Satellite imagery with Julia

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December 5, 2024

Table of Contents

Introduction to Satellite Data

Satellite data encompasses a wide range of information collected by satellites orbiting the Earth. This data is utilized across various fields and industries for diverse applications.

Global Coverage: The coverage is often global, allowing for monitoring and analysis of changes and trends on a planetary scale. It also enables resuse of models/research from one country to another.

Temporal Resolution: Data acquired at regular intervals at high frequency.

Spatial Resolution: Images are of high resolution allowing small areas to be studied.

Data Accessibility: Many satellite data sources are freely available to the public.

Untapped potential

File size Images recieved from satellites are typically bulky. They were costly to share. This cost has coming down. Services like Google Earth Engine host data on their servers.[1]

Computing resources Users of satellite data could do very limited work due to limitations on computing resources. Cloud computing has been helpful.

Efficient computing frameworks Tools used to process satellite data were closed source and inefficient. This is been rapidly changing. The Rasters package in Julia provides one of most efficient frameworks to process satellite imagery.

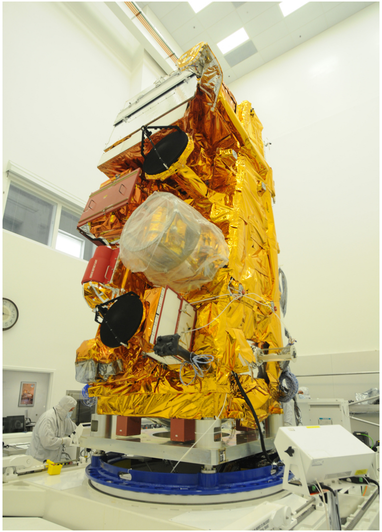
[1] GEE isn't covered today. Google hosts a very comprehensive workshop on GEE.

Agenda

- Deep dive into one satellite data source, VIIRS, but understand general concepts.
- Case studies.
- Working with satellite data in QGIS and Raster.jl in Julia.

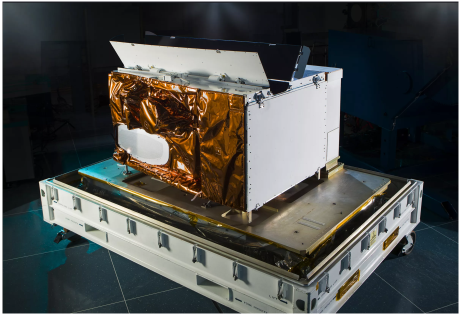
Table of Contents

Suomi National Polar-orbiting Partnership



- **Launch date:** 28 October 2011 at 3:18 pm IST
- **Operator:** NASA / NOAA / DoD
- **Period:** 14 times per day
- **Instruments:**
  1. Visible Infrared Imaging Radiometer Suite (VIIRS)
  2. Advanced Technology Microwave Sounder (ATMS)
  3. Ozone Mapping and Profiler Suite (OMPS)
  4. Cross-track Infrared Sounder (CrIS)
  5. Clouds and the Earth's Radiant Energy System (CERES)

Visible Infrared Imaging Radiometer Suite (VIIRS)

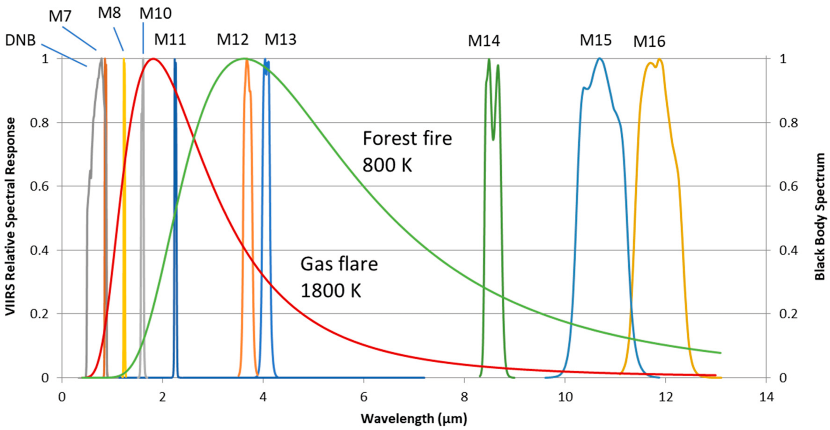


- **No. spectral bands:** 22
- **Uses:** Nighttime lights, fire anomalies, Vegetation Index, etc.

