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Aristotle University of Thessalokini

School of Geology

Department of Meteorology and Climatology

CLIMATE CHALLENGES FOR THE MOUNTAIN TOURISM OF EASTERN EUROPE AND JORDAN

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Research Team:

Prof. Christina Anagnostopoulou

MSc Stelios Petropoulos

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1. Introduction in Mountain Tourism

Mountain tourism is a rapidly growing sector within the global tourism industry, characterized by its unique blend of natural beauty, cultural richness, and recreational opportunities. It plays a significant role in the economic development of mountainous regions, offering both challenges and opportunities for sustainable development. The following sections explore various aspects of mountain tourism, drawing insights from the provided research papers.

Economic and Social Impact

Mountain tourism significantly contributes to the economic development of regions by generating income, creating jobs, and improving the quality of life for local communities. It is particularly beneficial for disadvantaged or unindustrialized areas, providing a source of economic stability and growth (Slusariuc & Bîcă, 2015). The sector is second only to coastal tourism in terms of global popularity, accounting for 15-20% of the global tourism market (Siddiqui and Imran, 2022). This growth is driven by the increasing demand for adventure and nature-based experiences. Domestic tourism has gained importance, especially in the wake of the COVID-19 pandemic, as destinations seek to balance economic benefits with cultural preservation (Kangai et al., 2024).

Sustainable Development and Environmental Concerns

Sustainable development is a critical focus in mountain tourism, with efforts aimed at conserving natural resources and minimizing environmental impacts. Proper planning and management are essential to prevent detrimental effects on the environment, flora, fauna, and local communities (Mohapatra & Biswas, 2024). The research highlights the importance of nature education, communication, and impact analysis to ensure that tourism activities do not exceed the carrying capacity of the environment (Mohapatra & Biswas, 2024). Climate change poses a significant challenge, affecting snow and water resources, which are vital for winter sports and other tourism activities in mountain regions(Reynard, 2020).

Research Trends and Knowledge Gaps

Mountain tourism research is an emerging field, with a growing body of literature focusing on sustainable development, tourism management, and the socio-economic impacts of tourism(Siddiqui and Imran, 2022; Río-Rama et al., 2019). Despite the increase in publications, there is a lack of comprehensive reviews and a need for more systematic research to explore trends and structures in mountain tourism(Siddiqui and Imran, 2022). Bibliometric analyses reveal that European countries are leading in mountain tourism research, with a strong focus on sustainable practices and the interplay between activity, people, and place (Río-Rama et al., 2019; Maher, 2016).

Cultural and Recreational Aspects

Mountain tourism offers a diverse range of activities, including hiking, mountaineering, and winter sports, which cater to both the physical and psychological needs of tourists (Slusariuc & Bîcă, 2015). The cultural and historical significance of mountain regions adds to their appeal, with many destinations offering unique experiences that blend natural beauty with cultural heritage. The interplay between activity, people, and place is a central theme in mountain tourism, highlighting the importance of understanding the motivations and experiences of tourists (Maher, 2016). While mountain tourism presents numerous opportunities for economic and social development, it also requires careful management to ensure sustainability and minimize environmental impacts. The research underscores the need for continued exploration of this dynamic field, with a focus on sustainable practices, stakeholder engagement, and the integration of new technologies and methodologies. As mountain tourism continues to evolve, it will be crucial to balance the demands of tourism with the preservation of natural and cultural resources.

Natural PARKS in Mountain Tourism

Natural parks in mountainous regions offer a multitude of benefits for tourism, contributing to both ecological conservation and socio-economic development.(Figure 1) These parks serve as key attractions for nature-based tourism, providing unique experiences that draw visitors while simultaneously supporting local communities and conservation efforts. The following sections detail the specific benefits of natural parks in mountain tourism. While natural parks in mountainous regions offer numerous benefits (Ecological and conservation; economic; social and cultural), they also face challenges such as ecological degradation due to increased tourist activity. Effective management strategies are essential to balance tourism development with conservation goals, ensuring that the benefits of mountain tourism are sustainable in the long term (Behrens et al., 2009).

Figure 1: The benefits of Natural Parks in mountain tourism (https://www.nps.gov/orgs/1778/vse2021.htm)

1.1 Mountain tourism in Europe

Mountain tourism in Europe is a significant sector that has seen considerable growth and transformation over recent decades. This growth is driven by the increasing demand for nature-based experiences and the economic potential of mountain regions. The sector is characterized by diverse offerings, from winter sports to hiking and wellness tourism, and is influenced by various factors including sustainability, economic development, and cultural diversity. Below, we explore the key aspects of mountain tourism in Europe, including economic impacts, sustainability, and regional characteristics. Mountain tourism significantly contributes to the economic development of European regions, particularly in areas that are otherwise economically disadvantaged. It provides economic benefits through increased visitor spending, which supports local businesses and creates jobs (Slusariuc & Bîcă, 2015). The determinants of visitor expenditures in mountain tourism include the duration of stay, household income, and choice of activities. These factors influence both direct spending at the destination and additional expenditures outside the destination (Fredman, 2008). In the Alps, the tourism boom has led to substantial real estate development and infrastructure investments, primarily driven by the popularity of skiing. However, the market is reaching saturation, necessitating diversification and innovation in tourism offerings (Macchiavelli, 2009). Sustainable development is a central theme in mountain tourism research, with a focus on balancing tourism growth with environmental conservation. This includes managing the impact of tourism on natural landscapes and promoting sustainable practices among tourists and businesses (Zeng, 2022; Zeng et al.,). The concept of sustainable tourism is particularly relevant in the context of climate change, which poses challenges to traditional winter sports and necessitates adaptation strategies. The importance of maintaining the ecological and cultural richness of mountain areas is emphasized, as these regions are home to diverse flora, fauna, and ethnic communities (Musiał, 2013).

Europe is a leading region in mountain tourism research, with a high volume of scientific output on the subject. This research highlights the diverse nature of mountain tourism across different European countries (Río-Rama et al., 2019). Eastern European countries, such as Romania, have unique mountain tourism developments influenced by national policies and historical contexts. These regions are exploring new opportunities for tourism growth and development (Tanase & Nicodim, 2020). The Alps remain a focal point for mountain tourism, but there is a growing recognition of the need for innovation and diversification beyond traditional winter sports to sustain the sector's growth (Macchiavelli, 2009). While mountain tourism offers significant economic and social benefits, it also presents challenges such as environmental degradation and cultural impacts. The need for sustainable practices is critical to ensure that tourism development does not compromise the natural and cultural assets of mountain regions. Additionally, the sector must adapt to changing consumer preferences and environmental conditions to remain viable in the long term. As research continues to evolve, there is a growing emphasis on understanding and addressing these challenges to promote a balanced and sustainable approach to mountain tourism in Europe.

1.1.1 Mountain tourism in Eastern Europe and Jordan

The growth of mountain tourism in Eastern Europe is driven by a combination of unique landscape features, socio-demographic factors, political changes, and economic development strategies. These factors collectively contribute to the region's appeal as a mountain tourism destination, setting it apart from other regions. The following sections delve into these primary drivers, highlighting the distinctive aspects of Eastern European mountain tourism.

Eastern Europe's mountain regions, such as the Carpathians, offer breathtaking landscapes and rich biodiversity, which are significant attractions for tourists seeking natural beauty and outdoor activities(Dax & Tamme, 2023). The region's cultural landscapes, including traditional villages and historical sites, enhance the tourism experience by providing a blend of nature and culture(Lun et al., 2016). The development of winter sports and ski resorts, particularly in Romania, has capitalized on the natural snow resources, making these areas popular winter destinations(Bacoş & Gabor, 2021) (Reynard, 2020). Socio-demographic changes, such as an aging population and migration trends, have influenced tourism development in the Carpathian Euroregion. These changes necessitate policies that enhance social development and improve the welfare of local populations, which in turn support sustainable tourism growth (Humeniuk et al., 2021). The economic transition following the political changes of the 1990s opened Eastern European countries to global tourism markets, boosting tourism's role in the economy and increasing the number of tourist arrivals(Pădurean, 2020) (Tanase & Nicodim, 2020).

Sustainable tourism development is a key focus in Eastern Europe, with initiatives like the "Mountaineering Villages" promoting balanced use of cultural landscapes and sustainable tourism practices(Dax & Tamme, 2023). This approach helps mitigate the environmental impact of tourism while enhancing the economic benefits for local communities (Zeng, 2022). Government and destination managers are encouraged to balance tourism development with environmental conservation, especially in the context of climate change and post-COVID-19 recovery (Zeng, 2022; Kangai et al., 2024).

Eastern Europe, particularly Romania, is leveraging its natural and anthropic resources to create competitive advantages in mountain tourism. The development of ski areas and the enhancement of accommodation facilities are part of this strategy (Bacoş & Gabor, 2021). Research on mountain tourism in Eastern Europe is growing, with a focus on sustainable development, climate change, and the integration of agriculture and tourism to provide authentic experiences (Río-Rama et al., 2019; Lun et al., 2016). While Eastern Europe has distinct advantages in mountain tourism, it faces challenges similar to other regions, such as environmental sustainability and the need for infrastructure development. The region's focus on sustainable practices and cultural integration offers a model for other mountain destinations. However, ongoing research and policy adjustments are necessary to address the dynamic challenges of tourism development in these sensitive ecosystems.

The growth of mountain tourism in Jordan is influenced by a complex interplay of socio-cultural and economic factors. These factors include the attitudes and perceptions of local communities, the economic benefits derived from tourism, the role of state and grassroots initiatives, and the natural and cultural attractions that draw tourists to the region. Understanding these elements is crucial for developing sustainable tourism strategies that benefit both the local population and the national economy.

- Local Community Perceptions: The attitudes of local communities towards tourism significantly impact its development. In rural areas like Ajloun and Jerash, residents generally support tourism due to its potential to create jobs and attract investment, although there are concerns about the loss of traditional values and environmental degradation (Khasawneh et al., 2023). In Petra, perceptions vary with education levels, with less educated individuals showing more positive attitudes towards tourism (Alhasanat & Hyasat, 2011).
- Cultural Heritage and Identity: Tourism in Jordan often revolves around its rich cultural heritage, such as the archaeological site of Petra. The local community's involvement in tourism can enhance cultural pride and identity, although it may also lead to cultural commodification(Farajat, 2012) (Alhasanat & Hyasat, 2011).
- Economic Benefits: Tourism is a vital economic driver in Jordan, providing employment opportunities and boosting local economies. In regions like Aqaba, the economic impact of tourism is significant, with the local community showing strong support for tourism due to its economic benefits(Jawabreh, 2021). Similarly, in Petra, tourism is the main source of income for many local communities(Farajat, 2012).
- State and Grassroots Initiatives: The development of adventure tourism in Jordan has been driven by grassroots initiatives that challenge traditional socio-economic structures. These initiatives have modernized the tourism sector and provided new economic opportunities, although they often operate without state support(Latorre, 2016).
- Ecotourism and Natural Reserves: Jordan's diverse ecology, including the green mountains of Ajloun and the desert landscapes of Wadi Rum, offers unique ecotourism opportunities. These natural attractions not only draw tourists but also contribute to the

economic and social well-being of local communities by improving living standards and promoting sustainable tourism practices(El-Harami, 2014).

- Rural and Adventure Tourism: The rise of rural and adventure tourism in Jordan is supported by the country's natural landscapes and cultural sites. This form of tourism is seen as a way to revitalize rural areas and provide economic benefits through increased tourist visits and investment (Al-Ajloni, 2012).

While the socio-cultural and economic factors discussed above largely promote the growth of mountain tourism in Jordan, there are challenges that need to be addressed. These include managing the environmental impact of increased tourist activity, preserving cultural heritage, and ensuring that the economic benefits of tourism are equitably distributed among local communities. Additionally, the lack of state support for grassroots tourism initiatives can hinder their potential to contribute to the national economy (Latorre, 2016). Addressing these challenges is essential for the sustainable development of mountain tourism in Jordan.

1.2 The impact of climate change on mountain tourism

Climate change significantly impacts mountain tourism, affecting both winter and summer activities across various regions. The consequences are multifaceted, influencing natural landscapes, tourism demand, and local economies. This overview explores the diverse impacts of climate change on mountain tourism, highlighting the challenges and potential adaptation strategies.

Impact on Winter Tourism

European ski tourism is highly vulnerable to snow shortages caused by climate change, with many resorts facing significant risks of insufficient snow under global warming scenarios of 2°C and 4°C. While artificial snowmaking can help mitigate some of these risks, it increases demand for water and electricity, thereby contributing to the industry’s carbon footprint (François et al., 2023). The declining reliability of winter snow is already affecting activities like skiing and snowboarding, pushing the need for winter tourism to diversify its offerings, including options like winter hiking and cultural experiences to maintain its appeal (Filho et al., 2024). Alpine tourism, heavily dependent on snow-based activities, is also struggling with reduced snow cover. Though artificial snowmaking is a common solution, it comes with high costs and environmental drawbacks. Some high-altitude resorts may temporarily benefit from changing tourist flows, but long-term prospects for the industry remain uncertain (Prettenthaler Neger, 2023).

Impact on Summer and Ecotourism

In Southern Mexico, climate change is shaping tourists' perceptions of nature-based tourism, influencing their decisions to visit ecotourism sites. As a result, community-based ecotourism businesses must adapt their offerings to sustain demand in the face of evolving climatic conditions (Deason et al., 2023). Meanwhile, in Austria, climate change may extend the summer tourism season, benefiting outdoor activities like hiking and biking. However, climate-induced changes could force shifts in destinations or activities, with adaptation measures often coming at a high cost (Pröbstl-Haider et al., 2021). The retreat of glaciers in the Alps poses significant challenges to glacier tourism, prompting stakeholders to adapt by implementing new management strategies, diversifying offerings, and even utilizing virtual reality to simulate the disappearing glaciers (Salim et al., 2021; Salim, 2023). Alpinists are also adjusting to changing conditions by modifying their routes and activities, with increased climate awareness fostering more adaptive behaviors and underscoring the importance of enhanced communication and climate services (Salim et al., 2023).

Socio-Economic and Cultural Impacts

Climate change is reshaping Himalayan tourism by altering landscapes and ecosystems, which in turn affects local communities and cultural heritage. To build resilience, sustainable tourism practices and collaboration among stakeholders are essential (Saxena et al., 2024). Additionally, mountain communities are facing significant economic and socio-political challenges as a result of climate change. A multidisciplinary approach, along with active stakeholder engagement, is needed to develop effective adaptation strategies (Steiger et al., 2022).

While climate change poses significant challenges to mountain tourism, it also presents opportunities for adaptation and innovation. For instance, the potential for increased summer tourism in some regions could offset losses in winter tourism. However, the complexity of climate impacts and the need for sustainable practices underscore the importance of comprehensive planning and collaboration among stakeholders to ensure the long-term viability of mountain tourism.

1.2.1 The impact of climate change in eastern Europe and Balkan

The impact of climate change on mountain tourism in Eastern Europe and the Balkans is multifaceted, affecting both winter and summer tourism activities. The region, heavily reliant on snow-based tourism, is experiencing significant challenges due to decreasing snow cover and depth, which are critical for ski tourism. This decline is attributed to rising temperatures and altered precipitation patterns, which are projected to worsen with global warming. The implications of these changes are profound, affecting the economic viability of ski resorts and necessitating adaptation strategies such as artificial snowmaking, which itself poses environmental and economic challenges. Additionally, while winter tourism faces substantial risks, there may be potential opportunities for summer tourism as climate conditions shift. The following sections delve into these aspects in detail.

Research indicates a pronounced decrease in snow depth and cover duration across the Balkans, with significant variability depending on the region and time of year (Masloumidis et al., 2024). This trend poses a substantial risk to ski tourism, a major economic driver in these mountainous areas (François et al., 2023). Without adaptation measures like snowmaking, a large percentage of ski resorts in Europe, including those in Eastern Europe and the Balkans, are at high risk of snow scarcity under future warming scenarios. Snowmaking, while mitigating some risks, increases water and energy demands, contributing to the carbon footprint of ski tourism.

The economic impact of reduced snow reliability is significant, threatening the sustainability of ski tourism and the livelihoods dependent on it. The Parnassos Ski Resort in Greece exemplifies these challenges, with projections showing a decrease in snow cover and snowfall, necessitating adaptation measures to maintain viability (Cartalis & Philippopoulos, 2023). The environmental footprint of adaptation strategies like snowmaking highlights the complex interplay between climate change adaptation and mitigation efforts, emphasizing the need for sustainable practices (François et al., 2023).

While winter tourism faces challenges, there is potential for growth in summer tourism as warmer temperatures may make mountainous regions more attractive compared to increasingly hot Mediterranean destinations. However, this potential is uncertain and depends on various factors, including visitor preferences and climate policy developments ("Opportunities and Drawbacks for Alpine Tourism Under Climate Change", 2023). Effective adaptation strategies are crucial for mitigating the impacts of climate change on mountain tourism. These include diversifying tourism offerings, improving infrastructure, and engaging stakeholders in developing sustainable tourism practices (Steiger et al., 2022).

The broader implications of climate change on tourism in the Balkans extend beyond ski resorts, affecting other sectors like agriculture and water management, which are also vulnerable to climate variability (Hadžić, 2022). This underscores the need for comprehensive adaptation policies that integrate environmental protection and resource conservation. Despite the challenges, there is a lack of consistent action from industry and policymakers to address these issues, highlighting the need for increased awareness and proactive measures to ensure the resilience of mountain tourism in the face of climate change (Gössling & Scott, 2024).

In conclusion, while climate change poses significant challenges to mountain tourism in Eastern Europe and the Balkans, particularly for winter activities, there are opportunities for adaptation and diversification. The region must balance the immediate needs of maintaining tourism viability with long-term sustainability goals, requiring coordinated efforts from stakeholders across sectors.

1.2.2 The impact of climate change in Jordan

Climate change significantly impacts mountain tourism in Jordan, particularly in areas like the Dana Biosphere Reserve, where ecotourism is a major attraction. The vulnerability of ecotourism in such regions is heightened due to climate-induced changes in temperature, precipitation patterns, and extreme weather events, which can alter the natural landscapes and biodiversity that attract tourists (Jamaliah & Powell, 2019). Globally, mountain tourism is highly sensitive to climate change, with winter tourism, such as skiing, facing predominantly negative impacts due to reduced snow cover, while summer tourism experiences mixed effects (Steiger et al., 2022). In Jordan, the shift in climate may lead to changes in tourist mobility and demand, as seen in other mountain regions where summer traffic has increased significantly, potentially leading to congestion and infrastructure challenges (Cavallaro et al., 2017). The broader tourism industry is affected by climate change through rising temperatures and altered precipitation, which can disrupt traditional tourism patterns and necessitate adaptation strategies to maintain sustainability ("Impact of Climate Change on Tourism", 2022; Siddiqui & Imran, 2019). Despite these challenges, there is a lack of comprehensive studies specifically addressing the impacts on Jordan's mountain tourism, highlighting a need for more localized research and strategic planning to mitigate these effects and capitalize on potential opportunities (Steiger et al., 2022). While the negative impacts are evident, there is also potential for adaptation and resilience-building in mountain tourism, which could help sustain the industry in the face of climate change.

Chapter 2

2. Data

Tourism is a key contributor to Europe's economy and society, which is why the Copernicus Climate Change Service (C3S) includes a dedicated Sectoral Information System (SIS) for the tourism sector. Within this framework, a comprehensive dataset called the Mountain Tourism Meteorological and Snow Indicators (MTMSI) has been developed in collaboration with winter tourism stakeholders through interviews and research. This dataset offers valuable insights and information for the entire winter tourism industry, helping to address current and future needs. The present study on mountain tourism in the Balkans and eastern Mediterranean is grounded in this dataset.

The MTMSI dataset was designed to encompass the broadest possible area of the pan-European region. It includes countries within the European Union, candidate nations, and members of the European Free Trade Association. In total, the dataset covers EU member states as well as Albania, Andorra, Montenegro, North Macedonia, Serbia, Turkey, the United Kingdom, Iceland, Liechtenstein, Norway, and Switzerland. The indicators were calculated at the NUTS-3 geographical level to offer information across Europe, addressing the requests from some interviewed stakeholders to connect climate data with other socio-economic information, in line with earlier studies (e.g., Damm et al., 2017; Tranos and Davoudi, 2014). NUTS-3 refers to a specific level of the Nomenclature of Territorial Units for Statistics (NUTS), which is a hierarchical system used by the European Union to collect, analyze, and compare regional statistics. NUTS-3 is the third level of this classification and typically represents small regions or districts within countries, allowing for detailed regional analysis. Each NUTS-3 area usually has a population ranging from 150,000 to 800,000 inhabitants, depending on the country.

