

Chapter 53

Earth Observation Technologies for Mitigating Urban Climate Changes



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Abstract Since 2010 United Nations declared that for the first time in history up to 50% of mankind is living in urban areas, implying that challenges connected with global changes need to be evaluated primarily within urban systems, using the most advanced available technologies. Earth observation is nowadays the most promising field of research assisting urban planners, city managers, and building designers in their work of improving urban resilience to cope with climate change effects, and the long-term changes connected with extreme climatic events. Even though the deep understanding of the functioning of urban systems is a key factor for improving the quality of life at all levels, urban development is still poorly monitored globally, and reliable and comparable satellite urban data across countries is still limited, slowing down international comparative research. The Copernicus UE programme, replacing the Global Monitoring for Environment and Security (GMES) programme, recognizes the strategic importance of Earth observation for emergency management. Copernicus programme provides global, continuous, autonomous, high quality, wide-area Earth and Atmosphere observation. Copernicus links Space observations to ground-based and atmospheric data collection and processing, providing operational services in the fields of environment, ground infrastructures, civil protection, and security, supporting the implementation of a large number of sectorial and transversal public policies. Of the six thematic macro-areas of the present programme observation and ground monitoring of the European urban systems lies in the first thematic area of the land monitoring service. The enormous and continuous data generation from the Copernicus programme is allowing the construction of an accurate and up-to-date database to the state of health of our cities and surrounding environments, providing research materials simply inconceivable only a few decades ago.

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53.1 Earth Observation: A European Overview

Among innovative technologies applied to the management of the built environment as well as urban and territorial infrastructures, one of the most promising is unquestionably Earth observation. Since the so-called “First Space Race”¹ in the 1960s, satellites have progressively played a fundamental role in better understanding of our planet, its atmosphere, and its terrestrial and marine ecosystems together with human infrastructures. With a clear understanding of the ever-increasing importance of autonomous access to Space, the European Union has launched since 1998² its own Earth observation, satellite, and aerospace research programme, essentially related to global observation, involving the most relevant European based entities in order to understand the effects of climate change and thus better respond not only to extreme climatic events, likewise to other events potentially creating risk to the safety of EU citizens, such as forest fires or extensive pollution on land, at sea, and in the sky (soil, water, and air pollution) (European Commission 2010).

The first programme was launched by European Union in order to coordinate Space and Earth observation activities as Global Monitoring for Environment and Security (GMES) focused on ensuring the implementation of timely, reliable, and continuous information services, for the support of institutional and private decision-makers in global and regional matters related to environment and security (European Commission 2010). The programme based its activities on the analysis of Earth observation data, provided both by satellites and in situ monitoring networks, to be analysed, coordinated and made available to end-users, namely national, regional, and local authorities and agencies, environmental and civil protection organizations and the scientific community (Cinquepalmi 2021).

Certain European member States had already relevant experience in Space related activities and research, with dedicated Agencies and large scientific and Industrial Communities, but for those countries without real Space capabilities, the Commission

¹ The *Space Race* was during the second half of the twentieth century, a substantial part of the scientific and technological but also communication and ideological rivalry between the United States and the Soviet Union through the Cold War, aimed to achieve superiority on spaceflight capability. The advantage deriving from the development of this technology was considered crucial for military uses but soon demonstrated its fundamental importance also for the civil sector.

² The relevance of Earth observation within the European Union was recognized with the “Baveno Manifesto”, a scientist and officials declaration laying the foundations of the EU Programme “Global Monitoring for Environment and Security (GMES), and committing Governments, Agencies, and the scientific community to the deployment of a shared Space programme, including environmental and security services towards satellites component (Joint Research Centre (JRC) 1998) (Cinquepalmi 2019b).

had to appeal to the principle of subsidiarity,³ in order to fulfil the mandate of granting to European citizens the benefits of the newly established Earth observation system.

