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## Abstract

In this chapter great diversity of climate in Georgia is analyzed. Almost all kinds of climate (except for equatorial and tropical climates) of the earth is distributed in our country's relatively small area, from the humid subtropics of the Black Sea coast of western Georgia and dry subtropics of eastern Georgia to the permanent snow and glacial climate of the Caucasus. Climate-creating factors and climatic elements of Georgia, circulation of the atmosphere, air temperature, hazardous meteorological phenomena, climate types, and climate change are the main body of this chapter.

The great Georgian lexicographer—Sulkhan-Saba Orbeliani had not mentioned “climate” in his dictionary “Sitkvis Kona” (in Eng.: The Bunch of Words), because this term was only introduced along with the Russian language from the beginning of the nineteenth century into the Georgian dictionary. It is noteworthy that at present, the “climate” and “hava” as synonyms

are equally actively used in modern Georgian climatology.

Georgia's climate is characterized by a great diversity. Almost all kinds of climate (except for equatorial and tropical climates) of the earth is distributed in our country's relatively small area, from the humid subtropics of the Black Sea coast of western Georgia and dry subtropics of eastern Georgia to the permanent snow and glacial climate of the Caucasus. As the Academician T. Davitaia noted, the mentioned peculiarity of the climate is the national wealth of Georgia, like which has no country in the world. The diversity of Georgia's climate is explained on the one hand, by the location of the country on the northern border of the subtropical zone, where the circular processes take place, characteristic of subtropical and temperate and sometimes for high latitudes, and on the other hand, by its complex physical-geographical conditions (Gagua et al. 2000).

Written information about the climate of individual regions of our country can be found still in the works of ancient Greek historians, geographers, and other scholars. It is noteworthy that Georgia was one of the most important centers of Mediterranean civilizations due to its location on the Black Sea coast, and therefore, it was at the center of attention of the old world thinkers.

Hippocrates (about 460–370 BC), while describing the climate of Colchis, underlines the characteristic of this region excessive

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atmospheric precipitations and the slightest fluctuations in the air temperature from season to season, as well as the foehn warm and dry wind “Kenkhron”, which is called “zenakari” in Guria (Kaukhchishvili 1965). Later (after about 3–4 centuries) Strabo (63 BC–24 AD) noted high humidity and abundant precipitations in the downstream of the Phasisi (Rioni) River, and the dry climate of Iberia, adorning it with epithets—blessed and pleasant to live.

Almost all foreign historians or geographers who describe eastern Georgia, characterize its climate as dry and good for health, though by Iakob Tsurtaveli, the author of “Torture of Shushanik”—the literature monument of the fifth century (the source of the source is not localized, but our assumption This is the south-east part of Kvemo Kartli A), the climate is like a “hot sun burning as fire in the summertime, dry winds and dangerous waters”.

By Procopius of Caesarea (6th c.), in Java-kheti and Artaani (part of the current Turkish territory) winter is strict and cold, the summer is long and relatively warm. In our opinion, the duration of summer is doubtful, but the winter is perfectly characterized by this historian. This territory is even now the coldest region of Georgia and it can be called “Siberia”.

Grigol Khandzteli (18–19th c.) notes that nature and climate in Meskheti and Shavsheti-Klarjeti (this is also a part of Turkey now) are beautiful. According to his description, the climate of this region is “kindly dressed from the sun and the air”.

By Giorgi Merchule (10th c.), in Apkhazeti (the Kolkheti lowland), in winter, because of warm and healthy climate, a man could “wintering” and have a good rest. However, according to him, “the country is hot”. It is surprising that he does not say anything about the excessive humidity of this region, which has always been noted by the majority of the historians.

According to the historian of David Agh-mashenebeli (11–12th c.), the Iori River flood-plain and the territory from Tbilisi to Barda (a city in Azerbaijan) are beautiful wintering areas, as winter is very warm there, but summer is hot and unhealthy.

As historical sources reveal, western Georgia was economically destroyed in the seventeenth century. Along with the termination of trade, the cutting of trees was stopped too. It may have caused to cover almost the entire area with impassable forests, resulting in the weakening of the eastern winds and increasing the humidity.

The Italian missionary—Don Arcangelo Lambert (his purpose was the propagation of Catholicism in the East) while description of Kolkheti special attention was paid to the great humidity of this region, where the waters flowed from rivers (Rioni, Tskhenistskali, Abasha, Enguri, Kodori, etc.) after the abundant atmospheric precipitation, widely covered the coastal area so, that the communication between villages was by means of boats. He also characterizes a thermal regime, comparing it to one of the Mediterranean regions (in particular, the Apennine Peninsula), and notes that winter in western Georgia, for example in Samegrelo, is colder than in Rome and warmer than in Naples. At the same time, he does not say anything about the eastern foehn winds, though he lived in Samegrelo for more than 15 years (1633–1650) (Don Arcangelo Lambert 1991).

From Georgian sources, the works of Georgian writers included in the “Kartli’s life” are very important, where there are scattered and fragmentary presented the materials of climate mainly of the medieval Georgia. Despite such scarcity of data, anyway, they are of great importance in research of historic climate of Georgia, because they contain very noteworthy information about the climate and it can be said of landscapes of individual regions of Georgia; and still a special role plays the “Description of Kingdom of Georgia” by Vakhushti Bagrationi.

According to the description of Vakhushti, there was a great “colorfulness” of climate in Georgia. There is nothing surprising because the complex relief (mountain ranges, uplands, plains, etc. of different directions and altitudes alternate each other here) has led to the formation of quite a lot of different climatic regions in the relatively small area of Georgia and their partial individuality by the main signs of the environment. Mainly by this is precisely explained the clearly

visible individuality of live rules and habits of the population of these regions, which led to the development of separate regions of Georgia.

No one has characterized the climate of Georgia, namely, the climate of Kartli, Kakheti, and Imereti in such accuracy and detail, as it did Vakhushti Batonishvili by its own observations of the natural processes and their generalization. It can be said that he was the first, before the famous travel of Al. Humboldt (1769–1859) in the northern Andes, who used the vertical zoning law based on natural conditions, the basis of which is the reduction of the air temperature and vegetation period according to the altitude of the area.

According to Vakhushti Batonishvili (1696–1758), in the eighteenth century, the climate of Kolkheti was still excessively humid like in the past centuries. He does not tell us anything about the existence of the eastern wind too. He writes about Odishi (Samegrelo): “winter is warm, but summer is wet and dewy and humid, but unharmed, windless and frost-free”. He describes Imereti as “a quiet place, where you can look from the high mountain, see entire Imereti as a forest and with no building anywhere” (Bagraioni 1997). By our supposition, he, by all means, assumes a huge and impassable forest of Ajameti, which was intensively cut along the formation of capitalism in the nineteenth century, which led to the increase of the frequency and speed of the eastern winds. However, despite such dry and strong eastern winds, a Russian military officer A. Tsimermann (1853) again noted the excessive humidity.

