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THE COMPLEX SYSTEMS

Truth is always born as heresy,
and dies as prejudice
Georg Wilhelm Friedrich Hegel

№3 (9), 2020

IN THE ISSUE:

Extreme precipitation recorded at 23 weather stations in the Crimea and at 12 meteorological stations on the Eastern coast of the Black Sea according to reanalysis data are discussed.

The analysis of the evolution of a number of characteristics in an abstract system of relations depending on the change in its maximum scale coefficient is given.

The features of the development of a complex system of humanity are revealed. The possibilities of human and human actions are included in the system model.

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RELATIONSHIP OF EXTREME PRECIPITATIONS IN THE CRIMEA WITH MACROCIRCULATION PROCESSES

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Abstract. The paper discusses extreme precipitation recorded at 23 weather stations in the Crimea. Reanalysis data were used. The relationship between precipitation at each station and elementary circulation mechanisms (ECMs) according to B.L. Dzerdzeevsky, V.M. Kurganskaya, and Z.M. Vitvitskaya has been analysed. The ECMs were revealed, at which precipitation extremes were noted simultaneously at several Crimean stations. It has been established at which ECMs in the Crimea, extreme precipitations most often occur and long-term changes in the duration of these ECMs were analysed.

Key words: elementary circulation mechanism, extreme precipitation, Crimea.

INTRODUCTION

Work on the connection between precipitations and macrocirculation processes according to the typification by B.L. Dzerdzeevsky, V.M. Kurganskaya and Z.M. Vitvitskaya [3] was carried out by S. B. Velev and N. K. Kononova since 1975 [1, 2]. The research methodology was perfected using these works. The Crimean economy is highly dependent on the availability of water resources, and taking into account the peninsula’s relief, extreme precipitations can be destructive; therefore, a study to identify the patterns of long-term fluctuations in precipitation is important and relevant at the present time. In this work, studies were carried out according to reanalysis data [8]. A comparison of the observational data and reanalysis data at Karadag station showed that there are some differences, but they do not prevent the identification of the main regularities. There has been identified a source of cyclone formation, from which they bring abundant and catastrophic precipitation to Crimea. The frequency of occurrence of extreme precipitations at different stations over the years and over the cold and warm semesters was established. Based on the analysis of fluctuations in atmospheric circulation, an assumption was made about a further increase in extreme precipitations in Crimea.

MATERIALS AND METHODS

Daily precipitation amounts exceeding 5% of the annual amount of the year under consideration (abundant precipitation) and 10% of the annual amount of a year (catastrophic precipitation) are taken for extreme precipitations in the paper [6]. Since such daily precipitation amounts do not occur every year, we have chosen the maximum amount of precipitation in each year. Sometimes it exceeds the catastrophic amount, but more often it does not reach the abundant level. The ECMs are determined for each day with the maximum amount of precipitation in each year [7]. It also takes into account the amount of precipitation between the estimated 5 per cent and the maximum amount, as well as ECMs, at which they came down. Calculation of ECMs frequency, which caused extreme precipitations in each year at each station, makes it possible to identify those ECMs, at which abundant precipitation falls in Crimea.

RESULTS AND DISCUSSION. LONG-TERM FLUCTUATIONS IN ATMOSPHERIC CIRCULATION

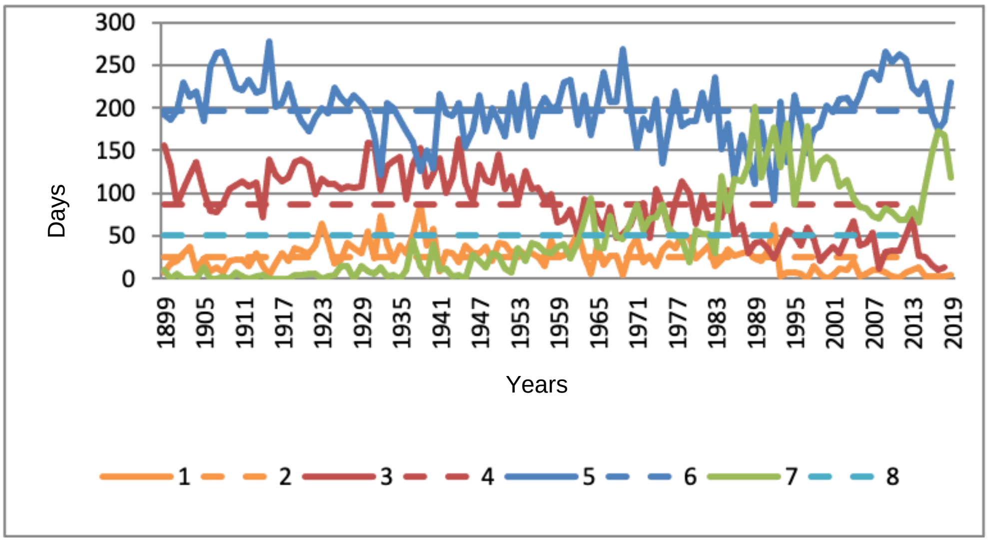

Fig. 1. *Duration of the circulation groups in the Northern Hemisphere: 1 - zonal, 2 – mean zonal, 3 - zonality disturbance, 4 - mean zonality disturbance, 5 - northern meridional, 6 - northern mean meridional, 7 - southern meridional, 8 - southern mean meridional*

As seen in Fig. 1 for the period under consideration in all years, except for the 30-40s and 80-90s of the XX century, the meridional Northern group of circulation (blocking processes) prevailed in the lower troposphere of the Northern Hemisphere [7]. In the 30s – 40s, it alternated with a group of zonality disturbance, and in the 80–90s with a meridional Southern zonality (the upcoming of cyclones from low to high latitudes). In 2010–2019, the duration of both groups was longer than their mean values. Until 2013, the duration of the meridional Northern group fluctuated at the highest level, then by 2018 it sharply decreased, and in 2019 it increased again. The duration of the meridional southern group until 2013 fluctuated at its lowest level since 1998, then increased sharply by 2018, and decreased again in 2019. From 2010 to 2012, the annual amount of precipitation behaved in accordance with the changes in the nature of atmospheric circulation.

ANNUAL AMOUNTS AND DAILY MAXIMUM PRECIPITATIONS AT CRIMEAN WEATHER STATIONS ACCORDING TO REANALYSIS DATA

Sebastopol. As seen in Fig. 2, from 2010 to 2012, the annual amount of precipitations in Sebastopol decreased from 535.8 mm to 306.3 mm. Then it gradually increased by 2016 to 525.5 mm, and in 2019 it was 361 mm.

Fig. 3 shows the repeatability of ECMs, at which extreme precipitations fell. In total, 12 extremes were noted over the decade (catastrophic precipitation coincides with the annual maximum). In half of the cases, they fell with ECMs 13w (Figs. 4 and 8, all dynamic schemes are given according to [5], all weather maps were taken from Synoptic Bulletins of the Northern Hemisphere for 2010 - 2019) , i.e. in the cold half-year, with cyclones passing from the Eastern Mediterranean through the Crimea to the European territory of Russia (ETR). In three cases, they fell during ECMs 12a (Figs. 5 and 9). It occurs all year round. This is a meridional Northern process with four blocking anticyclones and four upcomings of southern cyclones, one of which, as with ECMs 13w, passes from the Eastern Mediterranean through the Crimea to the ETR. In two cases, extreme precipitations occurred with ECMs 13s (Figs. 6 and 10). This, like ECMs 13w, is a meridional southern process, only during the warm half of the year. With it, an anticyclone forms over the EPR, and the Crimea is on the border between a cyclone and an anticyclone, therefore all precipitations fell onto the Crimea. In one case, abundant precipitations fell during ECMs 9a (Figs. 7, 11), in which the southern border of the anticyclone has recently been located near the Northern coast of the Black Sea, so that the southern cyclone resting on it, pours all its precipitations onto the Crimea (Fig. 11).

