



## **Remote sensing and interdisciplinary approach for studying Dubai's urban context and development**

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### **Abstract**

Outlining the different phases and features of the urban and socio-economic development of Dubai, this work is aimed at highlighting the potential of remote sensing and the interdisciplinary approach for the study of cities characterised by overwhelming growth processes. In this way Dubai represents an ideal laboratory since the processes that have been triggered in the last decades have radically modified the previous balances and layouts. Thus the image of a mirage city has been gradually diffused, a city where ambitious objectives can be achieved, targets reached that are difficult to pursue elsewhere, frenetic development processes realised, in a nevertheless increasingly delicate territorial-environmental fabric onto which such phenomena are grafted. The analysis of various remote sensed images, gathered over different periods of times, highlights a number of important aspects from the geological point of view, of the physical geography, the urban development and the direct growth in all directions, with a series of artificial islands and much publicised anthropic works.

**Keywords:** Dubai, Economic Development, Remote Sensing, Service Economy, Urban Growth and Transformations

### **1. “Geographical sensations” in a diachronic perspective...**

The Emirate of Dubai constitutes one of the most important and didactically significant examples of how a space – which had been relatively static for thousands of years, following archaic schemes of reference typical of traditional societies – can be radically transformed in such a short time. In fact, a complete metamorphosis has taken place in Dubai, a true spatial revolution,

which has brought about completely new territorial configurations, involving the population, which moreover has risen out of all proportion owing to very high immigration flows.

Spaces of stability, mobility and marginality have interacted and interact (Frémont, 2007, pp. 93-96; De Vecchis, 2014), organised in highly complex combinations and giving rise to a myriad of contrasts and to a city which the tourist guides – see for example Lonely Planet – define as

glamorous, exhilarating, trendy, overexposed, consumerist beyond all imagination (Walker et al., 2007).

A lot should be said, in environmental and social terms, about the many and serious problems linked to sustainability of such an overpowering and aggressive spatial organisation. A series of reflections are thus proposed – in order to simply grasp some of the “geographical sensations” in a diachronic perspective. These begin in fact with two interpretations that are very different one from the other, limited to a sequence of quotations that make up interesting sources to document the change and which to some extent connect Dubai’s past and present: those of the great 19<sup>th</sup> century French geographer Elisée Reclus and Walter Siti, writer, literary critic and contemporary Italian journalist.

The former was the author of an original work supported by lyricism and intuitions of rare insight (Frémont, 2007, p. 267), with its exceptional illustrations: a monumental encyclopaedic work in nineteen volumes (1876-1894) *Nouvelle Géographie Universelle. La Terre et Les Hommes*, Hachette Paris. In the ninth volume, *L’Asie Antérieure* (1884) is dealt with; in chapter VI which is dedicated to Arabia are some references to *The Trucial Coast* and to the life of its inhabitants, their sea-based livelihoods in particular (fishing, pearl fishing, coastal trade) and to a lesser extent to nomadic sheep-rearing.

## 2. ...from Elisée Reclus to Walter Siti

Reclus speaks about the wealth of fish in the area, noting that it is not in the least diminished by the various fishing activities:

The Persian Gulf, the sea of Oman are among the richest seas in animal life. Thousands of Arab boats, sailing in the midst of lively shoals of fish, have little or no effect on these multitudes, very soon replenished once again; big nets are cast for up to two hundred paces deep, and are hauled back, always full, by thirty or forty men. The sun-dried fish are used together with date paste to feed all the Arabs along the shoreline (Reclus, 1884, p. 860).

He also highlights the wretched conditions of many people subjected to forms of slavery and forced to live an extremely harsh life, going into the gathering of pearls in great detail, as one of the economic resources that was essential for those poor lands at that time. In the description of the various phases of this very risky activity, he expresses a heartfelt tension:

In the Arabian seas the concretions of the pearl oysters are not as white as those of Ceylon and Japan, but they are bigger and more regular in shape...By virtue of customs, the origin of law, the pearls belong to all the inhabitants of the shoreline; only they can go and gather the oysters on the sea bed and any foreign fisherman would be ignominiously driven away; nevertheless, almost all the pearl fishing profits belong to the Hindu or Arab money-lenders in advance, who with usurious loans have made the team of divers into a crew of slaves. The earnings are shared out: so much to the owner of the boat, so much to the divers and the servants; but before being handed out all these parts have already been forfeited by the lender; the fishermen’s daily meal is very scanty indeed. The way of using the oyster beds is still rudimental; the divers are weighed down by a stone attached to their feet, nostrils closed with a horn plug, ears plugged with wax earplugs, and descend to the sea bottom to 10, 20 or even 30 metres, then after 50 or 60 seconds searching for oysters, they surface with their booty; exposed to shark attacks they make this dangerous journey eight or ten times a day (Reclus, 1884, p. 861).

The decline of the pearl trade, which began around 1930 and continued after that also because of the progressive success of Japanese cultivated pearls, did not certainly contribute to improving the poor level of life of most of the population, which withdrew for a long time into the arid coastal areas of *The Trucial Coast* until after the middle of the last century. The account to be found in the essay on the Middle East by Stephen H. Longrigg is significant:

The social organization is tribal. The occupations are date-tending, pearl diving, camel breeding, fishing, rarely and scantily crop-raising, and, far more important, working in one or other of the great oil-fields of the Gulf (Longrigg, 1963, p. 167).

However, the spirit for trade and entrepreneurship for exchanges and trading was never lacking in Dubai, and with regard to this Reclus writes:

Dubai, whose port, similar to a lake, is connected to the sea by a canal opening into a white beach, where the waves push grains of amber, is more or less at the western limit of the area of the pearl bearing oysters (Reclus, 1884, p. 897).

The following year sheikh Maktoum bin Hasher strongly encouraged the already consolidated marine tradition, declaring the city a free port thus making it a strategic hub able to attract not only Arab traders but also Persians and Indians.

At the end of the 19<sup>th</sup> century the revenue deriving from oil extraction was still a thing of the future, so much so that at the beginning of the 1960s the black gold had still not been used in the area of Dubai, even though the contagious rush for this energy resource could not be avoided, already sought after following the agreements drawn up in 1937:

Exploration began immediately, but was discontinued throughout the war. Since 1948 intensive geological and geophysical work has been followed by drilling at a number of points in Abu Dhabi, and at one in Dubai; these tests have given negative, but not wholly uninteresting results (Bullard, 1958, p. 141)<sup>1</sup>.

With regard to the expectations and problems that the oil resource entails, Walter Siti dwells on this on various occasions in his *Il canto del Diavolo*, a book that is about a journey to the Arab Emirates and Dubai in particular, a city visited at the precise moment in which the

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<sup>1</sup> In a widespread Italian geographical encyclopaedia published at the beginning of the 1960s, the role of oil on the demographic layout of the area is highlighted: "The assumed lack of oil fields pushed the population, won over by the mirage of easy money, to emigrate to Qatar, the islands of Bahrein and Kuwait. It is estimated that during these years about half the inhabitants were forced to leave their deprived neighbourhoods" (Istituto Geografico De Agostini, 1961, p. 529).

international economic-financial crisis began to question its salient aspects.

The spatial-temporal categories are developed in such an abnormal way as to turn the normal chronological processes upside-down; Siti summarises these passages very expressively and effectively:

Oil was discovered in Dubai in 1966. In forty years it has gone from the Middle Ages to the post-modern, with a speed of transformation that must have seemed miraculous, or the stuff of witchcraft; from the huts made of palm leaves to skyscrapers of concrete-framed glass panels, from the seven day camel ride across the dunes to an hour and a half along the motorway by Ferrari; here the mobile phone arrived before drinkable water, the plane before the railway (even today there is not one single kilometre of railway line), the computer before the use of forks (Siti, 2009, p. 68).

But oil is not a renewable resource, for which reason it is necessary to diversify the economic offer, something that is all the more vital since unlike Abu Dhabi, the oil reserves in Dubai are limited in number:

This perhaps justifies Dubai's typical hysteria, the fear of being fragged mid-leap; now or never. The economy has already taken countermeasures: the income from oil is equivalent to just 6-7% of the GDP. The most substantial assets of the national budget are the financial exchanges, construction work and tourism (Siti, 2009, p. 69).

The tourist organisation, supported moreover by the efficient network of the air company *Emirates* with its headquarters in Dubai, marks a complete turning upside down of the classical models. Gleaming hotels, huge shopping malls (Photos 1 and 2), restaurants, bars and discos are the main attractions of a luxury oriented tourism.



Photos 1 and 2. Above, the Souk Madinat Jumeirah shopping mall. Below, a view of the inside.

It is the mysterious appeal of a city whose major attraction is a hotel (the Sail) [Burj Al Arab], that is, a place from which one should depart to visit the attractions; here, more than attracting it, tourism is put on the stage; what is shown is tourism itself (Siti, 2009, p. 71).