It is noteworthy that the peculiarities of the Georgian climate described by the Ancient and Medieval centuries’ historians did not change substantially; only with the changes in the economic and cultural situation of the country, did some of the local climate indicators were changing.

Scientific study (based on the materials obtained from instrumental observations) of the climate of Georgia has been started from the second half of the nineteenth century and continues even today.

## 8.1 Climate-Creating Factors and Climatic Elements of Georgia Solar Radiation

Because of the location on the north border of subtropical belt, Georgia receives a significant amount of solar radiation. Unfortunately, the data of eight actinometric stations, which characterize the radiation regime of Georgia, is not sufficient (Reference book of the climate of the USSR 1968).

According to the data obtained at the actinometric stations the average annual solar intensity in the territory of Georgia, in the case of cloudless sky, at 12:30 pm on 1 m<sup>2</sup> area, ranges from 852 to 1116.8 watts/m<sup>2</sup> (Table 8.1b). It varies according to the site elevation above sea level and concentration of aerosols in the atmosphere. It is quite logical that its low indicator was observed in Tbilisi and high—in high mountainous Kazbegi, the height of which is 3653 m above sea level, and where the atmosphere is much cleaner than in the capital of our country with almost a million and a half people.

If we consider the intensity of solar radiation in the clear sky 917 watts on average on the area of 1 m<sup>2</sup> and compare it to the solar constant ( $J_0 = 1.37 \text{ kg w/m}^2$ ), which decreases by 20% on average while passing the cloudless atmosphere, under our conditions, the solar constant decreases by 6% again, which should be explained by the low index of transparency of Georgia’s atmosphere and humidity.

Georgia is characterized by significant duration of sunshine which exceeds 2000 h annually almost everywhere except the territory of Achara-Guria (Table 8.1c). A number of cloudy days are 162–167 days a year (Table 8.1d), due to which the annual indicator of sunlight varies between 1828 and 1958 h. This figure is the lowest (1352 h) in Sairme due to its location in very narrow gorge. That is why, due to the closure of the horizon, the available duration of sunlight is reduced by 47%. Georgian steppe regions are distinguished by largest duration of sunshine, such as Gardabani, where the number

**Table 8.1** Some of the characteristics of solar radiation

Weather station	a	b	c	d	e	f	g	h
	The elevation of the site (m)	Average annual intensity of sunlight during the cloudless sky at 12:30 h (w/m <sup>2</sup> )	Duration of sunlight during the year (h)	The number of cloudy days during the year (day)	Q—Solar total radiation (m.j./m <sup>2</sup> ) <sup>a</sup>	S'—Direct solar radiation (m.j./m <sup>2</sup> )	D—Scattered solar radiation (m.j./m <sup>2</sup> )	B—Radiation balance (m.j./m <sup>2</sup> )
Martvili	40	866	2004	135	4944	2660	2284	–
Anaseuli	158	900	1828	167	4827	2598	2229	2363
Sokhumi	26	878	2120	146	5107	2941	2166	2485
Skra	607	886	2350	105	5698	3448	2250	2648
Telavi	568	900	2316	116	5434	3163	2271	2506
Tbilisi observ	404	852	2112	122	5057	3017	2040	2212
Tsalka	1457	935	1984	110	5045	2803	2242	–
Kazbegi h/m	3653	1117	2232	94	6410	3322	3088	–
Batumi	2	–	1958	162	–	–	–	–
Sairme	910	–	1352	135	–	–	–	–
Gardabani	300	–	2520	106	–	–	–	–
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Batumi	2	–	1958	162	–	–	–	–
Sairme	910	–	1352	135	–	–	–	–
Gardabani	300	–	2520	106	–	–	–	–

<sup>a</sup>m.j.—megajoule

of cloudy days is only 106 days a year and the duration of sunshine is 2520 h (Table 8.1c).

Because of the lack of a difference between the territory of Georgia and its geographical latitudes (41° 07' and 43° 35'), it can be said that no climatic indicator, including the duration of sunlight, varies completely according to the latitude. It mainly depends on the cloudiness and horizon openness (Fig. 8.1).

The intra-annual distribution of sunlight is characterized by one maximum (mainly in July) and at one minimum in winter period (mainly in December or January in some areas). For example in Tbilisi, the minimum (93 h) of this indicator is in December, and maximum (272 h) —is in July.

In the conditions of real transparency of cloudiness and average transparency of



**Fig. 8.1** Autumn in Svaneti (photo by R. Tolordava)

atmosphere, the annual income of total (direct and scattered) radiation in the territory of Georgia is equal to 65–75% of possible (in the case of a cloudless sky) total radiation and varies, respectively between 4827 and 5696 m.j./m<sup>2</sup> for low and foothill zones, and in the high mountainous zone, it reaches even 6410 m.j./m<sup>2</sup> (Table 8.1e).

It should be noted that the total solar radiation (roughly approximated) is 5315 m.j./m<sup>2</sup> on average during a year at the latitude of Georgia (Droz dov 1989). The scattered radiation share is 44% of the total income (or annual total radiation).

During the year, both the total solar radiation and direct solar radiation reach their maximums (678–411 megajoule, respectively) mainly in June in the horizontal surfaces with the area of 1 m<sup>2</sup> in the lower zones, for example, in the Kolkhetti lowland (namely, in Senaki), in June, and their minimums (172–75 m.j.)—in December. In the high mountainous zone, for example in Kazbegi, the maximum total radiation is in May and makes 842 m.j./m<sup>2</sup>, and minimum –264 m.j./m<sup>2</sup> in December–January.

Radiation Balance, which is the main climate-creating factor, is an essential component of heat balance. It determines the thermal regime of the study area, as well as evaporation and snow melting processes. The annual sum of radiation balance in low and foothill zones with the area of 1 m<sup>2</sup> is 43–49% of their total radiation. For example in Tbilisi, this indicator is 2212 m.j./m<sup>2</sup> and in Telavi—2506 m.j./m<sup>2</sup>, and it is 46% of total radiation (Table 8.1h).

In the cold period of the year, along with the decrease in the radiation, there is a decrease in the share of radiation balance too. In November and February it is 20–30% of total radiation, and in December and January—only 10–20%, and it varies between 8.4 and 29.3 m.j./m<sup>2</sup> in low mountainous and foothill areas, where the average temperature for all months of winter is more than zero. The exception is a weather station Skra, where the radiation balance is 29.3 m.j./m<sup>2</sup> in January, and the average air temperature is –1.7 °C. This can be explained for Shida Kartli plain, where Skra is located with its characteristic thermal inversions, as M. Kordzakhia notes



(Kordzakhia 1961). In his opinion, this region is characterized by more cold, snowy, and windy winters than the slopes of the mountains of same height around it.

While analyzing the materials of the actinometric stations to describe the radiation climate of Georgia the following should be foreseen: (1) the exceptional lack of the used stations for the country with complex relief, such as Georgia, where the 12.8% of the area is located up to 200 m above sea level, 34.4%—is occupied by the area up to 200–1000 m and 53.8% area—above 1000; (2) the shortness and oldness of actinometric observation rows (observation years 1953–1964). Considering the above factors, the conclusions obtained are only approximations.

