CARLETON UNIVERSITY

Relative Star Visibility

Ottawa-Gatineau Region

GEOM2007C

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A report on the making of a map to visualize the detrimental effects of light pollution on star visibility in the Ottawa-Gatineau region. The calculations are based on the elevation, light emission ("nighttime lights") and city building density.

Relative Star Visibility Based on Light Pollution

It seems pollution defies "gravity". It is constantly rising with no apparent downfall in the near future. Nowadays, we have "green" talks about how we can improve our critical situation. Most of the methods discuss the reduction of greenhouse gases such as carbon dioxide or methane. Although the latter may be the more urgent problem, there are many other types of pollutions that exist. Notably, light pollution is on the rise with population and housing constantly increasing. Before nearing the 21st century, the night sky would be filled with stars everywhere. Many photographs taken before in comparison to today are explicit examples of how detrimental light pollution is and how worse it has become. Light pollution also affects life in nature. Ecosystems are very sensitive: they are held in balance when conditions are relatively stable or unchanged. Some animals are being disoriented by this obstructive light. Others, their biological clocks are being disrupted. Increased night visibility from the glare (or skyglow, see figure 1 & 2) in the skies increases predation, competition, and decreases reproduction. It is harder for prey to hide and some nocturnal animals compete with diurnal (day) animals. Vegetation is also affected. Some plants only bloom during the dark of the night. In many cases, the increased lighting conditions prohibit these blooming (or flowering) cycles to occur. The result is some species can no longer reproduce. In extreme cases, this may lead to the extinction of such a species. It may also influence people's sleep patterns in certain areas.

Figure 1*: Comparison between a rural sky on the left and an urban sky on the right.*
Photo credit: Jeremy Stanley, 2007

That being said, this project aims to describe how modern light pollution affects the (naked eye) visibility of the stars in the night. Star visibility is affected by many things: brightness, luminosity, distance, cloud coverage, air pollution, glare (from light pollution), etc. As this is a rather complex matter, only a few criteria will be taken into account. This project is based mainly on the elevation (CDEM), the distance to (or rather density of) large city buildings and finally the relative (percentage) light magnitude or intensity measured from space by satellites (provided by NOAA). What is actually displayed in the map is the rating of light pollution, not actual visibility of the stars; visibility is the inverse, meaning light pollution highs are star visibility lows and vice versa. The light pollution rating is relative (*e.g.* 100%=worst, 5%=excellent). Originally, a scale was to be implemented. However since this is a relative comparison type of map, absolute values are not being described. Thus, no scale is needed. This map shows the linear comparison between the highest and lowest values of light pollution relative to the area of study which is the Ottawa-Gatineau region. In other words, the highest value, expressed as 100%, will be the highest value that can be found for this specific area of interest and not the highest value on the entire globe. This project assumes there is no interference from air pollution or clouds covering the sky (*i.e.* constant clear skies and fair weather).

***Figure 2**: Comparison between the suburban sky of Aylmer (on left) and an African night sky (on right). Photo credit: (left) Joachim de Fourestier, 2016 and (right) David Miko, 2013*

This study's target audience is the general public of the Ottawa capital region. This audience may include some people with a general interest in science or even environmentalists. In figure 2, we can observe the difference between a heavily polluted sky from Aylmer[1] (Quebec) and an unpolluted (Southern?[2]) African night sky. On the left, not a single star is visible despite it being 10 PM with minor cloud cover. Additionally, a background dispersal of skyglow is quite noticeable. On the other hand on the right, we have exemplary star visibility conditions. There is nearly no light pollution at all. The goal of this project is to demonstrate light pollution is on the rise with cities expanding: increasing population and the construction of new light emitting structures such as street lamps or office buildings.

[1] The picture was taken at 10:05pm with a shutter speed of 15/1 seconds. It was slightly edited to represent the actually visibility that was observed.

[2] The picture was taken at 11:45pm with a shutter speed of 30/1 seconds. Location was unspecified by the photographer. Contact could not be established to obtain additional information.

