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Spatial and temporal changes of temperature zones on Earth and in Türkiye according to Köppen (1884) climate classification

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Abstract

Using monthly air temperature data from, 3202 meteorological stations for the period 1971-1990, the temperature zones of the world are redefined according to the Köppen (1884) thermal zone classification. Moreover, using monthly air temperature data from 155 stations from 1961 to 2020, the spatial changes in temperature zones are analyzed according to the reference climate periods 1961-2020, 1961-1990, 1981-2010 and 1990-2020. The world temperature map based on meteorological measurements is largely similar to Köppen's map of 1884, which was prepared by utilizing various phytogeographic studies. The most obvious difference occurs in the polar belt in the Northern Hemisphere, which is not as widely distributed as in the 1884 map. However, some shifts in the boundaries of the so-called temperature belts were observed over Cape Horn, Madagascar island, southwest Australia and the Mediterranean Basin. On a larger scale, over Türkiye, the warm areas tended to shift further north and towards higher elevations, whereas the cold areas representing northeastern Anatolia shrank in area and the temperature regime changed. The results of this study reveal for the first time the spatio-temporal variation of the so-called Köppen (1884) temperature belts based on station data both in the world and in Türkiye. The results are useful for understanding the temperature characteristics on Earth and in Türkiye.

Keywords: *Köppen climate classification, Köppen (1884), changes in temperature belts, Türkiye.*

Resumen

Utilizando datos mensuales de temperatura del aire de 3202 estaciones meteorológicas para el periodo 1971-1990, se redefinen las zonas de temperatura del mundo según la clasificación de zonas térmicas de Köppen (1884). Además, utilizando los datos mensuales de temperatura del aire de 155 estaciones desde 1961 hasta 2020, se analizan los cambios espaciales de las zonas de temperatura según los periodos climáticos de referencia 1961-2020, 1961-1990, 1981-2010 y 1990-2020. El mapa mundial de la temperatura basado en mediciones meteorológicas es muy similar al mapa de Köppen de 1884, elaborado a partir de diversos estudios fitogeográficos. La diferencia más evidente se produce en el cinturón polar del hemisferio norte, que no está tan ampliamente distribuido como en el mapa de 1884. Sin embargo, se observaron algunos desplazamientos de los límites de los denominados cinturones de temperatura sobre el Cabo de Hornos, la isla de Madagascar, el suroeste de Australia y la cuenca mediterránea. A mayor escala, sobre Turquía, las zonas cálidas tendieron a desplazarse más al norte y hacia elevaciones más altas, mientras que las zonas frías que representan el noreste de Anatolia se redujeron en superficie y el régimen de temperaturas cambió. Los resultados de este estudio revelan por primera vez la variación espacio-temporal de los llamados cinturones de temperatura de Köppen (1884) basándose en datos de estaciones tanto en el mundo como en Türkiye. Los resultados son útiles para comprender las características de la temperatura en la Tierra y en Turquía.

Palabras claves: *Clasificación climática de Köppen, Köppen (1884), cambios en los cinturones de temperatura, Turquía.*

1 Introduction

Classification of climate is needed to understand the interrelations and interconnections within and between the components of the Earth system. The understanding of geographical regions and landscapes, the selection of economic activities and the planning of socio-economic activities depend on it. In this sense, many climate classification systems, both empirical and genetic, have been developed. The first empirical classification system that comes to mind is Köppen's (1884) climate classification. This classification, which is based on various phytogeography studies such as von Buch (1829), de Candolle (1855) and Grisebach (1866), is the classification that gives the best temperature regime among all climate classifications made until 1900 AD (Essenwanger, 2001). The biggest difference from the classifications made in its period is that it takes into account the average monthly temperature values and durations (Essenwanger, 2001; Rubel and Kottek, 2011). In the following periods, Köppen's first climate classification pioneered many other classification systems (Thornthwaite, 1948; Köppen, 1936; Geiger, 1954; Trewartha and Horn, 1980).

In previous studies, the latest version of Köppen-Geiger climate classification, which is the latest version of Köppen classification, is expected to be used in the coming years, and the observed and predicted changes in climate regions at various resolutions at the macro scale were revealed (Kottek et al., 2006; Peel et al., 2007; Rubel and Kottek, 2010; Kriticos et al., 2012; Beck et al., 2018). Rubel et al. (2017) found that significant elevation-dependent changes in vegetation belts were observed in the Alpine region and predicted significant shrinkage in the boreal (D) and alpine (E) belts, especially in the second half of the 21st century. Öztürk et al. (2017) and Yılmaz and Çiçek (2018) created a Köppen climate map of Türkiye based on stations and found that 10 different climate classes dominated by climate type C were observed in the region. However, Yılmaz and Çiçek (2018) reported that 13 different climate zones were formed in Türkiye with Dfc, Dsc and ET climate types in the model-based Köppen-Geiger classification.

