Guest Lecture: Nighttime Lights

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Why nighttime lights?

- Human activity is not easy to detect with daytime images, even at moderately fine resolution (e.g. 20-30 m)
- Most human activity (e.g. production, consumption, transport) by night requires some form of illumination
- More activity or concentration of people translates into higher light intensity by night
- Visible light at night is easily detected by satellites, even at a fairly coarse resolution (500 m to 1 km)

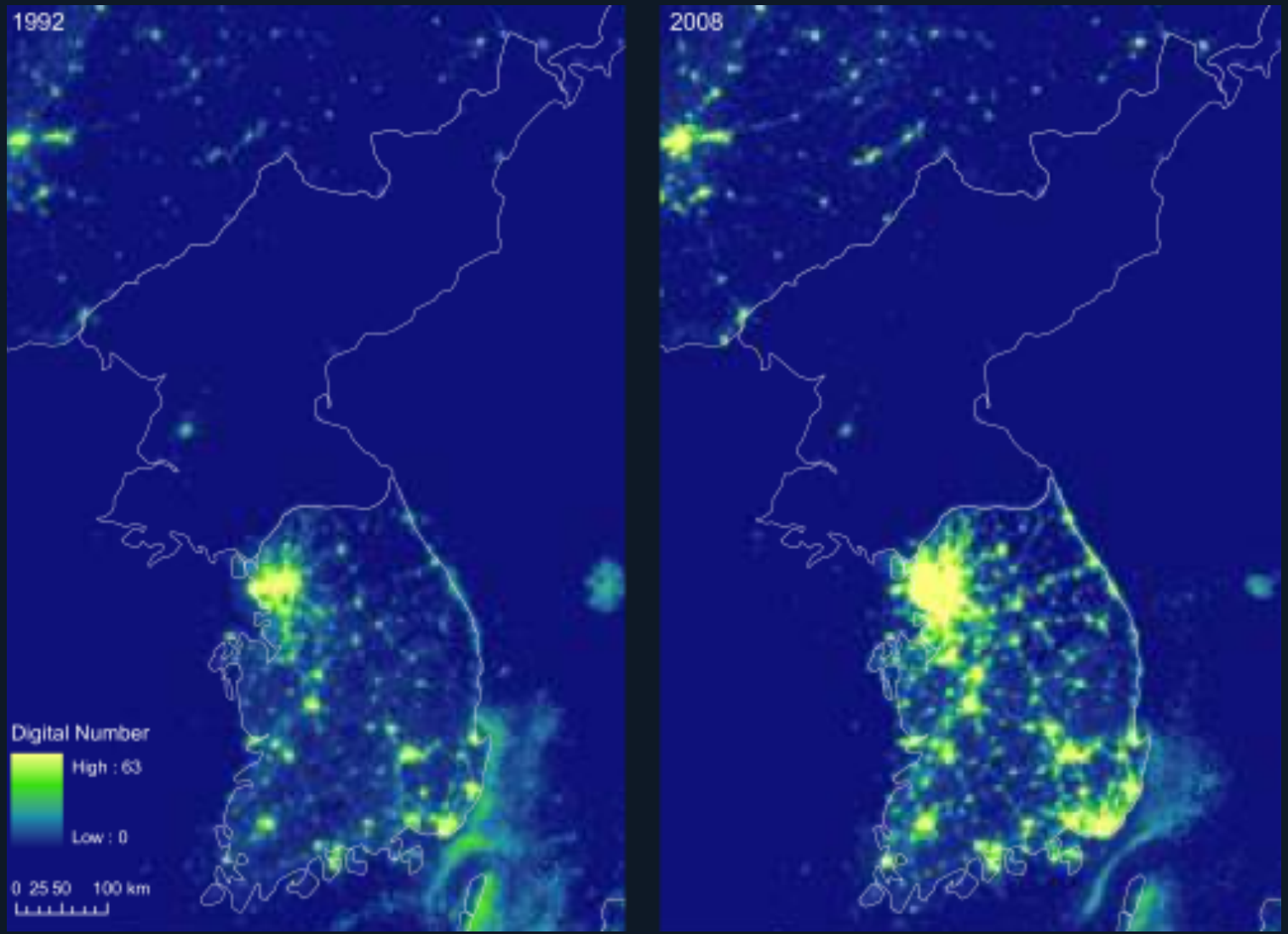
Argentina by day

Argentina by night

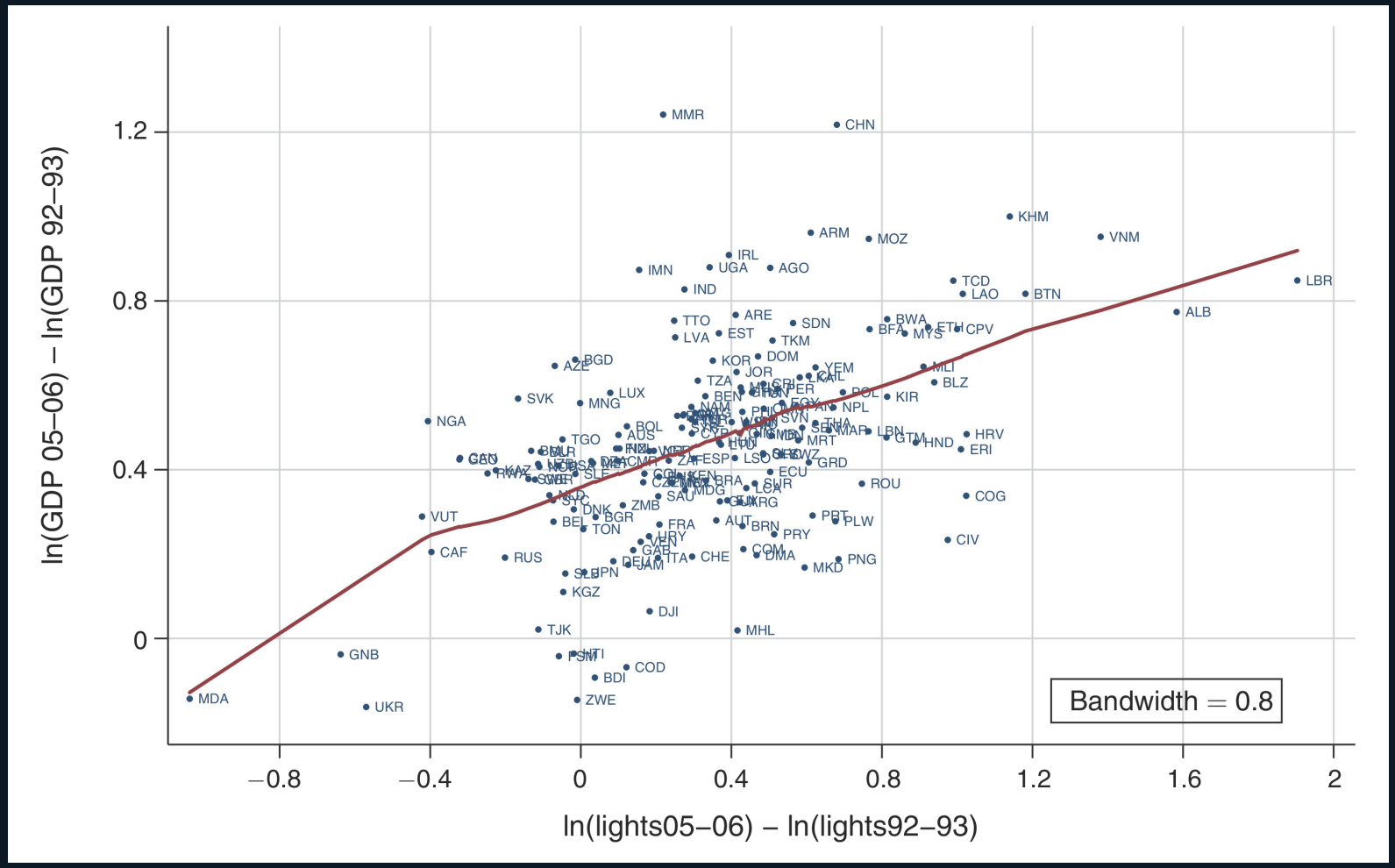
Why is this useful for tracking development?

