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Relationships between surface albedo and spring heat accumulation

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ABSTRACT

A correlation is found between the June warmth index and the March surface albedo at Tartu-Tõravere Actinometric Station for the period 1953–1992. To investigate the relationships between surface albedo and spring heat accumulation over larger areas, ISCCP C2-level data for the period 1984–1990 are used. Based on the concept of surface thermal forcing, a possibility to estimate spring heat accumulation is shown. At 45–60°N in Europe, the tendencies in heat accumulation during spring of an extremal year may be predicted by surface albedo in February or March.

1. Introduction

Surface albedo is most variable in late winter and early spring during the period of snow melting (Robock, 1980; Tooming, 1981; Groisman et al., 1994). The presence or absence of snow determines whether the incoming radiation is absorbed in the surface or reflected into the atmosphere and space. In conditions of relatively strong insolation, the shortwave radiation budget in late winter and early spring is highly sensitive to changes in surface albedo (Tooming 1981, 1984).

Due to interannual variations in surface albedo and shortwave radiation budget, there exist great year to year differences in spring heat accumulation. On the other hand, soil water storage and evapotranspiration in spring depend on the state of the snow cover. If the snow melting period ends already in late winter, the rise of temperature is usually considerable because of low surface albedo and high shortwave radiation budget. When the water storage in soil is exhausted the absorbed radiation transforms mostly into turbulent heat. As a result, temperature continues to rise and intense heat accumulation takes place. As supposed by Tooming (1984), severe droughts and anomalous high temperatures in spring and summer are more frequent if the surface albedo in late winter and early spring is small. This hypothesis was supported by an analysis of data from ground-based stations during the drought in the European part of the former Soviet Union in 1972 (Tooming, 1984).

In the years when snow melts late, albedo remains high for a long time, the absorbed radiation is mainly spent on evaporation and spring and early summer temperature is usually low.

To describe interaction between surface properties and energy budget, the notion of surface thermal forcing may be introduced. Surface thermal forcing is a set of processes that through the state of the surface influence absorption of incident shortwave radiation and heat accumulation at the surface. A noticeable surface forcing is run mainly by two factors. First, early spring incoming radiation is sufficient to influence considerably surface

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radiation budget. Second, variations in winter temperature exceed 0°C and may reduce snow cover. A corresponding decrease in surface albedo increases surface absorption and affects heat accumulation and air temperature during a long time (several months). However, not all heat will be used on the spot while heat storage is also influenced by advection.

One possibility to estimate quantitatively the heat accumulation is to introduce the terms of warmth indices that are widely used in agriculture, agricultural meteorology, phenology and climatology (Davitaja, 1964). We define the warmth index I_y as the sum of positive monthly mean air temperatures T_i (Kira, 1977) from February to May or June (incl.) as follows:

$$I_y = \sum_{II}^{y} T_i$$

The summation starts from months with $T_i > 0$°C (February or mostly March). The upper index y denotes May or June.

The aim of this paper is to investigate the heat accumulation in spring influenced by the snow cover and surface albedo in late winter and early spring. This problem will be considered locally from ground station data and in wide territories from satellite data.

2. Data

In the present paper measurement series of global and reflected radiation at Tartu-Tõravere Actinometric Station over the period 1953–1992 have been used. Surface albedo is defined as a ratio of monthly sums of reflected and global radiation.

Data for the snow cover fraction and surface albedo for wide territories have been drawn from the ISCCP-C2 CD-ROM. This data set consists of monthly mean values of 72 variables at a 280 km spatial resolution for a seven-year period from July 1983 to December 1990. In the present study mean snow cover, mean surface reflectance, and near-surface air temperature have been used. A more detailed description of the ISCCP data are given by Rossow and Schiffer (1991).

