CYPRUS UNIVERSITY OF TECHNOLOGY
FACULTY OF ENGINEERING AND TECHNOLOGY

MSc Dissertation

APPLICATION OF HIGH-RESOLUTION THERMAL INFRARED REMOTE SENSING FOR THE OBSERVATION OF THE URBAN HEAT ISLAND EFFECT IN THE AREA OF LIMASSOL, CYPRUS

Christiana Kaizer

Limassol 2015

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APPROVAL FORM

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Application of high-resolution thermal infrared Remote Sensing for the observation of the urban heat island effect in the area of Limassol, Cyprus

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ABSTRACT

The urban heat island effect is one of the major problems out of other environmental and socioeconomic problems a city can have, that cause urban growth. Due to this phenomenon the rural landscape has been replaced by manmade urban areas with surface that increases the heat carrying capacity and the urban warmth, and therefore, the urban air temperature is higher than that of the surrounding rural environment. In order to evidence the effect of this phenomenon in Cyprus and more specifically in Limassol area, an observation of the temperature fluctuations in the urban and rural areas is done through a methodology which has been followed. Thermal satellite images were taken through Earth Explorer online program of USGS Glovis and elaborated in the ERDAS IMAGINE CLASSIC INTERFACE software, in order to determine these temperature´s fluctuations. Furthermore, a visualization of the various data and results was taken from the study area and through the Excel program, graphs were exported. Through these graphs, the influence of urban heat island effect, in the area of Limassol, through the years was possible to be observed and also, correlations of the phenomenon with other important factors such as location, altitude, distance from the sea, vegetation, population etc. as well as the differences in temperature between urban and rural areas of Limassol were observed.

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ABBREVIATIONS

UHI: Urban Heat Island

NDVI: Normalized Difference Vegetation Index

PGAMS: Portable Ground Atmospheric Measurement System

CIR: Colour-Infrared

ETo: Evaporation

ETc: Evapotranspiration

DI: Discomfort Index

USGS GLOVIS: United States Geological Survey - Global Visualization Viewer

ETM+ SLC-on: Enhanced Thematic Mapper Plus sensor (on)

ETM+ SLC-off: Enhanced Thematic Mapper Plus sensor (off)

TIRS: Thermal Infrared Sensor

OLI: Operational Land Imager

TM: Thematic Mapper

GIS: Geographic Information System

DEFINITION OF TERMS

Urban Sprawl: the uncontrolled spread of urban development into neighbouring regions. This migration leads to the creation of overcrowded cities, suburbs and strip malls, as well as the need of infrastructure supply. It also leads to the relegation of natural land, including farmland and critical habitat (Http://www.askaboutireland.ie/enfo/irelands-environment/the-built-environment/unsustainable-development/, n.d.).

Urban Heat Island Effect:The urban heat island effect is the phenomenon where the rural landscape has been replaced by manmade urban areas with surface that increases the heat carrying capacity and the urban warmth and lead to this effect, where the urban air temperature is higher than that of the surrounding rural environment (Kleerekoper et al. 2012).

Remote Sensing: Remote sensing is the science of obtaining information about objects or areas from a distance, typically from aircraft or satellites ("http://oceanservice.noaa.gov/facts/remotesensing.html," n.d.).

USGS Glovis: The USGS Global Visualization Viewer (GloVis) is a quick and easy online search and order tool for selected satellite and aerial data. The viewer allows user-friendly access to browse images from the multiple EROS data holdings ("http://glovis.usgs.gov/ImgViewerHelp.shtml#SiteDescription," n.d.).

LANDSAT: Any of various satellites operated by US government organizations, used to gather data for constructing images of the earth's surface ("http://www.yourdictionary.com/landsat," n.d.).

GIS: Geographic Information Systems is a computer-based tool that analyses, stores, manipulates and visualizes geographic information on a map ("http://gisgeography.com/what-gis-geographic-information-systems/," n.d.).

INTRODUCTION

Urban growth is the new trend that started to expand this century and makes people want to escape from the city centres and search for a better life with better conditions and a friendly environment that offers peace and relaxation. There are many reasons that lead people to leave the centre and move to the suburbs and are focused mainly on the environmental, financial and social problems that a city has. One of the main environmental problems a city can have is the phenomenon of the urban heat island. The urban heat island effect is the phenomenon where the rural landscape has been replaced by manmade urban areas with surface that increases the heat carrying capacity and the urban warmth and lead to this effect, where the urban air temperature is higher than that of the surrounding rural environment. And as this expansion grows, many consequences, both positive and negative are caused to the environment and people´s life. Unfortunately, the consequences of urban growth are mostly negative, as it develops many environmental, socioeconomic and health problems. Nevertheless, in order to improve a city and make it worthy to live and work in it, there are some planning and design processes that can be made. Those processes include environmentally sustainable urban and rural reconstruction programs, principles of housing design, settlement planning and design principles for public squares. As it has mentioned above, one of the main problems on the environment of a city is the urban heat island effect. In order to evidence the effect of this phenomenon, an observation of the temperature fluctuations in different areas of Limassol is done through a methodology which has been followed. In this methodology, thermal satellite images were taken through Earth Explorer online program of USGS Glovis and elaborated in the ERDAS IMAGINE CLASSIC INTERFACE software, in order to determine the fluctuation of temperature in the city center and the suburbs of Limassol area. In the next stage, a visualization of the various data and results was taken from the study area and through the Excel program graphs which show the influence of urban heat island effect, in the area of Limassol, through the years was possible to be observed and also, correlations of the phenomenon with other important factors such as location, altitude, distance from the sea, vegetation, population etc. as well as the differences in temperature between urban and rural areas of Limassol were observed. Then, a comparison and evaluation of the results obtained from the elaborated satellite images and graphs.

In this dissertation there is a further elaboration of the above and description in detail both the stages and processes taken for the completion of the study. Specifically, Chapter 1 has as main theme, the different types of urban growth and the changes that have been made to the cities and people through it. The main problems of a city, which are mainly environmental and socioeconomic, led to the urban growth which has mostly negative effects on the environment of a city and on social life. All these are analysed in the Chapter 2 of this thesis. In chapter 3 some planning and design processes are recommended foe the improvement of the city centre, in order to reduce and prevent the urban sprawl. Chapter 4 contains a general reference to the topic of the dissertation, through literature review. For the observation of the urban heat island effect, a methodology has been made and is analysed in chapter 5. More specifically, in this chapter the purpose of this thesis with all the available data and software that have been used, are mentioned. In chapter 6 there is a further description of the part of methodology where the images acquisition and their further elaboration is mentioned. Through the Excel program, graphs are exported and an extensive analysis of the results is made and presented in Chapter 7. Lastly, the final conclusions and discussions of this thesis are conducted.

Despite the negative impacts that urban sprawl has on the environment and on people's lives, this trend does not seem to decline, and as a result there is greater need for the development and the implementation of strategies for environmentally sustainable urban and rural reconstruction.

1 Urban growth and development

1.1 Types of urban growth

With the urban growth, large cities are becoming a main habitat and this is something that must change. But in order to change that, first it has to be analysed and understood. There are two basic types of growth, the one that is sustainable and the other which is unsustainable. With the term sustainable growth or smart growth, it is meant the better way of building and maintaining towns and cities. This refers to a collection of land use and development principles who aim to enhance the quality of life, to support local economies and protect the environment (Http://www.smartgrowthamerica.org/what-is-smart-growth, n.d.).

As it said, sustainable growth includes a collection of some principles which are mainly referred to mix land uses, as neighbourhoods must be a mixture of homes, business and entertainment area. As for the areas, they must preserve open spaces and natural beauty, and also be environmentally sensitive. Neighbourhoods must also be well designed and compact in order to provide to residents a well living, working and entertaining environment where they can also afford a home of their choice and thus create diverse housing opportunities for all types of families. Furthermore, neighbourhoods must be able to provide a variety of transportation choices and encourage growth in their existing area. With these principles, each neighbourhood must have a unique identity and be vibrant, diverse, and inclusive.

Principles also refer to the protection and the improvement of agricultural lands in order to provide food security, employment and habitat. At last, they also refer to the citizens' participation and decision making of their neighbourhood (Http://www.smartgrowth.bc.ca/Default.aspx?tabid=133, n.d.).

On the other hand, there is the unsustainable growth, which mainly refers to the urban sprawl, which is another word for urbanization. This phenomenon started to occur many years ago when people started to migrate from populated towns and cities to low density residential development and more rural land. This migration leads to the creation of overcrowded cities, suburbs and strip malls, as well as the need of infrastructure supply. It also leads to the relegation of natural land, including farmland and critical habitat (Http://www.askaboutireland.ie/enfo/irelands-environment/the-built-environment/unsustainable-development/, n.d.).

1.2 Changes from urban growth

City growth started having a great impact at the change of some aspects by the end of the 20th century. It started changing the use of cities, the condition of humanity and the face of the earth, as the future of the biosphere is now determined.

Global urban populations have expanded from 15 in the 20th century to almost 70 per cent in the 21st century. Large cities are created and unfortunately small towns and villages started to disappear. Almost half of humanity live and work in urban areas. The size of modern cities is increasing year by year and there is a change in the use of land and resources and also in their environmental impact. Also, modern cities act in a different way than they used to act in the past, as people now actually live in a mobilisation than in a civilization. Cities now sprawl outwards along railway lines and motorways to their suburbs. Furthermore, cities are becoming global centres, as transportation by the use of fossil fuels is cheap enough and villages become places for those who move in order to work elsewhere and who use telecommunications as mean for income generation. These, have also environmental impacts as cities consume a lot of energy and resources and they will be disgusted in the following chapter.

As for the change of the condition of humanity, it is sad to observe that people draw more and more resources daily from distant hinterlands and make a bad use of biosphere, oceans and atmosphere. With these actions they managed to create diseases such as cholera, TB and typhoid in many developing cities and put themselves in a huge risk (Herbert, 1999).

2 Causes and consequences

From the analysis of the two types of urban growth and the changes that can be occurred from it, there are many causes and consequences that arise and are analysed in this chapter. Urban sprawl usually grows due to the big problems that a city fronts. These problems are mainly environmental, socioeconomic and political and have negative impact and consequences on the development and improvement of a city or a region.

2.1 Main problems on the environment of a city

2.1.1 Environmental problems

The main source of the environmental problems a city can have is the climate change which is well related to urbanization as well as to the changes in the climatic system and to the economy of a region. Generally, climate changes are referred to the raise of humidity, the precipitation, the cloud cover and the reduction of the wind speed. These changes have impact on the public health, outdoor thermal comfort, air quality and the energy consumption as they accelerate the depletion of natural resources. Manmade contributions are also important to the climate change, as human activities lead to the chemical composition of the atmosphere (Bhiwapurkar, 2010). The main of these activities is the production of thousands of tons of carbon dioxide and other pollutants due to the massive consumption of raw materials. Raw materials can be derived from industry, urban transport, cooling and heating systems etc., and by producing these pollutants they exacerbate the urban heat island effect (UHI), a major contributor to global warming of the planet and many other environmental problems.

Most cities suffer from several environmental situations, such as the huge amounts of ozone, the air and noise pollution, as well as problems with wastewater treatment and solid waste management. Also many cities have to front areas of rubble and rubbish dumps (rainwater areas and seas). In order to facilitate the arbitrary and uncontrolled urban sprawl, cities may also have to face the deforestation of forests or green areas and the desertification of fertile and rural areas (Sivitanidou, 2015).

The most significant environmental problem that cities have to deal with is the urban heat island effect which has already started to sprawl all around the big cities of the world.

The Urban Heat Island effect (UHI)

The urban heat island effect is the phenomenon where the rural landscape has been replaced by manmade urban areas with surface that increases the heat carrying capacity and the urban warmth and lead to this effect, where the urban air temperature is higher than that of the surrounding rural environment. This is due to the fact that the heat trapped by the urban surfaces and greenhouse gases over the city disturbs the energy balance of incoming and outgoing solar radiation (Kleerekoper et al. 2012). Also, the intensity of this effect is depended on the population, the size of the city, the topography and location, as well as on the weather conditions (Bhiwapurkar, 2010). Consequence of this effect is usually the variation of temperature in time and place and can change due to meteorological, geographical and urban characteristics.

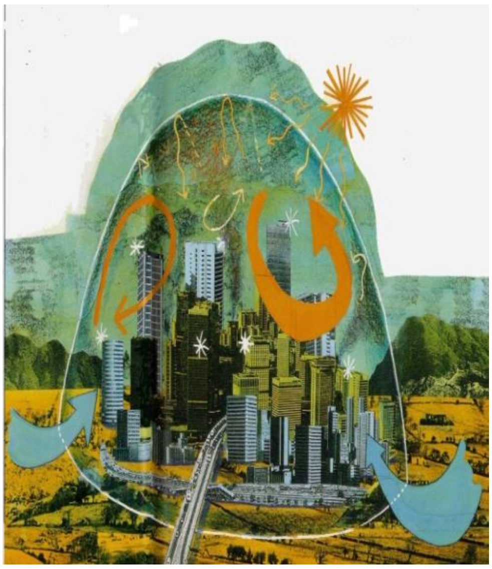


Figure 1: The Urban Heat Island Effect

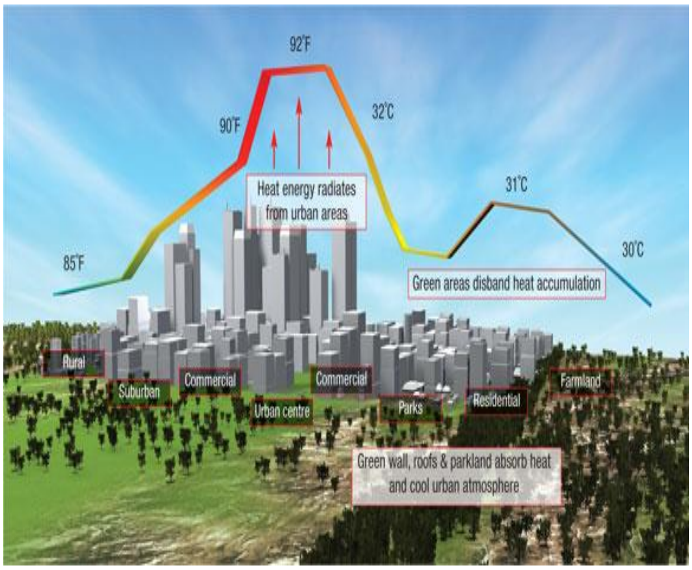


Figure 2: The Urban Heat Island Effect

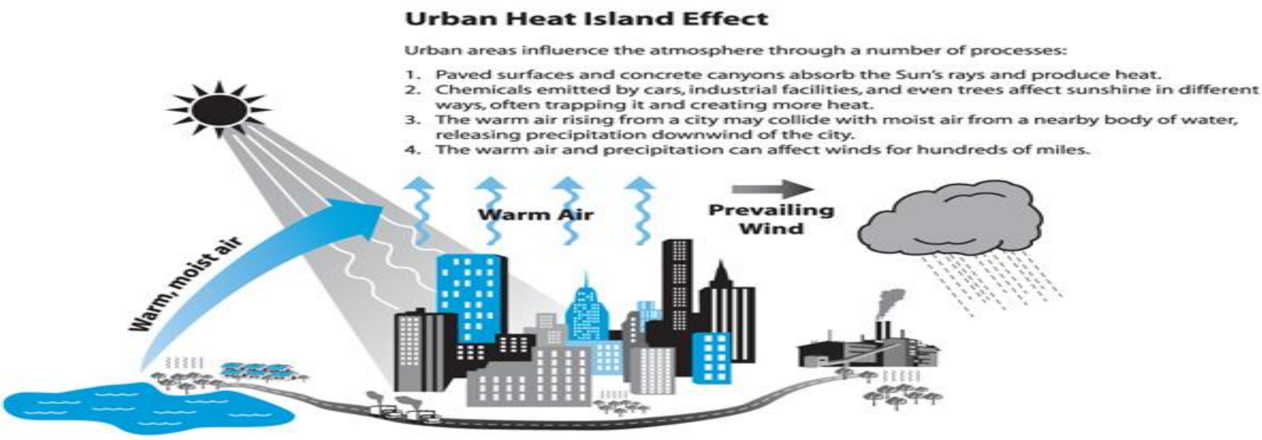


Figure 3: The Urban Heat Island Effect

(Source: "http://www.brighthubengineering.com/building-construction-design/42981-what-are-urban-heat-islands/," n.d.)

Causes of the urban heat island effect (UHI)

In greater detail, urban heat island effect may be caused by different factors. One of them is the short-wave radiation from the sun that trapped between the buildings and the street surface due to the fact that the materials that are used to build up the buildings make multiple reflections between them. Also, the urban environment can be effected by the air pollution in the urban atmosphere by absorbing and re-emitting long wave radiation.

Another factor that is of great importance is the existence of very high buildings such as the skyscrapers and the frequency of such type of buildings nowadays as well as the way in which they are arranged, could become an obstacle of the sky, having as a result the long-wave radiative heat to remain within the atmosphere of the city by preventing the sun's energy to escape and maintaining the very high air temperatures within the city. In contrast, in rural areas the area cool much faster as the air heat can escape more easily.

Another factor that affects the urban heat as a result of the combustion processes is the anthropogenic heat, such as traffic, space heating and industries. Some examples can be the air conditioning and refrigeration systems that release waste heat. Industrial processes and motorized vehicular traffic also contribute to the affection of the urban heat.

Furthermore, due to the fact that cities have larger surface area covered by buildings and roads and few green space this help the heat storage to increased, as the urban construction materials have large thermal admittance and radiation. As a result more sun's energy absorbed and stored in an urban areas than in a rural surface.

In an urban area "waterproofed surfaces" is much more than vegetation areas and this has as a consequence the evaporation to be decreased. Due to the lack of vegetation, urban areas dry more easily than the rural areas, as the majority of the surfaces are solid and quickly remove the water from the surface.

Another factor that affects the urban heat but not least, is the chaotic heat transports within the streets and it is decreased by a reduction of wind speed.

Impacts of the urban heat island effect (UHI)

The urban heat island effect is a phenomenon that increases year by year all around the world and especially in big urban cities and has negative impacts in several sectors. If this phenomenon continues to rise, it will double the urban to rural thermal ratio and thus increase the effects on the environment of a city or region. Some of these impacts which have already appeared in big urban areas are analysed below.

As the urban heat island is a phenomenon which significantly increases the temperature of an urban area in comparison with the rural areas and the suburbs, thus it creates great need of ways of confrontation. The ordinary way to front the high temperatures is the use of cooling systems, which consume large amounts of electricity, usually on hot summer weekdays afternoons (Http://www.epa.gov/heatislands/impacts/index.htm, n.d.).

This effect can also cause many meteorological impacts as it mainly initiates urban induced precipitation and thunderstorm events. It also causes reductions in the diurnal and seasonal range of freezing temperatures as well as in snowfall frequencies and intensities. As it raises the temperatures it is possible for plants and urban forests to obtain physiological and phonological perturbations (Http://thegreencity.com/the-causes-and-effects-of-the-urban-heat-island-effect/, n.d.).

As it mentioned above, the UHI effect causes high temperatures, mainly in ill-ventilated outdoor spaces or inner spaces of residential and commercial buildings with poor thermal isolation. This leads to great demand for electrical energy, especially in summer days and thus to the energy consumption for cooling and hence to the increase of air pollutant and greenhouse gas emissions. These primary pollutants from power plants can be sulfur dioxide, carbon monoxide, particulate matter, nitrogen oxides and mercury which contribute to global climate change and also have harmful impacts to human health. They can also contribute to formation of ozone precursors, which combined photochemically produce ground level ozone.

Furthermore, high temperatures may cause the increase of the temperatures of pavement and rooftop surfaces, resulting heat stormwater runoff. Thus, this runoff may drain into storm sewers and increase the temperatures of water as it is released into streams, rivers, ponds, and lakes. This effect is possible to have negative impact on the aquatic life, as water temperature affects all its aspects, especially the metabolism and reproduction of many aquatic species (Http://www.epa.gov/heatislands/impacts/index.htm, n.d.).

The urban heat island effect also affects the human health, as it increases the temperature, the air pollution levels and reduces the nightime cooling. These can contribute to the creation of thermal discomfort on the human cardiovascular and respiratory systems. If the weather conditions are extreme, (i.e. heat waves) this phenomenon can also cause respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality and wide number of diseases may become worse, particularly in the elderly and children (Http://thegreencity.com/the-causes-and-effects-of-the-urban-heat-island-effect/, n.d.).

2.1.2 Environmental and financial problems

Cities may have also problems that both affect the environment and the economic sectors of them. Many areas and buildings get desertification and degradation and the urban fabric is disintegrated, rotten and abandoned. There are half finished structures and sometimes infrastructure deficits. Despite of those problems, a city is required to build new structures, according to the spread of it or to maintain existing traffic and transport networks in perfect condition, as well as, the network of water supply and sewage system, the rainwater collection and treatment system, the desalination and sewage treatment plants. Another problem of this subcategory is the deindustrialisation and tertiarisation, as there is abandonment of industry and production. Cities now focus mostly on the tertiary sector of services, the commerce and tourism, instead of the agriculture and the livestock which form the first sector of services and the industry which is the second sector of services.

2.1.3 Socioeconomic problems

Another subcategory of the main problems on the environment of a city is the financial problems which are connected with the social sectors a city may fronts. The social exclusion and marginalization due to unemployment, educational level (youth), racial discrimination (women and foreigners, economic migrants) affect the environment in the form of ghettoization, vandalism and violence, and thus degrade and desolate the urban areas. Also, the ageing of productive population and the disproportionate migrations of young people in other big urban centres are big social problems.

Another factor that constitutes the socioeconomic problems of a city is the overpopulation, as the global population is growing exponentially and uncontrollably. The essence of the problem lies not in the absolute size of the population but in its relation to the resources available to a small planet about satisfying the needs of people. The surface of the Earth and the wealth-producing resources are naturally for granted and limited. Some problems which are caused due to the overpopulation are the worldwide poverty, the social exclusion, the continuous local wars, the environmental destruction, the overheating because of the urban heat island effect, the lack of drinking water, the diseases, the adverse living conditions, the migration of large population groups, the environmental refugees and even the traffic jams in cities.

These problems may also affect the social attitudes and arrangement as they have heavy impact on the daily lives of people in sociability, health and psychology. More deeply, there is significant increase in unemployment and lack of resources which lead to difficulties in securing basic necessities like food, clothing, medical care, etc. Also, many people have severe difficulty in finding a job and they are swamped of panic and uncertainty, stress and anxiety. There is also greater class chasm and increasing poverty which lead to more unequal quality of life and unequal distribution of natural resources. Due to the financial difficulties, elation of strikes, protests, crime and suicide is created as well as increase alcohol and drug abuse.

There are also effects of architecture and construction economy and form that consists the socioeconomic factors which causes problems on the environment of a city. Architecture is the artistic expression of society. Through the styles and construction materials the financial status of the users or owners is obvious. The way a building is used and the level of maintenance express the culture and characteristics of the society someone lives and works in it. So, the economic crisis affects the architecture and the built environment as there is lack of financial resources and liquidity that lead to a stagnant construction industry and to the increase of unemployment rates in the industrial and construction sector. Economic crisis also affects the built environment through the desertification and degradation areas of it, as opposed to palace creations of the upper class (Sivitanidou, 2015).

2.2 Causes of Urban Sprawl

Urban sprawl can be usually caused by several factors, similar to those which can cause urban growth. They are not always common, but most of the time they are interlinked. The most frequent factors that cause urban growth and thus sprawl, are presented below, in high detail.

Population growth: the main reason of urban growth is the rise in population growth. As number of people in a city grows beyond capacity, the local communities continue to spread farther from the centres, and this is due to the natural increase in population which results from excess of births over deaths, and the migration to urban areas. Migration usually happens because of the better conditions a big city may has. Generally, city centres are places where people can have better life, as there are better job opportunities, higher salaries, better lifestyle etc.

Economic growth: apart from the population growth, the economic growth also causes urban sprawl, as the number of working persons or the capita income increase, there is a demand for new spaces and houses for individuals (Bhatta, 2010).

Rise in standard of living: as there is economic growth, the standards of people are increased. Most people can pay more to travel and commute longer distances to work and back home, thus they seek for dwellings outside the centres, in order to live comfortably and have more quality life. Also the preferences of people are different and they need more land space in order to have larger homes with more bedrooms, balconies, gardens etc. (Http://www.conserve-energy-future.com/causes-and-effects-of-urban-sprawl.php, n.d.). And as there is a demand for new spaces and houses for individuals, the countryside development for more living space is encouraged. This is due to the fact that the cost of property is less in the countryside than in the inner city.

Lower property tax: as the living and property cost is higher in the city centres, countryside development is encouraged. In the suburbs the development and property taxes are lower and this is due to the fact that developers pay only a part of their costs which are related to their projects (community-infrastructure and public-service costs). This problem makes the development in the countryside looks cheaper and this is the reason why urban expansion and thus city growth are encouraged (Bhatta, 2010).

Lower land rates and land appreciation: as the land and houses costs are lower in the countryside, more and more people want to move in these areas and leave the city centres behind. Also, as the rate of increase in these areas grows, the expectation of land appreciation gets higher and thus more land is withheld for development (Http://www.conserve-energy-future.com/causes-and-effects-of-urban-sprawl.php, n.d.).

Speculation: without proper planning many problems may occur, such as the speculation about the future growth, policies and facilities which may consist premature growth (Bhatta, 2010).

Lack of urban planning: lack of urban planning leads to unprecedented development and has several effects on the environment of a city. Trees are cut, green cover gets lost, long traffic jams appear, the infrastructure gets poorer. All these force people to seek for other areas, more peaceful, comfortable and less trafficked (Http://www.conserve-energy-future.com/causes-and-effects-of-urban-sprawl.php, n.d.).

Lack of proper planning policies: another lack of planning is the lack of proper planning policies which also cause urban sprawl. If a city is not planned and separated properly (residential, commercial, industrial, office, institutional, or other land uses), this means that it does not have zoning policies. As a city is separated wrong, isolated islands are created and thus urban sprawl. A good way to front this problem is to allow to a city to have a mixed land use policy.

Public regulation: the public regulation in the countryside is not as controlled as it is in the city centres, so many developers choose such places which are suitable to build.

Industrialisation: due to the fact that land in the suburbs is cheaper, industrial sprawl has occurred. And as the industries increase in the countryside, the urban sprawl increases too and this is because of the requirements it has. For instance, the most part of the land is used for housing for workers.

Geomorphology: another factor that leads to development sprawl is the physical geography and the unsuitable physical terrain (rugged terrain, wetlands, mineral lands, or water bodies, etc.).

Transportation: transportation is an easy way for dwellers to excuse their trend to leave the city centres as routes open the access to the countryside (Bhatta, 2010).

2.3 Effects of urban growth

The effects resulting from the influence of the phenomenon of urban sprawl can be both positive and negative simultaneously. Although there are positive points to this effect, the negative effects are more numerous and more important, thus overshadow these points. The positive effects that result from this phenomenon focus mainly in the socio-economic advancement of the inhabitants. This is because of the higher economic output which results new opportunities for the low-paid and unemployed. Also, it contributes positively to the improvement of social life of people, and the expansion of public services (water, transportation, sewer, educational facilities, health care facilities etc.). But since this phenomenon is not controlled and is evolving rapidly, the impacts on humans and on the environment are huge and are detailed below.

Increase in public expenditure: urban sprawl leads to the development of public expenditure, as it requires more infrastructure and public services such as hospitals, schools, police stations etc. in the countryside. People tend to be more dispersed and prefer to reside in non-centralised cities, so they move to suburban areas, as a result the costs of community infrastructure and public services to be increased.

Impacts on social life: the urban sprawl is causing alienation of residents, after choosing to move to places outside the centre which cannot offer them social life due to technical and economic factors. This arises mainly because sometimes private utility systems serving the main segment of the settled area cannot be expanded. Also, urban sprawl develops spatial disparity in wealth between cities and suburbs and that is a thing that affects the social life of people.

Health issues: One of the main reasons people move to the suburbs is to escape to nature and feel the relaxation and tranquility that nature can offer them, which contributes to the improvement of their health and wellness. Therefore the negative impacts that may be caused to health by urban sprawl are more important. One of the main characteristics of the spread is the movement of people with private transport, especially by car. This mean of transport causes health hazards, including air pollution, motor vehicle. Also air pollution is caused which has consequences like breathing problems, skin diseases, and other health problems. Also, due to the fact that urban areas are warmer than rural, health hazard may be also caused. Relatively benign disorders include heat syncope, or fainting and other effects such as heat cramps, heat exhaustion vomiting, weakness, and mental status changes. The most serious of the acute heat-related conditions is heat stroke. Effects on the health of people may be caused due to the stress that this kind of life causes to them. The fact that they cannot afford housing to live within the city and the time spent in order to transport to and from the city center also makes people more restless (Bhatta, 2010).

Environmental issues

Urban growth may also affect the environment in many ways, which are analysed below.

Energy inefficiency: due to the urban sprawl, more people travel from the suburbs to the city centre and vice versa and this causes more fuel consumption and traffic congestion.

Disturbance of ecosystem: due to the uncontrollable urban sprawl, theconcentration of human presence in residential and industrial settings leads to alteration of ecosystems patterns and processes and as a result, forest areas, farmlands, woodlands and open spaces are decreased. Also, the development of roads, power lines, subdivisions and pipelines often must be done through natural areas and therefore there is fragmenting of wildlife habitat and altering of wildlife movement patterns.

Farmland loss: the presence of farms on the rural landscape provides benefits such as green space, rural economic stability, and preservation of the traditional rural lifestyle. However, urban growth contributes to loss of farmlands and open spaces. Due to the provincial tax and land use policies, there are financial pressures on farmers who force to sell their lands to speculators. These speculators often create rural residential development which contributes to the loss of hundreds of hectares of productive agricultural land. Therefore, fresh local food sources, habitat and species diversity are lost.

Increase in temperature: when the temperatures are higher in urban than in rural areas in warmer days, this is known as the urban heat island effect. As urbanization grows, the urban heat island effect grows too, in geographic extend and intensity, especially if the pattern of development features extensive tree-cutting and road construction. Also, due to the global climate change which is caused because of the fuel combustion and carbon dioxide production that urbanization causes, the urban heat island effect may be intensified in metropolitan areas.

Poor air quality: urban growth causes energy inefficiency as it has been mentioned above. Fuel consumption and emissions of greenhouse gases are increased with the result of the addition of pollutants to the air. The air quality becomes poorer due to pollutants such as carbon monoxide, carbon dioxide, ground-level ozone, sulphur dioxide, nitrogen oxides, volatile organic carbons, and microscopic particles, which can inhibit plant growth, create smog and acid rain, contribute to global warming, and cause serious human health problems.

Impacts on water quality and quantity: due to urban sprawl miles of roads, parking lots and houses have been paved and thus rainwater and snowmelt are unable to soak into the ground and replenish the groundwater aquifers (Bhatta, 2010).

3 Planning and design process

In order to improve a city and make it worthy to live and work in it, there are some planning and design processes that can be made. Those processes include environmentally sustainable urban and rural reconstruction programs, principles of housing design, settlement planning and design principles for public squares.

3.1 Strategies for environmentally sustainable urban and rural reconstruction

There is a need for an alternative approach in urban and architectural design, which may be based on a broader ecological approach. The urban reconstruction that stems from sustainable design and focuses on bioclimatic design issues can bring quality in urban neighbourhoods. In recent years, greater emphasis has been given to better relationship between buildings and open spaces, in order to create urban patterns with new social needs for a different future.

The sustainable built environment is one of the main priorities for all European cities in the 21st century. It is a fact that during the last few years, cities have been included in urban reconstructions through a new growth point of view, environmental, spatial, social and economic dimensions. For the process of reconstruction and sustainable urban lifestyle, identifying options, the areas of character, attractive routes for pedestrians and including new types of roads, enriched squares and open spaces are required.

The development of methodologies in urban reconstruction processes with ecological design issues should be the key to re discovered the meaning and the identity of a structured environment. However, to identify best development proposals and to offer a dynamic location for sensitive design intervention, reading and translation of the current situation (development mapping) of the studied area are essential and analysed below.

Traffic conditions: to become useable sites should be easy to access and is integrally bonded with their surrounding areas, and this requires attention to creating good connections with walking, cycling, public transport and the car. A good understanding of local and existing types of traffic is essential for designing a good reconstruction. It is therefore essential to achieve a closer link with the landscape or the immediate environment and that includes the following topics:

• Locality of the region into the rest of the town / village

• Connection to public transport
• Traffic Types: movement of vehicles, bicycles and on foot

Existing physical characteristics: the spaces in a city should be attractive and operated in cooperation with the natural landscape. But this requires a balance between natural resources, climate and existing ecological conditions. To create a sustainable reconstruction is important to recognize and assess the character of the area such as topography, local climate, the nature and quality of the region in the open green spaces, as well as the relationship between the built environment and landscape. Comprehensively it can be described by:
• The topography
• The outdoor green areas: natural and urban landscape
• Existing features of the microclimate of this period.

Development process and urban typology: for the reconstruction of the areas, the existing historical records, including the surviving historical patterns, architectural features, landmark and building styles, typologies of roads, and densities, should be taken into consideration. Therefore, researchers should take into account the nature and characteristics which have lost, recognizing and highlighting:
• The local planning policies and strategies
• The land use
• The historical development and building forms
• The architectural features and building typology
• The hierarchy and the resolution of typical roads

Social and cultural process: to improve specific areas a range of local social and cultural needs of the existing urban situation must be taken into account. This means reconstruction for flexible future changes in use and lifestyle, through the interpretation of new approaches to development. For the creation of urban structure should be considered history, local traditions and cultural background of the area. All other features that constitute the urban fabric must be taken into account as follows:
• Analysis of the quality of the urban landscape
• Character and variety of spaces
• Identity and readability of structural conditions

A good understanding of the analysis of the study area must recognize its potential for reconstruction such as:

• Dynamic points to grow again
• The neighbourhoods to become more sustainable
• Areas - cores to become more attractive
• The key nodes and the roads to be improved and to find connections between key points
• Existing buildings to be restored and become reused
• Environmental improvement of specific areas.

The next step is how the detailed analysis of the study area will be worked in urban planning and master plans that can be used in smaller - local scale. The urban planning process is the organization of the areas, in parallel with the process of building design, which can be seen as the pattern of building form. More specific, all the information for the area about the building form and the relationship between public and private spaces is need to be gathered as follows:

• Natural and spatial character of the area
• Surrounding circumstances
• Access and traffic in the region
• Optical qualities
• Uses Pattern
• Urban policies principles
• Building structure with environmental control

Approaching an environmentally sustainable urban design

In recent years, the urban planning which is based on sustainable and ecological factors has been the catalyst for the creation and upgrade of specific areas. However, it is essential for urban reconstruction to obtain a high quality built environment for more live cities.

The intention of the good urban design is to create a comprehensive urban structure, links and to organize ecological sensitivity of the area.

The principles of sustainable urban design can be mounted as follows:

• The identity and character of the area
• Environmentally friendly for the rest of the city and new connections with the neighbourhood
• Easy transport system: public transport, cars, pedestrians and bicycles
• Prioritization of the roads and good accessibility
• Distinct public and private spaces

- Attractive public spaces
- Mixed use development
- Distinct area - core
- Good legibility of the urban fabric: landmarks, sights, landmarks, land and building blocks
- Flexible and sustainable built environment
- Customizable buildings in correspondence of the roads and openings of squares and parks
- Sustainability and balance of the physical characteristics
- Use of renewable energy

The principles of sustainable urban design should help regions to strengthen their identity and their urban structure through specific development patterns. They have to do this in order to define better private and public spaces, giving quality in the urban environment, as well as to form the terrain of the region, respecting the natural characteristics. Also, to promote accessibility to and from the region, integrating land use and public transport, to promote good legibility and adaptability of urban pattern and to create more attractive areas through the mixing of uses that respond perfectly to the local community needs.

Designing in order to preserve the character may be an opportunity to create special areas where the new and the old coexist in harmony. In order to configure the development and the environment, the form of soil of a region and the existing natural elements has to be preserved (including rivers, streams and canals, lakes, hills and trees, and generally the local ecology). Moreover, the scale of the proposed development should take into account the buildings, topography, existing sights and landmarks.

Well-designed streets with safe and comfortable environment make the regions more attractive. New routes should be linked to existing, defining sustainable traffic patterns. The design of the landscape of roads need to be encouraged and in order to create traffic calming, hiking and cycling are considered keys.

Well-designed urban spaces can contribute to the success of public space, based on a variety of types of spaces for local economic, social and cultural life. Additionally, the design of public space should take into account the local climatic conditions, including daylight, wind and temperature. Good urban design can contribute to the proper siting and operation of buildings. The buildings of great architectural importance can provide orientation and identity points. The development of mixed uses can provide opportunities for such economic and social activities. It can provide good places to live, work and at the same time to enjoy the urban environment.

Definition of bioclimatic issues of the planning process

The introduction of ecological issues in the planning process is an important contribution to the reconstruction of a region. Moreover, the role of bioclimatic principles is essential both for the reconstruction of the region and for new urban development - extensions. The initial idea is that of well-interconnected network of green and open spaces through the entire fabric of the region. A provision for good interface between open spaces can encourage the movement from one region to another, creating a network of pedestrian and bicycle paths with an almost continuous vegetation cover. The physical connections between open outdoor spaces will allow pedestrian and bicycle traffic in the fabric of the area and within the city and areas beyond the city. The creation of urban green corridors on both sides of the roads will serve a full integration of the built environment of the area with the natural environment, providing continuous green spaces and enhancing the legibility and permeability of the urban structure. Therefore, existing rivers or streams and water are very important for the cohesion of local vegetation, so the strengthen of existing elements of the landscape or the improvement of them where they are not present, are of great importance and it is also important to promote:

• The planting strategy for creating attractive areas and for the encourage of new microclimatic conditions

• The use of water elements to create a dynamic urban and rural landscape.

The efficient use of planting trees to provide shading, natural ventilation and possible green visual conflict, can also create sustainable places for people. Also it can involve truly microclimatic benefits related to the cooling, natural ventilation and lighting, reducing noise pollution and improving air pollution.

The purpose of providing a continuous green network with well-connected open spaces can produce another layer in the planning process. Public open spaces are the obvious basis for the "greening" large scale. Private gardens and courtyards can also contribute to this. However, the "continuous green" on the relationship between built and open spaces, the "greening" of outdoor and public spaces should be achieved through planning, regarding the siting and orientation of buildings.

The main elements which have to be taken into account in the adoption of bioclimatic issues in the design are:

• Efficient use of space

• Orientation

• Topography

• Flexibility
• Environmental control of the construction of buildings: use of "green" materials
• Efficient buildings (for energy)

The orientation, in terms of both area and each building separately, can have influence on various environmental issues and, possibly, also have influence on the distances between buildings. Large buildings should be oriented in such way as to avoid excessive shading of public spaces and gardens of the houses. Furthermore, through an appropriate guide, it is possible to reap the benefits of natural heating and cooling as well as insolation during the day. The south oriented aspects gain more solar gains and certain types of buildings should be designed with the aim of mild preservation and sustainability through appropriate methods of optimum energy storage (Psillides, 2007).

3.2 Settlement planning

There are many factors that affect the choice of people to leave the city centres and seek for other places to settle, build their houses and start a new life. Most of these factors have been mentioned above. Nevertheless, sometimes the most favoured land for the people to make this begging may also be the most at risk, as informal settlements tend to grow on dangerous land where there is no access to basic services and infrastructure. In order to reduce this disaster-risk, settlement planning has to be taken into account and contains strategies as analysed below.

At first, a suitable area has to be selected and then a plan at a neighbourhood level has to be developed. Such plans are mainly prepared by an architect or a planner and are base on the site analysis. Before all these, the master plan for the whole area or city has to be checked in order to ensure compliance with its requirements. The settlement plan has to take into consideration all the natural hazards and the local climate conditions before it exports all the necessary information about the risk of buildings, roads, vegetation and access to infrastructure. This settlement plan has to explain how buildings should be set in order to have less impact on the surrounding environment or the closest ecosystems. Also it has to establish where infrastructure is laid, the orientation of the buildings on the plots, the urban socio-cultural requirements, the integration of suitable vegetation, as well as the arrangements of external and internal spaces. For the completion of this plan, there are some factors that have to be taken into account and are analysed below into four aspects, the technical, the socioeconomic, the environmental and the regulatory aspects.

As for the technical aspects, first it has to be checked whether the development of a new settlement plan is necessary, or there is a former plan which is still usable and valid. After this, the settlement plan has to be flexible for further extensions, for new accesses and for other adjustments as the habits and needs of the users are constantly changing. At the end, the access through appropriate streets (including the public transport system and the pathways) has to be assured.

As for the socioeconomic aspects, first of all, the social relationships among the community have to be retained as the social network is very important for the sustainable development of communities including poverty reduction. Also, land has to be used in such ways in order to retain and enhance its economic potential.

The environmental aspects are very important for the completion of the settlement planning and have to be taken into consideration. At first, an assessment about the environmental impact has to be carried out in order to identify the negative impacts on the environment and the opportunities to avoid or mitigate them. Second efficient step is the protection of the vegetation and the adding of new trees as they improve the quality of the air and provide aesthetic and recreational value in the city. Furthermore, the position of the buildings has to be set in such way to use the sun and wind more. In a hot climate the east and west facades have to be shaded so as the solar heating and the indoor temperatures are minimised. Also, buildings have to be in a staggered pattern in order to achieve proper ventilation. At the end, the streets and paths have to be arranged in order to save land and to provide better access to buildings and facilities.

As for the regulatory aspects, the settlement plan has to comply with the buffer zones, the building codes and the laws and regulations as they contribute to the maintenance of the minimum distance to neighbouring industrial areas and the airport, the minimum sizes of the plots and their subdivisions as well as the minimum plot density. Also it has to provide the heights of building and the numbers of floors, the purpose and usage of houses and the street width (IFRS, 2012).

3.3 Principles of housing design

The part of the housing design is the main issue of a reconstruction programme as it determines the level of ownership and acceptance by beneficiaries and communities. A proper and well-structured design requires a longer time-frame, lobbying efforts as well as additional work.

The most important aspect of the housing design is adequacy of the housing to accommodate users' needs, natural hazards (earthquakes, storms and floods) and climatic conditions. The energy efficiency and the conservation potential of housing play important role in the satisfaction of the users. This kind of design has to increase the resilience and vulnerability of a building, according to hazards it may get exposed, such as in an earthquake, where a building with open roofs or irregular shapes has more possibilities to fail. Also, houses which are built in an area of high snow probability must have snow-load capacity integrated into frames and roof structures.

For this type of design, some recommendations are analysed. First, there is the recommendation of favour environmental solutions which provide sustainability and energy efficiency. The use housing designs that are resistant to natural hazards such as earthquakes floods and storms are also recommended. This design also suggests flexible designs that are easy to upgrade and expand and favour simple low-cost robust and practical solutions. To move forward with the housing design, the incorporation of users' needs and cultural requirements is needed, as well as the assurance that the cost-effectiveness in all construction activities and the materials and tools needed to work the materials are available locally.

The house design phase of an intervention is very crucial and is the foundation of acceptance and ownership by communities. Another key recommendation is the assessment of the whole life cycle in the designing of a building such as the construction, the maintenance, the demolition, the reuse and the recycling phases. As for the maintenance, the use of plain housing styles is suggested.

In order to complete the housing design there are some steps that need to be taken into account. First, there is the preparation of a site or layout plan, then the provision of infrastructure and services at settlement level. Moreover is the preparation of the structural and technical drawings for the construction of a building as well as the drawings for infrastructure and services (drainage, sanitation etc.). Except of these drawings, detailed drawings of various building elements have to be prepared too. Then the design has to be approved from the relevant governmental authorities. At the end, some regular coordination with the various stakeholders and frequent updates with the project committees and relevant stakeholders have to be made (IFRS, 2012).

3.4 Design principles for public squares

Many rules and principles have been written and many ideal forms have been set out about the ideal public square, from the time of Vitruvius since now. But the recent cities are very complex so it becomes difficult to provide a set of criteria that will result in the ideal public square. All it has to be done is a synthesis of all these rules and principles according to the standards of today's cities. Further down, some suggestions about the design of public squares are analysed, as a set of guidelines, organized thematically.

Relationship to street

Squares must have a clear and simple relationship with the streets without significant changes in grade and boundaries between them must be defined. Buildings should be the markers of entry making easier the definition of the access points and in the end, special design attention has to be paid for the catchment area.

Size and shape

As for the size of a square, there are not exact rules but the average dimension for squares in historic cities is 140m x 60m. Also, squares do not have to be too large, so as activities and people become able to be distinct. As for the shape of a square, irregular shapes are recommended, as they provide to the people sense of intrigue and discovery.

Activities

It is obvious that activities in a square attract more people, especially if they are hubs of activities all days of the week and for twenty-four hours a day. For this reason, activities which make people to spend more hours in a square must be encouraged and supported. For example, outdoor dining or seating, are critical components of square activity. As for seating, it should be placed in protected locations with a good microclimate and view out over the space. Seating may be also movable in order for people to choose where they want to sit.

Edge and Centre

Edge zones in the squares are very essential places for people to congregate, sit and observe. Also, as building edges engage squares, they bring activities into the common space.

Spatial Enclosure

Enclosure is very important for public squares as it provides legibility to the space and a feeling of visual coherence. As for the buildings, they have to form a continuous surface, giving the impression of the walls of a room and also background buildings have to form the ground for the figure of the space. The height of the enclosing buildings has to be consistent as it entails the ceiling of the space. Finally, the corners of squares play an important role to the enclosure and they should not be punctured by wide streets.

Climate Moderation

Some strategies for the moderation of adverse climatic and weather conditions have to be implemented, in order for squares to be useful and active. First, to achieve warmer climate in some areas during the winter, a southern exposure for better solar access is needed. Also, some areas should be covered in order for the square to be useful during rainy days. As for the wind, an idea to front it is a localized shelter through hedges and fences. Moreover, in colder days some partially enclosed cafe and restaurant areas, or some heating lamps and warm chairs could make people feel more comfortable to visit the square, eat and have some drinks. On the other hand, on warmer days, some places of retreat from the sun should be provided, and the best way to do this is the implementation of some shading devices such as trees, arcades, awnings and open air pavilions.

Character

The character of a square is very important for the maintenance of its uniqueness and in order to achieve an unambiguous theme, the design of it has to be sophisticated. This design must provide to the square a strong sense of place, as well as a historical continuity. Also, people should feel safe in a square and a square should feel safe too and this could be accomplished by people around the square and in the buildings adjacent to it as they provide surveillance at night and on the weekends. Also, the sensory quality of a square has to be taken into account, especially that of the physical and aural qualities of water.

Access

The access to a square is very important and must be taken into consideration in the design of it. At first, pedestrians must have priority but is important to consider drivers too. Also, a way to make the square accessible to all the people, regardless their incomes and abilities, some public transit options should be provided. And at last, the entrances to parking are good to be located in the square.

Linkages and Network

Public squares should provide a good network to a city. At first, the public fields of a city should provide direct and logical routes and a clear hierarchy of spaces. Also, squares should be served as part of a coherent city-wide place network. There should be clear visual characteristics in the links between spaces.

4 Literature Review

4.1 Factors that affect the city growth

There are many factors that can have a negative influence on a city's or a region's growth or contribute so that a city or a region remains sustainably and developmentally stagnated. According to the functionality of a city or a region, these factors can be different or affect the growth differently. In order to develop a smart city or region, some of these factors have to be studied as well as, some other factors that can contribute to this development.

For example, Tegtmeier (2011) studied the case of what factors may contribute to the outward growth and development of the city of Lincoln, Nebraska. The two main factors she focused on are the Lincoln Public School planners and their placement of schools in the city, and the "American dream" of the people, concentrating at the places people of Lincoln would like to live throughout the city and at their daily habits. In order to understand how the placement of schools could affect the city's growth, Tegtmeier made a personal interview with Cecil Steward, a world expert on sustainable development and sustainable design. Steward states that once Lincoln Public School, which is one of the very first developers to choose land on the outer edges of the city, purchases a lot of land, there is a hope that private developers will follow. If this happens, a new community is going to develop and new suburb is going to be born. On the other hand, Tegtmeier tried to focus on citizens' daily habits in order to understand the main problem that affect city growth, as it is arises from citizens' behaviour. For that reason, she conducted a survey including questionnaires that concern Lincoln citizens. As shown from the results, the "American dream" of the people of Lincoln it is a driving force in the outward growth and development of the city. It can be seen, from the results that the respondents choose to drive their own personal vehicles instead of using public transportation, walking or biking. Also the survey shows that if housing is created on the outer edges of the city where the new schools are being built, then citizens would like to live in these new communities.