Generally, Köppen-Geiger climate classification is used to define climate types in most studies and its popularity continues. Therefore, Köppen (1884) thermal zone classification, which is the first version of Köppen climate classification, seems to be outdated in climate classification. However, Köppen (1884) classification can be used to describe the changes in temperature regime zones. In this study, it is considered as a scientific deficiency that this classification has not been mapped on a macro scale except Köppen, which areas of Türkiye are included in which temperature regime according to this classification and the changes in temperature belts have not been determined. In this study, it was aimed to reveal the temperature regime types and distribution characteristics on earth based on Köppen (1884) method and the spatial changes in temperature belts in Türkiye according to the reference climate periods. Spatial shifts in temperature belts and the factors affecting these changes were also included in the study.

2 Methodology

In the definition of Köppen (1884) temperature belts at the macro scale, monthly air temperature data of 3202 meteorological stations for the period 1971-1990 obtained from WMO were used. In addition, daily air temperature data of 155 meteorological stations for the period 1961-2020 obtained from the General Directorate of Meteorology were used (Figure 1). Here, the reference climate periods (1961-1990, 1981-2010 and 1990-2020) recommended by the World Meteorological Organization (WMO) were taken into consideration to reveal the spatial changes in temperature belts in Türkiye.

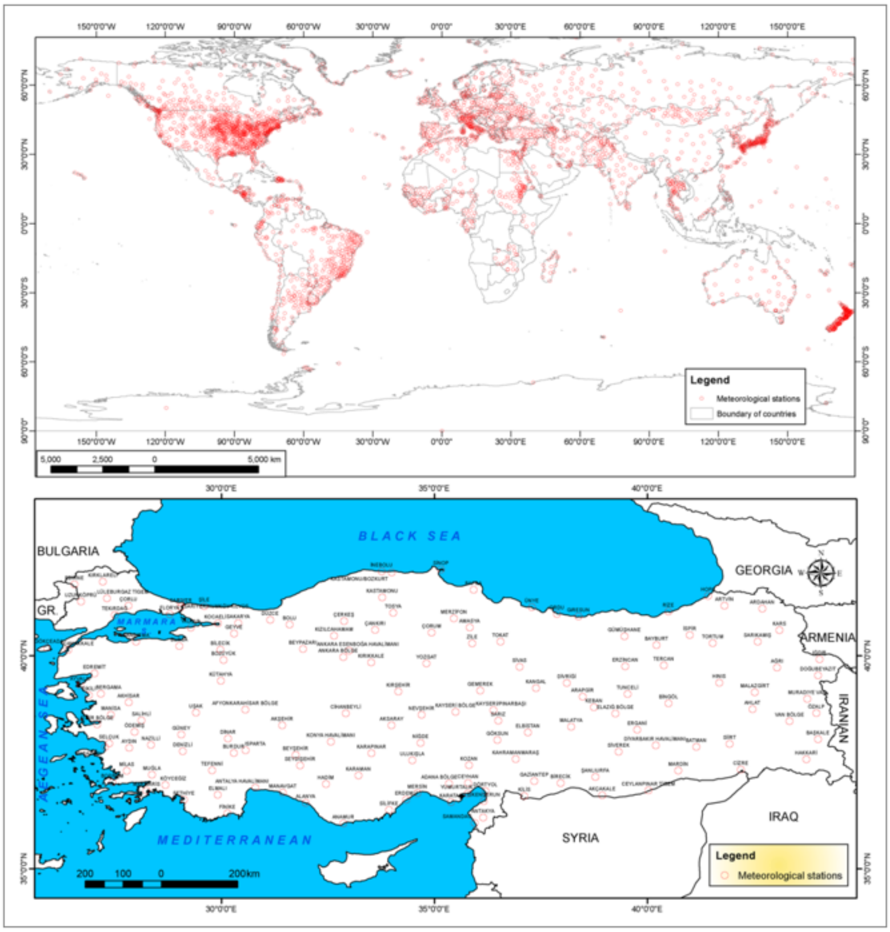

Figure 1: Spatial distribution of the stations used in this study.

