Life METRO ADAPT

Action C1

"Climate analysis and Vulnerability assessment at Metropolitan level"

Project Name:	**METRO ADAPT:** enhancing climate change adaptation strategies and measures in the Metropolitan City ofMilan	
Contract Number:	LIFE 17 CCMTI00008O — CUP 143E17000230007	
Deliverable number:	Report on state of the art, user requirements,methodology, input data and productsspecifications	
Due date of deliverable:	31/12/2018	
Actual submission date:	21/12/2018	
Deliverable leader:	e-GEOS	
Deliverable contributors :	Città Metropolitana di Milano, Ambiente Italia srl, CAP Holding S.p.A.	
Revision	1.0	

Nature of the deliverable		
R	Report	**X**
O	Other	
Dissemination level		
PU	Public	**X**
PI	Proprietary Information, only for Partner and Team members and, NOT for public information.	

ISSUE	DATE	AUTHOR	VERIFIED	APPROVED	REASON OF THE MODIFICATION
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1. INTRODUCTION

1.1. PURPOSE OF DOCUMENT

METRO-ADAPT C1 action on “Climate analysis and Vulnerability assessment at Metropolitan level” includes Vulnerability Assessment of Urban Heat Islands and Urban Sealing and Runoff.

Action C1 aims to facilitate decision-makers of the Metropolitan City of Milan (CMM) in the use of information useful for the development of effective governance tools at regional and local level. This action will provide the knowledge framework to support C2 and C3 actions through the development of different tools:

- Vulnerability assessment;

- Guidelines;

- Training tools;

This report is intended to describe the state of the art focused on the assessment of heat islands impacts and of the most vulnerable situations to this phenomenon, and on the most used methods to evaluate the relationship between changes in land use, in particular the increase in impervious soil surfaces, and temperature variations. It will also provide useful indications regarding the "Metropolitan Territorial Plan" with regard to urban flood risk management and agricultural vulnerability. Finally, based on the user's needs (CMM), it will define a preliminary hypothesis on the input data and methodologies to realize the products with the specific requests.

1.2. STRUCTURE OF THE DOCUMENT

The document is organised as follows:

- This chapter contains the introductory items
- Chapter 2 describes the territory of the Milan Metropolitan Area and its characteristics reflect the purpose of the project
- Chapter 3 gives a brief description of the projects or studies that have been analyzed to achieve the objectives of Action C1
- Chapter 4 reports the CMM user requirements
- Chapter 5 reports the description of Input Data for all Maps
- Chapter 6 illustrates all products specification and methodology

1.3. ACRONYMS AND ABBREVIATIONS

1.3.1. List of Acronyms and Abbreviations

Acronym	Meaning
CMM	Città Metropolitana di Milano

UIH	Urban Heat Islands
IPPC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
AVHRR	Advanced Very High Resolution Radiometer
NDVI	Normalized Difference Vegetation Index
GIS	Geographic information system
ESA	European Space Agency
MODIS	Moderate-resolution Imaging Spectroradiometer
LST	Land Surface Temperature
BLUE AP	Bologna Local Urban Environment Adaptation Plan
EIB	European Investment Bank
ARPA	Agenzia Regionale Protezione Ambientale
CNR	Consiglio Nazionale Ricerche
IBIMET	Istituto di BIoMETeorologia
ASCCUE	Adaptation Strategies Climate Change in Urban Environment
TOA	Top Of Atmosphere
IUAV	Istituto Universitario di Architettura di Venezia
FOMD	Osservatorio Milano Duomo Foundation
ECMWF	European Centre for Medium-Range Weather Forecasts
EVI	Enhanced Vegetation Index
CLC	CORINE Land Cover

1.4. APPLICABLE AND REFERENCE DOCUMENTS

1.4.1. Applicable Documents

[AD.01] Grant Agreement con l'Esecutive Agency for Small and Medium-sized Enterprises – EASME (di seguito Agenzia) relativo al progetto LIFE17 CCA/IT/000080 in data 5 giugno 2018

[AD.02] Partnership Agreement
METRO ADAPT - LIFE17 CCA/IT/000080 - CUP I43E17000230007

1.4.2. Reference Documents and Bibliography

[RD.01] Richiesta di finanziamento da parte di Città metropolitana di Milano, in qualità di beneficiano coordinatore all’attuazione del progetto “METRO ADAPT: - enhancing climate change adaptation strategies and measures in

the Metropolitan City of Milan" - LIFE1 7 CCA/IT/000080 – CUP l43E1 7000230007

[RD.02] Minuta di KOM del 30 ottobre

[RD.03] *https://landsat.usgs.gov/landsat-8*

[RD.04] *https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/product-types*

[RD.05] *https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/product-types/level-2-lst*

[RD.06] *https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/resolutions/radiometric*

[RD.07] *https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/coverage*

[RD.08] Sentinel-3 User Handbook. Issue 1.1. GMES-S3OP-EOPG-TN-13-0001

[RD.09] SENTINEL-3 OPTICAL PRODUCTS AND ALGORITHM DEFINITION. SLSTR ATBD LAND SURFACE TEMPERATURE. Issue 2.3. S3-L2-SD-03-T03-ULNILU-ATBD

[RD.10] *https://modis.gsfc.nasa.gov/about/*

[RD.11] *https://modis.gsfc.nasa.gov/about/specifications.php*

2. MILAN METROPOLITAN AREA

The Metropolitan City of Milan (45.4586° N, 9.1819° E) includes the city of Milan and other 133 municipalities. The Milan metropolan area accounts for a population of at least 3 million to 4 million, covering an area of 1575 km2. The metropolitan area is partitioned in seven homogeneous Zones characterized by geographic, demographic, historical, institutional features.

The CMM territory has this caracteristics:

- about 32% of the territory formed by build-up areas and infrastructures,
- 64% formed by agricultural areas,
- only 3.5% is formed by woodlands.

(Corine Land Cover-Geo Data Base 2017);

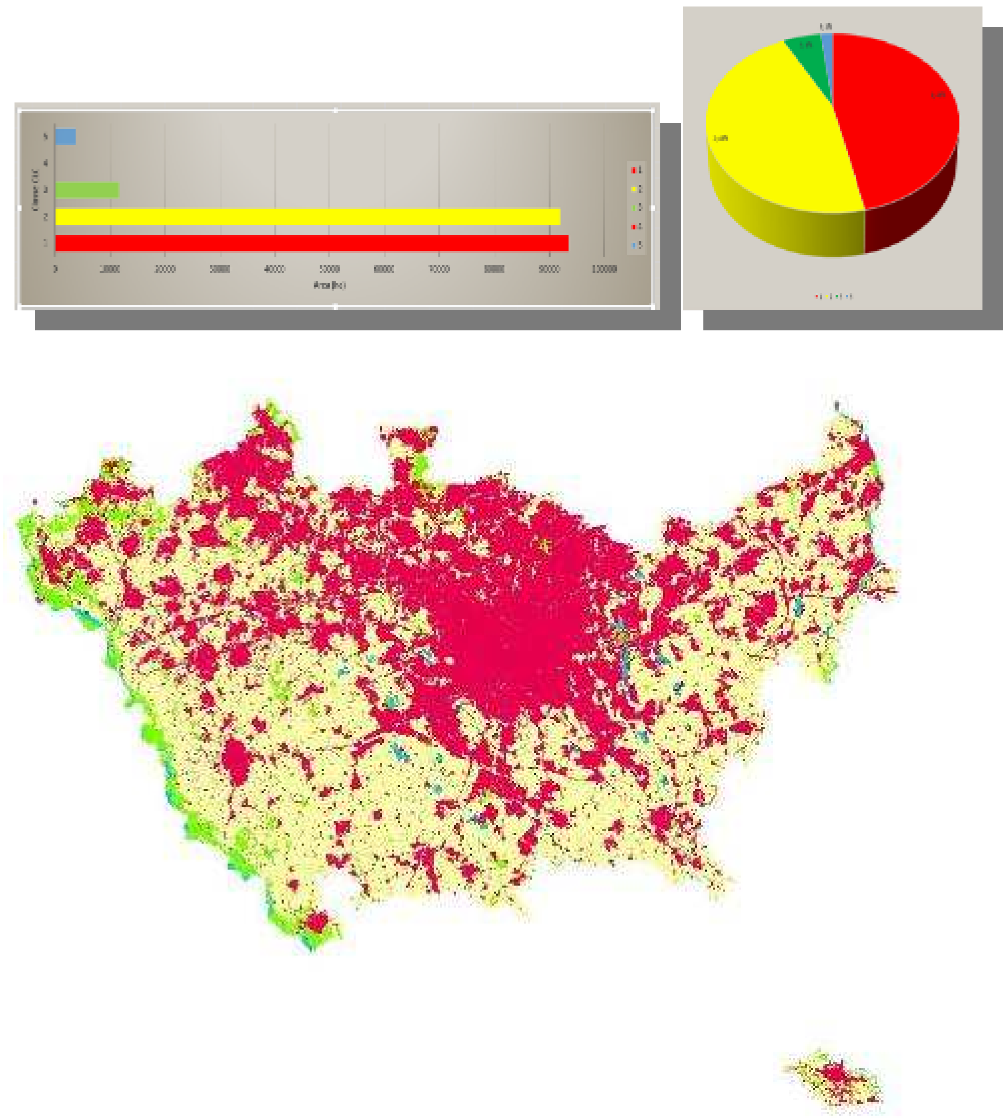


Figure 2.1 Metropolitan City of Milan.

This is a high density area with 2.038 inhabitants / km2 for a total of 3.2 million of inhabitants in 2016), demographic structure (22% over than 64 years old in 2016) and its climaticconditions (high temperatures and high humidity during summer time), is expected severalmunicipalities to have to deal with the phenomenon mainly in the Nord area where the urban structure is continuous and the population density is extremely high with seventeen municipalities with more than 3.000 inhabitants / km2 (see attched map).

Milan has a humid subtropical climate (Cfa. According to the Koppen climate classification with continental influences):the average temperature is 17.7 °C and the average precipitation 920 mm.

3. Previous studies and projects on UHI analysisand vulnerability

In the following section previous studies and projects involving the use of satellite imagery for the analysis of the UHI will be resumed.Previous studies and projects related to the impact of such phenomena on urban vulnerability will also be analyzed.

The following projects will be analyzed:

1. Satellite monitoring of summer heat waves in the Paris metropolitan areas; this project was funded in 2010 and performed by Benedicte Dousset et al.
2. Urban Heat Island and Urban Thermography focused on the following EU towns: Bari, Athens, Thessaloniki, Lisbon, Brussels, Madrid, Seville, Paris, Budapest, London; project funded by ESA(2016);
3. Integrated use of satellite remote sensing and cadastral data to identify Urban Heat Islands and population vulnerability during summer heat waves in Milan (2015) and Rome (2017); performed by e-GEOS and Legambiente
4. BLUE AP Project (LIFE11 ENV / IT / 119) for the implementation of the Climate Change Adaptation Plan for the Municipality of Bologna
5. DECUMANUS: Development And Consolidation Of Geospatial Sustainability Services For Adaptation To Environmental And Climate Change Urban Impacts
6. CNR IBIMET: high-resolution maps of the biggest Italian cities related to the spatial distribution of daytime and nighttime risk from urban heat for the elderly population
7. Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data
8. “Climate change and territory: guidelines and operational proposals of the Metropolitan City of Milan; pilot actions on 4 homogeneous zones “ - CMM-Cariplo Foundation Project (with Politecnico of Milan and IUAV of Venice)
9. Papers about the assessment of agricultural vulnerability (P. K. Thornton et al. (2014); Wang et al. (2016); A. Gusso et al. (2014)).

3.1. Satellite monitoring of 2003 summer heat waves in Paris

A university research study was conducted in 2010, focused on the satellite analysis of the summer 2003 heatwave in Paris. During the 2003 summer heatwave over 4,800 deaths were estimated due to high temperatures. The study showed that these deaths are specifically related to the prolonged days and nights of very high night temperaturesSatellite thermal data were used to assess minimum, maximum and average temperatures, in Paris. A sample of 480 elderly persons living in Paris was taken, half of whom died in those days. The maximum temperatures of the first ten days of August were35-40°C in industrial areas with night minimum temperatures of 20-26 °C. A conditional logistic regression model was used to assess the dependency between temperature/climate variables and deaths. From the logistic model it was possible to identify that, among the temperature variables, those of minimum night-time averaged (over 7 days or decades), were related to the identified attribute (deaths). So, according to the study, it is the high, and prolonged, nocturnal minima that cause the greatest number of deaths.

This result was confirmed by the comparative analysis with the year 1998, during which maximum daytime temperatures occurred on average higher than 2003 (+ 5 °C), but with average night minimums significantly lower (-8 °C), that have not activated a heat wave dangerous for health.

The analysis showed correlation between the hottest nights ("tropical" with Tair> 20°C and up to 26°C) and higher number of deaths. It is at night that urban areas release the accumulated heat of the day, which, in “geat islands” stagnates and accumulates as a result of urban conformation (asphalt roads, high buildings, poor ventilation).

Satellite images processing

76 NOAA-AVHRR images, from 21st July to 21st August 2003, were selected for the lowest presence of clouds and zenith angle less than 35°. The pixel resolution is 1.1 km. A multispectral SPOT-4HRV image of 23 July was acquired for the mapping of the urban area and land use, obtained with an unsupervised classification in 6 classes: 1. Water, 2. Dense urban area, 3 Sub-urban residential area, 4. Bare soil, 5. Forest and urban forests, 6. Fields and cultivated areas.
The albedo and the diurnal cloud cover were derived from the NOAA-AVHRR channel 2; the night cloud cover from the difference between channels 3 and 4. The Normalized Difference Vegetation Index was obtained from the visible channel 1 and near-IR 2; finally, the surface brightness temperature (BT) was calculated, which is affected by the absorption of water vapor and atmospheric gases, variability in the emissivity of the soil and in its spectral response, intra-pixel variations of the temperature with non-linear mean effects and to changes in radiation due to the urban structure. However, it has been verified that even at a resolution of 1.1 km, the pixel data is also sensitive to small urban variations (e.g. cooling of 1.5°C due to the presence of a garden).
During the 9 days of maximum heatwave, 50 NOAA images were processed, averaged at the tri-hour level and the minimum, maximum and mean day and nighttime temperature of each day was calculated.
The SPOT classification (20 m) is inserted in a GIS and superimposed with the NOAA elaborations (1.1 Km). Further ancillary cadastral data on the urban structure have been included in the GIS.

Hourly temperature data on the ground were acquired by the meteorological station in the Park of Montsouris. The Tair measurement of the control panel is different from the temperature measurement of the satellite pixel; a stronger correlation between Tair and satellite temperature was observed at night, while during the day the data is less correlated due to the greater influence of the emissivity of the various intra-pixel ground coverings. However at night the Tair is consistently higher by 1-2°C than the BT, with a difference of + 5°C in the night of maximum peak heat.

Analysis of health risk for elderly people

248 elders who died during the heat wave were taken into the test, and 248 others survived, as a comparison, under the same conditions (age, sex, socio-economic conditions). For each of them the temperature measured in the pixel containing the residence address has been assigned. Various temperature measurements were used in the model: minimum and maximum day and night, and their values averaged over 3, 7, 13 days. Data were entered into the logistic regression model for significance analysis.

Results

The average temperatures highlighted the existence of "heat islands", with differences between some dense edified and the suburban areas. The nocturnal satellite temperatures showed more persistent heat islands, with differences of over + 8 °C between hours 20-23 and 1-3, with repeated "tropical" nights with temperatures around 25 °C. The distribution of the temperatures follows the increasing density of the building and the asphalt, from the suburban area to the central and industrial ones. On the outskirts, the cooling effect of the vegetation allows a faster thermal lowering of 4 °C in the night, while in the center and in the dense urban areas and in the "urban canyons", the stagnation of heat causes hot temperatures to persist for longer. At dawn there is still 3-4 °C of difference between the zones. Industrial areas, with low thermal inertia but with low buildings and wide roads, are constantly warmer during the day (40 ° C) but less at night compared to the central ones.

Multivariate analysis using the conditional logistic regression model verified that daytime temperatures (maximum and average) are not significantly correlated with deaths. On the other hand, even an increase of + 0.5 °C in the weekly mean night produces a significant doubling of the risk of death.

3.2. ESA project "Urban Heat Island and Urban Thermography"

The European Space Agency (ESA) funded a project called "Urban Heat Island and Urban Thermography" 1 in the framework of the Data User Element - Earth Observation Envelope Program (EOEP 2008-2012).