- Statistical offices in developing countries are often underequipped and lack capacity to conduct surveys regularly.
- Example: After rebasing in 2014, Nigeria's 2013 GDP nearly doubled, Tanzania's grew by a third, Kenya's and Zambia's increased by a quarter, and Uganda's rose by 13 percent.
- Light intensity by night is associated with economic activity in the cross section and over time.
- The association is remarkably strong starting from the country level down to the individual village, but weaker for small geographies over time.

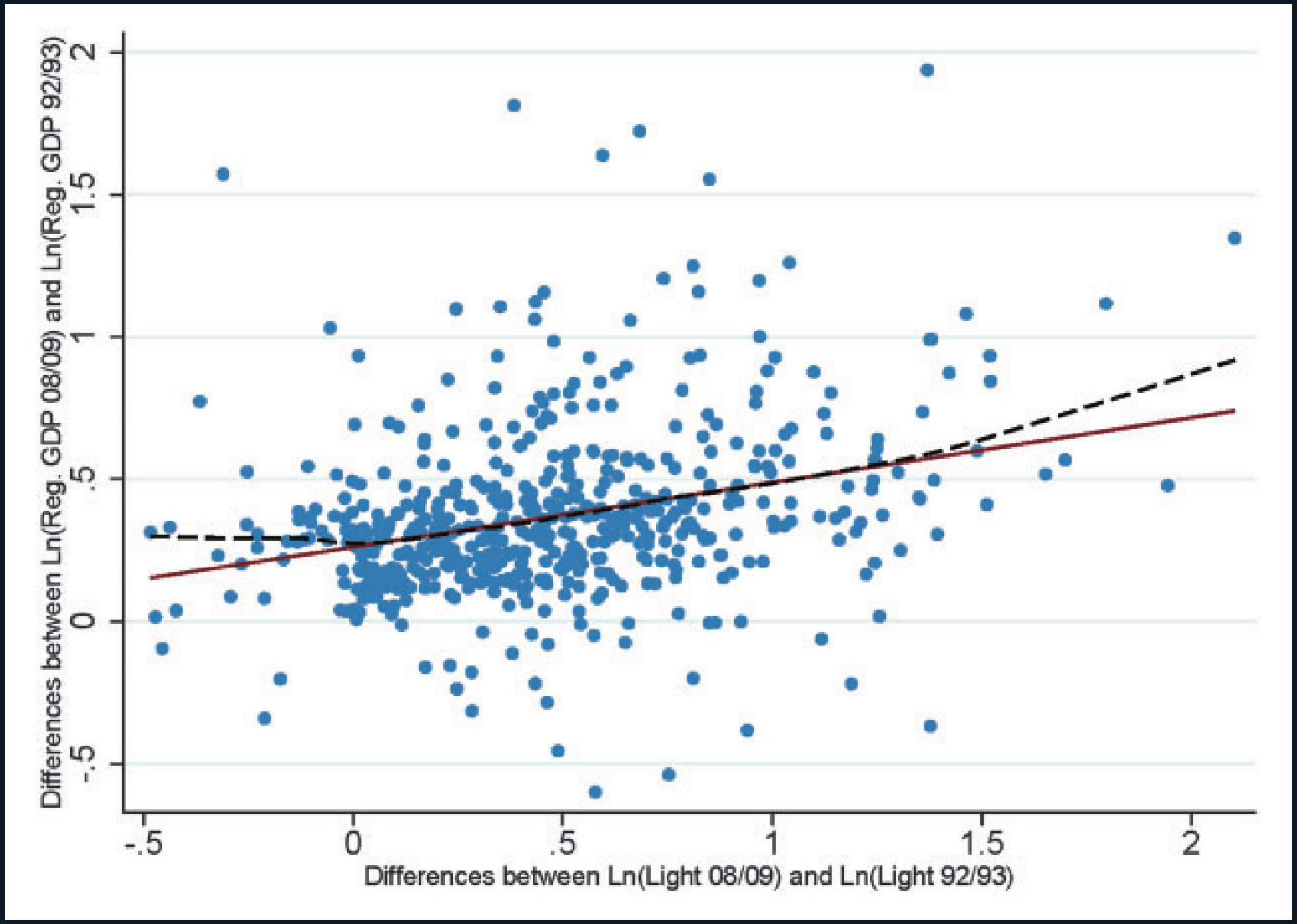
North and South Korea



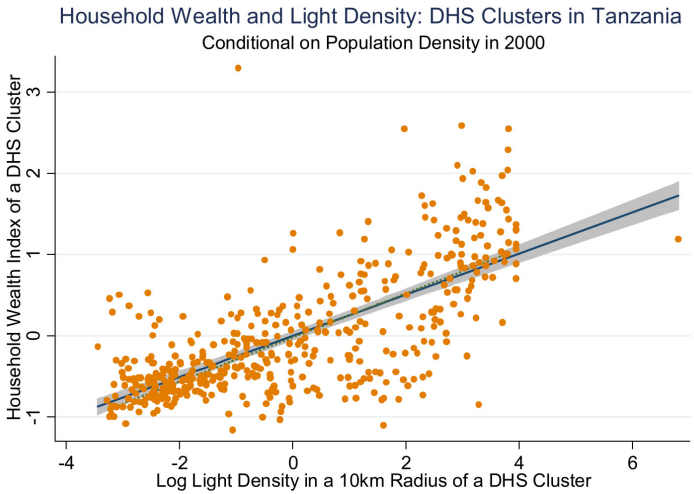
National GDP and light intensity (time)