Mapping and Analysis Methodology

The final map has two layers: “Places” and “Light Pollution”. Well known areas such as towns, suburbs, communities and cities are being represented as points. These well-known areas have been placed in the map in order to help the audience (map reader) mentally “geo-reference”, visualize and familiarize themselves with the map. The second layer is the “Light Pollution” relative to star visibility (based on elevation, light emission and building density). It is a special type of raster that in part shows the topography of the Ottawa region and another showing the bulk light pollution “plumes”. Its intensity is represented by a blue-to-yellow (named “Partial Spectrum” in ArcGIS) colour ramp: blue being the lowest and yellow being the highest possible value. This raster is created from the combination of multiple data sources.

The very first step was to do some research on light pollution in general in order to identify the important factors. The factors used within this project are elevation, light emission and buildings. Fortunately, this data was available openly and publicly. Two building data shapefiles were obtained from Ottawa Open Data and Two more from Gatineau Open Data. The Earth Observation Group from the NOAA (National Oceanic and Atmospheric Administration) National Geophysical Data Center provided the Earth’s light emission data that was collected at night from remote satellites in space. CDEMs (Canadian Digital Elevation Model) were procured from the NRCAN (Natural Resources Canada) Open Data. Once all the data files were downloaded and extracted, some preliminary processing had to be done.

The data frame’s coordinate system was set to NAD_1983_UTM_Zone_18N. When looking at the UTM (Universal Transverse Mercator) map, Zone 18N appears to the best corresponding zone which will give us the least deformation for the area of study. The obtained CDEM data was a large rectangle of raw data formed by areas 31K, 31J, 31I, 31F, 31G, 31H, 31C, 31B, 31A. This can be seen in figure 3.

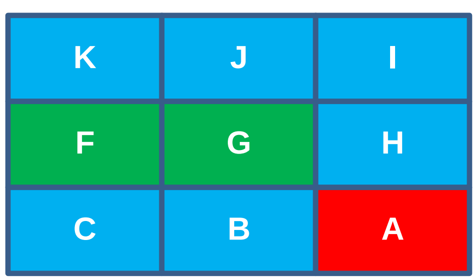

Figure 3: *A diagram of the raw CDEM data that was obtained: a part of area 31 (spans part of Ontario and Quebec). The areas depicted in green are the chosen areas. Red indicates incomplete or partial data due to the boundary with the neighbouring country (USA).*

The obtained “F182013” light emission data from NOAA, which can be seen in figure 4, shows us the brute sources of light pollution. These sources are undoubtedly directly related to the location of city buildings. This composite shows us valid information, but it is not as refined or specific to the subject of star visibility.

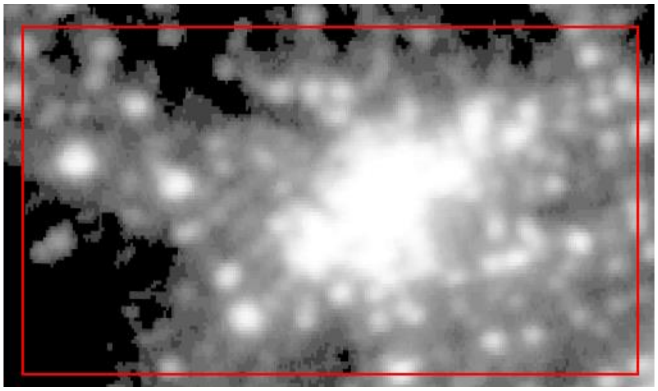

Figure 4: *A composite of the raw “Nighttime lights” data from NOAA. The red rectangle delimits the Study are that was chosen.*

Three raster composites were provided by NOAA: cloud-coverage, stable/clear and average (combination of the other two). The file “F182013v4_StableLight.tif” was chosen since it was the most recent one of the series available; this raster gives the relative (percentage based) raw light output measurements. Additionally, it was decided to cancel out the effects of cloud coverage: star observation is not usually preformed during cloudy conditions. When importing these raster files into ArcMap, there was an option to build “pyramids” for computation optimization and improved display performance. The options chosen: Resampling Technique was set to “Nearest neighbour” (since it the most common option for raster composites) and the Compression Method was set to “LZ77” (preferred over JPEG compression, since it is lossless). The city buildings shapefiles from Gatineau (ADRESSE.shp, LIEU_PUBLIC.shp) were provided as points, and those from Ottawa (OttawaBuildings.shp, large-buildings.shp) were provided as polygons. Some of the shapefiles were provided in a different coordinate system. They have been re-projected appropriately to NAD_1983_UTM_Zone_18N once all the data files had been imported.