[1] http://due.esrin.esa.int/page_project122.php

The main objective of the project, carried out by a consortium of 6 organizations from 5 EU countries, was the delivery of a methodology for the data integration between multi-sensor/multi-platform E.O. satellite thermal infrared imagery, and meteorological ground stations data (temperatures, humidity, wind speed and direction), via climate modelling. The aim is the real-time monitoring of the urban temperatures to provide early warning and alarm indicators of an incoming heat wave, to allow public administrations and policymakers to prevent the most dangerous effects of UHI phenomenon. The satellite analysis of UHI events also provides information for urban planners to support decisions on adaptation techniques such as green and blue infrastructures.

A second project objective was the study of the technical characteristics and requirements of an high spatial resolution thermal infrared sensor (for a future satellite mission), dedicated to thermal analysis of urban areas. Public administrations have stated that higher spatial resolution thermal data (respect to 1 km) are required for urban analysis.

The project was focused on the following EU towns: Bari, Athens, Thessaloniki, Lisbon, Brussels, Madrid, Seville, Paris, Budapest, London.Amulti-platform set of satellite data were acquired: low resolution MSG Seviri (3-5 km), medium resolution ATSR, AVHRR, MODIS (<= 1 Km), higher resolution Aster and Landsat (<= 100m), and very high resolution airborne thermal sensor (5-30m), to produce thermographic maps.

18 products were provided, including, among others: Land Surface Temperature Maps (LST); Surface albedo, emissivity and roughness length; climate modelling of air temperature from satellite data; near-real time alarms of incoming UHI events and 3 days forecasts to estimate Air Temperature at 1 km resolution; Hazard and Risk maps for emergency planning; energy balance and efficiency (from thermographic mapping) to assess energy efficiency of buildings and savings effect of green infrastructures (green roofs, planting of trees).

3.3. e-GEOS – Legambiente studies on UHI in Milan and Rome

e-GEOS, in collaboration with Legambiente, carried out two preliminary studies on the integrated use of satellite remote sensing and cadastral data to identify Urban Heat Islands and population vulnerability during summer heat waves in Milan (2015) and Rome (2017).

The aim of these studies was to verify the feasibility of a methodology to support the urban planning in local administrations to establish climate adaptation techniques, and Civil Protection to help population during the heat waves events.Analyzing the ground meteorological stations dataavailable in the areas, three different periods between July and August 2015, and other three during summer 2017, were highlighted (both in Milan and in Rome), when the temperatures exceeded 35°C, as maximum at daytime, and 24°C as minimum at nighttime, for several consecutive days. The highlighted days represent the "heat wave" periods.The previous study of Paris 2003 heat waves (see above) has demonstrated that the most critical parameter, for human heath, is the night temperature equal or above 25°C, and showed that the urban heat islands can be observed and identified in nighttime images, when the difference in temperature between the hottest areas and the surrounding rural zones may arise at up to 10°C. Within the so defined heat wave periods, nocturnal satellite thermal infrared imagery were downloaded, of the Landsat-8 TIRS, Modis (Milan 2015) and SLSTR Sentinel-3 sensors (Rome 2017).

Modis/Sentinel-3 daily nighttime thermal images (1 km spatial res.) were resampled over(the closest in the period)Landsat-8 available night thermal image (100 m res.,30 m pixel). The resulting images were daily thermal maps of the towns during the heat waves.

From these daily thermal images,mean temperatures maps for each of the periods under examination were produced.The hottest areas were highlighted as UHI.

The resulting three average-temperature UHI maps for 2015, and three for 2017 (one for each heat wave) were analyzed. The maps showed that the thermal behavior of the urban area is likely to respond in a coherent way even in different periods: i.e. the heat islands, which depend mainly on the urban configuration - buildings and roads -are likely to re-appear in the same areas. However, it has been found that meteorological phenomena, such as the presence of hot winds, may change the location of warmer areas, so further analysis is required to investigate the relation with weather conditions.

A synthesis map that combines the hottest areas in the selected periods, most subject to extreme temperatures, was produced to highlight all potential Urban Heat Island zones.

The integration, through a GIS, of the cadastral data of the population (in particular of the position of elderly people) allows to provide a Vulnerability Map, with special focus on the areas where there are UHIs and the highest population density of elders.Further socio-economic considerations, to exclude high-income areas where the effects of UHI are reduced by the use of air-conditioning systems, allows identifying precisely the priority areas in which urban planners may schedule interventions to improve adaptation to global warming. This is one of the objectives of current METRO-ADAPT project.

Summary and Results

In 2017 and 2018, two pilot studies were carried out by e-GEOS, in collaboration with Legambiente, focused on the thermal analysis of the summers 2015 in Milan and 2017 in Rome. For the Rome study, 19 Sentinel-3 images, 2 TIRS Landsat-8 images, 1 Sentinel-2 image (to extract the NDVI vegetation index) were used, plus data from 10 meteorological stations and cadastral data of the population. These studies have demonstrated the feasibility of using night-infrared thermal images

(Landsat-8 and SLSTR sensor of Sentinel-3 satellite or of Modis sensor on board the Terra and Aqua satellites), to analyze the distribution of temperatures inside of the city, highlighting the areas in which the phenomenon of urban heat islands has manifested itself.
The thermal map of synthesis highlighting the UHI areas was then crossed through a GIS with population census data, to assess where the number of older people most at risk during the heatwave is highest, useful in terms of civil protection and for the identification of priority intervention areas.
As a result from these pilot studies, the feasibility of the use of satellite remote sensing for urban heat wave analysis was positively demonstrated. It was possible to produce mapsof UHI areas, for Milan and Rome, in the heat wave periods. Starting from these maps, Vulnerability Maps were produced highlighting the priority areas of intervention, also as a function of population distribution.
In the next steps, foreseen in METRO-ADAPT project, further analysisof these urban thermal anomalies will be carried out in detail. Moreover, using the characteristics of the urban buildings, the areas that could best benefit from adaptation tools ("green" and "blue" infrastructures)will be identified in the areas subject to heat islands. Once the interventions have been identified, the improvements in climate resiliency will be simulated.
The procedure for the integrated analysis of low and medium resolution thermal satellite images has been implemented as a prototype in these studies; subsequently, within the METRO-ADAPT project activities, the procedure will be engineered to automate the generation of corrected thermal maps that can be extended to more cities, districts, public administrations, at a national, EU or global scale.

3.4. BLUE AP Project

Bologna Local Urban Environment Adaptation Plan for a Resilient City BLUE AP is a LIFE+ project (LIFE11 ENV / IT / 119) for the implementation of the Climate Change Adaptation Plan for the Municipality of Bologna. The BLUE AP Project was created with the aim of providing the city of Bologna with an Adaptation Plan to climate change, including the experimentation of some operational measures to be implemented at local level, to make the city less vulnerable and able to act in the event of floods, droughts and other consequences of climate change.
The Municipality of Bologna coordinates the project, which involved three other partners: Kyoto Club, Ambiente Italia and ARPA Emilia-Romagna. The planning and experimentation work carried out with BLUE AP in the city of Bologna allowed the creation of guidelines for the definition of similar Adaptation Plans, which may be adopted by all medium-sized Italian cities.
Bologna was therefore the pilot-city that first in Italy has delivered the tools to face the challenge of climate change, now considered a priority at European and national level.
The project also envisaged the elaboration of an economic scheme, which is a useful tool for evaluating the financing modalities of the identified actions and for allowing their concrete implementation.
At present, the city of Bologna is still among the first in Italy to adopt, in 2015, a Climate Change Adaptation Plan (elaborated within the Life BlueAp project). This plan was elaborated starting from the analysis of the local climatic profile of the

Municipality, which allowed to highlight the main critical aspects of the Bolognese territory that could be expected following climate change.
The Plan has identified 3 critical sectors, highlighted as "vulnerability": drought and water scarcity, heat waves, extreme events and hydrogeological risk.
For each "vulnerability" the Plan defines the objectives and the actions necessary to achieve them, with a time horizon set at 2025. The identified vulnerabilities concern problems already present today - and shared by citizens who played a key role, through a long and complex participation process of representatives from local associations and interests - which, with the emergence of the effects of climate change, will be further exacerbated.

Extreme events and hydrogeological Vulnerability
For the "extreme events and hydrogeological risk" sector, the Plan has identified 5 objectives.
The first objective is to minimize the growth of the waterproofed and built territory: the Bologna Urban Plan foresees an urban development mainly based on the redevelopment of already built areas.
As second objective, the Plan proposes to serve 1% of the territory occupied by public waterproofed surfaces (streets, squares and public car parks, equal to about 1,150 ha) with sustainable urban drainage systems.
The third objective of the Plan is related to a substantial reduction of the polluting load carried by flood spillers. The hydrographic system of Bologna - a dense network of channels fed mainly by the river Reno, built starting from Medieval Era - suffers from serious water quality problems. These problems are still largely due to the promiscuity between the sewerage (sewage collection) network and the artificial hydrographic network; a problem for which very expensive solutions have been in progress for decades. However, when, in perspective, the separation between sewers and channels fed by rivers and streams will be completed, the pollutant load will remain due to the spillways of mixed networks, which is likely to increase due to the increased frequency of intense meteoric events.
Finally, the Plan foresees two other objectives, which concern infrastructures and cultural assets particularly exposed to risk, which will have to become more "resilient" (able to withstand extreme events, returning to pre-existing conditions after the event) or adequately protected by the risk of landslides and flooding. To achieve the objectives, the Plan outlined several strategies and for each strategy a series of actions: strategies and actions related to "vulnerability". These Guidelines are one of the actions that cooperate in the strategy aimed at improving the hydrological response of the city. The European Investment Bank (EIB) has collaborated in drafting the document prepared by the Municipality of Bologna.

3.5. DECUMANUS Project

DECUMANUS was a project partly funded under the 7th Framework Programme of the European Commission. The project run from November 2013 to February 2016. The DECUMANUS consortium (11 partners) integrates representatives from the ICT community (Indra, DLR, UPM, Eurosense, GeoVille) with end-user engagement experts (UWE, CW) as well as five city application representatives (Antwerp, Helsinki, London, Milan and Madrid). In the following, an extract of the Project Context and Objectives is provided. For the full report please refer to (2).

[2] https://cordis.europa.eu/result/rcn/195373_it.html

DECUMANUS had a principal objective to develop and consolidate a set of sustainable services that allows city managers to incorporate geo-spatial products and geo-information services in their climate and environmental change strategies to support the sustainable management of the cities of Europe. The specification of the service portfolio and service sustainability had been based upon the strong engagement of the city users throughout project development and their commitment in relation to the validation activities. The project has been built upon previous research and development results and GMES products, generated by the project partners and others entities, supported by full users engagement with the project partner cities, and externally via the Stakeholder Board, and finally, underpinned by rigorous sustainability assessment and business case. DECUMANUS portfolio of information services addresses the key political concerns for Europe's cities including climate change impacts, monitoring of land-use development and urban sprawl, assessment of urban energy efficiency and securing healthy urban environments for all citizens including the vulnerable young and increasingly ageing population of Europe, specified as follows:

• Urban Climate Atlas (temperature / wind / humidity / precipitation / air pollution / energy balance / impact assessment);

• Land Monitoring (Urban Atlas change detection / green cover fraction / urban ecosystem);

• Energy Efficiency (hotspots / insulation / solar panels / light mapping)

• Citizen Health (forecast of health impact according with different scenarios)

• Water Quality (chlorophyll, turbidity, CDOM, Tª, etc)

All these products can be accessed and managed using the Decumanus Geoportal demonstrator, and advanced portal with analytics capabilities. Nodaway, it can be stated that DECUMANUS has fulfilled theirs objectives and that it has successfully entered in a commercial phase. Its philosophy is already participating in the Urban Management market, in free competition with existing ideas, services and visions of the market. Last trends technology inclusion to fulfil users' needs from different points of view has been crucial to achieve this success. In this way, final DECUMANUS services can be now connected with Internet of Thinks works, Smart cities solutions, Big Data Analysis, and exploitation. Another remarkable aspect of the results of the project is that also private companies have been engaged in the DECUMANUS framework, covering new market niches and promoting innovation in WO urban products applications. Finally, private and public institutions have allowed the Decumanus Consortium to create innovative and highly technology downstream services. These downstream services have been demonstrated using some demo uses cases developed during the last months of the project and especially after the final Workshop in Madrid (…).The original portfolio was grouped into 2 levels: Basic (or Strategic) and Premium Services. First level devoted to citizen level information publicly available over the web and with aims of self-sustainability in future years. The second level is devoted to services for city managers as requested and defined by them because their sustainability is subject to commercial operations for public administration and/or private sector. An advanced Geoportal with analytics capacities have been developed. This Geoportal was defined to satisfy the user´s needs regarding products and services accessibility and exploitation requirements. The project objectives in terms of services definition and downstream service fostering has been achieved and even overcome, creating a solid layer for downstream services development with high commercial opportunities. This fact has been possible thanks to the inclusion of technological improvements that make possible the immediate connections with Internet of Thinks (IoT), Social media impact and Big Data exploitation and applications, not forgetting the Smart cities solutions, in which platforms, Decumanus products could be included almost by default.

Project Results

To summary, the technical objectives of this second part of the project were:

• Define Premium services together with city users
• Implement the selected products
• Develop a project advances Geoportal, with high technological challenges
• Make users and stakeholders test the results
• Develop a proper business model and work in the corresponding agreement between partners of the consortium
• develop scientific dissemination
• Start commercial actions in the segments with more potentiality in this moment: energy efficiency, Health impact (...).

Finally, seven DECUMANUS services has been defined and the activity of the second year has been focused on the following Premium Level services development: 1) Urban Climate Atlas, including temperatures, heat waves, tropical nights, summer days etc. 2) Health impact, including analysis of changes in mortality due to cardiovascular problems or other causes; 3) Exposure variables: O3, PM10, NO2, EC, Heat waves, Apparent temperature, Mortality and morbidity economical cost; 4) Land Monitoring including Current and Potential Green Roof Mapping; 5) City Energy Efficiency; 6) Water Quality; 7) Population impact, including Population distribution, Simulation of some disaster events etc (…).
DECUMANUS has demonstrated a clear potential to significantly enhance the operation and capacities of urban planning in relation to the assessment and management of climate related and other environmental variables at the local level. It has in fact, demonstrated, a clear impact on the service chain of the targeted community, providing the basis for a significant uptake of the service products, and thereby create the conditions for self-sustaining development.

3.6. “The hot city” paper by the Institute of Biometeorology of CNR Italy

In the following, a translated extract of the original text. For the full paper please refer to (3).
The effects of heat on health are now confirmed by many papers. In fact, numerous epidemiological studies have demonstrated in many areas of the world a strong association between short-term effects of high temperatures and the health of the population in general and of specific categories of subjects considered as "at greatest risk". In particular, it has been observed that the mortality risk increases on average from 1% to 3% for a 1 °C increase in the air temperature over a specific threshold. The latter, generally higher in locations closer to the equator and generally in the warmer countries, also suggests an adaptation of the population to heat.
The effects of heat have shown the strongest impact on elderly people and on people living in urban environment: a recent American study has estimated a 3%

[3] https://aec-analisiecalcolo.it/pubblicazioni/aec/70/503/

increase in hospital admissions of elderly subjects (aged over 65) in the 8 days following extreme heat conditions.
In the urban environment the thermal effect is amplified by the typical anthropic phenomenon known as the "urban heat island". This phenomenon, characterized by urban areas that are much warmer than the surrounding suburbs or rural areas, is determined by the greater heat accumulation during the daytime period (favored by excessive overbuilding and presence of asphalt surfaces in the cities) and by the subsequent release of the heat during the night by radiation. In fact, during the nighttime hours the phenomenon of the heat islands is particularly intense, with differences between the central and rural areas that, in our cities, can also be higher than 5 °C. In large cities these differences can be even more pronounced, exceeding 10 °C.
The reasons for which there is great interest in this research topic are manifold.
As a consequence of the phenomenon of global warming, strong impacts of heat are expected in urban areas. UHI further intensifies a heat wave, with direct consequences for the population living in the city. Dark surfaces (such as asphalt roads) can reach temperatures of over +10 °C compared to the surrounding areas.
Currently, about 70% of the Italian population reside in urban areas and according to the most recent estimates this value is expected to increase, reaching 80% by 2050. It is therefore plausible to assume that in Italy more and more people will be exposed to the effects of high temperatures.
According to recent estimates, moreover, by 2050, about a third of the Italian population will be represented by elderly subjects (aged over 65), therefore potentially more vulnerable to the effects of heat, compared to 21% reported in the 2014 national census. It is also important to know that Italy is one of the countries with the highest average age in the world, with the highest proportion of elders (and therefore more vulnerable to heat) in Europe.
Despite this premise, at the moment in Italy there is a lack of information on the spatial distribution of heat risk in urban areas.
It is for this reason that some IBIMET researchers have developed, for the biggest Italian cities, high-resolution maps related to the spatial distribution of daytime and nighttime risk from urban heat for the elderly population (subjects over 65 years of age).
The cities included in the study have more than 200.000 inhabitants: five cities in the north (Milan, Padua, Turin, Bologna and Genoa), two in the center (Florence and Rome) and four in the south (Bari, Naples, Palermo and Catania).
In this study the researchers used two data sources:
a series of 13 years (2001-2013) of satellite MODIS data (Land Surface Temperature LST) with 1 km resolution, subsequently reported at a resolution of 100 m thanks to a complex downscaling procedure;
Density data of the total population and the elderly relative to 2001 (source Eurostat) extracted from the database of the Joint Research Center with a resolution at 100 m.
These data were processed using a recognized risk assessment methodology for the population linked to environmental hazards previously used in an international project aimed at evaluating strategies for adaptation to climate change in urban environment (ASCCUE, Adaptation Strategies for Climate Change in the Urban Environment). This risk is defined by the interaction of three fundamental components:

- the environmental hazard (natural hazard), represented in the study by the increase in the land surface temperature; the exposed population (exposure), represented by the total population;
- the vulnerable population, represented by the population over 65 years old.