Bands

Primary Earth Data Records	Band Name	Center (microns)	Width (FWHM)
4*Ocean Color Aerosol	M1	0.415	0.02
	M2	0.445	0.02
	M3	0.49	0.02
	M4	0.555	0.02
Imagery band	I1	0.64	0.075
Ocean Color Aerosol	M5	0.673	0.021
Nighttime Lights	DNB	0.7	0.4
Atmospheric Correction	M6	0.746	0.021
NDVI	I2	0.865	0.039
Ocean Color Aerosol	M7	0.865	0.039
Cloud Particle Size	M8	1.24	0.02
Cirrus Cloud Cover	M9	1.378	0.02
Binary Snow Map	I3	1.61	0.06
Snow Fraction	M10	1.61	0.06
Clouds	M11	2.25	0.05
Imagery band Clouds	I4	3.74	0.38
Sea Surface Temperature	M12	3.7	0.18
Sea Surface Temperature & Fires	M13	4.05	0.155
Cloud Top Properties	M14	8.55	0.3
Sea Surface Temperature	M15	10.763	1
Imagery band Clouds	I5	11.45	1.9
Sea Surface Temperature	M16	12.013	0.95

Bands



2 3

[2] Mikhail Zhizhin, Christopher Elvidge, and Alexey Poyda. "Night-Time Detection of Subpixel Emitters with VIIRS Mid-Wave Infrared Bands M12–M13". In: *Remote Sensing* 15.5 (Jan. 2023), p. 1189. ISSN: 2072-4292. DOI: 10.3390/rs15051189. (Visited on 04/02/2024).

[3] This figure doesn't contain all the 22 VIIRS bands

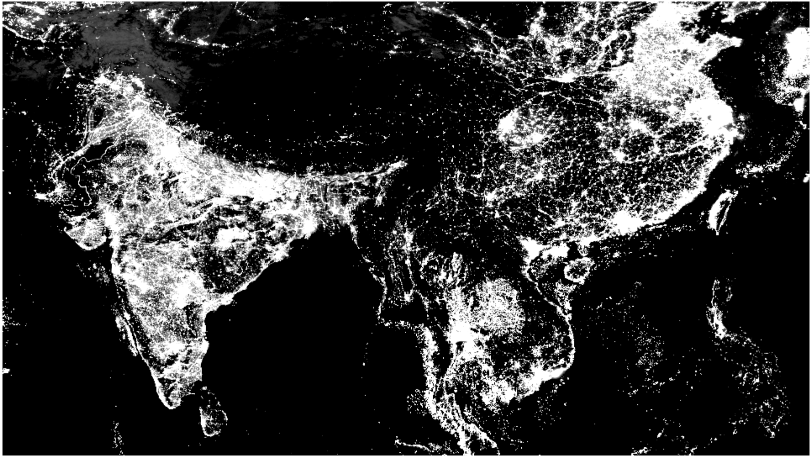
Combining spectral information to generate single band images

It is useful to combine the spectral information from the different bands to generate single band images. Each pixel has one value, which makes it easy to utilise them. NOAA often separately releases single band images generated from multiband data.
For example:

1. Nighttime lights: Radiance measured in $nW\ cm^{-2}\ sr^{-1}$.
2. Active fires: 0 or 1 indicating an active fire at that pixel.
3. Vegetation Index: A value between 0 and 1 indicating the amount of vegetation at that pixel.