The most limiting layers, in terms of geographical surface area size, were the city buildings shapefiles. The study area was chosen based on the building data’s spanned surface area. A rectangle, named “StudyArea”, was digitized and with a reasonable margin. Once that was done, it was clear that only the 31F and 31G CDEM raster composites were needed as the rest were outside of the area of interest (as shown in figure 3). Before clipping all the layers to the extent of “StudyArea”, the 31F and 31G CDEM raster layers were combined into one. To do so, the “Mosaic to New Raster” tool was used to merge “cdem_dem_031F.tif” with “cdem_dem_031G.tif”. The settings were left on default except for a few: Pixel Type was set to "16-bit_signed" (since it spans an integer value from -32768 to +32768 which is appropriate), Number of Bands was set to '1' (since it is only a one-layer type of raster going from black to white). The new merged raster layer was renamed to "CDEM_Zone31FG".

Now that the area of interest was decided, all the layers had to be clipped confining them to the "StudyArea" extent. For the elevation and light raster composites, the "Raster Clip" was used: "Output Extent" was set to the "StudyArea" layer and the "Use Input Features for clipping geometry" was enabled to assure the layers were confined correctly to the "StudyArea" polygon. The resulting CDEM layer was renamed to "Elevation" and the emission data to "Light" for simplicity. For the buildings (vector) data, the normal clipping tool (Analysis -> Extract -> Clip) was used with "StudyArea" as the Clip Feature.

For the building data, I obtained 2 shapefiles from Ottawa Opendata: "large-buildings.shp" (renamed as "Ottawa_LBs") and "OttawaBuildings.shp" (renamed as "Ottawa_Bs"). In these files, the buildings were all represented as polygons. These two files were checked for collisions. To do this, a "Select by Location" was performed as so: Select from "Ottawa_Bs" that intersect with "Ottawa_LBs". 14880 features were selected. A brief visual inspection was done: all buildings selected were in fact overlaying others. These collisions (selected features) were then removed from the Ottawa general buildings layer ("Ottawa_Bs"). These building polygons were then changed to points to match the Gatineau data (which were provided as points). To do so, "Feature to Point" was used with the "Centroid" option (to obtain the centres of all these individual polygons). For the Gatineau building data, 2 shapefiles were obtained: "LIEU_PUBLIC.shp" (public buildings) and "ADRESSE.shp" (general buildings). These two layers were also checked for collisions using the same method mentioned earlier. Only 3 collisions occurred: 2 had matching addresses but the last one, "Maison Wright-Scott", had a street address that was completely wrong. Instead of the correct address "28, boulevard Alexandre-Taché", it was set to "100 Rue Gamelin". To verify if this was intentional or actually a mistake, it was georeferenced and some minor research was done: a heritage page[3] about this public building was found on a Quebec government website displaying the correct address. This was manually fixed in the layer and the matter was reported to the Gatineau Open Data group. They have responded and have fixed this. These duplicate points (collisions) were then deleted from the "ADRESSE.shp" layer.

[3] See "Maison Wright-Scott" heritage webpage in Data Sources

The next step was to add attribute data to the points: the fields "city_ID" and "B_type" (short integer) created. These fields come in use later when combining all the building layers into one. For "city_ID", there were two possible values: 1 = Ottawa and 2 = Gatineau. For "B_type", a field describing the building type, there were three possibilities: 1 = General, 2 = Public and 3 = Large buildings. To process all of this in an efficient manner, rather than simply doing manually entry for each and every individual entity, the "Field Calculator" was used on the entire column to set the corresponding values on multiple entries at once. This was done for each of the four building layers.

