Mapping elements at risk from global to local level: the capabilities of remote sensing now and in the past

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Abstract

For a comprehensive and accurate risk assessment of multiple disaster types, understanding of both hazard and vulnerability components is essential. While the definition of hazards is well understood in today's scientific community, vulnerability still presents an ill-structured concept as it is both hard to define but also essential to measure for a comprehensive risk analysis due to the large-scale extent of human activities and thus exposed elements on our planet (Taubenböck et al., 2008). A definition that is exhaustively used for the term exposure in the earthquake and landslide risk community describes elements at risk, which are understood as objects potentially adversely affected such as people, properties, infrastructure or economic activities) (Geiß & Taubenböck, 2012). In this context, remote sensing holds great potential for the large-scale capturing of elements at risk on various spatial scales and the quantification and analysis of associated vulnerability indicators.

Mapping elements at risk from space

The product portfolio of EO derived geo-products has evolved from low resolution land cover datasets to high resolution spatially accurate building inventories. On the regional and global scale, remote sensing derived geo-products help to approximate the inventory of elements at risk in their spatial extent and abundance by mapping and modelling approaches of land cover or related spatial attributes such as night-time illumination (e.g. Elvidge et al., 2009) or fractions of impervious surfaces (e.g. Elvidge et al, 2007). Thus, remote sensing applications that use low to medium resolution data on this scale are limited to the mapping of large-scale human and physical exposure. In this regard, various geospatial information layers and approaches to model and assess situation-specific physical and human exposure are have been presented (Aubrecht et al., 2012) and validated (Potere & Schneider, 2009; Potere et al., 2009) in the past. On a local scale, the potential of remote sensing particularly lies in the generation of spatially accurate building inventories for the detailed analysis of the building stock's physical vulnerability (French & Muthukumar, 2006; Mueller et al., 2006; Taubenböck et al., 2009). Vulnerability-related indicators have been derived in various landslide- and earthquake-related studies and include building footprint, height, shape characteristics, roof materials, location, construction age and structure type (Geiß & Taubenböck, 2012). Especially last generation optical sensors featuring very high geometric resolutions are perceived as advantageous for operational applications, especially for small to medium scale urban areas (Deichmann et al., 2011).

With regard to user-oriented product generation in project SENSUM, a multi-scale and multi-source reference database has been set up to systematically screen available products with regard to data availability in data-rich and data-poor countries. From the final database content (figure 1), it becomes clear that data-poor countries of central Asia mainly rely past international mapping efforts using coarse resolution products of global coverage which, however, provide multi-category thematic detail. In contrast, medium and high resolution datasets are spatially restricted to the European test sites due to trans-European mapping efforts initiated there. However, two currently developed global products – namely DLR's Global Urban Footprint (Esch et al., 2013) as well as JRC's Global Human Settlement Layer (Pesaresi et al., 2013) – will be a major leap forward regarding the derivation of high resolution and accurate reference data for human exposures on a global scale – as they will provide consistent and geometrically detailed land cover information at unprecedented spatial resolutions. Furthermore, a viable option for future research and applications is presented volunteered geographic information (VGI) by crowd-sourcing of extensive mapping communities such as the Open StreetMap project. Since data availability in regions such as Central Asia is rather poor and mainly limited to global mappin efforts the paper gives a brief but comprehensive review of the available datasets.

