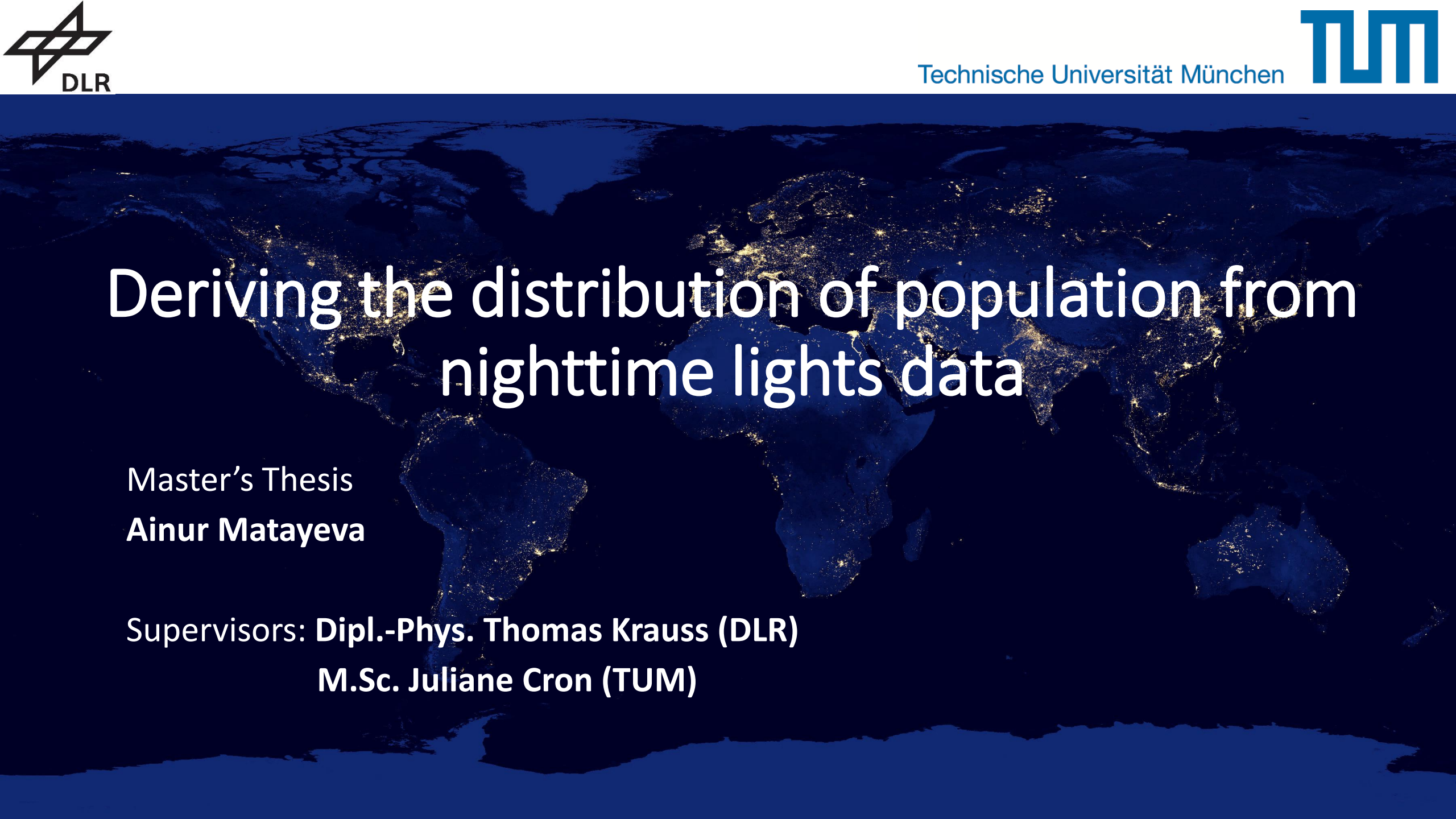


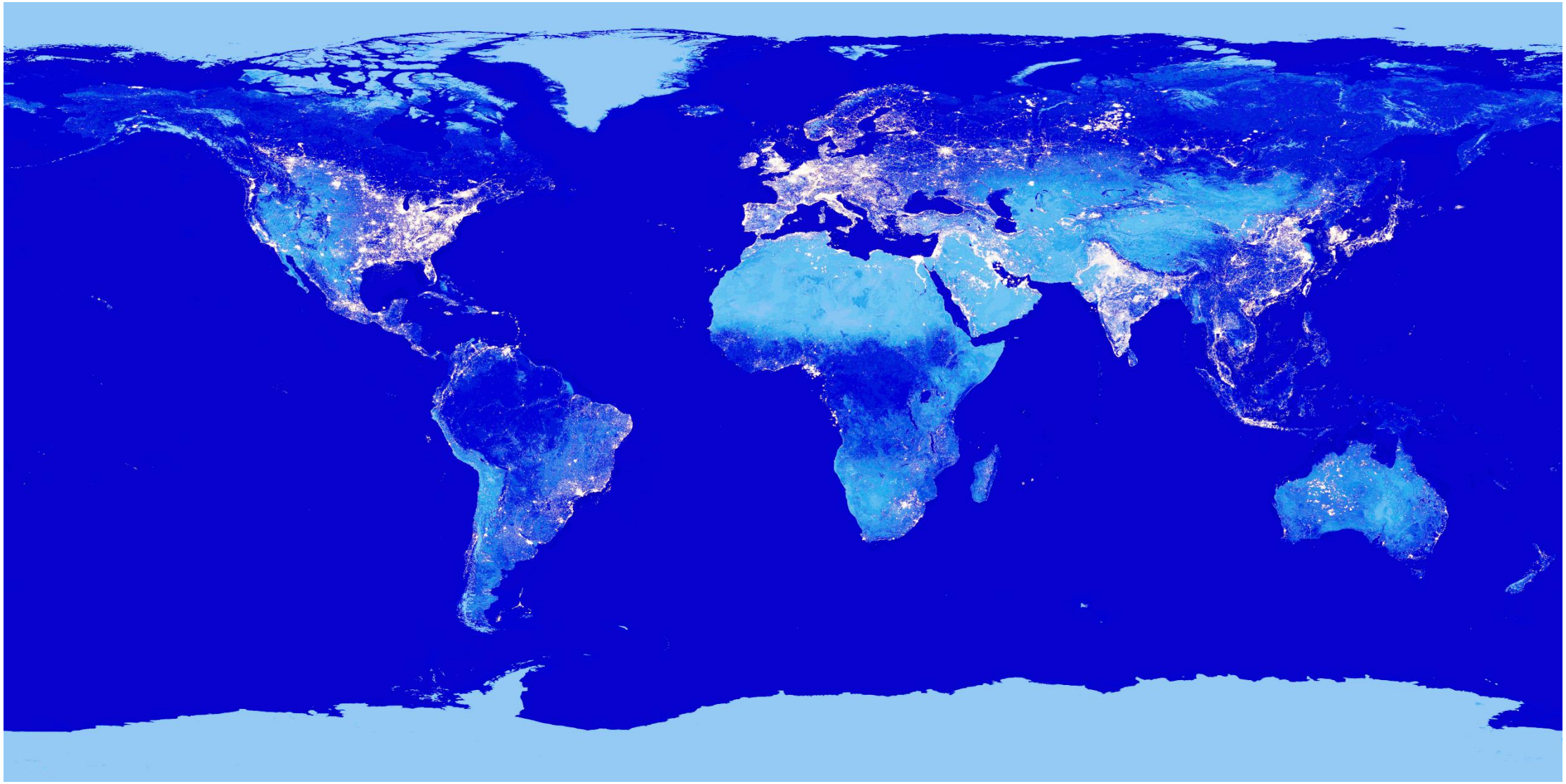
Deriving the distribution of population from nighttime lights data

Master's Thesis

Ainur Matayeva

Supervisors: **Dipl.-Phys. Thomas Krauss (DLR)**

M.Sc. Juliane Cron (TUM)



Source: NOAA/NGDC

Agenda

- Introduction
- Data description
- Methods & Experiments
- Results
- Discussion
- Conclusion and Outlook
- Questions

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- **Introduction**
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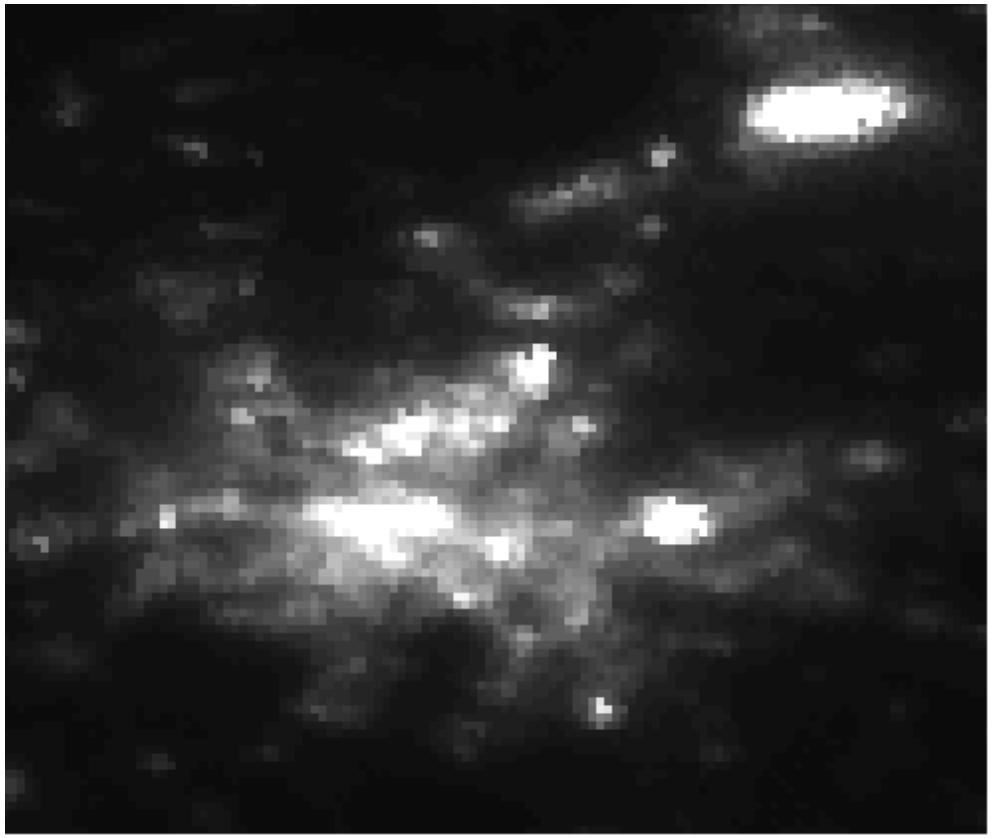
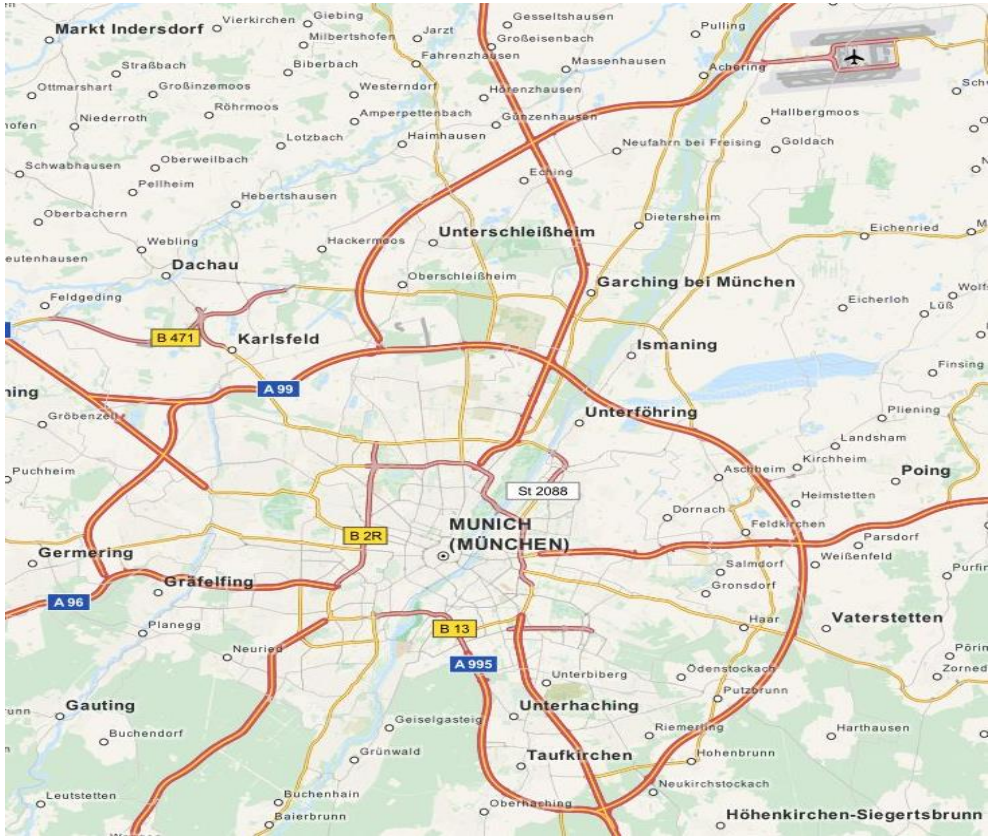
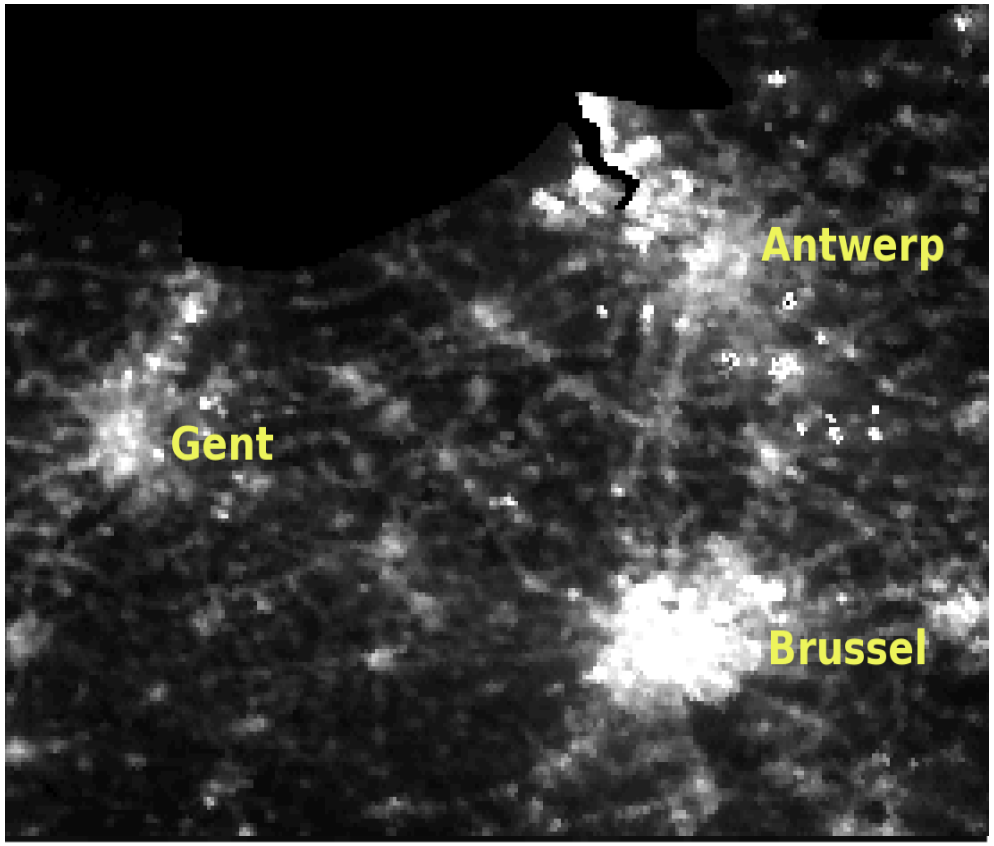
Munich nighttime lights and its overview in OSM

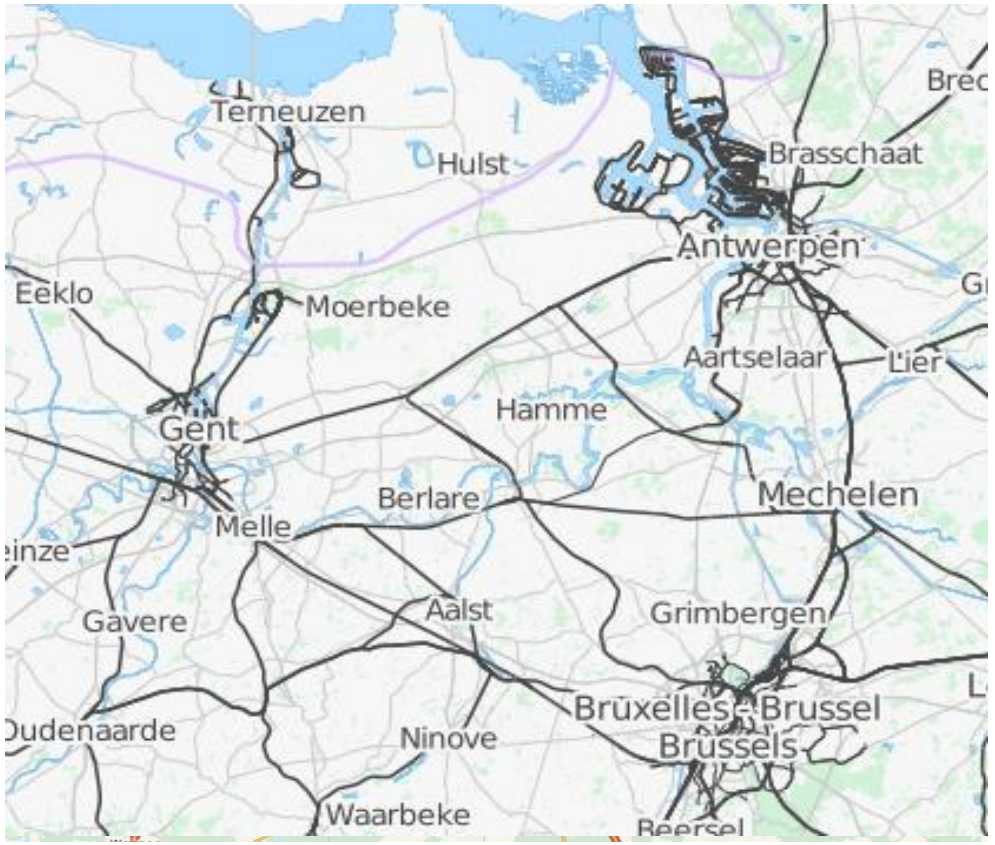


Source: NOAA/NGDC



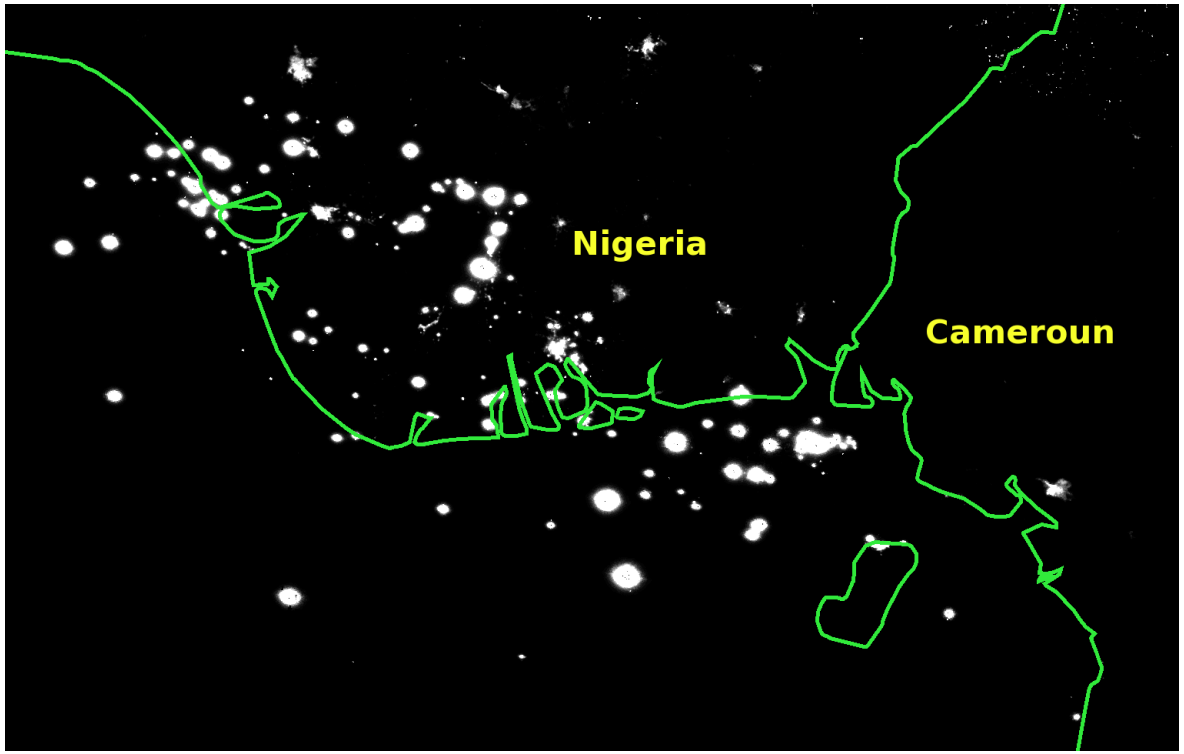
North Belgium nighttime lights and its overview in OSM