The day-night and night-time risk index for the elderly population was therefore calculated, called in the "Heat-related Elderly Risk Index (HERI)", which is spatialised throughout the urban context during the summer period. The index practically allows identifing 5 levels of heat risk for elderly subjects (very low, low, moderate, high and very high risk).
The maps developed in this study showed a clear spatial heterogeneity of daytime and nighttime risk in both inland and coastal cities, with the highest levels of risk generally (but not always) concentrated in the central areas of cities. It has also been observed that the higher level of heat risk is not always associated with the highest surface temperatures (especially during the daytime), but it is a function of how the population is distributed and especially the most vulnerable.
During the daytime period, most of the cities studied showed the highest average summer soil temperatures in the "moderate" heat risk level (from about 23 °C in Turin to over 32 °C of Catania). The other cities instead showed the highest soil temperatures in the "high" risk classes (Genoa with 20 °C) and "very high" (Milan with about 25 °C, Naples and Florence with almost 29 °C, Rome with over 31 °C).
During the night, however, almost all cities showed the highest LST coinciding with the highest level of risk (very high risk). In particular, the highest average summer nighttime surface temperature was observed in Bologna (19° C), followed by Florence, Rome and Palermo (just over 17° C). Surfaces in urban areas affected by the highest levels of heat risk (high and very high risk) were found to be higher on coastal cities (on average 11.3% of high risk area and 6.0% at very high risk) compared to cities inland (on average 8.1% of the high risk area and 3.3% at very high risk). In particular, the highest level of risk from heat (very high risk) has reached the maximum of day and night surface coverage in the city of Naples (about 15-16% of the total area), followed by Padua (8-9%) and Palermo (8%). This information is very useful as it provides information that is now non-existent at national level that is a very detailed description for each city of heat risk for the elderly, with a detail up to street level.
It is a useful tool for the planning of interventions during particularly disastrous phenomena such as heat waves which, besides causing great inconveniences among the population (in terms of the perception of the thermal environment), determine large losses every year in terms of human lives. The exact knowledge of urban areas at greater risk of the effects of heat for the population facilitates interventions by local authorities that deal with intervention strategies to quantify the effects of heat on an urban scale. For example the data can help to plan short-term interventions, such as an effective water supply, or the placement of temporary health services, or even the organization of specific transports of the most vulnerable subjects in air-conditioned centers. The spatial information obtained from these maps could be implemented in the heat wave warning services that have been active for a decade in many Italian cities (HHWS, Heat Health Warning Systems). But they would also be useful for medium / long-term actions, improving the planning of urban climate adaptation measures, identifying public and private areas suitable for a correct and strategic reintroduction of

vegetation, or by covering vegetation roofs (green roofs) or using reflecting materials, thus modifying the surfaces of buildings.
In the cities studied in these preliminary surveys it has been found that as the soil sealing increases, the daytime and nighttime surface temperature increases significantly. For example, for the city of Milan, for each 20 hectares of soil consumed, a diurnal increase in the average annual land surface temperature of around 0.6 °C was observed. This, therefore, represents a further contribution of the urban environment in aggravating the phenomenon of global warming.

3.7. Algorithm for Automated Mapping of Land Surface TemperatureUsing LANDSAT 8 Satellite Data [4]

A correct evaluation of Land surface temperature is a critical factor in the Urban Heat Island analysis, especially when the methodology requires the integration of different sources of data, such as SLSTR thermal sensor of Sentinel-3 satellite, Modis of TERRA and AQUA satellites and TIRS of Landsat-8.
Landsat-8 has advanced characteristics in terms of spatial resolution of thermal images: 100 m (30 m pixel) among the best for this kind of data, that allows a detailed and accurate analysis of heat distribution inside urban areas. However, while SLTR and Modis data are pre-processed to gather land surface temperatures LST, Landsat-8 data are not, so a further processing level is needed to allow the comparison and integration between Landsat-8 TIRS, SLSTR and Modis data. Avdan and Jovanovska have designed and tested an algorithm for the automatic mapping of LST from Landsat-8 TIRS band 10 data.
LST can be defined as the temperature as measured "putting the hands over the ground"; from a remote sensing perspective, LST is the combination of reflected solar radiance and emitted radiance, as measured by the sensor in TIR spectral bands.
While air temperature is a more homogeneous parameter, LST may strongly vary even in a narrow area, because it depends on type of soils and matters: physical, chemical, and biological factors of the Earth surface.
The algorithm aiming to produce LST from the first thermal band (band 10)of OLI sensorrequires the extraction of normalized difference vegetation index NDVI, from Red and NIR bands from the Landsat-8 OLI sensor (bands 4 and 5 respectively). The use of the second thermal TIRS band (Band 11)is not recommended due to calibration problems.
In the following a brief synthesis of the methodology is provided; in the linked paper (see the note) by the authors, a more detailed description of the algorithm is given.

Evaluation of Brightness temperature in °C

1. The first step of the algorithm is the retrieving of metadata from Landsat-8 band 10 to calculate top of atmosphere (TOA) spectral radiance, following USGS formulas;
2. the resulting spectral radiance needs one more correction step to become brightness temperature (BT), also using the band 10 metadata with thermal constants $K1$ e $K2$;

[4] U. Avdan and G. Jovanoska, Journal of Sensors, sVol. 2016, Article ID 1480307, http://dx.doi.org/10.1155/2016/1480307

3. the resulting radiant temperature is corrected by adding the absolute zero (−273.15 °C) to gather BT results in °C.

Soil Emissivity estimation

An important step of the processing chain towards the LST production is the estimation of soil emissivity using the NDVI, from Landsat-8 band 4 and 5. The soil emissivity is strongly related with the proportion of vegetation cover (PV) and with its condition; both parameters can be estimated from the NDVI index, to assess the soil emissivity. Emissivity is an indicator of the efficiency of the transmission of thermal energy from the soil towards the atmosphere.

- PV can be gathered using an NDVI model that suggests global values of "vegetation" as NDVI=0,5 and "soil" as NDVI=0,2 (although this is a rough assumption, due to the fact that NDVI may depend on the area and atmospheric conditions).
- The algorithm uses some assumptions, such as: NDVI <= 0 is water, with emissivity value fixed at0,991; 0 < NDVI < 0,2 is soil, with emissivity = 0,996; 0,2 < NDVI < 0,5 Is mixed vegetated and soil (emissivity depends on proportion PV); NDVI >= 0,5 is vegetation with emissivity fixed at 0,973;

The computation of brightness temperature in °C and emissivity factor, as obtained in 1) and 2), allows the final step of producing Land Surface Temperature in °C for each pixel in the thermal image, using a formula that only requires to introduce Plank and Boltzmann constants and light speed.

Algorithm validation

The authors have validated the results of the algorithm. Previous studies have compared the LST from satellite remote sensing, with measured ground temperature and air temperature. Due to the very high variability of ground temperature, if compared to a thermal pixel resolution of 100 m, the mean error between LST and ground measures is around ±2°C with peaks at up to 5°C. The comparison between LST and near-surface air temperature, as measured by ground meteorological stations, is however more appropriate, because near-surface AT is the temperature actually perceived by human beings. The authors have selected 6 validation areas, in two Canada provinces of Ontario and Quebec. Mean and actual temperature were measured by around 11-20 ground meteorological stations (for each area) at satellite passage time. Errors are expected, due to pixel resolution (the ground station measures in "a point", Landsat measures in "a surface") and to the physical difference between an LST starting at ground level, and AT measured at some meters above the ground (this difference may have sensible effects in some weather conditionsfor the effect of wind and humidity).The standard deviation of the difference between LST and AT resulted between 2,4 and 2,7°C.

3.8. Fondazione Cariplo – Milan Politecnico University project

The issue is the construction of a roadmap towards the drafting of a climate plan for the Metropolitan City of Milan. The work will aim to align the local context of the CMM to the international debate and to the new themes of climate planning integrated with spatial and territorial planning and to pursue the targets of

reduction of greenhouse gas emissions and response to adaptation already established at the international level.
Specifically, starting from the planning experience of the CMM and the technical capital on the proposed issues, the study aims to: (1) to bring knowledge and transfer climate change issues within local planning practices, rereading tools and plans in the perspective of territorial resilience; (2) to communicate and disseminate climate change challenges to local populations, defining a communication strategy; (3) to address spatial challenges (spatial planning) and climate challenges (environmental planning) in an integrated manner with effectiveness objectives.
Objectives:
(1) to raise awareness and transfer climate change issues within local planning practices, rereading tools and plans in the perspective of territorial resilience;
(2) Addressing spatial (spatial planning) and climate (environmental planning) challenges in an integrated way with effectiveness objectives.
(3) communicate and disseminate the challenges of climate change to local populations, defining a communication strategy.
Actions:
Preparation of a control room
WITH RESPECT TO THE OBJECTIVE OF MITIGATION
- Census of initiatives on climate change and sustainable energy
- Evaluation of a union of SEAPs
WITH RESPECT TO THE OBJECTIVE OF ADAPTATION
- Analyse policy agenda and local impacts
- Geo-spatial analysis
- Evaluation of the vulnerability of the territory and its resilience
- Transferability of results to the new MTP
Awareness and communication actions
Territorial area of reference 4 homogeneous zones:
- City of Milan
- South East
- South West
- Adda Martesana

In the following, an extract focused on the Vulnerability Assessment to heat waves.

The latest IPCC Report (IPCC, 2014) modifies the vulnerability assessment approach (respect to 2001 and 2007 reports) by bringing it closer to disaster risk reduction (DRR), defining it as "the predisposition to be negatively affected. Vulnerability includes a variety of concepts and elements including sensitivity or susceptibility to damage and a lack of ability to cope and adapt "(IPCC, 2014).
In the IPCC document, the following definitions are found:
● exposure: the presence of people, means of subsistence, species and ecosystems, environmental functions, services, and resources, infrastructures, or economic, social, cultural assets in places and contexts that could be negatively affected (IPCC, 2014);
● sensitivity: the degree to which a system or species is affected, either negatively or positively, by variability or climate change. The effect can be direct (i.e. a change in crop yield in response to a change in the mean or temperature variability) or

indirect (i.e. damage caused by an increase in the frequency of coastal flooding due to sea level rise) (IPCC, 2014);
● adaptive capacity: the ability of systems, institutions, human beings, and other bodies to adapt to potential harm, to take advantage of opportunities, or to respond to consequences (IPCC, 2014).
The approaches developed during the project activity are oriented to define methods for assessing the vulnerability with respect to the heat waves. To ensure this, numerous tests were carried out in support of the implementation of information through new ICT technologies and remote sensing.

Working methodology
In recent decades, numerous national and international studies have demonstrated the close synergy between the green and the urban environment, identifying the various roles that the green areas assume especially in urbanized contexts; in addition to the aesthetic-cultural, recreational, ecological-environmental and economic, the role of ecosystem services is of particular importance due to their direct relation to the research objectives. Analyzing the presence or absence of green in the city is one of the quantitative indicators of the resilience of an urban area towards the problems related to climate change such as: heat waves and extreme meteorological events.
The initial work phase was therefore concentrated in the production of a Land Surface Atlas, or an organized geo-database containing various information, in particular classifing the different surfaces of the city in "permeable surfaces" and "non-permeable surfaces".
The innovative analysis, made possible by the application of new geo-spatial instruments, allowed the creation of different shp files, necessary for the assessment of the vulnerability of the considered impacts, but not available from the existing information fields.
Using the ISTAT 2011 census database, further evaluations were made, regarding an assessment of "social" vulnerability.
The indicators created in this regard are:
● total population
● young sensitive population (<10 years)
● elderly sensitive population (> 65 years)

For each territorial unit in the geo-databse, we know the amount in m2 of vegetation, the percentage of vegetation in the area, m2 of impervious portion, m2 of buildings, average kWh for each roof, land surface temperature and Sky View Factror (SVF).
The assessment of the vulnerability to the "heat waves" impact
For the evaluation of areas subject to heat islands, we used the indices proposed by A. Mahdavi, K. Kiesel, M. Vuckovic (2012). The indices, in the assessment of the vulnerability to heat wave hazard, are used to evaluate the trends of the different urban areas to accumulate heat. The concentration of these elements, within a single urban unit (in this project represented by the ISTAT census areas), indicates a greater trend of an area to be vulnerable than another.
The vulnerability was so determined:
Sensitivity - adaptive capacity = vulnerability
The indicators that contribute to characterize the sensitivity are:
● Sky View Factor

● Built area fraction
● Impervious surface fraction
● Roofs Incoming Solar Radiation
● LST Land Surface Temperature
The indicators that contribute to characterize adaptive capacity are:
● Pervius suface fraction

Mapping phase

Following the single maps for each indicator, the final maps represent the different types of vulnerability with respect to the heat waves hazard. The data are aggregated by census units. These maps are used to locate the most vulnerable areas.

Heat Island Mapping: an original model

The analysis of the climatic stress in terms of exposure to heat waves was based on the air temperatures mapping, at the level of urban microclimate (about 2 meters from the ground), both day and night. In particular, a critical heat wave was observed, on August 4 2017, as reported by the ARPA weather station in Brera. For temperature mapping, data from ARPA weather stations were used, throughout the Lombardy region (total number: 185 for temperature), and remote sensing images provided by the Terra satellite, and the Landsat mission. The weather stations provide the air temperature at approx. 2 meters, but the data is not homogeneous in the territory, being a "point" measurement. The lack of coverage is then filled by the satellite information that provides a data in raster format, in a continuous and homogeneous grid, at 1 Km resolutions, for Terra satellite (MODIS sensor), and at 30 m resolution for Landsat data. Satellite information provides surface temperature measurements at ground level (Land Surface Temperature). To obtain a continuous air temperature data, information from weather and satellite stations was combined using a two-step geographically weighted regression model. At the first step the information from weather stations was combined with the LST obtained by the MODIS sensor to obtain air temperature values homogeneously distributed on a raster image (1 km res.). In a second phase, the air temperature measurements obtained by combining weather stations with MODIS were combined with the reflectance data (albedo) provided by the Landsat ETM + sensor and the elevation data (Digital Elevation Model) with a spatial resolution of 30 m. The statistical model has therefore allowed to obtain air temperatures at the level of urban microclimate (Near-surface Air Temperature) with a resolution of 30 m.
To test the robustness of the temperature simulation model on a continuous grid, various statistical indicators and the weather stations managed by the Osservatorio Milano Duomo Foundation (FOMD) have been used, which provide an alternative, and complementary, data to that provided by ARPA. The mean square error (RMSE) was lower than 0.6°C, in the case of daytime temperatures, or equal to 1°C, in the case of night temperature modeling.

3.9. Agricultural vulnerability previous studies

Weather fluctuations and other associated extreme events can cause severe losses to agricultural production with potential economic impacts. This kind of events is expected to increase in frequency and/or severity under climate change. Recent examples, such as the heat wave in Europe in 2003, have caused considerable damage to crops and agriculture and substantial economic damage. Increases in maximum temperatures have impact in terms of not only yield reductions and reproductive failure in many crops, but also in yield quality[5].

In the recent years remote sensing data associated with geostatistics tools have been applied in agricultural studies.Typically, EOS-MODIS (Earth Observing System-Moderate Resolution Imaging Spectroradiometer) satellite imagery data have been applied in the monitoring and modelling of bioclimatic processes, crop cycle development, agricultural production and biophysical parameter,confirming the potential of MODIS sensors for agriculture analysis. The results of this analysis We observed that variations of the averages of canopy-LST during flowering/grain filling periods of summer crops are closely associated with variations in soybean yields. The results indicate that heat waves that are slightly warmer than the optimal conditions for growth can potentially increase drought effects and yield loss by overheating the vegetation canopy and intensifying plant damage. Finally, we concluded that future studies on canopy-LST monitoring can significantly contribute to the regional characterisation of agriculture vulnerability and management of potential climate conditions and fluctuations.