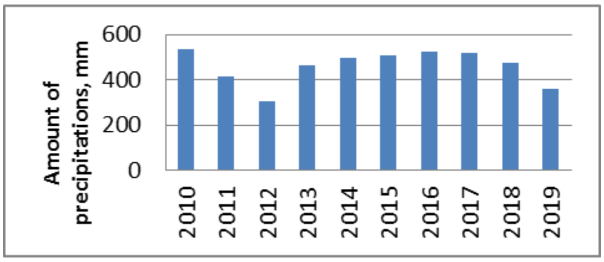

Fig. 2. *Annual precipitation amount in Sebastopol*

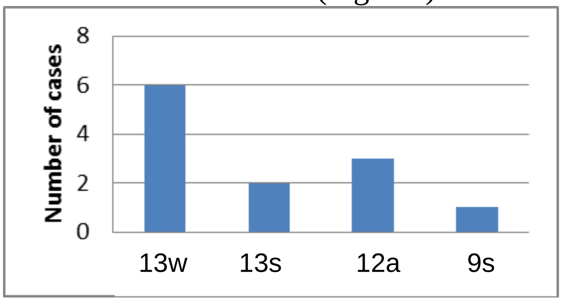

Fig. 3. *Number of ECM cases causing extreme precipitation in Sebastopol*

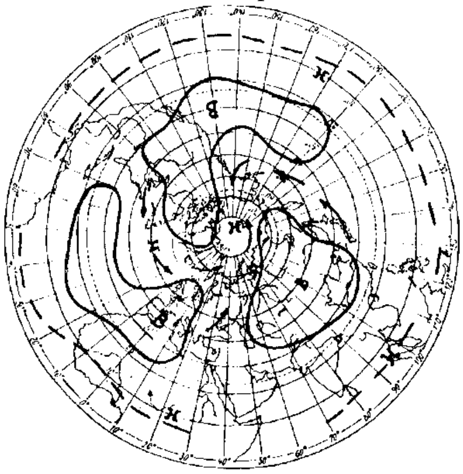

Fig. 4. *Dynamic scheme of ECMs 13w*

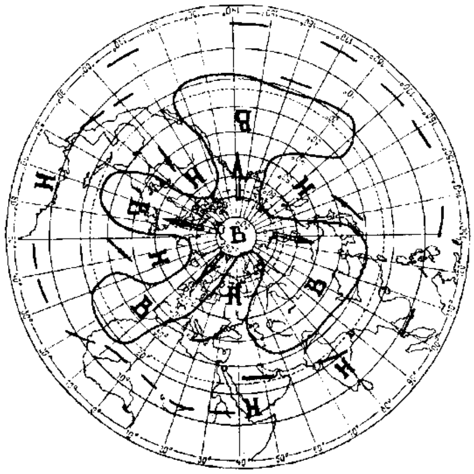

Fig. 5. *Dynamic scheme of ECMs 12a*

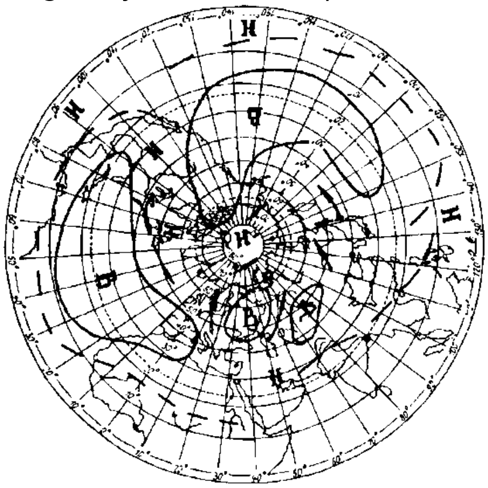

Fig. 6. *Dynamic scheme of ECMs 13s*

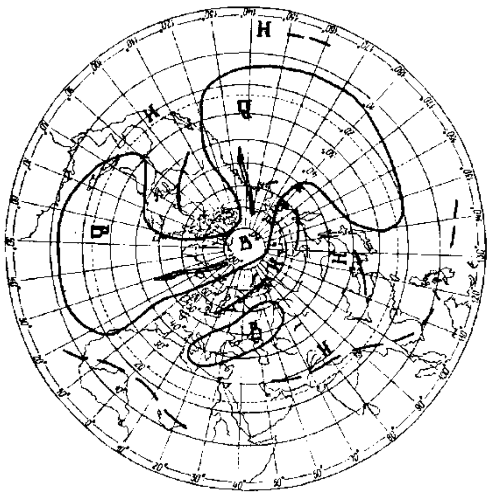

Fig. 7. *Dynamic scheme of ECMs 9a*

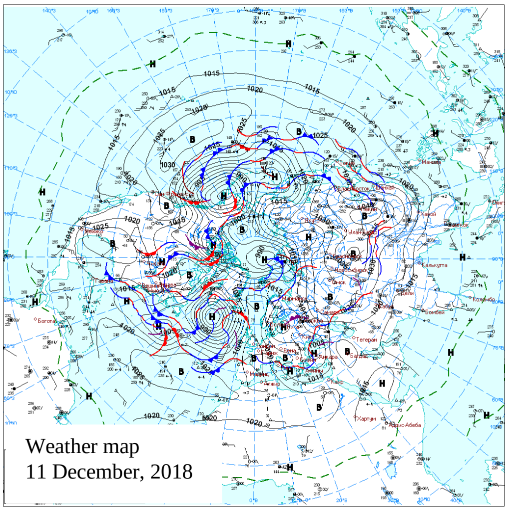

Fig. 8. *ECMs 13w H - cyclone B - anticyclone*

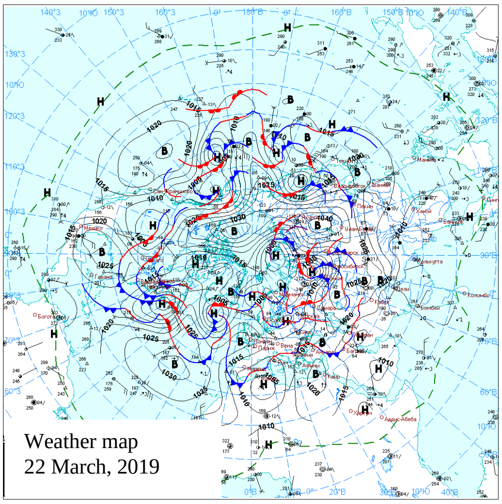

Fig. 9. *ECMs 12a*

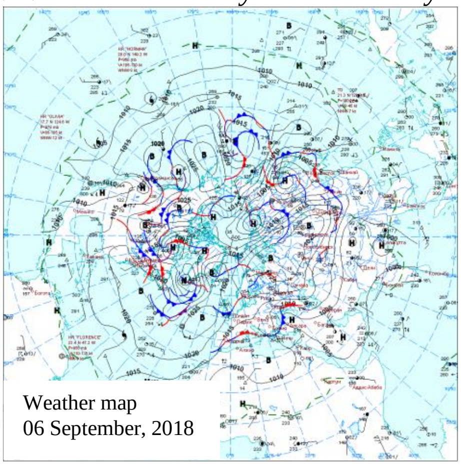

Fig. 10. *ECMs 13s*

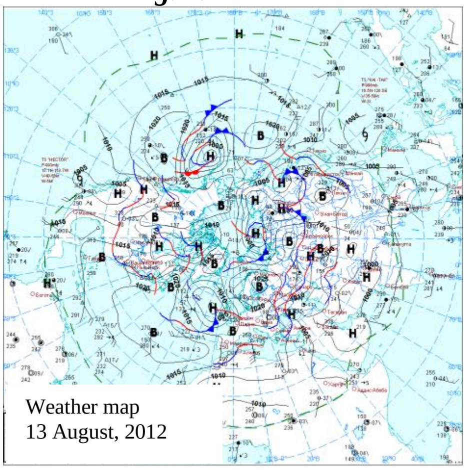

Fig. 11. *ECMs 9a*

Thus, in Sebastopol, the greatest amount of extreme precipitation falls in the cold half of the year with ECMs 13w when Mediterranean cyclones pass through the Crimea to the EPR.

Kerch. From 2010 to 2012, the annual amount of precipitations in Kerch (Fig. 12), like in Sebastopol, decreased from 471 mm to 261.2 mm. Then it grew unevenly by 2016 to 489.5 mm, and by 2019 it decreased to 329.9 mm. Unlike Sebastopol, the largest amount of rainfall was recorded in 2016 and not in 2010.

A total of 15 precipitation extremes were noted over the decade (Fig. 13). Most of the extremes (4) were observed with ECMs 12a (Fig. 5), 2 extremes were observed for ECMs 13s (Fig. 6) and ECMs 9a (Fig. 7) and one each for ECMs 6 – 13w (Figs. 14-19 and 4). There are 10 extremes in the warm half of the year and 4 in the cold one.

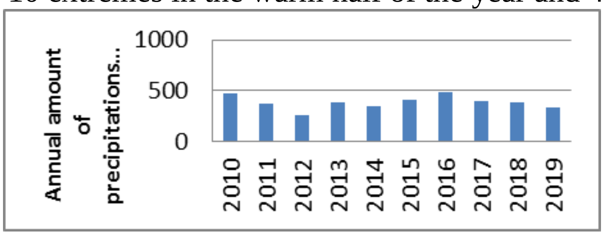

Fig. 12. *Annual amount of precipitations in Kerch*

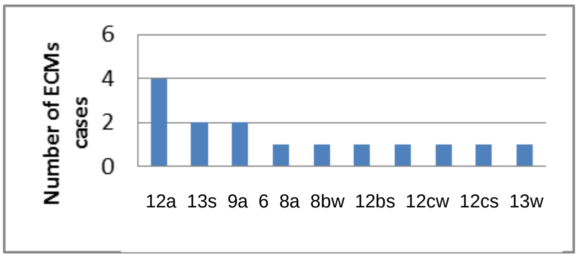

Fig. 13. *Number of ECM cases causing extreme precipitations in Kerch*

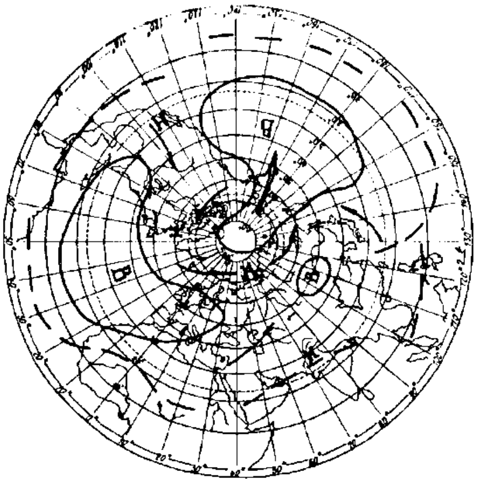

Fig. 14. *Dynamic scheme of ECMs 6*

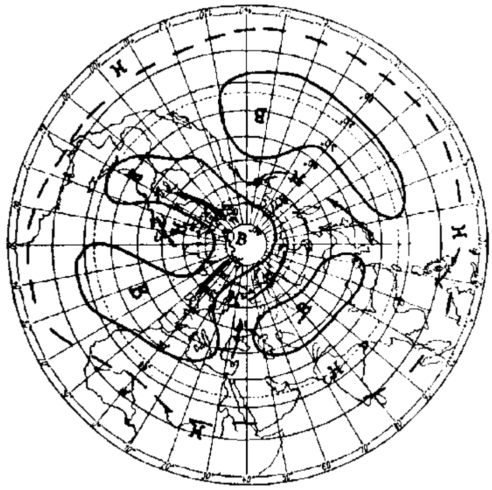

Fig. 15. *Dynamic scheme of ECMs 8a*

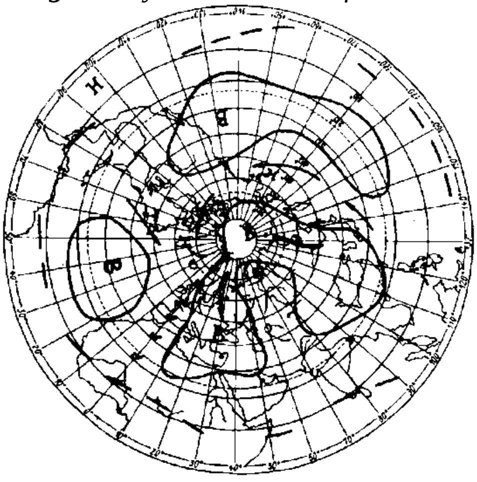

Fig. 16. *Dynamic scheme of ECMs 8bw*

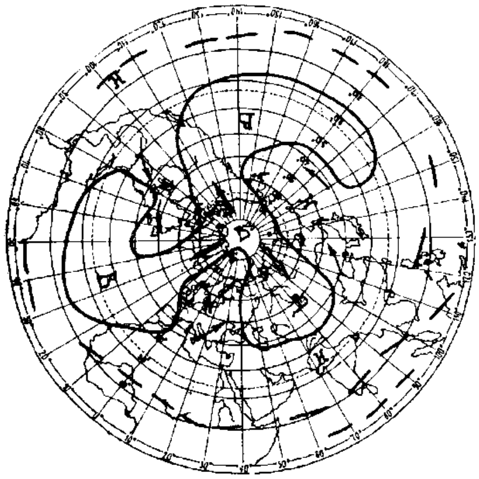

Fig. 17. *Dynamic scheme for ECMs 12bs*

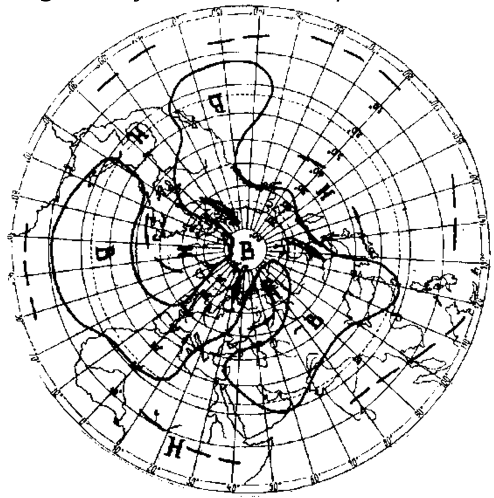

Fig. 18. *Dynamic scheme of ECMs 12cw*

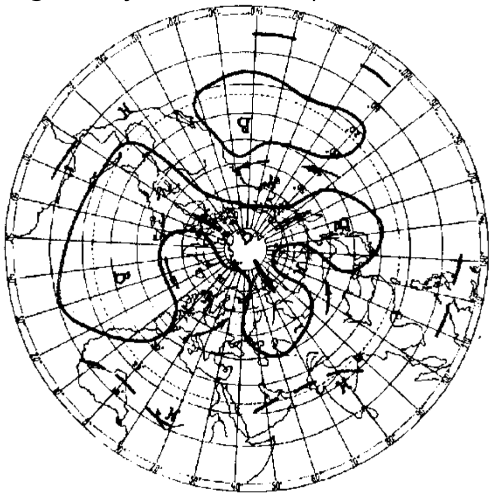

Fig. 19. *Dynamic circuit ECMs 12cs*

As can be seen in the above figures, in all cases, except for ECMs 8bw, Mediterranean cyclones freely pass through the Crimea to the ETR, while carrying abundant precipitations. ECM 8bw brings abundant precipitation at 23 Crimea stations only in three cases for 10 years (3 times out of 230 possible). Obviously, in these exceptional cases, the Arctic invasion shifted to the west and passed the Southern cyclone through the Crimea (Fig. 20).

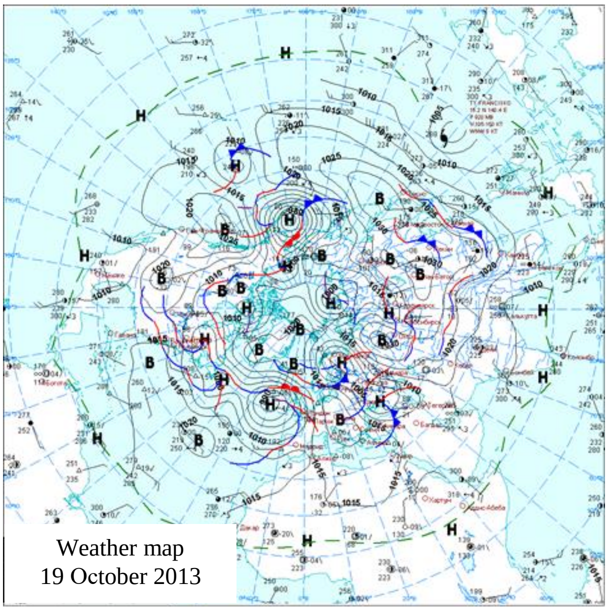

Fig. 20. *ECM 8bw*

Yalta. From 2010 to 2012, the annual amount of precipitations in Yalta (Fig. 21) decreased from 494.4 mm to 282.7 mm. Then it gradually increased by 2015 to 498.7 mm, and by 2019 it decreased to 340.4 mm. In contrast to the previous stations, the largest amount of precipitation was recorded in 2015.

In total, 14 precipitation extremes were noted over the decade (Fig. 22). Most of the extremes (5) were observed at the ECM 12a (Fig. 5), 4 extremes were observed at the ECM 13w (Fig. 4), 2 with ECMs 13s (Fig. 6) and one at the ECM 12bs (Fig. 17), 9a (Fig. 11) and 8a (Fig. 15). The warm and cold semester had 7 extremes each.

