NUMERICAL MODEL OF LAYER PRESSURE DYNAMICS BELOW PERMAFROST

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A one-dimensional numerical model of hydrostatic pressure field dynamics in subpermafrost thickness with its foot moving by the law defined as $h(\tau)$ (where h is foot depth and τ is time) is elaborated. The permafrost thickness is described as a semi-space filled with layered medium characterized comprehensively by layer thickness and two properties of permeability $K(x)$, m^2 and porosity $m(x)$ where x is a space coordinate and the ground surface is taken to be the origin at x=0. The model is built in two variants, (a) without and (b) with consideration of horizontal water exchange with an open talik. In variant (a), the pressure dynamics is simulated by the filtration equation

$$\frac{\partial\tilde{P}}{\partial\tau}=\frac{\partial}{\partial x}\frac{\rho K}{m\rho_0\cdot\mu\cdot\gamma}\frac{\partial\tilde{P}}{\partial x}, \tag{1}$$

where γ is water compressibility; P_0 is atmospheric pressure; μ is water viscosity; $\rho=\rho_0[1+\gamma(P-P_0)]$ is water density; ρ_0 is ρ value at $P=P_0$; g is acceleration of gravity; $\tilde{P}=P-P_0-\rho gx$, i.e. the sought for pressure P is expressed as the sum of the hydrostatic component $\rho gx+P_0$ and the component $\tilde{P}$ (let us call it differential pressure) that defines the vertical water exchange.

At the lower boundary ($x\to\infty$), the boundary condition (BC) is prescribed, of the 1st or the 2nd kind, respectively:

$$\left.\begin{array}{l} P_{/x\to\infty}=\rho gx+P_0,\ \text{or}\ \tilde{P}_{/x\to\infty}=0; \\ \dfrac{\partial P}{\partial x}_{/x\to\infty}=\rho g,\ \text{or}\ \dfrac{\partial\tilde{P}}{\partial x}_{/x\to\infty}=0, \end{array}\right\}; \tag{2}$$

at the upper BC of the 2nd kind, being a mathematical notation of mass balance of thawing or freezing water at the phase transfer:

$$\frac{K\rho}{\mu}\cdot\frac{\partial\tilde{P}}{\partial x}_{/x=\bar{h}+0}=-m\rho\left(1-\frac{\rho_{ice}}{\rho}\right)\frac{\partial\bar{h}}{\partial\tau}; \tag{3}$$

here (ρ_{ice}=917 kg/m^3 is the ice density, 0 is infinitesimal quantity.

The model presumes (and the physics of the process necessitates) that $\forall x,\tau$: $P \geq P_0$. Hence, it is postulated that at any point x adjacent to the front, when decreasing pressure reaches the value P_0, porous moisture is evaporated, resulting in the impossibility for further pressure decrease. This means that at $P_{/x=h(\tau)} \geq P_0$ the upper boundary $\bar{h}(\tau)$ of the countable area coincides with the given function $h(\tau)$; otherwise $\bar{h}(\tau)$ becomes unknown quantity, i.e. the solution of (1)-(3) is the field $P(x, \tau)$, in addition to such value of $\bar{h}(\tau) > h(\tau)$ of the upper boundary coordinate where $P_{/x=\bar{h}(\tau)} = P_0$. Subarea $(\bar{h}(\tau),h(\tau))$ becoming evaporation zone, is excluded from the countable area, and the pressure in all its points is taken equal to P_0.

