Introduction to NASA's "Black Marble" Night Lights Data

December 3, 2020

Course Structure and Details

- 1 Session: December 3, 2020

- Webinar recording, PowerPoint presentation, and homework assignment can be found at: https://appliedsciences.nasa.gov/join-mission/training/english/introduction-nasas-black-marble-night-lights-data
- Q&A: 20 minutes following the lecture

- Certificate of Completion
  - Attend webinar
  - Complete assignment accessed from the ARSET Black Marble webinar website (above)
  - You will receive a certificate approximately 1 month after completion of the course.

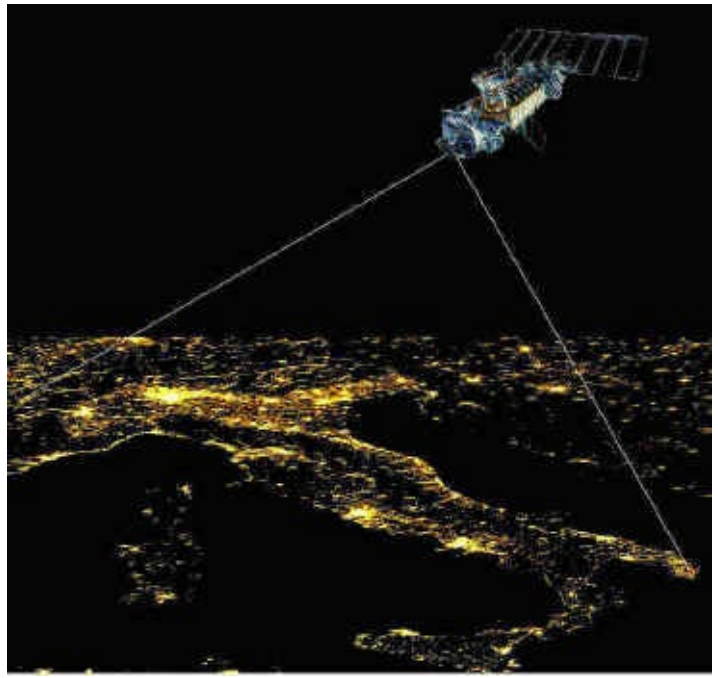
Course Instructors

- Eleanor C. Stokes, Ph.D.
  - Science PI of NASA's Black Marble Product Suite
  - Scientist at USRA's Earth from Space Institute

- Ranjay Shrestha, Ph.D.
  - Scientific Programmer/Analyst
  at NASA Goddard Space Flight Center

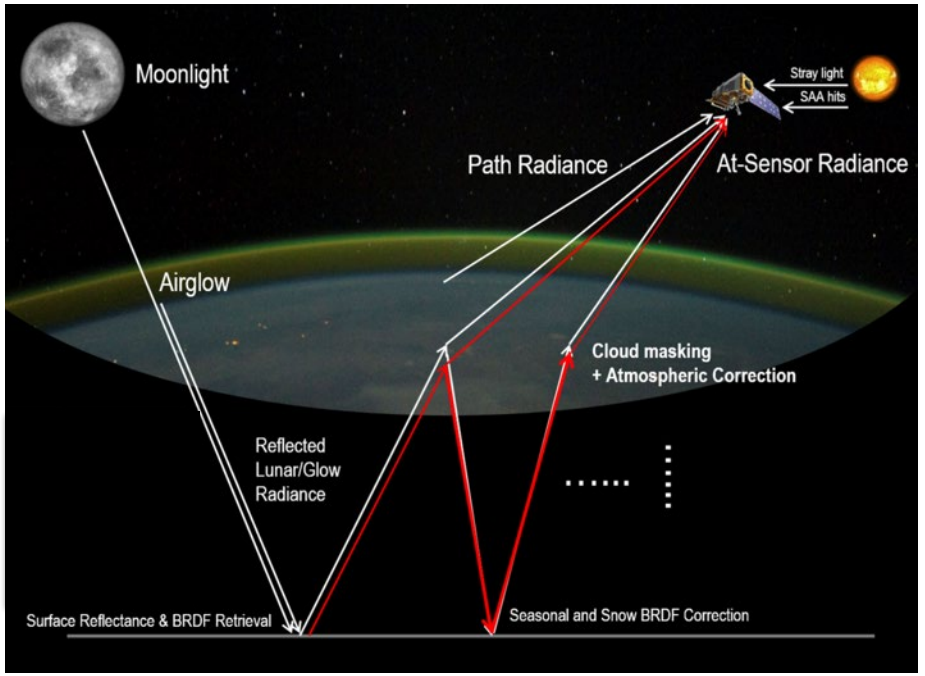
Course Outline

Part 1 (30 min)



Basics and Background of Nighttime Remote Sensing

Part 2 (15 min)



Black Marble Processing & Data Analysis

Part 3 (15 min)

Science and Applications

Learning Objectives

By the end of this presentation, you will understand:

Basics and Background:

- The light sources that are captured in Nighttime Lights (NTL) data.
- Differences between existing nighttime lights products.
- What is corrected and not corrected for in the Black Marble algorithm.

Acquiring and Using the Data:

- How to download Black Marble images via the Level-1 and Atmosphere Archive & Distribution System (LAADS).
- What are the different bands in the Black Marble Product?
- How to consider Quality Assessment indicators.
- How to process Black Marble data to get a time series.

Applying the Data:

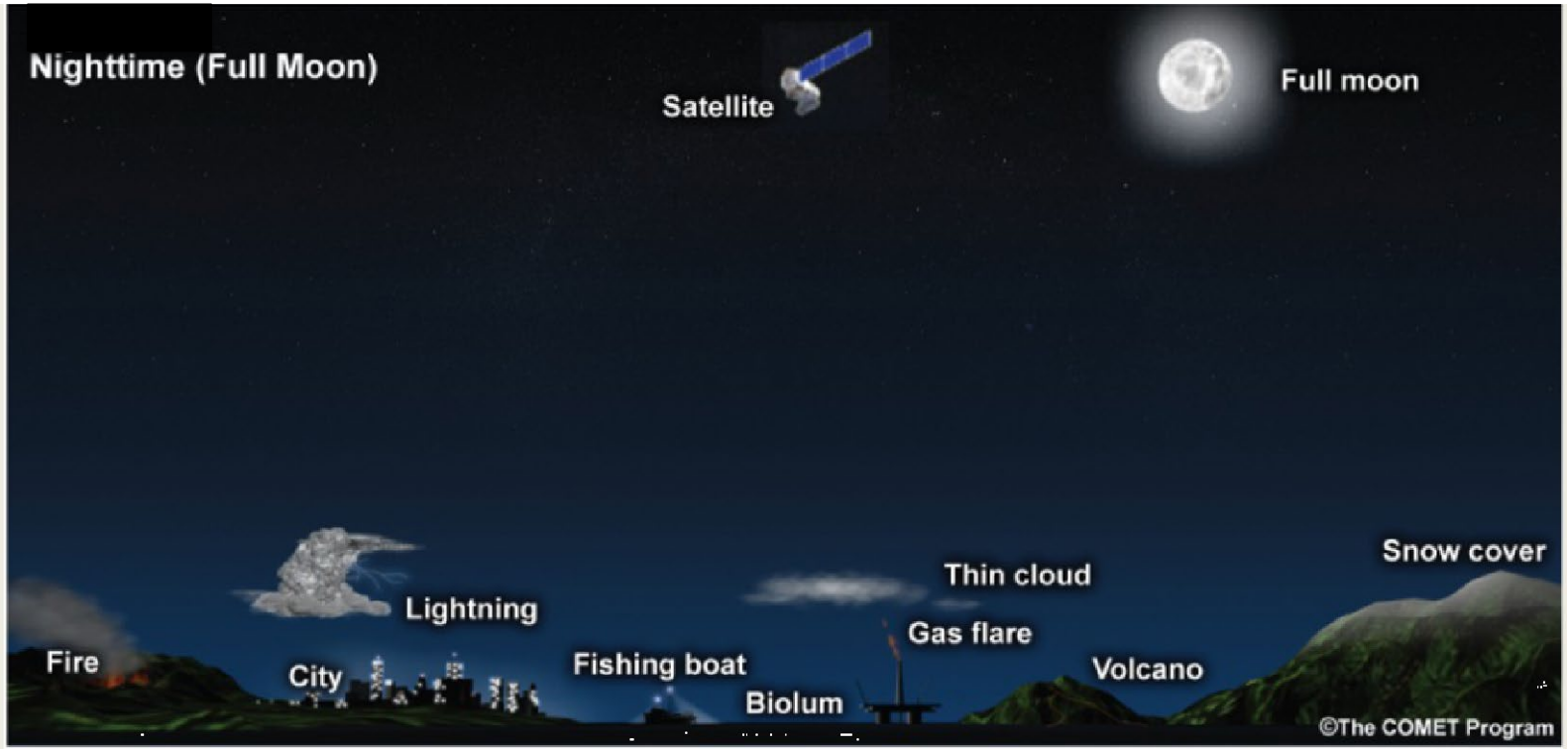
- How night lights data is being applied to
  - urban studies
  - disaster monitoring
  - COVID-19

Part 1: Basics and Background of Nighttime Remote Sensing

What can we study with nighttime remote sensing?

With moonlight:

- The reflectance of snow cover, smoke, airborne dust, sea ice, and land surface features are visible
- Imaging cloud cover to support short-term weather prediction is the primary purpose of nighttime sensors.

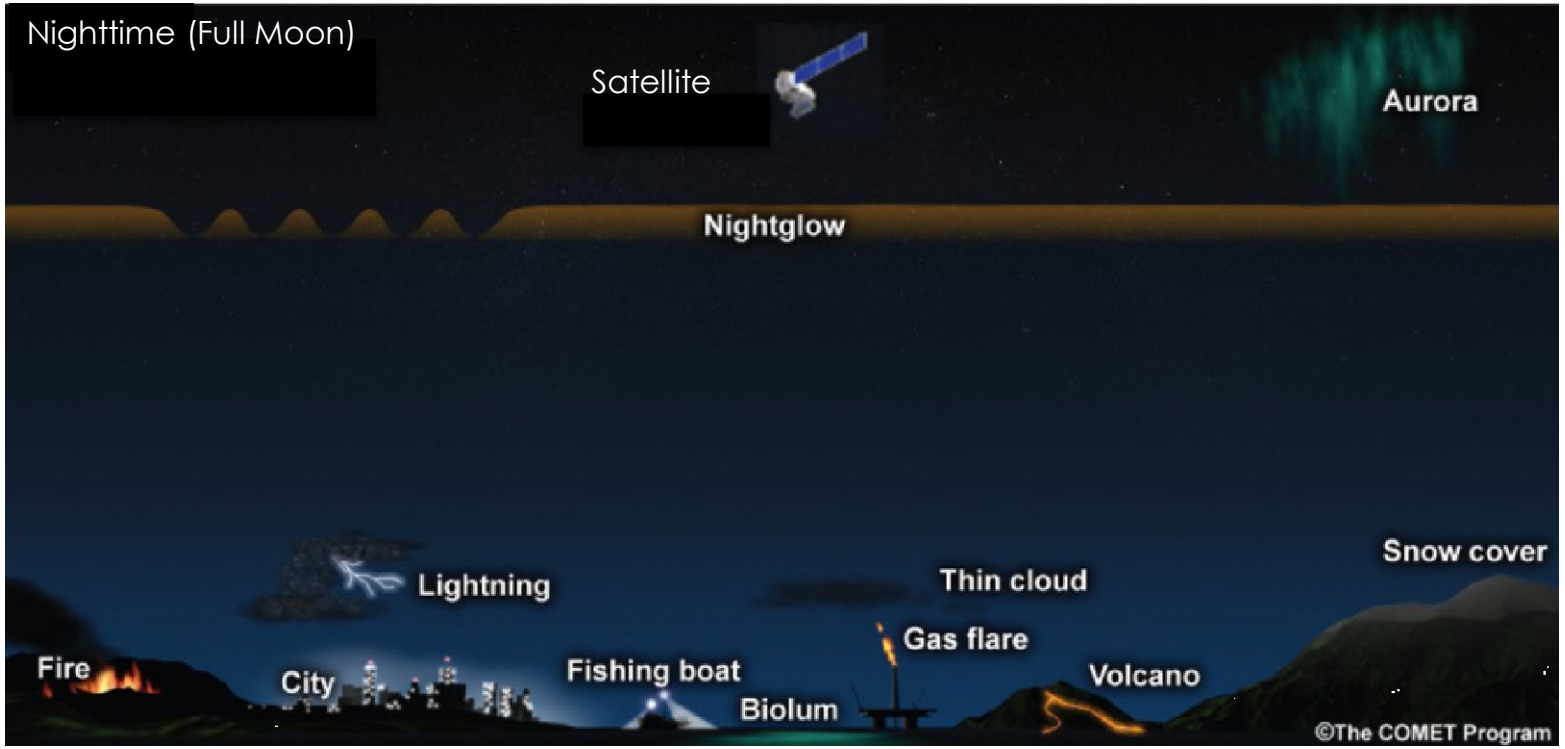


Miller et. al, 2013

What can we study with nighttime remote sensing?

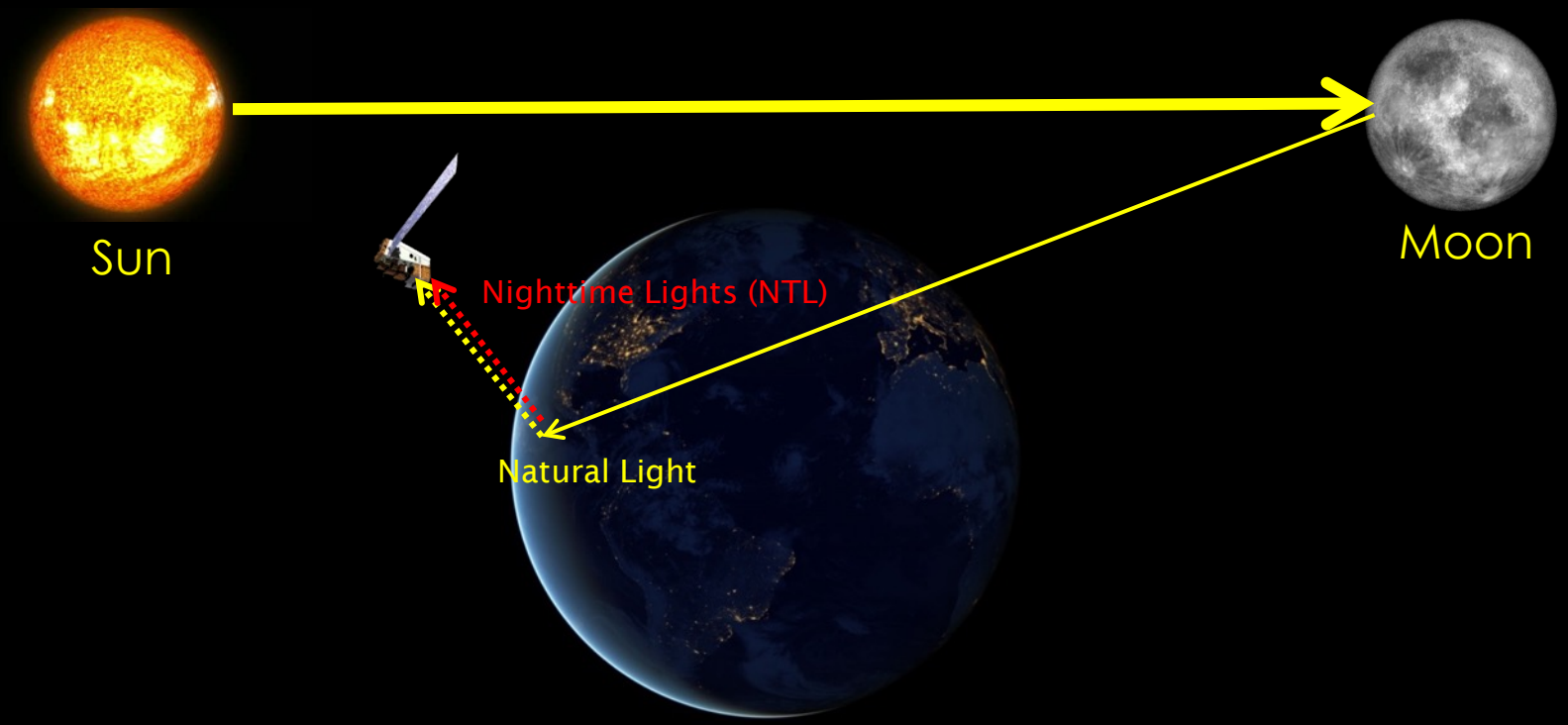
Without moonlight:

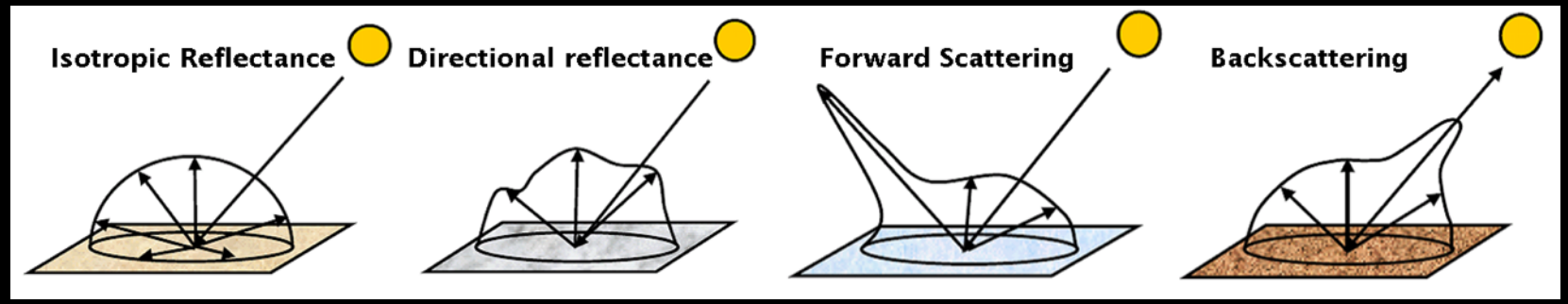
- Artificial lights like street and building lighting
- Fishing boats
- Gas flares
- Fires
- Aurora
- Bioluminescence
- Nightglow from the atmosphere



