Dependence of global radiation on cloudiness and surface albedo in Tartu, Estonia

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With 4 Figures

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Summary

The dependence of global and diffuse radiation on surface albedo due to multiple reflection of radiation between the surface and the atmosphere (base of clouds) is found on the basis of data obtained at the Tartu–Töravere Actinometric Station over the period 1955–2000. It is found that the monthly totals of global radiation increase by up to 1.38–1.88 times, particularly in the winter half-year between November and March, when snow cover albedo may be high. A semi-empirical formula is derived for calculating with sufficient accuracy the monthly totals of global radiation, considering the amount of cloudiness and the surface albedo. In the time series of the monthly total by global radiation a downward trend occurs in winter months. A decrease in global radiation by up to 20% in the past 46 years can be explained primarily by a relatively high negative trend in the snow cover duration and surface albedo (up to −0.24). As a result, days are growing darker, a new phenomenon associated with climate change, which undoubtedly affects human mood to some extent.

1. Introduction

Global radiation, short-wave radiation budget and surface albedo are primary factors affecting both global and local climate (Kondrat’ev, 1965; Ohmura et al., 1998; Gilgen et al., 1998) as well as biophysical, plant physiological and ecological processes near the Earth’s surface (Ross, 1981; Tooming, 1977, 1984). Solar radiation has been recognized as an important source for renewable energy and its use for heating houses and buildings has increased significantly (De Bruin et al., 1995). Changes in the annual totals of global radiation depend mainly on mean cloudiness and atmospheric transparency (Russak, 1990, 1994, 1997; Abakumova et al., 1996). A significant decrease in the annual amount of global radiation reaching the surface in Antarctica has been observed, although its cause is not known exactly (Stanhill and Cohen, 1997).

The presence or absence of snow determines whether incoming global radiation is absorbed by the surface or reflected to the atmosphere and space. The principal effect over high albedo surfaces is that multiple reflections between surface and cloud base contribute a substantial amount of downward radiation (Shine, 1984). Also air temperature in late winter and early spring is highly sensitive to changes in the snow cover duration and surface albedo in different years (Tooming, 1960, 1984, 1995; Tooming et al., 1995; Keevallik and Tooming, 1996). Furthermore, snow cover duration and surface albedo have decreased during the last 35–40 years in Estonia (Tooming and Kadaja, 2000).

In the present paper, based on the data of the Tartu–Töravere Actinometric Station obtained for 1955–2000, the dependence of global radiation on surface albedo and snow cover duration is
studied. We also try to establish a formula describing the dependence of global radiation on the amount of cloudiness and surface albedo. This formula may be used in our study region for analytical calculations of global radiation in climate models and agroclimate models of crop productivity, in which detailed radiative transfer calculations are not performed (Tooming, 1977, 1984). Empirical and semi-empirical formulas are also needed for devising quality control procedures for actinometric data which are afflicted with gross errors. An attempt is made to explain the negative trend in the time series of global radiation in the winter half-year due to diminishing snow cover duration and surface albedo.

2. Data

Data on global and diffuse radiation, surface albedo, snow cover duration and the amount (per cent) of cloudiness obtained for the Tartu–Tõravere Actinometric Station have served as a basis for studying the dependence of global radiation on surface albedo and cloudiness.

The Tartu–Tõravere Actinometric Station (\(\varphi = 58^\circ 16^\prime\), \(\lambda = 26^\circ 28^\prime\), height above sea level 70 m) of the Estonian Meteorological and Hydrological Institute belongs to the Baseline Surface Radiation Network (BSRN) and is situated in a rural area and has an open horizon.

The Yanishevsky thermoelectric actinometer AT-50 was used to measure direct solar radiation (Yanishevsky, 1957). Both diffuse and reflected radiation were measured by the Yanishevsky thermoelectric pyranometer M-80M at 1.5 m above the ground. Global radiation was calculated as the total of direct and diffuse radiation incident on a horizontal surface. Electronic integrators constructed by Reemann, especially for the automation of actinometric measurements, were used as recorders. Their error is about 1%. All actinometric instruments were calibrated once a month against a standard actinometer which itself was calibrated with a Yanishevsky pyrheliometer M-50J, this in turn was calibrated against the substandard of the former Soviet Union once every 4 to 5 years. Since 1997 they have been calibrated against the World Radiometric Reference using an absolute cavity radiometer PMO-6. The reliability and quality of the results of measurements of all radiation budget components at Tartu–Tõravere were ensured by carefully studying the instruments and accurately following all methodical instructions concerning measurement, data processing and 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 radiation budget components (Russak, 1990, 1994, 1997; Sulev, 1990). The errors of the Yanishevsky actinometers and pyranometers used do not exceed 3% and 5%, respectively.

In our case the surface albedo \(A\) is determined as the ratio of the monthly or annual totals of the reflected radiation \(R\) and the global radiation \(Q\). Observations of snow cover occurrence were made every day. The day was indicated as being snowy when the area surrounding a meteorological station or post was more than 50% covered with snow. In the present work a 46-year-series of global and reflected radiation, surface albedo and fractional cloud amount over the period 1955–2000 is studied. The fractional cloud amount at Tõravere is observed once per hour. Monthly mean values of fractional cloud amount (per cent) of low and all cloud types were also taken.

3. Dependence of global and diffuse radiation on surface albedo and snow cover duration in Tartu

Both direct and diffuse radiation depend mostly on the amount of clouds and their types. However, in the winter half-year the monthly totals of global radiation are low and the surface albedo changes across a wide range. The diffuse and global radiation therefore depend to some extent on the surface albedo and snow cover duration. It is quite well known that after the first snow has fallen, days become brighter.

In the present paper it is shown that there is a significant \((p < 0.05)\) dependence of the global and diffuse radiation on the surface albedo in Tartu–Tõravere for all winter half-year months (Fig. 1, Table 1):

\[
Q_{m,i} = a_Q A_{m,i} + Q_{b,m}, \quad D_{m,i} = a_D A_{m,i} + D_{b,m},
\]

(1)

where \(Q_{m,i}\) and \(D_{m,i}\) are the monthly totals of global and diffuse radiation; \(A_{m,i}\) – the mean monthly values of albedo; \(a_Q\) and \(a_D\) are the slopes, \(Q_{b,m}\) and \(D_{b,m}\) the intercepts corresponding to the