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Spatiotemporal aspects of interannual changes precipitation in the crimea

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ABSTRACT

Regional climate change affects natural processes, including the amount of precipitation and the spatiotemporal differentiation of areal precipitation. The study of such changes is especially important for the Crimea due to the aridity and the lack of water resources therein. In this study, we carried out regression modelling of the areal precipitation in the Crimea using data from 24 weather stations. The maps of precipitation in the Crimea within set epochs and periods were calculated based on the classification of atmospheric circulation processes in the Northern Hemisphere. The trends in the spatiotemporal dynamics of atmosphere areal precipitation due to the change in dominant circulation groups were shown. In general, the territory of the Crimea was characterised to have increasing precipitation during the period of instrumental measurements.

1. Introduction

The spatiotemporal distribution of precipitation is influenced by many factors such as the distance from the sea (Tim, Bravo de Guenni, 2016), the circulation of air masses (Nojarov, 2017), and the orographic peculiarities of land surface (Baldwin et al., 2019, Junquas et al., 2018). Considering the peculiarities of the spatial distribution of precipitation (Bac-Bronowicz and Grzempowski, 2018), the trends of land use can be rationalised.

Precipitation determines climate comfortability, specificity of agriculture, and water balance, which is of importance for the Crimean Peninsula. In this regard, not only the common peculiarities of precipitation with respect to agriculture (Rybalko and Baranova, 2018; Gorina et al., 2018), but also the frequency of extreme precipitation (or its absence) (Vyshkvarkova et al., 2016; Kholoptsev et al., 2018, Vyshkvarkova and Voskresenskaya, 2018) have been studied.

The authors hypothesised the increase in the precipitation in the area of the Crimean Peninsula based on the analysis of available literature and obtained spatiotemporal data. Previous studies have examined either the separate territories (foothill, southern coast of Crimea, etc.) (Mayboroda et al., 2018; Zhuk and Ergina, 2018) or the whole territory of Crimea (Ergina and Zhuk, 2017). Here, we decided to generalise the available information and describe the obtained data for the whole territory of the Crimean Peninsula.

Insufficient water resources, which leads to the shortage of fresh water, is one of the known features of the Crimean Peninsula. Currently, its main sources of fresh water are groundwater and precipitation, which are key components for the hydrological cycle that directly affects human societies (Barrett and Santos, 2014). According to previous works (Bokov, 2011; Cordova, 2016), the annual precipitation on the coast of the Black and Azov seas are about 300 mm; in the flat Crimea, 400–450 mm; in the foothills, 500–600 mm; in the mountains, more than 1000 mm; in the Western part of the Southern Coast of the Crimea (SCC), 400–600 mm; and in the Eastern part, 300–500 mm. The percentage of the annual precipitation that falls during the cold period, from November to March, is 20–25%, and 70–75% during the warm period from April to October. The intra- and interannual allocation of precipitation in the Crimean Peninsula has a number of features. Precipitation falls least in the flat Crimea in February and March, and in the mountainous Crimea and on the SCC, in May and August. The greatest amount of precipitation falls in June or July in the foothills and in January or December in the mountains on the southern coast of Crimea. The fluctuation of the amplitude of precipitation varies sharply from year to year. According to the data (Logvinova and Barabash, 1982) annual amplitudes range from 200–300 mm to 700–900 mm with average values of 450–490 mm in the foothills, from 200 to 300 to 1000 mm with average values of 430–650 mm in the SCC, and 410–1650 mm with the average value of 960 mm in the western parts of yails (the remnant-denudation plateau under the plant communities of mountain meadows, hornbeam forests, and undulating plateau with mountain

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meadows).

The allocation of precipitation is directly related to landforms (Lemus-Canovas et al., 2019; Mei et al., 2018). The southern and western windward slopes of the hills in the Crimean Peninsula receive more precipitation than the closed depressions and valleys (Bokov, 2011). The annual precipitation cycle in the greater part of the studied area matches a semi-continental type, with a slight excess of precipitation in the spring-summer period and maximum precipitation in the summer (EEA, 2017; Hatzaki, Wu, 2015). The SCC, the south-western part of the Crimean Mountains, and the west coast have a non-continental type of annual precipitation cycle with a significant excess of precipitation during the autumn-winter period (Logvinova and Barabash, 1982).

A number of works were devoted to the study of the spatiotemporal variability of areal precipitation. Parubets (2009, 2009a) showed that during the period of 1916–1986, in the territory of Crimea, there was a slow increase in the average annual precipitation. The cycles for both the entire Peninsula and its individual regions were also identified. Holoptsev and Parubets (2014) found that after 1970, there was a trend of increasing precipitation during some winter months and winter in general. They explained that this phenomenon occurs due to the cooling effect on the western part of the Black sea by the Mediterranean air that moves towards the Peninsula. Similar results of the interannual variability of precipitation were published in the works of Kosovets, Donich (2014), Nesterenko (2016), Carlos, and Cordova (2016).