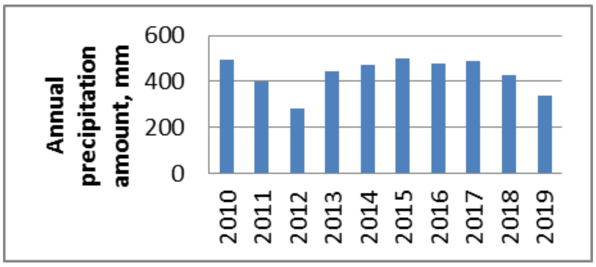

Fig. 21. *Annual precipitation amount in Yalta*

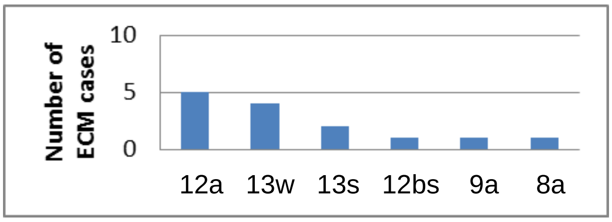

Fig. 22. *Number of ECM cases causing extreme precipitation in Yalta*

Yevpatoriya. From 2010 to 2012, the annual amount of precipitation in Yevpatoriya (Fig. 23) decreased from 501.8 mm to 272.7 mm. Then, with year-to-year fluctuations, it increased by 2018 to 463.8 mm and by 2019 it decreased to 330.4 mm. The largest amount of precipitations, as in Sebastopol, was noted in 2010 and the second maximum coincided with the longest duration of meridional Southern processes in a decade (Fig. 1).

In total, 11 precipitation extremes were noted over the decade (Fig. 24): 3 extremes each for ECMs 12a (Fig. 5), and 13w (Fig. 4), 2 - for the ECM 13s (Fig. 6) and one each for the ECM 7aw (fig. 25), 8a (fig. 15) and 10b (fig. 26). There are 8 extreme points in the cold half of the year and 3 in the warm half.

During ECMs 7aw (Fig. 25), cyclones from the Eastern Mediterranean pass through the Crimea to the ETR. With ECMs 10b (Fig. 26), an Arctic invasion to the Urals takes place. The formed anticyclone is united in the west with a spur of the Azores anticyclone.

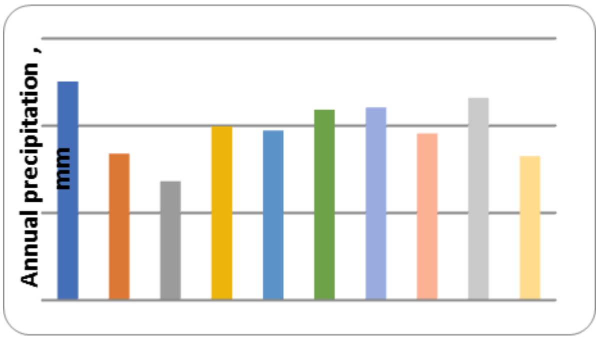

Fig. 23. *Annual precipitation amount in Yevpatoriya*

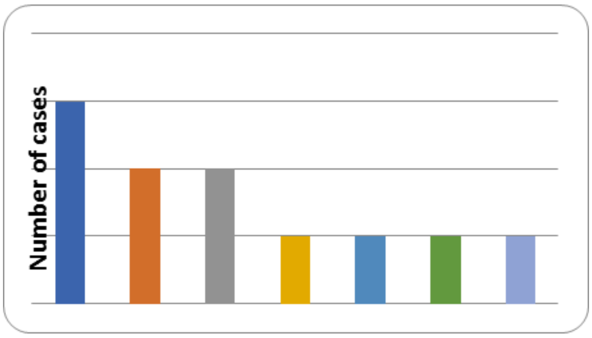

Fig. 24. *Number of ECM cases causing extreme precipitation in Yevpatoriya*

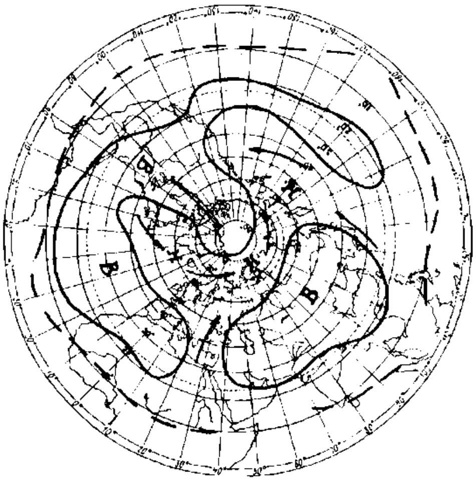

Fig. 25. *Dynamic scheme of ECMs 7aw*

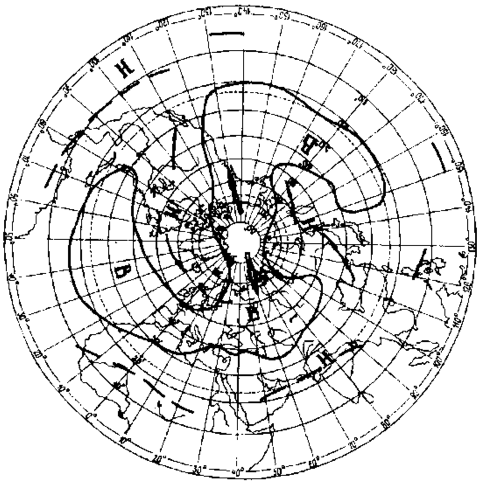

Fig. 26. *Dynamic scheme of ECMs 10b*

However, this time the invasion took place further east (Fig. 26a), and the Southern border of the anticyclone passed along the Northern shores of the Caspian Sea. A cyclone emerging from the Eastern Mediterranean met an obstacle in the form of this anticyclone on its way and poured 20.8 mm of precipitation onto Yevpatoriya per day. In just 10 years at 23 Crimean stations, these ECMs, as well as ECMs 8bw (Fig. 20), gave extreme precipitations only 3 times.

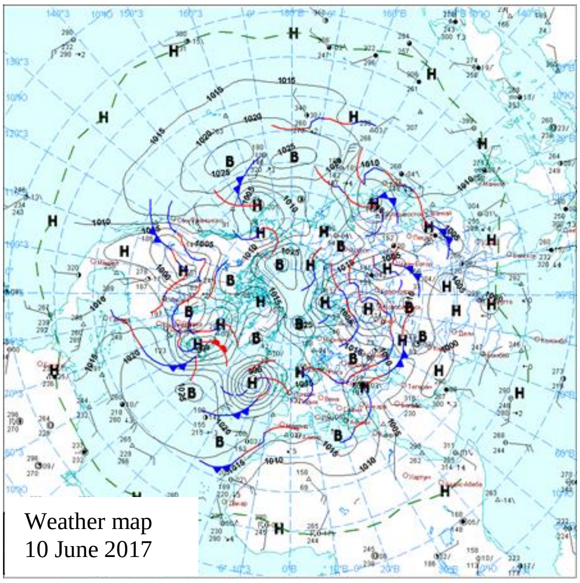

Fig. 26a. *ECMs 10b*

Mysovoye. From 2010 to 2012, the annual amount of precipitations in the village of Mysovoye (Fig. 27) decreased from 493.7 mm to 238 mm. Then, with interannual fluctuations, it increased by 2016 to 510.5 mm and by 2019 it decreased to 305.5 mm.

In total, 15 precipitation extremes were noted over the decade (Fig. 28): 4 extremes with ECMs 13w (Fig. 4), 3 with ECMs 12a (Fig. 5), 2 with ECMs 13s (Fig. 6) and 9a (Fig. 11), and one each for ECMs 6 (Fig. 14), 8a (Fig. 15), 8bw (Fig. 20) and 12bw (Fig. 29). There were 7 extremes in the cold half of the year and 8 in the warm half.

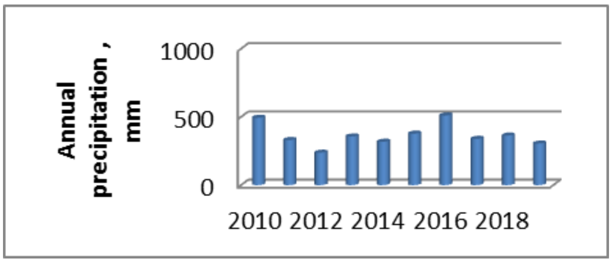

Fig. 27. *Annual precipitation amount in Mysovoye*

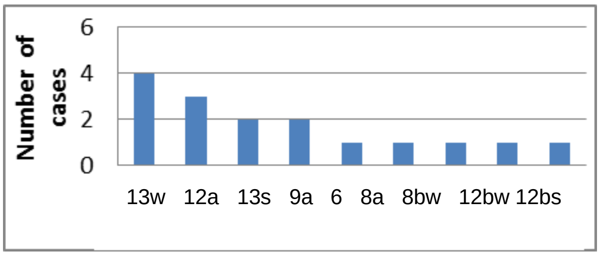

Fig. 28. *The number of the ECM cases causing extreme precipitation in Mysovoye*

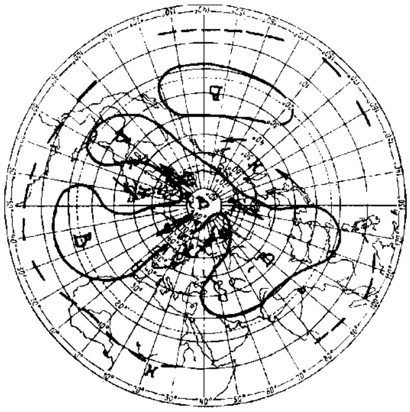

Fig. 29. *Dynamic scheme of ECMs 12bw*

Sebastopol, Chersonesos lighthouse. From 2010 to 2012, the annual amount of precipitations at the meteorological station at Sebastopol, Chersonesos lighthouse (Fig. 30) decreased from 529.7 mm to 302.9 mm. Then it gradually increased by 2016 to 517.7 mm and by 2019 it decreased to 356.4 mm. The maximum precipitation, as in Sebastopol, was noted in 2010.

In total, 13 precipitation extremes were noted over the decade (Fig. 31): 5 extremes each with ECMs 13w (Fig. 4) and 12a (Fig. 5), 2 extremes with ECMs 13s (Fig. 6) and 1 with ECMs 9a (Fig. 11). There are 8 extremes in the cold half of the year and 5 extremes in the warm half of the year.

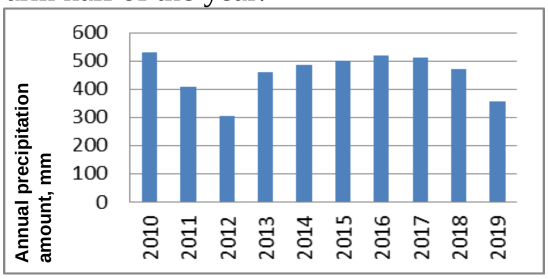

Fig. 30. *Annual precipitation amount at the station Sebastopol, Chersonesos lighthouse*

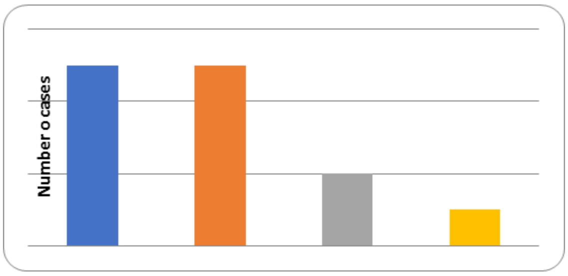

Fig. 31. *Number of ECM cases causing extreme precipitation at the same station*

Feodosia. From 2010 to 2012, the annual amount of precipitations in Feodosia (Fig. 32) decreased from 470.3 mm to 240.6 mm. Then it increased by 2016 to 469.2 mm, and by 2019 it decreased to 337.8 mm. The maximum annual precipitation, as in Sebastopol, was noted in 2010, although it exceeds the amount of 2016 by only 1.1 mm.

In total, 15 precipitation extremes were noted over the decade (Fig. 33): 4 extremes each for ECMs 13w (Fig. 4) and 12a (Fig. 5), 2 extremes for ECMs 13s (Fig. 6) and 9a (Fig. 11) each, and one for ECMs 6 (Fig. 14), 8bs (Fig. 34), and 9b (Fig. 35). With all ECMs, the Mediterranean cyclone reaches the ETR. There are 8 extremes in the cold half of the year and 7 in the warm half.

