FORMATION OF PRECIPITATION

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Keywords: Intensity and amount of precipitation, widespread and shower-type precipitation, vertical velocity, mesoscale vertical motions, moist-labile stratification, synoptic vorticity, condensation and sublimation of water vapour, droplet coagulation.

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temperature and pressure fields. Microphysical processes in the precipitation formation. Condensation and sublimation of water vapour. Coagulation of cloud particles.

1. Introduction

In most cases (more than 90 percent) precipitation falls from clouds consisting of drops of water and crystals of ice (mixed clouds). During the precipitation period the content of liquid water in a cloud (its water storage) is restored several times (from 7 up to 40).

The basic role in cloud formation and precipitation is played by the following dynamic factors: vertical motions, advective and turbulent inflows of heat and water vapour. With upward motion of air observed in the low-pressure areas (cyclones and troughs), the air temperature and mass fraction of water vapour at fixed levels are lowered, the relative humidity increases in time: water vapour comes nearer to a saturation condition. After achievement of saturation, the further rise of air is accompanied by cloud formation, increase in size of drops (crystals) under the influence of condensation (sublimation), and then also of coagulation. This process culminates in cloud precipitation - rain, snow, graupel, hail.

The type and intensity of precipitation significantly vary depending on what thermal stratification is observed near the condensation level when the saturation condition is achieved. With moist-steady stratification, the vertical velocity in the derived cloud remains the same as before its formation. In this case, a nimbostratus cloud forms producing steady rain characteristic of warm fronts.

Since with the upward motion the vertical gradient of temperature in the lower troposphere increases with time, it is also quite possible that moist-labile stratification could be registered in a cloud. Under its influence, mesoscale vertical motions originate in a cloud, their speed exceeding that of synoptic scale motions by one or two orders of magnitude. The mesoscale motions result in formations of cumulonimbus and showers. An essential role is played by the moist-adiabatic gradient. As the latter decreases with the temperature rise, with the conditions being the same (depth of a cyclone, initial gradient of temperature), the probability of formation of moist-labile stratification and showers is the greater, the higher the air temperature. This effect plays a relevant role in increase of probability for the formation of convective clouds and showers in the afternoon and summer, as contrasted to the night period and winter.

The essential influence on formation of precipitation is rendered by entrainment of the ambient air into a developing cloud. Despite its smaller duration, shower-type precipitation makes up the largest proportion (exceeding 70-80 percent) of its total quantity.

The role of the baroclinic factor - geostrophic advection of virtual temperature - is great in formation of synoptic vortexes (cyclones and anticyclones). With an advection of colder and drier air, cyclones would form; with an advection of warmer and moister air, anticyclones. The influence of this factor explains geographic features of precipitation distribution, as well as their seasonal fluctuations and connection with fields of temperature and pressure. The microphysical processes of precipitation formation are briefly reviewed: condensation and sublimation of water vapour, coagulation of cloud drops and ice crystals.

2. Basic information about precipitation

The formation of precipitation is intimately connected with the formation of field of clouds. Among those phenomena and values which are integrated by the concept of "weather", the clouds and precipitation possess a determining role.

Changing the thermal and radiation mode of the atmosphere, clouds and precipitation render essential influence on many sides of human activities, first of all, in the sphere of agricultural production, as well as on flora and fauna of the Earth. Visibility is sharply diminished by precipitation, clouds and fog. Therefore, different types of transport, primarily aircraft, are greatly affected by these phenomena.

Cloud is a visible set of drops of water and fragments of ice suspended in the atmosphere and located at some altitude1 above the earth's surface. If the lower boundary of this combination reaches the surface of the Earth, it is defined as fog (meteorological visibility less than 1 km) or mist (with visibility in the range from 1 to 10 km).

The drops of water and ice crystals falling out of the atmosphere on the earth's surface are called precipitation. The amount of precipitation is measured by the depth of liquid water (most often, in millimetres) that could be derived after falling on a horizontal impermeable surface: 1 mm corresponds to 1-kg water mass which has dropped out on 1 m^2.

The amount of precipitation which has fallen in a unit time (for example, 1 hr or 1 min) is referred to as intensity of precipitation.

