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[1] Res. Group Geophys. Envir. Phys., Hung. Acad. Sci., c/o Geophys. Dept., Eötvös Univ., Budapest, Hungary
[2] Geophysics Inst., Czech Acad. Sci., Praha, Czech Republic

High frequency variability in recent climate and the north atlantic oscillation

L. Bodri[1] and **V. Cermak**[2]

With 8 Figures

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Summary

High-frequency temperature variability was investigated in the temperature time series measured at Prague-Sporilov (Czech Republic) between 1994–2001. The calculations were performed for time series of surface air temperature averaged for 6-hour intervals. Variability was detected by the method of absolute difference of temperature anomalies between two adjacent discrete time periods. The results indicated a frequency dependence of variability. For 24-hour intervals the variability exhibits an irregular character and decreases with time in the eight-year observation period. Variability time series calculated for the 6-hour intervals did not reveal any significant trend, however, apparent quasi-seasonal oscillations exist. A significant correlation between the North Atlantic Oscillation (NAO) activity and temperature variability can be observed. Higher NAO-index values at all frequencies tend to be associated with higher variability.

1. Introduction

Climate systems are variable on all time scales. For better understanding of the nature of the climate changes an attention is to be focussed not only to the evolution of mean climate characteristics, but also to the changes in climate variability and to climate extremes. Climate model simulations associated with the build-up of greenhouse gases predict not only climate warming but also a general decrease in climate variability (e.g. McGuffie et al., 1999; Karl et al., 1999). Thus, the investigations of variability likewise the investigations of warming trends can be used for the validation of the simulated models for various scenarios of greenhouse-gas emission and land use. A detailed understanding of climate variability is also important to the prediction of extreme climatic events. It can be demonstrated that the frequency of climatic extremes is more sensitive to the changes in variability rather than to the mean climate state (Katz and Brown, 1992). Rebetez (1996) has shown that climate variability is one of the most important characteristics in the human perception of climate.

In this paper, we analysed eight-year-long surface air temperature (SAT) time series to study the pattern of variability variations at the scale of aggregation from 6 to 24 hours. Particular attention was paid to the potential influence of the North Atlantic Oscillation (NAO) upon the variability changes. Present work contributes to previous investigations of day-by-day variability changes from the historical SAT series (Karl et al., 1995; Moberg et al., 2000) and further extends these studies into higher frequency domain.

2. Data and methodology

A Surface air temperature (SAT) has been monitored at Prague-Sporilov (Czech Republic) since 1994 (Cermak et al., 2000), the station being located on the top of a low hill in the campus of the Geophysical Institute of the Czech Acad. Sci. (50.04° N, 14.48° E, 275 m a.s.l.) on the rim of the large urban agglomeration. The site was chosen for a long-term project to study the soil/air temperature coupling and temperature has been monitored at a number of selected depth/elevation levels below/above the surface. The data discussed here refer to the SAT measurements obtained by the zero-depth thermistor sensor installed on the top of a few millimetres of the rotten organic relics upon the compact soil ground. The individual measurements were taken in 15-minute intervals and then averaged to 6-hour regular grid; the precision of the individual readings is better than 0.01 °C (Fig. 1). The early years of observation suffered by several data gaps, an uninterrupted continuous record exists only for the period 1998–2001. There were no changes in the observational procedure or in the equipment installation during the whole experiment. The estimates of variability are thus not influenced by any data inhomogeneity problems, which otherwise may seriously bias the results (see e.g. Moberg et al., 2000).

The actual character of changes in the temperature variability may be distorted by the annual temperature variations when the slope of the annual cycle is steep in the spring and autumn seasons (Karl et al., 1995; Moberg et al., 2000). To minimise the potential influence of the annual cycle, the measured data before being processed, were converted into temperature anomalies. Figure 2 shows how this pre-processing works. The measured temperatures were expressed as T_L^Y, where index $Y = 1, \ldots, 8$ corresponds to years from 1994 to 2001 and index $L = 0, 1, \ldots, 1460$ corresponds to the serial number of the corresponding 6-hour long interval within the respective year. The mean annual temperature cycle contained 1461 points from 0 to 365 days at 6-hour intervals and was calculated by averaging eight-year values of $\overline{T_L} = \frac{1}{8}\sum_{Y=1}^{8} \overline{T_L^Y}$. The reference temperature was then obtained from this cycle using the mean value, first four harmonics of the Fourier analysis and the daily wave (wave number 365). Little, if any, additional variance could be explained when higher-order harmonics are used. To obtain the temperature anomaly the reference temperature was removed from measured temperature (Fig. 3).