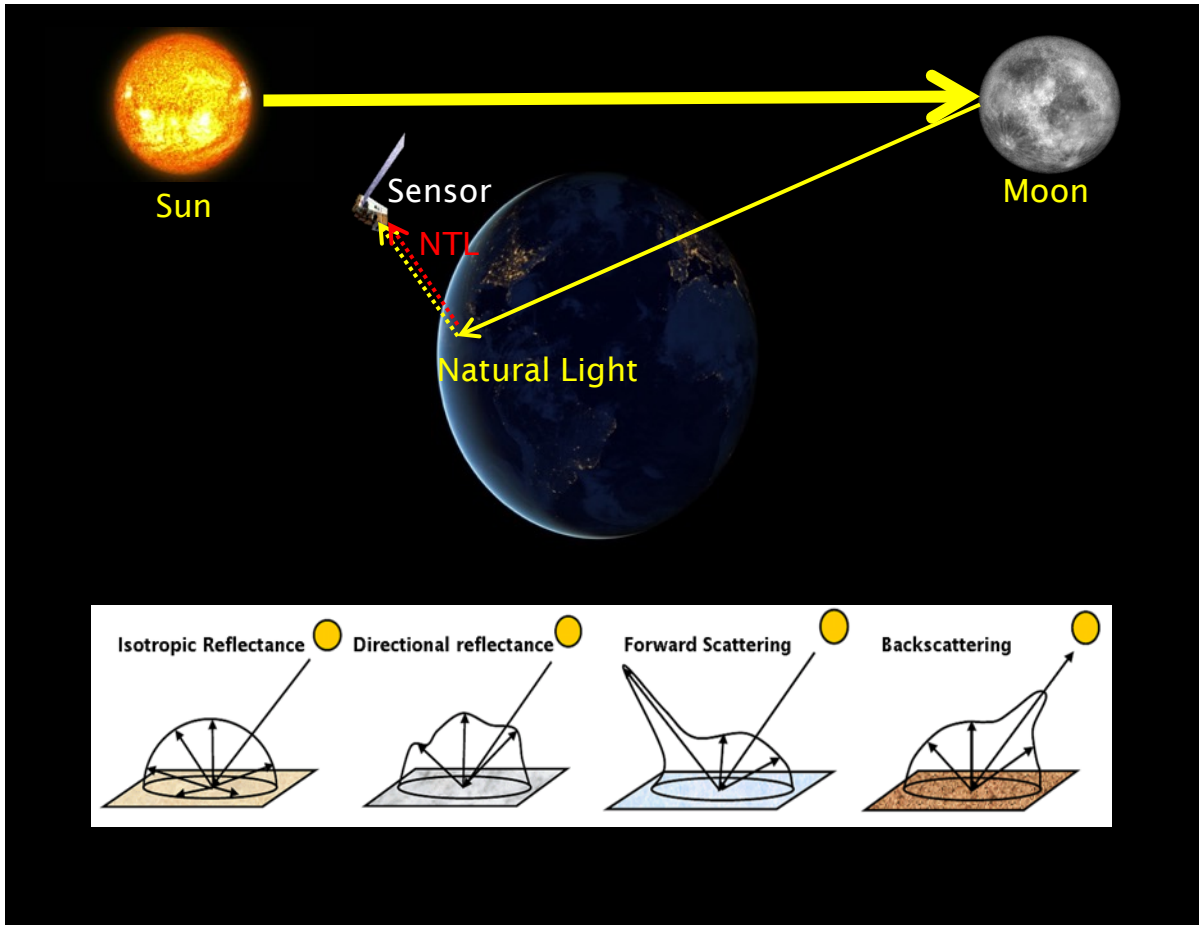
Miller et. al, 2013

Principles of Nighttime Remote Sensing





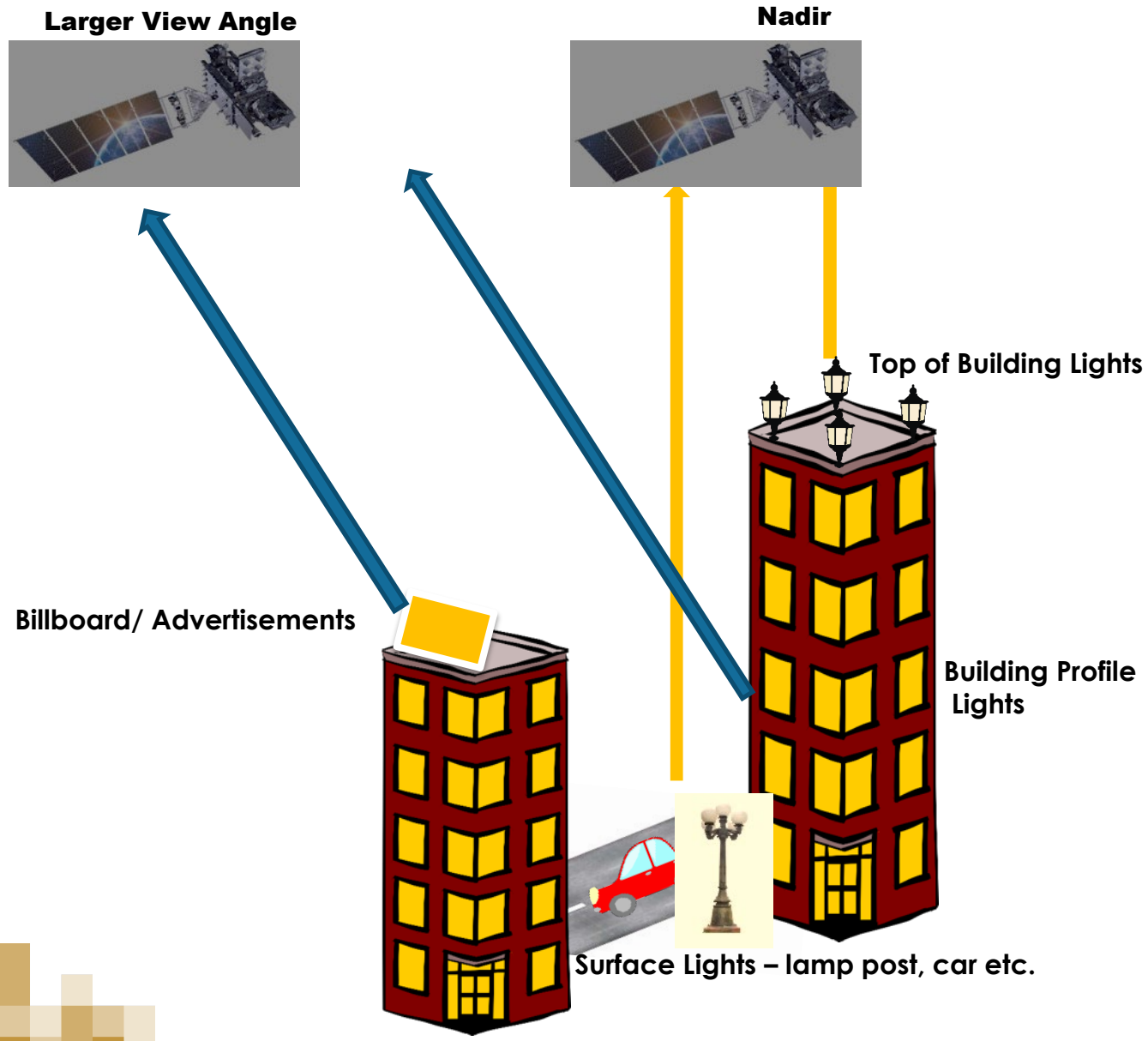
Principles of Nighttime Remote Sensing



Unlike in daytime remote sensing:

- There are multiple light sources.
- Observations include moonlight, light directly emitted by a source (e.g., buildings and transport), and light scattered by the ground.
- Snow (both under moon-illuminated and moon-free conditions) can also increase the signal during winter months.
- Land features (such as buildings and trees) can also block the light source during different time periods.

Principles of Nighttime Remote Sensing



- Light sources have different angular emission and reflection profiles.
- Different satellite viewing angles may change light sources captured.
- Angular differences are more prominent in city centers (downtown areas) with tall buildings.

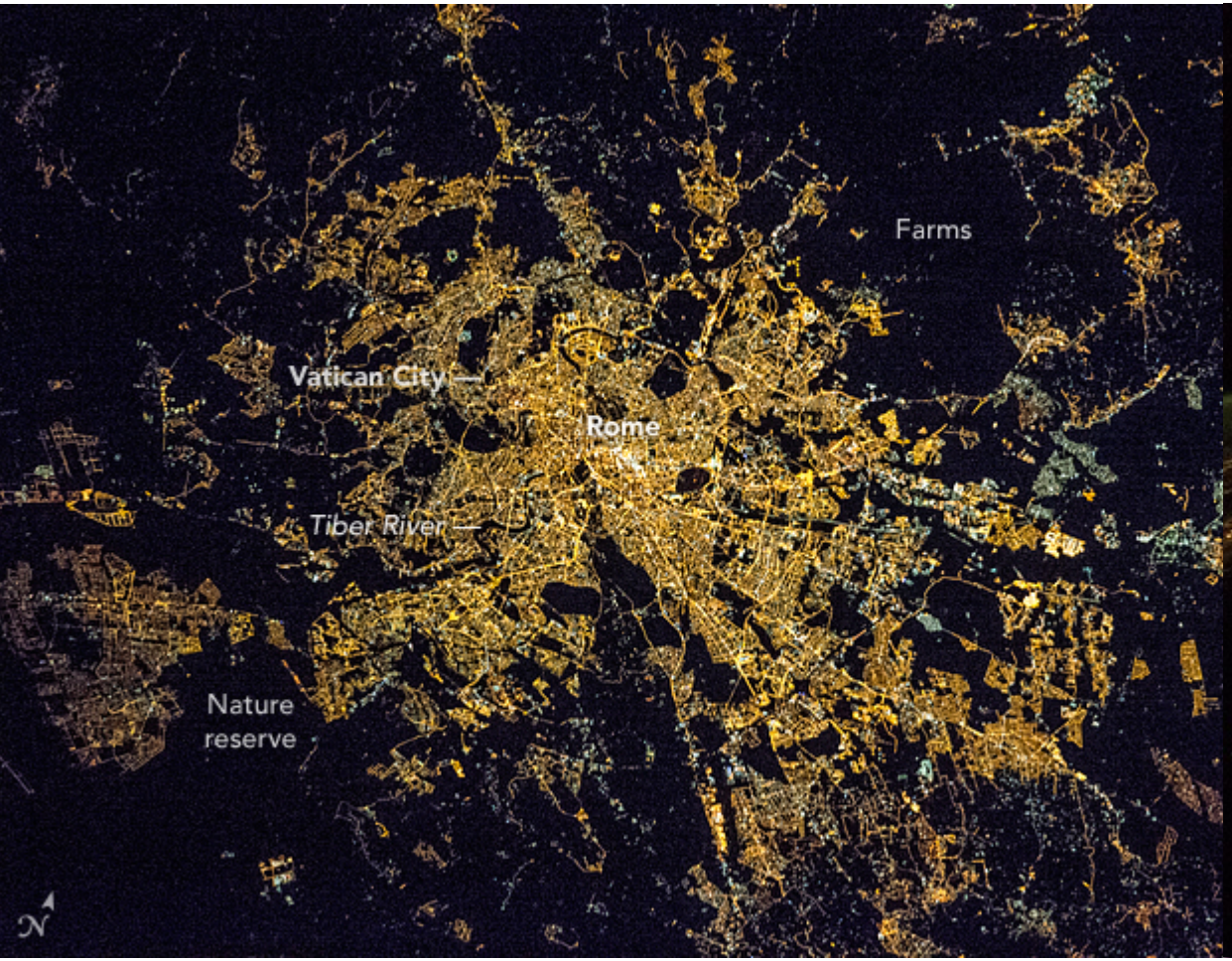
Nighttime Light Sensor/Products

International Space Station (ISS) Images

- Astronaut photographs of the Earth at night.
- Provides imagery information in 3 visible spectral bands (R,G,B).
- Quality greatly improved (10m-resolution) with the installation of the NightPod instrument in 2012.
- Images are not scientific data.
  - Lack of georeferencing makes it difficult to locate a specific city among millions of images.
  - No consistency across space or time.
- Images are available at NASA's "The Gateway to Astronaut Photography of Earth" (https://eol.jsc.nasa.gov/).
- "Atlas of astronaut photos of Earth at night" developed as an open directory with geotagged images of cites at night (http://www.citiesatnight.org/).

Nighttime Light Sensor/Products

International Space Station (ISS) Images



Rome at Night - Acquired on April 8, 2015, with a Nikon D4 digital camera, and is provided by the ISS Crew Earth Observations Facility and the Earth Science and Remote Sensing Unit, Johnson Space Center. (nasa.gov/mission_pages/station/images)

Italy at Night - acquired on October 21, 2014, with a Nikon D4 digital camera, and is provided by the ISS Crew Earth Observations Facility and the Earth Science and Remote Sensing Unit, Johnson Space Center. (nasa.gov/mission_pages/station/images)

Previous-Generation Nighttime Light Sensor/Product

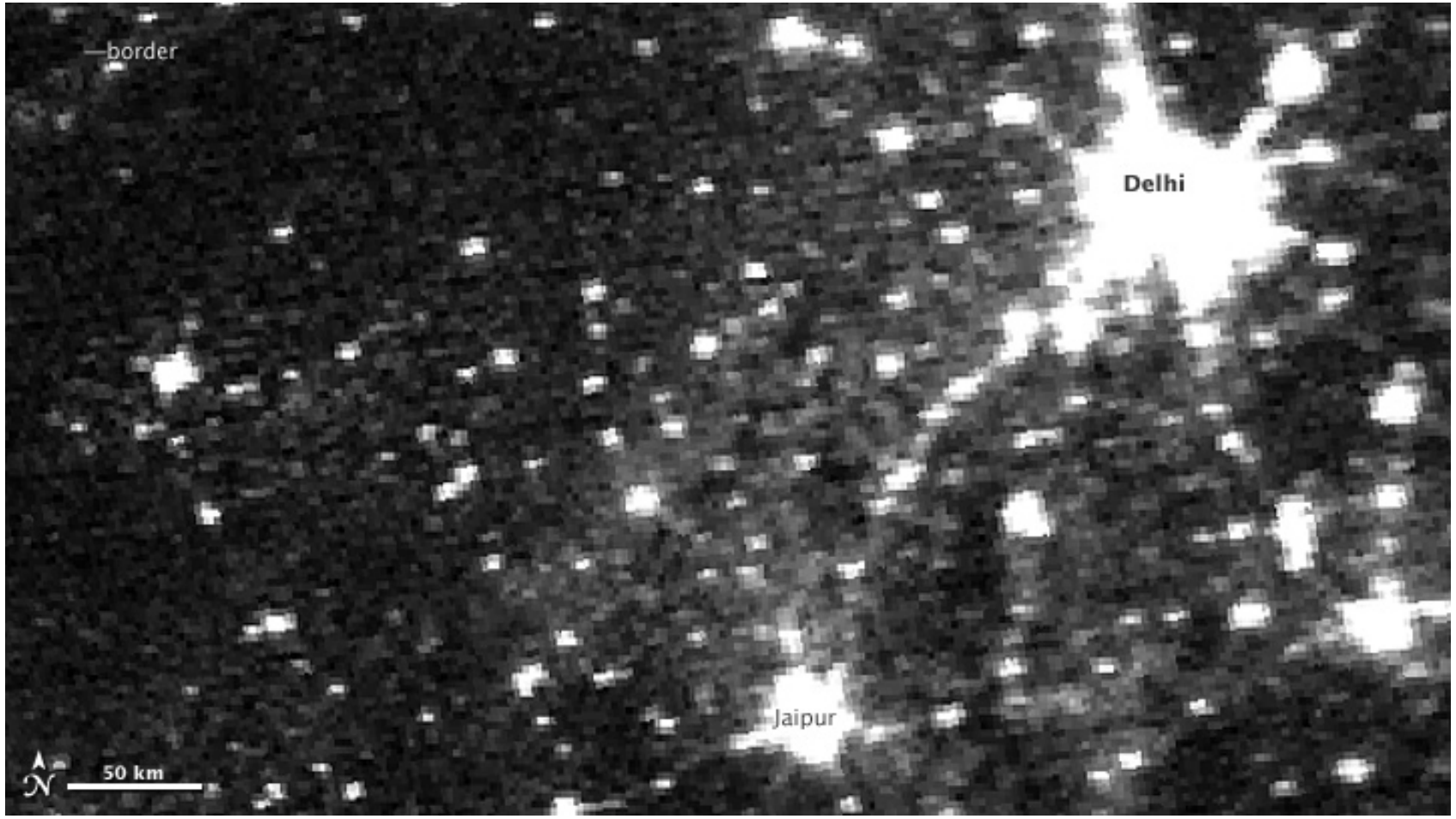
Defense Meteorological Satellite/Operational Linescan System (DMPS/OLS)

- Longest running system of global nighttime light detection from satellites.
- The digital data stream for the collection of DMSP-OLS began in 1992 and continues to this day.
- Many studies have taken advantage of extensive historical data to monitor artificial lights from space and study relationships between human activity and socio-economic variables.

DMSP Satellite
Source: NOAA

Previous-Generation Nighttime Light Sensor/Product

DMSP/OLS



- Monthly product
- 2.7 km
- No on-board calibration
- 20:00 overpass
- Saturates in urban centers (6 bit)
- Available since 1992

City, Village, and Highway Lights Near Delhi, India - Acquired in November, 2012

Next-Generation Nighttime Light Sensor/Product

The Visible Infrared Imaging Radiometer Suite Day-Night Band (VIIRS DNB)

- One of the 5 instruments onboard the Suomi National Polar-orbiting Partnership (Suomi-NPP) and Joint Polar Satellite System (JPSS) satellite platform operational since 2012.
- Joint partnership between NASA and NOAA.
- Orbits the Earth in ~102 mins, providing global coverage at ~14 orbits per day at 824 km orbital altitude.
- Sun-synchronous satellite captures the observation near 01:30 local solar time.

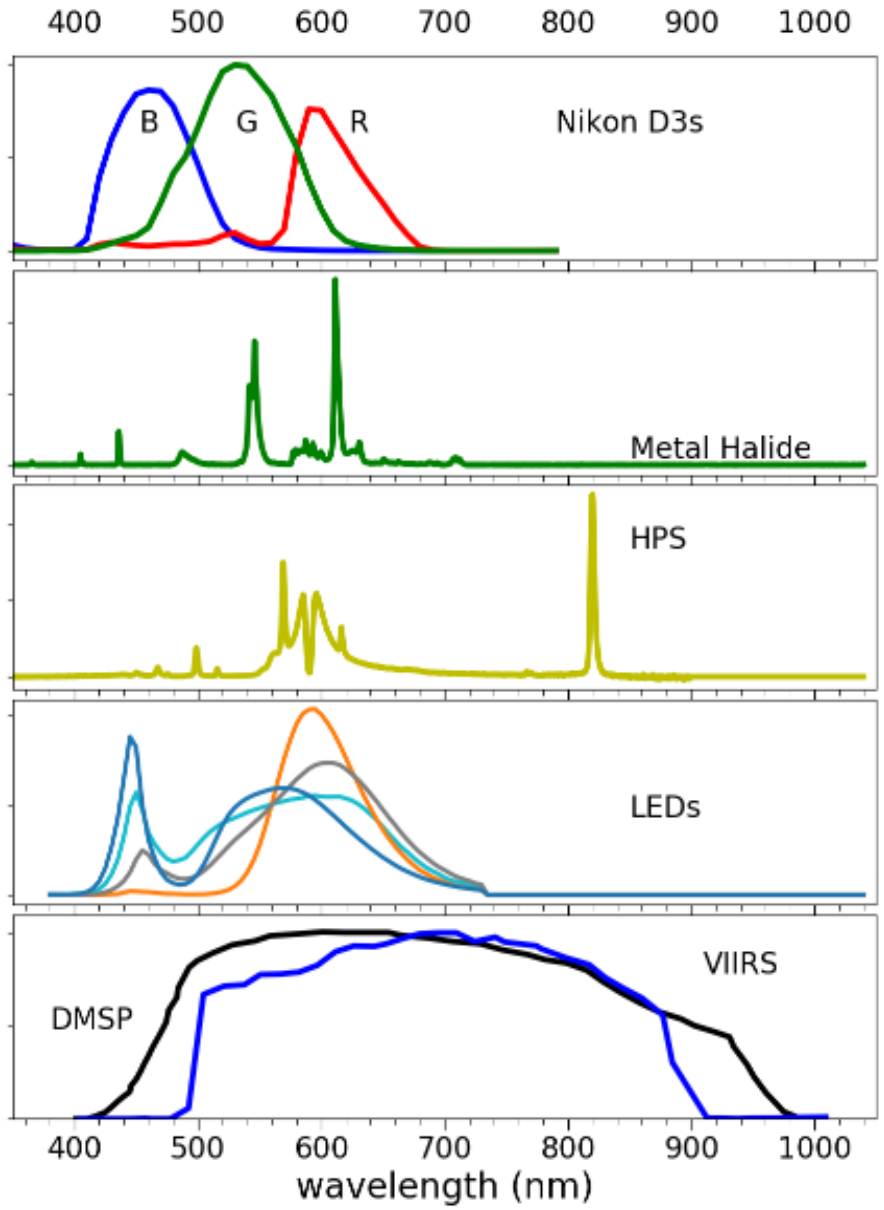
Suomi-NPP Satellite
Source NASA

Nighttime Light Sensor/Products

Comparison DMSP/OLS and VIIRS DNB

Attribute	DMSP/OLS	VIIRS DNB
Orbital Details	Sun-synchronous, ~850 km	Sun-synchronous, 824 km
Nighttime Overpass Time	~1930 UTC	~0130 UTC
Swath Width	3000 km	3000 km
Spectral Passband Bandwidth	Panchromatic 500–900 nm	Panchromatic 500–900 nm
Spectral Passband Center	~600 nm	~700 nm
Horizontal Spatial Resolution	5 km (Nadir)/~7 km (Edge)	<0.770 km (Scan) <0.750 km (Track)
Minimum Detectable Signal	4×10^{-5} W·m^{-2}·sr^{-1}	3×10^{-5} W·m^{-2}·sr^{-1}
Noise Floor	~5×10^{-6} W·m^{-2}·sr^{-1}	~5×10^{-7} W·m^{-2}·sr^{-1} (Nadir)
Radiometric Quantization	6 bit	13–14 bit
Radiometric Calibration	None	On-Board Solar Diffuser
Saturation, Stray Light Artifacts	Urban Cores, Substantial, Uncorrectable	None, Near-Terminator, Corrected