The method used in the research is Köppen's first classification system of 1884. This classification is an improved version of Supan's temperature system (1879) (Essenwanger, 2001). In addition to the 10 °C and 20 °C thresholds, this system consists of five thermal belts/regions to which the duration of the temperature degrees are added (Köppen, 1884; Essenwanger, 2001; Rubel and Kottek, 2011). This classical classification also forms the basis of the Köppen-Geiger climate classification, which is widely used in the world (Rubel and Kottek, 2011). In this study, the concept of thermal belt is used as temperature belt since it is related to temperature or as temperature regime zones since the duration of temperatures is taken into consideration and information on Köppen (1884) classification is presented in Table 1.

Table 1: Belts and temperature durations included in Köppen (1884) temperature classification (Köppen, 1884; Essenwanger, 2001; Rubel and Kottek, 2011).

Belt values	Temperature belts	Temperature belts
1.	Tropical belt	12 months $>$ 20°C
2.	Subtropical belt	1–8 months between 10 ve 20 °C, 4–11 months $>$20 °C
3.	Temperate belt	$>$ 20 °C for $\leq$ 4 months, 4–12 months between 10 ve 20 °C, $<$ 10 °C for $<$ 4 months
4.	Cold belt	10–20 °C for 1–3 months, 8–11 months $<$ 10 °C
5.	Polar belt	$<$ 10 °C for 12 months

All data obtained during the analysis phase were entered into Microsoft Excel 2010 and monthly temperature data were filtered to fit the classification. Then, these data were transferred to MapInfo 10.5, a Geographic Information System (GIS) program, and ArcGIS 10.5 and mapped. Ordinary Kriging interpolation method, which is frequently preferred in natural sciences, was preferred in mapping.

3 Results

Köppen (1884) temperature belts on Earth

Approximately 45% of the 3202 stations used on the earth's surface are in the temperate/moderate temperature zone (Table 2).

Table 2: Belts and number of stations included in Köppen (1884) temperature classification.

Belt values	Temperature belts	Number of stations
1.	Tropical belt	511 stations
2.	Subtropical belt	951 stations
3.	Temperate belt	1342 stations
4.	Cold belt	311 stations
5.	Polar belt	85 stations

The middle temperature zone is generally effective in the Northern Hemisphere (NH), where land covers a larger area (Figure 2).

According to Köppen (1884) temperature classification, the most important controller of temperature distribution in both hemispheres is geographical latitude. However, it is observed that the intergenerational temperature change in the NH has faster transitions and the homogeneity is disturbed at very short distances, while in the SH there is a relatively homogeneous distribution and slow transitions. The areas where homogeneity is clearly disturbed in the SH correspond to island surfaces and contact areas where water and land meet (Figure 1).

The thermal equator passes around 10°N latitude on average, especially between 1°-15°N latitude, especially in African countries located between 1°-15°N latitude, the temperature balance sheet is considerably higher than in other areas. In this area, it is seen that the average thermal equator expands towards 15°N latitude. East and West African countries such as Eritrea, South Sudan, Niger, Mali, Ethiopia, Djibouti and Kenya (especially the northern part) within the tropical belt constitute the countries with the highest temperature balance on earth with an average temperature above 29 °C. The regions with the lowest temperature balance sheet in the world correspond to the Antarctic continent, the Greenland autonomous region, Canada and the northern parts of Russia, with air temperatures of -15 °C and below. Especially in some areas in Antarctica, the average temperature falls below -49 °C and these areas are located entirely within the Polar Belt.

The mountain ranges extending in the north-south direction to different latitudes have caused significant changes /differences in the temperature regime, which is observed in the Andes Mountains in Chile and the Rocky Mountains in the USA and Canada (Figure 2 and Table 3). In addition, there are other regions where the elevation factor is prominent in temperature distribution. These regions correspond to the Tibetan Plateau, the Alps, the Carpathians, the Espinhaço Mountain Range, the Cordillera Oriental Range, the Cotopaxi and Chimborazo Mountains and the Muchinga mountains (Table 3). These mountainous areas also form the boundary of the temperature regime zones.

Table 3: Regions where the elevation factor is prominent in temperature distribution (Shaded areas correspond to regions where changes in temperature regime types are evident).