Apart from the socio-economic factors that affect the smart growth of a region, environmental factors can also contribute to this. Microclimatic conditions and effects like urban heat island, can mainly affect the environment with a result to prevent the development of a region.

Urban heat island (UHI) is an area that is warmer than its surrounding rural areas and this is mainly due to human activities. For the limitation of this phenomenon, factors that contribute to the existence of it should be studied and analysed and furthermore, more green areas should be imported in it.

Green areas can create a cooling effect that extends to the surrounding areas of an UHI and their existence is of high importance as there are phenomena of climate change, temperature increase, dryness and intensity of heat waves. In order to analyse the thermal performance of such areas, Oliveira et al.(2011), studied the influence in the surrounding atmospheric environment of a densely urbanised area in Lisbon. More specific, they took measurements at 8 different sites in the Garden Teofilo de Braga and surrounding streets (centre of Lisbon), during 6 summer days in 2006 and in 2007. The measurements they took were weather parameters that influence the human energy balance, such as air temperature, relative humidity, wind speed, solar irradiance and infrared radiation. These measurements were recorded in two sites, in the sun and in the shade in order to assess the influence of the solar exposure. The results of the measurements were tested using ANOVA and showed that, the garden was found to be cooler both in the sunny and in the shaded areas, for all the variables and that the existence of trees in the streets did not make a big difference on the thermal environment and this is mainly because of the irrigation in the garden, which allows intense evapotranspiration on hotter and dryer days. As for the influence of the spatial location, measurements showed that air temperature was lower in the garden than the surrounding streets and more clearly in sunny than in shaded conditions. Also they ended up that solar radiation has an important role and it can be reduced due to the shade effect of the plants.

As for the influence of the urban geometry, it was found that Street orientation is an important factor in many aspects of the air temperature, solar exposure and ventilation conditions as there were high differences between the streets with E-W orientation and N-S orientation.

With the above results they concluded that green areas can contribute so that a cooling effect could be created. They also found out that the factors which explain these results are the existence of many shaded areas in the garden, the strong evapotranspiration inside the garden and the intense built-up area.

Many phenomena can contribute to the existence of the UHI effect. As mentioned above, one of these phenomena is the temperature increase. In order to analyse the temperature differences between urban and rural areas and to describe the characteristics of the horizontal and vertical temperature distribution, Bornstein(1968) examined the temperature fields through the lowest 700 m of the atmosphere of the New York city, during the sunrise hours. More specific, between July 1964 and December 1966, he flew an instrumented helicopter in

34 different predetermined mornings, two hours before and two hours after the sunrise. In collaboration with the Sign-X Laboratories of Essex, Conn, they also made similar observations during eight additional mornings in 1966. For the progress of the study initially he observed the physical basis of the urban heat island by finding the energy balances between urban and rural regions. He also studied the previous observations of the urban heat island although the data was imperfect. Furthermore, he proceeded to the collection of his data. First of all, he determined the values of temperature and height of the layers to 0.1C and 15m respectively. These layers were very important for the diffusion of the pollutants and the heights were obtained from the pressure values. He obtained the sky cover during the test hours and the hours before the flight from the Weather Bureau stations and also the shelter level winds from the Scudder´s mesoscale wind analyses. Moreover, he proceeded to find the typical distributions of the temperature by observing the “clear” days without sky cover or high wind speed. The features of the temperature distribution of the two hours before and the two hours after the sunrise were mainly the intense surface inversions at non-urban sites, the lack of surface inversions all around the city, the weak elevated inversion layers of the city and the urban temperature excess which is relevant to height. He examined the frequency of surface and elevated inversions, from the data of the Weather Bureau station at John F. Kennedy Airport, and he ended up to a statistical comparison between urban and rural inversion patterns. Furthermore, he chose the warmest urban sounding through the lowest 150m and a sea level rural sounding in order to detect the height variation between urban and rural temperature differences. Through the results he took from the abovementioned steps he made, he concluded that urban surface temperature inversions were less intense and frequent than those in the non-urban areas. He also concluded that elevated inversion layers that were less intense than the rural surface inversions were in a high frequency. As for the height of the base of the urban elevated inversion layer, it was almost identical to the average level in which the differences between urban and rural temperatures were zero. He also ended up to the fact that the intensity of the heat island was really extended on mornings with high urban elevated inversion layers. From the morning tests, he noticed that an elevated cross-over layer of 200m depth had higher rural than urban temperatures and that the total heat energy was bigger over the city than over the non-urban areas.

In order to study the phenomenon of urban heat island, Lo et al. (1997)decided to apply an airborne high-resolution thermal infrared imagery, in the city of Huntsville in Alabama, USA. They chose this city because is not a typical American city, as two of the main land uses are the Redstone Arsenal and the Marshall Space Flight Centre of NASA, which are related to the

U.S. Government. It has also the campus of the University of Alabama which provides services and industries in order to serve them. Also, the topography of the city is different as it has combination of landforms. However, these all combined with the properties of urban construction materials and the layout of buildings and pavements, have affected the development of the urban heat island which has risen the temperatures by 1 to 2 °C the last 50 years. In order to have a more accurate typification of the thermal responses of the land cover types in the urban environment, Lo et al. (1997)used thermal infrared data from an aircraft which were acquired by the Lockheed Engineering and Science Company as Mission M424. The test was made on 7th of September 1994 which was a clear day with poor cloud cover in the sky, using the Advanced Thermal and Land Applications Sensor (ATLAS) sensor system on board a NASA Stennis Lear Jet. The data were acquired at 10m and 5m resolutions by the 15-channel at around solar noon and then repeated 2-3h after sunset in order to detect the warming and cooling of urban land surfaces. As for the ground data, which contained establishment of GPS ground control points and surface temperatures measurements at different cover types of the city, were collected from the overflights. They also used meteorological station data from the Army at Redstone Arsenal and at Marshall Space Flight Centre. The atmospheric correction data was obtained from the Portable Ground Atmospheric Measurement System (PGAMS). From the six thermal infrared bands, they collected data for the long-wave radiation which emitted by the natural and artificial surfaces of the city. After the collection of all these data, they proceeded to the analysis by studying the characteristics of the thermal signatures of each land cover type of the city. Initially, they created codes for all the cover types of the city and then they moved on the manual delimitation of each land cover type from the daytime and night time images into polygons. Moreover, they extracted the irradiance values and standard deviations of these polygons. After this, they computed the Normalized Difference Vegetation Index (NDVI) through a formula, as it is a good indicator of surface radiant temperature. After the analysis, they proceeded in two types of results. The first type was about the contrasts in irradiance between day and night. All the types of cover land in the city of Huntsville were cooler at night than during the day. The standard deviations in the irradiance values at night were small for the land cover types of water, vegetation and agriculture than for the land cover types of commercial, services and industrial. The second type of results was about the relations between NDVI and irradiance of land cover types. They found out that NDVI values had negative correlation with the irradiance of all the land use types during day and night, except of water, as it was correlated positively with the irradiance during the day. In some cases the irradiance values of services uses exhibited important correlation with NDVI values during day and night and this meant the existence of green environment for the location of offices in the city. The significant relationship between NDVI and irradiance in some types of cover land meant that surface temperatures could be dropped, due to the higher vegetation amount that characterized them. Moreover, by obtaining the results, they proceeded to the development of a spatial model of an UHI by using the GIS. They digitized and converted a land use/cover map of Huntsville which was obtained from a visual interpretation of the CIR aerial photographs. They also converted the map into maps of irradiance both for day and night using the assign attribute function of the GIS. They used the average thermal signatures of the 10 board classes of land use/cover of the city. From those maps and the differences between day and night, they saw that the layout of land use/cover for the city drove straight to the development of UHI as there were differences in temperature between the city and its periphery and also among agricultural, vegetation and commercial uses all around the city. These differences in temperature also favoured the development of many UHI throughout the city which was enhanced by the topography of it.

Similarly, Georgi and Dimitriou (2010) proceeded to a deeper study of the environmental effects that a city or a region can face. More specific, they studied the case of how vegetation affects the improvement of microclimatic conditions in urban areas, mainly in the city of Chania in Crete. They examined the bioclimatic role of green areas in urban sites as they affect the thermal comfort of residents, and studied the cross-correlation of factors that participate in this process. In order to achieve this, they have analysed the effect of vegetation with respect to evapotranspiration, and have recorded the existing vegetation of Chania city and the relationship with the geomorphologic and urban characteristics of the city. At first, they identified the urban microclimate parameters which were tree species, air temperature, relative humidity, wind speed, ETo, ETc for each tree species, DI (Discomfort Index) and the percentage reduction of the temperature and Discomfort Index in the shade of each tree compared with the plant-free micro-environments where the measurements were made. Furthermore, they determined the particular values associated with each parameter. The recording of these values was made in a sixteen day period in June, which was enough to monitor the changes of the climatic factors when there is a significant contribution to coolness from green spaces to coolness. The next step was the undertaking of measurements at selected study area, where they measured the shade afforded by some tree species. These measurements and the analysis of experimental data, showed the contribution of green spaces, via evapotranspiration, to the improvement of the urban microclimate. At the end, they

analysed the statistic methods in order to evaluate the importance of the results. They used one-way analysis of variance to examine the differences between temperature, relative humidity and DI in the different micro-environments. The results showed that the values of temperature and DI measured in the shade of plants are enough lower than that of sunlit pavements. Also, the values of temperature or DI and the micro-environments of planted and plant-free areas are the same but there is a difference in the values that are observed for the different species of tree. The results also showed that the values of relative humidity are lower in areas with no planting such as the regions of sunlit and shaded pavement. They realized that the environment of a shaded pavement always has higher values of temperature and DI.
Through these results, they concluded that evapotranspiration of plants influences their micro-environment by increasing the humidity of the dry summer atmosphere and also that, the conditions of planted regions are more pleasant and thermal comfortable. They also ended up with the fact that plants with a high level of evapotranspiration have the most thermal comfortable micro-environment as well as the lowest DI.

4.2 The environmental impact of cities

Due to the inexorable growth of cities, there is a great environmental impact on them. Again, depending on the factors affecting the development of cities, relevant impacts are created.
In order to understand the environmental impact in the city of Sydney, Newman (2006) focused on three approaches, the population impact, the Ecological Footprint and the sustainability assessment. To achieve this, he set some sustainability criteria for Sydney's development and then he assessed if they satisfy the city. From this assessment he is able to identify the main factors that environmentally affect the city of Sydney. The main purpose of his study is to reduce the city's Ecological Footprint and enhance the environment as well as the quality of life within the capacity constraints of the city. The eight criteria he set are the following, natural resources, environmental protection, places of high quality, housing diversity, jobs/economy, sustainable accessibility, quality and equity in services and governance. The first application of these criteria was in 2004, when the government wanted to assess the release of some new land on the urban fringe in order to provide homes for 200,000 households. In the assessment of these criteria, the development of some of them was strong, such as for natural resources, environment and governance. For some other criteria the

development was not as strong, such as for jobs/economy and sustainable accessibility as there was no provision for a link to the city's rail network in the plan.

4.3 Designing sustainable cities – cities' reconstruction

There is need of urban design of cities, in order to create a comfortable and healthy climate where citizens can live in it and where the thermal conditions will encourage them to use public spaces. In order to do that, factors that affect the growth of such a city, must be diminished and faced. As mentioned above, phenomena like urban heat island, microclimatic conditions, socio-economic factors etc., do not allow a smart and proper growth for a city. There are two ways of confrontation, either to create a new city from the beginning, or to change the city radically.

One of the most important factors that need to be faced is the urban heat island effect as it aggravates heat stresses and lead to effects that will be more severe in urban environments. For this reason, Kleerekoper et al. (2012), explored these effects and tried to provide tools for urban design and strategies for implementation for two neighbourhoods of the Netherlands. The design principles for Dutch cities are described in four categories: vegetation, water, built form and material so they should focus on these. They studied the cases of Ondiep and Transvaal neighbourhoods. In both cases, they separated the design based on three approaches, building plan, green plan and water plan and set some changes that had to be made. In the case of Ondiep, there are only few green spaces so the amount of dwellings needed to be decreased. As for the building plan, they suggested that in order to create more green space, the dwellings along the North side of the street had to be shifted backwards. So, new dwellings with four building layers had to be constructed. These changes leaded to the change of the height to width ratio which the more low it is, the more improves natural ventilation. They also suggested that in the white neighbourhood a recent developed white coating should be applied on the roofs as the coating reflects sunlight and keeps its high albedo because it repels dirt. As for the green plan of the Ondiep, they suggested that a six-storey high building with a green facade should form the entrance of the neighbourhood and the streets that form the car and bus route should cut through the whole neighbourhood. Also, a water storage system should be created so as to supply trees with enough water. There was a green zone along the river Vecht which needed an extension in order to improve the microclimate of the neighbourhood and offer more recreational space and stimulate bicycle

use. As for the water plan of the neighbourhood, they suggested the implementation of water applications to supply trees in order to enrich their cooling capacity and to cool the outdoor environment. They also suggested the reuse of water for household activities like toilet flushing and that the rainwater from roofs and pavement streams should be collected in shallow canals. In the case of the Transvaal neighbourhood, Kleerekoper et al. (2012) had to face a bigger problem, as it had a higher density that causes pressure on public space.
For the building plan, the neighbourhood had already started the rebuilding of some houses and the demolishing of some others, as well as the reconstruction of the main square. As for the square, they suggested to fill the large paved open space with water and to add water jets that switch on when it is a warm day. For the green plan, they decided to create a green roof landscape, as there was no space for green areas but more than 95% of the buildings with flat roofs. Except of this solution, they suggested to transform some alleys through building blocks into an oasis of peace. As for the water plan, in order to create space for seasonal water storage, they studied the case of demolishing a part of the neighbourhood and build a new one. Also, the same as Ondiep neighbourhood, they suggested the reuse of water for household activities like toilet flushing and that the rainwater from roofs and pavement streams should be collected in shallow canals.

As mentioned above, the heat island effect is a huge problem to the proper urban growth of cities and regions. In order to mitigate it, Alexandri (2005) studied the thermal effect of green roofs and walls on the built environment and whether they could be used in existing cities and more specific, in Athens, Mumbai and Riyadh. After studying where, when and why roofs and walls were covered with vegetation, she developed the one-dimension model. With this model she was able to compare concrete and green roofs for the above cities (three different climatic types). She found out that as the air is dry and roofs accept solar radiation, is more beneficial to cover the roof with vegetation. She also made a comparison between white roofs with lowered reflectivity and green roofs. She investigated that almost in the whole day, green roofs have lower temperatures than the white ones and ended up that it is more efficient to cover roofs with vegetation than with white paint. Furthermore, she proceeded to create a two-dimensional model in order to describe the microclimatic characteristics of an urban canyon and the effect of green roofs in it. Through the new model, she found out that the microclimate around the buildings can be importantly cooled in summer days if plants are placed on the roofs and the walls of them. Actually, plants decrease the air temperature through evapotranspiration. She also examined nine climatic types and concluded that, as the climate is hot and dry, it can be easier to create an oasis in the built environment through vegetation. In all climates, there are bigger temperature decreases by covering with green both the roofs and the walls, than only the walls.

In the continuing evolution of cities, essential role to the sustainable design of them, will always plays the design and construction of the urban public space. As the density of cities increases, quantity and quality of public space must do the same. Citizens can experience vibrant urban life in community, mainly through public squares. In order to show that public squares can contribute to the creation of catalysts for new development in a downtown and to encourage a renewed pedestrian experience for a city, Elliott and Arch (2013), studied the case of the downtown of Richmond, VA, a typical mid-sized city. By proposing the design and build of a new public square, they were willing to increase street life and resident density, as it is very vital for the downtown Richmond. This proposal could be used so as other public spaces in American cities which have suffered from depopulation and decentralization in the 20th century, could revive their downtowns.

Firstly, in order to understand the general idea about urban spaces, they studied three theories which presented important concepts for the design of public squares. The first theory, the figure ground one, analyses the importance of the spaces between buildings as formed by the surrounding and enclosing urban fabric. Linkage theory analyses the establishment of a system of connections between spaces in a city and finally place theory involves the character and history of a space and the way in which people experience it.

Important enough was also the study of the principles which had to be considered against the real circumstances of the sites in Richmond in order to be applied in designs for new public squares. After taking into consideration these principles, Elliott and Arch, proceeded to an urban analysis, showing through drawings, maps and figures some aspects of the city that had to be considered. They mainly concentrated on the figure ground, the streets and highways, the central grid, the railroads, the public space, the existing city fabric, the population and the neighbourhoods. This analysis took place in order to select the site of the public square and the intervention sites and after the selection, they categorized the public square into residential square, civic square, and market square, through the investigation of square typologies. For the residential square they proposed a liner to redefine the edge, for the civic square site they suggested the reconfiguration and integration of a historic building into a new building. As for the market square they proposed the utilization of an existing building as an entire edge to a new space.

Similarly to public squares, pedestrian realm is a public space which is created as an antidote to the excessive urban density and has to be protected as the survival of such spaces are threatened by future development. For this reason, Martin (2013) developed strategies in order to implement an urban pedestrian network in advance of development, in the ByWard Market area of Ottawa, Canada. He made these strategies flexible enough because he wanted other cities, which face similar development problems, to be able to apply them. By examining examples of factors that contribute to an unsuccessful and vital pubic space, he ended up to some principles that had to take into consideration so as the design of the pedestrian network could be applicable. In order to protect and designate spaces where densification will occur, he suggested as the government uses an implementation mechanism to define spaces for public use, through private property, so as to achieve the integration of people spaces throughout densification. More specific, he proposed the incorporation of the sections of the network through a phased system which aims to the visual indication of pathways, the occupation of the site with seating and planters and the building of more permanent features. Furthermore, Martin proceeded to the suggestions of the implementation ways that could be applied in the Market. He proposed that the implementation of pedestrian pathways would be done in three separated phases which were flexible so that they might change depending on the need and availability of the sites within the greater network. These three phases would allow a more natural integration into the city and the everyday lives of people who visit the Market. The first phase is called “path indication” which is a visual identification of network path spaces, the second one is called “occupying the site” where elements such as seating, planters and popup shops are being introduced. The third phase is called “infill” where there is a construction of buildings along the designated path spaces and the introduction of more permanent features. Also, Martin suggested the implementation of eight different potential segments for the pedestrian network which could be concurrent or consecutive depending on the opportunities and forces at play. At the end of his survey and after studying and analysing the implementation of the pedestrian networks, he made a list of guidelines in order to be used by property owners and enforced by municipalities to ensure the quality, safety and accessibility of spaces associated with pedestrian networks. These guidelines are about the dimensions, configuration, elevation, obstruction, seating, trees and plants, lighting, pavilions, signage, additional amenities and operation and building uses at ground level.

5 Methodology

5.1 Purpose

Through this thesis an analysis of the phenomenon of urban heat island effect is performed. The purpose of this project is to observe the temperatures of specific areas of Limassol during the summer months, from 1990 until today (2015). The observation of the temperature fluctuations in different areas of Limassol is primarily done in order to evidence the effect of this phenomenon, taking into account the passage of time and the development of those areas, linked with other factors that may influence this effect. The processes for the achievement of this objective are made by taking thermal satellite images through Earth Explorer online program of USGS Glovis and elaborating them using Remote Sensing through the ERDAS IMAGINE CLASSIC INTERFACE software for determination of temperature variations, and for better analysis and subsequent comparison of results through graphs in order to have a comprehensive point of view of the impact of the phenomenon in the Limassol area.

5.2 Comprehensive description of methodology

In order to collect the correct measurements for the observation of the temperature fluctuations, which are due to the urban heat island effect, over the last 15 years (1990-2015), a methodology had to be done and its specific steps are the followed below.

- Data collection. Landsat7 images were collected from the Landsat7 ETM+ SLC-off and Landsat7 ETM+ SLC-on data. Landsat Thematic Mapper (TM) images were collected from Landsat4 and Landsat5 satellites data. Images were also collected from the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) of the satellite Landsat8.
- Elaboration of the thermal channels images with ERDASIMAGINE CLASSIC INTERFACE software, in order to convert the radiation into temperature so as, the appropriate observations and comparisons could be made.
- Creation of graphs through the Excel program for visualization of the results, so as the fluctuations in temperatures, in the different study areas, to be more noticeable.
- Comparison and evaluation of the results obtained from elaborated satellite images and graphs.

5.3 Study case

For this thesis, the studied area was the city centre and the province of Limassol as shown on the picture below. Initially, the study focused on the city centre and then year by year started to spread to the suburbs as the urban heat island effect started to affect the city.

Limassol is a city on the southern coast of Cyprus. It's the second largest urban area in Cyprus, with an urban population of about 180,000 and its municipality is the most populous in the country with 101,000 inhabitants.

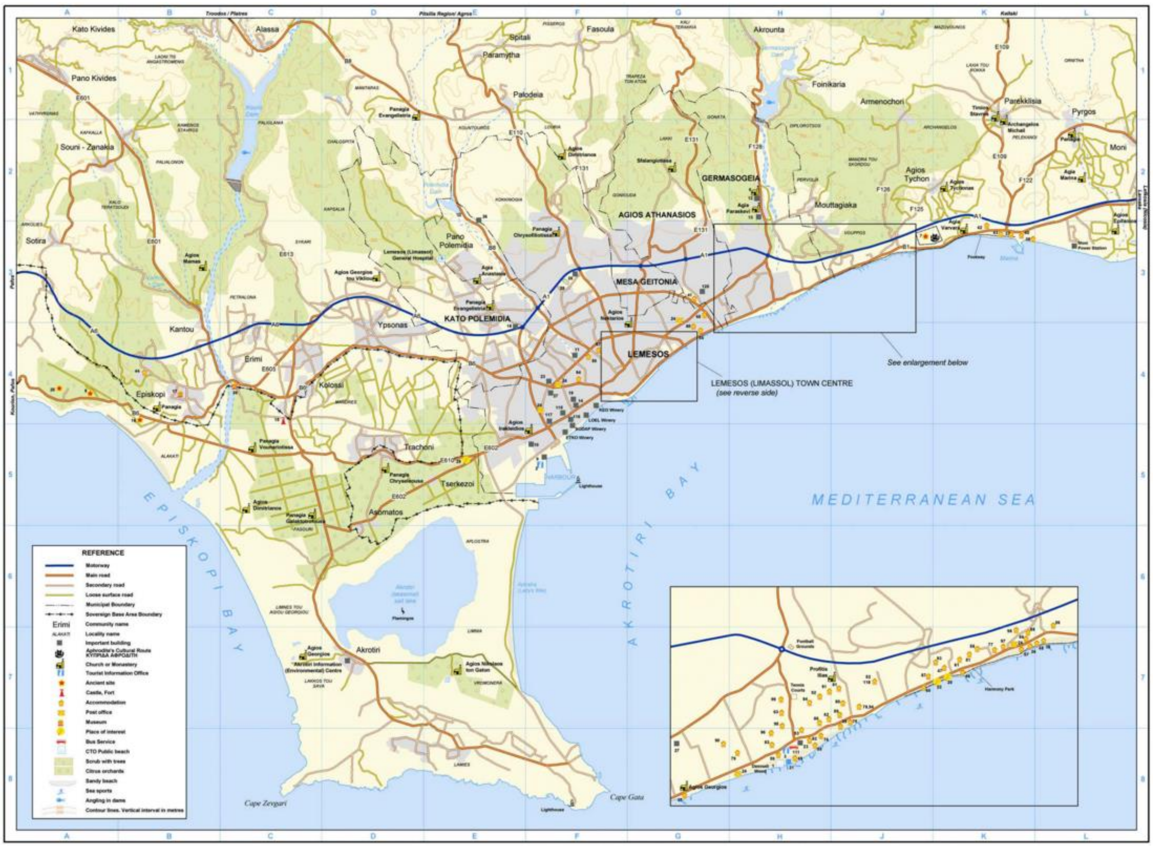


Figure 4: Study area
(Source: "http://www.mapsofcyprus.co.uk/limassol.php," n.d.)

Historical review

The city of Limassol, a few years before the independence in 1960, was limited around the area south of Makarios III Avenue. This explains the importance of this central area of the conurbation that acts as a service centre of the whole province, including simultaneously all components of an entire city. The development expanded rapidly in the suburbs after the independence. Due to the Turkish invasion of 1974 and the significant concentration number of displaced persons in the area of Limassol, the city had a further expansion towards the suburbs. There were situated several government housing settlements and self-help. The urban structure of the area generally follows the "radial" standard. Starting from the area of the harbour, the castle and its immediate surroundings, the city extended initially east along the beach and in the immediate hinterland to Anexartisias Street. This perpendicular to the beach road, that directly connects the centre with the suburbs, was the main city axis extending to the mainland. The areas between the radial roads were developed with some delay while some sections are still empty until today. The further expansion of the city east, in the form of coastal tourism development, intensified only in recent years, after 1974. The city of Limassol was not properly prepared for the sharp and sudden increase in population and in the total urban activities and functions. The above, combined with the rise of tourism, development and inertia observed in infrastructure, created serious organization urban problems and environmental stress. The coastal town of Limassol is a potential attraction of the province and the most important urban center in the southern coast of Cyprus. Limassol is sited in a triangular valley ending in a beautiful bay and is comfortably connected with other cities or areas of Cyprus with modern intercity highways (Town Planning and Housing, 2003).

The climate

The climate of Limassol is generally temperate to warm, with minimum temperature of 7 °C in winter (January and February) and average maximum 34 °C in summer (July and August). The proximity of the sea contributes to the existence of higher temperature in winter and lower in summer than those in Nicosia. The average annual rainfall (45.7 cm) is higher than the average rainfall nationwide. In the area the westerly and southwesterly winds are dominants, which in the summer months can be quite strong (Town Planning and Housing, 2003).

5.4 Available Data

For the observation of the phenomenon of urban heat island, initially, satellite images were taken from satellites Landsat7, Landsat8, Landsat4 and Landsat5 through the Earth Explorer online program of USGS Glovis.

In particular, the Landsat7satelliteimages were collected from the Landsat7 ETM+ SLC-off and Landsat7 ETM+ SLC-on data. Landsat 7 ETM+ SLC-off data refers to all Landsat 7 images collected after May 31, 2003, when the Scan Line Corrector (SLC) failed. The

Landsat Enhanced Thematic Mapper Plus (ETM+) sensor onboard the Landsat 7 satellite has acquired images of the Earth nearly continuously since July 1999, with a 16-day repeat cycle. These products have data gaps, but are still useful and maintain the same radiometric and geometric corrections as data collected prior to the SLC failure. Although the scenes have only 78 percent of their pixels, these data are still geometrically and radiometrically accurate enough, in comparison with all civilian satellite data in the world. Landsat 7 ETM+ images also consist of eight spectral bands with a spatial resolution of 30 meters for bands 1 to 7. The panchromatic band 8 has a resolution of 15 meters. All bands can collect one of two gain settings (high or low) for increased radiometric sensitivity and dynamic range, while Band 6 collects both high and low gain for all scenes ("https://lta.cr.usgs.gov/LETMP," n.d.).

The Landsat 8 satellite images were collected from the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) of the satellite Landsat8. The OLI sensor includes refined heritage bands, along with three new bands, a deep blue band for coastal/aerosol studies, a shortwave infrared band for cirrus detection. The TIRS provides two thermal bands. These sensors both provide improved signal-to-noise (SNR) radiometric performance quantized over a 12-bit dynamic range. Improved signal to noise performance enable better characterization of land cover state and condition. Products are delivered as 16-bit images. Landsat 8 images have a large file size, at approximately 1 GB compressed. Also, the Landsat 8 satellite images the entire Earth every 16 days in an 8-day offset from Landsat 7 ("http://landsat.usgs.gov/landsat8.php," n.d.).

Landsat Thematic Mapper (TM) images were collected from Landsat4 and Landsat5 satellites data. These data files consist of seven spectral bands. The resolution is 30 meters for bands 1 to 7. Thermal infrared band 6 was collected at 120 meters, but was resampled to 30 meters. The Landsat Thematic Mapper (TM) sensor was carried on board Landsats 4 and 5 from July 1982 to May 2012 with a 16-day repeat cycle, referenced to the Worldwide Reference System-2 ("https://lta.cr.usgs.gov/TM," n.d.).

Data were also taken from the Town Planning and Housing department of Cyprus. The Limassol land uses maps of 2003, 2006 and 2011 were used. From these maps information about land uses changes in the region which are correlated with the passage of time and with the urban heat island effect, were obtained. More specifically, through these maps the changes that have been made in the city center were observed, as well as the changes in green areas, the additions of new buildings and the creation of new habitation areas etc.

5.5 Software

For the processing of the images taken from satellites, remote sensing through the ERDAS IMAGINE CLASSIC INTERFACE software was done, whose analytical processing is described in the next chapter.

To visualize the results exported after the processing of the satellite images, the Excel program was used to export diagrams which show the fluctuation of temperatures for each year and the holistic influence of urban heat island effect through all these years.

6 Procedure of obtaining and elaborating the satellite images

For the proper processing of the images which were obtained from satellites Landsat4, Landsat5, Landsat7 and Landsat8, a series of processes was followed, which is detailed below.

Firstly, images were taken from satellites through the Earth Explorer online program of USGS Glovis. Then they were processed by the ERDAS IMAGINE CLASSIC INTERFACE software and results were exported, in order to observe the differences in temperature in different areas of Limassol from 1998 to 2015 which were caused by the urban heat island effect.

6.1 Images acquisition procedure

Initially, after survey, the Earth Explorer online software of USGS Glovis, was seen as the ideal for the reception of satellite images that were needed for the study of the phenomenon of urban heat island in Cyprus.

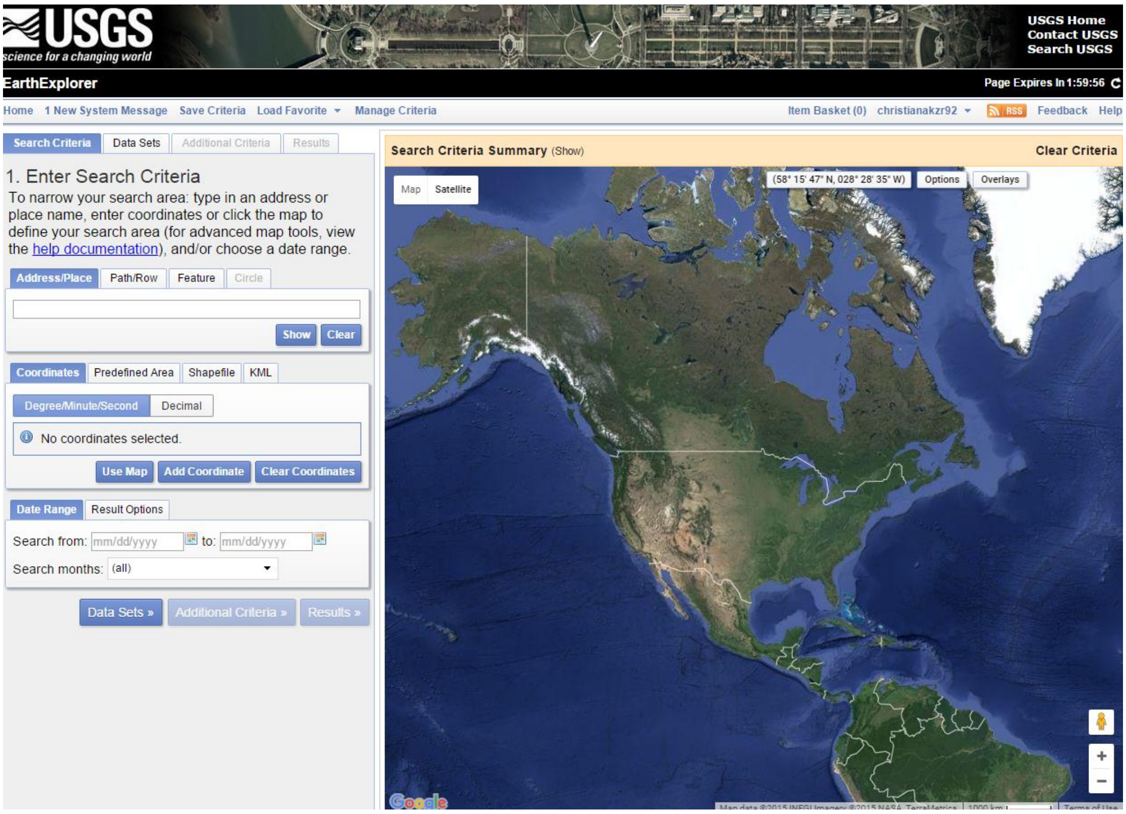


Figure 5: The Earth Explorer online software of USGS Glovis

After this, the selection of the study area was followed, which was mainly focused in the area of Limassol and it was selected using the map, as shown in Figure below.

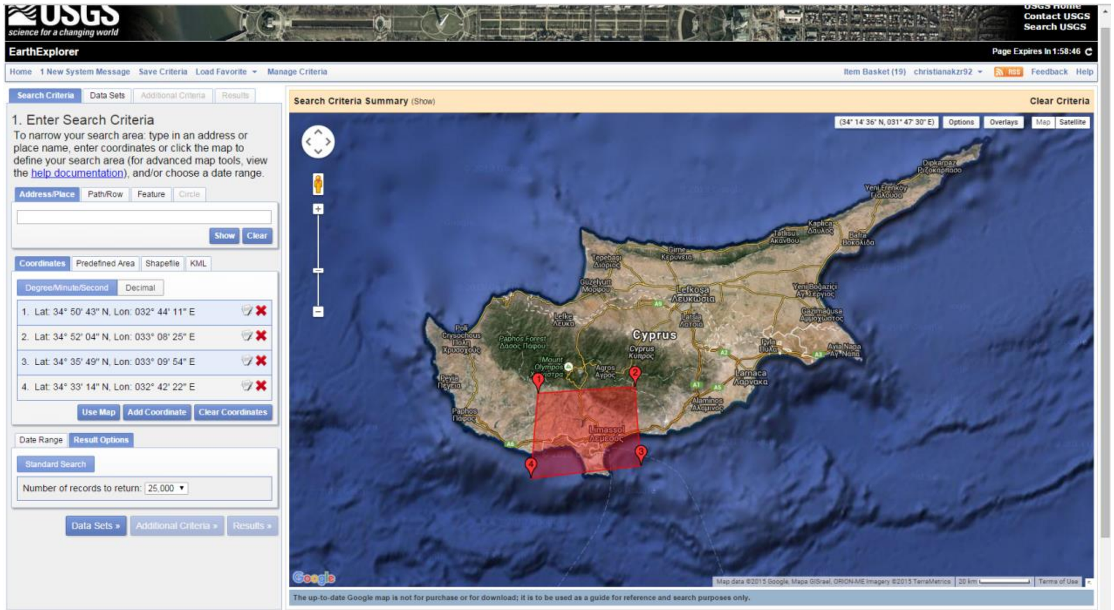


Figure 6: Selection of study area

Furthermore, the months to be selected for better observation of the urban heat island effect were set. Therefore the warmer months for Cyprus which are considered to be the months June, July, August and September were selected. The time limits were also set, which were from January 1st, 1990 until November 1st, 2015.

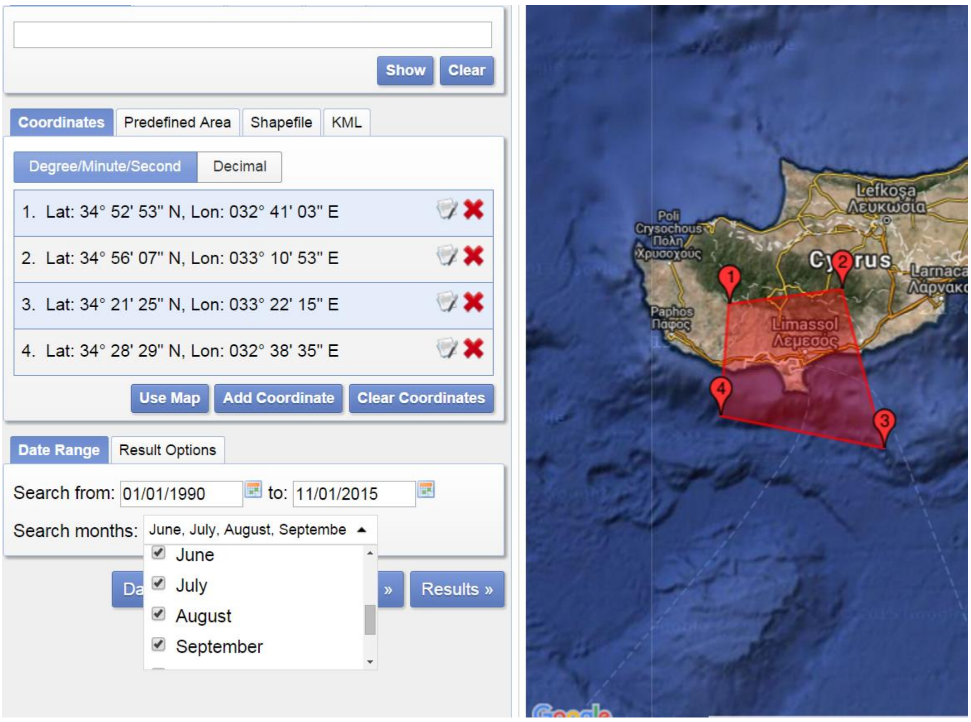


Figure 7: Date range and months selection

Then, a survey of the satellite images to Earth Explorer online program was conducted, in order to conclude which satellites to be selected that could give the most appropriate images. From the Landsat Archive the satellites L4-5 TM, L8 OLI / TIRS, L7 ETM + SLC-off (2003-present) and L7 ETM + SLC-on (1999-2003) were selected, as shown in the Figure below.

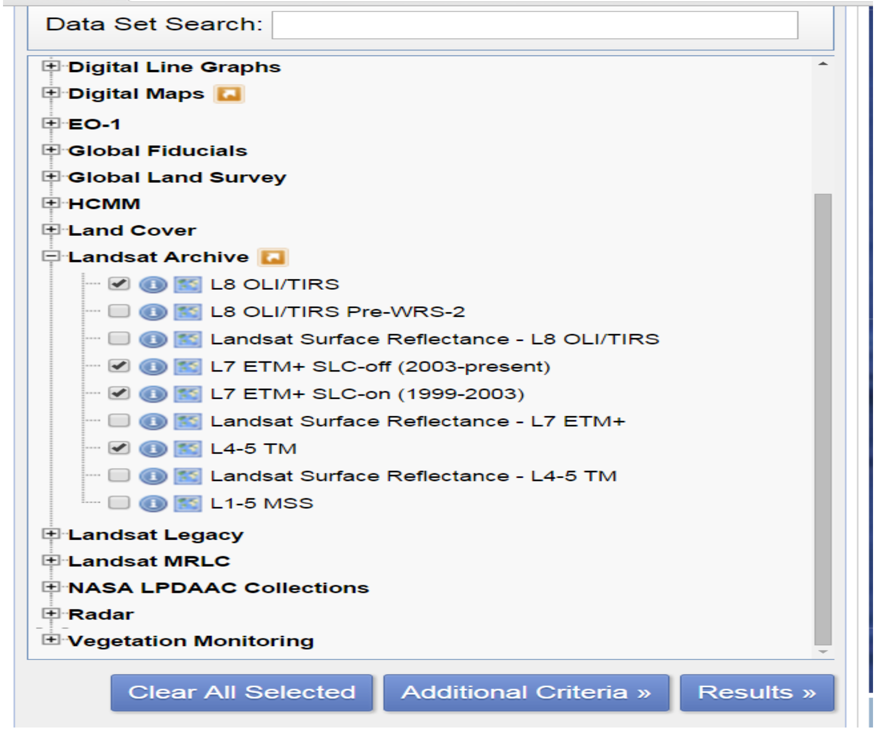


Figure 8: Selection of Landsat satellites

Also, in order to have best quality of each image the cloud cover was chose to be less than 10% for each data set.

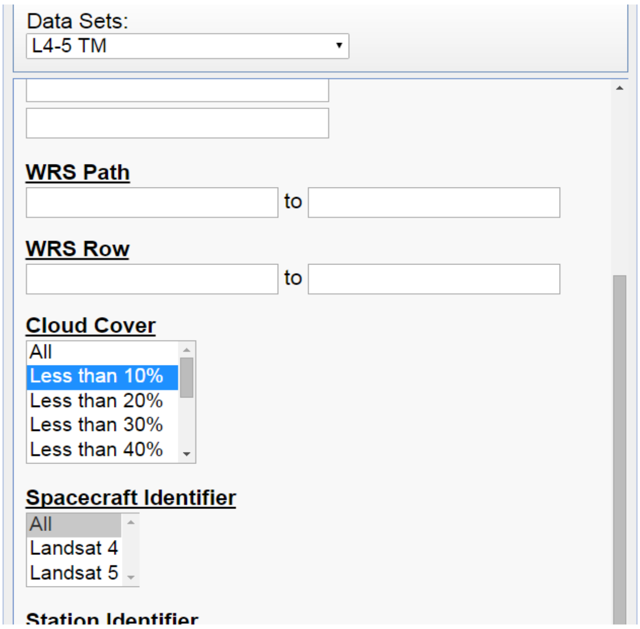


Figure 9: Selection of cloud cover

After some research, a total of 19 satellite images from 1990 to 2015 were received. From L7 ETM + SLC-on (1999-2003) a total of 3 images were received, which are from August 7th 2000, August 26th 2001 and August 13th 2002. From L7 ETM + SLC-off (2003-present) a total of 4 images was received, which are from September 19th 2004, June 18th 2005, July 28th 2008 and August 22nd2012. Through the L8 OLI / TIRS received a total of 3 images was received, which are from July 2nd 2013, June 19th 2014 and August 25th 2015. Finally, the L4-5 TM received a total of 9 images which are from August 4th 1990, June 7th 1998, August 13th 1999, July 23rd2003, September 17th 2006, September 4th 2007, July 23rd 2009, August 27th 2010 and July 13th 2011.

6.2 Elaboration of images

In order to observe the differences in temperature in urban and rural areas of Limassol, the images which were taken from the satellites, were also elaborated and gave results. In this procedure, some steps were followed in order to convert the images into images which show temperature. The steps were followed are shown below.

A. Layer stack

Initially the layer stack process is done so as to create a single image with all the bands in order to facilitate the simultaneous observation of temperature variations in one of the images and the location of the respective temperature in the other image with the layer stack modulation. The process of layer stack is shown in the Figure 10 and Figure 11 below.

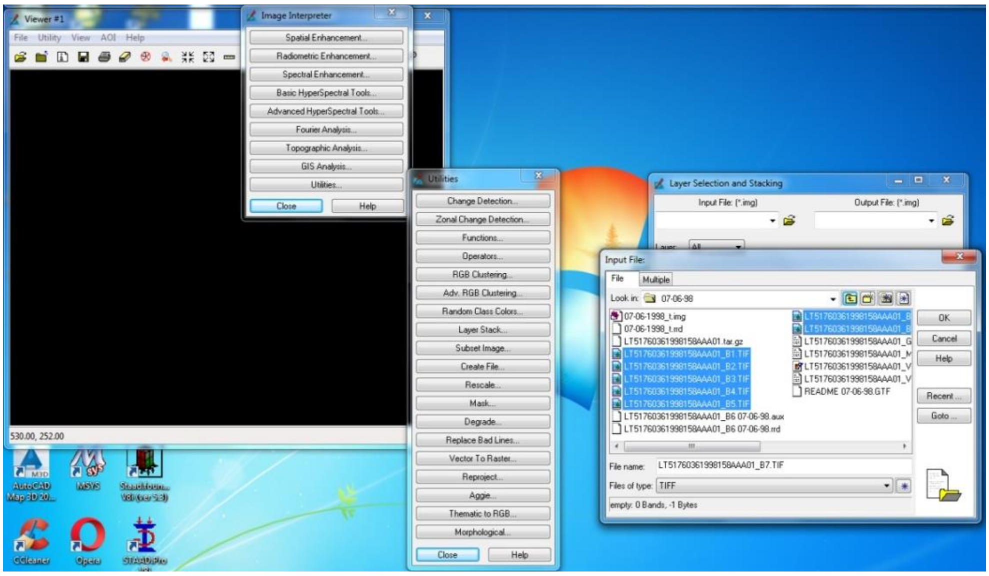


Figure 10: Layer stack process

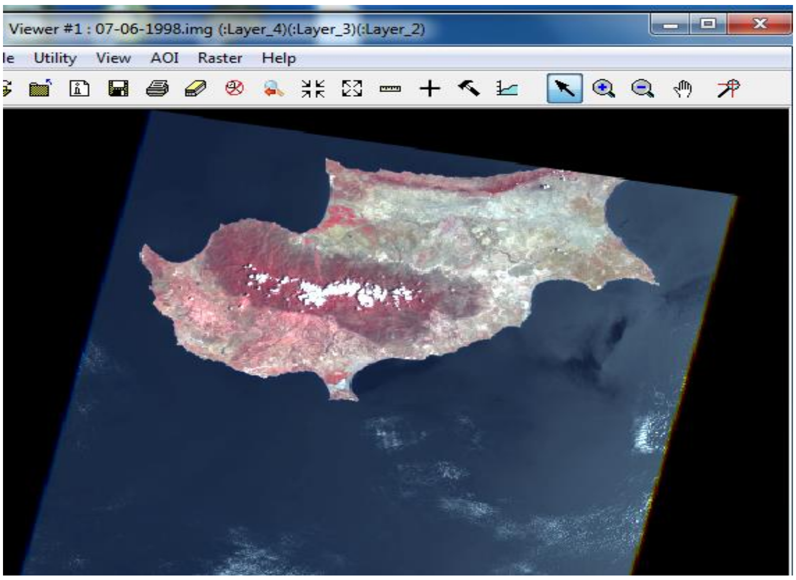


Figure 11: Layer stack process

B. Change of band combination

Then the band combination of the images changes into 3-2-1 due to the fact that this combination is as close to true color that a Landsat ETM image can get. This step is shown in the Figure 12 below.