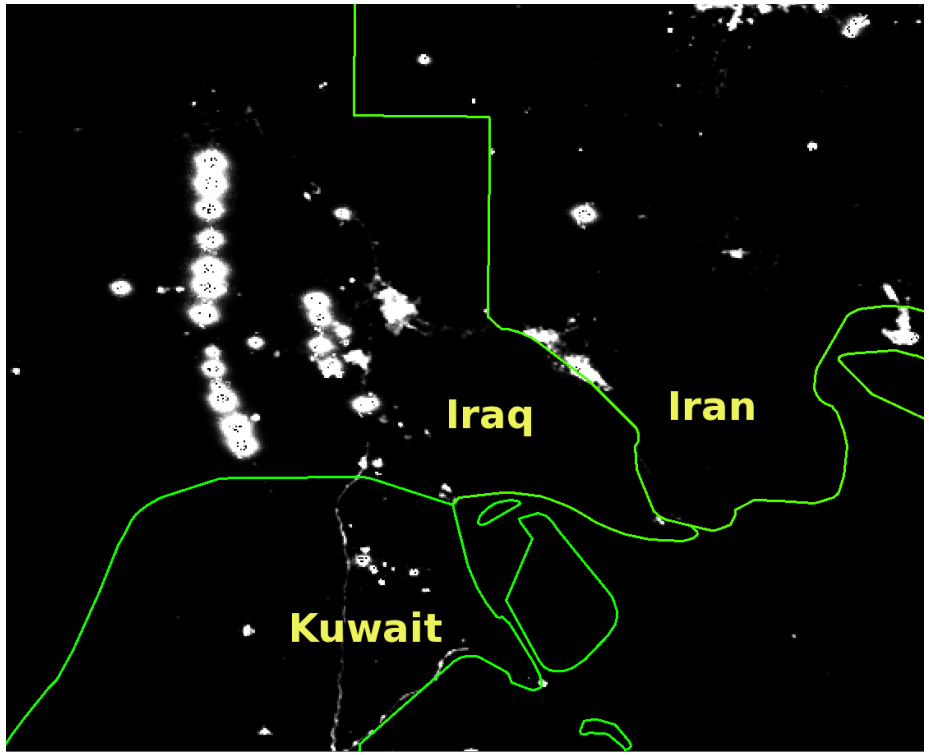




Source: NOAA/NGDC

Gas flares of oil fields

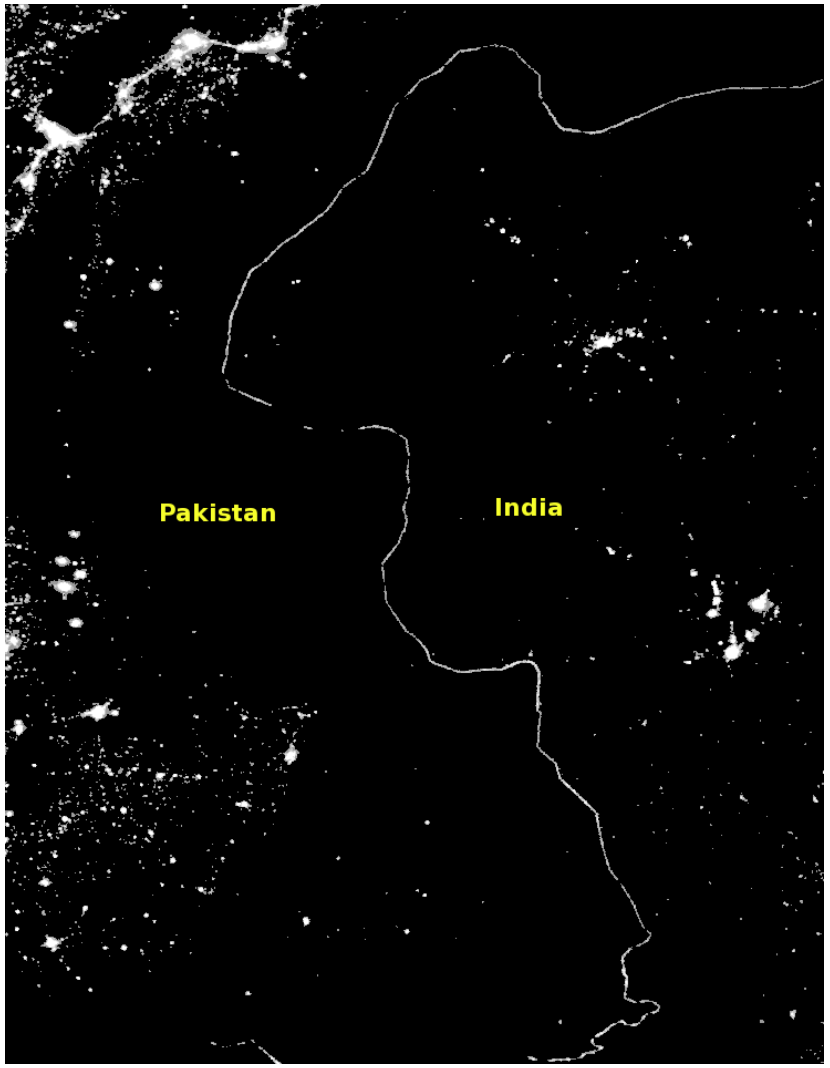




Source: NOAA/NGDC nighttime lights, ESRI shapefile

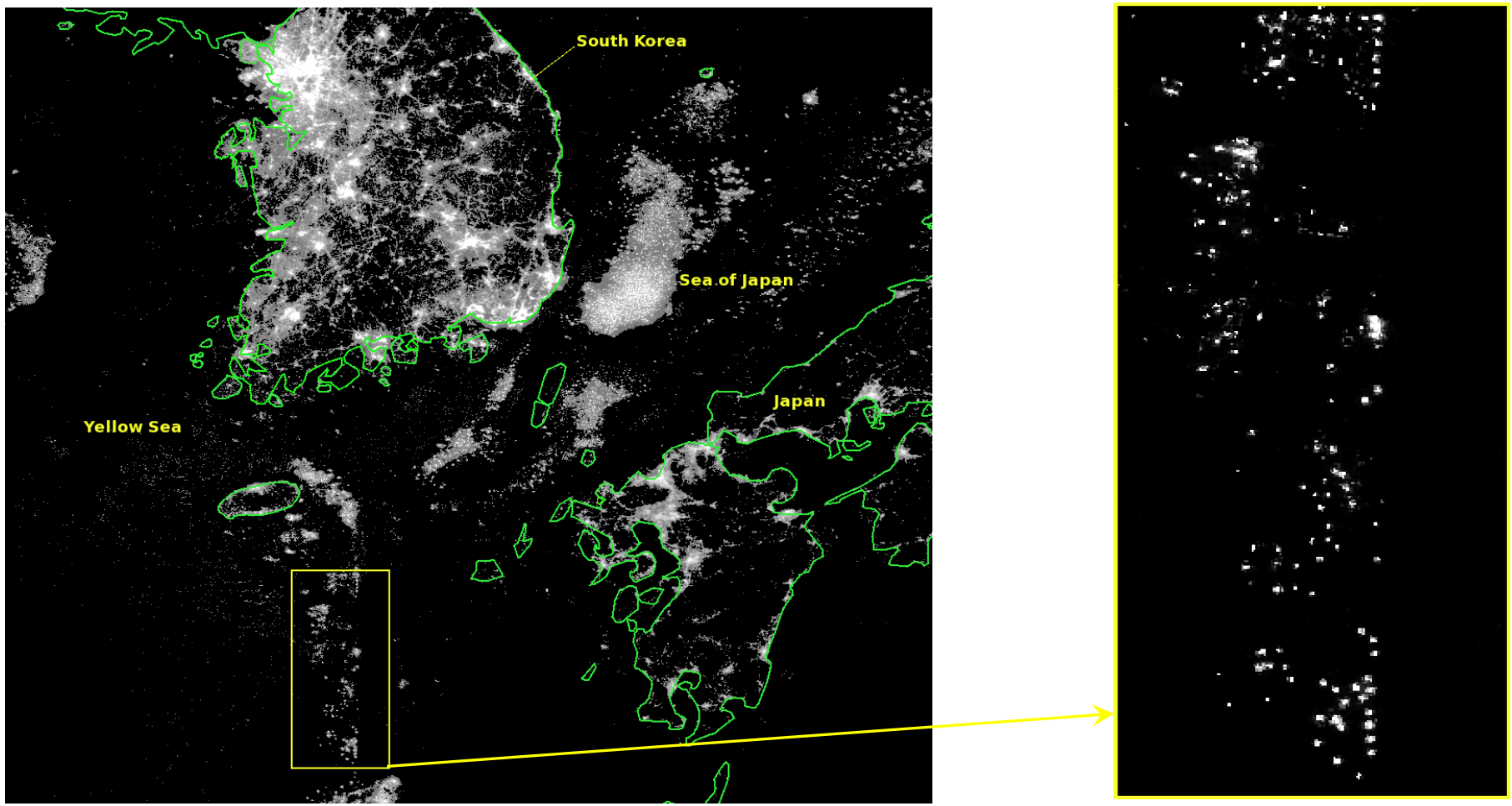
Floodlit border between India and Pakistan

Source: www.dailymail.co.uk; NASA



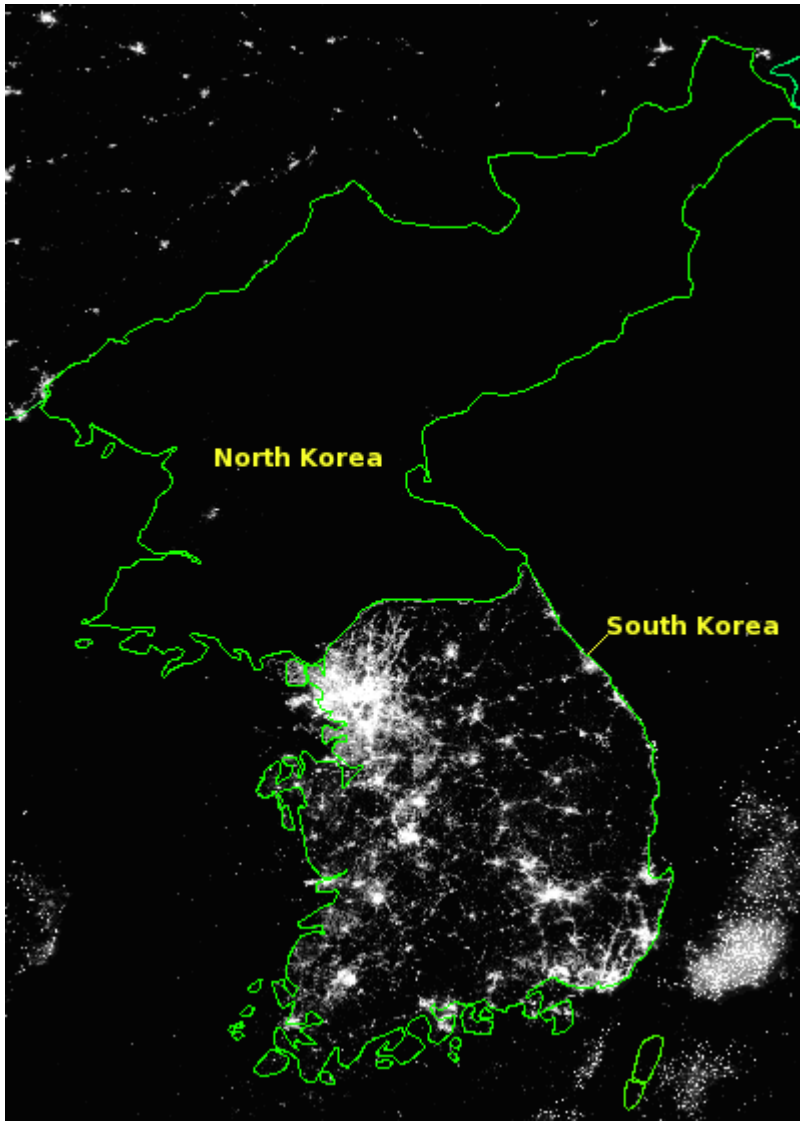
Source: NOAA/NGDC

Fishing boats in the Yellow Sea



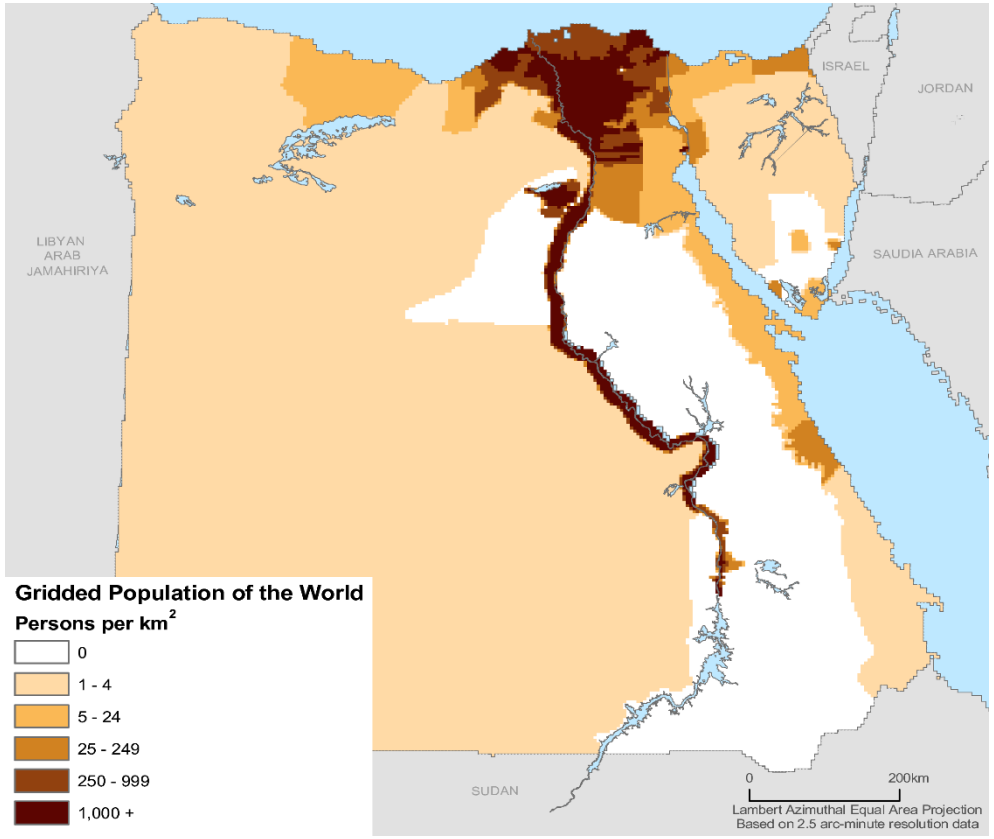
Source: NOAA/NGDC nighttime lights; ESRI shapefile

North and South Korea

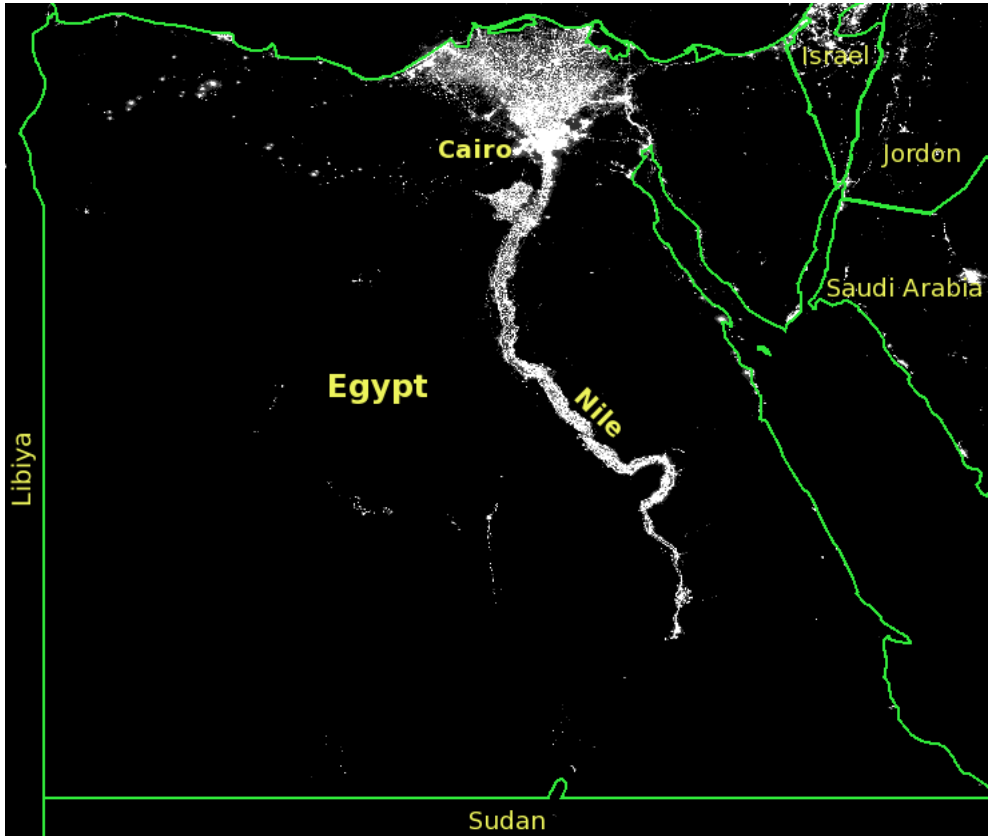


Source: NOAA/NGDC nighttime lights; ESRI shapefile

Egypt. Population density versus Nighttime lights

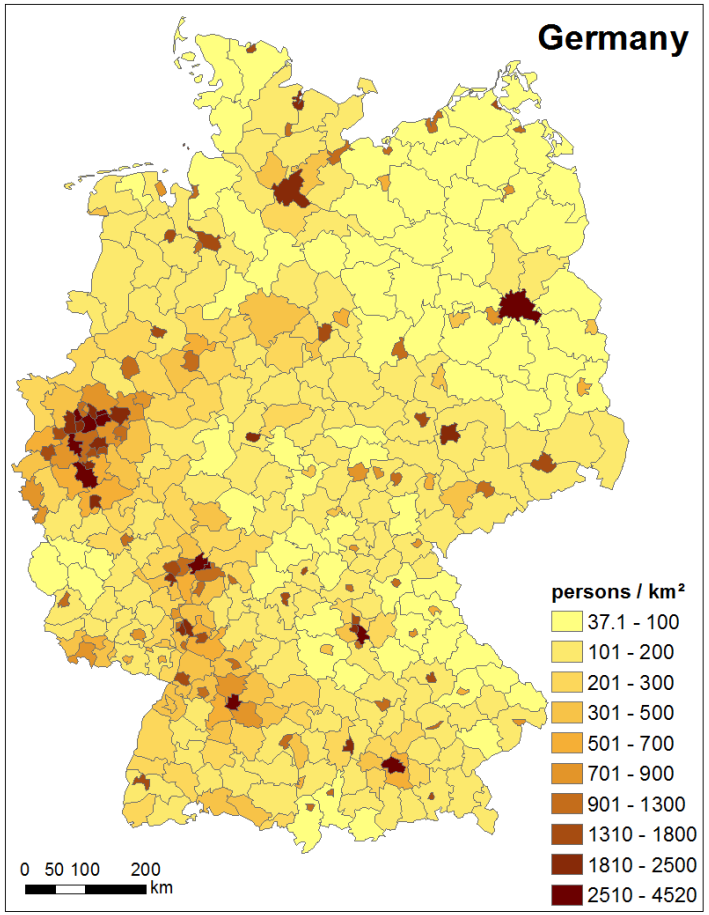


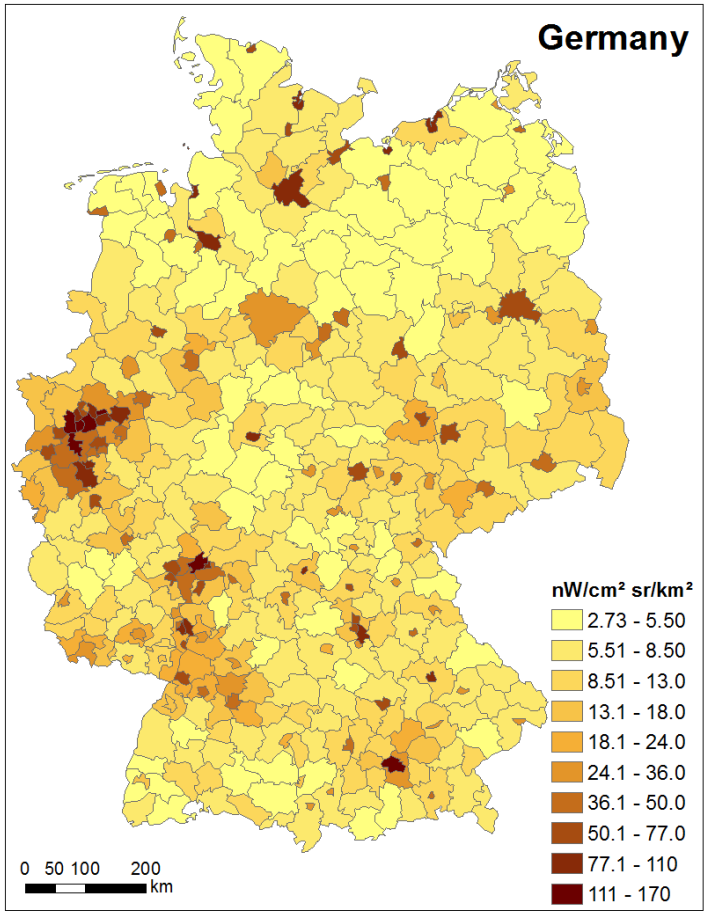
Source: CIESEN



Source: NOAA/NGDC nighttime lights, ESRI shapefile

Population density VS Nighttime lights density





Source: NOAA/NGDC nighttime lights; Naturalearthdata shapefile; Eurostat population data

