NOAA-21 VIIRS Surface Type Beta/Provisional Maturity

June 13, 2024

VIIRS Surface Type Team:
Xiwu Zhan (STAR); Chengquan Huang (UMD); Ivan (STAR)

Outline

- Surface Type Team Members
- Product Requirements
- Findings/Issues for NOAA-21 Maturity for Surface Type Monitoring
- Conclusions and Path Forward

STAR Surface Type Team

Name	Organization	Major Task
Xiwu Zhan	NESDIS/STAR	Surface Type lead
Chengquan Huang	UMD	Surface type algorithm/product lead
Zhenhua Zou	UMD	Code refinement and optimization
Jiaming Lu	UMD	Data processing
Undergraduate students	UMD	Training and validation data collection
Ivan Csiszar	NESDIS-STAR	VIIRS Land Team Lead

AST Requirements from JPSS L1RD

Attribute	Objective
Geographic coverage	Global
Vertical Coverage	
Vertical Cell Size	N/A
Horizontal Cell Size	1 km at nadir
Mapping Uncertainty	1 km
Measurement Range	17 IGBP classes
Measurement Accuracy	70% correct

- Evergreen Needleleaf Forests
- Evergreen Broadleaf Forests
- Deciduous Needleleaf Forests
- Deciduous Broadleaf Forest
- Mixed Forests
- Closed Shrublands
- Open Shrublands
- Woody Savannas
- Savannas
- Grasslands
- Permanent Wetlands
- Croplands
- Urban and Built-up Lands
- Cropland/Natural Vegetation Mosaics
- Snow and Ice
- Barren
- Water Bodies

JPSS/GOES-R Data Product Validation Maturity Stages – COMMON DEFINITIONS (Nominal Mission)

1. Beta

- Product is minimally validated, and may still contain significant identified and unidentified errors.
- Information/data from validation efforts can be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose.
- Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists.

2. Provisional

- Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from selected locations, time periods, or field campaign efforts.
- Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.
- Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists.
- Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.

3. Validated

- Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).
- Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.
- Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.
- Product is ready for operational use based on documented validation findings and user feedback.
- Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument.

Surface Type Maturity Evaluation Methodology

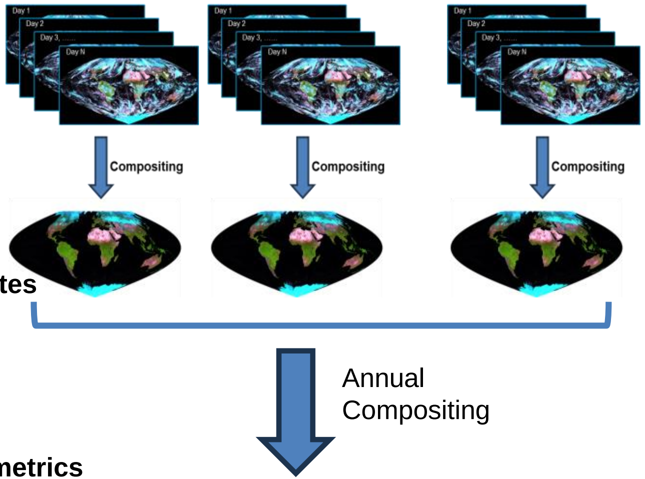
- Assess how comparable NOAA-21 and NOAA-20 data are for surface type monitoring
  - Directly compare NOAA-21 data to NOAA-20 data at each key step of the AST algorithm
  - S-NPP and NOAA-20 were found highly comparable for surface type monitoring during the NOAA-20 maturity review
- Demonstrate the synergy of NOAA-20/21 for surface type monitoring

Key Inputs to the Surface Type Mapping Algorithm

VIIRS Surface Reflectance Data (12 Months)

Month 1 Month 2 ………. Month 12

Daily mosaics



Monthly composites

Annual Compositing

Annual metrics

Metrics number(s)	Description
1	Maximum NDVI value
2	Minimum NDVI value of eight greenest months
3	Mean NDVI value of eight greenest months
4	Amplitude of NDVI over eight greenest months
5	Mean NDVI value of four warmest months
6	NDVI value of warmest month
7,14,21,28,35,42,49,56,63	Maximum band *x* value of eight greenest months
8,15,22,29,36,43,50,57,64	Minimum band *x* value of eight greenest months
9,16,23,30,37,44,51,58,65	Mean band *x* value of eight greenest months
10,17,24,31,38,45,52,59,66	Amplitude of band *x* value over eight greenest months
11,18,25,32,39,46,53,60,67	Band *x* value from month of maximum NDVI
12,19,26,33,40,47,54,61,68	Mean band *x* value of four warmest months
13,20,27,34,41,48,55,62,69	Band *x* value of warmest month

Note: *x* is the band used in annual metrics, which includes M1, M2, M3, M4, M5, M7, M8, M10 and M11.

Ancillary Data

>100K globally distributed points for training the classification algorithm

~6000 randomly selected points for validating the AST map

Ancillary data are updated annually using a semi-automated approach

Reference Data for Post-Processing (Partial List)

- JRC Landsat-based water product suite (2016-2020, 30m)
- GLC-FCS30: Landsat-based land cover map (2020, 30m)
- 2020 WorldCover (10m, by ESA)
- ESRI 2020 land cover product (10m)
- GlobeLand 2020 (30m)
- FromGLC (2017, 10m)
- GLAD global land cover (2019, 30m)

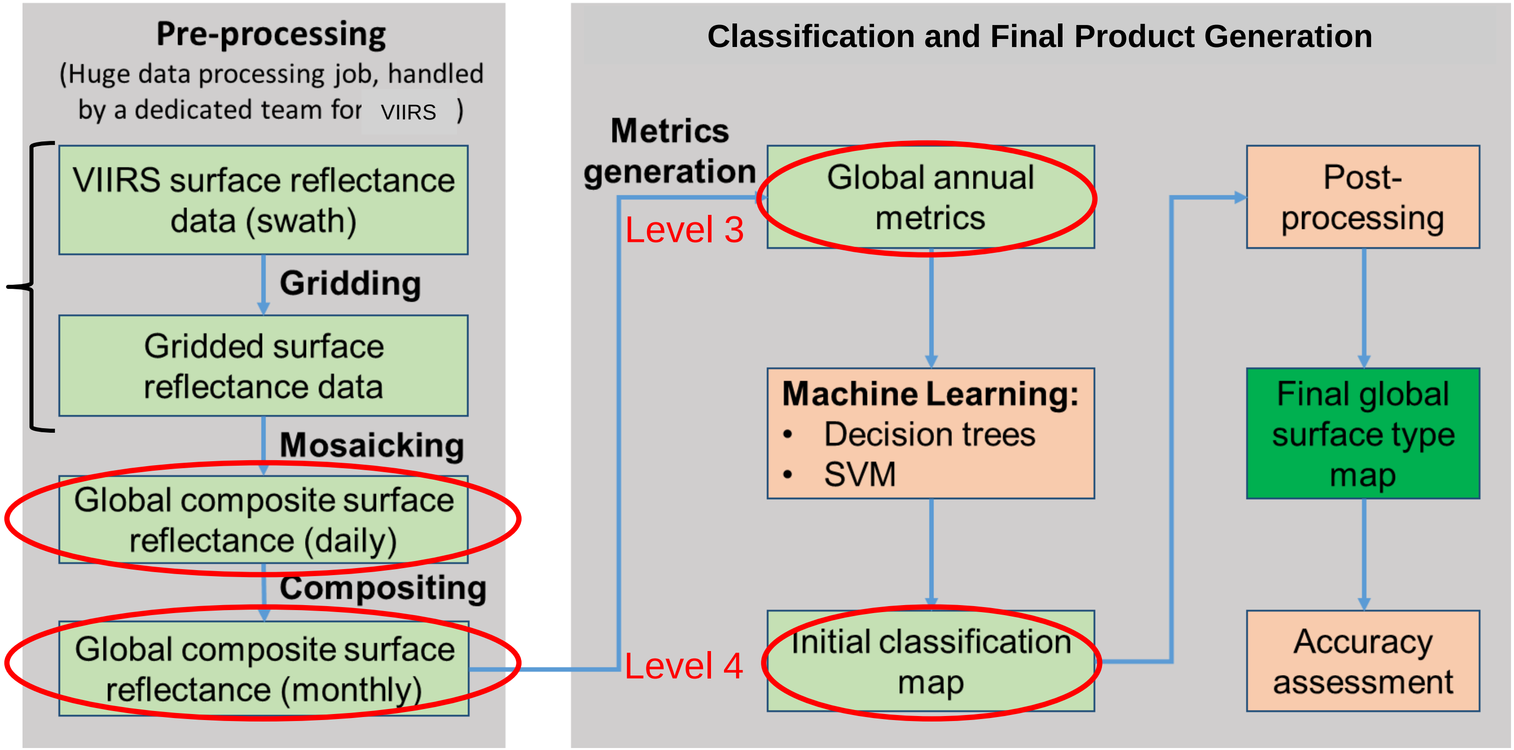
NOAA-21 VIIRS Annual Surface Type Product Algorithm

Swath level Comparison Impossible:

Pixels from different satellites cannot be aligned on top of each other before they are mapped to a common gridded space.

Level 1

Level 2



Comparison at levels 1-4 possible

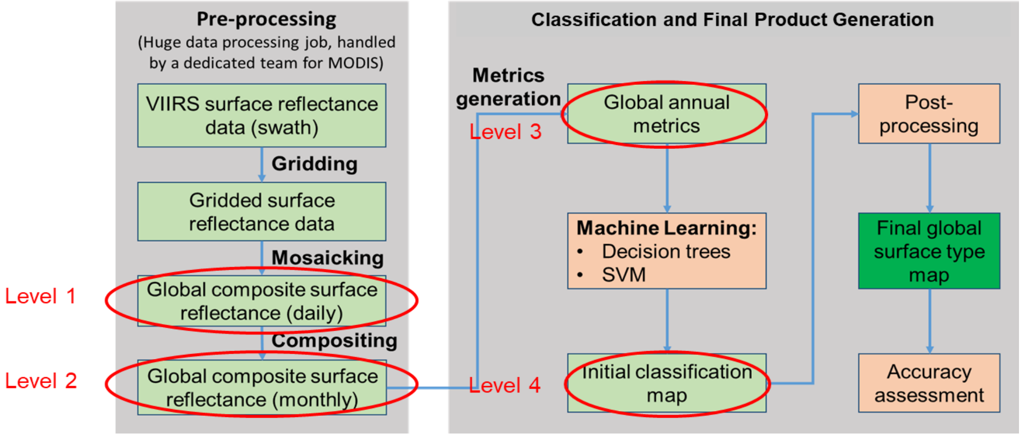
Major Steps of the VIIRS Annual Surface Type (AST) Algorithm

AST Algorithm and Product Evaluation Method

- Input and Output Data evaluated
  - Granule surface reflectance data from VIIRS SR team (downloaded from NOAA CLASS/AWS)
    - Gridded daily data (Level 1)
    - Monthly composites (Level 2)
    - Annual metrics (Level 3)
  - Annual surface type product (Level 4)

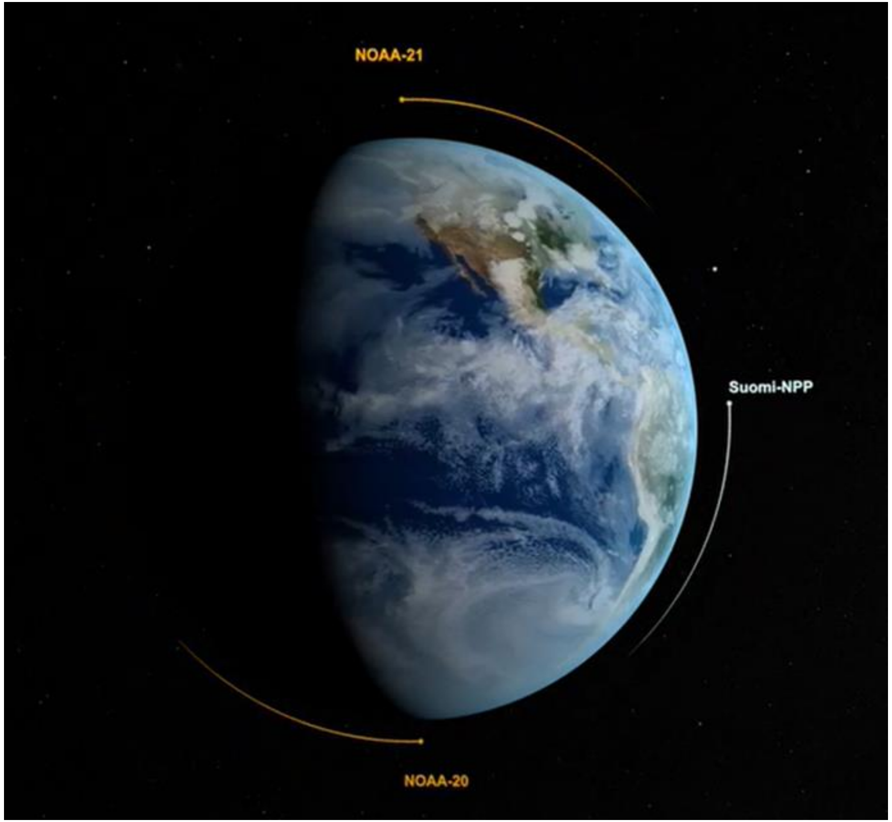
- Evaluation Approach
  - Image/map level: Visual comparison
  - Pixel level: Scatter plots

- Focus on bands used by the surface type mapping algorithm
  - M1-M5, M7, M8, M10, M11
- Be as thorough as possible
  - Include regions across the globe
  - Maximize the month range of NOAA-21 surface reflectance (SR) data available to this assessment (2023/11-2024/04)



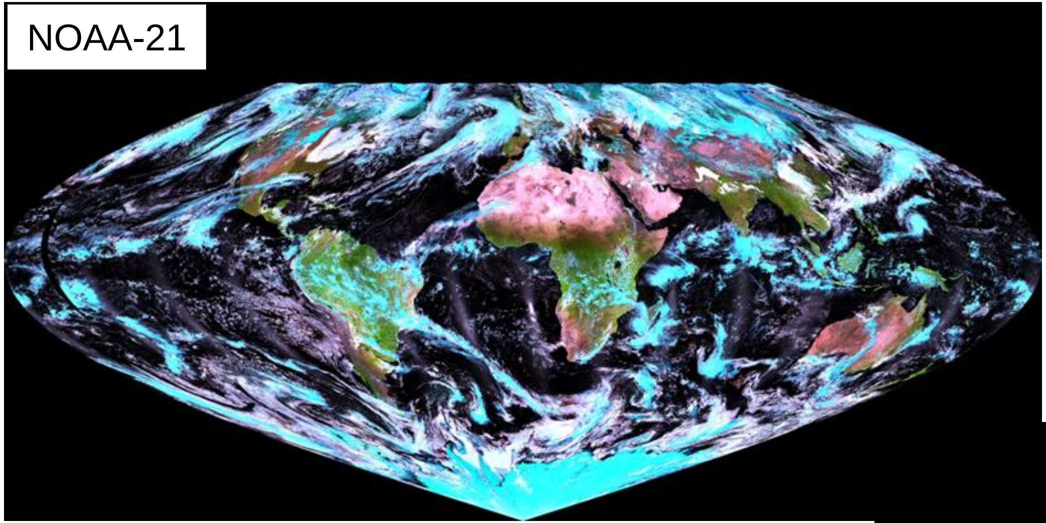
VIIRS on NOAA-21 and NOAA-20 Are Near Identical

- Same spectral bands
- Same spatial resolutions
- Follow each other on the same orbit
  - NOAA-21 leading S-NPP and NOAA-20 by ~25 and 50 minutes, respectively

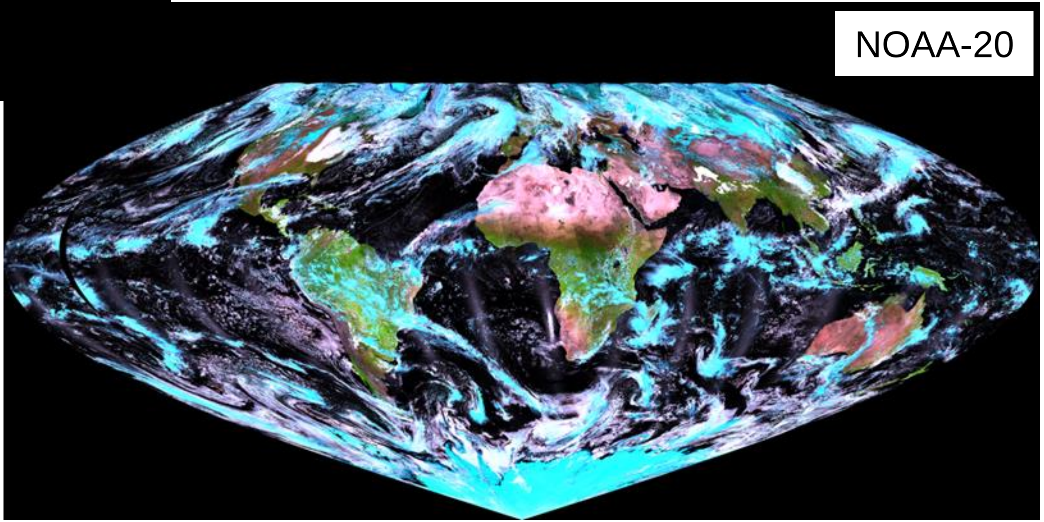


From: https://www.nesdis.noaa.gov/our-satellites/currently-flying/joint-polar-satellite-system

Level 1: Global Daily Mosaics Are Very Similar



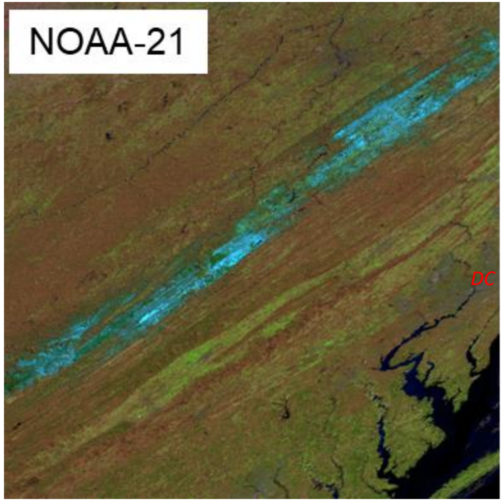
These composites were created using VIIRS observations acquired on 1/1/2024

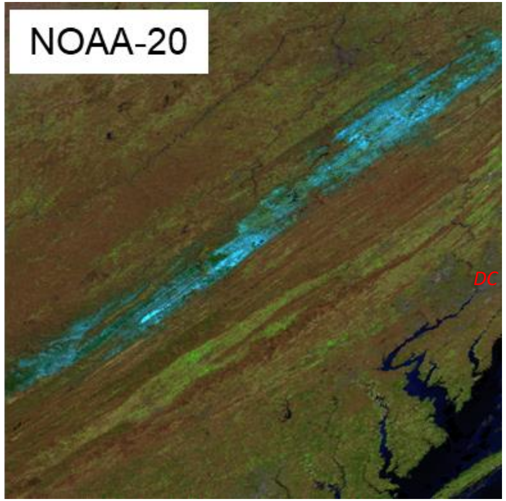


Note: All surface reflectance images in this review are shown with M10/M7/M5 in the red, green, and blue guns:

- Green tones – vegetation
- Black/dark blue – water;
- White/cyan – cloud
- Cyan – snow/cloud
- Brown/gray (various shades) – low/no vegetation cover

NOAA-21 and NOAA-20 Data Are Correlated

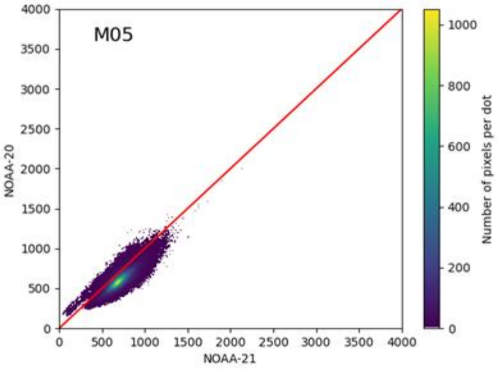


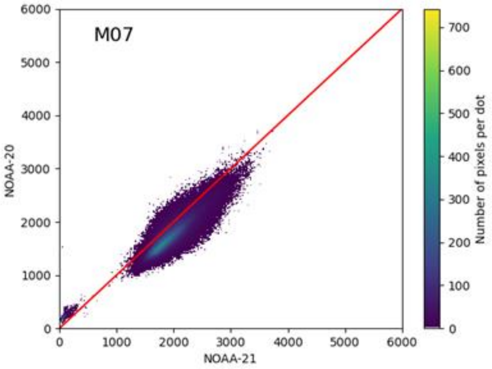


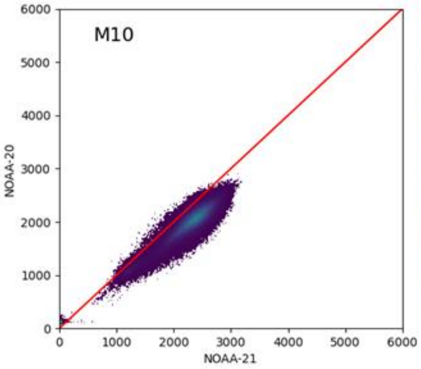
DC Area

3/11/2024

Note: *The units of the x- and y-axis of all scatter plots in this review are surface reflectance value x 10000. For example, 2000 means the surface reflectance value is 0.2, or 20%.*

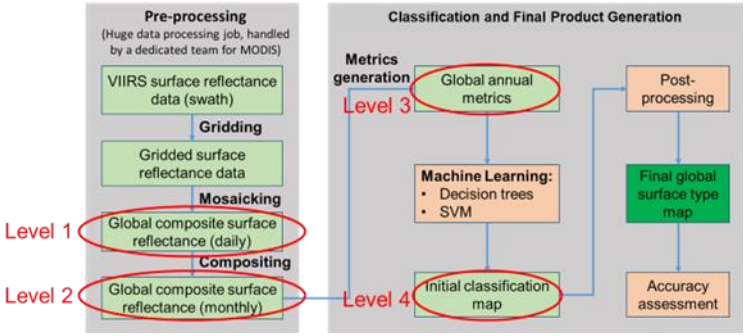


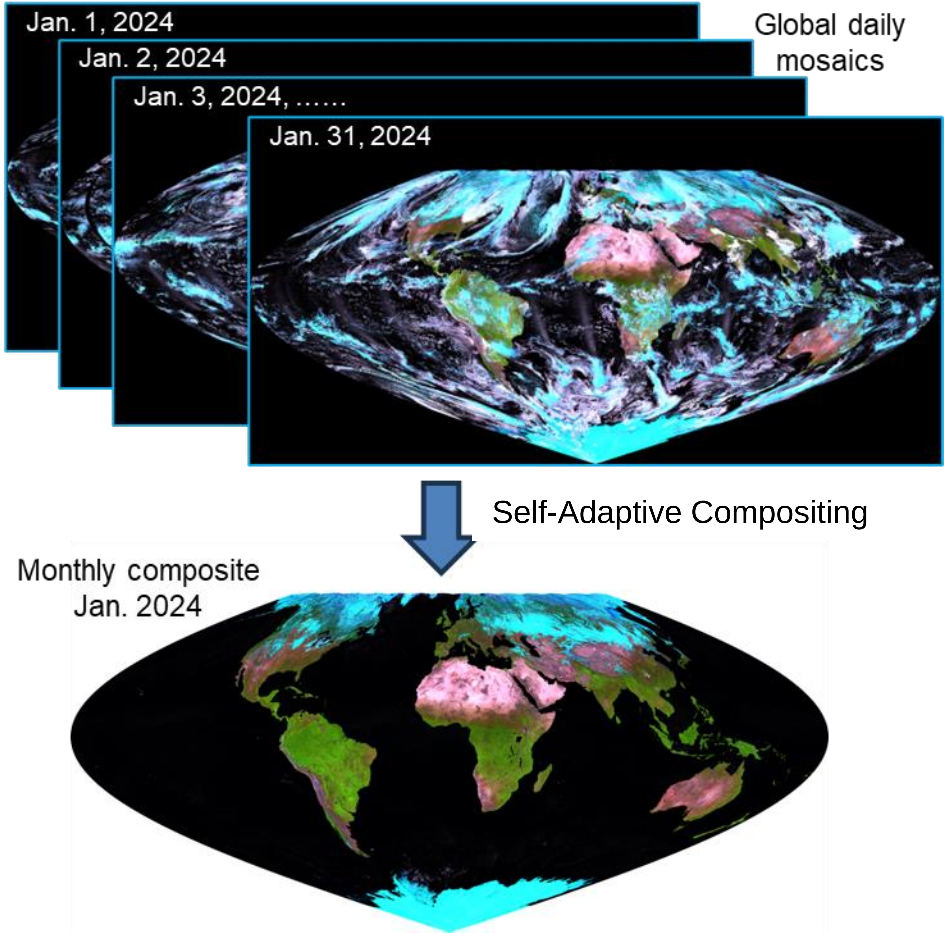




Level 2 Assessment: Monthly Composites

- **Purpose of monthly compositing**: required for calculating classification metrics for AST
- **Method**:
  - For each pixel, select the *best observation* within each month to represent data for the month
- **Input**:
  - Gridded daily composited surface reflectance for all days within the month
- **Output**
  - near cloud free surface reflectance for the month