J. Wang et al. (2016)[6] analyzed the drought occurred in 2012 in the Central Plains of the United States, using comprehensive satellite data from MODIS and TRMM, along with in-situ observations. This study documents the geophysical parameters associated with this drought providing a large-scale observation-based view of the extent to which the land surface temperature and vegetation can likely be affected by both the severe drought and the agriculture's response (irrigation) to the drought.

A. Gusso et al. (2014)[7]studied, on the entire state of Rio Grande do Sul, in Brazil, the periods in the soybean summer cycle that are sensitive to the occurrence of high temperatures. An analysis was performed on the variability of soybean yields associated with crop canopy temperatures during key development periods, based onthe monitoring of land surface temperature (LST) and Enhanced vegetation index (EVI) data series from MODISin the period between 2003 and 2012, during different phenological stages of the soybean. The results of this study highlighted that variations of the averages of canopy-LST during flowering/grain filling periods of summer crops are closely associated with variations in soybean yields. The results indicate that heat waves that are slightly warmer than the optimal conditions for growth can potentially increase drought effects and yield loss by overheating the vegetation canopy and intensifying plant damage.

[5] Climate variability and vulnerability to climate change: a review. P. K. Thornton et al.(2014)
[6] A Multi-sensor View of the 2012 Central Plains Drought from Space, J. Wang et al. (2016)
[7]Monitoring Heat Waves and Their Impacts on Summer Crop Development in Southern Brazil.A. Gusso, et al. (2014)

4. User requirement

In the current project, the CMM has been identified as a reference user for the identification of user requirements, in particular as regards the production of all the maps that will be implemented in Action C1. The following table summarizes these requirements.

FORMAT	shape file
LAYER	.qgs (Qgis) and .mxd (ArcGIS)
SCALE	1:2000
REFERENCE SYSTEM	WGS84/UTM32N (EPSG 32632)
EXTENSION	Citta Metropolitana di Milano
CUTTING OF THE DATA	Città Metropolitana di Milano – Aree Omogenee – Comunale – Sezione Censuaria
METADATING	Standard ISO
OTHER EXPORTATION	Geotiff – PDF

Table 4.1 User Requirements

5. Input Data

Below is a description of the data that will be used.

5.1. LANDSAT 8 DATA

The Landsat 8 satellite images the entire Earth every 16 days. Data collected by the instruments onboard the satellite are available to download at no charge from EarthExplorer, GloVis, or the LandsatLook Viewer within 24 hours of acquisition[RD.03].

Landsat 8 carries two push-broom instruments: The Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS).Landsat 8 images consist of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9. The resolution for Band 8 (panchromatic) is 15 meters. Thermal bands 10 and 11 are collected at 100 meters. The approximate scene size is 170 km north-south by 183 km east-west (106 mi by 114 mi).

A complete level 1 product consists of 13 files: The 11 band images, a product specific metadata file, and a Quality Assessment (QA) image. The image files are all 16-bit GeoTIFF images[RD.03].

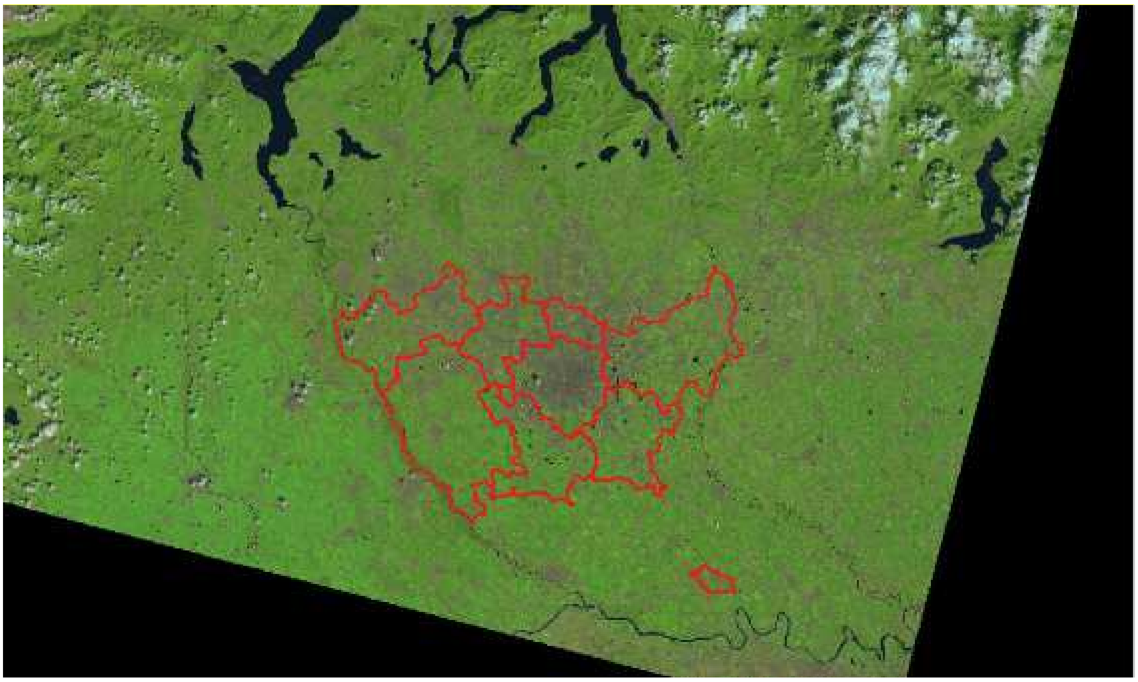
Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)		
Bands	**Wavelength (micrometers)**	**Resolution (meters)**
Band 1 - Ultra Blue (coastal/aerosol)	0.435 - 0.451	30
Band 2 – Blue	0.452 - 0.512	30
Band 3 – Green	0.533 - 0.590	30

Band 4 – Red	0.636 - 0.673	30
Band 5 - Near Infrared (NIR)	0.851 - 0.879	30
Band 6 - Shortwave Infrared (SWIR) 1	1.566 - 1.651	30
Band 7 - Shortwave Infrared (SWIR) 2	2.107 - 2.294	30
Band 8 – Panchromatic	0.503 - 0.676	15
Band 9 – Cirrus	1.363 - 1.384	30
Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100 * (30)
Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 * (30)

* TIRS bands are acquired at 100 meter resolution, but are resampled to 30 meter in delivered data product.

Table 5.1LANDSAT 8OLI and TIRS images spectral bands and resolution.

In the framework of this project, the LANDSAT 8 tile identified with the path 194 and row 028 will be used for the evaluation of the soil emissivity, while the path 054, row 216 will be the input for the resampling of the LST retrieved from MODIS. These two granules are the ones fully covering the metropolitan city of Milan, as can be seen in the following Fugure.



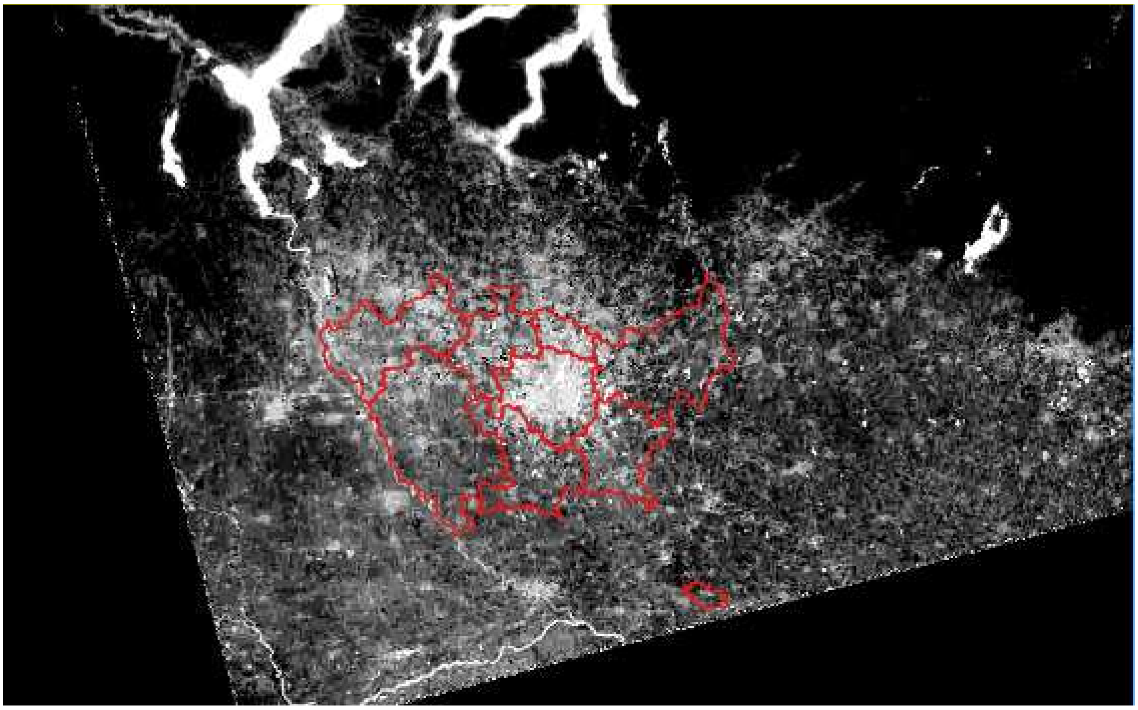


Figure 5.1(up) RGB composite of Landsat 8 tile (path 194 and row 028), acquired on 2018/08/15. (down) The nocturnal Termal image of Landsat 8 tile (path 054 and row 216), acquired on 2018/08/26. In red, the administrative borders of the Metropolitan City of Milan are superimposed.

5.2. SENTINEL 3 LST DATA

SENTINEL-3 is a European Earth Observation satellite mission developed to measure sea surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring[RD.08].The SENTINEL-3 orbit is a near-polar, sun-synchronous orbit at 814.5 km altitude with a descending node equatorial crossing at 10:00 h Mean Local Solar time. This satellite orbit provides a 27-day repeat [RD.07].

The spacecraft carries four main instruments[RD.07]:

- OLCI; Ocean and Land Colour Instrument
- SLSTR: Sea and Land Surface Temperature Instrument
- SRAL: SAR Radar Altimeter
- MWR: Microwave Radiometer.

The Sea and Land Surface Temperature Radiometer (SLSTR) is a dual scan temperature radiometer employing the along track scanning dual view technique. The main characteristics of the SLSTR are[RD.07]:

- swath width: dual view scan, 1 420 km (nadir) / 750 km (backwards)
- spatial sampling: 500 m (VIS, SWIR), 1 km (MWIR, TIR)
- spectrum: nine bands [0.55-12] μm
- noise equivalent dT: 50 mK (TIR) at 270 K

The radiometric bands of SLSTR are presented in the table below.

Band	Central Wavelength (µm)	Bandwidth (µm)	Function	Comments		Resolution (m)
S1	554.27	19.26	Cloud screening, vegetation monitoring, aerosol	VNIR	Solar Reflectance Bands	500
S2	659.47	19.25	NDVI, vegetation monitoring, aerosol			
S3	868.00	20.60	NDVI, cloud flagging,Pixel co-registration			
S4	1374.80	20.80	Cirrus detection over land	SWIR		
S5	1613.40	60.68	loud clearing, ice, snow,vegetation monitoring			
S6	2255.70	50.15	Vegetation state and cloud clearing			
S7	3742.00	398.00	SST, LST, Active fire	Thermal IR Ambient bands (200 K -320 K)		1000
S8	10854.00	776.00	SST, LST, Active fire			
S9	12022.50	905.00	SST, LST			
F1	3742.00	398.00	Active fire	Thermal IR fire emission bands		
F2	10854.00	776.00	Active fire			

Table 5.2The radiometric bands of SLSTR [RD.07].

The mean global coverage revisit time for dual view SLSTR observations is 1.9 days at the equator (one operational spacecraft) or 0.9 days (in constellation with a 180° in-plane separation between the two spacecraft) with these values increasing at higher latitudes due to orbital convergence.[RD.07]

	Constellation configuration	Revisit at equator	Revisit for latitude > 30°
SLSTR dual view (day and night)	One satellite	< 1.8 days	< 1.5 days
	Two satellites	< 0.9 days	< 0.8 days

Table 5.3Global coverage revisit times for SLSTR optical measurements[RD.07].

The principal objective of SLSTR products is to provide global and regional Sea and Land Surface Temperature (SST, LST) to a very high level of accuracy (better than 0.3 K for SST). The SLSTR product types are divided in six main products. Level-2 LST products are disseminated to the users and provide land surface temperature generated on the wide 1 km measurement grid [RD.04].

LST processing includes a split-window method, operating on thermal channels at 11 and 12 micrometers, and employing a coefficient approach to derive LST where the coefficients are derived by regression. This method assumes that the linearity of the relationship between LST and BT results from linearisation of the Planck function and linearity of the variation of atmospheric transmittance with column water vapour amount. The dependences on emissivity are indirectly incorporated via statistical regression coefficients calculated off-line and translated through biome/fractional vegetation maps for application to a particular SLSTR pixel. These coefficients also account for variations in atmospheric temperature and humidity. For further details please refer to [RD.09].

5.3. MODIS Land Surface Temperature and Emissivity (MOD11) DATA

MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra and Aqua satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands. [RD.10].

The MODIS instrument provides high radiometric sensitivity (12 bit) in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm. Two bands are imaged at a nominal resolution of 250 m at nadir, with five bands at 500 m, and the remaining 29 bands at 1 km. A ±55-degree scanning pattern at the EOS orbit of 705 km achieves a 2330-km swath and provides global coverage every one to two days.

In the following some specification are reported [RD.11].

Orbit: 705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular

Swath Dimensions: 2330 km (cross track) by 10 km (along track at nadir)

Spatial Resolution: 250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36) Design Life: 6 years

Primary Use	Band	Bandwidth[1]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 – 670	128
	2	841 – 876	201
Land/Cloud/Aerosols Properties	3	459 – 479	243
	4	545 – 565	228
	5	1230 – 1250	74
	6	1628 – 1652	275
	7	2105 – 2155	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 – 420	880
	9	438 – 448	838
	10	483 – 493	802
	11	526 – 536	754
	12	546 – 556	750
	13	662 – 672	910
	14	673 – 683	1087

	15	743 – 753	586
	16	862 – 877	516
Atmospheric Water Vapor	17	890 – 920	167
	18	931 – 941	57
	19	915 – 965	250
Primary Use	**Band**	**Bandwidth**[1]	**Required NE[Δ]T(K)**[4]
Surface/Cloud Temperature	20	3.660 - 3.840	0.05
	21	3.929 - 3.989	2.00
	22	3.929 - 3.989	0.07
	23	4.020 - 4.080	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.25
	25	4.482 - 4.549	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	150(SNR)
	27	6.535 - 6.895	0.25
	28	7.175 - 7.475	0.25
Cloud Properties	29	8.400 - 8.700	0.05
Ozone	30	9.580 - 9.880	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	0.05
	32	11.770 - 12.270	0.05
Cloud Top Altitude	33	13.185 - 13.485	0.25
	34	13.485 - 13.785	0.25
	35	13.785 - 14.085	0.25
	36	14.085 - 14.385	0.35

The Land Surface Temperature (LST) and Emissivity daily data are retrieved at 1km pixels by the generalized split-window algorithm and at 6km grids by the day/night algorithm. In the split-window algorithm, emissivities in bands 31 and 32 are estimated from land cover types, atmospheric column water vapor and lower boundary air surface temperature are separated into tractable sub-ranges for optimal retrieval. In the day/night algorithm, daytime and nighttime LSTs and surface emissivities are retrieved from pairs of day and night MODIS observations in seven TIR bands. The product is comprised of LSTs, quality assessment, observation time, view angles, and emissivities.

In the framework of this project, the MYD11A1.0068 granule will be exploited, which fully cover the area of interest.