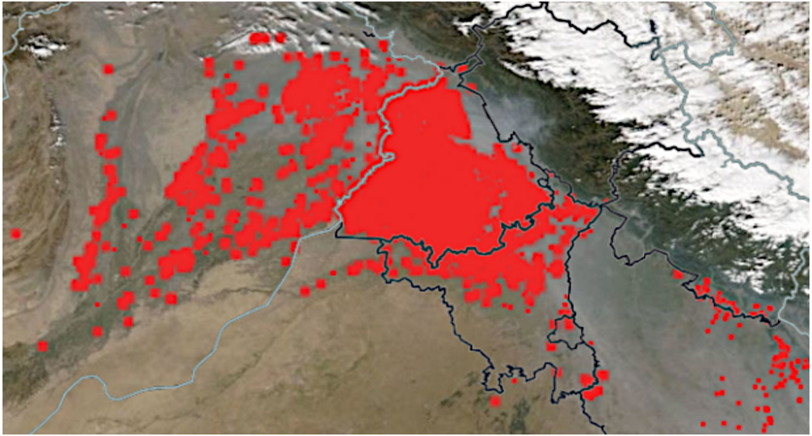
Nighttime lights

Example 1: January 2021



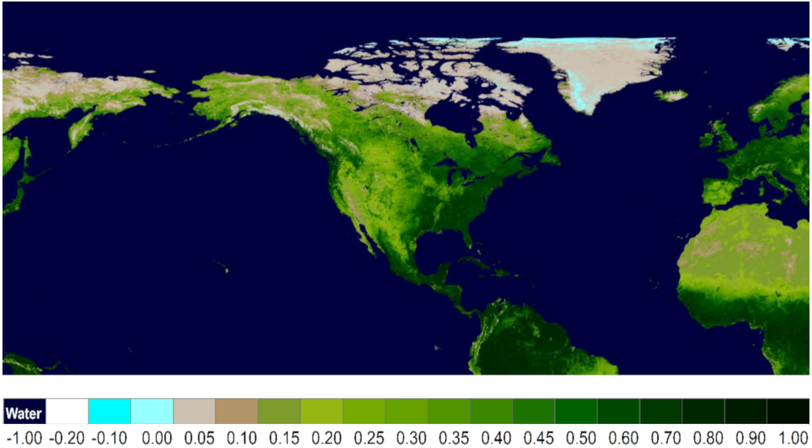
Active fires

Example 2: 1 November 2021



Enhanced Vegetation Index

October 2017



Constructing Vegetation Index from spectral information

While plants absorb blue light almost completely, they reflect some amount of red and near infrared (NIR) light. Vegetation indices can be created by combining the reflectance measurments at blue, red and NIR[4]. NOAA use the following formula for creating Enhanced Vegetation Index from spectral information.

$$EVI = 2.5\frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + 6\rho_{red} - 7.5\rho_{blue} + 1} \tag{1}$$

1. Red: 0.6 - 0.7 µm
2. NIR: 0.7 - 1.1 µm
3. Blue: 0.44 - 0.5 µm

This formula was initially used for data from MODIS, but any satellite dataset that contains these bands can be used to construct the EVI.

[4] Alfredo Huete et al. "Overview of the Radiometric and Biophysical Performance of the MODIS Vegetation Indices". In: *Remote sensing of environment* 83.1-2 (2002), pp. 195–213. DOI: 10.1016/S0034-4257(02)00096-2.

Bands in VIIRS data for EVI

Primary Earth Data Records	Band Name	Center (microns)	Width (FWHM)
4*Ocean Color Aerosol	M1	0.415	0.02
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Sea Surface Temperature	M15	10.763	1
Imagery band Clouds	I5	11.45	1.9
Sea Surface Temperature	M16	12.013	0.95

Bands in Landsat 9 data for EVI

Band name	**Wavelength (microns)**
Band 1 - Coastal aerosol	0.43-0.45
Band 2 - Blue	0.45-0.51
Band 3 - Green	0.53-0.59
Band 4 - Red	0.64-0.67
Band 5 - Near Infrared (NIR)	0.85-0.88
Band 6 - SWIR 1	1.57-1.65
Band 7 - SWIR 2	2.11-2.29
Band 8 - Panchromatic	0.50-0.68
Band 9 - Cirrus	1.36-1.38
Band 10 - Thermal Infrared (TIRS) 1	10.6-11.19
Band 11 - Thermal Infrared (TIRS) 2	11.50-12.51

Bands in Sentinel 2 for EVI

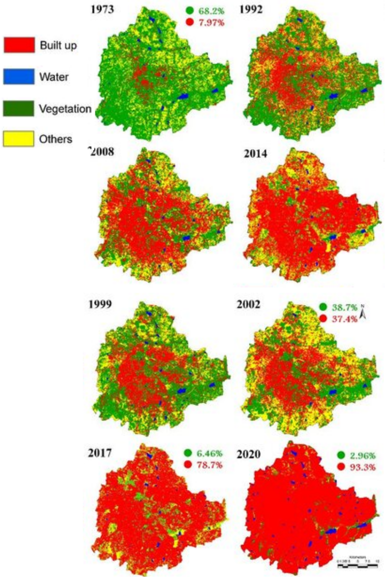
Sentinel-2 bands

	Sentinel-2A Central (microns)	Width (microns)	Sentinel-2B Central (microns)	Width (microns)
Band 1 - Coastal aerosol	0.442	0.21	0.442	0.21
Band 2 - Blue	0.492	0.66	0.492	0.66
Band 3 - Green	0.559	0.36	0.559	0.36
Band 4 - Red	0.664	0.301	0.664	0.31
Band 5 - Vegetation red edge	0.704	0.105	0.703	0.16
Band 6 - Vegetation red edge	0.740	0.15	0.739	0.15
Band 7 - Vegetation red edge	0.782	0.20	0.779	0.20
Band 8 - NIR	0.832	0.106	0.832	0.106
Band 8A - Narrow NIR	0.864	0.21	0.864	0.22
Band 9 - Water vapour	0.945	0.20	0.943	0.21
Band 10 - SWIR â Cirrus	1.373	0.31	1.176	0.30
Band 11 - SWIR	1.613	0.91	1.110	0.94
Band 12 - SWIR	2.202	0.175	2.185	0.185

Combining satellite datasets

Satellite datasets with overlapping bands are often combined to create long timeseries datasets. While one of the most important features of satellite data is high frequency, making long timeseries allow studying long term effects.