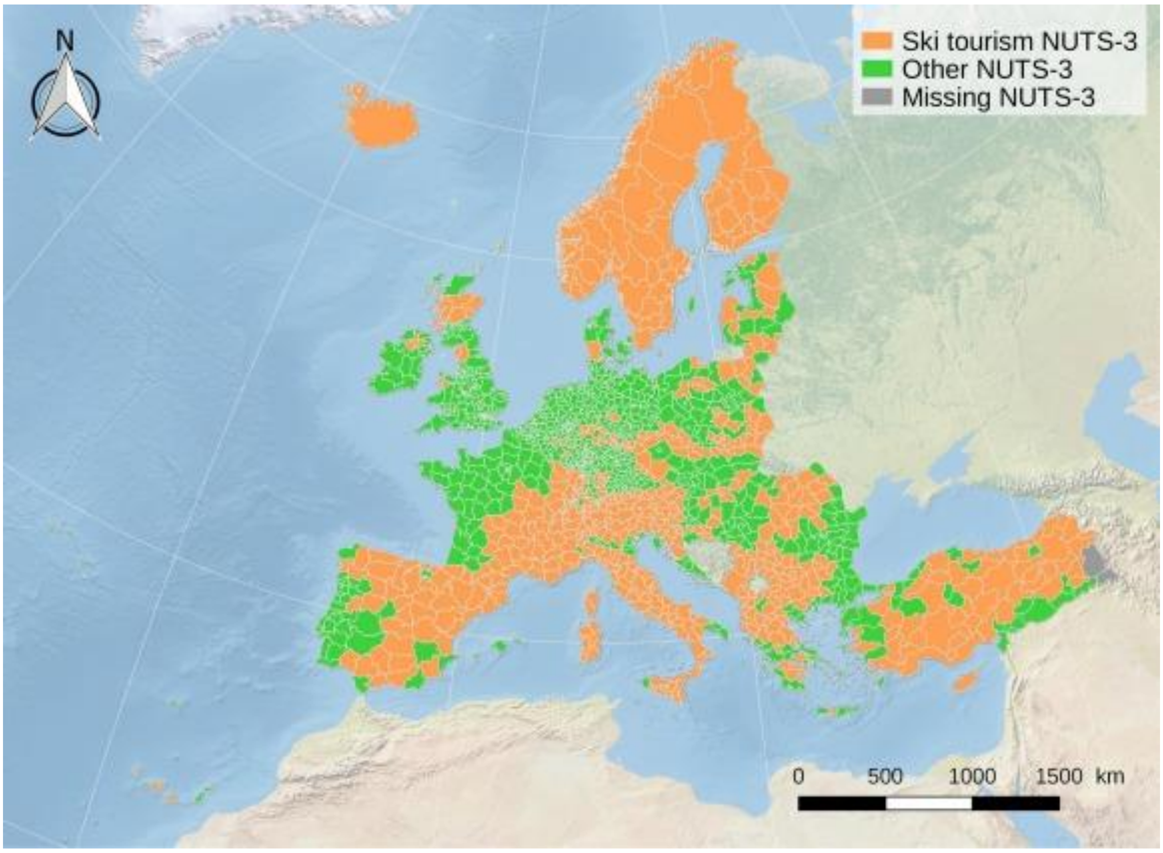


Figure 2 Overview of the NUTS-3 areas classified as holding ski tourism character, or not (Morin et al, 2021)

In this study, surface atmospheric variables from the UERRA 5.5 km reanalysis dataset (Soci et al., 2016) were utilized following the geographical analysis, selecting 5,652 points based on location and elevation within NUTS-3 regions. Additionally, 932 points were chosen to represent the mean elevation of all European NUTS-3 areas. Although UERRA 5.5 km points differ in their coordinates, within each NUTS-3 area, they were assigned the same latitude and longitude, corresponding to the barycenter, and their elevation was rounded to the nearest 100-meter elevation band. To integrate regional climate projections and minimize biases before running impact models, the ADAMONT method (Verfaillie et al., 2017) was applied to adjust EURO-CORDEX GCM/RCM pairs using UERRA 5.5 km reanalysis data as an observational reference. This adjustment was done through quantile mapping applied to daily data, with the mapping functions derived based on four weather types, categorized by synoptic fields from the 500 hPa geopotential height of the driving GCM, and across four seasons (DJF, MAM, JJA, SON). Both reanalysis and bias-adjusted climate projections were subsequently used to compute atmospheric indicators such as temperature, wet bulb temperature, and precipitation.

Table 1.GCM and RCM models used in the study

GCM model	RCM model	Historical period	RCP4.5	RCP8.5
CNRM-CM5 (CNRM, France)	ALADIN53 (CNRM, France)	X	X	X
MPI-ESM-LR (MPI, Germany)	CCLM4-8-17 (CLM-Community, EU)	X	X	X
MPI-ESM-LR (MPI, Germany)	REMO2009 (MPI-CSC, Germany)	X	X	X
CM5A-MR (IPSL, France)	WRF331F (IPSL, France)	X	X	X

Similarly, for this study area, daily data from four regional climate models were utilized (Table 1). The first column lists the Driving Global Coupled Models, which are the general circulation models, covering both the historical period from 1971 to 2000 and the future reference periods of 2031–2060 and 2071–2100, under the climate scenarios RCP4.5 and RCP8.5.

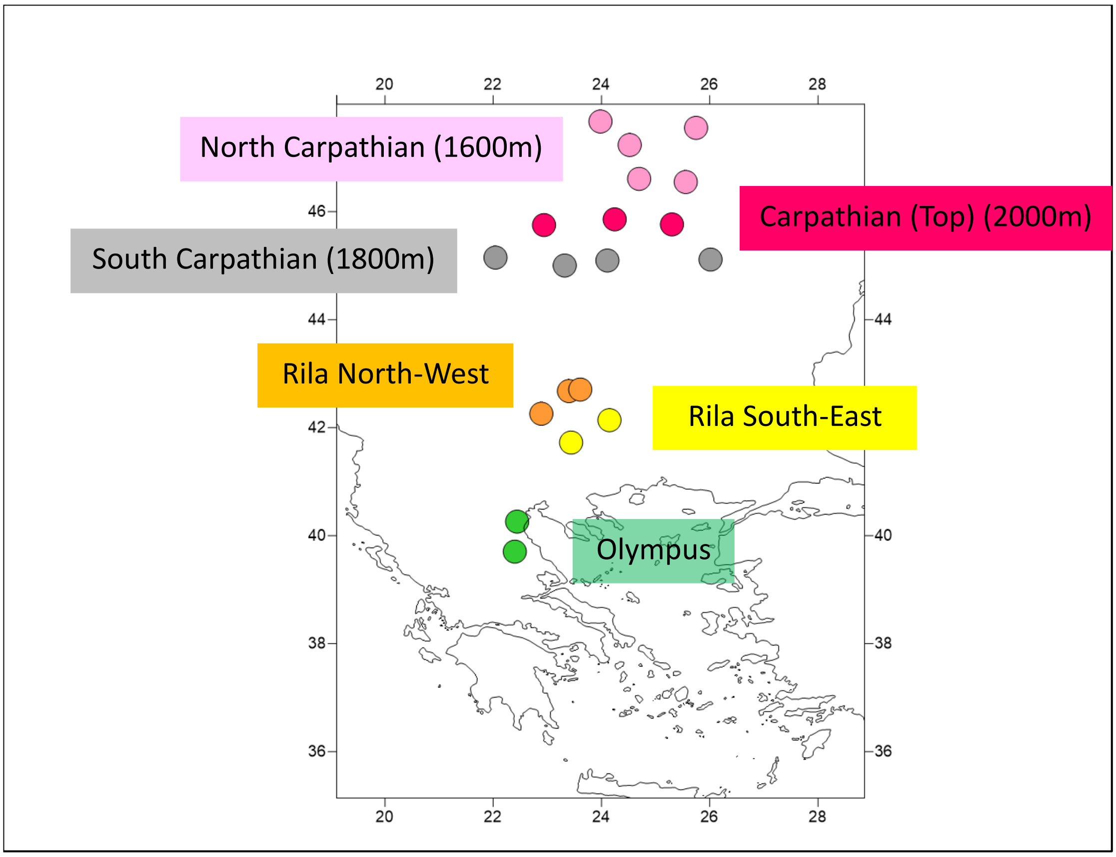
The climate data covers the reference time period from 1971 to 2000 and two future time periods: 2031-2060, 2071-2100 and cover the region Balkan. (Table 1, Figure 3). These data, after being extracted from the above simulations, were studied for the Balkan region and specifically 35-48o B and 19-29o A. these data were analyzed for the Balkan region, specifically within the latitude range of 35-48° N and the longitude range of 19-29° E. The grid colors represent different altitude levels in various mountain ranges. Purple indicates 5 grids at 1600m in the northern Carpathians, while pink marks 3 grids at 2000m in the central Carpathians. Grey represents 4 grids at 1800m in the southern Carpathians. In the Rila Mountains, orange shows 3 grid at altitudes of 2400m and 1700m in the northwest, and yellow represents 2 grid at 2300m and 2400m in the southeast. Green depicts 2 grid at 2200m, characterizing Mount Olympus (Figure 3). The selected parameters are presented in Table 2.

Table 2. Description of the selected climate parameters

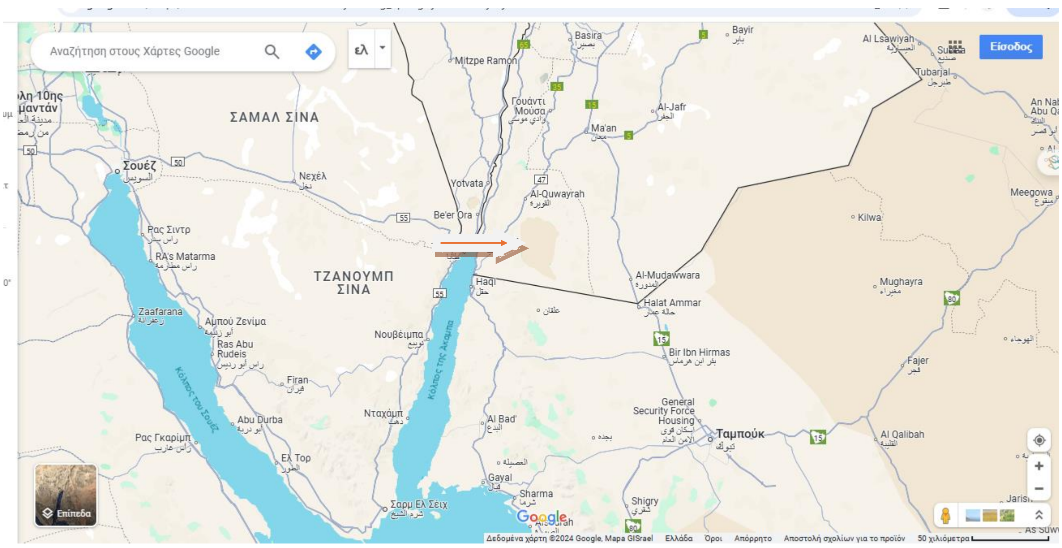
Index	Index name	Description
Tas	***Tas-winter (K)***	*Average (6-hour) air temperature 2m. above land or sea level from November of year N to April of year N+1*
PR	**Precipitation-amount-winter (Kg m^{-2})**	Total Precipitation *from November of year N to April of year N+1*
	Snowfall-amount-winter (Kg m^{-2})	Total Snowfall *from November of year N to April of year N+1*
BS-ES	**Beginning-season-30-NS (day)**	The beginning of season with Natural Snow (NS) at least 30cm-(start year 1st of August- end of year: 31 July)
	End-season-30-NS (day)	The end of season with Natural Snow (NS) at least 30cm-(start year 1st of August- end of year: 31 July)

General circulation models (GCMs) are numerical tools that simulate the physical processes occurring in the atmosphere, oceans, cryosphere, and soil surface (https://www.ipcc-data.org/). Local climates are determined by the interplay between planetary and local processes. GCMs are employed to model climate and climate change across various temporal and spatial scales, capturing both historical climate shifts and future climate characteristics. They represent climate using a three-dimensional grid that spans the globe, typically with a spatial resolution ranging from 250 to 600 km, featuring 10 to 20 vertical layers in the atmosphere and often up to 30 levels in the oceans. However, their relatively low spatial resolution is insufficient for accurately determining local climate systems in areas where topography significantly influences climate, making it difficult to simulate critical high-scale processes effectively. Many physical processes occur on a smaller scale that GCMs cannot adequately capture. Therefore, it is essential to conduct simulations of various climatic parameters at a higher spatial resolution. One approach to achieving improved spatial resolution is to dynamically downscale GCMs to regional climate models.

Regional climate models (RCMs) are numerical tools designed for climate prediction that utilize specific lateral, oceanic, and atmospheric conditions derived from general circulation models (GCMs) or observational databases (reanalysis). They simulate both atmospheric and surface processes while incorporating high-resolution topographic data, land-sea contrasts, surface characteristics, and other elements of the Earth system. Since RCMs focus on a defined area, limit values, known as limit conditions, must be explicitly established based on the outputs of a general circulation model or reanalysis data. RCMs operate using initial conditions and adjust to lateral atmospheric and lower surface boundaries with time-variable conditions. Consequently, regional climate models refine the scale of general circulation models to better simulate local climate variability.



(A)



(B)

Figure 3 The Balkan study regions and the locations of the selected NUTS of the regional climate models (a) and the Jordan study region (orange arrow).

Projected temperature changes for the 21st century using Representative Concentration Pathways (RCPs) 4.5 and 8.5 Wm−2 are analyzed for the study regions. RCPs are scenarios that include time series of emissions and concentrations of greenhouse gases (GHGs), aerosols and chemically active gases, as well as land use/land cover (Kim et al., 2013, Zhang et al., 2017). The word "representative" means that each RCP provides only one of several possible scenarios that would lead to the specific characteristics of forced radiation. The term scenario/path emphasizes that not only are long-term concentration levels interesting, but also that trajectory is important to achieve this outcome (IPCC, 2016). RCP8.5 is the most pessimistic scenario, in which pathway radiation reaches values greater than 8.5 W $^{m-2}$ by 2100 and continues to increase for some time (the corresponding RCM assumes stable emissions after 2100 and stable concentrations after 2250) (https://www.ipcc-data.org/guidelines/pages/glossary/glossary_r.html).

2.2Climate characteristics of study regions

The Balkan region is a climatically diverse area, with its mountainous terrain creating distinct microclimates that vary by altitude and geographic position.

The **Carpathian Mountains** have a cooler climate compared to the lowlands, with temperatures varying significantly by altitude and season. Winter temperatures at higher elevations can drop well below -10°C, while summer temperatures generally remain mild, averaging around 10–15°C at higher elevations and up to 25°C in lower valleys. The region receives moderate to high precipitation, with annual averages ranging from 800 mm to 1,400 mm, depending on elevation and exposure. Snowfall is frequent and heavy in winter, with snow cover lasting from November to April in higher altitudes, supporting winter sports in ski resorts like those in Romania and Slovakia. The Carpathians experience moderate humidity, higher in the valleys and during the warmer months. Winds can be strong, especially at higher elevations and during winter storms. On Carpathian Mountains, snow is prevalent in winter, with temperatures often dropping below freezing, especially at higher elevations, creating ideal conditions for skiing and other winter sports. Summers are mild, and temperatures are comfortable for outdoor activities, with lush vegetation and diverse wildlife, including large mammal species like bears and lynx. These seasons bring varied weather, with rainfall and milder temperatures, especially in autumn, when vibrant foliage attracts many visitors.

The **Rila Mountains**, particularly around Musala Peak (Bulgaria's highest at 2,925 meters), experience a cool mountain climate. Winters are cold, with average temperatures often below -

5°C and extreme lows below -20°C. Summers are mild, with average temperatures at higher altitudes around 10–15°C, while valleys are warmer, reaching 25°C. The Rila Mountains receive substantial precipitation, ranging from 800 to 1,200 mm annually. Snowfall is abundant in winter, with snow often lasting from October to May at higher altitudes, making it popular for winter sports. Humidity is moderate to high, especially in winter, with regular snowstorms. Strong winds are common at high altitudes, especially near peaks, where they intensify the cold.

Mount Olympus, Greece's highest peak at 2,917 meters, has a varied climate depending on altitude. The lower slopes have a Mediterranean climate, while higher elevations have a cool, alpine climate. Summer temperatures in the high-altitude zones range from 5–15°C, while in winter, temperatures frequently drop below -10°C with extreme lows at the summit. Mount Olympus receives higher precipitation than much of Greece, with annual averages between 900 and 1,200 mm, mostly concentrated in autumn and winter. Snowfall is common and heavy at high elevations from late autumn through early spring, with snow persisting at the summit into early summer. Humidity levels vary; higher elevations experience moderate humidity, and strong winds are common, especially during winter storms and along ridgelines.

Jabal Umm ad Dami, located in southern Jordan near the border with Saudi Arabia, is the highest peak in Jordan, standing at 1,854 meters (6,083 feet) above sea level. This mountain, nestled within the Wadi Rum Protected Area, has a unique climate due to its high elevation and desert surroundings, creating conditions distinct from the typical hot, arid lowlands of Jordan. The elevation at Jabal Umm ad Dami contributes to cooler temperatures than the surrounding desert lowlands. Average temperatures on the peak range from about 15°C in cooler months to 30°C in summer. The temperature difference between day and night is significant, typical of desert climates. During winter, nighttime temperatures can fall close to or even below 0°C, while summer days may exceed 30°C.

Despite the elevation, Jabal Umm ad Dami receives limited rainfall, consistent with its arid desert location. Annual precipitation is typically low, averaging 50–100 mm, with most rain falling between November and March. While uncommon, occasional snowfall may occur at the summit during particularly cold winter periods, especially during strong weather fronts. However, snow accumulation is typically light and short-lived. Like the rest of the Wadi Rum area, humidity on Jabal Umm ad Dami is generally low due to the surrounding arid desert, which leads to very dry air most of the year. The mountain's exposed location makes it susceptible to strong winds, especially in winter and spring. These winds can intensify the cooling effect, making temperatures feel colder than they are, especially at night.

Winter is the coolest season, with the mountain experiencing mild to cold days and cold nights. Occasional rain showers and rare snowfall can occur, making it one of the few places in Jordan to experience snow. Summer temperatures are warmer but remain cooler than the surrounding Wadi Rum desert, providing some relief from the intense heat found at lower elevations. These seasons bring moderate temperatures and are considered the most comfortable times for hiking and trekking. Spring, in particular, can bring brief vegetation growth, with small plants and flowers appearing in the rocky terrain.

Chapter 3

3. Temperature

3.1 ALADIN53 (CNRM, FRANCE)

The comparison of average winter temperatures in the Balkan region for different time periods and climate scenarios, as simulated by the Aladin regional climate model, is shown in Figure 4. During the historical period of 1971-2000, the highest average temperatures in the region are found over the south Greece, specifically in the southern Ionian and southern Aegean Seas, where temperatures range between 12 and 13°C. Moving inland, isotherms decrease from 10°C in the central Aegean to 5°C in the northern Aegean and the low-lying areas of Turkey at the same latitude. In the Black Sea region and the Danubian lowlands of Bulgaria and Serbia, average temperatures range from 0 to 4°C. Lower temperatures (0 to -3°C) are observed at higher altitudes in the continental parts of the Balkans, such as the Pindus and Mount Olympus, as well as in Albania. The coldest average temperatures (-3 to -5°C) are recorded at the highest altitudes and latitudes, specifically in the Rila and Carpathian mountain ranges.

Under the RCP4.5 climate scenario, the Balkan region is projected to experience a significant temperature increase. During the first future period (2031-2060), average temperatures in the southern Aegean and Ionian Seas are expected to rise to 13-14°C, reaching 14-15°C in the second future period (2071-2100). The 5°C isotherm, which remains in the northern Aegean and Turkey, extends into the Black Sea and Danubian lowlands in the first period, with temperatures rising to 5-7°C by the second period. In the mountainous regions, the 0°C isotherm continues to define higher altitudes, with temperatures in the Pindus, Olympus, and Albanian mountains increasing to -2°C in the first period and -1°C in the second. The coldest temperatures, represented by the -5°C and -3°C isotherms, disappear from the Rila and Carpathian mountain ranges by the second period.

Temperature increases of 1-1.5°C are expected in the southern regions and northern highlands in the first period, with larger increases of 1.5-2°C in areas like the Danubian lowlands, southern Carpathians, eastern Rila, and mountains in northwest Greece and Albania. In the second period, increases are more uniform, with rises of up to 2.5°C in southern areas and 2.5-3.5°C in northern and northeastern parts, including the Danubian lowlands and southern Carpathians.