Annual variability complicates the spatial picture of the increase of precipitation in the Crimea. Noake et al. (2012) and Polson et al. (2013) paid attention to the fact that the analysis of changes in local precipitation remains difficult due to the low resolution of the input data. Nevertheless, Bhend et al. (2008) showed the increase of the average observed precipitation in every decade since 1961 for Northern Europe which corresponds to the calculated growth. In the work of Holoptsev and Astafieva (2014), it was shown that in the western and south-western Crimea, during the period 1950–2012, there was a decrease of precipitation in the winter and an increase during spring (by March), which are due to the changes in the surface temperatures of adjoining waters. On the territory of the SSC, the maximum precipitation falls in December–January and the minimum, during spring. Mayboroda et al. (2017, 2017a) showed that in the western part of the SSC region, the amount of precipitation had increased until the end of the 1990s, and it decreased thereafter. The works of Balan Sarojini et al. (2012), Polson et al. (2013), and Bhend et al. (2008) indicated that to estimate and predict the in-season change of precipitation using data from a long period of measurements on a regional scale or on a smaller scale, it is necessary to identify the regional features of the factors affecting the change in precipitation, such as the anthropogenic factor or the atmospheric circulation factor.

The works of Vyshkvarkova et al. (2013, 2014, 2016), Zolina et al. (2004), Stocker et al. (2013) and EEA (2017) were dedicated to the study of extreme precipitation over the Peninsula. They showed that maximum of the extreme precipitation during winter occur in the Crimean Mountains, during the period of observation, as summer precipitation was allocated evenly. The forecasting of cases with extreme precipitation in the middle and at the end of the 21st century showed a change in their normally increasing trend.

In the work of Kononova and Parubets (Bokov, 2011), the influence of the atmospheric circulation in the Northern Hemisphere on the changes in precipitation were determined based on the data from six meteorological stations in the Crimea. The authors showed the features of spatial differentiation of precipitation within the boundaries of the circulation epochs and periods in the Northern Hemisphere.

There remains an absence of a full understanding of the spatial differentiation of the atmospheric areal precipitation on the territory of the Crimean Peninsula and the spatiotemporal dynamics in those areas as a result of climate change during the period of instrumental measurements. In view of this, the purpose of this work is to describe the spatial differentiation of the areal precipitation in the Crimea and to analyse the spatial changes in the precipitation in the Crimea due to the change in circulation epochs and periods in the Northern Hemisphere in the 20th century up to the beginning of the 21st century. The aim of the study is to show that change in circulation epochs and periods in the Northern Hemisphere at the regional level (Crimean Peninsula) and demonstrate the asynchronous change in the spatiotemporal differentiation of the precipitation areas.

2. Materials & methods

To describe the effect of atmospheric circulation on the formation of precipitation areas, the classification of elementary circulation mechanisms proposed by Dzerdzeevsky et al. (1946, 1968) was used. The classification identifies 41 elementary circulation mechanisms (ECMs), which differ in the direction and the number of simultaneous Arctic invasions (blocking processes) and outputs of southern cyclones in the hemisphere. Each type of ECM in each area has its characteristic weather (synoptic) conditions with corresponding precipitation indicators. It allows us to analyse the influence of atmospheric circulation on the formation of precipitation areas on the basis of the classification of the ECMs.

The ECMs, in accordance with the direction of the movement of baric formations in the hemisphere, were combined into four groups of circulation: zonal group (no blocking processes), zonal disturbance group (1 blocking process in the hemisphere), northern meridional group (2–4 blocking processes; 2–4 outputs of southern cyclones), and southern meridional group (cyclonic circulation over the Arctic without blocking processes; 2–4 outputs of southern cyclones in the hemisphere). Each ECM lasts for several days. The change of one ECM to another since January 1, 1899 is fixed in the calendar of consecutive change of the ECM (http://atmospheric-circulation.ru). An important feature of this classification is the existence of dynamic schemes for each type of ECM; therefore, the state of atmospheric circulation can be characterised over the extra-tropical latitudes of the entire Northern Hemisphere. This allowed us to track the movement of baric formations in a particular region.

The analysis of the deviations of the total annual duration of the northern meridional, southern meridional, and common zonal circulation groups enabled the identification of long periods (several decades) of positive anomalies in the duration of any circulation group. These periods are called circulation epochs (Dzerdzeevsky, 1956).

Since 1899, three circulation epochs have occurred in the Northern Hemisphere: two meridional (from 1899 to 1915 and from 1957–present) and one zonal (1916–1956) (Table 1).

The mapping of precipitation in the Crimea is usually focused on the mapping in the Crimean Mountains (Bokov, 2011; Bokov, 2010; Glushchenko, 2012). Because of this, the flat part of the Peninsula remains insufficiently explored. Using the results of previous studies, and considering the good results of the regression modelling of the areal precipitation in the Crimean Mountains, we attempted to build a regression model describing the flow of precipitation over the entire Crimean Peninsula.

