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Research Paper

Characteristics of water and heat changes in near-surface layers under influence of engineering interface

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HIGHLIGHTS

- Hydrothermal difference variation was analyzed in the soil and air near the engineering surface.
- The main engineering interface influence scope in hydrothermal changes is calculated.
- The warming effect of the engineering interface on air and the underlying soil was evaluated.

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ABSTRACT

The near-surface layer serves as a buffer layer in the discontinuous water–heat exchange between the atmosphere and soil. We analyzed the thermal regime and the water accumulation and mutation of the water–heat exchange based on the continuous in-situ water–heat monitoring data in air and soil from 2013 to 2014. The discontinuity scope was then divided. Results show that the surface temperature above the asphalt pavement was higher than the air temperature, except between November and January. The annual differences were 1.16 °C and 7.26 °C for the asphalt and sand pavements, respectively. The humidity above the asphalt pavement was 0.59 times that above the sand pavement. Therefore, asphalt pavement is not conducive to heat dissipation from soil to air. The heat absorption of the asphalt pavement is higher than that of the sand pavement. At the 5-cm depth, the soil heat flux under the asphalt pavement was 1.23 times that under the sand pavement. Meanwhile, high-aquifer layers with water mutations lay 5–30 cm beneath the pavement. According to the water–heat analysis and theoretical calculation, the interface influence scope changed by 2.55–3.29 mm and 28.2–46.44 cm above and below the asphalt pavement, and 2.9–4.31 mm and 15.8–43.6 cm above and below sand pavement. The water–heat change in the near-surface layer produces a warming effect on air and affects soil temperature. Therefore, design and maintenance engineering should pay attention to this layer in cold regions.

1. Introduction

Permafrost is the product of the exchange between the ground surface and the atmosphere. The near-surface layer links the water–heat exchange to the atmosphere and permafrost [1]. The water–heat properties in this layer directly and cumulatively affect the surface energy balance and permafrost thermal regimes, thereby causing significant long-term impact [2,3]. This effect deteriorates the ecological environment and weakens service performance in cold regions [4,5]. In addition, previous research found that this layer directly affects the permafrost environment and causes engineering problems [6,7].

Water and heat in the atmosphere enter the permafrost layer through the ground surface. The thermal properties of soil and atmosphere differ significantly in magnitude. For example, the thermal conductivities of the atmosphere, asphalt, and soil are 0.024, 0.062, and 0.6–2.3 W/m K, respectively [8]. High moisture content leads to high heat transfer rate [9]. Meanwhile, the boundary layer is a special water–heat exchange layer near the interface. In this layer, the magnitude and rate of water–heat exchanges are significantly different from those of the atmosphere and permafrost, with a sudden change in the vertical direction. The envelope formed by the highest ground temperature and the lowest temperature at each point is asymmetrical to that of the mean ground temperature. Below the boundary layer, the

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envelope was symmetric. This asymmetric range is called the water–heat discontinuity scope and is evident near engineering interfaces. Air temperature increases by 2.9–3.7 °C and 4.2–6.8 °C above the sand and asphalt pavements, respectively [10]. Engineering pavement has higher surface temperature and lower energy exchange coefficient and albedo than natural ground [11]. Sensible and latent heat flux is reduced, whereas heat absorption is increased [2,12]. The canopy effect of the ground surface inhibits evaporation and heat loss [13]. An increase in heat in the near-surface layer causes changes in the permafrost, including increased ground temperature [14] and water content, with some areas being near saturation [15]. Moisture and nutrients change with the thermal state of permafrost. For example, alpine swamp meadow changes into alpine meadow [16]. Engineering diseases, that are closely related to the differences in water–heat exchange properties manifest [17,18]. Engineering design and maintenance in cold regions may be improved by studying the water and heat exchange in engineering interfaces.

This study aims to investigate the water–heat variation near an engineering interface using data and information from a continuous record of water–heat parameters near asphalt and sand pavements in the Beiluhe basin on the Qinghai–Tibet plateau (QTP). Our work can be summarized in three parts. 1. We analyzed the temperature changes through the temperature offset relative to the pavement using the annual range of temperatures. 2. We analyzed water and humidity accumulation and mutation. 3. We divided the main impact scope for the engineering interface into water–heat change. Finally, we discussed the impact of this effect on air and ground temperature changes.