Nighttime Light Sensor/Products



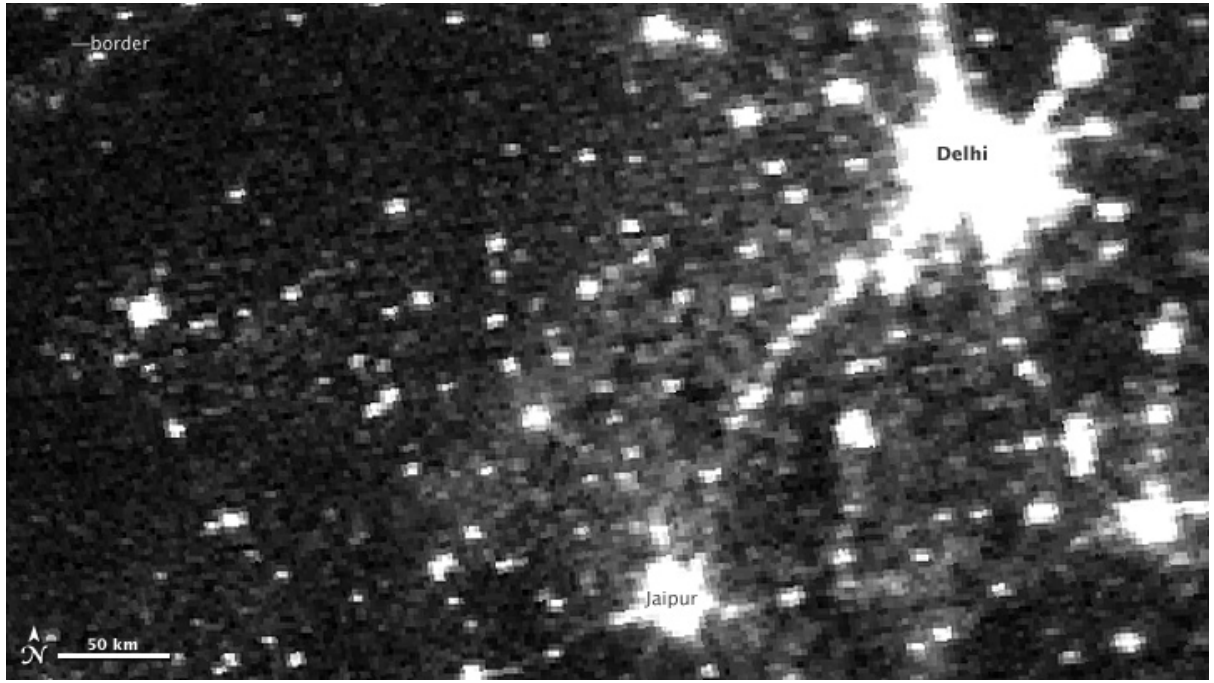
Spectral responses of the most popular sensors and light sources:

- Nikon D3s Cameras used by the astronauts at the ISS
- Metal Halide lamp, popular on architectural lights
- High pressure sodium (HPS) light, popular until 2014 on street lighting
- LEDs of 5000K (blue), 4000K (cyan), 2700K (grey), and PC-Amber (amber), popular on street lighting
- Representative spectral response of DMSP/OLS(black) and Suomi-NPP/VIIRS/DNB(blue)

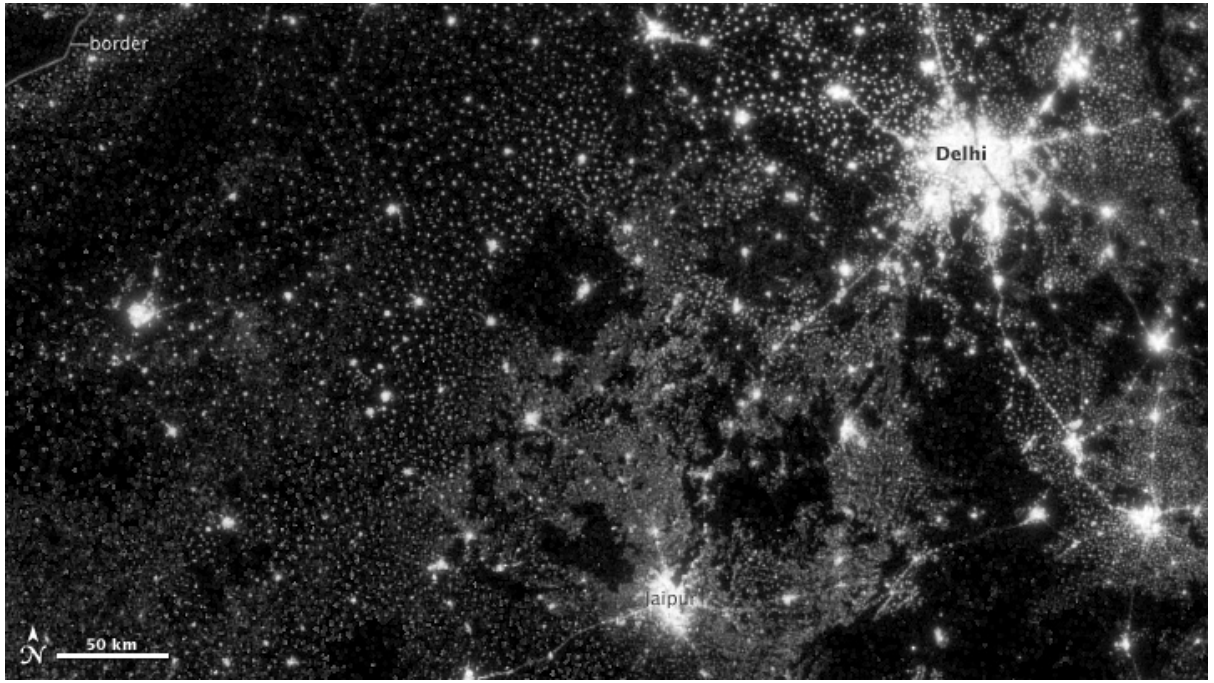
Levin *et al.*, 2020

Nighttime Light Sensor/Products

DMSP/OLS



VIIRS DNB



City, Village, and Highway Lights Near Delhi, India - Acquired in November, 2012

- Monthly product
- 2.7 km
- No on-board calibration
- 20:00 overpass
- Saturates in urban centers (6 bit)
- Available since 1992

- Daily product
- 500 m
- On-board calibration
- 1:30 overpass
- Can measure both bright and very dim lights (14 bit)
- Available since 2012

NASA’s Black Marble (VNP46) Data Product

Product Overview

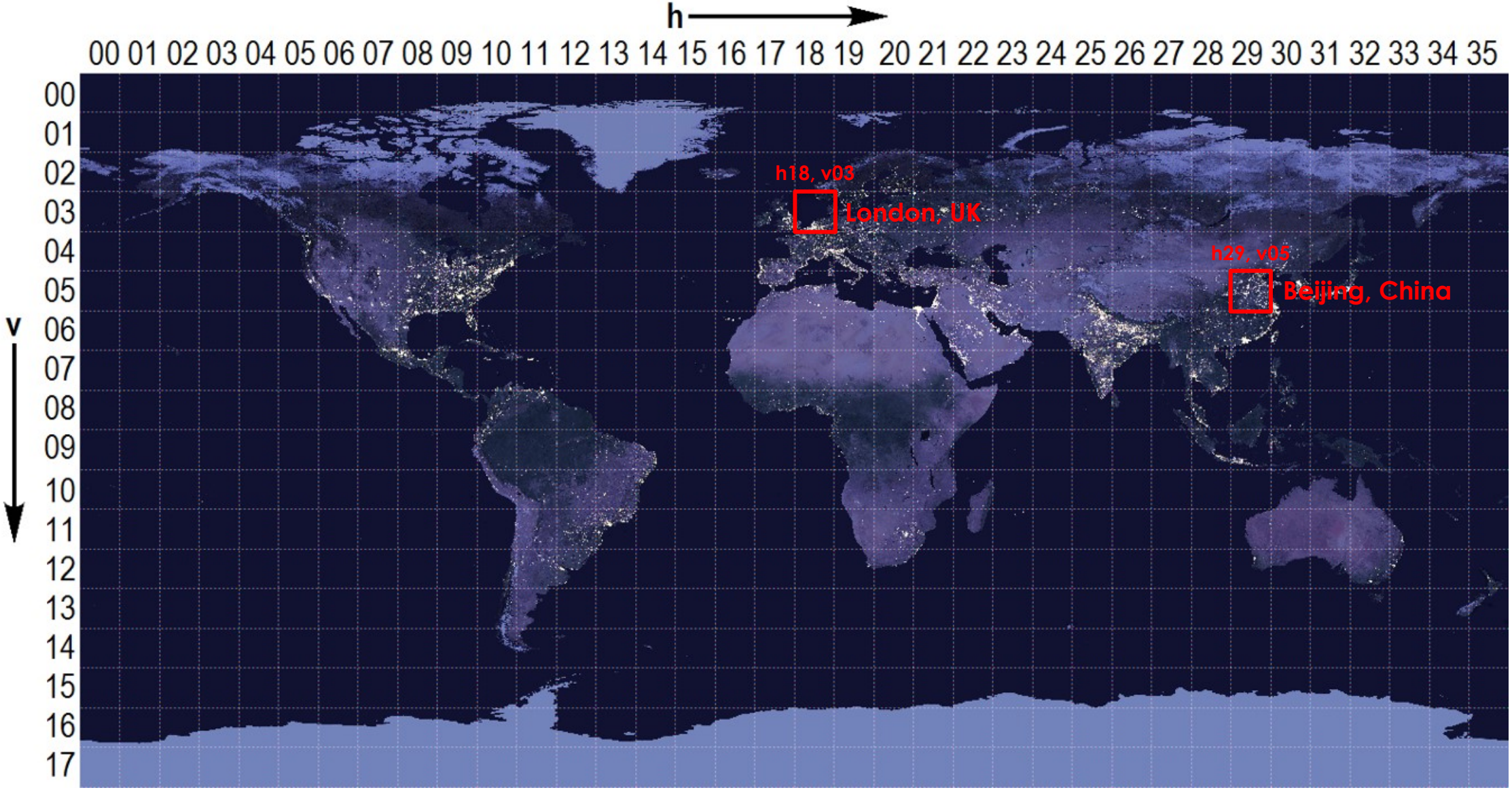
- Data from VIIRS DNB aboard Suomi-NPP satellite (Collection V001)
- Level 3 product
- Available for the entire Suomi-NPP time series record (c. 2012 – YTD) through NASA's Level-1 and Atmosphere Archive and Distribution System (LAADS) for science research and long-term analysis
- Processed within 3-5 hours after acquisition through NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) system, for rapid response applications

The image for the continental United States of NASA’s Black Marble 2016 annual composite.

Comparison of NOAA (DMSP-heritage) VIIRS Nighttime Lights and NASA Black Marble - What is corrected for?

	NOAA VIIRS V1	NASA Black Marble V1
Frequency	Monthly and annual composites	Daily, monthly, and annual composites
Moonlight	Uses moon-free nights	Uses all nights and corrects lunar reflectance effects
Snow	Uncorrected for snow reflectance	Corrects for snow BRDF effects
Stray light	Filtered	Filtered
Ephemeral Lights	Filtered (for Annual Products)	Not filtered
Atmospheric effects	Not corrected	Corrected
Clouds	Cloud-free	Cloud-free

For more information about the algorithm, refer to Román, M.O., Wang, Z., Sun, Q., Kalb, V., Miller, S.D., Molthan, A., Schultz, L., Bell, J., Stokes, E.C., Pandey, B. and Seto, K.C., 2018. NASA's Black Marble nighttime lights product suite. *Remote Sensing of Environment*, *210*, pp.113-143.

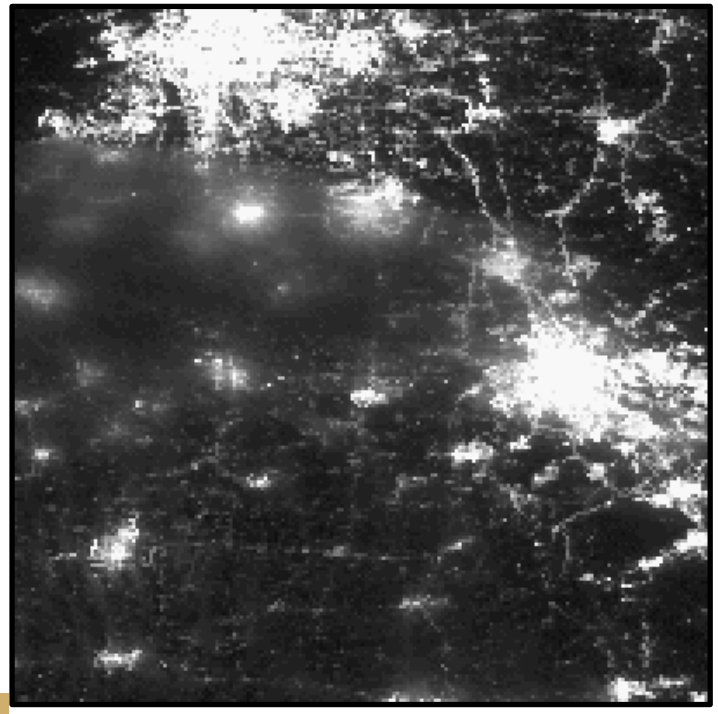


The Suomi-NPP VIIRS linear latitude/longitude (or geographic) grid consists of 460 non-overlapping land tiles which cover approximately 10° x 10° regions. Examples presented in this webinar are enclosed in red boxes.
https://blackmarble.gsfc.nasa.gov/tools/BlackMarbleTiles.zip

NASA's Black Marble Data Product

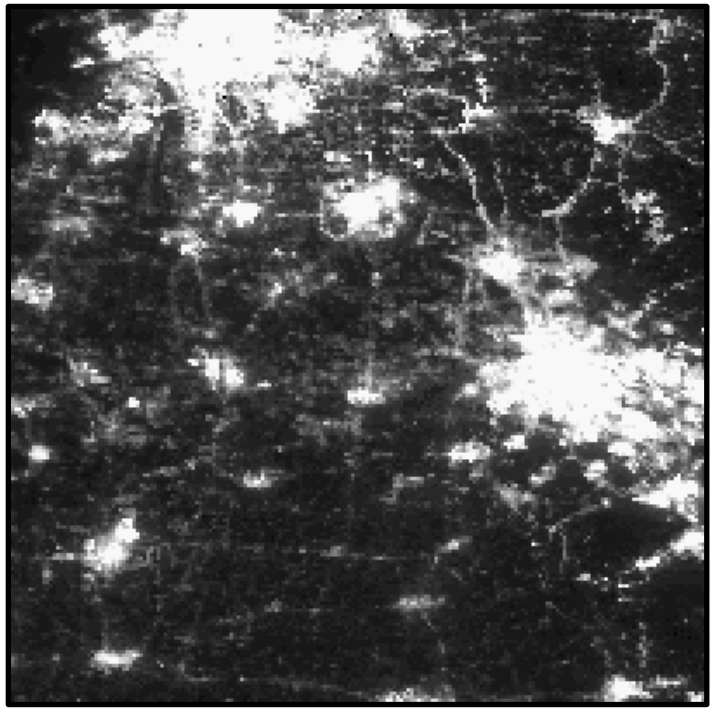
Location: Beijing, China
Tile: h29v05
DOY: 2020-063
Moon-Illuminated Fraction: 42.02%

VNP46A1-TOA



VNP46A2-Daily

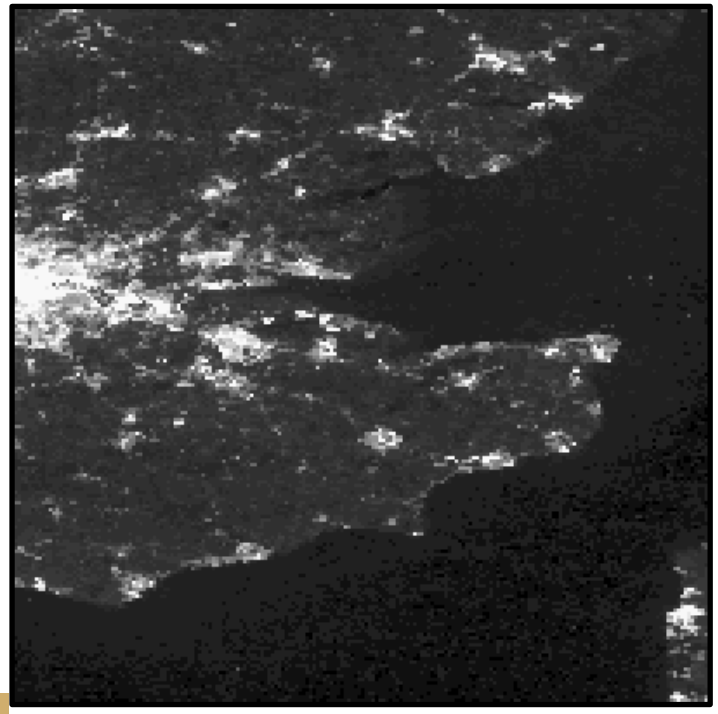
VNP46A2-GapFilled



NASA's Black Marble Data Product

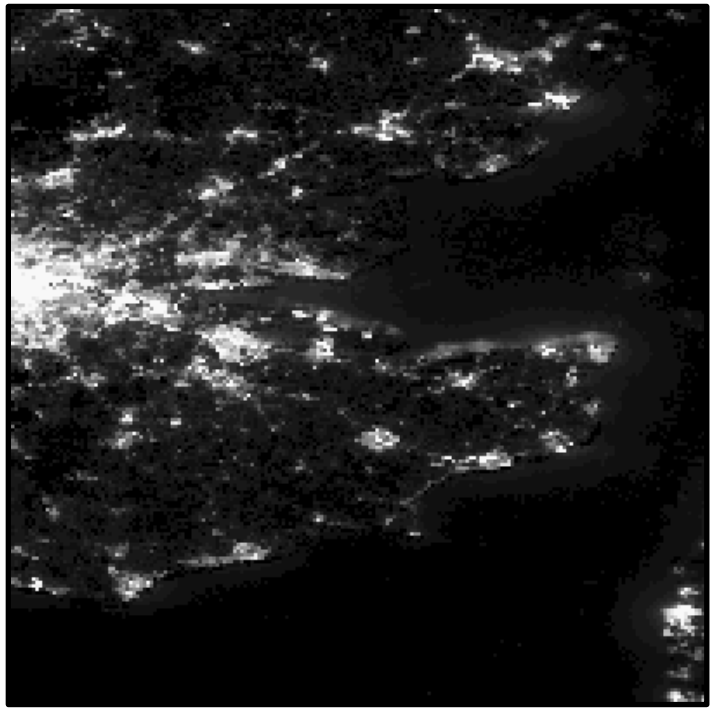
Location: London, United Kingdom
Tile: h18v03
DOY: 2020-096
Moon-Illuminated Fraction: 57.91%