A prominent feature of the temperature anomaly record is the prevalence of extremes in warm seasons of the year while extremes are relatively rarer in cold seasons. The probability distribution of the temperature anomalies (Fig. 4) is skewed

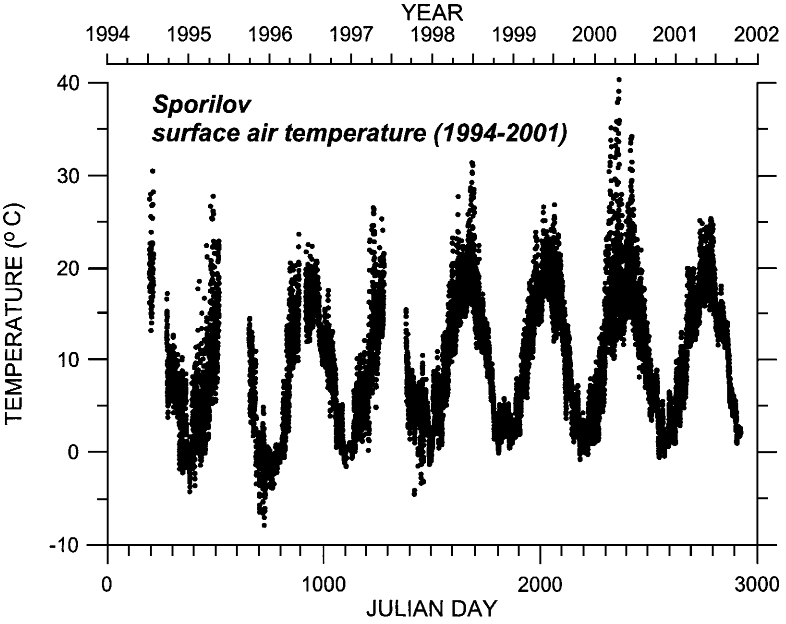

Fig. 1. Results of eight-year temperature monitoring of surface air temperature at Prague-Sporilov

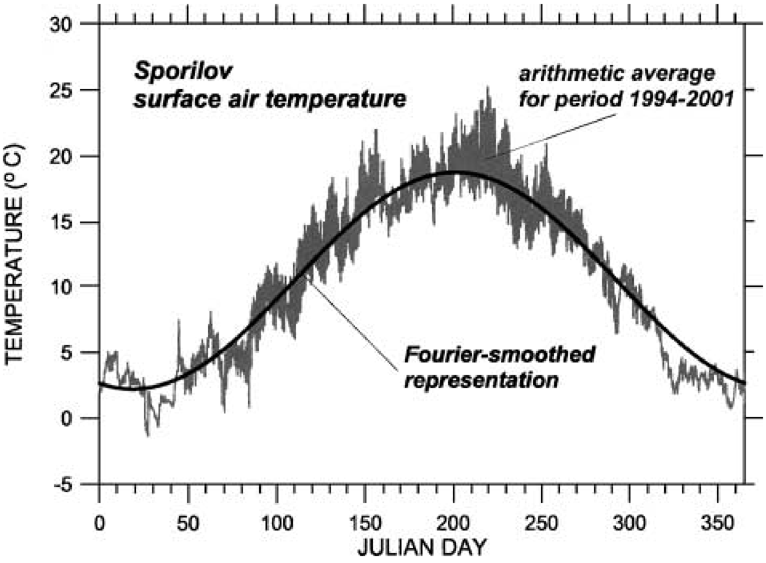

Fig. 2. The average annual cycle and its Fourier-smoothed representation (thick line)

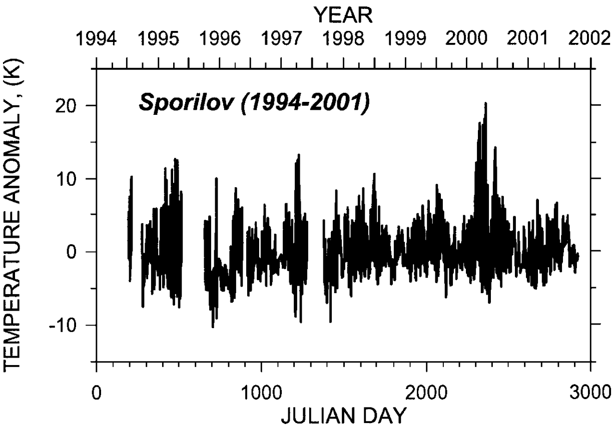

Fig. 3. Temperature anomalies calculated from the surface air temperature for the period of 1994–2001