We chose the following factors that influence the spatial differentiation of precipitation in the Crimea as the basis for modelling: the altitude above the sea, dissected terrain in a circle of a specified radius, difference in the heights of the terrain in relation to the prevailing moisture-bearing air masses in a circle of a given radius, forestation of the territory, distance from the coast, and distance from the axis of the main ridge of the Crimean Mountains. Some of these factors showed good results in the modelling of areal precipitation in previous works.

The research was carried out based on the data from the existing 24 weather stations in the Crimea for the entire period for which they have been operational (Table 2). The annual precipitation values were calculated for the entire period of observation of the weather station until 2013.

Table 1
Boundaries of the circulation epochs of the Northern hemisphere and periods within the third epoch (http://atmospheric-circulation.ru).

Circulation epoch	Duration of the epoch	Periods of epochs	Duration of the periods
Northern meridional	1899–1915		
Zonal	1916–1956		
Southern meridional	1957–present	Simultaneous increase of duration of the Northern and Southern meridional processes	1957–1969
		Increase of the duration of zonal processes	1970–1980
		Rapid growth of the duration of the Southern meridional processes	1981–1997
		Decrease of the duration of the Southern meridional processes and growth of the Northern meridional processes	1998–2018

The Shuttle Radar Topography Mission (SRTM) space image with the spatial resolution of 30 m was used to construct layers considering the characteristics of the terrain surface. The calculation of the forested area was made on the basis of Landsat 8 satellite image data with a spatial resolution of 30 m. Based on the images, a landscape layer was obtained to determine the forest areas and to calculate the percentage of forestation for a given radius. All works were made in ArcGIS 10.2 within the geographic coordinate system UTM WGS 1984.

The height of the raster cells above sea level was determined using the SRTM image. The relationship between altitude and precipitation are showed in Fig. 1.

The dissected terrain was calculated for each cell of the raster using focal statistics by calculating the difference between the maximum and minimum heights within a circle of a given radius. The best values for the correlation coefficients between precipitation and the dissected terrain were obtained when the values of dissection were within a radius of 6 km. The radius was determined by a series of cartographic experiments and by calculating the correlation coefficients with respect to the values of the dissected terrain and circles of different radii.

Fig. 2 shows the relationship between precipitation and the dissected terrain within a radius of 6 km.

Table 2
Weather stations in the Crimea.

WMO_ID	Weather station	Latitude	Longitude
33933	Ishun	45.926826	33.81596
33922	Razdolnoe	45.774075	33.476554
33934	Dzhankoi	45.704188	34.399811
33924	Chernomorskoe	45.521585	32.716105
33939	Klepinino	45.528945	34.181708
33962	Nizhnegorsky	45.44663	34.709921
33981	Mysovoe	45.449781	35.82272
33983	Kerch	45.374082	36.414785
33986	Opasnoe	45.368751	36.628949
33929	Evpatoria	45.189741	33.374426
33973	Vladislavovka	45.170356	35.37965
33966	Belogorsk	45.045392	34.598613
33946	Simferopol	45.040227	33.967153
33976	Feodosia	45.037194	35.381273
33957	Karadag	44.91203	35.198289
33960	Karabi	44.872405	34.505487
33945	Pochtovoe	44.832385	33.943667
33958	Angarsky Pass	44.755558	34.341097
33959	Alushta	44.674944	34.416347
33994	Khersonesus lighthouse	44.583151	33.382112
33991	Sevastopol	44.616882	33.532403
33999	Ai-Petri	44.469025	34.068282
33990	Yalta	44.481192	34.155302
33995	Nikita Garden	44.512668	34.240199

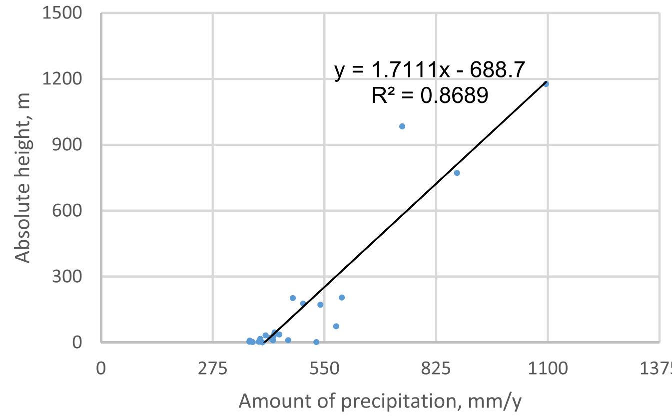

Fig. 1. Relationship between precipitation and the altitude of the terrain.

The difference between the heights of the landscape surface in the direction of the prevailing moisture-bearing air masses within the circle of a given radius were calculated through focal statistics and a raster calculator. For this purpose, the difference between the average height in a given sector of the circle with a radius of 6 km and the average height in the circle with a radius of 6 km was calculated. Calculations were made for four points: 0–90° (North-East direction), 90–180° (South-East direction), 180–270° (South-West direction) and 270–360° (North-West direction). Reliable values of the correlation coefficient were marked by the amount of precipitation with the dissected terrain in the North-East (−0.65) and South-West (0.69) directions. The relationship between the amount of precipitation and the height difference of the terrain towards the prevailing moisture-bearing air masses within the circle with a 6 km radius are shown in Figs. 3 and 4.