VNP46A1-TOA

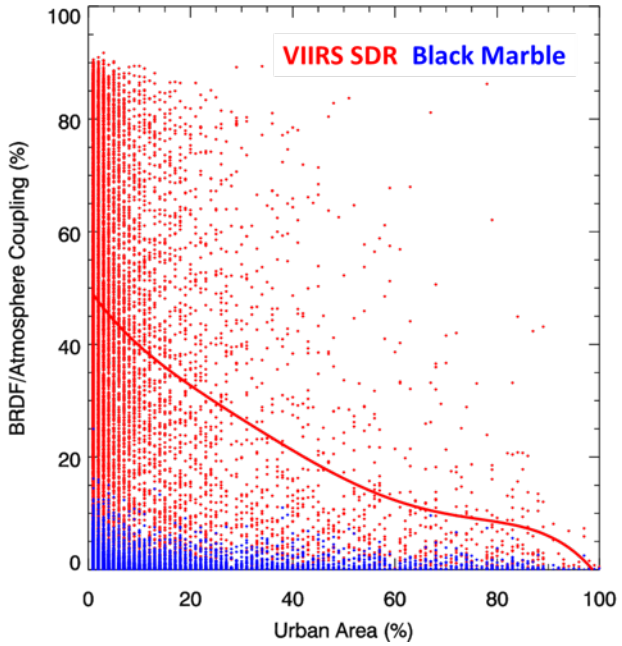


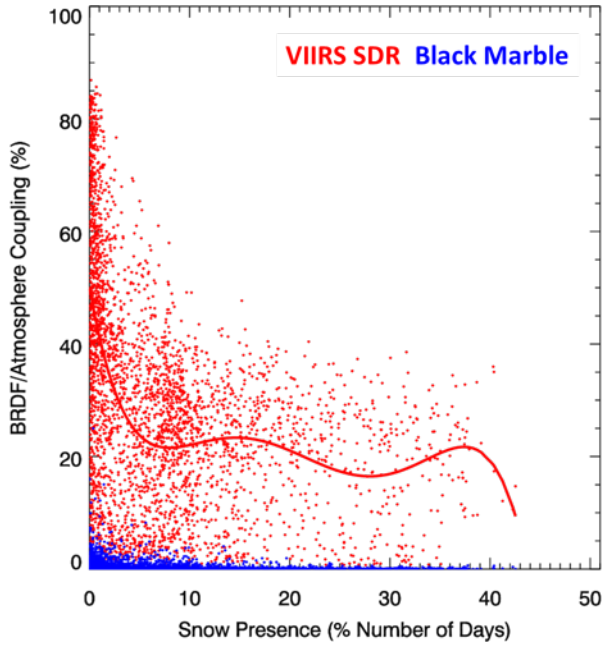
VNP46A2-Daily

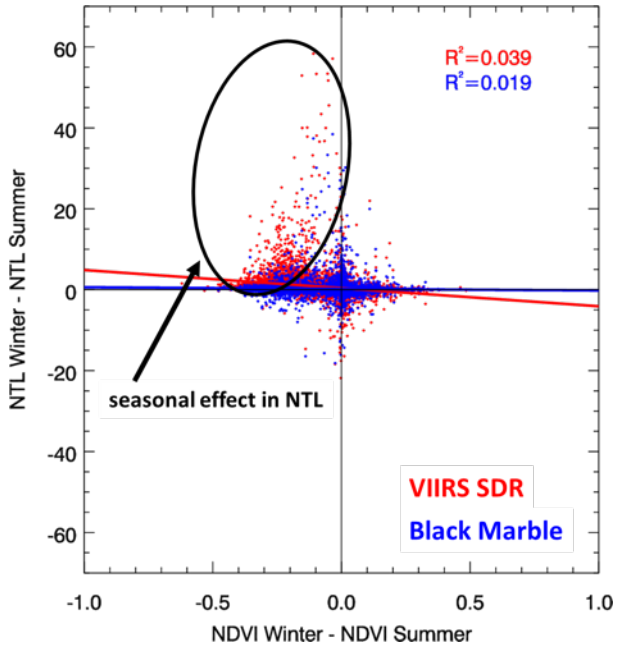
VNP46A2-GapFilled



Product Quality Assessment







Rural-Urban Gradient Test **Snow BRDF Test** **Vegetation Occlusion Test**

For more information, refer to Román, M.O., Wang, Z., Sun, Q., Kalb, V., Miller, S.D., Molthan, A., Schultz, L., Bell, J., Stokes, E.C., Pandey, B. and Seto, K.C., 2018. NASA's Black Marble nighttime lights product suite. *Remote Sensing of Environment*, *210*, pp.113-143.

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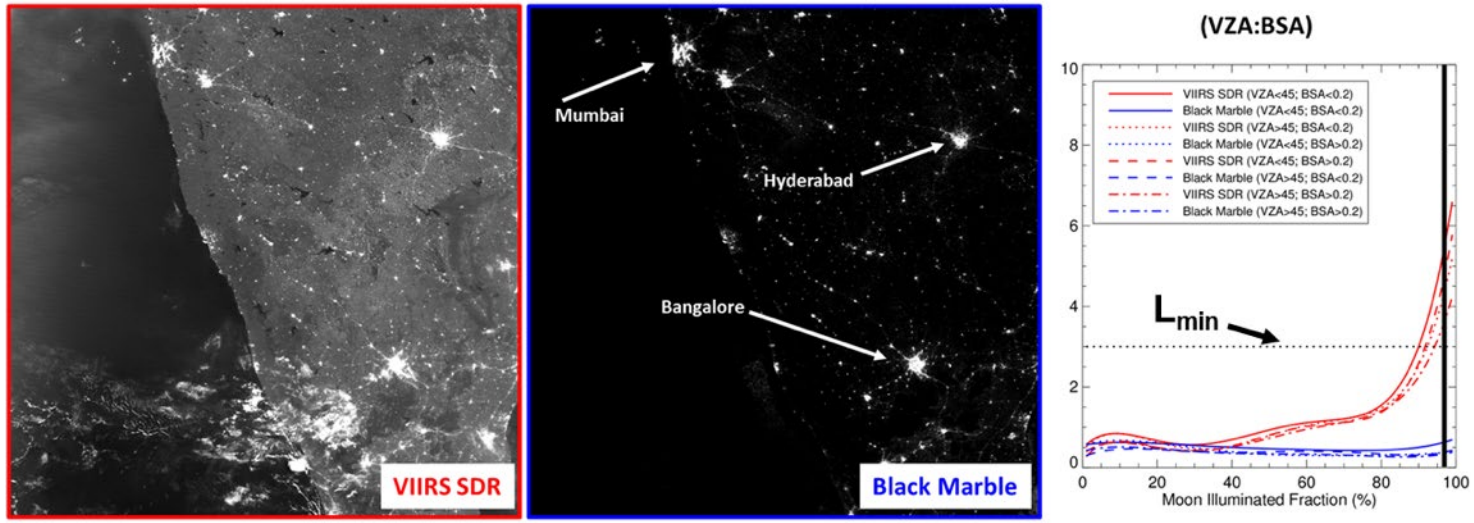
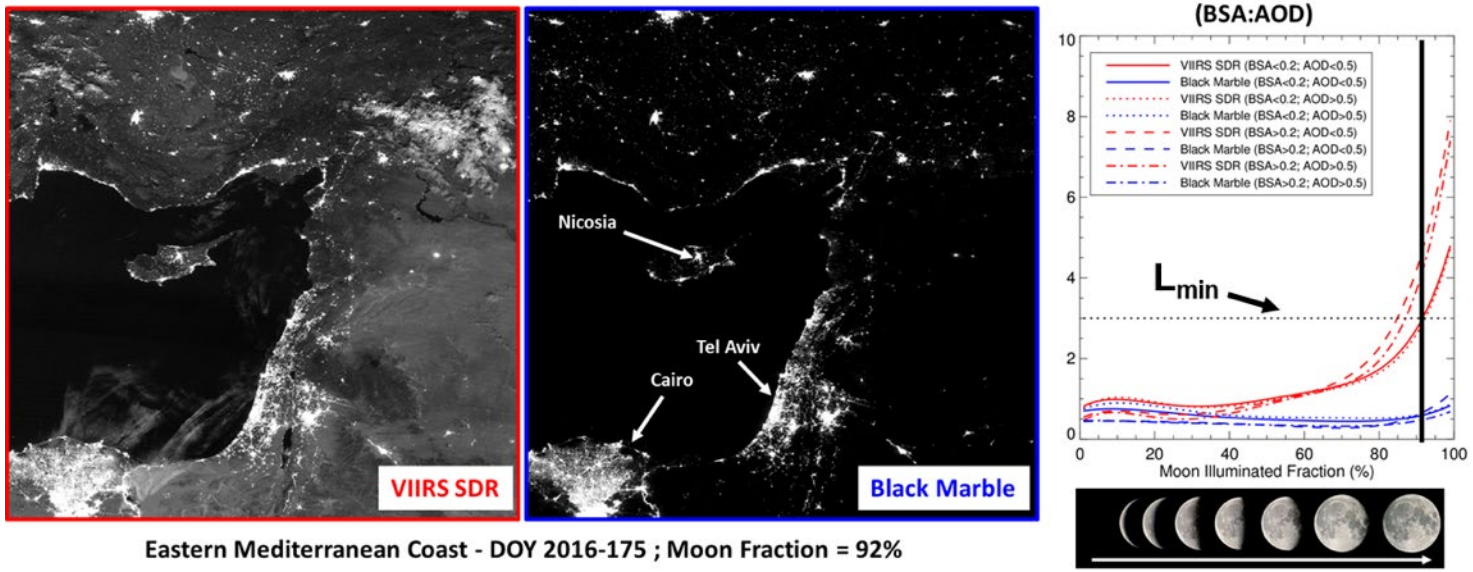


Western India - DOY 2013-323 ; Moon Fraction = 97%



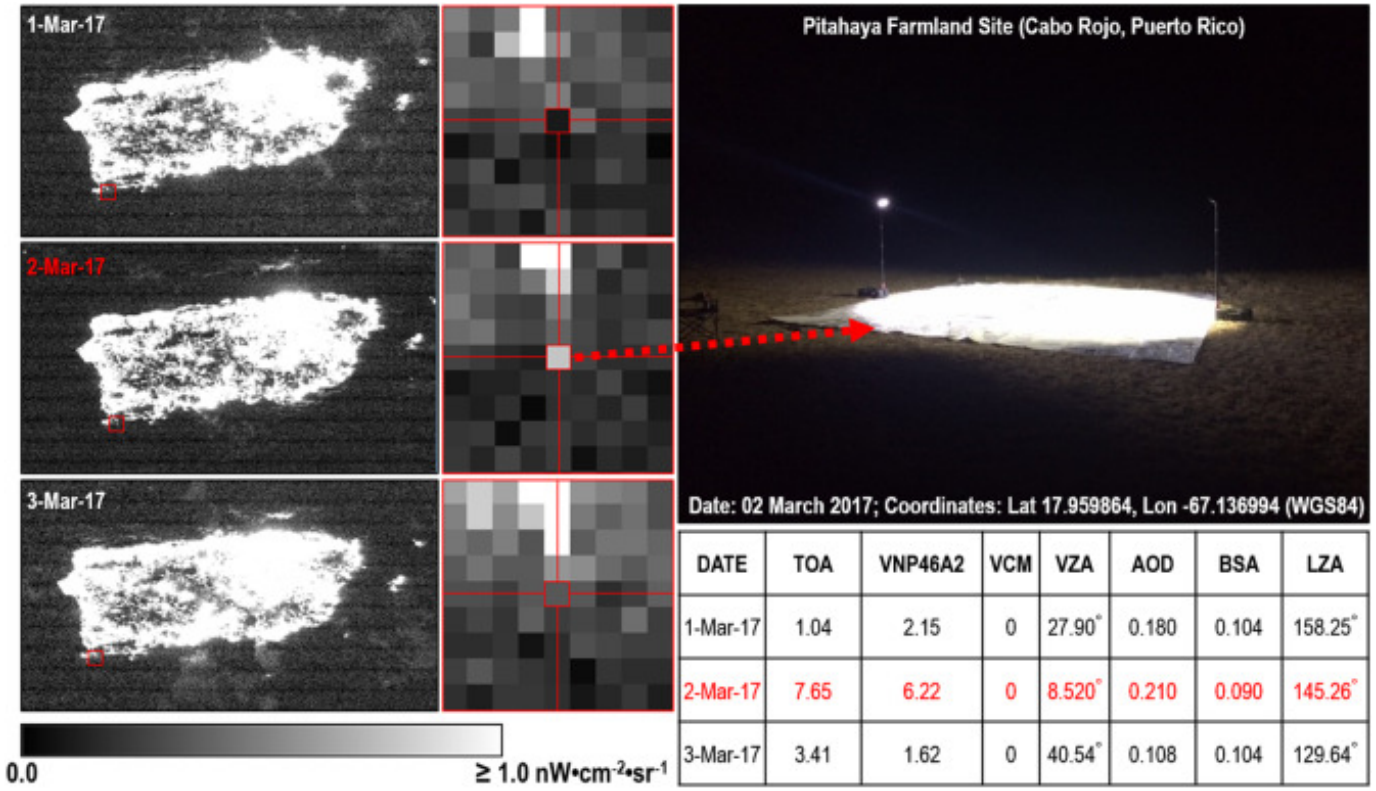
Eastern Mediterranean Coast - DOY 2016-175 ; Moon Fraction = 92%

For more information, refer to Román, M.O., Wang, Z., Sun, Q., Kalb, V., Miller, S.D., Molthan, A., Schultz, L., Bell, J., Stokes, E.C., Pandey, B. and Seto, K.C., 2018. NASA's Black Marble nighttime lights product suite. *Remote Sensing of Environment*, *210*, pp.113-143.

Product Validation

Field Experiments

- Conducted across multiple light pollution abatement zones in Puerto Rico
- Partnered with Puerto Rico's Working Group on Light Pollution (PRWGLP)
- A stable point source was reflected by a 30 m^2 Lambertian target to generate an in-band DNB radiance at sensor.



DATE	TOA	VNP46A2	VCM	VZA	AOD	BSA	LZA
1-Mar-17	1.04	2.15	0	27.90°	0.180	0.104	158.25°
2-Mar-17	7.65	6.22	0	8.520°	0.210	0.090	145.26°
3-Mar-17	3.41	1.62	0	40.54°	0.108	0.104	129.64°

The NTL radiances at the Pitahaya Farmland site in Cabo Rojo, PR on 1st, 2nd and 3rd March 2017. The top-right image shows the setup of the stable point source. TOA and VNP46A2 values are in nW·cm−2·sr−1. VCM = 0 represents cloud free overpasses. LZA is lunar zenith angle, and the values larger than 108° correspond to moonless nights.

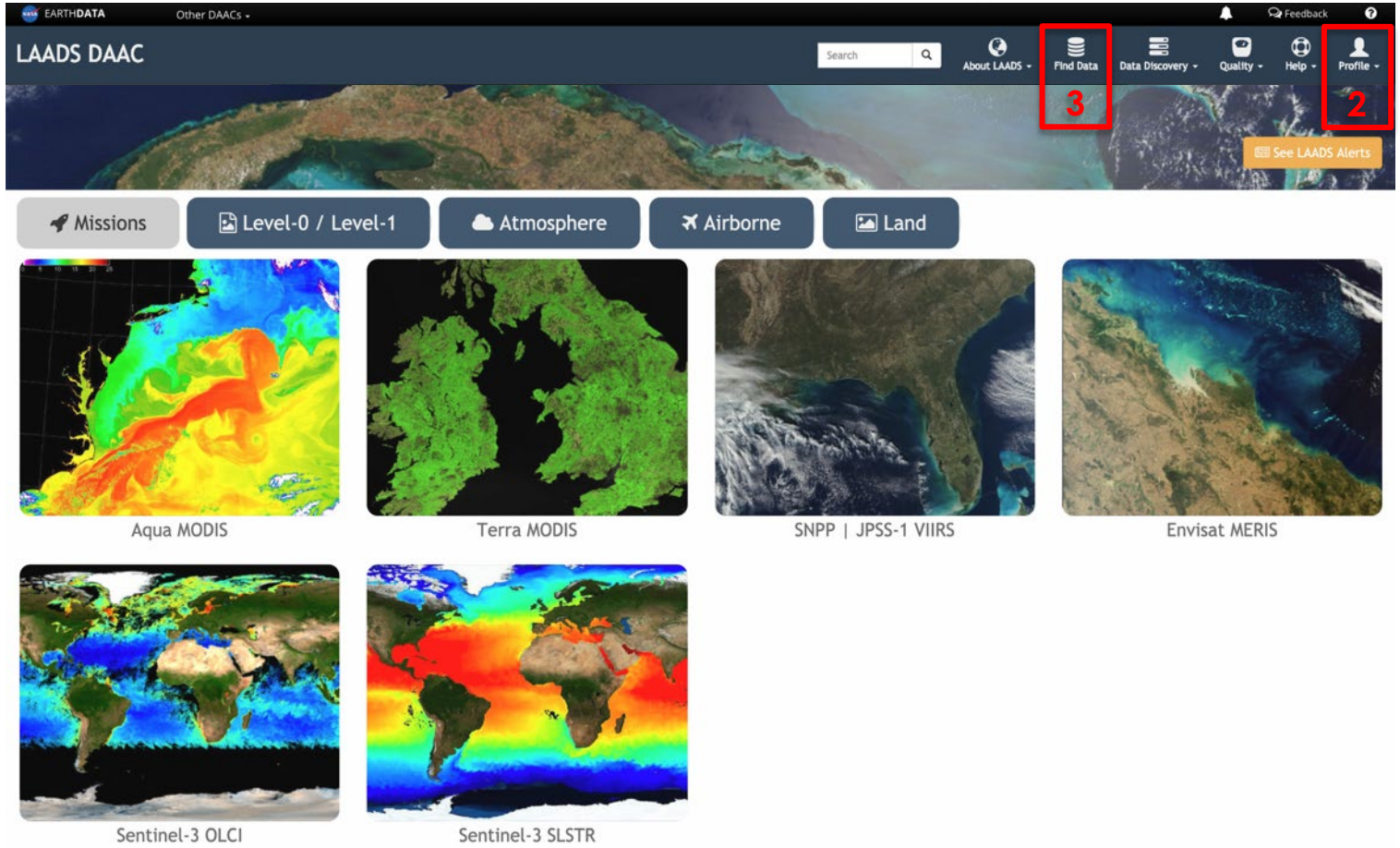
For more information, refer to Román, M.O., Wang, Z., Sun, Q., Kalb, V., Miller, S.D., Molthan, A., Schultz, L., Bell, J., Stokes, E.C., Pandey, B. and Seto, K.C., 2018. NASA's Black Marble nighttime lights product suite. *Remote Sensing of Environment*, *210*, pp.113-143.