Tours are organised, with rather expensive tickets, according to a completely new formula of intra-hotel tourism. One of the most popular tours to be found in the Burj Al Arab (Photo 3) is the Skyview Bar on the 27<sup>th</sup> floor. In the websites advertising it, one can read:

The Skyview Bar offers world-class cocktails, live music, and a decor that goads close conversation. Oh yeah, and astonishing 200-meter-high views over the Gulf!



Photo 3. The famous hotel “the Sail” (Burj Al Arab).

Another luxury hotel offering various extra packages for tourists is Atlantis (Photo 4), with the hotel’s website saying (<https://www.atlantis.thepalm.com/things-to-do#>):

There are lots of exciting activities that make Atlantis beach resort the epicentre of adventure and the greatest holiday experience ever.



Photo 4. The luxury hotel Atlantis.

The shopping malls offer widespread top level attractions which have an irresistible appeal for a huge number of tourists:

The malls are the true monuments of Dubai, the equivalent of what the churches and museums are in old Europe, with the difference being that in the shopping centres the objects on show are on sale. Coaches depart from the big hotels to go and visit the most famous ones... The malls are the highpoints of the urban fabric: their job is to exhibit showy attractions, figurative signatures that make the journey worth its while. The relationship has been overturned: while in the big 18<sup>th</sup> and 19<sup>th</sup> century stores the shimmer of the container was a pretext to sell the goods, now the goods are a pretext to entice the tourists towards the cathedrals of the new standardised beauty which throbs with superficiality (Siti, 2009, pp. 18-19).

In Dubai it comes as no surprise and it is no accident that in 1996 in this city, the *Dubai Shopping Festival* was set up and promoted by the government, organized in order to foster trade and commerce. As can be seen on the official website of the festival (<http://www.dubaishoppingfestival2013.com/>)

*this world famous festival is known as a shopper's paradise where you can view the best retail products... Dubai Shopping festival is something that has made Dubai proud... Innovative programs are organized every year, which makes the Shopping festival unique and remarkable. This festival is another technique of promoting tourism in Dubai. No doubt it has been a matter of pride for Dubai. Their authorities ensure to organize remarkable events to attract many tourists. This festival also improves the economic condition of the country... Through this festival the authorities exhibited the culture and styles of Dubai. Such was the success of this festival that the authorities to an oath to organize this festival every year. This festival has attracted many visitors across the world and is best known for their hospitality.*

Lastly, it remains to be seen whether or not this rapid anthropic upheaval of the landscape, completely other-directed, is a sign of actual progress and a valid model of human and social development, also considering that a vast

number of immigrant workers contribute to this economic growth, and who are destined to carrying out the most humble and exhausting work without enjoying the just rights.

### 3. An urban context symbol of astoundingly rapid development...

At world level Dubai represents one of the most significant examples of rapid and turbulent urban development (Photos 5 and 6)<sup>2</sup>. Concealed in a context made up of many contrasts and heterogeneous conditions, in physical-geological and socio-economic terms, Dubai is an example of “organised development”, which is founded on specific economic-commercial activities and characterised by a number of different aspects.



Photos 5 and 6. Above, the great number of skyscrapers, symbols of Dubai's tumultuous building growth. Below, other areas subject to construction processes.

<sup>2</sup> For example: “Dubai's six-year economic boom between 2003 and 2008 was extraordinary in its scale and rapidity” (Bloch, 2010, p. 943).

The economic development recorded over the last fifteen years has been accompanied by a considerable growth in population, which has radically modified the demographic-settlement layout of the city. According to the data of the *Calendario Atlante De Agostini* (2004, 2016), the population of Dubai has risen from 913,000 inhabitants (with a population density of 234 ab./km<sup>2</sup>) according to the 2001 estimate to 1,722,000 inhabitants (with a population density of 442 ab./km<sup>2</sup>) on the basis of the 2009 estimate (the last year recorded in the *Calendario*)<sup>3</sup>.

Particularly, “Dubai seems typical as an *entrepôt* in that it has attempted to jump directly from a pearling/trading society to a service society” (Hvidt, 2009, p. 400). Its transformations have been clear, marked, very rapid and have completely redesigned the features of a fast evolving reality and economy.

Four main phases have distinguished Dubai’s urban development since the beginning of the 20<sup>th</sup> century, with the introduction of specific elements (Pacione, 2005, pp. 259-260):

1900–1955: A period of slow growth and limited physical expansion due to constrained economic growth and marginal increase in population. At the beginning of the period Dubai’s population of 10,000 was concentrated in three residential quarters of

- Deira, consisting of 1600 houses and 350 suq shops, with Arabs, Persians and Baluchis making up the majority of the inhabitants.
- Al Shindagha, a former residence of the ruling family, where there was 250 houses but no suqs and only Arab residents.
- Dubai, the smallest of the settlement areas with 200 houses and 50 suq shops, and dominated by Persian and Indian merchants.

By 1955, the urban area remained a modest 3.2 km<sup>2</sup>.

<sup>3</sup> According to the Dubai Statistics Center (DSC), which “carries out daily and monthly estimates of the number of population permanently residing in Dubai within the geographic borders of the emirate, whether they are Emiratis or Non-Emiratis”, the population seems now more than 2,655,000 (<https://www.dsc.gov.ae/en-us>).

For the most part this was a period of transition, from an archaic society to some form of structure and connection among the various parts, with faint-hearted signs of growth in a context of “initiation”.

1956–1970: A period of compact growth based on a 1960 master plan, (prepared by a British architect), that called for provision of a road system, zoning of the town into areas for different land uses, and creation of a new town centre. These modest goals were in keeping with the emirate’s pre-oil resources. The master plan strategy was indicative also of strong central control over urban development.

This was still a phase of limited development but the features of organised development begin to appear, which follows the guidelines, indications and precise rules of a specific master plan.

1971–1980: A period of planned suburban growth. In 1971, as a result of urban expansion and the availability of development capital a new and more ambitious master plan was conceived. The plan made provision for ring roads around the city and a radial street network to the suburbs. Other major transport developments included the Shindagha Tunnel beneath the creek to connect Bur Dubai and Deira, and construction of two bridges, (Maktoum and Garhoud), thus linking city districts on both sides of the creek. [...]. The building of Port Rashid was also planned, and a large area, (now named Jumeirah), extending towards Jebel Ali was designated for residential use

and new services for health, education and leisure were built.

At social and strategic planning level, the changes begin to be considerable and the effects on the territory tangible. The preludes of rapid growth and the striving to obtain affirmation on the international stage can be seen (and which would shortly after this come to the fore) with something capable of attracting the immediate attention of the outside world and of focusing roles of primacy on itself on a global scale.

1980–Present: A period of rapid urban expansion, in terms of both the scale and diversity of development projects and physical

spread of the city, that in 2004 covered an area of 605 km<sup>2</sup> [...] and the strategic plan envisages extending the built up area by a further 501 km<sup>2</sup> by 2015. [...] In the early 1990s, the government commissioned the Dubai Urban Area Strategic Plan 1993–2012 to guide the economic and physical development of the city into the twenty-first century. Key challenges to be addressed were—

- To accommodate urban expansion by allocating additional land in a phased planned process to meet current and future needs for residential, industrial and commercial uses.
- To extend the existing transport network and infrastructure facilities.
- To promote continued economic growth.
- To support and attract private investment by ensuring a sufficient land supply, adequate infrastructure, simplified administrative and planning procedures, and by conducting publicly funded feasibility studies for major development proposals to minimise the risk to private capital.
- To encourage co-operation between private sector companies and government agencies in undertaking development ‘mega-projects’.
- To encourage expatriates to reinvest capital and profits in local enterprises.
- To develop an inter-departmental planning framework capable of reviewing, monitoring and implementing the Structure Plan.
- To devise a regulatory environment capable of operating within a strong market economy and incorporating the needs and interests of a large number of agencies and organisations.

A series of aspects become vital for the development of Dubai in order to: promote its accessibility; strengthen its economic-commercial role; make it the headquarters for unique top level services and structures; increase its international visibility; arouse the desire to visit it and speak about it, since able to achieve a status at a perceptive level and in the collective imagination; stimulate the desire to invest capital there, to purchase real estate, become part of a system that seems projected towards a future made up of innovative experiments and solutions of great scenic impact.

It is in this perspective of peculiar elements characterising Dubai’s development that nine key parameters are highlighted (Hvidt, 2009, p. 401):

- Government-led development (ruler-led)
- Fast decision making and “fast track” development
- Flexible labor force
- Bypass of industrialization—creation of a service economy
- Internationalization of service provision
- Creation of investment opportunities
- Supply-generated demand (“first mover”)
- Market positioning via branding
- Development in cooperation with international partners.

From the geographical point of view, such aspects draw huge attention and at least points 4 (*Bypass of industrialization—creation of a service economy*), 6 (*Creation of investment opportunities*) and 8 (*Market positioning via branding*) require further specific information.