In the first future period (see Table 3), all areas show a temperature increase of around 1.5°C, with the southern Carpathians showing the largest increase, about 1.8°C. In the second future period, temperature increases range from nearly 2.5°C on Mount Olympus to over 3.0°C in the lower-altitude regions of the Carpathians.°

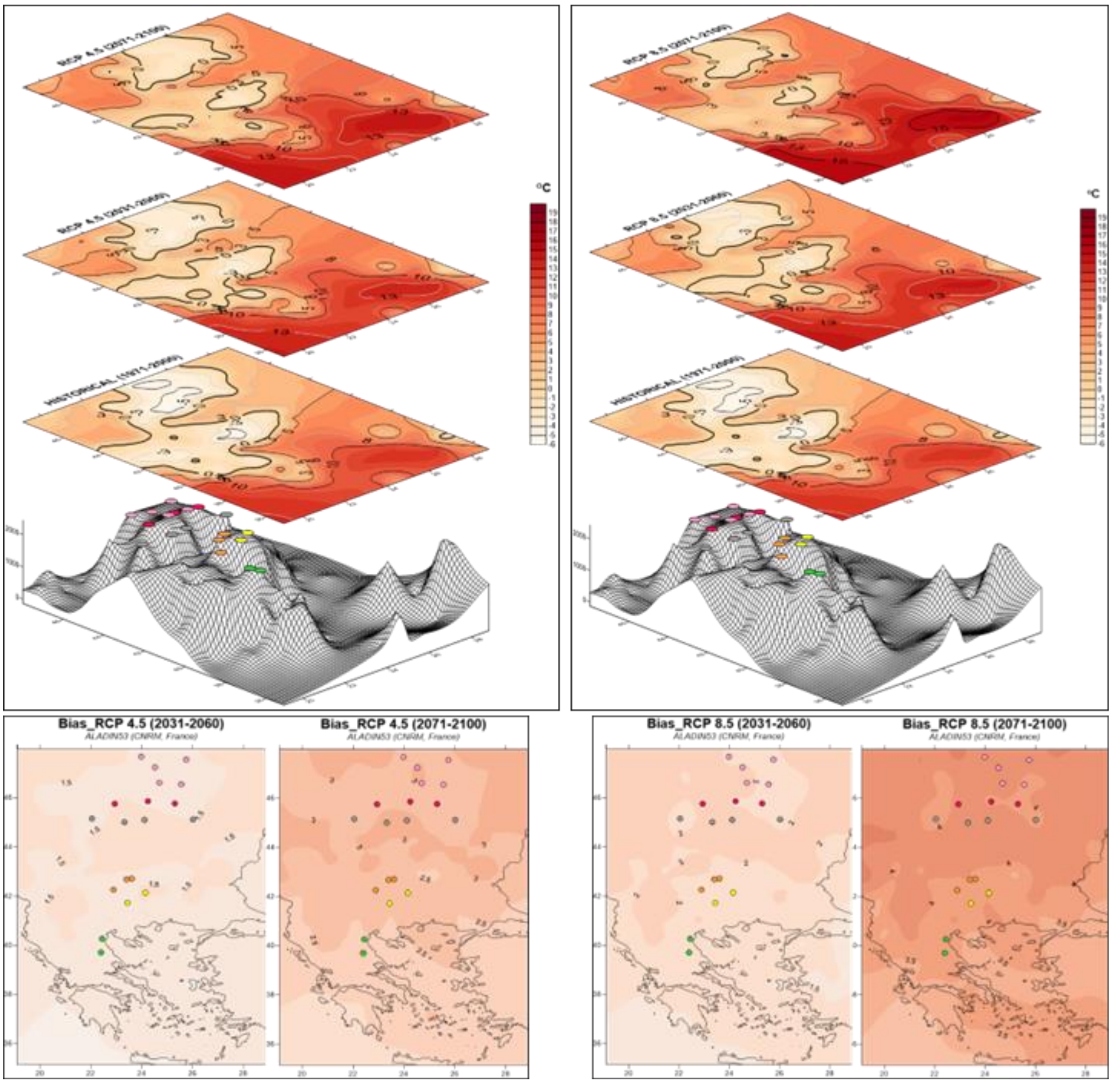


Figure 4 Mean temperature for the winter period, according to the climate model Aladin53 (CNRM, France). The climate scenarios RCP4.5 (top left) and its differences from the historical period (bottom left) and RCP8.5 (top right) and the differences from the historical period (bottom right) are depicted.

According to the RCP8.5 climate scenario (Figure 4), temperature changes in the first future period (2031-2060) are not significantly different from the RCP4.5 scenario. However, notable differences emerge in the second future period (2071-2100). In the first period, average temperatures reach 13-14°C in the southern maritime regions, 10-13°C in other southern coastal areas, and 4-6°C in the northern Danubian lowlands. In the mountainous regions, temperatures range from 0 to -2°C in the Olympus, Pindus, and Albanian mountains, and from 0 to -3°C in the Rila and Carpathian mountains, where the -3°C isotherm is present only in these areas.

In the second future period, the temperature increases more dramatically. The southern maritime regions experience highs of 15-16°C, the Danubian lowlands reach 5-8°C, and the Greek and Albanian mountains warm to 1-3°C, while the Rila and Carpathian ranges see temperatures from 0 to -1°C. A striking change is observed in the higher elevations of the Rila and Carpathian mountains, which were historically dominated by the -5°C isotherm. By the end of the century, these areas will be dominated by isotherms of 0 to -1°C.

Table 3 Temperature biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model ALADIN53 (CNRM, FRANCE)

ALADIN53 (CNRM, France)	**Historical (1971-2000)**	**RCP4.5 (2031-2060)**	**RCP4.5 (2071-2100)**	**RCP8.5 (2031-2060)**	**RCP8.5 (2071-2100)**
Olympos 1	-3.00 ºC	+1.42	**+2.55**	+1.93	+3.78
Olympos 2	-3.03 ºC	+1.33	**+2.42**	**+1.76**	+3.68
Rila 1 (SE)	-5.26 ºC	+1.33	+2.58	+1.82	+3.83
Rila 2 (SE)	-4.45 ºC	+1.63	+2.89	+1.98	+4.04
Rila 3 (NW)	-5.42 ºC	+1.38	+2.71	+1.89	**+3.76**
Rila 4 (NW)	-2.49 ºC	+1.43	+2.82	+2.00	+4.05
Rila 5 (NW)	-5.32 ºC	+1.35	+2.67	+1.85	**+3.75**
Carpathia 1 (S)	-4.89 ºC	**+1.78**	**+3.19**	**+2.15**	**+4.38**
Carpathia 2 (S)	-4.93 ºC	**+1.83**	**+3.23**	**+2.22**	**+4.52**
Carpathia 3 (S)	-4.73 ºC	+1.45	+2.72	+1.82	+3.84
Carpathia 4 (S)	-4.57 ºC	**+1.19**	**+2.53**	**+1.73**	**+3.59**
Carpathia 5	-5.01 ºC	**+1.54**	+2.88	+2.09	+4.08
Carpathia 6	-5.64 ºC	+1.28	+2.73	+1.88	+3.89
Carpathia 7	-5.68 ºC	+1.34	+2.70	+1.93	+3.85
Carpathia 8 (N)	-4.51 ºC	**+1.28**	+2.63	**+1.73**	+3.90
Carpathia 9 (N)	-4.60 ºC	+1.53	**+3.07**	**+2.25**	**+4.38**
Carpathia 10 (N)	-5.25 ºC	+1.47	+3.06	+2.04	+4.37
Carpathia 11 (N)	-4.55 ºC	+1.35	+2.83	+1.82	+4.05
Carpathia 12 (N)	-5.15 ºC	**+1.32**	+2.83	+1.87	+4.17

Based on bias maps, temperature increases in the first future period are moderate across both scenarios, with southern regions and mountainous areas like Rila and the eastern Carpathians seeing a rise of +1.5 to +2°C, while the Danubian regions and northern Balkan mountains experience an increase of +2 to +2.5°C. In the second future period, the northern parts of the region, including the Danubian lowlands and most mountainous areas, will see a temperature rise of over 4°C. The southern areas, including Mount Olympus, Rila, and the higher parts of the Carpathians, will experience increases of +3 to +4°C. Overall, the greatest temperature increases will occur in the Danubian lowlands, the northern sector, and the southern Carpathian regions.

Specifically, in the first future period under the RCP8.5 scenario (as shown in Table 3), all areas are projected to warm by 1.8°C to 2.25°C, with the southern Carpathians experiencing the largest increase. In the second future period, the maximum temperature rise is nearly 4.5°C in the Carpathians, with all other regions seeing increases of more than 3.5°C.

3.2 CCLM4-8-17 (CLM-COMMUNITY, EU)

Figure 5 illustrates the estimated average winter temperatures for the examined region, based on the CCLM4-8-17 regional climate model. During the historical period, the results align with previous models, showing higher temperatures in the southern Aegean and Ionian Seas (11-13°C). In the central and northern Aegean, as well as coastal areas of Greece and Turkey, temperatures range between 5 and 10°C. The Black Sea region and Danubian lowlands in Serbia and Bulgaria display isotherms of 0 to 4°C. In the mountainous regions, temperatures range from 0 to -3°C in Olympus, Pindus, and Albania, and from -3 to -5°C in the Carpathians and Rila mountains.

A similar pattern is observed across the region in both future periods of the RCP4.5 scenario and the first future period of RCP8.5, with no significant differences between these simulations. In these projections, the average temperature in the southern Aegean and Ionian Seas is estimated at 12-14°C, while the 5°C isotherm spans all coastal areas of Greece, Turkey, and the Danube region, as well as the Black Sea. In the mountainous areas of Greece and Albania, temperatures range from 0 to -1°C, while in Rila and the Carpathians, temperatures range from 0 to -3°C. Notably, the -5°C isotherm does not appear in any of these scenarios. The differences between the two future periods in this model are minimal (Table 4), with the temperature increase under the RCP4.5 scenario reaching 1.25°C for the first future period, and similar results for the second period.

However, the second future period of the RCP8.5 scenario shows more distinct temperature changes (Figure 5). Average temperatures in the southern Aegean and Ionian Seas rise to 15-16°C, while other coastal and semi-mountainous areas in Greece, Turkey, Bulgaria, and Serbia show temperatures between 5 and 10°C. In the Greek and Albanian mountains, temperatures range from 1 to 3°C, and from 0 to -1°C in Rila and the Carpathians. Under RCP8.5, the first future period (2031-2060) sees an increase of 1.5°C, while the second future period (2071-2100) shows a more significant rise, exceeding 4°C (Table 4). Mount

Olympus shows the largest increase, with other areas experiencing increases greater than 3.7°C.

The similarity between the first three simulations is also reflected in the bias maps. Under RCP4.5, the temperature increase is between +1 and +1.5°C across the entire region, except for the lowlands in the northeast and northwest, as well as the southern Carpathians. In the first future period of RCP8.5, this increase becomes more uniform across these areas. However, the second future period of RCP8.5 signals a more pronounced temperature rise, exceeding 3.5 to 4°C across most of the Balkans, including the Rila and Carpathians. Slightly higher increases (+4 to +4.5°C) are projected for the Aegean, eastern mainland Greece (including Mount Olympus), and parts of the western Balkans.

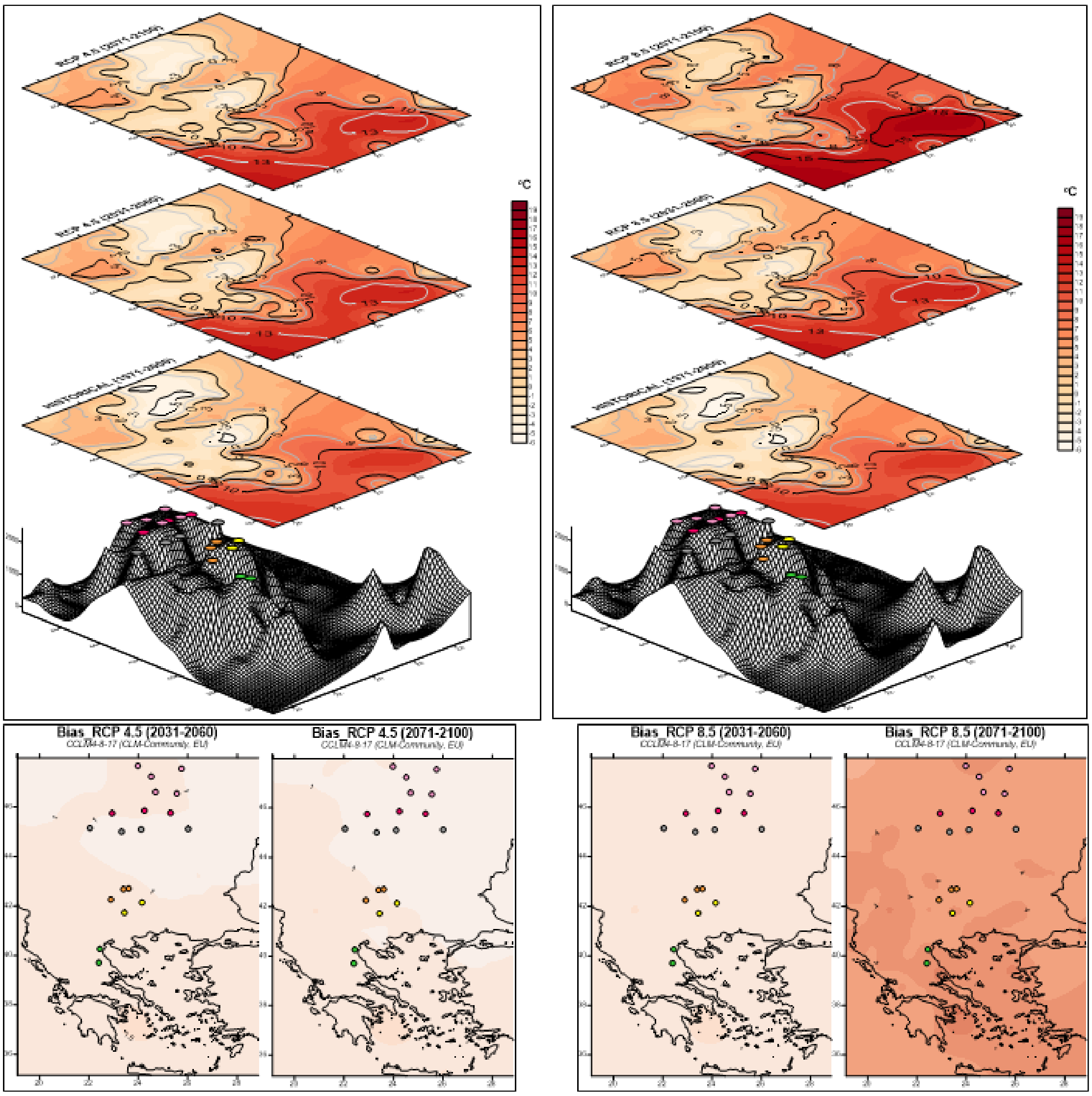


Figure 5 Mean temperature for the winter period, according to the climate model CCLM4-8-17 (CLM-COMMUNITY, EU). The climate scenarios RCP4.5 (top left) and its differences from the historical period (bottom left) and RCP8.5 (top right) and the differences from the historical period (bottom right) are depicted.

Table 4 Temperature biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model CCLM4-8-17 (CLM-Community,EU)

Σχήμα 6 Διακύμανση των μέσων ετήσιων θερμοκρασιών των ERA5 για το μέσο πεδίο της

CCLM4-8-17 (CLM-Community,EU)	**Historical (1971-2000)**	**RCP4.5 (2031-2060)**	**RCP4.5 (2071-2100)**	**RCP8.5 (2031-2060)**	**RCP8.5 (2071-2100)**
Olympos 1	-3.00 °C	**+1.19**	**+1.21**	+1.21	**+4.17**
Olympos 2	-3.03 °C	**+1.16**	**+1.16**	+1.25	**+4.08**
Rila 1 (SE)	-5.26 °C	**+1.25**	**+1.18**	+1.33	+4.06
Rila 2 (SE)	-4.45 °C	+1.08	+0.95	+1.26	+3.99
Rila 3 (NW)	-5.42 °C	+1.12	+1.03	**+1.16**	+3.87
Rila 4 (NW)	-2.49 °C	**+1.16**	+1.02	**+1.20**	+3.95
Rila 5 (NW)	-5.32 °C	+1.09	+1.01	**+1.16**	+3.79
Carpathia 1 (S)	-4.89 °C	**+0.91**	**+0.81**	+1.37	+3.92
Carpathia 2 (S)	-4.93 °C	**+0.97**	**+0.87**	**+1.40**	+4.03
Carpathia 3 (S)	-4.73 °C	**+0.81**	**+0.69**	+1.24	**+3.70**
Carpathia 4 (S)	-4.57 °C	+0.99	+1.00	+1.35	+3.91
Carpathia 5	-5.01 °C	+1.02	+0.90	+1.27	**+3.74**
Carpathia 6	-5.64 °C	+1.03	+0.88	+1.29	**+3.78**
Carpathia 7	-5.68 °C	+1.03	+0.87	+1.29	+3.79
Carpathia 8 (N)	-4.51 °C	+1.05	+0.91	+1.38	+3.96
Carpathia 9 (N)	-4.60 °C	+1.03	+0.88	+1.30	+3.88
Carpathia 10 (N)	-5.25 °C	+1.09	+0.89	+1.35	+3.99
Carpathia 11 (N)	-4.55 °C	+1.02	+0.94	**+1.40**	+3.94
Carpathia 12 (N)	-5.15 °C	+1.15	+1.01	**+1.44**	**+4.10**

3.3 REMO2009 (MPI-CSC, GERMANY)

The estimation of average winter temperatures using the REMO2009 climate model shows results similar to the CCLM model, with minimal differences between the first and second future periods of the RCP4.5 scenario and the first future period of RCP8.5 (Figure 6). During the historical period, temperatures ranged from 11-13°C in the southern Aegean and Ionian, 5-10°C in the rest of the Aegean and coastal areas of Greece and Turkey, and 0-4°C in the northern lowlands of the Balkans and the Black Sea. In the Greek mountains, temperatures were between 0 and -2°C, while in the Carpathians and Rila, they ranged from -3 to -5°C.

For RCP4.5 and the first future period of RCP8.5, temperatures in the warmest areas (southern Aegean and Ionian) increase by about 1°C to 13-14°C. The 5°C isotherm now extends into the northern lowlands (Danubian regions of Serbia, Bulgaria, Romania, and the Black Sea). In the mountains, temperatures are 0 to -1°C in Greece, -2°C in Albania, -3°C in Rila, and -4°C in the Carpathians, with no -5°C isotherm. In the second future period of

RCP8.5, the temperature increase is more pronounced, with an 18°C isotherm in the southern Aegean and temperatures ranging from 5 to 8°C in the lowlands of Serbia, Romania, and the Black Sea. In the mountains, temperatures reach 2-3°C. Overall, temperatures are about 1°C higher than in previous models.

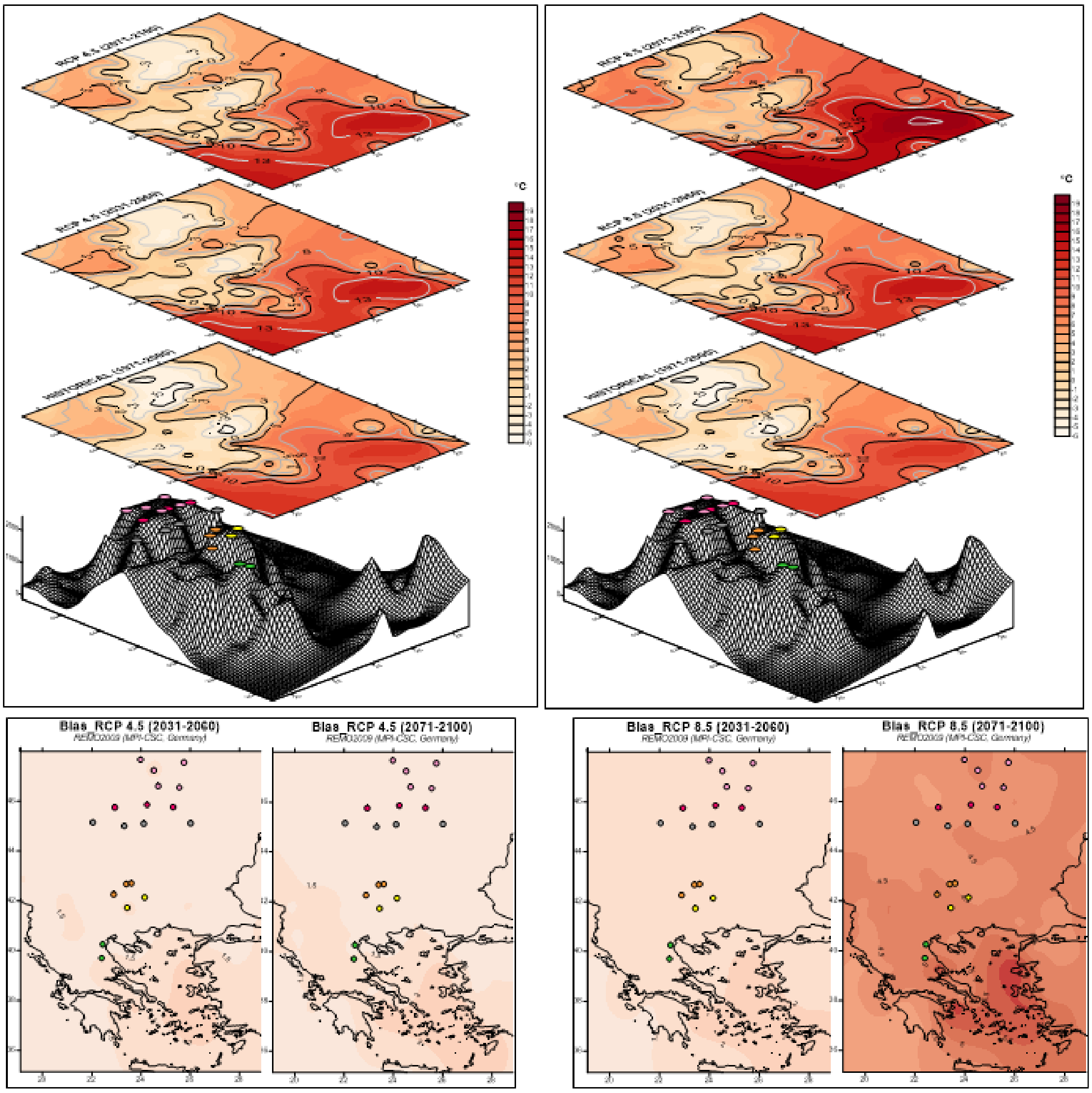


Figure 6 Mean temperature for the winter period, according to the climate model REMO2009 (MPI-CSC, Germany). The climate scenarios RCP4.5 (top left) and its differences from the historical period (bottom left) and RCP8.5 (top right) and the differences from the historical period (bottom right) are depicted.

According to bias maps, under RCP4.5, temperatures increase by +1 to +1.5°C across the region, with a slightly higher rise (+2°C) in the Aegean and western mainland areas in the second future period. In the first future period of RCP8.5, the increase is +1.5 to +2°C across the region and +2 to +2.5°C in the Aegean. By the second future period, temperatures rise by

+4 to +4.5°C in the Carpathians and northern Balkans, +4.5 to +5°C in the southeastern mainland (including Olympus and Rila), and +5 to +6°C in the Aegean.

