SNOW COVER

Kotlyakov Vladimir M
Institute of Geography, Russian Academy of Sciences.

Keywords: distance of snow transport, metamorphism of snow, permanent snow drift, recrystallization of snow, settling of snow, snow, snow cover, snow-storm (snow drifting), snow retention, snow drifts, wind-blown snow stream, zone of drifting snow acceleration.

Contents

Summary

Snow cover is a layer of snow on the earth's surface, which is mainly results from snowfalls. The snow cover can be temporary, when a snow melts during several hours or days after its formation, and it can be stable, when it remains for the whole winter or with short interruptions. The snow cover formation on the globe is determined (conditioned) by the geographical zonality, surface relief, and general circulation of the atmosphere. Solid precipitation is a source of snow cover; it remains on the earth surface at negative temperatures. Wind-blown snow transport results in sharp irregularity of its deposition, especially in mountains.

With time, snow thickness settles and consolidates; processes of sublimation and snow recrystallization take place inside the thickness, i.e., transformation of plate-like and column-like snowflakes into formless grains of different sizes. Snow cover has small density. Density of dry snow under a forest canopy is usually 10-15% lower than on open sites. With time, density of snow cover increases, particularly in spring, when liquid water appears in the snow. Reflective capability (albedo) of snow cover fluctuates from 80-90% when it is fresh down to 30-40% of old melting snow. But snow absorbs infrared radiation and itself radiates heat radiation almost like the black body. In winter, air above a snow cover is strongly cooled; in spring, a great amount of heat is spent for melting. Melt waters form the greater part of river runoff on the Earth.

Every year, snow cover occupies from 100 to 126 million km^2 of the Earth surface; approximately 2/3 of this area falls on the land and the rest 1/3 is sea ice. It has the maximal area by the end of winter of the Northern hemisphere; it is 96 million km^2, and it is minimal (44 million km^2) by the end of winter of the Southern hemisphere. About 17% of snow, annually formed, serves as a source of glacier alimentation.

Snow cover exerts immense influence upon climate, relief, hydrological and soil-forming processes as well as on plants and animals. Owing to its low heat conduction, it protects soil against strong cooling, and, thus, under-winter sowing against freezing. Snow cover contains considerable storage of moisture, and in many regions of mid-latitudinal zone it provides stable crop; then great role is played by the snow retention. In mountains, increasing of snow cover leads to snow avalanches, while on planes it results in snowdrifts. Snow is used as a source of material for building of winter automobile roads, snow-ice storehouses, etc. Scientific and applied aspects of snow cover are investigated by snow studies.

1. Distribution and Properties of Snow Cover

Snow cover is a layer of snow on the ground surface resulting from snowfalls. A snow cover can be temporary, when snow melts during several hours or days after its formation, or it can be stable (steady), when it remains during the whole winter or over short intervals. Formation of snow cover on the globe is conditioned by geographical zonality, terrain relief, and by general circulation of the atmosphere. A source of snow cover is the solid precipitation remaining on the ground surface at negative temperatures of air. Wind transport of snow results in drastic irregularity of its deposition, especially in mountains. On plains, the snow cover occurs most regularly under the forest canopy, while in the forest-steppe and steppe zones considerable part of snow is carried into gulches and balkas (small flat-bottom valleys).

The study of snow cover originated in Russia. In 1871, the well-known Russian climatologist A.I. Voeikov published a small paper (article) “Effect of Snow Cover on Climate”, in which he had shown for the first time importance of snow for the Nature. Several years later, the basis for new branch of the science was formulated in A.I. Voeikov’s big work “Snow Cover, Its Effect on Climate and Weather, and Ways of Investigation” (1889).

Snow cover	Area, million of km^2	Average accumulation, $g/(cm^2 \cdot year)$	Mass of seasonal snow, 10^{11} t
The Northern Hemisphere			
Permanent on land	2	25	5
Temporary on land	59	14	83
On permanent sea ices	9	10	9
On seasonal sea ices	9	12	11
The Southern Hemisphere			
Permanent on land	14	16	20
Temporary on land	2	15	3
On permanent sea ices	5	18	9
On seasonal sea ices	15	20	30
Total	115	16,5	170

Table 1. Area and mass of annually formed snow cover (mean values)

