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New dimensions of urban landscapes: The spatio-temporal evolution from a polynuclei area to a mega-region based on remote sensing data

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A B S T R A C T

Currently our world is facing a migration process of a huge dimension – from rural to urban areas. In 1975 37.7% of the global population were urban dwellers, 1990 already 43%, today little over 50%, and in 2050 the expected number is 67.2%. This great process shapes new spatial urban landscapes, in dimension and pattern. In this study we aim at analyzing the spatial evolution of a once polynuclei urban area to a mega-region in a 35 years time frame. Using multi-temporal and multi-source satellite data we classify urban footprints of a mega-region – the Hong Kong–Shenzhen–Guangzhou mega-region in Southern China – for the years 1975, 1990, 2000 and 2011. Based on this geospatial data set we aim at turning the qualitative and fuzzy definitions of mega-regions into a physical concept. Furthermore, we suggest a set of spatial features potentially characteristic for the evolution of mega-regions. In particular we apply and develop a multiude of spatial metrics at three spatial levels, namely the entire mega-region, the hinterlands between different cities and the cities themselves. The result is a novel spatial approach to capture, measure and analyze new shapes of urban landscapes.

Introduction

What shape do cities take? From the perspective of geography the city can be a physical place and can be measured by its size, volume or shape. Basically when we imagine the urban fabric we think of a dense center surrounded by a more or less complex halo of lower-rise buildings and suburbs. However, the dramatic urbanization now globally under way constitutes an epochal transformation. With the number of urban residents exceeding the rural population (UN, 2012), our world is inexorably becoming urban. Nevertheless, the physical, environmental, social, economic and political implications of this urban revolution are only beginning to be grasped, documented and analyzed by contemporary science (Lefebvre, 2003). Focusing on the physical expansion of cities Hollis (2013, p. 416) questions "….will the megalopolis grow so vast that it loses its center, continue to expand without end, making it impossible to identify the border between city, suburb, exurb or townscape? Will the endless expansion force us to rethink what a city is?"

Despite spatial growth and expansion of urban areas has long been studied at the local scale, the effects and change processes beyond a regional scale of urban expansion are virtually unknown. Especially as new dimensions and types of settlements and respective large-area urban landscape pattern are evolving. To classify these areas new concepts such as *mega-regions* or *urban corridors* are suggested (UN-Habitat, 2008, p. 244; cp. chapter 2). However, our understanding of urbanization at these scales is primarily based on United Nations population figures (e.g. UN, 2012), but these statistics do not provide information on the distribution, pattern, and evolution of the built environment (Zhang & Seto, 2011).

While the spatial dimension, connectivity or dynamics of large urban landscapes or systems can be studied based on various data such as on topographic maps, street networks, commuting, land use among many others, these data are seldom consistently available in space and time. Remote sensing data and techniques have already proven useful to provide a physical and consistent perspective on settlement patterns. With its synoptic views in space and time earth observation offers the capacity for mapping and periodic monitoring of large urban agglomerations such as mega-cities or mega-regions at various scales. Remote sensing information is hence of particular relevance in the world's developing countries because it provides fundamental information on growth related processes and their effect on the urban environment that are not available from other sources (Miller & Small, 2003), especially when areas to be considered become as large as 100s of km.

However, global urban maps relying on optical satellite data are available only at comparatively coarse resolution (Potere &

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Schneider, 2009) with a maximum spatial resolution of roughly 300 m (e.g. Bartholome & Belward, 2005; Bontemps et al., 2011; Elvidge et al., 2001; Schneider, Friedl, & Woodcock, 2005); hence naturally capturing the large areas of mega-regions. However, the products still lack appropriate temporal, spatial and/or thematic resolution to effectively support detailed analyzes on the characteristics of urban and especially peri-urban settlement patterns and their evolution. Currently, new EO initiatives aim at improving the geometric level for global urban mapping based on optical (Miyazaki, Shao, Iwao, & Shibasaki, 2012; Pesaresi et al., 2013) or radar data (Esch et al., 2012, 2013; Esch, Marconcini, Felbier, Roth, & Taubenböck, in press; Gamba & Lisini, 2013); however, to date a multi-temporal component is still absent.

At the regional scale recent applied research has documented spatial development of large urban areas across the globe at higher spatial resolution. Bhatta (2012, p. 125) reviews methodological approaches on classification of and change detection for urban areas and exemplifies monitoring of urbanization based on medium resolution Landsat data for mega-city Kolkata, India. Further applied examples include studies monitoring urban sprawl based on multi-temporal Landsat data e.g. for mega-city Dhaka, Bangladesh (Griffiths, Hostert, Gruebner, & van der Linden, 2010), Tokyo, Japan (e.g. Bagan & Yamagat, 2012) or Beijing among many cities in China (Deng, Huang, Rozelle, & Uchida, 2010). Taubenböck et al. (2012) classify and monitor spatial urbanization since the 1970s in the current 27 mega-cities across the world with multi-sensoral remote sensing data. Frolking, Milliman, Seto, and Friedl (2013) map urban expansion from 1999 to 2009 at macro-scale to document change of urban form and structure in mega-cities using multi-sensoral satellite data – NASA's SeaWinds microwave scatterometer and mean annual stable nighttime lights (NL) from DMSP/OLS. However, studies focusing on the spatial and temporal evolution of large urban areas such as multi-nuclei mega-regions are still underrepresented. Sexton et al. (2013) e.g. analyzed the Washington–Baltimore axis. Yang, Song, and Lin (2012) use selected spatial statistics to measure the demographic spatial pattern of individual mega-regions.