Latitude (°)	Country name	Landforms	Maximum height (m)
0°-15°S	Ecuador	Cotopaxi and Mount Chimborazo	5897-6263
	Peru	Cordillera Oriental Mountain Range	6372
15°-30°S	Chile	Andes Mountains	6962
	Brazil	Espinhaço Mountains	2072
	Zambia	Muchinga Mountains	>1890
30°-45°N	People's Republic of China	Tibet Platosu	8848
	USA and Canada	Rocky Mountains	4399
45°-60°N	İtaly, Switzerland, Austria, Slovenia	Alpine Mountains	4810
	Romanian	Carpathians	2655

Tropical Belt

The areas within the tropical temperature regime are located roughly between 0°-25°N and 0°-23°S latitudes. This temperature belt is a belt where the effect of latitude is felt more than other factors, and the areas where the zonality is disturbed are few. Except for the high plateaus and the northern parts of the Andes mountains, the Amazon basin in North America, the southern parts of Mexico in Central America and other small countries and island countries are regions with a completely equatorial temperature regime. The Congo basin in Africa, the Great Sahara in West Africa except for the Loma Mountains in Guinea and Mount Cameroon in Cameroon, the Indian Ocean coast of India, Sri Lanka and the countries of Southeast Asia in Asia are all regions with an equatorial temperature regime.

On Earth, the Himalayas are a boundary separating the tropical temperature regime from the subtropical temperature regime (Figure 2). This high mountainous mass prevents the tropical temperature regime from shifting northwards. However, in India, apart from the latitude factor, the Monsoon warm water current has a driving force in the expansion of the tropical temperature regime belt from the Indian Ocean coast to the inland. In Southeast Asia, the boundaries of the estimated equatorial temperature belt have shifted slightly further north than 15°N latitude due to the Equatorial Counter-Equatorial warm water current and the Kuroshio warm water current (Figure 2).

Subtropical Belt

The belt formed by the subtropical temperature regime is located between approximately 2°S-35°S latitude in the Southern Hemisphere (SH) and 6°N-55°N latitude in the Northern Hemisphere (NH). A subtropical temperature regime prevails in the southern half of the USA, in the Mediterranean and its surroundings, in the countries of the Middle East, in the lowland areas east of China in East Asia, in South Korea except the northeast, and in Japan except Hokkaido Island and the Japanese Alps. The so-called belt formed by the above-mentioned regions covers a wider area in the NH. Moreover, the horizontal and vertical distribution distortions in the subtropical belt are greater in the NH (Figure 2). This effect is particularly noticeable on the Tibetan Plateau, where the outer boundaries of the Subtropical Belt are shifted to about 10° south latitude and the temperature belt is significantly narrower. The main factors in this uneven distribution are the disproportionate distribution of land and sea in the NH and SH and the Kuroshio warm water, which is particularly effective around Taiwan, Japan, North Korea and South Korea. It is likely that a branch of this current pulled the subtropical belt northwards linearly.

Temperate Belt

In both hemispheres, the Middle Belt is generally located at latitudes 30°-60°N, and in the NH, especially in Central America, the temperature belt extends to the equator. In addition, in the SH, the Middle Belt Temperature Regime is effective, especially in the South Pacific and South Atlantic coasts of the South American continent and in the Patagonia geographical region, and the outer boundaries of the Middle Belt are expanding. Specifically, apart from the islands of Mauritius and Amsterdam in the Indian Ocean, New Zealand and Tasmania in the Southern Pacific Ocean are located entirely within the Middle Belt (Figure 2).

The Middle Belt in the NH rapidly transitions from latitude 45°N to longitude 15°W to latitude 60°N. The biggest factor in this is the Polar Jet Stream over North America and the Gulf Stream warm water current that affects the western coasts of the European continent, together with the resulting ridge. It is expanding along the coasts of Western Europe with the effect of the Gulf Stream current originating from the Gulf of Mexico. Gulf Stream and West Winds are effective in the temperature increase on the northeast Atlantic coasts. On the other hand, due to the large area of water surfaces in the SH, the estimated temperature belt extends in a zonal manner in general and conforms to the latitudinal distribution.

The inland parts of the land far from the sea, especially the inland parts of Asia, Eastern Europe and Central Europe, are areas with relatively high degree of continentality compared to other areas. High mountain masses such as the Himalayas, Caucasus, Alpine mountain ranges and their extensions (Pyrenees) and Carpathians in these areas have increased the degree of continentality in these areas compared to other areas. The fact that these mountain ranges run roughly parallel to the sea makes it difficult for warm and humid air masses to enter the interior and disrupts the homogeneous distribution in the Central/Humid Zone.

