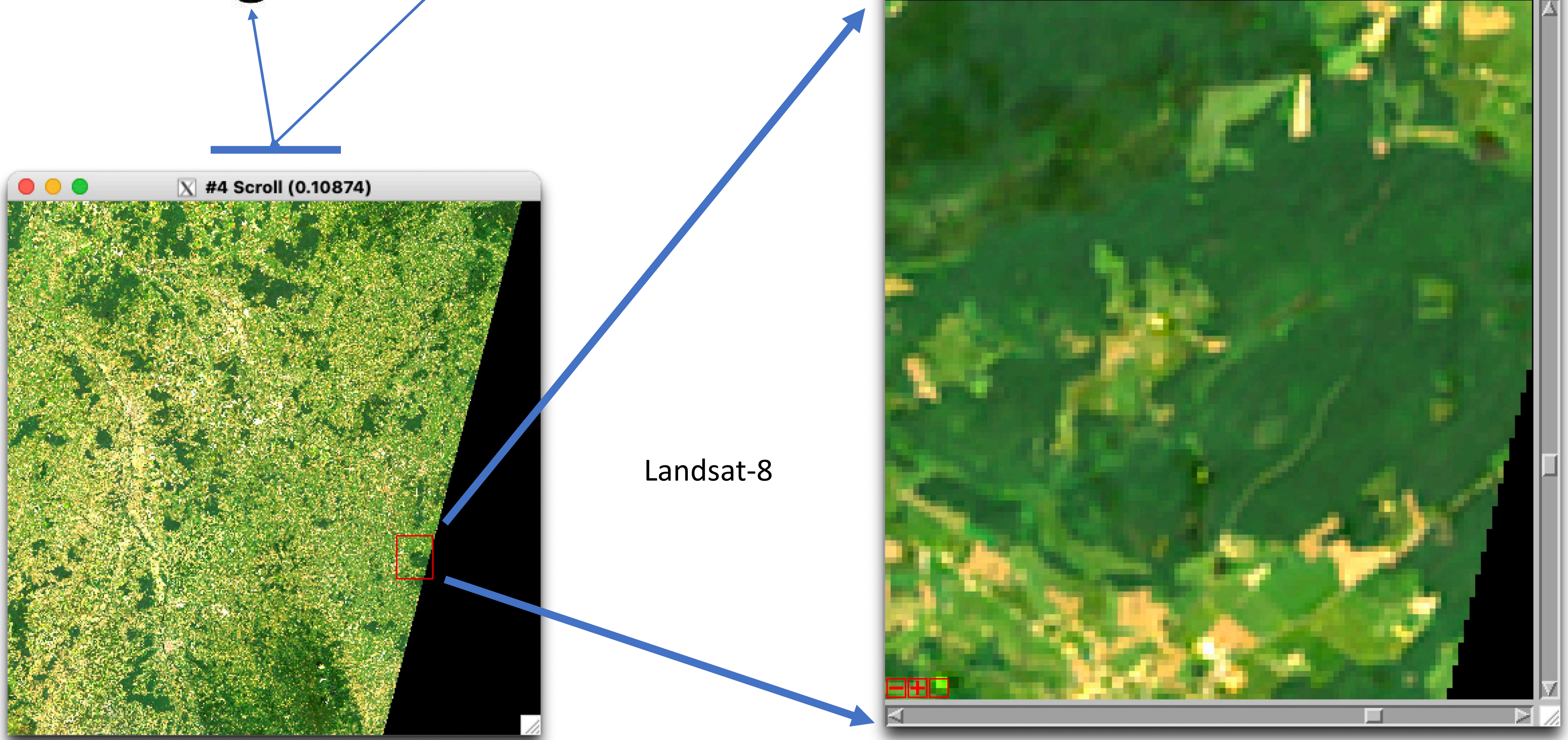


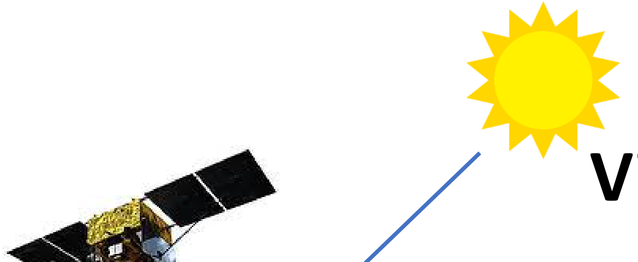


Criticism: Bauer-Marschallinger, B., Falkner, K., 2023. Wasting petabytes: Sentinel-2 UTM tiling grid…

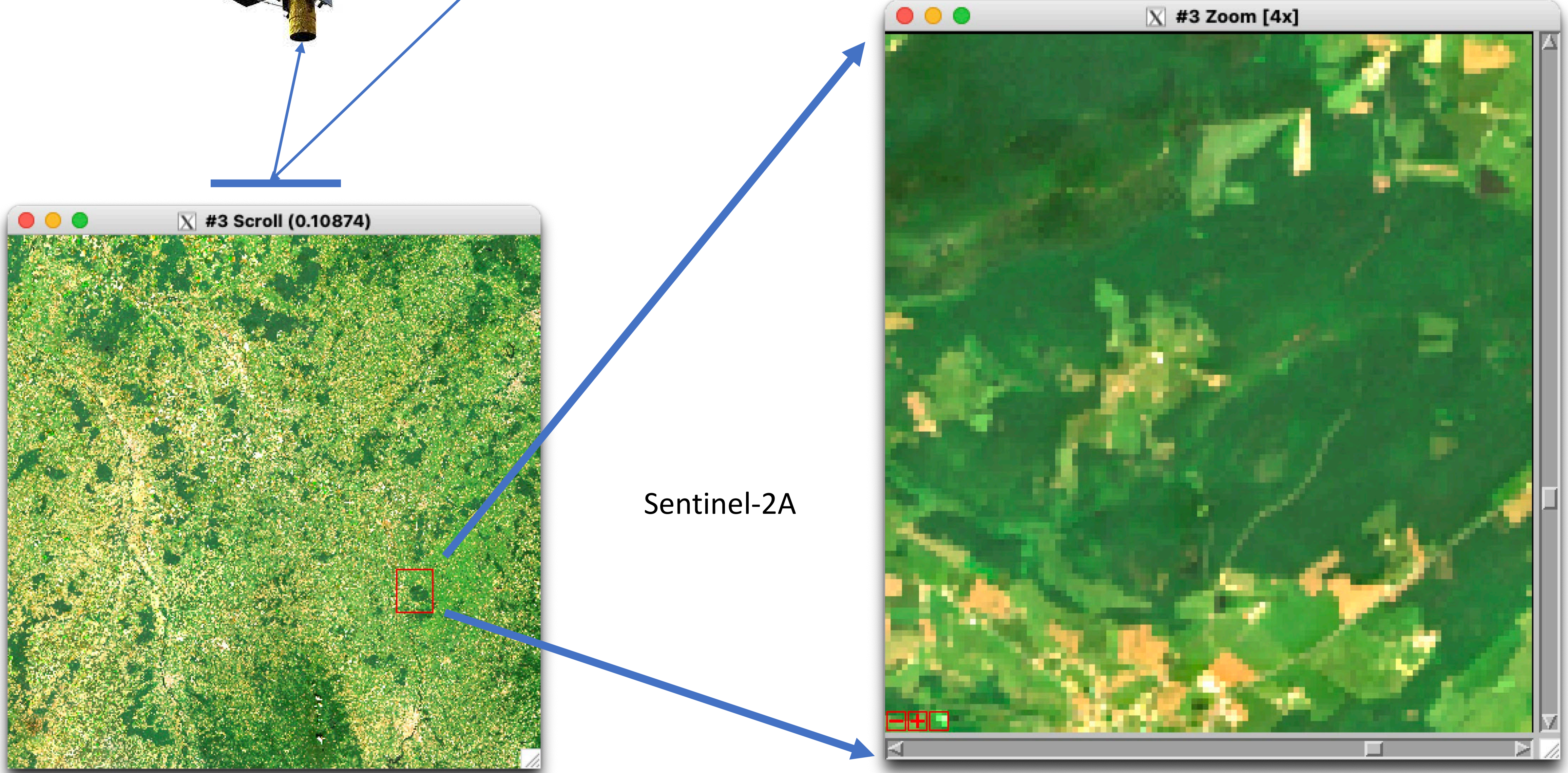
View Angle Effect for Narrow-view Sensors