Beyond mapping urban growth, spatial metrics have been used to compare and evaluate multi-temporal urban patterns classified from remote sensing data (e.g. Ji, Ma, Twibell, and Underhill (2006), Taubenböck, Wegmann, Roth, Mehl, and Dech (2009), or Seto and Fragkias (2005)). Schneider and Woodcock (2008) classify 25 metropolitan areas across the world evaluating their spatial configurations. Angel, Sheppard, and Civco (2005, p. 102) even classify 90 cities across the globe at two time steps (1990 and 2000) and apply spatial metrics for comparison of the dynamics and patterns of spatial urban growth. Yu and Ng (2006, 2007) analyze urban sprawl and the spatial effects along an urban–rural transect for Guangzhou, China. Shafizadeh and Helbich (2013) even use urban sprawl analysis based on EO-data as input for modeling future urban growth patterns at mega-city Mumbai, India.

In addition to these studies we focus on the following research questions by the use of large area, multi-temporal remote sensing data:

1) How can we turn a new type of an urban geographic concept – the '*mega-region*' – from the qualitative descriptive stage into a quantitative spatial definition?
2) Which *spatial configurations characterize a given mega-region* and allow for an *empirical definition* of spatial mega-region attributes?

For a systematic answer we apply the following workflow schematically illustrated in Fig. 1. The headlines represent the structure of the paper.

Mega-regions: from a conceptual to a physical approach

Today, the term '*mega-city*' is often associated to the largest category of urban agglomerations. However, the concepts of mega-cities (defined as agglomerations larger than 10 million) or even meta-cities (larger than 20 million) (UN, 2006) still derive from a medieval model with a defined, dense center surrounded by a more or less complex halo of lower-rise buildings and suburbs. This, though, is the city of history.

The very dynamic process of spatial urbanization creates different types of settlements and respective landscape patterns and thus spatial landscape configurations on a massive scale. This development led to varying terms trying to conceptualize these urban dimensions such as *urban field* (Friedmann & Miller, 1965), *megalopolis* (Gottman, 1976), *urban network* (Batten, 1995), *system of cities* (Pacione, 2009) or *polycentric urban regions* (van Houtum & Lagendijk, 2001).

In 2008 Florida, Gulden, and Mellander (2008) as well as UN-Habitat (2008) suggested new concepts using the terms *mega-regions*, *urban corridors* and *city-regions* to capture the new nature of urban landscapes. The concept of *city regions* is still ajar to mega-cities; defined as dynamic and strategic cities extending beyond their administrative boundaries absorbing semi-urban and rural

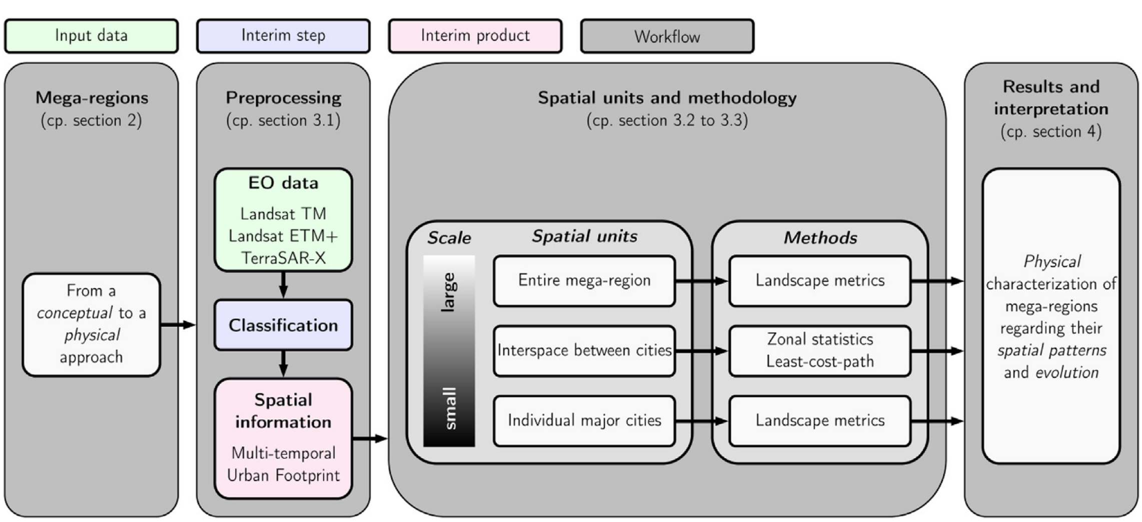

Fig. 1. Schematic overview of the workflow from a conceptual definition to the physical characterization of a mega-region.