If one can glance over the whole globe, huge areas covered by snow as well as drastic irregularity of its deposition in Northern and Southern hemispheres (Table 1) can be seen. There is much more of snow in the Northern hemisphere, where it covers in winter two largest continents, while in the Southern hemisphere its spreading is hindered by the oceanic spaces. As known, winter and summer in these two hemispheres come in opposite times of a year. When winter “reigns” in the Southern hemisphere, this is a height of summer in the Northern one. Because of this, the snow cover grows alternately in the north and in the extreme south of the Earth. The total area of snow cover (in millions of km^2) at the end of winter of the two hemispheres, i.e. in February and August, respectively, amounts:

	Northern hemisphere (February)	**Southern hemisphere (August)**
On land	75	18
At sea	23	29
Total	**98**	**47**

In February, i.e. at the end of winter of Northern hemisphere, snow covers 19.2% of the whole Earth’s area, and in this case it is 31% of the Northern hemisphere area and 7.5% of the Southern one. In August the situation is quite another. In this time snow covers only 9.2% of the whole Earth’s surface, but 14% of the Southern hemisphere and only 4.3% of the Northern one is under snow. Thus, in the Northern hemisphere the snow cover area varies during a year 7.2 fold, while in the Southern one this factor is 2. All values presented here characterize average conditions of snowiness, which are formed during the modern epoch (Shumsky, Krenke, 1965; Kotlyakov, 1968).

Satellite data allows estimating sensitivity of snow cover to the temperature changes on the Earth. It is found that in the Northern hemisphere an increase of mean annual temperature by 1°C causes the area of snow cover to shrink by 3.5-5.1 million km^2. This corresponds to a retreat of the southern boundary of the snow cover by approximately 2° of latitude.

The snow cover forms a specific connecting link of the global hydrologic cycle: the water exchange between oceans proceeds through the snow thickness in which the moisture is retained for several months. Calculations made on the basis of maps, constructed for the World Atlas of Snow and Ice Resources (1997), show that Eurasia receives 75% of its snow from the Atlantic moisture, 20% from the Pacific, and 5% from the Indian Ocean. Relationship of the return flow of melt waters is quite different as the significant portion of the moisture goes (comes) to the Arctic Ocean and very small amount returns to the Atlantic.

Mountains, on paths of the moisture-carrying air masses, make the air to rise into higher and colder layers of the atmosphere still at far distances from the mountains. The air masses drop snow over windward mountain slopes, and snowfalls here are more often. They form very thick snow cover. It results in that upper parts of slopes of mountain ridges, facing the moisture flows which are distinguished by increased snowiness which is also a reason for extensive glacierization. This feature of snow accumulation is typical for all mid-latitudinal mountains.

The larger the absolute value of snow storage, the smaller is its spatial variability: this is the general law repeatedly proved by investigations in mountains. That is why contrasts of snow accumulation are not large at high levels, while on lower parts of slopes they are wide. This is caused by quick growth of duration of the snow occurrence (existence) with height: in mountains of middle latitudes snow remains 45-55 days longer with (for) each kilometer of altitude. Important also for differences between lower and upper levels of mountains, is that at the time when there is snow at the top it is quite possible that it rains below. One can see this even on high city buildings. Snow does sometimes fall on roofs of skyscrapers while it drizzles on the pavement below.

In places of increased snow accumulation, snow patches may often form and remain during a part or the whole season after the surrounding snow cover melts away. Shady places are especially favorable for such patches, therefore in steppes they mostly often occur in ravines and balkas, in tundra – on the shore benches or ledges, in small valleys and ravines, near the feet of ridges and hills, in mountains – on windward sides of ridges, in narrow gorges and canyons as well as in channels, on benches and near foot of slopes.

The mountain Ben Nevis, the highest peak of Grampians in Scotland (1343 m), is widely known for large snow patches, as there are no glaciers here. During very snowy winters many snow patches become too large to completely melt for a summer. On the contrary, after winters with small amount of snow, and when spring is dry and summer is warm, the snow patches melt away in still the first half of summer season. In winter of 1975/76, exactly such conditions happened in Scotland and this resulted in disappearance of all snow patches in that year.

Snow cover plays an important role in the life of plants and animals. The white stillness of the new snow is rather deceptive. Take a close look, and you will see the footprints of hares, foxes, wolves, wild boars, and other wildlife of fields and forests. And if bears deeply sleep under snow in their dens, other animal, such as field mice, lemmings, etc., have very active way of life in snow and under it. Elks walk in deep snow on their stilt-like legs, wile boars tread paths and trenches through the snow, white hares jump on the snow crust, and fluffy foxes sweep the snow with their tails to conceal their footprints. It becomes bad for some animals, especially those with hooves, as they meet difficulties when snow cover is very thick, but it is still much worse for all animals, if the snow is scarce or blown by the wind.