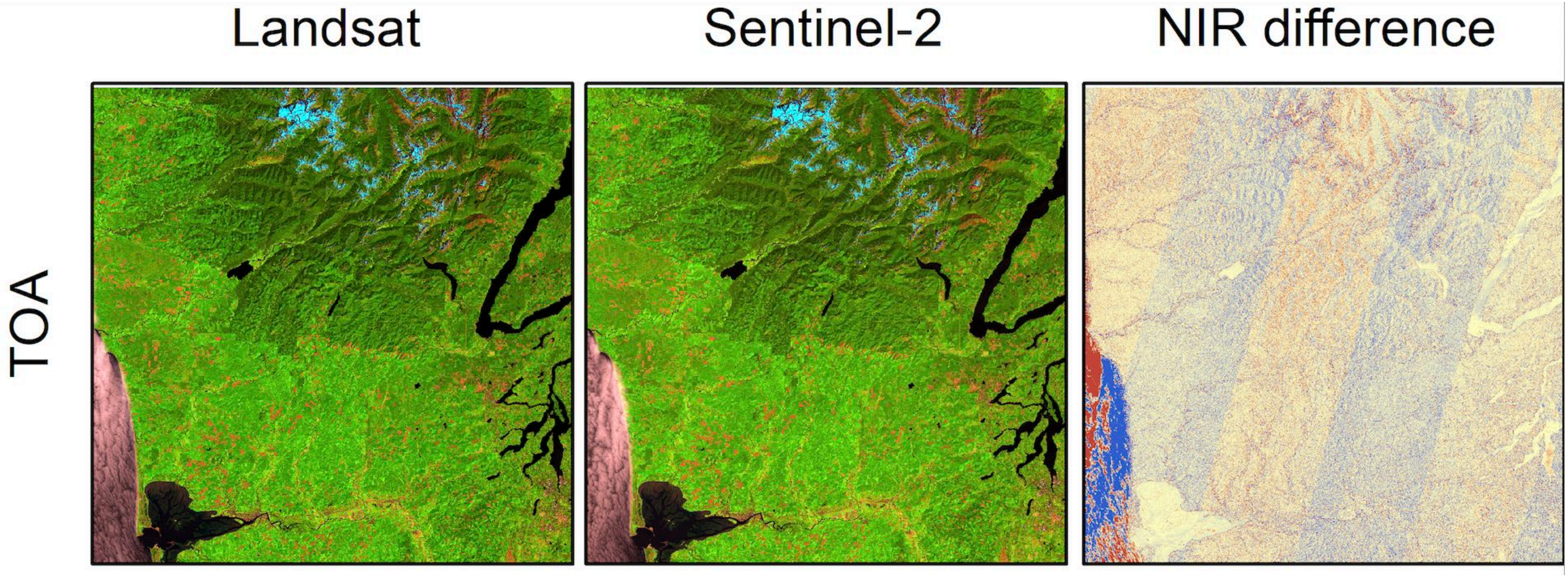




View Angle Effect for Narrow-view Sensors



Secondary BRDF effect due to the parallax angle induced by the staggered layout of the detector modules

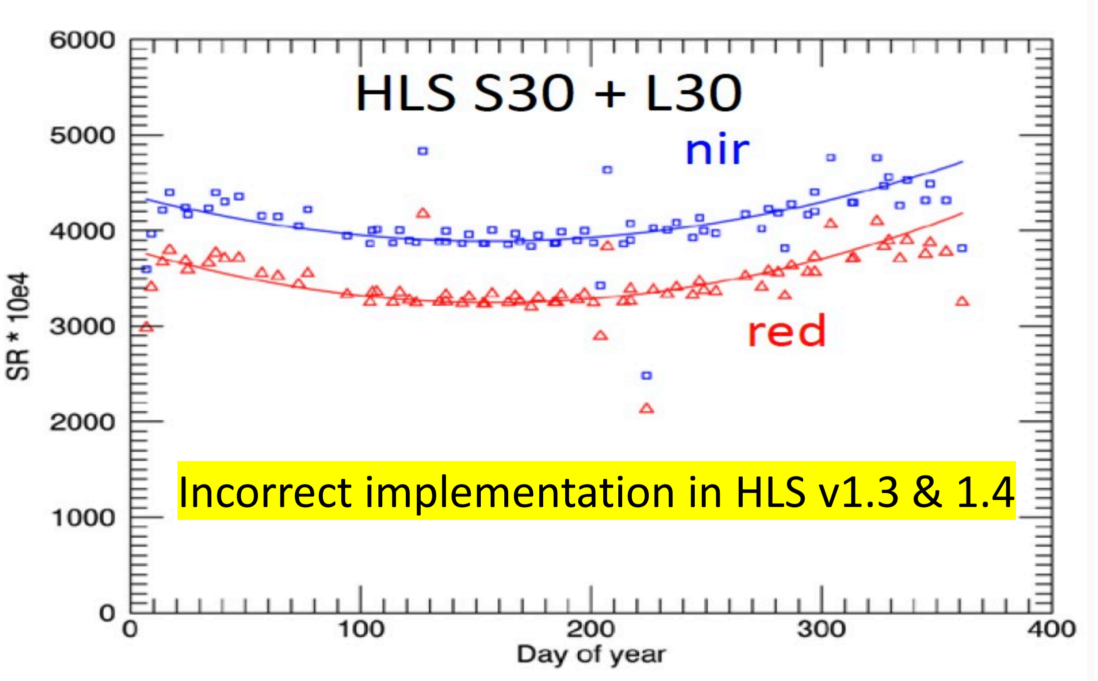


View Angle Normalization

$$\mathrm{NBAR}_\lambda(\theta_v = 0, \theta_s = \frac{\theta_s^{S2A,B} + \theta_s^{L8,9}}{2}) = c(\lambda) \times \rho_\lambda(\theta_v, \theta_s)$$

$$c(\lambda) = \frac{\hat{\rho}_\lambda^{\mathrm{MODIS}}(\theta_v{=}0,\ \theta_s{=}\frac{\theta_s^{S2A,B} + \theta_s^{L8,9}}{2},\ \phi_v{-}\phi_s{=}0)}{\hat{\rho}_\lambda^{\mathrm{MODIS}}(\theta_v,\ \theta_s,\ \phi_v{-}\phi_s))}$$