The initial GMES programme comprised an environmental and safety information services, combining the Member States' capacity in data collection on land, sea, and atmosphere (Cinquelpalmi 2019a). Since 2014 European Commission, launched the Copernicus programme, established with the new EU Regulation, repealing Regulation (EU) No 911/2010 as an evolution of the previous GMES programme (European Commission 2010), and dedicated to the Polish mathematician and astronomer Mikołaj Kopernik.⁴ Among the objectives of the Copernicus programme, the most relevant one is building up knowledge about the planet's state of health, needed for the implementation and support of several European and National key public policies (European Commission 2014).

53.2 Monitoring Urban Areas from the Sky: The Demographic Challenge

Among the monitoring and data collection activities of the EU Copernicus programme, perhaps one of the most relevant is the initiative dedicated to urban areas. Urban policies are presently considered among the most challenging sectors of public policies, having in mind that: *...according to the United Nations (World urbanization prospects—2014), approximately two-thirds of the world's population will be living in an urban area by 2050 (Kotzeva 2016).*

This trend of global change in the analysis of urban systems is resulting in more evident in Africa and Asia, also considering the overall demographic decline corresponding to the so-called mature economies, namely Europe, North America, and Japan towards developing and emerging economies, mostly facing the challenge of the Ageing society (European Commission 2009). According to an evaluation made by the United Nations, around the end of the twentieth century, the cities up to one million inhabitants were 371, with a perspective growth up to 548 by 2018, the same evaluation states that this number will increase reaching 706 cities of one million inhabitants or more before 2030. Urban areas with more than 10 million inhabitants, the so-called Megacities (Fig. 53.1), were 33 in 2018, potentially reaching the number of 43 by 2030 (United Nations Development Programme (UNDP) 2009).

The largest world megalopolis is presently Tokyo with 37 million inhabitants, followed by New Delhi with 29 million, Shanghai with 26 million, and São Paulo

³ Subsidiarity is a general principle of European Union law. According to this principle, the EU may intervene where the action of individual countries is evaluated as insufficient. The principle was established by the Treaty of Maastricht in 1992.

⁴ Mikołaj Kopernik (1473–1543 in Latin transliteration Nicolaus Copernicus) was an astronomer and mathematician who graduated in canon law from the University of Ferrara in 1503, he is famous for having advocated, defended, and finally definitively promoted the heliocentric evidence against the hitherto supported geocentrism in the western world. His scientific demonstration is also commonly known as the "Copernican Revolution".

THE WORLD'S TEN LARGEST CITIES IN 2018 AND 2030				
City size rank	city	Population in 2018 (thousands)	city	Population in 2030 (thousands)
1	Tokyo, Japan	37 469	Delhi, India	38 939
2	Delhi, India	28 514	Tokyo, Japan	36 574
3	Shanghai, China	25 582	Shanghai, China	32 869
4	São Paulo, Brazil	21 650	Dhaka, Bangladesh	28 076
5	Ciudad de México (México City) México	21 581	Al Qahirah (Cairo), Egypte	25 517
6	Al Qahirah (Cairo), Egypte	20 076	Mumbai (Bombay), India	24 572
7	Mumbai (Bombay), India	19 980	Beijing, China	24 282
8	Beijing, China	19 618	Ciudad de México (México City) México	24 111
9	Dhaka, Bangladesh	19 578	São Paulo, Brazil	23 824
10	Kimki M.M.A. (Osaka), Japan	19 281	Kinshasa, Democratic Republic of the	21 914

Fig. 53.1 Demographic evolution of megacities between 2018/2030. *Source* Cinquepalmi (2021)

and Mexico City with around 22 million each. Very close to 20 million inhabitants are Cairo, Mumbai, Beijing, and Dhaka. Kinshasa, the capital of the Democratic Republic of Congo, and Dhaka, the capital of Bangladesh is assumed to reach, respectively, 22 million inhabitants and 28 million inhabitants by 2030 (Cinquepalmi 2021).