Agenda

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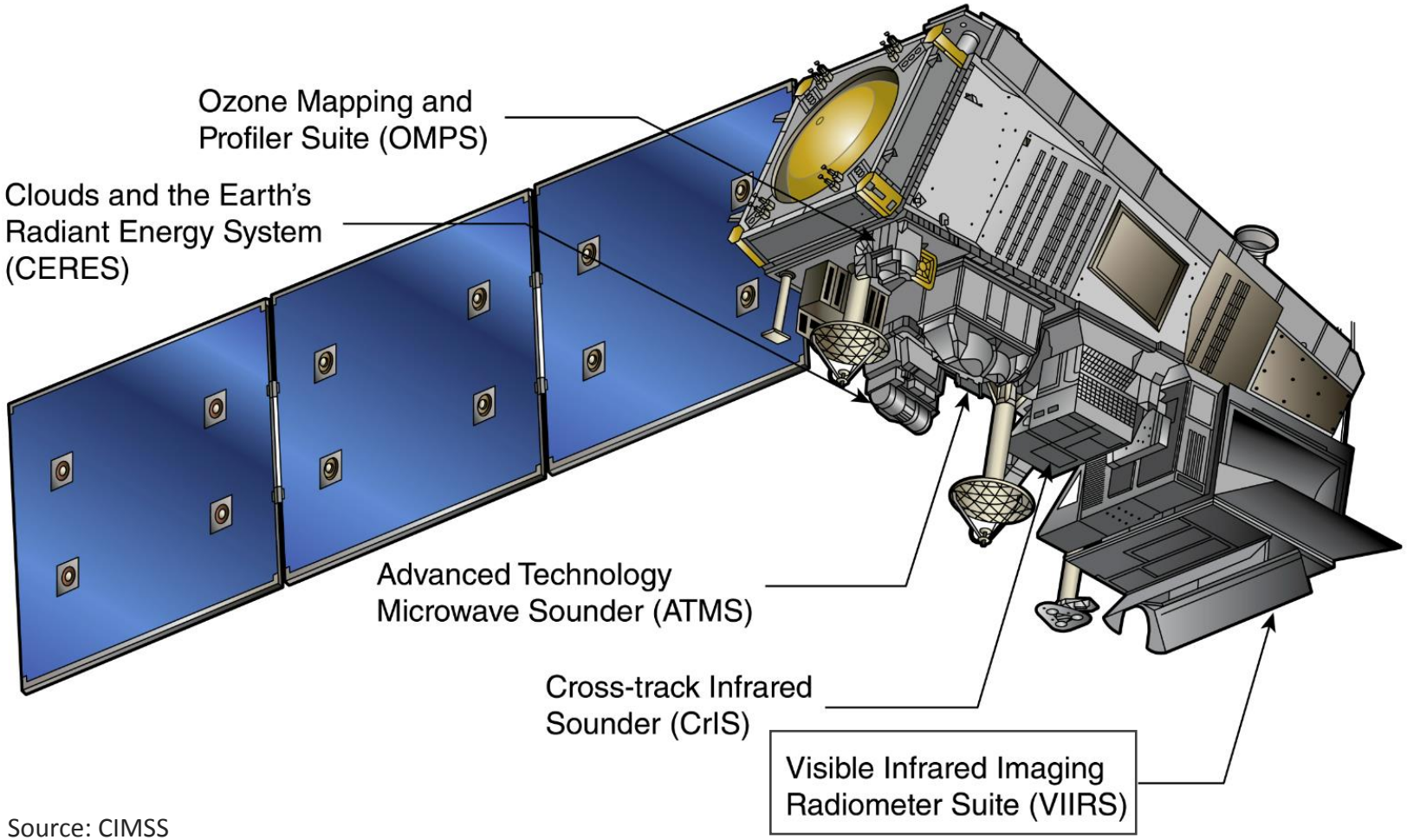
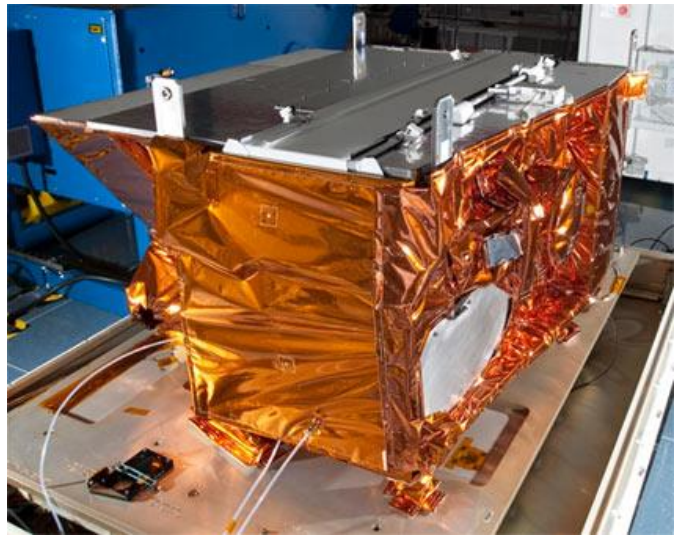
Suomi NPP satellite



Source: CIMSS

VIIRS



Source: NOAA/NGDC

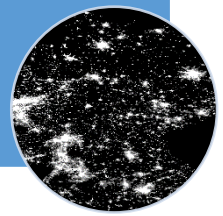
VIIRS DNB

- Cloud free monthly composite of January 2013
- Zero moonlight
- The background noise
- The unit is nano Watts / ($cm^2 * sr$)

The data

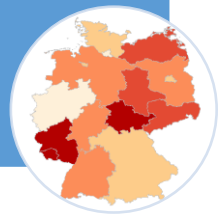
- VIIRS DNB

Nighttime Lights



- ESRI
- Natural earthdata
- Diva-GIS

Shapefiles



- Factbook
- Eurostat
- Other official authorities

Statistics

Agenda

- Introduction
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Finding the best correlation

- Comparison regression types

Population estimation

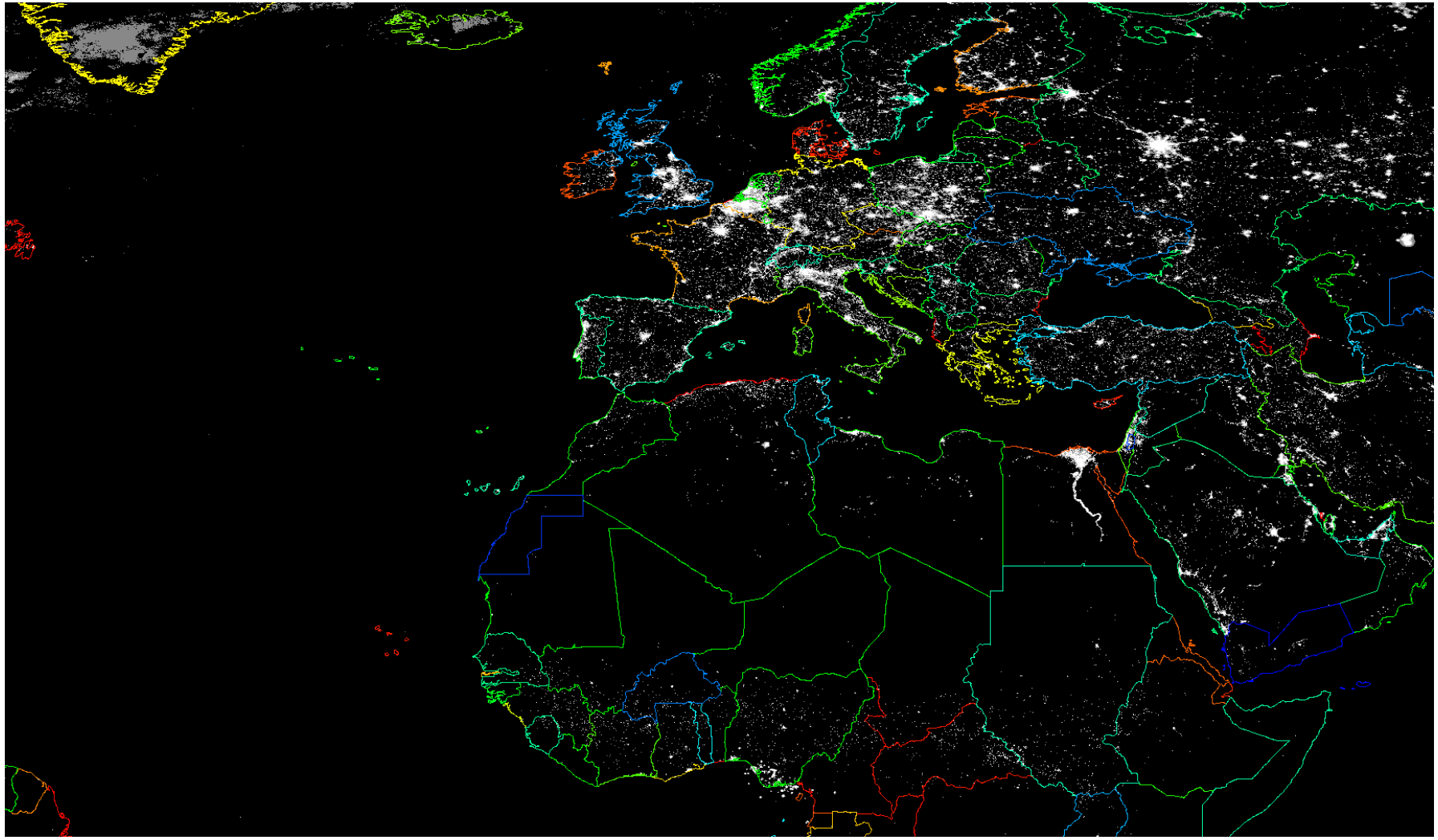
- Method 1 using NTL intensity
- Method 2 using NTL density

Nighttime light density

$$\lambda = L / A$$

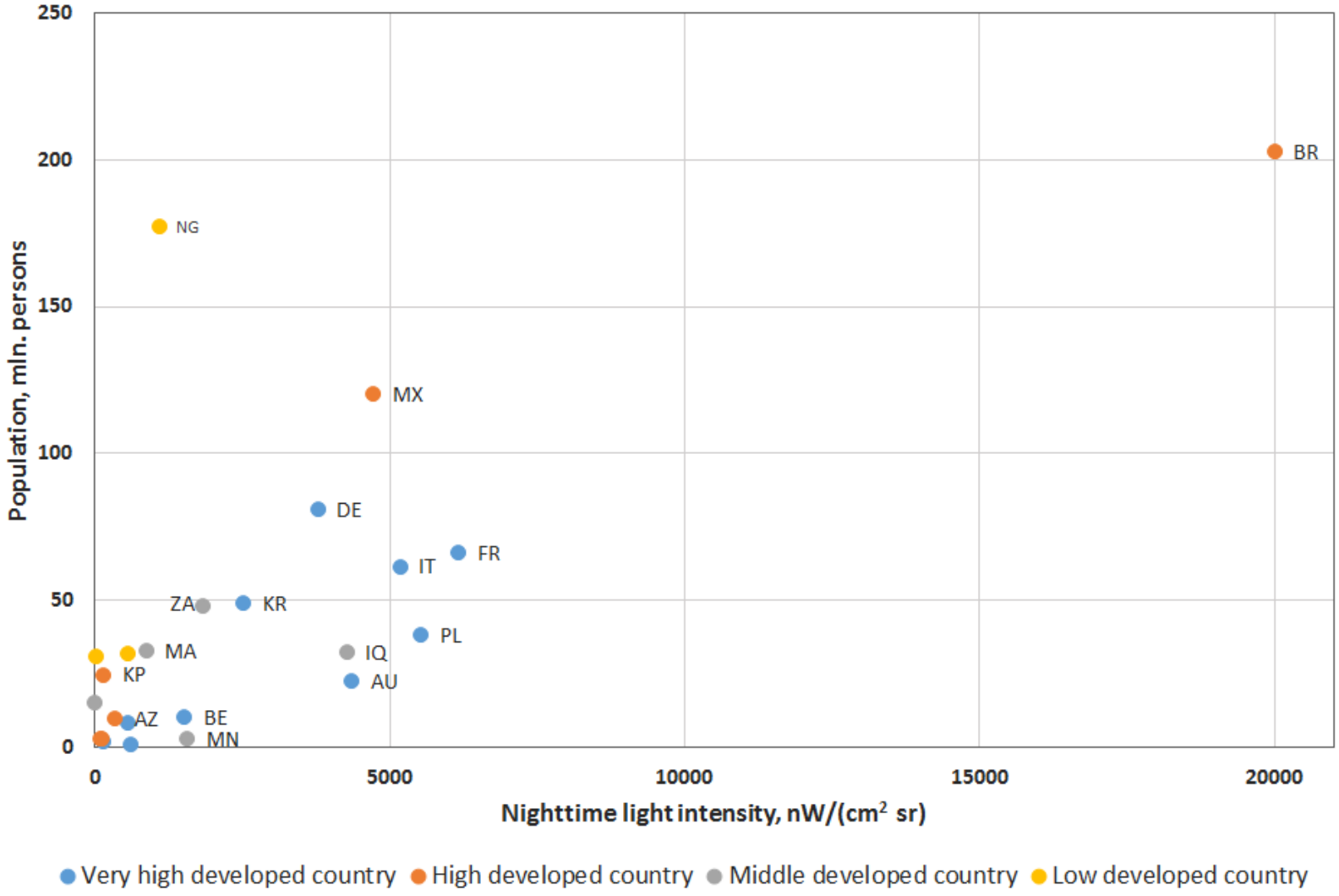
where,
λ - nighttime light density, nano Watts/($cm^2 * sr * km^2$),
L - nighttime light intensity, nano Watts/($cm^2 * sr$),
A - area of an administrative unit, km^2

Tile 2 with country borders

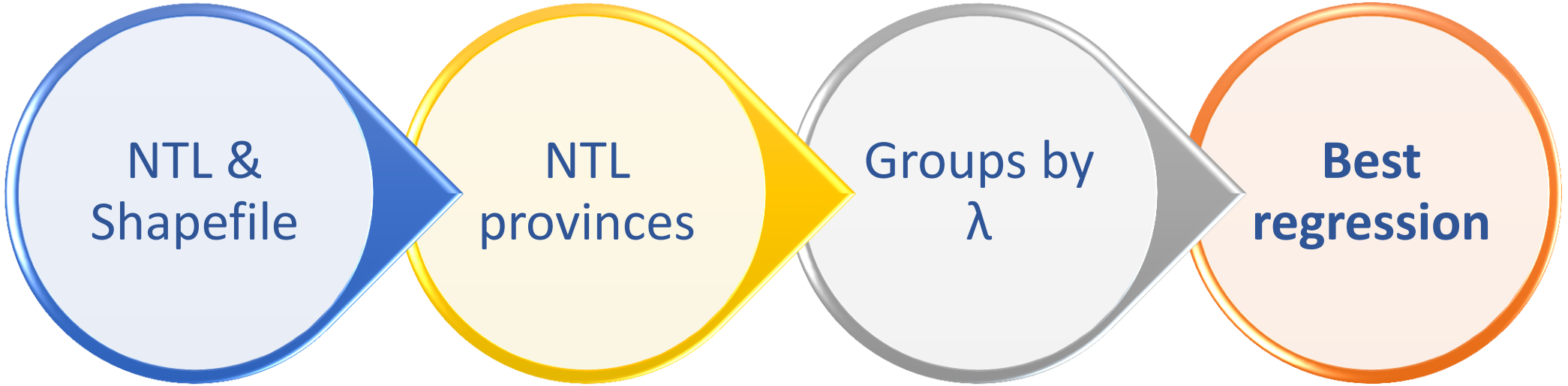


Source: NOAA/NGDC Nighttime lights image, ESRI shapefile

NTL versus Population



Finding the best correlation



- Masking
- Apply mask

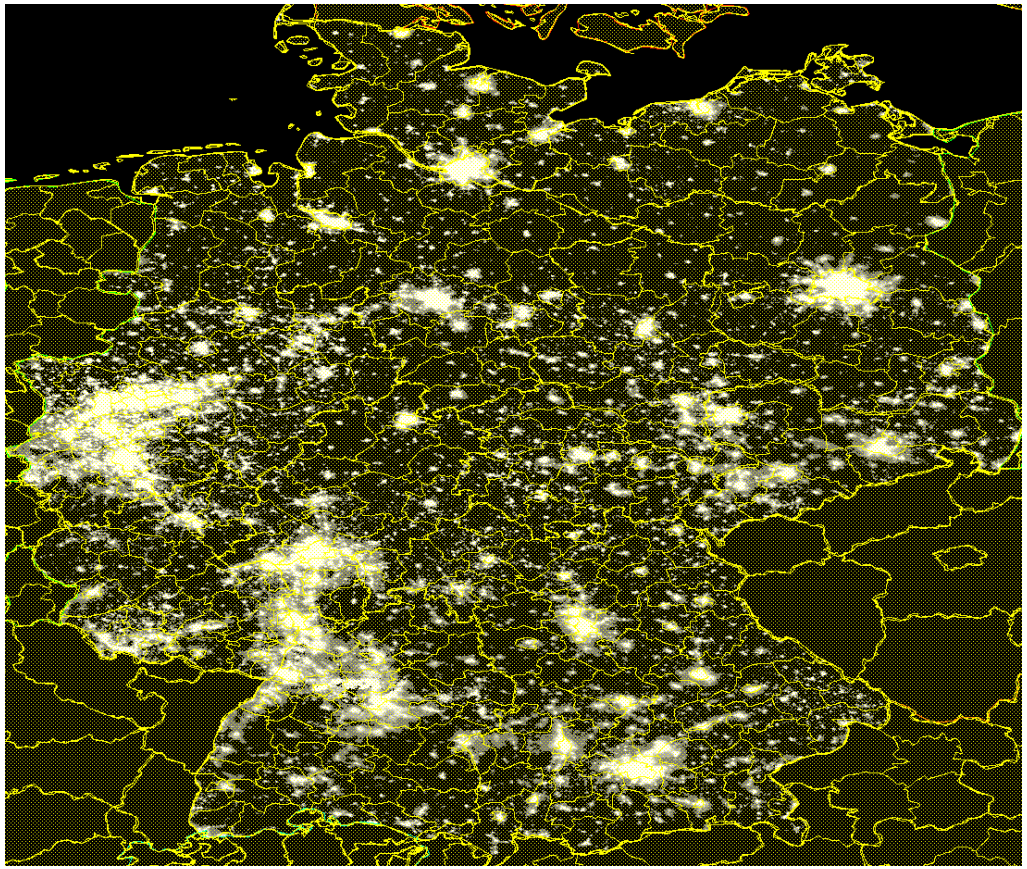
- Grouping by λ

- Scatter plot
- Population vs NTL

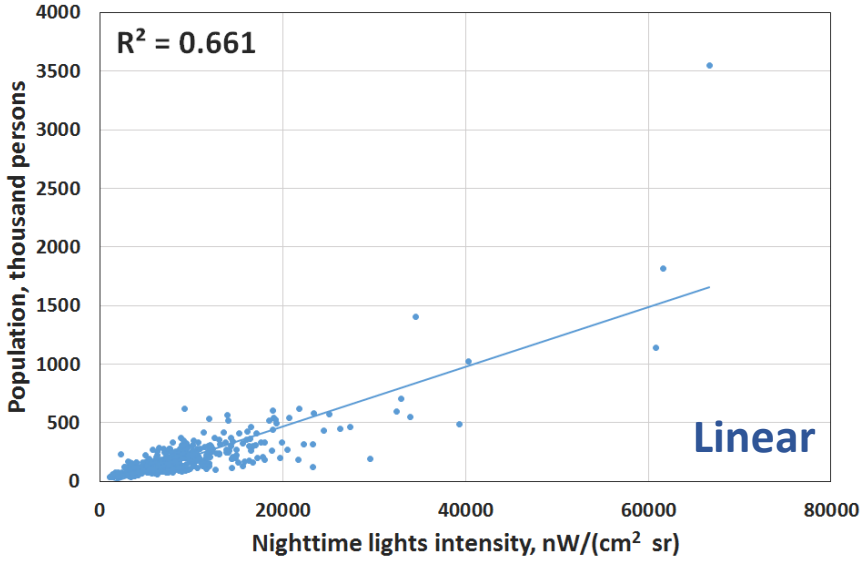
- Linear
- Logarithmic
- Exponential
- Power