Landuse dynamics in Bengaluru



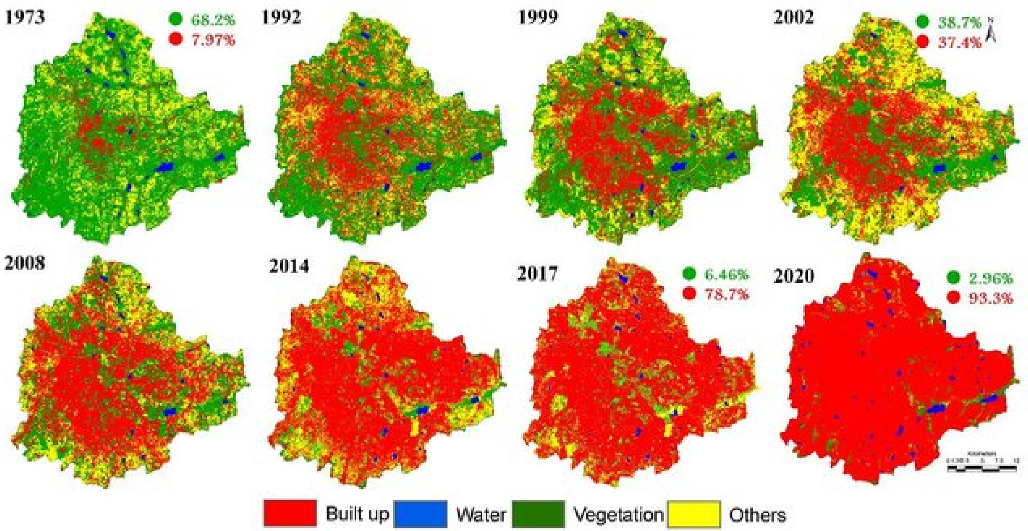
Two landsat datasets are combined with MODIS to create a long timeseries of landuse of Bengaluru.

- NIR and MIR bands (bands 3 and 4) of Landsat 1973 data to 23.5 m.
- 3 IR bands of Landsat (band 4-NIR, 5-MIR and 7-MIR) of 1992 to 23.5 m.
- 4 IR MODIS bands 2 and 5 to 7 (MOD 09 product) to 250 m.

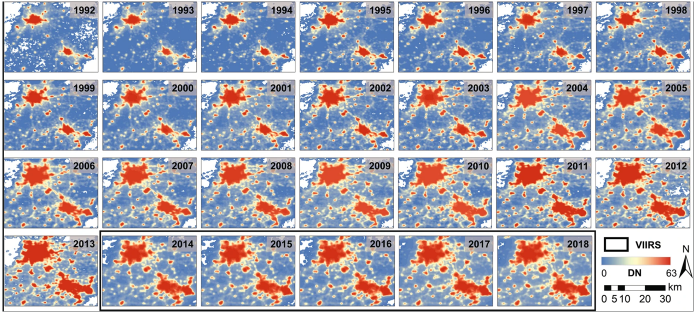
T V Ramachandra, Vinay Shivamurthy, and Dr. Bharath Aithal. *Frequent Floods in Bangalore: Causes and Remedial Measures*. Dec. 2017. DOI: 10.13140/RG.2.2.17517.90088

Landuse dynamics in Bengaluru

Previous image shown bigger



Harmonized nighttime lights



Combined data from DMSP (1992-2013) with VIIRS(2012-present). Xuecao Li et al. “A Harmonized Global Nighttime Light Dataset 1992–2018”. In: *Scientific Data* 7.1 (June 2020), p. 168. ISSN: 2052-4463. DOI: 10.1038/s41597-020-0510-y. (Visited on 04/02/2024)