Under the “warm” snow blanket, the vegetation gains strength for their summer life. But, sometimes they suffer from unpleasant heavy weight of snowdrifts. Under the weight of heavy snow, tree trunks and shrubs become crooked and bend to the ground, and continue to grow in such position (Fig. 1). This is called as snow-loaded forest, but then it can be a snow-damaged forest when the branches and trunks break as a result of the load. Snow damage is caused by abundant snowfalls and sometimes by heavy deposition of hoarfrost. Snow-induced damage to forests is particularly extensive in wide and thick bands of snow-protective plantings, when a snow bank grows up to tops of trees.

Snow cover consists of individual (separate) layers deposited under different conditions therefore it is not homogeneous in its structure and density. Snow, falling under calm weather, is very light in weight, like a down: only 10 kg/m^3. More commonly, a density of new snow is 50 kg/m^3. As wind becomes stronger, the density increases up to 150-180 kg/m^3, and when snowstorms take place for a long time, it can reach 400-500 kg/m^3. Wind is the most significant factor for the snow density. On tops of hills, where wind is usually stronger, the density is by 20% larger than in depressions. In a forest, it is by 10% larger on glades than under trees, and it is still (by 20%) larger on open terrains surrounding the forest. But, in such a case it is again is not uniform: the density is 15% greater on the windward side than that on the leeward place.

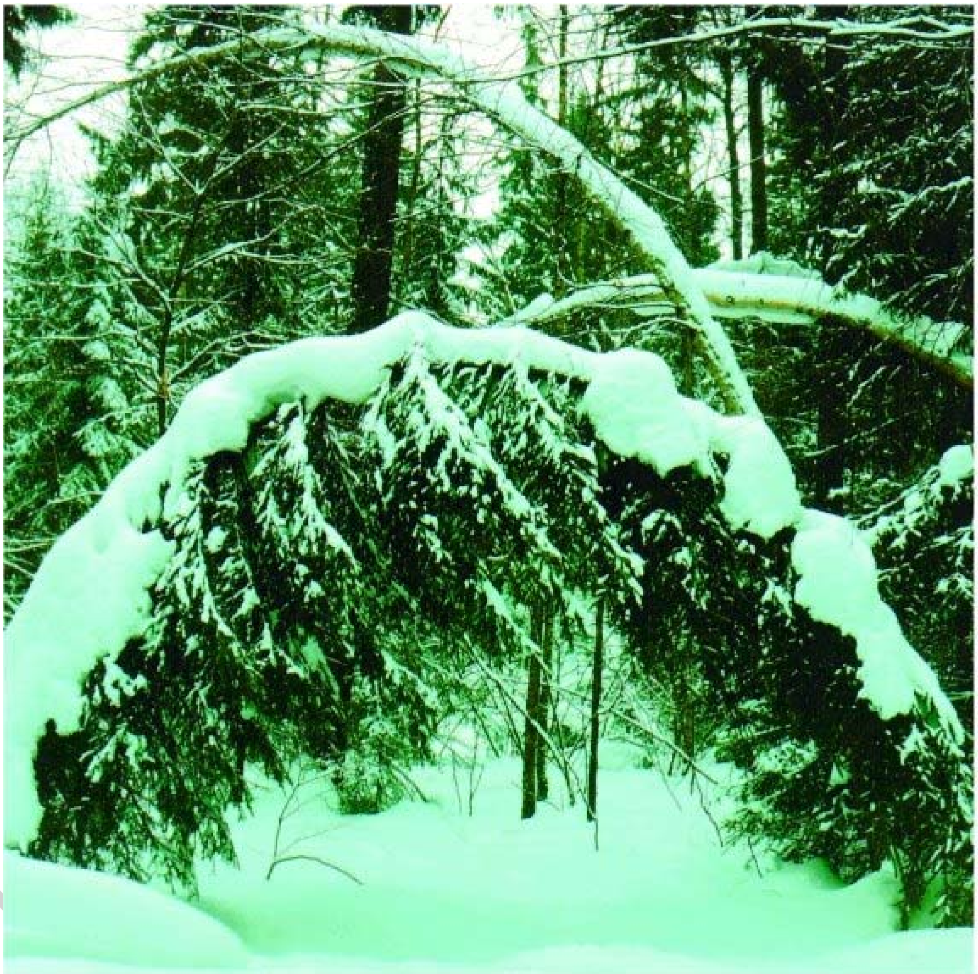

Figure 1. Great quantity of snow results in a snow-loaded forest, i.e. bending of trunks and branches of trees.

