



Traces of humankind – settlement patterns seen from space

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Radar satellites record global settlement patterns with hitherto unseen precision

The sometimes bold, other times delicate lines in the images that scientists from the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR) have created using data acquired by the German radar satellites TerraSAR-X and TanDEM-X resemble Chinese ink drawings. In truth, though, the black and white maps taken from an altitude of over 500 kilometres show the world's cities, villages and groups of houses wiggling along the course of rivers, following the lines of roads and rail tracks or spreading out into the arable countryside – with a precision currently unparalleled by other global surveys. "We think that the developed areas around the world are far larger than we have estimated so far," says Thomas Esch from the German Remote Sensing Data Center (DFD) within DLR. The resolution of three metres used for the radar images allows the satellites to detect even individual buildings.

Cityscapes from Los Angeles to Tokyo

2008 was the first year in which more people lived in urban areas than in rural regions. Now, over nine million inhabitants live cooped up in the cramped environment of the Tokyo Metropolis, while the Greater Tokyo Area is home to over 35 million. Nature defines clear boundaries for the urban sprawl, and the satellite images reveal a city packed tightly on the plains between the ocean and the mountains, with Tokyo passing seamlessly into Yokohama, the adjacent metropolitan region. Only a few tendrils of development snake their way into the mountains. In contrast, Los Angeles simply imposes its development on nature – covering the landscape block by block with its typical rectangular arrangements. Only broad highways or airport complexes remain visible as white corridors, since their smooth surfaces barely reflect the radar signals back to the satellites.

"Radar technology and the fully automated evaluation methodology enable us to record the characteristic vertical structures of settled areas, meaning primarily the buildings," explains Esch. And with the precision that the satellite images provide, the images may indeed show chimneys, pylons or even road signs; but they might be large individual trees in the African landscape or rocky outcrops in the desert. The scientists have taken great care to filter out these errors – and what remains are the settlement structures that, viewed from space, assume the guise of inimitable 'footprints'.

Networks, lines and dots

Minneapolis – surrounded by a patchwork of individual dots showing the widely dispersed farmhouses. Delhi – an urban region that has expanded its connecting links almost like a nerve cell to accommodate huge satellite cities. Paris – metropolitan in its sharply defined centre surrounded by a clearly delineated region of rural settlements with bunched and strung out villages. Many cities reveal their personal character when viewed from outer space. All around Cairo, the villages spread further and further along the arable Nile Delta and the course of the river, while the surrounding desert landscape remains unpopulated and empty. Straight lines of villages stretched along roads surround Brussels, clinging to the main thoroughfares in a web-like pattern. A few cities and settlements follow the infrastructure, whereas others were the reason for its construction. Some cities are penned in by nature, whereas others spread uninhibitedly and without obstruction. Frequently the settlement patterns and forms reflect the cultural history of a country, for instance in the wide expanses of the United States farmers were

able to acquire large rectangular parcels of land and constructed their farmhouses with substantial distances in between.

The overflights by the two radar satellites, TerraSAR-X and TanDEM-X, covered the entire surface of Earth within two years. This was possible as the sibling satellites are able to 'see' through clouds and can even record data at night. "This is a decisive advantage of radar technology compared to optical satellites", says Thomas Esch. "Optical technology always involves laborious piecing together of scenes undisturbed by clouds." The task facing the scientists was to calibrate the automatic survey process in such a way that structures like trees or lampposts would not be recorded, while individual houses could still be detected. This produced maps with a resolution of 12 metres that show urban structures, and hence the proportion of settled areas, the regional population distribution and the arrangement of rural and urban areas.

Precise data in the interest of science

The team of researchers processed and evaluated a total of 180,000 individual images and more than 308 terabytes of data for the precise Global Urban Footprints project. "Until now there has been no global record of settlement patterns with this kind of regional specificity", emphasises Esch. Previous global evaluations have not been able to record smaller villages, as the resolution of the satellites was no better than 300 metres. Small-scale structures do play an extremely important role, though, as the increase in settlements has an ever-growing influence on farmland and untouched regions in rural areas. Previous estimates suggested that between one and three percent of Earth's surface is covered by settlements. The initial results of the radar data evaluation show, however, that the proportion of developed areas has been frequently underestimated. "Even if we are merely talking about a few percentage points, they are of substantial practical relevance if we consider the immense ecological, economic and social impact of settlements, above all the urban conurbations", says Esch.

