Diurnal and seasonal variations of precipitation and factors contributing to its formation

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Diurnal and seasonal variations of precipitation are considered, and the contribution of dynamic and radiative-thermal factors to formation of the precipitation field is estimated using the parameter P, characterizing the fraction of precipitation formed due to unstable stratification in the near-ground atmospheric layer. Most often this fraction does not exceed 10%. The main role in the precipitation formation and in diurnal and seasonal (annual) variations of the precipitation amount is played by the dynamic factor, namely, vertical and vortex synoptic-scale motions.

Precipitation (amount, duration, and variations) is an important and the most variable climate-forcing agent. In addition, precipitation plays a key role in attenuation of optical radiation, causes its substantial variations, and contributes to formation of background noises.[1] Therefore, of great interest is to study diurnal and seasonal variations of the amount and duration of precipitation, and to estimate the role of different factors in formation of the precipitation field. The latter is important because the precipitation, and primarily rain showers falling from cumulonimbus (*Cb*) clouds, is commonly believed to be formed largely due to the radiation-thermal factor, i.e., due to solar radiation incident on the Earth's surface and associated dry-unstable thermal stratification. However, as argued in Ref. 2, this stratification in nature occurs only in the near-ground layer (200–300 m, not higher) and only during a day.

As it was indicated in Refs. 3 and 4, both *Ns* and *Cb* clouds and precipitation falling from them are formed primarily due to dynamic factors, namely, updrafts in cyclones and troughs, altitudinal growth of updraft velocity in the lower troposphere, as well as associated temporal decrease of temperature and increase of its gradient in this layer.

During the night, the precipitation can be formed due to dynamic factors alone, but in the day-time, the radiation-thermal factor joins. Since the precipitation formation due to the dynamic factor is equiprobable by day and night, the difference between daytime Q_d and nighttime Q_n precipitation amounts, divided by their sum $Q = Q_d + Q_n$:

$$P = (Q_d - Q_n)/Q$$

characterizes the contribution of the second, radiation-thermal, factor to precipitation formation.

Data on daytime Q_d and nighttime Q_n precipitation amounts for four five-year periods (from 1975 to 1994) in St. Petersburg and Belogorka are presented in Ref. 5. Table 1 gives the values of P, determined from these data.

It follows from Table 1 that all P values are less than 10%, and in 10 cases (out of 32 values presented in Table 1) the precipitation amount at night is even larger than during the day ($P < 0$). The 20-year average P values (%) for each site and season are:

	spring	summer	fall	winter
Saint Petersburg	0.0	5.4	3.4	–3.0
Belogorka	1.2	6.1	1.0	1.0

Even in summer, when conditions for unstable stratification near the Earth's surface and for manifestation of the radiation-thermal factor are most favorable, its contribution, as it is seen from Table 1, does not exceed 8%.

Table 1. Contribution (P, %) of the radiation-thermal factor to precipitation formation

Years	Saint Petersburg				Belogorka			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
1975–1979	–8.5	5.5	0.3	–0.5	–7.4	5.5	5.6	0.1
1980–1984	1.6	1.8	0.3	2.0	2.6	3.8	–2.7	0.7
1985–1989	2.0	6.0	3.9	–2.0	6.9	7.7	3.0	–1.7
1990–1994	2.7	6.8	–3.8	–4.0	8.6	7.7	–5.8	–3.3

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Since rain showers account for 70–80% of the total precipitation,[6] from the above data we can conclude that the radiation-thermal factor contributes insignificantly (less than 10%) to formation of rain showers. To support this conclusion, we present a sample, including information only on the rain showers in the region of Sosnovo (Table 2).

As in Saint Petersburg and Belogorka, in Sosnovo the role of the radiation-thermal factor is also insignificant, contributing no more than 6% not only to the amount but also to duration of precipitation. Underline that the precipitation characteristics are comparable not only for day and night as a whole, but also for particular observation periods. For instance, according to the data for 1991–1995, in Sosnovo in summer the duration of precipitation was 62 and 102 hours at 0 am and 12 am; 80 and 88 hours at 3 am and 3 pm; 79 and 73 hours at 6 am and 6 pm; and 67 and 82 hours at 9 am and 9 pm, respectively.

Table 2. Information on rain showers in Sosnovo during 1991–1995

Season	Precipitation amount, mm		P, %	Number of cases		Duration, h		P, %
	day	night		day	night	day	night	
Spring	381	349	4.3	168	168	416	444	−3.2
Summer	597	529	6.0	299	196	330	303	4.2
Fall	461	520	−6.0	338	287	781	814	−2.0
Winter	358	314	6.5	362	273	1037	1014	1.1

Also, from the above estimates of P, calculated for the precipitation amount (see Tables 1 and 2), it follows that in 11 cases of 36 (30%) $P < 0$, i.e., precipitation in the day baroclinicity time is less than at night. Among values of $P > 0$, only in 3 cases of 36 (8%) P exceeds 7%, and is much less than 7% in all other cases.