Harmonized nighttime lights

Previous image shown bigger

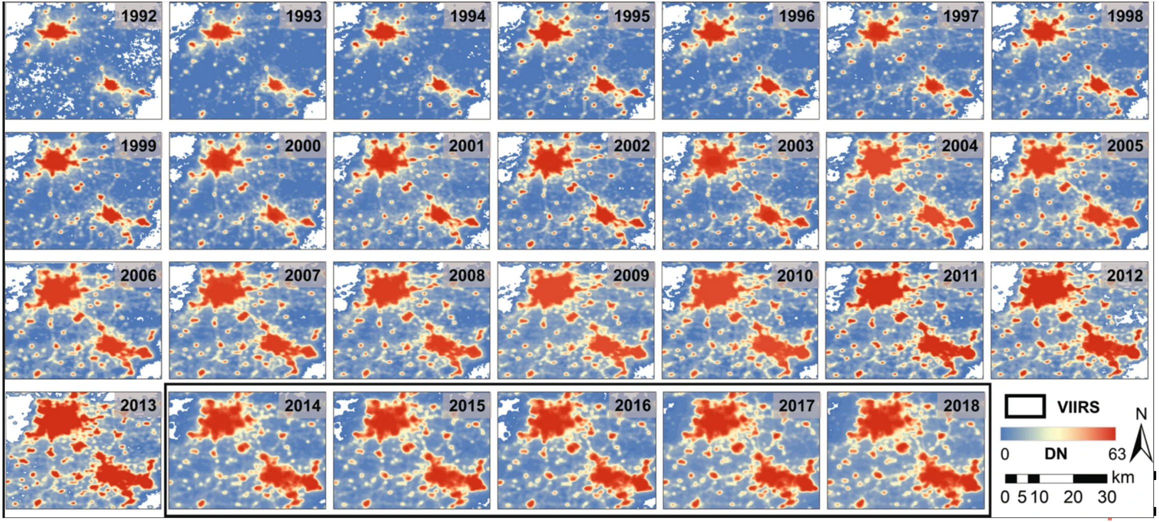
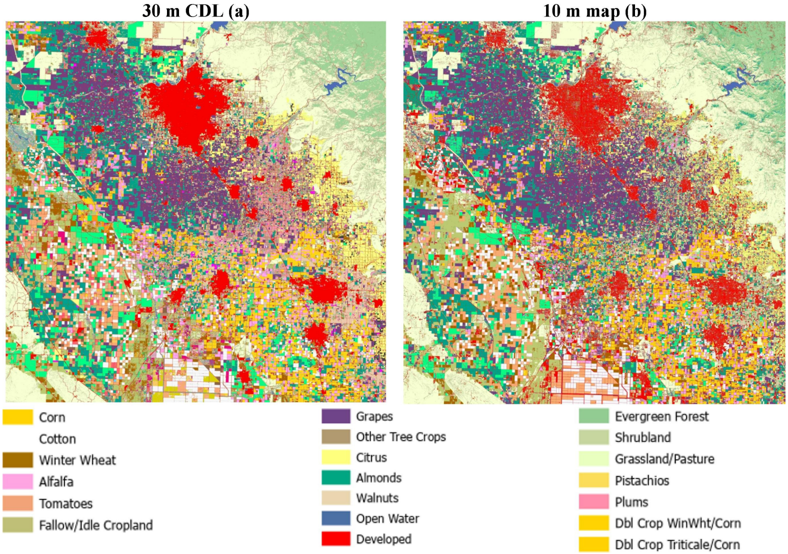


Table of Contents

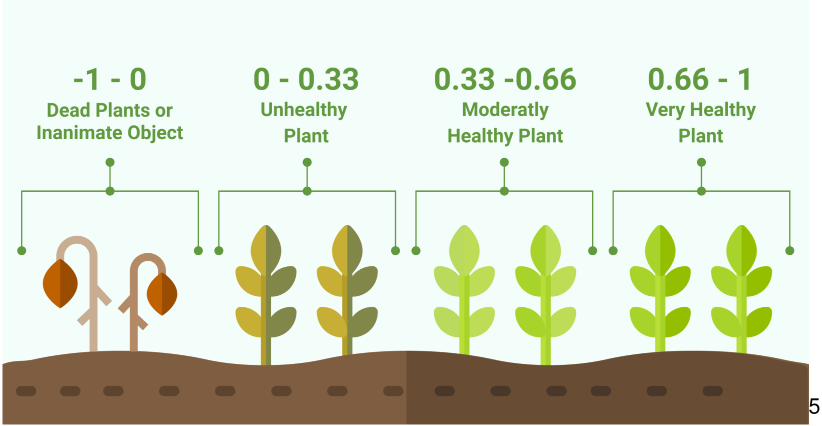
Crop type mapping using Sentinel-2



Used grouth truth (left) for training a model.

Khuong H Tran et al. “10 m Crop Type Mapping Using Sentinel-2 Reflectance and 30 m Cropland Data Layer Product”. In: *International Journal of Applied Earth Observation and Geoinformation* 107 (2022), p. 102692. DOI: 10.1016/j.jag.2022.102692