2. Data and method

2.1. Site description

The hydrothermal parameters were obtained from two engineering pavement sites in the Beiluhe basin at QTP (Fig. 1). The test points were 71 m apart in the southern region of the Beiluhe basin (92.92°–92.93°E, 34.82°–34.85°N). The altitude of this region is approximately 4628–4633 m. Generally, the soil begins to thaw in April or May and begins to freeze in October or November. Freeze time lasts approximately 5 or 6 months per year. The rainy season is from May to September, with an annual precipitation of 355–565 mm. The mean annual air temperature (MAAT) and mean annual ground temperature (MAGT) range from −2.79 °C to −3.58 °C and from −0.6 °C to −1.1 °C, respectively, and the active layer thickness is 1.6–2.3 m.

The test embankment was 13 m wide and 3.0 m tall. The asphalt pavement was 0.09 m thick and comprised a 0.04 m AC-13 fine grain-modified asphalt mixture and a 0.05 m AC-16 modified asphalt mixture (Fig. 1b). The pavement structure was intact and had no cracks. The sand pavement was covered by coarse sand and had no surface layer structure (Fig. 1c).

2.2. Data measurement

The monitoring sites were established in 2009, and the shallow hydrothermal change observation equipment was installed in September 2012. In this study, we used the test data gathered between January 2013 and December 2014, which are of good quality and continuity. The data consists of two parts: (1) the above-pavement and pavement surface part, and (2) the below pavement surface part.

2.2.1. Above-pavement and pavement surface part

The air temperature (T_a), humidity (H), wind speed (V_s), and surface temperature (T_s) were tested. An infrared sensor was installed at a height of 0.5 m to test the T_s. Other sensors were installed at 0.25, 0.5, and 1.0 m above the pavement surface (Fig. 2).

2.2.2. Below pavement surface part

The ground temperature (T_g), volumetric water content (W), and soil heat flux (G) were tested in soil. The soil temperature was tested with thermistors made by The State Key Laboratory of

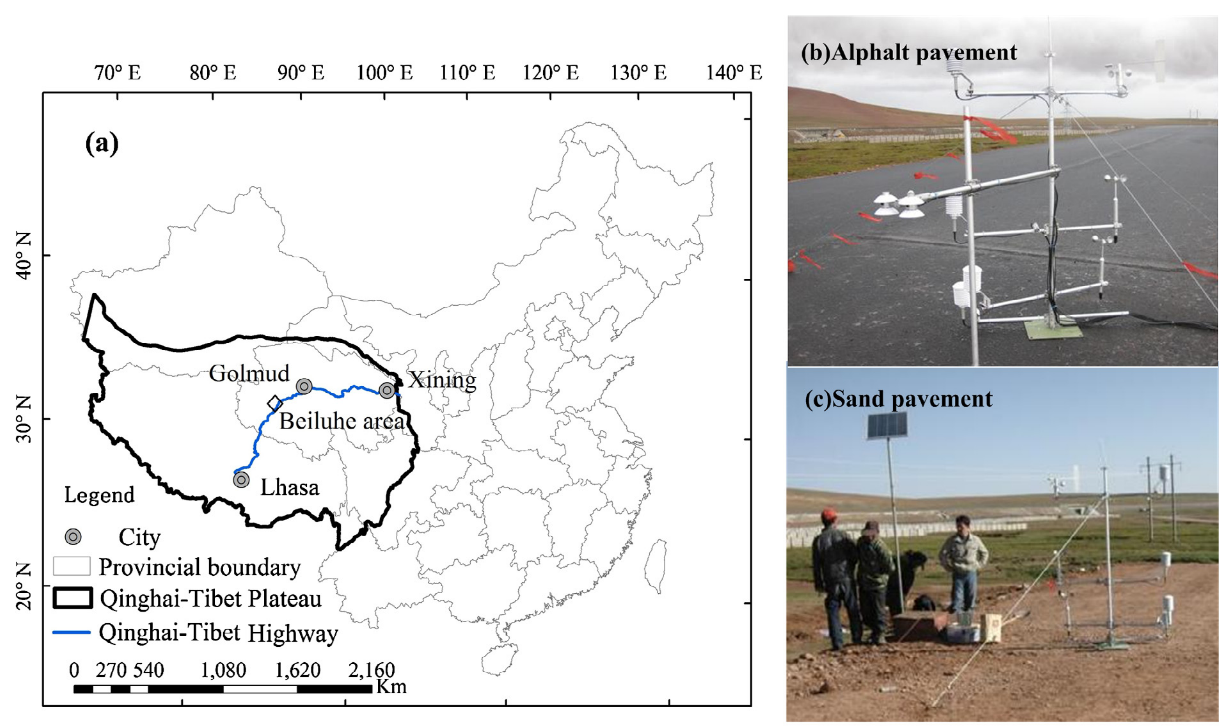

Fig. 1. Schematic of observation points.