HLS v2.0 corrects a mistake in view angle normalization of v1.3 & 1.4 =>

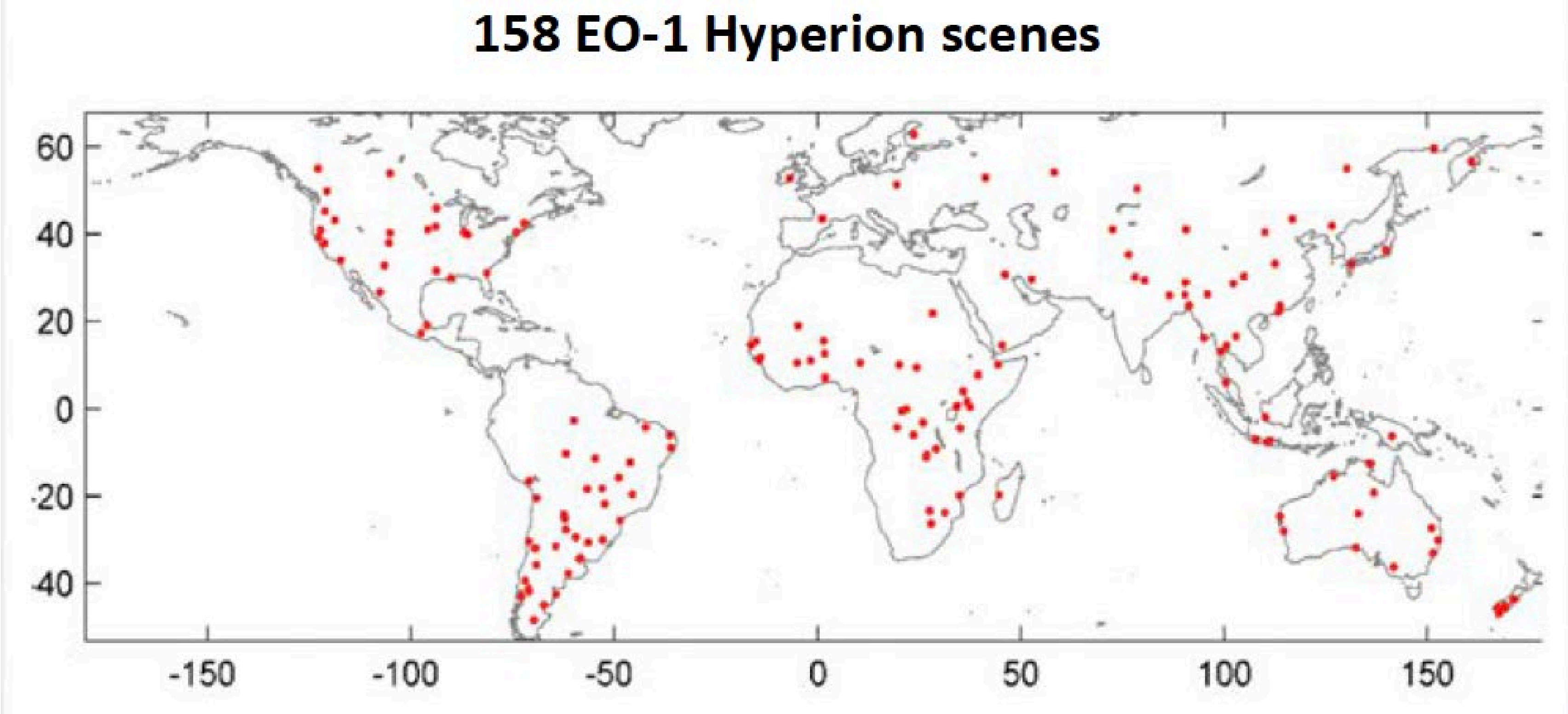


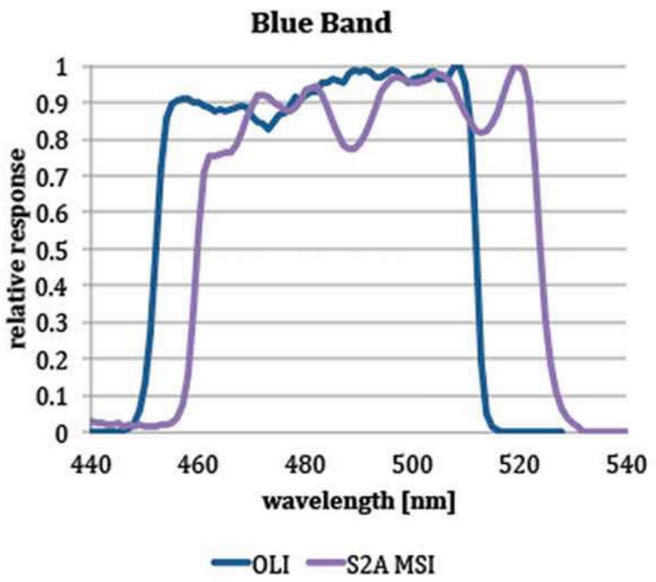
Roy, D.P., Zhang, H. K., Ju, J., Gomez-Dans, J. L., Lewis, P.E., Schaaf C.B., Sun, Q., Li, J., Huang, H., Kovalskyy, V., 2016. A general method to normalize Landsat reflectance data to nadir BRDF adjusted reflectance. Remote Sensing of Environment, 176, 255-271.

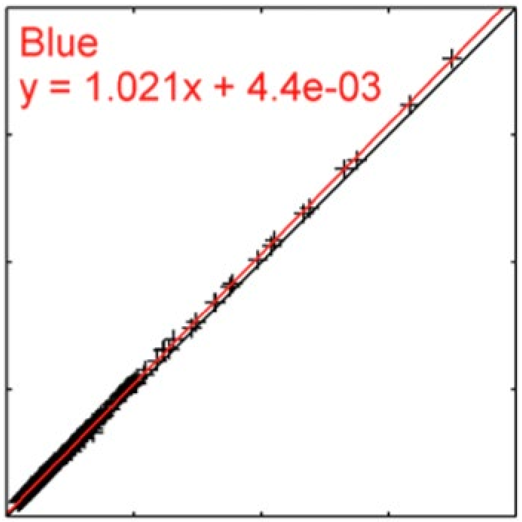
Zhang, H. K., Roy, D.P., Kovalskyy, V., 2016. Optimal solar geometry definition for global long term Landsat time series bi-directional reflectance normalization. IEEE Transactions on Geoscience and Remote Sensing, 54(3), 1410-1418.

Bandpass Adjustment

- Atmospherically corrected Hyperion data
- Convolve 10-nm Hyperion surface reflectance with Landsat and Sentinel-2 RSR
- Global regression to derive slope and offset







Claverie et al, 2018; Claverie, 2023

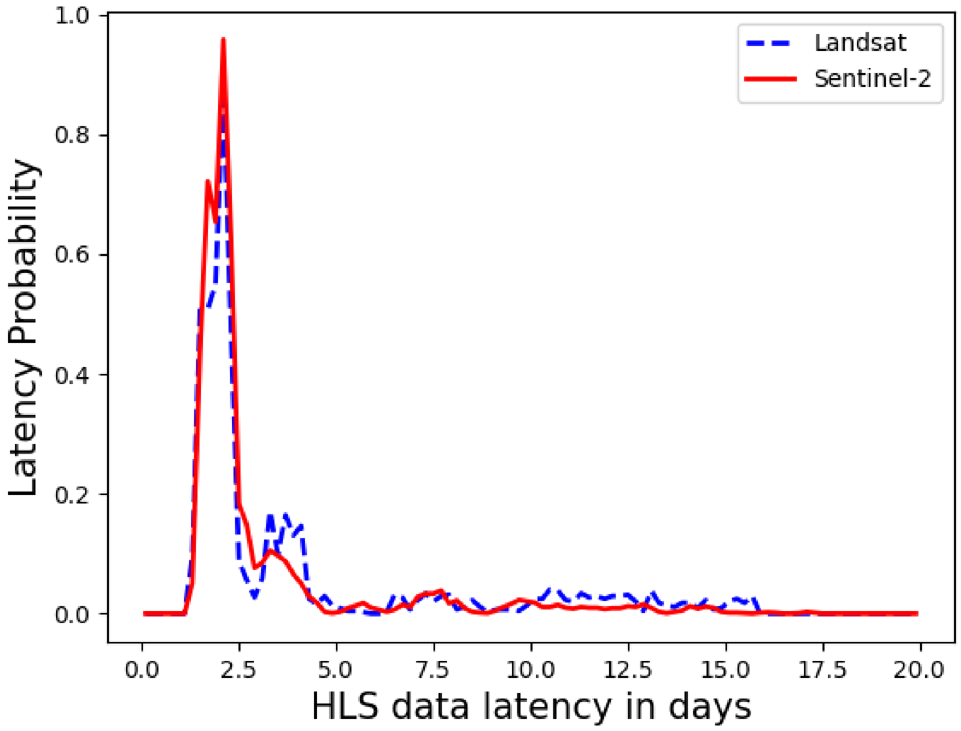
A Temporally Complete Global HLS v2.0 Data Set First Available in August, 2023