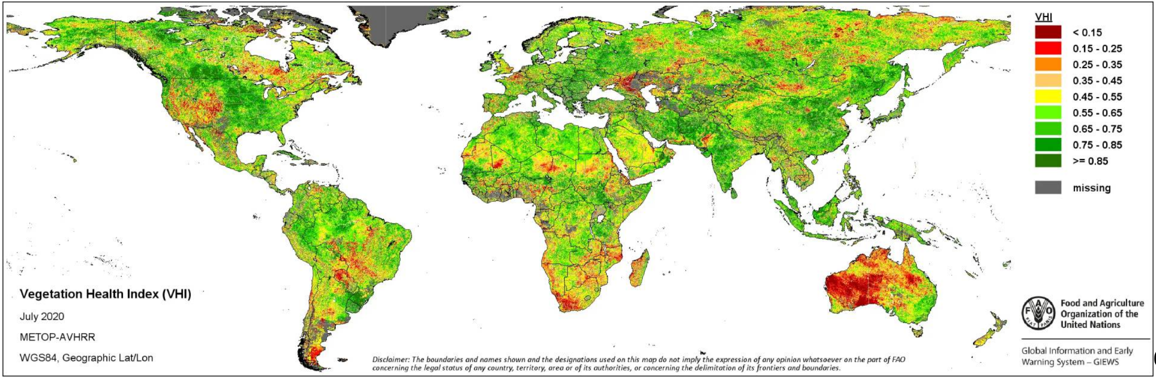
Crop health is estimated using the vegetation index, which was shown earlier.



[5]

[5] Source: https://phenospex.com/blog/digital-disease-quantification-in-plants-a-tailored-method/plants/

Crop health



[6]

[6] Source: https://data.apps.fao.org/map/catalog/srv/api/records/1eb5883d-05c6-427f-bbf7-8465bfb7069c/attachments/vhi_m.png

Numer8's OFish is a mobile application designed to help small-scale fishers navigate the ocean more efficiently and sustainably.
It uses the Sentinel data to understand ocean conditions and predict potential fish locations using the following information:

- Sea surface temperature
- Ocean currents
- Chlorophyll concentration

By combining this data with other factors like historical catch data and user-reported locations, OFish helps fishers to:

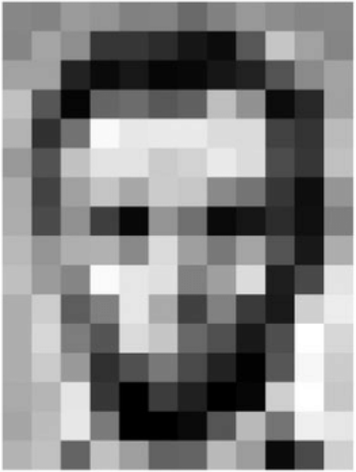
- Locate potential fishing zones
- Navigate safely by providing information on weather hazards
- Fish sustainably by targeting specific areas with higher fish concentrations

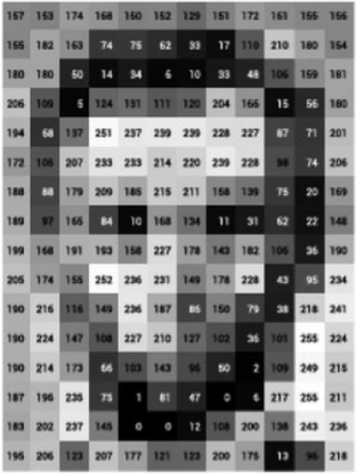
OFish also offers a complementary system for government authorities, enabling them to:

- Monitor fishing activity to combat illegal, unreported, and unregulated (IUU) fishing
- Improve fisheries management by understanding where and how fishing is taking place

