The MODIS 500-m map of global urban extent

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1. Description of the dataset

The MODIS 500-m global map of urban extent was produced by Annemarie Schneider at the University of Wisconsin-Madison, in partnership with Mark Friedl at Boston University and the MODIS Land Group. The goal of this project was generate a current, consistent, and seamless circa 2001-2002 map of urban, built-up and settled areas for the Earth's land surface. This work builds on previous mapping efforts using Moderate Resolution Imaging Spectroradiometer (MODIS) data at 1-km spatial resolution (Schneider et al., 2003; 2005), which was included as part of the MODIS Collection 4 (C4) Global Land Cover Product (Friedl et al., 2002). Here we addressed weaknesses in the first map as well as several limitations of contemporary global urban maps by developing a methodology that relies solely on newly released Collection 5 (C5) MODIS 500-m resolution data. Specifically, a supervised decision tree classification algorithm was used to map urban areas using region-specific parameters (see Schneider et al., 2009; 2010 for full details on methodology).

The map described here serves as the first stage in our development of a comprehensive database of urban land surface characteristics for 2001-2010. Recent research efforts and feedback from the user community have indicated that finer resolution data and sub-pixel information is needed. Our ongoing efforts are focused on: (1) creating updated maps of urban extent circa 2005-2006 and 2009-2010; (2) creating global maps that provide sub-pixel estimates of urban land use and vegetation; and (3) providing a more refined suite of land surface characteristics for urban areas by differentiating core downtown areas from low density residential areas. In addition, we hope to build on these results to create a globally consistent, validated map of "hot spots" of land cover change in rapidly developing metropolitan areas. Please check back for new developments on these projects in the coming year.

The intended audience for the MODIS 500-m map of urban extent is primarily the academic research community working at regional to global scales on questions related to the geophysical environment; please keep this in mind as you put the data to use.

2. Citing the dataset

We are happy to offer the data free of charge, but we ask that you cite the following publications when you utilize the data:

Schneider, A., M. A. Friedl and D. Potere (2009) A new map of global urban extent from MODIS data. *Environmental Research Letters*, volume 4, article 044003.

Schneider, A., M. A. Friedl and D. Potere (2010) Monitoring urban areas globally using MODIS 500m data: New methods and datasets based on urban ecoregions. *Remote Sensing of Environment*, volume 114, pages 1733-1746.

3. Additional publications

For more information on the accuracy assessment campaign for global urban maps, please see:

Potere, D., A. Schneider, S. Angel, and D. Civco (2009) Mapping urban areas on a global scale: which of the eight maps now available is more accurate? *International Journal of Remote Sensing*, volume 30, pages 6531-6558.

Potere, D. and A. Schneider (2007) A critical look at representations of urban areas in global maps. *Geojournal, Special Issue on Population Distribution*, volume 69, pages 55-80.

If you would like additional information on the MODIS Global Land Cover Map, please see the following publications:

Friedl, M. A., D. K. McIver, J. C. F. Hodges, Z. Y. Zhang, D. Muchoney, A. H. Strahler, C. E. Woodcock, S. Gopal, A. Schneider, A. Cooper, A. Baccini, F. Gao, C. Schaaf (2002) Global land cover mapping from MODIS: algorithms and early results. *Remote Sensing of Environment*, volume 83, pages 287-302.

Friedl, M.A., D. Sulla-Menashe, B. Tan, A. Schneider, N. Ramankutty, and A. Sibley (2010) MODIS Collection 5 Global Land Cover: algorithm refinements and characterization of new datasets. *Remote Sensing of Environment*, volume 114, pages 168-182.

For information on the MODIS 1-km map of Urban Extent (the foundational work for the 500-m map), please see:

Schneider, A., M. A. Friedl, D. K. McIver, and C. E. Woodcock (2003) Mapping urban areas by fusing multiple sources of coarse resolution remotely sensed data. *Photogrammetric Engineering and Remote Sensing*, volume 69, pages 1377-1386.

Schneider, A., M. A. Friedl, and C. E. Woodcock (2005) Mapping urban areas by fusing multiple sources of coarse resolution remotely sensed data: global results, in *Proceedings of the* 5^{th} *International Symposium of Remote Sensing of Urban Areas,* Tempe, Arizona, March 14-16, 2005.

4. Characteristics of the data

Data format:	raster image structure, generic binary format, also called ENVI Standard
Geographic extent:	global; dimensions vary
Data size:	8-bit data, roughly 3.5 gigabytes unzipped

The data is formatted for ENVI software and will open in ArcGIS if the header file is provided. Projection information may have to be set in ArcGIS (or other software) depending on the projection; for parameters, see below.

