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Changes in surface albedo and air temperature at Tartu, Estonia

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ABSTRACT

Changes in surface albedo, the duration of snow cover, and air temperature have been studied on the basis of observations made at the Tartu-Tõravere Actinometric Station between 1953 and 1994. Surface albedo has decreased substantially during the latest 42 years, especially in March (−21%) and April (−13%) due to the reduced duration of snow cover by 15–16 days in March and April. This reduction coincided with an increase in temperature over the same period, mainly observed in winter (up to 4.0°C in March). The seasonal decrease in albedo has intensified absorption of radiation in the surface and thereby contributed to a rise in air temperature.

1. Introduction

The state of the earth's surface and its albedo are important climatic factors. The relevant studies have been summarized by Kondrat'ev (1965), Budyko (1971) and Robock (1980). In the snow-covered areas changes in temperature and albedo exert a positive feedback. A rise in temperature leads to reductions in snow cover, while the resulting decrease in albedo, in turn, causes a further rise in temperature and thus accelerates snowmelt. Changes in the surface albedo are energetically most effective in early spring when the flux of incoming radiation is increasing. On the other hand, there is a considerable year-to-year variation in snow cover (Tooming 1981, 1984, 1990; Tooming and Kadaja, 1995). The presence or absence of snow in early spring determines whether the relatively high flux of incoming radiation is absorbed in the surface or reflected back into the atmosphere and space. Variations in the heat regime in spring due to the year-to-year variations of shortwave radiation absorbed in the surface have been detected at the Tartu-Tõravere Actinometric Station (Tooming, 1981, 1990; Keevallik and Tooming, 1996). The aim of this paper is to study the trends in surface albedo, snow cover duration and air temperature in Tartu-Tõravere Actinometric Station over the period 1953–1994.

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2. Methods of measurement and the description of the observation sites

The Tartu-Tõravere Actinometric Station has one of the longest records of observations in Northern Europe and is generally recognized as one of the most accurate and efficient actinometric stations on the territory of the former Soviet Union.

The Tartu-Tõravere Actinometric Station was founded in 1950 and for the first period of years (1950–1964) was at a site near Tartu at a distance of 1 km to SW from the town border ($\varphi = 58°21'$, $\lambda = 26°41'$, at the height of 76 m above the sea level). In 1965, with the establishment of a new

Observatory, the Actinometric Station was moved to the new site, called Tõravere ($\varphi = 58°16'$, $\lambda = 26°28'$, the height above the sea level 70 m). When the station was transferred to Tõravere, the equipment and methods remained the same. At both sites observations were made with an undisturbed horizon (Ross, 1990). Only in the NE and E directions from measurement area in Tõravere there are some buildings. They cover horizon no more than by 3°.5–4°.5. As the only changed factor, a little birch grove within 150 m from measurement point in the ENE-direction should be mentioned. By now it has reached 2°.7 above the horizon. The prevailing wind directions in both sites (W and SW) were upwind of the nearest town Tartu (about 100,000 inhabitants, situated about 20 km from Tõravere). Tartu is a university town without notable industry and no anthropogenic snow albedo changes were noticeable in the observation area due to pollution and urbanization effects. The observations carried simultaneously out between Tartu and Tõravere concerned only the total radiation and air temperature. The comparison period was too short (6 months) for analyzing possible small systematic differences in the long-time regimes in both sites. Nevertheless the data presented below indicate well (Fig. 1) that none of the detected trends in albedo and air temperature can be attributed to the change of sites in 1964 since these are of stedily declinining nature.

The Yanishevsky thermoelectric actinometer was used to measure direct solar radiation. Diffuse and reflected radiation were measured by the Yanishevsky thermoelectric pyranometer at the 1.5 m level above ground. Global radiation was calculated as the total of direct and diffuse radiation incident on a horizontal surface. According to Sulev (1990), the errors of the Yanishevsky actinometers and pyranometers used are not greater than 3% and 5% respectively.

Electronic integrators constructed by Reemann especially for the automation of the actinometrical measurements were used as recorders and their error is about 1%.