Same Compositing Algorithm for All VIIRS Data

Better Than MODIS

Heritage Methods

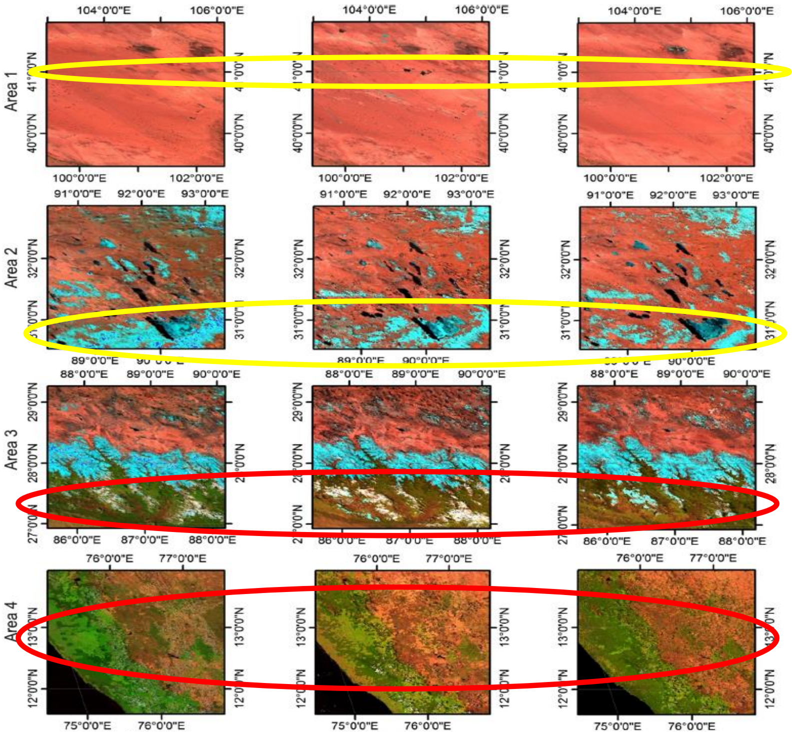
Less shadow

Non-snow selected when snow exists

Less cloud

Smoother results over vegetated and non-vegetated areas

MOD09A1 | NASA VNP09A1 | SA-Comp

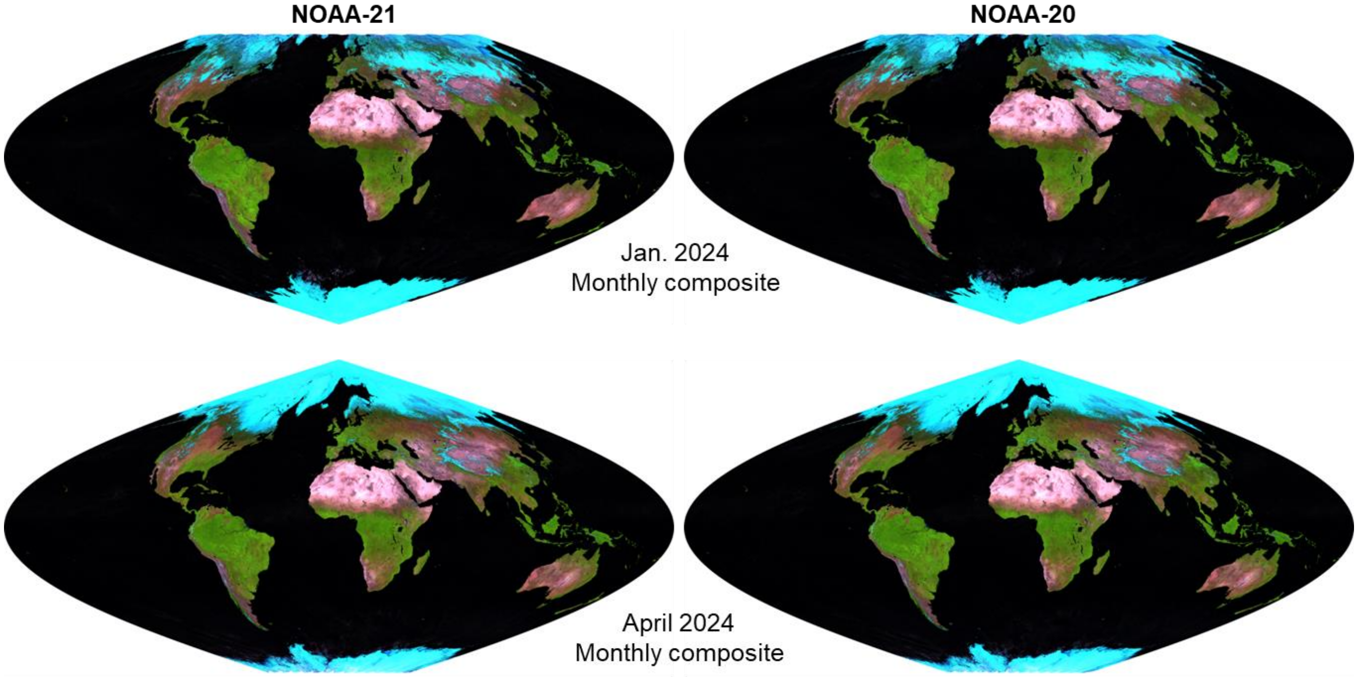


Bian, J., Li, A., Huang, C., Zhang, R., & Zhan, X. (2018). A self-adaptive approach for producing clear-sky composites from VIIRS surface reflectance datasets. *ISPRS Journal of Photogrammetry and Remote Sensing, 144, 189-201.*

Self-Adaptive Compositing (SA-Comp) Method for VIIRS

Monthly Composite Assessment Results

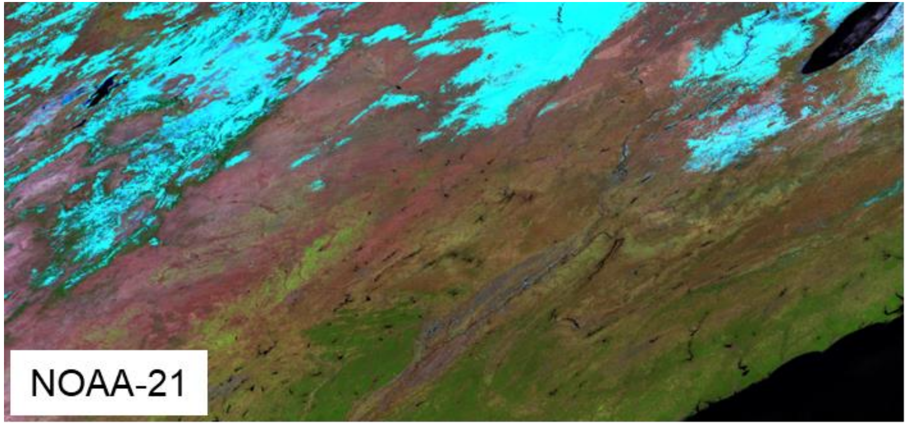
- Months considered: Nov. 2023 – April 2024
  - Full month of validated NOAA-21 SR data not available before Nov. 2023
- The composites from NOAA-21 and NOAA-20 are very similar at the global scale

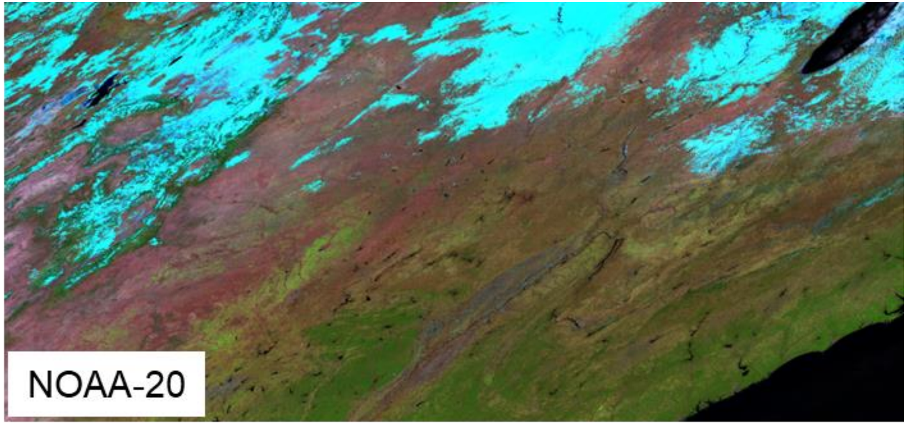


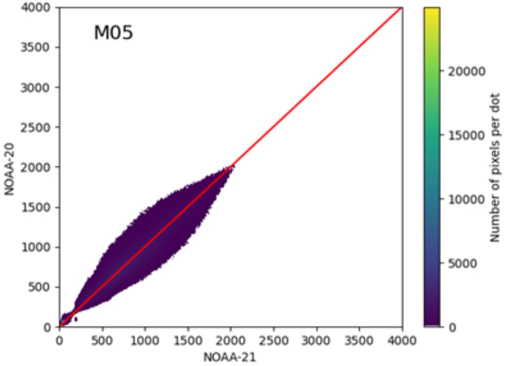
Pixel Level Comparison of Monthly Composites

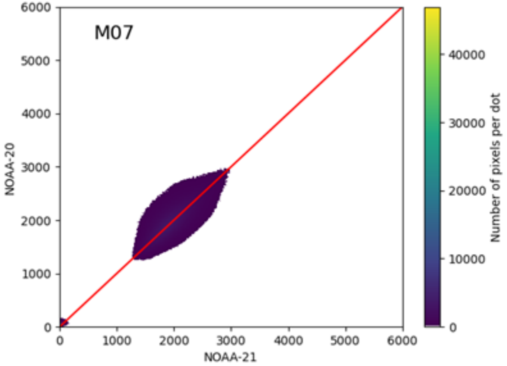
East/Central US

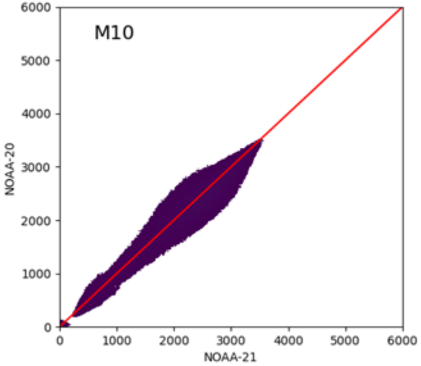
(~3000 km x 1400 km, Jan. 2024 monthly composite)











Level 3 Assessment: Classification Metrics

Purpose of Annual Metrics:

- Capture annual phenological patterns for each surface type
- Minimize spectral differences between northern and southern hemispheres and/or along other geographical gradients

Input: 12 monthly composites (May 2023 – April 2024)

- November 2023 – April 2024
  - NOAA-20 monthly composites used to create NOAA-20 metrics
  - NOAA-21 monthly composites used to create NOAA-21 metrics
- Other months
  - 2023 NOAA-20 data used to create both sets: No NOAA-21 composites before November 2023

Output: 69 metrics for AST algorithm (Zhang et al. 2016, 2017)

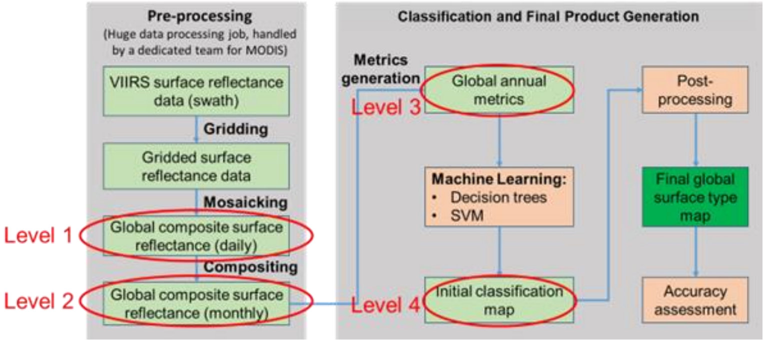


Table 2. Details of annual metrics used in classification.

Metrics number(s)	Description
1	Maximum NDVI value
2	Minimum NDVI value of eight greenest months
3	Mean NDVI value of eight greenest months
4	Amplitude of NDVI over eight greenest months
5	Mean NDVI value of four warmest months
6	NDVI value of warmest month
7,14,21,28,35,42,49,56,63	Maximum band *x* value of eight greenest months
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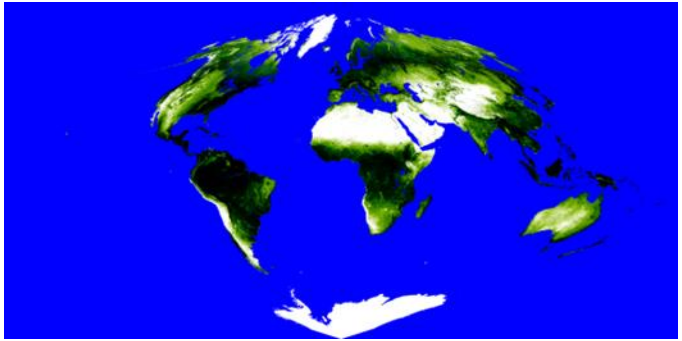
13,20,27,34,41,48,55,62,69	Band *x* value of warmest month

Note: *x* is the band used in annual metrics, which includes M1, M2, M3, M4, M5, M7, M8, M10 and M11.

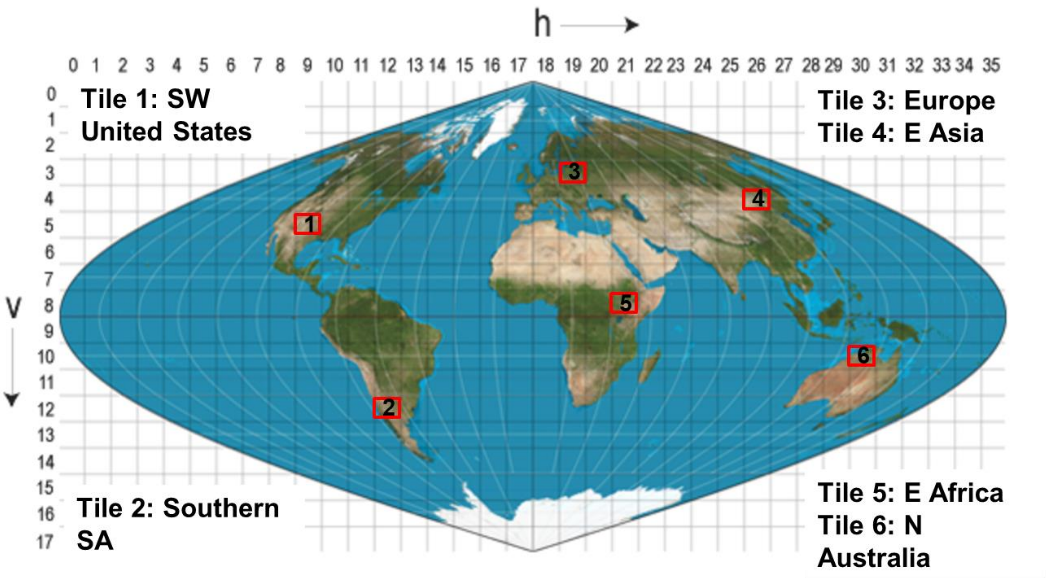
Metric 1: Max NDVI



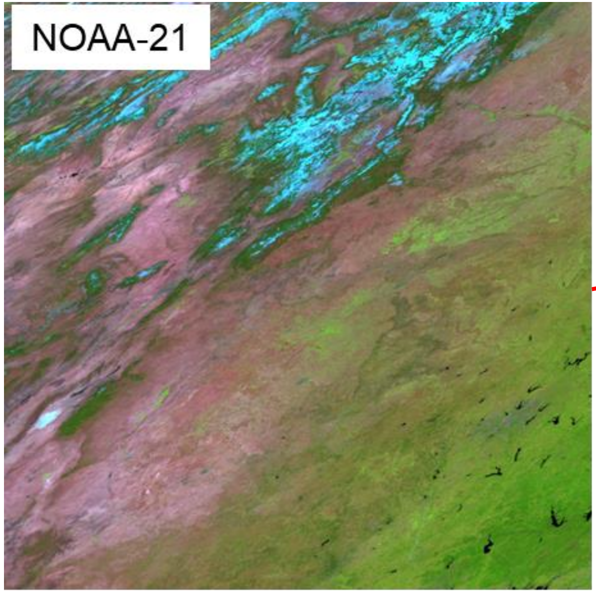
Results of the Metrics Assessment

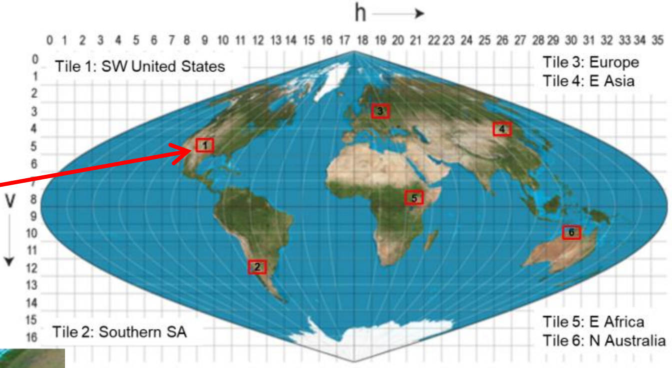
- 6 of 69 metrics over 6 areas presented
  - Max NDVI: Annual max NDVI value
  - Mean NDVI: Annual average NDVI
  - Mean4W NDVI: Average NDVI of four warmest months
  - Mean M05: Annual average M05 (red band) surface reflectance
  - Mean M07: Annual average M07 (near infrared band) surface reflectance
  - Mean M10: Annual average M10 (shortwave infrared band) surface reflectance

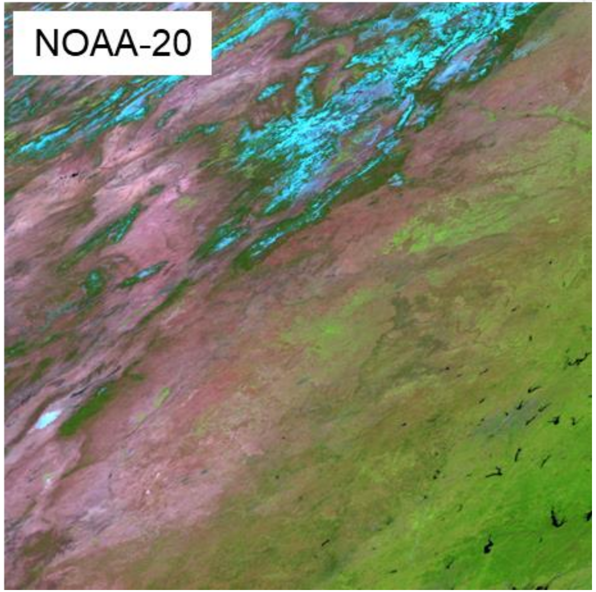
Location of the 6 selected tiles



Tile 1: Southwest US







Annual mean surface reflectance image shown with M10/M7/M5 in the red, green, and blue guns:

- Green tones – vegetation
- Black/dark blue – water;
- Cyan – snow/cloud
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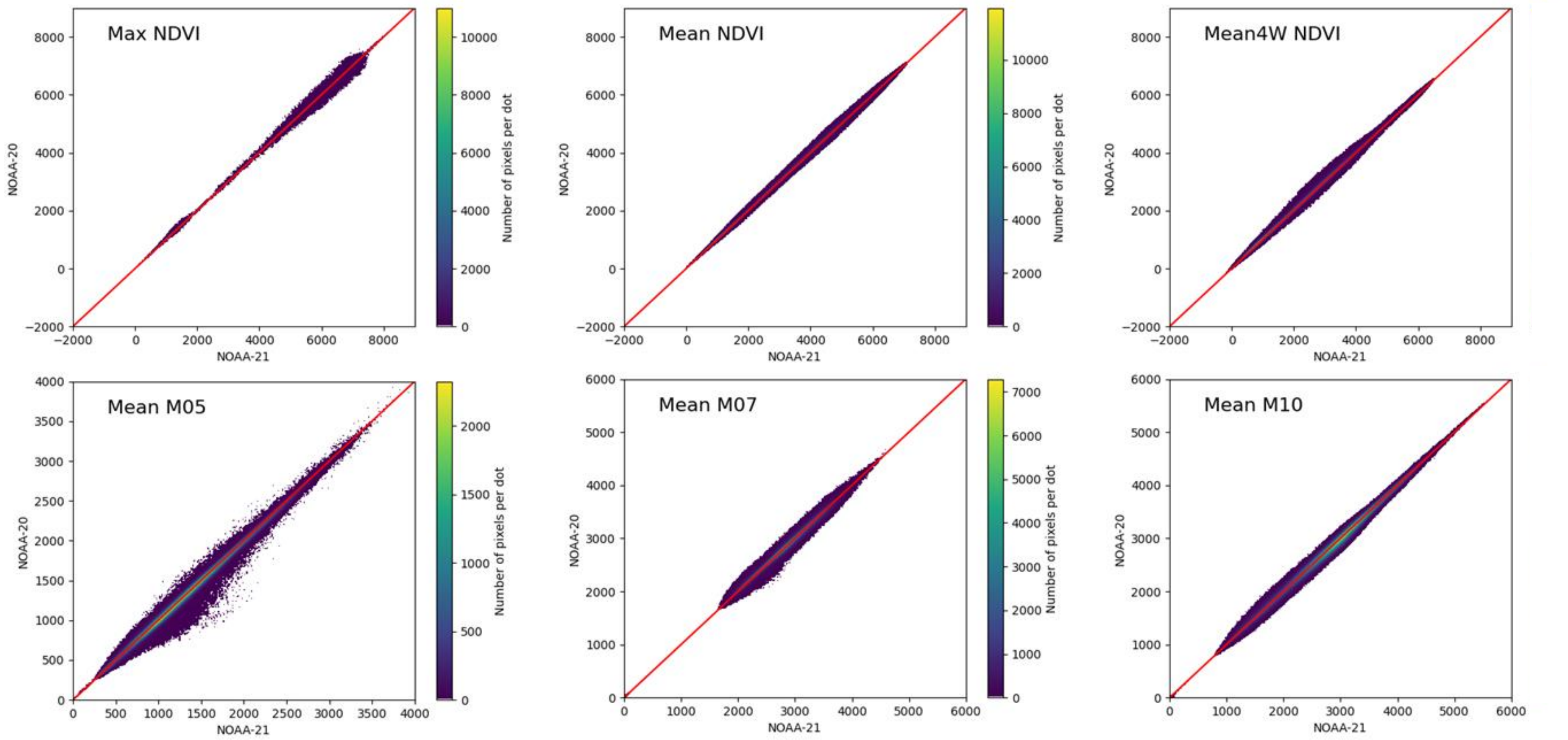
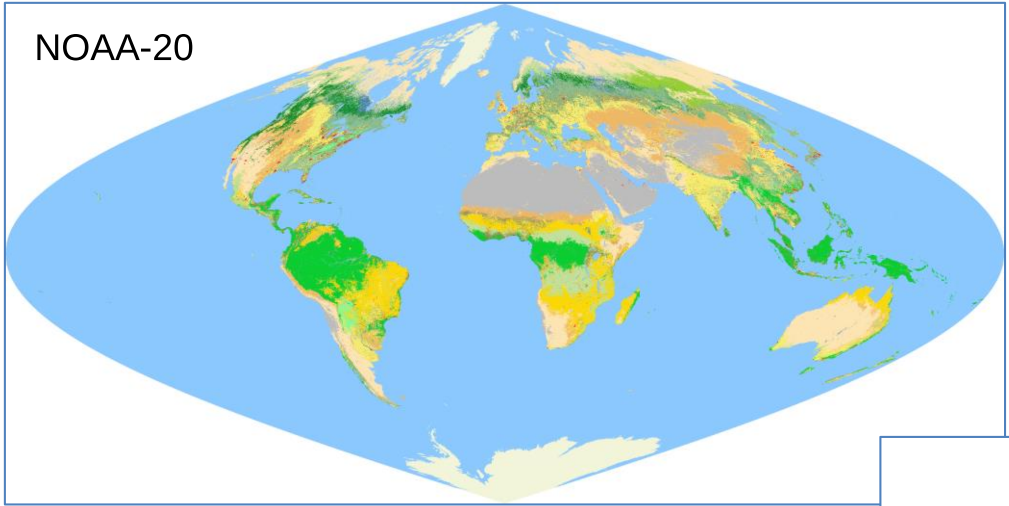
Tile 1: Southwest US