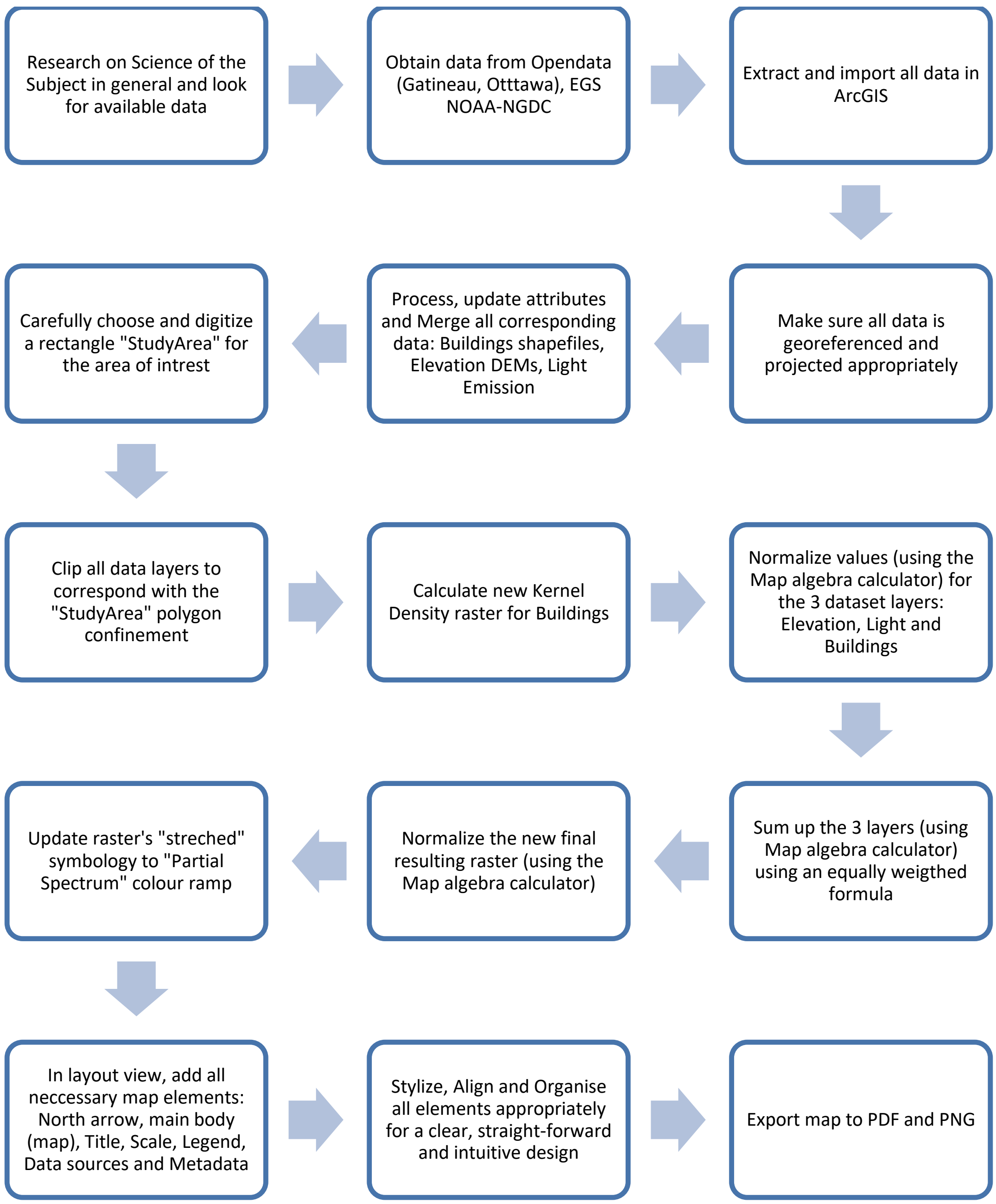

Figure 5*: A general flowchart (workflow) of the work done to create the final map.*

To allow merging of all these building point layers, the attribute tables had to be reorganized and changed. The fields were reordered in the same fashion for all point layers. Unneeded fields were subsequently deleted: such as “COTE”, “featureNum”, “MUNID”, “SHAPE_Leng”, etc. Lastly, the point layers were then merged into one layer named to “CityBuildings”. The merging process was done using “Data management tools -> General -> Append”.

Now that the data was merged and renamed appropriately, a geodatabase named “MapData.gdb” was created. All processed layers have been exported into it. Multiple backups were made during the project. Original copies of the source data had been left intact in case a step back would be needed. All the older (unprocessed) layers were then removed from the ArcGIS data frame since they were no longer needed. At first, the entire raw source data files extracted measured to be around 3.07 GB of data. With all the clipping and compression done during the preparation of the data, the total amount of data has been reduced to approximately 252 MB (only ~8.2% of the original data’s size).

