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EDITORIAL

Measuring and understanding global human settlements patterns and processes: innovation, progress and application

Human settlements – the places where people live and work – are rapidly evolving. Some of the processes driving the physical changes in human settlements are population and economic growth, rural-urban migration, and *in-situ* urban transformation that also includes the envelopment of small settlements by larger ones and land-expansive development. In some parts of the world, particularly the global South, urbanization occurs at rates that generate unprecedented city sizes (WUP 2018). With increasing city size comes unprecedented challenges including air pollution, uncontrolled and unplanned urban growth, and the need for improved efficiency in the transport sector as well as in fuel and energy consumption. Concomitant with these changes, small cities and towns are expected to experience rates of growth that may be unparalleled historically. In high income countries, settlements' spatial size may increase with little demographic influence due to increased demand for services or personal living space. Yet, even when settlements do not grow physically, their impact on the local and global environment may still increase, when change is associated with increased energy and material consumption and associated increased waste and pollution production, juxtaposing the requirements and quality of urban living with the challenges of urban and even global sustainability.

Traditional methods of collecting information on settlements may not deliver the needed information. For the most part – and where economic and political circumstances are conducive – information on human settlements has been generated for use at local or subnational levels because most decisions are taken at such scales. Statistical agencies have long been central to the collection and dissemination of information about the demographic character and socioeconomic well-being of the population (United Nations 2017) though not necessarily at the city-scale (Montgomery et al. 2003; Montgomery and National Research Council (U.S.) 2003). More recent attention from the physical sciences community is calling attention to the need for globally-comparable human settlement information (Acuto, Parnell, and Seto 2018). In fact, increases in size and activities of human settlements from an ever expanding economy also affect regional and global socio-economic processes such as human migration, as well as air pollution and carbon dioxide emissions, that need to be accounted for also at the global level (van Vliet, Eitelberg, and Verburg 2017). In addition, the request for information is also driven by the need to cover data poor regions of low income countries where the coverage of the information is rarely available outside the largest cities (Farrell 2017).

The demand for global information on settlements is addressed in this special issue and shared with the Human Planet Initiative (HPI), an activity promoted by the Group on Observation (Ryan and Ochiai 2017) that aims to foster the use of Earth Observation for societal benefit. HPI rests on the premises that the growing human presence and impact on planet Earth and the ensuing societal challenges call for actionable settlement information that should be made available as open and verifiable data, ideally through a network of cooperating institutions. In addition, the project recognizes that the EO based information needs to be integrated with statistical demographic and socio-economic records, and generated from new data sources including that of voluntary geographic information and human sensors on the move such as from mobile phones. The HPI aims to measure and monitor human presence on planet Earth and to improve the understanding of human activities and societal processes in settlements and their hinterlands, through the integration of global information layers and through modelling. The final aim of HPI is to disseminate information to a community of users and decision makers at all levels, also through the development of human settlement indicators. These three objectives are touched upon by the papers in this special issue on human settlements.

Central to the global analysis of settlements is the quantification of the built-up area (Pesaresi, Ehrlich, et al. 2016) or built-up land (Balk, Leyk, et al. 2018) referring to the physical space occupied by buildings and manmade constructions. To meet the demand for such information, the EO research community has been engaged in generating spatial–temporal built-up datasets from a variety of data sources, aiming initially to map the larger urban areas and the general built-up areas. Early attempts used coarse resolution sensors including MODIS (Schneider 2012), NOAA Nightlight imagery (CIESIN 2011; Zhou et al. 2015) and MERIS imagery (Arino et al. 2012). These coarser products were used to generate the second generation finer scale global built-up information products, that include the urban class in global land cover maps (Gong et al. 2013) the Global Human Settlement Built-Up layer (GHS-BUILT, Pesaresi, Ehrlich, et al. 2016) and the Global Urban Footprint (Esch et al. 2013). These newer, finer resolution products, now start to provide a more complete assessment of the human presence on Planet Earth (Florczyk et al. (2019), in this issue) and may be used to measure the spatial continuum (Uhl et al. 2019) between the smaller and the larger settlements.