(Mean: annual mean, Mean4W: mean of 4 warmest months)

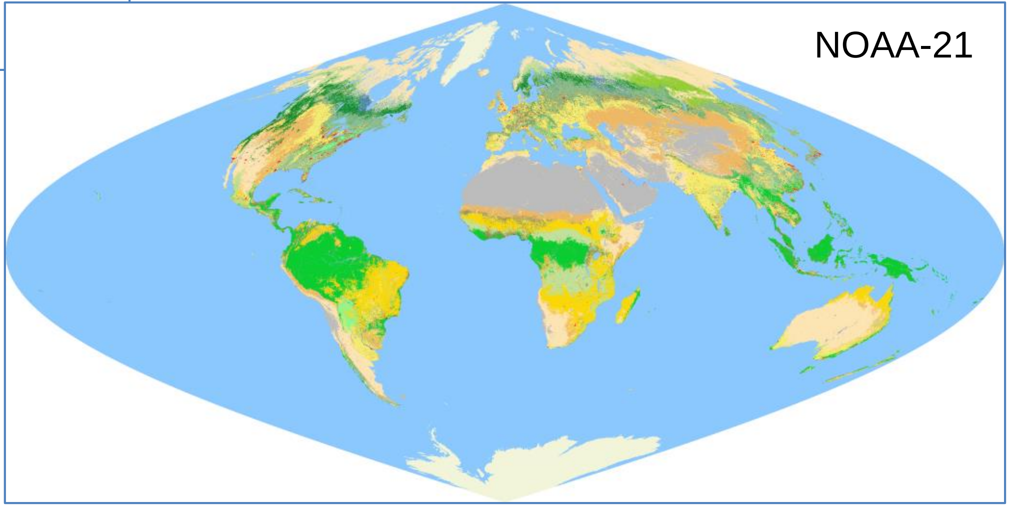
Level 4 Assessment: Annual Surface Type Maps



Inputs for the two surface type maps

NOAA-20 map: Annual metrics based on
- NOAA-20 monthly composites for May 2023 – April 2024

“NOAA-21” map: Annual metrics based on
- NOAA-20 monthly composites for May 2023 – October 2023
- NOAA-21 monthly composites for November 2023 – April 2024

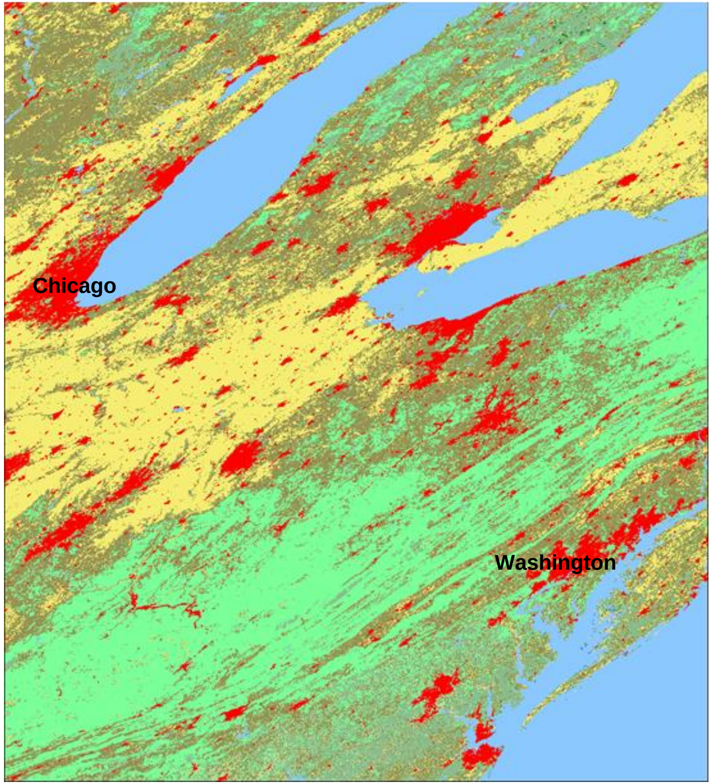


IGBP Legend

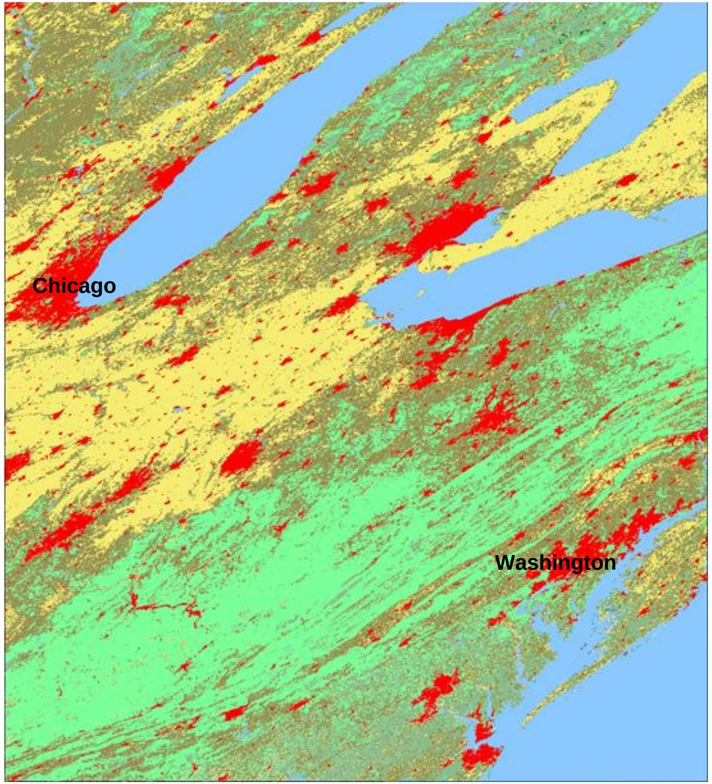
- Evergreen Needleleaf Forests
- Evergreen Broadleaf Forests
- Deciduous Needleleaf Forests
- Deciduous Broadleaf Forest
- Mixed Forests
- Closed Shrublands
- Open Shrublands
- Woody Savannas
- Savannas
- Grasslands
- Permanent Wetlands
- Croplands
- Urban and Built-up Lands
- Cropland/Natural Vegetation Mosaics
- Snow and Ice
- Barren
- Water Bodies

Level 4 Assessment: Annual Surface Type Maps

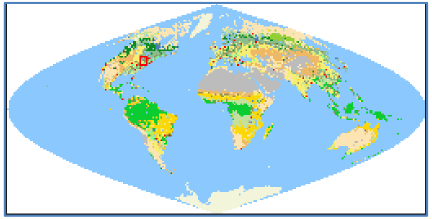
NOAA-20



NOAA-21



NE U.S.



Ground area covered by each window: 900 km x 1000 km

Surface Types

- Evergreen Needleleaf Forests
- Evergreen Broadleaf Forests
- Deciduous Needleleaf Forests
- Deciduous Broadleaf Forests
- Mixed Forests
- Closed Shrublands
- Open Shrublands
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Accuracies of Derived Annual Surface Type Maps

NOAA-20: Overall Accuracy = 78.25±0.56%

	Ground Truth (Proportion of area mapped)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	total	U Acc	P Acc
1	2.104	0.025	0.063	0.038	0.277	0.000	0.013	0.227	0.025	0.000	0.025	0.013	0.013	0.025	0.000	0.000	0.013	2.86	73.57	72.43
2	0.000	8.448	0.000	0.077	0.123	0.000	0.000	0.385	0.108	0.031	0.000	0.046	0.015	0.046	0.000	0.000	0.000	9.28	91.03	92.34
3	0.038	0.000	1.090	0.000	0.115	0.000	0.038	0.115	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	1.41	77.27	64.73
4	0.000	0.000	0.007	0.951	0.067	0.000	0.000	0.088	0.020	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	1.14	83.43	40.03
5	0.191	0.121	0.312	0.746	3.661	0.000	0.000	0.625	0.069	0.000	0.035	0.017	0.000	0.173	0.000	0.000	0.000	5.95	61.52	76.08
6	0.001	0.001	0.000	0.001	0.000	0.039	0.008	0.010	0.000	0.006	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.07	55.74	7.97
7	0.233	0.063	0.148	0.063	0.169	0.106	11.055	0.761	0.380	1.564	0.275	0.338	0.042	0.106	0.000	0.634	0.063	16.00	69.09	81.95
8	0.235	0.186	0.037	0.285	0.149	0.000	0.309	5.260	0.545	0.111	0.074	0.037	0.025	0.235	0.000	0.000	0.012	7.50	70.13	55.83
9	0.025	0.152	0.000	0.076	0.051	0.228	0.532	1.115	4.788	0.152	0.051	0.380	0.000	0.532	0.000	0.000	0.000	8.08	59.25	69.05
10	0.039	0.013	0.000	0.026	0.065	0.065	0.793	0.299	0.299	6.393	0.000	0.494	0.026	0.091	0.000	0.286	0.013	8.90	71.82	69.55
11	0.013	0.000	0.000	0.000	0.013	0.000	0.093	0.040	0.066	0.013	0.491	0.000	0.000	0.000	0.000	0.000	0.000	0.73	67.27	48.83
12	0.008	0.008	0.008	0.016	0.047	0.016	0.071	0.063	0.166	0.434	0.024	7.060	0.071	0.442	0.000	0.000	0.008	8.44	83.64	81.65
13	0.000	0.000	0.000	0.003	0.000	0.000	0.003	0.003	0.000	0.003	0.000	0.026	0.375	0.006	0.000	0.000	0.000	0.42	89.23	62.16
14	0.000	0.131	0.019	0.094	0.056	0.019	0.066	0.431	0.450	0.169	0.000	0.234	0.019	2.644	0.000	0.009	0.009	4.35	60.78	61.36
15	0.000	0.000	0.000	0.000	0.000	0.000	0.170	0.000	0.000	0.170	0.000	0.000	0.000	0.000	10.021	0.000	0.000	10.36	96.72	100.00
16	0.000	0.000	0.000	0.000	0.000	0.000	0.339	0.000	0.000	0.145	0.000	0.000	0.000	0.000	0.000	12.838	0.048	13.37	96.01	93.25
17	0.017	0.000	0.000	0.000	0.017	0.017	0.000	0.000	0.017	0.000	0.017	0.000	0.017	0.000	0.000	0.000	1.026	1.13	90.77	85.99
total	2.91	9.15	1.68	2.38	4.81	0.49	13.49	9.42	6.93	9.19	1.01	8.65	0.60	4.31	10.02	13.77	1.19			
P Acc	72.43	92.34	64.73	40.03	76.08	7.97	81.95	55.83	69.05	69.55	48.83	81.65	62.16	61.36	100.00	93.25	85.99			

NOAA-21: Overall Accuracy = 78.18±0.56%

	Ground Truth (Proportion of area mapped)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	total	U Acc	P Acc
1	2.095	0.025	0.063	0.050	0.276	0.000	0.013	0.226	0.025	0.000	0.025	0.013	0.013	0.025	0.000	0.000	0.013	2.86	73.25	72.49
2	0.000	8.447	0.000	0.077	0.124	0.000	0.000	0.402	0.093	0.031	0.000	0.046	0.015	0.046	0.000	0.000	0.000	9.28	91.01	92.05
3	0.038	0.000	1.090	0.000	0.115	0.000	0.038	0.115	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	1.41	77.27	64.61
4	0.000	0.000	0.007	0.951	0.067	0.000	0.000	0.088	0.020	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	1.14	83.43	39.99
5	0.191	0.122	0.313	0.748	3.654	0.000	0.000	0.626	0.070	0.000	0.017	0.035	0.000	0.174	0.000	0.000	0.000	5.95	61.40	75.17
6	0.001	0.001	0.000	0.001	0.000	0.040	0.007	0.008	0.000	0.006	0.001	0.002	0.000	0.002	0.000	0.000	0.000	0.07	56.67	8.16
7	0.215	0.065	0.151	0.065	0.215	0.086	11.141	0.710	0.366	1.635	0.237	0.258	0.043	0.129	0.000	0.645	0.043	16.00	69.62	82.42
8	0.234	0.185	0.037	0.283	0.148	0.012	0.283	5.296	0.567	0.086	0.086	0.037	0.012	0.222	0.000	0.000	0.012	7.50	70.61	56.21
9	0.026	0.181	0.000	0.077	0.052	0.232	0.491	1.110	4.750	0.207	0.052	0.387	0.000	0.516	0.000	0.000	0.000	8.08	58.79	68.79
10	0.051	0.013	0.000	0.013	0.077	0.064	0.907	0.306	0.306	6.257	0.000	0.511	0.038	0.089	0.000	0.255	0.013	8.90	70.30	68.36
11	0.013	0.000	0.000	0.000	0.013	0.000	0.088	0.038	0.076	0.013	0.491	0.000	0.000	0.000	0.000	0.000	0.000	0.73	67.24	50.98
12	0.008	0.008	0.008	0.016	0.047	0.016	0.071	0.063	0.166	0.434	0.024	7.060	0.071	0.442	0.000	0.000	0.008	8.44	83.64	81.55
13	0.000	0.000	0.000	0.003	0.000	0.000	0.003	0.003	0.000	0.003	0.000	0.026	0.375	0.006	0.000	0.000	0.000	0.42	89.23	62.10
14	0.000	0.131	0.019	0.094	0.056	0.019	0.066	0.431	0.450	0.169	0.000	0.234	0.019	2.644	0.000	0.009	0.009	4.35	60.78	61.44
15	0.000	0.000	0.000	0.000	0.000	0.000	0.170	0.000	0.000	0.170	0.000	0.000	0.000	0.000	10.021	0.000	0.000	10.36	96.72	100.00
16	0.000	0.000	0.000	0.000	0.000	0.000	0.240	0.000	0.000	0.144	0.000	0.048	0.000	0.000	0.000	12.844	0.096	13.37	96.06	93.38
17	0.017	0.000	0.000	0.000	0.017	0.017	0.000	0.000	0.017	0.000	0.017	0.000	0.017	0.000	0.000	0.000	1.026	1.13	90.77	84.11
total	2.89	9.18	1.69	2.38	4.86	0.49	13.52	9.42	6.91	9.15	0.96	8.66	0.60	4.30	10.02	13.75	1.22			
P Acc	72.49	92.05	64.61	39.99	75.17	8.16	82.42	56.21	68.79	68.36	50.98	81.55	62.10	61.44	100.00	93.38	84.11			

Example of Overall Accuracies of S-NPP-based maps:

- AST2015: 78.0 ± 0.6%
- AST2017: 77.6 ± 0.6%

Summary for Level 3/4 Assessment

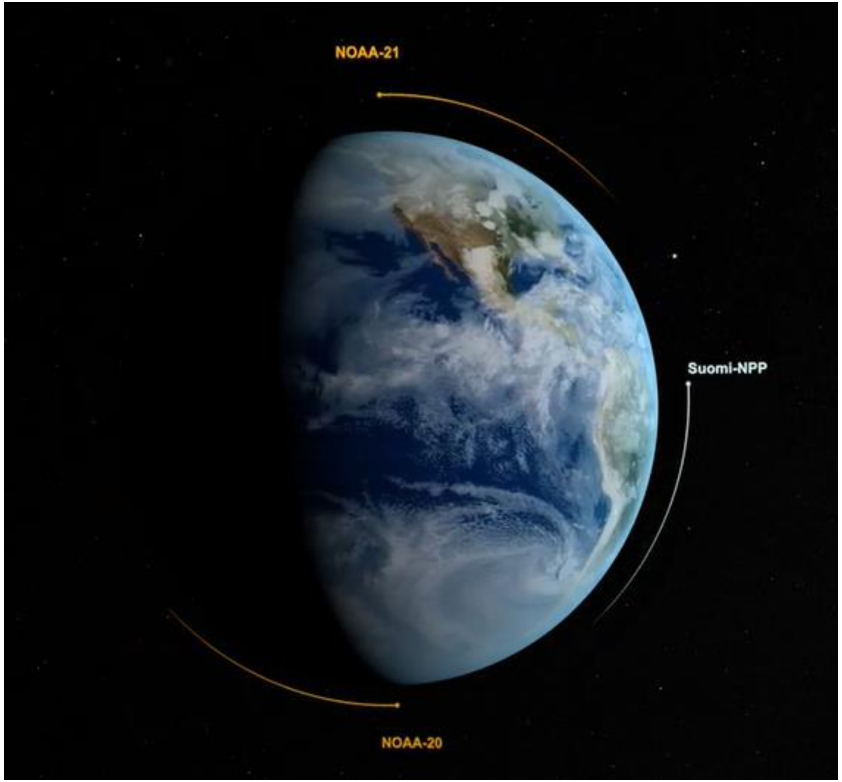
- NOAA-21 and NOAA-20 are comparable for annual surface type mapping:
  - Annual metrics calculated based on the two satellites are highly correlated with no obvious biases
  - Classification maps derived based on the two satellites have essentially the same accuracies, which exceed the 70% threshold specified by JPSS L1RD
    - These accuracies are comparable to those of S-NPP-based maps

Part II: Multi-Satellite Synergy for Surface Type Monitoring

- Two Goals for Part II Assessment:

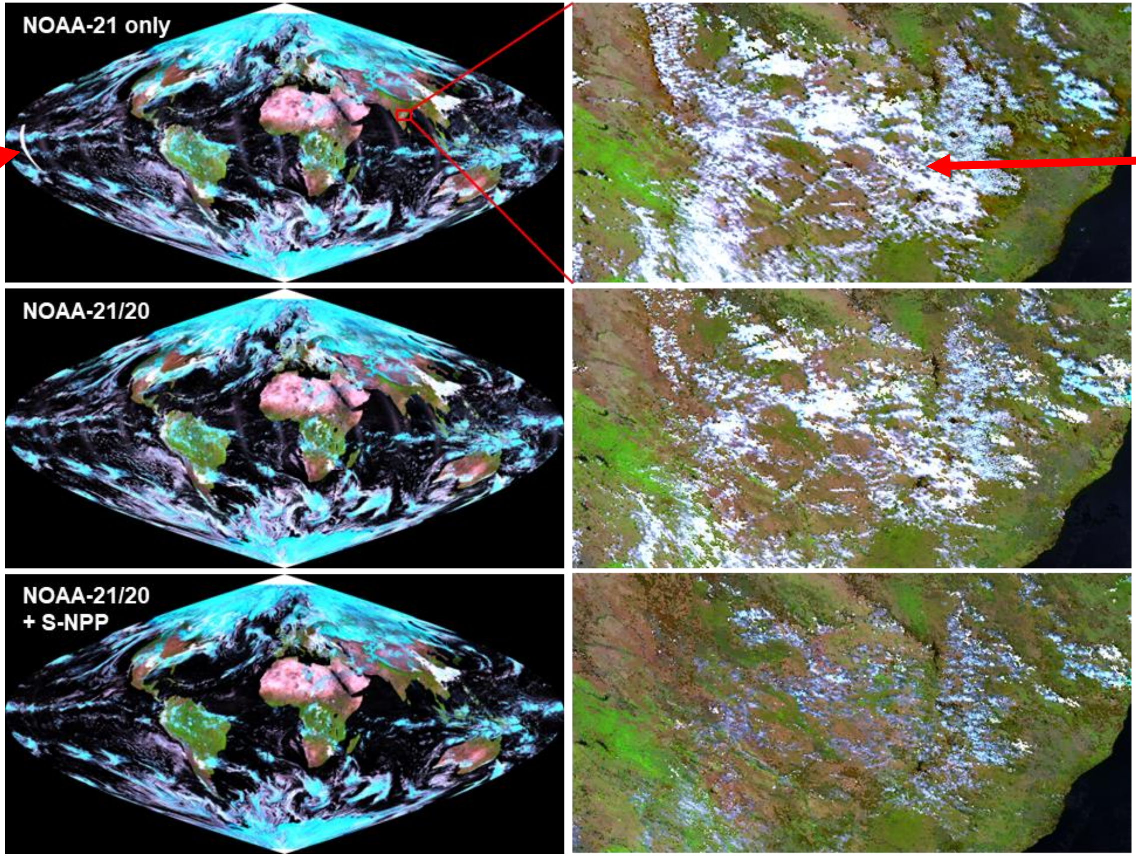
    1. Showcase benefits of increased observations provided by multiple satellites

    2. Demonstrate the feasibility to use NOAA-21 and NOAA-20 to produce global surface type products



Goal 1: Benefits of Increased Observations from Multiple Satellites

Data gaps filled using multiple satellites



Global daily mosaics created for March 15, 2024 (left) and zoom-in views over eastern India (right)

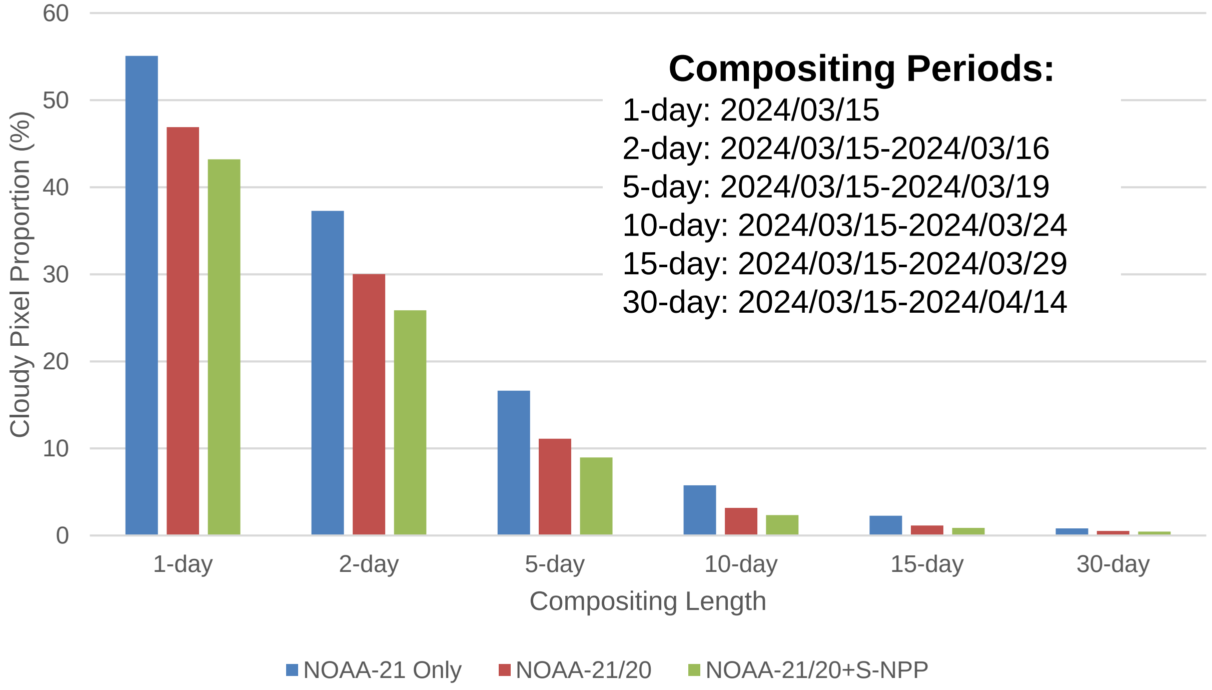
Clouds reduced using multiple satellites

Advantages of multiple satellites for daily mosaicking:

- **Reduce data gaps**
- **Reduced cloud cover**

Multi-Satellite Benefits More Significant over Shorter Compositing Lengths

Proportion of Cloudy Observations in Global Composites of Different Compositing Lengths Using Different Satellite Combinations



Observed Improvements over NOAA-21-only Composites

For short compositing lengths (1-2 days),

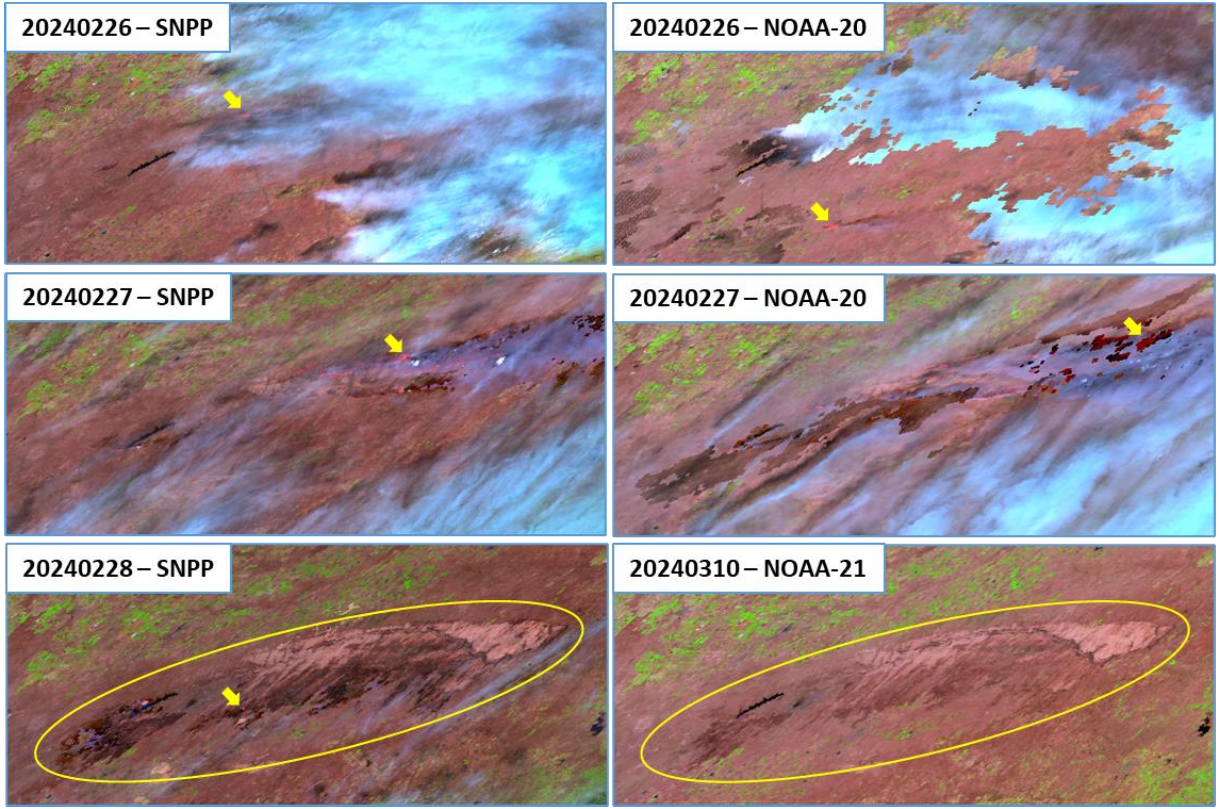
- Cloudy pixel proportions were reduced by ~7% and ~12% in absolute proportions by adding 1 and 2 satellites as compositing inputs.