Part 2: Black Marble Processing & Data Analysis

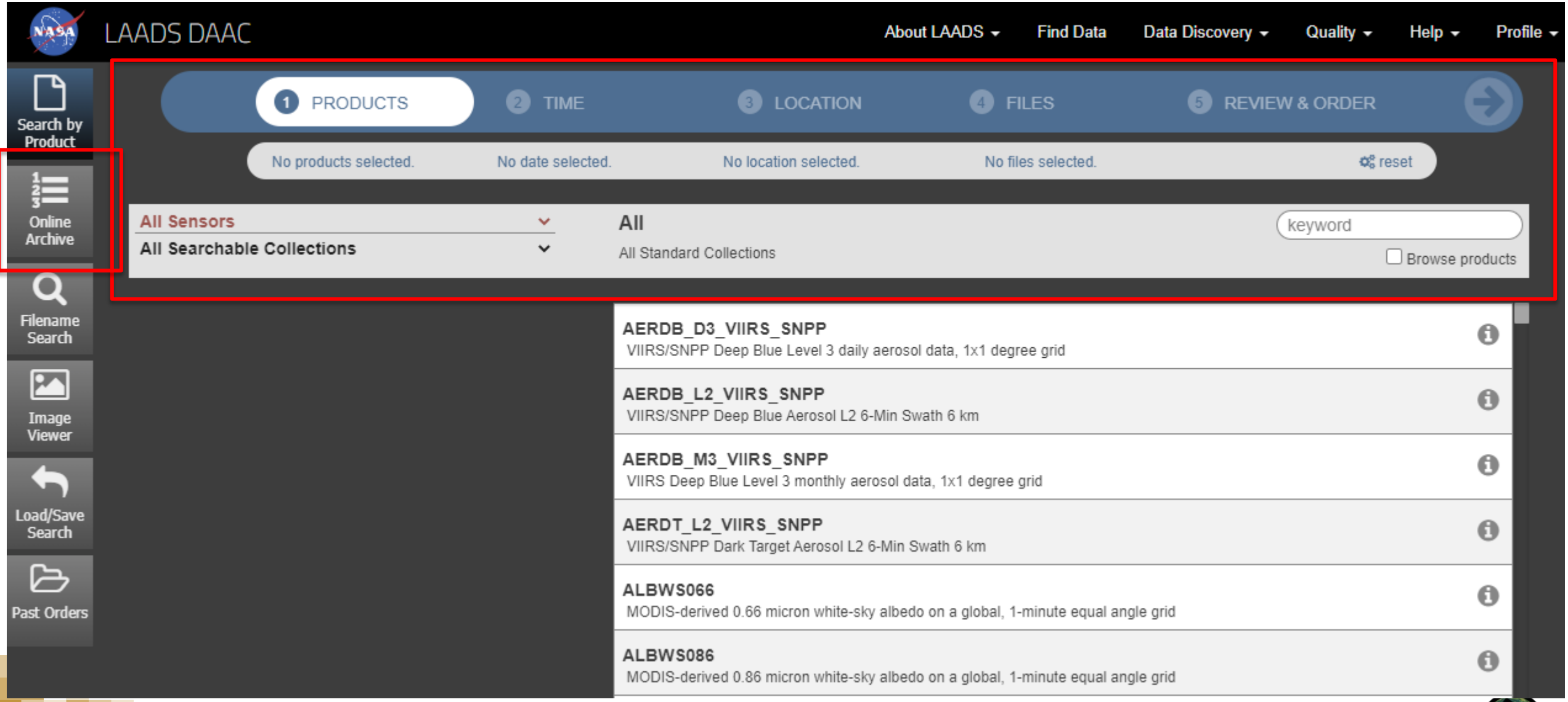
Where to Obtain the Black Marble Product

NASA's Level-1 Land and Atmosphere Archive and Distribution System Distributed Active Archive Center (LAADS-DAAC)

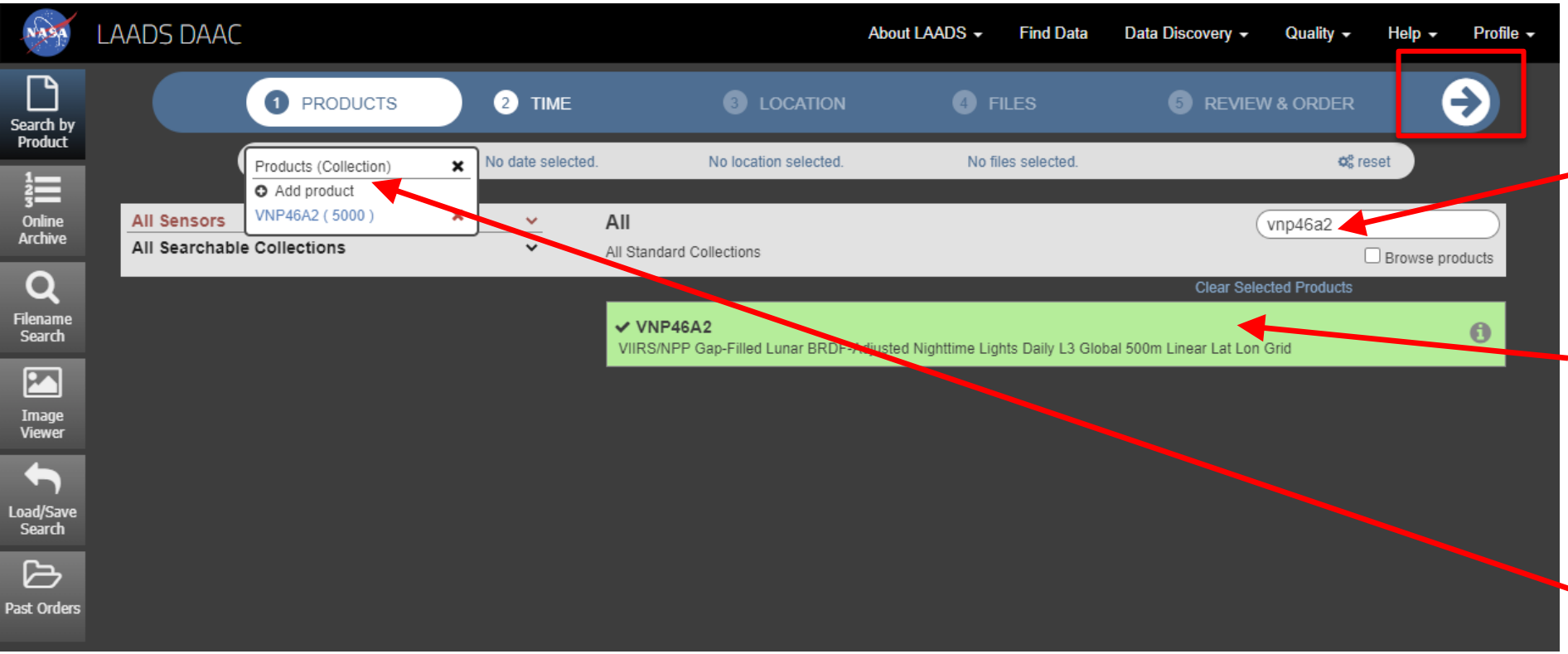
1. Go to:
   1 ladsweb.modaps.eosdis.nasa.gov
2. Create a username and profile
3. Click "Find Data"



Downloading Black Marble Images via LAADS

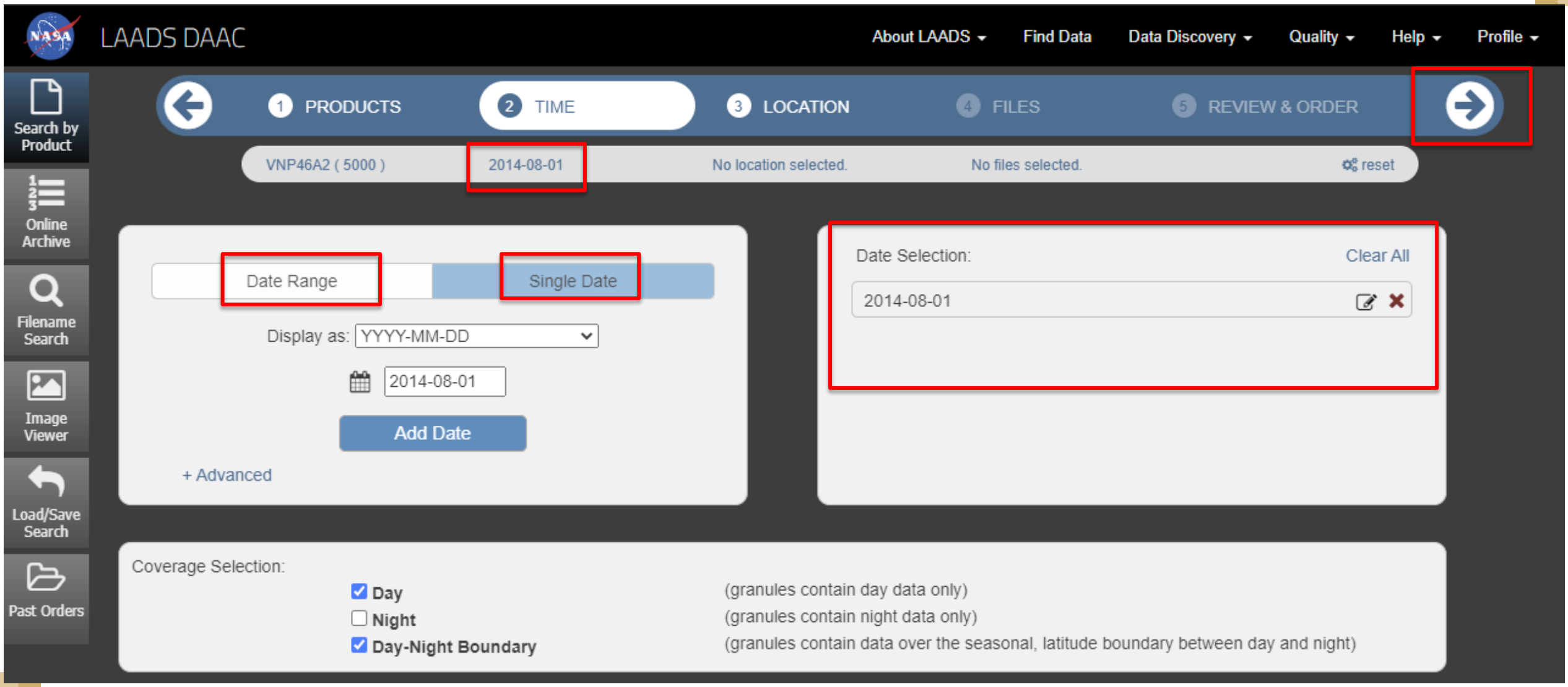


Downloading Black Marble Images via LAADS Web Portal



- In the search bar, type "VNP46A2"
- Select the dataset
- Dataset added

Downloading Black Marble Images via LAADS Web Portal



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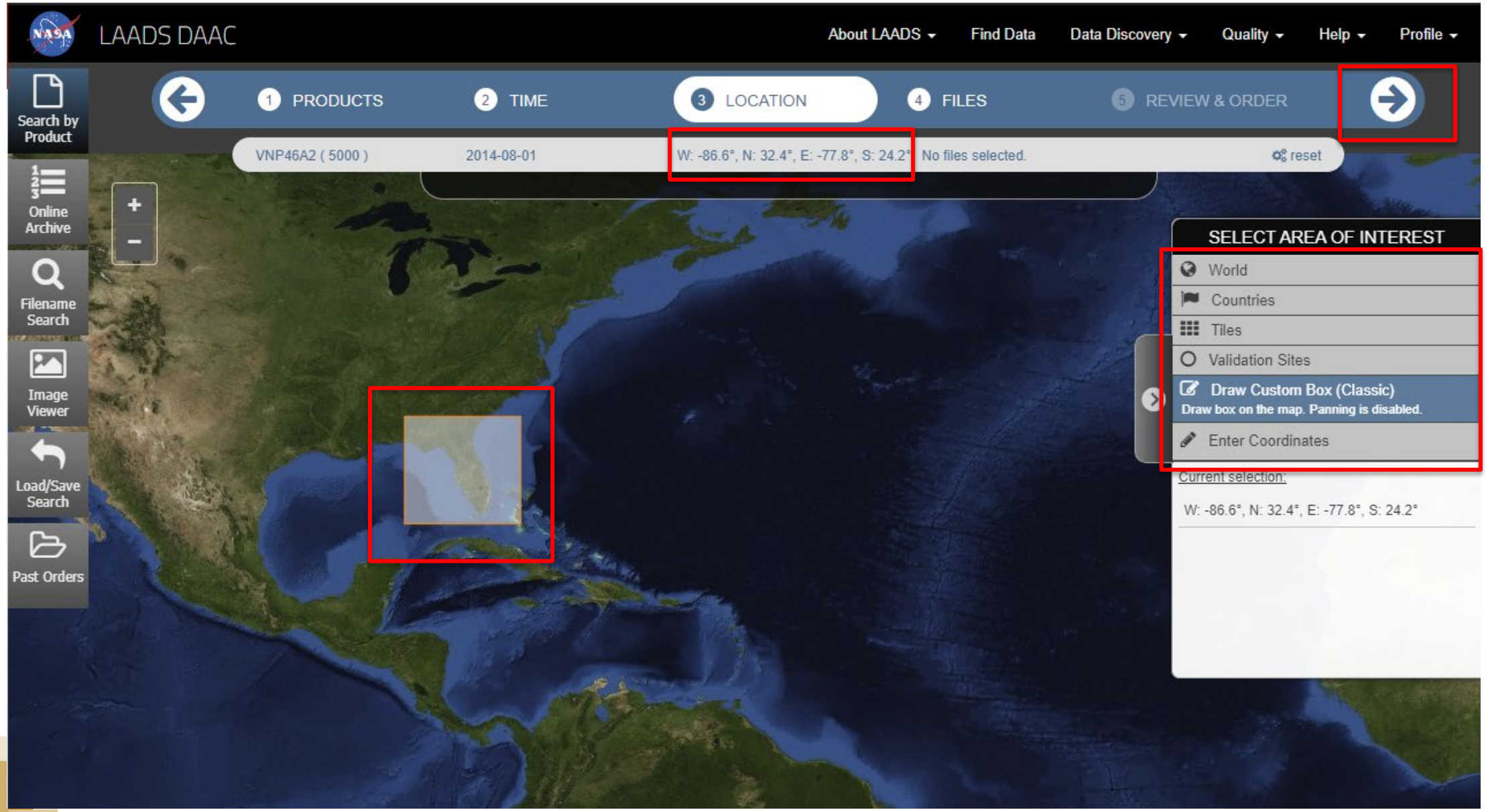

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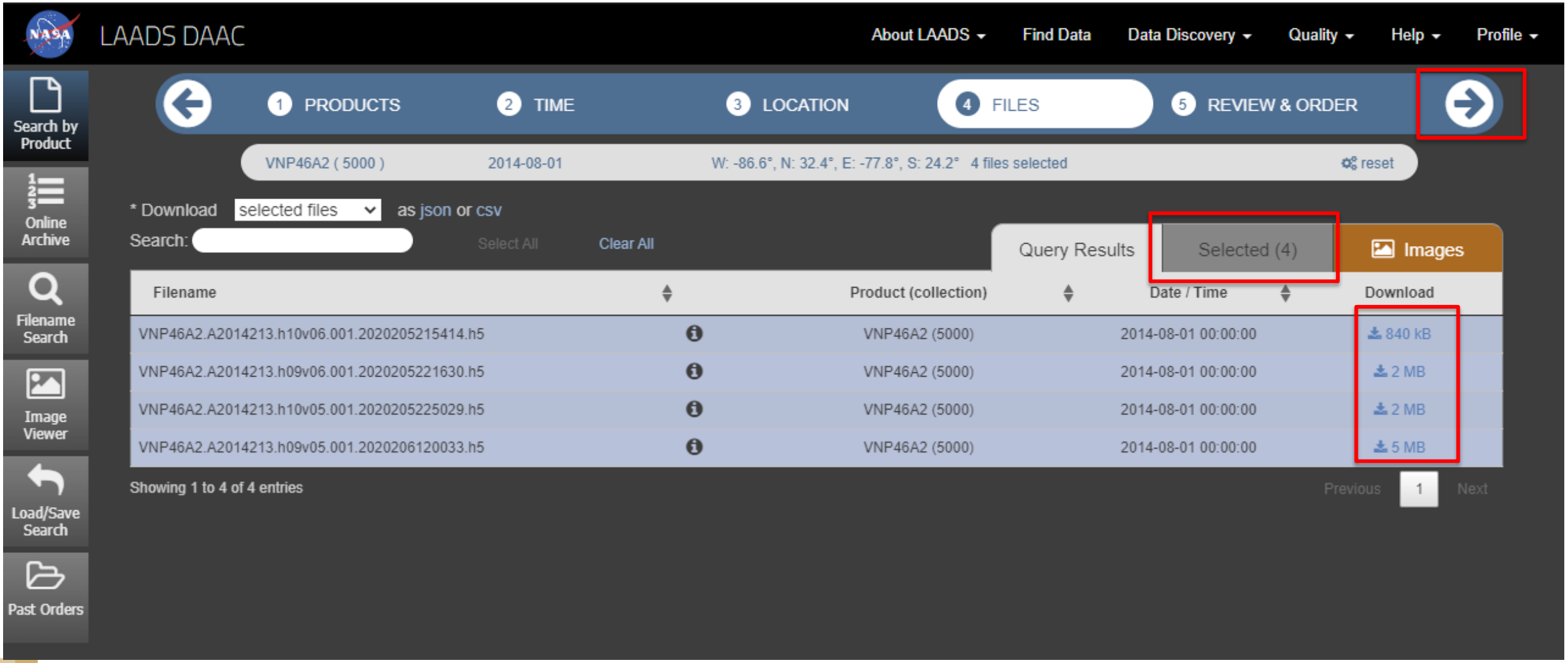

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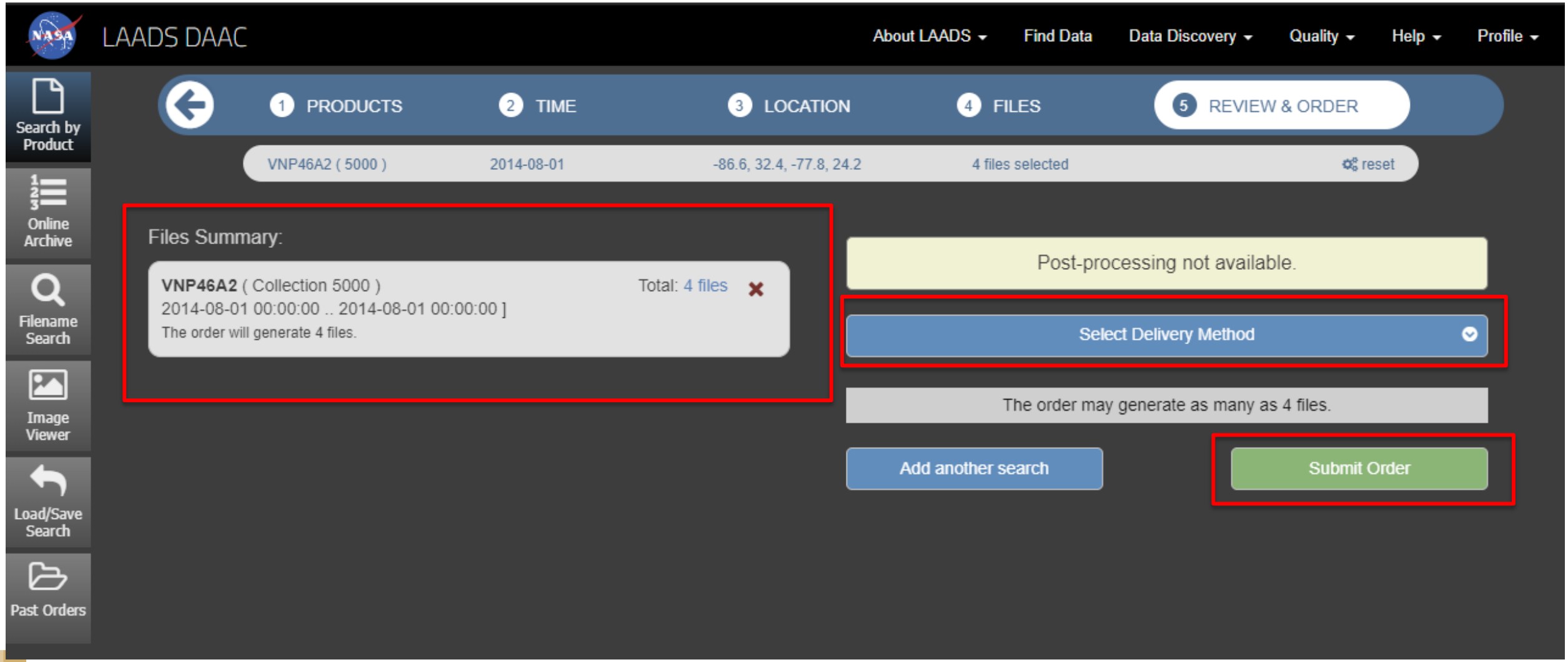

