`darksky` - user manual

1. Overview

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PURPOSE: The program calculates sky brightness in the zenith direction. GHSL data are taken as input (values from 0 to 1). If DEM is provided, the program takes into account shadowing effect. The unit of the results is magnitudo per arcsec squared.

If the program is used, cite following:

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2. Requirements

`Darksky` requires GDAL library and ezGDAL library. Description and tutorial for the GDAL library are available here: http://www.gdal.org/. GDAL library can be downloaded from this address: http://download.osgeo.org/gdal/. Easy GDAL – ezGDAL – library is a layer between GDAL library and the user program. It is available under LGPL license here: http://pawel.netzel.pl/index.php?id=software#a_ezgdal.

3. Obtaining **`darksky`** and installation

Darksky can be downloaded here: http://pawel.netzel.pl/index.php?id=software#a_darksky.

4. Model

The model used in `darksky` is a modified Berry's model. Original Berry's model [1] describes the night sky brightness in zenith in S10 units which is caused by a single light source. The model is based on the following equation:

$$B(D) = a\sqrt{P}\left(\frac{U}{D^2+h^2} + \frac{V}{\sqrt{D^2+h^2}}\right)e^{-k\sqrt{D^2+h^2}}$$

Eq. 1. Berry's model

where B is night sky brightness expressed in S10 units, D – distance from the light source, P – population of the city, which is a light source, h – height of the atmosphere layer in zenith which scatters light down towards the observer. Constants a, U, V, h, k are determined in the semiempirical way to fit the observations. In the original Berry's model, the input data are positions and population of cities, which are assumed to be point-like light sources.

Modifications implemented in [2] and [3] to the original model are as follows:

- input data is the Global Human Settlement Layer (raster map in 100 m resolution)
- calibration constants (a, U, V, h and k) are redetermined
- the shadowing effect is implemented in the model

`Darksky` calculates sky brightness at zenith by calculating contributions from all cells within given radius (see Sec. 5) with Eq. 1. Then contributions are summed up. These calculations are performed for all cells of the output map. Then natural sky brightness is added. Natural sky brightness is set to 250 S10 units which correspond to 21.79 mag arcsec^{-2}. The last step of `darksky` is converting map in S10 units to mag arcsec^{-2}.

4.1 Input data

Input data is the Global Human Settlements Layer (GHSL) [4]. The GHSL is a raster map, which contains information about the percentage of built-up area per spatial unit. The GHSL was created by the European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, Global Security and Crisis Management Unit (http://ghslsys.jrc.ec.europa.eu/).

Values in cells are from a range 0 to 1. This value represents a fraction of a cell covered by built-up area. Additionally, empty cells have value -1. Value -2 corresponds to water (ponds, rivers, lakes). For usage of the GHSL in `darksky`, we changed values -1 and -2 to 0, which means that these cells do not have any contribution to the night sky brightness. The GHSL has a spatial resolution of 100 m and is in Lambert Azimuthal Equal Area projection (EPSG:3035). We have used the GHSL values instead of population P in Eq. 1.

4.2 Calibration constants

Using different input data requires recalibration of the constants a, U, V, h and k. In Tab. 1. consecutive columns show constants, their values in the original mode, their values in `darksky` and physical interpretation.

Parameter	Berry (1976)	`darksky`	Physical interpretation
a	50	2.37583	Luminosity constant
U	2.59 km^2	5,96033 km^2	
V	0.08 km	0.02625 km	
h	2.4 km	1.13661 km	Scattering height
k	0.026 km^{-1}	0.03875 km^{-1}	Absorption coefficient

Tab. 1: Constants used in the original Berry's model and in `darksky`.

Values of the constants used in `darksky` were determined in [3]. Constants were determined using measured values of the night sky brightness and genetic algorithm method. Our tool to calibrate model is based on GALib library [5] . Parameters of a genetic algorithm are as follows: 100 populations, 100 chromosomes, probability of crossover is 0.9 and probability of mutation -0.1. Chromosomes represent the parameters of Berry's model (a, U, V, h, k) and an error of sky brightness estimation is a fitness function.

4.3 Shadowing effect

It is possible to take into account shadowing effect in calculations with `darksky`. For these calculations, it required is to provide the Digital Elevation Model raster map for the selected area. During calculations, `darksky` checks whether light beam from a given light source can reach zenith at height h above the observer or if it is cut off by the terrain. All light sources which are in a shadow of terrain do not contribute to total sky brightness at given observing point. Note, that taking into account this effect increases the time of calculations.

4.4 Output of `darksky`

The output is a GeoTIFF raster map in Lambert Azimuthal Equal Area projection (EPSG:3035) describing sky brightness in mag arcsec^{-2}. It includes natural sky brightness and artificial light sources contributions. Note, that area of the output map is smaller than input maps because at the edges of input maps `darksky` do not have contributions from light sources in given radius.