Data Production

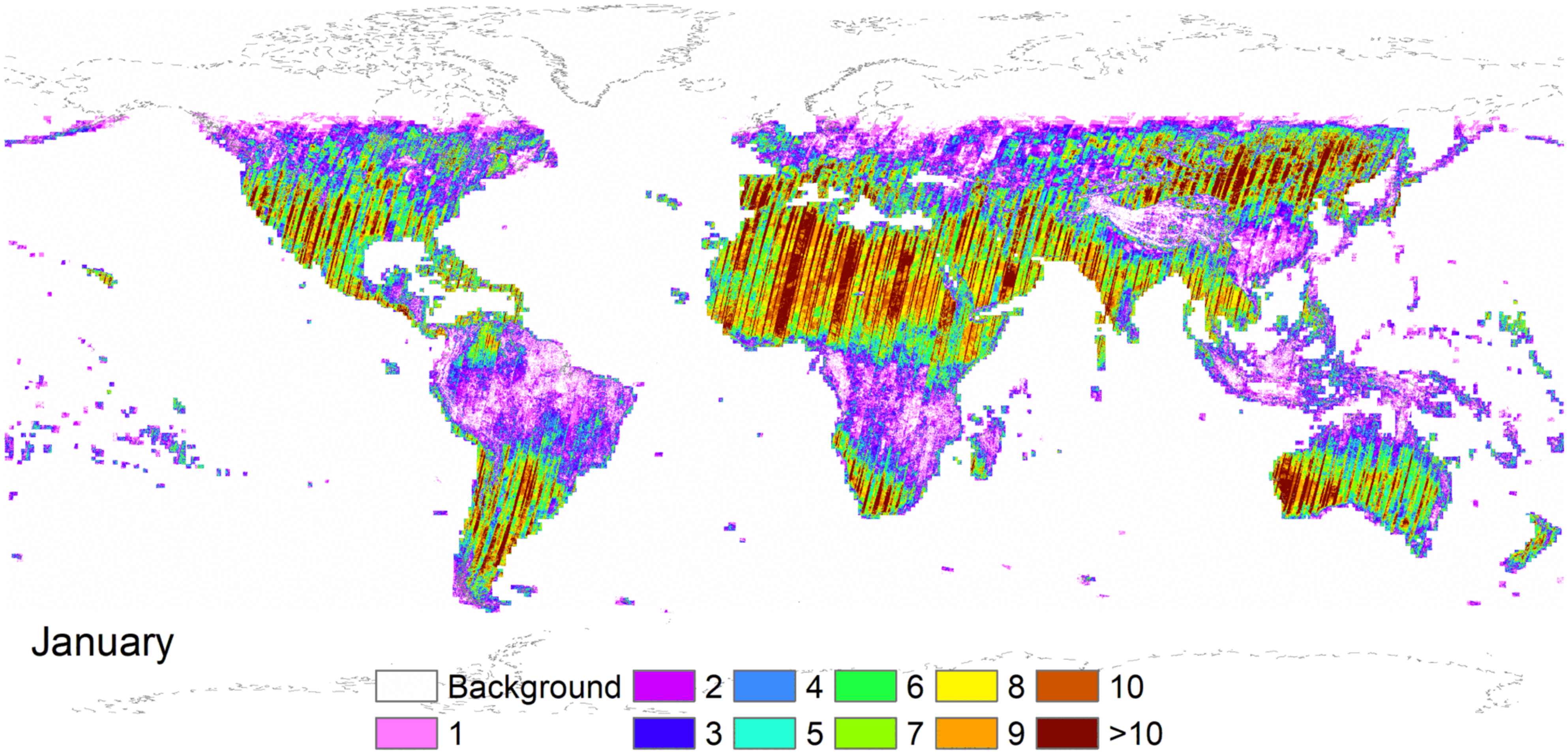
- Produced in AWS by NASA Marshall IMPACT team, with short latency, predominantly < 2.5 days
- Forward processing started in September 2021
- The processing of historical 2015-2021 Sentinel-2 data was finished in August 2023, i.e., a complete HLS v2.0 data set,
    - ❑ Landsat 8: 2013 – present
    - ❑ Sentinel-2A: 2015 – present
    - ❑ Sentinel-2B: 2017 – present
    - ❑ Landsat 9: 2021 – present

- ~5PB so far

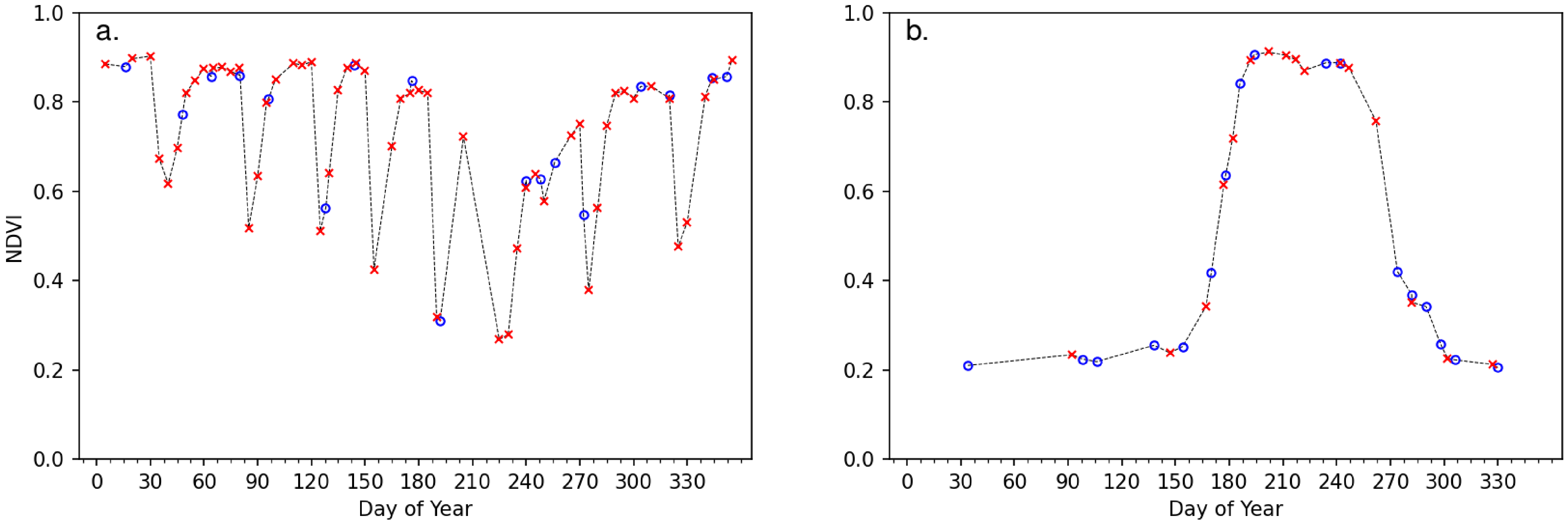
Data latency: from sensor overpass to product availability



The monthly number of cloud-free observations in HLS v2.0 2022 Data



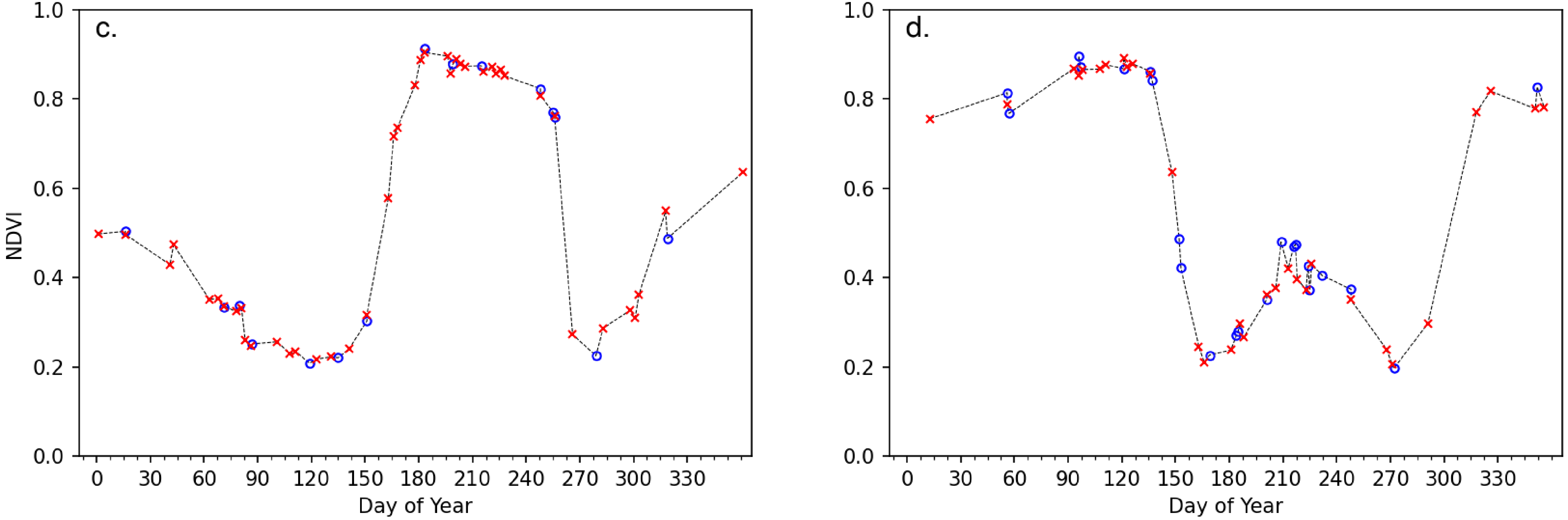
Zhou, Neigh, Ju, et al. (2024). Geophysical Research Letters (under review)



Example NDVI time series in 2022 for a few locations (o: Landsat, x:Sentinel-2).

