THERMAL STATE OF PERMAFROST IN ALASKA DURING THE LAST 20 YEARS

V. E. Romanovsky

Geophysical Institute, University of Alaska, Fairbanks, Alaska 99775 (ffver@uaf.edu)

Abstract

Permafrost temperatures were on the rise during the last 20 years in Alaska. Generally, an increase in permafrost temperatures in Alaska during the last two decades was more pronounced at the coastal Arctic sites (from 1.5 to 3.0°C at the permafrost table) and less pronounced in the Interior Alaska (from 0.5 to 1.5°C). This increase in permafrost temperatures was not monotonous. During the observational period, relative cooling occurred in the early 1990s (late 1980s in the Interior Alaska) and then again in the early 2000s. Unlike the permafrost temperatures, data on changes in the active layer thickness in Alaska are less conclusive. While some of the sites show a slightly noticeable increasing trend, most of them do not. The active layer was especially deep in 2005 in Interior Alaska. At many sites, the active layer developed during the summer of 2004 (one of the warmest summers in Fairbanks on record) was the deepest observed in the past 10 years and did not completely freeze during the 2004-2005 winter. At some locations within the discontinuous permafrost of the Alaska interior, permafrost is presently thawing in natural undisturbed conditions. Deepening of the permafrost table from 3.5 m in 1989 to 5 m in 2004 was observed within some areas at the Gakona Permafrost Observatory in central Alaska. However, a more common cause is the disturbances of the ground surface above the permafrost, both natural (forest fire, flood) and human-made (agricultural activities, roads and building constructions, etc).

Introduction

Recent climate warming (during the last 30 years) in permafrost affected regions raises many questions about permafrost's reaction to this warming, permafrost stability, and spatial occurrences and temporal rates of possible permafrost degradation. Permafrost degradation is a major threshold that, if crossed, can strongly impact the energy, water, and carbon cycles in the Arctic and sub-Arctic. In 1997, the Global Climate Observing System (GCOS) and the Global Terrestrial Observation System (GTOS) identified the active layer and permafrost thermal state as two key cryospheric variables for monitoring in permafrost regions. In 1999, the Global Terrestrial Network for Permafrost (GTN-P) was established under the GCOS/GTOS with the assistance of the International Permafrost Association (IPA). Overviews of the GTN-P program, its goals and establishment, activities, progress and planned future steps are given in Burgess et al. (2000).

Observations show a general increase in permafrost temperatures during the last several decades in Alaska (Clow and Urban, 2003; Osterkamp and Romanovsky, 1999; Osterkamp, 2003; Romanovsky et al., 2002), northwest Canada (Smith et al., 2005), and in Russia (Oberman and Mazhitova, 2001; Pavlov, 1994; Pavlov and Moskalenko, 2002; Romanovsky et al., 2001). At some locations near the southern boundary of permafrost in Alaska this warming has already resulted in permafrost thawing (degradation) from the top down (Jorgensen et al., 2001; Osterkamp and Romanovsky, 1999; Osterkamp et al., 2000; Romanovsky et al., 2005).

A comprehensive system of permafrost observatories was established in the late 1970s and early 1980s by the Geophysical Institute, University of Alaska Fairbanks along the Trans-Alaska Pipeline and at other locations in Alaska (Osterkamp, 1983; Osterkamp, 2003; Osterkamp and Romanovsky, 1999). Depths of these boreholes are typically 60 to 80 meters and measurements are usually taken annually. Many of these observatories are also equipped with shallow (down to 1 meter) cables for temperature measurements and soil moisture sensors. As a result of this effort, uninterrupted permafrost temperature records for more than a period of 20 years have been obtained along the International Geosphere-Biosphere Programme Alaskan transect, which spans the entire permafrost regions of Alaska. Some results of these measurements are presented in this paper.