In terms of *Bypass of industrialization—creation of a service economy*:

Three examples of the effort to establish a service-knowledge economy are the establishment of Dubai Media City, a free zone for news agencies and publications; Dubai Internet City, a free zone for information technology; and the Dubai International Financial Centre (DIFC). The last is a government-initiated endeavor in the field of financial services, and it includes both a financial and a mercantile exchange. The DIFC is competing with Singapore and Qatar to become the financial center for the entire region between Western Europe and East Asia—and thus an exchange with the same status as New York, London, and Hong Kong (Hvidt, 2009, p. 404).

These are areas of considerable dimensions created to carry out functions of high and top class levels, so as to compete with elements of gigantism on a global scale. With regard to the secondary sector, it must be stressed that the industries are for the most part commercial, since the passage to real productive firms has undergone a sort of leap in the usual passages; nevertheless, in a context of vast new spaces, logistic support, strategic activities and growth in specific infrastructures, the launch of the secondary sector is becoming increasingly important too, for example, with the “Dubai Industrial Park”, whereby the aim is to bridge previous gaps in

order to find suitable space on the international stage with cutting edge activities and technology (<http://www.dubaiindustrialpark.ae/>).

For what it concerns the *Creation of investment opportunities*:

Since the mid-1980s, leadership in Dubai has focused upon attracting foreign investment. Vision 2010 explicitly states that increasing amounts of FDI [Foreign Direct Investment] are a prerequisite for further development. [...]. A second major type of investment opportunity was created within the real-estate sector. This was truly innovative because there had been a customary and complete restriction on nonnationals owning property in Dubai, as elsewhere in the UAE. However, in March 2002, Dubai introduced freehold ownership, granting foreigners full ownership of apartments and houses. The residences on Palm Island were among the first sold under this arrangement. Later, the government allocated sections of the city to such housing. At Dubai Marina, for instance, around 200 residential building blocks, hotels, and so forth are currently being erected (Hvidt, 2009, p. 406).

The creation of new forms of investment, the attraction of foreign capital and the realisation of a real estate sector made up of impressive structures that “materialise” the dreams of people with huge capital at their disposal are operations that are being aimed to achieve chain benefits, in socio-economic terms and image spin-offs.

With regard to its *Market positioning via branding*:

Dubai has branded itself as ‘quality and innovation’. One part of this approach has been the erection of iconic buildings today known worldwide. Among these are the sail-shaped hotel, Burj al-Arab; the Palm Islands; the triangular Emirates Towers; and not least, Burj Dubai, the tallest building in the world (Hvidt, 2009, p. 407).

In this way an attempt has been made to create a sort of brand linked to two words with huge media impact. Quality and innovation seem to be the *leitmotifs* aimed at leading the economic-design market and life in Dubai,

characterised by distinctive elements as the symbol of a shared desire to emerge. Furthermore, among the different aspects, luxury is also a *cult* to be followed, to flaunt, both along the coast, where the highest levels of architectural imagination and expressive prominence are to be found, and towards the interior, with luxury hotels and structures connected to the “Desert Conservation Zone” (Ryan and Stewart, 2009), leading one to reflect on the social implications, unsustainable challenges and ecological pressure created by this type of tourism (Stephenson and Ali-Knight, 2010) and in general by urban growth (Bolleter, 2009, 2015), which has entailed also an indiscriminate use of resources and the violation of laws and labour regulations (Ramos, 2016, pp. 11-14)<sup>4</sup>.

Moreover, in terms of perception and identity, there has generally been the spread of

an image based on iconographic grandeur, monumental innovation and super-modernism. In doing so, the enquiry indicates that one fundamental sociological concern for destination Dubai is its perceived lack of cultural consistency, particularly in terms of the absorption of the old into the new (Stephenson, 2014, p. 723).

The rapid transformation process seems to wipe out the traces of the past and the possible elements of identity (as well as the physical-morphological features), that are substituted by a new temporary “identity” made up of the search for the modern and technologically advanced that inexorably overpowers whatever comes in its path.

All these aspects in a melange of coordinated initiatives aimed at the pursuit of one single concrete objective – that is the demonstration of a driving role for the economy of the United Arab Emirates (and the Arab Peninsula) and of a point of world reference for the possibility to transform projects into reality in a short time – have become symbolic elements, easily recognisable also at territorial level owing to the unmistakable changes and characterising elements that make it possible to interpret Dubai’s recent history.

<sup>4</sup> As recently affirmed (in a contribution just available online): “Dubai needs immediate intervention to retrofit its current development strategies with a new emphasis on sustainability” (Alawadi, 2017, p. 353).



The rapid developments appearing in the city may have to do with the vision of the government. Its aim is to transform Dubai from a regional business, financial and leisure hub into a global center. In the process capital is being invested in the purchase of concrete, glass and steel. Dubai's skyscrapers rise from the clusters, artificial islands rise from the sea and neighborhoods containing residences and offices rise from the sand (Fazal, 2008, p. 4).

And so, Dubai is “one of the fastest growing cities in the world” developed in “a hyperarid environment” where different areas, often desert, are progressively invaded and converted in an urban context (Nassar, Blackburn and Whyatt, 2014, p. 50).

As affirmed about ten years ago:

With ambitions to become a hub of global commerce, a top tourist destination and a shopping Mecca—a New York/Las Vegas/Miami rolled into one—Dubai has been spending billions of dollars to build an astonishing modern city nearly from scratch in a mere 15 years (Bagaen, 2007, p. 173).

In this way the aim has been to diffuse the image of Dubai – global city – as “metaphor”, as “hope”, as “mirage” (Kathiravelu, 2016, p. 28), in the “attempt to ascend in the ‘world urban hierarchy’ and establish itself as the image of the 21st century metropolis” (Acuto, 2010, p. 272).

#### 4. ...to be analysed by remote sensing

In a similar context, remote sensing represents an instrument of fundamental importance to record, follow and analyse, in a temporal perspective, the recent and extensive changes that have taken place in the city and economic-social plan. At the same time, remote sensing and the combined use of differentiated images make it possible to look at the physical-geological environment in which these changes are being made, not only in the north-south direction, not only towards the interior, but also with offshoots into the sea, with the creation of an unmistakable artificial landscape, which in its spectacular scenic nature tends to conceal a series of dichotomies and fragility. The overwhelming imperatives seem to be those of the innovative

search for extremely impressive elements, the desire to stand out, to arrive first, to act as an example that is unachievable for others, steaming ahead in intensifying the artificial nature of the components and expanding boundlessly.

Remote sensing, above all in the case of images relative to a time series recorded over a number of years, integrated in a GIS environment, makes it possible to:

- obtain specific information on the areas that have been progressively developed and the different directions of this expansion, also showing the contrasts between the stately buildings in the coastal zone and the characteristic forms of the desert (sand dunes etc.);
- evaluate and measure the changes that have taken place, distinguishing the areas subject to the greatest modifications, also in terms of categories of land use, from those that have maintained a relatively “intact” layout with respect to the first year of observation;
- have detailed and updated databases in order to define and visualise trade areas, with respect to elements of particular importance, or to calculate for example the areas of the polygons that represent the residential, commercial buildings etc.;
- focus on the new elements of economic-financial, tourist interest etc., which confirm and connote an urban reality in rapid expansion, bearing witness to its fervid activity;
- identify some ancient forms of villages and other small aggregations of huts or houses in the desert zones, which are very distant with respect to the modern skyscrapers and commercial buildings.

There are therefore many application possibilities and aspects for didactics and research, with urban realities like that of Dubai becoming emblematic examples for the geographical study of ongoing changes, documented by the differentiated sequences of remote sensing images.

#### 5. New islands in the Persian Gulf

The Emirate of Dubai is situated along the south-eastern coast of the Persian Gulf, also known as the Pirate Coast. Along with six other emirates, among which Abu Dhabi, Dubai is part of the United Arab Emirates. Its geographical position, at

25° north and 55° east, just slightly further north of the Tropic of Cancer, conditions its climate and topography: the interior of the territory is made up of sand dunes and is an integral part of the Arabian Desert, while the coast and the lowland are often covered in salt owing to the considerable sea water evaporation. As already considered, over the last twenty years Dubai has undergone a massive almost science-fiction like development, helped both by the discovery of oil and by a policy for an impetus in favour of tourism, commerce and business. The city of Dubai hosts cutting edge constructions, among which stands out the highest skyscraper in the world, the Burj Khalifa (more than 820 m), while the shoreline has undergone obvious changes with the creation of artificial islands, among which the Palms and the “World” have become famous.