(a) Salton Sea, California, USA (tile 11SPS, pixel (1514,1908));

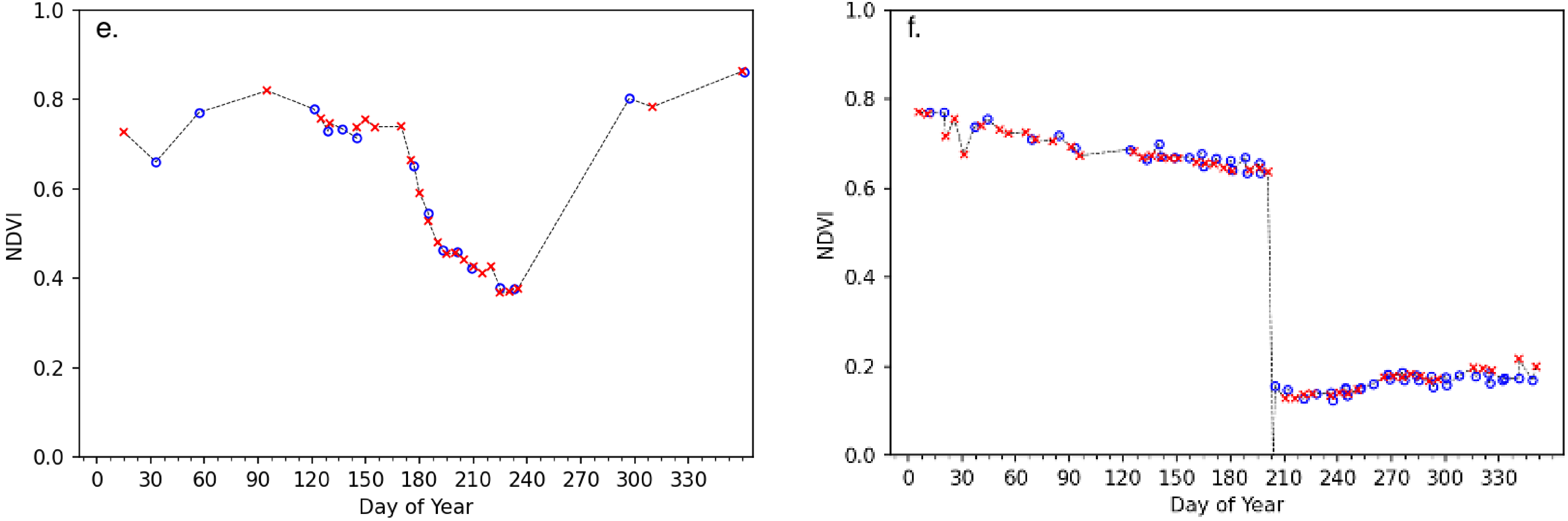
(b) Single-crop farmland near Sioux Falls, South Dakota, USA (tile 14TPP, pixel (2534,2158));



Example NDVI time series in 2022 for a few locations (o: Landsat, x:Sentinel-2).

(c) Single-crop farmland near Munich, Germany (tile 32UQU, pixel (282,2212));

(d) Winter-wheat with fallow summer in Shaanxi, China (tile 48SYD, pixel (1942,2780));



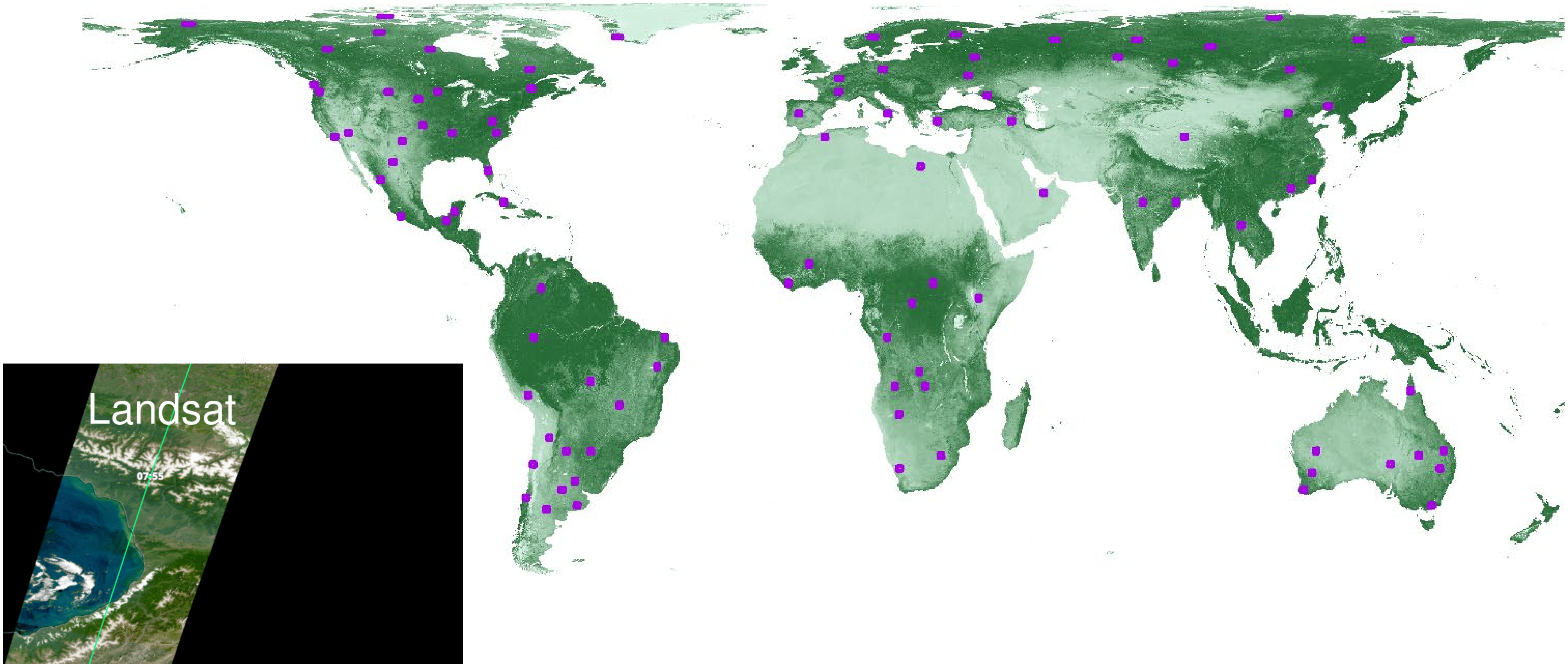
Example NDVI time series in 2022 for a few locations (o: Landsat, x:Sentinel-2).

(e) Farmland converted from forest in Brazilian Amazon (tile 20LNP, pixel (1938, 1658));

(f) 2022 Oak Fire in California, USA (tile 11SKB, pixel (1486, 1298)).

Data Consistency Evaluation Sites

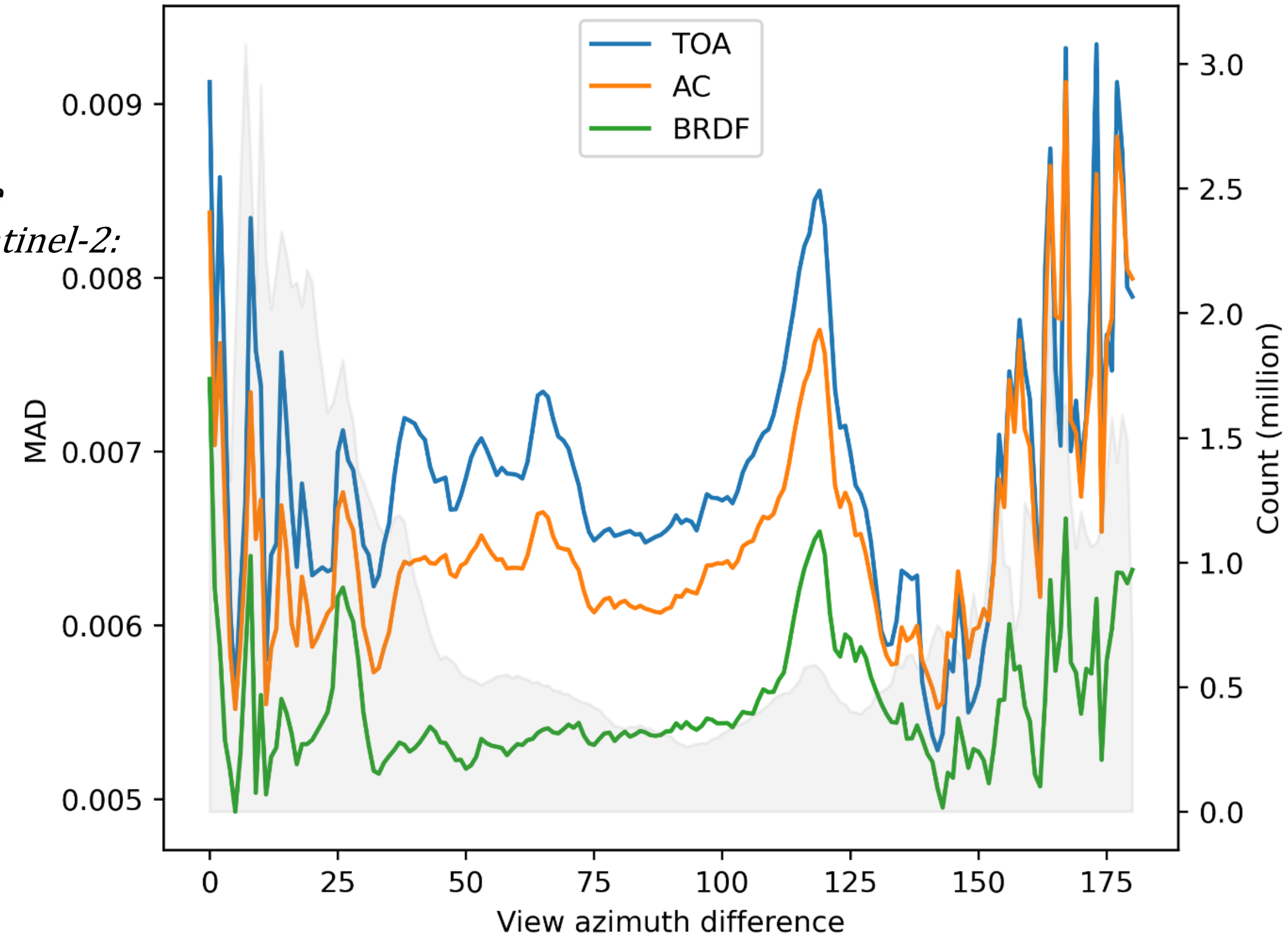
540 pairs of same-day Landsat and Sentinel-2 granules
over 96 tiles in 2021-2022