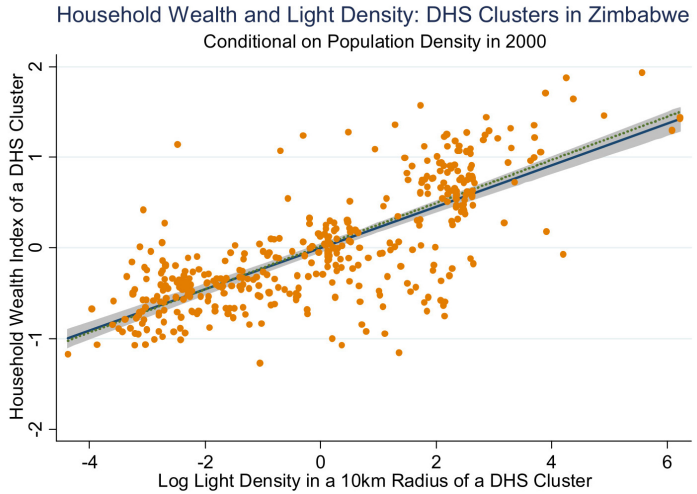


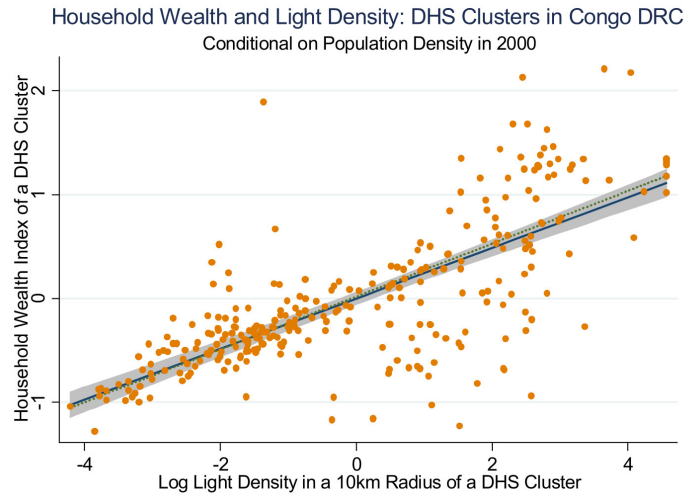
Regional GDP and light intensity (time)

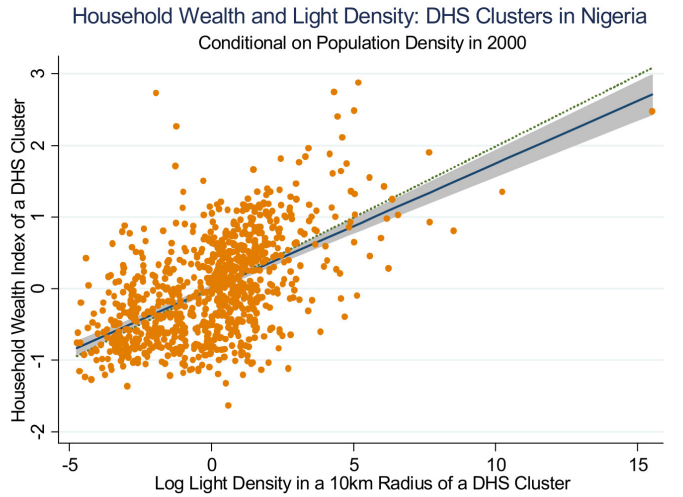


Household wealth and light intensity (x-section)

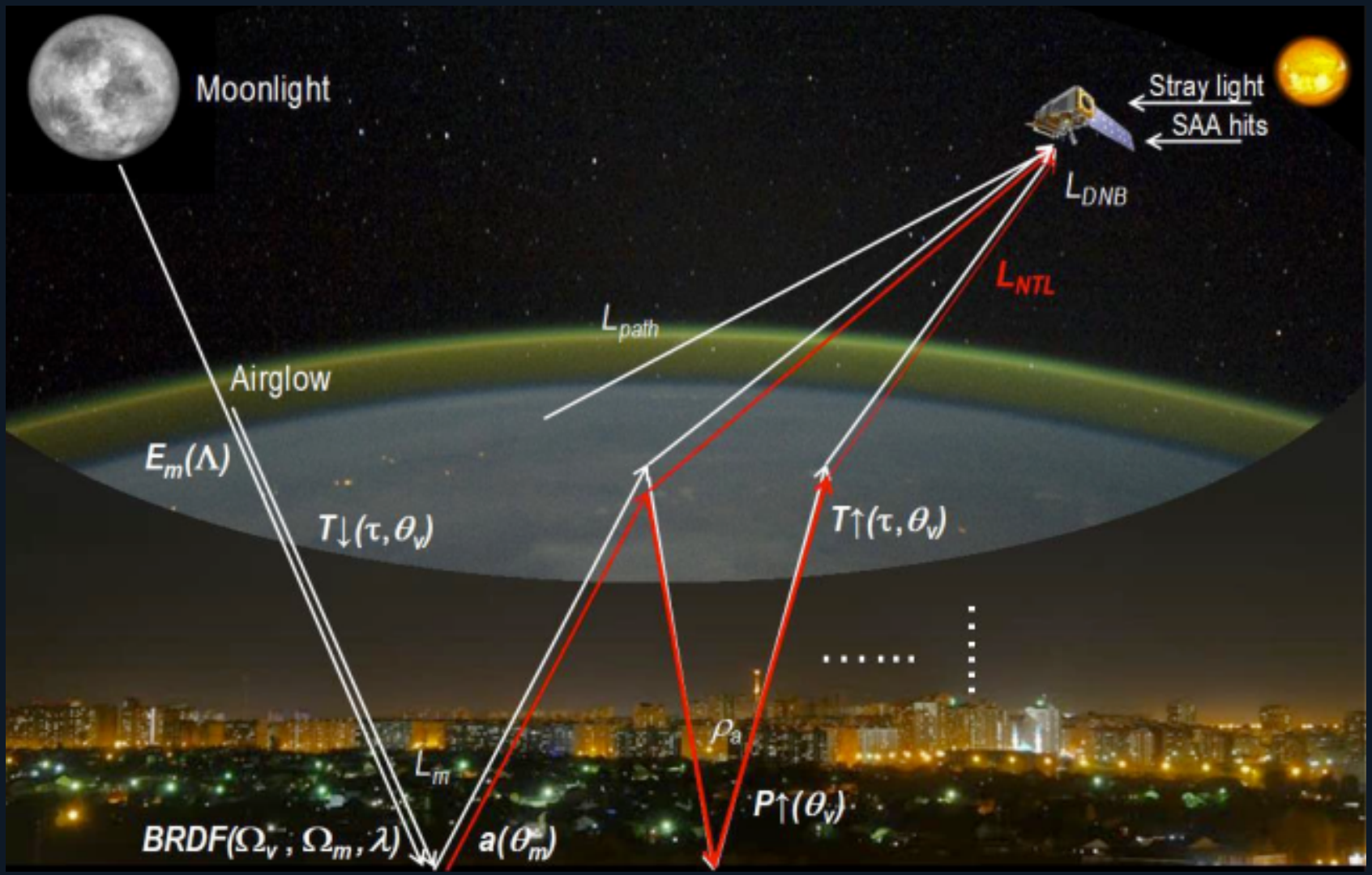








How it works


Moonlight
Stray light
SAA hits
L_{DNB}
L_{NTL}
L_{path}
Airglow
$E_m(\Lambda)$
$T\downarrow(\tau,\theta_v)$
$T\uparrow(\tau,\theta_v)$
ρ_a
L_m
$P\uparrow(\theta_v)$
$BRDF(\Omega_v, \Omega_m, \lambda)$
$a(\theta_m)$

Two major systems

DMSP-OLS instruments from NASA/NOAA

- Evening lights: 8:30-10:00 pm local time.
- Not radiometrically calibrated. Record dimensionless DN.
- Native (on-board) resolution of 2.7 km^2 $\rightarrow$ resampled to 30 arc seconds grid (about 1 km).