## 6. Innovation and collaboration strategy

The city of Dubai will host EXPO 2020, which will have as its theme: “Connecting minds, creating the future”. In this context, the seven United Arab Emirates have an excellent tradition of cooperation and strategy, extremely effective for development and innovation, which has led them to being in the forefront of many sectors. For example, the city’s international airport is the hub of Emirates, the national airline of the Emirate of Dubai which, together with Etihad, the national airline of the United Arab Emirates with headquarters in Abu Dhabi, represents excellence in scheduled commercial flights in the world. Moreover, the development of new infrastructures along the coast has led the Emirate of Dubai to build artificial islands in the sea of the Arabian Gulf, that is to say the Palms and the “World”.

## 7. From the sea to rocky desert

With regard to the geological aspects, in the Emirate’s territory along the coast, there are many marshy and salt crusted areas (*sabkha*), while in the interior Quaternary sand and gravel are mostly to be found, which give rise to sand dunes and aeolian dunes, reaching the mountain slopes towards the east, where instead clayey limestones and shales prevail. The images from space, which allow an overall visualisation to understand

relations and balances (or imbalances) among the components, well illustrate the difficult composite geographical environment in which the Emirate is situated and the physical-geological and anthropic variability from the west (coast) eastwards (mountains). Figures 1 and 2 were created from data acquired on 28 October 2015 (by the Operational Land Imager instrument–OLI of the Landsat-8 satellite) and were visualised in natural colours (RGB 432, Figure 1) and in false colours (RGB 542, Figure 2). Unless according to specific indication, these images are shown in orbital coordinates and therefore it is necessary to rotate them ideally by about 10° in a clockwise direction to obtain the geographical correspondence.

The image in natural colours (Figure 1) highlights a number of geological aspects and the present situation of the constructions along the coast, which owing to their imposing size and singularity do not escape attention. The faint light shades can be seen in the sea due to the sunlight reflected from the sand along the coastline eroded by the sea and transported by the currents, while the deep water appears black as it absorbs all the sunlight. Going up along the coast from the bottom left northwards are the *sabkha*, where the dark greenish marshy water alternates with the white of the salt pans, and to the east of these is the city of Abu Dhabi, which can be distinguished by the grey shades of its buildings. Northwards is the private industrial port used by Emirates Aluminium, still in the territory of Abu Dhabi; then one enters into the Emirate of Dubai and reaches the Palm Jebel Ali, the biggest of the artificial islands and clearly visible in the image. From here one practically enters the city and soon the Palm Jumeirah can be seen and just a little to the north the group of artificial islets that makeup the “World”, the last construction in order of time; in fact, the third palm had not yet been started at the time of the passage of the satellite in October 2015. Moving eastwards, it can be seen that the dunes have been substituted by more consistent soil and the change in colour towards the mountain shows the presence of clayey limestones and shales, making it possible to glean important information about the geological-pedological aspects too.

The visualisation in natural colours makes the identification of the few and limited vegetated zones quite difficult. The image in false colours (RGB

542, Figure 2) instead shows the distribution of the vegetation with respect to the built up areas. In fact, the colour red (Red) represents the information gathered in the spectral band of the Near InfraRed (NIR, band No. 5 of the OLI instrument), in which the leaves have a high reflectiveness in the sunlight, for which reason woods and cultivated areas appear in shades of red. From the image it appears that the vegetated or cultivated areas are rather reduced, mainly owing to the climate at those latitudes and the extreme hydrogeological environment, despite which green zones appear also within the urban area and along the routes of communication, subject to intense and rapid phenomena of expansion along with the evolution of the commercial, residential and tourist zones.

### **8. The evolution at the end of the second millennium**

The images from the Landsat-5 satellite, coming from the archive of the United States Geological Survey (USGS), unequivocally show the big change that the coast of Dubai has undergone in the last decades. The multi-spectral image in Figure 3 was taken by the Thematic Mapper (TM) instrument of the Landsat-5 satellite on 8 May 1987 and is visualised in natural colours (RGB 321): it shows the configuration of the Emirate's coast towards the end of the second millennium, with a "classical" type geographical situation, with the salt pans in the southern part, the port of Jebel Ali in the centre and the city of Dubai and Deira, separated by the River Dubai, above right, a stretch of sea that wedges its way inland for a few kilometres. In the visualisation in natural colours it can be seen that a strip almost white in shade extends along the coast, thus highly reflective in the sunlight: this is the salt plain that separates the coast from the desert dunes. With regard to this, it must be remembered that at the end of the summer the sea water in this part of the Persian Gulf reaches the highest temperatures recorded on Earth, well above 30° C. Lastly, the image shows the limited extension of the urban areas and the few communication routes by land into the interior. The port at the mouth of the River Dubai can be seen and, to the east of Deira, the runway of Dubai's international airport. The same TM data,

but visualised in false colours (RGB 431, Figure 4), highlight the absence of vegetation in the area under observation very well, in which the shades of red are few and far between!

The images gathered by the same satellite six years later on 9 June 1993 (Figures 5 and 6), show substantial changes, but there has not yet been a drastically significant evolution: the city is sprawling, the green areas are increasing, even though not excessively, but the image shows that, for example, Dubai's international airport has still only one runway.

### **9. The development at the beginning of the third millennium**

The situation of the Emirate in the last decade appears very different. The multi-spectral image in Figure 7 was taken by the OLI instrument of the Landsat-8 satellite on 18 July 2013 and is visualised in almost natural colours (RGB 432): the urban areas are much more sprawling, the road network into the interior much more ramified, new agricultural holdings have appeared, but what is impressive above all is the appearance of extended peninsulas and artificial islands along the coast and the new Dubai World Central in the hinterland of the port of Jebel Ali, with the immense Al Maktoum International Airport, already operational even if its construction is ongoing. The construction of most of these huge works, studded by a series of elements with massive visual impact, began in 2002 and in some cases is still not complete as said above: for example, opposite the islands of Deira at the top the third "palm" or the Palm Deira is being constructed. The analysis of the same data, but visualised in false colours (RGB 542, Figure 8), confirms the increase of green areas, highlighted by the growth in areas that appear in shades of red. By enlarging the image it is interesting to see in more detail the zone of new cultivated fields circular in shape seen previously to the south in the nearby Emirate of Abu Dhabi: the different shades of red of the circles indicate different crops or at a different stage of growth, in some cases limited to half the circular area, while in the same zone appear fields without colour or grey in colour, thus without already developed plants or even bare.