Table of Contents

Image as digits



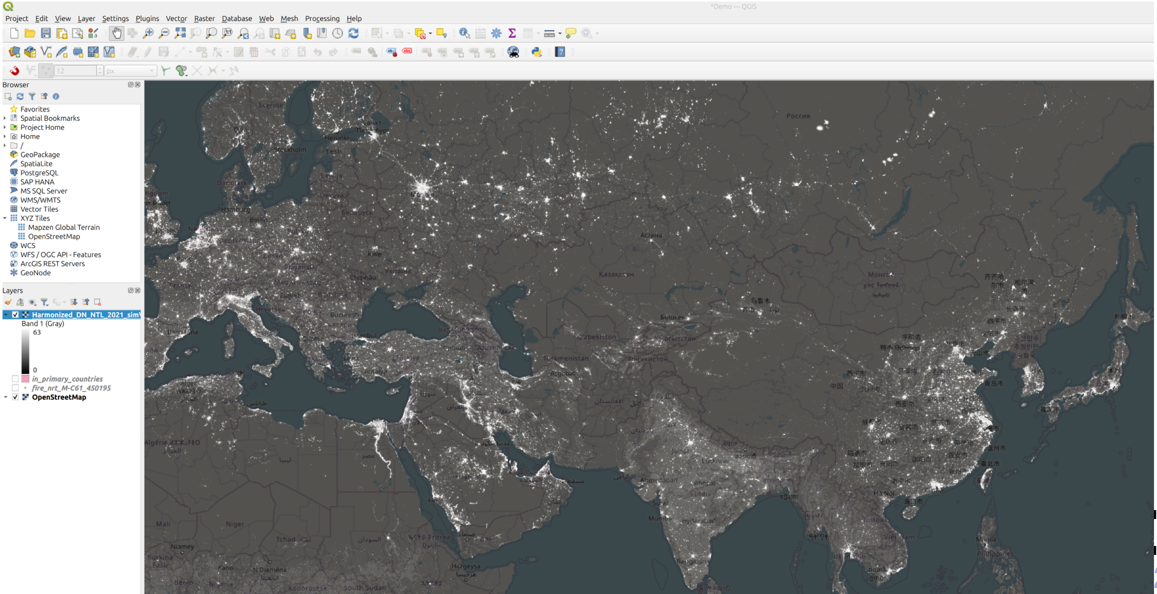


157	153	174	168	150	152	129	151	172	161	155	156
155	182	163	74	75	62	33	17	110	210	180	154
180	180	50	14	34	6	10	33	48	106	159	181
206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	75	20	169
189	97	165	84	10	168	134	11	31	62	22	148
199	168	191	193	158	227	178	143	182	106	36	190
205	174	155	252	236	231	149	178	228	43	95	234
190	216	116	149	236	187	86	150	79	38	218	241
190	224	147	108	227	210	127	102	36	101	255	224
190	214	173	66	103	143	96	50	2	109	249	215
187	196	235	75	1	81	47	0	6	217	255	211
183	202	237	145	0	0	12	108	200	138	243	236
195	206	123	207	177	121	123	200	175	13	96	218

Satellite image as digits

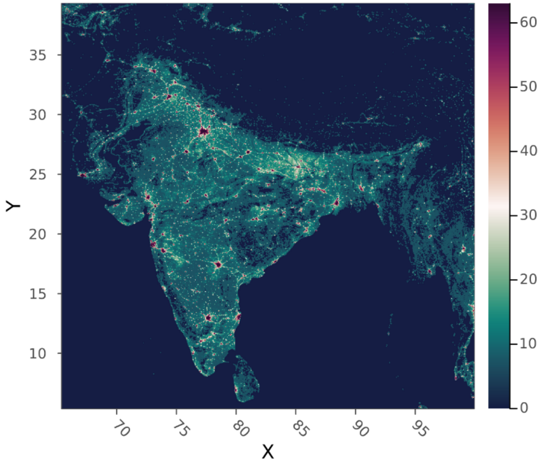
```
48x101 Raster{Float32,2} unnamed with dimensions:
X Mapped{Float32} Float32[72.783335, 72.7875, ..., 72.975, 72.979164] EPSG
Y Mapped{Float32} Float32[19.266666, 19.2625, ..., 18.854166, 18.85] EPSG
and reference dimensions:
Ti Sampled{DateTime} DateTime[DateTime("2012-12-01T00:00:00")]
extent: Extent(X = (72.78125, 72.98125), Y = (18.847916, 19.26875))
crs: EPSG:4326
mappedcrs: EPSG:4326
parent:
         19.2667  19.2625  19.2583  ..  18.8625  18.8583  18.8542  18.85
72.7833   1.52     0.84     0.64         0.09     0.06     0.07     0.06
72.7875   1.63     1.35     0.86         0.08     0.07     0.05     0.06
72.7917   3.3      2.28     1.26         0.09     0.08     0.07     0.11
:                                   :                      :
72.9708  31.7     37.09    42.36         1.23     1.06     0.97     0.93
72.975   21.98    28.94    38.1          1.19     0.95     0.86     0.94
72.9792  19.52    26.22    28.3          1.35     1.01     0.87     0.8
```

QGIS Demonstration



Raster.jl demonstration

```
bounds = X(Rasters.Between(65.39, 99.94)), Y(Rasters.Between(5.34, 39.27))
raster[bounds...] |> plot
```



https://deepnote.com/viewer/github/xKDR/datascience-tutorials/blob/main/rasters.ipynb
https://youtu.be/PqWuGsVQdLw

The effectiveness of Julia

- All the processes shown can be effectively done using other languages such as Python.
- Julia stands out when it a lot more processing is required, such as processing many images together.
- Rasters.jl allows images to be stacked together, processed efficiently.