Cold Belt

The boundaries of the Cold Belt are drawn around latitude 60°N in the LAC. On the European continent, the boundary of this belt passes further north of 60° latitude than on the North American continent. The main factor in this is that the Gulf Stream and its North Atlantic branch, the warm water current, are relatively stronger than the Alaskan current. The Cold Belt expands in Asia relative to North America and Europe, and its outer boundary extends down to 45°N latitude. The presence of a high and large mass such as the Himalayas in the Asian continent and the Siberian High Pressure being active in the region are effective in the observation of this situation.

The Cold Belt has almost disappeared in the SH. A cold heat island representing the Cold Belt was detected only around Cape Horn (Figure 2). This feature is due to local climatic conditions, where polar winds originating from the Antarctic Peninsula and strong cold ocean currents in the Drake Strait and heat transport to northern latitudes (around Cape Horn) are important physical controllers explaining these climatic conditions.

Polar Belt

The polar temperature regime is the temperature regime that includes areas with a 12-month average temperature of less than 10°C. In the SH, this temperature regime prevails over Antarctica and on islands such as the French Southern Territories and Macquarie Island, except for the southern tip of the South American continent. Since the estimated temperature belt extends up to latitudes of 49°S, the Polar Belt covers a larger area in the SH. Unlike the Arctic, Antarctica is an ice-covered high land mass and the continent is surrounded by three cold-core High Pressures.

Between latitudes 60-75°N, the estimated Polar Belt in the NH exhibits a latitudinal distribution, i.e. a regularity, in the North American continent and Greenland. When it reaches Iceland, this regularity starts to deteriorate, and on the coasts of Northern Europe, it is seen that it is completely disrupted and replaced by areas representing the Cold Belt (Figure 2). The low elevation and the Gulf Stream warm water current have an important effect on this. In Europe and Asia, the so-called Polar Belt is characterised by a narrowing or a northward shift of its outer boundary (73°N), with the Cold Belt being effective between approximately 60-70°N latitude. The relatively warm North Atlantic Current and its tributary, the relatively warm Norwegian Current, influencing the west coast of Europe explain the contraction of the Polar Warm Belt, while in North America, the West Winds and the Labrador cold water current affecting the Atlantic coast of Canada and Baffin Bay are important physical controllers explaining the expansion of the Polar Warm Belt.

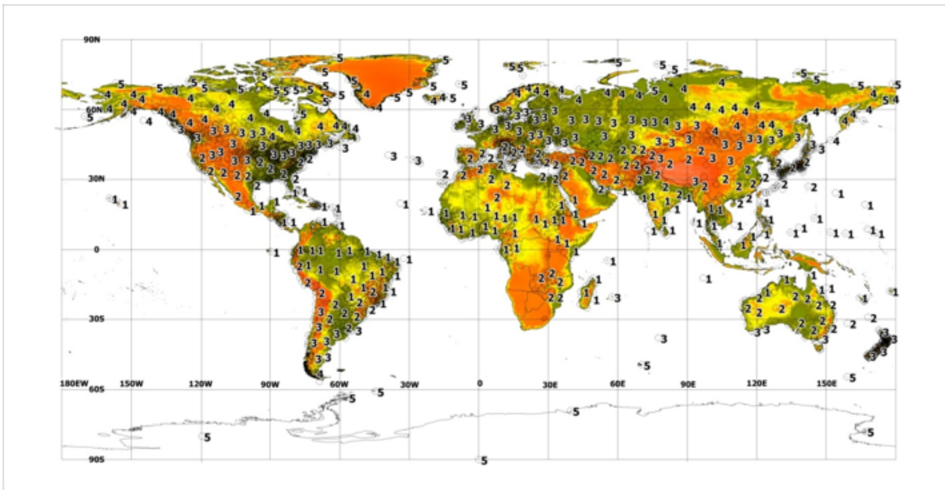

Figure 2: Köppen (1884) temperature map of the Earth.

Change of Köppen (1884) temperature zones in Türkiye

In the period 1961-1990, subtropical temperature regime type is observed in the Aegean and Mediterranean coasts, southeastern Anatolia (roughly Southeastern Anatolia and Upper Euphrates Region), while moderate/ temperate temperature regime type is dominant in other areas and Thrace. The cold temperature regime is observed in northeastern Anatolia (Erzurum Kars Region and Upper Murat Region) and in the southeastern end of Anatolia (Başkale Plain) (Figure 3).