Snow layer becomes increasingly more compact with time due to the following factors: wind effects, pressure of different layers produced by the force of gravity, winter thaws and spring melts, liquid precipitation, falling during snow deposition, and processes of recrystallization. Snow compactness means compression of pores and bringing together with partial accretion of snow grains. It results in formation of compacted fine-grain snow which is characterized by low air permeability, considerable strength, and at the same time it holds (retains) a high degree of plasticity.

Many of us are familiar with the cracking sounds that snow produces as one walks upon it; this is the sound of snow crystals being broken and displaced. The cracking of snow is well heard at temperatures from –2 down to -20°C, and the lower the temperature, the higher is tone and intensity of the sound, however at frost temperatures below -20°C it becomes weaker. In new snow velocity of sound propagation increases with the temperature, while in old snow it remains constant within the temperature range from 0 down to -17°C. Sound waves have good propagation inside snow cover, but on the interface between snow and air they are almost completely reflected. For this reason, people buried in avalanches easily hear steps on the snow above, but rescuers can't hear the people buried under the snow.

Snow cover undergoes continuous transformations, connected with the water vapor movement inside of snow. In the course of recrystallization intensive evaporation of substance goes on from the finest particles and from the most convex portions of larger ones while the water vapor resulted from the evaporation crystallizes onto large particles, especially onto their concave segments. Snow grains grow and their total quantity decreases. The rate of the grain growth increases as their radii becomes larger, and the degree of irregularity of the snow crystals increases as well; the rate also accelerates with increasing of number of contacts between the crystals and area of these contacts between neighboring ones.

The process of snow recrystallization takes place also when the temperature of the snow layer is homogeneous because, inside of this, the necessary diversity of forms and sizes of particles is always present. But the rate of recrystallization increases under sharp changes of the snow thickness temperature: the water vapor transfers from relatively warm layers of snow, where the saturated vapor pressure is large, into the cold ones where the pressure is low.

Accordingly, two types of the snow cover metamorphism are distinguished which are destructive and constructive ones. The destructive metamorphism takes place when the temperature vertical gradient does not exceed 1°C per 10 cm. It is connected with redistribution of water vapor between surfaces of snow grains with different values of curvature and this results in formation of chains consisting of rounded grains one stuck to another. The constructive metamorphism is caused by great differences (jumps) of temperature, usually more than 2°C per 10 cm. It leads the vapor sublimation in warm snow layers, loosening of them, and formation in such places of large cut crystals of deep rime (Figure 2).

Forms of such crystals are skeletal and cube-shaped, reaching sometimes 8-10 cm in diameter. They grow on the lower sides of cold crystals those are on the way of upward flow of water vapor. The deep rime was first described in 1858 in Lapland, but in detail, it was studied in 1930s in the Alps by a Swiss glaciologist V. Paulcke. It occurs in not only a snow cover, but also in frozen through cavities and caves where their sizes reach 10-50 cm.

In snow cover, warmer layers are normally located in the lower horizons of the snow thickness; therefore, the water vapor moves upward, that promotes formation of so-called loose-snow horizons filled with the deep rime crystals. Similar horizons are named the floating snow, as due to its friability and hardness the deep rime, being destroyed, becomes fluid. Being destroyed by weight of the above mass of snow, layers of deep rime (the floating snow) are frequently the cause of avalanches.