**The circulation of the atmosphere** is one of the main factors of climate formation. Air masses, which are periodically intruded in Georgia, are formed in the Arctic, moderate latitudes, or tropics.

The mountainous systems of our country—the Greater Caucasus Range and the highland of southern Georgia change the direction of movement of air masses. With its geographical location and different morphometric characteristics, the Caucasus significantly affects the atmospheric and radiation processes. It modifies the intensity and direction of the general circular forms of the atmosphere (western, eastern, and meridional), and ultimately affects the weather and climate of neighboring territories with low hypsometry.

Synoptic processes that stipulate the intrusion of air masses in the territory of Georgia are grouped into the following types: western, eastern, bilateral intrusion, anticyclone condition, and wave turbulence developed in southern highland of Transcaucasia.

These processes differ from each other by nature of the weather. Their recurrence and intensity, speed, and direction are changed by the influence of complex orographical units and morphometric indicators.

From above-mentioned processes, the role of the western process is important in establishing weather in Georgia. During this process, a significant decrease in air temperature in western Georgia, cloudiness, and precipitations are

observed, and in eastern Georgia, its influence is reduced, however, the western winds are intensified, especially in the Mtkvari River gorge.

Cold air masses coming from the north during the intrusion from the east cannot reach Georgia due to influence of the Caucasus; they flow around the range from the east and starts moving toward the west. Activation of this process in eastern Georgia is accompanied by rain, in winter—by snow, and in western Georgia, wind blows and weather is clean.

The bilateral intrusion is mainly developed under the influence of the Caucasus. Cold air masses coming from the north intrude simultaneously in the Transcaucasia from the west and east. During this process, the air temperature decreases considerably throughout Georgia and it is accompanied with abundant atmospheric precipitation.

The anticyclone condition can be strengthened after the completion of cold air masses intrusion. Orographic conditions facilitate the strengthening and duration of local anticyclones.

The wave turbulences of airflow, developed in the south of the Caucasus, develop mostly after completion of bilateral or western intrusions of air masses. Intrusion of tropical air masses in Georgia is connected with this process that rises very high the air temperature in the summer, even up to 40–41 °C.

**Air temperature.** Study of temperature field of surface for Georgia, the 3/5 of territory of which is covered by medium and high mountains, is very complex that is related with the lack of appropriate quantity and quality weather stations.

The mountainous system of the Caucasus, in certain parts of which a large part of the territory of Georgian is located, is one of the main reasons stipulating its climatic peculiarity, which means the changes in climatic elements such as air temperatures, atmospheric precipitation, etc. not by geographical latitude but hypsometrical zonality from west to east.

In Georgia, like everywhere on the earth's surface, the air temperature falls down by 0.5 °C on average per 100 m. In our country's complex orographic conditions the vertical thermal

gradient varies greatly according to the shape of the relief, the slope angle, the slope exposition, distance from the sea, and the seasons of the year. For visualization we give the numerical data of some thermal indicators of the air—the average temperatures of January, the absolute minimums and maximums of the air temperatures, and the sums of active temperatures for western Georgia' as well as for eastern Georgia's different vertical zones and their areas (Tables 8.2, and 8.3), (Climate Scientific-Applied Reference Book of Georgia 2004; Vladimirov et al. 1962, Reference book of the climate of the USSR 1967).

Replacement of subtropical humid climate by subtropical continental one from west to east (except distance from the Black Sea) is a result of the meridional Likhi Range outgoing from the Greater Caucasus Range that divides Georgia into two parts both territorially and climatically—into eastern Georgia and western Georgia. The location of the latter at the Black Sea determines the high-temperature regime in the cold period of the year. For example, on the Kolkheti lowland (0–200 m) the average air temperature in January varies between 4–7 °C (Table 8.2). It is noteworthy that this indicator is high in the coastal line not only in entire Georgia but also on the Black Sea western coast too. For example, the Black Sea coastal zone of Bulgaria, located on the same latitude, is colder by 4.5–5 °C

(Table 8.4) than the eastern coast of Georgia which can be explained by the immediate neighboring of the latitudinal Caucasus Range and by the peculiarities of marine water circulation processes (Mumladze 1988).

The average annual air temperature is the highest, both in the Black Sea coast and along the Rioni River gorge up to 500 m above sea level, and varies from 13 to 15 °C. In the upper zone of Achara-Imereti Range (Bakhmaro, 1926 m), it reaches 4–5 °C. It is noteworthy that the average annual air temperature of 0 °C starts just from 2395 m on Jvari Pass, for example, on the Mamisoni Pass (2854 m) it is –2.4 °C, and in high mountainous Kazbegi (3653 m) it is –6.1 °C. In eastern Georgia, Kvemo Kartli and Kakheti (12–13 °C) are distinguished with the highest average annual air temperature (Fig. 8.2).

Temperature of July is the highest (>25 °C) in Kvemo Kartli plain, on the Iori upland, and in the southern part of Alazani Valley; on the Black Sea coastline it is within 23 °C. With the increase in the height of the area, it is falling to 3 °C (Table 8.5) by the data of high mountainous Kazbegi weather station.

Absolute minimum air temperature in the coastal line is –8, –14 °C; with the distancing from the sea and increasing in altitude, the air temperature considerably falls to –28 °C (village Korbouli); the mentioned indicator in the plain

**Table 8.2** Distribution of thermal indicators and areas by altitudes in western Georgia

Vertical zones (m)	Area (km <sup>2</sup> )	January average (t °C)		Active temperature sums ( $\sum t$ ° > 10°)		Absol. minim. (t °C)		Absol. maxim. (t °C)	
		From	To	From	To	From	To	From	To
0–200	7673.2	4.0	7.0	3700	4600	–19	–8	40	42
200–400	2464.5	2.5	6.0	3750	4440	–22	–13	39	43
400–600	2104.6	–0.5	3.5	2900	4050	–25	–16	38	41
600–1000	4209.8	–2.5	3.0	2300	3550	–28	–19	36	39
1000–1400	4144.7	–4.0	–1.0	1950	2500	–31	–22	35	37
1400–1800	4028.6	–6.0	–3.0	1200	2050	–33	–26	34	35
1800–2200	3594.3	–8.0	–5.0	1100	–	–35	–29	32	33
2200–2600	2434.3	–10.0	–6.5	–	–	–	–	–	–
2600–3000	1303.4	–12.0	–8.5	–	–	–35	–	–25	–