Calculation

Once all the data was processed and organized, the next step was to proceed to the raster calculations. Originally, a scale similar to the Bortle[4] scale was to be implemented. When looking at this specific scale, some tests were made: it was plotted and proved to be linearly and directly proportional to NELM (naked-eye limiting magnitude). However, through multiple attempts at perfecting a formula separate from this, an acceptable end was met. A scale implementation was no longer needed. The aim of this project is to show star visibility of a specific area in a relative and not an absolute manner.

In order to give more quantitative value to the “CityBuildings” layer, it had to rasterized in a way that held both the type and the distance (between each other) in importance. This was achieved using Kernel Density: Input Feature was set to “CityBuildings”, Population Field to “B_Type” (this allows having the building type weighed), Search Radius to 5000 meters (5km tolerance), Area Units to “SOURCE_MAP_UNITS” (meters in this case). One last vital thing under Environment Settings had to be set before computing the raster: Processing Extent had to be set to use the extent of the “StudyArea” layer to avoid invalid truncation. The computed raster, named “Buildings_KDensity”, had areas of NoData values. To fix this, code similar to the following was used in the “Raster Calculator”:

```
Con(IsNull("raster"), 0, "raster")
```

This sets all NoData values to zero (0) avoiding warnings and errors during computation with larger raster composites.

[4] See “Bortle Scale” under Information References in the Data Sources section.

With this last step completed, all three raster layers ("Elevation", "Light" and "Buildings_KDensity") were now ready for the final computation.

A generalized mathematical formulation was written as so:

$$xN \cdot yD \cdot zE = value$$
$$x + y + z = 1$$

Where x, y & z are decimal values ranging between 0 and 1. 'N' represents the "Light" raster, 'D' the "Buildings_KDensity" and 'E' the "Elevation". This demonstrated how the three can be weighted and summed to 100% (or '1'). The following is pseudocode of what was used with the Raster Calculator: the two main attempts.

```
First Version (Unnormalized, shifted, equally weighted):
 Raster = (.33*(1-"Elevation")) + (.33*"Buildings_KDensity") + (.34*"Lights")
 Raster = ShiftUp("Raster")
 Raster = Normalize("Raster")

Second Version (Normalized, shifted, equally weighted):
 D_Normalized = Normalize("Buildings_KDensity")
 E_Normalized = Normalize("Elevation")
 L_Normalized = Normalize("Lights")
Raster = (.33*(1-"E_Normalized")) + (.33*"D_Normalized") + (.34*"L_Normalized")
Raster = Normalize("Raster")
```

Note that nor `Normalize()` or `ShiftUp()` are real functions. They have presented as so to simplify the pseudocode. They are based on the following presented formulas where 'r' represents a raster variable:

$$Normalize(r) = \frac{r - \min(r)}{\max(r) - \min(r)} \times 100 \qquad ShiftUp(r) = r + abs(\min(r))$$

And, here are their pseudocode equivalents.

```
Normalize("Raster") = (("Raster"-"Raster".minimum)/("Raster".maximum-
"Raster".minimum))*100

ShiftUp("Raster") = "Raster" + Abs("Raster".minimum)
```

The purpose of normalization is to change the range of pixel intensity values. "Shifting up" is to shift the range of pixel intensity values towards positive numbers. Due to the elevation producing a negative effect, this proved necessary and appropriate. Both `Normalize()` and `ShiftUp()` seem to produce no visible changes except in the range, for example: -20.56 to +78.89 vs. +0 to +100. However, normalization of the raster layers prior to adding them seems to affect the range with a loss of about 4.77958%. In other words, the ranges produced after the sums were similar to ranges from 0 to 95.22 or 4.78 to 100 instead of 0 to 100. This is possibly due to the margin of error being tripled in the normalization step. Another possibly is the precision loss during rasterization (*i.e.* how coarse the data is, in other words the cell size or resolution). That is why a final normalization is done after the sums.

Finally, within the raster layer's properties window under the Display tab, "Resample during display using:" was set to "Bilinear Interpolation (for continuous data)". This was done to give a more smoothed and less pixelated texture.