VIIRS-DNB instruments from the Suomi NPP (NASA and others)

- Nighttime lights: around 1.30 am local time.
- Native (on-board) resolution of 742 m $\rightarrow$ resampled to 15 arc seconds grid (about 500 m).
- More details later . . .

DMSP-OLS products

NOAA provides three major products:

- Stable lights
  - Light scale: 0 to 63 DN (*top-coded* & *bottom censored*)
- Average lights
  - Light scale: 0 to 63 DN (*top-coded* w/ background noise)
- Radiance-calibrated lights
  - Light scale: 0 to ∞ DN (not *top-coded* w/ background noise)
  - Only seven years between 1996 and 2010

The DMSP-OLS series was discontinued in 2014. Most data available from 1992 to 2013.

DMSP-OLS: Bottom coding, location accuracy and overglow

Bottom coding. System can detect at least one 1000 watt high pressure sodium lamp (about 93 household lamps at 100 watt) *but* NOAA filters dim and irregular lights (1-4 DN) for 'stable lights'.

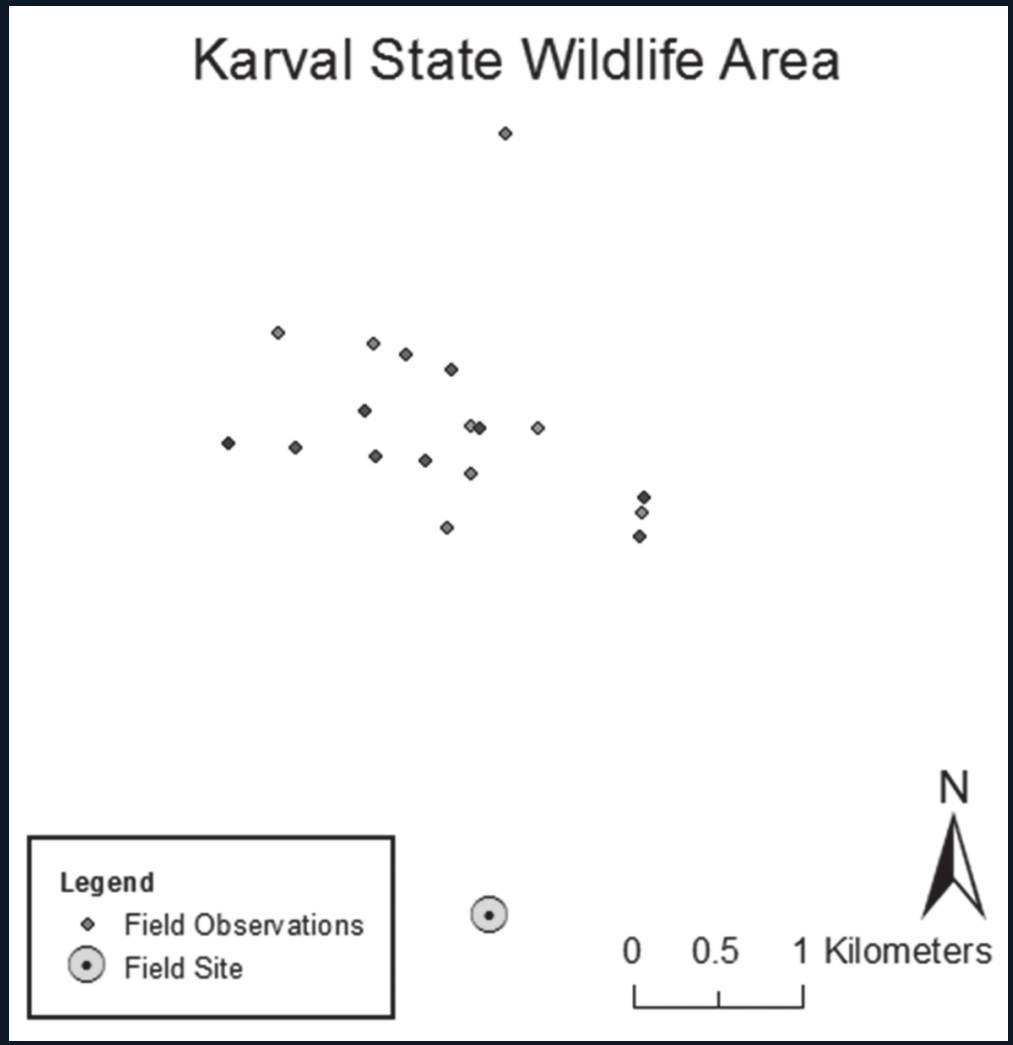
Location accuracy. GPS versus satellite coordinates:

- Data are shifted about 2.90 km to north – at least 3-4 pixels north in 30 arc seconds!

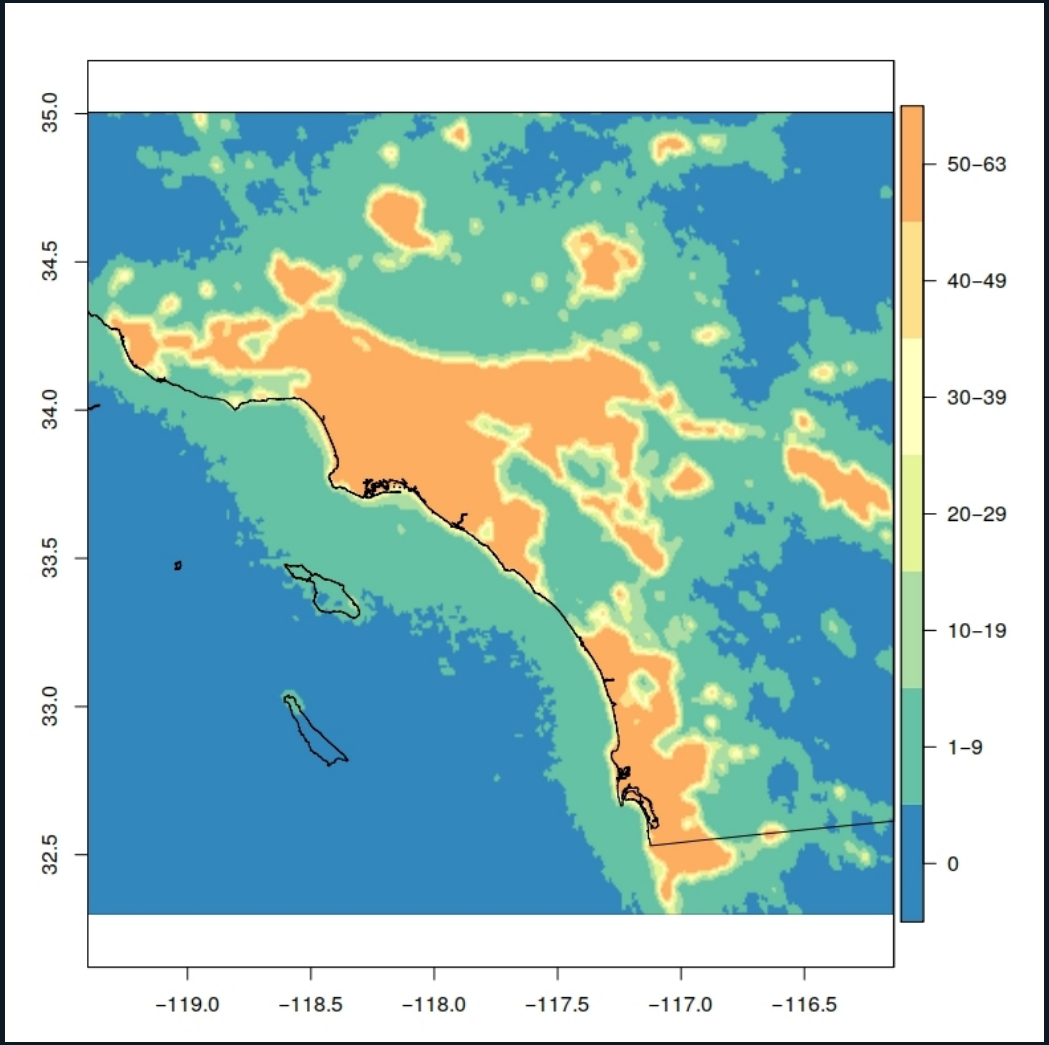
Overglow. Scan angles and on-board averaging matter for footprint of detected lights:

- A single light shows up in several fine resolution pixels.
- Overestimates built-up area by about a factor of 1.25.

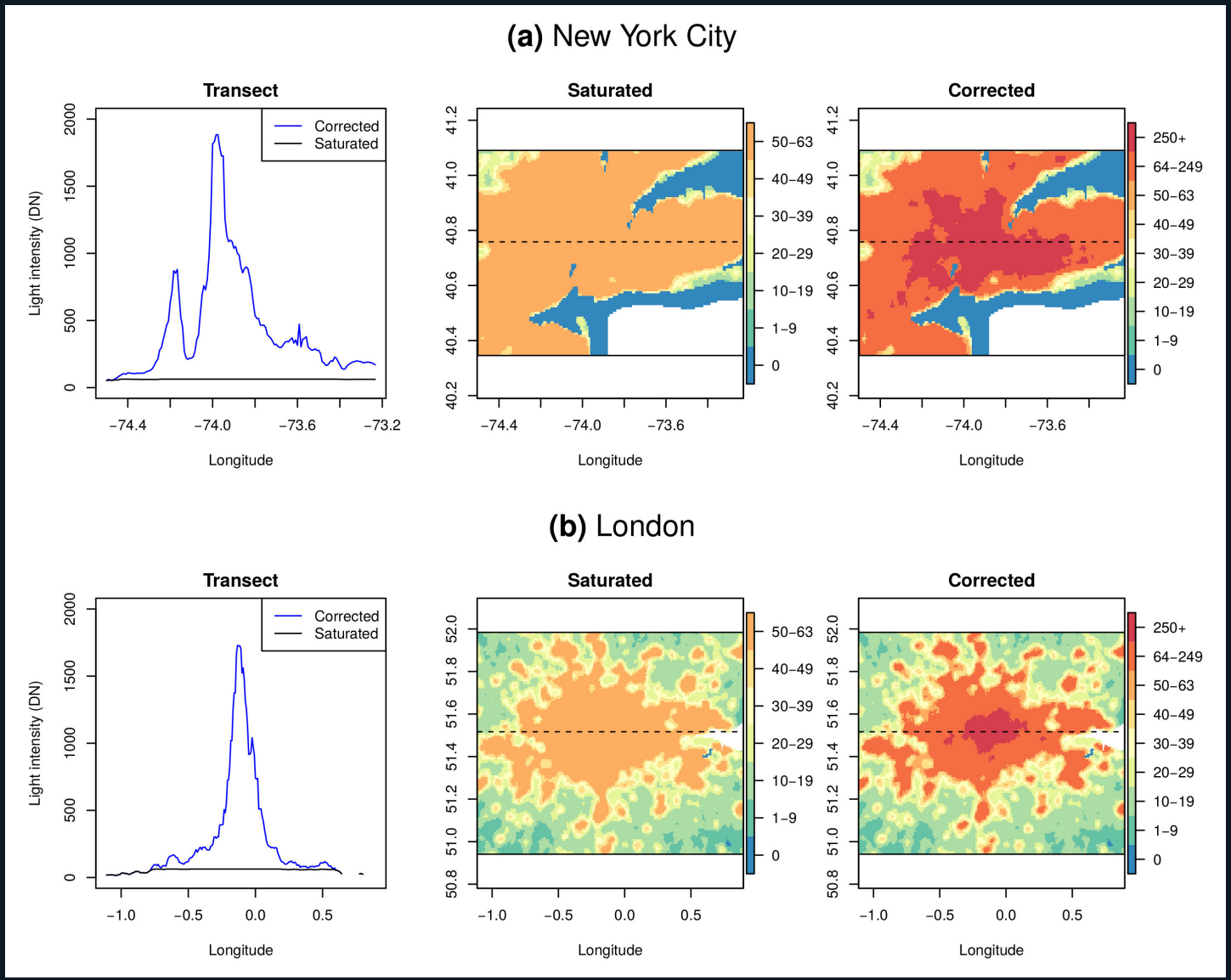
Location accuracy



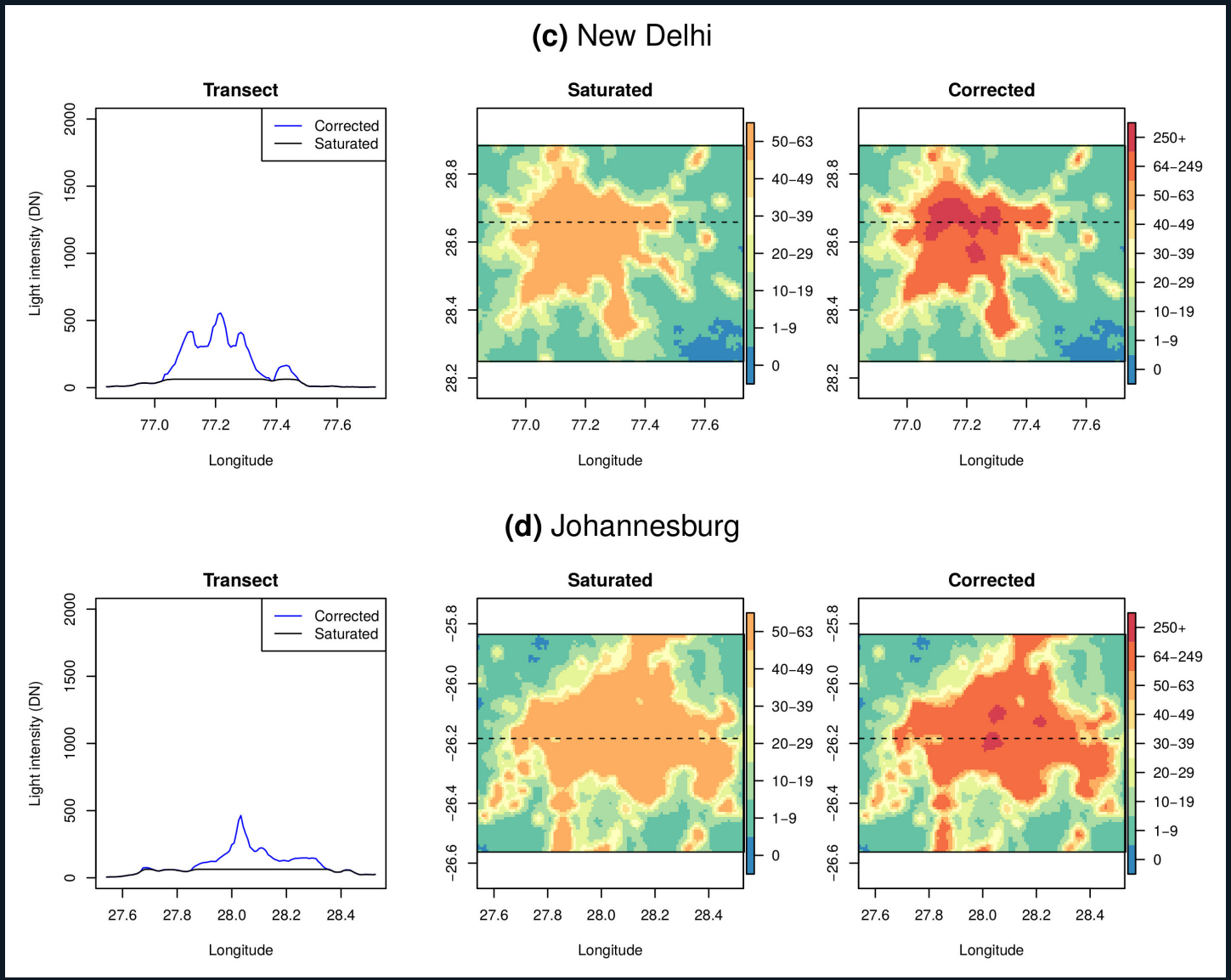
Overglow


35.0
34.5
34.0
33.5
33.0
32.5
−119.0
−118.5
−118.0
−117.5
−117.0
−116.5
50–63
40–49
30–39
20–29
10–19
1–9
0

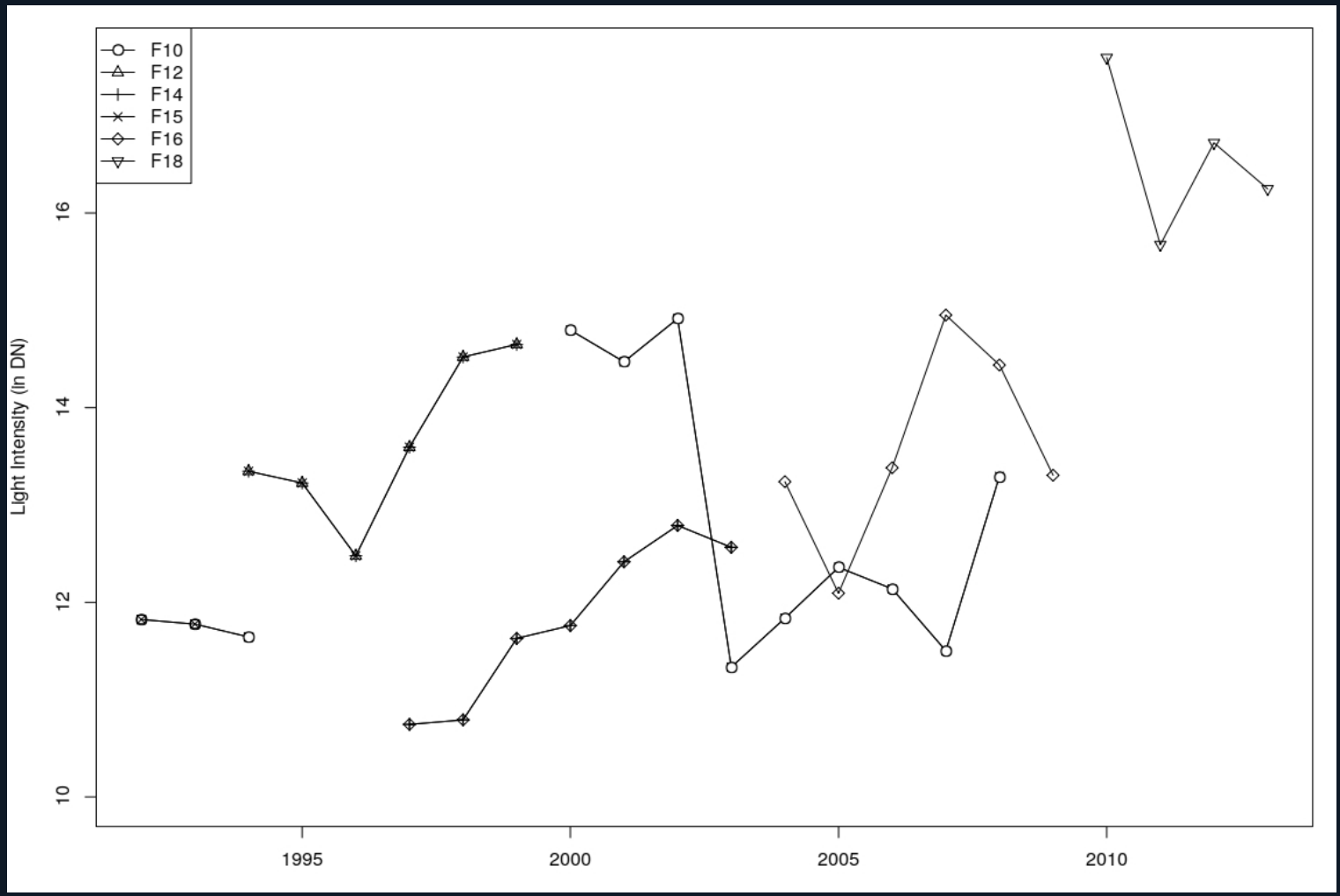
Top coding


(a) New York City
Transect
Saturated
Corrected
Corrected
Saturated
Light intensity (DN)
0
500
1000
1500
2000
−74.4
−74.0
−73.6
−73.2
Longitude
41.2
41.0
40.8
40.6
40.4
40.2
50–63
40–49
30–39
20–29
10–19
1–9
0
250+
64–249
(b) London
52.0
51.8
51.6
51.4
51.2
51.0
50.8
−1.0
−0.5
0.0
0.5

Top coding


(c) New Delhi
Transect
Saturated
Corrected
Corrected
Saturated
Light intensity (DN)
0
500
1000
1500
2000
77.0
77.2
77.4
77.6
Longitude
28.2
28.4
28.6
28.8
50–63
40–49
30–39
20–29
10–19
1–9
0
250+
64–249
(d) Johannesburg
27.6
27.8
28.0
28.2
28.4
−25.8
−26.0
−26.2
−26.4
−26.6