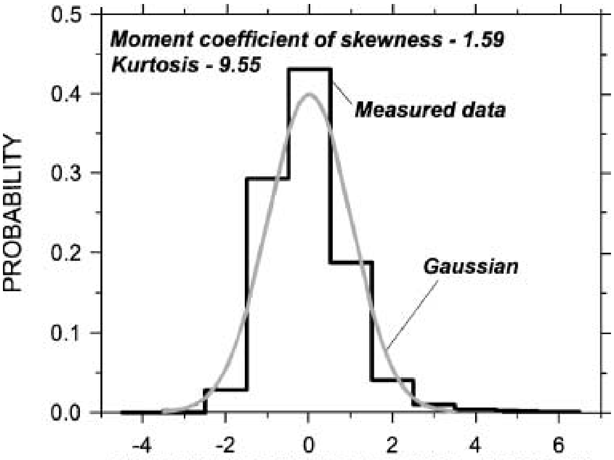

Fig. 4. Probability distribution of temperature anomalies, the Gaussian distribution is shown for reference

to the right and a more heavy right tail indicates that the warmer extremes are more frequent than colder extremes. This finding agrees well with the knowledge obtained for larger scales of aggregation. An infrequent occurrence of cold extremes in daily temperatures in the last two decades relative to warmer extremes was reported e.g. both for local and for global temperatures (Jones et al., 1999; Rebetez, 2001). Our data confirmed this fact for higher frequency variation up to 6-hour aggregation level. Notice, that the temperature anomaly distribution is also more peaked with the respect to the normal distribution.

The measure of variability used in present study is based on earlier works by Karl et al. (1995) and is defined by the absolute value of the temperature difference between two adjacent periods of time. The measure, which we call N-point change, is defined as the absolute difference between the average of a sequence of N successive temperature anomalies that begins at the measured point t and the similar average of N anomalies that begins at point $t + \Delta t$. As shown by Karl et al. (1995) this approach is free of disadvantages of other conventional methods, such as e.g. the standard deviation method, considering that it prevents confounding high- and low-frequency variability. Because of homogeneity of the data used in the present work this method can be used without the limitations stipulated otherwise in the work by Moberg et al. (2000). Generally, $\Delta t \leqslant N$, which implies the possibility of overlapping. The overlapping is useful for longer intervals when the application of the strictly non-overlapping differences artificially constrains their number, and may lead to noisy seasonal estimates.

3. Results

We have temperature anomalies time series T_1, T_2, $T_3, \ldots,$ $T_i, \ldots$ The measure of variability ΔT_N (N-point change) is defined as the absolute difference between the average of a sequence of temperature anomalies for N points that begins at point i and the average for the N-point long sequence beginning at point $(i+N-k)$

$$\Delta T_N = abs(\overline{T_i} - \overline{T_{i-k}})$$

where

$$\overline{T_i} = \frac{1}{N}\sum_{l=i}^{i+N-1} T_l \quad \overline{T_{i-k}} = \frac{1}{N}\sum_{l=i+N-k}^{i+2N-k-1} T_l$$

For the time lag $k > 0$ there are partly overlapping running differences (Karl et al., 1995).

The measure of variability was calculated successively for the whole temperature time series to obtain time series of variability measure. The values of N were chosen as 1, 2, 3, and 4 corresponding to the averaging intervals from 6 to 24 hours. Below we present only 6-hour and 24-hour (day-by-day) variability changes, the 12-hour and 18-hour patterns do not offer any special features and represent only a gradual transition from higher to lower frequency variability pattern. Daily variability itself (i.e. the daily