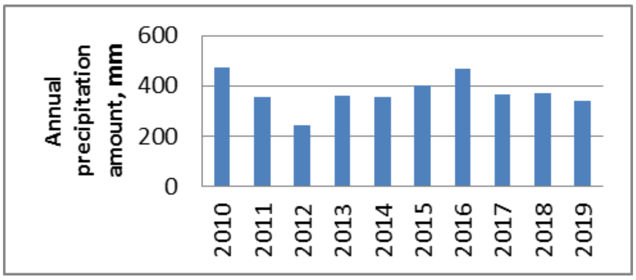

Fig. 32. *Annual precipitation amount in Feodosia*

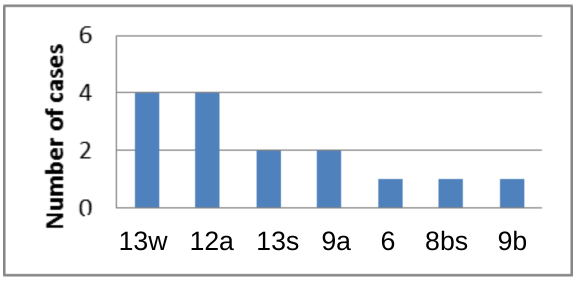

Fig. 33. *Number of ECM cases causing extreme precipitation in Feodosia*

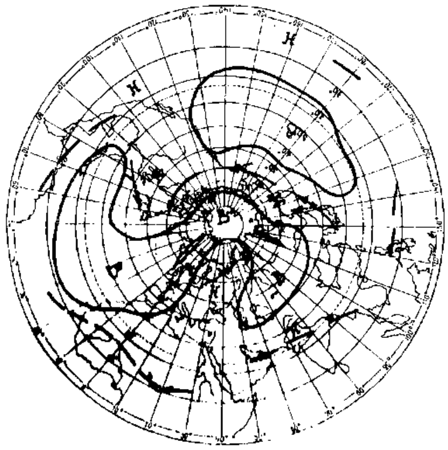

Fig. 34. *Dynamic scheme for ECMs 8bs*

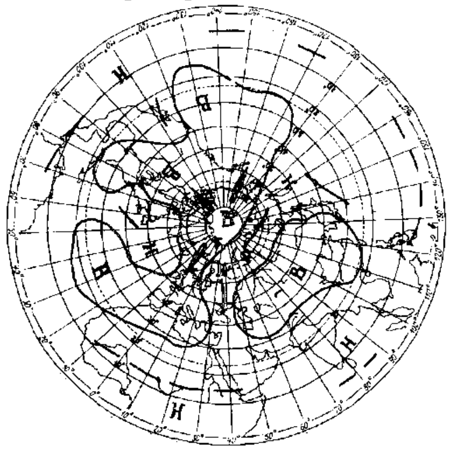

Fig. 35. *Dynamic scheme for ECMs 9b*

Chernomorskoye. From 2010 to 2012 the annual amount of precipitations in Chernomorskoye village (Fig. 36) decreased from 530.8 mm to 303.9 mm. Then it increased by 2016 to 453 mm and by 2017 it decreased to 342.6 mm; in 2018 it increased to 439.5 mm, and by 2019 it decreased again to 346.7 mm. The maximum annual amount of precipitations, as in Sebastopol, was noted in 2010; the minimum annual amount of precipitations, as in all previous years, was in 2012, and the secondary minimum was not in 2019, but in 2017.

In total, 15 precipitation extremes were noted over the decade (Fig. 37): 6 of them occurred during ECMs 12a (Fig. 5), 2 extremes were with ECMs 13w (Fig. 4) and 13s (Fig. 6) each and one extreme was with ECMs 3 (Fig. 38), 7aw (Fig. 25), 8a (Fig. 15), 8bs (Fig. 34) and 12bs (Fig. 17). Usually, with ECMs 3, an anticyclone was located over the ETR and the Black Sea, but on June 20, 2014 (Fig. 39), the anticyclone split into 2 cores and missed the Mediterranean cyclone. This was the only case at all 23 stations in 10 years when abundant precipitation (20.5 mm per day) fell during ECMs 3. There are 6 extremes in the cold half and 9 in the warm half of the year.

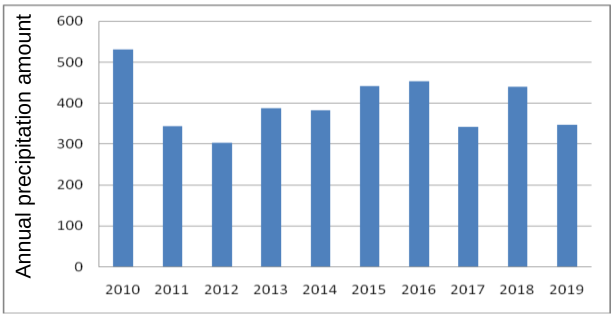

Fig. 36. *Annual precipitation amount in the Chernomorskoye village*

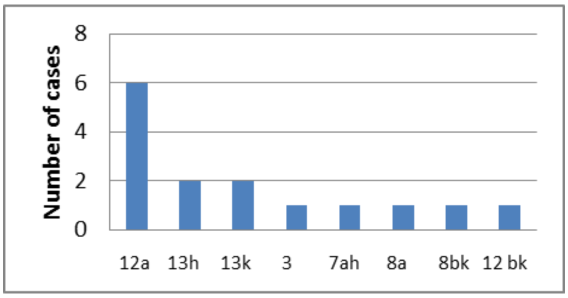

Fig. 37. *The number of the ECM cases causing extreme precipitation in the Black Sea*

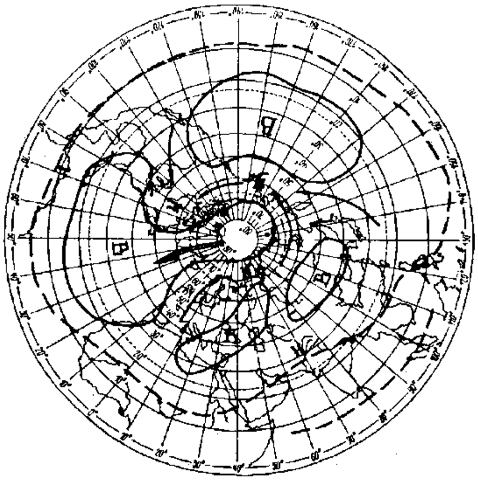

Fig. 38. *Dynamic scheme for ECMs 3*

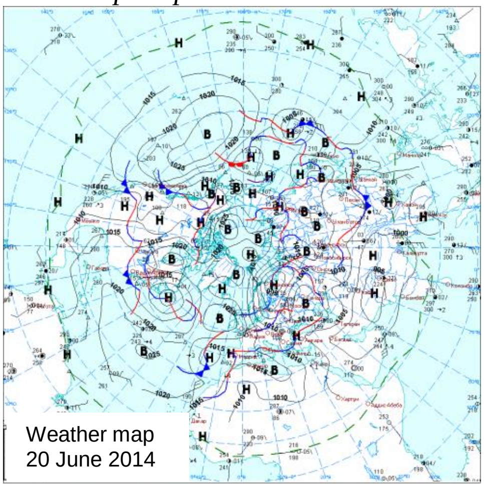

Fig. 39. *ECMs 3.*

Klepinino. From 2010 to 2012, the annual amount of precipitation in the village of Klepinino (Fig. 40) decreased from 505.1 mm to 246 mm. Then it increased by 2015 to 438.6 mm, and by 2019 it decreased to 347.7 mm; however, the secondary minimum precipitation was in 2011 (341.3 mm). The maximum annual amount of precipitation was noted in 2010, the minimum - in 2012.

In total, 14 precipitation extremes were noted over the decade (Fig. 41): 4 of them fell during ECMs 13w (Fig. 4), 3 extremes were during ECMs 12a (Fig. 5), 2 - during ECMs 13s (Fig. 6) and one during ECMs 6 (Fig. 14), 7aw (Fig. 25), 8bs (Fig. 34), 10b (Fig. 26, 26a), and 12bs (Fig. 17). This was the second time when abundant precipitations have been observed on 10 June, 2017 with ECMs 10b. For the first time, they were observed in Yevpatoriya. There are 6 extremes in the cold half of the year and 8 in the warm half.

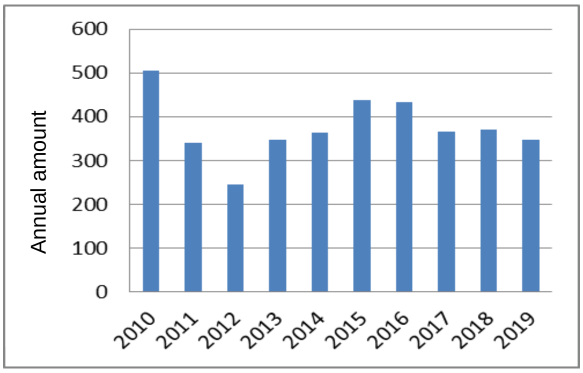

Fig. 40. *Annual precipitation amount in Klepinino*

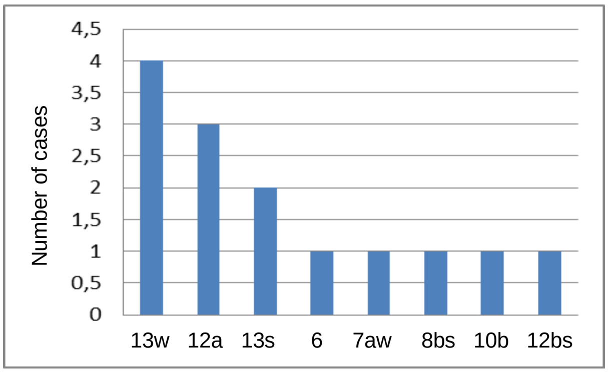

Fig. 41. *Number of ECM cases causing extreme rainfall in Klepinino*

Nikitsky Botanical Garden. From 2010 to 2012, the annual amount of precipitation in the Nikitsky Botanical Garden (Fig. 42) decreased from 478.2 mm to 272 mm. Then it increased by 2015 to 482.5 mm, and by 2019 it decreased to 328.2 mm. The maximum annual precipitation was observed in 2015, the minimum - in 2012, and the secondary minimum - in 2019.

In total, 14 precipitation extremes were noted over the decade (Fig. 43): 5 of them fell during ECMs 12a (Fig. 5), 4 fell during ECMs 13w (Fig. 4), 2 - during ECMs 13s (Fig. 6) and one during ECMs 8a (Fig. 15), 9a (Fig. 11) and 9b (Fig. 35). The cold and warm halves of the year had 7 extremes each.

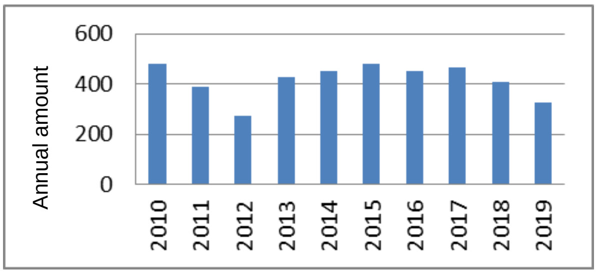

Fig. 42. *Annual precipitation amount in Nikitsky Botanical Garden*

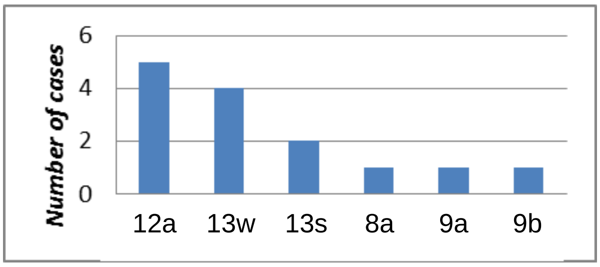

Fig. 43. *The number of the ECM cases causing extreme precipitation in Nikitsky Garden*

Alushta. From 2010 to 2012, the annual amount of precipitations in Alushta (Fig. 44) decreased from 459.4 mm to 248.8 mm. Then it increased by 2015 to 449.5 mm, and by 2019 it decreased to 313.5 mm. The maximum annual precipitation was observed in 2010, the secondary maximum - in 2015; the minimum - in 2012, the secondary minimum - in 2019. In total, 13 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 45. There are 7 extremes in the warm half of the year and 6 in the cold one.

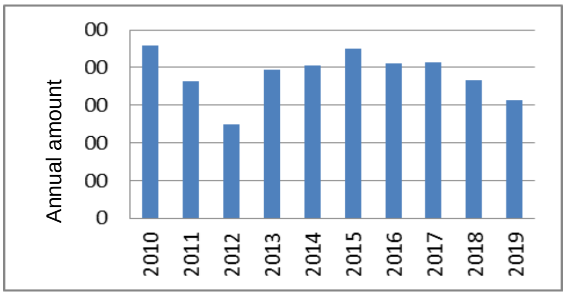

Fig. 44. *Annual precipitation amount in Alushta*

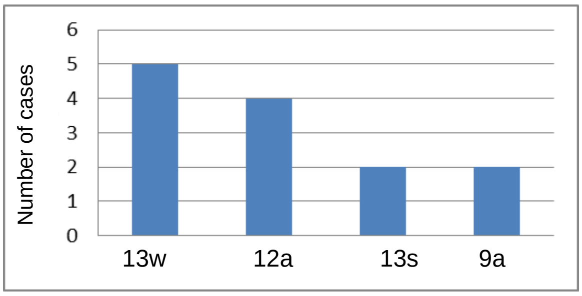

Fig. 45. *The number of the ECM cases that caused extreme precipitation in Alushta*

Ai-Petri. From 2010 to 2012, the annual amount of precipitation on Ai-Petri (Fig. 46) decreased from 509.4 mm to 292.3 mm. Then it increased by 2015 to 512.6 mm, and it decreased by 2019 to 353.6 mm. The maximum annual precipitation was noted in 2015, the secondary maximum - in 2017 (511.4 mm); minimum - in 2012, secondary minimum - in 2019. In total, 12 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 47. There were 7 extremes in the warm half of the year and 5 in the cold one.