**Table 8.3** Distribution of thermal indicators and areas according to the altitudes in eastern Georgia

Vertical zones (m)	Area (km <sup>2</sup> )	January average (t °C)		Active temperature sums ( $\sum t^{\circ} > 10^{\circ}$ )		Absol. minim. (t °C)		Absol. maxim. (t °C)	
		From	To	From	To	From	To	From	To
200–400	3405.7	0.5	2.0	4100	4255	–25	–23	40	41
400–600	4245.1	–1.5	0.5	3340	3975	–32	–22	38	41
600–1000	7671.3	–3.5	–1.0	2885	3575	–32	–24	36	41
1000–1400	5851.7	–5.0	–2.5	1960	3000	–34	–26	33	39
1400–1800	5708.1	–7.5	–4.0	1300	2070	–38	–34	31	37
1800–2200	4651.7	–9.0	–5.5	845	1665	–41	–33	27	33
2200–2600	2933.8	–12.0	–7.0	510	890	–	–	–	–
2600–3000	1737.7	–13.0	–8.5	–	–	–	–	–	–
3000–3500	601.8	–14.5	–10.5	–	–	–	–	–	–
3500–4000	178.4	–16.5	–12.0	–	–	–42	–	16	–

**Table 8.4** Monthly average air temperature (t °C) in the winter period

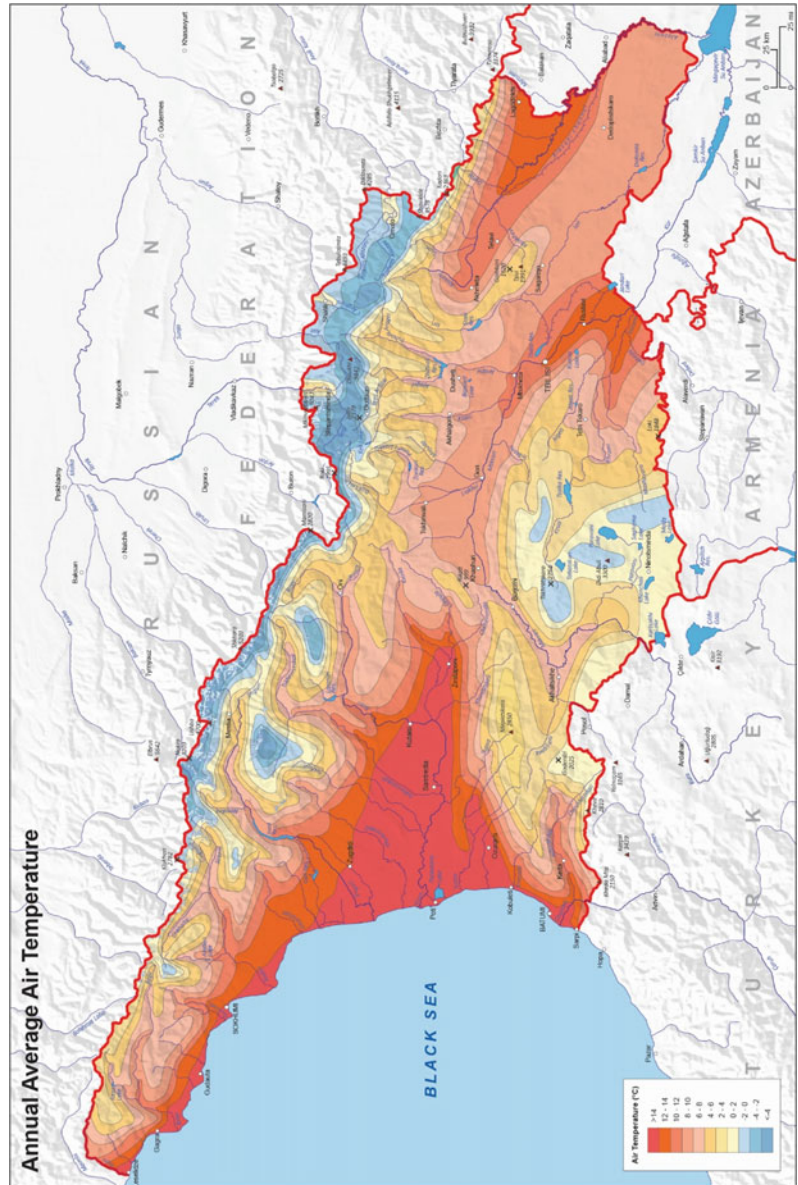
Weather station	Latitude	Latitude	January	February
Varna	43° 20'	3.8	1.2	2.4
Gagra	43° 20'	8.2	6.2	6.5
Sokhumi	43° 01'	8.1	5.8	6.7

**Table 8.5** Air temperature indicators (t °C)

Weather station	Height above sea level (m)	The coldest month (I or II)	The warmest month (VII or VIII)	Average annual	Absolute minimum	Absolute maximum
Poti	3	5.2	23.2	14.1	–13	41
Batumi	5	7.1	23.2	14.5	–8	41
Sokhumi	116	5.8	23.8	14.7	–14	41
Gardabani	300	0.3	25.3	12.9	–25	41
Tbilisi observ	403	0.9	24.4	12.7	–23	40
Gori	588	–1.2	22.3	10.9	–28	40
Telavi	568	0.5	23.0	11.8	–23	38
Mestia	1441	–6.0	16.4	5.7	–35	35
Akhalkalaki	1716	–7.2	16.4	5.3	–34	34
Kazbegi h/m	3653	–15.3	3.0	–6.1	–42	16



**Fig. 8.2** Annual average air temperature (National Atlas of Georgia, Steiner-Verlag, 2018)



zone of eastern Georgia changes between 20 and  $-28^{\circ}\text{C}$ ; in high mountainous areas it is  $-35$ ,  $-40^{\circ}\text{C}$  and even lower. The shape of relief and the underneath surface character, vegetation cover and, etc., are of great importance in the territorial distribution of absolute minimum temperatures. For example, in Shaori basin (1130 m), where the cold air masses are accumulated, the observed absolute minimum is  $-40^{\circ}\text{C}$ , while in high mountainous Kazbegi is

$-42^{\circ}\text{C}$ . At the same time, on the southern slope of the Caucasus, which is covered by dense forest, the absolute minimum air temperature is higher than in the Javakheti upland.

The absolute maximum temperature of the air is quite high in the lowland area, where it is 40,  $42^{\circ}\text{C}$ ; The highest temperature of  $43^{\circ}\text{C}$  is observed in Apkhazeti (village Lata) which decreases according to the height and is the lowest ( $16^{\circ}\text{C}$ ) in high mountainous Kazbegi.

The annual amplitude of air temperature varies between 17 and 25 °C. The lowest amplitude is in the coastal zone and high mountainous part (17–18 °C). High amplitude is in Kvemo Kartli and Javakheti upland (23–25 °C).

In the Black Sea coastline, the number of cold days (temperatures below 0 °C.) in winter does not exceed 5. With the increase in distance from the sea and the height of the place, this indicator increases, and at about 600 m height it makes 1 month. In eastern Georgia, it reaches 25–30 days at the height of 500 m.

Number of hot days (with the temperature over 25 °C) in the plain zone of eastern Georgia is more than 30 days. Hot days (20–25 days) are frequent in the lower part of the Rioni River gorge and in Apkhazeti (Gagra).

Frosts in the western Georgia's lowland zone begin in December-January and are expected to be up to mid-March; in the lowland part of eastern Georgia, frosts begin in November and end in the end of March. Thus, the duration of the frost-free period is 250–300 days in the western Georgia's lowland zone and in the eastern Georgia plain—180–250 days (Gagua et al. 2000; Reference book of the climate of the USSR 1967).