Overall, the REMO2009 model predicts an average temperature increase 1 to 1.5°C higher than the CCLM model (Table 5). The nodes showing the largest increases are in Olympus, Rila, and the northern Carpathians, while smaller increases occur in the southern Carpathians. Temperature increases at these nodes are 0.4-0.5°C higher than in the CCLM model. There is consistency between REMO2009 and CCLM, but differences are observed compared to the Aladin model, particularly in the southern Carpathians.

Table 5 Temperature biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model *REMO2009 (MPI-CSC, Germany)*-

REMO2009 (MPI-CSC, Germany)	**Historical (1971-2000)**	**RCP4.5 (2031-2060)**	**RCP4.5 (2071-2100)**	**RCP8.5 (2031-2060)**	**RCP8.5 (2071-2100)**
Olympos 1	-2.92 °C	**+1.49**	**+1.54**	+1.77	**+4.82**
Olympos 2	-2.76 °C	+1.38	+1.37	**+1.51**	+4.37
Rila 1 (SE)	-5.32 °C	**+1.56**	**+1.51**	**+1.86**	**+4.90**
Rila 2 (SE)	-4.15 °C	+1.41	+1.34	+1.69	+4.41
Rila 3 (NW)	-5.25 °C	+1.42	**+1.47**	+1.76	+4.62
Rila 4 (NW)	-2.28 °C	+1.38	+1.27	+1.69	+4.48
Rila 5 (NW)	-5.23 °C	+1.37	+1.33	+1.74	+4.44
Carpathia 1 (S)	-4.66 °C	+1.31	+1.33	+1.69	+4.45
Carpathia 2 (S)	-4.63 °C	+1.36	+1.37	**+1.88**	+4.53
Carpathia 3 (S)	-4.43 °C	**+1.19**	**+1.10**	**+1.53**	**+4.14**
Carpathia 4 (S)	-4.51 °C	**+1.16**	**+1.05**	**+1.46**	**+3.98**
Carpathia 5	-4.78 °C	**+1.09**	+1.11	+1.57	**+4.00**
Carpathia 6	-5.58 °C	+1.27	**+1.10**	+1.61	+4.15
Carpathia 7	-5.56 °C	+1.28	+1.12	+1.64	+4.15
Carpathia 8 (N)	-4.39 °C	+1.26	**+1.08**	+1.77	+4.36
Carpathia 9 (N)	-4.49 °C	+1.41	+1.19	+1.78	+4.44
Carpathia 10 (N)	-5.16 °C	**+1.60**	+1.40	**+1.95**	**+4.72**
Carpathia 11 (N)	-4.30 °C	+1.25	+1.11	+1.78	+4.27
Carpathia 12 (N)	-5.08 °C	+1.41	+1.23	**+1.86**	+4.42

3.4 WRF331F (IPSL, FRANCE)

The WRF331F climate model predicts significant temperature increases in the Balkan region, particularly in future periods compared to the historical period (1971-2000), with variations across different climate scenarios (Figure 7). During the historical period, temperatures align with previous models, but notable differences appear in future simulations.

Under the RCP4.5 scenario, temperatures increase by 2 to 3°C in the first future period (2031-2060) compared to the historical period. In the southern Aegean and Ionian regions, temperatures rise to 13-14°C in the first future period and 14-15°C in the second (2071-2100). In the Danubian lowlands of Serbia, Romania, and Bulgaria, temperatures range from 3-5°C, with 6°C in inland areas. In Greece and Albania's mountains, temperatures range from -1 to 0°C in the first future period and 0 to 1°C in the second. In the Rila and Carpathians, temperatures rise from -3 to 0°C in the first period and -2 to 0°C in the second. The bias maps show the largest temperature increases in the northeastern Balkans, Carpathians, and Aegean, with an increase of +2 to +2.5°C in the first period and +3 to +3.5°C in the second.

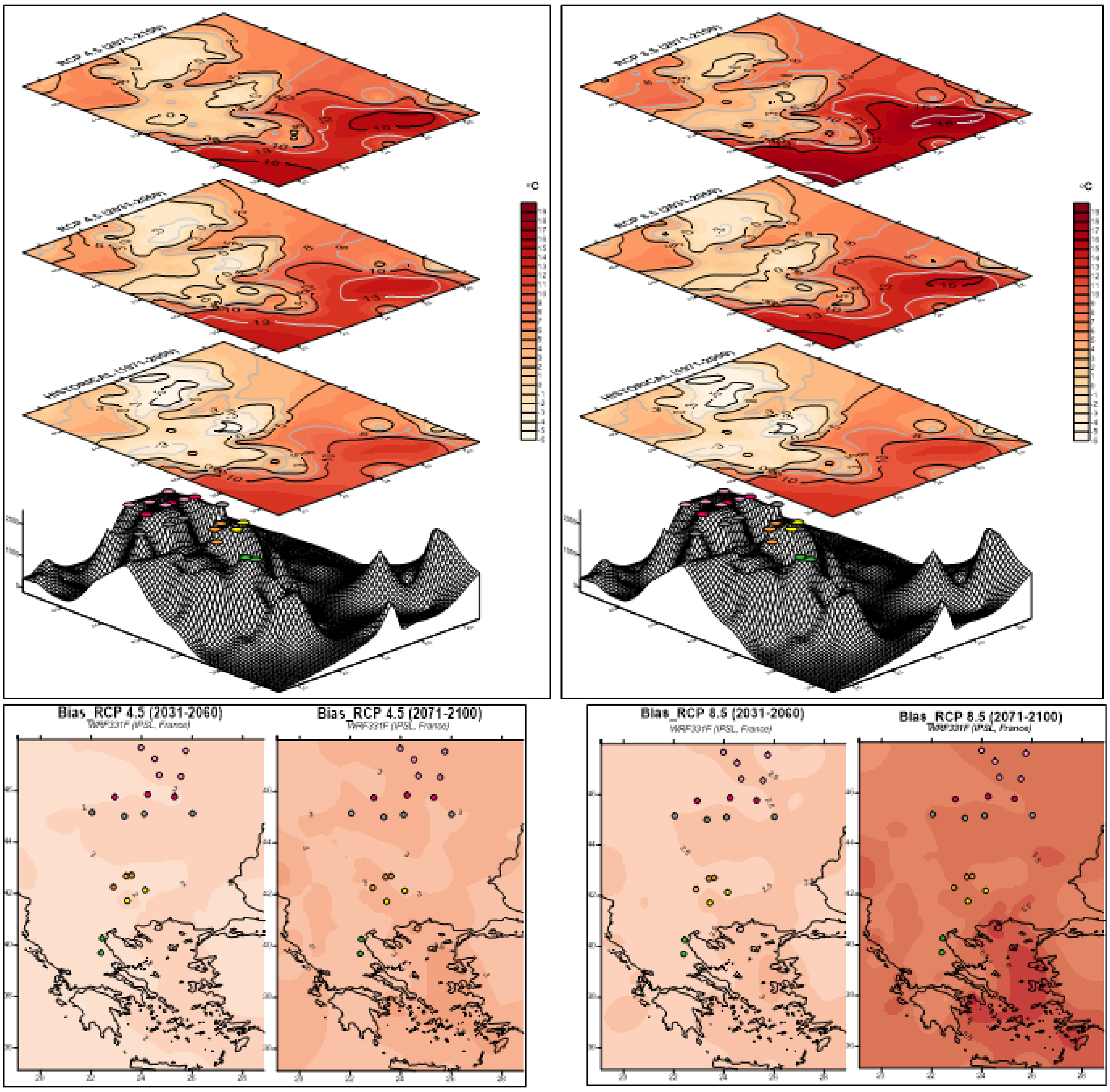


Figure 7 Mean temperature for the winter period, according to the climate model WRF331F (IPSL, FRANCE). The climate scenarios RCP4.5 (top left) and its differences from the historical period (bottom left) and RCP8.5 (top right) and the differences from the historical period (bottom right) are depicted.

For RCP8.5, the first future period mirrors the second period of RCP4.5, with temperatures ranging from -3°C in the Carpathians to 16-18°C in the southern Aegean and Ionian (Figure

7). However, the second future period under RCP8.5 shows a substantial increase, with temperatures reaching 16-18°C in the southern Aegean, 10-13°C in the southern lowlands, 5-9°C in the Danube regions, and 2-3°C in the mountains of Greece and Albania. The difference map for the second future period of RCP8.5 reveals increases of +5 to +5.5°C in the eastern and northeastern lowlands and mountainous regions like the Carpathians and Rila. The Aegean region shows an even higher increase of +5.5 to +6.5°C, making it the largest temperature rise among the models. The Rila 1 node records the highest increase at +5.67°C, particularly in the second future period of RCP8.5 (Table 6).

In summary, the WRF331F model predicts larger temperature increases compared to other models, particularly in the Rila and Carpathian mountains and the Aegean region, with Rila experiencing the greatest rise. Conversely, the Olympus region shows a smaller increase, consistent with the Aladin53 model.

Table 6 Temperature biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model *WRF331F (IPSL, FRANCE)*

REMO2009 (MPI-CSC, Germany)	**Historical (1971-2000)**	**RCP4.5 (2031-2060)**	**RCP4.5 (2071-2100)**	**RCP8.5 (2031-2060)**	**RCP8.5 (2071-2100)**
Olympos 1	-2.92 °C	**+1.49**	**+1.54**	+1.77	**+4.82**
Olympos 2	-2.76 °C	+1.38	+1.37	**+1.51**	+4.37
Rila 1 (SE)	-5.32 °C	**+1.56**	**+1.51**	**+1.86**	**+4.90**
Rila 2 (SE)	-4.15 °C	+1.41	+1.34	+1.69	+4.41
Rila 3 (NW)	-5.25 °C	+1.42	**+1.47**	+1.76	+4.62
Rila 4 (NW)	-2.28 °C	+1.38	+1.27	+1.69	+4.48
Rila 5 (NW)	-5.23 °C	+1.37	+1.33	+1.74	+4.44
Carpathia 1 (S)	-4.66 °C	+1.31	+1.33	+1.69	+4.45
Carpathia 2 (S)	-4.63 °C	+1.36	+1.37	**+1.88**	+4.53
Carpathia 3 (S)	-4.43 °C	**+1.19**	**+1.10**	**+1.53**	**+4.14**
Carpathia 4 (S)	-4.51 °C	**+1.16**	**+1.05**	**+1.46**	**+3.98**
Carpathia 5	-4.78 °C	**+1.09**	+1.11	+1.57	**+4.00**
Carpathia 6	-5.58 °C	+1.27	**+1.10**	+1.61	+4.15
Carpathia 7	-5.56 °C	+1.28	+1.12	+1.64	+4.15
Carpathia 8 (N)	-4.39 °C	+1.26	**+1.08**	+1.77	+4.36
Carpathia 9 (N)	-4.49 °C	+1.41	+1.19	+1.78	+4.44
Carpathia 10 (N)	-5.16 °C	**+1.60**	+1.40	**+1.95**	**+4.72**
Carpathia 11 (N)	-4.30 °C	+1.25	+1.11	+1.78	+4.27
Carpathia 12 (N)	-5.08 °C	+1.41	+1.23	**+1.86**	+4.42

3.5 Increased temperature in Jorden

The increase in temperature on the mountains of Jordan has significant environmental, social, and economic impacts. Warming trends are intensifying desertification, reducing water availability, affecting biodiversity, and threatening local agriculture and tourism.

Jordan has experienced an increase in mean annual temperatures by 0.3–0.4°C per decade over recent decades, a rate above the global average. Summer mean temperatures presents higher positive trend compared to winter one (Figure 8). By 2050, temperatures are expected to rise by 2°C to 4°C, with higher extremes in mountainous regions such as Jabal Umm ad Dami mountain. By the end of the century, the mean temperature could rise to °C depending to the season. Higher temperatures disrupt the habitats of native species, such as the Jordanian oak and other endemic flora. The loss of vegetation cover leads to soil erosion, further impacting ecosystems. Species adapted to cooler mountainous climates face habitat loss and migration challenges. For example, Jordan's mountainous biodiversity hotspots (like Dana Biosphere Reserve) are experiencing shifts, with some species moving to higher altitudes or declining in numbers. Mountain farming communities, which rely on crops like olives, grapes, and vegetables, are seeing reduced yields due to heat stress and water shortages. The reduction in productive land is estimated at 10-15% in some areas.

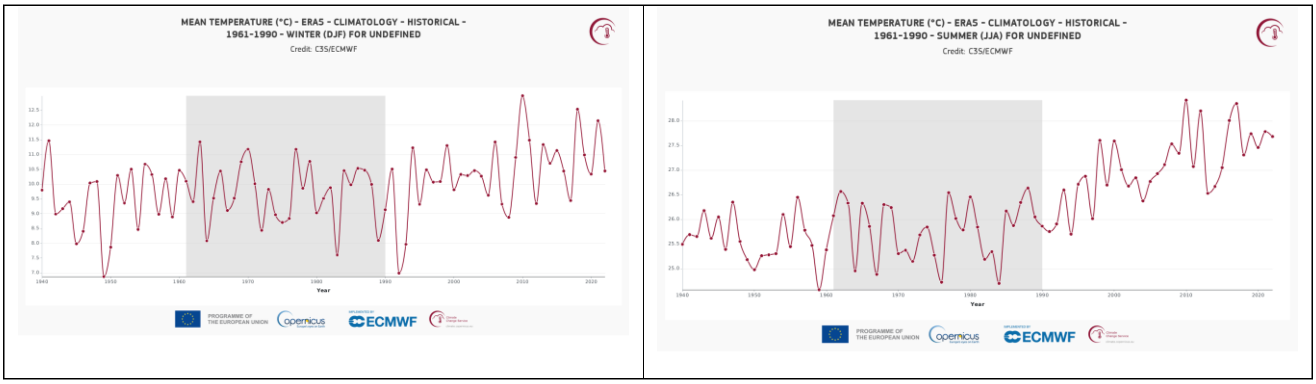
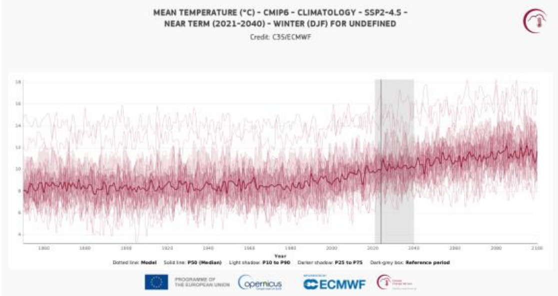
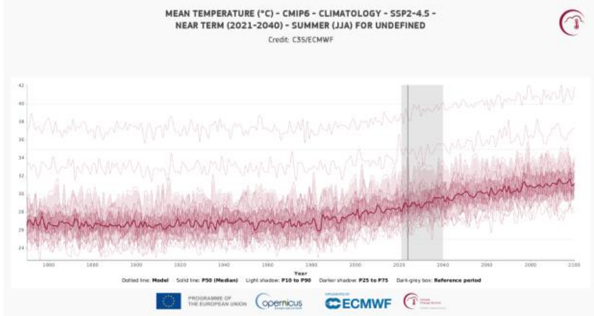
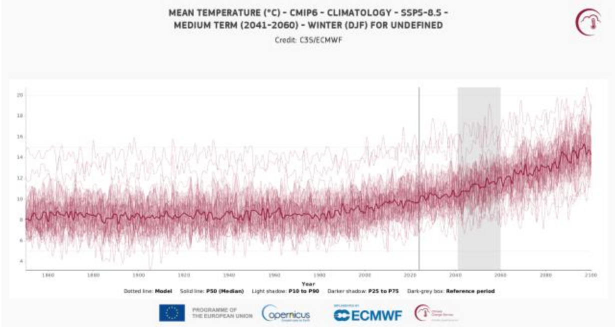
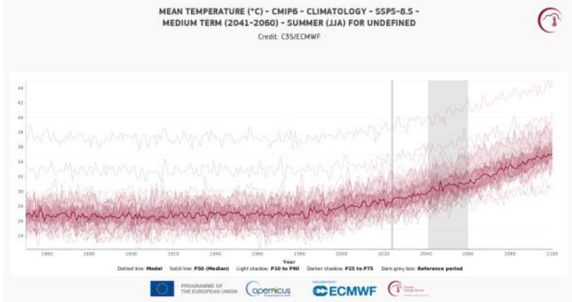


Figure 8 Mean Temperature variability for the Jabal Umm ad Dami mountain for winter (a) and summer (b)

Winter tourism, especially in areas like Jabal Umm ad Dami mountain, is at risk due to reduced snowfall and warmer winters. This reduction could lead to an estimated 20-30% drop in tourism revenue by 2050. Temperature rise exacerbates soil erosion on mountain slopes. The reduced vegetation cover, combined with heavy rain events, increases landslide risks. This has implications for infrastructure and agriculture, impacting rural communities economically and socially.

<table>
<tr><th></th><th>WINTER</th><th>SUMMER</th></tr>
<tr><td>RCP4.5</td><td>
</td><td>
</td></tr>
<tr><td>RCP8.5</td><td>
</td><td>
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</table>

Figure 9 Winter (left column) and Summer (right column) mean temperatures for the Jabal Umm ad Dami mountain of the CMIP6 climate projections.

Chapter 4

4. Precipitation

4.1 ALADIN53 (CNRM, FRANCE)

Figure 10 illustrates the total winter rainfall (November-April) for two climate scenarios, based on data from the Aladin climate model. Generally, the western Balkans (covering western Greece and Albania) experience the highest rainfall, while the Danubian lowlands in Serbia, Bulgaria, and Romania, along with the Black Sea and southern Aegean, receive the least.

In the historical period (1971-2000), average winter precipitation in the western Balkans ranged from 800-1200 mm, with 600-900 mm in other mountainous areas, such as Rila and Mount Olympus. The Carpathian region recorded somewhat lower values, between 400-600 mm, while lowland and coastal areas saw 300-400 mm.

Under the RCP4.5 scenario, rainfall in the western Balkans is expected to increase by approximately 100 mm during the first future period, with a peak value of 1300 mm in northern Albania and Montenegro. Precipitation in other Greek and Bulgarian mountains is projected to reach 1000 mm in the first future period and up to 1100 mm in the second. Similarly, rainfall in the Carpathians is estimated to rise to 500-700 mm in the first period and 600-800 mm in the second. In lowland and Aegean areas, precipitation is expected to remain stable at 300-400 mm.

This increase is also depicted in the bias maps of Figure 10, showing gains of 50-100 mm in most mountainous Balkan areas and 100-150 mm in the higher elevations of the Carpathians, southern Rila, and western Balkans. Only northern Albania, with the highest rainfall, is projected to exceed a 150 mm increase. In the second future period under RCP4.5, northern Carpathians, Pindus, and the Rhodope region may see increases of over 150 mm, while southern Turkey and the southern Ionian Sea are anticipated to see decreases of about 100 mm.

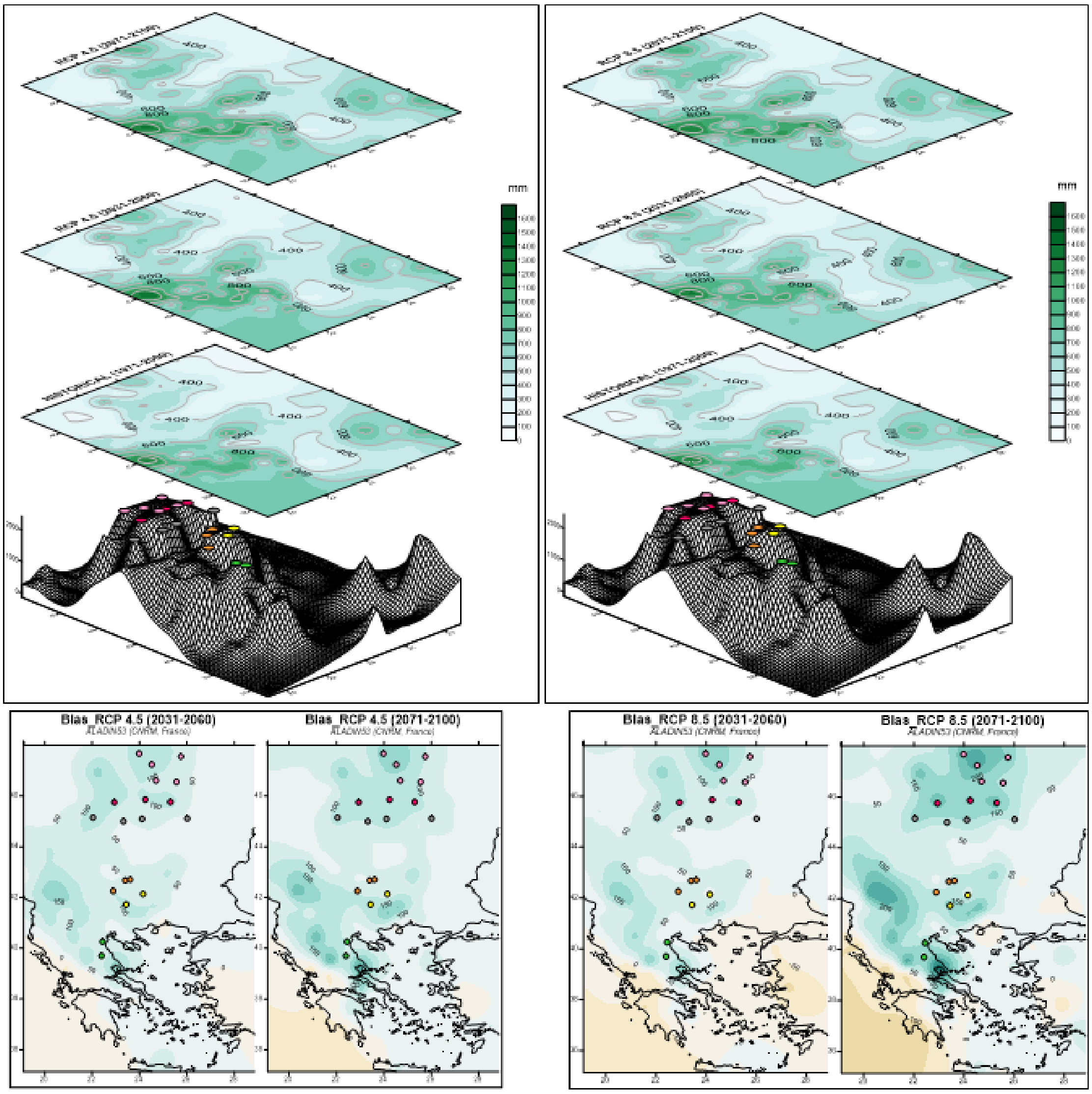

Figure 10 Mean Precipitation for the winter period, according to the climate model ALADIN53 (CNRM, FRANCE). The climate scenarios RCP4.5 (top left) and its differences from the historical period (bottom left) and RCP8.5 (top right) and the differences from the historical period (bottom right) are depicted.