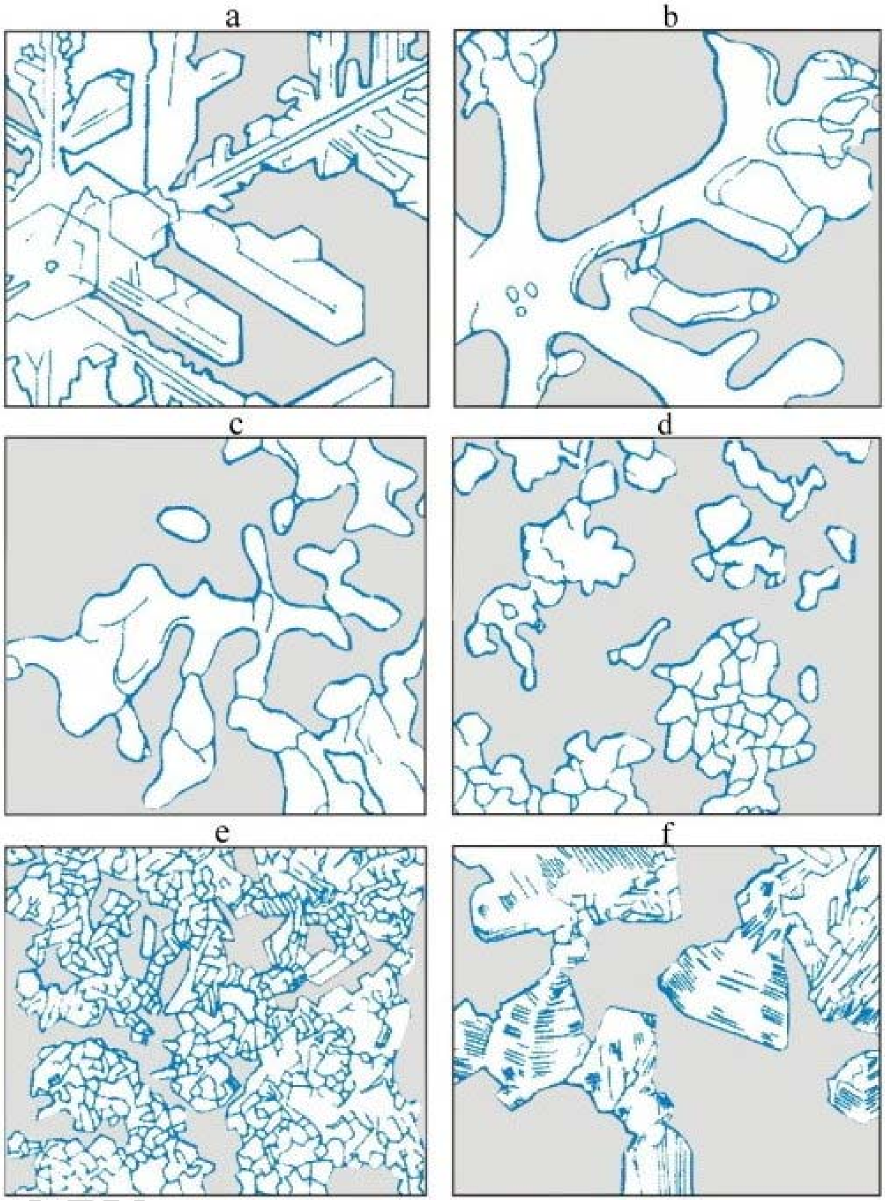

Figure 2. Different stages of destructive and constructive metamorphism of snow *a-g* – branching snowflakes transforms into rounded, more or less compact grains; *d-e* – fine snow grains transforms into large cup-shaped crystals of deep rime.

Quite different conditions exist on vast expanses of Central Antarctica. As a rule, the snow surface temperature here is higher than that in depth of snow thickness, and the water vapor moves downward. This results in packing (compacting) of lower layers, while the surface snow layer is loosened. As a result, passability of the Antarctic snow cover drastically gets worse: tow tractors and cross-country vehicles “stick” and “sink” in such snow, and skiers become quickly tired on a loose fresh snow cover. Still R. Amundsen wrote that one can easily drive a two-meter stick into the snow. This feature

makes great difficulties for travelers in the Antarctic continent. It could be one of the probable causes of the tragic finish of the Robert Scott's expedition to the South Pole.
Thus, two processes take place constantly in the snow thickness, those are the sublimation recrystallization and snow settling. Depending on conditions, one or the other becomes prevalent. The loosening takes place under recrystallization, while the compacting does under settling. Loosening of snow thickness is typical for extreme continental conditions, for leeward and southern slopes of internal mountain ranges as well as for upper layer of fresh snow cover after a snowfall. Compacting of snow prevails under moderately continental climate, on windward and northern slopes of mountains and in the lower part of fresh snow cover.

