Synoptic typification of heavy rain events in Perm region

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Abstract. Heavy rain is considered to be one of the most hazardous weather phenomena which may result in strong rain floods, disturb the normal operation of housing and communal services, and influence the formation of crops. At present research is commonly focused on detecting the mechanisms of heavy rains and showers formation in physical terms, while studies fail to provide the synoptic typification of heavy rains in most of the Russian Federation. This paper discusses a typification of synoptic conditions of heavy rains in Perm region for 1979-2015. Heavy rains (≥ 30 mm/12 h) have been detected by observation networks (meteorological stations, meteorological posts, agrometeorological posts, and hydrological posts) 287 times, thus allowing a comprehensive statistical processing of the information on conditions of the heavy rain formation. The article examines trends in the number of heavy rain events for 1979-2015. The prevailing synoptic situations, as well as the speed and direction of cyclones specific to heavy rain events are determined. The depth, stages of development, vertical evolving, diameter and square of the cyclones are analysed.

1. Introduction
Currently the problem of synoptic conditions typification of heavy rains formation in the warm season is underrepresented in the academic literature. In the Russian Federation such research works have been conducted for Arkhangelsk Oblast and Nenets Autonomous Okrug [1], and for the territory of Estonia [7]. According to these studies, heavy rains are primarily affected by the south, west-south, and local (formed in close proximity to the study area) cyclones.

Synoptic conditions typification of heavy rains formation in the cold season in different regions of the Russian Federation and other countries is described in papers [3-6]. Paper [4] shows that in the winter season blizzards are frequently observed when north-west and west cyclones shift to the territory of Perm region.

This paper describes synoptic conditions typification of heavy rains in Perm region for 1979–2015. The main goal of this study is to identify synoptic situations which induce heavy rains within the territory of Perm region. The frequency of the following cyclone characteristics is additionally calculated: the direction, velocity, stages of development, vertical extension, square and diameter of cyclones. Furthermore, trends in the number of heavy rain events for 1979–2015 are also analyzed.

It is noteworthy that heavy rains are observed in Perm region only during the warm season, specifically from April to October. The precipitation amounts vary greatly in particular cases.

2. Materials and methods of study
The synoptic conditions typification of heavy rains in Perm region for 1979–2015 included several stages:
1) heavy rain database formation,
2) definition of synoptic situation,
3) definition of cyclone features based on the data of climatological reanalysis (CFS): the travel speed, depth, stages of development, vertical evolving, diameter and square of cyclones,
4) statistical processing of the obtained data.

The information of meteorological stations, meteorological posts, agrometeorological posts, and hydrological posts was used to form a heavy rain database. A threshold value of 30 mm/12 h was chosen as a criterion for heavy rain. Definition of synoptic situation and cyclone features was carried out involving CFS data with 0.5×0.5° spatial and 6 h temporal resolution. Sea level pressure fields as well as geopotential heights of 850, 700, 500, and 300 hPa surfaces were used for the analysis. Statistical processing of the data reduced to the calculation of repeatability of synoptic situations and cyclones’ features in accordance with the methodology set out in [2]. The linear trend of heavy rain events number was calculated by means of linear regression in MS Excel.

3. Results and discussion
For 1979–2015, heavy rains in Perm region have been detected by the observation network 287 times. During the study period there was an increase in the number of heavy rains events (Figure 1).

![Figure 1](image-url)

**Figure 1.** Dynamics of the number of heavy rain cases in Perm region for 1979–2015.

The use of regression analysis allowed one to establish that the increase of heavy rain events was 3.1 cases per 10 years on average. The heavy rains number was 2.0 cases per year on average at the beginning of the period and then increased to 13.3 cases per year at the end of the period.

Most frequent is precipitation with an intensity of 30-40 mm/12 h (Figure 2). The greatest precipitation amount (107 mm/12 h) was recorded at the night of June 25, 2015 at the Gubaha weather station in the eastern part of Perm region during the passage of a mesoscale convective complex.
Analysis of sea level pressure fields showed that 87% of the heavy rain events are connected with the influence of cyclones and their frontal systems. In 11% of the cases heavy precipitation falls under the influence of anticyclones (most frequently in the western or northern periphery). Only 2% of the cases were recorded in low-gradient sea level pressure fields.

The cyclones were divided into 6 types according to the area of origin: Southern, Southwestern, Western, Northwestern, Northern, and local cyclones. Cyclones are called Southern if they are formed in the Caspian Sea area or over Northern Kazakhstan. Southwestern and Western cyclones are formed in the Black sea area and over Northern Europe. A local cyclone is a cyclone that has formed directly above Perm region area or adjacent regions. The directions of cyclones movement are shown in Figure 3.

The most frequent heavy rains are observed during the Southern and Western cyclones displacement. These cyclones account for 34% and 22%. In 14% of the cases, heavy rains are observed during the Northwestern cyclones displacement, and in 7% of the cases, during the formation
of local cyclones. The smallest number of heavy rain events was recorded with displacement of the Northern and Southwestern cyclones: only 6 and 4%.

The cyclone displacement speed at which heavy rains were observed varied from 3 to 43 km/h. The average speed of the observed cyclones is 19 km/h. Table 1 shows the distribution of heavy rain events according to the cyclone speed.