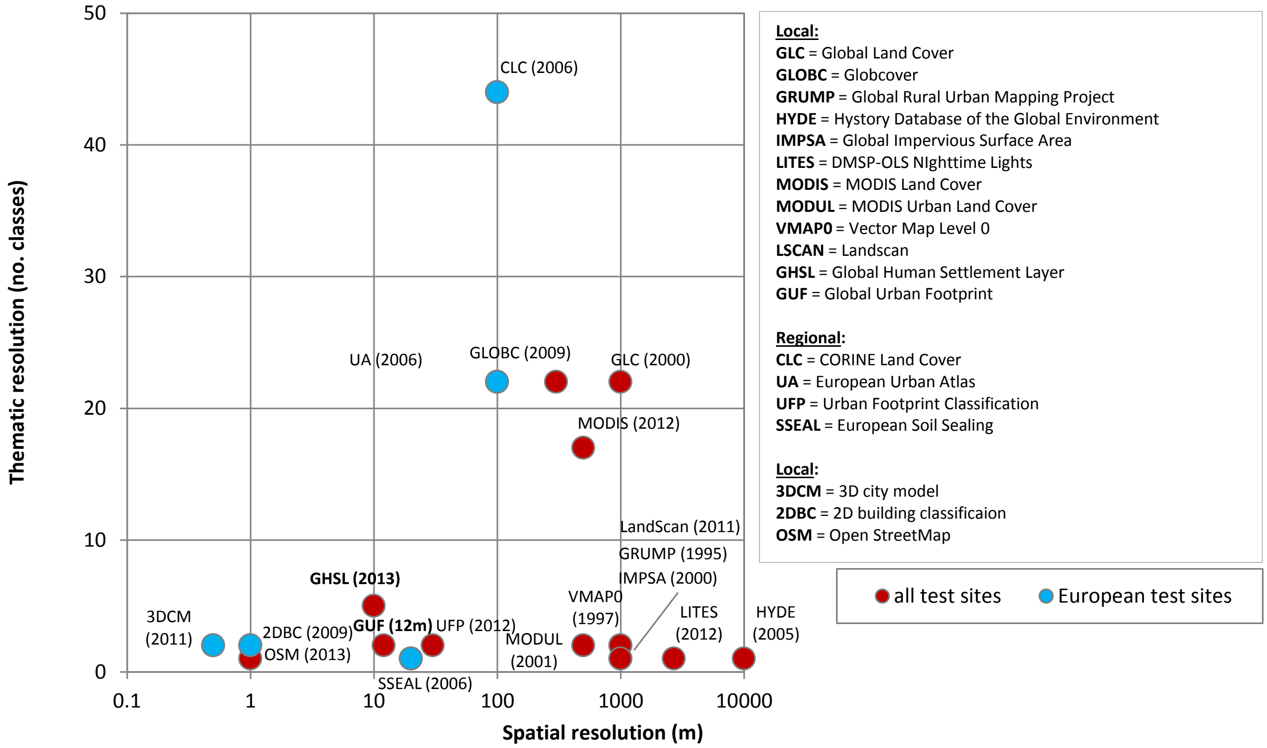


Fig. 1 Overview of datasets with regard to thematic/spatial resolution, reference year and spatial coverage

Review of global exposure datasets

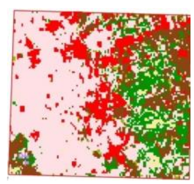
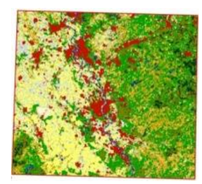
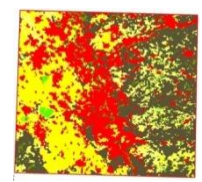
Accurate and up-to-date global land cover data sets can provide a valuable first level approximation of human developed land prone to or affected by a possible natural hazards. In recent years, substantial advancement has been achieved in generating such multi-category land cover products on the global scale:

The Global Land Cover 2000 (GLC) has been initiated by the European Commission's Joint Research Center (JRC) (JRC, 2003). The database contains a detailed, regionally optimized land cover data base for each continent and a less thematically detailed global legend. The datasets are mainly derived from daily data from the VEGETATION sensor on-board SPOT-4. The land cover inventory covers a range of 22 thematic classes including one for artificial surfaces and associated areas at a geometric resolution of 30 arcseconds (ca. 1km). The map was derived applying a "regionally tuned" supervised classification method on combinations of multispectral and multi-temporal EO data (Bartholome & Belward, 2005). Due to its long-time existence the GLC product has been thoroughly tested in previous validation efforts. Mayoux et al. (2006) analyzed the classification accuracy using ground observations, previously generated land cover maps and high-resolution satellite imagery for stratified random sampling of reference datasets stating a global overall accuracy of 68.8 percent.

GlobCover is a global land cover product that has been first published in 2005 and updated in 2009 under the lead of the European Space Agency (ESA). With a spatial resolution of ca. 300m it provided the very first medium resolution global land cover in 2005 (ESA, 2010). Like GLC it features 22 thematic land cover classes, one dedicated to artificial surfaces and associated areas defined as pixels having an urban area percentage of greater than 50 percent. GlobCover employs automated land cover classification by a sequential execution of regional stratification, spectral clustering, and rule-based class labelling using data from the Medium Resolution Imaging Spectrometer (MERIS) on-board ENVISAT. ESA (2011) has validated the GlobCover product by setting up a reference dataset of random points collected from various external information sources (e.g. Google Earth, Virtual Earth, Open StreetMap, SPOT-4 VEGETATION, etc.) and state an overall thematic accuracy of 70.7 percent. Potere & Schneider (2009) determine even higher overall accuracies exceeding 96 percent for urban areas and a strong agreement with the GLC dataset by inter-map comparison.

