Permafrost

Learning objectives

- You know the basic terms related to permafrost
- You know where permafrost occurs
- You know the relevance of permafrost for the society
- You know the climate, topographic and other site-specific parameters that can influence permafrost

Terms and Concepts

permafrost, active layer, permafrost table, permafrost base, zero annual amplitude, rock glacier, MAAT, MAGST

References and Further Reading

Literature

Williams and Smith (1989): The Frozen Earth: Fundamentals of Geocryology. Cambridge University Press. 306p.

Hoelzle et al. (2001): Surface energy fluxes and distribution models of permafrost in European mountain areas: an overview of current developments. Permafrost and Periglacial Processes, 12: 53-68.

Zhang (2005): Influence of the seasonal snow cover on the ground thermal regime: an overview. Rev. Geophys., 43, RG4002, doi:10.1029/2004RG000157.

Haeberli et al. (2006): Permafrost creep and rock glacier dynamics. Permafrost Periglac. Process., 17: 189–214. doi: 10.1002/ppp.561

Hauck and Kneissel (2008): Quantifying the ice content in low-altitude scree slopes using geophysical methods. In: C. Hauck & C. Kneisel (eds.), Applied geophysics in periglacial environments. Cambridge University Press, 153-164.

Salzmann (2006): The Use of Results from Regional Climate Models for Local-scale Permafrost Modelling in Complex High-mountain Topography – Possibilities, Limitations and Challenges for the Future. Geographie, Glaziologie und Geomorphodynamik 51, 181p. ISBN 3 85543 247 3

Gruber and Haeberli (2007): Permafrost in steep bedrock slopes and its temperature-related destabilization following climate change. Journal of Geophysical Research, 112 (doi:10.1029/2006JF000547)

Weblinks

Swiss Permafrost Monitoring Network (PERMOS) http://www.permos.ch

Global Terrestrial Network for Permafrost (GTNP) http://www.gtnp.org/

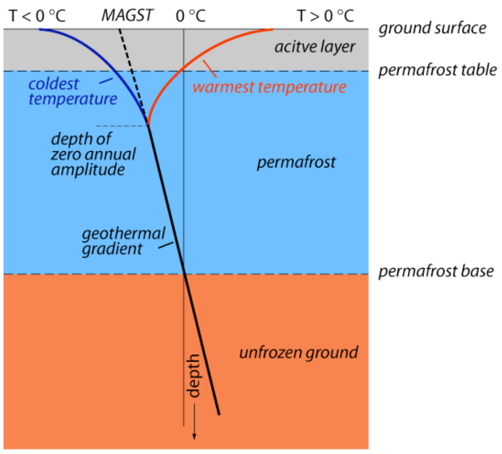
International Permafrost Association (IPA) http://ipa.arcticportal.org/

Frozen Ground Data Center (NSIDC) http://nsidc.org/fgdc/maps/ipa_browse.html

Additional Information

Definition

Permafrost is a thermal state and defined as lithospheric material that remains at or below 0°C for at least two consecutive years. According to this definition, the occurrence of permafrost does not necessarily require the existence of ice.



Schematic view of the ground thermal regime

Occurrence

The occurrence of permafrost is determined primarily by the regional climate and the site specific surface and subsurface characteristic and is in general to be expected where the MAAT (mean annual air temperature) is below 0 °C. About 20% of the global land surface is characterized by permafrost. These areas are located mainly at high latitudes and/or at high altitude. The presence of permafrost is often accompanied by impressive landforms such as pingos, and on high-mountain slopes by rock glaciers.

Prospective methods

Since permafrost is typically not directly visible, one needs different methods to prove the existence of permafrost. There are different methods in use, direct methods such as the drilling of boreholes and indirect methods like geophysical methods (geoelectric, seismic, radar).

Relevance of mountain permafrost

The practical relevance of mountain permafrost is mainly related to stability issues. The thawing of permafrost can lead to destabilization of steep slopes and rockwalls and to destabilization of engineered infrastructure.

Permafrost and changes in the atmospheric conditions

In general, the thermal boundary conditions of the uppermost layers of the lithosphere are determined by the atmospheric energy fluxes and the heat flow from the earth’s interior. The geothermal heat flux is relatively low and quite constant in space and time. In the context of permafrost, its variations caused by mountain topography can be neglected. As a consequence, the ground thermal regime and in particular its potential changes are determined mainly by the atmospheric net heat exchange at the surface, which is controlled by the local topography, by the surface and subsurface conditions and by the ground properties.

The surface energy balance Equation (1) describes the energy exchange of heat and moisture between the atmosphere and the ground surface. According to the conservation principle, the sum of all fluxes must be balanced for any time scale and every location.

$$Q^* + QH + QLE + QG + QM = 0 \qquad (1)$$

where Q* (net radiation) = K↓ + K↑ + L↓ + L↑ and where K↓ = incoming short-wave radiation, K↑ = reflected short-wave radiation, L↓ = incoming long-wave radiation and L↑ = outgoing long-wave radiation, QH = sensible heat flux, QLE = latent heat flux, QG = ground heat flux and QM = latent heat of fusion

From Equation (1) it is evident that solar radiation is the most important energy source of the surface (if geothermal heat is neglected; see above). Therefore, the surface temperature at a specific location depends significantly on the amount of incoming short-wave radiation, which varies on an annual cycle with latitude and topography. Furthermore, the partitioning of the energy balance components also varies significantly due to site-specific factors. In the following, the most important components of the energy balance are distinguished and discussed briefly for three situations in increasing order of complexity.

The propagation of the ground surface temperature into the ground depends on the ground thermal properties for heat transfer (Williams and Smith, 1998).

$$QG = -k(\Delta T / \Delta z) \qquad (2)$$

From Equation (2) it is evident that the rate of the specific heat transfer is a function of the thermal conductivity k [$Wm^{-1}K^{-1}$]. The thermal change in the medium depends, in the end, on the volumetric heat capacity C [$Jm^{-3}\ K^{-1}$]. The thermal diffusivity κ is defined with the coefficient of heat diffusion [m^2s^{-1}]

$$\kappa = \frac{k}{C} \qquad (3)$$

The final heat conduction equation for a simple, homogenous ground is:

$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial z^2} \qquad (4)$$

Modeling permafrost

There is a range of models (from simple to complex) available to simulate permafrost. Each model approach has its own advantages and disadvantages and the objective of a study determines which modeling approach is most appropriate.

Empirical models are based on proxies such as measured Bottom Temperature of Snowpack (BTS), temperature measurements within the active layer and applications of geophysical methods. They enable the assessment of probabilities for permafrost occurrence as a function of topographical parameters, i.e., elevation, aspect and slope, which primarily influence the energy balance and its modification by snow and its redistribution through snowdrift and avalanching.

Empirical-statistical models include in addition to empirical knowledge statistical relations, e.g. between potential direct solar radiation and MAAT.

Process-based models focus on a detailed understanding of the energy fluxes between the atmosphere and the permafrost. They explicitly parameterize the energy balance at the surface and require a correspondingly large amount of measured or computed data.