NATURAL HAZARDS CAUSED BY SOLID PRECIPITATION

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Contents

Summary

Solid precipitation is formed in the atmospheric air or on various surfaces in contact with the air. They include ice particles, suspended in the atmosphere and falling onto the Earth's surface, and also ice crystals which appear on the Earth's surface, ground objects and aircraft. They are divided into falling and deposited precipitation. The first is formed by condensation and sublimation in the air. These are snow, snow pellets, freezing rain, and hail. The other group is presented by deposited precipitation, and comprises hoar frost, rime, glaze, and icing. Heavy rime sometimes breaks wires and branches of trees. Glaze results from freezing of super-cooled rain drops, drizzle or fog, usually at temperatures from 0 to −3 °C, but it happens also under strong frost, down to −16 °C. Intensive glaze can cause the fall of electric masts and breaking of high-voltage lines. Glazed frost is formed on the Earth's surface after a thaw or rain, as a result of abrupt cooling. Intensive formation of deposited precipitation results in icing, i.e. formation of an opaque ice coating on surfaces of ground objects, ships and aircrafts.

Hail is usually observed in hot wet weather, and it can be very dangerous as it falls during periods of flowering, fruit formation and ripening of agricultural crops. Hail protection is carried out by means of seeding of hail clouds with particles of silver or lead iodide. In winter, snow drifting arise in windy weather when a snow-wind flow carries snow, recently precipitated or still not reaching the ground, together with snow lifted by the wind from the surface. There are upper snow drifting, i.e. a snowfall with a strong wind, and lower snow drifting when wind destroys the snow surface and brings into motion the snow deposited earlier. Snow transport is proportional to wind velocity to the cubic degree. According to the wind force, snow drifting is divided into five

categories: weak, usual (ordinary), strong (heavy), very strong, and super-strong. Snow drifting leads to snowdrifts which make people to permanently protect roads, airports, towns and settlements.

1. What is solid precipitation?

The eternal water cycle on Earth, like life itself, depends on one of the fundamental characteristics of the planet: the very small range of temperature and pressure variations, close to the triple point of water phase transition. At the triple point, at a certain combination of pressure and temperature, concurrent existence of all phase states of water is possible: liquid, solid, and gaseous. Domains of ice existence in the pressure –temperature field are now known for 9 of its 10 modifications, but these are all far from real conditions of the Earth's environment. And only the triple point "vapor–liquid water–ordinary ice" falls into the domain of usual natural temperatures and pressures.

In moist air water retains a vaporous state while vapor pressure is smaller than the saturation limit, which depends on the air temperature. But when the saturation limit is reached, transformation of the vapor into either liquid water or ice begins. At the saturation vapor pressure of 6.1 *hPa*, temperature of 0°C, and standard atmospheric pressure of 1013 *hPa*, all the three water phases can exist with the same degree of probability. Deep qualitative transformations of water begin at this point. At temperatures below 0°C water vapor transforms into ice usually escaping the liquid water phase.

Atmospheric precipitation occurs when either water droplets or ice particles, originated in clouds, become large enough to descend to the ground before they are vaporized. The higher the cloud base and the lower the relative humidity, the larger the droplet must be in order to reach the ground.

The condensation process itself cannot create rain or snow, since it results in formation of only cloud elements rather than droplets or ice particles. Precipitation is promoted by two other processes. The first is a collision or an adhesion of cloud droplets, initially having diameter sizes of only 0.005 to 0.05 *mm*. Larger droplets fall faster than smaller ones and capture the latter as they drop. As the process evolves, larger droplets grow and reach the size of rain droplets.

Another process leading to precipitation implies the co-existence of both liquid droplets and ice crystals in super-cooled clouds. Due to the difference in physical properties of water and ice, the water droplets evaporate while the ice crystals grow under such conditions. This process always acts under super-cooled conditions, but it most intensely runs at a temperature of about –25 °C.

Looking at the blue sky overhead one can easily see how a cloud forms. The air gradually thickens, and light white-gray shapeless formations start to wreathe. There are still not many water droplets and ice crystals per unit volume, usually about 1 $g{\cdot}m^{-3}$ in moderate latitudes. If a cloud grows to a kilometer thickness, then, having been transformed into precipitation, it produces only 1 *mm* of water layer. Actually, much greater amounts precipitate at the same time due to continuous vertical ascending of the moist air. Over plains, in winter, this rise occurs due to sliding of relatively warm air upward along the wedge of the cold one, whereas mountains force the incoming air to rise, causing enhanced formation of precipitation.

