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A climate impact assessment for the future of Greece and its adaptation capacity as influenced by socio-economic factors

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Master thesis, 30 credits, in *Physical Geography*

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Abstract

The occurrence of climate change will have a significant impact on society and adapting to a more sustainable environment is of key importance. The dangers of climate change will include temperature and precipitation patterns becoming more extreme creating a substantial impact on society. Greece's location and climate make it particularly vulnerable to a changing climate and climate impact assessments will become increasingly valuable for enhancing Greece's adaptability to the effects in the future. This study uses two separate climate models with the latest CORDEX data, inputted with a set of climate indices in order to assess the potential future characteristics of both temperature and precipitation for the whole of Greece and to recognise any patterns in the modelled outputs. Both climate models displayed an increase in both the occurrence of extreme temperature and an increase in the consecutive number of days by which these temperatures are seen. The majority of model simulations displayed a substantial increase between different time periods, often the occurrence of 'extreme events' in one time period became a normality and average event in the following time period. Drastic increases were also displayed from the near future to the far future. These scenarios provide an overall image of how climate change may impact the country of Greece, the impacts will be quite significant, particularly for various different sectors such as the tourism industry. Water and energy will be placed under a particularly high demand should the climate effects become apparent, therefore carefully planning adaptation strategies to reduce the overall damage inflicted to Greece will become an important field to consider.

Acknowledgements

I would like to express my sincere gratitude to my supervisor Anna Maria Jönsson for all of her guidance, quick email response and excellent feedback throughout the whole process. All of which made this project possible!

Also, a shout out to all of my family and friends in the UK and Sweden, what a great journey it was!

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1.0 Introduction

The threat of global warming is a widely pronounced issue that requires action. Europe is one of the areas which is set to see significant changes in climate, in particular, the area of the Mediterranean and Southeast Europe where warming is expected to rise at higher rates than surrounding regions (IPCC, 2014). The danger of such changes will bring a number of implications for the economies and societies for a variety of countries in Southeast Europe (Loizidou *et al.* 2016), in particular the country of Greece which is already experiencing increasing temperatures, causing substantial implications for the country to deal with. Warmer and drier weather looks set to see an increase going into the future with a higher frequency and intensity of extreme weather events occurring, placing added pressure on the country to mitigate against the persistent threat of climate change (Giannakopoulos *et al.* 2011).

One of the main targets of the upcoming Paris agreement in 2020 will be to keep the increase in global temperatures below 2^{o}C (based on pre-industrial levels) with an even more ambitious target to limit the increase to 1.5^{o}C – a pathway that would require a rapid and far-reaching transition to change. Regardless, the observations of ongoing global warming in recent years have become a continuing trend in the last couple of decades, impacts of such changes have already been witnessed on regional scales and there is significant concern that this will become much more frequent as climate change intensifies (Kjellström *et al.* 2018). However, predicting exactly how strong the climate will change across different regional and local scales for future scenarios remains a topic of strong interest for scientists - the level of attention we place on mitigating global warming will determine the pathway our planet will travel down and the level of damage arising from climate change.

Climate impact assessments have developed within the last two decades to get a more in depth understanding of the effects of climate change and how to suitably implement the correct strategies, further enhanced by the work of international institutes such as the Intergovernmental Panel on Climate Change - IPCC (Spyridi *et al.* 2015). The IPCC, in their Fifth Assessment Report, have defined a set of trajectories or scenarios of future climate change known as Representative Concentration Pathways (RCP's) which our planet will follow (Usually RCP2.6, 4.5 and 8.5). RCP scenarios assume pathways to numerous different targets for radiative forcing to the end of the twenty-first century. Therefore, the RCP8.5 scenario assumes an increase in radiative forcing of 8.5 W/m^2 by 2100 relative to pre-industrial conditions (IPCC, 2013). In contrast to previous emissions scenarios, RCP's also include trajectories for a range of stabilisation, mitigation and baseline emission scenarios provided by scientific research (Jacob *et al.* 2014). This study utilises the RCP8.5 scenario which is the most intense pathway set out by the IPCC that represents a 'worst case scenario' vision for the planet.

The main aim of this study is to use climate indices to assess the potential impact of climate change on the occurrence of extreme weather and climate events in Greece throughout the 21st century, comparing current conditions (2001-2030) with the near future (2031-2059) and the far future (2070-2099) as projected by two climate model runs representing RCP8.5.

An impact assessment can then be drawn to compliment the findings and to discuss the projected future changes that the country may face and assess how it may influence a number of different sectors across the country, notably, implications for human comfort levels in Greece, impacts on tourism and impacts for the future energy supply. An RCP8.5 trajectory would likely be witnessed by our planet if there was “no action taken” towards mitigating climate change, fossil fuels would continue to be over-exploited and sustainability procedures would be minimal. In comparison with the Paris 2020 targets, an RCP8.5 pathway would exceed the 2^{o}C threshold set out by the agreement, pushing the increase in global temperatures to 3^{o}C above pre-industrial levels, potentially as high as 4^{o}C by the end of 2100 (IPCC, 2013). This ‘worst case’ scenario is adopted in the study because it provides a very useful example of why action is needed against climate change, how we simply cannot just ignore the problem otherwise the effects in the future will be very damaging for society. Current examples of various different adaptation strategies across the country are also studied, most of which are being heavily influenced by the European Union which provides funding and a general direction for climate adaptation projects to help develop a more sustainable outlook for the future of Greece.

2.0 Background

2.1 Climate and Geographical characteristics of Greece

One of the Mediterranean crown jewels, Greece has a high level of influence for its relative small size in relation to the rest of Europe. The country has a total area of 131,957km^2 and occupies the southernmost extension of the Balkan Peninsula (Figure 1). The mainland accounts for 80% of its territory, whilst the other 20% can be divided among nearly 3,000 islands (Giannakopoulos *et al.* 2011). Greece contains a complex array of topographic features that influences a number of local climate characteristics for each region providing a number of different climatic variations across the country (Eleftheriou *et al.* 2018). Because of such contrasts, various climatic characteristics and meteorological parameters can alter the local climate, even within a few kilometres distance (Spyridi *et al.* 2015).

Fig. 1. Satellite map of Greece in relation to the Southeast Europe and the Eastern section of the Mediterranean Sea (Modified from Google Earth, 2018).

The Pindus mountain range spreads south across the spine of mainland Greece and is an example of how the geography of Greece intervenes quite heavily with its climate. West of the Pindus witnesses a generally wetter and cooler climate in comparison to the eastern side of the mountain range which experiences drier and more mild summers. The Rhodope Mountains also reaches parts of north-eastern Greece, stemming from Bulgaria to the north. Both the Pindus and Rhodope mountain ranges mean that large parts of Northern Greece are mountainous and can experience strong snowfall in the winter, in contrast to low lying regions and islands that make up most parts of southern Greece and the island of Crete where winters are generally quite mild.

Greece has an enticing Mediterranean climate where summers are characterised by long hot and dry spells where temperatures can exceed 30°C (Figure 2.1) whilst the winter months remain relatively mild in comparison with the rest of Europe. Upland areas across the country, mainly in the north, receive a much cooler winter period in comparison to low-lying areas. Temperatures become much warmer as spring advances whilst the peak summer months receive the highest temperatures with at least the whole of Greece witnessing a number of summer days with temperatures above 25°C, many coastal areas witness a number of tropical days with more intense temperatures above 30°C.

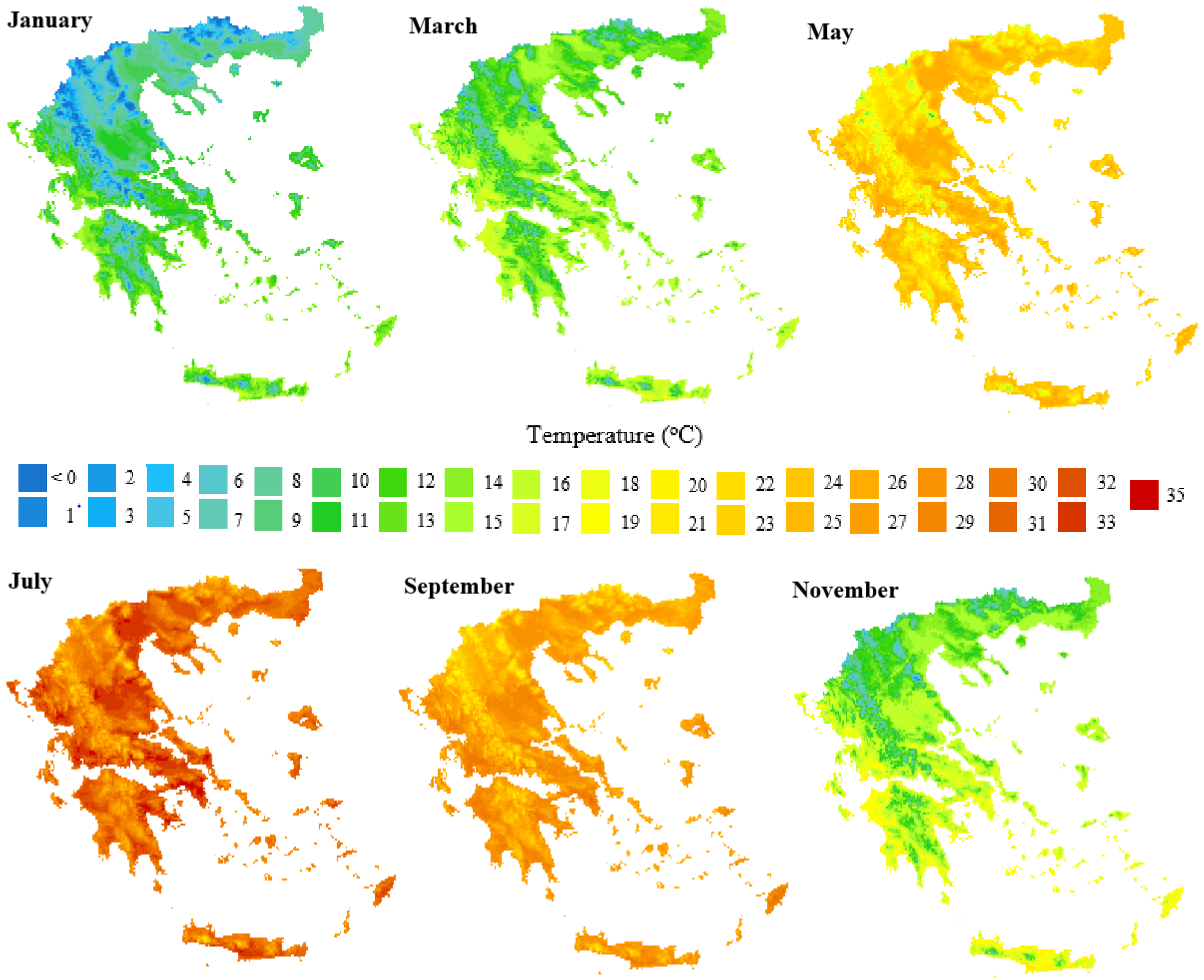


Fig. 2.1. Monthly maximum temperature data for Greece with the majority of the country witnessing a strong Mediterranean climate, as a result, the cooler winter months are followed by hot and humid summer temperatures that can extend to the shoulder months. Reference period of 1971-2000 (Observational data and map template modified from HNMS.gr, 2016).

The summer months across a number of different Greek cities (Figure 2.2) show a similar correlation of very high temperatures across the whole country. Despite Ioannina's location in the north, summer months are very mild because of its inland location and minimal air movement. In contrast, Heraklion often receives seasonal breezes from the Aegean making summer temperatures more comfortable. Both Athens and Thessaloniki show slightly more intense summer temperatures, most likely because of the urban heat island effect (UHI) where urban areas are generally warmer by a couple of degrees compared to surrounding rural areas (Paravantis *et al.* 2017). Much more variation occurs between cities in the north and south during the winter months with temperatures falling much lower in northern Greece compared to the southern region.

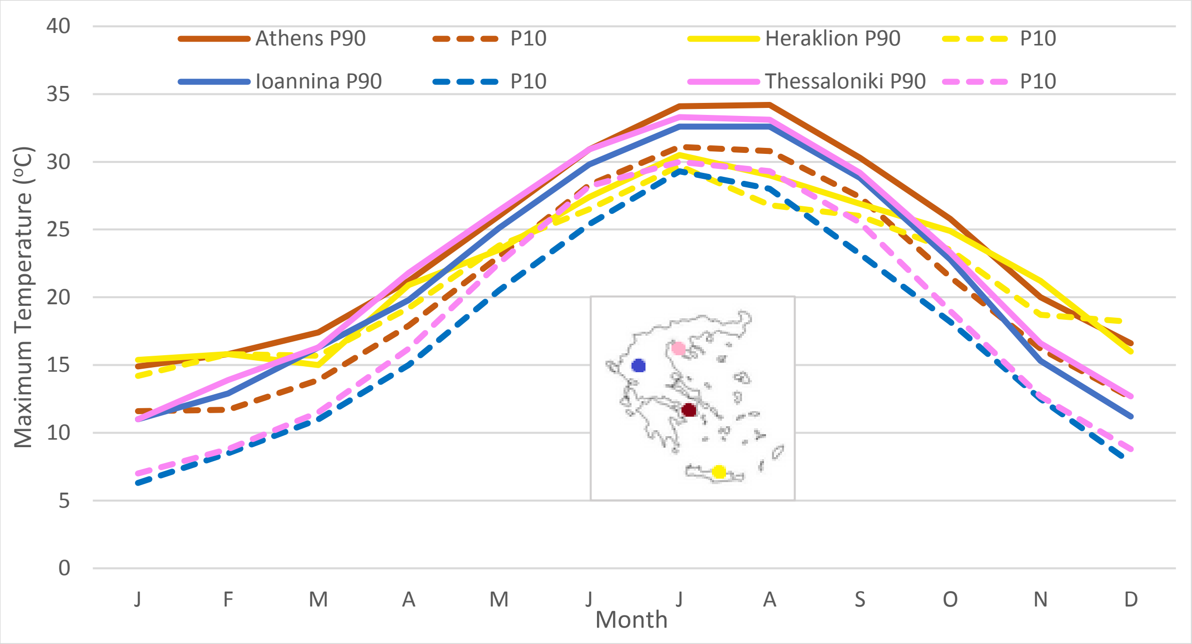


Fig. 2.2. P90 and P10 values for monthly maximum temperature data for four different locations in Greece. Temperature patterns are relatively uniform across the country, although there is some regional variation, most notably in autumn and winter. Reference period of 1971-2000 (Based on data from HNMS.gr, 2016).

Temperatures in Greece are relatively uniform whereas precipitation levels are spatially variable, mainly due to its topography. Rainfall patterns generally are higher on the western side of Greece (Figure 3.1). The late autumn/winter months produce the most significant amount of rainfall for Greece with Western Greece receiving much larger proportions - November often receives the highest levels of rainfall. Despite this, the majority of spring and summer months witness substantially low levels of precipitation, a pattern which is the case across the whole of the country. The uneven distribution of precipitation for many parts of Greece is a significant concern, most parts receive only 15% of their annual rainfall during summer months, coinciding with the largest seasonal influx of tourists (Stournaras *et al.* 2015).