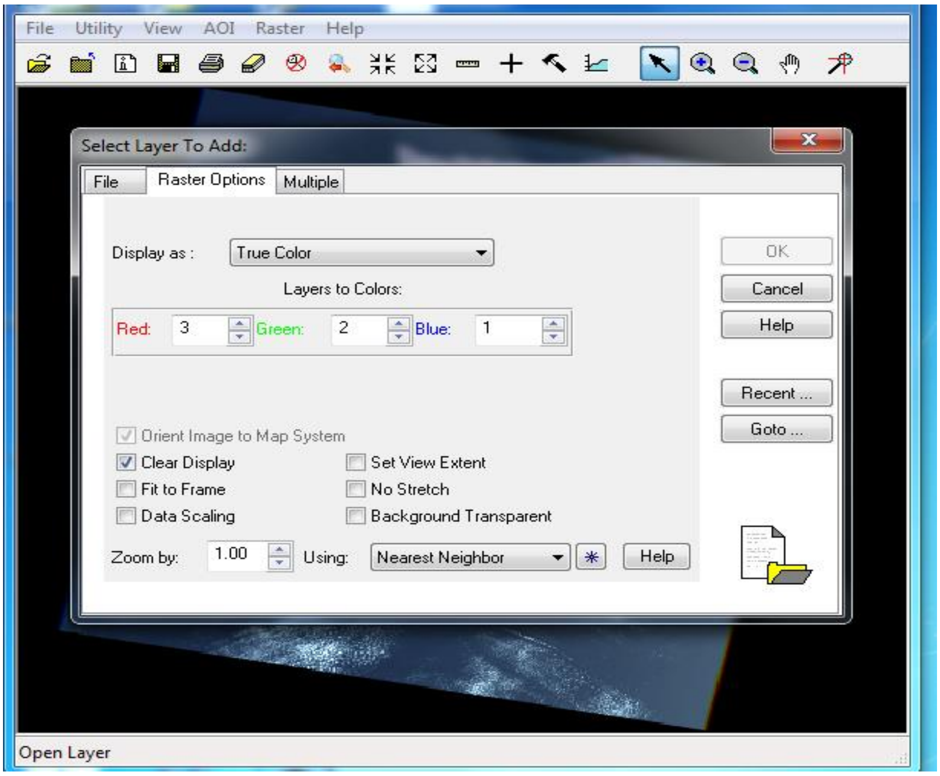


Figure 12: Band combination

C. Converting thermal bands to temperature

The converting procedure for Landsat TM and ETM+ differs from the one of Landsat 8 OLI/TIRS. But for both of them the first step is to convert DNs to radiance and the second one to convert radiance to temperature (Celsius). In order to convert DNs to temperature, the distance between the sun and earth in astronomical units, the day of the year (Julian date), and solar zenith angle have to be known. This information can be found in the metadata file of each image as shown below in the Figure 13.

```
    METADATA_FILE_NAME = "LT51760361990216XXX03_MTL.txt"
    CPF_NAME = "L5CPF19900701_19900930.09"
  END_GROUP = PRODUCT_METADATA
  GROUP = IMAGE_ATTRIBUTES
    CLOUD_COVER = 0.00
    IMAGE_QUALITY = 9
    SUN_AZIMUTH = 112.23366028
    SUN_ELEVATION = 56.02087087
    GROUND_CONTROL_POINTS_MODEL = 158
    GEOMETRIC_RMSE_MODEL = 5.391
    GEOMETRIC_RMSE_MODEL_Y = 3.437
    GEOMETRIC_RMSE_MODEL_X = 4.153
    GROUND_CONTROL_POINTS_VERIFY = 598
    GEOMETRIC_RMSE_VERIFY = 0.213
    GEOMETRIC_RMSE_VERIFY_QUAD_UL = 0.214
    GEOMETRIC_RMSE_VERIFY_QUAD_UR = 0.213
    GEOMETRIC_RMSE_VERIFY_QUAD_LL = 0.207
    GEOMETRIC_RMSE_VERIFY_QUAD_LR = 0.000
  END_GROUP = IMAGE_ATTRIBUTES
  GROUP = MIN_MAX_RADIANCE
    RADIANCE_MAXIMUM_BAND_1 = 169.000
    RADIANCE_MINIMUM_BAND_1 = -1.520
    RADIANCE_MAXIMUM_BAND_2 = 333.000
    RADIANCE_MINIMUM_BAND_2 = -2.840
    RADIANCE_MAXIMUM_BAND_3 = 264.000
    RADIANCE_MINIMUM_BAND_3 = -1.170
    RADIANCE_MAXIMUM_BAND_4 = 221.000
```

Figure 13: Information from metadata file

a) For Landsat TM and ETM+

The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors acquire temperature data and store this information as a digital number (DN) with a range between 0 and 255. The conversion of these DNs to Temperature may be possible and easy with the application of a two-step process. The first step is to convert the DNs to radiance values using the bias and gain values and the second step is the conversion of the radiance data to temperature using a formula in which the atmospheric correction is not included.

i) Step 1: Convert DN to Radiance

The used formula to convert DNs to radiance is the Gain and Bias (or Offset), where the values of gain and offset can be found in the metadata file of each image as shown in the Figure 14 below.

```
END_GROUP = IMAGE_ATTRIBUTES
GROUP = MIN_MAX_RADIANCE
  RADIANCE_MAXIMUM_BAND_1 = 169.000
  RADIANCE_MINIMUM_BAND_1 = -1.520
  RADIANCE_MAXIMUM_BAND_2 = 333.000
  RADIANCE_MINIMUM_BAND_2 = -2.840
  RADIANCE_MAXIMUM_BAND_3 = 264.000
  RADIANCE_MINIMUM_BAND_3 = -1.170
  RADIANCE_MAXIMUM_BAND_4 = 221.000
  RADIANCE_MINIMUM_BAND_4 = -1.510
  RADIANCE_MAXIMUM_BAND_5 = 30.200
  RADIANCE_MINIMUM_BAND_5 = -0.370
  RADIANCE_MAXIMUM_BAND_6 = 15.303
  RADIANCE_MINIMUM_BAND_6 = 1.238
  RADIANCE_MAXIMUM_BAND_7 = 16.500
  RADIANCE_MINIMUM_BAND_7 = -0.150
END_GROUP = MIN_MAX_RADIANCE
```

Figure 14: Values of gain and offset from metadata file

Here it has to be mentioned that for Landsat 4-5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) the band which is appropriate for the study is the Band 6 –Thermal Infrared which is useful for thermal mapping and estimated soil moisture as it shown below in Figure 15.

Landsat 4-5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+)

Band	Wavelength	Useful for mapping
Band 1 - blue	0.45 - 0.52	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 2 - green	0.52 - 0.60	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 3 - red	0.63 - 0.69	Discriminates vegetation slopes
Band 4 - Near Infrared	0.77 - 0.90	Emphasizes biomass content and shorelines
Band 5 - Short-wave Infrared	1.55 - 1.75	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 6 - Thermal Infrared	10.40 - 12.50	Thermal mapping and estimated soil moisture
Band 7 - Short-wave Infrared	2.09 - 2.35	Hydrothermally altered rocks associated with mineral deposits
Band 8 - Panchromatic (Landsat 7 only)	0.52 - 0.90	15 meter resolution, sharper image definition

Figure 15: Selection of thermal band for Landsat 4-5 and Landsat 7
(Source: "http://landsat.usgs.gov/best_spectral_bands_to_use.php," n.d.)

The formula to convert DN to radiance using gain and bias values is:

$$L = Gain * DN + Offset \qquad \text{Equation 1}$$

Where:

L is the cell value as radiance

DN is the cell value digital number

Gain is the gain value for a specific band (Gain= (Lmax - Lmin)/255)

Offset is the offset value for a specific band (Offset=Lmin)

The DNs to radiance conversion formula was applied in ERDAS IMAGINE software by using the Modeler, as shown in the Figure 16 and Figure17 below.

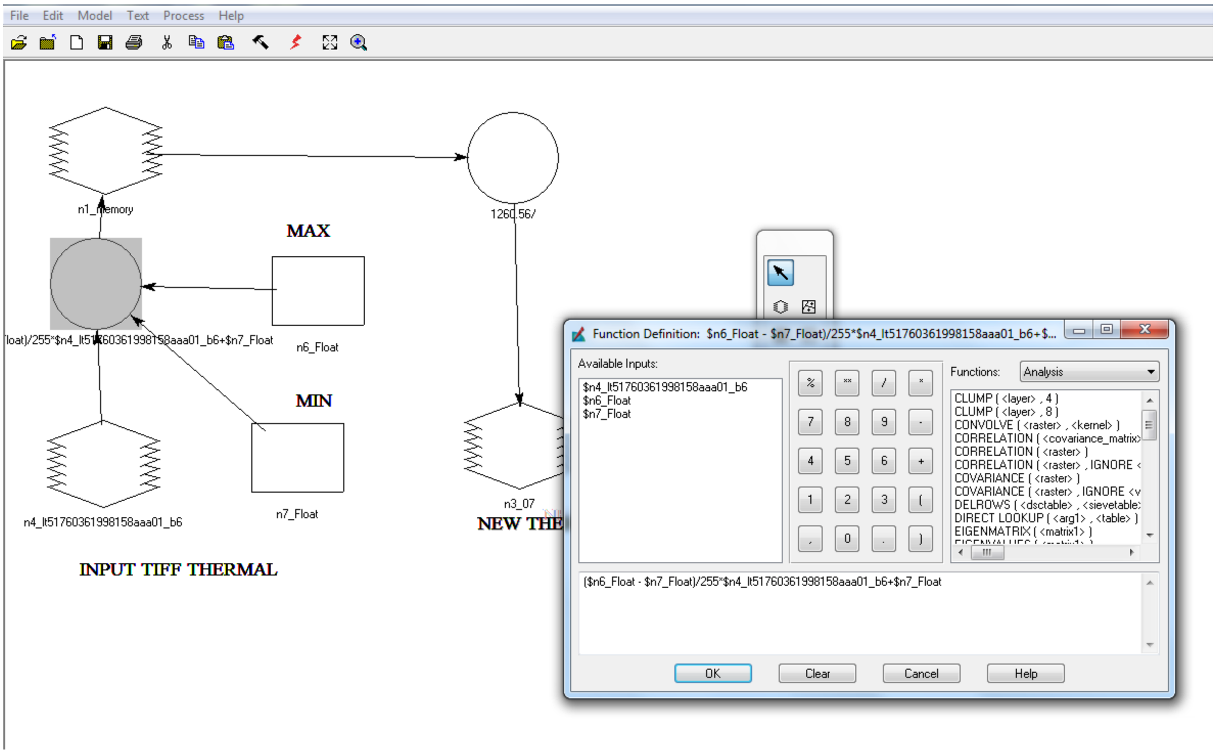


Figure 16: Application of conversion formula in Modeler

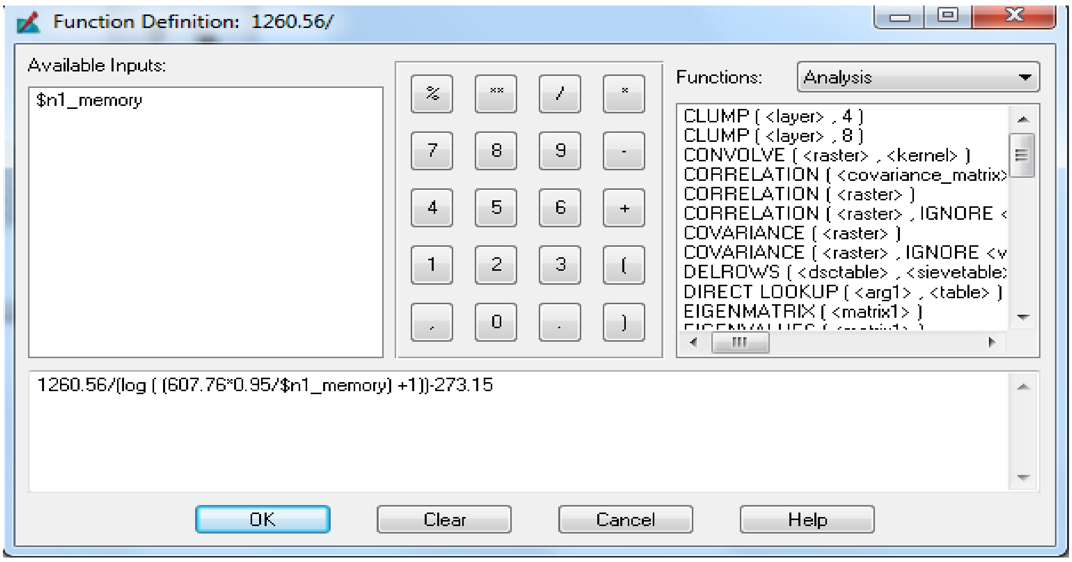


Figure 17: Application of conversion formula in Modeler

ii) Step 2: Convert Radiance to Celsius

After converting the DNs to radiance values, the second step is the conversion of the radiance data to temperature using a formula in which the atmospheric correction is not included.

The formula to convert radiance to temperature is:

$$T = \frac{K_2}{\ln\left(\frac{K_1 * \varepsilon}{CV_{R1}} + 1\right)} - 273.15 \qquad \text{Equation 2}$$

Where:

T is degrees Kelvin

CV_{R1} is the cell value as radiance

ε is emissivity (typically 0.95)

(The Yale Center for Earth Observation, 2010)

Table 1: Values of K_1 and K_2

	Landsat TM	Landsat ETM
K_1	607.76	666.09
K_2	1260.56	1282.71

(Source: The Yale Center for Earth Observation, 2010)

The radiance to temperature conversion formula was applied in ERDAS IMAGINE software by using the Modeler, as shown in the Figure 18 below.

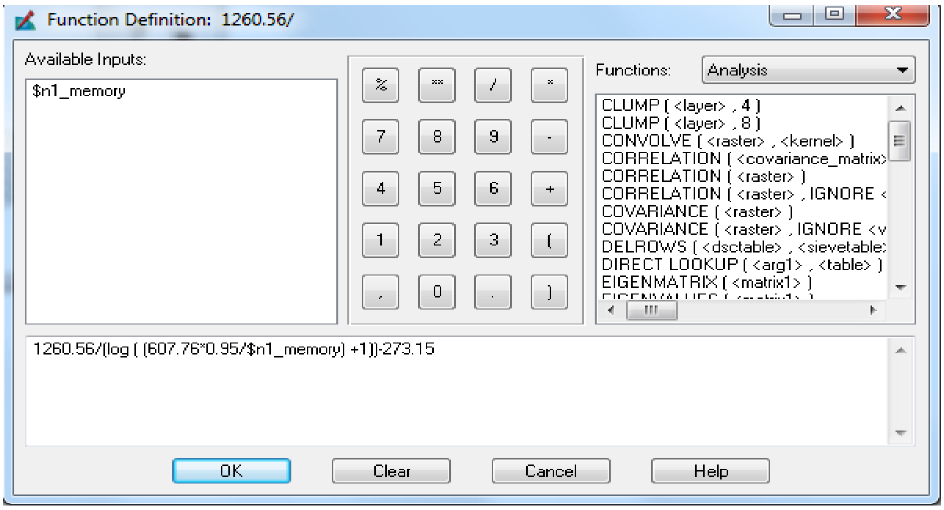


Figure 18: Application of conversion formula in Modeler

b) For Landsat OLI/TIRS

As in the procedure for Landsat TM and ETM+, the first step is to convert the DNs to radiance values using the bias and gain values and the second step is the conversion of the radiance data to temperature using a formula. Each pixel of processed Level 1 (L1) Landsat 8 ETM+ data is stored as a Digital Number (DN) with a value between 0 and 2^15** ("http://geohackers.in/2013/08/using-data-from-the-landsat-8-tirs-instrument-to-estimate-surface-temperature/," n.d.).

i) Step 1: Convert DN to Radiance

The formula to convert DN to radiance demands the radiance rescaling factors which are provided in the metadata file of each image as shown in the Figure19 below.

```
END_GROUP = MIN_MAX_PIXEL_VALUE
GROUP = RADIOMETRIC_RESCALING
  RADIANCE_MULT_BAND_1 = 1.2147E-02
  RADIANCE_MULT_BAND_2 = 1.2439E-02
  RADIANCE_MULT_BAND_3 = 1.1462E-02
  RADIANCE_MULT_BAND_4 = 9.6657E-03
  RADIANCE_MULT_BAND_5 = 5.9149E-03
  RADIANCE_MULT_BAND_6 = 1.4710E-03
  RADIANCE_MULT_BAND_7 = 4.9580E-04
  RADIANCE_MULT_BAND_8 = 1.0939E-02
  RADIANCE_MULT_BAND_9 = 2.3117E-03
  RADIANCE_MULT_BAND_10 = 3.3420E-04
  RADIANCE_MULT_BAND_11 = 3.3420E-04
  RADIANCE_ADD_BAND_1 = -60.73597
  RADIANCE_ADD_BAND_2 = -62.19437
  RADIANCE_ADD_BAND_3 = -57.31158
  RADIANCE_ADD_BAND_4 = -48.32835
  RADIANCE_ADD_BAND_5 = -29.57454
  RADIANCE_ADD_BAND_6 = -7.35492
  RADIANCE_ADD_BAND_7 = -2.47900
  RADIANCE_ADD_BAND_8 = -54.69440
  RADIANCE_ADD_BAND_9 = -11.55840
  RADIANCE_ADD_BAND_10 = 0.10000
  RADIANCE_ADD_BAND_11 = 0.10000
  REFLECTANCE_MULT_BAND_1 = 2.0000E-05
  REFLECTANCE_MULT_BAND_2 = 2.0000E-05
```

Figure 19: Rescaling factors from metadata file

Here it has to be mentioned that for Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) the bands which are appropriate for the study are the Band 10-TIRS 1 which is useful for 1-100 meter resolution, thermal mapping and estimated soil moisture, and Band 11-TIRS 2 which is useful for 100 meter resolution, Improved thermal mapping and estimated soil moisture as it shown below in the Figure 20.

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

Band	Wavelength	Useful for mapping
Band 1 – coastal aerosol	0.43 - 0.45	coastal and aerosol studies
Band 2 – blue	0.45 - 0.51	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 3 - green	0.53 - 0.59	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 - red	0.64 - 0.67	Discriminates vegetation slopes
Band 5 - Near Infrared (NIR)	0.85-0.88	Emphasizes biomass content and shorelines
Band 6 - Short-wave Infrared (SWIR) 1	1.57 - 1.65	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 7 - Short-wave Infrared (SWIR) 2	2.11 - 2.29	Improved moisture content of soil and vegetation and thin cloud penetration
Band 8 - Panchromatic	0.50 - 0.68	15 meter resolution, sharper image definition
Band 9 – Cirrus	1.36 - 1.38	Improved detection of cirrus cloud contamination
Band 10 – TIRS 1	10.60 – 11.19	100 meter resolution, thermal mapping and estimated soil moisture
Band 11 – TIRS 2	11.5 - 12.51	100 meter resolution, Improved thermal mapping and estimated soil moisture

Figure 20: Selection of thermal bands for Landsat 8

(Source: "http://landsat.usgs.gov/best_spectral_bands_to_use.php," n.d.)

The formula to convert DN to radiance using the radiance rescaling factors provided in the metadata file is:

$$L = ML * DN + AL \quad \text{Equation 3}$$

Where:

L is the cell value as radiance

DN is the cell value digital number

ML Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)

AL Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)

("http://landsat.usgs.gov/Landsat8_Using_Product.php," n.d.)

The DNs to radiance conversion formula was applied in ERDAS IMAGINE software by using the Modeler, as it shown below in the Figure 21 and Figure 22.

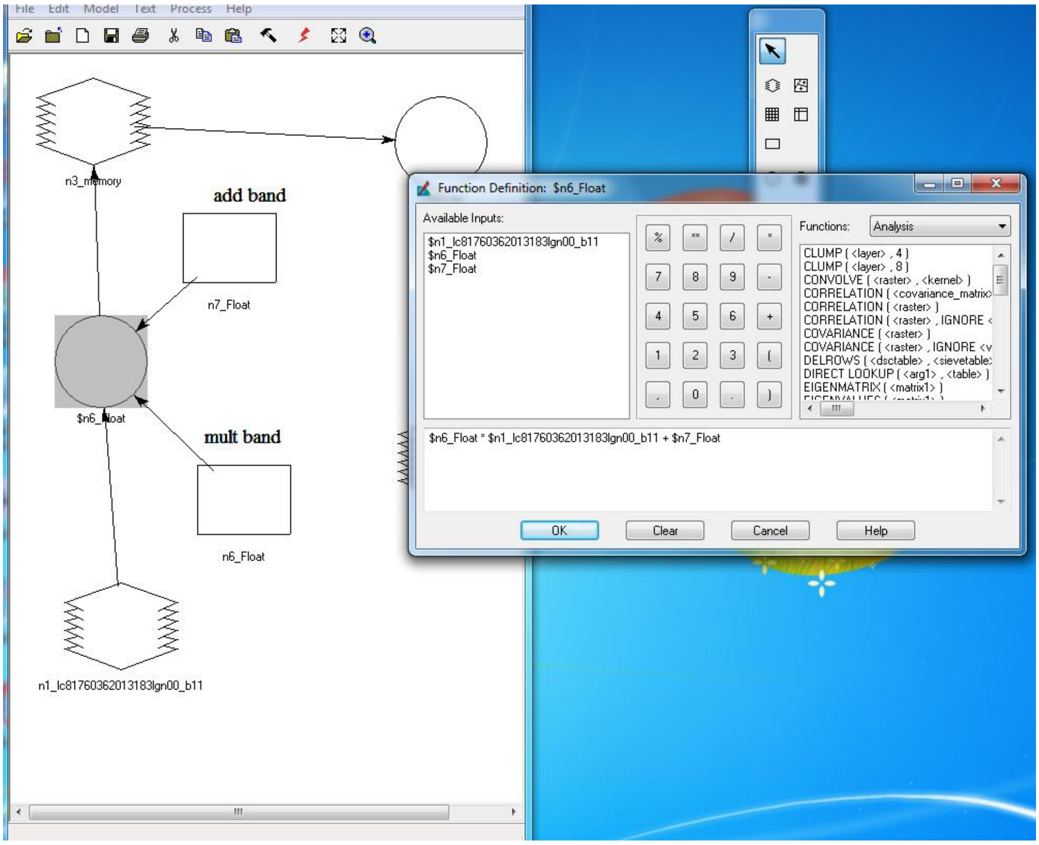


Figure 21: Application of conversion formula in Modeler

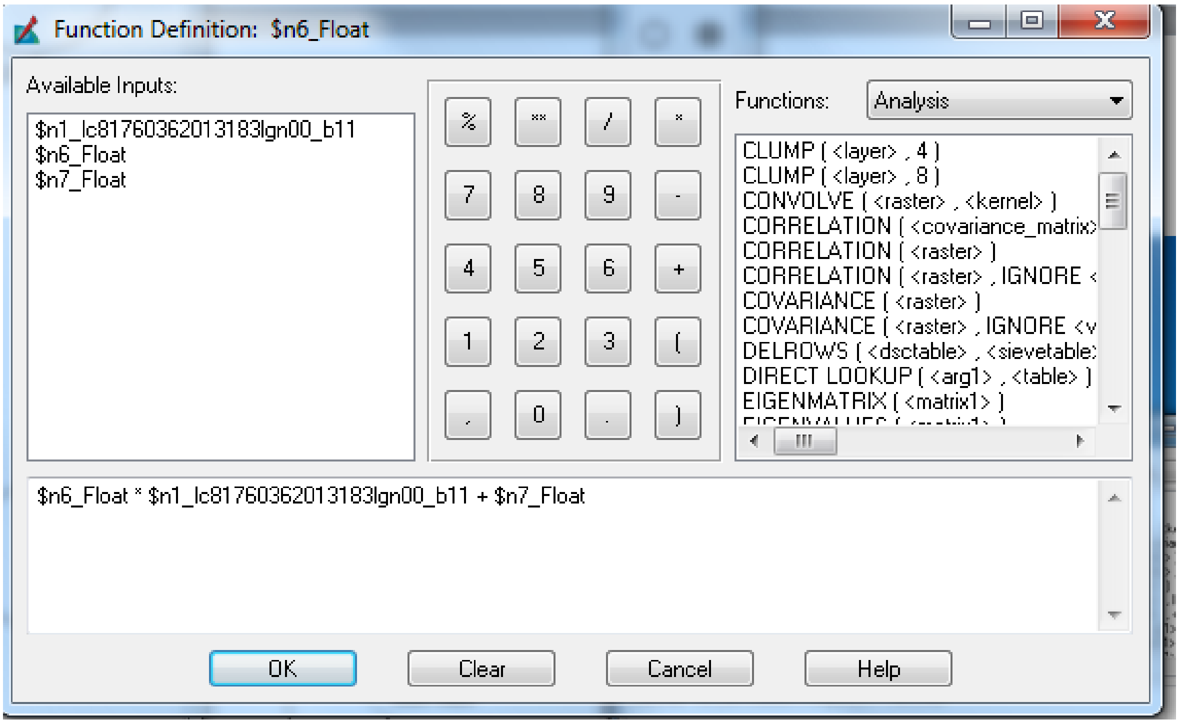


Figure 22: Application of conversion formula in Modeler

ii) Step 2: Convert Radiance to Celsius

After converting the DNs to radiance values, the second step is the conversion of the radiance data to temperature using a formula in which the atmospheric correction is included.

The formula to convert radiance to temperature is:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L\lambda}+1\right)} - 273.15 \qquad \text{Equation 4}$$

Where:

T At-satellite brightness temperature (K)

L_λ TOA spectral radiance (Watts/(m2*srad*μm))

K_1 Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)

K_2 Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

("http://landsat.usgs.gov/Landsat8_Using_Product.php," n.d.)

Thermal conversion constants can be found in the metadata file as shown in the Figure 23 below.

```
GROUP = TIRS_THERMAL_CONSTANTS
  K1_CONSTANT_BAND_10 = 774.89
  K1_CONSTANT_BAND_11 = 480.89
  K2_CONSTANT_BAND_10 = 1321.08
  K2_CONSTANT_BAND_11 = 1201.14
END_GROUP = TIRS_THERMAL_CONSTANTS
```

Figure 23: Thermal conversion constants from metadata file

The radiance to temperature conversion formula was applied in ERDAS IMAGINE software by using the Modeler, as shown in the Figure 24 below.

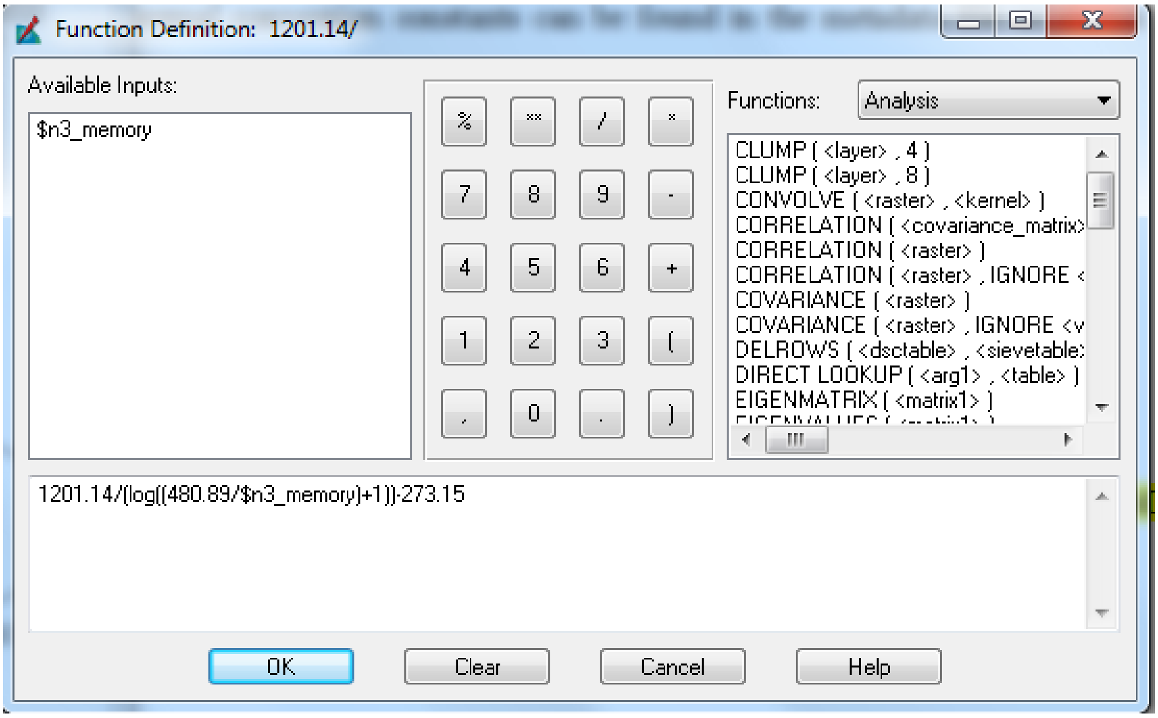


Figure 24: Application of conversion formula in Modeler

D. Observation of temperature fluctuations

In the ERDAS IMAGINE software there are two viewers which the one shows the layer stack image with all the bands and the other one shows the new formatted image that is converted into temperature. With the command View-Link/Unlink-Geographical these two images synchronised and then is possible to observe the temperature of every region on the first viewer which region is selected in the other viewer. This procedure is shown in the Figure 25 below.

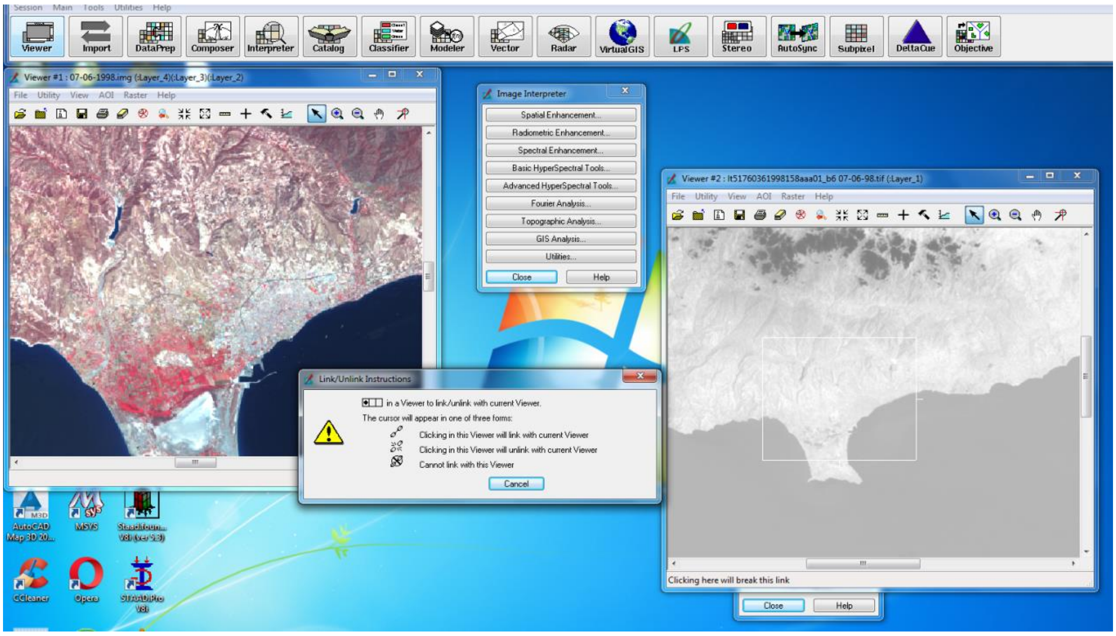
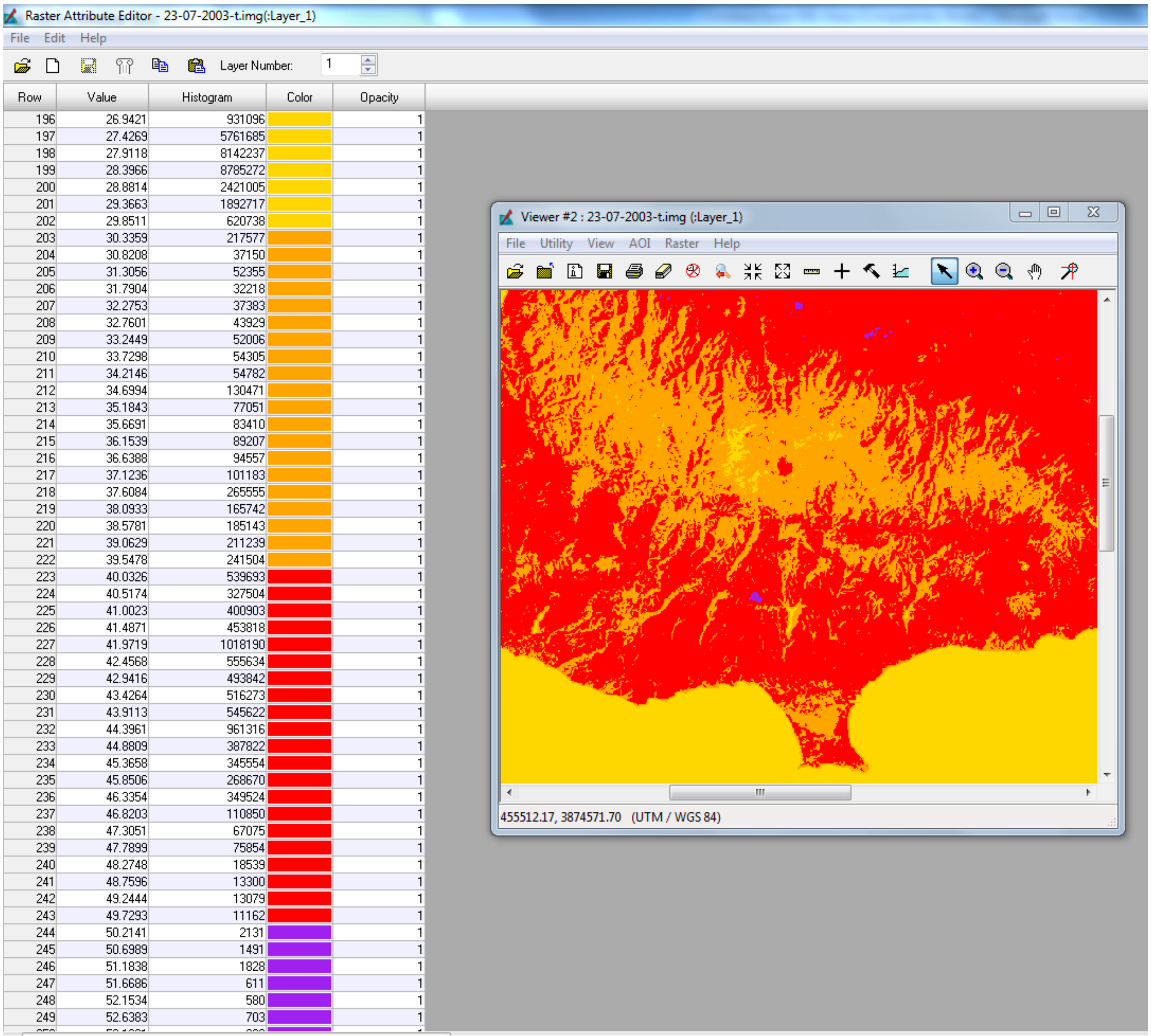


Figure 25: Observation of temperature fluctuations in two viewers

E. Separation of temperatures

In order to separate the temperatures and have a more analytical observation of the fluctuations of temperature in each area of Limassol (urban and rural), a procedure had to be done. Initially all the new images were converted into pseudo colour and then with the command Raster-Attributes in Viewer temperatures were separated into five different colours. For temperatures between 0-10°C the colour is beige, between 10-20°C the colour is yellow, between 20-30°C the colour is gold, between 30-40°C the colour is orange, between 40-50°C the colour is red and finally for temperatures above 50°C the colour is purple. This step with the set of colours in temperature values is shown in the Figure 26 below.



Row	Value	Histogram	Color	Opacity
196	26.9421	931096		1
197	27.4269	5761685		1
198	27.9118	8142237		1
199	28.3966	8785272		1
200	28.8814	2421005		1
201	29.3663	1892717		1
202	29.8511	620738		1
203	30.3359	217577		1
204	30.8208	37150		1
205	31.3056	52355		1
206	31.7904	32218		1
207	32.2753	37383		1
208	32.7601	43929		1
209	33.2449	52006		1
210	33.7298	54305		1
211	34.2146	54782		1
212	34.6994	130471		1
213	35.1843	77051		1
214	35.6691	83410		1
215	36.1539	89207		1
216	36.6388	94557		1
217	37.1236	101183		1
218	37.6084	265555		1
219	38.0933	165742		1
220	38.5781	185143		1
221	39.0629	211239		1
222	39.5478	241504		1
223	40.0326	539693		1
224	40.5174	327504		1
225	41.0023	400903		1
226	41.4871	453818		1
227	41.9719	1018190		1
228	42.4568	555634		1
229	42.9416	493842		1
230	43.4264	516273		1
231	43.9113	545622		1
232	44.3961	961316		1
233	44.8809	387822		1
234	45.3658	345554		1
235	45.8506	268670		1
236	46.3354	349524		1
237	46.8203	110850		1
238	47.3051	67075		1
239	47.7899	75854		1
240	48.2748	18539		1
241	48.7596	13300		1
242	49.2444	13079		1
243	49.7293	11162		1
244	50.2141	2131		1
245	50.6989	1491		1
246	51.1838	1828		1
247	51.6686	611		1
248	52.1534	580		1
249	52.6383	703		1

Figure 26: Separation of temperature in colours

6.3 Export of results procedure

For the observation and analysis of the fluctuations of temperature in the different areas of Limassol some results had to be exported and analysed, and this was achieved by following a process.

Firstly, two different classified images that show the urban area of Limassol in 2000 and 2012 were taken, in order to make the selection of points, in which the temperatures would be recorded, easier. These two images are shown below in Figure 27 and Figure 28 respectively.

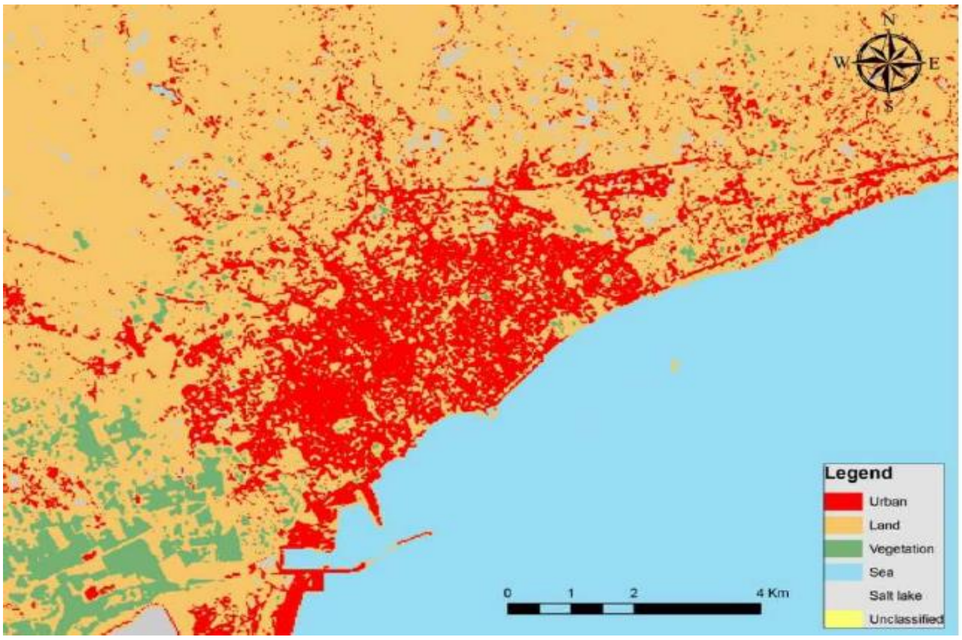


Figure 27: Urban growth of Limassol area, 2000
(source: www.cyprusremotesensing.com, n.d.)

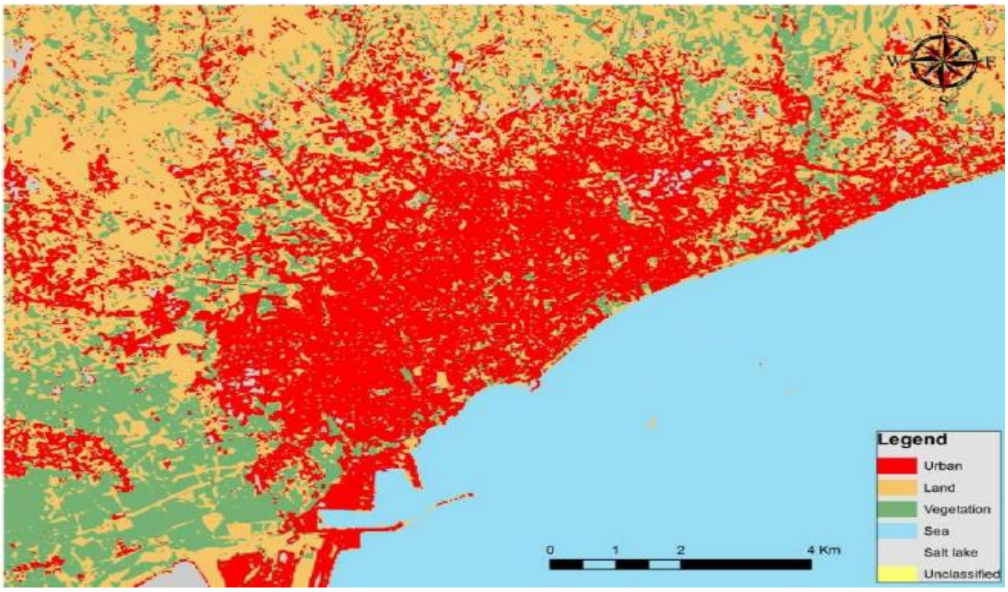


Figure 28: Urban growth of Limassol area, 2012
(source: www.cyprusremotesensing.com, n.d.)

Then, by observing the areas in which the urban has sprawl, some points were selected in the ERDAS IMAGINE software. The selection of the points was made based on the influence of urban sprawl. Where initially there was land and now there is urban, a point was added. Also, points were added in the suburbs, outside the urban area and in the areas where there is vegetation. Totally, they were selected 16 points as shown in the Figure 29 below.

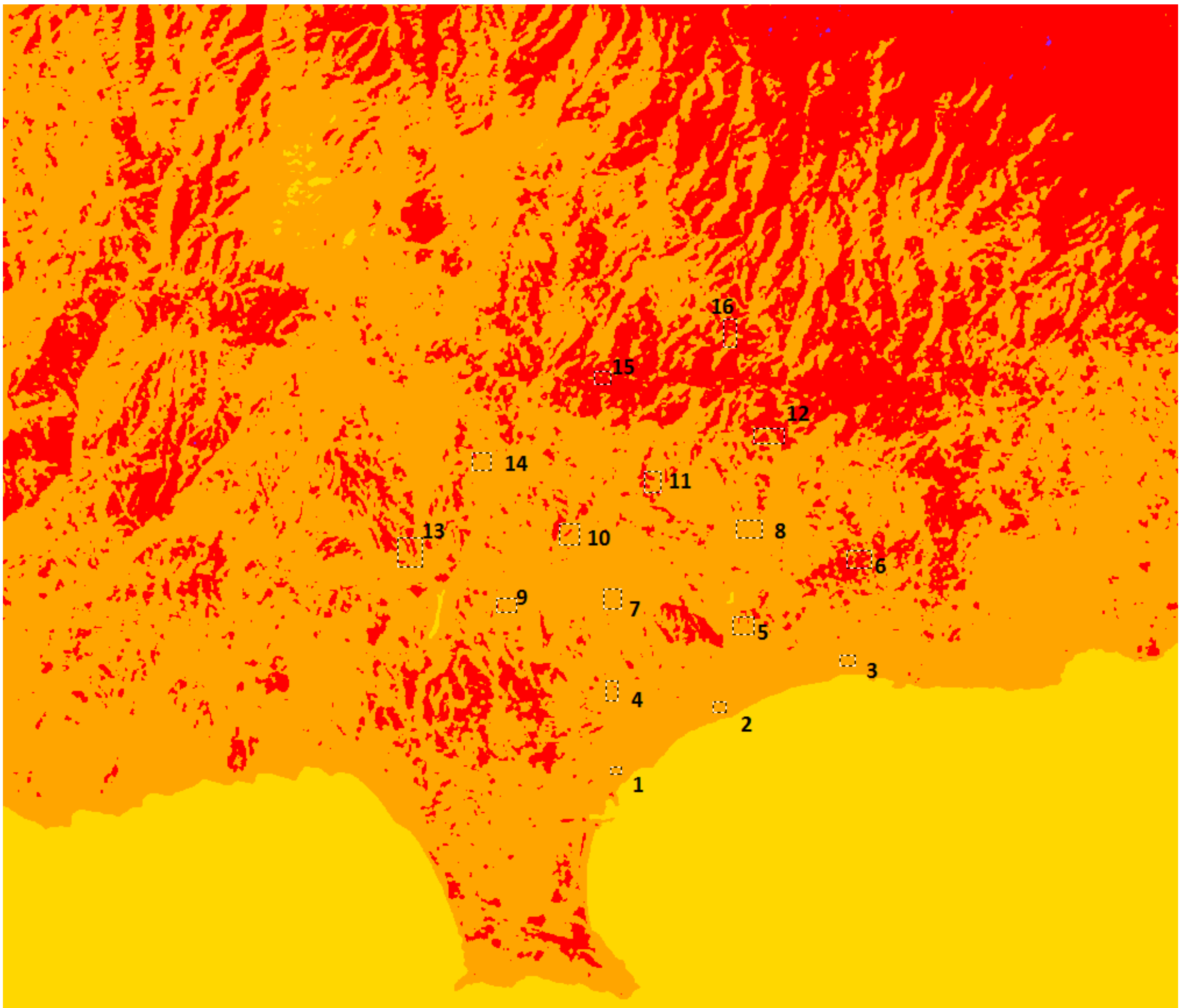


Figure 29: The selected points

With the command View-Link/Unlink-Geographical all the converted images were synchronised with the image with the points. With this step it was possible to observe the temperature of the same points for all the images. This step is shown below in the Figure 30.

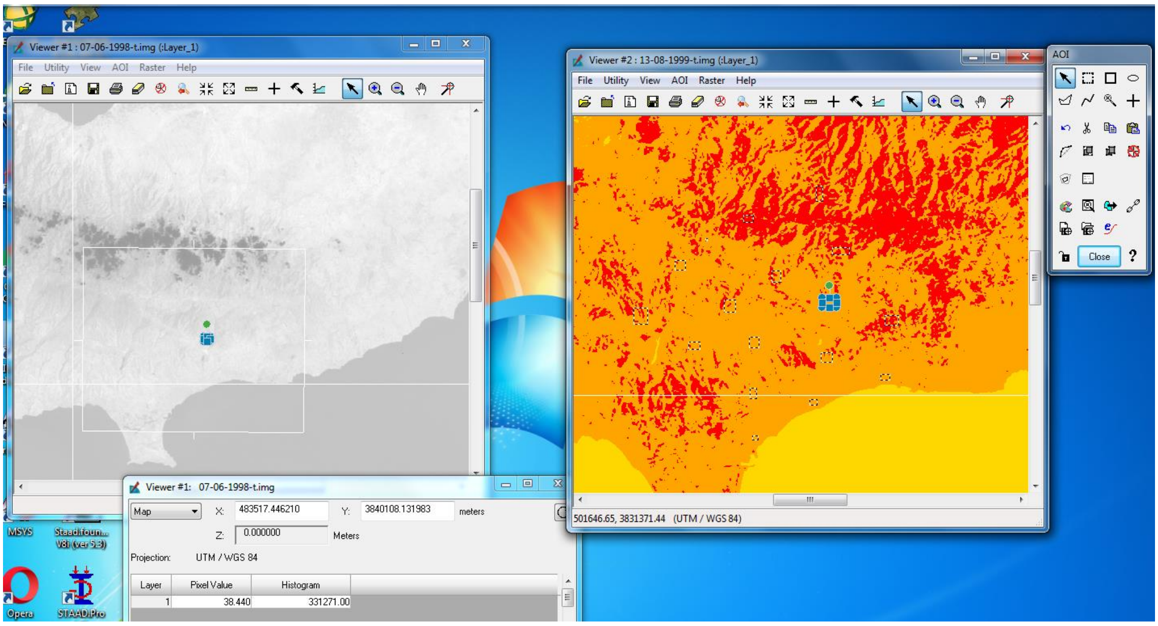


Figure 30: Synchronized images in two viewers

7 Results

After taking the satellite images from Earth Explorer, a methodology to elaborate them was done and analyzed in the Chapter 6 above. In the procedure of elaboration, these images converted into images which show temperature, in order to observe the influence of urban heat island effect in the area of Limassol from 1998 until now. Due to some technical problems on the modeler of the ERDASIMAGINE CLASSIC INTERFACE software, some images could not convert into images that give temperatures. These images are from L7 ETM + SLC-on (1999-2003) and L7 ETM + SLC-off (2003-present) and specifically from August 26th 2001, September 19th 2004, June 18th 2005, July 28th 2008 and August 22nd 2012.

With the ERDAS IMAGINE CLASSIC INTERFACE software temperatures were separated into five different colors in order to make it easier to observe the fluctuations all over the urban and rural area of Limassol for each year. Then, by setting specific points on the images, temperatures were recorded and transferred into an Excel sheet and then graphs were exported which show the fluctuation of temperatures for each year and the holistic influence of urban heat island effect through all these years.

7.1 Results exported from ERDAS IMAGINE CLASSIC INTERFACE

With the ERDAS IMAGINE CLASSIC INTERFACE software temperatures were separated into five different colors. For temperatures between 0-10°C the colour is beige, between 10-20°C the colour is yellow, between 20-30°C the colour is gold, between 30-40°C the colour is orange, between 40-50°C the colour is red and finally for temperatures above 50°C the colour is purple. This colour scale is presented in the Table 2 below.

Table 2: Colour Scale

Temperatures	Colour
0-10°C	Beige
10-20°C	Yellow
20-30°C	Gold
30-40°C	Orange
40-50°C	Red
Over 50°C	Purple

The new images with the colour scale that has been set were presented chronologically from 1998 to 2015, below in Figures 31 to 43.