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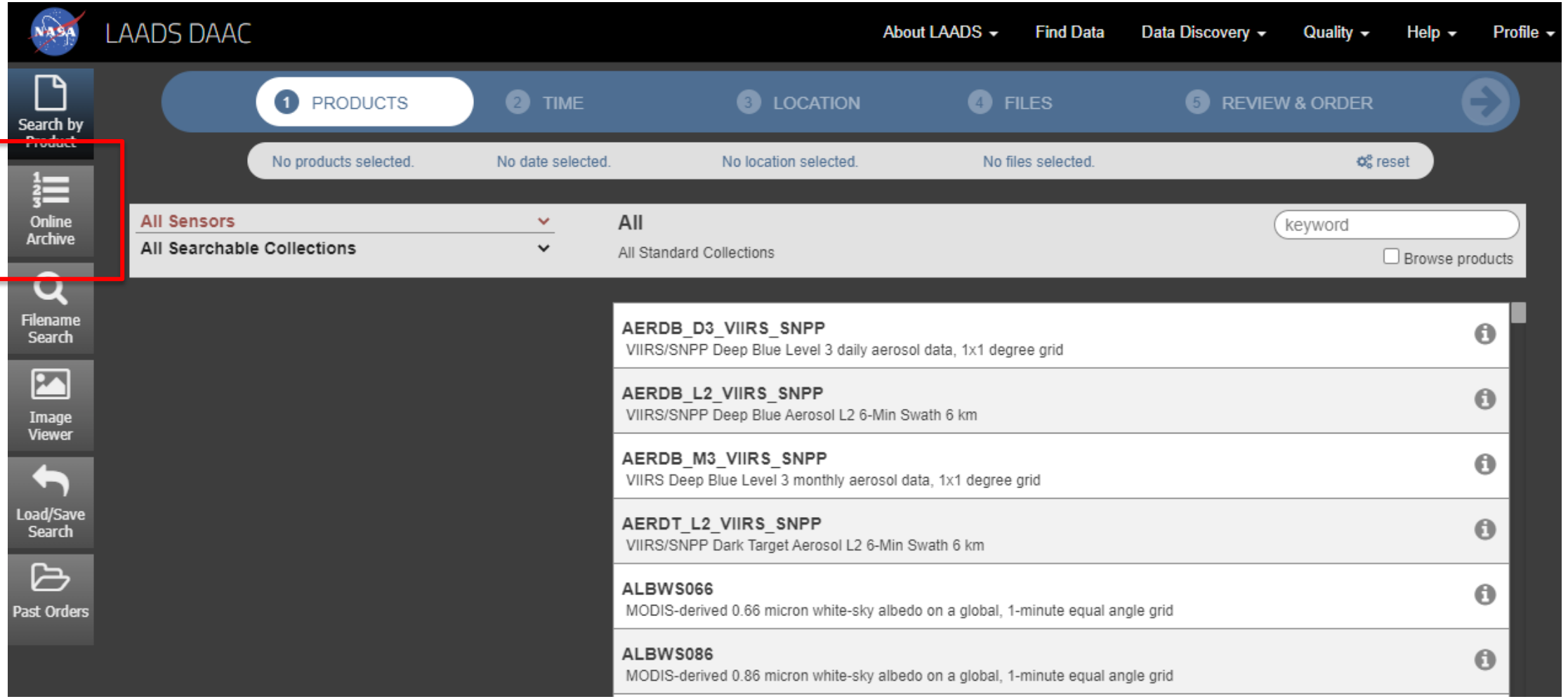

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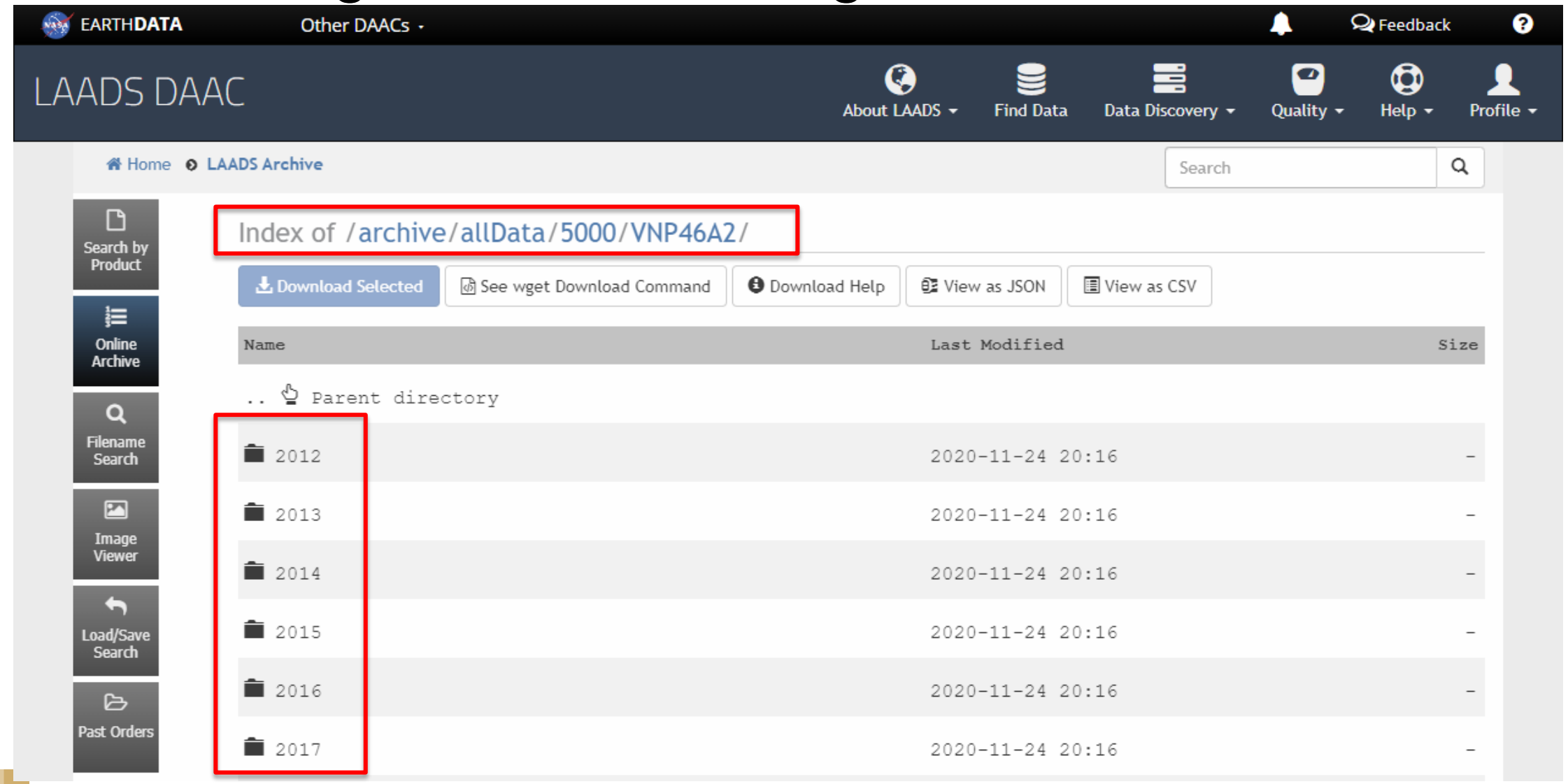
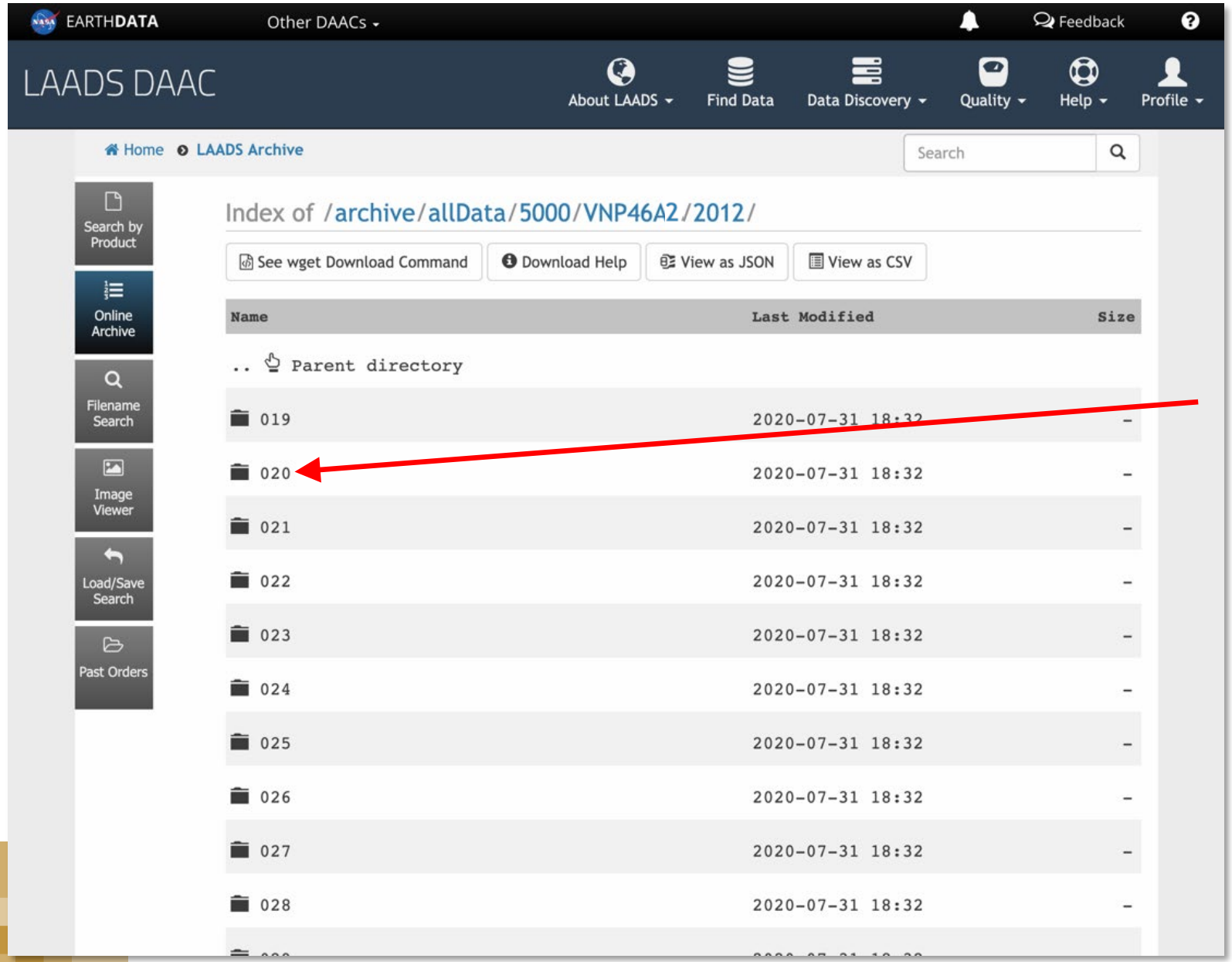


You can also directly type the link
https://ladsweb.modaps.eosdis.nasa.gov/archive/allData/5000/VNP46A2/

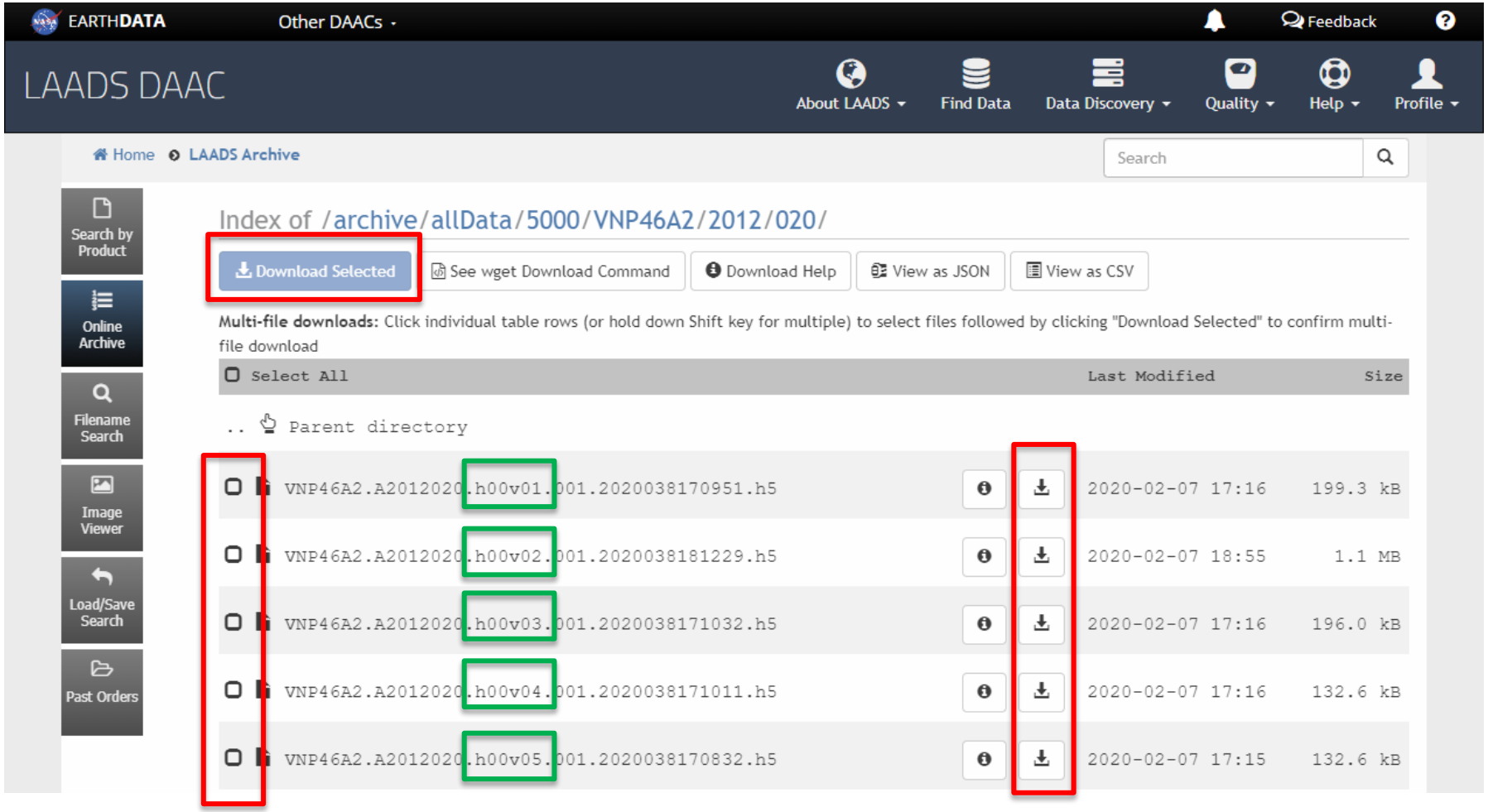
Downloading Black Marble Images via LAADS Online Archive



- Choose the Julian Day of interest*

*Julian Days for each year can be found here: https://landweb.modaps.eosdis.nasa.gov/browse/calendar.html

Downloading Black Marble Images via LAADS



- Choose the file with your (h, v) grid coordinates of interest (Green boxes)*
- A rule of thumb to use is:

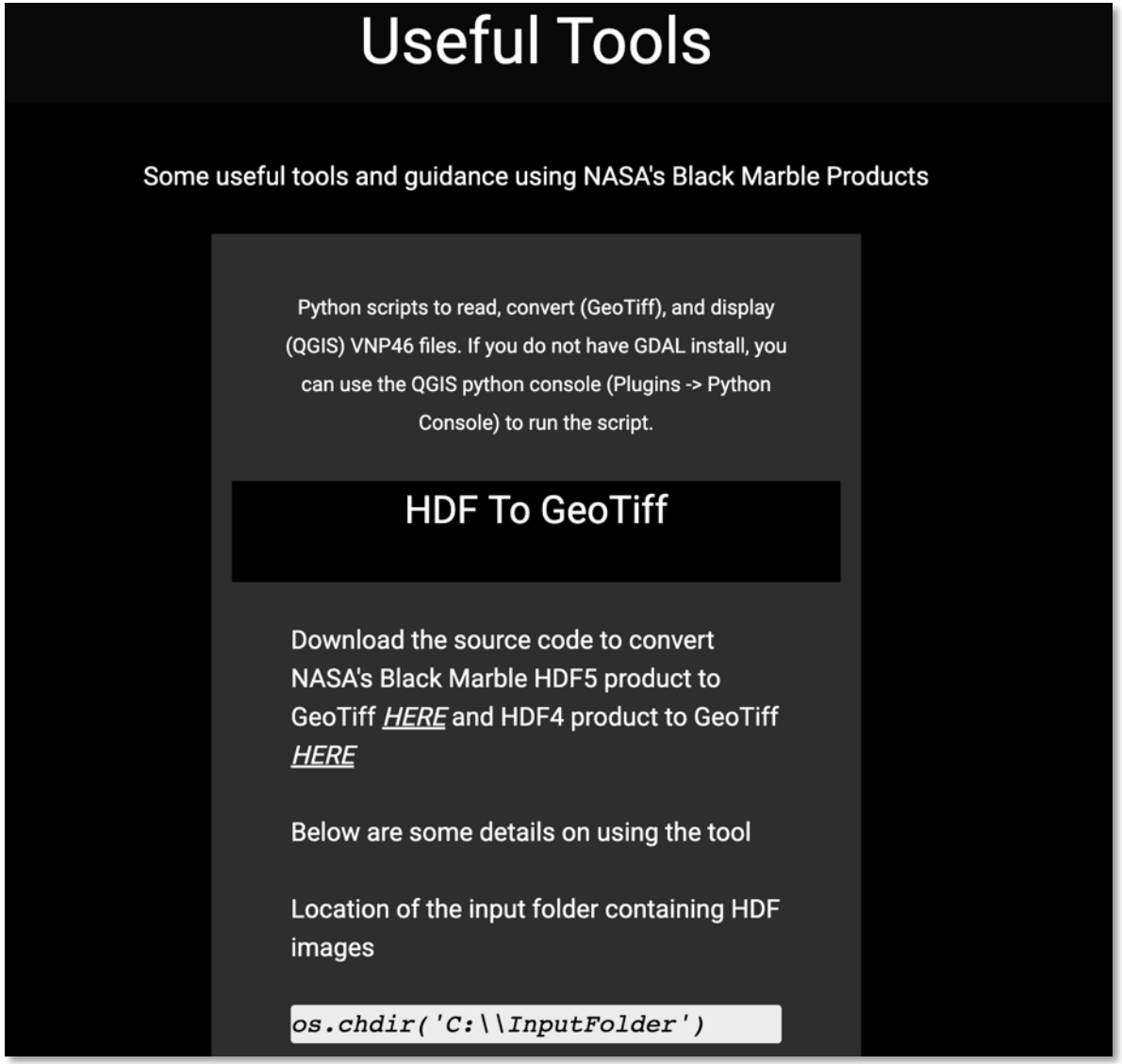
$$v=(90-lat)/10$$
$$h=(180+lon)/10$$

*You can download the spatial layer for the tile grid boundary from this link https://blackmarble.gsfc.nasa.gov/tools/BlackMarbleTiles.zip

Converting HDF-5 to GeoTIFF

- If you are using Black Marble in a GIS software like ArcGIS or QGIS, you will want to convert the HDF-5 data to a GeoTIFF data format.