The territorial distribution of **air humidity** is considerably dependent on the physical-geographical conditions of the area, season of the year, peculiarities of atmospheric circulation, soil surface conditions, and, etc.

The partial pressure (water vapor resilience) of the water vapor contained in the air and the relative humidity well characterize the atmospheric air humidity.

The annual course of the partial pressure of the water vapor in the atmospheric air is synchronized to the annual course of the air temperature both in the plain areas of Georgia and in mountains. Minimum is in winter (January–February), and maximum—in summer (July–August).

In winter, the highest value of water vapor is observed in Kolkheta lowland, especially in the coastal zone of Achara and Apkhazeti (6.5–7.5 millibars). In high mountains, for example, in Mamisoni it reaches about 2.0 millibars. In the

summer, namely in July, with the increase in air temperature, this indicator significantly increases and reaches even 24 millibars in the coastal zone of Apkhazeti, while the Mamisoni it is 8.6 millibars.

The average annual relative humidity in western Georgia is high in general. The coastal zone from Batumi to Anaklia is especially distinguished with high humidity (80–82%). In the distance from the sea, to the east, the relative humidity is decreasing in Kvemo Imereti, Racha-Lechkhumi, and the Acharistskali River gorge, which is mainly caused by the activity of foehn winds. On the slopes of the mountain ranges, with the increase in altitude, the relative humidity increases again.

In eastern Georgia, the steppe zone of its easternmost part (66–70%) and a significant part of the southern highland (64–70%) is characterized by the lowest relative humidity. Similarly to precipitation, the relative humidity increases along with the rising in altitude, at the height of 2500–3000 m, and afterward it decreases.

In the coastal lowland zone, the minimum relative humidity is in the winter (64–75%) and the maximum is in August–September (75–85%); in the distant areas from the sea, the minimum is in April (64–72%) and maximum—in July–August (76–84%). The main maximum in eastern Georgia is at the end of the autumn and beginning of winter (70–80%), and the minimum—is in summer, mainly in August (55–65%).

In the coastal line, the number of dry days (less than 30% relative humidity) varies between 2 and 10. Iori upland and a significant part of highland of southern Georgia are distinguished with dry days.

The number of humid days (relative humidity is more than 13 h or equal to 80%) is considerable (70–211 days) in the coastal zone; such days are few in Akhalkalaki plateau and Iori upland (Climate Scientific-Applied Reference Book of Georgia 2004; Reference book of the climate of the USSR 1970).

**Atmospheric precipitations** are one of the main climatic elements that define the water balance of the area. Complex orographic conditions, meridional direction of the Caucasus and

highland of southern Georgia as well as the neighboring seas modify the circulation of the prevailing atmosphere in such a way that the dry steppes are found in relatively small territory (with the annual sum of precipitations less than 400 mm) as well as the regions with excess humidity (with more than 4000 mm of precipitations).

According to Sh. Javakhishvili (1981, 1977), in Georgia, the highest amount of precipitation falls on the seaward slopes of the Meskheta Range—annual average of 4500 mm (Mt Mti-rala); the lowest amount of precipitation ( $\leq 400$  mm) is in the south-easternmost of eastern Georgia. In Kolkheti, in the coastal zone (Samegrelo, Guria), the amount of precipitations is 1600–1900 mm; it is noteworthy that it decreases to the north and makes 1550 mm in Anaklia. In the eastern part of the Kolkheti plain, it reduces to 1100–1200 mm and again increases up to 1500 mm on the slopes of the Likhi Range. In eastern Georgia, the amount of precipitations is small and fluctuates territorially from 400 to 1800 mm.

Table 8.6 provides data of some meteorological stations on the average annual amount of atmospheric precipitations and indexes of their variation (variation coefficient). It is known that the

lower is the sum of precipitations; the higher is the continentality and the variation coefficient. The variation coefficient of annual sums in western Georgia varies from 0.12 to 0.21, and in eastern Georgia—from 0.15 to 0.28. For comparison, we provided the data of some meteorological stations of Europe located in the latitude of Georgia.

Autumn and winter in the coastal zone of western Georgia are notable with precipitations, and spring is dry. Summer is rainy in high mountainous areas. The driest months in eastern Georgia are January and August, May and June are notable with abundant precipitation, and the secondary maximum is in September–October.

The following types of annual course of precipitations are distinguished in the territory of Georgia: **(a)** marine (maximum precipitation—in autumn, minimum—in spring), **(b)** Mediterranean (maximum—in winter, minimum—in summer), **(c)** continental (maximum—in spring or summer, minimum—in winter), **(d)** transition (maximum—in winter or summer, minimum—in spring), and **(e)** mixed (maximum—in autumn, minimum—in summer or winter).

Two main types are distinguished in the diurnal course of precipitations: marine and continental. The marine type prevails in the most parts of western Georgia—precipitations mostly

**Table 8.6** Average multi-annual sums of atmospheric precipitations and their variability

Weather station	Height above sea level (m)	Average multi-annual sum of precipitation (mm)	Variation coefficient (Cv)
Poti	3	1661	0.18
Batumi	5	2531	0.17
Sokhumi	116	1478	0.16
Kutaisi	114	1380	0.19
Gardabani	300	378	0.19
Tbilisi, observ	403	505	0.23
Gori	588	498	0.21
Akhalkalaki	1716	533	0.21
Kazbegi h/m	3653	1404	0.30
Rome	20	803	0.21
Tirana	89	1189	0.24
Belgrad	132	653	0.20
Sofia	540	622	0.25

fall in the morning hours; the continental type prevails in eastern Georgia—precipitations mostly fall in the evening.

The highest diurnal record maximum (350 mm) falls in Lanchkhuti. The heavy rain intensity is higher in eastern Georgia (7.3 mm/min in the village Tsemi).

The number of precipitation days (more than 0.1 mm precipitation in a day) in western Georgia varies from 203 (Bakhmaro) to 135 days (Gagra), and in eastern Georgia—from 183 (Gudauri) to 89 days (Gardabani). In the mountainous countries, particularly important is such number of precipitation days, when the precipitation diurnal sum exceeds 30 mm. The number of such days is from 1 to 28 days in western Georgia, and in eastern Georgia, it varies within 0.4–11 days.

The precipitation fallen in the cold period in the territory of Georgia is almost everywhere less compared to the warm period. The north-western part of Apkhazeti is an exception. The frequency of cyclonic activity causes the abundance of precipitations in winter. Similar situation is in the inner mountainous Adjara and in the central part of Meskhети Range.

In most parts of the territory of Georgia, 50–70% of precipitation fall in warm spells. The amount of precipitations fallen in warm period in western Georgia varies by territory within 300–800 mm and in eastern Georgia—within 160–600 mm.