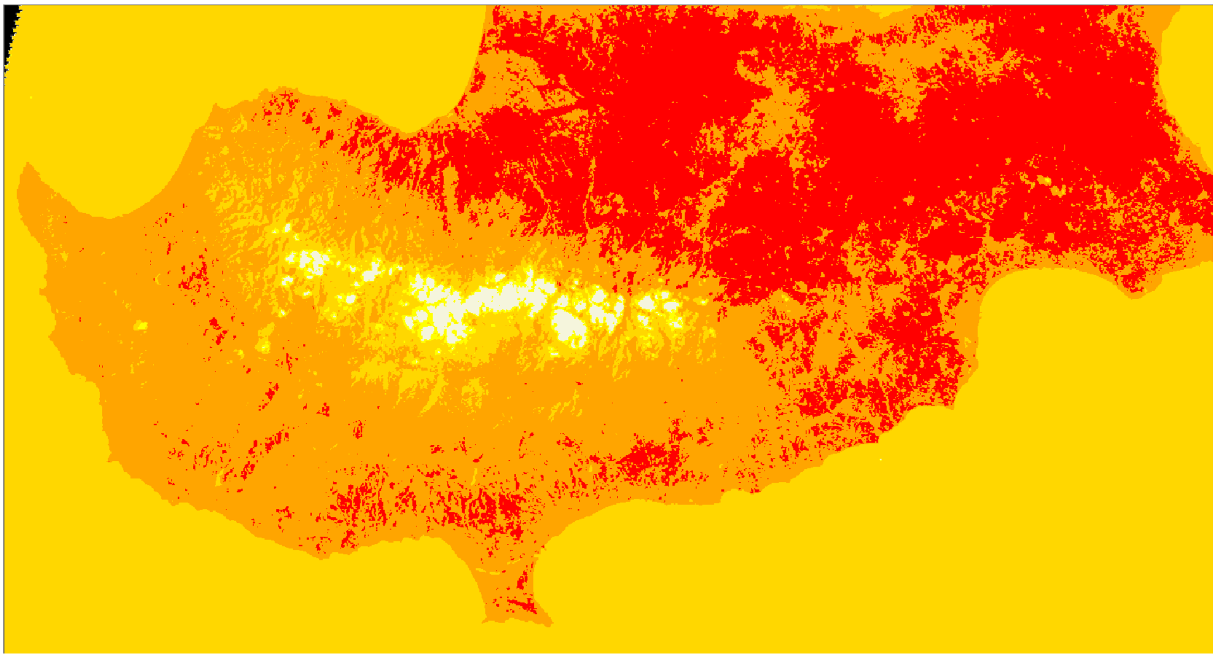


Figure 31: Visualization of temperatures through colours – June 7th 1998

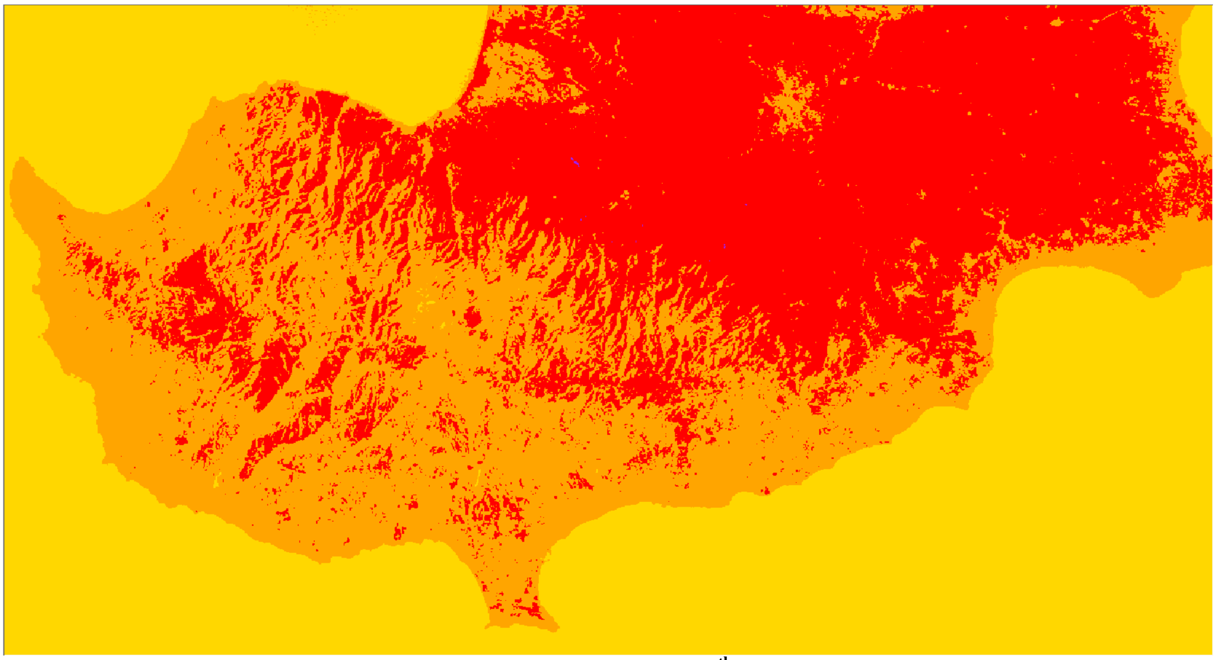


Figure 32: Visualization of temperatures through colours – August 13th 1999

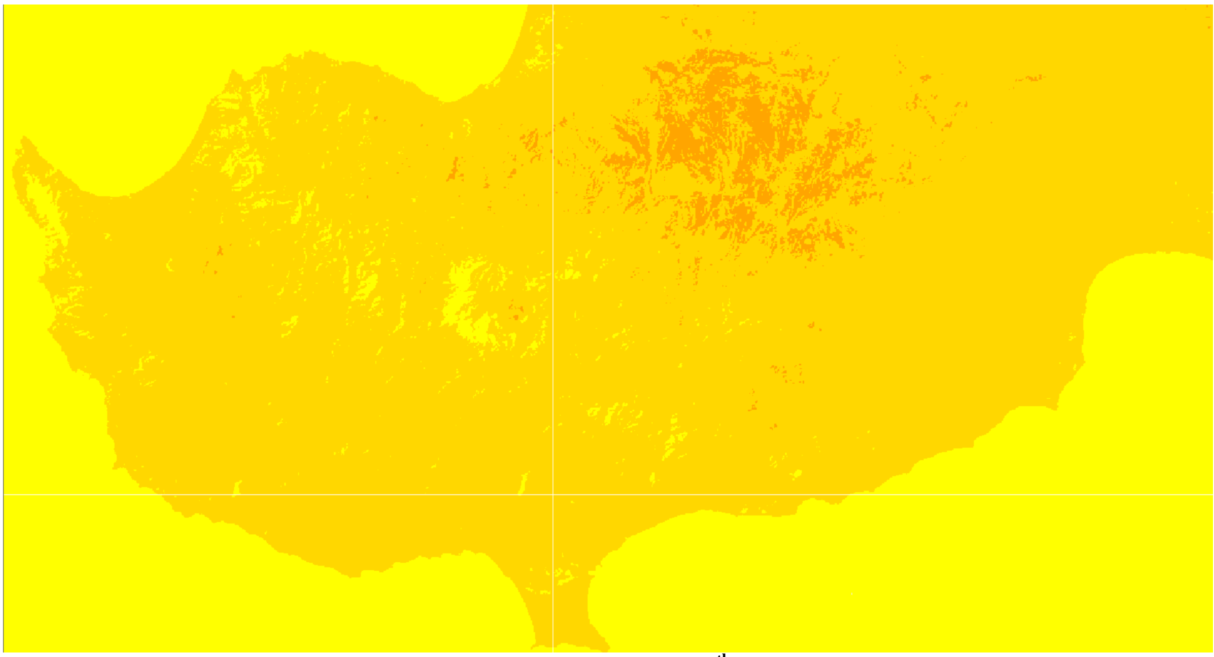


Figure 33: Visualization of temperatures through colours – August 15th 2000

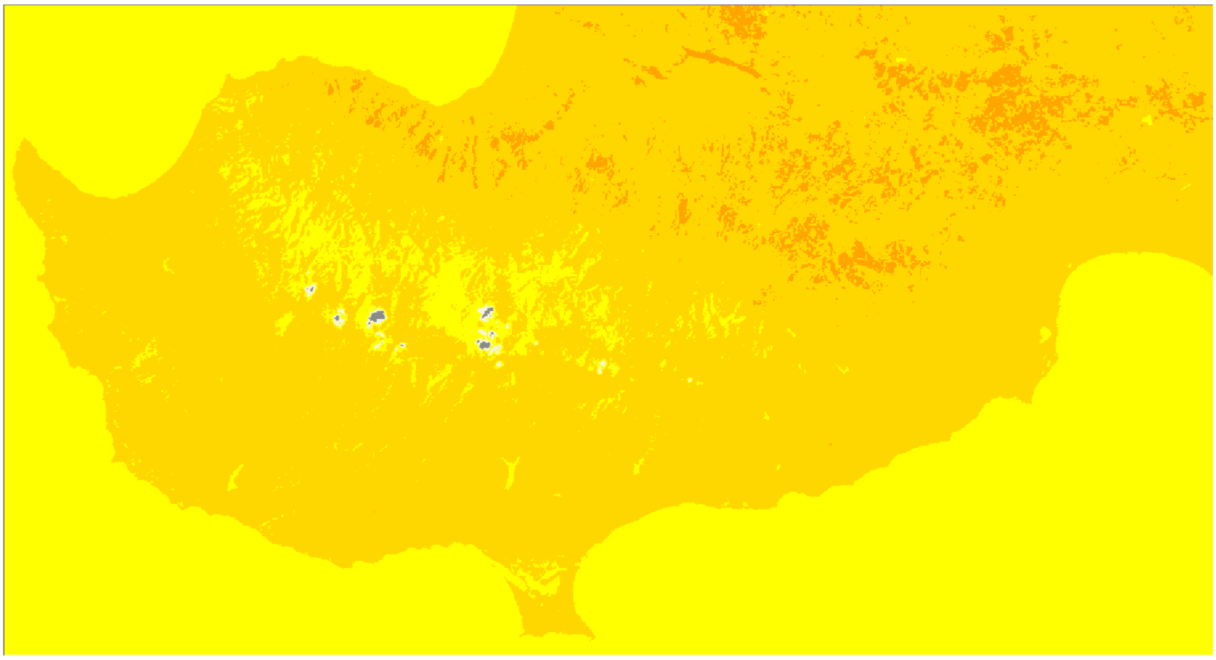


Figure 34:Visualization of temperatures through colours – June 18th 2002

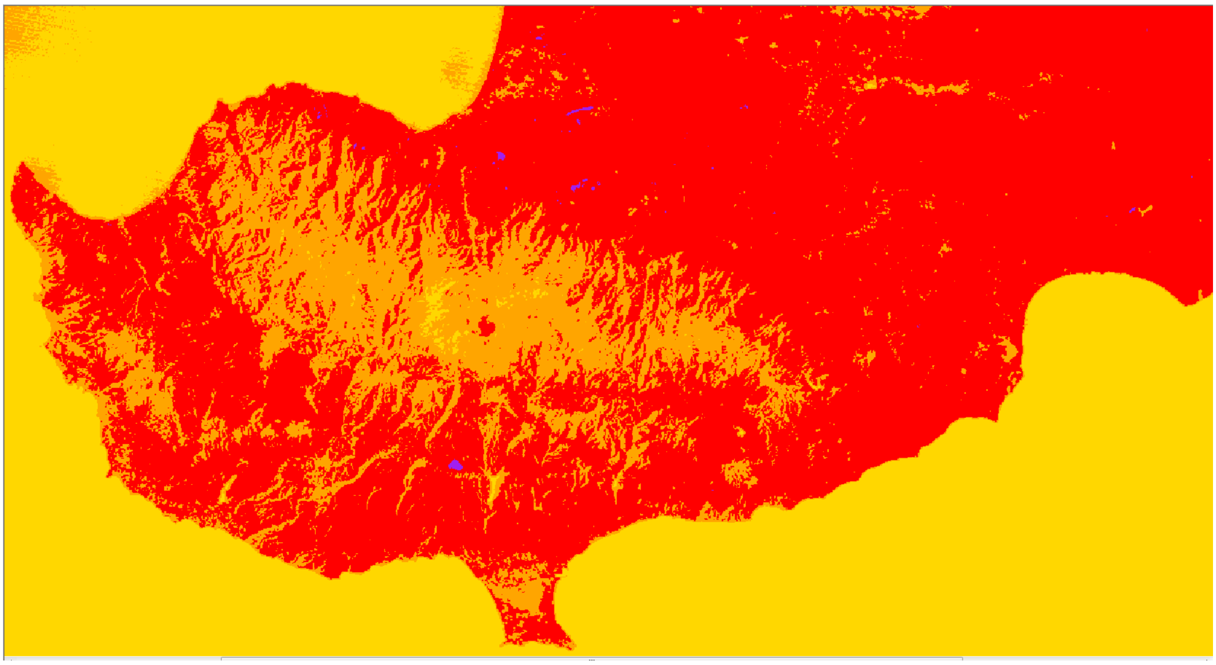


Figure 35: Visualization of temperatures through colours – July 23rd 2003

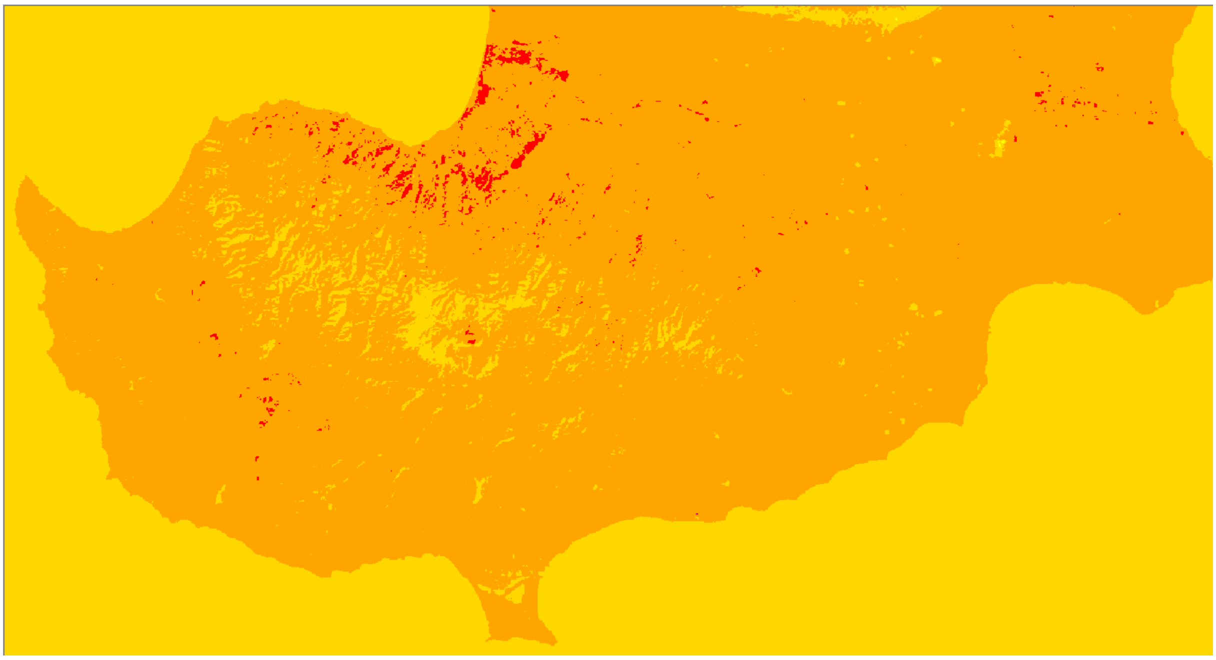


Figure 36: Visualization of temperatures through colours – September 17th 2006

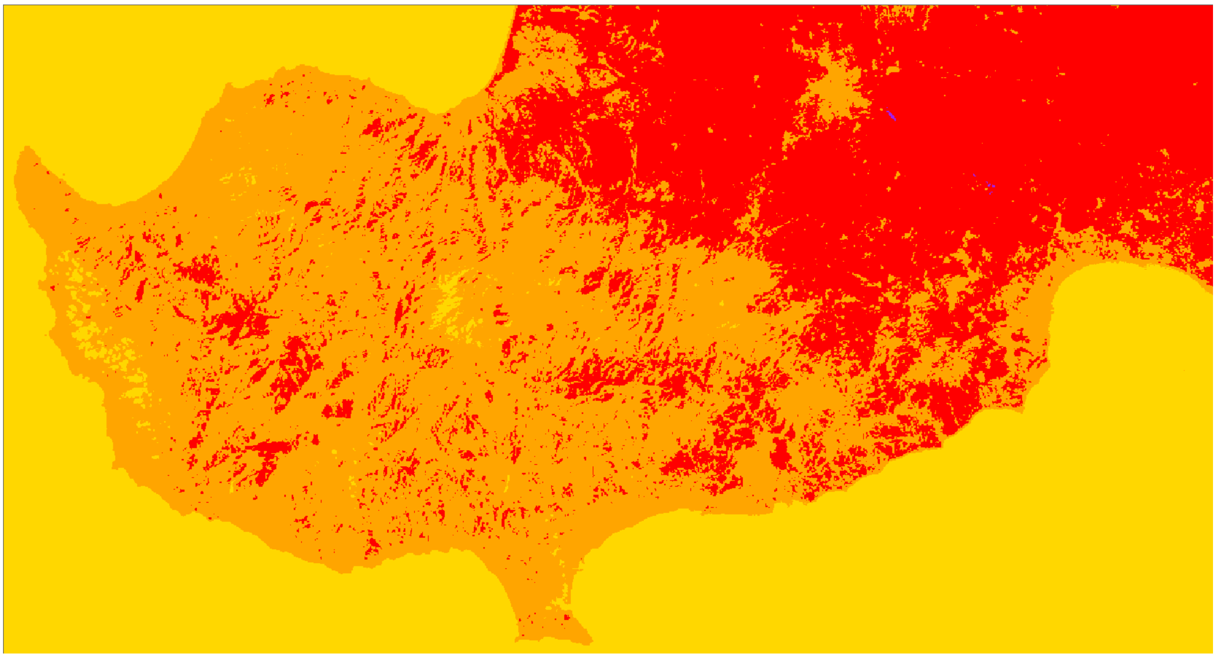


Figure 37: Visualization of temperatures through colours – September 4th 2007

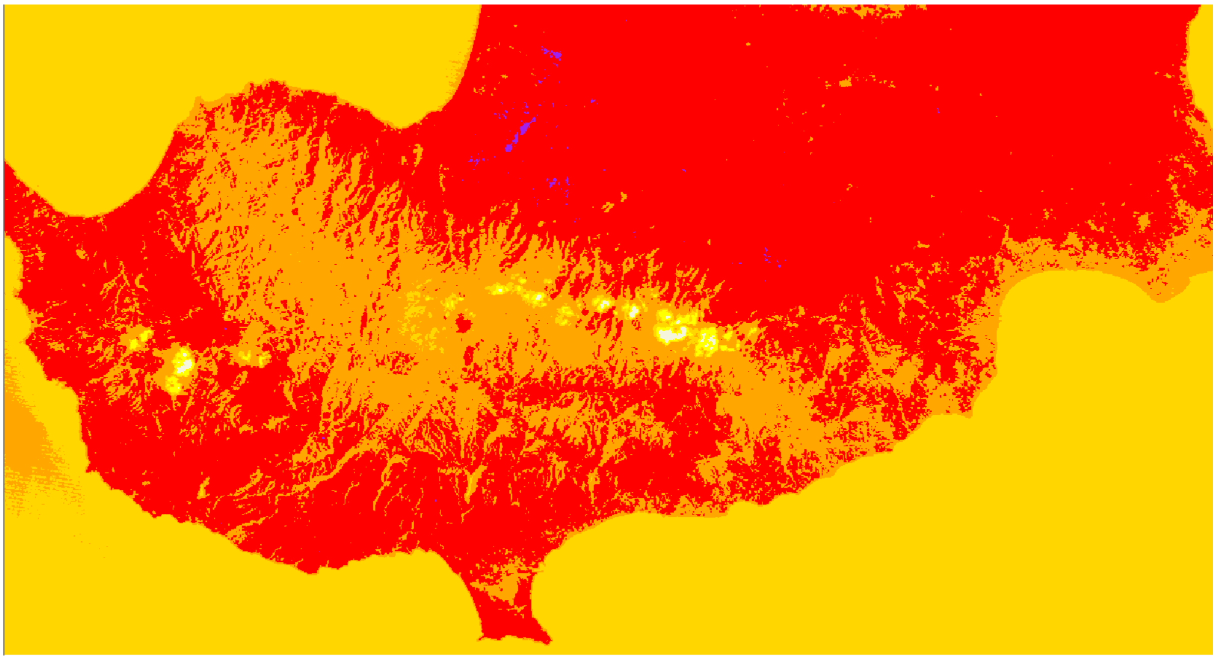


Figure 38: Visualization of temperatures through colours – July 23rd 2009

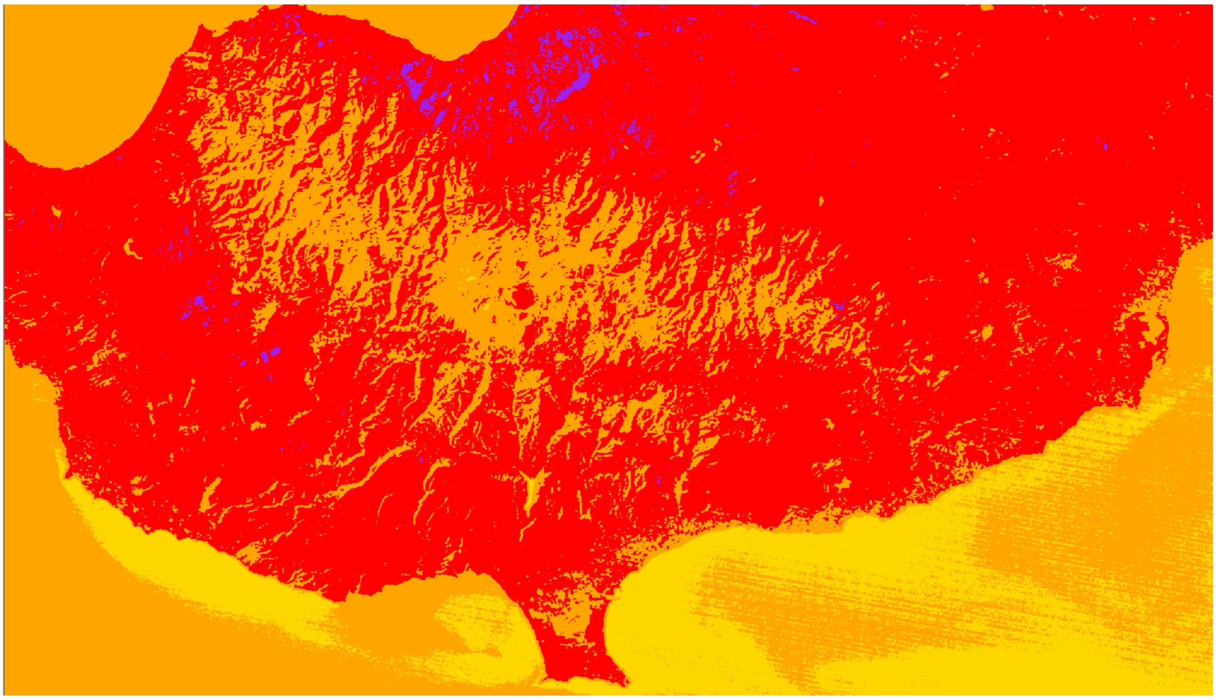


Figure 39: Visualization of temperatures through colours – August 27th 2010

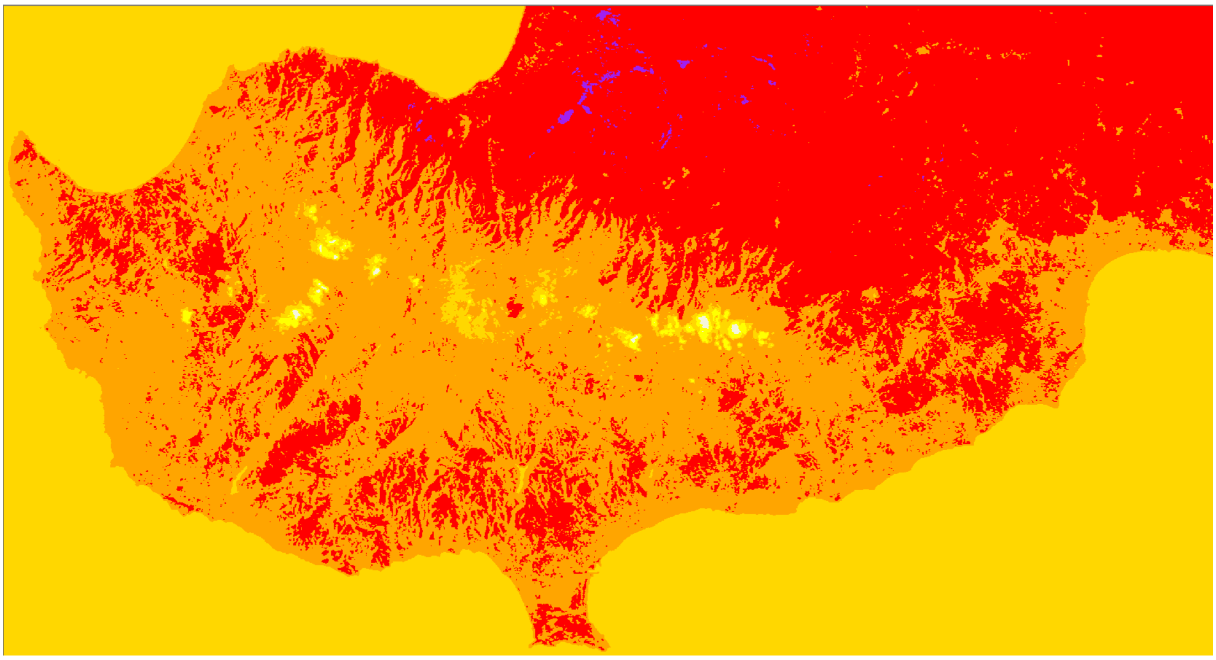


Figure 40: Visualization of temperatures through colours – July 13th 2011

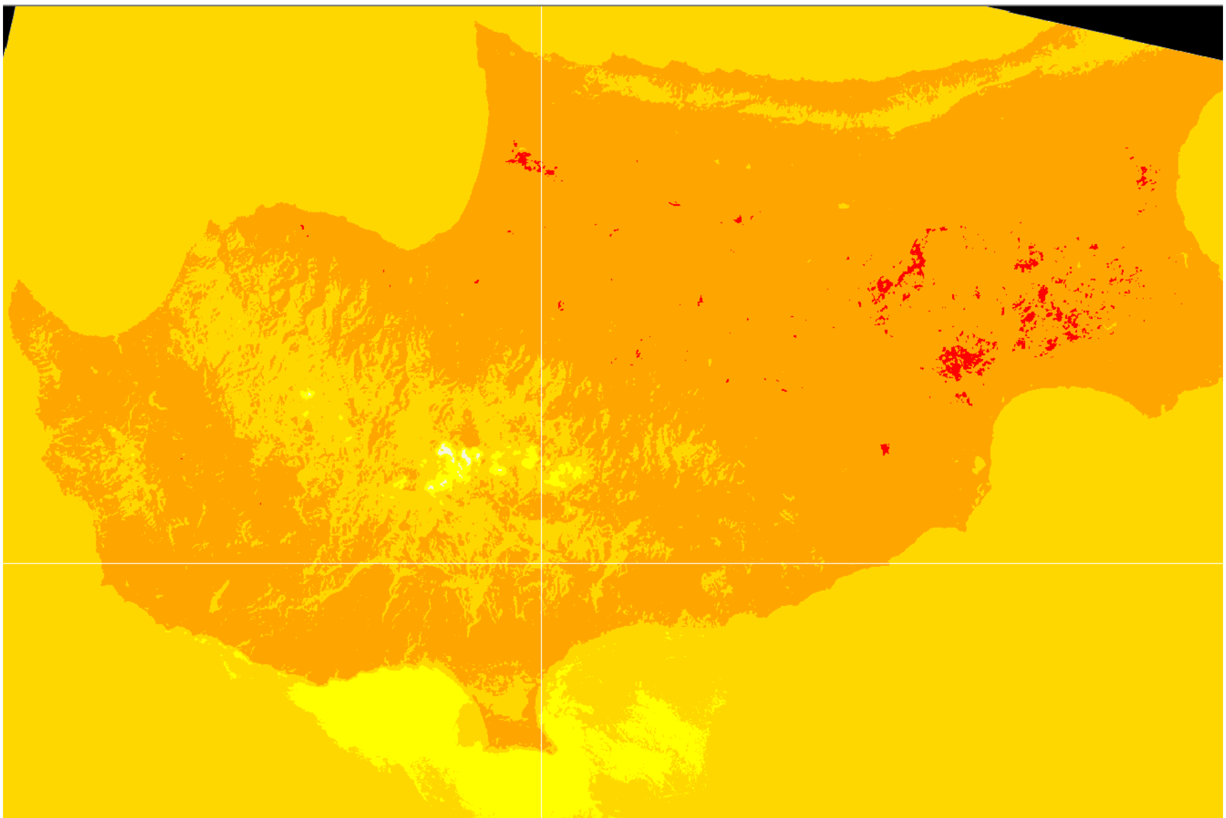


Figure 41: Visualization of temperatures through colours – July 2nd 2013

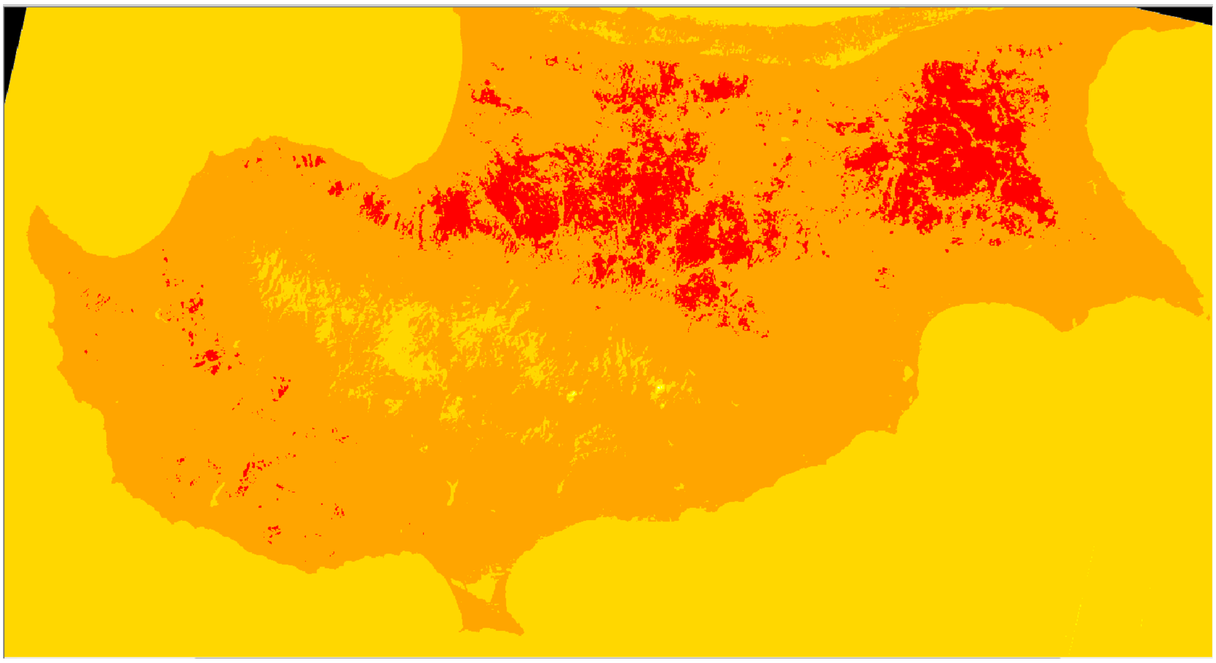


Figure 42: Visualization of temperatures through colours – June 19th 2014

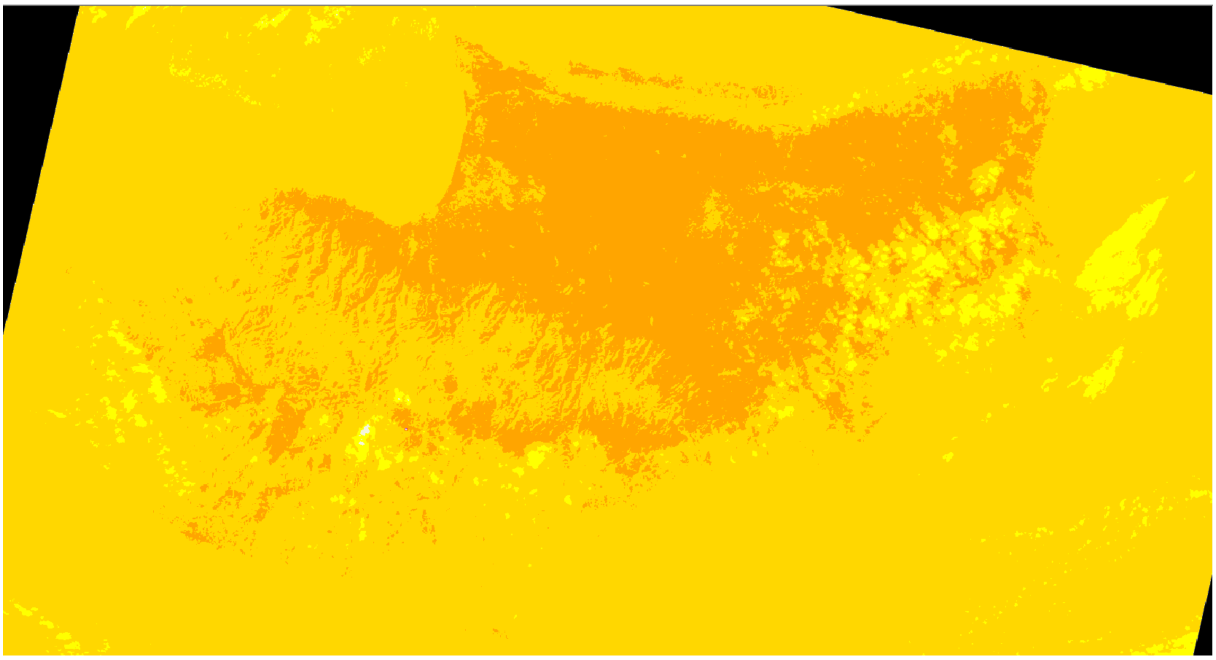


Figure 43: Visualization of temperatures through colours – August 8th 2015

7.2 Graphical visualization of the results

By observing the areas in which the urban has sprawl, 16 points were selected in the ERDAS IMAGINE software. The selection of the points was made based on the influence of urban sprawl and is shown in the Figure 29 above.

Also, as is shown in the Figure 30 above, through the command View-Link/Unlink-Geographical all the converted images were synchronised with the image with the selected points and all the temperatures of each point and each image were recorded and transferred into a sheet in Excel. Then, graphs which show the temperature of each point were exported for every image. Totally, they were exported 13 graphs and are shown below in Figures 44-56. With these graphs is possible to observe the temperature in each point in the urban and rural area of Limassol and draw conclusions about the urban heat island effect.

