HIGH-ALTITUDE CLIMATE ZONES AND CLIMATE TYPES

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Contents

Summary

This chapter gives a brief analysis of basic factors influencing highland climates and peculiarities of atmospheric circulation caused by mountain systems. Special attention is paid to characteristics of highland climate which are manifested in regimes of temperature, precipitation, wind, solar radiation, etc. Typical and exclusive features of highland climates in different large-scale climatic zones are considered.

1. Introduction

Description of highland climates is a most difficult problem because the outstanding feature of these climates is their great diversity. It is a task facing the future of climatology to provide an expounding generalization of highland climates in different aspects.

According to modern measurements, regions with altitude above 1000 m comprise about 10% of all land, and the area of upland regions in general is about 20% of the global land surface.

The climatic influence of mountain relief has two aspects. On one hand, it results in specific climatic patterns inside mountain regions; on the other hand, mountain systems have a significant influence on the climate of nearby areas.

Three scales of the influence of mountains on weather and climate can be distinguished. Firstly, due to dynamic and thermodynamic processes, essential modification of synoptic systems, or air currents, takes place in significant atmospheric layer. Secondary, there are typical regional weather conditions, including the system of winds, cloudiness and precipitation regime, caused by dynamic and thermodynamic processes. The third type of mountain effect results from differences in slopes and their orientations. This is mainly revealed at local scales from tens to hundreds of meters.

2. Basic controlling factors of highland climates

As well as geographical latitude and general atmospheric circulation, in highlands the following features are additional basic controls: (1) altitude, (2) shape and scale of relief, (3) exposure and steepness of slopes. Although the absolute height is the most influential, the various effects of relief shapes, exposures and degree of enclosure may be so important that they fully compensate for altitude. When we speak about the shapes of relief, we differentiate such forms as:

1) plain (plateau),
2) bulge (hills, individual mountains, tops, ranges, mountain chains),
3) concave (canyons, hollows, partly valleys), and
4) bulge-concave (saddles, passes) etc.

All these factors act on the complex of climatic characteristics in highlands: atmospheric pressure, radiation regime, air and soil temperature, precipitation, winds, etc. Due to these influences there is a great patchiness in spatial distribution of temperature, cloudiness, winds, and, in particular, rainfall and dangerous weather phenomena.

As to large-scale effects of mountain relief, firstly we have to mention the so-called mountain barrier effect. The high mountain ranges represent a serious obstacle for moving air masses that results in great differences of air temperatures from one side of the range to the other. In this manner the east-west chains are the natural boundaries for spreading cold air masses. The Himalayas decrease the southward flow of cold masses from Central Asia, the Alps hold much of the polar air away from the north of Italy. The Caucasus, Carpathians and many other mountain chains being subject to cold invasions are to some extent obstacles to penetrating cold air and promote higher temperature differences on either side of the range.

Near the coast in the middle latitudes the mountain chains have a strong influence on air temperature even if they are north-south oriented. The Cordilleras in North America, running along the meridian, act as a barrier to warm oceanic air masses in winter. To the east of this chain near the surface there is cold continental air. The Scandinavian mountains are of similar, but weaker, influence for Europe.

Altitude is a primary factor, which gives a possibility of finding common features in the diversity of highlands. The increase of altitude is accompanied by decrease of atmospheric pressure and air density. At high altitude the air composition is characterized by low contents of fine particles (dust, etc.) and moisture. As a result, on plateaus with increasing altitude, global irradiance rises, but its dependence on the height of the sun and, consequently, the annual range, decreases. At high altitudes there is higher proportion of shorter wavelength radiation (violet and ultraviolet), which does not penetrate to lower elevations. This is the reason for the severe action of mountain sunshine on plants and human skin.

The effectiveness of insolation on slopes varies greatly, depending on their exposures. In the northern hemisphere the northern slopes receive the least amount of radiation. As to the southern slopes, total radiation increases up to a particular value of steepness, but very steep slopes are less favorable than near horizontal, independent of their orientation. Many deep valleys and steep slopes are exposed to the direct rays of the sun for only a short time each day and some are in the shade throughout the day.

In general, higher altitude in mountains is associated with decrease of air temperature, although the lapse rate is smaller than in free atmosphere. Of course, this statement is valid only when comparing similar shapes of relief. The specialties of local relief result in essentially more complicated dependence on height.

One of the most distinctive features of thermal regime in mountains is the great difference between air temperature and the temperature of the upper soil layer in the daytime. This is caused by the absence of decrease in soil temperature with increasing elevation. Similarly, the daytime soil temperatures on slopes of different orientation are markedly differed.