53.3 Monitoring Urban Areas from the Sky: Copernicus and the Urban Atlas

Six priority thematic areas are identified within the Copernicus EU programme for Earth observation, namely soil (land monitoring service), sea (marine environment monitoring service), atmosphere (atmosphere monitoring service), climate change (climate change service), emergency management (emergency management service),

and security (security service): urban systems are analysed as part of the land monitoring service thematic area.⁵ The other Copernicus products in the land monitoring service area are very high-resolution mosaics; Riparian Zones; Urban Atlas EU-Hydro (Cinquelpalmi 2019a).

One of the most interesting outcomes of the programme is presently the Urban Atlas,⁶ a mapping of the Cities of Europe related to 513 million EU inhabitants, aimed to help decision-makers in their daily activities on public duty. The idea behind the Urban Atlas was to create a land monitoring service focused on defined “Hot Spots”, defined by a harmonizing approach between land cover and land use maps, covering hundreds of cities of the pan-European area corresponding to the 46 countries presently part of the Council of Europe⁷ (Fig. 53.2).

The Urban Atlas is monitoring urban areas essentially using land monitoring services data, applying to a number of uses such as air quality monitoring as well as the prior and postconditions of buildings and infrastructure assessment of after extreme climatic events, fires, or earthquakes. The entire system built on the combination between visual interpretation of very high-resolution (VHR) satellite images and (statistical) image classification and based on unit of analysis defined as Functional Urban Areas (FUA), a methodology developed by the OECD and primarily based on the economic functionality of the cities. The methodology proposed together by the OECD and the European Commission is based on a harmonized definition related to a reference grid of 1 square kilometre, which identifies urban areas as functional economic units (Functional Urban Areas—FUA). Using population density⁸ and labour mobility flows as key information, urban areas can be described as densely populated “urban centres” and “hinterlands” whose labour markets are highly integrated with the cores (OECD 2012).

⁵ The Copernicus products in the land monitoring service area are very high-resolution mosaics (general soil mapping) Corine Land Cover (CLC, which provides biophysical characteristics on land), Riparian Zones (which monitors long transition zones rivers and lakes), Natura 2000 (n2k that monitors the habitats protected from the naturalistic point of view), Urban Atlas (first service to create harmonized maps for land cover and land use on several hundred cities both in the EU that in the countries of the European Free Trade Association, namely Norway, Iceland, Liechtenstein, and Switzerland, EU Digital Elevation Model (EU-Dem, which combines data from different sources into a single system of data management).

⁶ The Urban Atlas is a joint initiative of the EC Directorate-General for Regional and Urban Policy and the EC Directorate-General for Enterprise and Industry, in the frame of the EU Copernicus programme with the support of the European Space Agency and the European Environment Agency <https://land.copernicus.eu/local/urban-atlas>.

⁷ The Council of Europe (CoE) is a multilateral organization founded on 5 May 1949, with the Treaty of London aimed to promote democracy, human rights, European cultural identity, and the possible way forward to social problems in Europe, presently composed by 46-Member States and based in Strasbourg, France. On 17 October 1989, the CoE was granted observer status at the United Nations General Assembly.

⁸ The source of the population grid data for European countries is population density data disaggregated with the Corine Land Cover dataset, produced by the Joint Research Centre for the European Environmental Agency (EEA) (Joint Research Centre (JRC) 1998).

Urban Atlas		2006	2012
Legend Code	Nomenclature		
11100	Continuous Urban Fabric (S.L.>80%)		
11210	Dicontinuous Dense Urban Fabric (S.L.: 50% - 80%)		
11220	Dicontinuous Medium Density Urban Fabric (S.L.: 30% - 50%)		
11230	Dicontinuous Low Density Urban Fabric (S.L.: 10% - 30%)		
11240	Dicontinuous Very Low Density Urban Fabric (S.L.: <10%)		
11300	Isolated Structures		
12100	Industrial, commercial, public, military and private units		
12210	Fast transit roads and associated land		
12220	Other roads and associated land		
12230	Railways and associated land		
12300	Port areas		
12400	Airports		
13100	Mineral extraction and dump sites		
13300	Construction sites		
13400	Land without current use		
14100	Green urban areas		
14200	Sports and leisure facilities		
20000	Agricultural + Semi-natural areas + Wetlands		
21000	Arable land (annual crops)		
22000	Permanent crops		
23000	Pastures		
24000	Complex and mixed cultivation patterns		
25000	Orchards		
31000	Forests		
32000	Herbaceous vegetarian associations		
33000	Open spaces with little of no vegetations		
40000	Wetlands		
50000	Water bodies		