5. Definition of urban areas and land cover classes

The data are provided for two different classification schemes:

Global Urban Extent (class 13), including land (class 1) and water (class 0) information
Global IGBP Land Cover Map (classes 1-17), including urban extent (class 13)

a. Urban areas

In both datasets, urban areas (coded class 13) are defined based on physical attributes: urban areas are places that are dominated by the built environment. The 'built environment' includes all non-vegetative, human-constructed elements, such as buildings, roads, runways, etc. (i.e. a mix of human-made surfaces and materials), and 'dominated' implies coverage greater than or equal to 50 percent of a given landscape unit (here, the pixel). Pixels that are predominantly vegetated (e.g. a park) are not considered urban, even though in terms of land use, they may function as urban space. Although 'impervious surface' is often used to characterize urban areas within the remote sensing literature, we prefer the more direct term 'built environment' because of uncertainty and scaling issues surrounding the impervious surface concept. Finally, we also define a minimum mapping unit: urban areas are contiguous patches of built-up land greater than 1 km^2.

b. Land cover classes

In the global land cover map, the classes are defined according to the International Geosphere-Biosphere Programme (IGBP) 17-class scheme shown in Table 1.

Table 1: Detailed definitions of 17 land cover classes.

No.	Class name	Description
1	Evergreen Needleleaf Forest	Lands dominated by woody vegetation with a percent cover > 60% and height exceeding 2 meters. Almost all trees remain green all year. Canopy is never without green foliage.
2	Evergreen Broadleaf Forest	Lands dominated by woody vegetation with a percent cover > 60% and height exceeding 2 meters. Almost all trees remain green year round. Canopy is never without green foliage.
3	Deciduous Needleleaf Forest	Lands dominated by woody vegetation with a percent cover > 60% and height exceeding 2 meters. Trees shed their leaves during the dry season; e.g. Siberian Larix.
4	Deciduous Broadleaf Forest	Lands dominated by woody vegetation with a percent cover > 60% and height exceeding 2 meters. Consists of broadleaf trees with an annual cycle of leaf-on and leaf-off periods.
5	Mixed Forests	Lands dominated by woody vegetation with a percent cover > 60% and height exceeding 2 meters. Consists of mixtures of either broadleaf or needleleaf trees and in which neither component exceeds 60% of landscape.

6	Closed Shrublands	Lands with woody vegetation with a height less than 2 meters. The total percent cover, including the herbaceous understory, exceeds 60%. The shrub foliage can be either evergreen or deciduous.
7	Open Shrublands	Lands with woody vegetation with a height less than 2 meters, and sparse herbaceous understory. Total percent cover is less than 60%. The shrub foliage can be either evergreen or deciduous.
8	Woody Savannas	Lands with and herbaceous understory, typically graminoids, and with tree and shrub cover between 30-60%. The tree and shrub cover height exceeds 2 meters.
9	Savannas	Lands with an herbaceous understory, typically graminoids, and with tree and shrub cover between 10-30%. The tree and shrub cover height exceeds 2 meters.
10	Grasslands	Lands with herbaceous types of cover, typically graminoids. Tree and shrub cover is less than 10%.
11	Permanent Wetlands	Lands with a permanent mosaic of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or fresh water. Only wetlands covering extensive areas (i.e., more than 500 km2) will be mapped (e.g., Sud, Okavanga, Everglades).
12	Croplands	Lands where crops comprise > 60% of the total land cover.
13	Urban Areas	See (a) above.
14	Cropland - Natural Vegetation Mosaic	Lands with mosaics of crops and other land cover types in which no component comprises more than 60% of the landscape.
15	Snow and Ice	Lands under snow/ice cover for most of the year.
16	Barren or Sparsely Vegetated	Lands with exposed soil, sand or rocks and has less than 10% vegetated cover during any time of the year.
17	Water Bodies	Oceans, seas, lakes, reservoirs, and rivers. Can be either fresh or salt water bodies. Coded as 0 in the MODIS-based maps.

Note: The number column refers to the digital number value in the raster dataset.

6. Data dimensions and projection parameters

The data are provided in three different projected coordinate systems. The following information is also located in the header file (e.g. image.hdr) associated with each map.

Native Sinusoidal projection

Columns = 86400
Rows = 43196
Pixel size = 463.312714 meters
Layers = 1
Data size = 1 Byte

Upper left x, y = -20015109.354000,10007554.677000 meters
Lower right x, y = 20015106.711349,-10005238.113297 meters
Projection = Sinusoidal
Spheroid = Sphere of Radius 6371007.181 meters (aka GRS 1980 authalic sphere)
False easting = 0
False northing = 0
Central meridian = 0
Latitude of origin = 0
Notes: In ArcGIS, the projected coordinate system *World Sinusoidal* can be used, but the Geographic Coordinate System must be modified to a *GRS 1980 authalic sphere* (under *spheroid*).