5. Usage

To see the help on how to run the code type following command:

```
./darksky
```

which prints the following output:

```
Software version: 0.1.5, build date: Jun 23 2017

Usage:
      ./darksky -g <file_name> [-d <file_name>] -o <file_name> [-a <dbl>] [-U <dbl>] [-V
<dbl>] [-h <dbl>] [-k <dbl>] [-N <n>] [--res_x=<dbl>] [--res_y=<dbl>] [--res_h=<dbl>] [-t
<n>] [--help]

  -g, --ghsl=<file_name>    name of GHSL file (GeoTIFF)
  -d, --dem=<file_name>     name of DEM file (GeoTIFF)
  -o, --output=<file_name>  name of output file (GeoTIFF)
  -a, --a=<dbl>             parameter 'a' in Berry's model (default: 2.37583)
  -U, --U=<dbl>             parameter 'U' in Berry's model (default: 5.96033)
  -V, --V=<dbl>             parameter 'V' in Berry's model (default: 0.02625)
  -h, --h=<dbl>             parameter 'h' in Berry's model (default: 1.13661)
  -k, --k=<dbl>             parameter 'k' in Berry's model (default: 0.03875)
  -N, --radius=<n>          model radius in cells (default: 300)
      --res_x=<dbl>         scale factor: column to km (default: 0.1)
      --res_y=<dbl>         scale factor: row to km (default: 0.1)
      --res_h=<dbl>         scale factor: height to km (default: 0.001)
  -t, --threads=<n>         number of threads (default 1)
      --help                print help and exit
```

- The input data is provided after the −g flag in the following way:

  ```
  -g /PathToTheGHSLfile/GHSL.tif
  ```

  Darksky is calibrated to use the GHSL data, which should be provided as a GeoTIFF file. It is, however, possible to use other input dataset in GeoTIFF format. In this case, it is advised to recalibrate the model and to use a different set of constants.

- The digital elevation model is provided after the −d flag in the following way:

  ```
  -d /PathToTheDEMfile/DEM.tif
  ```

  DEM file should be in the GeoTIFF format. Including DEM is not required to run the code. If DEM file is provided, the shadowing effect will be included in the calculations.

- Output file name is provided after the −o flag:

  ```
  -o /PathToTheOutputFile/output.tif
  ```

  The output file is in GeoTIFF format. It is a raster map with values corresponding to the night sky brightness in the zenith. The resultant map includes natural sky brightness set to 250 S10 units.

- By default, darksky uses constants determined by the authors (see Sec. 4.2). It is possible to use other values by typing correspoding flag and constant value. For example:

  ```
  -a 1.0 -U 1.0 -V 1.0 -h 1.0 -k 1.0
  ```

- By default, darksky takes into account light sources in the 30 km radius, which can be also changed using the following flag:

```
--radius=500
```

- By default, `darksky` performs calculations in 100-meter resolution, which fits the resolution of the GHSL data. For a given point it takes into account It is possible to change spatial resolution and height resolution in the following way:

```
--res_x=1.0 --res_y=1.0 --res_h=1.0
```

- It is possible to run `darksky` in multiple threads calculations. To do this add `--threads` flag:

```
--threads 5
```

Example of running the code with default parameters and with the shadowing effect included:

```
./darksky -g /PathToTheGHSLfile/GHSL.tif -d /PathToTheDEMfile/DEM.tif -o
/PathToTheOutputFile/output.tif
```

Then the output is:

```
Input file (GHSL): /PathToTheGHSLfile/GHSL.tif
Input file (DEM): /PathToTheDEMfile/DEM.tif
Output file (sky brightness): /PathToTheOutputFile/output.tif
Berry's model parameters: a=2.375830, U=5.960330, V=0.026250, h=1.136610, k=0.038750
                radius: 300
 - preparing environment ... OK
- calculating ...   9%
```

which sums up selected parameters. The last line of the output shows the progress of the calculations.

References:

[1] Berry R. L., Light Pollution in Southern Ontario, 1976, Journal of the Royal Astronomical Society of Canada, 70, 97

[2] Netzel H., Netzel P., 2015, Journal of Quantitative Spectroscopy and Radiative Transfer, 181, 67

[3] Netzel H., Netzel P., 2018, Journal of Quantitative Spectroscopy and Radiative Transfer, in press

[4] Pesaresi M, Huadong G, Blaes X, et al. A global human settlement layer from optical HR/VHRRS data: concept and first results. J Sel Top Appl Earth Obs Remote Sens 2013;6:2102.

[5] http://lancet.mit.edu/ga/