The distances from the seashore to both axes of the Main ridge of the Crimean Mountains were calculated using the proximity function for each cell of the raster. However, the correlation coefficients between the above factors and precipitation were below the reliability threshold. Therefore, we decided not to consider these factors in the regression data analysis.

Finally, a set of layers of input variables for regression analysis was defined. The values of these parameters were extracted from the data from the weather stations, and regression analysis was performed. The reliability of the final model was 96%. The resulting regression equation was used in the raster calculator to create a precipitation map.

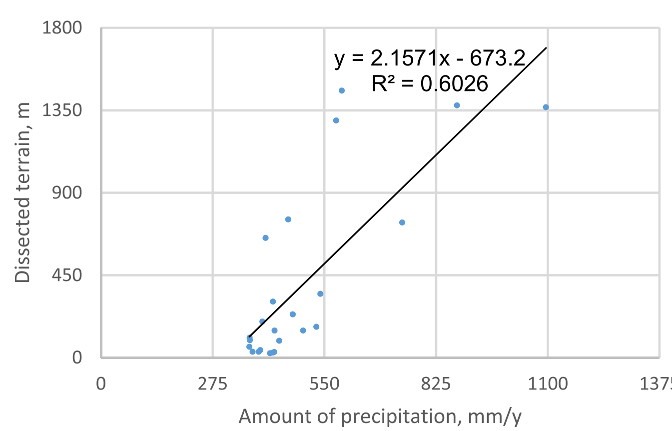

Fig. 2. Relationship between precipitation and the dissected terrain within the raster circle with a radius of 6 km.

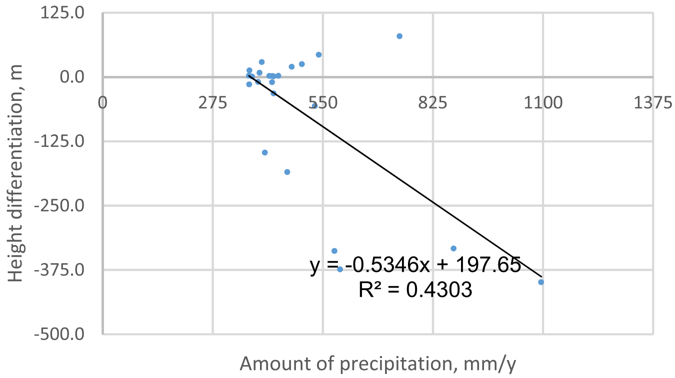

Fig. 3. Relationship between precipitation and the height difference of the terrain towards the northeast air masses within the raster circle with a radius of 6 km.

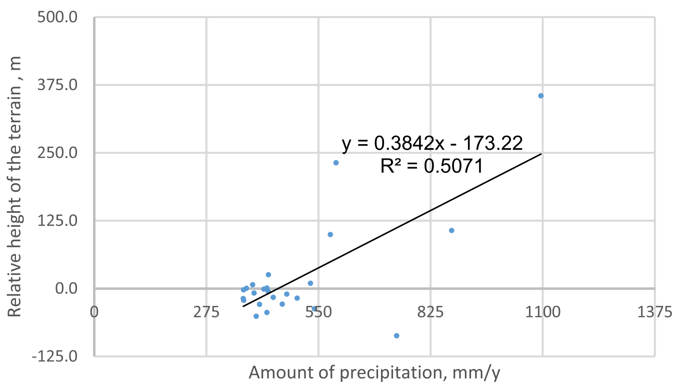

Fig. 4. Relationship between precipitation and the relative height of the terrain towards the South-West air masses within the 6 km radius of the raster cell.

3. Results & discussion

Based on results of the regression equation, the average annual precipitation map of the Crimean Peninsula was obtained (Fig. 5).

The map shows that the minimum amount of precipitation, not exceeding 460 mm/y, falls on the territory of flat Crimea. The maximum indicator for this territory was 421–460 mm/y, more specifically on its Central part encompassing the Tarkhankut and Kerch Peninsula and the Novoselov uplift. The minimum values (303–421 mm/y) were obtained for the coasts of the Karkinit and Kalamit bays, in the area of Lake Donuzlav and Prisivashie, as well as the Northern coast of the Kerch Peninsula.

The South-Western sector of the mountains had a maximum precipitation of more than 1200 mm/y. Two identified sectors were within the SCC. Due to the circulating position of the slopes, the precipitation of 500–800 mm/y was obtained for the western section, and less than 500 mm/y was obtained for the eastern section. On the northern macro slope, including the foothills, the maximum precipitation was 460–800 mm/y.

Based on the archival data of the weather stations and the regression modelling of the average annual precipitation, the maps for each circulation epoch and period were created (Fig. 6). However, the northern meridional circulation epoch was not analyzed due to the lack of instrumental data on the Crimea.