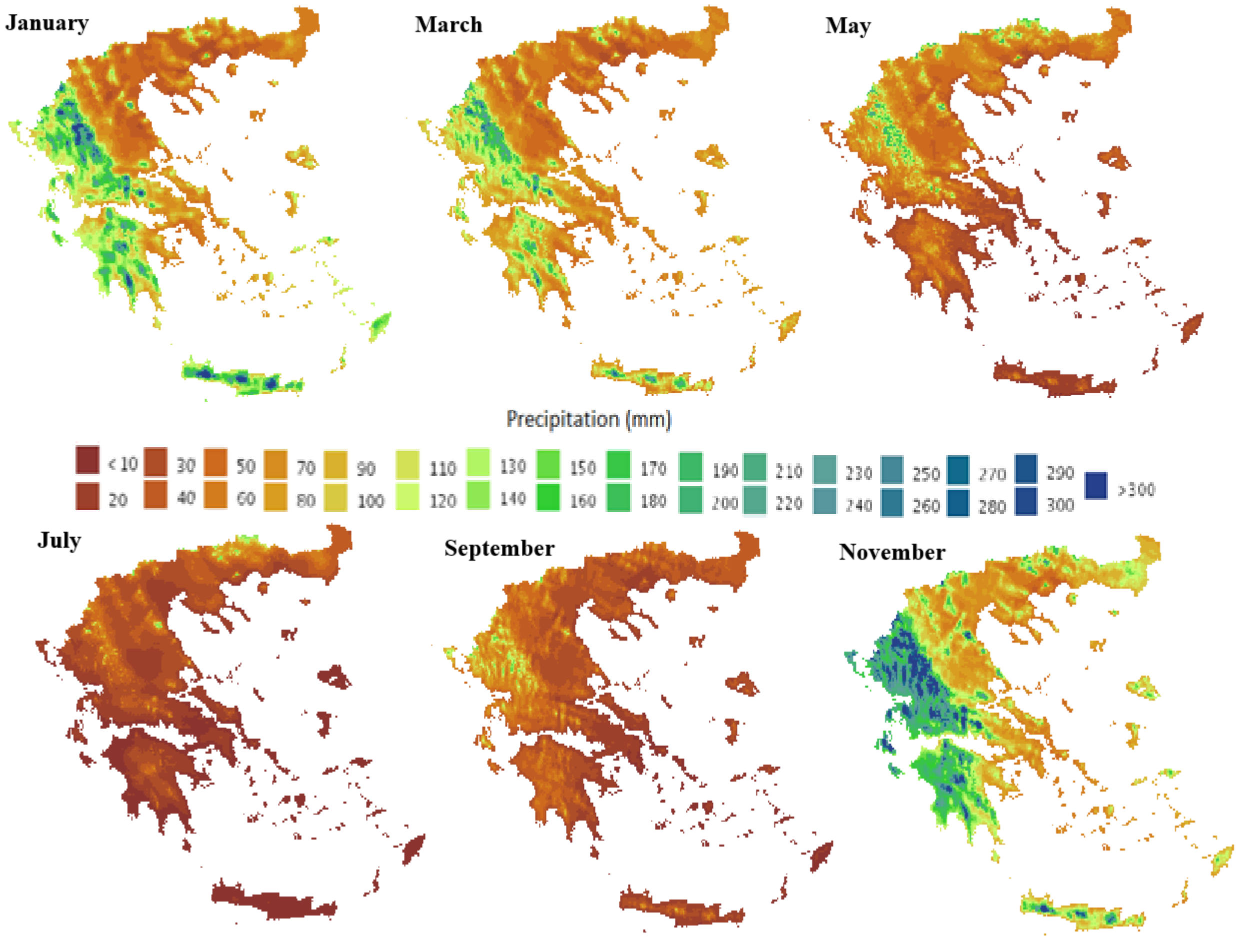


Fig. 3.1. Strong seasonality differences and geographical variations between precipitation in Western and Eastern Greece, considerable precipitation in late autumn and in winter, whereas minimal precipitation in late spring and in summer throughout Greece with a reference period of 1971-2000 (Observational data and map template modified from HNMS.gr, 2016).

Figure 3.2 highlights again the variability in levels of annual rainfall for Greece. Percentiles are used as a measure at which the percentage of the total values are the same as or below that measure. So, 90% of the data values lie below the 90th percentile, whereas 10% of the data values lie below the 10th percentile. The city of Athens receives a relatively low amount of rainfall throughout the year with the winter months providing the main source for precipitation. One clear pattern is that southern Greece generally sees periods of very limited rainfall in the summer months which is sometimes extended to May or September. Heraklion, and the island of Crete show the largest pronounced water shortage that extends for approximately 4-5 months from May to September (minimal rainfall in the three summer months, coinciding with the main tourist season). In the north, Thessaloniki has a much less turbulent rainfall profile, although levels of rainfall remain relatively low for the whole of the year. Ioannina in upland north-western Greece has by far the most substantial level of annual precipitation with large amounts of rainfall accumulating in the winter months despite a large dip in the summer months.

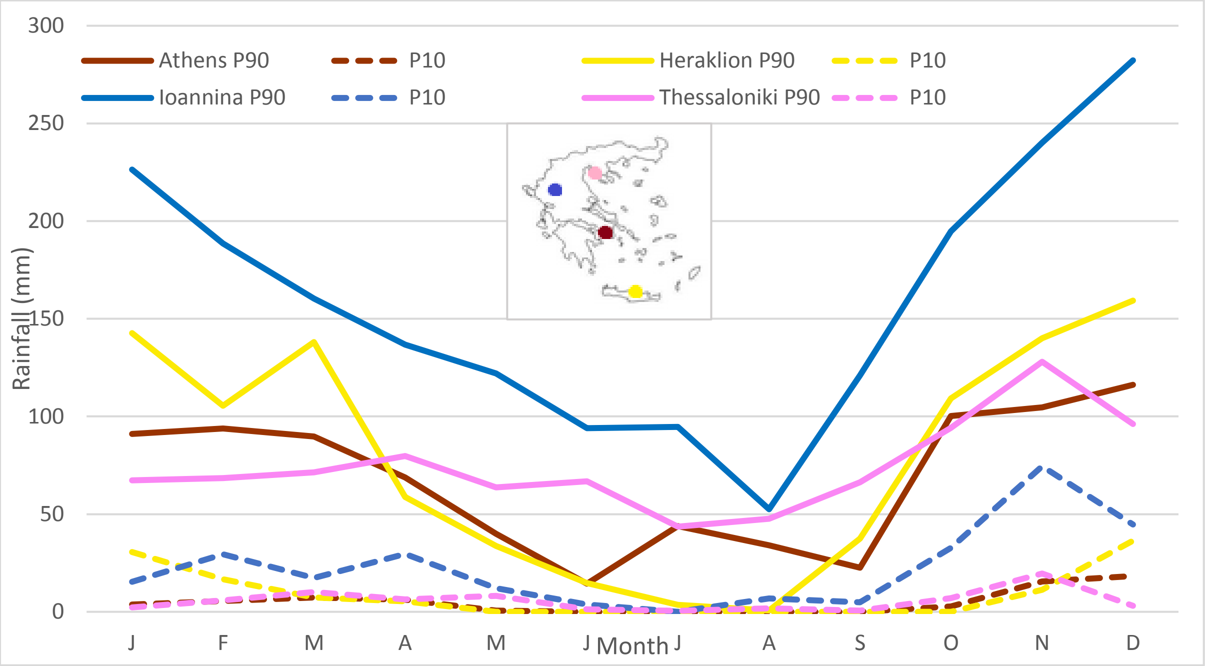


Fig. 3.2. 90th percentile (P90) and 10th percentile (P10) of monthly precipitation for four stations in southern Greece with a reference period of 1971-2000 (Based on data from HNMS.gr, 2016).

During the summer and early autumn months, the Aegean Sea where many Greek islands are situated, is controlled by a dominant localised wind system known as the ‘Etesian Winds’ (Anagnostopoulou *et al.* 2014). The wind regime is a result of a very sharp east-west pressure gradient produced by large scale circulation features. Due to their large size, they result in a band of low pressure over the Mediterranean and the Middle East, whilst creating a high pressure over Central and South-eastern Europe. The winds occur in a mainly diurnal cycle whereby they become stronger in the afternoon but become weaker during the night. One of the most prominent etesian winds is known as the Meltemi, which blows from north to northwest across the Aegean Sea, often bringing with it dry conditions and clear skies, eventually accompanied by a decrease in humidity and a raise in atmospheric pressure. This long period of wind means that there is great potential for wind energy within the Aegean Sea that is yet to be exploited, something that could be analysed in order to improve the sustainable future for Greece.

2.2 Climate Extremes and Heatwaves

Climatic extremes incorporate a range of potential meteorological events. Some of these extremes have a rather short-lived nature, such as heavy precipitation downpours or windstorms, often with a more local extent. Extremes of a more persistent nature such as heat and cold spells typically cover much larger affected regions hence why there is much importance for research on extremes. Examples of different types of climate extremes include maximum and minimum values, as well as interpreting specific threshold values over a period of time which, once exceeded or have fallen below, can indicate a climate extreme (Persson *et al.* 2007).

Heatwaves and heat spells are classed as extreme weather events. According to the IPCC, they are defined as "An extreme weather event that would normally be as rare as, or rarer than the 10th or 90th percentile of a probability density function estimated from the observations" (IPCC, 2013). A heatwave usually occurs after at least 5 days where the temperature is approximately 5ºC higher than average. They bring periods of uncomfortable heat where air humidity is high, and air quality deteriorates (Papanastasiou *et al.* 2015), they are responsible for causing more fatalities in Europe in recent decades than any other extreme weather event (World Health Organisation, 2017). In the future, because of the expected increase in global temperatures resulting from climate change, heatwaves are projected to become increasingly frequent with a higher level of intensity and persist for much longer time periods than current levels, Europe is especially susceptible to future climate change impacts because warming is continuing at a higher rate than the global mean (IPCC, 2013).

Heatwaves in Greece are mainly related to warm air advection and atmospheric stability coming from the Persian Gulf in combination with high Mediterranean Sea surface temperatures and enhanced heat fluxes (Nastos and Kapsomenakis, 2015). The increased occurrence and intensity of heatwaves within Greece has been evident over the last 30 years – a statistically significant increasing trend in the maximum duration of heatwaves ($b=1.33$ days/year, $p = 0.000$) annually has been observed since 1983 (Matzarakis & Nastos, 2011). During the 1990's, there was three times as many heatwaves that occurred compared to the previous 30-year period, coinciding with this, the decade of 1984-1994 was the worst drought period in the century for the cities of Athens and Thessaloniki (Baltas, 2013). A significant heatwave in the summer period of 2007 for Greece had both positive anomalies of temperature combined with extensive periods of high temperature. Three separate severe heat waves in all three summer months made it a rather exceptional period of persistent high temperatures. Simulations of future temperature extremes in comparison with the events of 2007 show that this exceptional event is more than likely to become a common occurrence by the middle of the 21st century (Nastos and Kapsomenakis, 2015; Matzarakis and Nastos, 2011; Founda and Giannakopoulos, 2009).

2.3 Heatwaves in urban areas and health implications

An increase in the occurrence of heatwaves creates a substantial amount of vulnerability on urban environments that is enhanced by an increase in urban population or an increase in rural-urban migration (Georgakis and Santamouris, 2017). Urbanisation itself can affect surface characteristics and the wider atmosphere surrounding cities that alter the climate between urban areas and rural settlements. The most apparent consequence of this is the Urban Heat Island (UHI) effect. This process revolves around the capacity of the built, urban environment to store and trap heat during daytime and release it during night time, combined with other human activities such as heating/cooling of buildings, traffic etc. resulting in warmer urban temperatures (Bank of Greece, 2011). The UHI effect is considerably enhanced during a heatwave period because of the higher ambient temperatures, especially during night time (Paravantis *et al.* 2017).

Various parameters can influence the magnitude and intensity of the UHI effect, most notably the urban characteristics such as the size or population can impact the development of a city and the more large buildings and hardened surfaces, the more likely it is to trap heat. Parameters that may affect a city also include local climatic or meteorological features– wind speed is becoming increasingly significant when measuring the UHI effect, the topography of the city or its surrounding areas, the type of building materials used to construct the urban environment and the amount of green areas situated within a city (Georgakis and Santamouris, 2017).

Almost two-thirds of Greeks live in urban areas and the country is heavily influenced by its two main metropolitan areas of Athens and Thessaloniki. The capital city of Athens, situated in Attica has a metro population of approximately 3.8 million people and Thessaloniki, situated in Central Macedonia has a metro population of approximately 1 million people (Hellenic Statistical Authority, 2011), both metropolitan areas combined represent around 45% of the total population of Greece. Over the last few decades, Athens has witnessed a substantial intensification of the UHI and the city witnessed a rapid increase in population and development between 1950 and 2000, although the total urban population has had a slight decrease since the turn of the century (Georgakis and Santamouris, 2017).

Human health is one of the largest concerns during prolonged heat spells. Heat stress caused by such consistent periods of extreme temperatures has been linked to excess heat mortality, heat-related illnesses and diseases. Heatwaves can result in uncomfortable conditions for the general public, heat strokes are the most severe complication for public health and its worst cases can lead to fatalities. The likely increase in frequency of heatwaves is of particular concern for the Greek population because approximately 19% of the population is above the age of 65, therefore a large section of society is considerably susceptible to heat stress and its corresponding impacts (World Health Organisation, 2017).

As a result of these climatic changes, Greece will be vulnerable to considerable stress on numerous socio-economic sectors that will have to be approached to avoid disruption that would have negative implications across the country (Figure 4).

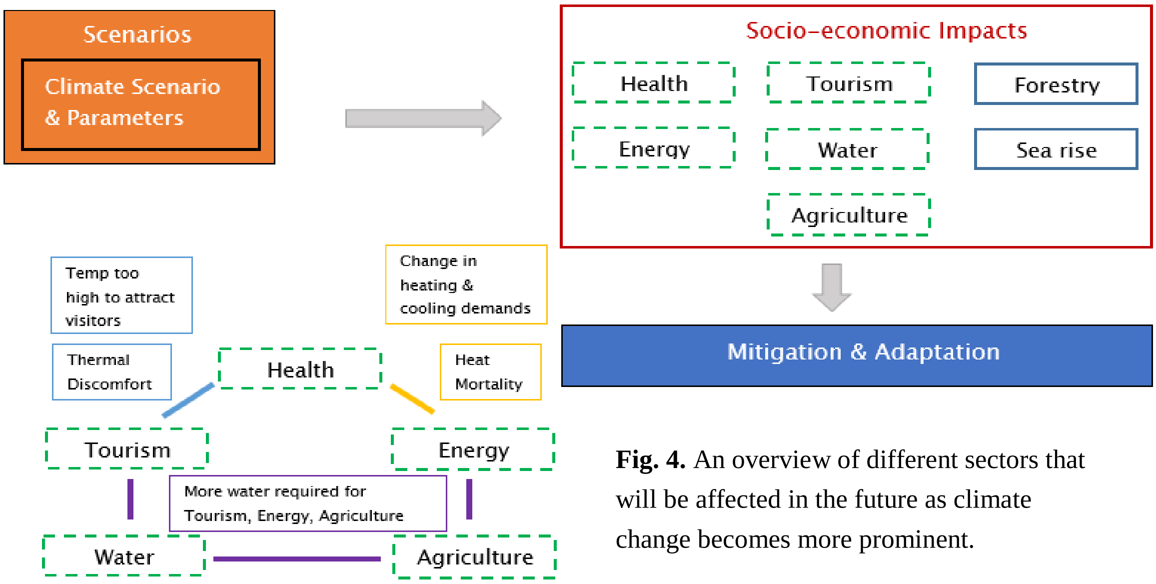


Fig. 4. An overview of different sectors that will be affected in the future as climate change becomes more prominent.