Angarsky pass. From 2010 to 2012, the annual amount of precipitation at the Angarsky pass (Fig. 48) decreased from 479.1 mm to 252.5 mm. Then it increased by 2015 to 459.1 mm, and by 2019 it decreased to 323 mm. The maximum annual precipitation was noted in 2015, the secondary maximum - in 2017 (419.3 mm), in 2016 the amount of precipitation was

419 mm. The minimum was noted in 2012, the secondary minimum - in 2019. In total, 13 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 49. There are 6 extremes in the warm half of the year and 7 in the cold one.

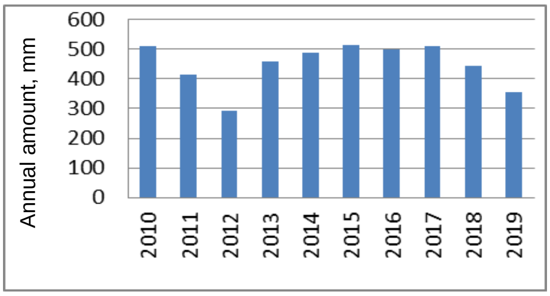

Fig. 46. *Annual precipitation amount on Ai-Petri*

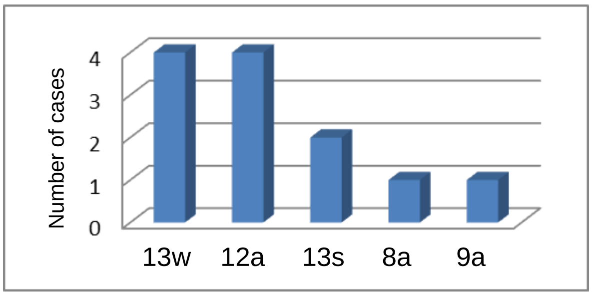

Fig. 47. *The number of the ECM cases that caused extreme precipitation on Ai-Petri*

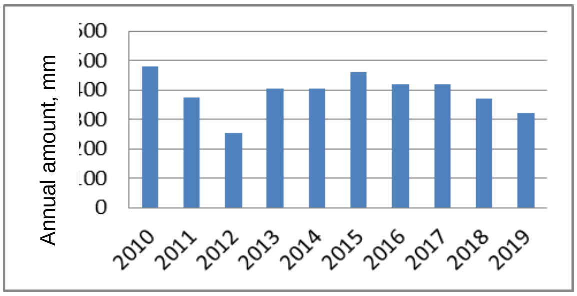

Fig. 48. *Annual precipitation amount for the Angarsky pass*

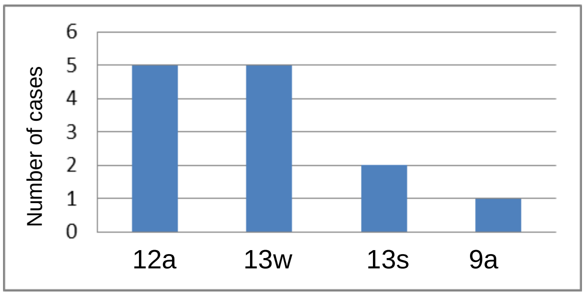

Fig. 49. *The number of the ECM cases that caused extreme precipitation for the Angarsky Pass*

Vladislavovka. From 2010 to 2012, the annual amount of precipitation in Vladislavovka (Fig. 50) decreased from 480.7 mm to 239.1 mm. Then it increased by 2016 to 477.8 mm, and by 2019 it decreased to 330.9 mm. The maximum annual amount of precipitation was noted in 2010, the secondary maximum - in 2016. The minimum was noted in 2012, the secondary minimum - in 2019. In total, 14 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 51. There were 8 extremes in the warm half of the year and 6 in the cold one.

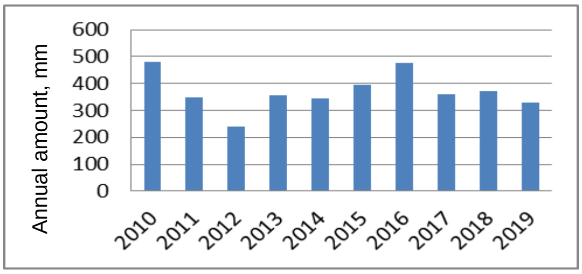

Fig. 50. *Annual precipitation amount in Vladislavovka*

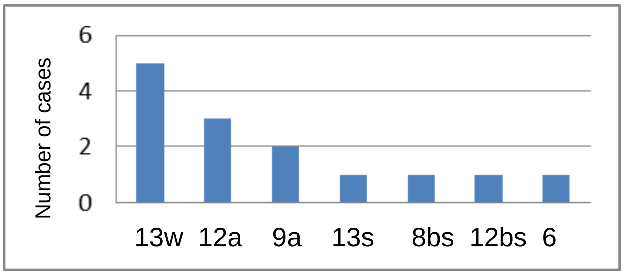

Fig. 51. *The number of the ECM cases causing extreme precipitation in Vladislavovka*

Dzhankoy. From 2010 to 2012, the annual amount of precipitation in Dzhankoy (Fig. 52) decreased from 506 mm to 238.8 mm. Then it increased by 2016 to 455.7 mm, and by 2019 it decreased to 340 mm. The maximum annual amount of precipitation was noted in 2010, the secondary maximum - in 2016. The minimum was noted in 2012, the secondary minimum - in 2013 (330.4 mm).

In total, 18 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 53. The warm half of the year has 11 extremes, and the cold one has 7.

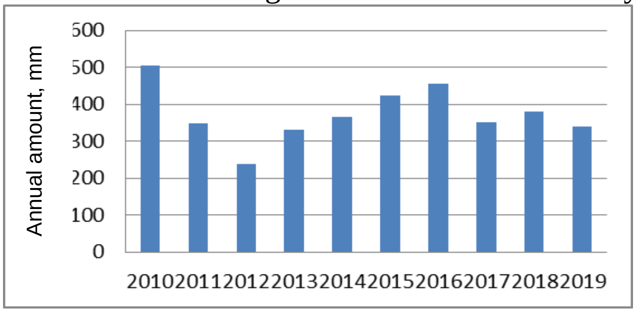

Fig. 52. *Annual precipitation amount in Dzhankoy*

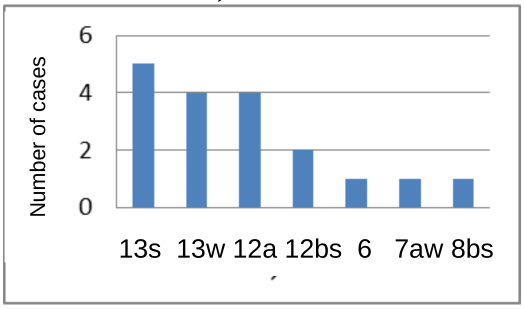

Fig. 53. *Number of ECM cases causing extreme precipitation in Dzhankoy*

Yishun. From 2010 to 2012 the annual amount of precipitation in Yishun (Fig. 54) decreased from 542.2 mm to 260 mm. Then it increased by 2016 to 508.9 mm, and by 2019 it decreased to 360.8 mm. The maximum annual amount of precipitation was noted in 2010, the secondary maximum - in 2016. The minimum was noted in 2012, the secondary minimum - in 2011 (312.3 mm). In 2017, precipitation was 324 mm.

In total, 15 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 55. There are 9 extremes in the warm half of the year and 6 in the cold one.

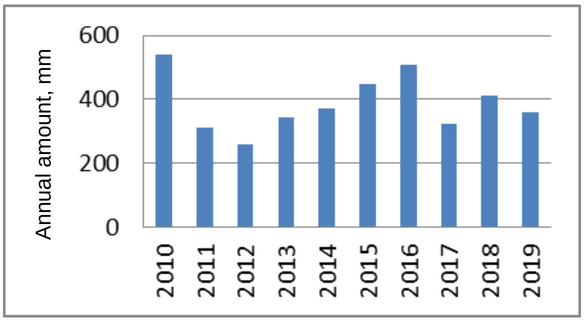

Fig. 54. *Annual precipitation amount in Yishun*

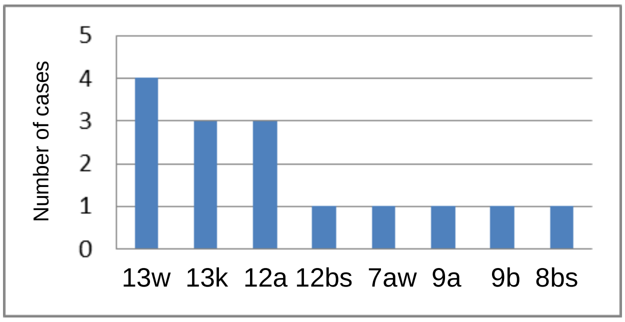

Fig. 55. *Number of ECM cases causing extreme rainfall in Yishun*

Plodovoye. From 2010 to 2012, the annual amount of precipitation in Plodovoye (Fig. 56) decreased from 505.9 mm to 240.1 mm. Then it increased by 2016 to 447.4 mm, and by 2019 it decreased to 339.5 mm. The maximum annual precipitation was observed in 2010, the secondary maximum - in 2016. The minimum was noted in 2012, the secondary minimum - in 2019. In total, 17 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 57. There are 10 extremes in the warm half of the year and 7 in the cold one.

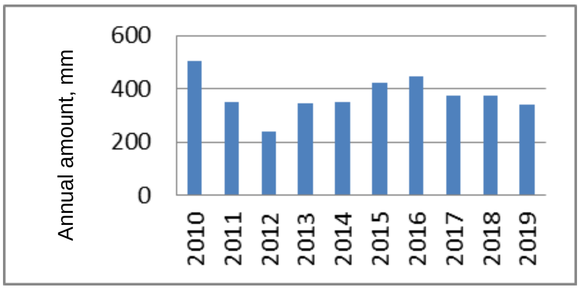

Fig. 56. *Annual precipitation amount in Plodovoye*

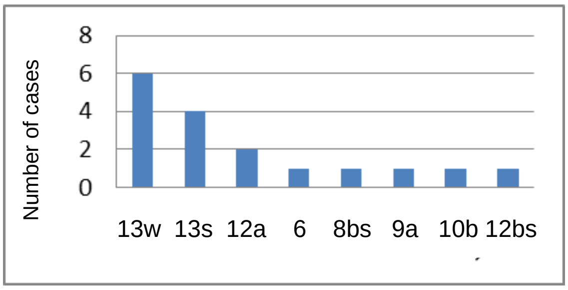

Fig. 57. *The number of the ECM cases causing extreme precipitation in Plodovoye*

Pochtovoye. From 2010 to 2012, the annual amount of precipitation in Pochtovoye (Fig. 58) decreased from 482 mm to 259.8 mm. Then it increased by 2015 to 453.3 mm, and by 2019 it decreased to 323.5 mm. The maximum annual amount of precipitation was noted in 2010, the secondary maximum - in 2015.The minimum was noted in 2012, the secondary minimum - in 2019.

In total, 14 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 59. There are 6 extremes in the warm half of the year and 8 in the cold one.

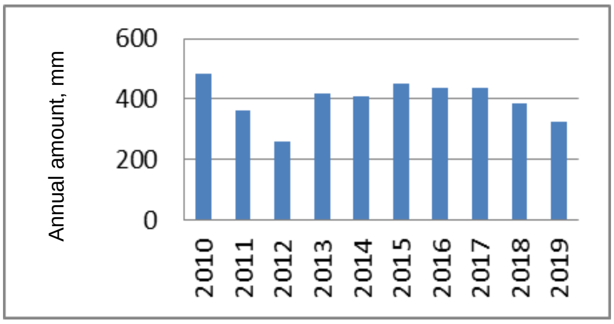

Fig. 58. *Annual precipitation amount in Pochtovoye*

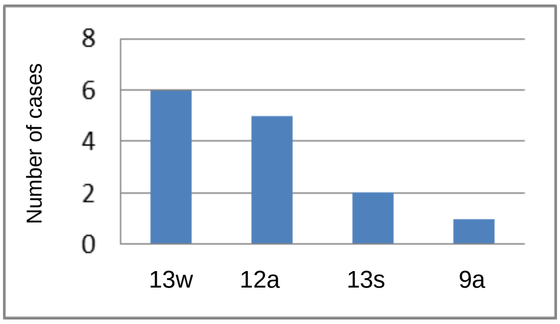

Fig. 59. *The number of the ECM cases causing extreme precipitation in Pochtovoye*

Razdolnoye. From 2010 to 2012, the annual amount of precipitation in Razdolnoye (Fig. 60) decreased from 538.8 mm to 278.8 mm. Then it increased by 2016 to 491.1 mm, and by 2019 it decreased to 372.2 mm. The maximum annual amount of precipitation was noted in 2010, the secondary maximum - in 2016. The minimum was noted in 2012, the secondary minimum - in 2011 (316.7 mm).

In total, 13 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 61. There are 8 extremes in the warm half of the year and 5 in the cold one.