The MODIS Land Cover Type by the United States Geological Survey (USGS, 2013) is updated annually and contains five classification schemes based on data of the Moderate Resolution Imaging Spectrometer (MODIS) on-board the National Aeronautics and Space Administration's (NOAA)Terra and Aqua satellites. Its primary legend established in the context of the *International Geosphere Biosphere Programme (IGBP)* identifies 17 land cover classes, one dedicated to urban and built-up areas. The data is provided at a geometric resolution of 15 arcseconds (ca. 500m) and has been derived based on a supervised decision-tree classification method using multispectral and thermal input data as well as ancillary such as Landsat or Geocover 2000 imagery for training and classification refinement. Results from a cross-validation conducted by Friedl et al. (2010) indicate an overall thematic accuracy of 75 percent with a relatively wide range of class-specific accuracies.

Table 1 Overview of global multi-category landcover datasets

	Global Land Cover	Globcover	MODIS Land Cover
Quicklook			
Spatial resolution	1,000m	300m	500m
Thematic resolution	22 thematic classes (1 urban)	22 thematic classes (1 urban)	17 thematic classes (1 urban)
Year	2000	2005 / 2009	2012
Originator	JRC	ESA	USGS

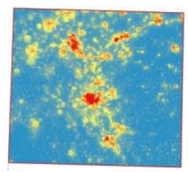
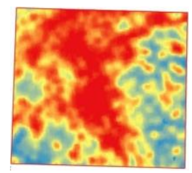
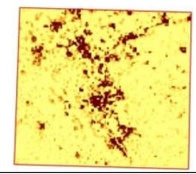
On the regional and global scale, remote sensing can further be employed to map spatially continuous variables related to human exposure and thus, approximate the inventory of elements at risk in their spatial extent and abundance. Spatial attributes commonly related to human activities are for example night-time illumination and the degree of soil sealing or artificial surfaces (Table 2):

The Global Impervious Surface Area (IMPSA) presents the global distribution and density of impervious surfaces at a spatial resolution of 30 arcseconds (ca. 1km) (Elvidge et al., 2007). For product generation, it mainly uses coarse resolution input data such as the DMSP-OLS Nighttime Lights time series from the reference years 2000 and 2001 as well as the LandScan 2004 gridded population database. Schneider and Potere (2009) thresholded IMPSA to determine urban extents and derived an absolute accuracy measures of 97.5% inlcuding low errors of commission and omission. In addition to that Elvidge et al. (2007) found a significant correlation between reference data of the United States and IMPSA, however, state a moderate over-classification in states of small but highly urbanized areas (urban hotpsots).

The Operation Linescan Sensor (OLS) oboard the Defense Meteorological Satellite Program's (DMSP) satellites records time series monitoring the intensity of stable lights of the earth's surface and thus provides useful for measuring stable human settlements and spatiotemporal urbanization through this indicator (Elvidge et al., 2009). Since 1992, several nighttime light products have been derived, one of them being a global cloud-free coverage especially designed to detect changes of human emitted lighting and thus, spatiotemporal urbanization processes. Although featuring a coarse resolution of roughly 1 km the dataset has been widely employed in modelling the spatial distribution of population or human activity and has been used as input to many other global land cover products (Potere et al., 2009).

LandScan is a commercial global population distribution dataset providing information in gridded format produced by the Oak Ridge National Laboratory (ORNL). It is today the highest resolution global population global database regarding spatial population distribution (ORNL, 2013) and data has been widely applied for modelling the spatial distribution of human assets at risk (Dobson et al., 2000). At 30 arcseconds (ca. 1 km) LandScan maps the **ambient population** averaged over 24 hours. It uses high resolution EO imagery from sensors such as SPOT as well as various additional data sources such as EO derived land cover products, roads and populated places, digital terrain models (DTM), nighttime lights as well as national and subnational population statistics for disaggregation through a multivariate dasymetric modelling approach. To verify and validate the modelling approach Dobson et al. (2000) quantified the correspondence with highest resolution census counts for the South western United States (87.8 percent) and Israel (91 percent).