Fig. 53.2 Urban Atlas—classes of surface analysis as identified within the Urban Atlas project and descriptive table of the evolution of the project. *Source* EU Copernicus programme, EC Commission 2013 (European Commission 2015)

The 17 classes originated by the application of the FUA methodology were defined since 2006 and summed to other 11 classes since 2012 and dedicated to agricultural land use, forestry and other vegetation land use, as well as wetlands and other water bodies, identified with unique codes and appropriate nomenclature as shown in Table 53.1 with a total number of 305 FUAs analysed in 2006, increased to 695 in 2012, passing from 640.500 km² in 2006 to 1.015.600 km² in 2012 as in Table 53.1.

Table 53.1 Urban Atlas—comparative table of the territorial coverage and description between 2006 and 2012 (EU Copernicus programme, EC Commission 2014 (Commission 2014))

Characteristic	Urban Atlas 2006	Urban Atlas 2012
No. of FUAs	305	695
Total area	640,500 km ²	1,015.600 km ²
Minimum mapping unit (MMU)	0.25 ha in urban areas, 1 ha in rural areas	0.25 ha in urban areas, 1 ha in rural areas
Min. mapping width	10 m	10 m
MMU change layer		Class 1 to class 1 = 0.1 ha Class 2–5 to class 1 = 0.1 ha Class 2–5 to class 2–5 = 0.25 ha Class 1 to class 2–5 = 0.25 ha
Positional accuracy	± 5 m	± 5 m
No. of classes	21	27
Min. overall accuracy for “artificial surfaces” classes	85%	85%
Min. overall accuracy (all classes)	80%	80%

53.4 Monitoring Urban Areas from the Sky: The Climatic Challenge

Without taking a side in the debate about global changes, we can certainly agree that the planet’s climate is changing and that urban areas are seriously endangered by this phenomenon. The broader and shared position of the global scientific community foresees in the course of the twenty-first century a rise in average global temperatures of approximately 2/2 degrees Celsius, which will result in unprecedented climatic and ecosystem changes, at least compared to the last 10 centuries (The Royal society 2008).

Climate worsening will become a dominant feature across the planet, with extreme climatic events, such as heatwaves, storms, and floods, increasing in frequency and severity (The Royal society 2008). Numerous initiatives have been launched to address the issue such as International Human Dimensions Programme on Global Environmental Change (IHDP) Urbanisation Science Project, *Diversitas* Science Plan on Urbanisation, International Union for the Scientific Study of Population (IUSSP) Urbanisations and Health Working Group, U.S. National Academies’ Panel on Urban Population Dynamics, U.S. National Academies’ Roundtable on Science and Technology for Sustainability’s Task Force on Rapid Urbanisation, UNESCO’s initiative on Urban Biospheres. What most scientists and researchers predict is that higher temperatures will cause melting of glaciers and polar ice caps, with sea-level rise and serious consequences over low-lying territories across the planet, affecting especially the most fragile populations and territories along the coastlines

(Cinquepalmi 2021). The most relevant impacts to be considered towards cities in relation with extreme climatic events and connected with climate change are resumed in Fig. 53.3.

The satellite data of most immediate use for the management of urban systems are those resulting from thermic sensors of the atmosphere. The variations of the local temperature inside densely built urban centres, both caused by the human activities (air conditioning and heating systems at full blast, high concentrations of car traffic) or and by climatic large and local scale effects, are the cause of substantial disturbance to the citizens quality of life, resulting in the phenomenon of the Urban Heat Island (UHI) (Solecki et al. 2005).

