Statistical correlation of precipitation with air pressure and temperature

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Data of daily observations at all meteorological stations in the European part of Russia for 1981–1990 have been used to establish the correlations between daily and ten-day mean values of air pressure and precipitation amount. Also, we estimated analogous correlations between precipitation amount and air temperature. The correlation coefficients for the ten-day mean are significantly (up to 1.5–2 times) higher (in the absolute value) than those for the daily mean.

Atmospheric precipitation is among phenomena influencing considerably economic activity, and it is an important part of general notions of weather and climate.

In Ref. 1 it is shown that the main role in formation of stratocumulus and cumulonimbus clouds, along with the continuous and shower precipitation, is played by dynamical factors: vertical synoptic- and medium- (meso-) scale motions and advective and turbulent influxes of heat and water vapor. These factors, in their turn, are closely related with air pressure field.

1. Precipitation and air pressure

The purpose of this paper is to estimate the influence of air pressure on precipitation amount. One of the most reliable characteristics of statistical interrelation between fields of random variables is the correlation coefficient r.

We used the data of meteorological observations for 1981–1990 to calculate r between monthly mean values of precipitation amount Q and air pressure p.

From simulations[2,3] of the main cloud types (nimbostratus and cumulonimbus) which precipitate, as well as daily observations, it can be assumed that the correlation between Q and p will be negative: for lower p (cyclone, trough) there will be corresponding higher precipitation amounts. Data of Table 1 agree with this supposition: all r values are negative ($r < 0$).

Correlation between Q and p is statistically significant because, in accordance with the well-known formula ($\sigma_r = (1 - r^2)/\sqrt{N}$), the standard deviation σ_r of correlation coefficient is generally much less (in absolute value) than r itself: $\sigma_r < |r|$.

No significant difference between winter and summer r values is observed. Hence, the basic factor of cloud and precipitation formation is the dynamical factor (because if the contribution of radiative-thermal factor were significant, the correlation between Q and p would be closer in summer than in winter).

Note that the r calculations are performed not only for daily mean Q and p, but also separately for daytime (from 08:00 to 20:00 local time) and nighttime values of these variables. The r values for day and night were found to be close to each other.

Table 1. Correlation coefficients between monthly mean values of precipitation amount and air pressure (Q and p). 1981–1990 (N is sample volume)

Station	Winter	Summer	N
Moscow (WANE)	–0.33	–0.25	60
Moscow (MSU)	–0.59	–0.56	60
Naro-Fominsk	–0.45	–0.68	58
Mozhaisk	–0.72	–0.33	60
Volokolamsk	–0.25	–0.34	30
Chelyabinsk	–0.51	–0.44	60

It is known[4] that in the land the transition from winter to summer is accompanied by increase of precipitation amount (by as much as a factor of 2 to 3) and decrease of the pressure (by a few tens of hPa). Calculation of correlation coefficients between changes (from summer to winter) of precipitation amount ($\Delta Q = Q_s - Q_w$) and air pressure ($\Delta p = p_s - p_w$) has shown that correlation between ΔQ and Δp is also negative ($r < 0$) but much less close than between Q and p. For instance, according to data for stations Ekaterinburg, Lipovskoe, and Bogdanovskoe, the correlation coefficients between monthly mean ΔQ and Δp (for 1981–1990) are, respectively, –0.12, –0.17, and –0.30.

Also, the correlations between Q and p are obtained for much larger sample volumes in the European part of Russia (EPR) (from here on refer to Table 3).

According to observations for 1981–1990 in the European part of Russia, the correlation coefficients between Q and p for daily and ten-day mean values are, respectively, –0.27 and –0.40.

To estimate the influence of thermal conditions, correlation coefficients between Q and p are also calculated for stations located in the European part of Russia northward of 60°N. For daily and ten-day mean values they are found to be –0.27 and –0.38.

Location of the stations has almost no effect on correlations, pointing once more to the key role of dynamic factor in precipitation formation (if thermal factor were important, correlations between Q and p,

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like between Q and T, would be significantly different for northern and southern stations).