MD as a function of view azimuth difference in the observation pairs

Mean Absolute Difference Between Landsat and Sentinel-2:

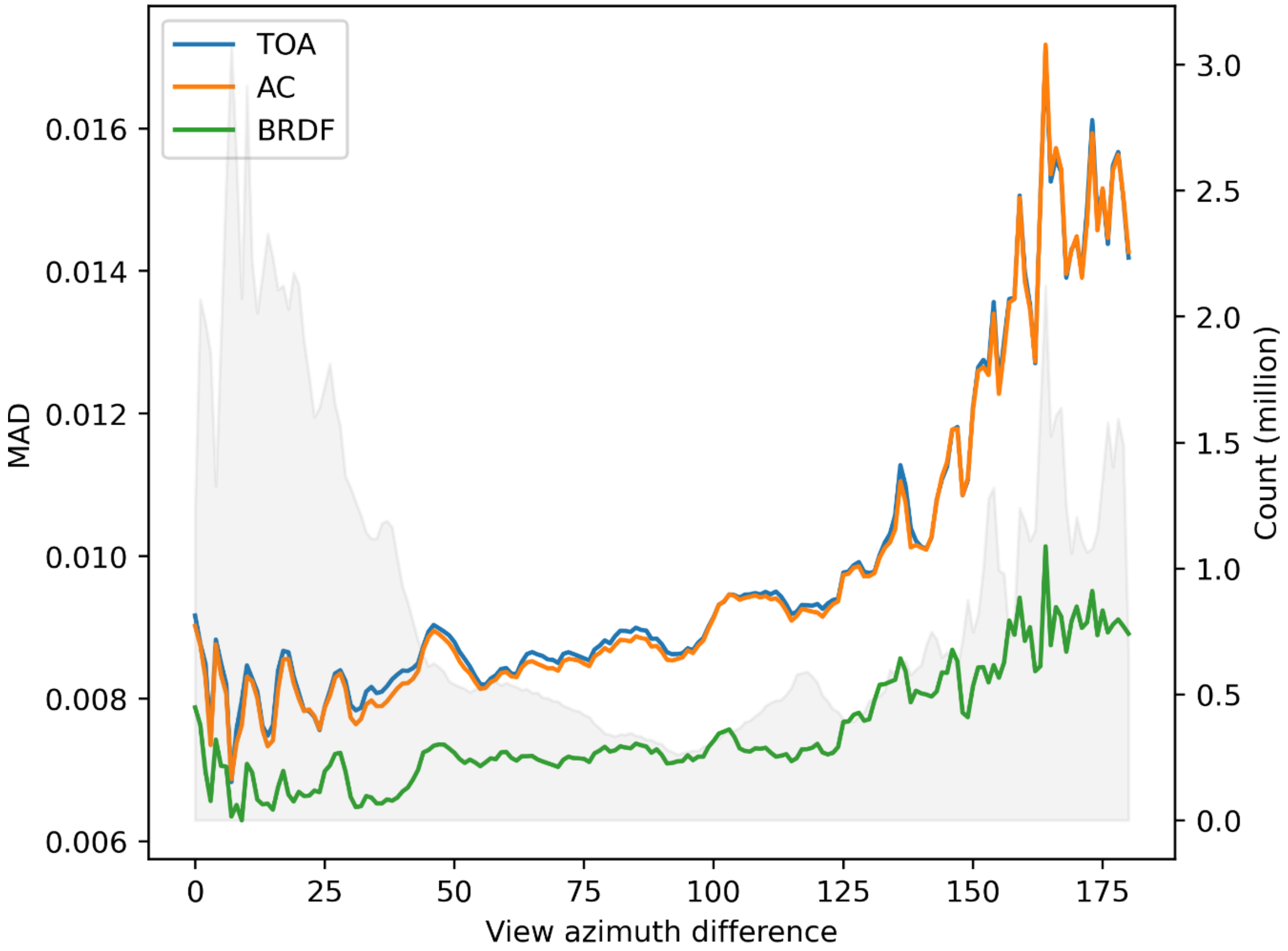
$$MD = \frac{\sum_i^n |r_i^S - r_i^L|}{n}$$



Red

MD as a function of view azimuth difference in the observation pairs

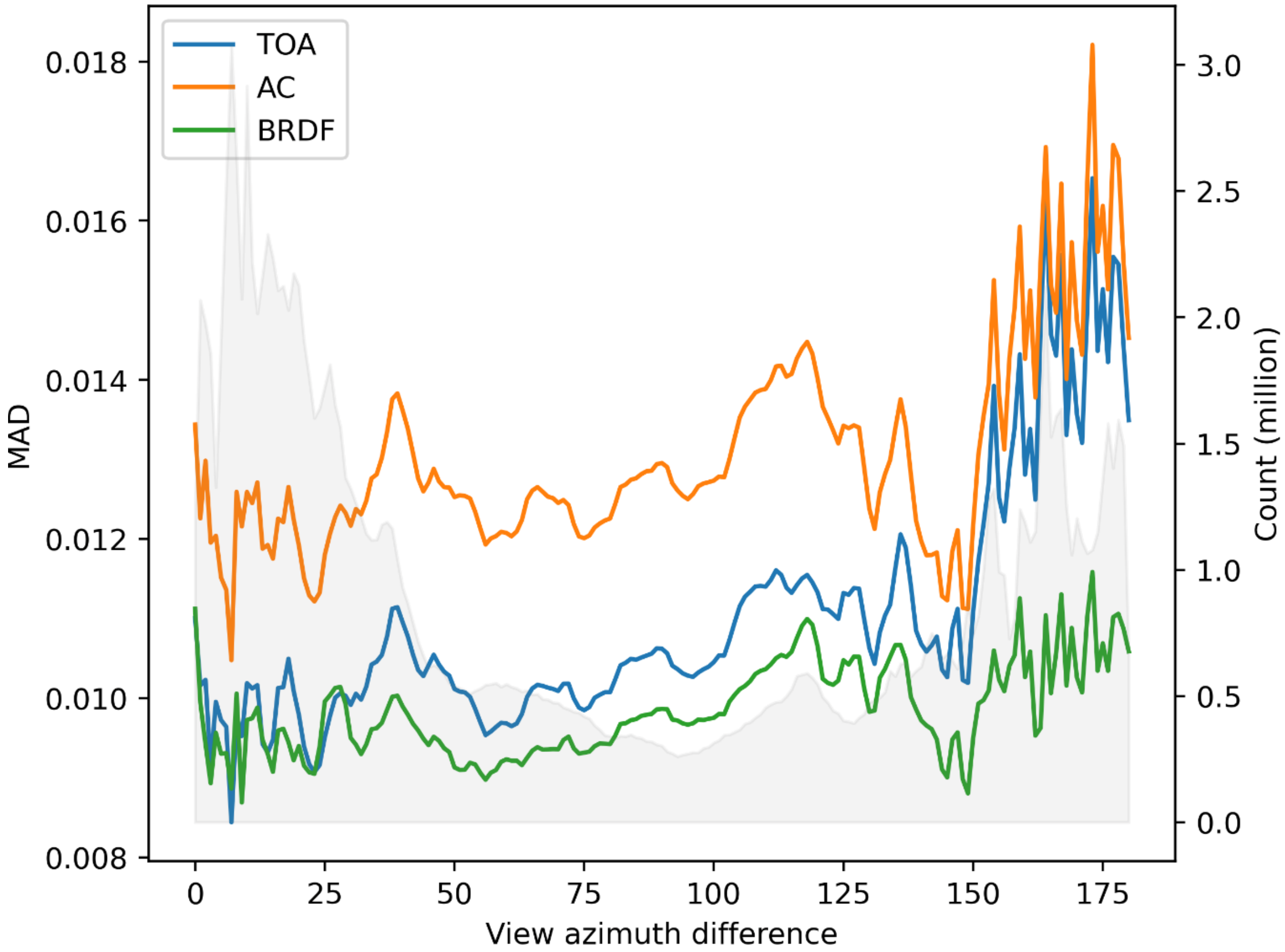
$$MD = \frac{\sum_i^n |r_i^S - r_i^L|}{n}$$