3. Local heat accumulation in spring

Correlation between the warmth index by the end of June and surface albedo in March has been noticed at Tartu Actinometric Station for the period 1953–1992 (Fig. 1). The correlation is weak ($r = 0.37$) but significant at a 5% significance level. A significant correlation ($r = 0.38$) exists also between the warmth index and March shortwave radiation budget. These relationships and a simple information analysis show existence of the surface forcing. Surface forcing has no obvious influence on heat accumulation in years with March albedo close to the mean value. Those years are mostly characterized by the scattering points in the centre of Fig. 1 and contain little valuable information about the following spring and summer warmth index. The majority of years belong to this group. Forecasting is possible in the years with extreme surface forcing. From this point of view, most informative are points on the right and especially on the left side of Fig. 1. These demonstrate that surface forcing and heat accumulation are noticeable in years with long lasting snow cover and in years without snow cover. Such years form about 25% of the whole observation period. In these years, in about 65–70% of cases, to the low values of March albedo ($A < 0.40$) correspond high values of June warmth index. The year 1974 was exceptional and the corresponding point is marked in

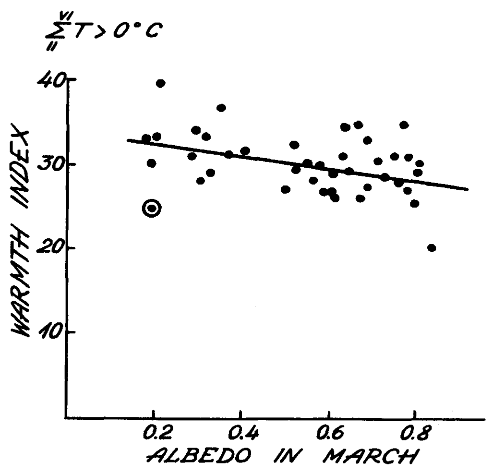

Fig. 1. Dependence of warmth index in June on surface albedo in March at Tartu Actinometric Station between 1953 and 1992.

Fig. 1. Namely, in that year March and April were without snow and albedo was low, but intensive cold air advection took place in early spring breaking heat accumulation.

The question arises if the relationship between the warmth index and early spring surface albedo is valid also over wide territories? For this purpose satellite data have been used to study near-surface temperature, warmth index, snow-cover fraction, and surface albedo relationships in the Northern Hemisphere, especially in the region of Europe.

4. Spring heat accumulation in wide areas

Although results of model experiments show that snow cover causes only a short-term local decrease in the surface temperature (Cohen and Rind, 1991), most authors find that snow cover suppresses air temperature even if the influence of air circulation is considered. Of course, the complete surface energy budget does not involve only the effects of changing surface albedo. A strong factor affecting the surface energy budget of a certain area is heat advection. Being zero on a global mean basis, advection increases with a decrease of the averaging scales. To reveal the influence of the surface albedo on the energy budget, the influence of advection should be minimized. Therefore the averaging scales should be as large as possible. On the other hand, studying the problem on a global scale does not give information on regional anomalies that are important for (long-term) assessment of the local temperature regime. Having chosen suitable averaging scales, we do not pay attention to other factors affecting the energy budget of the area and try to detect the surface albedo signal "behind" them.

Following Gutzler and Rosen (1992), the continents of the northern hemisphere are divided into seven orographically justified sectors (Fig. 2). These sectors are divided into 5° latitude zones, combining thus the 2.5° ISCCP zones by two. In this paper only the zone center is indicated, so that a zone labelled 60° lies between 57.5° and 62.5°. Monthly mean values of snow-cover fraction, surface albedo, and air temperature are averaged over a zone in a sector, and these products are regarded as observations in our further statistical analysis. Unfortunately the data set used is

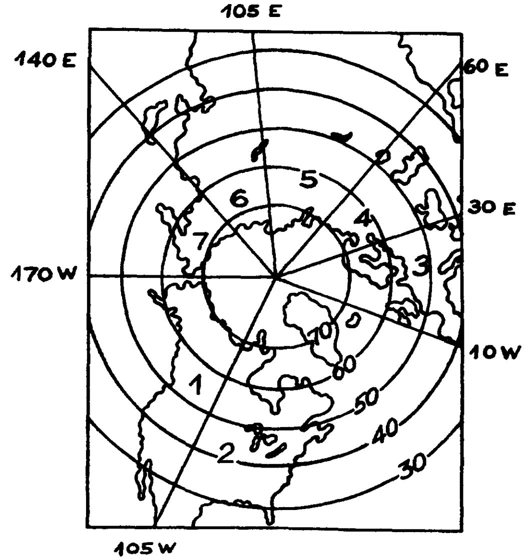

Fig. 2. The longitudinal sectors of the Northern Hemisphere according to Gutzler and Rosen (1992).

short and causes in some cases great difficulties in the statistical treatment.