At higher elevations, in transition from plains to plateau, the diurnal (annual) range of air temperature increases as a result of higher incoming solar radiation in the daytime (in summer) and outgoing radiation in the night-time (in winter). Bulge shapes of relief tend to decrease the range, and concave shapes, conversely, increase it. In mountains this rule is in action for all heights and space scales. Valleys and hollows have greater ranges than slopes and, in particular, tops. Diurnal and annual temperature ranges in wide valleys exceed the corresponding values in narrow canyons because of the less favorable conditions for insolation and cooling in canyons.

The difference between ranges (at the bottom and higher elevations) and local peculiarities of circulation gives rise to temperature inversions. There are some mountain regions where this phenomenon is the most characteristic feature of the climate.

Wind speeds at high altitudes are generally greater. The higher a site, the closer the wind direction corresponds to the broader pattern of circulation. In mountains prevailing winds are to a great extent conditioned by local relief. Here many kinds of special winds arise, such as winds of slopes, mountain-valley winds, and others. A significant part of local winds is the so-called foehns. These are dry, usually warm or hot, winds from mountains. They can be of various origins. These phenomena often occur in any mountain region with altitude sufficient to reach the anticyclone inversion or condensation level (see Weather System and Weather Forecasting). In mid-latitudes, typical forms of foehn are observed in mountain chains not less than 800 to 1000 m in height, but phenomena like foehn, for instance differential moistening of windward and leeward slopes of hills, can occur at heights of only about 100 to 200 m.

Variations in diurnal and annual patterns of relative humidity are attributable to local relief. Absolute humidity always decreases with altitude as well as air temperature, but in mountains, above a particular altitude, the type of diurnal pattern differs from the plain type in that there is only one peak of humidity, which occurs in the daytime. This rule is valid only for mountains; on plateaus the diurnal and annual progressions are the same as on plains. In the mountains beginning from a definite altitude a reversion of diurnal and annual progression of relative humidity takes place. In various climatic regions this reversion occurs at different altitudes.

Features of local relief greatly complicate and vary the distribution of cloudiness and fogs in mountains. With bulge shapes of relief, the convective type of cloudiness and fogginess prevails. In summer, at the end of the day, high mountains are practically always in clouds (apart from very dry regions, for instance, in Central Asia) and thunderstorms often occur. However, specific kinds of cloudiness and fogs are generated over mountains in the night-time too: cooling of underlying surface, especially of snow and ice, brings about radiation fogs, which are transformed into stratus clouds, forming "collar" around the top. In winter the cloudiness inside the mountain system is less due to weak development of convective movements and washing out of frontal cloudiness.

On slopes, passes and in high parts of valleys, similar processes dominate. This causes fogs to rise, when the difference between fog and cumulus clouds disappears. In mountains the term "fog" often corresponds to the concept of cloud surrounding the observer. When the observer is out of cloud, horizontal visibility is greater at high elevation. In general, high probability of both good visibility and fog is a characteristic feature of mountain climates.

The amount of precipitation decreases with altitude as well as moisture content. This can be seen by comparing precipitation on plains and in central parts of vast plateaus. The influence of slopes works in the opposite direction, so when moving up a slope, precipitation increases to that altitude where the decrease of moisture contents begins to prevail over the influence of the slope. The slopes regulate and intensify convective processes, particularly influencing the most heated slopes. This is manifested both inside a mountainous region and on its periphery. For this reason almost all mountain regions of middle and subtropical latitudes display a main or secondary summer maximum of precipitation, even in regions where this does not occur on the plains.

There are some specific effects connected with the passage of air masses and fronts over mountains. Three specific zones can be recognized, with extreme values of precipitation: (1) a domain of pre-ascending and maximum precipitation at the foot of a mountain, (2) domain of relatively high precipitation on windward slopes, and (3) "rain shadow", a domain of lower precipitation due to descending dryer flows on leeward slopes or intra-mountain hollows.

The altitude with maximum precipitation varies, for many reasons. With high values of humidity and instability of air masses, the effect of "pre-ascending" takes place with maximum precipitation at the foot of the mountain. In other cases, due to local circulation, precipitation can increase with altitude up the slopes.

In mountain regions clouds are often in contact with the slopes as they move, so favorable conditions arise for glaze or hoarfrost and other kinds of direct sediment of cloud or fog drops. To estimate the amount of moisture in such deposition it is useful to compare precipitation, registered in the usual way, and runoff. If runoff greatly exceeds precipitation, it can be explained by this direct transfer of atmospheric water to the land. On open slopes under conditions of sufficient winter moistening there are many days with such glaze. In Alps in some localities this occurs on nearly 150 days per year.