The RCP8.5 scenario projects rainfall levels similar to those in the second RCP4.5 future period, with a slight reduction anticipated in the northern Aegean and Turkey during the first future period compared to historical values. However, in bias maps, this variation is evident only in the first period. By the second future period, significant increases (+200 to +250 mm) are projected in highly mountainous areas of northern Albania, Pindus, eastern Thessaly, and the central and northern Carpathians, while a notable decrease (over 100 mm) is expected in the southern Ionian. Lowland and coastal regions are expected to remain stable in precipitation.

Table 7 Precipitation biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model ALADIN53 (CNRM, FRANCE)

ALADIN53 (CNRM, France)	**Historical (1971-2000)**	**RCP4.5 (2031-2060)**	**RCP4.5 (2071-2100)**	**RCP8.5 (2031-2060)**	**RCP8.5 (2071-2100)**
Olympos 1	949.3 mm	+ 65.9	+ 76.8	+ 41.7	+ 121.9
Olympos 2	916.8 mm	+ 91.8	+ 94.0	+ 62.1	+ 172.4
Rila 1 (SE)	1058.6 mm	+ 110.5	+ 127.8	+ 72.2	+ 168.9
Rila 2 (SE)	640.6 mm	+ 39.4	+ 45.5	+ 25.7	+ 65.0
Rila 3 (NW)	518.0 mm	+ 107.1	+ 95.3	+ 92.8	+ 137.8
Rila 4 (NW)	426.5 mm	+ 47.8	+ 47.6	+ 42.9	+ 71.7
Rila 5 (NW)	512.0 mm	+ 96.9	+ 85.8	+ 91.8	+ 153.9
Carpathia 1 (S)	563.7 mm	+ 44.1	+ 101.2	+ 59.9	+ 123.3
Carpathia 2 (S)	560.2 mm	+ 68.3	+ 142.1	+ 74.3	+ 160.2
Carpathia 3 (S)	450.5 mm	+ 43.7	+ 104.0	+ 40.2	+ 115.5
Carpathia 4 (S)	585.1 mm	**+ 147.7**	+ 135.6	**+ 122.2**	+ 181.8
Carpathia 5	611.3 mm	+ 118.1	**+ 159.5**	+ 116.7	+ 221.9
Carpathia 6	548.4 mm	+ 129.3	+ 127.9	+ 115.4	**+ 234.1**
Carpathia 7	568.5 mm	+ 105.5	+ 133.9	+ 96.5	+ 205.5
Carpathia 8 (N)	386.0 mm	+ 60.6	+ 92.9	+ 42.7	+ 122.0
Carpathia 9 (N)	381.2 mm	+ 78.3	+ 104.8	+ 94.3	+ 152.8
Carpathia 10 (N)	659.6 mm	**+ 152.7**	**+ 206.6**	**+ 189.8**	**+ 286.5**
Carpathia 11 (N)	347.5 mm	+ 84.7	+ 98.7	+ 83.9	+ 194.3
Carpathia 12 (N)	668.6 mm	**+ 133.5**	**+ 184.2**	**+ 187.7**	**+ 246.7**

4.2 CCLM4-8-17 (CLM-COMMUNITY, EU)

Projected winter rainfall (November-April) across the Balkans under two climate scenarios, RCP4.5 and RCP8.5 are presented in Figure 11, using the CCLM climate model. Historically, the western Balkans receive the highest rainfall (800-1200 mm), while lowlands and coastal areas receive less (300-400 mm). Under RCP4.5, rainfall in the western Balkans is expected to increase by 100 mm in the first future period, with peaks in northern Albania and Montenegro. The Carpathians and other mountain regions also see increases, while lowlands remain stable.

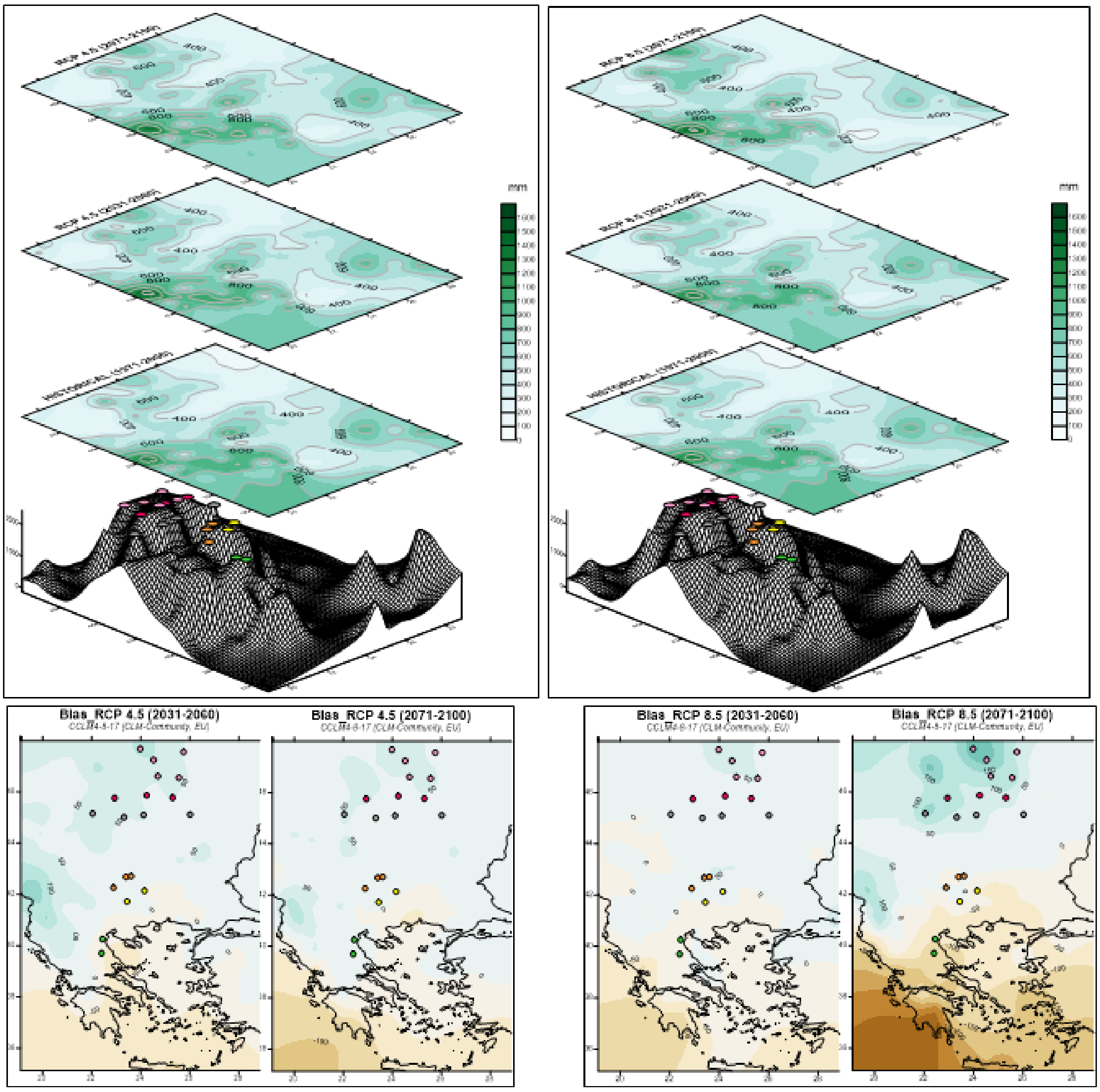

Figure 11 Mean Precipitation for the winter period, according to the climate model CCLM4-8-17 (CLM-COMMUNITY, EU). The climate scenarios RCP4.5 (top left) and its differences from the historical period (bottom left) and RCP8.5 (top right) and the differences from the historical period (bottom right) are depicted.

The RCP8.5 scenario reflects similar rainfall increases as RCP4.5, especially in the northern Aegean, Turkey, and mountainous areas. The second future period projects significant increases (+200 to +250 mm) in northern Albania and other mountainous zones, while decreases (over 100 mm) are anticipated in the southern Ionian. Lowland and marine areas remain relatively stable.

This CCLM4 climate model generally predicts wetter conditions than the Aladin model (see Table 8) for the historical period. Rainfall levels are projected to continue increasing overall, except in the Mount Olympus area, where a decrease is observed. However, the projected increases in this model are smaller than those in the Aladin model, particularly under the RCP4.5 scenario. For instance, while the Aladin model shows rainfall increases of 100 to 200 mm in the Carpathian region, this model projects smaller increases, ranging from 1 to 85 mm depending on the specific location. Under the RCP8.5 scenario, this model shows an increase about 3-5% in the Rila Mountain, while the increase of precipitation in the Carpathian Mountain is higher. The northern part of the Carpathian region presents increase from 20% to 35%.

Table 8 Precipitation biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model CCLM4-8-17 (CLM-COMMUNITY, EU)

ALADIN53 (CNRM, France)	**Historical (1971-2000)**	**RCP4.5 (2031-2060)**	**RCP4.5 (2071-2100)**	**RCP8.5 (2031-2060)**	**RCP8.5 (2071-2100)**
Olympos 1	972.3 mm	-37.0	-11.8	-10.4	-142.9
Olympos 2	941.5 mm	-35.0	+ 57.3	-7.8	-86.3
Rila 1 (SE)	1068.8 mm	+ 31.2	+ 38.8	-9.8	+ 31.0
Rila 2 (SE)	645.6 mm	-3.8	+ 10.8	+ 20.0	-52.1
Rila 3 (NW)	550.4 mm	+ 48.4	+ 31.2	+ 38.9	+ 11.9
Rila 4 (NW)	433.3 mm	+ 17.3	+ 24.2	+ 28.3	-17.8
Rila 5 (NW)	544.7 mm	+ 43.0	+ 38.2	**+ 60.7**	+ 25.2
Carpathia 1 (S)	565.5 mm	+ 48.5	-1.3	+ 9.3	+ 79.0
Carpathia 2 (S)	560.4 mm	+ 57.0	+ 24.1	+ 27.7	+ 100.3
Carpathia 3 (S)	470.9 mm	+ 39.5	+ 15.9	+ 31.8	+ 35.7
Carpathia 4 (S)	637.6 mm	**+ 107.5**	+ 59.1	+ 42.2	**+ 178.8**
Carpathia 5	648.6 mm	+ 75.0	+ 61.5	+ 24.9	+ 146.4
Carpathia 6	614.8 mm	+ 54.7	+ 48.0	+ 45.9	+ 90.0
Carpathia 7	609.6 mm	+ 42.8	+ 35.1	+ 20.5	+ 89.7
Carpathia 8 (N)	405.6 mm	+ 75.0	**+ 71.8**	+ 54.3	+ 144.8
Carpathia 9 (N)	402.9 mm	+ 50.6	+ 47.1	+ 40.5	+ 110.0
Carpathia 10 (N)	699.7 mm	**+ 95.7**	**+ 72.5**	**+ 89.8**	**+ 230.0**
Carpathia 11 (N)	392.8 mm	+ 46.9	+ 32.5	+ 32.6	+ 79.0
Carpathia 12 (N)	708.4 mm	**+ 121.1**	**+ 85.8**	**+ 87.4**	**+ 249.4**

4.3 REMO2009 (MPI-CSC, Germany)

Figure 12 shows projected winter rainfall (November-April) under two climate scenarios based on REMO model data. Generally, the western Balkans, including western Greece and Albania, receive the highest rainfall, while the Danubian lowlands in Serbia, Bulgaria, Romania, the Black Sea, and southern Aegean regions receive less.

From 1971 to 2000, winter precipitation in the western Balkans averaged 800-1200 mm, with 500-900 mm in other mountain ranges like Rila and Mount Olympus depending on altitude and the grid's location/orientation. The Carpathians saw lower values of 400-600 mm.

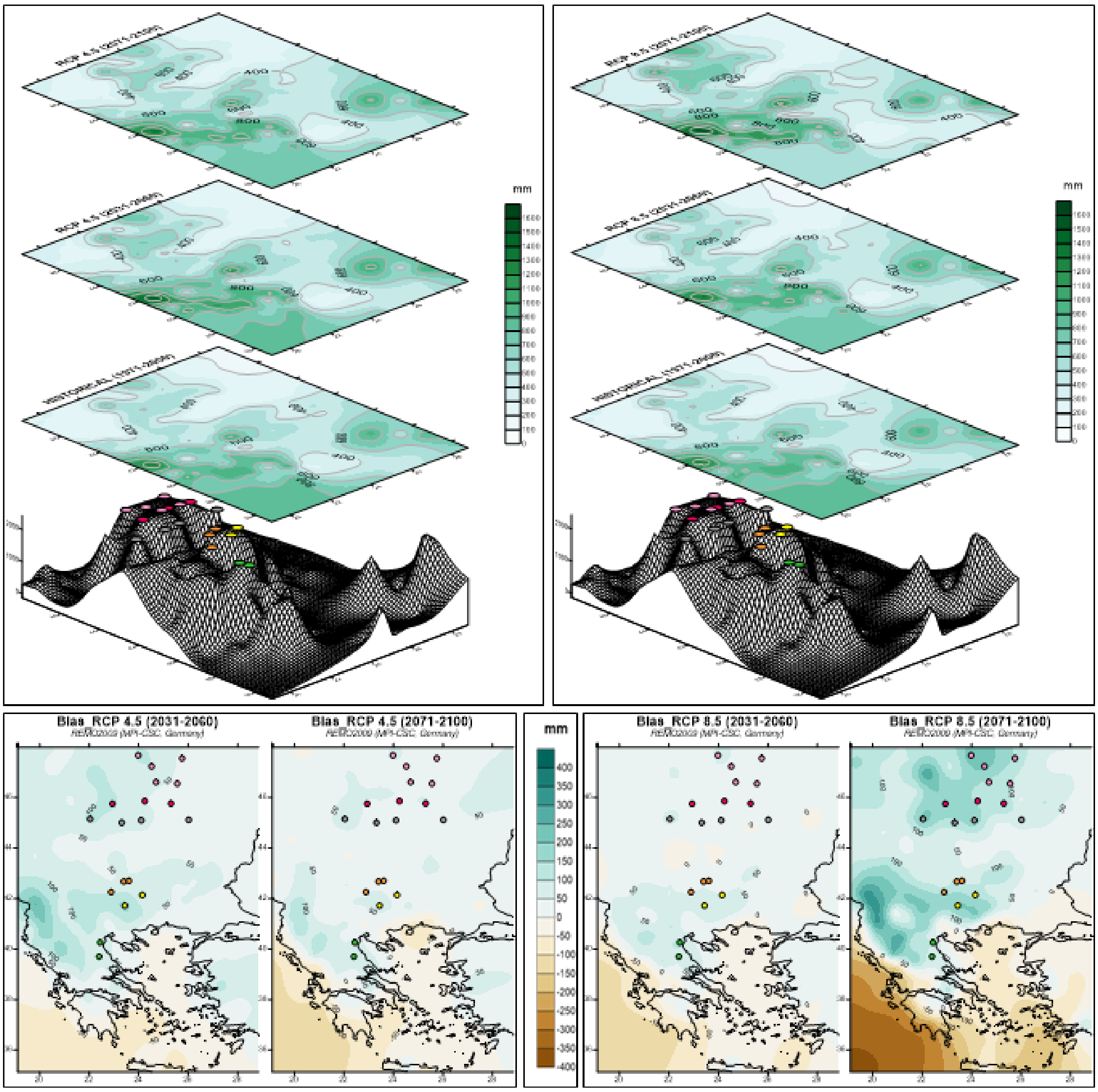

Figure 12 Mean Precipitation for the winter period, according to the climate model REMO2009 (MPI-CSC, Germany). The climate scenarios RCP4.5 (top left) and its differences from the historical period (bottom left) and RCP8.5 (top right) and the differences from the historical period (bottom right) are depicted.

The precipitation projections of REMO climate model are increased all over the study regions for the two scenarios (Table 9) In the RCP4.5 scenario, the rainfall increase is about 15-20% for the first future period (2031-2060) while this increase will be limited to 5-10% for the second time period (2071-2100). The Carpathians may see increases to 600-800 mm at the end of the century.

The RCP8.5 scenario predicts lower increases (mean increase for all grids is almost 50mm) for the first future period. The higher increases (+200 to +250 mm) are anticipated in northern Carpathians by the second future period.

Table 9 Precipitation biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model REMO2009 (MPI-CSC, Germany)

REMO2009 (MPI-CSC, Germany)	**Historical (1971-2000)**	**RCP4.5 (2031-2060)**	**RCP4.5 (2071-2100)**	**RCP8.5 (2031-2060)**	**RCP8.5 (2071-2100)**
Olympos 1	871.8 mm	+ 53.4	+ 50.0	+ 53.4	+ 59.3
Olympos 2	901.9 mm	+ 95.4	+ 81.4	**+ 139.6**	+ 107.3
Rila 1 (SE)	1084.6 mm	**+ 180.4**	**+ 99.7**	**+ 99.1**	+ 216.9
Rila 2 (SE)	610.9 mm	+ 52.2	+ 21.9	+ 44.2	+ 116.4
Rila 3 (NW)	533.0 mm	+ 89.6	+ 39.4	+ 48.2	+ 136.7
Rila 4 (NW)	394.9 mm	+ 53.1	+ 38.5	+ 47.5	+ 115.4
Rila 5 (NW)	554.0 mm	+ 56.3	+ 17.9	+ 19.8	+ 85.4
Carpathia 1 (S)	538.7 mm	+ 67.7	+ 4.8	+ 29.6	+ 128.8
Carpathia 2 (S)	522.8 mm	+ 74.9	+ 24.2	+ 51.7	+ 208.0
Carpathia 3 (S)	448.9 mm	+ 28.2	+ 26.6	+ 17.4	+ 101.8
Carpathia 4 (S)	612.4 mm	**+ 120.4**	**+ 95.5**	**+ 71.8**	**+ 235.4**
Carpathia 5	611.2 mm	**+ 108.9**	+ 46.4	+ 25.7	+ 199.7
Carpathia 6	591.4 mm	+ 44.3	+ 57.5	+ 46.6	+ 163.2
Carpathia 7	593.1 mm	+ 47.8	+ 47.8	+ 22.8	+ 135.4
Carpathia 8 (N)	368.6 mm	+ 42.8	+ 28.2	+ 5.5	+ 101.3
Carpathia 9 (N)	387.0 mm	+ 55.0	+ 47.4	+ 24.6	+ 129.3
Carpathia 10 (N)	671.1 mm	+ 100.4	+ 43.5	+ 44.9	**+ 227.9**
Carpathia 11 (N)	359.5 mm	+ 41.3	+ 36.9	+ 35.1	+ 145.3
Carpathia 12 (N)	647.7 mm	**+ 108.6**	+ 56.5	+ 56.6	**+ 248.9**

4.4 WRF331F (IPSL, FRANCE)

Projected Figure 13 illustrates projected winter rainfall (November-April) under two climate scenarios based on data from the WRF331F (IPSL, FRANCE) model. Similarly to the other three models the western part of Balkans presents the higher precipitation while the eastern part presents lower precipitation amounts. For the historical period 1971-2000, the highest winter precipitation (~ 1000mm) is observed in Mountain Olympus and the southern-eastern part of Rila Mountain, while all the other regions, from the selected grids, the mean total precipitation is about 600mm.