**Snow cover.** Due to the diversity of mountainous terrain and climate, both the number of snowy days and snow height considerably vary in the territory of our country. The duration of snow cover along with the increasing of altitude, increases rapidly, though in the eastern part of the highland of southern Georgia it does not obey this regularity and the number of snowy days is particularly small there. On the southern slope of the Caucasus, over 2500 m above sea level, the duration of snow cover is over 200 days. The permanent snow and glacier zone starts from about 3000–3200 m on average, which is located lower (2700–3200 m) in the western part of the southern slope of the Caucasus, compared to the eastern part (3200–3400 m).

Places in western Georgia located over 1000 m and in eastern Georgia—over 1200 m, are covered by snow throughout the winter.

Snow cover in the coastal line appears in the first decade of January and in the lower part of eastern Georgia—in the third decade of December. In the lowland, the average height of snow cover varies between 2 and 20 cm. According to the altitude of the site, its thickness significantly increases and exceeds 150 cm in the high-mountain zone of the Caucasus.

**The wind.** The origination of winds is closely related to the uneven heating and pressure distribution of the territory. The formation of wind regimes in our country greatly depends on the seasonal distribution of pressure on the Eurasian continent, the Black Sea and Caspian Sea basins, and complex orographic conditions.

In western Georgia, the eastern (terrestrial) winds are dominated in winter, and in summer, vice versa—the western (marine) winds are dominated. In west Georgia, the frequency of western winds is intensified by local winds—breezes, while in the eastern winds—by foehns. Except for the mentioned winds, in Georgia quite often emerge local, mountain-gorge winds.

Territorially the average annual wind speed in Georgia varies from 0.6 (Abastumani) to 9.2 m/s (Mount Sabueti). The number of strong wind (15 m/s) days is quite frequent; in this regard, Kutaisi (63 days a year) is distinguished in western Georgia, Khashuri (52 days)—in eastern Georgia, and in Likhi Range, in the Mount Sabueti, where the use of wind energy is foreseen, 162 days are windy. According to the wind regime along with other meteorological elements, it is obvious that the Likhi Range is a climate shed between western and eastern parts of Georgia.

In our country, warm and dry winds—foehns are distinguished by their frequency, direction of which is related to the locality; for example, in the Rioni River gorge the eastern winds are of foehn character and in the Mtkvari River gorge—the western winds are. Foehns are frequent and very strong in Imereti (Ajameti, Kutaisi, Sakara, and others). During the strong foehn, the wind speed may exceed 40 m/s, while the air

temperature rises by 10–15 °C and the relative humidity falls down even to 10%.

### 8.2 Hazardous Meteorological Phenomena

In Georgia, especially in its eastern part, the number of hail days can make up to 16–20 days a year. However, this number is only approximate, because the observer cannot notice the hail fallen far from the meteorological station. According to genesis the two types of hail are notable: frontal and intramassive. 80% of hail is a frontal character.

Hail is a rare phenomenon in western Georgia, and in eastern Georgia, the three main regions are distinguished according to hail days: central part of the upland of southern Georgia, south-eastern slope of the Caucasus Range, and Alazani Valley, or Shiga Kakheti (Fig. 8.3). In the first two regions, the loss caused by hail is not great, because hail falls on the pastures and cheap farm crops. As for Kakheti, almost every year, in June,

especially in May, hail falls on extensive farm crops like a vine, and therefore the country suffers great material losses.

Hail falls unsynchronized, which can be explained by the peculiarities of the orographic conditions, and what is most important, by the complex physical processes, which takes place in the hail clouds, especially in their motion. Hail falls in fragments in individual segments, and there are frequent cases in Kakheti, when hail falls in one village and does not fall in its neighboring one. Though, the harvest loss is still high. For example, in 1990–1992, because of hail fallen on 20 thousand hectares, the loss reached 25–30 mln GEL.

Among the hazardous phenomena strong winds ( $\geq 15$  m/s) occupy a special place. In Georgia, they are mainly observed in February and May, damaging high voltage power lines, hindering traffic work, etc., thus obviously cause a great material damage to the country. There may be distinguished several regions with strong winds on the territory of Georgia:

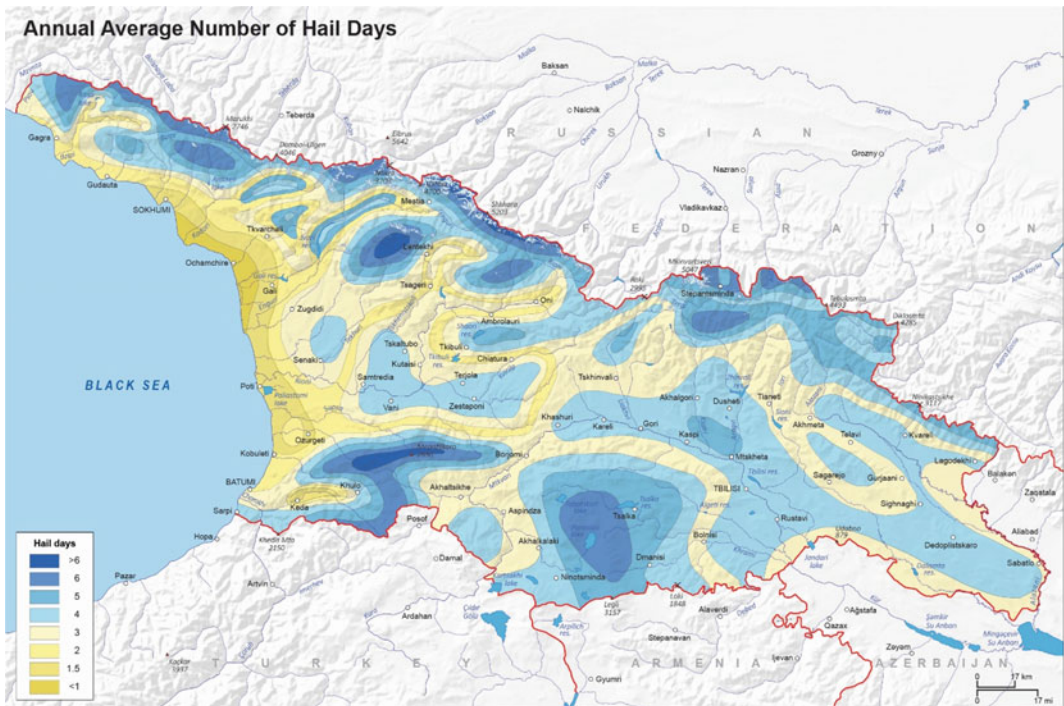


Fig. 8.3 Annual average number of hail days (National Atlas of Georgia, Steiner-Verlag, 2018)



1. The river Rioni gorge (Kutaisi);
2. The river Mtkvari gorge (Tbilisi-Samgori);
3. The western slope of the Likhi Range (Mount Sabueti).

It should be noted that in the latter region a number of days with strong winds ( $\geq 15$  m/s) is 141 days a year.

Georgia's complex relief of high hypsometry and the circular processes developed there, lead to the frequency of **thunderstorm** days throughout the country's territory, especially in its mountainous regions. For example, in Akhalkalaki and Bakuriani, it is 60 days a year, sometimes even 80–85 days. In Tbilisi, it reaches 35; mainly in May and June.