The NighttimeLights.jl package

https://github.com/xKDR/NighttimeLights.jl

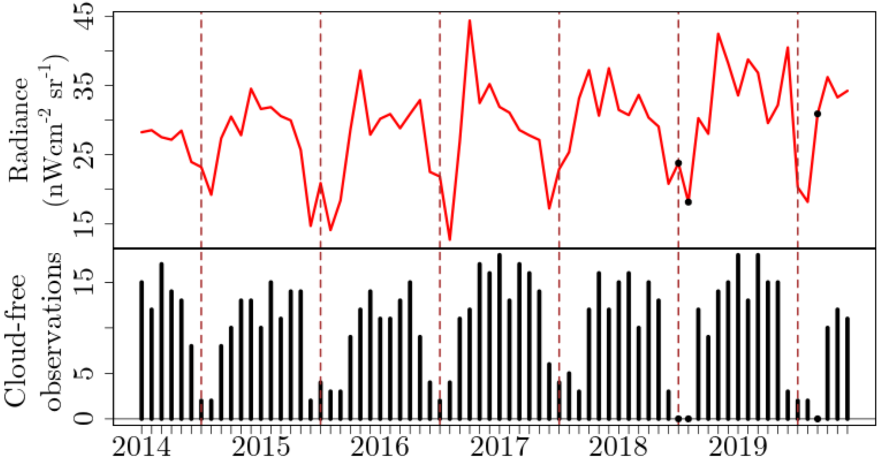
- The nighttime light package is built on top of Rasters.jl. It provides functions for cleaning the data.
- In some cases, 10s or 100s of images are stacked together, and processing is done for each pixel.

Ayush Patnaik, Ajay Shah, and Susan Thomas. *Foundations for nighttime lights data analysis*. Tech. rep. 2022

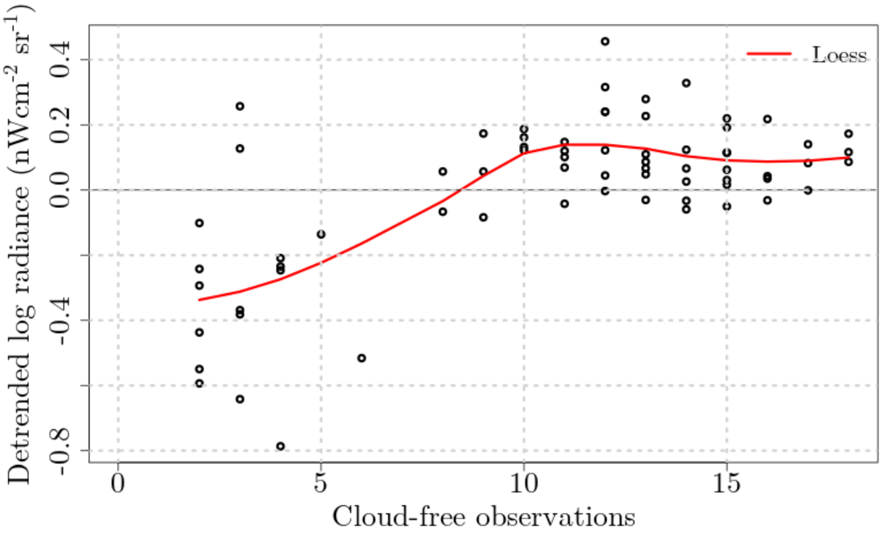
Attenuation-correction process

- For each pixel in the VIIRS monthly nighttime lights data, we get the radiance of that month and the number of days in the month that weren't cloudy.
- We find that months with low number of cloud-free days show lower radiance.
- This attenuation is corrected using a pixel level statistical process.

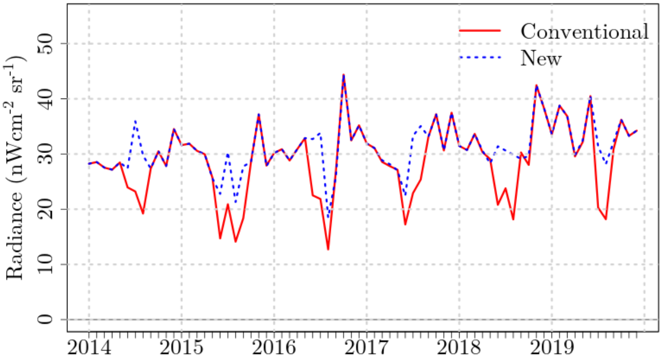
Attenuation of pixel's radiance



Relationship between radiance and cloudiness



Corrected radiance



This is done for each pixel in a selected region.
For reference, a bounding box around India contains ≈ 50 million pixels.
Ayush Patnaik, Ajay Shah, Anshul Tayal, et al. *But Clouds Got in My Way: Bias and Bias Correction of Viirs Nighttime Lights Data in the Presence of Clouds*. Tech. rep. 2021

Thank you.

https://xkdr.org

Bibliography I

[1] Alfredo Huete et al. “Overview of the Radiometric and Biophysical Performance of the MODIS Vegetation Indices”. In: *Remote sensing of environment* 83.1-2 (2002), pp. 195–213. DOI: 10.1016/S0034-4257(02)00096-2.

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