NIR

MD as a function of view azimuth difference in the observation pairs

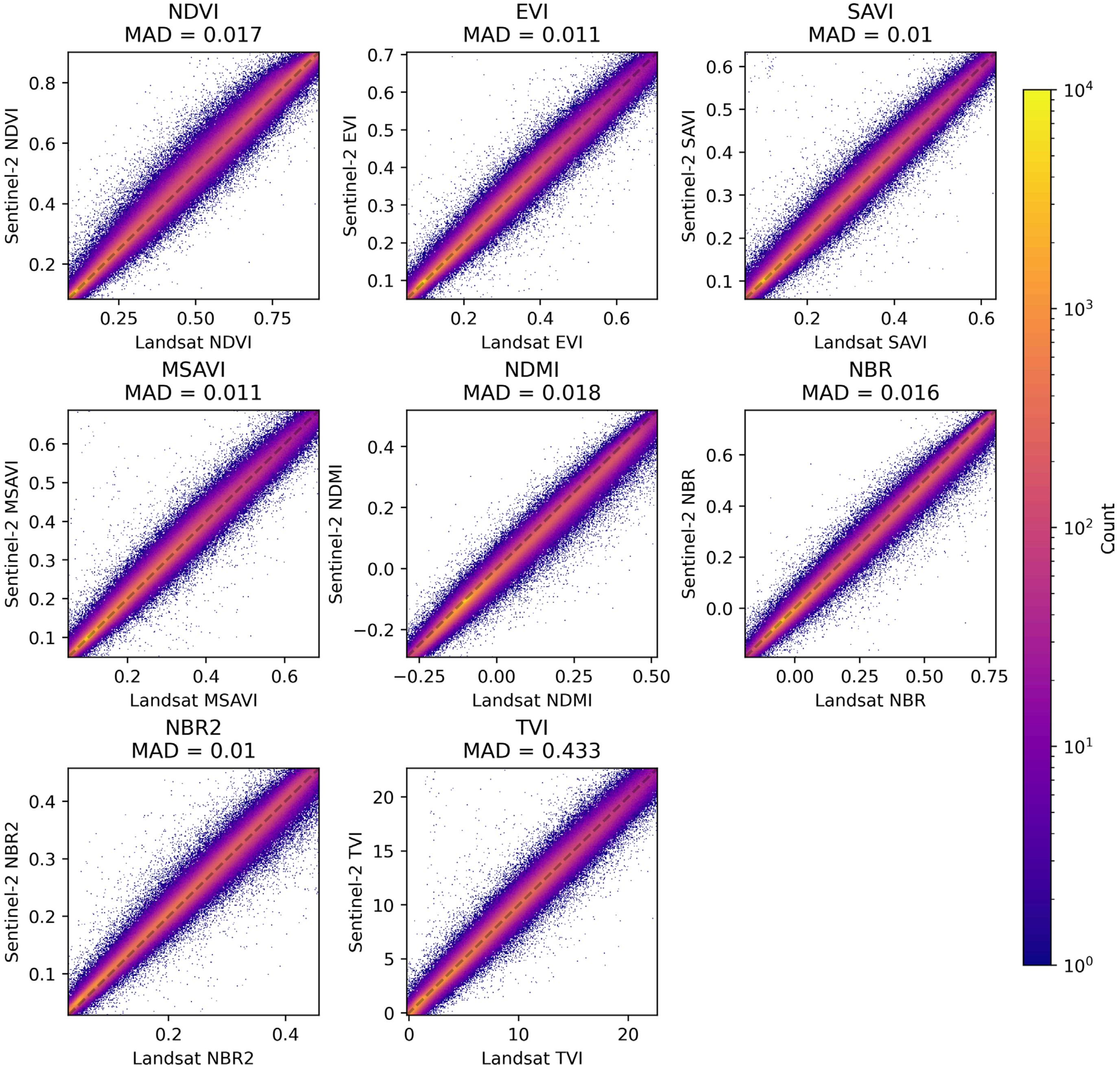
$$MD = \frac{\sum_i^n |r_i^S - r_i^L|}{n}$$



SWIR 1

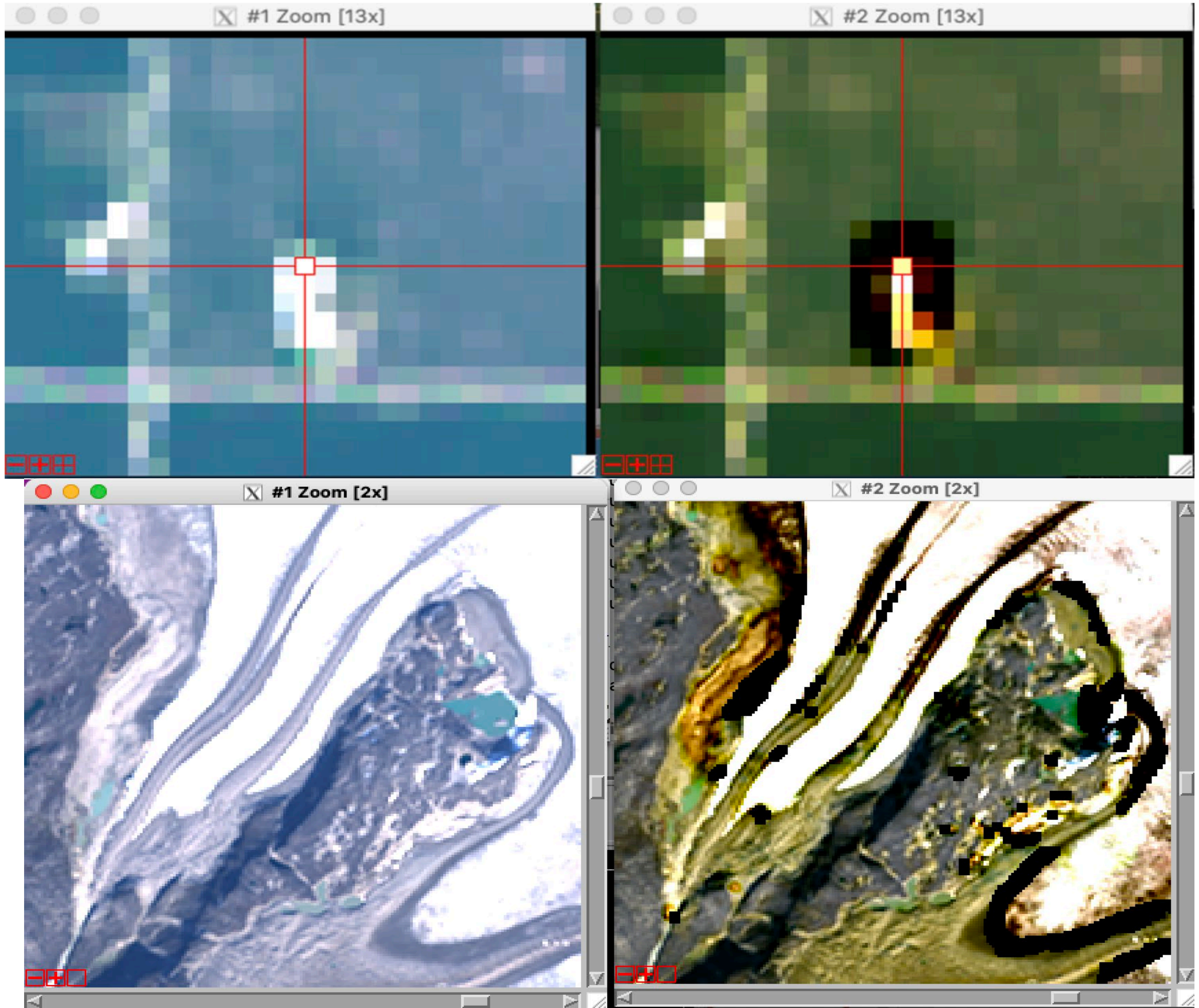
	TOA		Atmospheric correction		BRDF		Bandpass	
	MD	MD/Landsat (Percentage)	MD	MD/Landsat (Percentage)	MD	MD/Landsat (Percentage)	MD	MD/Landsat (Percentage)
Blue	0.0047	3.9	0.0055	9.0	0.0051	8.3	0.0048	8.2
Green	0.0041	3.4	0.0054	5.6	0.0054	5.6	0.0055	5.8
Red	0.0065	4.7	0.0066	5.2	0.0056	4.4	0.0052	4.2
NIR	0.0093	3.4	0.0099	3.6	0.0075	2.8	0.0076	2.8
SWIR1	0.0104	3.9	0.0131	4.7	0.0098	3.6	0.0093	3.4
SWIR2	0.0075	4.0	0.0087	4.3	0.0069	3.4	0.0065	3.2