- Use our HDF-5 to GeoTIFF converter tool here:
  - https://blackmarble.gsfc.nasa.gov/Tools.html



Scientific Datasets Included with VNP46A2

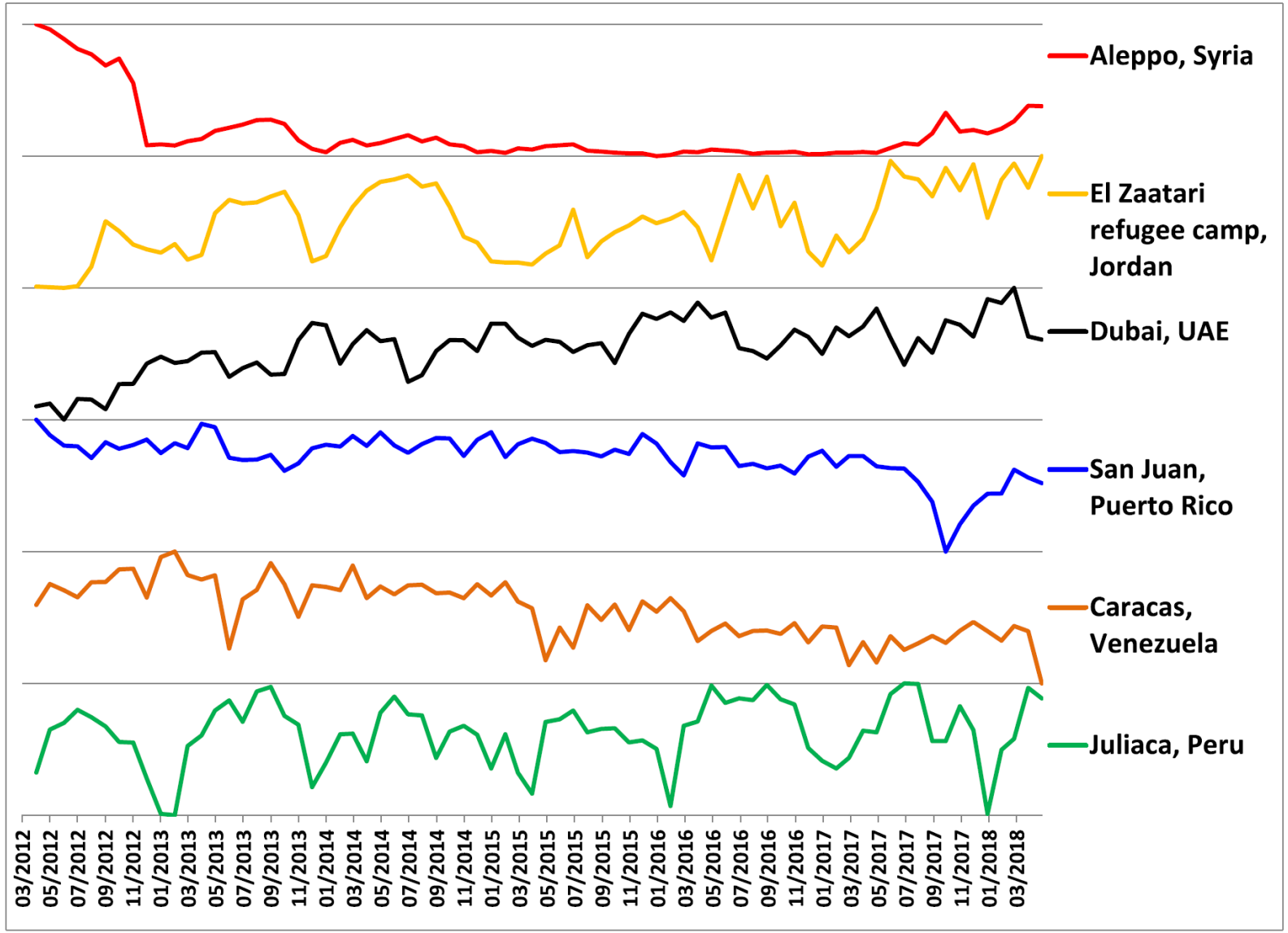
Scientific Data Sets (SDS HDF Layers)	Units	Bit Types	Fill Value	Valid Range
DNB_BRDF-Corrected_NTL	nWatts ·cm^{-2} ·sr^{-1}	16-bit unsigned integer	65,535	0 – 65,534
Gap_Filled_DNB_BRDF-Corrected_NTL	nWatts ·cm^{-2} ·sr^{-1}	16-bit unsigned integer	65,535	0 – 65,534
DNB_Lunar_Irradiance	nWatts ·cm^{-2} ·sr^{-1}	16-bit unsigned integer	65,535	0 – 65,534
Mandatory_Quality_Flag	Class Flag	8-bit unsigned integer	255	0 – 3
Latest_High_Quality_Retrieval	Number of days	8-bit unsigned integer	255	0 – 254
Snow_Flag	Class Flag	8-bit unsigned integer	255	0 – 1
QF_Cloud_Mask	Class Flag	16-bit unsigned integer	65,535	0 – 65,534

Considering QA indicators in the VNPA2 Product (DNB_BRDF-Corrected_NTL)

Value	Retrieval Quality	Algorithm Instance
00	High-quality	Main algorithm (persistent nighttime lights)
01	High-quality	Main algorithm (Ephemeral Nighttime Lights)
02	Poor-quality	Main algorithm (Outlier, potential cloud contamination or other issues)
255	No retrieval	Fill value

Part 3: Applying Black Marble Data

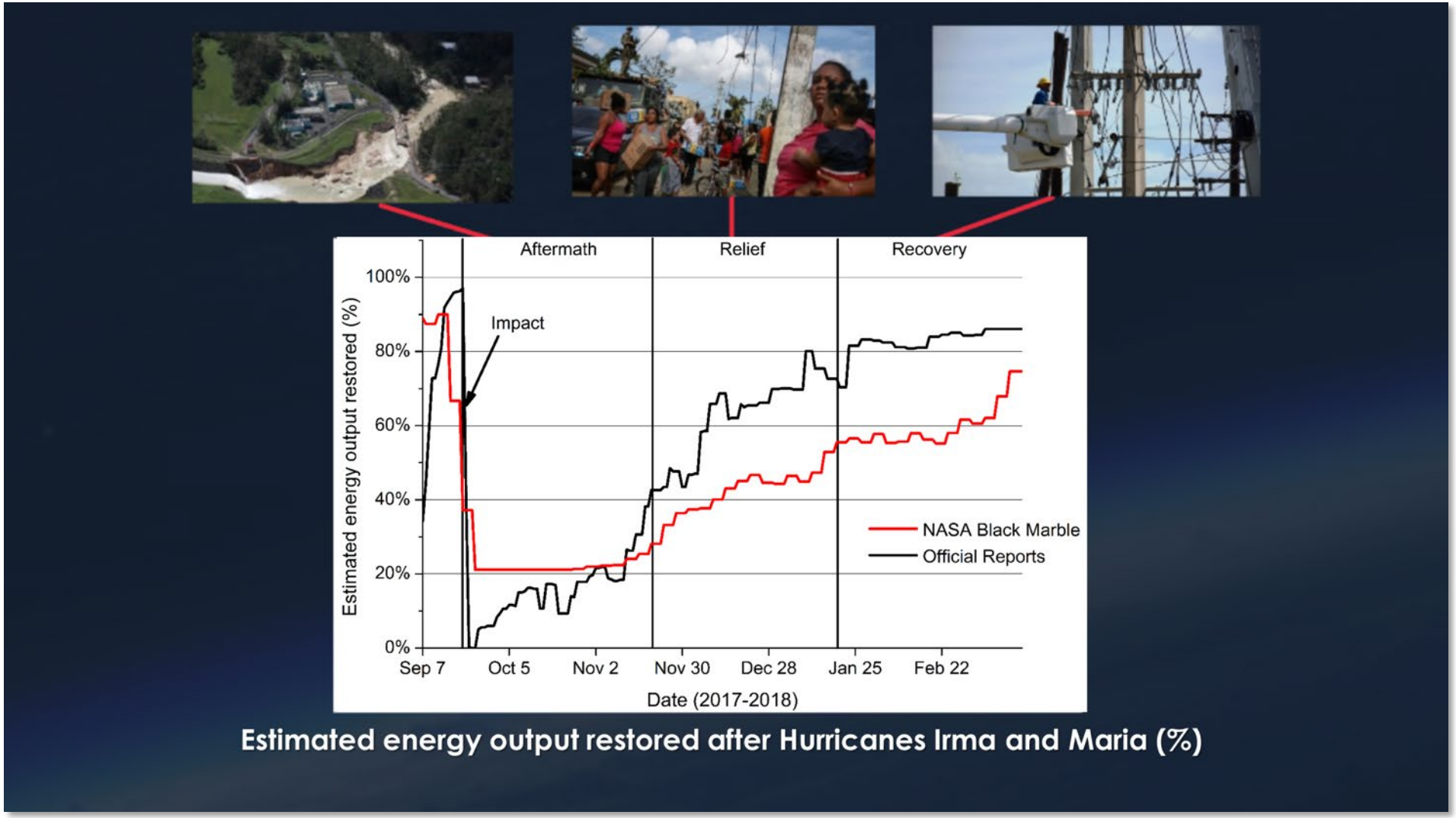
Case Study: Mapping Urban Areas and Urbanization



Monthly temporal changes in Black Marble nighttime brightness demonstrate various patterns. Each of the sites was normalized between its own min/max radiance values.

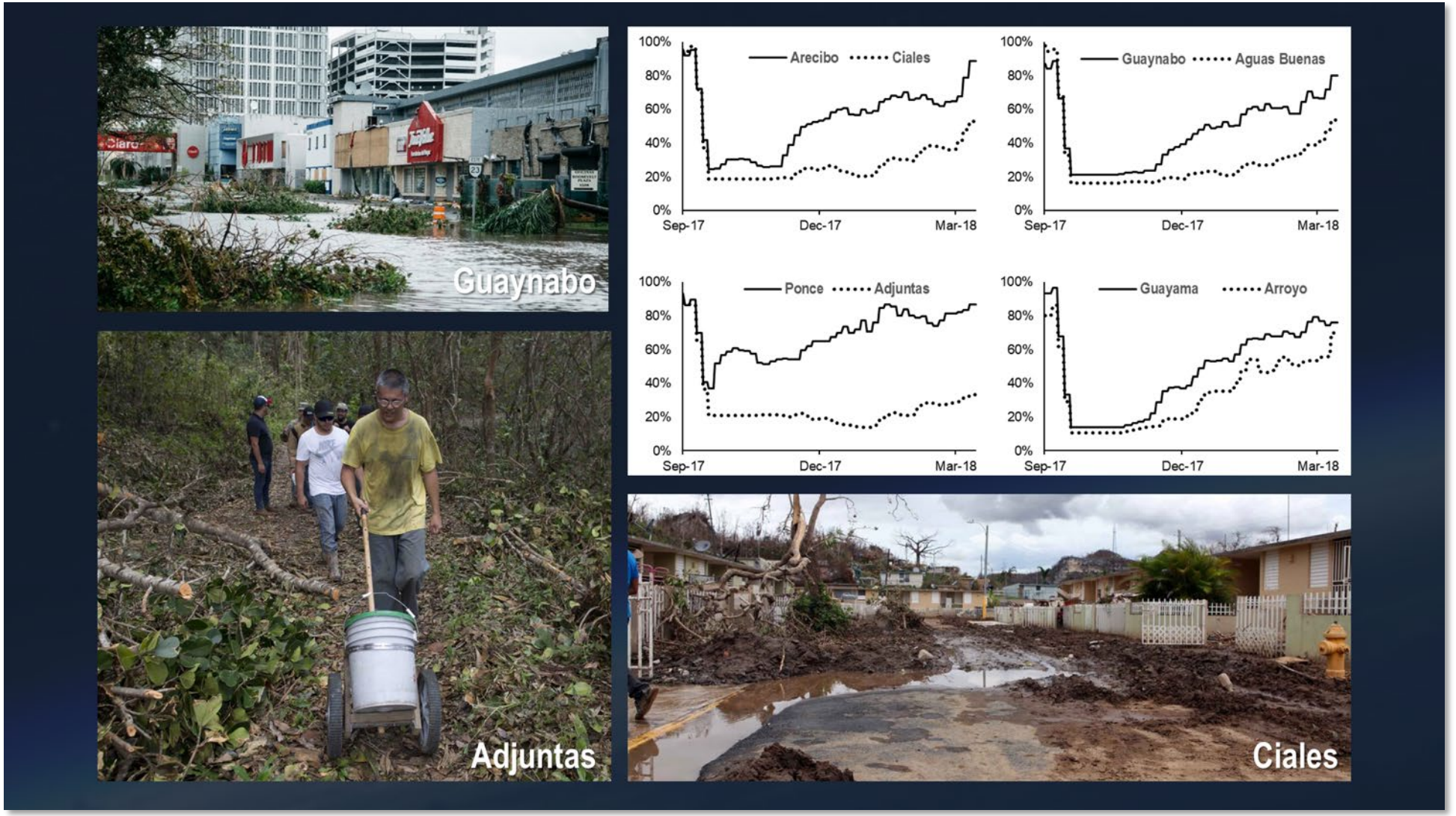
Levin *et al.*, 2020

Monitoring Disaster Impacts in Puerto Rico (2017-2018)



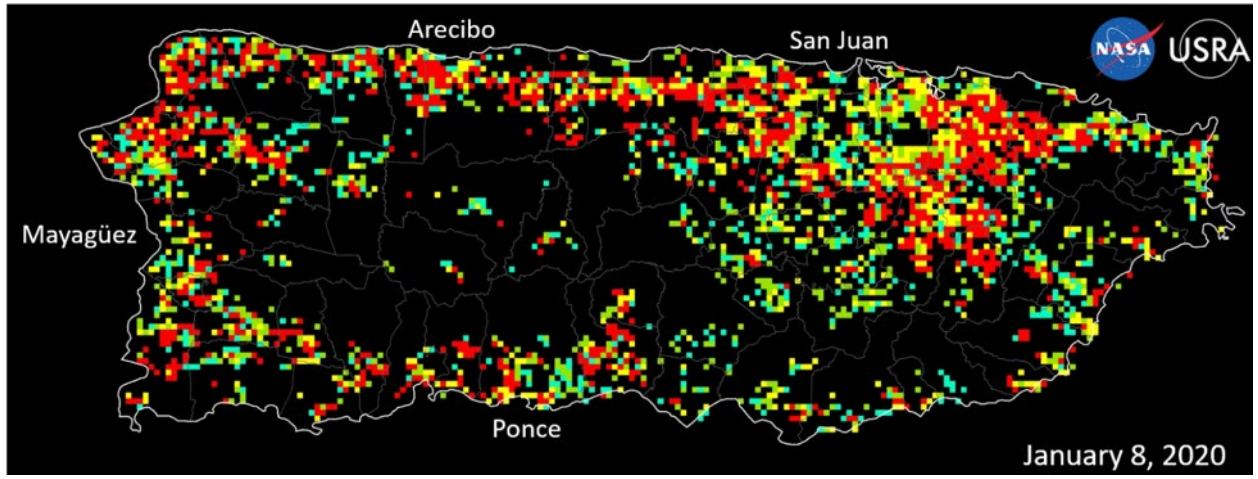
Román *et al.*, (2019) PLoS One

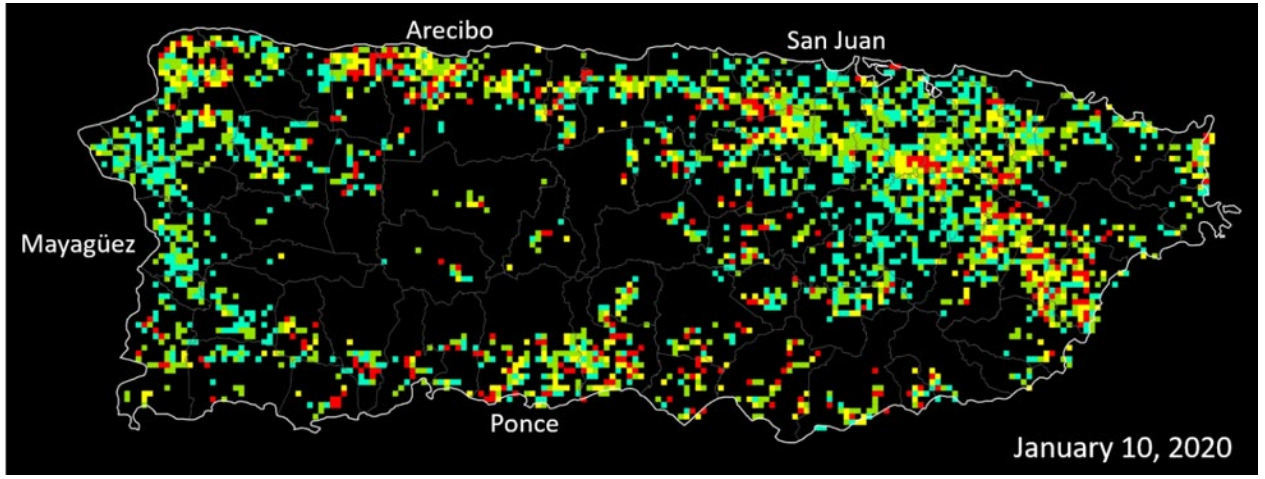
Monitoring Disaster Impacts in Puerto Rico (2017-2018)