2.4 Tourism in Greece

Tourism in Greece from international arrivals has witnessed a phenomenal increase since 2012 (Figure 5). After a relatively stagnant few years following the Greek economic crisis in 2009, the country has received a dramatic increase in visitors with 2017 being the year with the highest ever influx of tourists to Greece of all time according to the Greek Tourist Confederation (SETE). The increase each year since 2012 has been enormous, with an additional 6.3 million annual visitor arrivals coming to Greece in the space of 5 years. As a result of tourism influx, Greece is expected to witness a record amount of holidaymakers in 2018 that will likely hit the 30 million benchmark (Including cruise ship arrivals) – three times as many visitors as permanent residents, and an increase of 2.5 million visitors since 2016 (SETE, 2018).

The tourism industry continues to grow, in 2016, tourism was the source of creating 8 out of 10 new jobs in the country which has been highly beneficial considering the high levels of unemployment in recent years, such advancements represent the vital importance of this high tourist influx for Greece especially after the economic crisis that caused significant nationwide problems. It’s likely that climate change will have quite an impact on Greece’s tourism industry further into the future, it will potentially bring both positive and negative aspects with it by intensifying certain weaknesses whilst also highlighting new growth possibilities (Giannakopoulos *et al.* 2011).

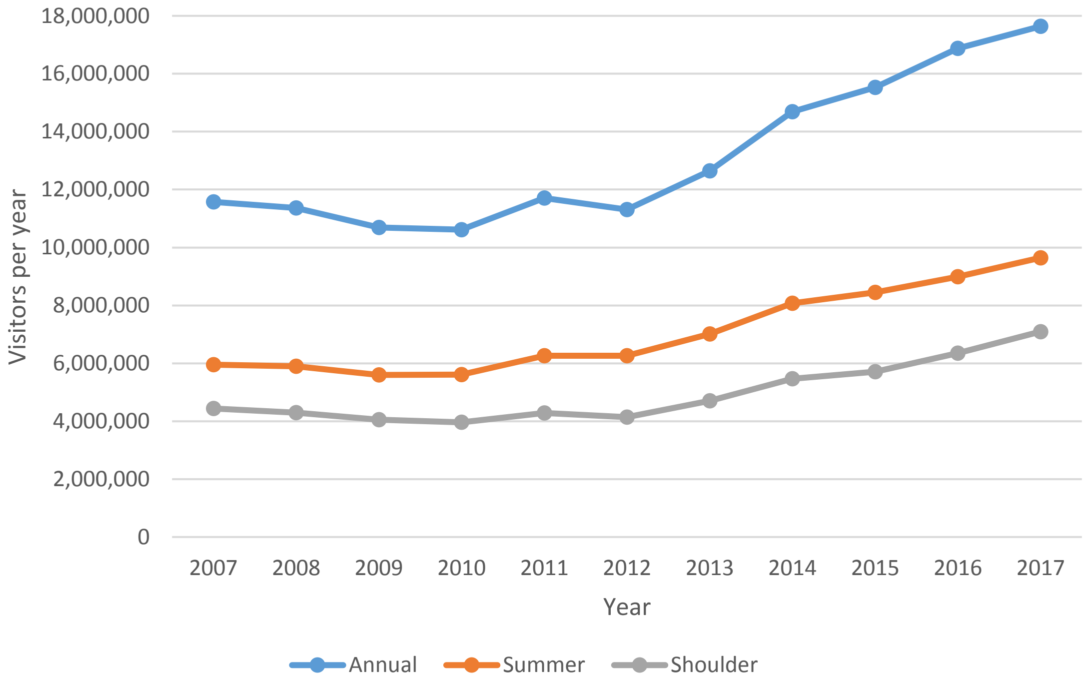


Fig. 5. International Air Arrivals for the whole of Greece between 2007 and 2017 for the entire year, the summer months (June, July & August) and the shoulder months (April, May, September, October). (Based on data from SETE, 2018).

The three largest tourist regions (minus Athens) have similarly witnessed a significant upward trend in tourism figures from air arrivals (Figure 6). Since 2015, numbers have substantially increased, notably a large rise between 2016 and 2017 for both summer and shoulder periods. Both Crete and the Southern Aegean (Includes both the Cyclades and the Dodecanese islands) attract large tourists for seven months of the year but significantly larger concentrations during the three summer months, coinciding with the most extreme levels of high temperatures combined with low rainfall. As a result, exceptionally large demands on the small water supply of these islands is exacerbated and the extra tourist influx increases the risk of water demand surpassing the water availability. On the island of Crete, 81% of water consumption is needed for agriculture and irrigation whereas tourist demand accounts for just 15%, the added strain on water from tourism influx will only heighten the water needed for visitors and will require the agriculture water supply to adjust – something that may have strong implications for rural populations whose livelihoods depend on their agriculture (Kourgialas *et al.* 2018).

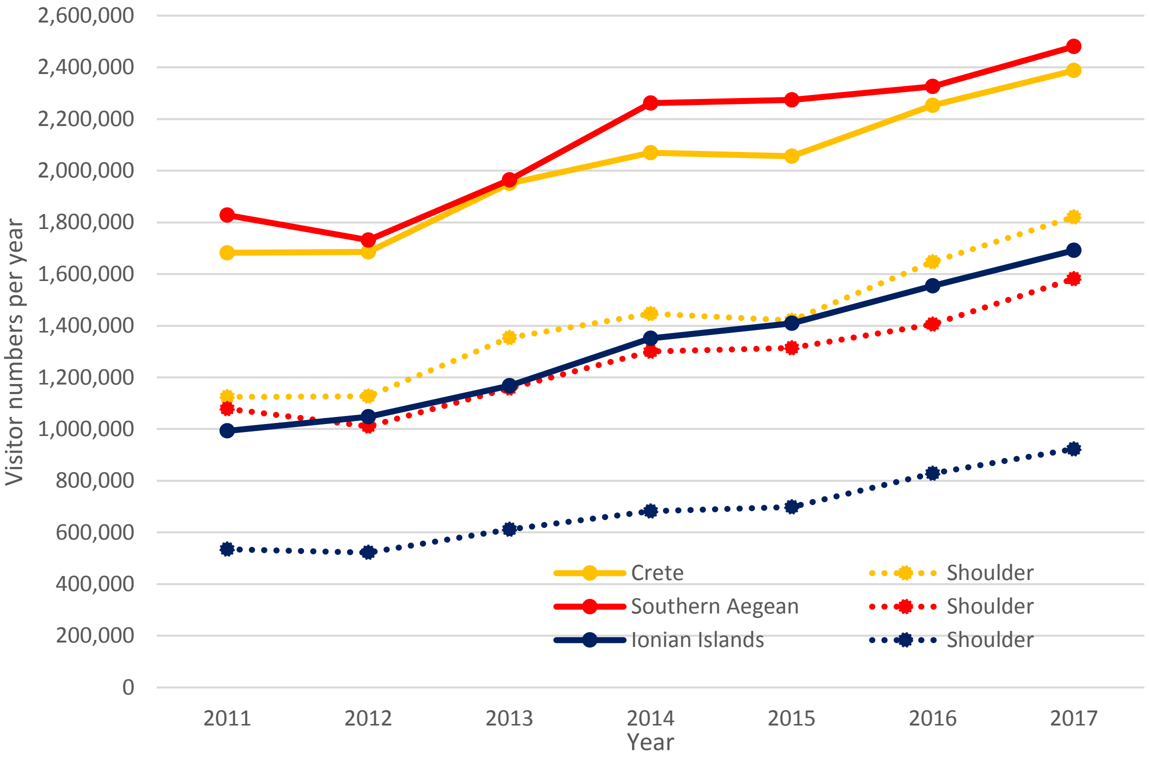


Fig. 6. International Air Arrivals for the three largest tourist regions in Greece (minus Athens) between 2011 and 2017 for the summer months (filled line) (June, July & August) and the shoulder months (April, May, September, October). (Based on data from SETE, 2018).

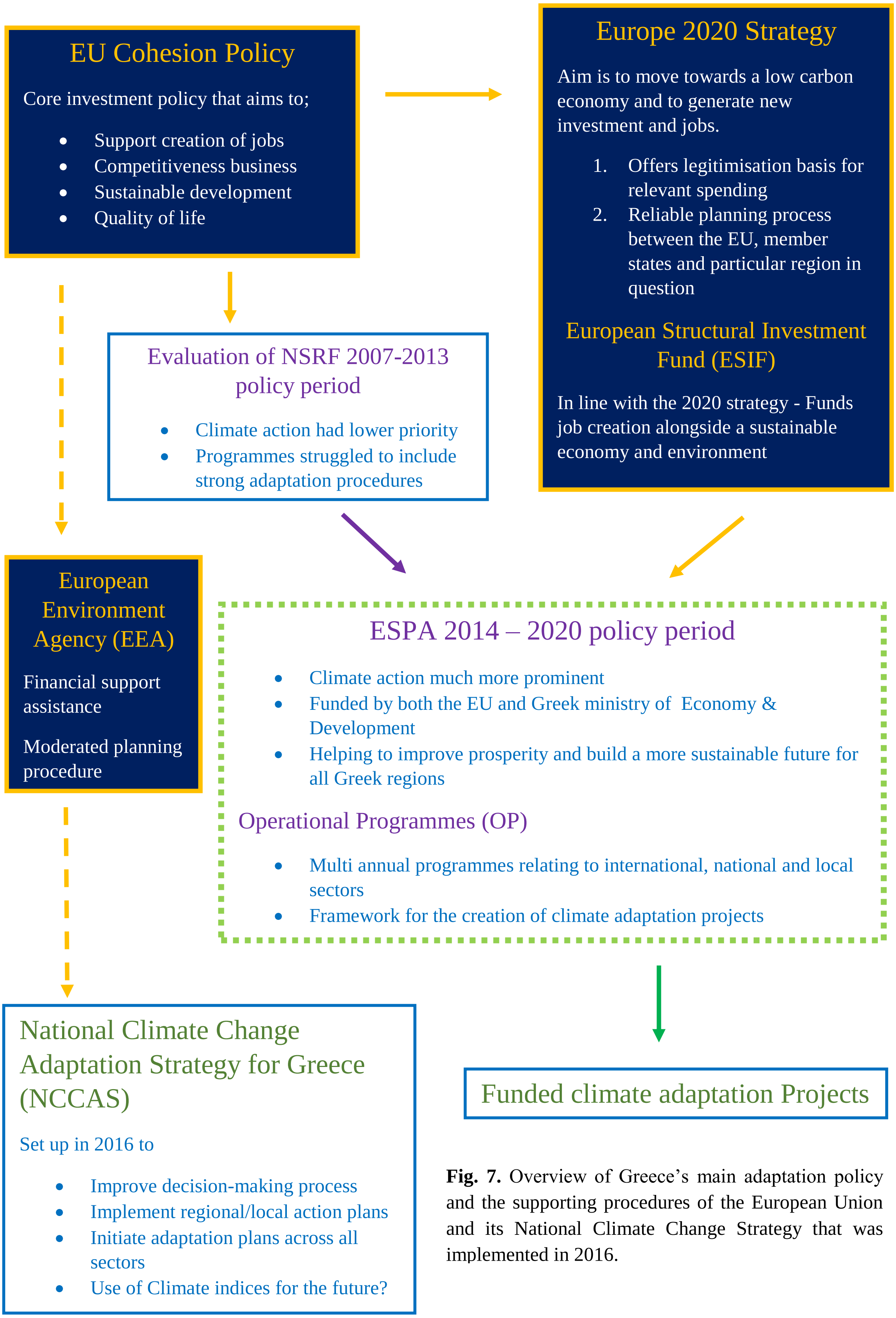
The World Travel & Tourism Council estimates that tourism in 2017 contributed to 19.7% of Greece's total GDP with a total of 12.2% of employment supported by the industry. For 2018, forecasts suggest an additional 5.3% rise in contribution to the GDP from tourism, with a 5.2% rise expected in supported employment. Additionally, a 3.6% rise is expected in 2018 for investment in travel and tourism, from a 2017 total of €17.1 billion (WTTC, 2018). Such an upward trend in tourism to the Greek islands will bring with it some environmental problems that will be a concern. An excessive amount of consumption of the water supply to deal with the extra influx of tourists will represent an additional pressure, which will likely be exacerbated in the future due to an increase in the intensity of heatwaves and drought periods (European Environment Agency, 2017).

The current tourist boom period will eventually slow and other countries will compete to attract a large chunk of Greece’s visitors. As a result, it is highly important that Greece continues to extend its tourist season as much as possible – something that may actually be beneficial in a future climate to relieve the strain in the summer, Greece must also work to expand its image by diversifying towards additional tourism demands instead of just a traditional sun and sea destination (Grillakis *et al.* 2016).

2.5 Adaptation & Mitigation

Adaptation is the process of adjustment to an actual or expected climate and its effects - it aims to exploit beneficial opportunities and avoid damage to human life. Mitigation of climate change is the human intervention to reduce the sources of greenhouse gases to limit climate change (IPCC, 2014). Mitigation and adaptation work in parallel with one and other, if more mitigation strategies are implemented, this will considerably reduce the risk of future climate change to society and the different sectors, whilst adaptation strategies will soften the negative consequences of the resulting future damages. Both options are implemented on the same local or regional scale and may be motivated by local or regional priorities and interests, as well as possible global concerns (IPCC, 2007). Climate change adaptation policies are created to address any damage or negative impacts that are considered most likely to arise from a change in the climate and they are often set up to protect the most vulnerable sectors. The most efficient strategies for mitigation and adaptation will consider various technological solutions and management strategies suitable to a particular area and will be adopted with consideration of an areas local characteristics (Spyridi *et al.* 2015).

For Greece, an overview of the different sources of funding from the EU and the current ESPA (European Structural Partnership Agreement) policy is given below in Figure 7, parts of this funding can then be used to create climate adaptation projects across the country involved in improving environmental quality (Figure 8), climate adaptation (Figure 9) and the energy infrastructure (Figure 10) of Greece to provide a more sustainable future and climate-resilient economy going forward.



EU Cohesion Policy

Core investment policy that aims to;

- Support creation of jobs
- Competitiveness business
- Sustainable development
- Quality of life

Europe 2020 Strategy

Aim is to move towards a low carbon economy and to generate new investment and jobs.

1. Offers legitimisation basis for relevant spending
2. Reliable planning process between the EU, member states and particular region in question

European Structural Investment Fund (ESIF)

In line with the 2020 strategy - Funds job creation alongside a sustainable economy and environment

Evaluation of NSRF 2007-2013 policy period

- Climate action had lower priority
- Programmes struggled to include strong adaptation procedures

European Environment Agency (EEA)

Financial support assistance

Moderated planning procedure

ESPA 2014 – 2020 policy period

- Climate action much more prominent
- Funded by both the EU and Greek ministry of Economy & Development
- Helping to improve prosperity and build a more sustainable future for all Greek regions

Operational Programmes (OP)

- Multi annual programmes relating to international, national and local sectors
- Framework for the creation of climate adaptation projects

National Climate Change Adaptation Strategy for Greece (NCCAS)

Set up in 2016 to

- Improve decision-making process
- Implement regional/local action plans
- Initiate adaptation plans across all sectors
- Use of Climate indices for the future?

Funded climate adaptation Projects

Fig. 7. Overview of Greece’s main adaptation policy and the supporting procedures of the European Union and its National Climate Change Strategy that was implemented in 2016.