Changes in permafrost temperatures

Most of the observatories show a substantial warming during the last 20 years. This warming was different at different locations, but is typically from 1.5 to 3.0°C at the permafrost table on the North Slope of Alaska (Figure 1) and from 0.5 to 1.5°C in the Alaska Interior (Figure 2). Figures 1 and 2 also show that an increase in permafrost temperatures was not monotonous. During the observational period, relative cooling occurred in the early 1990s (late 1980s in the Interior Alaska) and then again in the early 2000s. As a result, permafrost temperatures increase at 20 m depth slowed down and even a slight cooling occurred during these periods (Figure 1).

An even more significant cooling of permafrost was observed during the very late 1990s and the early 2000s in the Interior Alaska (Figure 2). A significant portion of this cooling is related to a shallower than normal winter snow cover during this period. During the last three years, there was a sign of recovery in mean annual soil temperatures at shallow depths. The 2005 temperatures reached the temperatures of the early to mid-1990s, which were the warmest during the last 70 years (Figure 2). Generally, an increase in permafrost temperatures in Alaska during the last two decades is more pronounced at the coastal Arctic sites and less pronounced in the Interior Alaska.

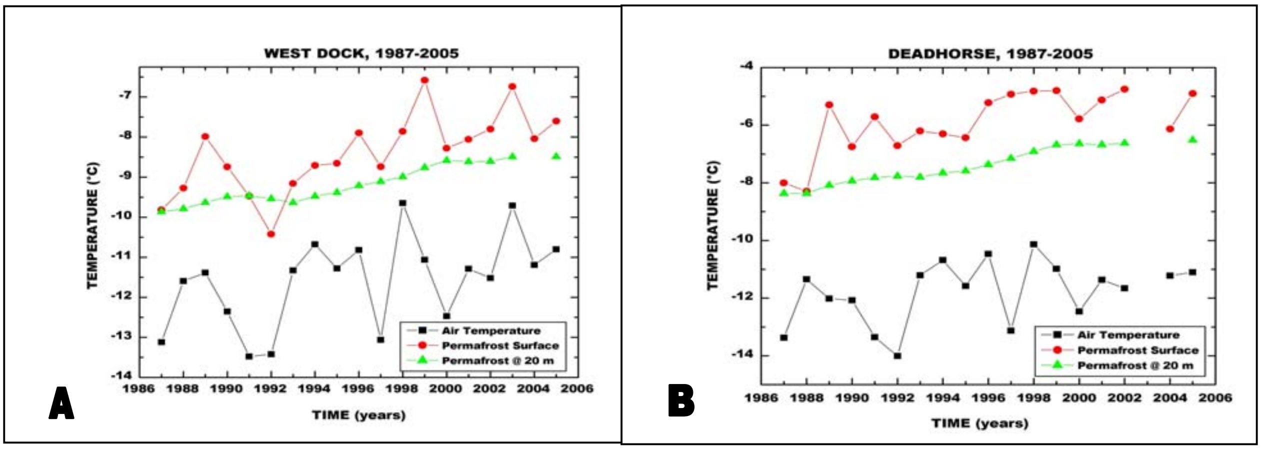

Figure 1. Mean annual air (squares) and permafrost table (circles) temperature dynamics during the last 19 years at the (A) West Dock (70°22.468'N; 148°33.13'W) and (B) Deadhorse (70°09.677'N; 148°27.918'W) Permafrost Observatories, the North Slope of Alaska. Changes in permafrost temperatures at 20 m depth are also shown (triangles).