As h(τ), is presumed to be a periodic function, initial conditions (IC) can be prescribed arbitrarily, whereas the desired solution finally comes to a periodically established pressure field; however, to speed up the transition, it is natural to assign BC corresponding to the pressure in the open talik, thus obtaining

$$P(x,0) = \rho g x + P_0 = \frac{\rho_0 g x}{1 - \rho_0 \gamma g x} + P_0 . \tag{4}$$

For the variant (b), assuming that the inflow rate follows Newton's law, we get

$$\frac{\partial \tilde{P}}{\partial \tau} = \frac{\partial}{\partial x} \frac{\rho K}{m \rho_0 \cdot \mu \cdot \gamma} \frac{\partial \tilde{P}}{\partial x} - \frac{\rho K}{m \rho_0 \cdot \mu \cdot \gamma \cdot L^2} \left(P - P_T\right), \tag{5}$$

L, m is a coefficient proportional to the distance to a talik; pressure $P_\eth$ (x) in a talik is distributed by (4). IC and BC are assigned as previously. Due to negligibility of γ and the weak dependence of ρ on pressure, it is possible, without loss of accuracy, to assume the differential pressure field in a talik $\tilde{P}_T(x) \equiv 0$ (the numerical experiment showed the lawfulness of such an assumption). Hence equation (5) takes the form

$$\frac{\partial \tilde{P}}{\partial \tau} = \frac{\partial}{\partial x} \frac{\rho K}{m \rho_0 \cdot \mu \cdot \gamma} \frac{\partial \tilde{P}}{\partial x} - \frac{\rho K}{m \rho_0 \cdot \mu \cdot \gamma \cdot L^2} \tilde{P} . \tag{6}$$

Both equations are solved iteratively by the two-layer three-point finite difference pattern on a spatial mesh of "floating" length, reflecting the movement of $\bar{h}(\tau)$ point. The search of $\bar{h}(\tau)$ at the evaporation zone appearance is made by the method of "front catching in a mesh knot".

A number of solutions were made for various structures: homogenous, two- and multi-layered; with water inflow and without any water exchange; with different layer properties. The calculations showed either decrease or increase of the layer pressure at thawing and freezing, respectively, the pressure fluctuations being phase-shifted relative to the foot fluctuations.

APPLICATION OF MULTITEMPORAL AEROPHOTOGRAMMETRICAL MONOPLOTTING FOR MAPPING PAST, AND MONITORING PRESENT, ROCK GLACIER DEFORMATION

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Multitemporal photogrammetrical measurements were carried out on an active rock glacier in the Central Alpine cirque Ässeres Hochebenkar (Ötztaler Alpen). Six sets of aerial photographs at scales in the range of 1:15,000 to 1:30,000 cover a period from 1953 to 1997.

This investigation assessed the potential of the monoplotting technique for measuring superficial deformation velocities of an active rock glacier. Published geodetic data of this site by Pillewizer (1953) and Vietoris (1972), additional unpublished surveying data as well as extended permafrost mapping by Haeberli and Patzelt (1982), and new geophysical investigations, provide the opportunity to a) compare the displacement vectors derived by different methods and b) correlate movement data with permafrost occurrence and development.

Monoplotting is a computer-based fast and comparatively cheap technique to obtain distortion-corrected and georeferenced images from aerial photographs. The software applied in this investigation requires camera calibration data, a digital elevation model and ground control points to produce a monoplot.

Aerial photographs were scanned on a rotation drum scanner at the maximum geometric resolution of 1200 dpi and a spectrometric resolution of an 8-bit greyscale. Images were processed by use of an orthophoto software package (PCI OrthoEngine) and displacement vectors were registered by use of a GIS (ARC/INFO) on a workstation computer. The occurrence of large boulders with diameters of more than 2 m on the rock glacier surface provided good conditions for the recognition of identical objects in the multitemporal images.

For detecting and measuring the movements of this rock glacier in the meter dimension, geometric accuracies of less than a meter are required. The calculated precision of the iterative resection process given by the orthophoto software show excellent results in the sub-meter dimension. Accuracy is extremely dependent on the availability of precise and stable ground control points.

The geometric resolution of the image with pixel sizes in the range of 0.3 to 0.6 m on the ground is sufficient for this investigation. The precision obtained and the fast application of computer based monoplotting shows good potential for extended use in a planned monitoring project. Due to a major limitation of multitemporal photogrammetric analysis, the recognition of identical ground objects, a higher geometric resolution of the images is still desirable.

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