Climate adaptation strategies set out by the EU help to enhance the need for adaptation and mitigation against future climate change, although, its priority can sometimes vary, depending on the country. A new European 2020 strategy set out by the EU and its integration into their cohesion policy dedicated to climate adaptation and mitigation has helped to drive sustainable thinking. For Greece and their current policy period - 2014-2020 (Figure 7), climate action has a much more prominent position with emphasis placed firmly on risk prevention and adaptation strategies. As a result of this, more emphasis can be placed on providing suitable projects that will help the country transition to a more sustainable future. Projects are already being implemented across Greece to help improve prosperity for citizens as well as building a more sustainable future for the different Greek regions on a smaller scale (Thoidou, 2017a).

Operational Programmes (OP) are multiannual programs that are used throughout the policy period, they relate to sectors and/or geographic regions at international, national or local level. All funded projects are created within the framework of the OP of the previous policy period, 2007-2013 (NSRF) and more are being developed for the 2014-2020 policy period that is currently ongoing. Financing for projects began during NSRF 2007-2013 and examples include enhanced protection and upgrading of national parks in Northern Greece, wastewater treatment facilities and the implementation of more environmentally friendly public transport in cities (ESPA, 2016).

The Europe 2020 strategy is provided with funding and mainstreamed within the EU cohesion policy (Figure 7) to achieve its goals of moving towards a low-carbon, climate-resilient economy that can generate newer investment opportunities and jobs. So far, the 2020 strategy is providing more direction for Greece and a sustainable future, it is providing a progressive level of funding for achieving policy goals and also a valid planning process, which is helping to build a reliable system of decision making between three levels, the EU, the member states, and the particular regions in question. (Thoidou, 2017b). The Partnership Agreement for the (ESPA) 2014-2020 policy period constitutes the main strategic plan for development and growth in Greece with a large funding base and support originating from the European Structural Investment Funds (ESIF) of the European Union, in line with the Europe 2020 strategy. Through this agreement, the ESPA aims to tackle the structural weakness that caused the economic crisis and attempt to bounce back the growth in Greece for the foreseeable future (ESPA, 2016). With assistance from the European Environment Agency (EEA), Greece was able to launch its National Climate Change Adaptation Strategy (NCCAS) in 2016 to help structure its adaptation planning, the next step in the future will be to set up sectoral adaptation plans to coincide with the NCCAS (EEA, 2017).

2.6 Sustainable climate projects in Greece

One of the key thematic objectives of the 2014-2020 policy period that receives funding is the "Preservation and protection of the environment and to further promote resource efficiency" (ESPA, 2016). The total environment budget is utilised by each region of Greece (Figure 8), although the regions with the largest urban and economic development evidently receive the largest proportion of budget for projects – Athens being situated in Attica (AT) and Thessaloniki located in Central Macedonia (CM), both have considerably larger populations than other areas of Greece.

Environmental projects with the budget cover a much broader spectrum than other objectives, but national projects are ongoing for regeneration and renovation of green areas across the country, green entrepreneurship in urban areas for a more sustainable Greek economy, innovations for environmental research and development, increased awareness for recycling, environmental education centres for the public and national flood protection (Ministry of Economy, Development and Tourism for Greece, 2018). By the end of the policy period in 2020, the aim is to have integrated more waste management implying an increase in recycling of approximately 650 thousand tonnes per year, increased the population served by waste water treatment facilities, increased protection of conservational areas and covered all of Greece with flood risk management plans. During this implementation, approximately 50,000 jobs are expected to be created. (ESPA, 2016).

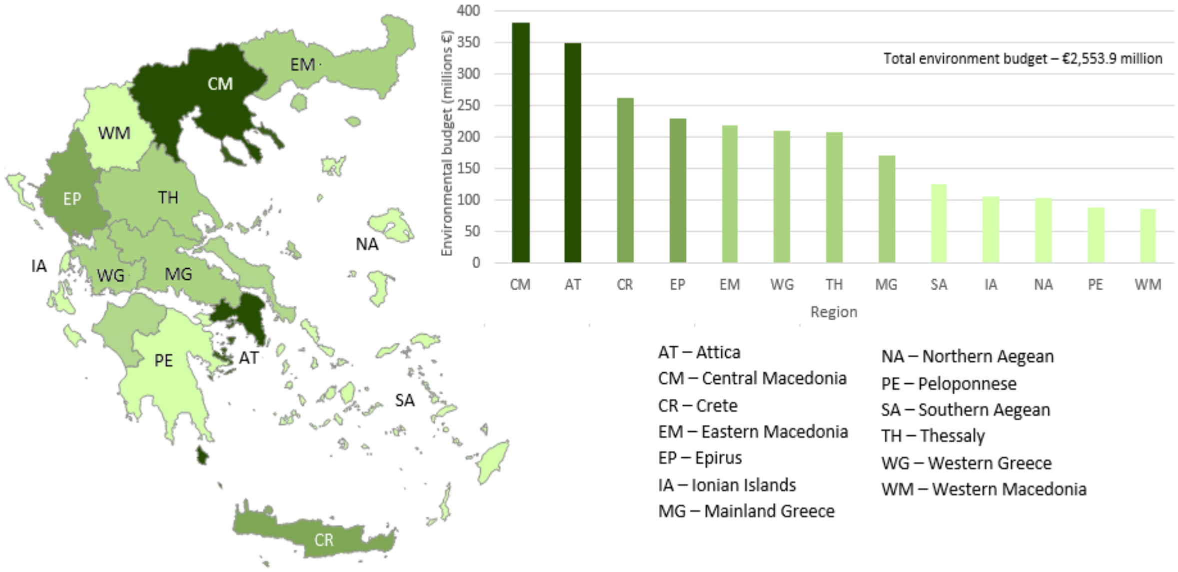


Fig. 8. Project analysis for total amount of approved projects for each Greek region for the environment budget for 2014-2020 policy period (Modified from Ministry of Economy, Development & Tourism for Greece, 2018).

The climate budget (Figure 9) is a separate fund that aims to “Promote climate change adaptation, risk management and management to prepare for changes in the future” (ESPA, 2016). The likelihood is that the climate budget will continue to increase in the future as more emphasis is placed on promoting its agenda. The majority of the budget is for the main urban areas with Athens considerably having a larger size. Projects for climate change management are still in very early development since the previous policy period where it was grouped with the environment budget, although regional plans are in place for both Athens and Thessaloniki for the local adaptation to climate change that is due to start in late 2018. (Ministry of Economy, Development and Tourism, Greece, 2016).

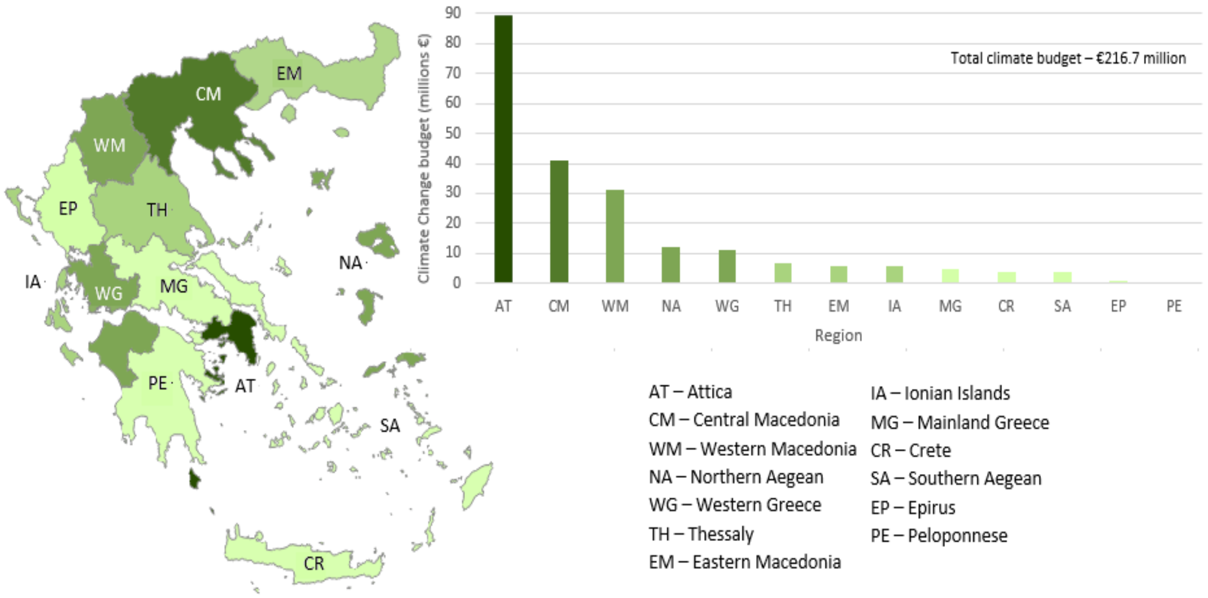


Fig. 9. Project analysis for total amount of approved projects for each Greek region for the climate change budget for 2014-2020 policy period (Modified from Ministry of Economy, Development & Tourism for Greece, 2018).

The main aims for national energy planning in Greece are to reduce the country's dependence on imported energy in order to make way for a larger distribution of energy from renewables, drastically reduce greenhouse gas emissions by 2050 and reinforce consumer protection. Greece's renewable sector is improving, they are on course to achieve a 20% share of energy from renewables by 2020 along with exploiting new renewable technologies (European Environment Agency, 2017). Attica receives the largest amount of budget for energy infrastructure (Figure 10) but there is also quite an equal distribution across much of northern Greece where there is considerable energy potential. Although there is a low budget across Crete and other Greek islands, there remains a relatively large wind potential for off-shore wind farms that could be exploited during late summer when Etesian Winds arrive. There is also a significantly large solar potential due to extensive sunshine hours with solar energy now accounting for 19% of Greece's renewables (International Energy Agency, 2017). It's also worth mentioning that there is a budget for transport that corresponds with the energy infrastructure budget for shifting towards a low-carbon economy. This budget is much larger and aims to improve road networks and to develop more sustainable and ecological urban transportation in Athens and Thessaloniki.

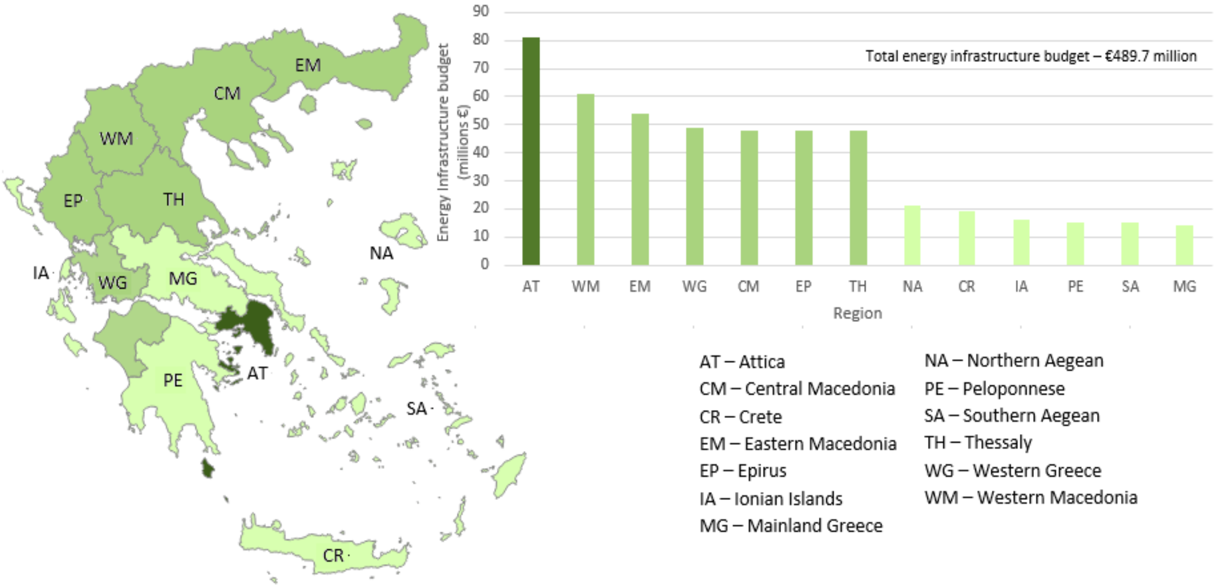


Fig. 10. Project analysis for total amount of approved projects for each Greek region for the energy infrastructure budget for 2014-2020 policy period (Modified from Ministry of Economy, Development & Tourism for Greece, 2018).

2.7 GCM's and RCM's

Both Global Circulation Models (GCM's) and Regional Climate Models (RCM's) help to improve our understanding of future climate possibilities. GCM's are complex three-dimensional computer-based models of the climate system and they form the platform to build climate change scenarios on. These climate scenarios provide the best available way of exploring anthropogenic activity that may change the composition of the atmosphere, how this may then alter the global climate and how this will then affect human activities and the environment (Baltas, 2013). GCM's have a relatively coarse resolution (typically 150-300km) therefore they have a limited extent to provide climate information on large spatial scales. Information at higher resolutions can be derived from initial conditions from GCM's to then drive the RCM's, providing boundary conditions on a much more local scale (IPCC, 2013).

The regional climate can be dependent on two separate factors, the large scale climatic state, and more regional distributing factors such as topography or land use. Dynamic downscaling is a process whereby known information at large scales from models is taken to make predictions at a more local scale, as opposed to the alternative approach, statistical downscaling which adopts statistic-based techniques to find relationships between large scale climate patterns by GCM's and local climate responses (Jacob *et al.* 2014). The recent advancements with RCM technology has enabled more dynamic downscaling to be obtained for climate research which has enabled more in-depth and accurate studies of smaller areas with complex topographic scenarios such as Greece over the last 10 years (Zanis *et al.* 2015).

2.8 Background to the CORDEX data

Similarly to the previous climate downscaling studies of PRUDENCE and ENSEMBLES, CORDEX has the aim of using climate models over an unprecedented range of spatial scales over Europe. CORDEX essentially has a twofold purpose to provide a framework to evaluate and benchmark model performance and to design a set of experiments to produce climate projections for use in impact and adaptation studies (Giorgi *et al.* 2009). Climate models maintain the aim of providing simulations at a high resolution of 0.11° (about 12km) and a low resolution of 0.44° (about 50km). In principle, both of these resolutions can integrate each other to enable the simulation of the interaction between large-scale dynamics and a more localised scale (Vautard *et al*. 2013). Since 2013, CORDEX data has been adopted across a number of different climate impact studies for analysing future projections for the European climate and the Mediterranean (Jacob *et al.* 2014; Koutroulis *et al.* 2016; Vautard *et al.* 2013).

2.9 Climate Indices

Climate indices based on climate model data can be used as a simplified way of communicating climate change impact relations. In order to detect climate extremes and how they may differ in the future, it is important to develop a set of indices that are statistically robust and can be used for comparison with other research on similar study areas (Zhang *et al.* 2011). The use of indices is often incorporated using daily or monthly means in the data and much focus can be made for extremities. As an example of how this is projected, a simple probability distribution for temperature can be made (Figure 11) where the higher the black line, the more likely the weather with those characteristics will occur. The mean or average point where conditions are stable can be shifted in a warmer or cooler climate. As an example, in a warmer climate, the mean will be shifted and therefore there will be a higher probability for hotter weather and more extreme hot weather will become more frequent, colder weather events will become less frequent (Figure 11).