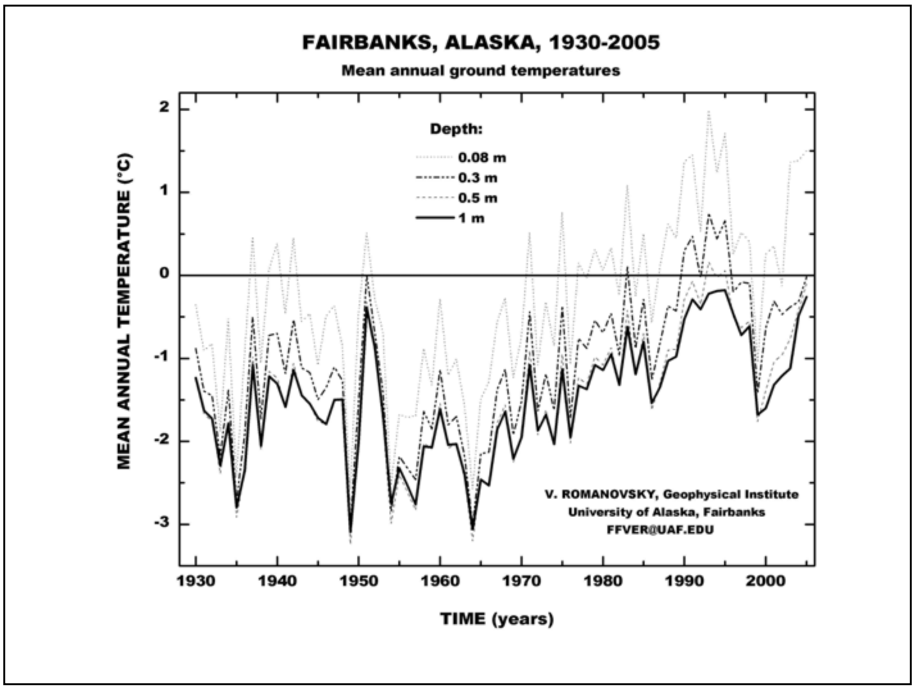

Figure 2. Mean annual ground temperature at several depths, calculated (1930 – 1995) and measured (after 1995) at a permafrost observatory near Fairbanks, Interior Alaska.

Changes in the active layer thickness

Data on changes in the active layer thickness (ALT) in Alaska are less conclusive. In the North American Arctic, ALT experiences a large interannual variability, with no discernible trends; this is likely due to the relatively short length of historical data records (Brown et al., 2000). At the same time a noticeable increase in the active layer thickness was reported for Mackenzie Valley (Nixon et al., 2003). Our relatively long-term records (1986-2005) of the active layer thickness at the three sites on the Arctic North Slope of Alaska are also inconclusive. While one of the sites (Deadhorse) shows a slightly noticeable trend, two others do not (Figure 3).