For longer compositing lengths,

- Adding NOAA-20 reduced cloudy pixels by ~20% - 30%
- Adding NOAA-20 and S-NPP reduced cloudy pixels by ~30% - 50%

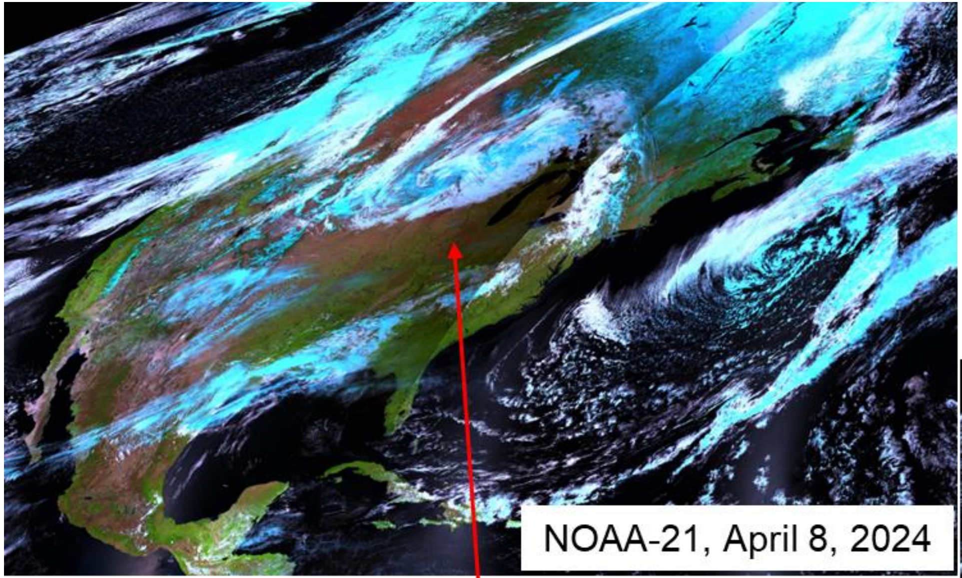
NOAA-21/20 And S-NPP Provide Multiple Views of Fire/Burn Scars

- *Just 25 minutes later than S-NPP, NOAA-20 recorded new fire pixels not seen by S-NPP on Feb. 26th.*
- *More fire pixels were observed by both S-NPP and NOAA-20 than by either satellite on Feb. 27th.*
- *S-NPP provided a clear-view image of the large burned areas on Feb. 28, but some burned areas already became spectrally indistinguishable from surrounding unburned areas in another clear-view image recorded by NOAA-21 on March 10th.*



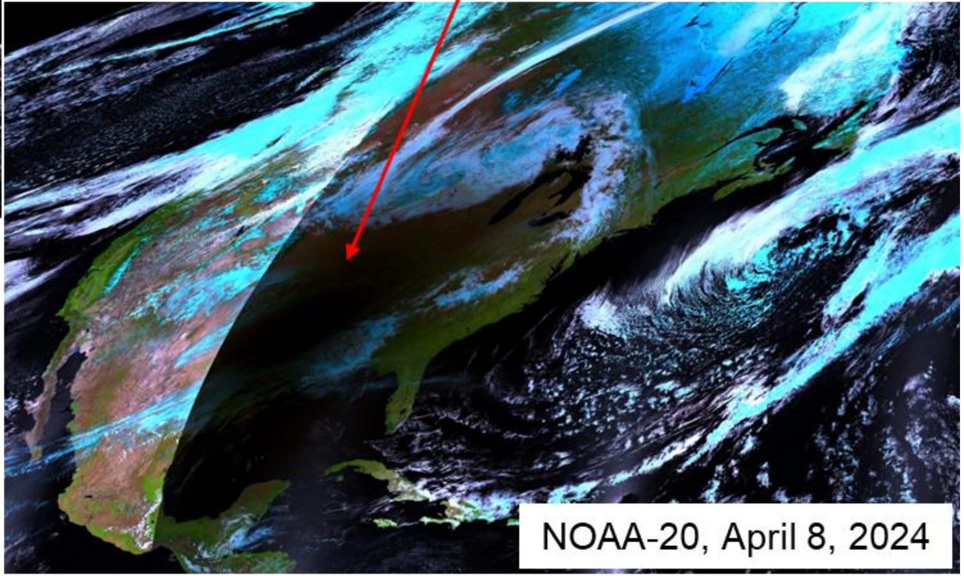
S-NPP and NOAA-20/21 Provide Multiple Views Per Day for Monitoring the Smokehouse Creek Fire (Largest Fire in Texas)

Multiple Satellites Have Better Chances to Observe Rare Events



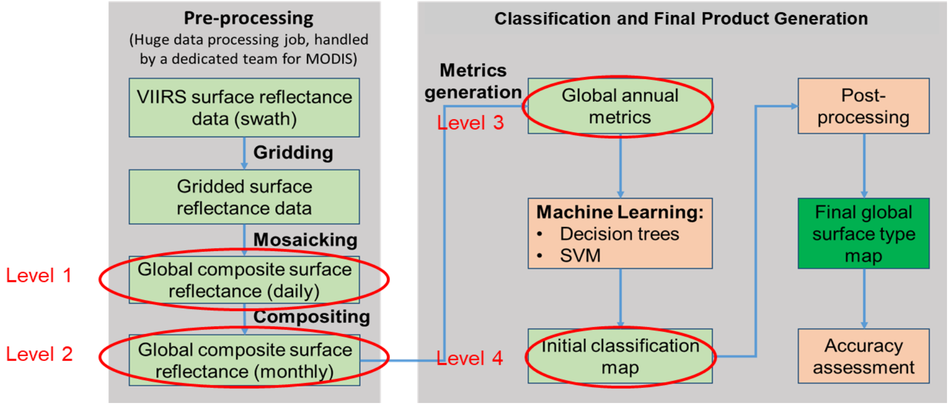
The total solar eclipse on April 8, 2024 happened to coincide with the local overpass time of NOAA-20 over central US from Texas to the Midwest. As a result, the image acquired by NOAA-20 over that region was very dark.

With an earlier (~50 m) local overpass time, NOAA-21 only captured a partial eclipse at the beginning of this event, resulting in slightly darkened observations over that region.



Goal 2: Annual Surface Type Mapping Using NOAA-21/20

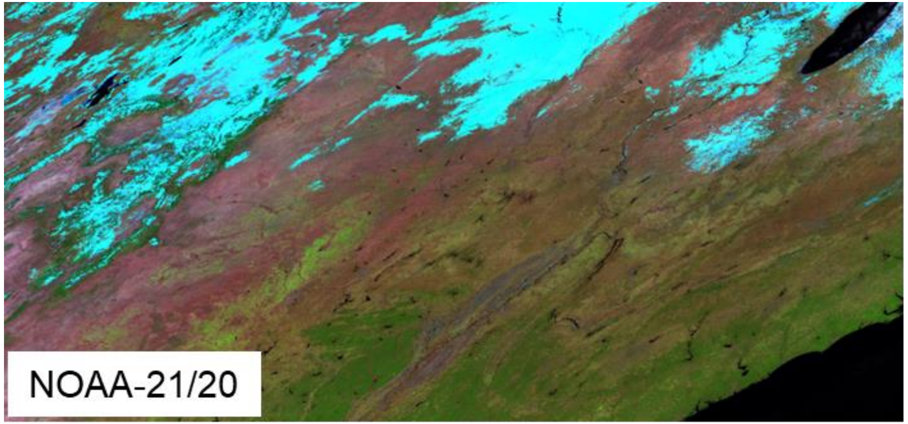
- Monthly composites used to create annual metrics
  - 2023/05 – 2023/10 (No NOAA-21 SR data): monthly composites were created using NOAA-20
  - 2023/11 – 2024/04 (NOAA-21 SR data available): monthly composites were created using both NOAA-21 and NOAA-20
- The rest of the surface type mapping algorithm was the same as the one used to produce NOAA-21 and NOAA-20 based surface type maps assessed earlier

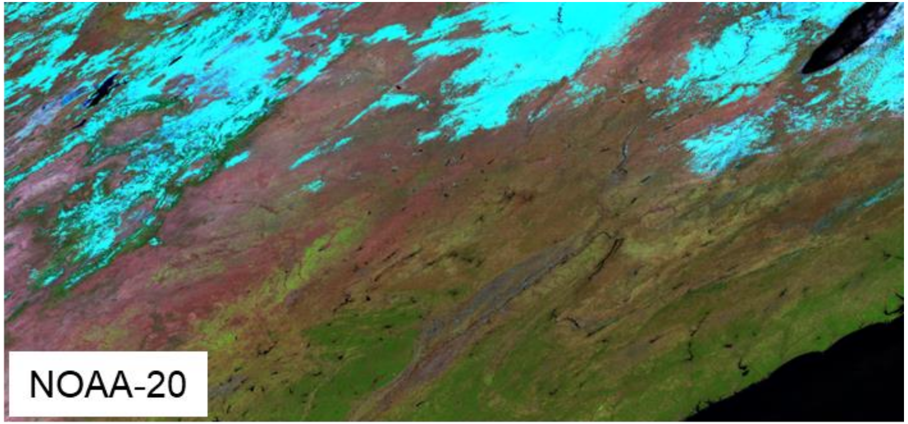


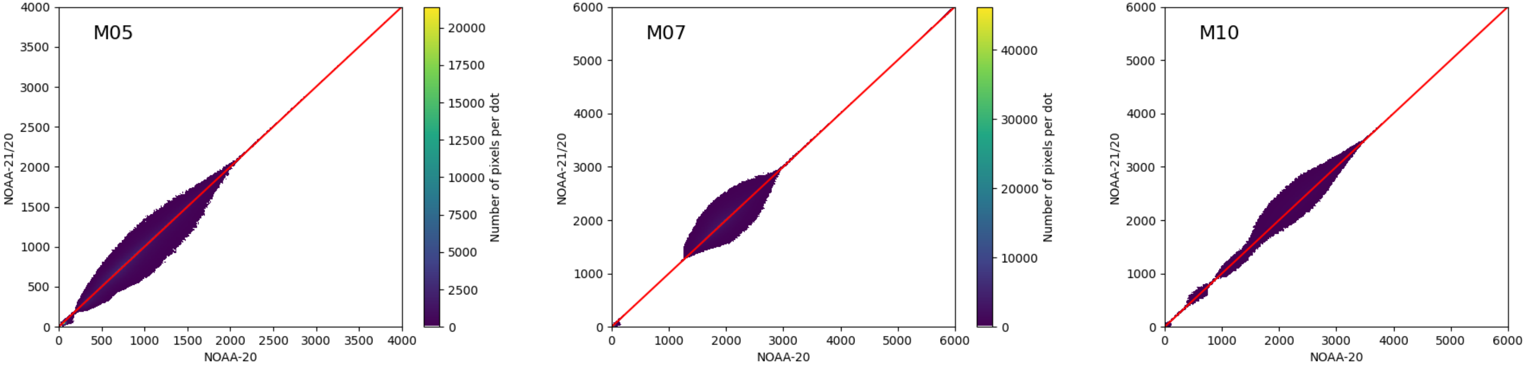
Monthly Composites from One and Two Satellites Are Consistent

East/Central US

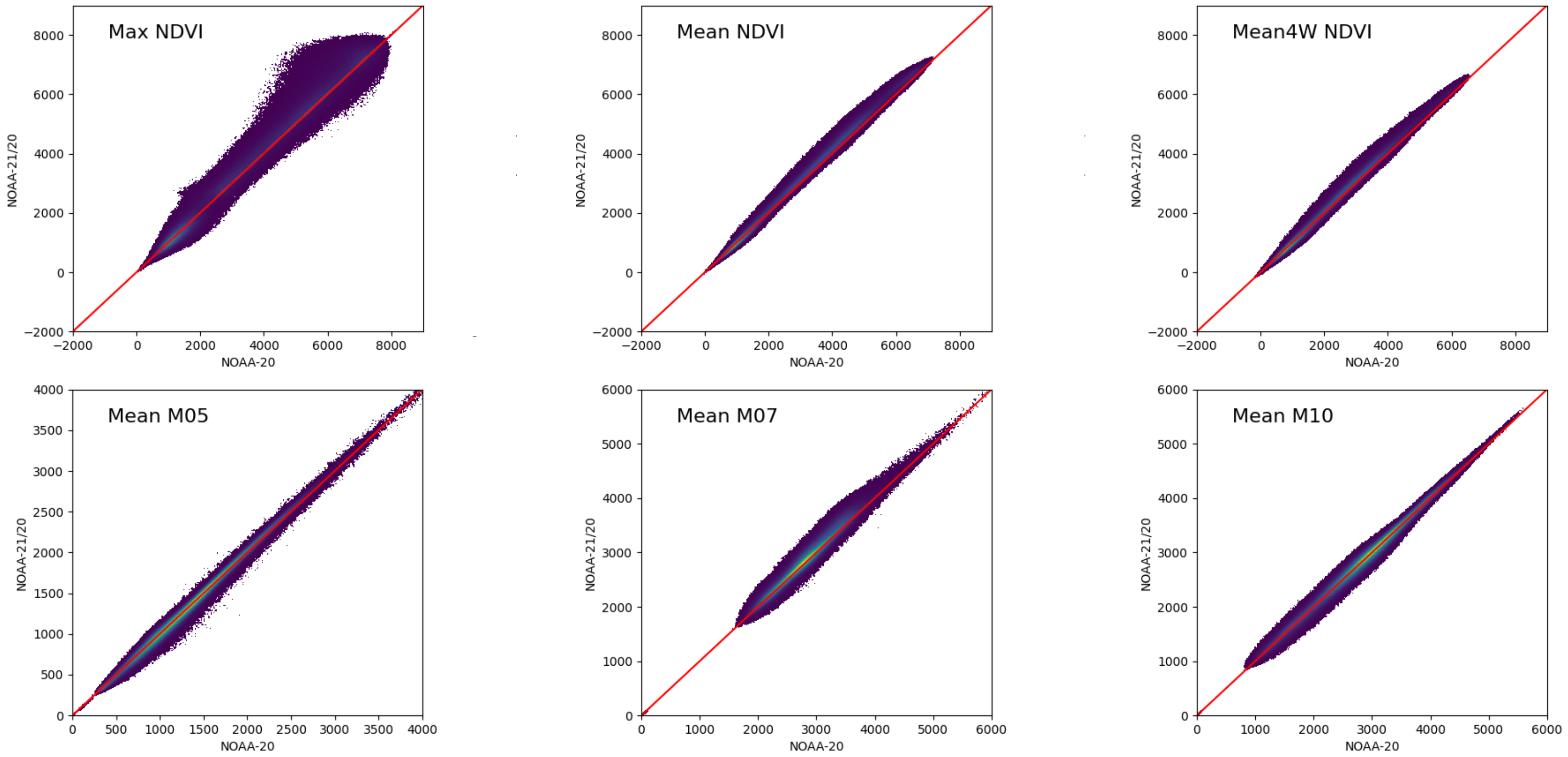
(3000 km x 1400 km, Jan. 2024 monthly composite)







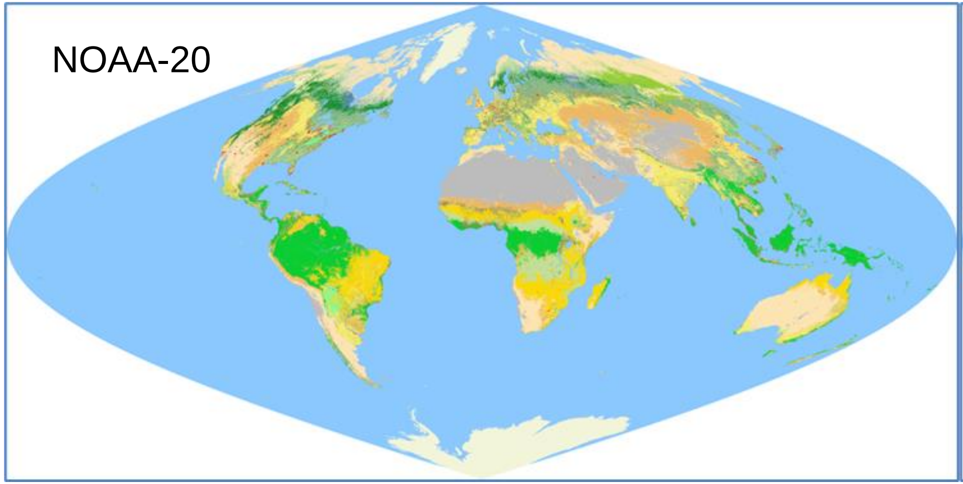
Annual Metrics from One and Two Satellites Are Consistent

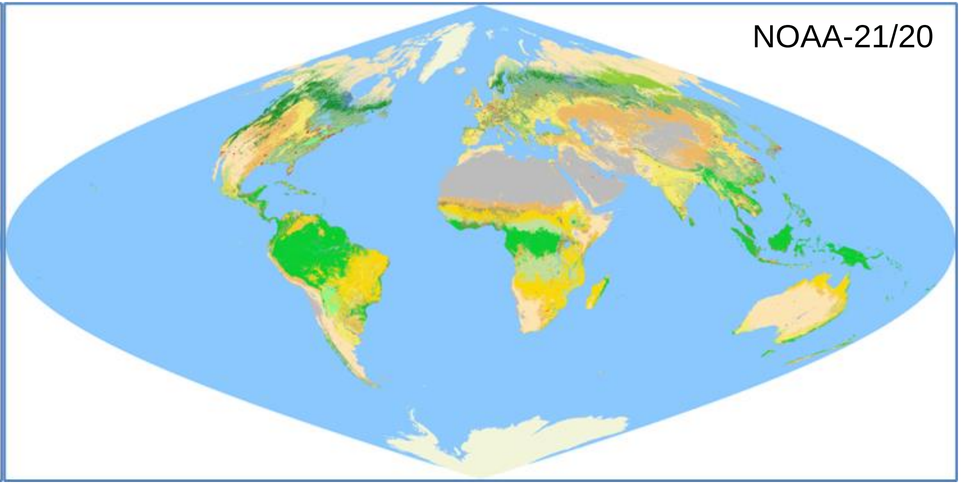


(May 2023 – April 2024, 1200km x 1200km area in SW US)

Maps from One and Two Satellites Are Consistent

Surface Type Maps for May 2023 to April 2024





IGBP Legend

- Evergreen Needleleaf Forests
- Evergreen Broadleaf Forests
- Deciduous Needleleaf Forests
- Deciduous Broadleaf Forest
- Mixed Forests
- Closed Shrublands
- Open Shrublands
- Woody Savannas
- Savannas
- Grasslands
- Permanent Wetlands
- Croplands
- Urban and Built-up Lands
- Cropland/Natural Vegetation Mosaics
- Snow and Ice
- Barren
- Water Bodies

How different are these VIIRS-based maps?