Under strong frosts a small amount of air moisture crystallizes without cloud formation. The smallest ice needles and frozen droplets 10-20 μm in size appear and cause thickening of the air. ***The ice mist*** arises and lowers the visibility down to several kilometers. It gradually turns into ice fog when it is impossible to discern objects even at a distance of hundred of meters. Ice fog is a usual phenomenon in Siberia at temperatures below –30 °C. In Yakutsk they sometimes remain continuously for a month or so.

In sunny weather and strong frost, myriads of small ice needles sparkle in the air. They slowly fall down to the ground, brightly sparkling in the sun's rays. This phenomenon is called '***diamond dust***' in Arctic and Antarctic regions. In the sparkling haze dog suns, columns, and other fantastic images sometimes appear. But then warm air arrives, stratus clouds drift over, the snow plain merges with the sky, the horizon disappears, and '***white haze'*** has arrived. The air is completely filled with scattered light which dazzles the eye, repeatedly reflecting from the snow cover and clouds. There is no shadow anywhere, not a contrast spot, and the eye loses its ability to orientate. It is impossible to estimate distances, or to determine one's location. Moving in fresh snow cover in such weather, people often used to walk away in completely the wrong direction, and even to disappear, and pilots lost their course in flight. They may lose any sense of position of the Earth's surface and sometimes they smashed into it. 'White haze' is an extremely dangerous phenomenon for travelers.

The passage of an atmospheric front, either warm or cold, brings weather change. In winter this usually leads to a ***snowfall***. If the air under a cloud has temperature lower than 0 °C, snowflakes can reach the ground. But if snowflakes get into a layer of warm air, they melt and turn into rain droplets. In mountain regions one can often see how it rains in valleys, while the slopes are being covered with snow.

In winter, a continuous homogeneous layer of nimbostratus clouds brings long continuous snowfalls, and, at, air temperatures close to 0 °C, snow showers typically fall suddenly from cumulonimbus clouds, which indicate an unstable air mass or a warm front. Still more suddenly a snow gust occurs, when an unstable cold air mass passes over a relatively warm surface. Sometimes a snowfall is so dense that the visibility decreases down to 1 *km* or less. In quiet air the fall speed of snowflakes depends on their mass, shape, and size. They fall several times slower than rain droplets of the same mass. Plates and starlets approach the ground with a speed of 0.5-1 $m \cdot s^{-1}$, needles and columns fall at a few decimeters per second, and snow and ice grains fall at up to 1-2.7 $m \cdot s^{-1}$.

Approaching the ground, a snowflake passes through air layers with different temperature and humidity, therefore its shape constantly varies. Hoar-frosting takes place, i.e. small ice crystals of various shapes grow on the surfaces of snowflakes at an angle with the plane of snowflakes. In a super-cooled cumulonimbus or stratocumulus cloud, small droplets freeze on the snow crystals, and snowflake graining occurs.

Sometimes snowflakes are completely covered with frozen droplets and acquire a ball or conical shape, which is called a ***pellet snow***. When falling down, snowflake consolidation also takes place, caused by collisions and merging with one another and with droplets. The abundance of different processes that impact a hovering snowflake leads to the countless variety of their shapes (Figure 1).

Figure 1. International classification of snowflakes.
1 - plates; 2 - stars; 3 - columns; 4 - needles; 5 - spatial dendrites; 6 - capped columns; 7 - irregular crystals; 8 - snow pellets; 9 - freezing rain; 10 – hail

Ice crystals belong to the class of hexagonal formations (this is the major crystallographic property of ice). Depending on temperature, there are two main types of crystal growth: the plate, when the temperature is higher than –20 to –25 °C, and the column, at lower temperatures. Plate crystals, until they are broken by wind, look like hexagonal plates or symmetric starlets with rays of several orders. Column crystals have the shape of extended prisms and cups with a large amount of internal bubbles extended in the same direction as the crystal itself.