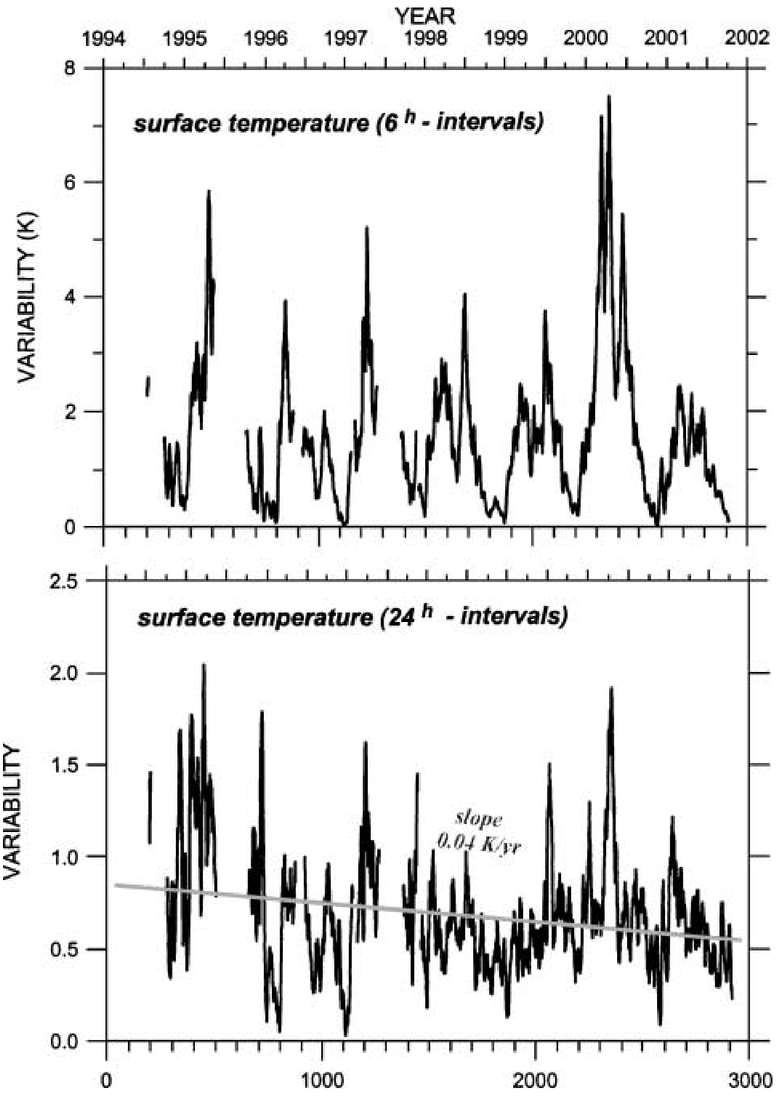

Fig. 5. Top: variations of the differences in average temperature anomalies for 6-hour averaging intervals. Low frequency changes are highlighted by a Gaussian filter, corresponding roughly to 10-day moving averages. Bottom: variations of the differences in average temperature anomalies for 24-hour averaging intervals and their linear trend (thick line)

wave) was removed from the observed temperatures (see above), thus it cannot have any influence on the calculated variability patterns discussed further.

Figure 5 shows 6-hour and day-by-day variability changes of the SAT for the last eight years. As seen, the pattern of variability depends on the length of the averaging interval *N*. Variability time series for 6-hour intervals do not show any significant linear trend, but they exhibit an apparent quasi-seasonal oscillations. In all studied time interval the variability increases during spring season (partly also in summer) and decreases in the autumn-winter seasons. Except of extremely variable year 2000, the spring "explosions" in variability are very short. This quasi-seasonality is relatively less pronounced in the day-by-day variability, the oscillations of which are more irregular. Day-by-day variability rarely falls to very low values and even it does then only for a short interval. On the other hand, the 24-hour variability exhibits a general decreasing trend of $-0.038 \pm 0.002\,\mathrm{K/yr}$ similar to what is predicted by the most of greenhouse warming simulations. Such decreasing trend existing during the second half of the 20th century was reported by Balling (1995) and Rebetez (2001), who investigated the changes in the diurnal temperature range in the daily SAT records. Probably, part of the decrease in variability observed in the Sporilov data may be attributed to the urbanisation effect (see e.g. Jones et al., 1990) characteristic for the intensively developing suburban part of city of Prague.

4. Variability and the NAO

Recent studies have indicated that the variability of atmospheric circulation patterns in the Northern Hemisphere may be affected by the differences in the sea level pressure between the Atlantic Subtropical High, centred near the Azores, and its Sub-polar Low near SW Iceland. This phenomenon is referred to as the North Atlantic Oscillation (NAO) which has a substantial influence on temperature and rainfall regimes in Europe especially in the wintertime (see e.g. Rodwell et al., 1999; and the references therein). The increase of the pressure difference between the Azores High and Icelandic Low leads to the strongest westerly flow of marine humid air from the North Atlantic, with the accompanying increase of cyclone activity, onto parts of Northern Europe, bringing precipitation and mild air to NW Europe. All this may contribute to the increase in temperature variability. Much of the Mediterranean region at the same time is influenced by more anticyclone conditions. During negative polarity of the NAO cold air flow to the NW Europe, which is associated with a more stable weather situation, while storms bring rainfall to the Mediterranean region.