- ~5% of non-water pixels have different class labels

How different are different MODIS land cover products:

- C4 vs C5: ~30% land pixels have different class labels (Friedl et al. 2010)
- Interannual differences: ~10% land pixels have different class labels between two different years (Sulla-Menashe et al. 2019)

AST Based on One and Two Satellites have Similar Accuracies

Error Matrix of NOAA-20-Based AST: Overall Accuracy = 78.25±0.56%

	Ground Truth (Proportion of area mapped)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	total	U Acc	P Acc
1	2.104	0.025	0.063	0.038	0.277	0.000	0.013	0.227	0.025	0.000	0.025	0.013	0.013	0.025	0.000	0.000	0.013	2.86	73.57	72.43
2	0.000	8.448	0.000	0.077	0.123	0.000	0.000	0.385	0.108	0.031	0.000	0.046	0.015	0.046	0.000	0.000	0.000	9.28	91.03	92.34
3	0.038	0.000	1.090	0.000	0.115	0.000	0.038	0.115	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	1.41	77.27	64.73
4	0.000	0.000	0.007	0.951	0.067	0.000	0.000	0.088	0.020	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	1.14	83.43	40.03
5	0.191	0.121	0.312	0.746	3.661	0.000	0.000	0.625	0.069	0.000	0.035	0.017	0.000	0.173	0.000	0.000	0.000	5.95	61.52	76.08
6	0.001	0.001	0.000	0.001	0.000	0.039	0.008	0.010	0.000	0.006	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.07	55.74	7.97
7	0.233	0.063	0.148	0.063	0.169	0.106	11.055	0.761	0.380	1.564	0.275	0.338	0.042	0.106	0.000	0.634	0.063	16.00	69.09	81.95
8	0.235	0.186	0.037	0.285	0.149	0.000	0.309	5.260	0.545	0.111	0.074	0.037	0.025	0.235	0.000	0.000	0.012	7.50	70.13	55.83
9	0.025	0.152	0.000	0.076	0.051	0.228	0.532	1.115	4.788	0.152	0.051	0.380	0.000	0.532	0.000	0.000	0.000	8.08	59.25	69.05
10	0.039	0.013	0.000	0.026	0.065	0.065	0.793	0.299	0.299	6.393	0.000	0.494	0.026	0.091	0.000	0.286	0.013	8.90	71.82	69.55
11	0.013	0.000	0.000	0.000	0.013	0.000	0.093	0.040	0.066	0.013	0.491	0.000	0.000	0.000	0.000	0.000	0.000	0.73	67.27	48.83
12	0.008	0.008	0.008	0.016	0.047	0.016	0.071	0.063	0.166	0.434	0.024	7.060	0.071	0.442	0.000	0.000	0.008	8.44	83.64	81.65
13	0.000	0.000	0.000	0.003	0.000	0.000	0.003	0.003	0.000	0.003	0.000	0.026	0.375	0.006	0.000	0.000	0.000	0.42	89.23	62.16
14	0.000	0.131	0.019	0.094	0.056	0.019	0.066	0.431	0.450	0.169	0.000	0.234	0.019	2.644	0.000	0.009	0.009	4.35	60.78	61.36
15	0.000	0.000	0.000	0.000	0.000	0.000	0.170	0.000	0.000	0.170	0.000	0.000	0.000	0.000	10.021	0.000	0.000	10.36	96.72	100.00
16	0.000	0.000	0.000	0.000	0.000	0.000	0.339	0.000	0.000	0.145	0.000	0.000	0.000	0.000	0.000	12.838	0.048	13.37	96.01	93.25
17	0.017	0.000	0.000	0.000	0.017	0.017	0.000	0.000	0.017	0.000	0.017	0.000	0.017	0.000	0.000	0.000	1.026	1.13	90.77	85.99
total	2.91	9.15	1.68	2.38	4.81	0.49	13.49	9.42	6.93	9.19	1.01	8.65	0.60	4.31	10.02	13.77	1.19			
P Acc	72.43	92.34	64.73	40.03	76.08	7.97	81.95	55.83	69.05	69.55	48.83	81.65	62.16	61.36	100.00	93.25	85.99			

Error Matrix of AST Based on NOAA-21/20: Overall Accuracy = 78.46±0.56%

	Ground Truth (Proportion of area mapped)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	total	U Acc	P Acc
1	2.095	0.025	0.063	0.050	0.276	0.000	0.013	0.226	0.025	0.000	0.025	0.013	0.013	0.025	0.000	0.000	0.013	2.86	73.25	72.44
2	0.000	8.462	0.000	0.077	0.124	0.000	0.000	0.386	0.093	0.031	0.000	0.046	0.015	0.046	0.000	0.000	0.000	9.28	91.18	92.09
3	0.038	0.000	1.102	0.000	0.103	0.000	0.038	0.115	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	1.41	78.18	65.74
4	0.000	0.000	0.007	0.951	0.067	0.000	0.000	0.088	0.020	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	1.14	83.43	39.61
5	0.191	0.122	0.313	0.748	3.689	0.000	0.000	0.626	0.070	0.000	0.017	0.000	0.000	0.174	0.000	0.000	0.000	5.95	61.99	75.60
6	0.001	0.001	0.000	0.001	0.000	0.037	0.008	0.011	0.000	0.005	0.001	0.002	0.000	0.002	0.000	0.000	0.000	0.07	53.12	7.66
7	0.213	0.064	0.128	0.085	0.234	0.107	11.229	0.703	0.384	1.534	0.256	0.277	0.043	0.107	0.000	0.575	0.064	16.00	70.17	82.86
8	0.238	0.188	0.038	0.288	0.150	0.013	0.275	5.288	0.538	0.100	0.088	0.038	0.025	0.225	0.000	0.000	0.013	7.50	70.50	56.12
9	0.025	0.176	0.000	0.075	0.050	0.226	0.502	1.104	4.743	0.251	0.050	0.376	0.000	0.502	0.000	0.000	0.000	8.08	58.70	69.30
10	0.052	0.013	0.000	0.013	0.052	0.052	0.763	0.336	0.272	6.391	0.013	0.530	0.026	0.103	0.000	0.272	0.013	8.90	71.80	69.13
11	0.014	0.000	0.000	0.000	0.014	0.000	0.081	0.041	0.068	0.014	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.73	68.52	49.82
12	0.008	0.008	0.008	0.016	0.047	0.016	0.071	0.063	0.166	0.434	0.024	7.060	0.071	0.442	0.000	0.000	0.008	8.44	83.64	82.07
13	0.000	0.000	0.000	0.003	0.000	0.000	0.003	0.003	0.000	0.003	0.000	0.026	0.375	0.006	0.000	0.000	0.000	0.42	89.23	62.11
14	0.000	0.131	0.019	0.094	0.056	0.019	0.066	0.431	0.450	0.169	0.000	0.234	0.019	2.644	0.000	0.009	0.009	4.35	60.78	61.72
15	0.000	0.000	0.000	0.000	0.000	0.000	0.170	0.000	0.000	0.170	0.000	0.000	0.000	0.000	10.021	0.000	0.000	10.36	96.72	100.00
16	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.000	0.143	0.000	0.000	0.000	0.000	0.000	12.848	0.048	13.37	96.09	93.75
17	0.017	0.000	0.000	0.000	0.017	0.017	0.000	0.000	0.017	0.000	0.017	0.000	0.017	0.000	0.000	0.000	1.026	1.13	90.77	86.02
total	2.89	9.19	1.68	2.40	4.88	0.49	13.55	9.42	6.84	9.24	1.00	8.60	0.60	4.28	10.02	13.70	1.19			
P Acc	72.44	92.09	65.74	39.61	75.60	7.66	82.86	56.12	69.30	69.13	49.82	82.07	62.11	61.72	100.00	93.75	86.02			

Multi-Satellite Synergy Assessment Summary

- Increased observations provided by multiple satellites have multiple benefits:
  - Reduce cloudy observations in global composites
  - Provide multiple views of rapidly evolving change events (e.g., fire)
  - Provide better chance to observe rare, short duration events

- Multiple VIIRS-carrying satellites can be used together to produce potentially more accurate global surface type products
  - The AST algorithm is **enhanced** to use VIIRS data acquired from more than one JPSS satellites
  - There will be no disruption to AST mapping or obvious accuracy change in the derived AST maps when old satellites (e.g., S-NPP) phase out or new satellites (JPSS-3) join the JPSS constellation

Documentations (Check List)

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	X
Algorithm Theoretical Basis Document (ATBD)	X
Algorithm Calibration/Validation Plan	X
(External/Internal) Users Manual	N/A
System Maintenance Manual (for ESPC products)	N/A
Peer Reviewed Publications (Demonstrates algorithm is independently reviewed)	X
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	X

Feedback

User Feedback

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations
Helin Wei	NCEP EMC	Noah LSM input	Currently MODIS, will use VIIRS AST soon
Michael Barlage	NCAR/ NCEP EMC	Noah-MP LSM input	Many sources, generally satellite based, tree cover map/vegetation continuous fields

Downstream Product Feedback

Algorithm	Product	Downstream Product Feedback
LST	LST	Deliver to NDE by ASSISTT
LSA	LSA	Deliver to NDE by ASSISTT

Risks, Actions, and Mitigations

Identified Risk	Description	Impact	Action/Mitigation and Schedule
Surface type change at Training locations	Current surface type label no longer correct due to surface type change	Less accurate classification model	Identify training sites that had surface type changes and relabel those sites
Surface type change at validation locations	Current surface type label no longer correct due to surface type change	More uncertainties with accuracy estimates	Identify validation sites that had surface type changes and relabel those sites

Check List - Beta Maturity

Beta Maturity End State	Assessment
Product is minimally validated, and may still contain significant identified and unidentified errors	This requirement has been exceeded.
Information/data from validation efforts can only be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose	This requirement has been exceeded.
Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists	This requirement has been exceeded.

Check List - Provisional Maturity

Provisional Maturity End State	Assessment
Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from select locations, periods, and associated ground truth or field campaign efforts.	Global NOAA-21 data over 6 months (November 2023 – April 2024) have been assessed.
Product analysis is sufficient to communicate product performance to users relative to expectations (Performance Baseline).	Product based on available data meets accuracy requirements.
Documentation of product performance exists that includes recommended remediation strategies for all anomalies and weaknesses. Any algorithm changes associated with severe anomalies have been documented, implemented, tested, and shared with the user community.	Yes.
Product is ready for operational use and for use in comprehensive cal/val activities and product optimization.	Yes.

Check List - Validated Maturity

Validated Maturity End State	Assessment
Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).	The derived products from available official NOAA-21 VIIRS input data sets met requirements.
Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.	*ATBD and journal publications for VIIRS AST products available to the public*
Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.	*Qualitative and quantitative assessments presented*
Product is ready for operational use based on documented validation findings and user feedback.	*Product based on NOAA-21 and NOAA-20 VIIRS data met L1RD Requirements.*
Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument	*Product validation is done before it's delivered to users and the public*

NOAA-21 Maturity Assessment Conclusions

- NOAA-21 VIIRS AST is highly comparable with NOAA-20 VIIRS AST:
  - The VIIRS instruments on both platforms are near identical
  - Same day observations from the two satellites are correlated but not identical
    - Local differences are mainly due to differences in local overpass time and solar/view geometries
  - Both monthly composites and annual metrics derived from the two satellites are highly correlated without significant biases
  - Annual surface type maps (May 2023 – April 2024) derived with the two satellites are similar and have similar accuracies that exceed the 70% L1RD requirement for the surface type product.
- AST maps based on NOAA-21 and NOAA-20 VIIRS data meet JPSS Requirements (DPS-820: better than 70% accuracy).
- Team recommends that the NOAA-21 VIIRS Annual Surface Type product reaches the beta and provisional maturity, and the validated maturity too.

Path Forward

- NOAA-21 VIIRS will be used together with NOAA-20 VIIRS to produce VIIRS AST maps
- Multiple VIIRS-carrying satellites will be leveraged to improve surface type monitoring
  - More features of surface type could be developed for future generation land surface models (e.g., Noah-MP) by integrating VIIRS and other satellite observations (such as NASA GEDI) :
    - Vegetation cover/canopy height
    - Water surface fraction
  - Multi-satellite synergy will allow short term monitoring at time steps ranging from weekly to near daily:
    - Reduce cloudy observations in global composites
    - Provide multiple views of rapidly evolving change events (e.g., fire)
    - Provide better chance to observe rare, short duration events

Thank you for your attention !!!

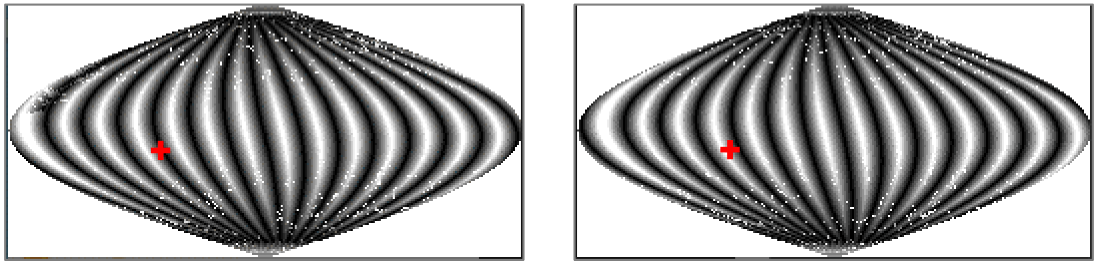
Locally, NOAA-21/20 Data Are Not Identical

- On any given day, observations acquired by the two satellites over the same ground location have
  - different local time, and hence different sun illumination geometry
  - different viewing geometries

VIIRS View Zenith Angle (VZA) Differences

March 15, 2024

NOAA-21 | **NOAA-20**

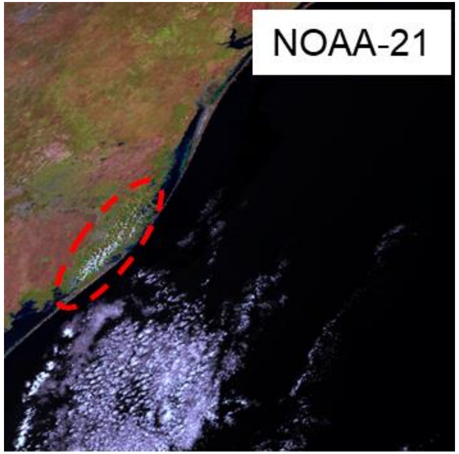


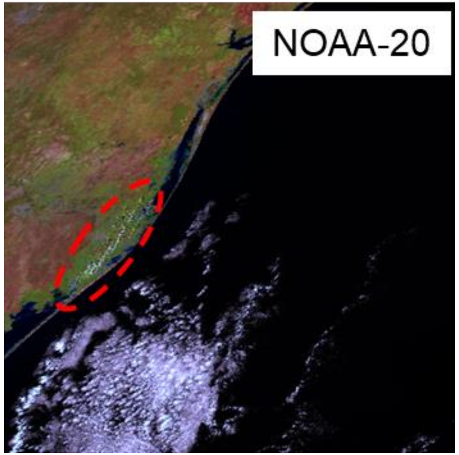
Gray tones for VZA: dark – low, bright – high

✚ indicates an area in Amazon where:
- NOAA-21 has low VZA
- NOAA-20 has high VZA

Summary for Level 1 Comparison

- Global daily mosaics from NOAA-21 and NOAA-20 are similar
- Locally,
  - Same day NOAA-21 and NOAA-20 data are correlated under clear view conditions
  - They are not identical because
    - Sun illumination angles are not the same
    - View geometries can be very different
- Cloud/shadow presence makes comparison meaningless
  - Clouds and cloud shadows can change a lot in 50 minutes





Clouds over the highlighted area changed substantially between the overpasses of NOAA-21 and NOAA-20

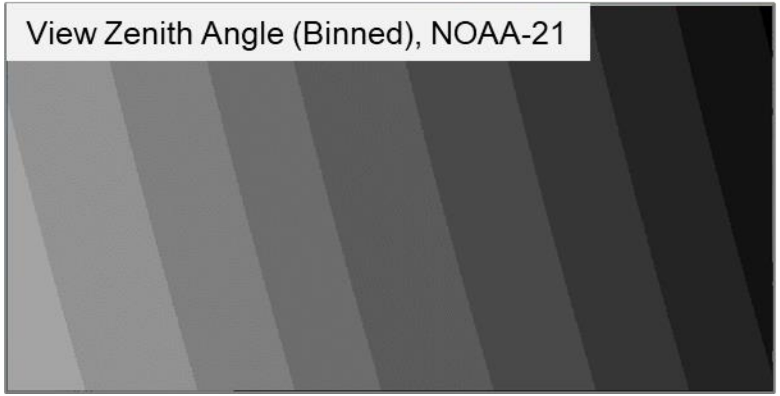
East coast of Mexico 2/20/2024

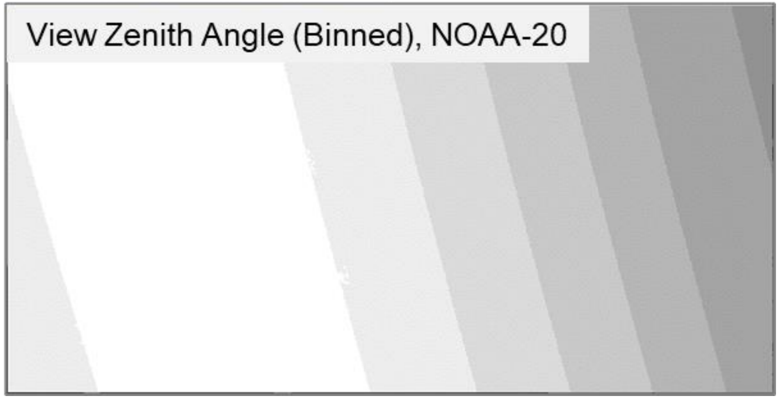
Monthly Composite Assessment Summary

- Monthly composites from NOAA-21 and NOAA-20 are highly comparable but not identical:
  - Visually, they look essentially the same
  - Statistically, they are correlated without noticeable biases
  - They can be different at the individual pixel level because for any given location
    - Composites for the two satellites may be selected from different dates
    - Even if the selected observations are acquired on the same day, they have different illumination and viewing geometries (see Level 1 assessment results)

View Angle Differences in the Tropics

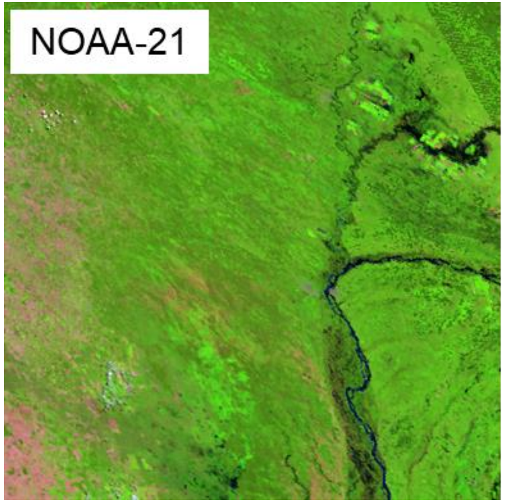
VIIRS Data Acquired on March 15, 2024 over Tropical Amazon

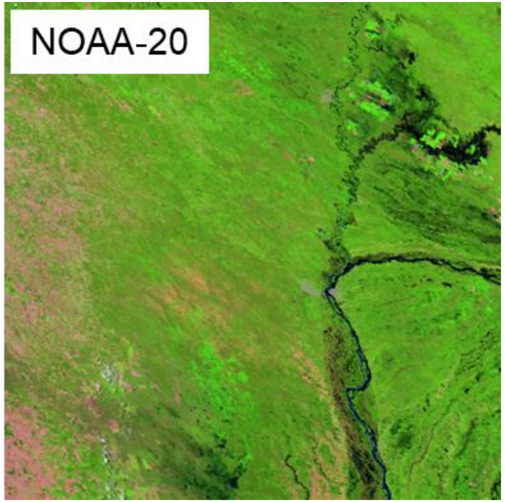




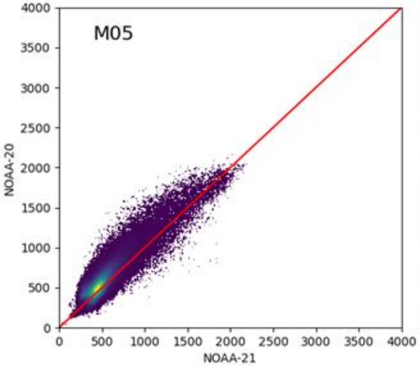
Gray tones for view zenith angle: dark – low, bright – high

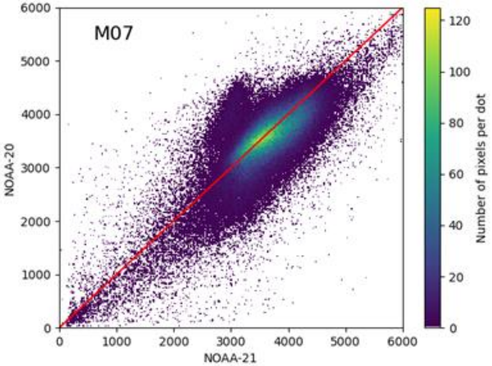
Clear View NOAA-21 and NOAA-20 Data Are Correlated

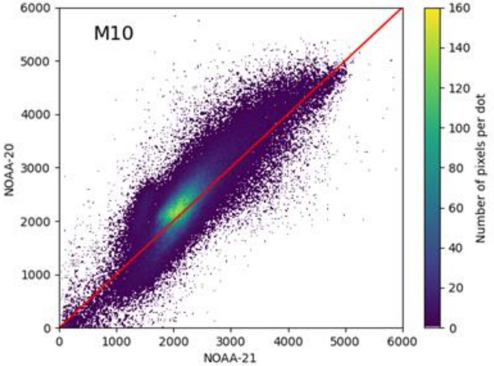




Argentina
1/6/2024

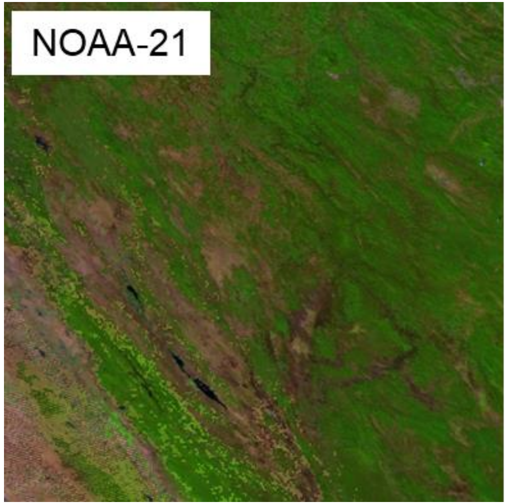


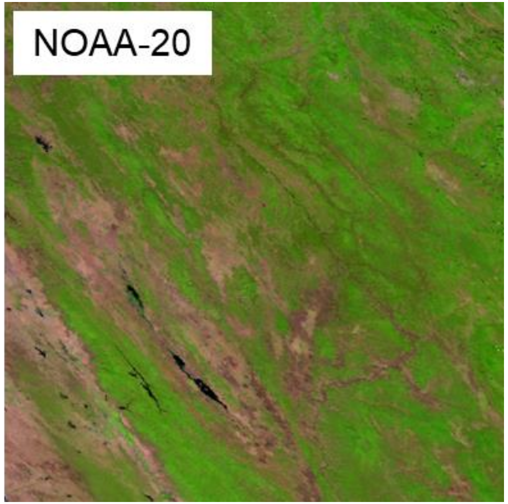




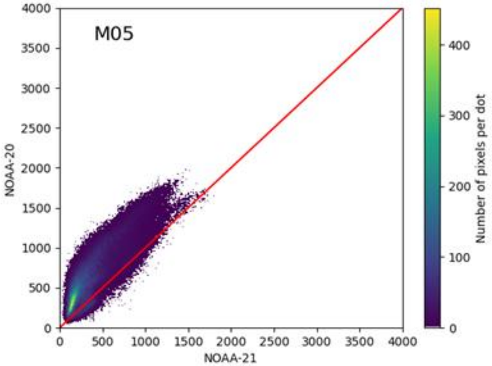
Clear View NOAA-21 and NOAA-20 Data Are Correlated

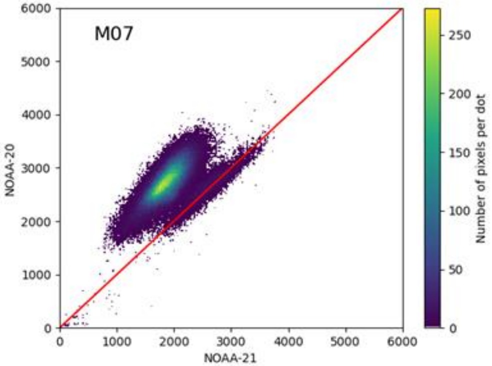
In the NOAA-21 image, darker and brighter pixels are from two different orbits. They have very different view zenith angles, resulting in two clusters in the scatter plots.