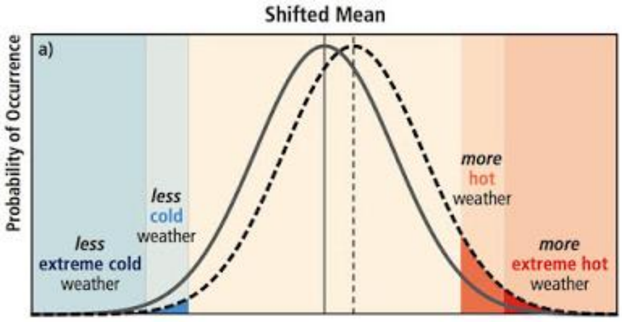


Fig. 11. The probability of occurrence of an extreme temperature event. If the average is shifted in a direction, there becomes a higher probability for one extreme (IPCC, 2012).

The general consensus is that, the more extreme an event is (can be at either end of the scale), the more likely it is to damage society or the environment and the more relevance it will bring with it. Having said this, the further out into the tail the extremity is, the more the uncertainty is generated. One of the main reasons for this is because such events occur with less and less frequency, therefore there is less data available to characterise any possible changes (Zhang *et al.* 2011). The expected climatic trends for Greece can be simulated and climate model data can be used to calculate climate indices for assessing the impacts and the effects of an increase in temperature. Indices can be extended from quite simple algorithms to more complex ones which depict how a substantial period of time with a continued climate extreme will have an impact. This can then be displayed to show how the future climate may look for an area in order to promote awareness for adaptation and mitigation.

3.0 Materials and Methods

3.1 Climate models

Climate data from two RCM's (Regional Climate Models) was used in this study in order to produce a number of temperature and precipitation maps for Greece to show potential changes in the current/imminent future (2001-2030) and both the near future (2030-2060) and the far future (up to 2100). These models adopted the RCP8.5 scenario - the most extreme scenario set out by the IPCC regarding future greenhouse gas emissions.

Modelled data for minimum and maximum temperature and mean precipitation was collected from two different regional climate models. Uncertainties associated with climate model data were addressed by using data from two separate climate models, both models were selected to represent the variation of the EURO-CORDEX dataset (Wilcke and Bärring, 2016). This dataset includes a total of 11 members representing RCP8.5 with a daily temporal resolution and a spatial resolution of 0.44 x 0.44° (approximately 50x50km). Elevation is an important factor when working with climate model data, the elevation of the different climate model data points (Figure 12) can represent different topographic details for Greece.

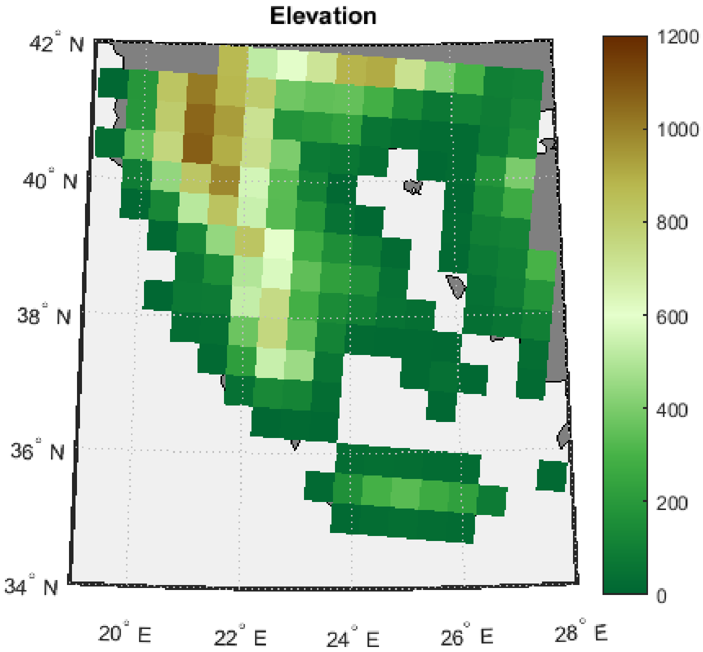


Fig. 12. Elevation map and coordinates for Greece in relation to climate model data points. Elevation given in metres above sea level.

The RCA4 model (EUR-44_CCCma-CanESM2_RCP85_r1i1p1_SMHI-RCA4_v3-SMHI-QM658-MESAN-1989-2010) is the latest Swedish Meteorological and Hydrological Institute (SMHI) atmospheric model, whilst the RACMO22E (EUR-44_ICHEC-EC-EARTH _RCP85_r1i1p1_KNMI-RACMO22E_v1-SMHI-QM658-MESAN-1989-2010) is an RCM created by the Royal Netherlands Meterological Institute (KNMI).

The design of the European section of the CORDEX experiment (EURO-CORDEX) aims to downscale CMIP5 simulations across Europe, it allows for such an evaluation in a controlled framework. CORDEX data is provided from the Earth System Grid Foundations (ESGF) which is the largest archive of climate data worldwide. It is widely used by various organisations and authorities including numerous different climate institutes across Europe such as the SMHI (EURO-CORDEX.net, 2018).

3.2 Bias-adjusted datasets

The obtained data has adjusted daily biases between observational and modelled data by quantile mapping for the RCM (Wilcke and Bärring, 2016). Often, a bias exists between modelled and observed extreme datasets that is generally influenced by small scale parameterised processes and local feedbacks that may not be picked up in a model. This is also more of the case for extreme temperatures rather than mean temperatures. A bias adjusted dataset such as the ones used in this project removes the mean bias of the observed index which helps to avoid the mean difference between the observed and modelled index which leads to more accurate results (Hanlon *et al.* 2015). As the climate data is bias adjusted, differences for the historical period at grid level have also been accounted for. This report used climate model data that had been bias corrected using MESAN for both models, which is reanalysed based on observations and climate model interpretations making it valid for bias correction purposes. The time period used for bias correction in this study is different to the time period used for the evaluation, so differences may occur in relation to underlying statistical distributions of observed/modelled weather events.

3.3 Calculation of climate indices

The obtained climate model data was used in calculations of climate indices. All calculations were performed using Matlab R2017a. Matlab code was developed to calculate the following climate indices for the current/imminent future (2001-2030) and both the near future (2030-2060) and the far future (up to 2100);

- Occurrence of ‘summer’ days with a maximum temperature of at least 25°C
- Occurrence of ‘tropical’ days with a maximum temperature of at least 30°C
- Occurrence of ‘tropical’ nights with a minimum temperature of at least 20°C
- Longest consecutive number of summer days (25°C)
- Longest consecutive number of tropical days (30°C)
- Longest consecutive number of tropical nights (20°C)
- Occurrence of cooling degree days with a maximum temperature of at least 18°C
- 10th percentile of annual precipitation sum (>0.1mm)

This selection of climate indices capture different aspects of high temperatures and low precipitation. To characterise the period and scenario specific climate conditions, average index values are presented along with standard deviation and the 10th and 90th percentiles (Table 1). The main analysis, focusing on the potentially most harmful extreme events within the 30-year periods, was based on the 90th percentile that represent the strongest accurate probability of an extreme event and its occurrence across future periods whilst eradicating any anomalies that lie above the 90th percentile.

4.0 Results

4.1 Modelled indices

Percentile-based indices are a useful, simplified method of demonstrating the extreme end of a reference period distribution. For 90th percentile values, the further out into the spectrum away from the mean, the more the degree of extremity, for the case of temperature, the hotter and more intense the temperature will be. Both models show a level of variation for numerous different indices, therefore it was decided to also include mean values from observational gridded values to evaluate how differently the models behave.

What is clear from the modelled results (Table 1) is the significant shift in percentile values between the near future and the far future period, highlighting a considerable increase in the likelihood, not just of the occurrence of high temperatures, but the frequency and duration of heatwaves and periods of unfavourable conditions. What is also worth noting when looking at these P90 values is the transition to the next time period, for the majority of indices, particularly occurrence of hot days and nights, P90 values in one time period become similar to the mean values for the next time period, sometimes the mean for the following period is actually higher than the previous P90 period, and this is also the case for consecutive heat days, something of a concern for the duration of heatwaves (Table 1). What this tells us is that the most intense extreme events in one period will potentially become common events and “less extreme” in the next period, therefore it is likely that extreme events will exceed our current adaptive capacity.

Table 1. Observed gridded mean values (Mean EOBS – 2001-2017), Mean, standard deviation, 10th percentile and 90th percentile values for the eight indices in this study for three different time periods; Current (2001-2030), Near future (2031-2060) and Far future (2071-2100) using the RCA4 model (1) and the RACMO22E model (2).

Climate indices	Mean EOBS	Mean (1)	Mean (2)	St Dev (1)	St Dev (2)	P10 (1)	P10 (2)	P90 (1)	P90 (2)
25^{o}C days									
Current	83	114	79	19	42	96	62	136	97
Near future		132	95	16	40	118	78	146	116
Far future		163	127	17	33	150	102	176	151
30^{o}C days									
Current	31	41	37	24	23	26	25	58	52
Near future		63	42	25	29	45	35	81	61
Far future		97	50	21	42	83	52	112	81
Tropical Nights 20^{o}C									
Current	54	60	60	42	44	58	55	75	75
Near future		82	78	46	50	71	70	98	95
Far future		123	116	50	57	109	93	137	141
Consecutive 25^{o}C									
Current	45	59	38	29	29	36	22	85	58
Near future		82	46	30	33	56	28	106	67
Far future		106	65	32	37	79	40	132	91
Consecutive 30^{o}C									
Current	12	17	12	14	12	8	6	29	20
Near future		32	14	21	15	16	7	52	22
Far future		55	21	24	20	34	11	77	34
Consecutive Nights 20^{o}C									
Current	15	16	19	23	27	10	11	25	30
Near future		28	26	33	34	18	17	40	38
Far future		52	44	46	45	37	28	68	61
CDD Days 18^{o}C									
Current	161	130	128	95	92	174	171	213	208
Near future		144	136	104	97	195	185	230	219
Far future		170	158	123	113	233	208	272	261
Precip Sum									
Current	72	99	108	74	79	86	95	111	120
Near future		95	107	71	78	85	92	106	122
Far future		89	100	67	73	79	87	101	115

4.2 Occurrence of summer days (25°C)

The 90th percentile of days during an extreme event within a 30-year period whereby the bias-adjusted maximum temperature reaches at least 25°C (SU25) under the RCP8.5 scenario using the RCA4 and the RACMO22E models (Figure 13). For both models, an increase in summer days is gradual throughout the different time periods until the far future period where the values rise sharply across the country. Many parts of Greece show an increase of about 40-50 days of 25°C during an extreme event between the current period and the far future. Coastal areas seem to be a little under-represented, more prominently seen in the outputs from the RACMO22E model.

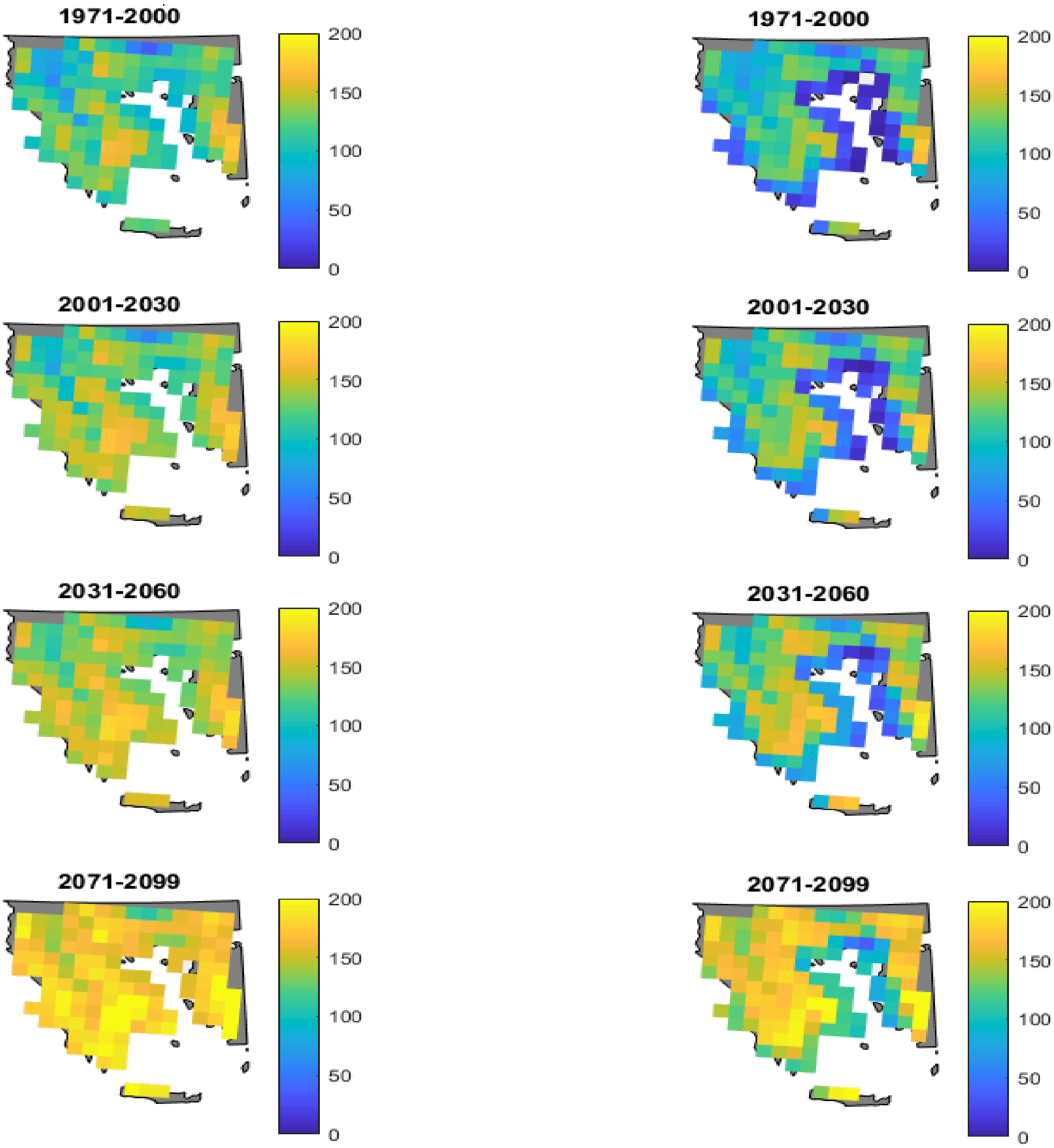


Fig. 13. 90th percentile days during an extreme event with a bias-adjusted maximum temperature of at least 25°C under an RCP8.5 scenario for the RCA4 (left) and RACMO22E (right) regional climate models. Reference period (1971-2000), alongside current/imminent future (2001-2030), the near future (2031-2060) and the far future (2071-2099).

4.3 Occurrence of tropical days (30°C)

The 90th percentile of days during an extreme event within a 30-year period whereby the bias-adjusted maximum temperature reaches at least 30°C (SU30) under the RCP8.5 scenario using the RCA4 and the RACMO22E models (Figure 14). An increase after every 30-year period is very gradual, similarly to SU25, until the far future where percentile values increase substantially. RACMO22E struggles to represent many coastal areas again and the increase in occurrence is less apparent than most areas in the RCA4 model.