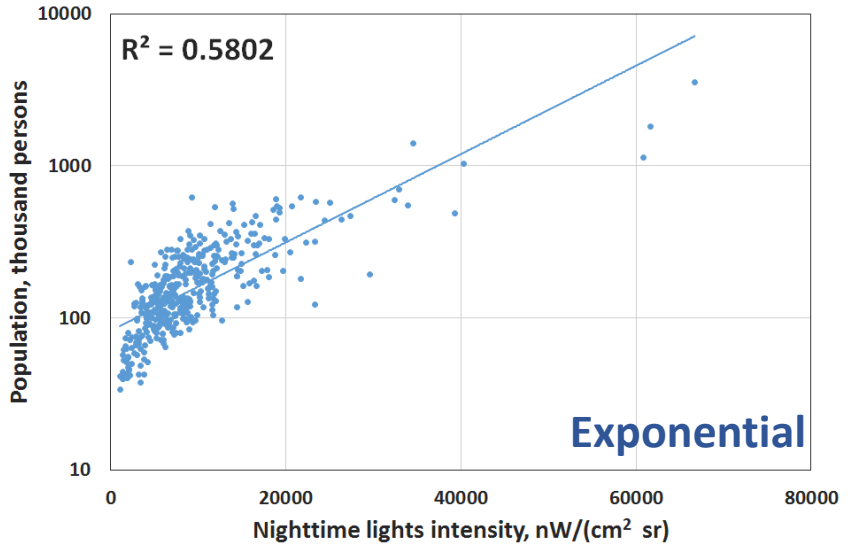
Nighttime lights of Germany

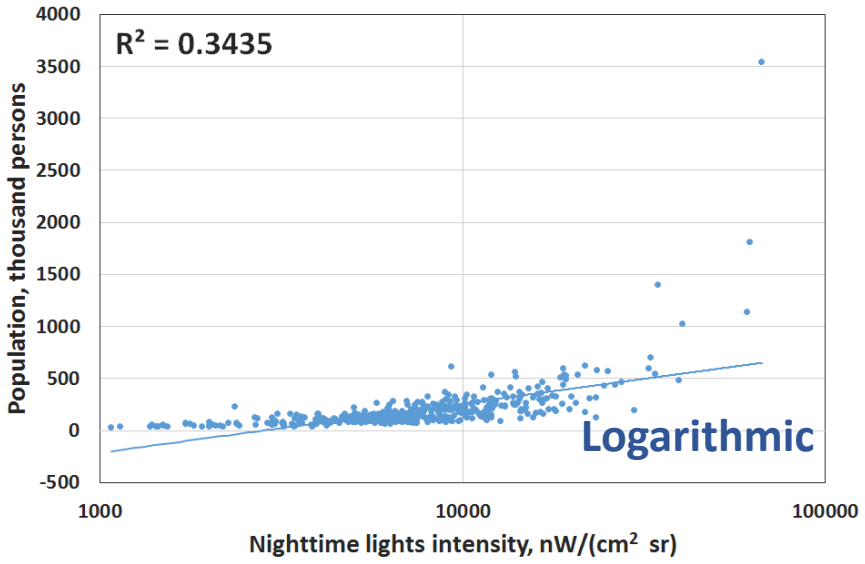
District (NUTS3) borders of Germany

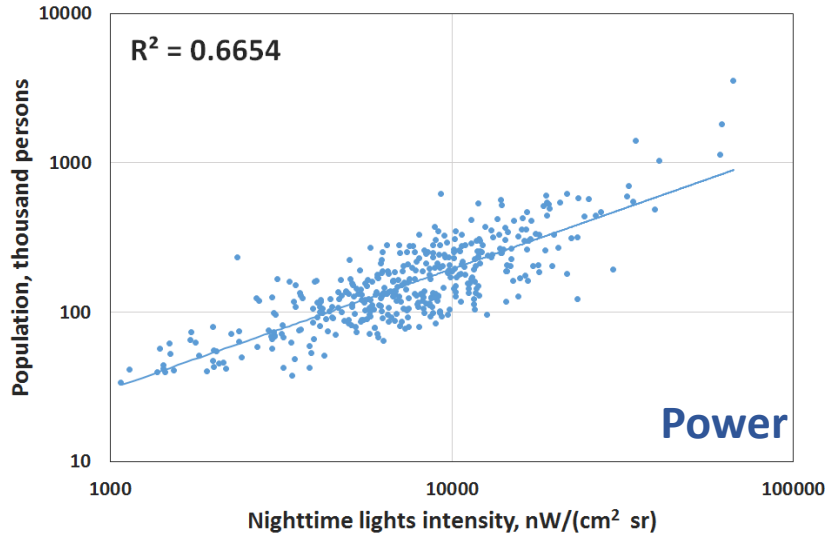


Source: NOAA/NGDC Nighttime lights image, naturalearthdata shapefile

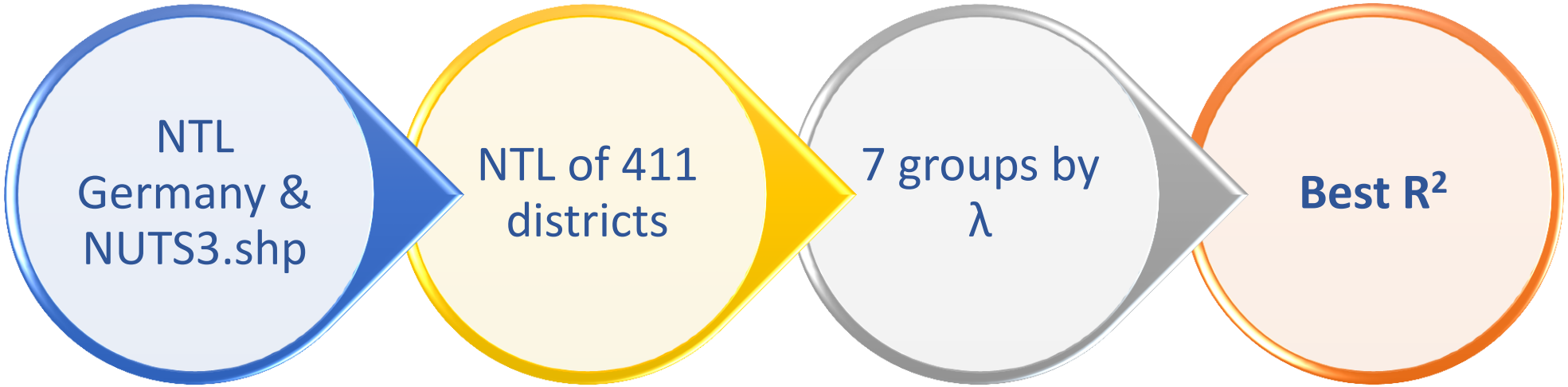

R² = 0.661
Linear
Population, thousand persons
Nighttime lights intensity, nW/(cm² sr)
4000
3500
3000
2500
2000
1500
1000
500
0
0
20000
40000
60000
80000


R² = 0.5802
Exponential
Population, thousand persons
Nighttime lights intensity, nW/(cm² sr)
10000
1000
100
10
0
20000
40000
60000
80000


R² = 0.3435
Logarithmic
Population, thousand persons
Nighttime lights intensity, nW/(cm² sr)
4000
3500
3000
2500
2000
1500
1000
500
0
-500
1000
10000
100000


R² = 0.6654
Power
Population, thousand persons
Nighttime lights intensity, nW/(cm² sr)
10000
1000
100
10
1000
10000
100000

Comparing regression types



- Districts masking
- Apply masks

- **Grouping by λ:**
- 2<λ<5
- 5<λ<7
- 7<λ<9
- 9<λ<13
- 13<λ<25
- 25<λ<50
- 50<λ<170

- Scatter plot
- Population vs NTL

- <R^2> Lin.=0.44
- <R^2> Log.=0.40
- <R^2> Exp.=0.43
- **<R^2>Power=0.53**

Correlation coefficients of compared regressions

λ range	Average λ	R^2 linear	R^2 logarithmic	R^2 exponential	R^2 power
2-170		0.66	0.34	0.58	**0.67**
2-5	3.5	0.12	0.13	0.13	**0.15**
5-7	6	0.25	0.28	0.29	**0.34**
7-9	8	0.32	0.35	0.34	**0.38**
9-13	11	0.44	0.41	0.45	**0.48**
13-25	19	0.37	0.43	0.44	**0.65**
25-50	37.5	0.82	0.72	0.60	**0.84**
50-170	110	0.77	0.51	0.78	**0.87**

Population estimation

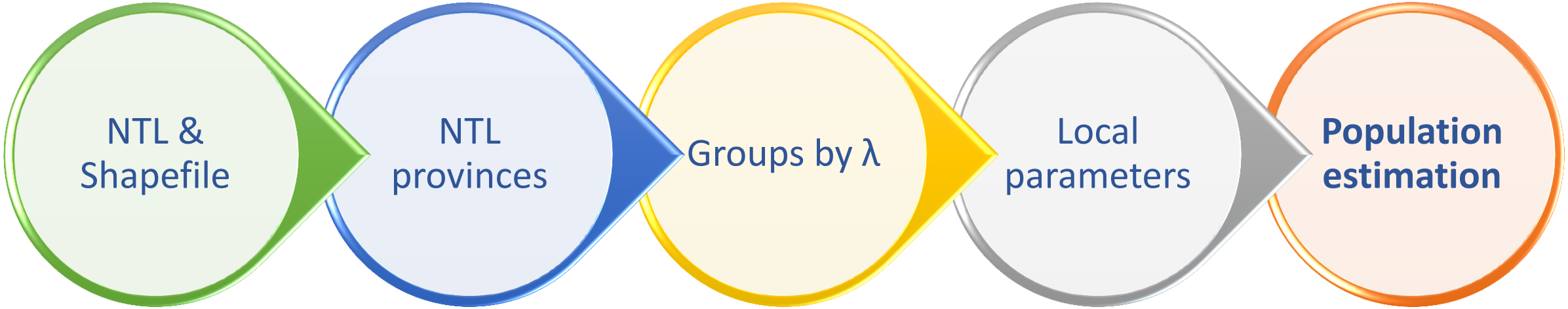
Method 1

- Population estimation using NTL **intensity**

Method 2

- Population estimation using NTL **density**

Deriving the population distribution



- Mask
- Apply mask

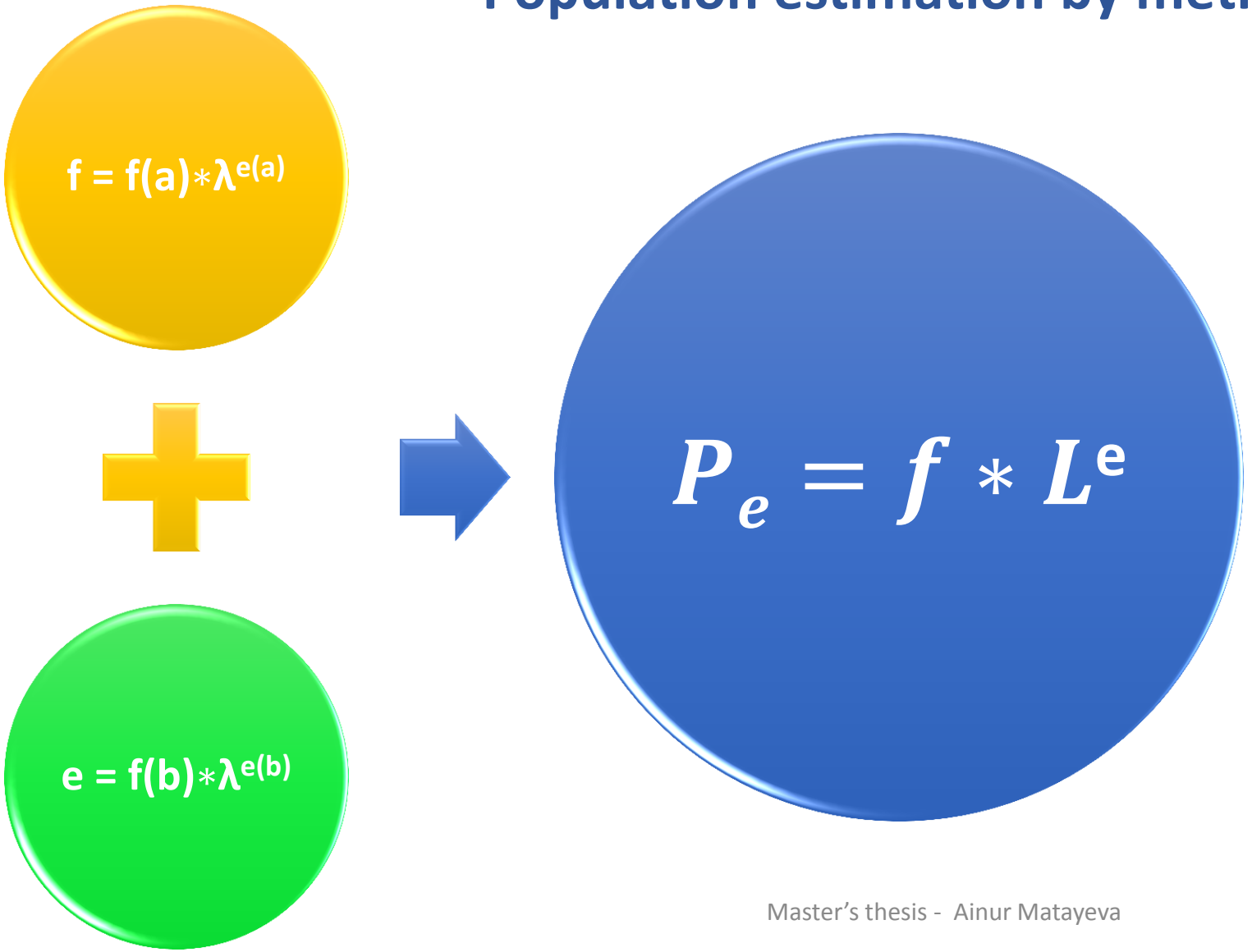
- Grouping by λ

- Scatter plot
- Population vs NTL
- Power regression

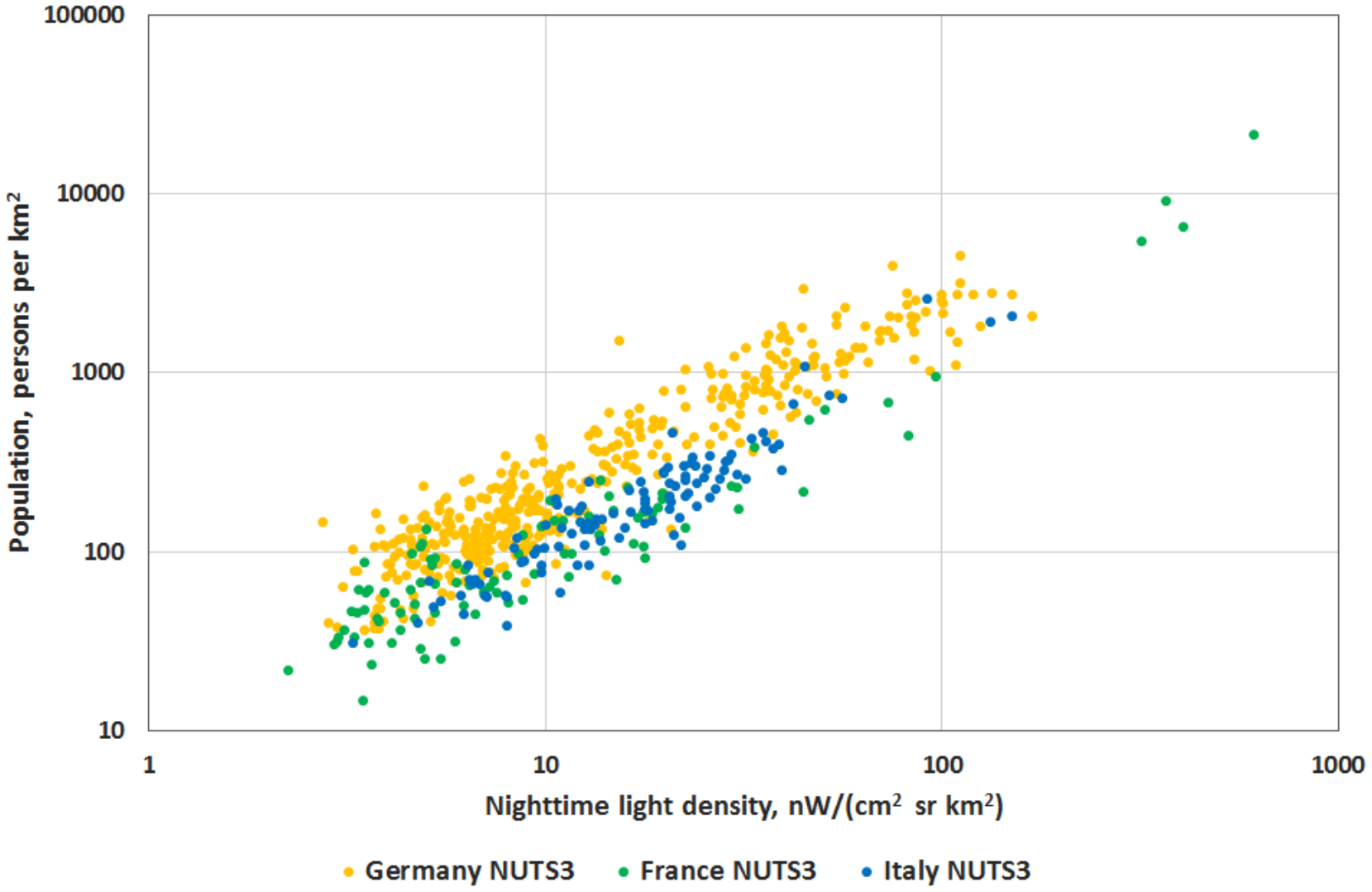
- Factor
- Exponent

- Derived equation

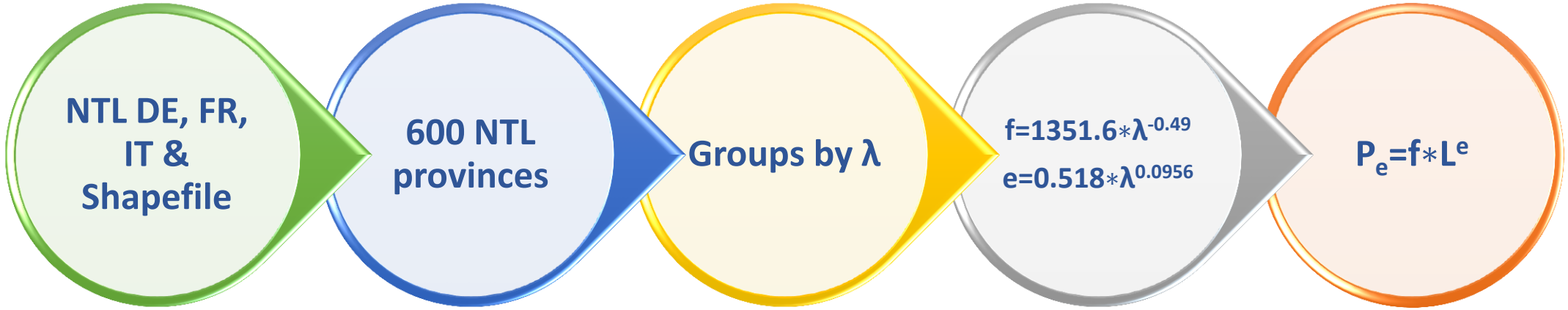
Population estimation by method 1



where,
P_e – estimated population
λ - nighttime light density
L - nighttime light intensity
f – factor
f(a) – factor to calculate f
e(a) – exponent to calculate f
e – exponent
f(b) – factor to calculate e
e(b) – exponent to calculate e


100000
10000
1000
100
10
Population, persons per km²
1
10
100
1000
Nighttime light density, nW/(cm² sr km²)
Germany NUTS3
France NUTS3
Italy NUTS3

Method 1 using NTL intensity



- Mask
- Apply mask

- λ < 100

Grouping by λ:

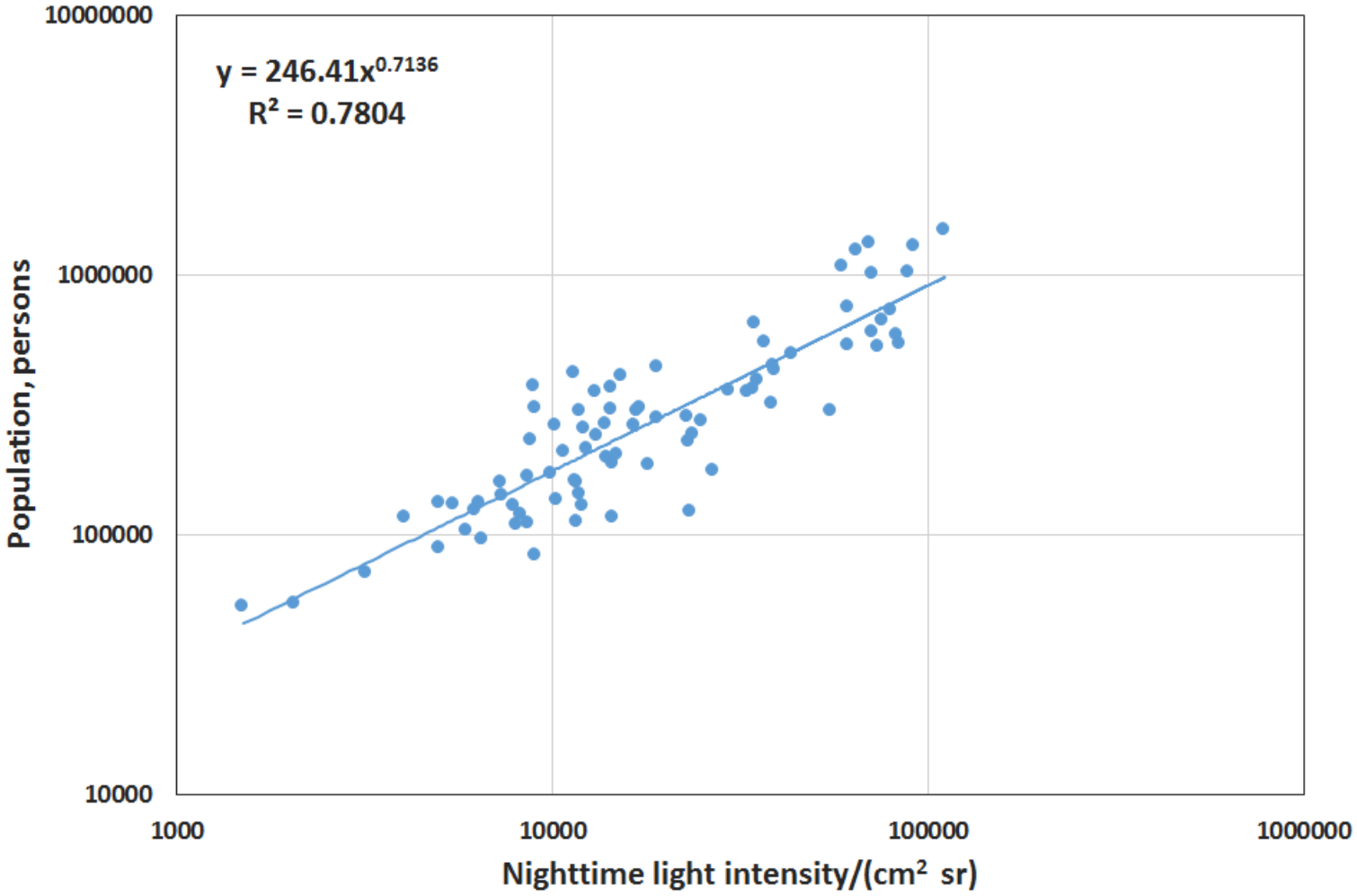
- 2<λ<5
- 5<λ<7
- 7<λ<10
- 10<λ<15
- 15<λ<25
- 25<λ<40
- 40<λ<100

- Scatter plot
- Population vs NTL
- Power regression

- Factor
- Exponent

- Population estimation

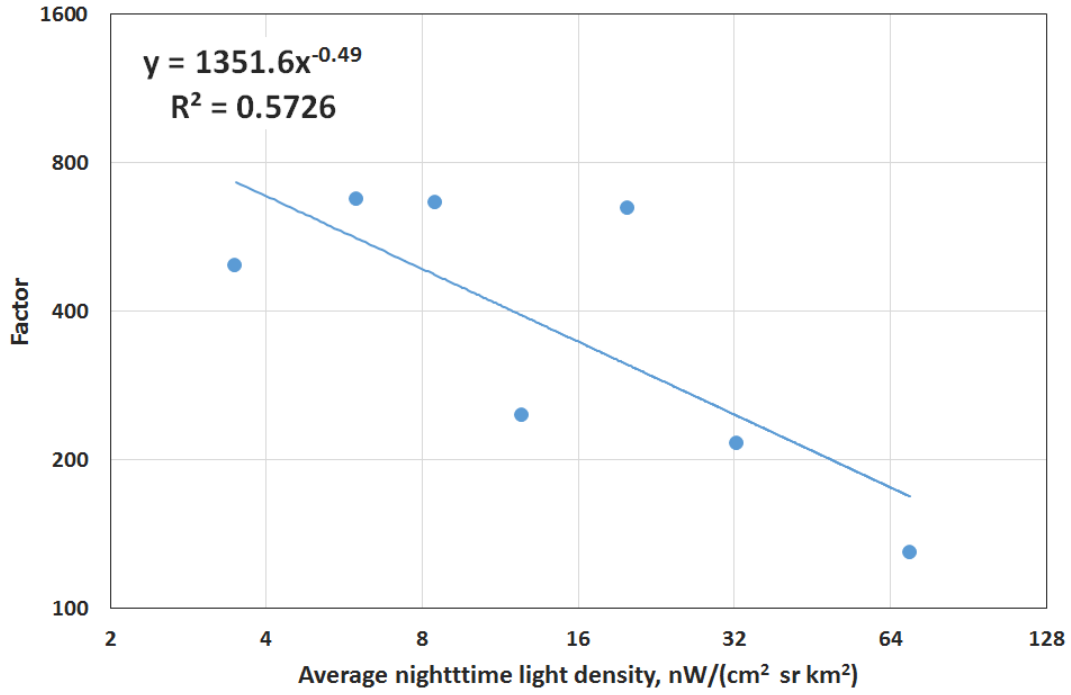
Example of extracting a factor and an exponent values from group 10<λ<15

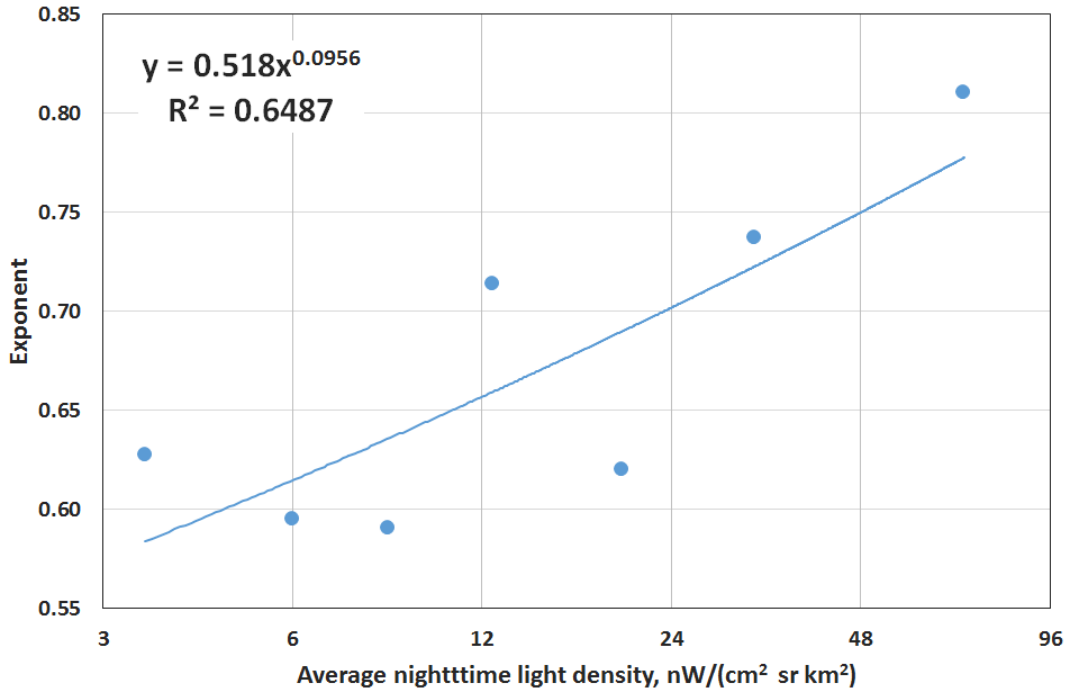


All extracted factors and exponents values

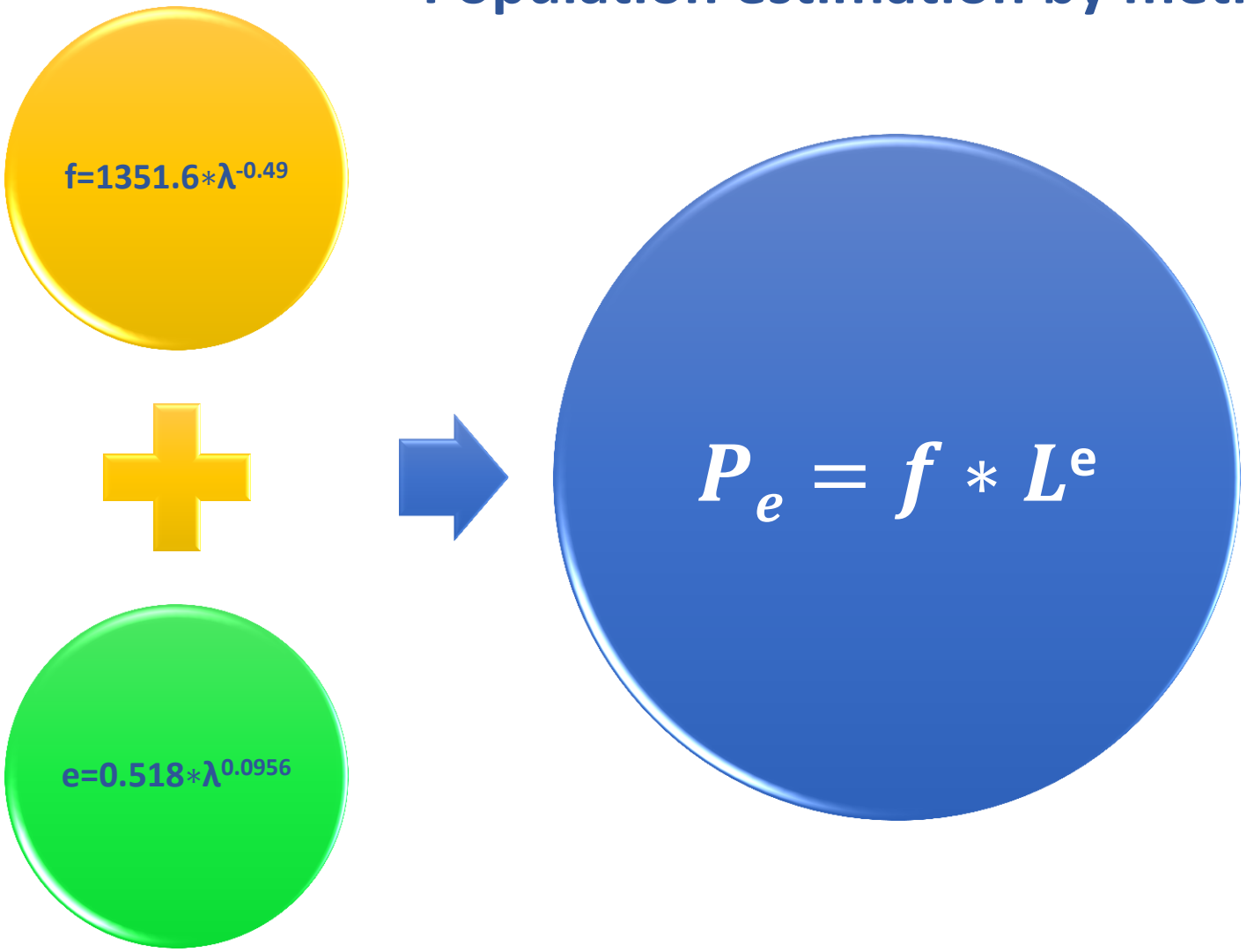
average λ of a group	3.5	6	8.5	12.5	20	32.5	70
factor	494.4	673.63	663.19	246.41	645.89	215.78	129.33
exponent	0.6277	0.5953	0.5906	0.7136	0.6201	0.7371	0.8103

Deriving a factor and an exponent by method 1



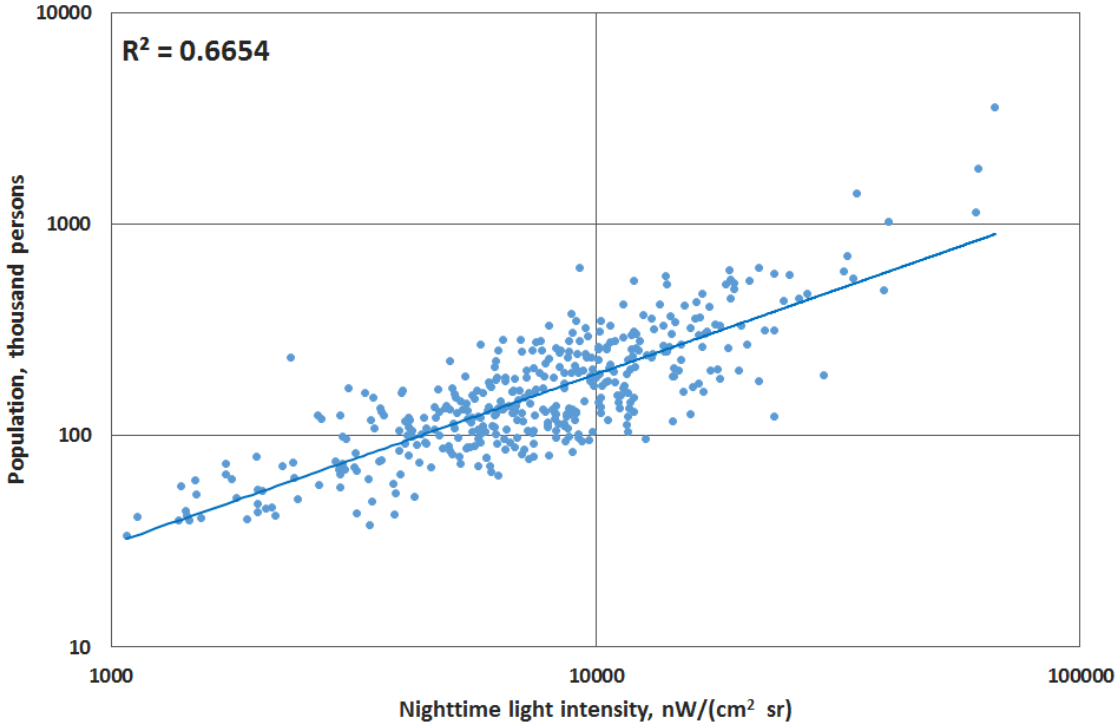


Population estimation by method 1

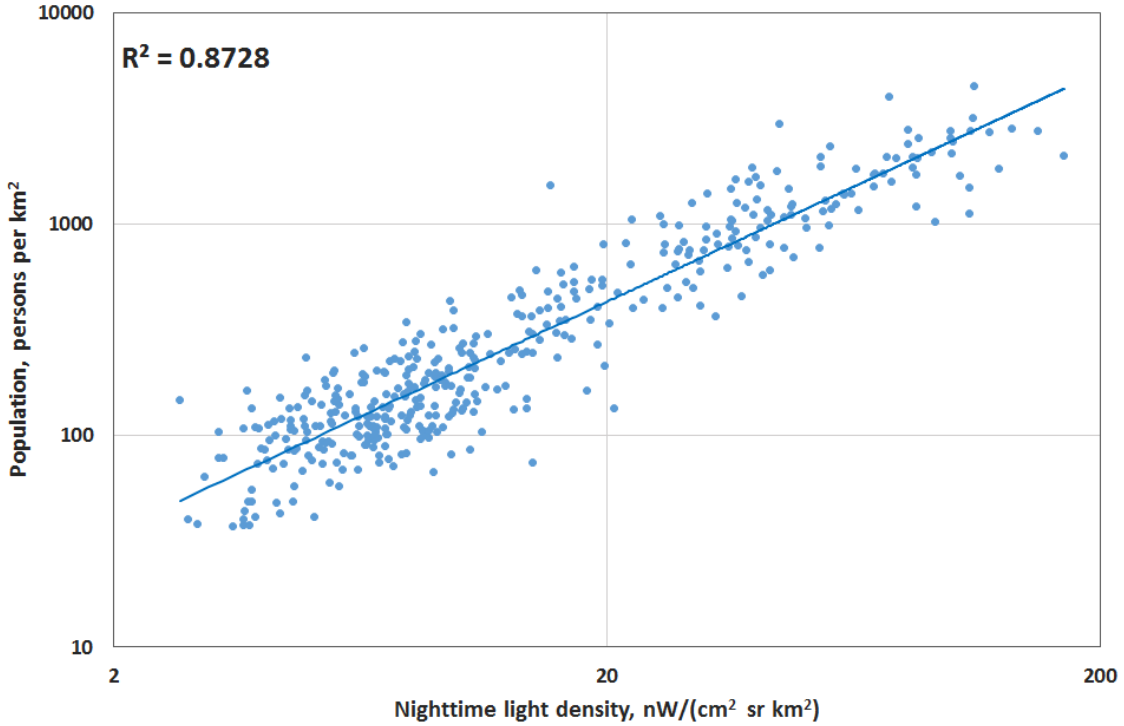


where,
P_e – estimated population
λ - nighttime light density
L - nighttime light intensity
f – factor
f(a) – factor to calculate f
e(a) – exponent to calculate f
e – exponent
f(b) – factor to calculate e
e(b) – exponent to calculate e

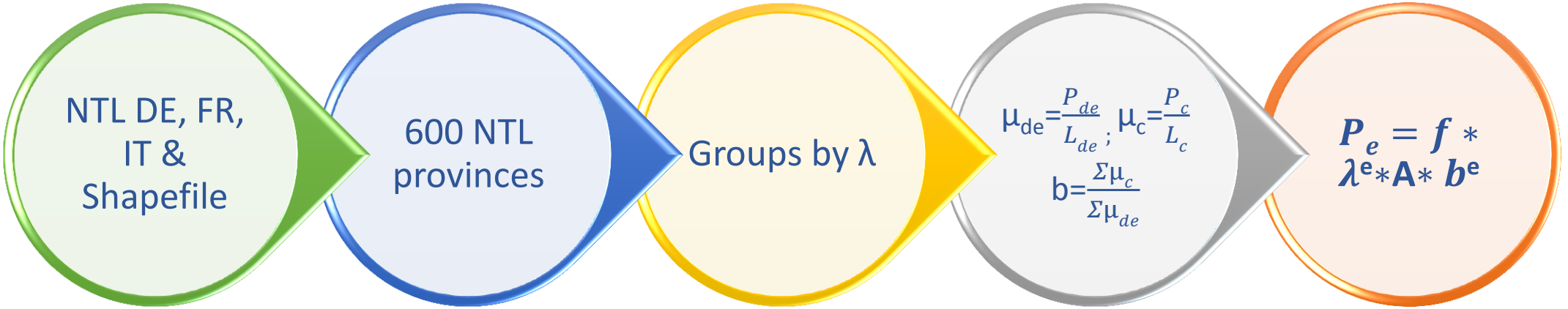
NTL intensity vs. Population



NTL density vs. Population density



Method 2 using NTL density



- Mask
- Apply mask

- λ < 100

Grouping by λ:

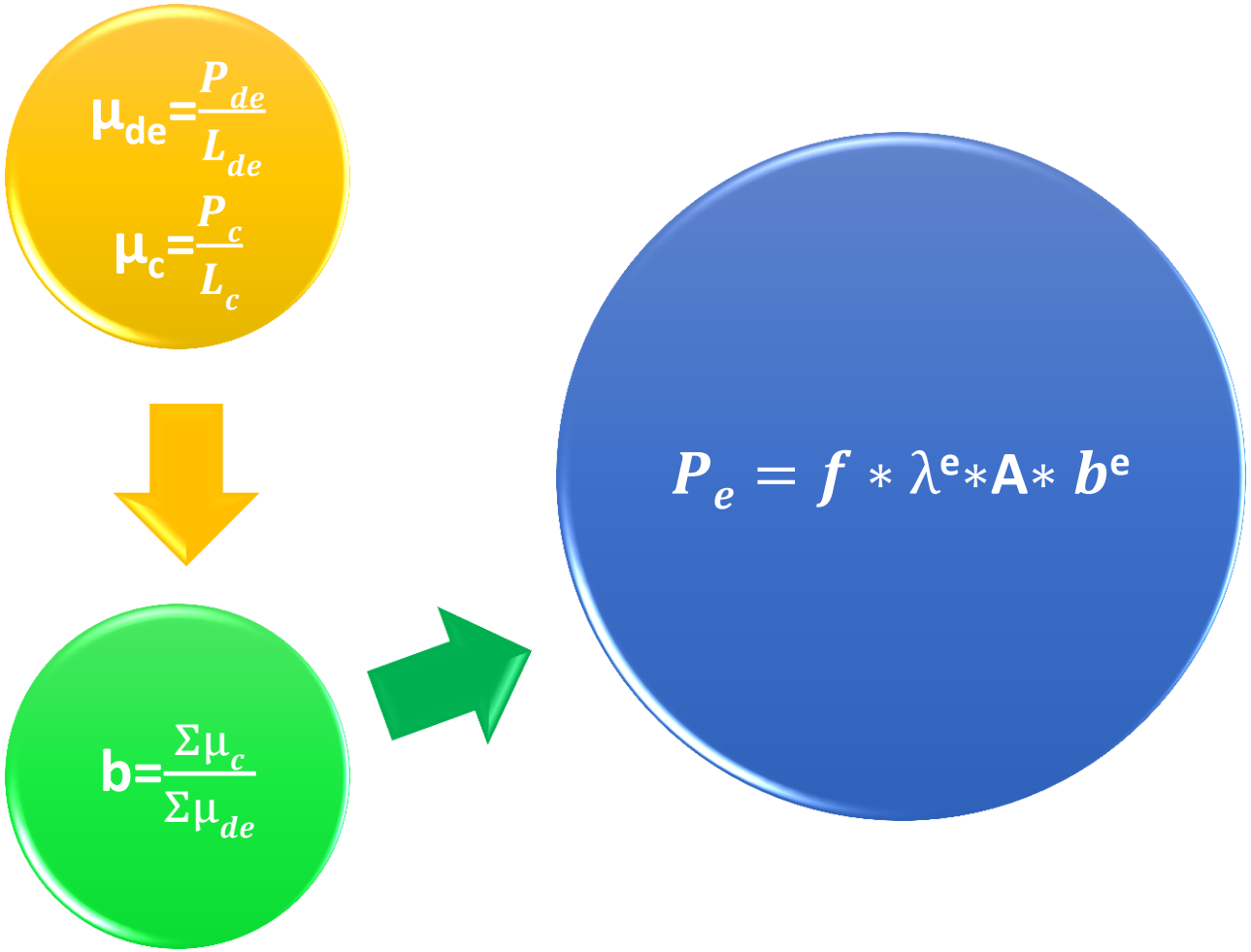
- 2<λ<5
- 5<λ<7
- 7<λ<10
- 10<λ<15
- 15<λ<25
- 25<λ<40
- 40<λ<100

- Scatter plot
- Population vs NTL
- Power regression

- Normalisation parameters

- Population estimation

Population estimation by method 2



where,
P_e – estimated population
P_c – country population
P_{de} – Germany population
λ - nighttime light density
L - nighttime light intensity
f – factor
e – exponent

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Results

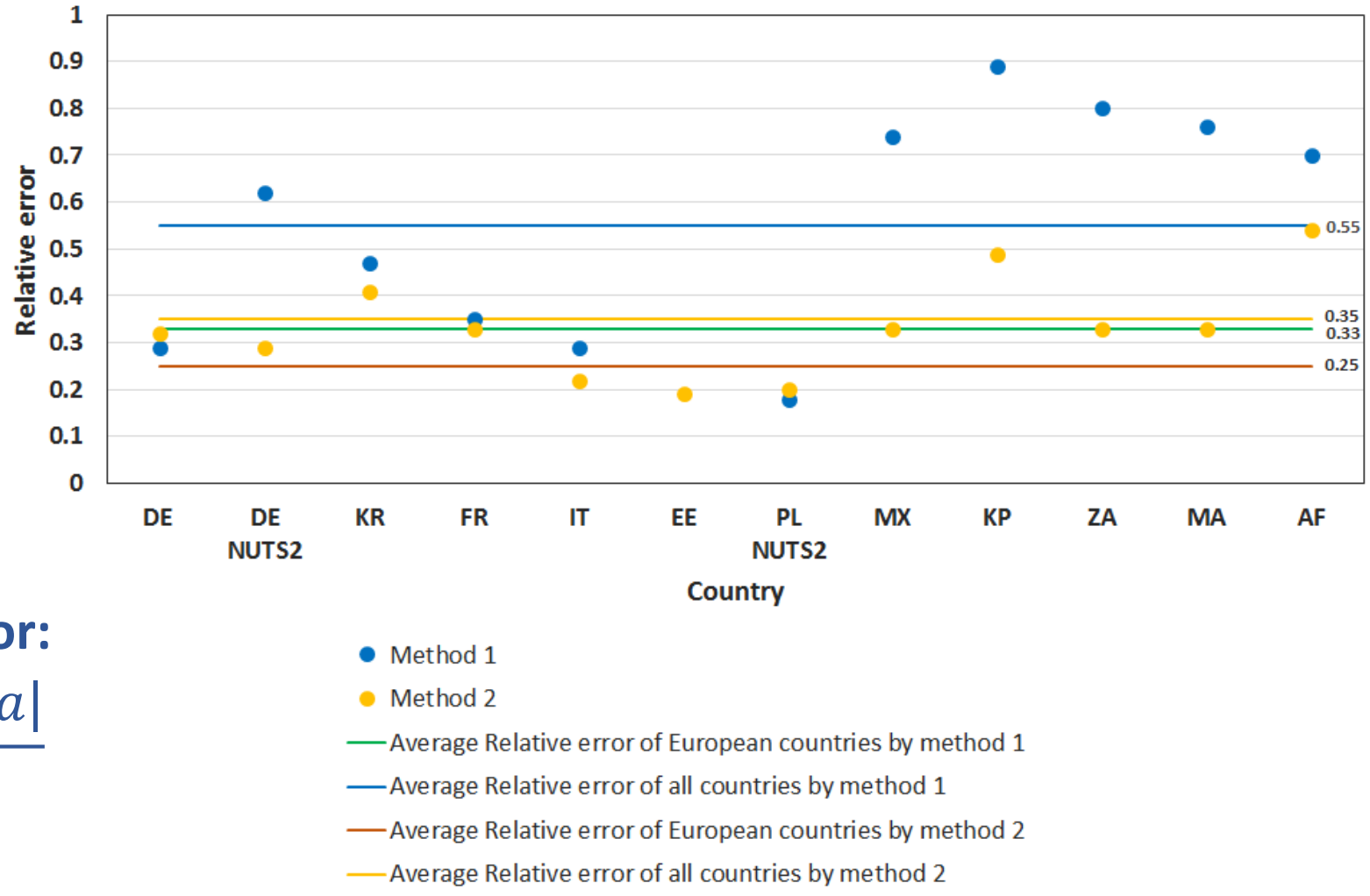
Cross validation

- 755 provinces
- 11 countries

Data Visualization

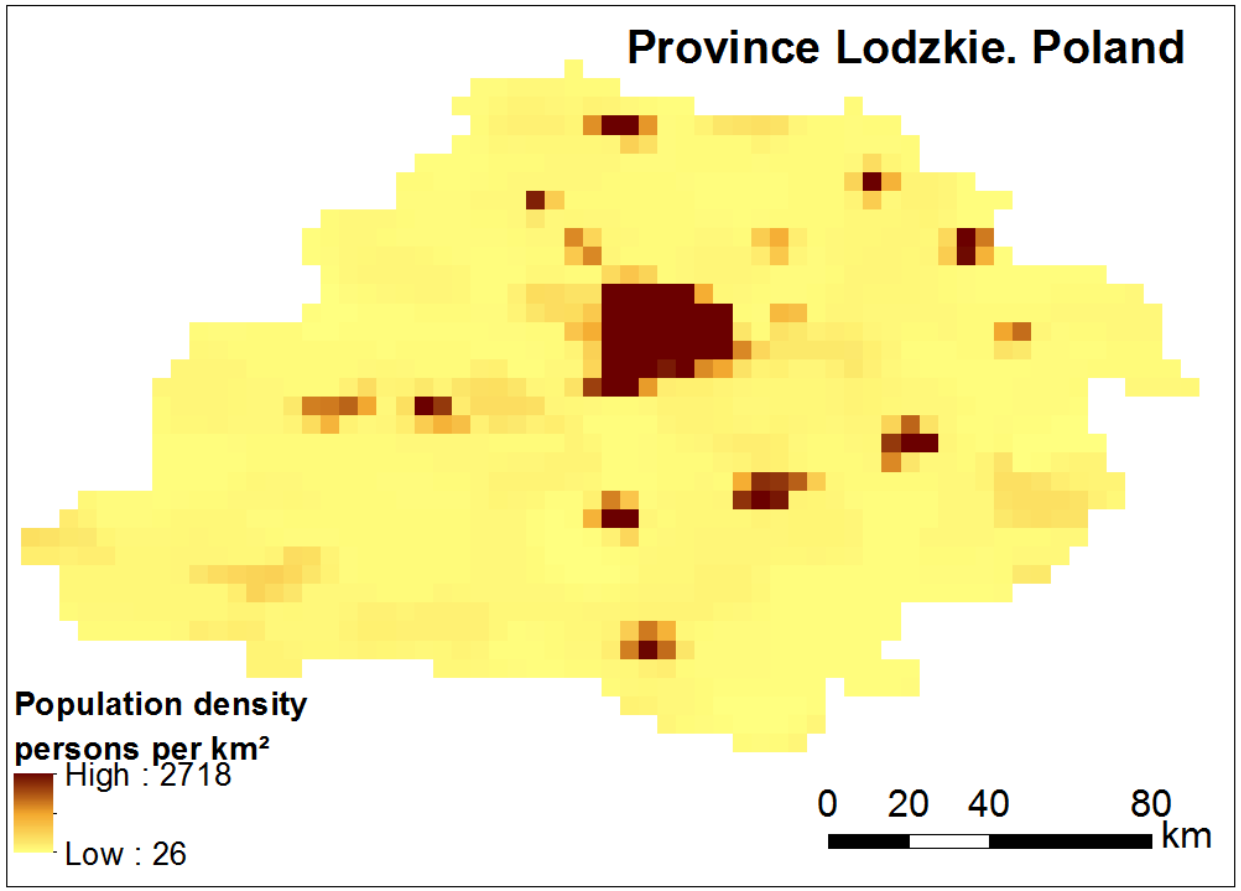
- *Method 1:*
  Poland and Lodzkie province of Poland
- *Method 2:*
  Estonia and Italy

Cross validation of 755 provinces



Relative error:

$$\varepsilon = \frac{|Pe - Pa|}{P_a}$$



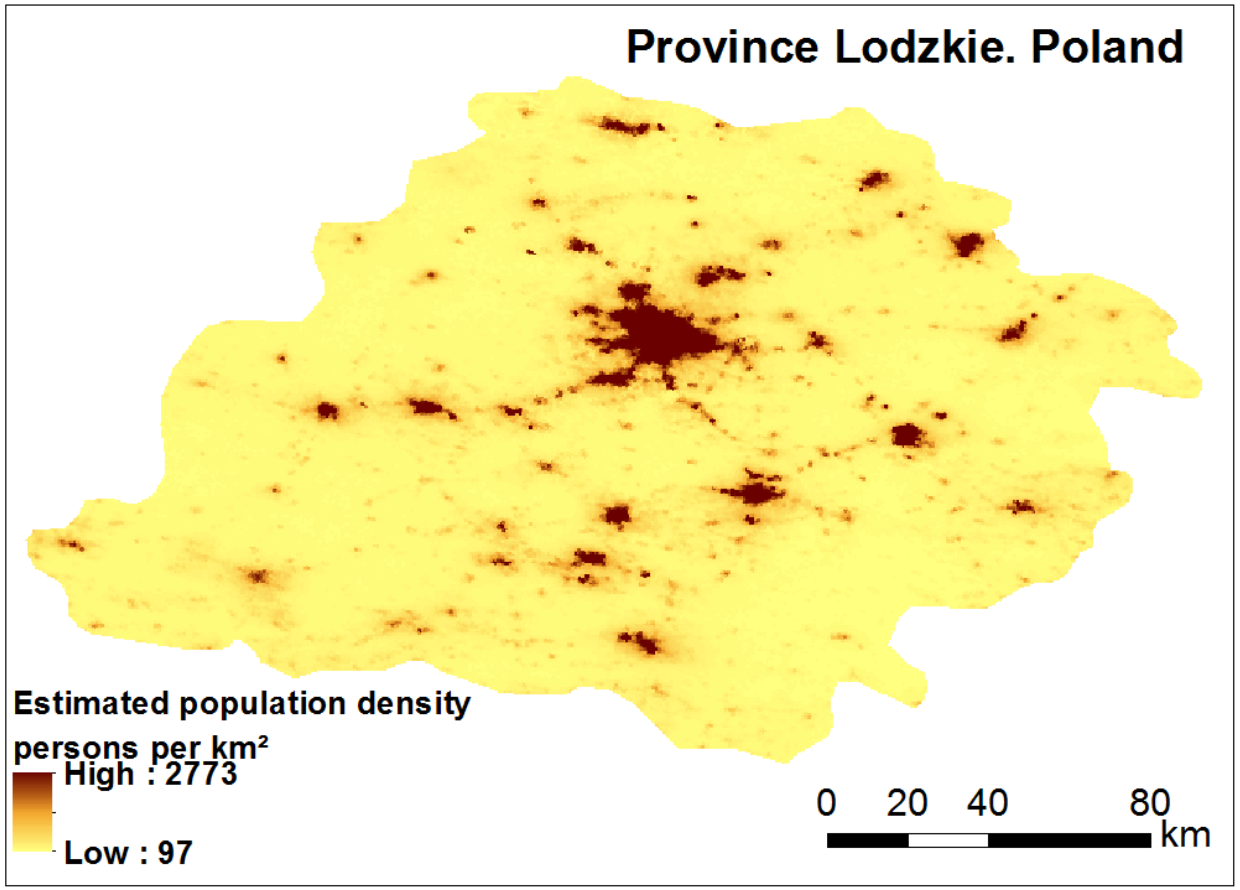
Population density per km² by GPW (2000)

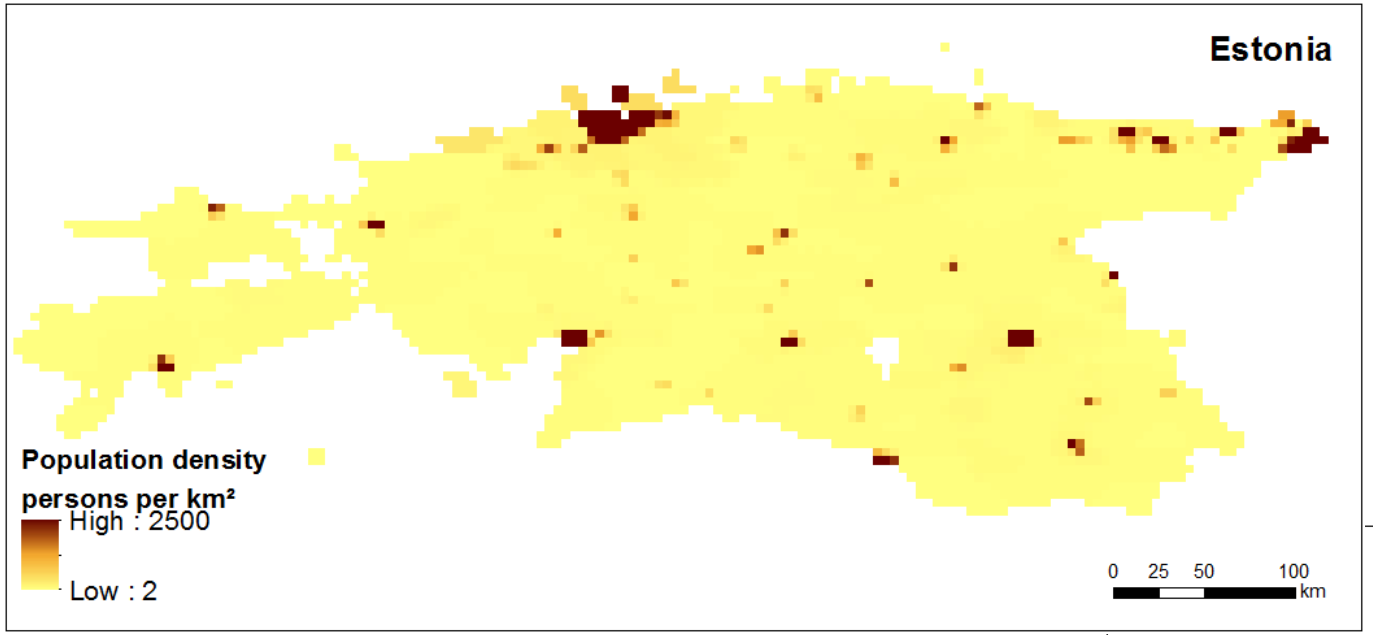
Spatial resolution: 5km

Source: GPW v2, naturalearthdata shapefile

Estimated population density per km² by method 1

Spatial resolution: 750m



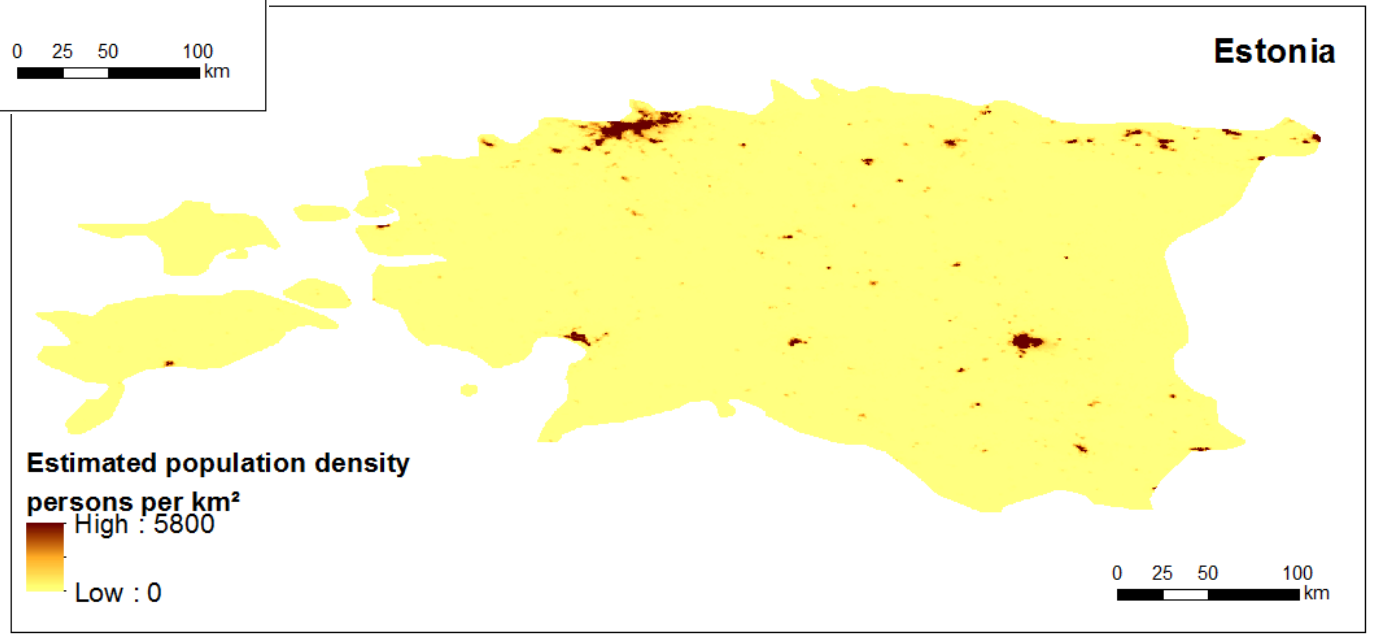


Population density per km² by GPW (2000)

Spatial resolution: 5 km

Estimated population density per km² by method 2

Spatial resolution: 750 m



Agenda

- Introduction
- Data description
- Existing work
- Methods
- Experiments
- Results
- **Discussion**
- Conclusion and Outlook
- Questions

Discussion

- General restrictions: gas flares, wildfires, auroras
- Method 1 restrictions: valid for European countries with evenly distributed population
- Negative values on VIIRS DNB: consequence of calibration

Agenda

- Introduction
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- **Conclusion and Outlook**
- Questions

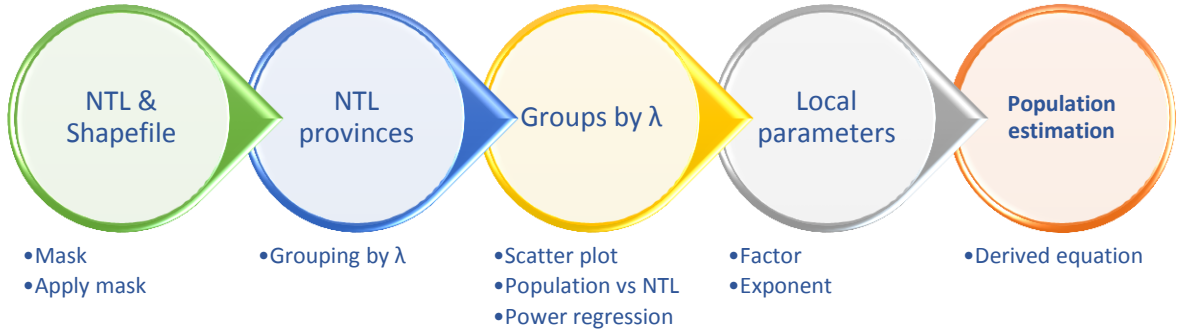
Conclusion

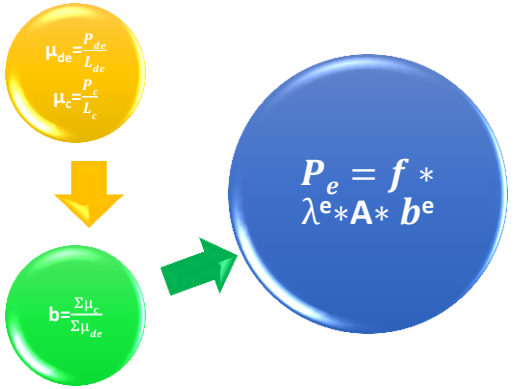
- ***Power law*** is the best among regression types
- Relationship of ***NTL density and Population density*** is stronger than NTL intensity to Population
- ***Method 2*** (ε_{all}=0.33; ε_{eu}=0.25) using NTL density is much better than Method 1 (ε_{all}=0.55; ε_{eu}=0.35)