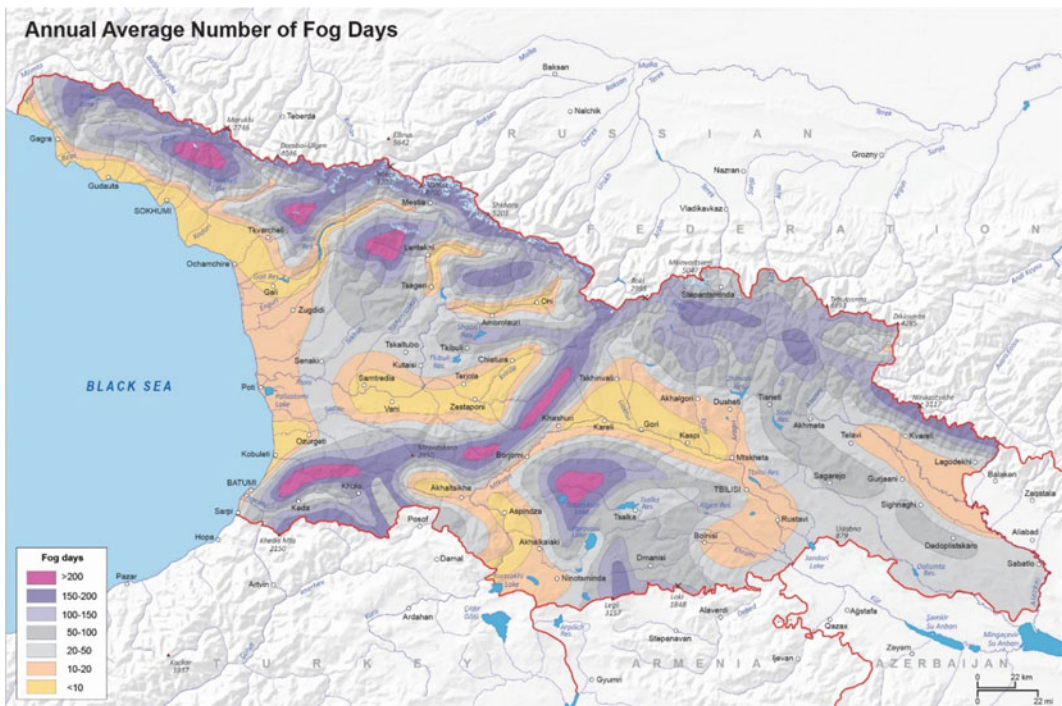
It is noteworthy that thunderstorm is often a cause of hindering aviation transport and electrical communication. It can also cause the forest fire.

Distribution of number of **foggy** days in the territory of Georgia is mainly of fragmentary or uneven character, which is stipulated by the complex orography of the study area (Fig. 8.4). Annually the number of foggy days fluctuates

within wide range, from 6 (Black Sea coast, Gagra) to 260 days (Mount Sabueti). Along with the increase in height, it increases both in western Georgia and eastern Georgia. For example, the number of foggy days in Gagra range is 189, on the Mount Mtrala—211, and on Tskhratskaro (2466 m)—241 days. The foggy days in Tbilisi are up to 35, mainly in the cold period of the year—in December and January, which significantly hinders transport movement (Reference book 1970).

In Georgia, as well as in the whole Caucasus, **droughty** years are quite frequent that the majority of researchers associated with the global warming climate. In the last decades, the droughty years can be considered 1976, 1992, 1996, 1998–2000, 2006, and 2010.

The drought of the summer of 2000 was distinguished with special strength, which led to an ecological catastrophe in the plain of eastern Georgia. According to the Tbilisi Airport data, a strong wind blew during 19 days, which contributed to the strong drying of soil arable layer. Loss reached several hundred million GEL. It is



**Fig. 8.4** Annual average number of fog days (National Atlas of Georgia, Steiner-Verlag, 2018)



worth to note the summer drought of 2010 when the air temperature exceeded many years norm by several degrees (5–6 °C). This period was especially difficult for one-year crops and vineyards.

### 8.3 Climate Types

The famous climatologist M. Kordzakhia having relied on the solar radiation regime, atmospheric circulation feature, and the weather conditions associated with them, divides the territory of Georgian into two circulation-climatic districts and one subdistrict (see a map—Climate Types), which, in turn, are divided into climatic zones, regions, and subregions. The author himself thinks that the climatic division of Georgia is schematic, even though, it is based on the most perfect and widespread classification of V. Kiopen (Kordzakhia 1961). We can say that we do not have a better and more precise division of climate of Georgian in Georgian climatology yet.

#### The marine subtropical humid zone

1. The marine humid climate with warm winter and hot summer:
  - (a) Excessively humid subzone with the prevailing throughout the year marine winds and maximum amount of precipitations in autumn and winter;
  - (b) Humid subzone with well-expressed musson winds and maximum amount of precipitations in summer and autumn;
  - (c) Sufficiently humid subzone with the abundance of northern winds throughout the year and a low fluctuation of number of precipitations by seasons.
2. Sufficiently humid climate with moderately cold winter and a relatively dry hot summer;
3. The humid climate with moderately cold winter and a lasting warm summer;
4. The humid climate with cold winter and lasting cool summer;

5. The humid climate with cold winter and short summer;
6. The high-mountain humid climate with the lack of true summer;
7. The high-mountain humid climate with abundant of permanent snow and glaciers.

#### Moderate humid subtropical climate zone

8. Climate of moderately warm steppes with hot summer and two precipitation minimums per year;
9. Transition from moderate warm step climate to moderate humid climate with hot summer and two precipitation minimums a year;
10. Moderate humid climate with moderate cold winter and hot summer and two precipitation minimums a year;
11. Moderate humid climate with moderate cold winter and lasting warm summer and two precipitation minimums a year;
12. Moderate humid climate with cold winter and lasting summer and two precipitation minimums a year;
13. Moderate humid climate with cold winter and lasting cool summer and precipitation minimum in winter;
14. Transition from marine humid climate to moderate humid continental climate with snowy cold winter and lasting summer;
15. Transition from marine humid climate to moderate humid continental climate with snowy cold winter and short summer;
16. Moderate humid climate with cold winter and short summer and precipitation minimum in winter;
17. High-mountain moderate humid climate with the lack of summer;
18. High-mountain climate with permanent snow and glaciers.

#### Climate subzone transition from moderate humid subtropical climate to dry subtropical climate of Western Asian highland

19. Transition from moderate humid climate to mountain steppes climate with cold winter and lasting summer;

20. Highland steppes climate with light snowy cold winter and lasting warm summer;
21. Highland steppes climate with light snowy cold winter and lasting cool summer;
22. Highland steppes climate with short summer and light snowy cold winter;
23. High-mountain moderate dry climate with the lack of true summer.