[8]MODIS_Grid_Daily_1km_LST:LST_Night_1km, available at https://search.earthdata.nasa.gov/

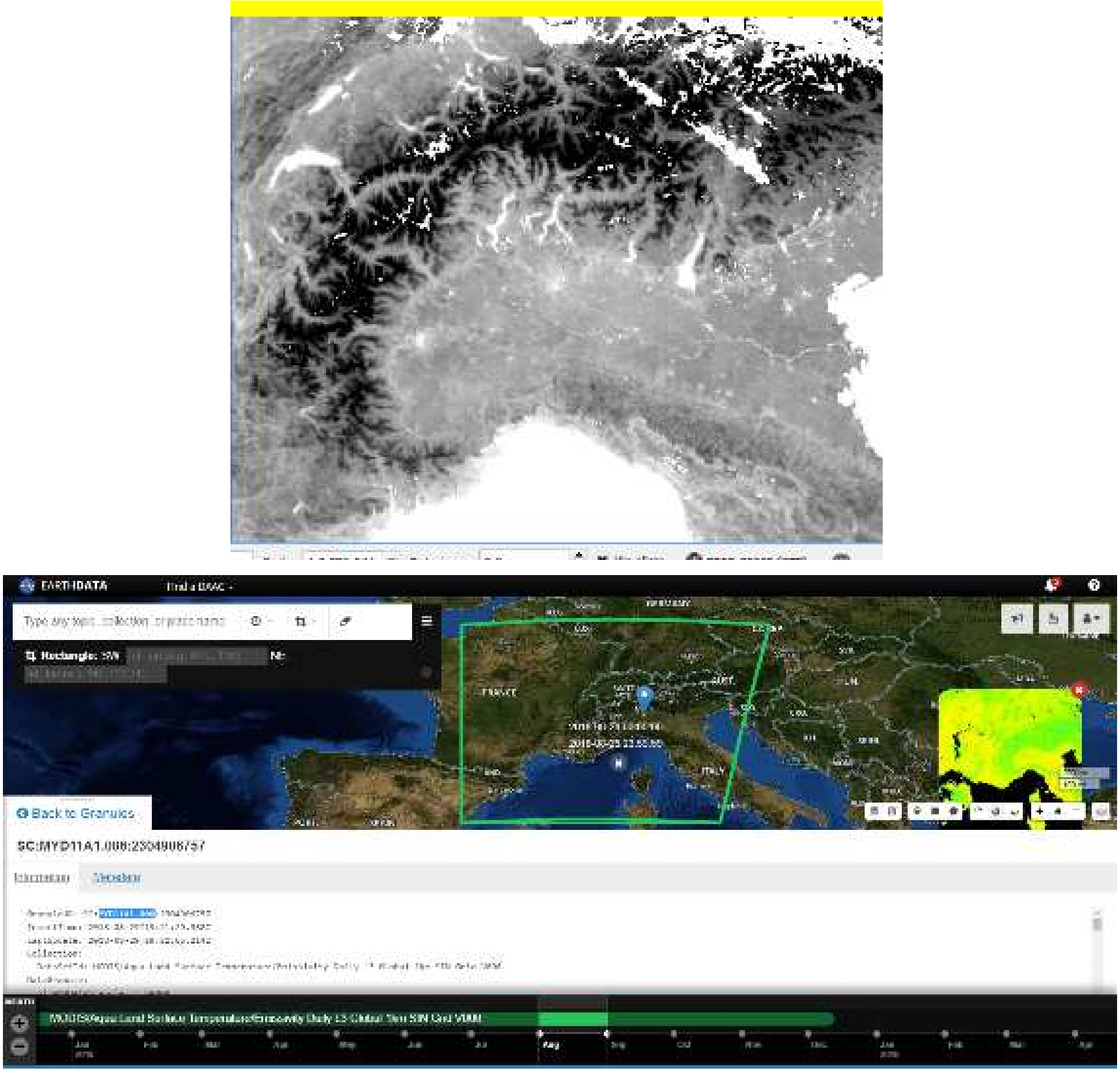
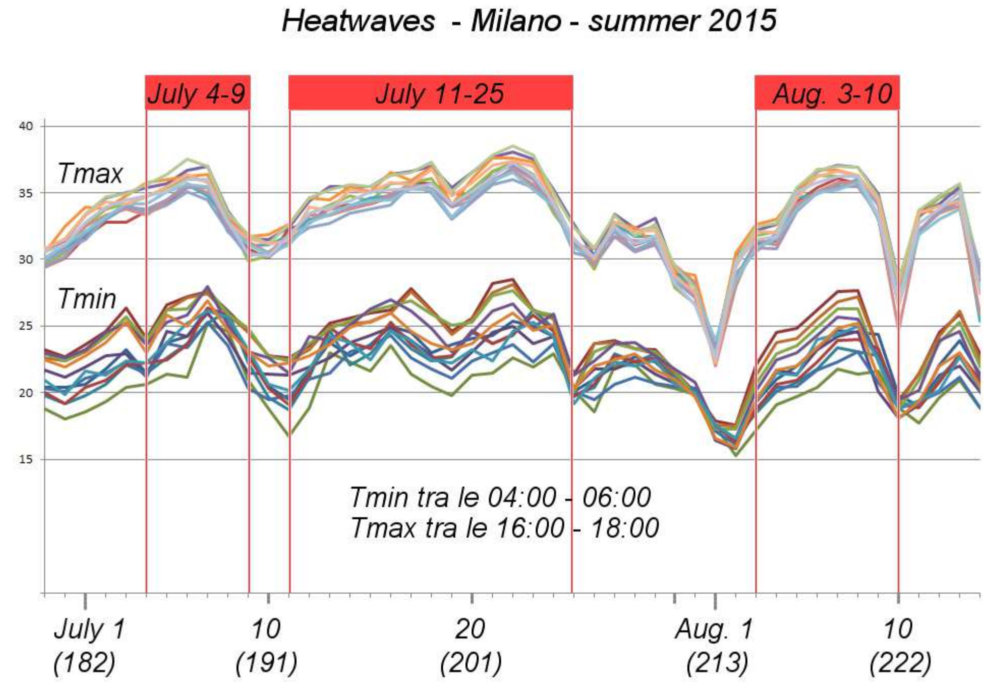


Figure 5.2 (up) Land Surface Temperature at night, form MODIS Daily product MYD11A1, regridded at 1 km resolution. The granule useful in the frame of this project is MYD11A1.006. (Down) EarthData interface for product search and download. It can be seen the granule coverage.

5.4. Meteo Data

Meteorological data will be used for many purposes. First of all, records of ground-measured temperature will be used to identify the summer heat-wave periods through the years. As example, maxima and minima in July and August 2015 in Milan shown in Fig. 5.4 indicate occurrence and duration of the summer heat-waves. These data also show the higher variability of the night minima with respect of the daytime maximaover the urban area of Milan.



Another important issue is the wind direction and intensity. The wind influences the shape of warm signature over the urban area. An example is given in Fig. 5.4 for summer 2015.

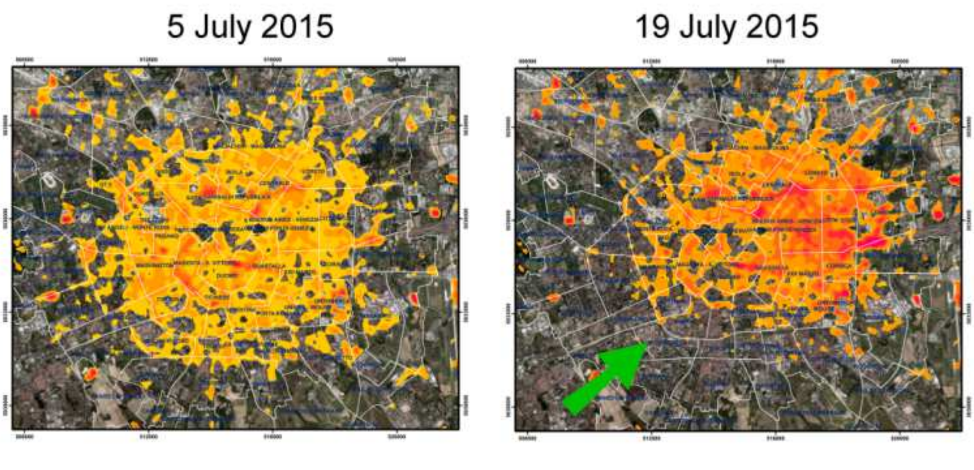


Fig. 5.4Thermal plumes over Milan detected by satellites in calm (5 July 2015) and weak wind from SW (19 Juy 2015).

Two sources of meteorological data will be addressed in the project. These are:

- Rete Regionale di Rilevamento Meteorologico di ARPA Lombardia,
- ERA-Interim archive of the European Centre for Medium-Range Weather Forecasts (ECMWF).

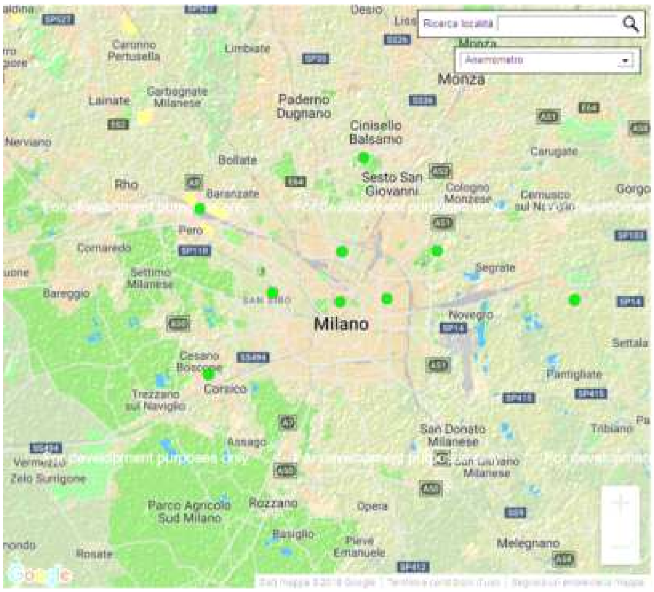


Fig. 5.5Distribution of wind stations (green spots) of ARPA around Milan.

The ARPA website provides many atmospheric parameters on hourly basis collected by a network of sensors covering the area. The spatial distribution of the anemometers around Milan is illustrated in Fig. 5.5.

The other source of atmospheric data, the ERA-interim archive, is a mixture of analysis fields, forecast fields and fields available from both the analysis and forecast. Historical and recent data are available on a regular grid at 1/8° of spatial resolution up to 4 times per day.

5.5. Cartography

According to the methodology that we will develop within the project and the data made available by CMM, we will summarize those that are presumed will be used for the realization of the maps provided for by the C1 Action.

GEO DATA BASE

The Geo Data Base is a geographical database made up of various digital spatial information that represents and describes the topographical objects of the territory and as a whole represents the basic cartography.

The Geo Data Base is the digital map base of reference for all planning tools prepared by both local authorities and the Region, as defined in art. 3 of Regional Law 12/2005 for the Government of the territory.

The main contents concern: roads, railways, bridges, viaducts, tunnels, buildings and appurtenances, building structures, natural and artificial watercourses, with relative riverbeds, lakes, dams, hydraulic works, electrical networks, waterfalls, altimetry, quarries and landfills, vegetable coverings divided into woods, pastures, agricultural crops, urban greenery, areas without vegetation.

Each object is made up of a cartographic component and a table, to which are added the altimetric component and any other information.

The scale is very detailed for urban areas (1:1.000- 1:2.000) and of medium detail for extra-urban areas (1:5.000- 1:10.000).

The Geo Data Base is the appropriate basis for municipal planning (PGT) and other planning tools. It is also the reference for all cartographic elaborations for anyone who has to submit project documents to the public administration.

The structure of the data, adapted to the national standards of Annex 1 of the d.p.C.m. November 10, 2011 "Technical rules for the definition of the content specifications of geo-topographic databases", was defined by decree no. 3870 of May 7, 2012, Annex B and subsequent amendments and additions of December 29, 2013. All technical specifications can be found at the following link: http://www.geoportale.regione.lombardia.it/specifiche-tecniche

In application of the European INSPIRE Directive, the Lombardy Region approved the "Conceptual scheme of the shared Geo Data Base in the Infrastructure for Spatial Information" and the "Table of correspondence between conceptual elements and shapefile" (Decree no. 3870 of May 7, 2012, Annex B). This data scheme has been adopted by the Region for the structuring of the Regional Geo Data Base, which is formed through the mosaicing and restructuring of the Geo Data Base produced by the local authorities, according to the technical production specifications of the DBTs approved in 2008 (see Annex).

The structure of the Geo Data Base responds to the national indications dictated by the Decree of the Presidency of the Council of Ministers of 10 November 2011 "Technical rules for the definition of the content specifications of geotopographic databases" (Official Gazette no. 48 of 27/02/2012 - S.o. no. 37).

The document defines the information content and the structure of the topographical data that will be exchanged between the different subjects participating in the Infrastructure for Spatial Information (IIT) of the Lombardy Region, in implementation of the model defined in the "Framework for updating the Geo Data Base and the exchange with the cadastral databases" approved by DGR no. 338 of 28 July 2010.

DERIVED THEMATIC CARTOGRAPHY:LAND COVER MAP

The land cover map indicates the characteristic of territory related to land use (agricultural, residential, ..) and its coverage.

This map shows and monitors the characteristic of territory and it can be used to collect informations to start planning actions.

The procedure to obtain the land cover map is based on the correlation between DBT classes (Territorial Database), that represents real land coverage, and the semantically ones related to the Corine land program at the I, II, III hierarchical level.

The Corine land cover project is the main technical-procedural reference at European level among the land cover maps.

Dataset extension	Distribution format	Normative informations
	WMS	Normative, technicals, nomenclature informations can be found at the following link http://land.copernicus.eu/pan-european/corine-land-cover
	WFS	
	GeoTiff	
	Web visualizer	

DERIVED THEMATIC CARTOGRAPHY: SOIL SEALING MAP

The Soil Sealing Map (Land cover impermeability) represents the territory characteristics related to soil sealing.

This map can be used to show and monitor territory characteristics to set up territorial planning actions. The soil sealing map is based on an automatic procedure that correlates every database class with a soil sealing value, referring to scientifics and internationals publications (Corticelli, 2008), (Burghardt, 2006) (Munafò, 2008), (Wood, 2006).

Values next to 1 refers to completely impermeable surfaces (buildings, roads, streets, etc..). Intermediate value refers to variable permeability surfaces.Values next to 0 refer to high permeable surfaces (forest, woods, garden …)

Dataset extension	Distribution format	Normative informations
	WMS	Normative, technicals, nomenclature informations can be found at the following link http://land.copernicus.eu/pan-european/corine-land-cover
	WFS	
	GeoTiff	
	Web visualizer	

INDEX OF INHOMOGENEITY OF HEIGHTS

The height inhomogeneity index measures the degree of height uniformity of the buildings for the reference surface.

Low values (green) indicate the presence of buildings of similar heights, while high values (red) indicate the presence of buildings with different heights within the same nucleus.

Distances are calculated as "Euclidean distances" on the map plane.

$$h = \left(\frac{fi}{fi\ max}\right)$$

h: inhomogeneity value referred to the heights in the single blocks

fi: standard deviation value relative to the individual urban nucleus in relation to the values assumed by the i-esimal volumetric units present

fmax: maximum standard deviation value

INDEX OF DISTANCE BETWEEN BUILDINGS

The distance between buildings index is the planimetric measurement between the vertex of a building and the nearest vertex of another building.

The index, applied to the geo Data Base of the metropolitan city of Milan, has a range from 0 (buildings that touch each other at least in one green vertex) to 1150 linear meters (building further away from the others in red).

The distances are calculated as "Euclidean distances" on the map plane.

VOLUMETRIC INHOMOGENEITY INDEX

The volume inhomogeneity index measures the degree of uniformity of building volumes for the reference area.

Low values (green) indicate the presence of buildings with similar volumes, while high values (red) indicate the presence of buildings with different volumes within the same nucleus.

$$v = \left(\frac{vk}{vk\ max}\right)$$

Dove:

v = valore di disomogeneità relativa ai volumi dei singoli isolati;

v_k = valore di deviazione standard relativo al singolo nucleo urbano, in relazioni ai valori assunti dalle *i-esime* unità volumetriche presenti;

v_{kmax} = valore di deviazione standard massimo.

v: inhomogeneity value referred to the volumes in the single blocks

vk: standard deviation value relative to the individual urban nucleus in relation to the values assumed by the i-esimal volumetric units present

vk max: maximum standard deviation value

POPULATION DENSITY INDEX

Index to relate the population to the territorial extent. It measures the average presence of population on the territory.

For example, for the municipal territory:

$$Dc = \left(\frac{PrCom}{ACom}\right)$$

Dc: population density at municipal level

PrCom: resident population at municipal level (n.Inhabitants)

ACom: Municipal Area (SKm)

POPULATION DENSITY INDEX ON BUILT-UP AREA

This index relates the population to the territorial extent. It measures the average presence of population in the built up municipal area.

For example, for the municipal territory:

$$Dae = \left(\frac{PrCom}{Aec}\right)$$

Dae: population density at the level of the built-up area

PrCom: resident population at municipal level (n.Inhabitants)

Aec: Municipal built area (SKm)

VOLUMETRIC DENSITY OF POPULATION INDEX ON BUILT VOLUME

This index measures the average presence of population in the municipality to the volume built in the same municipality

For example, for the municipal territory:

$$Dve = \left(\frac{PrCom}{Vec}\right)$$

Dve: Population density at building volume level

PrCom: resident population at municipal level (n.Inhabitants)

Vec: Municipal building volume

VOLUMETRIC POPULATION DENSITY INDEX

This index measures the average presence of population on the census territory at the surface of the territory itself.