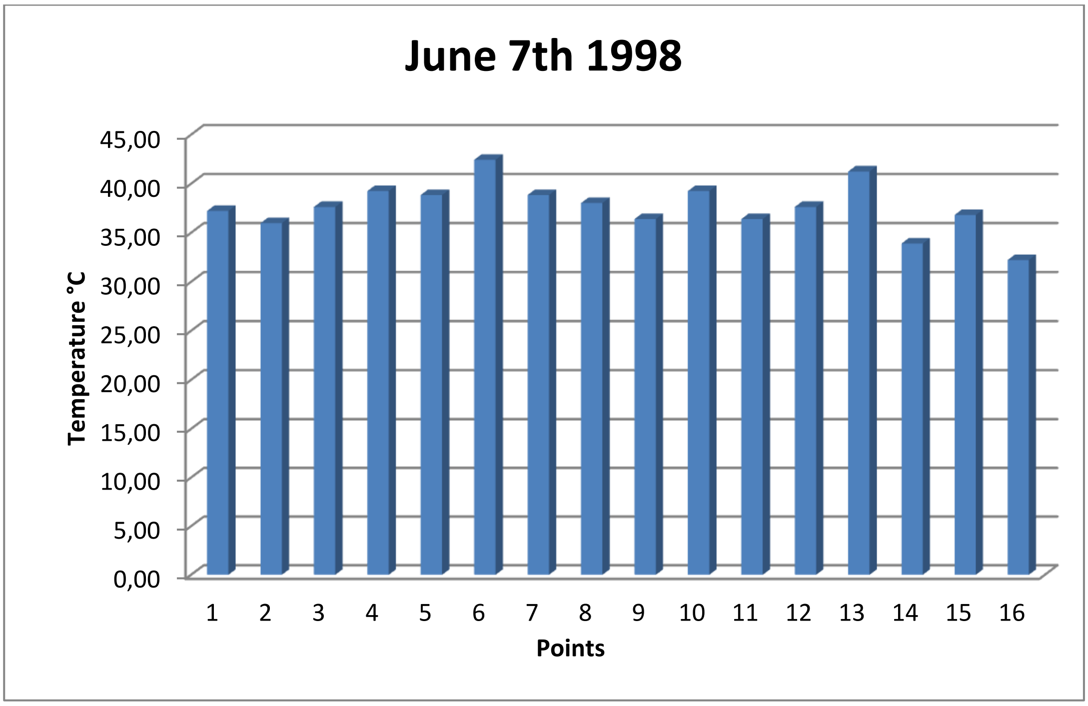


Figure 44: Temperatures of June 7th 1998

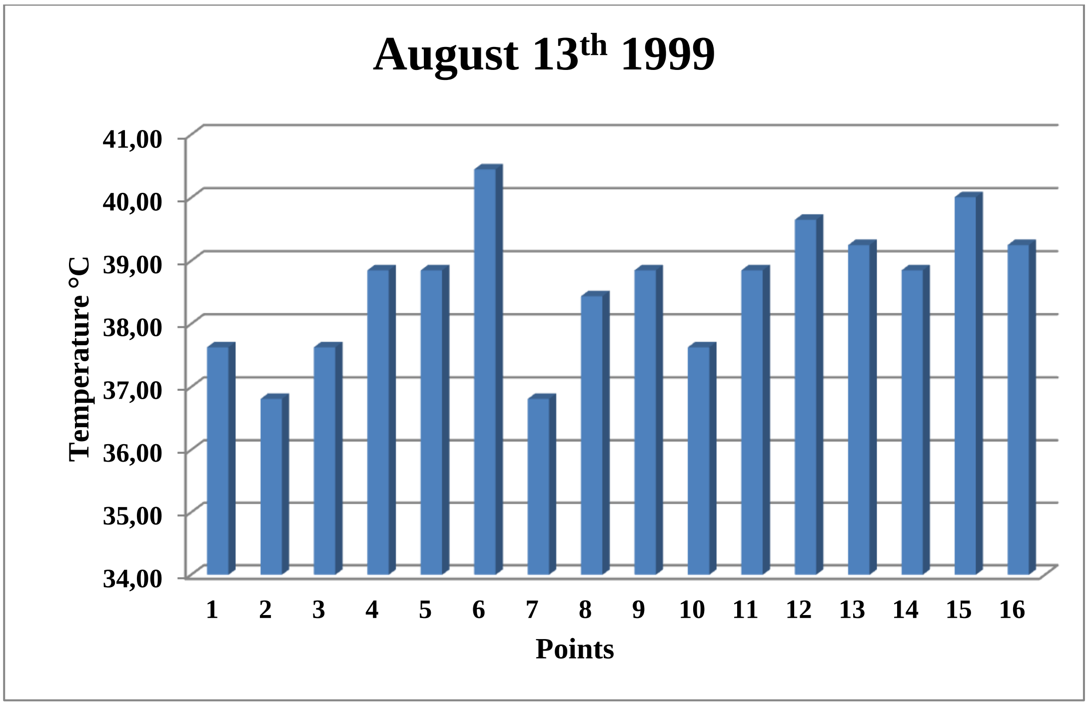


Figure 45: Temperatures of August 13th 1999

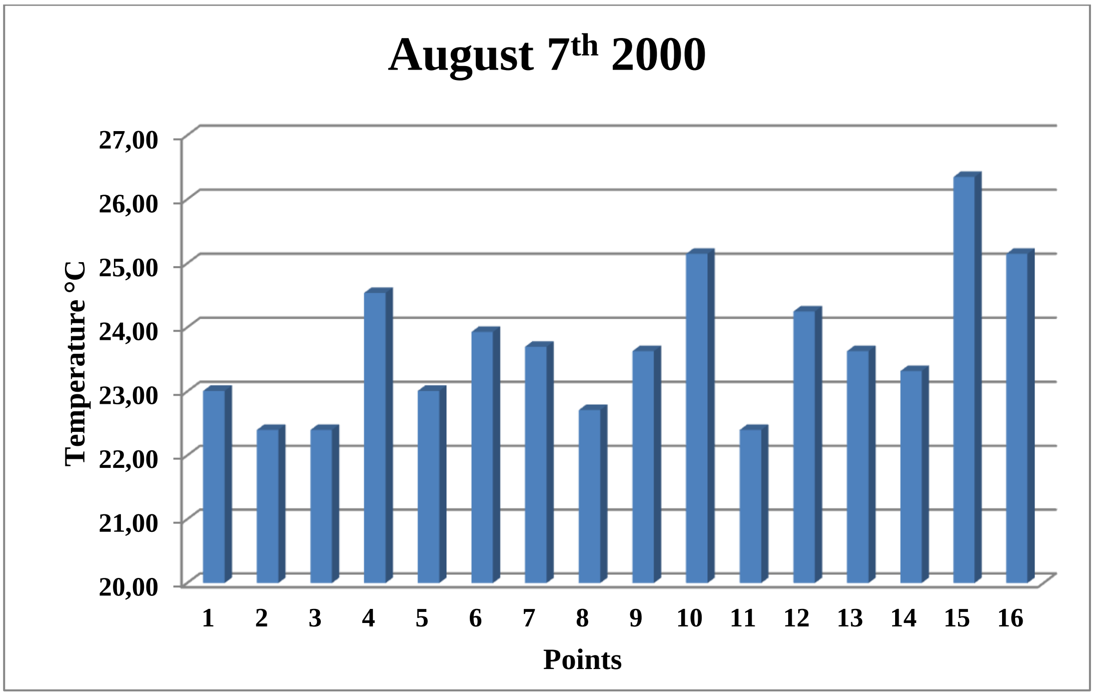


Figure 46: Temperatures of August 7th 2000

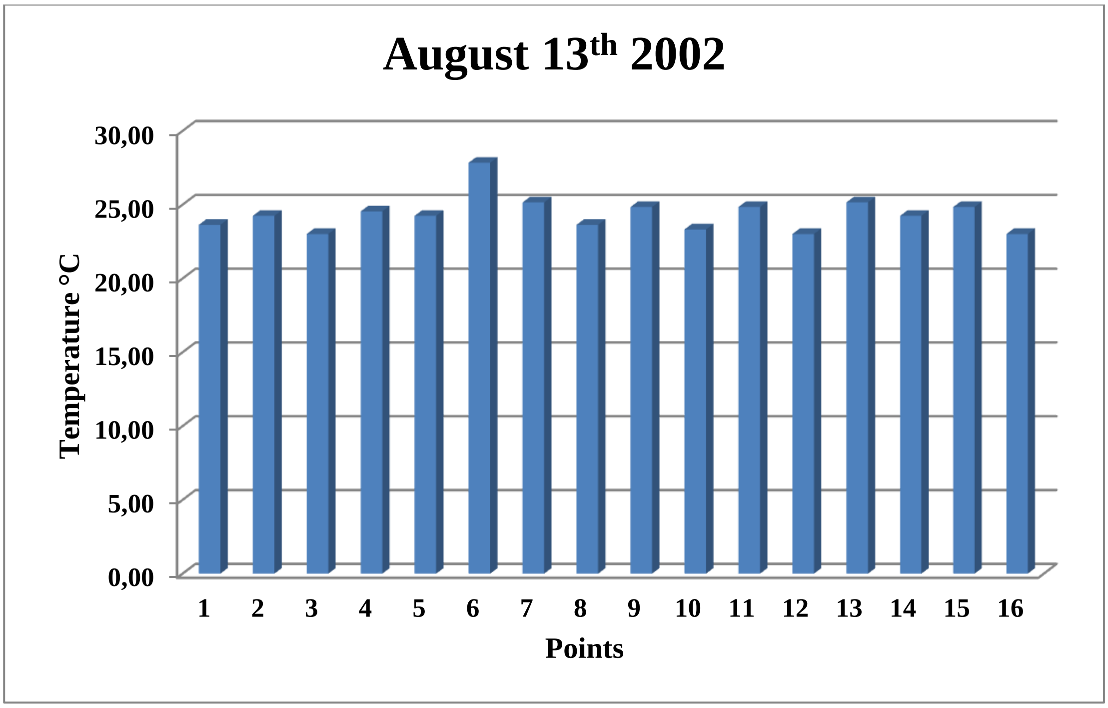


Figure 47: Temperatures of August 13th 2002

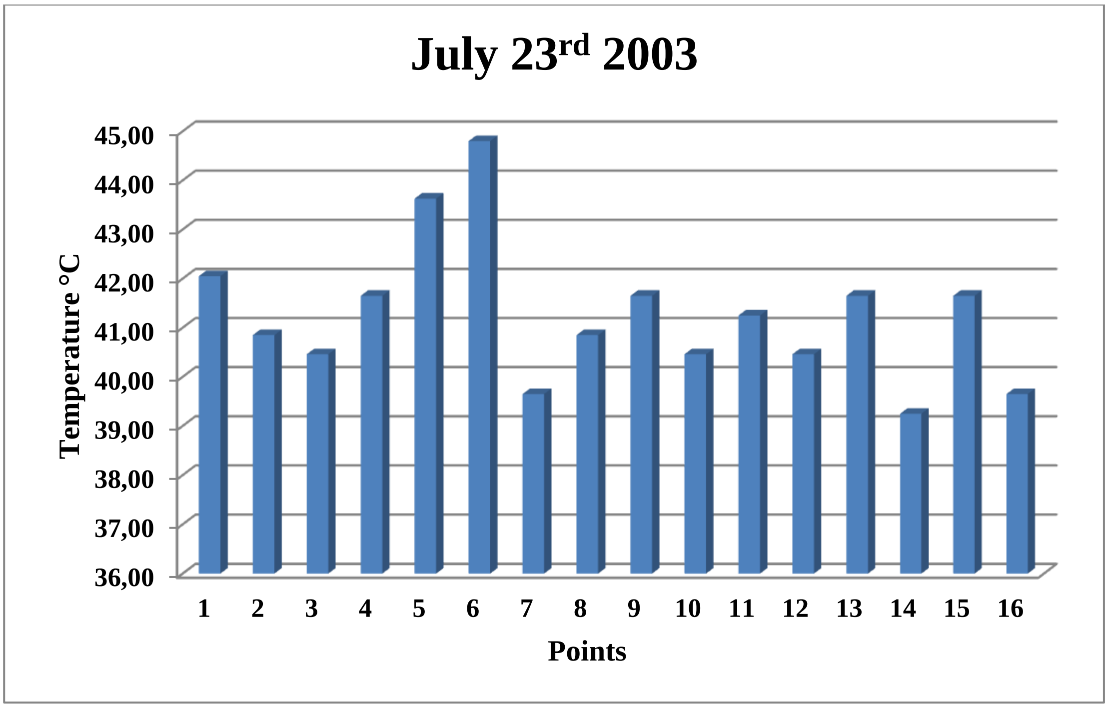


Figure 48: Temperatures of July 23rd 2003

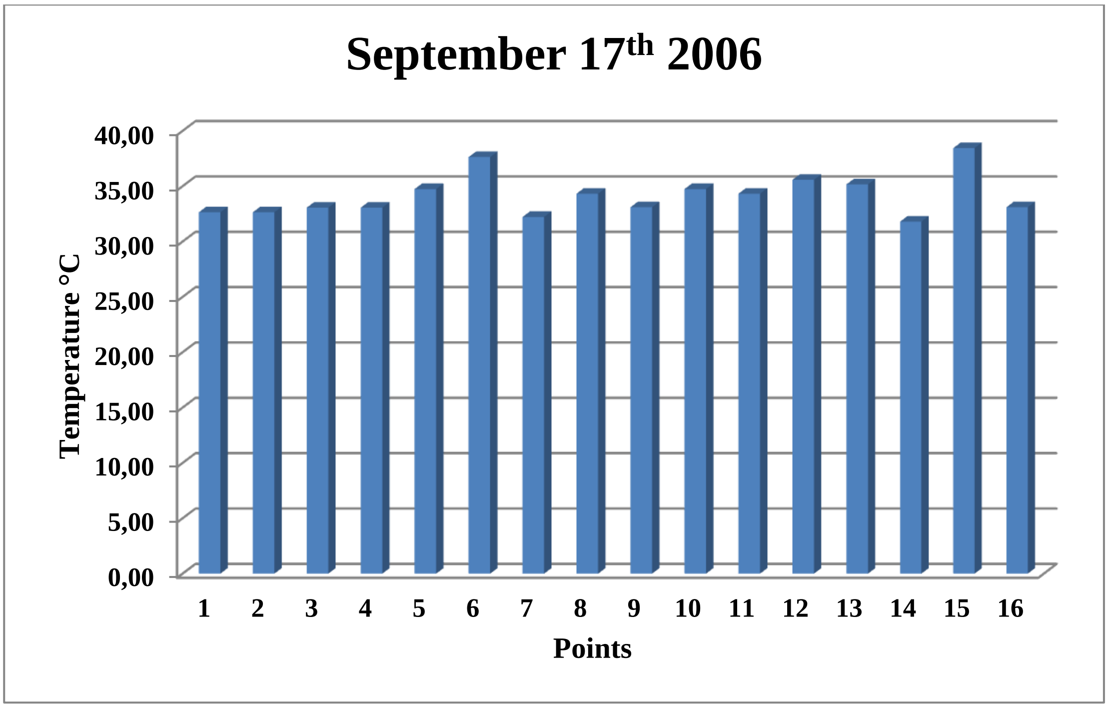


Figure 49: Temperatures of September 17th 2006

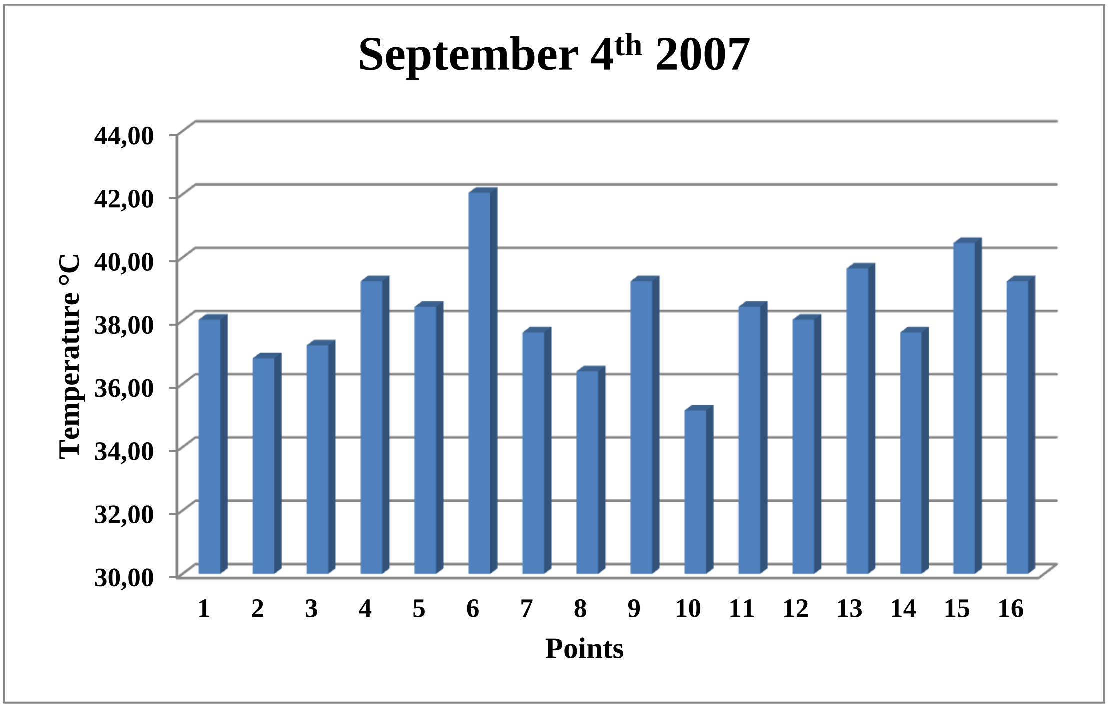


Figure 50: Temperatures of September 4th 2007

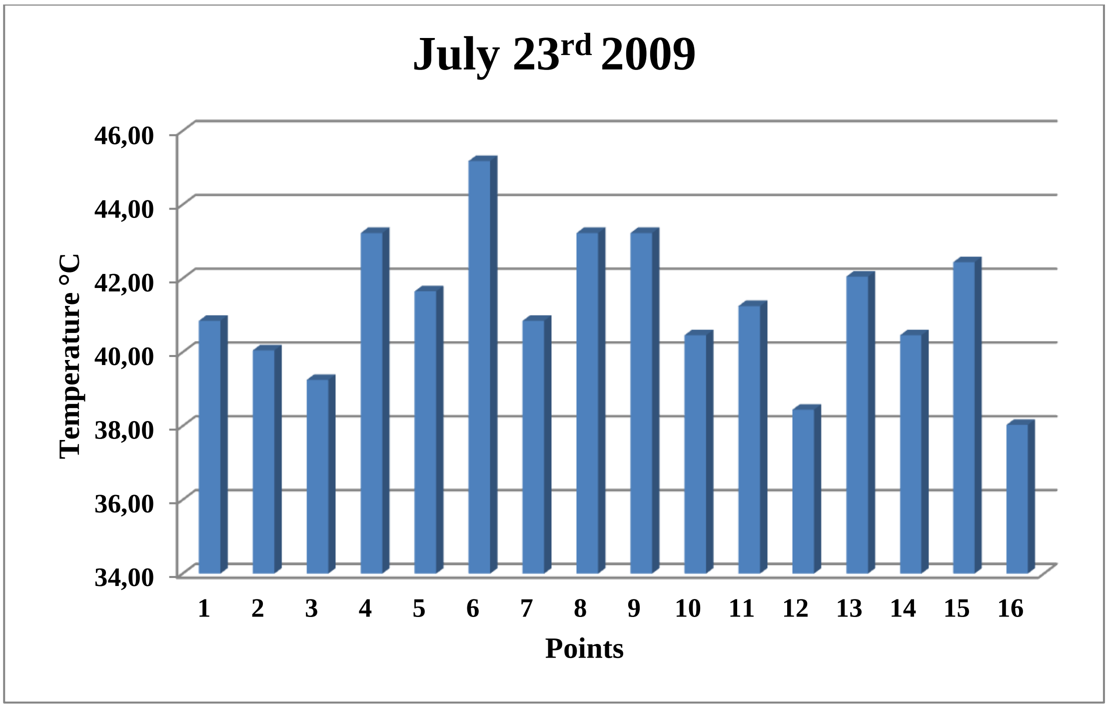


Figure 51: Temperatures of July 23rd 2009

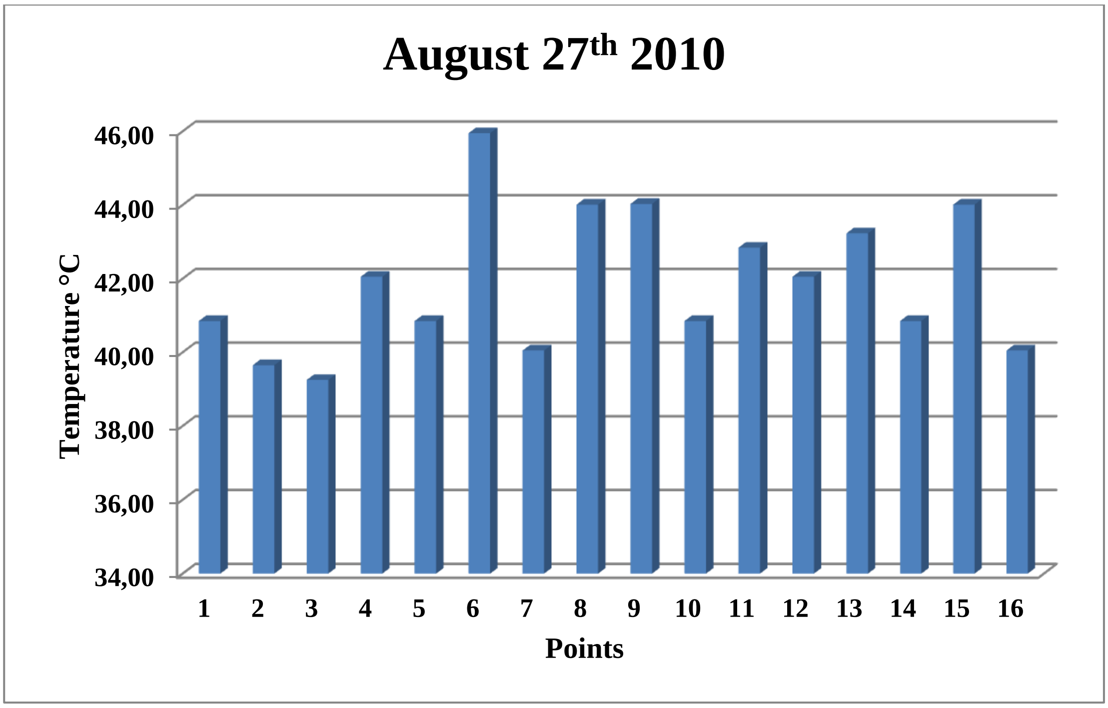


Figure 52: Temperatures of August 27th 2010

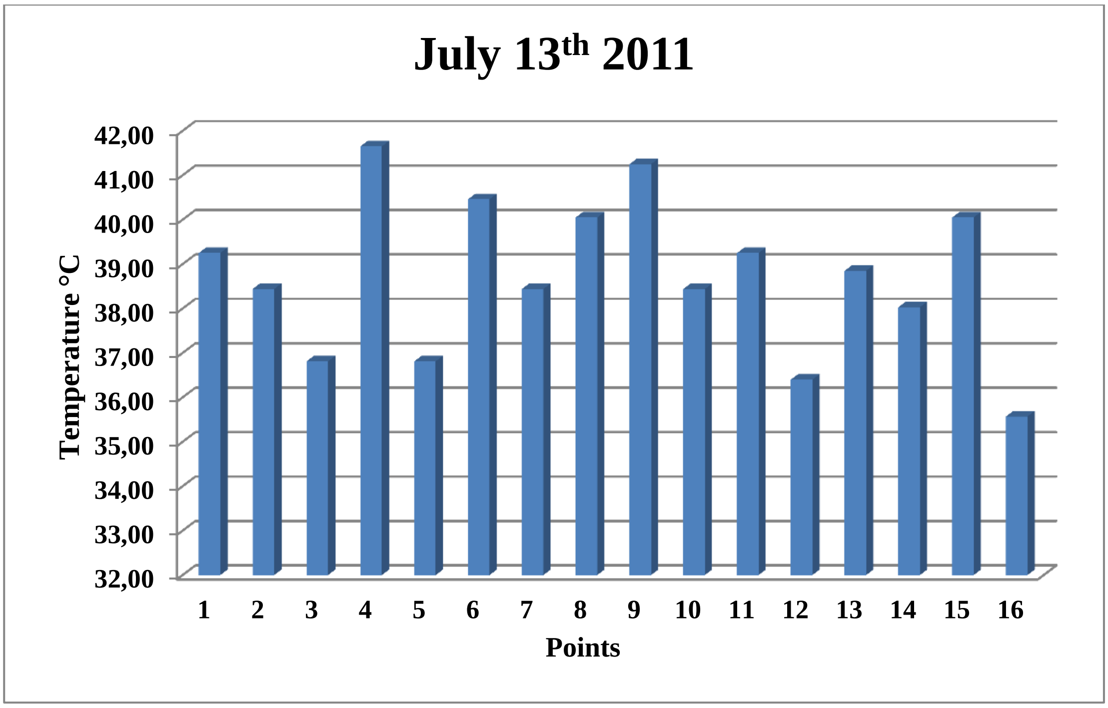


Figure 53: Temperatures of July 13th 2011

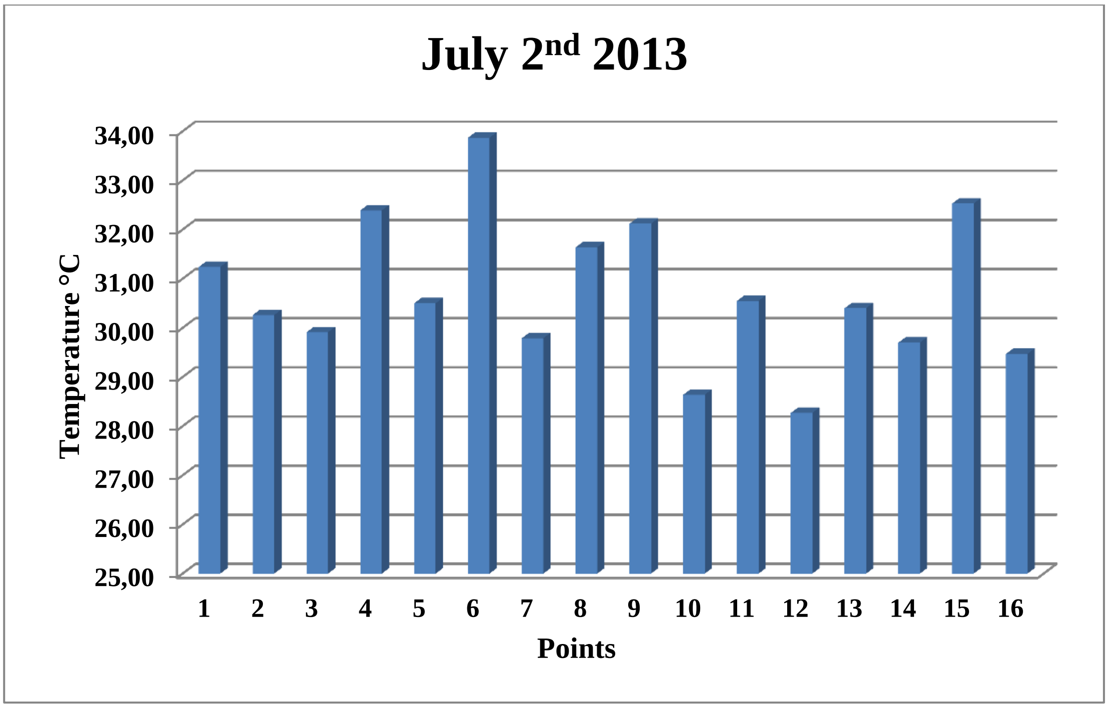


Figure 54: Temperatures of July 2nd 2013

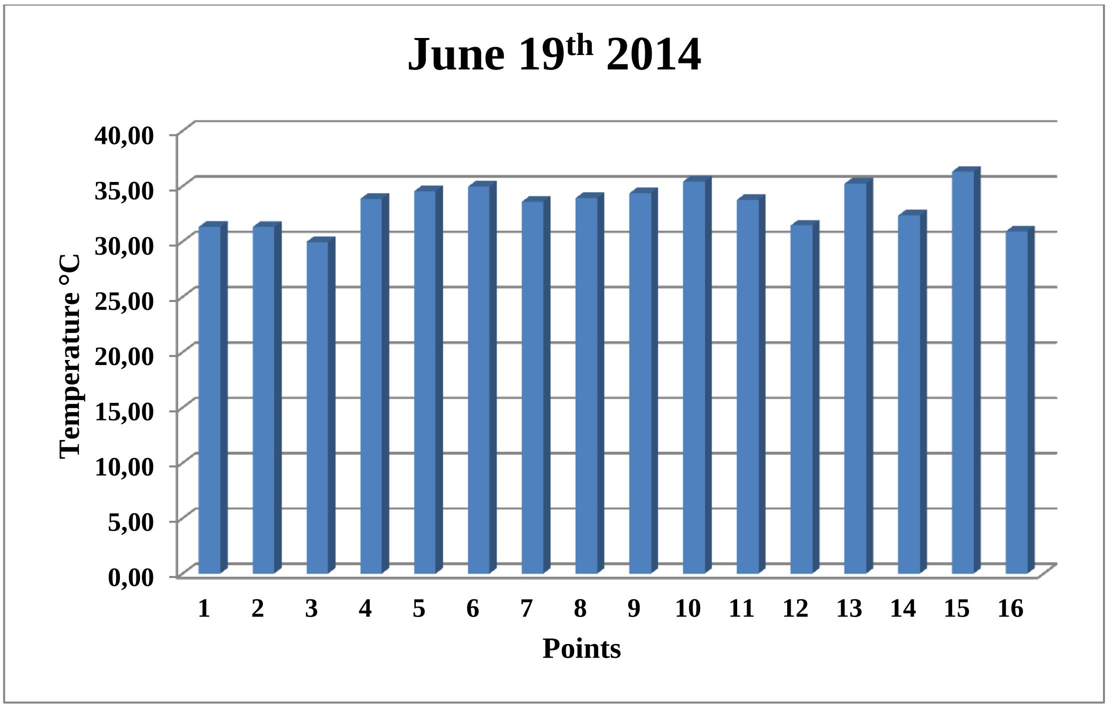


Figure 55: Temperatures of June 19th 2014

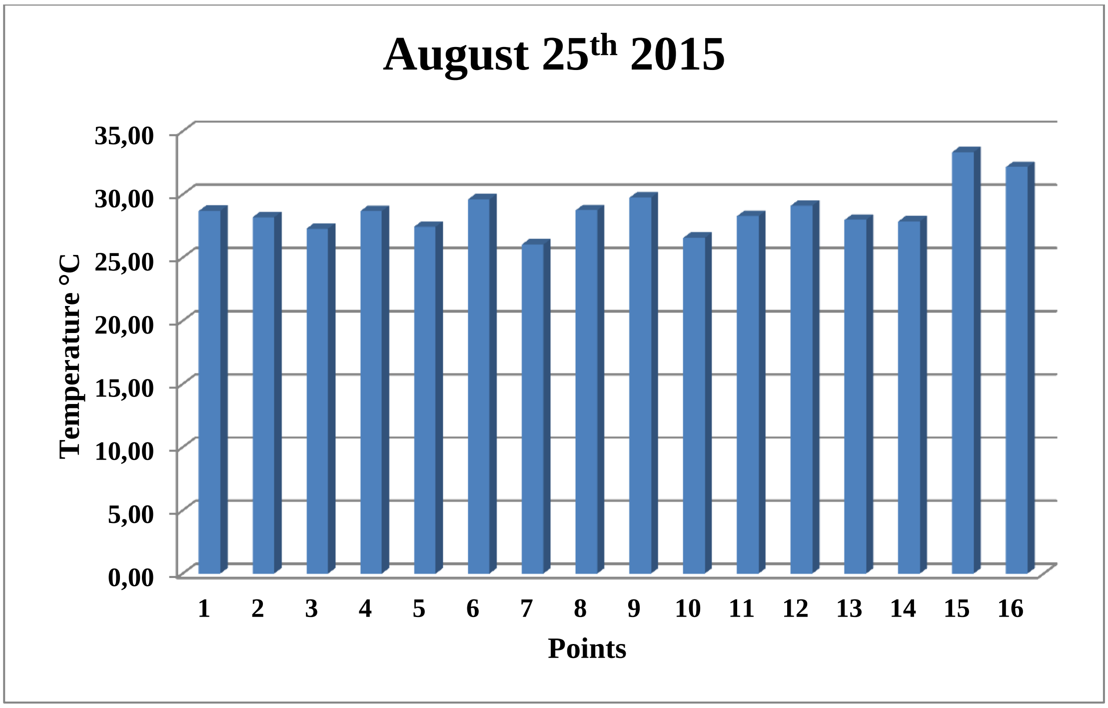


Figure 56: Temperatures of August 25th 2015

Then, a graph which shows the average temperature of each year was exported and shown in the Figure 57 below. With this graph is possible to observe the influence of the urban heat island effect through these years, in the area of Limassol. Discussions and conclusions about all the graphs and the results are mentioned in the next chapter.

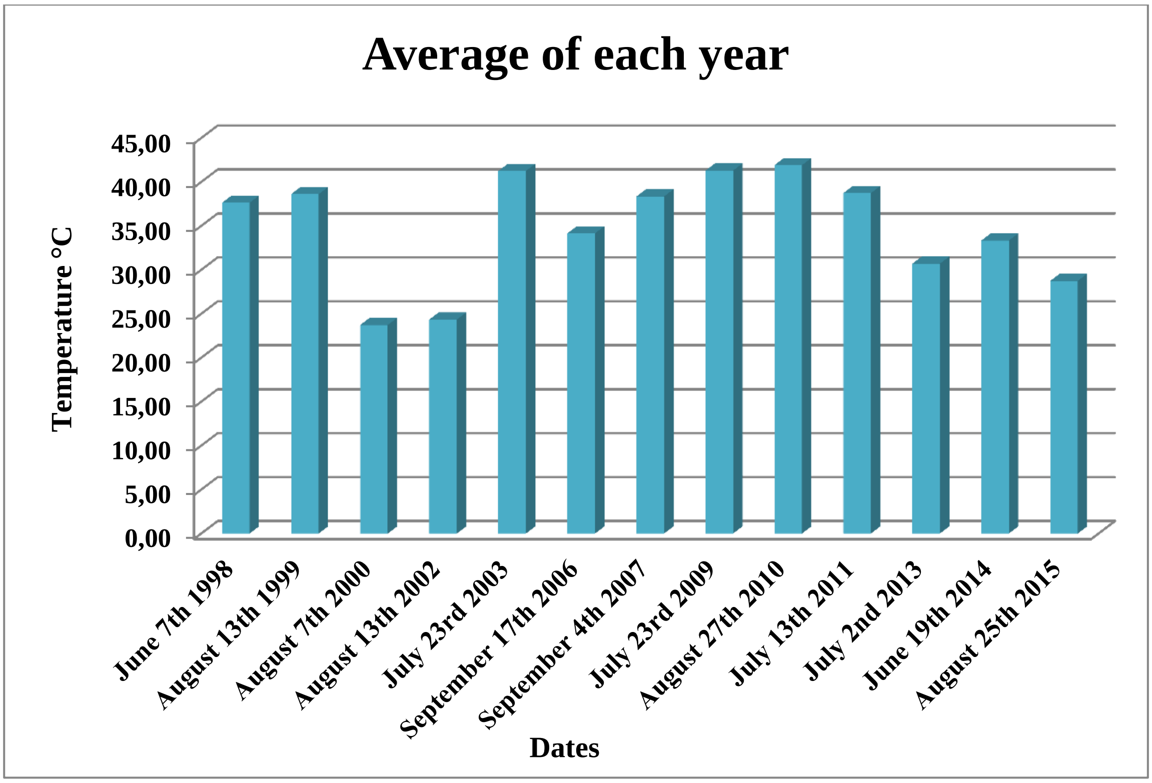


Figure 57: Average temperature of each year

Discussions

The urban heat island effect is a phenomenon where in general, the urban air temperature is higher than the surrounding rural environment temperature. According to this, the results which were exported from this thesis have to be relevant to this theory if the phenomenon does exist in Cyprus and more specifically in Limassol. In order to observe these assumptions, the results from the elaborated images and the graphs have to be analysed. Also, the two classified images which show the urban sprawl in Limassol in 2000 and 2012 were taken into account in order to set the points from which the temperatures were recorded. These two images are shown above in Figure 27 and Figure 28. Normally, if the urban heat island effect exists, the temperatures of the urban points (1-5) should be higher than the temperatures of the other points and as years pass, points 7 to 11 should have higher temperatures too. Initially, the graphs for each year is analysed and then more general observations are discussed.

In 1998, as it can be seen from the Figure 44, the temperatures ranged from 32,22°C to 42,44°C. In general, there were no noticeable fluctuations in the temperatures of each point and this shows that the urban heat island effect was not evident in 1998. If the phenomenon was existed then the temperatures of the points 14 to 16 should have been much lower than the temperatures of the other points, as the urban growth had not reached up those points in 1998.

From the satellite image of August of 1999, the results of the Figure 45 show that the temperatures ranged from 36,81°C to 40,45°C. There were many fluctuations in the values of the points with the highest at point 6. Also, temperatures of points 12 to 16 were higher than those of the urban points (1 to 5). This shows that the urban heat island effect did not exist in 1999.

In August of 2000, Figure 46 shows that the temperatures were very low for the normal standards of the season, with the lowest temperature to be 22,40°C and the highest 26,35°C. Maybe this is due to an error of the satellite or of the export of the results procedure. However, the urban heat island effect was not evident in 2000 too, as the temperatures of the rural points 15 and 16 were higher than the urban points.

In August of 2002 the temperatures of the points were also very low for the normal standards of the season, as shown in the Figure 47. The lowest temperature was 23,01°C and the highest was 27,84°C. Maybe there was error as it has been mentioned before for the temperatures of 2000. In general, the temperatures were quite the same in all the points, urban and rural. This observation shows that the urban heat island effect was not evident even in 2002.

In July of 2003 the temperatures were very high in comparison with the temperatures of 2000 and 2002. They ranged from 39,25°C to 44,80°C. However, the values of the urban points (1 to 5) in Figure 48 were higher than those of the rest points (rural points). This observation leads to the conclusion that the urban heat island effect started to appear in 2003.

The graph of September of 2006 in Figure 49 shows that the temperatures were stable in almost all the points. The lowest value was 31,80°C and the highest 38,44°C. There were not many fluctuations and something that was observed was the fact that the temperatures were quite high for the middle of September. Also, except from the rural point 15, the urban points (1 to 5) had higher temperatures than the rural points and this shows the existence of the urban heat island effect in 2006.

In September of 2007, the temperatures of the points fluctuated from 35,16°C to 42,05°C, high enough for the season. From the graph of the results in the Figure 50 it is not clear if the urban heat island effect influenced the temperatures because in some points are high and elsewhere are low.

In July of 2009, the values of the points were very high, with the lowest to be 38,03°C and the heist 45,18°C. In general, the urban points were higher than the rural points and the temperatures were very high in comparison with the previous years, as it can be seen in Figure 51.

The temperatures of August of 2010 and the July of 2011, in Figures 52 and 53 respectively, are also very high, like the temperatures of 2009. In 2010 the lowest temperature was 39,25°C and the highest was 45,95°C. From the graph of 2010 it is not clear if the urban heat island effect influenced the values of the points, because in some points are high and elsewhere are low. However, in the graph of 2011 it is very clear that the urban heat island effect exists, as the temperatures of the urban points are much higher than those of the rural temperatures. The lowest value in 2011 was 35,57°C and the highest 41,65°C. It is also obvious that the urban heat island effect has increased the temperatures of the area through these years.

After 2011 the graphs and the results of 2013, 2014 and 2015 were quite diversified as the temperatures were lower enough than those of 2009, 2010 and 2011. They were more closed to the values of 2002 and 2006 and this is not normal. Errors may have been caused in the conversion of the satellite images or from the data of the satellite (Landsat 8 OLI/TIRS).

In 2013 the temperatures fluctuated from 28,27°C to 33,87°C and the urban heat island effect was obvious, as the urban points had higher values than the rural points. This can be seen in Figure 54.

In 2014 and 2015 (Figures 55-56) the temperatures of the points were relatively closed and no big fluctuation was observed. The lowest temperature for June 2014 was 29,96°C and the highest was 36,32°C. As for the values of August of 2015, the lowest was 26,04°C and the highest was 33,35°C.

Disregarding the temperatures of the last 3 years (2013, 2014, 2015), the temperatures in the area of Limassol have been increased through these years and maybe this is due to the phenomenon of the urban heat island.

It is also observed that the points 6 and 15 had the highest temperatures in all the resulting graphs. They are both rural points and this is quite odd.

From the graph which shows the average temperature of each year (Figure 57) it is observed that the highest were in 2003, 2009 and 2010. However, this observation is not fairly valid, if the errors are taken into account.

The average value of each point, as well as the values of each point for each year, can be found in the Table 3 in the Appendices.

Conclusions – Recommendations

Urban growth leads the large cities to become main habitats and as a result many environmental and socioeconomic problems are caused. Since this phenomenon is not controlled and is evolving rapidly, the impacts on humans and on the environment are huge.

As this phenomenon is not easy to be avoided, some planning and design processes, that include environmentally sustainable urban and rural reconstruction programs, can be made in order to improve a city and make it worthy to live and work in it. Also, it is important for the citizens to understand the difference between sustainable and unsustainable development practices for the city, in order to preserve a high quality of life for citizens in future generations.

One of the biggest environmental problems that have occurred due to this fact is the urban heat island effect. The urban heat island effect is a phenomenon that increases year by year all around the world and especially in big urban cities and has negative impacts in several sectors. If this phenomenon continues to rise, it will double the urban to rural thermal ratio and thus increase the effects on the environment of a city or region.

To examine the impact of this phenomenon in Limassol area, a procedure had to be followed as discussed above. Through this process satellite images were received from the Earth Explorer online software of USGS Glovis which is easy to be used and very practical, as it has a wide range of satellite imagery that can be obtained and processed easily and quickly.

For the processing of satellite images the ERDAS IMAGINE CLASSIC INTERFACE software was used, through which the images were converted from Digital numbers in temperature by the application of simple formulas in Modeler. Also through this software all the images were associated with each other and results were derived for the same points in order the way, in which temperatures were taken for each of the points, to be accurate.

Through the classified images which were examined, the phenomenon of urban sprawl in the Limassol area from 2000 until 2012 was intensely observed. Therefore, the appearance of the phenomenon of urban heat island was anticipated.

Through the visualization of the results which were obtained through graphs for each year, the influence of urban heat island effect was observed to some extent in the Limassol area. The observation of the temperature increase the last 17 years was mainly done. Also in some of the years which were tested, increased temperatures were observed in urban areas than in rural.

Initially, in the present study the influence of the phenomenon of the urban heat island in relation to urban sprawl was examined. Nevertheless, this effect may be caused due to other factors, such as location, altitude, distance from the sea, vegetation, population etc., which are likely to increase the phenomenon and which will be examined in a future study.

Despite the negative impacts that urban sprawl has on the environment and on people's lives, this trend does not seem to decline, and as a result there is greater need for the development and the implementation of strategies for environmentally sustainable urban and rural reconstruction.

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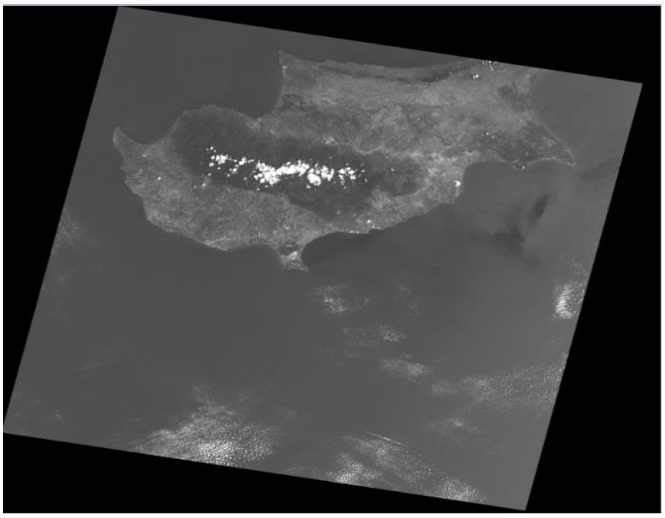
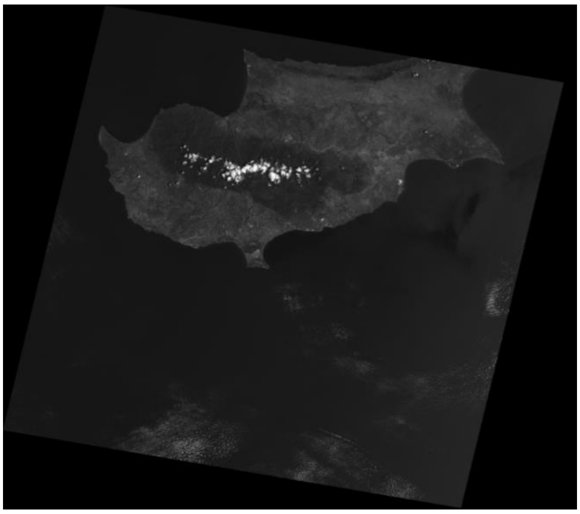
APPENDICES

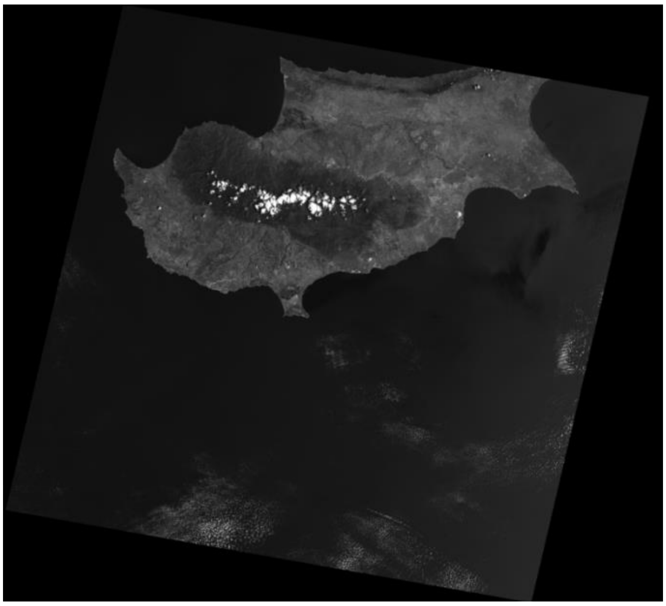
Appendix A - Images taken from Earth Explorer from 1998 to 2015

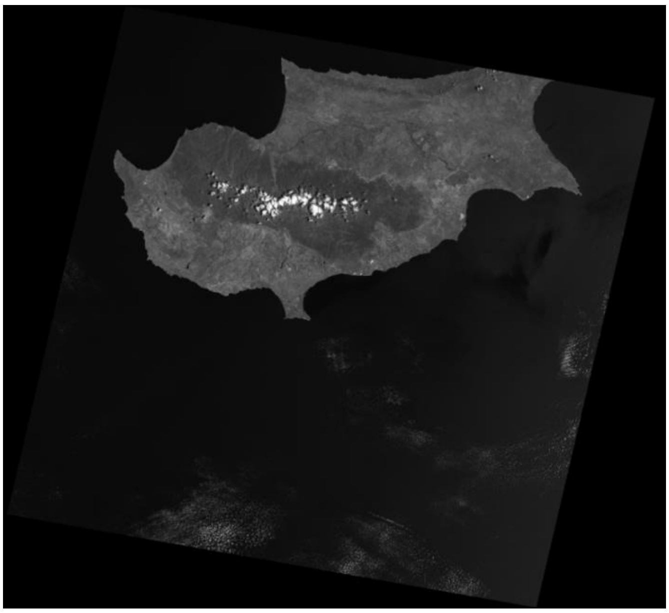
By receiving the satellite images from the Earth Explorer, all the band images were taken too. From L4-5 TM were taken 7 bands for each satellite image, from L7 ETM+ SLC-on (1999-2003) and L7 ETM+ SLC-off (2003-present) 8 different band images were received from each image and from L8 OLI/TIRS 11 different band images were received from each satellite image. All these band images are shown in Figures 34-50 below.

June 7th 1998 –L4-5 TM – Bands 1-7









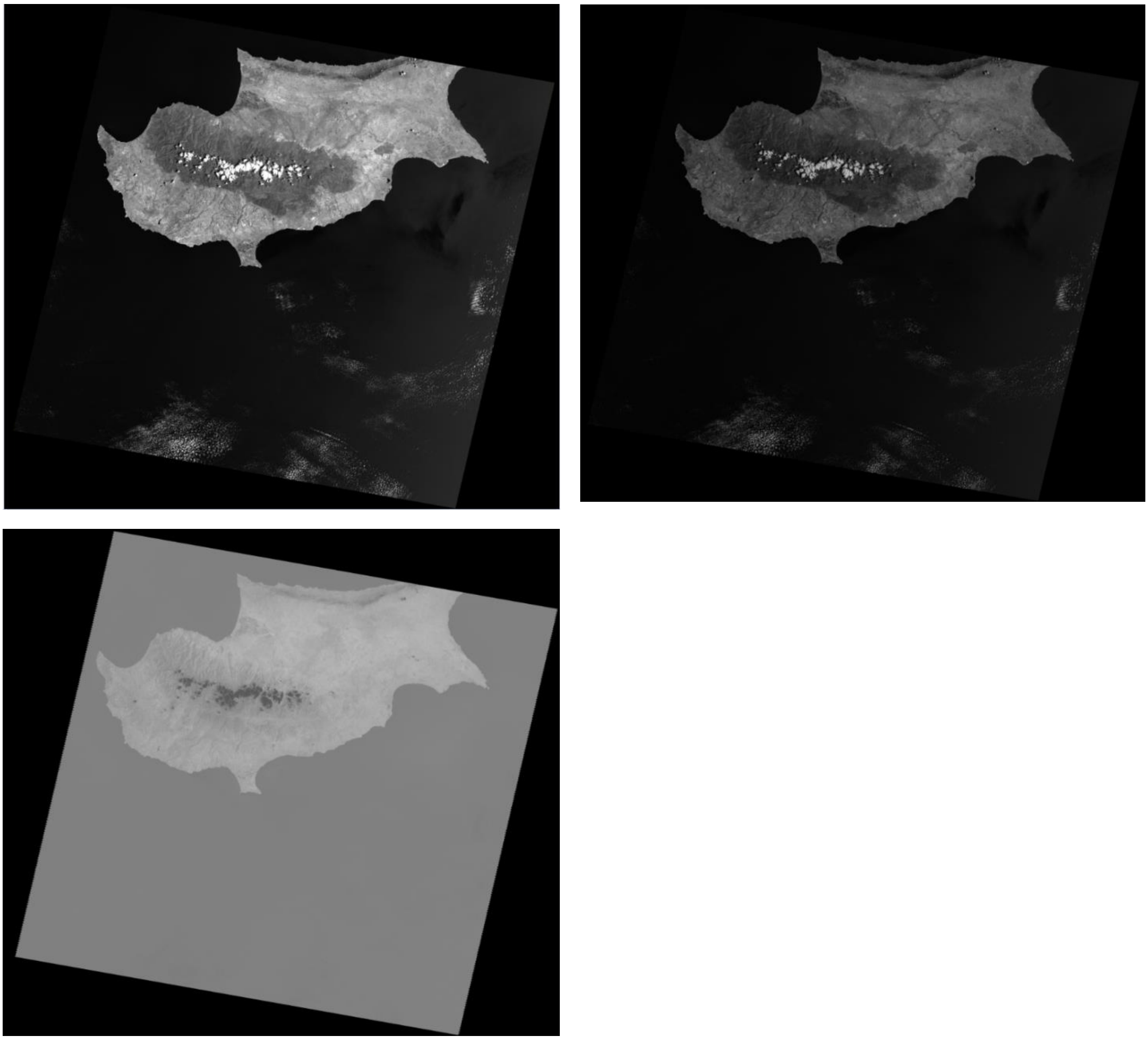
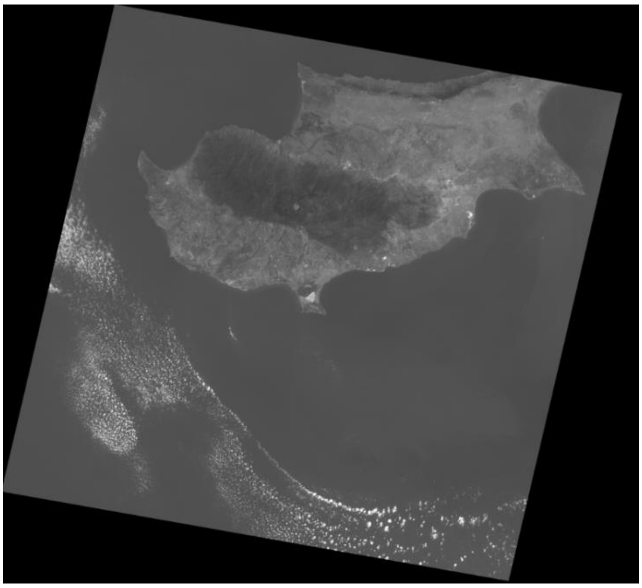
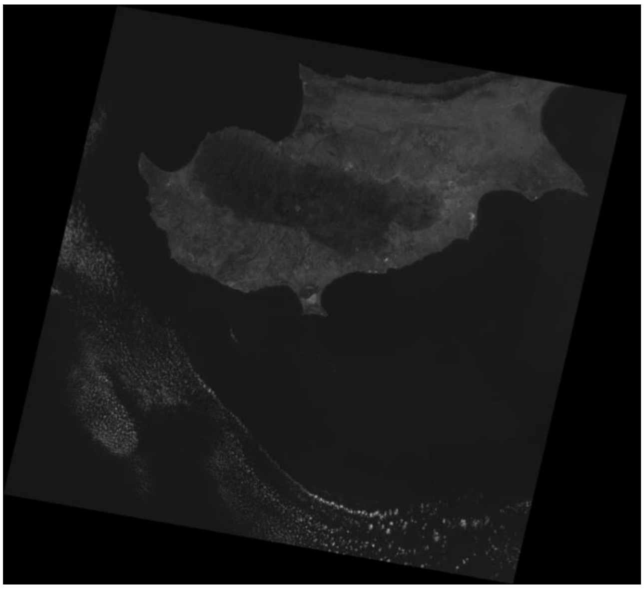
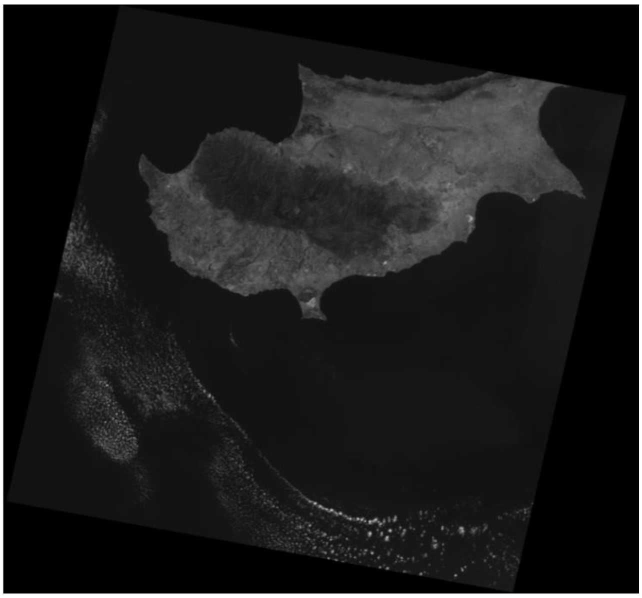


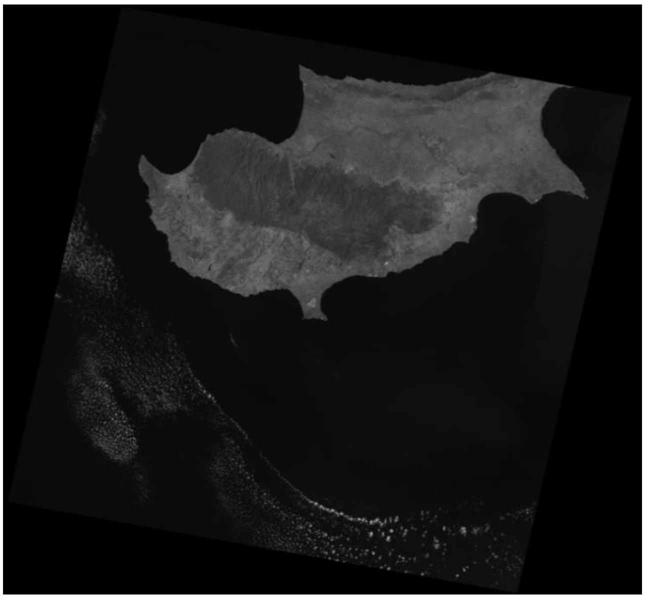
Figure 58: June 7th 1998 – L4-5 TM – Bands 1-7