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## 8.4 Climate Change

The climate has undergone sharp changes in geologic epochs. According to A. Borisov (1965), a humid tropical climate was in the Paleozoic territory of Georgia in the Proterozoic Era (2 billion years ago). The same climate was in Paleozoic (500 million years ago) too, and in the Mesozoic Era (155 million years ago) the subtropical climate was prevalent. The Cenozoic Era is interesting in terms of climate, as the certain radiation and circular factors of the atmosphere are developed in this period, and creation of modern natural conditions is associated with them. In the Tertiary period, the climate of Georgia was warmer compared to modern one. It was tropical. In the nearest geologic past—in Pleistocene, which is the largest section of the Quaternary period, the climate of Georgia, like the climate of other countries, has undergone significant changes. This is the time when the glacial and interglacial periods alternated with each other. If we take into account the increase in amplitude of climate change in Northern Hemisphere by latitudes and the function of the climate “wall” of the Caucasus, which has been weakening the southern distribution of cooling mechanism (in the form of sheet glaciers) directed from the north; these are the arguments that confirm the opinion of great geographer—L. Maruashvili (1956) on the fact that unlike the Alps, where Penny and e. Brühner confirm the four times glaciation (Günz, Mindel, Riss, Würm), there were only three glaciations with less power in the Caucasus, in particular in Georgia. That is why, during the glaciation, the

air temperature was 2–3 °C lower, and in the interglacial epochs higher by 2–4 °C compared to modern period.

As it was already noted, the recordings of travelers and historians about past climates that have reached us, do not allow us to think that during the last 2.5–3 thousand years the climate has been thoroughly changed, especially in Georgia.

Modern climate change is determined by many factors, the most important of which are solar activity, atmospheric circulation, volcanic eruptions, and anthropogenic influence.

Anthropogenic factors of climate change are considered: intensive growth of energy generated by humans, an important increase in carbon dioxide in the atmosphere, accompanied by “greenhouse effect”, change in concentration of atmospheric aerosols, and predatory exploitation of sub-surface.

All types of resources (oil, coal, natural gas, atomic, etc.) used by humans will eventually turn into heat, which is 41.9–62.8 m.joule/m<sup>2</sup> for developed industrial areas. It is calculated that an annual increase of production energy by 6% of will stipulate the increase in air temperature by 30% after one century.

Significant increase in carbon dioxide (CO<sub>2</sub>) is important in the study of anthropogenic influence on the climate. Yet in 1909, the famous Swedish scientist Svante Augustus Arrhenius (1859–1927) first noted the role of carbon dioxide as regulator of land surface air temperature. The feature of this gas is to let the solar rays pass to the surface of the earth and at the same time, to perform the role of the screen, which significantly restricts the scattering of heat from the earth into the atmosphere, as well as creates a “greenhouse effect” mechanism that contributes to the global increase in air temperature. Based on a number of studies, it is assumed that the content of the CO<sub>2</sub> in the atmosphere will be doubled by 2025 in comparison to 1850, which will increase air temperature by 2°–3°. However, not everybody shares such an opinion.

An important factor of climate change is the increase in the concentration of anthropogenic

aerosols. A large-scale change in the biosphere with uncontrolled economic activity of humans can lead to climate cataclysms that have occurred over historical epochs. For example, it is enough to name the thinning of ozone layer, in some cases even its perforation, the water, and air pollution, decrease in quantity and species of flora and fauna, etc. The problem is a global character and it is the subject of great interest in scientists.

In parallel with the modern climate change, in particular, the global warming, stipulated by anthropogenic factors, there is another idea, according to which the human race has already “entered the Little Ice Age” and that the future climatic background will be similar to the climatic conditions typical to the period between the sixteenth-seventeenth centuries when the global air temperature was less by 0.5–1.0 °C than many years norm.

From the end of the nineteenth century, the modern climate change, which was marked by considerable increase in air temperature, namely by 0.75 °C, covered almost all of the earth (Mumladze 1991). It is obvious that Georgia is no exception. The calculation proves that during the last 150 years, the average annual air temperature has increased by 0.6 °C in Georgia, mainly due to increase in winter temperature. In the last decades, the average air temperature of winter (mainly in January) has increased by about 1.3 °C mostly in eastern Georgia.

A complex study of climate main elements shows that for the last 4–5 decades, there has been an unfavorable regime of climate in Georgia. More frequent are droughts, strong winds, and at the same time, the abundant atmospheric precipitations that are accompanied by floods and landslides.

This mentioned change in climate along with aggravating ecological problems will create more difficulties for our country’s economy, especially in the plain area, where the exploitation of natural resources has exceeded the permitted limits a long time ago.

## References

- Archer D (2008) *Global warming, understanding the forecast*, 1st addition. Wiley-Blackwell
- Bagrationi V (1997) *Geography of Georgia*. Metsniereba, Tbilisi
- Borisov AA (1965) *Paleoclimates of the territory of the USSR*. Leningrad
- Climate Change, 2007 (2007) *Synthesis report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Pachauri RK, Rasinger A, and the main group of authors (eds). IPCC, Geneva, Switzerland, 104p
- Climate Scientific-Applied Reference Book of Georgia, Part I. *Separate Climatic Characters* (2004) Editorial Board: E. Elizbarashvili, L. Papinashvili, L. Kartvelishvili, N. Chikhradze. Bakur Sulakauri Publishing House. УДК 551.582(083) (479.22). Tbilisi
- Climatology (1989) Drozdova OA et al (ed) Leningrad
- Don Arcangelo Lambert (1991) *Description of Samegrelo*. Tbilisi
- Gagua G, Mumladze, Javakhishvili Sh (2000) *Climate*. In: Tatashidze et al (eds) *Geography of Georgia. Part I Physical geography*. Metsniereba, Tbilisi (in Georgian)
- James P, Martin J (1988) *All possible worlds (History of geographical ideas)*, Moscow
- Javakhishvili Sh (1977) *Climatology of Georgian SSR*. Tbilisi
- Javakhishvili Sh (1981) *Atmospheric precipitations on the territory of Georgia*. Tbilisi
- Javakhishvili Iv (1983) *Collection of works, vol II*. Tbilisi
- Kaukhchishvili T (1965) *Hippocrates and its information about Georgia*. Tbilisi
- Kordzakhia M (1961) *Climate of Georgia*. Tbilisi
- Maruashvili L (1956) *The expediency of reviewing existing ideas about the paleogeographic conditions of glacial period in the Caucasus*. Tb. P/H. Academy of Sciences of Georgia
- Mumladze D (1988) *Climate change in Kolkheti. Works of the Geographical Society of Georgian SSR, vol 17*. Tbilisi
- Mumladze D (1991) *The modern change of climate of Georgia*. Tbilisi
- Polievktov MA (1935) *European travelers of 13–18 centuries in the Caucasus*. Tiflis
- Reference book of the climate of the USSR (1967) No. 14. Air and soil temperatures. L
- Reference book of the climate of the USSR (1968) No. 14. Solar radiation, radiation balance and sunshine
- Reference book of the climate of the USSR (1970) No. 14. Cloudiness and atmospheric phenomena. L
- Vladimirov LA et al (1962) *To the hypsometry of the river basins of Georgia*. Bulletin of the Academy of Sciences of Georgian SSR, vol 28, № 4. IPCC, 2007