The built-up area, through 'the distribution of buildings by which people attach them- selves to the land' (Stone 1965), is also used as a spatial variable to model socio-economic parameters in human settlements. The built-up land is independent from administratively delineated areas or those derived from proxies of economic activities (such as, night-time lights data), each with value of their own. In fact, the temporally and spatially-explicit built-up measures are necessary inputs into a number of modelling activities that attempt to integrate datasets with different spatial units (Balk et al. 2006). For example, built-up is considered an important spatial proxy for disaggregating census population data to generate global gridded population datasets. Global built-up was used to produce the Global Human Settlement Population grids (GHS-POP; Freire et al. 2015), and is considered one of the most important variables in the production of population grids produced in WorldPop data collection (Tatem 2017). Some of the challenges of disaggregating population through combining demographic census data with proxy variables of population presence are addressed by Freire et al. (2018) in this issue.

The population grids and the built-up are considered essential variables, reflecting demographic and socioeconomic conditions, as they are used often in combination to address societal information needs (Ehrlich, Kemper et al. 2018). For example, GHSL BUILT and GHSL-POP layers are used together to measure the spatial extent of settlements globally in the Degree of Urbanization (Dijkstra and Poleman 2014) that partitions settlements information in classes based on population size and density along with built up density. The class with the highest population density, the 'urban centres', account for 13,000 spatial units in the year 2015. These spatial units have also been measured for other epochs and allow changes to be estimated in urban spatial extent over time (Melchiorri et al. 2018).

Understanding settlement patterns and change relies on measurements and on the development of robust spatial–temporal models for capturing and describing settlement spatial dynamics and integration with settlements' characteristics. Statistical information collected from demographic and health surveys and national censuses may be integrated in built-up and population grids. For example, natural hazards and vulnerability information combined with settlements are used to quantify exposure, needed to address disaster risk (Ehrlich, Melchiorri et al. 2018). Gridded Gross Domestic Product (GDP) is produced from population density grids and from GDP figures available at the national level (Kummu, Taka, and Guillaume 2018). The 13,000 urban centres spatial units derived from the Degree of Urbanization data have been attributed with urban carbon footprint (Moran et al. 2018), green urban areas (Corbane et al. (2018), in this issue), and used to map the travel time to city centres globally (Weiss et al. 2018). Built-up data used together with radar data, and population census data, have been used to assess the socioeconomic correlates and implications for use of energy of a volumetric and lateral expansion in Greater Saigon (Balk, Nghiem et al. 2018).

1. Papers of this special issue

This special issue presents eight papers that focus on key scientific challenges addressing the measurement and understanding of human settlements. Moore and McKee (2019) focus on improving the extraction of built-up from medium resolution Landsat imagery. The authors address the challenge of capturing the seasonal measures of vegetation or snow cover as measured from Landsat imagery on the extraction of built-up areas. The analysis is based on multi-temporal image datasets over selected cities in different ecological zones. The analysis benefits from high-quality ground reference data used in validating the results. The exercise provides important insights which can be used for expanding the processing to the global land masses and, in so doing, improving the extraction of relevant built up information for future analysis.

Uhl et al. (2019) address the advantages and shortcomings associated with the different information sources used in mapping settlements and to analyse the spatial extent from the largest to the smallest settlements along a rural-urban continuum. Their research integrates EO-derived built-up measures, census data and cadastral data and aims to shed light on the new definitions of urban and rural areas and improvements of the underlying methods for generating this data.

Florczyk et al. (2019) combine the built-up information from eight different global built-up maps to generate a 'generalized settlement area' with a view to maximize the likelihood of capturing all built-up at global level. Their research also compares the eight built-up information datasets and generates indicators of agreement of settlement space. The findings show that the products generated from medium resolution satellite imagery are better able to capture the global built-up when compared to the first generation products from coarse resolution imagery.

These assessment papers above collectively improve our knowledge of the built-up features of human settlements across the globe. They show that while the built-up area extents generated are not perfect, they are a valuable source of data for global level comparison and monitoring, even considering the enormous diversity of biophysical and socioeconomic conditions that exist globally.

Population gridding based on built-up information is addressed in two papers.

Freire et al. (2018) address the challenges in producing spatial population grids, and in particular that originating from discrepancies and anomalies embedded in census datasets. It also addresses the notoriously flawed administrative boundaries, especially in proximity of coastal areas. Stevens et al. (2019) provide insights on how the available built-up information products affect the ability to predict population density and distributions. The paper stresses that built-up data are very often the most important predictor of populated places and better insights in their accuracies may help in improving population density grids. However, other population predictors – when available – can provide superior results as shown for a number of countries addressed in the paper.