Two opposite types of the snow thickness development result in its different structure and are reflected in its stratigraphy. A snow cover, which is formed under mild conditions of moderately continental winter, is quite unlike the one, deposited under conditions of extremely continental winter with small amount of snow and very irregular snow accumulation. The reason is that a form of the atmospheric snowflake carries information about conditions of its origination in the atmosphere, i.e. temperature, humidity, dustiness, wind regime, while a form of crystal, gradually transformed from a snowflake within the snow thickness, reflects both external and internal processes, lasting for winter weeks and months.

The snow mass possesses a "memory" that can tell the past. Such properties are forms and structures of snow crystals, layering of the thickness, dustiness, and isotopic composition. Seasonal snow cover tells about all events of the past winter, while a perennial snow-firn thickness of polar glaciers stores information about passed hundreds and thousands years.

Diversity of conditions of the snow cover formation and deposition leads to a large number of types and modifications of snow. This is reflected in many classifications of snow. Several basic modifications are distinguished, among them are ***new snow*** which is a loose (up to 200 kg/m^3), depositing after snowfalls and drifting snow that takes place without strong winds. The ***downy snow*** with density of 10-50 kg/m^3, consisting of unbroken snowflakes, is formed under complete calm and slight frost. Moderate winds with snow-drifting results in formation of ***freshly deposited snow*** with its average density of 200-300 kg/m^3. Very dense and compact snow (up to 400 kg/m^3), consisting of fine fragments of crystals and re-deposited by strong low-blowing snow drifting, is called a ***drifting snow***. Re-crystallized snow, lying inside a snow thickness longer than a month, is related to ***old (mature) snow***; its modifications are mainly separated according to a degree of its graininess.

-
-
-

Bibliography

Handbook of snow. Principles, processes, management & use (2004). Edited by D.M. Gray, D.H. Male. The Blackburn Press 2004, 776 p. [Very comprehensive overview of the most data available on snow science over the last century. The bibliographies alone are worth to look through.]

Kotlyakov V.M., Smolyarova N.A. (1998): *Elsevier's Dictionary of Glaciology* [Four-language Glossary with definitions of glaciological terms in English and Russian].

Snow Ecology: An Interdisciplinary Examination of Snow-covered Ecosystems (by H. G. Jones (Editor), J. W. Pomeroy (Editor), D. A. Walker (Editor), R. W. Hoham (Editor)(2001): Cambridge University Press, 378 pp. [First book to integrate the study of snow and ice in the physical, chemical and biological sciences into a multidisciplinary overview of life in, on and under snow].

World Atlas of Snow-Ice Resources (1997): Volume 1 – maps; volume 2 – two books [Maps and description (both Russian and English) of the snow-ice resources in different parts of the globe], published in Moscow.

Casareto B.E., Suzuki Yoshimi, Okada Kikuo, Morita Masataka (1996): *Biological micro-particles in rain-water*: Geophys. Res. Letters, vol. 23, pp. 173-176. [Morphology, elemental composition and concentration of the micro-particles found in rain water are described]

Biographical Sketch

Vladimir Mikhailovich KOTLYAKOV (born in 1931) is a member of the Russian Academy of Sciences (elected in 1991). He is Director of the Institute of Geography, Russian Academy of Sciences. With particular interest in glaciology and physical geography in polar and mountain regions, he directed the twenty-year project resulted in the World Atlas of Snow and Ice Resources (published in 1997). He participated in many expeditions, working and wintering in some Arctic and Antarctic stations. He studied slopes of the highest summit of Europe, the Elbrus, headed the high mountain glaciological expeditions to the Pamirs. The main theoretical results of his works consist in elucidation of laws of snow and ice accumulation of the Antarctic ice sheet as well as ice sheets in general (1961), the snowiness of the Earth and its fluctuations within 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 for four glacial-interglacial cycles (1985 and further on). During the last years, he dealt with the global changes of the environment, geographical aspects of global and regional ecological problems, the problems of interaction between the Nature and society. He is the vice-president of the Russian Geographical Society and the President of the Glaciological Association. In 1983–87, was elected the President of the International Commission of Snow and Ice, in 1987–93, he was the member of the Special, and later Scientific, ICSU Committee of the International Geosphere-Biosphere Program, in 1988–96, the vice-president of the International Geographical Union. Now he is a member of the Earth Council and a member of International Organizing Committee for the coming International Polar Year IPY 2007/08. He is elected a member of the Academia Europaea and the Academy of Sciences of Georgia, a honorary member of the American, Mexican, Italian, Georgian, and Estonian Geographical Societies.