Lack of calibration

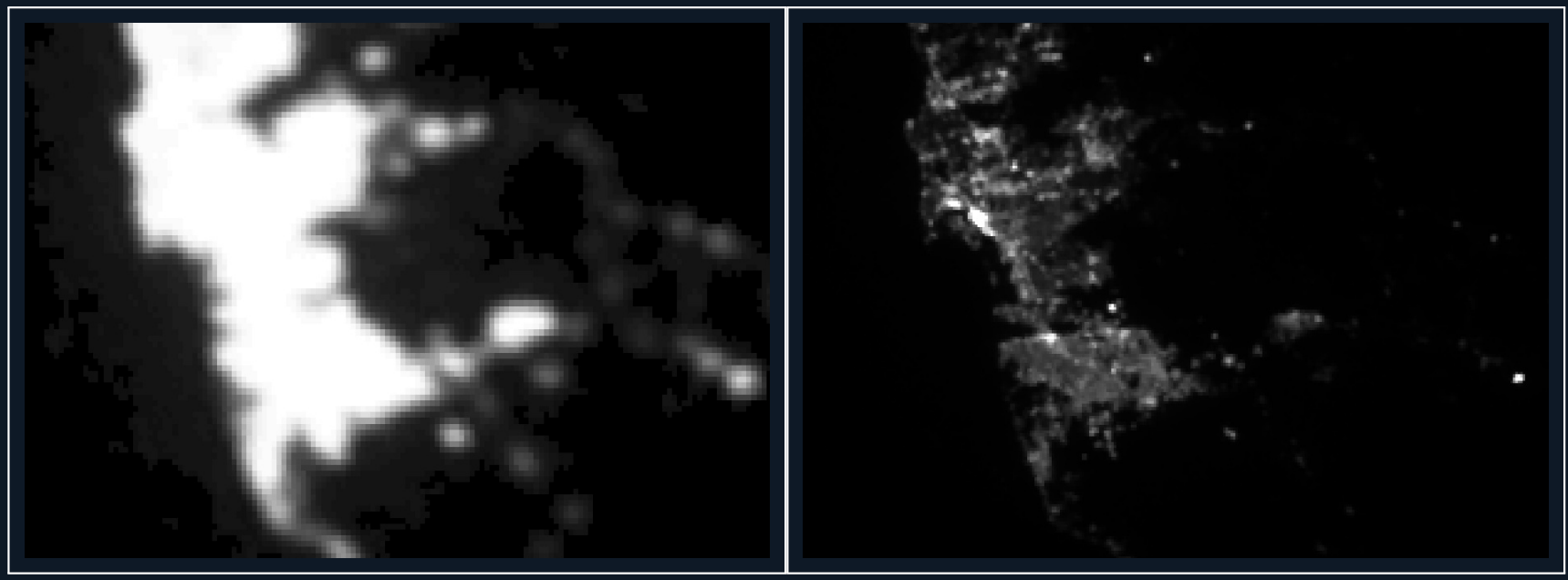


VIIRS to the rescue

VIIRS is a great leap forward relative to DMSP-OLS

- Orbiting since Nov 2011, data from Apr 2012 – today
- Resolution is 500 m, very little overglow
- Low and top light detection has been massively improved
- Sensors are *inter-calibrated* and lunar illumination recorded
- Sensors record a physical unit (radiance in $10^{-9} W/cm^2/sr$)
- Daily data is freely available from NASA DAAC
- Monthly data is freely available from NOAA and GEE
- Only one 2015 annual composite has been produced by NOAA

DMSP-OLS versus VIIRS



(a) DMSP

(b) VIIRS

Recent applications of night lights

Just to name a few:

- City growth, urban expansion and productivity
- Effects of development aid
- Effects of infrastructure projects
- The political economy of regional inequality
- Validating GDP reporting in dictatorships
- Comparing survey versus national accounts data
- Tracking economic loss from wars, earthquakes and other natural or man-made disasters
- Geospatial impact evaluations

Moving to GEE

GEE: DMSP-OLS

DMSP OLS: Nighttime Lights Time Series Version 4, Defense Meteorological Program Operational Linescan System

The Defense Meteorological Program (DMSP) Operational Line-Scan System (OLS) has a unique capability to detect visible and near-infrared (VNIR) emission sources at night.

Version 4 of the DMSP-OLS Nighttime Lights Time Series consists of cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for calendar years. In cases where two satellites were collecting data, two composites were produced.

Resolution
30 arc seconds

Bands

Name	Min	Max	Description
avg_vis	0*	63*	The average of the visible band digital number values with no further filtering.
stable_lights	0*	63*	The cleaned up avg_vis contains the lights from cities, towns, and other sites with persistent lighting, including gas flares. Ephemeral events, such as fires, have been discarded. The background noise was identified and replaced with values of zero.
cf_cvg	0*	126*	Cloud-free coverages tally the total number of observations that went into each 30-arc second grid cell. This band can be used to identify areas with low numbers of observations where the quality is reduced.
avg_lights_x_pct	0*	63*	The average visible band digital number (DN) of cloud-free light detections multiplied by the percent frequency of light detection. The inclusion of the percent frequency of detection term normalizes the resulting digital values for variations in the persistence of lighting. For instance, the value for a light only detected half the time is discounted by 50%. Note that this product contains detections from fires and a variable amount of background noise.

* estimated min or max value

Data availability (time)
Jan 1, 1992 - Jan 1, 2014

Provider
NOAA

Tags
noaa, dmsp, ols, yearly, nighttime, visible, lights, imagery

ImageCollection ID
NOAA/DMSP-OLS/NIGHTTIME_LIGHTS

Open in workspace

GEE: DMSP-OLS radiance calibrated

DMSP OLS: Global Radiance-Calibrated Nighttime Lights Version 4, Defense Meteorological Program Operational Linescan System

The Defense Meteorological Program (DMSP) Operational Line-Scan System (OLS) has a unique capability to detect visible and near-infrared (VNIR) emission sources at night.

This collection contains global nighttime lights images with no sensor saturation. The sensor is typically operated at a high-gain setting to enable the detection of moonlit clouds. However, with six bit quantization and limited dynamic range, the recorded data are saturated in the bright cores of urban centers. A limited set of observations at low lunar illumination were obtained where the gain of the detector was set significantly lower than its typical operational setting (sometimes by a factor of 100). Sparse data acquired at low-gain settings were combined with the operational data acquired at high-gain settings to produce the set of global nighttime lights images with no sensor saturation. Data from different satellites were merged and blended into the final product in order to gain maximum coverage. For more information, see this readme file from the provider.

Resolution
30 arc seconds

Bands

Name	Min	Max	Description
avg_vis	0*	6060.6*	Average digital band numbers from observations with cloud-free light detection.
cf_cvg	0*	175*	Cloud-free coverages, the total number of observations that went into each 30-arc second grid cell. This image can be used to identify areas with low numbers of observations where the quality is reduced.

* estimated min or max value

Data availability (time)
Mar 16, 1996 - Jul 31, 2011

Provider
NOAA

Tags
noaa, dmsp, ols, yearly, nighttime, visible, lights, imagery, calibrated, radiance

ImageCollection ID
NOAA/DMSP-OLS/CALIBRATED_LIGHTS_V4

GEE: VIIRS monthly composite

VIIRS Stray Light Corrected Nighttime Day/Night Band Composites Version 1

Monthly average radiance composite images using nighttime data from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB).