All actinometric instruments were calibrated once a month against the standard actinometer which was itself calibrated with an Ångström pyrheliometer; this in its turn was calibrated against the substandard of the former Soviet Union every 2 or 3 years. The reliability and quality of the results of the measurements of all components of the radiation budget at Tartu-Tõravere was ensured by carefully studying the instruments and accurately following all methodical instructions concerning measurement, data processing and the calibration of the instruments. Thus the data produced by the Tartu-Tõravere Actinometric Station are sufficiently reliable for the study of long time series of the radiation budget components (Russak, 1990, 1994) and surface albedo, as will be shown below.

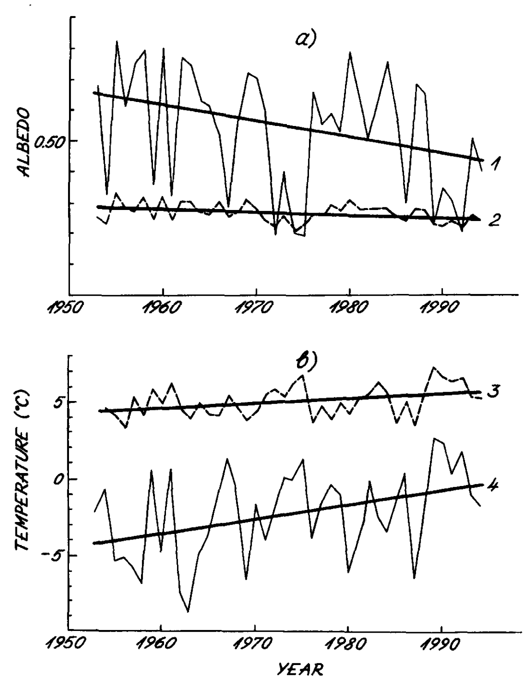

Fig. 1. Surface albedo (a), air temperature (b) and their trend lines in Tartu-Tõravere between 1953 and 1994: (1) monthly mean surface albedo in March, (2) annual mean surface albedo, (3) annual mean air temperature, (4) monthly mean air temperature in March.

3. Changes in surface albedo and temperature in Tartu

The surface albedo A is defined as the ratio of the monthly or annual sums of reflected radiation R and global radiation Q:

$$A = \sum R / \sum Q .$$

The mean monthly albedo A for the period 1953–1994 was highest for February (0.70) and lowest for May 0.20, the maximum monthly albedo 0.89 having been observed in February 1960 (Table 1). Due to the critical state of surface (snow or old grass), the albedo variations are most pronounced from November to April, with maximum standard deviation (0.20) in March. The annual albedo varies between 0.21 and 0.33, being most dependent on the albedo in March and April (Tooming, 1981).

The changes in surface albedo, in the duration of snow cover, and in air temperature may all be characterized by the same kind of trend equations with respective regression coefficients:

$$y-\bar{y}=c_y\,(t-\bar{t})/t_*\,,$$

where t denotes years elapsed since the start of the observation period (1953–1994), $\bar{t}=21.5$ years, $t_*=42$ years, y is the albedo A, the duration of snow cover τ or air temperature T, $\bar{y}$ denotes the average values of the mentioned characteristics, c_y are the regression coefficients. The latter indicate the change of the albedo, the duration of snow cover and temperature during 42 years and are tabulated for each month (Tables 1, 2).

A decreasing albedo trend in Tartu-Tõravere between 1953 and 1994 is obvious (Fig. 1). During these latest 42 years the albedo decrease in Tartu was highest in January, −0.22 (Table 1), but significantly negative albedo trends, are observed in all the months from December to April. The positive albedo trend in May and June is probably due to an earlier start of the growing season, caused by the earlier disappearance of snow cover and warmer spring months.

The albedo trends in winter and early spring are in fact caused by changes in the duration and state of snow cover (Table 2). The reduction in the duration of snow cover was between 4.9 days (February) and 8.8 days (March). The reduction in snow cover duration was some 15 days in early spring (March + April), and totalled by about 30 days over the entire snow season. If we compare our data with those of Kivi (1990a), we see that the negative trend has substantially continued during last 5 years. It is worth mentioning here that the short-wave radiation reflected from the ground surface has also decreased at Tartu-Tõravere over the period 1955–1992. The reduction in the mean annual totals of reflected radi-

Table 1. *Average, maximum and minimum values together with standard deviation σ for the monthly and annual albedo A at Tartu-Tõravere (1953–1994)*