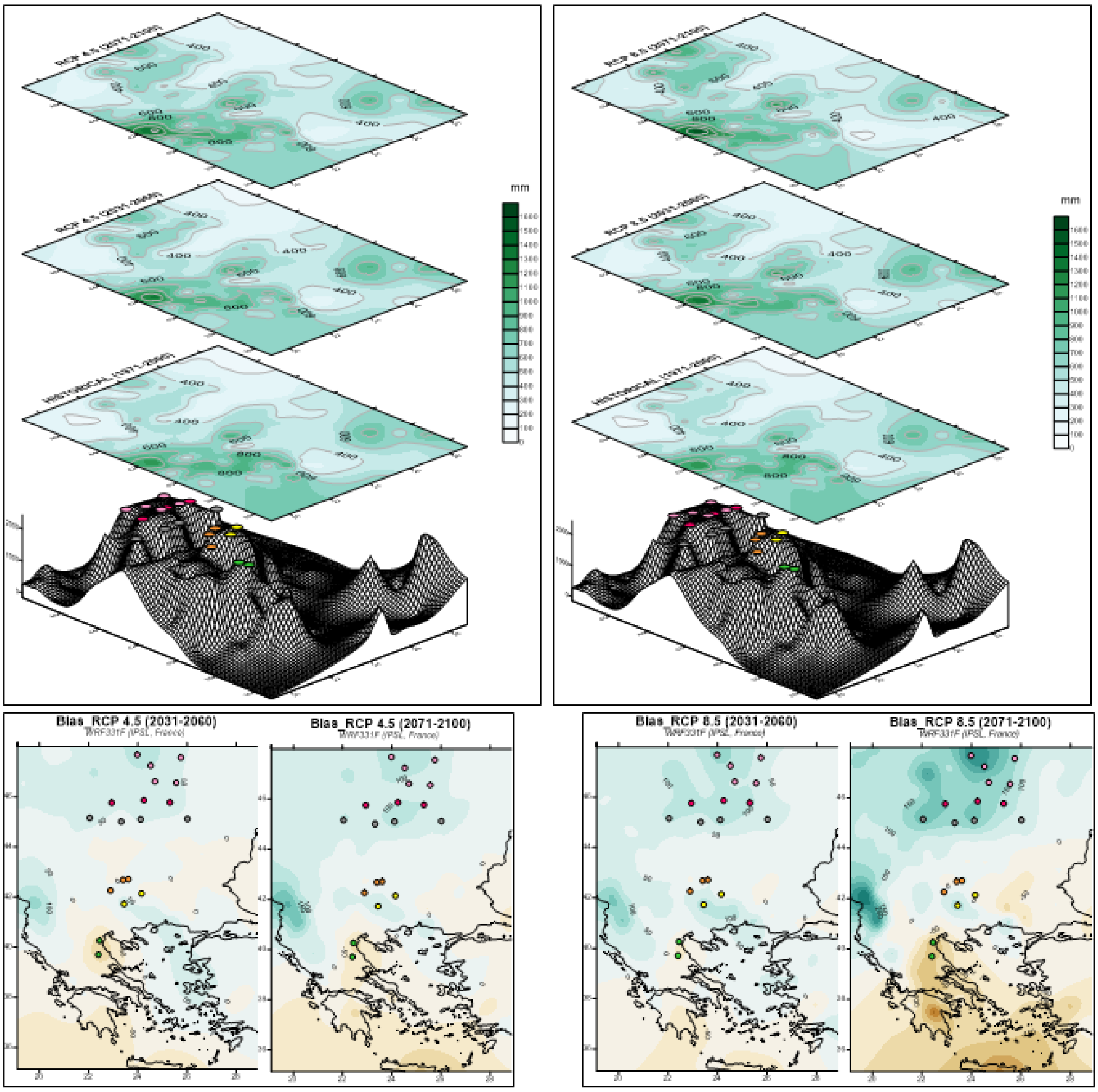

Figure 13 Mean Precipitation for the winter period, according to the climate model WRF331F (IPSL, FRANCE). The climate scenarios RCP4.5 (top left) and its differences from the historical period (bottom left) and RCP8.5 (top right) and the differences from the historical period (bottom right) are depicted.

The WRF model shows the greatest variability among the selected nuts, uniquely indicating a decrease in rainfall over Mount Olympus and areas of Mount Rila in Bulgaria (Table 10). Under the RCP4.5 scenario, the rainfall increases between the first and second future periods are relatively similar. However, under the second scenario, significant differences emerge between these periods. For example, on Mount Olympus, rainfall is projected to decrease by 6% in the first future period but by as much as 22% in the second. Conversely, in some nuts of the northern Carpathians, rainfall is expected to increase from 21% in the first future period (2031-2060) to 47% in the second (2071-2100).

Table 10 Precipitation biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model WRF331F (IPSL, FRANCE)

WRF331F (IPSL, France)	**Historical (1971-2000)**	**RCP4.5 (2031-2060)**	**RCP4.5 (2071-2100)**	**RCP8.5 (2031-2060)**	**RCP8.5 (2071-2100)**
Olympos 1	930.1 mm	-131.9	-90.5	-70.3	-160.9
Olympos 2	950.0 mm	-144.1	-124.7	-61.6	-212.5
Rila 1 (SE)	1041.9 mm	+ 82.2	**+ 124.5**	**+ 141.7**	+ 159.5
Rila 2 (SE)	639.6 mm	-14.5	-6.7	+ 0.2	-68.3
Rila 3 (NW)	539.8 mm	+ 18.0	+ 37.9	+ 50.0	+ 33.9
Rila 4 (NW)	430.8 mm	+ 1.7	+ 0.3	+ 13.0	-21.6
Rila 5 (NW)	537.2 mm	+ 9.8	+ 48.0	+ 61.3	+ 86.9
Carpathia 1 (S)	544.3 mm	+ 23.6	+ 87.2	+ 74.8	+ 161.9
Carpathia 2 (S)	537.6 mm	+ 63.1	**+ 125.3**	+ 131.2	+ 227.2
Carpathia 3 (S)	447.6 mm	+ 32.2	+ 69.5	+ 73.9	+ 86.4
Carpathia 4 (S)	646.0 mm	+ 90.7	+ 107.0	+ 112.4	**+ 253.8**
Carpathia 5	596.6 mm	+ 63.6	+ 90.9	+ 122.8	+ 205.2
Carpathia 6	603.9 mm	**+ 103.1**	+ 101.6	+ 110.3	+ 135.6
Carpathia 7	566.7 mm	+ 88.3	+ 102.8	+ 116.4	+ 206.5
Carpathia 8 (N)	405.9 mm	+ 63.0	+ 81.8	+ 96.0	+ 158.8
Carpathia 9 (N)	366.2 mm	+ 62.5	+ 76.7	+ 90.7	+ 160.0
Carpathia 10 (N)	647.7 mm	**+ 104.6**	**+ 133.7**	**+ 140.3**	**+ 307.0**
Carpathia 11 (N)	349.5 mm	+ 62.2	+ 95.1	+ 82.7	+ 163.6
Carpathia 12 (N)	688.5 mm	**+ 142.4**	**+ 154.4**	**+ 180.9**	**+ 361.7**

4.5 Changes of precipitation in Jorden

The precipitation rate of Jabal Umm ad Dami region present high variability (Figure 14).

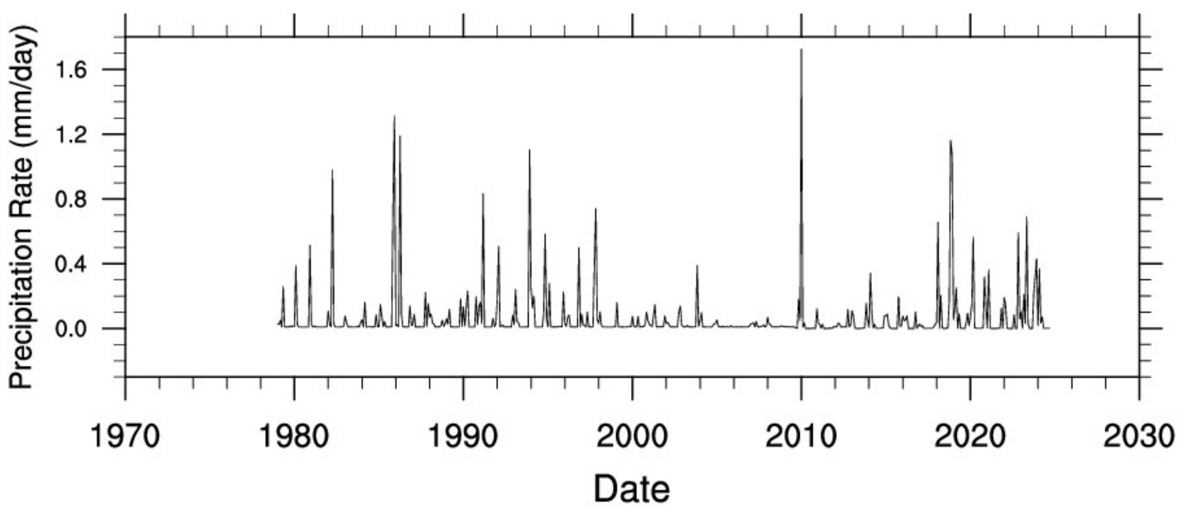

Figure 14 Precipitation totals for the region of Jabal Umm ad Dami mountain

Under RCP4.5, which represents a moderate emissions scenario with some global efforts toward mitigation, Jabal Umm ad Dami is likely to see a gradual decrease in annual precipitation. Jordan’s arid climate may become even drier, with reduced rainfall particularly affecting the cooler months when limited precipitation currently falls. While slight seasonal fluctuations may still bring occasional rain, the overall reduction could impact local water availability, stressing the few vegetation and wildlife species that rely on seasonal rainfall in this high-elevation desert region. The reduction in precipitation may also influence the timing of rare snowfall events, potentially limiting them to only the coldest years as temperatures increase.

In the RCP8.5 scenario, which represents a high-emissions trajectory with little mitigation, the effects on precipitation at Jabal Umm ad Dami are expected to be more pronounced. Under this scenario, the region may face increasingly erratic and less frequent precipitation events, with potential for more extreme drought periods due to higher temperatures and declining rainfall (Figure 15). This significant reduction in moisture availability would intensify arid conditions, leading to a harsher environment for native flora and fauna and further limiting the occurrence of snowfall at the summit. Additionally, under RCP8.5, the drying trend could exacerbate soil erosion, impacting the landscape and reducing the already limited water resources available for the communities and ecosystems depending on this unique desert-mountain environment.

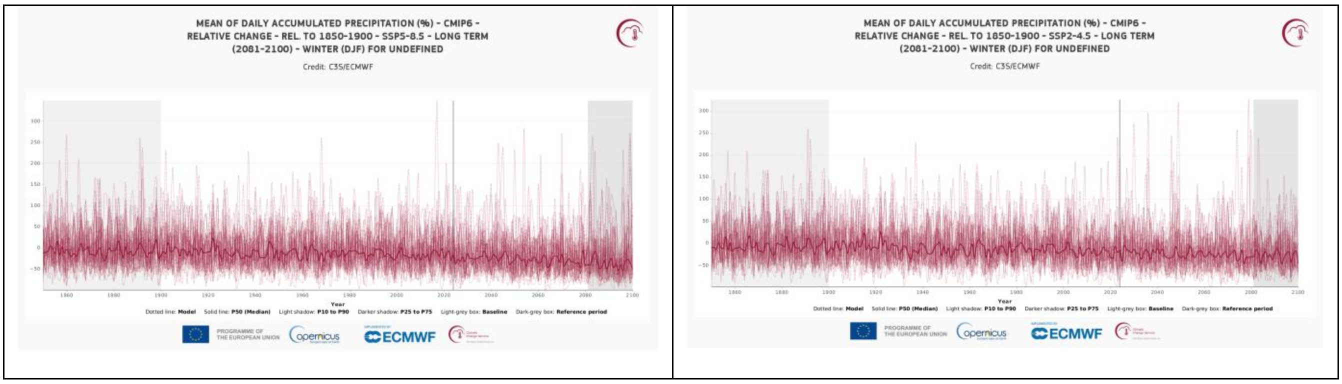

Figure 15 Precipitation projection for the Jabal Umm ad Dami doe the RCP8.5 and the CMPI6 Climate model

Chapter 5

5. Snowfall

Figure 16 shows snowfall patterns across the Balkan region for historical and future periods. According to the figure, the western Balkans, including western Greece and Albania, experience the highest snowfall, while the Danubian lowlands in Serbia, Bulgaria, and Romania receive the least. Snowfall reaches 700 mm in the Mount Olympus area, around 500 mm in the Rila Mountains, and about 400 mm on average in the Carpathians. All models indicate a decrease in snowfall across the region, with the extent of decrease varying by location (Figure 12). This trend persists and intensifies in the second future period, showing even more pronounced reductions.

Snowfall has been observed on Jabal Umm ad Dami, though it is quite rare. At an elevation of 1,854 meters, Jabal Umm ad Dami is the highest point in Jordan and is located in the southern desert region near the border with Saudi Arabia. This elevation occasionally brings temperatures low enough for snow, particularly during cold spells in the winter months (December to February). However, because of Jordan's arid climate, snowfall is infrequent and usually light, as the area receives minimal precipitation throughout the year.

When snow does fall on Jabal Umm ad Dami, it often melts quickly due to the high desert temperatures and strong sunlight. Snowfall events are typically brief, and accumulations are usually modest, making them an unusual but notable occurrence that draws local attention. Climate projections suggest that future warming could further limit these rare snowfall events, potentially making them even less frequent as the overall climate of the region becomes warmer and drier.

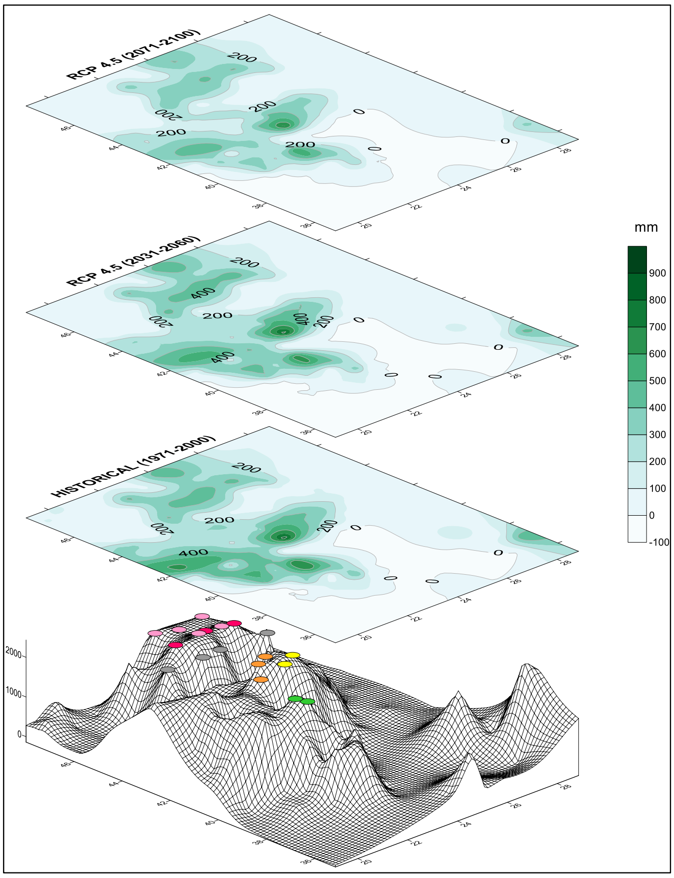

Figure 16 Mean Snowfall for the winter period, according to the climate models

Similarly, Figure 17 highlights differences in snowfall between the first and second future periods compared to the historical baseline. Key points for each region are shown as bullet points, reflecting a general decrease in snowfall across the study area, though a few regions show slight increases. Results from additional models are presented in the appendix.

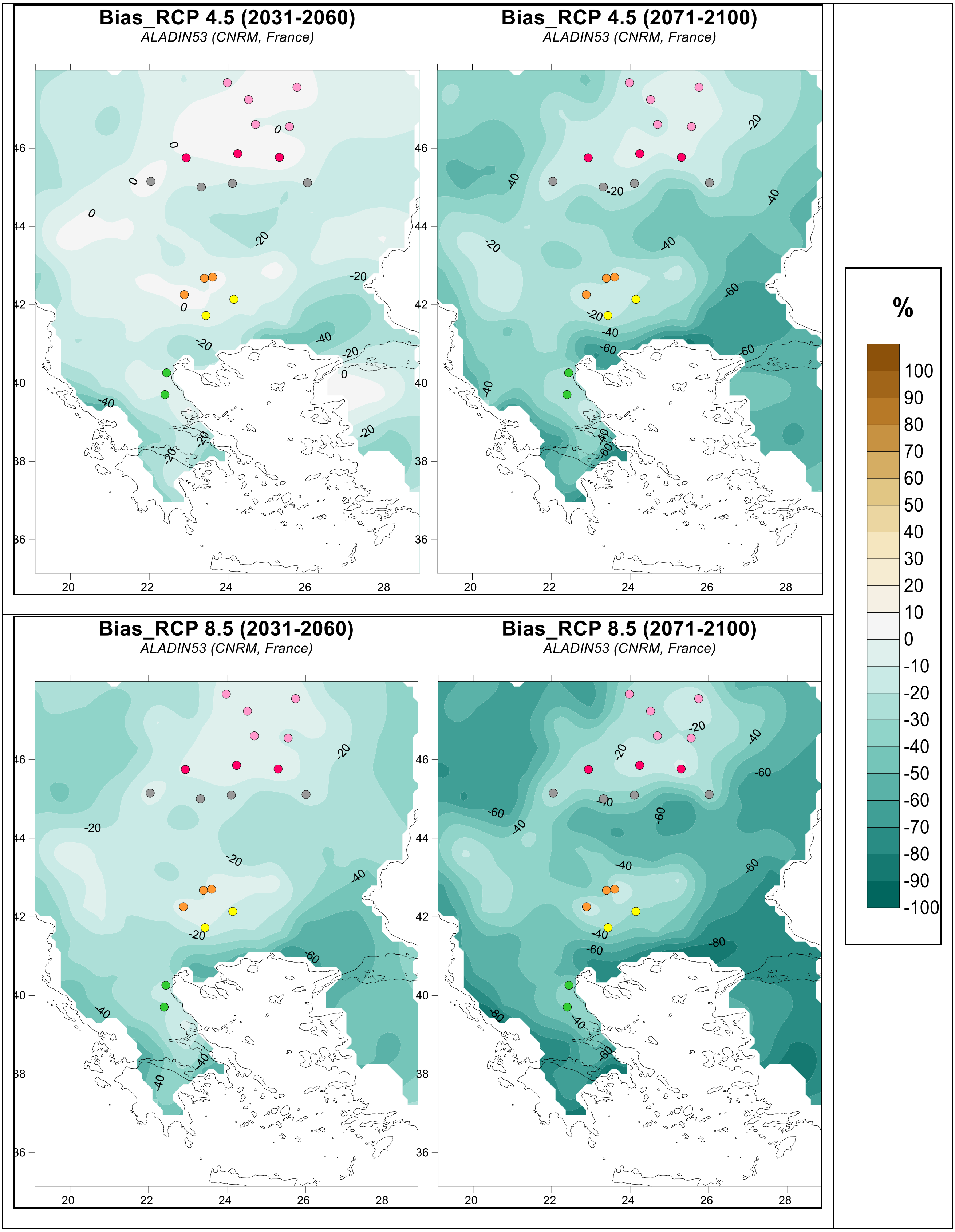

Figure 17 Biases of Snowfall. The climate scenarios RCP4.5 and its differences from the historical period (left column) and RCP8.5 and the differences from the historical period (right column).

Table 11 Snow total biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model ALADINS3 (CNRM, FRANCE)

ALADIN53 (CNRM, France)	**Historical (1971-2000)**	**RCP4.5 (2031-2060)**		**RCP4.5 (2071-2100)**		**RCP8.5 (2031-2060)**		**RCP8.5 (2071-2100)**	
Olympos 1	703.9	-75.5	**-10.70%**	-176.5	**-25.10%**	-153.8	**-21.80%**	-270	**-38.40%**
Olympos 2	719.5	-41.9	-5.80%	-120.1	-16.70%	-95	-13.20%	-224.9	-31.30%
Rila 1 (SE)	878.6	-13.3	-1.50%	-123.6	-14.10%	-75.6	-8.60%	-244.9	-27.90%
Rila 2 (SE)	539.9	-49	-9.10%	-120.3	**-22.30%**	-73.7	-13.60%	-174.1	-32.20%
Rila 3 (NW)	448.1	35.2	7.90%	-31.2	-7.00%	-6.6	-1.50%	-41.3	-9.20%
Rila 4 (NW)	289.4	-22.5	-7.80%	-79.4	**-27.50%**	-52	**-18.00%**	-113.6	**-39.20%**
Rila 5 (NW)	443.5	26.4	6.00%	-36.5	-8.20%	10.3	2.30%	-30.9	-7.00%
Carpathia 1 (S)	361.1	-34.4	**-9.50%**	-60.5	-16.80%	-53.3	**-14.80%**	-124.7	**-34.50%**
Carpathia 2 (S)	362.3	-40.2	**-11.10%**	-54.5	-15.10%	-45.4	-12.50%	-122.7	-33.90%
Carpathia 3 (S)	333	-27.2	-8.20%	-33	-9.90%	-39.7	-11.90%	-81.1	-24.40%
Carpathia 4 (S)	426.9	30.3	7.10%	-30.1	-7.10%	-14.5	-3.40%	-64.4	-15.10%
Carpathia 5	443.1	-2.3	-0.50%	-44.3	-10.00%	-40.3	-9.10%	-88.5	-20.00%
Carpathia 6	457.7	50.5	11.00%	-28.3	-6.20%	1.2	0.30%	-21.8	-4.80%
Carpathia 7	462.3	32.9	7.10%	-25.9	-5.60%	-15.3	-3.30%	-46.7	-10.10%
Carpathia 8 (N)	253.1	-9.4	-3.70%	-17.4	-6.90%	-33.2	-13.10%	-56.4	-22.30%
Carpathia 9 (N)	251.4	-3.6	-1.40%	-34.6	-13.80%	-23	-9.20%	-63.7	-25.30%
Carpathia 10 (N)	450.6	19.9	4.40%	-41.8	-9.30%	-13.8	-3.10%	-96.4	-21.40%
Carpathia 11 (N)	244.2	12.9	5.30%	-9.9	-4.00%	-7.5	-3.10%	-32.2	-13.20%
Carpathia 12 (N)	449	-7.9	-1.80%	-53.7	-12.00%	-6.4	-1.40%	-117	-26.10%

For a more detailed analysis, Tables 11-14 outline these snowfall changes. The ALADIN model, one of two models showing any increase, indicates a 5-10% rise in snowfall in the Carpathian region during the first future period of scenario RCP4.5, while Rila (Bulgaria) and Mount Olympus (Greece) show a 10% decrease (Table 11). In the second future period for this scenario, snowfall decreases across all locations, with reductions reaching up to 25% on Mount Olympus, 27% in Rila, and nearly 14% in the Carpathians.