Climatic phenomena	Main impacts expected on urban areas
INCREASE IN DAYTIME AND NIGHT-TIME TEMPERATURES	<ul style="list-style-type: none"> - Reduction of energy demand for heating - Increased energy demand for cooling - Decrease in air quality - Impact on winter tourism
INCREASE IN HEAT WAVES	<ul style="list-style-type: none"> - Reduction in the quality of life for people in warm areas
INCREASE IN HEAVY RAINFALL EVENTS	<ul style="list-style-type: none"> - Disruption of settlements, trade and transport due to flooding - Impact on urban infrastructure and real estate
INCREASE IN DROUGHT-AFFECTED AREAS	<ul style="list-style-type: none"> - Water shortages for inhabitants, industries and services - Reduction in energy production potential, especially hydroelectricity, but also nuclear and fossil fuels - Potential increase in migration phenomena
INCREASE IN TROPICAL STORMS	<ul style="list-style-type: none"> - Damage due to flooding and high winds - Disruption of public water supply - Potential increase in migration phenomena
SEA LEVEL RISE	<ul style="list-style-type: none"> - Flooding in coastal areas - Decrease in freshwater availability and saltwater intrusion - Potential increase of migration phenomena

Fig. 53.3 Expected impacts on urban areas from extreme weather and climate conditions. *Source* Revi et al. (2014)

The difference in temperature in such cases is substantially different between urban city centres and their surroundings, even by a few degrees Celsius, but above all remains significantly higher during the night than during the day. Such negative effect is amplified and worsened in case of absence of wind and periods of higher or lower temperature, i.e. in the middle of summer or winter. The association of the urban heat island with summer heatwaves results in very serious effects on human health, especially on the most fragile population groups and within economically deprived contexts, which are usually more frequent at those latitudes where such combination of factors is worsened by poor air quality due to the pollution, severe drought or extreme humidity (The Royal society 2008).

Air pollution at local and regional scales is another element detected by satellite sensors, helping scientists and policy makers to assess and possibly mitigate the phenomenon: ground temperatures together with winds and all other weather conditions help to understand the health condition of a city, combined with satellite sensors detecting nitrogen dioxide (NO₂) as shown in Fig. 53.4. Sensors dedicated to telemetry (remote sensing⁹) allows the acquisition of information in the wavelengths of visible light but also in the electromagnetic spectrum not visible to the human eye (microwaves, ultraviolet, X-rays, and gamma rays), capturing images even in cloudy weather conditions, and detecting even millimetric variation on land and water surfaces as well as on buildings, generating maps to be used by city administrators and civil protection as shown in Fig. 53.5 (Cinquelpalmi 2019a).

53.5 Conclusions: Moving Forward Urban Digital Twins

The increasing complexity of the built environment and more generally of urban systems requires the adoption of an interdisciplinary approach in order to relate the quality of structures with the environmental quality and with the quality of services that all together must serve to ensure the citizen's quality of life. The exponential growth of digital computing capabilities since 1972, together with the advent of the most advanced technologies for digital data management and the diffusion of a digital culture of information has also led to the digital evolution of Life Cycle Assessment (LCA) methodologies, completing its functionality with two other enabling tools, one at the scale of the individual building, namely the Building Information Modelling (BIM) and the other at territorial scale, namely the Geographic Information System (GIS); the fourth enabling technology completing this technological framework is the Earth observation technology as well implemented by the Copernicus programme (Agostinelli et al. 2019).

⁹ Remote sensing is a technique allowing the observation and study of objects located even at a great distance from the observer by using electromagnetic waves (emitted, reflected, or transmitted) thanks to optic-electronic instruments (sensors) installed on planes or satellites. Through the capture of digital tele-detected images, it is possible to observe, analyse, and study with incredible precision very large areas of the Earth's surface (Copernicus programme® 2016).