For example, for the census section:

$$Dsc = \left(\frac{PrAsc}{Asc}\right)$$

Dove:
Dsc = Densità popolazione a livello di sezione censuaria;
PrSc = Popolazione residente a livello di sezione censuaria (N. abitanti);
Asc = Area sezione censuaria (Km^2).

Dsc: Volumetric population density

PrSc: population living in a census section

Asc: census section area (SKm)

SETTLEMENT DENSITY INDEX

This index indicates the urbanized fraction of the territory and the non-urbanized spaces at municipal level.

For example, for the municipal territory:

$$Di = \left(\frac{Aet}{At}\right)$$

Di = Settlement density
Aet = Built area for the territory in question
At = Area for the territory in question

6. Products specification and Methodology

6.1. Urban Heat Island

Observations and reconstructions of global temperatureevolution indicate a pronounced warming during thelast 150 years, with an increase in the occurrence ofso-called heat waves, which are extended periods ofanomalously high summertime temperatures[RD.01].

Heat waves are especially deadly in cities due to populationdensity and urban surface characteristics. Urbanizationdrastically modifies the partition of the heat fluxescompared to suburban or rural surroundings, generating adifferential temperature effect called an urban heat island. The main contributing factors are (1) changes in the physicalcharacteristics of the surface such as albedo, emissivityor thermal conductivity owing to the replacementof vegetation by asphalt and concrete, and consequentlychanges in the radiative fluxes; (2) a decrease in surfacemoisture available for evapotranspiration; (3) changes inthe near-surface flow, owing to the complicated geometryof streets and tall buildings; and (4) anthropogenicheat[RD.01].

At night, urban areas gradually release the heataccumulated in structures during the day, whereas ruralareas cool off by unobstructed outgoing radiation. The lack of relief at night, rather than high daytime temperatures, threatens people'shealth. The elderly, infants, young children, and peoplewith chronic health problems such as asthma and cardiacdiseases are more vulnerable.Health risks increase with heat intensity,relative humidity, time exposure and high minimumnight-time temperatures.

6.1.1. Product Specification

The satellite data processing aims to merge the thermal information coming from satellites at high spatial resolution but poor revisit time (as Landsat) with satellite thermal data more frequently available but with low spatial resolution (as MODIS or SENTINEL-3). Day-time and night-time MODIS data are available on daily basis while both day-time and night-time Landsat-8 images are available every 16 days. However, the 15 days interval of night-time Landsat data becomes much longer as the USGS (United States Geological Survey) website, which distributes the Landsat products, publishes only few night-time images per year.

The satellite data processing provides a thermal map at the spatial resolution of Landsat every day, .i.e. at the revisit time of MODIS or Sentinel-3. The procedure, commonly defined 'downscaling', increases the spatial resolution of night LST of MODIS or SENTINEL-3 from 1km to 100m (but gridded at 30m of spatial resolution, see section 5.1) by using the thermal bands of Landsat-8.

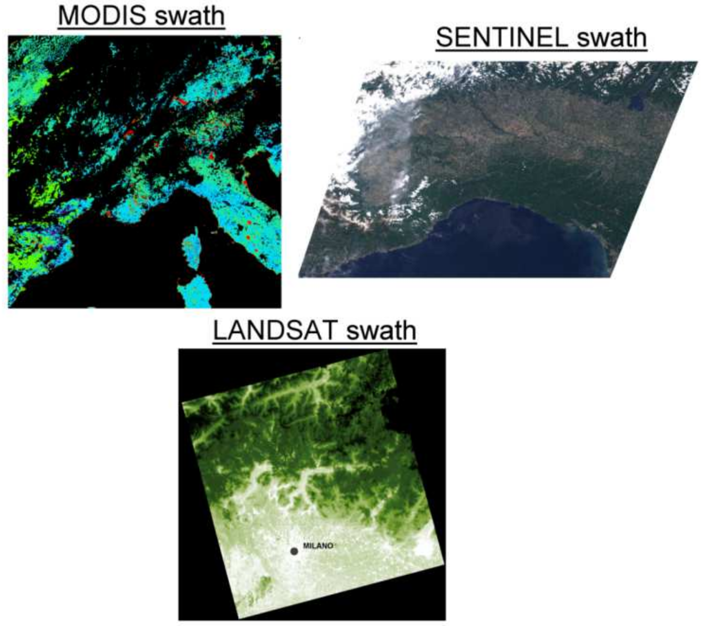


Fig. 6.1 - Swath of MODIS, SENTINEL-3 and Landsat-8 images acquired over North Italy.

An example of the product obtained is shown in Fig. 6.2. The MODIS LST at 1km is shown on the left and the product of downscaling at 100m of spatial resolution (but gridded at 30m) is shown on the right.

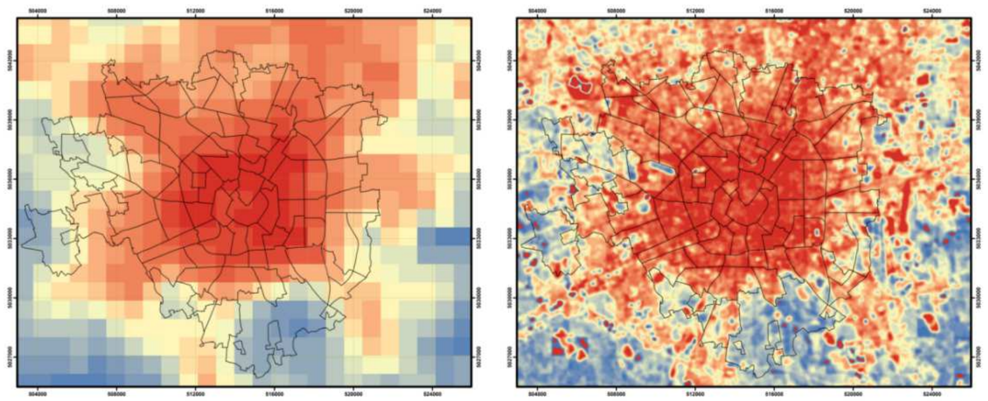


Fig. 6.2- Downscaling test of MODIS LST (left, 1km) over the Landsat grid (right, 100m) over Milan.

6.1.2. Methodology

The downscaling procedure is illustrated in Fig. 6.3. The MODIS or SENTINEL night LST (C) is accurately geo-referenced and the downscaling transformation (A) is applied to providea LST image at higher spatial resolution.

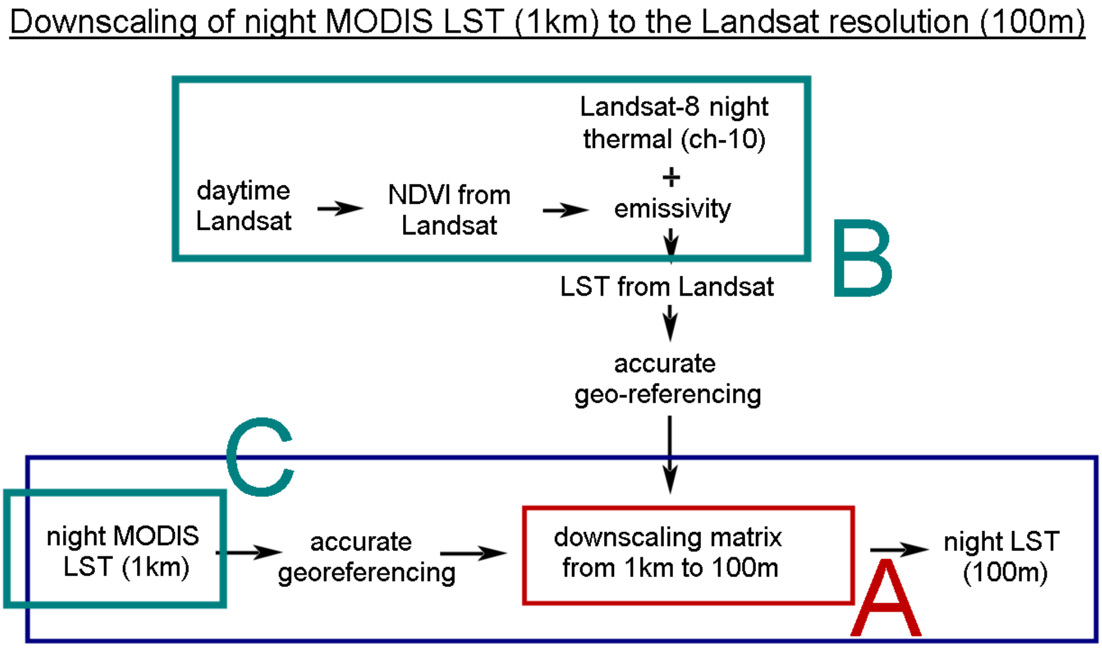


Fig. 6.3- – The 'downscaling' procedure.

The downscaling transformation

The downscaling procedure consists of multipling the LST image by a transformation matrix that is obtained as follows (B). The starting point is a night-time LST image of Landsat-8 shown in Fig. 6.4a. How the LST image is obtained will be detailed in the following section. The MODIS grid at 1km is superimposed to the Landsat LST (Fig. 6.4b) and the mean LST is calculated in each cell of 1 x 1 km. The downscaling matrix consists of the ratios between each LST pixel at 100m and the mean LST of the corresponding 1 x 1 km cell. These ratios, typically ranging from 0.70 to 1.40, allows passing from the MODIS LST value at 1 km to the LST value at 100m. An example of the 'downscaling' matrix is shown in Fig. 6.4c.

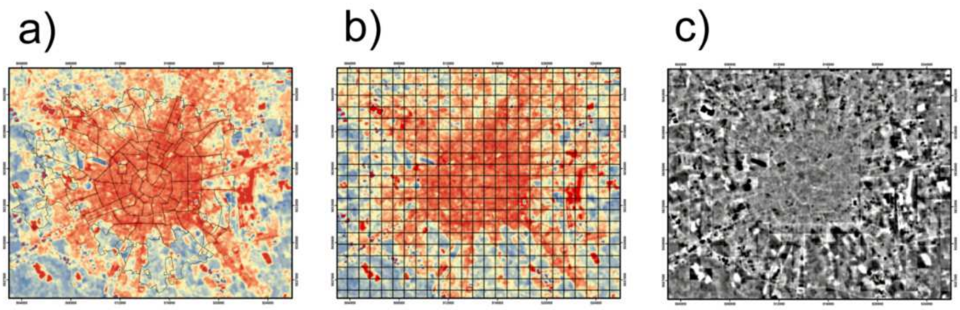


Fig. 6.4- Steps followed to obtain a downscaling matrix.

Landsat LST procedure

The algorithm for the automatic mapping of land surface temperature LST from LANDSAT 8 data (sub-scheme B in Fig 6.3) is described in this section. It exploits the fourth (red wavelength/micrometers, 0.64–0.67), fifth (near infrared (NIR) wavelength/micrometers, 0.85–0.88), and tenth (thermal infrared sensor (TIRS) wavelength/micrometers, 10.60– 11.19) LANDSAT 8 sensor bands. As we are interested in downscaling night-time LST, the thermal band 10 (100m) is extracted from a night Landsat-8 image while bands 4 and 5 necessarily comes from day-time Landsat images because these bands fall in the visible portion of the spectrum. Thus, the night Landsat-8 for band 10 and the day-time Landsat-8 for bands 4 and 5 should be close in time to assure that bands 4 and 5 have not changed too much from the date of the night Landsat image.

Because of the extreme heterogeneity of most natural land surfaces, LST is a difficult parameter to estimate and to validate. There are a number of factors that influence the derivation of LST including surface spectral emissivity at the channel wavelengths, clouds and large aerosol particles such as dust. Cloud flagging, which tends also to remove larger concentrations of aerosol dust, is usually performed independently of LST retrieval, and so is considered separately. The chief driver for LST algorithms is therefore surface spectral emissivity.

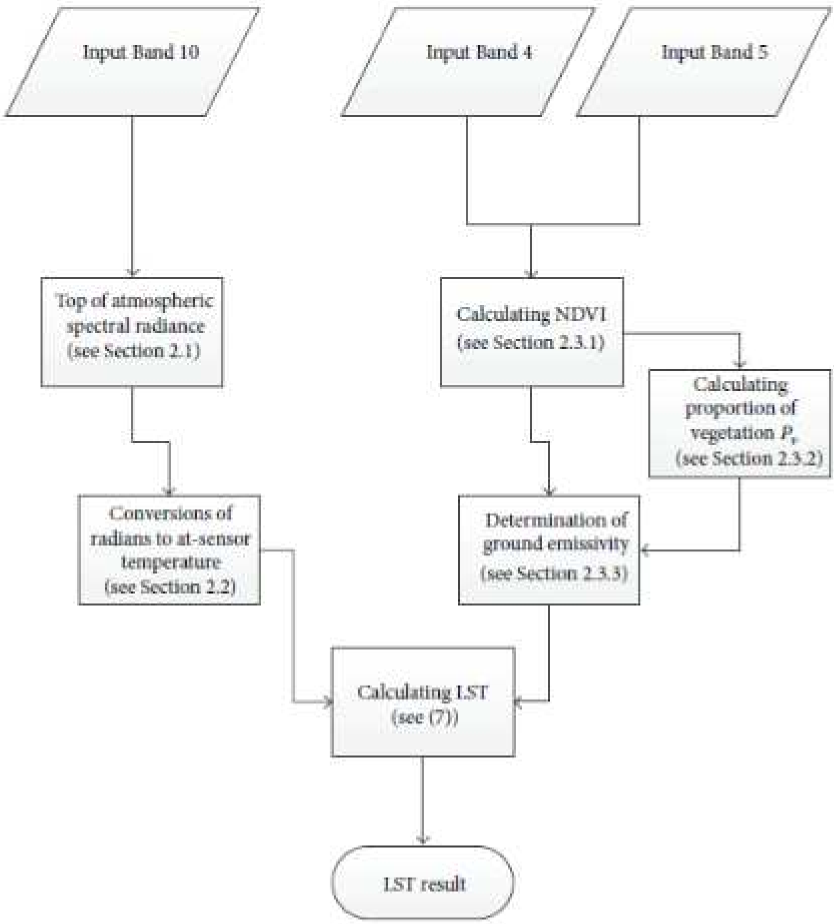


Fig. 6.5- Flowchart for LST retrieval.

The LST image can be retrieved following the steps indicated in Fiog. 6.5. The TIR band 10 is used to estimate brightness temperature and bands 4 and 5 were used for calculating the NDVI. The metadata of the satellite images used in the algorithm is presented in Table 6.6. The land surface emissivity (LSE (ε)) must be known in order to estimate LST, since the LSE relates the efficiency of transmitting thermal energy across the surface into the atmosphere and represents a proportionality factor that scales blackbody radiance (Planck's law) to predict emitted radiance. Emissivity (ε) is related to the proportion of the vegetation (PV), which in turn is highly related to the NDVI. In this approach, NDVI method for emissivity correction is exploited.

Thermal constant		
	K_1	1321.08
	K_2	777.89
Rescaling factor		
	M_L	0.000342
	A_L	0.1
Correction		
	O_i	**0.29**

Table 6.6LANDSAT 8 Metadata of the 10 band.

From the Band 10 the top of atmospheric (TOA) spectral radiance ($L\lambda$) is calculated:

$$L_\lambda = M_L * Q_{cal} + A_L - O_i \tag{6.1}$$

where ML represents the band-specific multiplicative rescaling factor, Qcal is the Band 10 image, AL is the band-specific additive rescaling factor, and Oi is the correction for Band 10 (Table 6.6). TIRS band data are converted from spectral radiance to brightness temperature (BT) according to:

$$BT = \frac{K_2}{\ln\left[\left(\frac{K_1}{L_\lambda}\right) + 1\right]} - 273.15 \tag{6.2}$$

where K1 and K2 stand for the band-specific thermal conversion constants from the metadata (Table 6.6). For obtaining the results in Celsius, the radiant temperature is revised by adding the absolute zero (approx. −273.15°C). Landsat visible and near-infrared bands are used for calculating the Normal Difference Vegetation Index (NDVI):

$$NDVI = \frac{\text{NIR (band 5)} - \text{Red(band 4)}}{\text{NIR (band 5)} + \text{Red(band 4)}} \tag{6.3}$$

where NIR represents the near-infrared band (Band 5) and Red represents the red band (Band 4). The Proportion of Vegetation PV is calculated according to:

$$P_v = \left(\frac{\text{NDVI} - \text{NDVI}_s}{\text{NDVI}_v - \text{NDVI}_s}\right)^2 \tag{6.4}$$

using the NDVI values for vegetation and soil (NDVIV = 0.5 and NDVIs = 0.2) to apply in global conditions. The determination of the ground emissivity is calculated conditionally as follows:

$$\varepsilon_\lambda = \begin{cases} \varepsilon_{s\lambda} & NDVI < NDVI_s \\ \varepsilon_{v\lambda} P_v + \varepsilon_{s\lambda}(1 - P_v) + C_\lambda & NDVI_s \leq NDVI \leq NDVI_v \\ \varepsilon_{s\lambda} + C_\lambda & NDVI > NDVI_v \end{cases} \tag{6.5}$$

where εv and εs are vegetation and soil emissivity respectively and C represents the surface roughness (C = 0 for homogenous and flat surfaces) taken as a constant value of 0.005. The condition can be represented with the following formula and the emissivity constant values shown in Table 1 [4]. When the NDVI is less than 0, pixel is classified as water, and the emissivity value of 0.991 is assigned. For NDVI values between 0 and 0.2 the pixel is classified as soil and the emissivity of 0.996 is assigned. Values between 0.2 and 0.5 are considered mixed pixels of soil and vegetation and the PV is applied to retrieve the emissivity. In the last case, when the NDVI value is greater than 0.5, pixel is considered to be covered with vegetation, and the value of 0.973 is assigned. The emissivity corrected land surface temperature Ts is computed as follows

$$T_s = \frac{BT}{\{1 + [(\lambda BT/\rho)\ln(\varepsilon_\lambda)]\}} \tag{6.6}$$

where Ts is the LST in Celsius (°C), BT is at-sensor bright temperature (°C), λ is the wavelength of emitted radiance (for which the peak response and the average of the limiting wavelength (λ = 10.895) will be used), $\varepsilon\lambda$ is the NDVI estimated, and ρ = hc/σ = 1.438 × 10 −2 mK, where σ is the Boltzmann constant (1.38 × 10−23 J/K), h is Planck's constant (6.626 × 10−34 J s), and c is the velocity of light (2.998 × 108 m/s).