Figures 6 and 7 show the superposition of the normalised monthly NAO indices (Jones et al.,

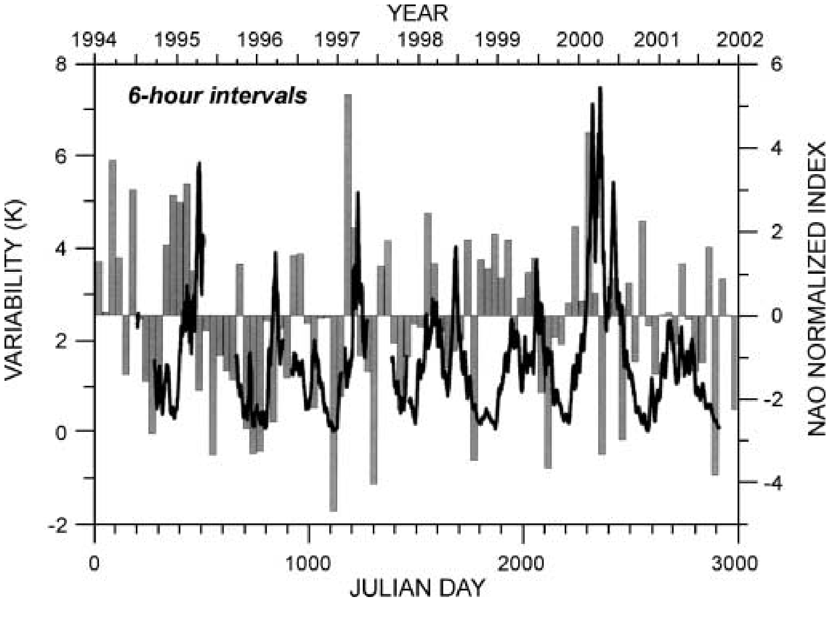

Fig. 6. Variability pattern for 6-hour averaged intervals superimposed on the monthly variations of the NAO index

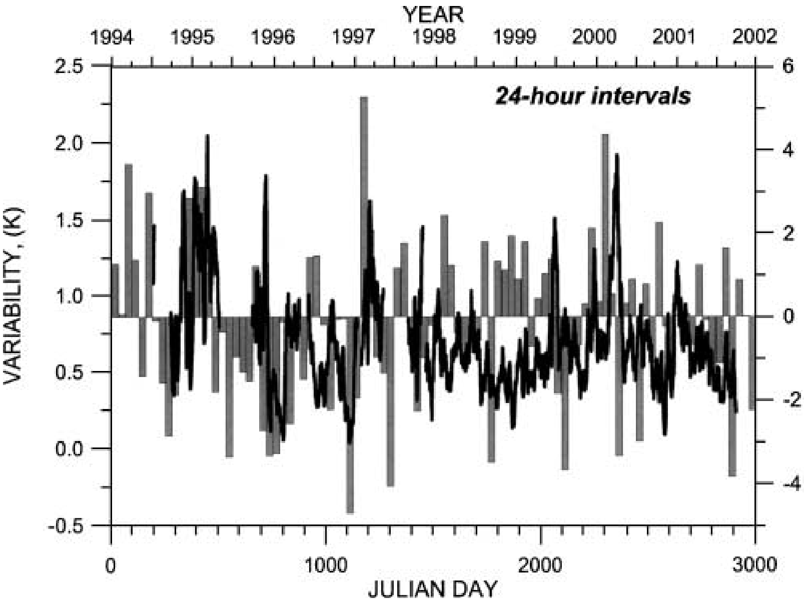

Fig. 7. The same as Fig. 6 for 24-hour averaged intervals

1997, corrected and updated, see www.cru.uea.ac.uk) and the variability patterns for 6- and 24-hour intervals, respectively. As seen, the NAO has a substantial effect on the variability. The variability "highs" are generally coinciding with the high positive NAO values and vice versa. The dependence of European temperatures on the NAO is particularly evident in winter; higher correlation between NAO index and the climate characteristics (temperature, precipitation) is typically observed from December throughout to March (Murrell, 1995). For this reason we focussed on the comparison of variability with the NAO specially for the winter season. Winters in the years 1994/1995 and 1999/2000 were characterised by especially high positive NAO values of 2.44 and 1.85, respectively, as well as by the increased variability. Extremely low negative value of the NAO index (– 2.32) in winter 1995/1996 was accompanied by low variability.