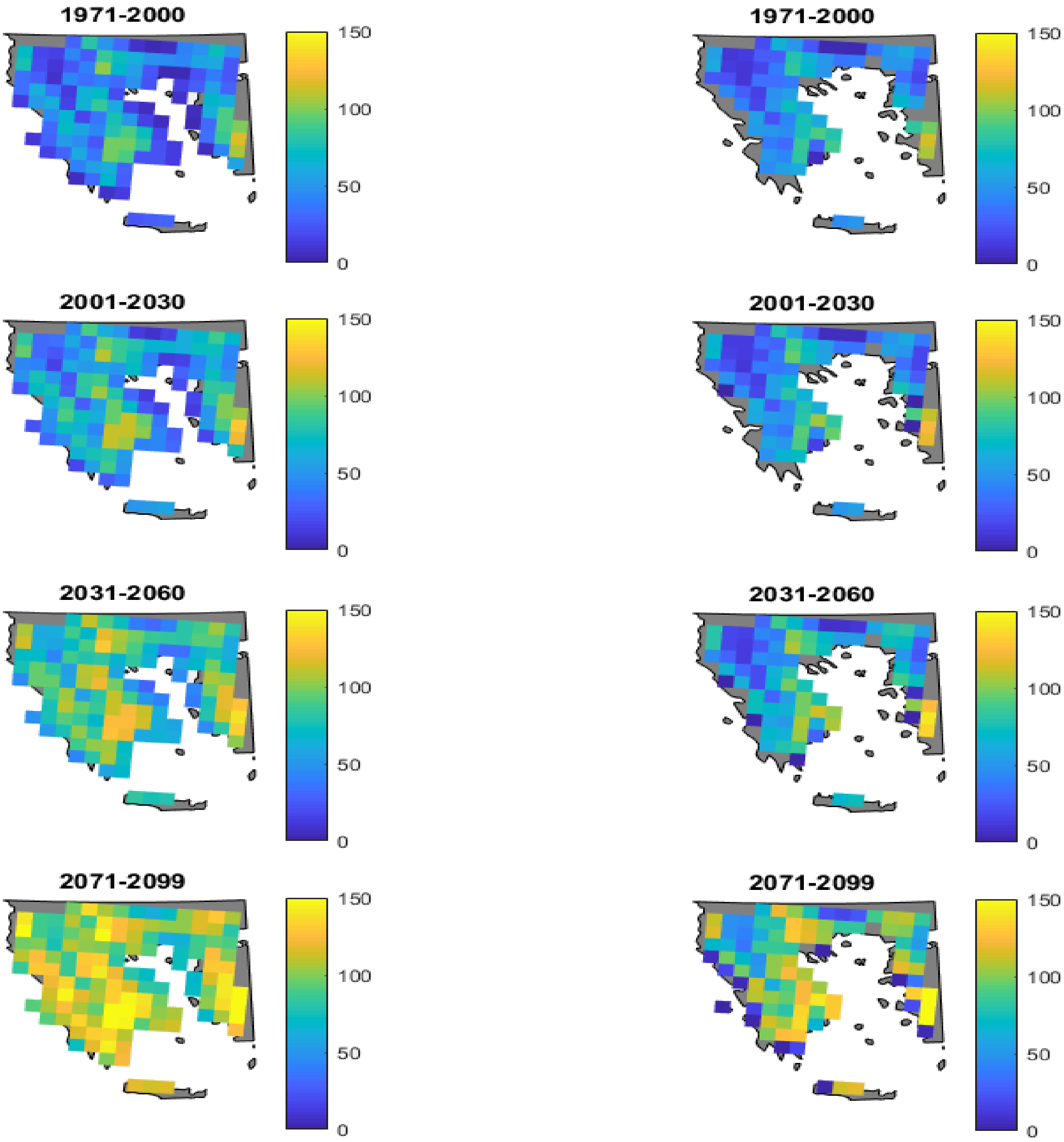


Fig. 14. 90th percentile days during an extreme event with a bias-adjusted maximum temperature of at least 30°C under an RCP8.5 scenario for the RCA4 (left) and RACMO22E (right) regional climate models. Reference period (1971-2000), alongside current/imminent future (2001-2030), the near future (2031-2060) and the far future (2071-2099).

4.4 Occurrence of tropical nights (20°C)

The 90th percentile of days during an extreme event by which the bias-adjusted minimum temperature reaches at least 20°C indicating a ‘tropical night-time temperature’ (TN20) under the RCP8.5 scenario using the RCA4 and the RACMO22E model for three different future periods (Figure 15). Both the climate models display very similar values between each other, likely because of bias-correction. The far future shows the largest degree of change, a substantial increase occurs for much of Southern and Eastern Greece and this is depicted similarly in both climate models. Upland regions in the north show little change in the occurrence of warmer nights.

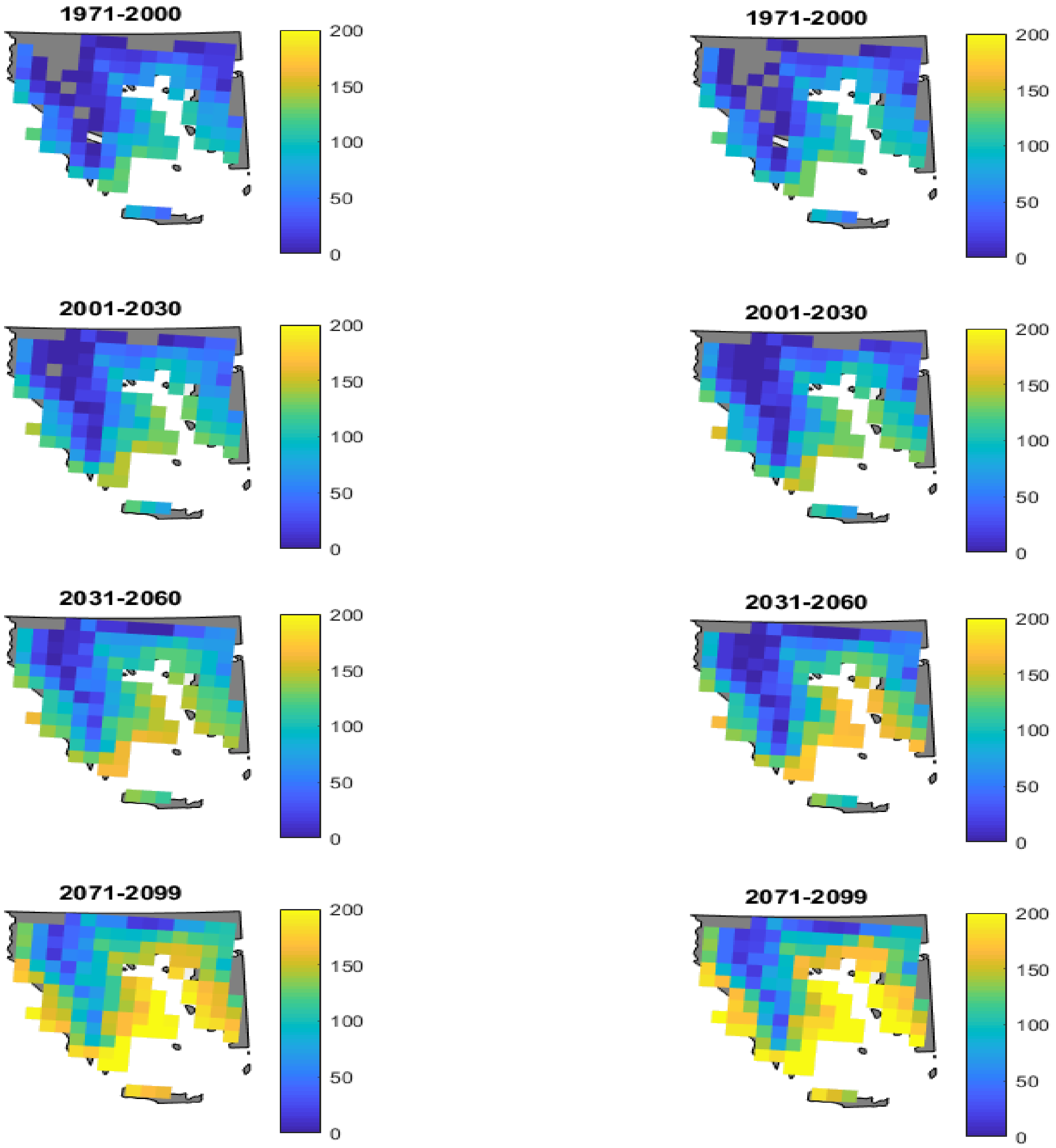

1971-2000
1971-2000
2001-2030
2001-2030
2031-2060
2031-2060
2071-2099
2071-2099

Fig. 15. 90th percentile days during an extreme event with a bias-adjusted minimum temperature of at least 20ºC under an RCP8.5 scenario for the RCA4 (left) and RACMO22E (right) regional climate models. Reference period (1971-2000), alongside current/imminent future (2001-2030), the near future (2031-2060) and the far future (2071-2099).

4.5 Consecutive summer days with 25°C

The 90th percentile of longest consecutive days where the bias-adjusted maximum temperature reaches at least 25°C under the RCP8.5 scenario using the RCA4 and the RACMO22E model for three different future periods (Figure 16). The RACMO22E model shows a steady increase in the distribution of consecutive summer days, particularly in the south. The same model shows very similar results across the first three periods, in contrast to the RCA4 model where a sharp increase can begin to be noticed at the near future. The RCA4 model shows a more extreme outcome for all of southern Greece, change in the north is less intense but still highlights a sizeable increase.

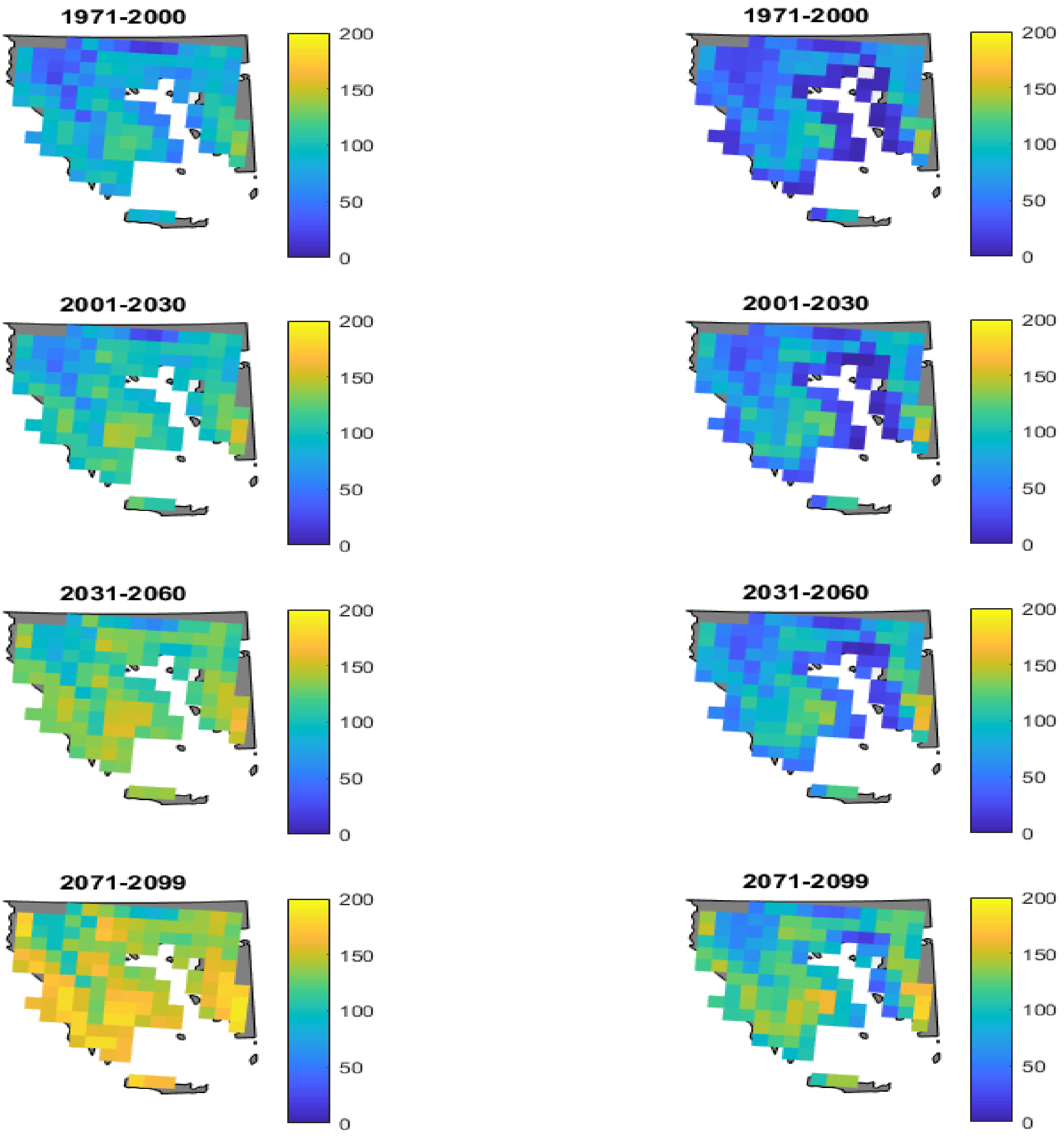


Fig. 16. 90th percentile of longest consecutive days in a year with a bias-adjusted maximum temperature reaching at least 25°C under an RCP8.5 scenario for the RCA4 (left) and RACMO22E (right) regional climate models. Reference period (1971-2000), alongside current/imminent future (2001-2030), the near future (2031-2060) and the far future (2071-2099).

4.6 Consecutive tropical days with 30°C

The 90th percentile of longest consecutive tropical days annually where the bias-adjusted maximum temperature reaches at least 30°C under the RCP8.5 scenario using the RCA4 and the RACMO22E model for three different future periods (Figure 17). The RCA4 model shows quite similar patterns to Figure 16 - much more intense amount of consecutive heat days with quite a significant increase for most of Southern Greece.

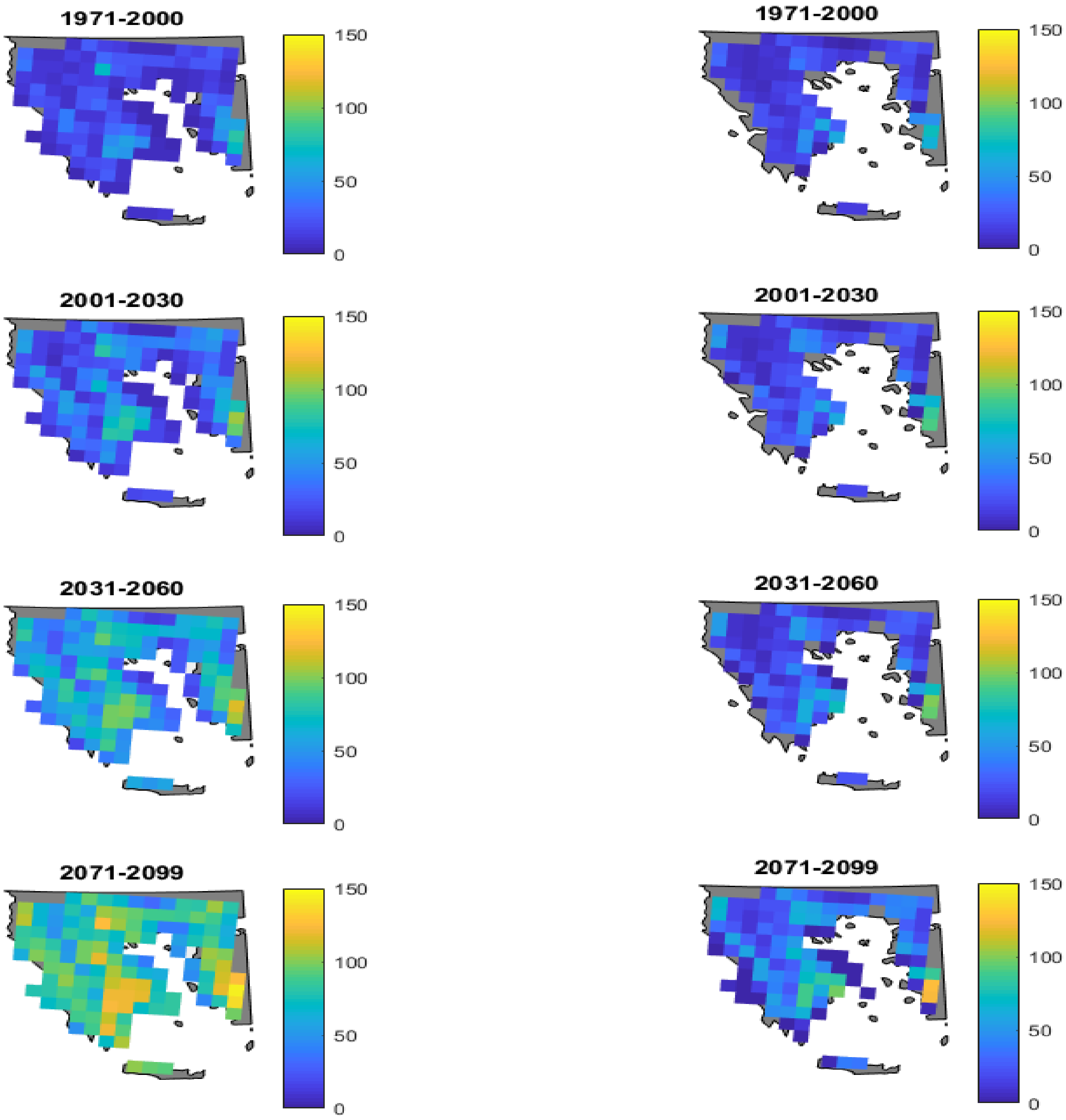


Fig. 17. 90th percentile of longest consecutive days in a year with a bias-adjusted maximum temperature reaching at least 30°C under an RCP8.5 scenario for the RCA4 (left) and RACMO22E (right) regional climate models. Reference period (1971-2000), alongside current/imminent future (2001-2030), the near future (2031-2060) and the far future (2071-2099).