Under the more pessimistic scenario (RCP8.5), the first future period shows a minor increase in snowfall (>1%) only at the Rila mountain inland site, while other locations experience decreases. In the second future period, the decline becomes significant across all regions: snowfall in the Carpathians drops by 5% at higher altitudes and nearly 35% in southern areas, while Rila sees a reduction of 7-39% and Mount Olympus shows declines between 31-38.5%.

The CCLM model suggests a modest increase in snowfall in specific areas of the Carpathians during the first but mainly the second future period under scenario RCP4.5 (Table 12), with increases estimated to be less than 5%. Conversely, snowfall in Rila (Bulgaria) is projected to decrease by approximately 10%, and reductions of around 10% are expected on Mount Olympus (Greece). By the second future period of the same scenario, all areas are anticipated to experience snowfall declines, with reductions reaching as high as 7% on Mount Olympus, 10% in Rila, and 16% in the Carpathians.

Table 12 Snow total biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model CCLM4-8-17 (CLM-Community,EU

CCLM4-8-17 (CLM-Community,EU)	**Historical (1971-2000)**	**RCP4.5 (2031-2060)**		**RCP4.5 (2071-2100)**		**RCP8.5 (2031-2060)**		**RCP8.5 (2071-2100)**	
Olympos 1	689.5	-55.5	-8	-46.9	-6.8	-48.1	-7	-319.5	-46.3
Olympos 2	683.5	-75.2	-11	-8.6	-1.3	-65.8	-9.6	-283.7	-41.5
Rila 1 (SE)	841.5	-80.1	-9.5	-86.1	-10.2	-130.3	-15.5	-301.6	-35.8
Rila 2 (SE)	513.7	-64.1	-12.5	-38.1	-7.4	-50.8	-9.9	-183.7	-35.8
Rila 3 (NW)	444.9	-14.8	-3.3	-11.4	-2.6	-23.6	-5.3	-123.5	-27.8
Rila 4 (NW)	286.2	-26.7	-9.3	-15.9	-5.6	-28.5	-10	-105.1	-36.7
Rila 5 (NW)	446.5	-14.8	-3.3	-12.4	-2.8	-8	-1.8	-111.2	-24.9
Carpathia 1 (S)	351	-18.1	-5.2	-21.5	-6.1	-56.4	-16.1	-86	-24.5
Carpathia 2 (S)	354.8	-20.9	-5.9	-25.7	-7.2	-58.7	-16.5	-86.7	-24.4
Carpathia 3 (S)	332.4	-2.1	-0.6	-0.6	-0.2	-22	-6.6	-83.9	-25.2
Carpathia 4 (S)	435.4	17.6	4	8.2	1.9	-30.9	-7.1	-68.6	-15.8
Carpathia 5	457.1	-3.9	-0.9	16.5	3.6	-54	-11.8	-93.4	-20.4
Carpathia 6	480	-11.2	-2.3	11.5	2.4	-29.8	-6.2	-73.4	-15.3
Carpathia 7	480.6	-5.6	-1.2	4.4	0.9	-40.7	-8.5	-66.8	-13.9
Carpathia 8 (N)	263.7	0.6	0.2	15.7	6	-29.9	-11.4	-40.2	-15.2
Carpathia 9 (N)	261.7	3.2	1.2	15.6	6	-12.2	-4.7	-33.4	-12.8
Carpathia 10 (N)	474.1	-21.2	-4.5	11.5	2.4	-31.7	-6.7	-80	-16.9
Carpathia 11 (N)	259.3	-8.1	-3.1	2	0.8	-25.6	-9.9	-54.7	-21.1
Carpathia 12 (N)	479.5	-18.8	-3.9	1.8	0.4	-43.5	-9.1	-96.1	-20

For the RCP8.5 scenario, the first future period shows all regions experience declines. In the second future period, significant reductions are projected across all areas: snowfall in the Carpathians may decrease by 20-25%, while reductions in Rila range from 28-37% and 42-46% on Mount Olympus.

Table 13 Snow total biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model REMO2009 (MPI-CSC, Germany)

REMO2009 (MPI-CSC, Germany)	torical (1971-20	RCP4.5 (2031-2060)		RCP4.5 (2071-2100)		RCP8.5 (2031-2060)		RCP8.5 (2071-2100)	
Olympos 1	673.9	-24	-3.6	-65.9	-9.8	-81.6	-12.1	-281.9	-41.8
Olympos 2	691	-19	-2.7	-47	-6.8	-39.9	-5.8	-246	-35.6
Rila 1 (SE)	886	-15.2	-1.7	-80.8	-9.1	-156.4	-17.6	-362.9	-41
Rila 2 (SE)	503.5	-8.8	-1.7	-35	-6.9	-21.5	-4.3	-81.8	-16.2
Rila 3 (NW)	449.1	11.3	2.5	-18.1	-4	-37.1	-8.3	-80	-17.8
Rila 4 (NW)	285.4	-12.6	-4.4	-9.3	-3.2	-26.7	-9.4	-57.1	-20
Rila 5 (NW)	453.9	-5.8	-1.3	-29.4	-6.5	-44	-9.7	-96.1	-21.2
Carpathia 1 (S)	357.9	-4.1	-1.1	-23.7	-6.6	-42.3	-11.8	-117.3	-32.8
Carpathia 2 (S)	365.8	-8.5	-2.3	-31.9	-8.7	-58.7	-16	-107.5	-29.4
Carpathia 3 (S)	326.1	1.9	0.6	3.2	1	-28.4	-8.7	-75.4	-23.1
Carpathia 4 (S)	444.9	6	1.3	25.4	5.7	-25.6	-5.7	-78.2	-17.6
Carpathia 5	428.7	42.8	10	17.9	4.2	-35.1	-8.2	-41.9	-9.8
Carpathia 6	475.1	5.6	1.2	17.7	3.7	-15.5	-3.3	-23.4	-4.9
Carpathia 7	473.2	14.5	3.1	20.9	4.4	-29.1	-6.2	-49.8	-10.5
Carpathia 8 (N)	256	12.8	5	6.7	2.6	-33.5	-13.1	-65.7	-25.7
Carpathia 9 (N)	261.6	10.1	3.9	21.9	8.4	-29.7	-11.3	-50.7	-19.4
Carpathia 10 (N)	472.3	-4	-0.8	-6.1	-1.3	-52.8	-11.2	-106.5	-22.6
Carpathia 11 (N)	243.4	10.9	4.5	13.6	5.6	-14.4	-5.9	-28.3	-11.6
Carpathia 12 (N)	456.5	7.1	1.6	3.9	0.9	-38.8	-8.5	-88.5	-19.4

The REMO model, one of the two models showing any increase especially at the northern part of the study region, it projects a 5-10% rise in snowfall over the Carpathian region during the first future period (2031-2060) under scenario RCP4.5, whereas regions like Rila (Bulgaria) and Mount Olympus (Greece) are expected to see a decrease in snowfall of less than 5% (Table 11). In the second future period for this scenario, snowfall reductions become remain unchanged, with Mount Olympus experiencing a reduction of up to10%, Rila up to 7-9. Under the more extreme RCP8.5 scenario, the first future period does not show any increase for snowfall, while all locations see declines (from 6-17%). During the second future period, snowfall decreases significantly across all regions: the Carpathians see a 10% reduction at higher elevations and nearly 33% in southern areas, Rila experiences declines between 16% and 41%, and Mount Olympus sees reductions from 35% to 42%.

The WRF model similarly projects modest snowfall increases in some areas of the Carpathians, especially during the first future period under the RCP4.5 scenario (Table 14), with gains estimated to remain below 3%. FO In contrast, snowfall in Rila (Bulgaria) is expected to decrease by approximately 15%, while Mount Olympus (Greece) may see reductions of around 28% as well. By the second future period of this scenario, however, all regions are anticipated to experience snowfall decreases, with declines reaching 35% on Mount Olympus, 25% in Rila, and 19% in the Carpathians.

Under the RCP8.5 scenario, snowfall decreases across all areas even in the first future period. These declines intensify in the second future period, with projected reductions of 35-38% in the Carpathians (regions with lower altitude), 40-50% in Rila, and 60% on Mount Olympus. These results highlight a substantial regional impact of warming scenarios on snowfall, especially for the more pessimistic RCP8.5 scenario, with notable reductions across critical mountain areas by the later period.

Table 14 Snow total biases for the selected regions for the two climate scenarios (RCP4.5 and RCP8.5) and the two future periods (2031-2060) and (2071-2100), climate model WRF331F (IPSL, France)

WRF331F (IPSL, France)	torical (1971-2(	RCP4.5 (2031-2060)		RCP4.5 (2071-2100)		RCP8.5 (2031-2060)		RCP8.5 (2071-2100)	
Olympos 1	705.2	-169	-24	-242.8	-34.4	-189.3	-26.8	-417.1	-59.1
Olympos 2	730.8	-209.6	-28.7	-254.1	-34.8	-200.6	-27.5	-440.3	-60.2
Rila 1 (SE)	855.3	-112.1	-13.1	-217.4	-25.4	-175.2	-20.5	-439.6	-51.4
Rila 2 (SE)	528.3	-68.2	-12.9	-99	-18.7	-81.3	-15.4	-230.2	-43.6
Rila 3 (NW)	449.1	-42.6	-9.5	-79.6	-17.7	-55.7	-12.4	-180.7	-40.2
Rila 4 (NW)	292.5	-48.5	-16.6	-74.4	-25.4	-54.5	-18.6	-147.1	-50.3
Rila 5 (NW)	450.9	-55.1	-12.2	-49.3	-10.9	-37.4	-8.3	-146	-32.4
Carpathia 1 (S)	373.4	-55.7	-14.9	-61.5	-16.5	-49.7	-13.3	-138.3	-37
Carpathia 2 (S)	372.6	-49.6	-13.3	-63.2	-17	-31.1	-8.4	-143	-38.4
Carpathia 3 (S)	339.7	-40.4	-11.9	-40.7	-12	-16.3	-4.8	-124.4	-36.6
Carpathia 4 (S)	435.9	-29.6	-6.8	-77.1	-17.7	-40.2	-9.2	-145.2	-33.3
Carpathia 5	422.2	-24.3	-5.8	-40.8	-9.7	-16.6	-3.9	-107.5	-25.5
Carpathia 6	471	13.5	2.9	-25	-5.3	4.2	0.9	-96.8	-20.6
Carpathia 7	457.9	2.4	0.5	-22	-4.8	1.3	0.3	-63.9	-14
Carpathia 8 (N)	258.3	-21.8	-8.4	-48.8	-18.9	-14.3	-5.5	-90.9	-35.2
Carpathia 9 (N)	249.7	-14.8	-5.9	-37.2	-14.9	-6.8	-2.7	-79.4	-31.8
Carpathia 10 (N)	446.9	-22.4	-5	-65.9	-14.7	-22	-4.9	-144	-32.2
Carpathia 11 (N)	243.9	-1.5	-0.6	-11.6	-4.8	9.6	3.9	-43.8	-18
Carpathia 12 (N)	461.5	-32.6	-7.1	-75	-16.3	-33	-7.2	-156.2	-33.8

Section 6

6. Snow spell of 30mm

As snow spells defined the consecutive days with a natural snow height greater than 30 mm. the first Julian day counting from 1st of August that present snow total greater or equal to 30mm is define as the start of the snow spell, while the end of the snow spell is the last of the consecutive days with snow total greater than 30mm. An example of snow spells is presented in Figure 18, where the decrease of length of dry spells in obvious.

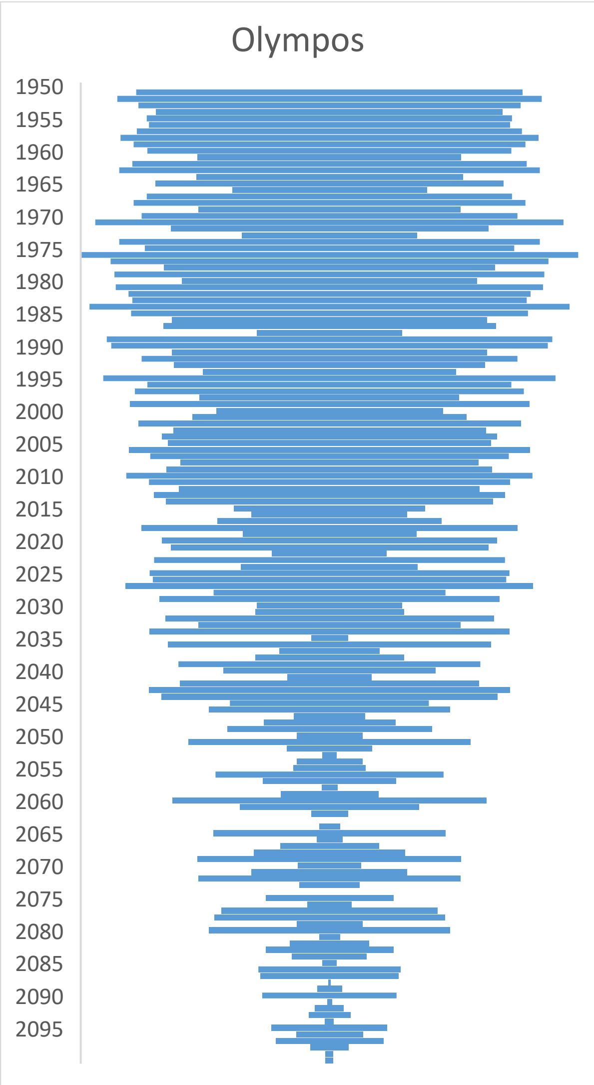

Figure 18 Snow spells of the Mountain Olympos for the period 1950 to 2100 according to the ALADIN climate model and the scenario RCP8.5

According to the analysis of snow spells and their trends (Table 15) southern mountains like Olympus and Rila are projected to experience the most rapid reductions in snow cover duration, likely due to their lower latitude and proximity to warmer climates, while the Carpathians exhibit a slower decline, particularly in central and northern areas, due to climatic moderation from higher altitude and latitude. Olympus shows the most severe declines, followed by Rila 1, suggesting southern locations are particularly vulnerable to warming. The Carpathians, especially the central and northern areas, show relatively milder declines, though they still experience a significant negative trend in snow spells. ALADIN and REMO climate model show the steepest reduces, especially under RCP8.5, highlighting sensitivity to high-emission scenarios. WRF shows the mildest negative trends across regions. More specific:

ALADIN climate model shows consistently strong negative trends across all regions and RCPs, with most values below -0.5 and some nearing -1.00 (notably Olympus under RCP8.5 at -1.00). The RCP8.5 scenario consistently shows larger negative trends than RCP4.5, indicating that higher emissions scenarios predict faster and more pronounced reductions in snow cover. Olympus, Rila 1, and Carpathia S have the largest declines, suggesting that ALADIN may be particularly sensitive to warming impacts in regions exposed to warmer air masses or southern locations.

CCLM also also reflects a strong declining trend in snow cover across regions, although trends are slightly milder than in ALADIN, with values mostly in the -0.14 to -0.79 range. As with ALADIN, RCP8.5 trends are more negative than RCP4.5, showing the expected increase in trend severity under higher emissions. Notable trends include Olympus and Rila 1, which show relatively high declines under both RCPs, suggesting CCLM captures strong responses to warming in these areas. REMO's trends are somewhat consistent with the other models, showing strong negative trends, though slightly less severe than ALADIN. Values range from -0.18 to -0.91, with Olympus again showing a maximum trend under RCP8.5. Similar to other models, RCP8.5 has stronger negative trends than RCP4.5, consistent with a future of limited emissions control. The REMO model appears to show slightly smaller reductions in Carpathia S and Carpathia than other models, indicating a less pronounced response in the more central or northern parts of the Carpathians.

WRF shows the least negative trends among the models, with values generally between -0.35 and -0.83. Although still showing notable negative trends, WRF's predictions under RCP8.5 are less severe than in ALADIN or REMO for the Carpathian region, particularly in Carpathia and Carpathia N, which stay closer to -0.7 and -0.68, respectively. Olympus and Rila show the largest declines under WRF, suggesting this model also captures more substantial impacts on southern mountain ranges.

All models predict significant declines in snow spells for Olympus, with values ranging from -0.35 to -1.00 across RCPs, especially under RCP8.5. The ALADIN model under RCP8.5 projects the strongest decline at -1.00, indicating that Olympus may experience the most severe reductions in snow spells among all regions. The steep declines across all models suggest that Olympus, being the southernmost and exposed to Mediterranean influences, is highly sensitive to warming and may face the most rapid reductions in snow cover.

Rila mountains consistently shows strong negative trends across all models, with values between -0.28 and -1.00. RCP8.5 projections are notably steeper, showing trends similar to Olympus, indicating that Rila 1 may also experience significant snow cover loss under higher emissions. Rila 2 (Table 15) trends are still negative but slightly less severe than Rila 1, ranging from -0.27 to -

0.79. This could reflect different altitudinal or local microclimatic conditions within the Rila range. Overall, both Rila locations show large negative trends, indicating significant vulnerability to warming, though Rila 1 appears to have slightly steeper trends across models and RCPs.

Southern Carpathia generally shows more negative trends than Carpathia and Carpathia N, with values between -0.16 and -0.82. Southern Carpathians may be more susceptible to warming due to their slightly lower latitude.

Highest Carpathia values range from -0.14 to -0.7, showing consistent but slightly milder declines compared to Olympus and the Rila Mountains. Central locations appear somewhat more resilient, possibly due to climatic buffering from altitude and latitude.

Northern Carpathia shows trends similar to Carpathia, with values between -0.17 and -0.72, indicating a moderate decline. WRF and REMO models predict milder declines in Carpathia N, suggesting that northern Carpathian areas may experience a slightly slower reduction in snow cover than more southern locations.

Table 15 Trends of snow spells for the period 1950 to 2100 for the four climate models (ALADIN, CCLM, REMO,WRF) and the two scenarios

C	*ALADIN RCP4.5*	*ALADIN RCP8.5*	*CCLM RCP4.5*	*CCLM RCP8.5*	*REMO RCP4.5*	*REMO RCP8.5*	*WRF RCP4.5*	*WRF RCP8.5*
Olympos	-0.55	-0.96	-0.37	-0.79	-0.35	-0.91	-0.83	-1.00
Rila 1	-0.54	-0.79	-0.28	-0.69	-0.34	-0.87	-0.6	-1.00
Rila 2	-0.49	-0.71	-0.27	-0.6	-0.32	-0.74	-0.52	-0.79
Carpathia S	-0.58	-0.82	-0.16	-0.52	-0.24	-0.7	-0.42	-0.78
Carpathia	-0.39	-0.64	-0.14	-0.5	-0.18	-0.54	-0.35	-0.70
Carpathia N	-0.45	-0.72	-0.17	-0.5	-0.2	-0.66	-0.41	-0.68

Section 7

7.1 Conclusions

Η παρούσα μελέτη σχεδιάστηκε για να προσδιορίσει τις επιπτώσεις της κλιματικής αλλαγής στις ελαιοκαλλιέργειες στη περιοχή της Χαλκιδικής. Τα δεδομένα που χρησιμοποιούνται σε αυτήν την έρευνα είναι τα κλιματικά δεδομένα του περιοχικού κλιματικού μοντέλου, SMHI και για δύο κλιματικά σενάρια, το αισιόδοξο RCP4.5 και το απαισιόδοξη RCP8.5.

Climate change has significant impacts on mountain tourism over Balkans, with distinct effects on winter and summer tourism due to their seasonal reliance on varying weather conditions. Here’s a breakdown of the impacts on each:

Winter Tourism

Winter tourism, heavily dependent on snowfall and cold temperatures, faces some of the most pronounced impacts of climate change:

1. **Reduced Snowfall and Shorter Seasons**: According to the results, it appears that most climate models show a 35-45% decrease in snowfall in the Balkan regions according to scenario RCP8.5. increasing temperatures (more than 3°C) have already led to decreased snowfall in many Balkans mountainous regions, shortening the ski season and reducing the reliability of natural snow. This impacts resorts that rely on early snow for holiday bookings and ski operations.
2. **Increased Snow-Making Costs**: To compensate for lower snowfall, many resorts invest in snow-making technology. However, the higher energy and water demands associated with artificial snow-making add significant costs. Furthermore, snow-making becomes less effective at higher temperatures, limiting its reliability as warming continues.
3. **Higher Elevation Advantage**: As lower-altitude ski resorts in Carpathian mountain and Rila Mountains lose snow earlier in the season, higher-elevation resorts are likely to experience a boost in demand. This concentration could lead to

overcrowding, environmental degradation, and infrastructure stress in these higher regions.

4. **Shift in Destination Preferences**: The unpredictability of snowfall has led many winter tourists to shift preferences toward locations that guarantee snow or offer indoor alternatives. This shift negatively impacts traditional ski destinations that rely heavily on seasonal consistency.