The correlation between winter (DJFM) NAO index, when the NAO controls the weather of the Northern Hemisphere is the strongest, and the variability averaged over this period is positive amounting to 0.67 and/or 0.56 for 6- and 24-hour intervals, respectively (Fig. 8). Both correlations are significant, the calculated integral probabilities (probability that the correlation does not exist) equal to only 9.8% and 19.3%, respectively. Linking higher variability to largest positive NAO indices is probably the result of

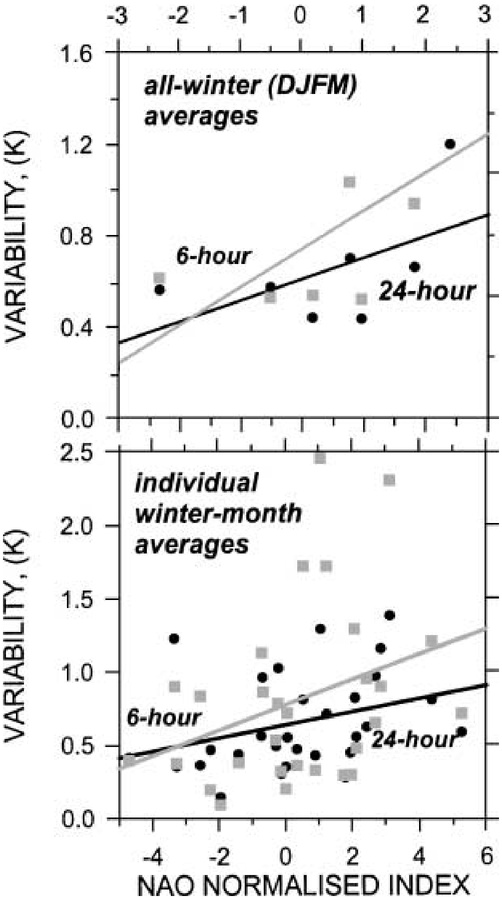

Fig. 8. Variability of SAT temperatures at different scales as a function of normalised NAO index. Thick lines correspond to the best fit of linear regression. Top: averages corresponding to all winter period (December to March) of respective year, bottom: averages for individual winter months

the growing cyclone activity due to increasing pressure difference between the Azores High and the Icelandic Low. The effect of high positive NAO values for the southern Europe should be opposite, and our results may complete the earlier studies of Rebetez (2001), who described the correlation between SAT variability and the NAO index for two meteorological stations in Switzerland. As shown by Rodwell et al. (1999) stronger NAO values were linked to high pressure and a stable weather situation, when both the weather type and the temperature are changing only little, over a large region across the Mediterranean (including also Switzerland). In accordance with this statement, Rebetez (2001) revealed a negative correlation between NAO index and SAT variability.

Above correlation was obtained for winter seasons, when correlation for the whole year is less obvious. For example, the correlation between monthly averaged NAO indices and variability values is no doubt still significant but equals to 0.34 and 0.32 only with the integral probabilities of 7.6% and 9.2% for the 6-hour and 24-hour averaging intervals, respectively. This suggests that the NAO alone cannot account for the oscillation of temperature anomalies. Variability patterns thus probably reflect different scales of local cyclone activity, and the NAO only strongly modulates the variability pattern.

5. Conclusions

a) SAT variability is frequency dependent, the 6-hour averaged intervals show quasi-seasonal oscillations, while the day-by-day scale variations are irregular and do not exhibit any recognisable pattern.
b) At the longer averaged intervals the variability shows decreasing trend, which can be predicted by most of greenhouse, warming models. This trend is absent in the higher frequency variability.
c) At all frequencies there is a significant correlation between variability and the NAO index. At the investigated location the correlation is positive and it is more prominent in winter periods, when the NAO control on the weather is stronger.

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Authors' addresses: L. Bodri (e-mail: bodri@pangea.elte.hu), Geophysics Department, Eötvös University, Pazmany setany 1/C, Budapest, 1117 Hungary; V. Cermak, Geophysics Inst., Czech Acad. Sci., Bocni II/1a, 141 31 Praha 4, Czech Republic.