Compared to the reference climate period of 1961-1990, in the period 1981-2010, the subtropical regime became dominant in some regions of the eastern Black Sea coast (around Giresun) as well as a significant expansion of the subtropical belt towards the north and inland. However, cold regions narrowed their area of influence. Compared to the periods of 1961-1990 and 1981-2010, the subtropical belt observed in the Aegean and Mediterranean coasts, eastern Black Sea coasts and southeastern Anatolia expanded inland and towards northern latitudes in the 1991-2020 period. Especially in the central and eastern Black Sea coastal belt and Thrace, the subtropical regime replaced the moderate temperature regime and new regions emerged. In addition, the cold temperature regime region dominating in northeastern Anatolia narrowed its area of influence in the 1991-2020 period compared to the 1981-2010 period, and this temperature regime was observed only in Ardahan and Sarıkamış stations (Ardahan Surroundings). In addition, the cold regime observed in the Başkale Plain disappeared and was replaced by the intermediate temperature regime (Figure 3).

According to Köppen's (1884) temperature regime, in the reference climate period of 1961-1990, subtropical temperature regime dominated approximately 31% of Türkiye and moderate temperature regime dominated 63% of Türkiye. During this period, regions with cold temperature regime emerged in northeastern Anatolia and southeastern Anatolia with severe continental character.

In the period 1981-2010, subtropical temperature regime dominates in about 36 percent of Türkiye, moderate/ temperate temperature regime in 62 percent and cold temperature regime in about 2 percent. Compared to the reference climate period of 1961-1990, 88% expansion was detected in the subtropical belt in the 1981-2010 period, while 1% contraction was detected in the moderate/ temperate belt. In the cold belt, this contraction increases up to 306%.

In the period 1991-2020, subtropical temperature regime is dominant in about 45% of Türkiye, moderate/moderate temperature regime in 53% and cold temperature regime in about 1%. Compared to the reference climate period of 1961-1990, an expansion of 69% in the subtropical belt was detected in the 1991-2020 period, while a contraction of 118% was observed in the middle/temperate belt. Parallel to the contraction observed in the middle belt, a significant contraction (448%) was observed in the cold belt.

The temperature regime type of Türkiye generally belongs to the Middle Belt continental temperature regime type. Especially in the Southeastern Anatolia Region, Çukurova, Antalya plain, Aegean Graben area, Southern Marmara Region and Iğdır plain, the temperatures are above 20 °C between 4 and 11 months and therefore, it is located in the subtropical belt. In inland areas, on the other hand, temperatures are above 20 °C for 3 months and below 10 °C for 3 months, as well as temperatures between 10-20 °C for 4 to 12 months, so it is completely included in the terrestrial Middle Belt temperature regime.

Temperatures increase roughly from north to south due to geographical latitude, and decrease from west to east due to elevation and continentality. The region where the subtropical belt shows the widest penetration is the Southeastern Anatolia Region. While the Southeastern Taurus Mountains increase the continentality, on the one hand, it breaks the effect of the cold air coming from the north during the cold period and on the other hand, it makes it difficult for the Persian Low Pressure, which is effective during the hot period, to descend to the northern slopes, which has led to a wide penetration of the Subtropical Zone in this region. The biggest factor in the disruption of the zonal distribution in Western Anatolia is the presence of graben and horst structures extending in the west-east direction, while in Eastern Anatolia, the Iğdır Plain is a microclimate area (Figure 3). In conclusion, the main factors affecting the average temperature regime in Türkiye can be listed as geographical latitude, elevation and continentality.

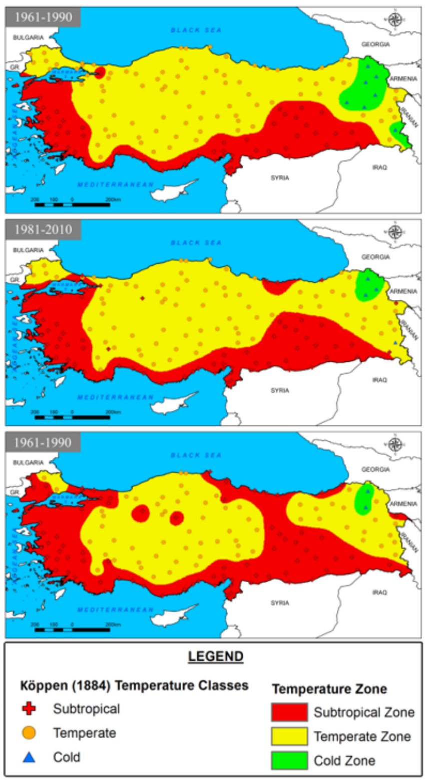

Figure 3: Change of Köppen (1884) temperature zones according to reference climate periods.