Table 2 Overview of global maps representing spatially continuous variables related to human exposure

	Global Impervious Surface Area	DMSP-OLS Nighttime Lights	Landscan
Quicklook			
Spatial resolution	1.000m	1.000m	1.000m
Thematic resolution	Impervious Surface fraction (%)	Intensity of stable lights (DN x percent frequency)	Ambient human pupulation (count per gridcell - 24h avg.)
Year	2000/2001	1992-2013	2010-2012
Originator	NOAA	NOAA	ORNL

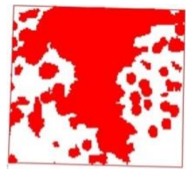
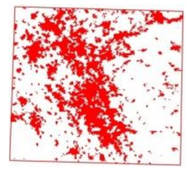
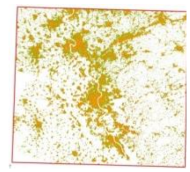
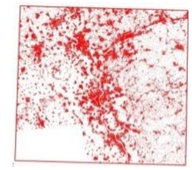
Although a clear and univocal delineation of urban areas is not trivial at a global scale due to significant variations of thematic definitions associated with this term (Taubenböck et al., 2012), the goal of many global urban mapping efforts is the generation of current, consistent and seamless maps of urban, built-up and settled areas for the Earth's land surface. In this regard, Potere and Schneider (2009) and Potere et al. (2009) give a thorough review of some of these maps of global urban extent listed in table 3.

The Global Rural-Urban Mapping Project's Urban Extent layer which was last updated in 1995 is a low resolution map elaborated by the Columbia University's Socioeconomic Data and Applications Center (SEDAC) representing binary information on the existence of global / rural extents (SEDAC, 2013). The product was derived using NOAA's DMSP-OLS nighttime light product from the reference period1994 to 1995 to detect stable human settlements. Furthermore, ancillary data was provided by the Digital Chart of the World's (DCW) populated places inventory for initial localization of human settlements at a scale of 1:1,000,000 (SEDAC, 2013). In addition to that, for areas of inadequate or limited electrical power sources the urban extents were extrapolated using a population-area ratio. In their investigations, Potere and Schneider (2009) as well as Potere et al. (2009) compared GRUMP to Landsat derived reference maps of urban extent from 140 cities around the globe and found overall accuracies of 84 percent – the lowest for all datasets assessed – featuring very high errors of commission and low inter-map agreement to other global products.

The global MODIS Urban Land Cover map was produced at the Center for Sustainability and the Global Environment (SAGE) at the University of Wisconsin-Madison (Schneider et al, 2009 & 2010). The higher-ranking goal of this project was to produce a seamless map of urban extent for the years 2001 and 2002. In this context urban, areas are defined as places that are dominated by the built environment which include a mix of human-made surfaces and materials greater or equal to 50 percent of a pixel. For spatial derivation multispectral MODIS data of 500m geometric resolution were employed through a sequential execution of region-specific stratification of eco-regions, decision tree classification based on training data from manual interpretation, and posteriori exploitation of class membership functions for classification optimization (Schneider et al., 2010). Using the same reference maps as for GRUMP the dataset yields an overall per-pixel accuracy of 93 percent (Kappa=0.65) (Schneider et al., 2010).

In this context mapping global urban extent, the two currently developed global products promise to be a major leap forward regarding the derivation of high resolution and accurate reference data for human exposures on a global level. With the GUF and the GHSL both featuring a spatial resolution of $\leq$ 12m these layers will provide consistent, up-to-date and geometrically detailed land cover information on unprecedented spatial detail in the near future. However, both layers are still in the phase of testing and refinement. Thus, validation efforts and analysis on the absolute accuracies are currently investigated by DLR to gain a stronger understanding of each map's strength and weakness.

Table 3 Overview of new and existing global maps of urban extent

	Global Rural Urban Mapping Project	MODIS Urban Land Cover	Global Human Settlement Layer	Global Urban Footprint (GUF)
Quicklook				
Spatial resolution	1.000m	500m	0.5-10m	12m
Thematic resolution	Urban / Non-urban	Urban / Non-urban	Urban / Non-urban	Urban / Non-urban
Year	1995	2001/2002	2011-2013	2011/2012
Originator	SEDAC	SAGE	JRC	DLR

Conclusion

The review of existing products capable of localizing human exposure on a global scale highlights the need for higher resolution data especially for large-scale urban landscapes of varying structural character, especially in remote, data-poor regions of the earth. First generation global land cover datasets and map representation of spatially continuous variables related to human exposure have been mainly produced based on coarse resolution satellite sensors such as MODIS or DMSP-OLS in the range of 300m to 1,000m. In contrast, the GUF and the GHSL present current mapping efforts employing finer scale optical and radar imagery which will provide information on global urban extent at an unprecedented geometric resolution and detail.

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