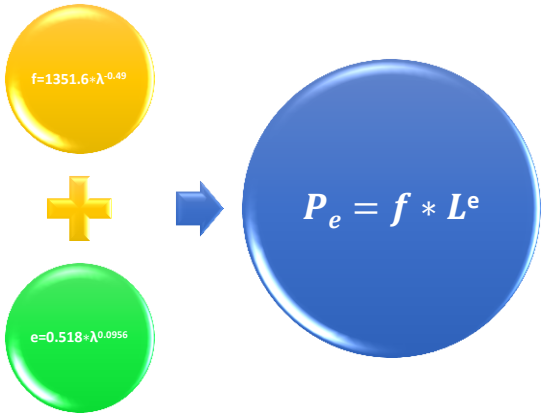
Outlook

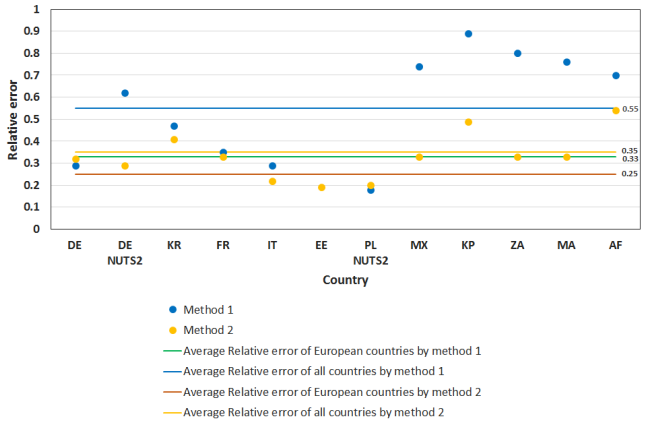
- Removing noise
- Using land cover
- Several year time lapse

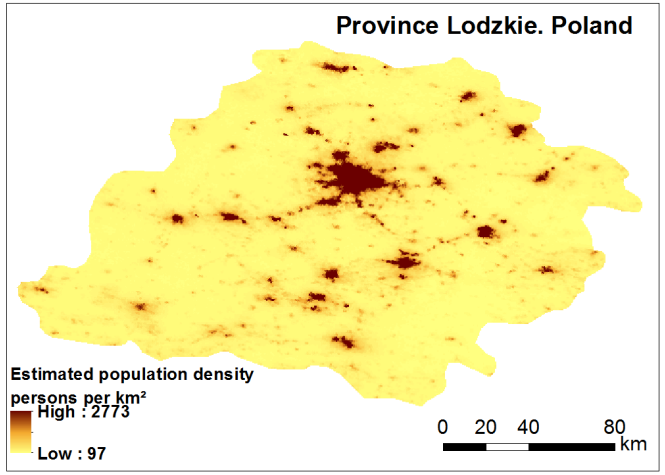
Questions?


NTL & Shapefile
NTL provinces
Groups by λ
Local parameters
Population estimation
•Mask
•Apply mask
•Grouping by λ
•Scatter plot
•Population vs NTL
•Power regression
•Factor
•Exponent
•Derived equation

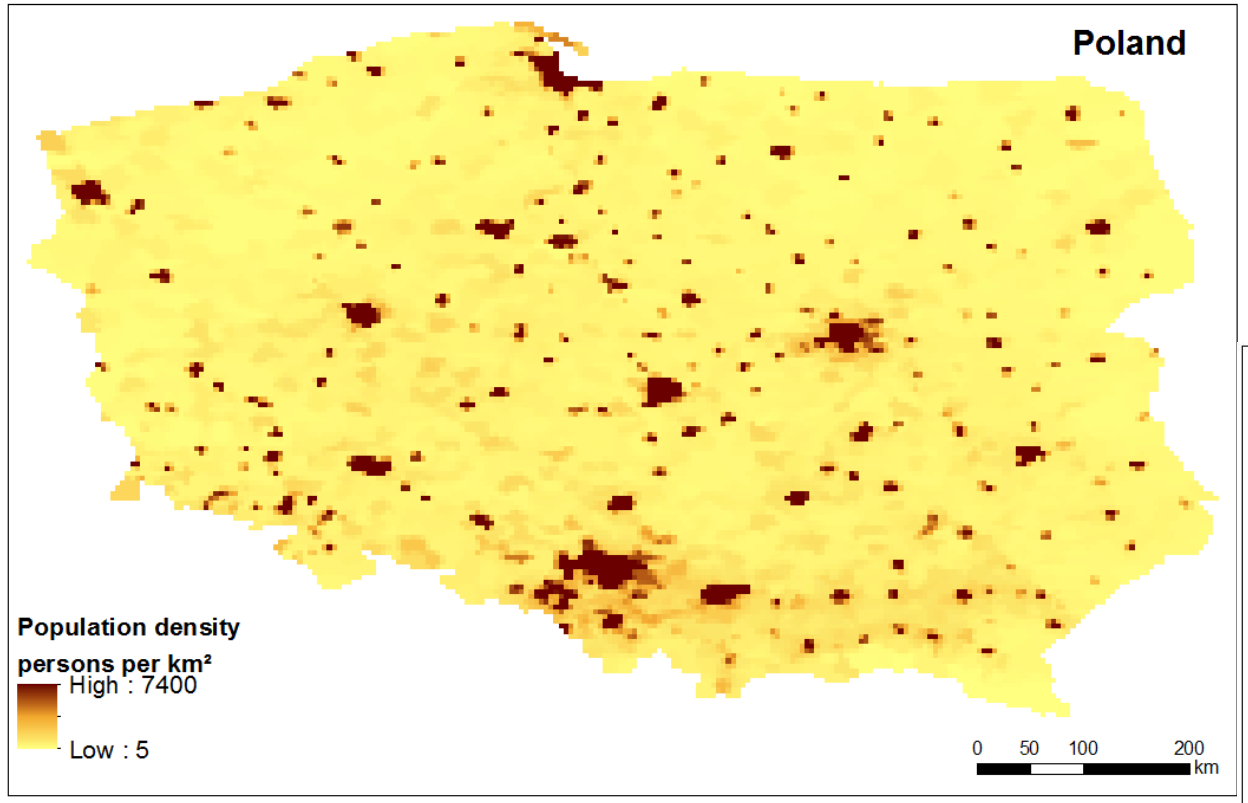

$\mu_{de}=\frac{P_{de}}{L_{de}}$
$\mu_c=\frac{P_c}{L_c}$
$b=\frac{\Sigma\mu_c}{\Sigma\mu_{de}}$
$P_e = f * \lambda^e * A * b^e$


$f=1351.6*\lambda^{-0.49}$
$e=0.518*\lambda^{0.0956}$
$P_e = f * L^e$


Relative error
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.55
0.35
0.33
0.25
DE
DE NUTS2
KR
FR
IT
EE
PL NUTS2
MX
KP
ZA
MA
AF
Country
Method 1
Method 2
Average Relative error of European countries by method 1
Average Relative error of all countries by method 1
Average Relative error of European countries by method 2
Average Relative error of all countries by method 2


Province Lodzkie. Poland
Estimated population density
persons per km²
High : 2773
Low : 97
0 20 40 80
km

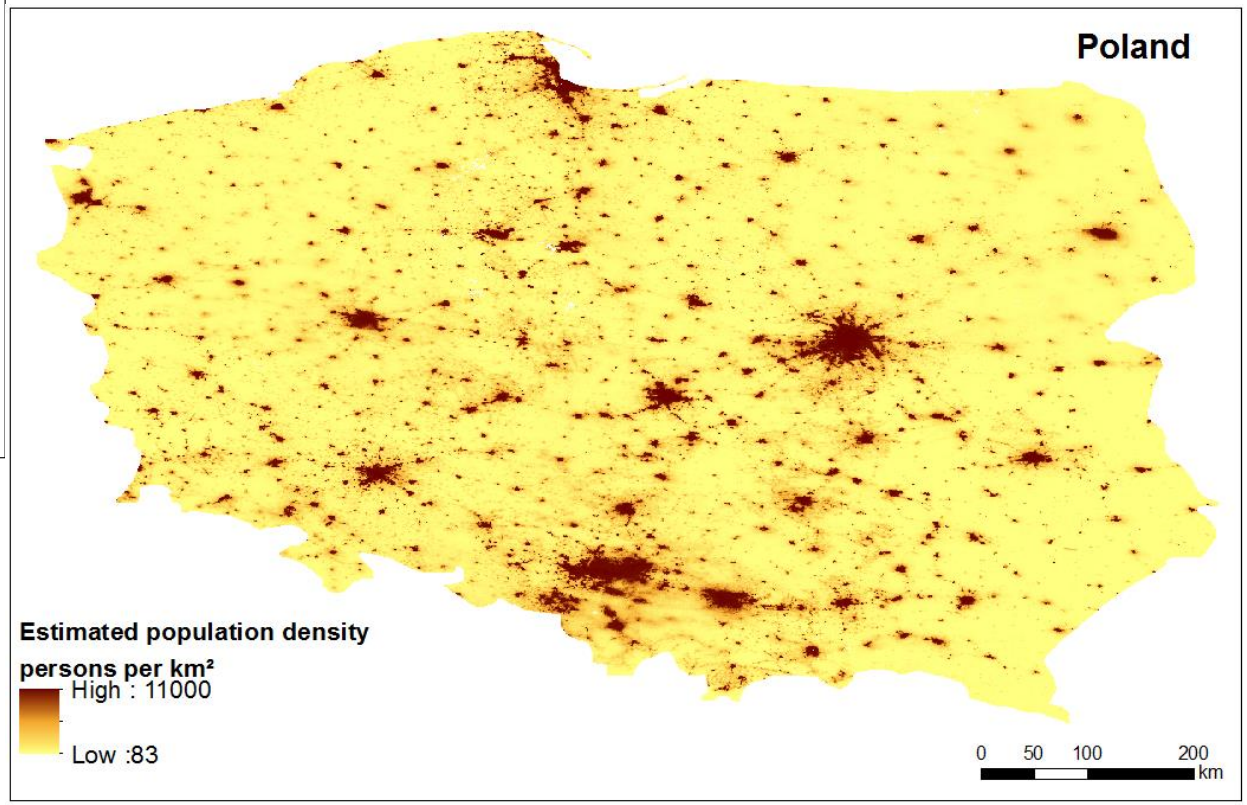
Thank you for your attention



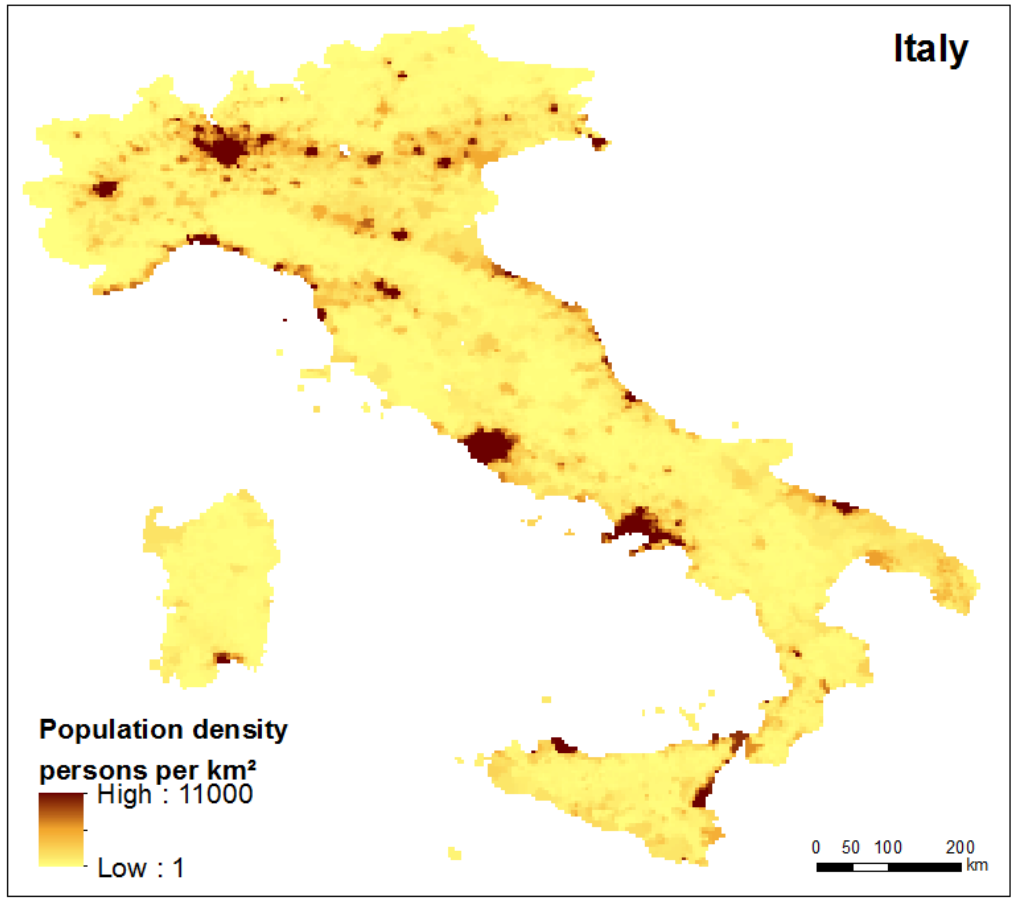
Population density per km² by GPW (2000)

Source: GPW v2, ESRI shapefile

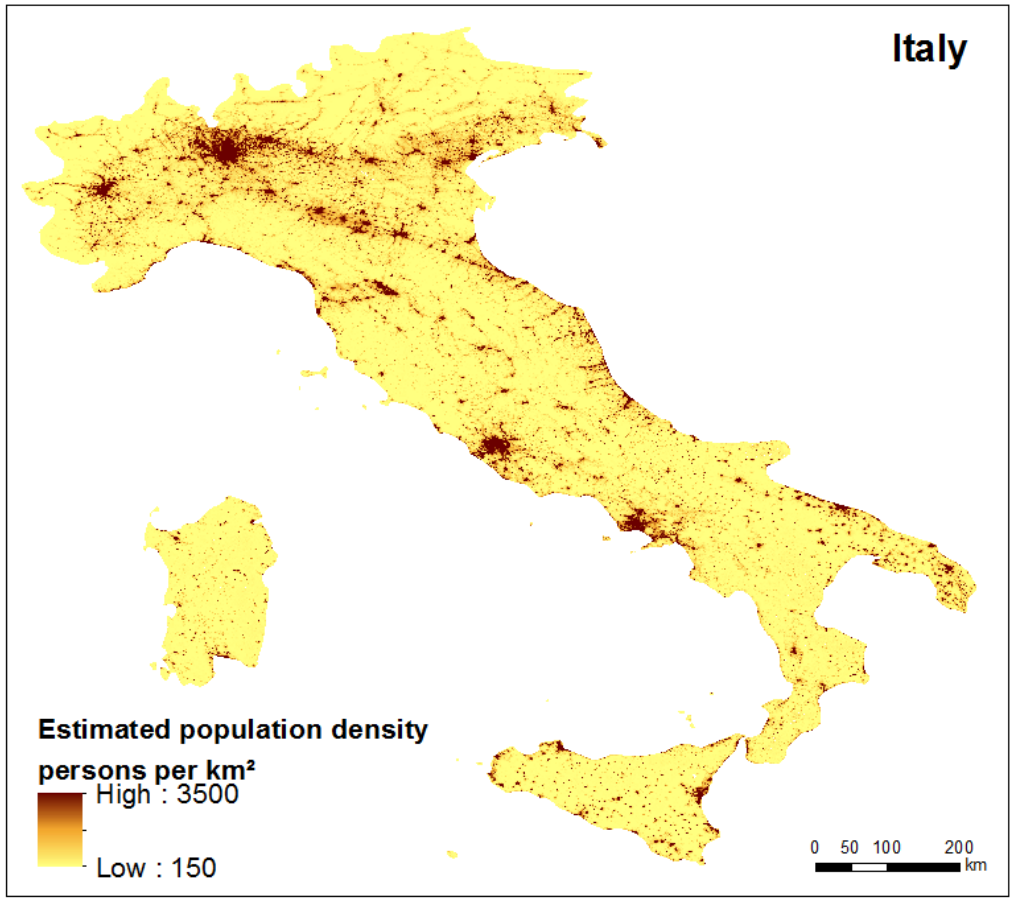
Estimated population density per km² by method 1



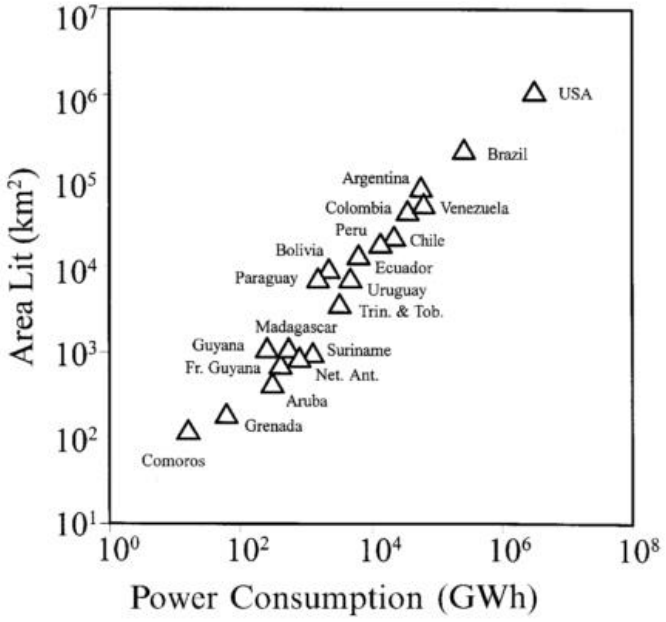
Population density per km^2 by GPW (2000)



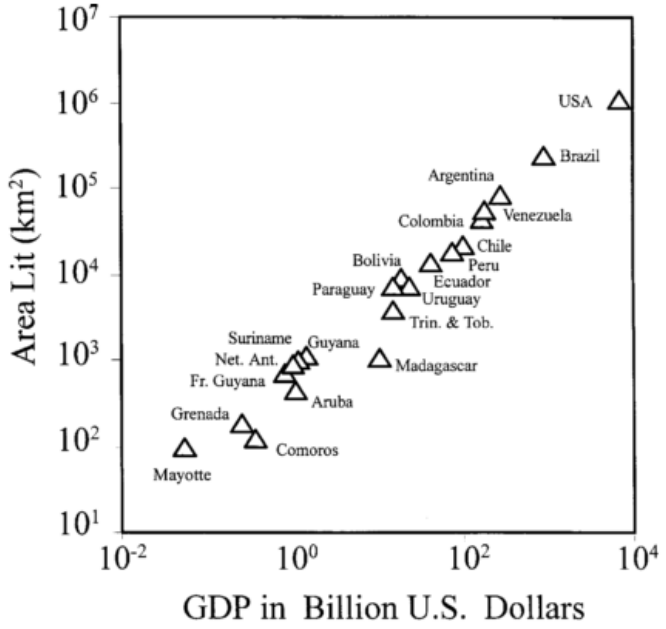
Estimated population density per km^2 by method 2