As these data are composited monthly, there are many areas of the globe where it is impossible to get good quality data coverage for that month. This can be due to cloud cover, especially in the tropical regions, or due to solar illumination, as happens toward the poles in their respective summer months. Therefore it is recommended that users of these data utilize the 'cf_cvg' band and not assume a value of zero in the average radiance image means that no lights were observed.

Cloud cover is determined using the VIIRS Cloud Mask product (VCM). In addition, data near the edges of the swath are not included in the composites (aggregation zones 29-32). Version 1 has NOT been filtered to screen out lights from aurora, fires, boats, and other temporal lights. This separation is under development and will be included in a later version of this time series. Also in development is a method to separate lights from background (non-light) values.

This product is an alternative configuration of the VIIRS DNB using a procedure to correct for stray light. The correction procedure extends visible areas closer to the poles and improves dynamic range. It should be noted some artifacts are introduced due to the procedure used in twilight regions; see reference paper for more details. This product excludes data impacted by cloud cover.

Resolution
15 arc seconds

Cadence
1 month

Bands

Name	Units	Min	Max	Description
avg_rad	nanoWatts/cm2/sr	-1.5*	193565*	Average DNB radiance values.
cf_cvg		0*	84*	Cloud-free coverages; the total number of observations that went into each pixel. This band can be used to identify areas with low numbers of observations where the quality is reduced.

* estimated min or max value

Data availability (time)
Jan 1, 2014 - Nov 1, 2019

Provider
NOAA

Tags
noaa, viirs, eog, monthly, stray-light, nighttime, visible, lights, dnb

ImageCollection ID
NOAA/VIIRS/DNB/MONTHLY_V1/VCMSLCFG

Open in workspace

Practice

1. Navigate to Nairobi (1.1° S, 36.95° E) using the function `Map.setCenter()`.
2. Open the image collection: "DMSP OLS: Nighttime Lights Time Series Version 4".
3. Filter the collection to the full year 2008.
4. Select the `stable_lights` band and average the two annual composites.
5. Open the `F182013` image directly, not via the collection.
6. Compute the difference from 2013 to 2008 using `yourimg1.subtract(yourimg2)`.
7. Add the image to the map. What do you think happened over this period in the area from Nairobi to Thika?

The script I

```
// view area from Nairobi to Thika
Map.setCenter(36.95,-1.1, 10);

// get the image collection
var ntl =
    ee.ImageCollection('NOAA/DMSP-OLS/NIGHTTIME_LIGHTS');
print(ntl);

// compute 2008 mean of F15 and F16
var ntl2008 = dataset.filter(
    ee.Filter.date('2008-01-01', '2008-12-31'));
var ntl2008_mean =
    ntl2008.select('stable.lights').mean();
```

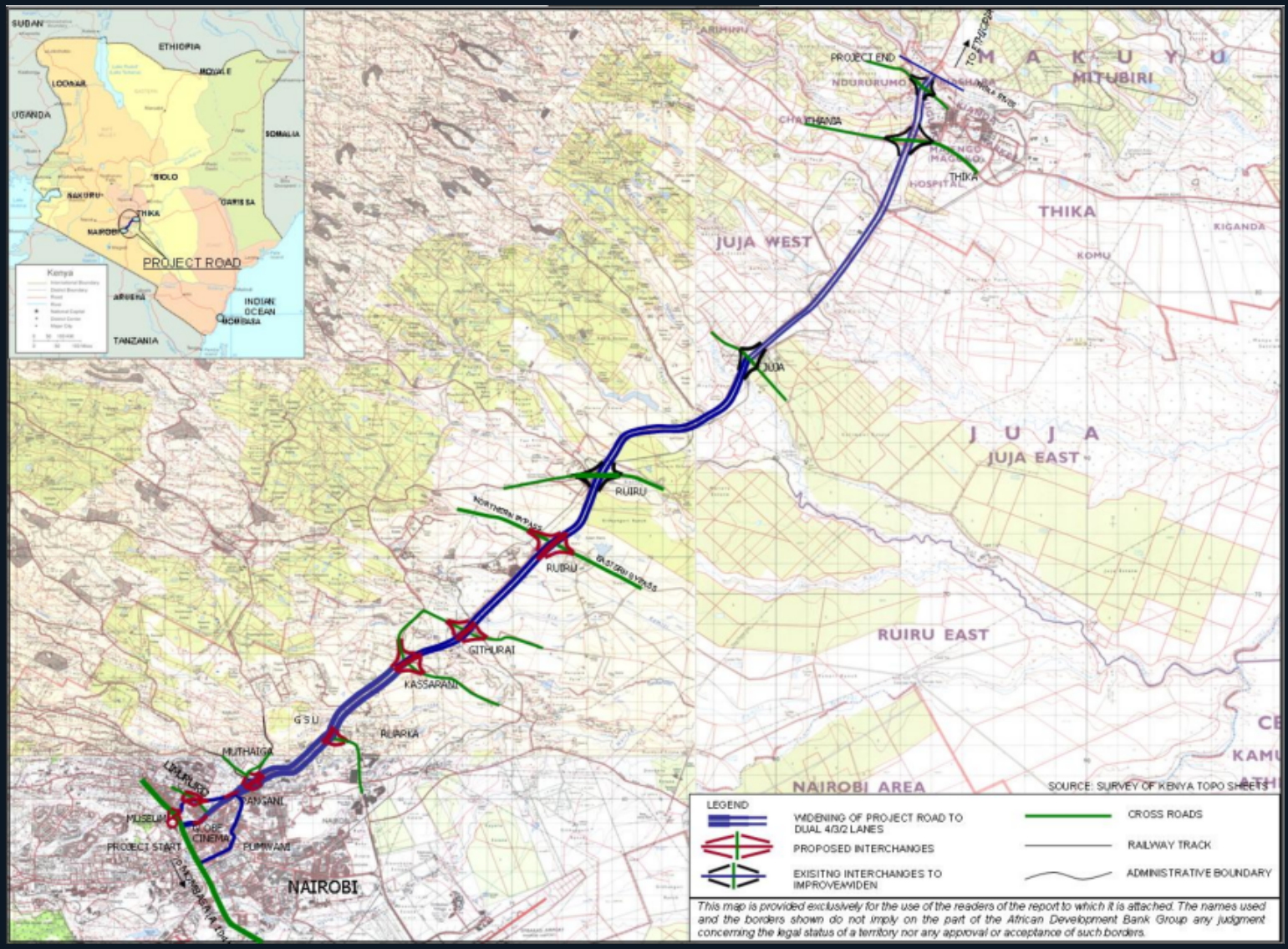
The script II

```
// 2013, only one sat, no averaging required
var ntl2013 =
    ee.Image('NOAA/DMSP-OLS/NIGHTTIME_LIGHTS/F182013');
var ntl2013 = ntl2013.select('stable.lights');
print(ntl2013);

// difference
var ntl_diff = ntl2013.subtract(ntl2008_mean);

// look at the result, scale from 0 to 63
Map.addLayer(ntl_diff, {min: 0, max: 63, opacity: .75});
```

The Nairobi-Thika highway was built



Questions on these materials?

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