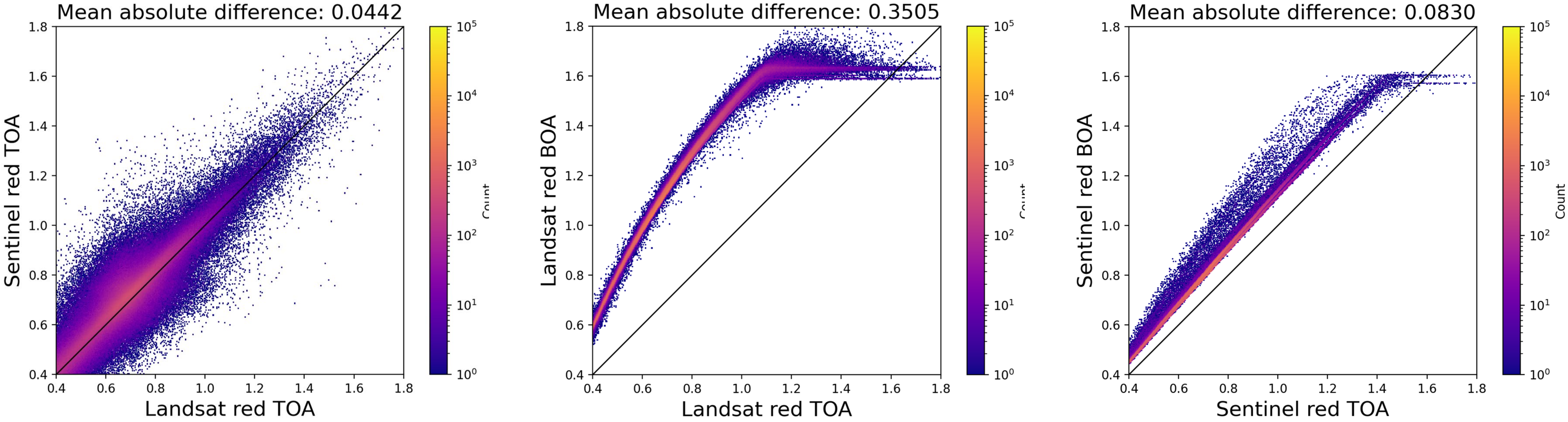
Vegetation Indices from Sameday Landsat and Sentinel Reflectance



Known Issues: dark ring around bright targets

TOA BOA




Mean absolute difference: 0.0442
Sentinel red TOA
Landsat red TOA
Count
Mean absolute difference: 0.3505
Landsat red BOA
Landsat red TOA
Count
Mean absolute difference: 0.0830
Sentinel red BOA
Sentinel red TOA
Count

Data Access and Utilization

Data Access

- https://www.earthdata.nasa.gov/
  both manual and API

  Example Bash script for bulk download
  https://git.earthdata.nasa.gov/projects/LPDUR/repos/hls-bulk-download/browse/getHLS.sh

- https://worldview.earthdata.nasa.gov/
  for exploratory and manual download

- Directly in AWS

- Google Earth Engine (L30 so far)

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  Example Bash script for bulk download
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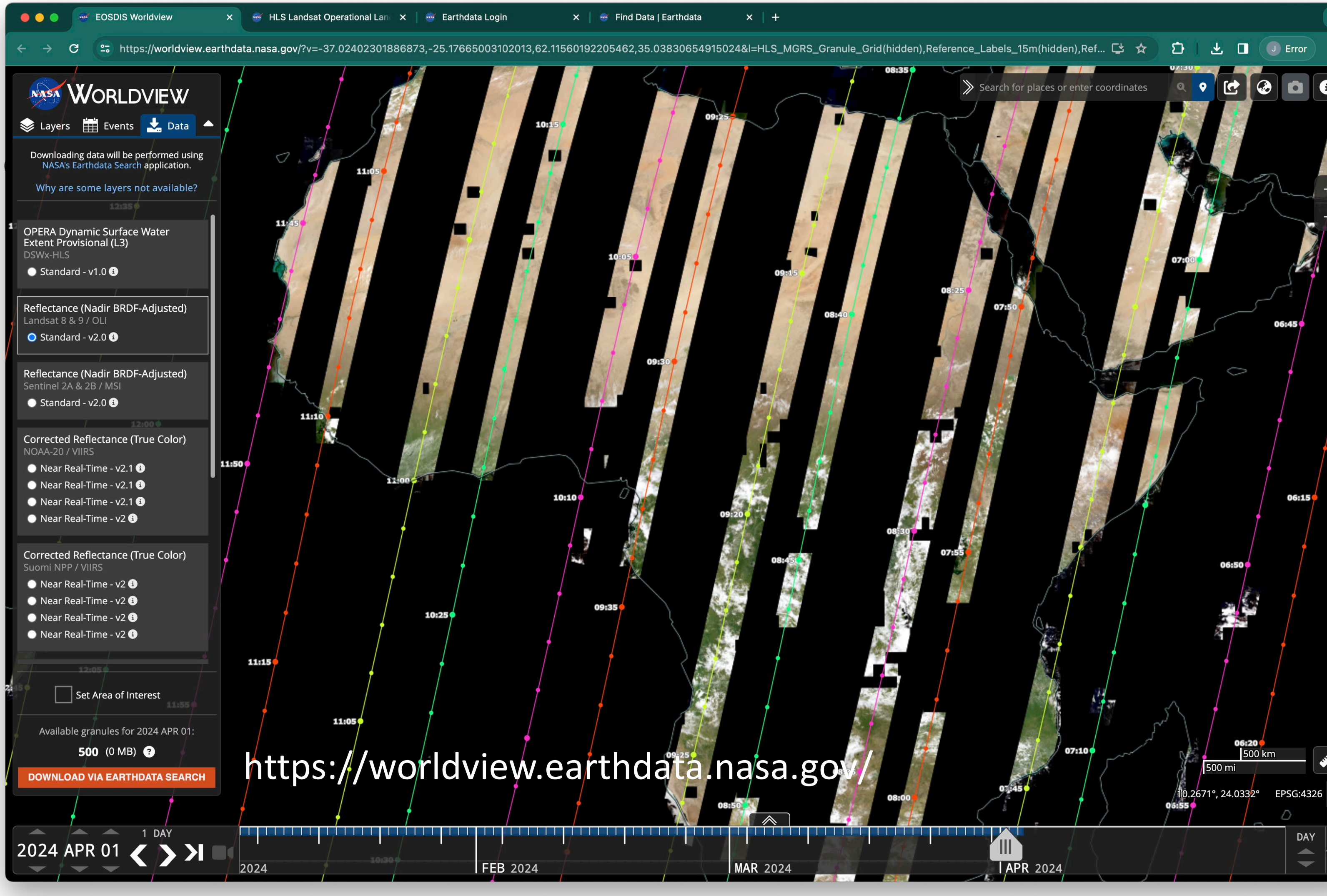

Example HLS Applications

- **HLS v1.4**

Phenology mapping of North America (Bolton et al., 2020)
Land cover mapping of Germany (Griffiths et al., 2019)
USDA crop emergence detection (Gao et al., 2021)
Crop yield prediction in Ukraine (Skakun et al., 2019)

- **HLS v2.0**

Observational Products for End-Users from Remote Sensing Analysis (OPERA):

- ❑ Dynamic Surface Water Extent (John Jones)
- ❑ Land Surface Disturbance product (DIST) (Matt Hansen)

HLS Future Plans

1. HLS Vegetation Index Suite
    - Production to begin
2. Cloud Mask Improvement by Zhe Zhu
    - Almost completed
3. LaSRC Improvement by Eric Vermote
    - To begin
4. 10m HLS?
    - More valuable with the improved geolocation in Sentinel-2 Collection 1 (< 6.1m uncertainty)
5. Reprocessing ?