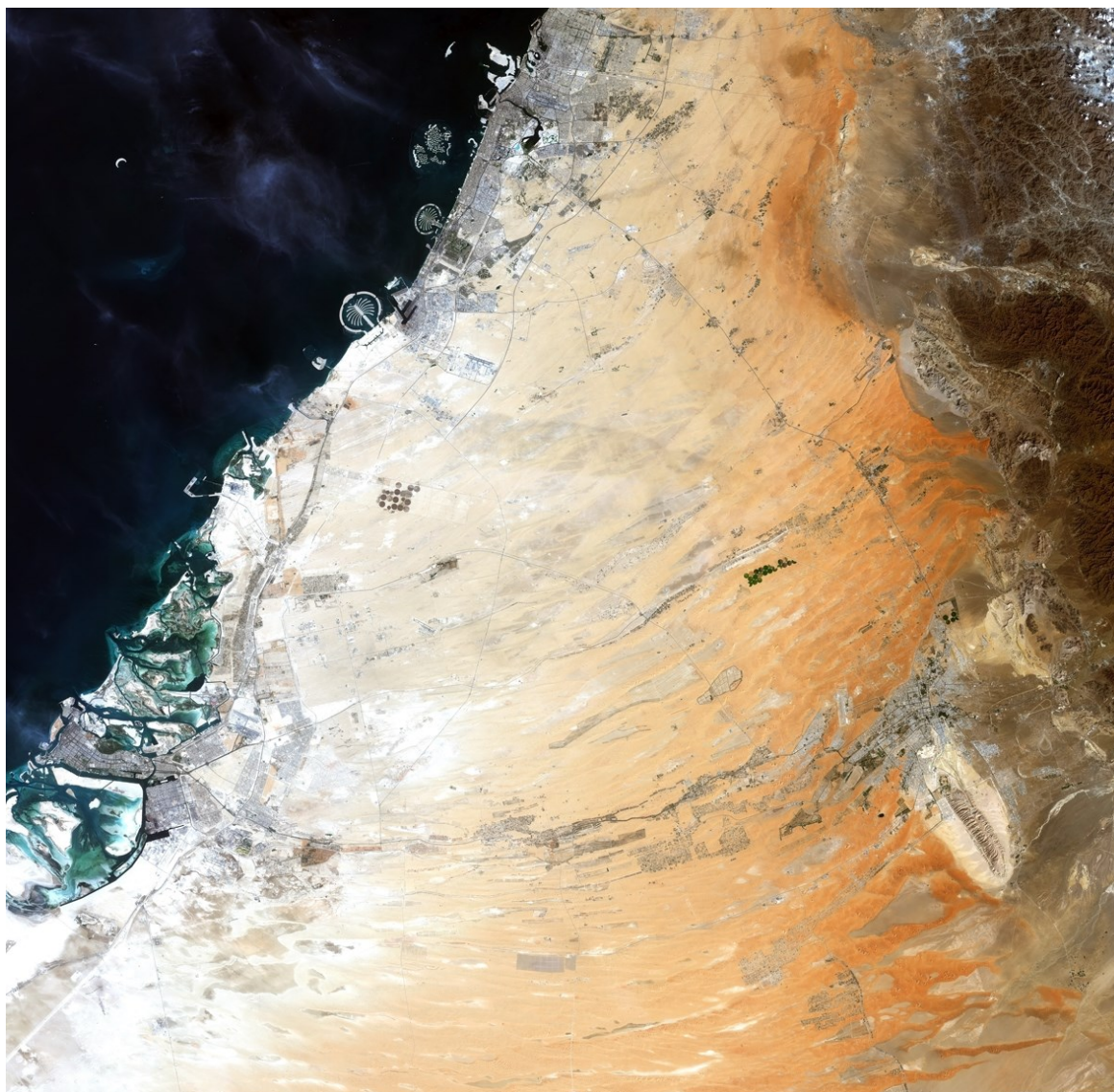


Figure 1. Multispectral satellite image of Dubai Emirate, generated from data acquired by the OLI instrument of Landsat-8 spacecraft on 28 October 2015 and visualized in natural colours (RGB 432). Source: USGS/ESA.

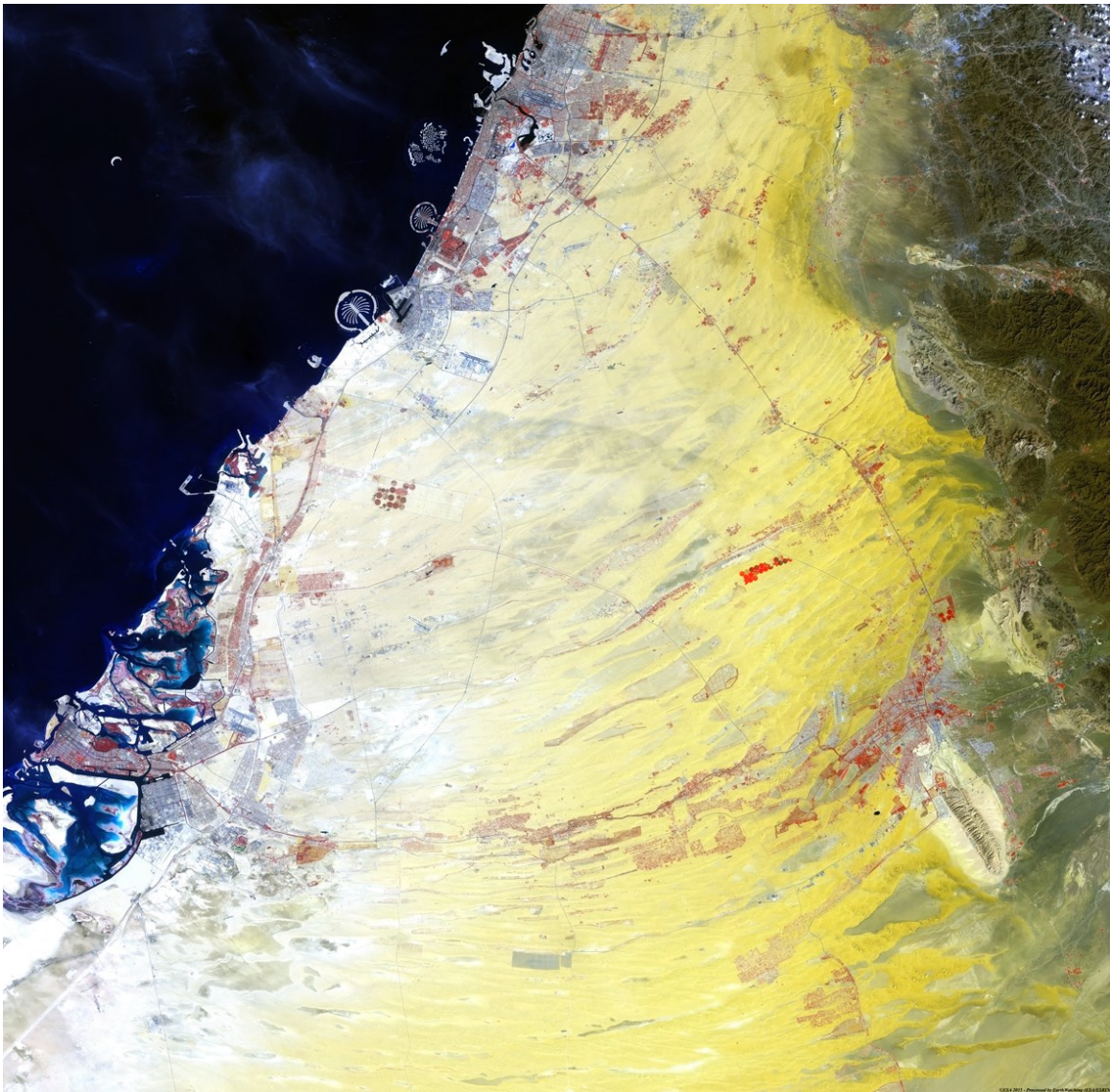


Figure 2. Image of Figure 1, visualized in false colours (RGB 542). Source: USGS/ESA.

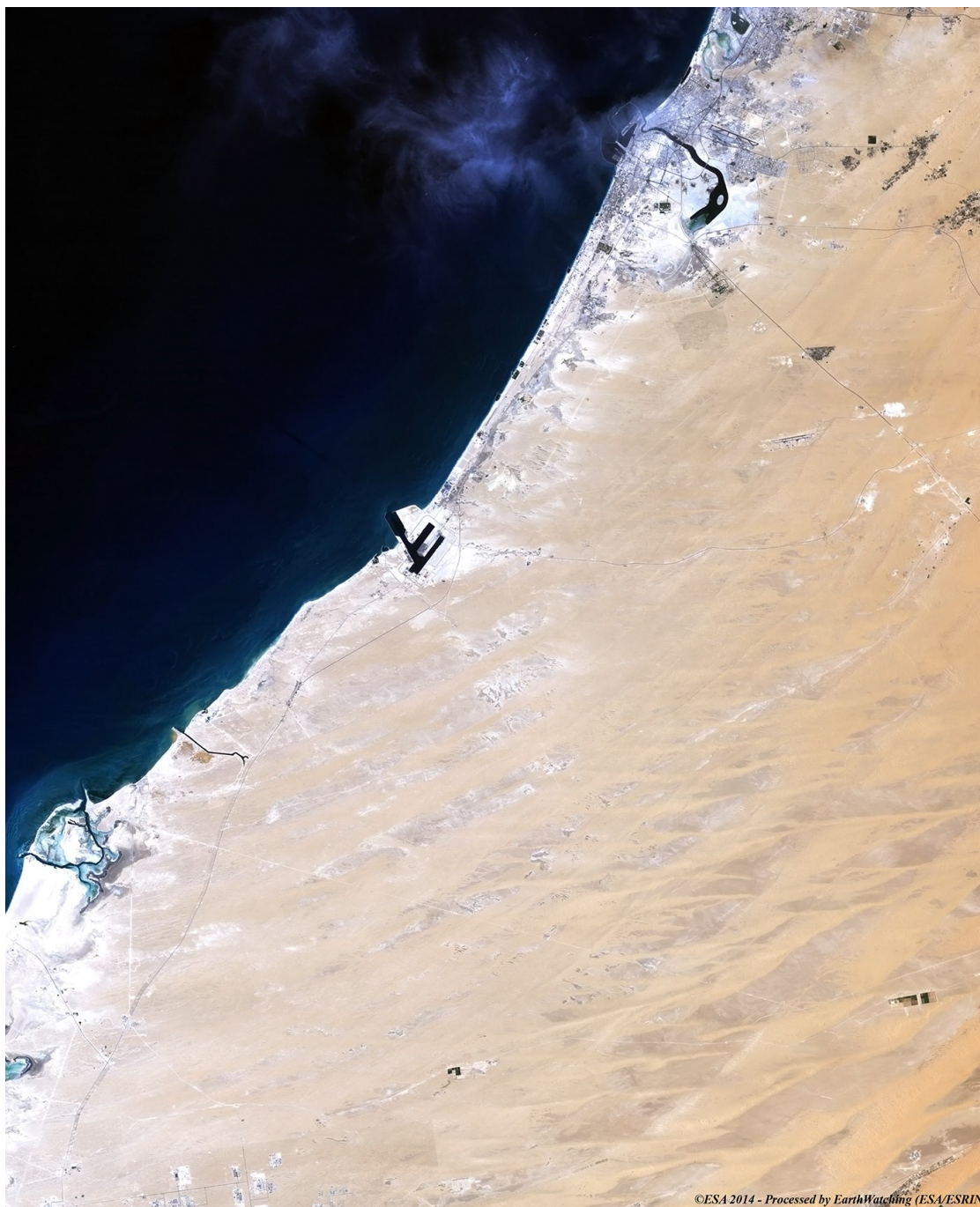


Figure 3. Multispectral satellite image of Dubai Emirate, generated from data acquired by the TM instrument of Landsat-5 spacecraft on 8 May 1987 and visualized in natural colours (RGB 321). Source: USGS/ESA.