4.7 Consecutive tropical nights (20°C)

The 90th percentile of longest consecutive tropical nights where the bias-adjusted minimum temperature reaches at least 20°C (TX20) under the RCP8.5 scenario using the RCA4 and the RACMO22E model for three different future periods (Figure 18). A very similar correlation with the occurrence of tropical nights – northern areas likely to witness little change whereas southern areas will witness longer periods of uncomfortable conditions. Both models show similar results with a substantial increase beginning to occur in the far future for large areas in the south and east.

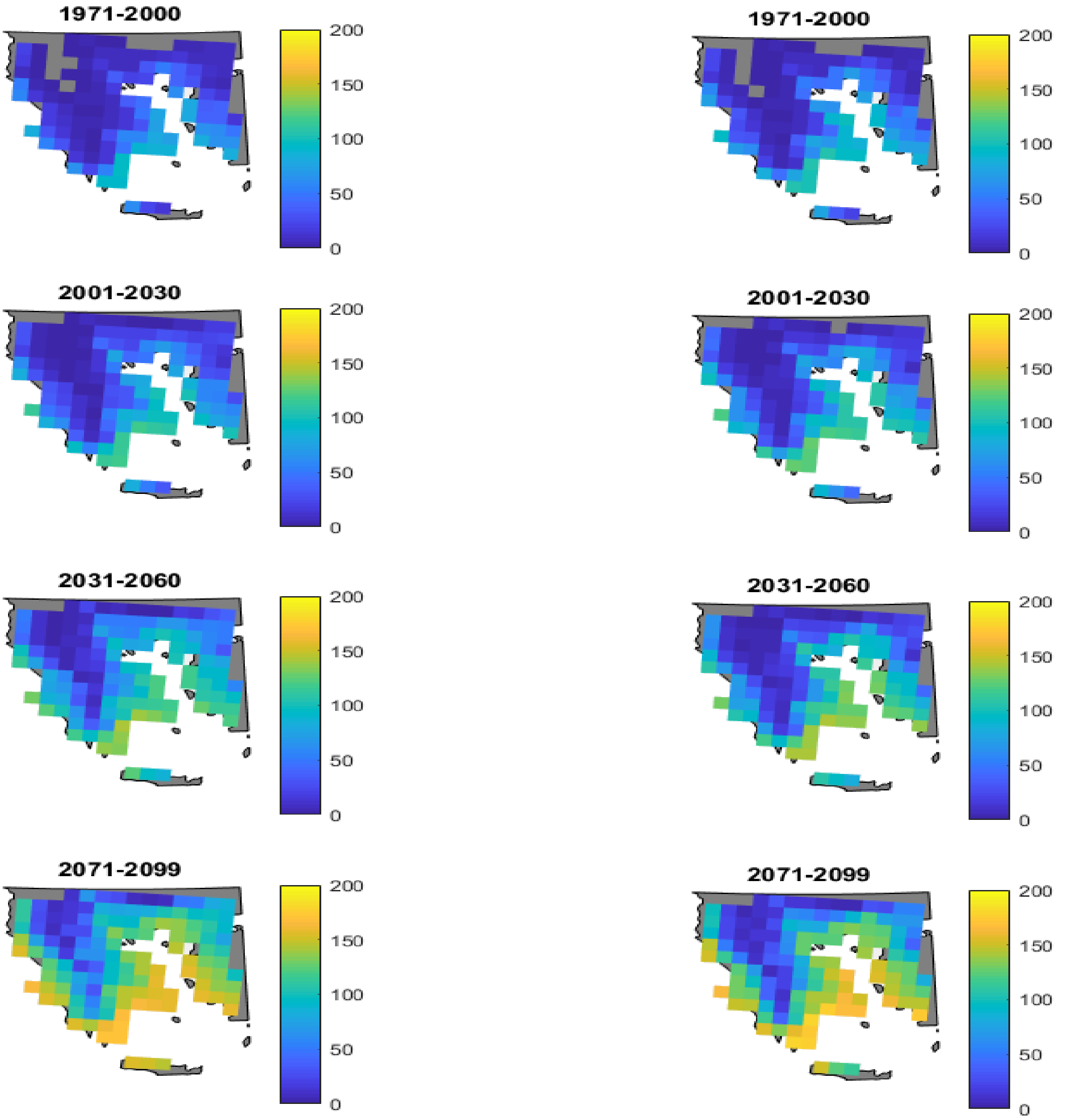


Fig. 18. 90th percentile of longest consecutive days in a year with a bias-adjusted minimum temperature reaching at least 20ºC under an RCP8.5 scenario for the RCA4 (left) and RACMO22E (right) regional climate models. Reference period (1971-2000), alongside current/imminent future (2001-2030), the near future (2031-2060) and the far future (2071-2099).

4.8 Occurrence of Cooling Degree Days (18 °C)

The 90th percentile of days where the bias-adjusted maximum temperature reaches at least 18°C which will trigger the need for cooling (Figure 19). An increase in the number of days witnessing at least 18°C during the day time is seen in both of the models, particularly for inland areas across the country. The RCA4 model shows that an increase will likely occur for all areas including upland areas, and the majority of central and southern Greece will witness daily temperatures hitting 18°C across the year, likely extended through the majority of spring and autumn months, potentially into winter months.

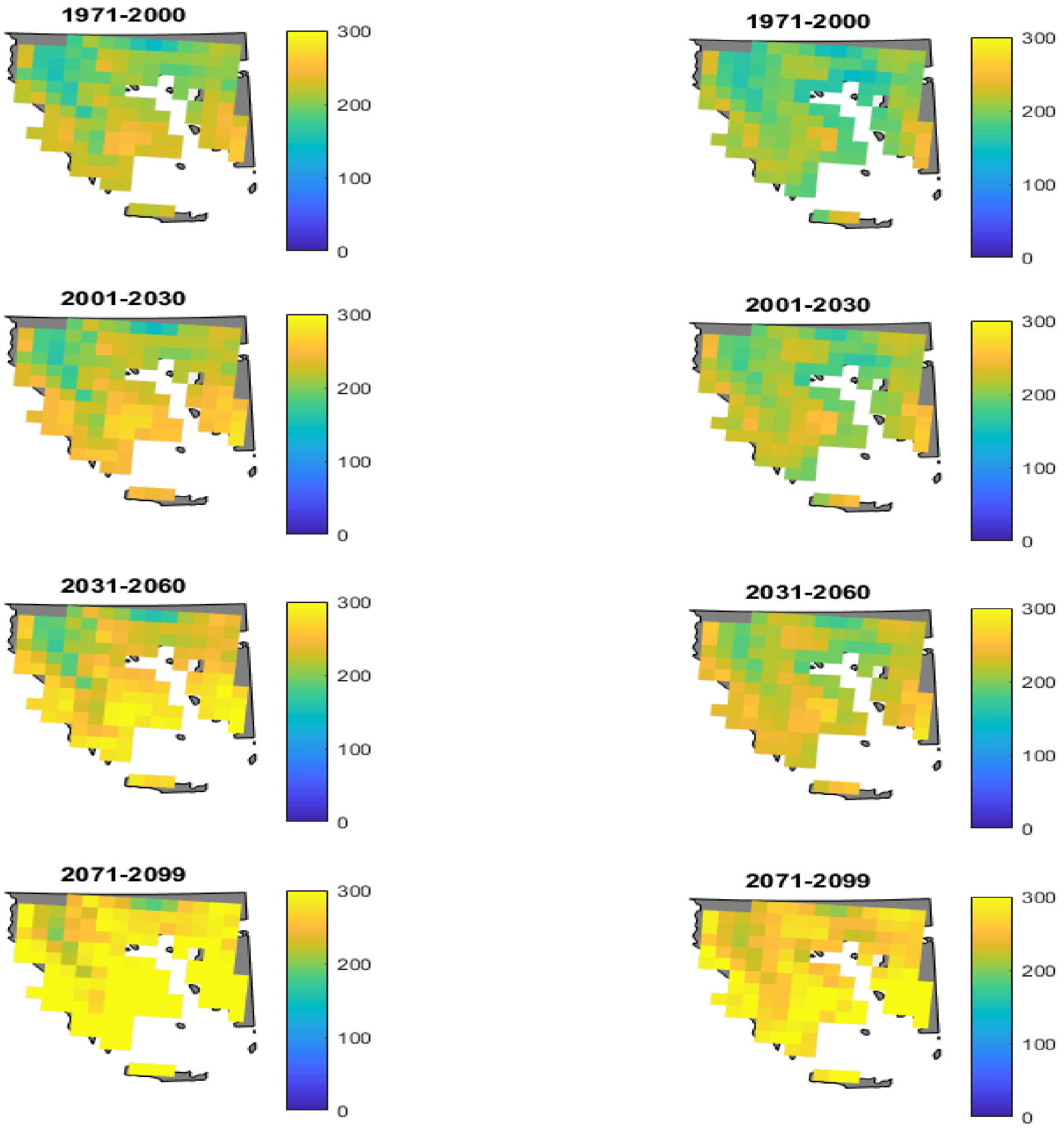


Fig. 19. 90th percentile of days during an extreme event where the bias-adjusted maximum temperature reaches at least 18°C under an RCP8.5 scenario for the RCA4 (left) and RACMO22E (right) regional climate models. Reference period (1971-2000), alongside current/imminent future (2001-2030), the near future (2031-2060) and the far future (2071-2099).

4.9 10th percentile of annual precipitation sum (>0.1mm)

The 10th percentile of the annual precipitation sum (precipitation events of at least 0.1mm) under the RCP8.5 scenario using the RCA4 and the RACMO22E model for three different future periods (Figure 20). Both models show a similar gradual trend towards more dryer conditions – precipitation sums become slightly lower through the time periods, the 10th percentile variable was used as it highlights that the 10% of the driest years on the extreme spectrum will become dryer.

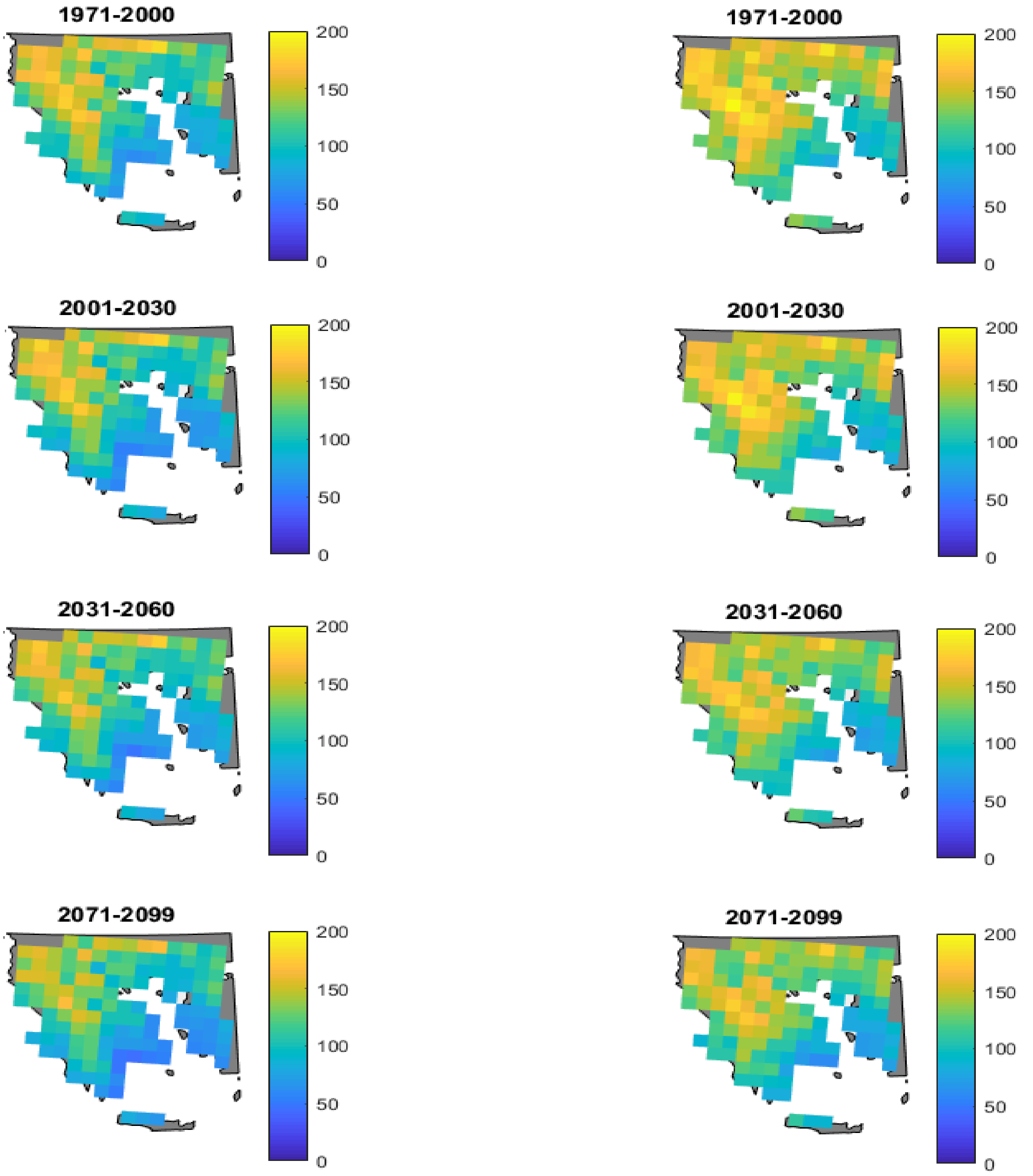


Fig. 20. Annual bias-adjusted precipitation sum with a 10th percentile (at least 0.1mm of rainfall) under an RCP8.5 scenario for the RCA4 (left) and RACMO22E (right) regional climate models. Reference period (1971-2000), alongside current/imminent future (2001-2030), the near future (2031-2060) and the far future (2071-2099).