MODIS LST

The choice to focus on night data is justified by the higher relevance of night temperature with respect to the daytime temperature during the summer heat waves. Furthermore, night temperatures have a higher spatial variability with respect to the uniform distribution of day-time maxima.

The MODIS LST products (MOD11 of TERRA and MYD11 of AQUA) include several layers indicated in the following Table.

SDS	Units	Data-type	Fill Value	Valid Range	Scale Factor	Additional Offset
Daytime land surface temperature	Kelvin	16-bit unsigned integer	0	7500–65535	0.02	NA
Daytime LSTE quality control	Bit-Field	8-bit unsigned integer	0	0–255	NA	NA
Daytime LST observation time	Hours	8-bit unsigned integer	0	0–240	0.1	NA
Daytime LST view	Degrees	8-bit	255	0–130	1.0	-65.0

zenith angle		unsigned integer				
Nighttime land surface temperature	Kelvin	16-bit unsigned integer	0	7500–65535	0.02	NA
Nighttime LSTE quality control	Bit-Field	8-bit unsigned integer	0	0–255	NA	NA
Nighttime LST observation time	Hours	8-bit unsigned integer	0	1–240	0.1	NA
Nighttime LST view zenith angle	Degrees	8-bit unsigned integer	255	0–130	1.0	-65.0
Band 31 Emissivity	None	8-bit unsigned integer	0	1–255	0.002	0.49
Band 32 Emissivity	None	8-bit unsigned integer	0	1–255	0.002	0.49
Daytime clear-sky coverage	None	16-bit unsigned integer	0	0–65535	0.0005	NA
Nighttime clear-sky coverage	None	16-bit unsigned integer	0	0–65535	0.0005	NA

Table 6.7Subset of the MODIS LST product

Night-time LST data, acquisition time, quality level and other ancillary information will be selected and processed to produce an LST image over the study area. In particular, only pixels with quality flags 0, 5, 17 and 21 (less than 53), meaning an LST error less than 1 K, will be used; the unfilled pixels will be flagged as no-data.

Integer_Value	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	QA_word1	QA_word2	QA_word3	QA_word4
0	0	0	0	0	0	0	0	0	LST GOOD	Good Data	Emiss Error <= .01	LST Err <= 1
2	0	0	0	0	0	0	1	0	No Pixel,clouds	Good Data	Emiss Error <= .01	LST Err <= 1
3	0	0	0	0	0	0	1	1	No Pixel, Other QA	Good Data	Emiss Error <= .01	LST Err <= 1
5	0	0	0	0	0	1	0	1	LST Produced,Other Quality	Other Quality	Emiss Error <= .01	LST Err <= 1
17	0	0	0	1	0	0	0	1	LST Produced,Other Quality	Good Data	Emiss Err >.01 <=.02	LST Err <= 1
21	0	0	0	1	0	1	0	1	LST Produced,Other Quality	Other Quality	Emiss Err >.01 <=.02	LST Err <= 1
65	0	1	0	0	0	0	0	1	LST Produced,Other Quality	Good Data	Emiss Error <= .01	LST Err > 2 LST Err <= 3
69	0	1	0	0	0	1	0	1	LST Produced,Other Quality	Other Quality	Emiss Error <= .01	LST Err > 2 LST Err <= 3
81	0	1	0	1	0	0	0	1	LST Produced,Other Quality	Good Data	Emiss Err >.01 <=.02	LST Err > 2 LST Err <= 3
85	0	1	0	1	0	1	0	1	LST Produced,Other Quality	Other Quality	Emiss Err >.01 <=.02	LST Err > 2 LST Err <= 3
129	1	0	0	0	0	0	0	1	LST Produced,Other Quality	Good Data	Emiss Error <= .01	LST Err > 1 LST Err <= 2
133	1	0	0	0	0	1	0	1	LST Produced,Other Quality	Other Quality	Emiss Error <= .01	LST Err > 1 LST Err <= 2
145	1	0	0	1	0	0	0	1	LST Produced,Other Quality	Good Data	Emiss Err >.01 <=.02	LST Err > 1 LST Err <= 2
149	1	0	0	1	0	1	0	1	LST Produced,Other Quality	Other Quality	Emiss Err >.01 <=.02	LST Err > 1 LST Err <= 2
193	1	1	0	0	0	0	0	1	LST Produced,Other Quality	Good Data	Emiss Error <= .01	LST Err > 4

Fig. 6.8. Quality flags of the MODIS LST product.

Another check is made in order to verify the acquisition time of the MODIS LST. Indeed, MOD11 or MYD11 products, in case of cloud coverage, are filled withLST pixelsacquired during different night-time or day-time passages, hence at different hours during the day or night. The case is illustrated in Fig. 6.9, where the AQUA night LST is an evident mosaic of different satellite passes.

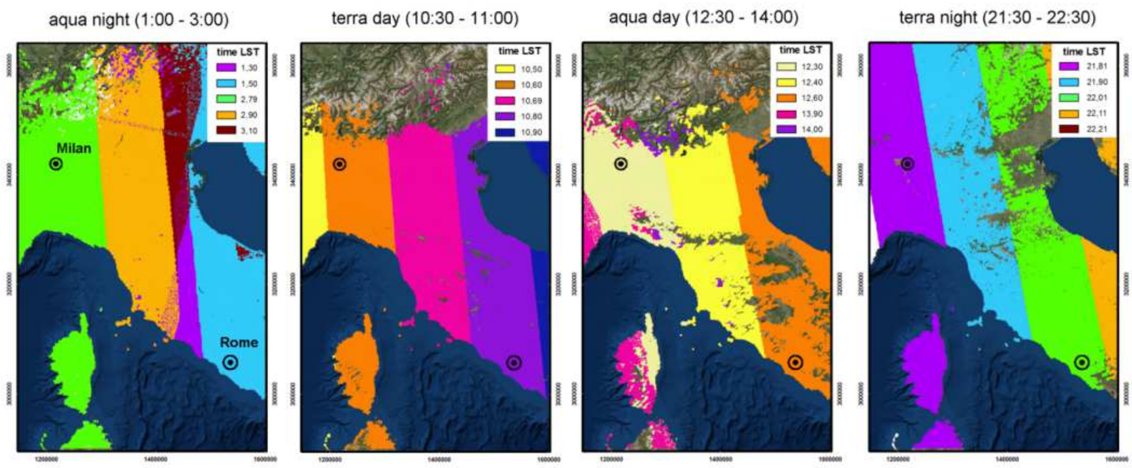


Fig. 6.9. Time of the LST products of MOD11 and MYD11.

6.2. Vulnerability Map of Urban Heat Islands

6.2.1. Product Specification

Developing appropriate measures to tackle the effects of Urban Heat Islands needs to analyze the components of a risk assessment framework: the hazard (the extreme meteorological event), the exposure (the population) and the vulnerability (for a specific group of people). This requires the investigation of the characteristics of physical environment and urban structure that affect people's exposure to UHI events in some areas of the town, and the vulnerability to heat of communities, depending on health status, socio-economic factors, age and location. Therefore, the Vulnerability assessment to UHI events will be carried out following a two-step procedure: in the first step, the physical effect of UHI over specific zones of MMC will be evaluated, mainly based on Land Surface Temperatures and urban structure; in the second, the analysis of population, density and distribution, and presence of vulnerable people (e.g. elders), will define the Vulnerability as a comprehensive index of Heat-Related Population Risk.

For the evaluation of the physical impact of heat waves in the urban structure, the project activity will be based on the methodology already carried out in "Climate change and territory - Guidelines and operational proposals of the Metropolitan City of Milan - Territorial Projects founded by Fondazione Cariplo 2017." In particular, for the "heat wave hazard", the methodology starts by investigating the different behavior between rural and urban areas with respect to accumulate heat and surface energy balance. In dense urban areas, the absorption of radiation by dark surfaces (asphalt, brick, concrete) is responsible for an increase in net radiation. The urban structure itself and its geometry, especially within "urban canyons", increase theradiation absorption due to multiple reflections. Moreover, dense built areas and tall buildings, with reduced "sky view factor", limit the reflection of the radiation back to the sky during the night, "keeping" the heat inside the urban structure.

6.2.2. Methodology

The vulnerability to heat can be seen as the difference between indicators of sensitivity, and adaptation capacity (the features, such as the presence of green, gardens and water, that increase local resilience to heat). Among the sensitivity indicators, the "Climate Change and Territory" MMC project suggests:

- Sky View Factor (SVF)
- Built area fraction or, as indicator of the Adaptive capacity, Green Area fraction
- Impervious surface fraction or, as indicator of the Adaptive capacity, pervious surface fraction (PSF)
- Roofs Incoming Solar Radiation
- LST Land Surface Temperature (nighttime)

LST is the main parameter, and it is directly related to the others (e.g. a more impervious soil produces an increase in LST respect to natural soil).
Following the results of previous studies, such as Paris in summer 2003, and Vienna in summer 2011 9, the analysis will be focused on the nighttime LST, that is more significant for both physical (during the night the UHI phenomenon is more evident) and human-related reasons, because consecutive "hot nights" have a greater impact on health, respect to daytime temperature.
Each indicator is represented in a map on a webGIS, with data aggregated by census units. This type of maps will be used to locate the most vulnerable areas respect to the environmental hazard, due to hot temperatures and urban structure.
In the second step, a risk assessment spatial analysis will be carried out following a methodology already defined in previous studies – see, for example, the United Kingdom 2007 "ASCCUE" project (Adaptation Strategies for Climate Change in the Urban Environment: Assessing Climate Change Related Risk in UK Urban Areas) 10. The methodology requires a characterization of the urban area into distinctive "urban morphology units" as the spatial framework for the analytical work.
Cadastral and ISTAT census data will be used for the risk assessment of the "exposed population" (total population, population density) and of the "vulnerable" category (elderly people over 65).
The available data sources are:
- Census data ISTAT
- CMM Database Topography (DBT)

From the ISTAT data, the population by age group and census section will be extracted. DBT residential buildings are extracted by census section.
Thanks to the height attribute (UN_VOL_AV) of the single volumetric unit, the number of floors per building is estimated and from these the total Gross Residential Floor Area (GLA) per building is deducted as shown in the following figure.

[9] A. Mahdavi, K. Kiesel, M. Vuckovic (2012)https://www.researchgate.net/profile/Milena_Vuckovic2/publication/279784784_Analysis_of_micro_climatic_variations_and_the_urban_heat_island_phenomenon_in_the_city_of_Vienna/links/562678d908aed3d3f1387967.pdf
[10]https://www.tandfonline.com/doi/abs/10.1080/13669870600798020

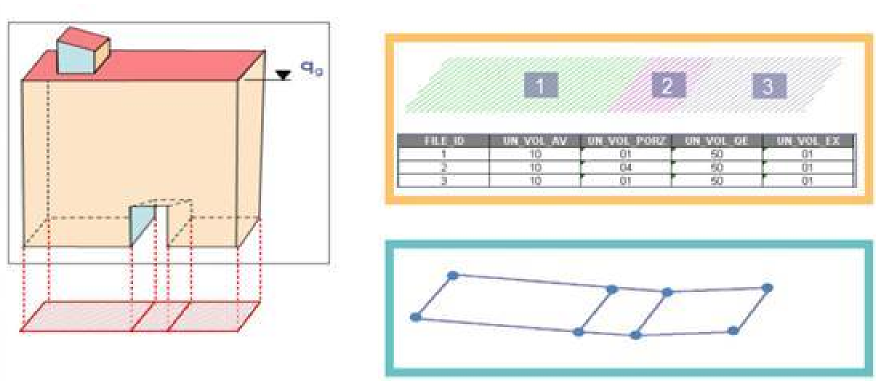


Fig. 6.10- Definition of the volumetric unit

As defined for the GLA, the gross floor area is: "the sum of the gross floor area of a building within the outer perimeter of walls of all habitable or usable levels, above or inside the ground of buildings whatever their intended use, including the horizontal projection of the walls of fixed and movable staircases and lift compartments".
According to the residential GLA of each building, the census population (already divided by age group) is then divided into the different buildings.
Moreover, socio-economic factors, such as the educational level, the average income of the population, should be taken into account in order to define the "Heat-Related Population Risk" index, that will produce 5 vulnerability classes: very high, high, medium, low, very low.
The highest risk class ("very high") to extreme heat events is generally due to a convergence of factors related to local temperature, socio-economic characteristics of the population, spatial distribution of the hazard, the urban structure and housing types present in the area.
However, even in some areas not necessary "the hottest", "high"-risk class could include some of the "vulnerable" class between the culturally impaired and economically deprived persons, due to the lack of cooling systems and/or poor knowledge of "good practices" to adapt the body to hot temperatures.

6.3. Vulnerability to Soil sealing and its effect on urban temperature

6.3.1. Product Specification

Soil sealing is one of the most critical aspects of a non-sustainable urban development. In the last decades, a huge percentage of population moved from rural areas to towns; in Italy 70% of population lives in urban areas and by 2050 this proportion is foreseen to grow up to 80%.
The land-use change from an agricultural soil, or pasture or forest to an artificial one (built areas, asphalt) represents an almost irreversible loss of the non-renewable resource that is the natural soil, and its ecosystem services, such as crop production, CO_2 absorption, permeability to enrich the aquifers, natural water depuration, increase of soil stability and prevention of floods. Loosing natural soil means a severe lack of services that make the territories more resilient to climate change. Among other negative effects, the increase of soil sealing has a clear impact on temperatures, because of the change in albedo – e.g. the ratio of solar radiation

that is reflected from a surface and the total irradiation received – and the loss of the cooling effect of plants and natural soil evapotranspiration.
The aim of this activity in the project is to analyze on a multitemporal scale, the effects of soil sealing over the mean temperature in an area where land use change has been detected during the last 15 years. To do this, Copernicus GIO Land satellite products will be used, such as Land Use, Land Use Change and Imperviousness at present is available for the years 2006 and 2012 at 20 m spatial resolution (former products are available as CORINE land cover products). It is expected the issue of the 2018 updated Copernicus products. Updated land cover maps, issued by Milan Metropolitan City for its area of competence, are available with a legend compatible to the CORINE land cover legend.

6.3.2. Methodology

The analysis will be carried out in the areas where a change from natural to impervious soil surface occurred, and an assessment of the variation of the average temperature for each area, on a yearly basis and in summer season, from 2003 to 2018 years, will be carried out, using the available historical set of MODIS Land Surface Temperature product.
An interesting study on this topic has been carried out in the paper "The hot city" by the Institute of Biometeorology of CNR Italy that analyzed the impacts of heat waves over the population in eleven Italian towns, including Milan urban area. Among other results, the study verified the impact of soil sealing on the increase of temperature: "In the cities studied in these preliminary surveys it has been found that as the soil sealing increases, the daytime and nighttime surface temperature increases significantly. For example, for the city of Milan, for each 20 hectares of soil consumed, a diurnal increase in the average annual land surface temperature of around 0.6 °C was observed. This, therefore, represents a further contribution of the urban environment in aggravating the phenomenon of global warming."
METRO-ADAPT methodology will take advantage from the availability of updated Copernicus products and from specific cartography available for the whole MMC area (therefore not limited to Milan urban area).