Generically, i.e., depending on physical conditions of formation, precipitation can be subdivided into the following types:

- widespread precipitation, prolonged and spreading over a large area, of moderate intensity (0.01-0.05 mm/min) falling from Nimbostratus clouds (Ns) as rain and snow, sometimes sleet;
- shower-type precipitation, falling from Cumulonimbus clouds (Cb) as rain, snow, graupel, hail; this precipitation suddenly begins and comes to an end; it is characterized by a sharp change in intensity, exceeding, as a rule, 0.05 mm/min; it is frequently accompanied by thunderstorms and squalls.

3. Relationship between precipitation and clouds

Though the duration of shower-type precipitation is much less than that of the widespread type, it makes the greatest contribution to the total amount of precipitation. So, in the European part of Russia the average share of shower precipitation makes up 73% in the warm half-year (April - October). At 11 stations (out of 26), this share exceeds 80 %, and at the foothills of the Caucasus it is more than 90 %.

Formation of precipitation and its intensity are related to microphysical structure and thickness of clouds. It follows from the data collected during 686 aircraft soundings of frontal clouds that the greatest recurrence (about 90 per cent) falls on the precipitation from clouds of totally mixed structure, throughout the entire thickness or in their considerable part. The precipitation falls from purely crystalline clouds and clouds consisting of separate strata in approximately 70 % cases; from purely water clouds, only in 9 % cases.

If the recurrence of precipitation is correlated with the total number of cases of cloud observation, the purely water clouds would produce 5 % of all cases with precipitation reaching the surface of the Earth; the clouds with separated strata, 55 %; and the clouds of wholly mixed structure throughout the entire thickness, 40 %.

There is a practically linear relationship between intensity of precipitation and thickness of clouds. The data obtained from 439 soundings indicate that drizzle falls from clouds with average thickness z_{cl} equal to 850 m; rain with drizzle at z_{cl} = 1400 m; rain, at z_{cl} = 2150 m; snow, at z_{cl} = 2300 m; snow with a rain, at z_{cl} = 2690 m; and rain formed through the melting of ice particles, at z_{cl} = 3150 m.

A dependence has been found between the precipitation phase and the temperature of air at the ground surface (T_0), as well as the mean temperature in an air column between isobaric surfaces of 1000 and 850 hPa (the characteristic of the latter being Φ, a relative geopotential of surface of 850 hPa above 1000 hPa, expressed in decametres): with $\Phi <$ 128 dam or $T_0 < -3^0$C only solid precipitation falls out; and with $\Phi >$ 132 dam or $T_0 > 3^0$C, only fluid precipitation. With values Φ = 128-132 dam, and T_0 within the range from -3 up to 3^0 C, snow, snow with rain (water snow) and rain are observed.

Precipitation is the meteorological phenomenon that is most changeable in time and space since its formation and intensity are determined by various atmospheric conditions.

By comparing the liquid water storage in a cloud at a particular moment of time dropping out of a cloud system that is passing over an observation point, it has been revealed that the amount of precipitation over 2-3 days is several times greater than the water storage in the system. On the average, this ratio is equal to 23; however, on occasion it can vary from 7 to 40.

The comparison of the areas covered by the cloud system and precipitation is also of interest. The ratio of the areas of the latter to the former varies within the limits of 0.37 - 053, the average value being 0.46. The greatest recurrence (45 %) in all seasons of the year is for the precipitation area of 0.25 - 0.5 mln km². As the cloud area grows to 4-5 mln km², precipitation area also increases; with the further increase in the cloud area, the precipitation area decreases.

With the average water content for the entire cloud equalling 1 g/m^3 and the vertical thickness of a Cumulonimbus cloud being 6000 m, the amount of shower precipitation falling from the cloud exceeds the water storage in the cloud, on the average, by a factor of 4.9 (the precipitation duration, 60 min). When precipitation intensity exceeded 1 mm/min (in the Kiev region), the amount of precipitation was, on the average, 8.8 times greater than the water storage in the cloud, fluctuating from 1.8 to 16.9. The water storage in a Cumulonimbus cloud is restored each 7-12 minutes. This above data indicate that during the existence of cloud systems the amount of precipitation falling from them exceeds the water storage in them at the fixed moment almost by one order of magnitude. It means that the entire mass of water in clouds is restored many times during their existence.