Global Urban Footprints should be available to scientists as early as the end of 2014, for instance as a basis for precise climate modelling, enhanced risk analyses in earthquake or tsunami regions or improved monitoring of human impact on ecosystems. "This means the new dataset will help acquire greater understanding of, and develop appropriate responses to, social challenges such as climate change, urbanisation and population explosion."

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Berlin



The German capital of Berlin displays a compact structure: the centre is densely developed and dominant. Nevertheless, the city spreads along the infrastructure and pervades the surrounding region, as shown on the map based on radar data from the German Aerospace Center (DLR) satellites TerraSAR-X and TanDEM-X.

Credit: DLR.

Tokio



Over 9 million people live cramped together in the centre of the Japanese capital, Tokyo. But the city has long since merged with other cities, such as Yokohama, themselves numbering over a million inhabitants. The radar data from the German Aerospace Center (DLR) satellites TerraSAR-X and TanDEM-X show how nature imposes limits on the urban sprawl, enclosing the metropole between the ocean and the mountains.

Optical satellite images of Tokyo



This image of the Japanese capital of Tokyo was taken using optical satellites. Smaller urban structures such as groups of buildings or individual houses are not recognisable.

Credit: USGS/Verarbeitung: DLR.



Los Angeles

The American metropolis of Los Angeles spreads out over a vast area. Given that vertical structures reflect the radar signals from the DLR satellites TerraSAR-X and TanDEM-X better than flat structures, this map is able to show the particularly dense build-up found in Los Angeles and its typical block-shaped pattern. The areas shaded white that contain no vertical structures indicate highways or airports.



The city and the surrounding countryside are directly adjacent, but clearly delineated; on this map - created using data provided by the DLR radar satellites TerraSAR-X and TanDEM-X the French capital of Paris is seen to be extremely compact, while merely a few smaller villages are dotted across the surrounding regions.

Credit: DLR.

Cairo



It's not just the Egyptian capital Cairo that is densely populated - people also live in the arable Nile Delta stretching along the river Nile. The white areas on the radar images by the German Aerospace Center (DLR), indicating that they are devoid of settlements, show the barren landscapes that remain without irrigation from the Nile.

Minneapolis



The radar images that scientists from the German Aerospace Center (DLR) processed as part of the Global Urban Footprints project even render individual farmhouses visible. Here we see Minneapolis and the surrounding rural regions. The area's history has defined the settlement patterns: farmers received large, usually rectangular parcels of land, which prompted them to construct their farmhouses far apart.

Credit: DLR.



Rectangular structures on Earth reflect the radar signals from the satellites TerraSAR-X and TanDEM-X well. Scientists from the German Aerospace Center (DLR) used the satellite data to examine the urban structures. Although the images show that the largest settlements along the river Rhine have grown in the region between Cologne (on the left in the image) and Bonn, numerous smaller villages are also dotted across the surrounding rural regions.

Optical satellite image of Cologne and Bonn



The optical satellite image of Cologne and Bonn shows the urban centres along the Rhine. But it is difficult to make out the smaller villages and houses in the rural areas.

Credit: USGS/Verarbeitung: DLR.



São Paulo

The Brazilian metropolis of São Paulo is densely developed and situated at a small distance from the coast. But the maps created using DLR radar data also show urban structures stretching along the coastline.

Ho Chi Minh City



Roughly 6,000,000 people live in Ho Chi Minh City in Vietnam (formerly Saigon). This view, created using radar data from the German Aerospace Center (DLR), shows that the urban structures follow the water canals in filigree lines. In contrast, the river delta, a mangrove region, is barely settled at all.

Credit: DLR.

Delhi



The vast urban sprawl of Delhi is surrounded by huge satellite cities. Villages have spread along the rail and road infrastructure towards these satellite cities. Here, the urban development follows the existing infrastructure. Scientists from the German Aerospace Center (DLR) created this map using data acquired from the radar satellites TerraSAR-X and TanDEM-X.

An image of Delhi from an optical satellite



This image, taken by an optical satellite, shows the Indian capital of Delhi from space.

Credit: USGS/Verarbeitung: DLR.



Region around Munich, Augsburg and Ulm

The rural regions between the cities of Munich, Augsburg and Ulm also boast settlements, as we see in the fine structures created using radar data from the DLR satellites TerraSAR-X and TanDEM-X.

Brussels



The Belgian capital of Brussels (to the left in the image) and surrounding cities like Liège (on the right in the image) present compact urban structures, connected via a network of villages strung out along the roads.

Credit: DLR.

Europe



Scientists at the German Aerospace Center (DLR) used the data acquired by the radar satellites TerraSAR-X and TanDEM-X to create maps of the urban structures.

Credit: DLR.

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