The spatial and temporal changes in the precipitation regime in the Crimea were obtained by subtracting the values of the precipitation maps of subsequent epochs or periods (Fig. 7).

During the zonal circulation epoch (1916–1956) the North-West and South cyclones of zonal circulation in the European sector brought precipitation to the Crimea (ECM 1b, 2b, 4c, 5b, 5d, 6, 7aw, 7bs, 8a, 8bs, 8cs, 9b, 11a). During this epoch, the average precipitation on the Peninsula ranged from 358 to 400 mm/y in some coastal areas up to 1000–1139 mm/y in the mountains.

A large part of the Peninsula (the Crimean Plains, Herakleian Peninsula, and part of the southern coast of Crimea, from Sudak to Cape Ilya) had 400–500 mm/y of precipitation. From the Internal ridge to the Main ridge there was a gradual increase in precipitation from 500 to 700 mm/y to a maximum of 1000–1139 mm/y on the remnant-denudation plateau under the plant communities of mountain meadows, hornbeam-beech forests, and undulating plateau with mountain meadows.

The circulation period of the simultaneous increase of the duration of the meridional Northern and Southern processes, which replaced the zonal circulation epoch in 1957, was marked by an increase in

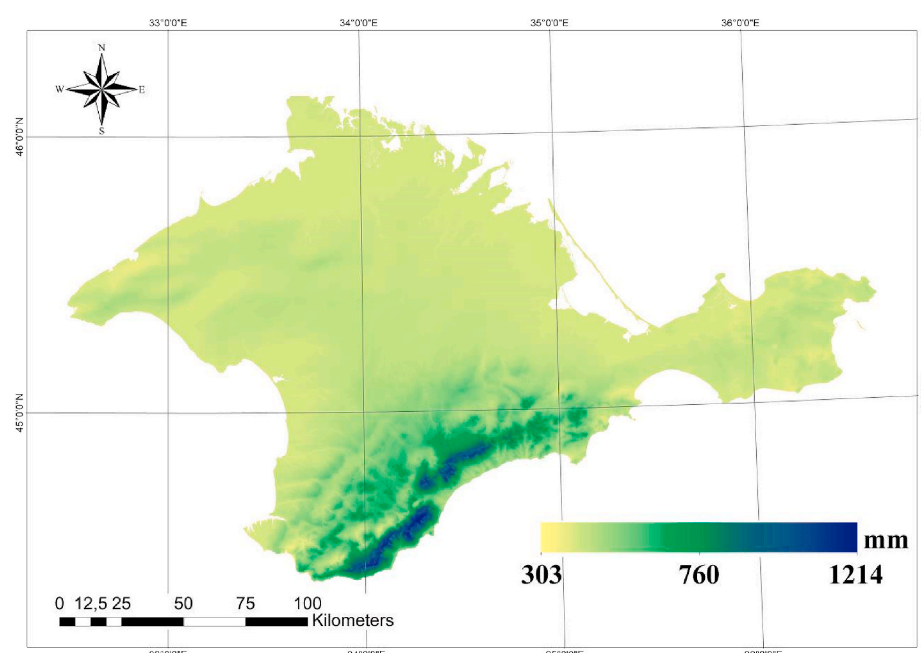

Fig. 5. Average annual precipitation in the Crimea (1916–2013), mm/y.