August 13th 1999 – L4-5 TM – Bands 1-7









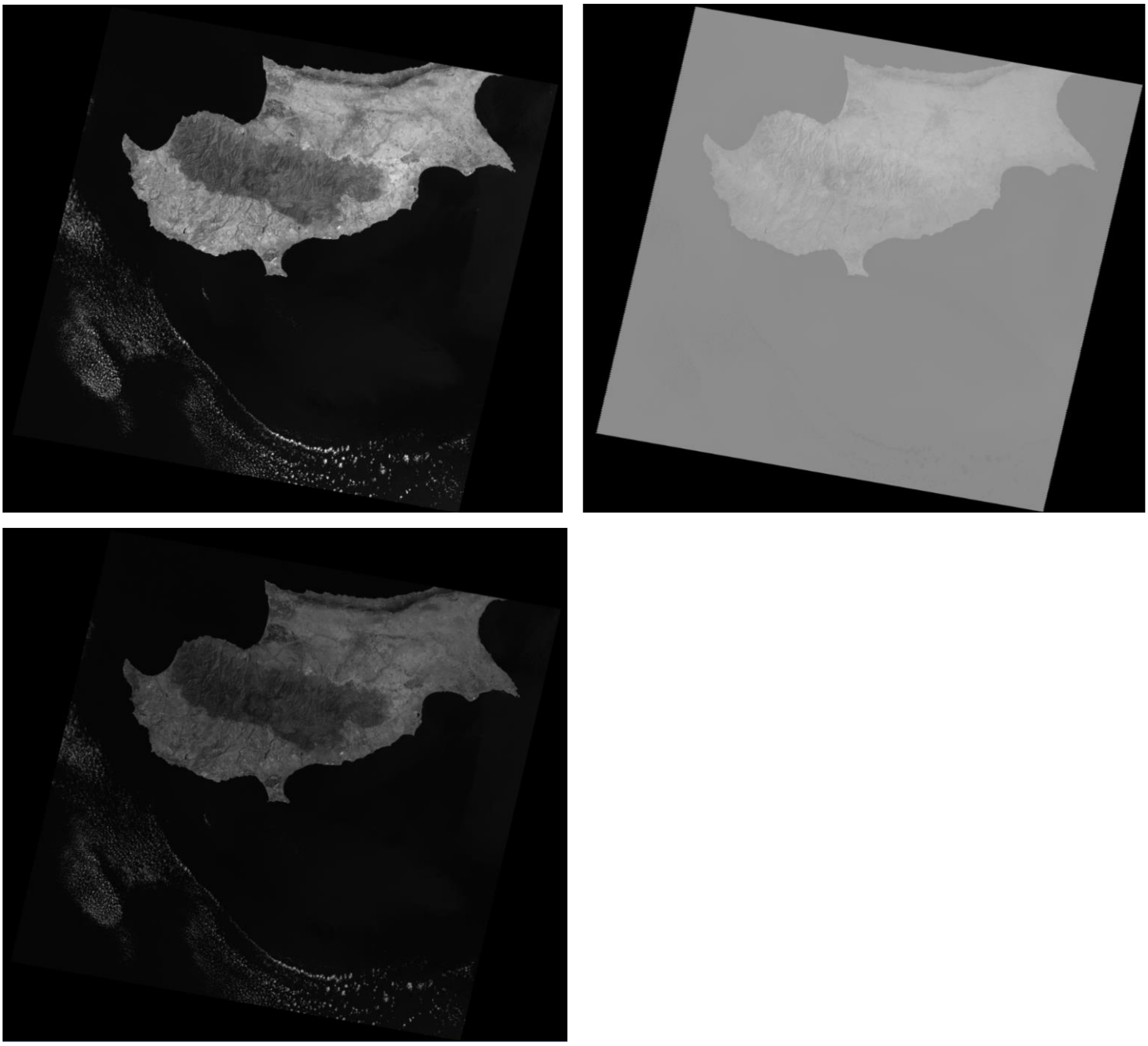
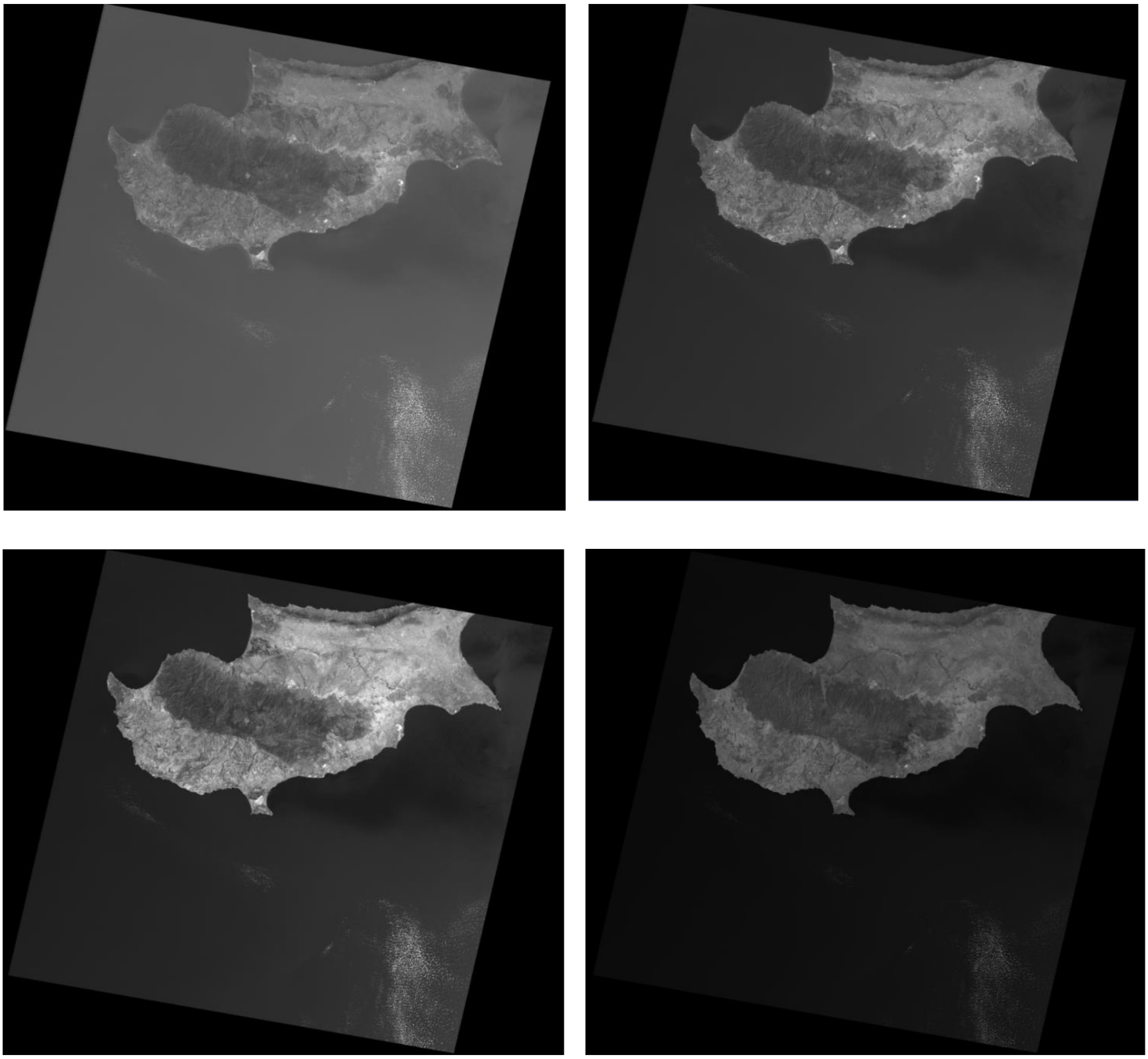


Figure 59: August 13th 1999 – L4-5 TM – Bands 1-7

August 7th 2000 - L7 ETM+ SLC-on (1999-2003) – Bands 1-8



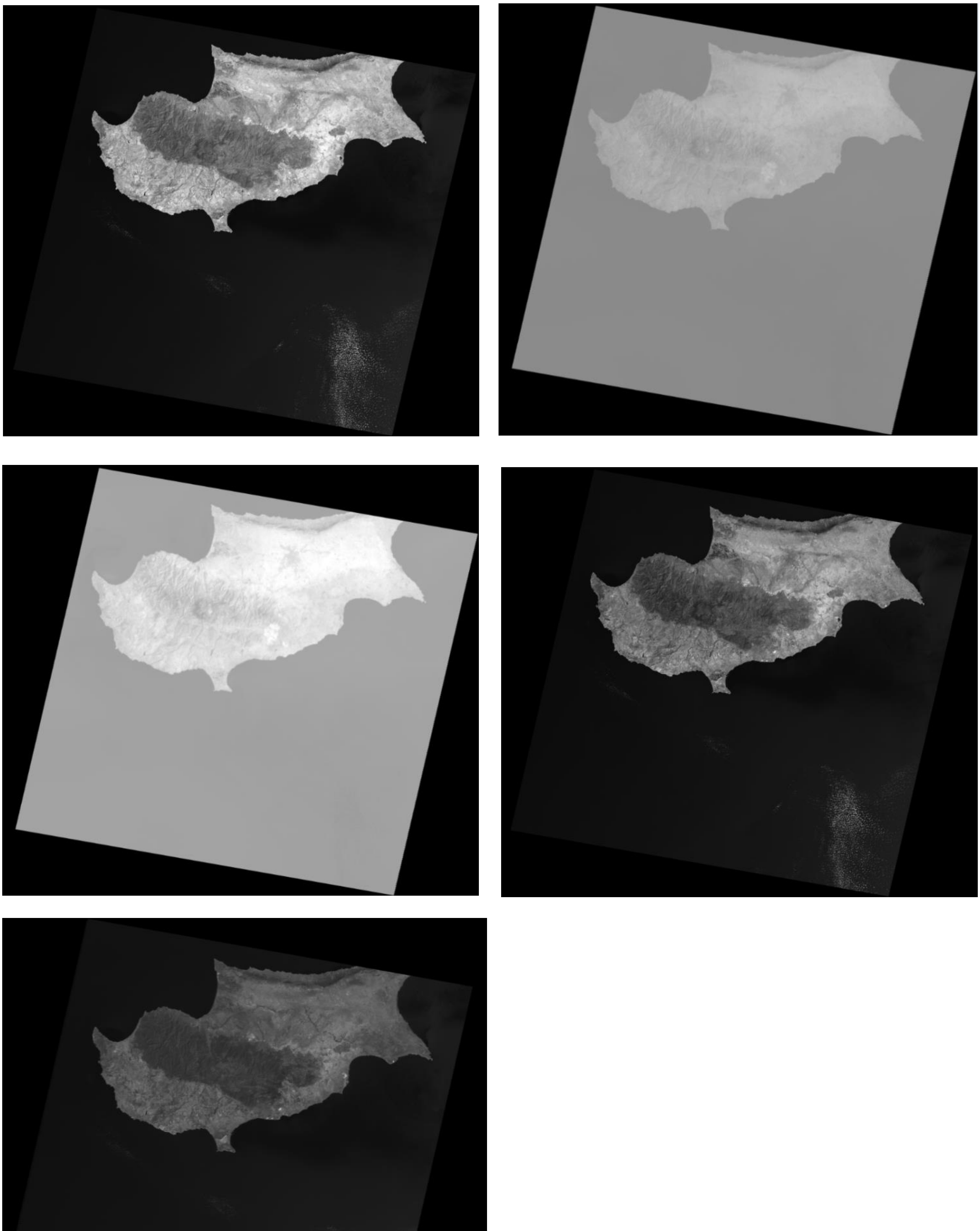
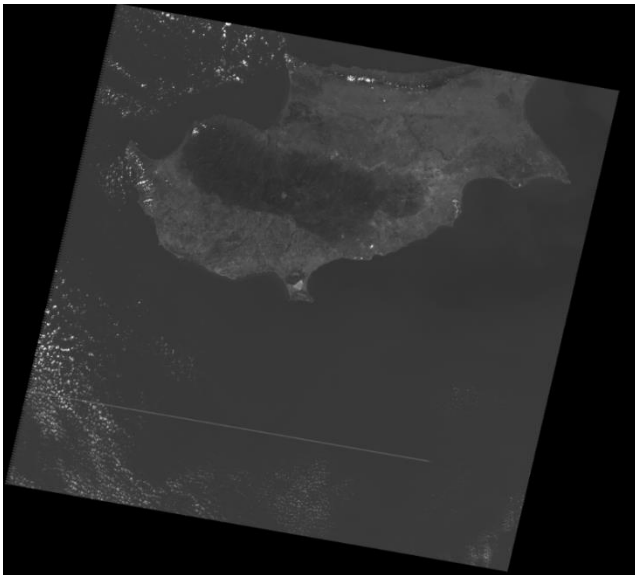
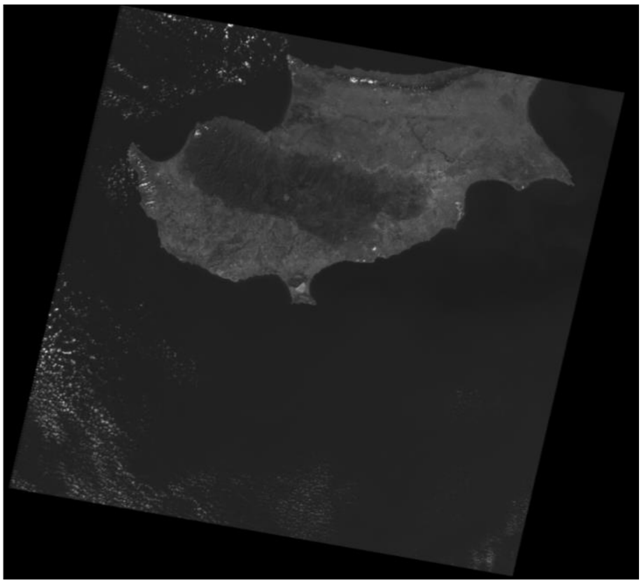
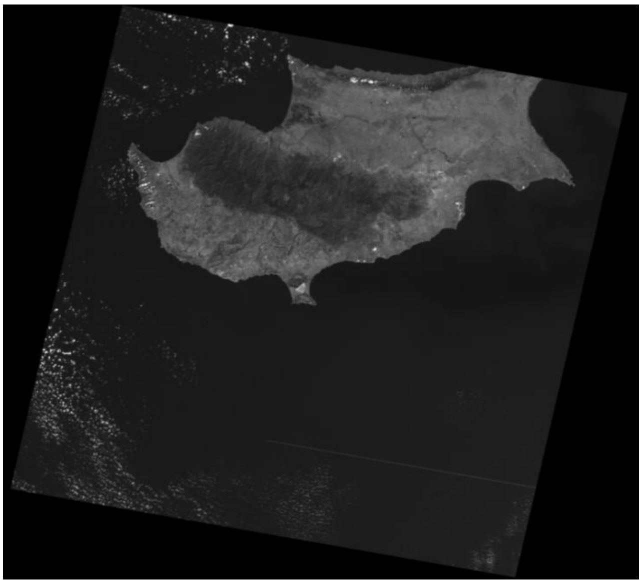
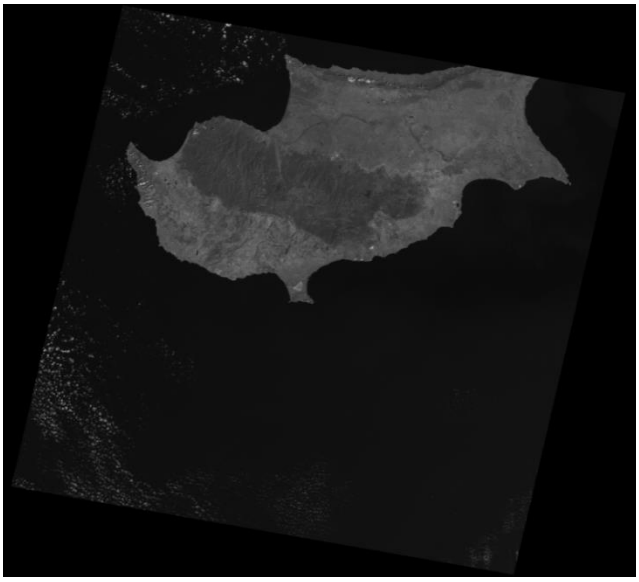
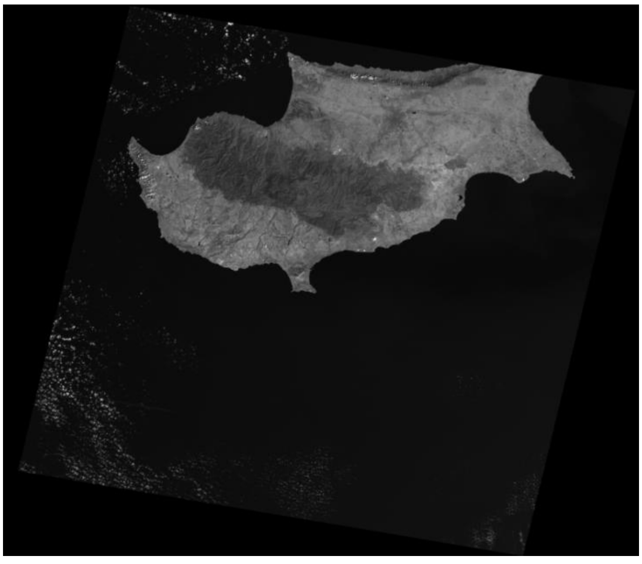
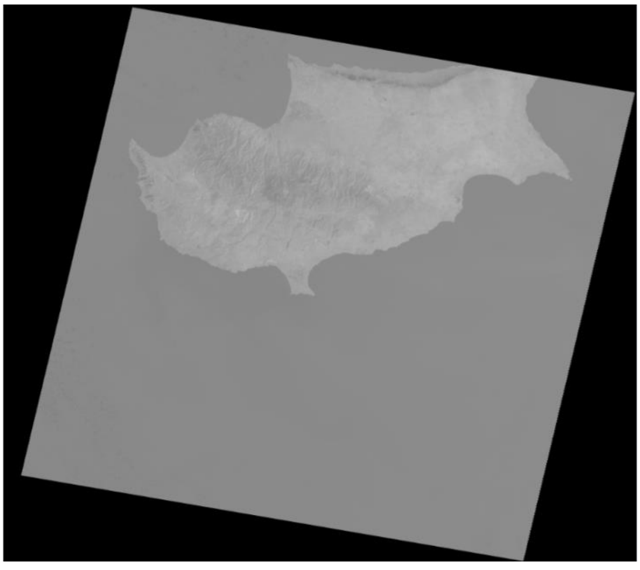
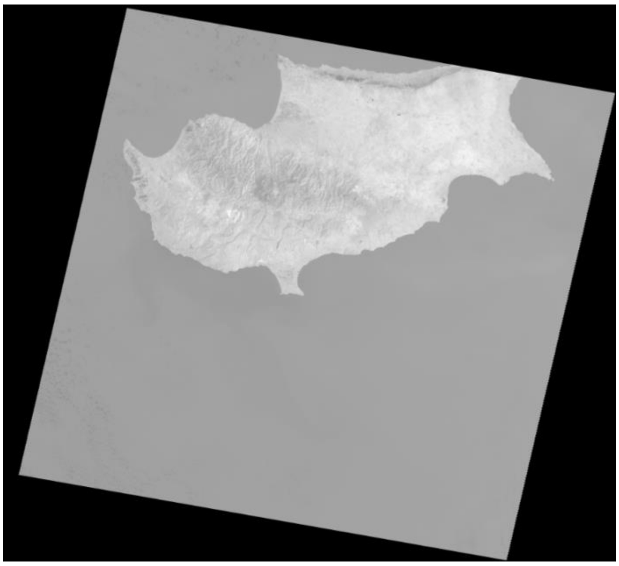
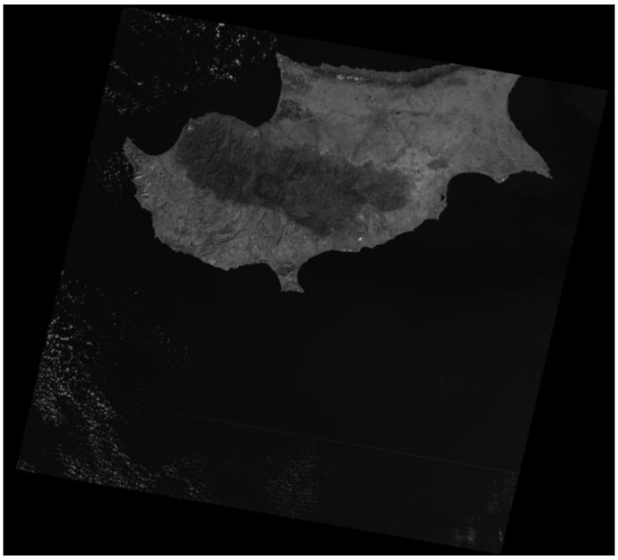


Figure 60: August 7th 2000 - L7 ETM+ SLC-on (1999-2003) – Bands 1-8

August 26th 2001 - L7 ETM+ SLC-on (1999-2003) – Bands 1-8





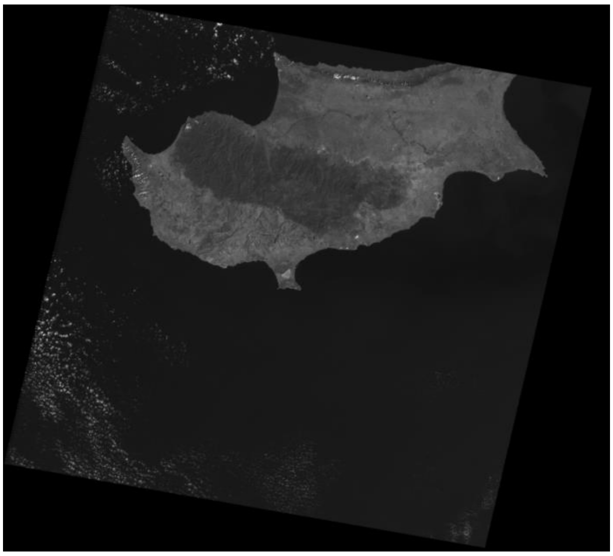
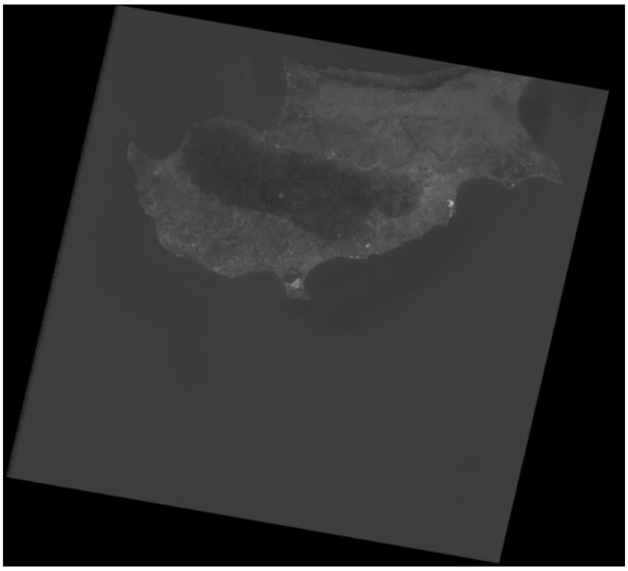
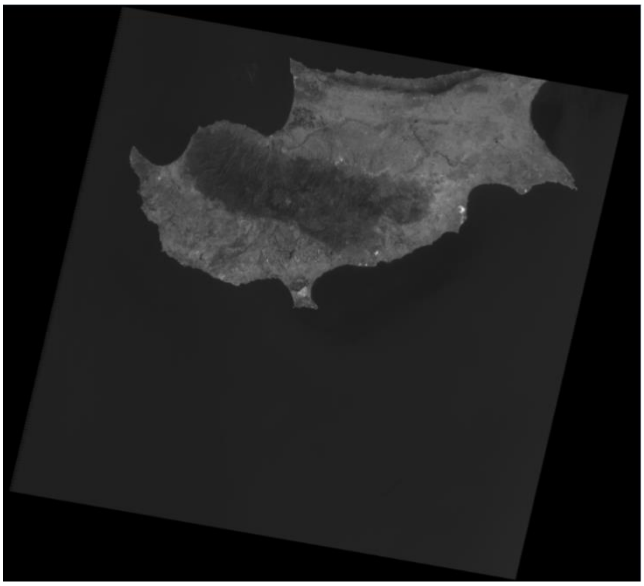
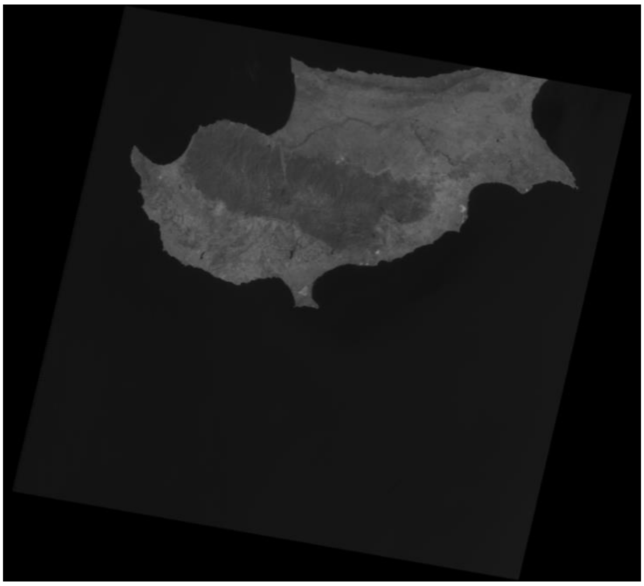
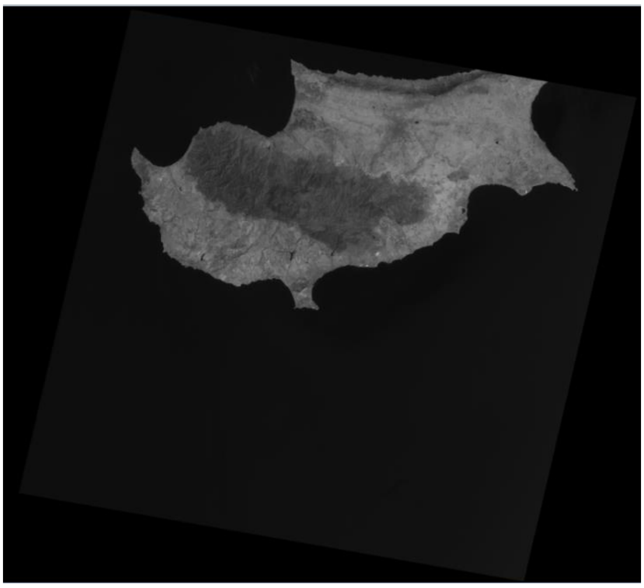
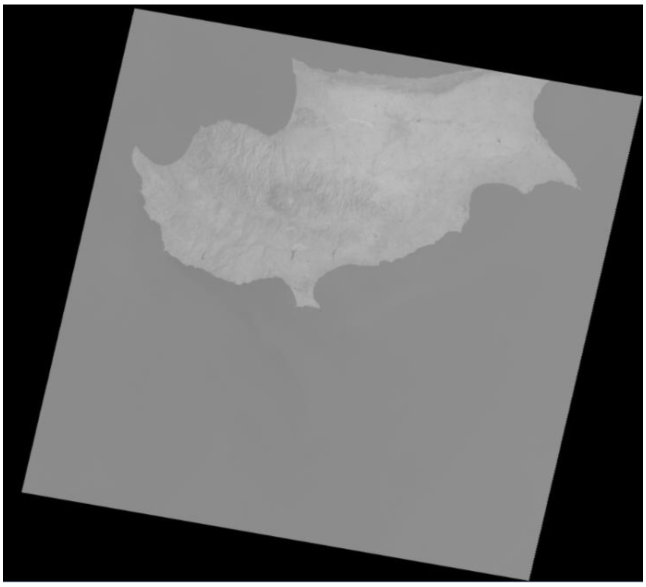
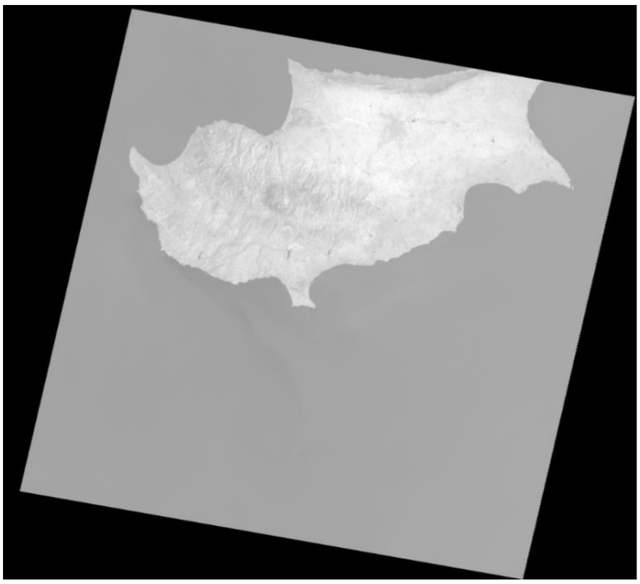
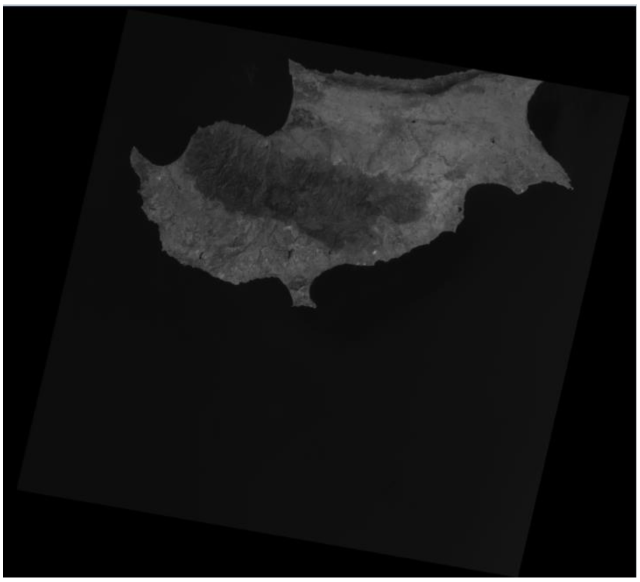


Figure 61: August 26th 2001 – L7 ETM+ SLC-on (1999-2003) – Bands 1-8

August 13th 2002 - L7 ETM+ SLC-on (1999-2003) – Bands 1-8



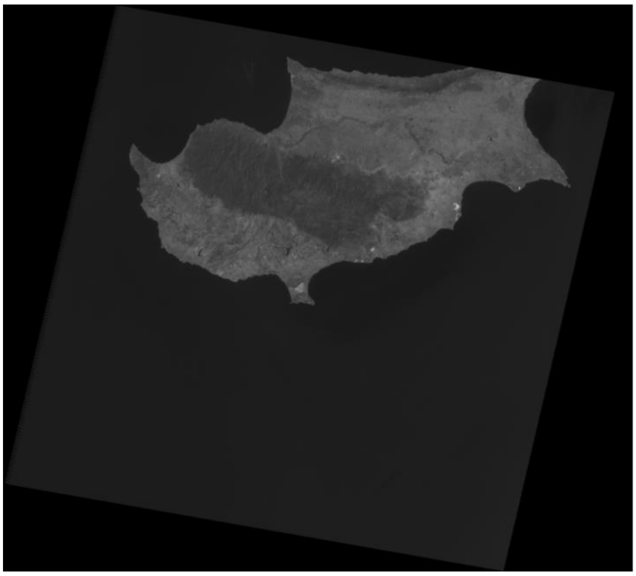
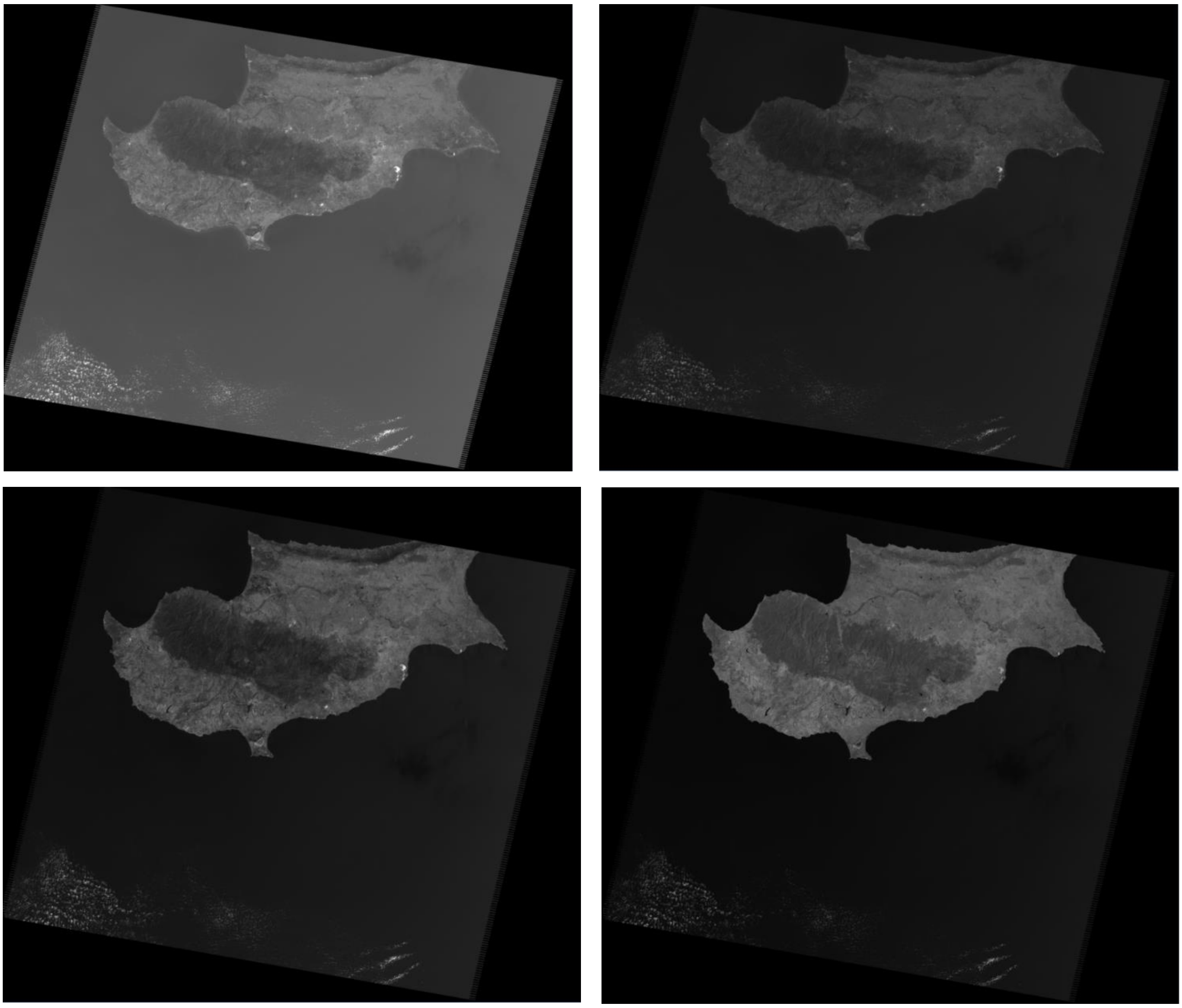


Figure 62: August 13th 2002 - L7 ETM+ SLC-on (1999-2003) – Bands 1-8

July 23rd 2003 – L4-5 TM – Bands 1-7



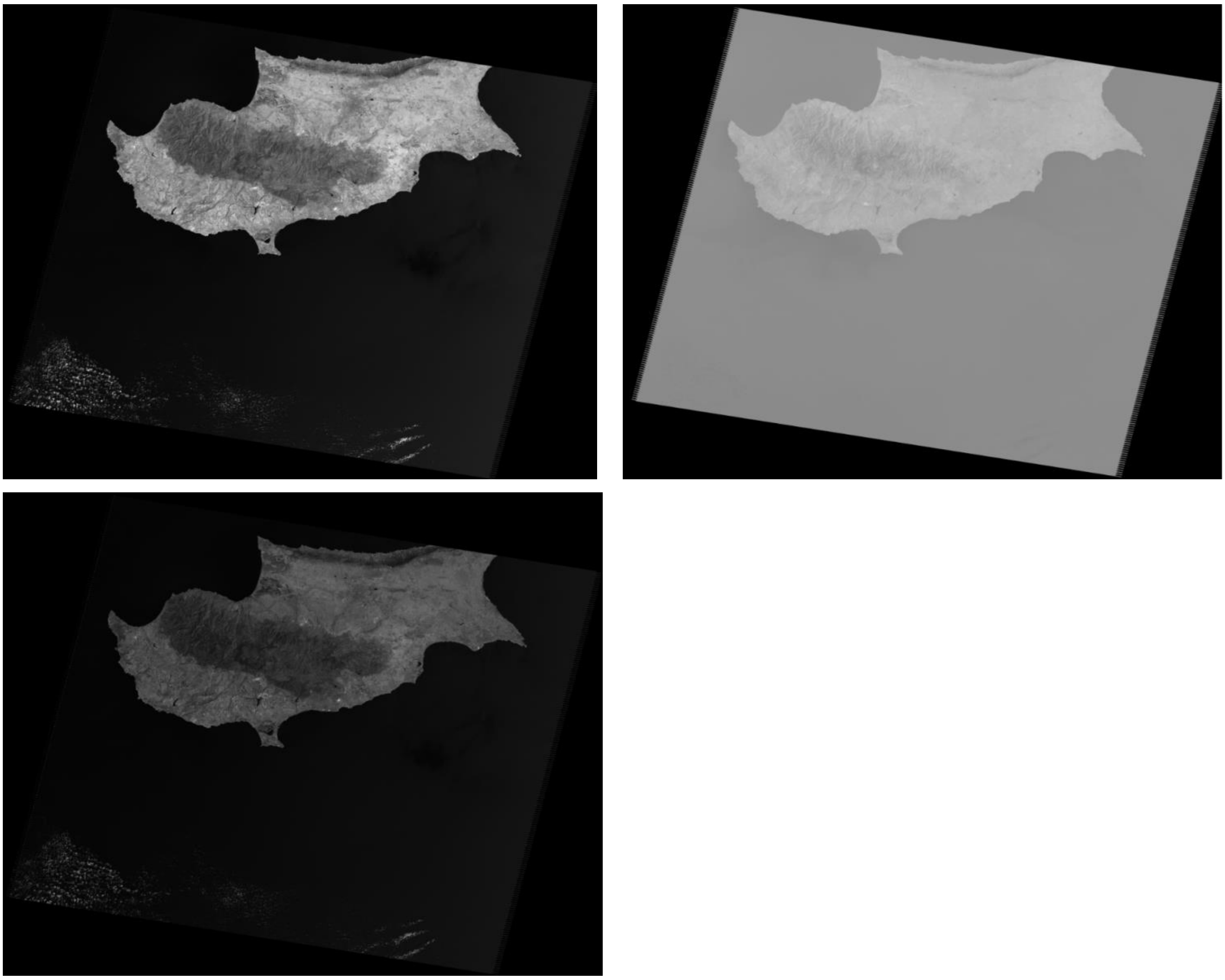
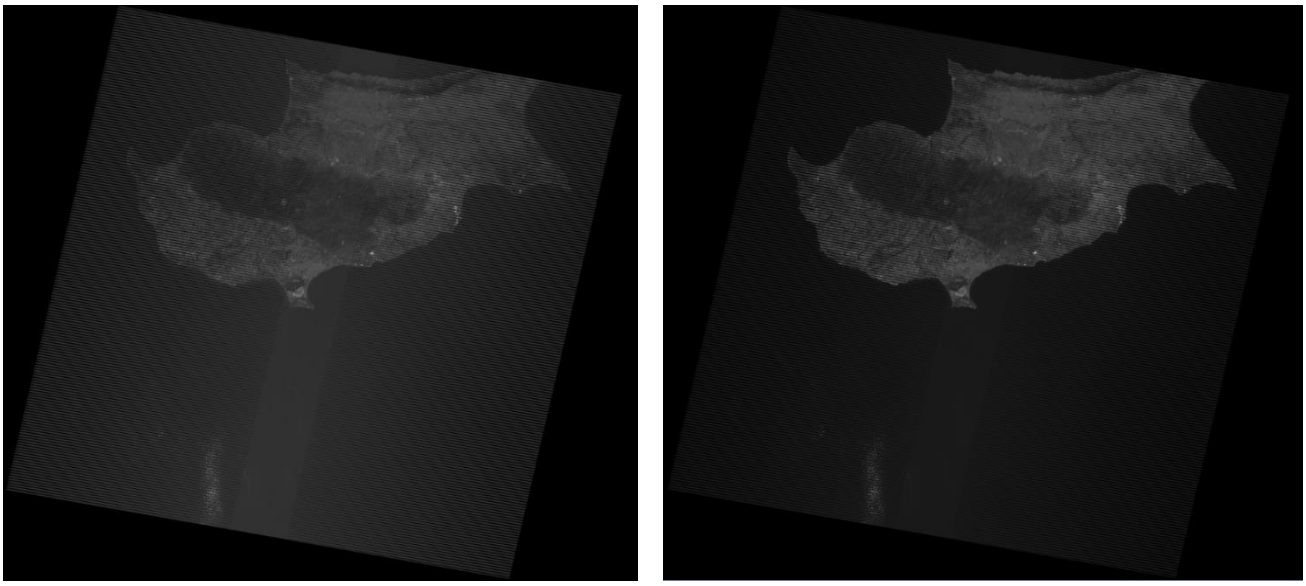
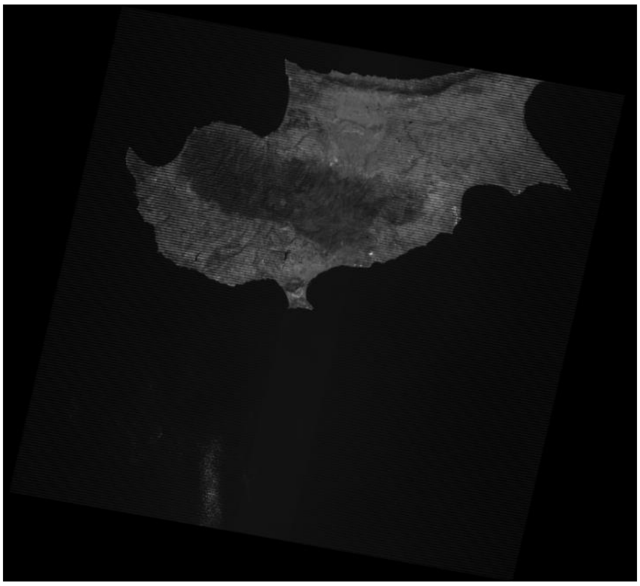
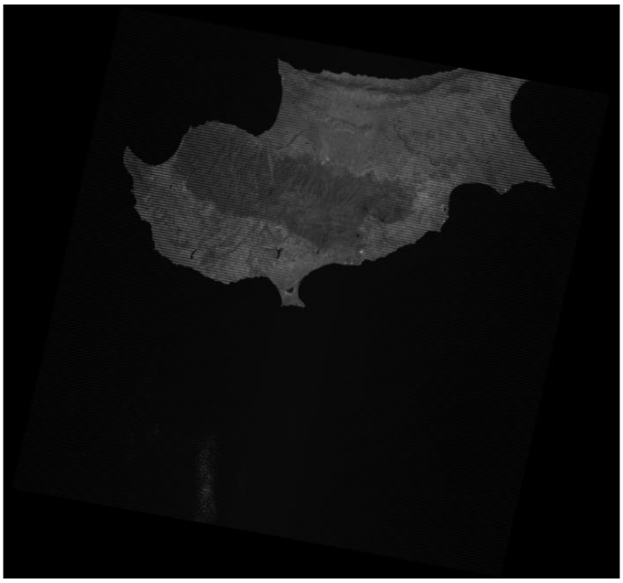
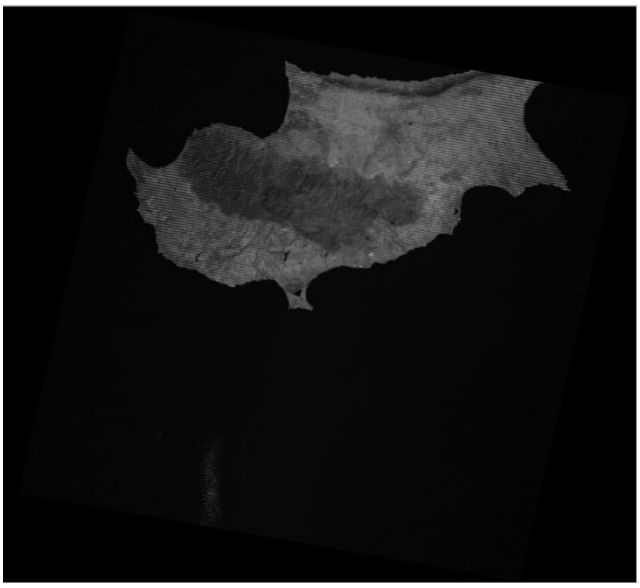
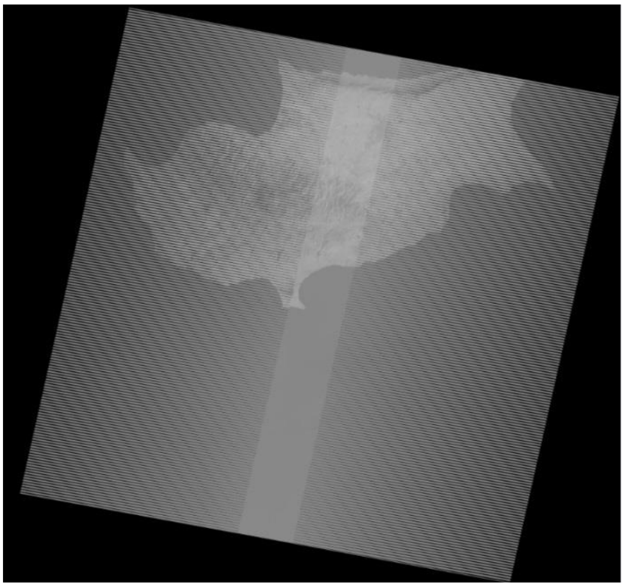
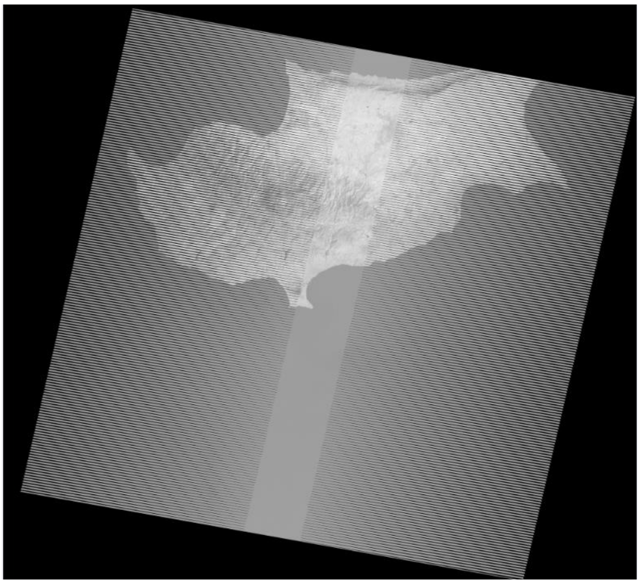
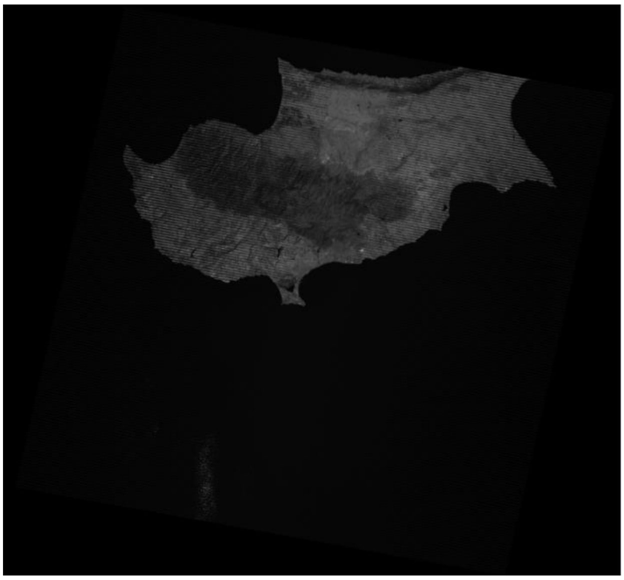


Figure 63: July 23rd 2003 – L4-5 TM – Bands 1-7

September 19th 2004 - L7 ETM+ SLC-off (2003-present) – Bands 1-8



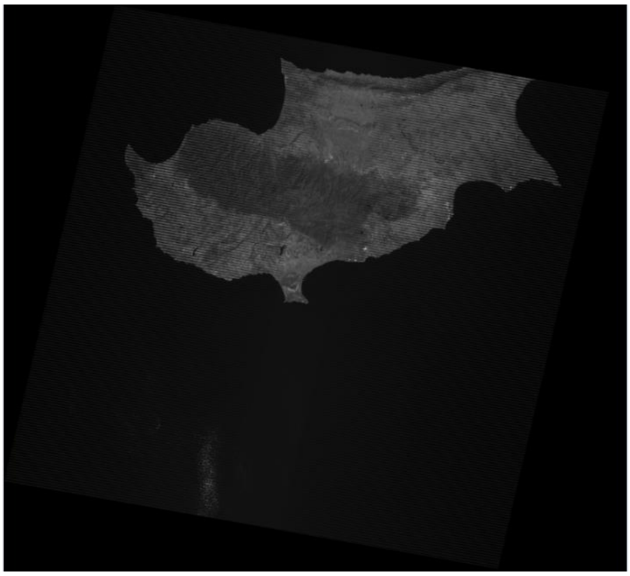
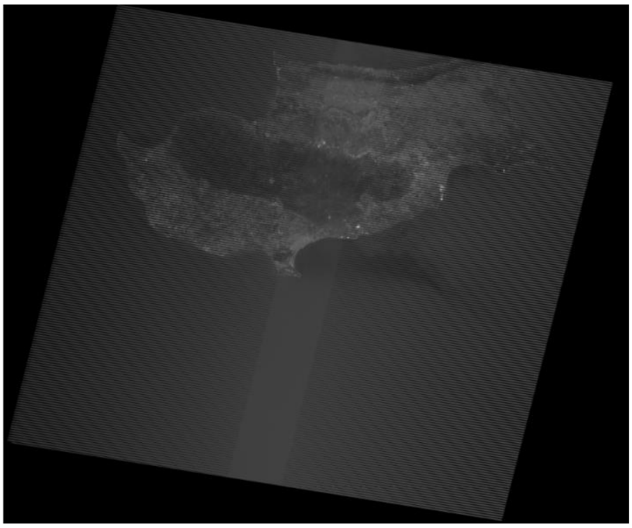
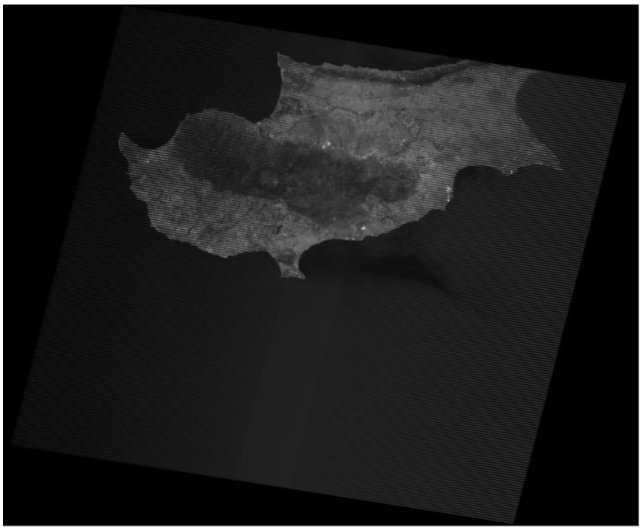