Ten-day averaging was performed in order to make this interval closer to natural synoptic-scale period (5–14 days), during which unfair (rainy) or fair weather dominates.

Ten-day averaging significantly increased (up to a factor of 1.5) correlation between Q and p.

2. Precipitation and air temperature

In addition to correlation between Q and p, we analyzed correlations between precipitation amount and air temperature.

As seen from Table 2, all correlation coefficients between Q and T are positive: an increase of temperature is accompanied by growth of precipitation amount. Of course, some increase of this correlation could be caused by the radiative-thermal factor. However, as shown in Ref. 1, its contribution does not exceed 10% and, moreover, only in summer (when unstable thermal stratification is possible in the near-ground layer).

Table 2. Correlation coefficients between monthly mean values of precipitation amount and temperature (*Q* and *T*). 1981–1990 (*N* is sample volume)

Station	Winter	Summer	N
Moscow (MSU)	0.29	0.20	60
Moscow (Losinoostrovskaya)	0.70	0.30	56
Mozhaisk	0.35	0.67	58
Pavlovskii Posad	0.10	0.20	60
Dmitrov	0.35	0.67	60
Ekaterinburg	0.25	0.13	60

As seen from Table 2, only at half of the sites the correlation coefficients are greater in summer than in winter; therefore, we can conclude that the thermal factor in this case had no effect even at 10% level.

The main role in establishing the correlation between Q and T again belongs to dynamic factor, now in an indirect way: higher temperature at observation site favors intensification of advection of cold and, as a consequence, appearance of cyclonic vortex and upwelling vertical motions. Due to these motions the air temperature decreases at all fixed levels except the earth's surface while vertical lapse rate increases in time.[3,5] If moist unstable stratification remains above condensation level, nimbostratus cloud and continuous precipitation form. In either case, the higher the temperature near the earth's surface, the higher the probability of precipitation and larger the precipitation amount.

According to observations at all stations of European part of Russia for 1981–1990, the correlation coefficients between Q and T are 0.13 and 0.29 for the daily and ten-day mean values, respectively.

According to observations at the northern stations (located northward of 60°N), the correlation coefficients obtained using daily and ten-day mean Q and T are, respectively, 0.14 and 0.29.

As in the case of correlation between Q and p, location of the stations (temperature background and thermal stratification) had no effect on correlation between precipitation amount and air temperature.

Ten-day averaging (making averaging period closer to natural synoptic-scale period) substantially increased (by a factor of two, for the given samples) the correlation between precipitation and air temperature fields.

The statistical correlations between Q and p are significantly closer than correlations between Q and T: the correlation coefficients for the former pair are a factor of 2 larger when calculated from daily data, and approximately a factor of 1.5 (in absolute value) larger when calculated from ten-day mean values, than for the latter pair. Moreover, according to some samples, for quite close correlation between Q and p (ten-day mean values of the coefficients r vary between −0.44 and −0.04) the correlation between Q and T is very weak: ten-day mean values of r do not exceed 0.22, while in spring and summer they are even less than zero.[4]

It should be stressed that r values presented in Table 3 are especially statistically significant because they are estimated from samples which include tens of thousands of observations.

Table 3. Correlation coefficients between daily (D) and ten-day (T) mean values of precipitation amount and pressure (*Q* and *p*), precipitation amount and temperature (*Q* and *T*). 1981–1990

Region of observations	Q and p		Q and T	
	D	T	D	T
EPR	−0.27	−0.40	0.13	0.29
North of EPR	−0.27	−0.38	0.14	0.29

Also stronger has been correlation of Q both with p and T for ten-day mean values of meteorological quantities compared to that for daily means. Although the correlation coefficients, calculated daily, ten-day (Table 3) and monthly (see Tables 1 and 2) mean values of the variables, are statistically significant, virtually all of them are less (in absolute value) than 0.40–0.50. An explanation may be that the samples include both days with precipitation and without precipitation.

Naturally, inclusion of precipitation-free days decreased the probability of dependence of precipitation amount on pressure, and in equal measure on temperature.

Also important is that the pressure is not uniquely related to vertical motions, the main factor of precipitation formation: for a given pressure the vertical velocity may substantially vary.

References

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