6.4. Vulnerability Map of Urban Runoff

Urbanization has changed the hydrological cycle, with a consequent increase in run-off rates, volumes and peaks in the drainage network; this has contributed considerably to the climatic variation underway, in particular due to the increase in short and intense rainfall. On the one hand, the increase in waterproofing, on the other hand, the increase in heavy rainfall has led to increasingly more likely situations of urban flooding.
The objective of this product is to provide a useful tool to CMM in planning strategies in the field of urban flooding in the context of the Metropolitan Plan.

6.4.1. Product Specification

With this in mind, the Map of Vulnerability to Urban Runoff will be the result of a geographical analysis aimed at summarizing the main data existing in the territory of the Milan Metropolitan Area on this issue.

The first information that will be used is that related to the identification of critical areas created by CAP, described below, to be understood as a database of critical issues related to the sewage network and the minor network.
Based on the location of these critical points, it will be searched in the archive data, if there are satellite SAR images of any periods of flooding and if so, the extensions of the flooded areas with ground data will be verified.
To such information will be added the data of the Basin Plans, of the extracting Plans and of all the spatial data that influence the ground discharge capacity.
As part of the activities to support the municipalities for the application of the Regional Regulation no. 7/2017, CAP should draft the municipal simplified document on hydraulic risk for most of the municipalities of the Metropolitan City of Milan (to date, 100 municipalities, corresponding to 1.445.364 served inhabitants).
In accordance with Article 14 of the same Regional Regulation, the municipal hydraulic risk simplified document contains the simplified evaluation of the conditions of hydraulic hazard that, associated with vulnerability and exposure to risk, identifies the risk situations, on which the structural and non-structural measures should be applied. In particular, it contains:

1. the identification of the areas of the municipal territory with hydraulic risk, that can be defined on the basis of existing planning documents, historical documents and local knowledge, including information of the integrated water service company;
2. the indication, including definition of the overall dimensions, of the structural measures of hydraulic and hydrological invariance, both for the already urbanized part of the territory and for the areas of new transformation, and the identification of the areas of intervention;
3. the indication of non-structural measures for the implementation of municipal-level hydraulic and hydrological invariance policies, such as the promotion of the extension of the hydraulic and hydrological invariance measures also on the surrounding buildings, as well as non-structural measures suitable for monitoring and possibly reducing risk conditions, such as civil protection measures and passive defences that can be activated in real time.

The drafting of the simplified document will be developed during the 2019 by acquiring and importing the information related to point 1 that is the delimitation of the areas with hydraulic risk, into the company tools (webGIS).

The preparation of this information layer can be considered as a first study of the vulnerability regarding flooding events and therefore it will allow the knowledge on a large part of the territory of the Metropolitan City.

6.4.2. Methodology

The analysis for the delimitation of the risk areas will be implemented starting from the information directly available within the PGTs (Territorial Administration Plans) of the municipalities, from the information available to CAP Holding regarding the known critical issues of the drainage system and to the operators of the hydrographic network, namely:

1.1-Analysis of hydraulic and hydrological problems in the Geological Component of the Territorial Administration Plan;
1.2-Analysis of the hydraulic and hydrological problems in the document of the Minor Hydrographic Network (Reticolo Idrico Minore – RIM) and in the General Urban Plan of underground services (Piano Urbano Generale dei Servizi nel Sottosuolo – PUGSS);
1.3-Analysis of the hydraulic and hydrological problems of the municipal sewage system;
1.4-Summary of hydraulic and hydrological problems at Municipal level.

The document summarizing the hydraulic and hydrological problems at municipal level will be imported into WebGIS for better consultation and planning of interventions at agglomeration / basin scale.

6.5. Vulnerability Map of Agriculture

The objective of the products is to analyze the impact of the heatwaves in the agriculture domain, through the analysis of the correlation between the increasing of temperatures and the presence of Vegetation Index (e.g. Normalized Differentiation Vegetation Index (NDVI)) anomalies that are biophysical parameters strictly associable to the crop growth and status and to the yield reductions.

The analysis will be based on satellite-based indicators of surface conditions during the 2003 – 2018 period. The time series of temperatures and vegetation index data will be generated from Land Surface Temperature (LST) and NDVI standard products derived by the Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument on-board NASA's Earth Observing System Terra and Aqua satellites. these years.

6.5.1. Product Specification

The methodology described in the next paragraph aims to generate the following products:

- Report including statistical analysis and graphs aimed to highlight, for different agricultural classes, the correlation between heatwaves and NDVI anomalies

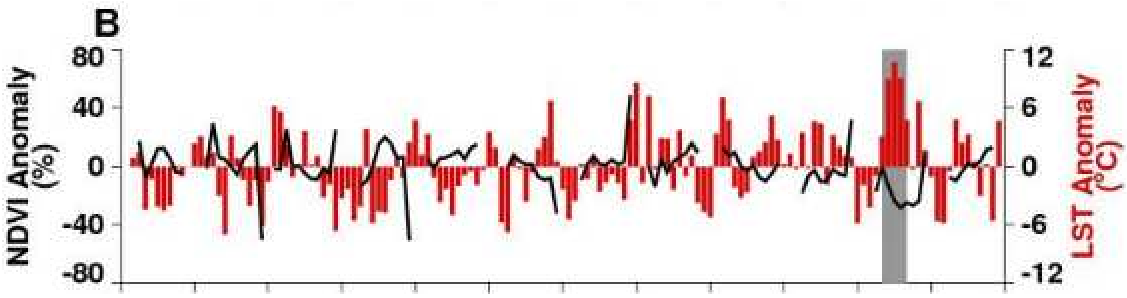


Fig. 6.11 -Example of product. Graph describing the monthly time series of 2000–2012 MODIS normalized difference vegetation index (NDVI; black line) and land surface temperature (LST; vertical red bars) anomalies for agricultural regions (Source: P. K. Thornton et al. 2014)

- Maps that's classify the area of interest in terms of LST and NDVI anomalies analyzed during the period of interest (heat waves and \or crop growth)

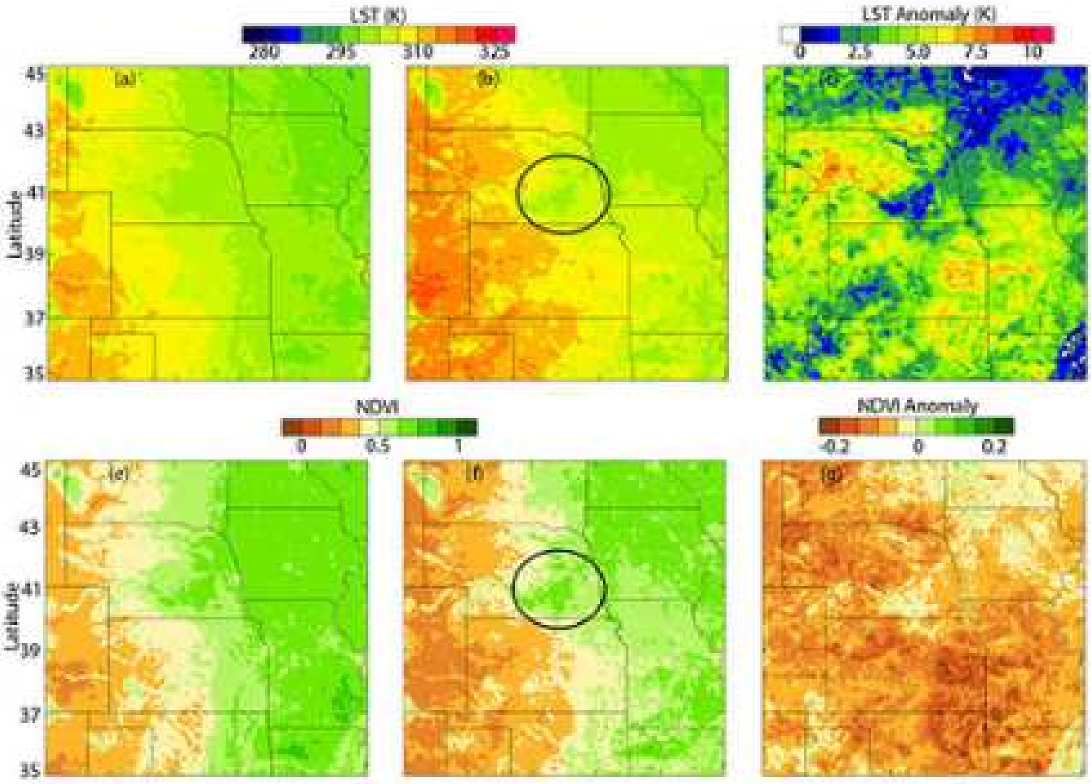


Fig. 6.12 - Example of product. Maps of land surface temperature and NDVI for the 10-year summer average (left column), 2012 summer average (second from the left column), and summer anomaly (third from the left column). The black circles denote the irrigated area in Nebraska (see for details). (Source: J. Wang et al. 2016)

6.5.2. Methodology

The methodology that will be applied to generate the products is based on the following main steps:

1. Identification of the agricultural areas in the AOI, in the historical period analyzed (2003 – 2018), that implies:
   - Retrieving of all the land cover\land use data available on the areas of interest in the historical period considered. The period of the analysis ranges from 2003 to 2018 that includes the last years in Italy, for which the summers have been exceptionally hot, characterized by various and persistent heat waves (2003, 2007, 2010, 2015, 2017)
   - Analysis of the land cover\land use legends to select only those areas with agricultural vocation. A preliminary analysis highlighted that on the AOI are available the CORINE Land Cover (CLC) Level 3 maps for the years 2000, 2006 and 2012. On the same area is also available the landcover derived on the correlation of the classes of the Carthographic Database of with the semantically coherent ones of the CORINE Land Cover program. CLC nomenclature includes 44 land cover classes, grouped in five main categories (artificial surfaces, agricultural areas, forest and semi-natural areas, wetlands and water bodies). The CORINE Land Cover of level 3, at the third hierarchy level, discriminates the agricultural class in 11 sub-classes, as described in the following figure.

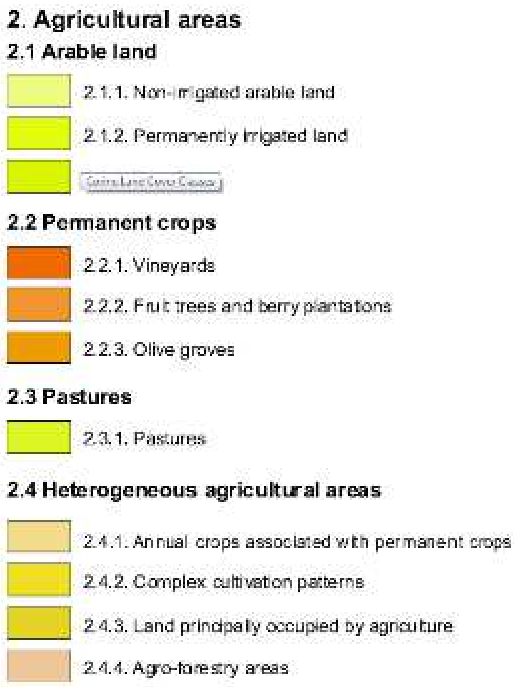


Fig. 6.13- CLC 3° level legend of Agricultural areas class

In case of availability of additional land cover\land use data useful to integrate, as much as possible, the missing years of the historical period considered, it will performed an analysis aimed to homogenize these legends with the CLC one, in order to be able to perform the study on comparable agricultural classes.

- Selection, on the basis of the historical land cover\land use dataset intersection, of the areas characterized by unchanged land cover class in the historical period considered, in order to have a common dataset, in terms of characteristics and extent, for the NDVI and Land Surface Temperature (LST) temporal trends analysis.

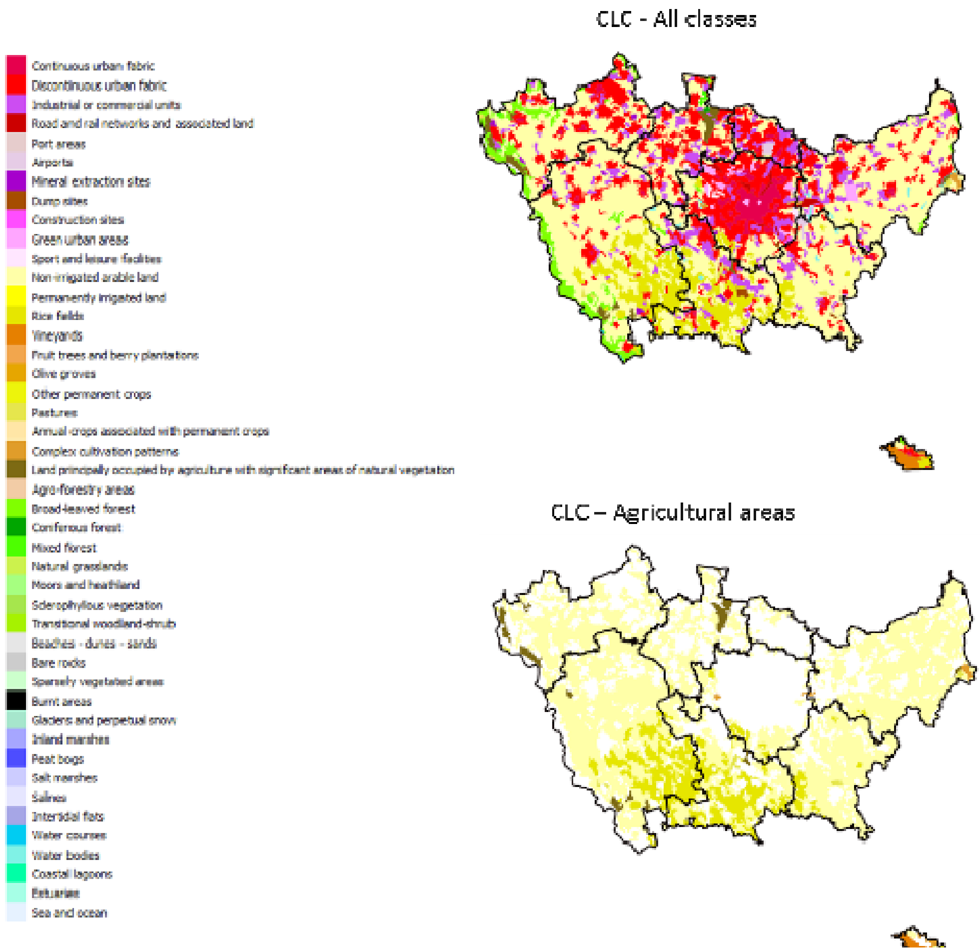


Fig. 6.14Selection of Agricultural areas class on CLC 2000 over the AOI

2. Analysis of the temporal trends of temperatures and vegetation status of the agricultural areas to detect anomalies potentially due to the heatwaves, through the following steps:
    - Retrieving NDVI and LST time series in the 2003-2018 period.
    - Extraction of the long-term mean trends of NDVI and LST values on the agricultural areas previously selected. The long-term mean trends will be generated excluding from the calculation the years that are outliers wrt to temperatures (2003, 2007, 2010, 2015, 2017), in order to have "standard" temporal trends representative of non-extreme or anomalous weather conditions
    - Detection of the NDVI and LST anomalies by expressing differences between the monthlyvalues and the "standard" long-term mean 2003–2018 values
3. Analysis of the NDVI anomalies and of their correlation with the LST anomalies, for each agricultural class considered and generation of the output products as described on section 6.5.1.

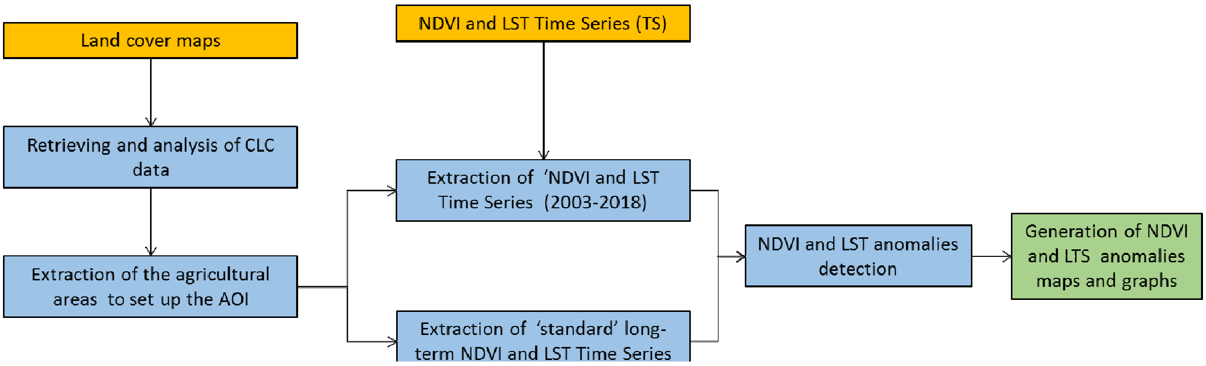


Fig. 6.15- Workflow description