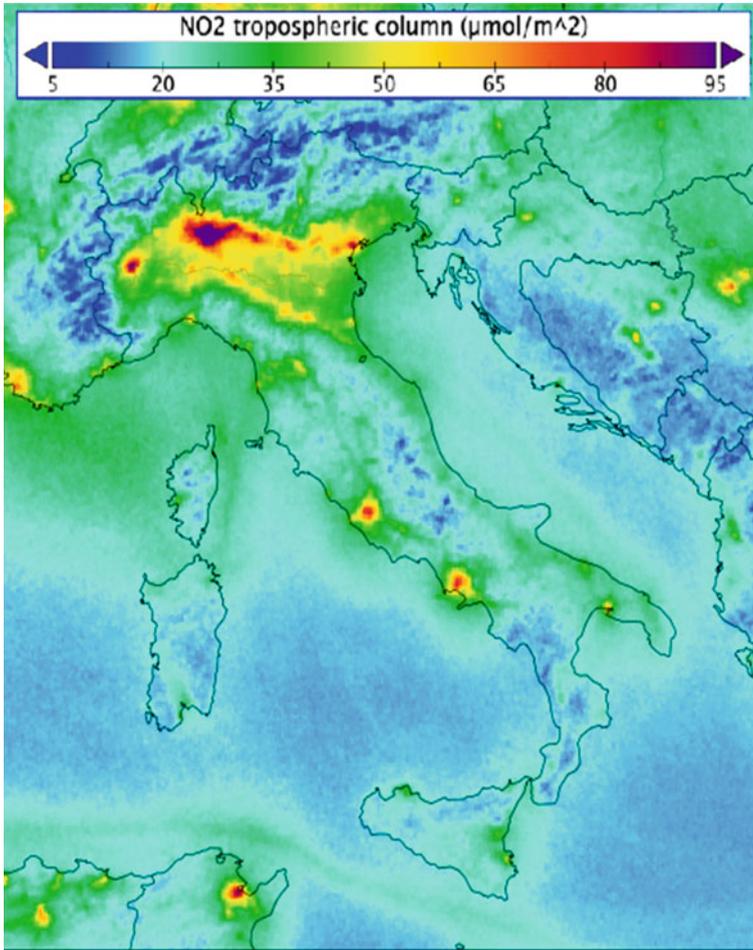


Fig. 53.4 Nitrogen dioxide over Europe evaluated in March 2019, with detail on Italy. The image shows the critical situation on the Pianura Padana as well as over Rome and Naples. Nitrogen dioxide pollutes the air mainly as a result of traffic and the combustion of fossil fuel in industrial processes. It has a significant impact on human health, contributing particularly to respiratory problems. [Contains modified Copernicus Sentinel data (©EU 2019), processed by ESA, CC BY-SA 3.0 IGO. Source Cinquepalmi (2019c)]

The composite interaction of all these digital technologies makes available a comprehensive picture of built environments and infrastructures, but the evolutionary leap we are currently witnessing moves this complex interactive system of information towards a more dynamic scenario, leading to the creation of the Digital Twins¹⁰

¹⁰ The so-called Urban Digital Twin Models are definable as the transposition of a real object into a virtual/digital representation, for the evaluation of its functionality and performance. (Ageing Report: Economic and budgetary projections for the EU-27 Member States 2009).



Fig. 53.5 High-resolution image of the flooding that occurred in Venice on 19th November 2019. The different levels of high tide flooding were scanned in real time by altimetry sensors. The restitution of the image represents the flooding with different

(DT) for built environment. Urban DT is designed as three-dimensional databases that are continuously fed with real time data representing both the building components as well as their qualities and other useful information, with the aim of giving a complete picture of the state-of-the-art and in the meantime simulating activities and management of processes of operation (Weekes 2019). The concept of DT implemented at the scale of urban environments is leading to the concept of City Digital Twin (CDT), a virtual model that takes the analysis from the single building (or even single housing unit) to a higher and more complex level, requiring the highest level of interdisciplinary integration to be jointly defined in the near future.

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