Close estimates of the role of the radiation-thermal factor are also obtained from data for Ekaterinburg, Chelyabinsk, Bryansk, Kemerovo, Krasnodar, Rostov-na-Donu, and some other sites (from 2 to 15) in the vicinity of these cities.

We can conclude from the analysis of all these data that the key role in precipitation formation is played by dynamic factor, namely, the vertical velocity arising due to convergence of airflows in synoptic-scale vortices, i.e., cyclones and troughs.

The origin and development of these phenomena is an independent, large, and very complex problem of atmospheric dynamics. Here, we only note that from qualitative-physical analysis of equations and simulation results[7,8] it follows that an important role in formation and evolution of vortices is played by baroclinicity of the medium, i.e., the dependence of air density not only on the pressure but also on the temperature and humidity. It is found that baroclinicity leads to formation of a new cyclonic vortex or its intensification in the case of advection of colder air (in particular, during its influx to a warmer surface), or anticyclonic vortex in the case of advection of warmer air (at its influx to a colder surface).

As is well known, the used land (continent) layer has a higher temperature in summer and a lower temperature in winter than the used water (ocean) layer. As a consequence, in summer the advection of cold air on continents is prevalent and cyclones are formed more frequently; and in winter there is a prevailing advection of warm air and more favorable conditions for anticyclone formation. In oceans, the reverse is true: summertime conditions are more favorable for formation of anticyclones, and wintertime conditions are more favorable for cyclone formation.

Since pioneer works of Pettersen and Pogosyan, many papers dealing with statistics of synoptic vortices have been published. One of the most full publications by Khairullin (Ref. 9) presents the information on synoptic vortices occurred over 20-year period (1962–1981) in land regions of the Northern Hemisphere (northward of 20°N). Over this period, 3101 cyclones and 1547 anticyclones were observed. The frequency of their occurrence (%) in different seasons is:

	spring	summer	fall	winter
Cyclones	31.3	50.0	12.4	6.3
Anticyclones	22.6	14.5	24.0	38.9

In accordance with the above regularity, the prevalence on the continents of cold air advection above warm land leads to formation of more than 80% cyclones in spring and summer, and prevalence of warm air advection leads to formation of 63% anticyclones in fall and winter. Note that in this season, in addition to advection of one sign (cold-air advection in summer and warm-air advection in winter), the advection of the opposite sign can also be observed; and the baroclinicity is not the only factor of the vortex formation. Nonetheless, the role of baroclinicity and the effect of the main regularity are obvious: on the continents, there appear 3.5 times more cyclones than anticyclones in summer and, conversely, 6 times more anticyclones than cyclones in winter.

Since upward vertical motions as the major factor of precipitation formation are uniquely connected with cyclones, it follows from the above data that in summer the continents have more favorable conditions for formation of precipitation than in winter. We emphasize that just cyclones (but not usually referred thermal stratification) are responsible for the increase of precipitation amount in summer comparative to other seasons.

According to Table 3, the ratio of the summer/winter precipitation amount Q in all cases exceeds a unity, generally lying between 1.19 and 2.88 in the daytime and between 1.01 and 2.36 at night.

Such a relationship holds not only for seasonal, but also for monthly Q values. According to data for 15 sites in Sverdlovsk Region over the period 1985–1989, the ratios of summer (VI, VII, VIII) to corresponding winter (XII, I, II) monthly Q values are: 1.70 (VI/XII), 2.02 (VII/I), 3.05 (VIII/II), and 2.19 (summer/winter).

Table 3. Ratio of summer/winter precipitation amount (letters a, b, c, and d denote the five-year periods indicated in Table 1)

Time of day	Saint Petersburg				Belogorka				Sosnovo
	a	b	c	d	a	b	c	d	1991–1995
Day	1.46	1.19	2.58	2.01	1.49	1.54	2.88	2.11	1.67
Night	1.27	1.01	2.10	1.62	1.34	1.72	2.36	1.45	1.05

In Chelyabinsk, the ratio of summer (Q_s) to winter (Q_w) precipitation amount during the night was found to be 2.57 in 1980, 2.11 in 1981, 4.50 in 1982, 3.73 in 1983, and 2.52 in 1984.

In addition to the qualitatively physical interpretation, the statistical relationship between Q, p, and T, as well as water vapor pressure e, was estimated. It was found that the 10-day averages of Q and p are most closely correlated, as well as of Q and T, and Q and e. Possibly, this can be explained by the fact that this interval is most close to the natural synoptic scale, during which the pressure field sign and weather type remain the same.