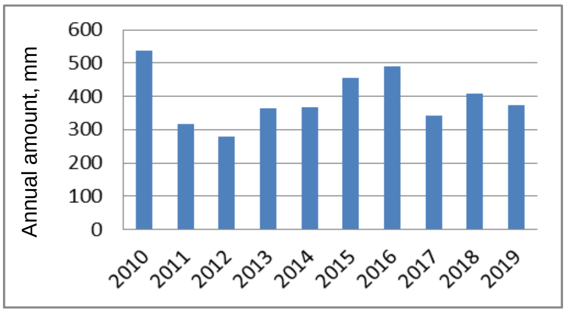

Fig. 60. *Annual precipitation amount in Razdolnoye*

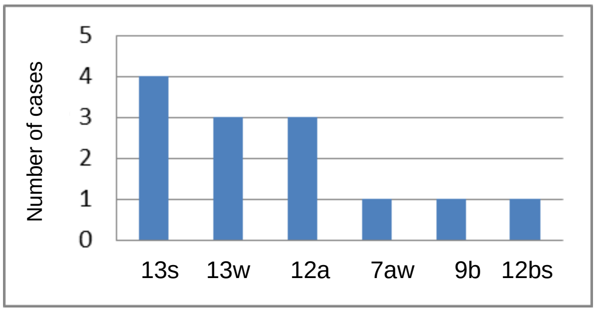

Fig. 61. *The number of the ECM cases causing extreme precipitation in Razdolnoye*

Simferopol. From 2010 to 2012, the annual amount of precipitation in Simferopol (Fig. 62) decreased from 474.4 mm to 244.2 mm. Then it increased by 2015 to 435.3 mm, and by 2019 it decreased to 315.8 mm. The maximum annual amount of precipitation was noted in 2010, the secondary maximum - in 2015.The minimum was noted in 2012, the secondary minimum - in 2019.

In total, 13 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 63. The warm half of the year has 6 extremes, the cold one has 7. This is the third time of occurrence of ECMs 10b, which is not typical for precipitations in the Crimea. This is the case (10 June, 2017 (Fig. 26a)), when the invasion took place to the east, and the Southern border of the anticyclone was near the Northern shores of the Caspian Sea. A cyclone that emerged from the Eastern Mediterranean met an obstacle in the form of this anticyclone on its way and poured abundant precipitation on Simferopol, Yevpatoria and Klepinino: 17.3 mm per day.

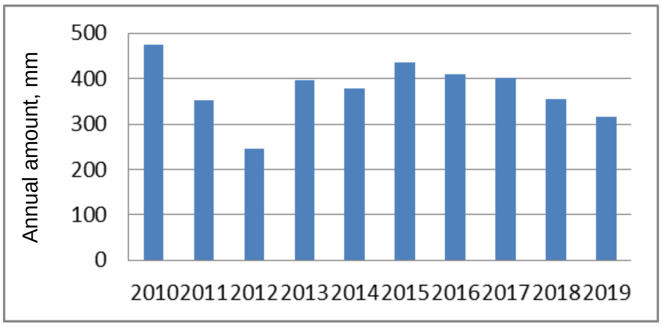

Fig. 62. *Annual precipitation amount in Simferopol*

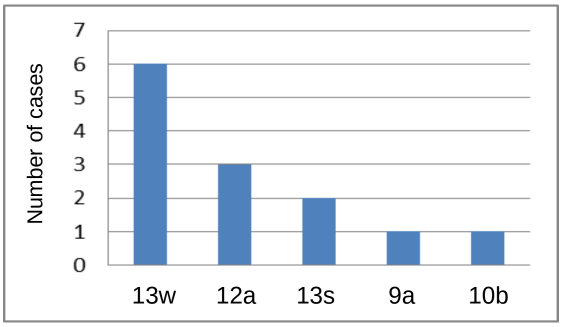

Fig. 63. *The number of the ECM cases causing extreme precipitation in Simferopol*

Belogorsk. From 2010 to 2012, the annual amount of precipitations in Belogorsk (Fig. 64) decreased from 496.5 mm to 243 mm. Then it increased by 2015 to 443.6 mm, and by 2019 it decreased to 337.9 mm. The maximum annual amount of precipitations was noted in 2010, the secondary maximum - in 2015.The minimum was noted in 2012, the secondary minimum - in 2019. In total, 13 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 65. There are 6 extremes in the warm half of the year and 7 in the cold one.

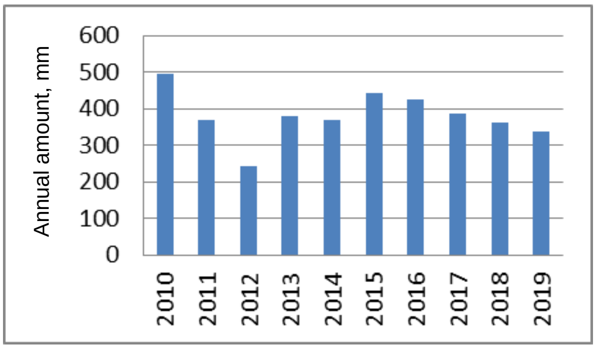

Fig. 64. *Annual precipitation amount in Belogorsk*

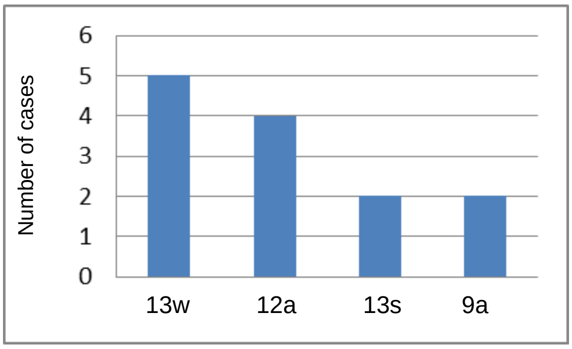

Fig. 65. *Number of ECM cases causing extreme precipitation in Belogorsk*

Karadag. The data of the Karadag background ecological monitoring station were used as source material for the analysis of changes in the amount of precipitations at this station. Compare them with the reanalysis data. As we can see, the data are different. The reanalysis data (Fig. 66) are underestimated. In addition, according to observational data (Fig. 67), the secondary maximum precipitation occurs in 2018 and coincides with the maximum duration of the upcoming of Southern cyclones (Fig. 1). According to the reanalysis data, the maximum falls on 2016.

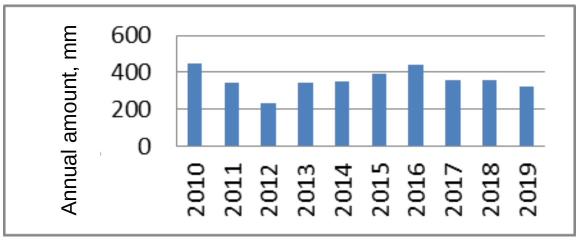

__Fig. 66.__ Annual precipitation amount in Karadag according to reanalysis data

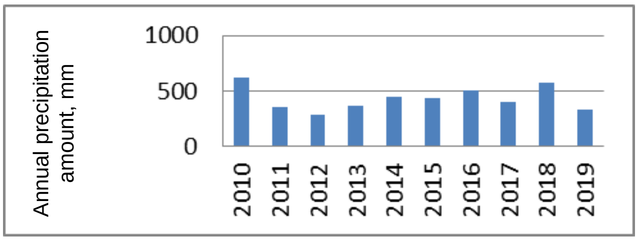

__Fig. 67.__ Annual precipitation amount in Karadag according to observations

Let us compare the observational and reanalysis data by precipitation extremes and their relationship with ECMs. According to the reanalysis data, the daily precipitation amounts rarely reach 5% of the annual amount than according to the observation data, and have never reached 10% of the annual amount. In total, according to the observation data, 34 cases of abundant precipitation (Fig. 68) and 9 cases of catastrophic ones (Fig. 69) were revealed. According to the reanalysis data, 14 cases of abundant precipitation were revealed (Fig. 70) and there was not a single catastrophic one. This indicates a significant underestimation of daily precipitation amounts, which is reflected in the underestimation of annual amounts. According to observational data, 19 cases of abundant precipitation and 5 cases of catastrophic ones occurred in the warm half of the year; 15 cases of abundant precipitation and 4 catastrophic cases were in the cold half of the year. According to the reanalysis data, there were 6 cases of abundant precipitation in the warm half of the year and 8 in the cold half of the year. According to both observations and reanalysis, there are more extremes in the cold half of the year.

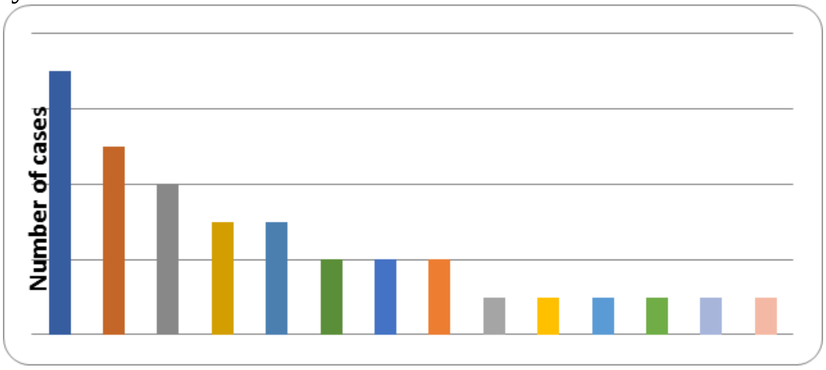

__Fig. 68.__ The number of ECMs with abundant precipitation (5% of the annual amount per day) according to observations at the Karadag station

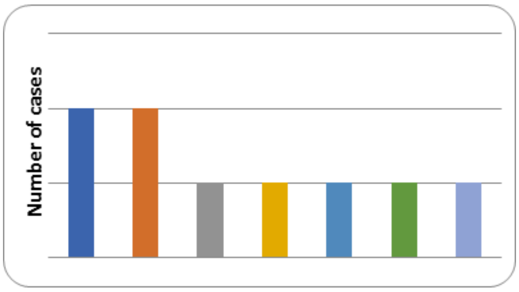

__Fig. 69.__ The number of ECMs with catastrophic precipitation (10% of the annual amount per day) at Karadag according to observation data

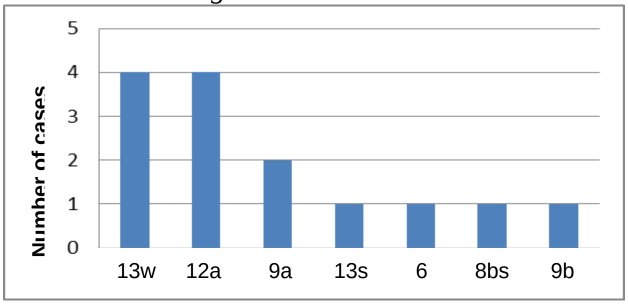

__Fig. 70.__ The number of the ECM cases that caused extreme precipitation in Karadag according to reanalysis data

Opasnoye. From 2010 to 2012, the annual amount of precipitations in the Opasnoye village (Fig. 71) decreased from 466 mm to 266 mm. Then it increased by 2016 to 486 mm, and by 2019 it decreased to 335.7 mm. The maximum annual amount of precipitations was noted in 2016, the secondary maximum - in 2010. The minimum was noted in 2012, the secondary minimum - in 2019.

In total, 15 precipitation extremes were noted over the decade. Their distribution by ECMs is shown in Fig. 72. There are 9 extremes in the warm half of the year and 6 in the cold one.

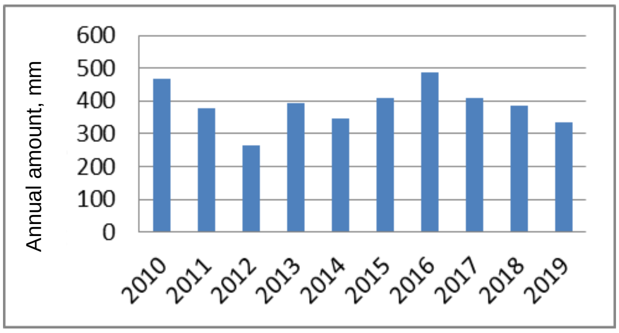

Fig. 71. *Annual precipitation amount in Opasnoye*

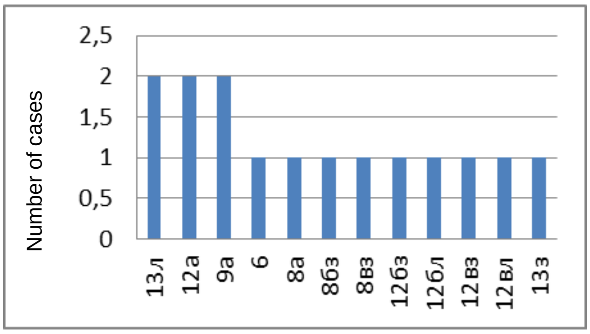

Fig. 72. *The number of the ECM cases causing extreme precipitation in Opasnoye*

ANALYSIS OF THE RESULTS

The data presented above are used to analyse the annual amounts and daily extremes of precipitation. According to observation data, at all stations without exception (including at the Karadag station), the minimum annual amount of precipitations falls on 2012. As can be seen Fig. 1, in 2012, the duration of the meridional Northern group of processes is the largest in a decade and is 257 days a year with an average duration of 197 days. This group includes only a few ECMs (12a, 12bw, 12bs, 12cw, 12cs), at which Mediterranean cyclones freely pass to the ETR, while during the remaining time, there are anticyclones over the ETR, often occupying the Crimea territory. In 2019, which accounts for the second minimum of annual precipitation at most stations, the duration of this group increased to 230 days a year from 185 days in 2018. Since the duration of meridional Northern processes in 2019 is 27 days less than in 2012, the decrease in precipitation in the Crimea is less significant.