4. Dynamic factors of precipitation formation

4.1 Equations vapour and heat fluxes of water

The cloud starts to form when the relative humidity of air $f = e/E$ reaches 100% (here e is water vapour pressure; E, saturation vapour pressure decreasing together with the temperature drop T). Two processes promote increase in f and achievement of the saturation state; a) pressure growth (content) of water vapour; b) lowering of temperature.

The variations in the water vapour content and air temperature in time (t) are determined by the equations of inflow (balance) of water vapour and heat:

$$-w\partial q/\partial z - \partial q/\partial t = (u\partial q/\partial x + v\partial q/\partial y) + \varepsilon_q/\rho, \qquad (1)$$

$$\partial T/\partial t = -w(\gamma_a - \gamma) - (u\partial T/\partial x + v\partial T/\partial y) + \varepsilon_T/(c_p\rho). \qquad (2)$$

Here u, v, w are projections of the speed of motion (wind) on axes x, y, z of the Cartesian co-ordinate system, respectively (the axis z is in the upward vertical direction); q, mass fraction of water vapour related to e by a ratio: $q=0.662\ e/p$; $\gamma = -\partial T/\partial z$, vertical gradient of temperature T; γ_a, dry adiabatic gradient (substituted in saturated air for the wet adiabatic gradient γ'_a); ε_q and ε_t are turbulent inflows of water vapour and heat; c_p is specific heat at constant pressure p; ρ is density of air. According to Eqs. (1) and (2), variations in q and T with time in fixed points of space are caused by three factors: 1) convective inflows conditioned by vertical air motion (w); 2) advective inflows associated with horizontal air motion (u, v); 3) turbulent inflows of water vapour (ε_q) and heat (ε_T).It should be emphasized that all these inflows depend not only on the velocity of air motion, but also on distribution of q and T in space. Generally, when constructing hydrodynamic models of cloud formation and precipitation, the set of equations (1) - (2) is supplemented by an equation of continuity (for determining the vertical velocity w) and equations of motion, from which horizontal components of speed u and v are obtained.

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Bibliography

Drozdov O.A., Grigoryeva A.S. (1971). *Long-term cyclic fluctuations of atmospheric precipitation on the territory of the USSR*. L.: Gidrometeoizdat, 158 pp. (in Russian). [The statistical relationship of the amount of precipitation and the air temperature over the territory of the Soviet Union has been studied.]

Alibegova G.D. (1985). *Spatial and temporary structure of the fields of liquid precipitation.* - L.: Gidrometeoizdat, 236 pp. (in Russian). [The spatial and temporal structure of the rain precipitation field has been considered.]

Alibegova G.D., Elizbarashvily E.Sh. (1980) *A statistical structure of atmospheric precipitation in the mountain areas*. - L.: Gidrometeoizdat, 136 pp. (in Russian). [Peculiarities of the statistical structure of precipitation in mountain conditions have been investigated.]

Shver C.A. (1984). *Principles of distribution of the amount of precipitation on the continents.* - L.: Gidrometeoizdat, 286 pp. (in Russian). [An extensive review of information on the amount of precipitation over continents is presented.]

Hairullin R.R. (1989). *Structure and dynamics of cyclogenesis in the Northern Hem*isphere. - Kazan: Kazan University Publishing House, 134 pp. (in Russian). [Information about the formation of cyclones and anticyclones in the Northern Hemisphere over 20 years is presented.]

Isaev A.A. (1986). Typization of anomalies of summer precipitation on the territory of the USSR. *Trudy VNIIGMI-MTsD*, No 132, 52-60.[A classification of anomalies in the summer precipitation over the Soviet Union is cited.]

Apasova E.G. (1985*).* Zonal profile of precipitation of the Northern Hemisphere. *Trudy VNIIGMI-MTsD*, No 116, 14-26.[Zonal profiles of precipitation in the Northern Hemisphere have been constructed.]

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