Table 4 presents correlation coefficients between decade values of Q and other day, night, and 24-hour meteorological variables (pressure, temperature, and water vapor pressure), calculated from data for Sosnovo over the period from 1991 to 1995.

Table 4. Correlation coefficients between decade values of cloud amount and other meteorological variables for Sosnovo (letters d, n, and b are for day, night, and both)

Season	r_{Qp}			r_{QT}			r_{Qe}		
	d	n	b	d	n	b	d	n	b
Spring	−0.39	−0.40	−0.48	0.07	−0.14	−0.07	0.12	−0.06	0.00
Summer	−0.29	−0.43	−0.47	−0.19	−0.26	−0.21	0.20	−0.07	0.14
Fall	−0.40	−0.39	−0.47	0.08	0.29	0.22	0.09	0.34	0.26
Winter	−0.62	−0.49	−0.64	0.09	0.04	0.07	0.15	0.09	0.14
Annual	−0.35	−0.35	−0.44	0.15	0.03	0.10	0.23	0.07	0.18

As expected, according to Table 4, most close correlation exists between Q and p: correlation coefficients r_{Qp} lie between − 0.29 and − 0.64, i.e., all of r_{Qp} are negative in value. This means that a decrease of pressure (during formation or deepening cyclones) is accompanied most frequently by increase of Q. The coefficients r_{Qp} are statistically significant: the mean-square deviations σ_r are no less than a factor of 10 smaller than the modulus of r.

Concerning the correlation between Q and temperature, that was given most attention to, we are about to say the following. First of all, the correlation between Q and T is much weaker than between Q and p: the values of r_{QT} are 2–7 times less (in absolute value) than of r_{Qp}, and most of r_{QT} (9 out of 15) are statistically insignificant. In addition, the values of r_{QT} change in sign during a year: they are positive in fall and winter and negative in spring and summer. This is not indicative of the temperature effect on precipitation, but sooner of inverse effect of clouds on the temperature. In fall and winter, the arrival of cyclone is accompanied by increase of precipitation and temperature (due to some decrease of efficiency of the surface emission); whereas in spring and summer, the relation between Q and T is reversed and $r_{QT} < 0$ when cyclone arrives.

Note that, in Ref. 10, based on monthly values of Q and T, also small values of r_{QT} are obtained: they reach 0.2–0.3 only in the south-eastern part of European Russia, and are less than 0.1 (in absolute value) or statistically insignificant elsewhere in the former USSR.

The same weak correlation is between precipitation and water vapor pressure: out of 15 r_{Qe} values presented in Table 4, 9 are statistically insignificant. In this regard, it is clear why numerous attempts to relate the precipitation with water vapor transport (in particular, from Atlantic Ocean to the territory of Russia), and to identify the contribution of local and external sources of water vapor to precipitation failed. The amount of water vapor itself is everywhere (except in arid and semiarid zones) quite sufficient to form any precipitation. The thing is only in the mechanism (process), capable to convert water vapor into liquid (precipitable) water. Such a mechanism is a cyclone, playing a role of self-exciting system: after its appearance, the cyclone involves air masses and water vapor from the distances several times greater than the cyclone's radius, moreover, it also involves water vapor from water and wetted land surfaces. Subsequent vertical transport of water vapor and mixing of the involved and cyclone air lead to formation of clouds and precipitation; while transport (advection) of colder air, spreading all over the cyclone mass, favors the cyclone self-excitation (regeneration).

According to the diurnally average data for 1994–1999, the values of r_{Qp} for all 14 sites of the former USSR (from Vilnyus to Vladivostok) are also negative. However, they are somewhat less (in absolute value) than those, determined from the decade data (see Table 4). For diurnal Q and p values, the values of r_{Qp} lie between −0.11 (Saint Petersburg) and −0.40 (Rostov), while eight (out of 14) r_{Qp} values exceed 0.20 (in absolute value).

From the same sample, we have determined the correlation coefficients between Q and diurnal variations of pressure (Δp). Again, all they are negative, with four values exceeding 0.20 (in absolute value), and four values being statistically insignificant.

Like the decade data, the diurnal data indicate that the correlation between Q and temporal temperature variations is much weaker than between Q and p: from 30 to 65% of r_{QT} and $r_{Q\Delta T}$ values are statistically insignificant.

The obtained results allow the following conclusion. The key role in formation of precipitation fields and in diurnal and seasonal variations of precipitation amount is played by the dynamic factor, i.e., the vortex-type and vertical synoptic-scale motions, whose formation and development, in turn, is substantially affected by the medium's baroclinicity.

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