Figure 64: September 19th 2004 - L7 ETM+ SLC-off (2003-present) – Bands 1-8

June 18th 2005 - L7 ETM+ SLC-off (2003-present) – Bands 1-8





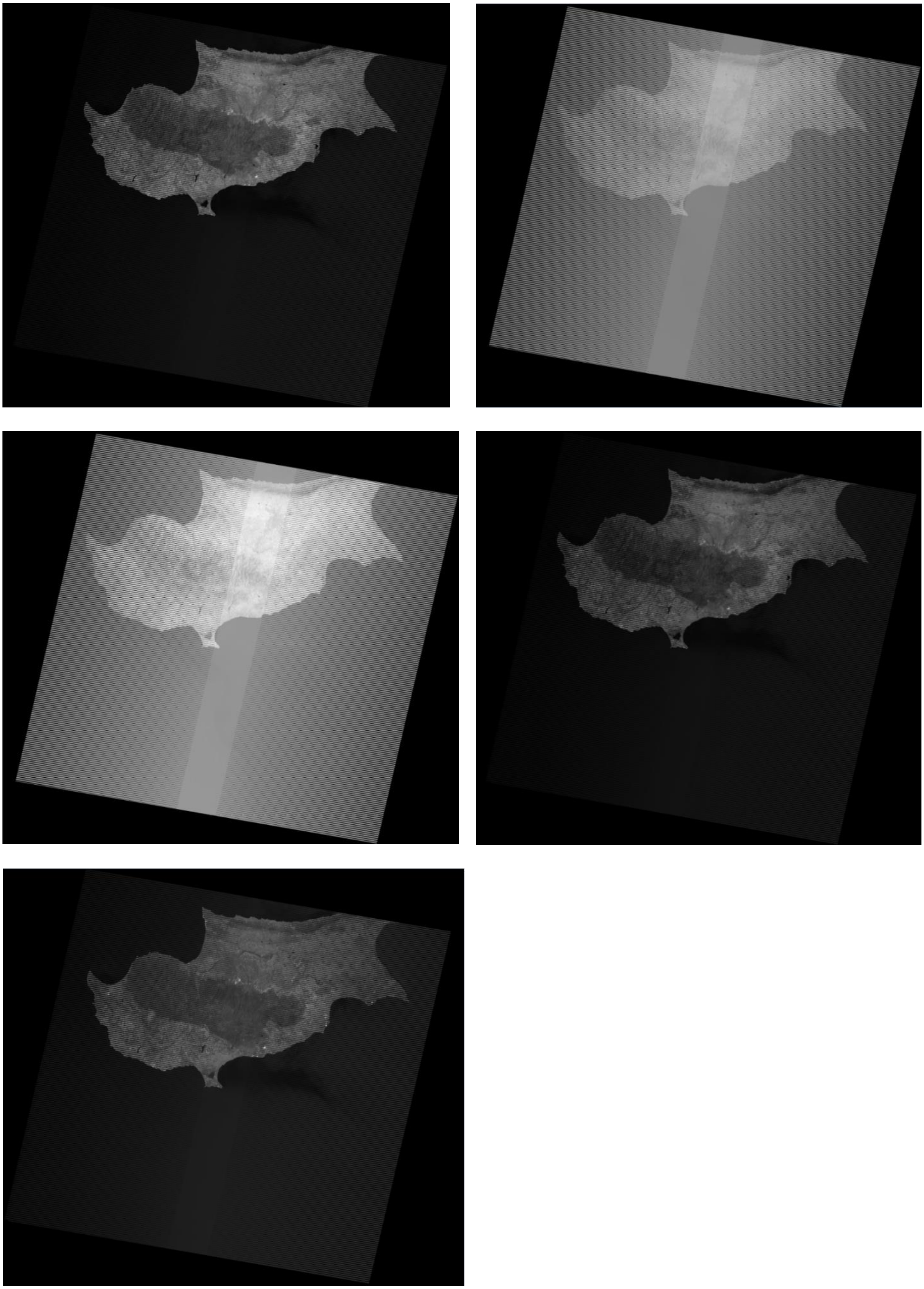
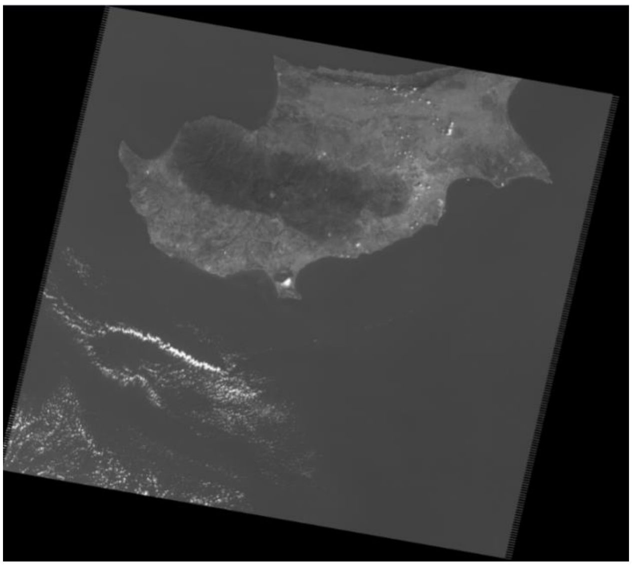
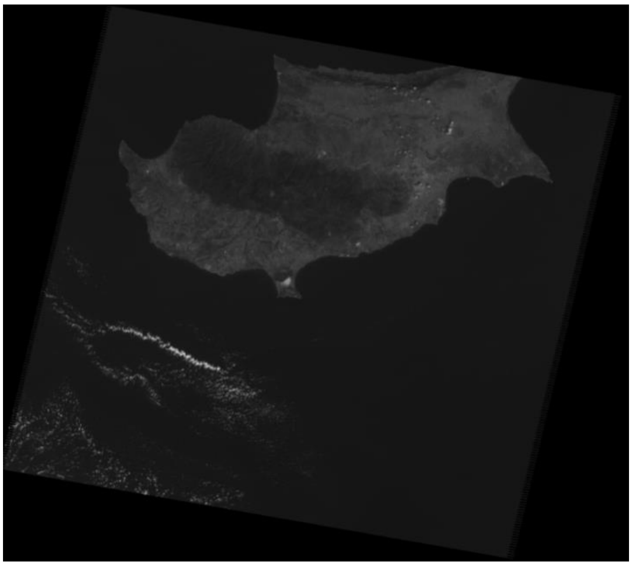
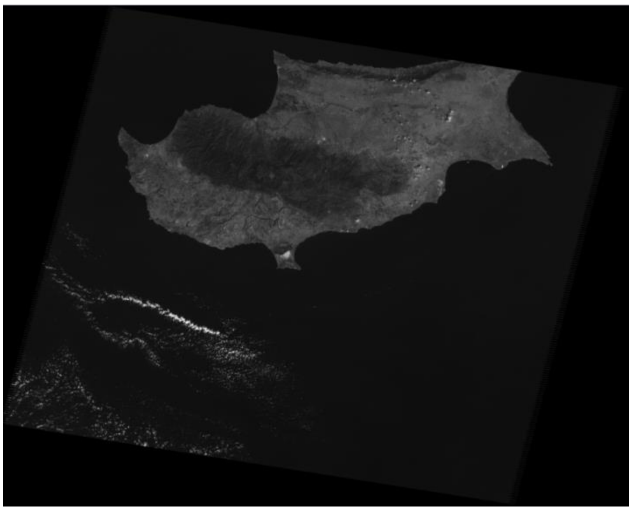


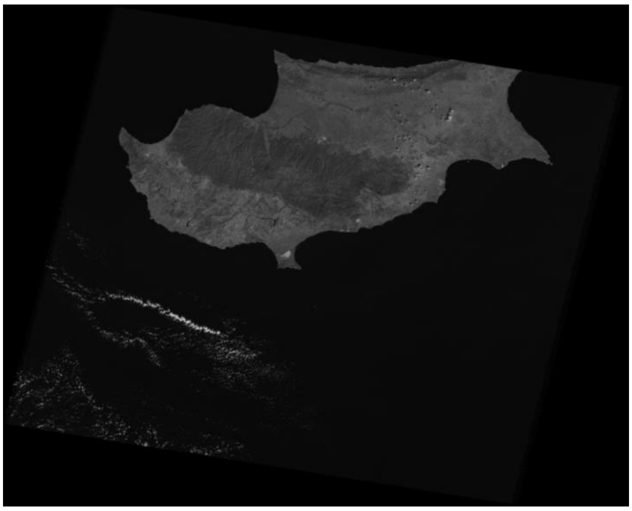
Figure 65: June 18th 2005 – L7 ETM+ SLC-off (2003-present) – Bands 1-8

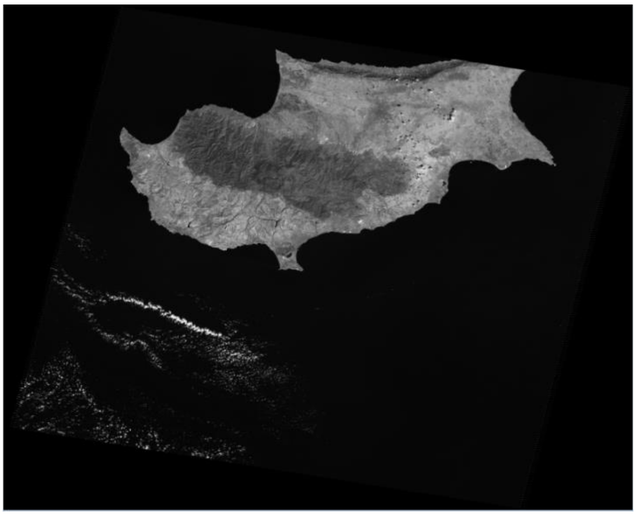
September 17th 2006 – L4-5 TM – Bands 1-7

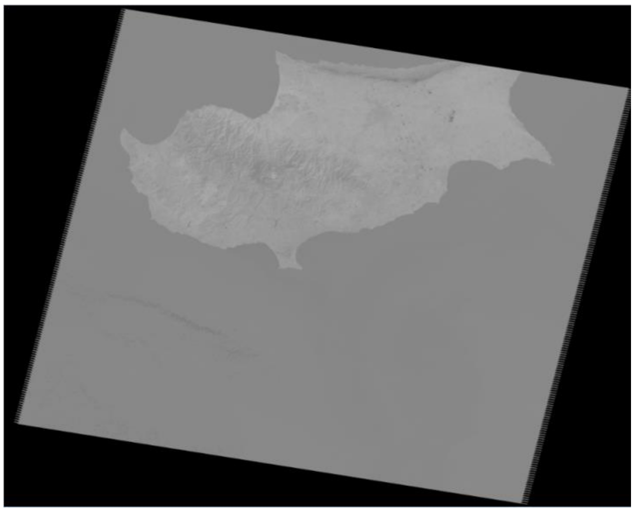












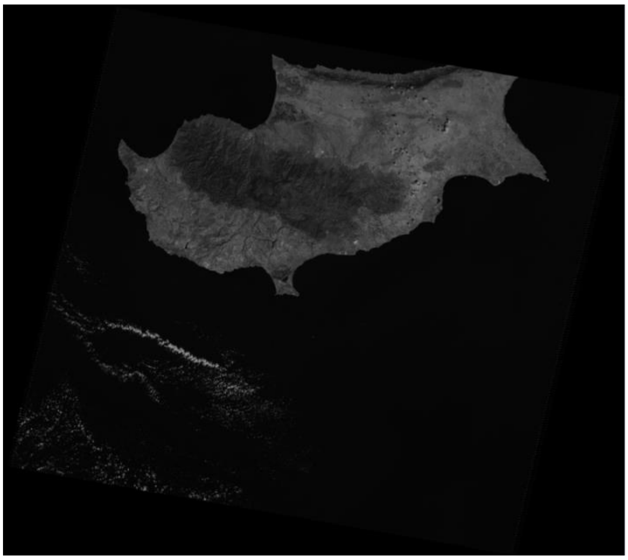
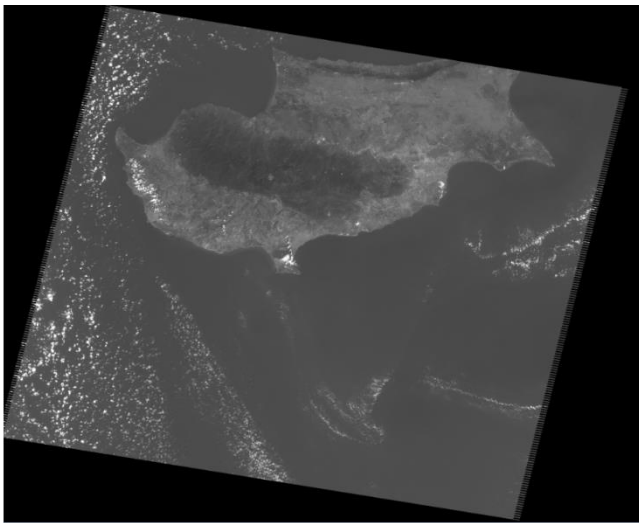
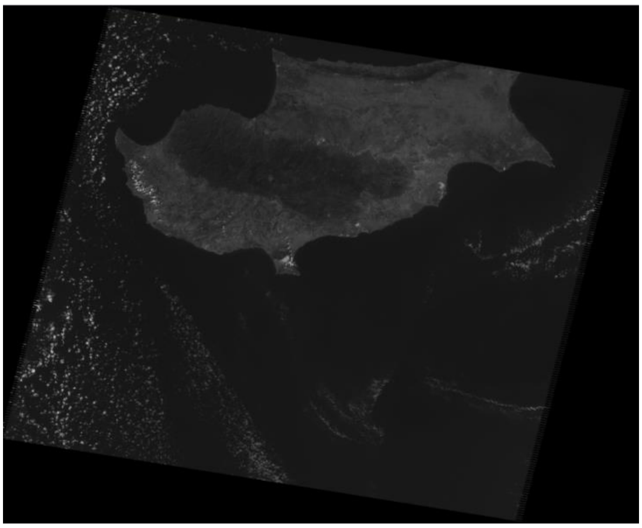
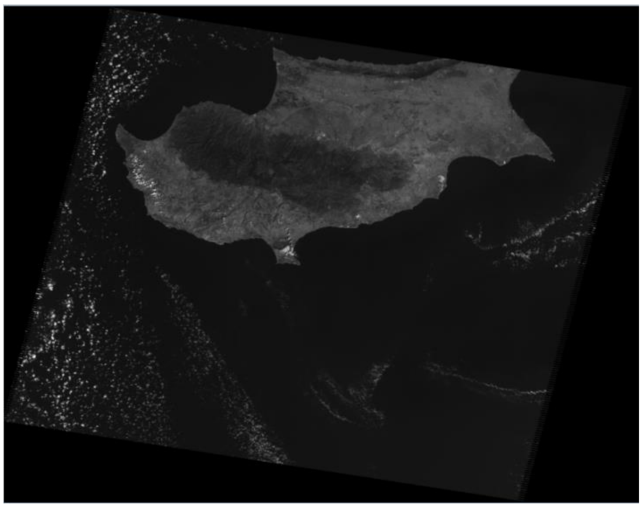


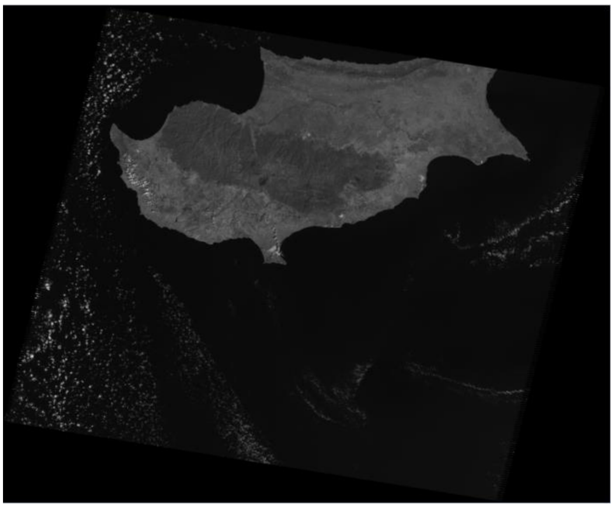
Figure 66: September 17th 2006 – L4-5 TM – Bands 1-7

September 4th 2007 – L4-5 TM – Bands 1-7









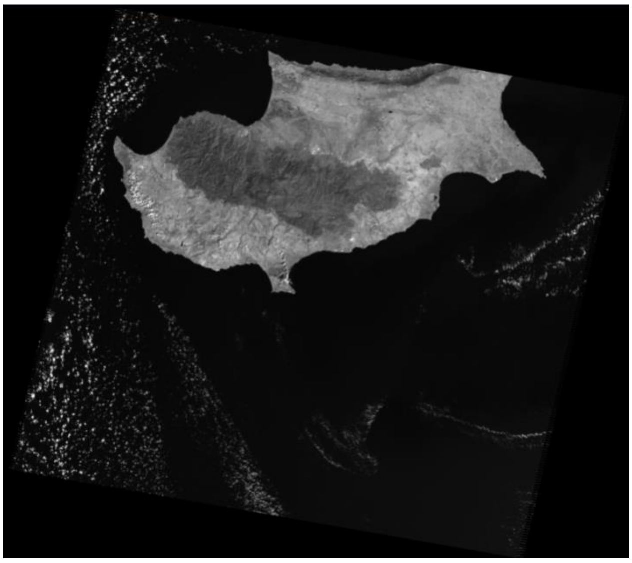
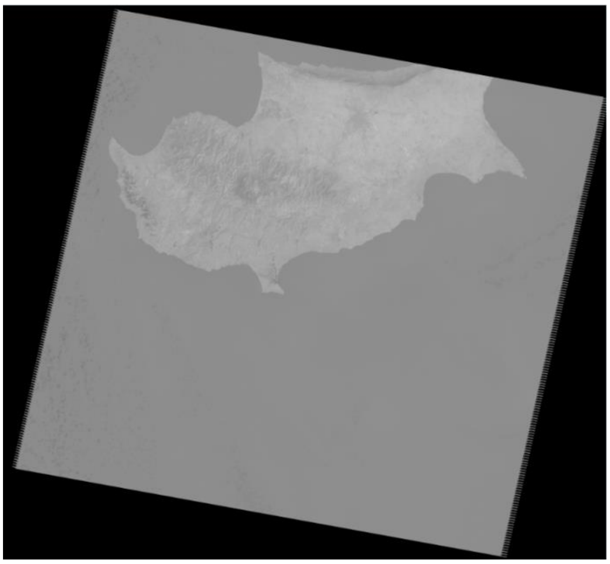
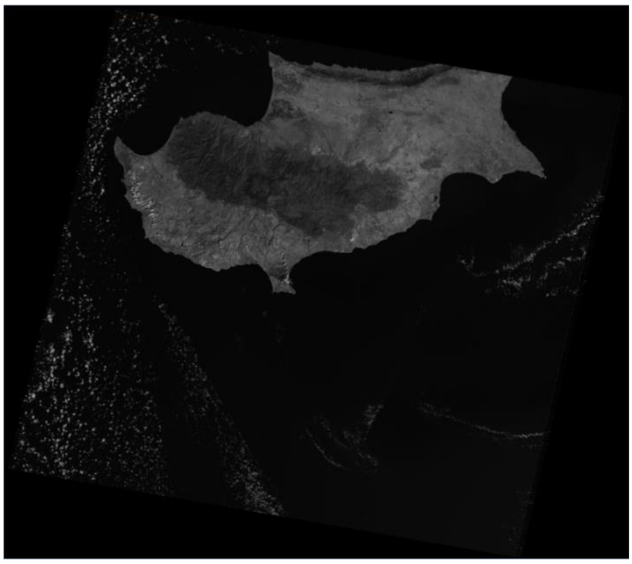
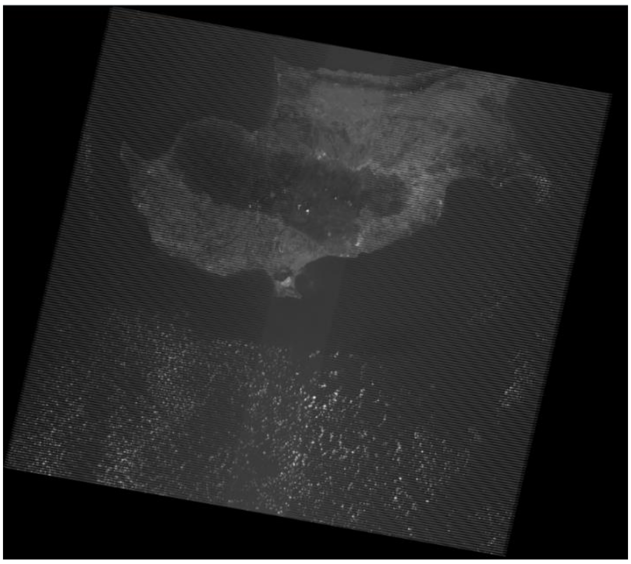
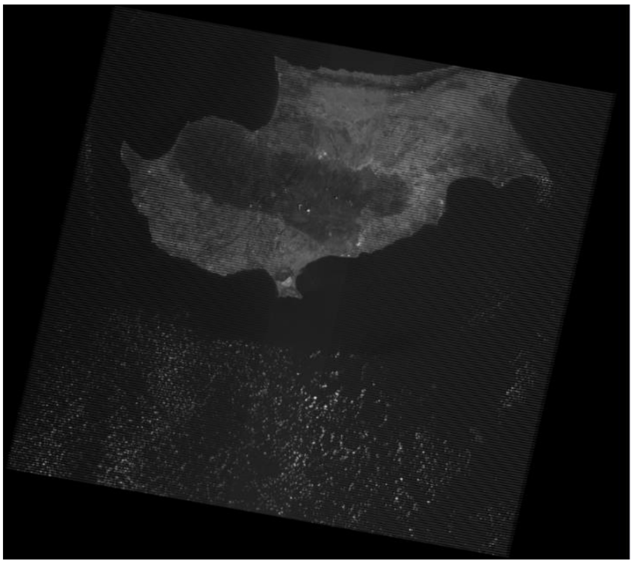
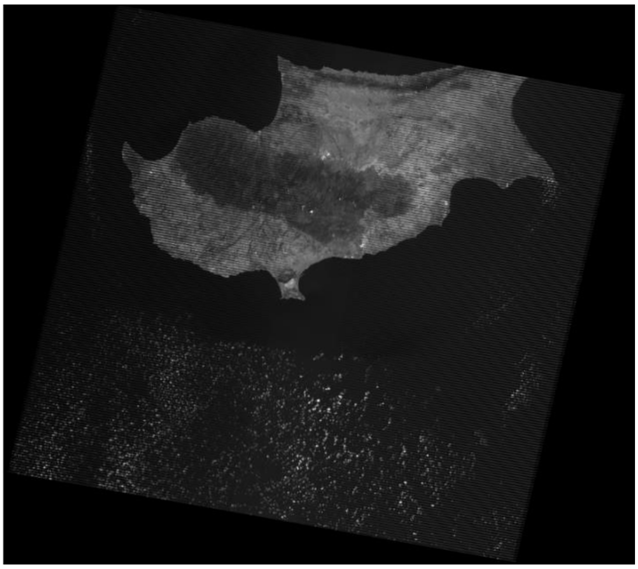
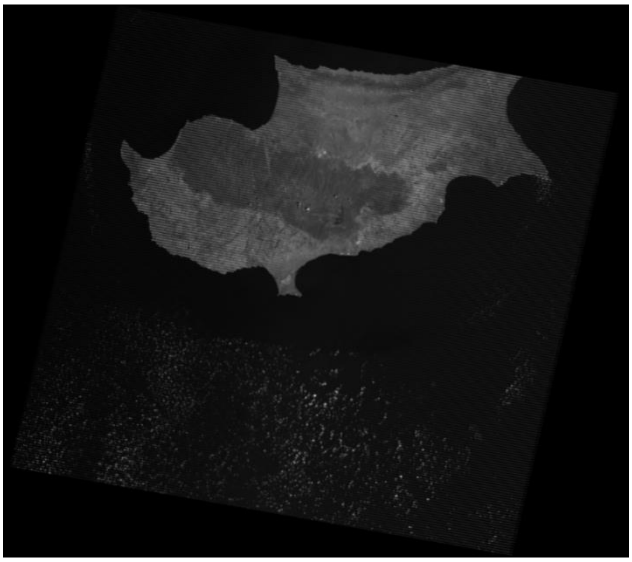
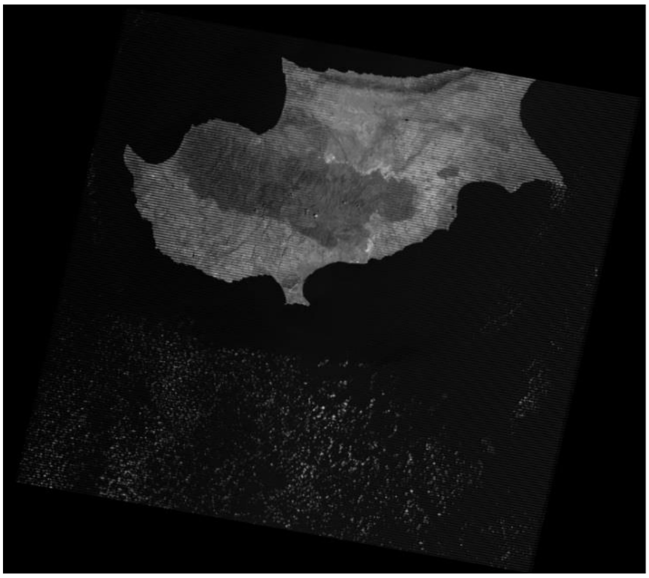
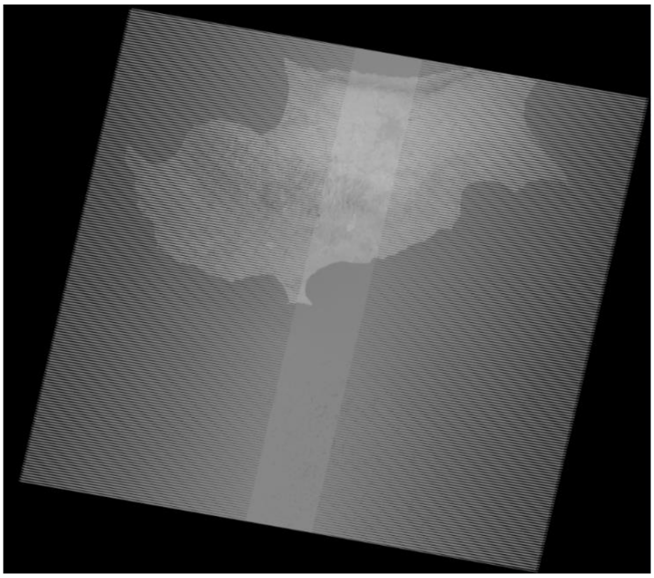
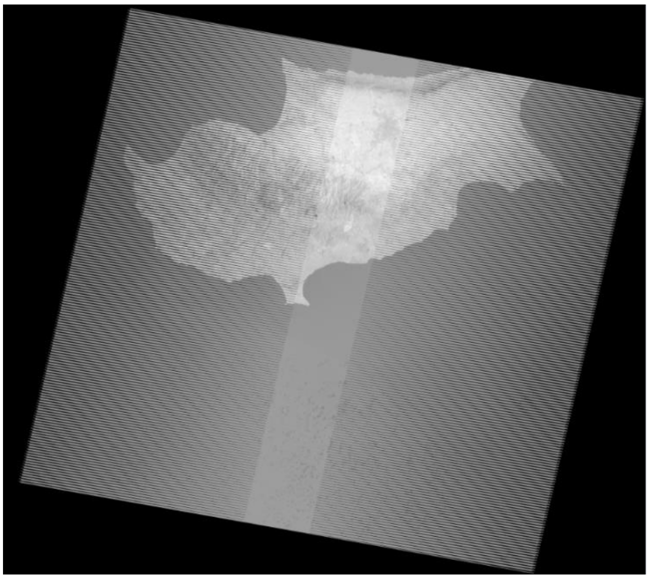
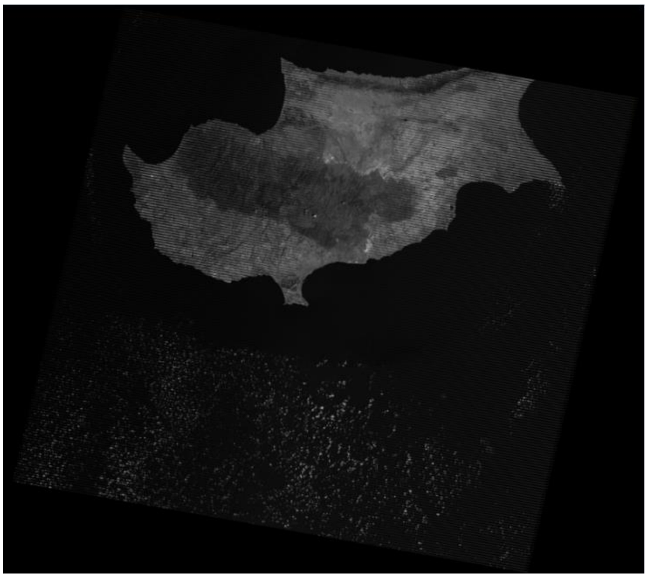




Figure 67: September 4th 2007 – L4-5 TM – Bands 1-7

July 28th 2008 - L7 ETM+ SLC-off (2003-present) – Bands 1-8

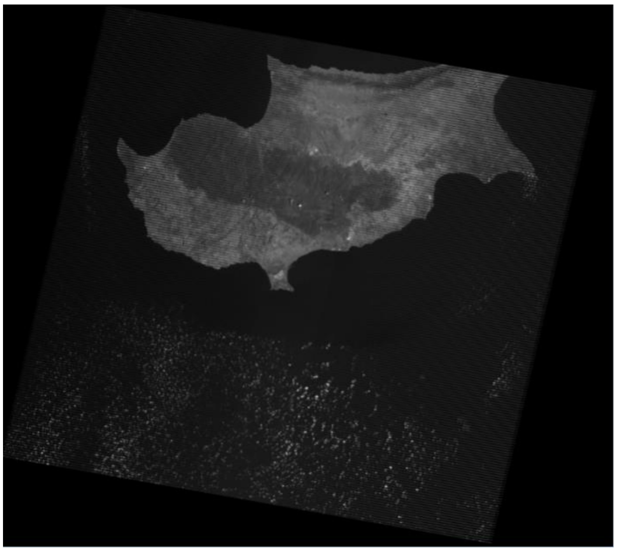
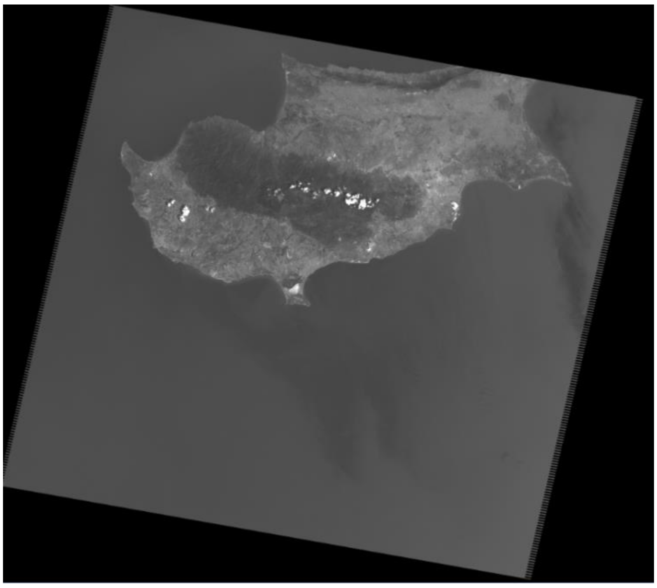
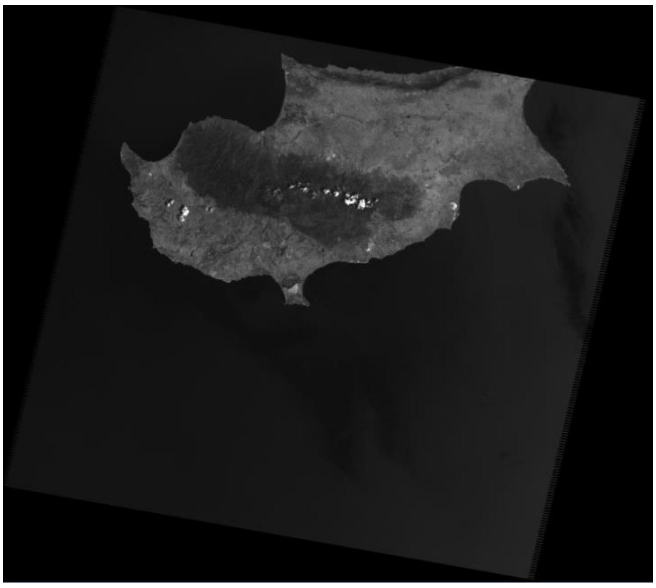
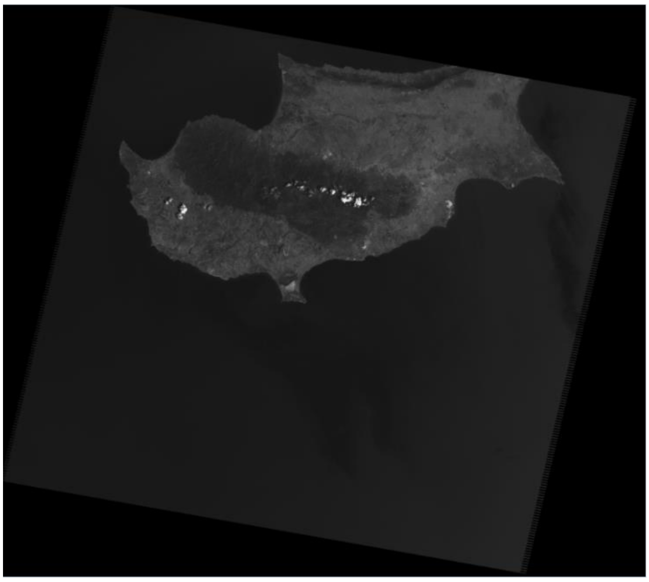


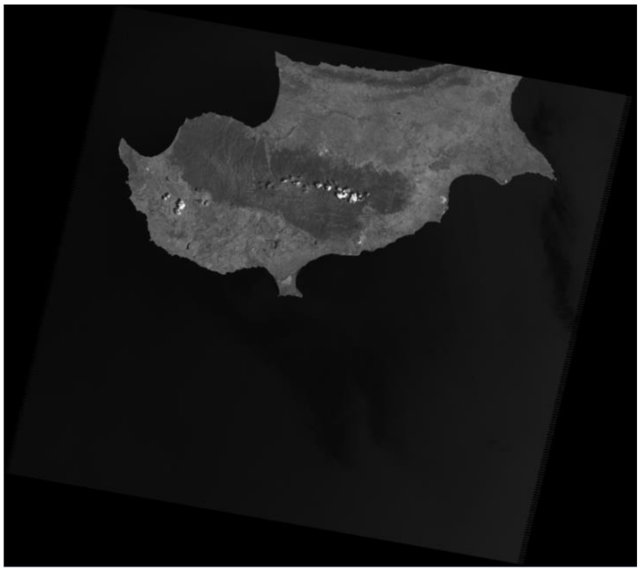
Figure 68: July 28th 2008 – L7 ETM+ SLC-off (2003-present) – Bands 1-8

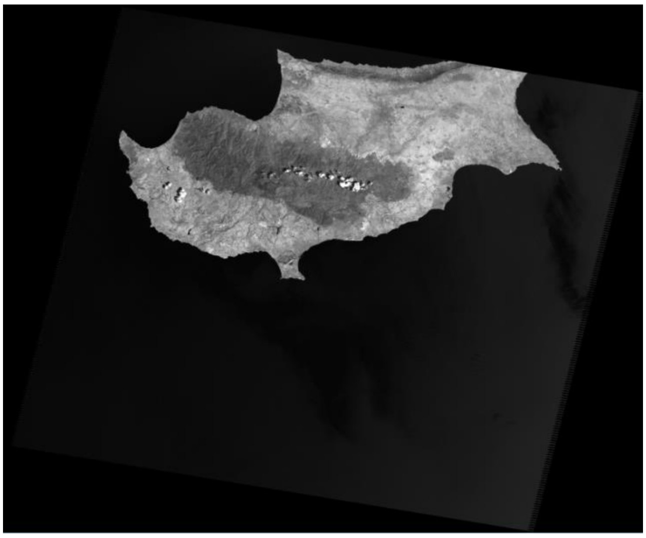
July 23rd 2009 – L4-5 TM – Bands 1-7

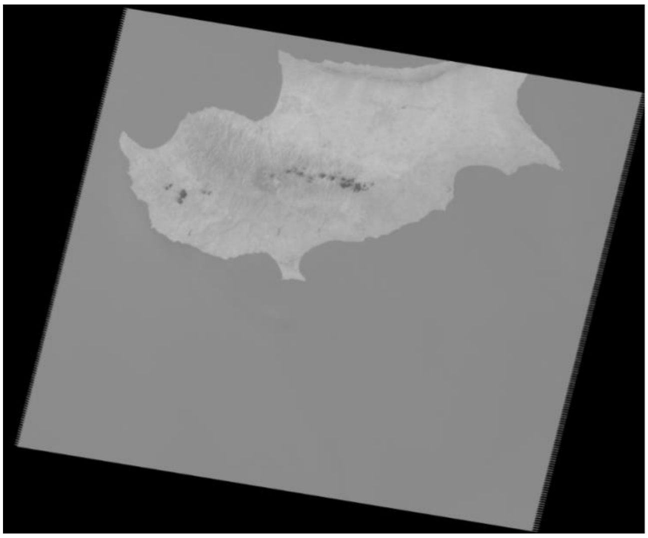












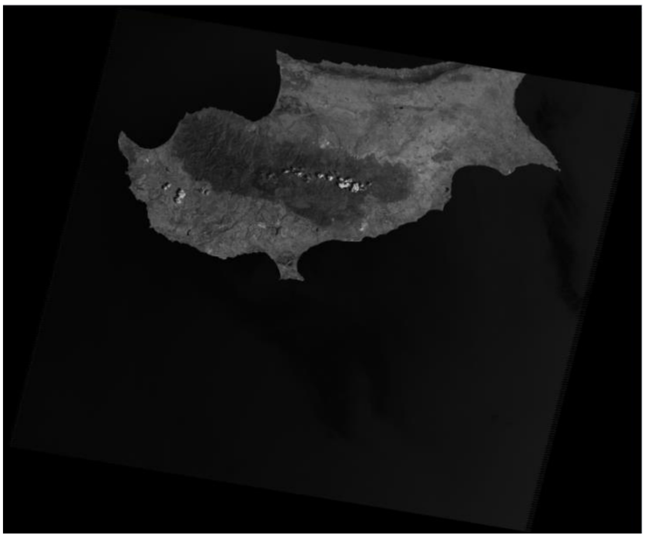
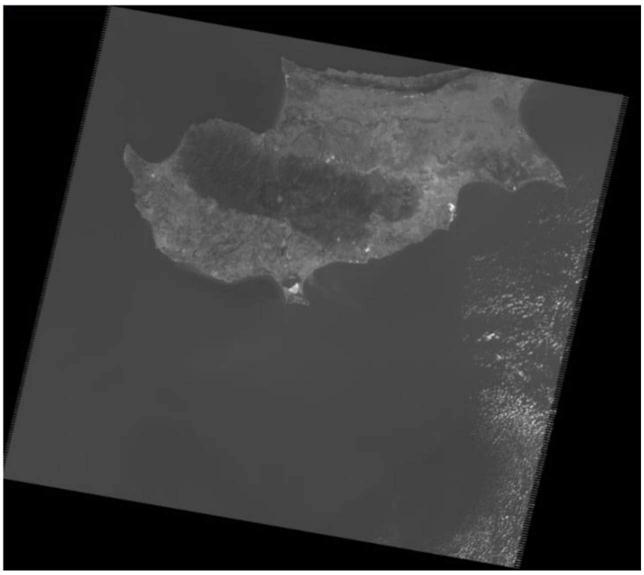
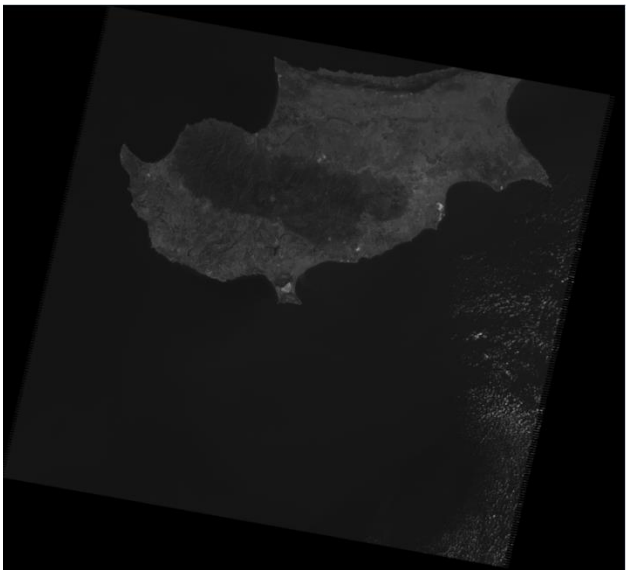


Figure 69: July 23rd 2009 – L4-5 TM – Bands 1-7

August 27th 2010 – L4-5 TM – Bands 1-7





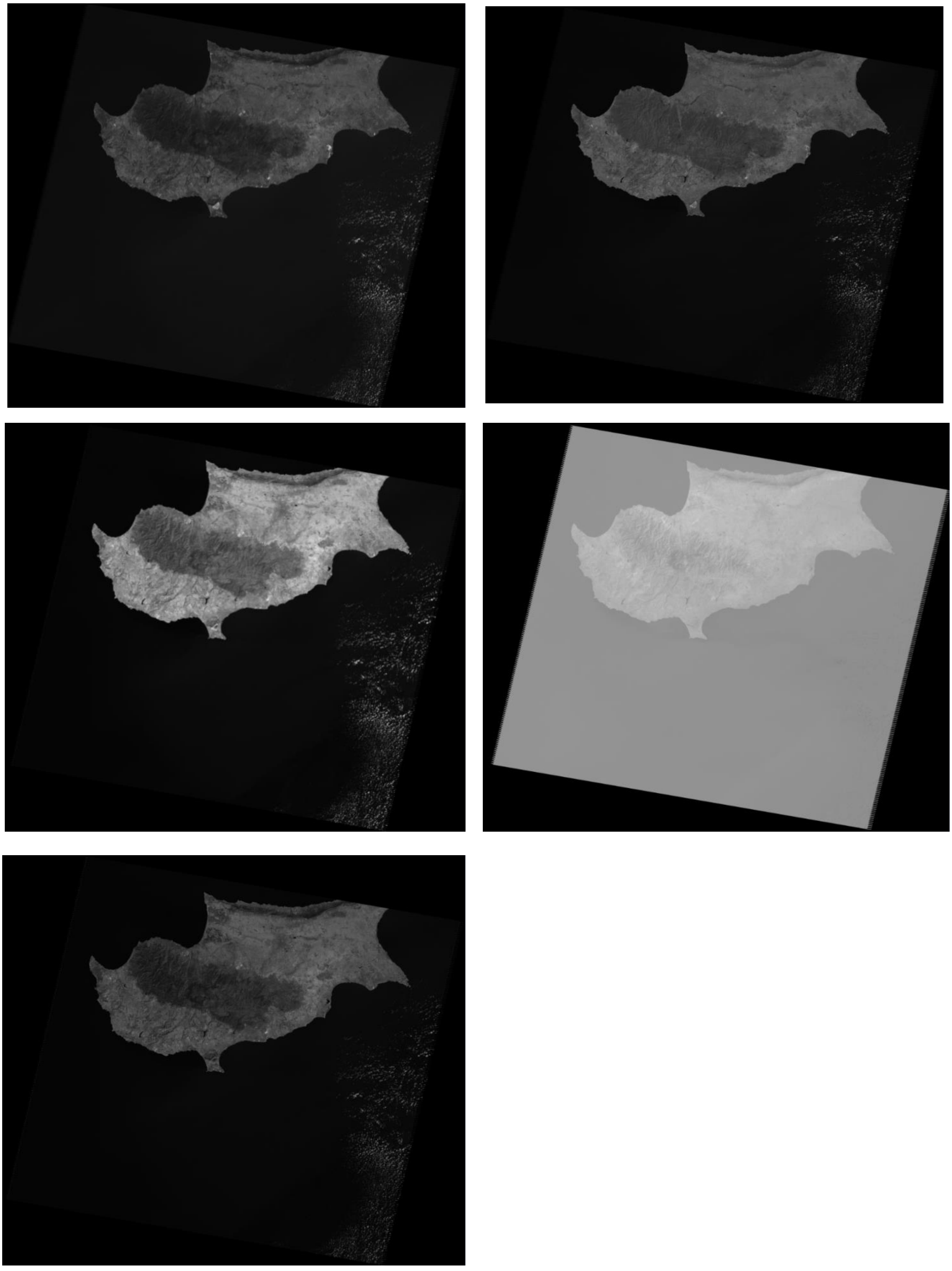
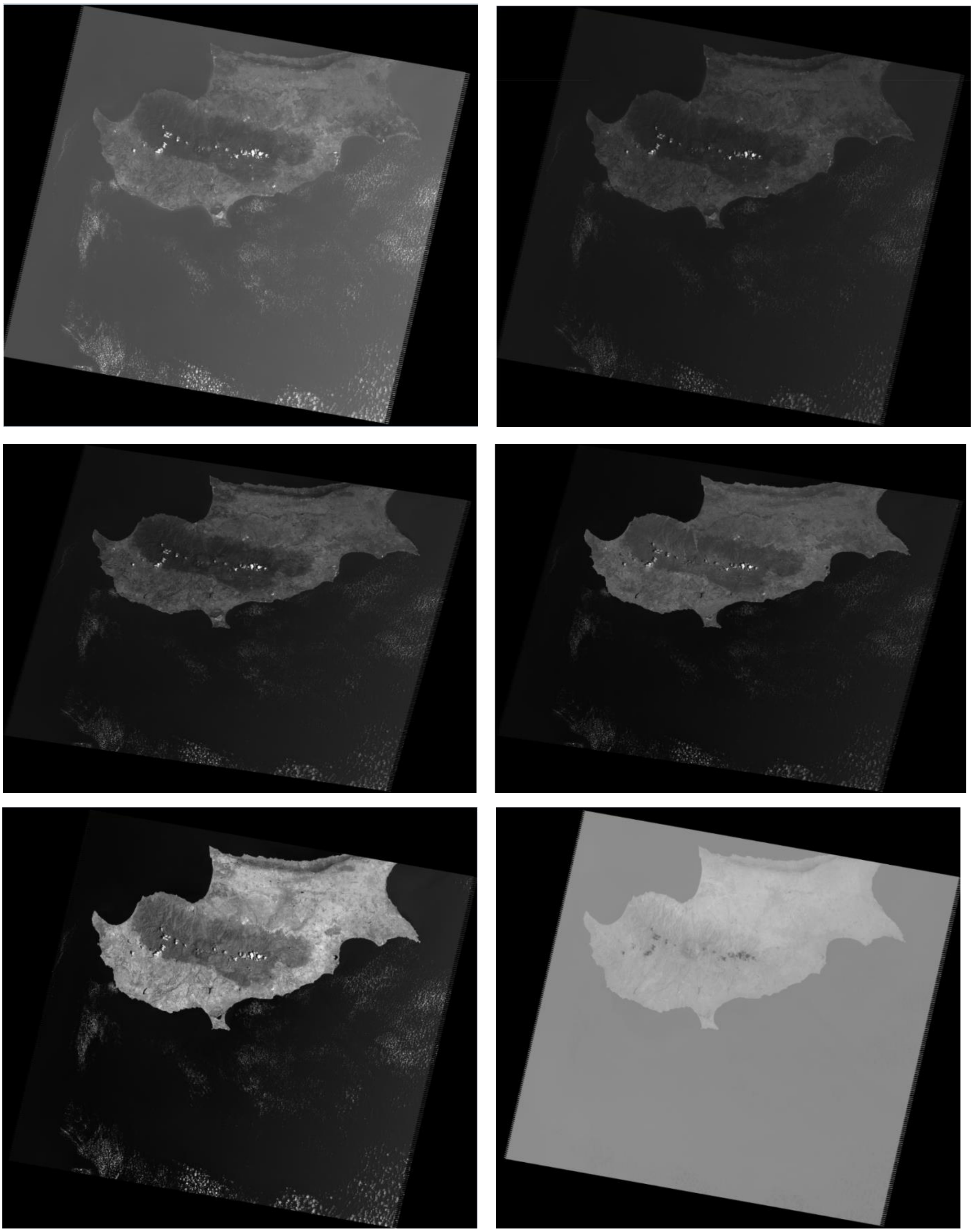