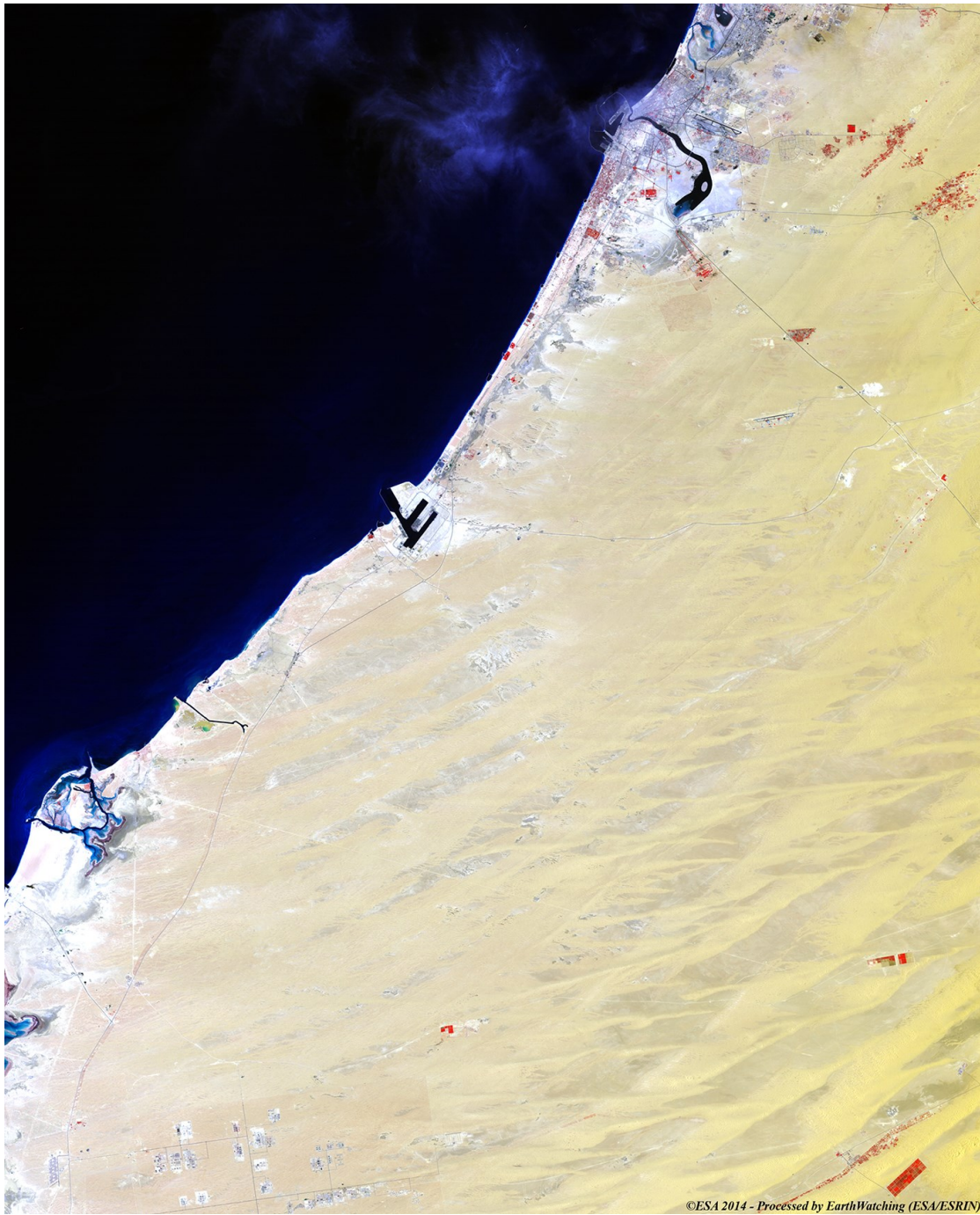


Figure 4. Image of Figure 3, visualized in false colours (RGB 431). Source: USGS/ESA.



Figure 5. Multispectral satellite image of Dubai Emirate, generated from data acquired by the TM instrument of Landsat-5 spacecraft on 9 June 1993 and visualized in natural colours (RGB 321). Source: USGS/ESA.



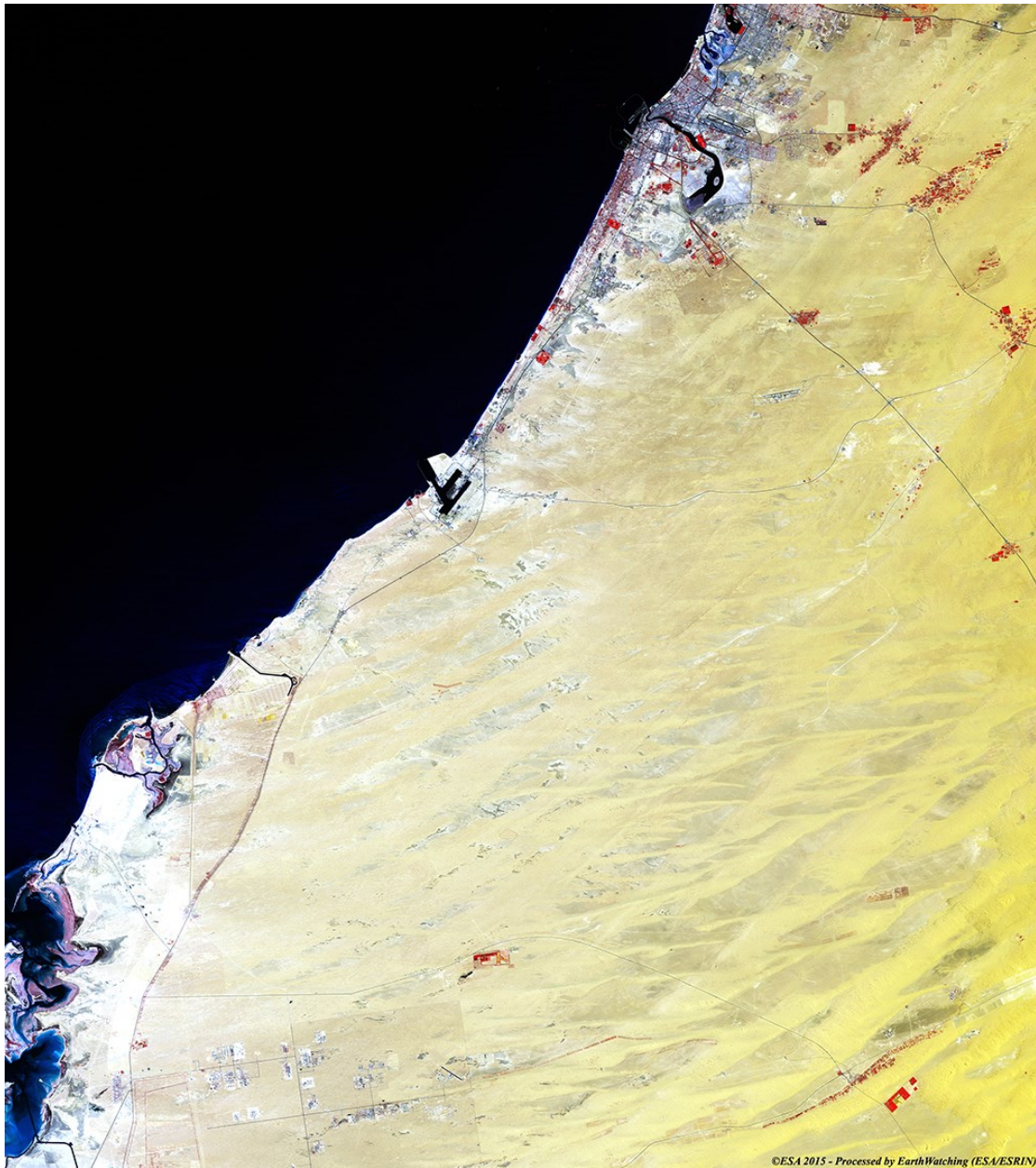


Figure 6. Image of Figure 5, visualized in false colours (RGB 431). Source: USGS/ESA.



Figure 7. Multispectral satellite image of Dubai Emirate, generated from data acquired by the OLI instrument of Landsat-8 spacecraft on 18 July 2013 and visualized in natural colours (RGB 432). Source: USGS/ESA.