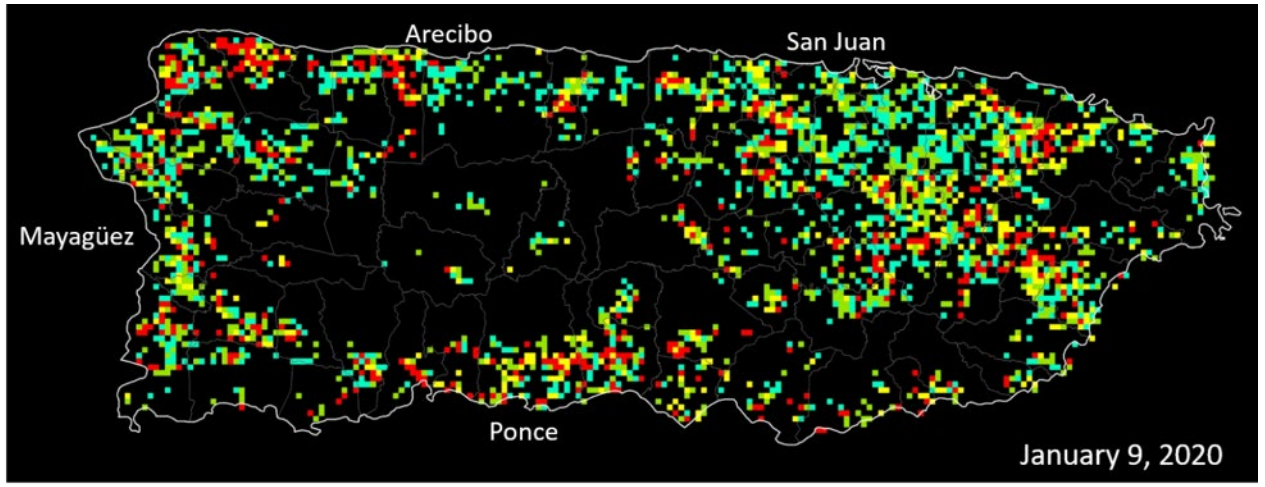


Román *et al.*, (2019) PLoS One

Monitoring Disaster Impacts in Puerto Rico – After Jan-2020 6.4 Earthquakes





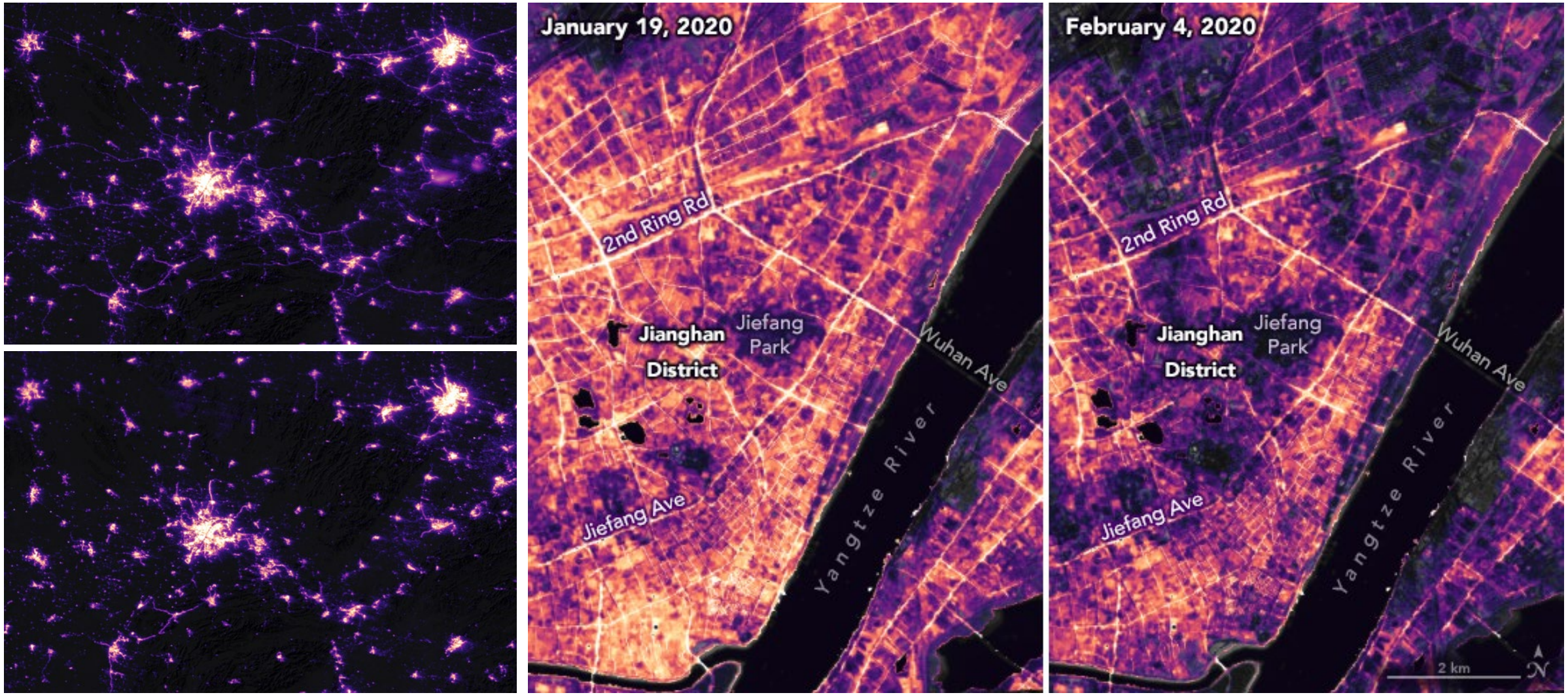


	Reduction in Outdoor Illumination	Radiance Decrease (%)	Population Affected on Jan 8	Population Affected on Jan 9	Population Affected on Jan 10
	Very High	75 – 100	666,259	214,623	142,207
	High	50 – 75	426,589	267,003	247,595
	Moderate	25 – 50	406,731	491,911	626,010
	Low	10 – 25	272,227	486,239	551,560

Reductions in outdoor illumination are widespread even after 3 days.

Román *et al.*, (2019) PLoS One

Monitoring COVID-19 Impacts on Urban Areas



Loss of light is observed along highways (left) and inside the commercial districts of Wuhan (right) after the COVID-19 lockdown.

More Information

- Check out our Black Marble website at: https://blackmarble.gsfc.nasa.gov/

- These articles from our team are particularly useful:
  - *As a reference manual:*
    - Román, M. O., Z. Wang, Q. Sun, V. Kalb, S. D. Miller, A. Molthan, L. Schultz, J. Bell, E. C. Stokes, B. Pandey, K. C. Seto, D. Hall, T. Oda, R. E. Wolfe, G. Lin, N. Golpayegani, S. Devadiga, C. Davidson, S. Sarkar, C. Praderas, J. Schmaltz, R. Boller, J. Stevens, O. M. Ramos Gonzalez, E. Padilla, J. Alonso, Y. Detrés, R. Armstrong, I. Miranda, Y. Conte, N. Marrero, K. MacManus, T. Esch, and E. J. Masuoka. 2018. "NASA's Black Marble nighttime lights product suite." *Remote Sensing of Environment 210 113-143 [* doi:10.1016/j.rse.2018.03.017*]*
  - *Case study of disaster applications:*
    - M. O. Román, Eleanor C. Stokes, Ranjay Shrestha, Zhuosen Wang, Lori Schultz, Edil A. Sepúlveda Carlo, Qingsong Sun, Jordan Bell, Andrew Molthan, Virginia Kalb, Chuanyi Ji, Karen C. Seto, Shanna N. McClain, and Markus Enenkel. 2019. "Satellite-based assessment of electricity restoration efforts in Puerto Rico after Hurricane Maria." *PLoS ONE 14 (6) [* doi:10.1371/journal.pone.0218883*]*
  - *Application to urban activity patterns:*
    - Román, M. O., and E. C. Stokes. 2015. "Holidays in lights: Tracking cultural patterns in demand for energy services." *Earth's Future 3 (6): 182-205 [* doi:10.1002/2014ef000285*]*
  - *General review of Nightlights and future outlook:*
    - Noam Levin, Christopher C. M. Kyba, Qingling Zhang, Alejandro Sánchez de Miguel, Miguel O. Román, Xi Li, Boris A. Portnov, Andrew L. Molthan, Andreas Jechow, Steven D. Miller, Zhuosen Wang, Ranjay M. Shrestha, Christopher D. Elvidge. 2020. "Remote sensing of night lights: A review and an outlook for the future." *Remote Sensing of Environment. Volume 237 [* doi:10.1016/j.rse.2019.111443*]*

Downloading Black Marble Images via LAADS

To batch download many files, consider using OPenDAP URL syntax to refer to each file.

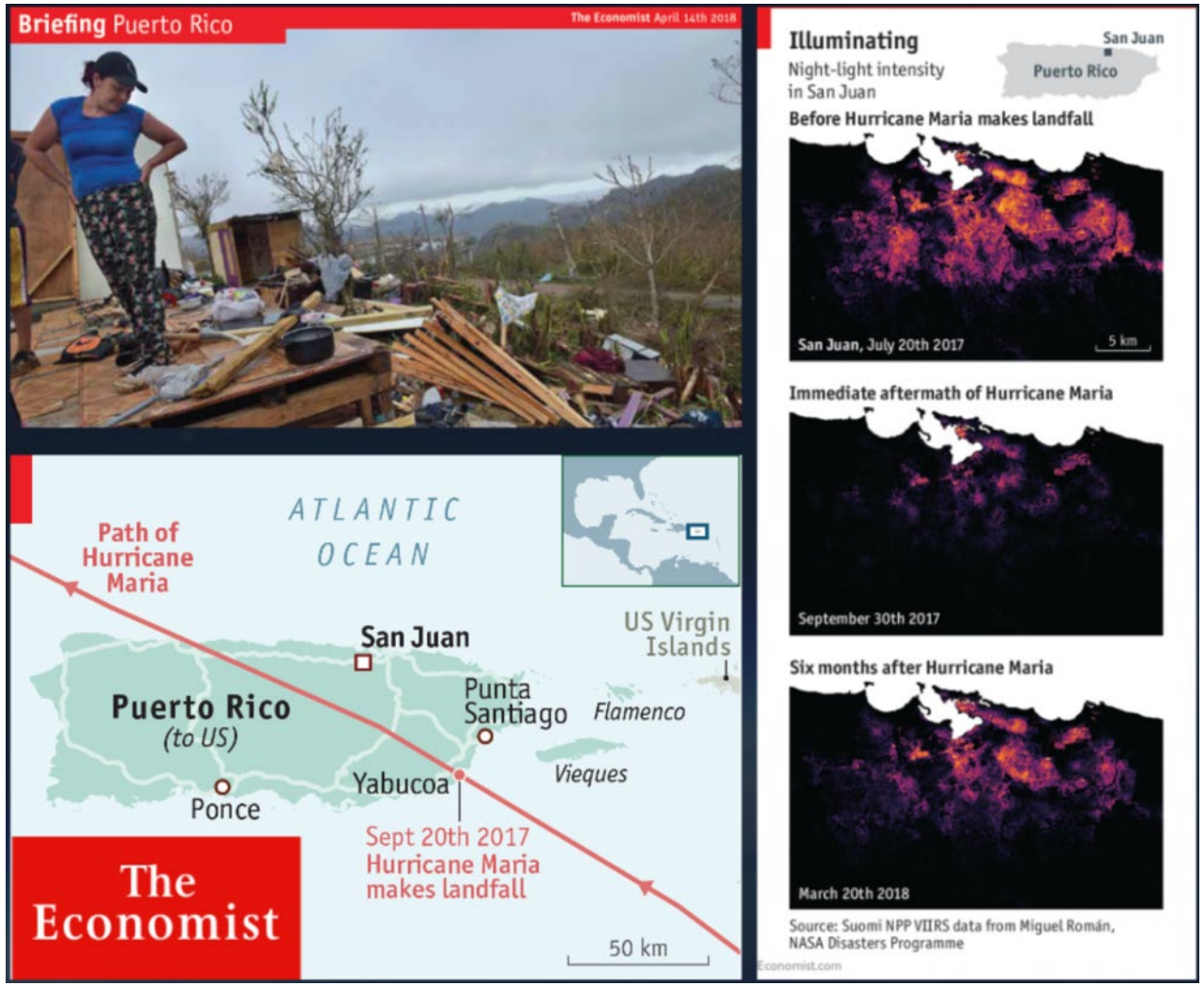
For example, to download Suomi-NPP-VIIRS VNP46A2 product from January 19, 2012, in grid H18v03 (London, United Kingdom), type into internet browser:

ladsweb.modaps.eosdis.nasa.gov/opendap/allData/5000/VNP46A2/2012/019/VNP46A2.A2012019.h18v03.001.2020038165547.h5.html

Practical Exercise

Case Study - Hurricane Maria in Puerto Rico

- Largest blackout in US history
- $90 billion in damages
- -15% loss of gross national product (GNP)
- 4,645 human lives lost
- 200,000 people migrated



Generating Time-Series – Caguas, Puerto Rico

- Location – Caguas, PR
- Date range:
  - July 1, 2017
  - Oct 26, 2017

Generating Time-Series – Caguas, Puerto Rico

1. VNP46A2 Data

- Download data zipped folder here
- https://drive.google.com/file/d/1BDWFgLdUFS8SGNIvR0ypwgQEQ9hHFhMO/view?usp=sharing
- Extract the data in your local folder

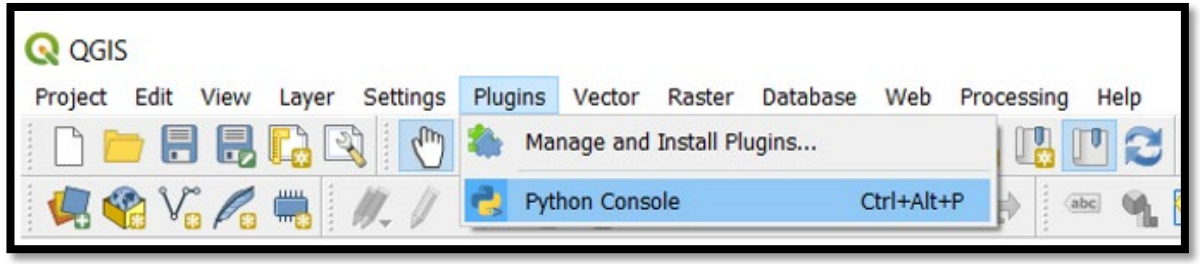
2. Python Script

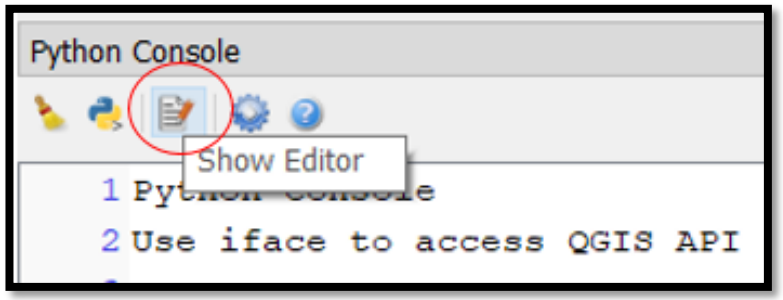
- Download the Python script here
- https://drive.google.com/file/d/1rvD8Bp7GP8BZAg0hhVpItctDpgj5ukJT/view?usp=sharing
- Save it in your local folder

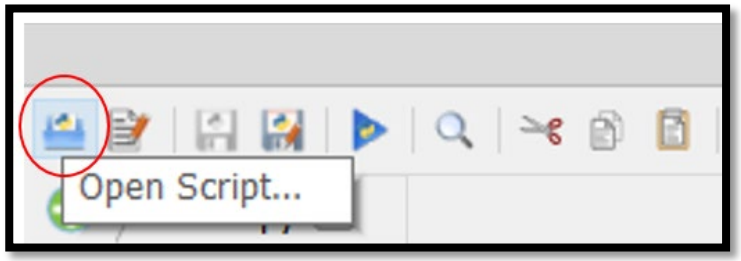
Generating Time-Series – Caguas, Puerto Rico

3. Executing the Python Script from QGIS

- Open QGIS
- From the **Plugins** menu, open **Python Console**.
- In the Python Console, click on the **Show Editor** icon.
- In the Editor, click on the **Open Script** icon, navigate to the Python Script you downloaded and open the script.







Generating Time-Series – Caguas, Puerto Rico

4. Code Update

- Once the Python Script is loaded in the editor, make the following **changes** in the script:

Line 11 – Change the folder path to the extracted VNP46A2 data folder you downloaded

>os.chdir('C:/ARSET/Assignment/Demo/Syria/Data_PR')

```
 9    #Input·VNP46A2·-·PR
10    ####Change·it·to·your·input·Data·Folder###
11    os.chdir('C:/ARSET/Assignment/Demo/Maria2020/Data_PR')
```

Line 15 – Change the folder path to a separate local folder to hold temporary files

>outputFolder = "C:/ARSET/Assignment/Demo/Syria/Output/"

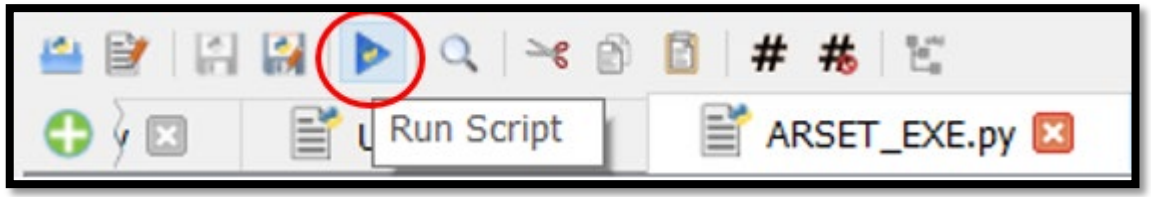
```
13    #Output·-·PR
14    ####Chage·This·Path·to·Output/Temp·Folder####
15    outputFolder·=·"C:/ARSET/Assignment/Demo/Maria2020/Output/"
```

Note – Please use either "/" or "\\" to define folder path.

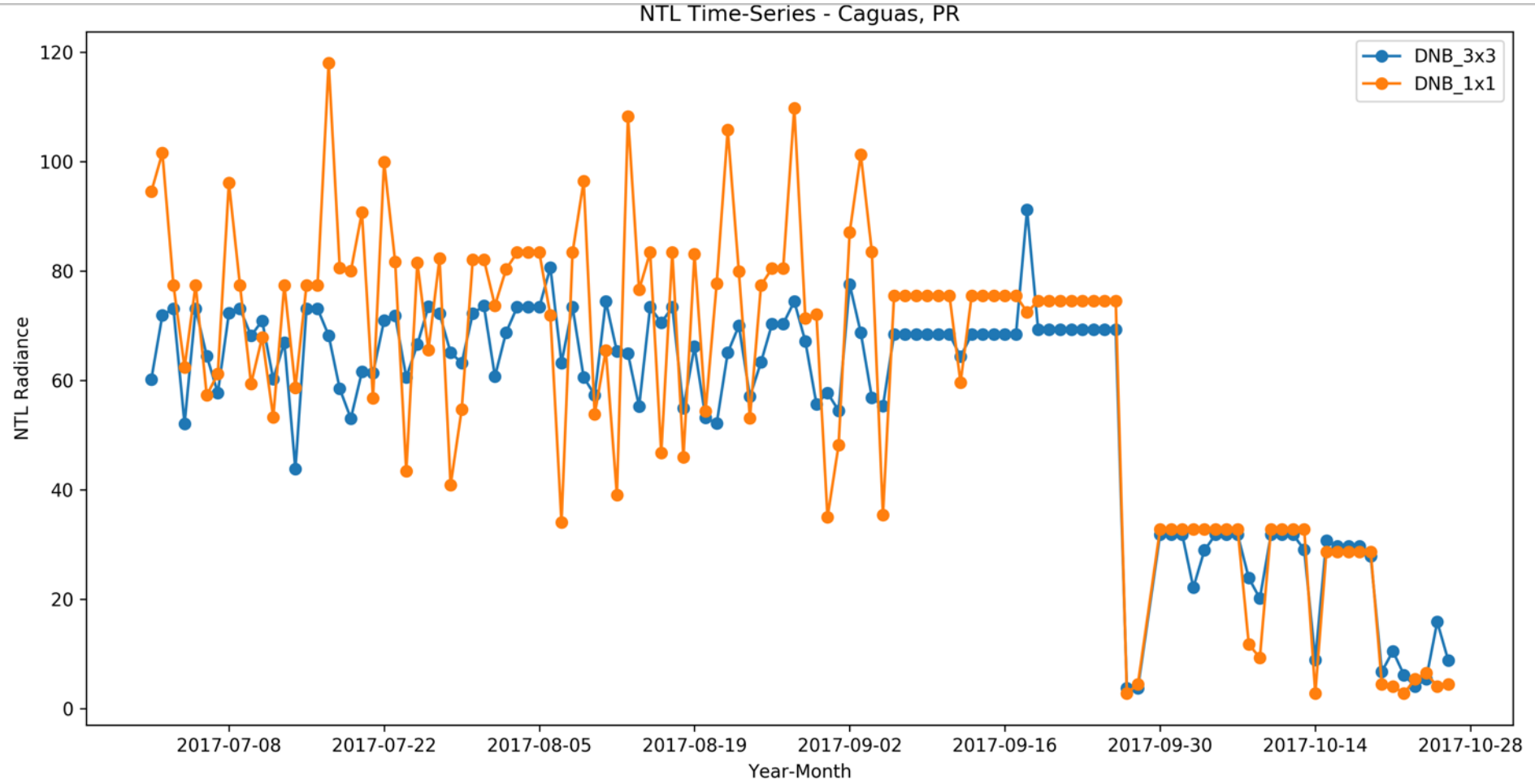
Generating Time-Series – Caguas, Puerto Rico

5. Executing the Python Script

- After the changes, execute the Python Script by clicking the **Run Script** icon.



Generating Time-Series – Caguas, Puerto Rico



3x3 pixel window-based time-series, smoother compared to a single (1x1) pixel-based.


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!