As for the extremes of precipitation, they were distributed over the years as follows. Maximum precipitation: 2010 - 15 cases, 2016 - 5 cases, 2015 - 3 cases. Secondary maxima: 2016 - 10 cases, 2010 - 6, 2015 - 5, 2017 and 2018 - one in each year. This is not entirely consistent with the total annual duration of the precipitation-forming ECMs.

It is known that precipitations in the Crimea fall mainly during such ECMs as 13w, 13s, 12a and 9a [4]. Their average total duration is 78.5 days a year. In 2010, it was 192 days, in 2015 and 2016 - 240 days each, in 2017 - 285 days and in 2018 - 256 days. The maximum of the extremes was in 2010. The analysis of daily extremes in 2010 at all stations allowed us to eliminate the apparent discrepancy. It turns out that all the extreme precipitations in 2010 fell from three Southern cyclones. The first cyclone came out on January 14 at the ECM 13w and brought extreme precipitation at Klepinino (19.7 mm) and Yishun (25.9 mm) stations. The second cyclone came out on June 29 with ECMs of 13s and on the first day it brought precipitation extremes at 4 stations, on June 30 - at 8 more stations and on July 1 - at 5 more stations (Table 1). The third Southern cyclone reached the Crimea on October 8 with ECMs 13w and brought precipitation extremes to Feodosia (27 mm), Vladislavovka (26.6 mm), Plodovoe (23.1 mm) and Karadag (25.9 mm). Thus, in 2010, abundant precipitation fell from three Southern cyclones within 5 days.

Table 1. *Abundant precipitations (mm) in the Crimea on June 29 - July 1, 2010*

June 29, the ECM 13s					
Kerch	39.2	Mysovoe	37.7	Dzhankoy	21,7
Opasnoye	38.3				
June 30, the ECM 13s					
Yevpatoriya	27.5	Chernomorskoye	37.5	Alushta	19.1
Pochtovoye	24.1	Angarsky pass	24.2	Razdolnoye	27.3
Simferopol	29.5	Belogorsk	30.8		
July 1, the ECM 13s					
Sebastopol	21.3	Chersonesos lighthouse	20.6	Nikitsky Garden	18.4
Yalta	19.7	Ai-Petri	20.7		

All the periods under review were analysed in a similar way. In 2011, most of the extremes of daily precipitation totals (18) fell on October 11–12, ECMs 13w (Table 2); and in Alushta, Pochtovoye, at the Angarsky Pass, in Simferopol and in Belogorsk, abundant precipitations occurred on both days. The next 7 cases of abundant precipitation were noted on May 5 with ECMs 8bs (Table 2). Another 2 cases were noted on October 18 with ECMs 8a at Yevpatoriya (16.8 mm) and Chernomorskoye (26.4 mm) stations and on December 24 with ECMs 12cw in Kerch (14.4 mm) and Opasnoye (15 mm), as well as in one case on February 12 with ECMs 12bw in Mysovoye (10.5 mm), on June 26 with ECMs 8bs in Chernomorskoye (27.9 mm) and on April 8 with ECMs 12a in Razdolnoye (15.3 mm). Thus, all extreme precipitation in 2011 fell at 7 Southern cyclones, came up at 7 ECMs. There were 23 cases in the cold half of the year in 2011, and 9 in the warm half.

Table 2. *Abundant precipitation (mm) in the Crimea in 2011*

October 11, ECMs 13w					
Sebastopol	20	Yalta	25.1	Chersonesos lighthouse	18.8
Alushta	23.1	Nikitsky Garden	24.1	Ai-Petri	26.5
Pochtovoye	21.5	Angarsky pass	24.7	Simferopol	21.9
Belogorsk	22.4				
October 12, ECMs 13w					
Klepinino	26.2	Dzhankoy	25.5	Plodovoye	26
Pochtovoye	22.6	Simferopol	23.9	Belogorsk	22.6
Alushta	18.1				
May 5, ECMs 8bs					
Feodosia	17.3	Vladislavovka	16.3	Yishun	17.8
Plodovoye	19	Dzhankoy	21.8	Klepinino	18.5
Karadag	15.7				

In 2012, 32 cases of abundant precipitation and one case of catastrophic one were noted with the minimum annual precipitation in a decade. The largest number of abundant precipitation cases (8) and one catastrophic case fell on May 25, ECMs 6 (Table 3), in which the path for Mediterranean cyclones through the Crimea to the ETR was free (Fig. 13). Catastrophic precipitations (34.1 mm) fell in Opasnoye. On December 1–2, ECMs 9b (Fig. 35) had 6 cases of abundant precipitations (Table 3). On August 13, ECMs 9a (Fig. 11), there were 5 cases of abundant precipitations (Table 3). On August 28, ECMs 12bs (Fig. 17), there were 4 cases of abundant precipitation at the stations of Chernomorskoye (18.6 mm), Dzhankoy (14.4 mm), Yishun (18.3 mm) and Razdolnoye (19 mm).

Table 3. *Abundant precipitation (mm) in the Crimea in 2012*

May 25, ECMs 6					
Kerch	32.9	Mysovoe	25.2	Feodosia	19.8
Klepinino	13.1	Vladislavovka	20.2	Dzhankoy	13.5
Plodovoye	16.5	Karadag	15.2	Opasnoye	34.1
December 1-2, ECMs 9b					
December 1, Yevpatoriya	13.4	December 1 Razdolnoye	14.7	December 2, Feodosia	14
December 2, Nikitsky Garden	8.9	December 2, Yishun	14.1	December 2, Karadag	12
August 13, ECMs 9a					
Sebastopol	13.9	Chersonesos lighthouse	13.8	Ai-Petri	9.2
Pochtovoye	16.1	Simferopol	15.2		

3 cases of abundant precipitation each fall on July 7, ECMs 9a, at stations Alushta (9 mm), Angarsky Pass (10.8 mm) and Belogorsk (14.1 mm) and on November 3-4, ECMs 12a (Fig. 5) at the stations of Feodosiya (November 3, 14.1 mm), Vladislavovka (November 4, 12.2 mm) and Karadag (November 3, 12.1 mm). Two cases of abundant precipitation were noted on January 14 (ECMs 12a) at Mysovoye (12.5 mm) and Opasnoye (13.2 mm) stations and one case on September 21 (ECMs 12bs, Fig. 17) in Yalta (8.7 mm). Thus, extreme rainfalls in 2012 fell three times in Feodosia and twice - in Dzhankoy, Vladislavovka, Mysovoye, Karadag, Razdolnoye and Opasnoye. There were 22 cases of extreme precipitation in the warm half of the year and 11 in the cold one.

In 2013, on October 1 with ECMs 13w, abundant precipitations fell at all Crimean stations, except for Razdolnoye (Table 4). The daily precipitation ranged from 18 mm (Yishun) to 36.7 mm (Pochtovoye). In addition, abundant precipitations fell on June 3 with ECMs 9a (Table 4). Most of all (23.4 mm) fell in the Nikitsky Botanical Garden. Abundant precipitations also took place on October 18 with ECMs 7aw (Table 4). Most precipitation fell in Chernomorskoye (27.2 mm).

Table 4. *Abundant precipitation (mm) in the Crimea in 2013*

October 1, ECMs 13w					
Sebastopol	39.6	Kerch	23.8	Yalta	30.7
Yevpatoriya	35.5	Mysovoe	28.4	Chersonesos lighthouse	39.5
Feodosia	28.9	Chernomorskoye	22.5	Klepinino	29.8
Nikitsky Garden	29.7	Alushta	29.2	Ai-Petri	31.7
Angarsky pass	32	Vladislavovka	29.2	Dzhankoy	24.2
Yishun	eighteen	Plodovoye	30.7	Pochtovoye	36.7
Simferopol	36.5	Belogorsk	34.2	Karadag	27.1
Opasnoye	23.2				
June 3, ECMs 9a					
Yalta	22.3	Feodosia	21.9	Nikitsky Garden	23.4
Alushta	22.4	Vladislavovka	19	Karadag	21.6
October 18, ECMs 7aw					
Yevpatoriya	21.4	Chernomorskoye	27.2	Klepinino	18.9
Dzhankoy	17.7	Yishun	26.5	Razdolnoye	26.4

The next day, October 19, with ECMs 8bw, an abundant precipitation (30.1 mm) occurred in Mysovoye; a catastrophic one (40.2 mm) took place in Kerch and 40.3 mm in Opasnoye. In total, in 2013 in the Crimea there were 35 cases of abundant precipitations and 2 cases of catastrophic ones. At the stations of Yalta, Feodosia, Nikitsky Botanical Garden, Alushta, Vladislavovka, Karadag, Yevpatoriya. Chernomorskoye, Klepinino, Dzhankoy, Yishun, and Mysovoe, abundant precipitations fell twice, and in Kerch and Opasnoye, at the first time it was heavy, and at the second time it was a catastrophic rainfall.

On September 23, 2014, abundant precipitations fell at 5 stations and catastrophic ones at 12 stations (Table 5), with ECMs 13s. On other days, abundant precipitation fell on May 18 with ECMs 13s in Feodosia (22.9 mm), Vladislavovka (22 mm), Dzhankoy (20.1 mm), and Plodovoy (21.8 mm); on June 20 with ECMs 3, in Chernomorskoye (20.5 mm); on October 18, with ECMs 12a at 5 stations (Table 5); on December 27 with ECMs 8a, in Kerch (18.7 mm), Mysovoe (19 mm), and Opasnoye (18.4 mm). In total, in 2014, there were 18 cases of abundant precipitation and 12 cases of catastrophic ones. All precipitations were brought by 5 Southern cyclones: 3 in the warm half of the year were marked by 22 cases of extreme precipitation, 2 - in the cold half of the year with 8 cases of abundant precipitations.

Table 5. *Extreme precipitations (mm) in the Crimea in 2014*

September 23, ECMs 13s, abundant precipitation					
Yalta	34.8	Nikitsky Garden	32.9	Alushta	31.4
Ai-Petri	36.6	Angarsky pass	36.6		
September 23, ECMs 13s, catastrophic precipitation					
Sebastopol	52.7	Yevpatoriya	59.6	Chersonesos lighthouse	52.8
Chernomorskoye	43.6	Klepinino	62.3	Yishun	61.8
Vladislavovka	63.5	Plodovoye	46.7	Pochtovoye	48.1
Razdolnoye	56.4	Simferopol	47	Belogorsk	38.5
October 18, ECMs 12a					
Feodosia	18.8	Alushta	20.2	Angarsky pass	20.2
Belogorsk	19.3	Karadag	20.4		

In 2015, 4 Mediterranean cyclones brought heavy and catastrophic precipitation to the Crimea. At 18 stations, precipitation fell on October 11 with ECMs 12a (Table 6). In Mysovoe, abundant precipitation (29.7 mm) fell on June 25, with ECMs 13s. On the same day, catastrophic precipitation fell in Opasnoye (44.2 mm) and Kerch (44.9 mm). On March 28, with ECMs 13w, abundant precipitation fell in Yishun (20.7 mm) and in Razdolnoye (20.4 mm). On October 1, with ECMs 8a, for the second time in the year, abundant precipitation fell in Yalta (28.4 mm), Nikitsky Botanical Garden (28.5 mm) and Ai-Petri (27.3 mm). In total, 24 cases of abundant precipitation and 2 catastrophic ones were recorded during the year. 23 cases of abundant precipitation occur in the cold half of the year; 2 cases of catastrophic and 1 case of abundant precipitation occur in the warm half of the year.

In 2016, extreme precipitations in the Crimea fell with 6 cyclones that reached the peninsula in different months. The first one came up on January 16 with ECMs 12a and brought abundant precipitation to Yevpatoriya (16.5 mm) and Chernomorskoye (22.9 mm). The second one came up on March 22, also with ECMs 12a and brought abundant precipitations at 5 stations (Table 7). The third cyclone reached the Crimea on May 11 with ECMs 12bs and brought abundant precipitation at 7 stations (Table 7). The fourth cyclone arrived to the Crimea on May 29 with ECMs 9a and brought 8 extreme precipitations, of which 3 were catastrophic (Table 7).