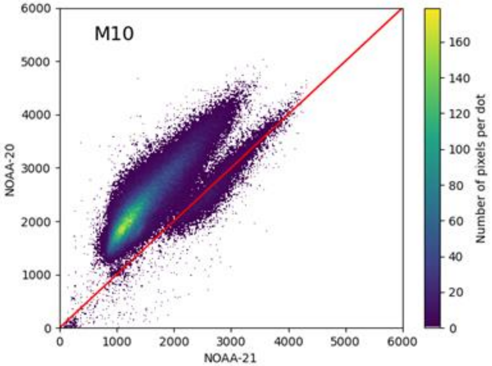




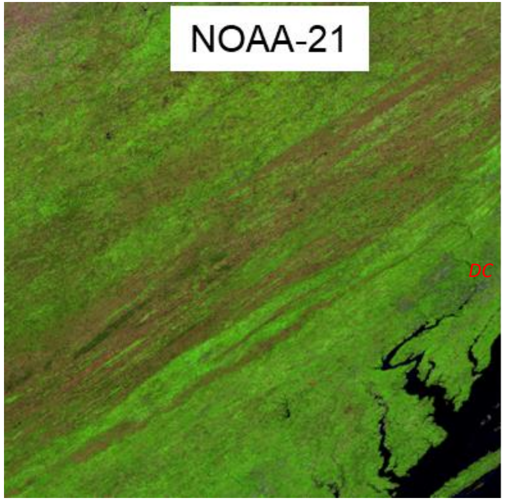
SE Asia
2/20/2024

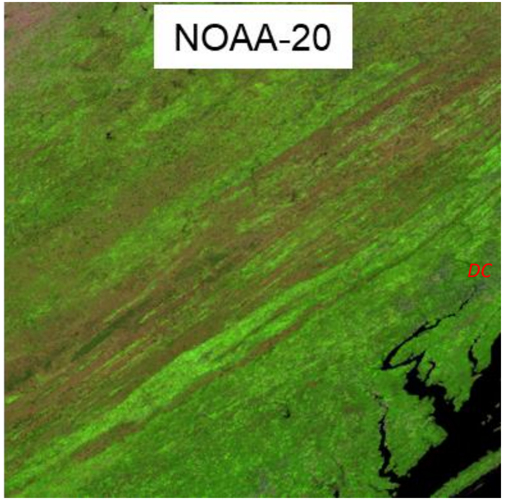




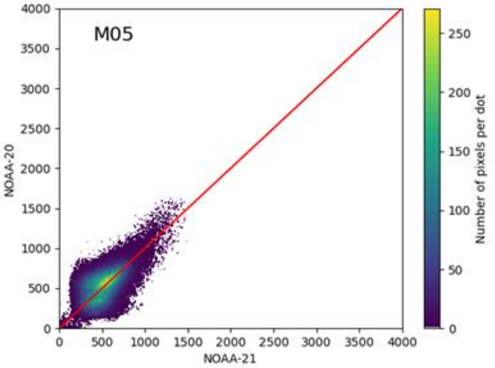


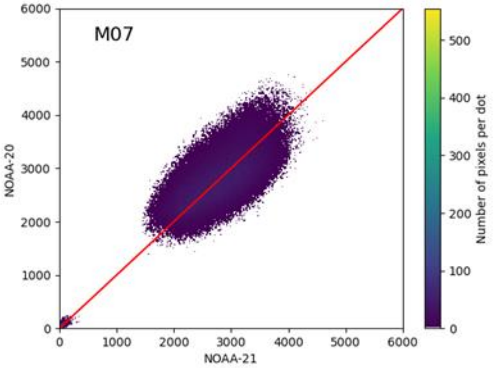
Pixel Level Comparison of Monthly Composites

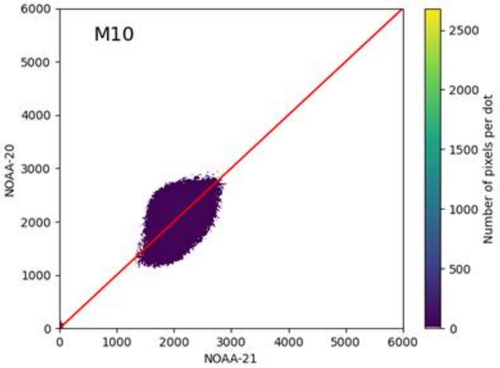




DC Area
(~400 km x 400 km)
April 2024
monthly composite



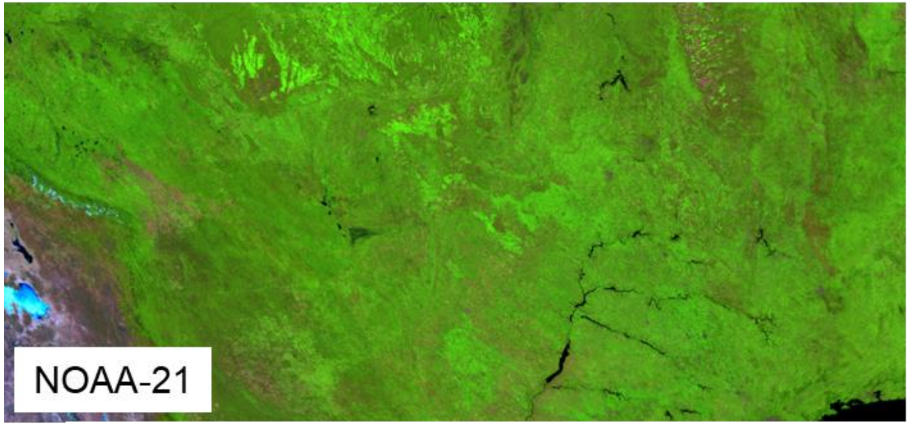


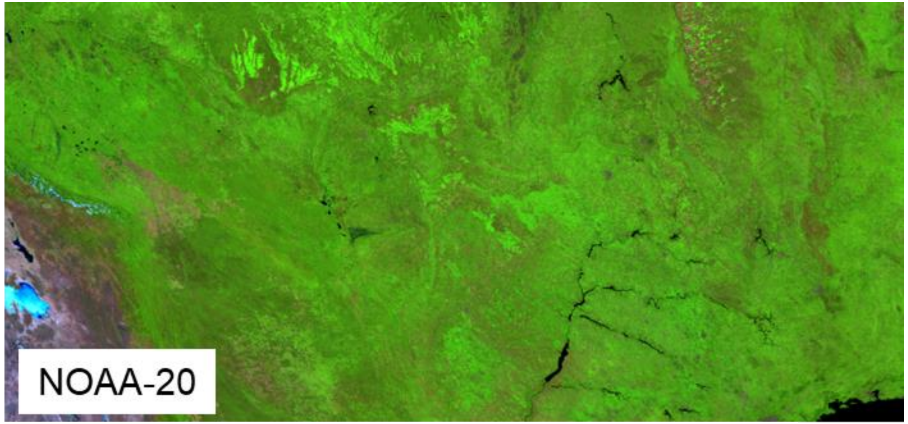


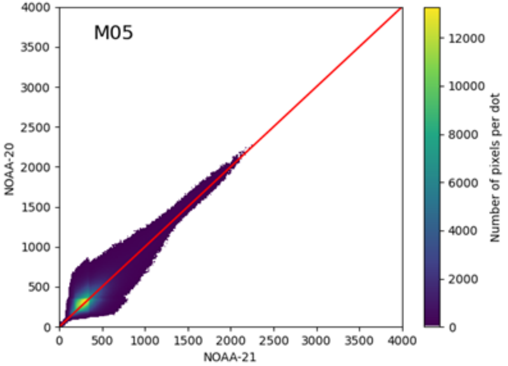
Pixel Level Comparison of Monthly Composites

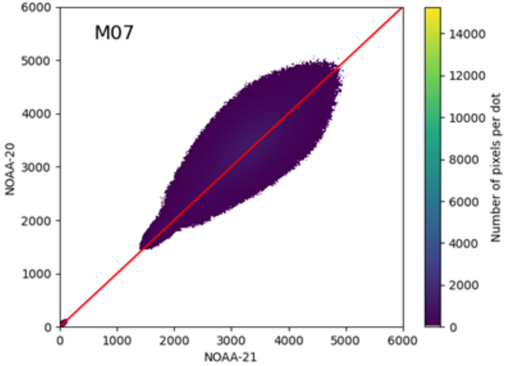
Central South America

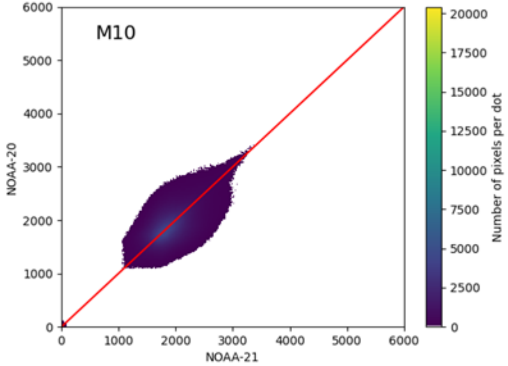
(~3000 km x 1400 km, Jan. 2024 monthly composite)







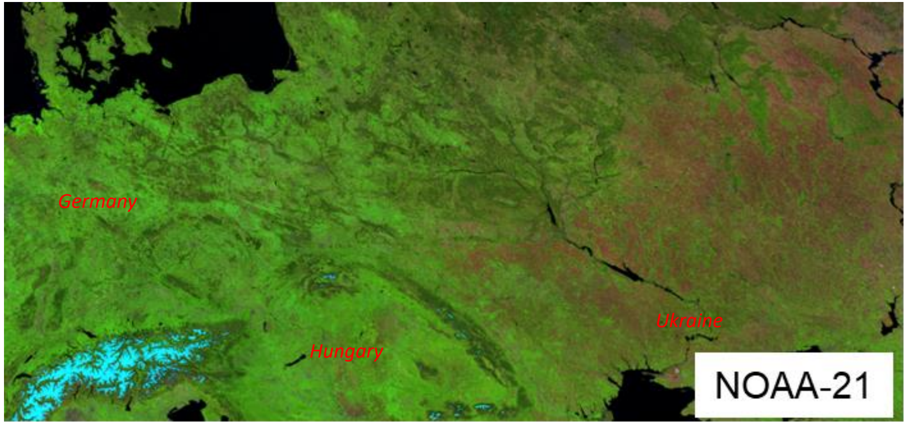


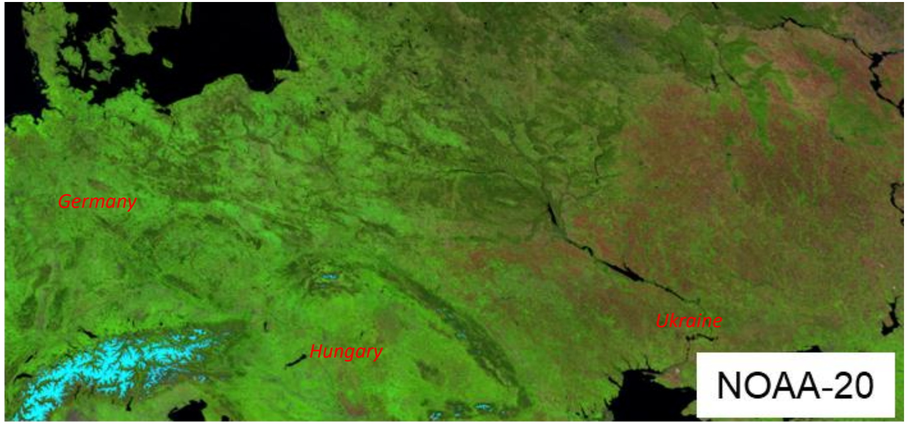


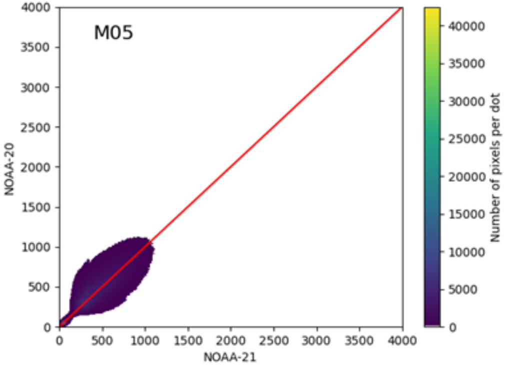
Pixel Level Comparison of Monthly Composites

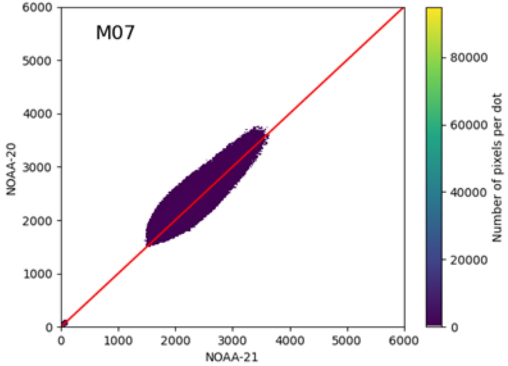
Europe

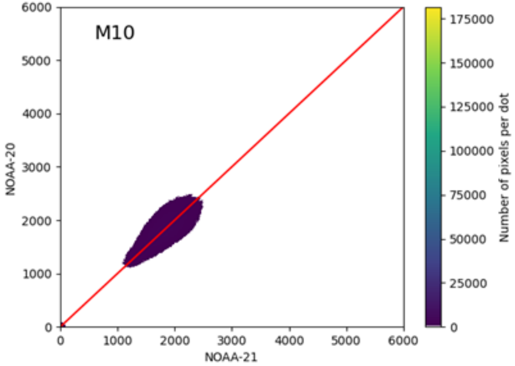
(~3000 km x 1400 km, April 2024 monthly composite)







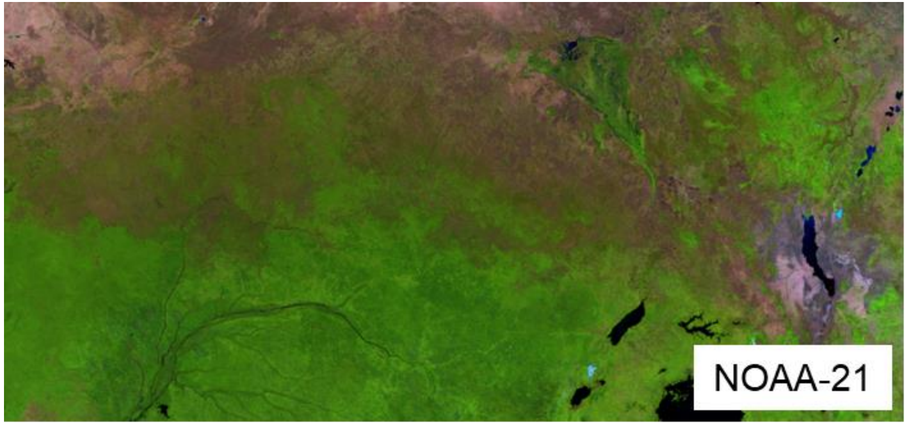


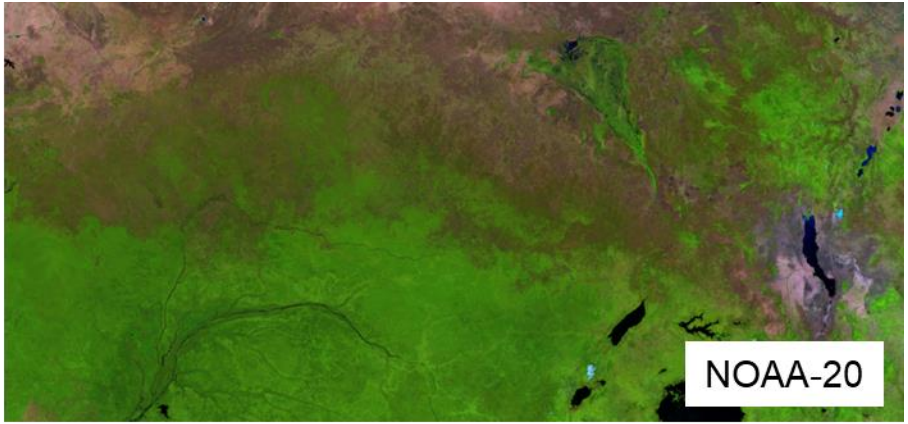


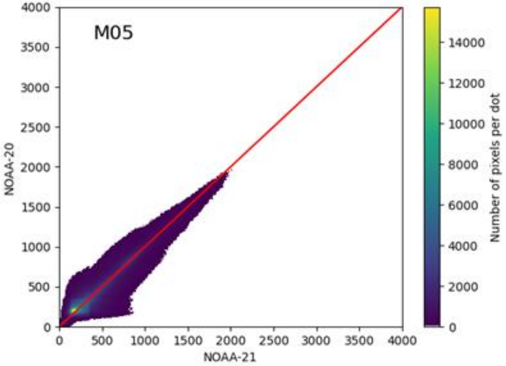
Pixel Level Comparison of Monthly Composites

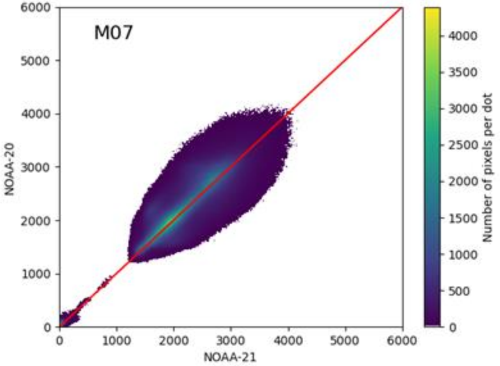
Central Africa

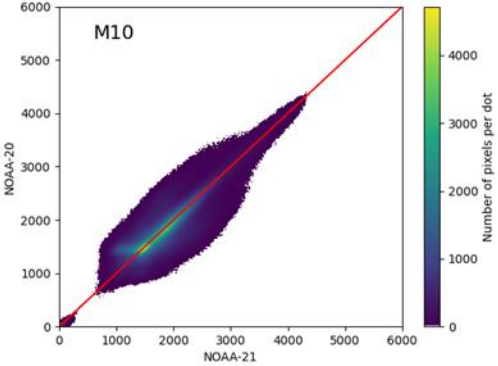
(~3000 km x 1400 km, Jan. 2024 monthly composite)







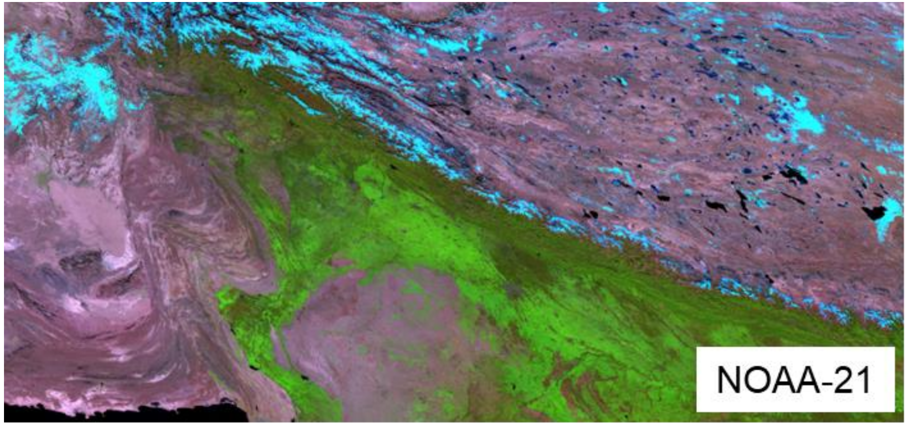


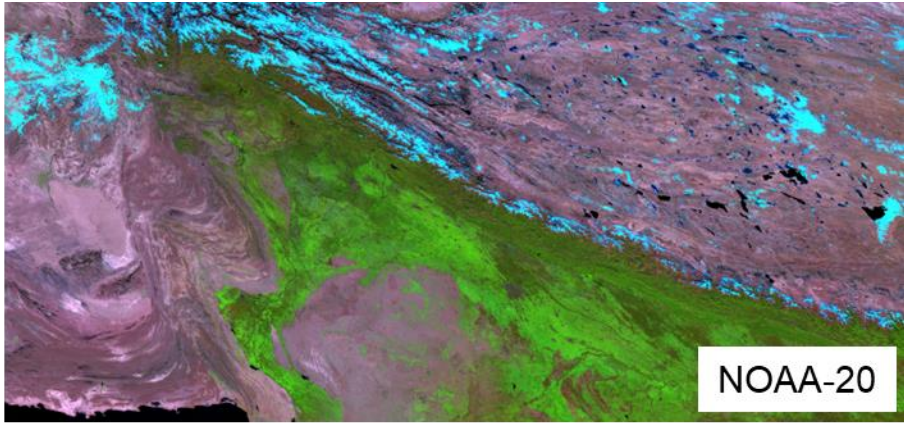


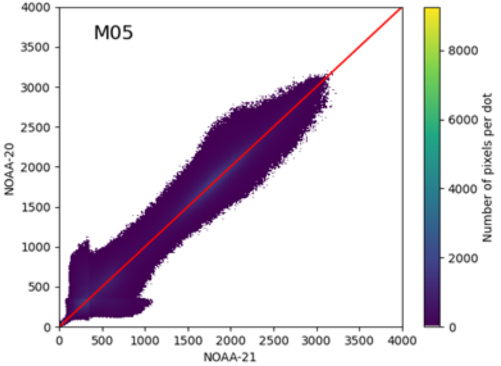
Pixel Level Comparison of Monthly Composites

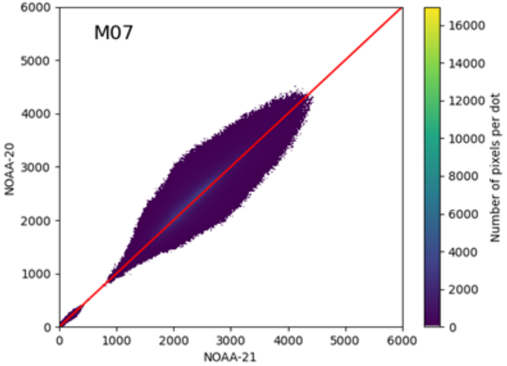
Central Asia

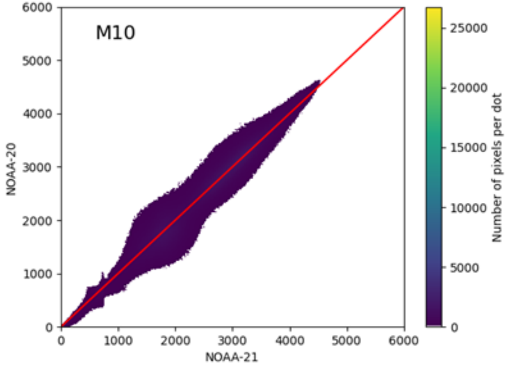
(~3000 km x 1400 km, Jan. 2024 monthly composite)



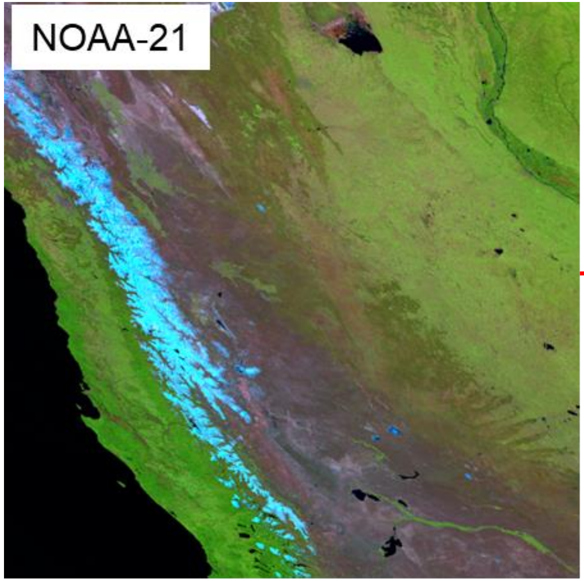


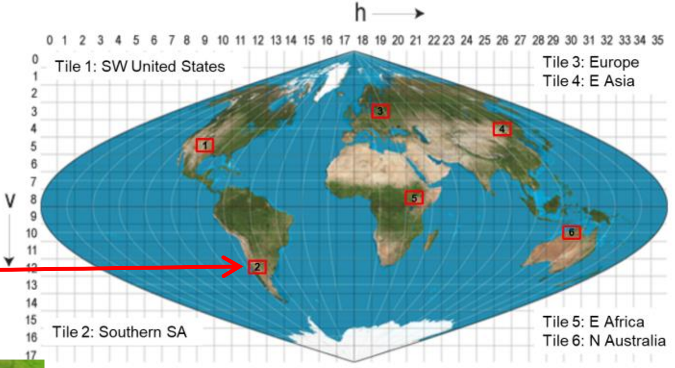


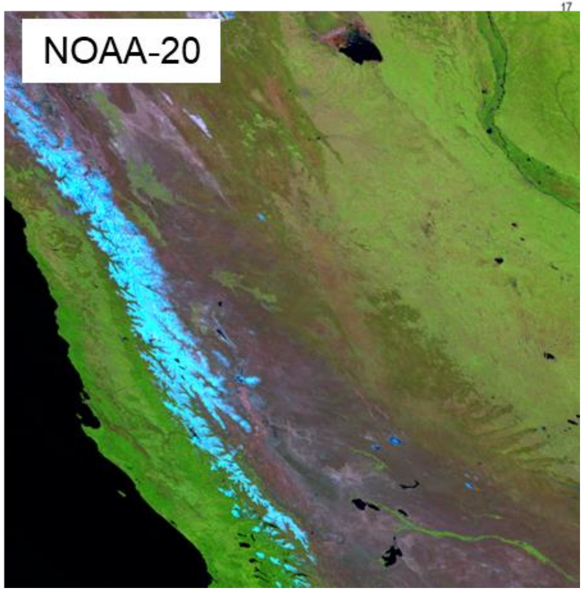




Tile 2: Southern South America



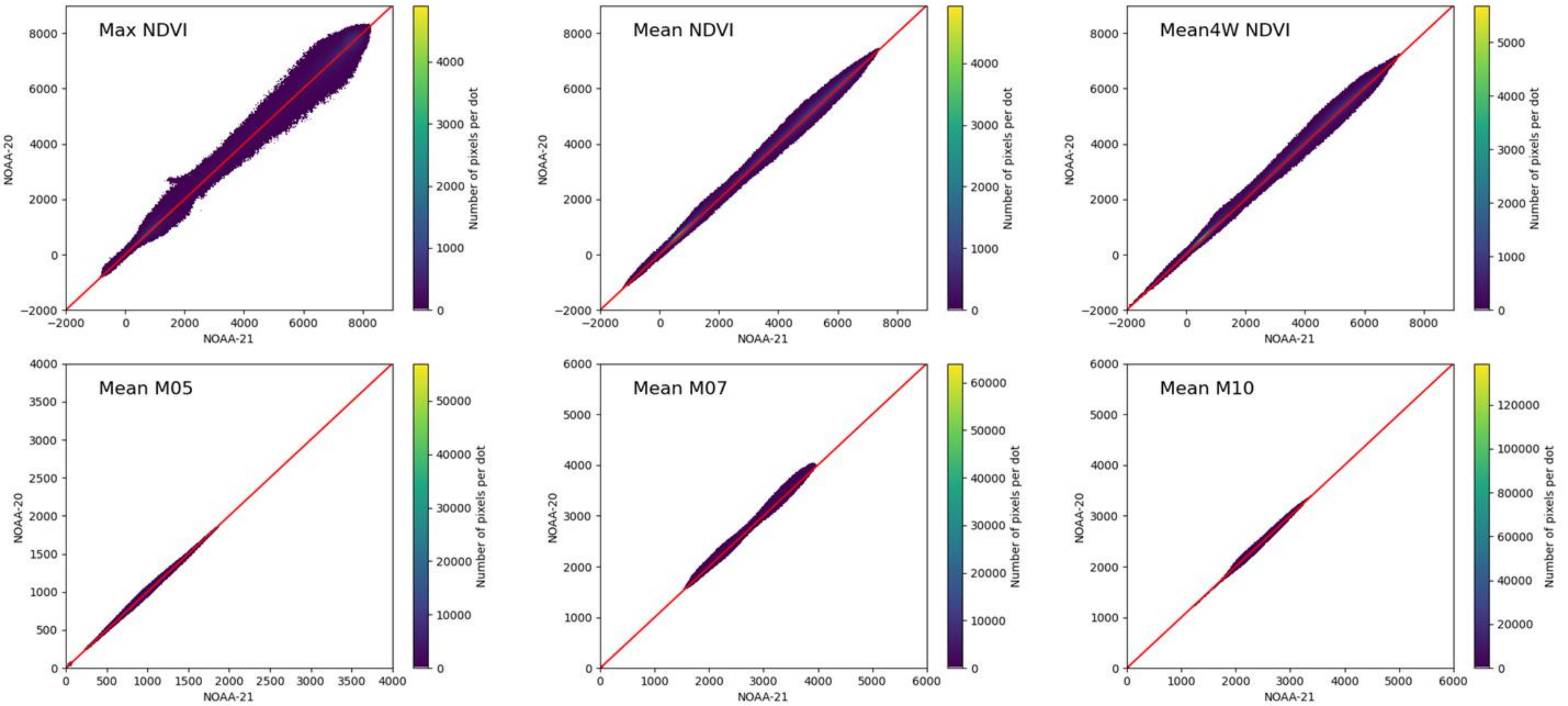




Annual mean surface reflectance image shown with M10/M7/M5 in the red, green, and blue guns:

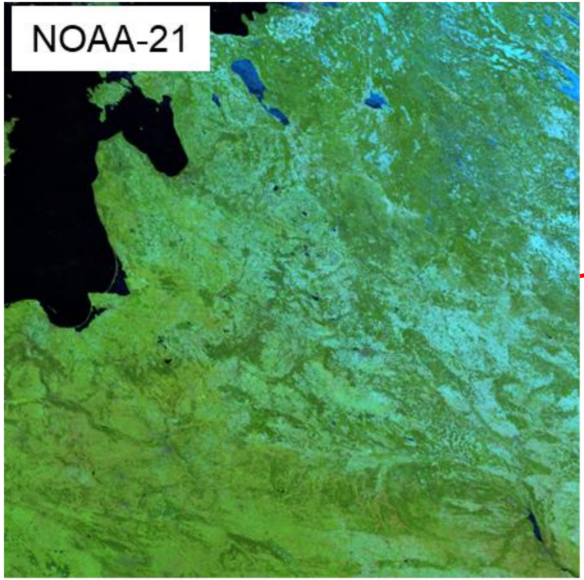
- Green tones – vegetation
- Black/dark blue – water;
- Cyan – snow/cloud
- Brown/gray (various shades) – low/no vegetation cover

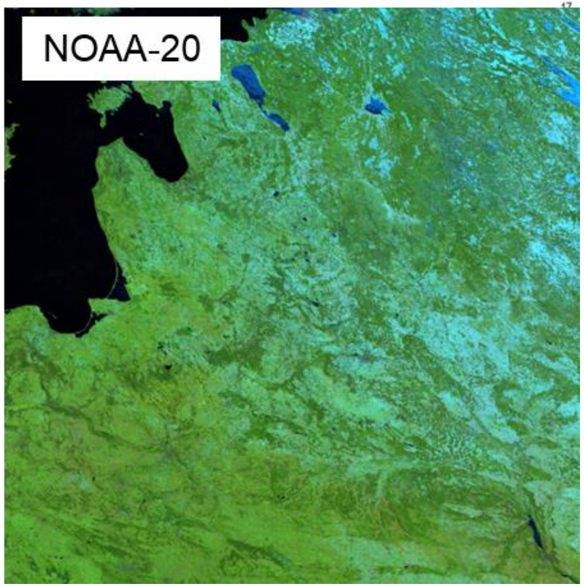
Tile 2: Southern South America

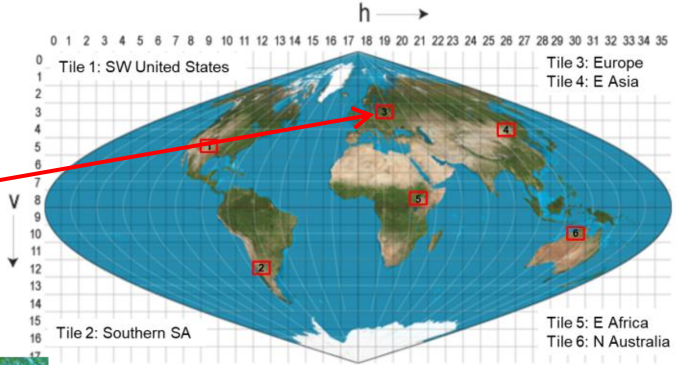


(Mean: annual mean, Mean4W: mean of 4 warmest months)

Tile 3: Central Europe



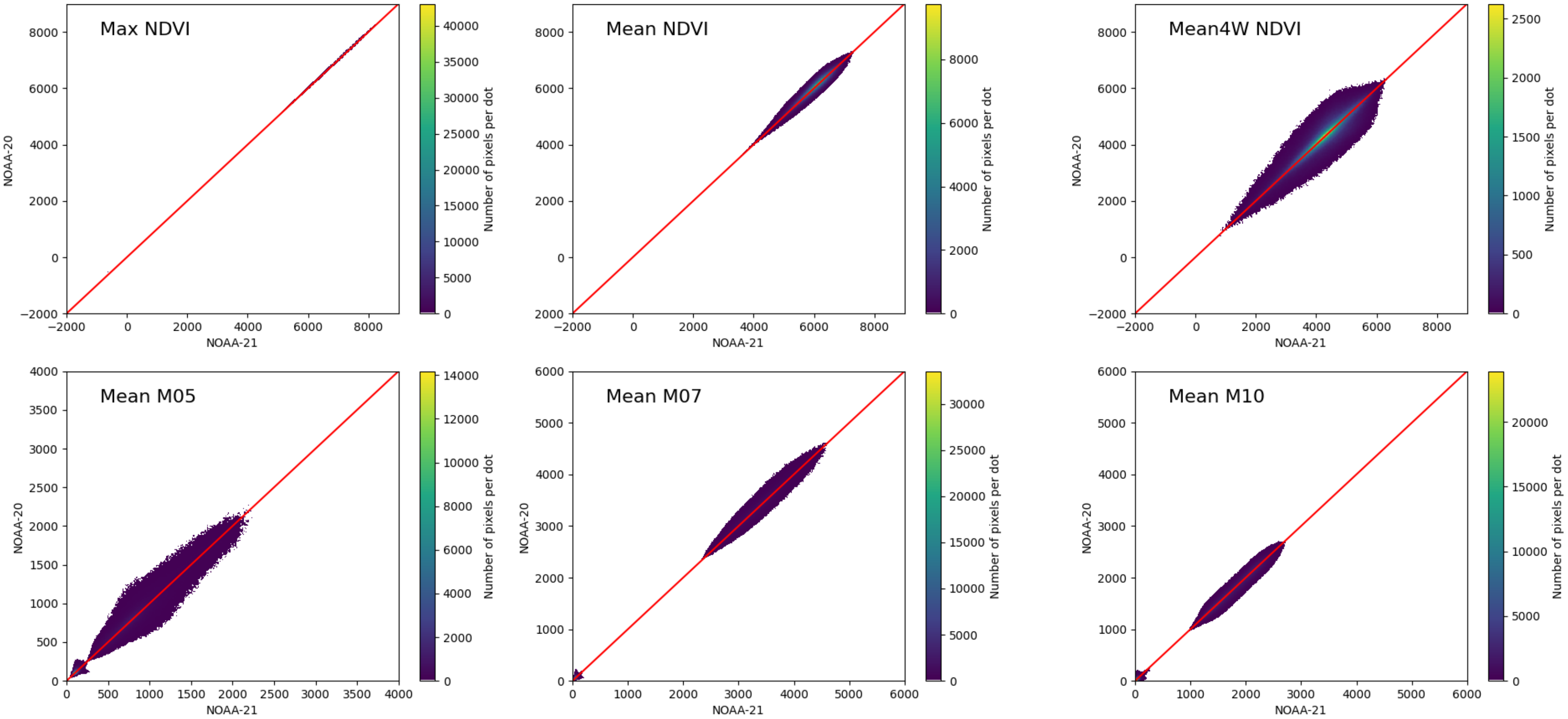




Annual mean surface reflectance image shown with M10/M7/M5 in the red, green, and blue guns:

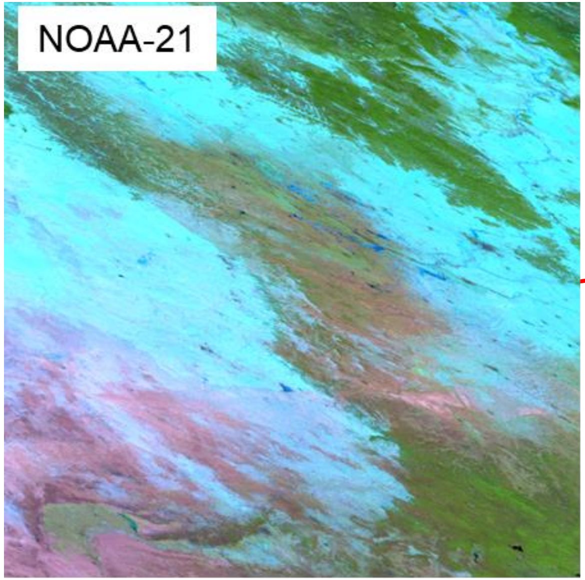
- Green tones – vegetation
- Black/dark blue – water;
- Cyan – snow/cloud
- Brown/gray (various shades) – low/no vegetation cover

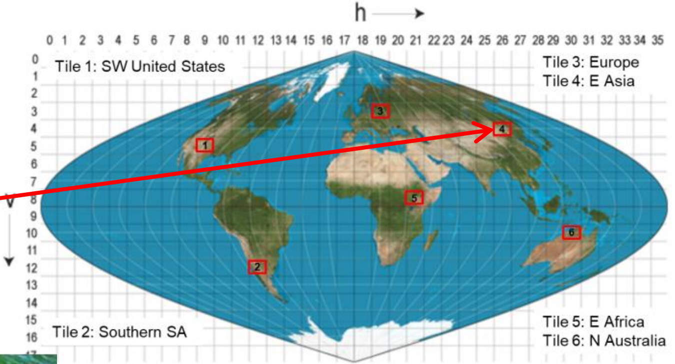
Tile 3: Central Europe

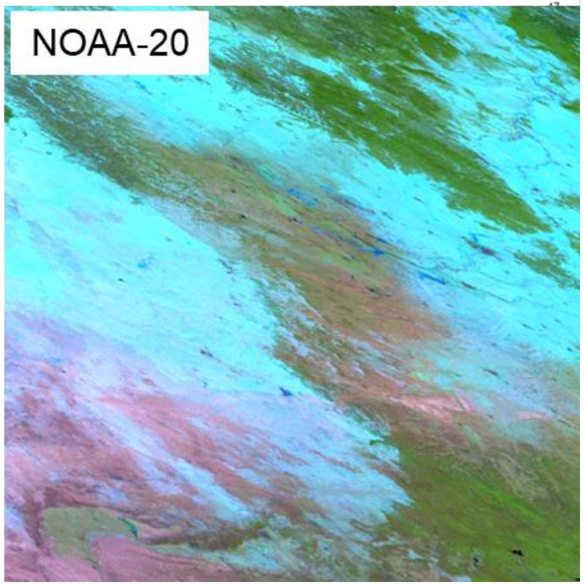


(Mean: annual mean, Mean4W: mean of 4 warmest months)

Tile 4: East Asia



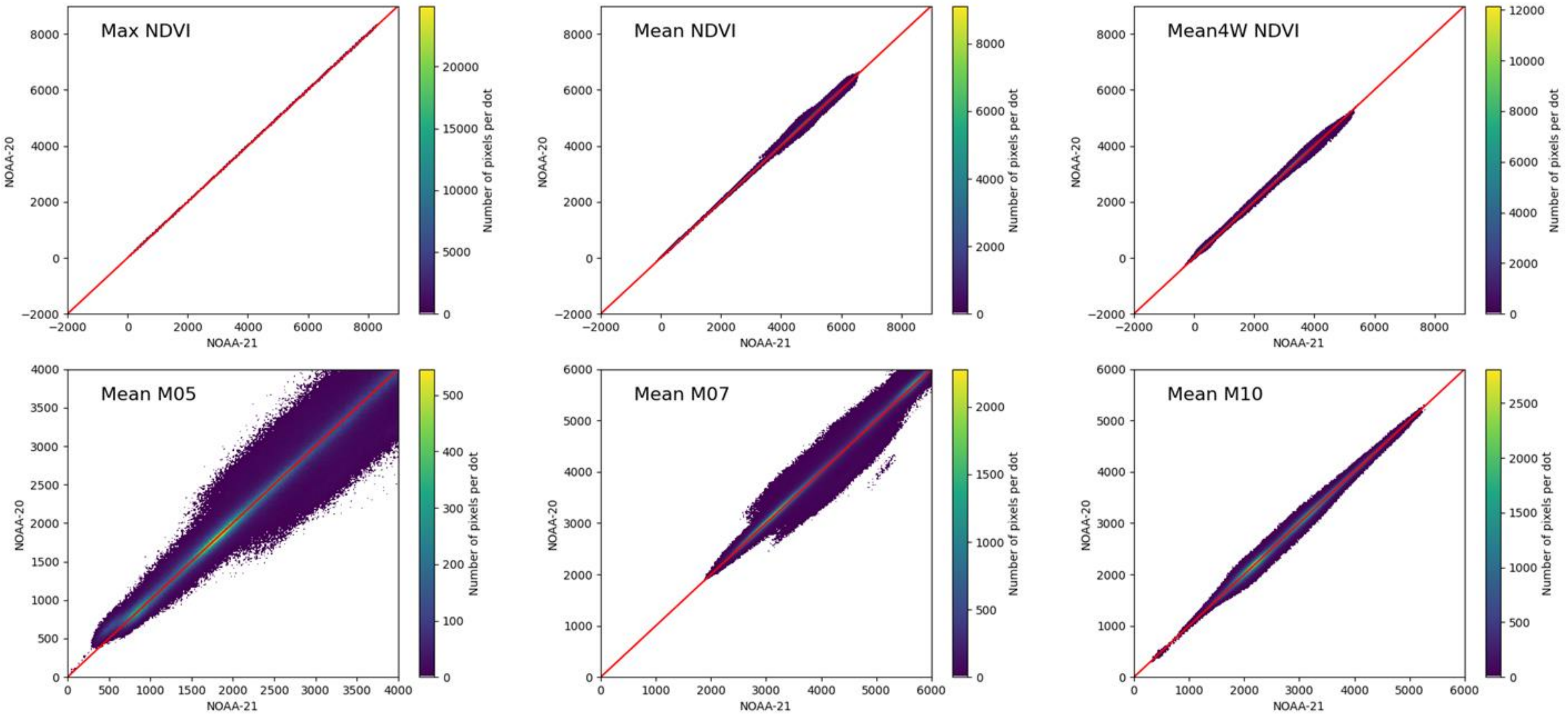




Annual mean surface reflectance image shown with M10/M7/M5 in the red, green, and blue guns:

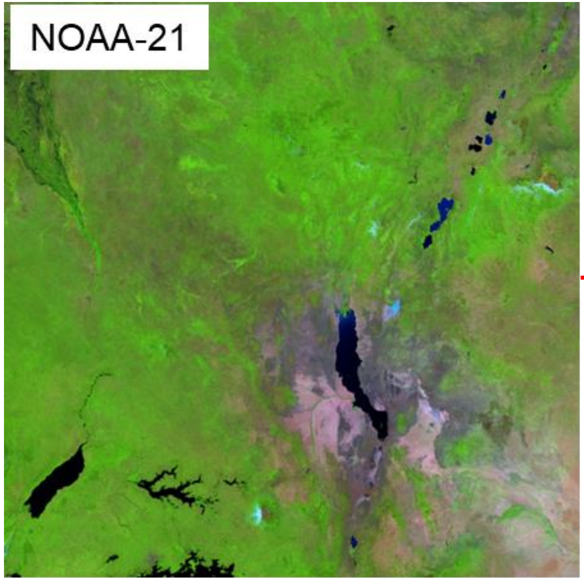
- Green tones – vegetation
- Black/dark blue – water;
- Cyan – snow/cloud
- Brown/gray (various shades) – low/no vegetation cover

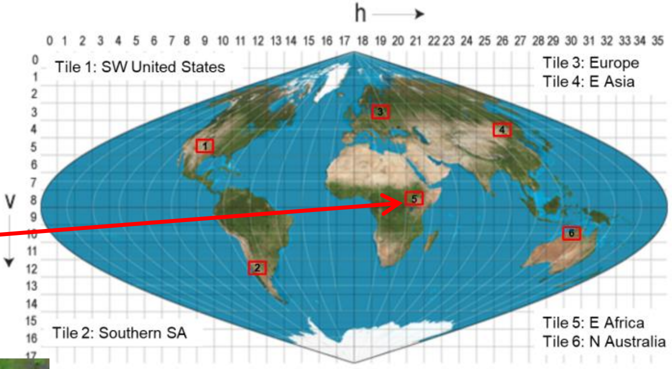
Tile 4: East Asia

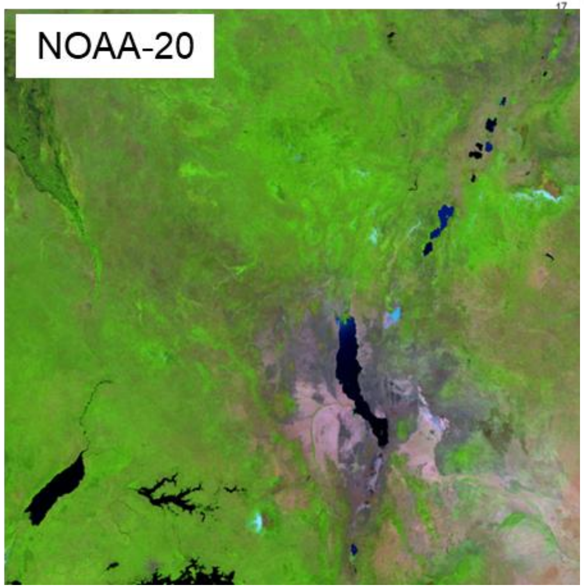


(Mean: annual mean, Mean4W: mean of 4 warmest months)

Tile 5: East Africa



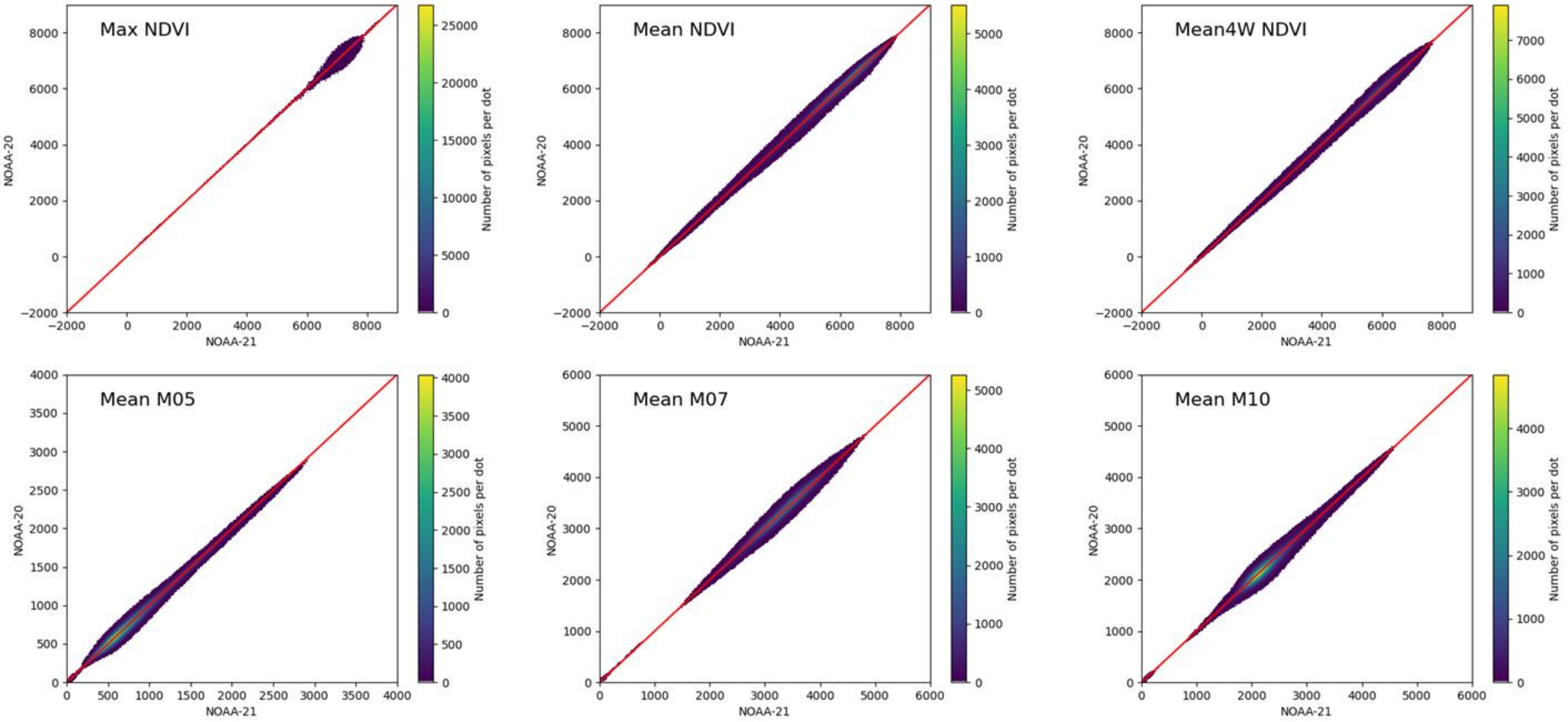




Annual mean surface reflectance image shown with M10/M7/M5 in the red, green, and blue guns:

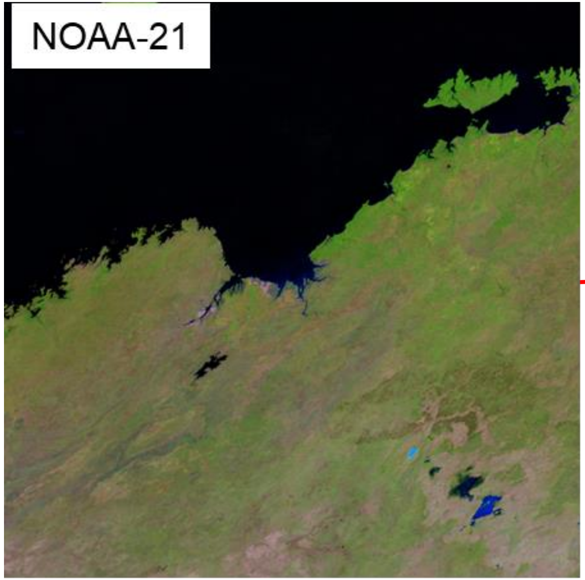
- Green tones – vegetation
- Black/dark blue – water;
- Cyan – snow/cloud
- Brown/gray (various shades) – low/no vegetation cover