Today, the cold zone in Türkiye is estimated to be active in a narrow area in northeastern Anatolia. When a profile line is drawn in the northwest-southeast direction from the dastern Black Sea to the Iğdır Plain, the lower boundary of this zone corresponds to the cold coniferous forest boundary and is generally covered with grassland (Figure 4). This temperature zone mainly consists of plateau and mountainous areas such as Yalnızçam Mountains, Erzurum-Kars Plateau, Ardahan Plateau and Allahuekber Mountains. Here, the Yalnızçam Mountains correspond to a topographic boundary between the temperate zone and the cold zone.

The most significant change in the temperature regime of the cold zone is in northeastern Anatolia. There is a significant narrowing of the cold zone in this area, with the elevation range of the lower boundary of the cold zone being 2407-965 m, 2226-2274 m and 1955-1973 m in the 1961-90, 1981-2010 and 1991-2020 climate normals, respectively. Another change is the emergence of a large-area subtropical zone along the eastern Black Sea coast in the last 30-year period (1991-2020), which is estimated to be effective up to 340 m (Figure 4). Thus, the recent climate normal has seen an expansion of the subtropical zone and a corresponding contraction of the temperate zone.

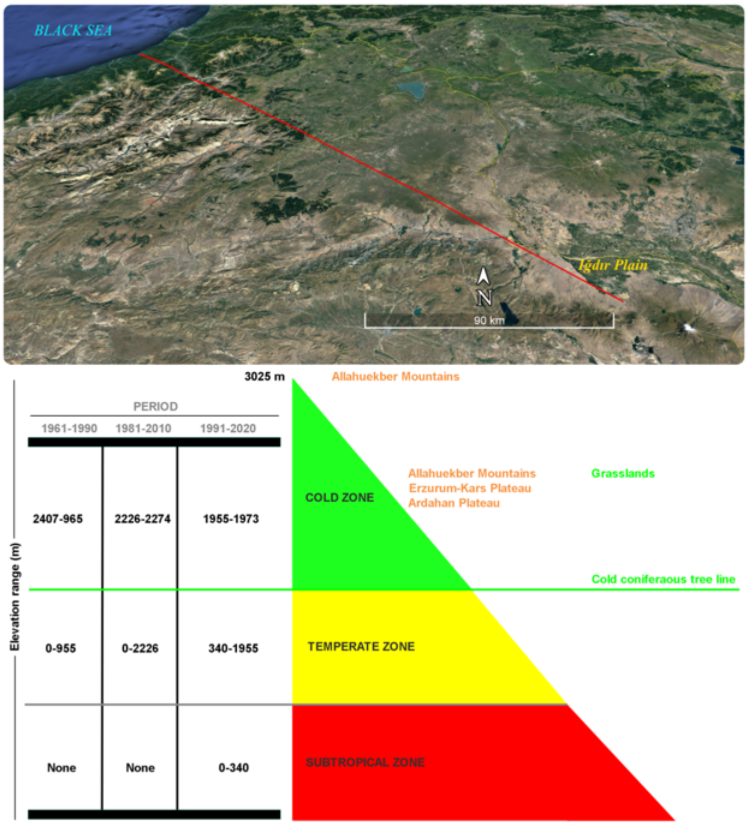

Figure 4: Shifts in the elevation ranges of Köppen (1884) temperature zones relative to climatological standard normals along a line from the eastern Black Sea coast to the Iğdır Plain (northwest-southeast direction, 289 km).

4 Discussion

Köppen (1884) explains the latitudinal shifts in the temperature belts well by land-sea distribution, the presence of Antarctica and albedo effect, as well as the mountain ranges covering large areas, ocean currents and low and high centers, ridges and wave troughs formed by jet streams (Alaska, Greenland).