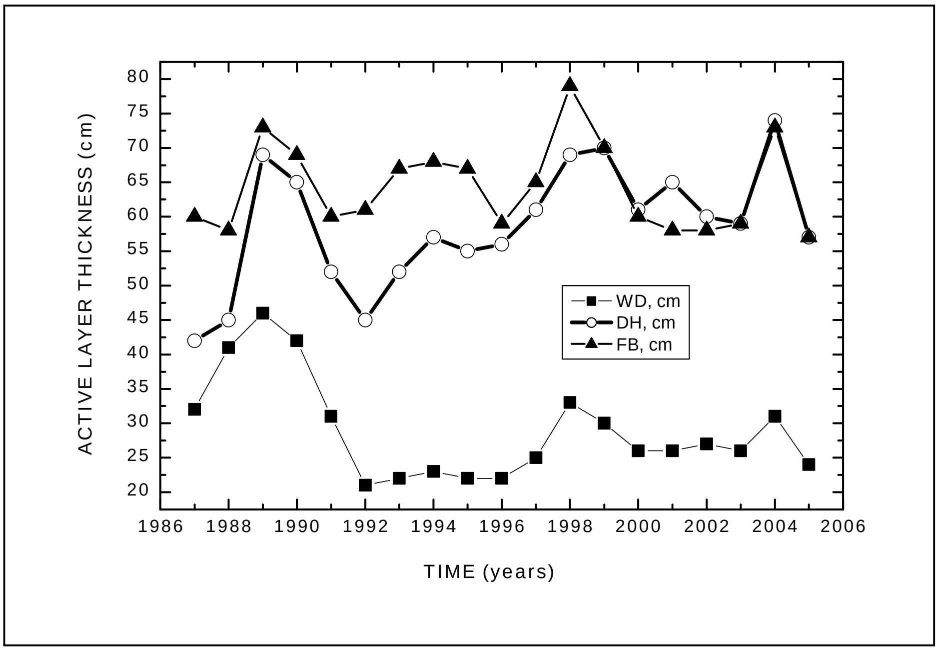

Figure 3. Changes in the active layer depths at three Alaskan North Slope sites: West Dock (squares), Deadhorse (circles), and Franklin Bluffs (69°39.308'N; 148°43.321') (triangles).

The active layer was especially deep in 2005 in Interior Alaska. At many locations around Fairbanks where continuous measurements of the active layer depths and temperatures have been made for the last 10 years, the active layer was the deepest for the entire period of measurements. Data from many of these sites show that the active layer developed during the summer of 2004 (one of the warmest summers in Fairbanks on record) did not completely freeze during the 2004-2005 winter. A thin layer just above the permafrost was practically unfrozen during the entire winter.

Permafrost thaw

While the lower boundary of permafrost moves very slowly (even in a case of relatively thin and warm permafrost of several tens of meters this movement is typically on the order of several to tens mm per year), the upper boundary of permafrost or so called "permafrost table" can move relatively fast. Besides the natural variability in the position of the permafrost table (movement both up and down), the major reason for a systematic downward movement could be a systematic increase in the active layer thickness (see the previous section) or a long-term thawing of permafrost. This long-term thawing of permafrost starts when the soil layer that was unfrozen during the summer above the permafrost would not refreeze completely even during the most severe winter. The residual unfrozen layer termed "talik" and the process is often being referred to as "talik formation". The cause of this event could be a climate warming and/or an increase in snow accumulation (for any reason) at the ground surface. Changes in the surface hydrology could also trigger long-term permafrost thawing. However, to this date, a more common cause of increased thawing is the disturbances of the ground surface above the permafrost, both natural (forest fire, flood) and human-made (agricultural activities, roads and building constructions, etc).

There are a very limited number of localities within the permafrost zone in Alaska where the process of a talik formation was carefully documented. Probably one of the best examples is the Tanana River Flats near Fairbanks, Alaska, where naturally occurring long-term permafrost thawing was studied and documented by Jorgenson et al. (2001). These studies revealed widespread and rapid permafrost thawing that caused a shift in ecosystems from birch forest to fens and bogs. Similar processes were reported in (Osterkamp et al., 2000) for the Tok area in Alaska. Deepening of the permafrost table from 3.5 m in 1989 to 5 m in 2004 was reported for some areas at the Gakona Permafrost Observatory in Alaska (Romanovsky et al., 2005). Thawing of permafrost as a result of forest fire and agricultural activities in Alaska have been reported (Osterkamp and Romanovsky, 1999; Romanovsky and Osterkamp, 2000; Yoshikawa et al., 2002).

Conclusions

During the last 20 years, permafrost temperatures in Alaska have been increasing noticeably. Generally, an increase in permafrost temperatures in Alaska during the last two decades was more pronounced at the coastal Arctic sites (from 1.5 to 3.0°C at the permafrost table) and less pronounced in the Interior Alaska (from 0.5 to 1.5°C). Unlike the permafrost temperatures, data on changes in the active layer thickness in Alaska are less conclusive. While some of the sites show a slightly noticeable trend, others do not. At some locations within the discontinuous permafrost of the Alaska interior, permafrost is presently thawing in natural undisturbed conditions. Deepening of the permafrost table from 3.5 m in 1989 to 5 m in 2004 was observed within some areas at the Gakona Permafrost Observatory in Alaska. However, to this date, a more common cause of permafrost degradation is the disturbances of the ground surface above the permafrost, both natural (forest fire, flood) and human-made (agricultural activities, roads and building constructions, etc).

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