Figure 70: August 27th 2010 – L4-5 TM – Bands 1-7

July 13th 2011 – L4-5 TM – Bands 1-7



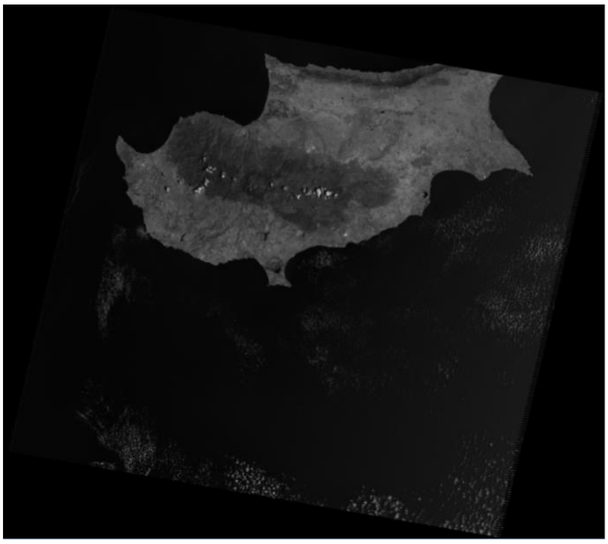
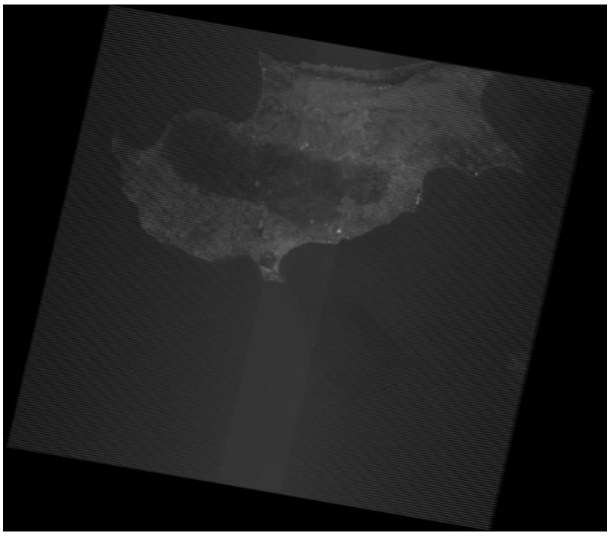
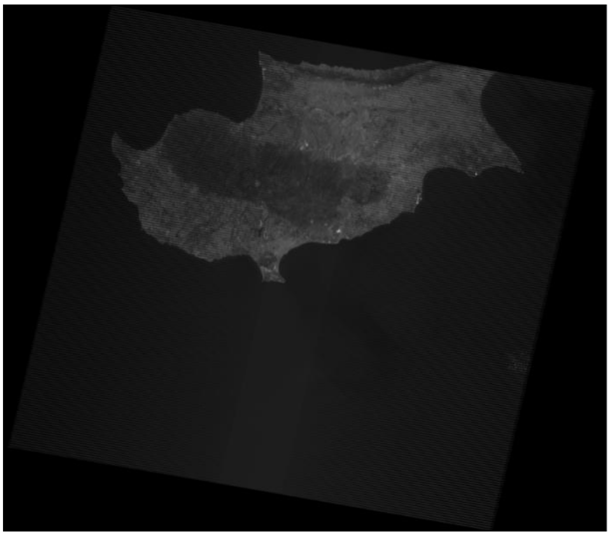
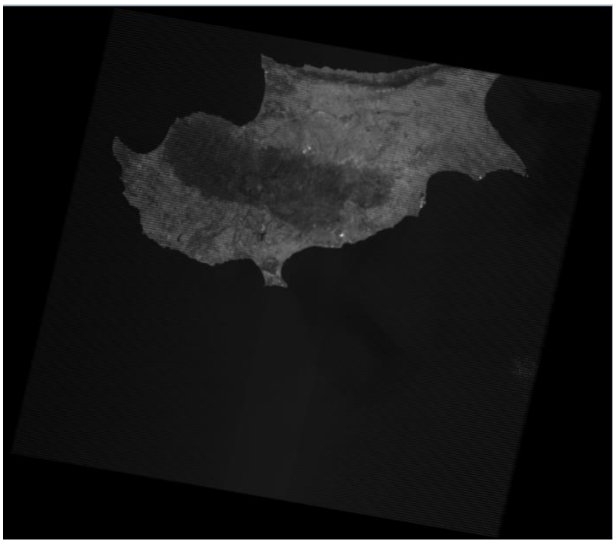


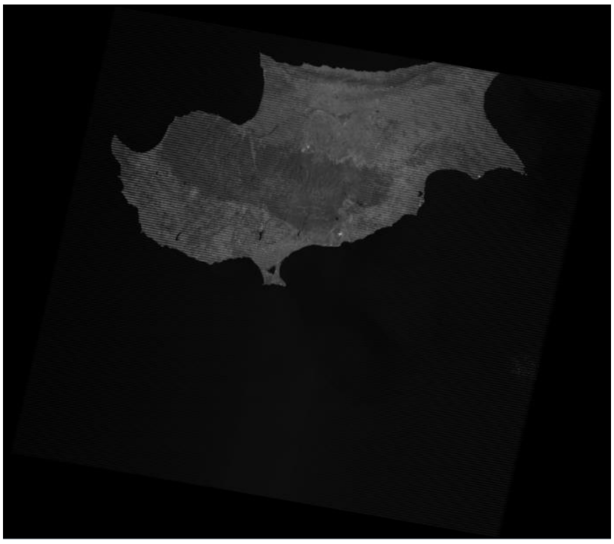
Figure 71: July 13th 2011 – L4-5 TM – Bands 1-7

August 22nd 2012 - L7 ETM+ SLC-off (2003-present) – Bands 1-8









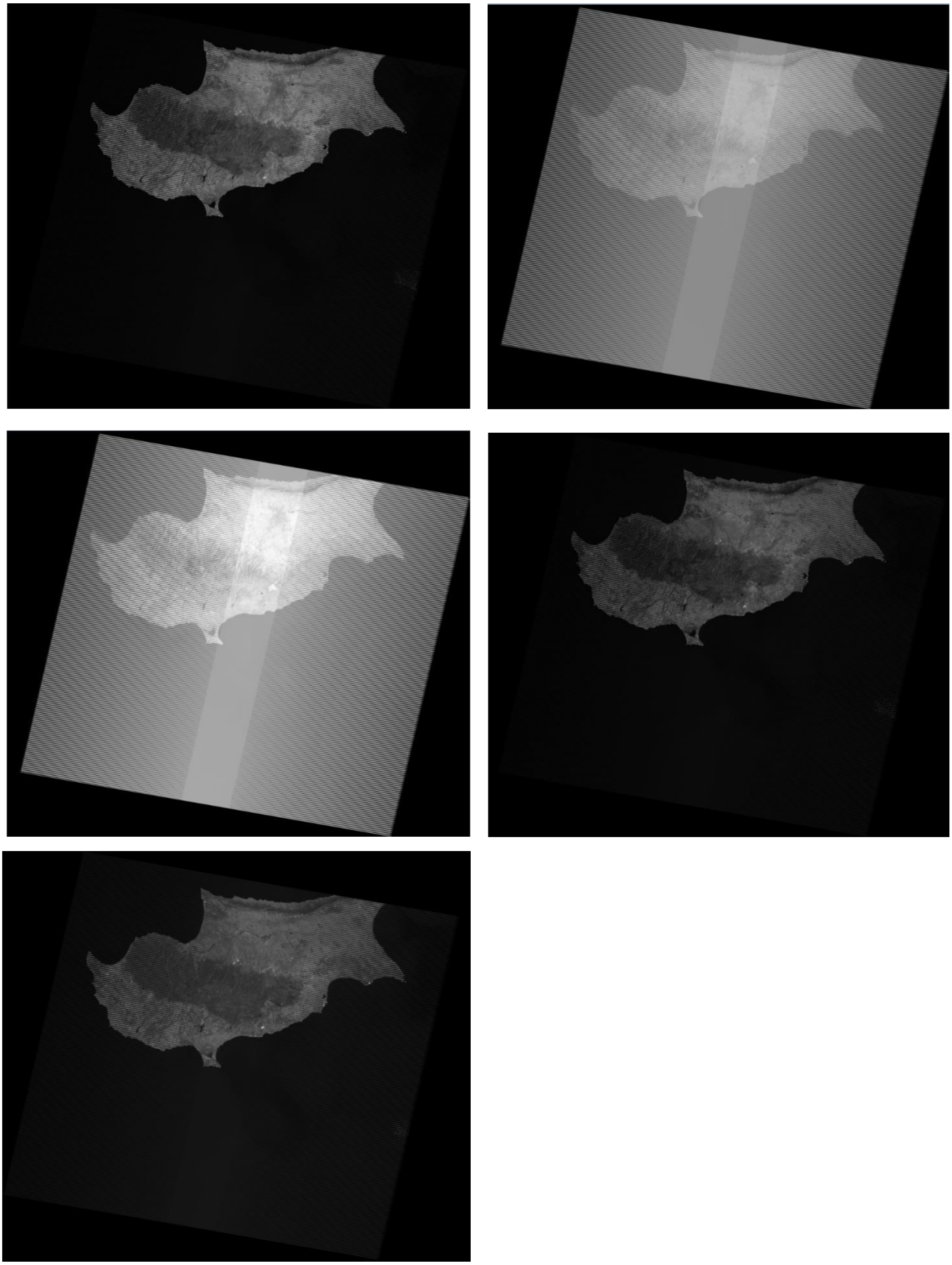
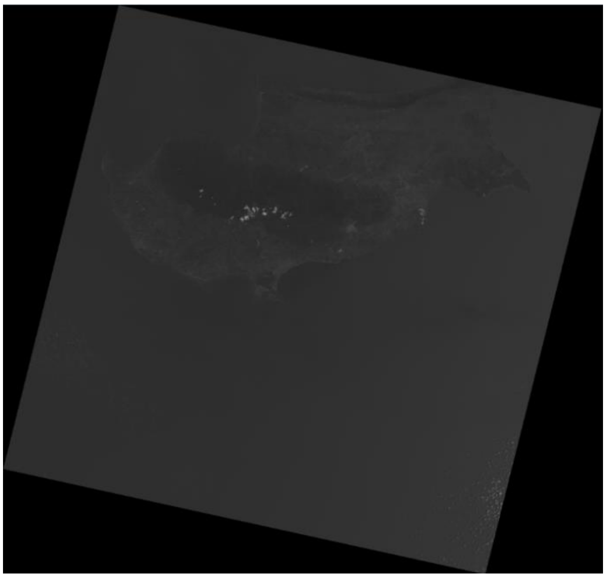
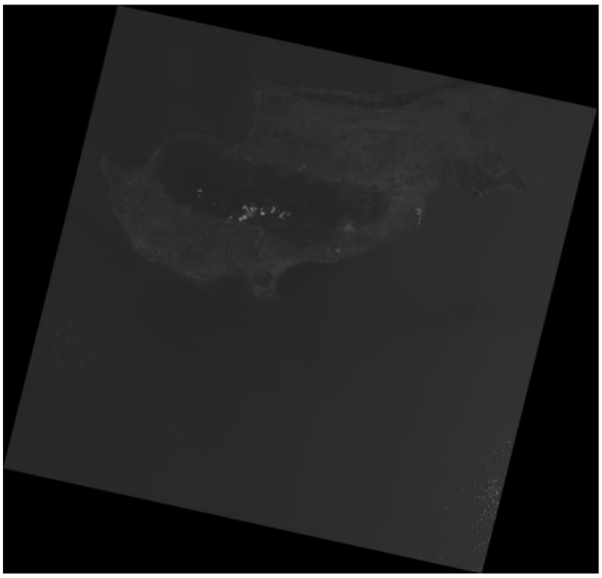
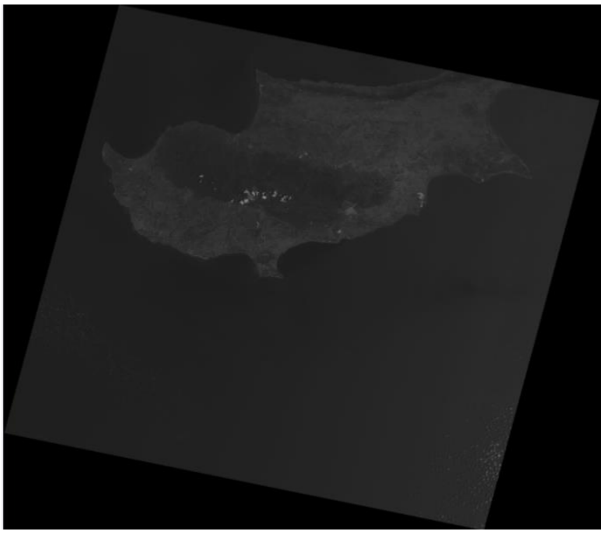


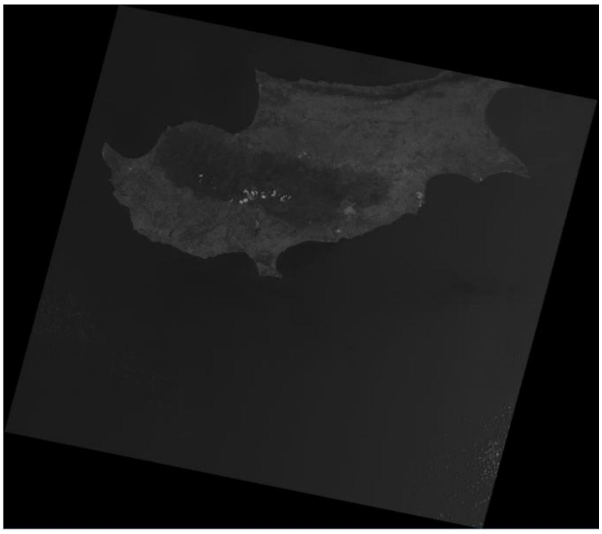
Figure 72: August 22nd 2012 – L7 ETM+ SLC-on (2003-present) – Bands 1-8

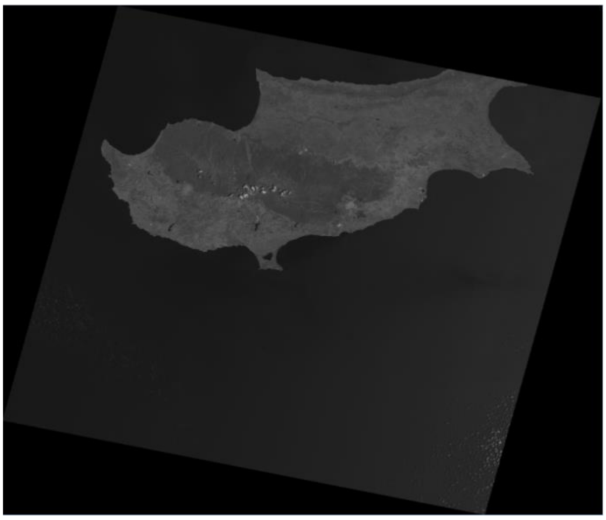
July 2[nd] 2013 – L8 OLI/TIRS – Bands 1-11

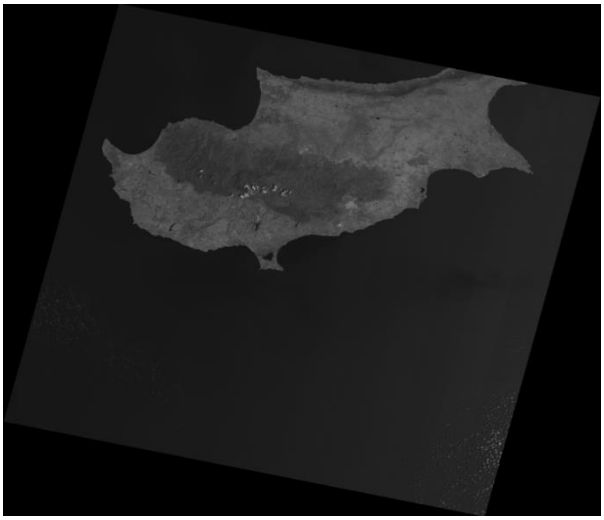












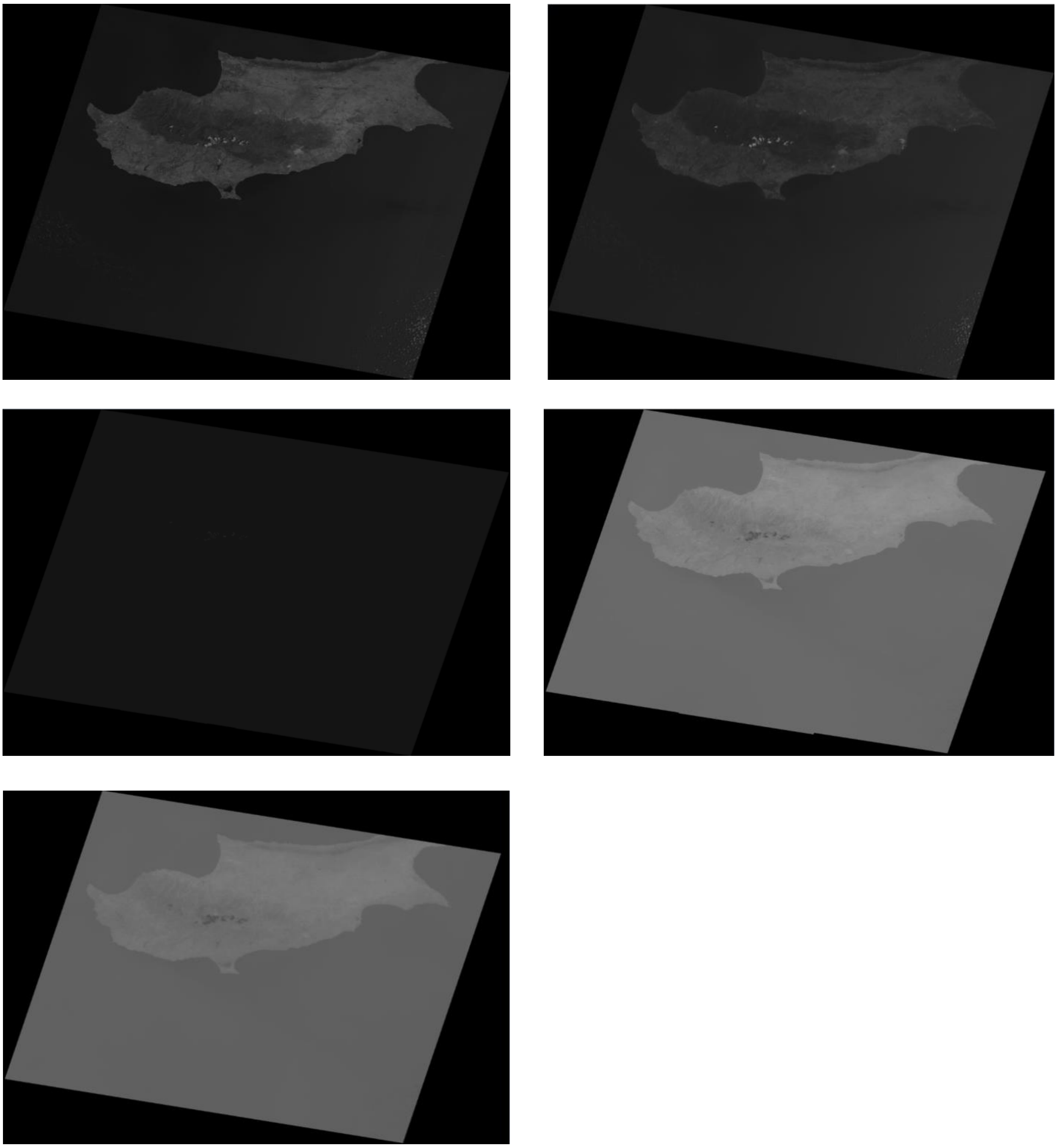
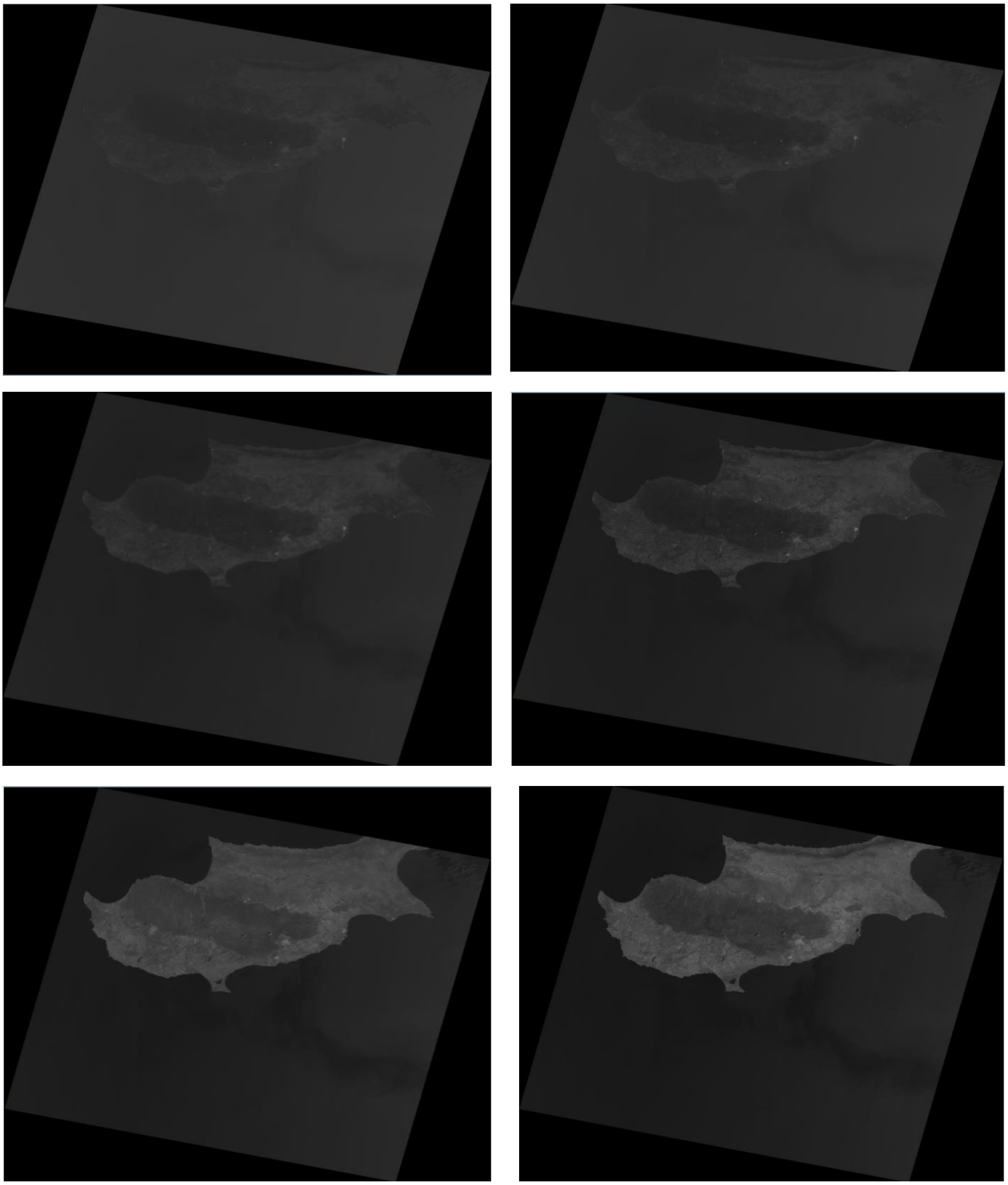


Figure 73: July 2nd 2013 – L8 OLI/TIRS – Bands 1-11

June 19th 2014 – L8 OLI/TIRS – Bands 1-11



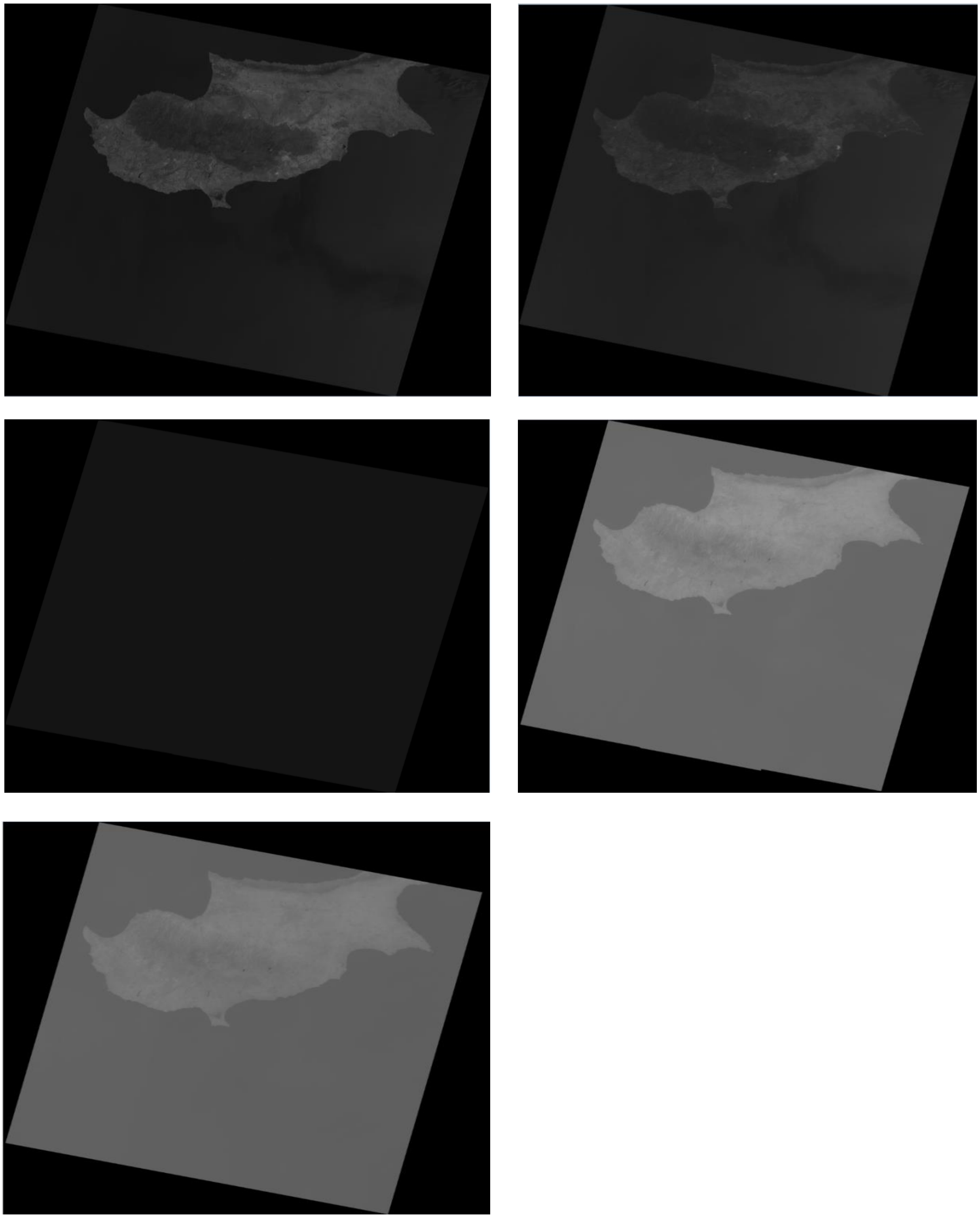
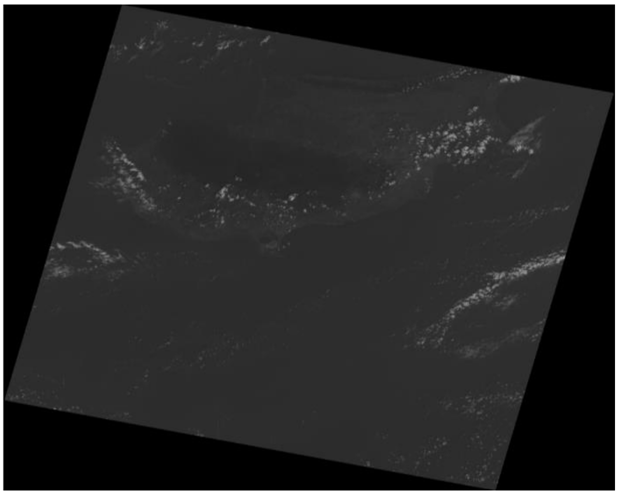
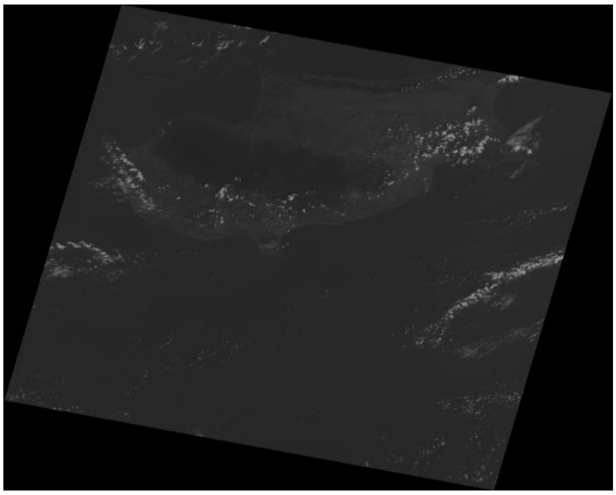
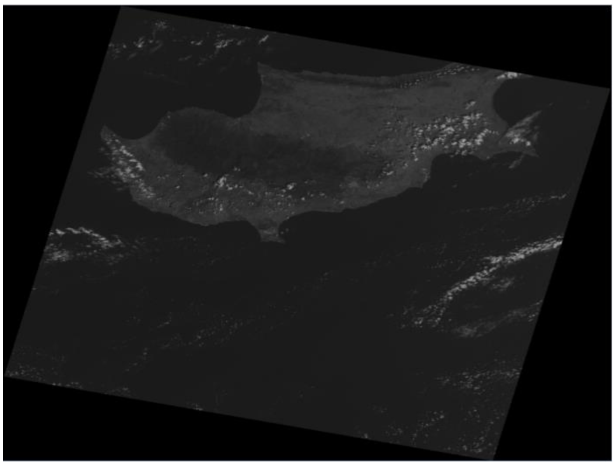
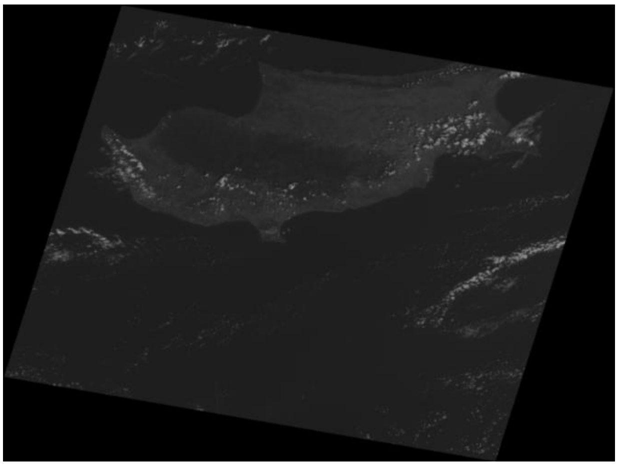
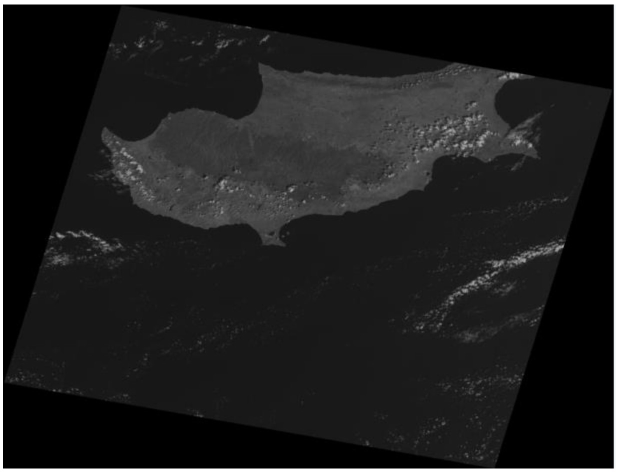
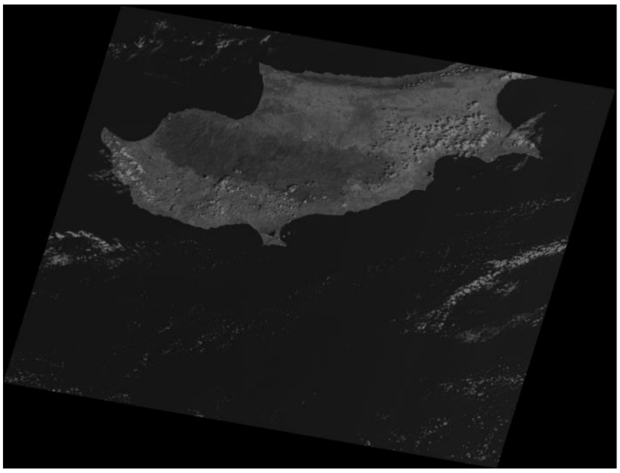


Figure 74: June 19th 2014 – L8 OLI/TIRS – Bands 1-11

August 25th 2015 – L8 OLI/TIRS – Bands 1-11

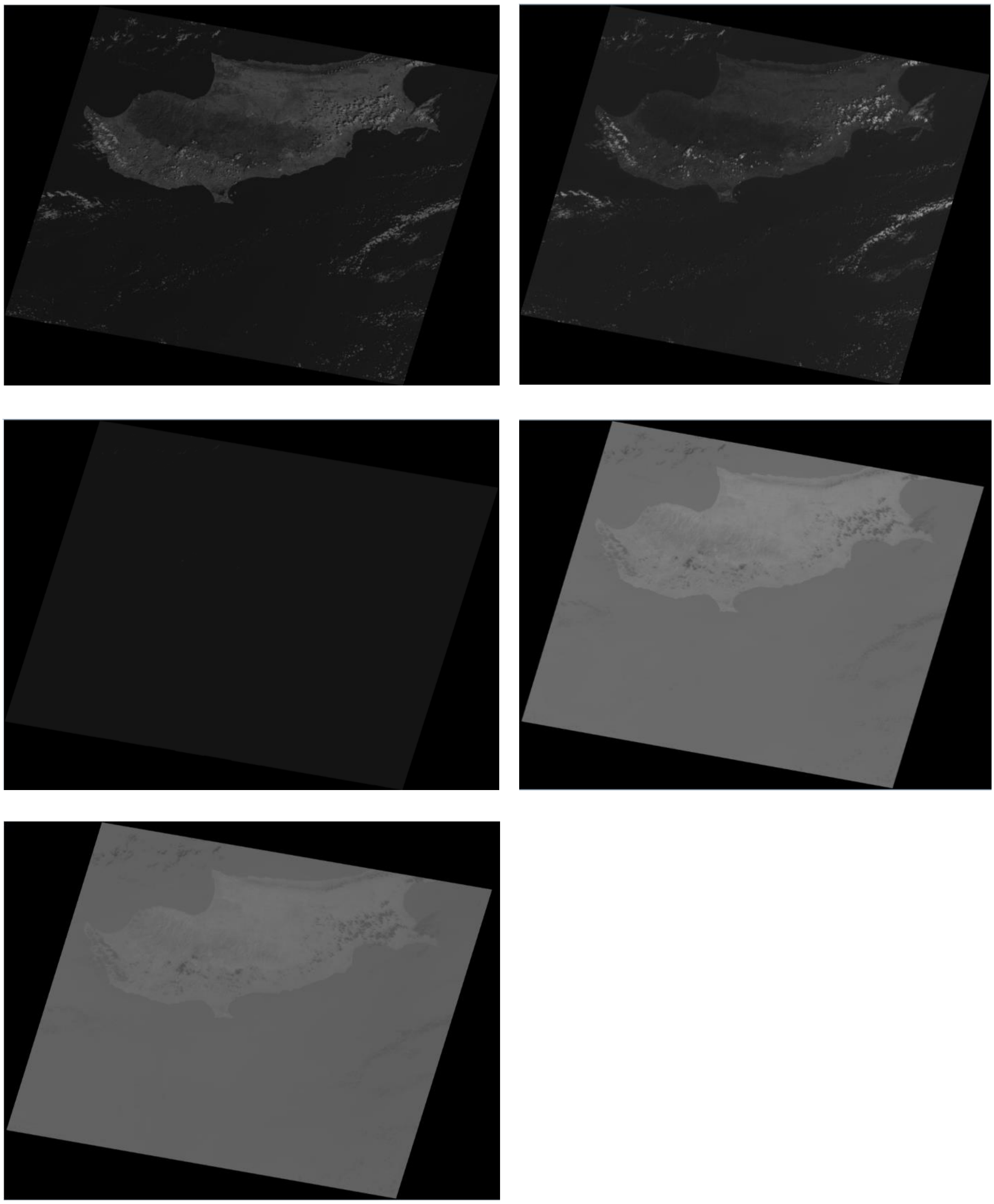


Figure 75: August 25th 2015 – L8 OLI/TIRS – Bands 1-11

Appendix B - Land uses maps

The Limassol land uses maps of 2003, 2006 and 2011, were obtained from the website of the Town Planning and Housing department of Cyprus and are shown below in Figures 76, 77 and 78 respectively. From these maps information about land uses changes in the region which are correlated with the passage of time and with the urban heat island effect, were observed.

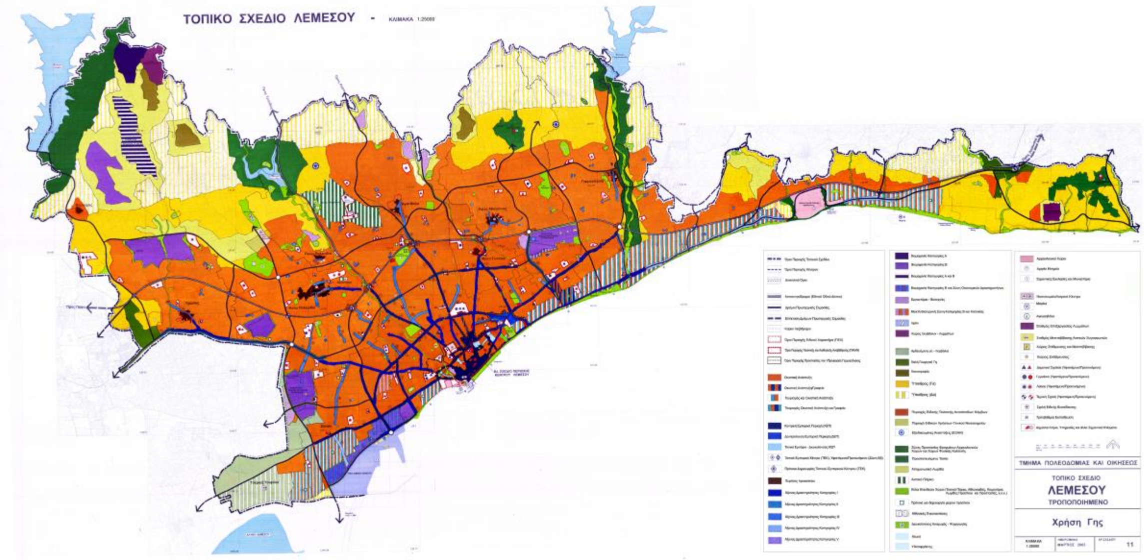


Figure 76: Land uses map of Limassol area - 2003

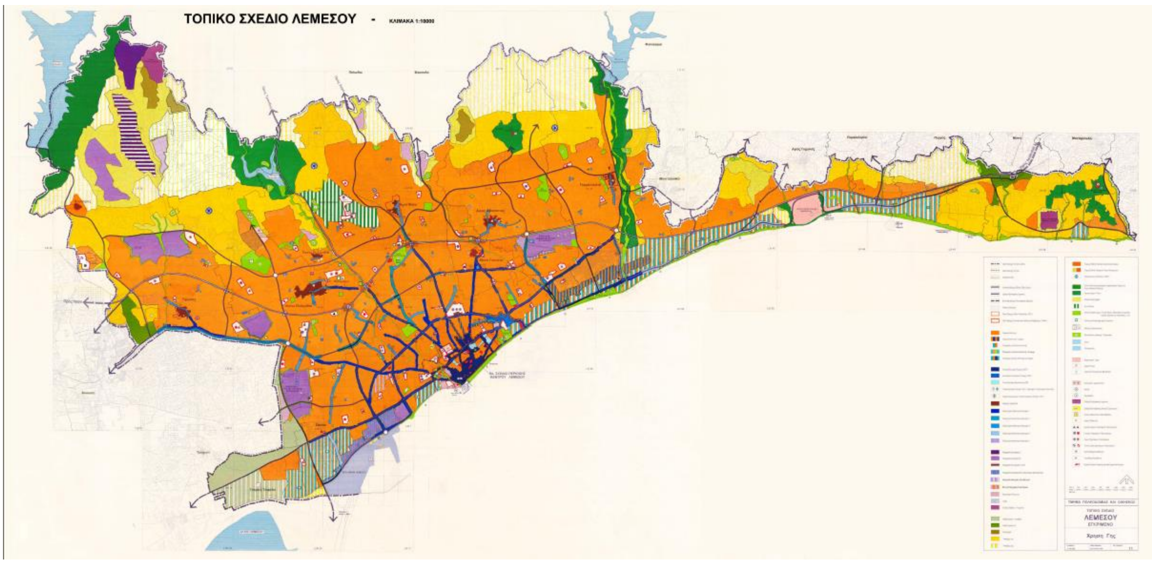


Figure 77: Land uses map of Limassol area - 2006

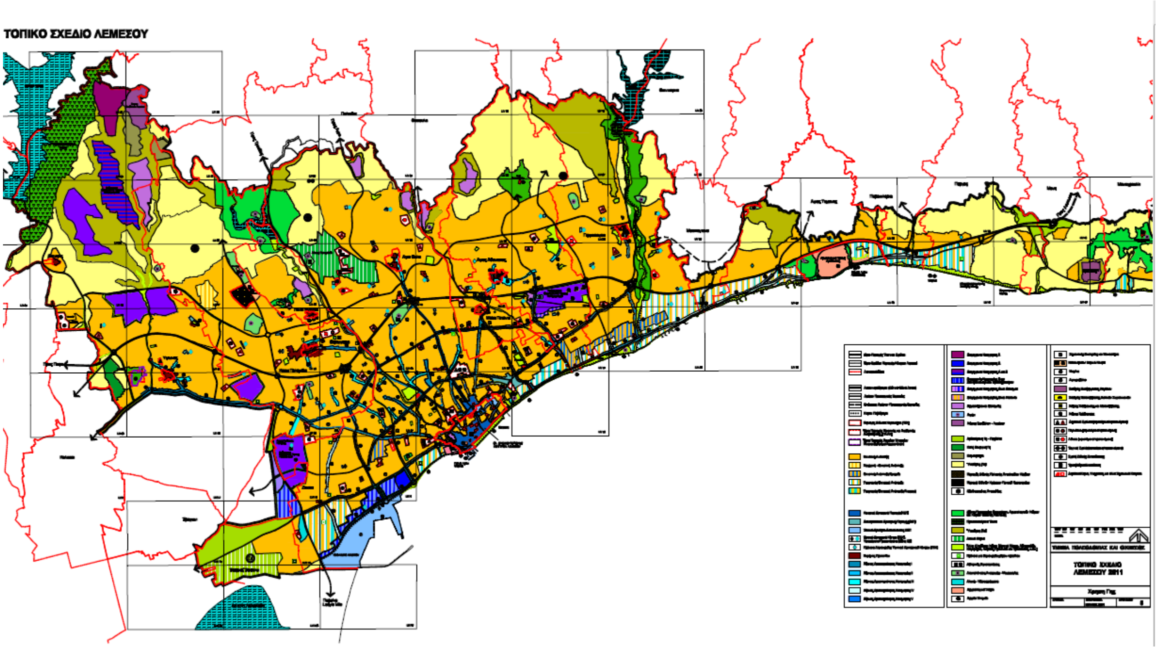


Figure 78: Land uses map of Limassol area - 2011
(Source:"http://www.moi.gov.cy/moi/tph/tph.nsf/All/8F1436BBF301C3F3C2257E540037CD31?OpenDocument&highlight=%CF%84%CE%BF%CF%80%CE%B9%CE%BA%CE%AC%20%CF%83%CF%87%CE%AD%CE%B4%CE%B9%CE%B1," n.d.)

Appendix C - Table of Temperatures

Table 3: Temperatures of each year for each point

Points	Dates												
	7/6/1998	13/8/1999	7/8/2000	13/8/2002	23/7/2003	17/9/2006	4/9/2007	23/7/2009	27/8/2010	13/7/2011	2/7/2013	19/6/2014	25/8/2015
1	37,22	37,63	23,01	23,63	42,05	32,64	38,03	40,85	40,85	39,25	31,24	31,32	28,70
2	35,98	36,81	22,40	24,24	40,85	32,64	36,81	40,05	39,65	38,44	30,26	31,31	28,20
3	37,63	37,63	22,40	23,01	40,46	33,06	37,22	39,25	39,25	36,81	29,91	29,96	27,29
4	39,25	38,85	24,54	24,54	41,65	33,06	39,25	43,23	42,05	41,65	32,39	33,85	28,68
5	38,85	38,85	23,01	24,24	43,63	34,74	38,44	41,65	40,85	36,81	30,50	34,54	27,45
6	42,44	40,45	23,93	27,84	44,80	37,63	42,05	45,18	45,95	40,46	33,87	34,96	29,61
7	38,85	36,81	23,70	25,15	39,65	32,22	37,63	40,85	40,05	38,44	29,79	33,59	26,04
8	38,03	38,44	22,71	23,63	40,85	34,32	36,40	43,23	44,01	40,05	31,64	33,93	28,75
9	36,40	38,85	23,63	24,84	41,65	33,10	39,25	43,23	44,03	41,25	32,12	34,37	29,75
10	39,25	37,63	25,15	23,32	40,46	34,74	35,16	40,46	40,85	38,44	28,64	35,43	26,57
11	36,40	38,85	22,40	24,84	41,25	34,32	38,44	41,25	42,84	39,25	30,55	33,78	28,29
12	37,63	39,65	24,25	23,01	40,46	35,57	38,03	38,44	42,05	36,40	28,27	31,46	29,12
13	41,25	39,25	23,63	25,15	41,65	35,16	39,65	42,05	43,23	38,85	30,40	35,23	27,99
14	33,90	38,85	23,32	24,24	39,25	31,80	37,63	40,46	40,85	38,03	29,70	32,36	27,87
15	36,81	40,01	26,35	24,84	41,65	38,44	40,46	42,44	44,01	40,05	32,53	36,32	33,35
16	32,22	39,25	25,15	23,01	39,65	33,10	39,25	38,03	40,05	35,57	29,47	30,93	32,17
Average	37,63	38,61	23,72	24,35	41,25	34,16	38,36	41,29	41,91	38,73	30,71	33,33	28,74
Min	32,22	36,81	22,40	23,01	39,25	31,80	35,16	38,03	39,25	35,57	28,27	29,96	26,04
Max	42,44	40,45	26,35	27,84	44,80	38,44	42,05	45,18	45,95	41,65	33,87	36,32	33,35