Geographic projection (latitude, longitude)

Columns = 86400
Rows = 43200
Pixel size = 0.00416667 degrees (15.0000 arc-seconds)
Layers = 1
Data size = 1 Byte
Upper left x, y = -180.00000, 90.00000 degrees (-648000.0000,324000.0000 arc-seconds)
Lower right x, y = 180.00000, -89.979167 degrees (647985.0000,-323985.0000 arc-seconds)
Projection = Geographic
Spheroid = Sphere of Radius 6370997 meters (aka Clarke 1866 authalic sphere, or Authalic sphere (ARCINFO))
False easting = 0
False northing = 0
Central meridian = 0
Latitude of origin = 0
Notes: In ArcGIS, this dataset will open with the default coordinate system WGS 1984. For correct alignment, the projection information should be set to the geographic coordinate system *Clarke 1866 authalic sphere* (under *spheroid*).

Interrupted Goode's Homolosine projection

Columns = 86400
Rows = 37442
Pixel size = 463.312714 meters
Layers = 1
Data size = 1 Byte
Upper left x, y = -20015109.354000,8673553.108578 meters
Lower right x, y = 20015107.740445,-8673422.693144 meters
Projection = Interrupted Goode's Homolosine
Spheroid = Sphere of Radius 6371007.181 meters (aka GRS 1980 authalic sphere)
False easting = 0
False northing = 0
Central meridian = 0
Latitude of origin = 0
Notes: In ArcGIS, the projected coordinate system *World Goode Homolosine Land* can be used, but the Geographic Coordinate System must be modified to a *GRS 1980 authalic sphere* (under *spheroid*).

Important notes:

The *upper left x, y* and *lower right x, y* values are associated with the center of the pixel. Different software packages define coordinate information as either the center or the edge of a pixel; please see specific software documentation for details.

7. Reliability and accuracy of the data

The MODIS 500-m map of global urban extent has undergone a rigorous assessment of accuracy prior to its public release. The results of this investigation are described fully in Schneider et al., 2009; 2010; Potere & Schneider, 2007; 2009).

8. Downloading the data

All data are available for download at:

https://uwmadison.box.com/v/modis500m

Download the files and the readme information. Note that the size of the zipped dataset is 12-100 mb, but upon unzipping is roughly 3.5 gigabytes.

9. Frequently asked questions

a. Can these maps be used to depict urban expansion or urban growth?

No. These maps are a static view of urban extent circa 2001 - they depict one point in time. There is *no information on urban growth/expansion*. The coarse spatial resolution (500 x 500m pixel) makes it difficult to detect change or urban expansion -- a large amount of land conversion has to occur in order to convert an entire 'big' cell to the urban category. It is a tricky issue. We have recently just completed maps of urban expansion for Asia, 2000-2010, using 250 m data; these will be available for download soon.

If you do use the MODIS land cover maps available for each year (e.g. from the EROS data center), the urban area class is the same as the circa 2001 map. We were not able to make a map of urban extent for each year, so we used the 2001 urban extent map for each land cover map from 2000 to 2010. This is not ideal, but is the best we could do given time and resources.

b. Why do the maps look coarse and blocky when zomed in to a local area?

These data are intended for regional and global use, so a lack of detail at a local scale is to be expected. In other words, the pixels are pretty big relative to urban features. This issue of resolution will generally have a very large impact on your analysis if you use these maps to assess maps at higher spatial resolution (e.g. maps of urban areas made with Landsat or finer resolution data). Any work with Landsat imagery or Google Earth will likely provide a more detailed, potentially more accurate view of urban extent than these maps.

Note that it is not good practice to use a coarse resolution dataset to validate or check the accuracy of a high resolution dataset. However, I realize that sometimes a quick check of a new map is important, so the MODIS maps may still be useful. Please use your best judgment.

c. Are there maps that might be a better choice for cartographic purposes?

Because the maps are intended for global applications, the dataset can appear pixelated when used for cartographic purposes. Thanks to Nathanial Kelso, there is a wonderful version of our data available at http://www.naturalearthdata.com. Go to

http://www.naturalearthdata.com/downloads/10m-cultural-vectors/

Scroll down to Urban Areas and click to download.

While these data are quite pretty when used in background maps, the smoothing process that is applied causes the actual area of urban land to shrink fairly substantially. In other words, even more detail is lost.

d. Are there new datasets available?

Yes. We have released a new dataset depicting urban extent c 2000 and 2010 at 250 m resolution (Schneider et al., 2015; Mertes et al., 2015). These data are now available for East and Southeast Asia. We are currently working on similar maps for the remaining global land area.

e. How accurate are the maps, really?

We have several additional papers describing these datasets, and comparing our maps to a range of other sources (Potere et al., 2007, 2009; Friedl et al., 2002, 2010, etc.). To download, please go to:

http://landcoverchange.com/gallery_post/publications/

I look forward to your feedback on the map (if any). If possible, it would be wonderful if you could send along information on results and any publications as they become available.

10. Contact information

All comments, questions and concerns should be directed to:

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