Synoptic conditions for cumuliform cloud formation

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From data of daily meteorological observations on the territory of Western Europe and Soviet Union in 1963 and 1964 and surface synoptic maps (00:00 and 12:00 GMT), we determined the conditions of formation of cumuliform clouds in different meteorological situations. Most often (in 60–70% of the cases) these clouds are formed in low-pressure regions (cyclones and troughs). In most cases, (70 to 100%) clouds are observed at distances longer than 500 km from the center of both cyclone and, especially, anticyclone. Mainly the formation of cumulus and cumulonimbus clouds is governed by the dynamic rather than radiative-thermal factor. The formation of cumulus cloud fields is strongly affected by the downward vertical motions acting to transform stratus clouds first into stratocumulus and then into cumulus.

Cumuliform clouds include two types (forms) of clouds: cumulus (Cu) and cumulonimbus (Cb). It is generally considered that clouds are formed due to influx of solar radiation to the earth's surface and ensuing unstable thermal stratification during sunlit portion of the day (in the general case of existence of positive balance of the heat of the earth's surface). This factor will be called radiative-thermal.

However, the data of observations indicate that cumulus clouds, let alone cumulonimbus clouds, are observed not only during day but also at night, not only in spring but in summer as well, and generally not only for positive but also negative radiation and total heat balance of earth's surface.

In accordance with qualitative-physical analysis[1,2] of equations describing cloud formation, as well as with numerical simulations,[3] Cu–Cb are formed due to two factors: radiative-thermal and dynamical. The latter is practically totally caused by vertical synoptic-scale motions and turbulent exchange, observed in synoptic vortices (cyclones and anticyclones).

To obtain quantitative estimates of these factors from empirical data, we performed analysis of cloud observations on the territory of Western Europe and Soviet Union in different synoptic situations (at 00:00 and 12:00 GMT).

According to Table 1, Cu–Cb clouds are formed in fall–winter no less frequently than in spring–summer (and even more often, according to sample data): 198 and 174 cases, respectively (noteworthy the sample includes all time intervals and days of 1963).

If the radiation-thermal factor were the governing one, it would be expected that predominantly the cumulus clouds occur in anticyclones (which, on the contrary, are characterized by clear-sky weather and large influx of solar radiation to the earth's surface).

In reality the relation is inverse: cumulus clouds in cyclones and troughs are formed 3.4 times more frequently in fall–winter and 1.5 times more frequently in spring–summer than in anticyclones and ridges.

Table 1. Frequency of occurrence (%) of cumulus and cumulonimbus clouds on the territory of Western Europe and Soviet Union in 1963 (*N* is the sample volume)

Season	Pressure system				*N*
	Cyclone	Trough	Anticyclone	Ridge	
Fall–winter	60	17	22	1	198
Spring–summer	43	17	26	14	174

The radiation-thermal factor can have an effect only in spring–summer. Unlike, the dynamical factor is practically unchanged both in spring–summer and in fall–winter (it is caused by the probability of formation of synoptic vortices). In cyclones and troughs during spring–summer the formation of clouds is even less intense than during fall–winter; hence, in low-pressure regions the Cu–Cb clouds are formed only due to dynamical factor.

Somewhat more cumulus clouds are observed in spring–summer (71 cases) than in fall–winter (47 cases) in anticyclones and ridges. In spring–summer, under the influence of the dynamical factor, the amount of formed clouds is the same as during fall–winter (i.e., 47); hence, the contribution of radiation-thermal factor in high-pressure regions is 20%:

$$(71 - 47)/118 = 0.20.$$

However, no less important mechanism of the cumulus cloud formation is transfer and transformation of stratiform clouds. Troughs (fronts) and cyclone, overall, move slower than air flow (are detached from the leading flow); therefore, the stratiform clouds (Ns, As), formed at the fronts or other parts of cyclone, due to upward motions some time later may be located at cyclone periphery and, subsequently, at the periphery of the neighboring anticyclone where air motion is downward.

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Naturally, under impact of the latter the transferred clouds start to spread (deplete in liquid water) and evolve (transform) into stratocumulus (Sc) and altocumulus (Ac) clouds.

The fields of temperature and humidity, and equally the vertical motion fields themselves, are inhomogeneous; therefore cloud liquid water vanishes (disappears) faster in some parts of the cloud than in other. A consequence of this mechanism is the formation of cumulus clouds with different cloud amounts. By the same mechanism, translucent clouds form, as well as very inhomogeneous stratocumulus and altocumulus clouds. These, strictly speaking, should already be called cumulus.

The significant role of transfer–transformation mechanism in formation of Cu–Cb clouds is illustrated in Table 2: only 24% of such clouds are formed at a distance up to 500 km from cyclone center. Note that these data also indicate that clouds (predominately cumulonimbus) form due to dynamic factor, because in spring–summer (the only period for thermal factor to be manifested) the frequency of cloud occurrence is just the same (24%) as in fall–winter.

Table 2. Frequency of occurrence (%) of cumulus and cumulonimbus clouds in Western Europe and USSR at different distances from vortex center. 1963 (C stands for cyclone, Ac for anticyclone, *N* is the sample volume)

Season		Distance, km					*N*
		<100	100–200	200–500	500–1000	>1000	
Fall–winter	C	7	3	14	52	24	151
	Ac	–	–	–	40	60	47
Spring–summer	C	–	7	17	30	46	103
	Ac	–	–	20	35	45	71

Most of the cumulus clouds are located on periphery of synoptic vortices, over 500 km away from the center: 76% in cyclone, while in anticyclones they occur in 100% of cases in fall–winter and in 80% of cases in spring–summer.

As in the central part, on periphery of cyclone all cumulus clouds are formed due to dynamical factor (in spring–summer the frequency of their occurrence is the same as in fall–winter). Since on the periphery of cyclone downward motions dominate, the transfer–transformation mechanism plays the main role here. This statement is even more valid for anticyclone characterized by downward motions.

As follows from Table 2, increase of cumulus clouds (in spring–summer in comparison with the fall–winter season) has taken place at distance 200–500 km from anticyclone center. At shorter distances, the cumulus clouds form neither in spring–summer, nor in fall–winter. This fact additionally evidences of that the dynamic factor plays the main role in cumulus cloud formation and not the radiation-thermal factor. Indeed, in the central part of anticyclone, where the clear-sky weather dominates, and the radiation and total heat balance is mostly positive the cumulus clouds do not form due to downward vertical motions, while the clouds transferred here from neighboring region of cyclone dissipate. Only over 200 km away from anticyclone center, where air motion is also downward but decelerated in comparison with the central part, the transferred clouds do not dissipate completely; they are first transformed to stratocumulus and then to cumulus clouds (predominately fairweather cumulus or cumulus mediocris). Due to radiation-thermal factor and unstable stratification in the near-ground layer, in spring–summer about 20% of these clouds form immediately at anticyclone itself (on anticyclone periphery).

General conclusion:

– Cu–Cb clouds in fall–winter form no less frequently (and even more frequently, in this sample) than in spring–summer;

– most (60–77%) of these clouds are observed in cyclones and troughs; and all Cu–Cb clouds in cyclones form due to dynamical factor;

– only in anticyclones in spring–summer, about 20% of cumulus clouds form due to radiative-thermal factor;

– cumulus clouds are observed predominately on periphery of synoptic vortices.

References

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