5. **Economic Impact on Local Communities**: Many mountain communities depend heavily on winter tourism for employment and income. Reduced tourism due to inconsistent snowfall could lead to economic downturns in these regions, affecting small businesses and local economies.

6. **Environmental Pressures**: The need for artificial snow-making, expanded infrastructure, and other adaptations can strain local water resources, increase energy usage, and impact local wildlife, resulting in a more significant environmental footprint.

Summer Tourism

Mountain regions are seeing some contrasting trends for summer tourism, with both potential benefits and challenges:

1. **Longer and Milder Summer Seasons**: Warmer temperatures in the Balkans have led to longer and more pleasant summers in many mountainous areas, potentially extending the season for hiking, camping, and other outdoor activities. Some regions are seeing an increase in visitor numbers as a result, benefiting local economies.

2. **Increased Risk of Natural Hazards**: Higher temperatures can increase the risk of wildfires, flooding from glacial melt, landslides, and avalanches, particularly in areas where glaciers are rapidly retreating. These hazards pose direct risks to visitors' safety and increase operational costs for resorts and national parks that must manage them.

3. **Biodiversity and Ecosystem Shifts**: Rising temperatures and changing precipitation patterns alter mountain ecosystems, with certain plant and animal species moving to higher altitudes. This can reduce biodiversity and diminish the unique natural appeal of some destinations, which is often a major attraction for summer tourists.

4. **Shift in Tourist Demands**: Climate-conscious travelers may increasingly seek eco-friendly destinations, putting pressure on mountain regions to implement

sustainable practices. As a result, destinations that invest in eco-friendly trails, low-impact accommodations, and conservation efforts may see greater appeal.

5. **Economic Diversification Opportunity**: While winter tourism faces losses, summer tourism can provide opportunities for economic diversification in mountain regions. Resorts and towns that traditionally relied on skiing are increasingly offering summer activities, such as mountain biking, zip-lining, and adventure sports, to attract visitors year-round.
6. **Water Resource Stress**: Warmer temperatures also increase demand for water in the summer months for irrigation, tourism facilities, and local consumption. This is particularly concerning in regions where glacier meltwater provides a key water source, as reduced snowpack and glacier retreat may diminish long-term water availability.

In summary, **winter tourism** in mountain regions is threatened by reduced snowfall, shorter seasons, and increased operational costs, while **summer tourism** may benefit from longer seasons but faces new challenges related to natural hazards, ecosystem changes, and water stress.

7.2 Adaptation

Adaptation measures for mountain tourism aim to reduce vulnerability to climate change impacts, ensure economic sustainability, and protect the natural environment. The strategies vary based on whether they are addressing the challenges in winter or summer tourism, but often overlap in terms of improving sustainability and resilience. Here are some proposed adaptation measures for each:

Winter Tourism Adaptation Measures

1. **Diversification of Tourism Offerings**: Balkans mountain regions could <u>shift from a winter-only focus to year-round tourism by offering a wider variety of activities that don't rely on snow</u>, such as spas, cultural events, scenic tours, and indoor recreation. Diversifying also includes investing in summer activities like hiking, mountain biking, zip-lining, and wellness retreats.
2. **Snow-Making Technology and Snow Farming**: Resorts are increasingly <u>investing in advanced snow-making equipment and snow farming</u>, where snow is stockpiled

during peak winter and used later in the season. This provides some assurance of snow availability, although the technique is costly, energy-intensive, and reliant on suitable water resources.

3. **High-Elevation and Glacial Resort Development**: To adapt to decreasing snow reliability at lower altitudes, tourism mountain regions in Balkans could build or expand facilities at higher elevations where temperatures remain low enough for natural snow. However, these projects must consider the potential for ecosystem disruption and stricter regulations.
4. **Climate-Resilient Infrastructure**: Resorts are investing in infrastructure that can withstand warmer temperatures and variable weather patterns, such as year-round lifts and transport systems, adaptable building materials, and weather-resistant accommodation and facilities. These upgrades are designed to improve resilience and reduce weather-related closures or maintenance costs.
5. **Eco-Friendly Operations and Green Certifications**: To reduce environmental impact, many mountain resorts could pursue green certifications, investing in renewable energy, and enhancing energy efficiency. Sustainability measures also include waste reduction, water conservation, and the use of bio-friendly materials. These efforts can appeal to eco-conscious travelers, as well.
6. **Risk Management and Safety Protocols**: Mountain resorts in the Balkans could develope advanced monitoring and safety protocols for natural hazards like avalanches, landslides, and snow storms, which are becoming more unpredictable. This includes installing avalanche barriers, creating early warning systems, and offering safety training for visitors and staff.

Summer Tourism Adaptation Measures

1. **Development of New Attractions**: As summers become longer, mountain regions are expanding activities to include wildlife safaris, cultural and heritage tours, botanical gardens, and eco-trails to attract a broader range of visitors. Activities that promote a connection to the natural landscape, such as outdoor education programs, guided nature walks, and birdwatching, are also growing in popularity.
2. **Investing in Resilient Trail and Park Infrastructure**: To accommodate increased summer visitors, there’s a push to reinforce trails, protect sensitive areas with boardwalks, and install weather-resistant facilities. Resilient infrastructure is

especially important in areas prone to erosion, floods, or landslides, helping to ensure visitor safety and protect natural resources.

3. **Sustainable Water Management**: With higher temperatures and increased visitation, water management is crucial. Mountain tourism regions in Jordan and Balkans could install efficient irrigation systems, rainwater harvesting, and educating visitors about water conservation. In areas that rely on glacier-fed streams, conserving water has become an urgent priority.
4. **Wildfire and Hazard Preparedness**: Balkan mountain regions at risk for wildfires or flash floods should adopt early detection systems, emergency response plans, and creating defensible zones around popular sites. This preparedness ensures visitor safety and minimizes disruption to summer activities.
5. **Promoting Eco-Friendly Practices**: Mountain regions should encourage low-impact tourism through sustainable transportation options (e.g., electric shuttles), promoting waste reduction (e.g., limiting plastic), and creating designated “eco-zones” with strict environmental guidelines. Many also offer sustainable accommodation options, which can help attract eco-conscious tourists.
6. **Community Engagement and Training**: Involving local communities of the Balkans or Jordan in adaptation strategies not only improves the sustainability of these measures but also enhances community resilience. Training programs in eco-tourism, guiding, hospitality, and safety management create employment opportunities for locals while fostering a deeper commitment to environmental preservation.

Cross-Seasonal Adaptation Strategies

1. **Economic Diversification**: By reducing reliance on a single season, mountain communities can stabilize their economies. Diversification may include developing other industries, such as local craft production, agriculture, and cultural tourism, alongside mountain tourism.
2. **Marketing and Communication Efforts**: Educating potential visitors about seasonal tourism opportunities beyond skiing can help attract year-round travelers. Marketing efforts often emphasize the natural beauty, cultural heritage, and eco-friendly tourism of the area.
3. **Policy and Regulation Support**: Governments and local authorities are increasingly playing a role by implementing policies that encourage sustainable tourism and

provide funding or incentives for eco-friendly infrastructure, risk management, and diversification.

4. **Research and Monitoring**: Continual research into climate impacts, visitor behavior, and environmental sustainability is essential to inform adaptation strategies. Many resorts collaborate with environmental scientists and local organizations to monitor changes and adjust their practices accordingly.

Overall, these adaptation measures are vital for maintaining the attractiveness and sustainability of mountain tourism in Balkans and Jordan in the face of climate change.

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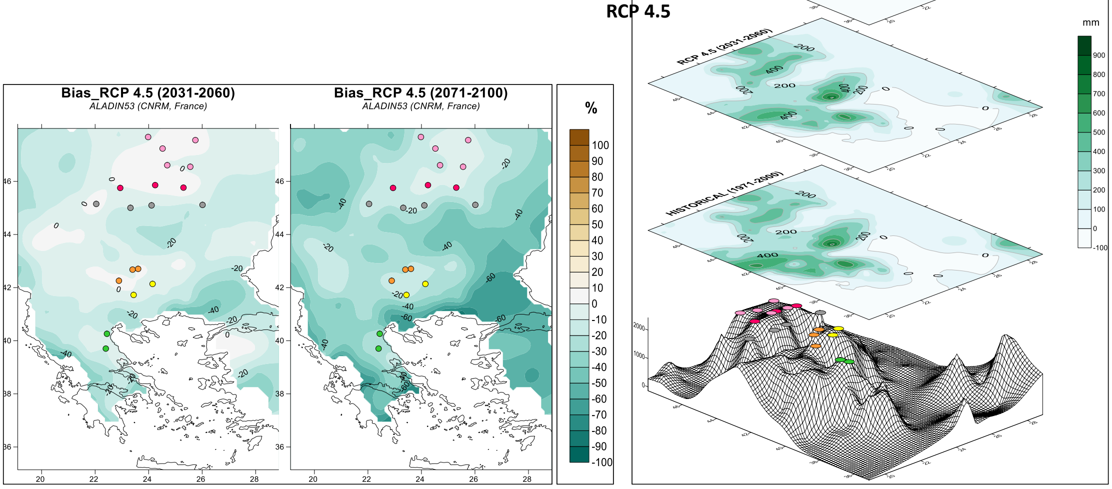
Appendix

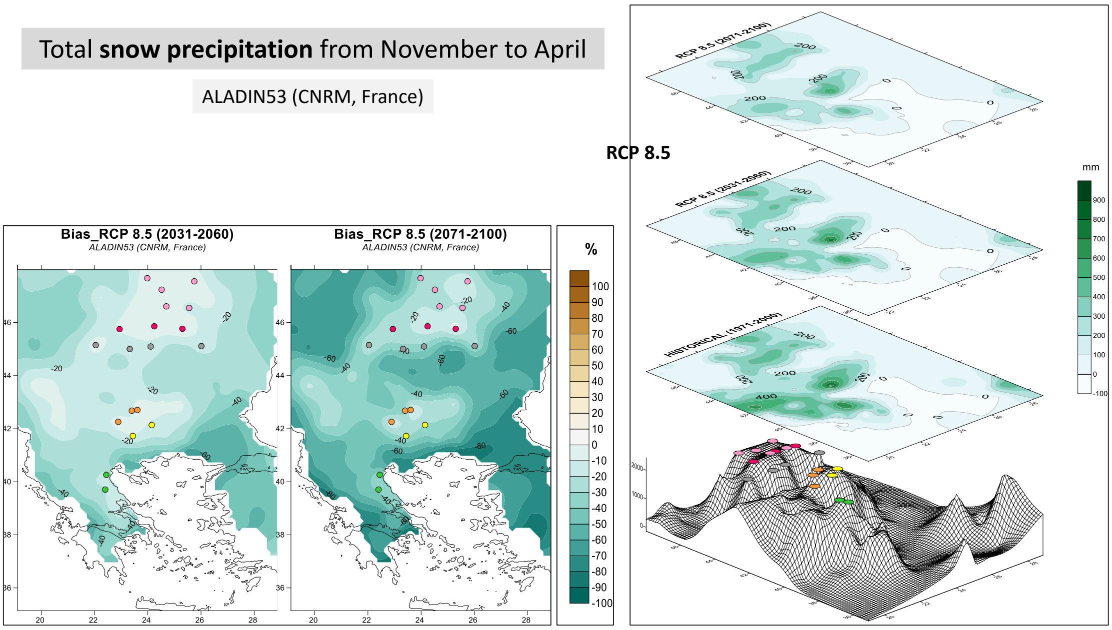
Total **snow precipitation** from November to April

ALADIN53 (CNRM, France)



Total **snow precipitation** from November to April

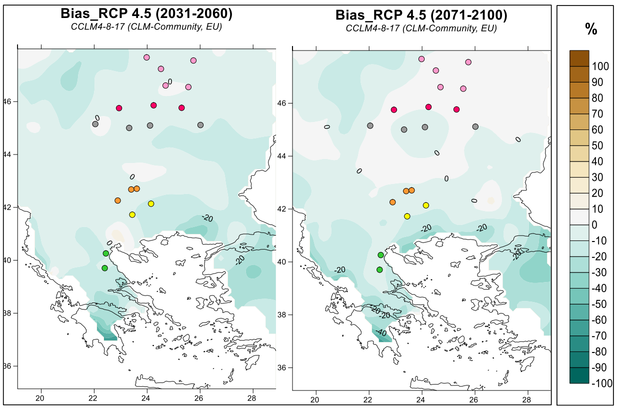
ALADIN53 (CNRM, France)

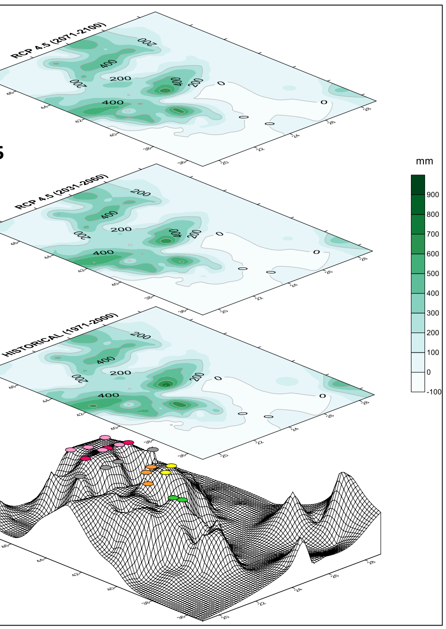


Total **snow precipitation** from November to April

CCLM4-8-17 (CLM-Community, EU)

RCP 4.5

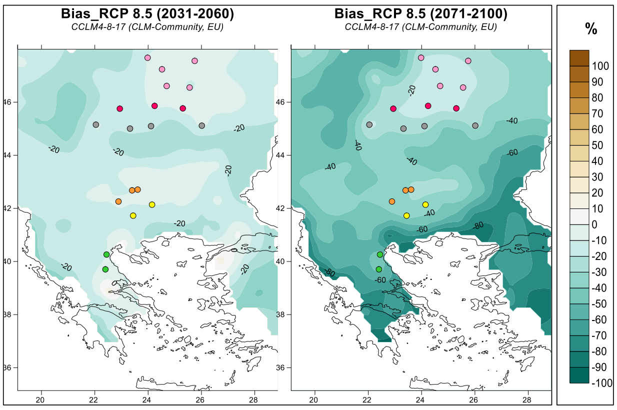


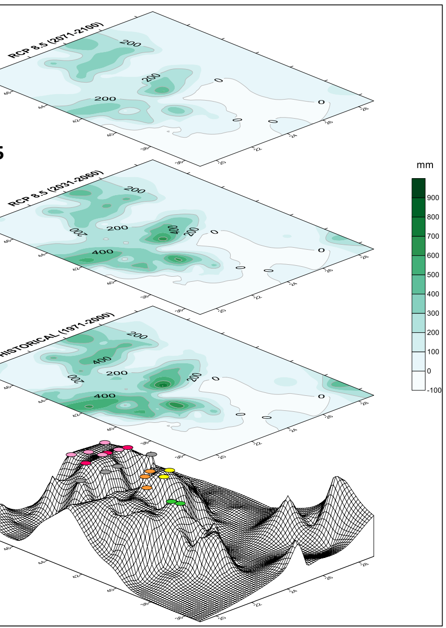


Total **snow precipitation** from November to April

CCLM4-8-17 (CLM-Community, EU)

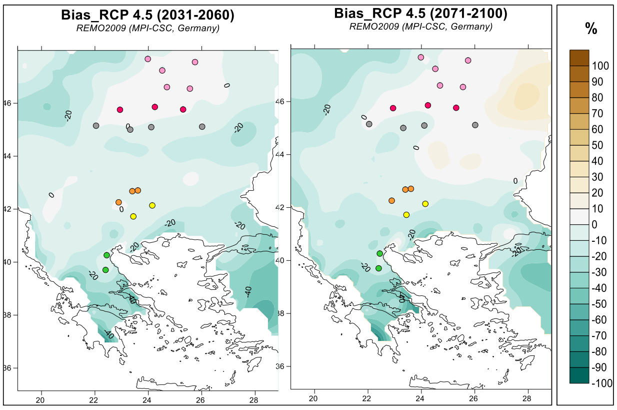
RCP 8.5

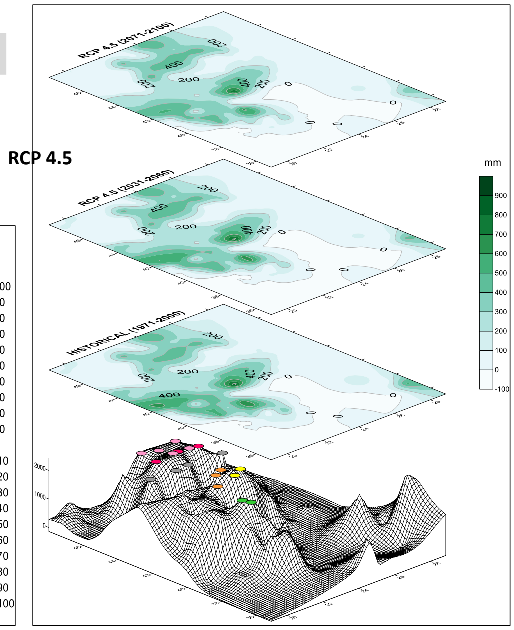




Total **snow precipitation** from November to April

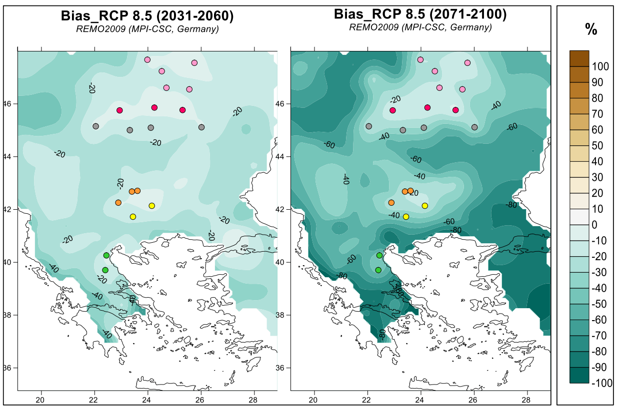
REMO2009 (MPI-CSC, Germany)

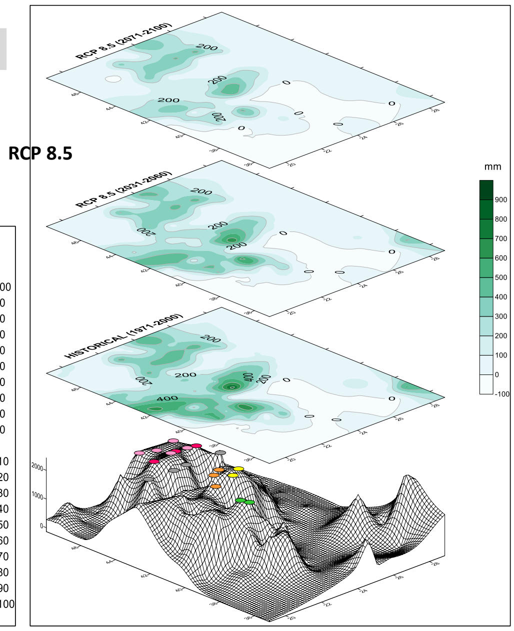




Total **snow precipitation** from November to April

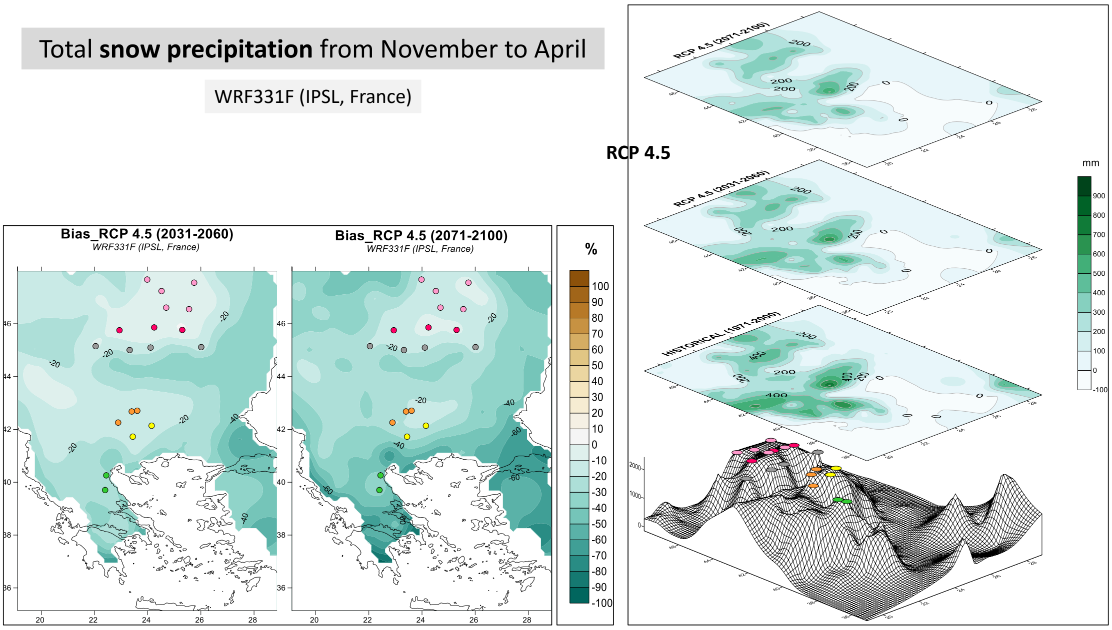
REMO2009 (MPI-CSC, Germany)





Total **snow precipitation** from November to April

WRF331F (IPSL, France)



Total **snow precipitation** from November to April

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