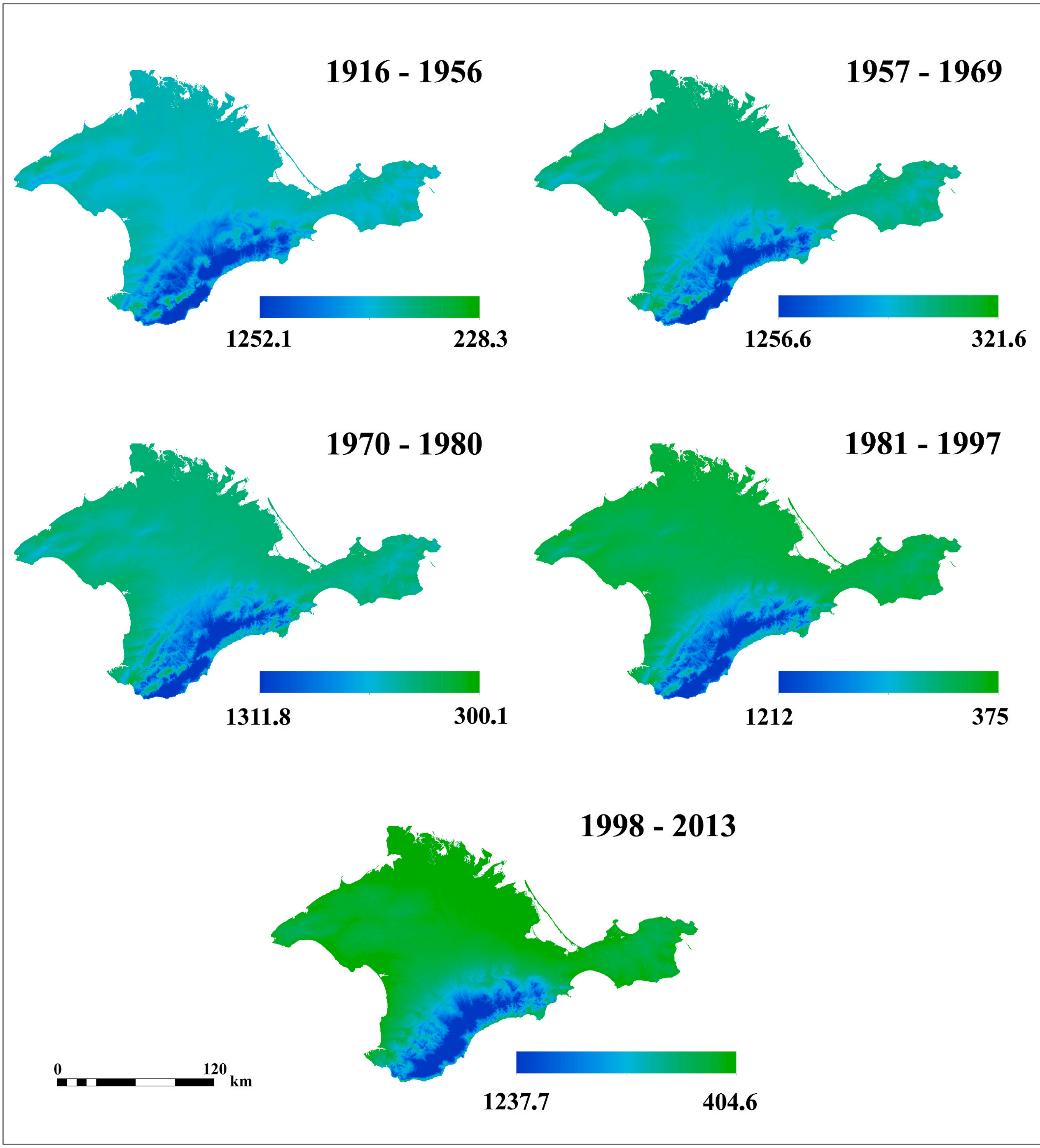

Fig. 6. Changes in the precipitation in the Crimea during epochs and periods of circulation.

precipitation. On the plains of the Crimea, the minimum value of precipitation was 400–500 mm/y. The External and Internal ridge had the same amount of precipitation at 500–600 mm/y. Areas characterised by precipitation of 600–700 mm/y occupied a larger area than in the previous epoch. On the territory of yails, the maximum precipitation of 1100–1187 mm/y was obtained. This value is greater by 48 mm/y in comparison with the zonal circulation epoch.

Values of the mean annual precipitation during the period between the zonal circulation epoch (1916–1956) and the first period of the southern meridional circulation epoch (1957–1969) ranged from 74 mm in the direction of decreasing precipitation (in the area of the Main ridge) to 168 mm in the direction of increasing precipitation (in the area of the Internal ridge) (Fig. 7). The greatest changes in precipitation primarily occurred in the landscapes in the southern part of the Peninsula. The amount of precipitation in the Northern, Western, and Central parts of the Crimean Peninsula did not change significantly. The Central and Western parts of the Crimea were characterised by a small increase in the precipitation (from 20 to 50 mm). Over the entire area of the