A great role in crystal growth is played by water vapor super-saturation: at low super-saturation column crystals are formed, and as super-saturation increases, plates appear. At the highest level of super-saturation, fragile dendrite crystals precipitate. As the temperature rises, snow crystals increase, and the wind quickly breaks fragile plate crystals, while it hardly affects compact column ones.

The mass of atmospheric ice on the Earth equals 1.68×10^{12} tones. This is about 18% of all the water vapor and 0.03% of the atmosphere mass. Atmospheric ice is formed in the air or it is deposited on various surfaces from the air. It includes ice particles being suspended in the atmosphere and precipitating on the Earth's surface, as well as ice crystals and solid deposits originating on the Earth's surface, ground objects, and aircraft in the air. This type of atmospheric precipitation is called ***solid*** and is subdivided into ***falling precipitation*** formed through condensation and sublimation in the air (snow, grain, ice rain, and hail), and ***rime-precipitation*** which are hoar-frost, rime, glaze, and airplane icing.

Very often in winter a thin layer of crystal ice appears on the surface of soil, grass, snow cover, and on the upper parts of objects. It forms through the sublimation of water vapor from the air as a result of radiative cooling of the surfaces down to negative temperatures colder than that of the air. It is a ***hoar-frost***. Its crystals have a shape of hexagonal prisms in a weak frost, plates in a moderate frost, and blunt-tipped needles in a strong one. Most often hoarfrost forms during clear quiet nights on rough surfaces with low thermal conductivity. Its formation is impeded by strong wind, but weak wind, by contrast, increases the contact of moist air masses with a cold surface, and encourages the growth of hoar-frost.

Often in autumn sharp cooling is accompanied by formation of ***hoar-frost flowers*** on the warm soil. These are depositions of groups of small ice crystals resembling leaves or flowers in shape. Most frequently they originate on loose bare soil and generally in places where relatively warm air is rising through the soil. They are often seen on the ice cover of rivers and lakes, along cracks and polynya.

Oftentimes, when the frost weakens, one can see a white deposit made of small ice crystals on stones, stone walls, and columns. It forms usually in dull weather after severe cold, due to the sublimation of water vapor, fog droplets, drizzle, or rain on the surfaces cooled during the preceding period, which had a lower temperature than that of the air at the moment of observation. This ***solid deposit*** a few millimeters thick can be either crystal, or granular, or sometimes it is a smooth transparent opaque crust.

All these phenomena often complicate human activity in winter but do not create serious difficulties. Hazards induced by solid precipitation are rime, glaze, hail, and snowstorms.

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Biographical Sketch

Vladimir Mikhailovich Kotlyakov was born in 1931. He is a member of the Russian Academy of Sciences (elected in 1991), and Director of the Institute of Geography, RAS. With particular interest in glaciology and the physical geography of polar and mountain regions, he directed the twenty-year project resulting in the World Atlas of Snow and Ice Resources (published in 1997).

He has participated in many expeditions. He worked and wintered in the Arctic, Antarctica, on the slope of the highest summit of Europe, the Elbrus, and he headed high mountain glaciological expeditions to the Pamirs.

The main theoretical results of his works consist in elucidation of laws of snow and ice accumulation on the Antarctic ice sheet as well as ice sheets in general (1961), the snowiness of the Earth and its fluctuations in time and space (1968), the tasks and abilities of the space glaciology (1973), the application of isotope and geochemical methods to the study of the environment and its evolution (1982), the study of the past four glacial-interglacial cycles (1985 and further on). In recent years, V.M. Kotlyakov has dealt with global changes of the environment, geographical aspects of global and regional ecological problems, and the problems of interaction between Nature and society.

V.M. Kotlyakov is vice-president of the Russian Geographical Society and President of the Glaciological Association. In 1983–87 he was President of the International Commission on Snow and Ice; from 1987 to 1993, he was a member of the Special, and later Scientific, ICSU Committee of the International Geosphere-Biosphere Programme, and from 1988 to 1996, Vice-president of the International Geographical Union. Currently, he is a member of the Earth Council.

V.M. Kotlyakov has been elected a member of Academia Europaea and the Academy of Sciences of Georgia, and an honorary member of the American, Mexican, Italian, Georgian, and Estonian Geographical Societies.