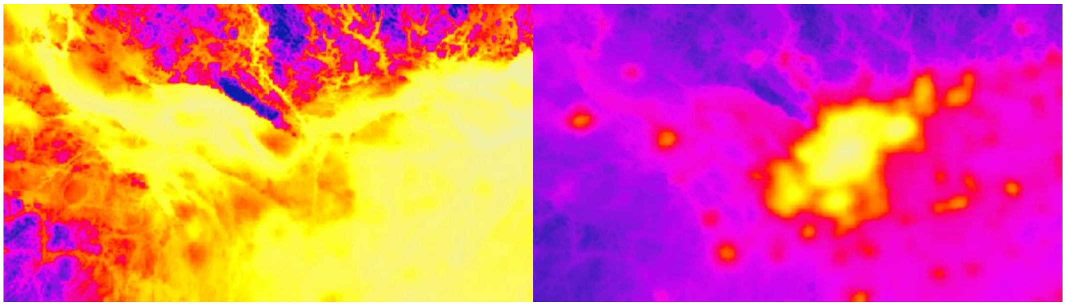

Figure 6*: Comparison between the unnormalized (left) and normalized (right) map.*

The unnormalized version of the map provides a view of how the background light pollution is being spread out. However, centroid sources of the light emission cannot be identified within in. The normalized version provides a view of these localized light emission "hotspots". This can be observed in figure 6. Additionally, the background light dispersal seen with the unnormalized version can also be witnessed (in shades of pink) in the normalized version of the map. The latter variant of the map proves to be visually more informative.

Conclusion

All that remained were the few finishing touches. The last layer for the well-known places (mentioned earlier) had to be added. In order to achieve this, an ESRI base map was temporarily added to find the individual locations. A new layer "Places" was created and each (coarse) location was digitized as a point. Label features were then set to be displayed on the map overlaying the "Light Pollution" raster. Finally in the layout view, all the map elements (title, north arrow, legend, scale, metadata and map composite) were added. A few design adjustments were made to present the map in a clear, simple yet intuitive manner. Observing the map, in the hills about 5 to 6 km ENE (east-northeast) of Luskville seems to be the closest area[5] for optimal star visibility. Hopefully, this will help inform the public about light pollution and help telescope fanatics in their ventures.

[5] This estimation assumes the location of Luskville being at 45°31'51.577"N, 76°2'4.427"W and the area with a pixel intensity value of 5.925% being at 45°33'28.328"N, 75°58'5.046"W.

Data Sources

- Earth Observation Group, NOAA National Geophysical Data Center.
  - http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html
  - http://ngdc.noaa.gov/eog/viirs.html
- NRCAN Open Data, Elevation of Ottawa-Gatineau Region:
  - http://ftp.geogratis.gc.ca/pub/nrcan_rncan/elevation/cdem_mnec/031/
- Ottawa Open Data, "Large Buildings" & "Buildings" in Ottawa-Gatineau Region:
  - https://library.carleton.ca/find/gis/base-layers#OttGat
- Gatineau Open Data, "Lieux publics" (Public) & "Adresses d'immeubles" (other) buildings:
  - http://www.gatineau.ca/donneesouvertes/fiche_metadonnees_en.aspx?id=1267315911
  - http://www.ville.gatineau.qc.ca/upload/donneesouvertes/ADRESSE.zip
- ESRI basemap for general place locations
- "Maison Wright-Scott" Quebec government heritage webpage: http://www.patrimoine-culturel.gouv.qc.ca/rpcq/detail.do?methode=consulter&id=110525&type=bien#

Information References

- Australia Telescope National Facility (ATNF), 2016
  - http://www.atnf.csiro.au/outreach/education/senior/cosmicengine/stars_luminosity.html
- Bortle Scale
  - http://www.skyandtelescope.com/astronomy-resources/light-pollution-and-astronomy-the-bortle-dark-sky-scale/
  - http://www.darkskiesawareness.org/nomogram.php
  - https://en.wikipedia.org/wiki/Bortle_scale
- Wikipedia, "Naked eye" & "Light Pollution"
  - https://en.wikipedia.org/wiki/Naked_eye#Space.2C_geodesy_and_navigation
  - https://en.wikipedia.org/wiki/Light_pollution
- General information on how light pollution affects life:
  - http://www.actionbioscience.org/environment/longcore_rich.html
  - http://physics.fau.edu/observatory/lightpol-Plants.html
- Used photos
  - Photo in figure1 by: Jeremy Stanley, taken in 2007, obtained from: https://commons.wikimedia.org/wiki/File:Light_pollution_country_versus_city.png
  - Photo in figure 2 (photo on right) by David Miko, taken in 2013, obtained from: http://generalfifi.deviantart.com/art/Night-sky-in-Africa-397822297