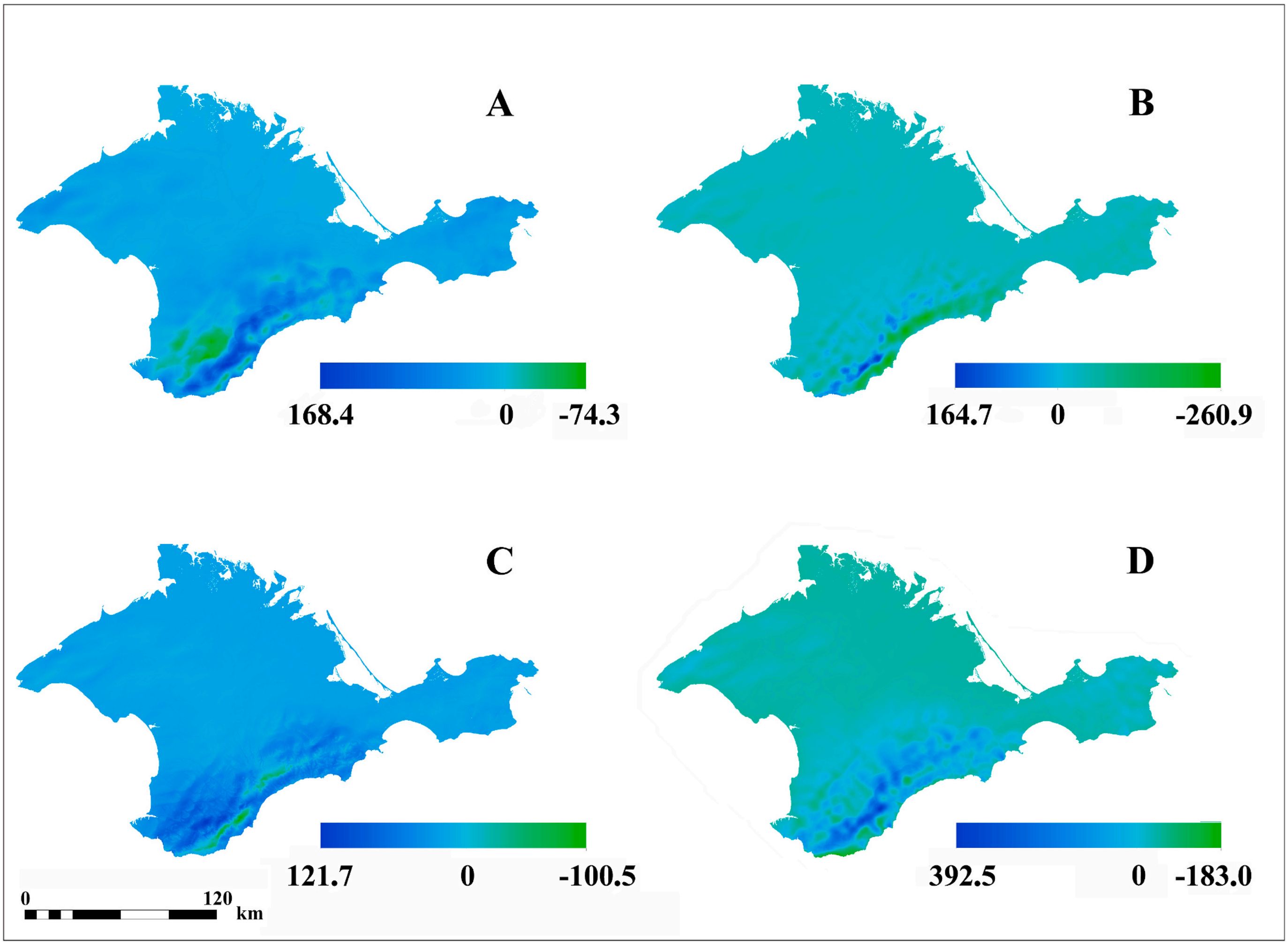

Fig. 7. Spatiotemporal changes in the precipitation in the Crimea: A) between the zonal circulation epoch and the first period of the Southern meridional circulation epoch; B) between the first and the second period of the Southern meridional circulation epoch; C) between the second and the third period of the Southern meridional circulation epoch; D) between the third and fourth period of the Southern meridional circulation epoch.

Kerch Peninsula, precipitation steadily increased by 50 mm. The greatest stress affected the landscapes of the Kachinsky uplift which experienced the largest decrease in precipitation of 240 mm.

In the second period of the meridional southern circulation epoch (1970–1980), duration of all circulation groups was close to the average. The maximum of precipitation for entire analyzed period was obtained. The spatial allocation of precipitation was similar to that of the zonal circulation epoch. During this period, the minimum values of 388–400 mm/y were typical for the same areas during the zonal circulation epoch. The values of 400–500 mm/y were usual for the territory of the Crimean Plains, part of the South coast (from Sudak to the village of Utes), and the Herakleian Peninsula. The maximum precipitation was registered on the yails at 1100–1218 mm/y.

During the change from the first to second period (Fig. 7) of the meridional southern circulation epoch, precipitation along the entire southern coast of the Crimean Peninsula decreased by a maximum of 260 mm/y. On the contrary, in the areas of the SCC (from Cape Sarych to Cape Troitsa), part of the Ai-Petri and Babugan-Yaila, Yalta, Nikita, and the Gurzuf yails there were an increasing of the average annual precipitation up to 160 mm. The Main ridge was still characterised by an increase of precipitation of 140 mm/y. The Kachinsky uplift was no longer a zone of full precipitation decrease (during the change of periods, a slight increase was noted here at 20–50 mm/y); however, within this territory, there were small areas that experienced a sharp decrease in precipitation, up to 280 mm/y. In the western part of the Crimea and in the Kerch Peninsula, a slight decrease in precipitation was registered (20–50 mm), and in the central and northern parts of the Crimean Peninsula, a fluctuation in the amount of precipitation (around 0 mm/y) was noted. The highest amplitude range was registered in the area of the Demerdzhi Mountain at 440 mm/y.

The third period (1981–1997) of southern meridional circulation epoch was characterised by an increase in the duration of the southern cyclones, but not all cyclones (at 13s ECM) travelled over the Crimean Peninsula. The territory of the Crimean Mountains was characterised by a clear differentiation of increasing precipitation with altitude. For the Internal ridge and a part of the SCC (from the Utes village to Sudak), precipitation was 500–600 mm; for areas around the yails and a part of the SCC (from Cape Aya to Utes village), 600–700 mm; and for the yails, around 700 mm up to the maximum of 1100–1135 mm.