Figure 8. Image of Figure 7, visualized in false colours (RGB 542). Source: USGS/ESA.

By using the high resolution data of the VNIR-2 instrument of the ALOS satellite on 2 November 2010, it is possible to see in more detail (Figure 9) the vast extension of the urban area of Dubai and Deira, practically united by now, the Palm Jumeirah, the “World” archipelago, made up of dozens of small artificial islands symbolising the Earth, and the islands of Deira where the Palm Deira will be built, of which can be seen on the sea what seems to be the outermost stretch of the future breakwater bow. Enlarging the image, it can be seen that the Dubai international airport now has a second runway.

The visualisation in false colours RGB 431 (Figure 10) makes it possible to better highlight the contrasts between the constructed or built up areas, such as the city, the infrastructures or the road network (in shades of blue), the green areas (in shades of red), above all in the city and the desert. It is moreover interesting to note that the slightly pinkish shade of the constructions along the coast and on the Palm seem to indicate the presence of trees and flower beds, while those of the inland areas maintain the blue shades, an indication of poor or even no vegetation.

### **10. Points of consideration at the change of season**

In order to show how remote sensing can be of help in assessing the environmental changes in time and therefore also from one season to another, Figures 9 and 10 should be compared

with Figures 11 and 12, or that is to say the situation in the same territory observed almost five months later by the same sensor and by the same satellite, in both cases with images acquired by the ALOS satellite in 2010. The difference is evident above all in the cultivations and the urban areas: bearing in mind that Dubai is at a latitude of about 25° north, in the images with false colours the different shade of red indicates that the vegetation was more luxuriant in May than in November.

### **11. A step ahead in the last five years**

The comparison of the data acquired by the Earth Observation satellites in 2010 (Figures 11 and 12) and 2015 (Figures 1 and 2) shows the huge development of constructions and infrastructures that has taken place in the last five years: the most interesting zones for growth have been the areas around the “Al Maktoum” international airport south-east of the Palm Jebel Ali, the Industrial Area of Jebel Ali and the Dubai Investments Park east of the Palm.

It is useful to underline that the satellite images acquired by the sensors using optical spectral bands show above all the situations on a horizontal plane, for example the extension of a city, while to have information on the vertical coordinate, or height, it is necessary to use the data acquired by active sensors that operate in the spectral bands of the microwaves, or that is to say from the synthetic aperture radar (SAR), elaborated with specific methodologies, such as interferometry.



Figure 9. Multispectral satellite image of Dubai Emirate, generated from data acquired by the AVNIR-2 of ALOS spacecraft on 2 November 2010 and visualized in natural colours (RGB 321). Source: JAXA/ESA.



Figure 10. Image of Figure 9, visualized in false colours (RGB 431). Source: JAXA/ESA.



Figure 11. Multispectral satellite image of Dubai Emirate, generated from data acquired by the AVNIR-2 of ALOS spacecraft on 19 May 2010 and visualized in natural colours (RGB 321). Source: JAXA/ESA.



Figure 12. Image of Figure 11, visualized in false colours (RGB 431). Source: JAXA/ESA.



## 12. The development of Dubai seen by means of microwaves

The observation of the territory in the microwave spectral band gives the chance to gather different but complementary information to that acquired by the use of optical remote sensing. Unlike the latter, which gives reflectiveness (in the reflected optic) or the surface temperature (in the thermal optic) of the objects under observation, a radar image gives information about the roughness and the degree of humidity of the surface being observed, and about the situations of multiple reflection by natural or artificial obstacles; moreover, the radar detection works also during the night and it is all weather, since the atmosphere and most of the hydrometeors are transparent to the radar pulses, so that the clouds are never visible in the radar images. The radar “illuminates” the objects with pulses sent with a regular sequence and the “signal” acquired by the radar is in reality the return echo picked up by the radar itself. The characteristics of the radar echo depend on the interaction between the pulse energy sent by the radar and the surface of the object illuminated by the same. Even today a satellite can transport only one radar instrument and this can work in one single spectral band: consequently, the radar data are visualised in black and white, as in the case of the optical panchromatic band. The shades of grey in every point (*pixels*) of the detected image are therefore associated with the intensity of the signal, or the return echo received from the radar: conventionally black indicates the absence of return echoes and white the maximum value of the signal.

As a first approximation it can thus be said that the shades of grey of the pixels of an image detected in the spectral band of the microwaves are proportional to the “roughness” of the surface illuminated by the radar pulses. The best example is represented by the image of a liquid surface in relation to the intensity of the wind blowing on it: when there is no wind and the sea is calm, the flat surface acts as a mirror and reflects the radar pulses far away, so that no echo returns towards the radar; when instead the wind increases the surface starts to get rough and the capillary wavelets on it send a part of the energy of the pulses to the radar, generating the

return echoes to the radar. Consequently, black pixels indicate a clam sea surface without any wind or a slick of oil on the sea, while light pixels indicate intense surface wind and choppy sea. The roughness of the surface is always measured in relation to the wavelength, in the sense that the unevenness of the surface (capillary waves) must have dimensions of the order of the wavelength used by the radar to give a strong echo. Therefore, the smooth asphalt of a parking area gives no echo and the asphalt appears black, while the walls of a building always give a strong echo owing to the multiple wall-asphalt road reflection. Stark land and desert areas are medium grey in shade.

The image generated by the data gathered on 8 March 1993 by the SAR instrument of the ERS-1 satellite (Figure 13) shows the surface of the sea rippled by the wind, some boats on the sea (white dots at the top), a fair urban development with the runway of Dubai’s airport (black almost horizontal strip top right), the coast in its natural configuration, with the port of Dubai-Deira to the north and the private port of Emirates Aluminium to the south, and the desert with its continuous belts of dunes. The image constructed from the data acquired on 30 May 1996 by the SAR of ERS-2 (Figure 14) does not show any particular variations, except for a slight increase in the number of buildings: the coast is still intact and there are some oil slicks on the sea. The image of 29 January 2004 from the ASAR of the Envisat (Figure 15) shows the city on a very windy day, as the surface of the water of the Khor Dubai is rough too, and it shows the initial phase of the construction of the Palm Jebel Ali to the south, with the central part of the external breakwater pier already finished, the completion of the foundation of the Palm Jumeirah in the centre and the presence of the second runway of Dubai’s international airport. The image of 2 February 2006 from the ASAR of the Envisat (Figure 16) shows that the sea is calm, with some areas rippled by a light wind, and that the construction of the Palm Jebel Ali is well ahead, while the urban development is growing and confirms that the works have begun for the construction of the “World” (the series of islets top left) and the new Al Maktoum international airport with the appearance of the first runway (horizontal segment centre bottom);

there is a myriad of white dots on the sea, which are boats coming in and out of the industrial port in the south and part of the traffic for the port of Dubai-Deira to the north. The image of 7 May 2009 from the ASAR of the Envisat (Figure 17) shows a day with a land breeze, which only makes the sea near the shoreline a little bit rough, including the water inside the Palms and the “World”; the built up area has grown even more, above all in the industrial zones to the south and in the infrastructures of the new airport, and the “World” has practically been completed, while it shows that the works for the Palm Deira, foreseen in the far north of the Emirate, opposite the mouth of the River Dubai, have practically stopped at a huge island on the surface of the water opposite the coast. The image of 12 March 2011 from the ASAR of the Envisat (Figure 18) confirms the completion of the “World” and the breakwater barrier, and the extension and consolidation of the urbanised and industrialised areas, including two ports and communication routes on the mainland, while the construction of the Palm Deira project has turned into the consolidation of the Deira islands near the coast.

Figure 19 shows the image of Dubai elaborated by data of the SAR of the Sentinel-1A on 30 September 2015 and has been visualised so as to facilitate the contrast in the shades of grey between the buildings, the sea and the desert. The radar image analysis is based on both the dielectric constant (therefore also on the contents of the water) and on the roughness

of the surface of the objects under observation. Numerous white dots can be seen on the sea: they show the considerable traffic of ships and boats in general, which backscatter a strong echo because they are made of metal and owing to the multiple reflection of the sides and the water. It can furthermore be seen that the dark grey colour filaments indicate a slight choppiness of the sea’s surface, suggesting the presence of land breeze in a SSE-NNW direction. Along the coast and immediately inland are the light colours of infrastructures and buildings, which highlight the geometry of the constructions: it is interesting to see that the latter begin at the level of the Palm of Gebel Ali, just a few kilometres north of the frontier with the Emirate of Abu Dhabi. At the centre on the coast the circular dams and the buildings of Palm Jumeriah can be identified, while the Palm Gebel Ali to the south and the islands of the “World” further north are not marked with shades of white, probably because the buildings are lower and therefore less reflective to radar pulses or due to a slightly different position of the radar illumination at the spacecraft pass; the works continue to complete the Deira islands, while of the original project of the third palm, the Palm Deira, there is only a short stretch of breakwaters offshore. The desert zones in the bottom right are also worthy of mention: the shades of grey seem to make out the dune systems of those arid parts, while in the centre towards the right the big communication route leading to the south-east of the United Arab Emirates is quite visible.