Table 1. Distribution of heavy rain events according to cyclone speed.

| Cyclone speed, km/h | 3.0-8.7 | 8.8-14.4 | 14.5-20.2 | 20.3-25.9 | 26.0-31.7 | 31.8-37.4 | 37.5-43.0 |
|---------------------|---------|----------|-----------|-----------|-----------|-----------|-----------|
| Number of cases, %  | 11      | 17       | 29        | 23        | 9         | 7         | 4         |

The depth of cyclones that cause heavy precipitation was determined during the study. The average depth of cyclones that cause heavy rain is 998.7 hPa. The minimum and maximum values are 982.0 and 1016.0 hPa, respectively. Table 2 shows the distribution of heavy rain events according to cyclone depth.

Table 2. Distribution of heavy rain events according to cyclone depth.

| Depth of cyclones, hPa | Number of cases, % |
|------------------------|--------------------|
| 982.0-986.2            | 6                  |
| 986.3-990.4            | 6                  |
| 990.5-994.7            | 15                 |
| 994.8-998.9            | 22                 |
| 999.0-1003.2           | 28                 |
| 1003.3-1007.4          | 14                 |
| 1007.5-1011.7          | 8                  |
| 1011.8-1016.0          | 2                  |

Information about the prevailing stages of cyclone development is valuable for operational practice. The largest number of heavy rain events is observed under the influence of young cyclones and cyclones at the stage of filling up. The share of these development stages is 37% and 35%, respectively. 26% of the heavy rain events are observed in the cyclones that are at the stage of maximum development. The least contribution is made by the cyclones at the wave stage (Table 3).

Table 3. Distribution of heavy rain events according to the stages of cyclone development.

| Stages of cyclone development | Number of cases, % |
|-------------------------------|--------------------|
| wave stage                    | 2                  |
| young cyclones                | 37                 |
| stage of maximum development  | 26                 |
| stage of filling up           | 35                 |

The question about the cyclones’ vertical development was also investigated. The majority of the heavy rain events (49%) are associated with the cyclones well developed vertically, which can be
traced on an isobaric surface of 300 hPa and above. With the cyclones which can be traced in layers of 700-500 and 500-300 hPa, 14 and 20% of the heavy rain events are associated, respectively. The share of the cyclones traced to an isobaric surface of 700 hPa inclusive is 17% of the cases (Table 4).

**Table 4. Distribution of heavy rain events according to cyclones’ vertical development.**

| Vertical development, km | Number of cases, % |
|--------------------------|--------------------|
| <3 (<700 hPa)            | 17                 |
| 3-5 (700-500 hPa)        | 14                 |
| 5-9 (500-300 hPa)        | 20                 |
| >9 (>300 hPa)            | 49                 |

In order to study the geometric characteristics of cyclones, the diameter and square of the cyclone were determined. Table 5 shows the distribution of heavy rain events according to the diameter and square of a cyclone.

**Table 5. Distribution of heavy rain events according to the diameter (a) and square (b) of a cyclone.**

(a)

| Diameter of cyclone, km | Number of cases, % |
|-------------------------|--------------------|
| 200-441                 | 18                 |
| 442-683                 | 23                 |
| 684-925                 | 22                 |
| 926-1167                | 16                 |
| 1168-1409               | 9                  |
| 1410-1651               | 6                  |
| 1652-1893               | 1                  |
| 1894-2135               | 3                  |
| >2136                   | 2                  |

(b)

| Square of cyclone, million km$^2$ | Number of cases, % |
|-----------------------------------|--------------------|
| 0.03-0.65                         | 61                 |
| 0.66-1.27                         | 21                 |
| 1.28-1.90                         | 10                 |
| 1.91-2.53                         | 2                  |
| 2.54-3.15                         | 3                  |
| >3.16                             | 3                  |

The diameter of cyclones with heavy rains varied from 200 to 3100 km. The average value was 876 km. About 80% of the heavy rain events occur in cyclones with a diameter of less than 1200 km. The square of the cyclones varied from 0.03 to 7.54 million km$^2$. The average value of the square amounted to 0.79 million km$^2$. About 80% of the cases are related to small cyclones which have a square of less than 1.20 million km$^2$.

4. Conclusions
A comprehensive statistical analysis of data about the cyclone characteristics associated with heavy rains in Perm region was carried out as a result of the study.

It was found that 87% of the heavy rain events are related to cyclones, while the rest 13% of heavy rain events occur in low-gradient sea level pressure fields.

The majority of the heavy rain events in Perm region are connected with southern and western cyclones (34 and 22% of the heavy rain events, respectively). The cyclones which cause heavy rains mostly shift in east or north-east directions. The average speed of the observed cyclones is 19 km/h.
The greatest contribution to the heavy rain formation is made by deepening and filling up cyclones (37 and 35% of the heavy rain events, respectively). Vertically developed cyclones which can be captured at 300 hPa or higher surfaces prevail in the heavy rain formation. The average depth of the cyclones which cause heavy rains is 998.7 hPa. In the research of geometrical features of the cyclones which cause the heavy rain formation, the average diameter and square of the cyclones were calculated. The average values of the diameter and square are 876 km and 0.79mln km², respectively.

A temporal distribution analysis of heavy rain events has revealed a positive trend in the heavy rain events during 1979-2015. On average, the increase was 3.1 events per 10 years.

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