In Figs. 3, 4 the growth of the sums of positive temperatures from February till June in the belt of 60°N of sector 3 and in the belt of 45°N of sector 2 are shown, respectively.

As we can see from Fig. 3, in the 60° latitude belt of sector 3 the character of heat accumulation varies greatly in different years between 1984 and 1990. When surface albedo in February and March is low, heat accumulation begins earlier (1989 and 1990). In these years also greater amounts of heat are accumulated by June. In 1985 and 1987 when surface forcing starts late, heat accumulation is less.

Heat accumulation in the latitude belt of 45°N of sector 2 shown in Fig. 4 is relatively similar in different years. Interannual variability of the warmth index is also smaller than that for the latitude belt of 60°N of sector 3. Even lower variability in heat accumulation can be noted in the Asian sectors 5, 6, and 7 (not shown in this paper).

Figs. 3, 4 demonstrate not only dependence of the warmth index on early spring surface albedo, but also persistence of atmospheric regimes, e.g., positive or negative temperature anomalies. Unfortunately we cannot separate these effects in

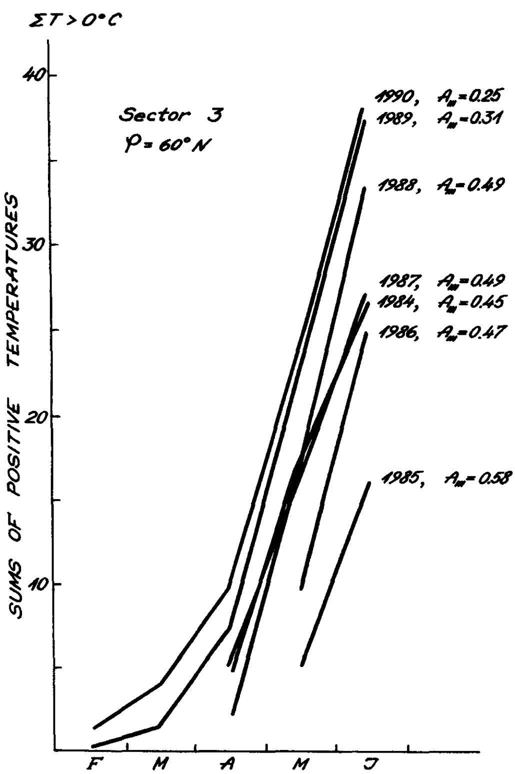

Fig. 3. Accumulation of sums of positive temperatures between February and June in different years in sector 3 at latitude 60°N. A_{III} shows surface albedo in March.

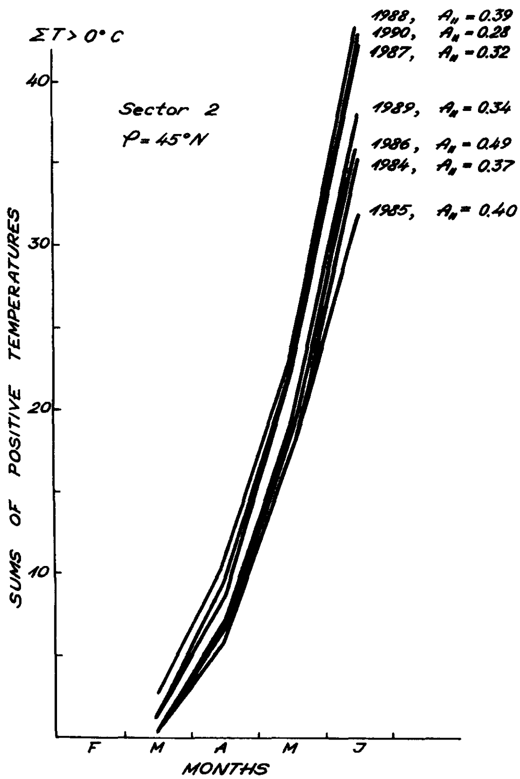

Fig. 4. Accumulation of sums of positive temperatures between February and June in different years in sector 2 at latitude 45°N. A_{II} shows surface albedo in February.

the frames of this paper that is based on correlation analysis. Correlating the warmth index with early spring temperatures would mainly demonstrate the relationship between a part and the whole: according to the definition of the warmth index summation starts with the February temperature. On the other hand, the phenomenon of surface forcing would be much easier to detect in case of stable weather regimes. A strong cold or warm advection interrupts the forcing processes and masks the relationship between surface albedo and warmth index.