The paper by Corbane et al. (2018) presents a systematic measurement of green areas over the period 1990–2014, across 13,000 urban centres globally, using the Landsat image archives. To date, no global data set on cities measures their 'greenness'. This paper highlights that core urban centres contain a substantial amount of vegetated areas that is often neglected in the analysis of urban areas. Their work shows that the average levels of greenness in many cities has increased, though patterns of greenness exhibit considerable spatial and temporal variability between and within cities and between cities and their hinterlands.

Roy Chowdhury et al. (2019) correlate settlement patterns from a selected number of cities to VIIRS satellite nightlight imagery to analyse energy consumption associated to specific settlement structures. While the paper is limited to a few cities, the methodology and procedure sheds new light on future attribution of settlements related to energy consumption, possibly inferred also by nightlight emissions captured by satellites.

Finally, Esch et al. (2018) introduce the technologies underpinning the Urban Thematic Platform that aims to facilitate the use of EO through web based services. It aims at different user communities addressing settlements analysis and decision making and supports three types of uses. First, it provides a computing space for image processing specialists to process large data volumes and data streams; second, it provides access of open information products on settlements grouped under specific windows; and, third, it facilitates the dissemination of information and results to potential decision makers. This paper is a welcome introduction on a changing paradigm to process, access and explore global urban data.

2. What's on the horizon?

Measuring and understanding human settlements patterns and their development processes is at the core of understanding human activities and societal functioning. The availability of EO image archives, of new information extraction technologies based on Artificial Intelligence and on expanded data processing platforms, provides new opportunities to generate new geo-spatial knowledge at a global scale. This current collection of papers provides a glimpse of some of the current cutting-edge developments and applications in EO for global human settlements mapping. This is a rapidly developing field of research, generating important new data sets to support policy development on the sustainability and resilience of human settlements globally. We envisage that more papers on human settlements patterns and processes will be forthcoming as the field further develops and expands into new application areas.

We look forward to future improvements in the extraction of information that will be coming from Big Data Earth Observation (EO) data archives (Corbane et al. 2017) and the incoming open source EO data streams. We look forward also to the challenges of extracting built up information globally from the very high-resolution image archives that may be made available in the near future. Improving the precision and accuracy of the built-up extraction from EO will remain a challenge for image processing, in light of the new image data streams that are being generated from the new imaging platforms. The papers here focus on the lateral expansion of settlements, but future work will also need to use new data to examine the vertical or volumetric changes that occur as small towns become cities and large cities become even larger and denser.

Integrating information from different datasets expands the possibility to meet the demand for data required in modelling physical and socio-demographic processes on climate emissions, urban land expansion, and economic growth. For example, settlement information can be integrated with material and energy flows to address the sustainability of resources, including energy, water and food. Environmental resilience information combined to settlements is used to derive policies of adaptation to global environmental change. Settlement information can be integrated with that of particulate matter concentration to assess air quality in cities across the globe and the hazard to human health that it generates. Settlements spatial extent can be used to store a number of attributes such as those made available by the city database as summarized in (EC 2018).

Settlement data need to be communicated and disseminated to different communities of users. Data need to be made available to scientists and practitioners that can build on these information products to produce new knowledge. Information and data should be communicated to policy makers. Many international frameworks the Sustainable Development Goals (UN General Assembly 2015), the Sendai Framework for Disaster Risk Reduction (UNISDR 2015), Paris Climate Agreements (United Nations Framework Convention on Climate Change 2016), and the New Urban Agenda (UN General Assembly 2017) all require human settlements information to feed indicators. The settlements information addressed in this special issue provide an initial, globally consistent, source of data for repeated monitoring. Findings on settlements should also be available to a non-specialized community of users that may use settlement information in reports, atlases – including those of the Human Planet Atlases (EC 2018; Pesaresi, Melchiorri, et al. 2016; Pesaresi et al. 2017) and dynamic visualization addressing the impact of human activities on the planet.

This special issue does not cover all aspects of EO research related to human settlements; its focus has been on work that is directed at global level data set production and analysis. The collection represents a large part of the current initiatives from research groups working in this area but may not be complete in all respects. Moreover, the collection does not include the vast amount of contemporary work on locally-based studies in which EO methods are being developed to improve urban data extraction in a myriad of ways. Such work, however valuable in its own right, was deliberately excluded from this special issue, though it too, may in time provide insights and methods that are also useful for global level human settlement analysis.

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