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
$\bar{A}$	0.64	0.70	0.54	0.24	0.20	0.22	0.21	0.21	0.21	0.21	0.32	0.52	0.27
A_{MAX}	0.86	0.89	0.84	0.60	0.23	0.25	0.24	0.25	0.26	0.36	0.60	0.80	0.33
A_{MIN}	0.27	0.27	0.19	0.16	0.14	0.18	0.18	0.17	0.16	0.14	0.15	0.18	0.21
σ	0.18	0.16	0.20	0.092	0.018	0.014	0.013	0.017	0.016	0.037	0.12	0.16	0.029
r	−0.35*	−0.34*	−0.32*	−0.33*	0.41**	0.39*	0.09	0.00	0.18	0.17	−0.05	−0.27	−0.35
C_A	−0.22	−0.17	−0.21	−0.13	0.042	0.017	0.00	0.00	0.00	0.042	0.00	−0.17	−0.034

Regression coefficients C_A are given for the trend equation $A-\bar{A}+C_A\,(t-\bar{t})/t^*$, where t denotes years since the start of the observation period (1953–1994); $\bar{t}=21.5$ years, and $t_*=42$ years. Correlation coefficients r, r^*, and r^{**} denote significance levels >0.05, <0.05, and <0.01.

Table 2 *Averages of monthly and annual snow cover duration τ (days) and air temperature T(°C) at Tartu-Tõravere (1953–1994)*

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
$\bar{\tau}$	25.2	24.3	21.7	4.6						1.0	8.7	19.6	105
r_τ	−0.31*	−0.21	−0.25	−0.36*						0.18	0.12	−0.18	−0.34
C_τ	−8.7	−4.9	−8.8	−6.5						1.3	2.6	−5.1	30
$\bar{T}$	−6.3	−6.6	−2.3	4.1	11.1	15.2	16.8	15.5	10.5	5.7	0.2	−3.7	5.0
r_T	0.23	0.23	0.40**	0.43**	0.27	−0.15	0.16	0.05	−0.10	−0.17	−0.06	0.14	0.34*
C_T	3.4	3.3	4.0	2.6	1.7	−0.8	0.8	0.2	−0.5	−0.9	−0.4	1.4	1.2

Correlation (r) and regression (C) coefficients given in the same way as in Table 1; correlation coefficients r, r*, and r** denote significance levels >0.05, <0.05, and <0.01.

ation constitutes 20.6% ($p<0.01$), while the respective change in total radiation amounts only to 6.4% (Russak, 1994). This effect is due to less-lasting snow cover in recent winters and early springs.

For the period 1880–1985, evidence for a global warming of 0.5°–0.7°C has been found (Hansen and Lebedeff, 1987). An estimate by Tarand (1994) for Estonia shows an acceleration in the warming this century. The rise in temperature in the spring-summer period during the 20th century has been +0.8°C. Recent reports (IPCC, 1990; Uchijima, 1993) predict a continued rise in global temperature due to an increase in the atmospheric CO_2 and other greenhouse gases. A rise in temperature may reduce surface albedo in winter and early spring. Such a decrease in albedo may intensify the absorption of radiation in the surface and, as a result, a further rise in the warmth index may occur (Keevallik and Tooming, this issue).

The trend for air temperature during the last 42 years at Tartu indicates a large increase in January (3.4°C) and February (3.3°C), but its significance level is rather low (Table 2). This trend for increasing temperature reaches its maximum in March (4.0°C) with a high significance level (Table 2). A significant trend is observed even in April (2.6°C). Since these trends are higher than those reported for the period 1955–1989 (Kivi, 1990b) the warming trend has continued. In other months the trend is smaller and is practically absent in summer and autumn. The increase in the annual temperature during the last 42 years is significant and reaches 1.2°C.

4. Conclusion

The changes in air temperature, snow cover duration and surface albedo during the last 42 years at Tartu are most obvious in winter and early spring. This result gains additional importance because the reduced albedo in late winter and early spring, strongly intensifies absorption of solar radiation at the surface and thereby leads to an increase in air temperatures near the surface. The trends reported in the present paper thus indicate a positive feedback loop (increased temperature — reduced albedo— increased solar heating — increased temperature) that is particularly effective in winter and early spring in this area.

The possibility cannot be excluded that the above trends probably reflect a phase in long-term periodical processes influencing snow cover duration, albedo and air temperature. Therefore the problem ought to be revisited after half-a-century.

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