With increased elevation there is a greater proportion of snow, and snow cover remains for a longer period of time. In mid-latitudes this duration increases approximately by 3 to 4 days for each 100 m of elevation, but on some slopes with heavy precipitation this gradient can be up to 10 days per 100 m.

Increase of snow cover in the mountains reduces the intensity and depth of permafrost, even to the extent of eliminating it. Elevation of the snow line (the lower limit of permanent snow and ice) increases from polar to tropical latitudes, where it reaches its maximum because of the dryness. Closer to the equator the altitude of the snow line drops a little. In mid-latitudes of the southern hemisphere the snow line descends lower than it does in the northern hemisphere.

An important characteristic of highland climate is the specific phenomenon “foehn”, a warm dry wind flowing from the mountains. It may occur in various situations: (1) air masses crossing a mountain ridge due to pressure difference caused by various factors, (2) subsiding and spreading air in anticyclones along the slopes, (3) inversions of compression in anticyclones which arise in free atmosphere.

Under the first type of foehn, which was the first to be studied, on windward slopes cloudy rainy weather prevails, but on leeward slopes there is fair weather with specific “lenticularis” clouds. On windward slope, when air rises there is less pressure upon it, and it expands and cools. On the level of condensation, the process of cloud formation begins, and rainfall removes a part of the moisture from the air. Upon subsiding it undergoes an increase in pressure and is warmed, moving away from the condition of saturation. These air temperature changes resulting from changes in pressure (without adding or subtracting heat) are called adiabatic.

The second type of foehn, called anticyclone foehn, has the characteristic feature of simultaneous presence of foehn along both slopes of the mountain backbone and, consequently, no air crossing the mountain system. Foehn in free atmosphere (the third type) is observed on bulge shapes of relief with absence of foehn phenomena at the mountain foot.

Foehn phenomena are often met in any mountain region with altitudes not less than the level of anicyclonic inversion or condensation level. In the middle latitudes typical kinds of foehn are observed in mountain chains of altitude not less than 800 to 1000 m, but some phenomena like foehn, e.g. variations in moistening on leeward and windward slopes of hillscan occur with altitude differences of only 100 to 200 m. In many mountain regions foehn weather is observed for a significant part of the year.

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Bibliography

Barry R.G. (1984). Mountain Weather and Climate, 311 pp., Gidrometeoizdat, Russia [in Russian] (originally published in English, 1981). [This is comprehensive detailed edition on mountain meteorology with emphasis on physical aspects]

Critchfield H.J. (1983). General Climatology. [This is a general guide on climatology including the description of the main climatic types and applied problems]

Drozdov O.A., V.A. Vasiliev, N.V. Kobysheva, A.N. Raevsky, L.K. Smekalova, E.P. Shkolny (1989). Climatology, 568 pp., Leningrad: Gidrometeoizdat [in Russian]. [This considers the main controlling factors of climate and the principles of climate classification]

Global Climate Normals 1961-90. US National Climate Data Center (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwAW~MP) [This CD-ROM contains information on the 1961 - 1990 global standard climate norms for over 4000 stations worldwide]

International Station Meteorological Climate Summary. Version 4.0. US National Climate Data Center (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwAW~MP). [This CD-ROM gives climatologic summaries for more than 2600 locations worldwide]

Landsberg H.E. (1969-87). World Survey of Climatology, vol. 1-15. [This is the comprehensive detailed edition on climates of particular regions of the Earth]

Monthly Climatic Data for the World. US National Climate Data Center (from 1948 up to present). [This publication contains monthly mean temperature, pressure, precipitation, vapor pressure, and sunshine data for approximately 2000 surface stations worldwide]

Strahler A.N. and Strahler A.H. (1987). Modern Physical Geography. [This contains the description of climates of the world according to Strahler's system of classification]

Trewarta G.T. (1981). The Earth's Climate Problems. [This contains a description of the Earth's main climatic types, soils and vegetation]

Biographical Sketch

E.I. Khlebnikova was born in 1945 in Leningrad, USSR. In 1963 she entered Leningrad State University, Mathematics and Mechanics Faculty, and in 1968 graduated from the Dept. of Theory of Probabilities and Mathematical Statistics of this University. In 1968 she began to work at the Main Geophysical Observatory in the Dept. of Climatology and in 1975, after postgraduate studies in meteorology and climatology, she received a scientific degree of Candidate in Math & Physics. Since 1998 she has been a leading scientist in the Dept. of Applied Climatology. Dr. Khlebnikova has thirty years of experience in climatology including research and statistical modeling of meteorological processes, methodology of climate monitoring and different aspects of statistical interpretation of meteorological and other observations. She has more than 50 publications in these fields.