The world temperature map based on meteorological measurements is largely consistent with the first map prepared by Köppen (1884), but some differences have naturally emerged between the boundaries of the temperature belts. For example, Cape Horn in the SH is a region where the temperate and cold temperature regime is effective in contrast to the polar temperature regime. However, Madagascar Island has a tropical character rather than a subtropical region, and temperate areas in south-western Australia have a narrow distribution in the coastal zone.

Looking at the extension of the belts in the NH, it can be seen that in the Mediterranean basin, including the southern coasts of Türkiye, the outer limit of the subtropical belt is slightly further north. In addition, the polar belt does not extend into the interior of Russia and east of Asia as far as the Kamchatka Peninsula. Moreover, the land areas east of the Baltic Sea are located in the temperate belt as opposed to the cold belt.

In the world temperature zones map prepared by Köppen (1884), İzmir (Seferihisar)-Antalya (Kemer) coastal belt in Anatolia and roughly Southeastern Anatolia are shown in the subtropical zone and other areas are shown in the temperate zone. Today, roughly half of Türkiye, including Anatolia and Thrace, is located in the middle zone and the other half in the subtropical and cold zone.

Compared to the reference climate period of 1961-1990, significant spatial changes in temperature zones were observed over Türkiye during the period 1981-2010, with warmer areas shifting further northwards and towards higher elevations, and growing spatially. On the contrary, the cold areas representing northeastern Anatolia have shrunk spatially and a significant part of the Kars-Ardahan Plateau has been transformed into moderate-temperature areas. These changes continued to increase in the 1991-2020 period and exhibited distinct spatial patterns. In addition, changes and shifts in all these temperature zones are faster and more pronounced in Thrace and northeastern Anatolia. As a result, the observed and predicted shifts in Köppen-Geiger climate zones (Rubel and Kottek, 2010; Chan and Wu, 2015; Cui et al., 2021) due to the shift towards warmer and drier climate types after the 1980s have been realized as an expansion in the subtropical region and an areal contraction in the cold region over Türkiye. The significant spatial decreases in climate type D, corresponding to the cold region, during the 1981-2020 period, especially in northeastern Anatolia and the southeastern tip of Anatolia, are also consistent with the global climate simulations by Chan and Wu (2015). As a matter of fact, Chan and Wu (2015) found that in the 1950-2010 period, an expansion in arid climate zones and a contraction in mid-latitude continental climates were observed in temperate and continental climates with a shift towards the poles and suggested that this trend will continue in the future.

It is predicted that the observed shifts in temperature belts in Türkiye will continue in the future (Rubel and Kottek, 2010). In the projections of climatic change based on the Köppen-Geiger climate classification (2030-2050), a significant expansion of the Mediterranean climate type (Csa) and subtropical steppe climate type (Bsk) and a significant contraction of the humid continental climate type (Dfa and Dfb) are simulated in the medium (2050-2070) and long term (2070-2090) (Rubel and Kottek, 2010). Similar trends were also observed in the Köppen-Geiger climate simulations prepared by Beck et al. (2018). The direction of changes/shifts in temperature zones in reference climate periods over Türkiye are consistent with these projection results and according to the results of the combination, it can be simulated that the subtropical region will naturally merge with the cold region in Türkiye.

5 Conclusions

In previous studies, Köppen's classical thermal zone classification system published in 1884 was mentioned as the pioneer of the modern Köppen-Geiger climate classification, but no application was made. Therefore, the 1884 map of the world's thermal regions, which was prepared by utilizing various topography, vegetation and temperature distribution maps and phytogeography and climate information, has not been updated. In this study, the spatial and temporal variation of Köppen (1884) thermal regions were analyzed worldwide and in Türkiye for the first time with station data sets of 20 years (1971-90) and 60 years (1961-2020), respectively. The results facilitate the understanding of global temperature distribution and provide more information for predicting climate changes over Türkiye. It is largely consistent with the first map prepared by Köppen (1884). The cold belt in the SH was detected only around Cape Horn. Apart from this, the tropical, subtropical, temperate, cold and polar belts on land surfaces in the period 1971-1990 lie roughly between 0°-25°N and 0°-23°S, 6°N-55°N and 2°S-35°S, 30°-60° latitude, 45-60°N, 60-75°N and 49-90°S, respectively. In Türkiye, subtropical and temperate areas have tended to shift further northwards and towards higher elevations over time, and the cold temperature regime zones have significantly narrowed spatially. Compared to the reference period of 1961-90, the most significant changes in temperature regime types were observed in Thrace, Central and Eastern Black Sea coasts and northeastern Anatolia.

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