5.0 Discussion

5.1 Overview of model results

The models both show a similar trend (Table 1) although the degree of intensity is different for both models which is why gridded observed (Gridded EOBS) values were obtained, the majority of observational values show closer similarities to the RACMO22E model, whereas the RCA4 model often displays a more extreme looking scenario. In general, regarding adaptation strategies, the increase in extreme events will have large implications for human health and for cooling during extensive heat periods, resources will have to be placed towards better forecasting for heat spells, improved public awareness of heat spells and how to cope during such an event as well as more guidance and resources for hospitals for dealing with patients suffering from heat stress (Keramitsoglou *et al.* 2017).

Coastal areas, and many of the Greek islands seem under represented, this will be because the models is having difficult to pick out these areas, particularly for Greece where many islands are too small for the model to represent in this resolution. The majority of the model runs show an increase further into the different periods, although the increase is quite a gradual difference, sometimes, as portrayed by the RACMO22E model for consecutive tropical days, the increase is minimal for the first three time periods. The far future shows the largest degree of change for each model simulation that was ran with drastic increases for the frequency and duration of intense temperatures throughout the year.

What is also clear from the model simulations is the divide between warming in the north and warming in the south – the southern section of Greece shows much more severe reactions to an increase in temperature unlike the majority of areas in the north. However some simulations, particularly for the far future do show a large increase throughout Greece such as the number of cooling degree days. Interestingly for northern Greece, throughout the whole simulation period, there is minimal change in the occurrence of tropical nights, something that is actually worth noting as this will reduce the severity of heatwaves if the temperatures drop below a certain level during the night.

5.2 Occurrence of summer and tropical days

Summer days with temperatures of 25°C (SU25) are recorded almost every day for the majority of Greece during the three main summer months with projections into the future pointing towards a definite increase in the amount of annual summer days (Nastos and Kapsomenakis, 2015). This tells us that shoulder months (months either side of summer) will more likely witness ‘summer-like’ days of at least 25°C. In this report, the two climate models both show an increase in 90th percentile days of an extreme event across all the different regions of Greece, with the region of Attica – the location of Athens, showing the highest increase in SU25. The area of Athens displays a higher temperature increase than its surrounding areas, most probably because of the UHI effect. Both models seem to pick up the Pindus Mountains in the north where temperatures will reach SU25 less frequently and where climate change is likely to be less intense when comparing upland areas with more coastal areas in the south (Zanis *et al.* 2015).

Referring back to the temperature maps in Background (Figure 2.1), with the exception of upland areas, there is generally little variation geographically across Greece and this can also been seen quite clearly for the RCA4 model for the reference period. However, looking further into the future, despite the uncertainty increasing, there is the possibility of more regional variation with a stronger shift towards southern Greece witnessing a higher frequency of summer days compared with other low lying areas in the north.

Tropical days with a temperature of at least 30°C can frequently occur during summers in Greece, they bring with them very humid conditions and periods of particular thermal discomfort and heat stress for residents (Papanastasiou *et al.* 2015). The modelled runs for the 90th percentile of days during an extreme event by which a maximum temperature of 30°C is reached shows an increase for the whole of Greece, in particular for the far future. The RCA4 model seems to announce a more intense amount of tropical days, and it predicts that by the far future, there could be as much as 90 days of the year witnessing daily 30°C temperatures for the majority of Greece, a cause for concern regarding thermal comfort and heat-related mortality in the country.

5.3 Heatwaves

The RCA4 model displays a rather significant increase in consecutive heat days (for both 25°C and 30°C) for the near future and then an even further rate of increase for the far future, whereas the RACMO22E model predicts a more moderate increase, with only a small rate of change until the far future. For simulating heatwaves, high temperature can persist for long periods of time, as a result, each day within a simulation period is assessed, although each day in such an event is not necessarily extreme by itself. Rather, it is the accumulated effect over a long period that becomes noticeable (Persson *et al.* 2007). Although the climate indices that analyse the severity of heatwaves generally concentrate on the intensity (daily maximum temperature) and the duration/persistence of a heatwave, it might also be worth considering the cumulative heat excess above a predefined threshold and the annual timing of a heatwaves occurrence as these both have a large impact on determining how severe a heatwave can be to human health (Keramitsoglou *et al.* 2017).

Such climate extremes can have widespread implications for society across a number of different sectors, particularly tourism. Extended periods of heat and uncomfortable conditions will cause tourist numbers across the Mediterranean to decline during summer months because of the heat becoming too intense as tourism shifts northwards up the continent (Zerefos *et al.* 2013). This highlights the importance for Greece to capitalise on diversifying their tourism market towards the shoulder months when temperatures for many visitors will be more comfortable, this may actually be quite beneficial for Greece in the future as it relieves the current extensive strain on tourism demand during the summer (Grillakis *et al.* 2016).

5.4 Cooling Degree Days (CDD)

Degree days are an ideal way of evaluating the energy demand in order to maintain comfortable conditions for being inside a building. Cooling degree days (CDD) can be defined as the outdoor ambient temperature by which cooling will begin for buildings in order to keep conditions satisfied for human thermal comfort. A base temperature is generally used as a threshold for CDD, but this base temperature can vary depending on the location of study and the preference of the people who live or work in a particular building (Stathopoulou *et al.* 2006).

The usual base temperature can vary between approximately 15ºC and 28ºC, often in research, the base temperature is usually around 23ºC, although in this study, it was chosen to use a slightly lower base temperature of 18ºC to try and account for the UHI effect and also because many buildings, especially in urban areas in Greece, absorb a lot of heat radiation because of the material used (Georgakis and Santamouris, 2017). The UHI and the local climate can have a significant negative impact on the environmental quality of a city because they increase the energy spent for cooling purposes and increase the peak electricity demand during summer months whilst reducing thermal comfort levels (Paravantis *et al.* 2017). In this report, cooling days are obviously relatively high for both models for all periods (Figure 19). The far future provides the greatest level of difference whereby according to the RCA4 model, the majority of Southern Greece will require energy for cooling for as much as 300 days a year, extending throughout spring and autumn months, potentially into periods during the winter months as well.

Fluctuations in weather can influence energy because power consumption is relatively sensitive to a change in temperature. As well as this, the consumption of energy is similarly sensitive to weather since large amounts of energy cannot be stored and thus energy generated has to be consumed immediately (Giannakopoulos *et al.* 2016).

5.5 Precipitation

The annual precipitation sum includes total rainfall (>0.1mm) from across the different seasons. From calculating this, percentiles can be generated to determine whether the model predicts the area to become wetter (Around the 90th percentile of precipitation sum) or dryer (10th percentile) over time. Using the 10th percentile for analysing patterns of dryness (Figure 20), the climate models both show an overall decrease in annual precipitation sums although the decrease is not as evident as the change from some of the temperature indices.

When referring back to the elevation map of Greece (Figure 12), the RCA4 model seems to correlate closely the areas with the highest elevation receive significantly higher levels of rainfall, whereas the RACMO22E model shows this, but also includes surrounding areas with lower levels of elevation to also receive similar level of precipitation. When referring to the precipitation maps in Background (Figure 3.1), it seems that the RCA4 model picks up the topography and variation between the west and east more fluently than the RACMO22E model.

Precipitation is one of the most relevant meteorological variables for projecting changes with the climate, although it can be difficult to simulate due to a number of different processes and factors that can have an influence. Clouds can add a particular amount of uncertainty due to many cloud processes not being well understood as of yet and their characteristics can be difficult to simulate in a model. Also, interactions between atmospheric flow with the surface and atmospheric circulation can add to the difficulty for precipitation simulations. Often the large known biases of GCM's for representing distributional precipitation patterns and the difference between different GCM's outputs under certain climate forcing scenarios can add to the uncertainty (Krakauer and Fekete, 2014), and GCM's can often underestimate precipitation intensities (Jacob et al. 2014). Also the number of islands in close proximity such as the case of Greece can have an effect on precipitation patterns (Zanis *et al.* 2015), the majority of Greek islands were not represented and localised changes in conditions may add to the uncertainty for predicting future precipitation events.

Climate change in the future is likely to substantially alter patterns of precipitation, many climate models project "less frequent yet more intense" periods of rainfall with a higher chance of more frequent droughts that will be more severe in exposed areas (Koutroulis *et al.* 2016). Under an RCP8.5 scenario from other research, Greece seems to have encountered a considerable decrease in heavy precipitation in summer months whereas an increase in heavy precipitation throughout the rest of the year, most significantly in autumn months, where an increase as much as 15% may be seen (Jacob *et al.* 2014).

Despite global studies comparing observed and modelled temperature data having a reasonably good agreement, there remains a relatively poor agreement with regards to precipitation observational patterns and trends. One possibility for this is that 'regional responses' of observational trends for precipitation extreme can be heavily influenced by various large-scale processes, some of which can be difficult, when combined, for GCM's to represent (Alexander & Arblaster, 2009). To elaborate on this, precipitation is harder to evaluate and is not expected to respond as consistently or strongly to greenhouse gas forcing's as temperature does (Lambert *et al.* 2005), as a result, it's often expected that it is more difficult for climate models to capture observed trends in extremes (Alexander & Arblaster, 2009).

5.6 Climate model projections and reflections

Overall, the use of climate models to simulate how the future global climate may look like in the future is an exceptionally important development, the inputting of various differing input arguments to highlight such a range of different pathways that our planet may take allows us to increase our knowledge of the future and build on our ability to adapt to such changes (IPCC, 2012).

In terms of localised changes for adapting to climate change, RCM's can provide a good impression of future changes relating to regional geography and topography, they are better at representing local variations in the climate than standalone GCM's which struggle to represent features at high resolutions. The results from the climate models in this experiment show certain areas that will be much more susceptible to climate change in the future – especially in the southern half of Greece and particularly inland areas as well as Athens and the surrounding region. As a result, they can be a good reference point for localised planning towards mitigation, they provide a simplified representation for illustrating how the climate may alter over different time periods and are easily manageable and understandable for communicating to different stakeholders and influential businesses and organisations, the use of percentiles helps to illustrate this in a simplified manor for different regions of Greece.

Both models show quite different values across many different indices, although most importantly, they both follow the same pattern whereby mean values and percentiles increase throughout the time periods, and for the far future, a drastic increase is often apparent. The point of this experiment was to highlight trends such as this to help improve our understanding of how the climate will be affected in the future depending on our actions, and to use different climate models with different setups to highlight this, as opposed to simply trying to discuss which model works the best and deciding to use that model alone for discussing future patterns of climate change.

Climate model uncertainties will remain apparent for predicting future changes in climate, even though some uncertainties will likely be narrowed with time (IPCC, 2012), which is why it is ideal to use a number of different climate indices and climate scenarios. There is a number of uncertainties regarding how our future climate will turn out and this is why model projections cannot be definitive, uncertainties include the unknown future greenhouse gas emissions and specifically which pathway we will take, as well as this, the radiative forcing of the climate and modelling the climates response to forcing are complex and problematic (IPCC, 2012) including the uncertainty regarding how GCM's can represent this on a regional scale. There is no single best scenario construction method or climate model appropriate for all applications, which is why it is welcomed to use a variety of contrasting climate models to generate projections that highlight numerous potential outcomes and to capture different aspects that can be described together rather than separately. In its most general terms, climate models point towards a changing climate where extreme events will occur on a more frequent basis, because of this, adaptation to climate change and decisions made need to be addressed quickly, particularly the decisions with long-term intentions. If the correct strategies are structured now, the effects of extreme events in the future will have less severe implications for society (IPCC, 2012).

What we know is that future climate change in Greece will have a considerable impact on temperature readings across Greece and the possibility of high extreme values being obtained for consecutive periods will likely intensify, but to the degree of which this will occur remains to be seen, based on our future emissions pathway. These models evidently show an alarming increase because of the RCP8.5 scenario that was chosen but it is difficult to justify that this is the exact path that our climate will take, it portrays more of a guideline for how our climate may look in the future if we continue on a "business as usual" road without any significant adaptation and mitigation procedures set out. The RCP8.5 scenario also represents a sharp contrast with the actual goals of the Paris agreement that is due to commence in 2020, the central aim of this agreement is to strengthen our climates response by keeping a global temperature rise this century well below 2^{o}C above pre-industrial levels. One of the main goals for the agreement will be to strengthen individual countries ability to tackle the impacts of climate change in order to avoid a potentially catastrophic scenario such as an RCP8.5 outcome (Kjellström *et al.* 2018).

One thing that is still difficult regarding the resolution of current RCM's is the representation of islands – a difficult scenario for Greece and all of its islands. In the model outputs, Crete seemed to be the only island that was represented, which makes it difficult to represent possible small differences in the model outputs for the rest of the Greek island archipelago. One way of tackling this could be to use a higher resolution if available, an 11x11km resolution might be able to pick up smaller islands. Statistical downscaling of point data measurements provided by local weather stations instead of dynamic downscaling of RCM's grid cells used in this study may be used as an alternative with the possibility of achieving higher accuracy for islands and coastal areas.

6.0 Conclusions

Climate change will likely have an adverse effect on the country of Greece in the future as a result of anthropogenic factors. In this study, two different climate models were used to analyse patterns of both temperature and precipitation changes for the current period, the near future and the far future in accordance with the RCP8.5 scenario. From the results of the simulated climate models, the occurrence of hotter and extremely high temperatures during the day and night will become apparent for the majority of Greece with areas in the south and the east proving to be particularly susceptible to such changes.

One of the most important findings from this report is the large increase in consecutive periods of both maximum and minimum temperature for many parts of Greece, this means that the climate models point towards a significant increase in the duration of heatwaves during the summer which will have considerable implications across many different aspects of society, something that will require attention in order to adapt correctly to such changes. Urban areas such as Athens and Thessaloniki come under a significant amount of danger as heat extremes will likely exacerbate further because of effects from the UHI - adaptation to reduce the damage on human health and damage to business and tourism should be given high priority. Precipitation levels will likely be reduced alongside this temperature increase, although additional research should be carried out to analyse patterns of interannual variability across the different periods to highlight dry and wet patterns for Mediterranean countries like Greece.

The huge tourism boost for Greece has helped the economy improve over the last 5 years although future characteristics of climate change could threaten the number of visitors Greece can attract if extreme events of high temperatures continue to extend across the year. The demand for energy is also a significant issue, with most parts of Greece requiring energy for cooling for 8-9 months of the year if climate change continues at pace. To add to this, the accumulation of effects, and the demand from the different sectors will place a considerable strain on the water availability for Greece, something that will have to be looked at closely.

Only in recent years has Greece prioritised climate adaptation as an essential source of funding, awareness is now increasing and more opportunities and projects are being created for addressing the danger, but adaptation is still in its early stages. The use of climate models as a tool for indicating the potential dangers of climate change for the future can help to support adaptation and prioritise climate projects to improve sustainability. One of the great benefits of utilising climate indices is that they can be simplified and can also be easily communicated to various different areas of the public for raising awareness about climate change and what can be done for remediation. Climate models, such as the ones used in this report, provide an effective overall visual representation of how extreme events may unfold in the future. Determining the exact outcome of how the country will look remains uncertain because of various factors, but what is apparent from the models is that action to protect society against threats from climate change is needed throughout Greece as temperatures look set to intensify for much longer periods of time.

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