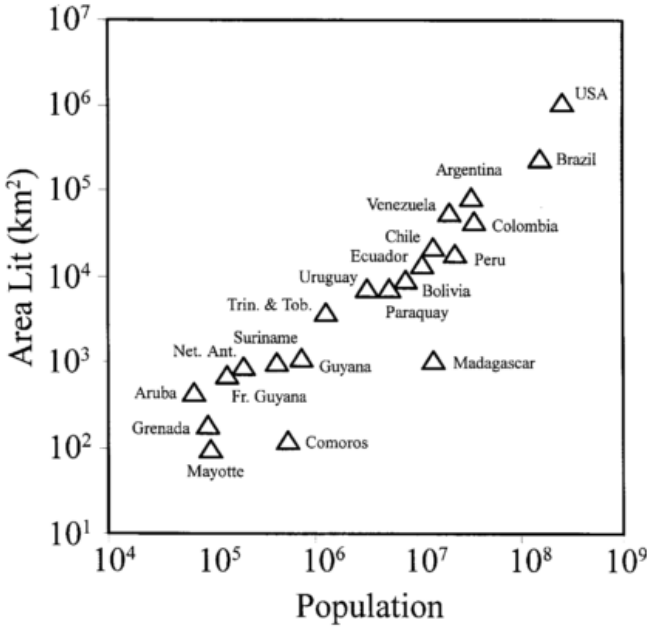
Log-log plots of 21 countries



R^2=0.96

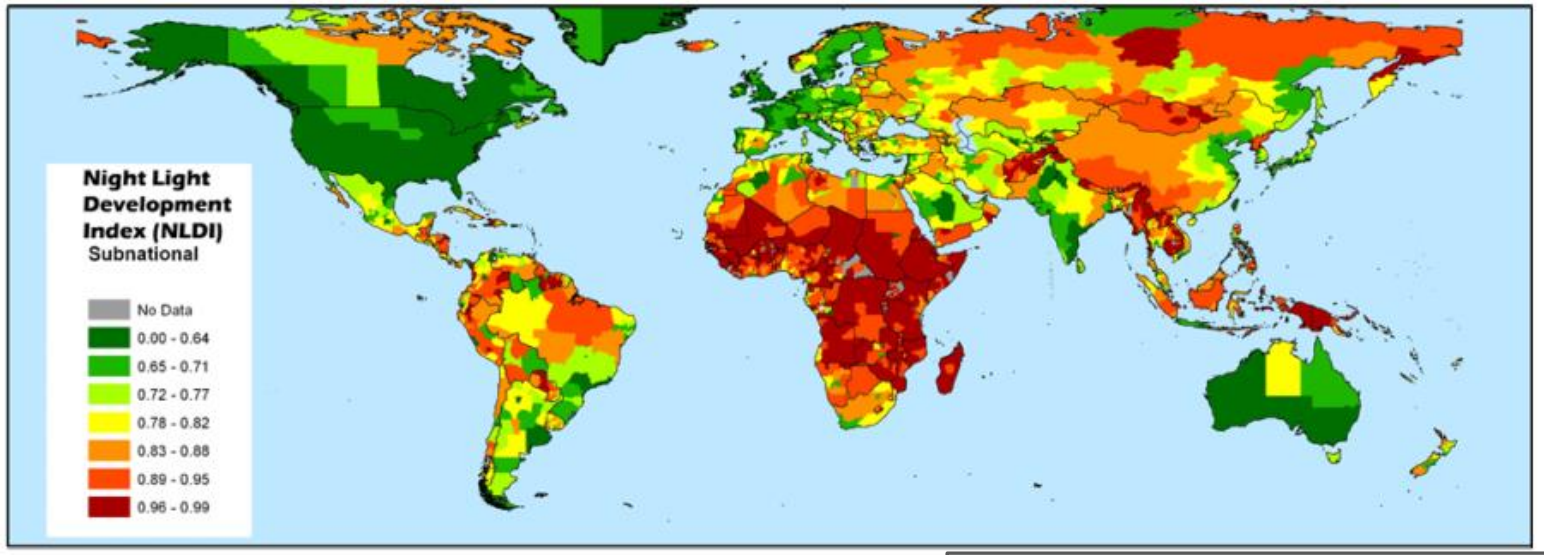


R^2=0.97



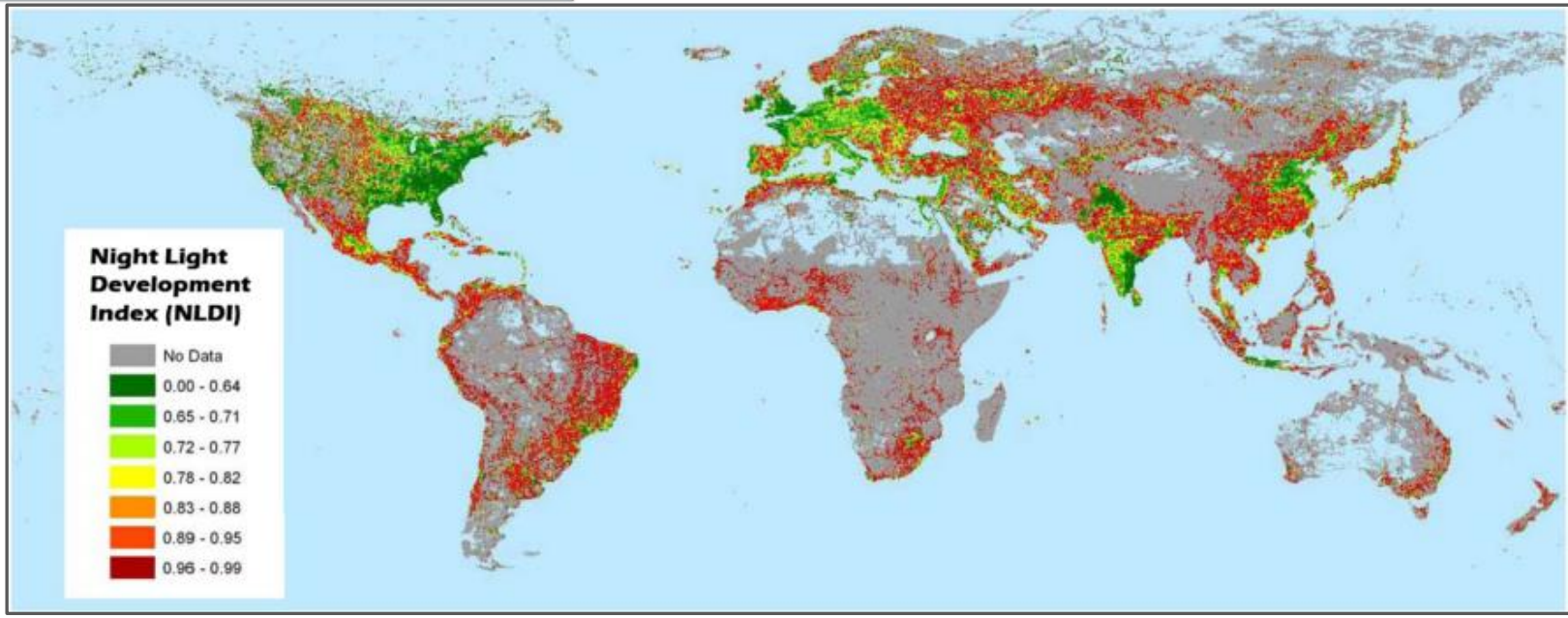
R^2=0.85

Source: Elvidge et.al.,1997



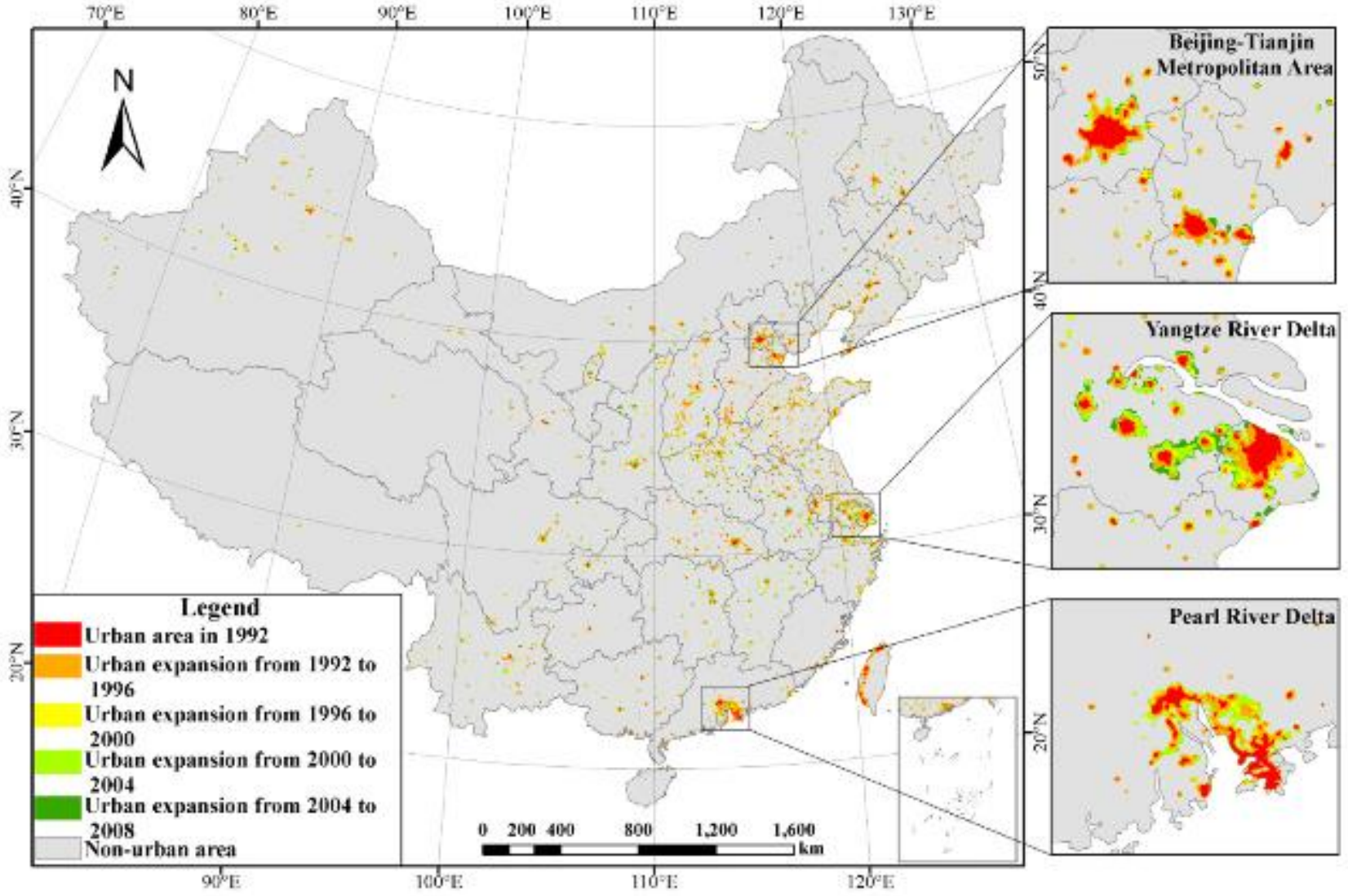
Map of a subnational NLDI

NLDI values produced on a 0.25 degree spatial grid



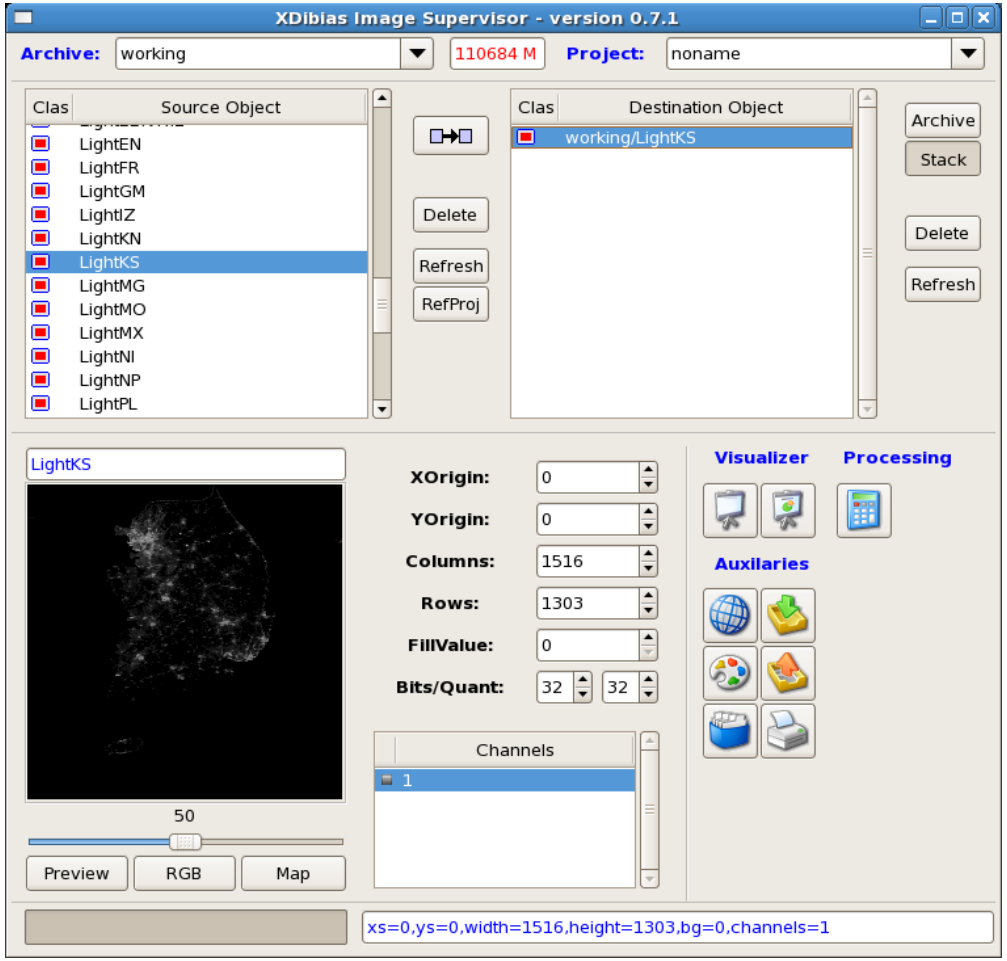
Source: Elvidge et.al., 2012

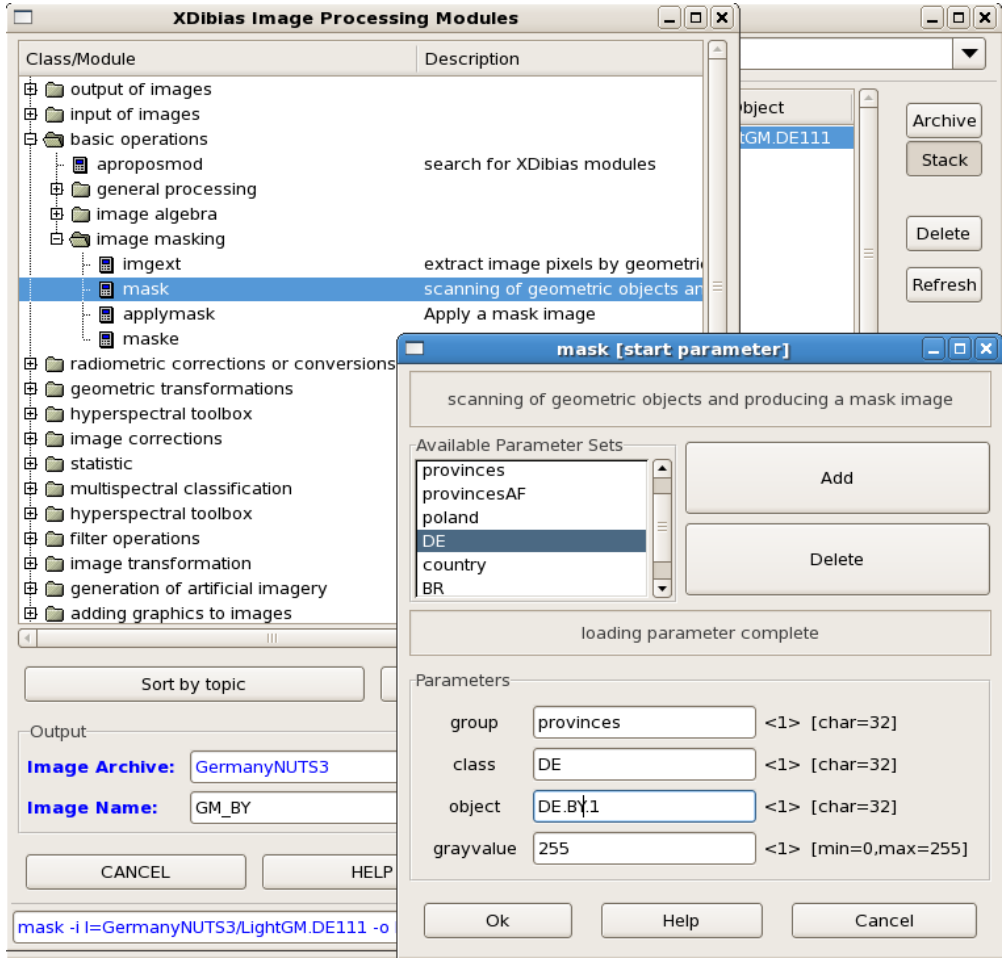
The dynamics of urban expansion in China from 1992 to 2008.



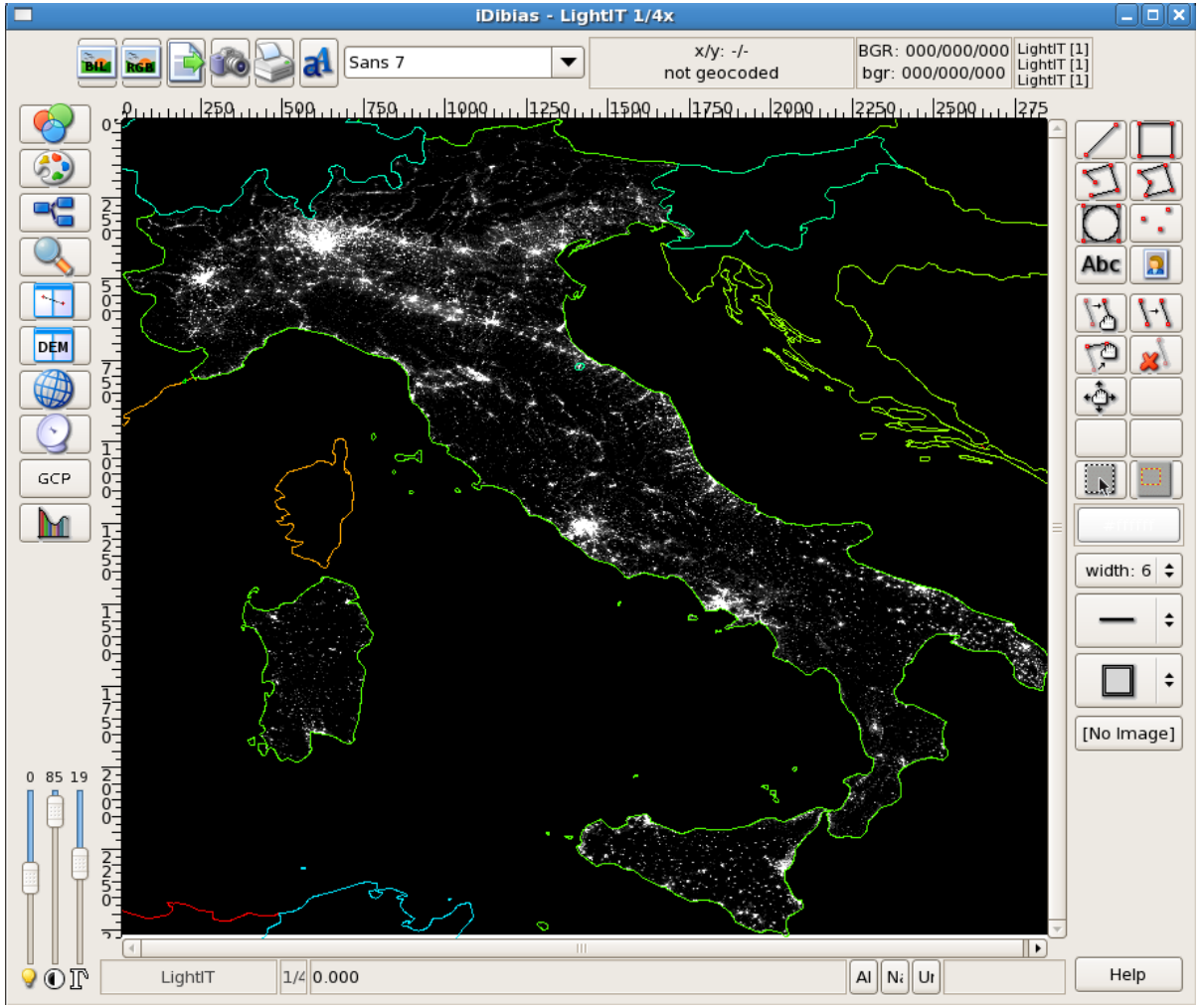
Source: Liu et al., 2012

XDibias – image processing system developed by IMF at DLR





Idibias interface – Xdibias image viewer



Tile 2. Europe and Northern Africa

Source: NOAA/NGDC

Reference

1. C. D. Elvidge , K. E. Baugh , E. A. Kihn , H. W. Kroehl , E. R. Davis & C. W. Davis (1997) **Relation between satellite observed visible-near infrared emissions, population, economic activity and electric power consumption**, *International Journal of Remote Sensing*, 18:6, 1373-1379.
2. Elvidge, C. D.; Baugh, K. E.; Anderson, S. J.; Sutton, P. C.; Ghosh, T. (2012) **The Night Light Development Index (NLDI): a spatially explicit measure of human development from satellite data,** *Social Geography,* 7(1):23-35
3. Liu, Z.; He, C; Zhang, Q.; Huang, Q.; Yang, Y. **Extracting the dynamics of urban expansion in China using DMSP-OLS nighttime data from 1992 to 2008**. *Urban Planning*, 2012, 106, 62-72.