We suppose that due to the surface forcing there exists a possibility to predict annually springs with the extremal heat accumulation and the warmth index. Especially important are such predictions for regions with high interannual variability of the warmth index. The respective regressions for different latitudes in sector 3 and sector 2 are shown in Fig. 5. The correlation coefficients for the dependencies in sector 3 are higher than 0.76 and correspond to a 5% significance level. In sector 2 the correlation coefficients are lower and regression lines do not correspond to the 5% significance level. Statistical analysis and Fig. 5 (a) show that here variation of surface albedo is low and thus this quantity cannot act as a good predictor. Significant correlation between the late winter surface albedo and early summer warmth index can be established also in the latitude belt 37.5°–52.5° of sector 4 (not shown in this paper).

Our results show that even in conditions of heat advection the surface albedo in late winter includes some information for forecasting early summer warmth index and temperature. This is particularly important in Europe where the variability of both the surface albedo and warmth index is high.

The relationship between the June warmth index and early spring surface albedo has been got by means of the correlation analysis and its

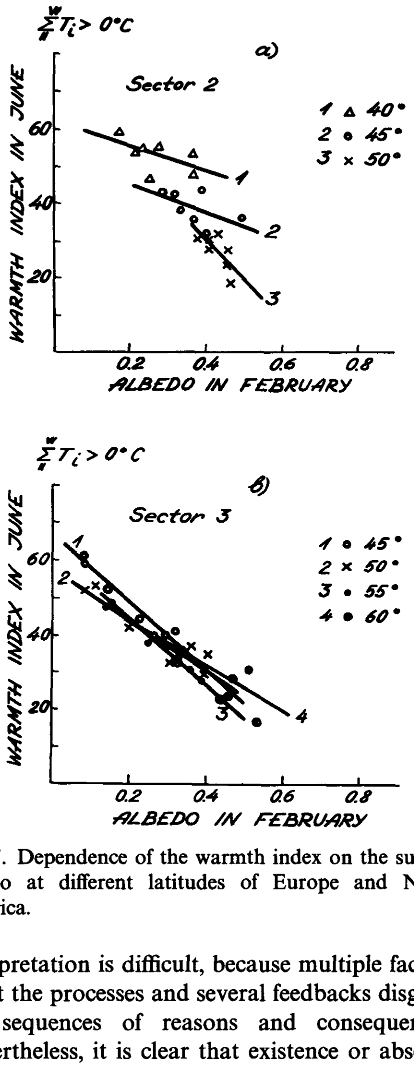

Fig. 5. Dependence of the warmth index on the surface albedo at different latitudes of Europe and North America.

interpretation is difficult, because multiple factors affect the processes and several feedbacks disguise the sequences of reasons and consequences. Nevertheless, it is clear that existence or absence of snow cover during early spring period when solar radiation is intensive gives a strong negative or positive impulse to the surface radiation budget and releases a series of processes that we call surface thermal forcing. In extreme years these processes can be described by means of the following schemes.

(1) Years with low early spring albedo

High temperature and/or little precipitation in winter→early snow reduction→low surface albedo→high shortwave radiation budget→high evapotranspiration→exhausted soil moisture storage→high sensible heat→high heat accumulation.

(2) Years with high early spring albedo

Low temperature and/or much precipitation in winter→long lasting snow cover→high surface albedo→low shortwave radiation budget→late snowmelt→long lasting evapotranspiration→low sensible heat→low heat accumulation.

Our aim was to show that in extreme years the heat accumulation is different and influenced by the surface albedo in late winter and early spring. This influence is weak and mixed up with weather regime variability, but still existing.

To conclude, we must say that the results of this paper should be regarded as preliminary. We intend to continue our analysis using other time series and different averaging scales.

5. Acknowledgment

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