Comparative Energy Balance Study for Arctic Tundra, Sea Surface, Glaciers and Boreal Forests

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Abstract: Seasonal change in the energy balance on the arctic tundra is presented. The thermal stability of a dry snow cover is investigated in detail. In addition to high reflection by the snow cover, a significant absorption of solar radiation on the very surface of the snow cover was found responsible for the thermal stability. The efficient absorption of solar radiation by the surface rather than the interior of the snow cover and the almost immediate removal of the absorbed energy through radiative emission and turbulent heat fluxes keep the temperature of the snow cover low.

The energy balances for the melt and postmelt period for various arctic surfaces are compared. The most important difference of the energy balance between the tundra and other low altitude arctic surface, such as the sea and ablation areas of glaciers, is not the net radiation but the latent heat of fusion. Extremely small heat consumption through the melt on the tundra is the basis for higher temperature, characteristic to the tundra climate in the Arctic.

Introduction

The characteristic climate of the arctic tundra emerges during the snow melt period and becomes most distinctive during the post-melt period in summer. The most frequently reported feature of the summer climate on the arctic tundra is its high air temperature (Böcher 1949, Jackson 1959, Bliss 1962, Clebsh and Shanks 1968, Cobert 1969, Romanova 1971, Barry et al. 1981). The characteristics of air temperature on tundra in relation to the altitude and the distances from glaciers and a coastal line were discussed by Ohmura and Müller (1977). In addition to the higher mean temperature, the climate on the tundra shows the following features (Ohmura 1981): larger daily temperature range, larger diurnal temperature amplitude, longer frost-free period, fewer freeze-thaw exchange days, lower relative humidity, higher specific humidity, longer sunshine duration, less total cloud amount, less frequent occurrence of stratocumulus, stratus and fog, higher frequency of cumulus, and lower wind speed. These characteristics are to a great extent due to the peculiarity of the energy balance on the tundra surface. The author presents the results of the energy balance program of the Axel Heiberg Island Expedition 1969 and 1970. Together with the results of other tundra experiments in the Arctic, main features of the energy exchange on the surface of the arctic tundra are summarized. Further, the main features of the energy exchange on the arctic tundra are compared with those of the ablation and accumulation areas of polar glaciers, the Central Arctic Ocean, and the boreal forests.

Experimental Site

The field work was carried out on the upland tundra at the base camp of the Axel Heiberg Island Expedition of McGill University (79°20' 45" N, 90°30' W, 200 m amsl). The research station is located on the midwest coast of Axel Heiberg Island, NWT in the Canadian Arctic. The area of the island is 37,200 km², of which 11,718 km² or 31.5% is presently ice covered (Ommanney 1969). The glacierriz-
tion is concentrated in two areas of the central mountain range, Miller Ice Cap (previously called McGill Ice Cap) in the northern part of the island and Steacie Ice Cap to the south. The major outlet glaciers on the island descend directly from one of these ice caps. The ice caps are joined in the marginal area by smaller valley glaciers. Outside of these areas, a number of small ice caps occur at lower elevations especially in the northwestern sector of the island. The tundra extends between the limit of the glaciers and the coast. The average width of the tundra on the west coast is 40 km. The McGill research station is located 4 km W of the nearest glacier snout and 8 km E of the head of Expedition Fiord, which leads to the Arctic Ocean 50 km to the west.

**Methods and Instruments**

The choice of methods and instruments was made to enable continuous measurement of the important components of the surface energy exchange in a relatively inaccessible region of severe and cold climate. The following energy fluxes were measured: global radiation, sky diffuse radiation, short-wave reflected radiation, net radiation, surface emission, sensible heat flux, latent heat flux, snow- and soil heat flux. The heat of fusion was estimated from the energy balance equation.

All the radiative components except for the surface emission were measured by relevant radiometers. The surface temperature for calculating the surface emission was measured by five pairs of US gauge 36 copper and constantan thermocouples. The radiation fluxes are expressed in the IPS 1956. Three methods were employed to measure sensible and latent heat fluxes, the profile method based on flux-gradient relationships, the Bowen ratio energy balance method and the energy balance method with a weighing lysimeter. Detailed information on the methods, instruments and calibrations is described in Ohmura (1981). The accuracy of each method for measuring the turbulent heat fluxes is presented in Ohmura (1982).

**Seasonal Transition of the Energy Exchange**

The seasonal change in the surface energy balance is schematically presented in Fig 1. Detailed description on hourly, daily energy balance conditions is given in Ohmura (1982).

When net radiation turns positive in April sensible heat flux turns upward. During the last ten days in April net radiation and subsurface heat flux contribute 89 and 11% to the surface respectively. 90% of the heat gain is removed from the surface through sensible heat flux and the remainder is used to sublime snow.

Global radiation reaches its annual maximum in late May, about a month prior to the summer solstice. This is mainly due to less cloudiness and higher surface albedo for May in comparison with June. Although global radiation decreases after late May, net radiation continues steadily to increase through late May and early June as well as other main heat flux components. In particular, latent heat flux increases rapidly due to the warming of the snow cover at the expense of sensible heat flux. This is also the period of the most rapid warming of the snow cover with a rate of 0.6°C d⁻¹ which corresponds to a daily heat storage of 84 kJ m⁻² d⁻¹ (2 cal cm⁻² d⁻¹) for a snow cover of an average depth (28 cm) and density (350 kg m⁻³ or 0.35 g cm⁻³).

This heating rate is, however, equivalent to 0.3% of global radiation or 1.6% out of net radiation of the same period. The extremely inefficient energy conversion and storage are the basis for the stability of the dry snow cover and must