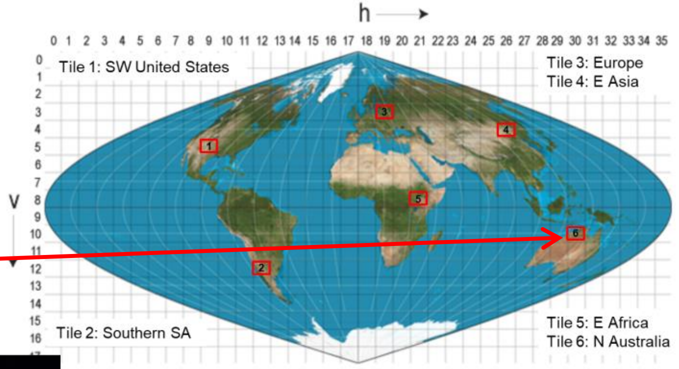
Tile 5: East Africa

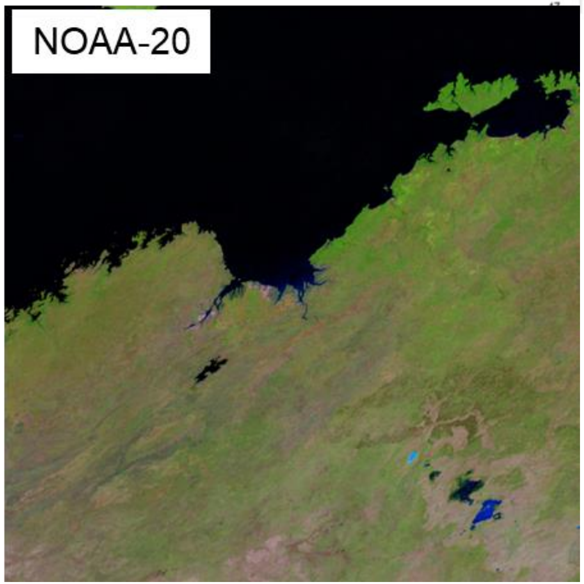


(Mean: annual mean, Mean4W: mean of 4 warmest months)

Tile 6: Northern Australia







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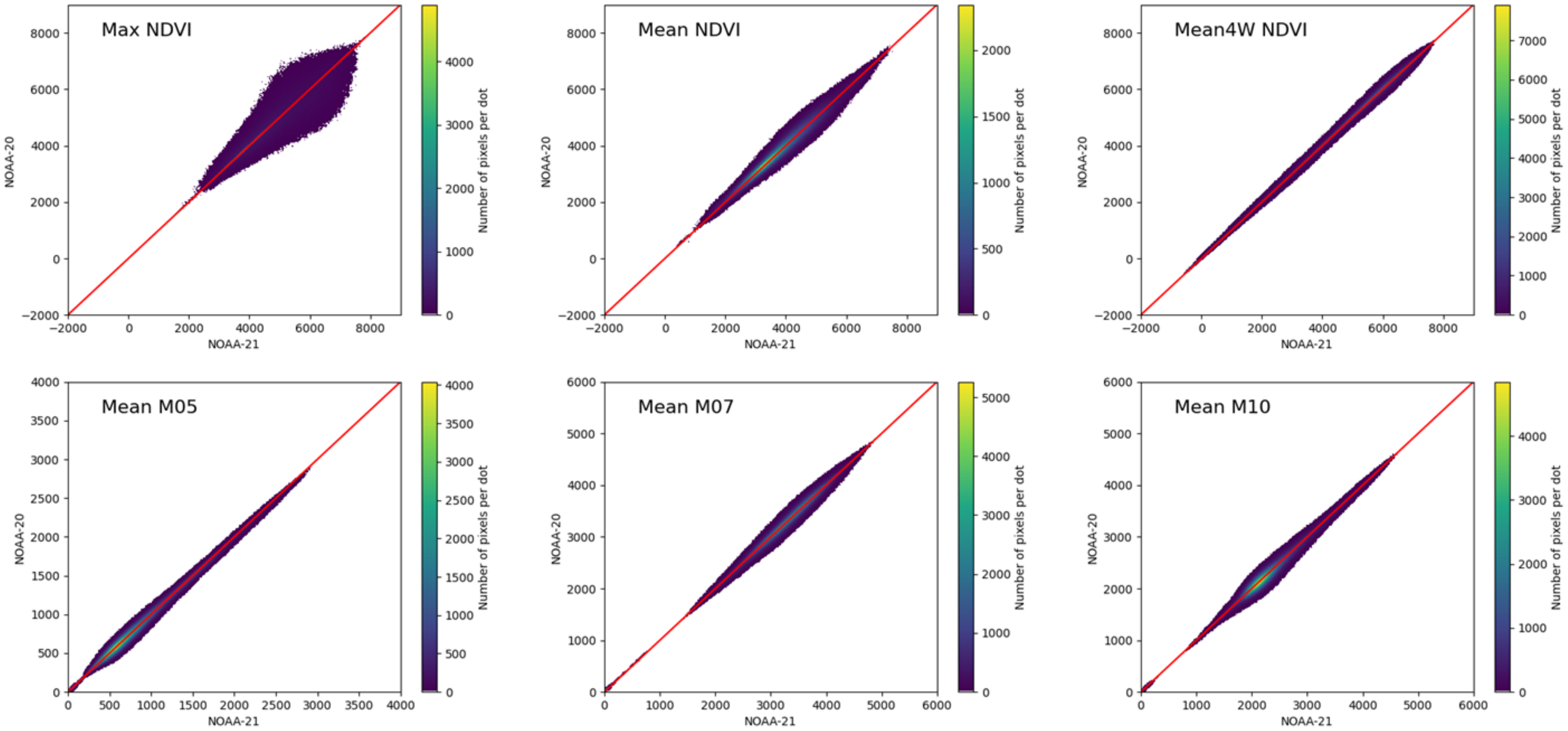
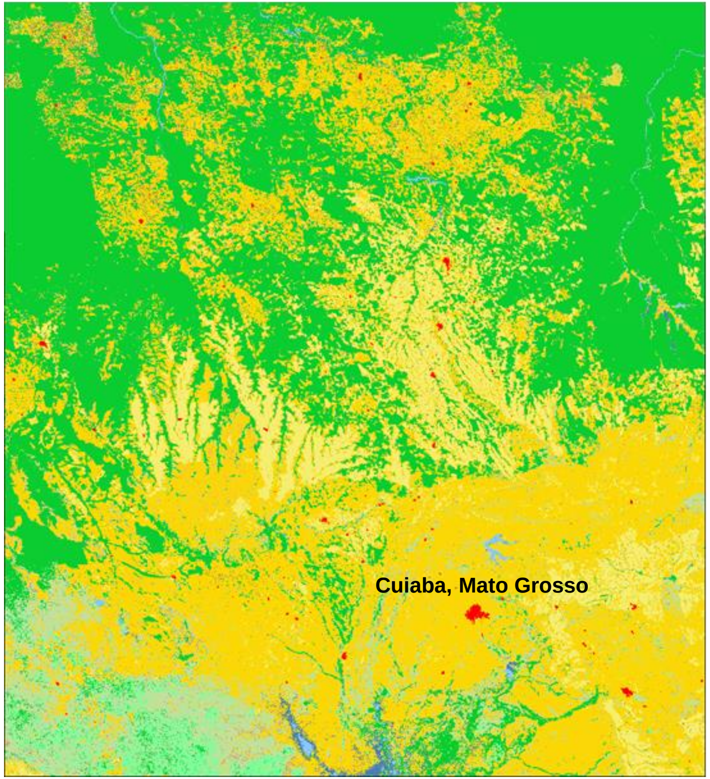


(Mean: annual mean, Mean4W: mean of 4 warmest months)

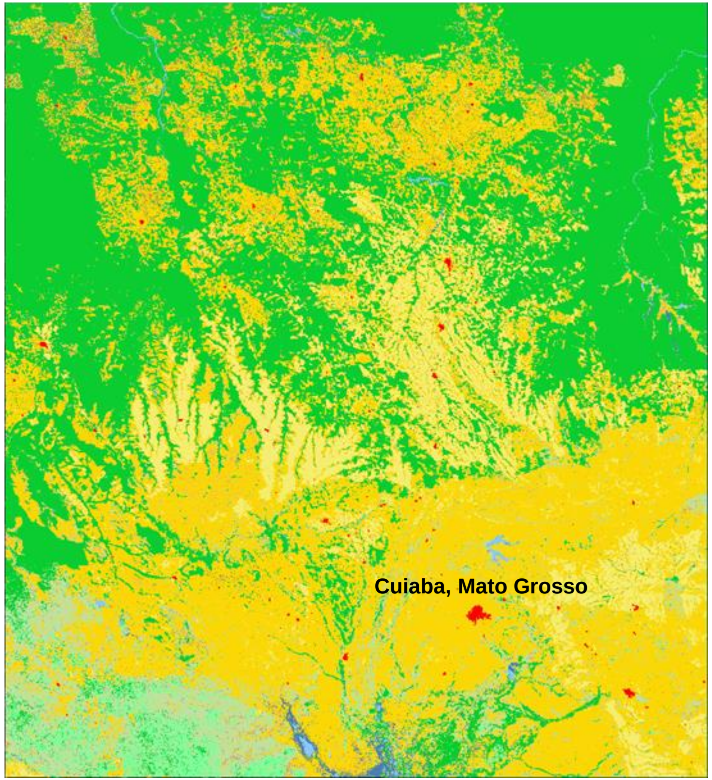
Level 4 Assessment: Annual Surface Type Maps

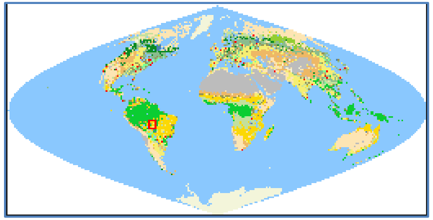
SW Brazil

NOAA-20



NOAA-21



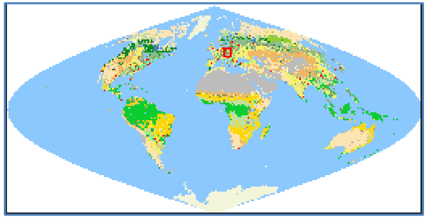


Surface Types

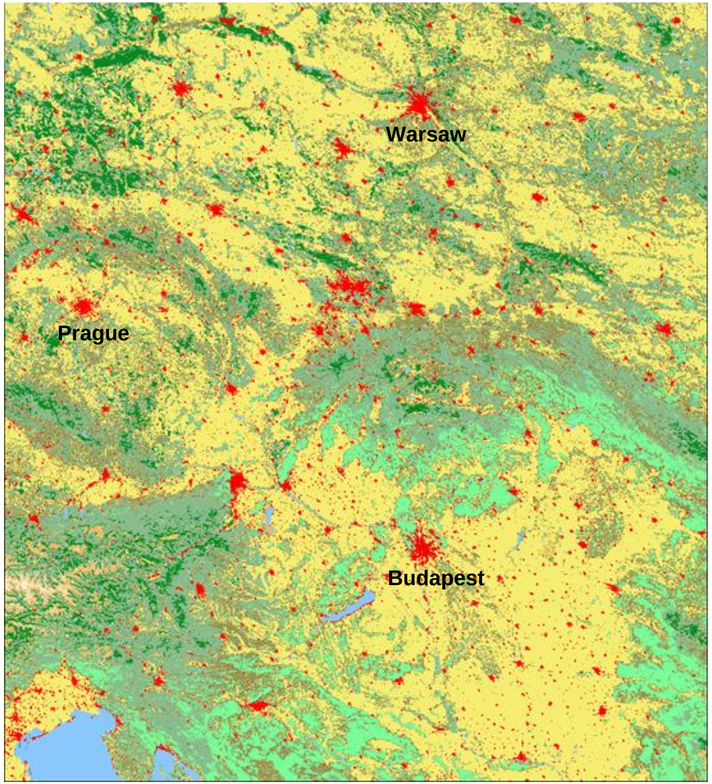
- Evergreen Needleleaf Forests
- Evergreen Broadleaf Forests
- Deciduous Needleleaf Forests
- Deciduous Broadleaf Forests
- Mixed Forests
- Closed Shrublands
- Open Shrublands
- Woody Savannas
- Savannas
- Grasslands
- Permanent Wetlands
- Croplands
- Urban and Built-up Lands
- Cropland/Natural Vegetation Mosaics
- Snow and Ice
- Barren
- Water Bodies

Level 4 Assessment: Annual Surface Type Maps

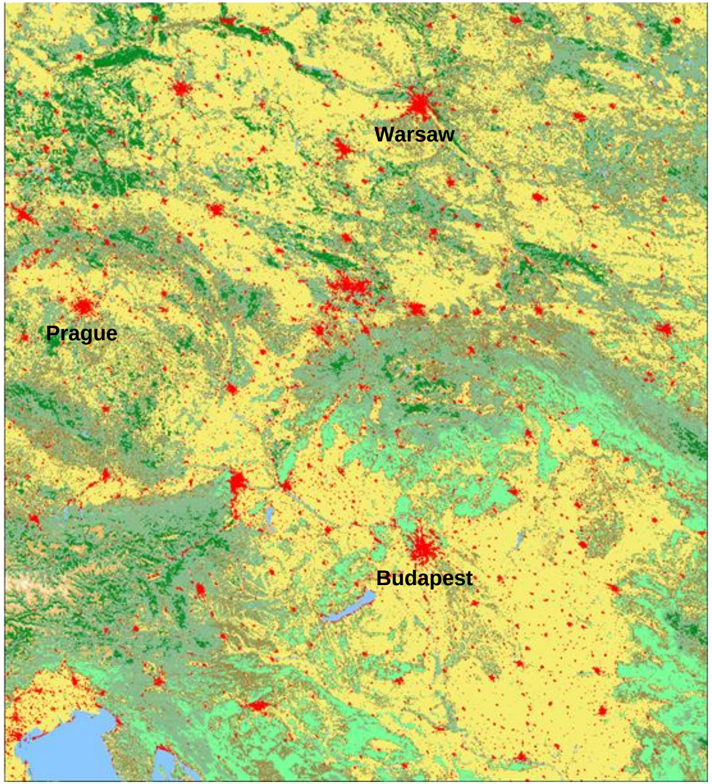
E Europe



NOAA-20



NOAA-21



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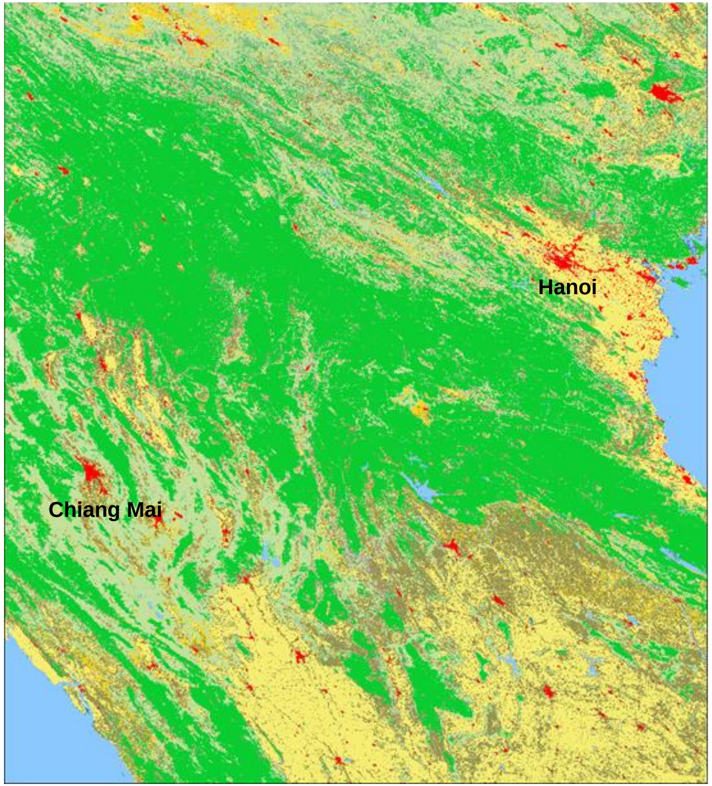
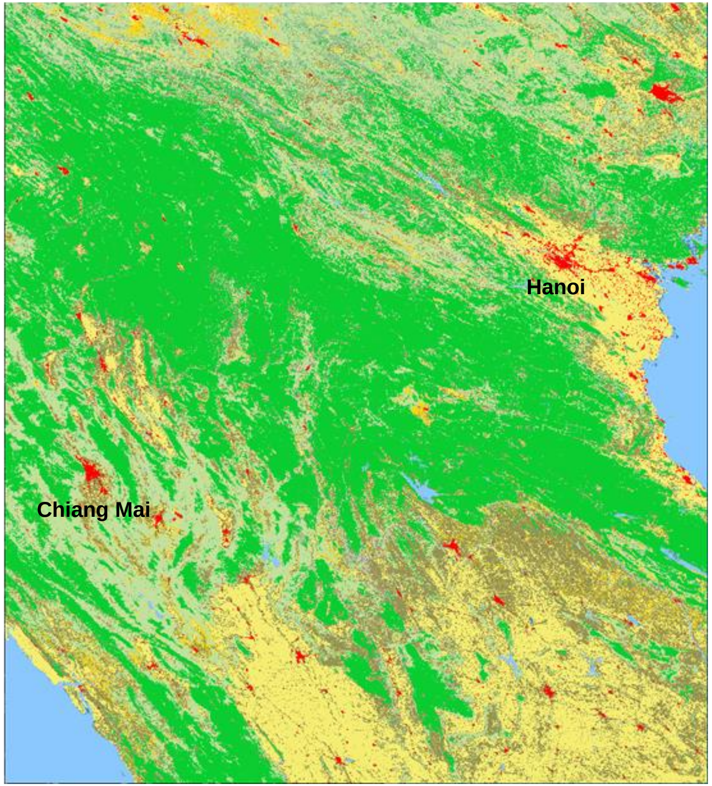
Level 4 Assessment: Annual Surface Type Maps

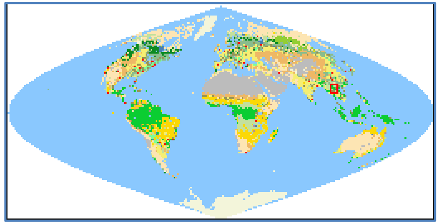
SE Asia

NOAA-20



NOAA-21





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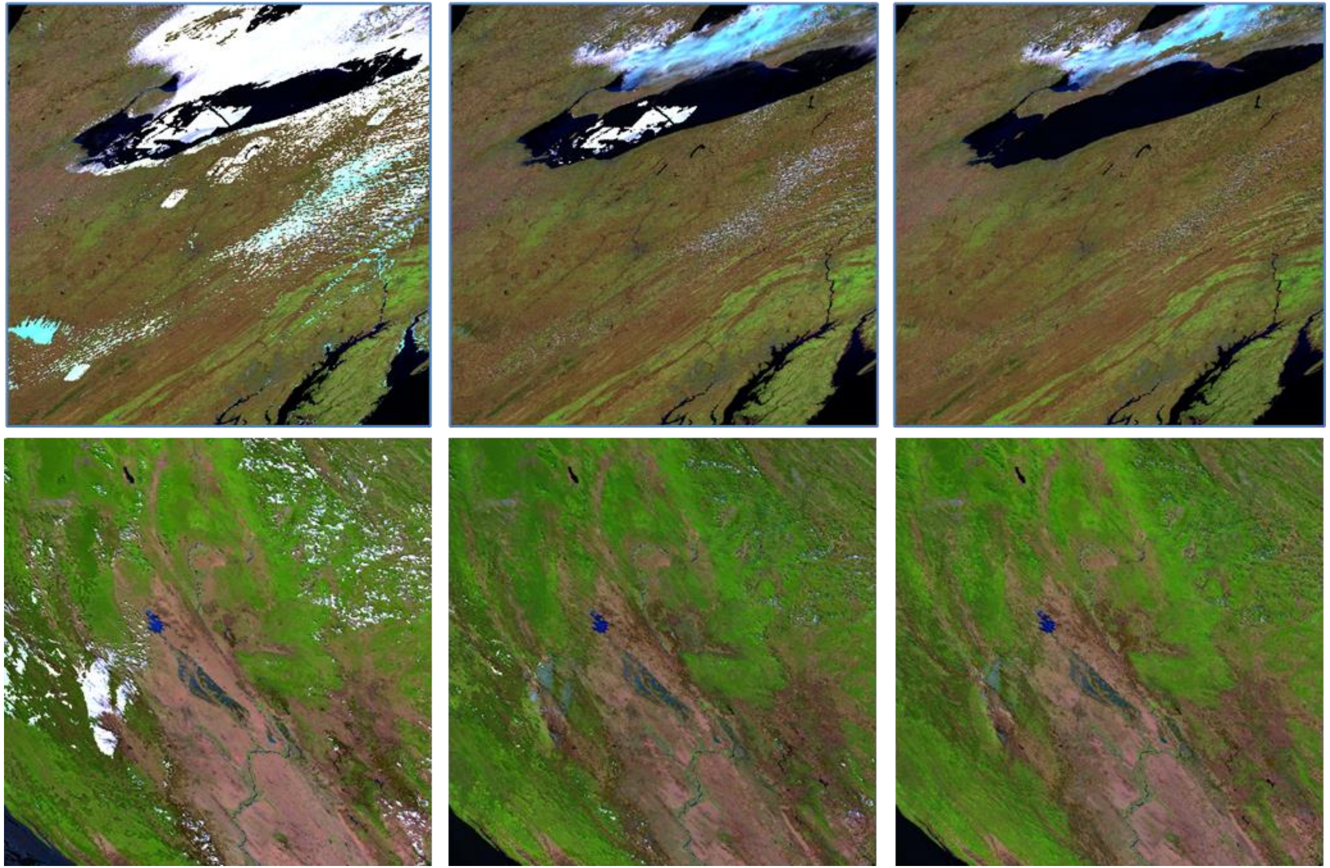
Reduce Cloud Cover in Short-Term Composites

VIIRS 2-day composites (March 15-16, 2024)

NOAA-21 Only | NOAA-21/20 | NOAA-21/20 + S-NPP



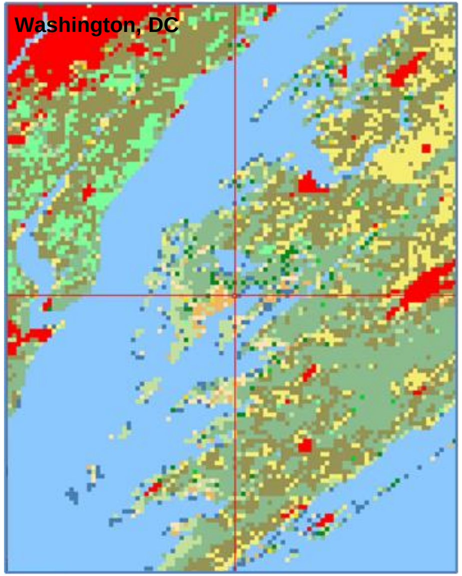
DC-Great Lakes Region

Southeast Asia

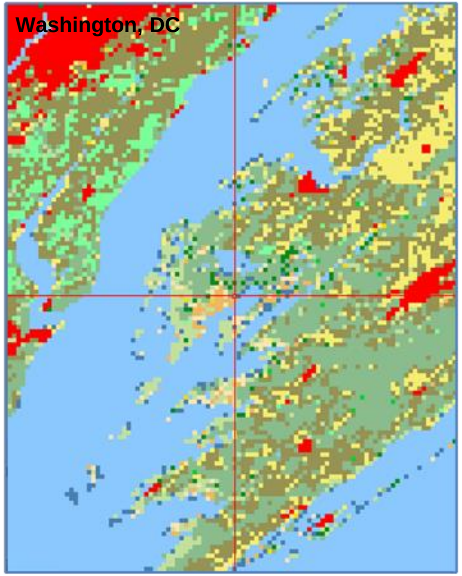
Example Differences Over DMV Region

Surface Type Maps Based on Data Acquired in 12 Months (May 2023 to April 2024)

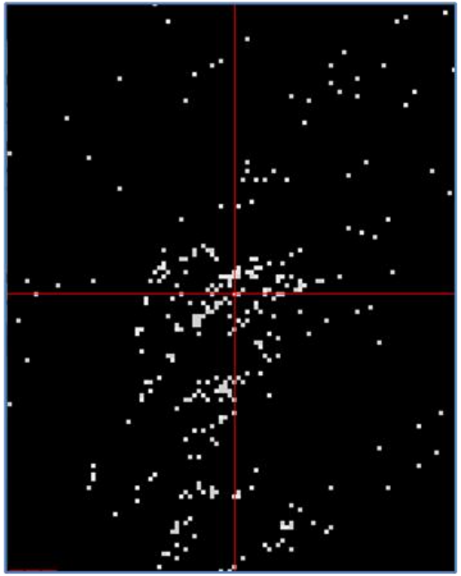
NOAA-20



NOAA-21/20



Difference Map



Google Earth Image

IGBP Legend

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- Barren
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Most of the differences are:

- Edge pixels
- Mixed pixels
- Spectrally confused classes