During the change from the second period to the third period of southern meridional circulation epoch, a moderate change (from −100 to +121 mm) in the annual precipitation was registered (Fig. 7). The period of change was also characterised by the inversion in the trend of precipitation. During this period negative dynamics of the average annual precipitation (50–100 mm) was registered in the southern part of the Main ridge. On the other hand, the Internal and External ridges received more precipitation during this period, from 20 mm (North-Eastern parts) to 120 mm (South-Western parts). In the Central parts of the Crimean and the Kerch peninsulas and in some areas of the Western part of the Crimean Peninsula, the average of annual precipitation decreased slightly (10–40 mm). In the remaining areas of the Western and Northern parts of the Crimean Peninsula, changes in the precipitation within the range of −5 to +5 mm were observed. The maximum amplitude of precipitation (222 mm) during this period was registered in the mountains of Chatyrdag.

In the last period (1998–2013) of the meridional southern circulation epoch, precipitation increased again due to the fact that the trajectories of Mediterranean cyclones reached the Crimean Peninsula, with the most frequent at ECM 12a. This period was characterised by a significant increase in the precipitation. For the territory of the Crimean Plains, the amount of precipitation of 400–500 mm remained unchanged. The External ridge and the Herakleian Peninsula were characterised by 500–600 mm of precipitation, when in previous periods it was only 400–500 mm, similar to the Crimean Plains. In the Internal ridge and part of the SCC (from Utes village to Sudak) the value of total precipitation did not change. For the areas encircling yails and part of the SCC (from Cape Aya to Utes village), precipitation was 600–700 mm which was typical. On the territory from the Baidar hollow to Karabi-yaila, the amount of precipitation increased from 700 up to the maximum values of 1100–1166 mm on the flat saddles with mountain meadows and areas of hornbeam-beech forests and on the remains-denudation plateau with mountain meadows and hornbeam-beech forests.

During the final change in period (Fig. 7), the change in the amount of precipitation was within −183 and + 392 mm. The Main ridge and parts of the External ridges had a strong increase in precipitation, up to a maximum value of 392 mm. On the coast of the SCC (from Cape Sarych to Cape Troitsa), precipitation decreased by 183 mm. The Kerch Peninsula, the Western part, and the foothills of the Central part of the Crimean Peninsula had a positive dynamics with respect to the average annual rainfall, from 100 to 150 mm. In the central and northern parts of the Crimea, no change in the precipitation was observed. The greatest amplitude of 575 mm was registered in one landscape contour marked as the districts of Yalta and the Demerdzhi mountain range.

4. Conclusions

Atmospheric circulation is one of the leading and dynamic factors that affect precipitation. The averaging period is particularly important for the analysis of the annual averages of precipitation. When the precipitation maps for the whole period of instrumental observations (Fig. 5) and precipitation maps for the last period of southern meridional circulation epoch (Fig. 7) were compared, the difference in the range of the maximum and minimum precipitation and spatial differentiation were visible. Therefore, for landscape planning, it may be beneficial to take into account the actual situation of the atmosphere.

The first and the third change of period were characterised by smooth transitions and maximum amplitudes of 240 and 222 mm, respectively. During the last or the fourth change of period, the most significant changes were observed and the maximum amplitude of 575 mm was obtained. In the Northern and Central parts of the Crimea, precipitation was relatively stable in that changes did not exceed ±20 mm. Precipitation in the Western part of the Crimea and in the Kerch Peninsula was slightly higher and ranged from −40 to +50 mm. Changes in precipitation in the Main ridge and the South-Western part of the Internal ridge were the most intense, from −260 to 392 mm.

According to Fig. 6, the zonal epoch (1916–1956) and first period of southern meridional epoch (1957–1969) were characterised by a slight increase in the amount of precipitation in the mountains and the plains. The second (1970–1980) and the third (1981–1997) period of the southern meridional epoch was characterised by shifting changes in the amount of precipitation: the increase in the mountains led to the decrease on the plains, and vice-versa. The fourth period (1998–2018) showed a small difference, −20 mm in the mountains, in comparison with the first and second periods, and a significant increase in the amount of precipitation on the plains up to 400 mm. This was the maximum value for the plains during the studied period. Thus, the territory of the Crimean Peninsula was characterised to generally have an increasing amount of precipitation.

In summary, pictures of the spatial differentiation of the areas of atmospheric precipitation were created for each circulation epoch and period on the Crimean Peninsula. It was associated with regional and macrolocal differentiation factors.

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CRediT authorship contribution statement

Roman Gorbunov: Conceptualization, Methodology, Formal analysis, Visualization, Supervision. **Tatiana Gorbunova:** Software, Investigation, Writing - review & editing. **Nina Kononova:** Validation. **Anastasia Priymak:** Resources. **Anton Salnikov:** Data curation. **Anna Drygval:** Resources. **Yaroslav Lebedev:** Writing - original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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