Table 6. *Extreme precipitation (mm) in the Crimea in 2015*

October 11, ECMs 12a					
Sebastopol	32.5	Yalta	thirty	Yevpatoriya	25.8
Chersonesos lighthouse	32.4	Feodosia	19.1	Chernomorskoye	19.1
Klepinino	24.5	Nikitsky Garden	29.1	Alushta	27
Ai-Petri	30.8	Angarsky pass	27	Vladislavovka	19.2
Dzhankoy	19	Pochtovoye (disaster.)	48.1	Simferopol	25.1
Belogorsk	25	Karadag	20.6	Plodovoye	23.3

The fifth cyclone reached the Crimea on June 3 with ECMs 13s and brought abundant precipitations to Dzhankoy (25.8 mm), Yishun (31.2 mm), Plodovoye and Razdolnoye, 23.9 mm each. The sixth cyclone arrived to the Crimea on June 22 with ECMs 12a and brought abundant precipitation to the Nikitsky Botanical Garden (20.4 mm), Alushta (18.2 mm), Ai-Petri (22 mm), and Pochtovoe (21.3 mm). In total, 27 cases of abundant precipitations and 3 cases of catastrophic ones were recorded during the year. In Plodovoye, abundant precipitations fell three times, in Mysovoye and Vladislavovka - abundant and catastrophic ones at a time; in Kerch, Dzhankoy and Opasnoye, abundant precipitation fell twice. 7 cases of abundant precipitations fell on the cold half of the year, all the rest are on the warm half of the year.

Table 7. *Extreme precipitations (mm) in the Crimea in 2016*

March 22, ECMs 12a					
Sebastopol	24.1	Yalta	21.9	Chersonesos lighthouse	23.6
Angarsky pass	18.7	Simferopol	19.6		
May 11, ECMs 12bs					
Kerch	37.1	Mysovoe	37.7	Klepinino	22
Vladislavovka	25.5	Dzhankoy	30.6	Plodovoye	29.5
Opasnoye	36.5				
May 29, ECMs 9a, catastrophic precipitations					
Mysovoe	54.2	Feodosia	47.7	Vladislavovka	47.9
May 29, ECMs 9a, abundant precipitations					
Kerch	30.2	Plodovoye	24.4	Belogorsk	25.5
Karadag	40.4	Opasnoye	24.9		

In 2017, there was no any catastrophic precipitation in the Crimea; there were only abundant ones. They were brought by 9 Mediterranean cyclones at different times of the year. The first cyclone brought 18.1 mm precipitation to Sebastopol on March 19 with ECMs 13w. The second one came up on April 18 with ECMs 12a and brought 22.9 mm of precipitation to the Chernomorskoye station. The third arrived on April 23 with ECMs 12a and brought abundant precipitations to 12 Crimean stations (Table 8).

The fourth cyclone came on May 14 with ECMs 9a and poured 17.7 mm onto Yishun. The fifth cyclone on June 10 brought abundant precipitation to Yevpatoriya (20.8 mm), Klepinino (21.3 mm), Plodovoe (21.2 mm), and Simferopol (17.3 mm). The sixth cyclone on July 7 with ECMs 13s brought abundant precipitation to Yishun (23.6 mm) and Razdolnoye (19.8 mm). The eighth cyclone on November 18 with ECMs 12a came to the Crimea and poured 17.7 mm of precipitation onto Dzhankoy. Then there was no abundant precipitation in the Crimea for 2 days. On November 21, it regenerated and gave abundant rainfall in Kerch (36 mm) and Opasnoye (38.4 mm). The last cyclone with abundant precipitations came up on December 4 with ECMs 12a and poured 17.8 mm onto the Chersonesos lighthouse and 16.8 mm onto Pochtovoe. In total, 29 cases were noted: 6 in the cold half of the year and 23 in the warm one; in Plodovoye, abundant precipitation was noted three times, and in Kerch, Dzhankoy, Yishun and Klepinino - twice.

Table 8. *Extreme precipitation (mm) in the Crimea in 2017*

April 23, ECMs 12a					
Kerch	34.3	Yalta	22.8	Mysovoe	30.3
Feodosia	27.8	Nikitsky Garden	22.9	Alushta	22.5
Ai-Petri	22.8	Angarsky pass	22.9	Vladislavovka	27.2
Plodovoye	18.8	Belogorsk	20.6	Karadag	27

In 2018, extreme rainfall in the Crimea was caused by seven Mediterranean cyclones. The first one came out on June 16 with ECMs 12cs (Fig. 18) and brought abundant precipitation to Kerch (18.6 mm) and Opasnoye (20.2 mm). The second one arrived on September 6 with ECMs 13w (Fig. 4) poured abundant precipitations on 11 stations (Table 9) and on September 7 on Chernomorskoye (29.7 mm), with the same ECMs.

On September 14 with ECMs 12a (Fig. 5), the third cyclone brought abundant precipitation (29.9 mm) to Yishun. On October 21 with ECMs 13w, the fourth cyclone brought 6 cases of abundant precipitation and one catastrophic precipitation (Table 9). On October 31, the fifth cyclone with ECMs 13w brought abundant precipitation (31.1 mm) to Klepinino. On November 19 with ECMs 13w, the sixth cyclone brought the maximum daily precipitation that year to Razdolnoye (17.7 mm), although it is less than 5% of the annual precipitation. On December 11 with ECMs 13w, the seventh cyclone brought abundant precipitations to 5 stations (Table 9). In total, in 2018 in the Crimea, 27 cases of abundant precipitation and one catastrophic one were noted. At the stations of Sebastopol, Chersonesos lighthouse, Vladislavovka, Pochtovoe and Simferopol, abundant precipitations fell twice. There were 15 cases of extreme precipitations in the warm half of the year and 12 in the cold one.

Table 9. *Extreme precipitation (mm) in the Crimea, 2018*

September 6, ECMs 13w					
Sebastopol	32.8	Yalta	28.9	Chersonesos lighthouse	32.1
Nikitsky Garden	27.1	Alushta	21,7	Ai-Petri	thirty
Angarsky pass	21.2	Vladislavovka	21.2	Pochtovoye	24.4
Simferopol	20.1	Chernomorskoye (07.09)	29.7		
October 21, ECMs 13w					
Mysovoe	28.8	Feodosia	26	Vladislavovka	30.3
Dzhankoy	15.5	Belogorsk	31.9	Karadag	26.8
Plodovoye (catastrophic)	42.4				
December 11, ECMs 13w					
Sebastopol	33.1	Yevpatoriya	26.2	Chersonesos lighthouse	34.1
Pochtovoye	21.1	Simferopol	18.2		

In 2019, abundant precipitations in the Crimea (there were no catastrophic ones) was caused by eight Mediterranean cyclones. The first one came up on January 10 with ECMs 12a (Fig. 5) and was noted with five cases of abundant precipitations at 5 stations (Table 10).

Table 10. *Abundant precipitations (mm) in the Crimea on January 10, 2019*

Sebastopol	31	Yalta	23.1	Chersonesos lighthouse	30.6
Nikitsky Garden	20.9	Pochtovoye	20.2		

The second cyclone on April 14 with ECMs 12a brought 14 cases of abundant precipitations at 13 stations: abundant precipitations at Chernomorskoye station fell on April 14 and 15 (Table 11).

Table 11. *Abundant precipitations (mm) in the Crimea on April 14, 2019*

Yalta	20.9	Chersonesos lighthouse	23.8	Chernomorskoye (April 14)	17.5
Chernomorskoye (April 15)	21.1	Klepinino	28.9	Nikitsky Botanical Garden	20.3
Ai-Petri	21.6	Angarsky pass	21.6	Dzhankoy	27.8
Yishun	25.3	Pochtovoye	23.6	Razdolnoye	23.6
Simferopol	23.6	Belogorsk	21.5		

On May 8 with ECMs 12a, the third cyclone poured 16.9 mm of precipitation onto Kerch and 17.2 mm onto Mysovoye. On May 19 with ECMs 12a, the fourth cyclone brought abundant precipitations to Klepinino (21.1 mm), Dzhankoy (17.1 mm), Yishun (24.7 mm), and Razdolnoye (28.6 mm). On May 25 with ECMs 12a, the fifth cyclone brought 18 mm of abundant precipitations to Kerch and 21.3 mm to Opasnoye. On October 5 with ECMs 12a, the sixth cyclone brought 17.6 mm of abundant precipitations to the Chernomorskoye. On November 13 with ECMs 13w, the seventh cyclone poured 23.4 mm onto Yevpatoriya. The most abundant precipitation (17 cases) was brought by the cyclone on November 29 with ECMs 13w (Table 12). In total, there were 46 cases of abundant precipitations in 2019, 24 cases in the cold half of the year and 22 in the warm one.

Table 12. *Abundant precipitation (mm) in the Crimea on November 29, 2019*

Sebastopol	33.2	Yalta	29.1	Mysovoe	17.6
Feodosia	18.1	Chersonesos lighthouse	32.5	Nikitsky Garden	27.5
Alushta	23.4	Ai-Petri	30.1	Angarsky pass	23.4
Vladislavovka	19.1	Yishun	18.8	Plodovoye	23.3
Pochtovoye	27.8	Razdolnoye	18.8	Simferopol	24.7
Belogorsk	21,7	Karadag	17.5		

All known cases of extremes in the Crimea over the last decade were distributed by ECMs as follows (Fig. 73). All extreme precipitations are associated with the upcoming of Mediterranean cyclones.

In the cold half of the year, there were 143 extremes in total for all stations, and 149 extremes fell onto the warm half of the year. The outstanding ones were the stations of Plodovoe (10 extremes in the warm half of the year and 7 in the cold one), Kerch (10 extremes in the warm half of the year and 5 in the cold one), Dzhankoy (11 extremes of the warm half in the year and 7 in the cold); some stations demonstrated the opposite ratio:

Sebastopol (4 extremes in the warm half of the year, 8 - cold, Yevpatoriya (3 and 8) and Chersonesos lighthouse (5 and 8).

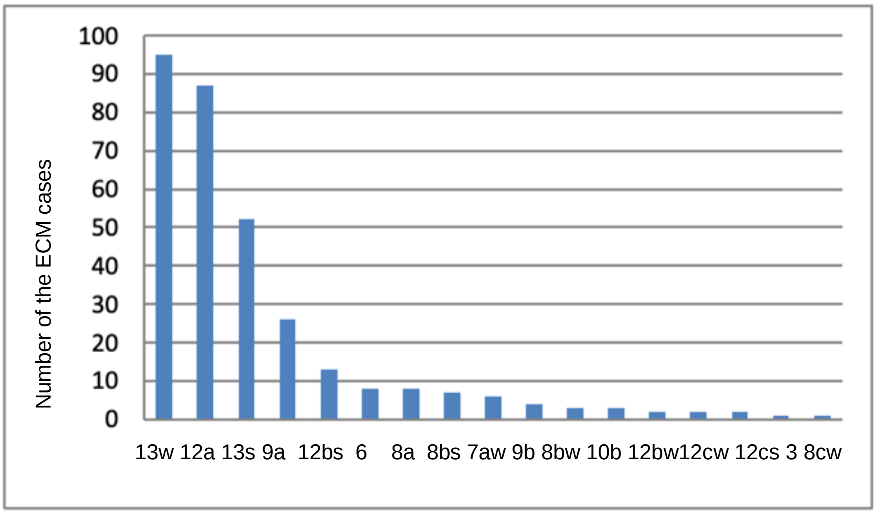

Fig. 73. *The number of the ECM cases causing extreme precipitation in the Crimea in the period 2010-2019.*

CONCLUSION

The analysis made it possible to reveal the fluctuation of the annual precipitation amount in the Crimea. The minimum precipitation at all stations is noted with an increase in blocking processes, in 2012. The second minimum is noted in 2019 and is also associated with an increase in the duration of blocking processes. The precipitation maximum is noted at different stations in 2010, 2015, 2016 and 2018, which is associated with an increase in the duration of the Southern cyclones emerged in these years. The ECMs was also identified, at which extreme precipitation fell in the Crimea in the last decade. Most of the cases (95) occur with ECMs 13w, at which, in the cold half-year, Mediterranean cyclones emerge behind a powerful and vast Siberian anticyclone. The second place in terms of the frequency of its occurrence is occupied by the ECMs 12a (87 cases), at which Mediterranean cyclones reach the Crimea in the rear of the anticyclone formed as a result of the Arctic invasion in Siberia. These ECMs occur all year round. This is followed by the ECMs 13s (52 cases), at which a Mediterranean cyclone in the warm half of the year encounters an obstacle on its way in the form of an anticyclone core over the Russian Plain and pours all precipitations onto the Crimea and the Black Sea coast. A similar situation also develops with the ECMs 9a (26 cases) during the warm half of a year. The rest of ECMs play a lesser role, but all precipitation extremes are associated with the upcoming of Mediterranean cyclones. The distribution of extreme precipitations was approximately the same over a half-year period: 143 cases in the cold half-year and 149 in the warm half-year. Most of the cases of abundant precipitation were observed in 2019 (46 cases). There were no catastrophic precipitations this year. Most of the catastrophic precipitations occurred in 2014 (12 cases). From 21 (2010) to 46 (2019) cases of extreme precipitations were recorded in the Crimea every year. Since the duration of ECMs causing extreme precipitation in recent decades is significantly higher than the long-term average value, the frequency of extreme precipitation in the Crimea will increase.

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