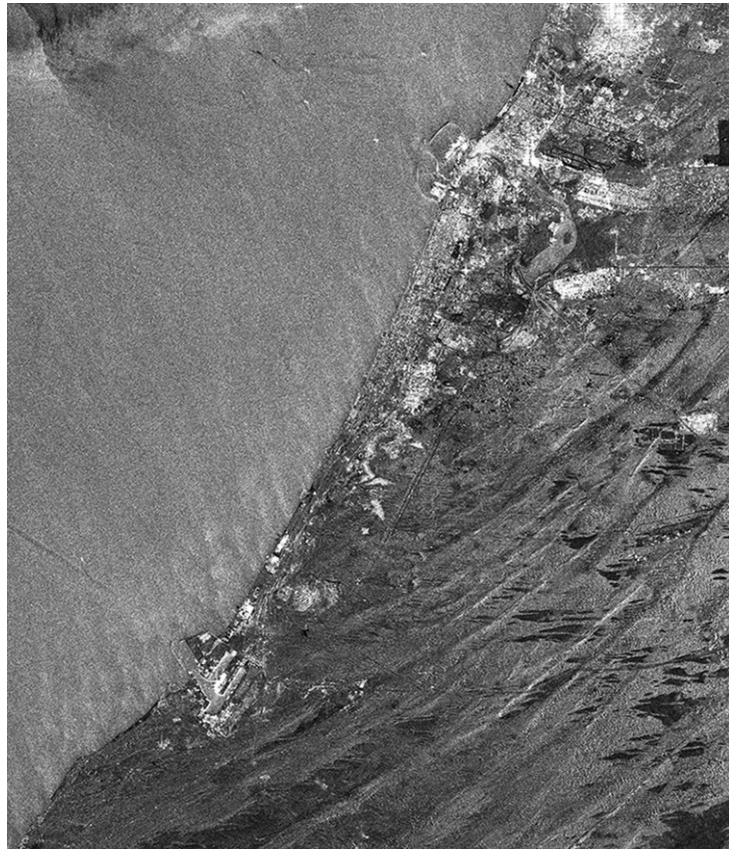


Figure 13. Radar image generated from data acquired in the microwave spectral band by the Synthetic Aperture Radar of ERS-1 spacecraft on 8 March 1993. Source: ESA.

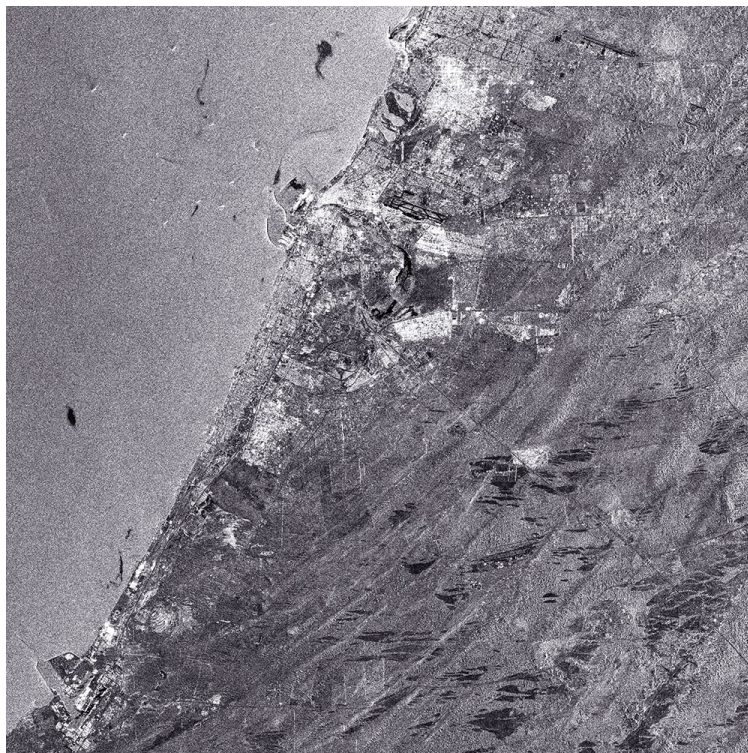


Figure 14. Radar image generated from data acquired by the SAR instrument of ERS-2 spacecraft on 30 May 1996. Source: ESA.

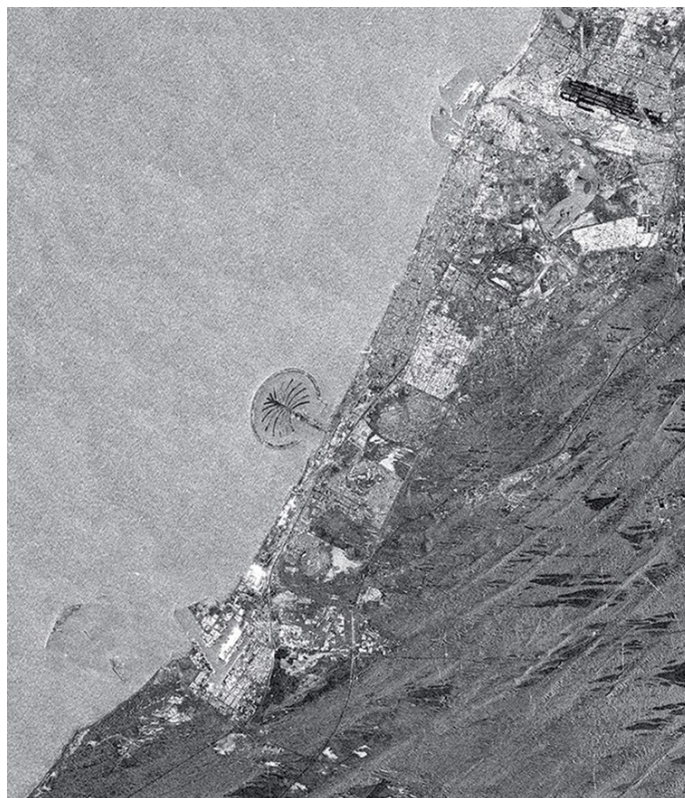


Figure 15. Radar image generated from data acquired by the ASAR instrument of Envisat spacecraft on 29 January 2004. Source: ESA.

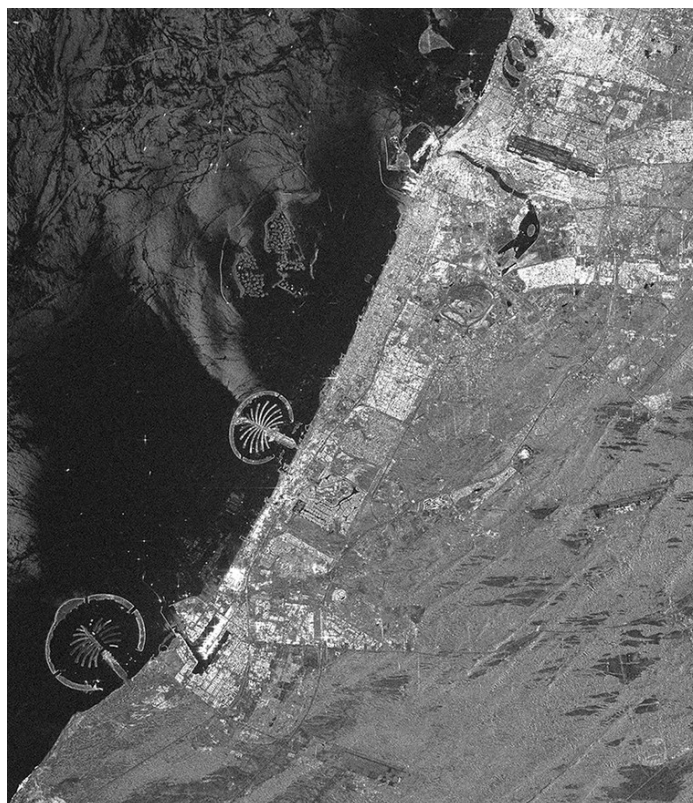


Figure 16. Radar image generated from data acquired by the ASAR instrument of Envisat spacecraft on 2 February 2006. Source: ESA.



Figure 17. Radar image generated from data acquired by the ASAR instrument of Envisat spacecraft on 7 May 2009. Source: ESA.



Figure 18. Radar image generated from data acquired by the ASAR instrument of Envisat spacecraft on 12 March 2011. Source: ESA.



Figure 19. Radar image generated from data acquired by the SAR instrument of Sentinel-1A spacecraft on 30 September 2015. Source: Copernicus Sentinel Data/ESA.

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